Frontier Detectors for Frontier Physics

15th Pisa meeting on advanced detectors

La Biodola Isola D'Elba Italy 22-28 May 2022

A new cylindrical detector for borehole muon radiography.

Giulio Saracino

On behalf of

Fabio Ambrosino, Luigi. Cimmino, Mariaelena D'Errico, Vincenzo Masone, Lorenzo Roscilli

INFN and University of Naples *Federico II*

INFN Istituto Nazionale di Fisica Nucleare

Università degli Studi di Napoli Federico II

stress

TECNO IN® Geosolutions

Muon radiography: introduction

Famous for its archaeological applications, muography is used in many other fields

- Vulcanology
- Geological Prospecting
  - A. Cervelli: Open-Sky muon tomography for Glacier Monitoring
- Cargo scanning nuclear waste
- Nuclear plants monitoring
- Control of the blast furnace process



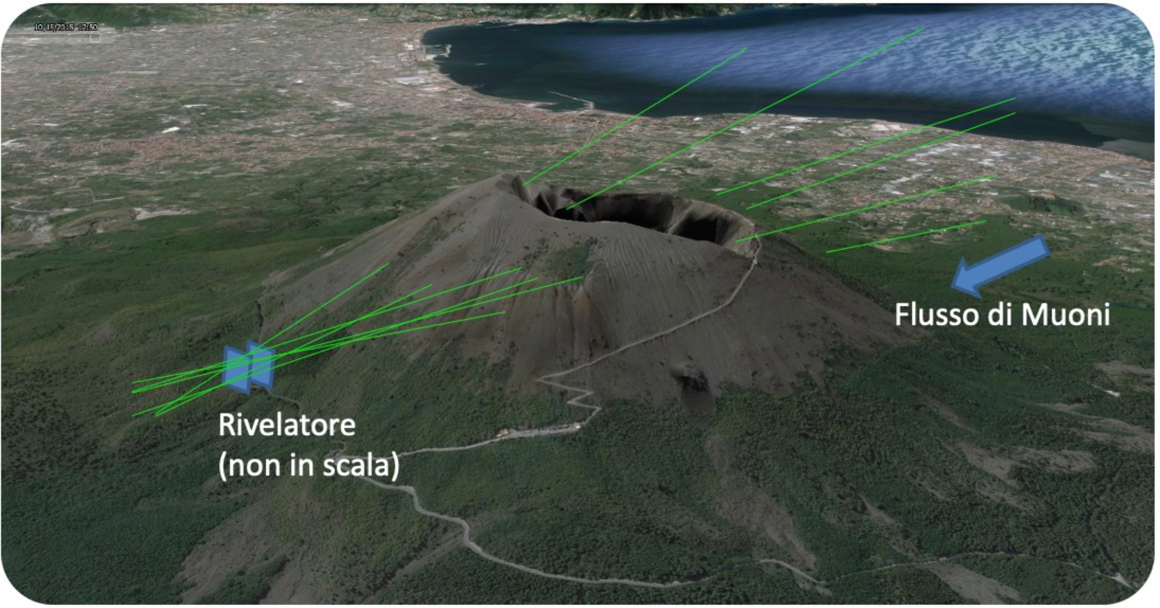


Muon radiography: how it works

Absorbtion/transmission:

Physical phenomena: energy loss, that depends on the mass density.

Measured quantity: muon's flux attenuation after the target. This is linked to the *opacity* $X = x{*}\rho$.

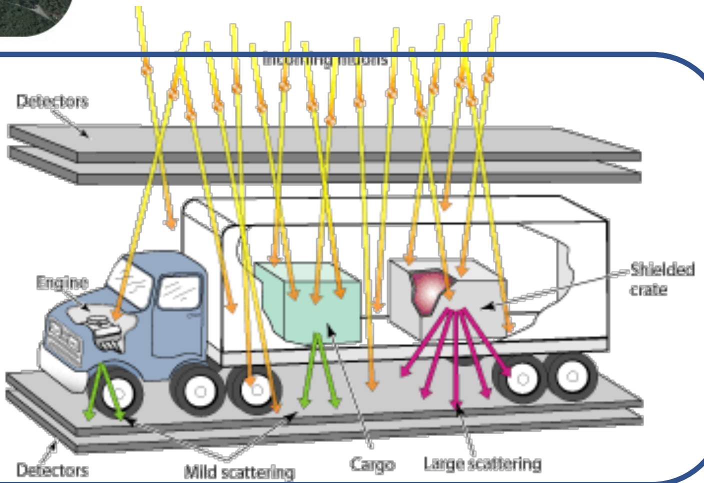


A single tracker can be used, positioned downstream with respect to the target..

This is similar to standard X ray radiography,

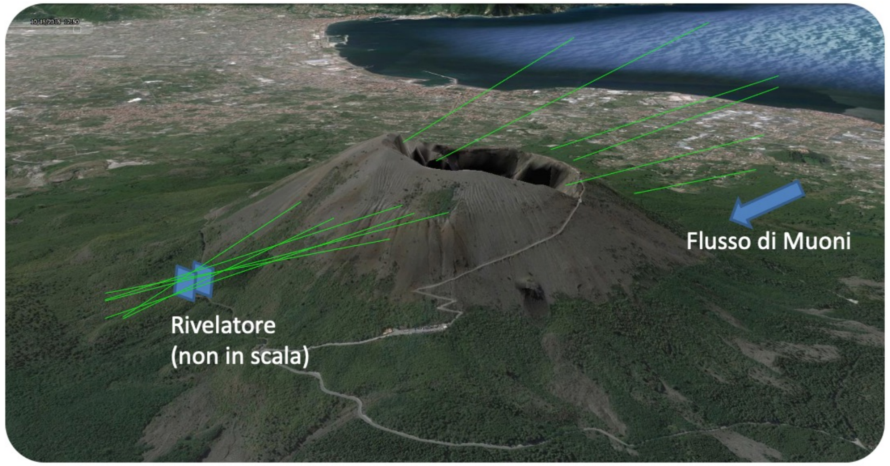
The scattering tomography is instead based on the measurement of the muon deflection with two trackers.

Not used in geophysics



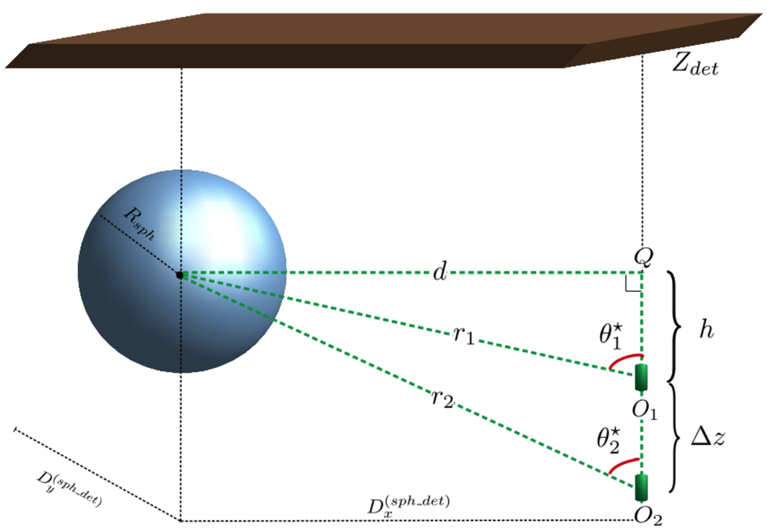
Muon radiography: detector position

The detector must be below the volume to be examined



Side position: Almost horizontal muons

Gallery location



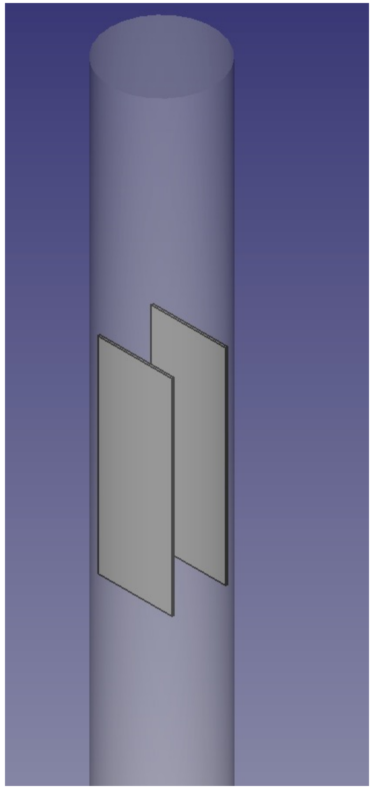
Borehole position

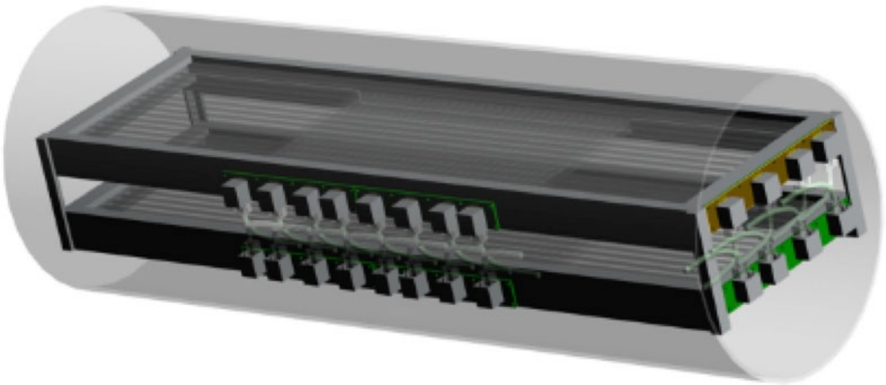
Borehole detectors: examples

Borehole detectors have been designed for applications in detection of ores in mines, archeology and for CO_2 storage monitoring

Planar geometry with scintillating rods and WLS fibers:

- simple to realize ☺
- not optimized in acceptance 🙄



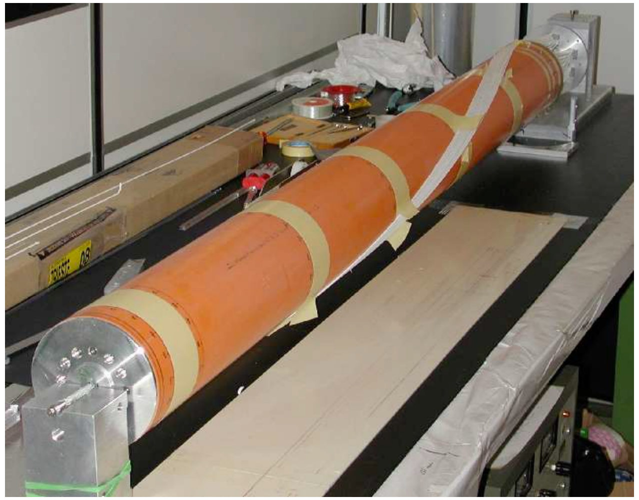


Bonneville et al. NIM 2017

Scintillator bars and fiber with helix layers:

- Compact and good acceptance ☺
- Large number of channels 🙄

14 cm diameter 384 chs

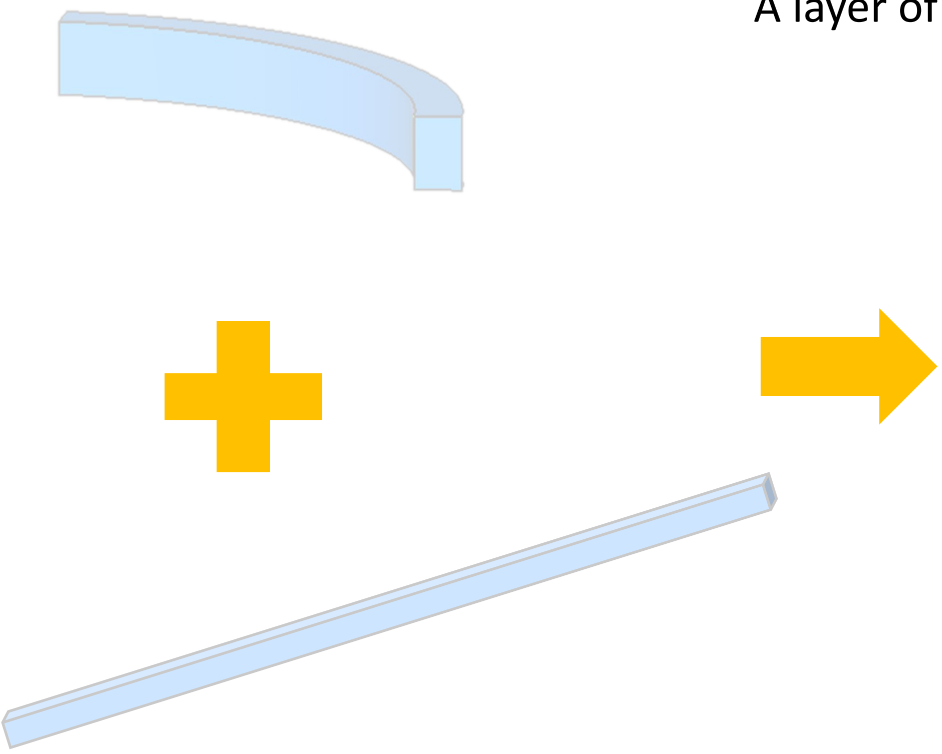


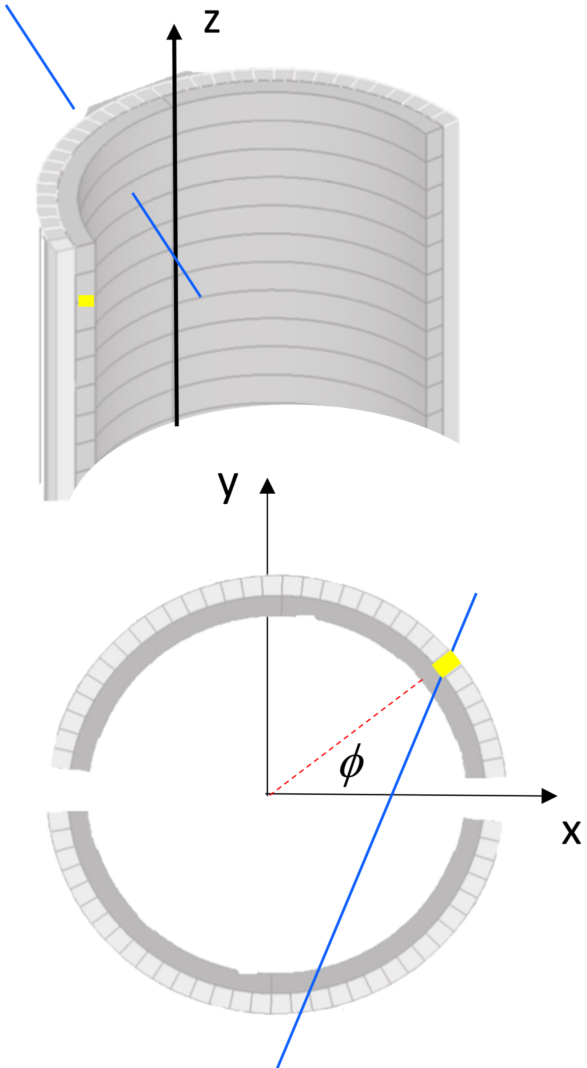
M. Menichelli et al. NIM 2007

A new design: arc shaped scintillators

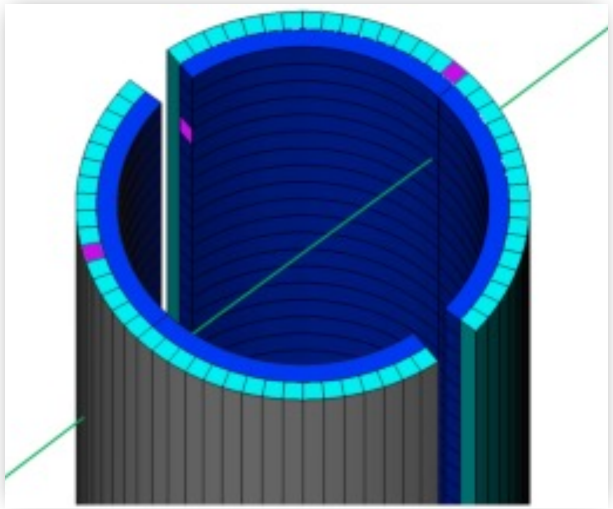
Arc shaped scintillators and bars for true cylindrical coordinates and optimization of the geometrical acceptance

A layer of arcs and bars provide z and ϕ coordinates.



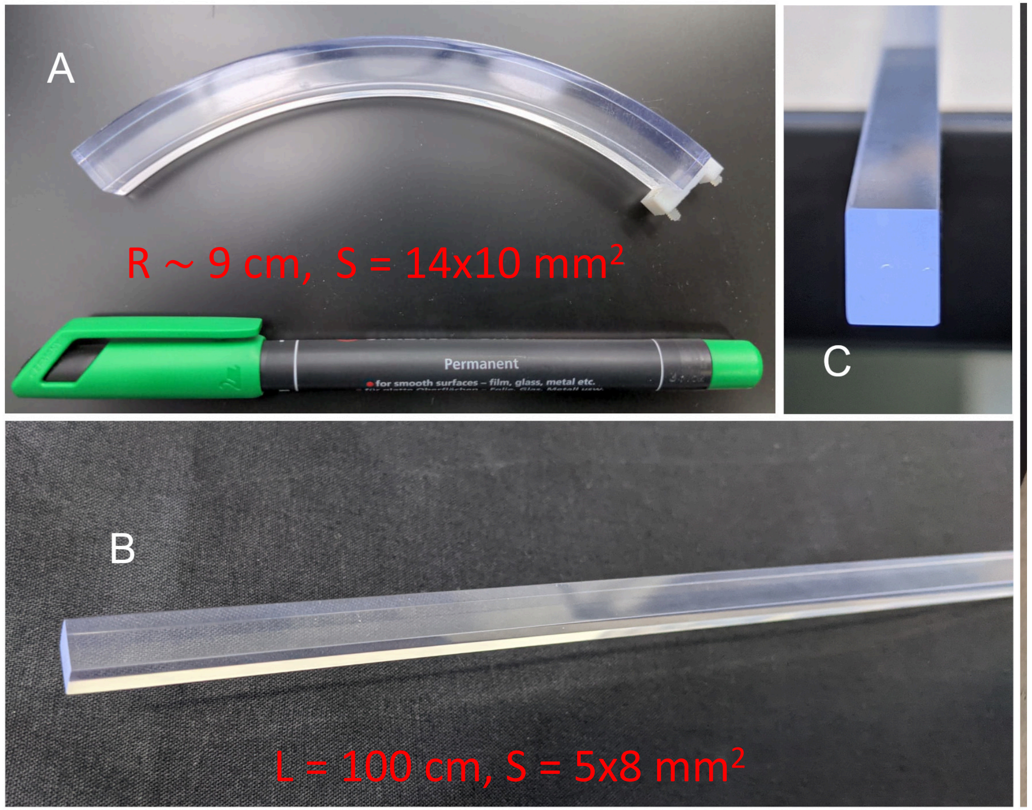


- Muons cross the cylinder in 4 elements: 2 arcs and 2 bars
- Bars measure the horizontal angle
- Arcs measure the z- coordinate



Geometry

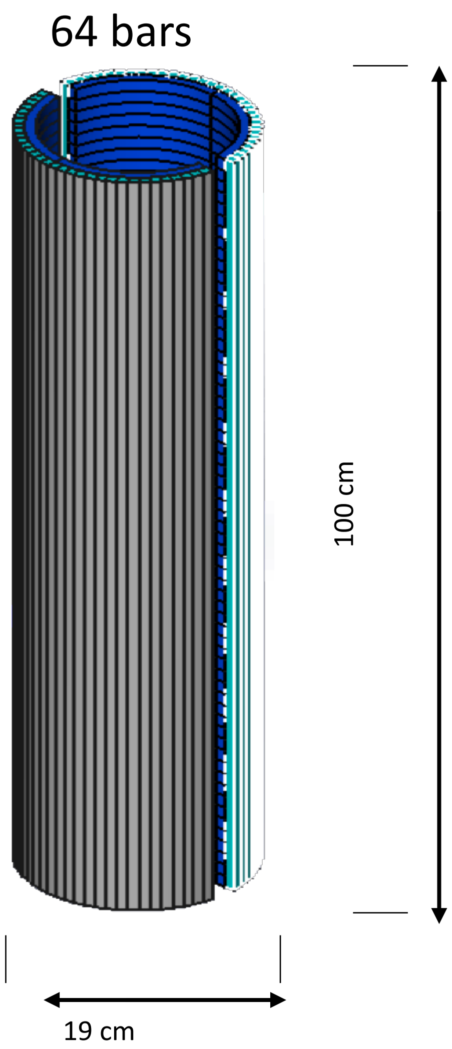
The detector has been designed for borehole with 25 cm diameter, with a reasonable effective surface and angular resolutions



Sensible surface

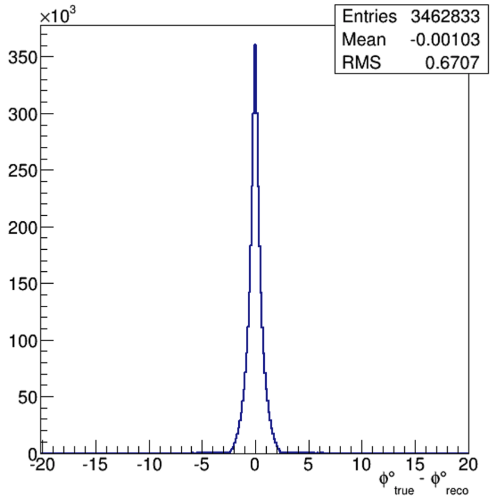
64 layers
4 arcs/layer

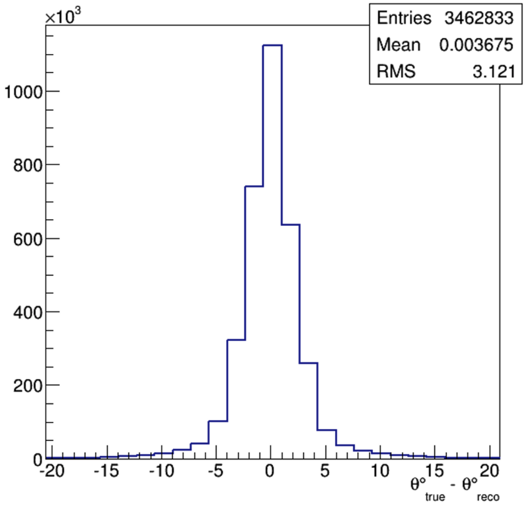
320 elements

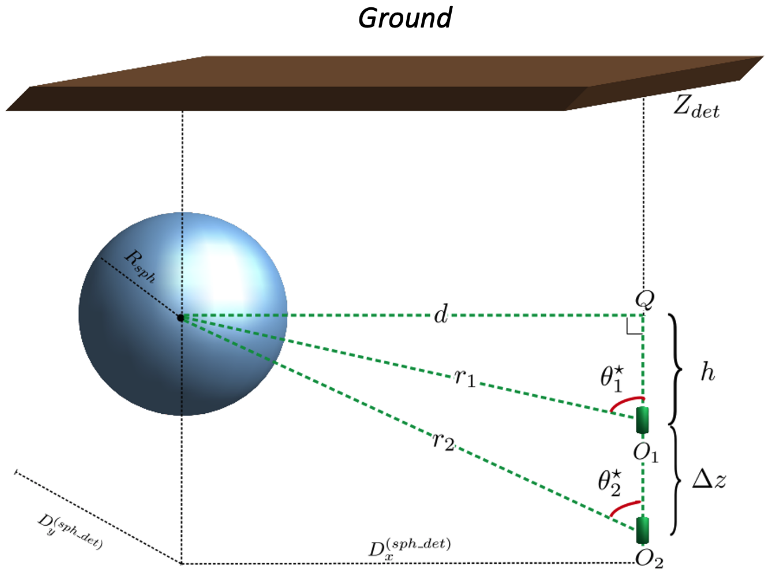


Expected performances

GEANT 4 Simulations

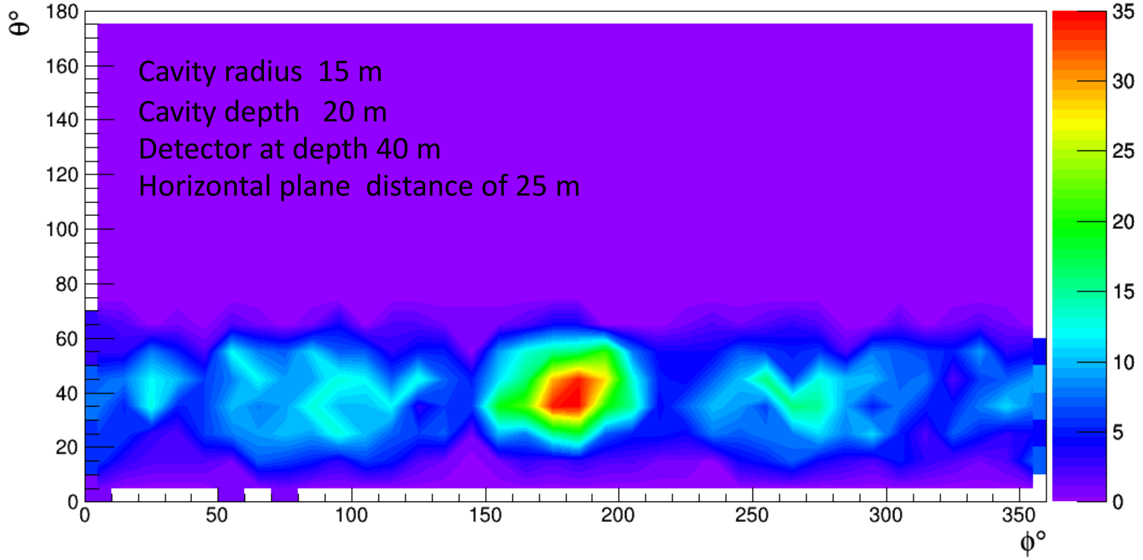






Angular resolutions:

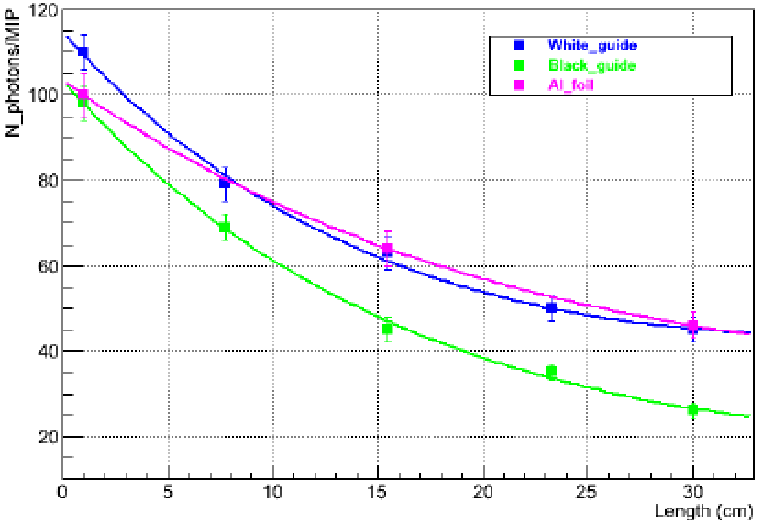
- 0.67° azimuth
- 3.12° zenith

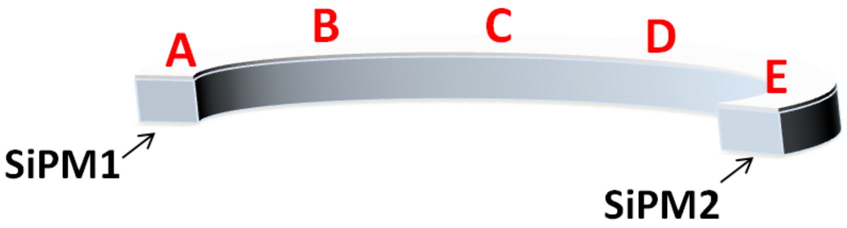


Scintillators, light collection and photodetection

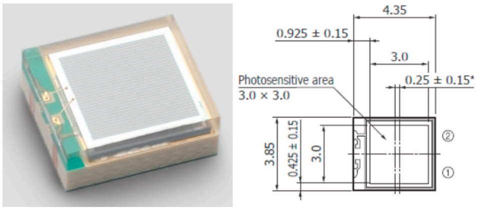
To simplify the assembling the light transmission along the arcs and bars is obtained by internal reflections without the use of WLS fibers.

The scintillators are *suspended* in air producing a good transmission by internal reflection. SiPM are directly coupled.

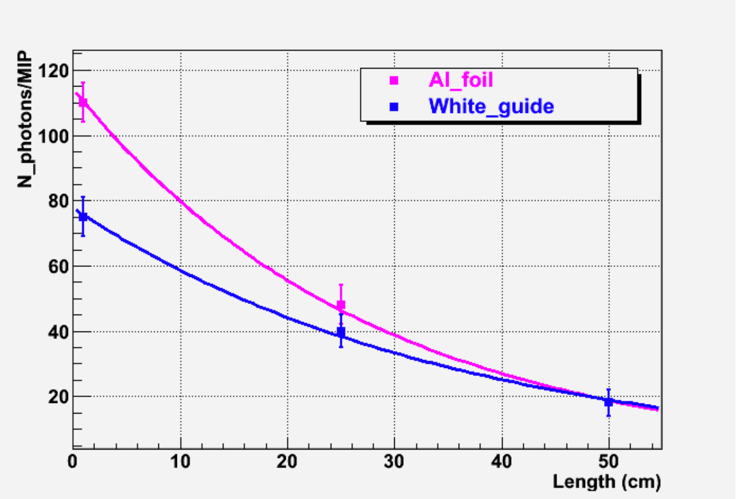


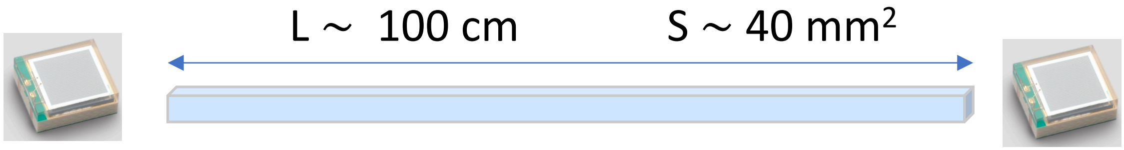


L ~ 30 cm (15 cm in the detector)
S ~ 140 mm^2



- Hamamatsu SiPM S13360-3050PE
- 3x3 mm^2 active area

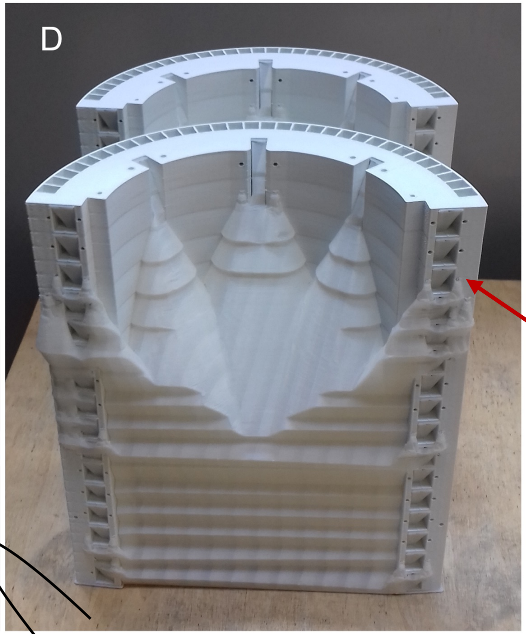




Extruded polystyrene-based plastic scintillator UPS-923A

Assembling the detector (I)

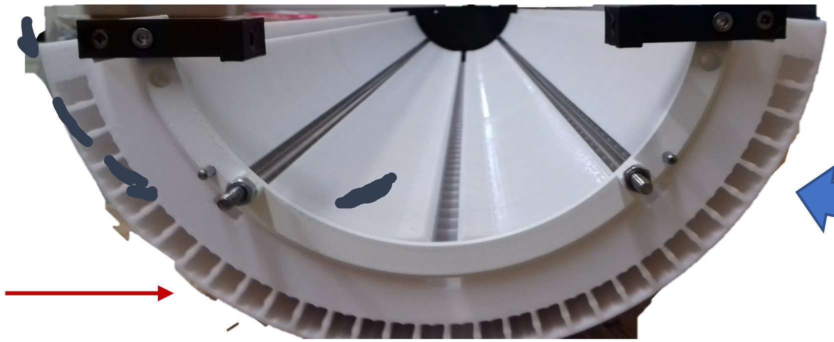
3D printed *shells* for the scintillators positioning



guides to insert arcs

Thin spacers ensure
a constant layer of air

Top view

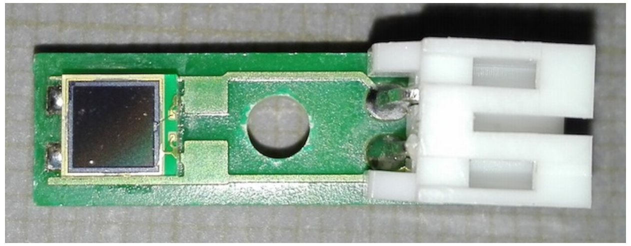


guides to insert bars

4 shells are assembled together forming an half cylinder

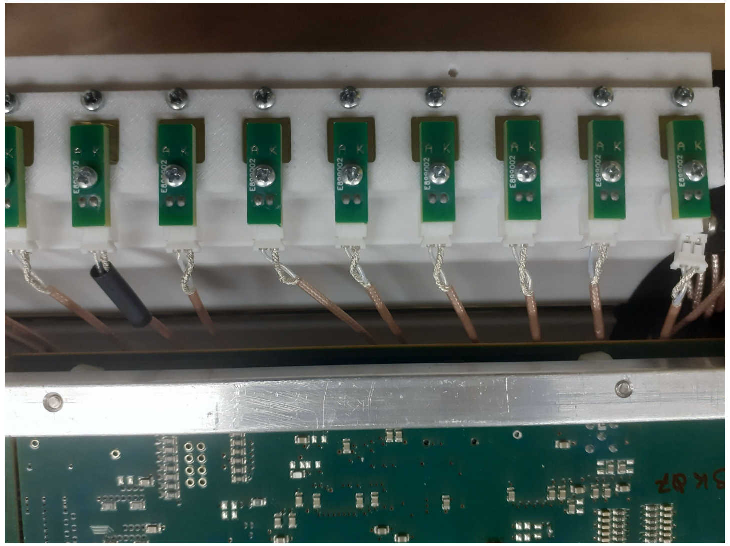
Assembling the detector (II)

SiPM coupling with scintillators

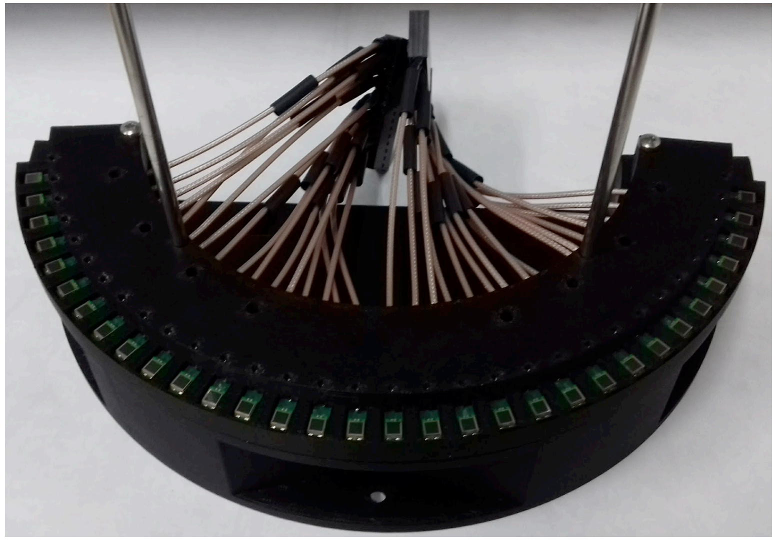


SiPM soldered on a PCB with connector

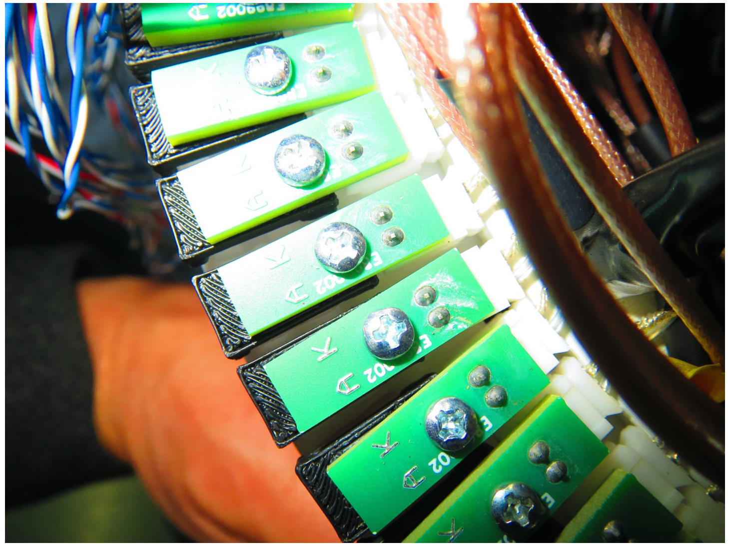
SiPM coupled to the arcs



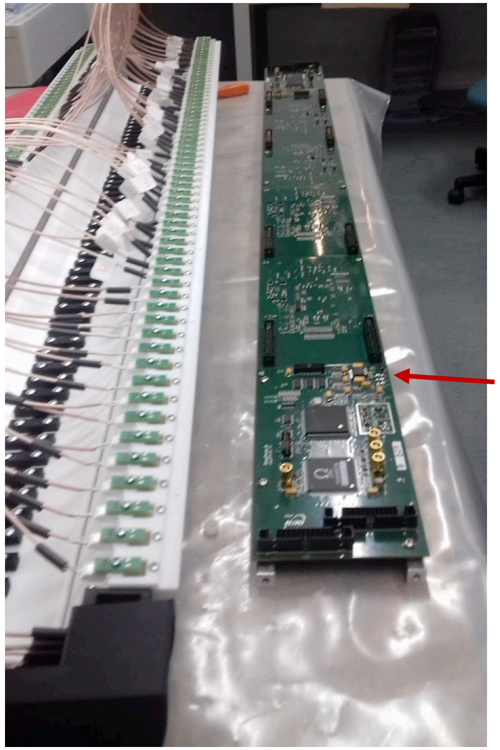
SiPM for the bottom coupling to the bars



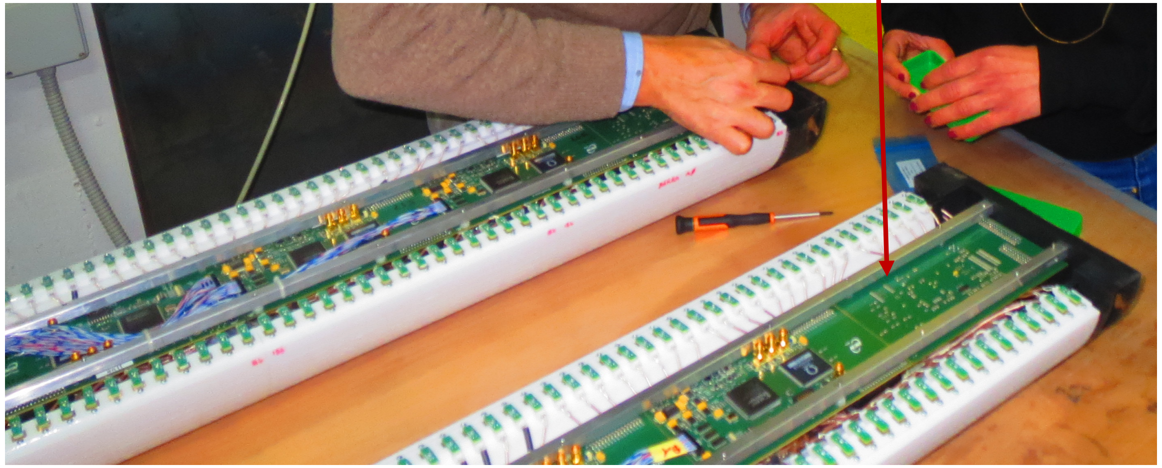
SiPM coupled to the top side of bars

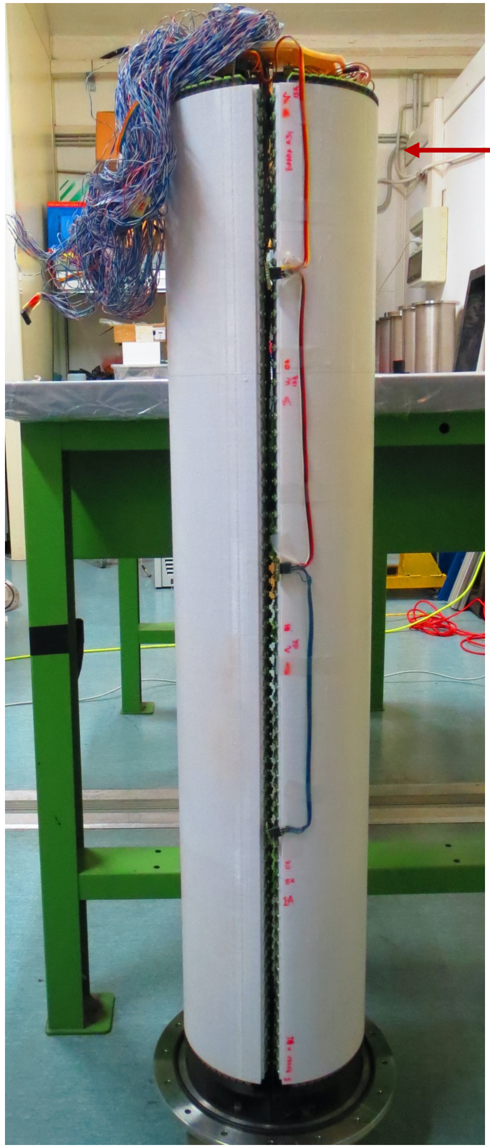


Assembling the detector (III)

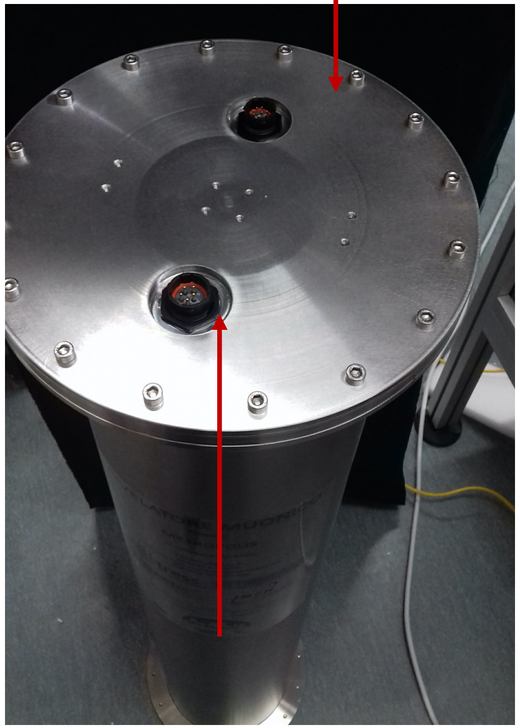


6 FEE board for each half cylinder



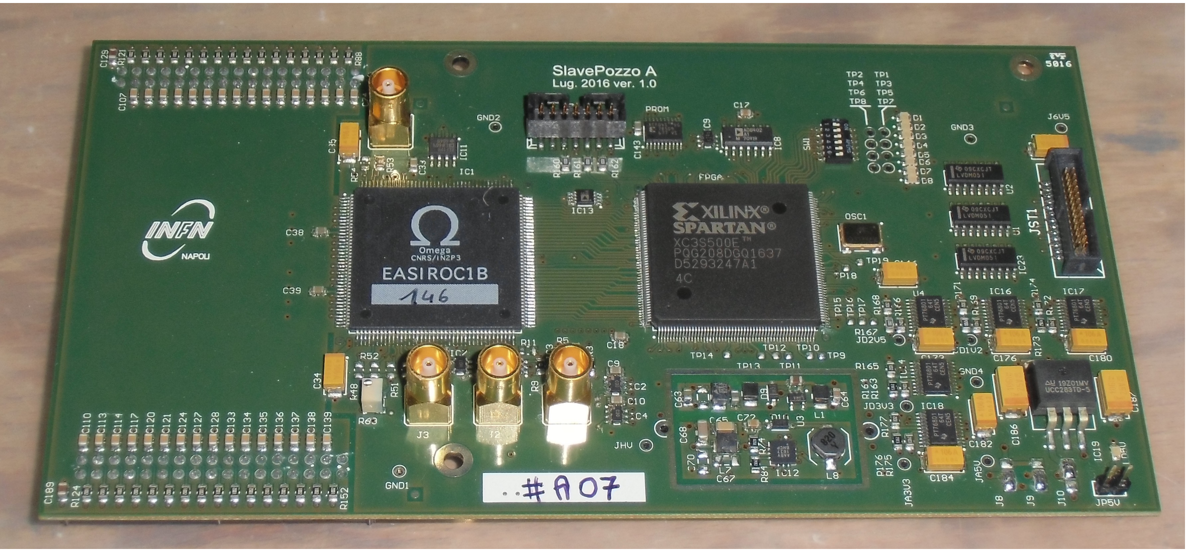


The cylinder is obtained by fixing the two semicylinders on a steel base which is closed with a waterproof stainless steel shell



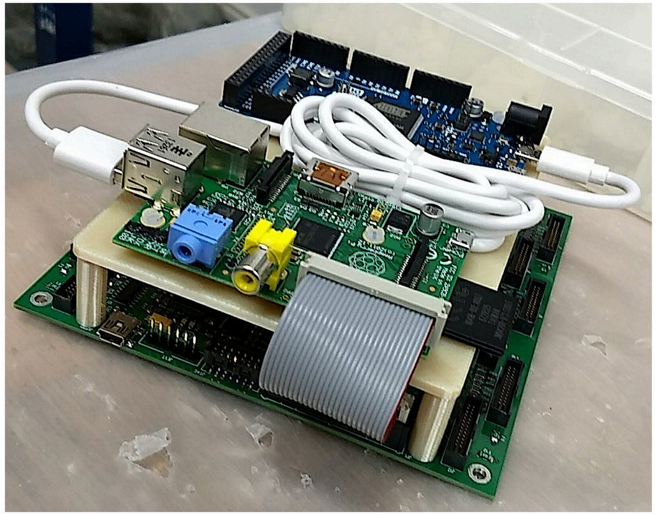
Ethernet and power plugs are attached on the top cap

F.E.E and DAQ

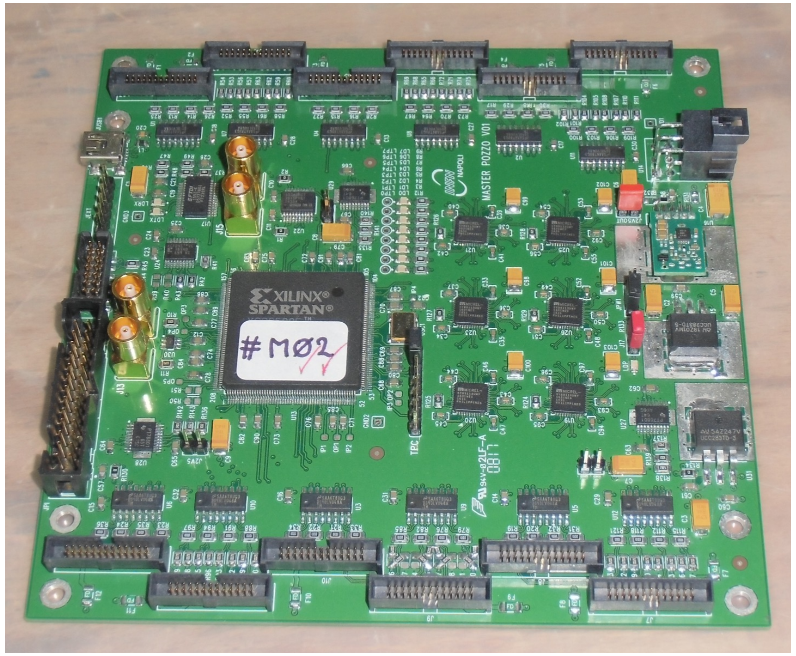


F.E.E. from Mu-RAY and MURAVES experience

- EASIROC chip
- Low power consuming (3W/32chs)
- FPGA controlled



- The Master controlto 12 FEE boards
- Programmable trigger logic

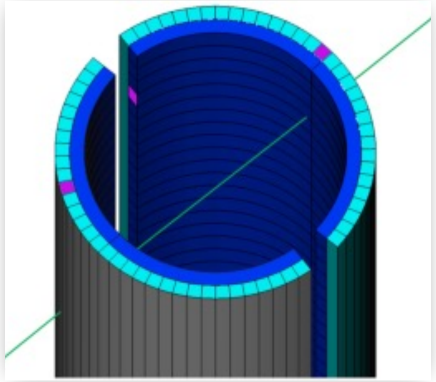


Rpi and Arduino boards on the top of the the MASTER

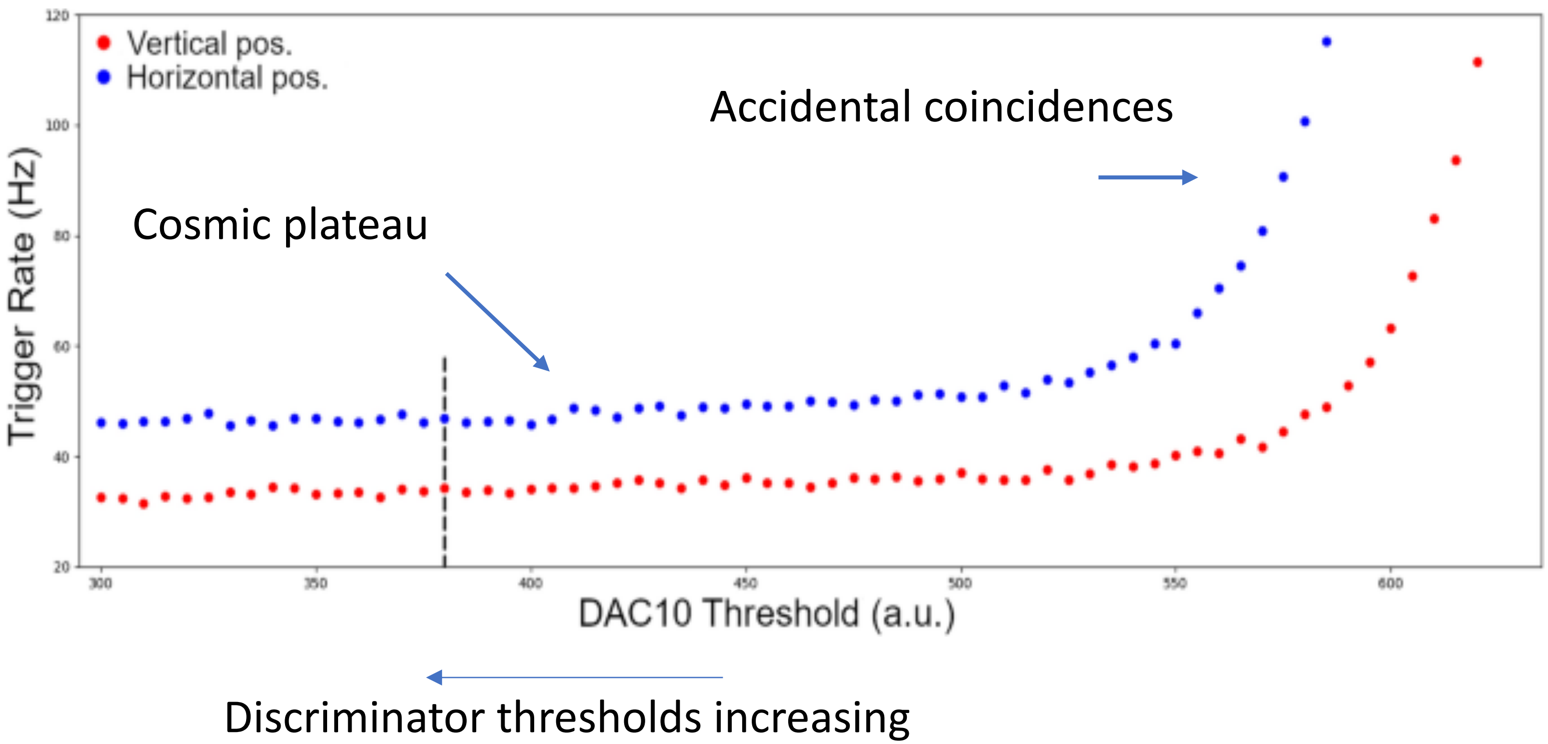
Laboratory test: cosmic rays plateaus

Trigger rates : A large plateau with open sky cosmic rays

Trigger logic: at least one bar and one arc in coincidence

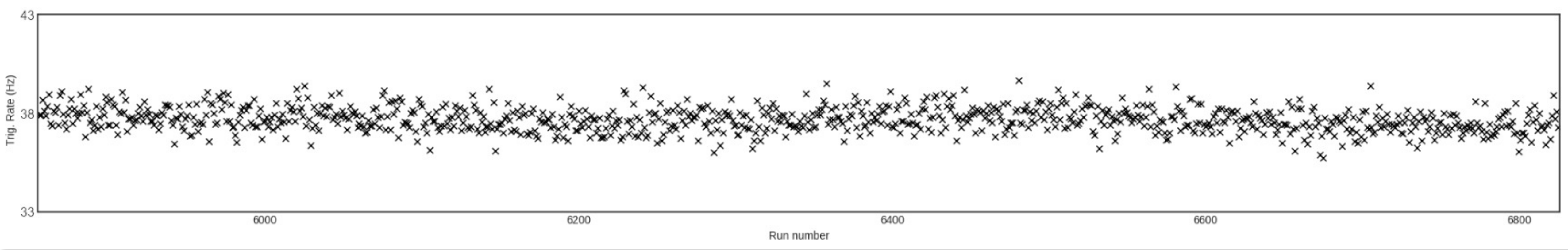


- 48 Hz detector placed horizontal
- 37 Hz detector placed vertical

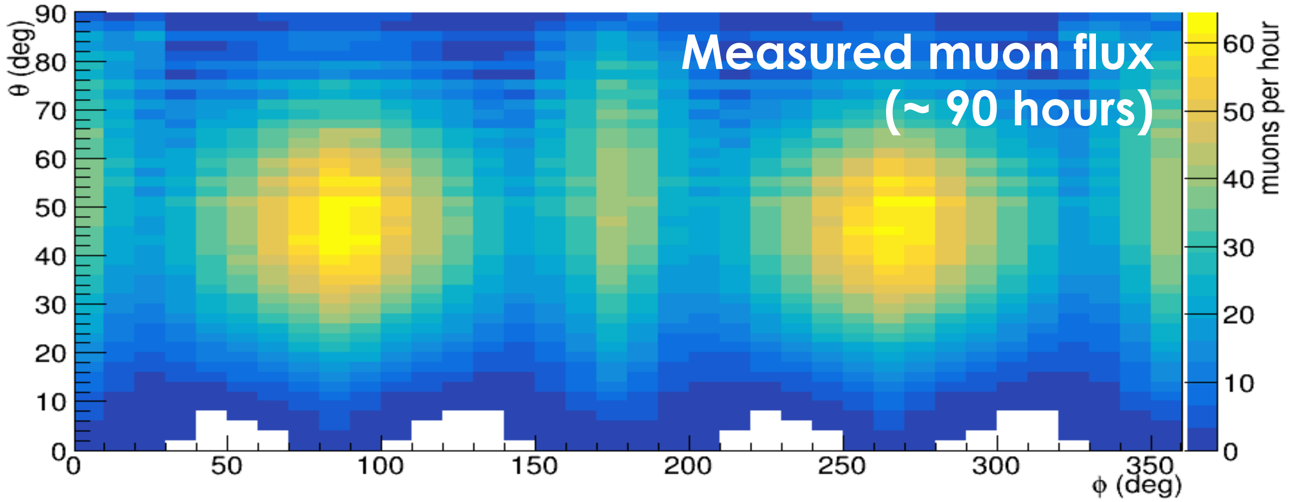


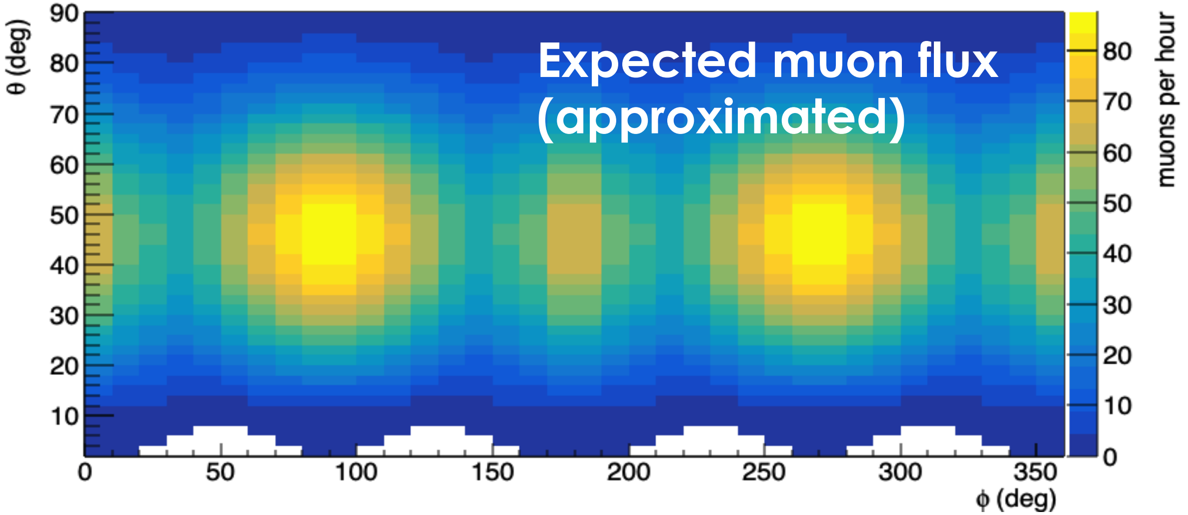
Open sky calibration

Trigger rate stable in time



good agreement between measured and expected open-sky muon flux distributions



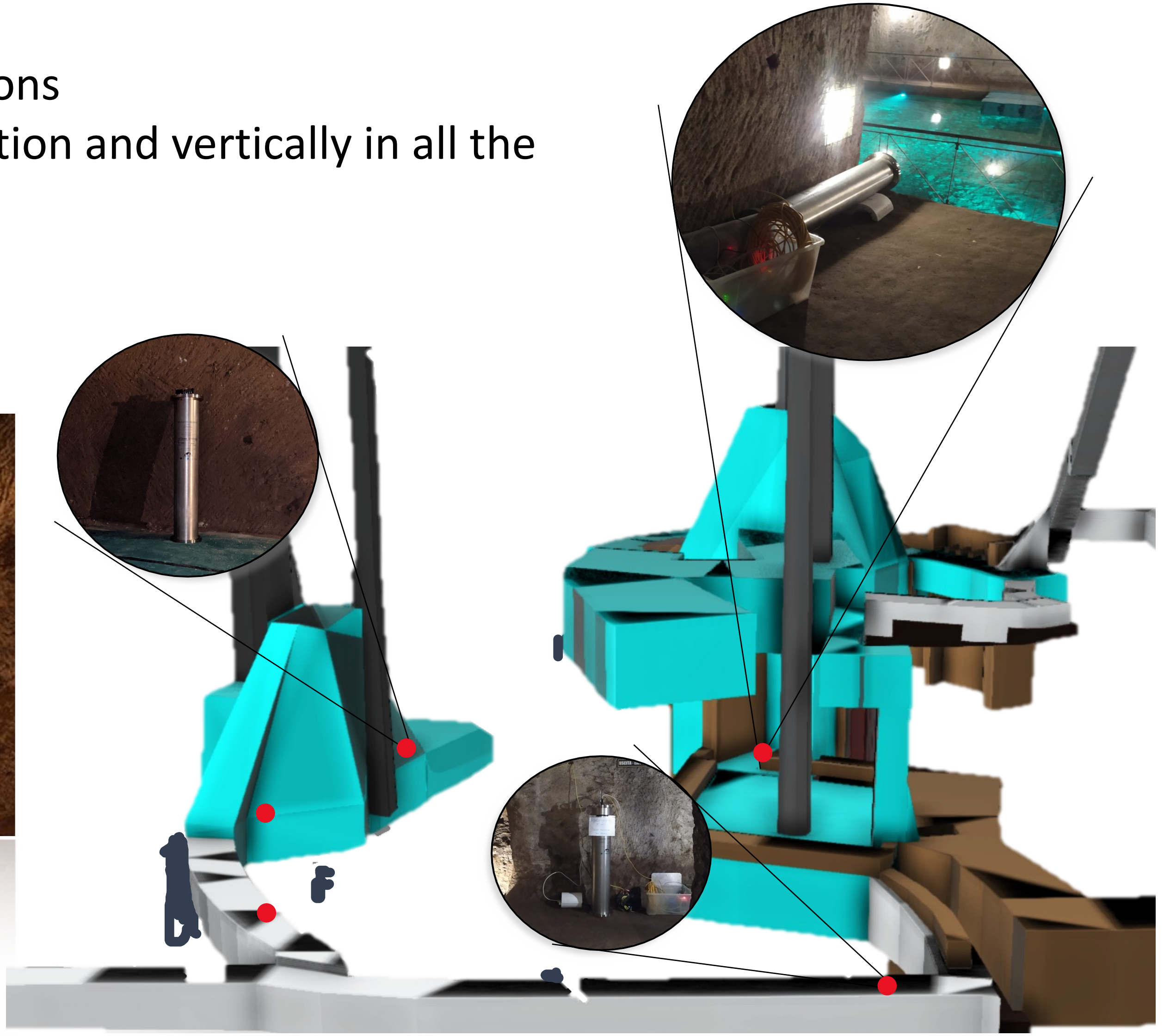


First test underground: Mt Echia in Naples

- Since June 2021 the detector is acquiring data in the 'Galleria Borbonica' a complex of cavities excavated in the underground of the little hill of Mt. Echia in Naples (Italy)
- The detector has been already moved indifferent locations
- The detector has been installed horizontally in one location and vertically in all the others

Mt. Echia from the street

Underground of Mt. Echia



First test underground

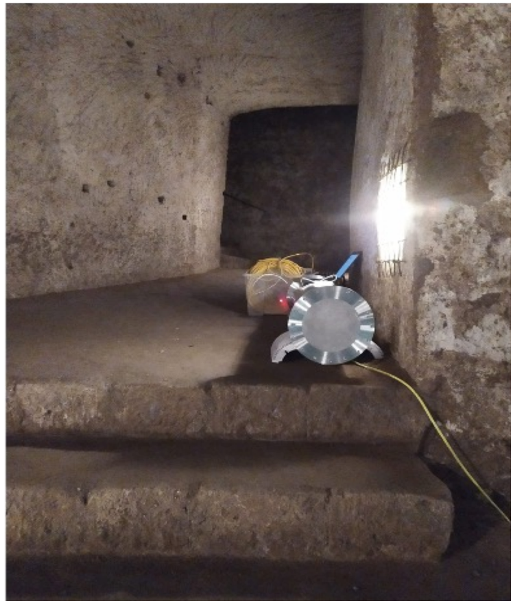
Background environmental radiation

Natural radioactivity of volcanic rocks, as the Neapolitan yellow tuff, can produce signals in the detector.
Since the cylinder is gas tight and shielded with 3 mm of steel, the main source is from gamma rays

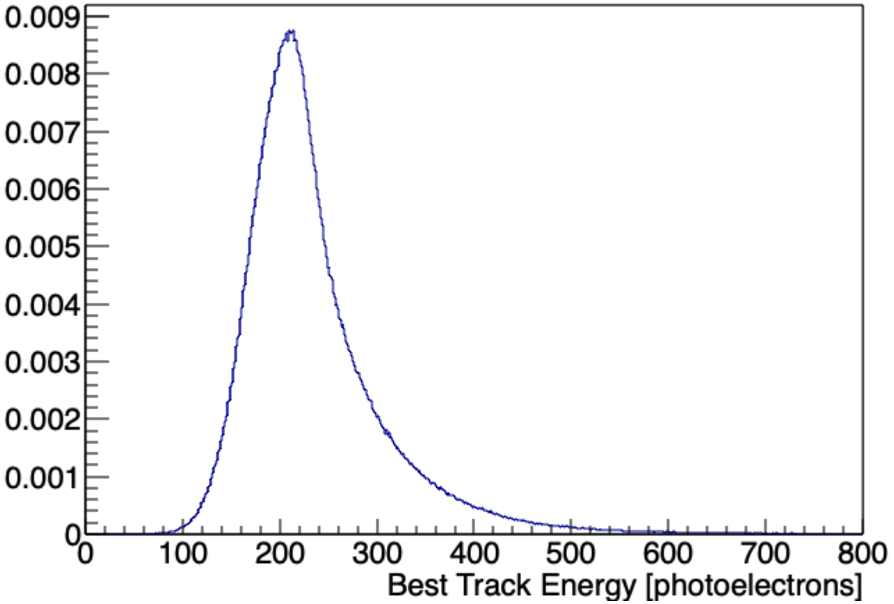
^{232}Th, ^{226}Ra and ^{40}K are commonly present and their daughters can produce gamma:

For example ^{232}Th daughters ^{212}Bi, ^{208}Tl and ^{228}Ac produce gamma at 727, 860 and 911 keV respectively.

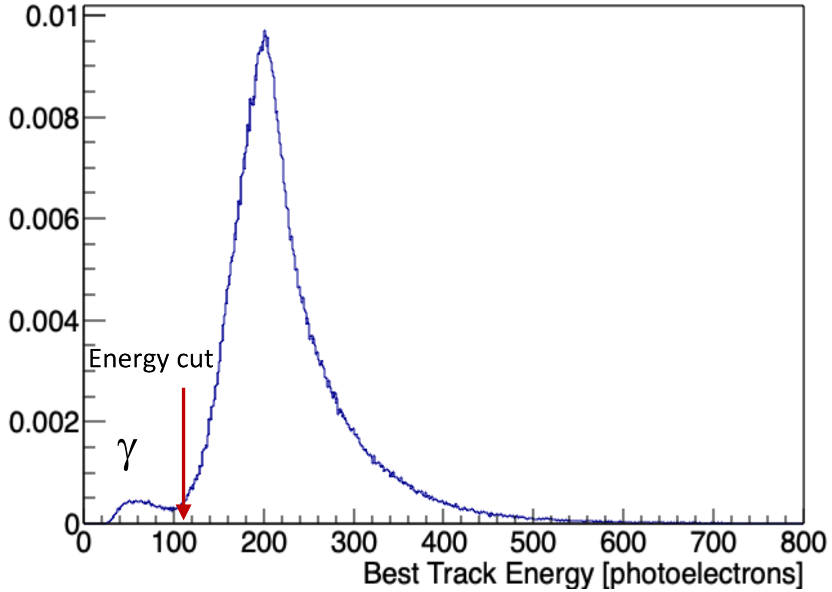
Most of this interactions cannot produce triggers (2 hits) or tracks (4 hits),
The residual can be easily identified by the small energy associate to the track with respect to cosmic muons



Total *energy* of the track



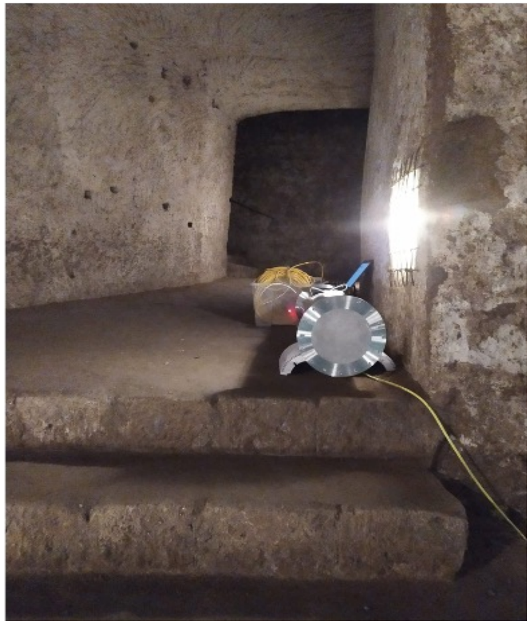
Open sky (no radiactivity)



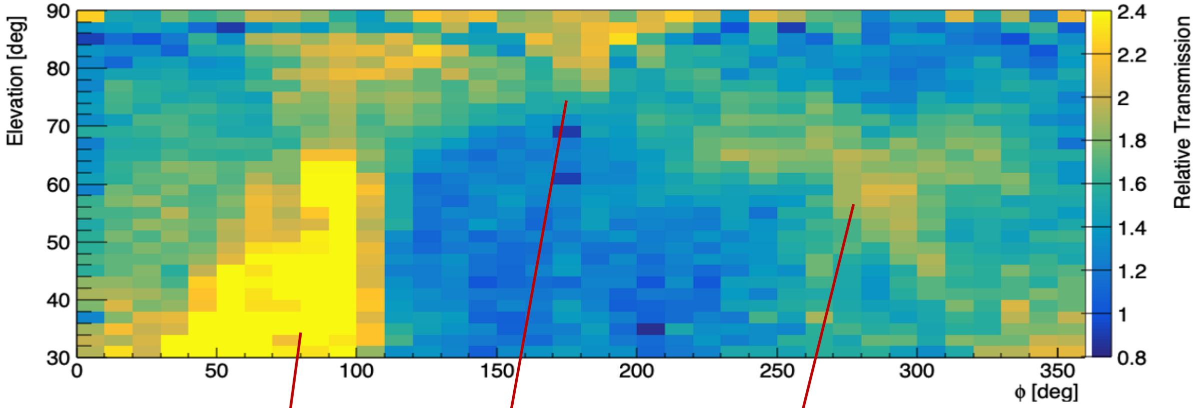
Mt Echia underground

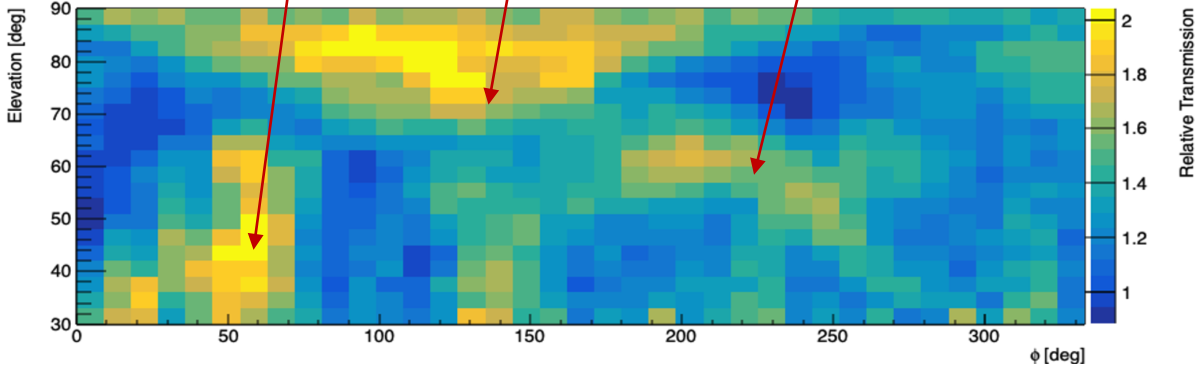
First test underground: measurement of known voids

The first location was in correspondence of a previous investigation with a planar, 1m^2, detector (Mu-Ray)

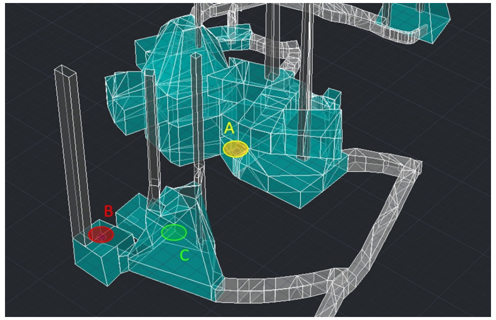


Borehole (~ 2 days)





Mu-RAY (26 days)



Comparisons between the two muography

Conclusions and future planes

- Muography: an expanding technology
- Borehole detectors: an interesting tool for geophysical applications
- The arc shaped scintillator detector: optimize acceptance and angular resolution
- The borehole detector was patented in 2020
- Good results obtained in cavity detection underground
- Test in a borehole coming soon

Project Funded by Italian Ministry of University and Research METROPOLIS PON 03PE_00093_4 in collaboration with STRESS SCARL and TECNO_IN SpA

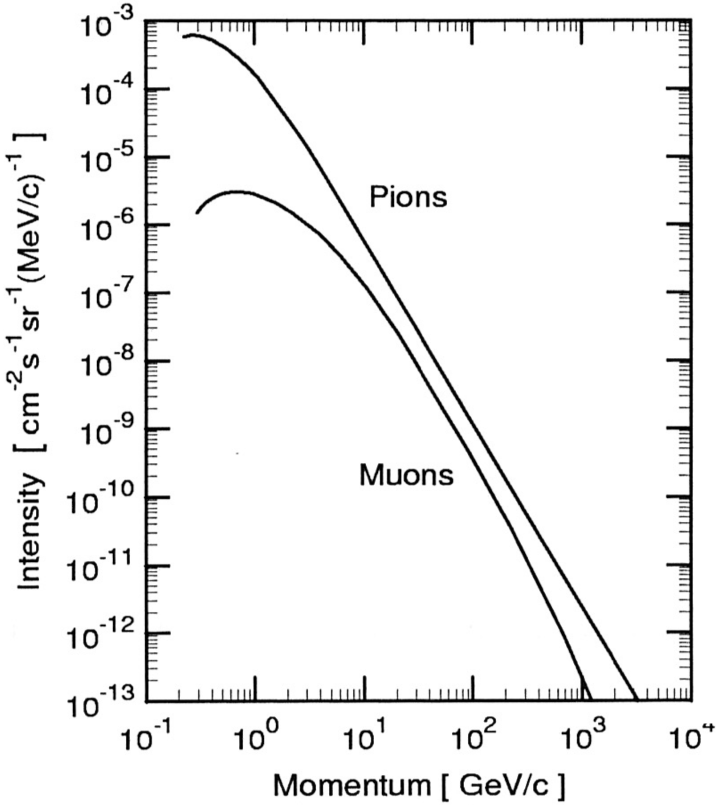
Special thanks to the Association *Borbonica Sotterranea* for the hospitality

Spares

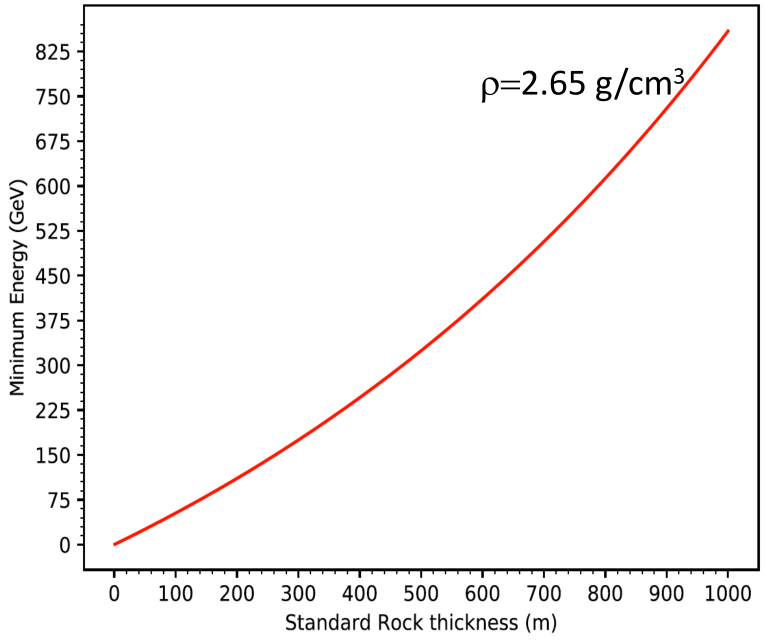
Muon radiography: why it works

Cosmic muons are produced with large energies and can penetrate matter deeply

Energy spectrum



Energy vs rock thickness



Flux vs rock thickness