Study of Angular Reconstruction of Showers with Cores Outside of the Array Boundaries

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Introduction

In this note I would like to address the question of showers with cores outside of the array. In particular: should we keep them or not? To answer this question I will use a combination of Monte Carlo and real data. The monte carlo (CYGSIM by S. Biller) is used to estimate the fraction of our triggers with such cores, and the angular resolution for events with cores outside of the array. The data is used to measure any systematics associated with the angular reconstruction of these showers.

If we knew the core position we would merely suffer a degradation in angular resolution, however the fact that we don't know the core position (and always place it within the array, closer than it should be) leads to a systematic error in our pointing. We will see below that we tend to tilt the shower axis away from the array.

The Problem

Here we use showers whose cores land within the CYG II array. Figure 1 shows the array and the box shows which showers where selected for this analysis. Showers with cores in this box represented 3.3% of our triggers (Run 2337), which tells us that roughly $15 - -20\%$ of our triggers are reconstructed with similar (in)accuracy. This is supported by the Monte

Carlo; 16 % of triggered showers lie beyond a box defined by the outer detectors of CYG I.

Method

If CYG I triggers (by checking bit 6 of IVCHQ(29)), and the core is located in the box drawn on Figure 1 ($400. < xcore < 1300.$ and $-120. < ycore < 400.$ (feet)) the event is retained. Each event is processed twice: first using CYG I and CYG II to locate the core and reconstruct the zenith and azimuthal angles, then just CYG I information is used to obtain the same quantities.

Results

Figures 2 and 3 show the radial and azimuthal errors in core location, in all figures the quantities plotted are $CYG(I+II) - CYG(I)$, measured in feet and degrees respectively. Figures 4 and 5 show the xcore and ycore errors. The coordinate system is the usual one: positive x due east and positive y due north.

Figure 6 shows the error in zenith angle reconstruction and Figure 7 the azimuthal angle error. And Figure 8 gives the space angle difference between the two reconstructed directions. So far everything looks good, merely a degradation in resolution (seemingly making our angular resoltion to be 1.3 degrees for these events: $\sqrt{0.8^2 + 1.0^2}$ but no systematic effect.

However, after calling VICE to return the right acsension and declination of the event, we see a systematic error (more pronounced in the right ascension due to the event selection) in our pointing (Figures 9 and 10). The reason for the systematic is evident from the following plots. Figure 11 shows the error in zenith angle versus zenith angle of the event: all looks good. Figure 12 shows the error in azimuthal angle versus azimuthal angle; we see a clear correlation. This correlation is more pronounced for the error in zenith angle as a function of azimuthal angle - Figure 13. Finally, Figure 14 is a plot of the error in azimuthal angle versus zenith angle of the event: no correlation.

Our angular reconstruction is dependent upon which side of the shower cone CYG I lies. For events landing in CYG II coming from CYG II

$(270. < \phi < 90.)$ we assign a larger zenith angle than we should and for events landing in CYG II and coming from CYG I we assign a smaller zenith angle than we should (and similarly for the azimuthal angle). We are in effect always tilting the shower axis away from us (CYG I).

Effect on Sensitivity

First the RA error is fit to a gaussian plus an exponential tail, $x exp(-x/\lambda)$ (the fit is superimposed on Figure 9). The exponential decay constant is $\lambda = 1.0°$. The RA error is chosen because of the placement of CYG II relative to CYG I.

Using the BILLER monte carlo (CYGSIM), the nominal angular resolution for showers landing outside of the array, coming from zenith, is 1.5° (Figure 15 showers the angular resolution for these events versus PCUT: the minimum number of particles required for a counter to be included in the fit. PCUT = 1 in REPLAY). So as not to double count the effect of core mislocation, the true core location was used in fitting these events.

Figure 16 is a convolution of this angular resolution with the systematic (only the exponential part) pointing error. 35% of the events are within 1.2° of 0.0. If not for the systematic 63% of the events would be in this bin.

At this point we have 2 options: keep the events or throw them out. If we define $S/\sqrt{B}$ to be the the signal to noise ratio for events with cores in CYG I, then by keeping the events we have:

$$\begin{aligned}\sigma &= \frac{S + .2 \times .35S}{\sqrt{1.2B}} \qquad (1)\\ &= 0.98\frac{S}{\sqrt{B}} \qquad (2)\end{aligned}$$

A 2% degradation in our signal to noise. Given the difficulty in finding these events (CORELOC only fails half of the time it should) and the very marginal improvement, it seems that we might as well keep these events.

Improving Angular Resolution for Exterior Events

We saw in Figure 15 that as we enlarge PCUT the angular resolution for events with exterior cores improves rather dramatically. It is natural to wonder if we might apply a larger PCUT to these showers, the offsetting factor being that we can fit fewer events. Figure 17 shows the number of events fit versus PCUT, and Figure 18 $\sqrt{N_{events}}/\theta_{res}$ (signal to noise ratio) versus PCUT. We see that there is essentially no change in our sensitivity.

Conclusion

Contrary to popular opinion, not making a core cut on showers does not help our sensitivity. While it leads to a 20% increase in rate, the reconstruction of these events is poor, so the rate increase for signal is only $.20 \times 33\%$. This in fact causes a degradation in our sensitivity, but by a small amount ($\approx 2\%$).

It was also found that by inncreasing the demand on particle number in a counter in SKYFIT, dramatically improves the angular resolution of exterior events, but at the price of fewer successfully fit events. In fact there is no change in our sensitivity over a wide range of choices for PCUT.

If it ain't broke don't fix it.

List of Figures

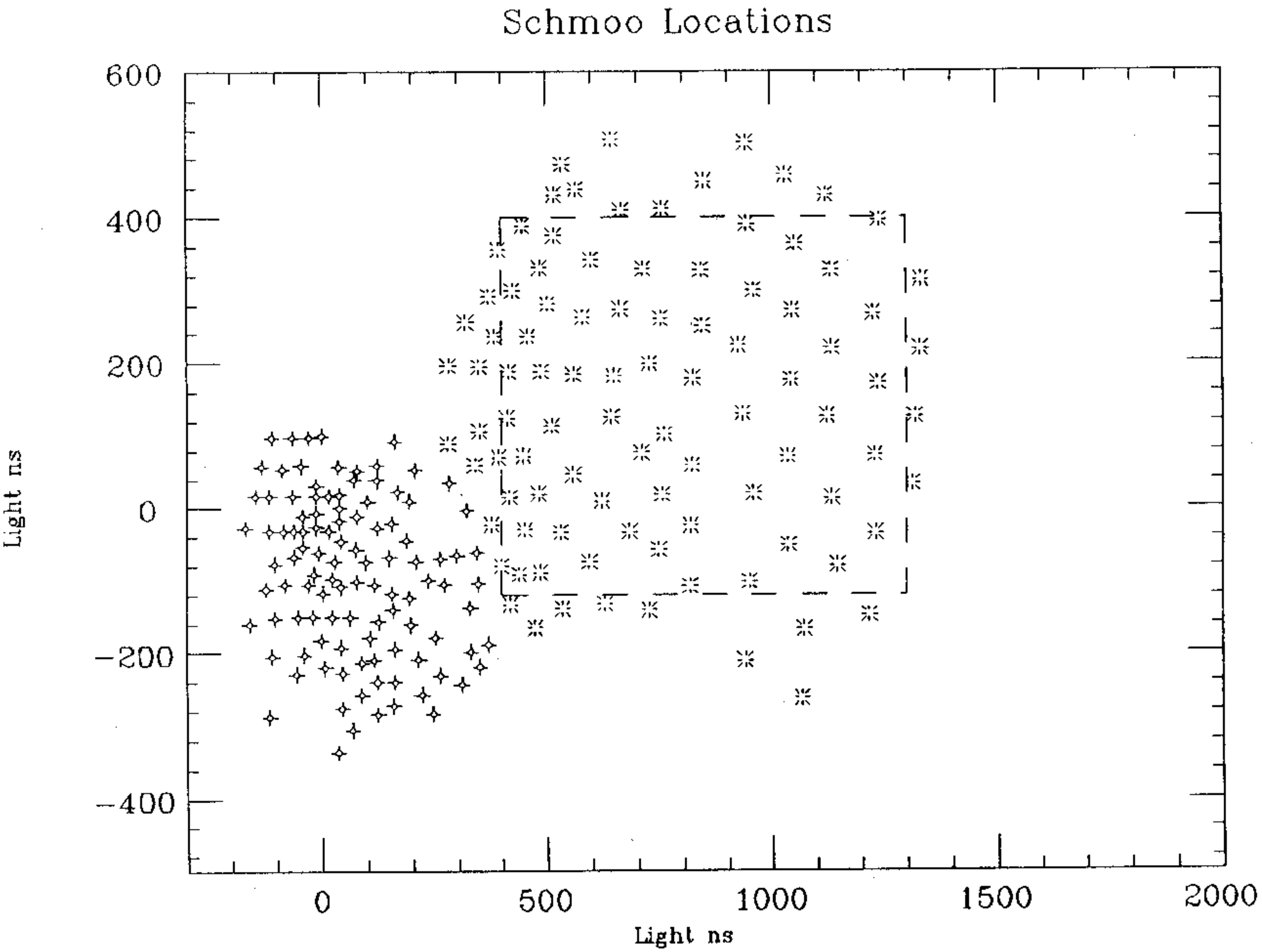

Schmoo Locations
600
400
200
0
−200
−400
Light ns
0
500
1000
1500
2000
Light ns

Figure 1.

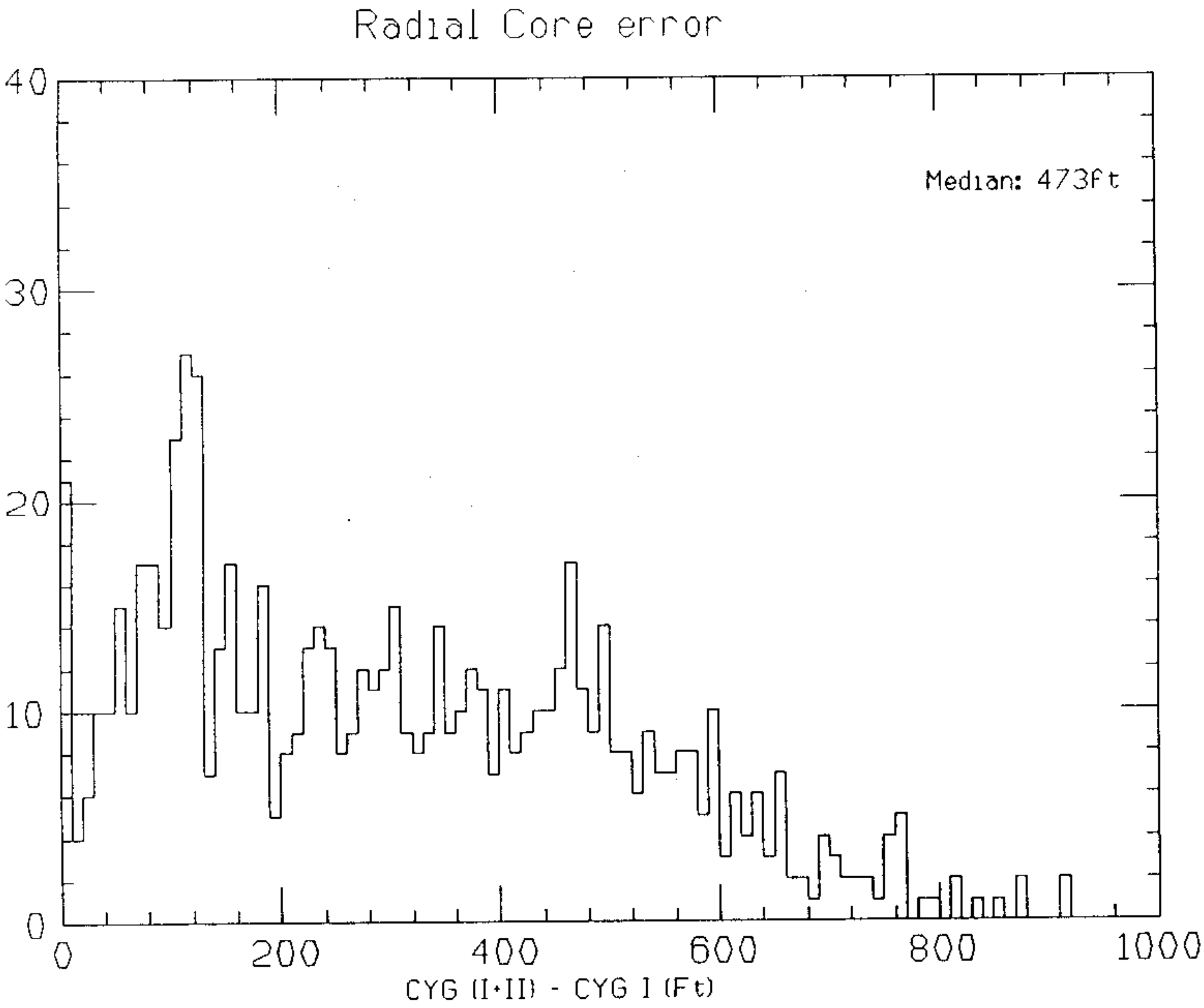

Radial Core error
Median: 473ft
0
10
20
30
40
0
200
400
600
800
1000
CYG (I+II) - CYG I (Ft)

Figure 2

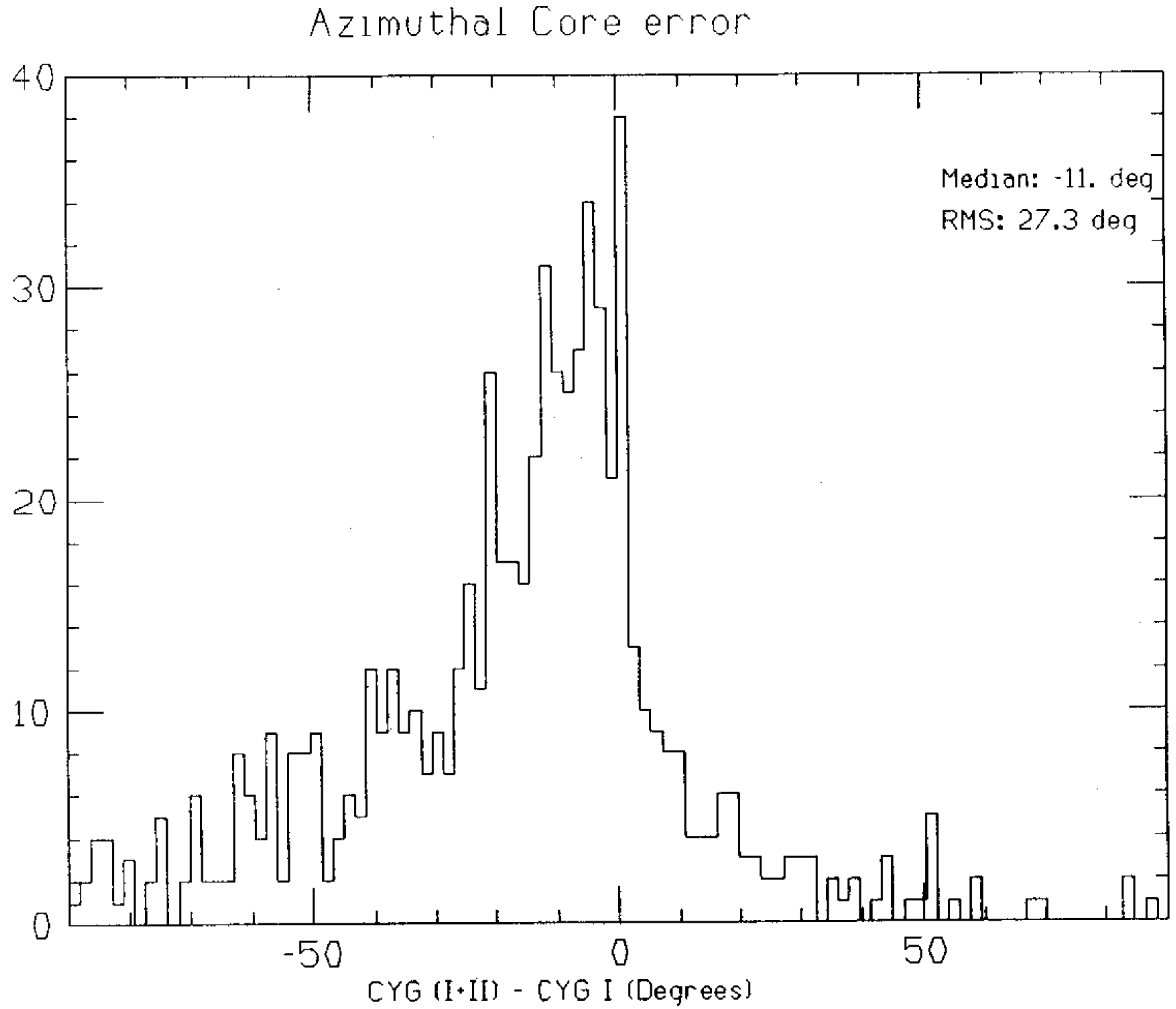

Azimuthal Core error
Median: -11. deg
RMS: 27.3 deg
40
30
20
10
0
-50
0
50
CYG (I+II) - CYG I (Degrees)

Figure 3

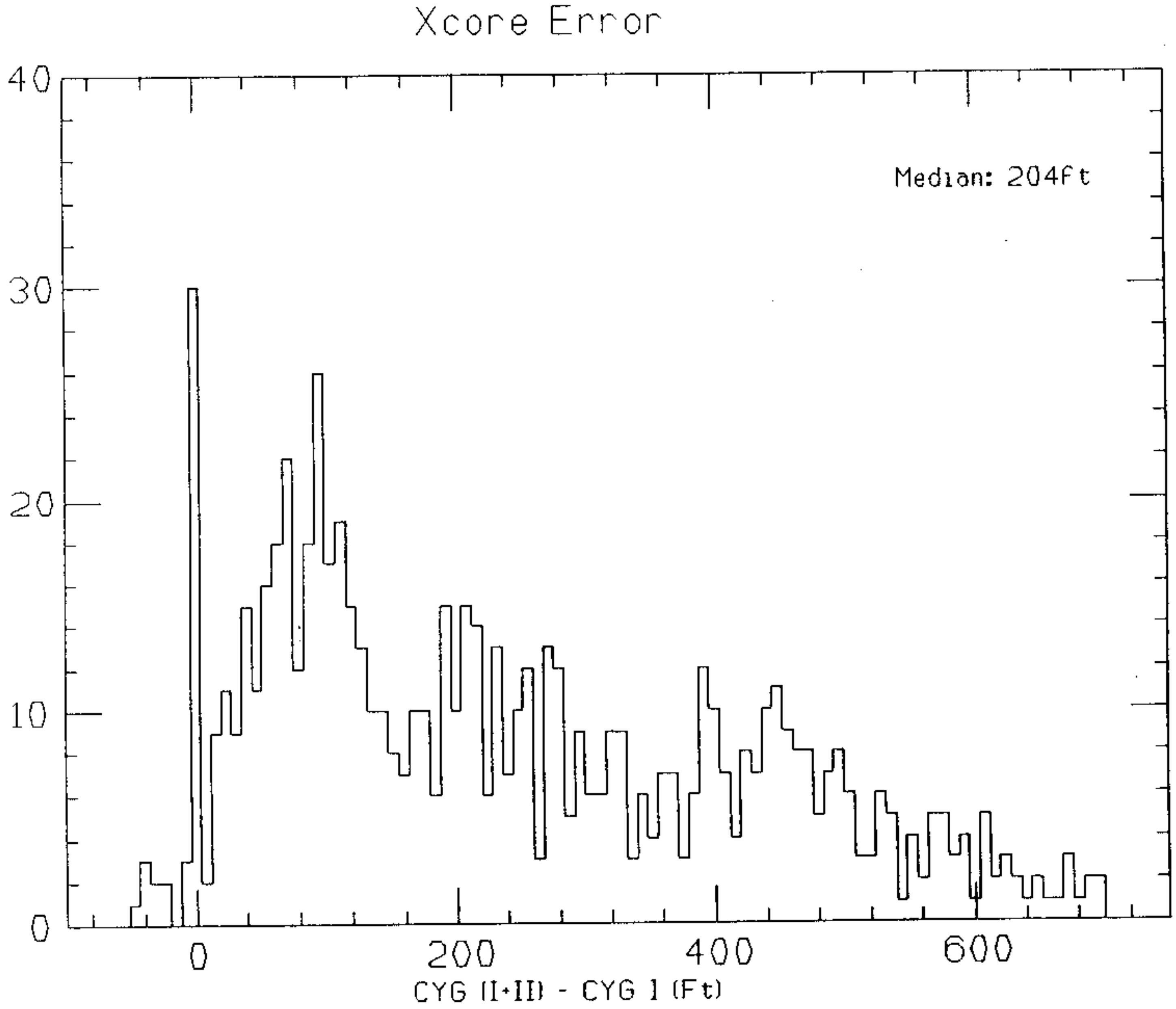

Xcore Error
Median: 204ft
40
30
20
10
0
0
200
400
600
CYG (I+II) - CYG I (Ft)

Figure 4

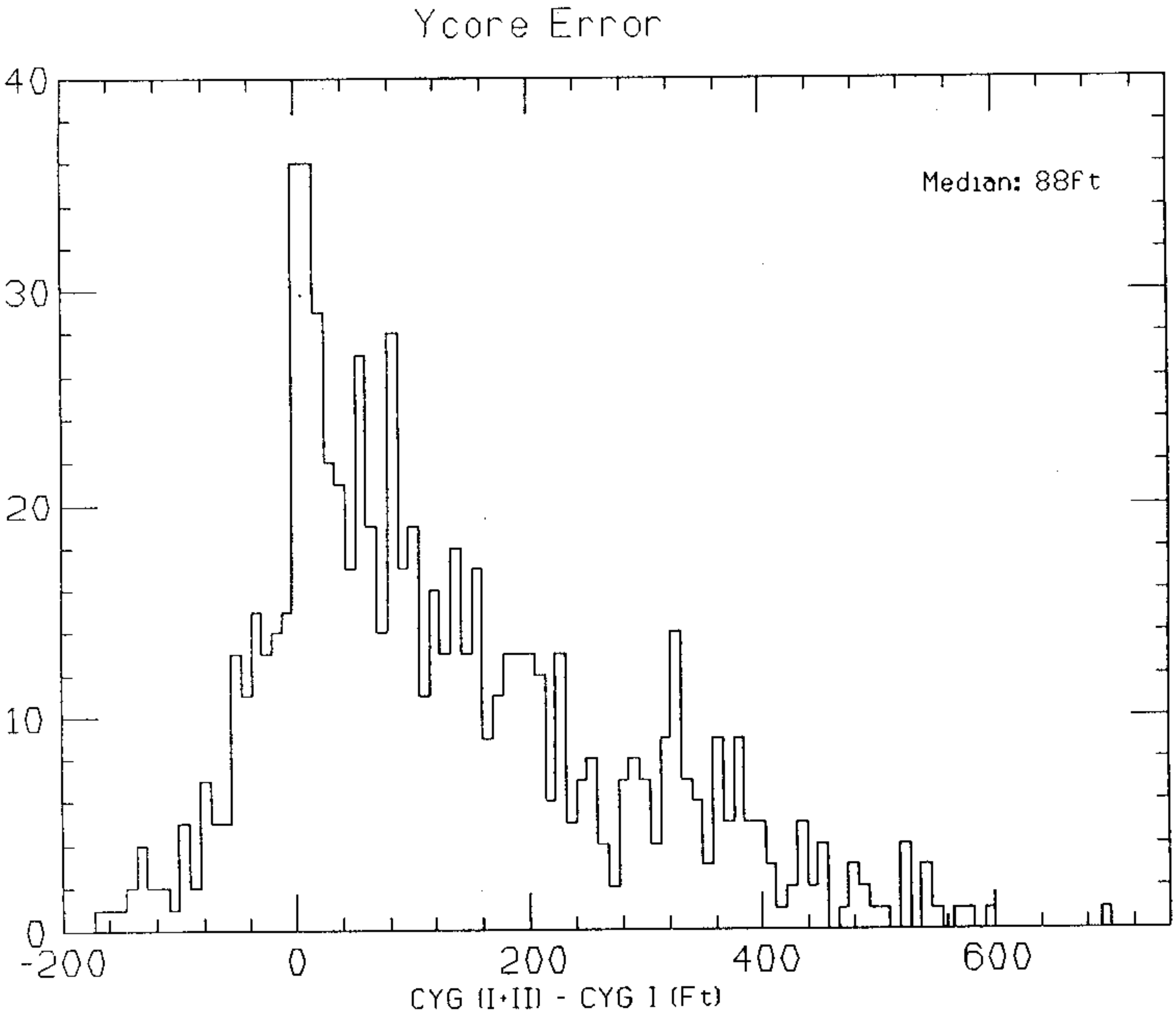

Ycore Error
Median: 88ft
40
30
20
10
0
-200
0
200
400
600
CYG (I+II) - CYG I (Ft)

Figure 5

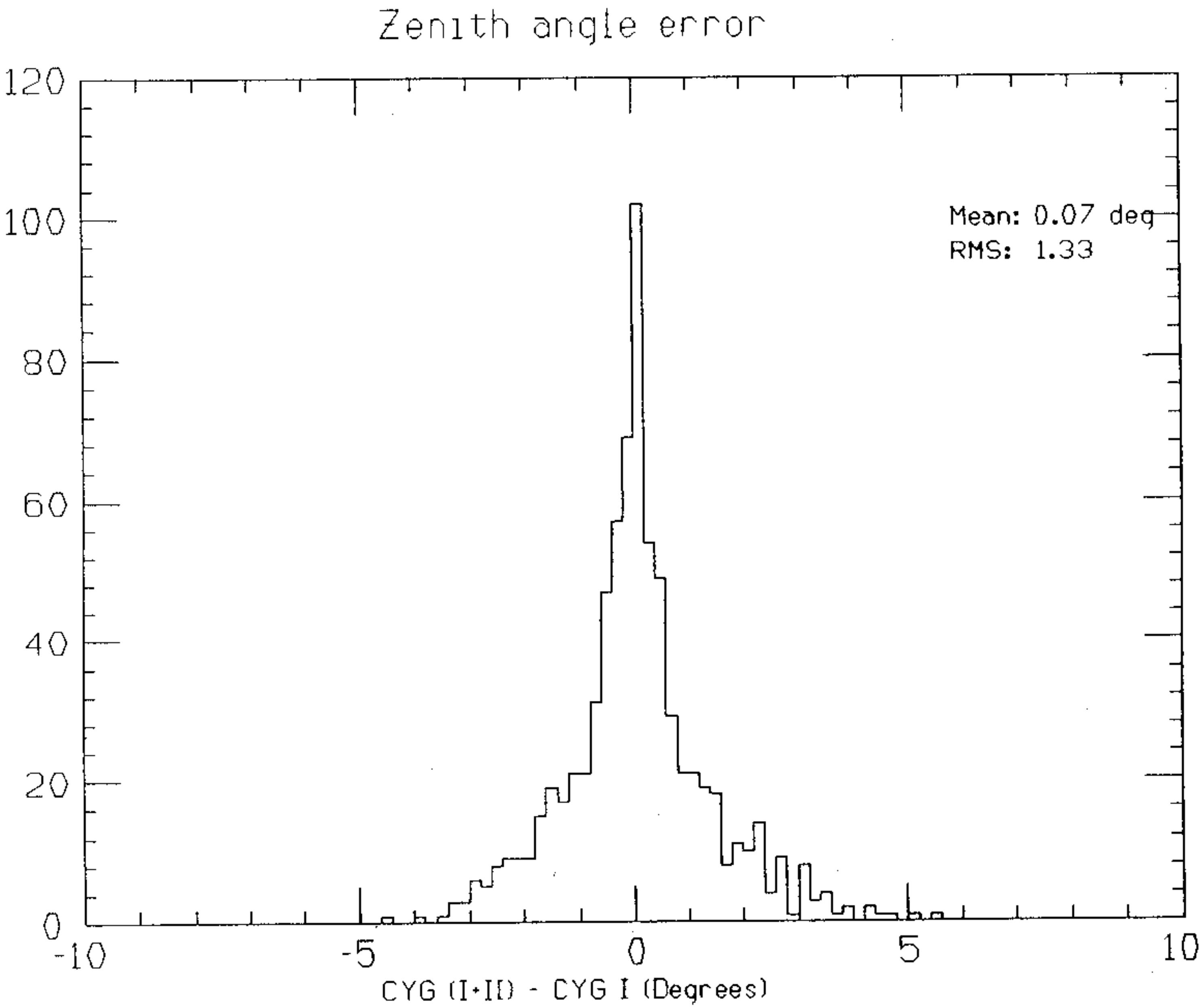

Zenith angle error
120
100
80
60
40
20
0
-10
-5
0
5
10
Mean: 0.07 deg
RMS: 1.33
CYG (I+II) - CYG I (Degrees)

Figure 6

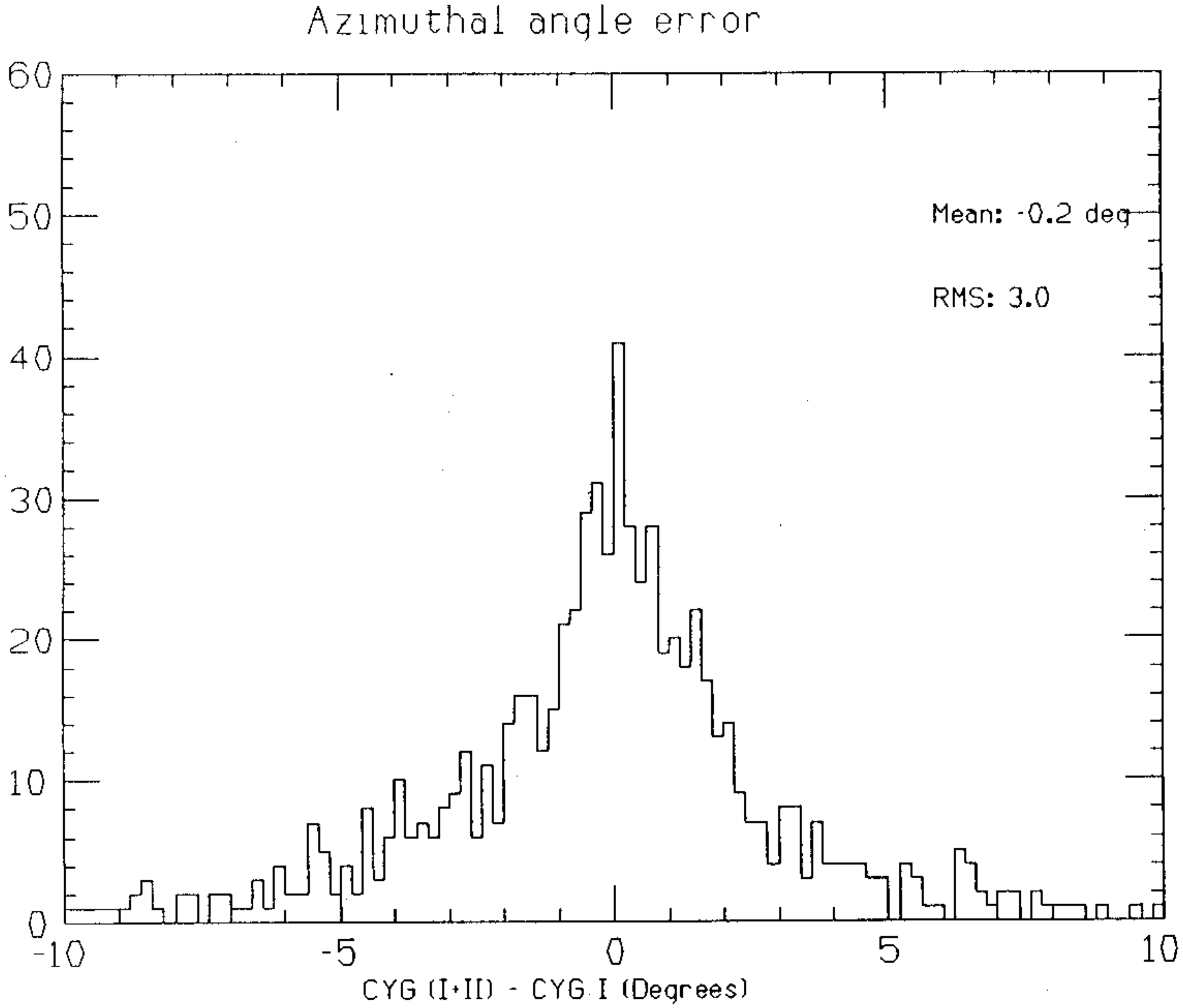

Azımuthal angle error
Mean: -0.2 deg
RMS: 3.0
60
50
40
30
20
10
0
-10
-5
0
5
10
CYG (I+II) - CYG I (Degrees)

Figure 7

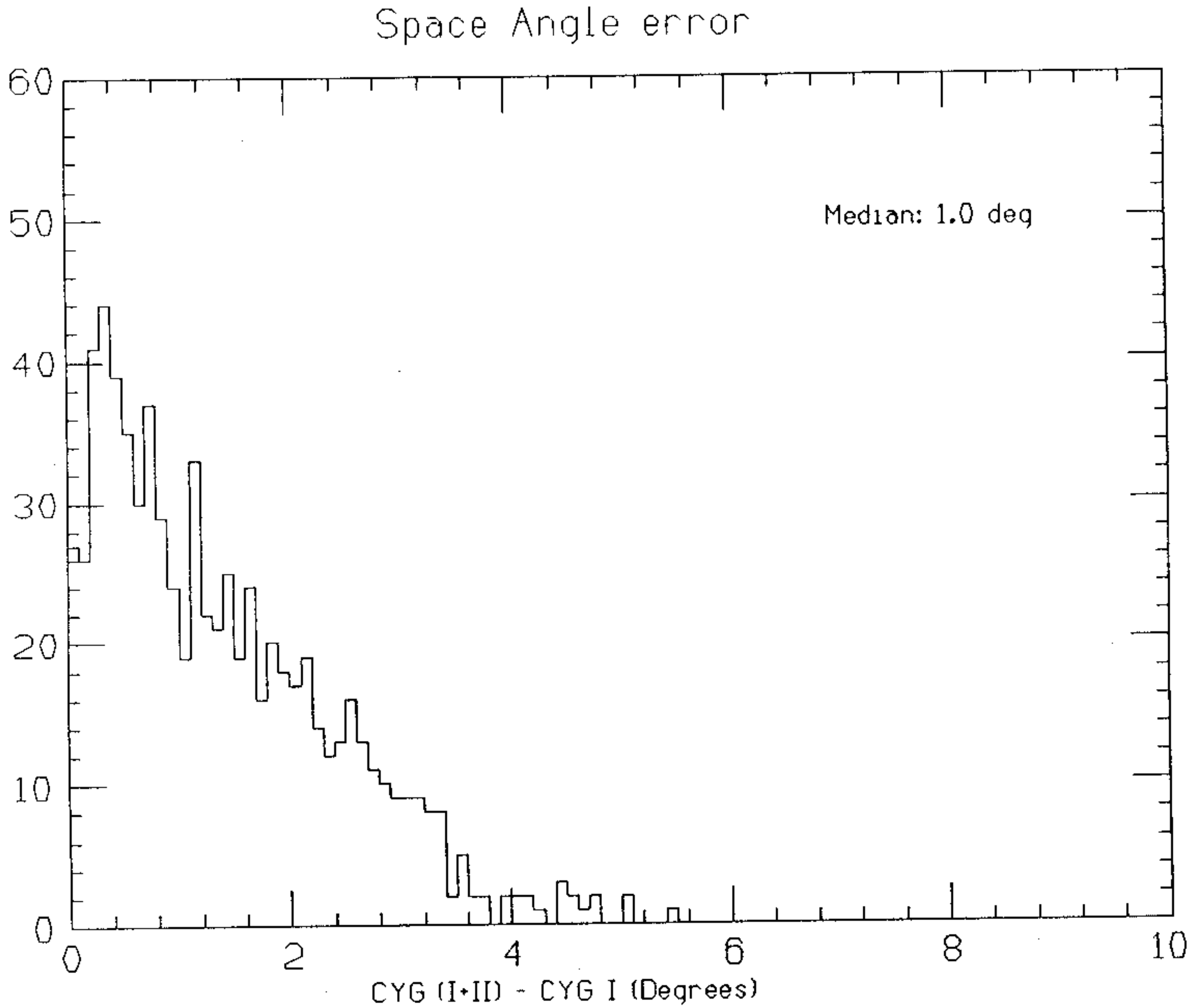

Space Angle error
Median: 1.0 deg
0
10
20
30
40
50
60
0
2
4
6
8
10
CYG (I+II) - CYG I (Degrees)

Figure 8

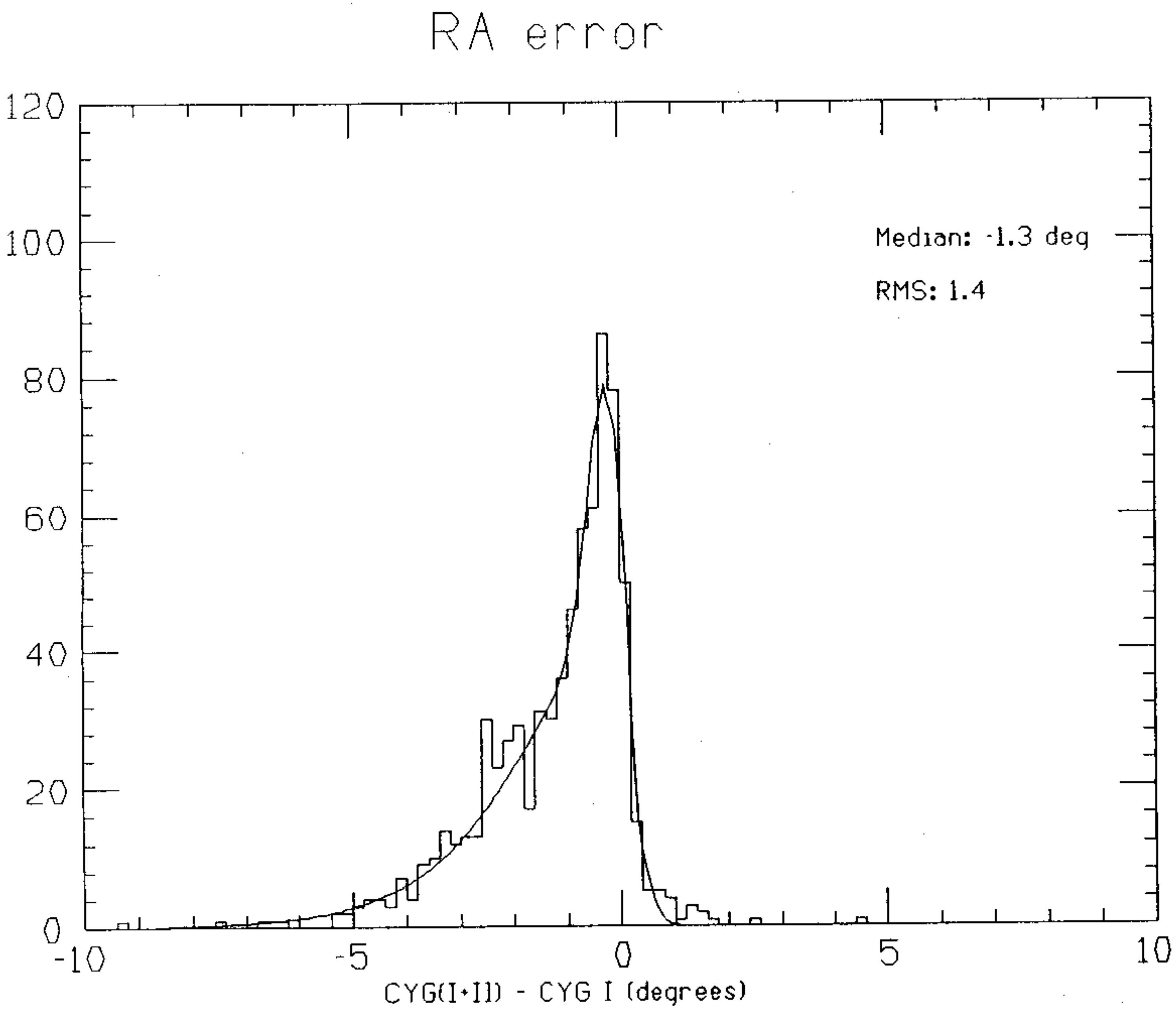

RA error
Median: -1.3 deg
RMS: 1.4
120
100
80
60
40
20
0
-10
-5
0
5
10
CYG(I+II) - CYG I (degrees)

Figure 9

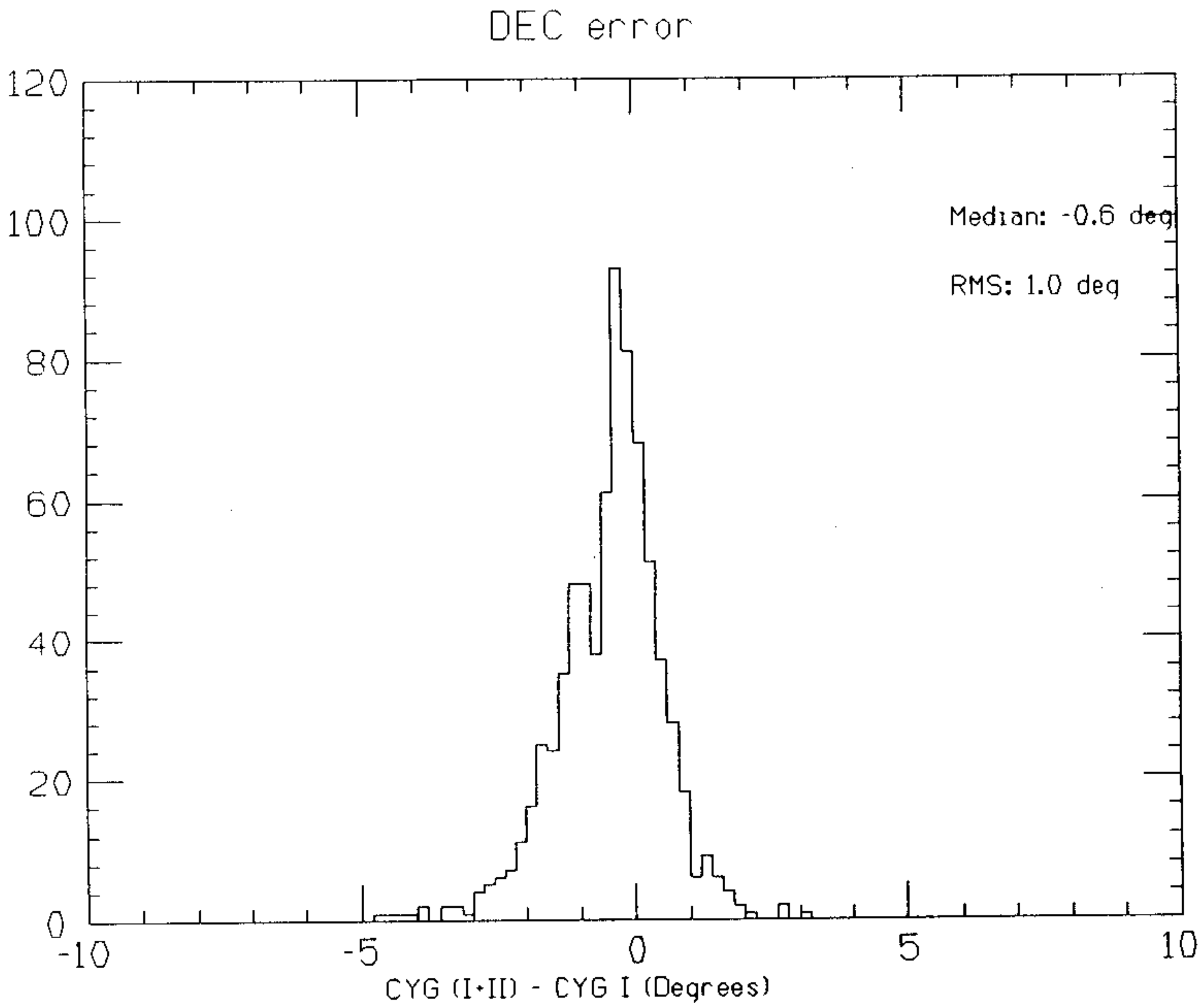
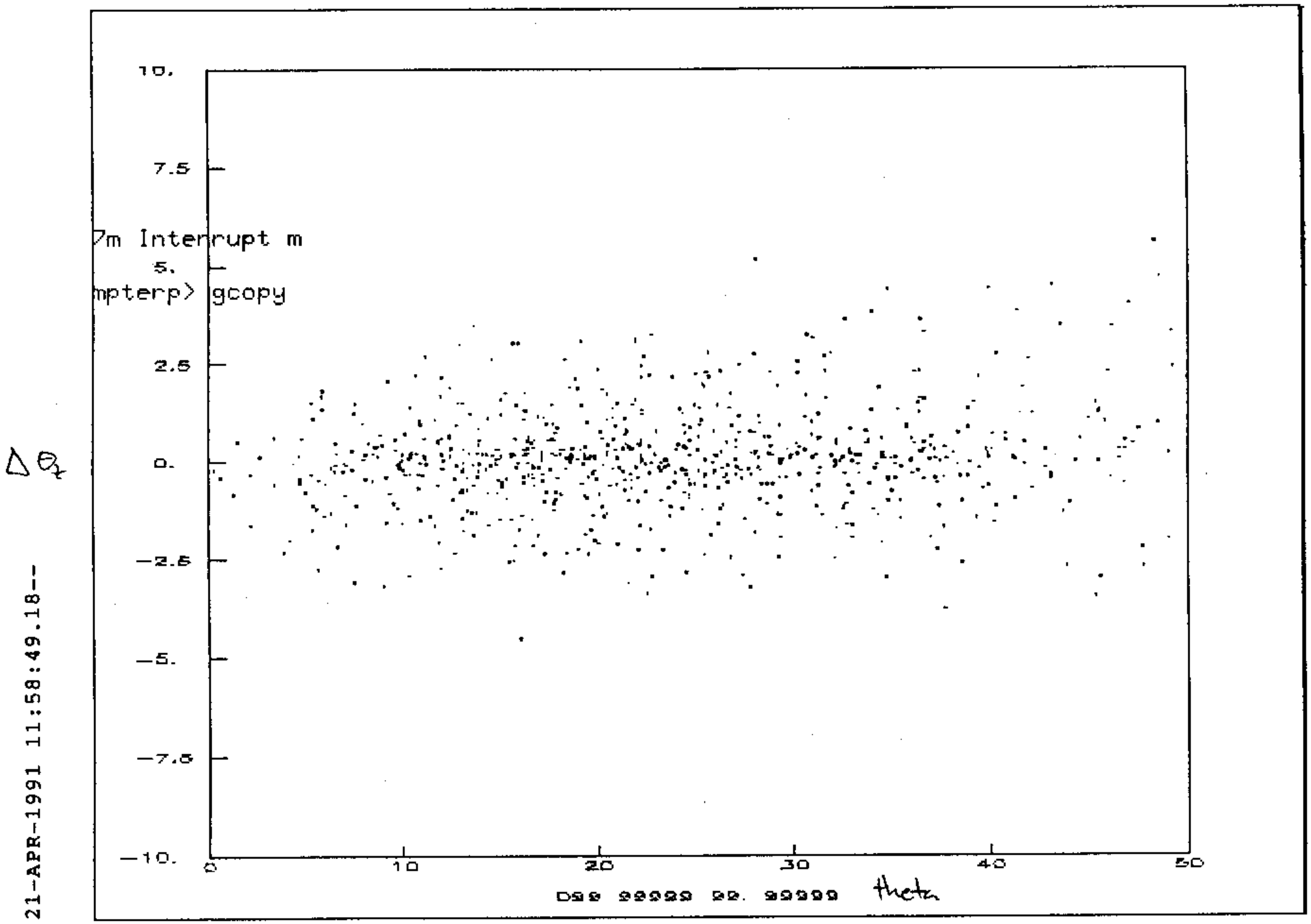

DEC error
120
100
80
60
40
20
0
-10
-5
0
5
10
Median: -0.6 deg
RMS: 1.0 deg
CYG (I+II) - CYG I (Degrees)

Figure 10



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7m Interrupt m
mpterp> gcopy
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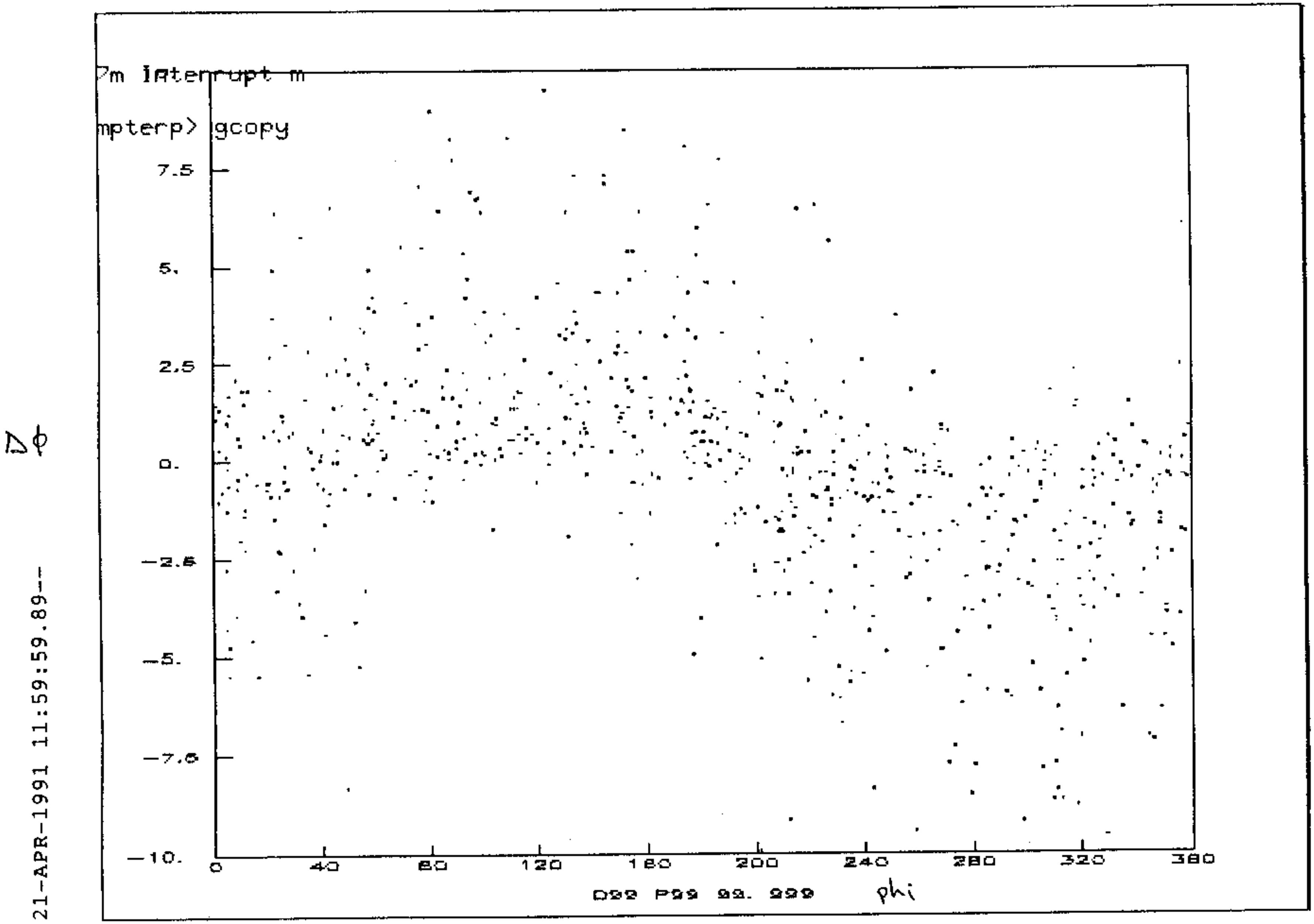
Figure 11



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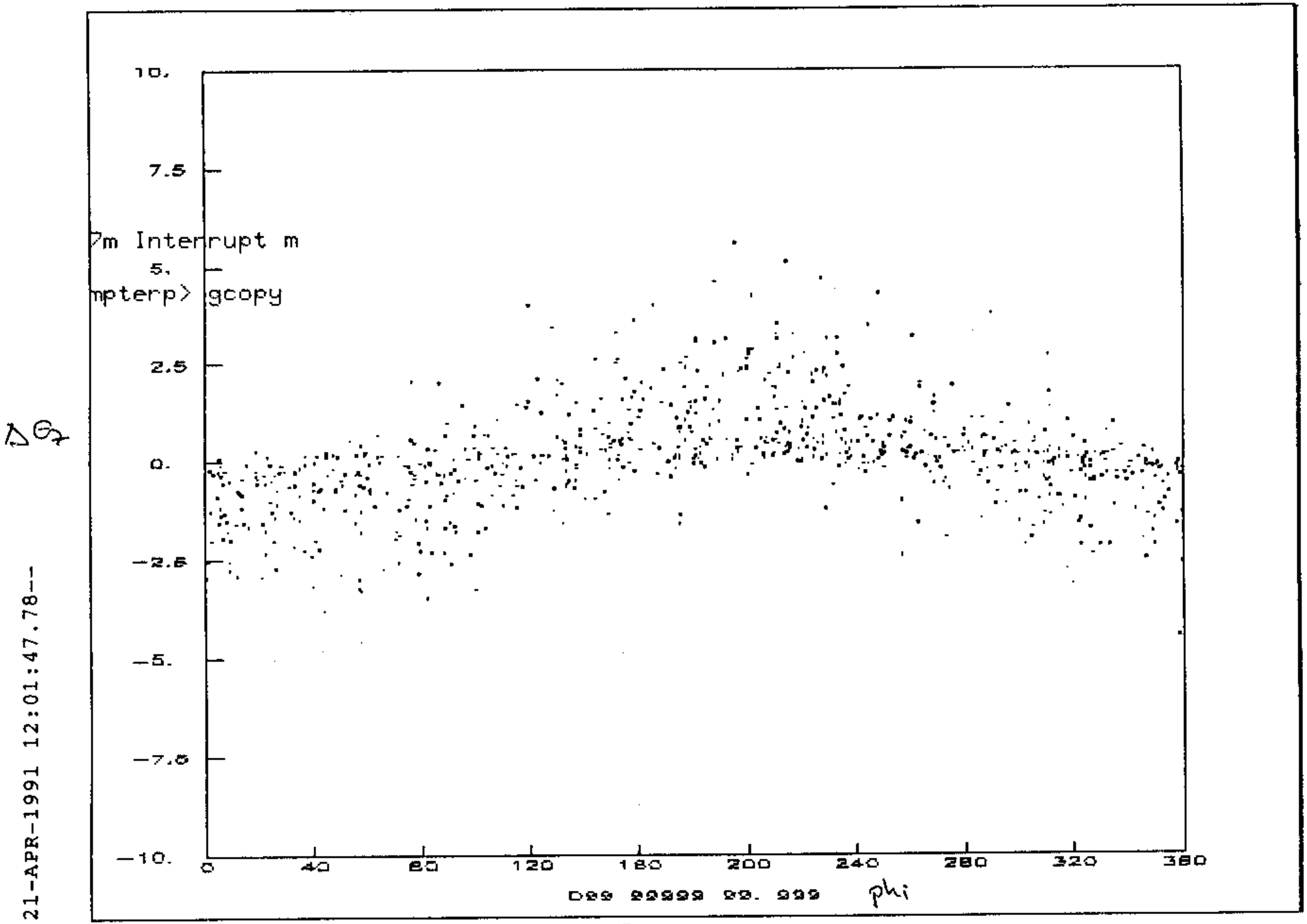
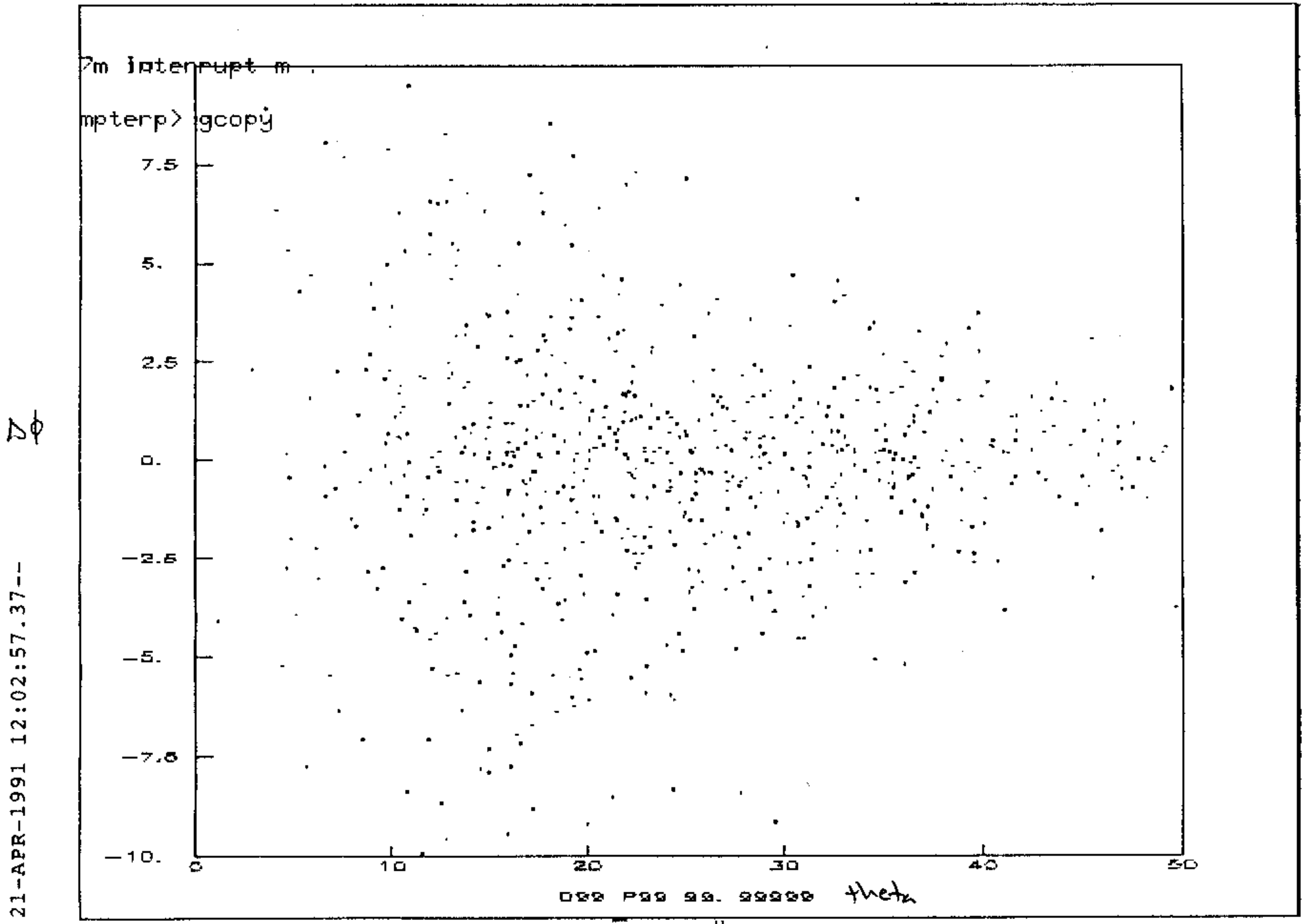
7m interrupt m
mpterp> gcopy
```

Figure 12



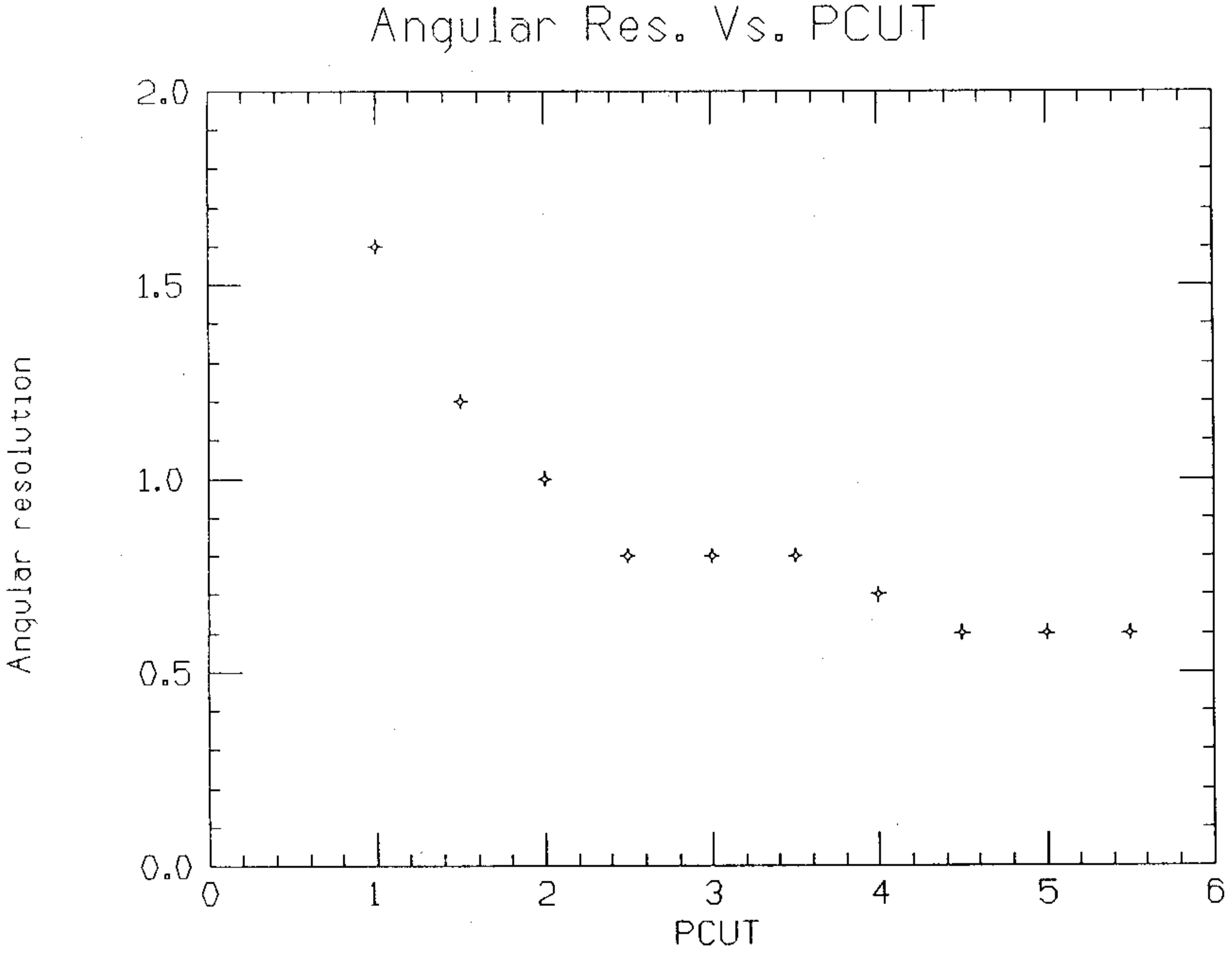
```
7m Interrupt m
mpterp> gcopy
```

Figure 13



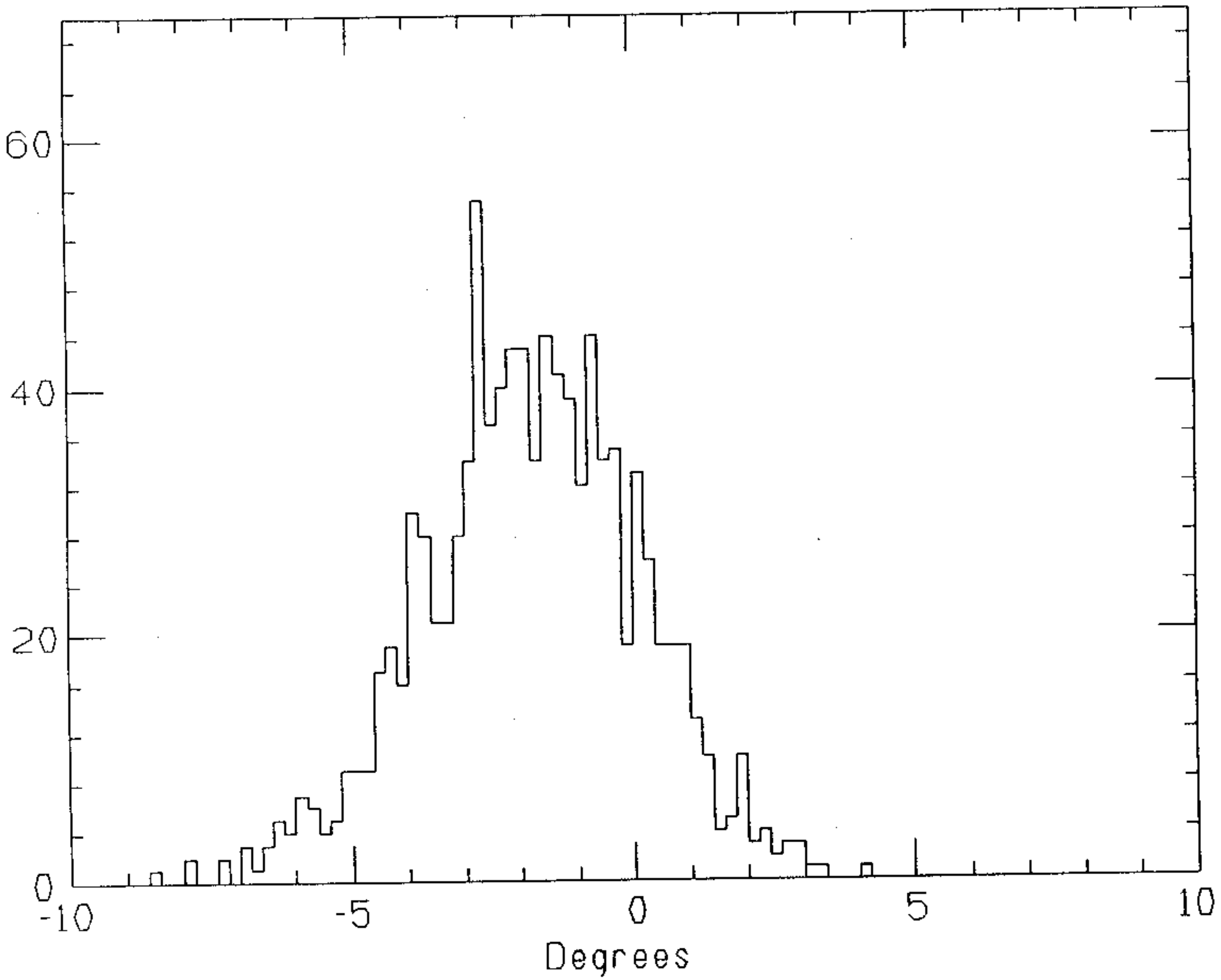
```
7m interrupt m .
mpterp> gcopy
```

Figure 14



Angular Res. Vs. PCUT
Angular resolution
PCUT
0.0
0.5
1.0
1.5
2.0
0
1
2
3
4
5
6

Figure 15



Angular Response of CYG I for exterior cores

Figure V6

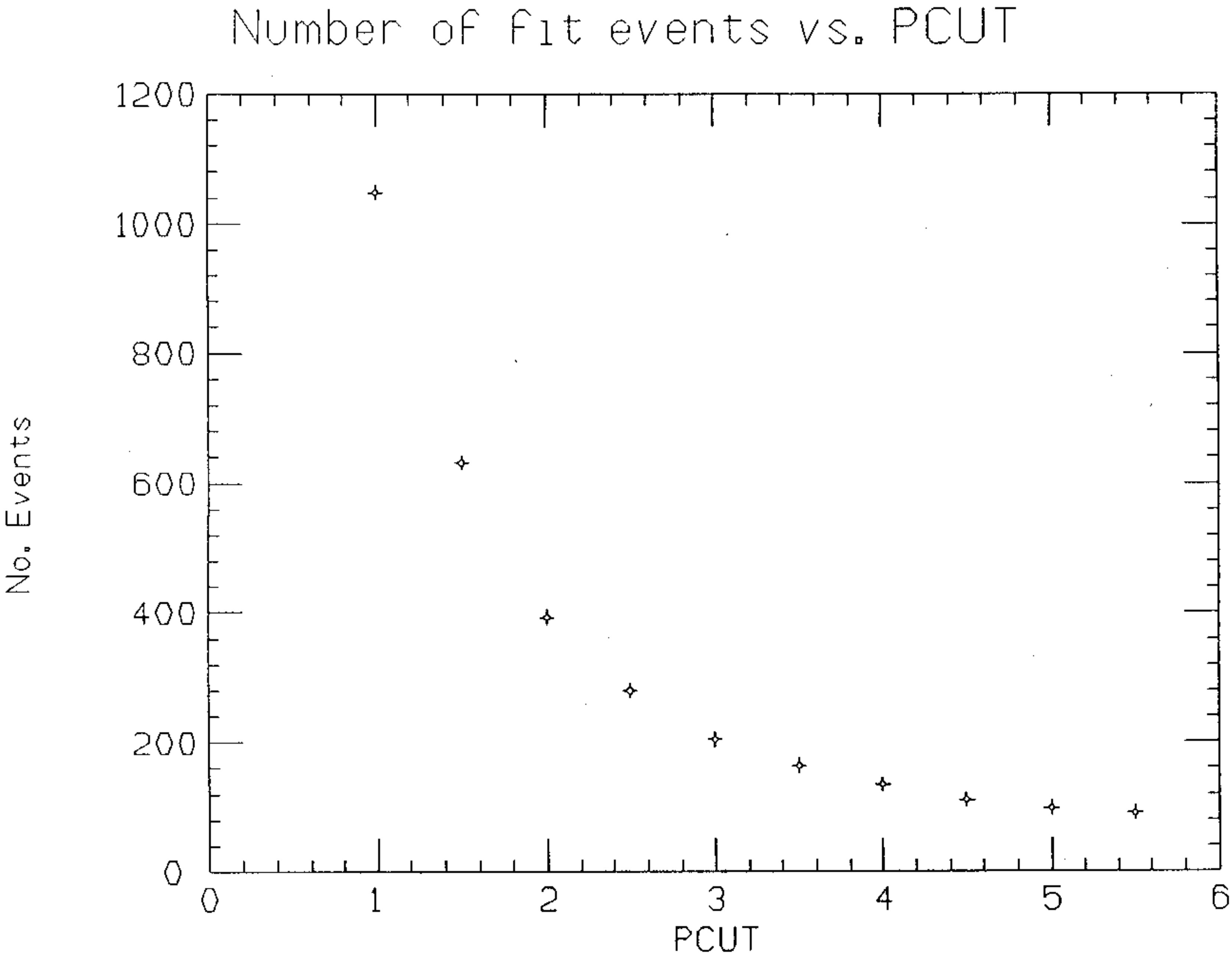

Number of fit events vs. PCUT
No. Events
PCUT
0
200
400
600
800
1000
1200
0
1
2
3
4
5
6

Figure 17

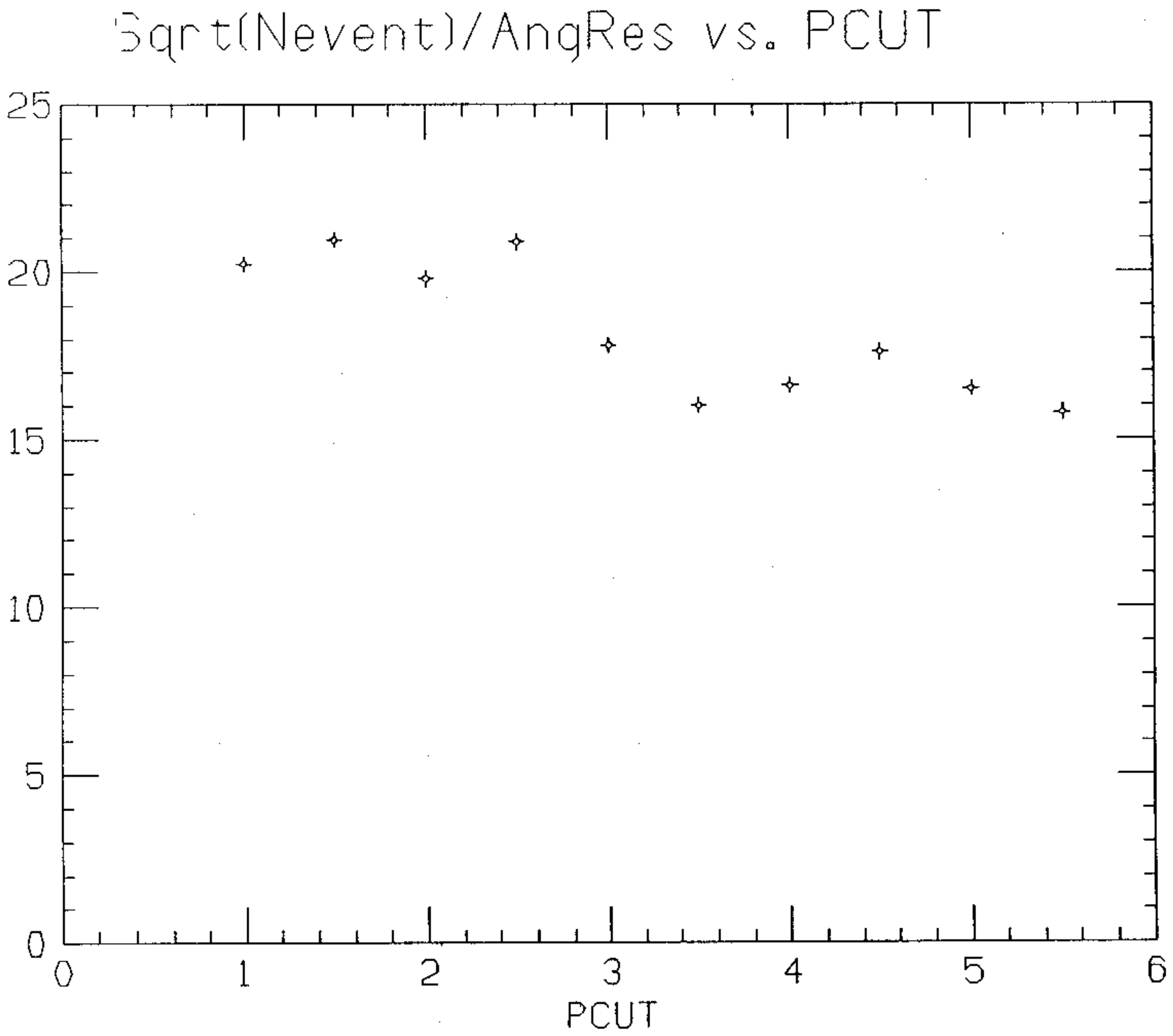


Figure 18