Exploring the Great Pyramid

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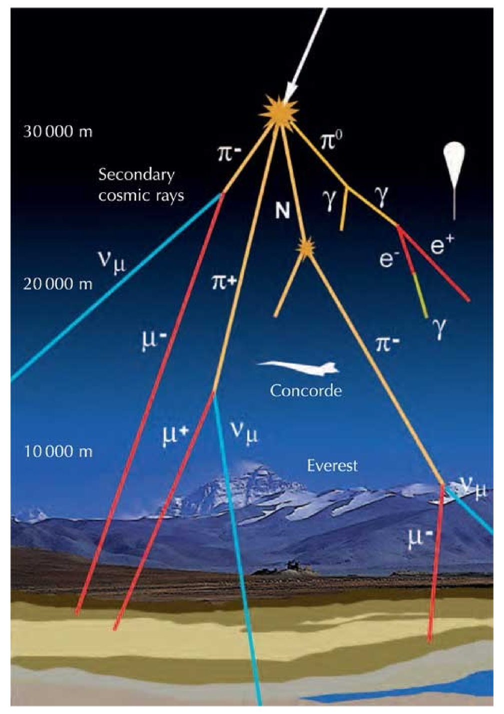
Background

For centuries, the pyramids at Giza have been the object of frequent speculation and study. L. Alvarez et. al in 1970 and the ScanPyramids collaboration in 2017 have very successfully implemented HEP detector technology to image the pyramid of Khafre and the Great Pyramid of Khufu, respectively. Numerous questions about Khufu's structure remain, however. The EGP project aims to undertake a new study of this enigmatic monument's interior by applying high-resolution tomographic imaging and reconstruction, which will permit a detailed understanding of internal variations in density and may offer insight regarding exactly how Egypt's largest pyramid was built.

Cosmic-Ray Muon Tomography

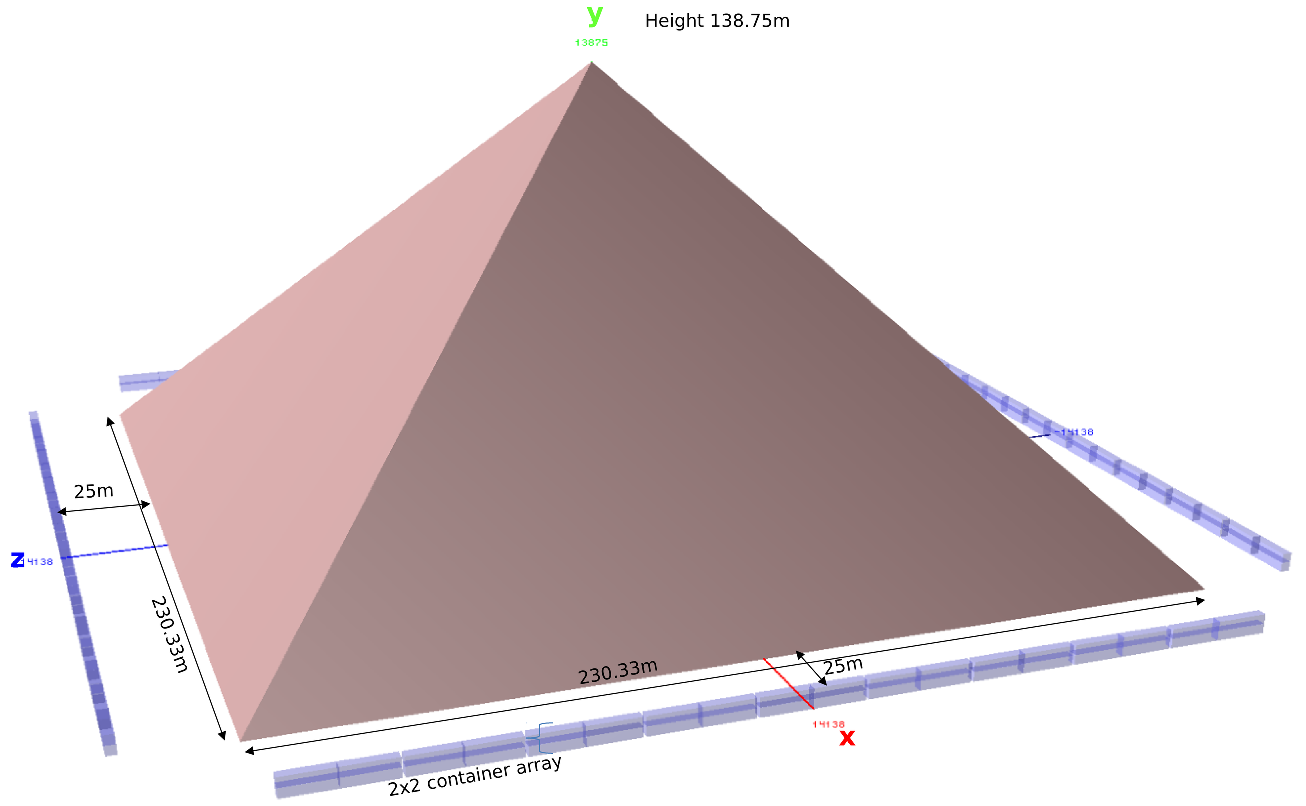
When cosmic particles such as protons interact with Earth's upper atmosphere, they produce muons; upon reaching the planet's surface, many of these muons remain energetic enough to penetrate massive edifices like the Great Pyramid. By measuring the rate at which the muons reach the other side as a function of angle, we can obtain information about the pyramid's internal structure. Repeating such measurements at several locations around the perimeter of the monument permits full 3D image reconstruction.



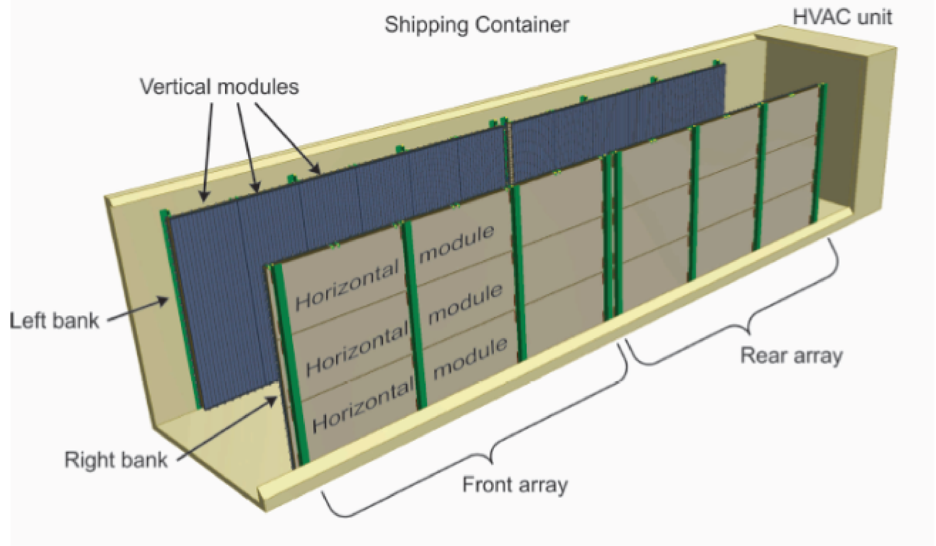
Generation of cosmic-ray muons in Earth's upper atmosphere

EGP Detector Proposal

We plan to field eight detectors, housed in 40-ft. steel shipping containers, and move these around the pyramid perimeter to observe events at a variety of angles. Each detector will consist of two planes of scintillator strips, embedded with wavelength-shifting fibers and read out by SiPMs (see below). Data collection will continue for a total of 1-2 years.

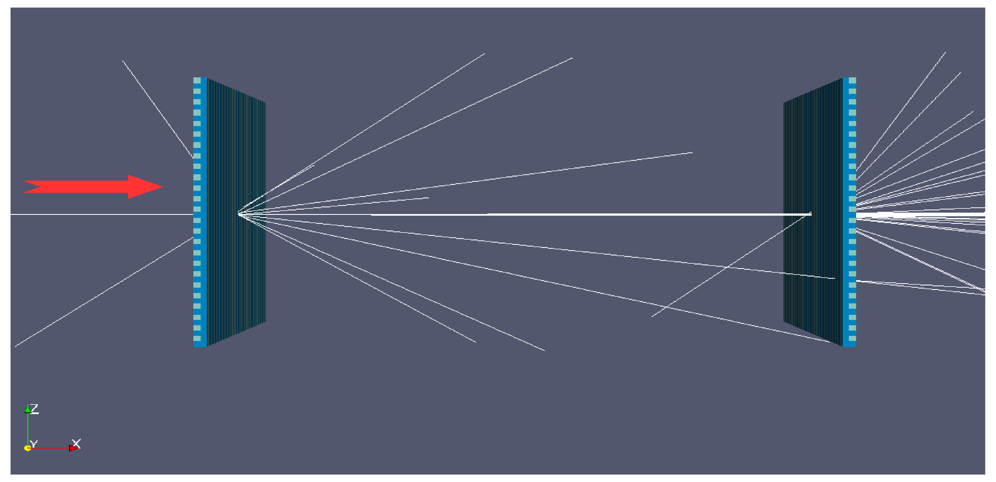


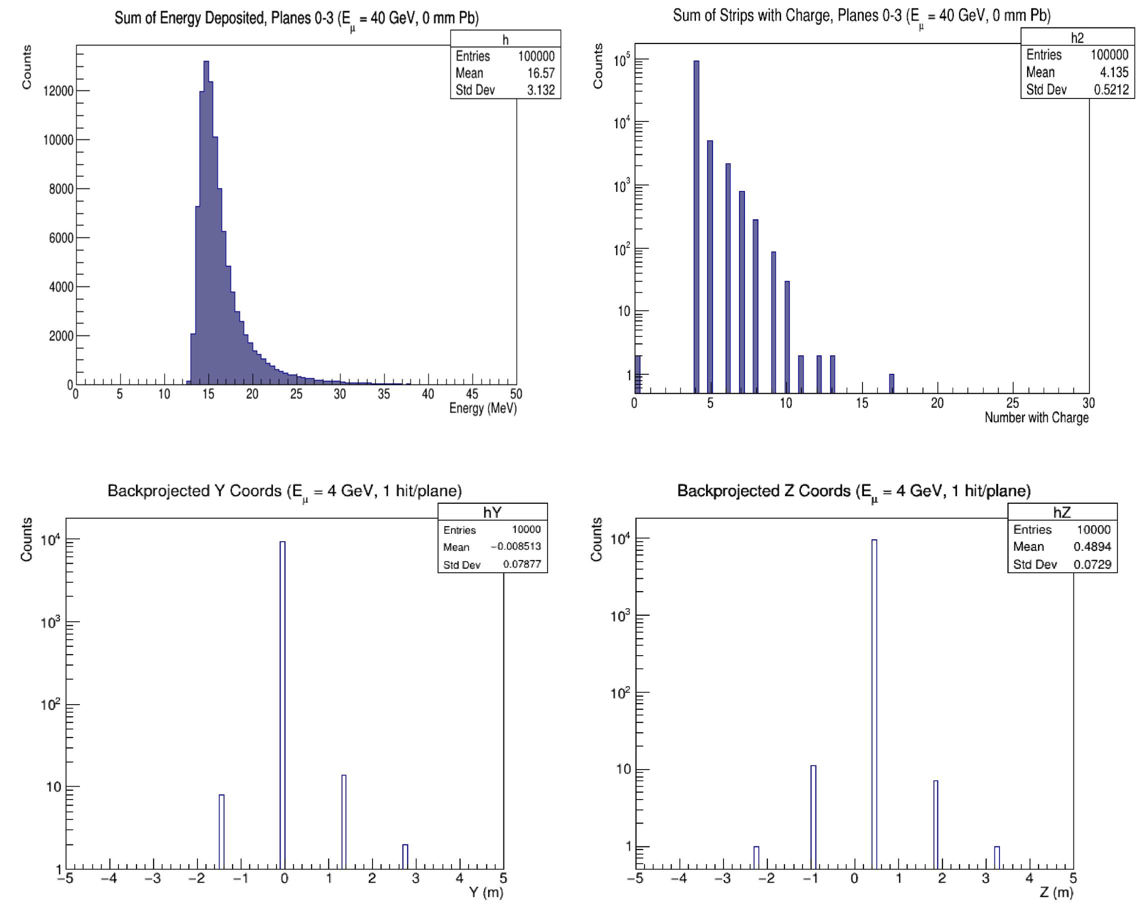
GDML image of pyramid and possible detector placements; there will only be eight containers around the pyramid at any given time.



Acknowledgments

I would like to sincerely thank my supervisor, Alan Bross, and the rest of the EGP group for their support and patience as mentors. My thanks to the SIST committee for allowing me to participate in research at Fermilab this summer.

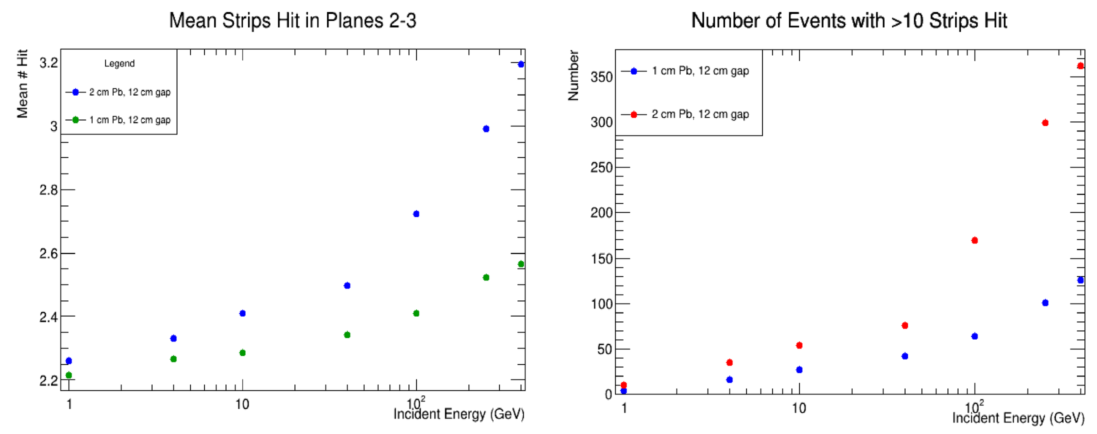


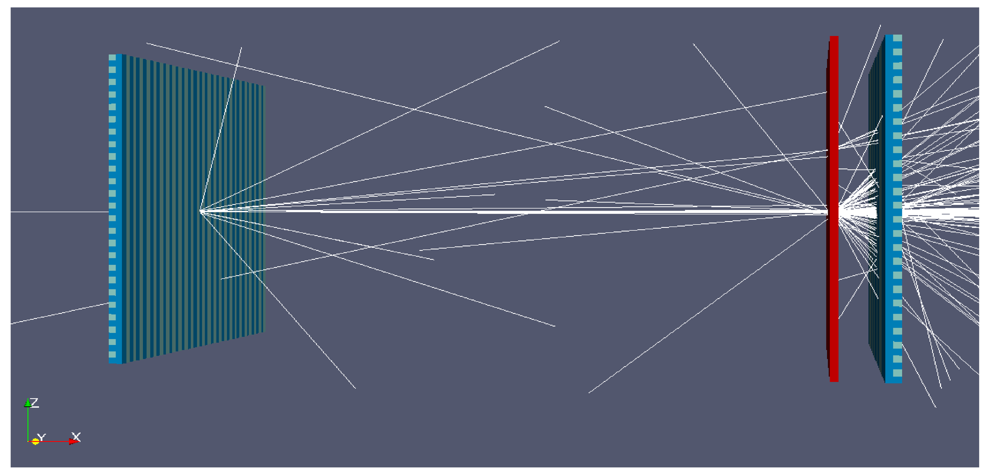


Above: each of the 2 simulated detectors consists of 2 1m x 1m scintillator planes, and each plane is composed of 50 2cm x 2cm x 1m strips. G4ParticleGun produces a single muon for each event, always with the same initial momentum and position. Right: example energy deposition summed over all 4 planes; preliminary results from position resolution algorithm (beam at normal incidence, backprojected a distance of 140 m).

Independent GEANT4 Detector Study

To help optimize detector design, we used the GEANT4 toolkit to simulate a 1m x 1m "toy model" detector placed in the path of a simple particle gun. The primary objectives of this study are to determine the necessary detector resolution in light of multiple scattering effects and to investigate the possibility of using energy deposited in the scintillator to sort muons by their incident momenta. The latter, if successful, could result in improved image reconstruction by allowing us to restrict events used to those that fall within an ideal energy range.





The modified detector design included a Pb sheet of varying thickness between the two detectors, and the placement of this sheet ranged from 12 cm – 20 cm upstream of detector 2. The goal of the addition was to increase the number of secondary particles striking detector 2 without substantially compromising position resolution. This configuration yielded a strong correlation between incident muon energy and number of scintillator strips with charge, as hoped. However, it is likely unusable, as the total increase in mean strips hit over the energy range of interest is relatively small and the fraction of muons that resulted in an increased number of hits is also quite small.

Conclusions and Future Work

Because it produces only small increases in energy deposition for increasing incident energy, inserting a Pb sheet in the space between detectors does not provide a viable means of determining muons' incident momenta. Further simulation is needed to fully answer the question of detector resolution: next steps include varying the angle of the muon beam, refining the position & angular resolution algorithms, and adding a concrete block upstream of the detector to mimic the presence of the Great Pyramid.