Moon Shadow - Simulation Study

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Abstract

Results of simulations to study the effect of deflection in the geomagnetic field for zenith angles greater and less the 45° are presented. These were done for two different assumed resolutions, 0.4 and 0.6 degrees and the expected deflections were calculated using energy spectra for triggers of Milagrito based on Milagritosim simulations. For $\theta < 45°$ the shadow is considerably degraded while for $\theta > 45°$ the shadow degradation is considerably less.

1 Energy spectra

The energy spectra for triggered events with nhit > 80 were generated. Proton showers were generated using EAShower on a -1.7 spectrum starting at 500 GeV and 1 TeV for zenith angles less than and greater than 45 degrees respectively. They were then processed thru Milagritosim to determine the spectra for triggered events. The Median energy for triggers was found to be 4.84 TeV for $\theta < 45°$ and 30 TeV for $\theta > 45°$. These spectra were fitted with power law forms and used in the simulations for studying the shadow of the moon. Input spectra used in the simulation are shown in Figures 1 and 2. I want to point out that even though for zenith angles larger than 45 degrees the mean energy is 30 TeV there are a large number of protons with energies down to 1 TeV. The geomagnetic field will produce substantial deflection for these lower energy particles.

2 Moon shadow simulation

Events were generated with these energy spectra uniformly distributed within ±10° from an assumed moon position in RA and Dec(taken to be ramoon = 30° and decmoon = 0°). The event positions were wiggled about their positions assuming an angular resolution and were deflected in RA using the formula -1.7°/(energy in TeV). This formula represents the sense of deflection and the magnitude of deflection for a trajectory coming in from infinite distance. The space angle between the event direction and the moon position were calculated and all events within 3° of the moon were retained. An output file was written with simulated energies and space angle deviation from the moon for four cases:

(1) no geomagnetic field perfect angular resolution

(2) no geomagnetic field and finite angular resolution,

(3) geomagnectic field and theta greater than 45 ° and finite angular resolution and

(4) geomagnetic field and theta less than 45 ° and finite angular resolution.

Samples of about 20 million events were generated within ± 10 degrees of the moon in RA and DEC and some 2 million were within 3 degrees of the moon.

The effects of geomagnetic deflections are illustrated in Figure 3. These figures were produced for the case of infinitely good resolution with only magnetic field included in the figures for theta greater and less than 45 degrees. What is graphed is the deviation from the moon in the RA direction for events which miss the moon and which have a deviation in declination of less than the size of the moon. The figures show that the major effect of magnetic deflection is to decrease the significance of the shadow, hardly affecting the location of the shadow, i.e. the shadow shift is difficult to quantify. In what follows, therefore, the shadow is studied without any shift of the apparent position of the moon.

3 Results:

These data were then fitted to a constant background and expected moon deficit and a two dimensional gaussian whose σ was determined. Equal area curves with geomagnetic field deflection and for the cases corresponding to $\theta > 45°$ and $\theta < 45°$ are shown in figures 4 and 5, respectively. In these figures the assumed angular resolution was 0.4°. The signficance was determined by calculating the number of sigmas for an angular bin whose size was 1.58×(fitted angular resolution).

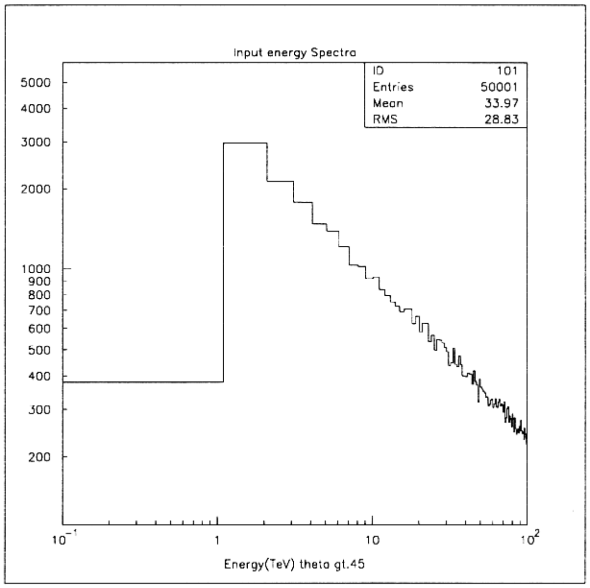

Figure 1: Theta gt 45°

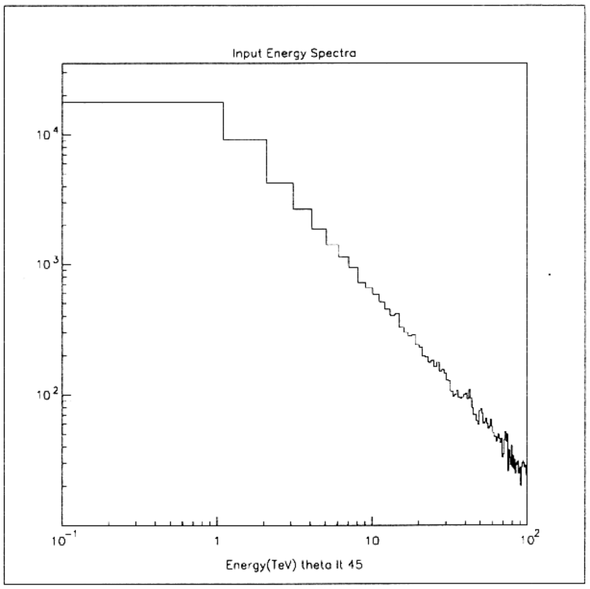

Figure 2: Theta lt 45°

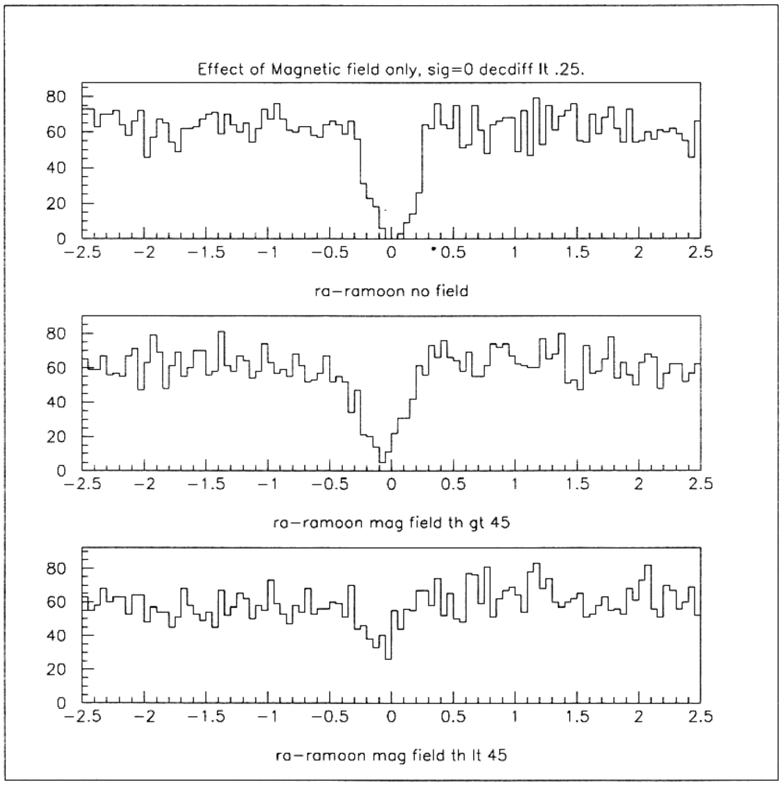

Figure 3: Study of shadow shift due to geomagnetic field

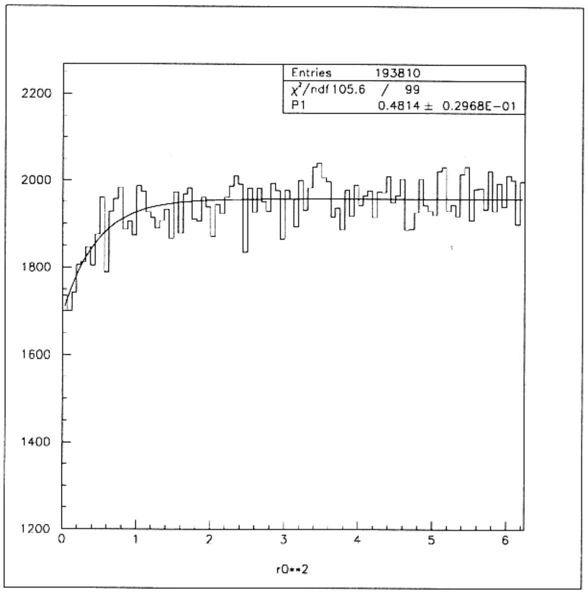

Figure 4: Geomag defl $\theta > 45°$

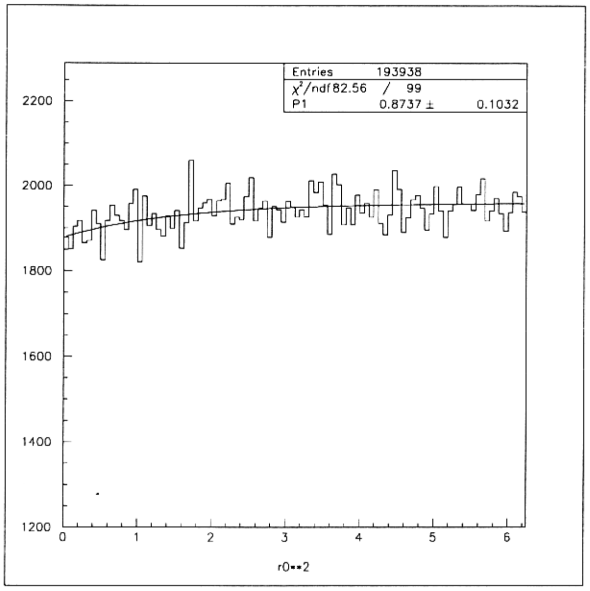

Figure 5: Geomag defl $\theta < 45°$

For large sample of events within 2.5 degrees of the moon position the results obtained for angular resolutions of 0.4 and 0.6 degrees are shown in Table I. The numbers in the table show that for 0.4 degree intrinsic angular resolution, the resolution derived from the Monte-Carlo data sample for $\theta > 45°$ is worse by about 0.09/0.4 or 22 percent. While for the $\theta < 45°$ sample the resolution degrades by 110 percent.

Fluctuations in fitted angular resolution and their signficance are shown in Figure 6, where input σ was 0.4 and each run corresponded to about the median event sample for a daily transit of the moon for $\theta > 45°$, about 5000 events. Distributions are shown separately for $\theta > 45°$ and $\theta < 45°$.

Table I

Input Resolution	Mag Field	Theta	Events in Fit	Output Resolution	Significance No of sigma
0.4°	No	-	390000	0.42 +.08 -.01	12.41
0.4°	yes	$\theta > 45°$	390000	0.49 +.08 -.02	10.8
0.4°	yes	$\theta < 45°$	390000	0.84 +.1 -.07	5.9
0.6°	no		190000	0.62 +.09 -.05	5.64
0.6°	yes	$\theta > 45°$	190000	0.76 +.12 -.08	4.51
0.6°	yes	$\theta < 45°$	190000	0.93 +.15 -.14	3.56

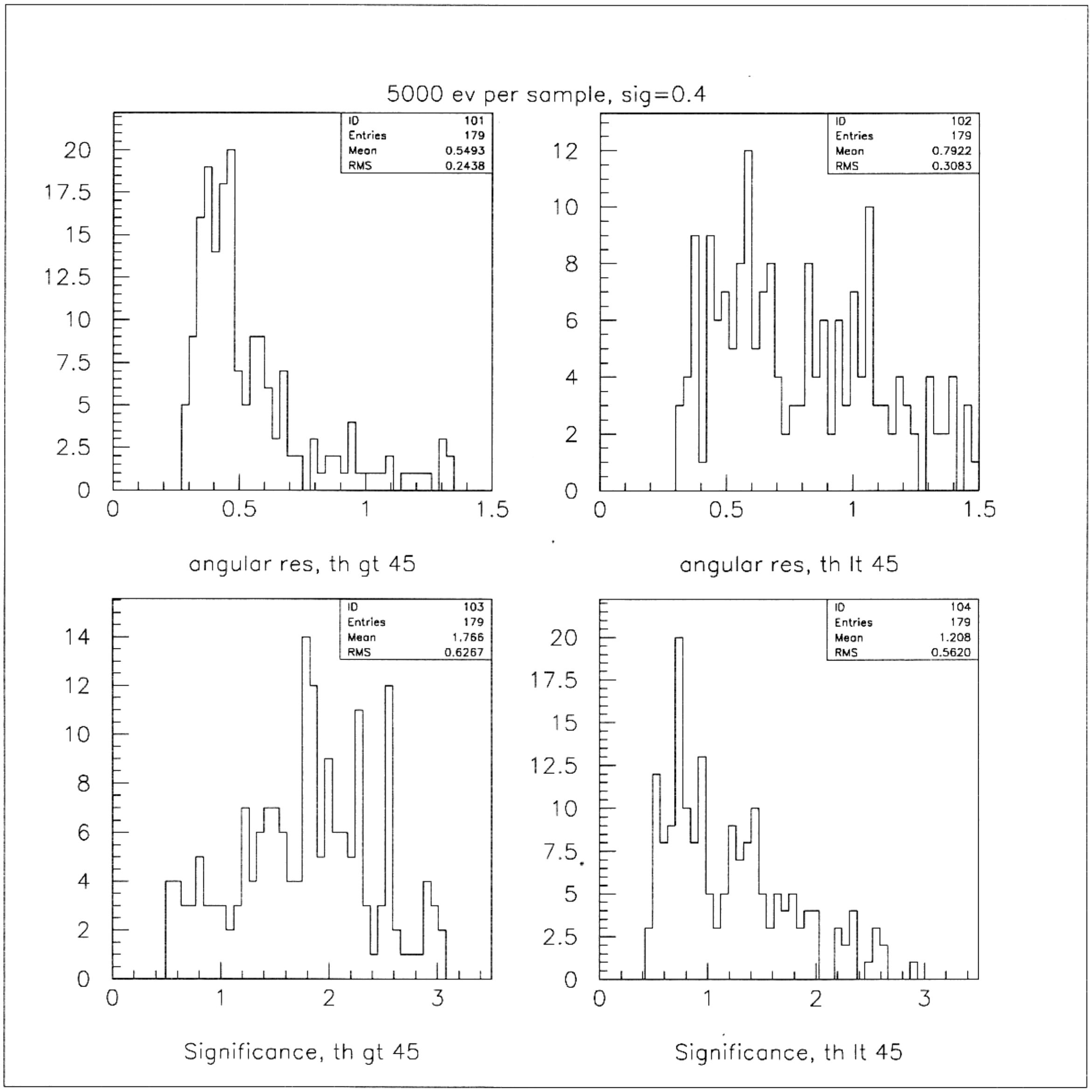

Figure 6: Fluctuations for daily samples of 5000 events

4 Discussion

This study clearly shows that the shadow is degraded considerably for events with $\theta < 45°$ because of deflections in the geomagnetic field of low energy triggers. It also shows that the the intrinsic resolution should be better than one we determine from the study of moon shadow using Milagrito.

Several questions should be addressed in further studies:

(1) How good does the energy resolution have to be in order to be able to correct for the magnetic deflection on an event by event basis?

(2) If that is not feasable, is there a way to cut the data to ensure that energy of events used to study the moon shadow is larger than some minimum energy, for instance say 5 TeV?

I would welcome any other suggestions for avenues to explore on the question of the shadow of the moon.