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Investigating the Expected Cosmic Event Rate Distribution on the GlueX Barrel Calorimeter Using a Monte Carlo Simulation

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1 Motivations

A month or so prior to embarking on this project, it became apparent that there was a surprisingly large difference in the rate of cosmic events in the barrel calorimeter (BCAL) between the most active and least active modules. This was first noticed when looking at histograms of the maximum pulse heights recorded from cosmic events as a function of channel and module. The histograms all had roughly the same average values, indicating that the gain of each channel was comparable, but the number of events binned in these histograms varied by more than a factor of ten from the least to most active regions (Figure 1). While some variation is to be expected due to the relative geometry of the scintillating trigger panels and the BCAL (Figure 4), this factor was substantially more drastic than one would intuitively expect. It was noticed, after preliminary inspection, that there was an asymmetry with the top scintillator and the vertical axis of symmetry of the BCAL, but even this difference seemed too minute to give rise to the observed variation. In order to rigorously test whether this asymmetry (and other factors like angular distribution of cosmic rays) could give rise to the observed results, an investigative simulation was designed.

2 Development: Overview

Several versions of the program have been constructed to analyze this issue. The first version was designed to yield a rough approximation of the observed rate; this was to make sure that I properly understood the geometry and method of data acquisition of the BCAL. I made sure to account for the cosine squared distribution of cosmic rays (cosmic rays in normal energy ranges are distributed along the Earth's surface proportional to $cos^2\theta$, where θ is the angle with respect to the zenith)[3], and all the relative geometry of the BCAL and scintillators. In this first version, the size and shape of the channels were approximated and identical to one another. Once this was done, it become clear that a more precise simulation was needed to adequately compare to reality. A second version was designed which additionally portrayed each channel's geometry as accurately as possible, using code borrowed from a more sophisticated simulation [1]. This version was capable of accurately displaying what should be going on from module to module. However, as the analysis continued, it became more useful to look at the individual channels of a module by layer, and so a third version of the program was created to simulate this.

3 Development: First Version

This version gave a good estimation of a more sophisticated simulation that would later be developed. To quantify the positions of every channel on the BCAL, two arrays of size 768 were created, corresponding to the x and y values at the middle of each of the 768 channels of the BCAL. Then, a random number generator creates a set of two x values corresponding to a location on the top and bottom scintillators, respectively. These two points, paired with two y values for the vertical displacement of the scintillators, form a line through the BCAL which represents the path of a cosmic ray - one set of these points is an event. Next, the program checks if, within an error bound proportional to the size of a channel, the path of the cosmic ray intersects any of the channels of the BCAL. Effectively, this is done by generating a line equation for the given event and seeing if any pair of channel coordinates satisfy the equation. Once a channel has been hit, there is a boolean operator which flags the module so that it may not be marked as hit again until the next event. The user is able to input how many events they would like, and once the program is done it produces a graph of the number of events versus module number. The event distribution in this, and all subsequent versions, is weighted by $cos^2\theta$.

4 Development: Second Version

Due to both the approximate nature of the channel positions in the first version, and the difficulty in visualizing the events on the actual BCAL from the graphs produced, a second version of the program was designed to output an accurate representation of a cross-section of the BCAL, complete with various degrees of shading corresponding to variations in activity. To draw the BCAL, some code was borrowed from hdview2 [1] and manipulated to produce a canvas drawing of the BCAL. This code proved to be particularly useful, in that all the channels were already drawn and defined accurately with boundaries (each channel was drawn with a polyline). By dividing the event trajectory into arbitrarily small segments, one could then check if any of these sections were inside a given channel polyline. The user now has two parameters to enter: the number of events, and the precision factor. The larger the precision entered, the more sections the event line is divided into, and thus the smaller chance there is that a channel which should be hit by a line will be missed. Although one would ideally want infinite precision, the precision factor tends to slow down the running time of the program substantially, so a precision factor of 1000 is recommended for both accuracy and speediness. The output of this version includes a graph of events versus module number, as before, as well as a picture of the BCAL cross-section shaded according to the data produced.

5 Development: Final Version

The second version of the program was adequate in simulating the rate of events for all modules; however, it still had not answered the original question regarding the ratio of activity from module to module, and it did not completely mimic the distribution of event rate seen in the real data. (Figure 1) Looking only at modules was too coarse of a measurement, and so a third version was developed from the first two which analyzed the four layers of channels separately for all modules. This proved to be useful in gathering information about where the discrepancy from simulation to reality originated from. Only slight modifications were needed to produce the third version from the second - this version still asks for event and precision input, but now produces a superimposed graph of event rate versus module for all four layers, as well as a BCAL cross-section picture which is channel-specific.

6 Results

The results of the various stages of the simulation are shown in the figures below. While they all have similarities, there are several changes and improvements from version to version. The first version shows, at a very basic level, the general distribution one would expect to see, which mostly agrees with the observed data. There are peaks at the top and bottom modules, where activity should be greatest, and troughs at the side modules, where activity should be diminished (See figure 5).

In the second version, one can see an interesting pattern of peaks and troughs. The largest peaks and troughs are similar to the first version, but there are now extra minima and maxima intermittent between these large peaks (See figure 6 and 7). More granularity was necessary to make sense of these peaks and troughs, so the final version looks at individual channels, by layer, as opposed to modules only. With this added granularity, the extra peaks actually grew instead of shrinking. As suspected, and will be discussed below, the largest peaks are found in the outside layer of the BCAL, where the channels are composed of a sum of 4 SiPMs.

The second and third versions both have a simulation corresponding to the actual geometry of the BCAL and scintillators, as well as a symmetric case, where the positions of the panels are encoded as being symmetric about the y axis. The latter is used to ensure that the simulation is running correctly, and to discern the magnitude of the effect of the asymmetry. Comparing the symmetric case to the non-symmetric, one can see that there is not a very large difference between the two.

Looking at the symmetric case for the final version, the peaks of the outside layer are all roughly equal in height (Figure 10). In the asymmetric analog, the highest peak has about 3610 events. The lowest peak has about 2900 events, meaning it is about 80 percent as large as the other peak (Figure 12). Even from the highest peak to the lowest trough, the trough is still (at 1700 events) 47 percent the height of that peak. In the data, the low point sits at around 250 events, while the peak is at 3100. This means the low point is only about 8 percent of the peak value. While the asymmetry of the panels does make a difference, it is not nearly large enough to be the sole cause of the low event rate, and bizarre shape, seen in the south side modules.

As one can see, none of these simulations reproduce the data exactly. There are components of the data that are reflected in the simulations, but there are large areas of difference as well - most notably in the south side modules (modules 13 to 36). Possible explanations for these differences will be outlined in the comparison section.

7 Comparison and Discussion

Being the most detailed and representative of reality, we will exclusively look at the final version in this section. At first glance, even this version appears quite different from reality. While it is not in perfect agreement, there are some striking agreements that indicate the simulation is functioning properly.

The original motivation for creating the simulation was to investigate some irregularities with the data itself - most notably the ratio of activity from most to least active modules. The region of lowest activity resides in the south side modules (modules 13-36). The most glaring difference between simulation and data is that instead of a series of peaks and troughs comparable in size to those on the north side, there is a drastic drop forming a wide trough (Figure 1). This deficit could indicate a problem with the south side crates, such as low gain or broken channels. A second cause of the deficit might be from the bottom scintillating panels. Split approximately along the y-axis of the BCAL coordinate system, there are actually two scintillating trigger panels connected together to form the bottom trigger (See figure 4). If the panel on the south side was malfunctioning, it could produce a much lower event rate in the south half of the BCAL that would not be reflected in the north. From comparing the symmetric simulation cases to their non-symmetric partners, we can see that the asymmetry of the top scintillating panel is not large enough to produce the drop in the south side that we see - it appears that something else, like a faulty scintillator or broken channels, is causing the significantly lower rates on the south side of the BCAL.

If we look only at the north side modules (modules 1-12 and 37-48), the data and simulation agree with a high degree of accuracy - this is further evidence of a problem with the south side modules (See figures 14 and 15). First, the outside peaks are in the correct location. In the physical data, the peaks are located at modules 7 and 42 (Figure 1). In the simulation, there are also peaks exactly at module 7 and 42 (Figure 12). In both cases, the larger peak is at module 42. Secondly, although the number of events differ between the two graphs, the ratio of events from peak to trough is nearly identical for the two. Looking at the first peak for cosmic data, (Figure 2) and quantitatively comparing to the first peak in the simulation (Figure 12), we can construct ratios of events between module 1 (a minima) and 7:

$$\frac{R_{M1,cosmic}}{R_{M7,cosmic}} = \frac{1920}{2700} = 0.711$$

$$\frac{R_{M1,sim}}{R_{M7,sim}} = \frac{2500}{3525} = 0.709$$

We can do the same thing for the outer peak, looking at module 42 and 48:

$$\frac{R_{M48,cosmic}}{R_{M42,cosmic}} = \frac{1980}{3100} = 0.639$$

$$\frac{R_{M48,sim}}{R_{M42,sim}} = \frac{2490}{3610} = 0.690$$

In both cases, they are very close, confirming that with the correct number of events the two would agree very well (Figure 15).

Another curious aspect of the simulation's results are the troughs located at modules 13 and 37 (Figure 12). These modules are at the top and bottom of the BCAL, so one would not intuitively expect minima there. Interestingly, Andre Semenov's symmetric simulation plots [2](Figure 16) show minima at these modules as well, and the reason for their existence lies in the effective area of channels. These troughs are especially pronounced in the outside layer of channels, because the outside layer of channels have the longest, most rectangular shape. For vertical modules, these rectangular channels have a small width with respect to the vertical, and so any given cosmic ray trajectory will be more likely to miss a particular module, or outside channel, than if that module, or channel, was more horizontal. The more horizontal a module is, the greater chance it has of being hit by a passing cosmic ray. Thus, there are minima at vertical modules due to their smaller effective area.

If this was the only effect at work, we would expect the horizontal modules to have the highest event rates. However, the scintillating panels have a finite length which limits the range of cosmic rays that can strike, and be detected by, the BCAL (Figure 4). This means that cosmic rays are more likely to be detected when they are closer to the vertical modules like 13 and 37. Secondly, cosmic rays do not have a uniform angular distribution. They are distributed proportional to the squared cosine of the angle with respect to the zenith[3], so more vertical trajectories are also more likely for that reason. One can directly see this effect in the first layer of channels (Figure 12). Since these channels are roughly square in shape, their orientation does not greatly disturb their effective area. The rate of events in these channels is most influenced by this second effect, and one can see that the maximum event rates for these channels are around the area of vertical modules (Figure 12).

Together, the effective area of a module and its position act against one another. When these two effects are combined, the most active modules would seem to be modules which have found a compromise between the two extreme cases; modules that have a large enough effective area to get struck by many cosmic rays, but also are close enough to the vertical to have many triggered events, should be the most active. Indeed, this effect is observed in both simulation and the real data (and is most obvious in the symmetric cases). The most active modules in the simulation are the diagonally oriented modules, such as 7, 19, 31, and 42. In the real data, the two maxima are around modules 31 and 42 as well - indicating again that the south side is malfunctioning.

8 Conclusion

The simulation agrees very well with the data from the north side crates of the BCAL. The peaks and troughs of the event rate plots match up, and have the same relative size (Figure 15). On the south side, the data is suspiciously low, and cannot be properly accounted for through arguments of asymmetric scintillating panels alone. It seems there may be an issue with the crates on the south side of the BCAL, or the bottom scintillating panel on the south side, which is leading to very low event rates. The issue is quite apparent, but the nature of this issue is, as of yet, uncertain.

References

[1] https://halldsvn.jlab.org/repos/trunk/sim-recon/src/programs/Analysis/hdview2

[2] logbooks.jlab.org/entry/3285969

[3] http://pdg.lbl.gov/2013/reviews/rpp2013-rev-cosmic-rays.pdf
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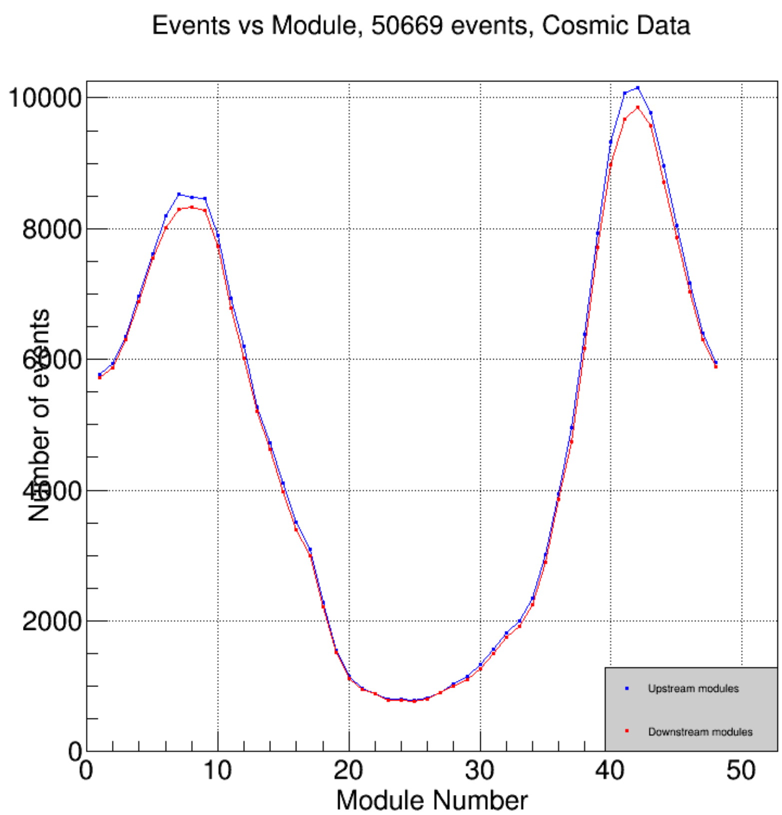

Figure 1: A tandem cosmic run, showing the amount of hits over the whole run for each module. Blue is for downstream, red is for upstream.

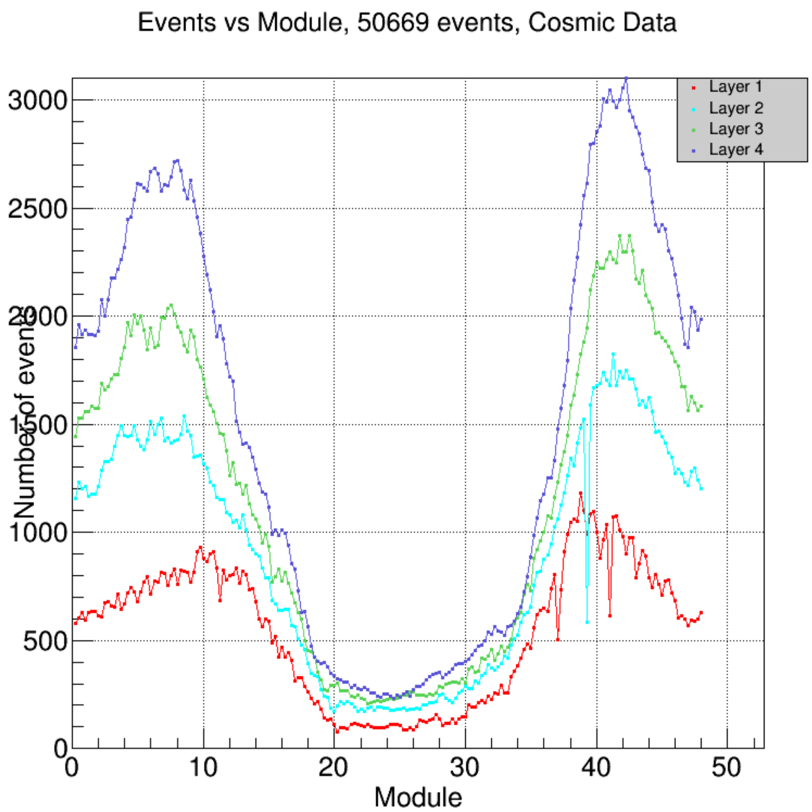

Figure 2: A tandem cosmic run, showing the amount of hits over the whole run for each layer (downstream).

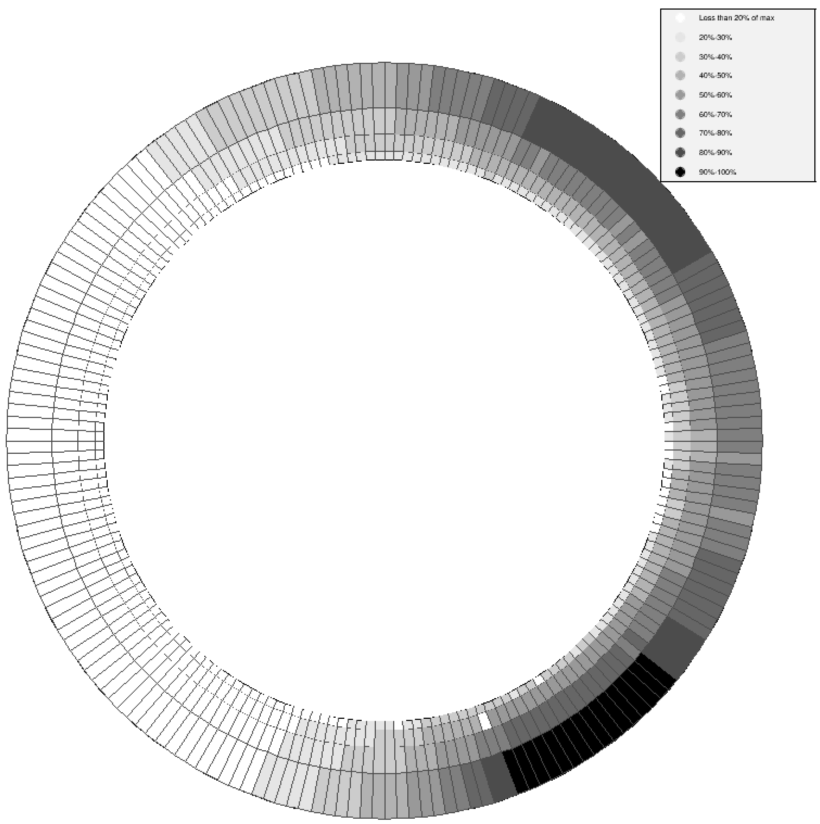

Figure 3: A tandem cosmic run, showing the amount of hits over the whole run for each channel. Darker regions correspond to more active regions. The north side is on the right, south is on the left. Modules begin at 3 o'clock and increase counter-clockwise.

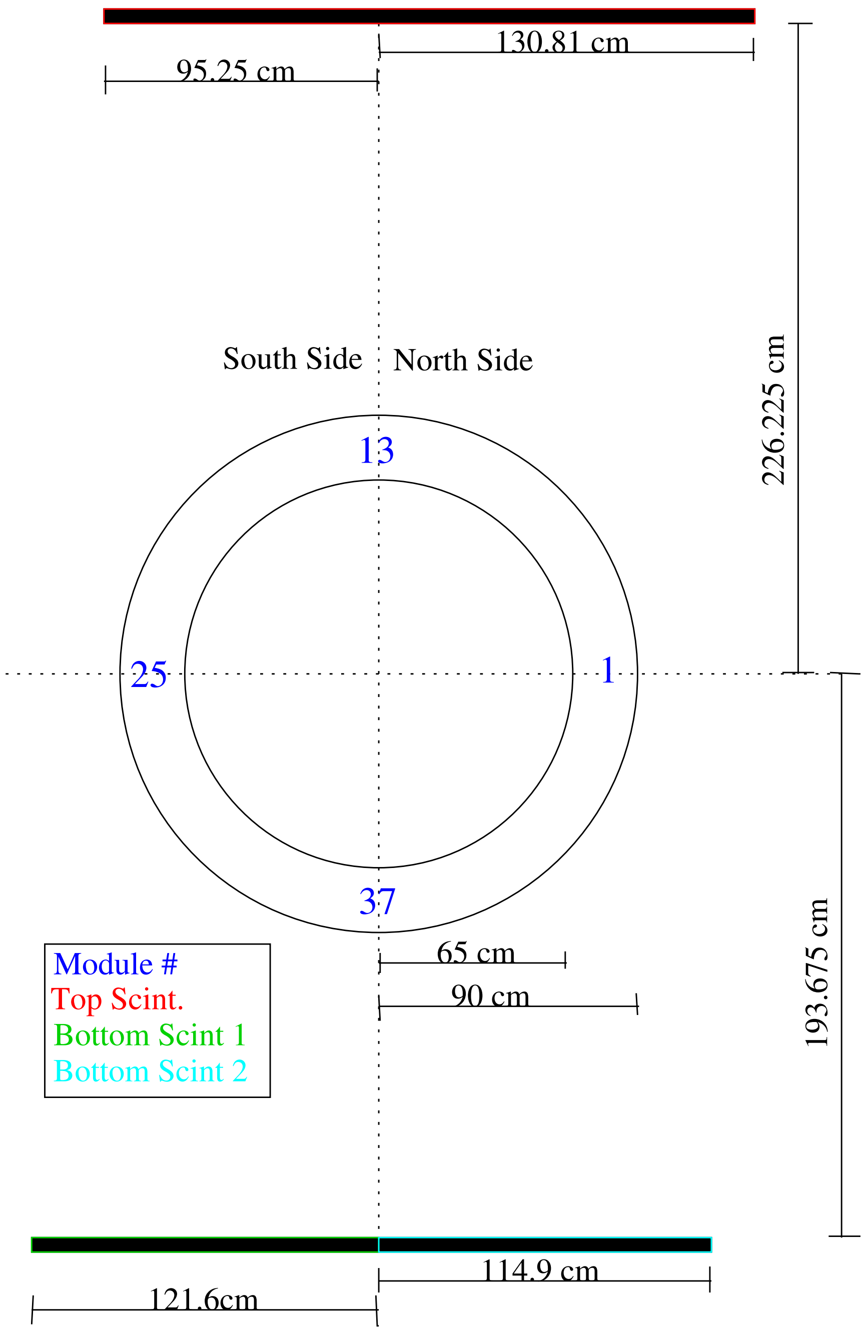

Figure 4: A to-scale drawing of the geometry of the BCAL. All measurements are in cm.

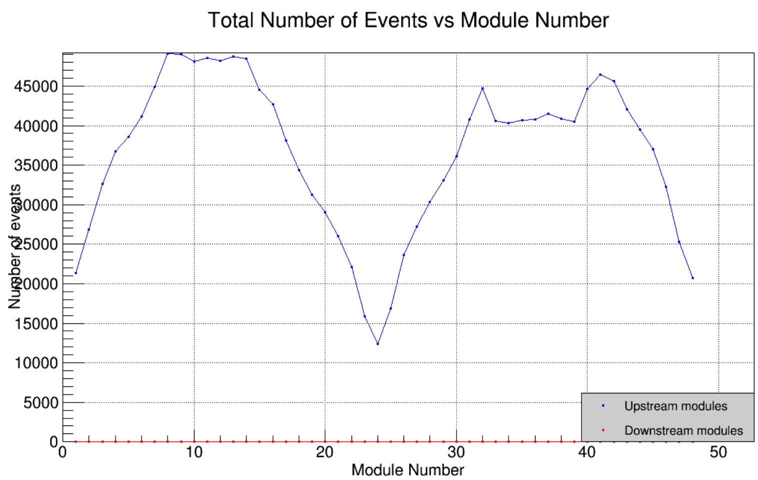

Figure 5: A test of the first version of the simulation - 1 million events.

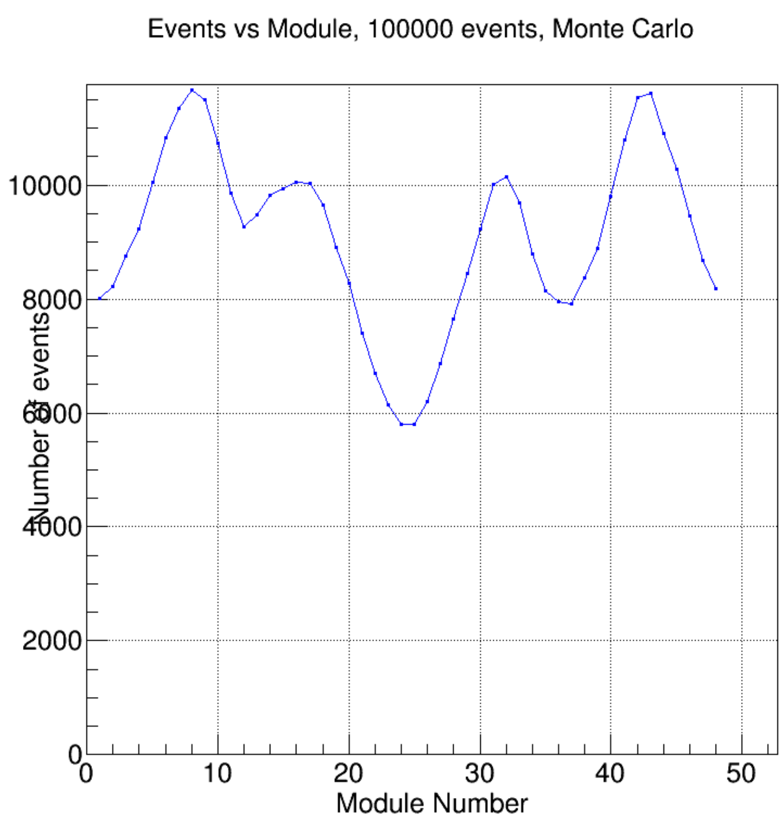

Figure 6: A test of the second version of the simulation - 100,000 events.

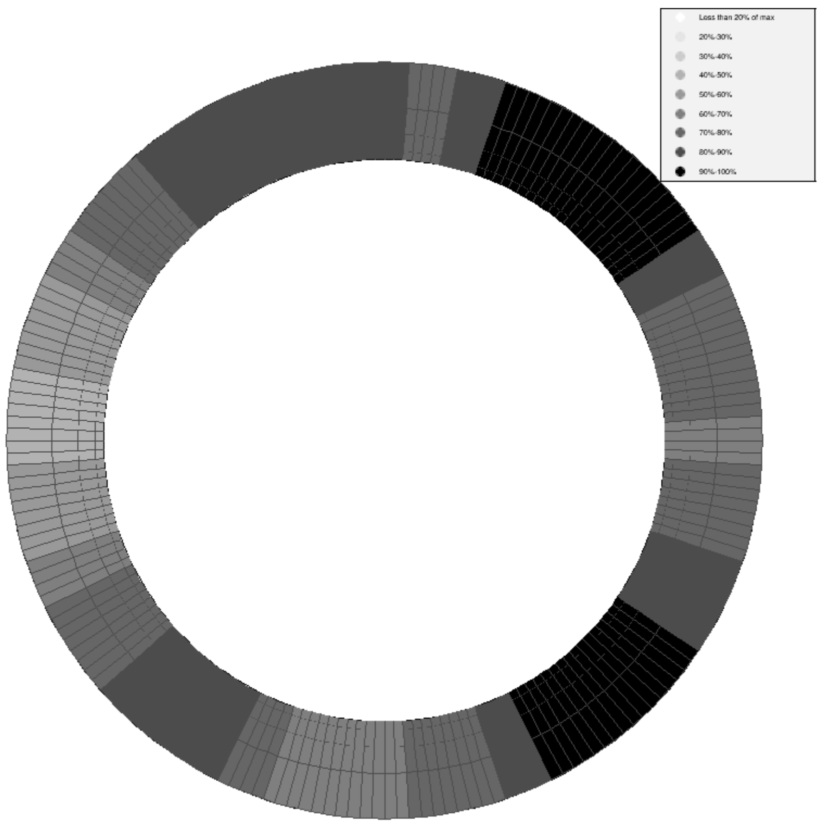

Figure 7: A test of the second version of the simulation - 100,000 events.

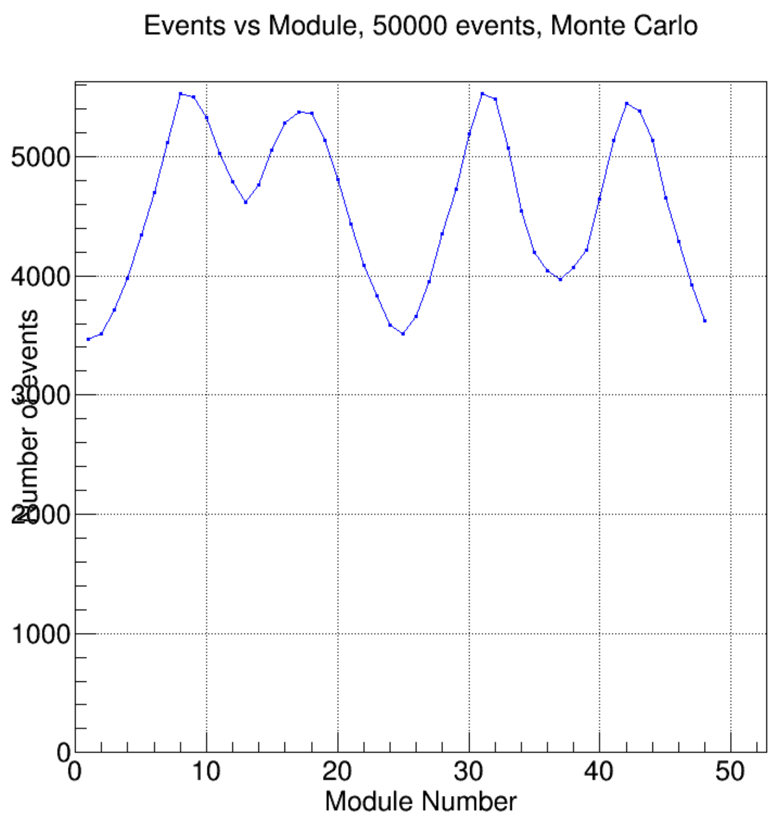

Figure 8: A test of the second version of the simulation for the symmetric case - 50,000 events.

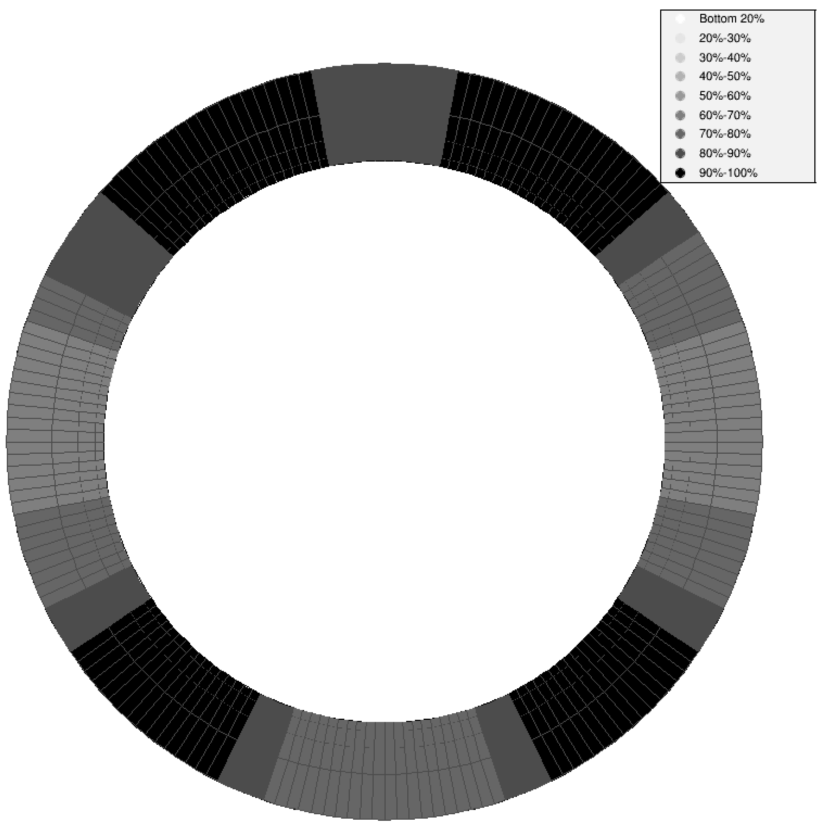

Figure 9: A test of the second version of the simulation for the symmetric case - 50,000 events.

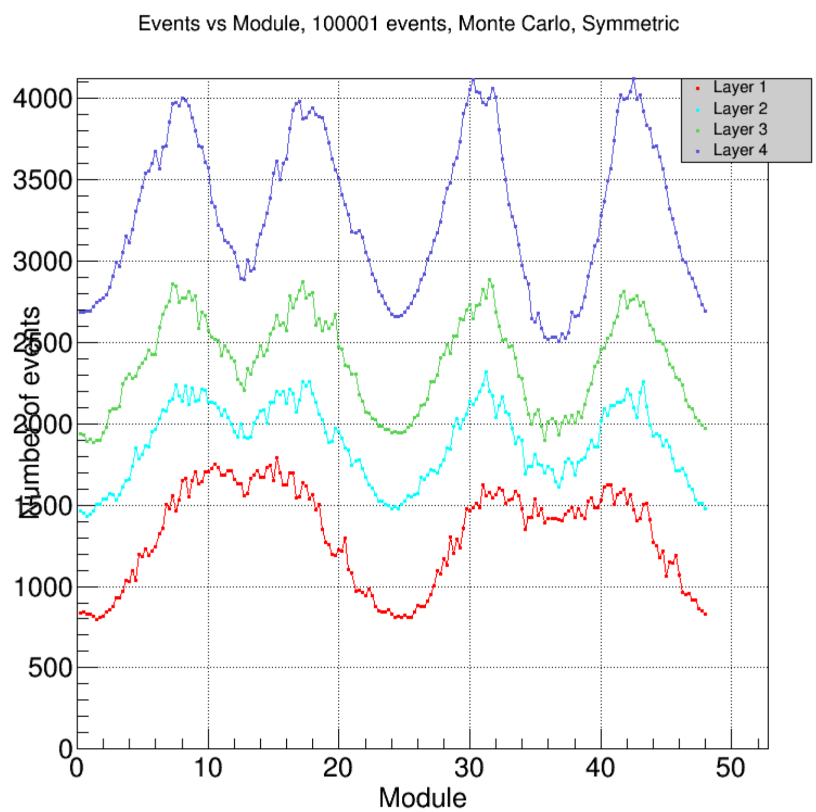

Figure 10: A test of the final version of the simulation for the symmetric case - 100,001 events. Channels are organized into layers.

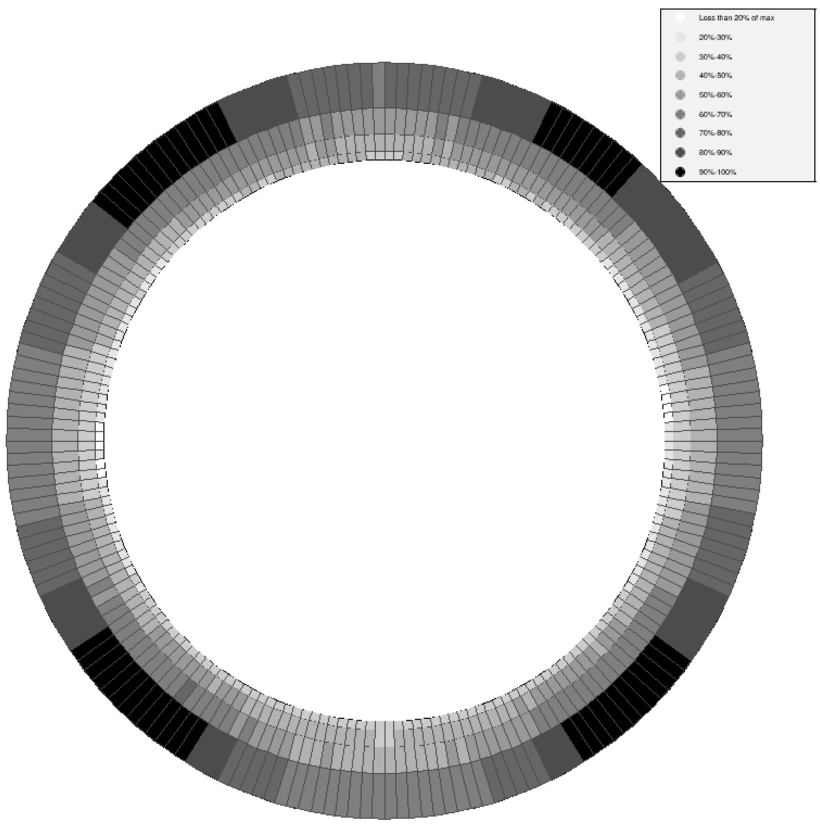

Figure 11: A test of the final version of the simulation for the symmetric case - 100,001 events.

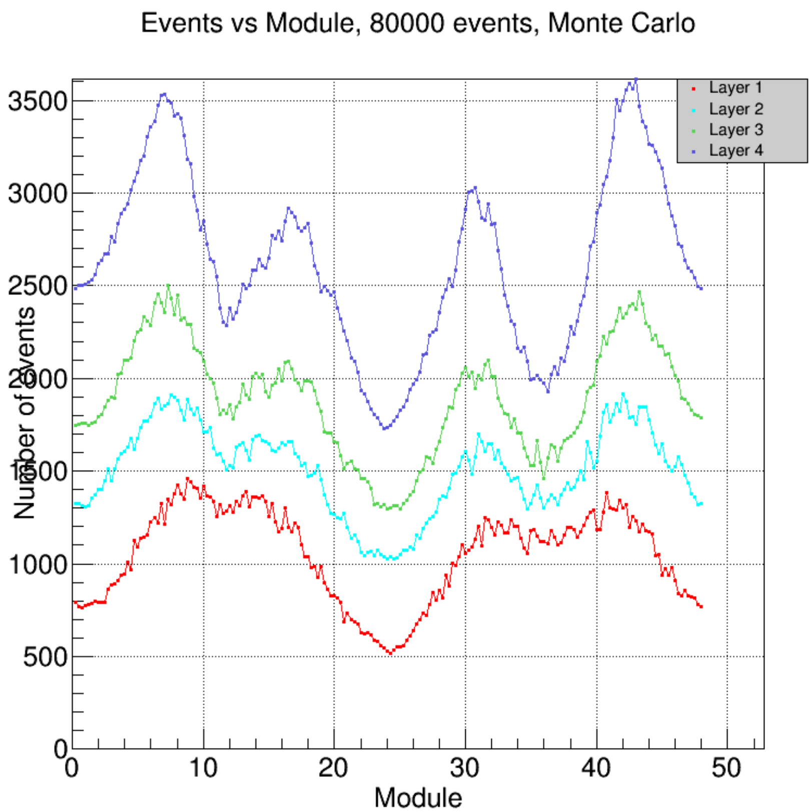

Figure 12: A test of the final version of the simulation - 80,000 events.

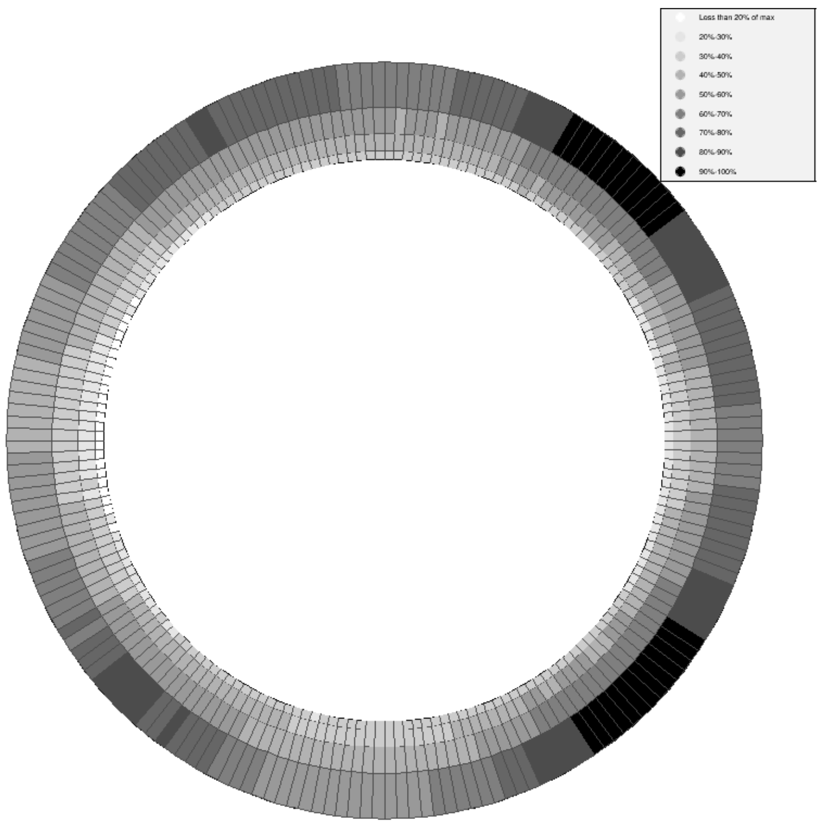

Figure 13: A test of the final version of the simulation - 80,000 events.

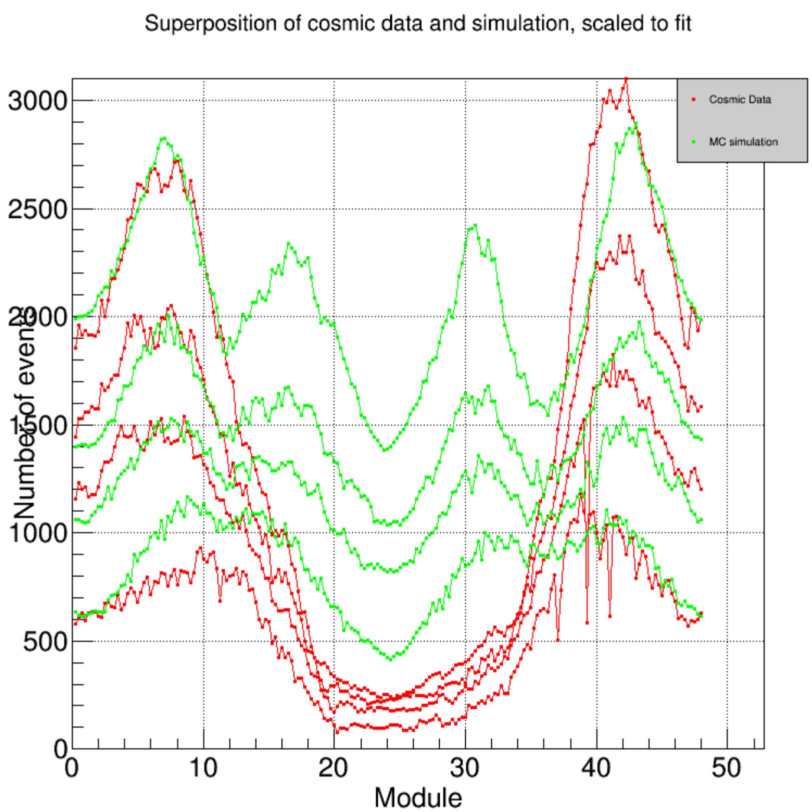

Figure 14: Superimposition of the cosmic data with the simulation, scaled appropriately.

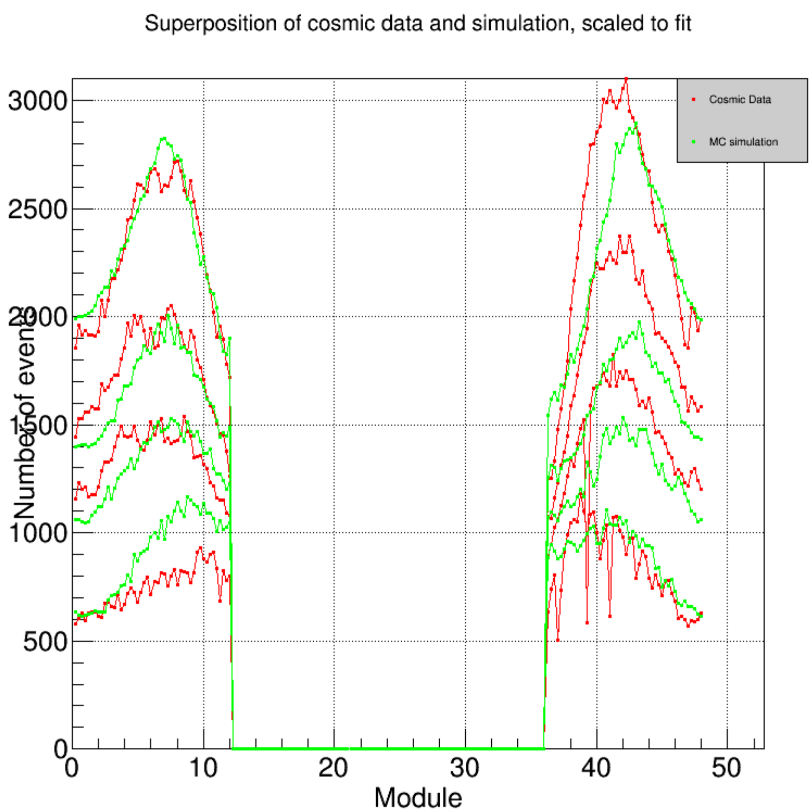

Figure 15: Superimposition of the cosmic data with the simulation, scaled appropriately. North side only.

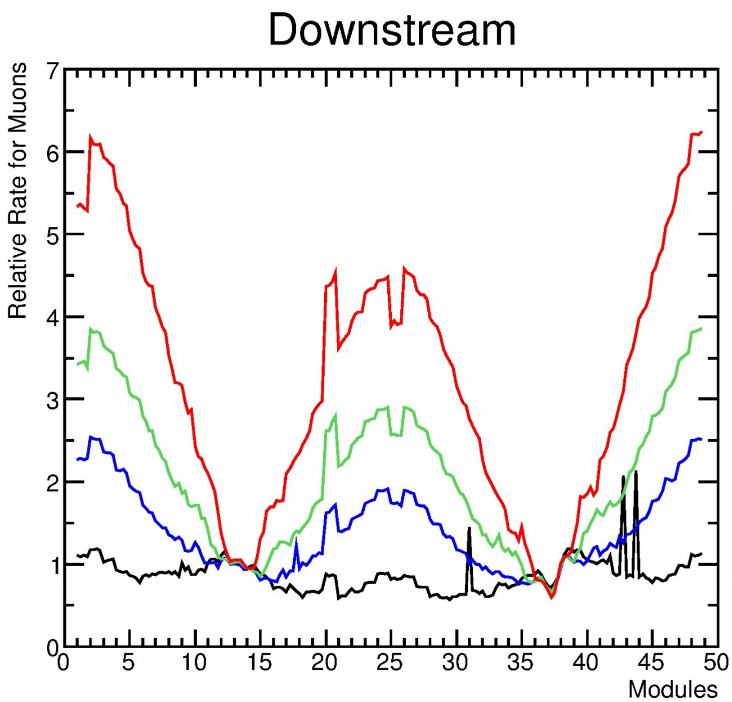

Figure 16: Taken from a logbook entry by Andre Semenov [2]. Symmetric simulation of event rate versus module.