in collaboration with:

Muon tomography at LIP

R. Sarmento
on behalf of the LouMu collaboration

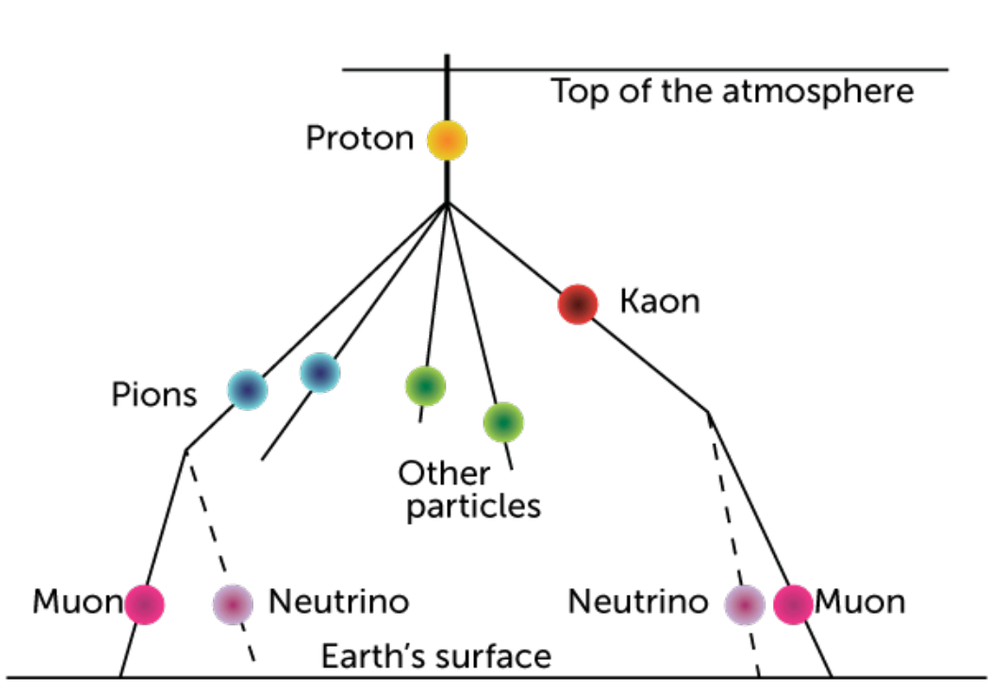
Santiago de Compostela, July 4th, 2022

Contents

Muon tomography

Technique that uses the natural flux of muons to produce images of objects with large sizes

- Abundant flux ≈ 10^4 m^{-2} min^{-1}
- Small rate of energy loss
- Quasi-linear trajectory through several meters of matter before decaying or being absorbed

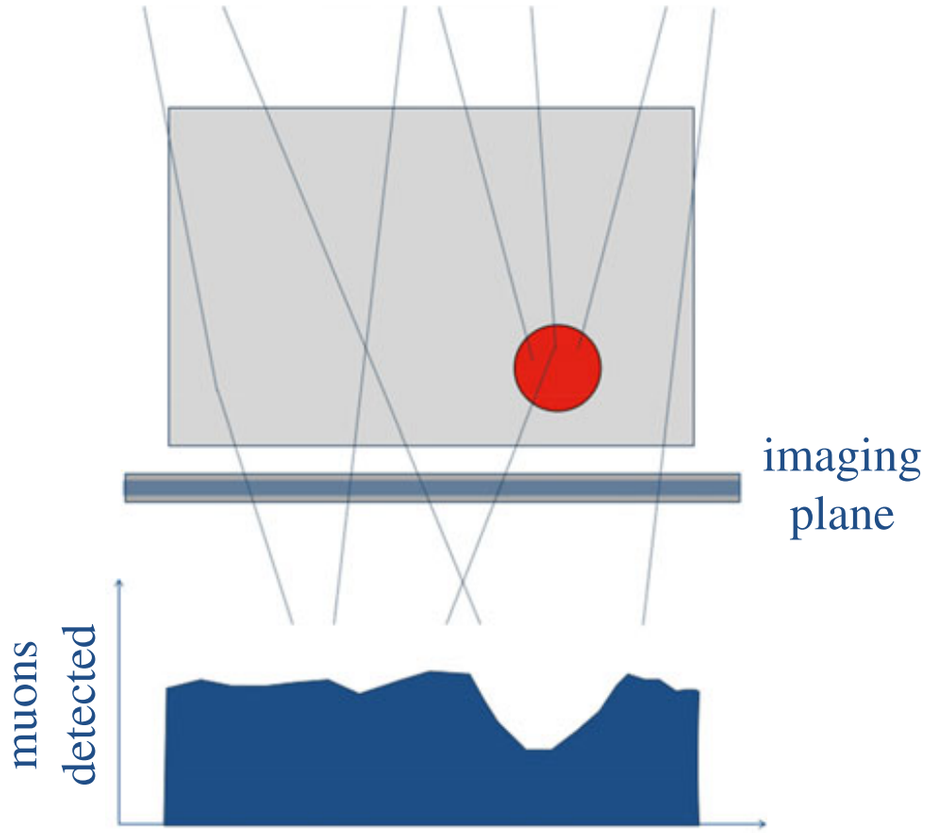


From: **Giammanco**

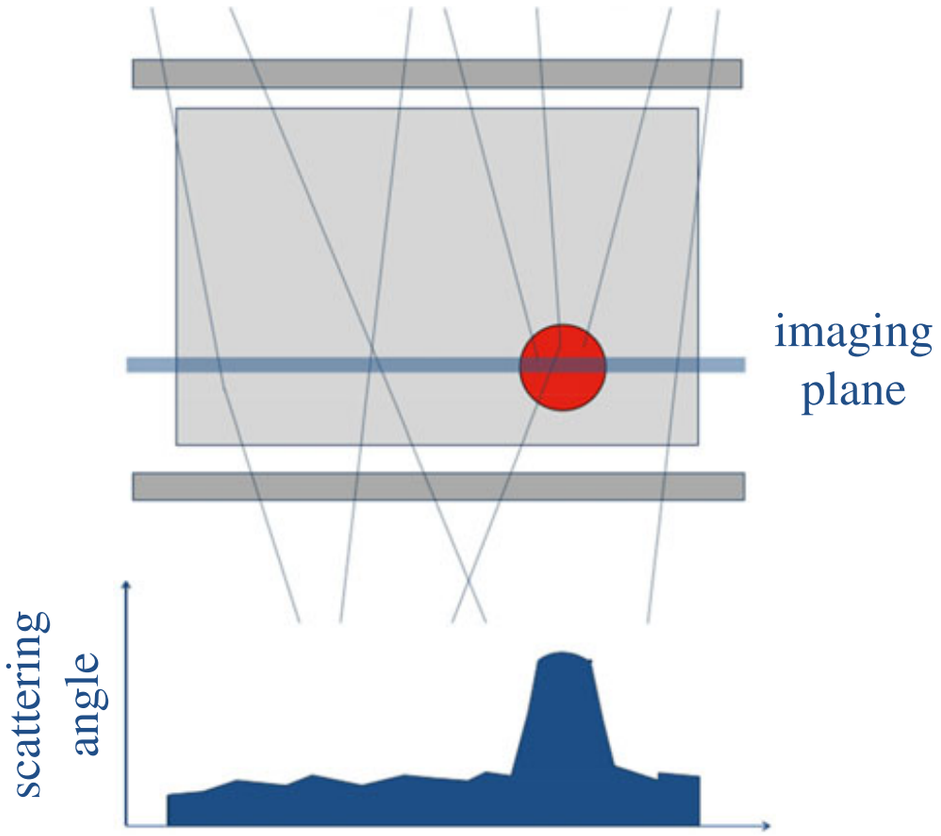
Muon tomography

Techniques

transmission tomography



scattering tomography

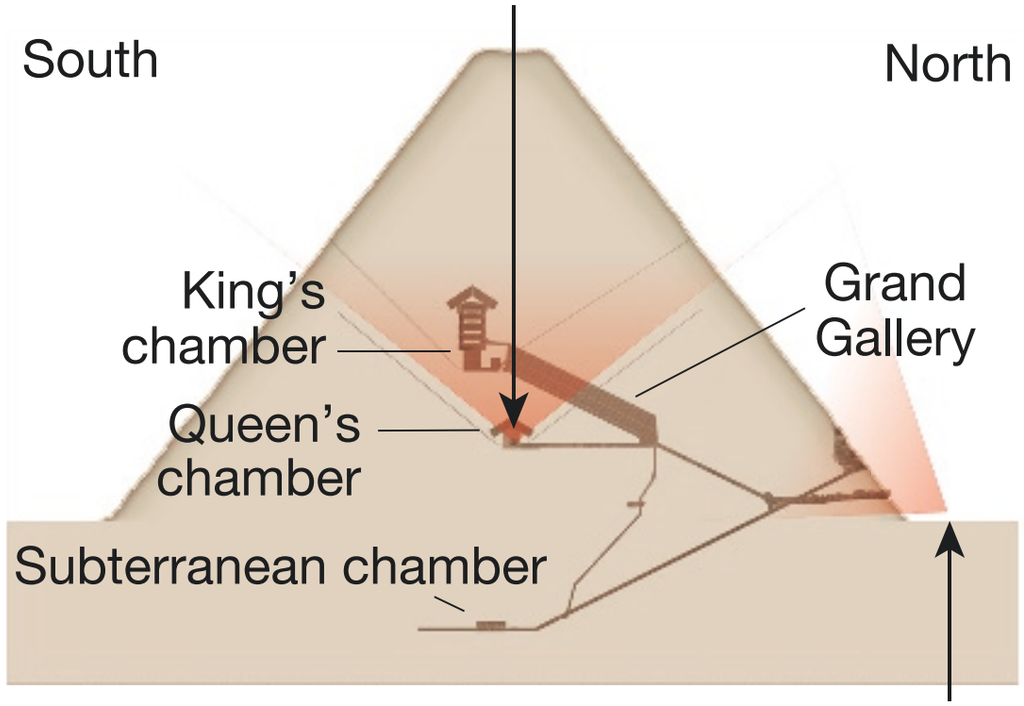


From: **rsta.2018.0049**

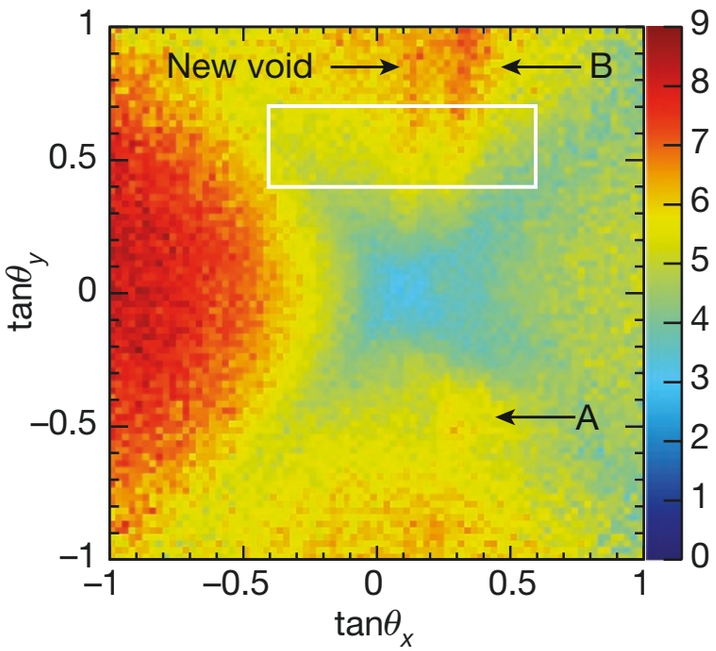
Muon tomography
Applications

- Archaeology, vulcanology, civil engineering, industrial safety, etc

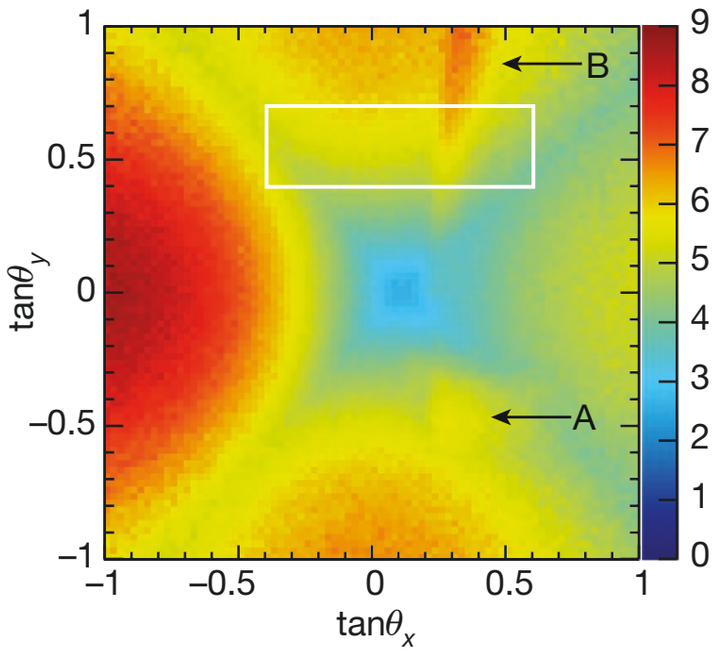
ScanPyramid's Big Void at the Great Pyramid of Giza

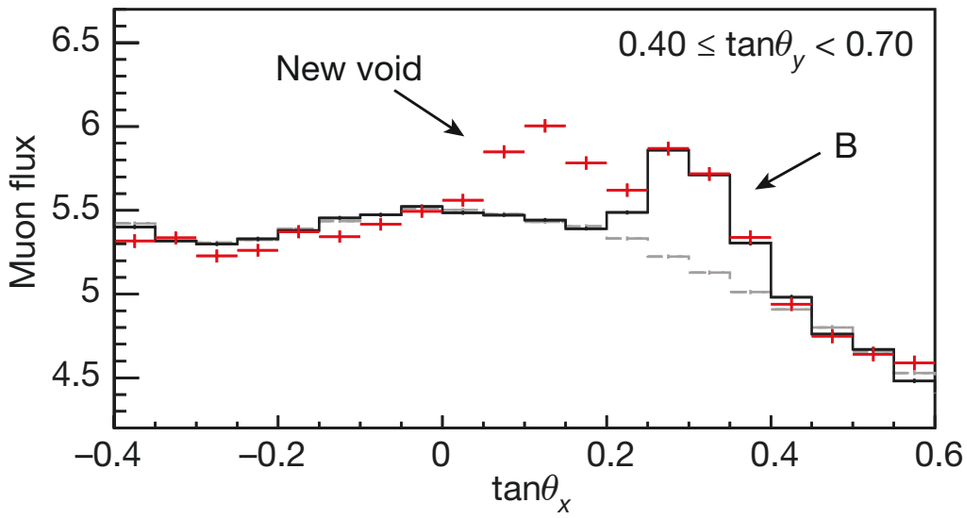


data



simulation





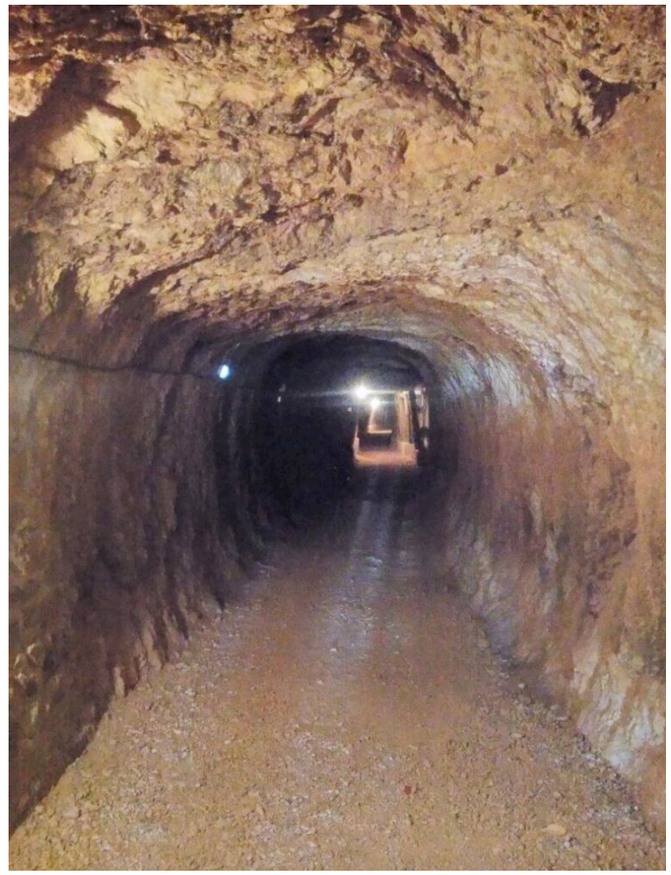
From: **nature24647**

LouMu project

Goal

- Transmission muography at the Lousal mine for geological characterization

- Reference geological model from conventional geophysics measurements



LouMu project
Timeline

underground surveys

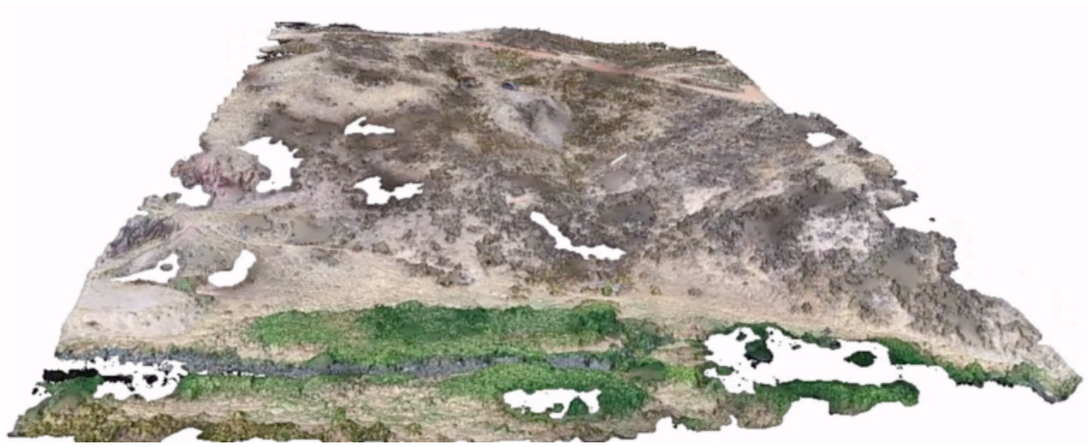
geological samples

laser scans

surface surveys

seismic refraction

ground penetrating radar



drone photogrammetry

- Geophysical measurements campaigns:

<u>June, 2019</u>
1st campaign

<u>November, 2021</u>
2nd campaign

<u>May, 2022</u>
3rd campaign

LouMu project

Timeline

<u>February, 2019</u>
MiniMu at Lousal

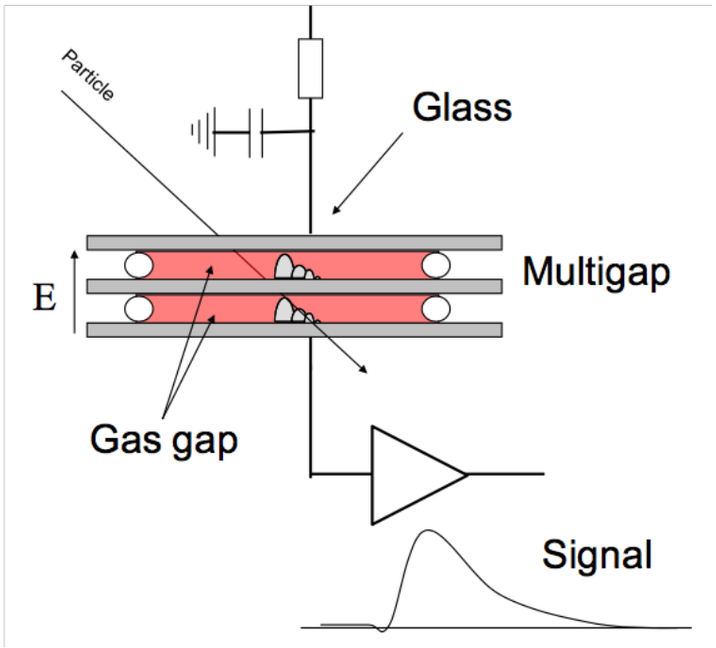
<u>from March, 2020</u>
CorePix at Coimbra

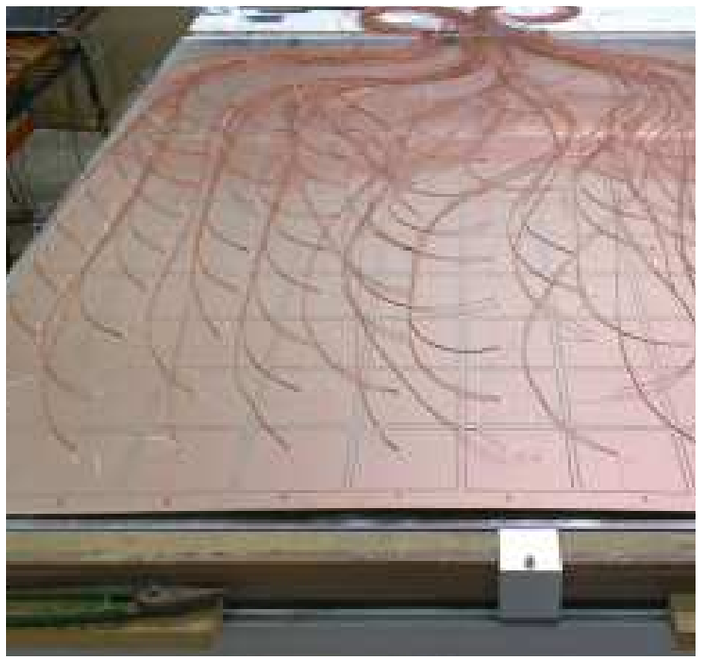
<u>April, 2022</u>
CorePix at Lousal

Muon telescope
Resistive plate chambers

MAROC outputs
and trigger board

- 4 planes of RPCs
- Segmented readout planes for positional information



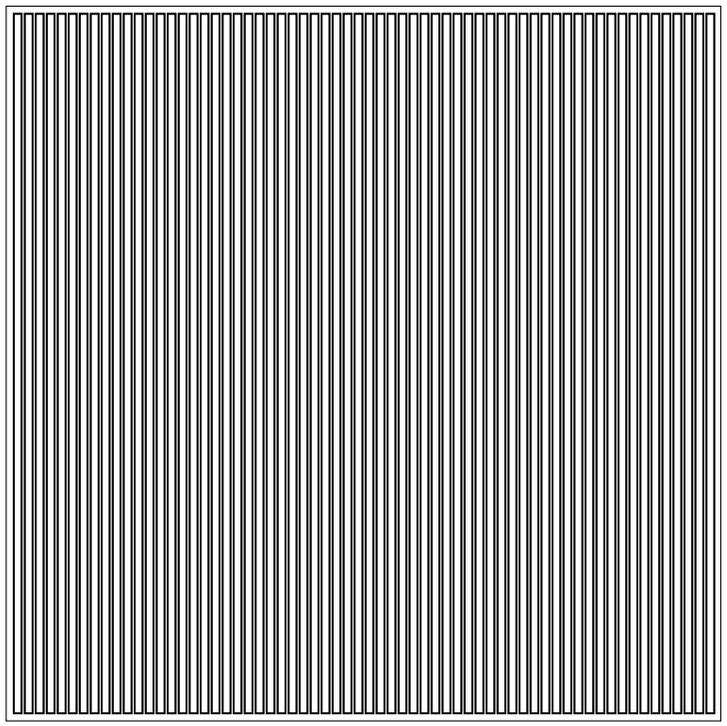


CorePix

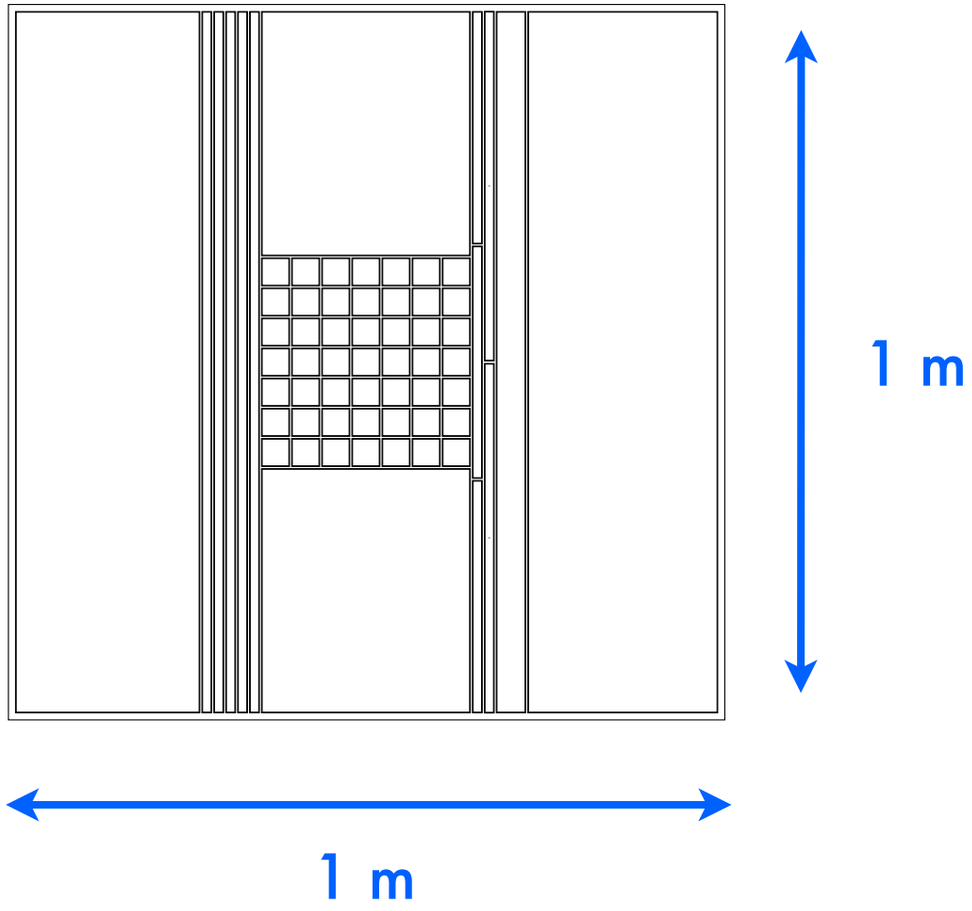
Muon telescope

Geometrical configuration

Upper plane



3 lower planes



- 64 strips
- Background removal and studying the strips response

- 7x7 central pads matrix for higher angular resolution
- Outer region for higher statistics

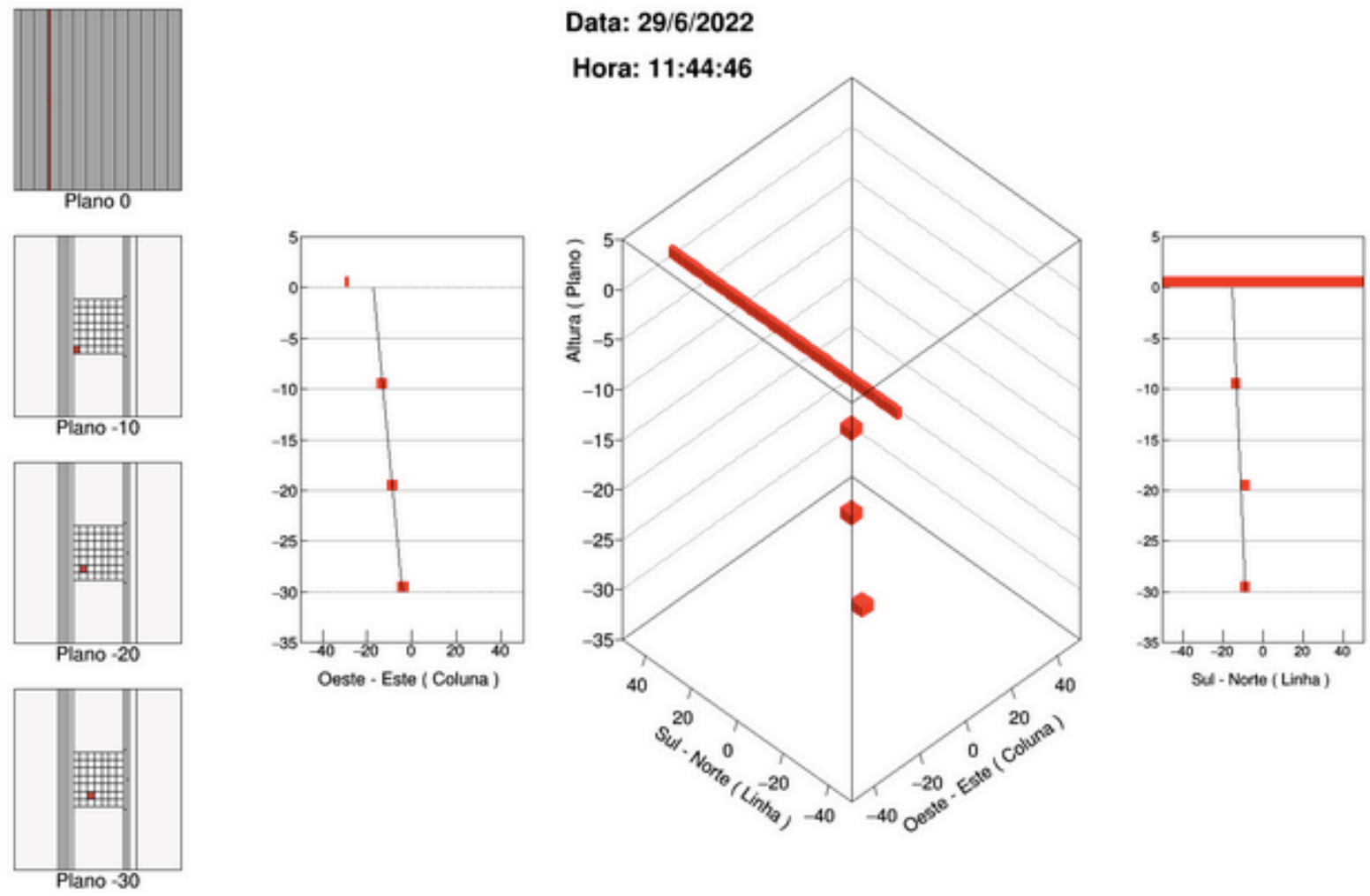
Muon telescope

Trajectory reconstruction

- Event trigger: coincidence between signals in two planes within 30 ns time-window

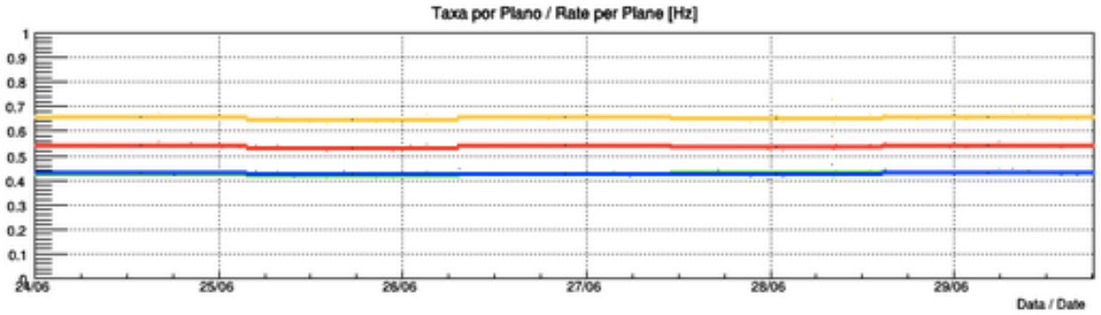
- Resolution from the current operational conditions:
  - $\theta \approx 3°$
  - $tg(\theta) \approx 0.05$
  - x,y ≈ 2 cm

Event from last week

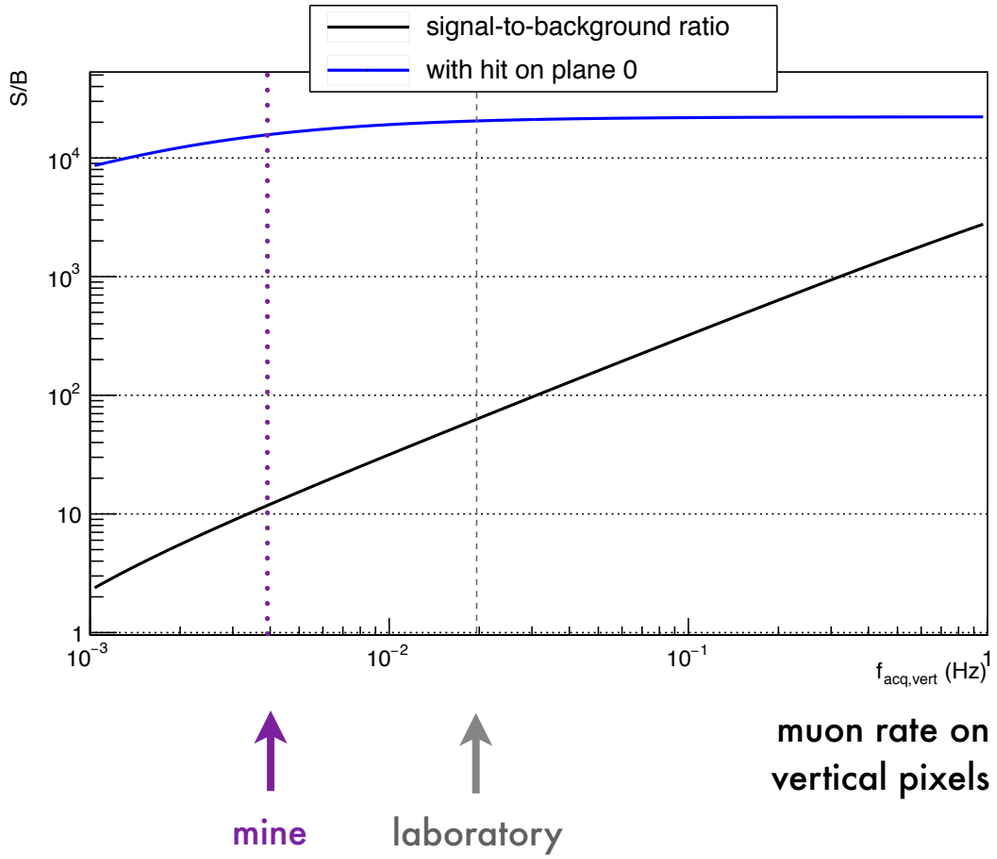


Muon telescope
Response studies

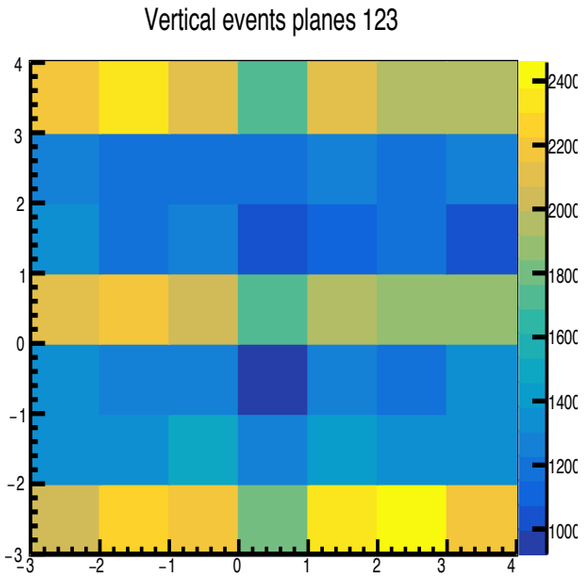
Time stability



Signal-to-background ratio



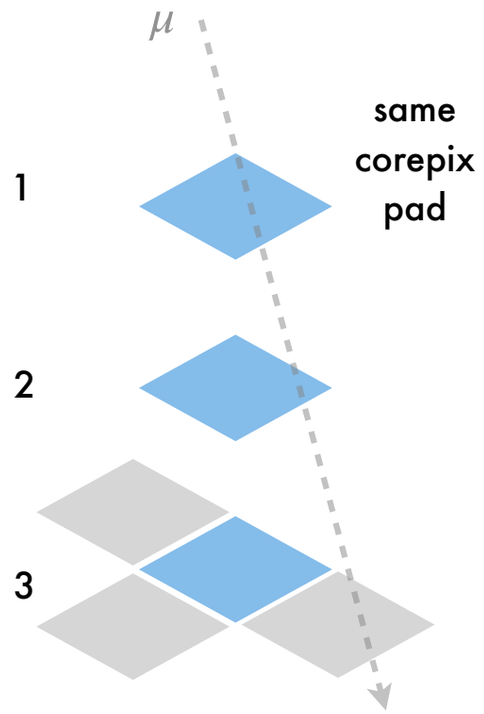
Spatial uniformity

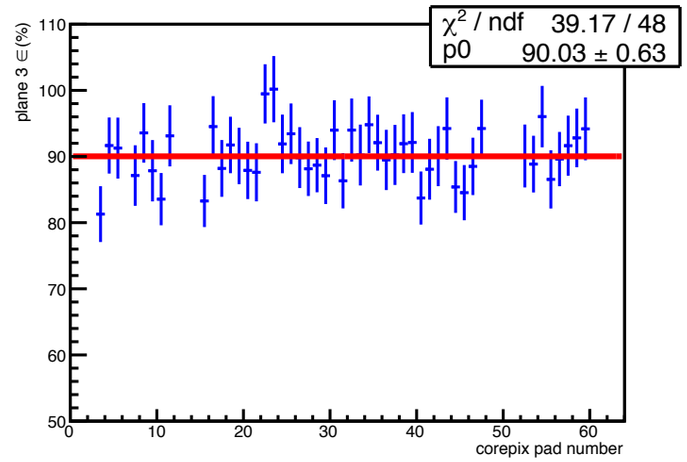


15	19	10	28	35	53	44
3	7	23	29	36	41	57
16	20	11	30	37	54	45
4	8	24	31	38	42	58
17	21	25	32	39	55	46
5	9	26	33	52	43	59
18	22	27	34	40	56	47

spacers

Vertical efficiency





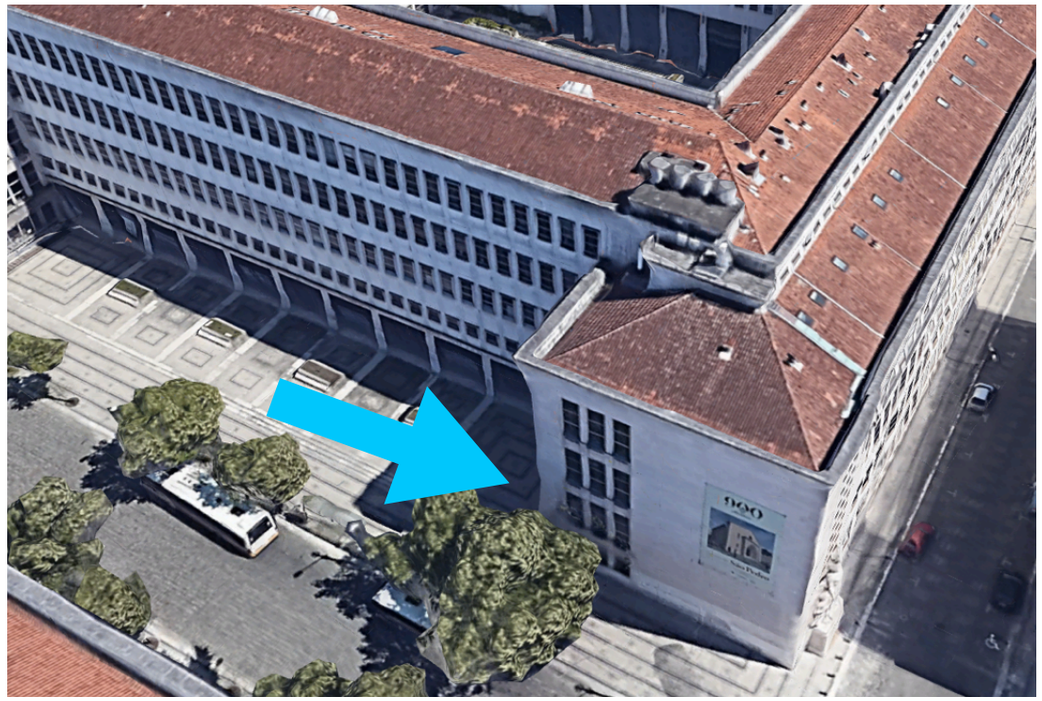
$$\epsilon_3 = \frac{N_{123}}{k_3 N_{12}}$$

$$k_3 = \frac{N_{123}^{sim}}{N_{12}^{sim}} \sim 0.25$$

First muographs

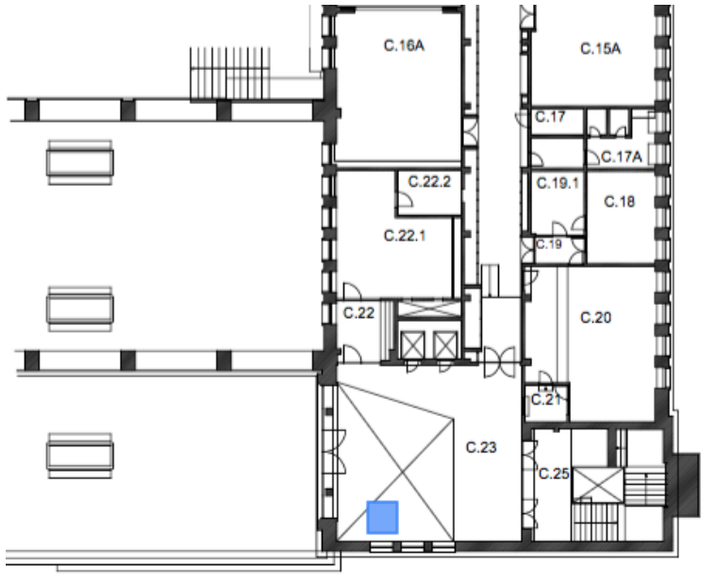
Coimbra building - setup

- Telescope at the entrance of the Coimbra University Physics Department



detector position - photo

detector position - top view

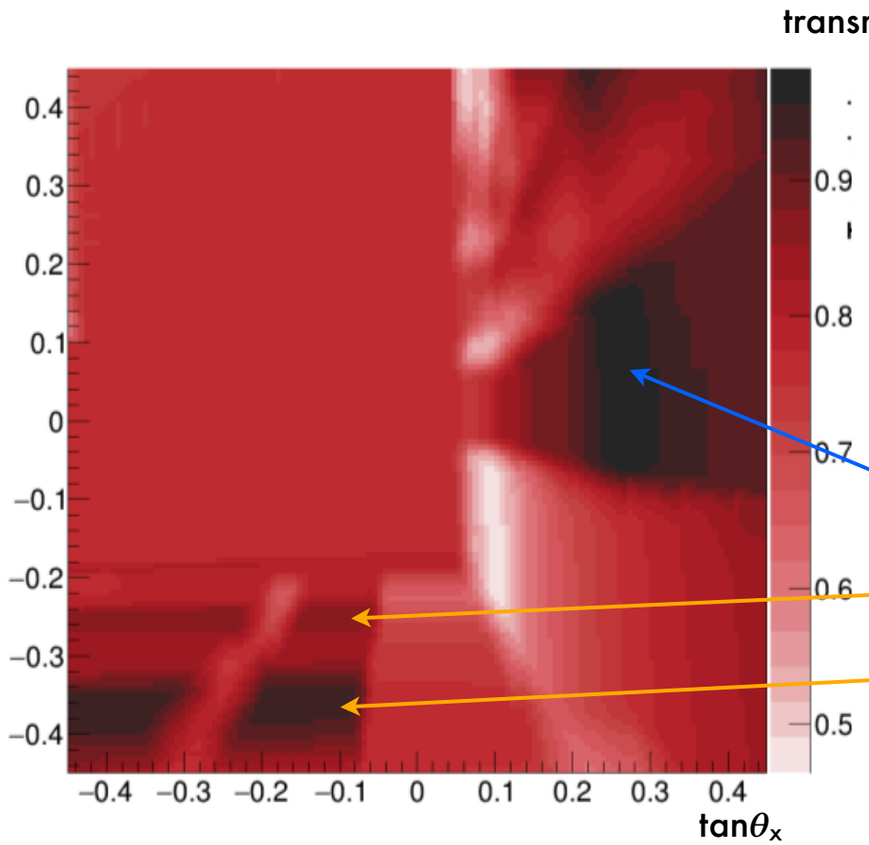


detector position - side view

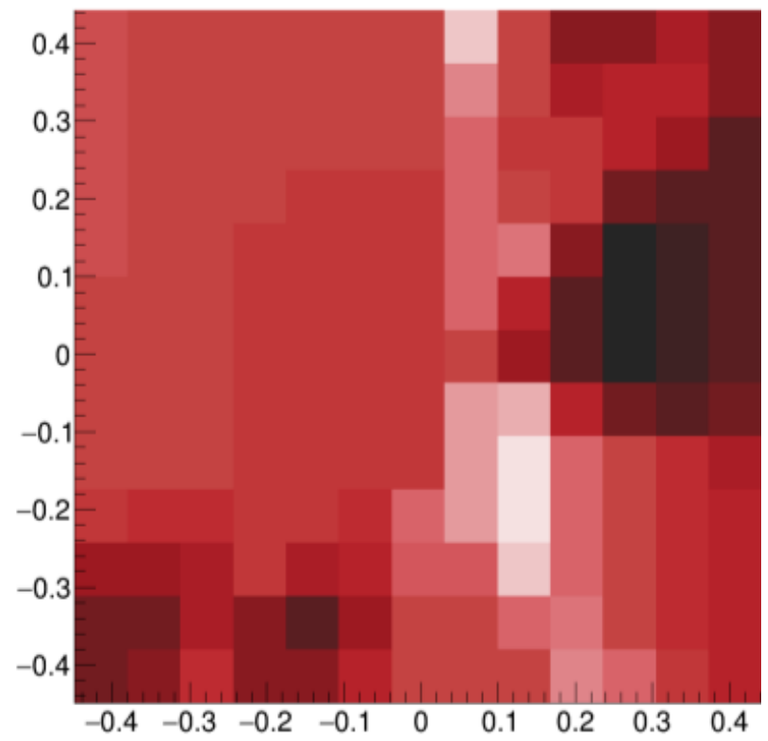
First muographs

Coimbra building - model

high resolution

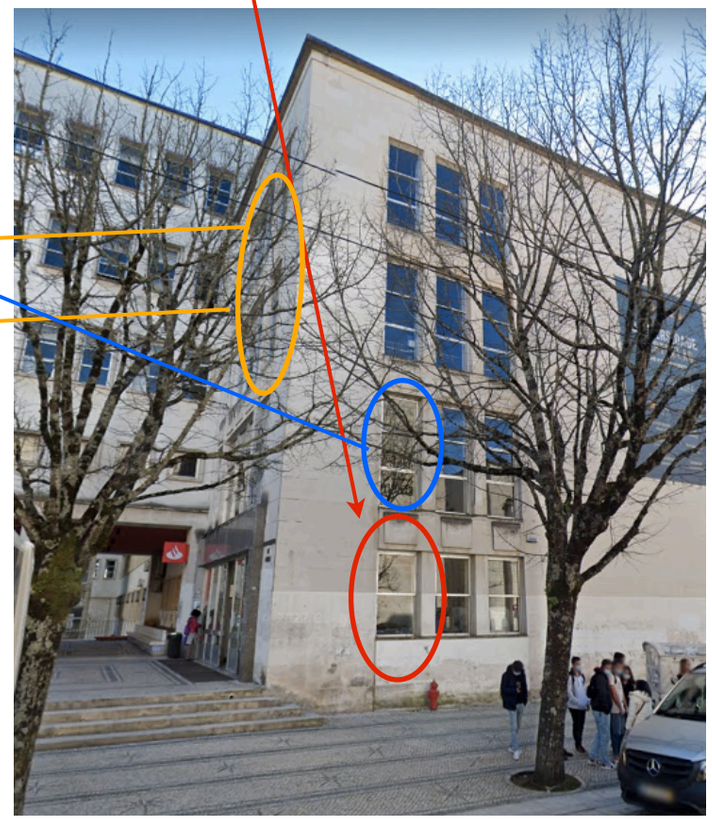


telescope resolution



inside

outside



- Analytical computation of the muon transmission through the building

First muographs

Coimbra building - data

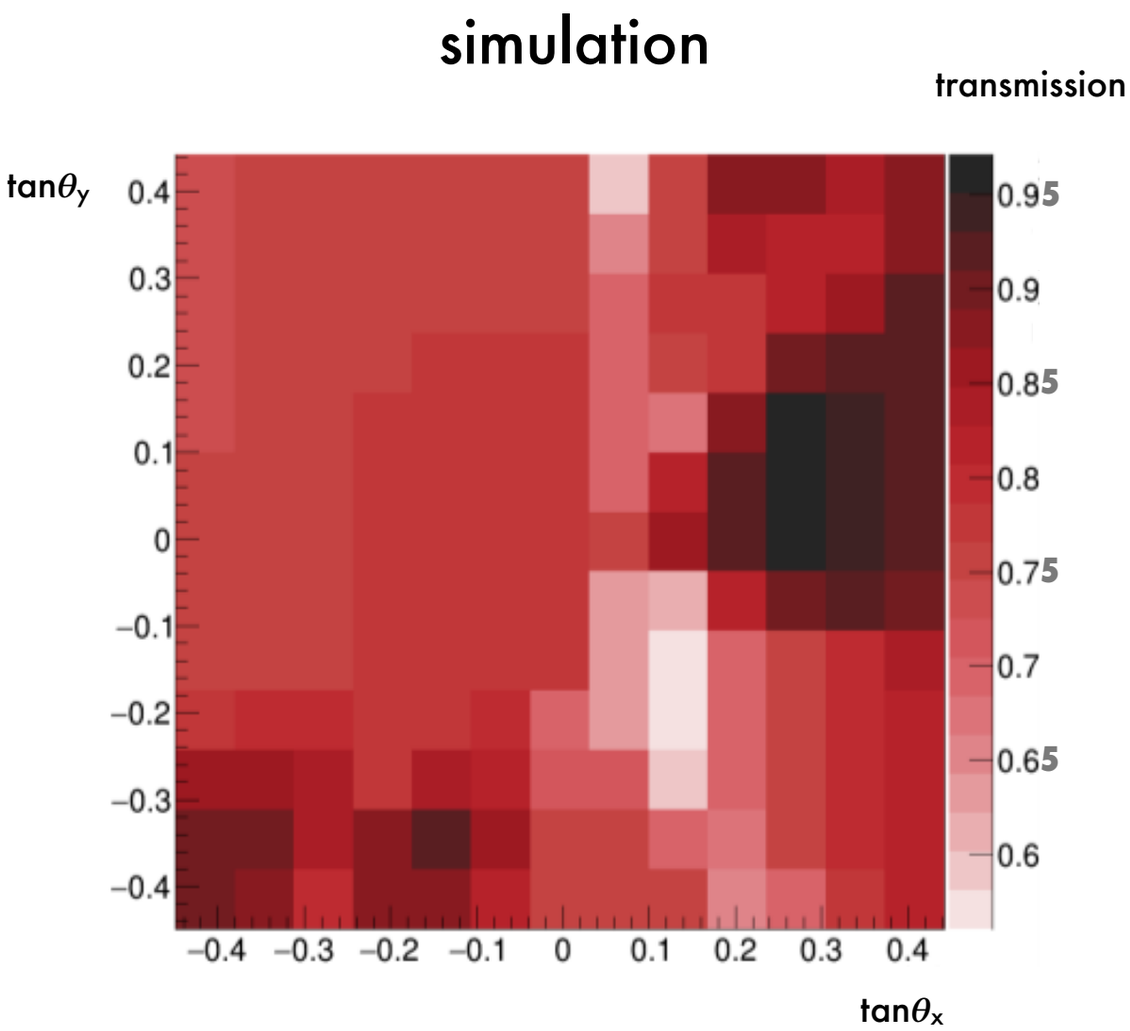
Rate = Flux × Transmission × Acceptance × Efficiency

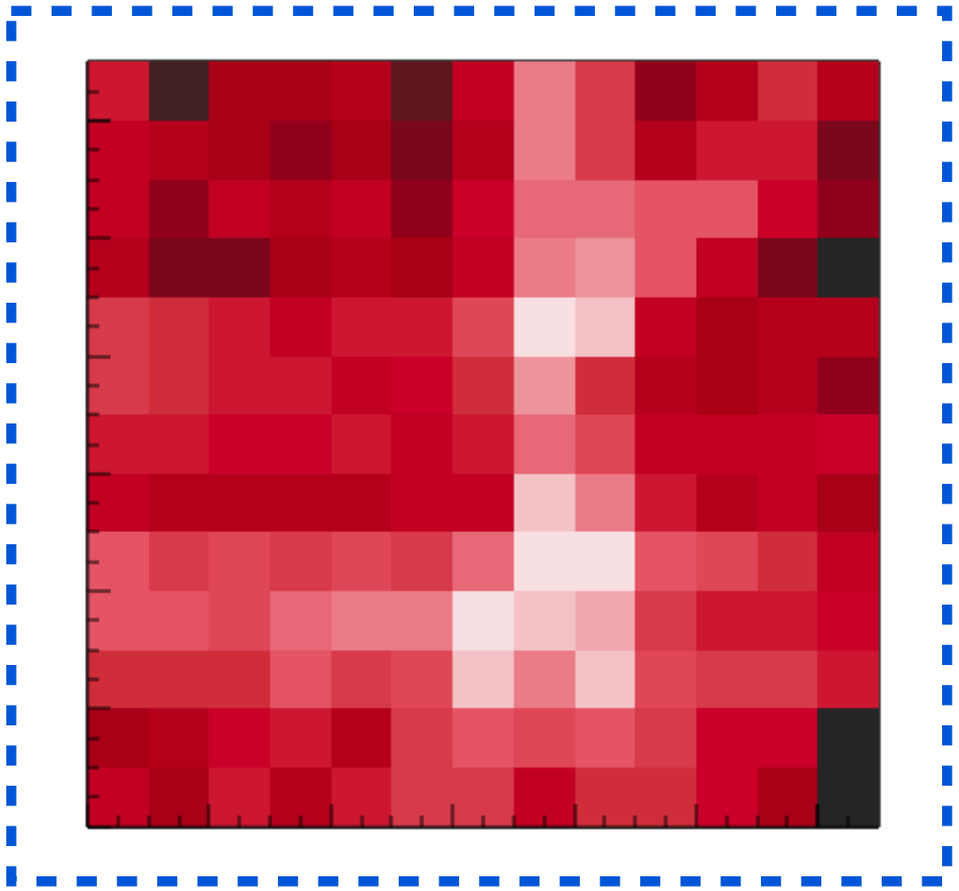
MC (PDG) MC (geometry) detector effects

measurement ⟶ see the building!

First muographs

Coimbra building - data





First muographs

Coimbra building - data

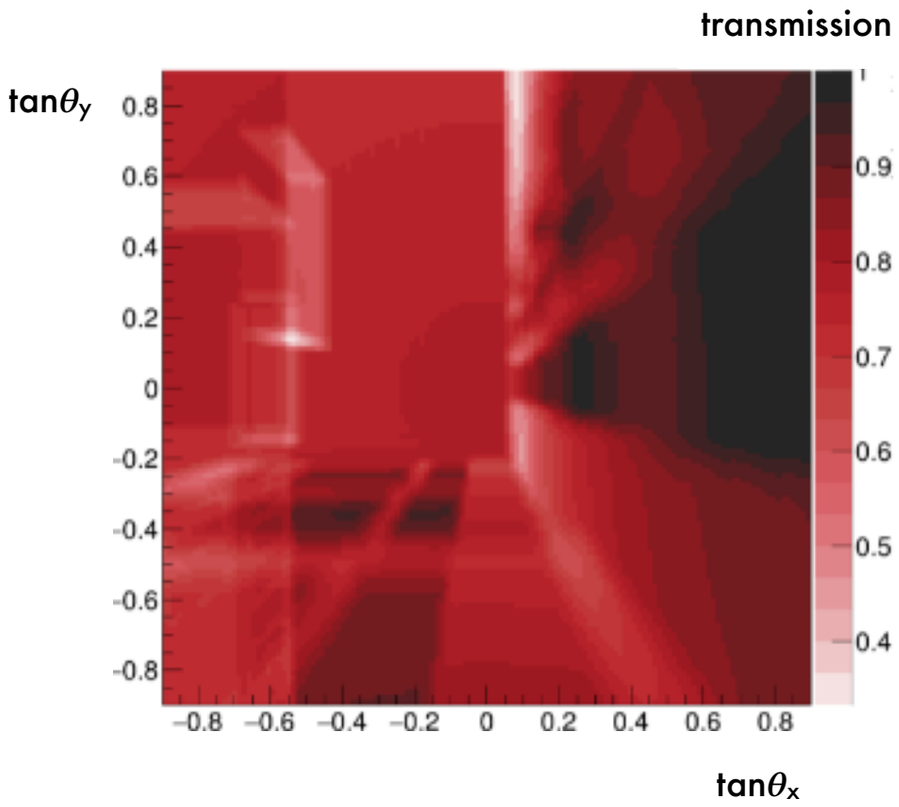
Improving the images by:

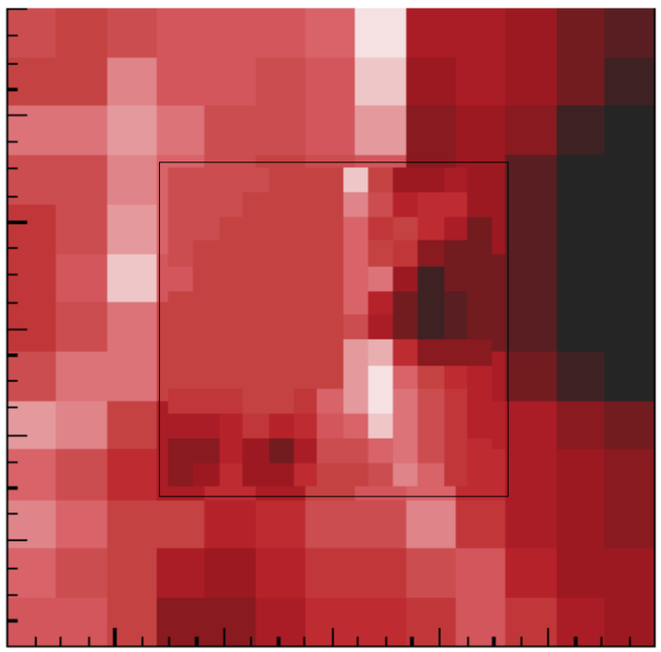
- using another pair of planes
- combining different telescope positions and inclinations

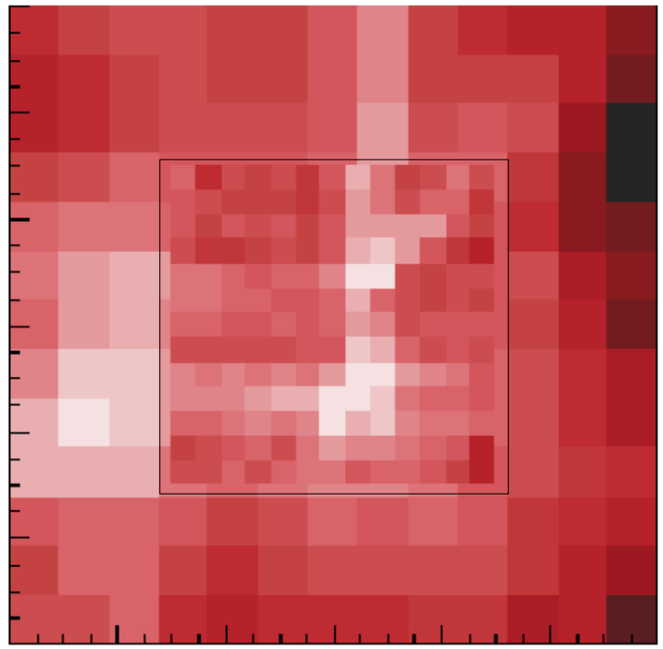
high resolution simulation

telescope resolution simulation

data







First muographs
From Coimbra to Lousal

- Features from amount of roofs/walls → average soil density

- Muon flux at detector: factor of ≈8 reduction

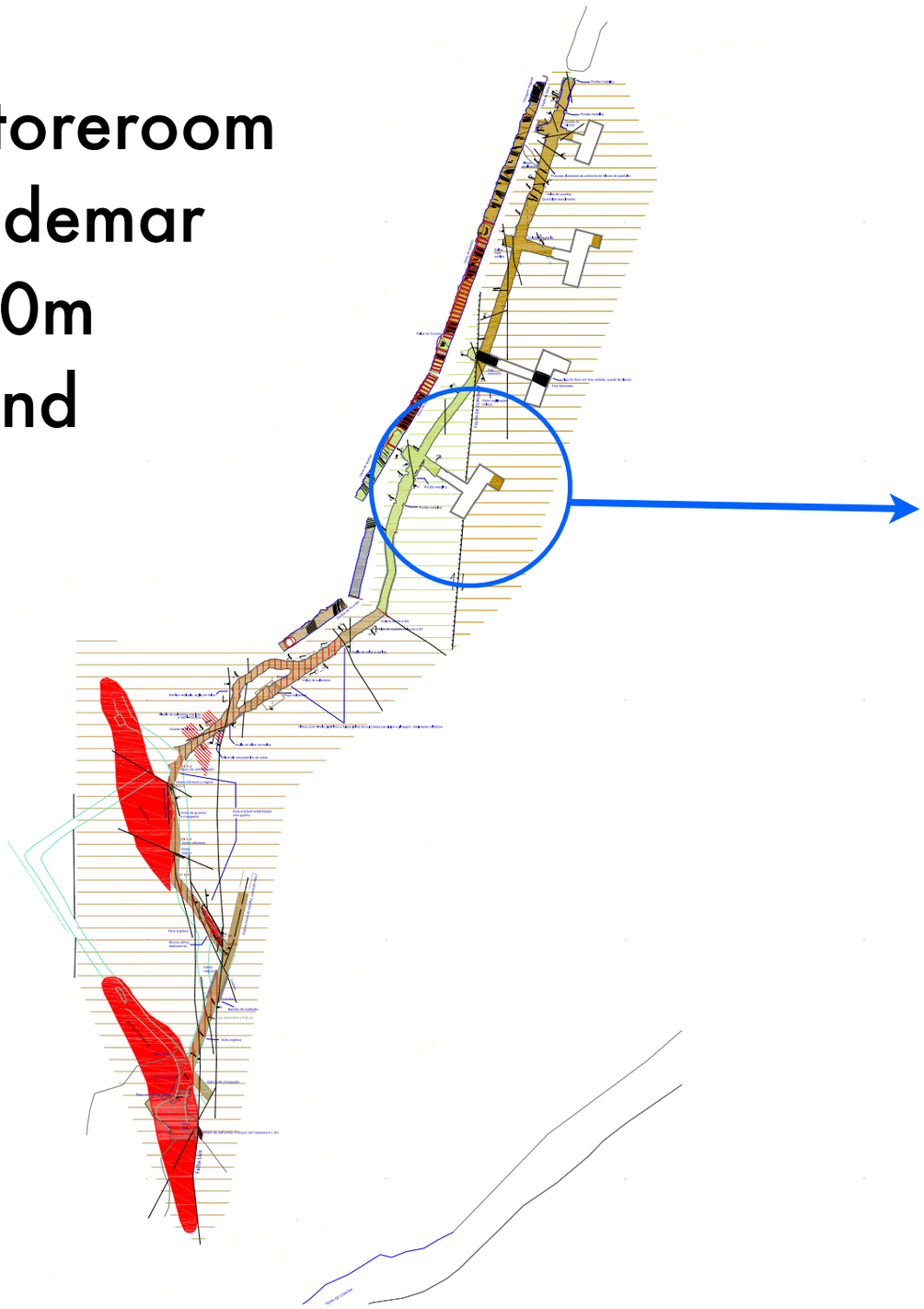
- Higher muon scattering, expected resolution loss

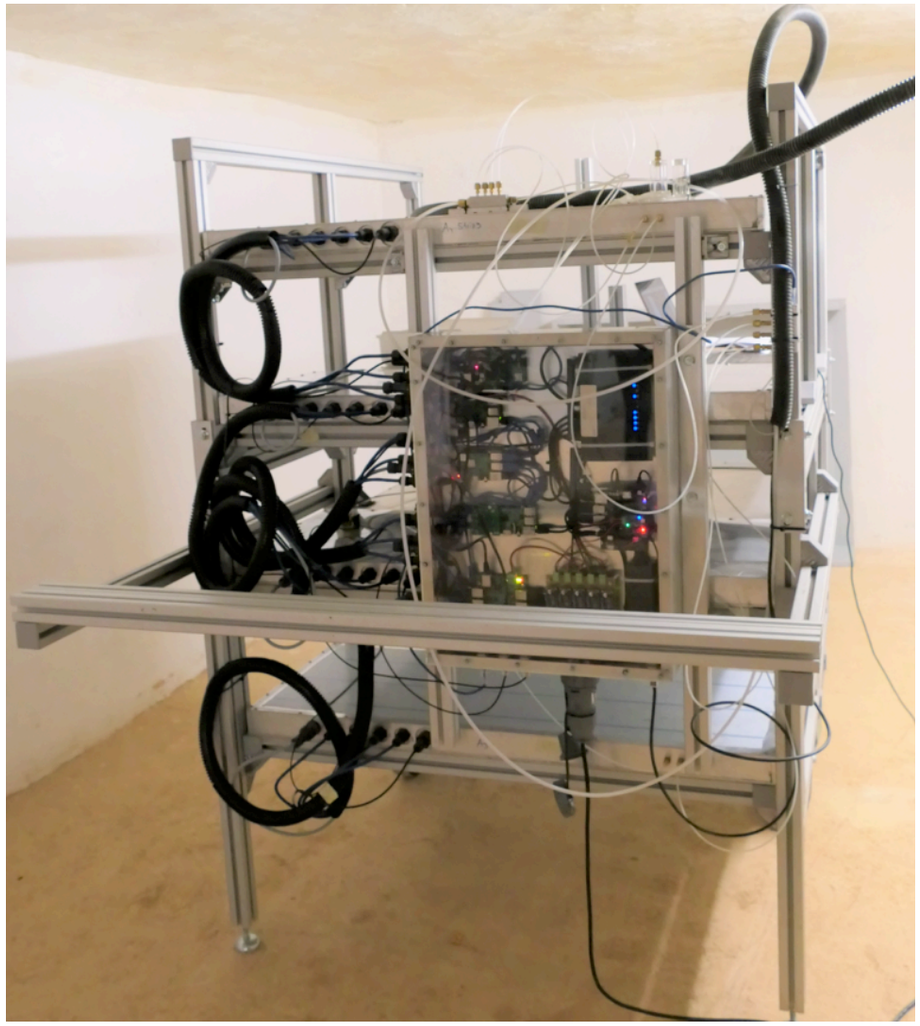
- More stable environment but no expected effect on detector stability

First muographs

Lousal mine - setup

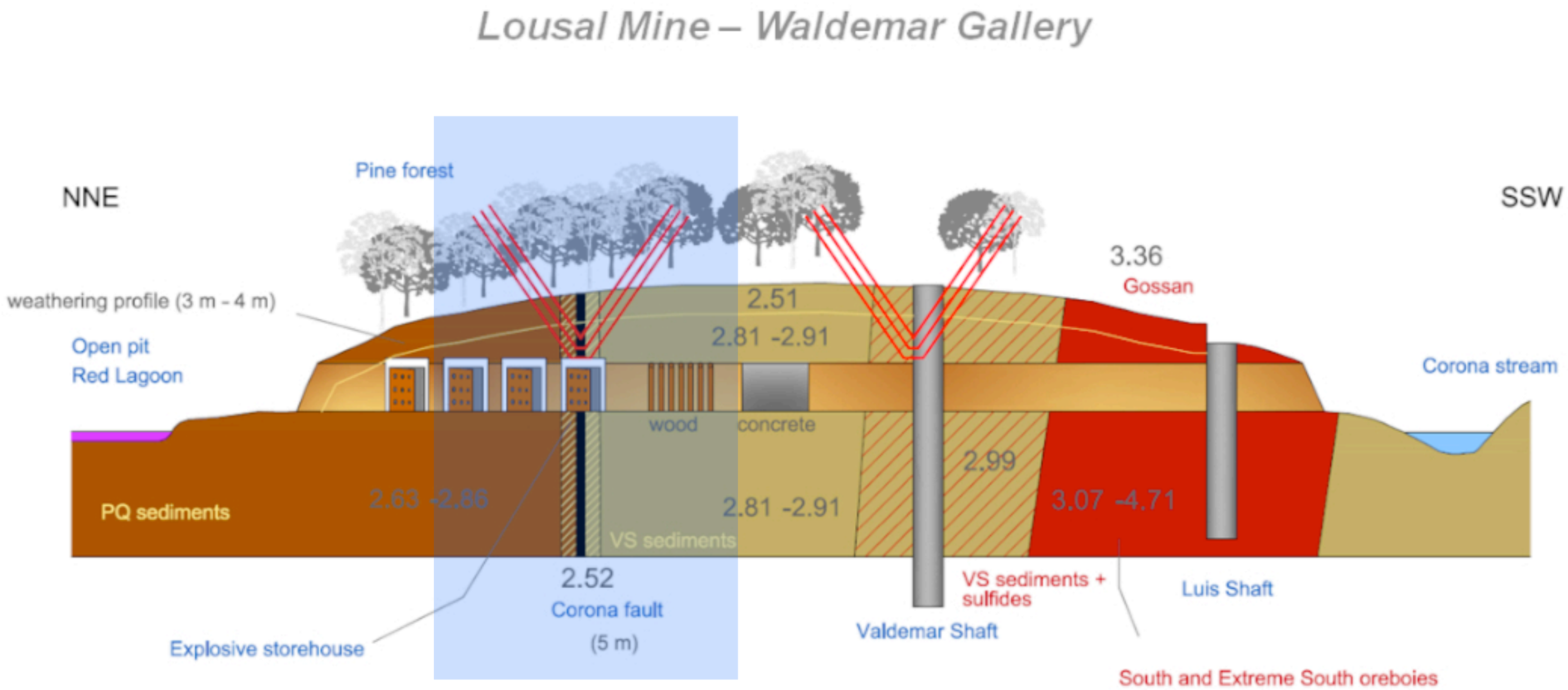
- Fourth storeroom of the Waldemar gallery ≈20m underground





First muographs

Lousal mine - model

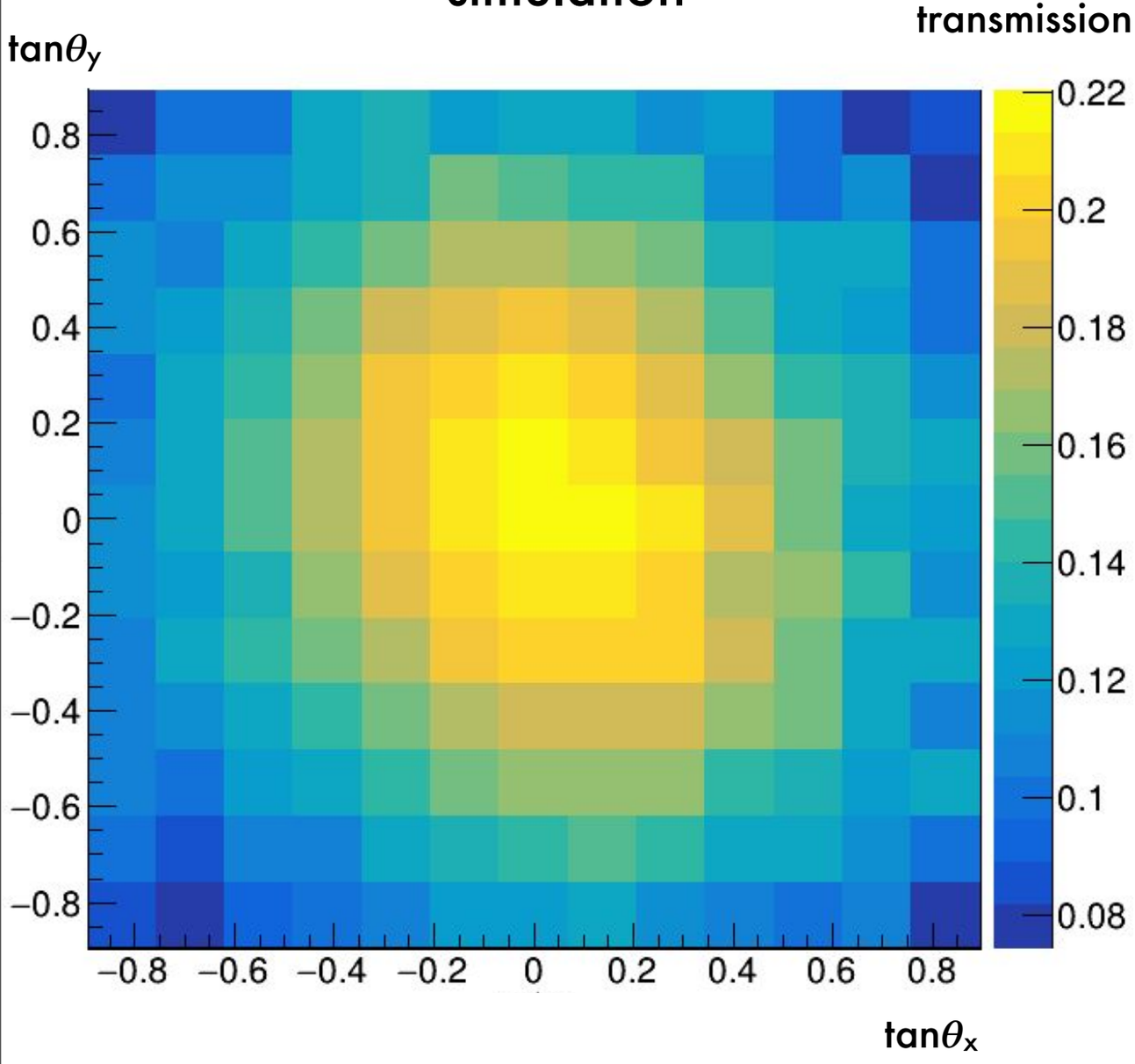


- The telescope location stands in the intersection of the Corona fault, with rock density ≈10% smaller than around

First muographs

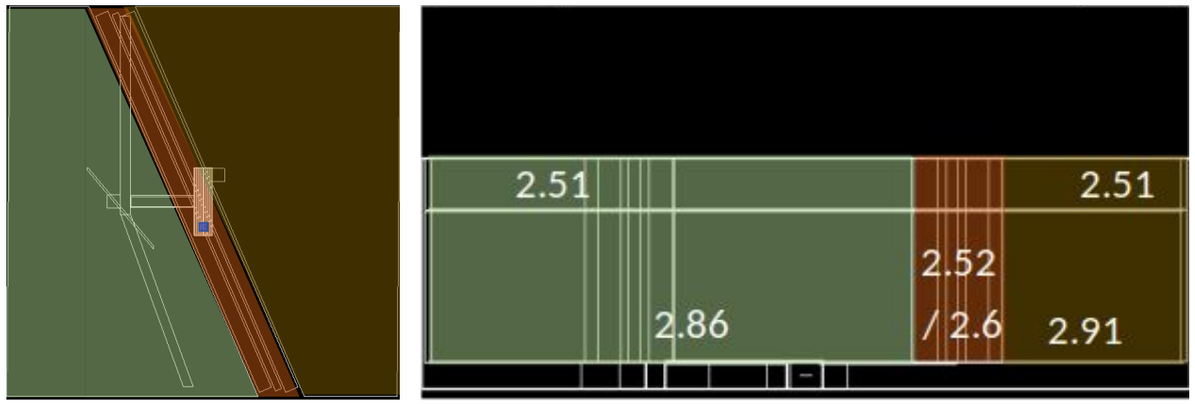
Lousal mine - model

VERY PRELIMINARY



Two-steps simulation:

- Geant4 implementation of the geological model



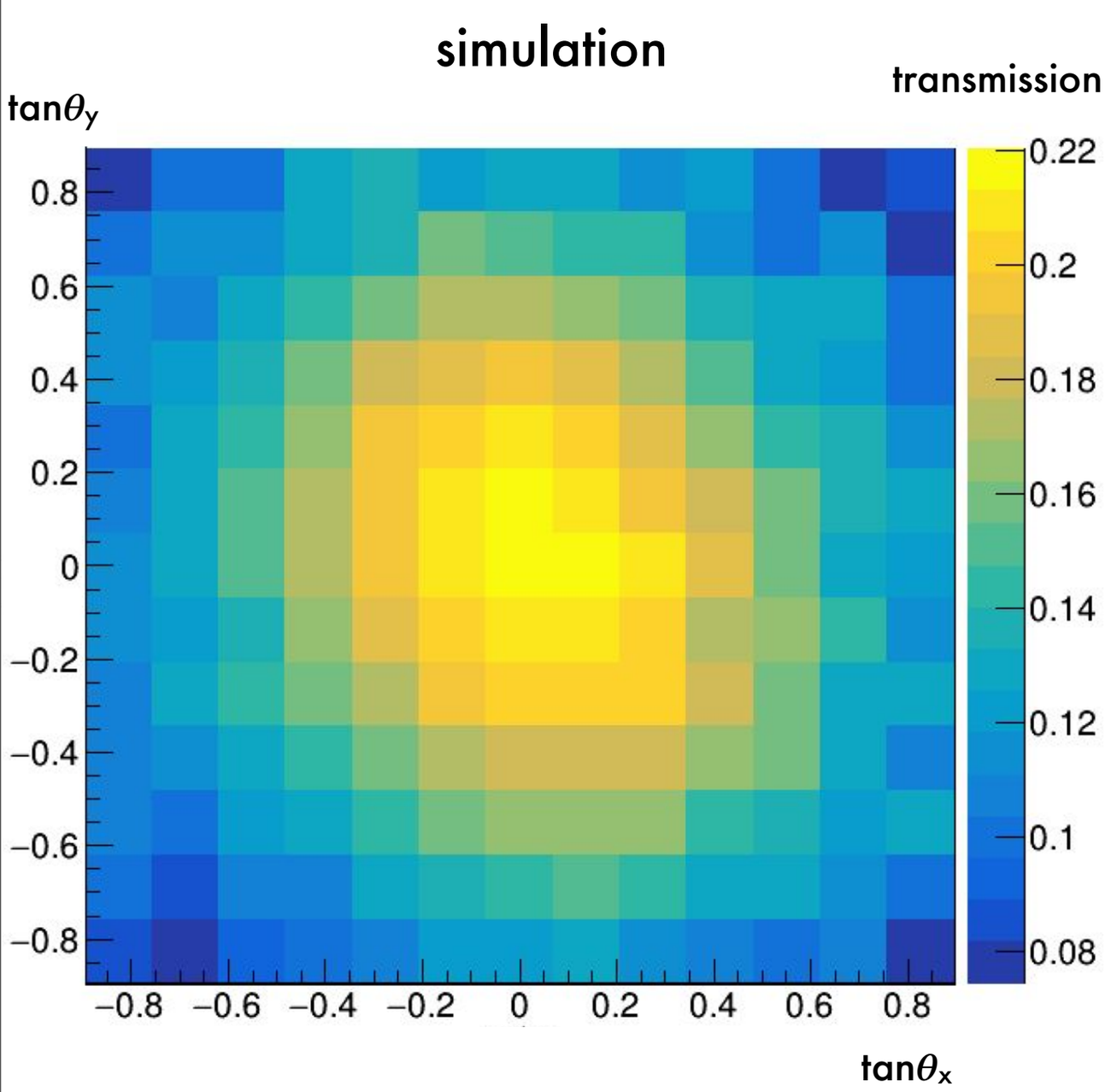
muon flux at the detector location

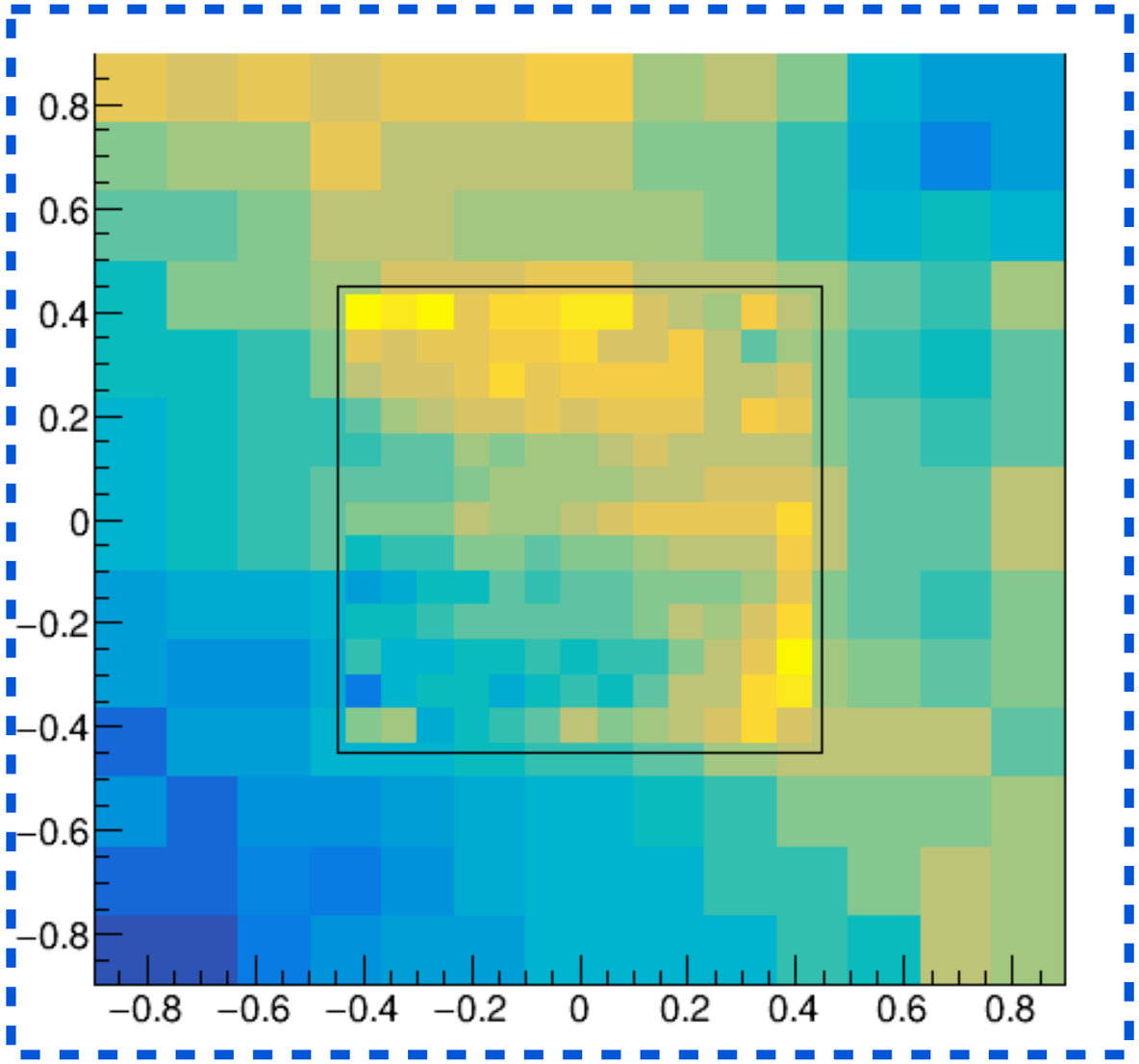
- Fast simulation of the telescope geometry and response

First muographs

Lousal mine - data

VERY PRELIMINARY





Outlook

Coimbra data:

- Development of algorithms for improved resolution
- Development of 3D images
- Refinement of the detector model and systematics
- Guidance for upgraded telescopes

Lousal campaign:

- Gathering more muon statistics
- Joint inversion of muographic/geophysical data
- Assessing the usefulness for geological characterization

Subjects of potential interest:

- Iberian islands with volcanic activity

Outreach

Visit the Lousal science center and mine complex!

LouMu

Science with Cosmic Muons at the Lousal Mine

LouMu is a scientific research project combining particle physics and geophysics in order to map large geological structures, using the Muon Tomography technique.

The partners in the project are LIP — Laboratory for Instrumentation and Experimental Particle Physics, the Institute of Earth Sciences of the University of Évora, and the Mine of Science – Lousal Ciência Viva Science Centre.

Centro Ciência Viva do Lousal
Mina de Ciência

UNIVERSIDADE DE ÉVORA

ICT Instituto de Ciências da Terra

LIP Laboratório de Instrumentação e Física Experimental de Partículas

FCT Fundação para a Ciência e a Tecnologia

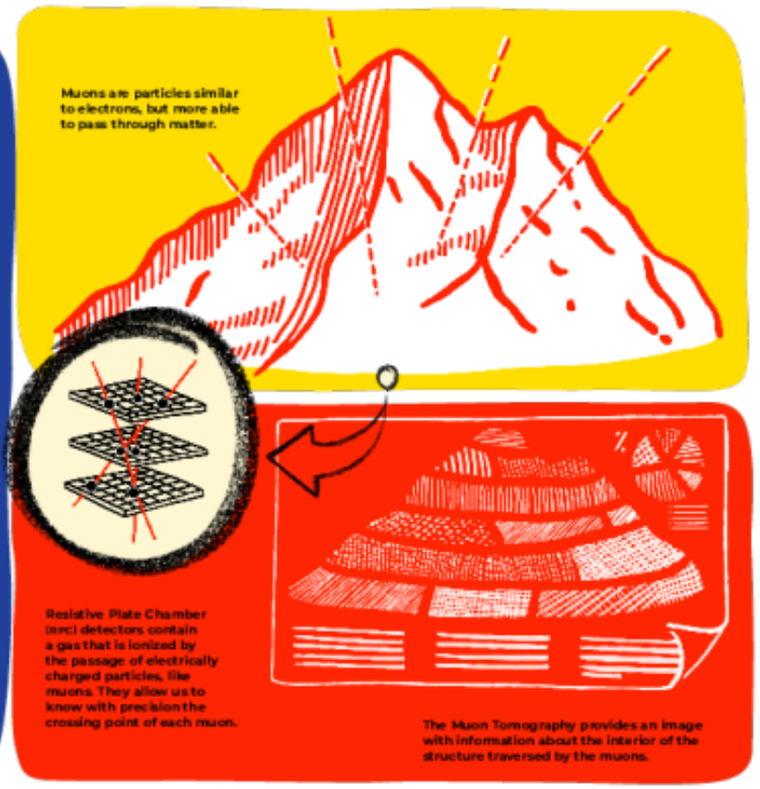
Planet Earth is constantly being struck by particles coming from space, known as cosmic rays.

As they collide with atoms in the atmosphere, a shower of new particles is created. Among them are muons, particles that can reach the surface of the Earth and pass through rocks.

Taking into account the number of muons that reach us, it is possible to figure out the different densities in the interior of rocks. In this way, the invisible becomes visible.

This is a Muography: like a radiography, but with muons.

In the Lousal Mine a muon detector is installed which, in combination with other geophysical techniques, will enable the Muon Tomography, three dimentional information, to let us better understand the interior of the mine and of other geological structures.



Acknowledgements

Funding

Cofinanciado por:

FCT Fundação para a Ciência e a Tecnologia

COMPETE 2020

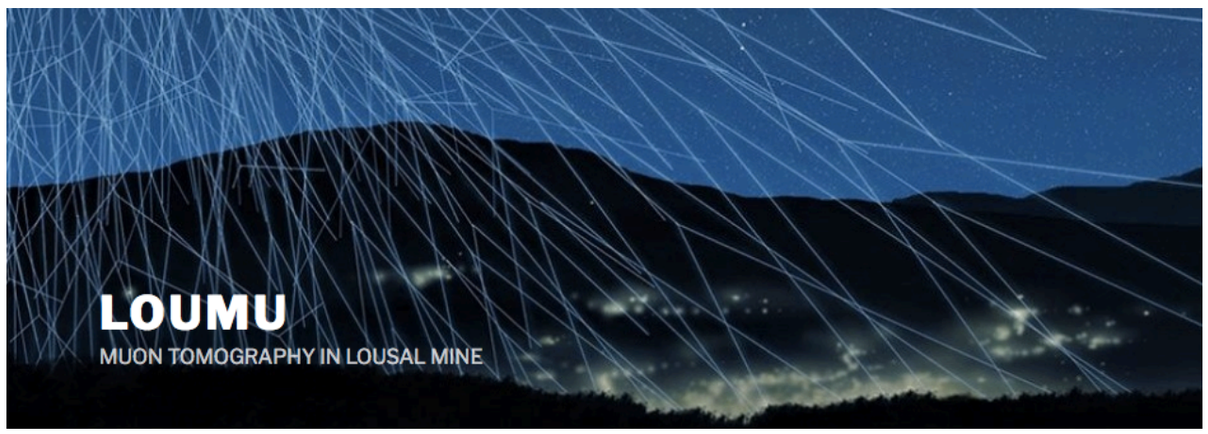
Lisb@20[20]

REPÚBLICA PORTUGUESA

UNIÃO EUROPEIA
Fundo Europeu de Desenvolvimento Regional

FCT project: EXPL/FIS-OUT/1185/2021

Webpage



https://pages.lip.pt/loumu

Team

Instrumentation and Particle Physics Team (LIP)

Lisbon Pole:

Bernardo Tomé, Isabel Alexandre, Lorenzo Cazon, Marco Pinto, Mário Pimenta, Luis Afonso, Pedro Assis, Sofia Andringa

Coimbra Pole:

Alberto Blanco, João Saraiva, Jorge Francisco Silva, Luís Lopes, Paolo Dobrilla

Minho Pole:

Magda Duarte, Raul Sarmento

Geophysics Team

ICT – UÉvora:

Bento Caldeira, José Borges, Mourad Bezzeghoud, Pedro Teixeira, Rui Oliveira

LNEG:

João Matos

Outreach Team

CCV do Lousal:

João Costa, Vanessa Pais