pi0's near sea-level from Air-Showers

March 3, 2003

1 Introduction

The idea is that we want to see if we can reconstruct a peak in the invariant mass distribution due to pi0's from air-showers while GLAST is sitting on the ground (i.e. by looking for pairs of gamma-rays from a pi0 decay). This would show that things were working. The purpose of this study was to get a feel for whether the rate of pi0's near the ground is reasonable and what the background (from random gamma-rays) might look look like.

An air-shower is initiated when a cosmic-ray proton or nucleus collides with atmospheric matter. The collision produces nucleons, pions and other hadronic debris and all particles are strongly beamed in the direction of the initiating cosmic-ray. Neutral pions decay producing gamma-rays which initiate electromagnetic cascades. The secondary nucleons and charged pions (with sufficient energy), continue to multiply in successive generations of nuclear collisions until the energy drops below that required for multiple pion production. Since most of the hadrons re-interact, most of the energy ends up in the electromagnetic component, much of which is eventually dissipated by ionization losses. Lower energy charged pions decay to producing muon component to the shower. The particle density is highest in the center of the shower, which is known as the shower core. The transverse momentum of hadronic interactions is much greater than that of electromagnetic interactions. Because of this, the hadrons get kicked sideways and the nucleonic cascades in cosmic-ray air-showers tend to occur in clumps located far from the shower core. This is convenient as it means that the gammas from pi0 decays may fall in less dense parts of the air-shower. (it also makes cosmic-ray induced showers much more clumpy and chaotic than gamma-ray induced showers which is handy if you are a ground based gamma-ray astronomer and wish to distinguish between them).

2 Simulations

I used CORSIKA (http://ik1au1.fzk.de/ heck/corsika/) to simulate the development of the air-shower in the atmosphere. The proton cosmic-ray spectrum measured by JACEE is:

$$dN/dE = 0.111(E)^{-2.8} m^{-2} sr^{-1} s^{-1} TeV^{-1} \quad (1)$$

I threw a set of proton simulations from 20 GeV to 100 TeV on an E-2.8 spectrum, with zenith angles from 0-45 degrees. Thus integrating the above expression the rate of cosmic-ray protons is $N(>20GeV, 0-45deg) = 129.79 m^{-2} s^{-1}$. 49.6×10^6 proton showers were generated, which corresponds to $106 hr m^2$ worth of protons. The rate of muons (above 1 GeV) in these simulations is $0.5 min^{-1} cm^{-2}$ which seems reasonable. The observed muon rate is 1, but I have not included heavier nuclei or showers between 45 degrees and the horizon.

I looked for pairs of gamma-rays from pi0 decays which reached the ground within 1 meter of one another. In the entire sample there were 240 $(2.3hr^{-1}m^{-2})$ pairs of gamma-rays above 500 MeV from 213 proton showers and 118 $(1.1hr^{-1}m^{-2})$ pairs of gamma-rays from 103 proton showers. So these events are not all from the same few showers (instead they are from a small number of unusual showers). The distribution of energies of the gamma-rays from pi0 decays which reach the ground within a meter of one another is shown in Figure 2 (there is a lower energy cut of 500 MeV). This distribution is fairly flat. In these events often the gamma-rays are carrying a substantial fraction of the shower energy.

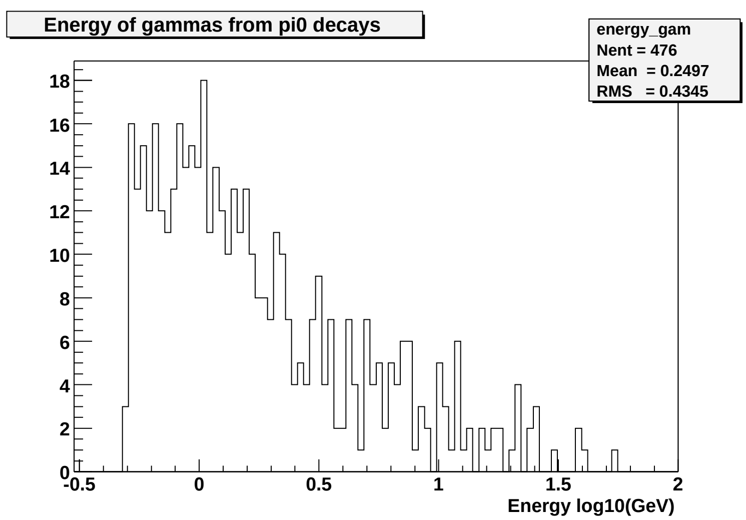

Figure 1: Distribution of energies of gamma-rays on the ground from pi0 decays

The median incident angle (assuming we are pointing at zenith) is at 18 degrees. The distribution of incident angles is shown in Figure 2.

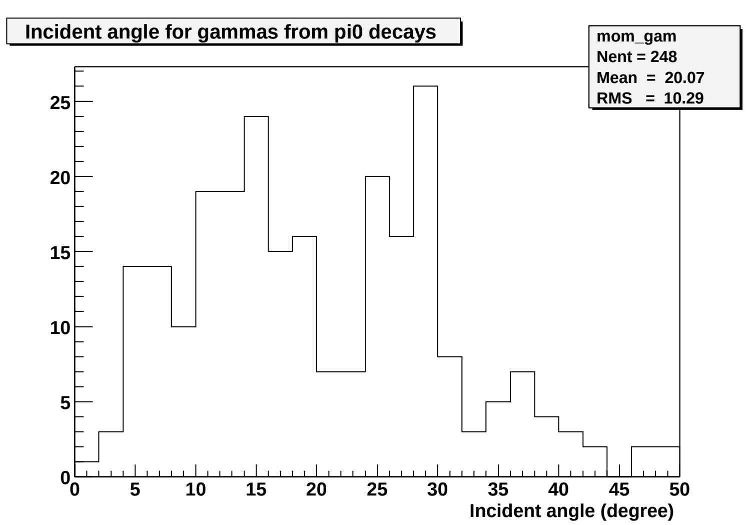

Figure 2: Distribution of zenith angles of gamma-rays on the ground from pi0 decays. The median is at 18 degrees.

These gamma-rays often come accompanied by charged particles, usually pions or protons. Figure 2 shows the distribution of distances from one of the gamma-rays (not either) to the closest charged particle. 29 (0.26/hr) of the 118 pairs of gamma-rays are more than 1 m from the nearest charged particle. These events are very “clean” in that there are also very few accompanying gamma-rays. Figure 2 shows the the distribution of the number of additional gamma-rays within a meter of these 29 events.

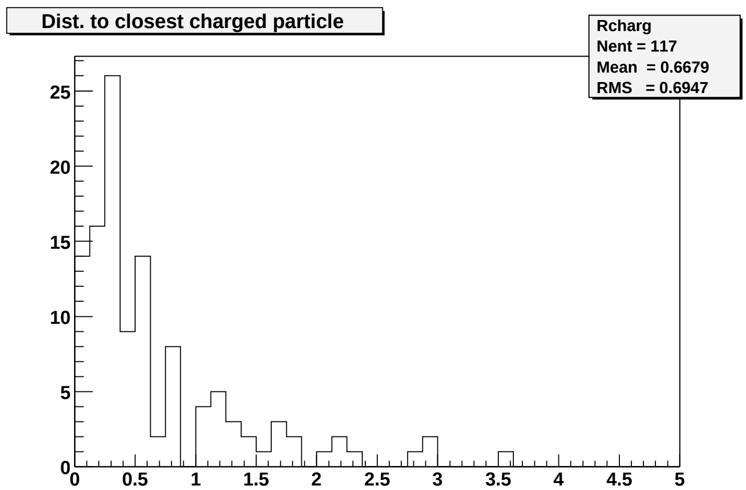

Figure 3: Distance between the gamma-ray and the closest charged particle. 29 events have a distance of more than a meter to the closest charged particle.

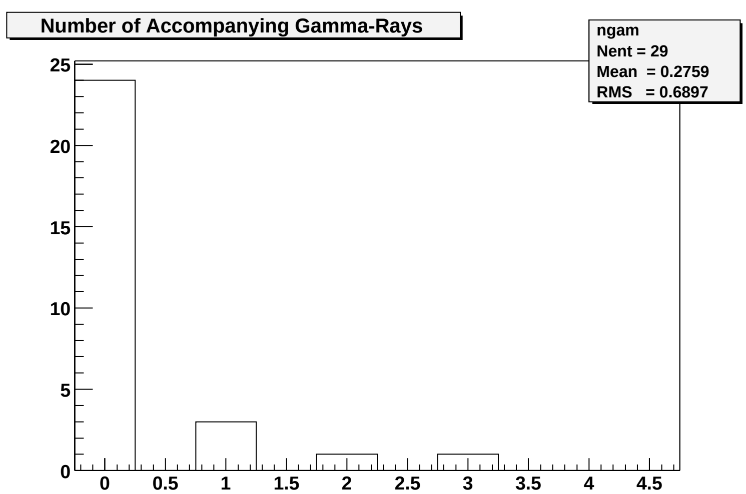

Figure 4: Number of accompanying gamma-rays (within a meter) for the 29 gamma-rays pairs not accompanied by a charged particle

3 Backgrounds

Most gamma-rays at ground level in an air-shower come from electromagnetic sub-showers, not from pi0 decays. These will form a population of background events. This is illustrated in Figure 3. The top panel shows the distribution of invariant mass for pairs of gamma-rays (>1 GeV) which land within a meter of one another. The bottom panel shows the same thing, but with the energies of the gamma-rays smeared by 10% (but still assuming perfect angular resolution). These figures are somewhat deceiving because unlike the gamma-rays from pi0 decays, most of the background pairs come from a few events which have a very large number of particles reaching the ground. The background events would likely be quite challenging to reconstruct because the density of particles is so high (and it is unlikely that we would want to given that gamma-rays from pi0 decay usually happen in less dense parts of the shower). So in reality the background is less of a problem than it appears in these plots.

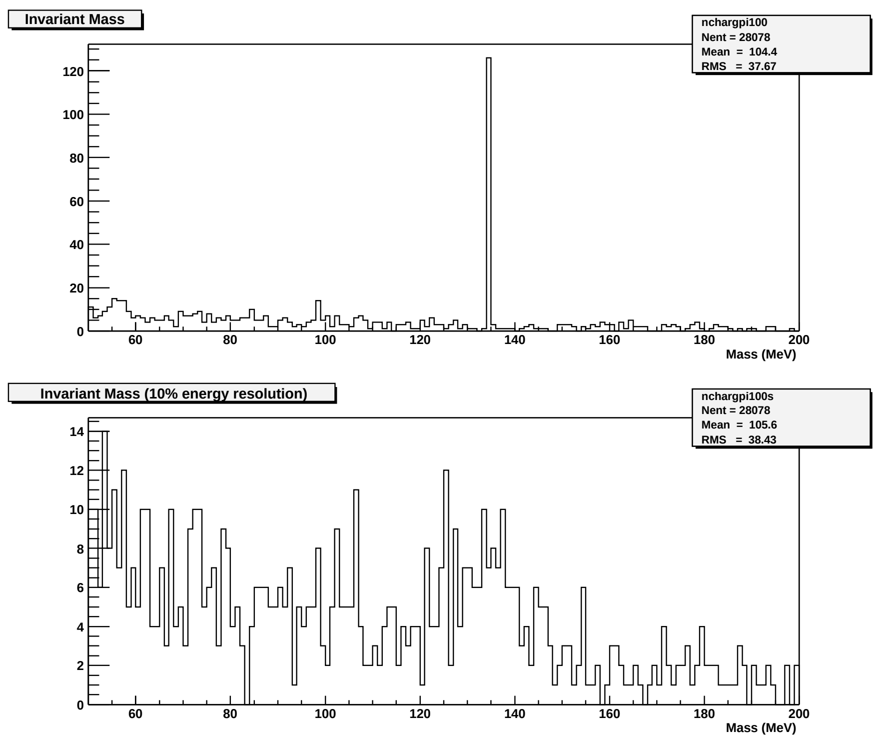

Figure 5: The top panel shows the distribution of invariant mass for all gamma-rays above 1 GeV which land within a meter of one another for the 106 hours of proton simulations. The bottom panel shows the same thing, but with the gamma-ray energies smeared by 10%.

Most of the background pairs of gamma-rays come from electromagnetic subshowers, so they are almost always accompanied by some electrons. Figure 3 shows the distribution of invariant mass for pairs of gamma-rays more than a meter from the nearest charged particle. If we can identify and reconstruct events containing a pair of gamma-rays and nothing else, we should be able to identify a pi0 peak in the invariant mass distribution within a few days to a week.

4 Conclusion

The purpose of this study was to see whether it would be feasible to measure a peak in the invariant mass distribution due to pi0's in air-showers. This may be fairly straightforward because these events are generated in fairly sparse parts of the air-shower and are thus

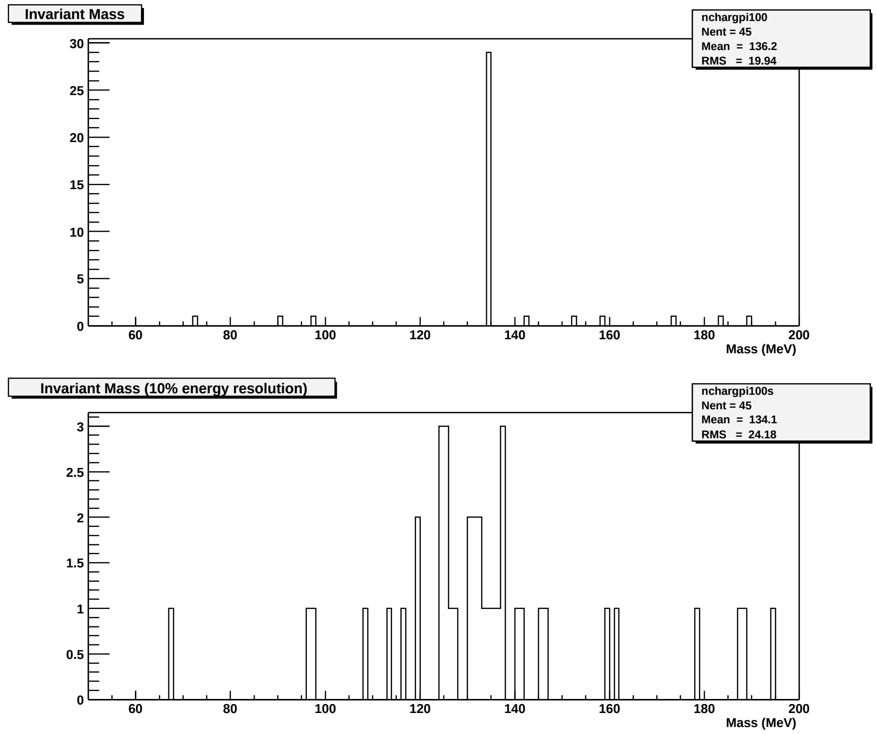

Figure 6: Requiring that the gamma-rays are more than one meter from the nearest charged particle. The top panel shows the distribution of invariant mass for all gamma-rays above 1 GeV which land within a meter of one another for the 106 hours of proton simulations. The bottom panel shows the same thing, but with the gamma-ray energies smeared by 10%.

distinguishable from background pairs of gamma-rays (which more likely occur in dense regions). The results are summarized in Table 4, which gives the rate of pi0 decays which result in both gamma-rays reaching the ground within a meter of each other.

	E > 500 MeV	E>1GeV	E>1GeV, rcharge>1.0 m
rate hr^{-1} m^{-2}	2.3	1.1	0.26

Table 1: The rate of pi0 decays which result in both gamma-rays reaching the ground within a meter of one another. E is the energy of the gamma-rays, rcharge is the distance to the closest charged particle.

These numbers are probably an underestimate. I have not included helium primaries. I suspect that this may not be too important as helium nuclei usually interact higher in the atmosphere than proton primaries, so the probability of a hadron from a helium induced shower penetrating the atmosphere and interacting to producing a pi0 close enough to the ground is probably quite low. The distribution of primary proton energies producing these events peak at ∼30GeV, but the distribution looks like will continue below 20 GeV (which was not included). This is a fairly small effect 5%-10%. The cut on the gamma-ray energy of 1 GeV is somewhat arbitrary, it may be better to loosen this a bit to get more events as background is not all that much of a problem.