Simulation of the Moon Shadow Including Magnetic Deflection

R. Ellsworth, 7 July 2003

- There is now a large set of simulated events with proton and helium primaries.
- These events, together with calculated magnetic deflections, may be compared with data to test the "energy scale" of the Monte Carlo.

  (The method described here is similar, but not the same, as that given by Frank at the NYU meeting.)

- To use these events to simulate a moon shadow, account must be taken of the following differences between the Monte Carlo events and the moon shadow data:
  - The MC event primary directions have an isotropic distribution. The distribution of moon directions is not isotropic.
  - The untriggered MC events have core distances drawn from a flat distribution in core radius.
  - The MC event primary energy distribution is

slightly different from the actual measured distribution.

To account for these differences, the MC events may be **weighted** using methods described below, which include the calculation of the uncertainties in the MC quantities. (Methods described more in Ty's thesis.)

General Procedure

For each Monte Carlo event

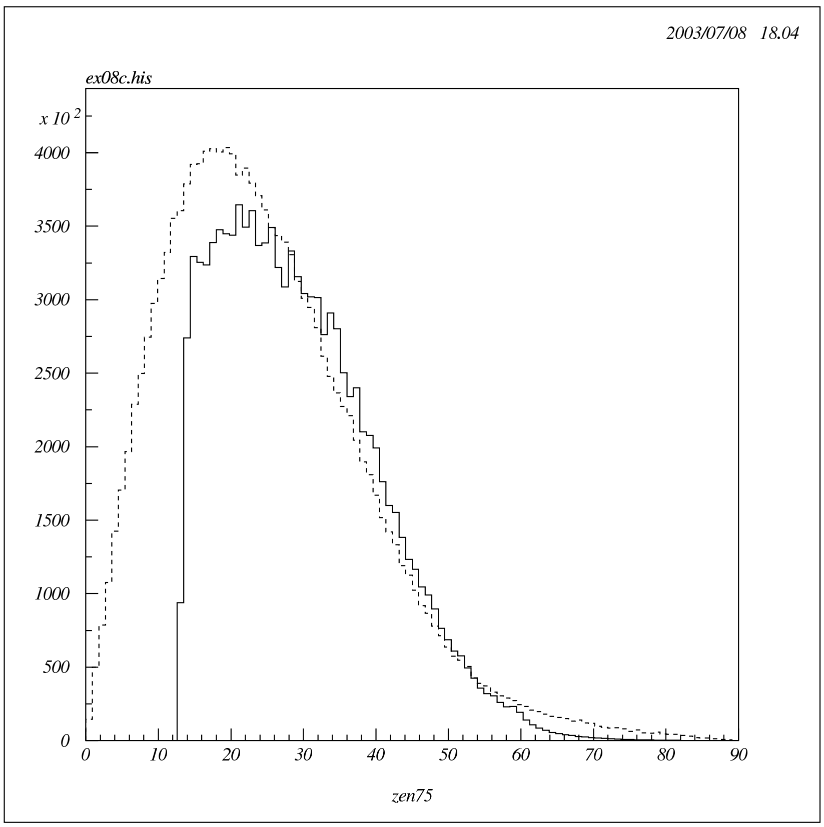
1. Start with E, θ_{recon}, ϕ_{recon}, θ_{actual}, ϕ_{actual}
2. Determine the overall weight $w = w_{radial}\, w_{angular}\, w_{energy}$
3. Use E, θ_{actual}, ϕ_{actual}. to determine the magnetic deflection.
4. Find $\Delta\alpha$, $\Delta\delta$
5. Put this into a map, including the weight.

Then,

1. Compare the MC shadow with the data shadow; compute χ^2
2. Multiply all MC energies by an **energy scale factor** (eg. 1.25); repeat the above procedure.
3. Find the energy scale factor which minimizes χ^2.

Angular weighting

Some zenith angle distributions of all data, and of events close to the moon are shown in Figure (the distributions are not normalized).



In the approximation that the azimuthal distribution is uniform and uncorrelated with zenith angle, the angular weight is

$$w_{angular} = \frac{dn}{d\theta_{data}} / \frac{dn}{d\theta_{MC}}$$

in which the two distributions are normalized.

(Later, if considered necessary, the 2-dimensional distributions $\frac{d^2n}{d\theta d\phi}$ may be used.)

Core Distance Weighting

The Corsika-Geant Milagro Monte Carlo program, developed by Stephan and Julie throws events on the detector with a distribution which is flat in radius.

We need to weight each event by r.

In a weighted histogram, there are N events:

$$N_j = \sum_{k=1}^{n_j} r_k$$

It can be shown that:

$$\sigma_N^2 = \frac{n\overline{r^2}}{r_0^2}$$

See memo
umdgrb.umd.edu/ellswort/mcuncert.pdf

From this equation, it can be seen that, generally,

$$\sigma_N^2 = n\overline{w^2}$$

This equation should be valid for the overall weights.

Energy weighting

The Monte Carlo data already uses energy spectra which are close to those measured in balloon experiments. If necessary, energy weighting can be done in a manner similar to angular weighting.