The Buckarray (draft)

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1 Introduction

The BuckArray is a prototype array of symbiotic radio-frequency (RF) and cosmic-ray muons and photon counters. If feasible, the prototype will be deployed in Apple Creek, Ohio, on a land managed by the OARDC branch of The Ohio State University, having a two-fold purpose: to serve as and engineering prototype for future, larger-scale arrays, and to be a educational outreach opportunity for local area people, to learn about astroparticle physics.

The prototype is planned to consist of 200-400 MHz radio antennas and smartphones, engineered to be particle detectors. This instrumentation will be sustainably powered through photo-voltaic panels, and have minimal impact on the land. The physics goal is to detect cosmic-ray extensive air showers (EAS) via the natural RF and muonic signatures at ground level.

Thus far, only analysis on the muonic signature has been done, and is still in progress.

2 Simulation

We want to test the feasibility of Buckarray. This is to be done by simulating cosmic ray showers, and estimating the number of detectable[1] particles expected to hit the array. The simulations are performed with CORSIKA.

By using the simulation program CORSIKA, we can obtain information about secondary particles in a cosmic ray shower. This information includes the type of particle, its momentum $(p_x,\ p_y,\ p_z)$ and position at a given observation level, among others described in the documentation of CORSIKA. This program also allows us to control features such as the type and energy of the primary particle, its position (i.e. altitude, polar coordinates), the Earth magnetic field, observation levels (up to 10 altitudes at which we can gather information about the secondary particles), and among others. Additionally, we will use CoREAS, a C++ code for the simulation of CORSIKA-based Radio Emission from Air Showers, which allow us to calculate the radio signal strength that would be (ideally) detected by an antenna near the region.

For our trial, we have been using protons as primary particles, with energies in the range $10^{15} - 10^{18}$ eV, with random initial position. The geomagnetic field and altitude have been modified to those of Wooster, Ohio, where Buckarray is planned to be set.

[1] With detectable, we mean muons of some energy and above

Roughly, the Buckarray design we have been using consist of an array of 143 cell-phones arranged in an approximately 50 m $\times$ 50 m rectangle, as showed in Figure 1.

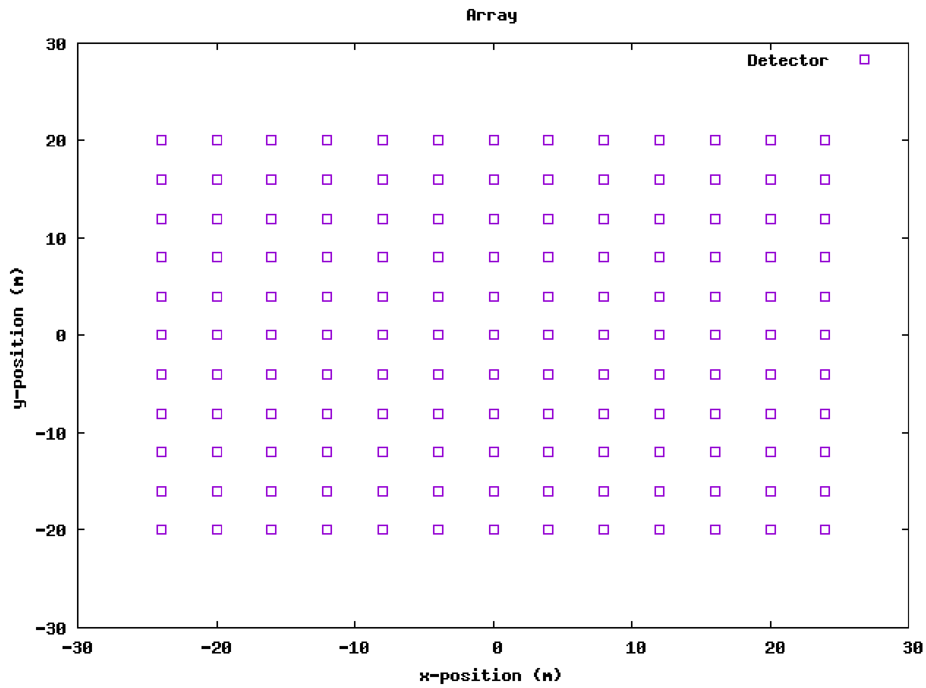

Figure 1: Array of detectors. Each square represents a cellphone (not drawn to scale).

We also tested with the geometry showed in Figure 2. However, based on what we obtained from simulations, see Figure 3, we opted for the normal array (Fig 1). **Keep?**

Our testing has mainly consisted of counting the number of electrons, positrons, muons, anti-muons, or photons that hit the camera in any of the phones, for a given camera area. Similarly, some cuts are placed in the simulation in order to account for the particle's energy loss when traveling through the cell-phone/camera glass, i.e., we calculated the minimum amount of energy needed for the particle to travel throughout the camera glass.

Our cuts are based on the energy loss calculated by using the Bethe-Bloch and Bethe-Heitler formulas for electrons and positrons (See Figure 4). By using our codes, we estimated that, for a primary proton of 10^{15} eV and a camera thickness of 2 mm, approximately 5.5×10^3 electrons survive the 1 MeV cut at ground level. **Unanswered: What height do protons interact, energy threshold of camera (depends on kind of particle?)**

3 Results

3.1 Energy vs. Signal Strength

We simulated an antenna centered at the core of the shower, for different primary particle (proton) energies. The results are showed in Figure 5. Also, a plot of time vs. signal strength for some energies

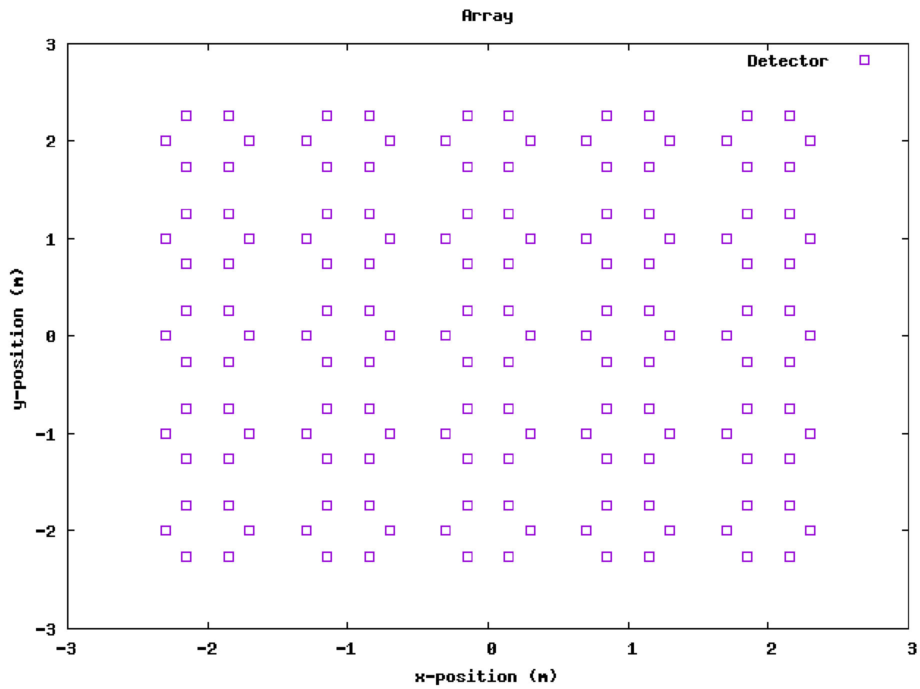

Figure 2: Hexagonal array of detectors. Each square represents a cellphone (not drawn to scale).

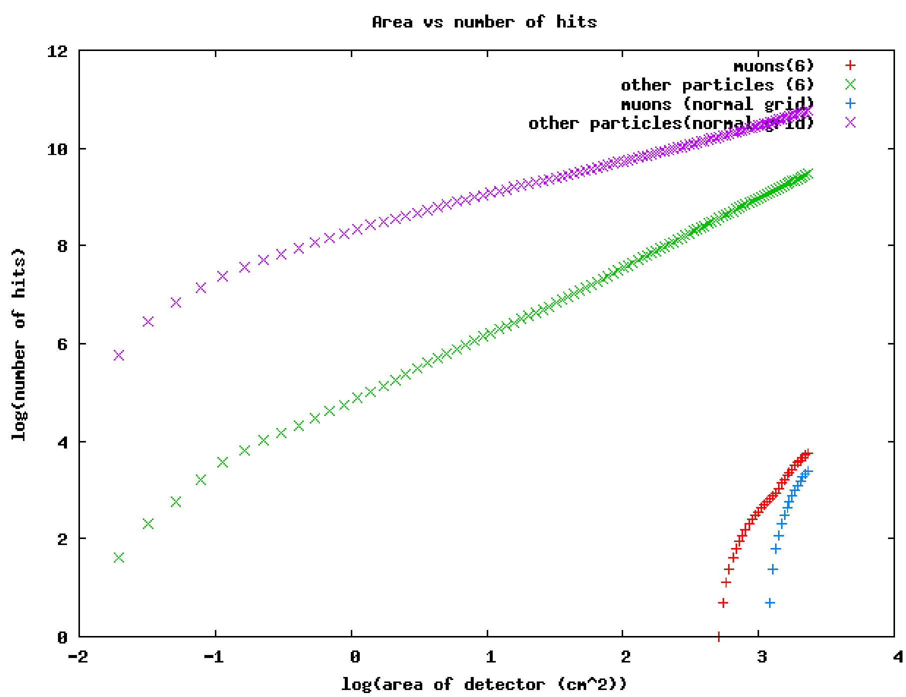

Figure 3: "area of detector" refers to the area of a single cell phone camera. In the plot legend, "(6)" refers to the hexagonal grid (Fig. 2).The energy of the primary particle was 10^17 eV.

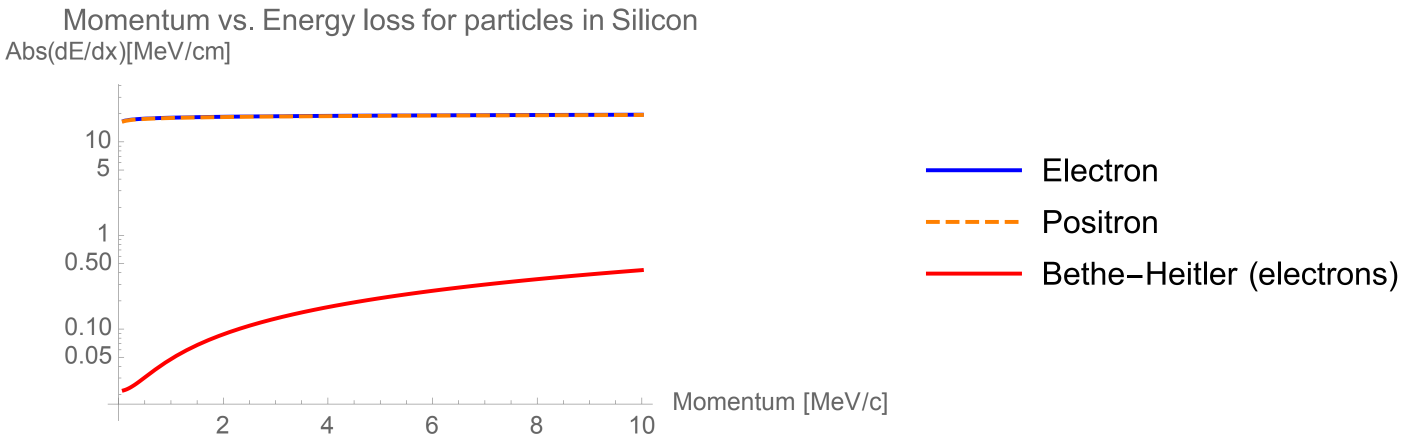

Figure 4: Momentum vs. Energy loss for particles in Silicon

is showed in Figure 6.

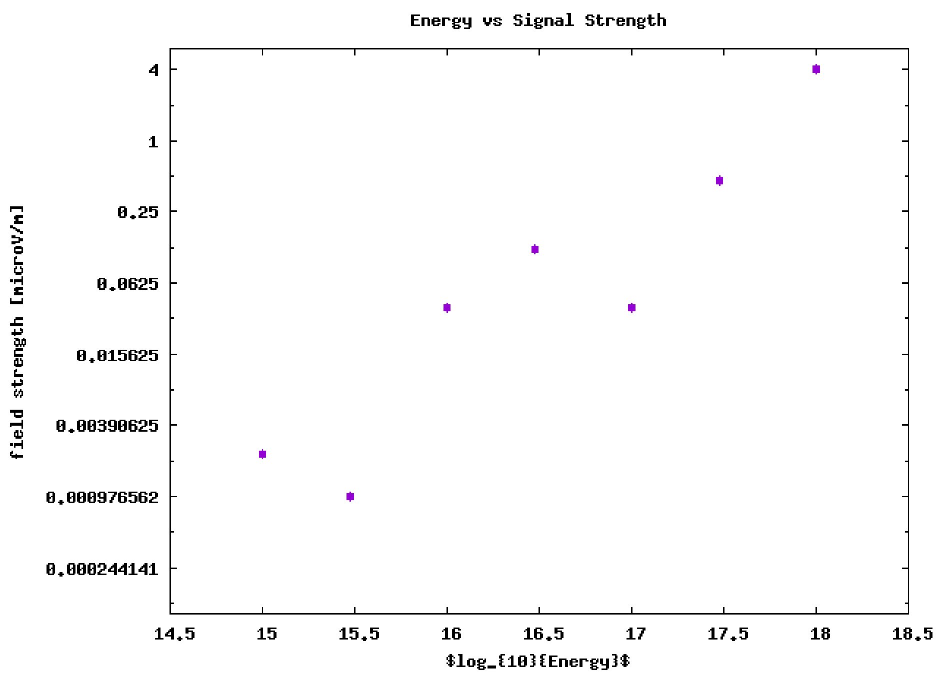

Figure 5: The simulation was performed for one event, so it may be not statistically significant

3.2 Scattering plot of some secondary particles

We were keeping track of particles that could possibly be detected with CRAYFIS, such as electrons, positrons, muons, antimuons, and photons (above certain energy). Plots showing the position of secondary particles at ground level (primary particle of 10^{17} eV) are shown in Figures 7, 8, 9

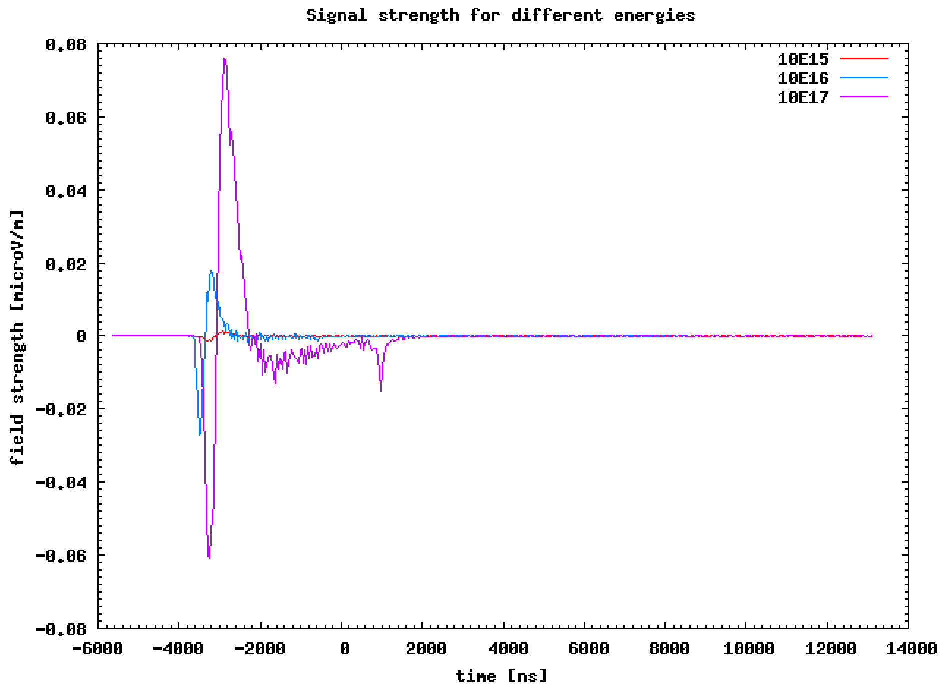

Figure 6: The simulation was performed for one event, so it may be not statistically significant

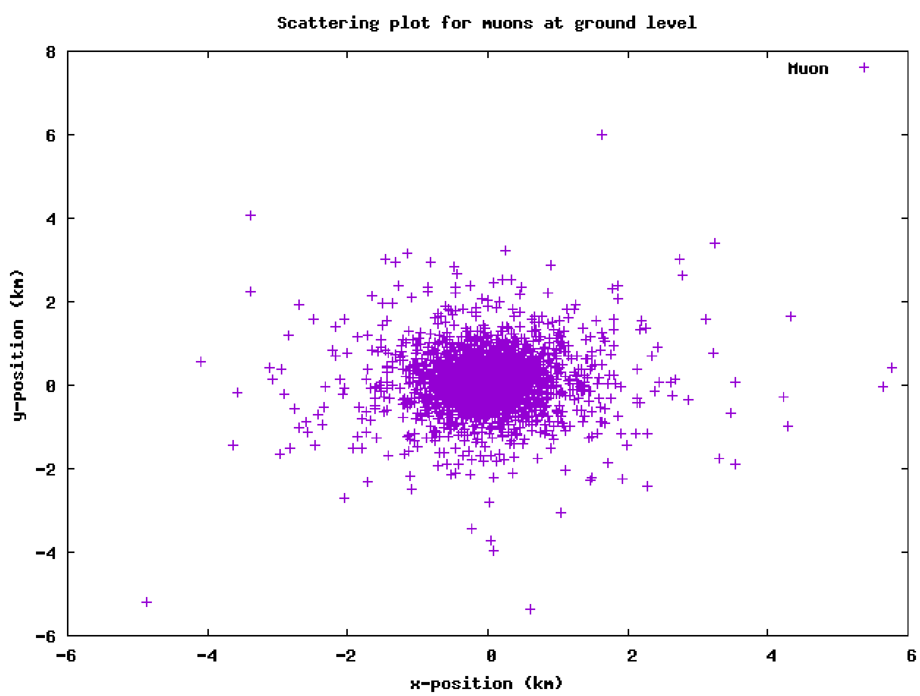

Figure 7:

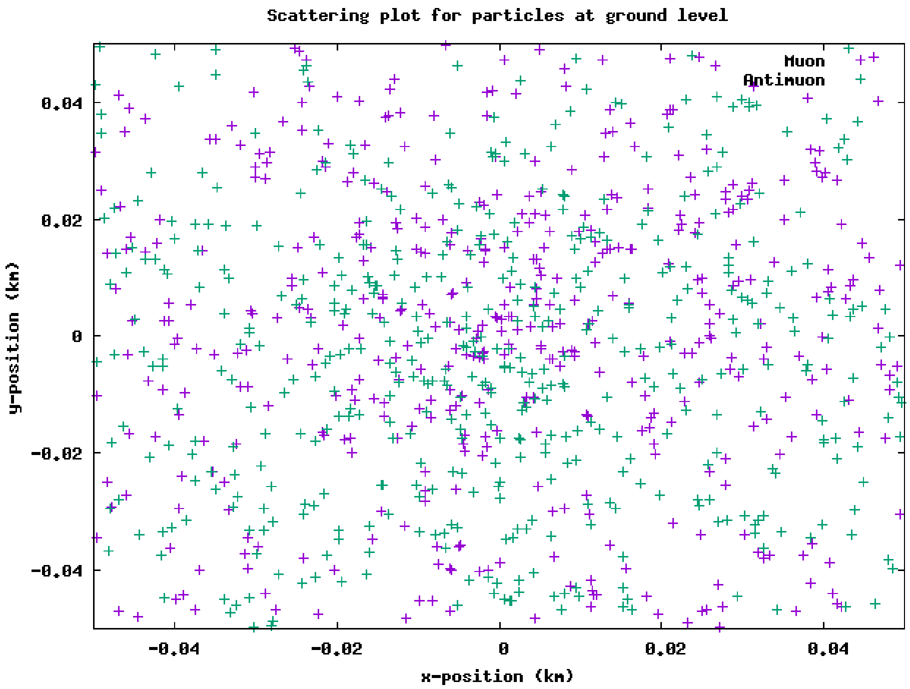

Figure 8:

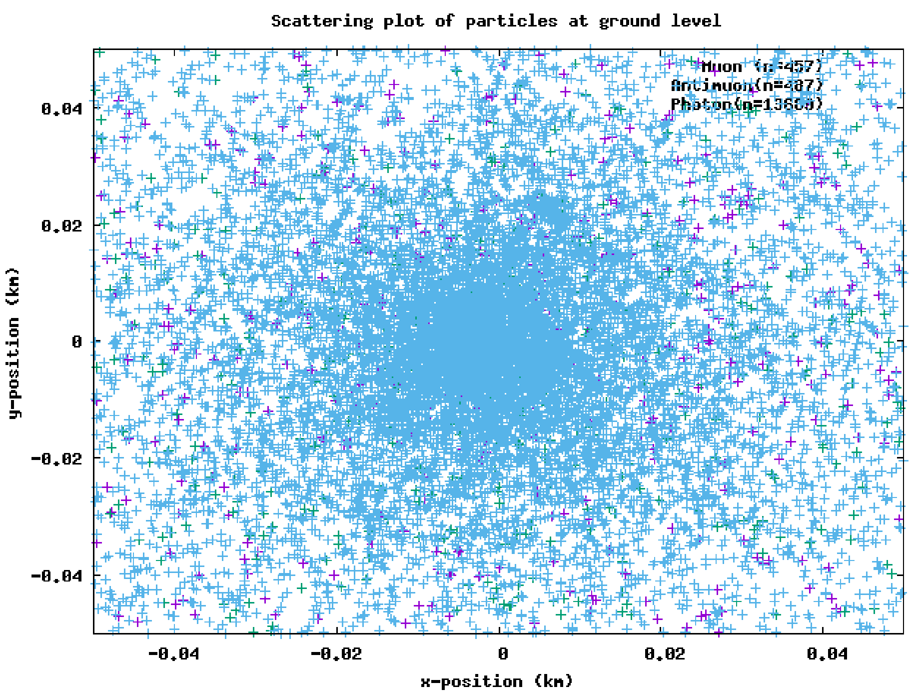

Figure 9:

3.3 Momentum Spectra of Secondary Particles

We are interested in the energies of the secondary particles, as they will experience energy loss while traveling through the camera glass. This serves to estimate how many particles will survive after crossing the glass, and to make some cuts that speed up the simulations.

We show the energy spectra for different secondary particles from a 10^{16} eV primary proton in Figures 10, 11, 12, 13.

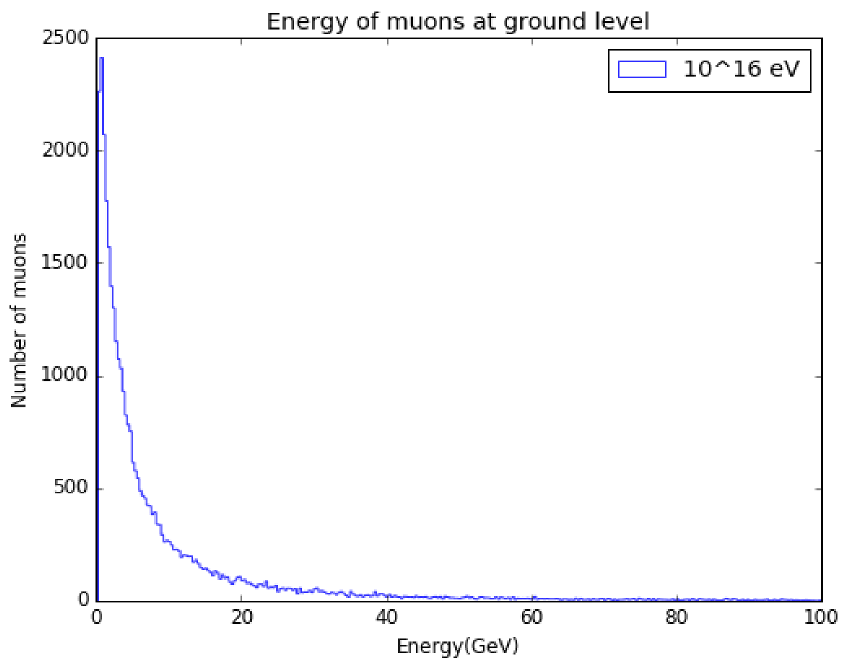

Figure 10:

As described above, CORSIKA can collect information about secondary particles at given observation levels. The following figures show the momentum spectra for electrons and photons observed at 3400 meters above sea level (MASL), from a 10^{16} eV primary particle.

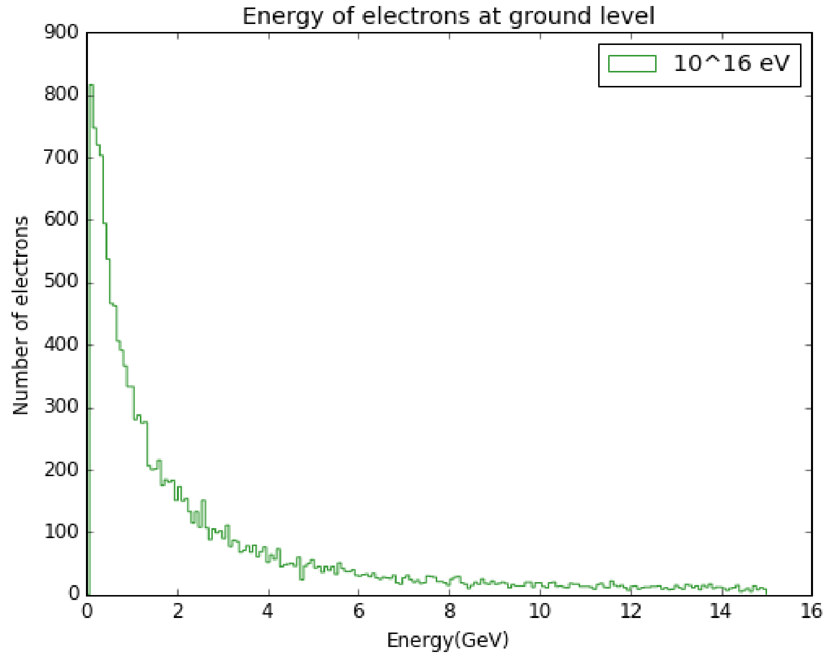

Figure 11:

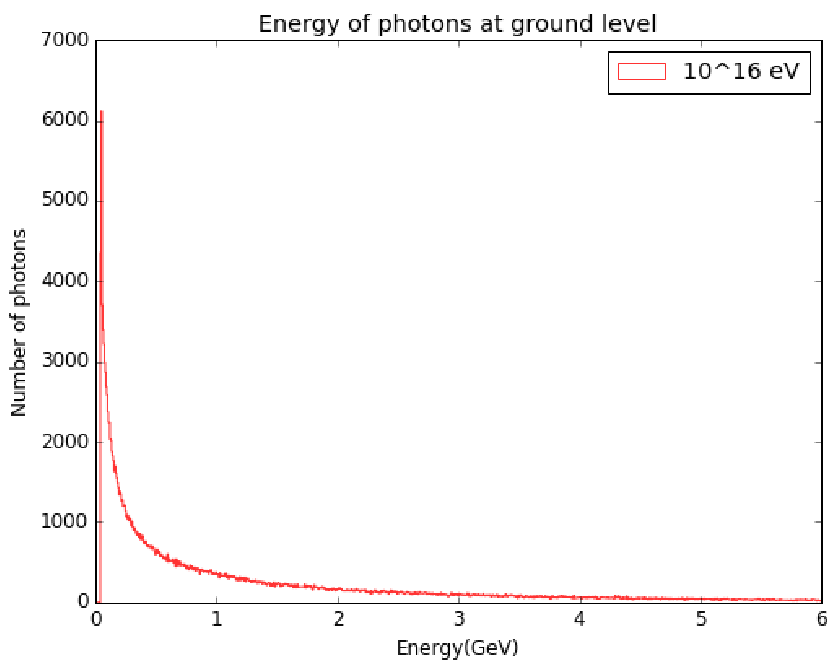

Figure 12:

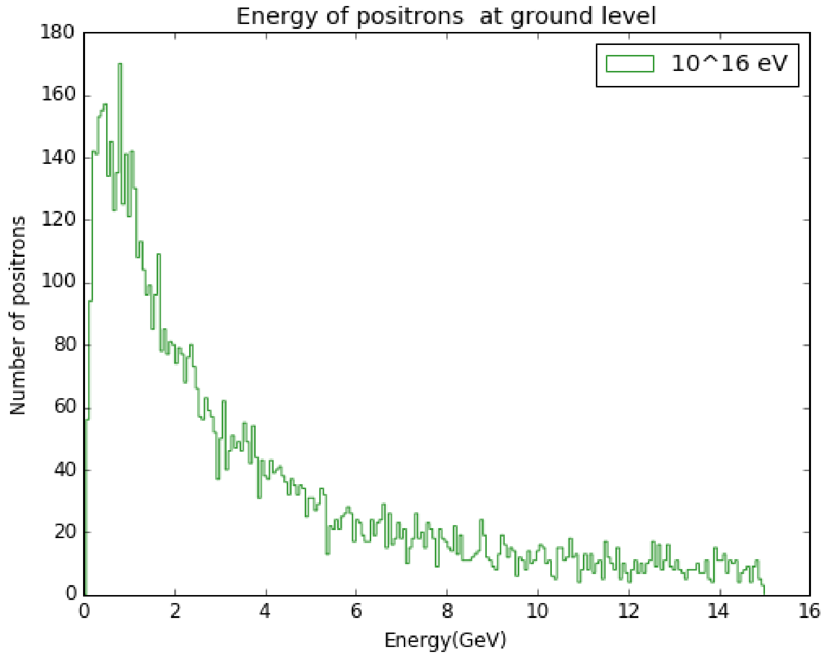

Figure 13:

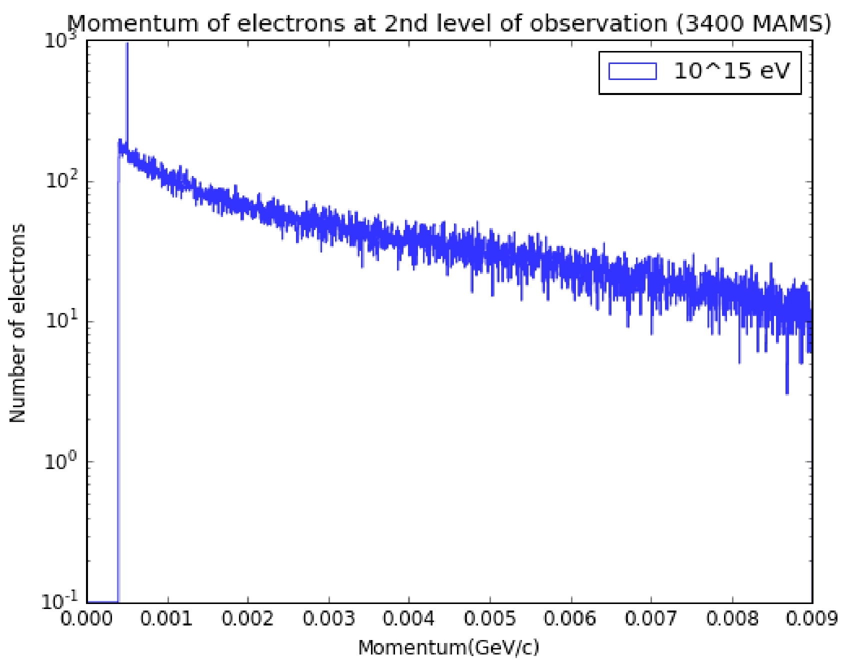

Figure 14:

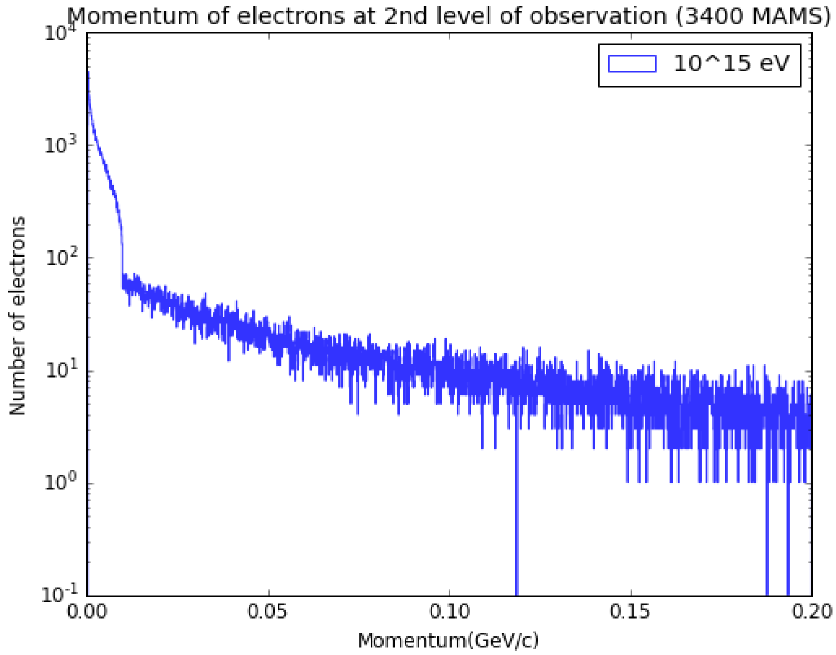

Figure 15:

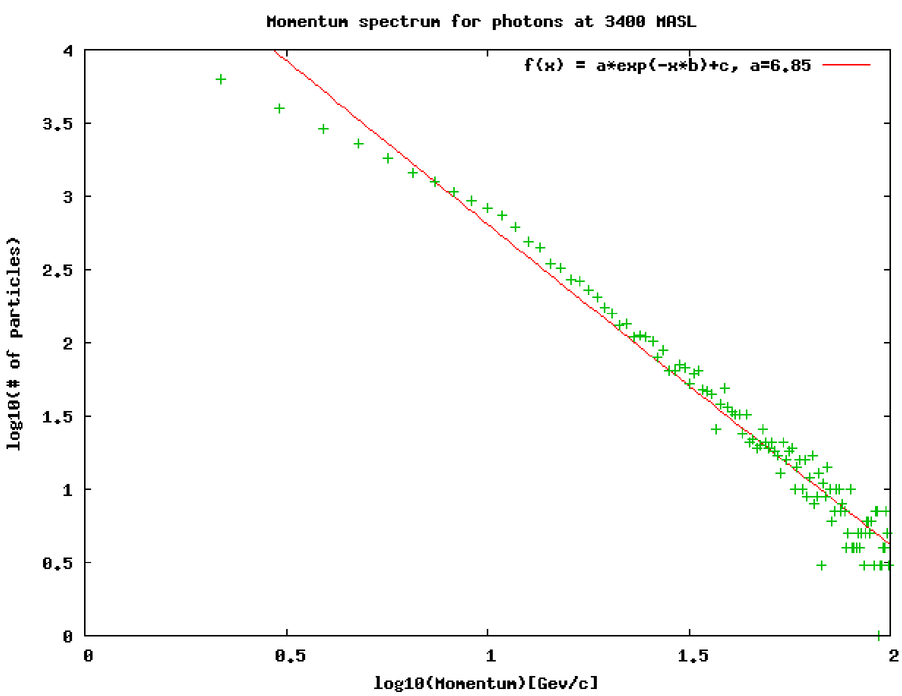

Figure 16:

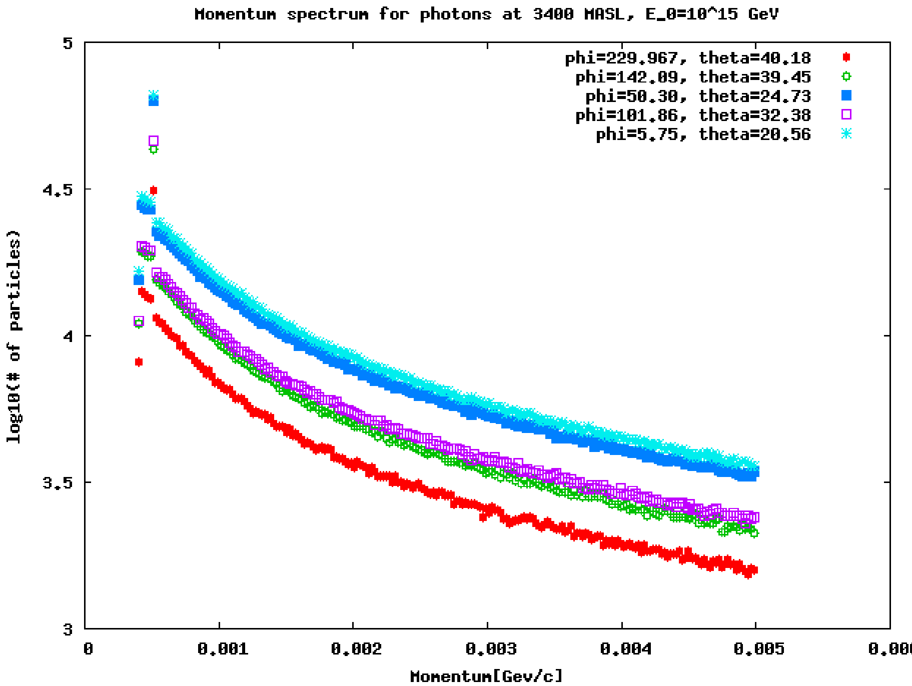

Figure 17:

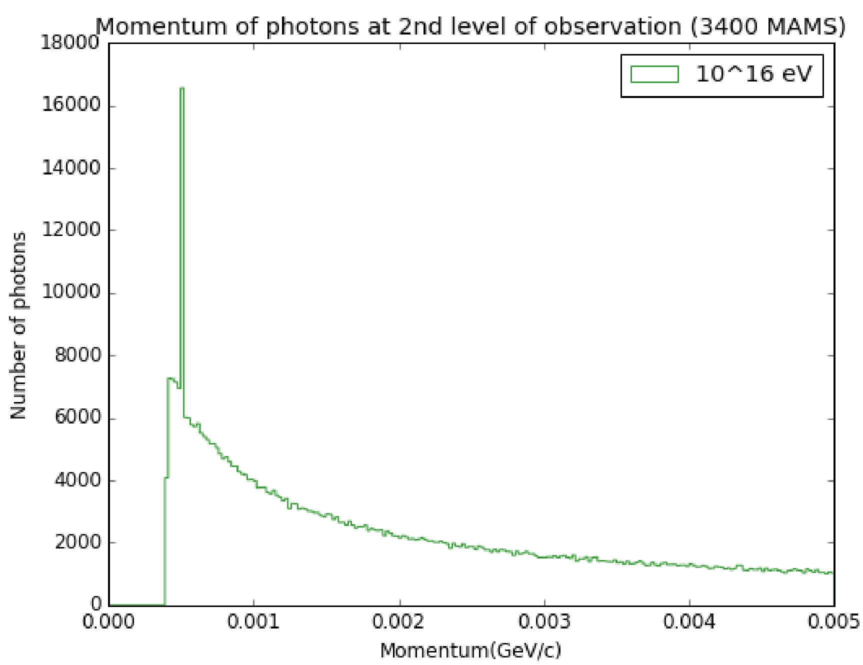

Figure 18:

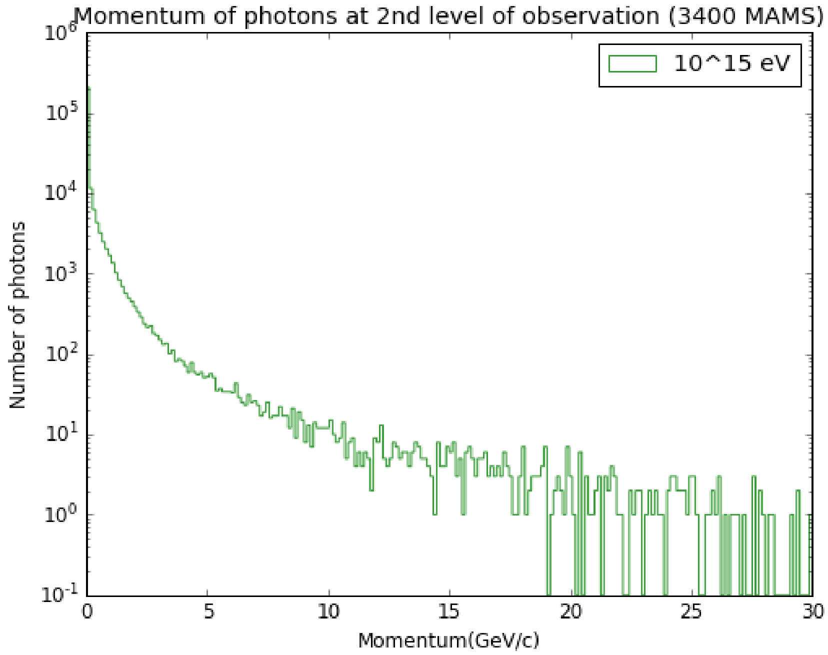

Figure 19:

4 Background (computation done by Jordan)

Suppose that the primary background is muons, with a normalization $\Gamma \sim 70$ s^{-}1 m^{-}2 str^{-}1, and angular dependence $\Gamma(\theta)\ \cos^2(\theta)$, where θ is the zenith angle.

Let's now consider a horizontal detector, and integrate over the full azimuthal angle. This gives $\Gamma_{\text{total, muons}} \sim 1$min^{-}1 cm^{-}2. Since we know the rate at which muons hit the Earth and the fact that events are independent of the time interval between them, we use Poisson statistics to describe them. This is, for a given area $\mathcal{A}$, the total background in certain interval of time t is given by

$$P_{\text{muons}} = \Gamma_{\text{total, muons}} \times \mathcal{A} \times t \tag{1}$$

For a squared camera sensor of area $\mathcal{A} = 0.25cm^2$ and $t = 1$ s, we get a probability if get hit of $P \sim \frac{1}{200}$. Assuming our phones have a time resolution of 1 second, a cosmic ray should be well above background.

Including backgrounds, we obtain the following plot

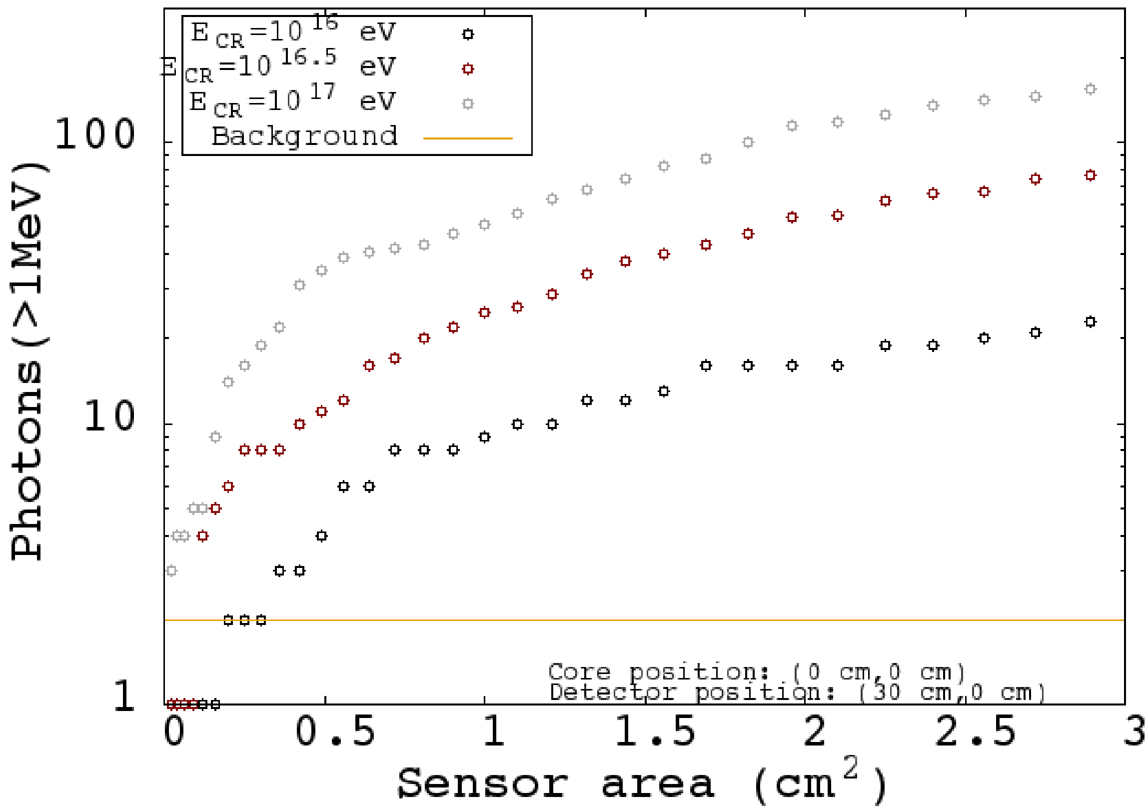
E CR=10 16 eV
E CR=10 16.5 eV
E CR=10 17 eV
Background
Core position: (0 cm,0 cm)
Detector position: (30 cm,0 cm)
Photons(>1MeV)
Sensor area (cm 2)
1
10
100
0
0.5
1
1.5
2
2.5
3

Figure 20: