Pyramid Hunters

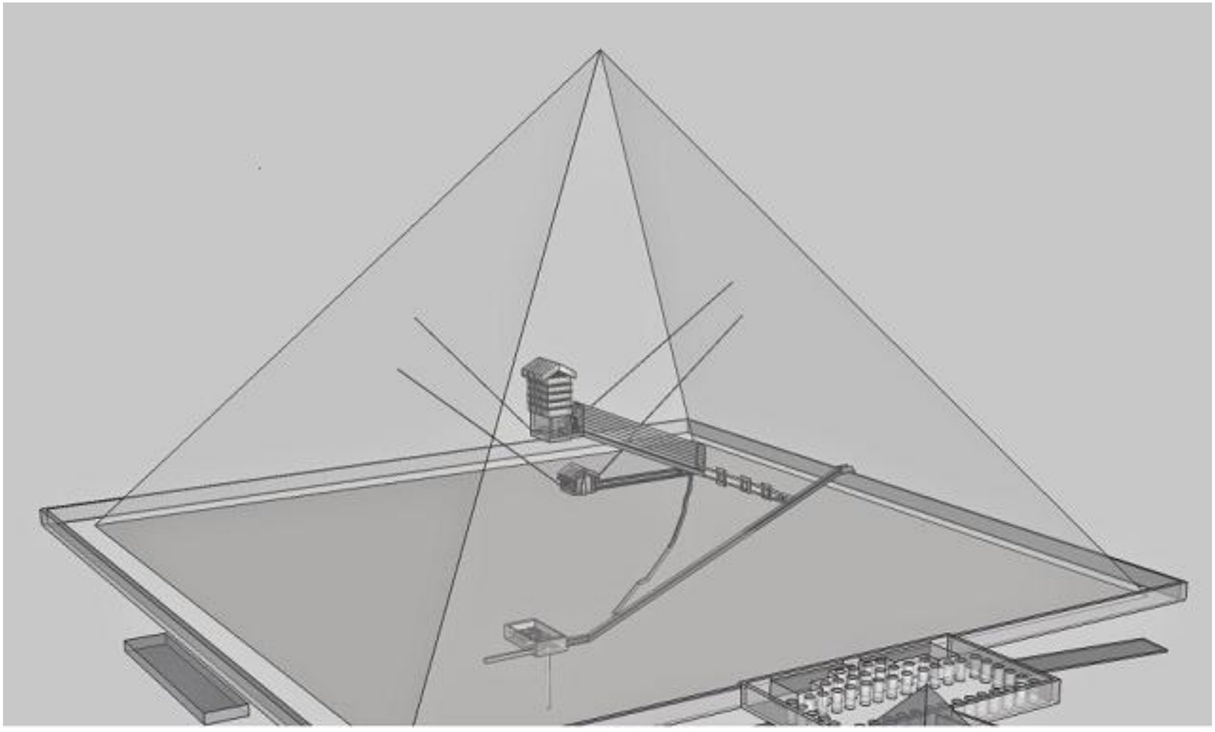
Proposal of an experiment
for
BEAMLINE FOR SCHOOLS
competition
2016

The secret chambers in the Chephren Pyramid

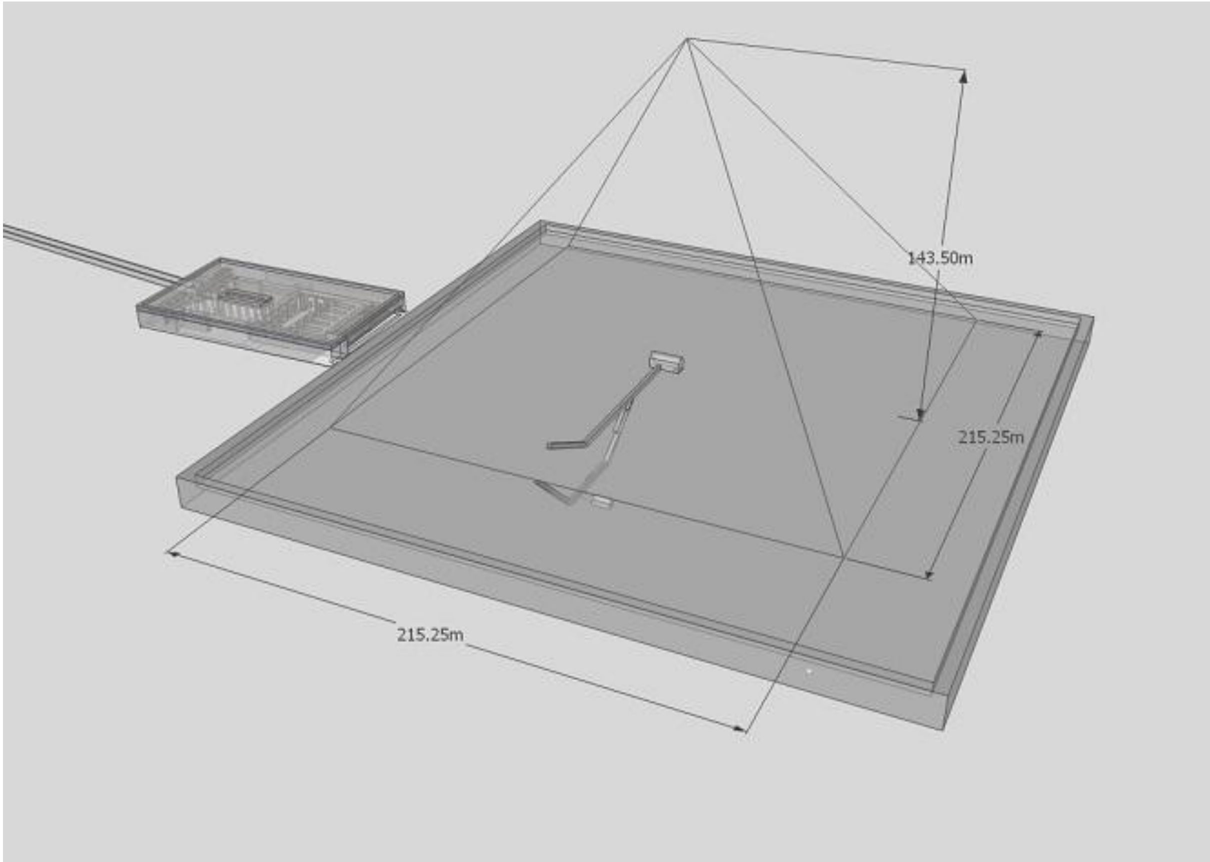
1. What's the mystery of the pyramids?

Pyramids - the greatest architectural achievement of ancient civilization. There is no other building that has been so carefully researched and has been so many books and articles written about it. However, the pyramids are still the most mysterious pieces of architecture and it seems that they still hide numerousness mysteries.

One of the biggest and the most intriguing to us is the internal structure of the pyramid of Chephren. Unlike his father's, Cheops', Great Pyramid which has many sophisticated internal structures: the King's Chamber, the Queen's Chamber, the Great Gallery– Chephren Pyramid does not seem to hide any more than a modest Belzoni Chamber. The fact that the Egyptians set up 2.5 million stone blocks without any purpose seems to be unimaginable. So we would like to try to examine the internal structure of the pyramid using muon tomography.



Cheops Pyramid



Chephren Pyramid

We didn't have the possibility to visit Egypt. Fortunately we managed to create computer model of the pyramid and compare our model calculations with the experimental data of Luis W. Alvarez[1].

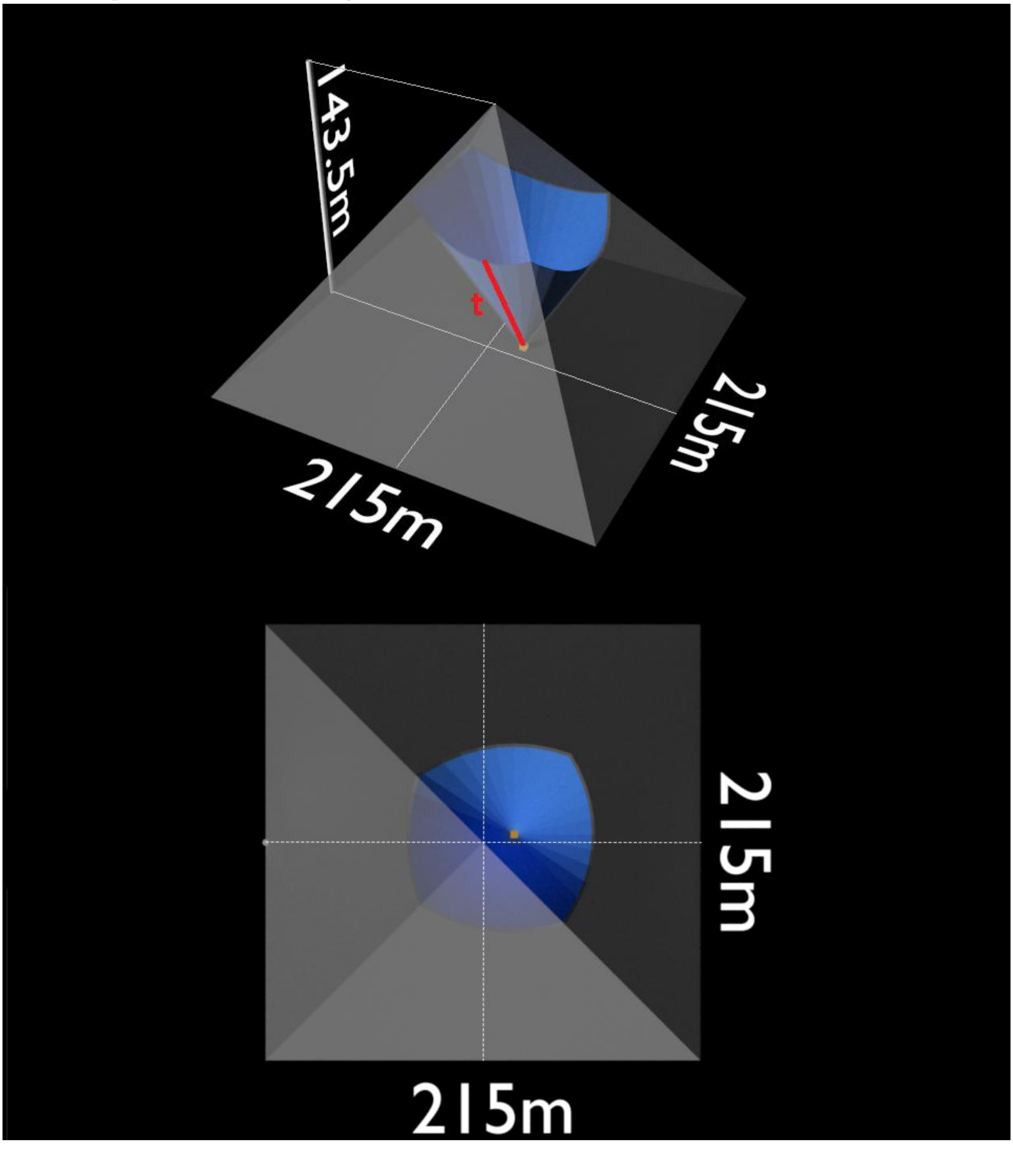
[1] Luis. W. Alvarez, *Search for Hidden Chambers in the Pyramids* (Science 06 Feb 1970)

2. Our mathematical model and calculations

We would like to reproduce and to understand Alvarez' data. He installed his detectors (spark chambers) in Belzoni Chamber. But the Belzoni chamber is displaced from the centre of the base by y_0 =13.5 m east and x_0 = 4 m north. Therefore, in this configuration we have to calculate the distance covered by muons to the chamber, when pass through the rock. This is accomplished with the following calculations. By using the equation of the plane surface N, W, S and E of the pyramid and taking the initial point where muons enter into the pyramid from the top, we get to formulas from which we are able to calculate the distances to the Belzoni chamber (introduced the scale factor $k = \frac{4}{143.5}$) and we have:

$$t = \frac{8y_0 + 24}{3\sqrt{3} - 4\sin\alpha} \quad \text{for the East side,}$$

where α represents azimuthal angle.



3. Cosmic muons

We used some of the equations found in C. Grupen's book to derive necessary formula[2].

$$N(>E_\mu, R) = A{E_\mu}^{-\gamma}$$

N- the integral energy spectrum of muons
R- muons' range inside the rock.
Then we derived the formula for muon energy as the function of R

$$R = \frac{1}{b}\ln\left(1 + \frac{b}{a}E_\mu\right)$$

We derive a formula for muon energy from this equation.

$$E_\mu = \frac{a}{b}\left(e^{Rb} - 1\right)$$

From Taylor's theorem we know that:

$$e^{Rb} \approx 1 + Rb$$

By substituting it into the formula, we get:

$$E_\mu = \frac{a}{b}\left(e^{Rb} - 1\right) \approx \frac{a}{b}\left(1 + Rb - 1\right)$$

Hence:

$$E_\mu \approx aR$$

We also know that:

$$R = \rho t$$

By substituting these into the first equation we obtain:

$$N(>E_\mu, R) \approx A(a\rho t)^{-\gamma}$$

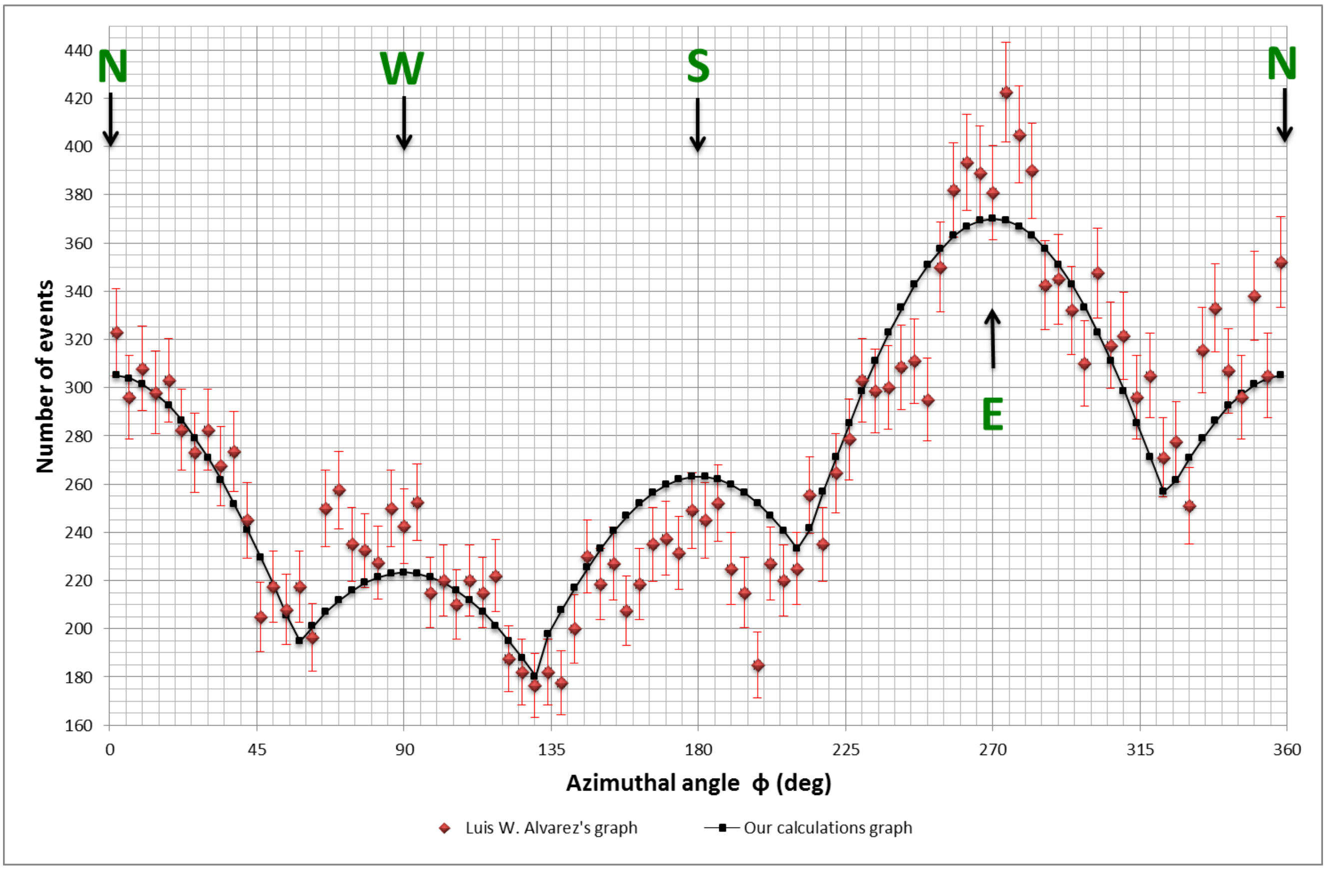
Now, we're using two different ranges:

$$\frac{N(>t_1)}{N(>t_2)} = \frac{A(a\rho t_1)^{-\gamma}}{A(a\rho t_2)^{-\gamma}} = \left(\frac{t_1}{t_2}\right)^{-\gamma}$$

$$\gamma \approx 2$$

[2] C. Grupen, *Astroparticle Physics Springer 2005*

After receiving the number of muons coming from constant 30° zenithal angle and different azimuthal angles we can compare the results of our calculations results with the Alvarez' data.



It shows about 650.000 muons after selection from the angles between 20° and 40°. Our calculations are normalised to the number of muons which can be observed in the depth between the West and South walls (180).

Excluding unexpectedly high peak in the point 270° (perhaps there's a corridor) our calculations are generally by consistent with Alvarez' data, except for two areas.
Between the angle 62° and 72° we see evident increase of number of events in comparison to the model. We concluded that the only explanation could be a chamber located there, similar in size to the King Chamber in the Great Pyramid. The second worrying area is between 192° and 203°. We believe that it can be explained by the object of much higher density (e.g. pharaoh gold).

What we would like to measure with the muon beam at CERN:

To check whether our observations are correct, we would like to exam the effects of three factors, which can disturb the muon tomography measurements:

A- the most important factor: the muon range fluctuations occurring in the last two meters of the rock layer

B- influence of different arrangements of materials, which the pyramid consists of for measurements (limestone, granite and air)

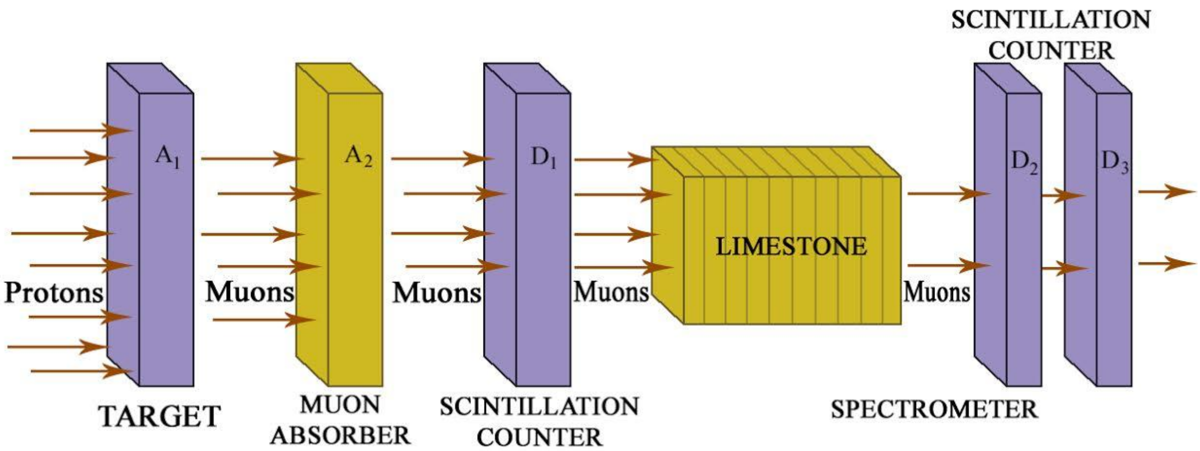
C- presence of measurements disturbance which could be caused, as suggested by some people on the internet, by objects electrified by movement of hot air (pharaoh sarcophagus)

4. Experiment

A.

To measure fluctuations of running muons in limestone of pyramid we designed the following experiment.

We want to direct the muon beam (originating from the PS protons impacting on the target in the East Area where relatively low momentum beams are available) into a lead absorber to reduce further the muon beam momentum from ~0.5 – 1GeV/c down to a few hundreds of MeV (preferably 286 MeV). The absorber should be preferably followed by a Muon Filter which will remove the particles other than muons. Afterwards, the muon beam travelling through the scintillation counter (Scint) counting the number of muons impacting the limestone block. Our target is made of blocks of limestone of density of 2.2 g/cm3 (which were probably used to build the pyramid) and of dimensions of 10 cm x 10 cm x 2 cm. The length of limestone absorber is chosen to enable absorption of some of the muons in the stone. Detector D_1 (Scint) will count the number of muons, which fall on the stone. Detector D_2 (Scint) will count the number of muons, which escape from stone. Furthermore, if it will be possible, we would like to measure the momenta of the muons outgoing from the rock out by detector D_3 by use of the spectrometer made of the magnet MNP17 installed upstream the detector D_3. The momentum reconstruction calibration and alignment can be performed by varying the magnetic field of the magnet. For optimal momentum reconstruction performance, the detector D_3 should be composed of at least two (preferably three) layers of tracking detectors. The best candidate is the available Four-layer Straw Detector providing high spatial and angular resolution.



By using absorber A_2 we will create muon beams of different momenta and we choose the proper length of limestone target to enable full absorption.

Theoretical data for standard rock[3]

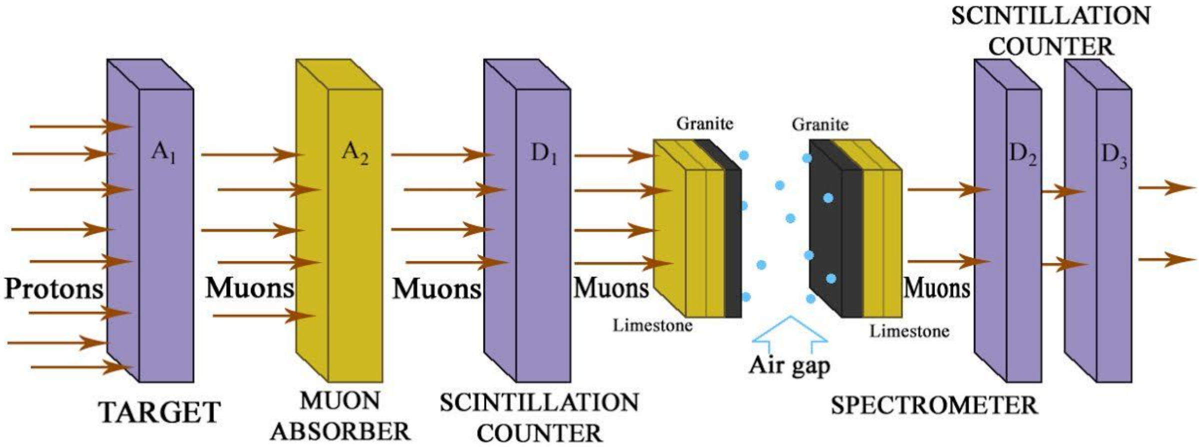
Muon momentum [MeV/c]	Range [g/cm^2]
176,4	36,96
286,8	93,32
391,7	152,4
494,5	211,5
891,5	441,8

We will focus on muons which reach detector D_2 and D_3 and determine the magnitude of fluctuations. We measure the difference between the standard rock and the limestone.

[3] *Atomic Data and Nuclear Data Tables* **78**, (2001)

B.

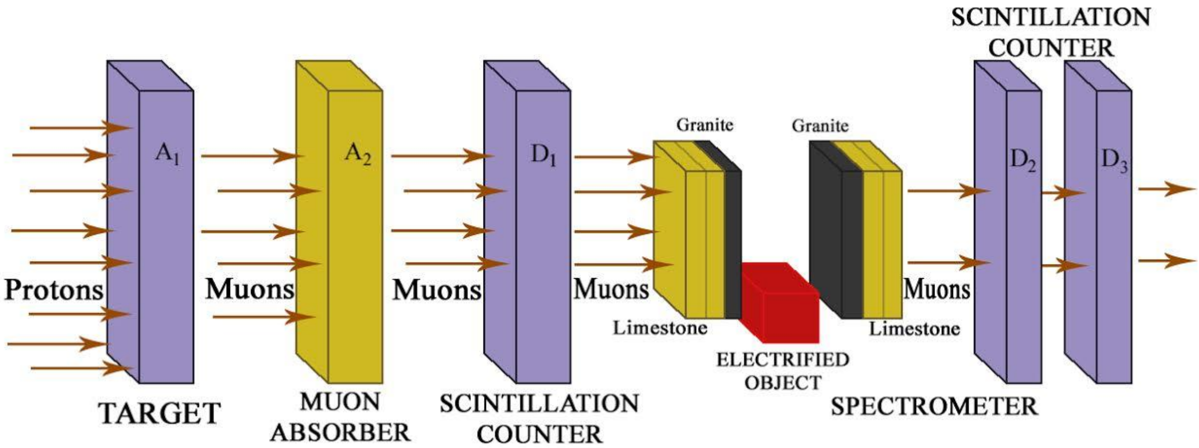
Another subject of study are the properties of muon beam undergoing materials of different density. For this purpose, we locate blocks of granite (2.6 g/cm^3) and limestone (2.2 g/cm^3) which have the same absorbing properties as blocks of limestone of length of 93.32 g/cm^3 and we impact muon beam of momentum close to 286.8 MeV/c, as shows the figure below:



Similarly to the first experiment, we will compare the number of muons hitting the rock (D_1) and coming out from the stone (D_2) and (D_3).

C.

The next hypothesis we want to check is the possibility of disturbing the results of muon tomography by electrified objects. For this, we locate an electrified object, representing sarcophagus. Muon beam will have momentum of 286.6 MeV/c and we obtain results using detectors 1 and 2.



5. Predictions

In the first experiment we expect that some muons will go through the stone and reach the detectors D_2 and D_3. However, numbers of these muons is still an unknown. Knowing the magnitude of fluctuations in the number of muons coming out of the rocks we can prove that there is an invisible Pharaoh chamber between the 62° and 72°.

In the second experiment we expect that muons won't reach detectors (D2-D3) and that the structure will show greater absorption properties.

Then, we will check if electrified objects in the third experiment can cause similar disturbing effects.