Galactic Plane: Improved Statistical Power and a Check of Background Offset.

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1 Introduction.

This note reports further examination of the evidence for a non-zero galactic plane signal reported in Roman Fleysher's Thesis (Ref.1). For the Milagro Inner Galaxy this was a 3.5sigma excess of $(3.77 \pm 1.08) \times 10^{-4}$ in the fractional distribution with the gamma hadron separation cut. The search was for a uniform signal in a $\pm 5°$ band in the longitude region from $20°$ to $100°$.

In this note we replace the "uniform source" assumption. The Milagro data itself does not have the statistical power to give information about the spatial shape of the Galactic plane signal. Instead, we make use of the EGRET data about the spatial distribution of the Galactic plane gamma ray emission at energies of 1 - 30 GeV to characterize the signal for the Milagro search. This implies that the interstellar molecular clouds that act as cosmic ray targets for the EGRET's gamma ray signal are also the source of any TeV signal for Milagro, which is a reasonable assumption, although other contributions are also possible (Ref.2).

The statistical test of the null hypothesis, that all of the events are due to isotropic background, optimized against this alternative, may result in a higher significance if the alternative is true.

In the second half of the note we examine the question of an offset in the background subtraction, by allowing for a possible existence of a contribution of unknown origin with a broad spatial signature, not associated with the Galactic emission in question.

2 The EGRET Galactic Plane Ridge.

By the courtesy of Brenda Dingus and Stan Hunter (Ref.3), we have received EGRET galactic longitude distributions, as well as latitude profiles in $10°$ longitude bands. In the Milagro Inner Galaxy(IG) region between a longitude of $20°$ - $100°$ there are 8 such bands. Fig.1 is a LEGO plot of the EGRET ridge.

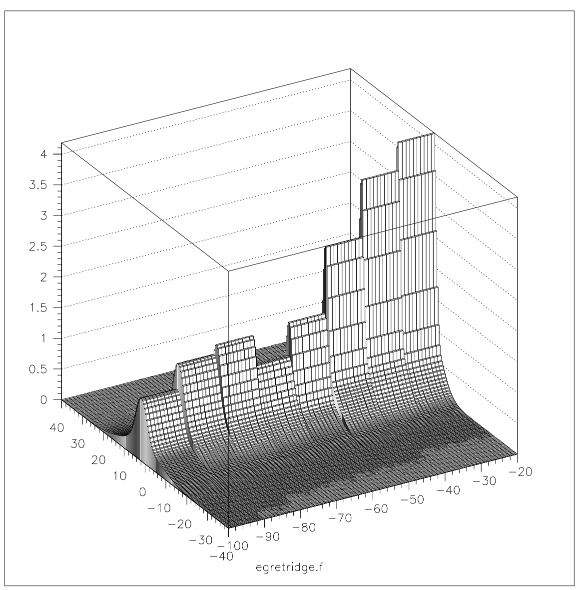

Figure 1: Egret Galactic Ridge in Milagro IG region.

Fig.2(a) shows the 8 IG latitude profiles [1]. The profiles are definitely nongaussian, but can be parametrized well as the sum of two gaussians. We use such a parametrization. The profiles are narrow and vary considerably across the IG longitude region. The galactic warp, or centroid shift, observed by EGRET(Ref.3) in the profiles near $90°$ longitude is not negligible compared to the width of the distributions. The longitudinal profile (in a $\pm 6°$ latitude band) in Fig.2(b) shows the the strong longitude dependence of the galactic emission.

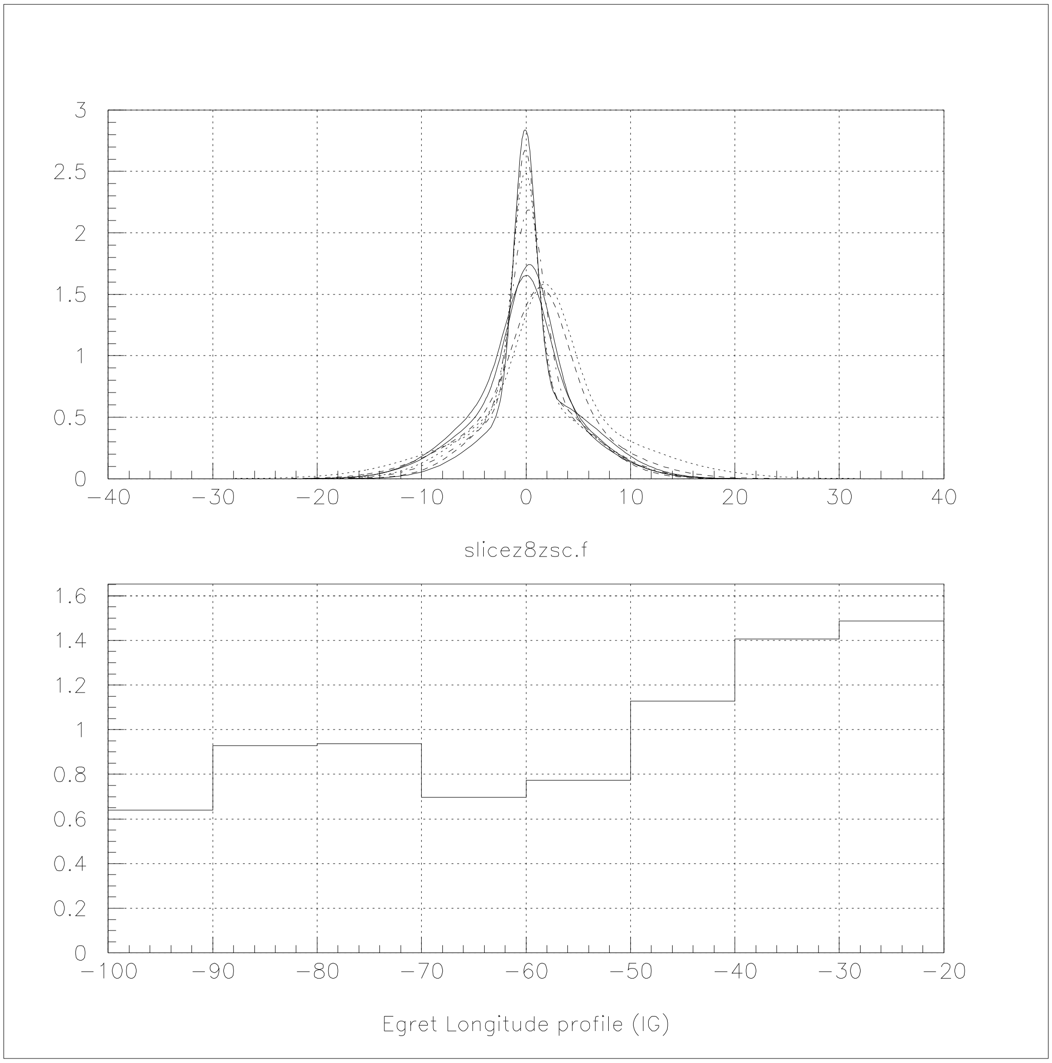

Figure 2: Milagro IG region: (a) Egret latitude profiles.(b) Egret longitude distribution.

3 Fitting the Milagro IG Data.

The starting point of the fit is the subtracted two-dimensional fractional galactic coordinate sky map of Ref.1. The methods and corrections for obtaining this sky map are fully decribed there; we will not recapitulate them here.

To utilize the 8 different EGRET profiles, we take the experimental galactic coordinate sky map and project 8 one-dimensional latitude histograms in the 8 $10°$ wide longitude bands of the IG. Fig.3 gives the exposure in the 8 bands and an example of the fractional signal (s-b)/b for a band, in $0.5°$ bins. Because of the steep EGRET profiles, we keep this narrow binning for the analysis, even though the eye is distracted by the large single bin error bars.

[1] The EGRET profiles had been smoothed by $0.5°$ We have convoluted them by another $0.5°$ for an assumed Milagro resolution of $0.7°$.

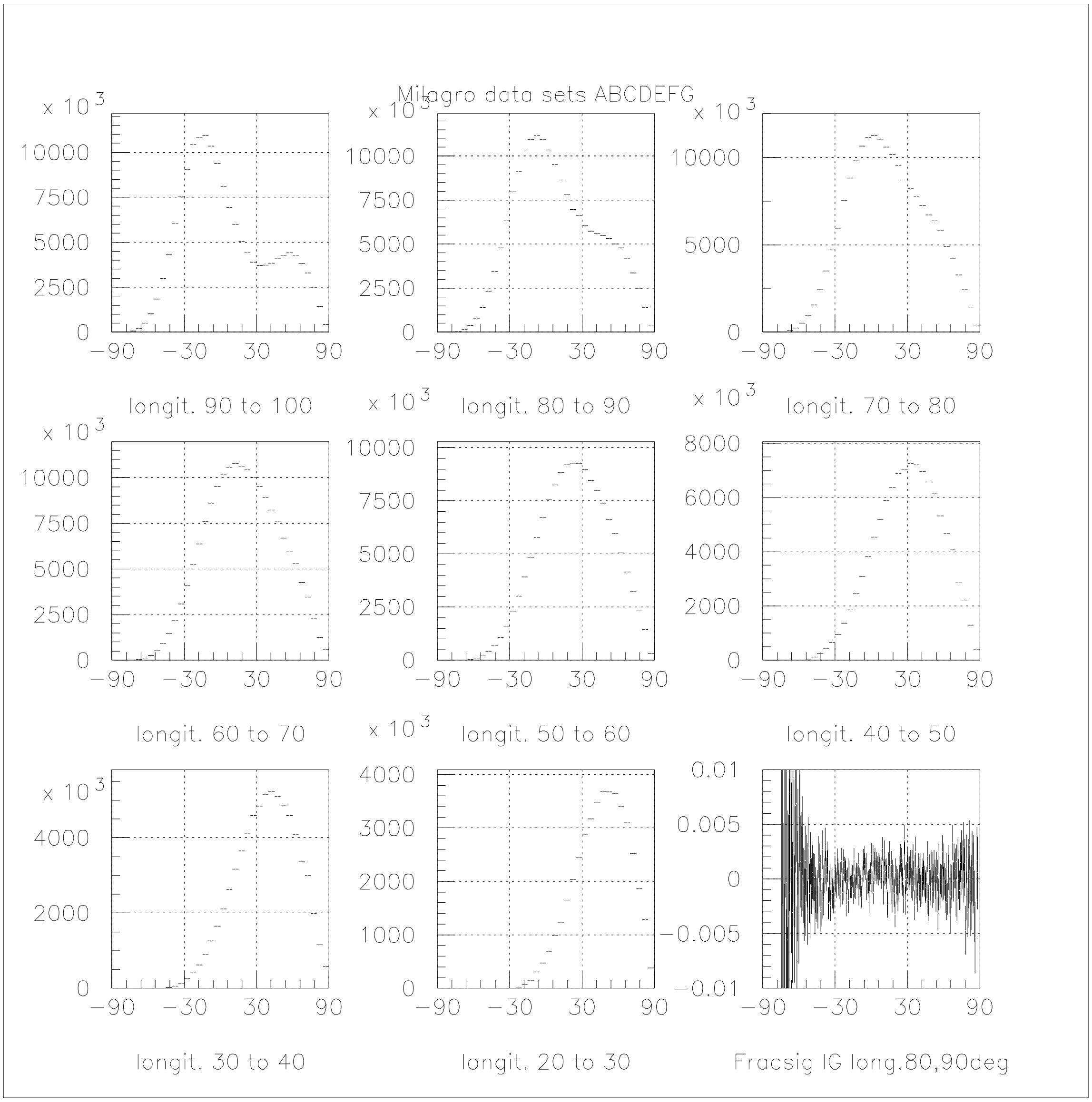

Figure 3: Milagro IG Exposure in 8 bands; Fractional Signal for band 2.

We do 8 separate experiments, fitting for the amplitude of the EGRET ridge. Fig.4 shows the individual ridge fit outcomes. The individual band amplitudes and their errors, plotted against the longitude bin, are shown in Fig.5, where the data is fitted to the longitudinal profile of Fig.2(b). This last step gives the final result for the IG fractional signal [2]:

$$(4.51 \pm 0.93) \times 10^{-4} \text{ (4.75sigma)}$$

compared to the 3.5sigma result of Ref.1. The added external information on the spatial distribution has in fact resulted in increased statistical significance for the observed signal.

[2]We have inflated the errors in the fit by 4.2%, a heuristic estimate of a correction for a small correlation of the single bin errors in the time-swapped background generation. This estimate could be refined further.

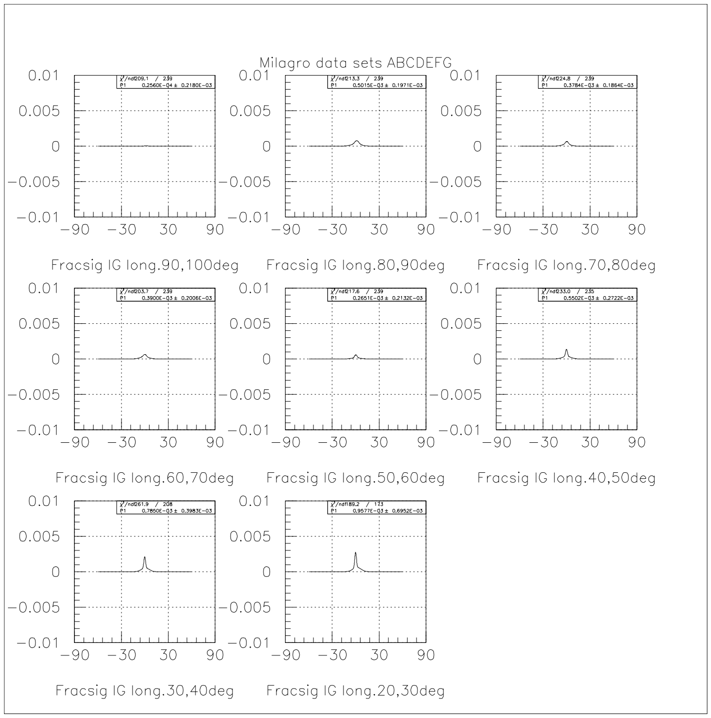

Figure 4: Eight Latitude Profile Fits.

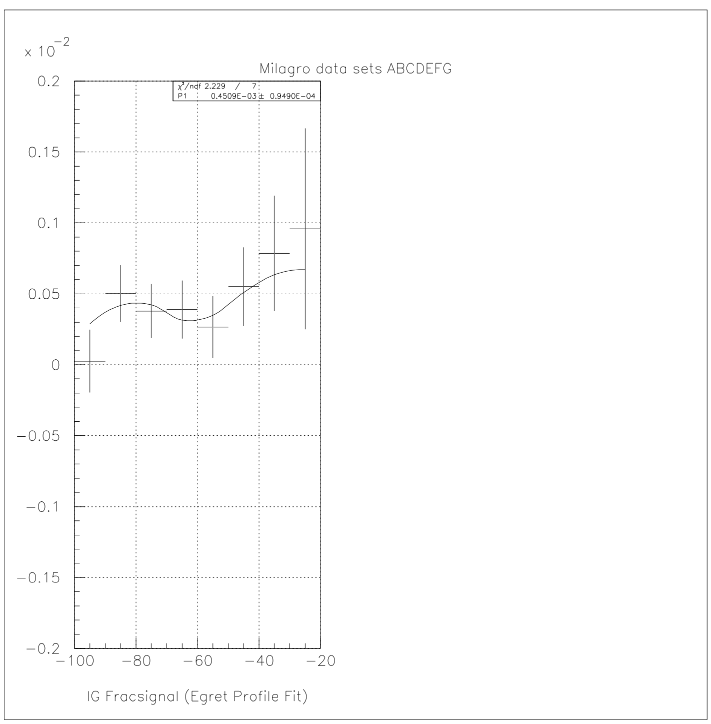

Figure 5: Fit of Amplitudes to Egret Longitude Distribution.

4 Check for a Background Offset.

An alternate source for a signal at the galactic equator could be a residual nonzero level of background due to approximations in generating the background extrapolated into the signal region, i.e. an offset in the background subtraction.

The subtracted background is the dominant cosmic rays, whose random magnetic bending results in an effective point spread function of order of a radian. Therefore, even if the cosmic ray sky is not perfectly isotropic as assumed in the analysis, such an unknown contribution should show up as broad hills and dales in the subtracted data. We utilize the very distict signatures expected from the two sources to estimate their contributions separately, by fitting the data to free parameters for **Ridge** and **Hillndale** contributions.

In each of the 8 IG bands we do a 4parameter fit, one free parameter α for the Ridge amplitude as before, and parametrize the Hillndale contribution as a quadratic function over the full fit region in latitude (3 free parameters). For the results below we choose a fit region of $\pm 60^\circ$.

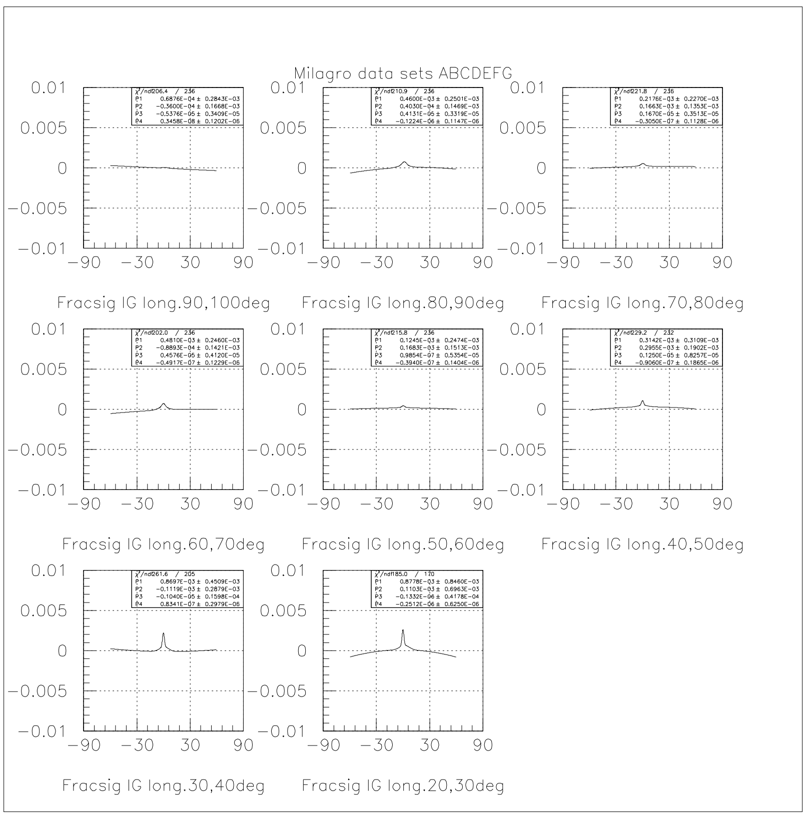

Figure 6: 8 Latitude Profile Fits to Ridge plus Quadratic Background.

Fig.6 shows the 8 individual fit outcomes; the eye can easily pick out the Hillndale and Ridge contributions. Fig.7(a) shows the Ridge amplitudes and errors vs. longitude and the longitudinal profile fit to it. Fig.7(b) shows the Hillndale amplitudes evaluated at the galactic equator and with their errors, vs longitude.

The IG Ridge signal is now $(3.76 \pm 1.14) \times 10^{-4}$ (3.3sigma). The average equatorial Hillndale signal is $(0.72 \pm 0.61) \times 10^{-4}$. Given a choice, the data is seen to ask for a significant Ridge signal, while the equatorial Hillndale signal is much smaller and consistent with zero.

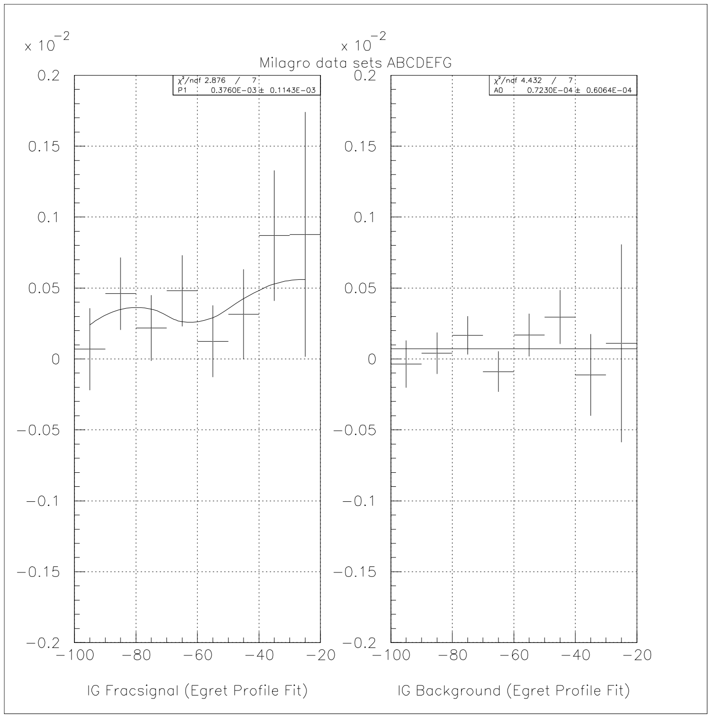

Figure 7: Fits to (a) Ridge Amplitude. (b) Equatorial Hillndale Amplitude.

5 Stability Checks.

We check the stability of the results from sections 3 and 4 by varying some conditions. All the results are in units of 10^{-4}. The latitude fit region is shown in brackets. For section 3 we list the Ridge amplitude.

- 4.51 ± 0.95.....[$-60°$,$60°$] (from section 3)
- 4.52 ± 0.94.....[$-60°$,$60°$] EGRET unsmeared.
- 4.45 ± 0.95.....[$-10°$,$10°$]
- 4.77 ± 1.01.....[$-60°$,$60°$] (exclude first and last long. bin)

For section 4, we list the Ridge and Equatorial Hillndale amplitudes.

- 3.76 ± 1.14.....0.76 ± 0.61.....[$-60°$,$60°$] (from section 4)
- 3.88 ± 0.17.....0.57 ± 0.66.....[$-50°$,$50°$]
- 3.95 ± 0.23.....0.56 ± 0.76.....[$-40°$,$40°$]
- 3.84 ± 1.12.....0.60 ± 0.57.....[$-70°$,$70°$]

6 A High Offset Monte Carlo Check.

As a check of the analysis we have generated a large offset, using a Montecarlo simulation with no galactic signal, and an unreasonably exaggerated 1% anisotropy (0.01cos(RA)), at the data generation. The data were then analyzed with the standard data reduction and analysis with its usual isotropy assumption at the data treatment. The results are in units of 10^{-4}.

Doing a single parameter Ridge fit, one gets significant fake signals of $3.93 \pm .93$ (4.2sigma) and 3.81 ± 0.83 (4.6sigma) for IG and OG respectively.

The 4-parameter Ridge plus Hillndale fit, on the other hand, gives Ridge Signals of 1.19 ± 1.13 (1.05sigma) and -0.20 ± 1.45 (-0.15sigma) for IG and OG respectively, both consistent with zero. The equatorial Hillndale signal shows up with high significance, 2.44 ± 0.73 (4.5sigma) and 3.00 ± 0.94 (3.2sigma) for IG and OG respectively.

7 Outer Galaxy.

In the Milagro Outer Galaxy(OG) region,140° - 220°, the profiles are much wider and quite similar, as seen in Fig. 8(a). The intensity variation with longitude in Fig.8(b) is less than 20%. Therefore, the new method fo profile fits makes much less difference.

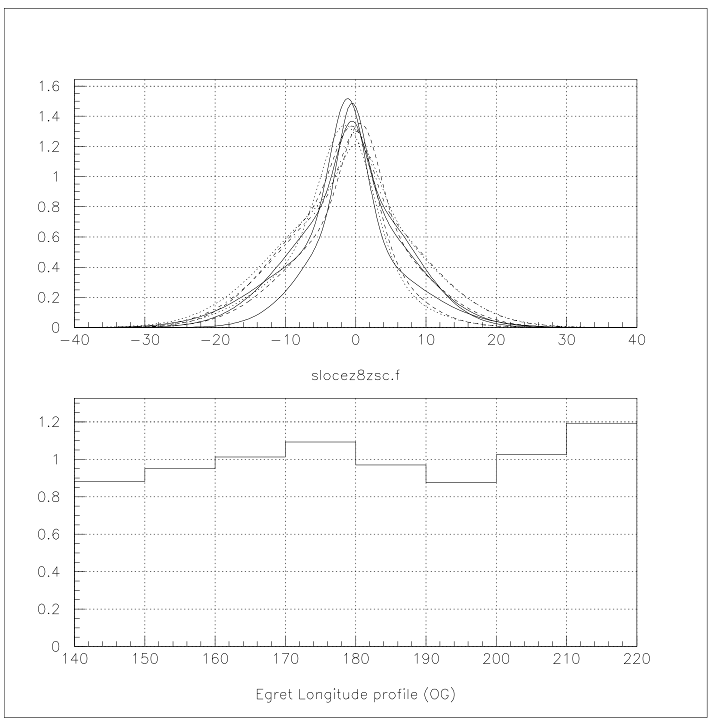

Figure 8: OG: (a)Egret latitude profiles.(b) Egret longitude distribution

With a one-parameter Ridge fit, the Ridge amplitude is $(-1.09 \pm 0.84) \times 10^{-4}$ (-1.3sigma). With the four-parameter fit the Ridge Amplitude is $(-1.30 \pm 1.47) \times 10^{-4}$ (-0.8sigma) and the average equatorial Hillndale signal is $(0.2 \pm 1.0) \times 10^{-4}$.

The result is in accord with the conclusion of Ref.1 that the Milagro data give an upper limit only for the OG.

8 Conclusions.

With the physics assumption that the EGRET galactic ridge angular distribution is also characteristic of the angular distribution at TeV energies, the analysis of the Milagro data gives a fractional galactic plane signal of $(4.51 \pm 0.93) \times 10^{-4}$, a statistical significance of 4.75sigma, for the Milagro Inner Galaxy. We add a caution: the error result uses a small heuristic correction for correlation in the background, to be refined.

A check for an offset, allowing both a Ridge Signal and a quadratic contribution for the possility of a residual background signal, yields a dominant Galactic Ridge Signal of $(3.6 \pm 1.14) \times 10^{-4}$ (3.3sigma), and a small equatorial background contribution of $(0.70 \pm 0.60) \times 10^{-4}$, consistent with zero.

9 Acknowledgement.

We thank Brenda Dingus for fruitful discussions and for her help in obtaining the EGRET data in a useable form.

References.

1. Roman Fleysher: "Search for Gamma Ray Emission from Galactic Plane with Milagro. Dissertation submitted in partial fulfillment of the requirements of the degree of Doctor of Philosphy. New York University, Sept. 2002

2. F. A. Aharonian and A. M. Atoyan, astro-ph/0009009 (2000).

3. S. D. Hunter et al., Astrophysical Journal 481, 205 (1997), and private communication.