AN EMERGING FIELD:
MUON TOMOGRAPHY

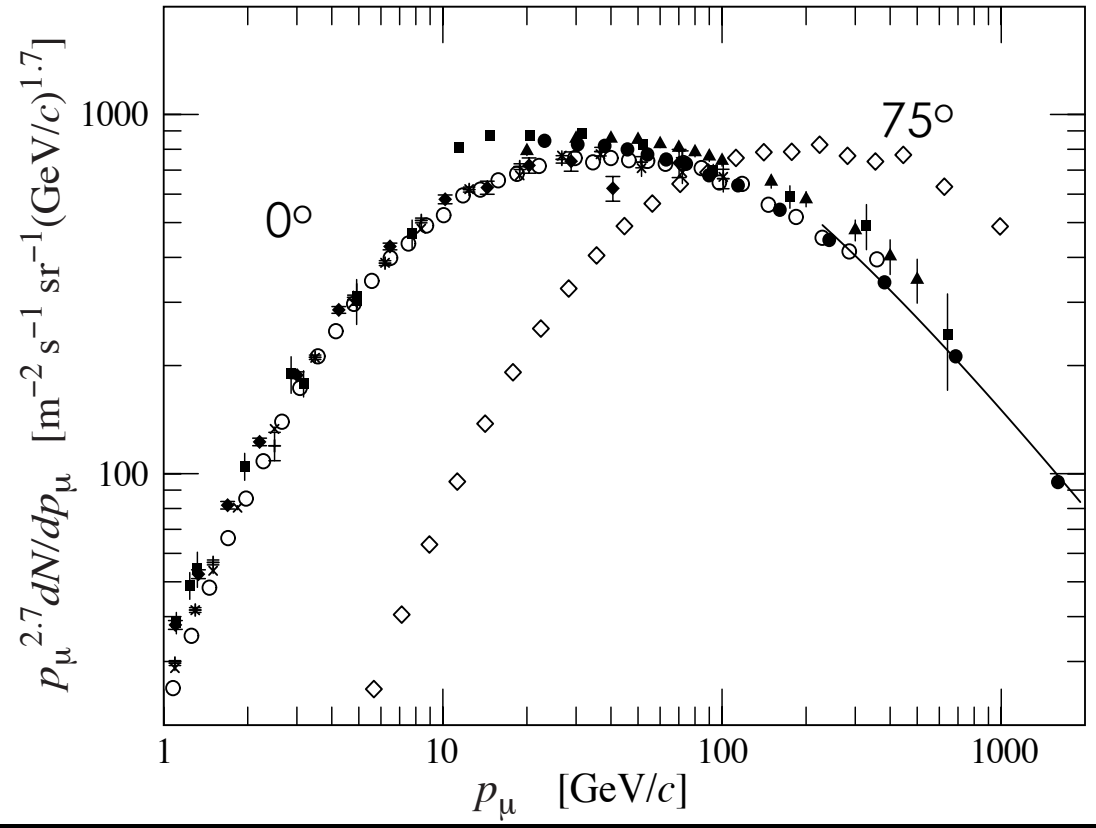
LouMu: A pilot project in the Lousal Mine

IGFAE-LIP 26/4/2019

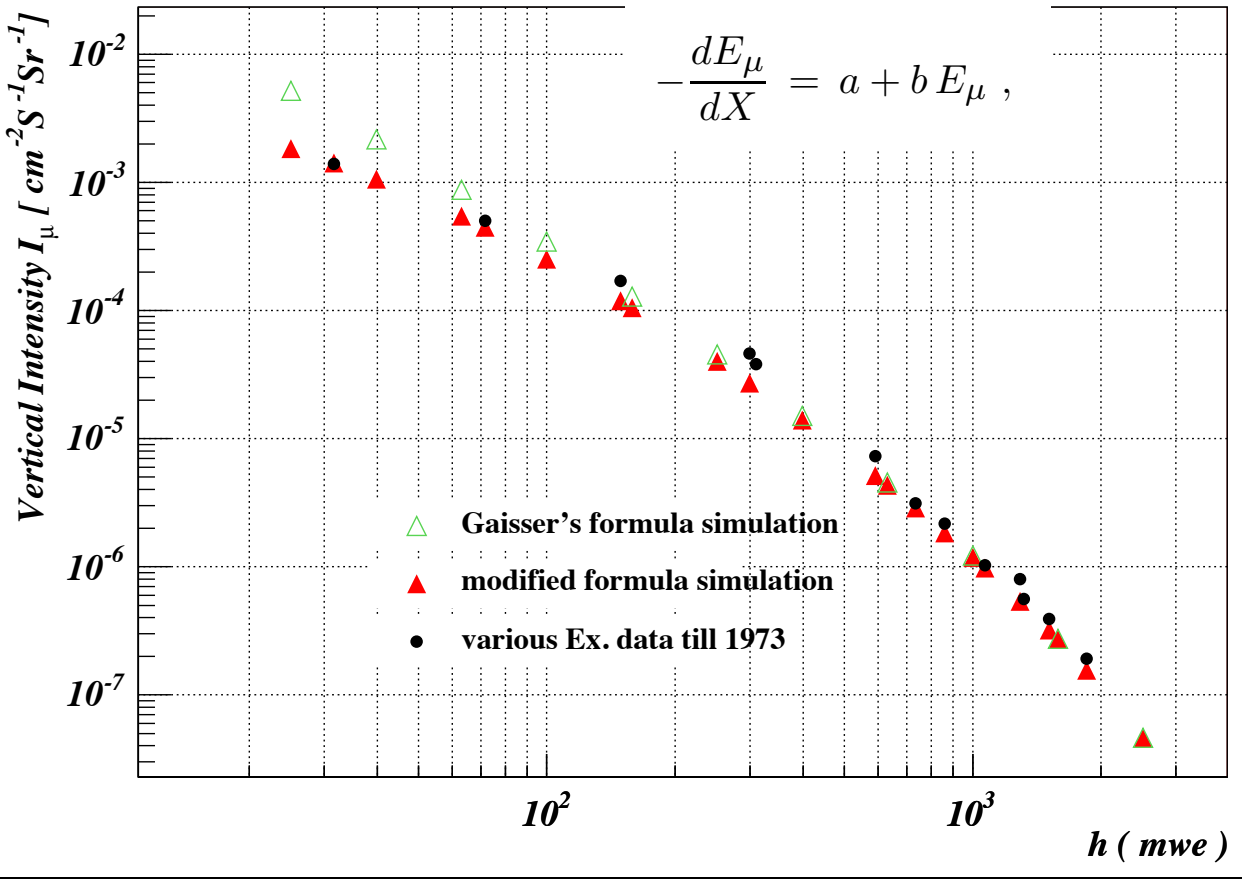
L. Cazon

- Introduction
  - some numerical considerations
  - transmission & scattering
- History and applications
- LouMu

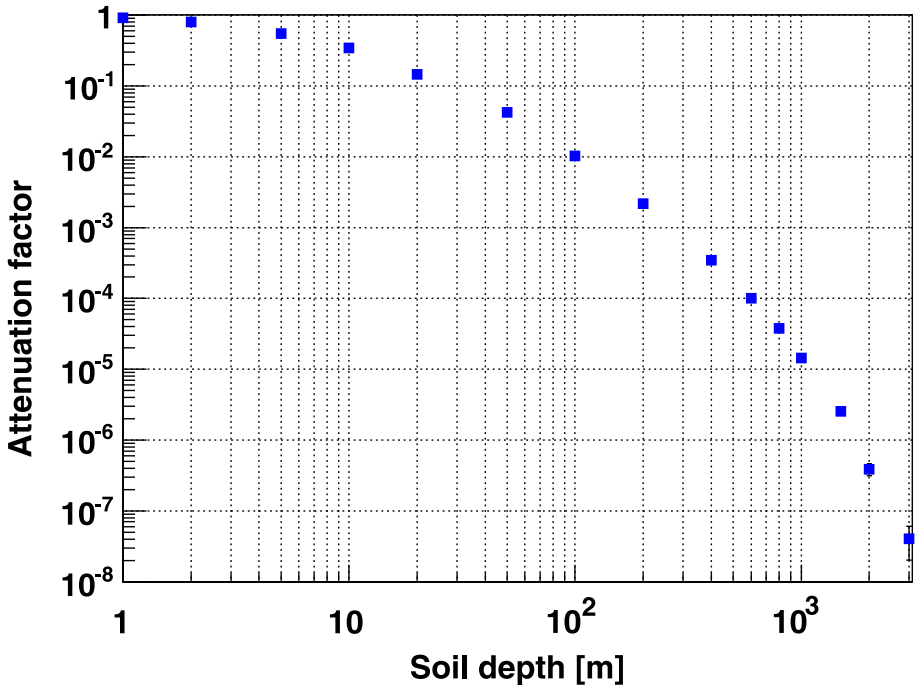
ATMOSPHERIC MUONS



$$\frac{dN_\mu}{dE_\mu d\Omega} \approx \frac{0.14\, E_\mu^{-2.7}}{\mathrm{cm}^2\ \mathrm{s}\ \mathrm{sr}\ \mathrm{GeV}} \times \left\{ \frac{1}{1 + \frac{1.1 E_\mu \cos\theta}{115\,\mathrm{GeV}}} + \frac{0.054}{1 + \frac{1.1 E_\mu \cos\theta}{850\,\mathrm{GeV}}} \right\} ,$$



ENERGY LOSS & SCATTERING



$$-\frac{dE_\mu}{dX} = a + b\,E_\mu \ ,$$

E_μ	R	a	$b_{\rm brems}$	$b_{\rm pair}$	$b_{\rm nucl}$	$\sum b_i$	$\sum b$(ice)
GeV	km.w.e.	MeV g^{-1} cm^2	—	10^{-6} g^{-1} cm^2		—	
10	0.05	2.17	0.70	0.70	0.50	1.90	1.66
100	0.41	2.44	1.10	1.53	0.41	3.04	2.51
1000	2.45	2.68	1.44	2.07	0.41	3.92	3.17
10000	6.09	2.93	1.62	2.27	0.46	4.35	3.78

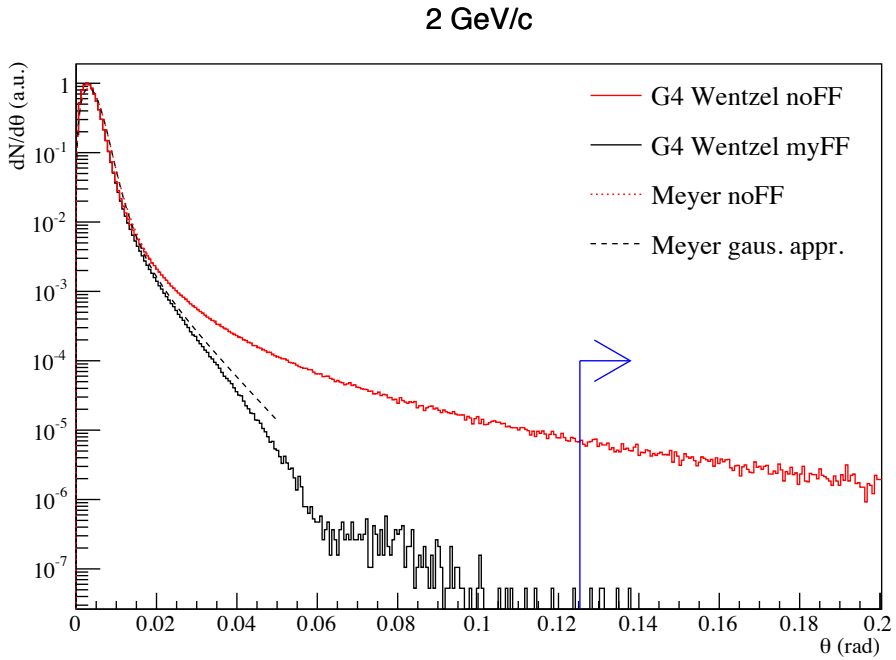


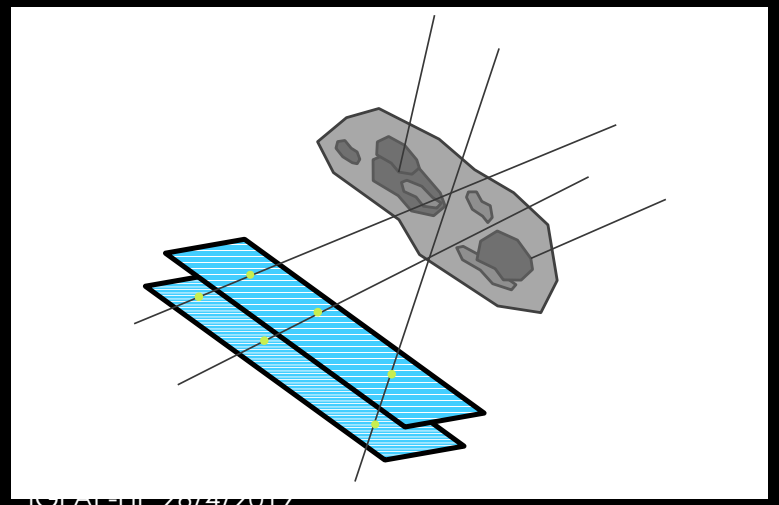
Fig. 3. Distribution of the scattering angle for 2 GeV/c muons impinging orthogonally on a 1 mm thick lead target according to the prediction from the theory of Meyer (lines) and to the GEANT4 based simulation described in the text (histograms). Both the cases of a point-like or extended nucleus are shown in red and black respectively. The arrow marks the angle corresponding to the OPERA signal region (Sect.VII).

TWO BASIC TECHNIQUES

- Transmission Tomography

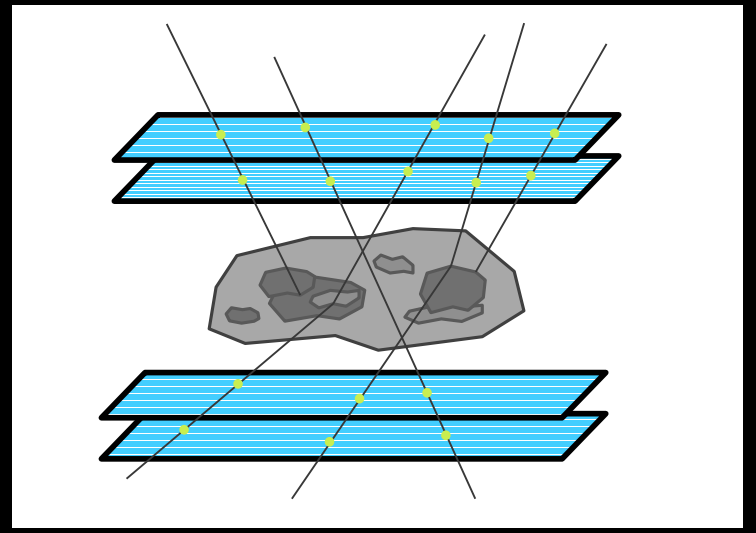
Reconstruction of the flux as a function of the incoming angle

Muon Radiography, Muography



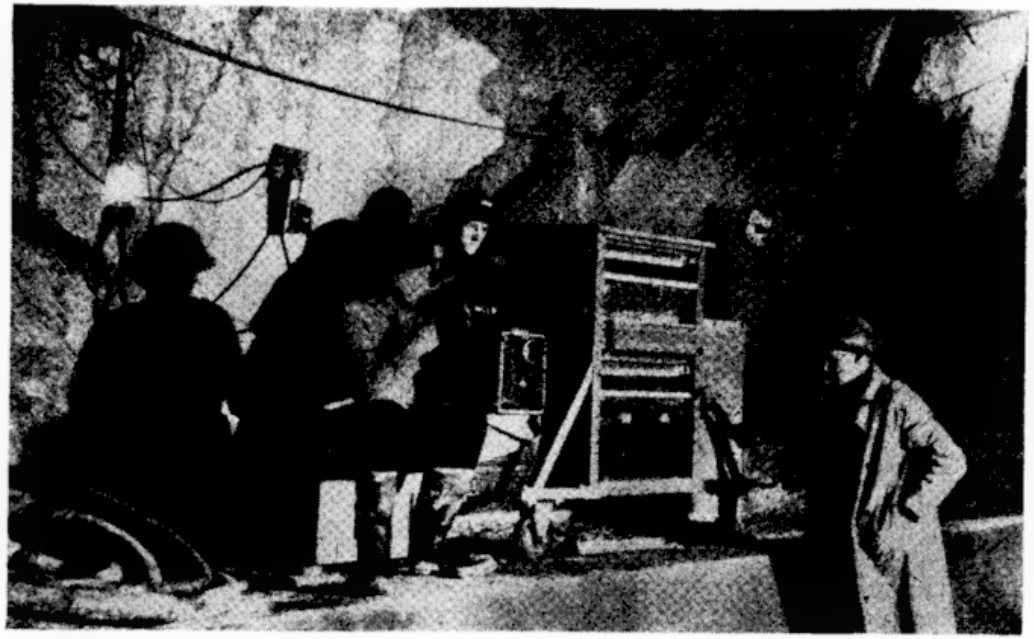
- Scattering Tomography

Reconstruction of the vertices of each large angle scattering for each muon.



1955 ICE THICKNESS ABOVE A TUNNEL IN AUSTRALIA.

Cosmic Rays Measure Overburden of Tunnel



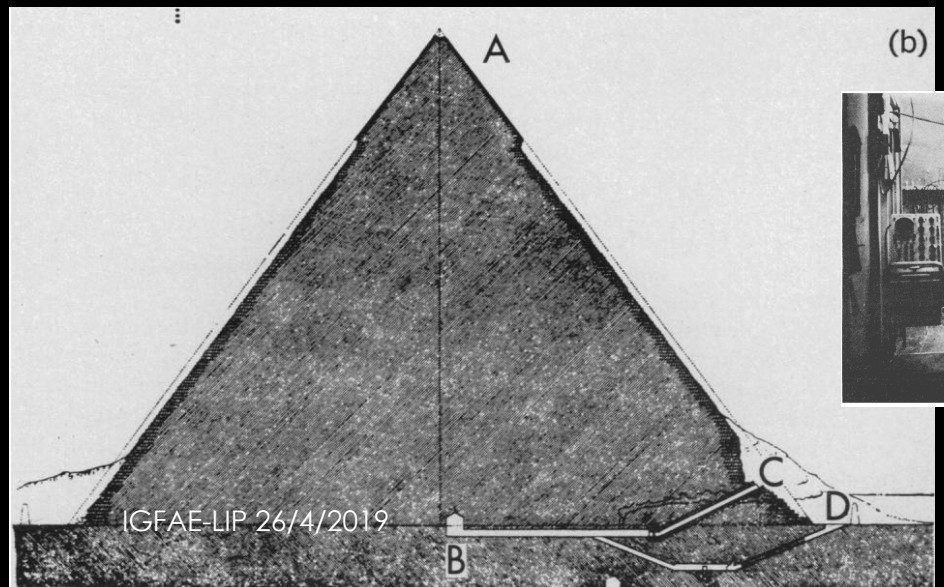
● Fig. 1—Geiger counter "telescope" in operation in the Guthega-Munyang tunnel. From left are Dr. George and his assistants, Mr. Lehane and Mr. O'Neill.

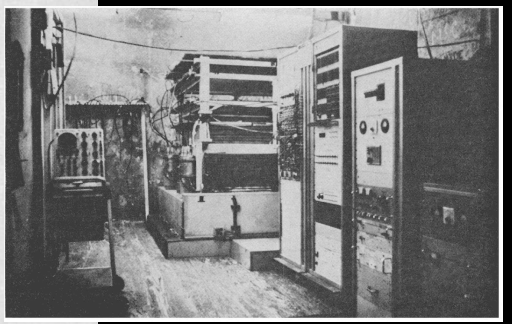
Geiger counter telescope used for mass determination at Guthega project of Snowy Scheme . . . Equipment described

By Dr. E. P. George*
University of Sydney, N.S.W.

1969 MUON RADIOGRAPHY IN CHEPHREN PYRAMID

- Luis Alvarez team looked for hidden chambers in Chephren Pyramid in Egypt. The detection was made with spark chambers and scintillation counters. No additional chambers were found at that time.





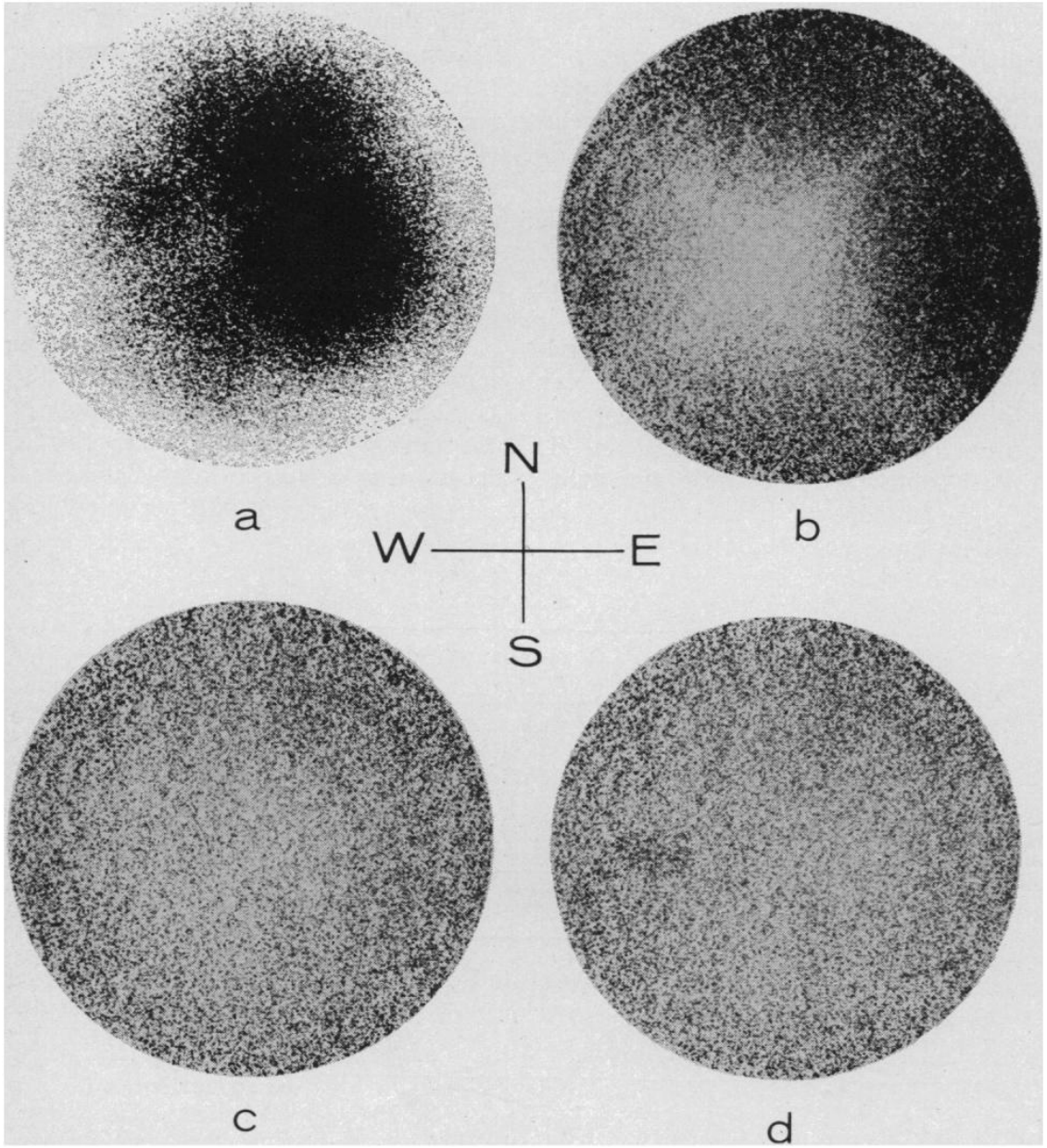


Fig. 13. Scatter plots showing the three stages in the combined analytic and visual analysis of the data and a plot with a simulated chamber. (a) Simulated "x-ray photograph" of uncorrected data. (b) Data corrected for the geometrical acceptance of the apparatus. (c) Data corrected for pyramid structure as well as geometrical acceptance. (d) Same as (c) but with simulated chamber, as in Fig. 12.

2016 WATER TOWER EXPERIMENT

Saclay, France

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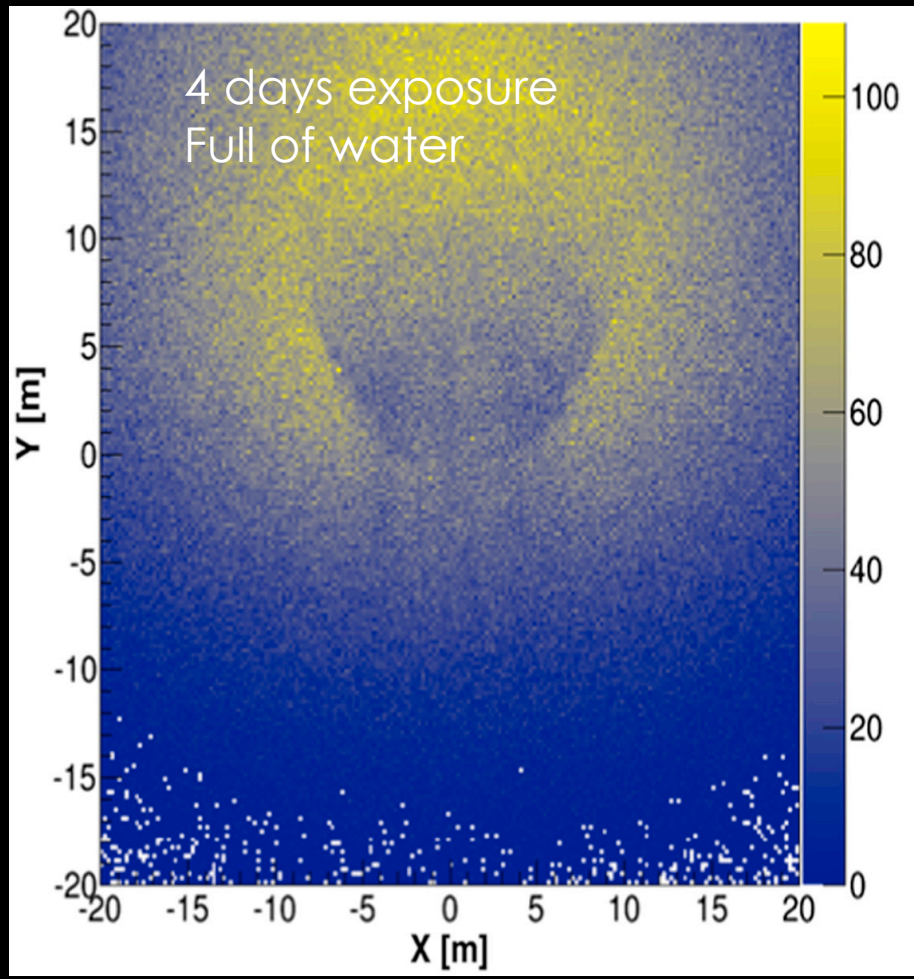
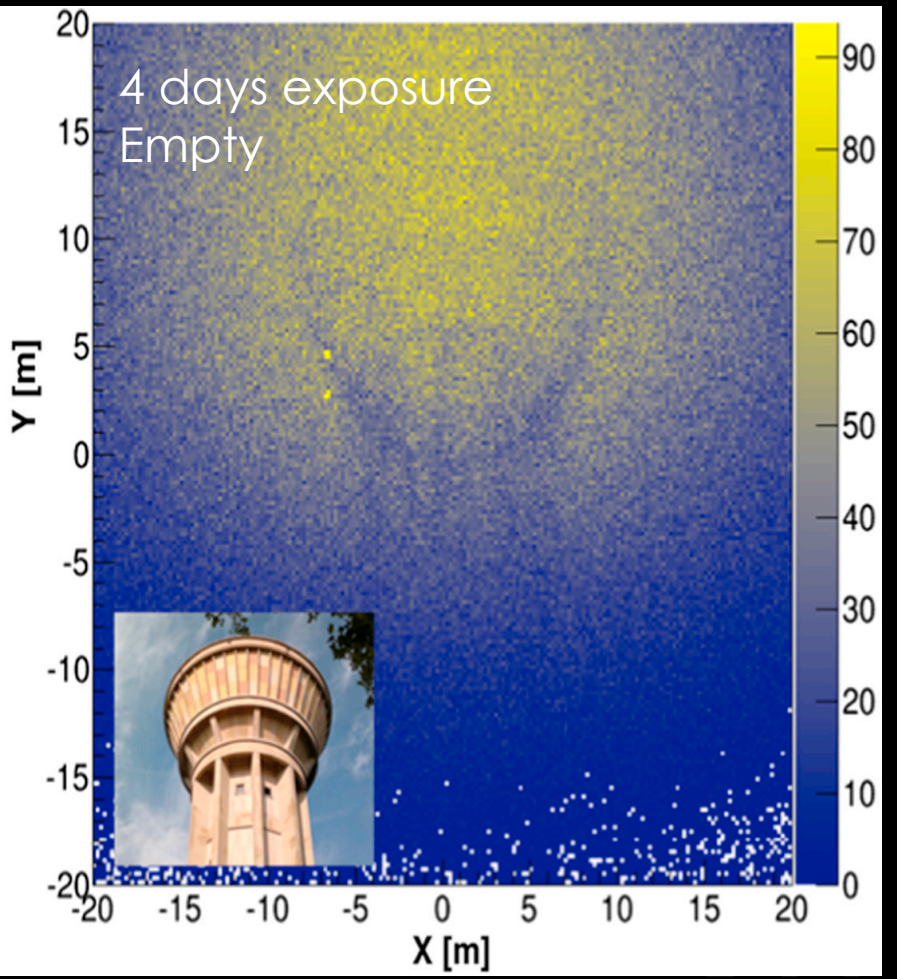
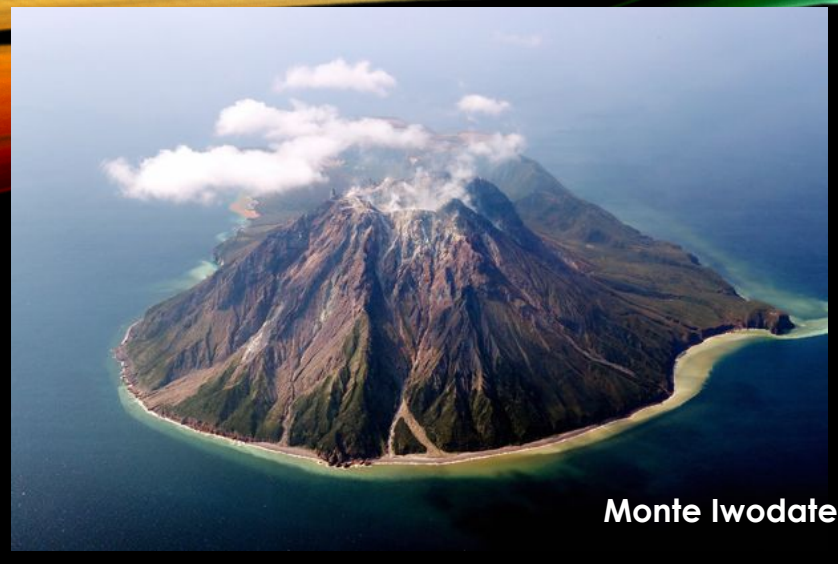




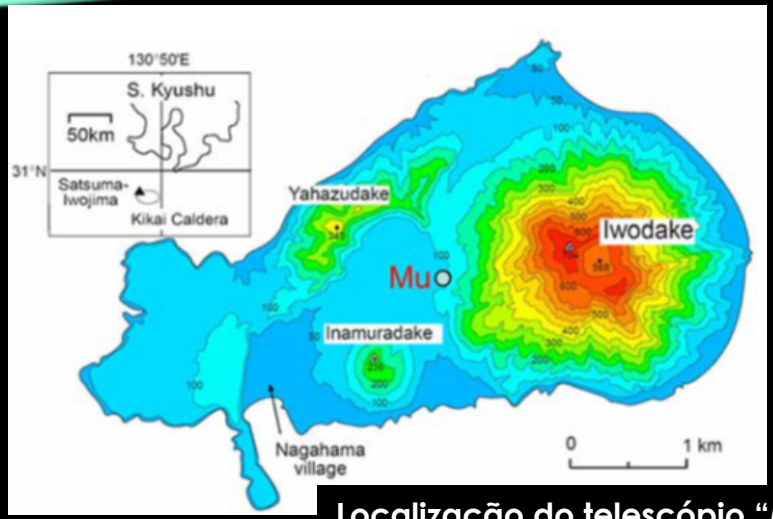
ILHA SATSUMA-IWOJIMA

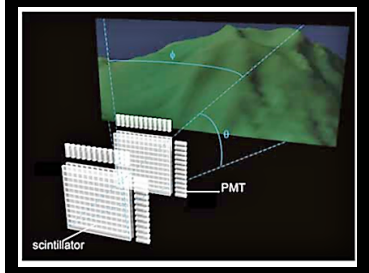
O Monte Iwodate é um vulcão ativo situado na Ilha Satsuma-Iwojima no Japão.

- O trabalho de muografia realizado no local por Tanaka *et al*. (2009) identificou a localização da chaminé vulcânica no interior do vulcão.

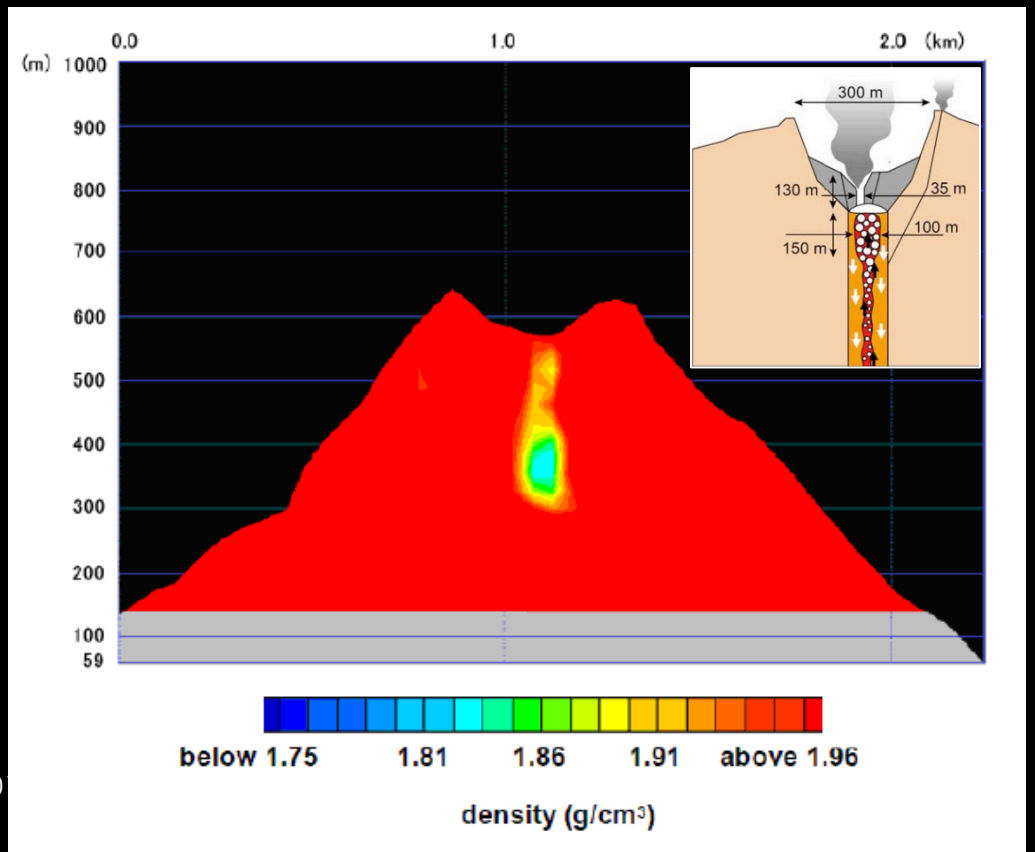


Monte Iwodate





Localização do telescópio "Mu" na Ilha Satsuma-Iowjima



- Os detetores possuíam uma área de 1 m^2 e eram constituídos por uma matriz de 12 x 12 pixeis de 8 cm.

- Distribuição das densidades médias da região da chaminé vulcânica no interior do cone vulcânico.

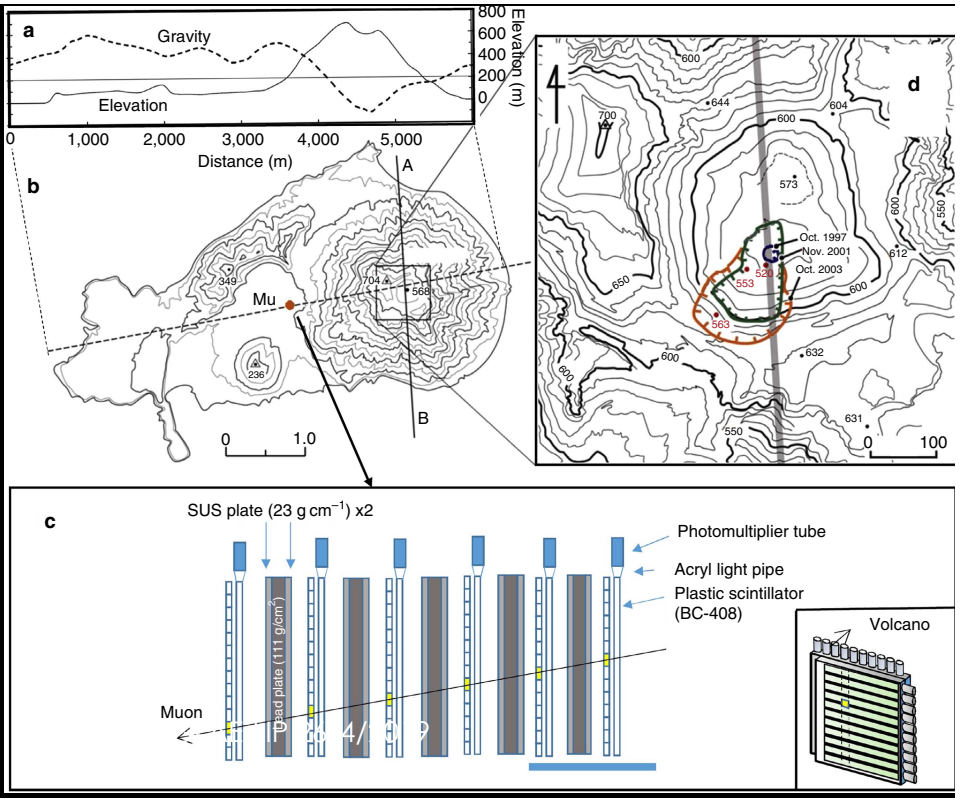
- A forma da chaminé está de acordo com o modelo do fluxo do magma responsável pela libertação dos gases.

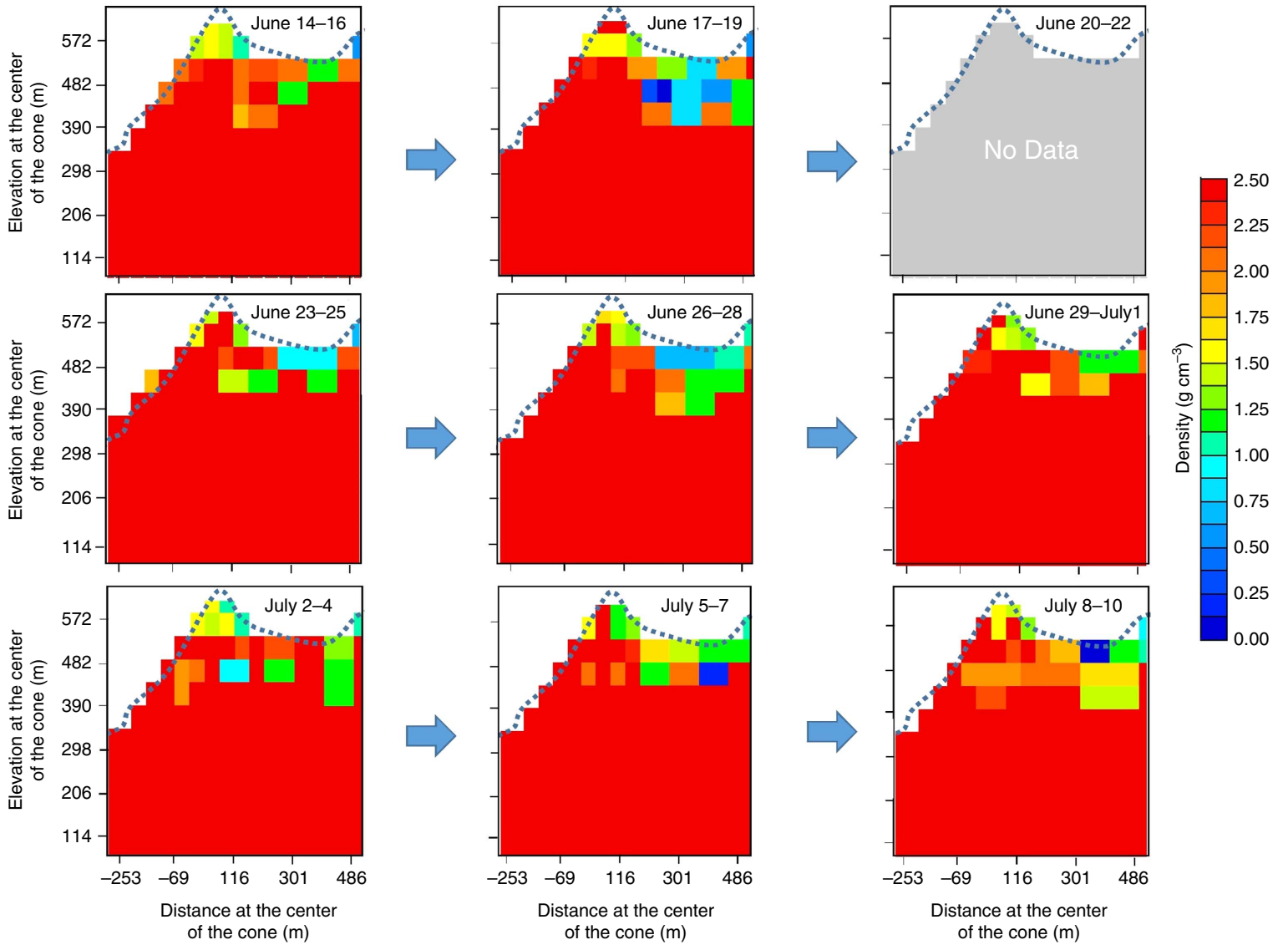
(Imagens: Tanaka *et al*, 2009)

Radiographic visualization of magma dynamics in an erupting volcano

Hiroyuki K.M. Tanaka[1], Taro Kusagaya[1] & Hiroshi Shinohara[2]

Radiographic imaging of magma dynamics in a volcanic conduit provides detailed information about ascent and descent of magma, the magma flow rate, the conduit diameter and inflation and deflation of magma due to volatile expansion and release. Here we report the first radiographic observation of the ascent and descent of magma along a conduit utilizing atmospheric (cosmic ray) muons (muography) with dynamic radiographic imaging. Time sequential radiographic images show that the top of the magma column ascends right beneath the crater floor through which the eruption column was observed. In addition to the visualization of this magma inflation, we report a sequence of images that show magma descending. We further propose that the monitoring of temporal variations in the gas volume fraction of magma as well as its position in a conduit can be used to support existing eruption prediction procedures.

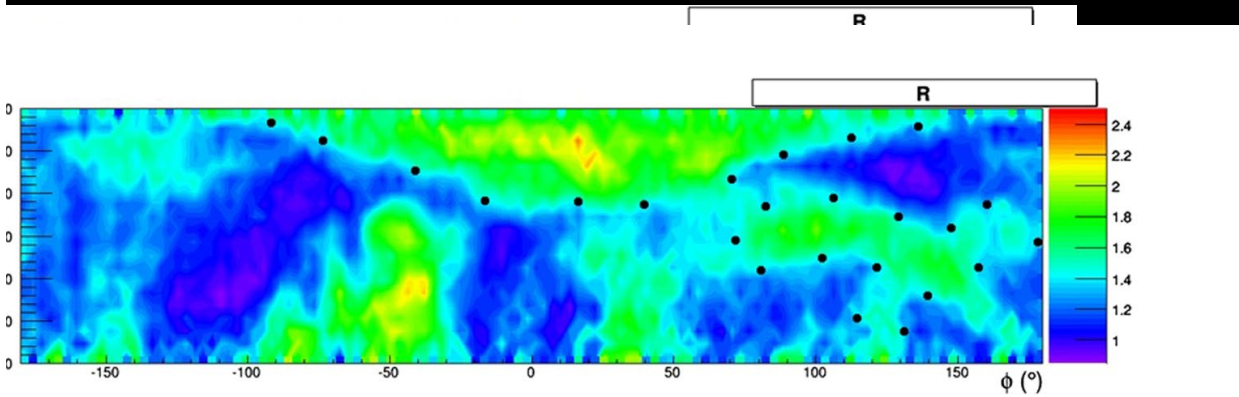


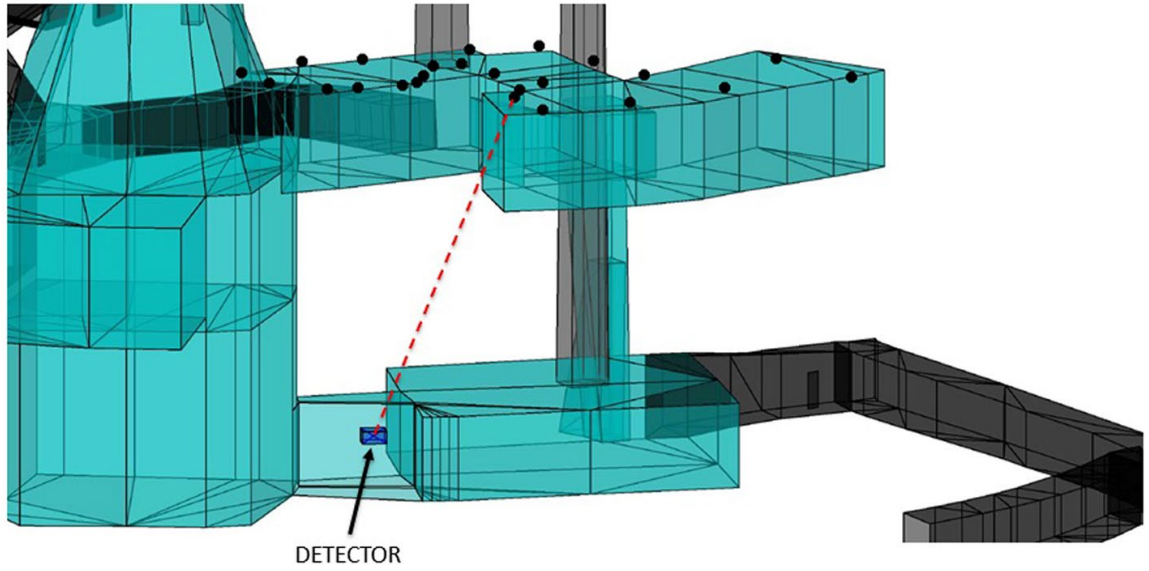


Imaging of underground cavities with cosmic-ray muons from observations at Mt. Echia (Naples)

G. Saracino[1,2], L. Amato[3], F. Ambrosino[1,2], G. Antonucci[3], L. Bonechi[4], L. Cimmino[2], L. Consiglio[5], R. D.' Alessandro[4,6], E. De Luzio[7], G. Minin[7], P. Noli[2], L. Scognamiglio[5], P. Strolin[1,2] & A. Varriale[5]

Muography is an imaging technique based on the measurement of absorption profiles for muons as they pass through rocks and earth. Muons are produced in the interactions of high-energy cosmic rays in the Earth's atmosphere. The technique is conceptually similar to usual X-ray radiography, but with extended capabilities of investigating over much larger thicknesses of matter thanks to the penetrating power of high-energy muons. Over the centuries a complex system of cavities has been excavated in the yellow tuff of Mt. Echia, the site of the earliest settlement of the city of Naples in the 8th century BC. A new generation muon detector designed by us, was installed under a total rock overburden of about 40 metres. A 26 days pilot run provided about 14 millions of muon events. A comparison of the measured and expected muon fluxes improved the knowledge of the average rock density. The observation of known cavities proved the validity of the muographic technique. Hints on the existence of a so far unknown cavity was obtained. The success of the investigation reported here demonstrates the substantial progress of muography in underground imaging and is likely to open new avenues for its widespread utilisation.

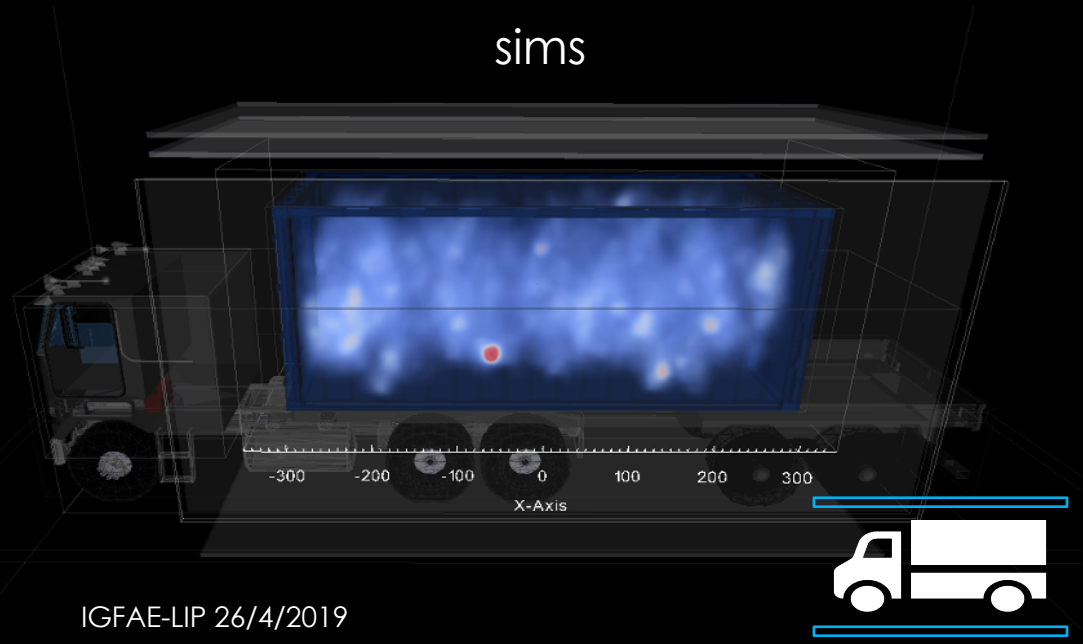




SCATTERING TOMOGRAPHY

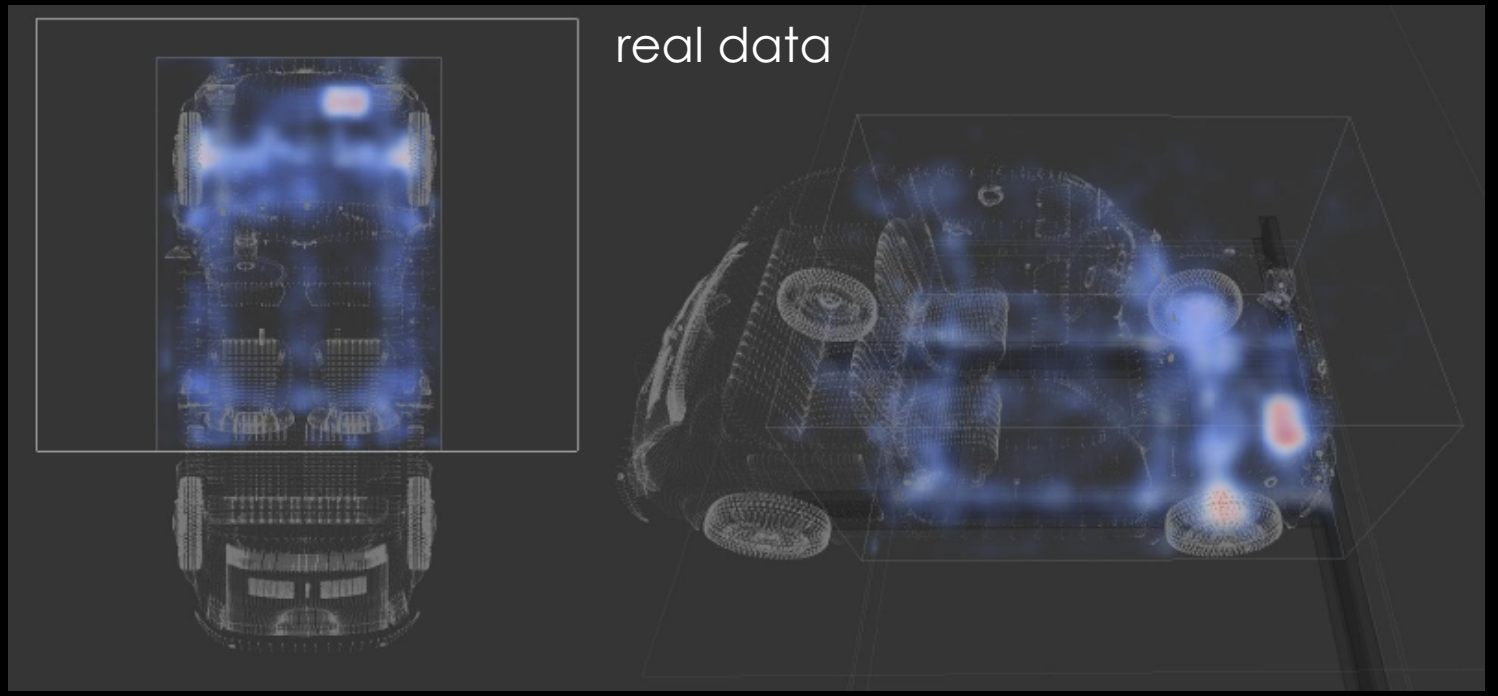
- Legnaro National Laboratory (Italy)
- Detection of radiactive materials in ~1min

sims

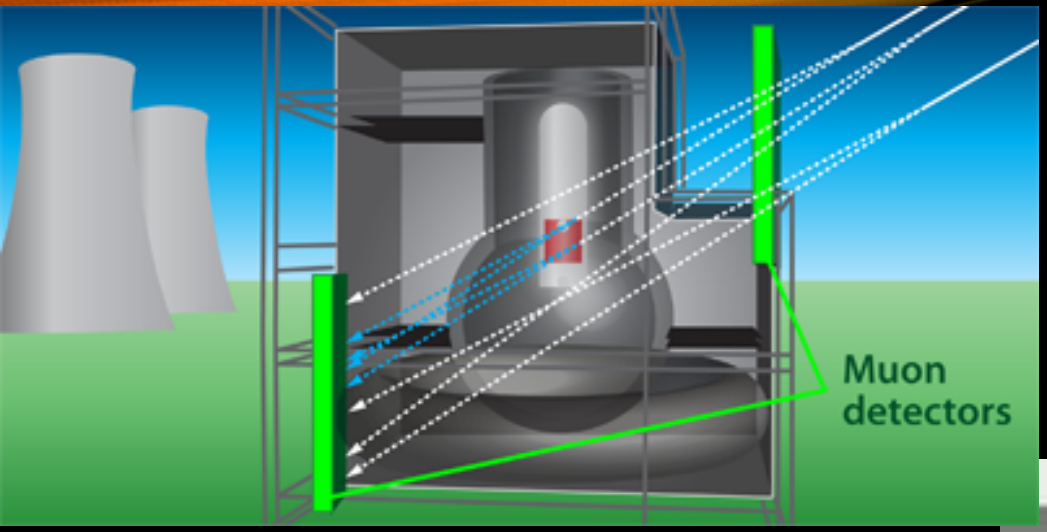


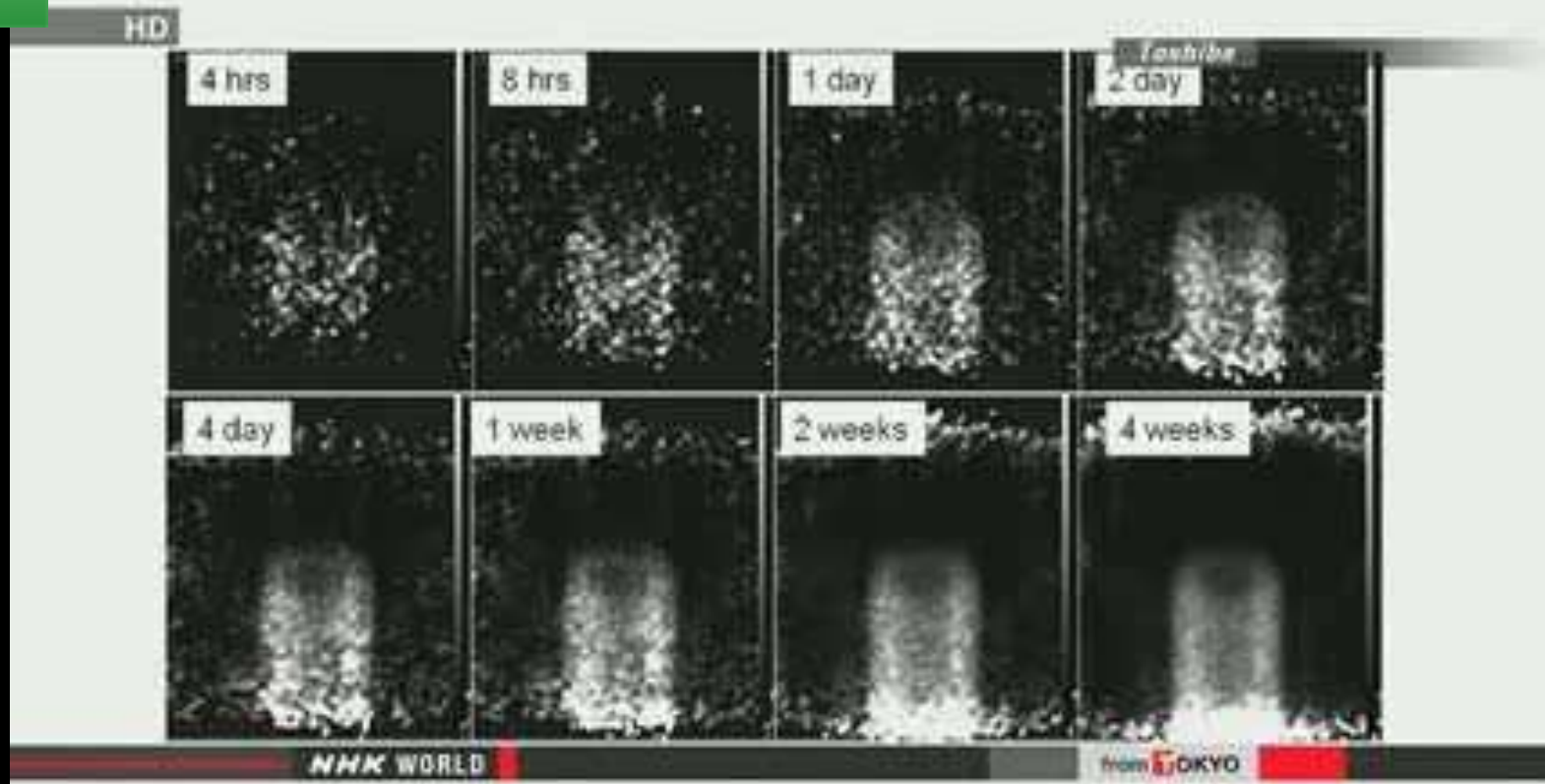
sims


ALTA
TENSIONE

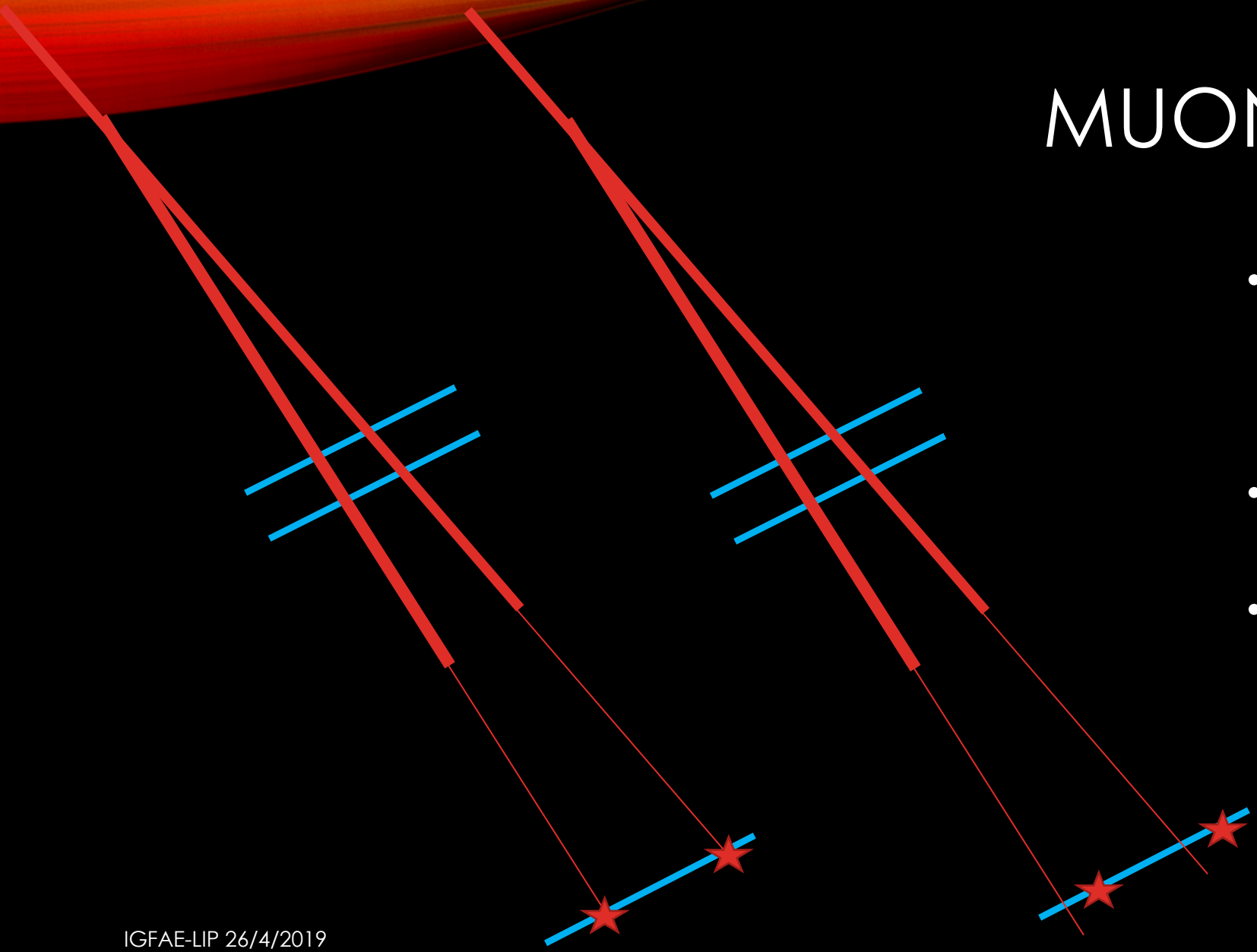

real data

2012-FUKUSHIMA-DAICHI





MUON METROLOGY



- We can monitor very slow relative drifts (~mm-cm per day/month/year) between detectors
- Detectors can be optically blocked, buried, etc
- Many applications in civil engineering and maintainance

LouMu

caracterizar a mina do Lousal com tomografia muónica

Parceiros

LIP
LABORATÓRIO DE INSTRUMENTAÇÃO E FÍSICA EXPERIMENTAL DE PARTÍCULAS
partículas e tecnologia

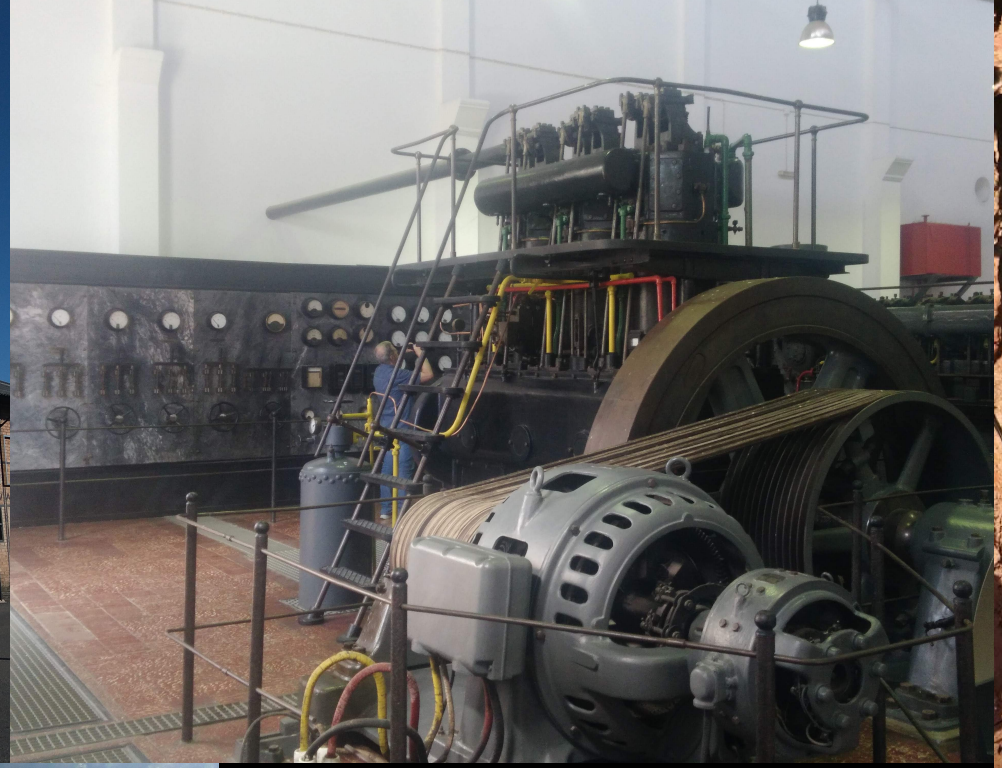
UNIVERSIDADE DE ÉVORA

ICT
Instituto de Ciências da Terra
Institute of Earth Sciences

Centro Ciência Viva do Lousal
Mina de Ciência

Muões na Mina do Lousal


MINA DE CIEN
CENTRO CIÊNCIA VIVA




Mina do LOUSAL
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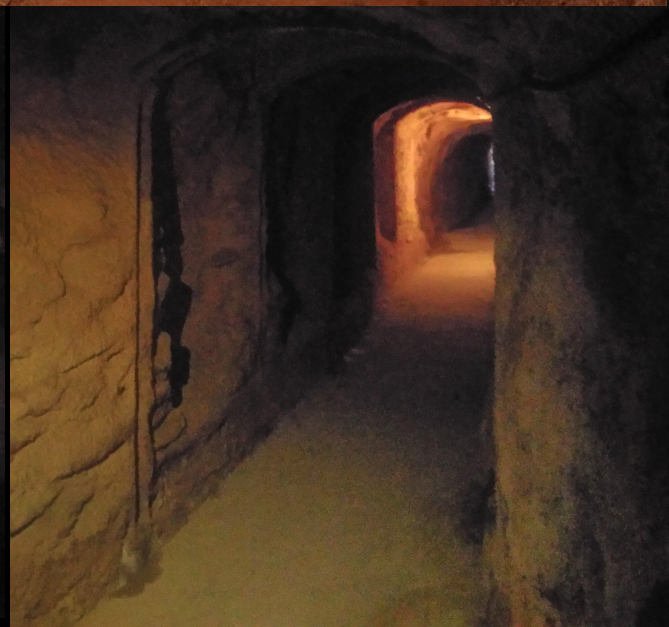
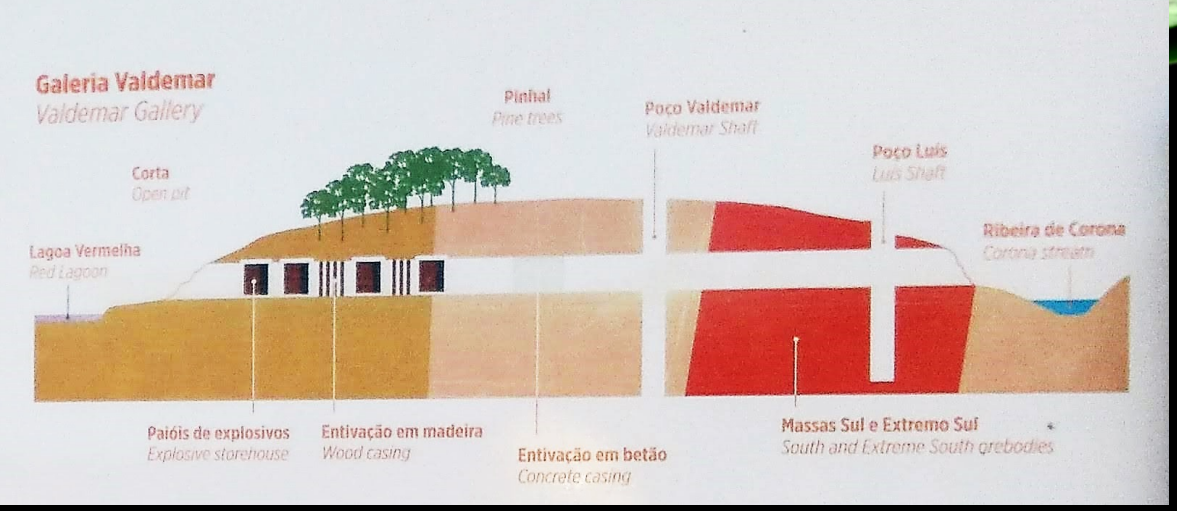


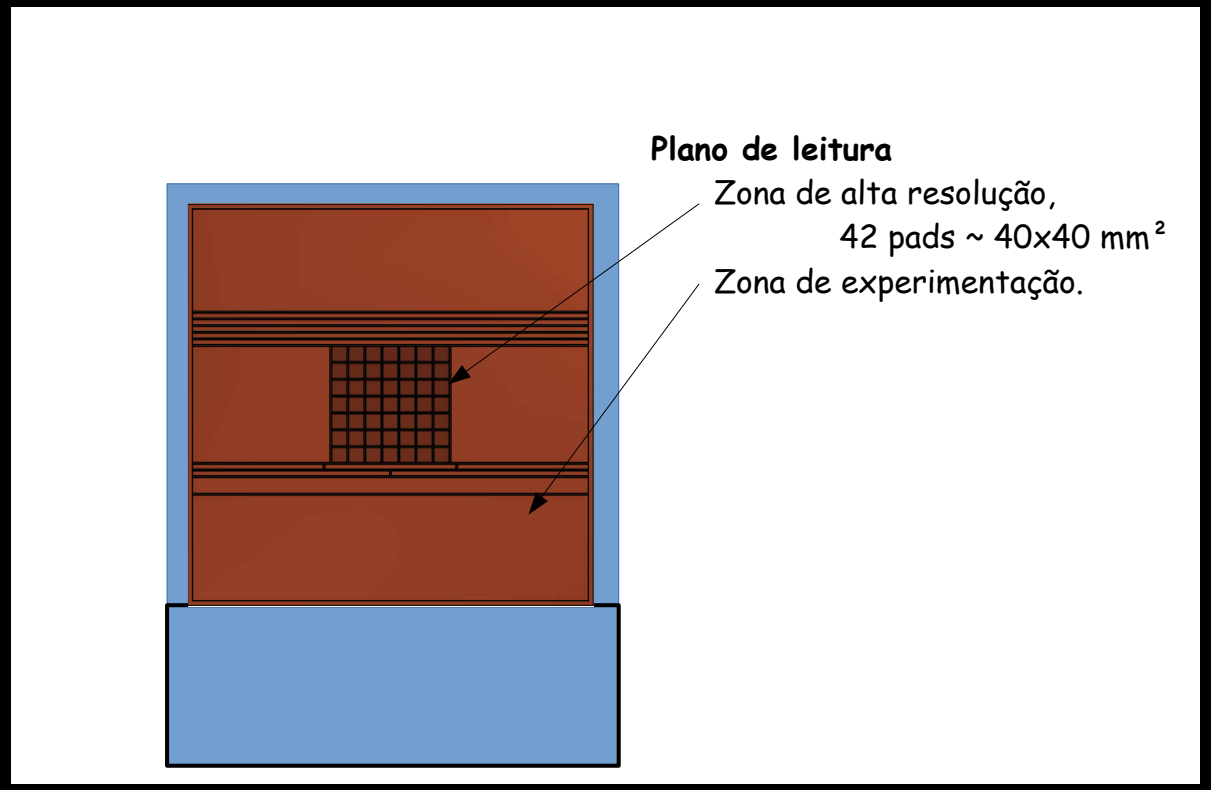


- Well known inactive mine
  - very well surveyed and excellent infraestructure
- Multidisciplinary team: Detector R&D, Astroparticle Physics and Geophysicists
- Develop combined muon-gravimetric mass inversion
  - gravimetry is also connected to mass density
- Test sensitivity to different over/under densities:
  - Mineral deposits, voids, solid/fragmented rock, water,humid/dry soil
- Long term goals: seed for more interdisciplinary projects

RPC TELESCOPES

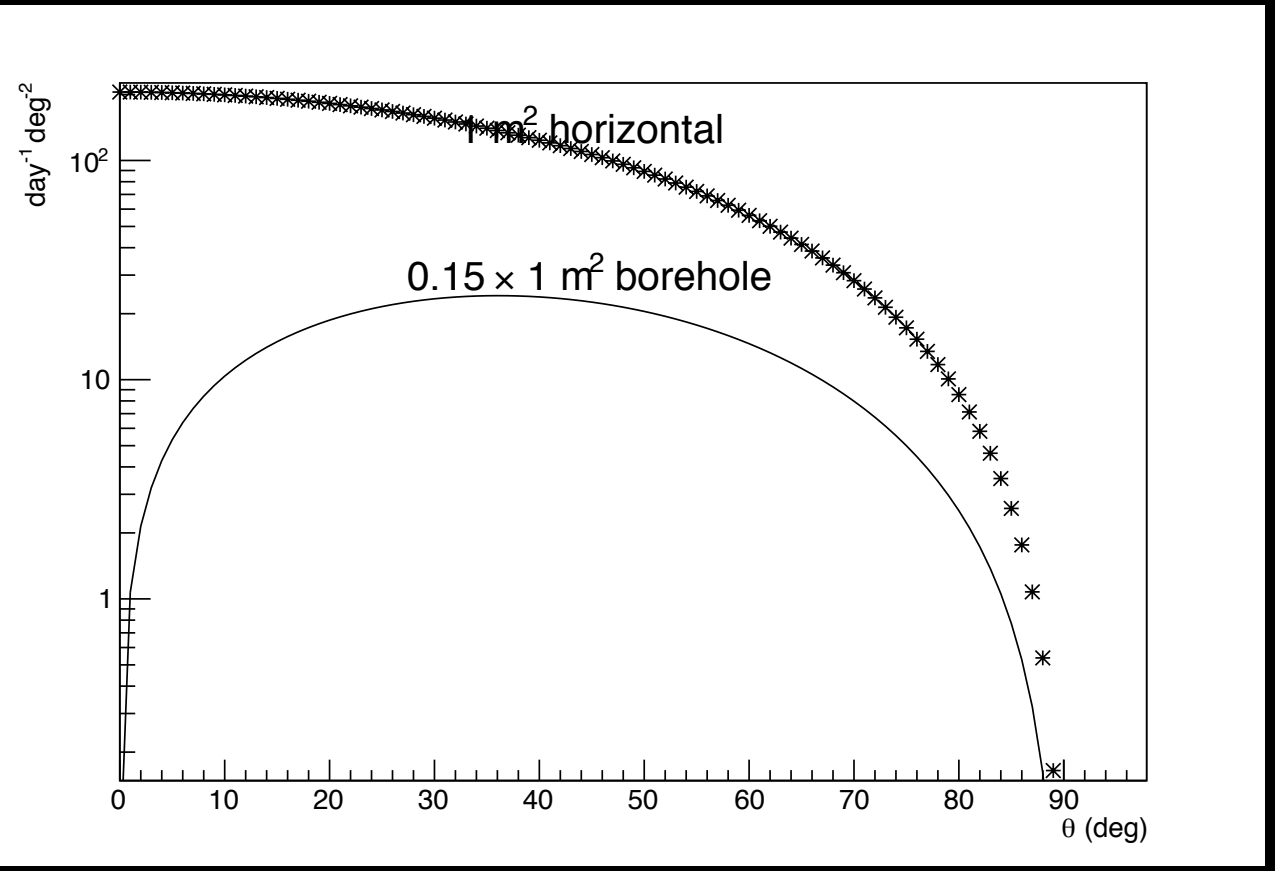
- 1st installed telescope "MiniMu"
  - Demonstrator for outreach and initial coms and performance tests
  - 2 planes
  - 3 x 3 pixels (~30x30 cm)

- 1st prototype (under construction)
  - 4 planes, 64 channels
  - 7x7 pixels inprecission core
  - 15 strips for testing
    - 32x32 xy strips in future

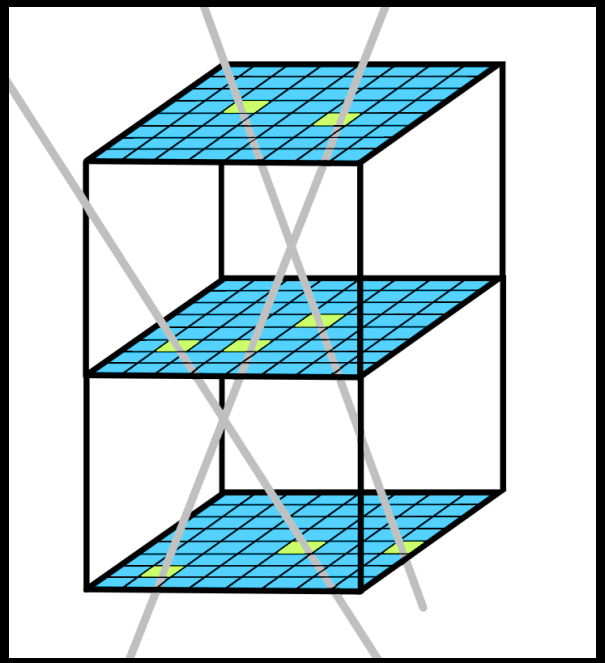


CONCLUSIONS

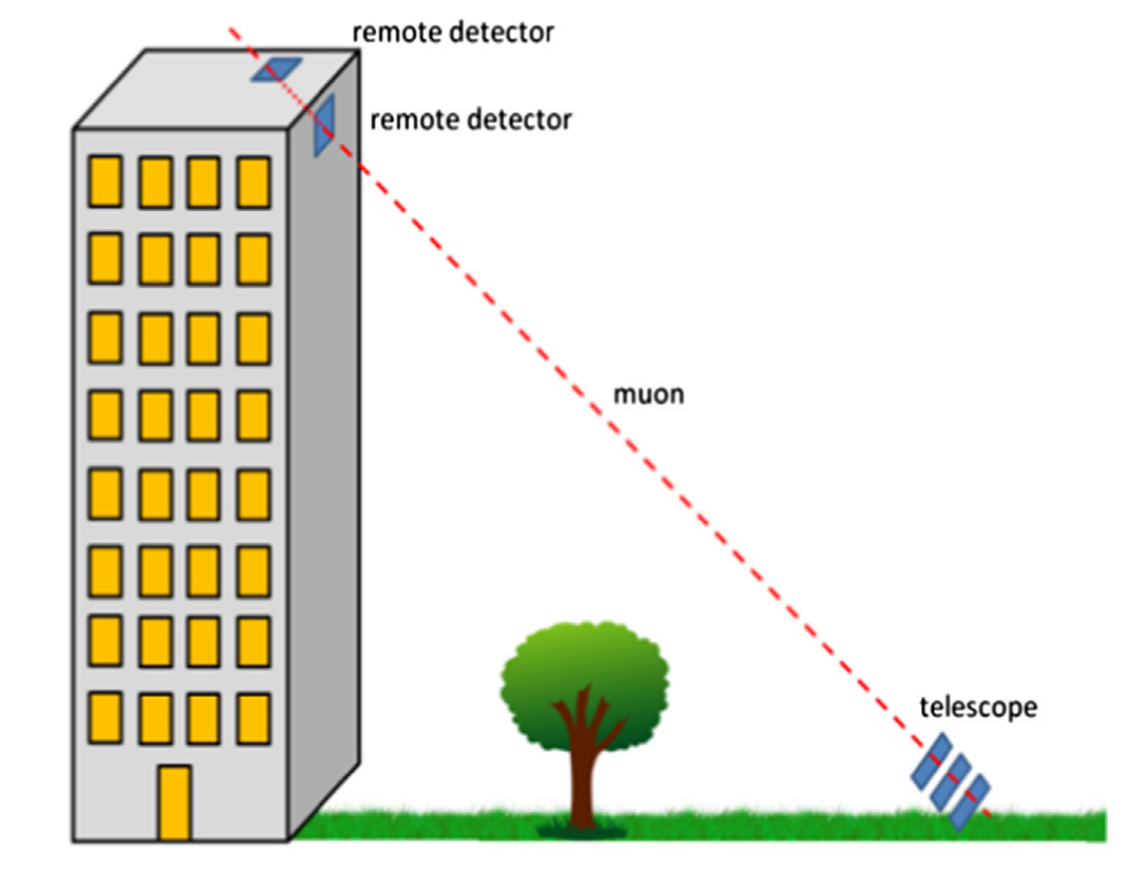
- Muon Tomography and Metrology is an emerging field
- 'Boom' in the last ~10 years.
  - Due to R&D in detectors
- Wide range of applications
  - Geology, Mining, Geophysics.
  - Geotechnics, Civil Engineering.
  - Archaeology
  - Nuclear safety, Metallurgy, CO2 reservoir monitoring
- LIP has formed a interdisciplinary group
  - Proof of concept project in Lousal Mine
- RPC technology is extremely competitive in this field due to the
  - optimal high-quality/cost ratio



- 25 m deep (rho=2.6 g/cm3)



MUON METROLOGY



- Monitoring of relative drifts between detectors