Cosmic Ray Telescope
Lenka Raska
Advisors: Dr. Julia Thompson and Dave Kraus
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REUP-FOM/SIUE

1 Background

This project was done by Lenka Raska, as a preparatory exercise to making a trigger for scintillating fibers being studied by Prof. David Kaplan. As often happens, the project took longer than anticipated, and several by-ways were studied. In the end, the project became a study of the two small counters in the cosmic ray telescope, their performance, and the (initially unexpected) coincidence rates they displayed when separated. Ms. Raska's paper was written as a microsoft word document, and not quite finished. The most relevant parts are transcribed here. In some cases, additional commentary or information has been added; due to scheduling constraints, these changes were not completed in summer, 2002.

2 Telescope

The one built by Ms. Raska is typical of such devices: two different size scintillating counterss attached to photomultiplier tubes. As a muon passes through the counter, the energy it deposits excites the atoms in the scintillator. The exctied atoms emit light that is delivered to a photomultiplier tube upon total internal reflection. In the tube the light is converted to an electrical signal at the photocathode due to the photoelectric effect. The electrons then cascade through 12 dynodes. The total 1900 V potential differences is divided among the 12 stages and at each stage the electrons are multiplied. The electrical signal is then delivered to either a telescope or other electronics where it can be analyzed.

There are many different particles in cosmic ray showers, but muons are especially desirable for a couple of reasons. Muons move with relativistic velocities and therefore provide us with a standard signal. They are produced at about 15 kilometers int eh atmosphere and are the most numerous particles at the sea level. On their way to reach the Earth's surface, theylose about 2 GeV due to ionization, so their mean energy at the ground is about 4 GeV. Also, the mass of muons is about 200 times larger than the mass of electrons. So at the same momentum electrons travel wtih much higher velocities than muons and therefore electrons interact more electromagnetically.

The signals were first displayed on an oscilloscope, and on the screen, we could see a size of one photoelectron produced by our PMT: abuot 2 mV, and about 20 nanoseconds in duration.

The electronic setup is as follows:

1. QVT - measures charge of the signal: convert it froma nalog signal to a digital one and sends the signal to the computer. In addition, it has its own discriminator.

2. Discriminator – selects signals that are of equal or greater value than the size selected by the discriminator.

3. Logic module – indicates whether or not there is a coincidence. It means that there must be signals coming from both counters simultaneously.

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Table 1: Concidences of A and B counters as a function of overlap

$A_{overlap}$ (cm)	A singles cts/30 sec	No. evts	No. coinc.	Expect.	Obs.	Unc.	Hist
15.5 x 32	274	1000	598	6.5	5.4	0.5	6666
15.5 x 31.	274	999	633	6.24	5.7	0.5	6667
15.5 x 24	282	998	515	4.8	4.7	0.31	6668
15.5 x 9.5	282	1001	187	1.9	1.7	0.14	6670
15.5 x 0.	282	995	13	0	0.12	0.03	6671
15.5 x 32	282	1002	612	6.5	5.7	0.34	6672

4. Timer and Scaler – give us readings for single counts and coincidence counts.

"I" [Ms. Raska] started looking at coincidence rates using the QVT. The goal was to see how the rate changes with different areas of overlap and then to compare our observed data with expected valeus. The expected rate was calculated as follows:

$$A_{overlap} * R_{muonspenetrate1sq.m/sec} = ExpectedValue$$

For example:

$$0.05m^2 * (130muons/m^2/sec) = 6.50counts/sec$$

Table 1 shows the expected and observed overlaps as a function of overlap. We can see clearly that the maximum coincidence rate corresponds to the maximum area of overlap and as the area decreases the rate also decreases.

The results are also summarized in Figure 1 and Figure 2.

2.1 CAMAC

Another wasy to analyze coincidence rates is to use CAMAC. The advantage of this system is that it can work with larger data samples and can be more flexible; it also has a longer memory and can transfer data to the PC.

A block diagram showing our setup is shown in Figure 3

We repeated the same procedure with varying overlap wtih CAMAC as well. Our collected data for coincidences were consistent with previous QVT measurements.

Figure 1: Graph of coincidences observed vs expected coincidences, for various overlap distances

Figure 2: Graph of coincidences observed vs various overlap distances

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Figure 3: Block diagram of CAMAC and cosmic ray telescope.

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Table 2: Rates for different delays between counters A and B. jt note: I have transcribed these as they are in Ms. Raska's paper. I believe the convention is that delay inserted into the A signal line is negative, and that inserted into the B signal line is positive

Chan. A delay	Chan. B delay	Coin (30 sec)	Coin (1 sec)
-10	0	386	12.9
-20	0	332	11.1
-25	0	314.	10.5
-30	0	168	5.6
0	10	234	7.8
0	20	206	6.9
0	25	96	3.2
0	30	9	3

3 Puzzle of Coincidences with counters separated

Inconsistencies started to appear when we started to look at accidental rates. The expected accidental rate is calculated as follows:

$$A_{single} * B_{single} * \Delta t = ExpectedAccid.rate$$

where Δt is the time window used for the coincidence.

In our case:

$$(1700cts/30sec.) * (4100cts/30sec) * 50ns = 4 \times 10^{-4}cts/sec.$$

But the observed accidental rates was 1 counts/30 seconds! These are clearly inconsistent. Therefore our new task was to inspect the equipment and see if our instruments were working properly.

3.1 Delay curve: is the coincidence window right?

We tested different delay cables for each channel. Results are shown in Table 3.1 and in Figure 4

Figure 4: Coincidence vs relative delay between counters A and B.

Our calcualtion above shows that the time window for real coincidences is $\pm$ 3.2 ns. But the time windown for accidental rates is $\pm$ 50 ns, which is determined by the width of the pulse. To see the relative time of arrival, we increased the length in each counter's cable. The results met our expectations – the rate goes down as the relative different time changes with increasing length of each cable.

Following is a calculation of how long it takes light to travel a distance of 0.32 m in a counter. The index of refraction in the counter is 1.6. so the velocity at which light travels in it is

$$3 \times 10^8/1.6 = 2 \times 10^8.$$

To get the time difference between two pulses then we divide the distance to be traveled by the above velocity:

$$T = x/vT = 0.32m/(2 \times 10^8) = 1.6ns$$

Then multiply by 2 and we get 3.2 ns time difference in a case of complete overlap.

Knowning that each bin in our histogram is 50 picoseconds (= 0.05 nanoseconds), we can calculate the number of bins over which the time difference we just calculated will be spread.

$3.2ns/0.05 = 64bins$

After all the equipment was checked we could now move ont o investigate the physics behind the unexpectedly high accidental rates.

4 Delta rays?

Looking at runs where the counters were separated (expected accidentals), we see sharp peaks. We don't know what causes them at this point, but "delta rays" (electrons liberated from atoms when particles lose a lot of energy in an electromagnetic interaction wtih the electrons in the atoms) are a possibility. Delta rays can be produced above the counter in the air and do not need to have enough energy to penetrate both counters.

For the complete overlap, we see big pulses caused (perhaps) by Cerenkov radiation if the muon hits the PMT on the top counter, which is smaller, or a big solid angle.

For the partially overlapped case, we see smaller pulses equally distributed, more uniformly. This can be explained by the fact that the light produced by coincidence muons now travels equal distances before it arrives to the PMT. We don't see any large pulses, becaues, in cases there was a muon that went through a PMT, that muon had a very small chance of making a coincidence signal, so it was not registered.

Cerenkov radiation occurs when a particle enters a medium at a speed greater than light moves in that medium. It rapidly slows down while emitting electromagnetic radiation.

When a charged particle enters a medium, it can be rapidly decelerated by the Coulomb field of the nucleus. Then a part of the particle's kinetic energy is transformed into photons and emitted as light.

The most surprising result is that we always end up with a very tight time coincidence, even when the counters are separated. It could happen if delta rays are produced by the muon in the air or material above the scintillators. It does not appear that the coincidences are truly accidental, that is, coming from unrelated mechanisms. (For true accidentals, the time differences between the signals in the two counters would be uniformly distributed).

Even if a high energy particle goes through a photomultiplier tube, the signal will not be as big (Cerenkov radiation). Ont he other hand, some delta rays could have enough energy to penetrate the counter and can be a part of the big signal.

4.1 Moving counters outside the building.

Delta ray production depends on the conditions inside and outside the building. The shape of the signal is changed after we insert delay cables (which we must do in order to take the counters outside the building), but the charge is not. The time of arrival might change but the ADC should stay approximately the same.

We then tested for accidentals at several different places and for different overlap/separation conditions.

We see a component of small pulses in the coincident events. The timing remains rather tight, even for small pulses in both counters A and B.

One can also see with the half-overlap runs, shown in Figure 5, dotted that the pulses reduce in size (compared to the solid line full-overlap run), since the ovelap region is in the center of the counters: Cerenkov pulses in the light guide and PMT are excluded, and there is some attenuation as the pulses travel to the PMT's. The partial overlap events also are tighter in time, since the spread of times due to different travel times in the scintillator is reduced.

5 Stack

Our next step was to work with a stack of six large scintillating counters. We placed the small counters on top of the stack and triggered on counters A and B and on the very bottom one. This way we made it difficult for delta particles to make it all the way through the stack, since they don't have enough energy and we made sure the coincidences we were getting now were caused by muons. In this configuration, we noticed that the small pulses (which we tentatively assign to delta rays) were missing. [jt note: what were the rates here?]

Figure 6 shows the pulseheights for the A and B coincidences, with the bottom stack counter required, overlapped, showing the small component substantially suppressed in each counter.

The suppression of the small pulse height events when the trigger requires a penetrating particle, lends support to the hypothesis of delta rays as a part of the coincidence rate. A quantitative analysis of the delta ray trigger rate is beyond the scope of work in 2002.

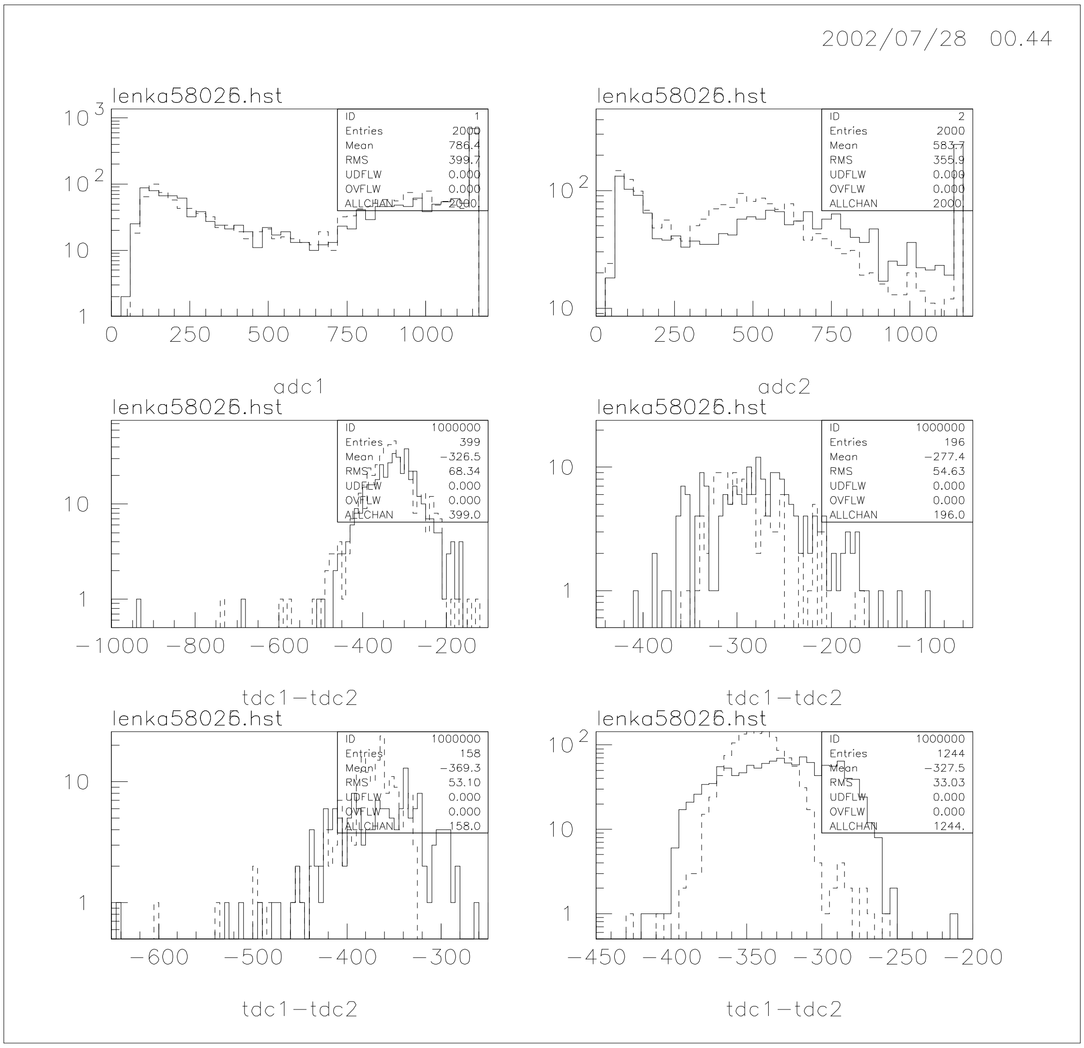

Figure 5: Plots for no penetrating particle required in the trigger. Full and partial overlap plots are superimposed

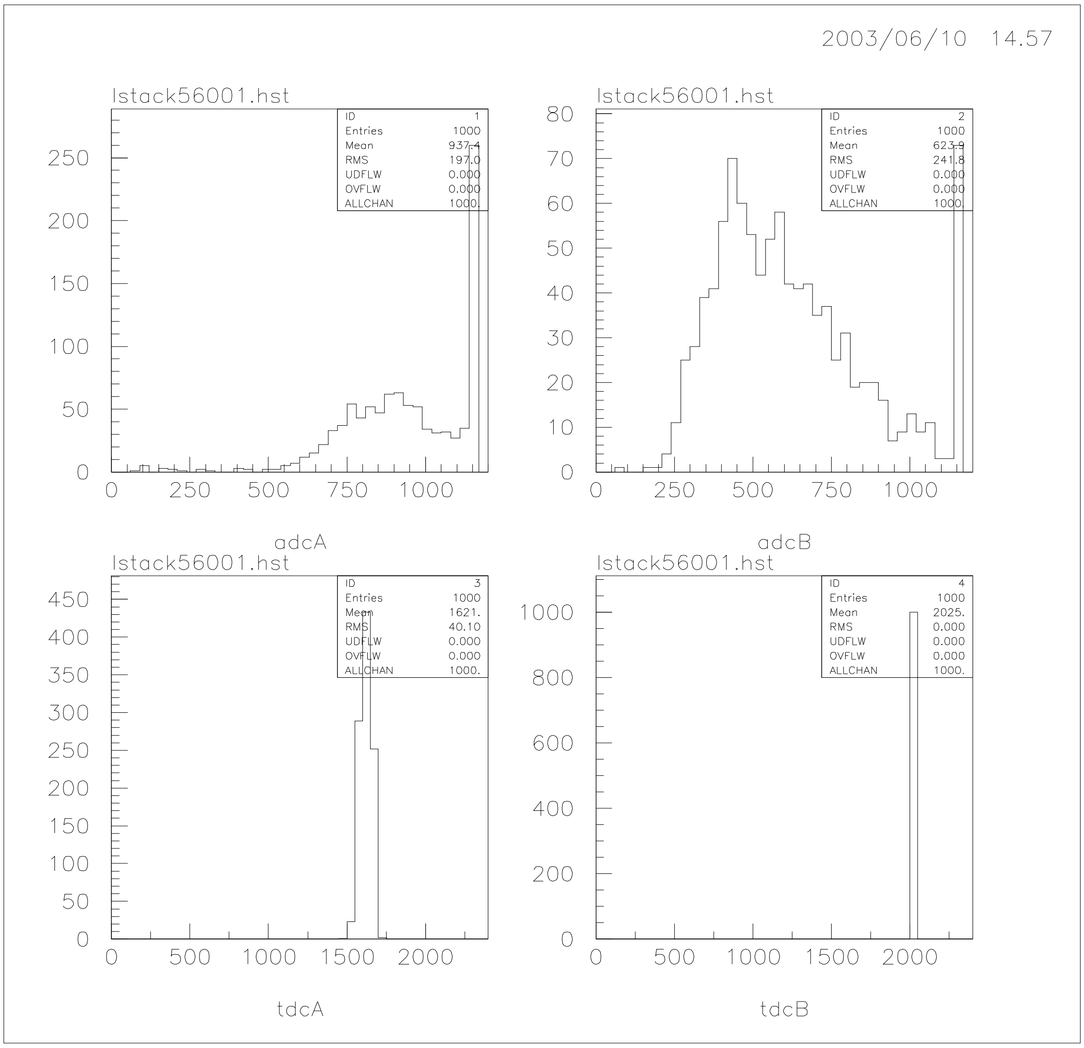

Figure 6: Graph ADC and TDC plots for A and B coincidences, overlapped, on top of the stack, with the bottom stack counter required.

	Overlap(cm)	Lab (cts/sec)	Hall (cts/sec)	Outside (cts/sec)
	Full	6.87	7.07	8.4
	27	–	–	6.7
	17	–	4.6	3.1
	10	–	1.9	2.06
hbt	-10	0.22	0.18	0.1
	-50	0.05	–	0.07
	-100	0.06		0.02
	-150	–	0.016	–
	-400	0.004	–	–

Table 3: Coincidences vs overlap: lab, hall, outside

6 Taking the counters outside

Next we wanted to study these phenomena outside, where the building overburden would be substantially suppressed. But first, we needed to check the effect of running the ADC and TDC signals through the long delay cables necessary if we were to study different stack configurations.

Figure 7 shows the pulseheights for the A and B coincidences with the countes overlapped (without any stack requirement?), showing a component of both large and small pulseheights in each counter, as before. The pulseheights are slightly smaller than without the delay cables in place, as expected due to attentuation in the cables.

Table 3 shows the rates for various degrees of overlap, both inside and outside the building.

Due to lack of time, the remaining runs outside have not been discussed (except for the inclusion of the rates, above) in this paper.

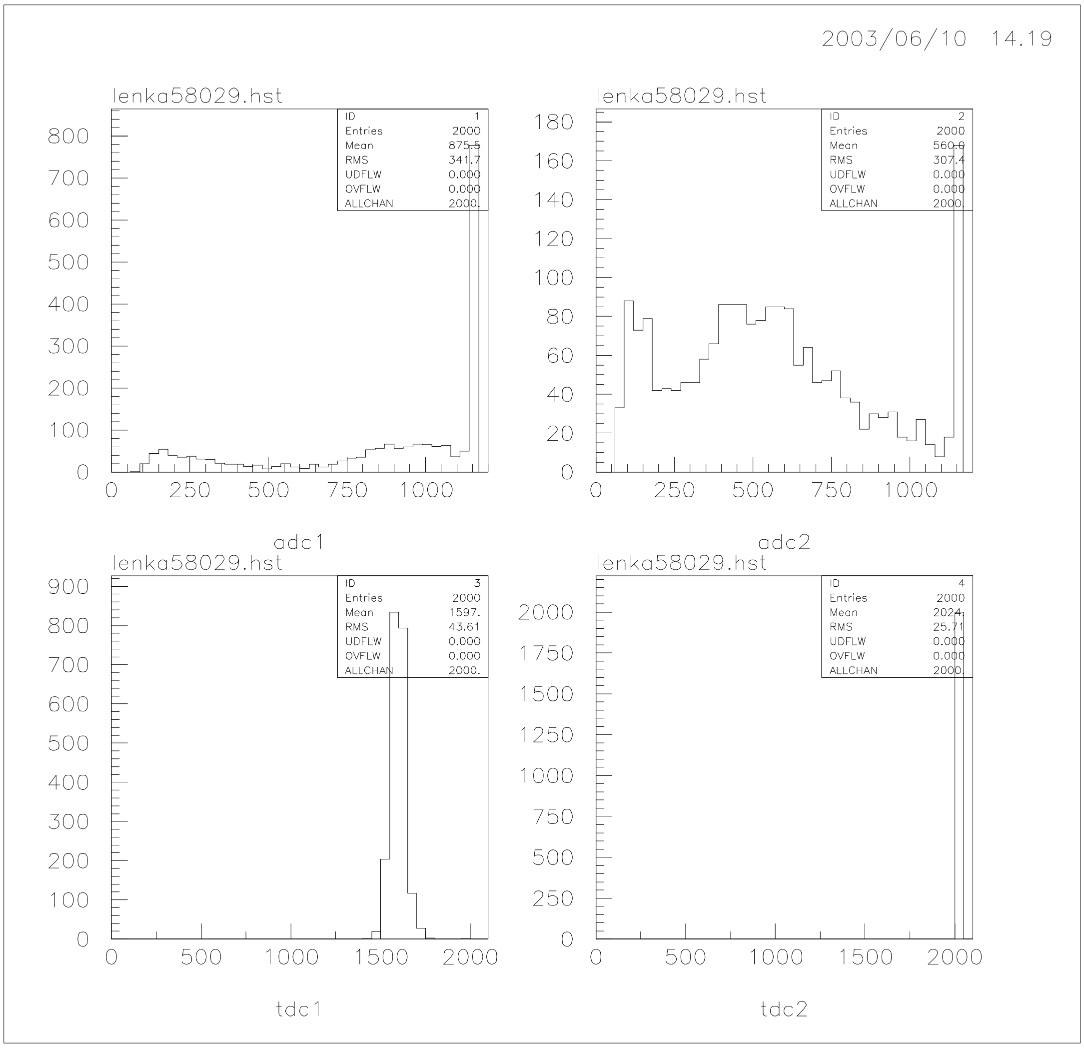

Figure 7: Graph ADC and TDC plots for A and B in coincidence, in the hall, with delay cables in place.

7 Conclusions

Counters A and B are well studied, and their coincidence rates, once a penetrating particle is required, roughly correspond to rates from the stack of 6 large scintillating counters. Pulse height distributions and coincidences qualitativesly support the hypothesis that the small pulseheight events are due to delta rays caused by muons as they travel through the atmosphere or other material.

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