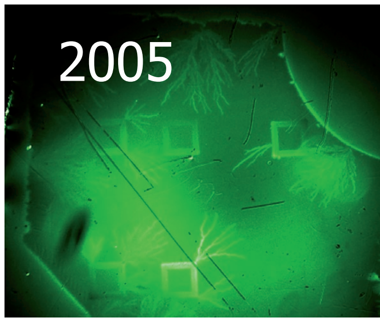
ANNUAL REPORT

JYFL

DEPARTMENT OF PHYSICS • UNIVERSITY OF JYVÄSKYLÄ



ANNUAL REPORT

JYFL

DEPARTMENT OF PHYSICS • UNIVERSITY OF JYVÄSKYLÄ

2005

DEPARTMENT OF PHYSICS
UNIVERSITY OF JYVÄSKYLÄ

P.O. BOX 35
FI–40014 UNIVERSITY OF JYVÄSKYLÄ
FINLAND
Tel. +358 14 260 2350
Fax +358 14 260 2351

Contents

Department of Physics

Jukka Maalampi

Research

In our Department, the activity of highest priority is research, carried out in three major areas, nuclear and accelerator based physics, materials physics and theoretical high-energy physics. Focusing of intellectual and material resources on these few areas has resulted in a clear research profile and has guaranteed a strong basis for successful research training.

The quality of research in our Department has been under continuous evaluation, for example when applying for outside funding from the Academy of Finland, Tekes, EU, or some other funding agents, and as a whole the outcome of this evaluation has always been quite positive. Two important evaluations took place in 2005, the Evaluation of Research Activities in 2000-2005, which concerned the whole University, and the competition for the Center of Excellence funding by the Academy of Finland. The results of both these evaluations were again most satisfying.

The evaluation panel of the Research Activities, consisting of eight foreign and one Finnish renowned experts in mathematics and sciences, concluded that our Department has a strong international research program in our all three main research areas.

The activity and achievements in nuclear physics, which has been the core area of research in the Department from the early days, was evaluated exceptionally high. The research program was found broad and strong in all of its various aspects. The significance of the accelerator laboratory in providing students with unusual hands-on experience with design, construction and operation of world-class nuclear physics experiments was recognized. The research in materials physics got very positive evaluation, too. The subjects addressed were considered to be at the forefront of contemporary research, and the considerable attention in the international community, received by the results of the relatively small research teams, was also pointed out. In high-energy physics the well-established activity in the theoretical investigation of ultrarelativistic heavy-ion collisions got appreciation of the evaluation panel, who pointed out its significant impact on developments in that field.

The research activity of our Department as a whole was ranked so high that we are amongst the top three units at the University. The Faculty of Mathematics and Sciences was clearly number one among the faculties, as all of its Departments got very good evaluation results. One should expect this to have implications on the future policies of the University, for example when defining the areas of strength and future potential, and when allocating material resources.

During 2000-2005 the research groups of nuclear and accelerator based physics and materials physics acted as a Center of Excellence and received funding from the CoE Program of the Academy of Finland. In the competition for the CoE funding for 2006-2011 the Department participated with three applications: nuclear and accelerator based physics, nanoscience in collaboration with biologists and chemists of the neighbouring

Some statistical data in 2005

Personnel	160	(60)
- professors	12	(11)
- lecturers	3	(4)
- senior assistants	11	(10)
- assistants	5	(4)
- researchers and research assistants	98	(4)
- technicians	27	(23)
- administration	4	(4)

( ) = permanent posts

Undergraduate students	570
of which new students	86
Graduate students	65
MSc degrees	46
PhD degrees	8
Credits (national)	7659
Median time to complete MSc (years)	5,3
Number of foreign visitors	~220
- in visits	~335
Visits abroad	~250
Peer reviewed publications	114 (+ 11 outside JYFL)
Other scientific reports	40
Newspaper articles etc.	10
Confrence contributions	
- Invited talks	65
- Other talks	70
- Posters	48
Seminars outside JYFL	63
Funding (million €)	10,1
* University budget (incl. premises)	5,8
* External funding	4,3
- Academy of Finland	1,6
- Technology Development Centre	0,4
- International programmes	0,8
- HIP, HUT etc.	0,7
- Contract research	0,7
- Others	0,1

Departments, and theoretical high-energy physics in collaboration with the University of Helsinki. All three applications got very positive evaluations and were short-listed for the final ranking. In the final selection the nuclear and accelerator based physics group was among those 23 research units who will get CoE funding for the next six years.

One particular appreciation in connection with research needs still to be mentioned and to be congratulated for. Professor Päivi Törmä, together with twenty-four other outstanding young researchers, was awarded the European Young Investigator Award. These awards, each worth 1.2 million euros, were divided as a result of a competition open to outstanding young researchers from all over the world and in all fields.

The Department of Physics serves the general community, apart from its basic research and education, by collaborating with industry and industry-related research institutions. The work in the physics of paper production has a well-established record in our Department, and we have educated a plenty of specialists in this field. Collaboration with VTT in this activity has been close and fruitful, and it has included in the past recent years a shared professorship. The Department decided in 2005, when the temporal period of the shared professorship was approaching its end, to establish a permanent professorship for continuation of this activity and for strengthening the teaching and research of applied physics in the Department.

An important event in 2005 was the official Inauguration of the RADEF facility on 27 May. RADEF is a facility for proton and heavy ion irradiation studies of semiconductor materials and devices, and it is one of the three external irradiation test facilities used by the European Space Agency ESA. In connection with the inauguration of RADEF, ESA organized its "QCA Final Presentation Days" in the Department, the first time outside ESA.

The main part of this Annual Report is devoted to the description of research activities of the Department. Detailed information of publications, talks and scientific visits are also given. The high level of research activity was satisfactorily maintained in 2005: the number of peer review publications was 124, 65 invited talks and 70 other talks were given, we had about 300 visits by foreign scientists and we made about 250 visits abroad.

Education

As for teaching activities the year 2005 was also quite satisfactory. The number of MSc degrees awarded was 46, a new record, and for the first time in the history of the Department the officially set goal was reached. Curiously, about a half of these degrees were awarded in December. The number of PhD degrees was 8, five short of the official goal.

The transition to the new two-tier study system, consisting of three-year candidate studies and two-year master studies, took place in the beginning of the autumn semester 2005, and thanks to careful preparations everything seemed to work fine, including the change from the traditional 1-3 grading to 1-5 grading.

The Department started its third year as one of the high-quality education units in Finland. Special activities related to this status were the development of student laboratory exercises and the follow-up of the "flying start" initiative.

Our Department participates in five national graduate schools and coordinates one of them, the Graduate School in Particle and Nuclear Physics. In 2006 will start the Graduate School in Nanoscience under the coordination of our Department. A new system for doctoral student admission was applied for the first time in the autumn semester. The admission was made more formal than before in order to have a better control of the quality of the students, and to allow for a better overall planning for the allocation of funding. The selection

will be made twice a year on the basis of applications. More than 20 new doctoral students were accepted in the first selection. We are thus looking forward to witnessing a substantial growth in the yearly number of doctoral dissertations in the future!

Administration

As a result of the election of new administrative bodies in the spring 2005, some changes took place in the administration of the Department. Head of the Department, professor Matti Leino, was elected as Vice Rector of the University. His responsibilities in this important position include also research matters. Matti Leino was replaced by professor Jukka Maalampi as Head of the Department. Professor Rauno Julin was elected as Vice Head of the Department, and lecturer Juha Merikoski acts as the Pedagogical Director. Professor Matti Manninen was elected as the Dean of the Faculty, for his third consecutive term in that office.

During the last few years the financial situation of the Department has not been as good as one would have hoped. The deficit in the running-cost funding has hampered the research conditions, in the experimental groups in particular. The main reason for the unfortunate development is the new allocation model for the funding launched by the University in 2004, which has turned out to be unfavourable to our Department in comparison with the situation before. The model will be re-evaluated during 2006, and one can justifiably expect it to be modified such that it will better take into account the special needs of natural sciences, in particular the needs of experimental facilities and laboratory space. It should also encourage outside funding better than the present model.

In the spring some worry and turbulence was caused among the personnel by three letters, UPJ, which stand for the new salary system that will be effective from the beginning of 2006. All of us went through evaluation discussions where the demands of our job and our performance were evaluated and ranked. This was something we have not been accustomed to, but must unavoidably do so from now on. The implementation of the UPJ so far has not been very encouraging from the employees' point of view, but a result-oriented unit like us should expect that, after the transient period, the new system will have a positive influence and open up new possibilities.

Events

A hundred years ago, in 1905, Albert Einstein, an idol for many of us, published during six months five ground-breaking papers, including the photon theory of light and the theory of special relativity. This was a good reason for the United Nations to declare 2005 as the International Year of Physics, and physicists all around the world organized many kinds of activities to raise public awareness of physics. Our Department took part in this effort by organizing an Open Doors Day on 8 October, with a popular talk on Albert Einstein's contributions to physics and to our every-day life, and with interactive physics demonstrations.

The Year of Physics was also one of the themes in the Alumni Meeting that took place in the Department on 29 January. The meeting gathered some 180 alumni and other friends of the Department to hear about high-lights of our present activities and to listen to the entertaining talks by two charming invited speakers, professor Cecilia Jarlskog and Chief Editor Tuula Koukku. Tuula Koukku, the Chief Editor of the science magasin Tiede and an alumna of the Department, talked about the importance and difficulty of science popularization. Cecilia Jarlskog, who is professor of theoretical physics at the University of Lund, told the interesting history of how Einstein got the Nobel prize. The day of many happy reunions ended with a dinner at the Sonaatti restaurant, where emeritus professor Pertti Lipas gave the toast.

Excellence

Center of Excellence in Nuclear and Condensed Matter Physics 2000–2005

Juha Äystö

General

The Centre of Excellence in Nuclear and Condensed Matter Physics has carried out research on several subjects which have formed a compact programme focusing on different aspects of the structure of matter. About 80 % of the research effort of the Department of Physics (JYFL) was funded under this CoE contract. The funding period of the programme covered the years 2000-2005.

One area of research comprised of nuclear physics where the experimental part has been carried out at the JYFL Accelerator Laboratory. The second part consisted of applied research accompanied by a research programme on ion beam - matter interactions. The third part concerned condensed matter physics where the experimental part is mainly carried out by the JYFL Nanophysics group.

In general, the programme proposed originally for the CoE has been realized in an excellent way. This is true both for the quality of the scientific output as well as for the statistics on publication activities and education of young scientists. The CoE status has had important impact on the improved situation for new post doctoral fellow and graduate student recruiting. The most important benefit from the CoE funding programme has been its long-term duration allowing for concentration on actual work as well as for making possible easier opening of new projects and areas of research.

The following persons have acted as group leaders in the CoE.

Nuclear physics, ion beam physics and particle accelerators:

Prof. Rauno Julin
Prof. Matti Leino
Prof. Juha Äystö
Prof. Esko Liukkonen (-31.7.2003),
Docent Pauli Heikkinen (1.8.2003-)
Prof. Jyrki Räisänen (-31.1.2003),
Docent Ari Virtanen (1.2.2003-)
Prof. Jouni Suhonen

Condensed matter physics and nanotechnology:

Prof. Matti Manninen,
Prof. Jukka Pekola (-31.5.2002),
Docent Ilari Maasilta (1.6.2002-31.1.2004)
Prof. Markus Ahlskog (1.2.2004)
Prof. Jussi Timonen

Scientific Board of the Centre of Excellence at JYFL
Niels E. Christensen, professor (chairman), University of Århus
Paul Kienle, professor, Technical University of Münich
Timo Tiihonen, vice-rector, University of Jyväskylä
Kari Rissanen, professor, Academy of Finland
Pasi Sihvonen, secretary general, Academy of Finland

Research Activities at COE

In nuclear and accelerator based physics the research is focusing on studies of atomic nuclei and nuclear matter under extreme conditions, with many links to materials physics and applied research. The JYFL Accelerator Laboratory has become one of the leading stable-ion beam facilities in Europe. The facility is very reliable, providing more than 6500 beam time hours per year. The Accelerator Laboratory is one of the few university laboratories in Europe, where PhD students and young researchers form an essential part of the manpower. The key instruments available for experiments at the JYFL accelerator are the Ion Guide Isotope Separator On-Line (IGISOL) facility developed at JYFL and the gas-filled magnetic recoil separator RITU constructed at JYFL, which is one of the leading instruments in the world for studies of exotic heavy nuclei. Other important installations are HENDES - High Efficiency Neutron DEtector System, the large universal scattering chamber, the special irradiation facility (RADEF) for radiation effects in materials and electronics components and the facility for radioactive isotope production.

The nuclear theory group gives theoretical support to the experimental nuclear structure studies. The non-accelerator part of the research of this group is devoted to the description of nuclear processes involved in the weak-interaction physics, neutrino physics and the detection of cold dark matter in the universe.

The research teams in nuclear physics have acted as partners or coordinators in seven EU-FP4-FP5-RTD projects for the development of new joint-European instrumentation. The teams have also created other exchange programmes including a significant transfer of scientists and equipment to JYFL. The foreign investments in instrumentation already exceed 10 M€, which is unique in Finnish scientific research.

Research projects are carried out in collaboration with European teams and also with teams from the University of Helsinki, Helsinki University of Technology, Helsinki Institute of Physics (HIP) and Åbo Academy. The experimental CERN-ISOLDE activities of JYFL form a part of the Nuclear Matter programme of HIP.

The themes of the condensed matter physics are nanophysics and nanotechnology, soft condensed matter physics and statistical physics. The nanophysics research belongs to the multidisciplinary Nanoscience Centre consisting of parts of the Physics, Chemistry and Biology departments. The focuses are electronic and thermal properties and quantum coherence of nanoscale structures, molecular electronics, catalytic properties of clusters, nanosensors, and many-particle physics of quantum dots and nanowires. International collaboration includes coordination of one EU STREP network and partnership of two other EU networks and of several NordFork networks.

The most challenging research plans are manipulation of macromolecules on chip by using nanoscale fields, quantum computing with superconducting qubits, controlled electron and ion transport in carbon nanotubes, understanding of nano- and biocatalysis, and developing theoretical models for suspension flows in living cells.

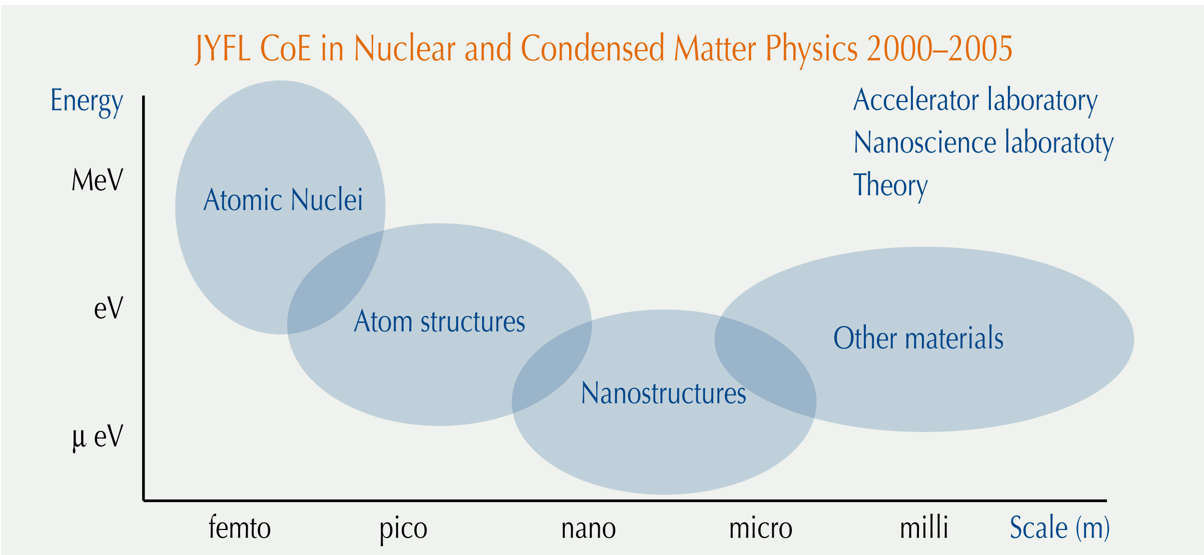
The Nanoscience Centre has been recognized as one of the strengths of the University and it has received additional funding from the Ministry of Education and from surrounding industry and district. This has helped to build up to date laboratories. The Nanoscience Centre has had a leading role in developing national programmes for nanosciences in Finland. It is expected that the special funding of nanosciences research will continue still several years.

The research of soft matter and statistical physics focuses on fracture of brittle materials, fluid flow in porous structures, dynamics of liquid-particle suspension, and properties of stochastic systems. Applications include bone research and paper technology. A new direction is to development of modern tomographic methods for gaining accurate structural information of small systems in three dimensions.

Impact of CoE

The scientific work performed at the CoE has been on a high international level. This is evidenced by the extensive list of publications in high impact journals. Nuclear and accelerator based physics research renewed its status of a Finnish Centre of Excellence for the period 2006-2010. However, Materials Physics research of the present CoE also advanced to the final selection round but was not chosen for funding. A new application is planned. Since 1996 (in FP4, FP5 and FP6), the Accelerator Laboratory has been one of the EU major research infrastructures. It also has the status of a Marie Curie Host Training Site of the EU-FP5 and furthermore receives part of its funding directly from the Ministry of Education as a National Facility.

The CoE activities have also had an effect on the society in general. The large number of research visitors (around 200 annually) has had a non-negligible effect on the society and even on the economics of Jyväskylä. Several spin-off companies, such as Nanoway, Ltd. Gammapro, Ltd., Nanolab Systems Ltd., Magnasense Ltd. and Radef Research, Ltd., have been founded for commercialisation of innovations of our research in nanophysics and radiation and accelerator-based physics. The expertise of the Accelerator Laboratory attracted a spin-off company from the Radiation and Nuclear Safety Authority of Finland, Doseco, Ltd., to Jyväskylä. A very important activity is the collaboration with MAP Medical Technology, Ltd., which uses the cyclotron weekly for radioisotope production and provides all the ^{123}I needed in Finnish hospitals. The recently awarded 4-year status as an accredited radiation test facility for space electronics of the European Space Agency ESA provides an important link to applied sciences.



Research

Nuclear and Accelerator Based Physics

Summary of Activities in the Accelerator Laboratory

Rauno Julin

In 2005, the total operating time of the cyclotron was 7253 hours, beam being on target for a total of 5495 hours. A total of 28 different isotopes from protons to ^{136}Xe were accelerated for experiments and applications. The number of scheduled experiments was 36.

The modified multipole structure for the 6.4 GHz ECR ion source of the cyclotron was completed. As a consequence, an improvement of a factor of four has been achieved in the intensity of highly-charged ion beams. ECR plasma potential measurements in conjunction with emittance measurements have shown a clear correlation between the plasma potential and the beam quality.

At IGISOL, a sextupole ion guide is now in operation and development of laser ionization allows, for the first time, simultaneous operation of Copper Vapour Laser and NdYAG pump lasers. In addition, optical pumping of radioactive ions in the RFQ has been demonstrated for the first time.

The success of the JYFLTRAP project at IGISOL has resulted in the measurement of about 100 atomic masses for nuclear structure and nuclear astrophysics along with precision decay energy measurements of superallowed beta emitters. Finally, the collinear laser spectroscopic study of charge radii and hyperfine structure of a long chain of neutron-rich yttrium isotopes has been performed.

Experiments at the CERN-ISOLDE facility are also carried out by the IGISOL team as a part of the Nuclear Matter Programme of the Helsinki Institute of Physics (HIP).

A total of 109 days of beam time were devoted to the tagging experiments of the JUROGAM campaign carried out in collaboration between the JYFL gamma- and RITU groups and groups from foreign institutes. The first successful in-beam experiment for a Z = 103 nucleus revealed bands based on proton single-particle orbitals in ^{255}Lr. Excited states in ^{106}Te were observed for the first time by employing the $^{54}Fe + ^{54}Fe$ reaction with a cross-section of only 25 nb. A successful proof-of-principle experiment for recoil-beta tagging was carried out for the N = Z nucleus, ^{74}Rb. The power of the GREAT spectrometer at the focal plane of RITU was demonstrated in a study of K isomers in ^{254}No.

For future in-beam studies of heavy-elements at JYFL, a bid of approximately £1.6 M from the UK EPSRC for construction of the combined electron- and gamma-ray spectrometer SAGE has been funded. Another grant of 0.8 M£ awarded by the EPSRC includes funds for a detector array known as LISA that will be used to observe very fast proton emitters at the target area of RITU.

The JYFL-ALICE activity forms a part of HIP Nuclear Matter Programme. JYFL bears the main responsibility for T0 – the trigger and fast timing detector of ALICE. All 2005 milestones such as radiation hardness testing, full chain readout, and the detector Production Readiness Review were successfully met. The tracking team has finalized the reconstruction algorithm and the needed physics analysis required to extract the expected yields of reconstructed kaon decays.

The Nuclear Reaction team continued its experimental program with 10 in-beam experiments and several off line measurements of the fission of ^{252}Cf.

Reno Harboe-Sorensen awarded a RADEF-medal for his work in promoting the contract between ESA and JYFL. The medal was handed to Reno by Ari Virtanen.

During 2005 the accelerator-based material physics -group was truly formed and four new PhD-students began various projects. Construction of the ion beam lithography end-station started and commissioning is planned to take place before summer 2006. Furthermore, a collaboration was formed with the local group from the Department of Health Sciences in order to study bone growth on biomimetic surfaces. These surfaces were produced using the sputter deposition technique. Material physics research was strengthened by the installation of a new ion gun for sputter depth profiling of IGISOL implanted radioactive species.

The upgrade of RADEF's SEE-beam line for ESA was completed in August when the acceptance test was performed. The official opening of the facility was held on May 27 (See Fig). The inauguration was preceded by a two day event with 70 representatives from the European radiation effects community, RADECS.

A users meeting devoted to tagging experiments at JYFL was organized on January 25-26, 2005. JYFL was co-organizer of the FINUSTAR (Frontiers In NUclear STructure, Astrophysics and Reactions) conference held at Kos island in Greece. The main organizer was the Institute of Nuclear Physics, NCSR-Demokritos.

A new Integrated Infrastructure Initiative for Nuclear Structure Physics (EURONS) in the 6th framework programme of the EU commenced on January 1, 2005. In addition to the Transnational Access Activity (TNA) of EURONS, the JYFL Accelerator Laboratory is a partner in 6 different Joint Research Activities (JRA) of EURONS. They are: INTAG for further development of tagging methods, AGATA for development of a gamma-ray tracking array, DLEP for low-energy particle detection, ISIBHI for development of an advanced ECR ion source, LASER for development of resonance ionisation laser ion sources and TRAPSPEC for development of spectroscopic methods at ion traps.

Physicists from JYFL participate in different EURISOL-DS tasks dealing with physics and instrumentation, beam intensities and beam preparation issues. The latter task is also coordinated by JYFL.

JYFL teams also participate in the preparatory design work for the HISPEC/DESPEC, LASPEC and MATS projects at the NUSTAR facility of FAIR at GSI.

JYFL continued coordination of the National Graduate School in Particle and Nuclear Physics (GRASPANP) and the Accelerator Laboratory held the status of a Marie Curie Training Site of the EU. The Marie Curie students in 2005 were Mikael Sandzelius from Stockholm, Martin Venhart from Bratislava, Iain Darby from Liverpool, Ben Tordoff from Manchester, Andrew Steer from York and Bruce Marsh from Manchester.

The proposal for a Finnish Centre of Excellence (CoE) in Nuclear and Accelerator Based Physics was approved by the Academy of Finland. In total, proposals from 142 Finnish research units were submitted, from which 23 were finally awarded CoE status. This status will provide stability in funding of the experimental and theoretical physics programme in the JYFL Accelerator Laboratory from 2006 to 2011.

Research

Accelerator Facilities

Pauli Heikkinen

The cyclotron exceeded 6000 hours/year of running for the tenth year in row. The total operating time was 7253 hours, out of which the beam-on-target time was 5495 hours. The rest of the total time consisted of stand by time due to the user, beam tuning and developing.

Proton has always been the most used ion, and it counts for almost 40% of the total due to weekly ^{123}I production for MAP Medical Technologies and due to IGISOL experiments. ^{48}Ca was the next mostly used ion (10 %). Altogether 28 different isotopes from protons to ^{136}Xe were accelerated for experiments and applications in 2005.

During the year we had some water leaks in the cyclotron RF-system due to corrosion. We suspect that one important reason for the increased corrosion was the major maintenance for the cooling system in 2004 when a lot of new water had to be added into the system and hence the oxygen content became high. We have paid special attention to the cooling water quality in order to minimize forthcoming water leaks. In addition, we plan to make spare parts of the most critical RF-components so that we can replace the old ones without a long shut-down period.

Research and development work at the ion sources has been active. A new method, known as the Modified Multipole Structure (MMPS), for increasing the radial magnetic field strengths has been developed and tested by the ion source group. The MMPS plasma chamber has been designed, constructed and installed in the JYFL 6.4 GHz ECRIS. The ion beam intensity increased almost linearly as a function of the ion charge-state being up to 4 fold for highly charged ions like Ar^{14+}. Also the studies of gas mixing and plasma potential have been continued. The plasma potential and energy spread of

Pauli Heikkinen, chief engineer
Hannu Koivisto, senior assistant
Pekka Suominen, graduate student
Olli Tarvainen, graduate student
Arto Lassila, laboratory engineer
Veikko Nieminen, laboratory engineer
Teuvo Poikolainen, laboratory engineer
Kimmo Ranttila, laboratory engineer
Juha Ärje, laboratory engineer
Jani Hyvönen, operator
Anssi Ikonen, operator
Hannu Leinonen, technician
Raimo Seppälä, technician
Pentti Frondelius, MSc student
Tommi Ropponen, MSc student
Laura Tuomikoski, MSc student
Outi Virtanen, MSc student

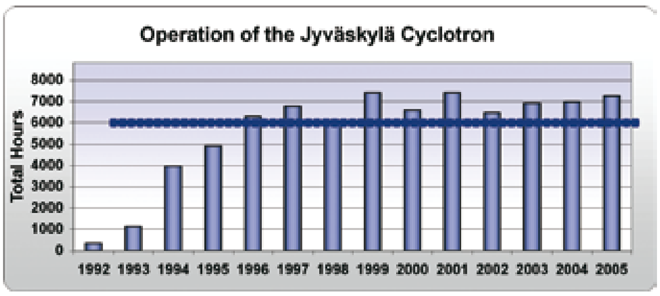


Fig. 1. Operation of the Jyväskylä cyclotron in 1992-2005

the ion beams were studied with a plasma potential instrument developed at JYFL. The results obtained in the emittance measurements support the conclusion that the ion temperature changes due to gas mixing. The effect of the energy spread on the measured emittance in the bending plane of the magnet can be several tens of percent.

Multiple-frequency heating is known to increase the performance of ECR-sources. Three-frequency heating experiments were carried out with the aid of the microwave oscillator borrowed from the Finnish Airforce (C4IS MC). According to the first results the intensity of highly charged ions, like Xe^{30+} ion beam, increased 30 – 50 % compared to the two-frequency heating operation. In another experiment the charge-state enhancing effects of broadband microwave radiation (bandwidth: 200 MHz) was tested and demonstrated by comparing the high-charge-states of Ar ion beams, produced by the JYFL 6.4 GHz ECRIS. The results of these studies show that the ratio of broadband to conventional bandwidth (≈ 1.5 MHz) generated high-charge-state beams continually increases for charges-states $q > 9$ and improvement of up to 2 was achieved. This work was suggested and carried out in collaboration with the ion source group of Oak Ridge National Laboratory.

Research

Exotic Nuclei and Beams

Ari Jokinen
Iain Moore
Heikki Penttilä
Kari Peräjärvi
Juha Äystö

Our activity in 2005 has continued along the well established path consisting of numerous experiments and R&D on instrumentation at JYFL and ISOLDE, CERN. The work at ISOLDE is carried out within the Nuclear Matter Program of the Helsinki Institute of Physics (HIP). In addition, our group, with support of the Helsinki Institute of Physics has actively participated in the planning of the experiments for the super fragment separator at the future Facility for Antiproton and Ion Research (FAIR) at GSI.

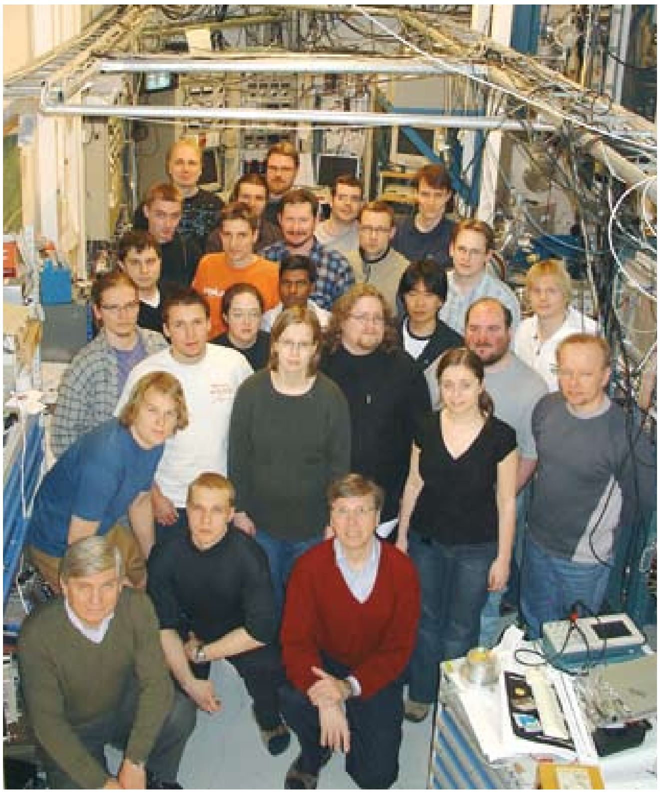
Major technical achievements at IGISOL have been the implementation of a new Sextupole Ion Guide for guiding the ions from the gas cell into the separator. The computer control software has been implemented to operate the JYFLTRAP setup in a nearly full automatic mode. The FURIOS laser ion source setup has been upgraded significantly so that both the Copper Vapour Laser and Nd:YAG pump lasers can now be operated simultaneously providing broad range mixed dye-Ti:Sapphire laser schemes. Optical pumping of radioactive ions in the RFQ has been demonstrated for the first time.

The main highlights of the experiments performed at the IGISOL-JYFLTRAP setup include the first accurate mass measurement of over 80 neutron-rich isotopes from fission and measurement of charge radii and hyperfine structure of a long chain of neutron-rich yttrium isotopes. Moreover, high-precision measurements on the decay energies of the superallowed Fermi decays have been done for a number of cases of which ^{62}Ga has been studied for the first time. Another new area for mass measurements was opened by measuring the masses of 17 neutron-deficient nuclei of interest for the rp-process near the Z=N line above the A=80 region.

Research group 2005

Juha Äystö, professor
Ari Jokinen, senior researcher
Iain Moore, senior researcher
Heikki Penttilä, academy researcher
Kari Peräjärvi, senior researcher 1.8. – (Helsinki Institute of Physics)
Valery Rubchenya, senior researcher
Saidur Rahaman, postdoctoral researcher 1.7.–
Tetsu Sonoda, postdoctoral researcher
Viki-Veikko Elomaa, graduate student
Tommi Eronen, graduate student
Ulrike Hager, graduate student
Jani Hakala, graduate student
Anu Kankainen, graduate student
Pasi Karvonen, graduate student
Thomas Kessler, graduate student
Sami Rinta-Antila, graduate student
Antti Saastamoinen, graduate student
Bruce Marsh, Marie Curie graduate student – 6.4.
Benjamin Tordoff, Marie Curie graduate student
Joonas Koivisto, MSc student
Juho Rissanen, MSc student
Janne Ronkainen, MSc student
Perttu Ronkanen, MSc student 1.10. -
Jani Turunen, MSc student 1.11. -

Apart from mass measurements JYFLTRAP has been applied in various other studies, including decay spectroscopy after the purification trap (ref 4), charged



particle spectroscopy inside the trap (ref 5) and the fission yield studies employing ion counting after the purification trap (ref 6).

At ISOLDE our team members have been involved in several experiments, including structure studies of n-rich Mg isotopes near the island of inversion, in the mass measurement of the n-rich Zn isotopes as well as in developing the new ion beam cooler for the ISOLDE facility. Finally, experimental studies for a potential new neutrino detector based on ^{100}Mo have been continued and finished at IGISOL.

Our team has been benefiting significantly from collaborations with several groups from Europe and the US as well as from EU-funded JRA projects NIPNET, LASER, DLEP and TRAPSPEC as well as from the Design Study projects EURISOL and DIRAC.

Technical Development

Laser Ion Source Development (ref 8)

Yttrium is one of the elements of choice for extensive testing of the FURIOS laser ion source. Several optical excitation and ionization schemes have been developed, including the first mixed dye-Ti:Sapphire laser scheme. In parallel a new Heavy-Ion laser ion guide has been built. Incorporating selective laser ionization into the gas volume will begin in earnest in 2006.

In order to achieve highest selectivity, development of the LIST (Laser Ion Source Trap) began in 2005 with the installation of a new sextupole ion guide (SPIG), replacing the skimmer system. The SPIG has been a great success with on-line efficiencies for reactions improved by a factor of 3 compared to previous IGISOL measurements. In early 2006 the first off-line LIST measurements were successfully performed on stable bismuth atoms. This work not only highlighted the selectivity of using the LIST method, but also the ability to perform resonance ionization spectroscopy at the ion source on a sub-millisecond timescale. This offers the promise of nuclear structure studies on isotopes and isomers with half-lives well below 1 ms.

Ion Guide Development

The development work of ion guides concentrated this year on improvements and tests of the HI-induced fusion reaction ion guide, HIGISOL (Ref 11). A HIGISOL chamber equipped with an electron emitter whose function is to compensate the positive space charge was tested on-line with the reaction $^{32}S+^{nat}Ni$ at 140 MeV. A factor of more than 10 increase in the yield was observed. The absolute efficiency of the ion guide was, however, low due to stopping gas impurities. These experiments clearly showed that employing an electric field and an electron emitter are beneficial also in the on-line conditions.

The first on-line tests of a liquid helium-filled ion guide employing superfluid liquid helium took place in late 2005 using 13 MeV protons (ref 7). This project is related to the production of cold ion beams at the future FAIR facility of GSI and is conducted within the EU-funded DIRAC design Study project.

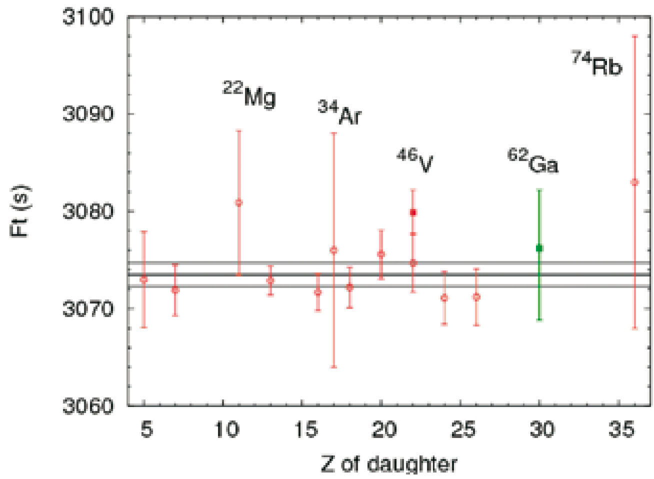


Fig. 1. The most precisely known Ft-values and the world average as given in the recent compilation by J. Hardy and I. Towner. The five newest measurements are labeled by the nuclide. The values labeled by the filled squares are not included in the world average.

Experimental Highlights

The Q_{EC}-values of Superallowed Beta Decays (ref1)

At IGISOL we have initiated a high-precision mass measurement programme to obtain the Q-values for the superallowed Fermi decays that are used in testing the Conserved Vector Current (CVC) theory and the unitarity of the CKM matrix of the Standard Model. The first cases under study are ^{26}Al, ^{26}Si, ^{42}Sc, ^{42}Ti, ^{46}V and ^{62}Ga. As the first case, the beta-decay Q-value of the superallowed 0^+ emitter ^{62}Ga was determined at JYFLTRAP during the spring of 2005. Since the other experimental contributions - the branching ratio and the half life - to the Ft value had been measured precisely, the measurement of the Q-value significantly improved the ^{62}Ga Ft-value precision. The new ^{62}Ga Ft value has a comparable precision to the other well known superallowed beta emitters and it adds further support to the conserved vector current (CVC) hypothesis as can be seen in Fig. 1.

Mass Measurements with JYFLTRAP (ref 2)

Since commissioning of the JYFTRAP more than 80 atomic masses of neutron-rich isotopes from Ge (Z = 32) up to Pd (Z = 46) have been measured thus far with a typical accuracy of 10 keV or better. All these isotopes were produced in the proton induced fission of ^{238}U. Singly charged ions delivered by IGISOL were bunched and cooled in the RFQ, mass purified in the purification trap and finally their masses were determined in the precision trap by employing the TOF-technique. Reference isotopes for mass measurements were produced in identical conditions.

The obtained mass data deviates remarkably in some mass chains from the values given in the latest Atomic Mass Evaluation 2003. This observation underlines an importance of the precision measurements. In general, precision binding energy data is of importance for the development of mass predictions as well as for nuclear astrophysics predictions. Precision data is also a useful tool to obtain information of underlying nuclear structure effects.

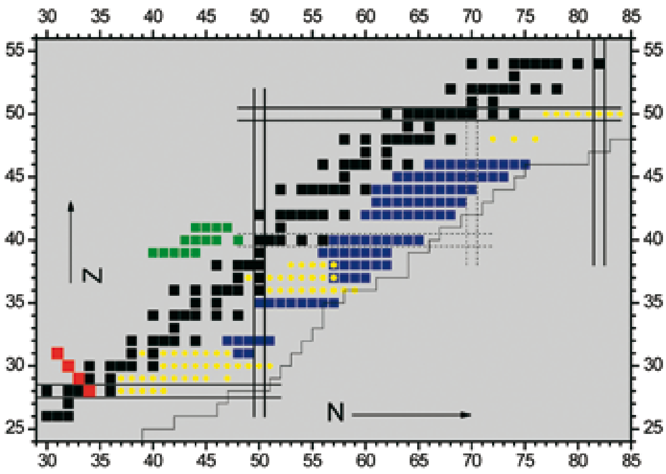


Fig. 2. A nuclide chart displaying the precision mass measurements for neutron-rich nuclei. The yellow circles show the recent mass measurements of ISOLTRAP and the blue squares correspond to the JYFLTRAP measurements. In addition, recently measured neutron-deficient isotopes at A=62 and in the A=80-90 region are illustrated with red and green symbols, respectively.

Independent Fission Yields with JYFLTRAP (ref 6)

Independent fission yield distributions are important as input parameters in simulations of future ISOL-based radioactive beam facilities such as EURISOL. Although the initial energy of the projectiles from a driver accelerator can be high, a considerable fraction of the fission yield is due to secondary low-energy protons and neutrons. A new approach to determine the independent yields of fission fragments mass separated by IGISOL was developed. It is based on identifying and detecting fission product ions by direct counting after separation in the purification trap of the JYFLTRAP system with a typical mass resolving power of 10^5. Due to a fast separation time of IGISOL (few ms) only directly produced ions are detected and hence independent yields measured. The information on the fission yields gathered using this technique also supports the on-going theoretical work to develop a reliable model to calculate the fission product yields. The drawback of the method is currently that it provides only relative isotope yield distributions due to slight variations of the IGISOL efficiency for different elements. Fig. 3 shows the relative fission yield curves for isotopes of some highly refractory elements in 25 MeV proton induced fission of ^{238}U.

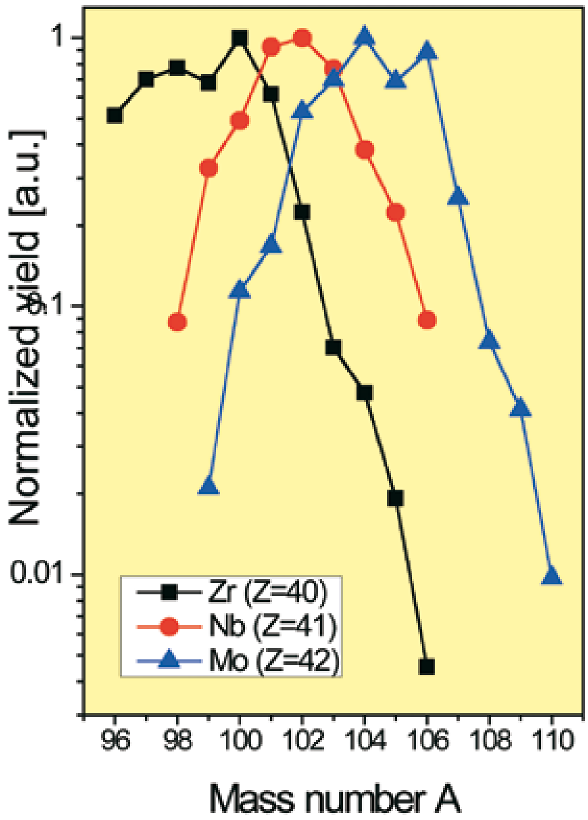


Fig. 3. Isotopic distribution for Zr, Nb and Mo isotopes determined from isobaric scans after the purification trap. Yields are normalized to one for the maximum of each yield curve.

Laser Spectrosopy (ref 10)

In 2004 the laser-IGISOL collaboration reported measurements on near-stability neutron-deficient yttrium isotopes and isomers. Those measurements were a vital prerequisite for our subsequent study of yttrium fission fragments. This has revealed charge radii information on 25 ground and isomeric states together with magnetic and quadrupole moments – previously almost entirely unknown.

The optical spectra displayed in figure 4 cover the region from N = 53 to 63 where a sudden onset of deformation has been observed in neighbouring chains. This shift, at N = 59 in yttrium, is first observed between the ^{98}Y ground state and isomer and arises as the ground state changes from oblate to strongly prolate. Subject to spin confirmation, ^{102}Y may lie past the point of maximum deformation.

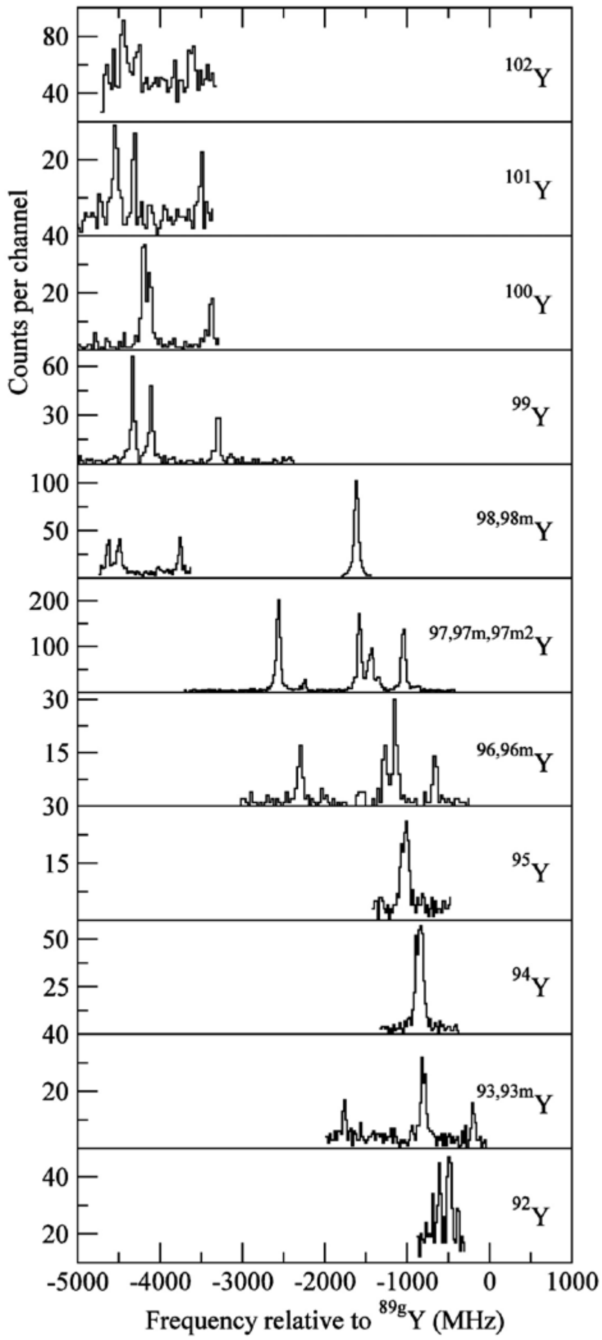


Fig. 4. Resonance fluorescence spectra for the yttrium fission fragments.

In the isotope ^{97}Y, two isomeric states of spins I = 9/2 and I = 27/2 were observed. Compared with the one-quasiparticle I = 9/2 ^{97}Y isomer, the rms charge radius of the I = 27/2 isomer is smaller. Four similar examples of such behaviour have been observed (two measured by the collaboration previously at JYFL) for deformed multi-quasiparticle K-isomers. In none of these isomers can the reduction be attributed to a reduction in quadrupole deformation.

The first known example was the 31 year ^{178}Hf I = 16^{+} isomer which, despite the slightly larger deformation, has a smaller charge radius than the ground state. The I = 16^{+} isomer is a combination of two 8^{-} 2-quasiparticle states, one being a 4 second isomer also studied by the collaboration this year. The spectrum is shown in Fig. 5. A decrease in size relative to the ground state is again apparent. The reduction in the mean-square charge

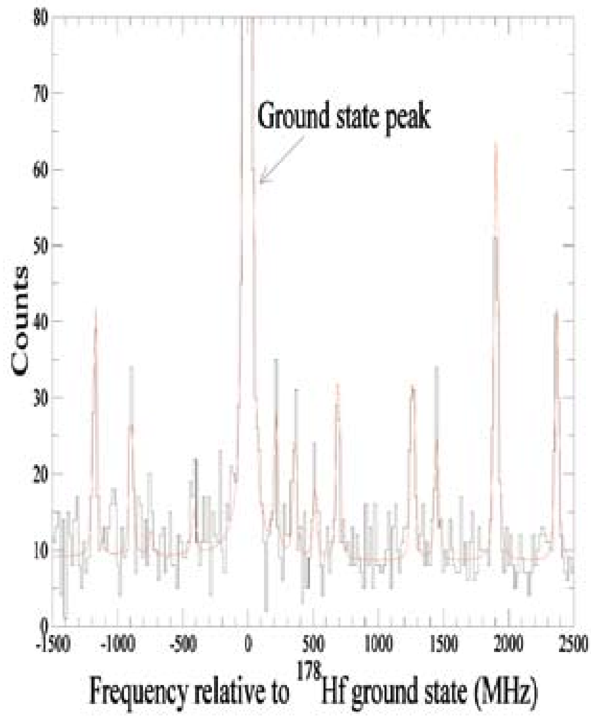


Fig. 5. The fitted hyperfine structure of the 8^{-} isomer and ground state of ^{178}Hf.

radius for this 2-quasiparticle configuration compared with the ground state is around 45 % of that observed for the 16^+ isomer. The reduction in charge radius thus seems to be a general feature of multi-quasiparticle states and may be caused by the reduction of pairing correlations in these states.

Optical Manipulation of Ions within an RFQ Device

For the past four years the RFQ cooler-buncher at the IGISOL facility has been successfully used to permit a highly efficient and low background variant of collinear laser spectroscopy to be performed. For ionic spectroscopy, however, cooling and bunching of the reaction products limits the optical spectroscopy to transitions from the electronic ground state. Metastable state populations, which in many cases are far more attractive starting points for laser spectroscopy, relax in the cooler during beam preparation.

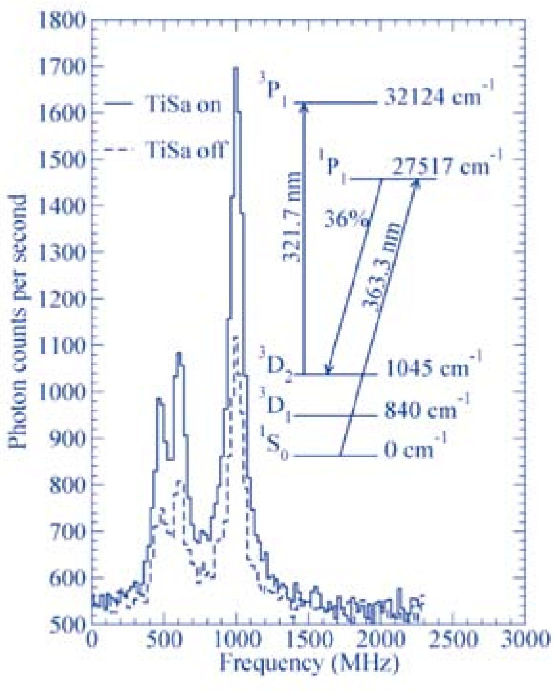


Fig. 6. Fluorescence spectrum of cooled $^{89}Y^+$. The optical transition is excited from the second metastable state of Y^+ and the effect of laser optical pumping is shown.

Recently, efficient manipulation of ionic state populations using optical pumping within the RFQ cooler buncher has been demonstrated by the Birmingham-Jyväskylä-Manchester laser collaboration. Pumping is achieved by illuminating the thermalisation axis of the cooler with light from a pulsed Ti:Sapphire laser. Fig. 6 shows two resonance fluorescence spectra observed in $^{89}Y^+$ obtained using the collinear laser spectroscopy technique. For both spectra the optical transition is excited from the same metastable state and the effect of optical pumping in the cooler can be observed. The ability to manipulate state populations using broad bandwidth pulsed lasers will greatly extend the laser spectroscopy program at the IGISOL facility.

EC Branching of ^{100}Tc Decay (ref 9)

The EC decay branch of ^{100}Tc is important for two reasons. The experimental value of the EC matrix element is the most uncertain of the values needed for ^{100}Mo double-beta decay calculations. Secondly, it has been proposed to build a neutrino detector based on the neutrino capture of ^{100}Mo, which is an inverse process to EC of ^{100}Tc. The most precise value for this matrix element has been thus far measured indirectly from the charge exchange reaction ^{3}He+^{100}Mo → ^{3}H + ^{100}Tc. At IGISOL the ^{100}Tc activity was produced via (p,n) reactions on an enriched ^{100}Mo target. The determination of the branching was based on the intensities of the 540 keV gamma ray in the ^{100}Tc decay to ^{100}Ru, observed in coincidence with betas, and the Mo X-rays observed in anticoincidence. The deduced value is three times larger than the previously measured one. However, it is consistent with EC log ft systematics in this region.

Work at ISOLDE

Research on the "island of inversion" continued with a dedicated experiment to look for an E0-transition in

^{30}Mg from a tentative deformed second 0^+ state. The feasibility study resulted in an upper limit for such an E0 branch, but the sensitivity has to be increased for the positive identification of the E0 decay.

Several on-line measurements were conducted at ISOLTRAP during 2005. Masses of ^{71}Zn to ^{81}Zn were measured with high precision as well as masses of $^{120,122,124}Cd$. We have also participated in the new project aiming to implement a tape station above ISOLTRAP for decay spectroscopy with isobarically or even isomerically purified samples.

The ion cooler and buncher project has progressed well with a financial support from the scientific board, EPSRC, in the UK. Parallel to hardware, a new control system was implemented for RF-devices and all power supplies. The same principle for control will also be used for the rest of the ISOLDE control system.

List of collaborators

Manchester University Collaboration
Jonathan Billowes, head
Paul Campbell
Bradley Cheal
Malamatenina Avgoulea
Ben W. Tordoff
Bruce A. Marsh
Ernesto Mane Junior

Birmingham University collaboration
Garry Tungate, head
David Forest
Katarzyna Baczynski
Matthew Gardner
Mark Bissel

Mainz University collaboration
Klaus Wendt
Katja Wies

KVI RIASH collaboration
Peter Dendooven
Sivaji Purushothaman
Kurt Gloos (University of Turku)

ISOLTRAP and SHIPTRAP groups

Experiment spokespersons and collaborating institutes in 2005

[1] B. Blank, T. Eronen, Szerypo, CNBG, Bordeaux, France; LMU München, Germany; Texas AM University, USA
[2] A. Jokinen, S. Kopecky, LMU, München, Germany; IKS Katholieke University, Leuven, Belgium
[3] Yu. Novikov, St. Petersburg Nuclear Physics Institute, Gatchina, Russia; Michigan State University, East Lansing, Michigan, USA; St. Petersburg State University, Russia; Giessen University, Germany
[4] S. Rinta-Antila,
[5] A. Jokinen, NIPNET RTD project
[6] H. Penttilä, V. Ricciardi, Khlopin Radium Institute, St. Petersburg, Russia; GSI, Darmstadt, Germany
[7] P. Dendooven, KVI, Groningen, Netherlands; Institute of Modern Physics, Lanzhou, China; Osaka Gakuin University, Japan; University of Turku
[8] I. D.Moore, K.D.A. Wendt, University of Mainz, Germany; University of Manchester, UK
[9] A. Garcia, University of Washington, Seattle, USA; Argonne National Laboratory, Argonne, USA
[10] P. Campbell, University of Manchester, UK; University of Birmingham, UK
[11] A. Popov, P. Dendooven, St. Petersburg Nuclear Physics Institute, Gatchina, Russia; KVI, Groningen, Netherlands; ION CATCHER RTD project

Research

In-beam Spectroscopy

Paul Greenlees
Pete Jones
Rauno Julin
Sakari Juutinen

Rauno Julin, professor
Sakari Juutinen, senior assistant
Pete Jones, senior researcher
Paul Greenlees, academy researcher
Panu Rahkila, graduate student
Janne Pakarinen, graduate student
Tuomas Grahn, graduate student
Markus Nyman, graduate student
Juha Sorri, graduate student
Mikael Sandzelius, Marie Curie graduate student –15.5.
Jani Leskinen, MSc student
Katri Mäntyniemi, MSc student
Pauli Peura, MSc student
Steffen Ketelhut, visiting MSc student

Tagging Experiments with JUROGAM

As in 2004, a significant part (109 days) of the JYFL beam time was devoted to the in-beam gamma-ray spectroscopy experiments of the JUROGAM campaign. The majority of the measurements employed the Recoil-Decay Tagging (RDT) technique whereby the JUROGAM array is coupled to the RITU gas-filled recoil separator and reaction products are identified with the aid of the GREAT focal-plane spectrometer. The campaign was therefore carried out in close collaboration with the RITU group.

JUROGAM is an array of 43 EUROGAM Phase I-type Compton-suppressed Ge detectors supplied from the EUROBALL and UK-France detector pools which surrounds the target of the RITU separator. The photo-peak efficiency of the array for the detection of 1.3 MeV gamma rays is approximately 4.2 %. Combined with the RITU separator, the U.K. funded focal plane spectrometer GREAT and associated Total Data Readout (TDR) acquisition system, it forms the world's most powerful spectrometer system for studies of the structure of heavy proton drip-line and transfermium nuclei.

Instrumentation Developments for In-Beam Experiments Using JUROGAM

Two tests were performed during 2005 whereby JUROGAM detectors were instrumented with digital electronics. In collaboration with IReS, Strasbourg, the TNT2 digital sampling ADC was used to instrument 4 Phase I detectors together with their Compton Suppression Shields. In addition the unit was interfaced into the TDR system in such a way that the traditional analogue signals could be combined with the digital signals. In-beam tests were performed using the ^{36}Ar + ^{nat}Ag reaction at 160 MeV and increasing the beam intensity to cover the germanium counting rate in the region of 10-100 kHz. Whereas the spectra from the current analogue instrumented detectors suffered deterioration in quality after a counting rate of 10 kHz, the same digitally instrumented detector remained usable up to a counting rate of 50 kHz.

Following on from this, a second test was performed using a Clover-type detector (comprising 4 Ge crystals) and Compton shield. A test rig was set up with the detector replacing one half of the JUROGAM array to compare under experimental conditions the spectrum quality of the Clover versus the current detectors. The same test reaction was performed and the Clover detector instrumented using both analogue and digital electronics, and the beam intensity steadily increased. The same results were concluded, that a reasonable limit of 50 kHz could be tolerated. However the increased efficiency of the Clover detector in comparison with the Phase I type detectors showed a 50% increase in statistics, with comparable peak-to-background.

The tests show that the current JUROGAM detectors could be instrumented using digital electronics and allow for increased beam intensities. This is of importance to those experiments which are currently limited by the prompt counting rates. In addition the upgrade of the array using Clover detectors in place of some of the current detectors would both allow for improved statistics and solve the counting rate problem. Indeed, such an upgrade would only be feasible using the latest digital sampling technology with pulse shape processing.

SAGE – a Combined Electron- and Gamma-Ray Spectrometer

A bid for approximately 1.6 million pounds from the UK EPSRC for the SAGE project has been funded. The application was from Daresbury Laboratory and the University of Liverpool for the spectroscopy of superheavy nuclei. The grant is for four years and includes funds for the SAGE spectrometer, which is a combined electron- and gamma-ray spectrometer to be used at the RITU target area for tagging studies of heavy nuclei.

LISA – an Array to Observe Very Fast Proton Emitters

The UK EPSRC has also decided to fund the LISA project, proposed by the Universities of Liverpool and Surrey

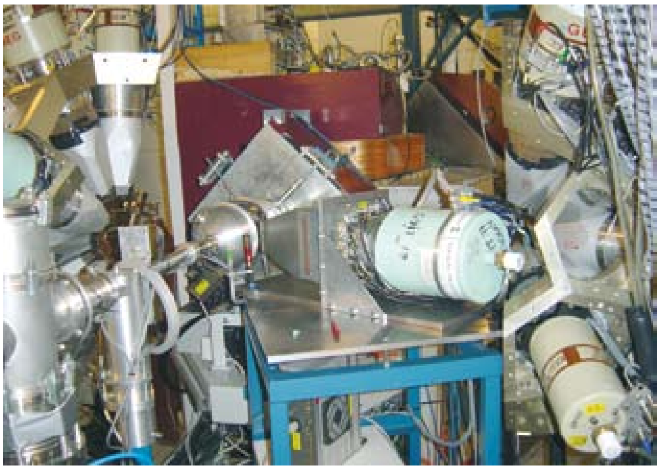


Fig. 1. Testing digital electronics with a Clover detector at JUROGAM

and Daresbury Laboratory. This four year grant is approximately 0.8 million pounds and is for the study of heavy proton-rich nuclei. The grant includes funds for a detector array known as LISA that will be used to observe very fast proton emitters at the target area of a recoil separator in tagging experiments.

Details of the JUROGAM Experiments

A total of 109 days of beam time were devoted to the tagging experiments of the JUROGAM campaign carried out in collaboration between the JYFL gamma- and RITU groups and groups from foreign institutes. The experiments were:

[1] Proof-of-principle for recoil-beta tagging
[2] Alpha decay tagging of ^{106}Te and ^{107}Te
[3] In-beam gamma-ray spectroscopy study of ^{253}No
[4] In-beam gamma-ray spectroscopy of the transfermium nucleus ^{255}Lr
[5] Identification of excited states in the proton unbound nucleus ^{166}Ir
[6] Recoil-decay tagging of exotic light neutron-rich (N = 28, Z = 18) nuclei employing the alpha-decaying nuclei produced in deep-inelastic reactions

[7] Shape co-existence in very-neutron deficient ^{189}Bi
[8] Identification of excited states in the deformed proton emitter ^{117}La using recoil-decay tagging with JUROGAM, RITU and GREAT
[9] Search for deformed excitations in ^{185}Pb
[10] Commissioning the second multi-wire proportional counter for GREAT
[11] Search for N=82 shell quenching for neutron-rich nuclei

Analysis of the new data from most of these experiments is still in progress. The following sections report preliminary results along with more detailed analysis of some experiments from the earlier JUROGAM campaigns.

First Observation of Rotational Structures in ^{255}Lr

In a continuation of the programme of experiments to study the properties of transfermium nuclei close to the deformed N=152 shell gap, the properties of ^{255}Lr were studied in an experiment employing JUROGAM, RITU and GREAT. The ^{255}Lr nuclei were produced in a ten-day irradiation using the ^{209}Bi(^{48}Ca,2n)^{255}Lr reaction at a bombarding energy of 221 MeV. The resulting recoil-gated gamma-ray spectrum is shown in Fig 2.

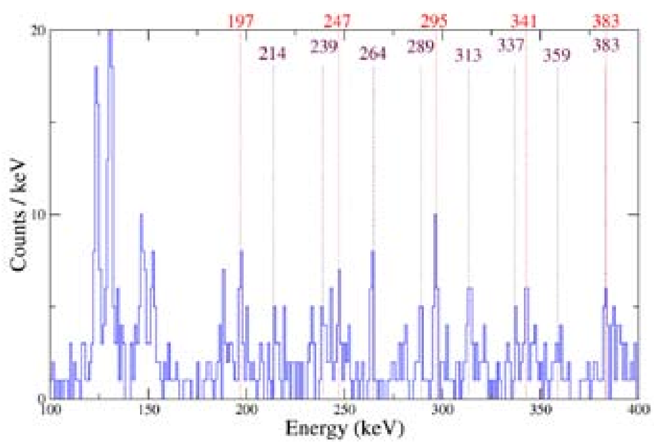


Fig. 2. Recoil gated gamma-ray spectrum associated with ^{255}Lr

Close inspection of the complex spectrum reveals three possible rotational structures with similar moments of inertia. Earlier studies carried out at JYFL and GANIL investigated the alpha-decay properties of ^{255}Lr and the daughter activity ^{251}Md. These studies revealed that the ground state of ^{255}Lr is a $1/2^-$[521] state, with a $7/2^-$[514] state at an excitation energy of 37 keV [1]. The $1/2^-$[521] orbital slopes down strongly and belongs to the $2f_{5/2}$ spherical shell-model state. The $f_{7/2} - f_{5/2}$ spin-orbit splitting determines the size of the possible shell gap at Z=114. In-beam studies of ^{251}Md (also carried out using the JUROGAM, RITU and GREAT combination) showed clear evidence for a rotational sequence of gamma rays with energies of 195, 245, 292, 336, 377, 415 and 450 keV. The absence of a signature-partner band suggested that this sequence belongs to the $1/2^-$[521] state, which has a decoupling parameter of close to one. Inspection of the spectrum shown in Fig. 2 shows a sequence of transitions (197, 247, 295, 341 and 383 keV) with very similar energies to the $1/2^-$[521] band in ^{251}Md. Again, no clear signature partner band is observed in ^{255}Lr, leading to the conclusion that the same $1/2^-$[521] band is observed in ^{255}Lr. Searching through the spectrum for other similarly-spaced sequences reveals two more structures, as marked in the figure. The two regularly-spaced bands suggest a strongly-coupled structure based upon the $7/2^-$[514] state. Gamma-ray spectra tagged with the alpha-decays from the relevant states also support this interpretation. ^{255}Lr is thus the heaviest nucleus for which in-beam spectroscopic data has been obtained.

Onset of Collectivity in the Tellurium Isotopes

In an attempt to extend the RDT measurements towards lighter nuclei, an experiment for ^{106}Te was performed. The symmetric reaction ^{54}Fe(^{54}Fe,2n) ^{106}Te was used, which was a challenge for the RITU separator. The short half-life of 70μs for the ^{106}Te α decay enabled a clean tag of the γ-rays detected by JUROGAM.

The production cross-section of ^{106}Te was only 25 nb, which sets a new limit for in-beam γ- ray spectroscopy. Five γ-ray transitions in ^{106}Te were identified. On the basis of intensity and coincidence information they form an irregular E2 yrast cascade in ^{106}Te (Fig.3). Shell model calculations restricted to the $2d_{5/2}$ and $1g_{7/2}$ subshells for both neutrons and protons qualitatively reproduce the observed level pattern. The result reveals an abrupt transition in the structure between the yrast 4^+ and 6^+ states for neutron number below N = 56. This is different from the gradual depression of the 4^+ - 6^+ level spacing observed close to the top of the neutron shell. This effect could emanate from a shift in the balance between single-particle (seniority) coupling and collective vibrational behavior that is due to residual proton-neutron interactions. It may imply that the vibrational collectivity in the neutron deficient tellurium nuclei is sustained by the influence of isoscalar neutron-proton residual interactions that become favourable as N approaches Z.

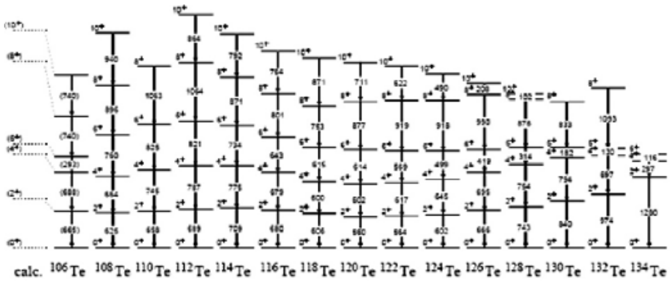


Fig. 3. Level systematics of even-A Te isotopes and a scheme for ^{106}Te based on shell model calculations.

Super Deformation in ^{191}Bi

An in-beam γ-ray spectroscopic study of ^{191}Bi was carried out in order to systematically investigate the evolution of various nuclear shapes in odd-mass bismuth isotopes. A previous experiment, also performed at JYFL, did not provide enough statistics for reliable γγ-coincidence analysis. The aim of the current experiment was to use the improved experimental set-up to address the so far unresolved features of ^{191}Bi. Surprisingly, a rotational band characteristic of nuclear superdeformation was observed (Fig. 4). This is the first time such a band has been observed in a nucleus that is populated so weakly that the Recoil-Decay-Tagging technique is required for identification. The decay out of the superdeformed minimum was not observed, but the band appears when tagging with α-decays from the 1/2$^+$ intruder state of ^{191}Bi. The band does not appear when tagging with the α-decays from the 9/2$^-$ ground state. Presently about 80 rotational bands associated with superdeformed shapes in mass region A~190 have been identified in various isotopes of Au, Hg, Tl, Pb, Bi and Po. In bismuth nuclei superdeformation has been previously observed in ^{195,196,197}Bi. In 2005, an RDT experiment on ^{189}Bi was carried out to continue systematic studies of light odd-mass bismuth isotopes.

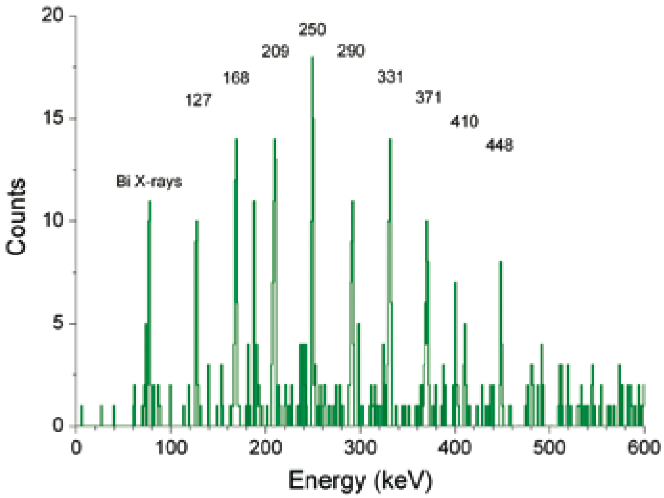


Fig. 4. The RDT gamma-ray spectrum associated with a superdeformed band in ^{191}Bi

Quadrupole Collectivity of Intruder States in ^{186}Pb, ^{188}Pb and ^{194}Po

Preliminary results from the lifetime measurements of prolate intruder states in ^{186}Pb and ^{188}Pb and oblate intruder states in ^{194}Po were reported in the earlier JYFL annual reports. In these measurements the RDT method was used for the first time by replacing the JUROGAM target chamber with the modified Köln plunger at RITU. The final results in the form of transition quadrupole moments $|Q_t|$ are shown in Fig. 5 for the low-lying yrast states.

The unmixed character of the spherical ground state of ^{186}Pb and ^{188}Pb is reflected in the low collectivity of the 2^+ to 0^+ transition. The observed high collectivity of the 4^+ to 2^+ transition indicates a large collective (prolate) component in the 2^+ states of these nuclei. In fact, the first excited 2^+ state in ^{186}Pb is revealed to be a pure member of the prolate band. By using the average $|Q_t|$ value of the transitions between the assumed pure prolate 2^+, 4^+, 6^+ and 8^+ states in ^{186}Pb and the 4^+, 6^+ and 8^+ states in ^{188}Pb, a quadrupole deformation parameter $|\beta_2| = 0.29(5)$ for both of these nuclei can be extracted. This value is in agreement with the theoretical values obtained from various approaches.

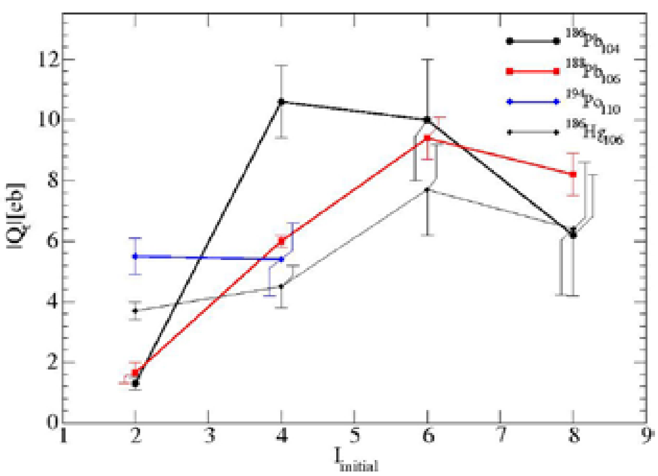


Fig. 5. Transition quadrupole moment $|Q_t|$ determined for yrast transitions in ^{186}Pb, ^{188}Pb and ^{194}Po. For comparision, the values extracted for ^{196}Hg from Proestel et al. in Phys. Lett. 48B, 102 (1974) are shown.

For ^{194}Po the present results reveal that the collectivity of the 2^+ to 0^+ and 4^+ to 2^+ transitions is much lower than that of the transitions between the prolate states in ^{186}Pb and ^{188}Pb. The similar $|Q_t|$ values for the 2^+ to 0^+ and 4^+ to 2^+ transitions indicate that the assumed oblate component in the ground state is large. From the average of the $|Q_t|$ values a deformation parameter $|\beta_2| = 0.17(3)$ for ^{194}Po is obtained.

Spokespersons and Collaborating Institutes Outside Jyväskylä of the JUROGAM Campaign in 2005

[1] D.G. Jenkins,
University of York, U.K.; University of Liverpool, U.K.

[2] B. Cederwall,
KTH- Stockholm, Sweden;
University of York, U.K.; University of Liverpool, U.K.; Daresbury Laboratory, U.K.

[3] R.-D. Herzberg, P. Reiter,
University of Liverpool, U.K.;
University of Köln, Germany

[4] P.T. Greenlees, R.-D. Herzberg, Ch. Theisen,
University of Liverpool, U.K.;
DAPNIA/SPhN CEA Saclay, France;
GANIL, France; IReS Strasbourg, France;

[5] C. Scholey, D.T. Joss,
KTH- Stockholm, Sweden;
University of Liverpool, U.K.;
Daresbury Laboratory, U.K.

[6] J. Uusitalo,
University of Paisley, U.K.

[7] S. Juutinen, Y. Le Coz,
DAPNIA/SPhN CEA Saclay, France

[8] J. F. Smith,
University of Manchester U.K.

[9] A.N. Andreyev,
TRIUMF, Canada; Comenius University, Slovakia

[10] D.M. Cullen,
University of Manchester U.K.

[11] X. Liang,
University of Paisley, U.K.

The JYFL Gas-filled Recoil Separator RITU

Matti Leino
Juha Uusitalo

As during previous years, the activity of the RITU group in 2005 focused on recoil decay tagging in-beam γ-ray spectroscopy (JUROGAM campaign) studies. The RITU separator was successfully used in a large variety of experiments. In the region of the heaviest elements an in-beam experiment of ^{255}Lr [1] was performed with very low background conditions. In the lead region many nuclei were again studied using both asymmetric and symmetric reactions. The isotope ^{106}Te [2] was produced using the symmetric reaction of a ^{54}Fe beam impinging on a ^{54}Fe target and was successfully separated from the primary beam.

Tests with the ^{36}Ar + ^{46}Ti and ^{36}Ar + ^{40}Ca reactions were carried out using the updated RITU separator. In these tests it was demonstrated that the light N ~ Z nuclei with A = 70 ~ 90 can be studied using RITU, provided that they are produced at energies around the Coulomb barrier. These experiments involved in-beam β-decay tagging tests, where the idea to use fast β-decay to tag γ-rays of certain residues was demonstrated to work well. In these experiments, the conventional 300 μm thick DSSD implantation detector was replaced with a 700 μm thick detector [3].

The idea to use α-decaying target-like recoils to tag γ-rays from neutron-rich beam like recoils produced in deep-inelastic reactions was tested. Beams of ^{48}Ca, ^{65}Cu, ^{86}Kr and ^{136}Xe were used on ^{209}Bi targets at Coulomb barrier energies [4] (Fig. 1). Coulomb barrier energies were used to allow the heavy fragments to enter the RITU separator. The tests demonstrated the feasibility of this new method to study neutron-rich nuclei.

Matti Leino, professor
Juha Uusitalo, senior researcher
Catherine Scholey, post doctoral researcher
Sarah Eeckhaudt, graduate student
Ari-Pekka Leppänen, graduate student -30.11.
Jan Sarén, graduate student
Iain Darby, Marie Curie graduate student -30.4.
Andrew Steer, Marie Curie graduate student -10.7.
Martin Venhart, Marie Curie graduate student 7.3.-
Ulrika Jakobsson, MSc student
Erna Kaleva, MSc student

A new Multi-Wire Proportional Counter (MWPC) system, placed at the focal plane of the RITU separator, was commissioned [5]. The idea was to enhance the performance

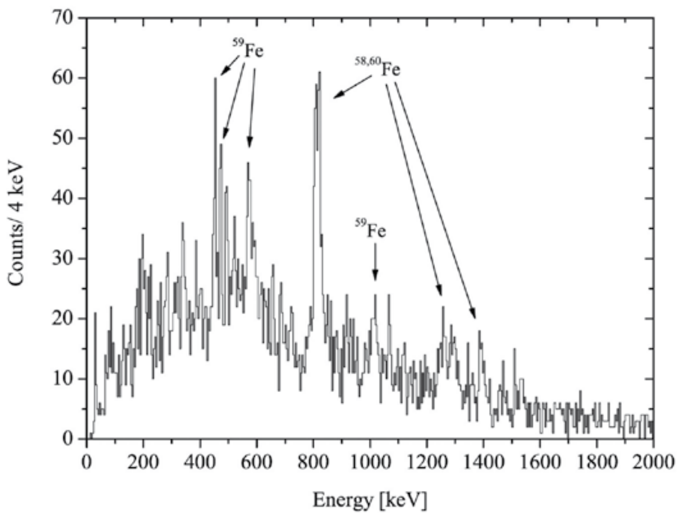


Fig. 1. Gamma-ray spectrum of beam-like particles measured in the JUROGAM array using a ^{65}Cu beam on a ^{209}Bi target and tagged with α particles originating from ^{213}Rn.

of recoil-isomer tagging at the proton drip line in the mass region A ~ 140. The new MWPC detector allows a larger reaction implantation rate (up to 20 kHz) at the focal plane to be used. This rate is limited to 5 kHz when the GREAT Double-Sided Silicon-Strip Detector (DSSD) is used.

In total four stand-alone studies were performed at the focal plane of the RITU separator. The power of the GREAT spectrometer combined with the RITU gas-filled separator was demonstrated in an experiment to study isomeric states in ^{254}No. Using a method suggested by Jones (G.D. Jones, NIM A488 (2002) 471), the sum energy signal from a cascade of conversion electrons is measured in the DSSD's of GREAT. The conversion electrons are produced in the decay of rotational bands in high-Z nuclei, in this case No (Z=102). Combined with the standard (recoil-electron/recoil-electron-alpha) correlation technique, the electron sum energy signal can be used to "tag" γ rays detected in the Planar and Clover Ge detectors of GREAT. Two high-K isomers in ^{254}No were identified and further analysis is in progress [6] (Fig. 2).

Neutron-deficient W, Os and Pt nuclides in the transitional region have been studied extensively in Jyväskylä in the near past. The systematic trends of excited states in these nuclei have been established when approaching the N=82 shell closure. To continue this work a search for the new nuclides ^{160,161}Os was performed in May 2005. The isotope ^{161}Os is predicted to be the first two-proton unbound osmium isotope. This nucleus and its α decay was observed for the first time. Also, from this study, as a side product, the new proton emitting isotope ^{159}Re was identified as well [7] (Fig. 3).

One of our main research activities has been to study proton unbound trans-lead nuclei. In May 2005, a search for the astatine isotope ^{189}At (which is predicted to be a proton emitter) was carried out. For this study the new ^{84}Sr beam (used on ^{107,109}Ag) was developed. This time the available beam intensity was not enough for the production of isotope ^{189}At. Nevertheless, as a side

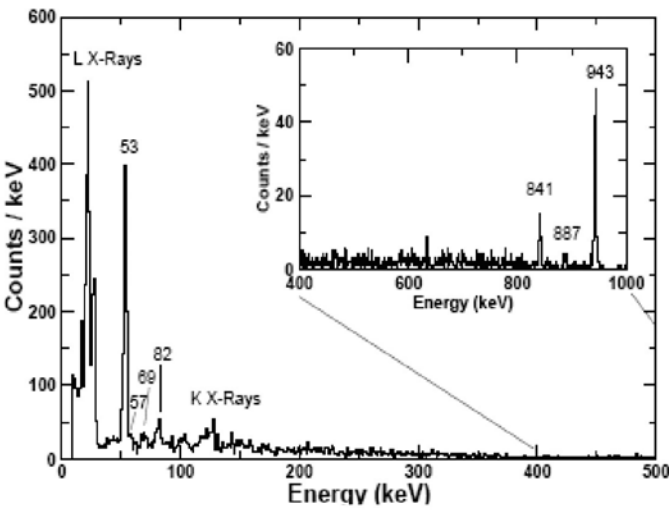


Fig. 2. An illustrative spectrum showing γ-rays associated with the decay of a 266 ms isomer in ^{254}No. The low-energy part is detected with the Planar germanium detector, the high-energy part with the Clover germanium detector.

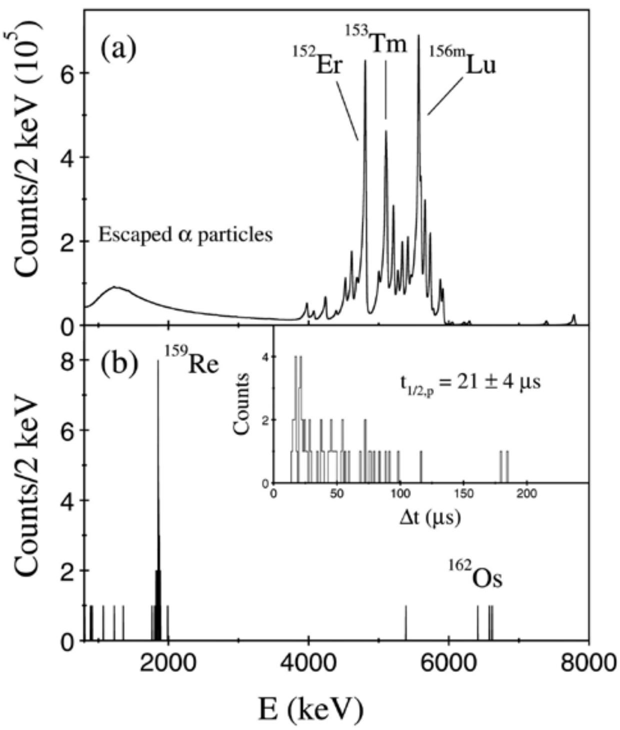


Fig. 3. Energy spectra of α particles (and protons) measured in the DSSSD and vetoed with the gas counter using the reaction ^{58}Ni + ^{106}Cd: (a) all decays, (b) decays following recoil implants and tagged with ^{158}W α particles.

product, the even-mass astatine isotope ^{190}At was newly identified [8].

In July 2005, a second experiment in the heavy trans-lead proton unbound region was carried out. The francium isotopes ^{198,199}Fr were studied using ^{60}Ni beam on a ^{141}Pr target. For ^{199}Fr much improved decay data were collected and for the new isotope ^{198}Fr α-decay data were obtained [9].

Alongside the RITU separator a new separator concept has been started. While the RITU separator is well suited when the heaviest elements are studied, the new separator is planned for studies in the lower mass region (A ≈ 50-150). The design for this new separator will be an energy and angle focussing recoil mass spectrometer. This plan is now in a stage that at end of the year 2005 the invitation to submit tenders was sent to four different companies [10].

Spokespersons and collaboration institutes:

[1] P. Greenlees, Ch. Theisen, R. D. Herzberg, DAPNIA/SPhN CEA-Saclay, University of Liverpool
[2] B. Cederwall, B. Hadinia, Royal Institute of Technology (Stockholm), University of Liverpool, University of York, CLRC Daresbury Laboratory
[3] D. Jenkins, University of York
[4] J. Uusitalo, R. Chapman, University of Paisley, University of Manchester
[5] D. Cullen, C. Scholey, University of Manchester
[6] P. Greenlees, R. D. Herzberg, University of Liverpool
[7] D. T. Joss, I. G. Darby, R. D. Page, CLRC Daresbury Laboratory, University of Liverpool, Keele University, Royal Institute of Technology (Stockholm)
[8] C. Scholey, J. Uusitalo
[9] J. Uusitalo, J. Sarén
[10] J. Uusitalo, M. Leino, J. Sarén

Research

ALICE and Nuclear Reactions

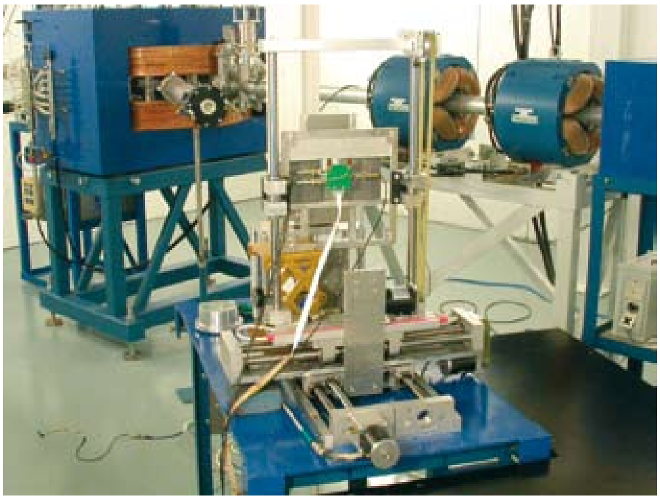
Wladyslaw Trzaska

Installation of detectors in the central region of ALICE scheduled for 2006 has put a considerable pressure on our team. Jyväskylä bears the main responsibility for T0 – the trigger and fast timing detector. Without fully operational T0, normal data taking with ALICE is not possible. T0 performance will have a direct impact on vertex determination, Time of Flight results, operation of Transition Radiation Detector, V0 monitoring, and data normalization. Both T0 and V0 will play the dominant role already in extracting the – so called – Day One Physics that includes measurements of pseudorapidity density dN/dη, p_T spectra, multiplicity distributions, dependence of mean transverse momentum on multiplicity, etc. The scientific community eagerly awaits these values and if T0 and V0 detectors work perfectly, ALICE will be the first LHC experiment to deliver them.

Wladyslaw Trzaska, senior scientist
Jan Rak, senior assistant 1.12.-
Manfred Mutterer, visiting scientist (250 days)
Sergey Khlebnikov, visiting scientist (93 days)
Vladimir Lyapin, researcher (HIP/JYFL)
Grigori Tyurin, visiting researcher (106 days)
Mariana Bondila, graduate student (HIP/JYFL)
Sergey Yamaletdinov, graduate student
Tomasz Malkiewicz, graduate student
Risto Paju, graduate student 1.8.-
Galina Knyazheva, CIMO scholarship student (110 days)
Teppo Harju, MSc student
Mikko Sillanpää, MSc student

Due to the highly restricted space in the central region of ALICE, the acceptance of T0 is very limited. It has a total of only 24 detector modules. At the same time both the complexity and cost per channel (module) is by far the highest of all ALICE sub-detectors. In 2005 all of the key construction parameters were finally frozen. In May 2005 T0 electronics underwent a comprehensive review by a panel of independent experts appointed by LHCC. The result of this 3 ½ hour ordeal was very positive. The reviewers had no major objectives to our electronics scheme and were impressed by the 28 ps time resolution reached for the amount of light corresponding to 1 MIP. In June 2005 T0 completed Production Readiness Review giving a green light for the production of all detector modules. The final support construction has now considerably less material. It resulted in reducing the radiation length by half as compared with the first carbon fibre prototype. The next major milestone was crossed in November 2005 with the successful completion of the full chain electronics readout. While the super-fast front end electronics is unique to T0, to save the development costs and to avoid reinventing of the wheel, our detector is meant to use the readout electronics designed specifically for TOF. Although it sounds straight forward, the task of adopting T0 signals to work with TOF readout was by no means trivial. We are very happy to report that all worked perfectly well. We were able to reproduce the 28 ps resolution for 1 MIP and reach 13.6 ps for 30 MIP signals from the calibration laser.

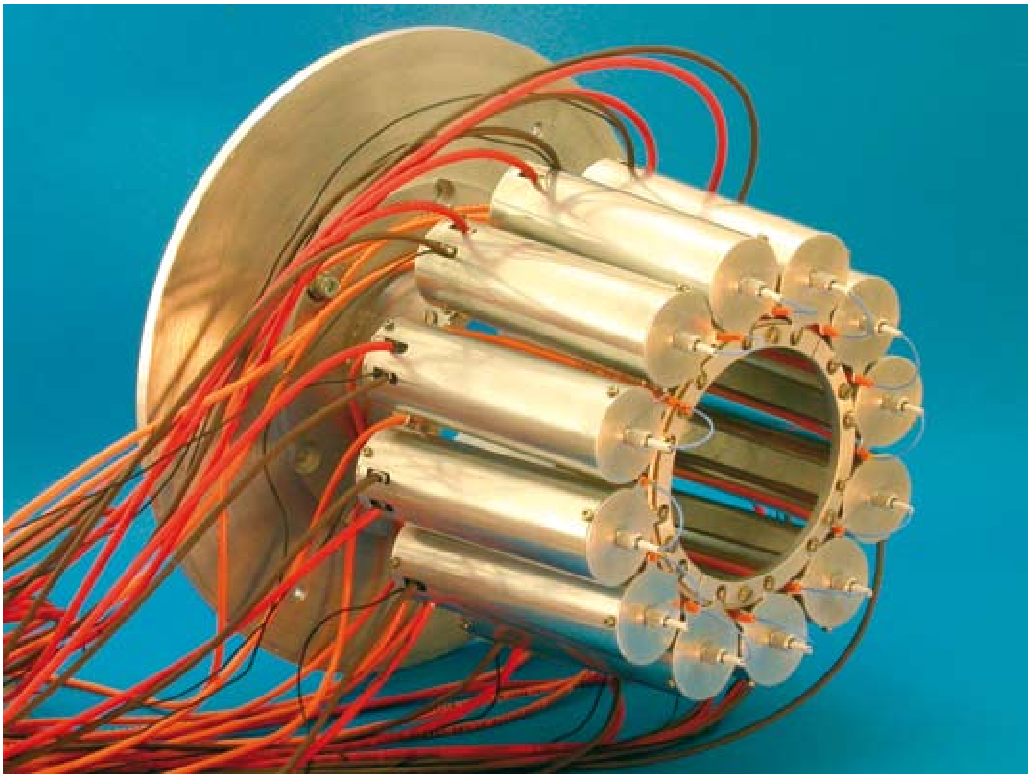
An important issue for ALICE Forward Detectors is radiation hardness. In August 2005 a series of irradiations were carried out at JYFL with the beam of 60 MeV protons. The 1 nA beam was dissipated on 0.2 mm thick Tungsten plate yielding at the distance of 1.8 m from the plate a uniform flux of about 84 million protons per second per cm^2 over the area of at least 25 cm^2. The irradiated components included all key elements of V0 detector and T0 front end electronics. Protons reaching the electronics had the energy of about 57 MeV. The irradiations had a progressively increasing duration (from 20 to 2000 second) and each time were followed by thorough tests of the investigated components. The tested T0 electronics worked perfectly for the first 5000 seconds. After a total of about 7000 seconds of irradiation (90 krad/cm^2) a 2% drop in both +6 and -6 V low voltage power supply current was noticed that however did not affect the amplification gain. After 9000 seconds of operation (112 krad/cm^2) the unit was damaged (flat 2V on the output). The +6V current increased by a factor of 2 and the -6V current drain was down by a factor of 2. The damage was fatal and the unit did not recover from the radiation induced damage. This test has shown that the dose sufficient to kill the front end electronics is of the order 100 krad/cm^2. The calculations assumed that one 57 MeV proton induces a dose of 1.5×10^{-10} krad. According to the latest estimations, this is well in excess of the expected integrated dose during 10 years operation of ALICE.



Radiation hardness tests at JYFL of T0 and V0 detectors for ALICE experiment.

Physics and Tracking

Analysis of the observed hadron spectra and correlations at RHIC reveal three transverse momentum ranges with distinct behaviour: a soft range $p_t \leq 1.5$ GeV/c containing the remnants of the bulk collision, an intermediate range $1.5 \leq p_t \leq 6$ GeV/c where hard processes compete with the soft ones, and a hard-scattering range $p_t \geq 6$ GeV/c providing partonic probes of the early stage of collision matter. Nevertheless, many of the RHIC findings, especially the unexpected ones, require further investigation. The emerging picture shows that there is not yet a direct experimental evidence for deconfinement. It also shows clearly that strange quark production in hot QCD is far from being settled and experimental cross-checks that require high statistics and precision data in a larger p_t range are needed to fully explore the observed phenomena and their connection to properties of dense matter. Recent theoretical studies by Rafelski suggest that at LHC energies strangeness may be further enhanced relative to RHIC given that at LHC we reach greater initial temperatures and more explosive flow. Kaons as the lightest strange hadrons are expected to dominate the strange sector by virtue of canonical thermodynamics. With a significant kaon production at LHC energies, owing to kaon’s high branching ratio to the muonic decay channel and to the large angular acceptance of the central barrel of ALICE, the reconstruction of the kink topology is a key technique for identifying kaons over a momentum range much wider than the one achieved by combining PID signals from different detectors. One question that arises naturally is whether the identification range we achieve for charged kaons allows us to use them to get insight into phenomena related to each of the three transverse momentum ranges mentioned above. Over the last year Jyväskylä team has finalized the reconstruction algorithm and the physics analysis required to extract the expected



ALICE T0 detector.

yields of reconstructed kaon decays at LHC. The results have been published in the Performance Physics Review vol.2 of ALICE.

PHENIX Experience

Jan Rak

PHENIX experiment at Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory, NY, USA contributed to many discoveries made in 6 years operation of RHIC. PHENIX was designed to measure the rare probes like e.g. J/Ψ, Ψ', Φ and direct-γ. Although the J/Ψ suppression was predicted as a one of the most direct signatures of the Quark Gluon Plasma (QGP) formation the first ground shaking discovery at RHIC arose from the observation of strong suppression of high-p_T π^0 particles measured by PHENIX electromagnetic calorimeter. High-p_T π^0 suppression together with other unexpected observations like large elliptic flow, disappearance of the away side jet and heavy quark suppression contributed significantly to our understanding of QGP formation and evolution.

Experience from PHENIX is helping us to formulate specific research topics for ALICE. For instance, our group is using high-p_T particle correlation technique to studying nuclear modifications of such parton properties like intrinsic transverse momentum k_T, fragmentation, and parton distribution function. From the jet shape analysis we try to disentangle various processes of the parton energy loss. We are also involved in the direct-γ analysis. The inclusive direct-γ spectra provide a unique "thermometer" of the early plasma formation and the measurement of the associated particles with direct-γ yields the access to the measurement of the fragmentation function.

Nuclear Reactions

Wladyslaw Trzaska

Thanks to the substantial help and contribution by our visitors who have stayed for the total of 1105 days at JYFL in 2005 we were able to continue our very intense experimental program. For instance, we have completed a study of fission characteristics in the proton induced fission of ^{232}Th at E_p =13, 20, 40 and 55 MeV with a setup consisting of **HENDES, CORSET**, **DEMON**, and 12 **BaF_2** γ-detectors. Mass-kinetic energy distributions of fission fragments, double differential neutron spectra, and mean multiplicity and energy of γ-rays have been measured. Special attention was paid to measure very asymmetric region at A_L < 80 amu. The neutron probe is important for estimations of excitation energy of compound nuclei and strength of nuclear friction. Particle emission at pre-compound and pre-scission stages influence on the composition and excitation energy of the nucleus at the scission and on the fission product yields. The neutron- and proton-induced fission of ^{232}Th are of interest due to the advantageous production of radioactive beams with A < 90 compared to the ^{238}U target.

In addition to 10 in-beam experiments we have completed 83 days of off-beam measurements; mostly studying ^{252}Cf decay. Especially fruitful was 8 months stay with us by one of the world expert on fission, detection techniques and electronics – Dr. Manfred Mutterer from Technical University Darmstadt. The analysis of the latest experiments will take some time but we hope, among other goals, to give new information on the low energy part of ternary alpha spectra and confirm fine structure in the mass – TKE spectra of fission fragments. We have also initiated collaboration with **CHICSi** experiment. One of the goals is to use this high granularity detector system to perform a detailed experimental study of higher-order modes of particle accompanied fission, such as "Quaternary Fission" and the newly postulated "Quinary Fission".

Setting up of HENDES, CORSET, DEMON and BaF_2 detectors at JYFL.

Research

Accelerator-Based Materials Physics

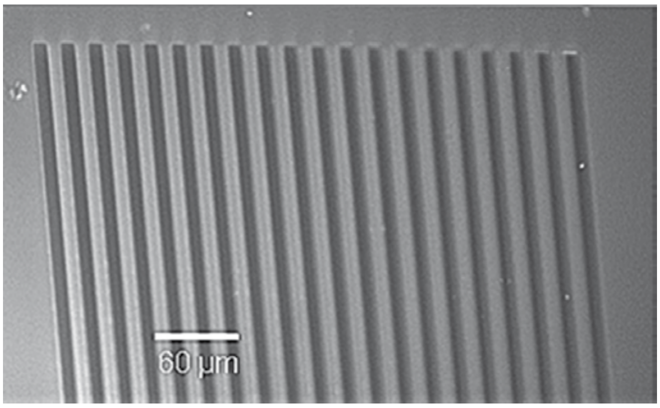
Timo Sajavaara
Harry J. Whitlow

The accelerator-based materials physics group's work has under 2005 become more directed towards biomedical research with ion beams. The areas on which we focus are: (i) the development of MeV ion beam lithography (ii) modification of material with ion beams and (iii) the application of radioactive ion beams from the IGISOL facility. Other areas of activity have been molecular dynamics simulation of nanometre-scale amorphisation processes in Si and high-depth resolution analysis of surface layers.

Harry J. Whitlow, professor
Timo Sajavaara, senior researcher
Sergey Gorelick, graduate student 1.2.-
Mikko Laitinen, graduate student 1.9.-
Ananda Sagari A.R., graduate student 1.9.-
Elisabeth Wieslander, external graduate student (EU Joint Research Centre, IRMM Centre for reference materials and measurement, Geel, Belgium)
Terho Räisänen, MSc student
Tommi Ylimäki, MSc student

MeV Ion Beam Lithography

Construction started during 2005 on a MeV ion beam lithography system for the Jyväskylä cyclotron. This is being made in a series of stages that will start with 10 μm and work towards writing features on a 10's of nm scale. The instrument is intended for fabrication of 3-dimensional structures for research in cell biology, such as the high aspect ratio cell growth substrate in Fig. 1.



Sputter-Deposition of Hydroxyapatite Films

To facilitate study *in vitro* under the microscope the growth of osteoblast cells (these cells produce new bone material) requires that the cells receive the correct chemical and 3-dimensional topographical signals. In order to do this we have investigated the sputter deposition of 30-300 nm films of hydroxyapatite, the mineral constituent of bone tissue (Fig. 2). These films are sufficiently thin to allow light transmission for microscopical examination and sufficiently thick so as to provide the correct chemical signals to stimulate osteoblast growth. Fig. 3 illustrates osteoblast growth on our sputter-deposited substrates. The significant dendritic growth is indicative of chemical signaling from the hydroxyapatite.

Fig. 1 Test osteoblast growth structure produced by proton beam lithography (unpubl. from the Jyväskylä – Singapore – Malmö collaboration) *(unpublished data)*.

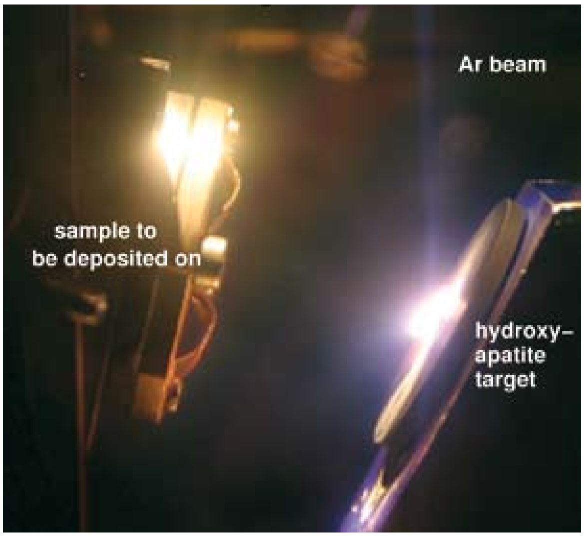


Fig. 2. Ion-sputtering deposition of hydroxyapatite films using a 6 keV Ar^+ ion beam.

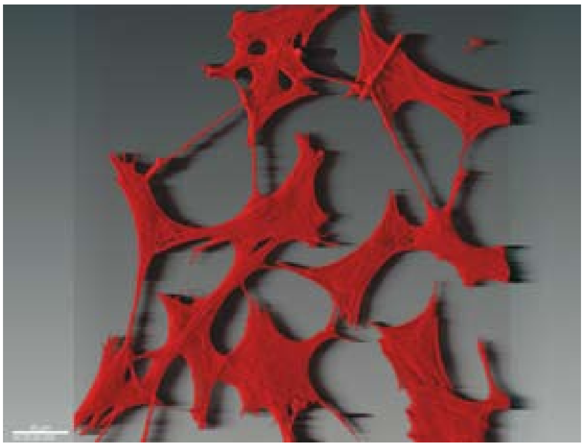


Fig. 3 Transformed mouse osteoblast cells (MC 3T3 E1) growth on a glass substrate coated with a 100 nm hydroxyapatite film. In the image the actin which makes up the cytoskeleton is stained with alera 488 labled phollodin in order to show the focal attachment points where the actin is concentrated. (unpublished data).

Ion Irradiation System

A multi-purpose ion-irradiation system has been constructed around a small ECR ion source. The system is designed for sputter-depth profiling in conjunction with

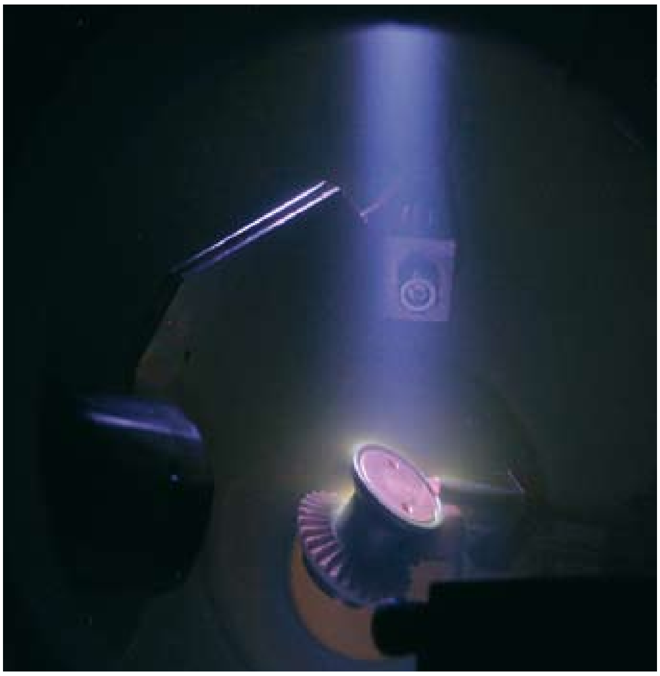


Fig. 4. A 1 keV ion beam in the new multi-purpose ion-irradiation chamber.

IGISOL diffusion measurements. The system is equipped with an oven for heat treatment up to ~1800 °C. The ion gun is also be intended for general low-energy (0.2-2 keV) ion bombardment. (Fig. 4.)

Molecular Dynamics Studies of Ion Induced Si Amorphisation on a Nanometer Scale

Together with researchers from Okayama University of Science, Japan and the Technical University of Vienna molecular dynamics together with the pixel mapping technique have been used to study formation of Si self-interstitial atom clusters (SIA) during 5 keV Si^+ bombardment. For a Tersoff interaction potential, monomers were found to be most prevalent and the number of clusters formed decreases with the number of atoms in the cluster. Dimers were found to be dominantly oriented along <110> directions. To overcome difficulties associated with the tetrahedral ligand field

From the left: Ananda Sagari, Harry J. Whitlow, Elisabeth Wieslander, Mikko Laitinen, Timo Sajavaara, Iiro Riihimäki (from industrial applications group) and Sergey Gorelick.

assumed the Tersoff potentials, a new code based on the more realistic EDIP (Environment Dependant sIlicon Potential) is under development.

High-Depth Resolution Analysis of Surface Layers

The collaboration with IMEC and IKS from Leuven, Belgium has continued. The goal is to achieve better depth resolution with ion beam techniques. The use of forward scattered heavy incident ions in combination with a time-of-flight-energy (TOF) telescope provides a powerful tool for the analysis of very thin (5-30 nm) films. Because of the forward scattering angle, the sensitivity is greatly enhanced, thus reducing the ion beam induced changes in the sample during the analysis of very thin films. The drawback of forward scattering angle is the limited mass separation for target elements. We have demonstrated the performance of the technique for analysis of 25 nm thick NiSi films and atomic layer deposited 6 nm thick $Hf_xSi_yO_z$ films on silicon using 3-8 MeV ^{16}O ions as projectiles (Fig. 5). In these measurements, a depth resolution of 2 nm was obtained at the surface, while deeper in the film the resolution was limited by multiple scattering.

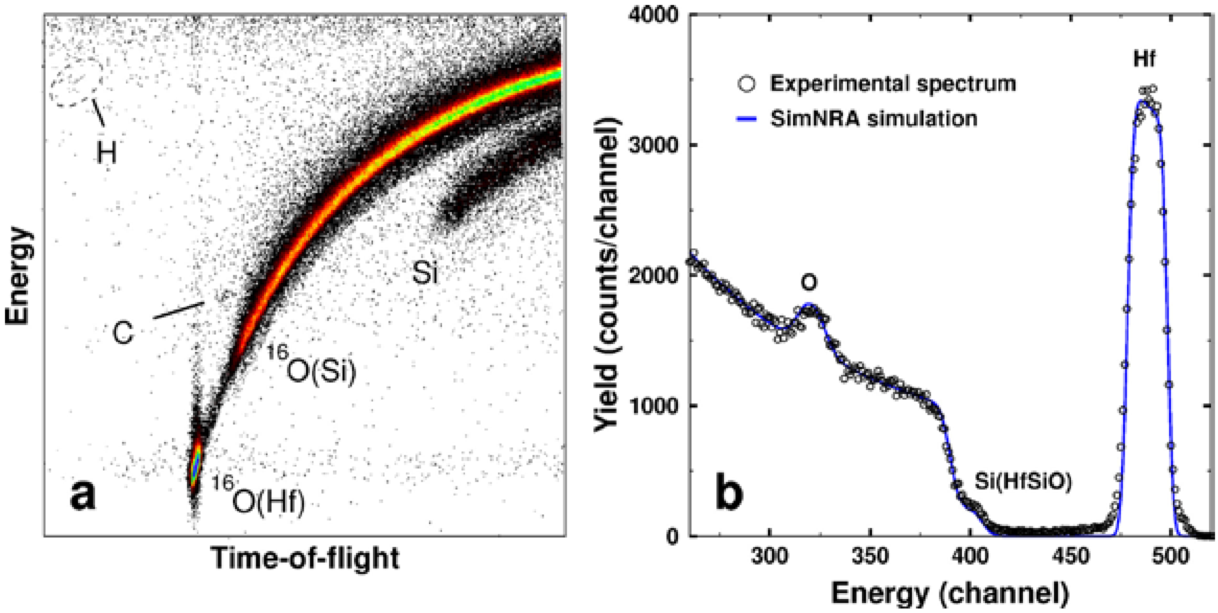


Fig. 5. A raw TOF-energy histogram (a) from Si-rich atomic layer deposited $Hf_{0.14}Si_{0.19}O_{0.67}$ film. This 6 nm thick film was measured using 3 MeV ^{16}O incident ions at IMEC, Belgium. Light impurities such as H and C can be quantified as well. In (b) the corresponding ^{16}O energy spectrum is shown together with SIMNRA simulation.

Main collaborators

- Prof. Frank Watt, Dr. Jeroen van Kaan, Dr. Andrew Bettiol, Assoc. Prof. Thomas Osipowicz, Ren Minquin, National University of Singapore, Singapore.
- Docent Yanwen Zhang, Dr. C.M. Wang, Dr. D.E. McCready, V. Shutthanandan, L. Saraf, B. W. Arey, S. Thevuthasan. Pacific Northwest National Laboratory, Richland, Washington, USA.
- Prof. Johan Helgesson, Dr. Lennart Karlsson, Dr. Jörgen Ekman, Malmö högskola, Sweden
- Prof. Juhani Keinonen, Prof. Jyrki Räisänen, Department of Physical Sciences, University of Helsinki, Finland.
- Prof. Sulin Cheng, Paavo Rahkila, Department of Health Sciences, University of Jyväskylä, Finland.
- Prof. Ragnar Hellborg, Prof. Bo Jakobsson, Docent Kristina Stenström, Dr. Per Persson, Mariusz Graczyk, C.T. Jönsson, Docent Ivan A. Maximov, Department of Physics, University of Lund, Sweden.
- Dr. T. Weijers, Australian National University, Canberra, Australia.
- Dr. Heiko Timmers, Australian Defence Force Academy, Canberra, Australia.
- Prof. Sachiko Nakagawa, Okayama University of Science, Japan.
- Prof. Gerhard Betz, Technische Universität Wien, Austria.
- Prof. Wilfried Vandervorst, Bert Brijs, IMEC, Leuven, Belgium.
- Dr. Kai Arstila, Prof. André Vantomme, IKS, K.U.Leuven, Belgium.
- Dr. Kaupo Kukli, Prof. Mikko Ritala, Department of Chemistry, University of Helsinki, Finland.
- Prof. Lauri Niinistö, Dr. Matti Putkonen, Laboratory of Inorganic and Analytical chemistry, Helsinki University of Technology, Finland.

Research

Industrial Applications

Heikki Kettunen
Vladimir Tuboltsev
Ari Virtanen

Space Related Study

The upgrade of the RADiation Effects Facility, RADEF, which started in 2004, was completed when the acceptance test campaign for European Space Agency, ESA, was performed in April. In the commissioning the setup was successfully approved to fulfil the requirements set by the contract and RADEF was accepted as one of ESA's external European Component Irradiation Facilities (ECIF). There are two members besides RADEF. The first facility, the Proton Irradiation Facility (PIF) at the Paul Scherrer Institut (PSI), Villigen, Switzerland, was developed primarily for proton testing. The second facility, the Heavy Ion Facility (HIF) was developed at the Centre de Researchers du Cyclotron (CRC) of the Universite Catholiqué de Louvain (UCL), Louvain-la-Neuve, Belgium. RADEF provides both heavy ions and protons in the same facility. Its other specialty is the high penetration cocktail, which was developed during the upgrade phase with the maximum energy of 1.22 GeV for xenon. The available high penetration cocktail (9.3 MeV/u) is given in table 1 and the both beam lines are illustrated in figure 1.

Ari Virtanen, senior scientist
Vladimir Tuboltsev, senior scientist
Heikki Kettunen, assistant
Pasi Jalkanen, graduate student
Arto Javanainen, graduate student
Taneli Kalvas, graduate student (USA)
Iiro Riihimäki, graduate student
Kimmo Ranttila, laboratory engineer
Maria Palomäki, MSc student
Sasha Pirojenko, MSc student
Suvi Päiviö, MSc student
Mikko Rossi, MSc student

Also, a new user site was furnished. There the all relevant parameters needed during the data acquisition are monitored via the video projector onto the wall of the shack. The tuning and operation of both the beam dosimeter elements and cyclotron can now be performed from the same site. This is illustrated in figures 2 and 3.

Table 1. The available RADEF cocktail.

Ion	Energy [MeV]	LET(SRIM) @surface [MeV/mg/cm2]	Range(SRIM) [microns]	LET(SRIM) @50µm [MeV/mg/cm2]	LET(SRIM) @ Bragg peak [MeV/mg/cm2]
15N+4	139	1,8	202	2,1	5.9 (@198µm)
20Ne+6	186	3,6	146	4,4	9.0 (@139µm)
30Si+8	278	6,4	130	7,8	14.0 (@120µm)
40Ar+12	372	10,1	118	12,6	19.6 (@105µm)
56Fe+15	523	18,5	97	24,3	29.3 (@77µm)
82Kr+22	768	32,1	94	39,2	41.0 (@69µm)
131Xe+35	1217	60.0	89	69,2	69.2 (@48µm)

The inauguration of the station was held on May 27, 2005. Greetings and addresses were presented by the university rector Aino Sallinen, Mr. Reno Harboe-Sørensen from ESA and Jyväskylä city mayor Markku Andersson. National Technology Agency (TEKES) was represented by deputy director Antti Joensuu from Ministry of Trade and Industry. Professor Jean Gasiot from the University of Montepellier wished RADEF welcome to a member of European RADECS community. Dr. Ari Virtanen told about history and development of the project. The inauguration was followed by a tour to RADEF and the accelerator. A photo taken before the inauguration ceremony is shown in figure 4.

The opening was preceded by a two day event with 70 representatives from the European satellite companies, national space organizations and ESA. DAY 1 was dedicated to presentations reporting the results of radiation studies and tests recently performed under ESA's QCA contracts. On DAY 2 a "RADECS Thematic Workshop on European SEE Accelerators" took place. The Workshop technical programme featured invited oral presentations describing European SEE accelerators, facility upgrades, users' experiences and address European needs, LET calculations/Ion penetration and Proton Testing via three Round Tables. A photo taken in a social event organized after the meeting is presented in figure 5.

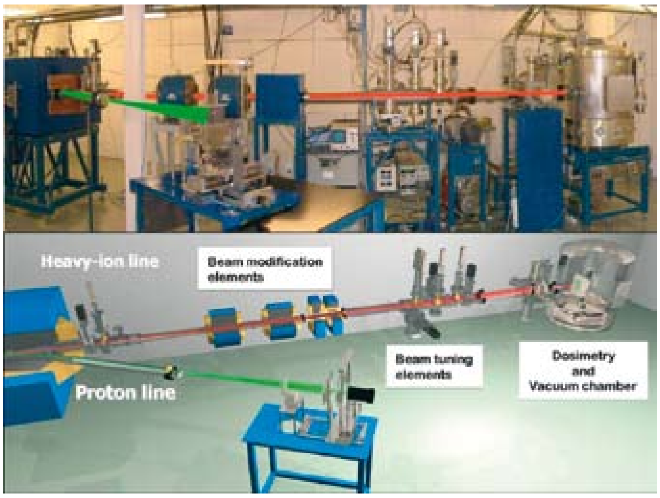


Fig. 1. Layouts from the RADEF facility with its two beam lines.

Fig. 2. Dr. Heikki Kettunen tuning a proper beam for the test.

Ion Beam Applications

Ion beams offer powerful tools for fabrication and modification at a nanometer scale promising in view of potential industrial applications in nanotechnology.
Aluminum-on-silicon is a widely used combination in micro- and nanofabrication due to high compatibility with conventional photo/electron beam lithography and well controllable Al oxidation advantageous for fabrication of nanoelectronic components, e.g., tunnel junctions. Following the general trend in developing increasingly smaller metal-based components operating at ultra-low temperatures, it is of high importance to know how reduced dimensions and impurities affect the superconductive properties. Ion implantation is used in our projects for introducing impurities into superconducting matrices in order to change the critical transition temperature Tc at will. Apart from study of superconductivity fundamentals in doped low dimension structures, the implantation method was proved to allow for accurate in-situ post-processing modification in the fabrication of components which functionality

Fig. 3. Mr. Reno Harboe-Sørensen testing components during the acceptance test.

Fig. 4. From left: Mr. Reno Harboe-Sorensen from ESA, Dr Ari Virtanen, Rector Aino Sallinen and City mayor Markku Andersson (sitting) discussing before the start of the ceremony .

is determined by Tc (e.g. in CBT thermometry). In view of potential applications, the method may provide an effective way for an increase in production yield by fine-tuning the component's characteristics via Tc adjustment, e.g., sensors calibration etc.

Another topic of active research related to ion beam applications in nanotechnology is fabrication and modification of 1D nanostructures, e.g., *nanowires*. The main interest lies on study of quantum effects in quasi-1D metallic structures fabricated by ion beams in combination with conventional nanofabrication techniques such as electron beam lithography, reactive ion etching and deposition. Theoretically predicted quantum effects in 1D mesoscopic systems are believed to be observable in a nanowire with a characteristic cross section diameter in sub-10 nm range. An ion beam based method has been developed for fabrication of such nanowires. An application is now in active preparation for submission to patent the method.

The projects are carried out in close collaboration with NanoScience Centre, Jyväskylä.

Radio-Medicine

The high-intensity proton beams, produced from the LIISA ion source, are used weekly in the production of ^{123}I radioisotope for MAP Medical Technology Ltd. This production covers the needs of radioactive iodine for the 20 largest hospitals in Finland. The ^{123}I based radio-medicines produced by MAP are mainly used in diagnosing brain-based diseases. They are also delivered for medical research work to many other European countries. During the year 2005 36 production runs were performed with the intensities between 40 to 50

Fig. 5. Emeritus professor Jean Gasiot from the University of Montpellier is admiring old Finnish residential buildings around the country restaurant, where the meeting's social event took place.

microamperes. To increase the effectiveness and reliability three new irradiation chambers were planned and manufactured in the department's workshop.

Other Collaborations

Cooperation with several Finnish companies and organizations also continued. With the funding from national technology agency a joint project with VTT Processes from Jyväskylä started in February and contains studies of different radiation based analyzing techniques of biofuels. A joint project with Metso Paper Co. ended and in this project a new type of energy controlled β-radiography device was constructed and concluded in a MSc. thesis. Two other undergraduate thesis projects for a local company and Central Finland Health Care District were also finalized.

MSc Mikko Rossi and the β-radiography device he constructed for his MSc-thesis in the project done together with Metso Paper Co.

Major national collaborators are:

- Doseco Ltd.
- Gammapro Ltd.
- Helsinki Institute of Physics
- Jyväskylä Science Park Ltd.
- MAP Medical Technologies Ltd.
- Metso Paper Co.
- National Technology Agency of Finland, TEKES
- Patria New Technologies Ltd.
- Radef Research Ltd.
- University of Helsinki
- VTT Processes, Technical Research Centre of Finland

Major foreign collaborators are:

- Alenia Alcatel Space Ltd., Toulouse, France
- Centre National d'Etudes Spatiales, CNES, Toulouse, France
- CERN, Geneva, Switzerland
- EADS Astrium Space Ltd., France
- EADS Space Transportation GmbH, Bremen, Germany
- European Space Agency, ESA/ESTEC, Noordwijk, The Netherlands
- HIREX Engineering Ltd., Toulouse, France
- Paul Scherrer Institut, Villigen, Switzerland
- RISØ National Laboratory, Denmark
- Saab-Ericsson Space Ab, Sweden
- Swedish Space Corporation, Sweden
- The French Aeronautics and Space Research Center, ONERA, Toulouse, France
- Universite Catholiqué de Louvain (UCL), Louvain-la-Neuve, Belgium
- Ørsted Laboratory, the Niels Bohr Institute, Copenhagen University

Research

Nuclear Structure, Nuclear Decays, Rare and Exotic Processes

Jouni Suhonen

Nuclear Matrix Elements Related to Double Beta Decays

Jouni Suhonen, professor
Jussi Toivanen, assistant
Johannes Hopiavuori, docent
Eero Holmlund, assistant -31.7.
Markus Kortelainen, graduate student
Jenni Kotila, graduate student
Sami Peltonen, graduate student
Heikki Heiskanen, Msc student
Mika Mustonen, MSc student
Heidi Tarvainen, MSc student

Detection of the neutrinoless double beta decay is essential in probing physics beyond the standard model of electroweak and strong interactions. At the moment there is considerable uncertainty associated with the calculation of the involved nuclear matrix elements. This uncertainty can be diminished by suitably chosen nuclear probes, like beta decays and nuclear muon capture.

The nuclear matrix elements involved in the double beta decays (neutrinoless and two-neutrino) can be probed by known beta-decay rates. The transition amplitude of double beta decay consists of virtual single-beta-decay transitions from the ground state of the even-even mother nucleus to the virtual states of the adjacent odd-odd nucleus (the 'left leg'), and from the virtual states further to the states of the even-even daughter nucleus of double beta decay (the 'right leg'). The left and right legs can be tested by comparing beta-decay data with computed rates for beta-decay transitions from the odd-odd nucleus to the daughter and mother nuclei of double beta decay. We have studied this recently and found that beta decays are excellent probing tools for the lowest-energy virtual transitions. Use of this probing method is limited by the scarse amount of data. This is why related experiments are urgently called for.

We have suggested recently that the above-described virtual transitions can be probed by experiments measuring muon-capture rates to the involved virtual states. This process involves the capture of a negative muon from the atomic s orbital without emission of a gamma quantum. Muon capture does not probe directly the virtual transitions but rather the wave functions of the virtual states. According to our recent calculations muon capture could be a powerful probe of double beta decays in light nuclei. These calculations predict that the same virtual states are significantly populated both in the double-beta-decay and muon-capture transitions in the A=36, A=46 and A=48 double-beta chains.

We have also decomposed the nuclear matrix elements involved in the neutrinoless double beta decay into multipoles in order to study the spin-parity of the virtual states which exhaust most of the double-beta-decay amplitude. At least for the studied four cases significant contribution comes from the first-forbidden virtual transitions to the low-lying 2^- states. This contribution can be up to 50 per cent of the total nuclear matrix element. Such an observation suggests that independent experimental probes of these virtual transitions would be effective in reducing uncertainties in the computed matrix elements.

Detection Rates for Supersymmetric Dark Matter from Large-Scale Shell-Model Calculations

Recent particle-physics theories favour the lightest neutralino, the lightest supersymmetric particle (LSP), as possible source of cold dark matter (CDM) in the Universe. Nucleus-LSP elastic scattering can be used for direct detection of the LSP and that is why it is of great interest to chart the possible detector nuclei and their sensitivity to the LSP detection.

Recently we have made calculations for the ^{71}Ga, ^{73}Ge and ^{127}I detector nuclei by using the nuclear shell model. Since the scattering rate of the LSPs is spin dependent for the used odd-mass detector nuclei, the description of the magnetic moments of the ground states of these nuclei is extremely important. Our shell-model results reproduce the measured magnetic moments quite well. We were able to summarize our results by tabulating the relevant nuclear-structure coefficients. This enables evaluation of the LSP detection rates for the above detector nuclei independently of the used parametrizations of the supersymmetric particle-physics models used to produce the LSPs. Hence, studies of detection-rate predictions via scatter plots of supersymmetric parameter spaces are easily accomplished. Studies of the inelastic channels of LSP detection are in progress.

Systematics of Alpha-Decay Hindrance Factors

A systematic, fully microscopic calculation of hindrance factors of alpha decays to excited 2^+ states in spherical and nearly spherical nuclei has been done. Several isotopic decay chains have been treated within this framework in order to study the interplay between the isoscalar/isovector part of the interaction and the electromagnetic and alpha-decay rates. Further studies of the population of rotational 2^+, 4^+ and 6^+ states by alpha decays have been performed for a large group of well-deformed even-even nuclei by using a coupled-channel approach. Experimental trends were nicely reproduced for the decays to the 2^+ and 4^+ states, whereas decays to the 6^+ states turned out to be more problematic. Further studies for nearly spherical nuclei are currently being carried out.

Gamma and Beta Decays Involving Two-Phonon Structures

We have developed the Microscopic Anharmonic Vibrator Approach (MAVA) for microscopic description of low-lying two-phonon states in even-even nuclei. The main building blocks are the quasiparticle random-phase approximation (QRPA) phonons. A realistic microscopic nuclear Hamiltonian is diagonalized in a basis containing one-phonon and two-phonon components yielding a dynamical mixing of these two degrees of freedom. We have used MAVA to describe energetics and gamma decays of low-lying collective states in chains of even-even Cd, Ru and Mo isotopes. In these studies we have focused on evolution of the two-phonon type of structures and their gamma decays with increasing neutron number. We have followed these chains of isotopes in order to see how far an anharmonic description of nuclei can be pushed before it breaks down at a kind of phase-transition point between anharmonic vibrator and well-deformed rotor nuclei. The Ru nuclei seem to offer a nice example of such a phase-transition point.

Recently an extension of the MAVA to describe odd-odd nuclei and their beta decay to the adjacent even-even nuclei has been accomplished. This model, known as the proton-neutron MAVA (pnMAVA), has been applied to describe beta-decay feeding of the low-lying collective states in the ^{106}Pd and ^{108}Pd nuclei. As an example in Fig. 1 the computed relative gamma-decay rates and beta-decay feeding of the low-energy collective states of ^{106}Pd have been compared with available data. The obtained results encourage us to apply the pnMAVA to other nuclear systems to compute beta transitions between low-lying more or less collective states, to produce Gamow-Teller strength functions and, eventually, to apply pnMAVA to calculations of double-beta-decay rates.

Large-Scale Shell-Model Calculations with the Program 'EICODE'

The shell-model code EICODE has been designed to carry out very large nuclear shell-model calculations. The parallel version of EICODE has become mature. It has been tested and it is now been used in the IBM eServer cluster of the CSC (the Finnish IT organization for Science) and in other distributed memory supercomputers in Finland.

The serial version of EICODE has been used to calculate the approximate ground-state wavefunctions of the medium-heavy nuclei ^{73}Ge, ^{71}Ga and ^{127}I. In addition to these truncated calculations, large unrestricted shell-model calculations for the accurate ground state and excited-state wave functions of these nuclei are currently being computed in the pfg shell. Part of the results of these calculations has been published already.

EICODE is our testbed for truncation and speedup methods that allow accurate calculations of nuclear shell model wavefunctions consisting of billions of Slater determinants. In year 2005 new methods to speed up large scale shell-model calculations were developed. The methods and resulting shell model calculation results will be published in the beginning of year 2006.

Large-Scale Computation with the MOVA Model Family

The MOVA (Monster-Vampir) model family is based on solid approximations of the exact many-body problem, potentially applicable on the entire chart of nuclei. Currently, the real mean-field MOVA models are being modified to allow userfriendly calculations globally on the entire chart of nuclei. Nuclear masses and energies of the first excited 2^+ states of all known doubly even nuclei are used as the first experimental data set to be studied. Preliminary results using a G-matrix as a two-body interaction are promising.

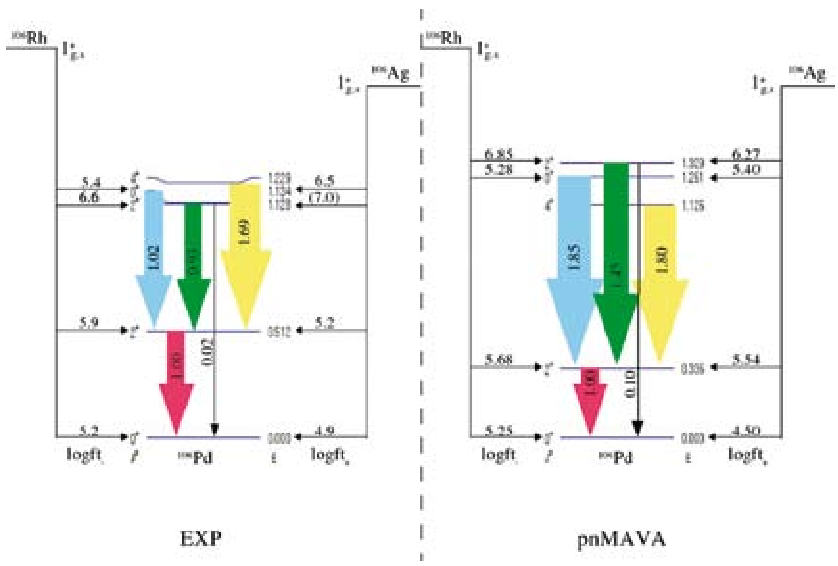


Fig. 1. Experimental (left panel) and theoretical (right panel) relative gamma-decay rates and beta-decay feeding of collective states in ^{106}Pd.

Research

Materials Physics

Nanophysics and Nanotechnology

Markus Ahlskog
Konstantin Arutyunov
Ilari Maasilta
Sorin Paraoanu

The Nanophysics group is mainly dedicated to experimental research in some of the key issues in nanoscale or mesoscopic physics. Main activities are mesoscopic superconductivity, thermal effects in mesoscopic devices, and the fundamentals of solid state quantum computing. In addition, we have during 2004 begun research on the physical properties of single carbon nanotubes.

Markus Ahlskog, professor
Konstantin Arutyunov, senior researcher
Ilari Maasilta, academy researcher
Sorin Paraoanu, academy researcher
Shadyar Farhangfar, senior researcher
Tommy Holmqvist, graduate student - 21.10
Terhi Hongisto, graduate student
Jenni Karvonen, graduate student
Kimmo Kinnunen, graduate student
Panu Koppinen, graduate student
Minna Nevala, graduate student
Lasse Taskinen, graduate student
Maciej Zgirski, graduate student
Asaf Avnon, MSc student
Chunrok Bae, MSc student
Mohamed Hassan, MSc student
Matti Heikinheimo, MSc student
Olli Herranen, MSc student
Jaakko Leppäniemi, MSc student
Jarkko Lievonen, MSc student
Harri Niiranen, MSc student
Mikael Pajunen, MSc student
Harri Pitkänen, MSc student
Kari-Pekka Riikonen, MSc student
Lasse Väistö, MSc student
Sami Ylinen, MSc student

Thermal Properties of Nanostructures and Radiation Detector Development

Ilari Maasilta

The main research direction of the thermal nanostructure research team led by Dr. Maasilta is to (a) understand energy flow mechanisms in low-dimensional geometries, and (b) ulitize this knowledge in the development of ultrasensitive thermal and radiation sensors (bolometry).

Electron-Phonon Interaction in Nanostructures

We have continued to utilize normal-metal-superconductor tunnel junctions (NIS) for ultrasensitive thermometry in sub-Kelvin temperature range. NIS-junctions can be used to characterize the electron-phonon (e-p) interaction in metals very accurately. The main results achieved in 2005 are: (a) Successful measurement of the e-p interaction in the case where 3D electrons are coupled to 2D phonons in a membrane geometry (Fig. 1).

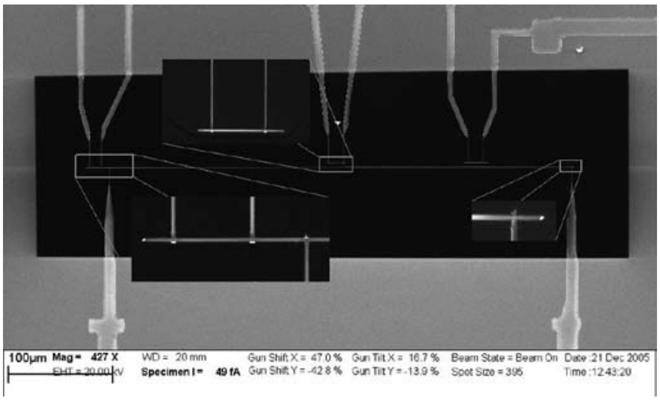


Fig. 1. SEM image of a suspended 30 nm thick 2D phonon sample with SIN tunnel junctions fabricated on the membrane.

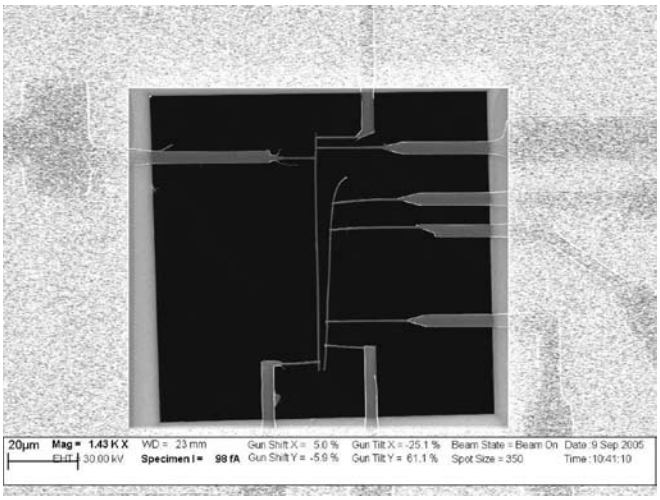


Fig. 2. SEM image of a suspended NIS structure used to measure near-field thermal photon heat transport.

The results show the weakening of the interaction due to the phase space restrictions, and, clearly demonstrate the expected change in the temperature dependence of the scattering rate. (b) We have developed a way to evaporate Aluminum doped with Manganese, and managed to measure the e-p interaction in it for several Mn concentrations. Strikingly, the strength of the interaction varies significantly with the concentration. This has important consequences for the operation of bolometers and coolers made from AlMn. Higher sensitivity seems achievable with higher concentration of Mn. (c) We have continued the development of our novel ac measurement technique, where any thermal relaxation rate can be measured directly without any fitting parameters. Exact theory of this technique has been worked out for the case of photon emission into transmission lines. Results on e-p scattering are in agreement with earlier dc measurements.

Thermal Near-Field Photon Emission from Suspended Nanostructures

In addition to phonon emission, electrons can also dissipate energy by emitting photons. Typically, at low temperatures the thermal radiation power into free space in negligibly small, however, if another object is brought to the near field of the dominant photon modes (distance much less than the thermal wavelength), thermal emission is increased by several orders of magnitude. We have fabricated suspended tunnel junction samples (Fig. 2), where the effect of photon emission can be studied in detail. Initial results demonstrate that a signal is seen. This process needs to be taken into account as an additional dephasing signal in quantum computing, as well as in closely spaced thermal detector arrays.

Thermal Transport in Insulating Nanostructures

Theoretical and experimental work on phonon transport in low-dimensional structures is a new focus field. Numerical solutions of full elasticity equations for 2D have been developed in collaboration with prof. Manninen's group. Results on ballistic phonon transport show that, quite surprisingly, thermal conduction can be improved by thinning the membrane in the 2D limit. This is due to the dependence of the non-linear dispersion relations on the membrane thickness. We have also started the experimental project to study phonon transport in novel insulating materials, such as SiC and AlN. High quality piezoelectric AlN for this purpose is processed by reactive sputtering and laser deposition in collaboration with Uppsala University and the Indian Institute of Technology, Kanpur. Numerical FEM modelling of phonon transport in complex boundary geometries is performed in collaboration with mathematicians at the St. Petersburg State University.

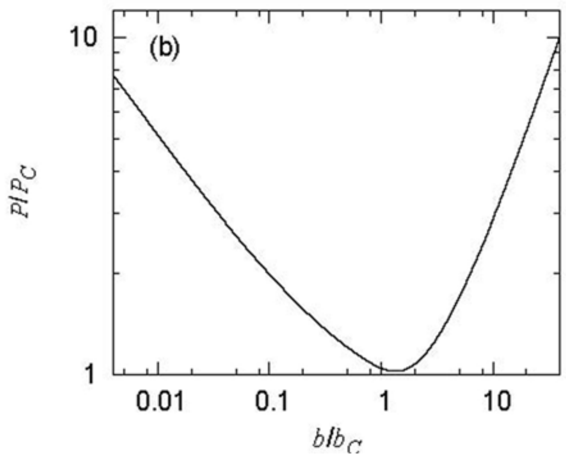


Fig. 3 The radiated ballistic phonon power *P* as a function of the membrane thickness *b*. Below the critical value b_c the phonons are fully 2D.

Development of Tunnel Junctions

As tunnel junctions are of critical importance in our applications, we have also studied how their characteristics could be improved. We have built a vacuum system, where samples can be annealed in vacuum or in some atmosphere, up to around 1000 degrees C. For tunnel junctions, one serious problem is aging, i.e. slow drift of their characteristics with time. We have found a solution to this problem: by annealing Al-AlOx-Al tunnel junctions up to 400 degrees C we have artificially aged them so that they became stable after the treatment. This technique appears to have wide relevance in applications.

Flux Penetration in Ultrahigh Quality Niobium Nitride

NbN is a conventional superconductor, whose critical temperature can reach up to 17 K. We are participating in a collaborative project between NSC, Indian Institute

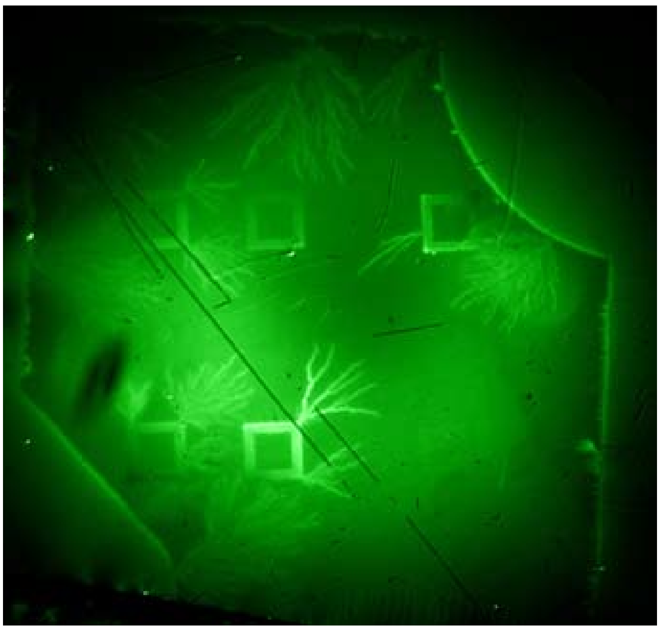


Fig. 4. Flux penetration into an epitaxial NbN film measured by magneto-optical imaging. Image courtesy of T. Johansen, Oslo University.

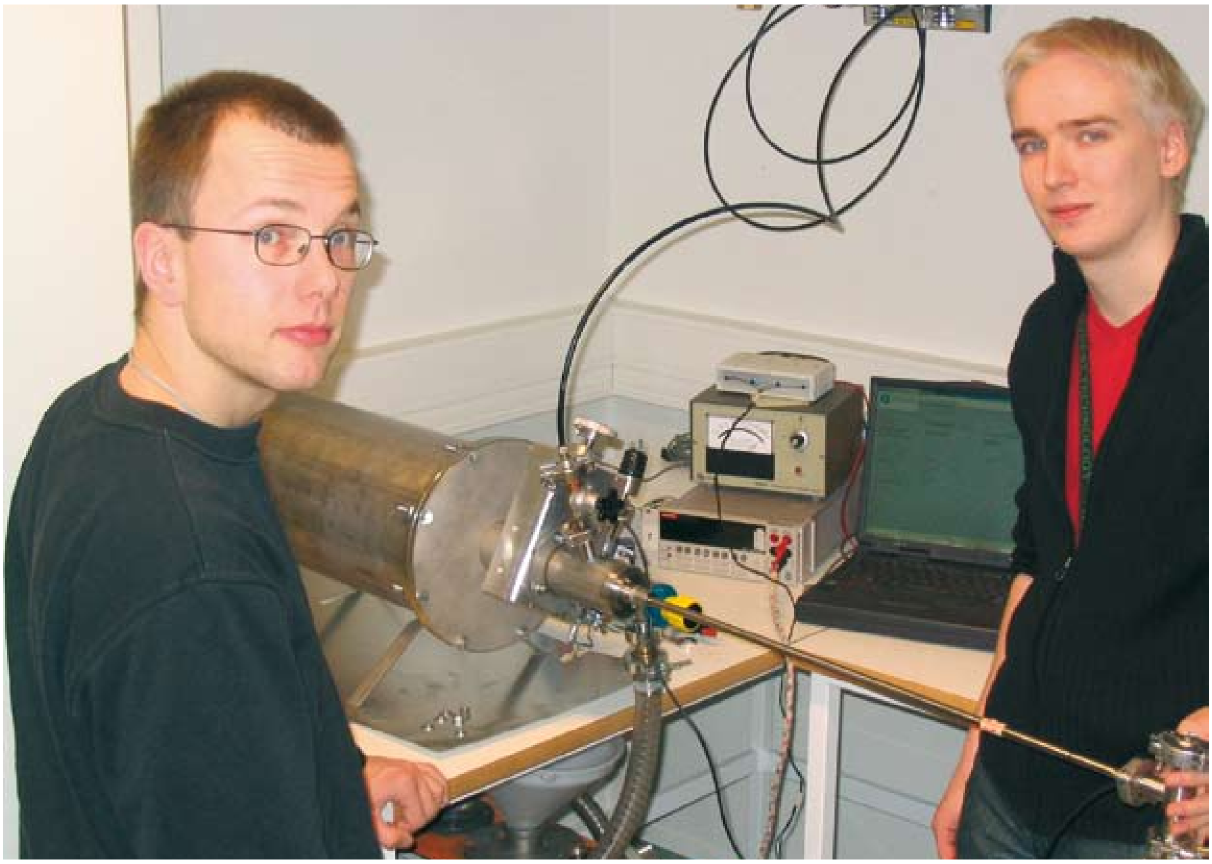


Fig. 5. Vacuum annealing system and its operators Lasse Väistö and Panu Koppinen.

of Technology Kanpur and University of Oslo, where the goal is to study flux penetration into epitaxial NbN films. Images are obtained with the magneto-optical technique (measurements performed in Oslo). Fig. 4 shows some initial data, showing how the flux penetrates from sharp corners etched into the film and from irregularities of the boundary. The flux forms sophisticated dendritic avalanche patterns and can have a fractal dimension.

Superconducting Transition Edge Sensors (TES) for X-ray Calorimetry

Superconducting transition edge microcalorimeter development continued with a project funded by the European Space Agency, in collaboration with Oxford Instruments Analytical Oy. The long term goal for ESA is to develop a cryogenic imaging spectrometer in the 0.1- 10 keV band with a few eV resolution, to

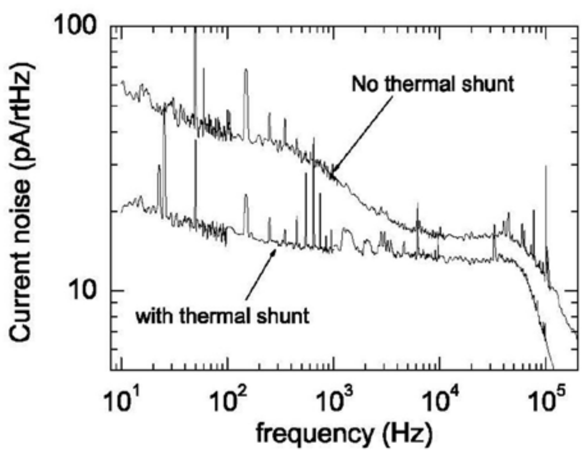


Fig. 6. Suppression of thermal noise in TES sensors.

be installed onboard a satellite (XEUS). We have optimized our SQUID preamplifier setup (SQUID work in collaboration with the National Institute of Standards and Technology (NIST) in Boulder, Colorado), and discovered a novel way to block thermal noise from the circuit, which degrades the resolution of the detector. In addition, we have calculated how to optimally operate TES sensors, when their heat dissipation is limited by a ballistic phonon flow in membranes (has shown to be a realistic situation).

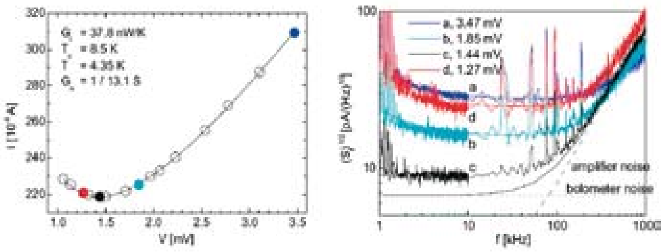


Fig. 7. Current-voltage and noise characteristics of a sub-mm Nb air-bridge bolometer. Colors on the points in the I-V curve correspond to bias values of the noise spectra on the right.

Superconducting Nb Microbridge Bolometer

In collaboration with VTT, we continued the development of superconducting sub-mm Niobium bolometers. New room temperature readout was developed at VTT, achieving the photon shot noise limit from a room temperature source (Fig 7). Work on novel higher T_c materials is in progress.

Mesoscopic Superconductivity

Konstantin Arutyunov

Electron Transport in 1D Superconductors

Below a certain temperature Tc (typically cryogenic) some materials lose their electric resistance R entering a superconducting state. With the natural tendency of integration of greater number of electronic components it is desirable to use superconducting elements to minimize heat dissipation. It is expected that this basic property of a superconductor (dissipationless electric current) will be preserved at reduced scales required by modern nanoelectronics. Unfortunately, there are indications that there is a certain limit ~ 10 nm below which a 'superconducting' wire is not any more a superconductor in a sense that it acquires a finite resistance. We have applied our proprietary method of progressive reduction of nanostructure dimensions by ion sputtering to this problem. We have observed the experimental evidence of

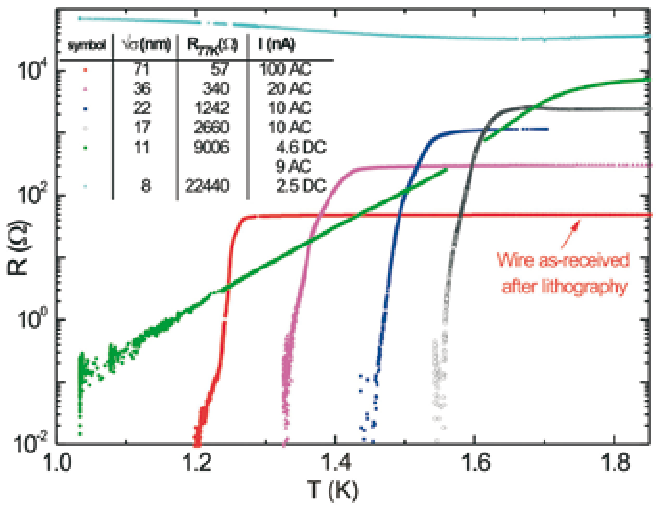


Fig. 8. Resistance vs. temperature for the *same* wire of length L = 10 µm after several sputtering sessions. The sample and the measurement parameters are listed in the table. For low-Ohmic samples lock-in AC measurement with the front-end preamplifier with input impedance 100 kΩ were used, for resistance above ~ 500 Ω we used DC nanovolt preamplifier with input impedance ~ 1GΩ. The absence of data for the 11 nm sample at T ~ 1.6 K is due to switching from DC to AC set up. Note the qualitative difference of R(T) dependencies for the two thinnest wires from the thicker ones.

quantum phase slip behavior in ultra-narrow aluminium nanowires *(Nano Lett 5, 1029 (2005))*.

Electron Transport in 1D Semimetals

Textbook quantum mechanics states that when a particle with mass m^* is placed in a potential 'box' with characteristic dimension *L*, the energy spectrum is quantized: $E_n = (h^2/8m^*L^2)n^2$. The same is applicable for free electrons in metals: when the corresponding dimension is sufficiently small the discreetness of the conducting band should come into play. Two related effects might be observed: periodic modulation of kinetic properties as a function of the effective dimension L, and metal-insulator transition at $L < \lambda_{dB}$, where $\lambda_{dB} = h / (8m^*E_F)^{1/2}$ is the conducting electron de-Broglie wavelength and E_F is the Fermi energy. We have experimentally studied these quantum size effects in 1D and 2D bismuth structures.

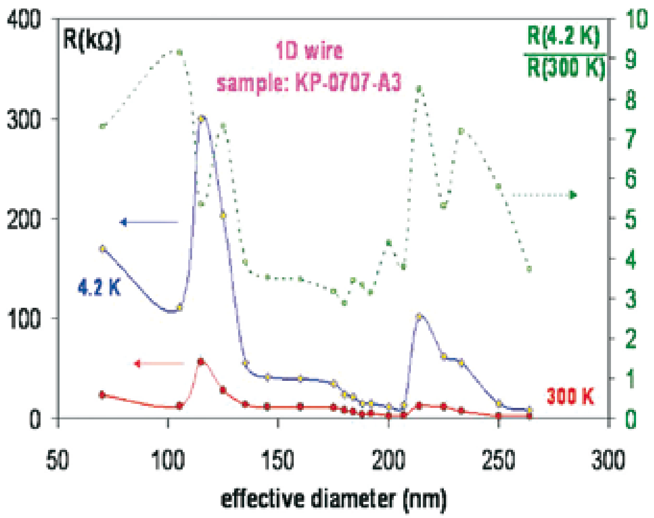


Fig. 9. Bi nanowire resistance vs. effective diameter for two temperatures 300 K (red) and 4.2 K (blue).

Solid State Quantum NIS Interferometers

Hybrid normal-metal–insulator–superconductor microstructures were fabricated. The structures consist of a superconducting loop connected to a normal-metal electrode through a tunnel barrier. An optical interferometer with a beam splitter can be considered as a classical analog for this system. All measurements were performed at temperatures well below 1 K. The interference can be observed as periodic oscillations of the tunnel current (voltage) through the junction at fixed bias voltage (current) as a function of a perpendicular magnetic field. The magnitude of the oscillations depends on the bias point. It reaches a maximum at energy *eV*, which is close to the superconducting gap and decreases with an increase of temperature. Surprisingly, the period of the oscillations in units of magnetic flux ϕ_0 is equal neither to *h/e* nor to *h/2e*, but significantly exceeds these values for larger loop circumferences. In collaboration with the theorists from University of Antwerpen (Prof. F. Peters and Dr. D. Vodolazov) we have developed a microscopic model describing behavior of the device. The results have been submitted to the PRL.

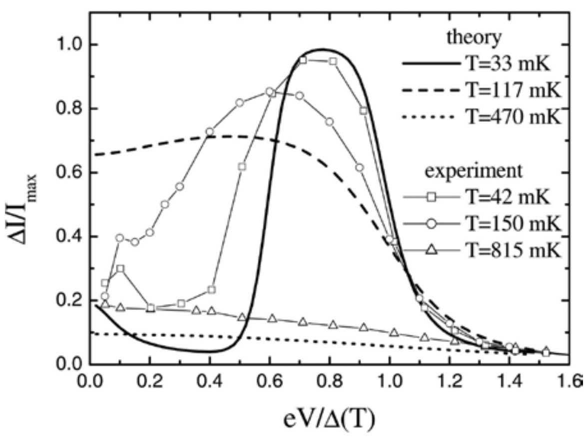


Fig. 10. Normalized magnitudes of the low field B < 5 mT current oscillations $\Delta I/I_{max}$ as function of the normalized bias $eV/\Delta(T)$ in a superconducting loop with parameters: T_c=1.2 K, $\xi(0)$=150 nm, w=5 µm , d=120 nm, T=106 mK.

Superconductivity Suppression in Aluminum Films by Ferromagnetic Ion Implantation

In collaboration with the material science group (Dr. V. Tuboltsev and MSc P. Jalkanen) for our experiments thin Al films were implanted with Fe ions in order to find out how the superconductive properties of the metal can be modified at will. The purpose was twofold, viz. first to study basic physics of superconductivity in low dimensional metallic structures doped with impurities. The second purpose was to apply ion implantation for suppression of undesired superconductivity in aluminum widely used for fabrication of micro- and nanodevices operated at low temperatures. In many applications transition to superconductive state is detrimental for the devices functionality, for instance in those based on Coulomb blockage (CB) effect (e.g. in CB thermometry). The results are published in J. Appl. Phys. 98, 016105 (2005).

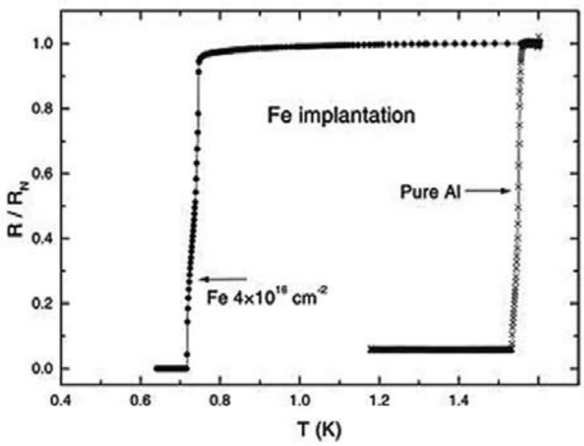


Fig. 11. Influence of the implantation of Fe^+ ions on superconducting transition of 100 nm thick Al film

Quantum Engineering

Sorin Paraoanu

The Quantum Engineering (QE) unit of the NanoPhysics group (S. Paraoanu, A. Halvari, M. Hassan, S.Ylinen, and H.T.Pitkänen) is studying transport phenomena and quantum coherence effects in superconducting devices based on the Josephson effect.

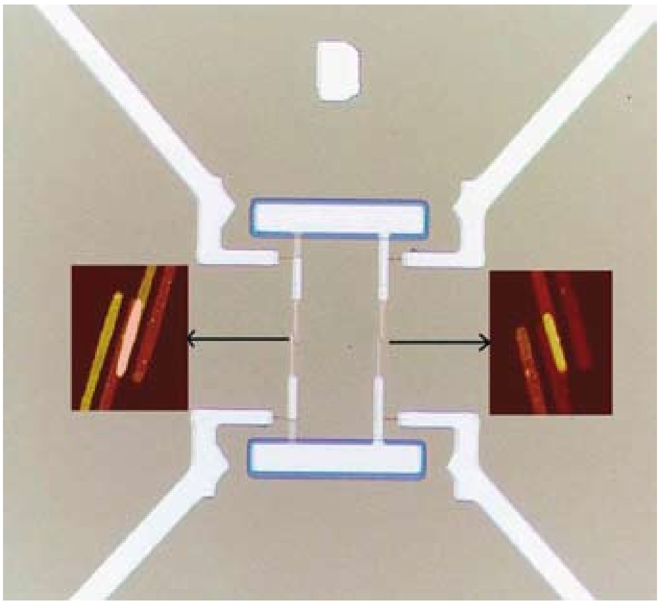
Coupled Phase Qubits

We have fabricated a system of coupled Josephson junctions (Figure-left below). The fabrication technology consists of 2 lithographic steps: during the first one we fabricate the capacitors (deposit 4nm Ti and 20nm Pt) and we evaporate a 20-60nm layer of Al_2O_3 as the dielectric of the capacitor. The second step consists of evaporating and oxidizing Al to create the junctions.

The circuit can be operated in two ways: we use one junction as an ac-Josephson effect oscillator and excite the other junction (the qubit), or as a system of coupled phase qubits.

From the first tests (Figure right) we conclude that the coupling between the circuits is strong enough to have them operated as a Josephson oscillator – phase qubit system. What we see is essentially a change in the IV characteristic of the qubit junction due to microwaves emitted by the other junction.

We have also performed numerical simulations of the circuit in the classical regime, we are now working to extend them in the quantum regime.



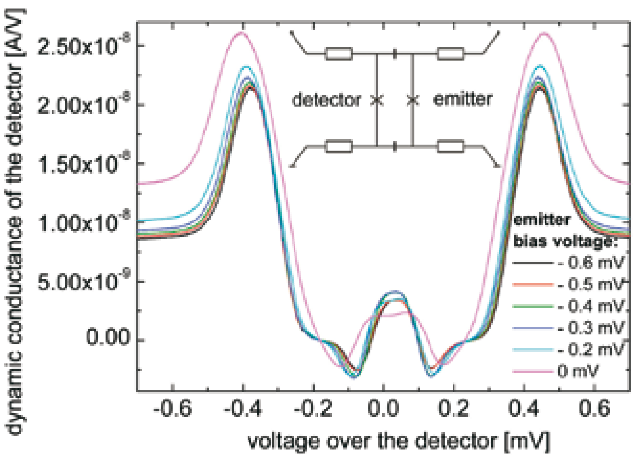


Fig. 12. (picture above) SEM picture of two Josephson junctions coupled through on-chip capacitors and isolated from the external leads by Pt resistors evaporated onto the same chip. (picture below) dI/dV versus V characteristic of one of the junctions when the other one is biased at various voltages (shown in the inset).

Flying Qubits

Another superconducting quantum circuit that we have fabricated consists of two Josephson junctions (phase qubits) coupled capacitively to a CPW resonator. The purpose of this circuit is to study the possibility of using superconducting resonators as quantum buses for the transmission of quantum information between two phase qubits. At this moment we are improving the fabrication process of this device.

3. Theoretical work. On a more general theoretical level, we have investigated the quantum dynamics of the phase of a Josephson junction in the running-wave state. We derived analytic expressions for the macroscopic quantum wavefunction. A different theoretical work concerns the possibility of so-called interaction-free measurements in superconducting quantum circuits. The role of the ultrasensitive quantum object is played here by the continuum of states outside the well of a washboard potential. We show that with current technology, by using a sequence of Ramsey pulses, it is possible to achieve a 2-3% success rate in detecting the existence of a current bias pulse in an interaction-free way. Finally, we investigated theoretically a system of two coupled Quantronium (charge-flux) qubits and show that quantum gates can be implemented in this system by manipulating the power of the incoming microwave irradiation.

Carbon Nanotubes and Scanning Probe Microscopy

Markus Ahlskog

The research activity on carbon nanotubes (CNT) was begun during 2004. During 2005 one Master's Theses was completed within this topic and two more will soon be ready. Carbon nanotubes are seen as one of the main components in future nanotechnology and already today as a superb system in which the phenomena of nanoscale physics can be investigated. The carbon nanotube consists of one or multiple concentric shells of seamless graphite sheets. A single wall nanotube (SWNT) has a diameter of 1-3 nm while the multiwalled nanotube (MWNT) may have any diameter in the range of 2-50 nm. Depending on the wrapping angle of the graphite sheet (chirality), an individual nanotube can be either metallic or semiconducting. A fact of fundamental importance is that the charge carriers in nanotubes of all sizes are truly delocalized. Ballistic conduction over μm-sized distances have been measured in carbon nanotubes. The axial Young's modulus of an individual nanotube sheet is approximated by the in-plane modulus of graphite (≅ 1 TPa), which makes the carbon nanotube one of the stiffest material that exists. A single carbon nanotube is thus an excellent freestanding electrical conductor. In the near future we will concentrate on the carbon nanotube. For our research the atomic force microscope (AFM) is an instrument of central importance, which we are using to probe the properties of single nanotubes. A new AFM was purchased during 2005.

The electronic and mechanical properties of CNTs are likely to be significant in micro- and nanoelectromechanical systems (MEMS & NEMS) that are currently being vigorously investigated for advanced technological applications. Nanoelectromechanical systems also have a demonstrated capability for novel measurements and detection methods in fundamental physics and related sciences. A variety of methods to produce suspended nanotubes is of interest, since this is the starting point for CNT based NEMS devices. We have investigated with atomic force microscopy moderate bending of multiwalled carbon nanotubes (MWNT) in the perpendicular direction from flat substrates. The tubes were in the diameter range 3-13 nm and deposited over lithographically fabricated gold lines whose height determined the total bending. In our model for the bending profile we take account of the Van der Waals attraction between the substrate and the MWNT and the opposing elastic bending force. With reasonable parameters for the competing forces we obtain an agreement between the model and the experimental data for the critical distance between two adjacent lines when the Van der Waals attraction no longer can prevent elastic forces from straightening the tube to a suspended position between the lines. However, for the smallest nanotubes a simple classical elasticity model is clearly insufficient.

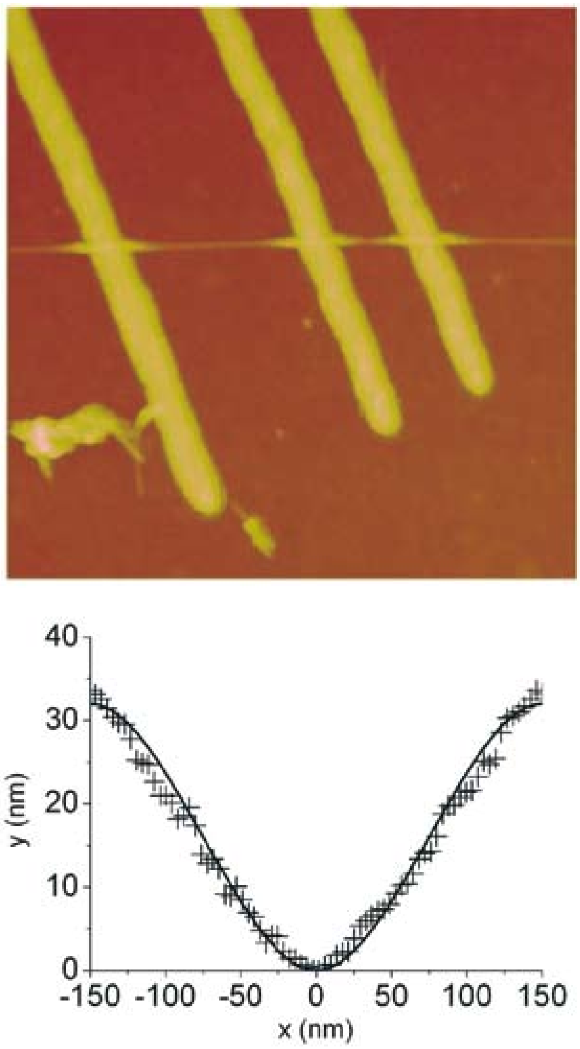


Fig. 13. AFM image of a MWNT partially suspended between two gold lines and the measured curvature of the bending tube, between the two electrodes to the right.

Research

Nanoelectronics and Nanotechnology

Päivi Törmä

Ultracold Atomic Fermi Gases

In year 2005, the final proof for the superfluidity in an atomic Fermi gas was achieved with the observation of a vortex lattice in a rotating gas. This superfluidity, together with the possibility of controlling all important system parameters, now allows the testing of different theories in various fields of physics e.g. high-T_c superconductivity and color superconductivity.

We have proposed an effective higher order theory for describing quantitatively the RF spectroscopy of an ultracold atomic gas that can be used for probing superfluidity and the superfluid excitation gap. Moreover,

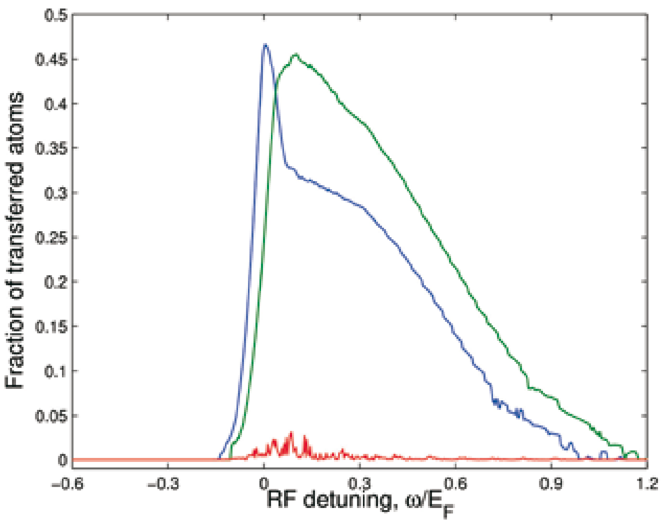


Fig. 2. The fraction of transferred atoms as a function of RF-field detuning in the RF-spectroscopy of a trapped strongly interacting Fermi gas. The high-order perturbation theory (green line for zero temperature, blue line for $T = 0.07\ T_F$) agrees with the experiments, whereas the linear response theory (red line) is only in qualitative agreement.

Päivi Törmä, professor
Kari Loberg, lecturer
Jussi Toppari, senior researcher
Lars Melwyn Fjelsted, postdoctoral researcher 1.11.-
Jani Martikainen, postdoctoral researcher -31.7.
Pasi Kivinen, assistant -31.7.
Tommi Hakala, graduate student
Anu Huttunen, graduate student (Helsinki University of Technology)
Jami Kinnunen, graduate student
Timo Koponen, graduate student
Anton Kuzyk, graduate student
Markus Rinkiö, graduate student
Sampo Tuukkanen, graduate student
Janne Haatanen, MSc student
Lasse Hirviniemi, MSc student
Mikko Laitinen, MSc student -31.8.
Heli Lehtivuori, MSc student
Mikko Leskinen, MSc student
Tomi Paananen, MSc student

The group belongs to the Nanoscience Center (NSC) of the University of Jyväskylä.

we suggested the use of the method for detecting the possible FFLO-type oscillating order parameter at the edge of a polarized Fermi gas cloud. We have also studied different theoretical models for strongly interacting Fermi gases relevant for high-T_c physics.

Motivated by the rapid progress in trapping and manipulating degenerate atoms in optical lattices, we have studied different aspects of ultracold fermions in optical

lattices. First, one-dimensional optical lattice splits the atomic cloud into weakly coupled quasi two-dimensional layers. We have studied how a transition from a purely two-dimensional problem into a three-dimensional one is manifested in the BCS theory of fermions and found a characteristic stepwise behavior associated with the energy level structure of the quasi two-dimensional site. Furthermore, we demonstrated how this is experimentally reflected in the radio-frequency spectroscopy.

We have also studied three-dimensional optical lattices. We have focused on the velocity of sound in cubic lattices and the dimensional crossover between one-, two-, and three-dimensional lattices. In the symmetric (3D) limit we have found that increasing the interactions of the atoms smoothens out the van Hove singularity that is evident in the weak-interaction BCS limit. We have also found that in the one- and two-dimensional limits of the asymmetric lattice the velocity of sound shows behaviour that is qualitatively different to the symmetric case.

Fig. 1. The group in the lobby of the Nanoscience Center.

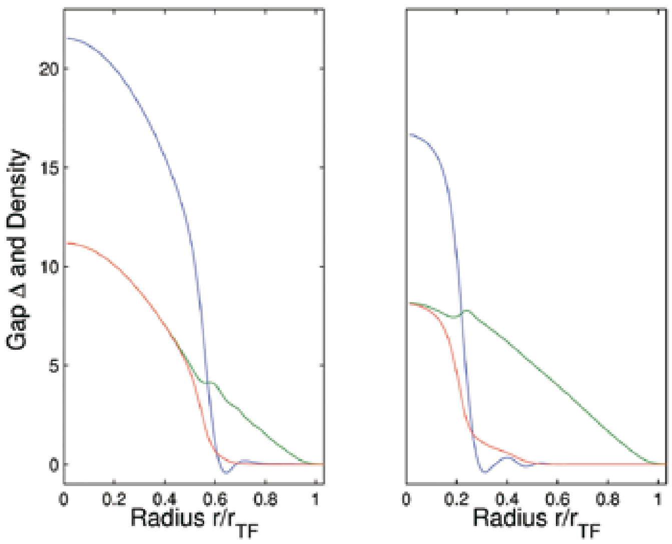


Fig. 3. The order parameter (blue line) and density profiles (red and green lines) of a polarized Fermi gas for two spin-density polarizations (0.33 for left plot and 0.89 for right). At the center of the trap, the densities are equal and the atoms show typical BCS-pairing, while at the edges the order parameter shows FFLO-type oscillations.

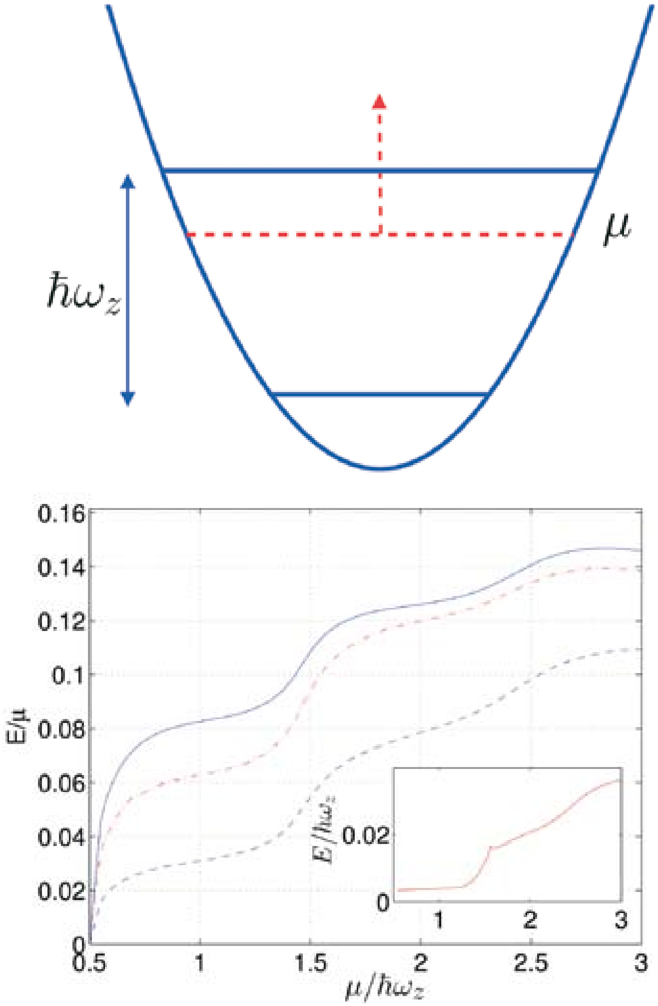


Fig. 4. Chemical potential crosses the energy levels of the harmonic trap (left), which causes discrete, observable steps in the superconducting order parameter (right).

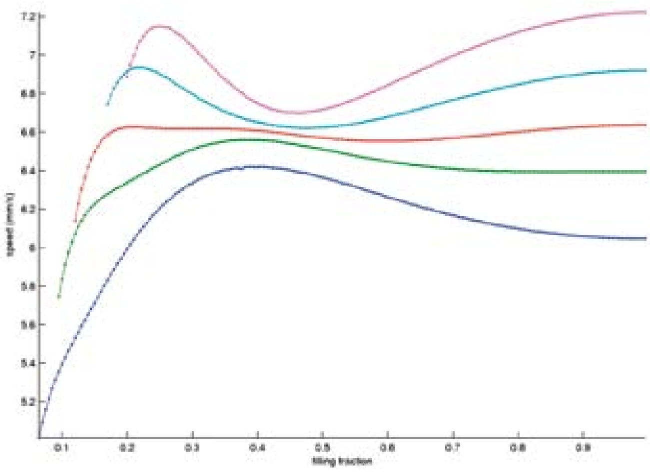


Fig. 5. The velocity of sound in a superfluid Fermi gas in an non-symmetric lattice showing dimensional cross-over: uppermost line 3D, lowest nearly 2D.

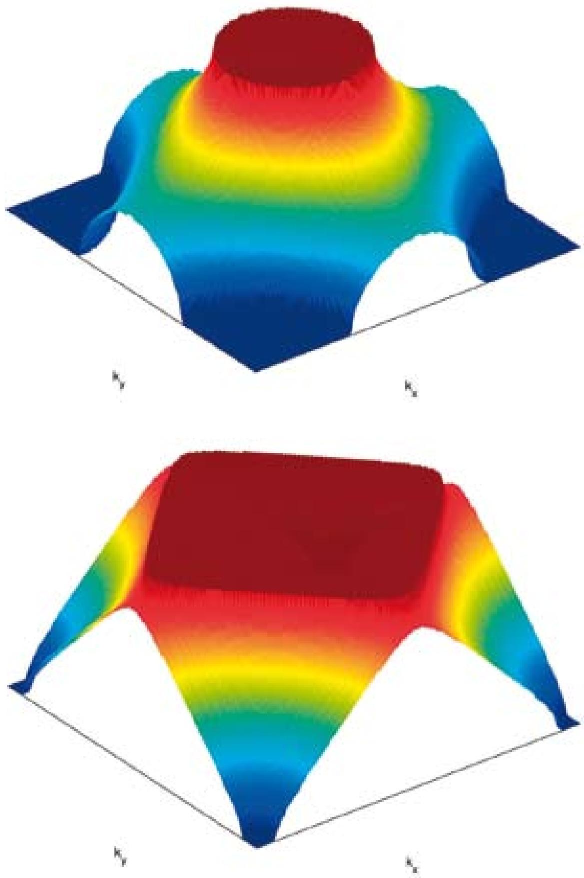


Fig. 6. The Fermi surface of a dilute superfluid Fermi gas in an optical lattice (left). When the density of the gas approaches the van Hove singularity, the Fermi surface becomes disconnected (right).

Three component Fermi gases are also experimentally realistic in the very near future and have, until now, received only scant attention. For this reason, we studied a homogeneous three component Fermi gas, where the components are different alkali atoms. We generalized the well known two component BCS-theory into three component BCS theory.

Dielectrophoresis and Electrical Measurements of Nanoscale DNA Molecules

DNA and other molecules with self-assembly properties hold a promise as components in future molecular electronics. We focus on trapping and manipulating such atoms, and on the study of their electrical properties. A key open question in molecular electronics is the role of molecule-metal contacts. For DNA, the nature of charge transport along the molecule is not fully understood either. Apart from the molecular electronics perspective, electrical properties of DNA could potentially be utilized in single mutation detection applications.

We have used dielectrophoresis (DEP) (the motion of polarisable particle under the effect of non-uniform electric field) for trapping single nanoscale DNA molecules. In the case of nanoscale objects, the Brownian motion poses a challenge and high field gradients are needed for successful trapping. We have studied dielectrophoresis (with AC fields) of various sizes (from 27 bp (base pairs) (9 nm) to 8461 bp (2.9 µm)) dsDNA and the immobilisation of 414 bp (140 nm) thiol-modified dsDNA *in situ* under the confocal microscope (see Fig. 7). For DEP, finger-tip type nanoscale gold electrodes (with about 100 nm separation) were fabricated using e-beam lithography. We have also demonstrated the use of carbon nanotubes as electrodes for even more precise DNA trapping.

Our AC-DEP technique has a reasonably high yield allowing repeatable and reliable electrical conductivity measurements of single or a few molecules (see Fig. 8). Electrical DC conductivity measurements of the samples showed insulating behaviour in the dry environment (30% relative air humidity), which is in agreement with many recent observations by other groups. In contrast, in moist conditions (80-90% humidity), several samples showed clear increase in conductivity which was much higher than observed in the reference samples.

Our results suggest that the conductance change is related to a humidity induced conformational change of the molecular structure, and thus associated with a contribution from electron transfer. Further research is required, however, to identify in detail the contributions from electrons, water ions and counterions.

In order to study the contribution of metal-molecule contacts to the electronic properties of the device, we have started a project where different types of linker molecules are compared, including both experimental and theoretical [by Hannu Häkkinen's group] studies. This work has been done in collaboration with chemists and biologists at NSC.

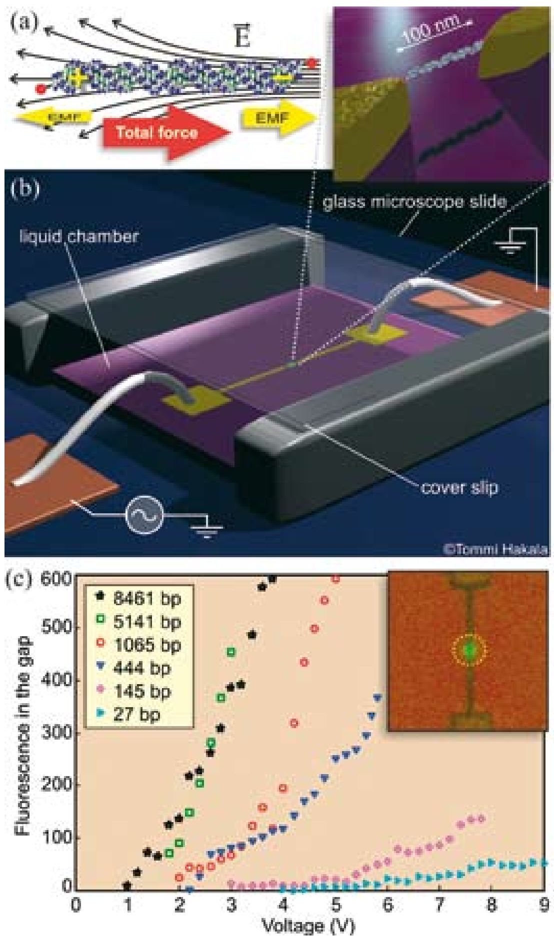


Fig. 7. (a) Principle of DNA DEP. (b) Schematic view of the experimental setup for the DNA DEP under confocal microscope. (c) Dielectrophoretic trapping of DNA of different lengths (in base pairs) under the confocal microscope. Fluorescence intensity in the gap (circle area) is measured as a function of the trapping voltage. Inset is the fluorescence image taken during DEP.

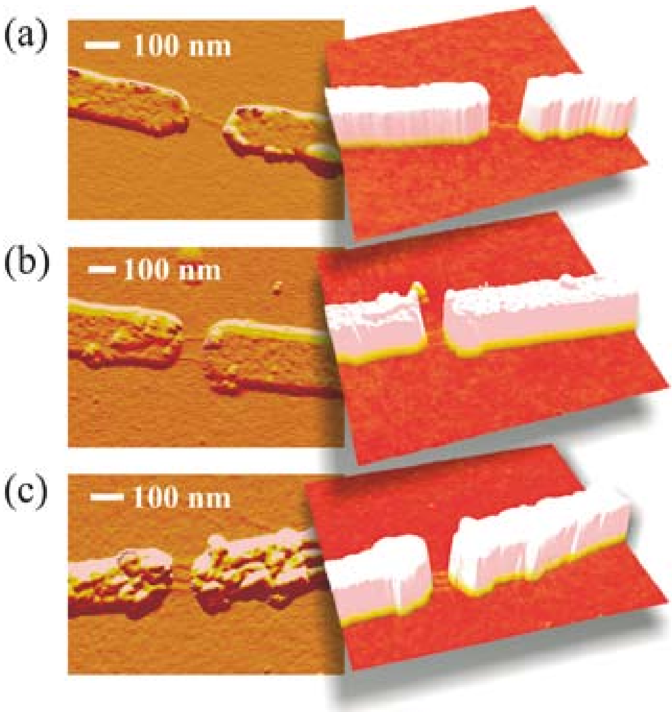


Fig. 8. (a-c) AFM images of the single DNA molecules trapped between nanoelectrodes.

Molecular Scale Memory Elements

Due to fundamental physical limitations, the scaling down silicon-based microelectronics will eventually reach a limit. Molecular electronics can, in principle, overcome such limitations and especially carbon nanotubes (CNTs) are an attractive material due to their unique electronic, mechanical, and chemical properties. Depending on the diameter and the chirality of the CNT, it behaves as one-dimensional metal or semiconductor. These properties together with their great mechanical toughness and chemical inertness make them promising material for creating reliable high-density arrays of molecular-level devices.

Commercial multi walled carbon nanotubes (MWNTs) and single walled carbon nanotubes (SWNTs) were used as a FET like conduction channel in a study of memory effects in carbon nanotube devices. Lithography and AFM methods were used for the fabrication and characterization of the samples. The DC current-voltage characteristics of the fabricated devices were measured with and without gate voltage.

The device exhibited hysteretic behaviour which followed the gate voltage. The memory effect was studied and the results are presented in Fig. 11. Carbon nanotubes devices are known to show such memory effects, and we aim at optimization of these effects towards device applications.

The research has been done in collaboration with the Nanodevices group and the Nanophysics group at NSC.

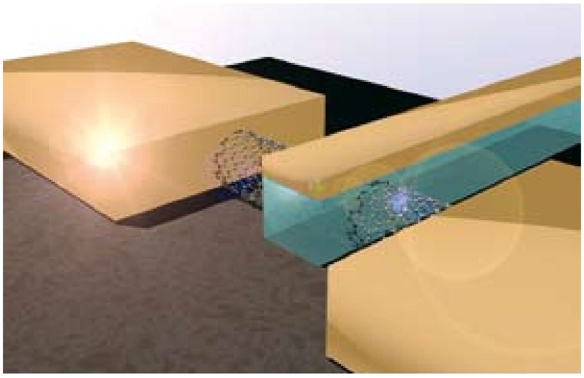


Fig. 9. An artistic view of a carbon nanotube –based memory element.

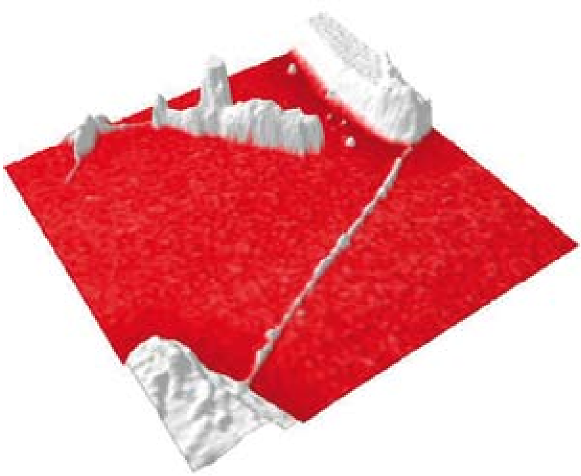


Fig. 10. An AFM image of a carbon nanotube between two gold electrodes.

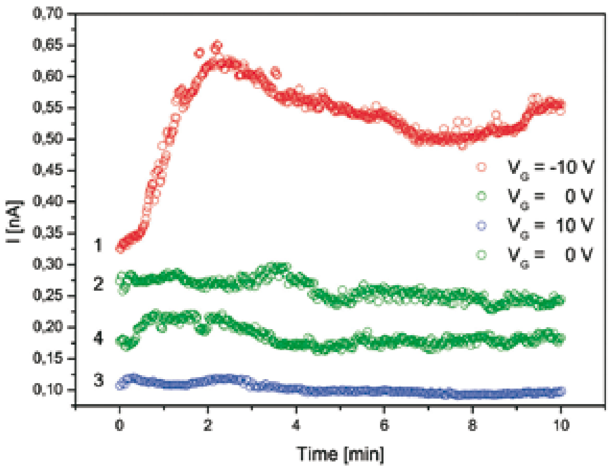


Fig. 11. Memory effect of the device at 4.2 K. The measurements are performed one after the other in the order of numbering. After gating with a positive or negative voltage, the zero gate voltage currents shows different values.

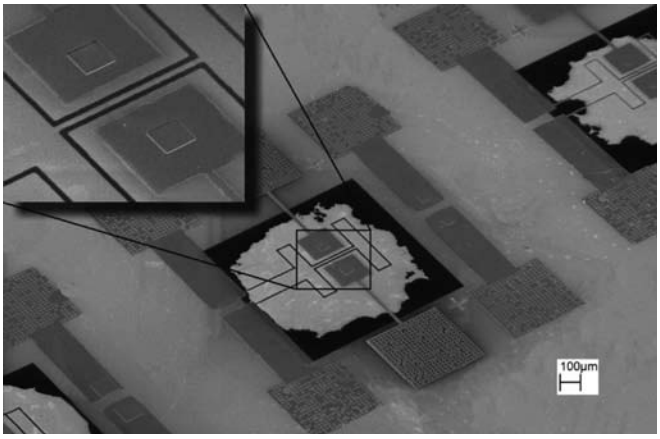


Fig. 12. Scanning electron micrograph of one of the fabricated calorimeter.

Nano- and Microsensors

We have developed, to our knowledge, the first microcalorimeter using Schottky junctions, fabricated on a Si island in the middle of a SiN membrane, as a thermometer (see Fig. 12). The device is capable of measuring samples down to subnanoliter size. In addition, a hybrid microcalorimetric measurement method capable of providing simultaneous quantitative information directly about sample temperature, power production/consumption as well as of sample heat capacity and its variations via ac-calorimetry, is introduced. The method uses low heating rates and small temperature variations and may be used at room temperature, which makes it particularly suitable for biological and chemical purposes. A schematic of the measurement setup is shown in the Fig. 13 (left).

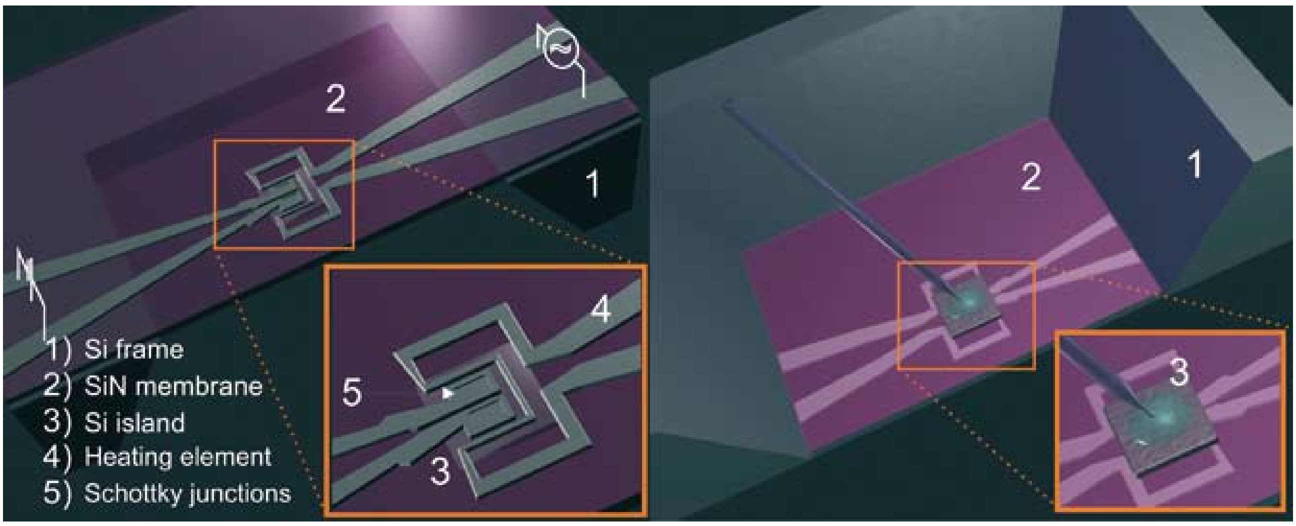


Fig. 13. A schematic of the measurement setup (left). The samples were injected on the flip side of the chip (right), which also provides a reaction chamber for liquid samples with high volumes.

Electron-Phonon Coupling

We have studied electron-phonon energy relaxation in Si at sub-Kelvin temperature. Si is a many-valley semiconductor and the electron-phonon coupling is in it therefore influenced by the electron scattering between the valleys (Fig. 14). Because of lack of screening, the electron-phonon energy flow rate is strongly enhanced in many-valley semiconductors in comparison to single-valley ones at the diffusive low-temperature limit. In Si, or in general in all semiconductors, due to small electron density, the e-ph interaction can be described by deformation potential coupling constants, which do not depend on the electronics variables. This is not the case in metals, where the coupling strongly depends on the electron momentum.

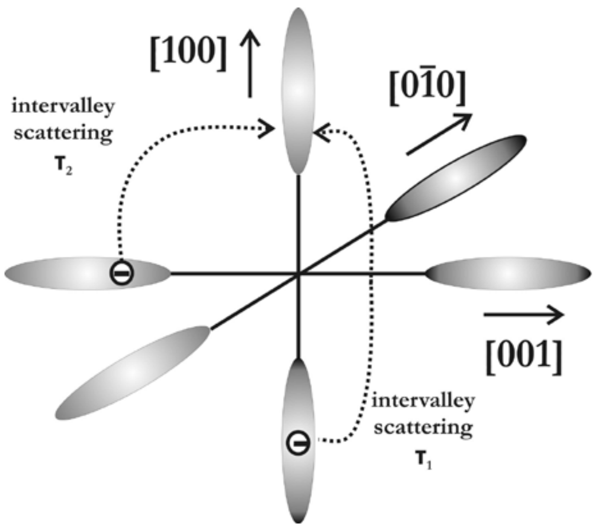


Fig. 14. Schematic illustration of the intervalley scattering between the constant energy ellipsoids. The valleys are located close to the X point in the first Brillouin zone. Scattering rates 1/τ and 1/τ couple the different classes of the valleys (scatterings are g- and f-processes, respectively).

We have calculated the total electron-phonon energy flow rate in Si by using the phonon energy attenuation rate and performed electron heating experiments to doped n-type Si samples at low temperature. Electron and phonon gases are simultaneously heated and temperatures independently measured (Fig. 15). The experimental and theoretical results can be compared by using the slope S as a single fitting parameter. The values given by the experiments and the calculated intervalley electron scattering time show excellent agreement.

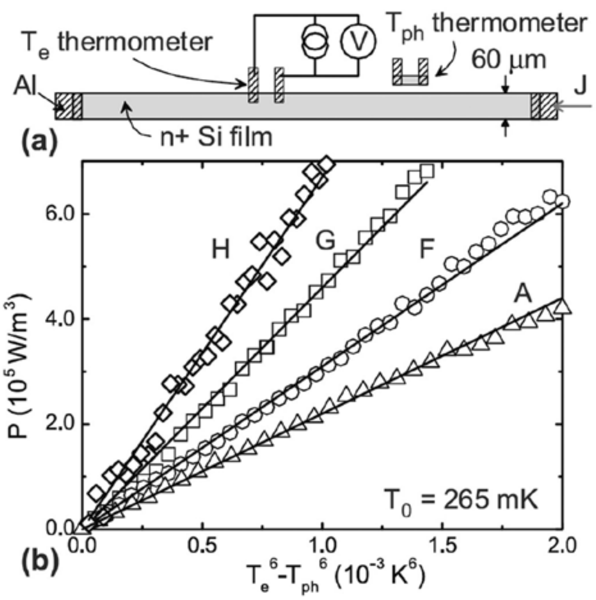


Fig. 15. (a) The sample geometry and the measurement setup. The long n+ Si bar is heated with a dc current density J. T_e and T_{ph} are acquired using the current biased Al-Si-Al contacts (here only the biasing circuit for T_e is depicted). The T_{ph} thermometer is electrically isolated from the main Si bar by a ~ 1 µm gap. (b) The power density P vs. $T_e^6 - T_{ph}^6$ in samples with different carrier concentrations.

Photonic Band Gap Materials

Photonic crystals are periodic dielectric structures for which the period is of the order of the wavelength of light. Photonic crystals exhibit band gaps for light as a result of interference. Light with a frequency inside the band gap cannot exist in the photonic crystal. Photonic crystal fiber has a photonic crystal cladding, i.e., the cladding of the fiber is periodic in the plane that is perpendicular to the direction of propagation of light in the fiber. Many of the limits of fiber optics have been overcome with this new class of fibers.

We have studied photonic crystal fibers that are used as fiber amplifiers. In high-gain efficiency fiber amplifiers, the overlap between the light distribution and the doped area of the fiber is maximized, and thus they usually have small mode areas. Photonic crystal fibers with small mode areas have relatively large dispersion and nonlinearity, and these parameters also depend strongly on the wavelength. The effect of the wavelength dependence of gain, nonlinearity and dispersion in high gain efficiency photonic crystal fiber amplifiers was investigated using the optical nonlinear Schrödinger equation. The wavelength dependence of the parameters was shown to create asymmetry to the spectrum and chirp, but to have a moderating effect on the pulse broadening.

Research

Computational Nanosciences

Matti Manninen
Hannu Häkkinen

Theory of Quantum Dots and Wires

Matti Manninen

Matti Manninen, professor
Hannu Häkkinen, senior assistant
Matti Koskinen, researcher -30.4.
Jaakko Akola, postdoctoral researcher 1.8.-
Karoliina Honkala, postdoctoral researcher
Pekka Koskinen, postdoctoral researcher -31.1.
Kirsi Manninen, postdoctoral researcher -30.6.
Vesa Ruuska, postdoctoral researcher -31.5.
Michael Walter, postdoctoral researcher
Katarzyna Kacprzak, PhD student 1.7.-
Thomas Kühn, graduate student
Kimmo Kärkkäinen, graduate student
Kari Rytkönen, graduate student
Timo Santa-Nokki, graduate student -23.11.
Juha-Pekka Nikkarila, MSc student
Sami Malola, MSc student
Peter Mikula, MSc student

Rotating Electrons in Quantum Dots

In an external magnetic field, electrons in a quantum dot will polarize and start to rotate around the center of the dot. The rotation induces first vortex formation and when it becomes fast enough the electrons will localize to a Wigner crystal. We have studied the system of rotating electrons using exact numerical diagonalization of the many-particle Hamiltonian of interacting electrons in a two-dimensional harmonic trap. For small number of particles and high rotational states the electrons crystallize. This crystallization in seen from the rotational spectrum as a periodic oscillation of the energy as a function of the angular momentum, as seen in Figure 1 for seven electrons.

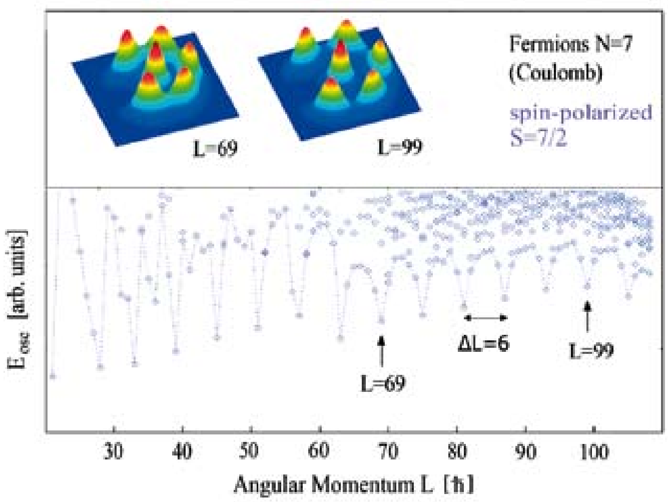


Fig. 1. Energy spectrum of seven electrons in a quantum dot as a function of the angular momentum. The inset shows examples of pair correlation functions.

For large number of particles and small angular momentum the rotational spectrum also shows oscillations. In this case, however, they are caused by localized vortices. We have shown that the vortex localization has the same origin as the elecron localization: The vortices are holes in the Fermi see and have the same properties as electrons (Manninen et al, Phys. Rev. Lett. 94, 106405 (2005)). Figure 2 shows formation of four vortices in a quantum dot with 36 electrons.

Quantum Wires

Scattering of electrons from impurities and connecting leads becomes increasingly important when the wire is made thinner and thinner. Single electron resonances in quantum wires are generally Fano resonances, which are characterized by a sharp phase drop. We have analysed multichannel Fano resonances of a simple three prong potential. Our results show that the scattering phase shift shows sharp drops only in some particular scattering channels while other channels do not show phase drop.

Those channels that do not show the phase drops seem to be the more informative channels in determining the density of states.

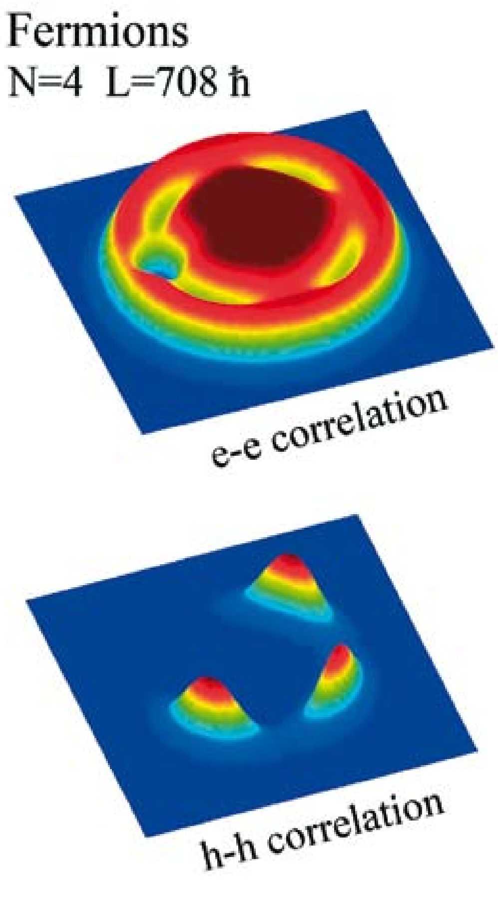


Fig. 2. Pair correlation function of 36 electrons showing four minima corresponding at the position of four vortices. The lower figure shows the vortex-vortex correlation.

Secrets of Nanocatalysis Unfolding

Hannu Häkkinen and Karoliina Honkala

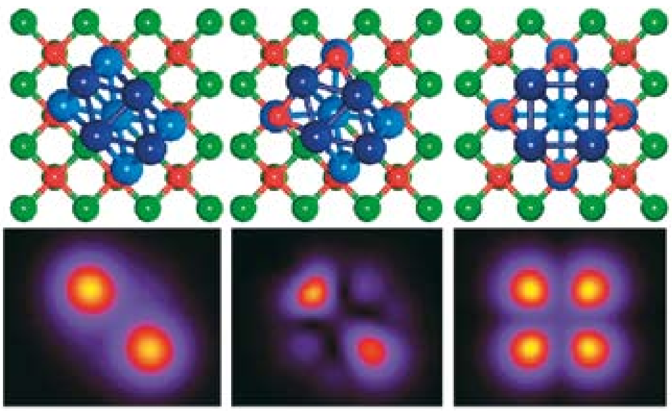
Ultrafine metal nanoparticles are active and selective catalysts for several important reactions but their functions at the atomic scale are often poorly known. Recent computational research has led to new insights on the oxidation mechanisms, activity towards ammonia synthesis and selective C-C and C-H bond activation promoted by gold, palladium, ruthenium and nickel "nanocatalysts".

The role of oxide-supported gold and palladium clusters in the catalytic oxidation of carbon monoxide were studied in collaboration with groups in Georgia Institute of Technology (Atlanta, USA), TU Munich and Fraunhofer IWM (Freiburg, Germany). The most recent results highlight the novel properties of clusters with size of just about 10 atoms. Gold clusters can catalyze a reaction between carbon monoxide (CO) and molecular oxygen (O_2) at a very low temperature of –120 C via a charge-transfer mechanism that weakens oxygen-oxygen bonds in O_2. Palladium clusters, on the other hand, completely dissociate molecular oxygen and store the oxygen atoms inside the cluster by forming a nanosized palladium-oxide crystal (see Figure 3). The energy cost of breaking the oxygen molecule as well as of the subsequent reaction between stored O atoms and a CO molecule adsorbed on the palladium-oxide nanocrystal is only about half of what is needed for larger palladium particles routinely used in commercial catalytic converters.

On the basis of density functional calculations of adsorption energies of the reactants, intermediates and products, activation energies of the elementary steps, and of the shape of the Ru catalyst nanoparticles, a kinetic model was formulated. This model was used to calculate the rate of ammonia synthesis. The calculated rates were very close to the measured ones. This is the first time when reaction rates of a complicated catalytic process have been predicted solely from the quantum mechanics.

The reactivity of catalytic surfaces is often dominated by very active low-coordinated atoms such as step-edge sites. Very little knowledge is available for the role of the step edges on selectivity in reactions having multiple reaction pathways. From the interplay between quantum mechanical calculations and scanning tunneling microscopy measurements it was found that for ethylene decomposition on a nickel surface the step-edge effect is more pronounced for the C-C bond breaking than for the C-H bond breaking, and thus the steps play an important role in bond breaking selectivity.

The new insights given by computer simulations and highly sophisticated experiments on ultrafine particles point now to a novel class of "nanocatalysts", where the active particles are so small that "everything is surface" and the chemistry is dictated by quantum mechanical interactions between the particle and the reactant molecules. In the future it might be possible to design new metal nanocluster catalysts that are optimized for maximal activity, sensitivity and selectivity for wanted reactions.



Clusters and Nanocatalysts

Hannu Häkkinen and Michael Walter

Investigations of the physical and chemical properties of metal clusters are currently largely motivated by the question how their various remarkably size-dependent properties could be best utilized while the clusters are interacting with the environment, e.g., bound on or implanted in a support, or stabilized and surface-passivated by molecules. Understanding factors that dictate the stability, structure and function has relevance regarding atomic-scale design of components that could be of potential use in future nanotechnologies. To this end, spectroscopic tools and density functional theory (DFT) calculations can provide valuable insights.

Polarization-resolved optical spectra of magnesia-supported gold clusters Au_N/MgO (N=1,2,4,8), bound at a surface color center Fs of the MgO(100) face, are calculated from the time-dependent density functional theory. The optical lines for N=1,2 are dominated by transitions that involve strong hybridization between gold and Fs states whereas for N=4,8 intracluster transitions dominate. The theoretical optical spectra are sensitive to cluster structure and adsorbants (here CO and O_2 molecules on Au_8/MgO) which suggests polarization-resolved optical spectroscopy as a powerful tool to investigate structures and functions of chemically active, supported clusters (see Figure 4).

Fig. 3. Top: A nine-atom Pd cluster (blue) supported on a MgO surface (green-red) rearranges while adsorbing and dissociating oxygen molecules. Dissociation of two oxygen molecules on the cluster results in a perfect epitaxy with the underlying MgO-support (top, right). Bottom: Simulated STM images of the corresponding structures. For details see B. Huber et al., Nature Materials 5, 44 (2006).

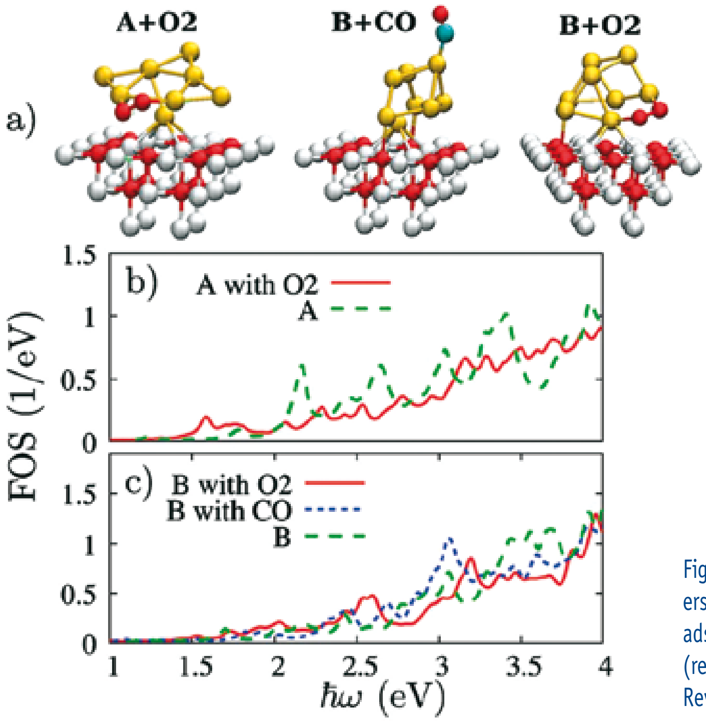


Fig. 4. Calculated optical spectra of MgO-supported gold octamers A and B (green curves) compared to changes induced by adsorbed carbon monoxide (blue curve) and oxygen molecules (red curves). For details see M. Walter and H. Häkkinen, Phys. Rev. B 72, 205440 (2005).

Research

Soft Condensed Matter and Statistical Physics

Markku Kataja
Juha Merikoski
Jussi Timonen

Statistical Physics

Jussi Timonen, professor
Markku Kataja, professor
Juha Merikoski, lecturer
Andrei Rybin, docent
Antti Koponen, senior researcher (part time)
Petro Moilanen, postdoctoral researcher -30.9.
Markko Myllys, postdoctoral researcher
Pasi Raiskinmäki, postdoctoral researcher (part time)
Urpo Aaltosalmi, graduate student -31.8.
Janne Juntunen, graduate student
Jari Hyväluoma, graduate student
Ari Jäsberg, graduate student
Jussi Jääskeläinen, graduate student -30.6.
Tomi Kemppinen, graduate student
Viivi Koivu, graduate student
Keijo Mattila, graduate student
Lasse Miettinen, graduate student
Otto Pulkkinen, graduate student
Marko Rasi, graduate student
Esa Rehn, graduate student
Tuomas Turpeinen, graduate student
Juha Vinnurva, graduate student
Tuomas Airaksinen, MSc student
Janne Kauttonen, MSc student
Pilvi-Helinä Kivelä, MSc student
Arto Lähteelä, MSc student
Tuomas Nuorento, MSc student
Tuomas Tallinen, MSc student
Mikko Voutilainen, MSc student

Fragmentation of Brittle Matter

We have previously introduced a generic model for brittle material in which mass points are connected by massless elastic beams with a threshold in the amplitude of deformation for breaking. This model was implemented numerically such that it described two-dimensional objects embedded in three-dimensional space. We found that when the system was let to expand homogeneously ('slow explosion'), fragments formed in the early phase of the fragmentation process continued to fragment further. The combined fragmentation process was found to include a scale-invariant component leading to a power-law fragment-size distribution in the small fragment-size limit. The related scaling exponent was 1.17. This exponent is in close agreement with earlier experimental results for impact fragmentation of gypsum disks, and with very recent results for explosive fragmentation of egg shells.

In the early stages of running of the CRESST dark matter search using sapphire crystals as detectors at very low temperature, an unexpectedly high rate of signal pulses appeared. Their origin was finally traced to fracture events in the sapphire crystals owing to the very tight clamping of these detectors. During extensive runs the energy and time of each event was recorded, providing large data sets for such phenomena. We believe this is the first time that the energy release in fracture has been directly and accurately measured on a microscopic event-by-event bases. The energy threshold in the detection system corresponds to the breaking of a few hundred covalent bonds, which appears to be many orders of magnitude smaller than in previous techniques.

We found that the energy distribution of the fracture events appears to follow a power law, dE/dN being proportional to $E^{-\beta}$, similar to the power law for earthquake magnitudes, and after an appropriate transformation, with a similar exponent. In the time domain, the waiting time (τ) distribution has power-law behaviour at small τ and an exponential fall-off at large τ, such that it is proportional to $\tau^{-\upsilon}e^{-\tau/\tau_0}$. The time series of the fracture events has the characteristics of fractal Gaussian intermittent noise, which is also true, as shown recently, for earthquakes. The autocorrelation function shows time correlations lasting for substantial parts of an hour. Large events are preceded, on the average, by periods of increased event rate, but this kind of 'statistical precursor' cannot be used to predict large events which can also appear without any warning.

Stochastic Systems

We have demonstrated that height-fluctuation distributions of one-dimensional low-combustion fronts in paper obey the so-called Tracy-Widom distributions, which are related to those of the largest eigenvalue of certain random-matrix ensembles. We observed experimentally two of these distributions, one for the transient dynamics and another for the stationary state. To confirm the interpretation of the experimental results, necessarily for finite systems, computer simulations were employed on two phenomenological models in the KPZ universality class with parameters determined from experimental data. More recently, we have built a realistic two-dimensional phase-field model to account for the relevant details of front dynamics when approaching the pinning limit.

We also continued our studies of stochastic particle systems. First, we used analytical and computational methods to examine condensation phenomena in processes defined on graphs or in graph-valued processes, and driven by zero-range dynamics. For these, we constructed generic phase diagrams and determined the related critical exponents. Another research theme was coupled stochastic processes. For coupled one-dimensional interfaces, which can be mapped onto particle models, we observe a non-monotonic behaviour of the interface roughness as a function of the interaction strength, even in the stationary state. This behaviour is found for spatially discrete finite systems only, but for quite large systems. We also studied one-dimensional zero-range processes coupled locally to non-Markovian sources. Contrary to some expectations, the non-Markovian behaviour is propagated by the zero-range dynamics. Very recently, we considered the coupling of internal degrees of freedom with the translational motion of polymers in the presence of a time-dependent spatially asymmetric external field. We found that a suitable external field can be used to overcome the so-called trap states, which otherwise freeze the motion.

Non-Adiabatic Manipulation of Slow-Light Solitons

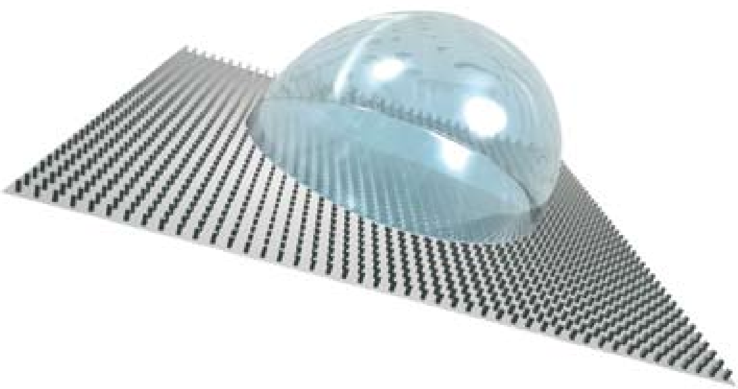
Recent progress in experimental techniques in coherent control of the interaction of slow light with matter opens new opportunities for interesting practical applications. This control can be realized in the case of electromagnetically induced transparency by coherent population oscillations, or by other induced-transparency techniques. We addressed in this connection the problem of slow-light solitons, i.e. soliton excitations in a three-level quantum system with two quantum channels. The velocity of such soliton depends on the magnitude of the controlling field, which can be switched off, thus making the soliton slow down and then stop. We followed the dynamics of the system especially when a shock wave of another laser field overtakes the slow-light soliton and stops it, while the optical information contained by this soliton excitation is recorded in the medium in the form of a spatially localized memory bit. The 'quantum information' thus stored can be retrieved by re-accelerating the frozen slow-light soliton.

Soft Condensed Matter Physics

Transport Properties of Porous Materials

We combined several techniques for analyzing flow in fibrous porous materials. The methods used included high-resolution X-ray microtomography together with image analysis, whereby one can produce a realistic three-dimensional description of the pore space of the sample with one-micrometre resolution, and *ab initio* fluid-flow simulations by the lattice-Boltzmann method in the porous structures thus produced. Various samples of paper and pigment tablets were analyzed for their transverse and in-plane permeability, porosity, specific surface area, and tortuosity, using these methods. For structures with the typical pore size clearly larger than the imaging resolution, such a combination of methods can already lead to accurate predictions for fluid-transport properties.

We analyzed in particular the capillary penetration of a wetting liquid in a tomographic image of paper board, whose linear dimension was close to the average length of wood fibres. In spite of the size of the system not being large with respect to the size of structural inhomogeneities in the sample, for unidirectional penetration the simulated behaviour was described well by that of the Lucas-Washburn equation, while for radial penetration a radial capillary equation described the behaviour. In both cases the average penetration depth of the liquid front as a function of time followed a power law over many orders of magnitude. Capillary penetration of small droplets of liquid was also simulated in the same 3D image of paper. In this case the simulation results could be described by a generalized form of the radial-penetration equation.



A liquid droplet on an inclined plane which is textured so as to make it superhydrophobic. Visualization was made by Jarmo Pirhonen, CSC.

Rheology of Liquid-Particle Suspensions

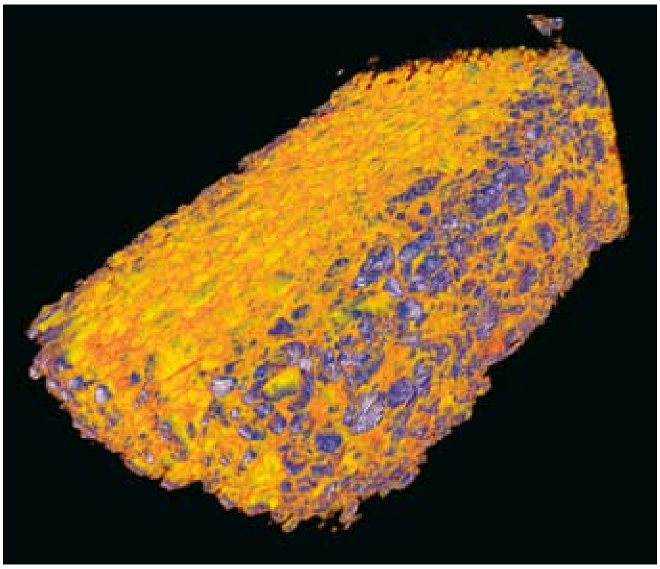
Non-colloidal model suspensions were studied with capillary and rotational rheometry. The size of the suspended particles was 10 µm so that the colloidal and Brownian forces were not important. The liquid used in the suspension was a viscous oil, which prevented sedimentation of the particles. The rheological properties of model colloidal suspensions were also investigated with rotational rheometry for varying particle size, particle concentration and interparticle colloidal forces. The viscosity of the monodisperse suspension was highest for the smallest suspended particles due to the largest relative increase in their effective particle size. However, colloidal forces tended to reduce this particle-size effect. The measured viscosity increased with increasing particle concentration in accordance with the Krieger-Dougherty and Eiler models.

The behaviour of a liquid-particle suspension when a sheared velocity field was induced into it was analyzed by numerical simulations based on the lattice-Boltzmann method. When the velocity and thereby the strain of the initially immobile suspension began to increase, its viscosity first stayed almost constant, but, after a concentration-dependent threshold in velocity, increased rapidly to a clearly higher level. This increase in viscosity was shown to be related to formation of clusters of suspended particles. More precisely, the increase in the viscosity was shown to result from enhanced momentum transfer though clustered particles. This is the mechanism behind the strain-hardening phenomenon observed in small-strain experiments on liquid-particle suspensions. We also expect this mechanism to be responsible for the shear-thickening behaviour typical of liquid particle suspension before other mechanisms, especially instabilities related to inertial effects, set in for still higher velocities.

We included short-range particle-particle interactions for increased numerical stability in our lattice-Boltzmann code for particle-fluid suspensions, and other improvements were also made in handling the particle phase for an effective implementation of the code for parallel computing. In order to better understand the origin of the shear-thickening behaviour observed in real suspensions, two simplified cases were considered with the new code. A chain-like cluster of suspended particles was shown to increase the momentum transfer in a shear flow between channel walls, and thereby the effective viscosity of the suspension in comparison with random configurations of particles. A single suspended particle was also shown to increase the effective viscosity under shear flow of this simple suspension for particle Reynolds numbers above unity, due to inertial effects that change the flow configuration around the particle. These mechanisms are expected to carry over to large-scale particle-fluid suspensions.

High-Resolution Computed X-ray Tomography

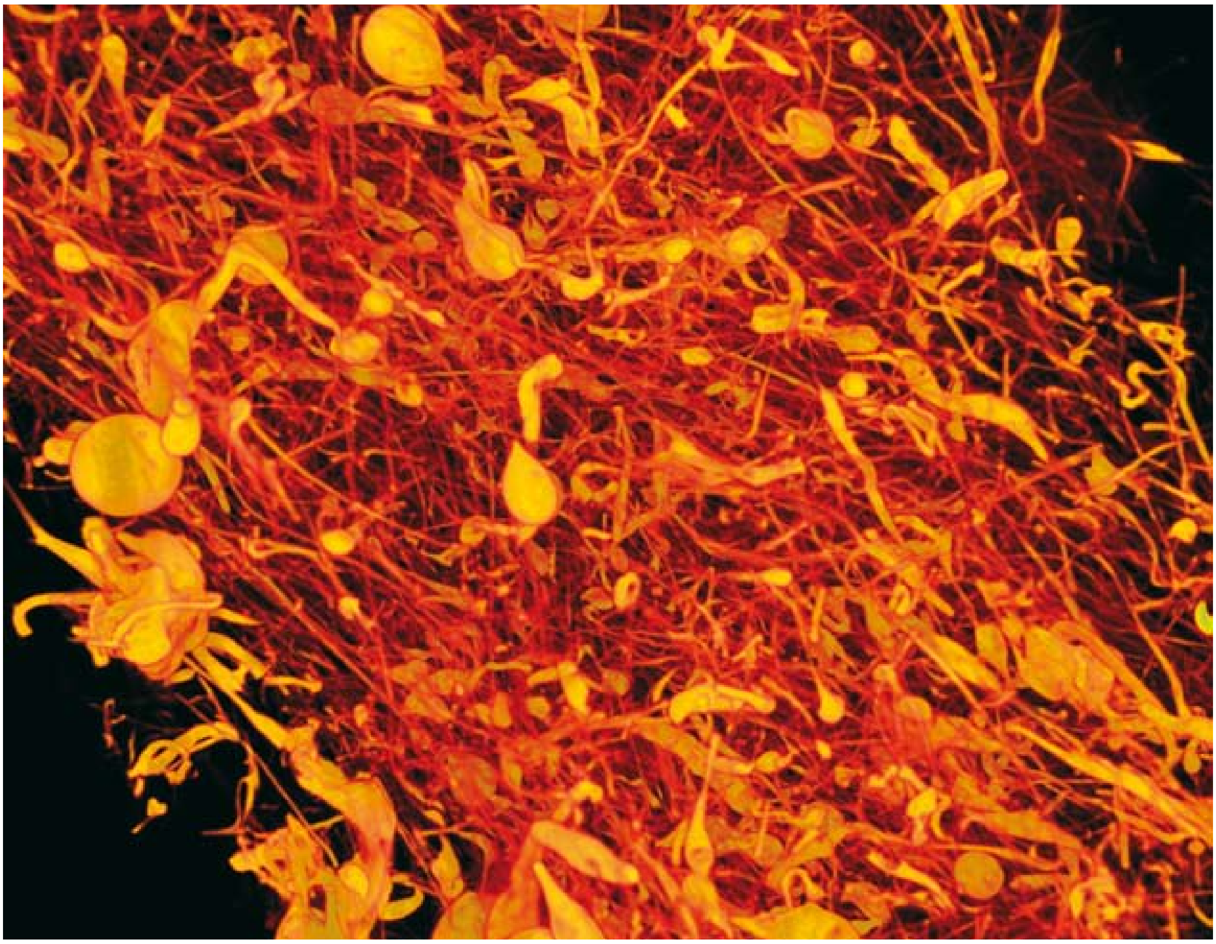
Computed tomography (CT) can be used to obtain a 3D construction of the internal mass distribution of the sample based on the measured attenuation of X-rays. The internal structure of the sample can thus be disclosed due to varying mass density. We have imaged a number of different porous materials, with an X-ray micro-CT system with a nominal resolution of 0.9 μm, and with synchrotron radiation at the European Synchrotron Radiation Facility with a nominal resolution of 0.7 μm. New methods were also developed for noise reduction in the images, as well as for segmenting different material components. Some of these tomographic images were used for analyzing their fluid-transport properties by lattice-Boltzmann simulations, as described above. For most samples the interest was mainly in their structural properties, such as porosity and pore-size distribution. More extensive analysis was made of the properties of coating layers in paper, and of their correlations with those of the base paper. Also, determination of the amount of uranium-containing minerals and of the three-dimensional structures of fractures was made for rock samples. A topic of much recent interest is the change of the structure of fibrous materials under compression. This problem was analyzed for paper and mineral wool. Finally, with some specific techniques we managed to image how a liquid fills the pores of a tablet made of mineral pigments.



A 3D tomographic reconstruction of a sample made of mineral pigments with an average size of about 100 micrometers.

Assessment of Bone by Ultrasonic Guided Waves

Determination of cortical bone thickness is warranted e.g. for assessing the level of endosteal resorption due to osteoporosis or other bone pathologies. We have shown previously that the velocity of the fundamental antisymmetric (or flexural) guided wave, measured for bone phantoms and bones in vitro, correlates with the cortical thickness significantly better than those by other axial ultrasound methods. An inversion scheme based on guided wave theory, time domain filtering and two-dimensional fast Fourier transform, was now introduced for the determination of cortical thickness from the measured velocity of guided waves. The method proposed was validated using acrylic plates and tubes with varying wall thickness. In addition, forty fresh human radius specimens were also measured. For plates and tubes with a thin wall, plate theory could be used to determine the wall thickness with a precision of 4%. For tubes with a wall thicker than 1/5 of the outer radius, tube theory provided the wall thickness with similar accuracy. For the radius bone specimens tube theory was used, and the ultrasonic cortical thickness was found to be UTh = 2.47 (0.66) mm. It correlated strongly (r=0.85, p<0.001) with the thickness measured by computed tomography, CTh = 2.66 (0.53) mm. We can conclude that the guided-wave inversion scheme introduced here is a feasible method for the determination of cortical bone thickness. The in vivo application of the method is being developed.



A three-dimensional tomographic reconstruction of a sample of mineral wool.

High Energy Physics

Ultrarelativistic Heavy Ion Collisions

Kari J. Eskola
Vesa Ruuskanen

The primary goal of ultrarelativistic heavy ion collisions (URHIC) is to study strongly interacting elementary particle matter, Quark Gluon Plasma (QGP), and its transition to a gas of hadrons.

The success of the Relativistic Heavy Ion Collider (RHIC) at Brookhaven since 2000 and the anticipation of the ALICE experiment at the CERN Large Hadron Collider (LHC) in 2007-8 have inspired and intensified also the theoretical research. In URHIC theory, we aim at solid predictions for observables measurable at RHIC and LHC/ALICE, as well as at better understanding of the QCD matter properties. In particular, we (1) study QCD dynamics in hadronic and nuclear collisions in terms of perturbative QCD (pQCD) and parton distribution functions (PDFs), (2) predict the produced QGP densities by using pQCD and gluon saturation, (3) model the evolution of produced matter from the calculated initial state to observable final free hadrons by relativistic hydrodynamics, (4) obtain hadronic observables from the hydrodynamic calculation, (5) compute high-p_T hadron spectra based on QCD factorization and energy losses of high-p_T partons in the QGP, (6) calculate emission of electromagnetic probes by combining thermal rates with the hydrodynamical model, (7) study the deconfinement phase transition by using effective theories for QCD and QCD-like theories at finite temperature and density, and (8) extend the methods developed for strongly interacting theories to electroweak modelling and LHC Higgs physics.

Vesa Ruuskanen, professor
Kari J. Eskola, academy research fellow -31.7., senior assistant 1.8.- (JYFL/HIP)
Kimmo Tuominen, assistant (JYFL/HIP)
Pasi Huovinen, postdoctoral researcher (HIP/JYFL) -31.3.
Vesa Kolhinen, postdoctoral researcher (HIP/JYFL)
Thorsten Renk, postdoctoral researcher (HIP/JYFL) 1.10.-
Heli Honkanen, graduate student -31.3.
Harri Niemi, graduate student
Sami Räsänen, graduate student
Jussi Auvinen, MSc student
Topi Kähärä, MSc student
Suvi Laitinen, MSc student
Perttu Mäkinen, MSc student
Hannu Paukkunen, MSc student

This research is financially supported by the Academy of Finland (SA). With prof. Kajantie's Finite Temperature Field Theory group (U. Helsinki), we form the *URHIC* theory project lead by Eskola at the Helsinki Institute of Physics (HIP) in 2002-7. We are also in a close contact with prof. Rummukainen (U. Oulu, CERN/TH) and with the ALICE group at JYFL. Our collaborators come from, e.g., CERN/TH, Niels Bohr Institute and U. Frankfurt in Europe, and from Lawrence Berkeley National Lab. and U. Virginia in the USA. We run an active visitor program and participate in international URHIC meetings such as *Quark Matter '05*, and joint theory efforts such as the CERN workshops on *Hard Probes* and *HERA-LHC physics*. In collaboration with prof. Hoyer (U. Helsinki), we participate in the *European Graduate School of Complex Systems in Hadrons and Nuclei* (Giessen-Copenhagen-Helsinki-Jyväskylä-Torino), also by organizing topical lecture weeks in Finland. Together with Kajantie, we participate in the EU network I3HP for *Hadron Physics* in 2004-6. We also participated in the proposal for the SA *Center of Excellence in Theoretical Physics Research* (prof. Enqvist, Helsinki), which survived to the shortest list. Honkanen and Räsänen reached their PhD degrees and got postdoc offers from abroad. Paukkunen graduated as MSc. A new postdoc, Dr. Renk, started in our group in 10/2005.

Hard Processes and Parton Distributions of Bound and Free Nucleons

Specific QGP signals in URHIC are examined against the reference cross sections of inclusive hard processes, such as production of direct photons, Drell-Yan dileptons and large-p_T hadrons, which are computable through the QCD factorization theorem. Number densities of different parton types in the colliding nuclei, the nuclear parton distributions (nPDFs), are needed in the calculation of all factorizable QCD processes. Previously, we have pioneered a global pQCD analysis, where the DGLAP-evolving nPDFs are constrained by experimental data from hard processes in nuclear collisions and by conservation laws. Our *EKS98* parameterization, which is in the CERN program library in a worldwide use, is a standard reference in the field. We are now, after extensive further work, about to publish updated results containing e.g. a more quantitative statistical error analysis. Further data constraints have also been investigated: we suggest that the NuTeV weak-mixing angle anomaly observed a few years ago in (anti)neutrino+Fe deep inelastic scatterings in Fermilab, could in fact be explained within the Standard Model by suitable modifications of the nPDFs. Next, we shall extend the global nPDF analysis to NLO and study further the possible nonlinear effects in the pQCD scale evolution of the bound and free nucleon PDFs.

Suppression of Large-P_T Hadron Spectra

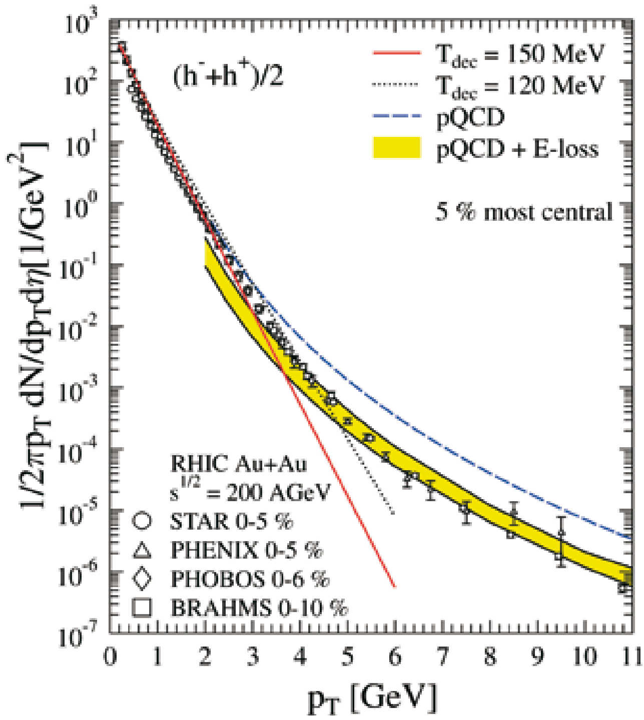
One of the most promising QGP probes, and one of the hot topics in the field, is the observed factor 5 suppression of high-p_T hadrons in central Au+Au collisions at RHIC. The absence of such suppression in d+Au collisions supports the interpretation of the phenomenon in Au+Au as energy loss of high-p_T partons penetrating through a very dense medium. Using QCD factorization, pQCD cross sections folded with nPDFs and fragmentation functions, we have shown that the nuclear effects in the PDFs are not responsible for the suppression. Folding in also the parton energy loss probabilities computed by our collaborators at CERN/TH, and accounting for the detailed production geometry, we have determined the parton energy loss strengths on the basis of the RHIC data, and predicted the suppression pattern out to larger values of p_T. The RHIC data now confirms our result. We have also published our prediction for the corresponding suppression pattern at the LHC. Next, correlations of high-p_T hadrons, another hot topic, will be studied.

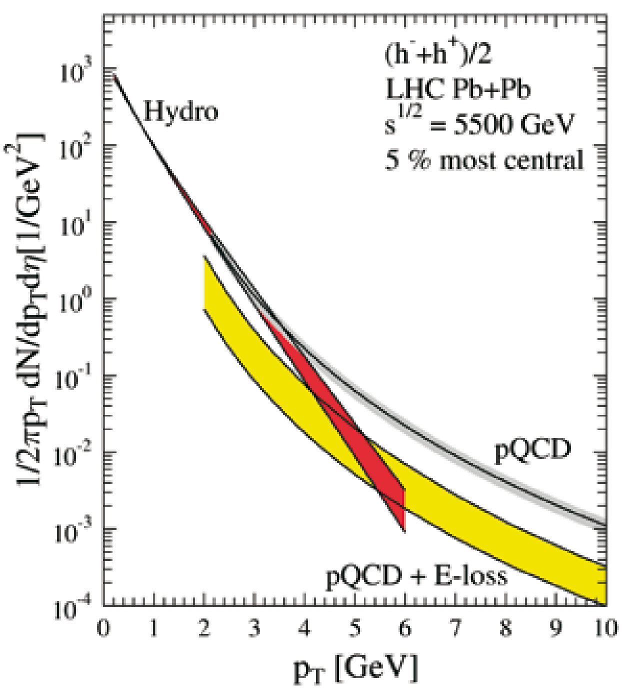
Hydrodynamic Modelling of Nuclear Collisions

Relativistic hydrodynamics provides a method to study the evolution of a locally thermalized expanding system. Strong features in its favour are the implementation of conservation laws and the QCD phase transition through the equation of state (EoS). In addition to enabling the calculation of hadron spectra, it also provides a reasonably sound framework to study phenomena during the expansion stage like electromagnetic emission or flavour evolution. Experimental evidence from RHIC, the very large energy densities combined with strong elliptic flow and significant suppression of high-p_T hadrons, is remarkably consistent with a picture where a very short QGP formation stage is followed by hydrodynamically describable expansion of the QGP, the QCD phase transition, expansion of the hadron gas and decoupling, followed finally by resonance decays.

In addition to the hydrodynamic modelling itself, one of our pioneering specialities is the pQCD based computation of the QGP initial densities for hydrodynamic evolution. Gluons and quarks with transverse momenta of a few GeV, minijets, are expected to dominate the QGP formation at collider energies. Production of such quanta can be computed using QCD factorization. A further QCD element needed is gluon saturation: at sufficiently high densities gluon fusion is conjectured to inhibit the production of gluons at smaller momenta and a dynamically generated few-GeV saturation scale govern the initial parton production in A+A collisions (A~200) at RHIC and LHC. Based on the minijet initial conditions, and on an isentropic hydrodynamic evolution, we originally predicted correctly the charged-particle multiplicities for central Au+Au collisions at several cms energies at RHIC. The benefits of the pQCD+saturation approach are that the framework is closed and predictions can be made, computation of infrared-safe quantities can be extended to NLO, and chemical decomposition of the initial QGP can be addressed.

Using the pQCD+saturation initial conditions for the QGP, we have computed the hydrodynamical p_T-spectra of hadrons in central A+A collisions at RHIC and LHC. The bulk features, multiplicities and low-p_T parts of pion, kaon and (anti)proton spectra measured at RHIC in central Au+Au collisions at different cms energies are well reproduced when a single, rather high, decoupling temperature is used. Also the net-baryon number originating from the pQCD+saturation model leads to a net-proton number consistent with the RHIC measurements. Based on these RHIC-tested results, we have published our prediction for the hydrodynamic hadron spectra, multiplicities and net-proton number in central Pb+Pb collisions at the LHC/ALICE. We have also, for the first time, simultaneously considered both the hydrodynamic and the pQCD fragmentation spectra for RHIC and LHC (see the figs). As discussed above, these components dominate at opposite ends of the hadron p_T-spectra, and in particular, we can identify the theoretically challenging transition region where both components become important. Based on the successful tests against the RHIC data, we predict a larger p_T-region of applicability for the hydrodynamic spectra at the LHC than at RHIC.





Apart from the decoupling temperature, the hydrodynamic hadron spectra are not very sensitive to the details of the QCD matter EoS. On one hand, this reduces the quantitative uncertainty in the computed hydrodynamic spectra but on the other hand it suggests that the bulk spectra are perhaps not the best observable for pinning down the QCD matter properties. We have, however, shown that hydrodynamically computable elliptic flow, the azimuthal asymmetry in the p_T spectra of hadrons in noncentral collisions, does depend on the EoS to an extent that the RHIC measurements should be able to distinguish between different possibilities.

A heatedly discussed new phenomenon possibly already seen at RHIC is whether an energy-loosing high-p_T parton traversing the QGP with a supersonic velocity can create an observable Mach cone. Also we have launched studies on this exciting question. We also aim at a benchmark prediction of elliptic flow at the LHC, as well as ultimately developing a code for full 1+3 dimensional hydrodynamics without any symmetry assumptions.

Electromagnetic Probes

Once the hydrodynamic evolution is under control and the measured hadron spectra are well reproduced, one may more reliably compute the signals from secondary collisions, such as thermal photon and dilepton production. Previously, we have computed the spectrum of thermal photons in URHIC at the CERN-SPS and made a prediction for RHIC. Within the CERN Hard Probes, we have also released a prediction for the LHC. The photon spectrum now measured at RHIC looks consistent with our prediction and it seems that a thermal component can be identified. This is, naturally, one of the hot topics in the field as well. Studies on the possible chemical non-equilibrium effects in the QCD matter EoS will be pursued further, as well as new studies on jet-to-photon conversion will be launched.

Effective Theories for QCD and QCD-Like Theories at Finite Temperature and Density

Deconfinement and chiral symmetry restoration have always attracted much interest. In the past work we have constructed effective theories for QCD at finite temperature and explained how deconfinement and chiral symmetry restoration intertwine into a single phase transition as observed in the lattice measurements. Currently we are extending these results to finite chemical potentials, and in the future we will include the diquark condensation phenomenon, possible only at finite chemical potential, into the effective theory framework. This will allow novel investigations of relativistic BEC-BCS crossover within a controllable field theory setup.

Studies of QCD are motivated by experimental needs. However, important clues about nonperturbative behaviour of strong interactions may be obtained by considering various other QCD-like theories. For example, we have discovered the tetracritical point in the phase diagram of two-colour adjoint QCD at finite temperature and chemical potential. In addition, investigations of the dynamics of various strongly interacting theories have far reaching consequences also beyond hadron physics: The electroweak symmetry breaking may be driven by a new kind of strong interaction termed Technicolor. This scenario had severe phenomenological problems regarding the electroweak precision measurements, and was thought already ruled out. Using cutting edge techniques developed in the context of supersymmetric Yang—Mills theories we have introduced new Technicolor theories and shown that these are within one standard deviation of the current precision measurements, and must be further investigated at the LHC. The Higgs particle is expected to be light, with a mass of 150 GeV and well within reach at the LHC. These theories have interesting consequences for cosmology and collider phenomenology which are currently under investigation.

High Energy Physics

Theoretical Particle Physics and Cosmology

Kimmo Kainulainen
Jukka Maalampi

Neutrino Physics

Jukka Maalampi

The key issue of neutrino physics is the question of the origin of neutrino masses and the mixing of neutrino flavours. Empirical information about these fundamental properties of neutrinos has been obtained through oscillation phenomena both in experiments with man-made neutrino beams and with neutrinos from natural sources, such as the Sun, cosmic rays, and supernovae.

Jukka Maalampi, professor
Kimmo Kainulainen, senior assistant
Tai-fu Feng, postdoctoral researcher -30.6.
Petteri Keränen, postdoctoral researcher
Matti Herranen, graduate student
Minja Myyryläinen, graduate student
Janne Riittinen, graduate student
Daniel Sunhede, graduate student
Risto Hautala, MSc student
Tuomo Puumalainen, MSc student
Pyry Rahkila, MSc student
Jussi Virkajärvi, MSc student

The group of theoretical particle physics and cosmology. Standing (from left) Jussi Virkajärvi, Minja Myyryläinen, Janne Riittinen, Daniel Sunhede, Matti Herranen, Johanna Piilonen and Pyry Rahkila. Sitting Kimmo Kainulainen (left) and Jukka Maalampi.

The intense experimental efforts of the past decade have revealed the main features of the mass spectrum and the mixing pattern of neutrinos. It is a challenge of theoretical studies to make now conclusions on the basis of this empirical information about the underlying particle theory. This may turn out crucial for solving the more general problem of the origin of mass of the basic constituents of matter.

The recent activity of the neutrino physics group at JYFL has concerned with astrophysical neutrino phenomena. In particular, we have studied the effects and observational signals of the possible sterile neutrinos in astrophysical environments. Sterile neutrinos have no interactions with matter, except that they can mix quantum mechanically with the ordinary active neutrinos and form as a result a part of the propagating neutrinos that have a definite mass. They are predicted by many theoretical models, and they may have an important role in neutrino mass and mixing mechanism. Most recently we have investigated these issues in connection to supernova explosions, where neutrinos encounter the effects of the matter of the star envelope they traverse. We have created a code that numerically solves the six-dimensional density matrix equation and gives the evolution of the neutrino states in the envelope. This has also lead us to study a more general question of level crossing, so called multilevel Landau-Zener problem, in the case of non-linearly varying Hamiltonians.

Physics Beyond the Standard Model

Supersymmetry is considered as the most natural extension of the Standard Model, and supersymmetric particles have been searched in particle physics experiments already for two decades. It is probable that first evidences of supersymmetry are not superparticles themselves but rather the indirect radiative effects caused by virtual supersymmetric particles. We have investigated low-energy predictions of the minimal supersymmetric extension of the Standard Model, the MSSM model, applying the so-called effective theory approach. We have studied the MSSM predictions for the electric dipole moments of the neutron and the c quark, investigated the two-loop gluino effects on the radiative decay of the B meson, and analysed the new contributions of the MSSM to the neutrino mass generation in the case of broken R-parity.

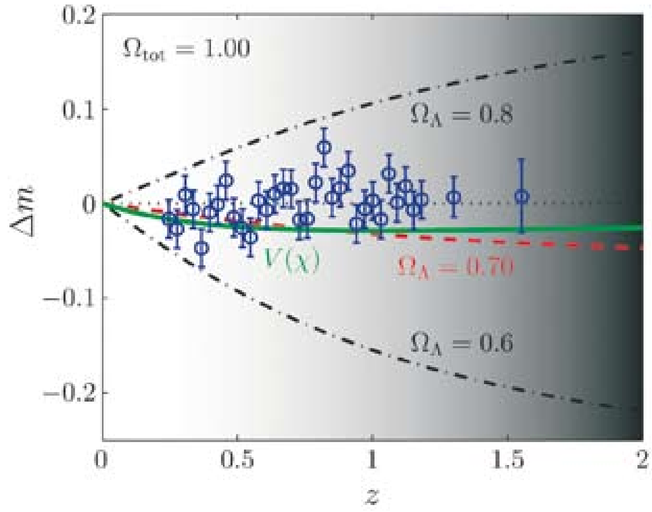
Cosmology

Kimmo Kainulainen

Extended Gravity and Dark Energy

Perhaps the greatest mystery for the present cosmology concerns the origin and the nature of the so-called “dark energy” (DE), which has been recently been shown to be dominating the expansion of the universe. Our group has studied the DE-problem in the context of scalar-tensor extensions of the classical Einstein-Hilbert-theory. Such scalar-tensor gravity models (STGm) originate naturally in the context of many large extra dimensional models. We have demonstrated that such STGM’s can lead to an acceptable expansion history for the universe with the right amount of DE today, at the same time fulfilling all post-Newtonian bounds on local gravity. Our current acitivities concentrate on studying if the STGm’s can lead to phantom energy solutions with extreme equation of state $p = w\rho$ with $w < -1$, testing for the magnitude of the chameleon-effect (slightly changing strength of the gravity in the presence of a matter concentrations in some STGm’s) and developing the formalism for computing the matter power spectrum in the context of

LED-induced STGm's. We are also studying the formulation of the extended gravity theories in the context of the Palatini-variational principle. Our group has strong collaborative effect with the cosmology group in Helsinki, including our study of the chameleon effect and also of issues related to locality and non-gaussianities in the primordial perturbation spectrum.



Shown is the prediction for the magnitude-redshift relation of supernovae, normalized to a cosmolgical constant model with Omega_Lambda 0.67, against the simulated SNAP-data. Green curve is the STGm-prediction and dashed and dash-dotted curves represent different constant models.

Quantum Transport Problem and Electroweak Baryogenesis

Another intriguing problem in modern cosmology concerns the origin of the baryon asymmetry, excess of matter over the antimatter, in the Universe (BAU). Our group has studied the creation of BAU in the electroweak phase transition (EWPT). A proper treatment of electroweak baryogenesis calls for the use and development of the quantum transport equations (QTE) in non-equilibrium plasmas and in spatially changing backgrounds. The QTE's for EWBG were first derived by us in the WKB approximation. We then have explored the more fundamental derivation of QTE's in the context of the Schwinger-Keldysh closed time path (CPT) formalism, and the WKB-limit was recovered in the limit of slowly varying backgrounds and weak interactions through a controlled expansions in gradients and in coupling constants. We are currently extending the quantum transport formalism to include non-local quantum coherence effects (reflection) and developing a numerical code to solve for the momentum dependent diffusion of the CP-even and –odd currents in realistic situations both in the WKB- and in the thin wall limits. We are also including the thermal corrections to the quasiparticle dispersion relations and reformulating the theory directly in the plasma rest frame. One of our goals is to compute the BAU in the context of the minimal supersymmetric standard model including also the CP-violating currents from the neutralino sector.

High Energy Physics

Quantum Gravity

Markku Lehto

Spacetime and Quantum Mechanics

Owing to the fact that no natural observations involving, e.g., genuine interactions of gravitation and quantum mechanics have as yet been identified, the question concerning quantum gravity's subject matter remains open. For this reason, there are as many interpretations of quantum gravity as there are independent researchers of it: ambiguities concerning what quantum gravity is *about* lead to ambiguities concerning what quantum gravity *is*.

It is possible to understand the problem of quantum gravity not as a matter of quantizing general relativity, but as a matter of investigating what quantum theory—so far the only branch of science forced to confront directly the problem of existence—has to say about the still open issue of the physical existence of *empty* spacetime.

According to our best available understanding provided by general relativity, empty spacetime is void of all fields, including the metric field $\mathbf{g}(x)$. This means that *empty spacetime is void of all geometric magnitudes*, i.e., of all quantitative geometry. With the removal of $\mathbf{g}(x)$, the line elements ds^2 go as well, and empty spacetime is thus tantamount to bare spacetime points. These geometric objects are intrinsic to the notion of field, since fields $f(P)$, where P is a point, consist of localized physical magnitudes. However, according to the diffeomorphism invariance postulate of general relativity, *spacetime points are not observable* by means of any physical tests.

Markku Lehto, senior assistant
Diego Meschini, graduate student
Ari Peltola, graduate student
Johanna Piilonen, graduate student, –31.10.2005

Einstein advocated thus the view that empty spacetime (i.e., a collection of spacetime points) is not physically real. But because in the above quantum theory was not taken into account, we must challenge the certainty of his conclusion by proposing to search for observables intrinsic to empty spacetime. This search should be carried out guided by quantum theory and some physical principle *directly relevant to the existence* of empty spacetime, and via strictly non-geometric methods; i.e., going beyond the intrinsic geometric description of spacetime [1].

The physical insight that we follow is afforded by the principle of *diffeomorphism invariance*. At face value, it states that a "displacement"' of spacetime points does not cause any observable effects and that, in consequence, spacetime points are not physically real. However, an earlier attempt [2] insinuated that when this principle and quantum theory are *both* taken into account, they lead together to the result that spacetime points display mutual *correlations*. We hold these to be the key to their possible observation.

Thus, one must not search for the individuality of spacetime points, but rather if and how they "interact" with each other, i.e., what observable correlations they might display. In field-theoretic language, the idea is that a field $f(P)$ at point P dragged onto another point Q, $\phi^*[f(P)]$, and then pulled back again, $\phi_*[f(Q)]$, could carry properties pertaining to Q back with it, so that a comparison of $f(P)$ and $\phi_*[f(Q)]$ could yield that they are not physically the same. This is *analogous* to the parallel transport of a vector around a closed loop in curved spacetime.

The challenge is to find observables which reveal this possible behaviour of field $f(P)$. If spacetime points had any physical reality, then $f(P) \neq \phi_*[f(Q)]$, in which case—identifying $f(P)$ with $\mathbf{g}(P)$—there would be some long-range correlations seen in the line element ds^2 (Figure 1).

The existence of spacetime correlations, however, would point to things beyond geometry or even pregeometry. We understand what we presently describe geometrically as "correlations between spacetime points" to be actually the effect of quantum-mechanical, *metageometric* things. In particular, we expect the geometric interval $ds^2_{PP'}$ to result as a geometric remnant or trace of such things [3].

In fact, a sounder ontological comprehension of quantum theory itself can be achieved on the basis of measurement results a_i, and metageometric premeasurement and transition things, $P(a_i)$ and $P(a_j | a_i)$, familiar to human experience. When viewed in this manner, the theory gets rid of some of the philosophical problems that plague it; e.g. the geometric state vector and its controversial ontology (cf. the geometric points and their controversial ontology).

Black Holes

A black hole is a region of spacetime where the gravitational effects are so strong that not even light can escape from it. The existence of black holes is predicted by general relativity. These peculiar objects are shown to form, for instance, as the final states of massive stars. At the classical level, i.e., when quantum-mechanical effects are ignored, black holes shut themselves completely out of their surroundings. The two-dimensional surface of spacetime, which separates a black hole from the rest of the universe, is known as the *event horizon*. However, when quantum-mechanical effects are taken into account, it turns out that black holes are not completely black but emit thermal radiation with a spectrum similar to that of a black body.

How can a black hole emit any radiation when it is by definition a "region of no escape"? The answer to this question is that radiation does not come from the interior of the hole but from the instant vicinity of the event horizon. It was shown by Hawking in the beginning of 70's that, when spacetime is treated classically and matter fields quantum-mechanically, there exists a steady flux of particles which seems to come out of the black hole. Since this kind of analysis includes elements both from classical and quantum theories, the Hawking effect is said to be a *semiclassical* result.

The temperature of a black hole may be inferred from its radiation spectrum. Since the hole has a certain temperature, it also has a certain entropy. The black hole entropy is proportional to the

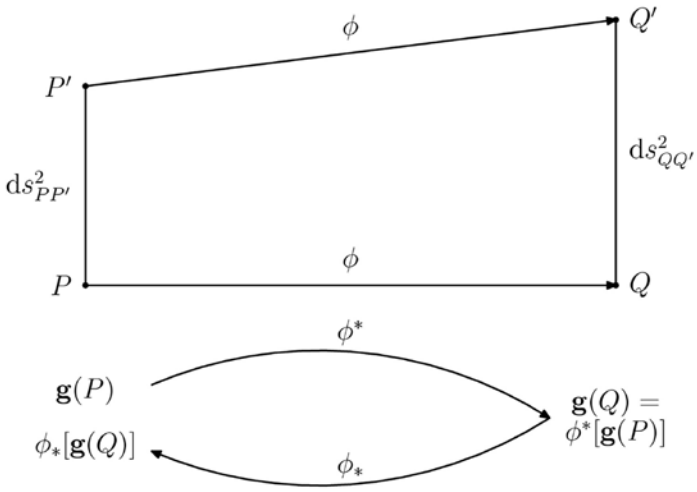


Fig. 1. Schematic representation

area of its event horizon, and the correct value for the constant of proportionality is, in the units where $G = \hbar = c = k_B = 1$, equal to one quarter. According to statistical mechanics, entropy is the natural logarithm of the number of microstates corresponding to a certain macrostate of a physical system. It can be shown that the macrostate of a black hole can be characterized by only three quantities: mass, electric charge and angular momentum. Therefore there must exist an enormous number of quantum-mechanical degrees of freedom giving rise to the entropy. It is one of the greatest challenges of modern physics to identify these quantum-mechanical degrees of freedom. Black hole radiation gives us one of the few known clues to the search for quantum gravity: the quantum theory of gravity should be able to explain the microscopic origin of black hole entropy.

There are good reasons to believe that the quantum-mechanical degrees of freedom of the black hole are due to the microscopic structure of spacetime at the event horizon. Therefore one is led to probe the microscopic properties of the event horizon. It is possible, for example, to construct the horizon from microscopically small black holes such that the correct (statistical) entropy is produced [4]. This is an encouraging result since it has been proposed that microscopic black holes might have something to do with the structure of spacetime at the Planck-length scale. The concept of entropy may be associated with other horizons of spacetime as well [5] and, at least to some extent, even with any space-like two-surface of spacetime [6]. An understanding of the nature of black hole radiation may therefore give valuable insights into the microscopic theory of spacetime.

References

[1] D. Meschini, M. Lehto, J. Piilonen, Studies in History and Philosophy of Modern Physics 36 (2005) 435, arXiv:gr-qc/0411053
[2] M. Lehto, H.B. Nielsen, and M. Ninomiya, Nuclear Physics B 272 (1986) 228
[3] D. Meschini, M. Lehto, arXiv:gr-qc/0506068 (2005). Accepted for publication in Foundations of Physics.
[4] J. Mäkelä, A. Peltola, Physical Review D 69 (2004) 124008
[5] A. Peltola, J. Mäkelä, arXiv:gr-qc/0508095 (2005)
[6] J. Mäkelä, A. Peltola, arXiv:gr-qc/0406032 (2004)

Industrial Collaboration

Industrial Collaboration

Jussi Timonen
Päivi Törmä
Ari Virtanen

The Department has numerous contacts with domestic and foreign industry and research laboratories.

In *industrial applications* group an important milestone was reached when the acceptance test of the RADEF irradiation station for ESA was successfully performed. The official inauguration of the RADEF facility was held in May. To attract potential customers to Jyväskylä ESA and RADECS (RADiation Effects on Components and Systems) association organised a two day event in JYFL with about 70 space electronics experts from biggest European satellite and avionics companies and national organisations. This "RADECS Thematic Meeting on European SEE Accelerators" included the recent reports performed under ESA's contracts and 11 invited presentations from European accelerator laboratories with latest SEE facility upgrades. During this event RADEF was welcomed in the community and, as a result, Jyväskylä was chosen to host the RADECS 2008 workshop with over 200 participants expected from all around the world. In addition to ESA, Alcatel Alenia Space, Saab-Ericsson Space, Technical University of Braunschweig and IDA Institute from Germany performed their test campaigns at the RADEF facility during the autumn.

Another important branch of industrial collaboration is related to the medical application. The Iodine-123 production for MAP Medical Technologies was continued at a constant level during 2005. A total of 36 production runs were performed, in which the beam current was 40-50 μA. Collaboration with Doseco Ltd. continued in terms of one MSc project, which included a co-operation with the Central Finland Health Care District and the national Radiation and Nuclear Safety Authority. Yet another medical project was continued in collaboration with Gammapro Ltd. and Jyväskylä Radiotherapy Hospital. The aim of this long term project is to develop a new kind of γ-field detector for oncology to operate in the whole accelerator voltage range of 5 to 25 MV commonly used in therapy.

Collaboration of the group with paper and paper machine industry continued also actively in terms of an MSc projects with Metso Paper Corporation. In this project radiation was employed for studying formation profiles in paper. A new type of energy controlled β-radiography device was planned and built for the use in the company's research laboratory. A new project was launched in a joint proposal with the Technical Research Centre, VTT, to Tekes. The work will be done in collaboration with VTT Processes and eight private companies. The aim is to study controlling possibilities of biomass flow used in fuel peat power plants.

The *nanophysics* and *nanotechnology group* has well established collaboration with a few companies in Finland. For about three years ultrasensitive radiation detectors based on calorimetry and bolometric sensing for x-rays and IR-radiation have been developed in collaboration with Oxford Instruments Analytical company from Espoo (formerly Metorex International). At the first stage the work has been motivated by the need of on-chip integrable ultrasensitive sensors in space research, and collaborative projects are continuing, funded by the European Space Agency. In addition, a TEKES funded project in collaboration with VTT Information technology and VTT Millilab has continued to develop superconducting bolometers in the sub-millimeter band.

The *nanoelectronics and nanotechnology group* has established contacts with industry. The professorship in electronics has been sponsored by local municipalities and industry. The nanoelectronics group was funded by Tekes within the ELMO ("Miniaturization of Electronics") research programme. The project focused on micro- and nanosensors and was in collaboration with the companies Enermet, Metso Drives, Nanoway and JSP (Jyväskylä Science Park). A patenting process has been started as a result of the project. The industry collaboration is continued under new projects and including companies interested in nanotechnology such as Nokia, Planar and Vaisala, with funding from the FinNano Nanotechnology Programme of Tekes. The Nanoelectronics Education and Investment programme took place during the years 2002-2004 in collaboration with several companies such as Enermet, Nokia, JSP, Nanoway, Aplicom. The programme was mainly funded by EU via the regional government and partly by companies. The programme allowed developing the teaching in electronics and investments to equipment essential for research in nanoelectronics and nanotechnology. The Nanoscience Center research infrastructure programme 2004-2006, also funded by EU via the regional government and partly by companies (now about ten participating), is also an important platform for industry collaboration. Through this programme, companies can have a so called "Window to Nanotechnology" to follow the rapid development of the field.

The soft condensed matter and statistical physics group continued its long-term collaboration with a number of companies in several branches of industry. The research group participated in three large national research consortia funded by Tekes and industry, and in one funded by the Ministry of Trade and Commerce. These projects focussed on developing new experimental and numerical techniques for flow in porous media, on basic and applied research on the rheological properties and dynamics of liquid-particle suspensions, and on structural properties of heterogeneous materials by tomographic imaging. Ultrasound anemometry and optical wall-layer measurements were used to study the basic flow properties of fibre suspensions in a pipe flow. Tomographic imaging of various porous materials was continued as an international collaboration (Trondheim, Grenoble, St. Paul) at the European Synchrotron Radiation Facility, and locally with the recently acquired microtomographic device with almost the same resolution. This work concentrated on the structural properties of materials like paper and paper board, layers of mineral pigments, and mineral wool. For better understanding the flow of liquids in such materials, numerical simulations based on the lattice-Boltzmann method were also carried out on tomographic images made.

Several projects involved also direct collaboration with industry. These projects included experimental research, numerical simulation and modelling of processes such as paper forming, tomographic imaging and the related three-dimensional structural analysis of paper and mineral wool, transport of fluid in paper and matrix diffusion. Some of these projects involved MSc theses carried out in industry. Industrial collaborators in these projects included Metso Paper, Stora-Enso, Paroc and Posiva.

Education

Education

Jukka Maalampi
Juha Merikoski

The Department of Physics offers a wide program of study at all academic levels. A particular strength, together with the diversity of choices of specialization in experimental, theoretical and applied physics and teacher education, is that education from the very beginning of studies is closely connected with research. The students get involved in the activities of the Department and they have many opportunities to participate in work done in a highly international research environment. The Department has attained a strong reputation as a good study place. For the years 2004-2006 the Department was elected by the Ministry of Education as a national high-quality education unit, the only such unit in exact natural sciences.

Jukka Maalampi, professor
Juha Merikoski, lecturer
Kimmo Kainulainen, senior assistant
Inkeri Halkosaari, graduate student
Jussi Helaakoski, graduate student
Teemu Kekkonen, MSc student
Joona Kiiski, MSc student
Petri Laitinen, MSc student
Tiina Lampinen, MSc student
Sami Lehesvuori, MSc student
Matti Leppänen, MSc student
Jari Loimula, MSc student
Kaisa Malmberg, MSc student
Toni Rautiainen, MSc student
Katja Turpeinen, MSc student

In 2005 there were about 570 undergraduate students at the Department. The 76 new students, who started their studies in the fall 2005 within the new degree system, first aim at the degree of Bachelor of Science and then continue to work for the degree of Master of Science. The number of post-graduate students aiming at the degree of Doctor of Philosophy was about 65. In addition, a few students were forking for the degree of Licentiate of Philosophy. Some 30 students, many of them with a polytechnic engineering background, studied in the Master programs for industrial physics, nanoelectronics and renewable energy.

Graduation

In 2005 the number of master's degrees taken at the Department was 46, which is an all-time record and a ten percent increase from the previous year. Of them, 12 obtained teacher qualification. In this year the Department produced 8 PhD degrees, as in the previous year. The employment of the newly graduated students has continued to be good. According to the recent survey, the employment among the graduates of the years 2000-2004 is 98%.

Student Enrolment

In the summer 2005 there were 470 applicants for physics studies, with 280 indicating physics as their first choice for their master's studies. The entrance examination was organized together with universities of Helsinki, Kuopio, Oulu and Turku. The majority of students were admitted on the basis of their high school record and national maturity test result. As a whole, 86 undergraduate students enrolled in 2005. About one quarter of the applicants and enrolled students were women. Direct enrollment to teacher education has become popular and 18 students chose it this year.

Other Education Activities

In addition to its regular teaching program, the Department has organized in co-operation with the Open University supplementary-education program for teacher qualification, participated by about 50 mainly engineers and unqualified school teachers. The Department is an active part in the Jyväskylä International Summer School, which was organized for the 15th time.

The Department has had active co-operation with schools in the Central Finland district. Physics students frequently visit high schools to increase interest in studies in natural sciences. The Department has collaborated with schools in the framework of their CERN Network by organizing training lectures prior to the CERN visits of student groups. The Department has maintained its popularity as an excursion destination for school students.

Teaching Development

The first-year crash course *Flying start* was given for the fifth time, this time slightly modified to better fit in the new degree system and to make the schedule more convenient for the students. During the course

new students learn about the most recent research and applications of physics, get to know the personnel of the Department and each other, and learn to work together in small groups. This year the groups were formed such that students coming from same areas of the country were put in same groups, with the exception that, to provide some local knowledge, a couple of students from Jyväskylä were included in each group. This way the groups became full of life faster than before.

According to recent research, the effects of the *Flying start* have been very positive in improving students' awareness of professional possibilities available for physicists and their motivation to complete their studies at the Department. For the rest of the curriculum, the Department has devoted significant efforts to develop the teaching to take it closer to the students and to make it better correspond to the requirements of the physics profession in practice. These include promoting teamwork and developing lecture demonstrations, as well as relating teaching to current research and industrial and other practical applications at all stages of studies. This also very well fits in the goals of the new degree system adopted in the fall 2005.

The Department has continued to expand its summer student program for familiarizing students with research work. In summer 2005 the number of paid summer students was 64. To make better use of the summer term, three compulsory master level courses were, in addition to giving them as conventional lecture courses, offered during the summer as guided self-study courses.

Research in physics education

The Department participates in the Finnish Graduate School of Mathematics, Physics, and Chemistry Education with five students working on a degree of doctor or licentiate of philosophy in physics education. One of the research projects concerns with the development of laboratory work as a part of physics curriculum. To support the further development of the Flying start and the transfer of its key ideas to other physics courses, a research project is in progress.

Personnel

Email addresses:
forename.surname@phys.jyu.fi
Note: ä=a, ö=o, å=a

Heads of the Department

Matti Leino, prof. -31.7.
Jukka Maalampi, prof. 1.8.-

Vice-Heads of the Department

Vesa Ruuskanen, prof. -31.7.
Rauno Julin, prof. 1.8.-

Professors

Markus Ahlskog
Rauno Julin
Markku Kataja (joint profersorship with VTT)
Matti Leino
Jukka Maalampi (on leave 1.6.-)
Matti Manninen
Vesa Ruuskanen
Jouni Suhonen
Jussi Timonen
Päivi Törmä (on leave 1.10.-)
Harry J. Whitlow
Juha Äystö

Research professor

Päivi Törmä 1.10.- (EURYI award)

Lecturers

Kari Loberg
Juha Merikoski
Matti Piiparinen

Senior assistants

Konstantin Arutyunov
Kari J. Eskola 1.8.- (JYFL/HIP)
Hannu Häkkinen
Ari Jokinen -31.3.
Sakari Juutinen
Kimmo Kainulainen
Hannu Koivisto
Markku Lehto
Gheorghe-Sorin Paraoanu -31.7.
Jan Rak 1.12.- (JYFL/HIP)
Timo Sajavaara 1.4.- (on leave)
Jussi Toppari
Vladimir Tuboltsev -31.10.

Assistants

Tommi Hakala 1.8.- (on leave)
Eero Holmlund -31.8.
Heikki Kettunen
Pasi Kivinen -31.7.
Jussi Toivanen 1.8.-
Kimmo Tuominen (JYFL/HIP)

Academy grants and researchers

Kari.J. Eskola -31.7. (JYFL/HIP)
Paul Greenlees 1.8.-
Jukka Maalampi 1.6.-
Ilari Maasilta
Gheorghe-Sorin Paraoanu 1.8.-
Heikki Penttilä

PhD scientists

Jaakko Akola 1.8.-
Shadyar Farhangfar
Tai-Fu Feng -30.6.
Lars Melwyn Fjelsted 1.11.-
Paul Greenlees -31.7.
Pauli Heikkinen
Karoliina Honkala
Pasi Huovinen (HIP/JYFL) -31.3.
Ari Jokinen 1.4.-
Pete Jones
Petteri Keränen
Vesa Kolhinen (HIP/JYFL)
Antti Koponen (part time)
Pekka Koskinen -31.1.
Matti Koskinen -30.4.
Kimmo Kärkkäinen 1.9.-
Ari-Pekka Leppänen 1.10.-30.11.
Kirsi Manninen -30.6.
Jani Martikainen -31.7.
Petro Moilanen -30.9.
Iain Moore
Markko Myllys
Janne Pakarinen 1.10.-
Kari Peräjärvi (HIP/JYFL) 1.8.-
Saidur Rahaman 1.7.-
Pasi Raiskinmäki (part time)
Thorsten Renk (HIP/JYFL) 1.10.-
Valery Rubtchenya
Vesa Ruuska -31.5.
Timo Sajavaara 1.2.-
Catherine Scholey
Tetsu Sonoda
Jussi Toivanen -31.7.
Wladyslaw Trzaska
Vladimir Tuboltsev 1.11.-
Juha Uusitalo
Ari Virtanen
Michael Walter

MSc scientists

Urpo Aaltosalmi -31.8.
Mariana Bondila (HIP/JYFL)
Iain Darby -30.4. (Marie Curie training site)
Viki-Veikko Elomaa 1.7.-
Tommi Eronen
Sarah Eeckhaudt
Sergey Gorelick 1.2.-
Tuomas Grahn
Ulrike Hager
Jani Hakala
Tommi Hakala
Inkeri Halkosaari
Tommy Holmqvist -21.10.
Matti Herranen 1.7.-
Jussi Helaakoski
Terhi Hongisto
Heli Honkanen -31.3.
Pasi Jalkanen
Arto Javanainen
Janne Juntunen
Jari Hyväluoma
Jussi Jääskeläinen -30.6.
Ari Jäsberg
Katarzyna Kacprzak 1.7.-
Anu Kankainen
Jenni Karvonen
Pasi Karvonen
Tomi Kemppinen
Thomas Kessler
Jami Kinnunen
Kimmo Kinnunen
Galina Knyazheva -31.3.
Viivi Koivu
Timo Koponen
Panu Koppinen
Markus Kortelainen
Jenni Kotila
Anton Kuzyk 1.8.-
Thomas Kühn
Kimmo Kärkkäinen -31.8.
Mikko Laitinen 1.9.-

Ari-Pekka Leppänen -30.9.
Vladimir Lyapin (HIP/JYFL)
Tomasz Malkiewicz
Bruce Marsh -6.4. (Marie Curie training site)
Keijo Mattila
Diego Meschini
Lasse Miettinen
Minja Myyryläinen
Minna Nevala
Harri Niemi (HIP/JYFL)
Markus Nyman
Risto Paju 1.8.-
Janne Pakarinen -30.9.
Ari Peltola
Sami Peltonen
Johanna Piilonen
Otto Pulkkinen
Panu Rahkila
Esa Rehn
Iiro Riihimäki
Janne Riittinen
Marcus Rinkiö
Sami Rinta-Antila
Kari Rytkönen
Sami Räsänen
Antti Saastamoinen
Ananda Sagari 1.9.-
Mikael Sandzelius -15.5. (Marie Curie training site)
Timo Santa-Nokki -23.11.
Jan Sarén
Juha Sorri 1.9.-
Andrew Steer -10.7. (Marie Curie training site)
Daniel Sunhede
Pekka Suominen
Olli Tarvainen
Lasse Taskinen
Benjamin Tordoff (Marie Curie training site)
Tuomas Turpeinen
Sampo Tuukkanen
Martin Venhart 7.3.- (Marie Curie training site)
Juha Vinnurva
Sergey Yamaletdinov
Maciej Zgirski

MSc students are listed in research reports.

Computer systems

Vera Hansper
Janne Kulju
Hannu Laru
Jukka Peltola 1.3.-31.7.
Olli Peltonen 1.3.-31.5.

Laboratory engineers

Väinö Hänninen
Arto Lassila
Veikko Nieminen
Einari Periäinen
Teuvo Poikolainen
Kimmo Ranttila
Antti Nuottajärvi
Juha Ärje

Operators

Jani Hyvönen
Anssi Ikonen

Other technicial staff

Martti Hytönen
Atte Kauppinen
Erkki Kosola
Hannu Leinonen
Esa Liimatainen
Alpo Lyhty
Paavo Onkila (part time) -31.1.
Erkki Pesu
Hannu Pohjanheimo
Kai Porras
Marko Puskala
Raimo Seppälä
Suppula Tarmo
Markku Särkkä

Administration

Anna-Liisa Blå
Marjut Hilska
Soili Leskinen
Ritva Väyrynen

Boards and Commitees

Department Council 1.8.2002-31.7.2005

Matti Leino, professor (chairman)
Markku Kataja, professor
Jukka Maalampi, professor
Matti Manninen, professor
Päivi Törmä, professor
Pauli Heikkinen, chief engineer
Sakari Juutinen, senior scientist
Juha Merikoski, lecturer
Inkeri Halkosaari,student
Mikko Laitinen, student
Paula Kuokkanen, student

1.8.2005-31.7.2008

Jukka Maalampi, professor (chairman)
Markus Ahlskog, professor
Matti Leino, professor
Jouni Suhonen, professor
Jussi Timonen, professor
Hannu Laru, computer support
Juha Merikoski, lecturer
Kimmo Tuominen, assistant
Tero Mononen, student
Perttu Mäkinen, student
Jouko Perkkiö, student

Scientific Board of the Centre of Excellence at JYFL

Niels E. Christensen, professor (chairman), University of Århus
Paul Kienle, professor, Technical University of Münich
Timo Tiihonen, vice-rector, University of Jyväskylä
Kari Rissanen, professor, Academy of Finland
Pasi Sihvonen, secretary general, Academy of Finland

Program Advisory Committee (PAC) of the Accelerator Laboratory

Reiner Krücken, Chairman, Technical University of Munich (chairman)
Yorick Blumenfeld, IN2P3-CNRS, Orsay
Thomas Døssing, NBI Copenhagen
Rauno Julin, JYFL
Jürgen Kluge, GSI Darmstadt
Matti Leino, JYFL
John Simpson, CCLRC Daresbury
Jan Zylicz, University of Warsaw
Juha Äystö, JYFL
Paul Greenlees, Scientific Secretary, JYFL

Peer Reviewed Articles

Accelerator Facilities

H. Nassar, M. Paul, I. Ahmad, D. Berkovits, M. Bettan, H. Koivisto et al.
The stellar (n, gamma) cross section of ^{62}Ni
Phys. Rev. Lett. 94 (2005) 092504

O. Tarvainen, P. Suominen, T. Ropponen, T. Kalvas, P. Heikkinen and H. Koivisto
The effect of gas mixing technique on the emittance and plasma potential of the JYFL 14 GHz Electron cyclotron resonance ion source
Rev. Sci. Instrum. 76 (9) (2005)

Exotic Nuclei and Beams

G. Canchel, B. Blank, M. Chartier, F. Delalee, P. Dendooven, C. Dossat, J. Giovinazzo, J. Huikari, A. S. Lalleman, M. J. Lopez Jimenez, V. Madec, J. L. Pedroza, H. Penttilä and J. C. Thomas
Precision measurement of the half-life and the decay branches of ^{62}Ga
Eur. Phys. J. A 23 (2005) 409

A. Kankainen, G.K. Vorobjev, S.A. Eliseev, W. Huang, J. Huikari, A. Jokinen, A. Nieminen, Yu.N. Novikov, H. Penttilä, A.V. Popov, S. Rinta-Antila, H. Schatz, D.M. Seliverstov, Yu.P. Suslov, and J. Äystö
Isomers of astrophysical interest in neutron-deficient nuclei at masses A = 81, 85 and 86
Eur. Phys. J. A 25 (2005) 355

A. Jokinen, T. Eronen, U. Hager, J. Hakala, S. Kopecky, A. Nieminen, S. Rinta-Antila, and J. Äystö
Ion manipulation and precision measurements at JYFLTRAP
Eur. Phys. J. A 25, Supplement 1 (2005) 27

D. Rodriguez, V. Kolhinen, G. Audi, J. Äystö, D. Beck, K. Blaum, G. Bollen, F. Herfurth, A. Jokinen, A. Kellerbauer, H.J. Kluge, M. Oinonen, H. Schatz, E. Sauvan, and S. Schwarz
Mass measurement on the rp-process waiting point ^{72}Kr
Eur. Phys. J. A 25, Supplement 1 (2005) 41

H. Mach, L.M. Fraile, O. Tengblad, R. Boutami, C. Jollet, W.A. Plociennik, D.T. Yordanov, M. Stanoiu, M.J.G. Borge, P.A. Butler, J. Cederkäll, Ph. Dessagne, B. Fogelberg, H. Fynbo, P. Hoff, A. Jokinen, A. Korgul, U. Köster, W. Kurcewicz, F. Marechal, T. Motobayashi, J. Mrazek, G. Neyens, T. Nilsson, S.Pedersen, A. Poves, B. Rubio, E. Ruchowska and the ISOLDE collaboration
New structure information on ^{30}Mg, ^{31}Mg and ^{32}Mg
Eur. Phys. J. A 25, Supplement 1 (2005) 105

S. Rinta-Antila, Y. Wang, P. Dendooven, J. Huikari, A. Jokinen, V. S. Kolhinen, G. Lhersonneau, A. Nieminen, S. Nummela, H. Penttilä, K. Peräjärvi, J. Szerypo, J.C. Wang, and J. Äystö
Structure of doubly-even Cd nuclei studied by beta-decay
Eur. Phys. J. A 25, Supplement 1 (2005) 119

A. Kankainen, S.A. Eliseev, T. Eronen, S.P. Fox, U. Hager, J. Hakala, W. Huang, J. Huikari, D. Jenkins, A. Jokinen, S. Kopecky, I. Moore, A. Nieminen, Yu.N. Novikov, H. Penttilä, A.V.Popov, S. Rinta-Antila, H. Schatz, D.M. Seliverstov, G.K. Vorobjev, Y. Wang, J. Äystö and the IS403 collaboration
Beta-delayed gamma and proton spectroscopy near the Z=N line
Eur. Phys. J. A 25, Supplement 1 (2005) 129

H. Scheit, O. Niedermaier, V. Bildstein, H. Boie, J. Fitting, R. von Hahn, F. Köck, M. Lauer, U. K. Pal, H. Podlech, R. Repnow, D. Schwalm, C. Alvarez, F. Ames, G. Bollen, S. Emhofer, D. Habs, O. Kester, R. Lutter, K. Rudolph, M. Pasini, P. G. Thirolf, B. H. Wolf, J. Eberth, G. Gersch, H. Hess, P. Reiter, O. Thelen, N. Warr, D. Weisshaar, F. Aksouh, P. Van den Bergh, P. Van Duppen, M. Huyse, O. Ivanov, P. Mayet, J. Van de Walle, J. Äystö, P. A. Butler, J. Cederkäll, P. Delahaye, H. O. U. Fynbo, L. M. Fraile, O. Forstner, S. Franchoo, U. Köster, T. Nilsson, M. Oinonen, T. Sieber, F. Wenander, M. Pantea, A. Richter, G. Schrieder, H. Simon, T. Behrens, R. Gernhäuser, T. Kröll, R. Krücken, M. Münch, T. Davinson, J. Gerl, G. Huber, A. Hurst, J. Iwanicki, B. Jonson, P. Lieb, L. Liljeby, A. Schempp, A. Scherillo, P. Schmidt and G. Walter
Coulomb excitation of neutron-rich beams at REX-ISOLDE
Eur. Phys. J. A 25, Supplement 1 (2005) 397

I. Podadera, T. Fritioff, A. Jokinen, M. Lindroos and F. Wenander
Preparation of cooled and bunched ion beams at ISOLDE-CERN
Eur. Phys. J. A 25, Supplement 1 (2005) 743

H. Penttilä, J. Billowes, P. Campbell, P. Dendooven, V-V. Elomaa, T. Eronen, U. Hager, J. Hakala, J. Huikari, A. Jokinen, A. Kankainen, P. Karvonen, S. Kopecky, I. Moore, A. Nieminen, A. Popov, S. Rinta-Antila, Y. Wang, J. Äystö
Performance of IGISOL 3
Eur. Phys. J. A 25, Supplement 1 (2005) 745

K. Peräjärvi, J. Cerny, J. Hakala, J.Huikari, A.Jokinen, P. Karvonen, J. Kurpeta, D. Lee, I. Moore, H. Penttilä, A. Popov and J. Äystö
New ion-guide for the production of beams of neutron-rich nuclei between Z = 20 - 28
Eur. Phys. J. A 25, Supplement 1 (2005) 749

J. Äystö
Concluding remarks of the ENAM'04 Conference
Eur. Phys. J. A 25, Supplement 1 (2005) 767

I. D. Moore, A. Nieminen, J. Billowes, P. Campbell, Ch. Geppert, A. Jokinen, T. Kessler, B. Marsh, H. Penttilä, S. Rinta-Antila, B. Tordoff, K.D.A .Wendt and J. Äystö
Development of a laser ion source at IGISOL
J. Phys. G 31 (2005) S1499

H.O.U. Fynbo, C.A. Diget, U.C. Bergmann, M.J.G. Borge, J. Cederkäll, P. Dendooven, L.M. Fraile, S. Franchoo, V.N. Fedosseev, B.R. Fulton, W. Huang, J. Huikari, H.B. Jeppesen, A.S. Jokinen, P. Jones, B. Jonson, U. Köster, K. Langanke, M. Meister, T. Nilsson, G. Nyman, Y. Prezado, K. Riisager, S. Rinta-Antila, O. Tengblad, M. Turrion, Y. Wang, L. Weissman, K. Wilhelmsen & J. Äystö
Revised rates for the stellar triple-alpha process from measurement of ^{12}C nuclear resonances Nature 433 (2005) 136

K. Peräjärvi, J. Cerny, J. Hakala, A. Jokinen, P. Karvonen, J. Kurpeta, D. Lee, I. Moore, H. Penttilä, A. Popov and J. Äystö
New ion-guide for the production of beams of neutron-rich nuclei between Z=20-28
Nucl. Instr. & Meth. A 546 (2005) 418

C.Aa. Diget, F.C. Barker, M.J.G. Borge, J. Cederkäll, V.N. Fedosseev, L.M. Fraile, B.R. Fulton, H.O.U. Fynbo, H.B. Jeppesen, B. Jonson, U. Köster, M. Meister, T. Nilsson, G. Nyman, Y. Prezado, K. Riisager, S. Rinta-Antila, O. Tengblad, M. Turrion, K. Wilhelmsen and J. Äystö
Properties of the ^{12}C 10 MeV state determined through beta-decay
Nucl. Phys. A 760 (2005) 3

D.G. Jenkins, C.J. Lister, M.P. Carpenter, P. Chowdury, N.J. Hammond, R.V.F. Janssens, T.L. Khoo, T. Lauritsen and D. Seweryniak, T. Davinson, PJ. Woods, A. Jokinen and H. Penttilä
Mirror energy differences in the A=31 mirror nuclei ^{31}S and ^{31}P and their significance in electromagnetic spin-orbit splitting, V_{eso}
Phys. Rev. C 72 (2005) 031303

H. H. Knudsen, H. O. U. Fynbo, M. J. G. Borge, R. Boutami, P. Dendooven, C. Aa. Diget, T. Eronen, S. Fox, L. M. Fraile, B. Fulton, J. Huikary, H. B. Jeppesen, A. S. Jokinen, B. Jonson, A. Kankainen, I. Moore, A. Nieminen, G. Nyman, H. Penttilä, K. Riisager, S. Rinta-Antila, O. Tengblad, Y. Wang, K. Wilhelmsen, and J. Äystö
Beta-decay of ^{13}O
Phys.Rev. C 72 (2005) 044312

J. Aaltonen, E. A. Gromova, K. Helariutta, V. A. Jakovlev, W. H. Trzaska, J. Huikari, V. S. Kolhinen, and S. Rinta-Antila
Production of ^{234,235}Np and ^{236}Pu in bombardment of ^{236}U with protons in the energy range from 17 to 40 MeV
Radiochim. Acta 93 (2005) 377

In-Beam Spectroscopy

J. Pakarinen, I. Darby, S. Eeckhaudt, T. Enqvist, T. Grahn, P. Greenlees, F. Johnston-Theasby, P. Jones, R. Julin, S. Juutinen, H. Kettunen, M. Leino, A.-P. Leppänen, P. Nieminen, M. Nyman, R. Page, P. Raddon, P. Rahkila, C. Scholey, J. Uusitalo, R. Wadsworth
Probing the three shapes in ^{186}Pb using in-beam gamma-ray spectroscopy
Eur. Phys. J. A Direct (2005)

P.T. Greenlees, N. Amzal, J.E. Bastin, E. Bouchez, P.A. Butler, A. Chatillon, O. Dorvaux, S. Eeckhaudt, K. Eskola, B. Gall, J. Gerl, T. Grahn, A. Görgen, N.J. Hammond, K. Hauschild, R.-D. Herzberg, F.-P. Heßberger, R.D. Humphreys, A. Hürstel, D.G. Jenkins, G.D. Jones, P. Jones, R. Julin, S. Juutinen, H. Kankaanpää, A. Keenan, H. Kettunen, F. Khalfallah, T.L. Khoo, W. Korten, P. Kuusiniemi, Y. Le Coz, M. Leino, A.-P. Leppänen, M. Muikku, P. Nieminen, J. Pakarinen, P. Rahkila, P. Reiter, M. Rousseau, C. Scholey, Ch. Theisen, J. Uusitalo, J. Wilson, H.-J. Wollersheim
In-beam and decay spectroscopy of transfermium elements
Eur. Phys. J. A Direct (2005)

T. Grahn, A. Dewald, O. Möller, C.W. Beausang, S. Eeckhaudt, P.T. Greenlees, J. Jolie, P. Jones, R. Julin, S. Juutinen, H. Kettunen, T. Kröll, R. Krücken, M. Leino, A.-P. Leppänen, P. Maierbeck, D.A. Meyer, P. Nieminen, M. Nyman, J. Pakarinen, P. Petkov, P. Rahkila, B. Saha, C. Scholey, J. Uusitalo
RDDS lifetime measurement with JUROGAM + RITU
Eur. Phys. J. A Direct (2005)

S. Harissopulos, A. Lagoyannis, A. Spyrou, Ch. Zarkadas, S. Galanopoulos, G. Perdikakis, H.-W. Becker, C. Rolfs, F. Strieder, R. Kunz, M. Fey, J.W. Hammer, A. Dewald, K.-O. Zell, P. von Brentano, R. Julin and P. Demetriou
Proton and alpha-particle capture reactions at sub-Coulomb energies relevant to the p process
J. Phys. G 31 (2005) S1417

H. Mach, P.M. Walker, R. Julin, M. Leino, S. Juutinen, M. Stanoiu, Zs. Podolyak, R. Wood, A.M. Bruce, T. Bäck, J.A. Cameron, B. Cederwall, J. Ekman, B. Fogelberg, P.T. Greenless, M. Hellström, P. Jones, W. Klamra, K. Lagergren, A.-P. Leppänen, P. Nieminen, R. Orlandi, J. Pakarinen, P. Rahkila, D. Rudolph, G. Simpson, J. Uusitalo and C. Wheldon
Application of ultra-fast timing techniques to the study of exotic and weakly produced nuclei
J. Phys. G 31 (2005) S1421

D.T. Joss, N. Amzal, D.E. Appelbe, T. Back, C.J. Barton, M.A. Bentley, B. Cederwall, J.F.C. Cocks, D.M. Cullen, S. Eeckhaudt, T. Grahn, P.T. Greenlees, B. Hadinia, K. Helariutta, P.M. Jones, R. Julin, S. Juutinen, H. Kankaanpaa, A. Keenan, H. Kettunen, S.L. King, P. Kuusiniemi, K. Lagergren, M. Leino, A.P. Leppänen, M. Muikku, P. Nieminen, R.D. Page, J. Pakarinen, E.S. Paul, P.Rahkila, C. Scholey, A. Savelius, J. Simpson, M.J. Taylor, J. Uusitalo, S.J. Williams, D.D. Warner, D.R. Wiseman, R. Wyss
Probing structural changes in the very neutron-deficient Os isotopes with recoil-decay tagging
J. Phys. G 31 (2005) S1593

J.N. Orce, T. Kibédi, G.D. Dracoulis, R. Julin and S.W. Yates
Conversion-electron study of 0^+ excitations in ^{208}Pb
J. Phys. G 31 (2005) S1705

D.T. Joss, J . Simpson, D.E. Appelbe, K . Lagergren, C.J. Barton, B. Cederwall, S . Eeckhaudt, T. Grahn, P.M. Jones, R. Julin, S. Juutinen, B. Hadinia, H. Kettunen, M. Leino, A.-P. Leppänen, P. Nieminen, R.D. Page, J. Pakarinen, E.S. Paul, J. Perkowski, P. Rahkila, M.A. Riley, C. Scholey, J. Uusitalo, K. Van de Vel, D.D. Warner, D.R. Wiseman
Yrast structures in the light Pt isotopes $^{169-173}$Pt
J. Phys. G31 (2005) S1715

J. Pakarinen, I.G. Darby, S. Eeckhaudt, T. Enqvist, T. Grahn, P.T. Greenlees, V. Hellemans, K. Heyde, F. Johnston-Theasby, P. Jones, R. Julin, S. Juutinen, H. Kettunen, M. Leino, A.-P. Leppänen, P. Nieminen, M . Nyman, R.D. Page, P.M. Raddon, P. Rahkila, C. Scholey, J. Uusitalo, R. Wadsworth
Evidence for oblate structure in ^{186}Pb
Phys. Rev. C 72 (2005) 011304

B. Hadinia, B. Cederwall, J. Blomqvist, E. Ganioglu, P.T. Greenlees, K. Andgren, I.G. Darby, S. Eeckhaudt, E. Ideguchi, P.M. Jones, D.T. Joss, R. Julin, S. Ketelhut, K. Lagergren, M. Leino, E.S. Paul, M. Petri, P. Rahkila, M. Sandzelius, C. Scholey, J. Uusitalo, R. Wadsworth , R. Wyss
First identification of excited states in ^{106}Te and evidence for isoscalar-enhanced vibrational collectivity
Phys. Rev. C 72 (2005) 041303(R)

The JYFL Gas-filled Recoil Separator Ritu

K. Van de Vel, A.N. Andreyev, D. Ackermann, H.J. Boardman, P. Cagarda, J. Gerl, F.P. Hessberger, S. Hofmann, M. Huyse, D. Karlgren, I. Kojouharov, M. Leino, B. Lommel, G. Munzenberg, C. Moore, R.D. Page, S. Saro, P. Van Duppen, R. Wyss
Prolate structures in ^{189}Po and ^{185}Pb
Eur. Phys. J. A 24 (2005) 57

S. Eeckhaudt, P.T. Greenlees, N. Amzal, J.E. Bastin, E. Bouchez, P.A. Butler, A. Chatillon, K. Eskola, J. Gerl, T. Grahn, A. Görgen, R.-D. Herzberg, F.P. Hessberger, A. Hürstel, P.J.C. Ikin, G.D. Jones, P. Jones, R. Julin, S. Juutinen, H. Kettunen, T.L. Khoo, W. Korten, P. Kuusiniemi, Y. Le Coz, M. Leino, A.-P. Leppänen, P. Nieminen, J. Pakarinen, J. Perkowski, A. Pritchard, P. Reiter, P. Rahkila, C. Scholey, Ch. Theisen, J. Uusitalo, K. Van de Vel and J. Wilson
Evidence for non-yrast states in ^{254}No
Eur. Phys. J. A 26 (2005) 227

F. P. Heßberger, S. Antalic, B. Streicher, S. Hofmann, D. Ackermann, B. Kindler, I. Kojouharov, P. Kuusiniemi, M. Leino, B. Lommel, R. Mann, K. Nishio, S. Saro, B. Sulignano
Energy systematics of low-lying Nilsson levels in odd-mass einsteinium isotopes
Eur. Phys. J. A 26 (2005) 233

S. Eeckhaudt, N. Amzal, J.E. Bastin, E. Bouchez, P.A. Butler, A. Chatillon, K. Eskola, J. Gerl, T. Grahn, A. Görgen, P.T. Greenlees, R.-D. Herzberg, F.P. Hessberger, A. Hürstel, P.J.C. Ikin, G.D. Jones, P. Jones, R. Julin, S. Juutinen, H. Kettunen, T.L. Khoo, W. Korten, P. Kuusiniemi, Y Le Coz, M. Leino, A.-P. Leppänen, P. Nieminen, J. Pakarinen, J. Perkowski, A. Pritchard, P. Reiter, P. Rahkila, C. Scholey, Ch. Theisen, J. Uusitalo, K. Van de Vel, J. Wilson, H.J. Wollersheim
In-beam gamma-ray spectroscopy of ^{254}No
Eur. Phys. J. A Direct (2005)

A.-P. Leppänen, J. Uusitalo, S. Eeckhaudt, T. Enqvist, K. Eskola, T. Grahn, F.P. Heßberger, P.T. Greenlees, P. Jones, R. Julin, S. Juutinen, H. Kettunen, P. Kuusiniemi, M. Leino, P. Nieminen, J. Pakarinen, J. Perkowski, P. Rahkila, C. Scholey and G. Sletten
Alpha-decay study of ^{218}U; a search for the sub-shell closure at Z = 92
Eur. Phys. J. A Direct (2005)

C. Scholey, M. Sandzelius, S. Eeckhaudt, T. Grahn, P.T. Greenlees, P. Jones, R. Julin, S. Juutinen, M. Leino, A.-P. Leppänen, P. Nieminen, M. Nyman, J. Perkowski, J. Pakarinen, P. Rahkila, P.M. Rahkila, J. Uusitalo, K. Van de Vel, B. Cederwall, B. Hadinia, K. Lagergren, D.T. Joss, D.E. Appelbe, C.J. Barton, J. Simpson, D.D. Warner, I.G. Darby, R.D. Page, E.S. Paul, D. Wiseman
In-beam and decay spectroscopy of very neutron deficient iridium nuclei
J. Phys. G 31 (2005) S1719

S. Rigby, D.M. Cullen, D.T. Scholes, C. Scholey, P. Rahkila, S. Eeckhaudt, T. Grahn, P. Greenlees, P.M. Jones, R. Julin, S. Juutinen, H. Kettunen, M. Leino, A. Leppänen, P. Nieminen, M. Nyman, J. Pakarinen, J. Uusitalo
Mass-140 isomers near the proton dripline
J. Phys. G 31 (2005) S1949

M. Leino
Structure and decay properties of the heaviest elements
Nucl. Phys. A751 (2005) 248

J. Uusitalo, M. Leino, T. Enqvist, K. Eskola, T. Grahn, P.T. Greenlees, P. Jones, R. Julin, S. Juutinen, A. Keenan, H. Kettunen, H. Koivisto, P. Kuusiniemi, A.-P. Leppänen, P. Nieminen, J. Pakarinen, P. Rahkila, C. Scholey
α decay studies of very neutron-deficient francium and radium isotopes
Phys. Rev. C 71 (2005) 024306

D. Seweryniak, J. Uusitalo, P. Bhattacharyya, M.P. Carpenter, J.A. Cizewski, K.Y. Ding, C.N. Davids, N. Fotiades, R.V.F. Janssens, T. Lauritsen, C.J. Lister, A.O. Macchiavelli, D. Nisius, P. Reiter, W.B. Walters, and P.J. Woods
Multiparticle configurations in N=84 isotones located at the proton drip line
Phys. Rev. C 71 (2005) 054319

P. Reiter, T.L. Khoo, I. Ahmad, A.V. Afanasjev, A. Heinz, T. Lauritsen, C.J. Lister, D. Seweryniak, P. Bhattacharyya, P.A. Butler, M.P. Carpenter, A.J. Chewter, J.A. Cizewski, C.N. Davids, J.P. Greene, P.T. Greenlees, K. Helariutta, R.-D. Herzberg, R.V.F. Janssens, G.D. Jones, R. Julin, H. Kankaanpaa, H. Kettunen, F.G. Kondev, P. Kuusiniemi, M. Leino, S. Siem, A.A. Sonzogni, J. Uusitalo, and I. Wiedenhover
Structure of the odd-A, shell-stabilized nucleus ^{253}No
Phys. Rev. Lett. 95 (2005) 032501

ALICE and Nuclear Reactions

Yu.G. Sobolev, A. Budzanowski, E. Bialkowski, et.al
Energy dependence of total reaction cross section of the ^{4,6}He,^{7}Li-^{28}Si interaction at 5-50 AMeV
Bull. Rus. Acad.Sci., Phys. Ser. Vol. 69, N11 (2005)1605

P. Jessinger, Yu.N. Kopatch, M. Mutterer, F. Gönnenwein, A.M. Gagarski, J. v. Kalben, V. Nesvizhevsky, G.A. Petrov, W.H. Trzaska and H.-J. Wollersheim
New experimental studies on the quartenary fission of ^{233,235}U(n_{th},f) and ^{252}Cf(sf)
Eur. Phys. J. A 24 (2005) 379

M. Bondila, V.A. Grigoriev, F.F. Guber, V.A. Kaplin, A.I. Karakash, O.V. Karavichev, T.L. Karavicheva, A.I. Klimov, K.N. Kozlov, A.B. Kurepin, V.A. Loginov, V.V. Lyapin, T. Malkiewicz, V.V. Marin, A.I. Maevskaya, E.A. Meleshko, A.I. Reshetin, W.H. Trzaska, S. Yamaletdinov
ALICE T0 Detector,
IEEE Trans. Nucl. Sc., 52 (2005) 1705

V.Yu. Ugryumov, I.V. Kuznetsov, E. Byalkovski, A. Kugler, K.A. Kuterbekov, I.N. Kukhtina, V.F. Kushniruk, V.G. Lyapin, V.A. Maslov, Yu.E. Penionzhkevich, Yu.G. Sobolev, W. Trzaska, G.P. Tyurin, S.V. Khlebnikov, S.R. Yamaletdinov
Energy dependence of the total reaction cross section of silicon induced by ^{4}He ions with silicon nuclei
Phys. Atomic Nuc. 68 (2005) 16

E. Piasecki , L. Swiderski, P. Czosnyka, M. Kowalczyk, , K. Piasecki, M. Witecki, T. Czosnyka, M. Kisielinski, T. Krogulski, M. Mutterer, S. Khlebnikov, W.H. Trzaska, K. Hagino, and N. Rowley
Puzzling absence of structure in the ^{20,22}Ne + ^{118}Sn quasi-elastic barrier distribution
Phys. Lett. B 615 (2005) 55

J. Perkowski, W.H. Trzaska, J. Andrzejewski, V .Lyapin, T. Malkiewcz
Energy loss of ^{40}Ar in Au: Comparison of TOF-E and TOF-TOF method
Nucl. Instr. & Meth. B 240 (2005) 333

O. Alyakrinskiy, A. Andrighetto, M. Barbui, S. Brandenburg, M. Cinausero, B. Dalena, P. Dendooven, E. Fioretto, G. Lhersonneau, V. Lyapin, G. Prete, G. Simonetti, L. Stroe, L.B. Tecchio, W.H. Trzaska
Neutron yield from a thick ^{13}C target irradiated by 90 MeV protons
Nucl. Instr. & Meth. A 547 (2005) 616

See also: Exotic Nuclei and Beams: Radiochim. Acta 93 (2005) 377

Accelerator-Based Materials Physics

M. Putkonen, T. Sajavaara, L. Niinistö, J. Keinonen
Analysis of ALD-processed thin films by ion-beam techniques
Anal. Bioanal. Chem. 382 (2005) 1791

S. T. Nakagawa, K. Ikuse, T. Ono, H. J. Whitlow, and G. Betz
Crystallographic analysis of extended defects in diamond-type crystals
Nucl. Instr. & Meth. B 232 (2005) 322

Y. Zhang and H.J. Whitlow
Modification of materials by mev ion beams, in: Electrostatic accelerators: fundamentals and applications
ed. R. Hellborg (Springer, Berlin, 2005) p. 506

H.J. Whitlow and H. Timmers
Charge exchange and electron stripping, in: Electrostatic accelerators: fundamentals and applications
ed. R. Hellborg (Springer, Berlin, 2005) p. 181

Industrial Applications

P. Laitinen, J. Räisänen, I. Riihimäki, J. Likonen and E. Vainonen-Ahlgren
Fluence effect on ion implanted As diffusion in relaxed Si-Ge
Europhysics Letters 72 (2005) 416

V.S. Touboltsev and P. Jalkanen
Erbium Implanted Silicon-Germanium
J. Appl. Phys. 97 (1) (2005) 13526

J. Härkönen, E. Tuovinen, P. Luukka, E. Tuominen, Z. Li, A. Ivanov, E. Verbitskaya, V. Eremin, A. Pirojenko, I. Riihimäki and A. Virtanen
Particle detectors made of high-resistivity Czochralski silicon
Nucl. Instr. & Meth. A 541 (2005) 202-207.

V. Tuboltsev, P. Jalkanen, M. Kolodyazhnaya and J. Räisänen
Composition dependence of Si_xGe_{1-x} sputter yield
Phys. Rev. B 72 (2005) 205434

See also: Nanophysics and nanotehnology:
J. Appl. Phys. 98 (2005) 016105 and Nano Letters, 5 (2005) 1029

Nuclear Structure, Nuclear Decays, Rare and Exotic Processes

M. Kortelainen and J. Suhonen
Probing double beta decay by the nuclear muon capture in MUONS
(New Research) Ed. J. Caparthy, NOVA Publishers 2005
(Invited Monograph) ISBN: 1-59454-175-2

J. Suhonen
Theory of double beta decay
Nucl. Phys. A 752 (2005) 53c

O. Civitarese and J. Suhonen
Extracting information on the $0\nu\beta\beta$ decays from the $2\nu\beta\beta$ decays
Nucl. Phys. A 761 (2005) 313

M. Kortelainen and J. Suhonen
Analysis of the $2\nu\beta\beta$ decay and muon capture reactions for the mass *A=46* and *A=48* nuclei using the nuclear shell model
Nucl. Phys. B 138 (2005) 227

J. Suhonen
Nuclear matrix elements and the neutrinoless double beta decay
Nucl. Phys. B 143 (2005) 240

M. Kortelainen and J. Suhonen
Probing double beta decay by nuclear muon capture
Nucl. Phys. B 143 (2005) 551

J. Suhonen
Nuclear matrix elements of $\beta\beta$ decay from β decay data
Phys. Lett. B 607 (2005) 87

O. Civitarese and J. Suhonen
Universality of the nuclear matrix elements governing the mass sector of the neutrinoless double beta decay
Phys. Lett. B 626 (2005) 80

S. Peltonen, D. S. Delion and J. Suhonen
Systematics of the α-decay to vibrational 2^+ states
Phys. Rev. C 71 (2005) 044315

F. Deppisch, H. Päs and J. Suhonen
Double beta decay versus cosmology: Majorana CP phases and nuclear matrix elements
Phys. Rev. D 72 (2005) 033012

R. Arnold, C. Augier, J. Baker, A. Barabash, G. Broudin, V. Brudanin, A.J. Caffrey, E. Caurier, V. Egorov, K. Errahmane, A.I. Etienvre, J. L. Guyonnet, F. Hubert, Ph. Hubert, C. Jollet, S. Jullian, O. Kochetov, V. Kovalenko, S. Konovalov, D. Lalanne, F. Leccia, C. Longuemare, G. Lutter, Ch. Marquet, F. Mauger, F. Nowacki, H. Ohsumi, F. Piquemal, J.-L. Reyss, R. Saakyan, X. Sarazin, L. Simard, F. Šinkovic, Yu. Shitov, A. Smolnikov, I. Štekl, J. Suhonen, C. S. Sutton, G. Szklarz, J. Thomas, V. Timkin, V. Tretyak, V. Umatov, L. Vála, I. Vanyushin, V. Vasilyev, V. Vorobel and Ts. Vylov
First results of the search for neutrinoless double-beta decay with the NEMO3 detector
Phys. Rev. Lett. 95 (2005) 182302

Nanophysics and Nanotechnology

G. S. Paraoanu and A. M. Halvari
Suspended single-electron transistors fabrication and measurement
Appl. Phys. Lett. 86 (2005) 093101

P. Jalkanen, V. Touboltsev, H. Koivisto, P. Suominen, T. Suppula, K. Yu. Arutyunov, and J. Räisänen
Superconductivity suppression in Fe-implanted thin Al films
J. Appl. Phys. 98 (2005) 016105

T. Walkeajärvi, J. Lievonen, M. Ahlskog, J. Åström, A. Koshio, M. Yudasaka, and S. Iijima
Bending of multiwalled carbon nanotubes over gold lines
J. Appl. Phys, 98 (2005) 104301

Gh.-S. Paraoanu and T. D. Stanescu
Self-duality and periodicity at finite filling factors
J. Phys. A: Math. Gen. 38 (2005) 2785

M. Zgirski, K.-P. Riikonen, V. Touboltsev, and K. Arutyunov
Size dependent breakdown of superconductivity in ultranarrow nanowires
Nano Letters, 5 (2005) 1029

J. T. Karvonen, L. J. Taskinen and I. J. Maasilta
Observation of disorder-induced weakening of electron-phonon interaction in thin noble-metal films
Phys. Rev. B 72 (2005) 012302

G. S. Paraoanu
Running-phase state in a Josephson washboard potential
Phys. Rev. B 72 (2005) 134528

Nanoelectronics and Nanotechnology

S. Tuukkanen, A. Kuzyk, J.J. Toppari, V.P. Hytönen, T. Ihalainen, and P. Törmä
Dielectrophoresis of nanoscale dsDNA and humidity effects on its electrical conductivity
Appl. Phys. Lett. 87 (2005) 183102

S. Tuukkanen, J.J. Toppari, V.P. Hytönen, A. Kuzyk, M.S. Kulomaa, and P. Törmä
Dielectrophoresis as a tool for nanoscale DNA manipulation
Int. J. of Nanotechnology 2 (2005) 280

A. Huttunen, K. Varis, K. Kataja, J. Aikio, and P. Törmä
Guiding and reflecting light by boundary material
Opt. Comm. 244 (2005) 147

A. Huttunen, and P. Törmä
Optimization of dual-core and microstructure fiber geometries for dispersion compensation and large mode area
Opt. Express 13 (2005) 627

A. Huttunen and P. Törmä
Effect of wavelength dependence of nonlinearity, gain, and dispersion in photonic crystal amplifiers
Opt. Express 13 (2005) 4286

J.-P. Martikainen and P. Törmä
Quasi two-dimensional superfluid Fermi gases
Phys. Rev. Lett. 95 (2005) 170407

M. Prunnila, P. Kivinen, A. Savin, P. Törmä, and J. Ahopelto
Intervalley-scattering induced electron-phonon energy relaxation in many-valley semiconductors at low temperatures
Phys. Rev. Lett. 95 (2005) 206602

Computational Nanosciences

K. Manninen, P. Pyykkö and H. Häkkinen
A small spherical liquid: DFT molecular dynamics study of WAu12
Chem. Phys. 7 (2005) 2208

T. Santa-Nokki and H. Häkkinen
Anomalous binding sequence of CO ligands to an anionic triplatinum carbonyl complex
Chem. Phys. Lett. 406 (2005) 44

H. Häkkinen and M. Walter
Computational Spectroscopy of Supported Cluster nanocatalysts
Computer and Computational Sciences, Vol. 4 (2005) 990

K. Manninen, T. Santa-Nokki, H. Häkkinen and M. Manninen
Magic clusters Na^-_{57} and Na^+_{59}
Eur. J. Phys. D 34 (2005) 43

V. Ruuska and M. Manninen
Composite fermions from the algebraic point of view
Phys. Rev. B 72 (2005) 153309

K. Kärkkäinen, M. Koskinen, S.M. Reimann, and M. Manninen
Magnetism in one-dimensional quantum dot arrays
Phys. Rev. B 72 (2005) 165324

M. Walter and H. Häkkinen
Optical absorption of magnesia-supported gold clusters and nanoscale catalysts: Effects due to the support, clusters, and adsorbants
Phys. Rev. B 72 (2005) 205440

M. Manninen, S. M. Reimann M. Koskinen, Y. Yu, and M. Toreblad
Electron-hole duality and vortex rings in quantum dots
Phys. Rev. Lett. 94 (2005) 106405

B. Yoon, H. Häkkinen, U. Landman, A. Wörz, J.-M. Antonietti, S. Abbet, K. Judai, U. Heiz
Charging effects on bonding and catalyzed oxidation of CO on Au_8 clusters on MgO
Science 307 (2005) 403

M. Walter and H. Häkkinen
Photoionization using Kohn-Sham wave functions
Eur. Phys. J D 33 (2005) 393

Soft Condensed Matter and Statistical Physics

R. Lohikoski, J. Timonen and A. Laaksonen
Molecular dynamics simulation of single DNA stretching reveals a novel structure
Chem. Phys. Lett. 407 (2005) 23

L. Miettinen, M. Myllys, J. Merikoski and J. Timonen
Experimental determination of KPZ height-fluctuation distributions
Eur. Phys. J. B 46 (2005) 55

A.V. Rybin, I.P. Vadeiko, and A.R. Bishop
Stopping a slow-light soliton: an exact solution
J. Phys. A: Math. Gen. 38 (2005) L177

A.V. Rybin, I.P. Vadeiko, and A.R. Bishop
Driving slow-light solitons by controlling laser field
J. Phys. A: Math. Gen. 38 (2005) L357

O. Pulkkinen and J. Merikoski
Phase transitions on Markovian bipartite graphs
J. Stat. Phys. 119 (2005) 881

J. Hyväluoma, P. Raiskinmäki, A. Koponen, M. Kataja and J. Timonen
Lattice-Boltzmann simulation of particle suspensions in shear flow
J. Stat. Phys. 121 (2005) 149

A.V. Rybin, I.P. Vadeiko, and A.R. Bishop
Non-adiabatic manipulation of slow-light solitons
New Journal of Physics 7 (2005) 146

R. Holmstad, U. Aaltosalmi, S. Ramaswamy, M. Kataja, A. Koponen, A. Goel and Ø.W. Gregersen
Comparison of 3D structural characteristics of high and low resolution x-ray microtomographic images of paper
Nord. Pulp Pap. Res J. 20(3) (2005)

I. Vadeiko, A. V. Prokhorov, A. V. Rybin, and S. M. Arakelyan
Nonlinear interaction of light with a Bose-Einstein condensate: Methods to generate sub-Poissonian light
Phys. Rev. A 72 (2005) 013804

R. P. Linna, J. A. Åström and J. Timonen
Dimensional effects in dynamic fragmentation of brittle materials
Phys. Rev. E 72 (2005) 015601(R)

A. V. Rybin, I. P. Vadeiko, and A. R. Bishop
Theory of slow-light solitons
Phys. Rev. E 72 (2005) 026613

J. Hyväluoma, P. Raiskinmäki, A. Koponen, M. Kataja and J. Timonen
Strain hardening in liquid-particle suspensions
Phys. Rev. E 72 (2005) 061402

P. Moilanen, P. H. F. Nicholson, V. Kilappa, S. Cheng and J. Timonen
Measuring the phase velocity of guided waves in free and immersed plates as bone phantoms
Ultrasound in Med. and Biol. 31 (2005) 633

Ultrarelativistic Heavy Ion Collisions

K.J. Eskola, H. Honkanen, C.A. Salgado and U.A. Wiedemann
The fragility of high-p(T) hadron spectra as a hard probe
Nucl. Phys. A 747 (2005) 511

P. Huovinen
Anisotropy of flow and the order of phase transition in relativistic heavy ion collisions,
Nucl. Phys. A761 (2005) 296

K.J. Eskola, H. Honkanen, H. Niemi, P.V. Ruuskanen and S.S. Räsänen
RHIC-tested predictions for low-p(T) and high-p(T) hadron spectra in nearly central Pb + Pb collisions at the LHC
Phys. Rev. C 72 (2005) 044904

F. Sannino and K. Tuominen
Orientifold theory dynamics and symmetry breaking
Phys. Rev. D 71 (2005) 051901

D.D. Dietrich, F. Sannino and K. Tuominen
Light composite Higgs from higher representations versus electroweak precision measurements: Predictions for LHC
Phys. Rev. D 72 (2005) 055001.

D. Molnar and P. Huovinen
Dissipation and elliptic flow at RHIC
Phys. Rev. Lett. 94 (2005) 012302

Theoretical Particle Physics and Cosmology

R. Ouyed, P. Keränen, and J. Maalampi
Ultrahigh-energy cosmic rays from hypothetical quark novae.
Astrophys.J.626 (2005) 389-395.

T.-F. Feng, X.-Q. Li, J. Maalampi, and X. Zhang
Two-loop gluino contributions to neutron electric dipole moment in CP violating MSSM.
Phys. Rev. D 71 (2005) 056005

Quantum Gravity

D. Meschini, M. Lehto, and J. Piilonen
Geometry, pregeometry and beyond
Studies in History and Philosophy of Modern Physics, Vol 36/3 (2005) 435

Other Peer Reviewed Articles (outside JYFL)

R. van Harrevelt, K. Honkala, J.K. Norskov and U. Manthe
The reaction rate for dissociative adsorption of N_2 on stepped Ru(0001): Six-dimensional quantum calculations
J. Chem. Phys. 123 (2005) 234702

C.H. Christensen, R.Z. Sorensen, T. Johannessen, U.J. Quaade, K. Honkala, T.D. Elmoe, R. Kohler and J.K Norskov
Metal ammine complexes for hydrogen storage
J. Mat. Chem. 15 (2005) 4106

R.Vang, K. Honkala, S.Dahl, E.K. Vestergaard, J.Schnadt,E. Laegsgaard, B.S. Clausen, J.K. Norskov and F. Besenbacher
Controlling the catalytic bond-breaking selectivity of Ni surfaces by step blocking
Nature Mat. 4 (2005) 160

K. Honkala, A. Hellman, I.N. Remediakis, A. Logadottir, A. Carlsson, S.Dahl, C.H. Christensen and J.K. Norskov
Ammonia synthesis from first-principles calculations
Science 307 (2005) 555

J. Niinistö, N. Petrova, M. Putkonen, L. Niinistö, K. Arstila, T. Sajavaara
Gadolinium oxide thin films by atomic layer deposition
Journal of Crystal Growth 285 (2005) 191

A. Niskanen, A. Rahtu, T. Sajavaara, K. Arstila, M. Ritala, M. Leskelä
Radical-enhanced atomic layer deposition of metallic copper thin films
Journal of the Electrochemical Society 152 (2005) G25-8

P. J. Soininen, K.-E. Elers, V. Saanila, S. Kaipio, T. Sajavaara and S. Haukka
Reduction of copper oxide film to elemental copper
Journal of the Electrochemical Society 152 (2005) G122

J. Niinistö, M. Putkonen, L. Niinistö, S. L. Stoll, K. Kukli, T. Sajavaara, M. Ritala, and M. Leskelä
Controlled growth of HfO2 thin films by atomic layer deposition from cyclopentadienyl-type precursor and water
J. Mater. Chem. 15 (2005) 2271

M. Van Hove, Y. Travaly, T. Sajavaara, B. Brijs, W. Vandervorst, A. Lauwers, O. Chamirian, J. A. Kittl, A. M. Jonas, and K. Maex
Study of thermal stability of nickel silicide by X-ray Re ectivity
Microelectronic Engineering 82 (2005) 492

N. P. Barradas, N. Addedc, W. M. Arnoldbik, I. Bogdanovic-Radovic, W. Bohne, S. Cardoso, C. Danner, N. Dytlewski, P. P. Freitas, M. Jaksic, C. Jeynes, C. Krug, W. N. Lennard, S. Lindner, Ch. Linsmeier, Z. Medunic, P. Pelicon, R. P. Pezzi, C. Radtke, J. Rhrich, T. Sajavaara, T. D. M. Salgado, F. C. Stedile, M. H. Tabacniks and I. Vickridge
A round robin characterisation of the thickness and composition of thin to ultra-thin AlNO films
Nucl. Instr. & Meth. B 227 (2005) 397

K. Kukli, T. Pilvi, M. Ritala, T. Sajavaara, J. Lu, and M. Leskelä
Atomic layer deposition of hafnium dioxide thin films from hafnium tetrakis (dimethylamide) and water
Thin Solid Films 491 (2005) 328

Theses and Degrees

Theses

MSc Theses
(alphabetical order)

Jukka Elfström, Mittauselektroniikan suunnittelu ja valmistaminen kapasitiiviselle anturille

Viki-Veikko Elomaa, JYFLTRAPin systemaattisista ominaisuuksista

Pentti Frondelius, ECR-ionilähteen magneettikentän lämpötilariippuvuus

Ville Föhr, Pallomaisen TPC-ilmaisimen ominaisuuksien tutkiminen supernovaneutriinojen havaitsemiseksi

Janne Haatanen, Kaksoishilatransistori esivahvistimena

Ari Halvari, Nb –based junctions: subgap transport phenomena

Teppo Harju, Reaktion vaikutusalan mittaukset

Hannu Hautamäki, Paperin impulssikuivatuksen Pounderin malli

Matti Herranen, Kvanttikuljetusyhtälöt sähköheikossa baryogeneesissä

Eemeli Hytönen, Lämmönsiirtokertoimet viiran läpi tapahtuvassa päällepuhalluskuivatuksessa

Veikko Kasper, Puolijohdekomponenttien lämpötilariippuvuus

Janne Kauttonen, Stokastiset mallit polymeerin liikkeelle ajasta riippuvassa kentässä

Teemu Kekkonen, Opetusesimerkkejä kuljetinjärjestelmien tuotekehityksen fysiikasta

Joona Kiiski, Planeettaliikkeen mekaniikkaa

Timo Kosonen, Ionioptisia testimittauksia RITU:lla

Paula Kuokkanen, Modelling the activity of the auditory nerve after hearing loss

Anton Kuzyk, Dielectrophoresis of nanoscale dsDNA and its electrical conductivity

Petri Laitinen, Jyväskylän yliopiston aineenopettajakoulutuksen onnistuminen fysiikan opettajaksi valmistuneiden mielestä

Mikko Laitinen, Huoneenlämpötilan nanokalorimetri bioteknologisiin sovelluksiin

Tiina Lampinen, 7.-ja 8.-luokkalaisten fysiikan osaamisen ja asenteiden vertailua (TIMSS 199 –tutkimuksen aineistosta)

Merja Laukkanen, Magnetic field simulations of a Barkhausen noise sensor

Sami Lehesvuori, Fysiikan oppituntien puheanalyysi

Matti Leppänen, Viimeinen teoria fysiikan historiassa

Mikko Leskinen, Eroja suprajuoksevien fermikaasujen teorioissa

Jari Loimula, Fysiikan viittomia –multimediaesitys

Kaisa Malmberg, Peruskoulun yhdeksäsluokkalaisten asenteet fysiikkaa kohtaan

Nuutti Matintupa, Mikrovirtausjärjestelmä osana ainemääräanturia

Mika Mustonen, ^{113}Cd:n ja ^{115}In:n perustilan beetahajoaminen MQPM-mallin avulla laskettuna

Jarkko Niemelä, PET-CT ja sen mahdollisuudet syövän hoidossa

Teemu Nissilä, Suurten fotoniannosten mittaaminen termoloistemenetelmällä

Tomi Paananen, BCS-teoriaa kolmikomponenttisessa kylmässä fermikaasussa

Hannu Paukkunen, A survey to the NuTeV anomaly: significance of the nuclear parton distributions

Mikko Pynnönen, Linux-yhteensopivien alustojen soveltuvuus sulautetussa mittausjärjestelmässä

Pyry Rahkila, Neutriinojen aktiivi-steriili-oskillaatiot ja nukleosynteesi

Toni Rautiainen, Tietotekniikan henkilökuntakoulutus oppilaitosympäristössä

Juho Rissanen, JYFLTRAP:n soveltuvuus loukun sisäiseen konversioelektronispektroskopiaan

Janne Ronkainen, Studies on charge exchange and molecule formation reactions in the ion guide buffer gas

Tommi Ropponen, ECR-ionilähteiden plasmapotentiaali ja ambipolaarinen diffuusio

Mikko Rossi, Energialtaan säädettävä β-radiografialaite

Pia Saksala, Fysiikan oppimateriaali sosiaali- ja terveysalan koulutukseen

Juha Sorri, SAGE spektrometrin esivaiheet

Tarmo Suppula, Mikrometri –kokoluokan sinisliitosten valmistus mekaanisella piinitridimaskilla ja kulmahöyrystyksellä

Erkki Tarvainen, Kerrospaksuusmittalaitteiden luotettavuustarkastelu

Katja Turpeinen, Lukiolaisten graafisten esitysten tulkinta- ja tuottamistaidot

Tuula Walkeajärvi, Moniseinämäisten hiilinanoputkien taipuminen kultaelektrodin reunalla

Jussi Virkajärvi, Pimeän aineen ongelmat standardi- ja kvintessenssikosmologiassa

Mikko Voutilainen, Kaalin kraatterin kivinäytteiden huokoisuuden ja kokonaistilavuuden määrittäminen

PhD Theses

Heli Honkanen, Perturbative QCD study of initial and final state effects in hadronic and nuclear collisions
JYFL Research Report No. 1/2005

Pasi Kivinen, Electrical and thermal transport properties of semiconductor and metal structures at low temperatures
JYFL Research Report No. 2/2005

Urpo Aaltosalmi, Fluid flow in porous media with the Lattice-Boltzmann method
JYFL Research Report No. 3/2005

Janne Pakarinen, Probing non-yrast structures of ^{186}Pb in a RDT measurement employing the jurogam array
JYFL Research Report No. 4/2005

Ari-Pekka Leppänen, Alpha decay and decay tagging studies in heavy elements using RITU separator
JYFL Research Report No. 5/2005

Kimmo Kärkkäinen, Density-functional studies of coupled quantum dot structures
JYFL Research Report No. 6/2005

Sami Räsänen, Hydrodynamical analysis of hadron spectra and thermal photon emission in ultrarelativistic heavy ion collisions
JYFL Research Report No. 7/2005

Olli Tarvainen, Studies of electron cyclotron resonance ion source plasma physics
JYFL Research Report No. 8/2005

Degrees

BSc Degrees (main subject)

Lappalainen, Jukka (physics)
Nikkarila, Juha-Pekka (physics)

MSc Degrees (main subject)

***=MSc includes teachers pedagogical studies**

Elfström, Jukka (electronics)
Elomaa, Viki-Veikko (physics)
Frondelius, Pentti (physics)
Föhr, Ville (physics)
Haatanen, Janne (electronics)
Harju, Teppo (physics)*
Hautamäki, Hannu (appl. physics)
Herranen, Matti (theor. physics)
Hytönen, Ville (physics)
Kasper, Veikko (electronics)
Kauttonen, Janne (physics)
Kekkonen, Teemu (physics)*
Kiiski, Joona (physics)*
Kosonen, Timo (physics)
Kuokkanen, Paula (physics)
Kuzyk, Anton (physics)
Laitinen, Mikko (electronics)
Laitinen, Petri (physics)*
Lampinen, Tiina (physics)*
Laukkanen, Merja (physics)
Lehesvuori, Sami (physics)*
Leppänen, Matti (physics)*
Leskinen, Mikko (theor. physics)
Loimula, Jari (physics)*
Malmberg, Kaisa (physics)*
Matintupa, Nuutti (physics)
Mustonen, Mika (theor. physics)
Niemelä, Jarkko (physics)
Nissilä, Teemu (physics)
Paananen, Tomi (theor. physics)
Paukkunen, Hannu (theor. physics)
Pynnönen, Mikko (electronics)
Rahkila, Pyry (theor. physics)
Rautiainen, Toni (physics)*
Rissanen, Juho-Antti (physics)
Ronkainen, Janne (physics)
Ropponen, Tommi (physics)
Rossi, Mikko (physics)
Saksala, Pia (physics)*
Sorri, Juha (physics)
Suppula, Tarmo (electronics)
Tarvainen, Erkki (appl. physics)
Turpeinen, Katja (physics)*
Walkeajärvi, Tuula (physics)
Virkajärvi, Jussi (theor. physics)
Voutilainen, Mikko (physics)

PhD Degrees

Aaltosalmi, Urpo (appl. physics)
Honkanen, Heli (theor. physics)
Kivinen, Pasi (electronics)
Kärkkäinen, Kimmo (physics)
Leppänen, Ari-Pekka (physics)
Pakarinen, Janne (physics)
Räsänen, Sami (theor. physics)
Tarvainen, Olli (physics)