Cosmic Ray Detection

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List of Figures

List of Tables

Contents

1 Overview

This project was performed during the summer of 2003 with several purposes in mind. These purposes were to learn about cosmic ray components, where they come from, what we detect at the surface of the earth, and how the detectors work. After building the detector it was tested and calibrated. This report includes a brief summary of the calibration of my detector and my coincidence data for two detectors for a specific experiment.

2 Composition of cosmic rays

Cosmic rays consist mostly of high speed protons from space, but include all stable charged particles and nuclei with lifetimes of order 10^6 or longer.

Primary cosmic rays are those produced/accelerated at astrophysical sources and include:

p+, e-, He, C, O, Fe, and others

Secondary cosmic rays are produced in interaction of the primaries with other particles in space prior to our atmosphere, such as interstellar gas, or components in our atmosphere. Secondary cosmic rays include:

Li, Be, B, most antiprotons, and most positrons

The earth is continually bombarded by these particles, which collide with atoms in the stratosphere to produce more particles that can be detected throughout the atmosphere. These particles are referred to as cosmic ray showers.

3 Cosmic ray sources

Possible sources for this cosmic rain includes supernovas, the emplosive late stage in the evolution of stars much more massive than our sun. Most of the cosmic rays probably originate within our Milky Way Galaxy, but a few, more energetic rays appear to be coming from very much farther away than our own galaxy.

4 Particles we are detecting and how many arrive at the surface

According to the Particle Physics Booklet, July 2002, pg. 199, the earth receives a total cosmic ray flux crossing a unit horizontal area are shown in Table 4:

Table 1: Cosmic ray flux at the surface of the earth, passing through a 1 m^2 surface.

Total	Hard mu+/mu-	Soft e-/e+
$180/m^2 s$	$130/m^2 s$	$50/m^2 s$

The leptons mu- and e-, and their antimatter counterparts mu+ and e+ are the charged particles we detect at the surface, after the primary cosmic ray has passed through our atmosphere. The majority of primary cosmic rays are p+ and these produce secondary pi+ and pi- particles which decay to mu+ and mu- respectively along with their corresponding neutrinos. Additionally, the secondary cosmic ray particle, pi (zero) is produced which instigates photon and e+,e- cascades through the atmosphere.

Table 2: Detector data (a sample)

Date	Time	Volt.	Atten.	Ped.	1 pe peak	C.R. peak	Gain	Npe/CR
6/18	15:45	2100	5x	42	48	500	$4x10^7$	83
7/2	11:00	2100	5x	40	48	620	$6x10^7$	78

5 Basic detector design

Particle collecting scintillator material is connected to a light guide, the light guide is attached to a photomultiplier (PMT). Some light is produces electrons through the photoelectric effect at the photocathode, and the electrons produced are amplified through a several stage dynode multiplication chain. Charge at the PMT anode is sent on 50 ohm impedance cable to an oscilloscope, qVt, ADC, or other device for analysis. Also the scintillator itself is wrapped in aluminized mylar and 4 mil black plastic sheeting to prevent (hopefully) photons and other non cosmic ray particles from entering the detector.

6 Cosmic ray interaction with the scintillator

Charged particles, mu-, mu+, e-, e+, pass through the scintillator, exciting atoms and ionizing some atoms. These excited scintillator atoms return to a lower, non-excited, energy state via photon emission. These photons bounce to the end of the scintillator and are channeled to the PMT cathode via the light guide. About 25% of the time an electron is emitted from the photocatode via the photoelectric effect.

7 Calibration of detector

The electronic logic systems used to analyze detector data can be set up to trigger on detector 1, detector 2, or both, when looking for cosmic ray data. When calibrating a detector the most reliable data is obtained when both detectors are in the logic system. There is a certain amount of trickle current, generated within the electronics, that must be determined and accounted for in calculations. The charge of 1 photoelectron must also be determined to understand the collected charge data. If you trigger on detector 1 and look for the data in detector 2 that will show you the trickle current, which is called the pedestal, for detector 2. To determine the 1 photoelectron peak (which from now on will be called the 1 pe peak) the electronics should be set up to trigger on 2 and look at 2.

Finally, reliable cosmic ray data can be taken with the electronic logic set up to read both detectors and only report a result when a particle is observed in both detectors. This is called the coincidence.

Table 2 shows a sample of calibration data, a more detailed data set is included and attached separately.

8 Experiment

This experiment was performed using two detectors, the one I made and another made the previous week by Kari Van Brunt. We were looking for coincidence readings through the two overlapped scintillator detectors, within the 50 nanosecond gate time window. We used the electronic logic

Table 3: Coincidence Rates, Varying Overlap

Overlap cm	Ctr 1 cts/sec	Ctr 2 cts/sec	Coincidence rate w. uncertainty cts/sec
32.5	11.5	90.9	4.93 +/- .22
27.0	9.8	86.6	4.27 +/- .12
21.0	10.7	89.0	3.37 +/- .11
12.3	8.2	92.7	2.20 +/- .08
8.0	9.0	92.0	1.31 +/- .066
2.0	8.9	87.8	0.51 +/- .041
0.0	7.9	88.9	0.32 +/- .033
-6.0	7.7	91.4	.036 +/- .011
-140.0	9.4	89.9	.011 +/- .004

systems to read only those events which went through both detectors, which would hopefully reflect cosmic rays as opposed to other effects or particles that may enter either detector alone.

First we needed to determine how many cosmic rays our specific scintillator could detect. This is calculated by finding the area of the scintillator plate in m^2 and multiplying by $180/m^2s$, the surface cosmic ray flux discussed earlier.

$$L \text{ x } W \text{ x } 180/m^2s = .142m \text{ x } .307m \text{ x } 180/m^2s = 7.8/s$$

Now we also must calculate the theoretical accidental coincidence rate.

Just by chance there is a certain number of coincidences we may observe that would have nothing to do with real cosmic rays. This is calculated by multiplying the rate in counts per second of each counter by the gate time window, 50 nanoseconds ($50 \text{ x } 10^{-9}$ s).

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Rate(cps of counter 1) x Rate(cps of counter 2) x 50 x 10^-9sec

11.5/s x 90.9/s x 50 x 10^-9sec  =  ~5 x 10^-5/s
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This is negligible compared to the full overlap rate, translates to seeing only 5 non cosmic ray counts by chance in a 28 hour time frame.

For this experiment, we also took rate data on the counters individually, so we could compare it to the coincidence rate (as noted above in the accidentals discussion). In addition, we studied the rates as a function of the overlap area of the counters. We started with the 2 scintillator plates completely overlapped and gradually moved them apart in 6-9 cm increments. Multiple trials were performed at each separation distance. Table 8 is a summary of the averaged data and uncertainty. Counter 1 was run at 1600 volts and counter 2 was run at 1800 volts to bring the individual characteristics of each detector into close alignment. The vertical separation of the plates was 6-8 cm. Also it should be noted that the lights in the room were off during this experiment and it was a cloudy day. We had also performed light infiltration tests on each counter and made pre and post light repair measurements to determine there were no stray photons getting into our wrapped scintillators.

The uncertainty was calculated using the square root of the entire data set, using the total counts in 300 seconds, utilizing all three 100 sec trials.

Figure 8 shows close to a linear decline as the plates are moved apart from total overlap of 32.5 cm to 0 cm overlap. After 0 cm separation the counts begin to level off and the coincidence counts change very little from 0 cm to -140cm. For the separated counters, the coincidence rate

Figure 1: Coincidence rates as a function of overlap distance. Negative distances correspond to separation distances. Full overlap corresponds to 32.5 cm.

is approximately 0.01/sec, still substantially more than the small expected accidental coincidence rate. Thus these coincidences for separated counters seem to be real. Two possible explanations for this effect are:

1. "Delta" rays, or atomic electrons from ionization events in which (as rarely happens) the electrons are ejected from the atom with large energies, of order an MeV. These can happen either in the roof of the building or in the atmosphere of the earth.

2. Two earth-level cosmic rays which come from the same primary cosmic ray shower.

In Figure 8 the negative distances have been removed to analyze a linear curve fit to the remaining data. It produced a correlation of 0.999 to the line plotted on top of the data. This line reflects a slope of 14.6 counts/100 seconds per centimeter. Therefore, for every additional centimeter of overlap the counts should increase by 14.6 counts per 100 second data collection time. This graph is linear, as expected.

One puzzle in our results is that our cosmic ray expected counts/sec was 7.8 based on the size of detector 1. The experimental data showed 4.9 counts/sec. If we round these off, we expected to see 8, but only saw five, roughly 63% of the expected. This deserves additional study at some time in the future, to repeat the experiment and verify this percentage. Also, the discrepancy may be inherent to differences in the detectors. Perhaps the plates were not exactly the same size, they were not overlapped properly, or the voltage used during the experiment was insufficient to detect all the cosmic rays produced.

9 Conversion of Counters to Portable Unit

The next step in our progression toward making these counters available to high school students is to convert the detectors to a more portable unit. Several adaptations were undertaken in the following order to accomplish this goal. The original large photomultiplier tubes were replaced by smaller photomultiplier units which had the necessary high voltage source imbedded in them. The large electronics stack was replaced with a single logic board approximately 10cm x 15cm. (based on the electronics developed by Howard Matis, of Lawrence Berkeley Laboratory; the basic board was provided free of charge by Matis). This board does not have the same capabilities as the qvt, discriminator, etc. of the large stack, but it will allow individual counts and coincidence counts to be taken in a classroom. Even though it has limited capabilities, it has definite advantages because the set up takes up much less space and the high voltage source is imbedded and no longer a danger to students. Table 9 shows calibration data was collected on each of these portable units during a mid conversion point, with new PMT's, but with the large electronic stack.

det	HV	ped.	atten.	1pe peak	1pe	CR	gain
S1	1300	42	X5	49	7	331	5.5×10^7
S2	1400	42	X5	46	4	270	3.1×10^7

Table 4: Calibration data for S1,S2 after PMT change

These two counters were then fully converted with the small electronics board and data was taken for singles and the coincidence rate between our now fully transportable counters. Yea! To accomodate the lower discriminator setting on the small electronics board, data at several voltage settings were taken and evaluated to bring our counts per second of coincidence to an appropriate level. This done and the data in Table 9 was obtained.

Figure 2: Coincidence rates as a function of overlap distance. Only positive (and zero) overlap distances are included. Full overlap corresponds to 32.5 cm.

Table 5: Final coincidence data, new PMT's, LBL electronics

det	HV	single rate(cps)	coincidence(cps)
S1	900V	135	
		134 133 137 133	
S2	900v	28 30 30 30 28	
triggering on new S1,S2			
			10 12 10 11 10

The accidentals were calculated using a gate window of 100 x 10^{-9} seconds, although at this point in the experiment that is an approximation of the new electronics. The formula for this calculation was discussed earlier in this document and will be applied here. Theoretical accidental coincidence rate = 3.9 x 10^{-4} counts / second. This rate is again very small and amounts to 1 count in about 11 hours, well below the coincidence counts we observed. In conclusion, this project has proceeded logically from initial learning about cosmic rays, building and testing a detector that resembles what some researchers are currently using and finally to converting a detector for use in the high school classroom. This goal now appears to be plainly in sight and well within the realm of possibility for this particular researcher. I look forward to using these detectors in my physics class this coming school year. I intend to introduce particle physics in our momentum discussions and return to actual data collection of particles while doing nuclear and particle physics.