Conceptual design of a Scintillator-based Telescope for Muon Tomography and its advantages over the archaeological way.

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Abstract

Muon Tomography is an application of a muon detector that is used to study and observe unreachable parts of objects or structures by creating a three-dimensional image without destructing them. This paper will be centered on the Pyramids that archeologists and Egyptologists study. The main objective of this paper is to answer our initial question: Is doing Muography cheaper and more reliable than the classical method?

The two main goals of this article are, on the one hand, to present a conceptual design of a muon detector, including the materials, cost, and its main functions. On the other hand, to learn how archeologists study structures, including the methods and materials they use. Finally, compare the proposed muon detection technology with the archaeological way.

Keywords:

Muon Tomography, detection technology, scintillator, pyramid

1. Introduction

The pyramids of Egypt have captured the interest of archaeologists and Egyptologists in exploring and studying their construction and internal structures. By using invasive (drilling and digging [1], [2]) and non-invasive (Microgravimetry [3]) techniques, the pyramids still have some mysteries

To explore these kinds of structures without damaging them, cosmic rays are useful for obtaining images (x-ray like) of their interior design.

Cosmic rays are high-energy particles that come from different parts of the universe and are mostly composed of protons. On striking Earth's atmosphere, it creates a cascade of different types of particles that can be detected, one of them being muons (μ). About 10,000 μ per m^2 every minute reach the Earth's surface, they are more massive, have a longer lifetime than the other particles, and have sufficient energy to penetrate matter in their path. With these properties, muons can be used to scan structures by detecting the muons that pass through them; the denser the structure, the more muons are absorbed, and consequently, less detected muons.

Muon tomography was first used in studying the pyramids by Luis Alvarez [4] and his team to study the Second Pyramid (Khafre's Pyramid) of Giza in 1967. With a help of a spark chamber (see Section 2), they recorded the tracks of muons that passed through the detector. Although, no hidden chambers were found, detecting the cap and the four corners of the second pyramid showed the effectiveness of the new technique.

In 2015, the "ScanPyramids" mission started to examine the largest pyramids in Egypt (Khufu, Khafre, Bent and Red pyramids Fig.1) with the aim to know their internal structure. Using three different non-destructive technologies, including emulsion films, scintillation hodoscopes and gas detector (see Section 2), they discovered a large void in the Great Pyramid (Khufu's pyramid) which was publicly announced in 2017 [5].

The goal of this paper is to understand the different muon technologies used to study the Pyramids of Giza and how excavations and studies are performed in the classical way. Based on these techniques, we designed a muon scintillator-based detector that could be used for Muon Tomography.

2. Muon detection technologies

In this section, we focus on explaining the different types of muon detectors used to scan the Pyramids of Giza.

2.1. Scintillator and Spark Chamber

A scintillator [6] is a transparent plastic plate that emits photons when a charged particle passes through it. The emitted photon will be detected in the attached photomultiplier tube (PMT) in its photocathode and owing to the photoelectric effect, it emits electrons, which are multiplied by the dynodes of the tube. When the electrons arrive at the end of the PMT, the anode obtain the electrons and converts them into an electronic signal.

A spark chamber [7] is made of separated metals between scintillators and is filled with a mixture of noble gases. When a charged particle passes through it, it ionizes the noble gas along its path (electron emission). By applying a high voltage to every

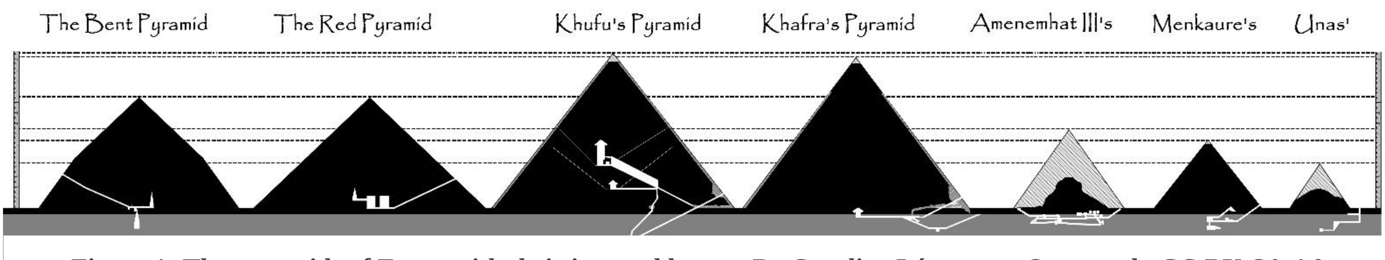

Figure 1: The pyramids of Egypt with their internal layout. By Caroline Lévesque - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=116521250

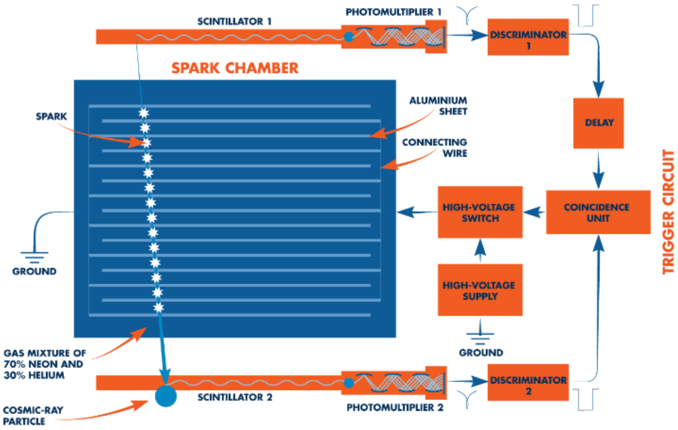

Figure 2: Schematic representation of a Spark [7]

other plate, an electric field is created that causes ionized electrons to move from the ground to the anode, and by a series of avalanche effects [8] it originates a highly conductive plasma in the path of the particle that creates a spark (Figure 2).

2.2. Emulsion films

An emulsion film is a photographic film that can detect a three-dimensional track of a cosmic ray particle consisting of an emulsion gel with distributed silver bromide (AgBr) crystals above and below a plastic base. When a charged particle passes through them, a chemical reaction with the AgBr crystals occurs that results silver particles that follows the track and can be visualized using an optical microscope. [5]

2.3. Micromegas detector

A micromegas detector is a Micro-Pattern Gaseous structure that consists of parallel two-layer plates in a box filled with a combination of nonflammable gases [5]. Each layer has a micro-mesh in between, which helps achieve a high gain. This kind of detector has the same working principle as the spark chamber with gas ionization [9].

	Nuclear emulsion *Nagoya University*	**Hodoscopes** *KEK*	**Gas detectors** *CEA*
Angular Resolution	2-14 mrad	7-10 mrad	0.8 - 4 mrad
Angular Acceptance	45 degrees	34 - 45 degrees	45 degrees
Active area	30 cm x 25 cm / unit:	1.2 m x 1.2 m	50 cm x 50 cm
(for this analysis)	0.75 m x 0.6 m (NE1)		
	0.9 m x 0.5 m (NE2)		
Position Resolution	1 µm	10 mm	400 µm
Height	0.2 mm	1-1.5 m	60 cm
Power requirement	No	Yes (300W)	Yes (35W)
Data taking	Need development	Real time	Real time

Table 1: Comparison of the three muon detection technologies. From the "Scan Pyramids" mission [5].

2.4. Detectors performance

Each detector has some advantages and disadvantages, in Table 1 we see the comparisons of the muon technologies used by the "ScanPyramids" mission.

2.4.1. Angular and Spatial resolution

Angular resolution determines how capable a detector can differentiate different tracks. The angle (in radians) is the estimated distance between two different traces. However, spatial resolution is the capability to locate the impacts of the particles in the detector.

2.4.2. Angular acceptance

The acceptance angle refers to the maximum angle at which the apparatus can detect incoming particles. For the telescope, angular acceptance is determined by the distance between the plates or scintillator counters. The more separated the plates, the better the angular resolution and the lower the angular acceptance.

3. Classical methods carried on at the Pyramids of Giza

Investigators in the 19th century had a lot of curiosity about what was hidden in the Pyramids; as they were closed, some excavations were needed to get inside. Their first intention was to discover mummies that could lead to valuable objects [1], and then they began to excavate more to understand the pyramids' internal design.

Colonel Richard Howard-Vsye (1837) [1] wanted to discover new spaces and the design of pyramids, he and his team used invasive methods to penetrate stones. Using chisels and gunpowder (an explosive chemical), they cut and broke them and mostly stumbled on spaces filled with sand or stones used for filling. In Figure 3, we see an example of R. Howard-Vsye's work on the King's Chamber forcing a passage until the higher cavity.

A robot (2002) [2] was sent to one of the air-channels of the Great Pyramid to probe in a door-like stone and ended up encountering a small space before another stone.

Another method used to detect hidden cavities is Microgravity measurement (usually applied in dams and power

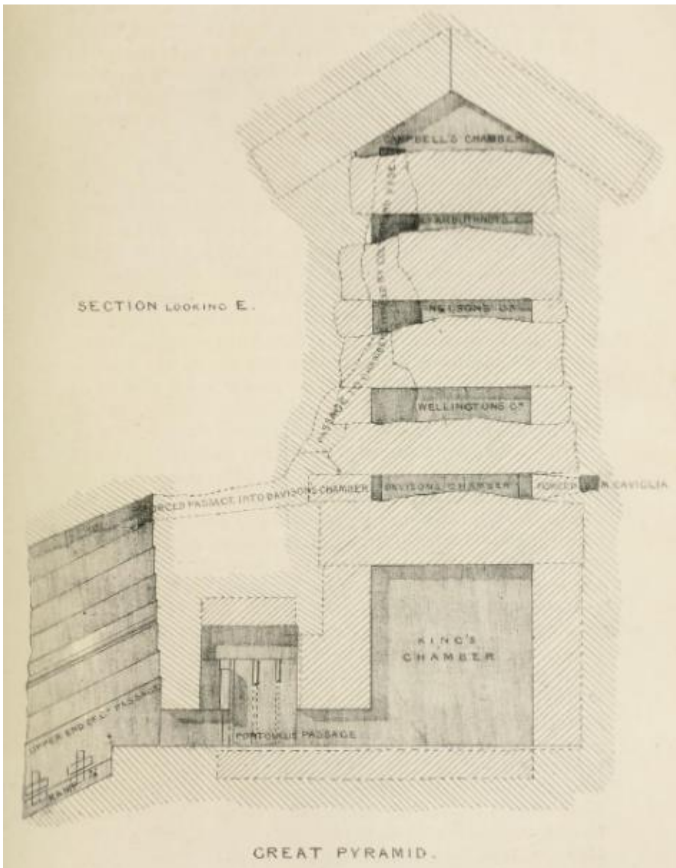

Figure 3: A sketch of the King's Chamber of the Great Pyramid. The forced passage done by R. Howard-Vyse is shown. (Public Domain)

plants) [3], which estimates difference in gravity that could indicate the existence of variations in density. After the method concluded that a cavity could exist, the team penetrated through stones and encountered a sand-filled space.

4. Conceptual design

By adapting the hodoscope scintillator-based and Micromegas-based telescope used to scan the Great Pyramid, we designed a scintillator-based telescope that can be used both outside and inside the pyramids.

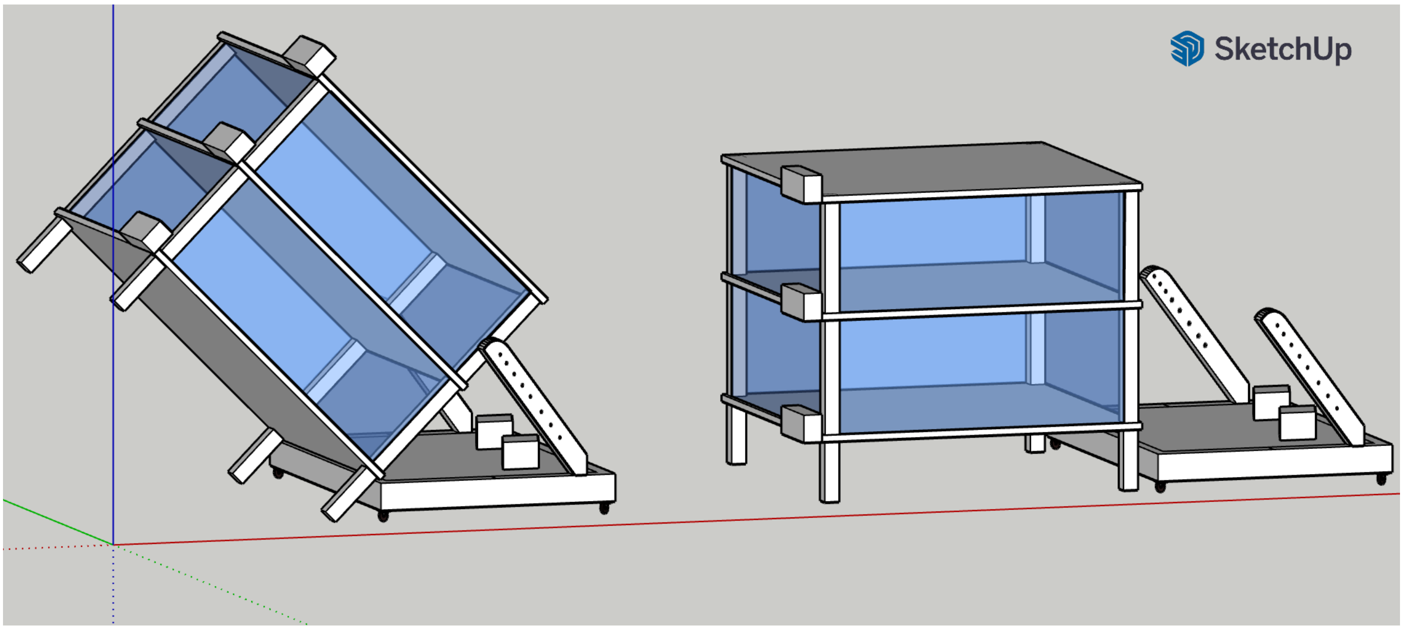

Figure 2: The proposal design of a Scintillator-based Telescope. Its inclination above the horizon is variable (left). The Telescope can also be used vertically (right). Designed with SketchUp Online [13].

4.1. Scintillators

Scintillators (see Section 2) are the main components of our telescope. We used three units of scintillators layers separated by the distance of 0.5m and the active area is 1.8x1.8m.

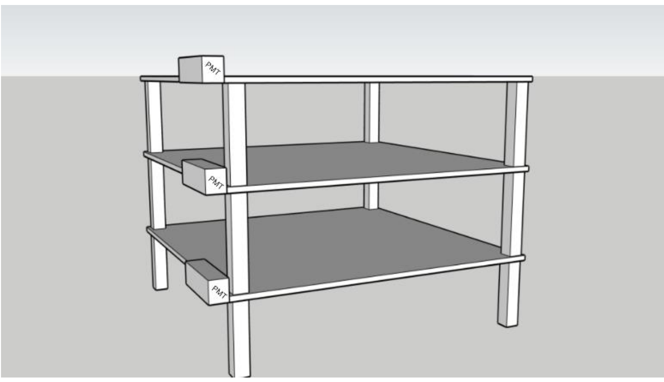

Figure 5: Three units of scintillators each with an active area of 3.24m2 and vertically separated by 0.5m. Designed with SketchUp online [13].

4.2. Electrical components

The electronic components are in a DAQ box (Data Acquisition) that contains an amplifier for the signals received from the PMTs once they received coincidence, and a signal converter and send them to a computer.

4.3. Support structure

Following the WatTo telescope design [9], a support structure that enable the telescope to be easily moved and its inclination above the horizon can be changed. This support base is also designed to carry on the electronic components, like the DAQ box.

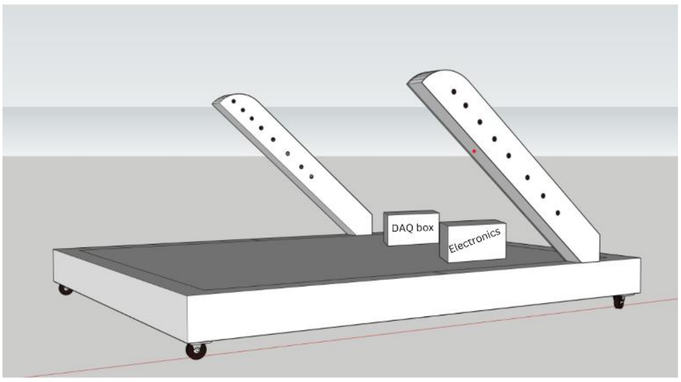

Figure 6: The support base of the telescope that can be easily moved, and inclination can also be changed. It contains the electronic components. Designed with SketchUp online [13].

4.3 Performance and cost

Our designed muon detector can be used to scan any large structures, such as Pyramids, for discovering unknown voids inside without having to destroy them. Our scintillator-based telescope is intended to be used both inside and outside the structures, as it can be easily moved and inclined from different angles by the structural design of its base.

Low-cost scintillators cost approximately 35-50 € and could cost even higher for their quality, while PMTs could cost more than a thousand euros (based on the PMTs and scintillators mentioned in [10]), and the other components, support base and electronic components, are also expensive.

5. Discussions and Conclusions

We have studied the different techniques, invasive and non-invasive, that have been used to better understand the structure of the Pyramids of Giza. We also proposed a telescope design by adapting the detectors mentioned in the previous sections.

The different techniques with muon detection technologies mentioned in Section 2 were found to be efficient by finding unknown spaces inside structures with highly expensive materials. The methods mentioned in Section 3, from the classical perspective, could have led to new discoveries, however, these techniques caused damages to the structures, and, in most cases, it led to dangerous situations for the workers employed.

The advantages of Muon Tomography are, first, its non-destructive way of probing the inner structures. Second, it can be used as an indicator of voids before archaeological methods are applied. Finally, applying Muon Tomography prevents accidents. Nonetheless, we cannot say that the archaeological method is not useful for new discoveries in structures-like pyramids, but its combination with the modern way is the best option.

Finally, returning to our initial question of whether doing Muography is cheaper and more reliable than the classical way. We can conclude that muon detectors are expensive, but their high efficiency for the detection of unknown voids has been proven and could lead to new discoveries in the future.

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