Moon Memo Part 1: The $\Delta\theta$ vs. θ systematic and the Moon Shadow

by **Morgan O. Wascko**

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Abstract

I describe the parameterization of the angular resolution and $\Delta\theta$ vs. θ systematic effect using the Milagrito Monte Carlo. I describe how these parameterizations are used in the moon shadow simulation. I compare the offset position of the shadow in data and simulation and find that the magnetic field effects contribute only to a net offset in right ascension, and that it is the $\Delta\theta$ vs. θ systematic that causes the declination offset.

1 Parameterizing the detector effects

At the time of this writing, we have almost a million MC proton showers for Milagrito. The work in this memo uses only version 23 of the offline reconstruction code. This results in a whopping 3091 triggers with an 80 tube threshold. I split those triggers into 7 nfit bands of roughly equal population. This is not enough triggers to directly use them in a source (or shadow) simulation, but it is certainly enough to draw reasonable parameterizations.

1.1 ΔAngle

ΔAngle is the space angle difference between the throw angle and the reconstructed angle of an event. It is, by definition, always positive. It is also expected to be distributed as $r \times$ *Gaussian*, because it is the projection in r of a two-dimensional Gaussian.

The ΔAngle distributions are well fit by $r \times$ *Gaussian* (see Figures 1 and 3), with the exception of long tails in the lower nfit bands. These tails disappear for high nfits. I have also refit these distributions as the sum of two $r \times$ *Gaussian* functions, in an effort to account for the tails. However, I haven't implemented this

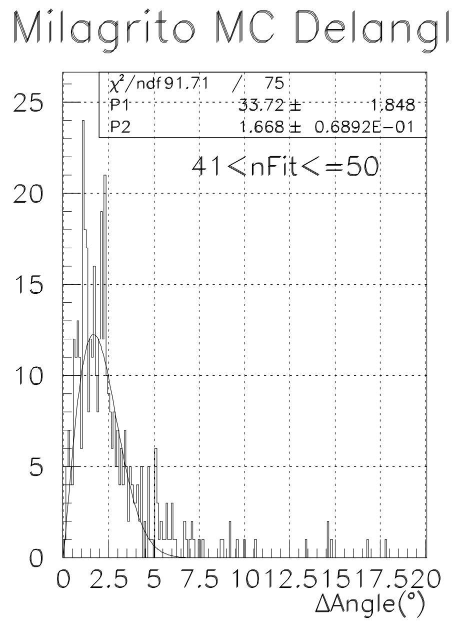

Figure 1: Typical delangle plot. The histogram is fit to the function $P1 \cdot x \cdot e^{-x^2/2(P2)^2}$, with the fit parameters shown.

parameterization into the moon shadow simulations yet. ΔAngle is found to be a strong function of nfit, as shown by Figure 5.

1.2 $\Delta\theta$ vs. θ

The $\Delta\theta$ vs. θ systematic is a tendency to reconstruct showers with larger zenith angles than the actual zenith angle of the incident primary. To parameterize $\Delta\theta$, I make profile plots of θ_{throw}–θ_{recon} for each nfit band and fit these to a straight line (see Figure 2 and 4). I only fit these plots from 5^o up to 45^o because this parameter is biased at zenith due to the fact that θ must always be positive. And, of course, we currently have no showers past 45^o. The plots show that this effect is a strong function of nfit, as shown by Figure 5.

2 Simulating the Moon Shadow

I generate events by finding the moon's position for a given day and time, applying the geomagnetic deflection and then smearing the deflected position to account for the detector effects. The geomagnetic deflection is done as a function of incident angle and rigidity. For events that trigger the detector, I smear the position by a 2-D Gaussian with σ given by the fit of the ΔAngle distribution for the nfit of the event. Then I impose $\Delta\theta$ on the position, using $\theta_{throw}+\Delta\theta$. A full description of that work will follow this memo.

Over the course of a transit, the offset in declination due to the magnetic field cancels out, and the only net offset due to geomagnetic deflection is in right ascension. It is the $\Delta\theta$ systematic offset that shifts the shadow of the moon down in declination. But my parameterization gives about twice the offset we see in the data. If I naively cut the parameterization in half, it gives an offset very close to that seen in the data, as shown in Figure 6.

Applying this half-parameterization to the data does correct the offset in declination. (See Figure 7.) But the width of the deficit increases and the significance therefore decreases slightly after this change (see Figure 8). Note that the measured resolution, as defined by the width of the deficit, is better in the data than the simulations would predict.

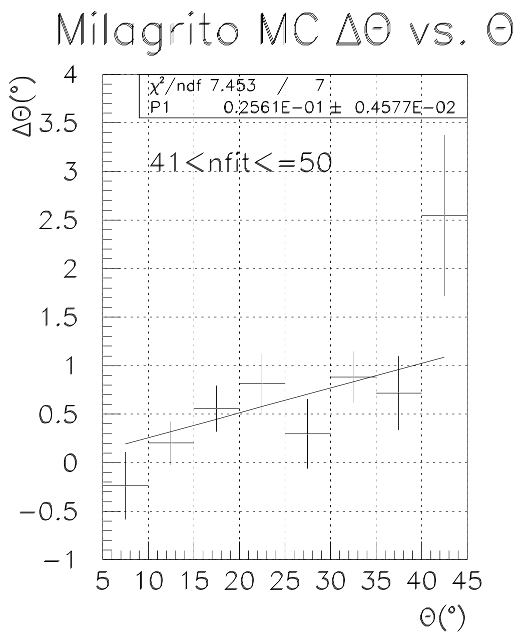

Figure 2: Typical $\Delta\theta$ vs. θ plot. The histogram is fit to a straight line, with the intercept constrained to be zero. The error bars shown are the errors on the means.

3 Conclusions

The offset of the position of maximum deficit of the Mlagrito moon shadow is due to the combined effects of the geomagnetic deflection and the $\Delta\theta$ vs.θ systematic. The RA offset is due to the geomagnetic deflection of cosmic rays, but $\Delta\theta$ vs. θ systematic is needed to explain the net Dec offset.

3.1 What's Next?

The next thing to do is to try to figure out a better parameterzation of the systematic effect. The errors on $\Delta\theta$ are much larger for the lower nfit bands, so tinkering with the parameterization in these regions is probably the best place to start. In the high nfit bands, the errors on $\Delta\theta$ are much smaller and the paramterization fits have smaller χ^2 values, so changing them seems less likely to be successful. Also, Figure 6 shows that the MC predicts that the width of the deficit should not change with or without the $\Delta\theta$ correction, so I need to tinker with the parameterization to elicit this behavior as well.

Finally, helium and nitrogen initiated showers must also be used for a proper simulation.

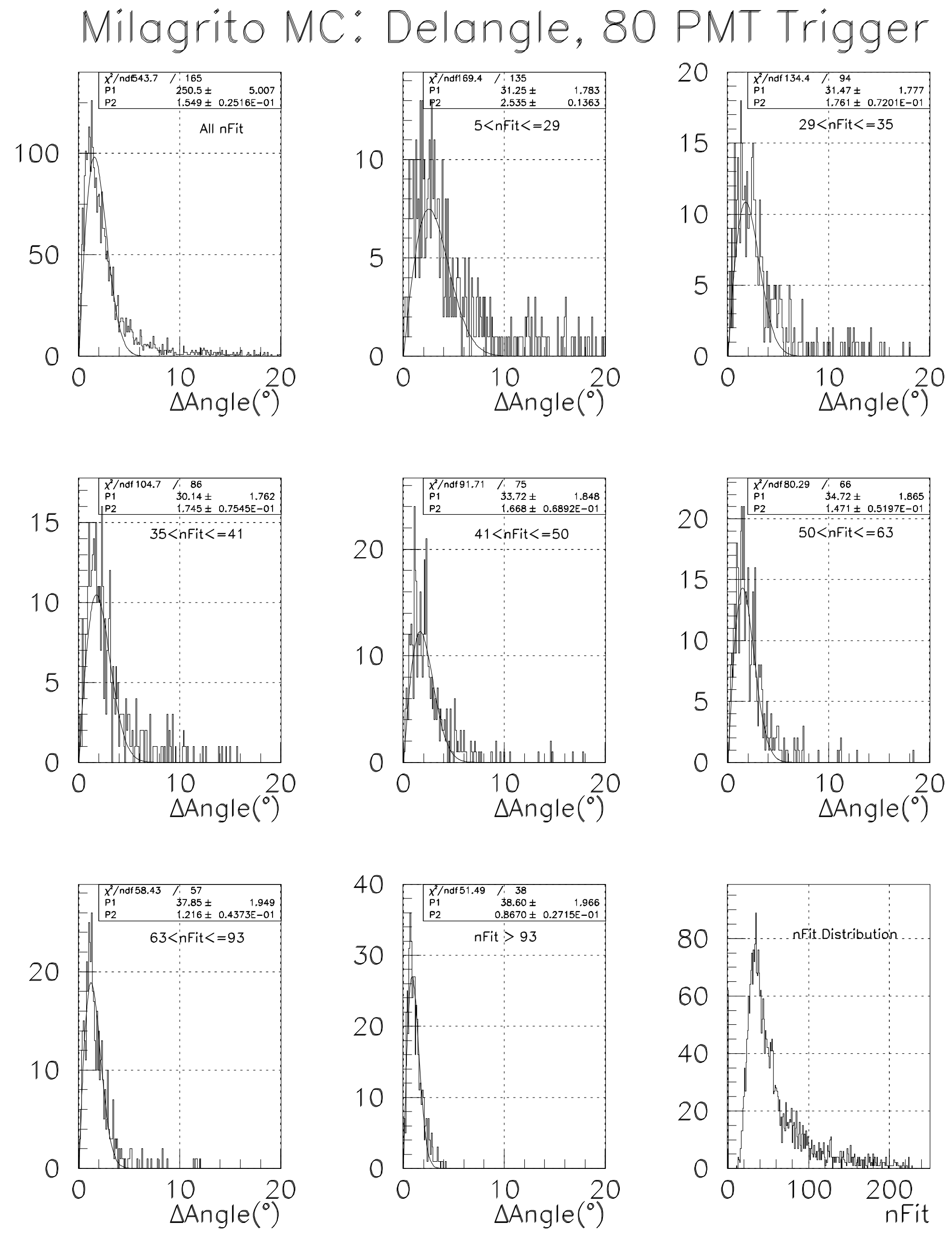

Figure 3: The delangle plots for each nfit band. Shown also is the delangle plot for all events and the nfit distribution.

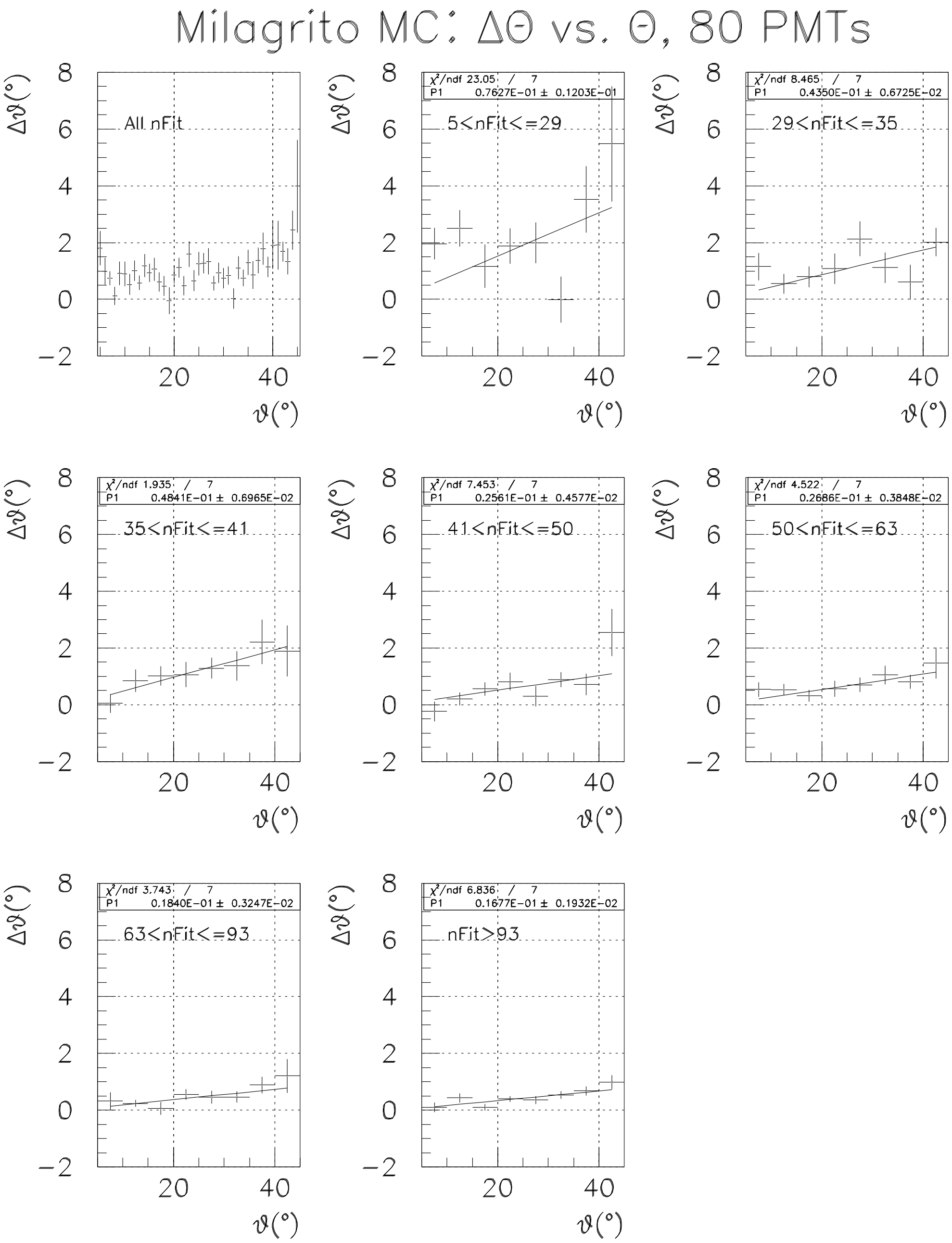

Figure 4: The deltheta vs. theta plots for each nfit band.

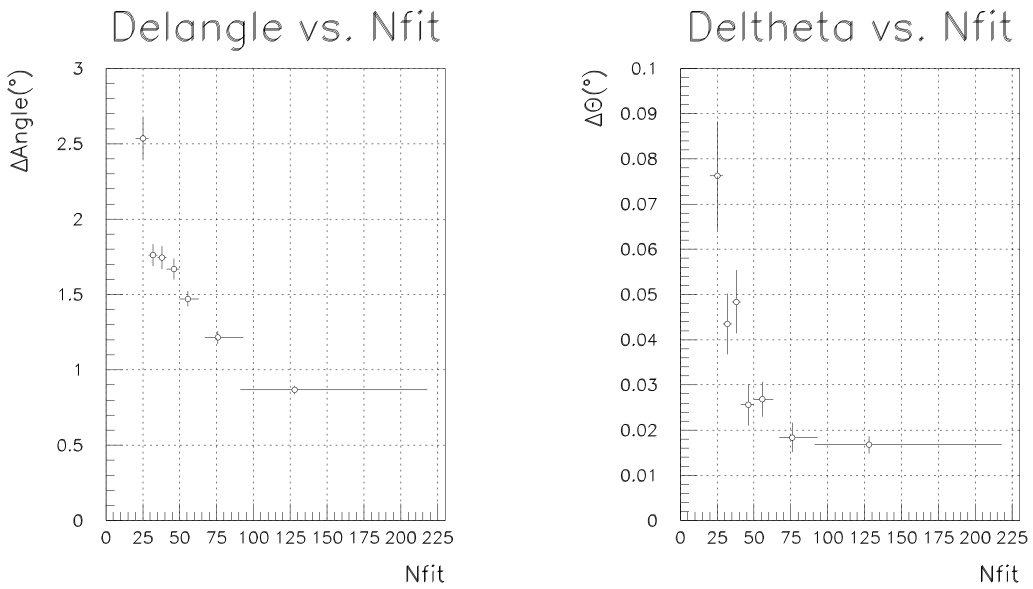

Figure 5: Delangle vs. nfit, and delth vs. nfit. On the abscissa of each plot, the position of the point is placed at the median value of nfit, and the error bars represent the band containing 90% of the data for that nfit band.

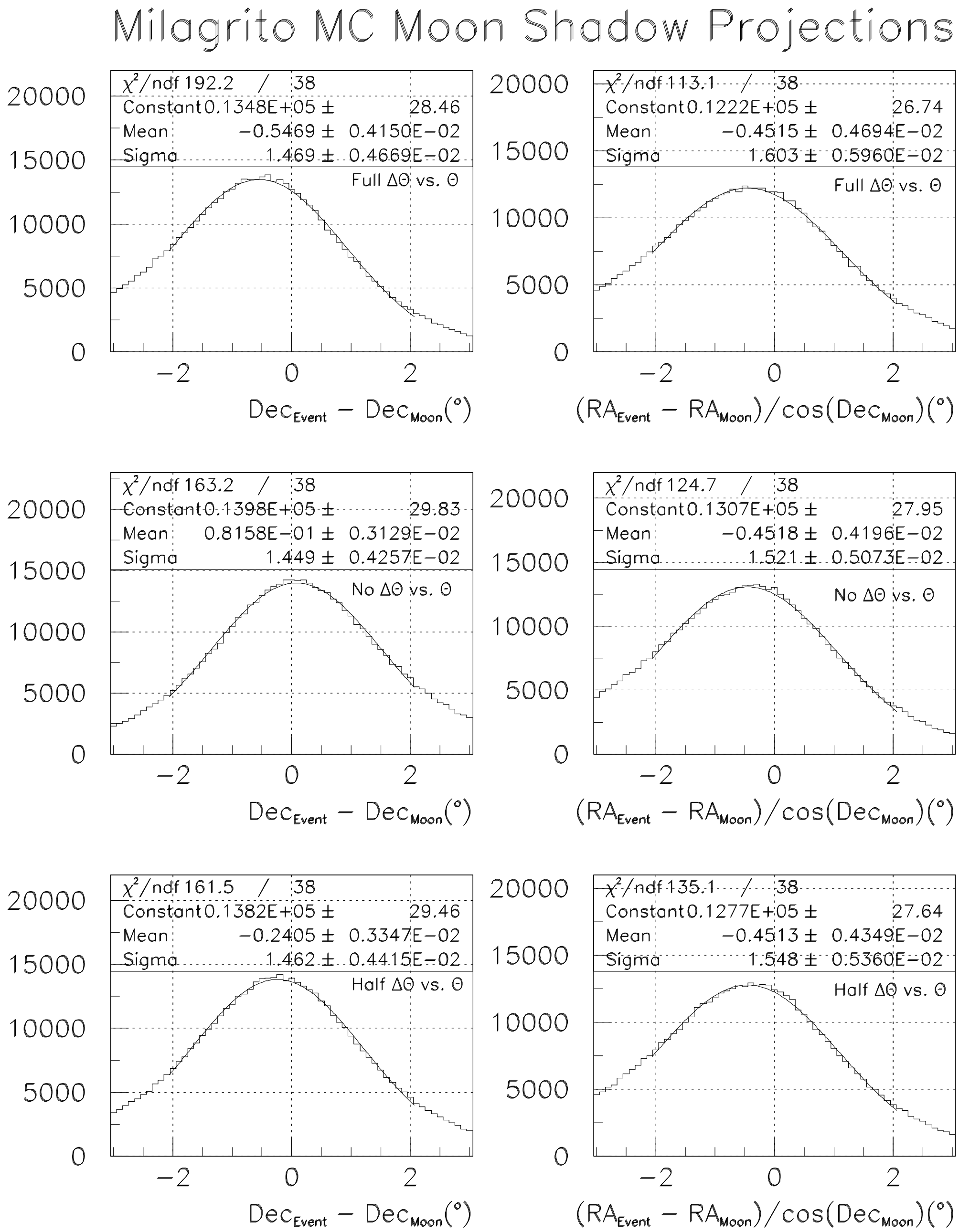

Figure 6: The projections of the Monte Carlo results. These are simulated moon "source" events, which would be missing from the expected background in a moon shadow plot. Before deflections and smearing, the central bin in teh projections contains about 1.46×10^5 events. It was found that the magnitude of the offset in declination changes linearly with the magnitude of the parameterization, as expected. The deflection in right ascension is not affected because this is due primarily to the geomagnetic field.

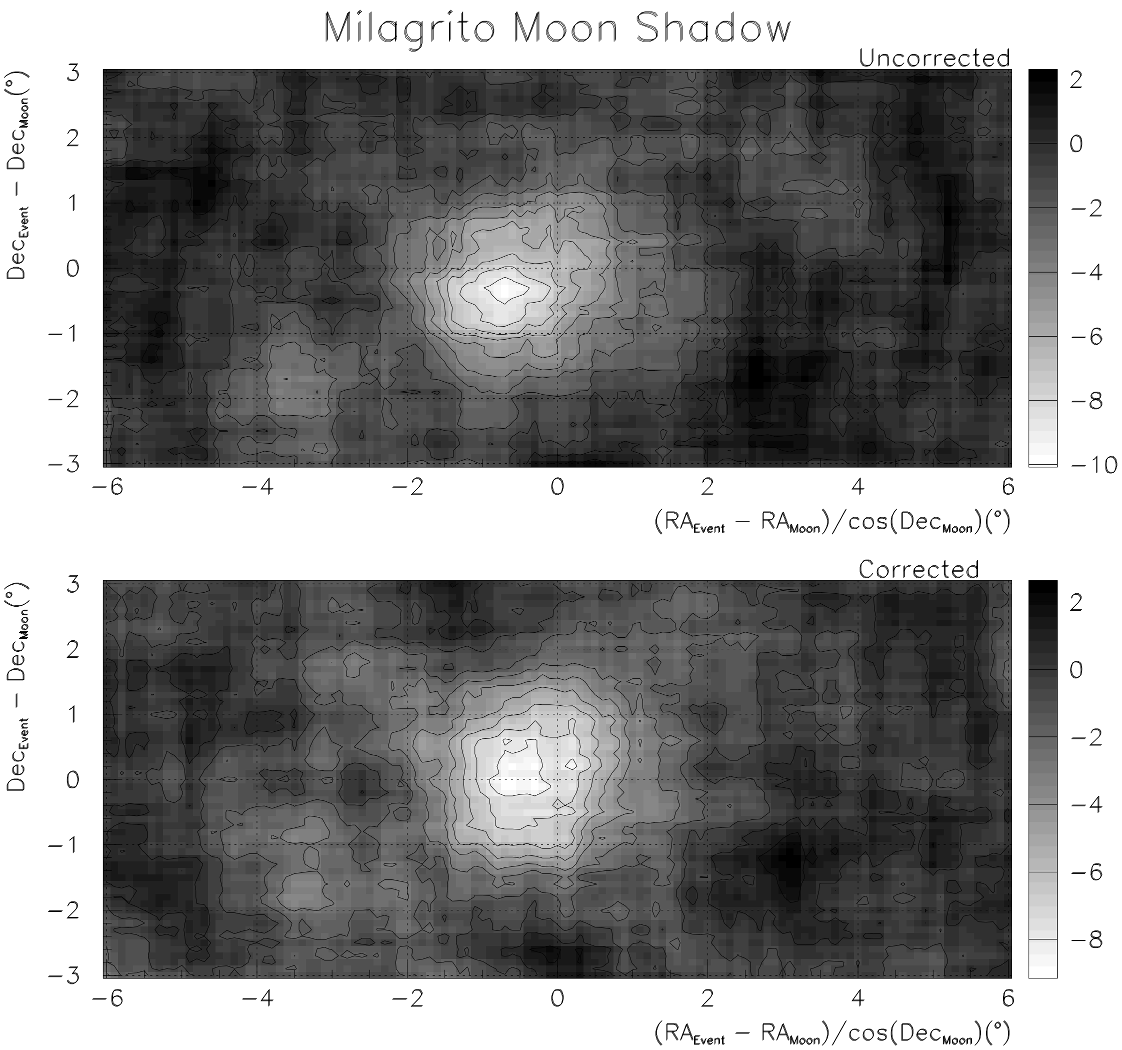

Figure 7: The moon shadow significance plots for Milagrito. Each plot contains zenith angles only up to 45^o, for the entire 'Grito lifetime. The top plot shows the shadow with events reconstructed positions, and the bottom shows those same events "corrected" for the $\Delta\theta$ vs. θ systematic.

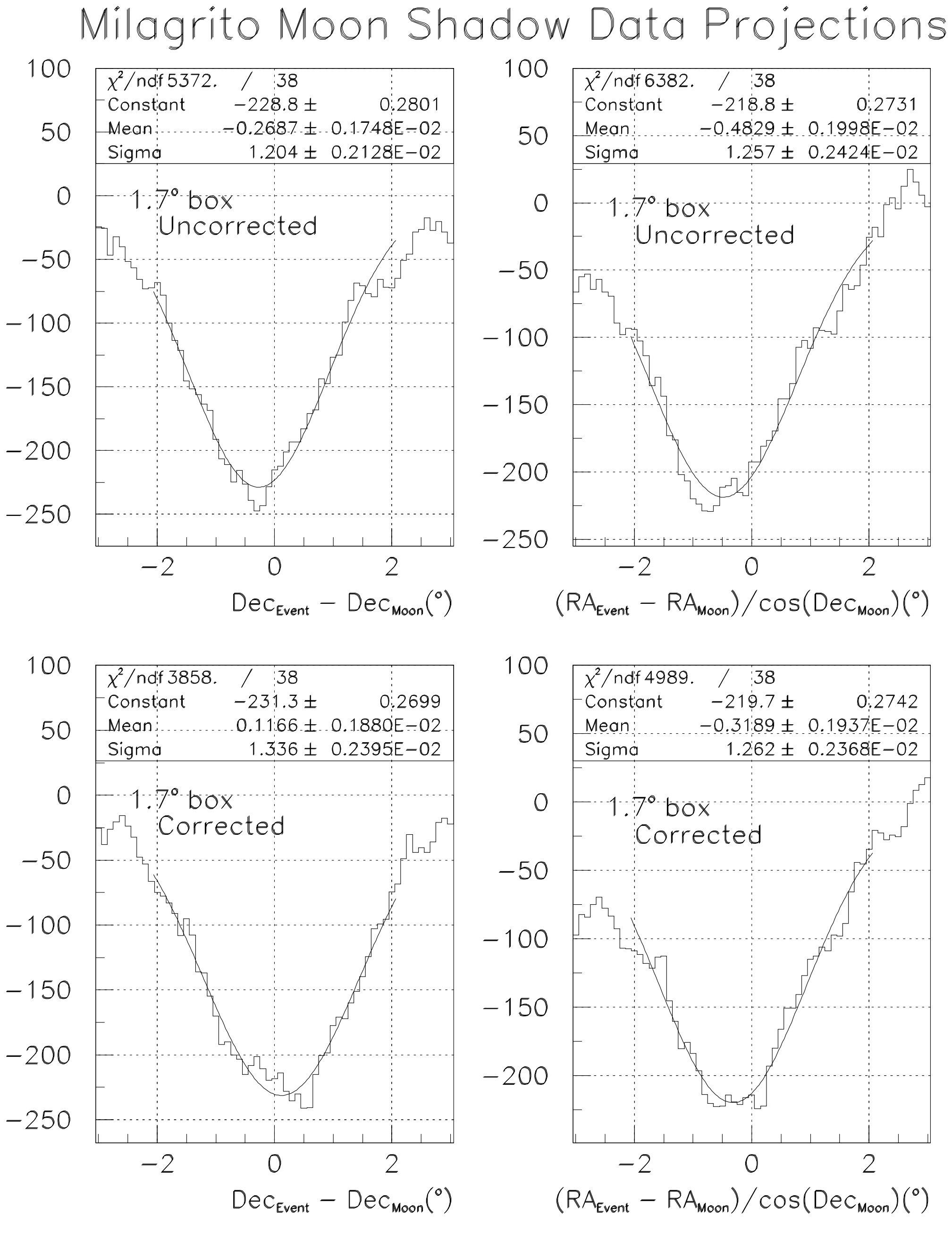

Figure 8: The data projections. Each plot is a projection of a 5.1^o band ($\pm 2.55^o$ centered on the position of maximum deficit) of the moon shadow significance plot. The plots were smoothed with 1.7^o square boxes. The top two plots are uncorrected, i.e. they are simply events reconstructed with version 23 of the offline code. The bottom two plots have been "corrected" for the $\Delta\theta$ vs. θ systematic effect.