Review of Muography in Italy (Vesuvio and Stromboli)

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Raffaello D'Alessandro
Università di Firenze & INFN-Firenze

Muon Radiography in Italy

- Very much alive:
- Groups involved with active detectors:
  - University of Naples & INFN Naples
  - University of Florence & INFN Florence
  - INGV – Osservatorio Vesuviano
- Emulsion detector groups also involved:
  - University of Naples & INFN Naples
  - University of Salerno

Mt. Vesuvius & Stromboli & Puy de Dome (France)

Emulsions in Italy

- Developed enormous experience with the OPERA detector
- A technique that is complementary to active detectors
- Campaign underway on Stromboli, data is still being analysed
- Thanks to Valeri Tioukov from INFN-Naples, more details in his talk and those of his collaborators.

Motivations for the Stromboli exposure

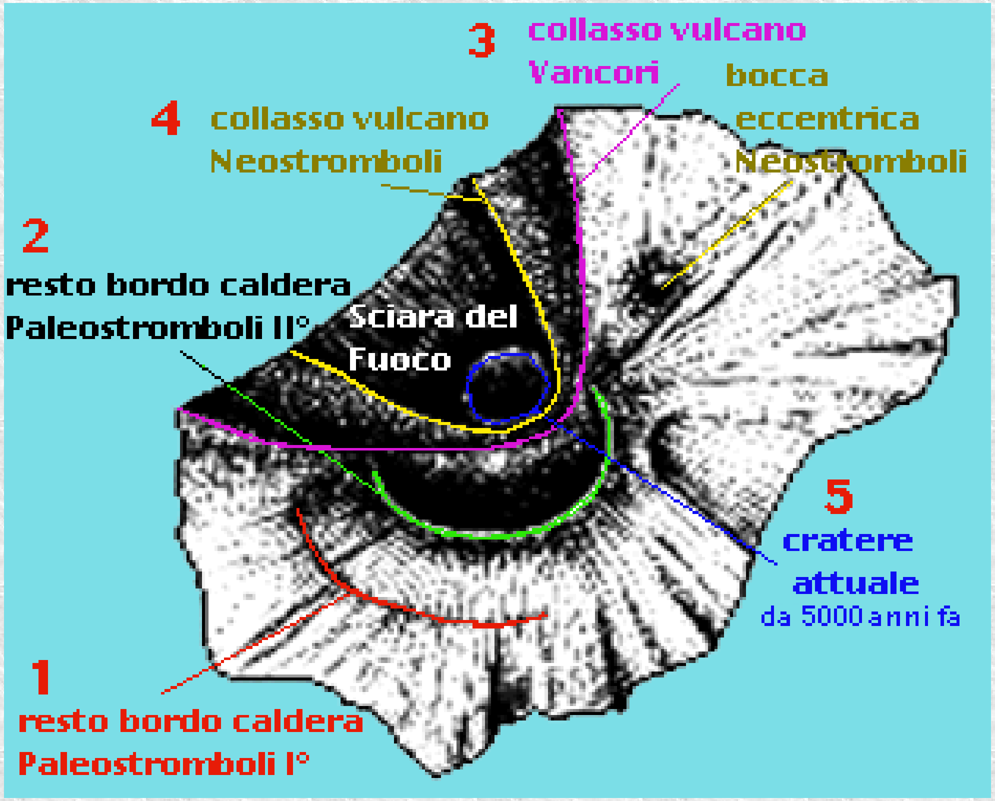
Stromboli is one of the most known and most active volcanoes in the world

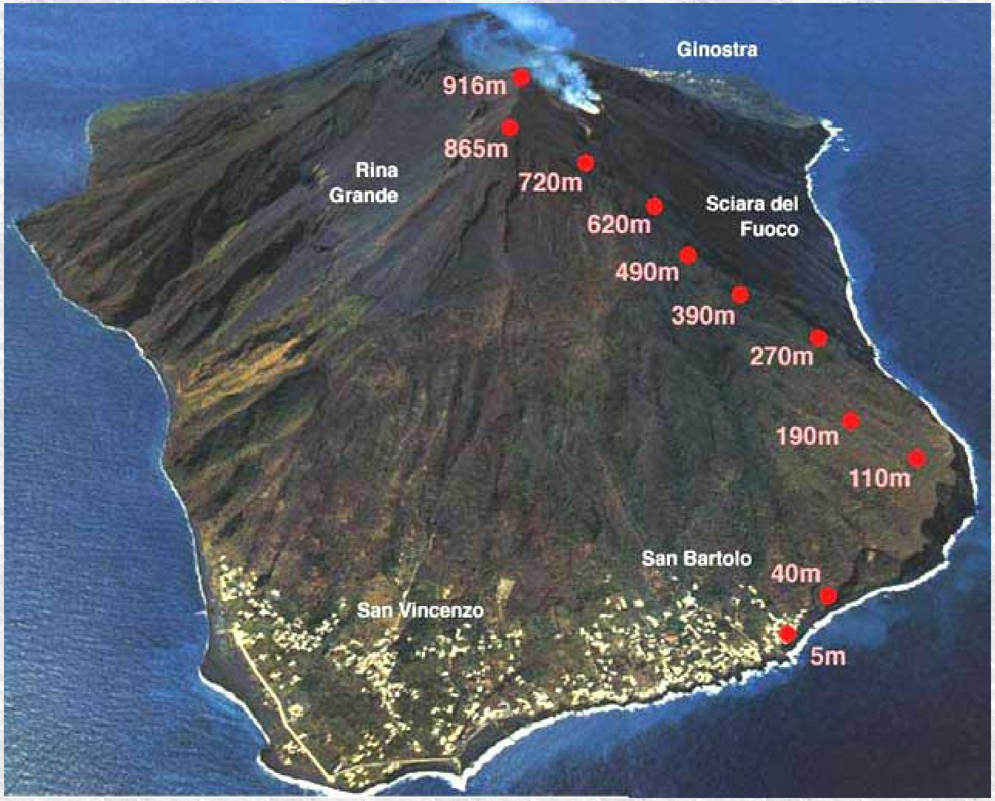
Great amount of monitoring equipment is installed on the volcano slopes, but the exact internal structure of the region below craters is not well understood yet

There is a possibility that the explosion source mechanism is representative of two cracks dipping $\sim 60^{\circ}$ that are located approximately 220-260 m, beneath the active craters, probably representing parts of an echelon system of fissures

Muon radiography can be an independent technique for investigating the internal structure of the cone and revealing the location and extent of the conduits that feed the continuous explosions

Region under “Sciara del Fuoco” is the one of interest to us


3 collasso vulcano Vancori
4 collasso vulcano Neostromboli
bocca eccentrica Neostromboli
2 resto bordo caldera Paleostromboli II°
Sciara del Fuoco
5 cratere attuale
da 5000 anni fa
1 resto bordo caldera Paleostromboli I°


Ginostra
916m
865m
720m
620m
490m
390m
270m
190m
110m
40m
5m
Rina Grande
Sciara del Fuoco
San Bartolo
San Vincenzo

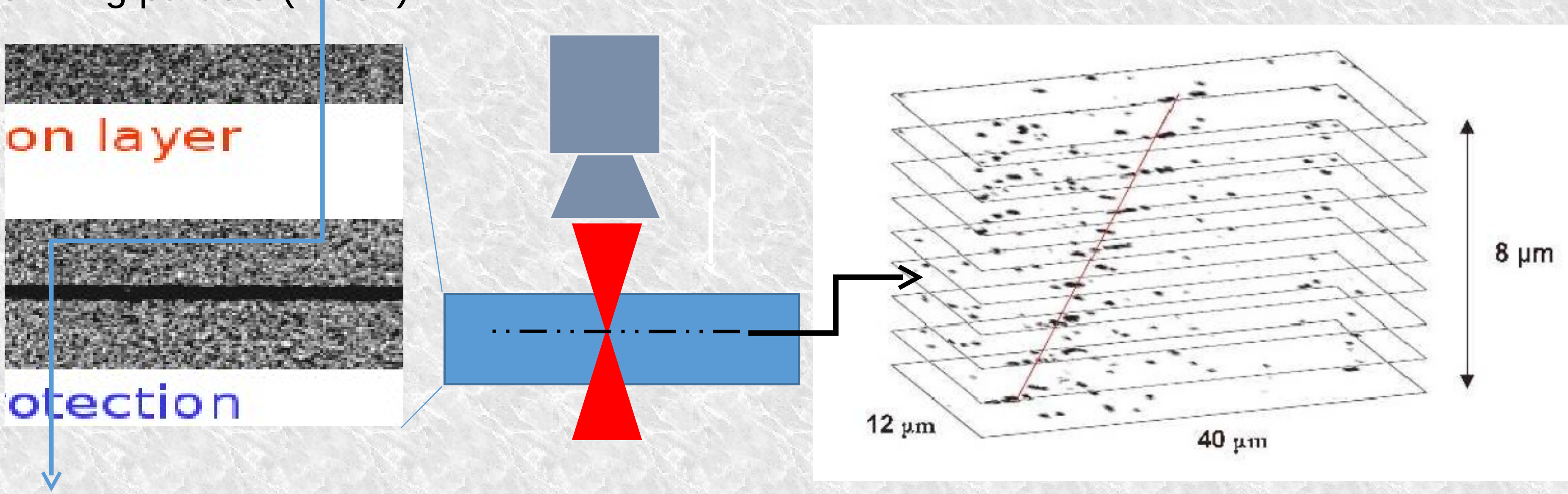
Emulsions

- Position resolution better then 1 micron
- **Angular resolution 2-3 mrad**
- Scanning speed of one ESS 20/cm2/h
- Used mainly for High Energy Physics experiments

Tomography images taken with the step of 2.5 microns

Ionizing particle (muon)

44 microns



Nuclear emulsions as a detector for muon radiography

- Able to provide new information complimentary to other methods used for volcanoes survey

Advantages

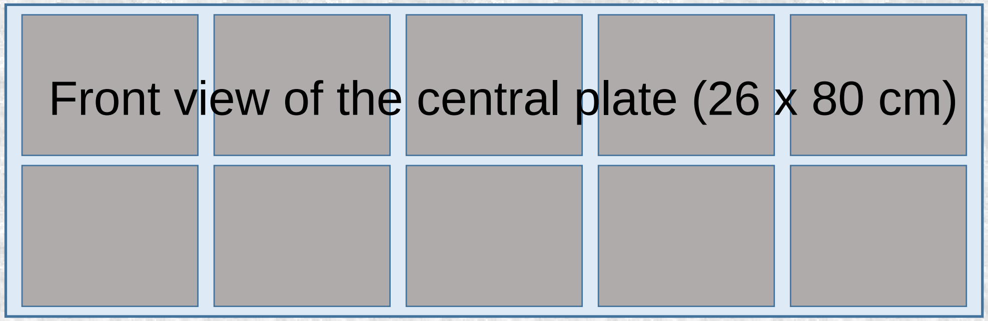
- Perfect intrinsic angular resolution (better then 2 mrad)
- Compact and easy to transport
- No electricity required
- Can be installed in a harsh environment

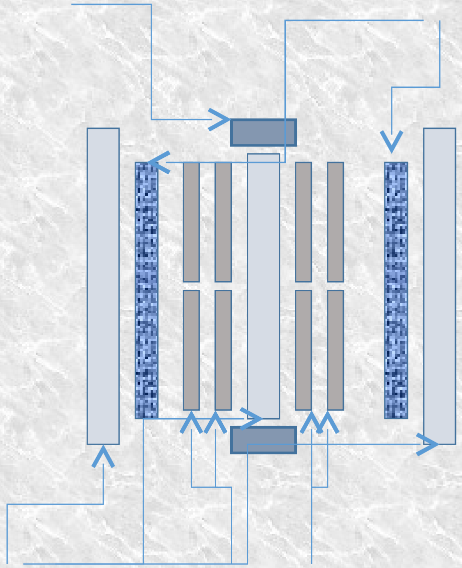
Disadvantages

- No time information
- Complicated data acquisition and reconstruction
- Accepted temperature range for long-term exposures is below 25^{o}C
- Single-use sensitive part

Scheme of the module structure

One module with 10 emulsion “cells”
Each cell has 2 emulsion doublets attached
to both sides of the central metal plate.

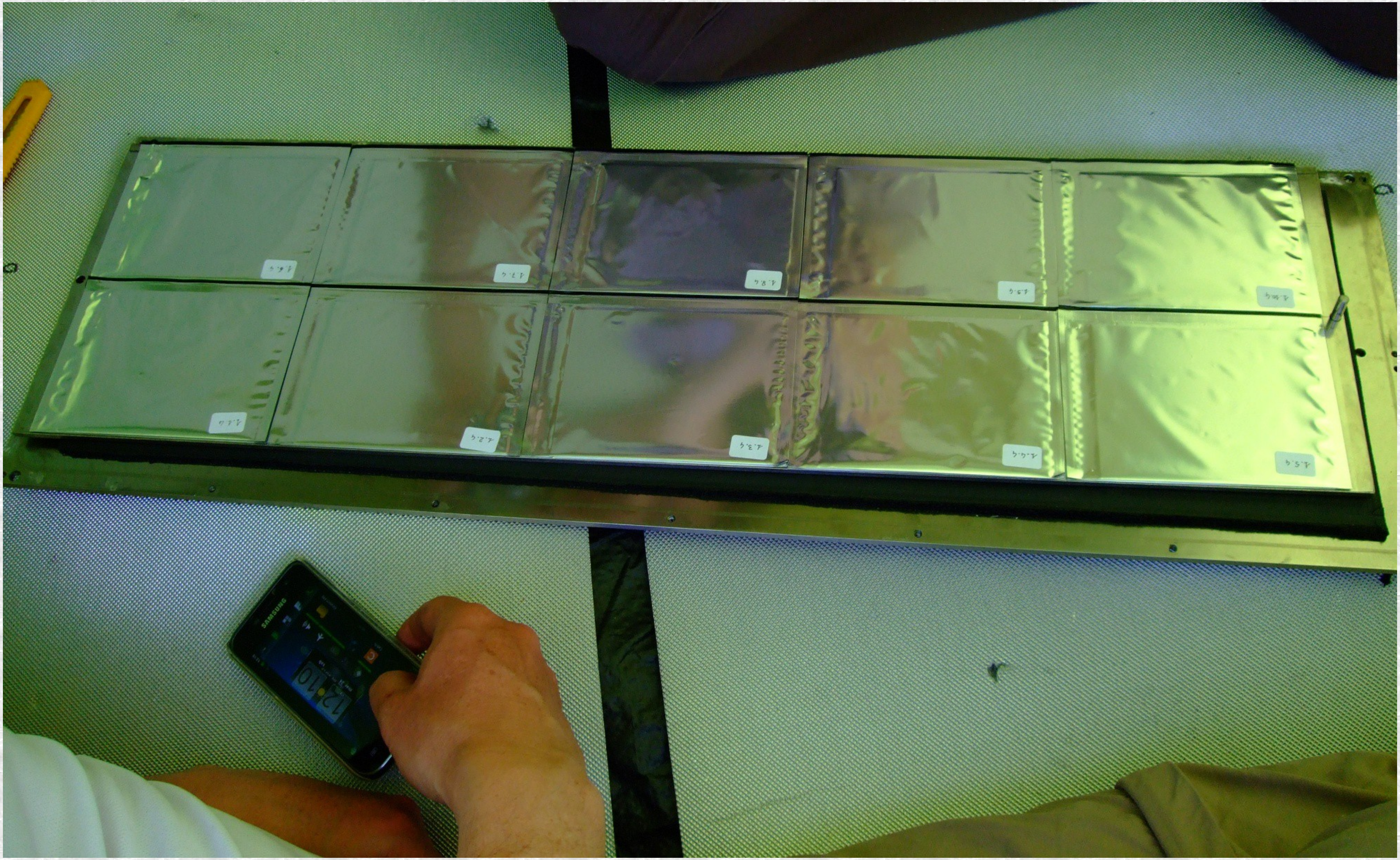




The total weight of one module is of 26 kg
Total amount of emulsions/module: 40
The active surface covered is of 1200 cm2

The overall weight of 8 modules and the
support frame is about 250 kg

After 5 months exposure

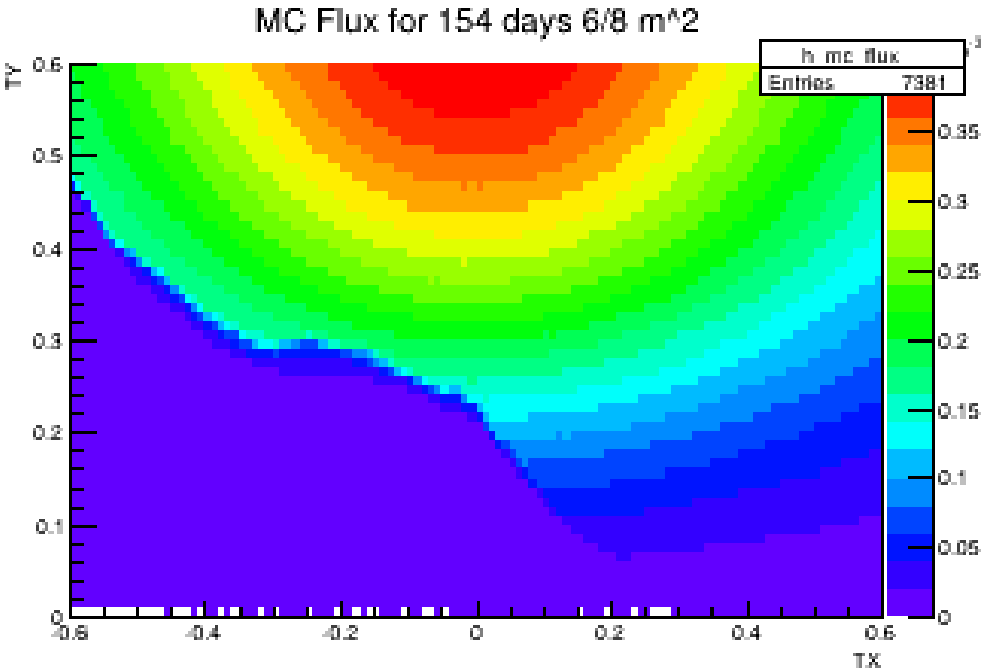


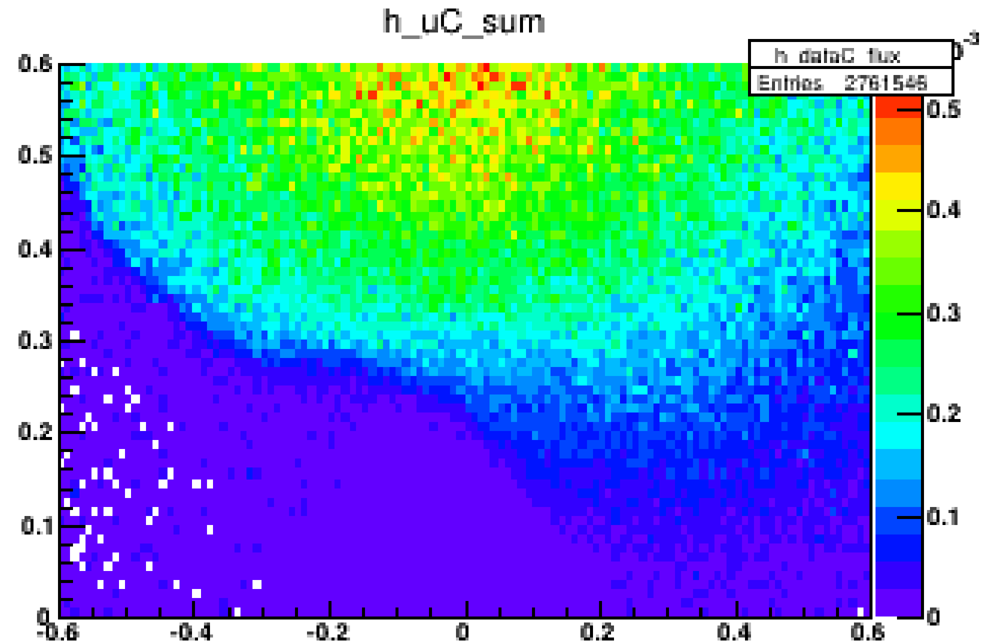
Oct-2011 before the detector installation.
Helicopter was the only way to bring the 250 kg structure to the selected place

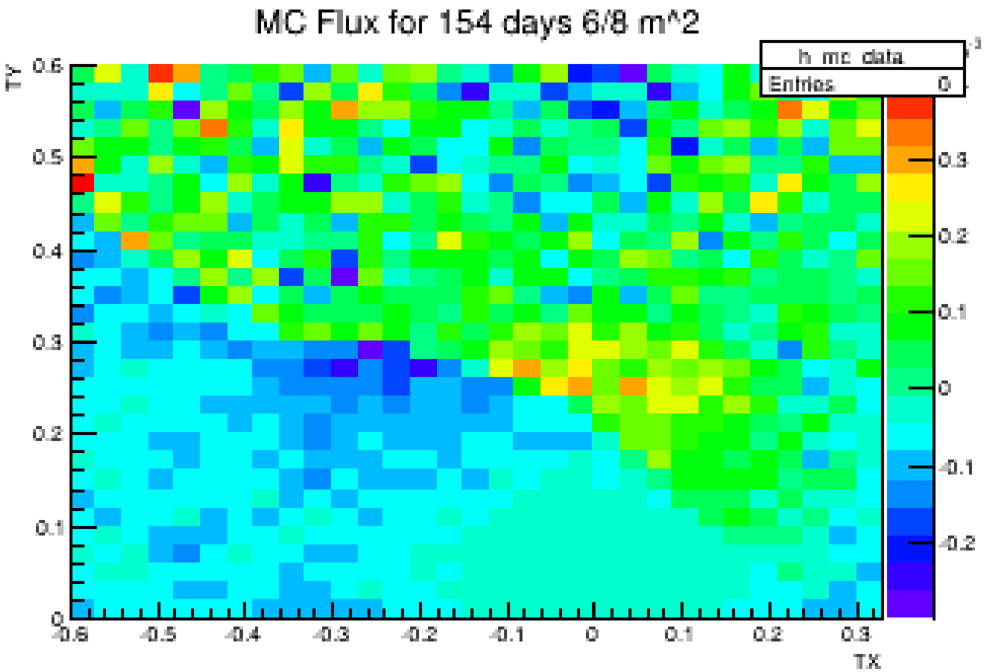
After 5 months of data taking the detector was found in a good shape well protected from sun heat and from moisture by rubber foam (armaflex) and by porous clay

A look at the data (vs Monte Carlo)

- The first exercise of data-MC comparison on the incomplete statistics
- Some data excess was observed in a crater region with respect to MC
- It is difficult yet to judge about finer effects
- It is quite clear that the MC Sky is not the same as the data one – the reason could be a not perfect efficiency correction
- I have not given details nor mentioned precise digital maps required for the analysis


MC Flux for 154 days 6/8 m^2
h_mc_flux
Entries 7381
TY
TX


h_uC_sum
h_dataC_flux
Entries 2761546


MC Flux for 154 days 6/8 m^2
h_mc_data
Entries 0
TY
TX

Emulsions in Italy, very promising

- The muon radiography of the Stromboli volcano is performed using the emulsions-based detector
- More then 50% of data are processed
- We observe a good agreement between photo, DEM and data-obtained mountain shape – it means the good understanding of the detector positioning and DEM treatment
- Some discrepancy of the MC and data Sky distributions are observed – we need to understand better this item before going to the fine data interpretation
- First MC-data comparison looks promising

Muray Project

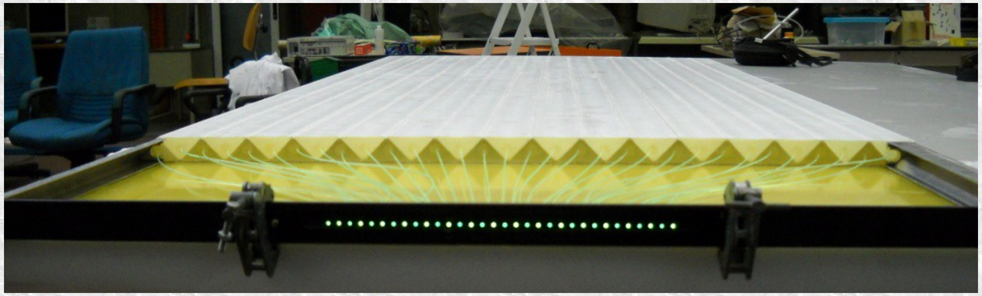
- Active telescope
- Only brief overview with "future"outlook in other fields too
- New contacts have been pursued.
- For more details on **volcano radiography** see tomorrow's talk by **Luigi Cimmino**.

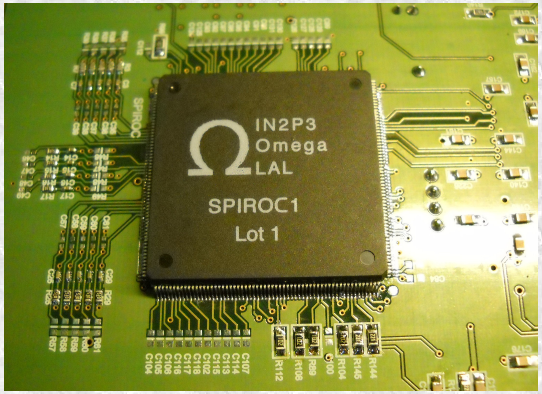
Muon telescope requirements

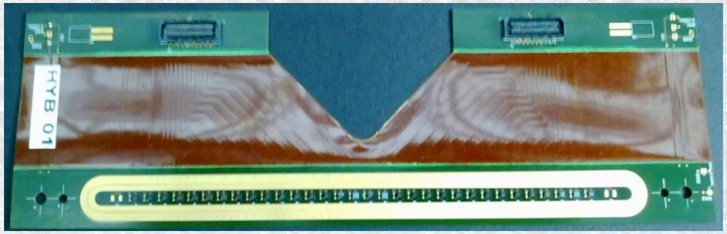
- Tracking capability: direction of muons with relatively high spatial/angular resolution (few millirads)
- Uniformity of response
- Redundant background suppression capability
- Low cost/channel: larger telescope area and/or higher resolution
- Resistant and modular structure: usage in volcanic area
- Low energy consumption : usage in volcanic area
- Electronics and sensors must perform from below zero to 50-60 ^{o}C

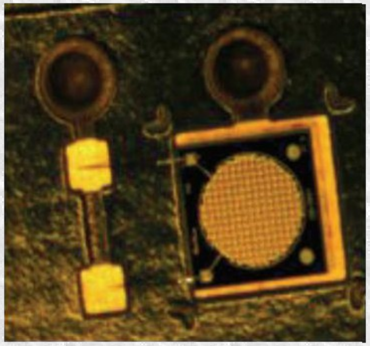
MuRay Detector Choices

- Triangular plastic scintillator bars: robust, fast, chip, spatial resolution.
- Fast WLS fibres photon collection
- SiPM light read-out: low power, robust , fast, chip
- One single 32-SiPMs connector/hybrid per module
- EASIROC FE electronics: SiPM dedicated, low power consumption
- Dedicated low power consumption FE and DAQ electronics
- Peltier cooling









R. D'Alessandro
Università di Firenze & INFN-Firenze

MuRay Prototype Design

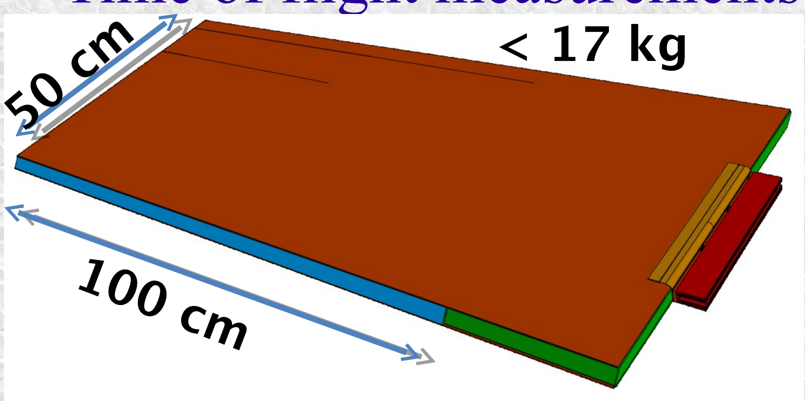
Several solutions originally proposed by Mu-Ray are nowadays «standard» design practice for proposed detectors in the muon tomography field:

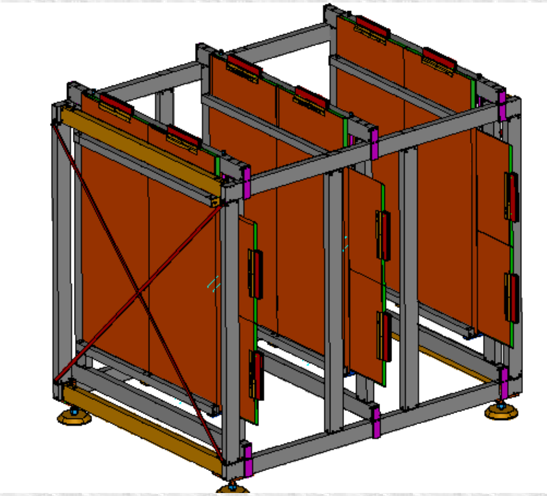
- At least three planes, each with both X and Y measurement
- Azimuthal rotation for flux calibration

Time of flight is still unique to Mu-Ray, due to its unique time resolution which allows to distinguish the direction of the traveling muons.

Space/time resolution, background rejection, large active area, low cost.

- **Three X-Y stations of 1x1 m^2 sensitive area**
- **12 modules easy to transport and to assemble**
- Time of flight measurements

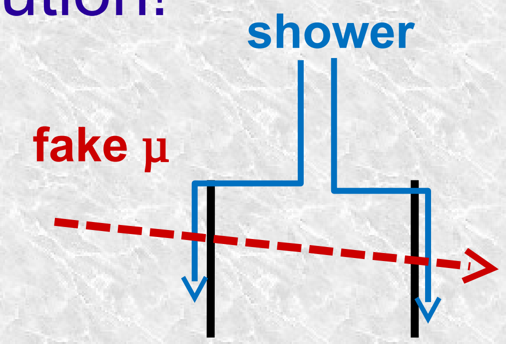




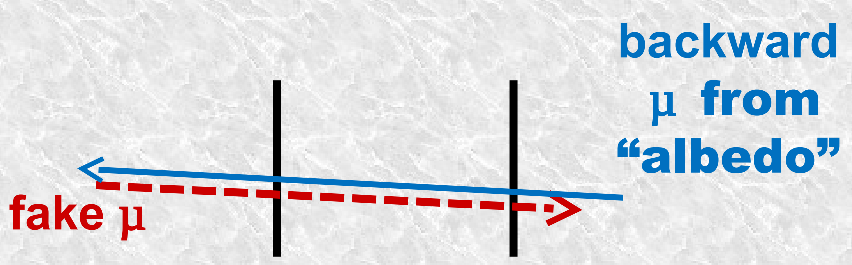
< 280 kg

Background from other sources

- Showers of charged particles created in the atmosphere can mimic a straight track -> use at least 3 planes, increase resolution!



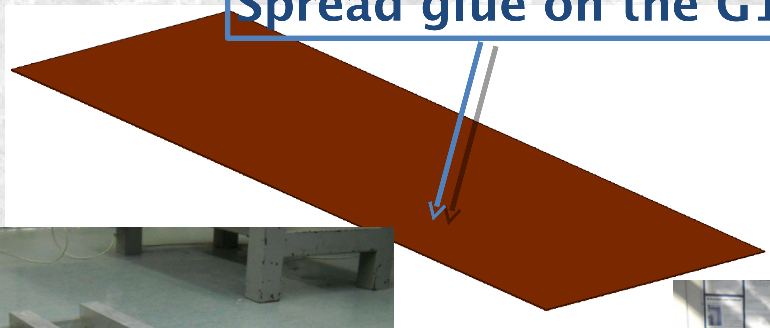
- At low angle re-scattered «albedo» muons coming from the opposite direction (where there is no volcano….) can mimic the muon-> measure Time Of Flight (TOF)



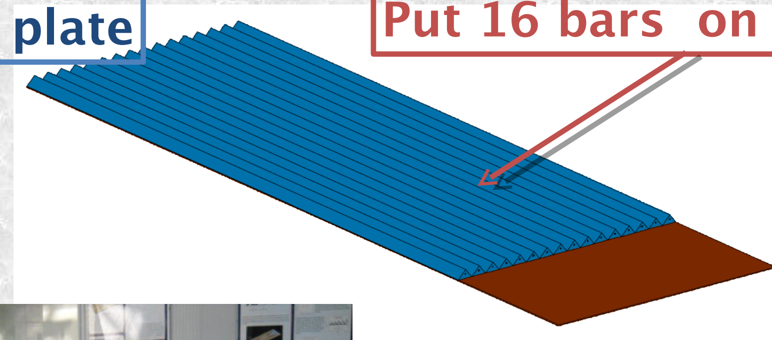
Scintillator Module Construction (1)

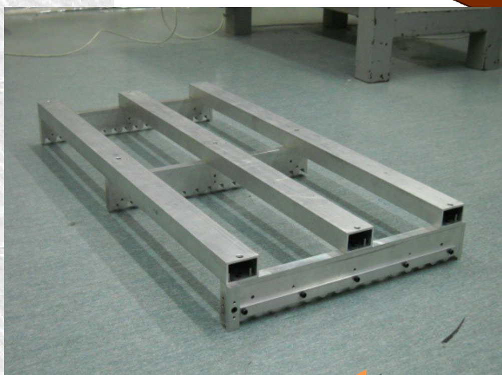
- 12 modules have been constructed

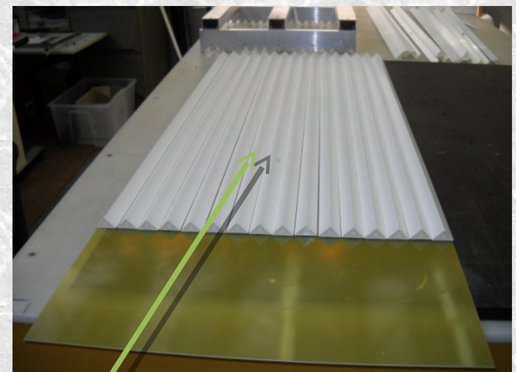
Spread glue on the G11 plate



Put 16 bars on the plate

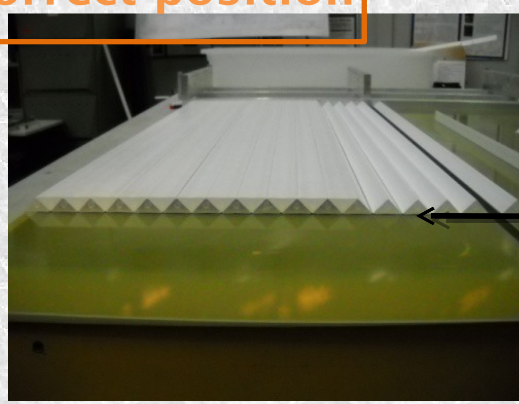






Jig holding the scintillator bars in the correct position

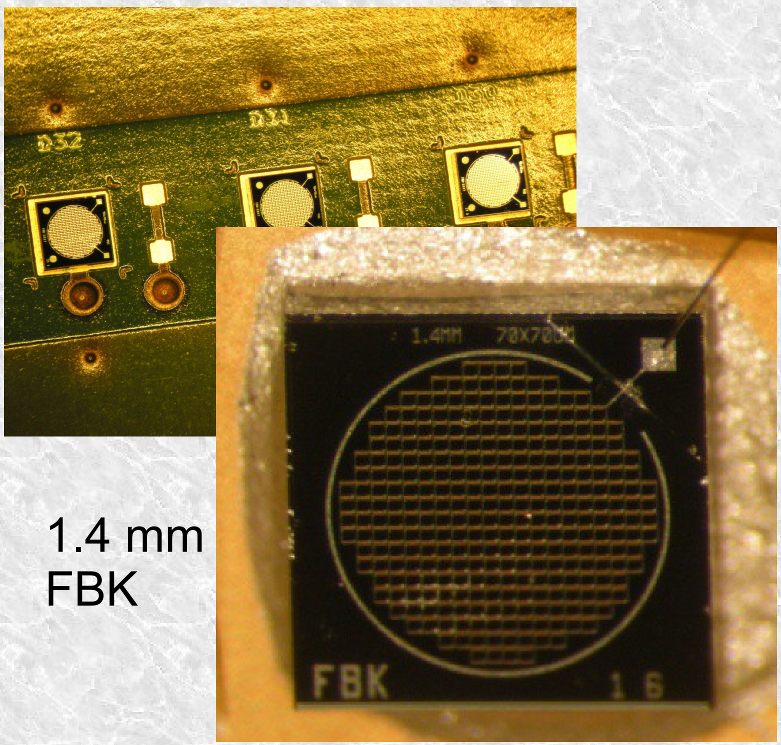
After the glue sets the jig is removed



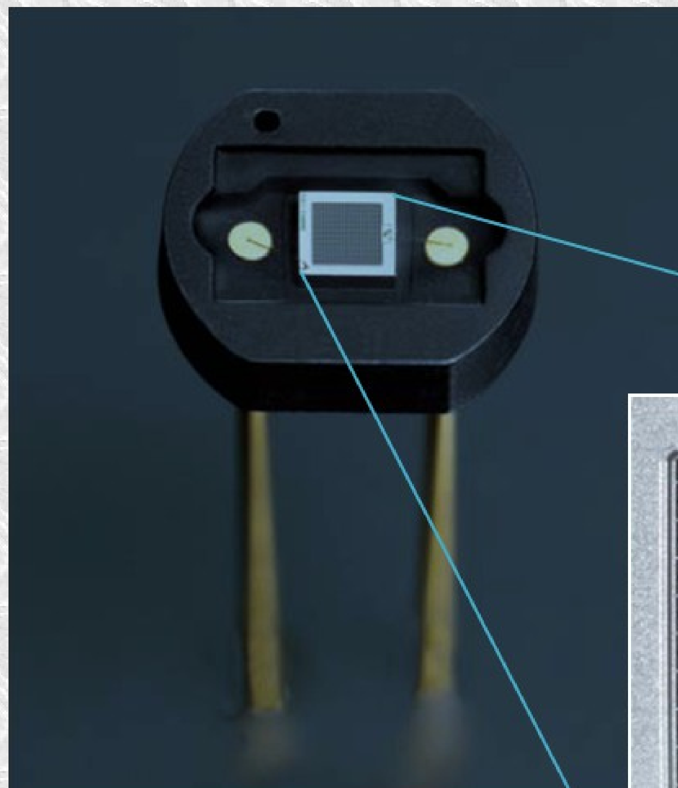
Now it's possible to glue the second scintillators layer

SiPM

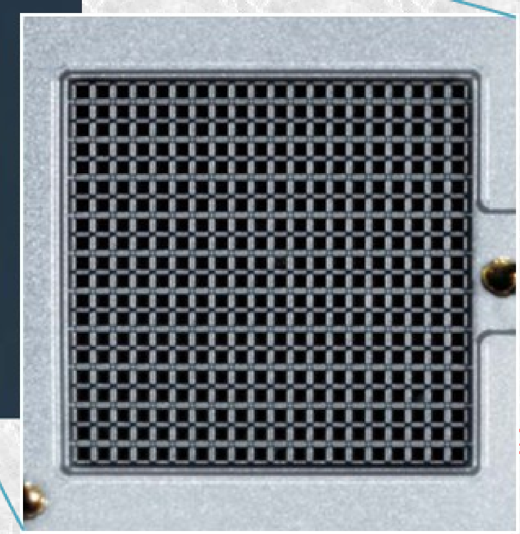
- New concept in light detection
- Array of APD cells working in self-quenching Geiger mode
- High level of miniaturization and integration
- Light detection efficiency higher, and gain comparable to traditional PMTs
- “Digital” linear response (each APD cell works in on/off mode)



1.4 mm
FBK



1.3 mm
HM



R. D'Alessandro
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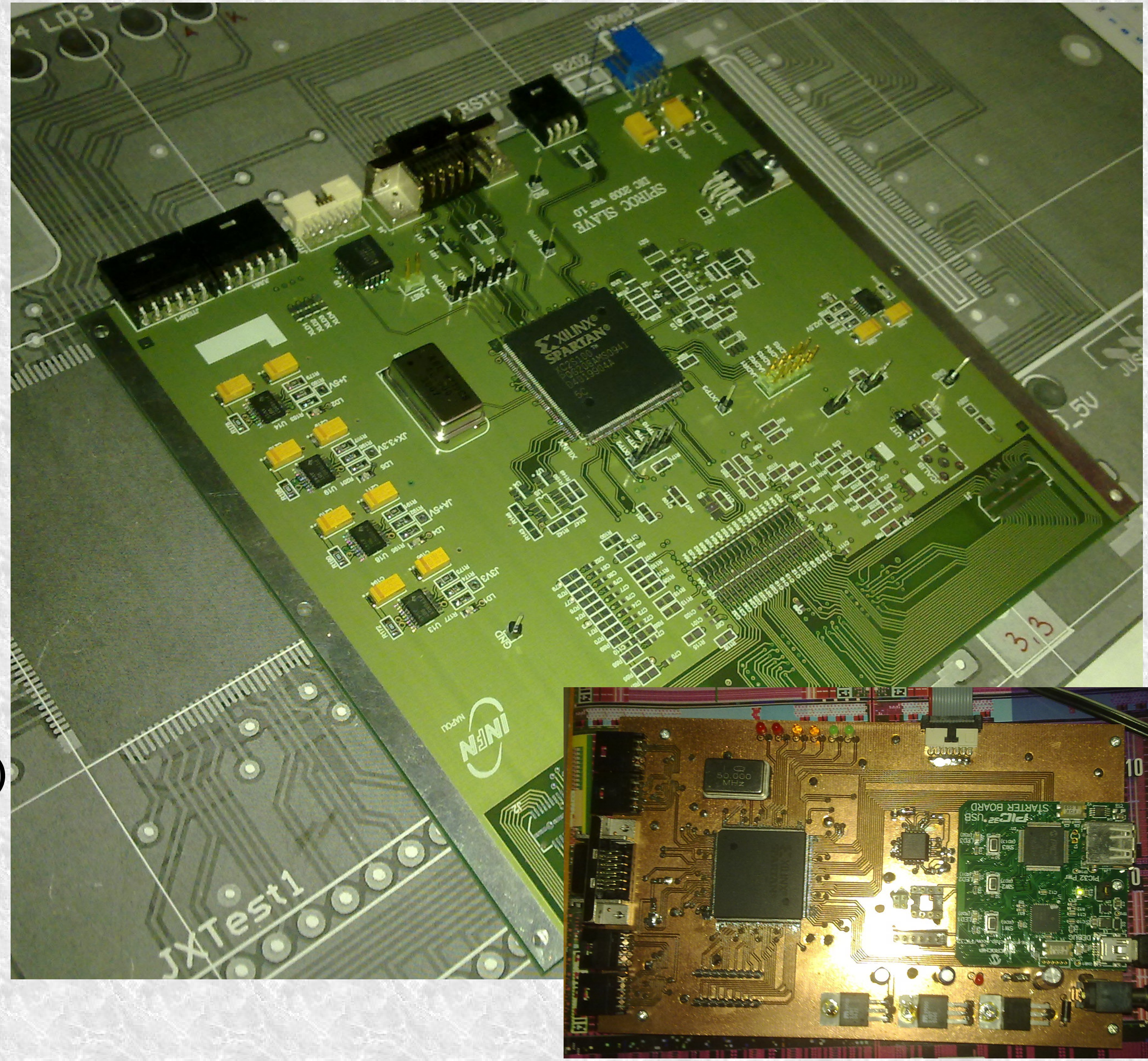
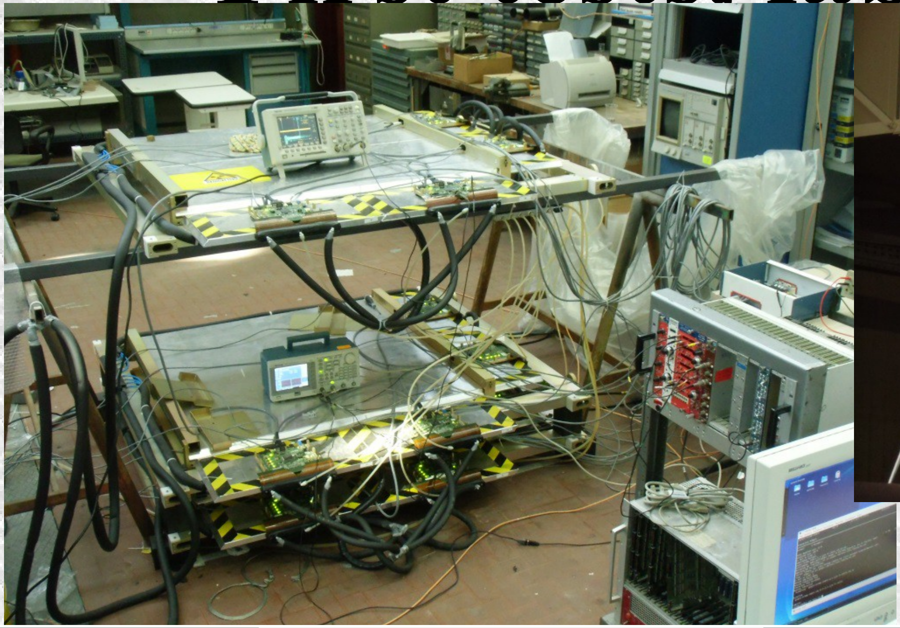
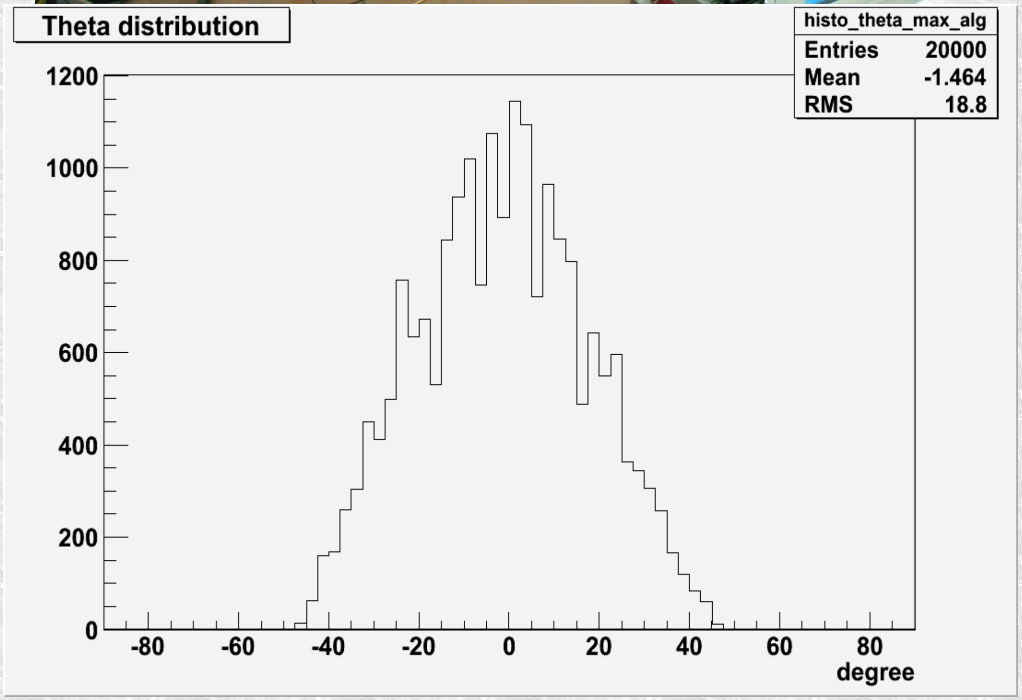
The MuRay SPIROC Board

- Board designed by the Servizio di Elettronica in Naples
- Logic functions implemented XILINX Spartan FPGA
- Houses the SPIROC (LAL) chip
- Has a time expansion TDC.
- In the inset a board with a PIC to control temperatures (and other slow parameters)



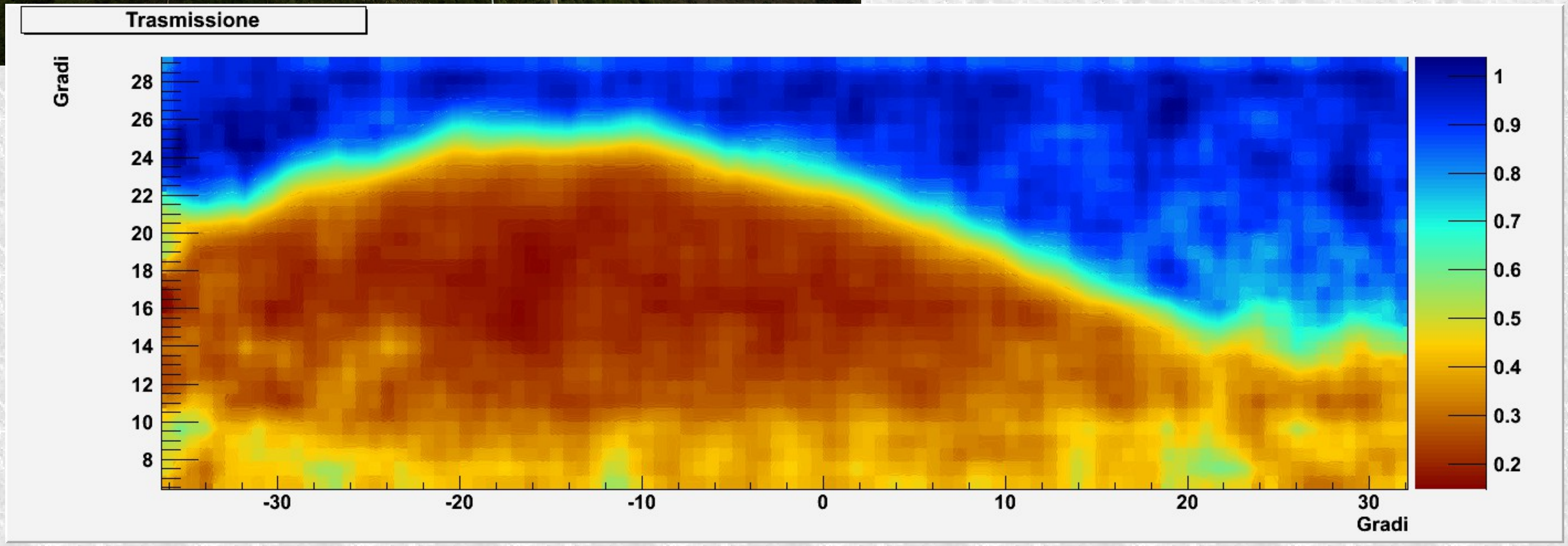
First tests, laboratory Naples





Vesuvius very difficult volcano

- Many km thickness, first SiPMs first version of the prototype telescope
  - Many problems, including having reliable power
  - Still ….. with only six days effective data taking:

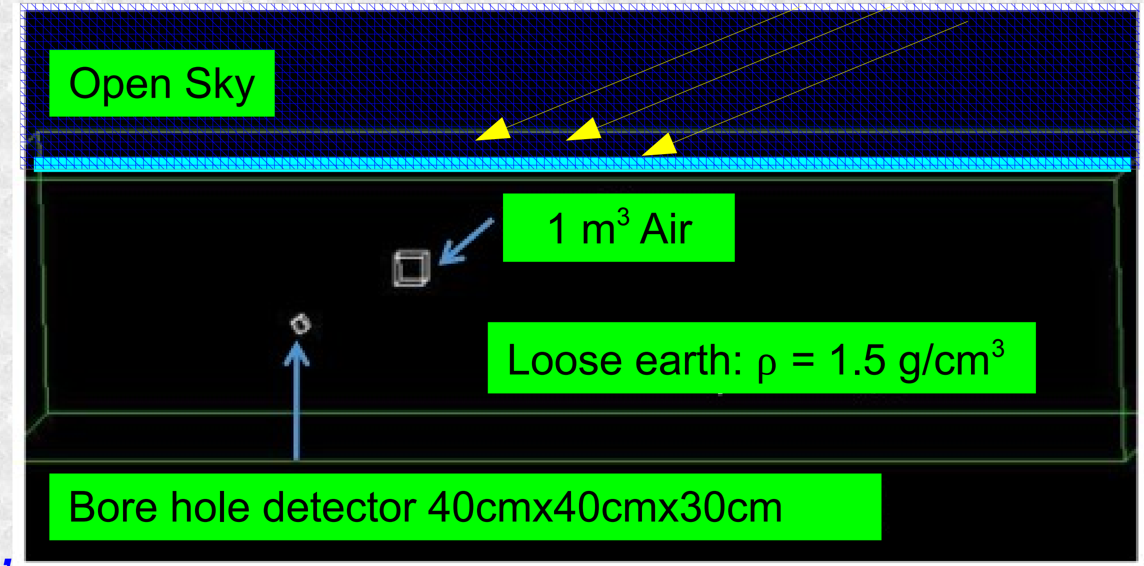


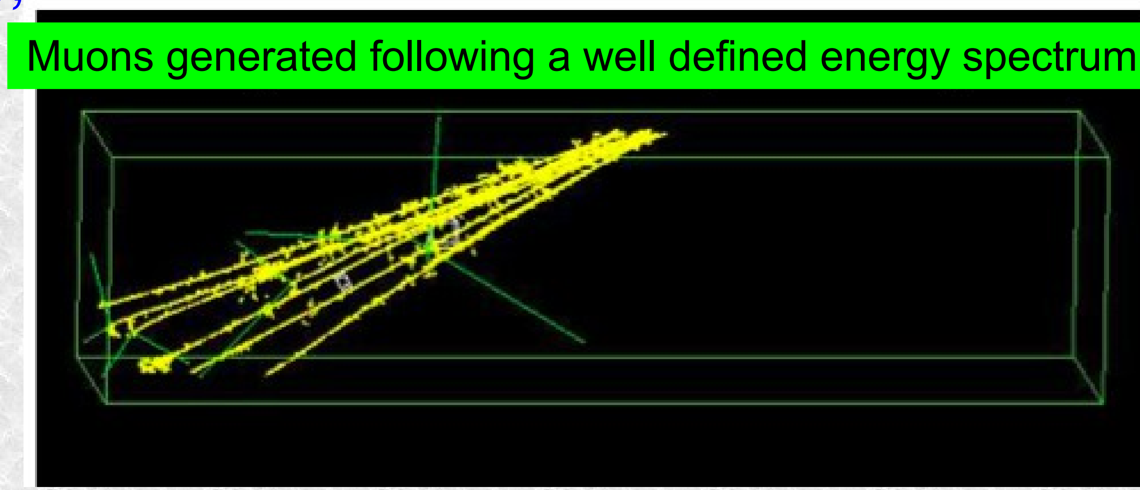
Developments

- We have contacted and have been contacted by Public Institutes and Private Enterprises, working in the fields of archeology, waste management, and geological mineral surveys.
- Seminars have been given by members of our collaboration (i.e. Giulio Saracino, Lorenzo Bonechi) illustrating the potentialities of muon radiography.
- We have also started the development of a GEANT4 framework, within which we can simulate with a "true" Monte Carlo various study cases.

Feasibility studies

It is important to understand the potential and limitations of the method also for the optimization of the detectors.
We are developing a software environment, based on GEANT4, which integrates the knowledge developed in MURAY in terms of energy spectra of muons, outside of GEANT4 and which are of fundamental importance to obtain reliable simulations.

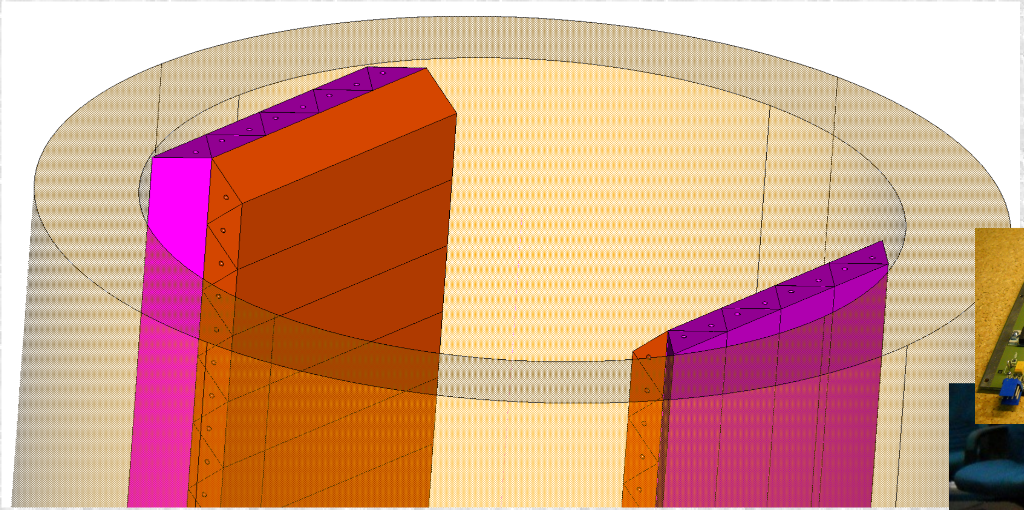


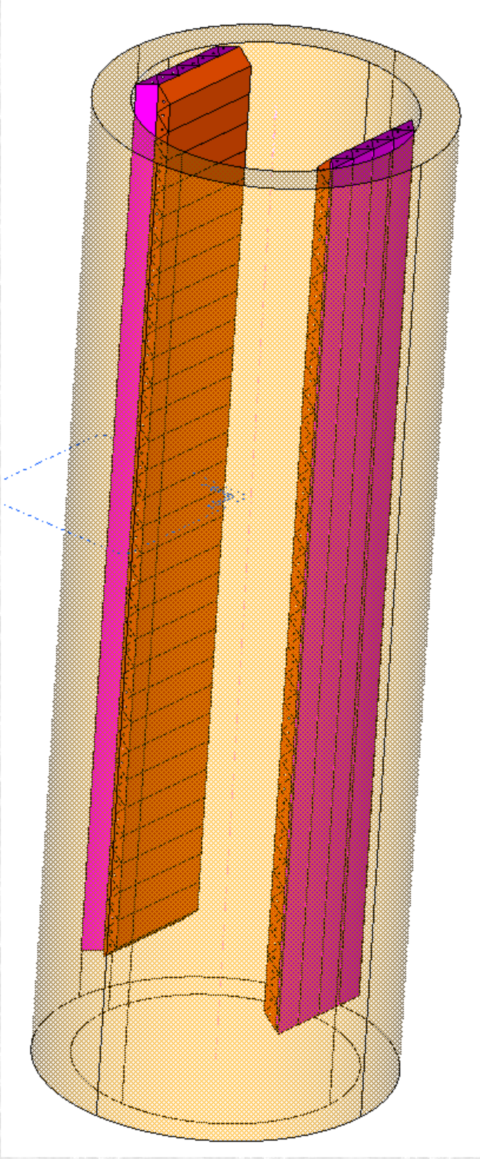


The framework developed allows a relatively easy insertion of various geometries both for the detector and the "case" under study.

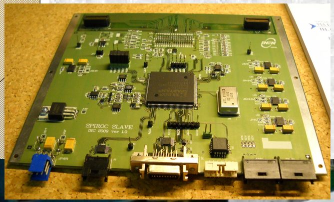
Borehole detectors

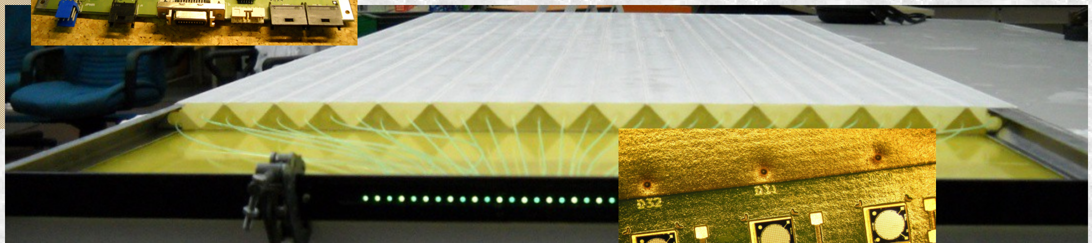
- We are designing and planning to build prototypes of two detector for boreholes and wells, with flat sides, one for medium-diameter (50cm) and one for small diameter (<30 cm).
- The technology will be primarily based on that developed by MURAY: triangular section plastic scintillators coupled to SiPMs, FEE ASIC-based EASIROC

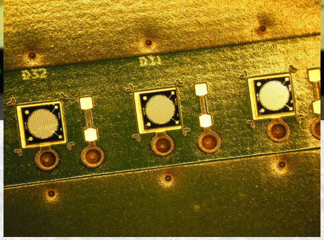


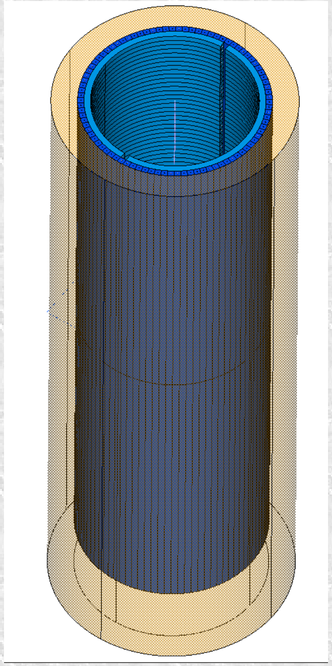


Schematic of a small diameter (30cm) telescope. 1 metre long, 140 channels.



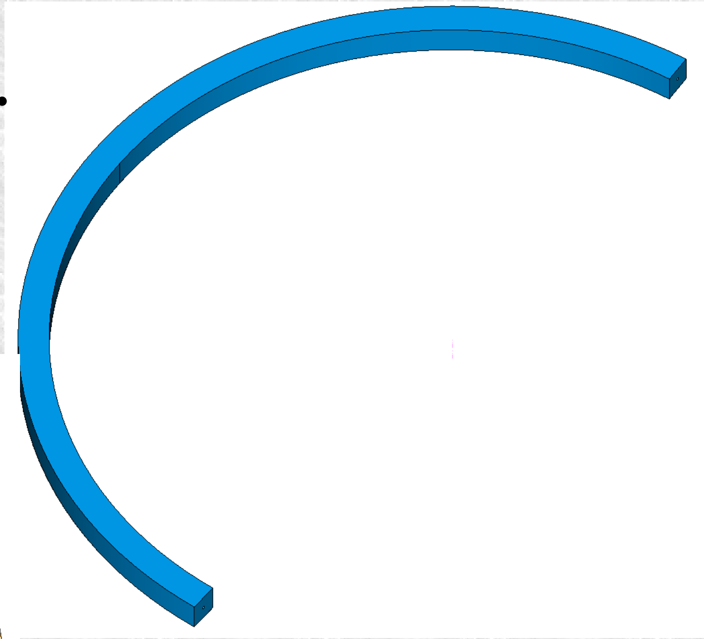


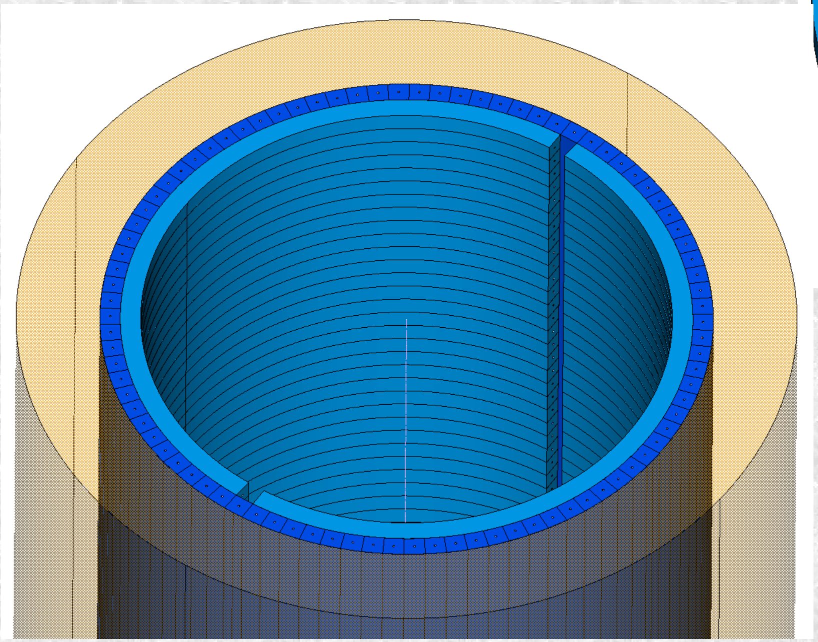


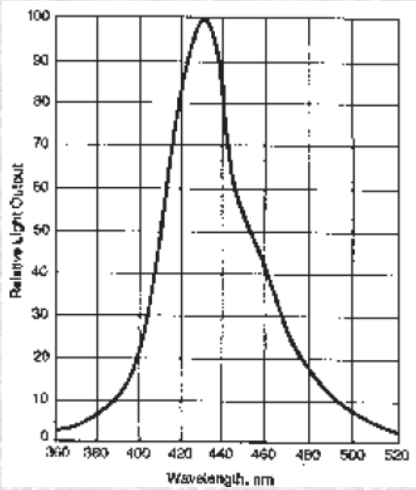


R&D for borehole detectors

- Circular scintillators ?
- Possible with die cast resins.
- Embedded WLS fibres.







Interests pursued

- Earth Sciences Department of the University of Milan
- Archeological Department of the University of Florence and University of Siena
- Region of Campania for underground surveys
- Waste management for the UK Nuclear National Laboratories

Conclusions

- The Mu-Ray telescope is now taking data
  - Performance much improved with new SiPMs from IRST
  - It will improve further (TOF) with next generation of devices
- The SPIROC based FE board is being replaced by a newer and more functional one based on EASIROC
- Cooling with Peltier elements is now in prototyping stage in Florence and Naples
- Improved DAQ with Raspberry boards in development in Naples
- Start a long measurement campaign in autumn on Vesuvius ?
  - Logistic problems
  - Power reliability

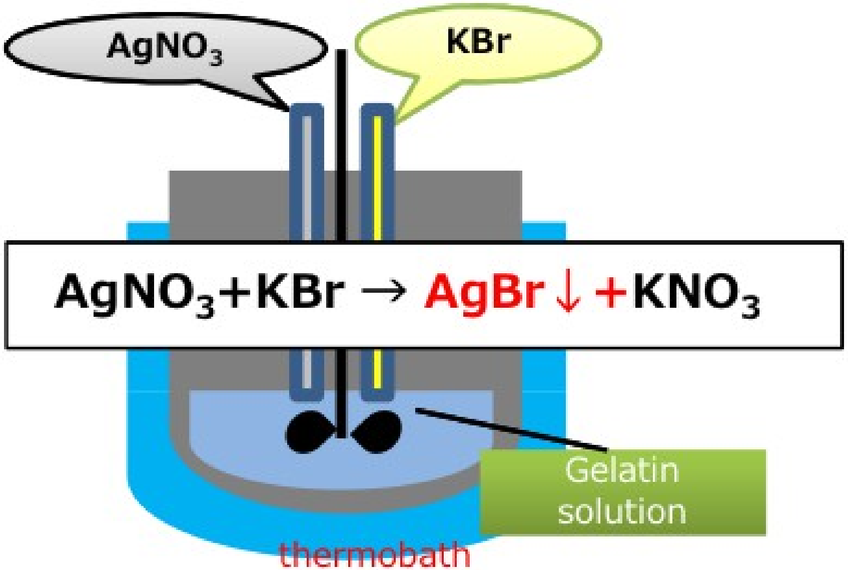
Nagoya emulsions

Tatsuhiro Naka
Institute for Advanced Research,
Nagoya University

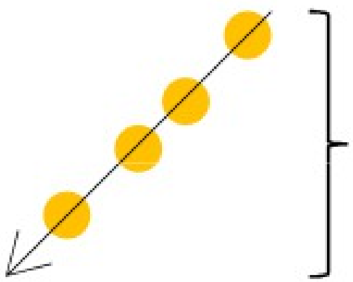
2. Production facility of fine grained nuclear Emulsion

2.1 Nuclear emulsion production by ourselves

Now, we can produce the nuclear emulsion by ourselves in Nagoya university , Japan. By this technology, various type of emulsion can be produced.



Silver halide crystals are generated via reaction between $AgNO_3$ and KBr. Here, temperature, rotation speed and addition speed is essential factor to define the crystal size.



Spatial resolution depends on crystal size and density

↓

Fine grain is essential for higher spatial resolution.