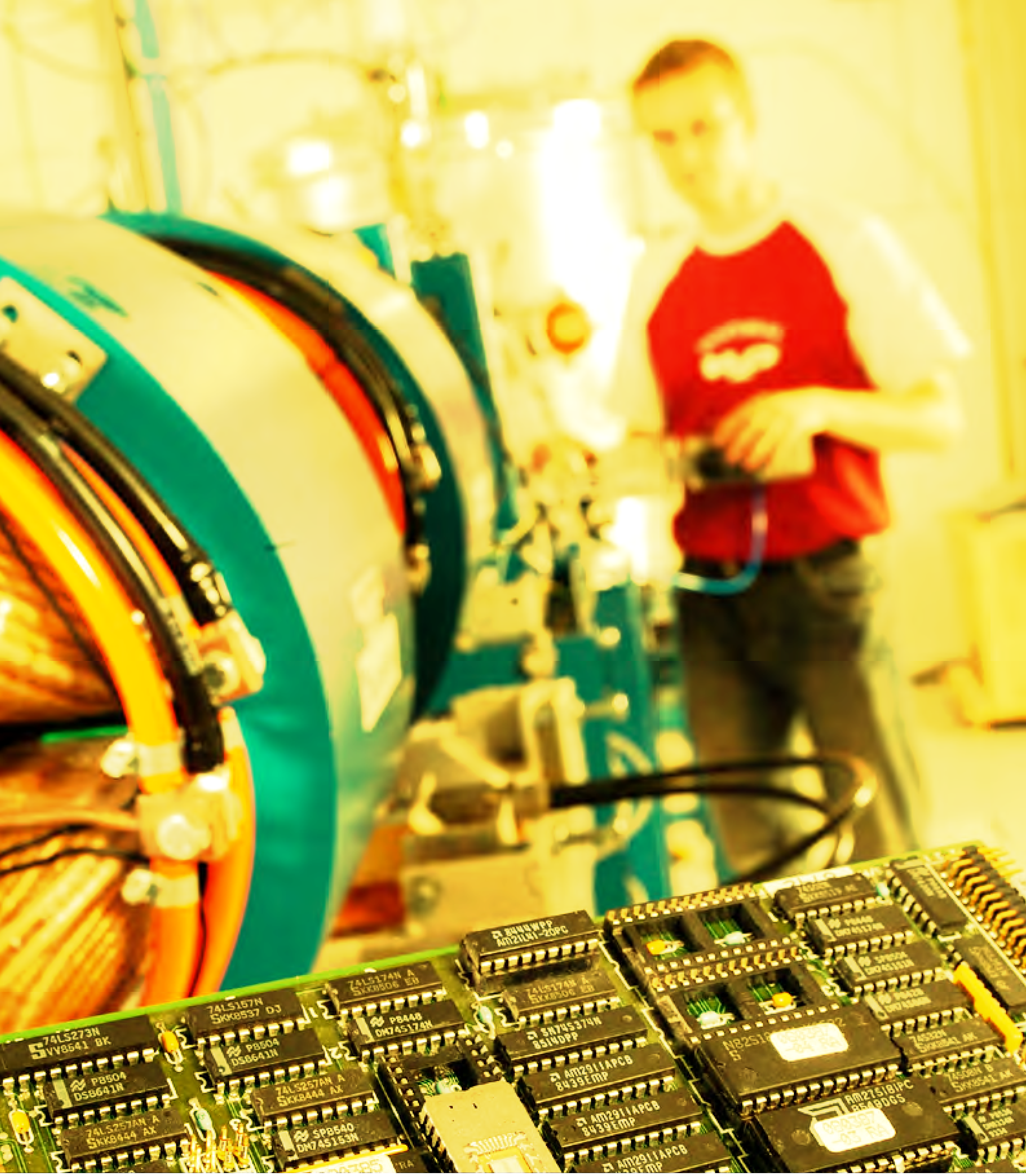

ANNUAL REPORT 2015

Department of Physics

UNIVERSITY OF JYVÄSKYLÄ

PRESS: GRANO

GRAPHIC DESIGN:MINJA REVONKORPI | TAIDEA

CONTENTS

PREFACE

The year 2015 will be remembered for the turmoil caused by budget cuts and the governmental aims for restructuring of the Universities. At the Department of Physics, these developments have led to a tightening of resources and sharpening of the research profile. The operational budget of the Department effectively decreased in 2015, continuing the unfortunate tendency of the preceding years and causing the positive progress of some indicators of productivity to slow compared to previous years. Nevertheless, relying on our creativity in research, our constant efforts to improve our teaching and supervision, and the unique spirit among our personnel and students, we can trust that we have a bright future ahead of us.

There were many delightful successes at the Department in 2015. These include the nomination of Hannu Häkkinen, professor in computational nanoscience and alumnus of the Department, as Academy Professor for a period of five years, and the award of a five-year ERC Consolidator Grant to Tuomas Lappi in the field of strong interaction particle physics.

The Department of Physics is the most influential centre in the field of sub-atomic physics and accelerator-based materials studies in Finland, and also highly recognized internationally. The Department of Physics Accelerator Laboratory is Finland's largest research infrastructure and is one of the leading nuclear physics facilities worldwide. The University of Jyväskylä has chosen nuclear- and particle physics, cosmology and accelerator-based materials physics (under the title "Research on matter with accelerator methods") as one of its strategic profiling areas. Profiling actions at the Department in 2015 included the nominations of two new professors, Iain Moore in experimental nuclear physics and Timo Sajavaara in accelerator-based materials physics. Sami Nurmi was recruited as a university lecturer in the field of cosmology.

Investments in experimental facilities and infrastructure remained at a high level in 2015. The construction of the new ion source facility HIISI continued, the vacuum-mode recoil-mass spectrometer MARA proceeded to the commissioning phase, and the helium ion microscope (HIM) was successfully commissioned in the premises of the Nanoscience Center. A linear electron accelerator, donated by the Kuopio University Hospital, was re-engineered to serve as an additional electronics radiation test facility strengthening the position of the Accelerator Laboratory as a test laboratory of the European Space Agency ESA.

In 2015 some 70 new students enrolled at the Department. Fortunately, the fall-off in the number of students that occurred at some other universities was not apparent here. Nevertheless, the recruitment of students both at the bachelor and master level, as well as reducing the number of drop-outs, remains a great challenge for us for the years to come.

Professor Jussi Timonen, who started his versatile and very successful career at the Department more than 40 years ago, retired at the end of the year. Dedicated to his calling, Jussi continues his research work as an emeritus.

Jukka Maalampi
Head of Department

SOME STATISTICAL DATA FROM 2015

Personnel	~180
- Professors incl. Research professors	20
- University lecturers and researchers	33
- Postdoctoral researchers	29
- Doctoral students	~80
- Technicians	30
- Administration	6
+ Several research assistants (MSc students)	
Undergraduate students	430
of which new students	~75
Doctoral students	~80
BSc degrees	29
MSc degrees	24
PhLic degrees	1
PhD degrees	10
Median time to complete MSc (years)	6
Number of foreign visitors	243
- in visits	304
Visits abroad	307
Peer reviewed publications	~250
Conference proceedings	~30
Other (articles in books etc.)	~25
Conference and workshop contributions	
- Invited talks	~160
- Other talks	~90
- Posters	~80
Funding (million €)	15,4
- University budget (incl. premises)	8,8
- HIP cooperation	0,6
- External funding	6
* Academy of Finland	3,7
* European Union	0,9
* Technology Development Centre, European regional development fund	0,2
* Contract research	0,8
* Other	0,4

In addition the Department received 1,6 million euros for research infrastructures.

ACCELERATOR LABORATORY

Ari Jokinen

The Accelerator Laboratory is an integral part of the Department of Physics. Presently it includes four accelerators with a variety of ion sources and innovative instrumentation for basic research, ion-beam based material physics and applications.

In 2015 the layout of the ion source room and injection line to the K130 heavy ion cyclotron were drastically modified to open up space for the new 18 GHz ECR ion source HIISI (Heavy Ion Ion Source Injector) and to improve the injection into the K130 cyclotron. Despite the extended shutdown periods, the main K130 accelerator provided 6135 hours of beam time for basic research and industrial applications in 2015. The number is comparable to earlier years.

Demand for beam time remains high. Altogether 29 new proposals were submitted to the Program Advisory Committee (PAC) in 2015. In addition to the PAC proposals, a significant fraction of the beam time is given directly for commercial use. The request for the latter exceeded the allocated beam time.

The year 2015 was the first year of the second 3-year period of the present Centre of Excellence (CoE) in Nuclear and Accelerator-Based Physics. Funding for the CoE is granted by the Academy of Finland and the level of funding for the second period 2015-2017 is similar to the first period in 2012-2014.

JYFL-ACCLAB is the only national infrastructure on the roadmap of the Ministry of Education and Culture (OKM) for 2017-2020 in the category “Natural Sciences and Technology”. A position on the roadmap shows the importance of the facility nationally and supports national infrastructure funding (FIRI) proposals. In 2015, the Accelerator Laboratory applied for funding to the level of 1.43 M€ for a project to upgrade the control system and scientific instrumentation in the laboratory. The proposal that covers the years 2016-2017 was approved.

In the new strategy of University of Jyväskylä for 2015-2020, the study of basic natural phenomena is recognized as research strength with accelerator-based physics as one of the key disciplines. In 2015, the university profiling scheme commenced, which included the Accelerator Laboratory. As a result, two new professors, Timo Sajavaara and Iain Moore were hired to strengthen and widen the research program of the Accelerator Laboratory.

The Accelerator Laboratory is a partner in the Horizon 2020 proposal ENSAR2, which was approved in 2015 and preparation for signing of the final contract was started. Due to the time-consuming preparation phase, support for external users was not available in 2015, but will start in spring 2016.

The 13th Nordic Meeting on Nuclear Physics was organized by JYFL in Saariselkä 13-17.4.2015, the latest in a regular series organized in different Nordic countries. The meeting gathered 63 participants from the Nordic countries and beyond to discuss recent trends and achievements in nuclear physics. The workshop was supported by the Federation of Finnish learned societies and the Accelerator Laboratory.

The recently commissioned IGISOL-4 facility has provided beam time on a regular basis for internal and external users. A setup consisting of the TASISpec double-sided silicon detector array for particle detection combined with a Cluster and Clover detectors was installed after JYFLTRAP to determine the proton-decay branch from 19/2−, 3174-keV isomer in ^{53}Co. The nuclear structure group from Warsaw University have bought six new Ge-detectors to form an array for low-multiplicity, high-intensity studies at IGISOL, either as a stand-alone decay setup or combined with JYFLTRAP for trap-assisted spectroscopy.

In 2015 two new projects were started at IGISOL. The first one deals with gamma-ray super-radiance in a Bose-Einstein Condensate. The required installation of an atom trap setup was started towards the end of 2015. The “nuClock” consortium funded via the Horizon 2020 Future and Emerging Technologies (FET-OPEN) call aims to develop a nuclear clock based on a unique low-energy nuclear transition in 229Th.

The nuclear spectroscopy group had another busy year executing the experimental campaigns centered on RITU and the germanium array JUROGAMII. After a break of several years due to cyclotron transmission issues, it was possible to carry out decay spectroscopic studies at RITU using high-intensity beams along with in-beam studies. One highlight was the study of fast (microsecond) decays of 250No which employed digital electronics to effectively remove any deadtime.

Construction of the new vacuum mode separator MARA was finished in 2015, followed by an intense testing period for high voltage operation, offline runs with an alpha source and four on-line runs with heavy ions. The commissioning phase has been extremely successful and the apparatus fulfills the expectations compared to the ion optical simulations. In order to prepare for the research program at MARA, a dedicated workshop called “MARA2015: Status, Physics and Future” was organized in the Physics Department on the 15th – 16th December.

A helium-ion microscope (HIM) was installed and commissioned in 2015. It will be used for thin film research, nano patterning and biological studies by the researchers of the Accelerator Laboratory and Nanoscience Center. The investment with a value of 1,25 M€ was supported by the Academy of Finland under the FIRI scheme for years 2015-2016.

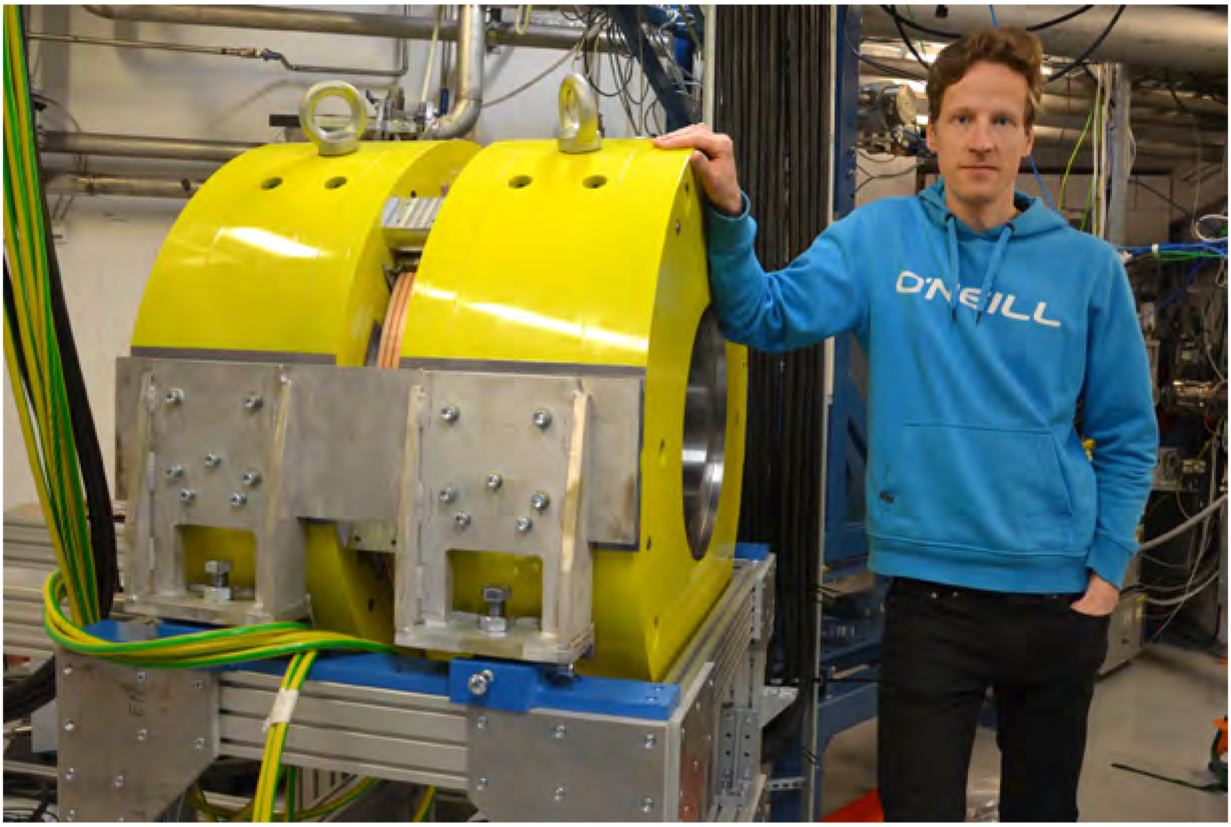

Figure 1. Solenoid coils for the 18 GHz ECR ion source HIISI installed on-site.

Commercial services continued to grow in 2015. In 2015 there were 48 campaigns for 22 different companies, institutes or universities using a total of 1201 hours of K130 beam time, which corresponds to approximately 20 % of the total. The total revenue of RADEF in 2015 was 878 k€, which is a new record. The RADEF facility remains an accredited laboratory of European Space Agency (ESA). ESA has further supported the Accelerator Laboratory in 2015 with partial funding of the new ECR ion source HIISI and by supporting the commissioning of the new e-linac, which was also commissioned in 2015. The E-linac will play a crucial role in testing the radiation hardness of components to be included in the Jupiter Mission.

FAIR AND ISOLDE

Scientists of the Accelerator Laboratory participate actively in the research and development at FAIR and ISOLDE. The SPEDE conversion electron spectrometer developed at JYFL was coupled with the MINIBALL gamma-ray spectrometer at ISOLDE. The development of GEM-TPC beam tracking detectors for FAIR has progressed well with on-line tests at GSI and JYFL in 2015. This work is done in close collaboration with the Detector Laboratory of Helsinki Institute of Physics.

Administration and contact persons:
Head of the Accelerator Laboratory: Ari Jokinen
Leader of the Center of the Excellence: Rauno Julin
Beam time coordinator: Mikael Sandzelius

Members of the Programme Advisory Committee of the JYFL Accelerator Laboratory:
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Dario Vretenar, University of Zagreb, Croatia
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Sami Heinäsmaa, science adviser, Academy of Finland

www.jyu.fi/accelerator/

THE FIDIPRO

K. Bennaceur, J. Dobaczewski, A. Idini, M. Kortelainen

In 2015, the FIDIPRO project continued with the third year of being funded within the second FIDIPRO grant awarded by the Academy of Finland and matched by the University of Jyväskylä. The FIDIPRO team included ten researchers working together on common project goals. The Helsinki Institute of Physics nuclear theory project works in close collaboration with the FIDIPRO project. The main focus of the project was on defining the non-local energy density functionals including three-body pseudopotentials, and on applying self-consistent methods to superheavy nuclei, multipole modes in deformed nuclei, and particle transfer differential cross sections.

www.jyu.fi/accelerator/fidipro/

SEMICONTACT THREE-BODY INTERACTION

To solve difficulties related to the use of nuclear density functional theory applied in its beyond-mean-field version (essentially due to the use of density dependent interactions and to the violation of the Pauli principle), we introduced a semicontact three-body effective interaction [1]. We showed that this interaction is a good candidate to replace the widely used density-dependent effective interaction. The resulting new functionals are able to describe symmetric, neutron, polarized, and neutron polarized nuclear matter as well as the effective mass properties simultaneously. The new interaction is a good candidate for multireference calculations, for instance, to restore symmetries or to account for configuration mixing beyond the independent particle picture.

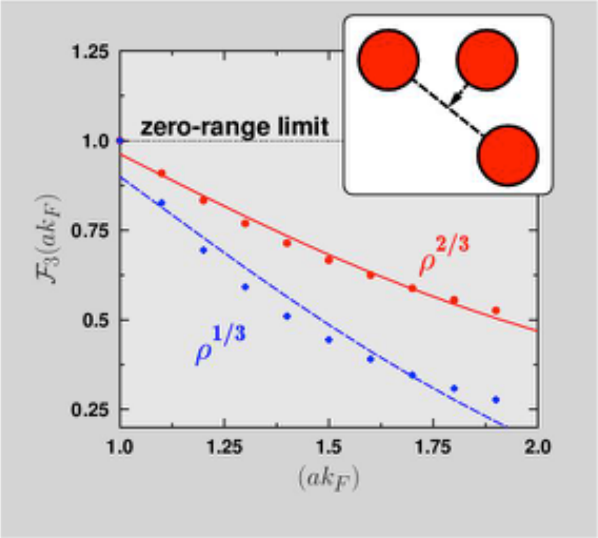


Figure 1. Infinite-mater characteristics of the semicontact three-body interaction (lines) as compared to two density-dependent contact interactions (dots).

PROPERTIES OF NUCLEI IN THE NOBELIUM REGION

We calculated properties of the ground and excited states of nuclei in the nobelium region for proton and neutron numbers of 92 $\leq Z \leq 104$ and 144 $\leq N \leq 156$, respectively [2]. We used three different energy-density-functional (EDF) approaches, based on covariant, Skyrme, and Gogny functionals, each with two different parameter sets. A comparative analysis of the results obtained for quasiparticle spectra, odd–even and two-particle mass staggering, and moments of inertia allowed us to identify single-particle and shell effects that are characteristic to these different models and to illustrate possible systematic uncertainties related to using the EDF modelling.

The obtained results suggest that further work on improving the performance of the EDF methods is very much required. First, one can hope that within the existing forms of EDFs, one can still find better global parameterisations. Second, one can hope that various beyond-mean-field corrections, not included in the present analysis, may have strong impact on the results, and thus modify the current conclusions. In addition, there is still a possibility of building new functionals, with beyond-mean-field effects incorporated from the very beginning.

MULTIPOLE MODES IN DEFORMED NUCLEI

We presented a computationally efficient, fully self-consistent framework to compute the QRPA transition strength function of an arbitrary multipole operator in axially deformed superfluid nuclei [3]. The method is based on the finite amplitude method (FAM) QRPA, allowing fast iterative solution of QRPA equations. Compared to traditional matrix formulation of the QRPA, FAM solves the QRPA problem with a fraction of the CPU time cost, allowing an efficient computation of the transition strength function. A numerical implementation of the FAM-QRPA solver module has been carried out for deformed nuclei. In particular, we calculated the quadrupole and octupole strengths in a heavy deformed nucleus ^{240}Pu, without any truncations in the quasiparticle space. The new FAM implementation enables calculations of the QRPA strength function throughout the nuclear landscape. The method is also very well suited for parallel computing. This will facilitate global surveys of multipole modes and β decays and will open new avenues for constraining the nuclear energy density functional. This work demonstrated the first practical application of the iterative QRPA method for deformed superfluid nuclei.

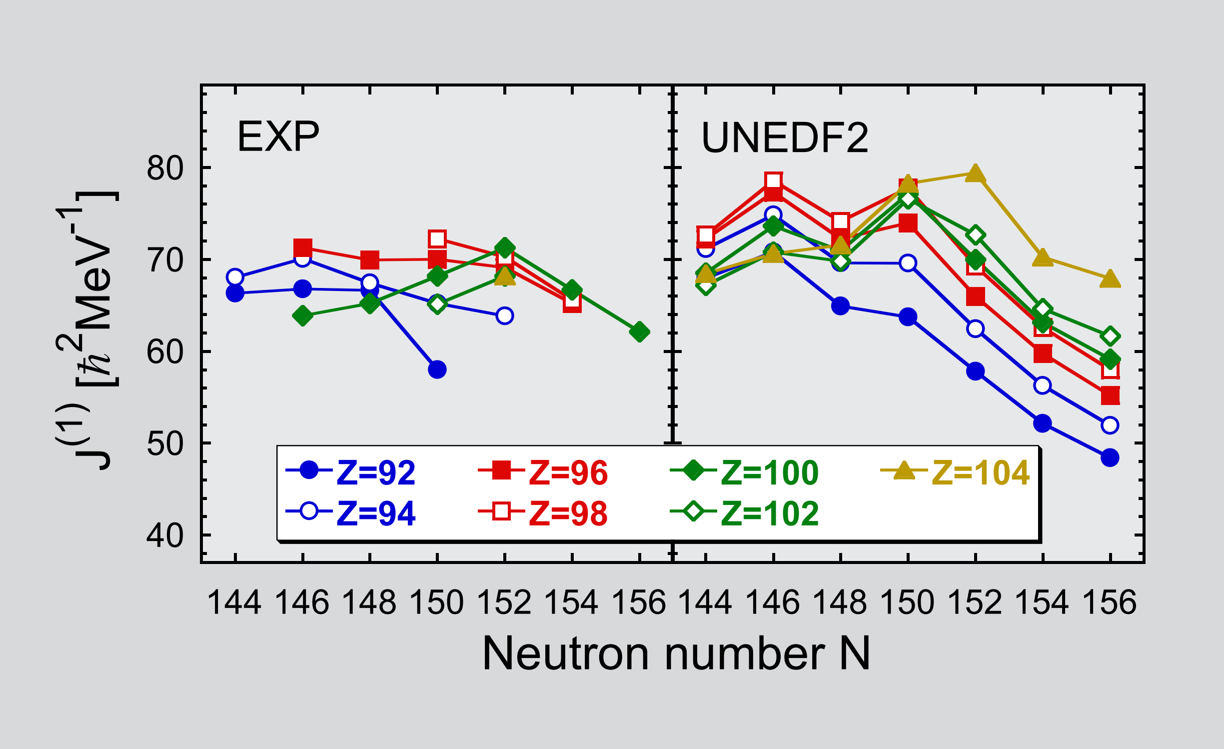


Figure 2. Kinematic moments of inertia of yrast rotational bands of even–even nuclei in the nobelium region. Theoretical values, calculated for the functional UNEDF2 are compared to experimental values.

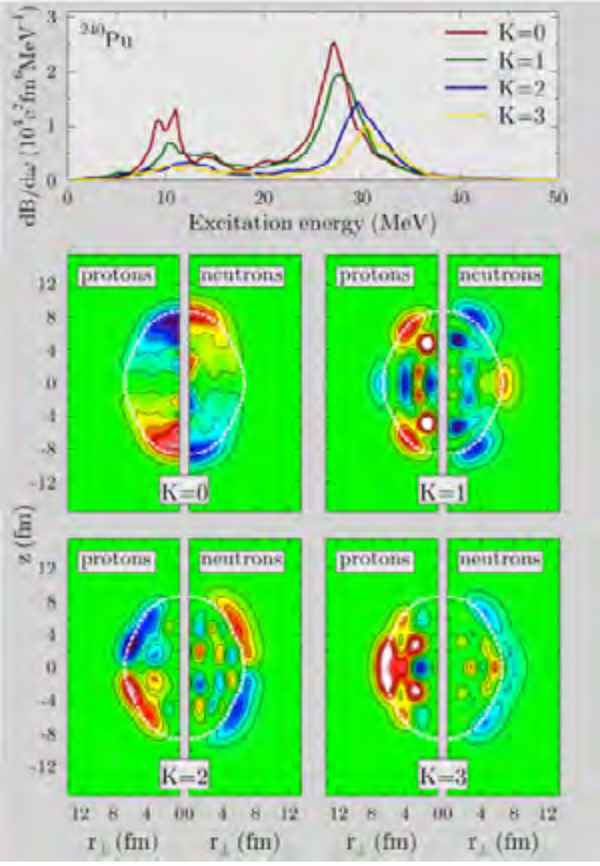


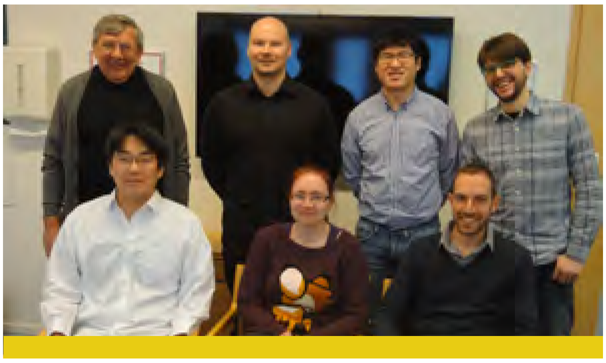
Figure 3. Topmost panel: Isovector octupole transition strength function in ^{240}Pu as a function of excitation energy. Lower panels: Induced transition densities in function of axial coordinates r and z.

SELECTED PUBLICATIONS

[1] D. Lacroix and K. Bennaceur, Semi-contact 3-body interaction for nuclear density functional theory, Phys. Rev. C91, 011302(R) (2015)

[2] J. Dobaczewski, A.V. Afanasjev, M. Bender, L.M. Robledo, and Yue Shi, Properties of nuclei in the nobelium region studied within the covariant, Skyrme, and Gogny energy density functionals, Nucl. Phys. A944, 388 (2015)

[3] M. Kortelainen, N. Hinohara, and W. Nazarewicz , Multipole modes in deformed nuclei within the finite amplitude method, Phys. Rev. C92, 051302(R) (2015)



EXOTIC NUCLEI AND BEAMS

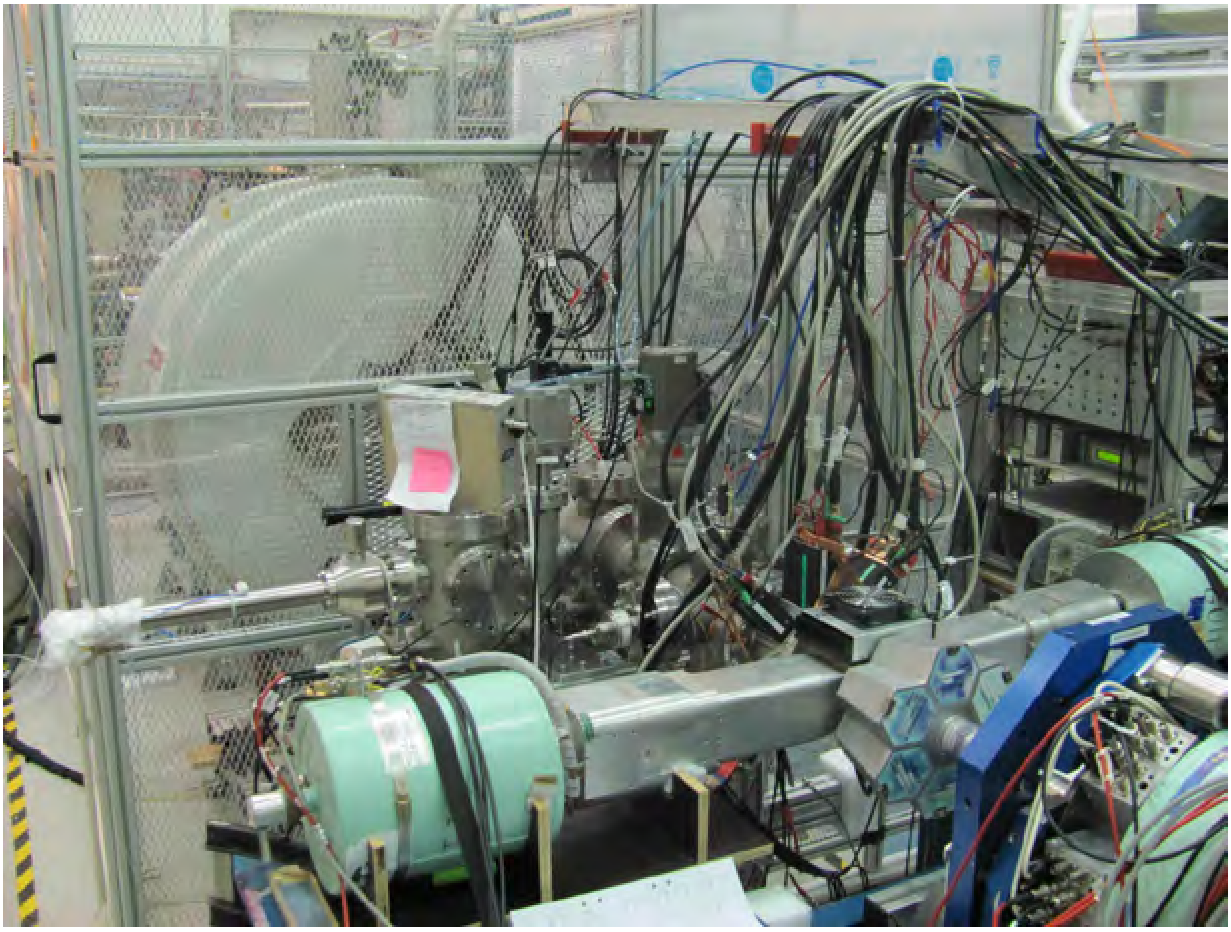
Anu Kankainen, Iain Moore and Heikki Penttilä

The exotic nuclei and beams group studies properties of nuclei employing Penning-trap mass spectrometry as well as laser and decay spectroscopy at the IGISOL-4 facility. In 2015 seven major experiments with 50 days of beam time were performed. The mass measurement programme for nuclear astrophysics, funded by the Academy of Finland, was strengthened with a new post-doctoral researcher Dmitrii Nesterenko. The "nuClock" consortium funded via the Future and Emerging Technologies (FET-OPEN) call in Horizon 2020 started in 2015 with a goal of developing a nuclear clock based on a unique low-energy nuclear transition in ^{229}Th. The first ^{232}Th samples for testing at IGISOL arrived from Vienna in December 2015, just in time for our new PhD student Sarina Geldhof who started working for the project in October. Novel post-trap decay spectroscopy experiments were performed in 2015 in collaboration with research groups from Lund University, GSI and the University of Warsaw.

Our group has been also very active internationally taking part in research and development work at other facilities, such as GANIL, ISOLDE (CERN) and GSI, the site of the future RIB-facility FAIR. Many of our international activities were carried out in close collaboration with the Helsinki Institute of Physics but also international research networks has played an essential role. The EU support from the FP7 program CHANDA (Challenges in Nuclear DAta) is also greatly acknowledged, as well as the FIRI support by the Academy of Finland.

www.jyu.fi/accelerator/igisol

Figure 1. The TASISpec setup after JYFLTRAP at the IGISOL facility in April 2015. TASISpec was originally designed for superheavy element studies after the TASCA gas-filled separator at GSI Darmstadt. The Lund-GSI-JYFL collaboration resulted in a very successful experiment.



QUANTUM-STATE SELECTIVE DECAY SPECTROSCOPY: PROTON DECAY BRANCH OF $^{53}Co^m$

Proton radioactivity was discovered 45 years ago by observing protons from the 19/2−, 3174-keV isomer in ^{53}Co. To date, the proton-decay branch of this ℓ=9 decay has been based only on estimations, partly due to similar half-lives of the ground and isomeric states. With JYFLTRAP, a pure beam of ^{53}Co^m was delivered to a setup consisting of the TASISpec double-sided silicon detector array for particle detection combined with a Cluster and Clover detectors. In a successful experiment a precise, lower than estimated value for the proton-decay branch was obtained. The measured value yields information on the proton-decay width, essential for understanding high-ℓ proton decays and for improving theoretical description. The ^{53}Co^m study represents the lowest nuclide production cross section ever studied at JYFLTRAP. It was a pioneering experiment aiming to initiate a series of similar experiments along the proton drip line.

COLLINEAR LASER SPECTROSCOPY OF LONG-LIVED Pu ISOTOPES

Following the development of a new gas cell dedicated for the production of low-energy beams of long-lived isotopes of heavy elements, the first resonance laser ionized beams of ^{239,240,242,244}Pu were delivered to the collinear laser spectroscopy station. Samples up to ~10^{16} atoms of ^{244}Pu to ~10^{12} atoms of ^{238}Pu were provided by the Nuclear Chemistry department of the University of Mainz.
Collinear laser spectroscopy was performed on an ionic transition from the $^8F_{1/2}$ ground state to the $^6P_{1/2}$ excited state at 27523.61 cm^{-1}. Isotope shift measurements were made and the hyperfine A factor was measured for ^{239}Pu. Example optical fluorescence spectra are indicated in Fig. 2. Plutonium represents the heaviest element to date studied using collinear laser spectroscopy and represents an important step towards providing ground state nuclear structure information in this region of the nuclear chart.

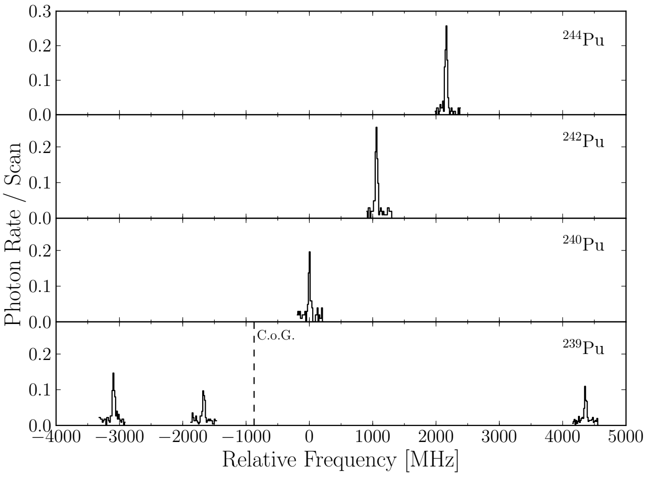


Figure 2. Optical fluorescence spectra of long-lived Pu isotopes. The centre of gravity of ^{239}Pu is marked as a vertical dashed line.

SINGLE AND DOUBLE BETA DECAY Q-VALUE OF ^{96}Zr

Both single (β) and double (ββ) beta decay Q-values of ^{96}Zr are relevant for studying physics of neutrinos and nuclear structure. ^{96}Zr has the third largest ββ-decay Q-value and is also unstable against single beta decay, a property it shares only with ^{48}Ca. If double beta decay is observed in either of these systems, matrix element calculations can be directly tested for ββ-decay.

Just prior to our work, the double beta decay Q-value of ^{96}Zr was found to be nearly 7 keV higher than the most recent mass evaluation (AME2012) using Michigan State University's LEBIT trap. The LEBIT experiment did not give information as to whether the single beta decay Q-value was also discrepant. Our measurement confirmed the 7 keV discrepancy in the ββ-decay Q-value. No discrepancy to the evaluation was found in the single beta decay Q-value, whose precision was improved by a factor of 20. The project was performed in collaboration with the Universities of Münster, Calgary, Bratislava and the JYFL theory group of J. Suhonen.

SELECTED PUBLICATIONS

A.-A. Zakari-Issoufou et al. and IGISOL collaboration, "Total Absorption Spectroscopy Study of 92Rb Decay: A Major Contributor to Reactor Antineutrino Spectrum Shape"
Physical Review Letters 115 (2015) 102503 DOI: 10.1103/PhysRevLett.115.102503

J. L. Tain et al. "Enhanced γ-Ray Emission from Neutron Unbound States Populated in β Decay"
Physical Review Letters 115 (2015) 062502 DOI: 10.1103/PhysRevLett.115.062502

B. Bucher et al. "New lifetime measurements in 109Pd and the onset of deformation at N=60"
Physical Review C 92 (2015) 064312 DOI:10.1103/PhysRevC.92.064312

M. Ranjan et al. "Design, construction and cooling system performance of a prototype cryogenic stopping cell for the Super-FRS at FAIR"
Nuclear Instruments and Methods A 770 (2015) 87-97 DOI: 10.1016/j.nima.2014.09.075

PhD Theses:
Volker Sonnenschein: Laser developments and high resolution resonance ionization spectroscopy of actinide elements

Dmitry Gorelov: Nuclear fission studies with the IGISOL method and JYFLTRAP

NUCLEAR SPECTROSCOPY

Paul Greenlees, Juha Uusitalo, Cath Scholey,
Janne Pakarinen, Joonas Konki, Hussam Badran

The group is one of the largest in the Accelerator Laboratory whose work is focused on fundamental studies of the structure of the nucleus. The main focus of the research is on experimental investigations into heavy and neutron-deficient nuclei, using in-beam and decay spectroscopic techniques. As in previous years, the group used a significant proportion of the K130 cyclotron beam time, using a total of 96 days for 9 different experiments. The group members were co-authors on 23 peer-reviewed journal articles and 7 conference proceedings. Some highlights from the year are presented in the following pages.

www.jyu.fi/accelerator/nucspec

MARA SEPARATOR COMPLETED AND IN COMMISSIONING PHASE

The construction of the new vacuum-mode recoil mass spectrometer MARA, was finally completed. MARA will be used for studies performed at the proton drip line below mass number 140 using symmetric (or slightly inverse) fusion-evaporation reactions. A variety of tests to study the ion-optics of the separator were performed using alpha-particle sources. The first accelerated beams were taken to MARA and it was demonstrated that MARA is able to separate the unreacted beam from fusion products. Furthermore, it was also possible to physically separate the fusion products based on their A/q ratio. In December, a workshop dedicated to MARA physics was organised and an exciting new program of experiments can be expected in the near future.

SPEDE ALSO COMPLETED AND COMMISSIONED

SPEDE is a conversion electron spectrometer developed by an international collaboration led by Janne Pakarinen, which allows direct measurement of conversion electrons in Coulomb excitation experiments. Early in 2015 the final in-beam tests were made in JYFL using the K130 cyclotron. SPEDE then made the trip to ISOLDE where it was coupled with the MINIBALL gamma-ray spectrometer (figure 1). At ISOLDE, SPEDE will use the radioactive ion beams from the newly upgraded HIE-ISOLDE with higher beam energies that will allow for multi-step Coulomb excitation experiments. These complex experiments benefit greatly from simultaneous in-beam gamma-ray and conversion-electron spectroscopy.

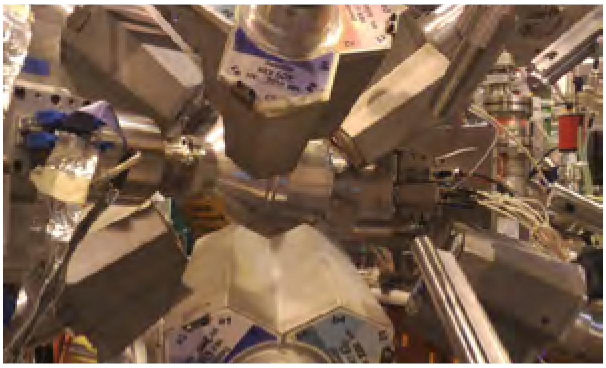


Figure 2. SPEDE spectrometer coupled to the MINIBALL gamma-ray spectrometer.

In November, SPEDE was installed at the target position of MINIBALL and the first commissioning test was performed using the reaction ^{196}Pt(^{133}Cs,^{133}Cs*). At the end of 2015 SPEDE returned to Jyväsklyä for further development. It will return to ISOLDE later in 2016 for an experimental campaign.

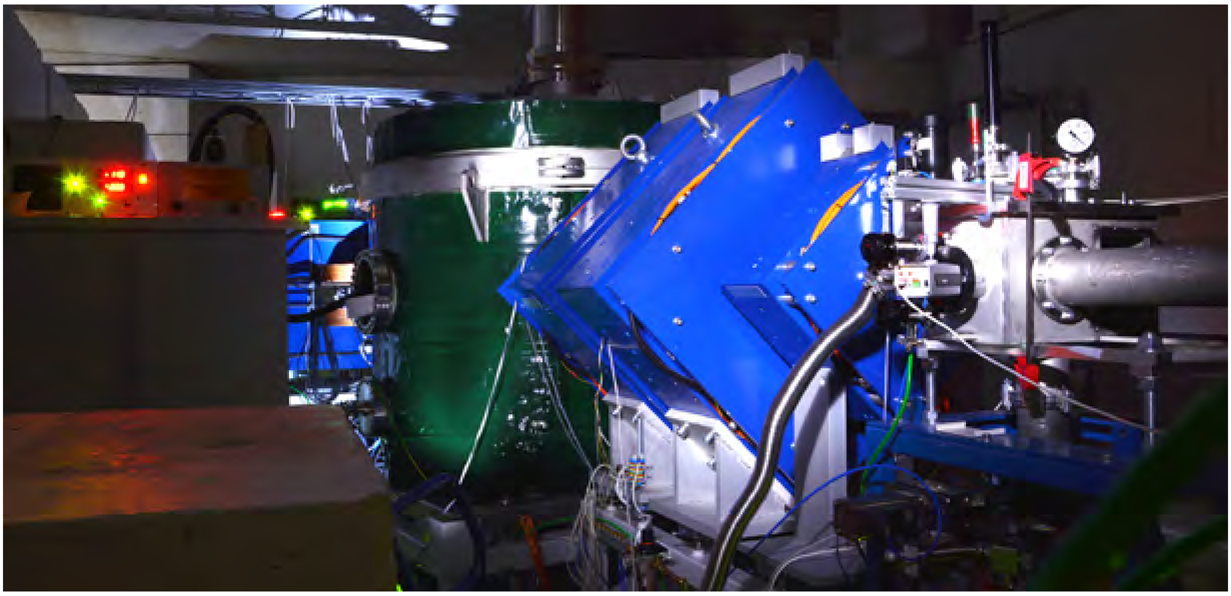


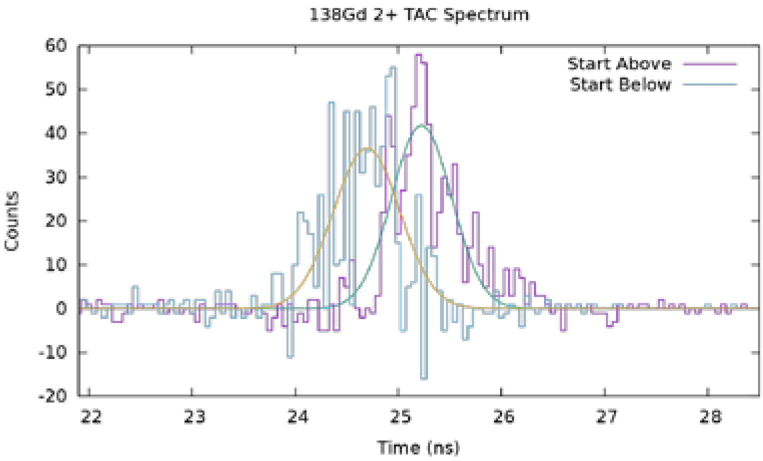
Figure 1. Ready for action. The MARA recoil mass spectrometer.

DECAY SPECTROSCOPY AT RITU

A number of decay-spectroscopic experiments were carried out at the focal plane of RITU. Of particular note were the studies of ^{179}Pb and ^{250}No. Continuing studies of the neutron-deficient Pb isotopes, the ^{104}Pd(^{78}Kr,3n)^{179}Pb reaction was used to study ^{179}Pb with a cross section of around 200pb. Alpha and alpha-gamma coincidence spectroscopy allowed the ground state spin of 179Pb to be assigned as 9/2. The search for other lowing-lying, possibly isomeric states continues. Figure 3 shows that focal plane gamma-ray spectroscopy can be performed at the 200pb level.

The study of ^{250}No with the ^{204}Pb(^{48}Ca,2n)^{250}No reaction exploited the possibility of instrumenting one face of the GREAT DSSDs with digital electronics to sample and directly digitise the output from the preamplifiers (traces). Direct analysis of the traces effectively removes all dead time and allows the study of very fast nuclear decays (down to tens of nanoseconds). The experiment resolved a long-standing question regarding the nature of spontaneous fission and isomerism in this nucleus.

In 2014, an experiment to produce a new isotope ^{240}Es was performed. According to systematics and previous studies of odd-odd einsteinium isotopes, a significant electron-capture delayed fission (ECDF) branch was predicted. In ^{240}Es the QEC value exceeds the fission barrier height and allows fission to compete with electromagnetic decay when an excited state in the daughter nucleus is populated. Subsequent analysis has indeed provided evidence for the enhanced ECDF branch.



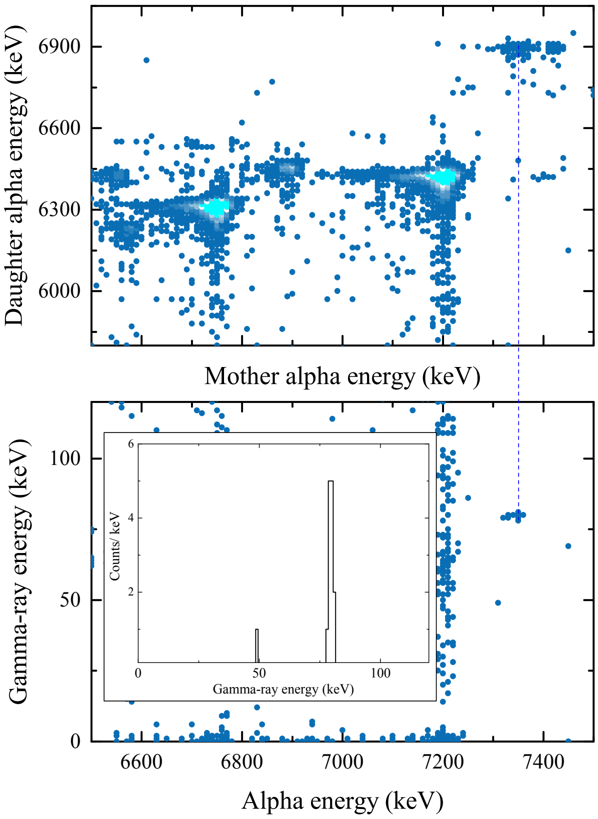


Figure 3. Top panel: 2D matrix of alpha-alpha correlations. Lower panel: 2D matrix of coincidences between alpha particles and gamma rays. The inset shows gamma rays in coincidence with 179Pb alpha-particles.

In August, eight LaBr$_3$ detectors, which belong to the UK NUSTAR collaboration, were installed at the focal plane of RITU (see figure 4). A proof-of-principle experiment to demonstrate that nuclear state lifetimes could be measured at the focal plane of RITU via fast timing was carried out. The main aim of the experiment was to prove that lifetimes can be extracted from a distributed source of recoils, where the position of the recoil implant is used to correct for the different flight times to each of the detectors. The test experiment focused on measuring the lifetime of the first 2+ state in 138Gd. The initial results from the centroid-shift method are shown in figure, which are encouraging and pave the way for future campaigns with this setup.

Figure 4:
a) The LaBr$_3$ array being cabled up by Michael Mallaburn, a Ph.D student from the University of Manchester, UK, who spent a year at JYFL as a long term attachment student.
b) Preliminary timing spectra from the ^{138}Gd experiment, showing the centroid shift due to the lifetime of the 2^+ state.

SELECTED PUBLICATIONS

A full listing of the group publications can be found online at the group web page via the link at the beginning of this section.

INSTRUMENTS AND METHODS IN NUCLEAR, PARTICLE, AND ASTROPARTICLE PHYSICS

Wladyslaw H. Trzaska

In this section we describe our involvement in the cosmic ray experiment EMMA, T0 and FIT fast timing detectors for ALICE experiment at CERN, and Nuclear Reaction studies at the K130 cyclotron at JYFL. R&D on neutrino detectors is presented in the Neutrino Physics section.

www.jyu.fi/physics/accelerator/hendes

EMMA EXPERIMENT

The photo, taken in Pyhäjärvi in August, shows the Finnish team of the EMMA Collaboration together with our 2015 summer students.

EMMA experiment, together with other scientific activities at the Center of Underground Physics in Pyhäsalmi, were evaluated in May 2015 by the Scientific Advisory Board (SAB) consisting of Anatoly Erlykin, Andreas Haungs (chair), and Jacek Szabelski. The SAB judged our team to be very active and highly motivated, with young researchers and students working seamlessly together. SAB was impressed by the quality and scientific content of the delivered presentations and discussions. Good progress was maintained despite absence of any direct funding for EMMA in 2015. To continue data taking and maintenance of the setup, our group accepted additional activities funded through a European Horizon 2020 application. They include involvement in an open-call for CALLIO-LAB, design and construction of a new laboratory space at 1430 m level and measurements of C14 contamination of liquid scintillators. In September the progress of our work was presented during the TAUP 2015 conference in Torino, Italy.

ALICE T0 AND FIT DETECTORS

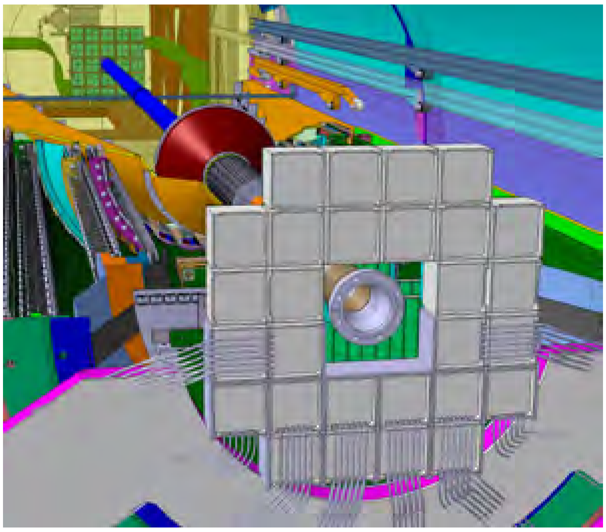
This photo was taken in October 2015 during the second phase of in-beam tests of the prototypes of the Fast Interaction Trigger (FIT) for the upgrade of ALICE experiment. The first test beam period was in June. Throughout the year FIT has reached several key R&D milestones achieving new time resolution records obtained with the modified prototypes. Our T0+ module consisting of Cherenkov radiator coupled to a MCP-PMT sensor clocked 22/18 ps with a broad/narrow beam and the V0+ scintillator module has, for the first time, reached 200 ps resolution. By modifications to the PMT-MCP light sensor we have significantly reduced the electronic crosstalk and increased the output amplitude without changing of the amplification. In 2015 the number of institutes participating in FIT has increased from 9 to 14.

2015 has marked the end of the Long Shutdown 1 and the start of the LHC Run 2. The upgrade has increased the collision energy to $\sqrt{s} = 13$ TeV for pp, and to $\sqrt{s_{NN}} = 5.02$ TeV for the PbPb collisions. Throughout the 2015 running period T0 has performed flawlessly. 0TVX – the main trigger signal generated by T0 remained very clean, free from after-pulses, and not sensitive to the events resulting from the beam-gas collisions. The time resolution throughout the pp run was ~40 ps and in PbPb run, better than 25 ps! Despite the increase in luminosity, by so far, no signs of PMT ageing were detected. 0TVX served as the main luminometer for pp data taking. We have also prepared 0TSC – a new semi-central trigger requested by the trigger coordination. It provides a very clean signal, free from after-pulses and with reduced sensitivity to the electromagnetic component making it suitable for PbPb luminosity measurement.

EMMA tracking stations in the Pyhäsalmi mine.

NUCLEAR REACTIONS

In 2015 we (see photo) have continued the study of inelastic scattering and multi-nucleon transfer reactions measuring angular distributions of the differential cross sections for the ^{9}Be (α, α') 9Be*, ^{9}Be (α, 3He) ^{10}Be, ^{9}Be (α, t) ^{10}B, ^{9}Be (^{3}He, ^{6}Li) ^{6}Li, and ^{9}Be (^{3}He, ^{7}Be) ^{5}He reactions. The information on the cluster structure of the reaction products was obtained and analyzed in the framework of the optical model, coupled channels, and distorted-wave Born approximation. An attempt was made to estimate the relative strengths of different configurations in ^{9}Be. We have confirmed our previous result that the first excited state of ^{9}Be (½+, 1.68 MeV), located only 20 keV above the decay threshold and playing an important role in nucleosynthesis, has a neutron halo structure. The cluster (α + ^{5}He) configuration is more compact and the (^{3}He + ^{6}He) one is significantly suppressed.



Conceptual drawing of Fast Interaction Trigger for ALICE upgrade.

ACCELERATOR-BASED MATERIALS PHYSICS

Timo Sajavaara

The research group focuses on thin film deposition, and materials characterization and modification using ion beams. The key infrastructure of the group is the Pelletron accelerator and all the research equipment in its beamlines. In Nanoscience Center (NSC) clean room the group is a very active user of the helium ion microscope (HIM) which was installed in 2015. The main tool for the deposition is the versatile atomic layer deposition (ALD) tool installed in 2013 to the NSC clean room. The group is an active link between the two research infrastructures Accelerator Laboratory and Nanoscience Center. In addition, the group focuses strongly in detector development related to the ion beam techniques. The group is also tightly linked to the other thin film research groups and industry in Finland.

www.jyu.fi/accelerator/abasedmat/

PELLETRON LABORATORY

The 30 years old 1.7 MV Pelletron accelerator is still a very well performing research instrument. The three ion sources provide beams from hydrogen to gold and the maximum energy available for heavy ions is roughly 20 MeV. The most actively used research instrument is the time-of-flight elastic recoil detection analysis (TOF-ERDA) setup, which can be used to generate quantitative depth profiles of elements from hydrogen to the heaviest masses. Other available characterization tools are Rutherford Backscattering Spectrometry (RBS) and external-beam particle induced X-ray emission (PIXE). A unique instrument in the lab is the 160 pixel transition edge sensor X-ray detector, which is used for PIXE measurement in vacuum with an energy resolution down to 3 eV and energy range of 1 to 10 keV. The tools, data acquisition and analysis software are constantly developed so that the whole infrastructure can be better used for both basic and applied research.

INSTALLATION OF HELIUM ION MICROSCOPE

In September 2015 the helium ion microscope (HIM) funded by the Academy of Finland through FIRI funding and University of Jyväskylä was installed to the NSC clean room. It is a joint instrument between the Department of Physics and Department of Biological and Environmental Science. The unique features of this instrument include the resolution of 0.5 nm or better, the possibility to image fully insulating samples and the ability to modify the samples by means of focused ion beam. The latter is especially achieved when using Ne ions as an alternative beam. The new instrument will greatly benefit not only the materials research but also the biological research. As a national infrastructure, the instrument is also open for external users.

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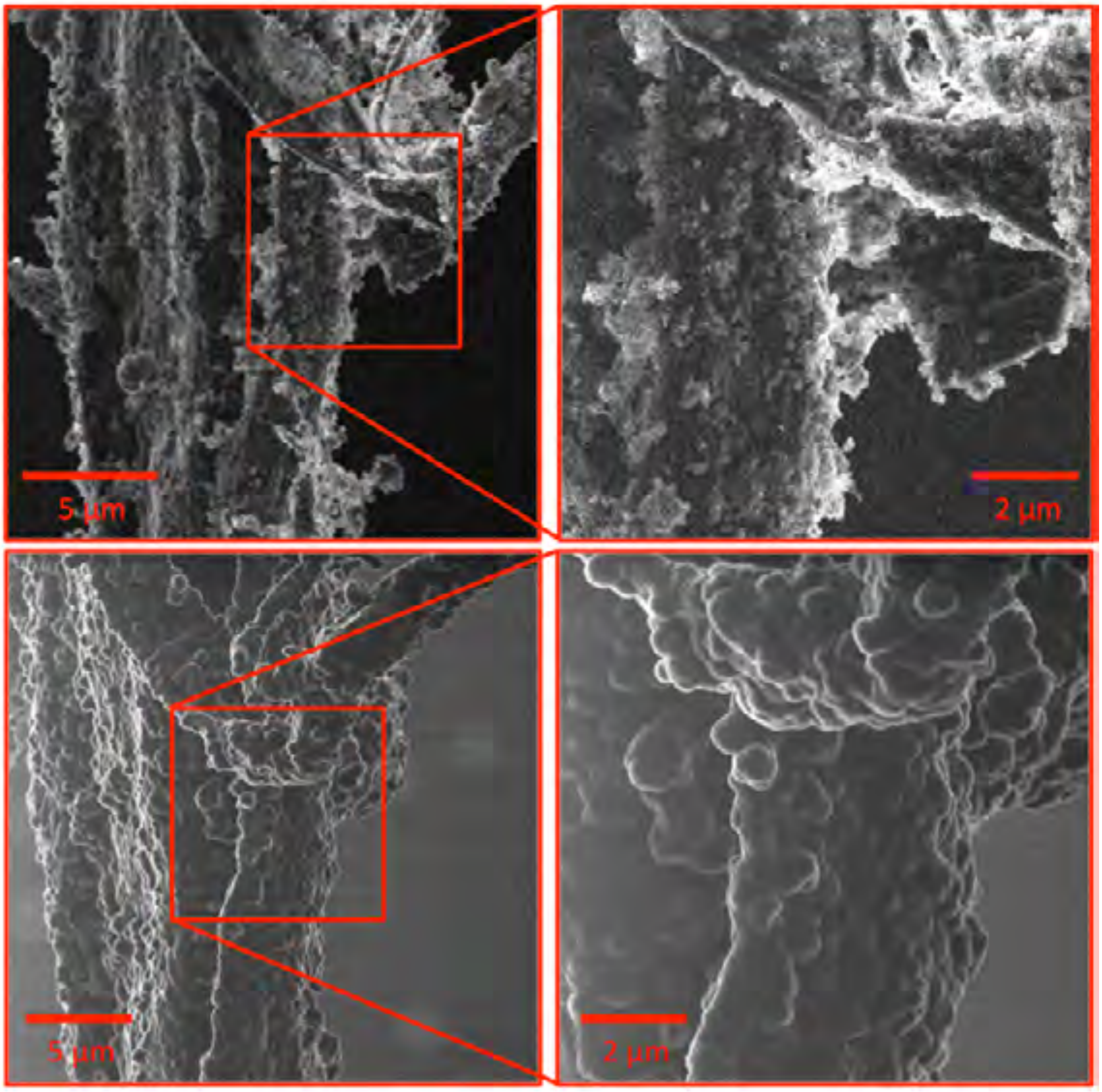
[2] Mari Napari, Jari Malm, Roope Lehto, Jaakko Julin, Kai Arstila, Timo Sajavaara, Manu Lahtinen, Nucleation and growth of ZnO on PMMA by low-temperature atomic layer deposition J. Vac. Sci. Technol. A 33 (2015) 01A128

Participants of the 2015 Jyväskylä summer school doing lab PIXE experiments in the Pelletron laboratory with an external beam.



Fibrillated cellulose fiber (VTT: Panu Lahtinen, Jaakko Pere) imaged with a helium ion microscope before (upper row) and after 200 nm thick Al2O3 film grown by atomic layer deposition.

INDUSTRIAL APPLICATIONS

Ari Virtanen

The industrial applications group is specialized in applied research around nuclear- and accelerator-based technologies. Its scope of activities ranges from irradiation testing of electronic components to separate R&D projects. The group has direct access to the laboratory's research capabilities and the knowledge acquired from the laboratory's technical and scientific programs to carry out different services and projects with national and international partners. Collaborations have been done with the European space industry, medical industry and many others. The most significant current application is the operation of Radiation Effects Facility, RADEF, for irradiation tests of space electronics. RADEF is an accredited external test facility of European Space Agency, ESA, and the group has performed irradiation tests for leading space organizations (ESA, NASA, JAXA, CNES etc...) and European space and electronics companies since 2005. During the last few years, the group has also participated in EU projects; for example, the first Horizon 2020 project of the university was granted to RADEF.

The use of beam time in 2015 was 1201 hours corresponding to about 20% from the total beam time of the K-130 cyclotron. Altogether, 48 campaigns for 22 space companies, institutes and universities were performed and the annual revenue, 878 k€, hit a new record in 2015.

COMMISSIONING OF THE CLINAC

The main highlight of the year was the commissioning of a Varian Clinac electron accelerator in a new RADEF cave extension. ESA allocated funding from its General Support Technology Programme, GSTP for this purpose. It expands the available beam selection from heavy ions and protons, at the moment available at RADEF, to the electrons and X-rays. The machine can provide intense electron beams with discrete energies of 6, 9, 12, 16 and 20 MeV and bremsstrahlung X-rays with end point energies of 6 and 15MeV. The accelerator delivered its first beam on August 12th, 2015. Technician Jan Hedström from Varian provided safety expertise during the first trials. In Figure 1 Heikki Kettunen, who did the successful machine commissioning work, and Jan Hedström are smiling with relief after successful start-up.

Among incoming irradiation studies, we foresee the group's involvement in the next large-scale ESA satellite mission JUICE, which is aimed to be launched in 2022. The data measured previously in Jovian missions indicate an extremely severe radiation environment, particularly in terms of electron fluxes. The new RADEF-Clinac facility's electron beams can be used to test space components which are to be exposed to the Jovian environment, as well as electron-rich medium Earth orbits (MEO).

Figure 1. Heikki Kettunen (left) and Jan Hedström after the start of CLinac.

INDUSTRIAL APPLICATIONS

NUCLEAR STRUCTURE, NUCLEAR DECAYS, RARE AND EXOTIC PROCESSES

Jouni Suhonen and Mikko Haaranen

The nuclear-theory group of JYFL engages in development of nuclear-structure models and their application to topics of weak-interaction physics. The topics include neutrino-nucleus interactions at supernova energies, rare weak decays like high-forbidden beta decays and double beta decays, and direct dark-matter detection. The group is theory member of large experimental underground collaborations, like SUPERNEMO and COBRA. The group has strong theory collaboration with La Plata in Argentina, Bucharest in Romania and Yale University in USA. The group hosts currently one professor, one post-doctoral researcher and four graduate students.

www.jyu.fi/physics/research/accelerator/nuctheory

VALUES OF WEAK COUPLING CONSTANTS FROM FORBIDDEN NON-UNIQUE BETA DECAYS

Experimental verification of the existence of neutrinoless double beta ($0\nu\beta\beta$) decay of atomic nuclei is at present one of the top priorities in the particle-physics community. If verified, the decay then implies that neutrino is a massive Majorana particle and that lepton-number conservation is violated. Current experiments give only lower limits for the decay half-lives at the level of 10^{25} years. Future experiments aim at the 10^{27} years level.

In order to access the necessary sensitivities of the future double-beta experiments one needs to evaluate the participating nuclear input in the form of nuclear matrix elements. A compilation of such matrix elements has recently been but forward in [1-3]. The $0\nu\beta\beta$ decay rate of nuclei depends on the fourth power of the weak axial-vector coupling constant g_A. This very strong dependence of the rate on g_A makes the (effective) value of g_A play a key role in estimation of the theoretical $0\nu\beta\beta$ half-lives and the needed sensitivity of the future $0\nu\beta\beta$ experiments. Recently, attempts have been made to derive the effective value of g_A from the measured half-lives of single beta decays and two-neutrino double beta ($2\nu\beta\beta$) decays [3-8]. It appears that deviations from the bare nucleon value of $g_A=1.26$ can be very significant depending on the nuclear-structure model used to extract the effective g_A.

In addition to the effective value of g_A, there have been attempts to access the possible quenching in the value of the weak vector coupling constant g_V. In a recent work [9] a least-squares fit to measured first-forbidden non-unique (1st-f-nu) beta-decay transitions in nuclei around neutron numbers N=80,82 and N=126 yielded a value $g_V=0.51$, deviating strongly from the canonical value $g_V=1.0$. The mentioned 1st-f-nu decay transitions constitute an example of the larger class of n-forbidden non-unique (n-f-nu) decays, where n=1,2,3,... The theoretical rates of these decays have a very complex structure with lengthy sums of products of phase-space integrals and nuclear matrix elements, each term multiplied by g_V or g_A [10].

In a recent study [11] a new type of approach is introduced to aid at determination of the effective values of g_V and/or g_A. This approach is coined the spectrum-shape method (SSM) and it is based on the observed strong sensitivity of the theoretical shape of the electron spectrum of an n-f-nu decay transition to the values of g_V and g_A. In the SSM the extraction of these values is done by comparing the computed spectrum shape with that obtained in the present and future beta-decay experiments. The degree of

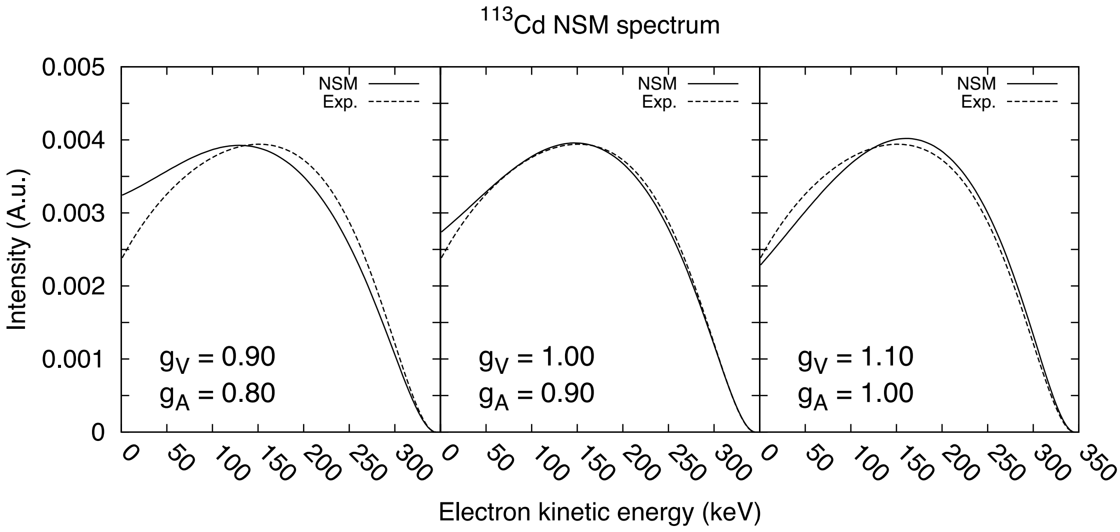


Figure 1. Fourth-forbidden non-unique beta-decay transition from the ground state of ^{113}Cd to the ground state of ^{113}Sn. Comparison of the calculated shape of the electron spectrum with the one measured experimentally.

sensitivity of SSM is shown in Figure 1 for the sample case of the ground-state-to-ground-state decay of ^{113}Cd to ^{113}Sn [11]. Here the used nuclear-theory framework is the nuclear shell model. This study case shows robustly that g_V practically retains its canonical value $g_V=1.0$ and g_A acquires a value $g_A=0.9$. Similar results are obtained by using another type of nuclear-structure approach [11]. A slight contradiction appears when the SSM derived g_A is compared with the one derived from the measured decay half-life. Further calculations and accurate spectrum-shape experiments are needed in the future to exploit fully the potential of SSM, as also to settle the conflict between the SSM and half-life results in the present example case.

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MOLECULAR TECHNOLOGY

Markus Ahlskog

The Molecular Technology group studies primarily the experimental electronic and mechanical properties of carbon nanotubes (CNTs) and devices that are based on them. The interests include both fundamental and applied aspects of CNT science and technology. The research in the group has extensively explored the basic electronic transport properties of high quality multi-walled carbon nanotubes (MWNT). Other topics within the group include the interaction between CNTs and liquid interfaces and the functionalization of CNTs with molecular species. The group utilizes for its research effort the modern microscopy instrumentation and the good fabrication and measurement facilities of the Nanoscience Center.

www.jyu.fi/physics/research/material/nanophys/moltech

ELECTRONIC TRANSPORT IN MWNTS

The published works on the fundamental science of single wall carbon nanotubes (SWNT) is many times more numerous than that on multiwalled carbon nanotubes (MWNT). One major reason for this is that SWNTs appear in both metallic and semiconducting forms, while in MWNTs mainly diffusive/quasiballistic metallic states have previously been reported, in a few experimental works on MWNTs electronic low temperature transport and high magnetic field properties. However, these studies have been fragmentary. For example, before our work [1,2], there was no consistent, experimentally verified description of semiconductivity in MWNTs. Transport properties on MWNTs have to date not been probed systematically at different diameters. In particular, for reasons mainly due to synthesis technology, there has been very few reports on MWNTs with the diameter within the interesting range 3 - 10 nm, the majority of the works (excluding those on double wall carbon nanotubes (DWNT)) having dealt with tubes of diameter ≥ 10 nm. This fact has left the experimental studies on MWNTs rather disconnected from those on SWNTs and DWNTs. Moreover, the present situation is confused in that, within the reported works, the extent of disorder varies due to very different synthesis techniques, with some demonstrating quasiballistic conduction and others transport close to strong localization.

In most studies on MWNTs, the working assumption has been that the outer layer, or possibly few layers, is solely responsible for the low bias transport properties. One motivation for this assumption is the very large anisotropy of conductance in graphite and few layer graphene. In principle, one should find among MWNT-based devices a division into metallic or semiconducting types, for example with respect to the outer layer. In semiconducting SWNTs, the conventional tight-binding theory calculation, gives for the dependence of the bandgap (E_G) on diameter (D) as:

$$E_G=\beta/D \qquad [1]$$

where $\beta \approx 0.7$ eVnm. Thus, in a first approximation, Eq. 1 is expected to apply to the semiconducting outer layers of MWNTs. The semiconducting properties of a MWNT can be measured, at least qualitatively, in a three-terminal field-effect device configuration, Fig. 1(a), where its bandgap shows up as a transport gap, which is the range of gate voltages where the conductance decreases strongly or vanishes, as shown in Fig. 2(b).

In this work [2], low temperature transport in MWNTs has been studied at different diameters and lengths, within 2 - 10 nm, and 0.3 - 3.5 µm, respectively. In a majority of the samples, semiconductivity showed up as a transport gap in the gate voltage controlled conduction, but metallic MWNTs are found in all diameters. The transport gap is seen to be quantitatively determined by a diameter dependent bandgap, and length dependent localization of charge carriers. From an analysis of about 80 devices, we obtain an estimate for the bandgap of semiconducting MWNTs, as shown in Fig. 3(c). This bandgap is estimated to be smaller than that extrapolated from the conventional expression, eq. 1, applicable to semiconducting single wall carbon nanotubes.

Our results constitute the first systematical study on size dependent transport and especially of semiconductivity in MWNTs. These results have significant similarities to the current research on graphene nanoribbons (GNR). As graphene does not intrinsically possess a bandgap, GNR's are fabricated, where a gap is created via quantum confinement due to the narrow width of the channel/nanoribbon. The size of the gap is then roughly in a similar inverse relation with the width of the constriction, as in the case of the diameter dependence of the MWNT's in our work.

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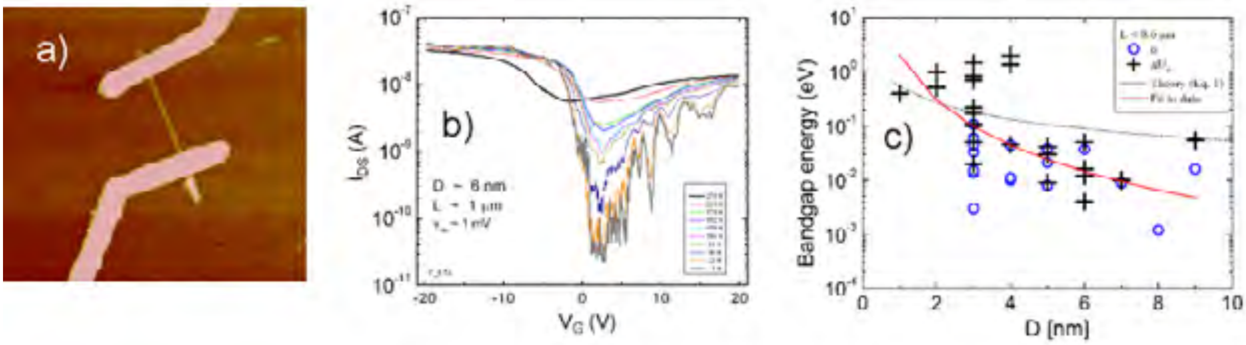

Figure 1. a) AFM image of typical MWNT device on Si/SiO$_2$. The highly doped Si substrate acts as a back-gate. b) Gate voltage (V_G) dependent conduction at different temperatures of a semiconducting MWNT. c) The bandgap energy vs. diameter D, estimated from experimental values from the low temperature conduction experiments. The black dotted line shows the standard tight-binding theory value (Eq. 1) for the diameter dependent bandgap E_G of semiconducting SWNTs.

MOLECULAR
TECHNOLOGY

THERMAL NANOPHYSICS

Ilari Maasilta

The main research direction of the thermal nanophysics research group is to understand and engineer energy flow mechanisms in low-dimensional geometries, develop thermometric techniques for the study of thermal phenomena and use the obtained physical know-how in the development of ultrasensitive radiation sensors for materials science applications (bolometry). The group is a heavy user of the facilities of the Nanoscience Center (NSC), where most of the experiments are performed in sub-Kelvin temperature range, using either helium dilution refrigerators or adiabatic demagnetization refrigerators to reach such low temperatures. A lot of expertise has also been developed in nanofabrication using different lithographic and self-assembly methods, including electron-beam lithography and two-photon, three-dimensional laser lithography. Recently we have also started a push to develop helium ion beam lithography and milling using the latest helium ion microscope tool at the Nanoscience center.

The group has currently 1 postdoc, 6 graduate students and 4 master's students. It is one of the heaviest users of the NSC clean room facilities, and also collaborates with top national and international groups from all over the world, for example with NIST Boulder, NASA Goddard, VTT Micronova, Aalto University and Oslo University to name a few.

www.jyu.fi/physics/research/material/nanophys/thermal

A FEW HIGHLIGHTS OF THE ACTIVITY IN 2015:
PHONONIC THERMAL TRANSPORT USING PHONONIC CRYSTALS

We have continued our ground breaking research on controlling thermal conductance coherently using periodic nanoscale structures (phononic crystals) [1], with most of the focus on two-dimensional structures consisting of nano- to microscale holes in a thin SiN plate. Initial results showed maximally a factor of 30 reduction in thermal conduction. However, in our most recent results [2] we have managed to increase that factor to a whopping 130, over two orders of magnitude! The mechanism behind this effect is that the phonon waves interact strongly with the phononic crystal structure and change their speed and density of states by orders of magnitude. In the future, the demonstrated concept can possibly be used in the development of ultrasensitive radiation detectors, where the control of heat transport is essential. In addition, if the demonstrated concept can be made to work at room temperature range, it might have impact on the development of future more efficient thermoelectric devices, which can be harnessed to generate electricity from waste heat.

DEVELOPMENT OF SUPERCONDUCTING TUNNEL JUNCTION THERMOMETERS AND COOLERS

We have continued our investigations to use novel superconducting materials for normal metal-insulator-superconductor (NIS) junctions. This is interesting, since by increasing or decreasing the energy gap from the standard material, Al, thermometers and coolers can be developed which work better at higher of lower temperatures. In addition to our previous work on Nb, NbN TaN NIS junctions, we recently succeeded in fabricating junctions where atomic layer deposited (ALD) titanium nitride (TiN) was used as the superconducting electrode [3]. We can also, alternatively, deposit TiN with infrared pulsed laser deposition (PLD). As TiN has a higher critical temperature than Al, there are future possibilities to develop NIS microrefrigerators for higher operational temperature than the current 0.3 K.

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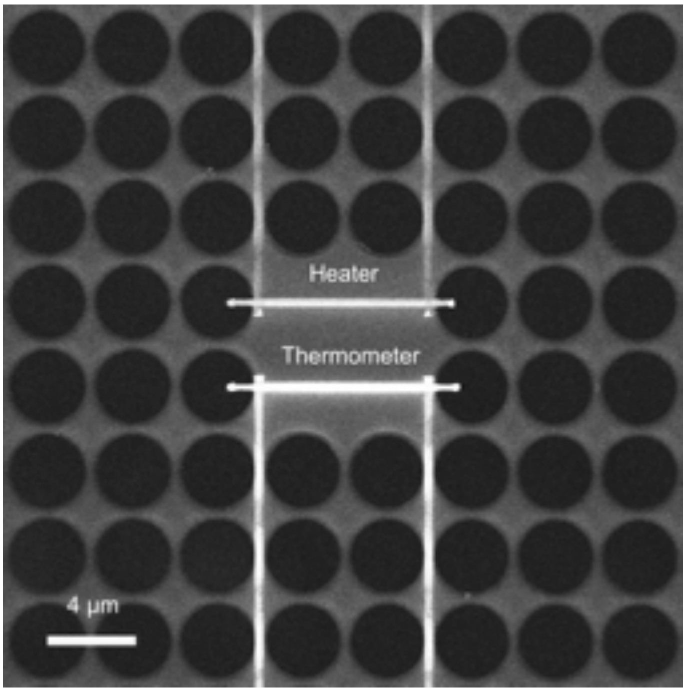

Figure 1. A scanning electron micrograph of a 4 µm period hole array phononic crystal structure, with a tunnel junction heater and thermometer in the middle.

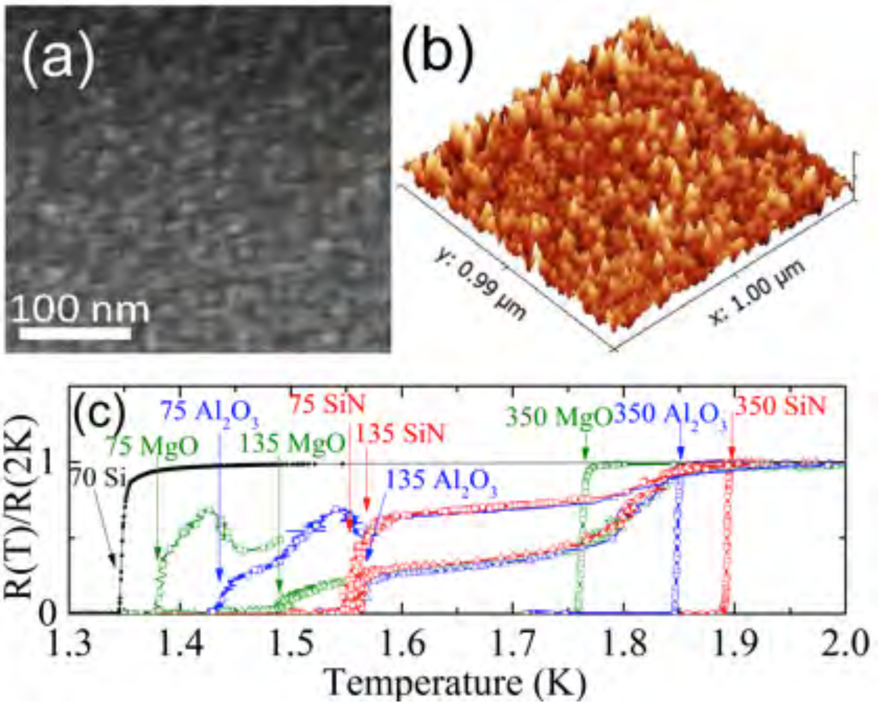

Figure 2. Room temperature (a) scanning electron and (b) atomic force micrograph of TiNx film grown on silicon. (c) Measured temperature dependence of the resistance, normalized to its value at 2 K, of TiNx films of different thickness (number gives thickness in nm), grown on different substrates.

MOLECULAR ELECTRONICS AND PLASMONICS

Jussi Toppari, Boxuan Shen, Kosti Tapio and Heli Lehtivuori

The group studies nanoelectronics and plasmonics, especially phenomena related to molecules. One of the main interests, on which the group has a long experience, is self-assembled DNA structures. The main focus is on DNA origami structures; their modifications and utilization in nanofabrication of electronic and optical/ plasmonic nanodevices. Another main interest, is the coupling between surface plasmons and molecules, especially on a strong coupling limit, which yields hybrid plasmon-molecule -states possessing new fundamental properties enabling, e.g., totally new ways for controlling chemistry in molecular level. Other topics studied are utilization of plasmonics for solar energy, surface enhanced Raman spectroscopy (SERS) of microbes, as well as optical and plasmonic properties of fluorescent proteins, carbon nanotubes, graphene and conducting polymers.

www.jyu.fi/physics/research/material/nanophys/plasmonics/

CUSTOM-SHAPED PLASMONIC METAL NANOSTRUCTURES BASED ON DNA ORIGAMI SILHOUETTES

The plasmonic metal nanostructures have gained huge interest due to the promising applications of their unique optical properties. However, the fabrication of nanoshaped structures with desired properties by conventional methods, remains challenging. DNA self-assembly, especially the DNA origami, provides a precise and programmable way to form nanoscale structures. Although numerous efforts have been made to synthesize metallic nanostructures by DNA constructs, the quality and uniformity of such nanostructures have been far from ideal so far.

By combining the precision of the DNA origami and the maturity of conventional nanofabrication techniques, we have developed a novel method for fabrication of smooth sub-100-nanometer visible-range plasmonic nanostructures with designable shapes. The method is developed mostly by the group's PhD students Boxuan Shen and Kosti Tapio, and it employs a selectively grown SiO_2 layer with DNA origami silhouettes as hard mask for metal evaporation on silicon substrate (Fig. 1). The resulting nanostructures have the shape of the origami template within a nanometer accuracy, and thus has much higher resolution compared to other approaches so far [1]. The work has been carried out in collaboration with Dr V. Linko and Asst. Prof. M. Kostiainen (Aalto University). In order to push our process closer to industry, we have developed in collaboration with Asst. Prof. S. Tuukkanen (Tampere Univ. of Tech.) a cost-effective spray-coating-based deposition method for covering large scale substrates with DNA origami structures [2]. These metal nanostructures have ready applications in fluorescence enhancement, SERS and can even be used to construct metamaterials in visible range.

DEVELOPMENT OF NEAR INFRARED FLUORESCENCE DYES – PHYTOFLUOR

During the past decades, fluorophores active in the near infrared (NIR) have attracted ongoing attention due to their diverse applications in biomedical research, materials science and related fields. The phytochrome family of light-switchable proteins in NIR region has long been studied by biochemical, spectroscopic [3,4], crystallographic [3] and x-ray scattering [5] means. The discovery of bacteriophytochromes in the 1990s greatly accelerated this work. The NIR fluorescence properties of bacteriophytochromes, phytofluor, offer potential to tissue imaging, although high fluorescence quantum yield remains an elusive goal [3,4]. Our academic postdoc Heli Lehtivuori was able to improve the quantum yield to 9% as a Fulbright research fellow in University of Wisconsin-Madison [3].

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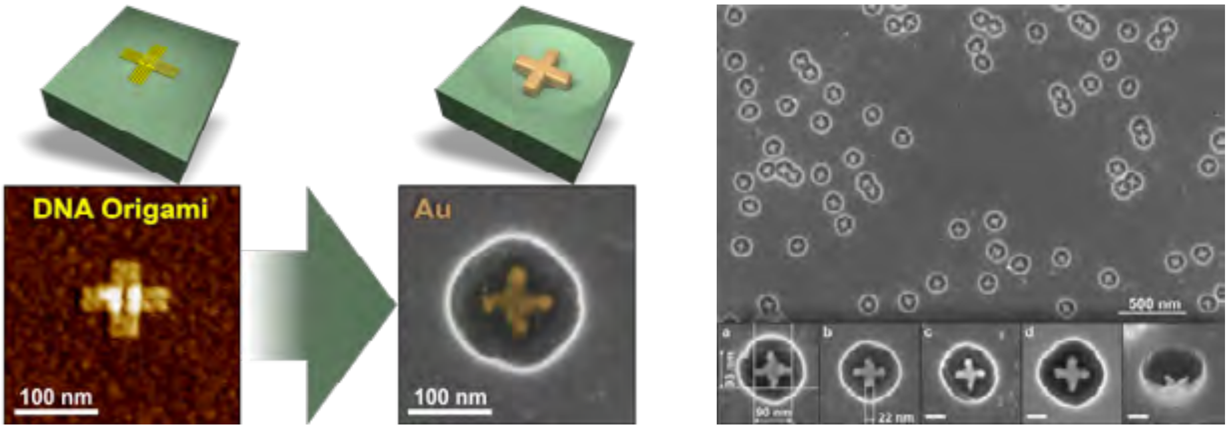

(a)

(b)

Figure 1. (a) Illustrations of a DNA origami and a fabricated metal nanostructure with the same shape (upper row). Atomic force microscope image of a cross-shaped DNA origami and a false-color scanning electron micrograph of the gold nanostructure fabricated from it (lower row). (b) Large-area scanning electron micrograph of cross-shaped metal nanostructures and zoom-ins of individual ones. Inset scale bar 50 nm.

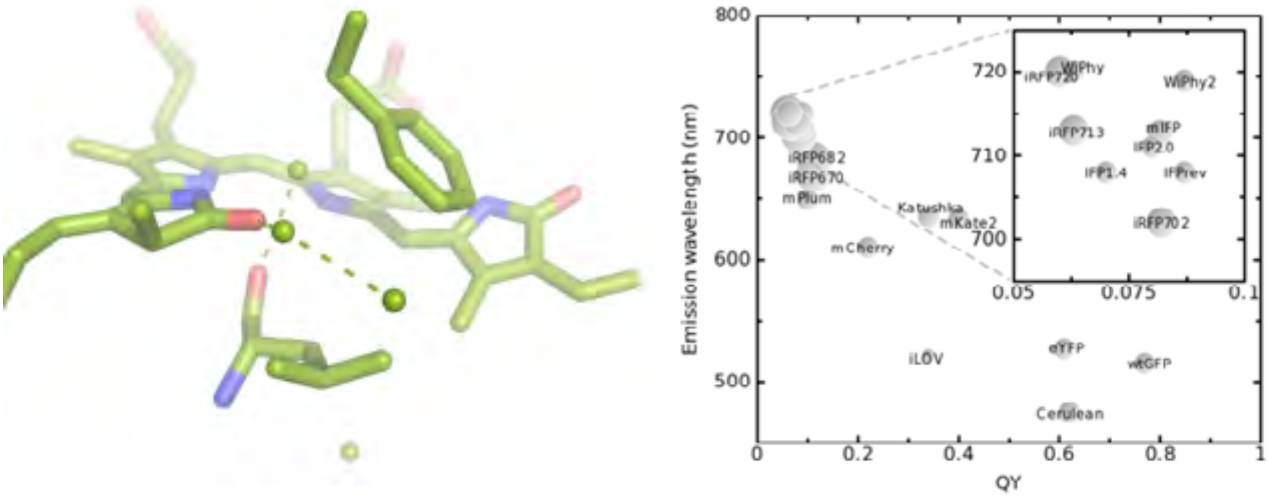

Figure 2. A crystal structure of new phytofluor, WiPhy2, reveal that removal of polar interactions leads to enhanced fluorescence. WiPhy2 possesses the best compromise, achieved to date, between high fluorescence quantum yield and long illumination wavelength in this class of fluorophores. [3]

COMPUTATIONAL NANOSCIENCES

Hannu Häkkinen, Robert van Leeuwen, Tero Heikkilä, Francesco Massel, Pekka Koskinen

Our computational nanosciences group focuses on the basic research of atomic clusters, low-dimensional structures, hybrid correlated systems and other nanoscale objects. We use various computational and phenomenological approaches, including density-functional theory, non-equilibrium Green's functions, real-time path integral techniques, quasiclassical techniques, molecular dynamics, and Monte Carlo methods. Our group is interdisciplinary by mixing researchers from physics, chemistry and biology departments, and it consists of three professors, six senior researchers, ten post-docs, as well as around 15 PhD and master students.

www.jyu.fi/physics/research/material/theornanophys

NONEQUILIBRIUM GREEN'S FUNCTION APPROACH TO TRANSIENT PHOTOABSORPTION SPECTROSCOPY

Transient photo-absorption spectroscopy has become a popular laser technique to investigate the ultrafast dynamics of electrons and nuclei in atoms and molecules. In this experiment atoms or molecules are exposed to a strong light field followed by a weak probe field after an adjustable delay time. However, the theoretical description of the phenomenon has lagged behind the experiment since the strong external laser fields in combination with electron-electron interactions poses a difficult many-body problem. We developed a first-principles nonequilibrium Green's function technique to describe this situation and applied the method to explain a recent experiment on a gas of Krypton atoms. We found good agreement with experiment and moreover found that a qualitatively and quantitatively correct description of the experiment requires dynamical correlation effects inaccessible by mean-field approaches.

SQUEEZING A MACROSCOPIC OBJECT BELOW "THE SOUND OF SILENCE"

The Heisenberg uncertainty principle represents one of the most well known aspects of quantum mechanics. The prototypical example of uncertainty relations between conjugate variables is given by the uncertainty relation between position and momentum of an object. However, position can be determined with arbitrary precision, at the expenses of the uncertainty associated with momentum, and vice versa, leading to the definition of a squeezed state.

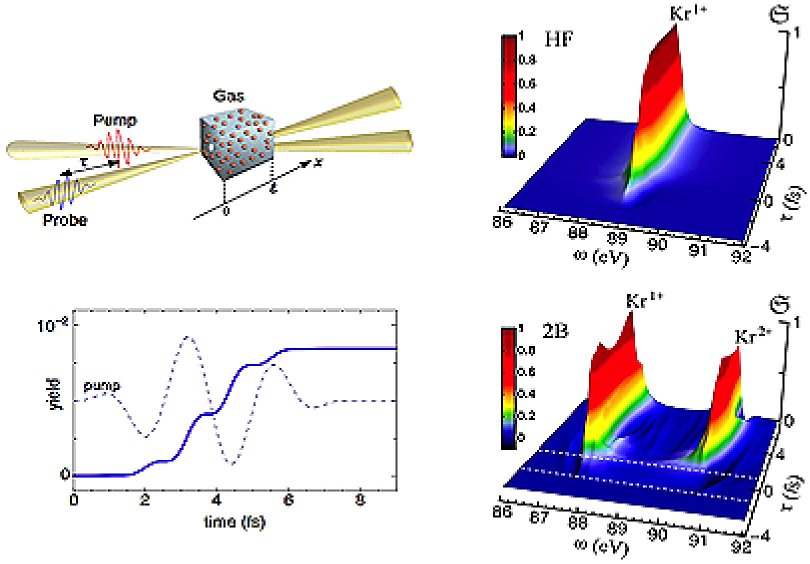

Figure 1. A description of the pump-probe experiment on Krypton atoms (top-left), ionisation yields (bottom-left) and transient photoabsorption spectra as a function of the delay in the time-dependent Hartree-Fock (top-right) and the second Born approach (bottom-right).

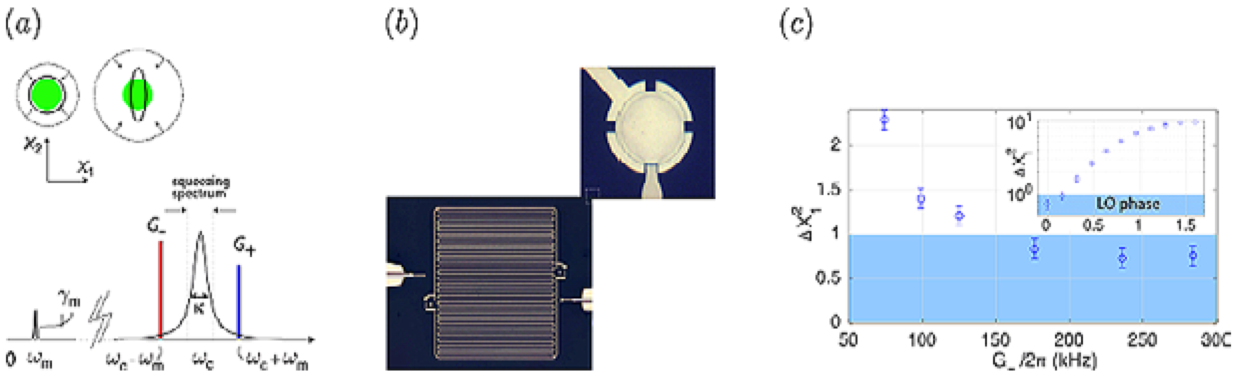

Figure 2. from ref. [2], outlining the concept of squeezing along with the cavity driving principle (a), the experimental setup (b), and the squeezing below the standard quantum limit (c).

In our recent work [2], we realised the squeezing of a nearly macroscopic mechanical object in the context of cavity optomechanics in the microwave regime. With a combination of the techniques used for cooling and amplification, we achieved the ground-state cooling of a mechanical Bogolyubov mode, exhibiting a squeezed uncertainty ellipse with a minor axis 1.1±0.4 dB below the standard quantum limit.

SIMULATIONS PREDICT FLAT LIQUID

Recent experiments have shown that, in addition to covalent materials, also metals like iron can display an atomically thin free-standing solid phase. This phase can be created when existing hole in free-standing graphene is patched by metal atoms. We investigated such a metal patch by density-functional -based molecular dynamics simulations when the patching material is gold.[3] Simulations showed that while at room temperature gold displays a solid phase, at elevated temperatures it displays an atomically thin liquid phase. This stability of free-standing gold to remain planar even upon two-dimensional diffusion is outright remarkable and has its origins in relativistic effects.

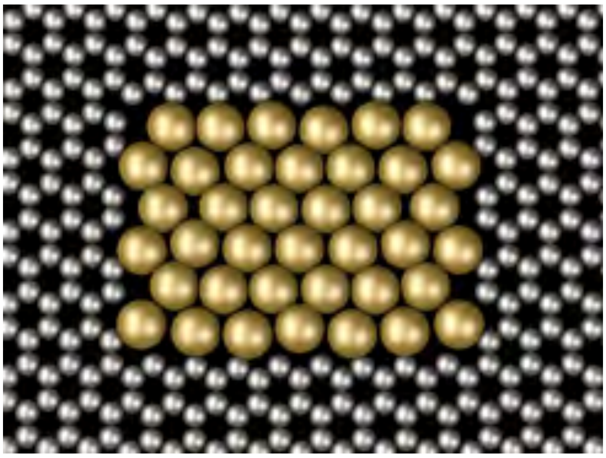

Figure 3. Simulations predict that golden patch (yellow spheres) in graphene pore displays flat liquid phase at elevated temperatures. The entire structure remains atomically thin.

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SOFT CONDENSED MATTER AND STATISTICAL PHYSICS

Markku Kataja and Jussi Timonen

The group has long experience in heterogeneous materials research, theoretical and numerical modelling, complex fluid mechanics and rheology, X-ray tomography and 3D image analysis, as well as their applications in various industrial problems. The group runs an extensive X-ray Tomography Laboratory that includes three x-ray scanners used in non-invasive three-dimensional imaging and analysis of the internal microstructure a wide range of heterogeneous materials. The research topics of the group include also statistical characteristics of random packings of elongated particles, properties of biological materials such as growing soft tissue, structural analysis related to development of new biocomposites, complex flow dynamics and transport in heterogeneous materials.

www.jyu.fi/physics/research/material/tomolab

X-RAY TOMOGRAPHY LABORATORY

During the past decade, X-ray micro and nanotomography has proven effective and versatile technique for heterogeneous materials research. The primary research facility within the X-ray Tomography Laboratory includes three up-to-date tomographic scanners including two microtomographs and a nanotomograph. Together, these devices are capable of non-intrusive three-dimensional imaging of the internal structure of heterogeneous materials with resolution ranging from 40 µm up to 50 nm. The laboratory is equipped with comprehensive set of instruments for sample preparation and manipulation. The laboratory is also equipped with specific devices for measuring various transport properties of materials. The entire facility had a high utilization rate in basic and applied research related e.g. to development of novel organic materials, and to analysis of structural properties of minerals and biological materials such as cells (soft X-ray tomography at LBNL), bone and bentonite clay.

(a)

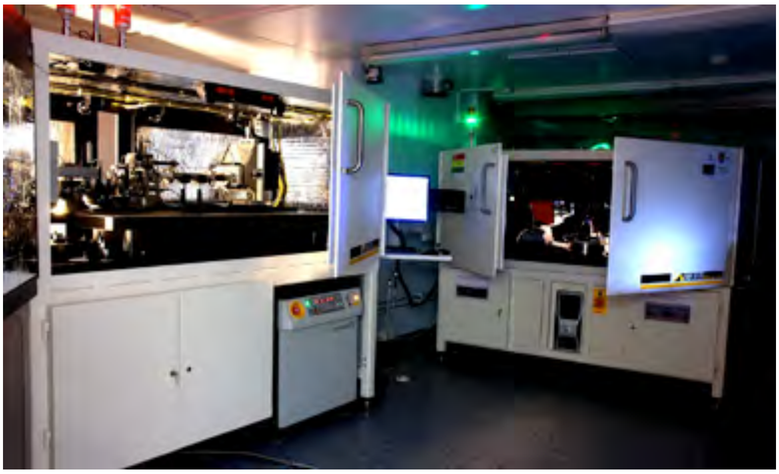
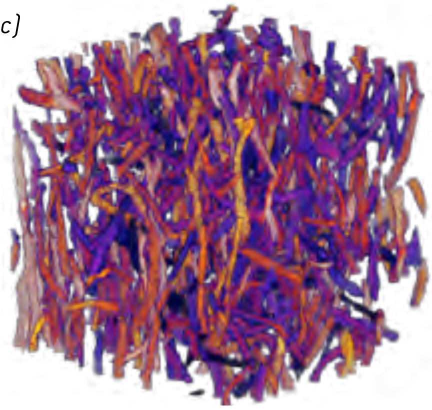
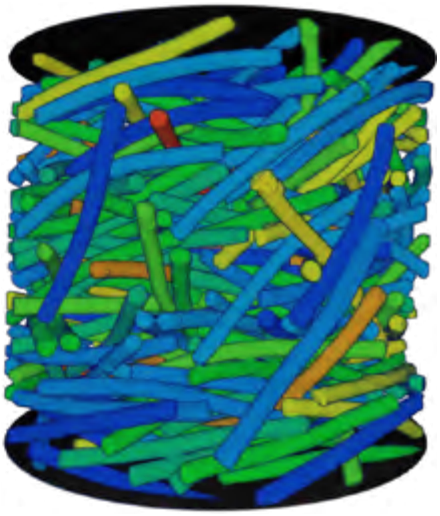


Figure 1. (a) Xradia Multiscale X-ray tomographic facility. A microtomograph (right) and a nanotomograph capable of 50 nm resolution (left). Head of Chironomus larvae (b), color-coded length of regenerated cellulose fibres (c) and color-coded number of contacts per particle in a pile of spaghetti (d). Images are obtained with Xradia multiscale X-ray tomographic facility.

(c)



(d)



(b)

SWELLING OF BENTONITE CLAY

Highly compacted bentonite clay is planned to be used as engineered barrier in the current high level radioactive waste repository designs as they show low hydraulic permeability that minimizes water income to the waste. Recent safety assessments of nuclear waste repositories have shown that, in certain conditions, erosion of the bentonite buffer might take place due to ground water flow in the bed rock cracks in the vicinity of the repository space. The main objective of this study is to understand the main mechanisms of free swelling of bentonite into bed rock cracks leading to possible erosion from the bentonite surface, and to produce detailed experimental data for validating numerical models devoted to analyse such a process. To this end, axial wetting and free swelling of compacted MX-80 bentonite samples were measured using X-ray imaging. The experiments were carried out using an X-ray tomographic scanner in a 2D imaging mode. The measurement yields time evolution of the axial distribution of dry density and of water content during the wetting process. The method is similar to that for full tomographic reconstructions used for MX-80 bentonite samples in closed, fixed-volume cells [1]. Figure below shows the measured axial distribution of dry density and water content of bentonite in the initial state and at two instants of time during wetting. Also shown are the original X-ray images used to obtain the measured results.

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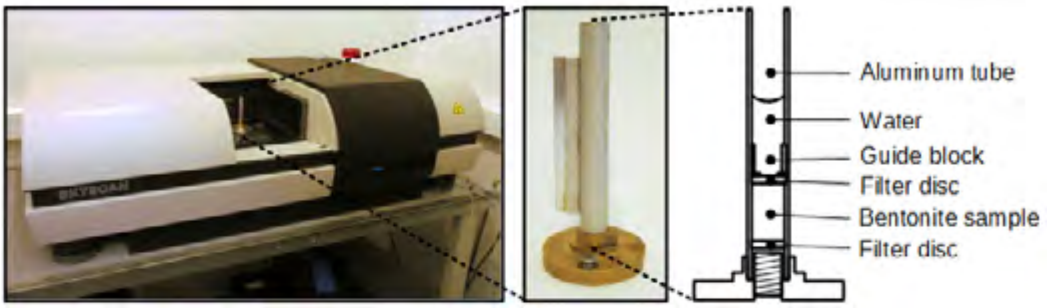


Figure 2. Skyscan 1172 X-ray Micro-CT -device and photographic image and schematic illustration of an aluminum tube used as a sample holder in bentonite free swelling experiments.

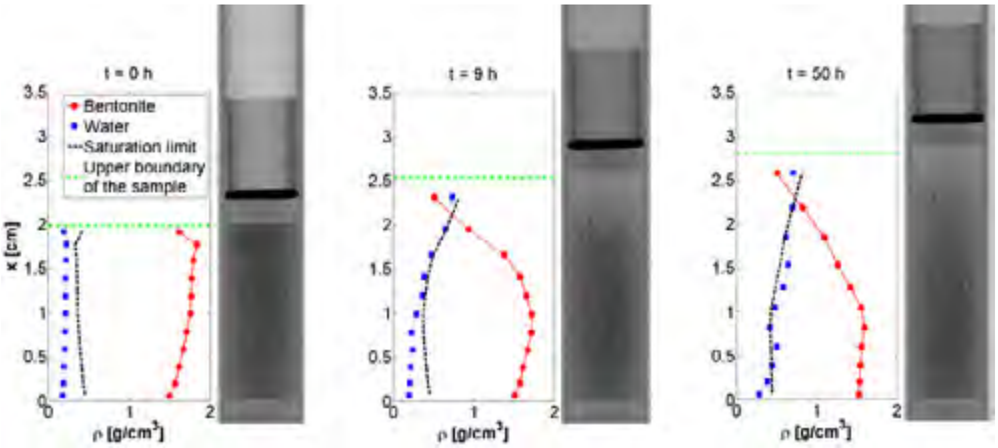


Figure 3. Axial water content and dry density distribution in a MX-80 bentonite sample swelling in an aluminum tube at various instants of time and position. Also shown are the original X-ray images used to obtain the data.

A LARGE ION COLLIDER EXPERIMENT – ALICE

Jan Rak, Wladyslaw Trzaska, Sami Räsänen and DongJo Kim

The main purpose of relativistic heavy ion collisions is to study properties of the Quantum Chromo Dynamics (QCD), the theory of the strong interactions. There are quite solid experimental evidences that the phase transition from normal nuclear matter to the deconfined and excited thermal state of QCD, called Quark Gluon Plasma (QGP), is reached in the ultra-relativistic heavy nuclei collisions. ALICE is one of the four big experiments at the Large Hadron Collider (LHC) at CERN and it is dedicated to the study of the high-density, high-temperature phases of strongly interacting matter. ALICE Collaboration has currently more than 1600 collaborators representing 156 institutes from 41 countries.

At the beginning of 2015, after the 2 years long shutdown period, the RUN2 has started. LHC delivered proton-proton collision at 13 TeV, very close to the design value (14 TeV). ALICE was collecting the data during both, the proton-proton [1] and lead-lead collisions [2] (c.m. energy per nucleon 5.02 TeV) campaigns. Contribution of our group includes the data analysis, responsibility for the trigger and timing detector T0 and for the single-photon trigger system utilizing the electromagnetic calorimeter. We are also deeply involved in the upgrade of the Time Projection Chamber (TPC), and the Fast Interaction Trigger (FIT) system, the successor of the T0 detector. Our main task within the TPC upgrade is to perform quality assurance studies of about 300 m2 of Gas Electron Multiplier (GEM) foils, which will replace the old TPC readout chambers. It includes the optical scanning to map the gain uniformity and the leakage current measurements of newly produced GEM foils. The infrastructure for this large-scale quality assurance tests is already prepared in the HIP clean room facility and the mass production is going to start in the first half of 2016.

Details on the T0 and FIT detectors upgrade are provided in the Instruments and Methods section of this Annual Report.

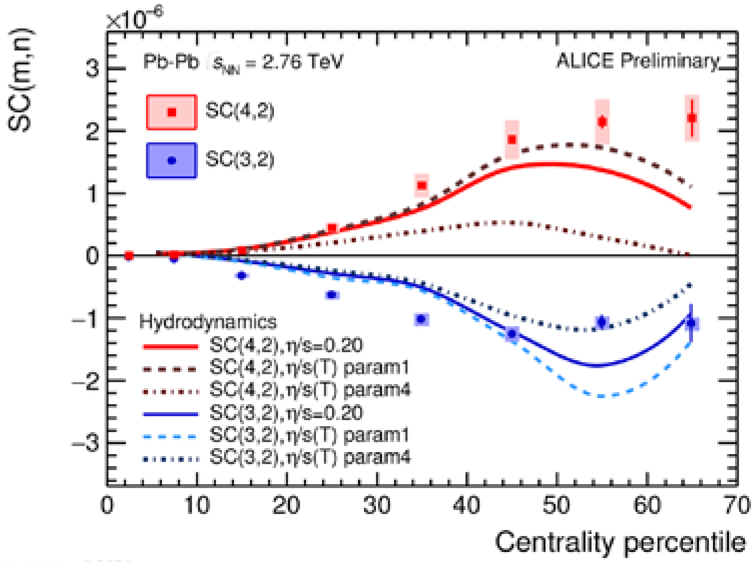
Main directions of the physics analysis developed in our groups are: (i) Correlations among the high-pT particles to study the soft QCD radiation of highly virtual partons propagating through the nuclear medium. The modification of the radiation pattern studied in p-Pb and Pb-Pb with respect to proton-proton collisions (so called vacuum radiation) can reveal the information about the cold nuclear matter (p-Pb) and QGP (Pb-Pb). (ii) Azimuthal anisotropy of the bulk particle production in Pb-Pb collisions as a measure of the thermalization and collectivity in the early stages of the nuclear collisions. Using various techniques of flow parameters measurement (essentially the n-order Fourier coefficients of the particle distribution in the azimuthal angle) one can access the basic feature the QGP phase like the rate of thermalization, shear viscosity and initial temperature. These techniques have been recently applied to the p-Pb and even p-p collision where no collective phenomena induced by QGP phase transition were expected. However, the analysis of the data taken at highest c.m. energies at LHC shows interesting patterns resembling those observed on Pb-Pb. These observations provide an interesting hint of QGP formation even in small system like p-Pb or p-p.

For more details see
www.jyu.fi/accelerator/alice

Two interesting results of the ALICE data analysis are discussed in the following below.

EVENT-BY-EVENT FLUCTUATIONS OF FLOW HARMONICS

Collective flow stems from the pressure gradients in the hot QCD matter produced in the heavy ion collisions. In non-central collisions the interaction region is almond shaped which leads into stronger gradients into the short direction of the almond. This leads into anisotropic collective flow, which then “transforms” the initial geometrical anisotropy into the azimuthal anisotropy of momentum distributions of emitted particles. The Fourier transform of such particle distribution in azimuthal angle results in positive values of second Fourier coefficient v2>0. Fourier coefficients are also called “flow harmonics”. It is also widely accepted that the positive third flow harmonics are induced by the geometrical fluctuations and hot spots of the collision system. Recently ALICE has measured event-by-event correlations of the product of different flow harmonics over the product of their average values labeled as SC(m,n) (shown in Figure 1) for 4th and 2nd harmonic, SC(4,2), and 3rd and 2nd harmonic, SC(3,2). Positive value of SC(4,2) means that if one finds 2nd harmonic to be over it’s average value (upward fluctuation), then most likely also 4th harmonic fluctuates in the same way. And negative SC(3,2) states similarly that upward fluctuation in 2nd harmonic is likely to be accompanied with downward fluctuation of 3rd. Such a detailed event-by-event correlation is found to be sensitive to the temperature dependence of the shear viscosity of strongly interacting matter. Curves in Figure 1 shows a comparison to three different parametrizations for temperature dependence by H. Niemi, et al.



ALI-PREL-96671

Figure 1. A positive correlation between 2^{nd} and 4^{th} flow harmonic SC(4,2) and negative correlation between 2^{nd} and 3^{rd}, SC(3,2), as compared to theory calculation with different temperature dependence on shear viscosity. Note the scale of the correlation.

PRECISION MEASUREMENT OF THE MASS DIFFERENCE BETWEEN LIGHT NUCLEI AND ANTI-NUCLEI

One of the big advantages of ALICE as compared to the other LHC experiments is the excellent particle identification capability.

One of the interesting by-product of this unique feature of ALICE experiment is the capability to detect not only wide zoo of particles but also nuclei like deuteron, helium and their anti-nuclei accompanies. Recently, ALICE performed the most precise measurement of the mass differences of deuterons and anti-deuterons, and also helium and anti-helium nuclei [3]. If the CPT symmetry, i.e. invariance of physics laws under simultaneous charge conjugation and parity and time reversal, is exact, then masses of nuclei and anti-nuclei should be the same. This symmetry holds for example in the Standard Model of particle physics. The measurement by ALICE provides a stringent constraint to any effective theory beyond the Standard Model where the CPT-symmetry is broken.

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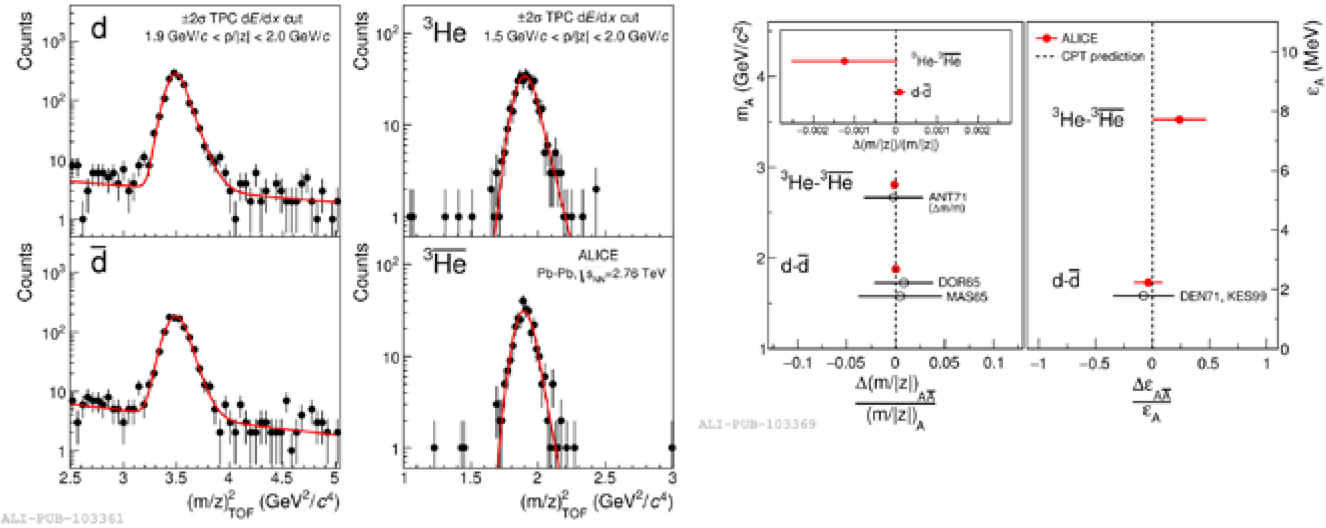


Figure 2. Left: Squared mass-over-charge ratio distributions for deuterons (left) and 3He (right) in selected rigidity intervals, top particles and bottom anti-particles. Right: mass-over-charge ratios as compared to previous measurements. With exact CPT invariance both should be zero.

ULTRARELATIVISTIC HEAVY ION COLLISIONS – THEORY

Kari J. Eskola and Tuomas Lappi

The main goal of ultrarelativistic heavy ion collisions (URHIC) is to explore strongly interacting elementary particle matter, the Quark Gluon Plasma (QGP). We aim at understanding QCD matter properties and nuclear collision dynamics through various observables at CERN-LHC and BNL-RHIC. Our main tools are perturbation theory, renormalization group equations, the classical color-field formulation of QCD, and relativistic hydrodynamics. We are funded by the Academy of Finland, the PANU graduate school and private foundations. We are also associated with the Helsinki Institute of Physics via Lappi's QCD theory project. In 2015 we contributed to the physics planning of possible future colliders in the U.S. (EIC) and CERN (LHeC, FCC), and participated with a high profile in the largest conferences in our field. Zhu started as our new postdoc. Niemi moved to Frankfurt and got a Marie Curie fellowship there. Paukkunen was hired as a postdoc in C. Salgado's ERC-StG project. Mäntysaari reached the PhD degree and started as a postdoc at the BNL. Lappi got a highly competed ERC Consolidator grant for 2016-21.

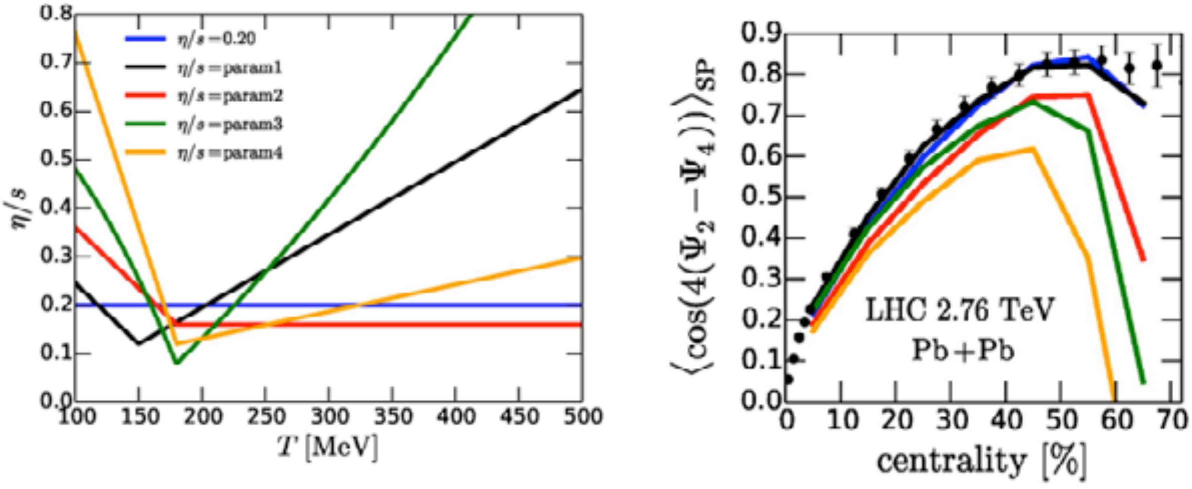
www.jyu.fi/physics/research/highenergy/urhic

HEAVY ION PHENOMENOLOGY: EVENT BY EVENT EKRT MODEL

Relativistic hydrodynamical studies of QCD matter spacetime evolution – our group's longtime specialty – are now a cornerstone of URHIC physics. In 2015, we developed an event-by-event version of our perturbative-QCD + saturation + hydro ("EKRT") model, where we compute the produced fluctuating QCD-matter initial densities from next-to-leading order perturbative QCD using a saturation conjecture to suppress soft particle production. The space-time evolution of the QCD matter is then described with dissipative fluid dynamics, event by event. We computed the centrality dependence of hadronic multiplicities, transverse momentum spectra and their azimuthal asymmetries, probability distributions of relative fluctuations of elliptic flow, and event-plane angle correlations. Comparing these simultaneously with LHC and RHIC measurements, we were able to put state-of-the art constraints on the temperature dependent QCD matter shear viscosity (Fig. 1) [1]. Our predictions also fared very well in comparisons with the new LHC heavy-ion data from the higher collision energy reached late in 2015.

NUCLEAR PARTON DISTRIBUTION FUNCTIONS (nPDFS)

nPDFs are needed for the computation of all collinearly factorizable hard-process cross sections in nuclear collisions. Our global EPS09 analysis literally defines the current state of the art for the nPDFs and their uncertainties: our EPS09-paper was cited over 100 times in 2015 alone, exceeding also the 500 citation benchmark. In 2015, we continued to explore the constraints from the LHC proton-nucleus data on nPDFs using a Hessian PDF reweighting technique recently developed by us. We also studied the prospects of measuring top quarks in proton-lead and lead-lead collisions at the LHC. Accounting for realistic kinematic cuts and tagging efficiencies the yields of top-quark pairs were found large enough to be observed [2].



(a) (b)

Figure 1. (a) Shear viscosity-to-entropy ratio as a function of temperature [1]. (b) An example of the computed and measured event-plane angle correlations in 2.76 TeV Pb+Pb collisions at the LHC [1]. Color code is the same in both panels.

COLOR GLASS CONDENSATE (CGC)

In the CGC framework we study different aspects of high energy QCD scattering, in particular the initial stages of heavy ion collisions. In the CGC picture the dense system of brehmsstrahlung gluons inside a high energy nucleus is described as a classical gluon field. One possible experimental signature of the structure of these color fields are multiparticle azimuthal correlations in the collision of a small projectile off the dense color field target. In 2015 we solidified the theoretical description of this mechanism and clarified the differences between related classical field calculations of these correlations. In a Physical Review Letter [3] we also related a similar azimuthal anisotropy in deep inelastic scattering to the linearly polarized gluon distribution.

An important tool in the CGC picture is the Balitsky-Kovchegov (BK) evolution equation. It is a weak coupling renormalization group equation describing the energy dependence of correlators of the classical fields that are needed for calculating QCD scattering cross sections. In 2015, as the first group worldwide, we published a numerical solution of the next-to-leading order BK equation [4]. We also successfully applied our earlier leading order BK-evolved dipole cross section parametrizations to computing production cross sections for J/Psi mesons at forward rapidities in proton-nucleus collisions [5]. This work largely solved the puzzle of a surprisingly large nuclear suppression in this cross section in earlier calculations in the same framework.

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NEUTRINO PHYSICS

Jukka Maalampi and Wladyslaw H. Trzaska

Our group is involved in phenomenological and experimental research of neutrino oscillations. In 2015 this field of particle physics received the highest possible recognition when the Nobel Prize in physics was awarded to Takaaki Kajita (from the Super-Kamiokande experiment) and Arthur B. McDonald (from the SNO experiment) for the discovery of neutrino oscillations and experimental verification of neutrino masses. At present, the main scientific goals of neutrino oscillation physics are the still open questions of neutrino mass hierarchy, leptonic CP violation, and verification of the existence of sterile neutrinos. Our group participates in the R&D for the next generation of oscillation experiments aimed at resolving these questions. By determining the values of the relevant oscillation parameters we should be able to shed more light on the origin of the mass spectrum of neutrinos and to probe Physics Beyond the Standard Model (BSM).

www.jyu.fi/physics/research/highenergy/

LONG BASELINE NEUTRINO OSCILLATIONS

During 2015 there was a remarkable progress in the field of long-baseline neutrino oscillation physics. Fusing the expertise gained from LAGUNA and LAGUNA-LBNO Design Studies with that of our US colleagues from the LBNE project and backed by the support from FNAL and CERN, the DUNE Collaboration was formed. By the end of the year it numbered 800 members representing146 institutes from 27 countries. Deep Underground Neutrino Experiment will project neutrino beams produced at the Long-Baseline Neutrino Facility at Fermilab towards a 4x10 kton Liquid Argon Time Projection Chamber detector complex located 1300 km away and 1.5 km underground in the Sanford Underground Research Facility in Lead, South Dakota.

Figure 1. Participants of the DUNE general meeting in Arlington in January 2016.

Our main contribution to DUNE comes thought the WA105 experiment at CERN. The 6 x 6 x 6 m^3 dual-phase LAr TPC being developed by the WA105 Collaboration is now recognized as the ProtoDUNE DP. In parallel, a similar prototype of the Single Phase LAr TPC will be constructed and tested with charged particle beams from CERN SPS. In July we have represented the WA105 Collaboration at the PhotoDet 2015. In December 2015 our group has formally applied to join DUNE, and since January 14, 2016 we are full members of the Collaboration.

REACTOR NEUTRINO EXPERIMENT JUNO

In January JUNO experiment celebrated the ground-breaking ceremony in Jiangmen, China. Our team contributes to JUNO R&D with oscillometry studies and by developing a setup for radiopurity measurements of organic scintillators in the new underground laboratory at the 1430 m level in the Pyhäsalmi mine. Together with our colleagues from Oulu University, we have organized JUNO Liquid Scintillator Workshop in Pyhäjärvi (https://www.jyu.fi/fysiikka/en/juno2015). It was attended by 35 participants from 6 countries.

NDM2015 MEETING

Together with Jouni Suhonen and his group, we have organized and hosted Neutrinos and Dark Matter in Nuclear Physics 2015 meeting in June (https://www.jyu.fi/en/congress/ndm15). The meeting attracted to Jyväskylä 125 researchers from Europe, Asia, North- and South America, working in the field of neutrino physics, astrophysics, and dark-matter physics, to discuss experiments and theories which need nuclear-physics input. The program covered a large variety of topical nuclear and particle physics themes, including supernova neutrinos, dark-matter searches, nuclear double beta decays, neutrino mass measurements, neutrino oscillations and synthesis of elements.

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Figure 2. Participants of the NDM'15 photographed at the main entrance to the Physics Department.

COSMOLOGY

Kimmo Kainulainen and Sami Nurmi

Our group works mainly in the interphase between particle physics and cosmology. Our research topics include the dark matter and dark energy problems, baryogenesis problem, cosmic inflation and inhomogeneous cosmologies. In one recent article we introduced a model for dark matter with gauge coupling unification. In another we studied radiative corrections during inflation including space-time curvature, and in yet another we found novel isocurvature constraints on very weakly coupled portal dark matter models. Our group currently consists of two permanent staff members, two postdoctoral researchers and six PhD-students.

www.jyu.fi/physics/research/highenergy/particle

INFLATION AND SPACETIME CURVATURE

We have shown that stability of the Standard Model vacuum is intimately tied to space-time curvature. We found that gravitational production of Higgs particles at reheating triggers a transition to a negative energy vacuum for a wide range of the curvature coupling ξ. Combining this with the lower bound $\xi > 0.1$, imposed by vacuum stability during inflation, we found that the minimal scenario of Standard Model, in a background of conventional high-scale inflation constrains ξ to be close to its conformal value $\xi = 1/6$.

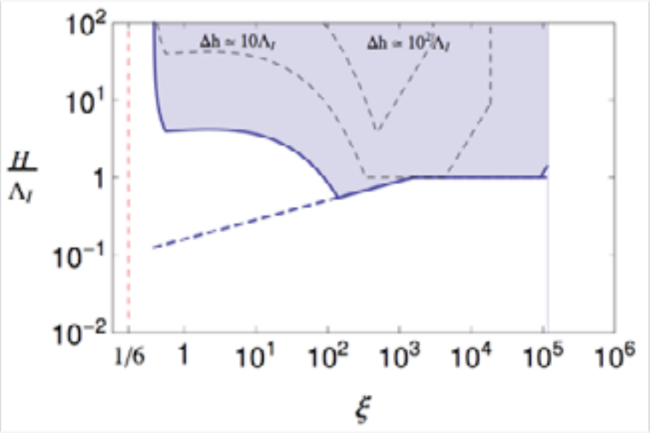


Figure 1. Shown is the (shaded) instability region as a function of the conformal coupling ξ and the energy scale of inflation. Stability during inflation requires $\xi > 0.1$.

MINIMAL WALKING TECHNICOLOR DARK MATTER AND GAUGE UNIFICATION

We proposed a technicolor (TC) model for dark matter (DM), which unifies all the standard model and TC coupling constants at a scale MU ≈ 2.2×10^{15}GeV with the unified coupling αU ≈ 0.0304. Our theory predicts that the TC sector becomes strong at the TeV scale. DM can have a mass in the range mDM ≈ 30−800 GeV consistent with all current constraints. Yet, the model may be tested by the next generation of DM search experiments and by precision electroweak parameters.

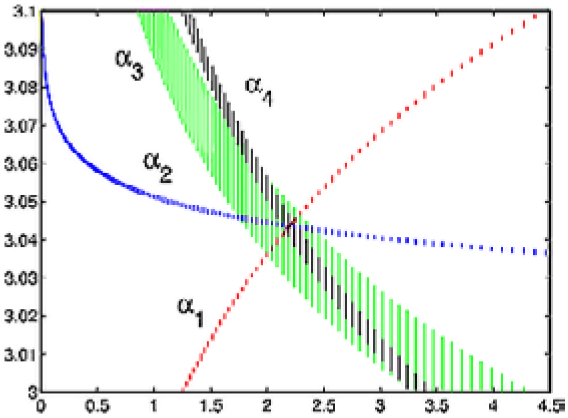
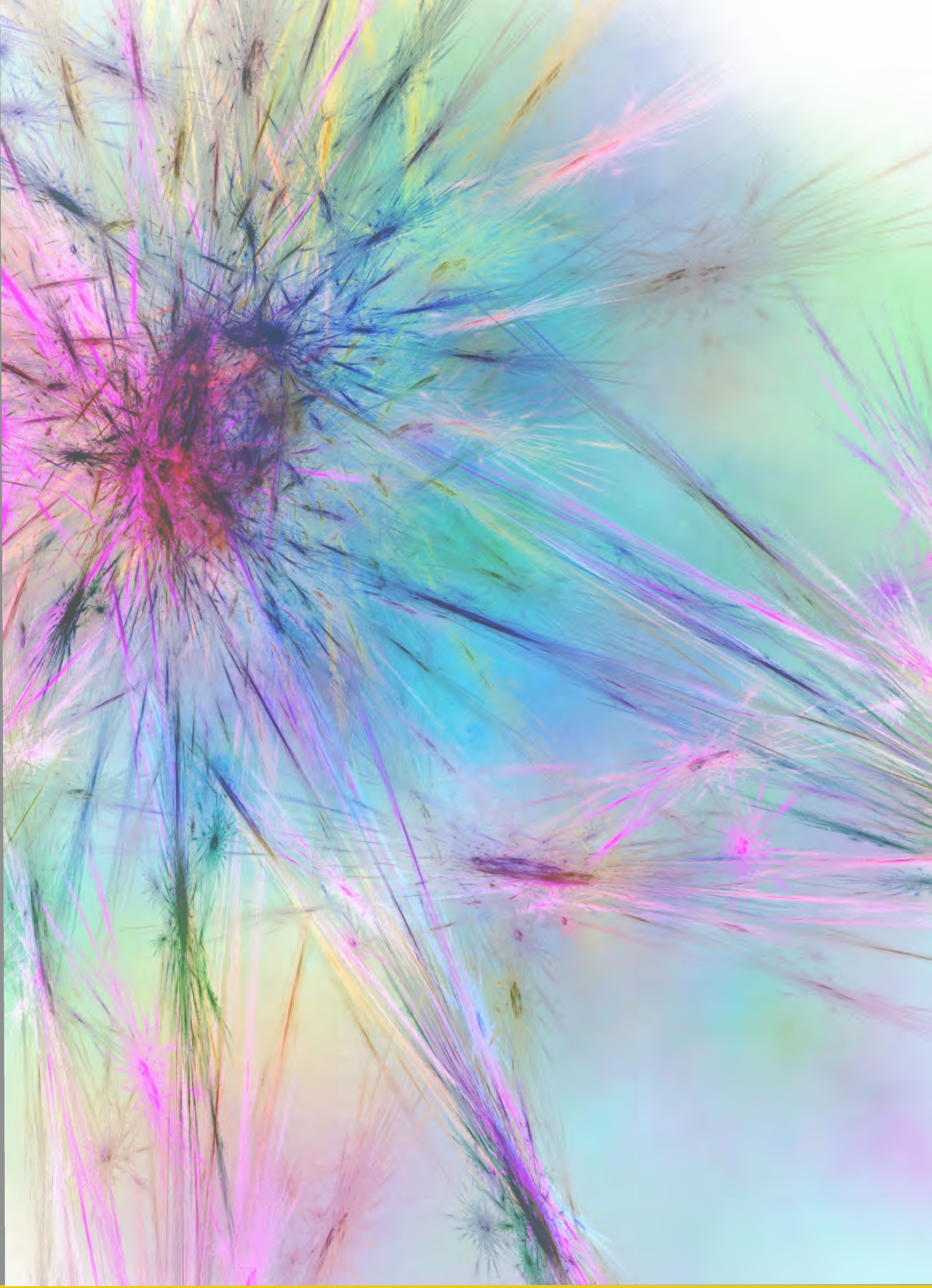


Figure 2. Shown is the evolution of SM- and TC-gauge couplings as a function of the energy scale. a1 is the hypercharge- and a2 and a3 are the weak and the strong couplings and a4 is the TC-coupling constant.

SELECTED PUBLICATIONS IN 2016

[1] Matti Herranen, Tommi Markkanen, Sami Nurmi and Arttu Rajantie, Spacetime curvature and Higgs stability after inflation, Phys. Rev.Lett. 115 (2015) 241301, arXiv:1506.04065.

[2] Kimmo Kainulainen, Kimmo Tuominen and Jussi Virkajärvi, A model for dark matter, naturalness and a complete gauge unification, Published in JCAP 1507 (2015) 034, arXiv:1504.07197.



INDUSTRIAL COLLABORATION

Ari Virtanen, Timo Sajavaara, Ilari Maasilta, Markus Ahlskog, Jussi Toppari, Jussi Timonen and Markku Kataja

Several research groups at the Department of Physics have continued their long-term collaboration with a number of Finnish and European companies in long-term and short-term applied research projects. As a fine example of such collaboration, a demonstration cloud chamber was developed and built at the department as part of a Master's degree study supervised by Mikko Laitinen and delivered to the European Space Agency (ESA). The cloud chamber detects the amount of space radiation at ground level. It was on display at the Paris Air Show, which is globally the biggest meeting point in avionics and space industry, with about 300 000 participants and 2 300 exhibitors. The chamber was located in the pavilion of ESA, where it was visited e.g. by ESA-astronaut Thomas Pesquet (Figure 1).

The Industrial Applications group of the accelerator laboratory continued the utilization of RADEF facility under ESA's Technical Research Programme (TRP). This is done in close collaboration with European space industry. The total revenue in 2015 was 878 k€. The use of RADEF K-130 beam time was 1201 hours, which is about 20% from the total running hours of the cyclotron. In total, 48 test campaigns for 21 space companies or institutes were performed at RADEF. Also, customers from USA, like Cobham Semiconductor Solutions from Colorado Springs and Naval Research Laboratory from Washington DC were among the testers last year.

Figure 1. ESA-astronaut Thomas Pesquet and the JYFL-cloud chamber in the forefront of the picture. (Photo: ESA. See http://www.esa.int/spaceinimages/Images/2015/06/Cloud_chamber_at_Le_Bourget)

Two new contracts with ESA were launched in 2015. The first one was funded from Agency's General Support Technology Programme (GSTP) for two years. Its two goals are to develop a new high-energy beam cocktail for K-130 cyclotron and put into operation our Varian's Clinac electron accelerator. The second contract was ESA's Networking/Partnering Initiative (NPI) support for a PhD work, which will be carried out in collaboration with CERN. The duration is three years. RADEF started also as a beneficiary partner in an EU project, where a new type of radiation hard random access memory will be developed (http://www.r2ram.eu/). Project was the first Horizon 2020 project of the university and is funded by Union's Research and Innovation Action (RIA). Coordinator of the project is a German company IHP-Microelectronics GmbH.

The Accelerator Based Materials Physics group within the Accelerator Laboratory has continued its active industrial collaboration both with international and domestic companies in 2015. The export of JYFL designed and constructed analysis instruments continued by installing a gas ionization chamber to the previously delivered time-of-flight telescope at Imec, Belgium. The installation of helium ion microscope in late 2015 has already opened up new collaborations in the nanometer scale characterization of especially insulating. Several pilot studies of culture heritage objects were conducted in connection to the RECENART consortium, and most probably this Tekes funded project will turn into a company in 2016.

The Experimental Nanophysics groups have well established collaboration with a few companies in Finland and abroad. The superconducting radiation detector work has involved collaboration with global, industry leading small and medium scale high tech companies, including one from the USA. In addition, national laboratories such as VTT Micronova and NIST Boulder have been involved. Some work involving novel laser lithography was also done for electronic industry.

The Molecular electronics and plasmonics group continued collaboration with lamit.fi, a company from Jyväskylä concentrating on renewable energy. This Academy funded project on building integrable solar energy collection involves research groups also from Germany, India and Norway. In 2014 started TEKES project on surface enhanced Raman spectroscopy based detection of microbial contamination in food has been successfully carried out in collaboration with several companies: Fimlab Laboratoriot Oy, Oy Panimolaboratorio – Bryggerilaborator, BioNavis Oy, Orion Diagnostica Oy and Merieux NutriSciences - Sino Analytica from China, as well as Chinese research groups. The project has resulted in potential new detection methods for further testing and several publications will be published. In addition, the Molecular Technology group has collaborated with Morphona Oy, a local start-up company, in investigating the conductive properties of carbon nanotubes solubilized with hemi-cellulose. The company obtained in 2013 a patent on the solubilization method.

The Soft Condensed Matter and Statistical Physics group utilizes the X-ray tomographic facility in applied research with industrial partners, e.g. for the analysis of structural and transport properties of fibre based materials, ceramics and minerals. Experimental work was complemented with material modelling taking basic research results of the group in immediate practical use. Individual projects were related e.g. to development of novel bio-based materials, safety analysis of repositories of spent nuclear fuel, structural properties of fibrous materials and the analysis of defects in products made of composite materials. The group also continued its long-term participation in development of ultrasound methods and devices for the assessment and monitoring of bone quality, and for diagnosing osteoporosis.

The collaborators included several major Finnish forest industries as well as domestic and European companies and applied research institutes related to materials manufacturing, research and development. Especially, the close collaboration with VTT Technical Research Centre of Finland was continued, involving e.g. 3D structural analysis of various types of materials of industrial relevance, and development of novel methods for materials analysis. In addition to industry, funding to applied research was received from Finnish Program for Strategic Centres for Science, Technology and Innovation (SHOK), Academy of Finland, Technology Development Centre of Finland and the Ministry of Employment and the Economy.

INDUSTRIAL COLLABORATION

EDUCATION

Pekka Koskinen, Jukka Maalampi, Jussi Maunuksela and Juha Merikoski

The Department of Physics is a major physics educator in Finland. It educates Candidates in physics, and Masters, Licentiates and Doctors in physics, theoretical physics and applied physics. About one third of the masters graduated have physics' teacher's qualifications and move to a career in education, one third is employed in industry, and one third aims research and doctor's degree. The Department is continuously developing the syllabus and the content of the courses in order to better meet the demands of physicists' working life.

DEVELOPMENT OF PHYSICS TEACHING AND LEARNING

The development of teaching has continued at the Department, with emphasis put on peer learning in small groups and self-directed studies, known to be a more effective and deeper way to learn than traditional lectures. The new teaching practices, applied in many courses, have activated students and resulted in better learning outcomes. To support self-directed learning, a program was started to create videos for the basic courses, freely available on the internet. This was piloted in the second-year Thermodynamics and Optics' course, and it turned out the students made good use of this new learning possibility. The material is now available also in the Opetus.tv net service.

A NEW WAY OF TEACHING COMMUNICATION AND LANGUAGES FOR PHYSICISTS

The language and communication courses, a part of every student's curriculum, have proved not to support optimally our students' communication and language competence. To better the situation, the University's Language Centre, in collaboration with the staff and students at the Department, has been developing a new way of training these skills, where the communication and language teaching are integrated into students' discipline-specific studies. In the first phase, this development process focused on interaction and group work skills, study skills and multilingualism. These courses were piloted on autumn semester 2014. The second phase has focused on communication and presentation competence as well as multilingualism. This course was piloted on second year physics students in the beginning of academic year 2015-2016.

Figure 1. Videos for the basic courses is being created to support self-directed learning. (Photos: Pekka Koskinen)

Applicant's Day 2015 for high school students.

EDUCATION

JYFL ANNUAL REPORT 2015

Personnel

Heads of the Department
Maalampi Jukka, professor, Head of Department
Jokinen Ari, professor, Vice Director, Head of the Accelerator Laboratory
Kataja Markku, professor, Vice Director

ACCELERATOR LABORATORY

Administration and contact persons:
Jokinen Ari, Head of the Accelerator Laboratory
Julin Rauno, Leader of the Center of the Excellence
Sandzelius Mikael, Beam time coordinator

Members of the Programme Advisory Committee of the JYFL Accelerator Laboratory:
Neyens Gerda, KU Leuven, Belgium (Chair)
Walker Philip M., University of Surrey, UK
Vretenar Dario, University of Zagreb, Croatia
Ibrahim Fadi, Orsay, France
Cederwall Bo, Stockholm, Sweden
Blank Bertram, Bordeaux, France

Scientific Advisory Board of the Centre of Excellence in Nuclear and Accelerator Based Physics:
Nazarewicz Witold, professor, NSCL, Michigan State University, USA
Krücken Reiner, Head of the Science Division at TRIUMF, Canada
Koskela Pekka, professor, University of Jyväskylä
Pekola Jukka, professor, Academy of Finland
Heinäsmaa Sami, science adviser, Academy of Finland

Research groups

NUCLEAR AND ACCELERATOR BASED PHYSICS

The FIDIPRO

Dobaczewski Jacek, professor, team leader
Bennaceur Karim, university researcher
Gao Yuan, doctoral student
Haverinen Tiia, doctoral student, 1.9.2015-
Idini Andrea, postdoctoral researcher
Kortelainen Markus, postdoctoral researcher
Oishi Tomohiro, postdoctoral researcher
Salvioni Gianluca, doctoral student
Shi Yue, postdoctoral researcher, 1.9.2015-
Yu Lingfei, doctoral student, -31.8.2015

Exotic Nuclei and Beams IGISOL

Jokinen Ari, professor
Moore Iain, professor
Äystö Juha, professor (on leave of absence -31.12.2015)
Kankainen Anu, academy research fellow
Eronen Tommi, senior researcher (on leave of absence 1.10.2015-)
Penttilä Heikki, senior researcher
Rinta-Antila Sami, senior researcher
Campbell Paul, visiting researcher (University of Manchester, -31.7.2015)
Nesterenko Dimitrii, postdoctoral researcher (17.8.2015-)
Simutkin Vasily, postdoctoral researcher
Voss Annika, postdoctoral researcher
Canete Laetitia, doctoral student
Gorelov Dmitry, doctoral student
Hakala Jani, doctoral student
Pohjalainen Ilkka, doctoral student
Koponen Jukka, doctoral student
Geldhof Sarina, doctoral student (1.10.2015-)
Reinikainen Juuso, MSc student
Vilén Markus, MSc student
Murray Ian, MSc student (-23.10.2015)
Poleschuck Oleksii, MSc student (-28.10.2015)
Poleschuck Kateryna, MSc student (-9.9.2015)

Nuclear Spectroscopy

Greenlees Paul, professor
Julin Rauno, professor
Juutinen Sakari, senior lecturer
Uusitalo Juha, senior researcher
Scholey Catherine, senior researcher
Grahn Tuomas, senior lecturer
Pakarinen Janne, academy research fellow
Sandzelius Mikael, senior researcher
Rahkila Panu, senior researcher
Papadakis Philippos, senior researcher
Sarén Jan, postdoctoral researcher
Cox Daniel, postdoctoral researcher
Peura Pauli, postdoctoral researcher -31.3.2015
Auranen Kalle, doctoral student -17.6., postdoctoral researcher 18.6.-31.12.2015
Partanen Jari, doctoral student
Sorri Juha, doctoral student
Stolze Sanna, doctoral student
Konki Joonas, doctoral student
Badran Hussam, doctoral student
Mallaburn Michael, doctoral student -24.8.2015
Defranchi Bisso Federica, MSc student
Lightfoot Alexandra, MSc student
Leino Matti, professor emeritus

Instruments and Methods in Nuclear, Particle, and Astroparticle Physics

Trzaska Wladyslaw Henryk, senior researcher
Loo Kai, doctoral student
Slupecki Maciej, doctoral student
Hissa Johannes, doctoral student (Oulu University)
Mukhamejanov Yerzhan, doctoral student (Almaty University, Kazakhstan)
Virkajärvi Antto, MSc student (Lappeenranta Technical University)
Sorjonen Jukka, MSc student
Sarala Roope, MSc student
Karppinen Katja, MSc student (Oulu University), 1.9.-31.12.2015
Edyko Patryk , MSc student, 1.6.-31.8.2015
Cierluk Konrad, MSc student, 1.6.-31.08.2015
Frątczak Zofia, MSc student, 1.6.-31.8.2015
Sędzicki Przemysław, MSc student, 1.6.-31.8.2015
Ollikainen Joni, MSc student, 1.6.-31.8.2015
Koulikovski Jordan, MSc student, 1.6.-30.9.2015
Tiurin Grigori, visiting researcher (Radium Institute, Russia)

Accelerator-based Materials Physics

Sajavaara Timo, professor
Arstila Kai, Senior researcher
Malm Jari, postdoctoral researcher
Laitinen Mikko, laboratory engineer, PhD
Julin Jaakko, doctoral student
Mättö Laura, doctoral student
Napari Mari, doctoral student
Käyhkö Marko, doctoral student
Kinnunen Sami, MSc student
Kivistö Henri, MSc student
Leppänen Kasper, MSc student

Industrial Applications

Virtanen Ari, research director
Kettunen Heikki, laboratory engineer
Javanainen Arto, postdoctoral researcher
Jaatinen Jukka, laboratory engineer
Kalvas Taneli, postdoctoral researcher
Rossi Mikko, laboratory engineer
Bosser Alexandre, doctoral student
Tali Maris, doctoral student

Nuclear Structure, Nuclear Decays, Rare and Exotic Processes

Suhonen Jouni, professor
Kotila Jenni, postdoctoral researcher
Almosly Wafa, doctoral student
Haaranen Mikko, doctoral student
Hyvärinen Juhani, doctoral student
Pirinen Pekka, doctoral student
Jokiniemi Lotta, MSc student

MATERIALS PHYSICS

Experimental nanophysics and nanotechnology

Molecular Technology

Ahlskog Markus, professor
Hokkanen Matti, doctoral student
Shao Dongkai, doctoral student
Lukkarinen Antti, MSc student
Lautala Saara, MSc student
Saari Joonas, MSc student

Thermal nanophysics

Maasilta Ilari, professor
Puurtinen Tuomas, postdoctoral researcher
Geng Zhuoran, doctoral student
Julin Juhani, doctoral student
Leppänen Miika, doctoral student
Räisänen Ilmo, doctoral student
Tian Yaolan, doctoral student
Torgovkin Andrii, doctoral student
Heiskanen Samuli, MSc student
Helenius Ari, MSc student
Mastomäki Jaakko, MSc student
Savytskyi Mykhailo, MSc student
Kinnunen Kimmo, laboratory engineer (shared)
Suppula Tarmo, laboratory engineer (shared)

Molecular electronics and plasmonics

Toppari Jussi, senior lecturer
Johansson Andreas, senior researcher
Simonen Janne, senior researcher
Lehtivuori Heli, academic postdoctoral
Lemma Tibebe, postdoctoral researcher
Baieva Svitlana, doctoral student
Isoniemi Tommi, doctoral student
Shen Boxuan , doctoral student
Tapio Kosti, doctoral student
Borovsky Jan, doctoral student
Kautto Mikael, MSc student
Nuuttila Lauri, MSc student
Saliniemi Alex, MSc student
Roberts Kevin, MSc student
Hiltunen Vesa-Matti, MSc student
Manninen Jyrki, MSc student

Computational nanosciences

Group leaders and senior scientists:
Häkkinen Hannu, professor (physics and chemistry)
van Leeuwen Robert, professor
Heikkilä Tero, professor
Apaja Vesa, senior researcher
Honkala Karoliina, lecturer (chemistry)
Groenhof Gerrit, academy research fellow (chemistry)
Koskinen Pekka, academy research fellow
Lehtovaara Lauri, academy research fellow (chemistry)
Massel Francesco, academy research fellow

Postdocs:
Chen Xi, postdoctoral researcher (chemistry)
Djorwé Philippe, postdoctoral researcher
Bazhenov Andrey, postdoctoral researcher (chemistry)
Clayborne Andre, postdoctoral researcher (chemistry) (9/2015)
Donnini Serena, postdoctoral researcher (biology)
Gokarneswar Sahoo, postdoctoral researcher (chemistry)
Hyart Timo, postdoctoral researcher
Kuklin Mikhail, postdoctoral researcher
Lindgren Johan, postdoctoral researcher (chemistry)
Malola Sami, postdoctoral researcher
Morozov Dmitry, postdoctoral researcher (chemistry)
Virtanen Pauli, postdoctoral researcher

PhD students:
Agasti Souvik, doctoral student
Aikebaier Faluke, doctoral student
Arjoranta Juho, doctoral student (6/2015)
Cort Luis, doctoral student
Gell Lars, doctoral student(chemistry)
Hyrkäs Markku, doctoral student
Kaappa Sami, doctoral student
Karlsson Daniel, doctoral student
Korhonen Topi, doctoral student
Luukko Perttu, doctoral student
Lynn Richard, doctoral student
Nevalaita Janne, doctoral student
Parviainen Teemu, doctoral student
Peltonen Teemu, doctoral student
Pohjolainen Emmi, doctoral student
Semina Elena, doctoral student (chemistry)
Säkkinen Niko, doctoral student
Tuokko Sakari, doctoral student (chemistry)
Tuovinen Riku, doctoral student
Uimonen Anna-Maija, doctoral student (8/2015)

Undergraduate students:
Antikainen Saku, MSc student
Asikainen Aili, MSc student
Lautala Saara, MSc student
Kiiskinen Sampsa, MSc student
Manninen Juuso, MSc student
Moisala Terhi, MSc student
Selenius Elli, MSc student
Sääksvuori Juuso, MSc student
Koivula Juho, MSc student

Soft Condensed Matter and Statistical Physics

Timonen Jussi, professor
Kataja Markku, professor
Merikoski Juha, senior lecturer
Myllys Markko, senior lecturer
Takalo Jouni, senior researcher
Mattila Keijo, postdoctoral researcher
Kähärä Topi, postdoctoral researcher
Moilanen Petro, postdoctoral researcher
Tallinen Tuomas, postdoctoral researcher
Puurtinen Tuomas, postdoctoral researcher
Aho Vesa, doctoral student
Ekman Axel, doctoral student
Harjupatana Tero, doctoral student
Kilappa Vantte, doctoral student
Kuva Jukka, doctoral student
Miettinen Arttu, doctoral student
Riikilä Timo, doctoral student
Turpeinen Tuomas, doctoral student
Väisänen Markku, doctoral student
Lehto Roope, doctoral student
Pirhonen Jalmari, doctoral student
Lämsä Joni, MSc student
Kääriäinen Topi, MSc student
Parkkonen Joni, laboratory engineer
Alaraudanjoki Jarno, laboratory engineer

PARTICLE PHYSICS

A Large Ion Collider Experiment - ALICE

Rak Jan, professor
Trzaska Wladyslaw, senior researcher
Kim Dong Jo, senior researcher
Räsänen Sami, senior researcher
Brücken Erik, scientist (Helsinki)
Hildén Timo, scientist (Helsinki)
Chang Beomsu, doctoral student
Viinikainen Jussi, doctoral student
Vargyas Marton, doctoral student
Snellman Tomas, doctoral student
Slupecki Maciej, doctoral student
Barba Elias, MSc student

Ultrarelativistic Heavy Ion Collisions – Theory

Eskola Kari J., professor
Lappi Tuomas, academy research fellow, HIP project leader
Paukkunen Hannu, postdoctoral researcher
(HIP/Santiago de Compostela)
Ducloué Bertrand, postdoctoral researcher
Zhu Yan, postdoctoral researcher 1.10.2015-(HIP)
Mäntysaari Heikki, doctoral student -30.9.2015
Peuron Jarkko, doctoral student
Ramnath Andrecia, doctoral student
Paakkinen Petja, summer trainee, doctoral student 5.11.2015–
Stylman Tapani, MSc student, summer trainee

Neutrino Physics

Maalampi Jukka, professor
Trzaska Wladyslaw, senior researcher
Loo Kai, doctoral student
Slupecki Maciej, doctoral student
Vihonen Sampsa, doctoral student

Cosmology

Kainulainen Kimmo, professor
Nurmi Sami, senior lecturer
Karciauskas Mindaugas, postdoctoral researcher
Herranen Matti, postdoctoral researcher
Rahkila Pyry M., doctoral student
Vaskonen Ville, doctoral student
Jukkala Henri, doctoral student
Koskivaara Olli, doctoral student
Laulumaa Laura, doctoral student
Leskinen Juuso, doctoral student

Others

Educational Development Group

Maalampi Jukka, professor
Leino Matti, professor emeritus
Juutinen Sakari, senior lecturer
Maunuksela Jussi, senior lecturer
Merikoski Juha, senior lecturer
Koskinen Pekka, academy research fellow
Laitinen Mikko, laboratory engineer
Saren Jan, postdoctoral researcher
Haverinen Tiia, MSc student
Laulumaa Laura, doctoral student
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