Muon Tomography

@ LIP

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for the LouMu collaboration

4 LIP/IGFAE 2023

imaging with muons

from ScanPyramid project – 3d imaging & tests

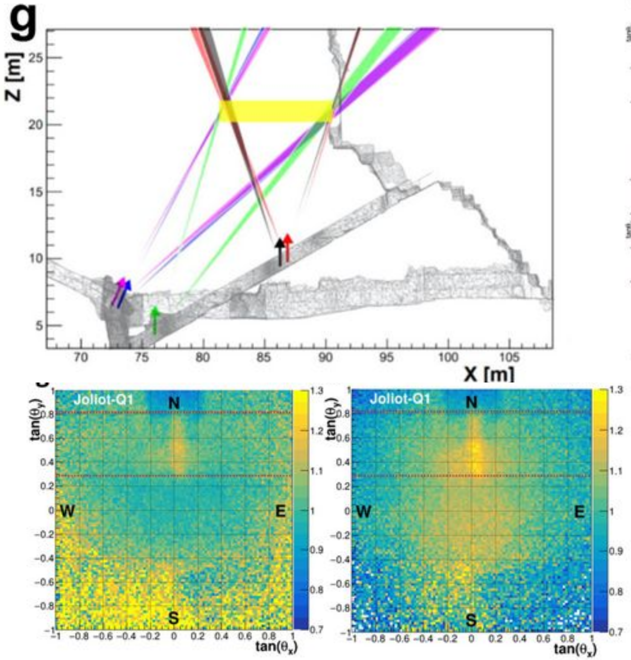
- muon scattering on high Z materials, measured with object within two telescopes (each muon contributes with one 3D point)

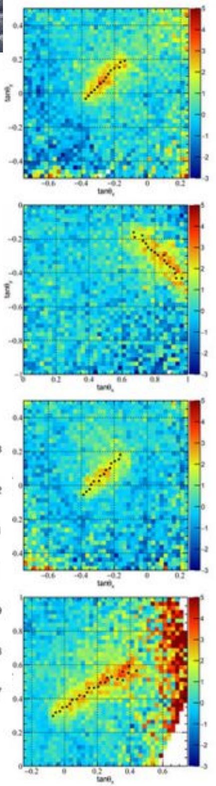
- flux attenuation by constant energy loss, measured with one telescope far from the object (statistical reduction in a direction map)

can be used for imaging large objects
but can only see objects above horizon

need a reference model for muon flux
better to confirm with our measurements

3d can be obtained by combining images





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the LouMu project

End-to-end test of muography for sub-surface geophysical surveys: how useful is it?

develop tools, methods and a team, and communicate the possibilities of muography

1st: telescope; 2nd: a building; 3rd: a mine; 4th: generalization

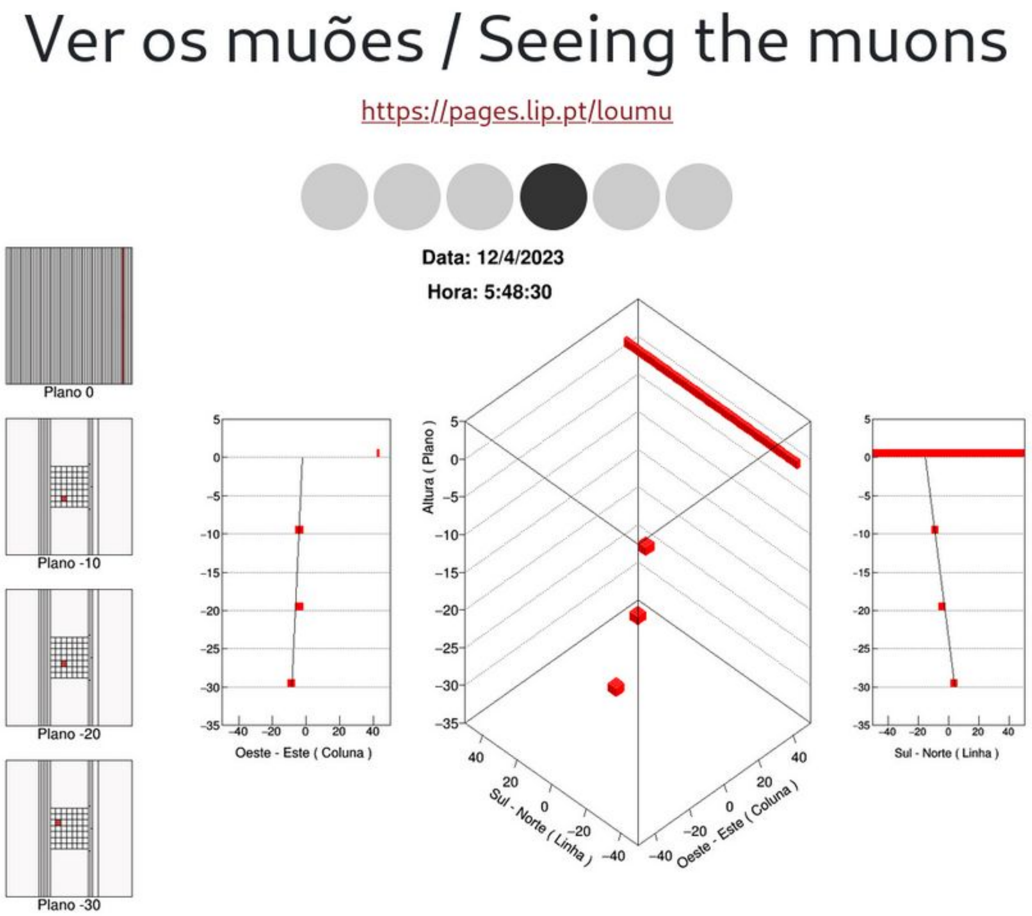
the LouMu project

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

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

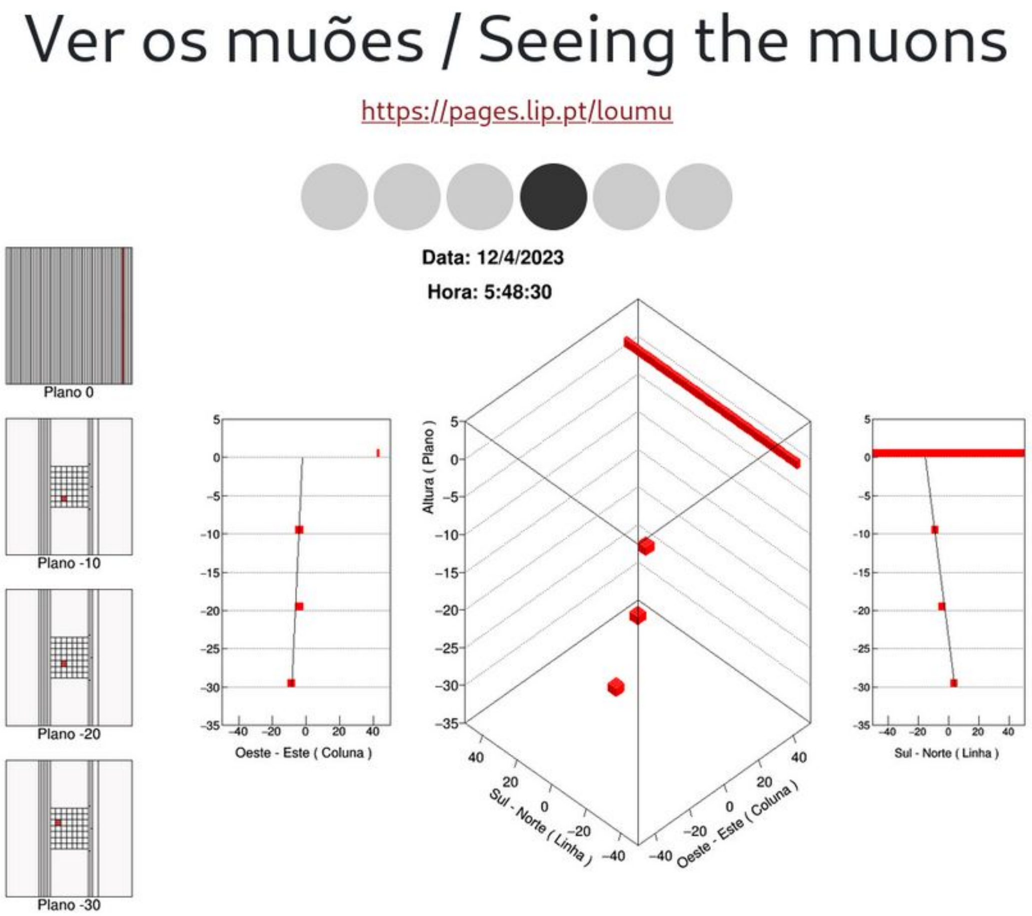
<u>April, 2022</u>
CorePix at Lousal

our muon telescope



gas fed/recovered from 100 m away
plane 2 with a window for outreach...

our muon telescope



Trigger with 30 ns coincidence
on high resolution CorePix

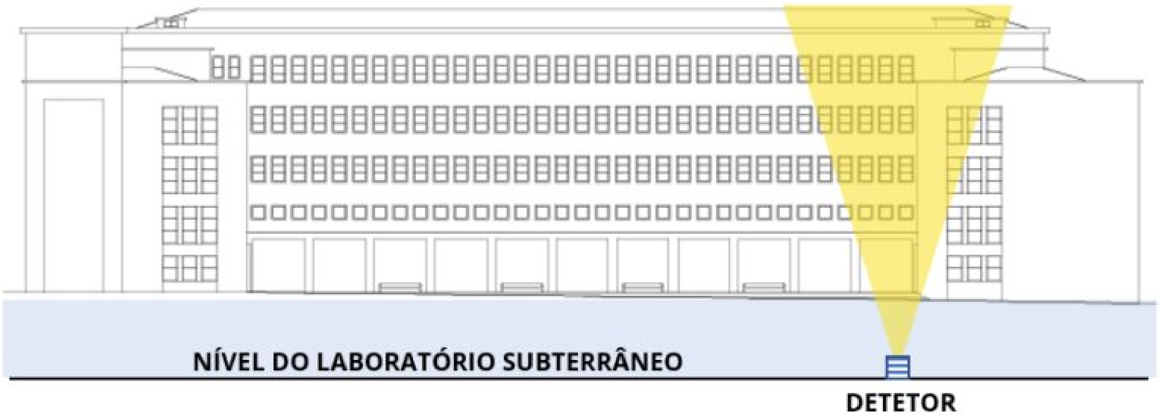
(3 planes, 7 x 7 pads of 4 x 4 cm²)

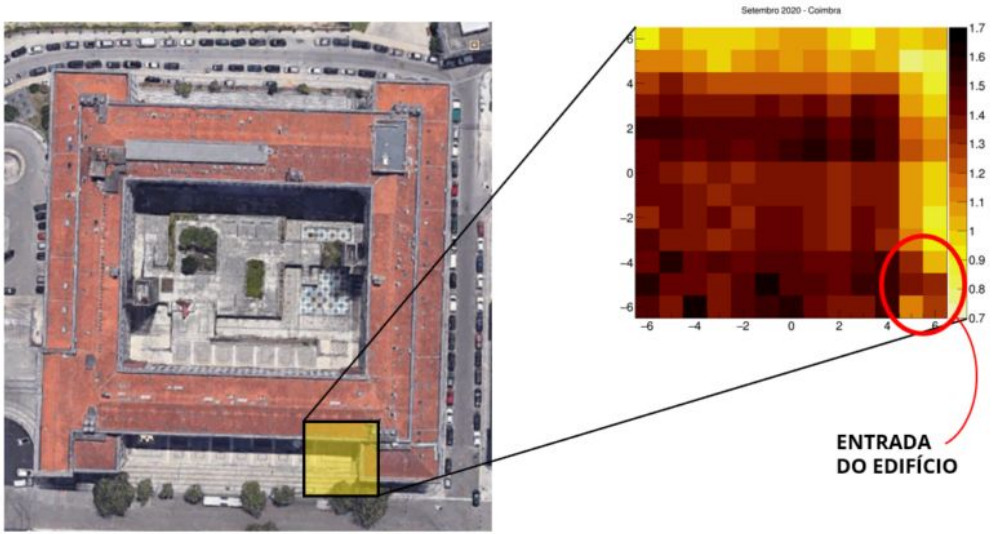
Map images in tanX, tanY:

- smaller FoV with high resolution (13 bins for -0.4 < tanX < 0.4)

- larger FoV with lower resolution (13 bins for -0.8 < tanX < 0.8)

reading the first images





the same telescope in two positions

a high constrast / uniform coverage

Canceling most systematics:

from the open-air muon flux
from the detector response

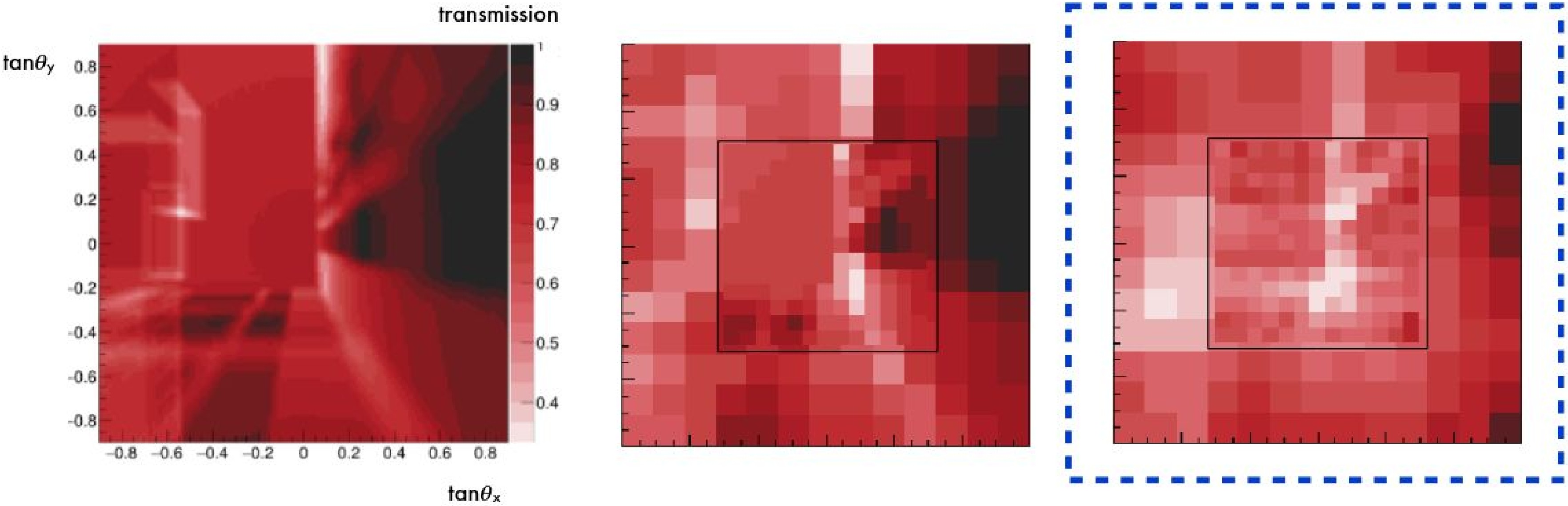
imaging the building

and modelling what we expect to see

high resolution simulation

telescope resolution simulation

data



from muons to images

Measured Flux

=

Open Air Flux ~ 130 muons / cm^2 / s / sr . $\cos^3\theta$

confirmed after correcting other factors

x

Attenuation exponential with some characteristic length

T=0.97 for each vertically crossed ceiling

x

Acceptance simple geometrical model with details of each plane

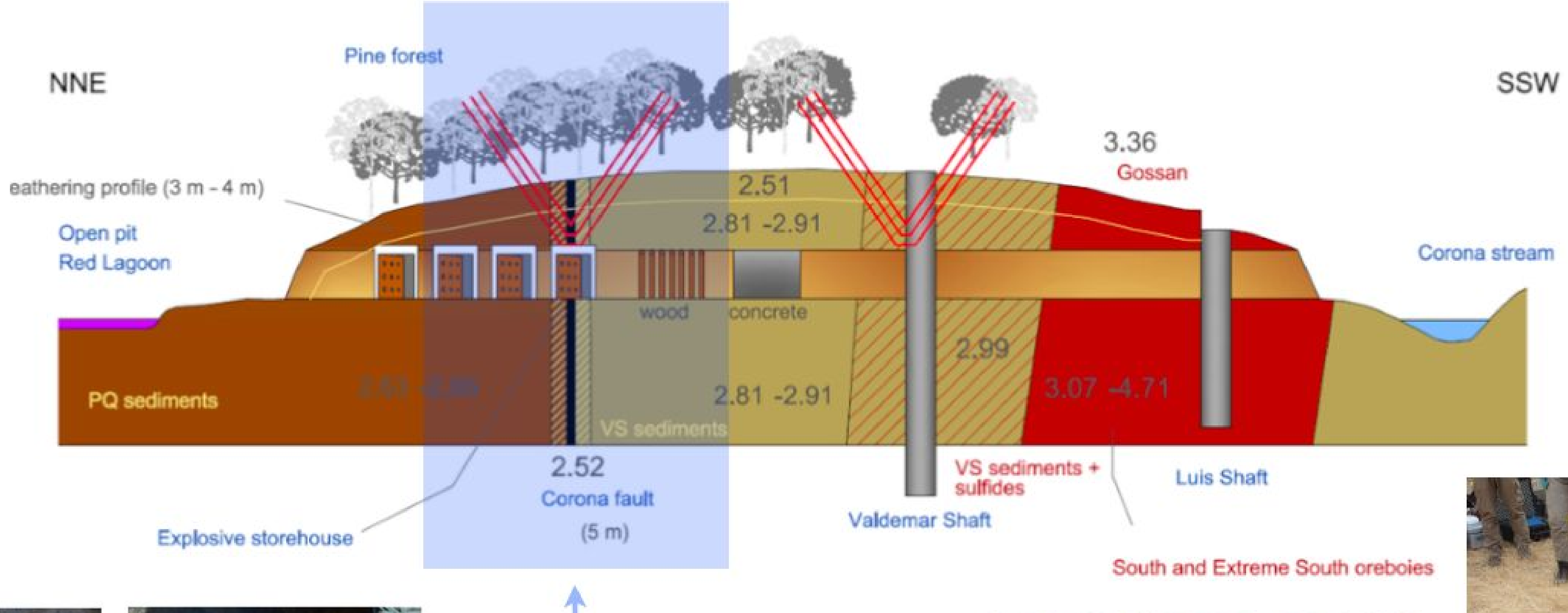
inner structure of detector visible after gain equalization

x

Efficiency measured for each pad in each plane from the same data

reasonably constant as RPC compensates E/N for T,P,H

geological imaging



geological samples

laser scans

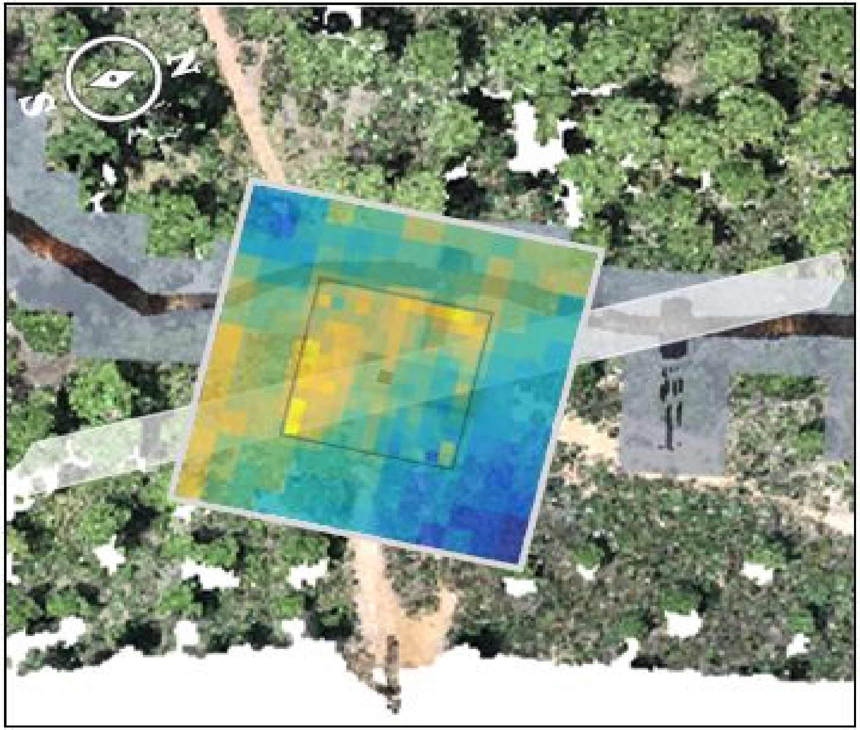
On-going campaings for seismic refraction tomography with grid of source / receiver

seismic refraction

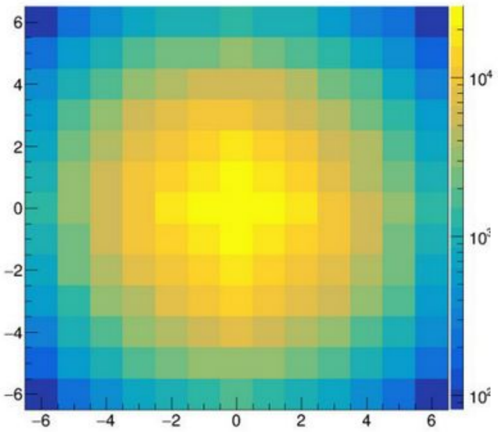
ground penetrating radar

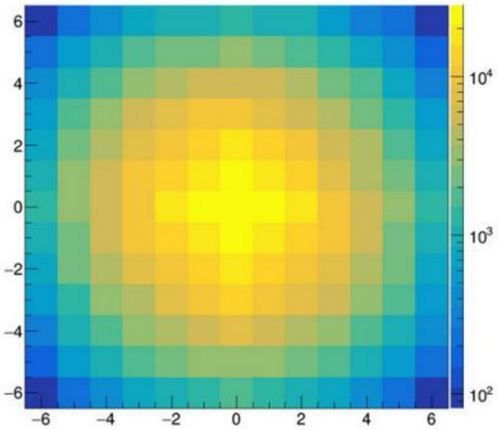
geological imaging

ENQUADRAMENTO DA OBSERVAÇÃO DO COREPIX NO LOUSAL

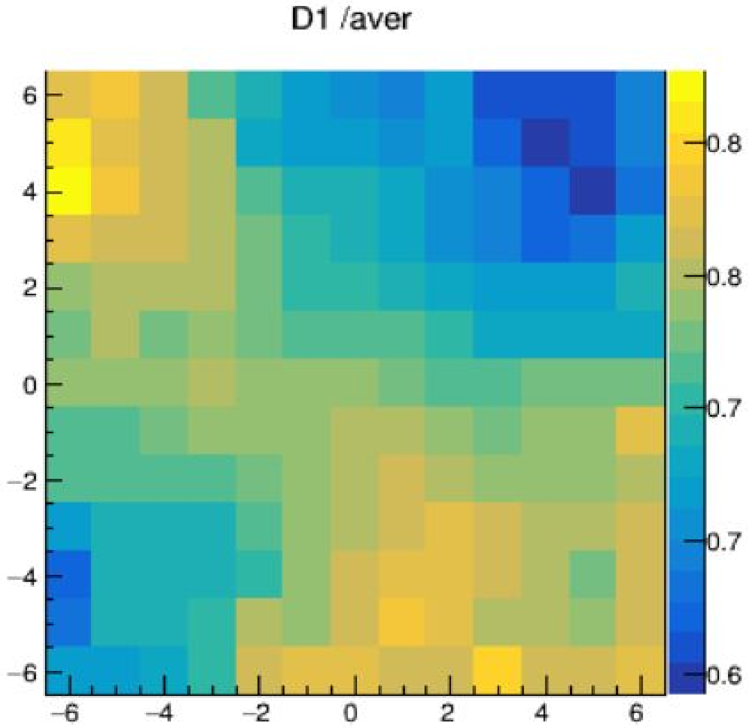


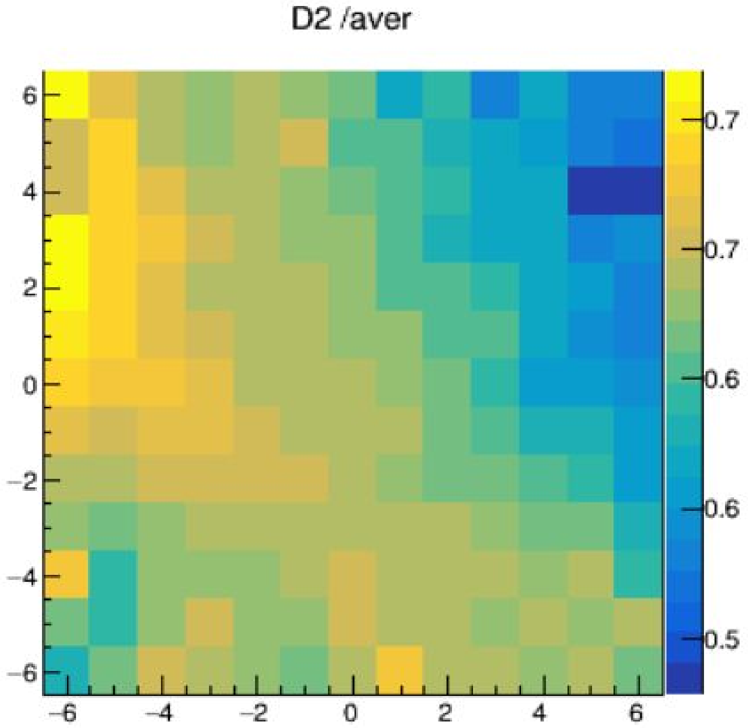
looking again from two positions



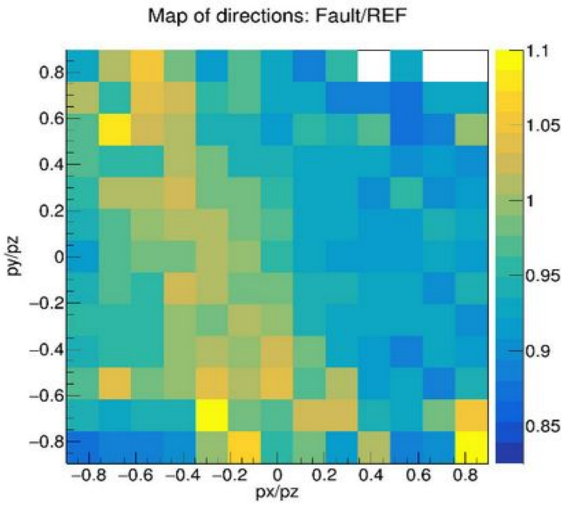


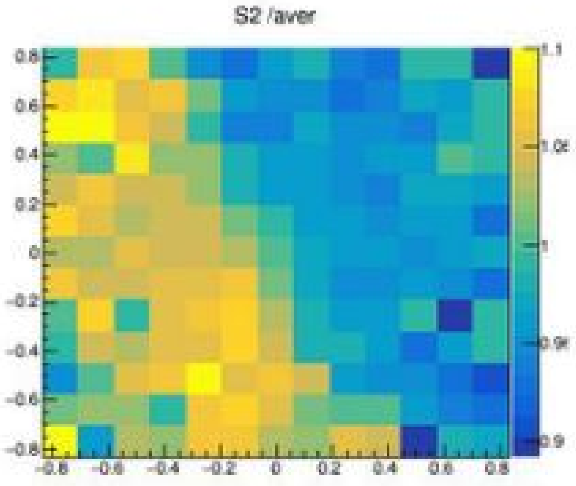
raw data is symmetric, dominated by flux and detector acceptance
averaging over the four quadrants we can obtain a “flat” reference

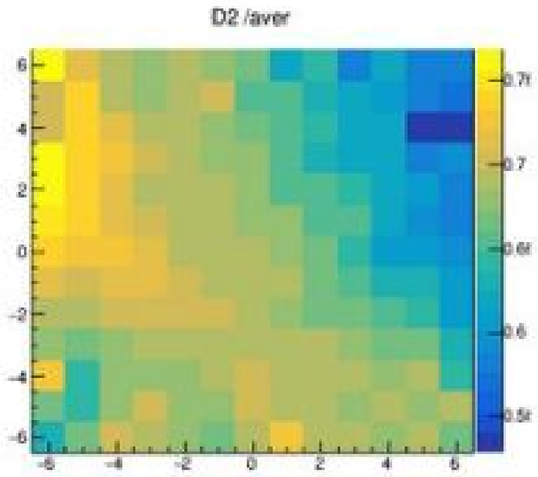




testing the models







Geant 4 (30 days) /
Geant 4 (30 days)

Fast sim. (30 days) /
constant density model

Data (60 days) /
symmetrized data

Compatible energy and
angular spectra: E.cosQ

Scattering can be ignored

No energy, angular distribution
validated in symmetrized data

Normalization more uncertain

translation to density

Measured Flux

=

Open Air Flux — $F(E,\cos\theta) = f0(E'=E.\cos\theta) . (E' \cos\theta^{1.7} + 5 \cos\theta^{2.7}) / (E'+5)$
almost $\cos\theta^3$ at E' ~ 0, as we used in Coimbra

x

Attenuation — Integrate $F(E,\cos\theta)$ for E > X [g/cm²] . mip [MeV/(g/cm²)]
height is constant in Lousal => $E.\cos\theta > H.mip.\rho$ [g/cm³]

x

Acceptance — another $\cos\theta^3$ for reaching two detector planes
partial superposition between adjacent direction pixels

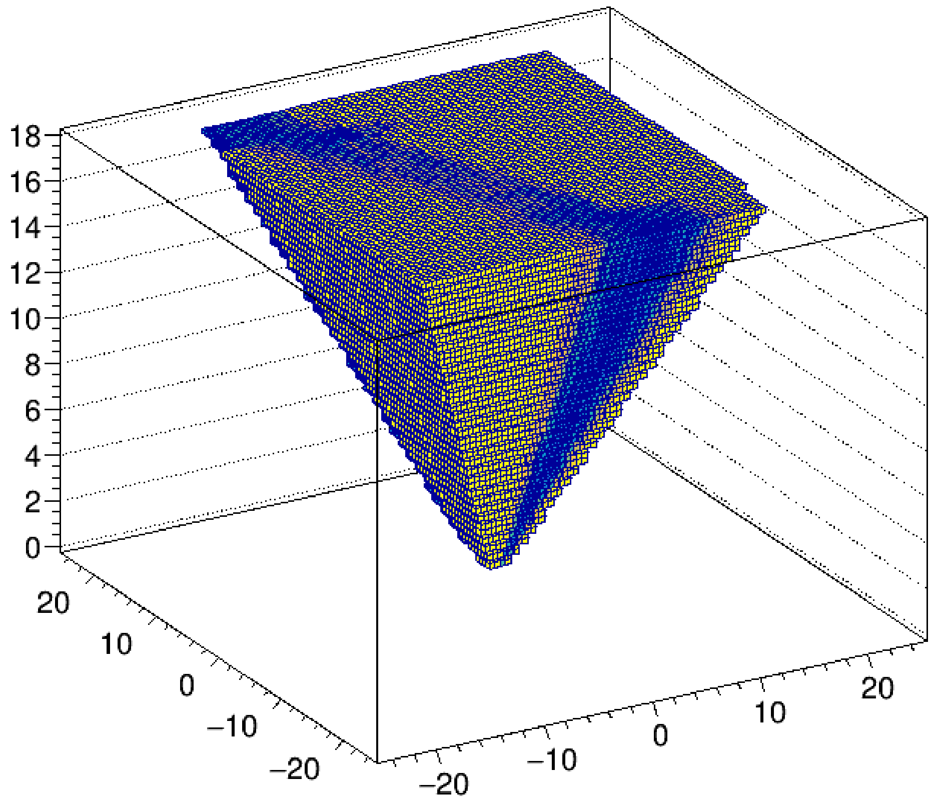
x

Efficiency — Telescope status, more variations than antecipated at Lousal
a few lessons learned about the detector, analysis underway

This works well in simulation !

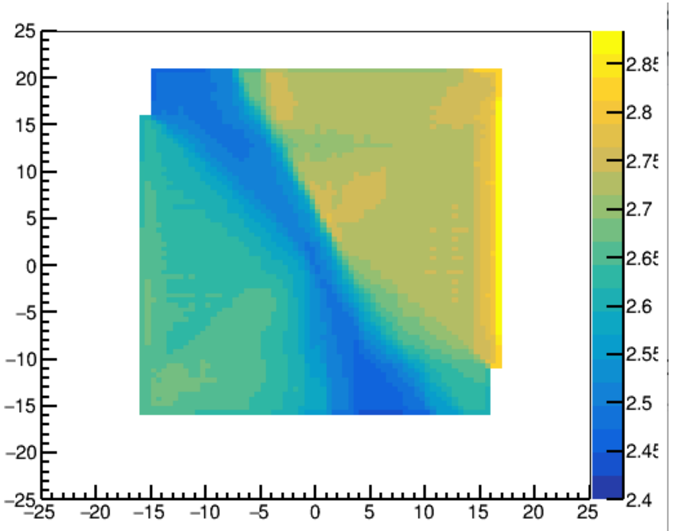
going to 3D

Having two positions, we can recover the fault geometry and density more precisely!



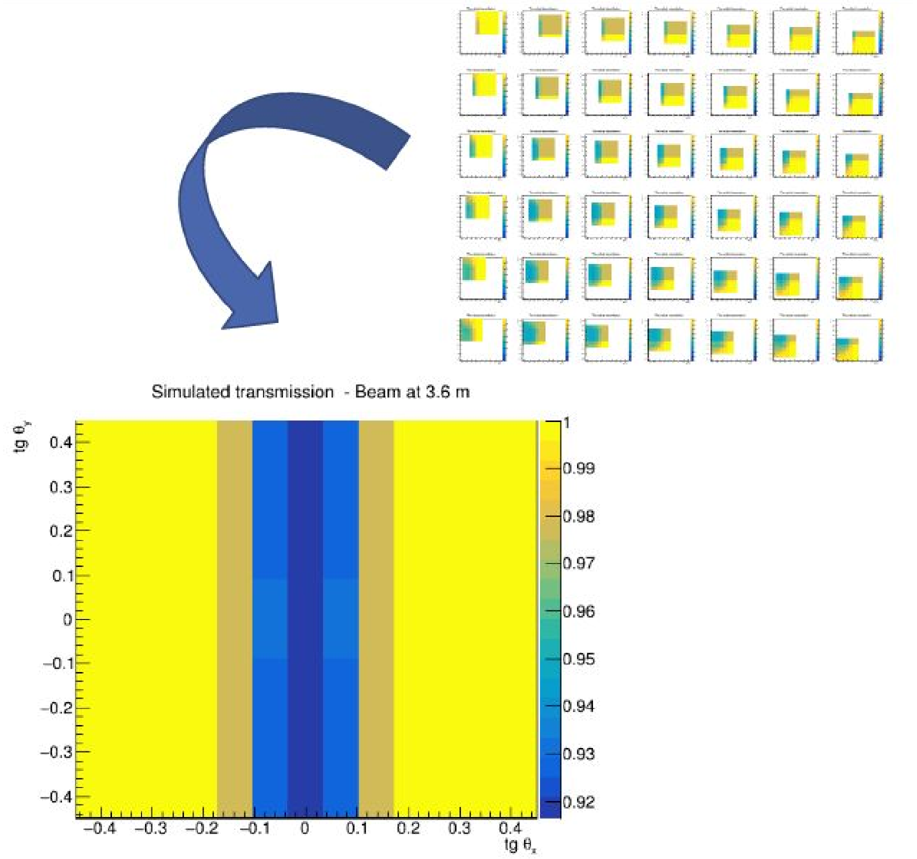
Testing in simulation an iterative method (SART, used in medicine and muography)

Will cross-check with constrained inversion, as used for the other geophysical analyses



going to 3D

Testing also using the full detector information, for resolution improvement in the building



Each position gives 3 maps x 49 sub-maps!

All compatible in 2D for far-away objects

- a way to check for systematics
- a way to improve 2D resolution

All providing 3D info for close-by objects

- search for the best 3D model,
ie, that minimizes the residuals
(taking into account uncertainties)

Catching up with recent work in muography!

going further

Seeing the geological fault was our first target, we will soon have its 3D density map

Will then compare & combine muon tomography with seismic refraction tomography

Using the Coimbra building to test more precise target analyses, to repeat at Lousal

Using the Lousal geophysical analyses to better understand the usual requirements

Simulating other scenarios, with different depths, shortened exposures, movement

The team is looking forward to new applications of the developed tools and methods

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COMPETE 2020

Lisb@20[20]

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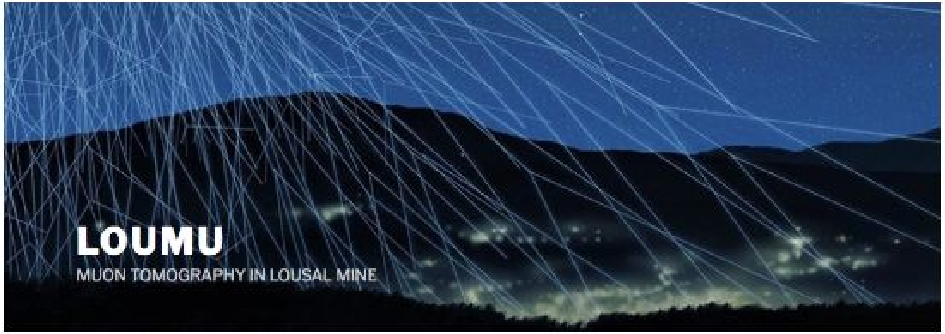
FCT project: EXPL/FIS-OUT/1185/2021

Webpage



https://pages.lip.pt/loumu

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