MUON TOMOGRAPHY ON EARTH AND ON MARS

LIP INTERNSHIP PROGRAM 2020

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LABORATÓRIO DE INSTRUMENTAÇÃO E FÍSICA EXPERIMENTAL DE PARTÍCULAS
partículas e tecnologia

TÉCNICO LISBOA

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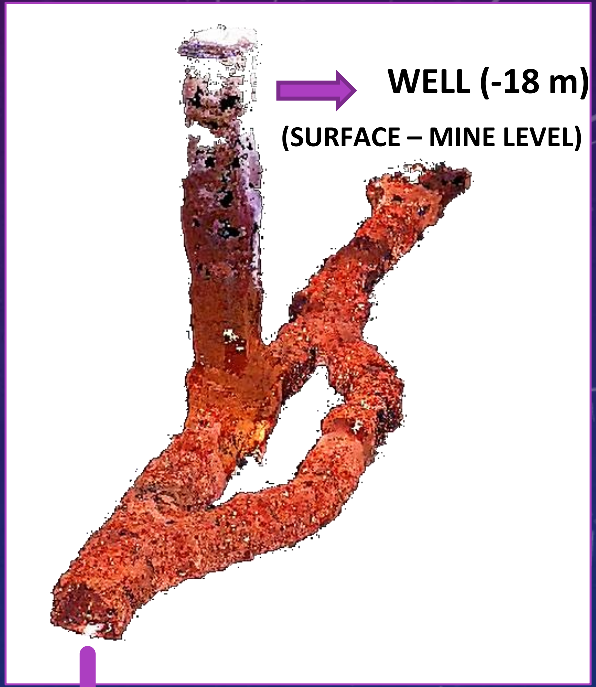
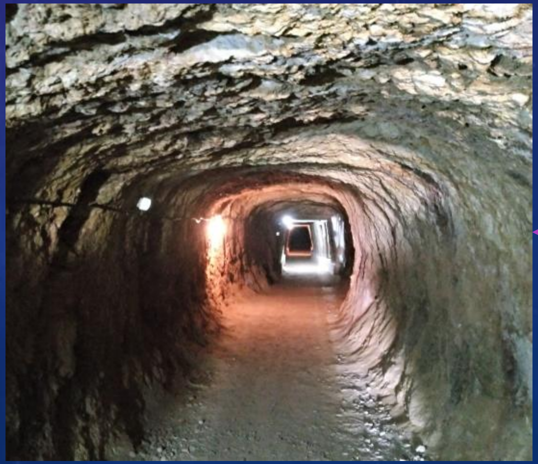
MOTIVATION – LOUMU PROJECT

- **Objective:** To apply the techniques of Muon Tomography in Geophysics in order to make a geological reconaissance of the ground above the Lousal mine

Can this be applied in future Mars Rovers missions to discover more about the planet´s surface?





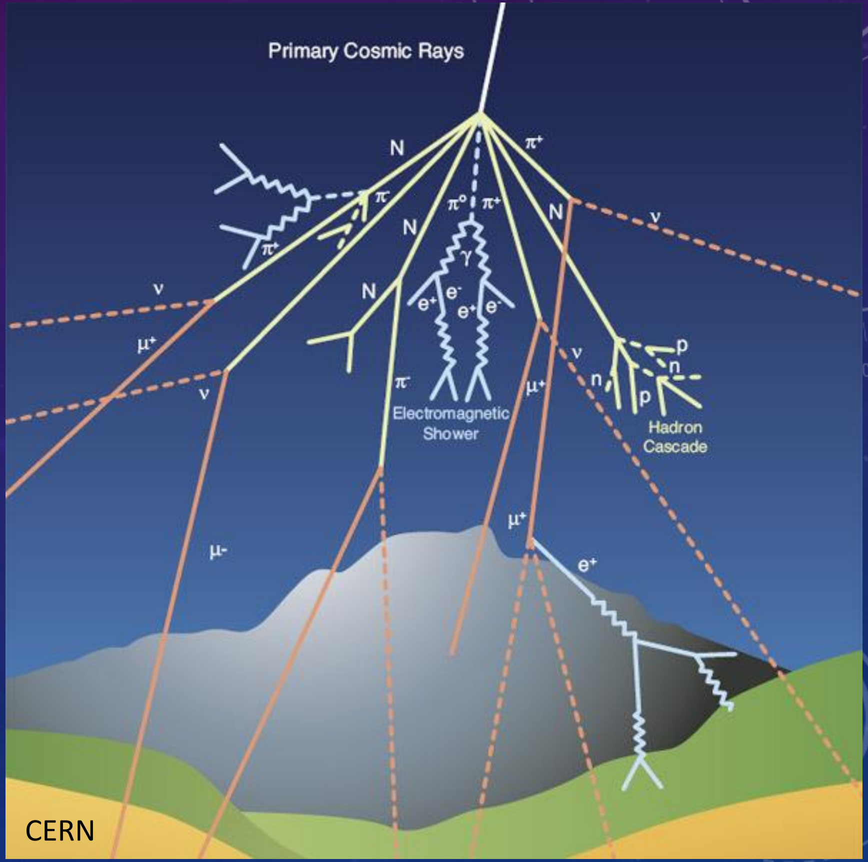
INTRODUCTION - MUONS

- Particles created by the interaction of cosmic rays with the Earth´s upper atmosphere

- Higher mass and energy allows them to travel long distances and penetrate deep in matter

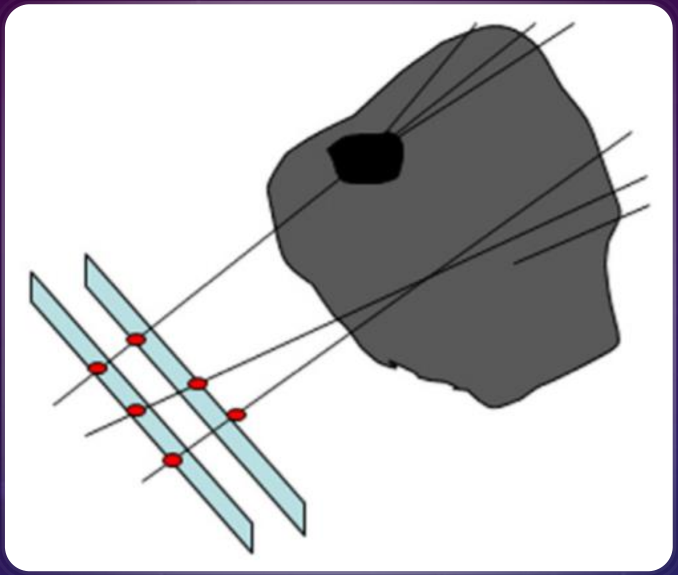
- Easily detectable and present all around us

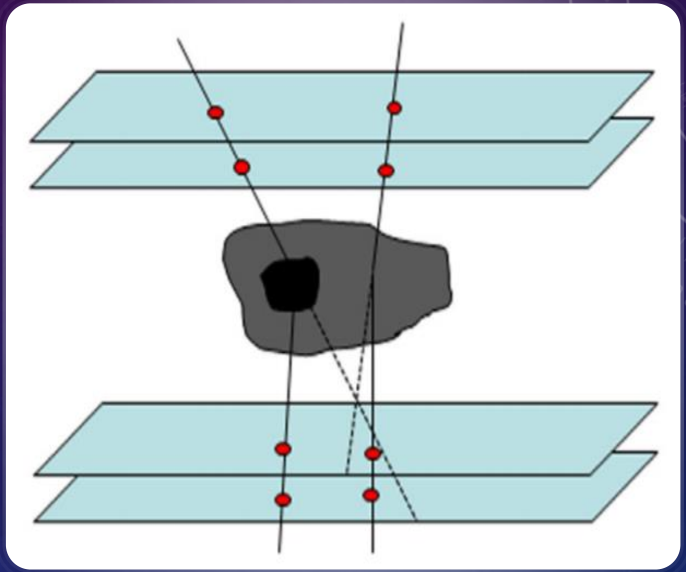
- Main application: **Muon Tomography**



APPLICATIONS – MUON TOMOGRAPHY

Transmission Tomography **VS** **Scattering Tomography**

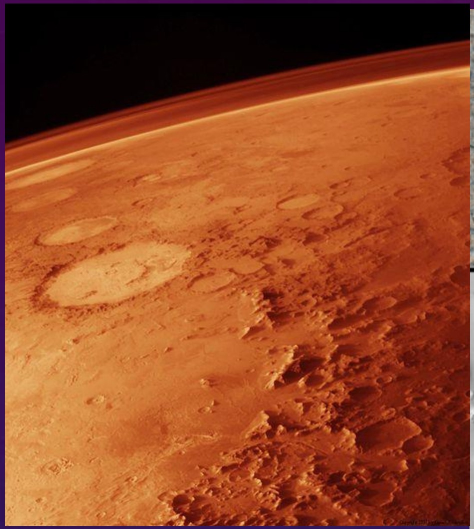


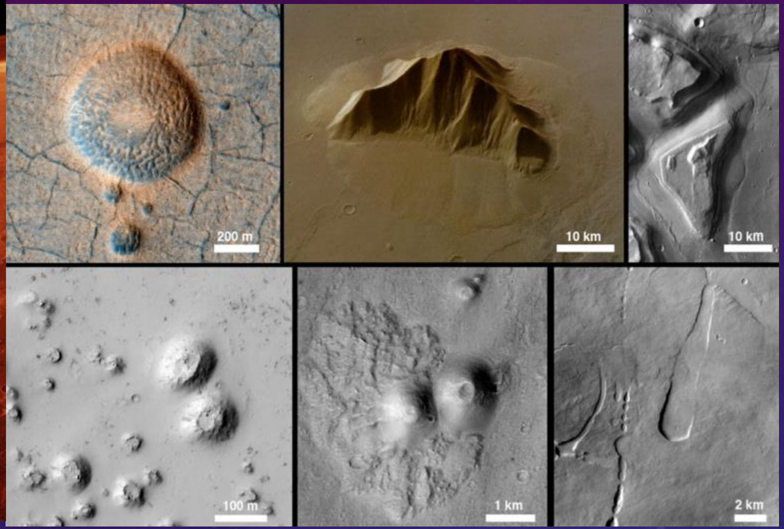


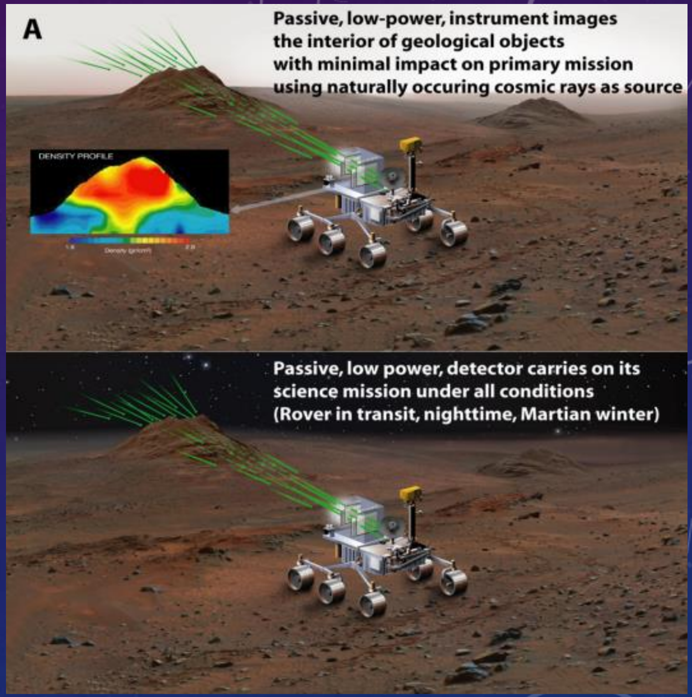
- Technique based on the absorption or transmission of muons through matter
- Measurements in different directions produce a map of the material densitiy
- Great when the muon flux is well known (Earth)
- Technique used in LOUMU project

- Technique that works due to the scattering effect of muons when interacting with matter
- Object must fit between detectors
- Offers richer information and allows 3D density maps
- Good for initial Tomographies on Mars, since the muon flux is not very well known

MUON TOMOGRAPHY ON MARS







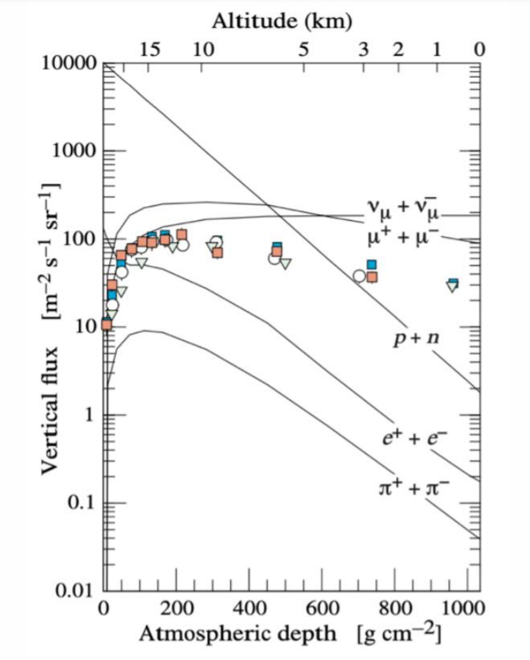
It is a non invasive technique that works under any metereologic conditions

- Mars has a thinner atmosphere, but studies indicate that the muon flux arriving at the surface is enough for the application of Muon Tomography
- Using real data from the Curiosity rover we can simulate the ground of Mars

Challenges:

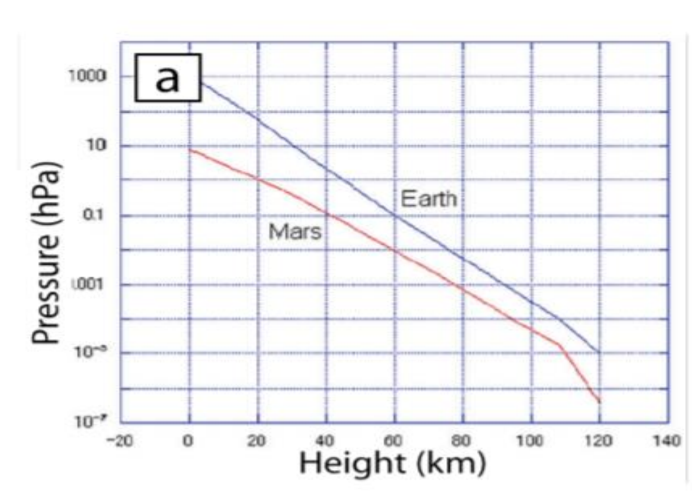
- Detectors must be able to withstand the voyage to Mars and the landing process
- The Mars atmospheric radiation is different than Earth´s

MUON TOMOGRAPHY IN MARS – DIFFERENCES IN THE MUON FLUX



Vertical Muon Flux on Earth

- Due to the thick atmosphere of the Earth, the cosmic ray shower maximum is reached at or at ~ 15 km altitude – **High muon production rate in the atmosphere**
- The Mars surface pressure is ~ 1/100 that of Earth and the atmosphere is thinner, resulting in a **lower muon production rate in the atmosphere**
- Unlike on Earth, a large fraction of the primary rays are likely to reach the Martian surface, resulting in a **higher muon production rate underground**
- Higher horizontal flux of protons, leading to more **background counts**



Depth (hPa)	7	100	200
Proton (m^{-2}s^{-1}sr^{-1})	9000	5000	2000
$\pi^{+/-}$ (m^{-2}s^{-1}sr^{-1})	2	10	8
$\mu^{+/-}$ (m^{-2}s^{-1}sr^{-1})	40	200	300

(Keder et al., 2013)

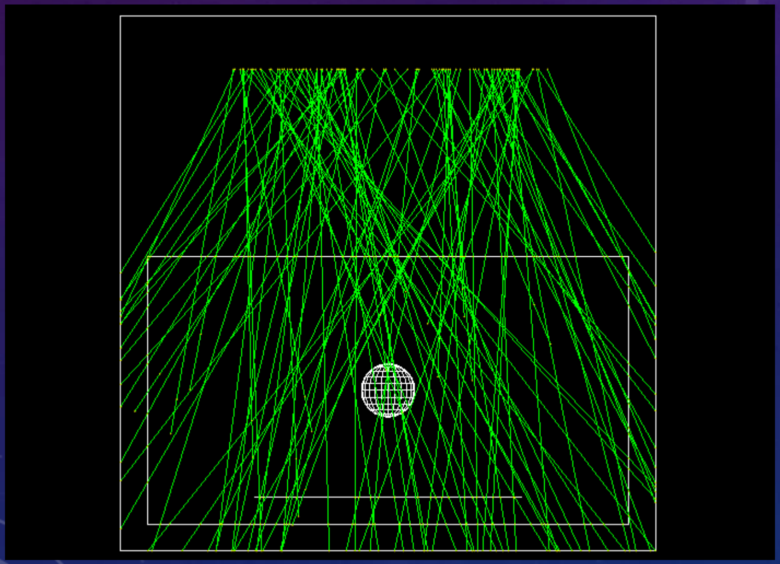
Particle flux for different values of pressure

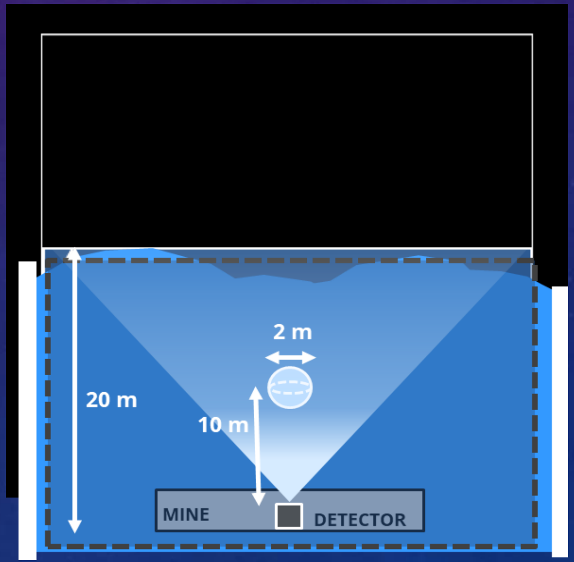
GEANT4 AND SIMULATIONS USING MUTOMO APP

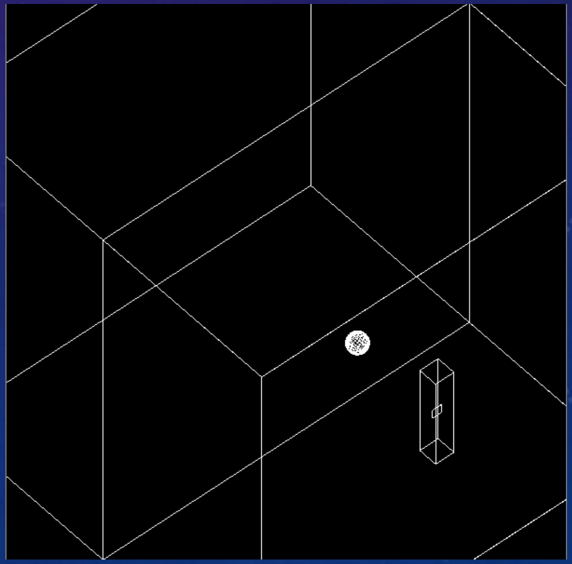
- Geant4 is a software tool developed by CERN, with the main goal of drawing and simulating the trajectories of particles, as well as every interaction along the way

- MuTomo is an application developed in LIP which allows the creation of geometries like the Lousal Mine or the *Olympus Mons*, the highest volcano on Mars

- The Mars radiation is simulated using the Energetic Radiation Environment Models (dMEREM and eMEREM) which are currently being developed for the European Space Agency (ESA) by LIP





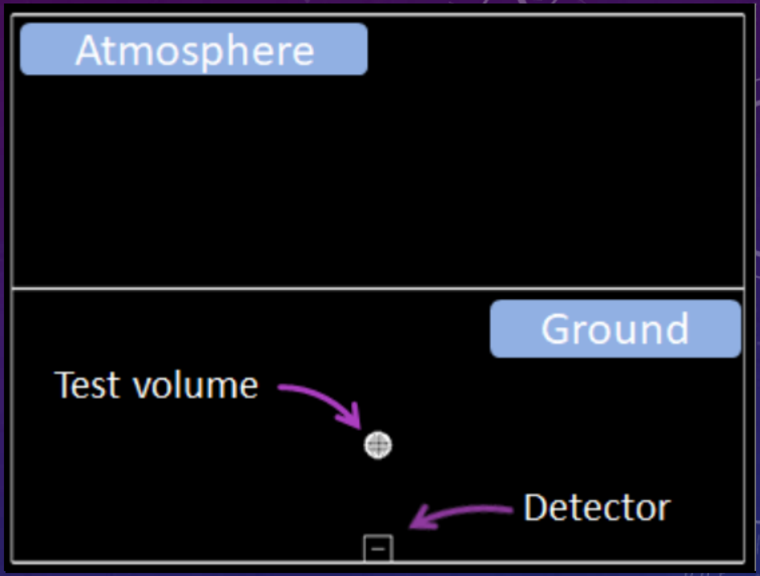


Geometry in MuTomo app

WORK DEVELOPED

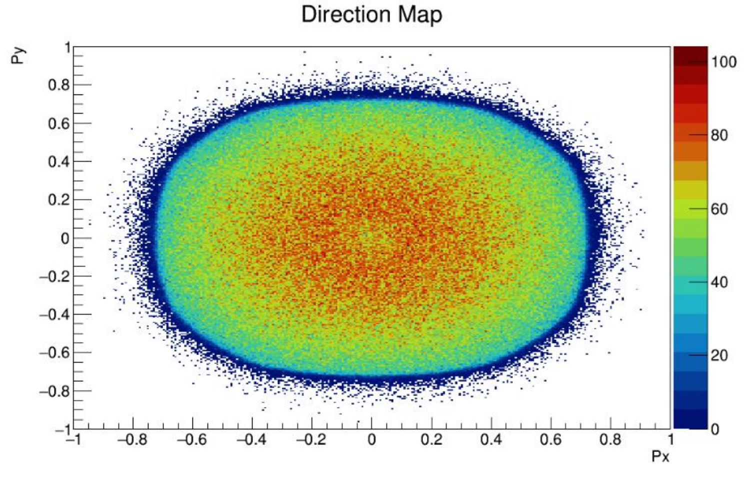
Creation of a script able to calculate the Earth muon flux at a certain depth for a material of a certain density

Learning how to create geometries and materials while manipulating gdml files



Example of a geometry used in simulations

Simulate geometries on Earth and create density maps (Muographs)



Use the MEREM models and new Martian geometries to simulate Tomography on Mars

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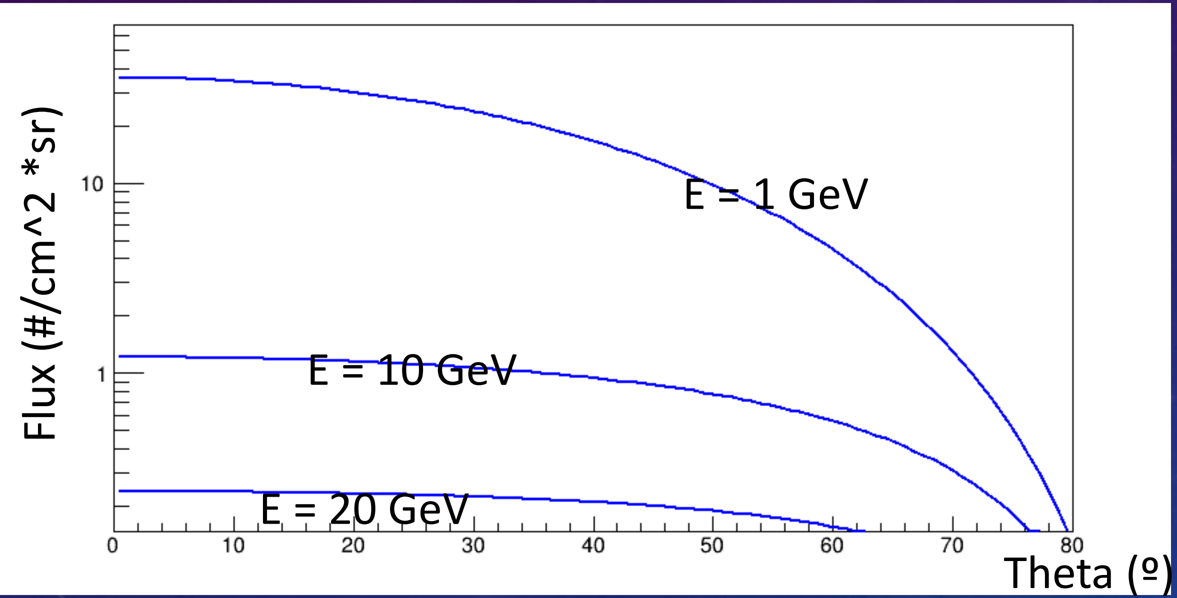
SCRIPT TO CALCULATE MUON FLUX

- Developed in C++ using ROOT
- Parametrizes the Earth´s muon flux into a function that only depend on the Energy and Angle
- Calculates the muon flux for a certain **depth** and material density (per second and m^2) by integrating the flux in an **Energy interval** and in **solid angle**



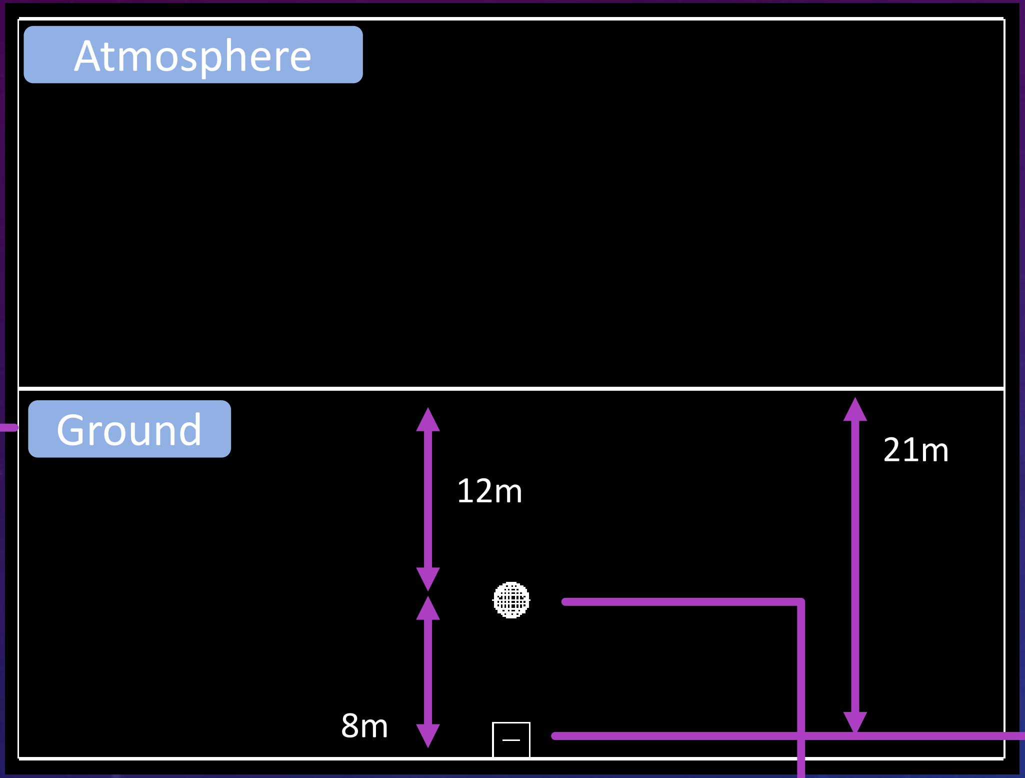
Graph of the variation of muon flux for diferente fixed energy value

Example: theta = 60º, ρ = 2.6, depth = 20m

```
cout << IntegratedFlux(60, 2.6, 2000) <<endl;
```

```
root [0]
Processing Fluxo.C...
The muon flux is 27.5849 muons per second*m²
```

GEOMETRY SETUP AND ANALYSIS OBJECTIVES



Detector inside cave
(1x1 m^2)

Earth´s ground density – 2.6 g/cm^3
Mars´s ground density – 2.8 g/cm^3
(near Gale crater – Curiosity data)

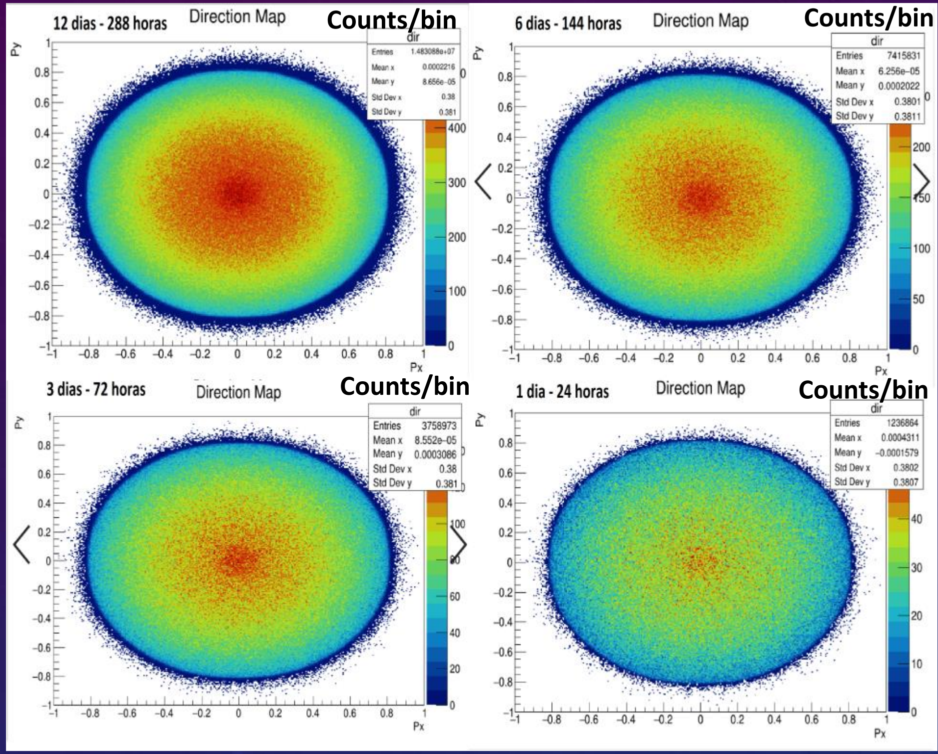
Test-Volume: Sphere (radius = 1m)
Materials: FeO (ρ = 5.74 g/cm^3)
Air (ρ = 0 g/cm^3)
Shale (ρ = 2.6 g/cm^3)

Objetives:

- Create 2D density maps of the geometry and compare for sphere of different materials and for different exposition times (1, 3, 6 and 12 days)
- Quantify the atenuation in the muon flux caused by the presence of the sphere

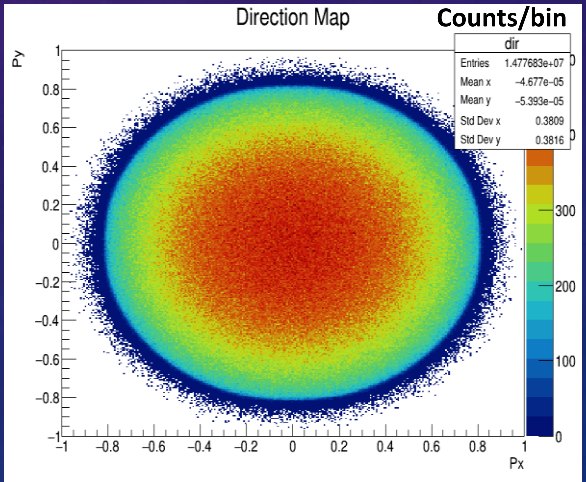
RESULTS: EARTH – DENSITY MAPS

- Sphere of Air (ρ = 0)
- Exposition time: 1, 3, 6 and 12 days



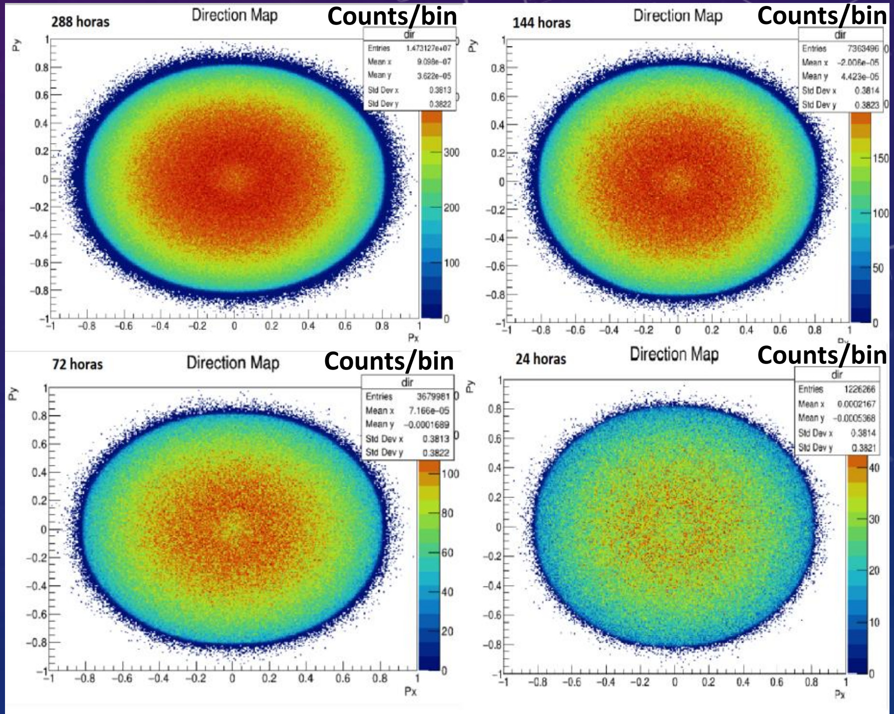
- Increase in the accumulation of muons in the region of the sphere

- Sphere of Ground material (Shale, ρ = 2.6 g/cm^3)
- Exposition time: 12 days



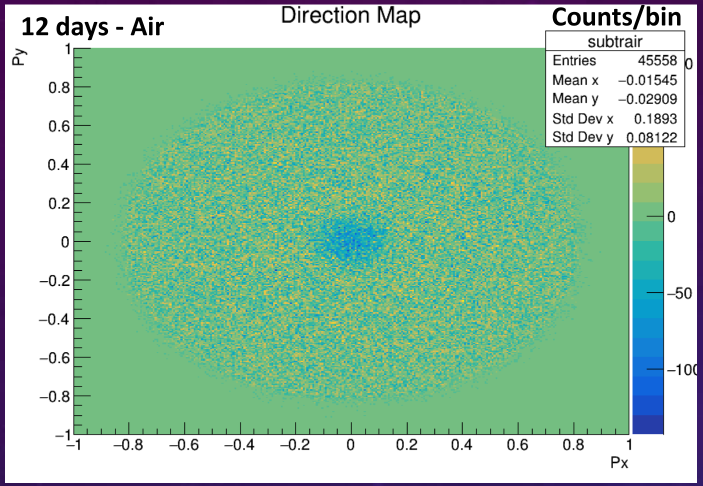
- Muography for reference

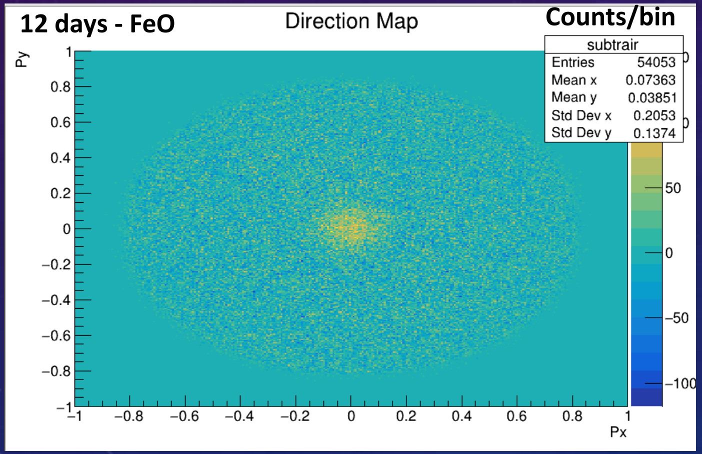
- Sphere of FeO (ρ = 5.74 g/cm^3)
- Exposition time: 1, 3, 6 and 12 days



- Decrease in the accumulation of muons in the region of the sphere

RESULTS: EARTH – ATTENUATION FACTOR





- Histograms without background – spheres clearly visible

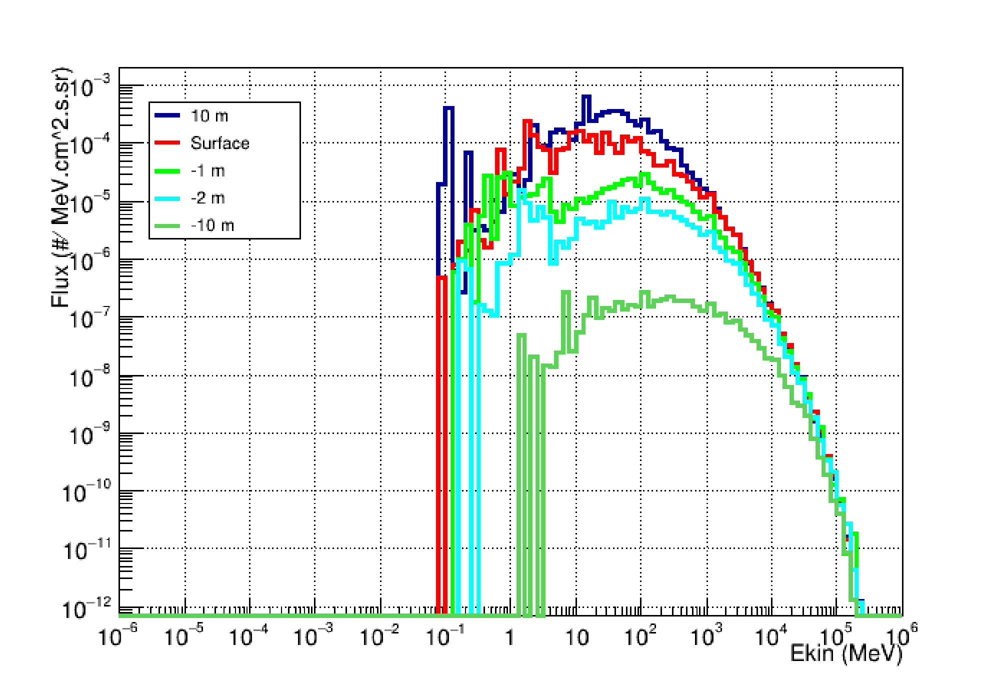
- Calculate and average the number of counts in the sphere region
- Divide by the reference value (sphere of Shale)

	Shale (Ground)	Air	FeO
Counts/bin	18875	21130	16920
Attenuation factor (%)	0	+11.94	-10.4

As expected, the FeO sphere attenuated the flux, and the Air sphere allowed more muons to pass through and be detected!

FOR THE FUTURE..

- Simulate Martian muon flux and ground composition (ρ = 2.8 g/cm^3)



Simulation using DMEREM

- Muons must be injected in the geometry under the surface (-10 m)
- At that depth, the flux is almost 100% muons

- Analyse the resulting muographies and test the viability of using Muon Tomography on Mars

THANK YOU!

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