

## Anisotropy Analysis From Stereo Fly's Eye Data

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### ABSTRACT

The arrival direction of cosmic rays detected by both Utah's Fly's Eye 1 and Fly's Eye 2, and reconstructed by stereo geometry, have been studied to search for large-scale anisotropy of the cosmic ray distribution. No significant galactic latitude gradient or galactic plane excess were observed for energy greater than 0.3 EeV.

### 1. INTRODUCTION

The arrival direction of cosmic rays detected both by Fly's Eye 1 and Fly's eye 2 can be reconstructed by stereo geometry. ( Cassiday, et al, 1990 ) This analysis compares the number of observed events and the number of events predicted by an isotropic distribution, in 2 dimensional galactic arrays of 36 x 11 bins and 4 energy intervals. The large-scale anisotropy of the cosmic ray distribution is analyzed by fitting these arrays to two models, ( 1 ) galactic latitude gradient,  $I(b_i) = I_0(1 + sb_i)$ , and ( 2 ) galactic plane excess,  $I(b_i) = I_0(1 - f) + 1.402 fe^{-b^2}$  ( Chi et al 1992 ).

### 2 OBSERVED DATA

Stereo data has a better angular resolution than single eye data. The typical uncertainty in zenith angle  $d\theta$  is  $1.7^\circ$  in stereo data, compared to  $d\theta 8.6^\circ$  in mono data.

For statistics reason, we choose equal-area bins with the bin size  $10^\circ$  in galactic longitude and  $0.1743$  in  $\sin(\text{galactic latitude})$ . The galactic latitude bin has a  $10^\circ$  width near the galactic plane, and ranges from  $-71.3^\circ$  to  $75.4^\circ$ . The bin center is chosen so that Cygnus X-3 will sit in the center of one of the bins. This binning is consistent with previous Fly' Eye papers ( Baltrusaitis et al 1986 ).

There are 4 energy bins, 0.3 to 1 EeV, 1 to 3 EeV, 3 to 10 EeV, and greater than 10. EeV.

The required events must pass a data quality cut. This cut excludes events that have relative errors in shower energy, shower maximum, shower width, greater than 10. Events with angular uncertainty greater than one half of their range are cut out. Events with track length less than  $30^\circ$  and impact parameter, the perpendicular distance from shower axis to detector, less than 1 kilometer are also cut. Events failing in these cuts are distributed randomly in galactic coordinates.

The running period is from Nov. 86 to Jul. 92, and is separated into five epochs corresponding to different detector conditions. The total live time is 180.92 days. The valid event number and live time of four energy bins in each epoch are listed in table 1.

### 3 ISOTROPIC BACKGROUND PREDICTION

The isotropic background is computed using a scrambled event method. Because of the stereo geometry, the detector has a different efficiency for different zenith and

Table 1: Event number and exposure time of all epochs

Epoch	Date	Energy bin ( EeV )				event number	exposure time( day )
		0.3-1.	1.-3.	3.-10.	10.		
2	11 /86 - 06/87	518	205	31	5	759	23.21
3	07/87 - 06/88	1611	452	93	12	2168	37.88
4	07/88 - 04/90	2105	594	134	22	2855	63.32
5	05/90 - 09/91	1030	328	63	20	1441	35.24
6	10/91 - 0/92	0	193	42	3	94	21.26
Total		5971	1772	363	62	8168	180.92

azimuth angles. The algorithm of the scrambled event method is stated below:

1. Start from first observed event's  $\theta$  and  $\phi$ , of the desired epoch and energy bin, add/subtract a random portion of  $d\theta$ ,  $d\phi$  weighted by Gaussian probability,
2. Choose an event's time randomly, and compute the galactic coordinates and uncertainties.
3. Assuming the arrival direction follows a 2 dimensional Gaussian distribution, save the integral of probability of each bin to the scrambled event arrays.
4. Repeat this process about 50,000 event are generated.

Because of the randomization of time, these scrambled event depend on the  $\theta$ - $\phi$  correlation and live time only, therefore are independent of any galactic model or any particular sources.

The predicted event array is calculated from the scrambled events and renormalized to the total number of events of the corresponding epoch and energy bin. The result for energy 0.3 -1. EeV is shown in figure 1.

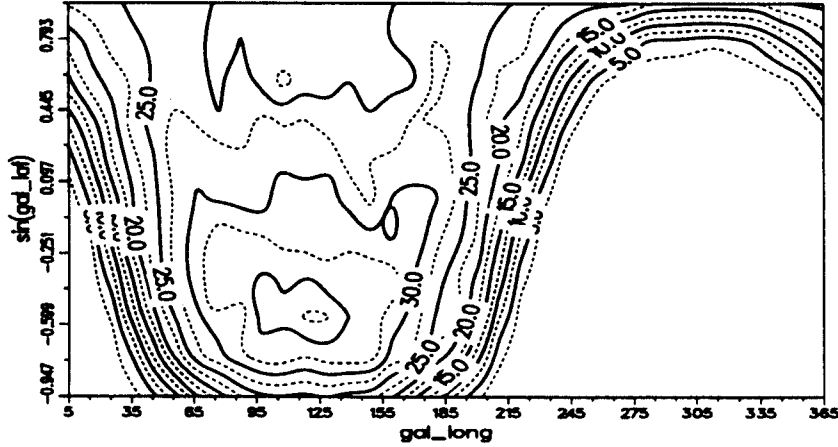


Figure 1: The contour map of predicted events generated by scrambled event method.

Figure ?? and figure ?? show the projection of observed and predicted events in galactic longitude and latitude, the error bar is set at  $\pm 1\sigma$ , where  $\sigma$  is assumed to equal to square root of the predicted value.

All the reduced chi-square,  $\chi^2_{\sigma}$  and probability, reported in table 2, are approximately 1. From these data and plots, we conclude that the observed cosmic rays distribution is consistent with the isotropic distribution of scrambled events.

Table 2:  $\chi^2_{\sigma}$  of observe and predicted event number

Energy ( EeV )	0.3 -1.	1. - 3.	3. -10.	10.
$\chi^2_{\sigma}$	0.6876	0.6642	0.7701	0.88 0
$P(\chi^2_{\sigma})$	0.99996	0.99999	0.99977	0.99999

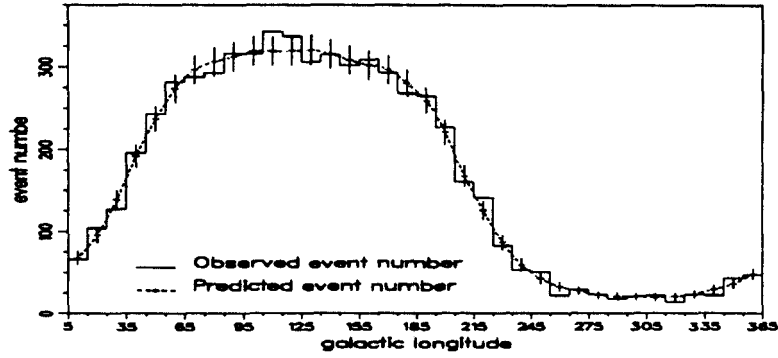


Figure 2: The observed/predicted event number as function of galactic longitude

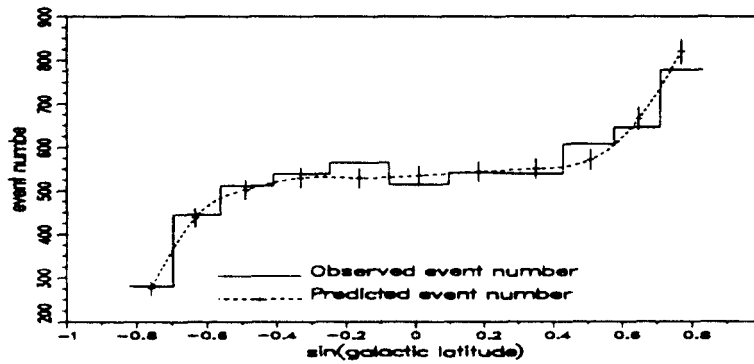


Figure 3: The observed/predicted event number as function of sin( galactic latitude )

#### 4 MODEL FITTING

Two model are used in the large-scale anisotropy analysis. The first model is the galactic latitude gradient model, which fits the observed and predicted event ratio by

$$ratio( b_i ) = R_0( 1 + s x b_i )$$

The second model is the Wdowczyk and Wolf endale galactic plane enhancement, which fits the ratio to their recent formula ( Chi et al 1992 ).

$$ratio( b_i ) = R_0( 1 - f ) + f x 1.402 x e^{-bi^2}$$

We project the observed and predicted events in galactic latitude and then fit them to the two models. The result are reported in table ?? . Figure ?? and figure ?? shows the fit for the two models, for energy 0.3 - 1 EeV. The probability that this fit comes from an uncorrelated parent population are all above 5%, except for the gradient fit of energy bin 3, 3 -10 EeV. These fit fail to pass the 95% C.L. and the large uncertainty of s and f suggests that the best fit values are not statistically significant and are consistent with zero, i.e. isotropic distribution.

#### 5 CONCLUSION

With the much improved angular resolution data, our analysis shows the cosmic rays distribution is consistent with isotropic prediction and no significant galactic latitude gradient or galactic plane enhancement.

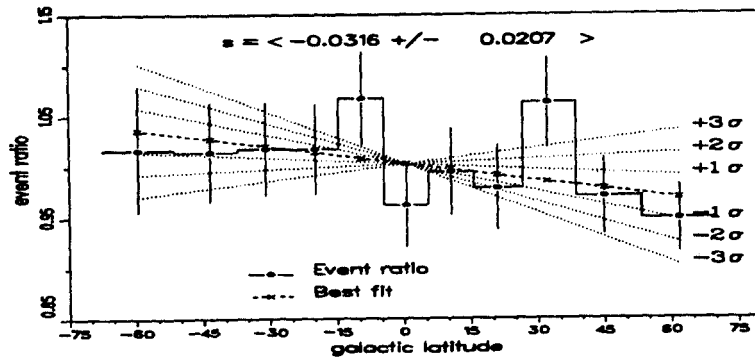


Figure 4: The galactic latitude gradient fit

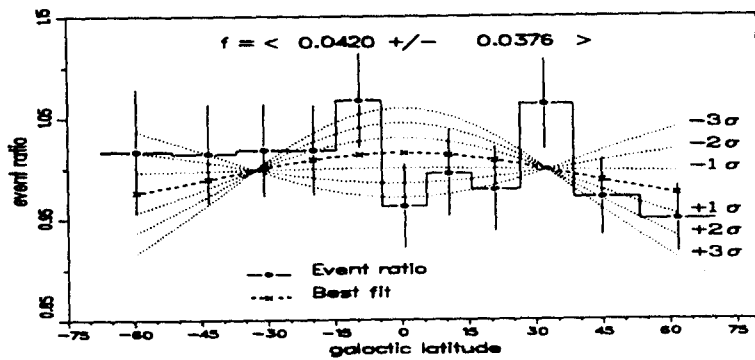


Figure 5: The galactic plane enhancement fit

## ACKNOWLEDGEMENTS

We thank Colonels Frank Cox and James King and the staff of the Dugway Proving Grounds for their continued cooperation and assistance. This work has been supported in part by the NSF grant number PHY-9119278 and the U.S. Department of Energy.

## REFERENCES

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Table 3: Model fitting of 4 energy

	$s \pm \delta_s^1$	Probability <sup>2</sup>	$f \pm \delta_f$	Probability <sup>2</sup>
1	$-0.0316 \pm 0.0207$	0.0988	$0.0420 \pm 0.0376$	0.2465
2	$-0.0757 \pm 0.0384$	0.0189	$0.0551 \pm 0.0688$	0.4092
3	$0.1422 \pm 0.0829$	0.1543	$0.0863 \pm 0.1080$	0.1397
4	$-1.7776 \pm 0.6030$	0.0706	$0.2360 \pm 0.3486$	0.7893

1. The unit of slope is 1/radian.
2. The probability that the fitting function and ration of events are uncorrelated.