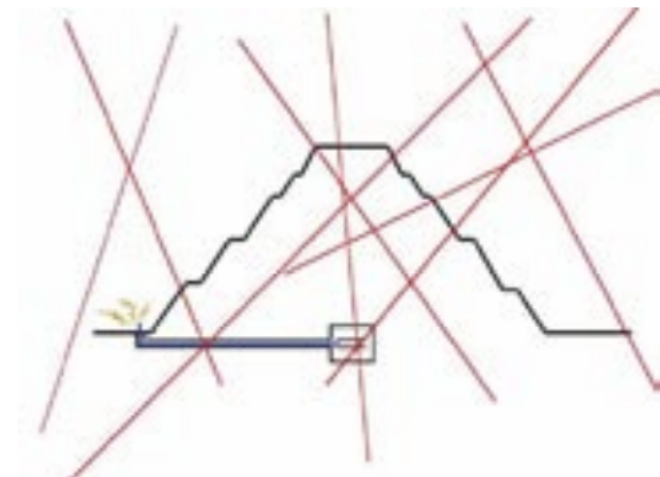


Physics in the service of Archeology



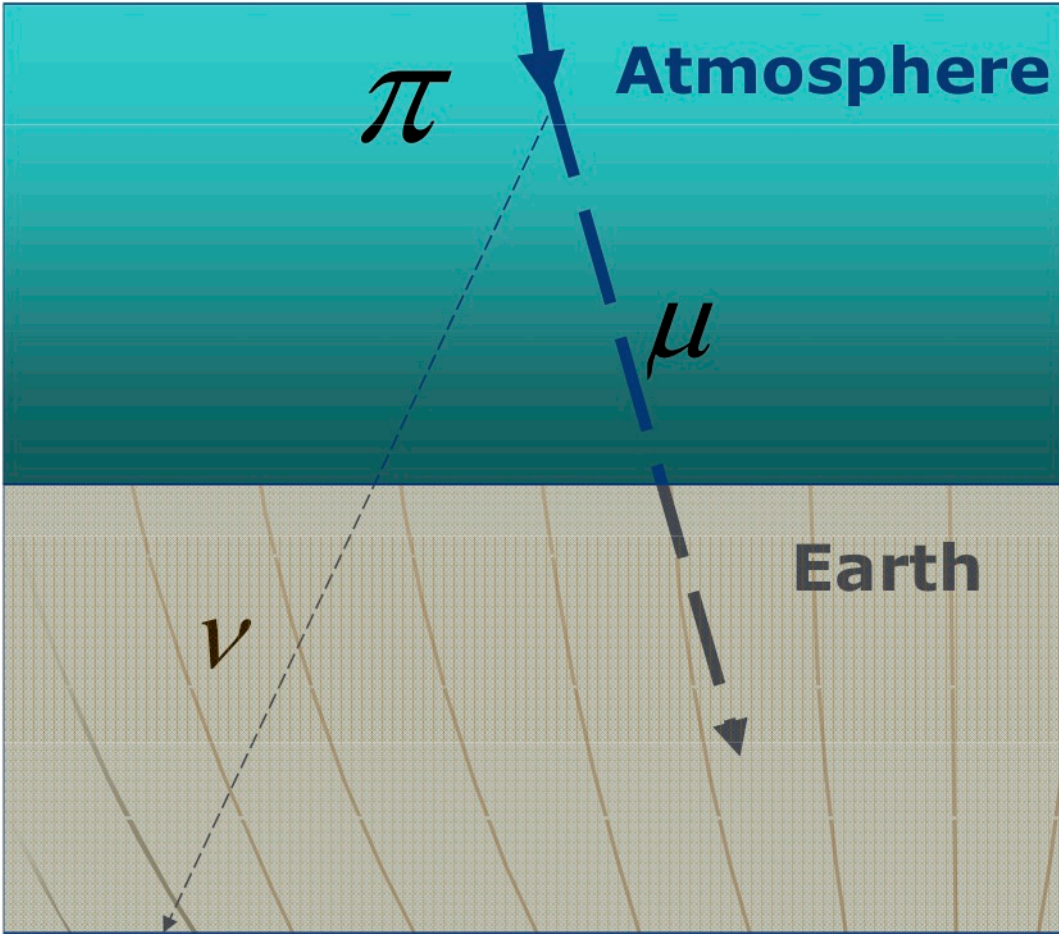
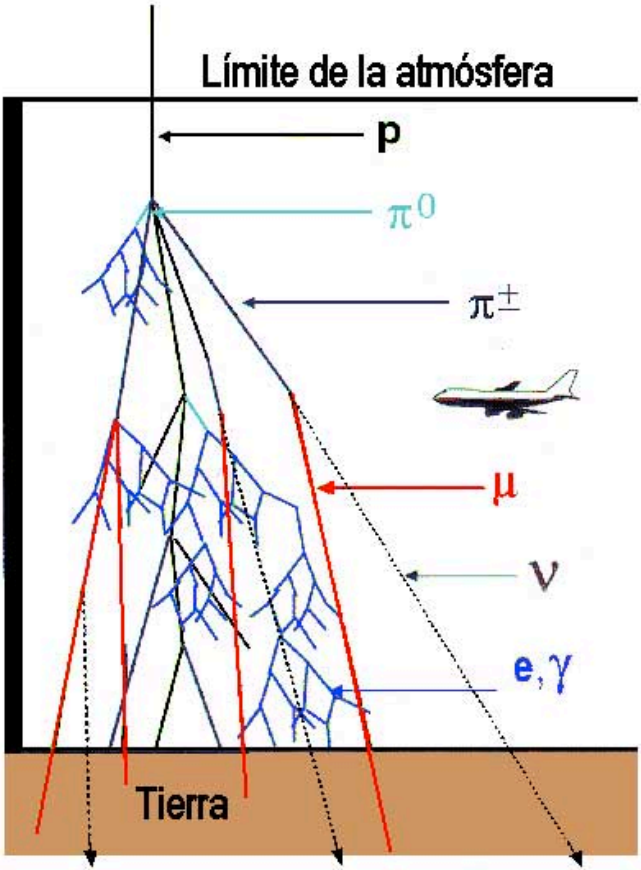
Looking for hidden chambers with muons

Ruben Alfaro-IFUNAM

IPPOG WG on Applications for
Society - 4th meeting

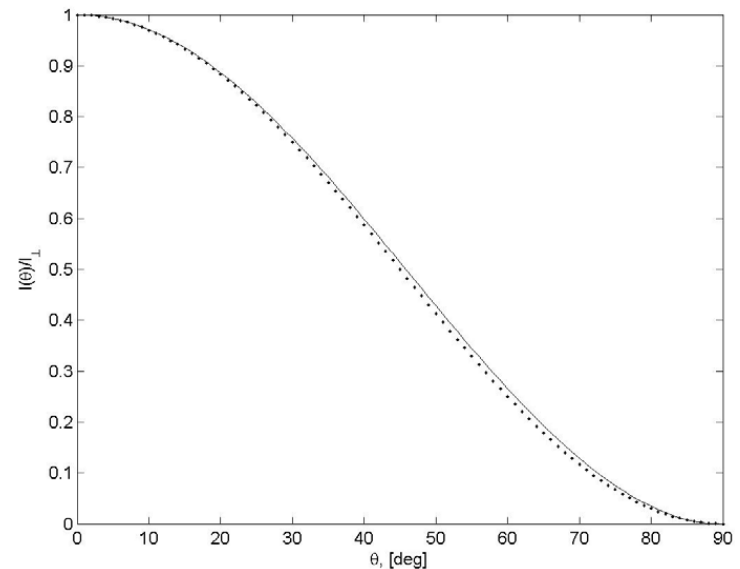
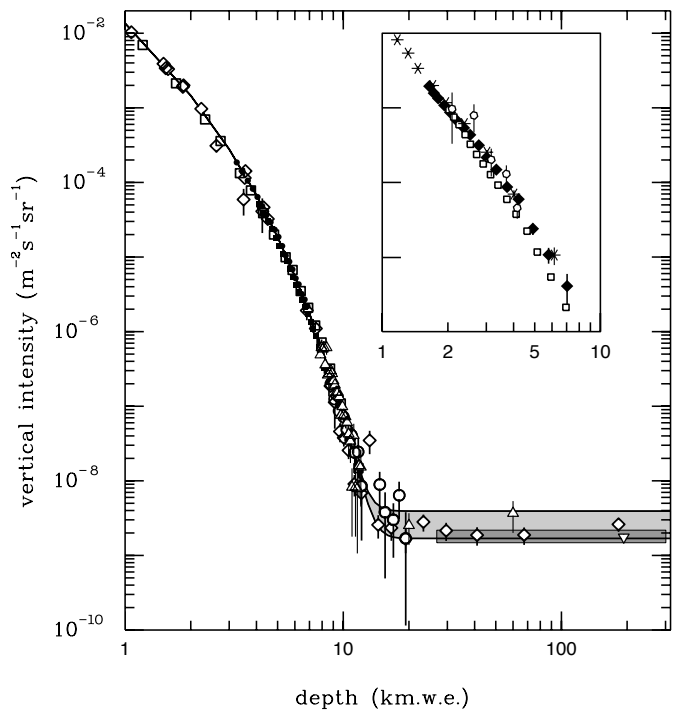


Muons as a radiation source



Flux attenuation and angular distribution

Their main features has been very well studied and measured therefore it can be used as a controlled source of radiation



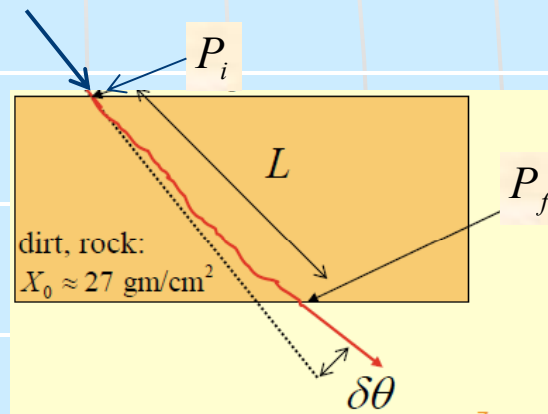
$$I(E, \theta) = k E^{-2.09} (\cos \theta)^{-0.02}$$

For energies 60-300 GeV

Trajectory

$$\delta\theta \sim \frac{13.6\text{MeV}}{\sqrt{P_i P_f}} \sqrt{\frac{L}{X_0}}$$

$$P_i - P_f = L \frac{dE}{dx}$$



For 200 GeV muons angular dispersion less than 15 mrad

In general, a reasonable and well characterized source of radiation.

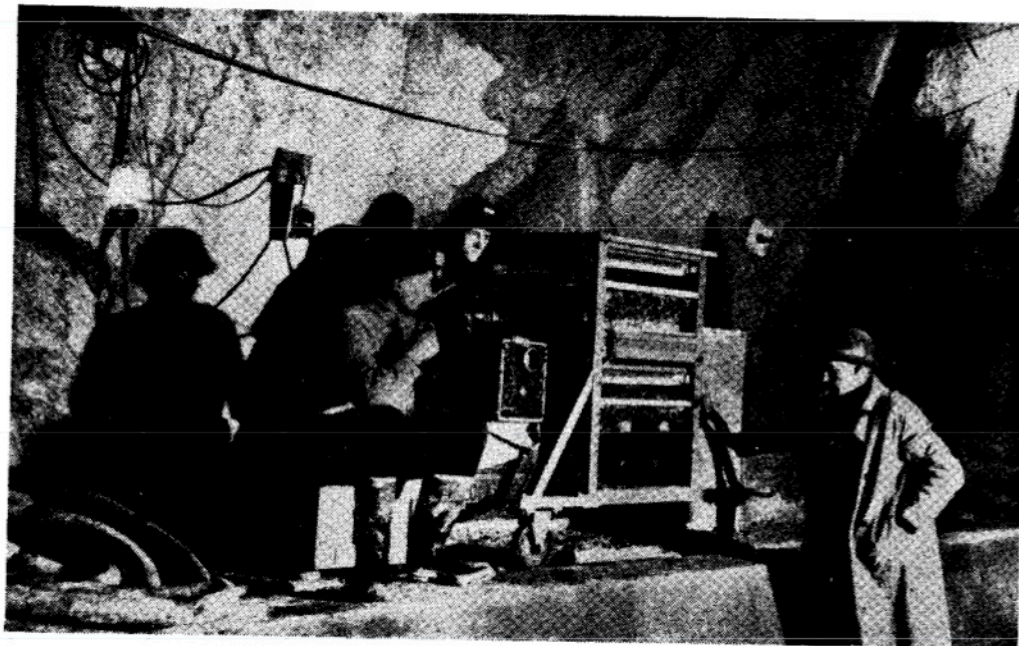
Pioneer work

Commonwealth Engineer, July 1, 1955

455

Cosmic Rays Measure Overburden of Tunnel

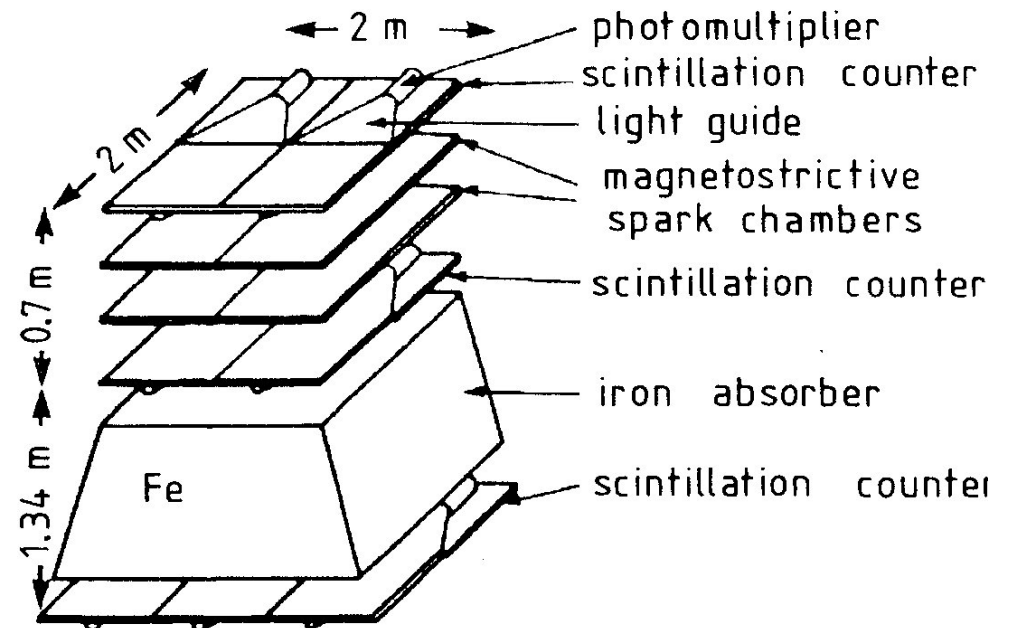
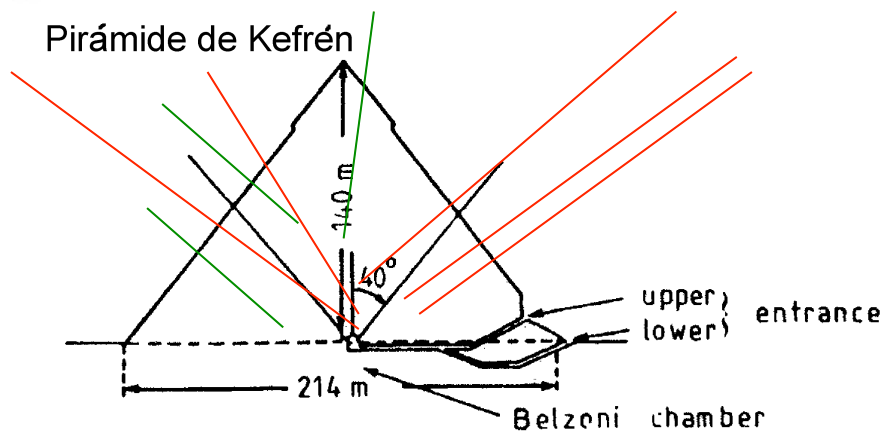
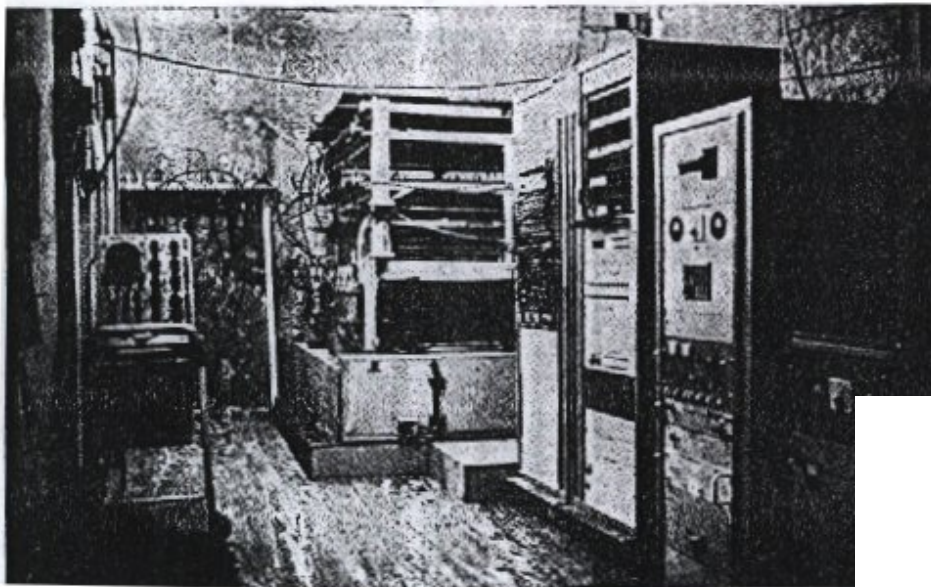
- Fig. 1—Geiger counter “telescope” in operation in the Guthega-Munyang tunnel. From left are Dr. George and his assistants, Mr. Lehane and Mr. O’Neill.



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.

Luis Alvarez experiment



Mexican Archeology



J.M Velasco, 1878

Teotihuacan is still a mystery

Started ~0
Declined ~600

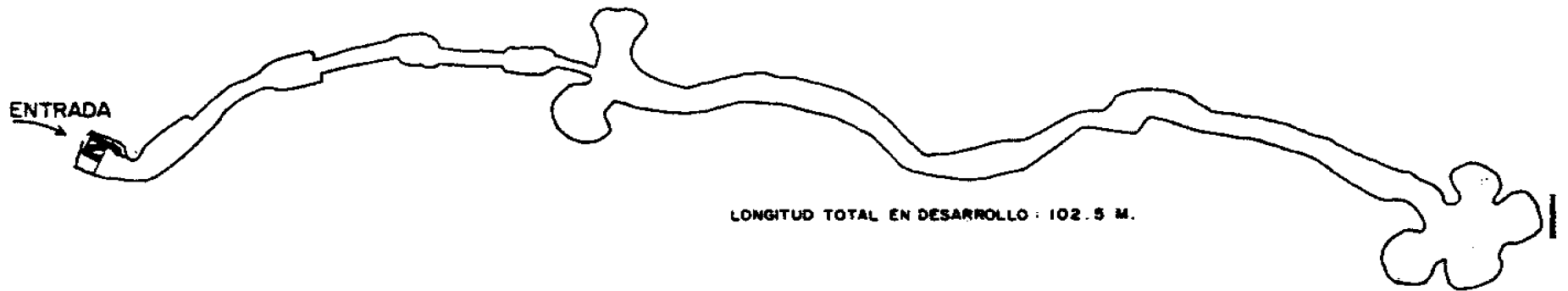
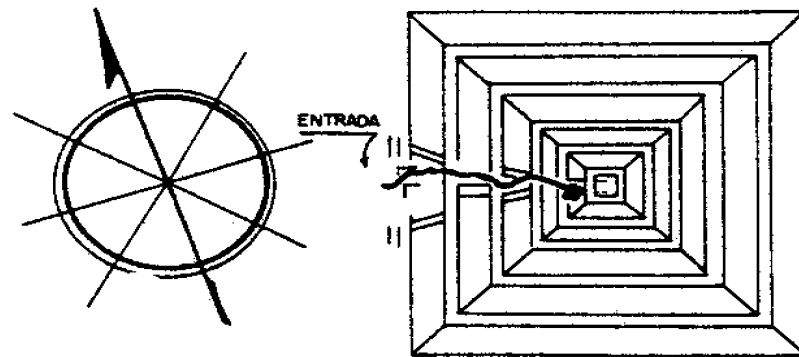
Aztecs arrived
~1300

Who founded?
Government?
What caused
Falldown?



Prehispanic Tunnel (1976)

Localización y orientación de la cueva situada bajo la pirámide del Sol en Teotihuacan. Edo. de México



REDIBUJADO DE HEYDEN , 1981.

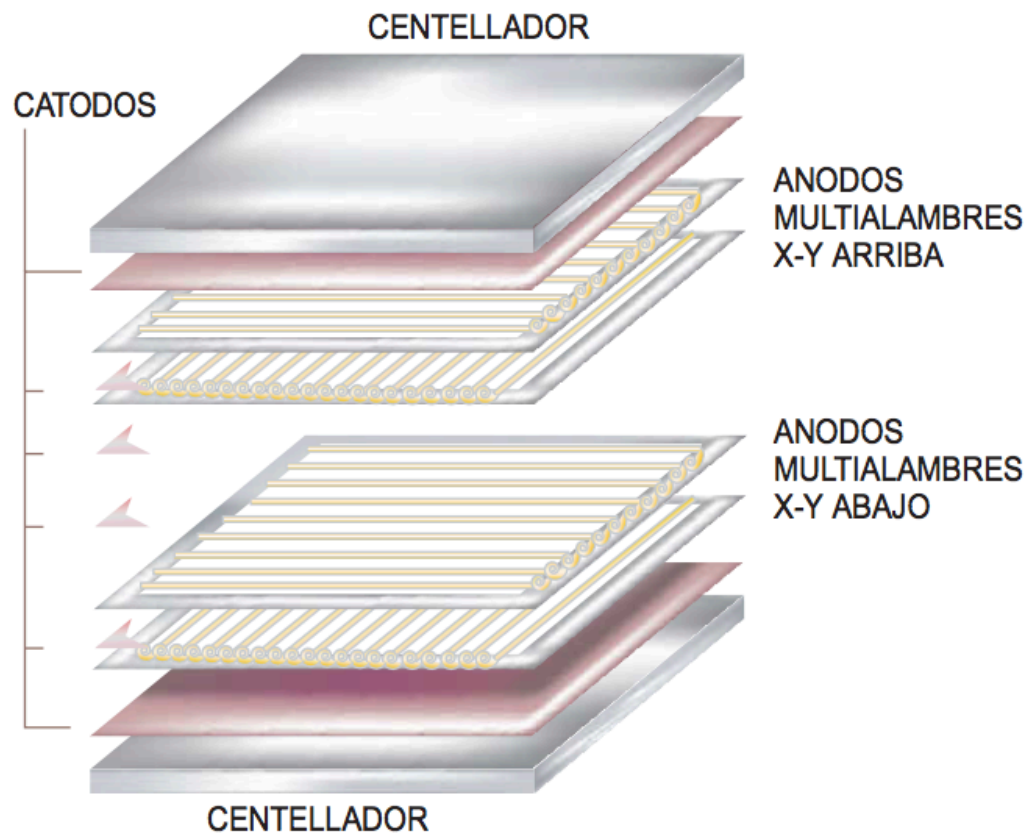
Archaeologist and Physicist



Tunnel end

Entrance

Muon tracker



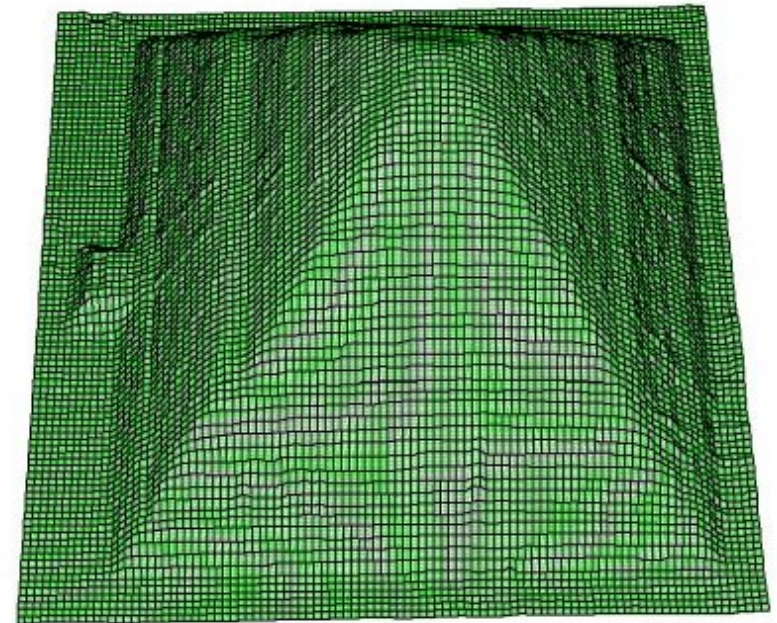
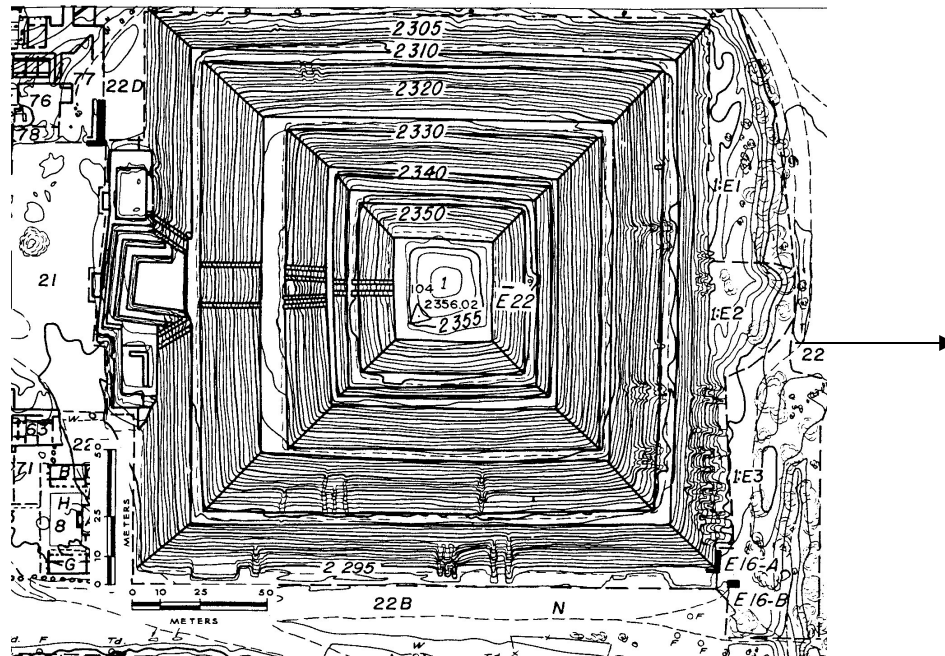
Hardware:

- **2 Scintillators**
- **4 MWPC (2 X-Y planes)**

Esquema del detector

Simulation

CORSIKA
GEANT
3DField



The experience



Reduce entrance only
Some sections 60 cm width
80 cm height

100% humidity

26 degrees.

No possibility to modified
the environment.

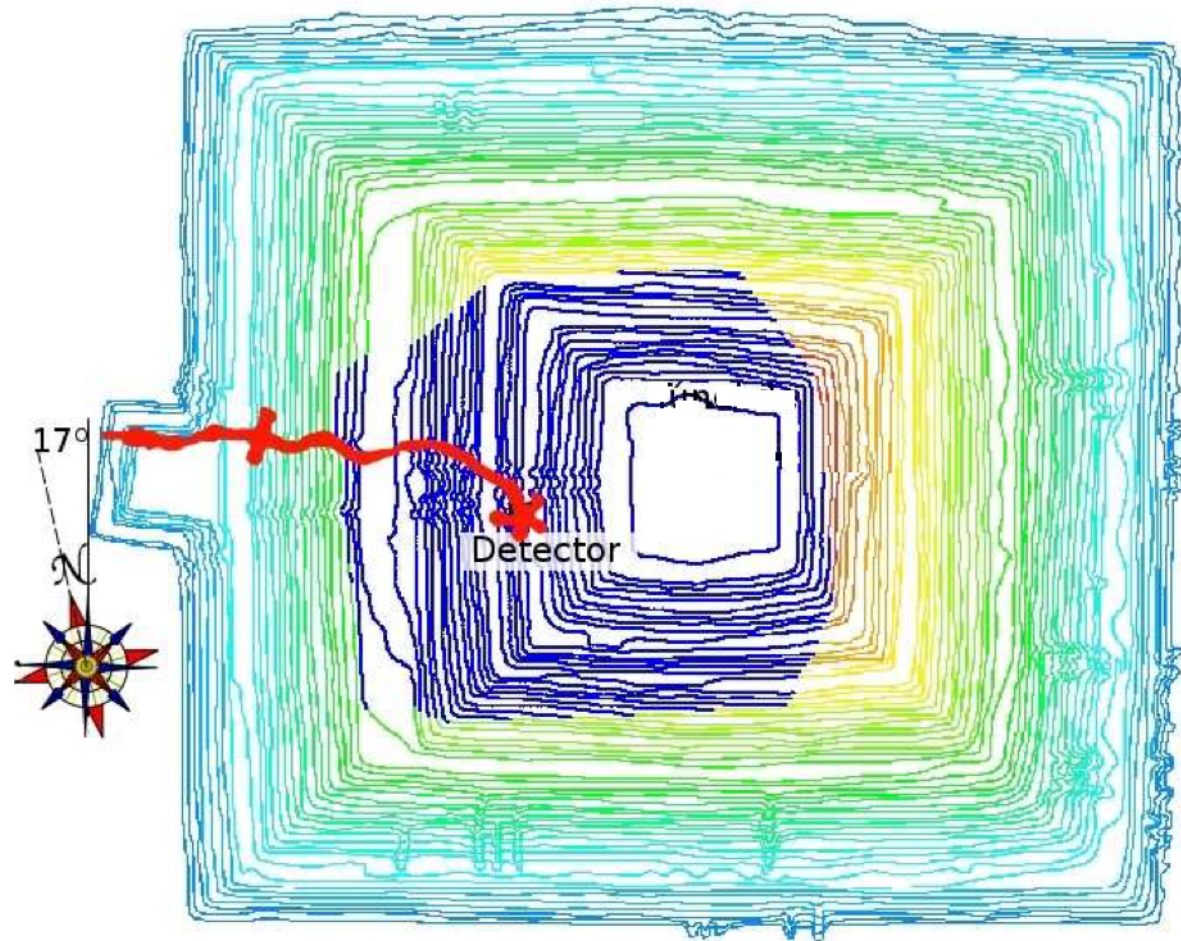


The detector

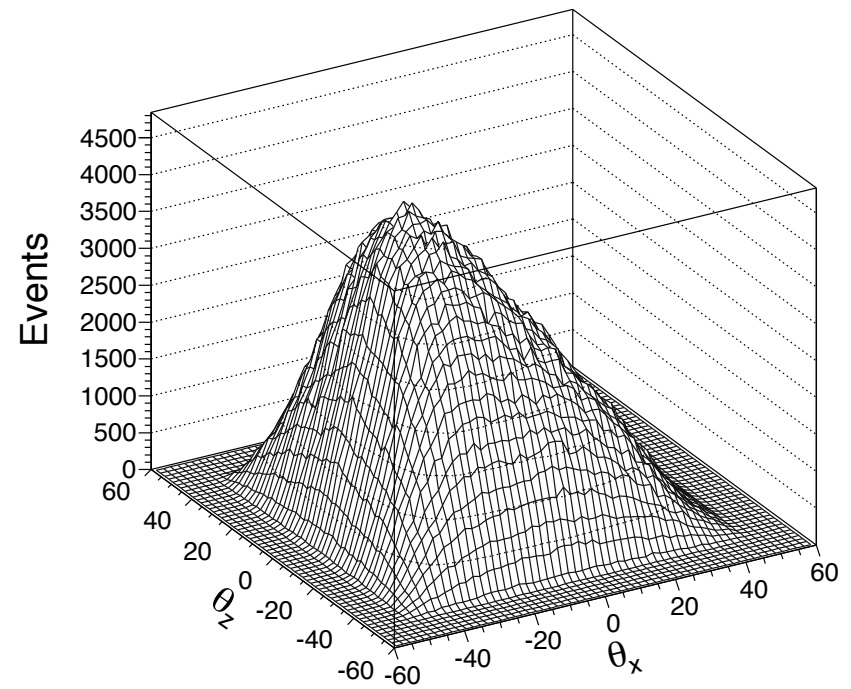
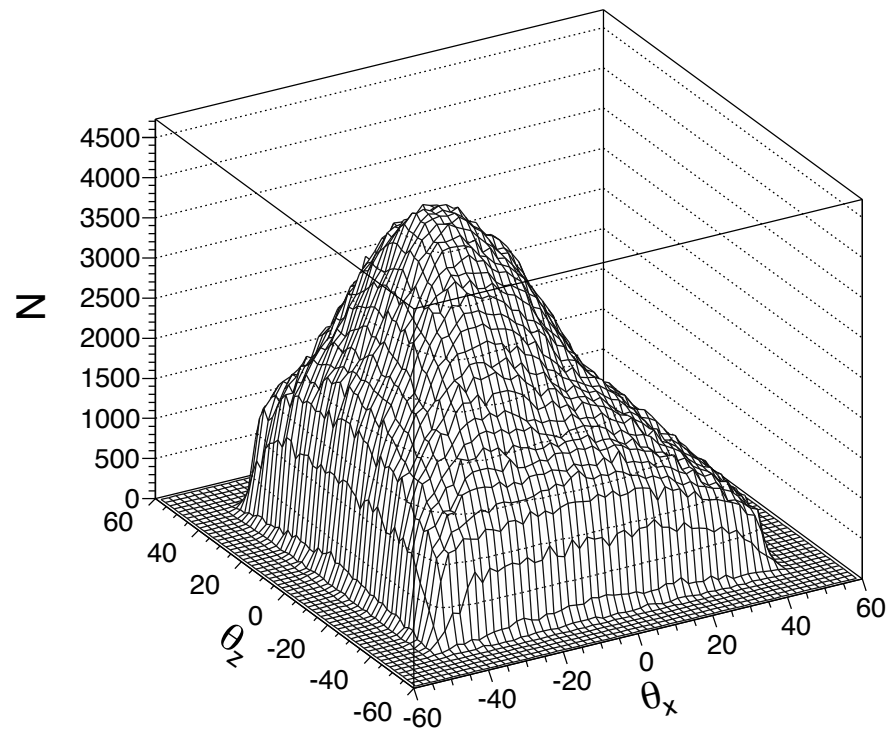


Detector Position

Blue contours
Detector FOV

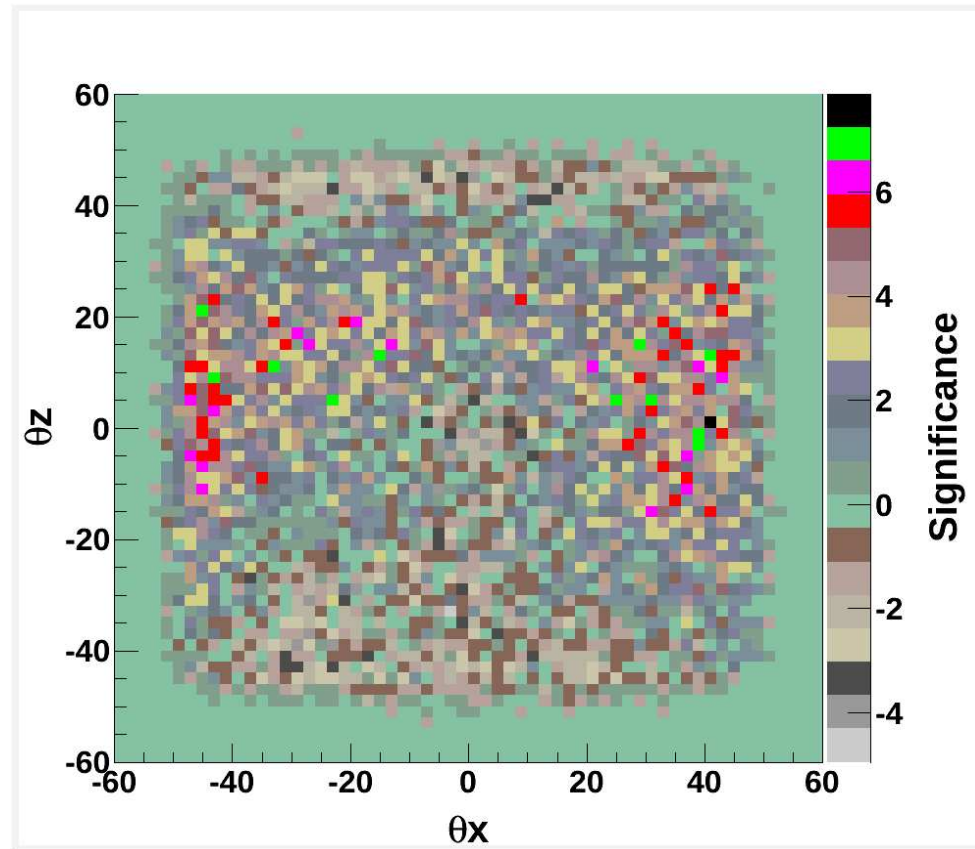


Simulation vs Data



Not buried chamber but ..

There is a density
Asymmetry.
Could be because
Less humidity in the
soil?.



Summary and reflections



Prospection by detecting muons is a suitable option

Sun Pyramid seems does not have a empty buried chamber.
However the results can help to restore and preserve the pyramid.

Why get involved in a project like this?

It gives visibility and shows the importance of science.

Politically correct (funding agencies like it)

Bring science closer to students,

R&D can be used for other projects. (monitor Volcanoes)