Exploring the Great Pyramid – EGP
High-Resolution Muon Tomography of the Great Pyramid

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Abstract

In 1970 L. Alvarez *et al.* reported on the first experiment to use cosmic-ray muons to investigate the interior of a very large structure. This structure was Khafre's Pyramid at Giza. The group used, for that era, state-of-the-art instrumentation from the field of high-energy physics: spark chambers. In the intervening 40+ years, the technology used for determining the trajectories of elementary particles has advanced significantly. In November of 2017, the Scan Pyramids team used modern-day instrumentation to discover a new large void in the Great Pyramid pyramid. However, the size ($\simeq$ a few m^2) of this new system was not very much bigger than the one used by Alvarez's team. In order for the technique of muon tomography to be able to answer detailed questions regarding the core structure of pyramids, a new approach must be taken. In this paper we describe an advanced concept for a high-resolution study of the internal structure of the Great Pyramid which will not only look for voids but investigate the ancient building techniques on a much more detailed scale than ever attempted before.

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1 Executive summary

It has been nearly half a century since Luiz Alvarez and his team used cosmic-ray muon tomography to look for hidden chambers in Khafre's Pyramid. Advances in instrumentation for High-Energy Physics (HEP) have now allowed the Scan Pyramids team to make important new discoveries at the Great Pyramid (Khufu), utilizing the same basic technique that the Alvarez team used, but now with modern instrumentation. Although there are other modern methodologies that can be used to "interrogate" the internal structure of Khufu, the Scan Pyramids team chose to use the same technique employed by Alvarez's team, because cosmic-ray muon tomography presents a very powerful tool that can see into the core of the structure. However, as in Alvarez's case, they set out looking for "hidden" chambers or voids.

The Exploring the Great Pyramid (EGP) mission proposes to field a muon telescope system that will be transformational with respect to the field of cosmic-ray muon tomography. Using materials and techniques developed and perfected in our laboratories, we plan to field a telescope system that has upwards of 100 times the sensitivity of the equipment that has recently been used at Khufu. This increased sensitivity will allow us to apply the technique not only to look for voids in the structure, but will permit a detailed analysis of the core fabric, the basic construction techniques used throughout the entirety of the pyramid itself. The system will be large, very large, compared to any comparable system used in archaeological or geophysical studies to date and it will have tremendously enhanced capabilities. The key elements and strengths of the EGP mission are enumerated below.

1. Significantly increased resolution to ascertain not just voids in these majestic buildings, but yield new information on subtle details of their internal structure. These data can give a comprehensive picture regarding the construction techniques used to build the pyramid.

2. The large size of the telescope system yields not only the increased resolution, but enables fast collection of the data, which minimizes the required viewing time at the site. 1-2 year mission time (for a structure the size of Khufu) is anticipated.

3. The telescope is very modular in nature. This makes it very easy to reconfigure and deploy at another site for future studies. In effect, we are building an "Observatory," which instead of being stationary (as with an optical or radio telescope) can be moved to the source. In this case, another archaeological site.

4. From a technical perspective, the system being proposed uses technology that has been fully engineered and tested in our laboratories. It draws on 20 years of experience building these types of detectors for experiments in high-energy physics and presents a very-low risk approach.

5. The first phase of the EGP mission will focus on a detailed and exhaustive computer simulation study of the capabilities of the system. The computer tools and techniques that we will use also come from the field of high-energy physics and, over the past 25 years (and 10 person-millennia of effort), have produced a software environment that has astounding precision. If the modeling, computer simulation and analysis predict that the EGP telescope system will be able to make a particular discovery, then we can state with a very-high degree of confidence, that the final system will perform in real life, just as the simulation predicts.

6. The EGP mission team, for the first time in this field, we believe, is comprised from the outset of both physicists and archaeologists. Archaeologists at the Oriental Institute, University of Chicago (who have experience in excavating 4th Dynasty structures related directly to Khufu's reign through the discoveries at Wadi el-Jarf and have the experience of excavating at the royal pyramid and related mastabas cemetery at Abu Rawash, which dates to Khufu's successor) are key members of the mission and will help to define the observational goals for the telescope.

The Exploring the Great Pyramid mission will, for the first time, offer the opportunity to make a detailed study of the entire interior of the Great Pyramid. The resolution that these large muon telescopes offer is ground-breaking and, if successful, will allow future scans to be done on other pyramids constructed both before and after the Great Pyramid. This will allow Egyptologists and Archaeologists to assemble a more complete history regarding the architectural techniques used to construct these large structures.

2 Introduction

The recent discovery by the Scan Pyramids team [1] has vividly demonstrated the efficacy of using muon-tomography to explore the interiors of very large structures. It has been over 40 years since the Alvarez team [2] used cosmic-ray muon tomography to look for hidden chambers in Khafre's Pyramid. Although advances in detector technology for high-energy physics (HEP) have been extraordinary over the past 40 years, the similarity in the approach that the two teams used is that in both cases, the active area of their systems was limited to a few m^2. We propose to use a special type of plastic-scintillator technology that was developed and perfected at Fermi National Accelerator Laboratory (Fermilab). [Note: one of the detectors used by the Scan Pyramids team used a small amount of this type of plastic scintillator material, which was supplied by (Fermilab).] This technology offers the possibility of fielding a system that has upwards of 100 times the sensitivity of the equipment used by the Scan Pyramids team. Muon tomography is basically sensitive to one thing – differences in density within the structure being studied. Both the Scan Pyramids team and the Alvarez team were looking for voids (air pockets) within their respective structures. The ratio of the density of air to that of cut stone is $\simeq$ 1:2000. The goal of the Exploring the Great Pyramid mission is to reach a sensitivity level 1:1.3, basically be able to distinguish between cut stone and the pyramid's core masonry. This can only be done by accumulating roughly 100 times more data than the Scan Pyramids project has done for the current Khufu study (with roughly a 2 year viewing time). Putting much larger muon telescopes in the field is the only way to accomplish this in an acceptable amount of time.

3 Motivation for a high-resolution tomographic investigation of Khufu

Although Egypt's two largest pyramids, the Great Pyramid of Khufu and the second Giza pyramid of Khafre, look much the same, the internal structure of these two pyramids differ remarkably. The known internal spaces of the Great Pyramid are far more complex, most notably demonstrated by its spectacular Grand Gallery, an 8-meter high passageway with corbelled masonry walls. The Grand Gallery rises to meet the granite-lined King's Chamber at one-third the height of the pyramid. Complex, above ground internal structure is also evident in the superstructures of the two colossal pyramids of Sneferu, Khufu's predecessor and probably his father. These are the Bent Pyramid and the North Pyramid at Dahshur. However, in none of the pyramids that followed the Great Pyramid have passages or chambers been found built within the pyramid body high above grade. Why is this? And what might still be missing in our understanding of this structure? This mission will attempt to answer theses two fundamental questions by taking the technology to the next logical step beyond what has been accomplished to date. Instead of just looking for chambers (voids) in the structure, we can begin a study of the very fabric of the core of the Great Pyramid itself.

What we know of the structure of the Great Pyramid today is mostly limited to what we can see with our eyes or can be detected with a camera or other optical instruments, such as laser scanners. Behind the casing stones (now mostly gone) and the very-large backing stones (what we see today) is the core of the pyramid, which makes up most of the volume of the structure and is mostly of unknown structure. It is possible that the core is also made of large stones, as in the backing layer, that are arranged in continuous horizontal layers across the breadth of each level. It is also possible that the core is similar to the core of the Step Pyramid at Saqqara, which we can observe. It consists of "accretion layers", an onion-skin like arrangement with stones inclined inward (around 72-74 degrees from vertical), rising in sets of two to various heights to make steps. However, the irregularity of the fill observed in probes made by early explorers in the Khufu Pyramid offer little support for either hypothesis. Still another possibility is that the builders created the pyramid core with a few massive steps or tiers composed of mastaba-like chunks. The Egyptians constructed mastaba tombs by surrounding a core of debris or loose masonry with a massive stone retaining wall and then added an outer casing of finer masonry. More complex internal structures of this type have been observed elsewhere in Eygpt. At Abu Rawash, the core of debris and loose masonry was further stabilized through smaller internal intersecting cross walls in addition to massive backing and casing stones. The Great Pyramid's core might consist of these structures built one against another in a Lego-like fashion, thus forming great stepped tiers.

With the above as context, a minimum requirement of the EGP mission is that it must be able to measure with high precision the mean density and density variations within the bulk of the pyramid's core. The expected scale of these variations is small, 30% (less dense), compared to the density of cut stone. As mentioned above, to detect a void (a density 1/2000th that of stone) is much easier. High-resolution tomographic data would reveal much about the detailed makeup of the pyramid's core and would thus allow us to distinguish between the construction techniques enumerated above. With the expected improvement in resolution, we expect that the EGP mission will be able to detect traces of accretions, mastaba chunks and tiers, continuous horizontal coursing, or debris filled retaining walls and potentially distinguish between them. In addition, the method used to raise stones to the higher parts of the pyramid might have left detectable structural discontinuities. A number of theories regarding the nature of the ramps used to raise the stones have been proposed in recent years and these theories should be eminently testable through the use of the high-resolution muon tomography in the EGP mission.

4 Muon telescopes

The fundamental philosophy of the EGP mission is to follow the concepts that were first developed for geophysical studies [3] (plastic scintillator arrays), but make them much larger and assemble them in oversea inter-modal containers (see Figure 1), in order to make the telescope systems very robust and easily portable. The basic unit is 40' long, by 8' wide, by 9.5' tall. We propose that

Figure 1: Inter-modal cargo container

the containers be outfitted with two scintillator banks that are constructed from horizontal and vertical modules (see Figure 2), which will provide the two views (X-Y) of each bank. Matching a hit in a horizontal module with one in a vertical module produces a unique point in the bank. Connecting two points, one in the right bank and one in left bank, defines the trajectory of the cosmic-ray muon. Collecting muons of muon trajectories in this way allows us to build the tomograph. Figure 3 shows a 1m × 1m scintillator module constructed in our laboratory. Details regarding the scintillator strips themselves are given in Section 4.1 and details on the telescope design are given in Section 5.1.

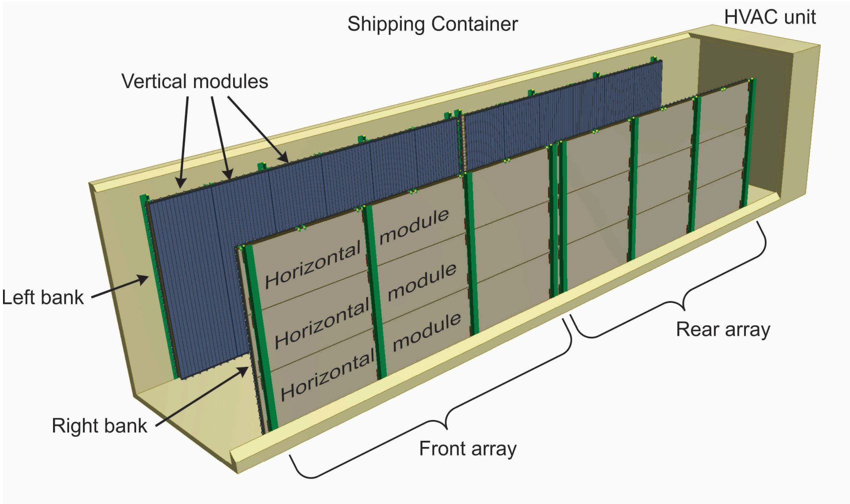

Figure 2: Shipping container with side and top removed showing the detector layout.

Figure 3: Representative X-Y detector plane

Phase I of the EGP mission will consist only of computer modeling and simulation. In the model, the telescopes will consist of two detectors of size 80' long and 19' tall that are located on the surface next to the pyramid. Our simulation will place two such detectors at 90° to each other (along two adjacent faces of the pyramid). The simulation will be used to optimize the basic scintillator strip design (see Section 4.1), module (H&V) design and the electronics. The simulation will also be able to tell us how long a viewing time is required to reach the full resolution capacity of the system. We estimate that a full survey of the pyramid would consist of 3 viewing intervals of $\simeq 6$ months each. Each telescope would be moved $1/3$ the distance along the base of the pyramid after 6 months and then again after 12 months to the far corner of the pyramid base on each face. This will allow detection of muons traversing the structure over all possible angles.

4.1 Scintillator

Plastic scintillation detectors have been used in nuclear and high-energy physics for many decades [4]. They are based on the light-emitting capability demonstrated by certain plastic materials when they are exposed to ionizing radiation. They exhibit good light yield, fast response time, ease of manufacture and great versatility. During the late 1980s and early 1990s, wavelength-shifting (WLS) fiber became commercially available and was utilized in numerous scintillation detector applications. The concept of WLS fiber readout of scintillator is illustrated in Figure 4 [5]. Light produced in the scintillator by ionizing radiation (in the case of the EGP mission, cosmic-ray muons) is absorbed by the WLS fiber. The fiber then re-emits light isotropically where after approximately 5% of this light is captured within the fiber and piped to a photo-detector. This concept allows a relatively small photo-detector to read out a large active area. This is the basic detector element that makes up the horizontal and vertical modules described above.

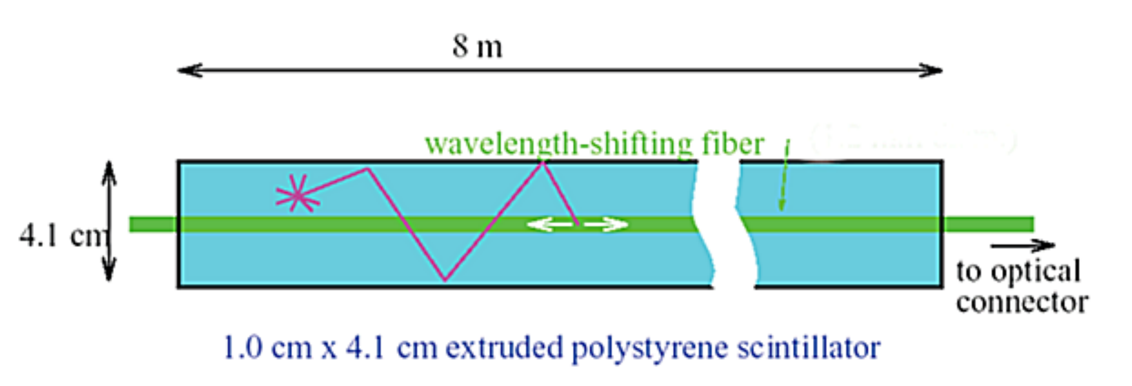

Figure 4: Concept of WLS fiber readout of plastic scintillator

Extruded plastic scintillators have found wide-spread use in recent years, as the need for building large plastic scintillation detectors for high-energy physics detector applications has arisen [6, 7]. The largest system ever constructed was for the MINOS [7] experiment at Fermilab, where 32,000 m^2 of scintillator was produced, which utilized the detector element shown in Figure 4. The scintillator facility at Fermilab [8] has prepared extruded scintillator for many neutrino experiments that required large plastic scintillation detectors. This facility has been in operation since 2003 at Fermilab.

5 Details of the telescope design

The muon detection system that we will describe in this section has been fully engineered for the upcoming μ2e experiment to be performed at Fermilab [9]. Pre-production prototypes have been fully tested and meet all performance specifications. Production of these parts is starting now.

The overarching performance requirement for this detector system was its efficiency to detect a cosmic-ray muon, where the specification was an efficiency of greater than **99.99%**. This is a very-high benchmark and most systems like it used in high-energy physics experiments did not have this requirement. This level of performance is much greater than that needed in the EGP mission. However, a by-product of this requirement is that the resolution on the amount of energy each muon deposits in the telescope's detector elements is very high also (this is related to the amount of light produced in the scintillator) and is completely correlated with the detection efficiency requirement (more light – better detection efficiency – better resolution on energy loss by muons). In section 5.2 below, we will detail how we can use the muon energy loss in the detector elements to possibly improve the tomographic imaging of the Great Pyramid.

5.1 The Detector System

In this section we describe a provisional detector; details are to be determined after simulation studies have been completed, as mentioned above. [Note: However,] The detector is designed to be modular, simple to transport, easy to fabricate, easy to operate and robust. It fits into widely-available, standard inter-modal shipping containers. Given the environmental rigors of operating in the desert, we are designing with the intent of using insulated, temperature-controlled containers. The technology we have chosen is the use of long extruded scintillator strips with embedded wavelength shifting (WLS) fibers, read out by silicon photomultipliers (SiPMs) [10]. Similar detectors are being used in several major particle physics experiments at high-energy physics laboratories throughout the world. An inexpensive readout system using all commercial off-the-shift parts, designed for a particle physics experiment, will be used.

The fundamental detector element is a polystyrene scintillator counter, and co-extruded with a 0.25-mm thick titanium dioxide coating, used to reflect light towards the WLS fiber. The optimal size of the counter is to be determined by simulation studies. For now, we will assume that each counter is 50 mm wide by 20 mm thick. Nominal lengths are 2.400 m (4.800 m) for the vertical (horizontal) counters. Two channels in each extrucsion contain wavelength-shifting fibers which capture light from the scintillator and re-emit it, a fraction of which is channeled by internal reflection to SiPMs at either end. Excellent light yields have been obtained in test-beam studies with this configuration. Two extrusions are glued side-by-side to make a to make what we have

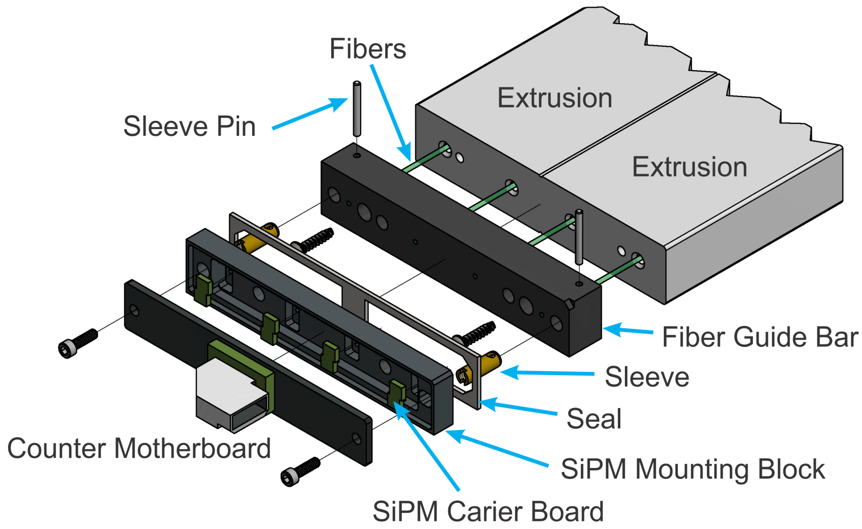

Figure 5: Exploded view of the readout manifold placed on both ends of a dicounter.

termed a “dicounter.” A fiber guide bar, made of acetal, is glued to each dicounter end after the wavelength-shifting fibers have been inserted and then flycut. The readout manifold, which holds the SiPMs, is attached by screws to the fiber guide bar as shown in Fig. 5. It consists of an anodized aluminum lower piece called the SiPM mounting block, four SiPMs on their carrier boards, and a small electronics board, called the counter motherboard, which also serves as the cover of the readout manifold. The design can accommodate fibers of different diameters, the fiber diameter effectively being the knob that allows the light yield, and hence the efficiency, to be tuned to the desired level.

The $2{\times}2\,\mathrm{mm}^2$ SiPMs are mounted by the manufacturer on tiny carrier boards that fit into rectangular wells in the SiPM mounting block. They are gently pushed against the fiber ends by pogo-pins soldered to the counter motherboard, which provide the electrical connections to the SiPM anode and cathode. The counter motherboard also has two flasher LEDs and a temperature sensor for calibration purposes. The manifold is designed to be easily removable as it is expected that SiPM failures will require occasional counter motherboard replacement. A module consists of eight dicounters that are glued to a 12.7 mm-thick aluminum strongback to which mechanical supports are attached. A thin aluminum cover protects the counters from damage and makes them light tight. All modules are 804 mm wide and 35.9 mm thick. Modules come in two sizes: horizontal (vertical) modules are 4.800 m (2.400 m) long. The modules are mounted vertically in arrays that consist of 3 horizontal and 6 vertical modules. On each side of the shipping containers is a bank consisting of two arrays, the banks separated by 2 m, as shown in Fig. 2. In each container there are a total of 24 (12) vertical (horizontal) modules, with 384 (192) vertical (horizontal) counters. We estimate that eight containers will be needed with 192 (96) vertical (horizontal) modules, a

Table 1: Detector parameters.

Item	Number
Containers	8
Banks/container	2
Modules	288
Module size (hor/vert) (m)	4.900×0.804 / 2.400×0.804
Counters / module	16
Counters	4608
Number of readout channels	18,432
Counter length (hor/vert) (m)	4.800 / 2.400
Total length of counters (m)	14,863
Detector area (total) (m^2)	392.0

total of 3,072 (1,536) vertical (horizontal) counter, and 18,432 m of fiber. The total detector area of a single container is $49\,m^2$; all eight cover $392\,m^2$. The electronics consists of: (1) a SiPM mounted on its carrier board; (2) a counter motherboard mounted on the manifolds on both ends of the dicounters; (3) a front-end board (FEB), which reads out and digitizes signals both in time and amplitude, controls the flasher LED, runs calibrations, and provides bias voltage to the SiPMs; (4) a readout controller, which takes data from up to 24 front-end boards and sends it to the data acquisition system, provides a means of communication with the front-end boards, and powers the front-end boards; and (5) a commercial data transfer controller PCIe card which receives the data from up to eight readout controllers. A timing module provides an absolute GPS time stamp for the events. The counter motherboard communicates to the SiPM carrier boards via pogopins; the front-end board communicates to the counter motherboards via HDMI cables; the readout controller communicates to the front-end boards via CAT 6 Ethernet cables, which also power the front-end boards through the commercial Power-over-Ethernet (PoE) protocol; and the data acquisition computer communicates to the readout controllers via optical fiber. The readout has the ability to see single photoelectrons, a dynamic range of 2000, and a time resolution of 1 ns (which will allow the direction of the muons to be determined). Both counter ends will be read out, providing a longitudinal resolution from time-of-flight differences of about 200 mm. The transverse resolution is 14 mm.

A salient feature of the design is the use of commercial off-the-shelf parts; no custom integrated circuits are employed. The system was designed for the cosmic ray veto detector for the Fermilab Mu2e experiment; only minor modifications are needed to tailor it to the pyramid tomography project. The system consumes little power: the total amount needed per container is only 706 W.

Each front-end board can read out up to 16 dicounters (64 SiPMs). Hence each module needs one front-end board, or 18 for each bank, 36 for each container, and 288 for the entire system. Two readout controllers serve each container and two data transfer controllers are needed for the entire system. The zero-suppressed data rates are modest and can be handled by a simple data acquisition system.

The extrusions will be fabricated at the NICADD facility at Fermilab. The module factory set up at the University of Virginia for the Mu2e experiment has all of the needed jigs to take extrusions, wavelength shifting fibers, and readout manifolds and assemble them into working modules. Only slight modifications are needed to repurpose the jigs for the pyramid tomography detector. Module fabrication requires a modest amount of labor: a technician leader, technician assistant, and four undergraduate student helpers. Four modules can be fabricated and tested every week: the entire production will take a year-and-a-half at one facility. The assembly jigs are relatively simple to duplicate if a second or third module factory were to be used to speed up production. After fabrication and testing, the modules will be mounted in the containers and then shipped to the site.

5.2 Improving the tomographic image

When relativistic charged particles (muons, for example) pass through matter they produce ionization, atomic and collective excitations. This leads to energy loss in the medium, where the losses are usually small, but increase with increasing particle energy (velocity). The theory of energy loss was developed by Hans Bethe [11]. This theory allows one to calculate the mean energy loss as a function of the incident particle's energy (velocity or momentum). Figure 6 [12] shows the mean energy loss in MeVg $^{-1}$ cm^2 loss for a number of materials. For the data shown in this figure, carbon would be most representative of plastic scintillator. Looking at the curve for carbon, we see that the mean increases from $\sim$ 1.8 MeVg $^{-1}$ cm^2 at a muon momentum of 1 GeV/c to $\sim$ 2.4 MeVg $^{-1}$ cm^2 at 100 GeV/c, or an increase of $\simeq$ 33%. Given the light output we expect from the detector system described above, we believe that we will be able to obtain a resolution on dE/dx of 2-5%. This is quite sufficient to map out this range of muon momenta (1-100 GeV/c) and would provide information to allow us to be able to estimate the momentum of each detected muon.

The telescope measures the momentum of the muon after it has passed through the Great Pyramid, obviously. It takes a rather energetic muon to pass through the Great Pyramid, something like 50-60 GeV depending on the angle, etc. If a muon exits the pyramid with very little remaining energy, it would have scattered quite significantly on its way out and then the angle that the muon telescope determines for the muon's trajectory might have nothing to do with the angle in which the muon entered the pyramid. On the other hand, a muon that exits the pyramid with very-high energy, would have entered with even higher energy and may not be very sensitive to any variations in the material in the pyramid along the muon's trajectory. So, there might be a set of muons that are "just-right", not too soft and not too hard (in energy). For the first time in cosmic-ray muon tomography applications, the EGP mission will be able to use our muon telescopes to record information about the muon energy. A selection of a subset of the detected muons is likely to give us the most precise tomographic image of the interior. In a sense, this "tagging" of the muon energy is analogous to a focus ring on a camera lens.

The actual improvement we can attain with this added information will require detailed simulation, since Bethe's theory does not describe all energy-loss effects and the mean energy loss can be biased by a small number of very-large losses. However, the simulation framework that we will be using is very capable of taking all these effects into account.

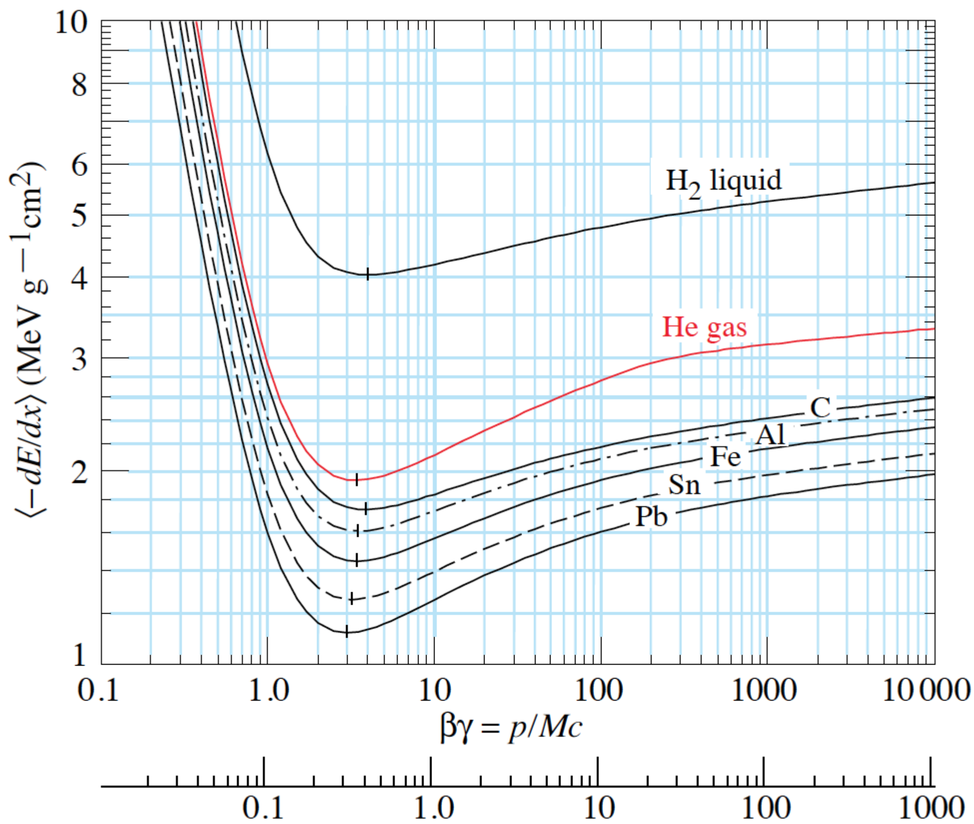

Figure 6: Mean energy loss rate for muons in liquid hydrogen, gaseous helium, carbon, aluminum, iron, tin, and lead. From [12].

6 Simulations

A comprehensive computer model of the pyramid and the detectors is being developed in order to optimize the detector parameters, study the sensitivity of the apparatus to variations in the internal structure of the pyramid, determine running time and conditions, develop reconstruction algorithms, and investigate different tomographic reconstruction strategies. We are employing a sophisticated simulation program that uses the GEANT4 toolkit [13, 14]. GEANT is almost universally used in the particle physics and nuclear communities and has growing use in space sciences and medical technology. It was designed to study the response of complex high energy physics detectors to collisions of elementary particles produced in accelerators. After 30 years of development and 1000s of person-years of effort, the GEANT4 framework is tremendously capable and astoundingly precise.

A CAD model of the pyramid and detector will be incorporated into GEANT. To model the cosmic-muon flux we use code first developed by the Daya Bay collaboration [15] and modified by the Mu2e collaboration. It uses a modified Gaisser spectrum [16].

The primary goal of the simulation is to finalize the detector parameters and to demonstrate the ability of the detector to image the interior of the pyramid. Software "phantoms" will be added to the model of the pyramid to show the size and type of structures that can be imaged.

6.1 Mu2e Cosmic Ray Background Simulation

The simulation for the EGP mission is based on that used in the Mu2e experiment to model the rate of background events produced from cosmic-ray muons and to determine the performance of the Cosmic Ray Veto detector (CRV), whose design the EGP telescopes will be modeled after. An extremely detailed, soup-to-nuts simulation was developed over a period of years. The very detailed detector response simulation has been validated against test-beam data. This simulation includes the capture and transport of the light to the photodetectors; the detailed response of the photodetectors, including effects such as cross-talk, timing jitter, afterpulsing, etc.; and the response of the front-end electronics. Figure 7 shows the light yield response to incident high-energy test-beam protons of a counter identical, in all but length, to that we expect to use for the EGP mission. The simulated response is overlayed: very good agreement is achieved demonstrating the validity of the model of the counters and their response.

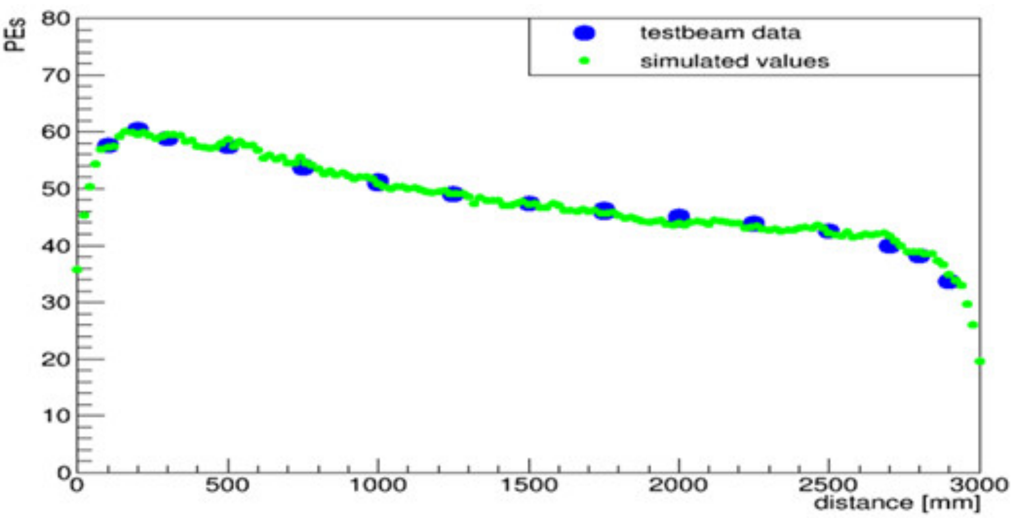

Figure 7: Response of a 3-m long counter to normally incident 120 GeV protons (blue) as well as the simulated response (green).

Four years of cosmic-ray muons were simulated for this study: 3.7 *trillion* events in what is most likely the largest number events ever simulated for any physics process. This required tens of millions of cpu hours on the Open Science Grid. A similar simulation will be done for the EGP mission, however, it will be quite a bit simpler for several reasons, and hence require far less computing resources. First, unlike the Mu2e simulation, the simulation for the Great Pyramid study will not have to model the production and propagation of secondaries from muon interactions.

Second, the Mu2e detector hall and detector is far more complicated than the Great Pyramid and the muon telescopes we plan to use on the EGP mission. And finally, the rate of muons that penetrate the Great Pyramid and make it to the detectors is much less than those impacting the Mu2e apparatus: fewer muons will have to be simulated.

7 Outlook and conclusions

The Exploring the Great Pyramid mission will, for the first time, offer the opportunity to make a detailed study of the entire interior of the Great Pyramid. The resolution that these large muon telescopes offer is ground-breaking and, if successful, will allow future scans to be done on other pyramids constructed both before and after the Great Pyramid. This will allow Egyptologists and Archaeologists to assemble a more complete history regarding the architectural techniques used to construct these large structures, put together a clear understanding on how these techniques evolved and may, in the end, provide insight into why they were built the way they were. These telescopes can be deployed to tomograph any structure that has a line-of-sight view towards the sky and can become a facility that could be used for other missions by other teams.

Phase I of the EGP mission will confirm the technical basis of our mission plan. The simulation framework that will be used is extremely sophisticated and has now been tested on numerous detector systems and fully vetted. The output of the simulation study will be extremely precise and will predict with great accuracy how the final system will perform. Phase II of the EGP mission will be to finalize the design of the telescope systems, construct the various individual telescope modules and deploy at the Giza site. This will be a very large and expensive project relative to past endeavors of this type, but the risk of the system under-performing will be very low, given the very-high degree of credibility we can place on the conclusions obtained in Phase I of the mission.

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