

Comparison of Magnetic Deflection Calculations and Study of the Energy Dependence of the of the Deflection Direction

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1 Summary

We present here the results of a comparison of calculations of magnetic deflection of protons moving between the vicinity of the Moon and the Milagro site. The calculations agree to within a few hundredths of a degree. The direction of the magnetic deflection has some dependence on particle energy.

2 Introduction

Accurate calculations of magnetic deflections by the earth's and other magnetic fields are required for analysis of the shadows of the Moon and Sun. Over time, several people, including the authors, and Morgan Wascko ¹, have developed algorithms for these calculations. The methods were developed independently, and are somewhat different, so a comparison of their predictions is a useful test of the methods.

3 Some details

A data set was generated by one of us (AM) and sent to other. Times were chosen randomly over a 10-day period in December 2002. The Moon RA and DEC were determined, as well as local coordinates, and magnetic deflections calculated.

Separate data sets were made for energies of 100 GeV and 1 TeV. ²

Various quantities were calculated, but the one chosen for comparison was the following: an antiproton was trajected from the Milagro site, initially pointing in the direction of the Moon. When the Moon distance was reached, the differences, $\Delta\alpha$ and $\Delta\delta$ in topographic (parallax-corrected) RA and DEC between final and initial directions was found for each event.

¹PhD Thesis, posted on <http://scipp.ucsc.edu/milagro/papers/>

²RE used the date and time to find the moon location and its local coordinates and compare with AM's. They agree within a few hundredths of a degree.

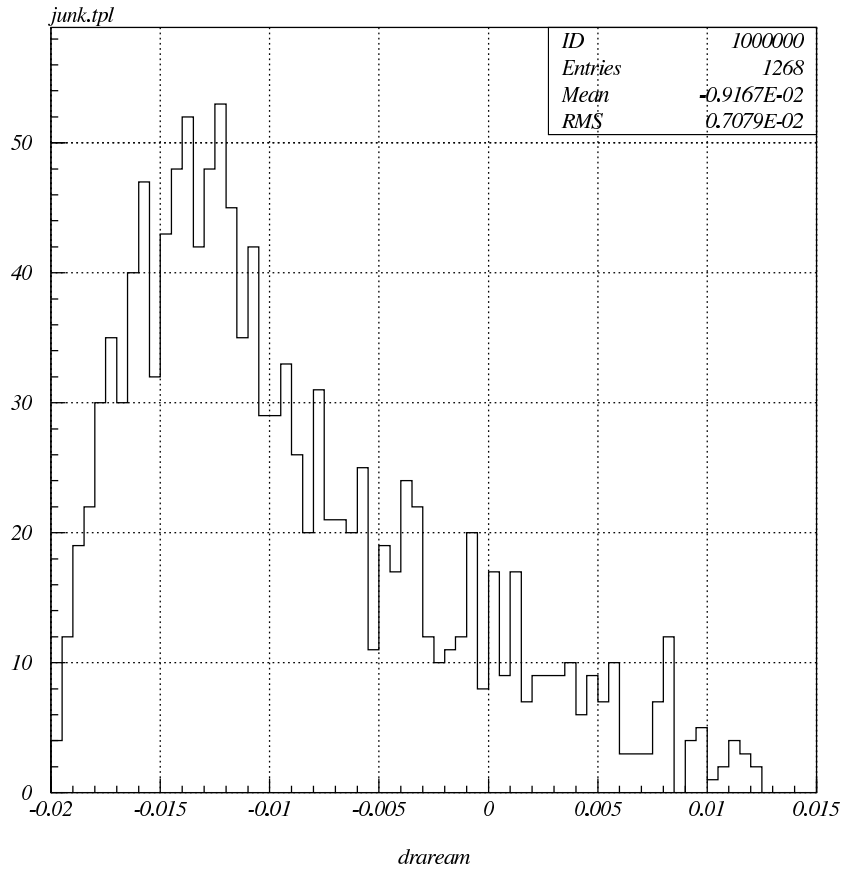


Figure 1: $\Delta\alpha_{RE} - \Delta\alpha_{AM}$, $\approx 100\text{GeV}$ data.

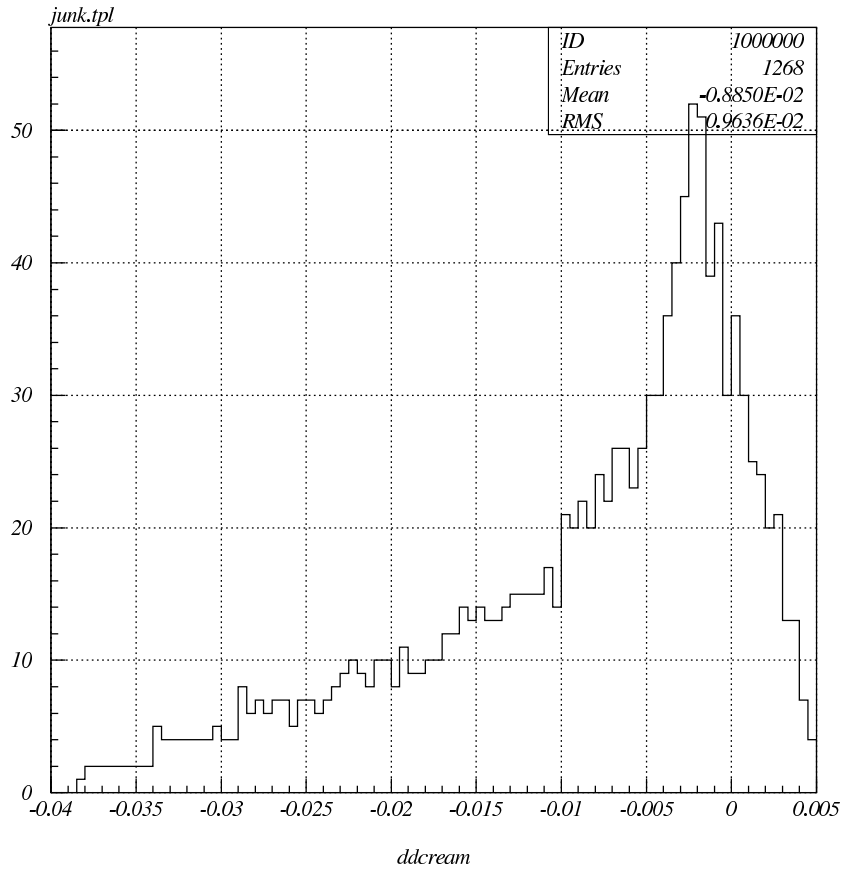


Figure 2: $\Delta\delta_{RE} - \Delta\delta_{AM}$, $\approx 100\text{GeV}$ data.

Small initial differences between the routines in the starting altitude, and location of magnetic poles, and the magnitude of the earth's dipole moment were zeroed out.

The difference between calculations, eg. $\Delta\alpha_{RE} - \Delta\alpha_{AM}$ and $\Delta\delta_{RE} - \Delta\delta_{AM}$ for the $\approx 100\text{GeV}$ data, are shown in Figures 1 and 2.

The mean and rms are $-.009^\circ$ and $.007^\circ$, and $-.009^\circ$ and $.01^\circ$ for RA and DEC respectively.

For the $1 - \text{TeV}$ comparison, the corresponding quantities are: Mean and rms are $-.001^\circ$ and $.006^\circ$, and $-.003^\circ$ and $.004^\circ$ for RA and DEC respectively.

4 Energy Dependence of Deflection Direction

A routine was written which finds the velocity vector at Milagro of an anti-proton which hits the Moon, and the the velocity vector of a neutral particle aimed at the Moon. The trajecting procedure tested above was used, and iterated until the launched antiproton comes within $.02^\circ$ of the moon center. The particle energy is input to this routine.

For several, fixed local hour angle-DEC pairs, the routine was used to compute the deflections and then the angle between the deflection direction and the RA direction. These results are shown in the next figure. It is evident that in the TeV range the deflection direction is roughly independent of energy. In the few-hundred GeV region, however, the direction is energy-dependent.

This means that the method of “rotating” moon-shadow data to a frame in which the deflection is along one axis and there is no deflection along the other axis is an approximation. From experience, we know that the method works fairly well, but we cannot expect it to work perfectly.

The overall effect of this energy dependence will be studied with proton Monte Carlo data.

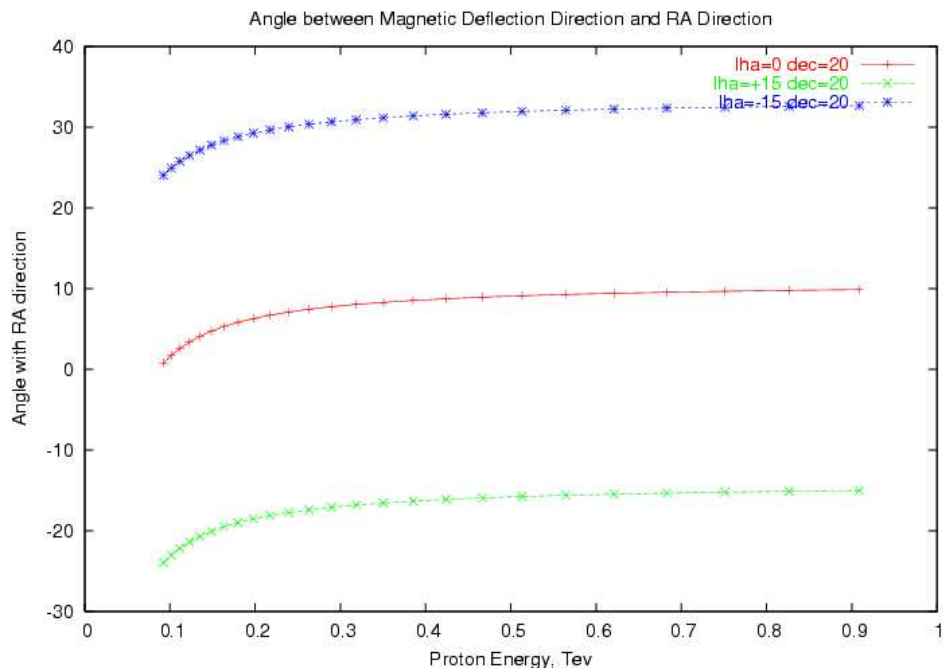


Figure 3: Angle between deflection direction and RA direction, vs. energy, for $\delta = 20^\circ$, $lha = -15^\circ, 0^\circ$, and 15°