Status of Milagrito Moon Shadow

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March 10, 1997

1 Introduction

At the last collaboration meeting (at UCI), I presented results of my *toy* reconstruction. I computed calibration constants for each pmt to convert from time-over-threshold (tot) to photoelectrons (pes). I also computed complete (shower+electronic) slewing corrections using the dependence of the peaks of TChi distributions on pulseheight. I also showed distributions of space-angle differences from dividing the pmts into two independent sub-arrays. The median space-angle difference (DELEO) for all events was 3.4°. Assuming that the angular resolutions varies as $1/\sqrt{Nfit}$, this corresponds to an angular resolution of 1.4°.

The only way to determine what the *real* angular resolution obtained with my reconstruction process is to try to observe the shadow of the moon. This memo presents the current status of my effort to observe the moon's shadow using Milagrito data.

2 Method

2.1 Data stripping

On February 24, 1997, I began reconstructing (angles only) and stripping events within 15° of the moon. I did this by installing my reconstruction program on kahuna.lanl.gov in the directory /usr/people/daq/recon. The program checks for an "unprocessed" data file in the directory /data1/archiveRun (place where runs are put to be archived). If one is found it reconstructs all events and produces a MOONrrrr_ssss.dat file. The rrrr is the run number, i.e. 0012, and the ssss is the subrun number, i.e., 0001. This output file contains a PROC_DATA structure (see procData.h file) and a list of pmt hits (grid #, pes, time). This allows one to re-reconstruct the events if needed. The hit times written have already been slewing corrected using my values.

From these MOON files, I generated a set of files containing:

1. Run number (int)
2. Sub Run number (int)
3. Julian date (int) (from January 1, 1996, see email by David Williams)
4. event time (double) (U.T. seconds)
5. theta (float) (zenith angle)
6. phi (float) (azimuth angle)
7. Chi-squared per degree of freedom (float) (from angle fit)
8. number of pmts in angle fit
9. number of pmts hit

A copy of these strip files are in my directory on milagro.lanl.gov (/disk03/people/shoup/mi as moon0012.dat through moon0024.dat. There is also a C routine there to read the files: geteventmoonst.c. It can be called from fortran or C. Please feel free to use these as you wish.

To date, I have 396,000 events within 15° of the moon. These have come from runs 12 through 24. Only run 24 contains events from a full moon transit. All the others are incomplete transits due to down time of the DAQ. See Table I for a list of events per run and etc.

2.2 Shadow Fitting

To fit the shadow, I used my standard event-by-event maximum liklihood fitting method. The probability function used was:

$$P(r;\sigma_{res}) = \frac{r}{N}(1 - \frac{R^2_{moon}}{2\sigma_{res}} e^{\frac{-r^2}{2\sigma^2_{res}}}) \quad (1)$$

$$N = \frac{1}{2}(R^2_{max} - R^2_{moon} * (1 - e^{\frac{-R^2_{max}}{2\sigma^2_{res}}})) \quad (2)$$

where r is the angular separation between the moon and event, σ_{res} is the sigma of the two dimensional Gaussian, R_{moon} is the angular radius of the moon, and R_{max} is the maximum r used which was 5.0°.

In maximizing the liklihood, I used two methods. First, I only allowed the Gaussian width to vary, with the Gaussian centered on the true moon position. Second, I allowed an offset in RA and DEC as well as the Gaussian width to vary in the fit.

I tried to fit shadows for all the data and for events where the zenith angle of the moon was greater than 45°. The cut on moon zenith angle was an attempt to increase the median event energy so as to minimize the magnetic deflection caused by the earth's geomagnetic field. According to Gus Sinnis and Gaurang Yodh, the defection should be 0.033 radians per TeV in energy, which corresponds to about 1.7° at a TeV.

3 Results

Table II lists the results obtained from my shadow fitting. Figures 1 through 3 are the density plots and Figures 4 through 6 are the deficit plots for these results.

I have also performed a couple of systematic checks of my shadow fitting method. First, I moved the center of the Gaussian 5.0° away from the true moon position with offsets of (+5.0, 0.0), (-5.0, 0.0), (0.0, +5.0) and (0.0, -5.0) in (RA,DEC). Each of these gave a result consistant with no shadow.

I also removed my slewing correction and tight cuts on TChi's in the reconstruction process and refit the moon events to see if the shadow would go away. Figure 7 is a density plot of the results.

4 Discussion

The significance of these results is exciting, but not conclusive. The derived angular resolution is significantly better than that indicated by my DELEO results. However, I really don't know how well DELEO is related to the *real* angular resolution. I also don't know exactly how to compute the true angular resolution from DELEO.

The angular resolution from these shadow fits is consistent with the resolution derived from Monte Carlo studies where the pmt hit times have been corrected for effects of slewing/curvature. I did not think that my slewing corrections would have reduced the slewing/curvature effects so as to give such a good angular resolution. If true, it is a nice surprise.

The offsets in RA and DEC listed in Table II are significant at about the 1 to 1.5 sigma level. However, we really do not know what are median event energy is for either the all data set or the data set with the moon zenith angle greater than 45°, so I do not if these are reasonable.

I will continue to strip moon events until the online reconstruction starts. It is a rather labor intensive process since I have to ftp my MOON files to UCI and then strip the event parameters from them. I also have to dump them to tape, because of disk space. I have more that 2.0 GB of data so far.

I am certain I have not answered everyone's questions on this, but hope you are more informed than before. If you do have question/suggestions, please let me know.

5 Figure Captions

- Figure 1. Event density versus angular distance from moon. This is for all data. Cooresponds to first line in Table II.

- Figure 2. Event density versus angular distance from moon. This is data with moon zenith angle greater than 45° and NO offsets. Cooresponds to second line in Table II.

- Figure 3. Event density versus angular distance from moon. This is data with moon zenith angle greater than 45° with offsets in RA and DEC. Cooresponds to third line in Table II.
- Figure 4. Deficit (from constant density) versus maximum angular distance from moon. This is for all data. Cooresponds to first line in Table II.
- Figure 5. Deficit (from constant density) versus maximum angular distance from moon. This is for data with moon zenith angle greater than 45° and NO offsets. Cooresponds to second line in Table II.
- Figure 6. Deficit (from constant density) versus maximum angular distance from moon. This is for data with moon zenith angle greater than 45° with offsets in RA and DEC. Cooresponds to third line in Table II.
- Figure 7. Event density versus angular distance from moon. This is for data with moon zenith angle greater than 45° and with on slewing corrections in the angle fitting.

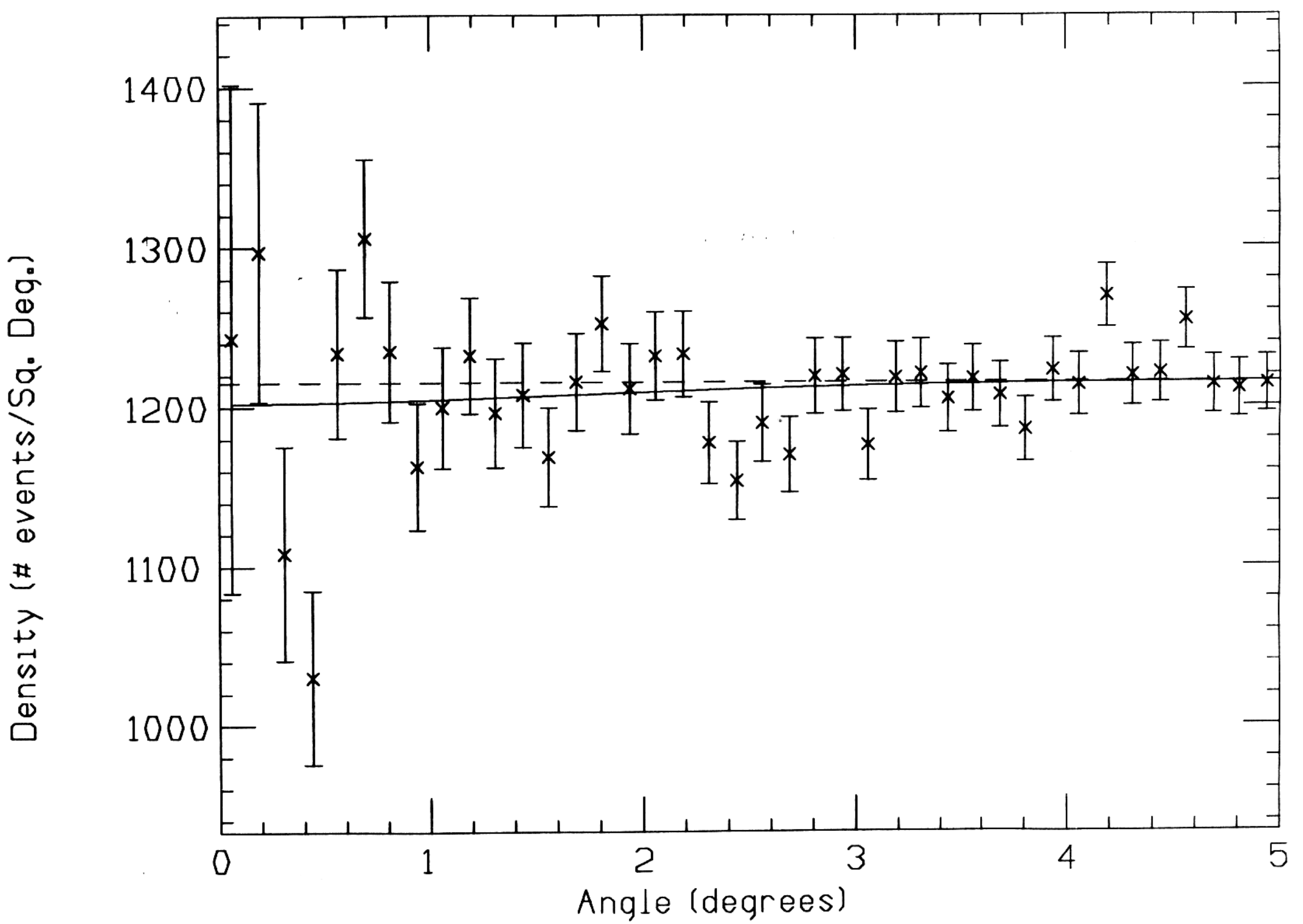
Table I. Run Statistics

Run #	# of Events	Average Event Zenith Angle (°)
12	11087	43.7
13	12307	46.1
14	12047	51.0
15	1153	65.6
16	1432	64.2
17	4143	57.0
18	2381	63.4
19	2657	57.6
20	6542	57.9
21	5071	51.4
22	4133	55.1
23	11090	45.0
24	21076	42.5

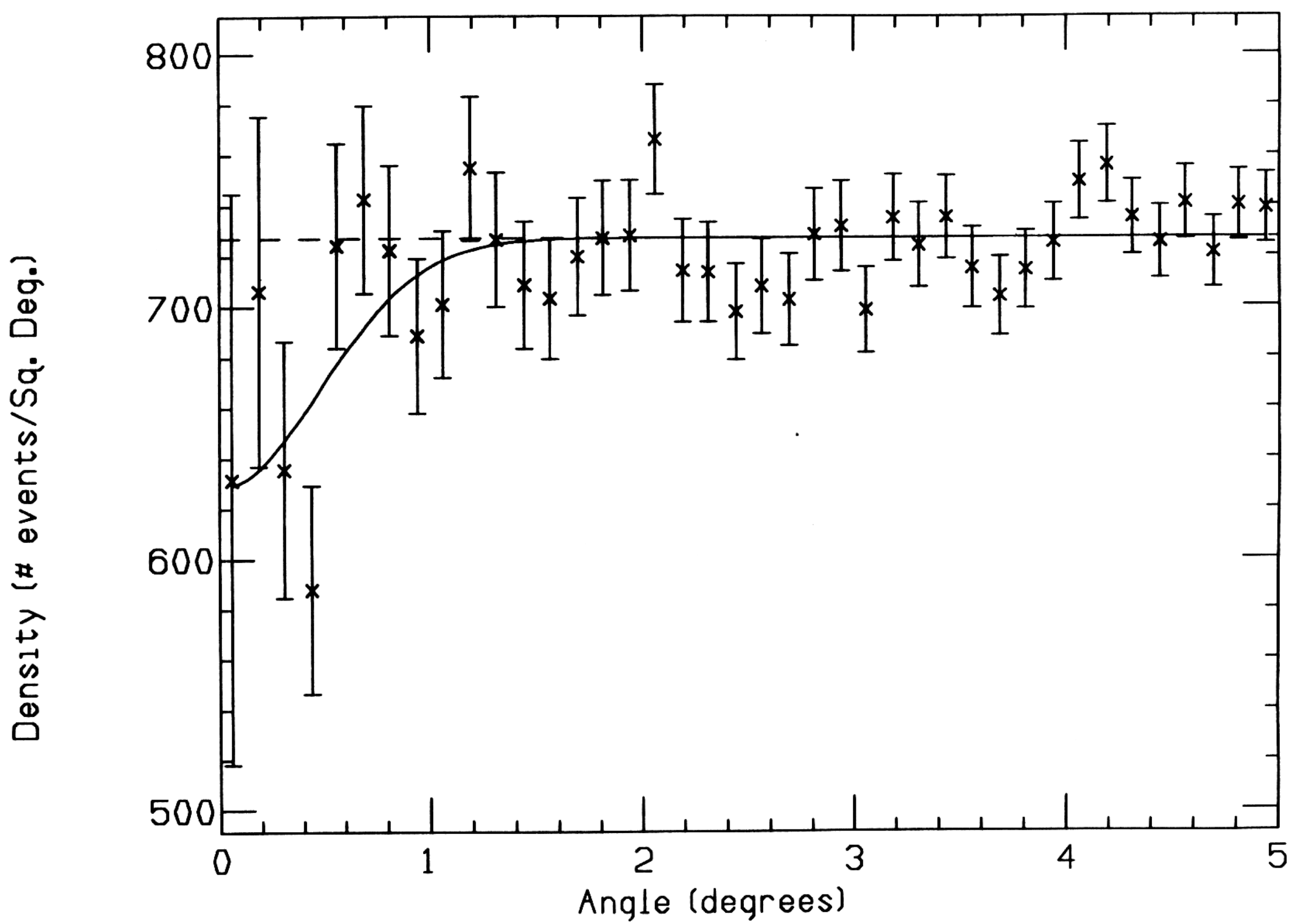
Table II. Moon Shadow Fit Results

Moon Theta Cut	# of Events	σ_{res}	$\Delta\alpha$	$\Delta\delta$	Signficance (σ)
0-90	95220	$1.7^{+1.2}_{-0.6}$	-	-	1.4
45-90	56963	$0.46^{+0.16}_{-0.09}$	-	-	2.8
45-90	57000	$0.36^{+0.09}_{-0.06}$	-0.11	-0.23	3.2

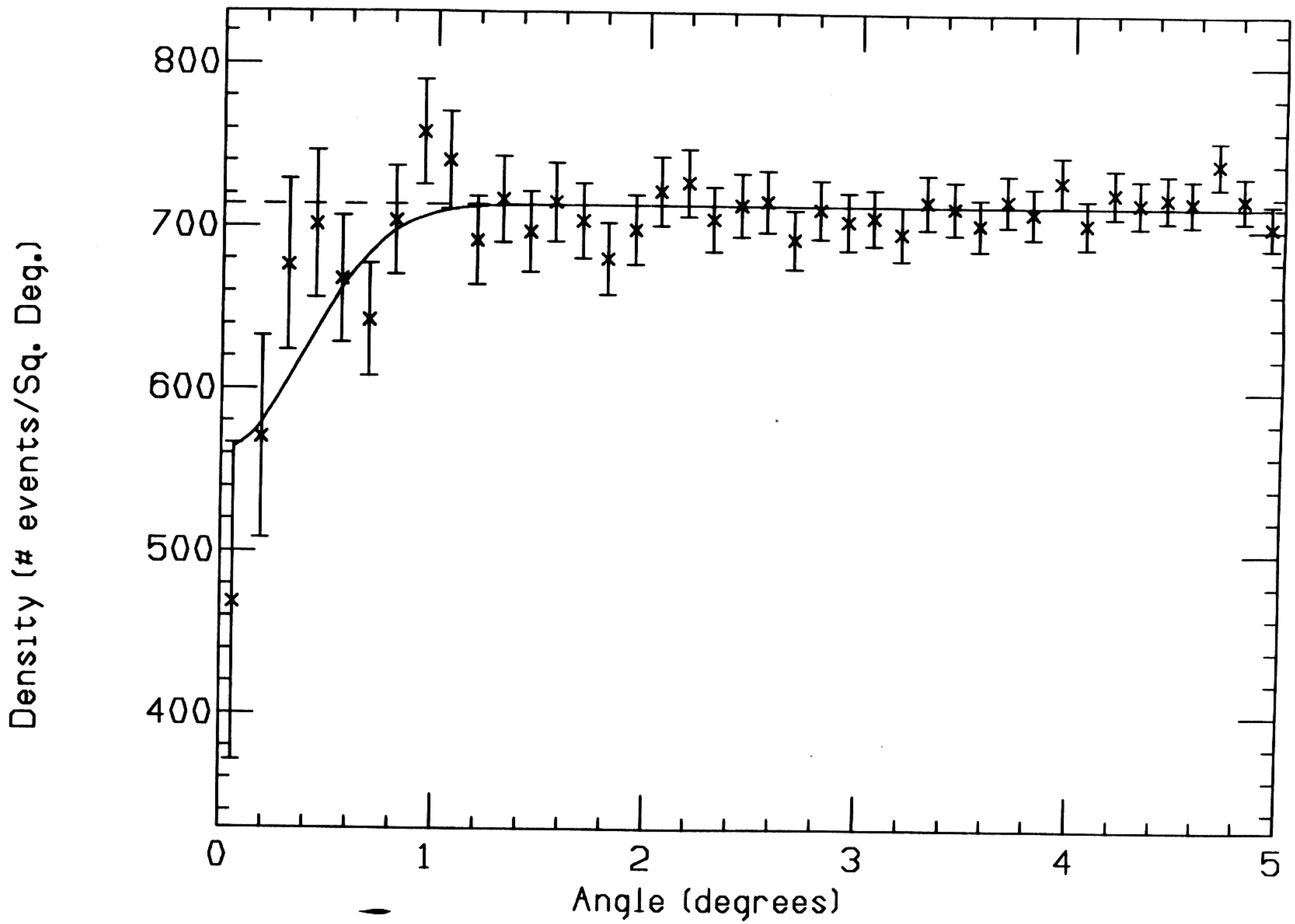
Density vs. Angle (Figure 1)



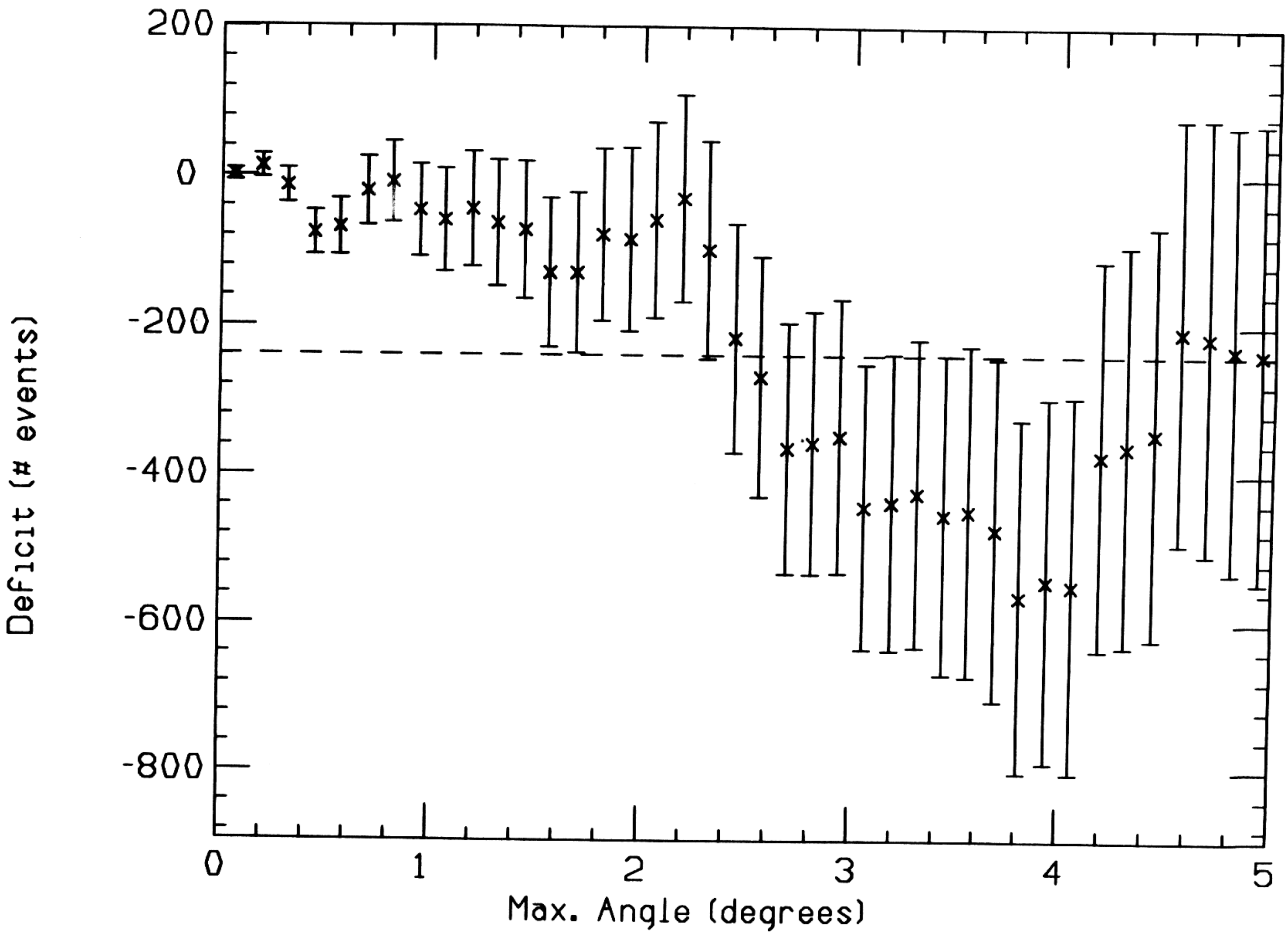
Density vs. Angle (Figure 2)

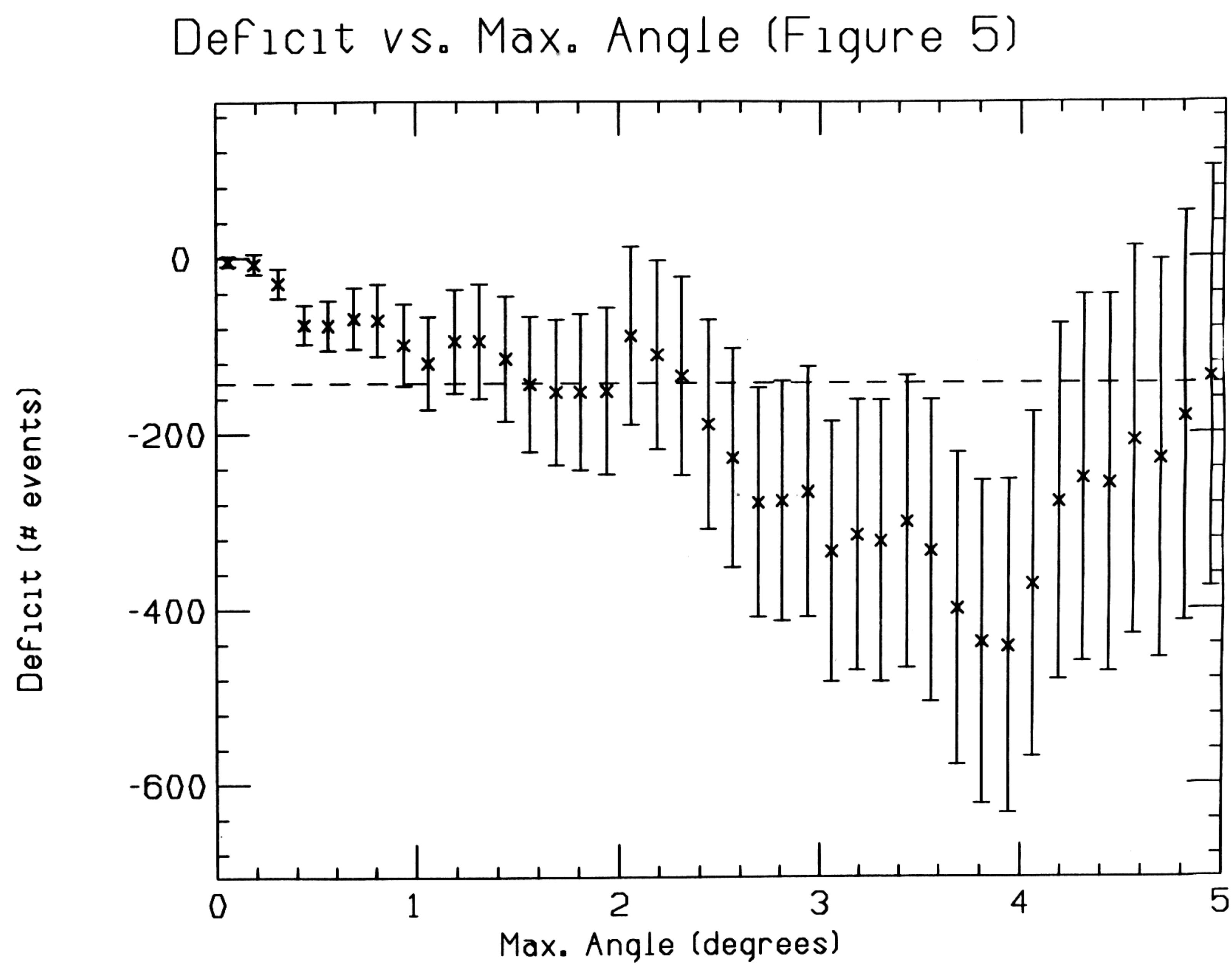


Density vs. Angle (Figure 3)

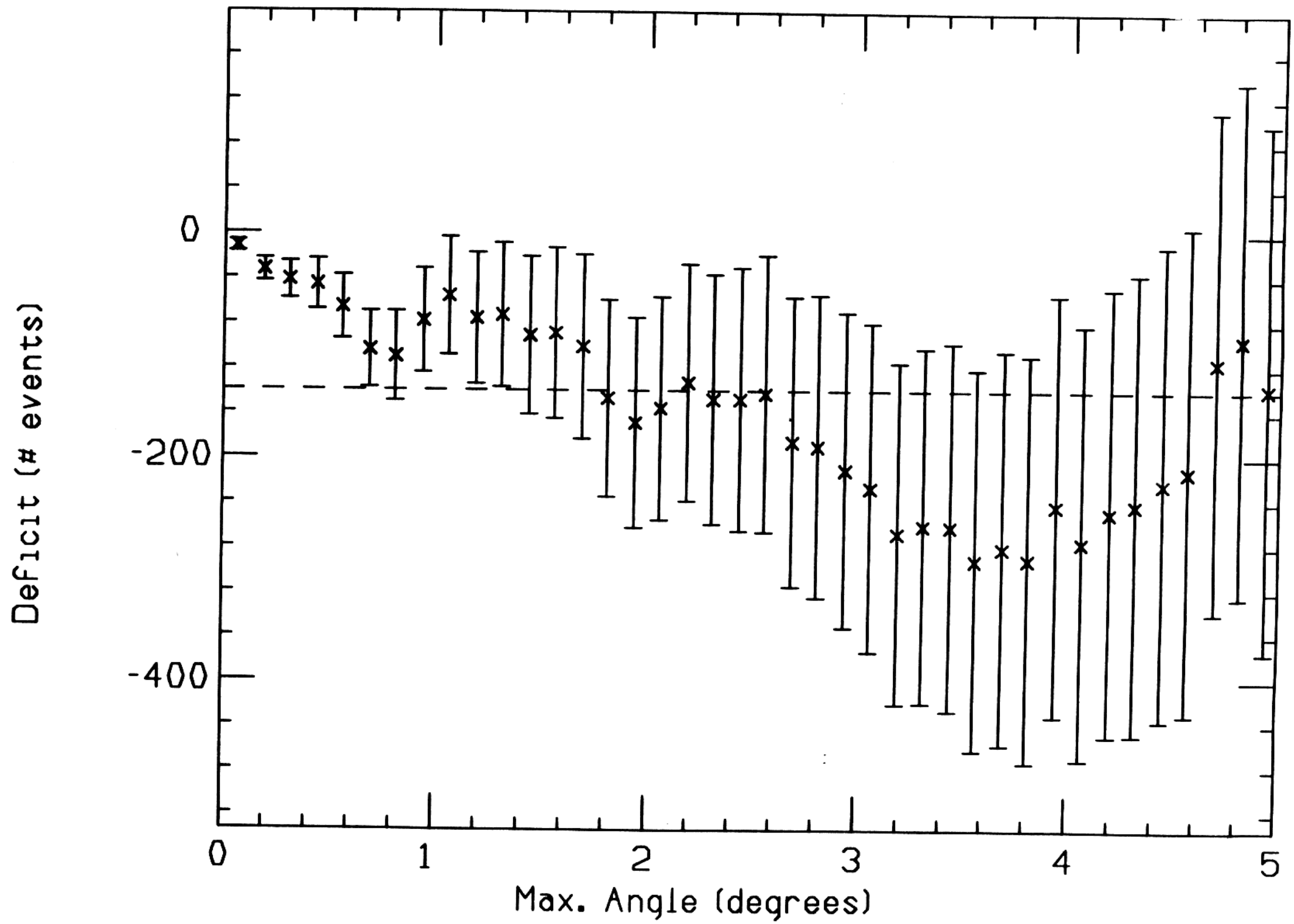


Deficit vs. Max. Angle (Figure 4)




Deficit vs. Max. Angle (Figure 5)
Deficit (# events)
0
-200
-400
-600
0
1
2
3
4
5
Max. Angle (degrees)

Deficit vs. Max. Angle (Figure 6)



Density vs. Angle (Figure 7)