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Study of Backgrounds to the Cerenkov Signal in the RICH Prototype

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Abstract

This tardy note studies the background to the claimed Cerenkov photo-electron yield of 12.5 - 13.0 photo-electrons per image in the RICH prototype data. By studying cosmic ray data with tracks passing through the photon detector we find another, incoherent source of photo-electrons being produced in the LiF radiator. This other form of photon emisssion is found to be isotropic and consistent with the Cerenkov yield expected from delta rays produced by the cosmic ray muon in the LiF. Extrapolating to the trigger configuration of our photon data, we estimate a background of 0.7 photo-electrons/image.

1 Introduction

In this note I summarize a study of the backgrounds to the Cerenkov signal in our RICH prototype. In his study of the Cerenkov yield, Ray Mountain found 12.5 - 13.0 photo-electrons per cosmic ray image using data collected this summer when 5.0σ pedestal cuts were applied.[1] These data agree with the smaller dataset presented by myself at the May RICH meeting using similar cuts.[2] However, in that same presentation, I noted that Alex's Monte Carlo calculation of the RICH yield, with no fudge factors, *etc.*, predicted 12.0 photo-electrons/image, not 13. It has been common lore in the group that the "background" to our number of 13.0 is approximately 1/2 to 1 photo-electron/image. This number is based upon scanning images.[3]

Other sources of clusters detected in the wire chamber ("background photoelectrons") can include (i) electronics noise; (ii) Cerenkov light produced in the CaF_2 windows; (iii) Cerenkov light produced by δ-rays in the LiF – these δ-rays can be produced by the cosmic ray muon; (iv) multi-particle cosmic ray showers not effectively vetoed by the veto counters; (v) scintillation light produced in the LiF by the cosmic ray muon. The observation of (v) was claimed by the CERN prototype group in Reference [4]. They observed an isotropic gas of hits in their photon detector away from their Cerenkov rings. However, they did not prove that the observed background were indeed single photo-electrons, and concluded that the background was scintillation based only on the fact that it was isotropic.

To study the background to the Cerenkov signal, we use the charged track data: in these data, the Cerenkov ring is outside the acceptance of the photon detector, hence any additional signal we observe besides the MIP signal may be used to give evidence for other sources of hits in the chamber besides the usual Cerenkov ring. In Section 2 of this note, I measure the number of background hits per cosmic ray image and characterize their angular distribution and demonstrate that these are most likely single photo-electrons from photons produced in the LiF radiator. In Section 3 I propose a mechanism which explains the observed background. Section 4 summarizes.

2 Analysis of Charged track data

The data used are runs 609 - 708 and 747 - 756 taken this summer. These runs comprise most of the charged track data taken, and consist of nearly 3000 triggers. Because of the large number of chamber trips, the data were scanned and events with window voltage tripped off were removed from the sample. The data were taken with $U_a = 1500$ and 1525 Volts, and the window voltages in these two data sets were adjusted by 50 Volts to achieve the same gain (according to Min's calculations). The data were analyzed using Ray's and Min's pedestal program. Clusters are formed by requiring a seed pad with pulse height $> 7\sigma$ and adding in any nearest- neighbor pads $> 5\sigma$ until no further nearest-neighbor pads pass pedestal cuts.

Three types of trigger data were taken:
(1) Triggers with the charged track passing through the chamber
(2) Same as (1), but passing through a LiF piece
(3) Same as (2), but with the expansion volume open to air.
The situation is shown schematically in Figure 1. In addition to the standard 6x6x1 cm^3 LiF piece used to create our Cerenkov rings, a second LiF piece was mounted above the chamber for the charged track data. The S2 scintillators were configured to trigger on tracks either over or away from this second LiF piece.

Figure 2 shows some of the characteristics of the MIP signal observed in the chamber. The data for these plots were collected with the first type of trigger ("(1)") – ie: taken away from the LiF. Unlike the clusters due to single photo-electrons, these clusters are nearly always in saturation, and typically have 9 - 10 pads passing pedestal cuts. The MIP signal at this gain is in excess of 2000 ADC Counts = 3.6 $10^5 e^-$. Note that the leakage of the MIP signal into the adjacent pads is very small, as demonstrated in Figure 2(d): less than 1% of the MIP charge is typically found on the adjacent pads which fail the pedestal cuts.

As an aside, we actually checked that the MIP signal made sense by looking at lower gains: at $U_a = 1200$ Volts, the mean MIP = 1.6 $10^4 e^-$, which is a gain of 800 assuming 53 e^-/cm in CH_4. Steve and Franz observed that the gain should increase by a factor of 10 for every 200 Volts increase. Thus, at 1450 Volts, we expect the single photo-electron gain to be 4 10^4, in good agreement with what is observed in the photon data [1]. Also, these measurements imply that an unsaturated MIP signal at 1500 Volts would be 1.7 $10^6 e^-$, so that at least 80% He would be required in the photon detector in order to have non-saturated MIP signals.

Thus far we have discussed only the signal left by the minimum-ionizing muon, and have made no mention of any other signals that may be observed in the detector. When we take data in trigger configuration (1), the MIP is the most prominent feature of the event images. However, when we take data in trigger configuration (2), we observe quite a number of other clusters besides the MIP. This observation is shown in Figure

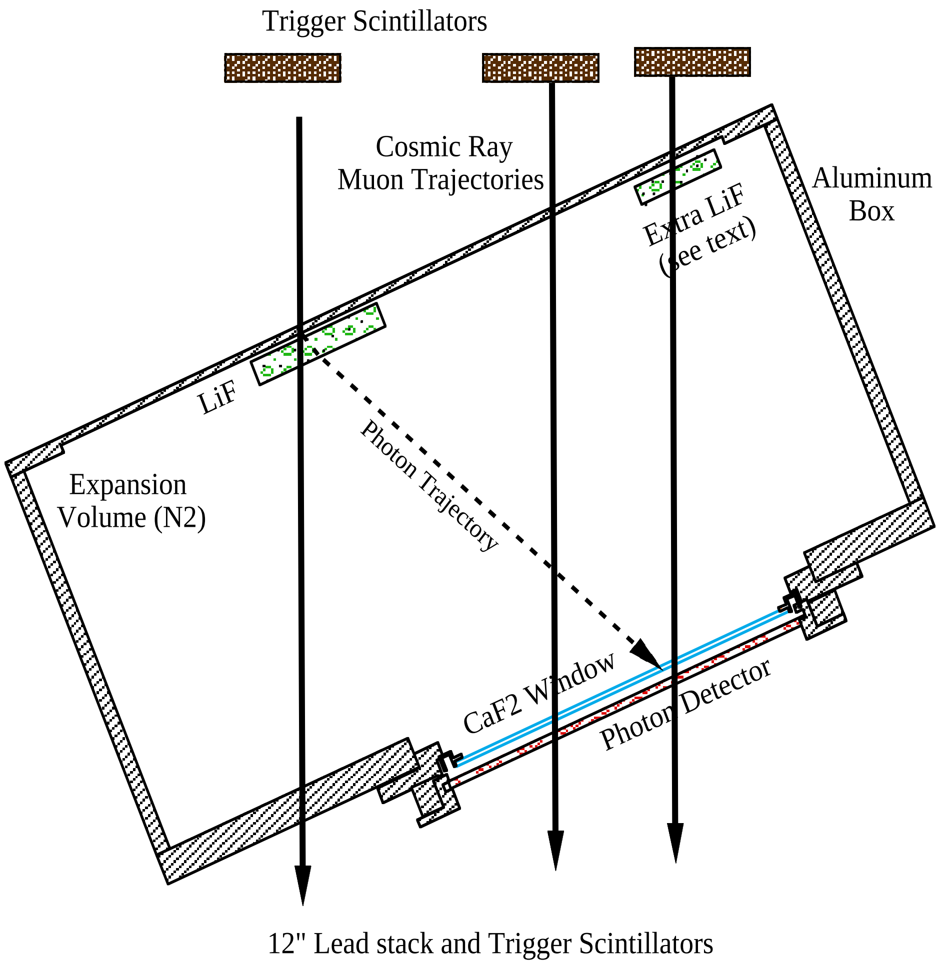

Figure 1: The configurations of the cosmic ray stand during charged-track data taking in Summer of 1995. In addition to the S1 and S2 trigger scintillators above the prototype box, veto counters, as well as the S4 paddle and 9 inches of lead were used in the trigger.

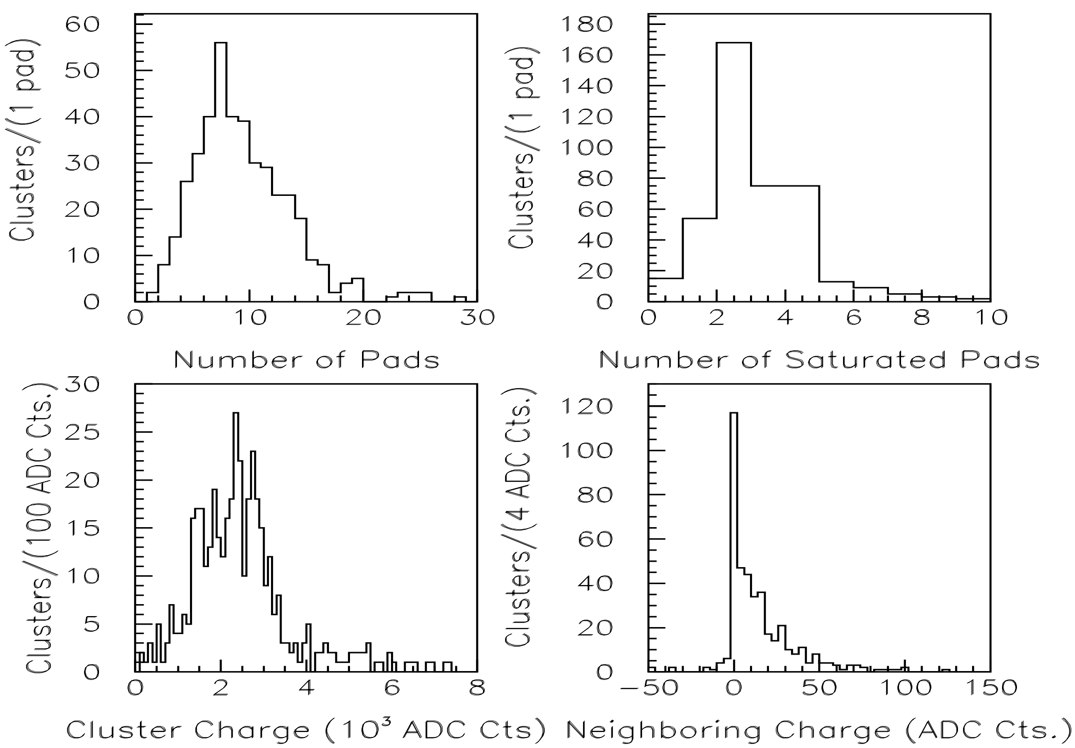

Figure 2: Characteristics of the minimum-ionizing signal left by cosmic ray muons in the RICH prototype: (a) the number of pads in the MIP cluster; (b) the number of pads in the cluster that are in saturation; (c) the total charge in the cluster; (d) the total charge on all nearest-neighbor pads to the cluster.

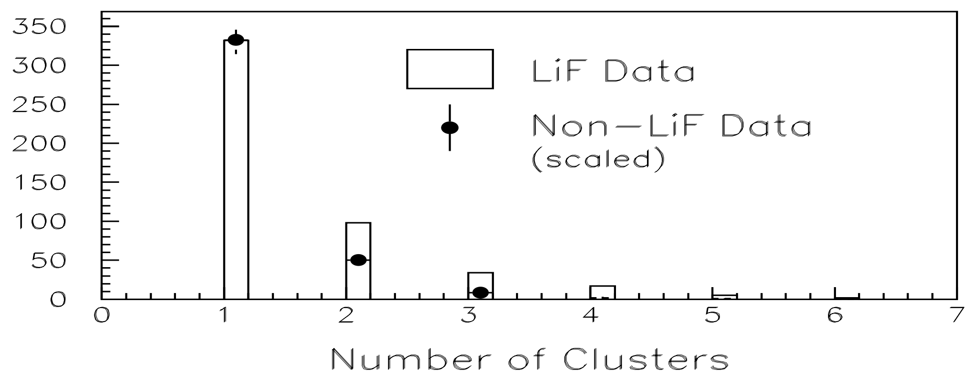

Figure 3: Comparison of the number of clusters observed per event in the LiF data (trigger type 2) and the non-LiF data (trigger type 1). The non-LiF data have been scaled to the same number of events as the LiF data.

3, which compares the number of clusters observed per event in the LiF and non-LiF data (the non-LiF data are scaled to the same number of events as the LiF data). In this plot, one cluster observed indicates that only a MIP signal was observed. The LiF show a tendency to have additional clusters in each event: in the LiF data, 253 “extra” clusters are observed in 489 events, while in the non-LiF data have only 64 extra clusters in 423 events. In terms of rates, the LiF and non-LiF data have 0.52 and 0.15 extra clusters per event, respectively. Thus, the non-LiF data shows an excess of 0.37 ± 0.03 extra clusters per event over the non-LiF data.

From the above observations, we conclude that the presence of the LiF radiator induces the presence of extra hits in an event. Where are these extra clusters located? In Figures 4 and 5 we show that, while the extra clusters in the non-LiF data tend to be near the MIP cluster, the extra clusters are scattered all about in the non-LiF data. It is tempting, given the nature of the non-LiF data, to explain the extra clusters there to Cerenkov light created in the CaF_2 window. The LiF data in Figure 5 also has such a component peaked near the MIP, but also has a component at larger distances. This is demonstrated again in Figure 6, where the distribution of the non-LiF data is subtracted from the LiF data. It looks very much like the $1/r^2$ distribution expected from an isotropic distribution of hits in the chamber (note that a sphere intersected with a plane yields a $1/r^2$ distribution in the plane). Thus the extra hits induced by the LiF appear to be emitted isotropically.

We next demonstrate that the extra clusters due to isotropic emission in the LiF are consistent with single photo-electrons from UV photons emitted in the LiF radiator. First, we note in Figure 7 that the pulse height spectrum of the extra clusters is much softer than that of the MIP signal, and is consistent with that expected for single photo-electrons (the mean pulse height is $7\ 10^4 e^-$). Furthermore, if the expansion volume is not flushed with pure N_2 gas, but is instead left open to air (this is trigger configuration (3)), we observe only 151 extra clusters in 711 events, for a rate of 0.21 extra clusters per event. This yield is more like the non-LiF data yield, and the distribution in separation from the MIP shows the same peaked tendency near zero as the non-LiF data. Thus, we may conclude that this excess, isotropic source in the LiF requires

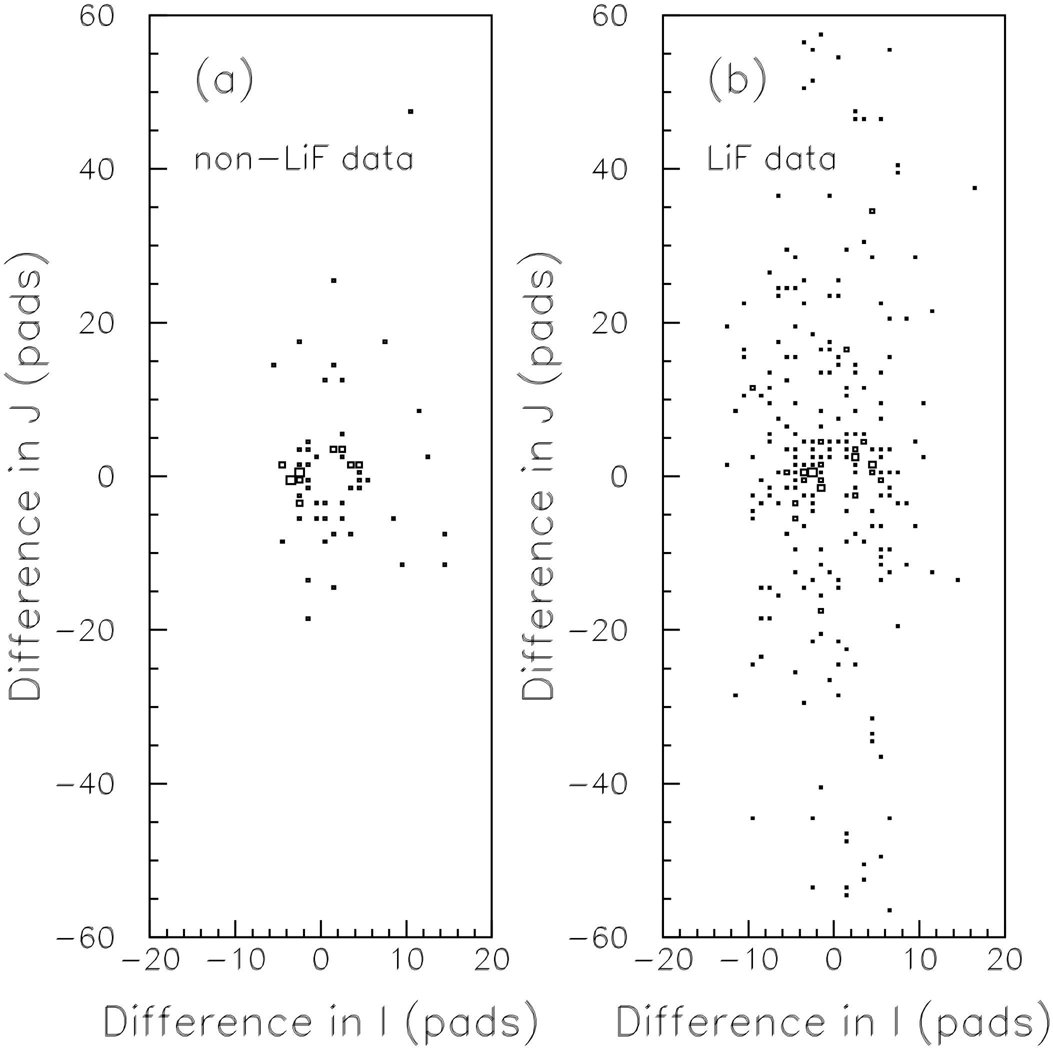

Figure 4: Scatter plots of the separation of the extra clusters in an event from the MIP cluster in the "I" and "J" directions in the chamber (the long axis of the chamber is in the J direction): (a) non-LiF data and (b) LiF data.

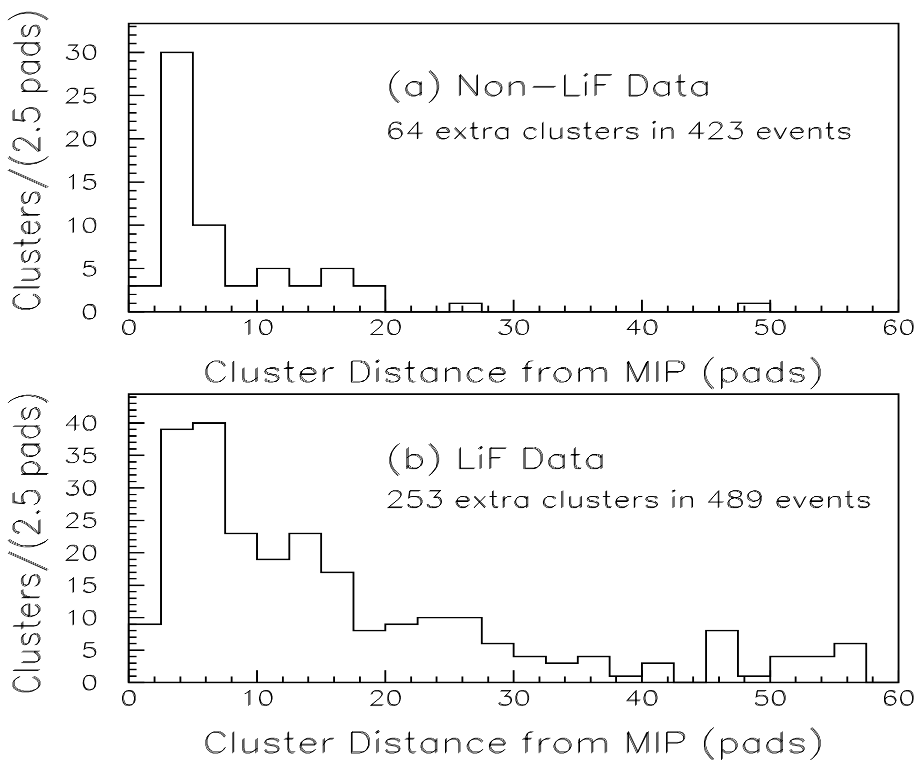

Figure 5: Distance in the photon detector plane between the extra cluster in an event and the MIP cluster: (a) non-LiF data and (b) LiF data.

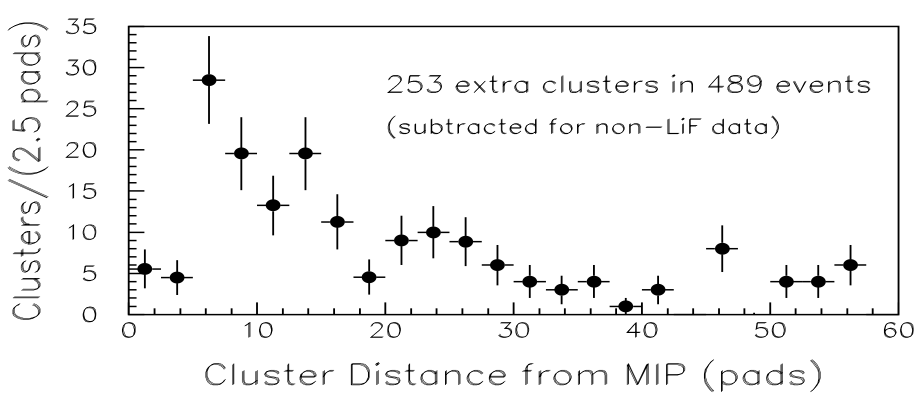

Figure 6: The difference between the distributions in the previous Figure. The non-LiF distribution was scaled to have an area of 73 extra clusters, consistent with what would be expected in the 489 LiF events.

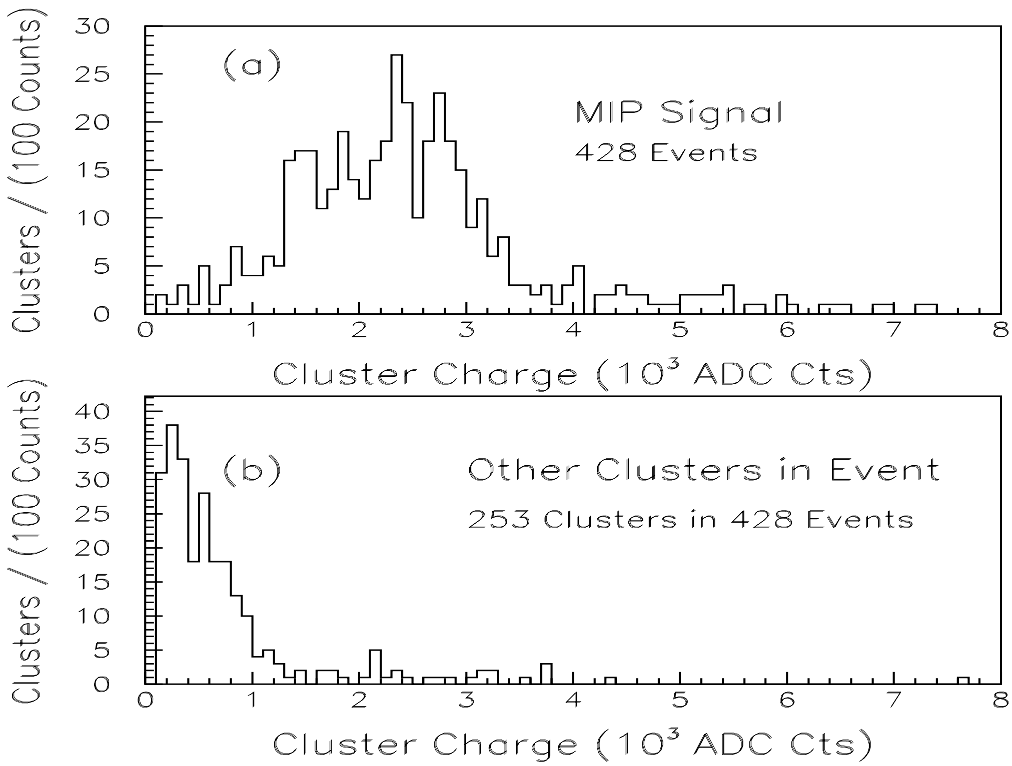

Figure 7: The pulse height distribution of clusters observed in the LiF data: (a) the pulse from the minimum-ionizing muon; (b) all other clusters in the LiF events.

a clean expansion volume in order to propagate to the chamber, much like what is expected for UV photons.

The conclusion of this section is that we observe isotropic emission of photons from the LiF. The yield of the emission is found to be $0.34 \pm 0.02(stat) \pm 0.03(sys)$ extra clusters per cosmic ray image, where I have averaged the trigger (1) and trigger (3) yields to use for a "non-LiF" yield, and used the spread between them as an estimate of the systematic uncertainties due to time-dependence or geometric acceptances.

3 Model for the Observed Backgrounds

In the previous section, we dicussed observations of sources of photons observed in the RICH prototype detector other than the usual Cerenkov ring. These had a yield of 0.34 photons/event when in the charged track configuration, and had a distribution that was isotropic. In this section, we describe one possible source for such photons, and calculate the yield expected in both the charged track and photon data trigger configurations.

In a paper by Grove and Mewaldt [5], it is noted that delta rays produced by the cosmic ray muons in the LiF (also called "knock- on eleclectrons") can themselves produce Cerenkov light if they are above the Cerenkov threshold. In fact, δ rays produced in the Aluminum prototype box in front of the LiF can contribute if they manage to propagate into the LiF. They produce curves of the quantity

$$r \equiv \frac{\text{number photons from } \delta \text{ rays}}{\text{number of photons from Cerenkov ring}}$$

vs. the kinetic energy of the primary particle and for several choices of radiator index of refraction and amount of material upstream of the radiator. The closest calculation relevant to us is Fig 3(a), shown for Lucite (n=1.49), in which case the photon yield from δ rays gives $r \approx 0.1$. This value is not a strong function of the material upstream, but for the record we have 1/8" Al = 0.9 g/cm^2. Their plot is for 4cm Lucite, which is of relevance only for the δ rays coming from the Al. So, given that we see $\mathrm{N_{p.e.}} \approx 13$ in our Cerenkov ring data, we can conclude that approximately 1.3 additional p.e.'s come from δ rays. How many of these δ ray induced photons make it into our chamber acceptance (the above number 1.3 can go anywhere in the prototype box)? I performed a crude little Monte Carlo calculation to show the angular distribution of the photons from δ rays is indeed $1/r^2$, just like what is observed in our data. The calculation follows these steps:

(1) Generate δ rays with an energy distribution given by the Bethe-Bloch formula:

$$\mathrm{N(E)} \approx (1/E^2)dEdx,$$

where E is the energy of the δ ray.

(2) calculate the angle of the δ ray given by kinematics, $\cos^2\psi \approx \frac{E-1}{E+1}$, where ψ is the angle between the muon and the δ ray. This combined with step (1) gives us:

$$\mathrm{N}(\psi) = \sin^4\psi \cos\psi \, \mathrm{d}(\cos\psi)$$

(3) The δ rays are put through multiple scattering with rms scatter given by the usual $(13.6\mathrm{MeV/p})\sqrt{\frac{x}{X_0}}$.

(4) If the energy of the δ ray exceeds the Cerenkov threshold, it is allowed to emit light and the light is propagated away from the LiF. Refractions are taken into account as the light leaves the LiF.

The resulting angular distributions of both the δ rays and the resulting light emitted is shown in Figure 8. The vertical scales in these plots are propotional to $\mathrm{d}N/\mathrm{d}(\cos\psi)$. In these distributions, the cosmic ray muon trajectory is at an angle of zero degress. A flat distribution represents a distribution that is isotropic in space (uniform in solid angle

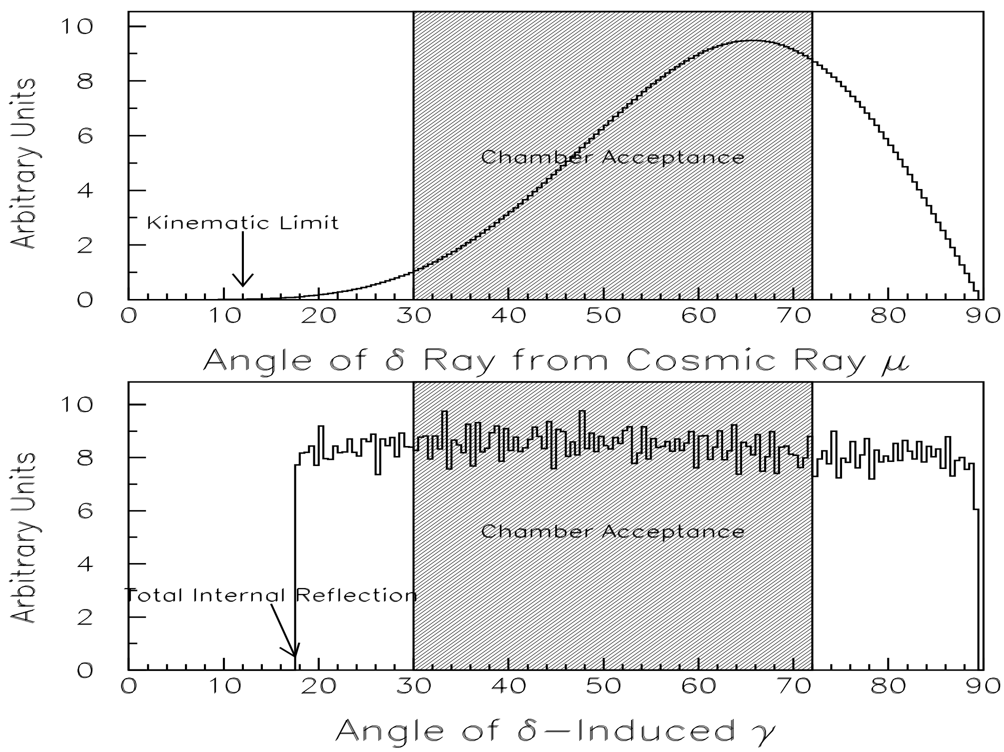

Figure 8: The angular distribution with respect to the cosmic ray muon of (a) δ rays produced in the LiF (before multiple scattering) and (b) of the resulting Cerenkov light from these δ rays. In these plots, zero degrees indicates the cosmic ray muon trajectory. The position of the chamber acceptance is noted for the case of photon data taking.

d(cosψ)). Figure 8(a) is just the $\sin^4\psi\cos\psi d(\cos\psi)$ distribution mentioned above, while the distribution in d(cosψ) of the resulting light is quite flat in space. This fact results from the fact that the δ rays are of such low energy that they go through tremendous scattering in the LiF. The kinematic limit of δ ray production, as well as the limit due to total internal reflection of the light at the LiF boundary, are noted.

Also noted in Figure 8 is the chamber acceptance for the photon data taking configuration. Thus, while there are 1.3 p.e.'s expected from δ rays, only 55% of these make it into the detector during photon data taking, which is a background due to delta rays of (0.55)(1.3)=0.7 p.e.'s per event. Note that during charged track data taking, the zero of this plot is shifted by about 30 degrees, so that only 1/3 of the 1.3 p.e.'s would make it into the detector: (0.33)(1.3) = 0.4 p.e.'s / event. This number agrees quite well with the 0.34 measured in our own data, and the calculated isotropic distribution agrees quite well with the data too.

4 Conclusions

We have made measurements of photon production in the LiF other than due to the usual Cerenkov light production. The observations in the charged track data of 0.34 p.e.'s /image and the observed $1/r^2$ distribution are consistent with the isotropic emission of light by scattered δ rays produced in the LiF. Given these observations, we expect 0.7 p.e.'s/event are non-Cerenkov ring background in our photon data. It should be noted that these observations are consistent with those of Ref. [4], but do not leave much room for their conclusion that the light is due to scintillation in the LiF.

References

[1] This is Ray's most recent analysis of the photon data from the Summer. It is described in Steve's paper for the Uppsala RICH conference and my write-up for the IEEE '95 Conference (RICH Note No. 3).

[2] See my transparencies from the May 1995 RICH meeting at Cornell.

[3] See, for example, Figure 2 of Steve's Uppsala write-up.

[4] R. Arnold *et al.*, Nucl. Inst. and Meth. **A350** (1994) 430.

[5] J.E.Grove and R.A.Mewaldt, Nucl. Inst. and Meth. **A314**, (1992) 495.