Radiografia muonica in impianti di stoccaggio scorie

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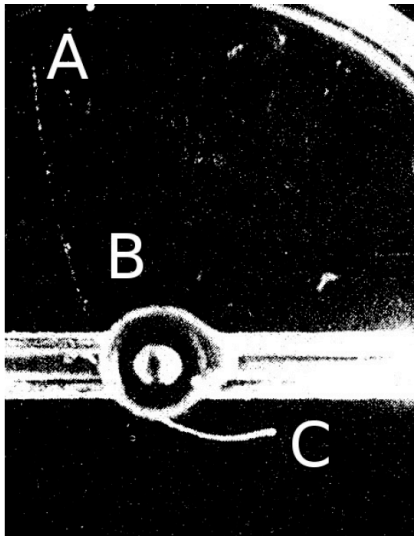
Summary

- Introduzione alla radiografia muonica
- L'esperienza MU-RAY
- Possibili applicazioni al caso Sellafield
- Conclusioni

Introduzione alla radiografia muonica elementi base:

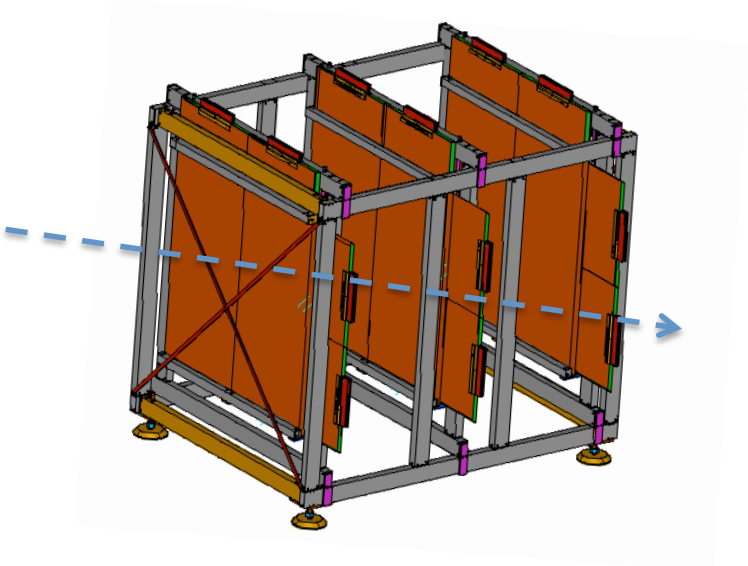
Cosmic muons:

- high energies
- high penetration capability
- Available 24/24 h (for free)



“Muon telescope”:

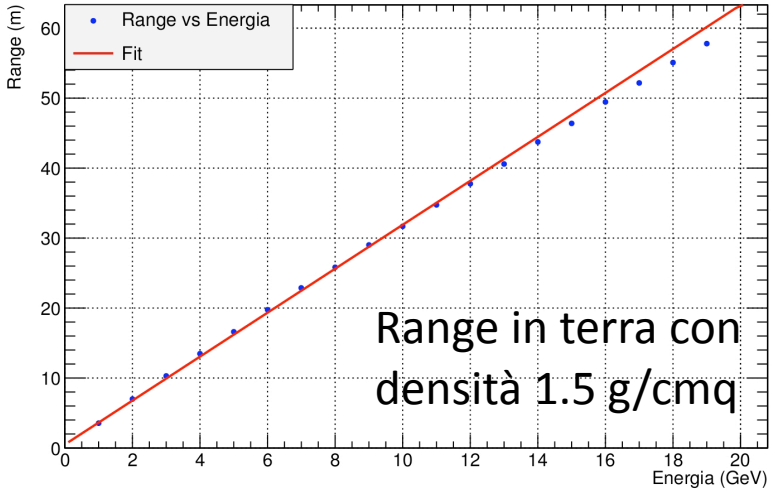
Detector able to measure the muon direction and to count them



Muons

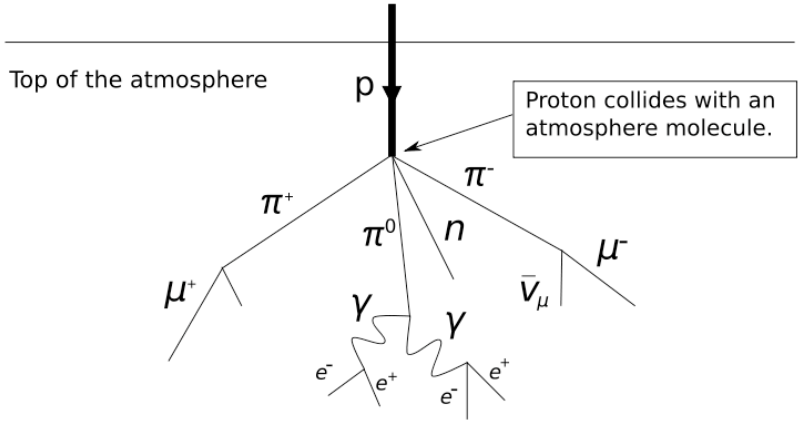
Muons:

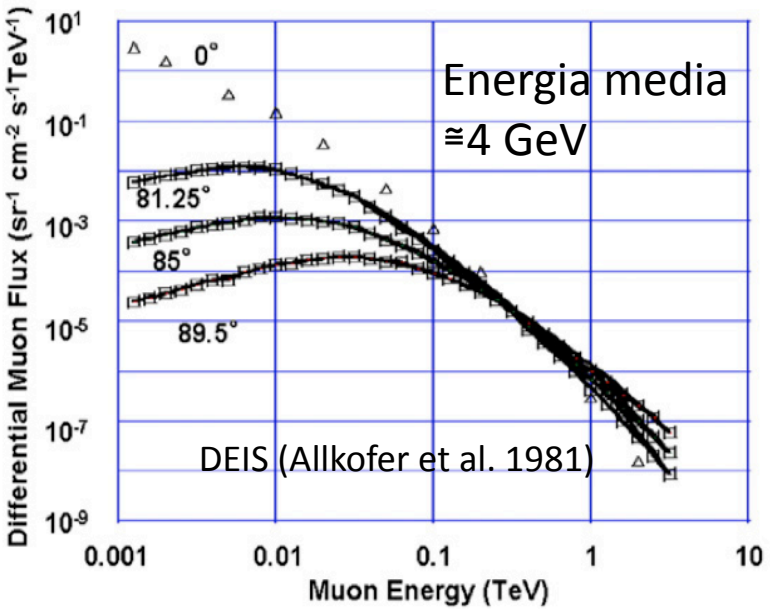
- m ≅200 m_e
- only weak and e.m. interactions
- high penetration capability



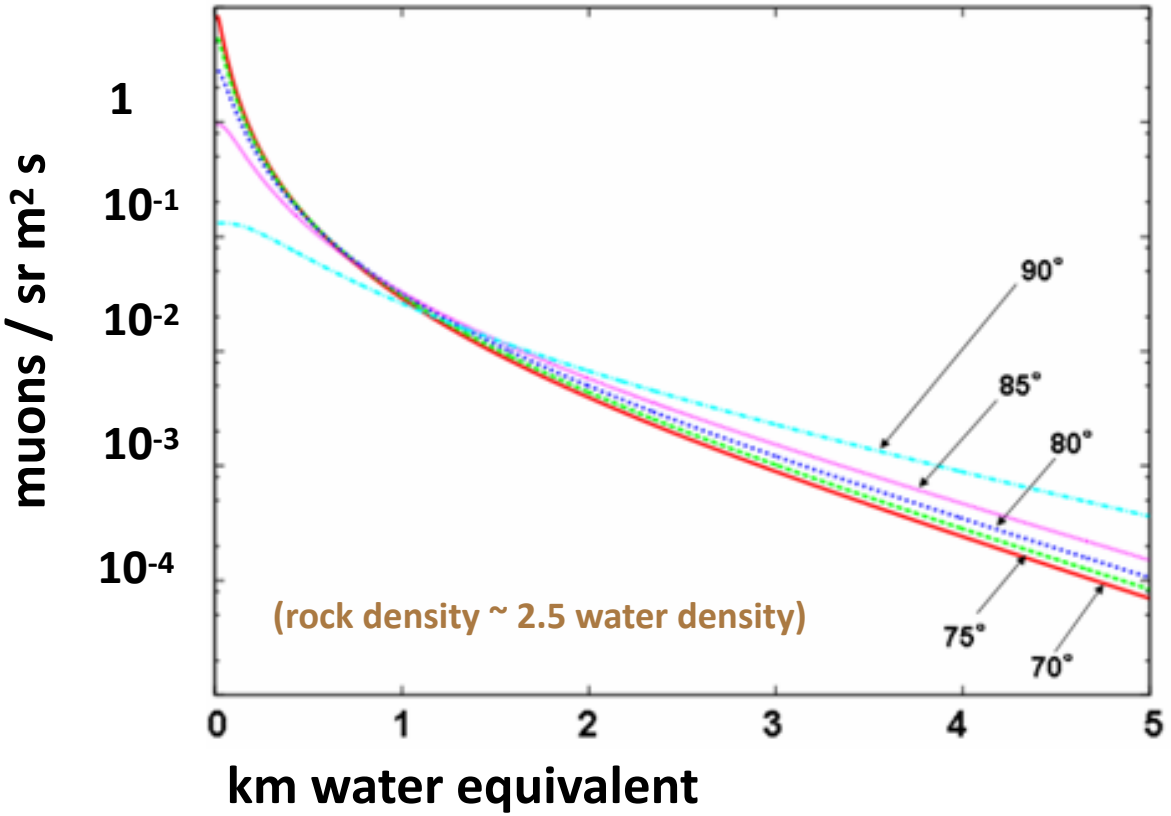
Cosmic Muons on Earth

- primary cosmic radiation (proton) hadronic shower by pion and kaon decay
- High energy





High penetration capability



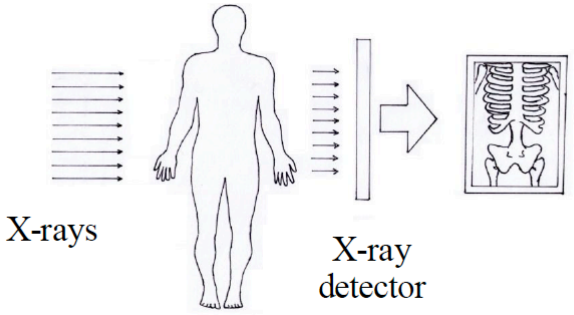
Expected rates for a $1m^2$ area detector, with 1m distance between planes:

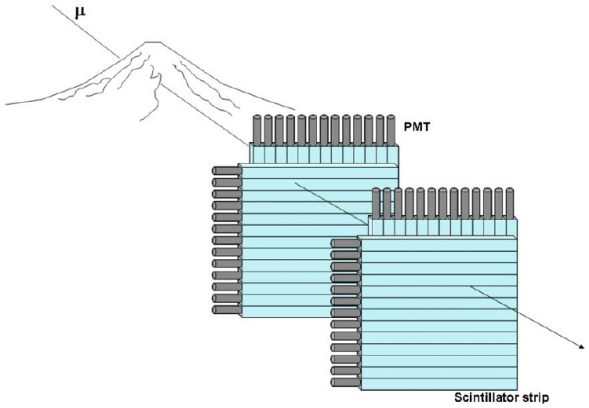
10^3 events/day for 2 km of W.E.

10^2 events/day for 4 km of W.E.

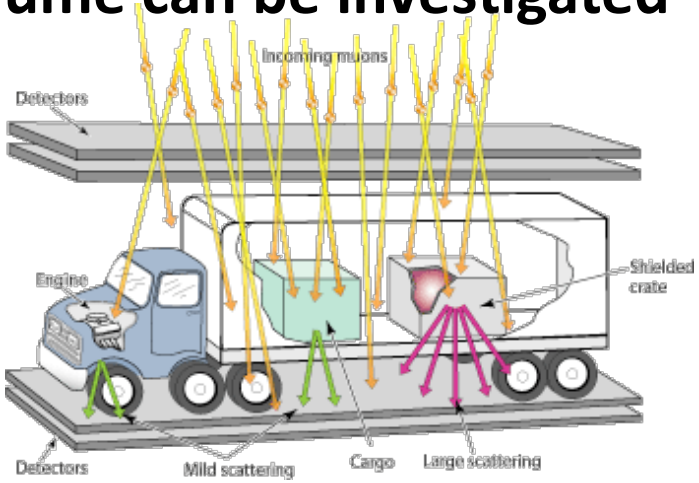
Muon Radiography

By absorption: applicable to large size objects (i.e. volcanoes)
one detector needed



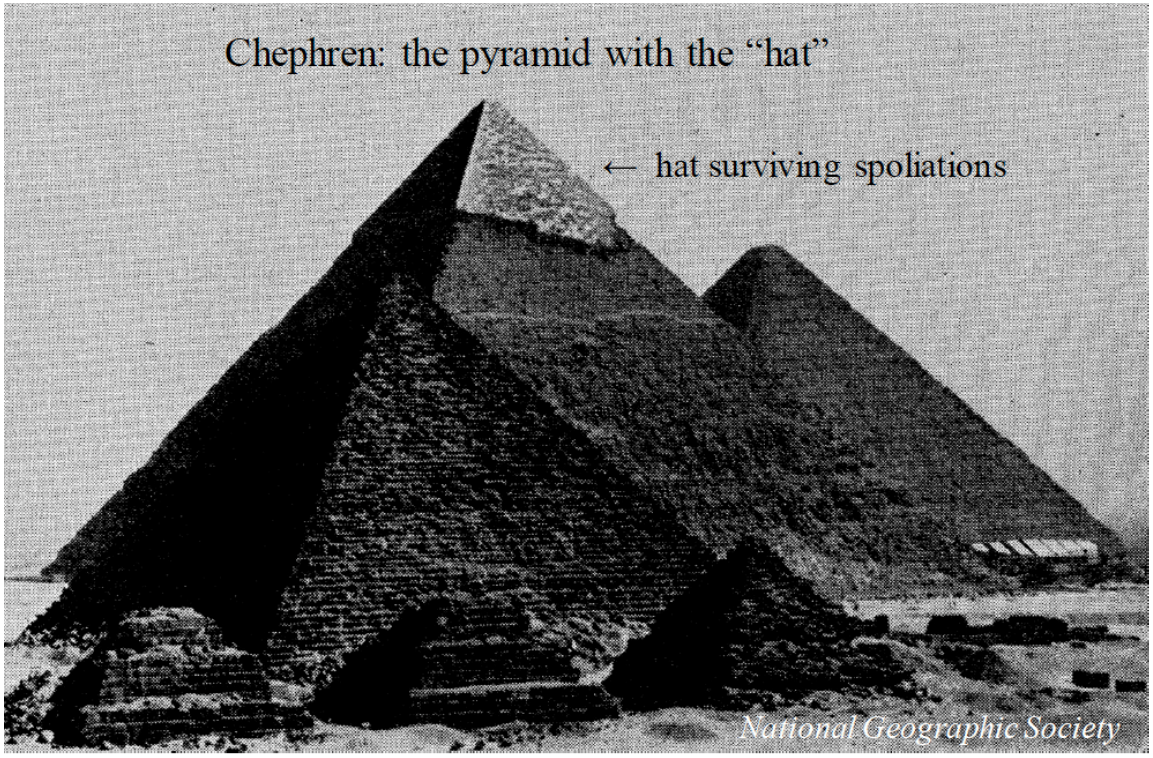


By multiple scattering: sensitive to very small quantity of high Z material
two detectors needed, smaller volume can be investigated

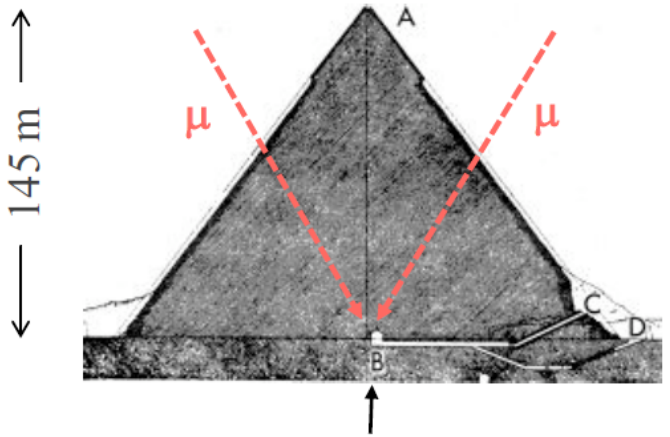


Application: archeology

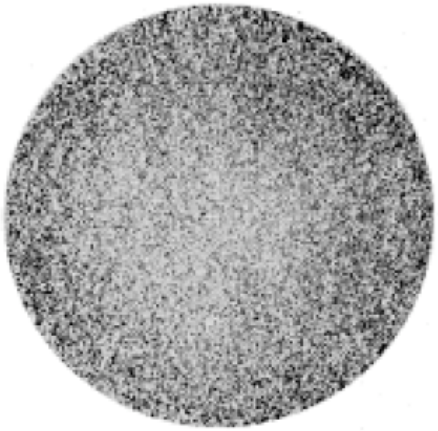
Alvarez, he searched for a possible hidden chamber in the second Chephren pyramid (1969-1970)



No evidence of an unknown chamber found.
(within a cone of half-angle 35° from the vertical, corresponding to a 19% of the pyramid volume

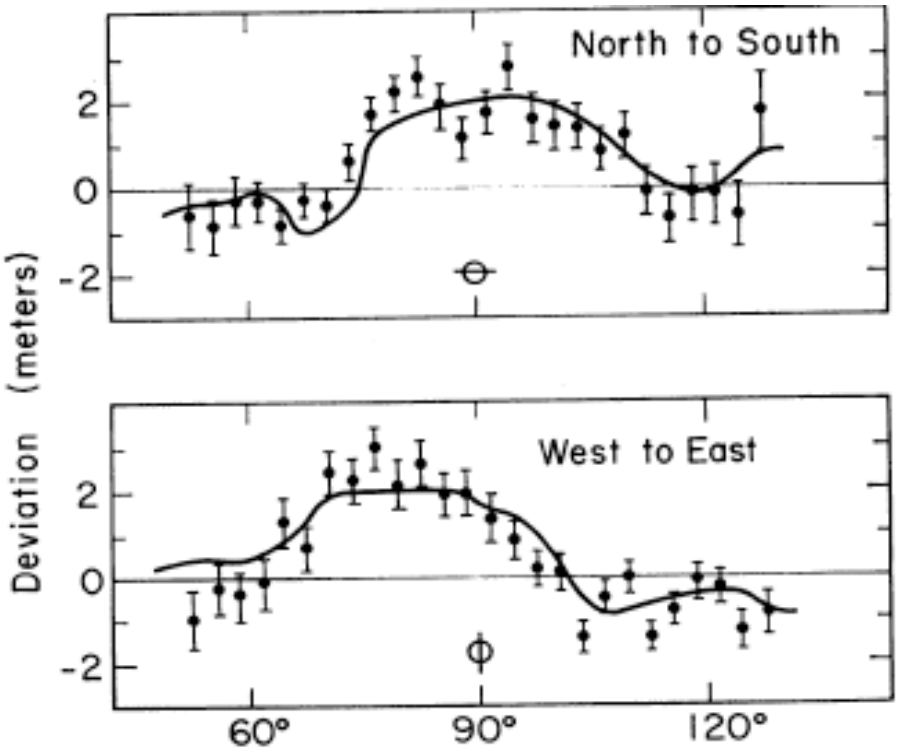


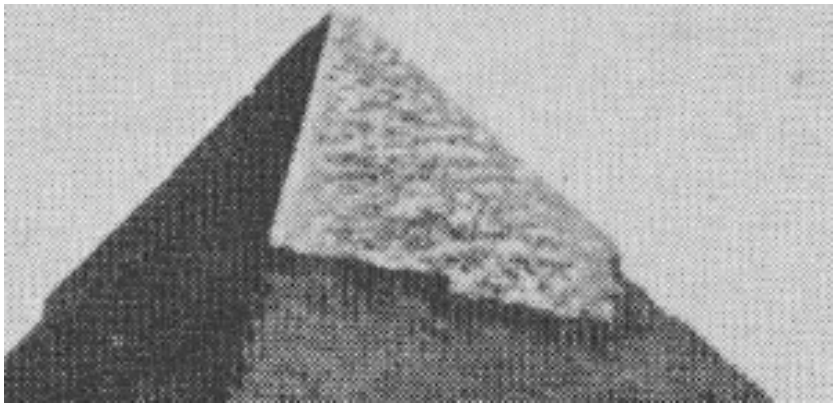
Telescope in Belzoni chamber



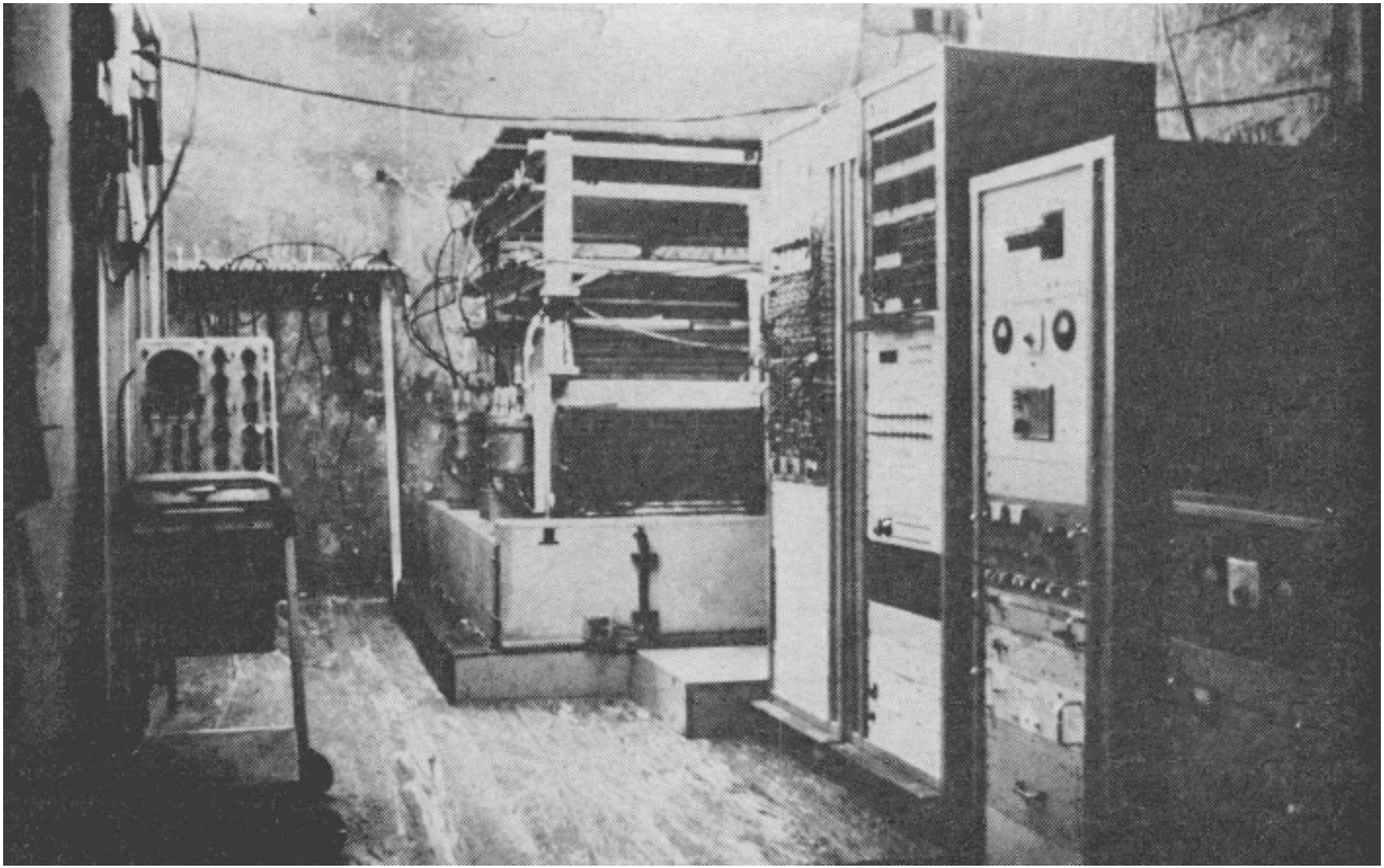
reconstructed and corrected data

2% density variation sensitiveness on 100 m of limestone





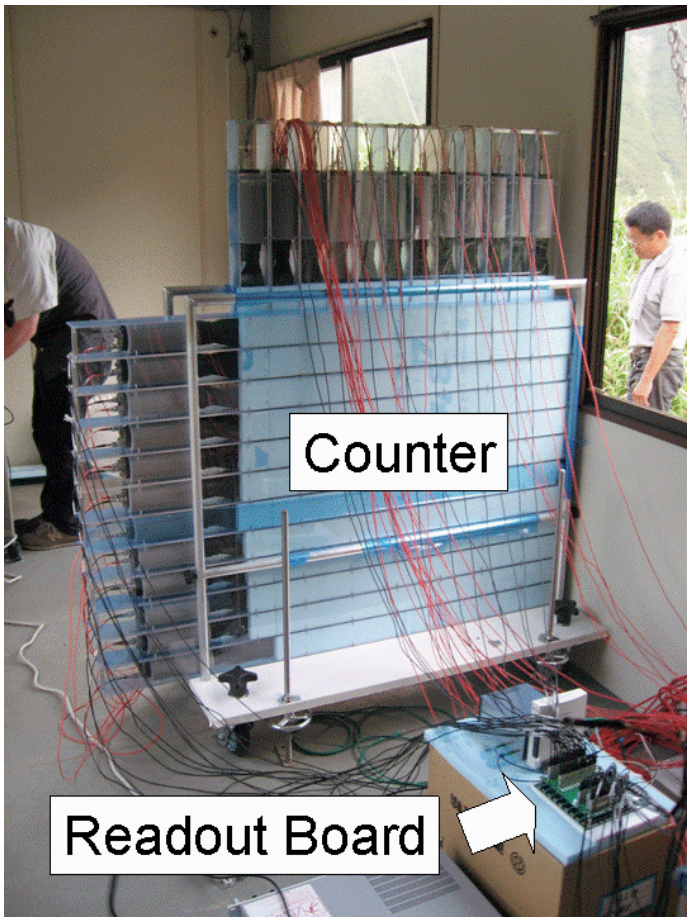
Alvarez equipment

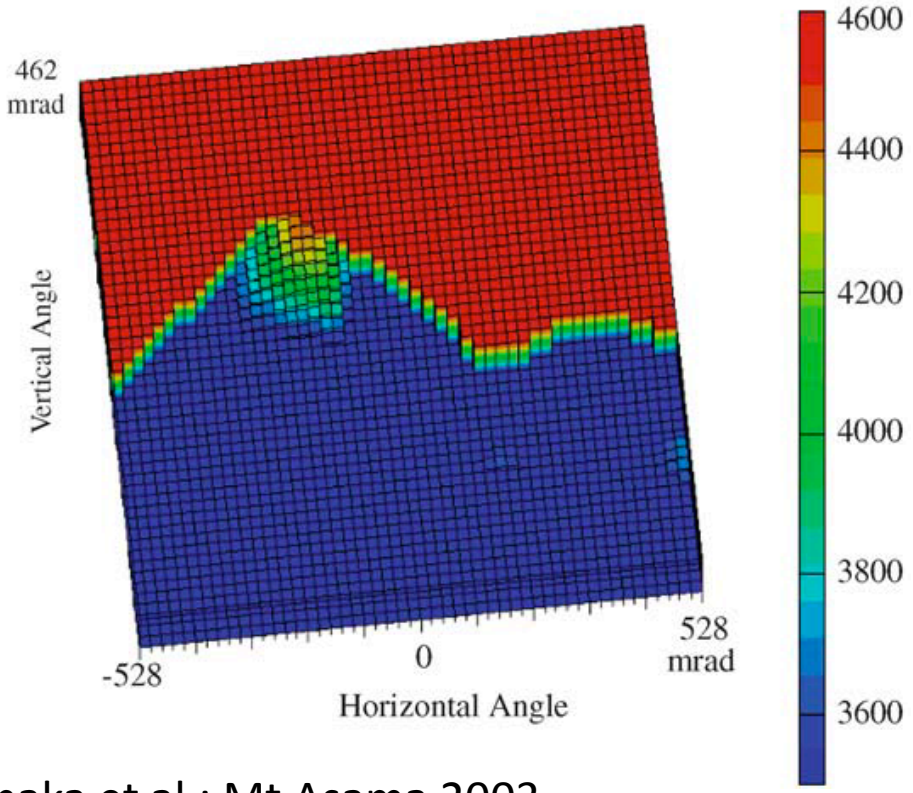


Technology progresses in detector

Current technology allow for better, low-power, remotely controlled and transportable detectors

Possible use in volcanic areas: first generation of muon telescopes





Tanaka et al.: Mt Asama 2003

Detector requirements:

- Transportability and easy-installation
- Low power consumption
- Low human presence: high reliability + remote controls
- Low noise and high background suppression
- High efficiency (especially for more than two planes)

Good spatial resolution and low costs are welcome...

The MU-RAY Project

The MU-RAY project started in 2009 with goals to introduce this methodology in Italy and to improve the performances of the first generation detectors.

- Improve the space resolution
- Increase the segmentation
- Introduce a third plane for background suppression
- Time of flight measurement for background suppression

Preserving the main features for these detectors:

- Low power consumption
- Transportability

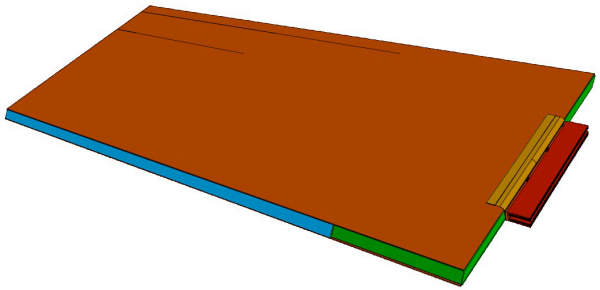
The project is funded by INFN with the Naples and Florence divisions involved.

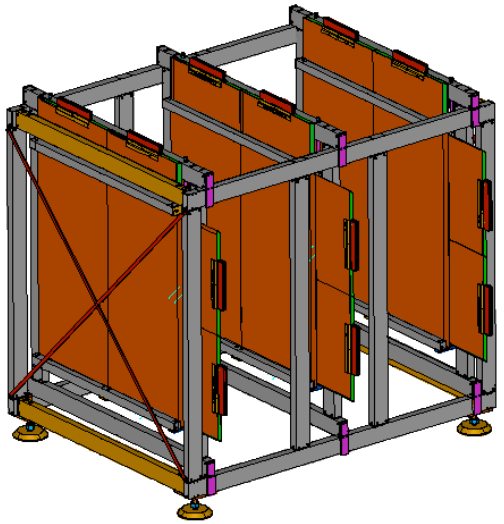
Other Institutes and Universities involved are:

- INGV- Osservatorio Vesuviano
- ERI-Tokyo University
- Florence and Naples Universities
- Fermilab
- LAL-Orsay

The MU-RAY Detector

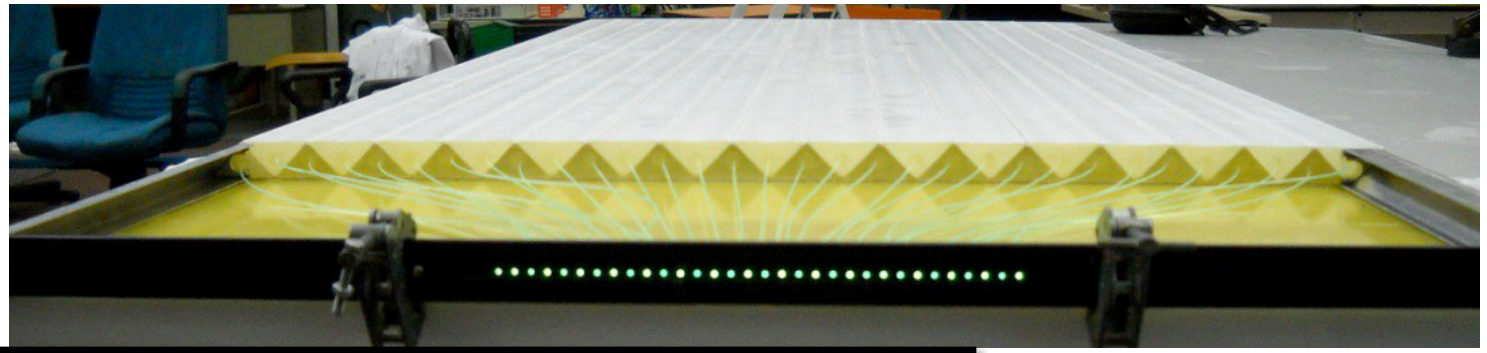
The detector was designed with three x-y planes assembled with 12 modules. Each module is 1m long and half meter large, with a weight of ≈18 kg, so that they can be carried by hand

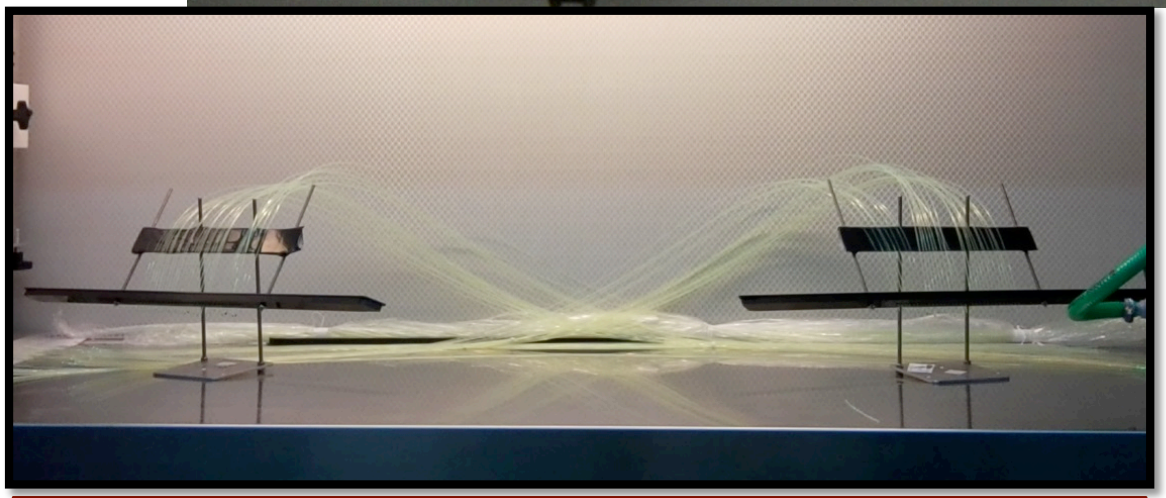
12 x  =

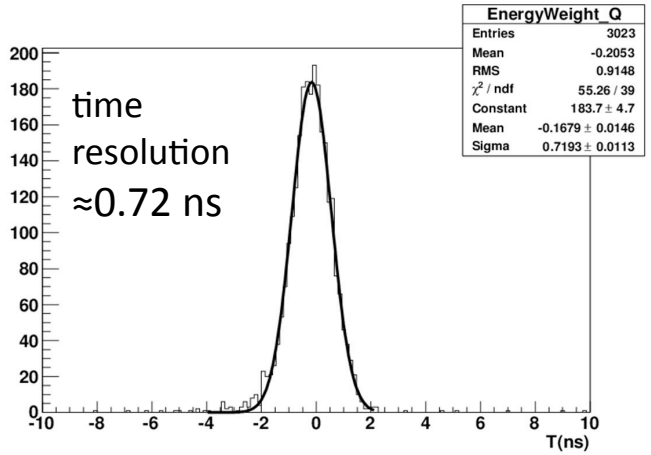


The module

The module consists of 32 scintillator bars with triangular shape and with WLS fibers collecting the light to SiPM. One fiber edge is mirrored with sputtered Al. The other edges are grouped on a custom connector for the photo-sensor coupling.







BCF92 multi-clad: fast emission time (≈ 2.7 ns) mirrored at one side.

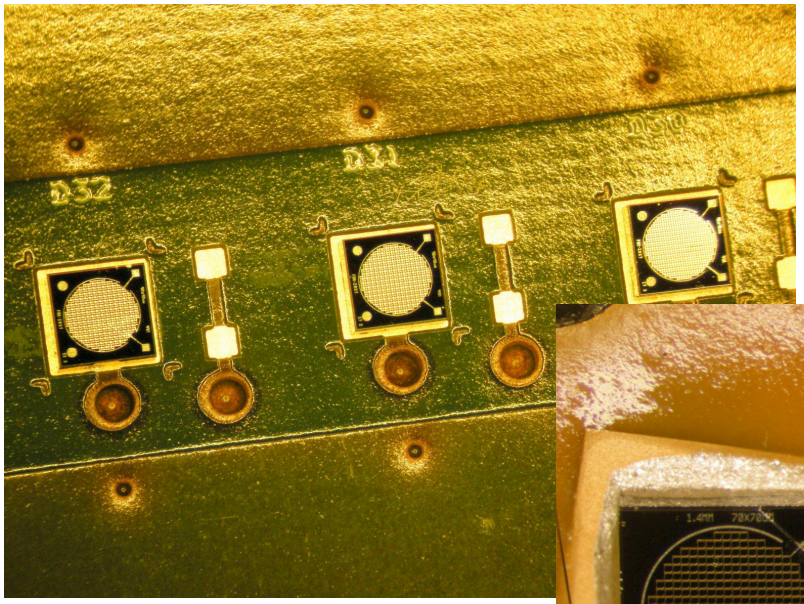
Sub nanosecond time resolution achievable: muons time of flight!

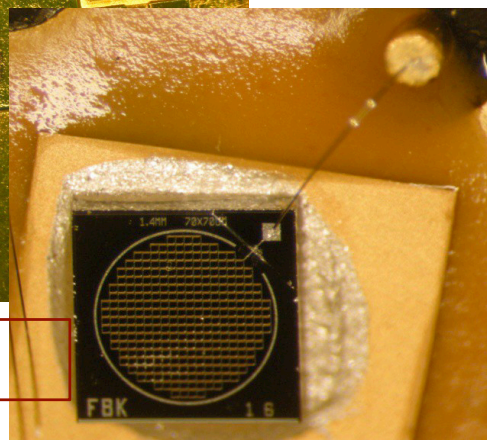
Silicon Photomultipliers

Light from WLS is converted in electric signals by SiPMs

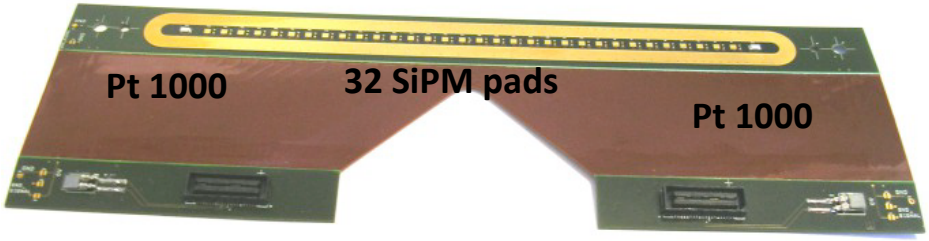
- **high level of integration and miniaturization: ideal to couple with fibers ☺**
- **light, robust and low power consuming: fine for muon radiography ☺**
- **temperature dependences: to be controlled or compensated ☹**

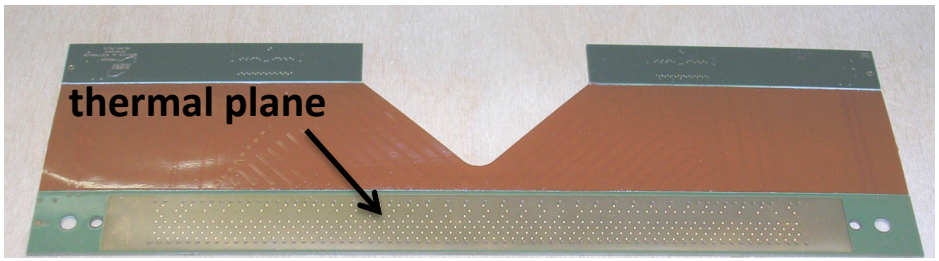
SiPMs are mounted (die) on a custom PCB allowing thermal control





Hirst-FBK 1.4 mm, 70 μm



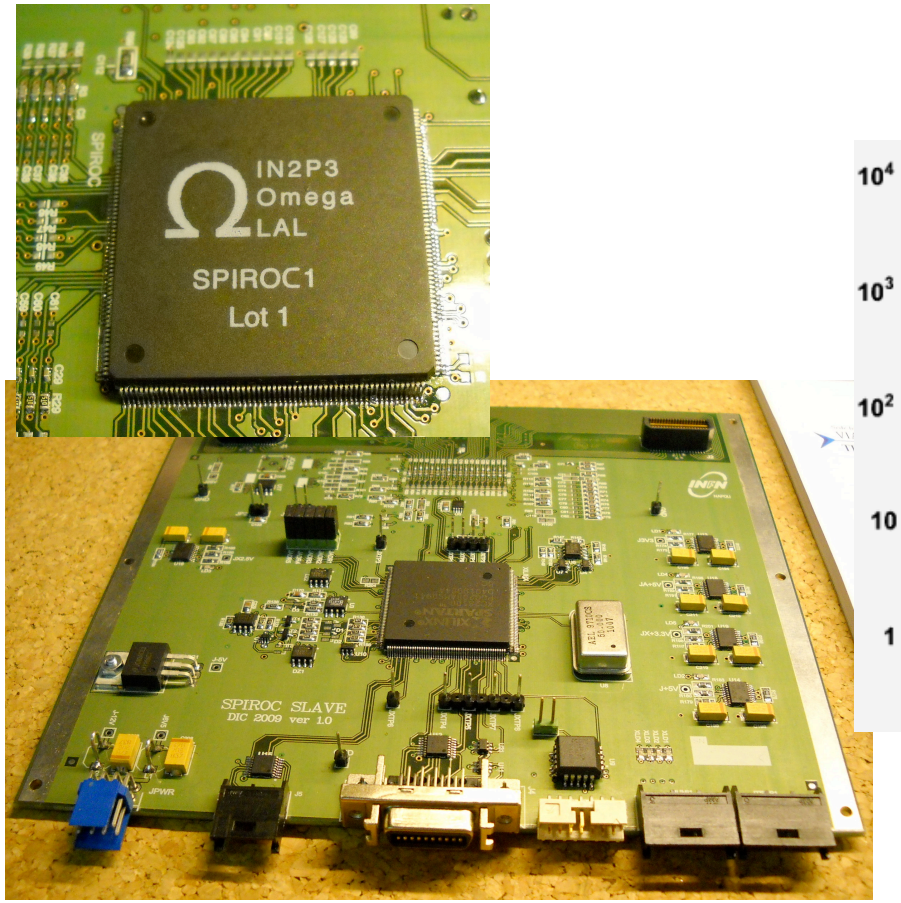


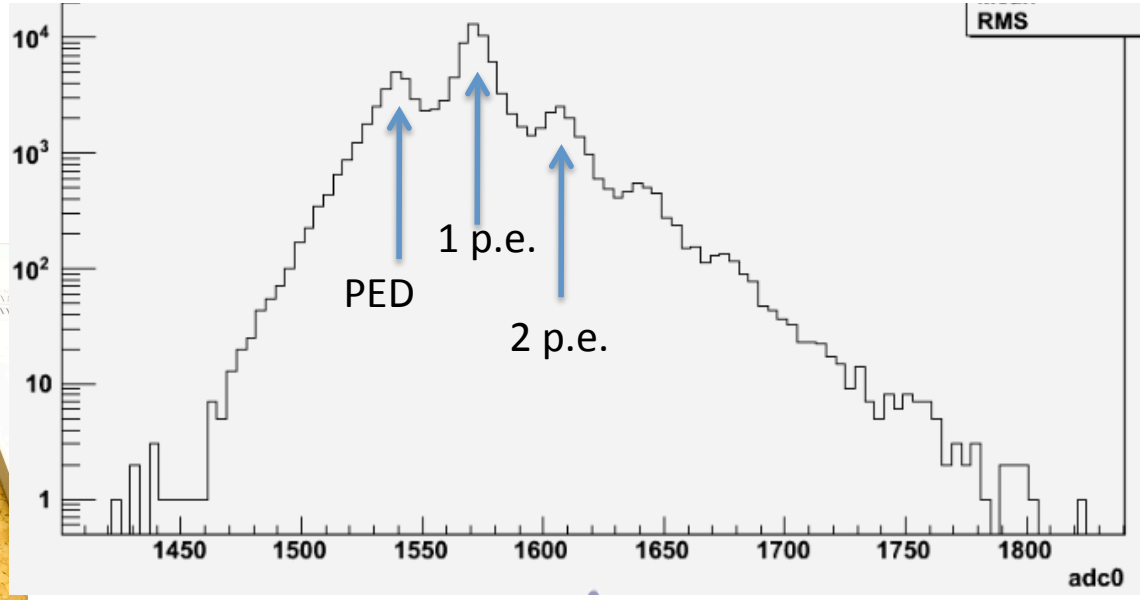
F.E.E. and DAQ

The FEE is based on SPIROC chip, developed by OMEGA group in ORSAY.

Main features

- 36 channels/chip (32 used)
- Individual bias voltage tuning (0÷4.5 V ;17 mV step)
- Fast discriminator response (Logic OR of all ch.)
- individual Sampling and Hold of the signals stored in analog memory



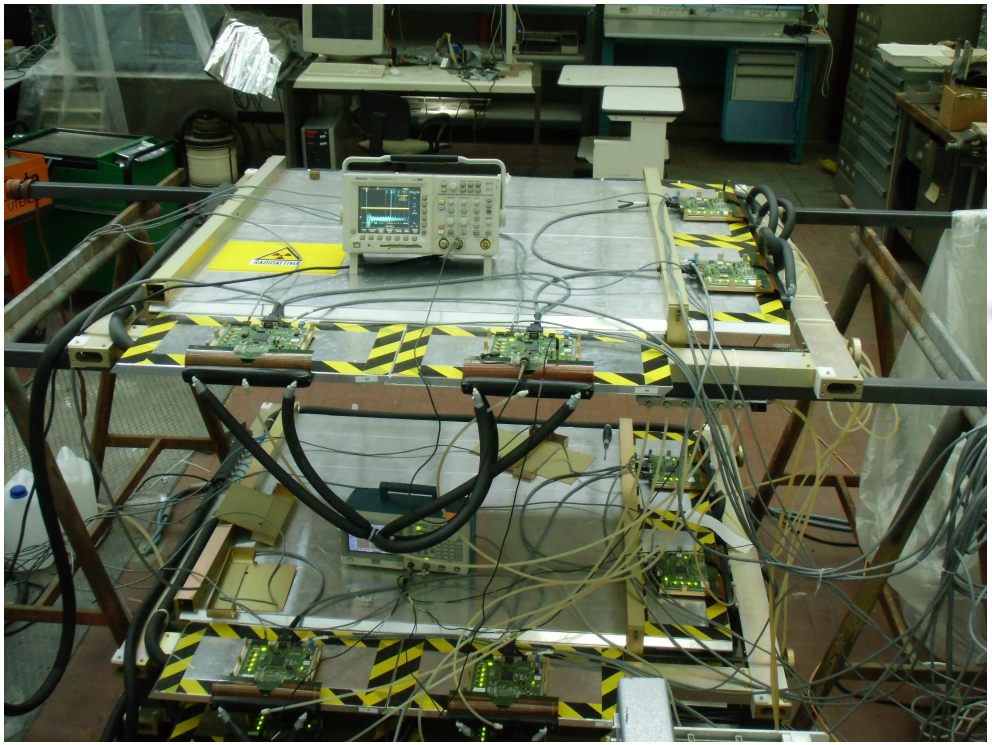


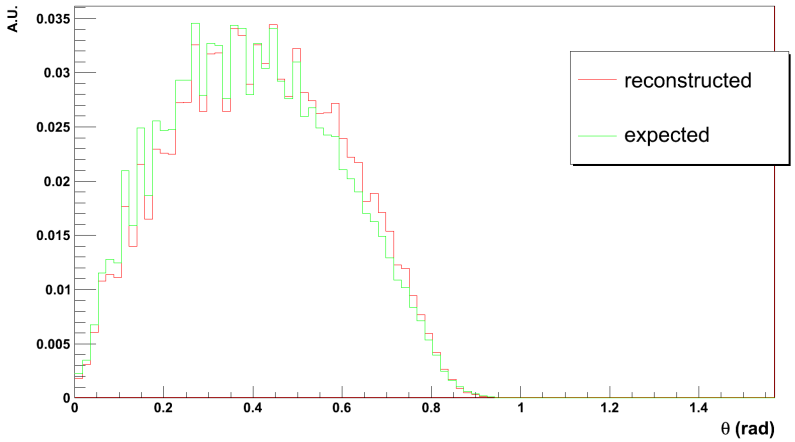
Dark noise spectrum

The MU-RAY detector

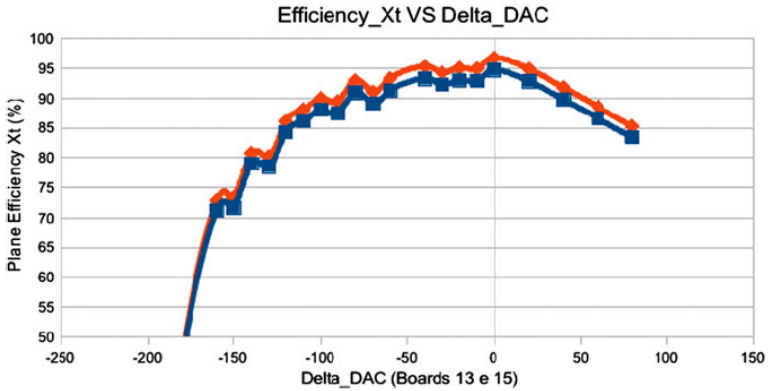
Commissioning

The detector was mounted with planes in horizontal for efficiency and reconstruction studies.





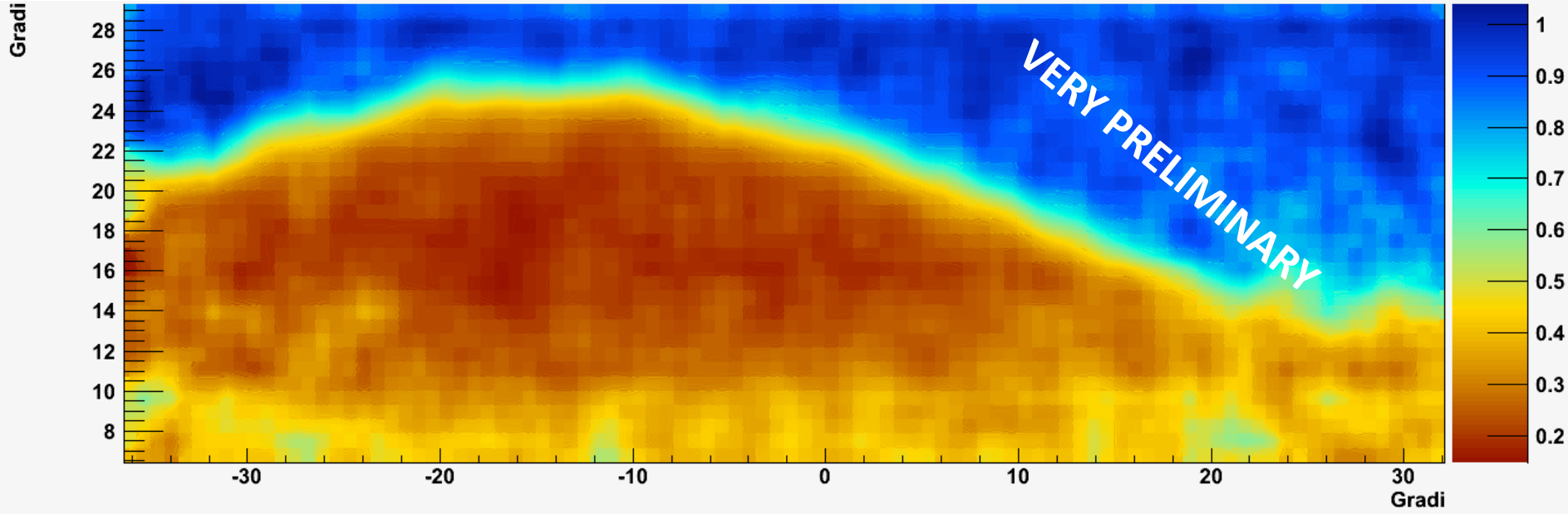
reconstructed and simulated cosmic zenith angle distribution



One plane efficiency as function of discriminator threshold

First data from Vesuvio

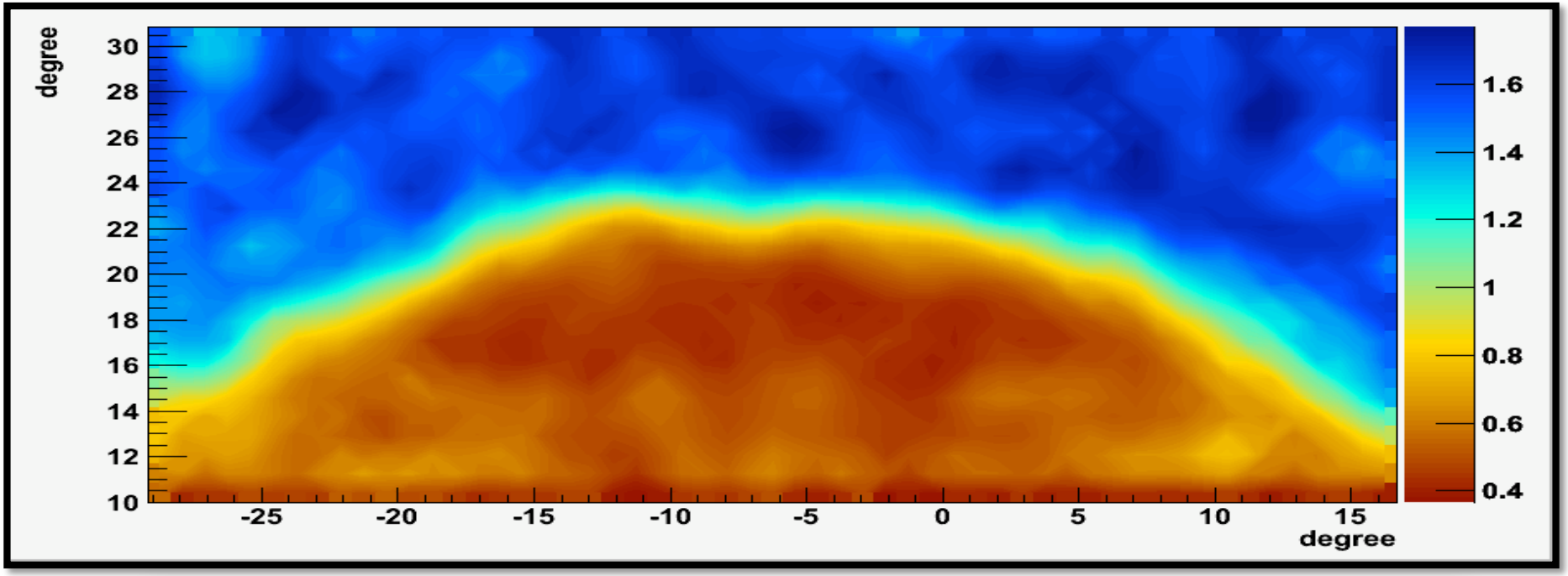
Transmission



Installazione al Puy De Dome (Clermont Ferrand FR) Giugno/Luglio 2013

ToMuVol

The data acquisition at Puy de Dome (in corso)



Applicazioni in impianti di stoccaggio scorie: Sellafield UK Legacy Nuclear Waste

Measuring 2 square miles, over two hundred nuclear facilities and over one thousand buildings. 10.000 workers

The primary mission on the site is risk and hazard reduction

1.5 bn/year £ funding.

MAGNOX REPROCESSING PROGRAM

The Magnox (Magnesium non-oxidising) type nuclear reactor was the first type to generate nuclear electricity in the UK.

A total of eleven Magnox power stations were commissioned during the 1950s, 60s and early 70s.

Uranium fuel surrounded by a magnesium alloy 'swarf' cladding. Before reprocessing, irradiated Magnox fuel must be stored for at least 180 days in ponds to allow short lived fission products to decay.

Then the swarf is stripped from the fuel rod in the Fuel Handling Plant (decanning).

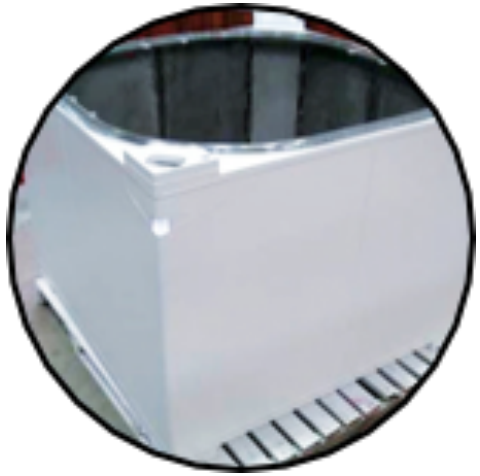
The fuel is then transported to the Magnox Reprocessing Plant

A facility was built to hold irradiated de-canning wastes (Magnox swarf and miscellaneous intermediate level waste)

MAGNOX REPROCESSING PROGRAM

The swarf stripped from the fuel elements is Intermediate Level Waste (ILW). Shown is a cross section view of ILW which has been grouted in cement for long term storage

The ILW is stored in 500-litre stainless-steel waste containers.



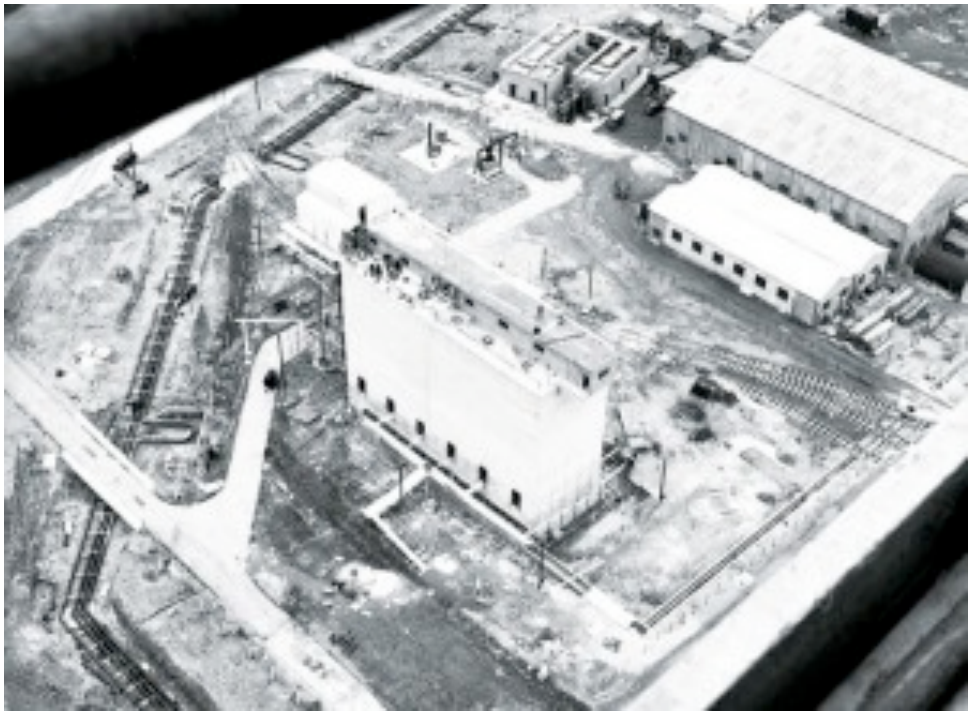
Durante il decanning un porzione della barra si può staccare e viene involontariamente incluso nel contenitore.

Magnox Swarf Storage Silos (MSSS)

- Constructed during the 1960's through to the 1980's
- Constructed to hold irradiated decanting wastes (Magnox swarf primarily)
- Received waste until 2000

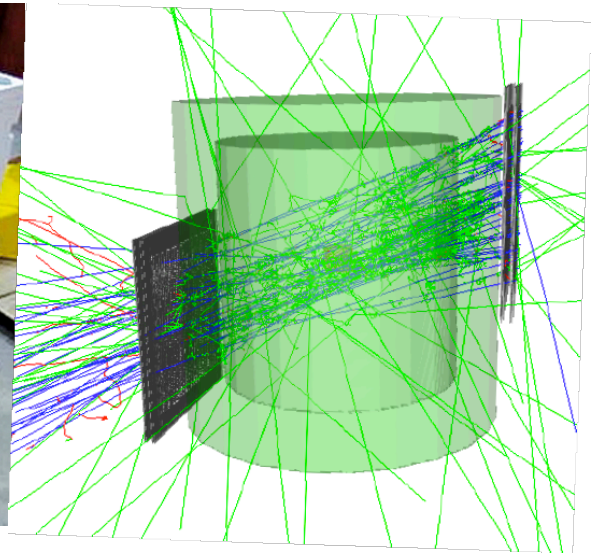
Pile Fuel Cladding Silo – History

- Commissioned in 1952 – the first ILW (Intermediate Level Waste) store to be built at Sellafield



- Silo full by 1964 – Waste Tipping operations cease

The Three possible scenarios



Scenario #1: 3m3 box Scenario

#2: Small silo Scenario

#3: Large silo

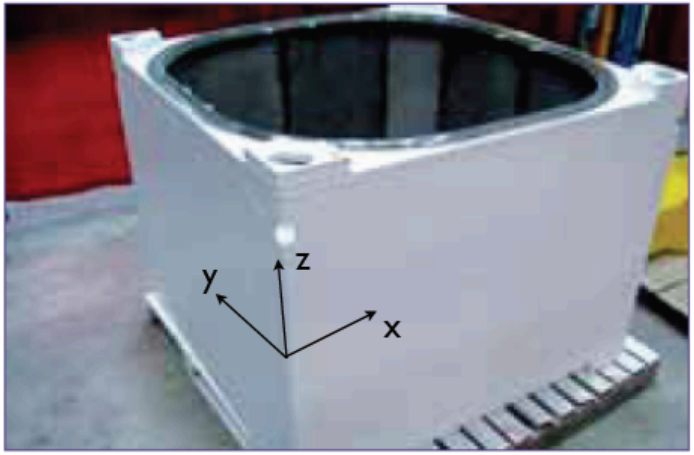
Per lo scenario 1 la tecnica basata su M.S. sembra essere promettente.
L'università di Glasgow sta portando avanti un programma in tal senso

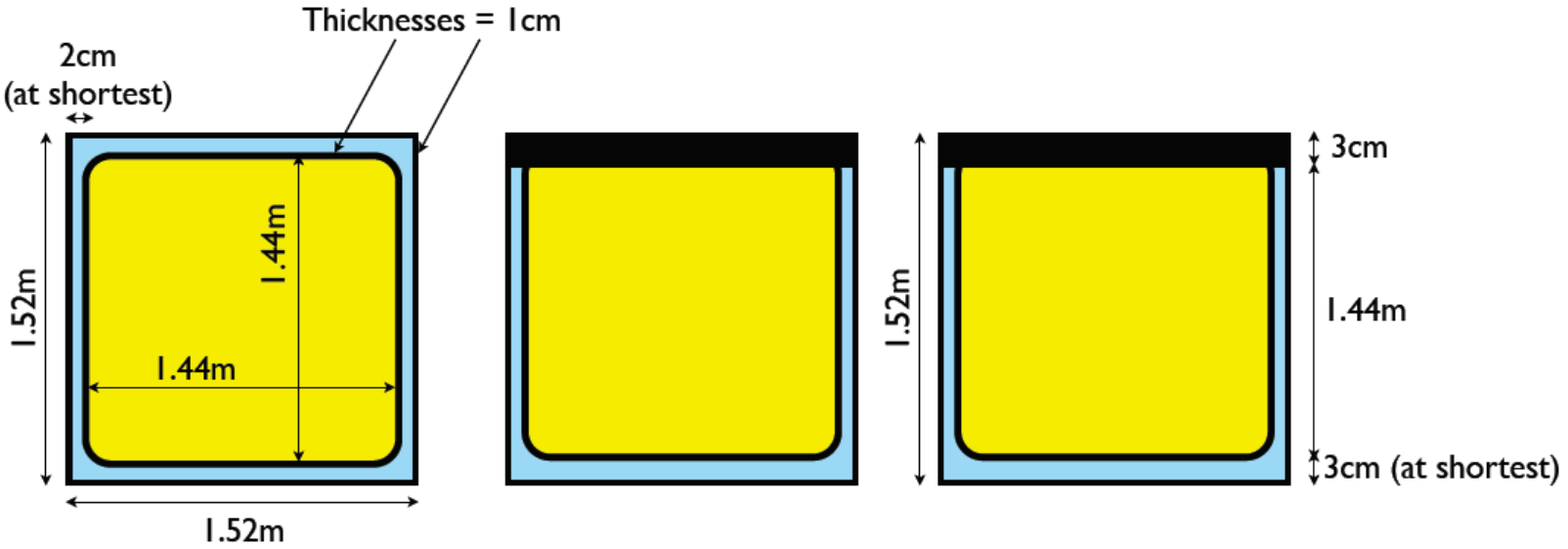
Per gli scenari 2 e 3 la tecnica basata su M.S. potrebbe essere di difficile applicazione.
Per questo motivo siamo stati contattati da U.K. National Nuclear Laboratory per valutare l'uso della radiografia muonica per assorbimento.

Sellafield: studi di fattibilità

Scenario #1: 3m³ Box

(Magnox Swarf & miscellaneous ILW)





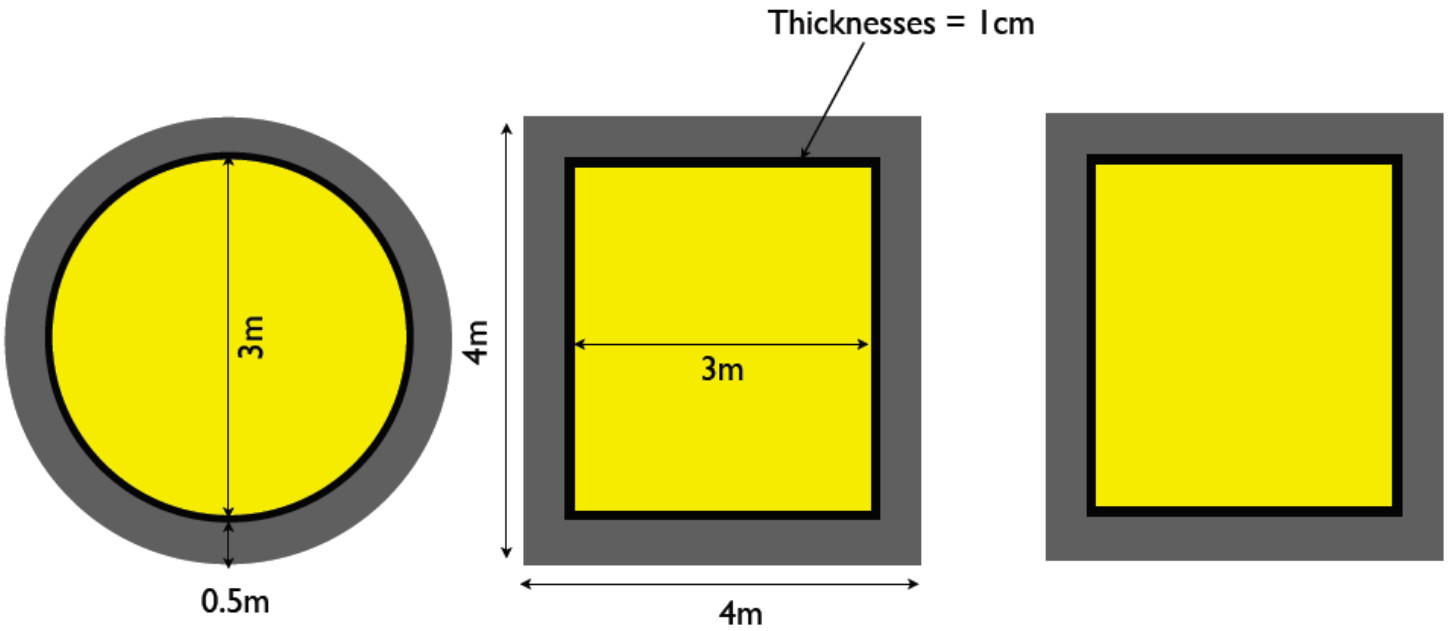
Above: Dimensions at (0,0,0) in the z, x and y planes

Colour Key: = Magnox Swarf & Concrete = Cast Iron = Air = Uranium

Sellafield: studi di fattibilità

Scenario #2: Small Silo

(Magnox Swarf & miscellaneous ILW)



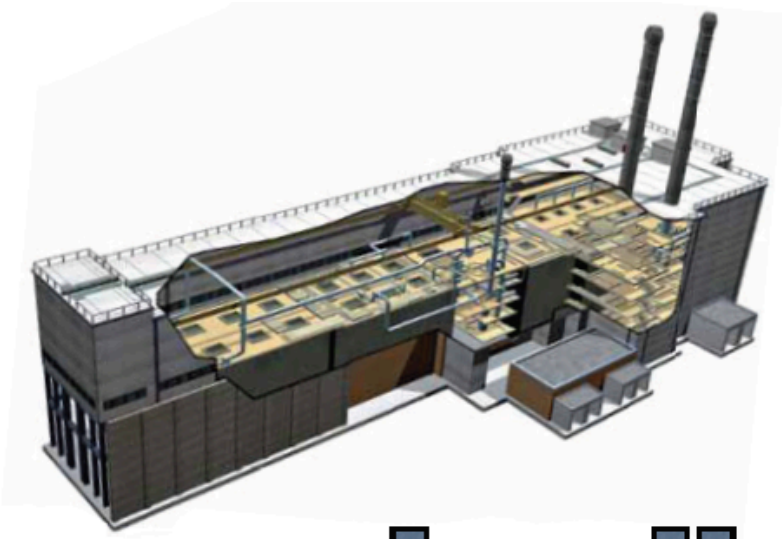
Above: Dimensions at (0,0,0) in the z, x and y planes

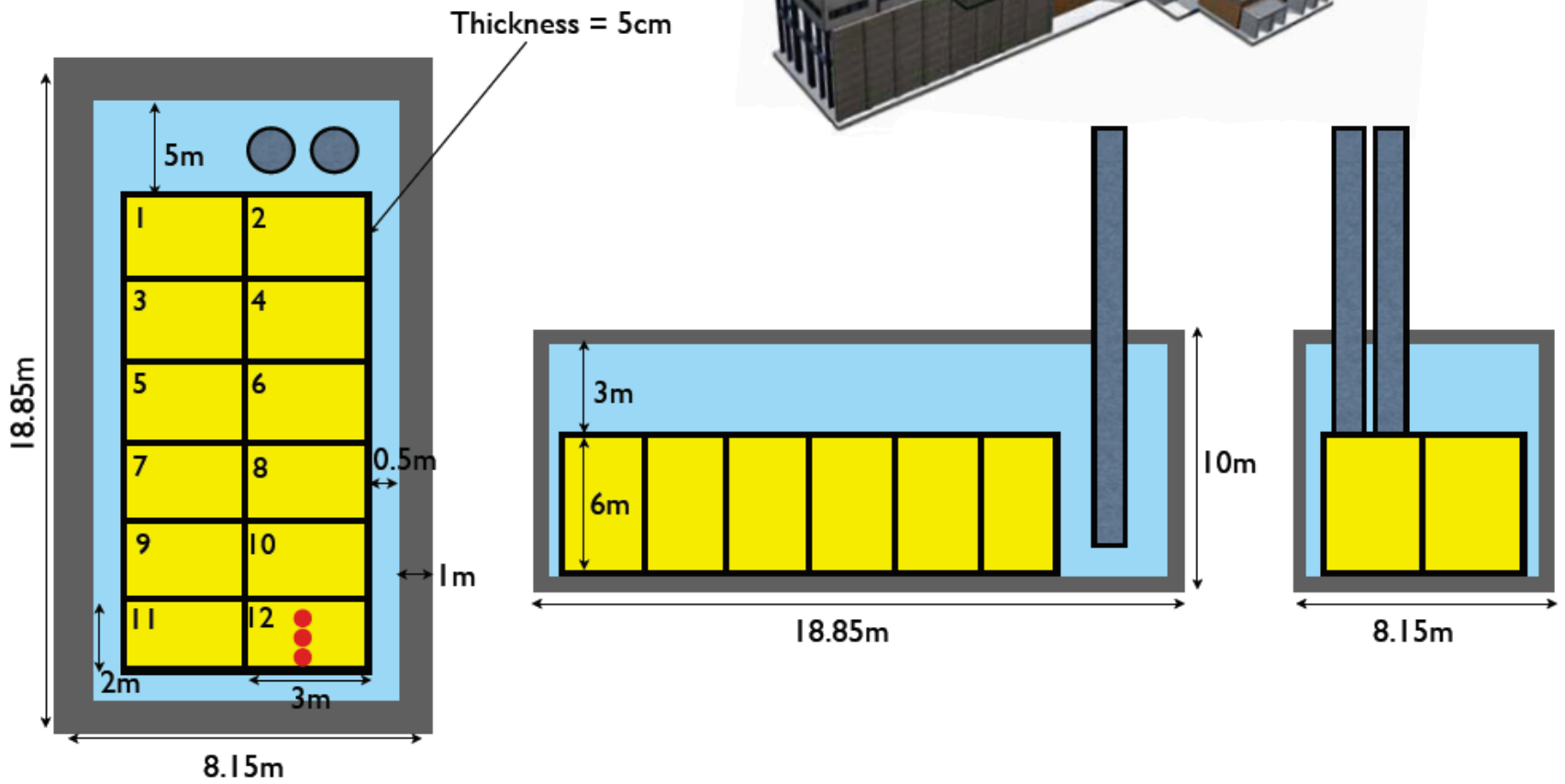
Colour Key: = Magnox Swarf & Concrete = Stainless Steel = Reinforced Concrete = Uranium

Sellafield: studi di fattibilità

Scenario #3: Large Silo

(Magnox Swarf & miscellaneous ILW)



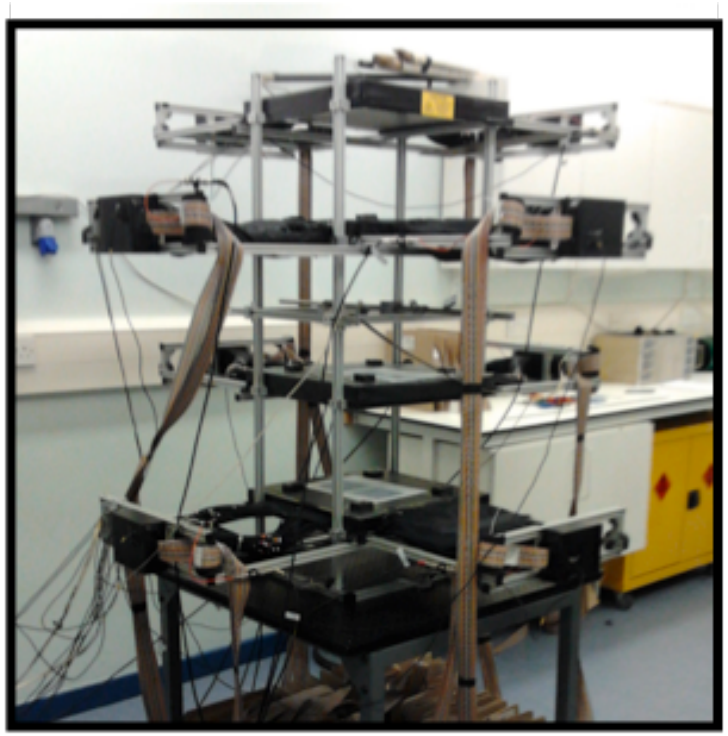


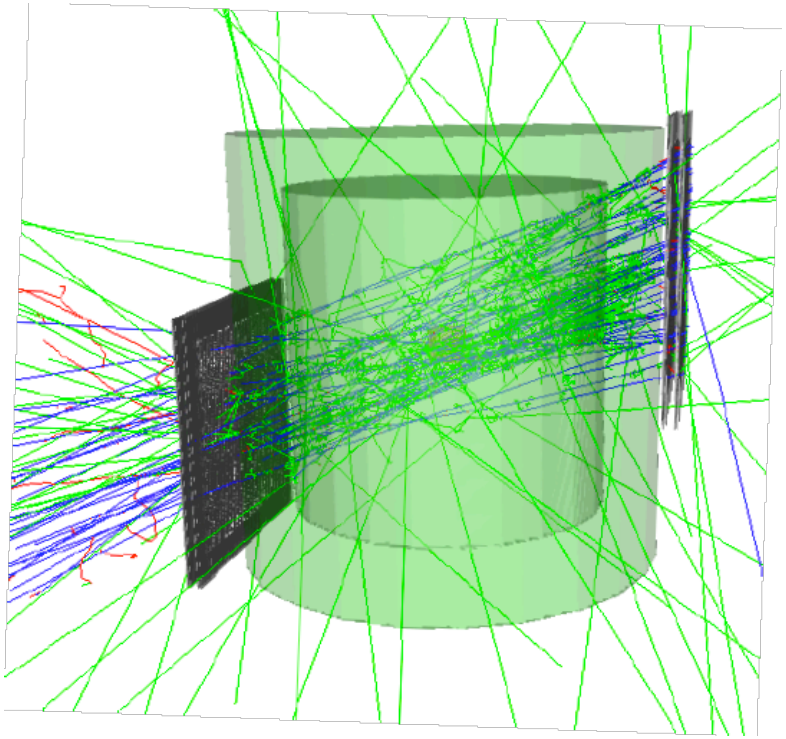
Colour Key: = Magnox Swarf & Concrete; = Stainless Steel; = Reinforced Concrete; = Uranium; = Air

Sellafield: studi di fattibilità scenario 1

The Glasgow Muon Tomography Project:
Overall aim of the project is to assess the feasibility of deploying cosmic-ray muons for use in the interrogation of the interior of waste storage structures which cannot be probed by conventional techniques (e.g. X-rays etc.)
Industrial Collaboration with UK National Nuclear Laboratory (NNL)
undertaken on behalf of Sellafield LTd. and the UK Nuclear Decommissioning Authority

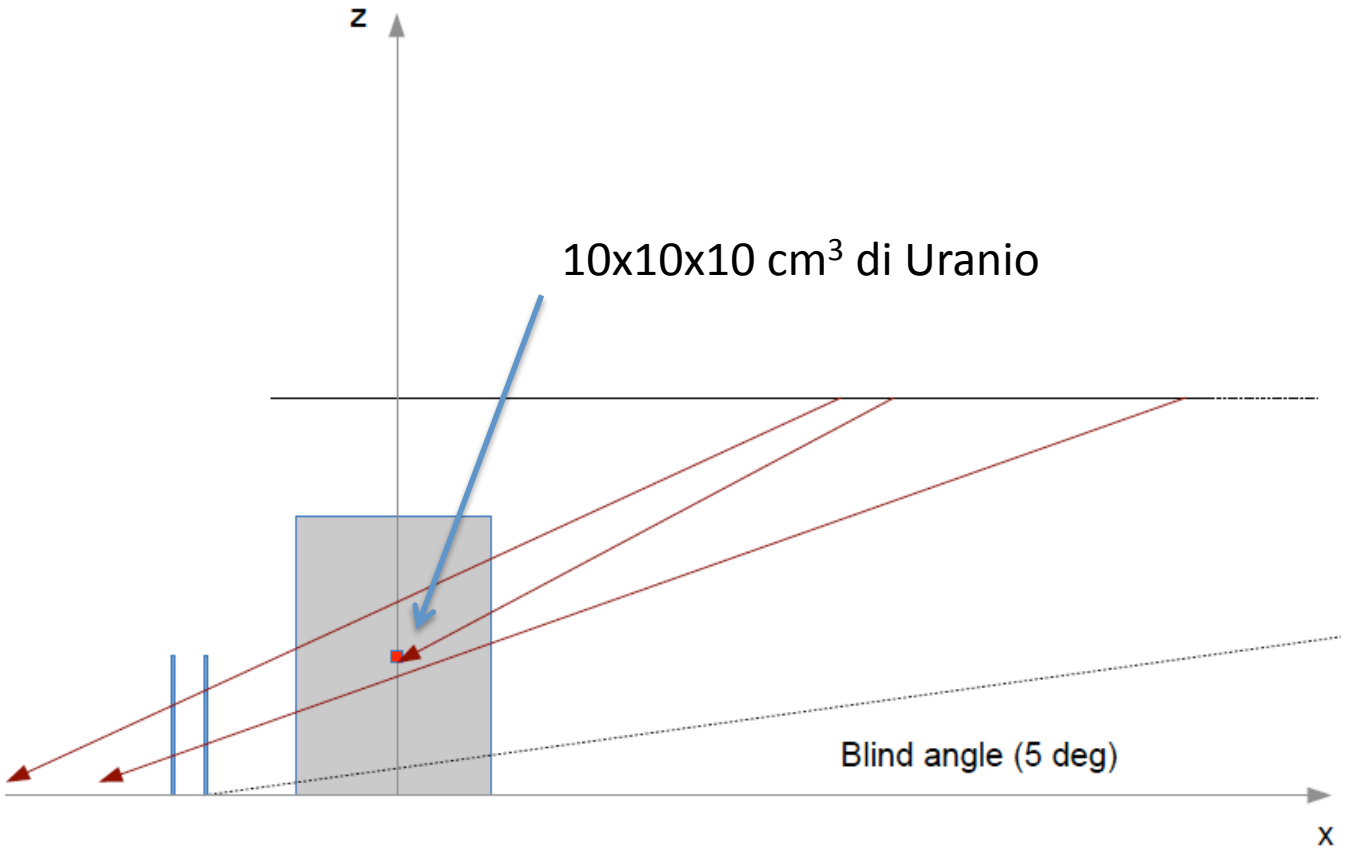
Tecnica del M.S., prototipo 25 cmx25 a fibre scintillanti
studi di fattibilità: due tracciatori 1mx1m



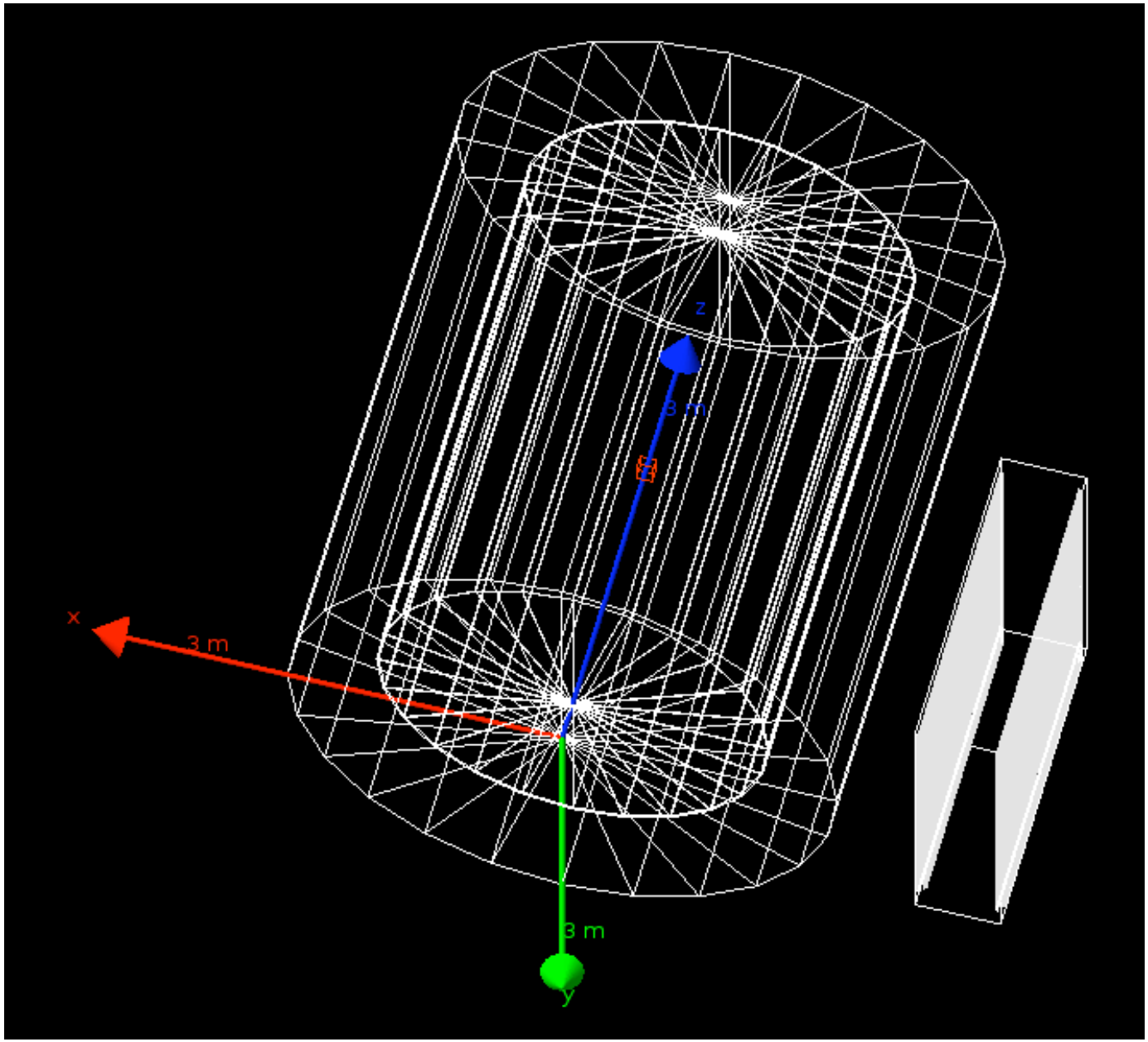


Scenario 2: studio di fattibilità (Firenze e Napoli)

Tecnica di assorbimento: un solo tracciatore 2m x 2m



Sellafield: GEANT4 scenario #2



Studi di fattibilità

- Realizzazione dei modelli per la simulazione dei possibili scenari
- Ottimizzazione del codice GEANT4
- Sviluppo di algoritmi per la rivelazione
- Studio e realizzazione di generatori per muoni atmosferici

Conclusioni

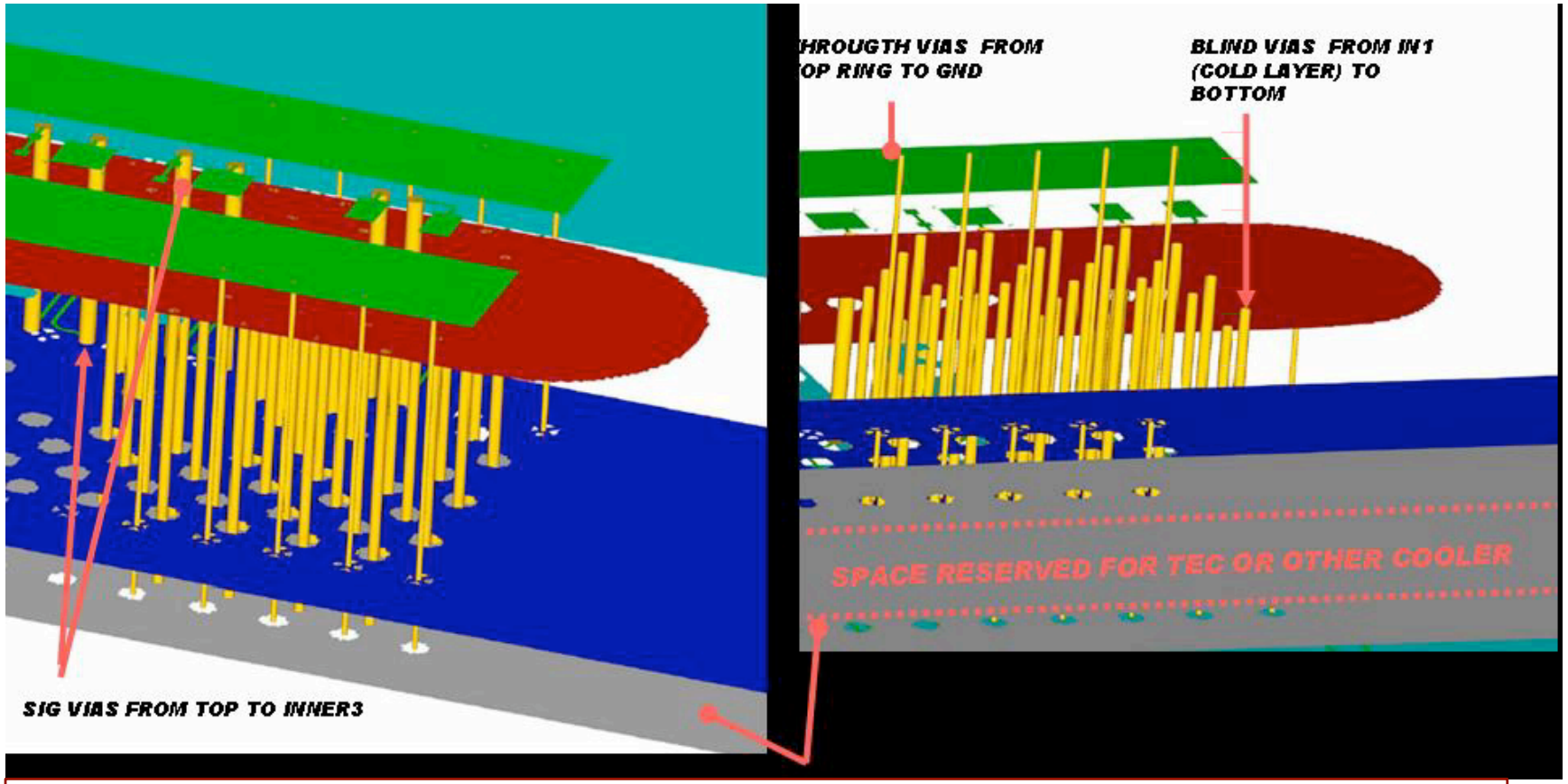
- E’ in atto una riqualifica del sito di Sellafied con priorità nazionale
- Sono in corso studi e verifiche di fattibilità per l’***imaging*** di contenitori e silos attraverso la tecnica della radiografia muonica
- E’ in in atto una collaborazione con NNL e l’Università di Glasgow per studi di fattibilità
- 1 borsa 6 mesi estendibile ad altri 6 mesi è stata erogata da NNL
- Due meeting nel 2013 tenuti in italia (Napoli/Maggio, Firenze/ Ottobre)
- 2 meeting al mese via SKYPE per aggiornamenti regolari

Back-up

Thermal control

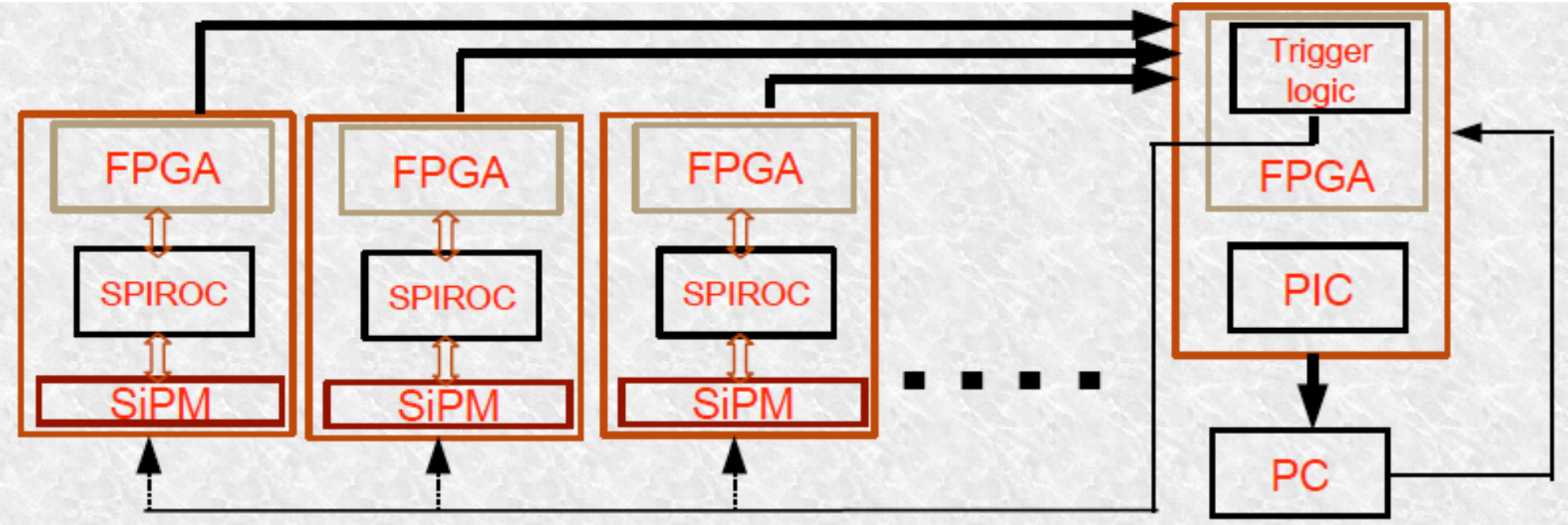
SiPM pads

Inner copper plate 75 μm from SiPM pads



Copper vias improves thermal conductibility between cold plate and inner plate below SiPM

F.E.E. and DAQ



Master board provides the trigger logic and communication with SLAVEs and external world

Until a trigger is not provided by the MASTER all slave boards work in “run” mode i.e. the FPGA clock is off, all the logic is combinatorial and power consumption is limited : 1.5 W/board, 3W for the MASTER

“L’eredità”

Legacy Waste Silos: historical facilities currently house Magnox swarf

Moreover:

Early waste management activities involved the storage of untreated waste from the first generation reprocessing operations associated with the military programme which took place at Sellafield during the 1950s. Waste arising from the programme was historically held in ponds and silos with no plans for future treatment and disposal.