Preliminary Evidence for TeV Gamma Ray Emission from the Galactic Plane using the Milagro Detector

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Abstract

The majority of galactic gamma rays are produced by interaction of cosmic rays with matter or radiation fields. This results in a diffuse radiation concentrated in the galactic plane where the flux of cosmic rays and the density of material (mostly atomic, molecular and ionized hydrogen) is high. The interactions producing gamma rays include the decay of π^0 produced in spallation reactions and inverse Compton scattering of electrons on cosmic microwave background.

Milagro is a water Cherenkov extensive air shower array capable of continuously viewing the entire overhead sky and is sensitive to gamma rays with energies below 1 TeV. The combination of a large duty factor and a large field of view results in a higher sensitivity to the diffuse emission from the galaxy compared to previous experiments in the same energy band. Preliminary evidence for TeV gamma emission from the galactic plane using Milagro data will be presented at the conference.

1. Introduction

Cosmic rays are accelerated by unknown objects in our Galaxy and are trapped (for about 100 million years) by Galactic magnetic fields. The interaction of high energy cosmic rays with the interstellar material produces γ-rays by a combination of electron bremsstrahlung, inverse Compton and nucleon-nucleon processes. The nucleon-nucleon interactions give rise to π^0's which decay to gamma rays and are expected to dominate the flux at energies above several GeV. In this manner, the regions of enhanced density (clouds of mostly atomic and molecular hydrogen) act as passive targets, converting some fraction of impinging cosmic rays into gamma rays. This should appear as a diffuse glow concentrated in the narrow band along the Galactic equator with maximum intensity in the directions of Galactic center ($b = 0°$ and $l = 0°$) and decreasing towards the edges ($b = 0°$ and $l = \pm 180°$). Indeed, such an emission was detected by the space-borne EGRET detector [6] at energies up to 30 GeV. The data made available by the EGRET collaboration [7] may be used to build the expectations for the Milagro air shower detector. Because of the change of the primary emission mechanism between MeV and GeV energy regions from bremsstrahlung to π^0 decay [3], we

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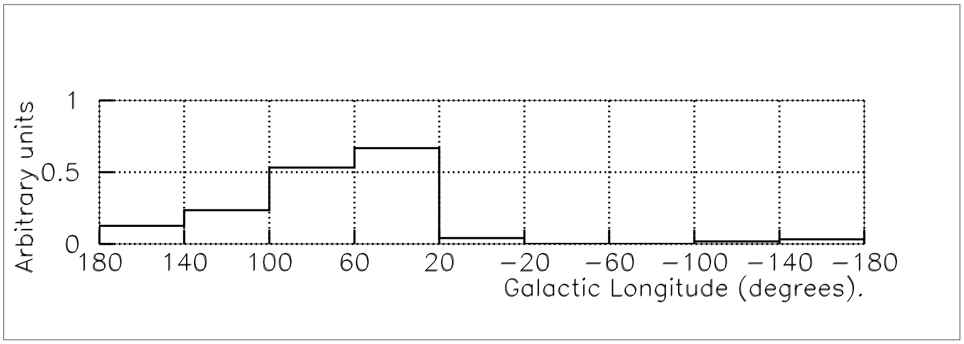

Fig. 1. The expected relative significance in the units of standard deviations of the normal distribution as a function of Galactic longitude l.

used only the highest EGRET energy data points in this determination. The expected significance which is roughly proportional to the product of the signal flux and the square root of Milagro exposure is presented on figure 1. Thus, the region of the Galactic disk with $l \in (20^\circ, 100^\circ)$ is the region where highest significance is expected provided that the Galactic longitude profile of the emission at TeV energies is similar to that observed by EGRET. EGRET's latitude profile suggests the choice of the region with $|b| < 5^\circ$. Therefore, the region of $l \in (20^\circ, 100^\circ)$, $b \in (-5^\circ, 5^\circ)$ is selected as the inner Galaxy for the Milagro analysis.

2. Data Analysis

The results presented are obtained from analysis of data collected by the Milagro detector between July 19, 2000 and September 10, 2001. The analysis of a further data set is under way. The starting date corresponds to the commissioning of the hadron rejection algorithm which improves signal to background ratio by factor of 4.5 in the inner Galaxy region, the ending date is when the experiment was turned off for a major scheduled maintenance. To ensure high quality of the data, several data quality selection cuts were applied. The data analysis technique used in this work is based on the modified time swapping method [5] which allows consistent use of the standard time swapping method of background estimation [1] and the test statistic proposed in [10] by excluding the source region from background generation. The null hypothesis tested consists of:

- There is no emission from the Galactic plane except for background.
- All of the detected events are due to background and background is isotropic except for $\pm 5^\circ$ region around the Sun and the Moon. (Events from these regions are vetoed.)

- The detector acceptance is stable on the scale of 8 hours, except for a diurnal zenith modulation [4].

Because the emission from the Galactic plane is under investigation, events arriving from the $|b| < 7°$ band along the Galactic equator are excluded from the background generation. This also excludes possible influence of the Crab nebula known to emit gamma rays in the TeV energy region [2] on the background generation. The results with the hadron rejection cut are: the average number of events detected from the region of Milagro inner galaxy N_s is estimated as $(10823.8 \pm 1.0) \cdot 10^4$, its corresponding background estimate $N_b = (10819.7 \pm 0.5) \cdot 10^4$, the ratio of average signal to background counts $N_\gamma/N_b \equiv (N_s - N_b)/N_b = (+3.77 \pm 1.08) \cdot 10^{-4}$. The null hypothesis is rejected with the significance of 3.5; equivalently, the probability that it is rejected by chance fluctuations is $2.3 \cdot 10^{-4}$.

3. Large scale anisotropies

In the analysis it was assumed that no anisotropy on the sky is present. Because of the random bending of cosmic rays in the galactic magnetic fields which are responsible for the isotropy of the background, small deviations from isotropy are expected to be smooth and therefore reveal themselves as large angular scale structures. According to indications in the literature from underground muon experiments [8] a slight anisotropy in Right Ascension (α) may be present which is parametrized by the authors as $R(\alpha) = 1 + r_0 \cos(\alpha - \alpha_0)$ where $r_0 = (5.6 \pm 1.9) \cdot 10^{-4}$, $\alpha_0 = 8.0° \pm 19.1°$. The contribution to the N_γ/N_b in the Milagro inner Galaxy is calculated to be about $-0.4 \cdot 10^{-4}$. However, it should be noted that the muon anisotropy need not be identical to that of the cosmic ray air showers in the Milagro energy range.

If it is assumed that a large-angular-scale anisotropy is present and is modeled as a broad plateau in the region of $5° < |b| < 60°$ and inner galactic longitudes, a linear interpolation into the equator region results in an estimated contribution of $(+0.54 \pm 0.34) \cdot 10^{-4}$ to the measured ratio N_γ/N_b. Although this simple interpolation may not be perfect, we choose to subtract this contribution to obtain the preliminary result of $N_\gamma/N_b = (3.23 \pm 1.15) \cdot 10^{-4}$ for the diffuse Galactic signal.

4. Interpretation of the results

The results for the inner Galaxy, interpreted as gamma ray emission, may be used to calculate the gamma ray flux. The ratio of the gamma ray and the cosmic ray fluxes becomes $F_\gamma/F_{cr} = (7.2 \pm 2.8) \cdot 10^{-5}$. Assuming simple power law integral emission spectrum ($F_\gamma(> E) = F_\gamma(> 1TeV) \cdot E^{1-\alpha_\gamma}$, E is energy in TeV) independent of Galactic coordinates for Galactic gamma rays, given the measurements of EGRET and assuming that power law index α_γ is constant above 10 GeV we obtain the differential spectral index and integral flux that is consistent with the EGRET and Milagro data: $\alpha_\gamma = 2.63 \pm 0.08$ and $F(> 1TeV) = (8.0 \pm 3.3) \cdot 10^{-10}\ cm^{-1}\ sr^{-1}\ s^{-1}$ in the region of Milagro inner Galaxy. This preliminary measurement is compatible with earlier upper limit obtained by the Whipple observatory at 500 GeV [9]. The spectral index in the energy range above 1 GeV as measured by EGRET and averaged over the Milagro inner Galaxy is equal to 2.365 ± 0.016. Thus, the measurement of the index in the Milagro inner Galaxy seems to contradict to the possibility of constant spectral index in this part of the galaxy and requires softening of the spectrum between EGRET and Milagro energy regions. We note that no such softening is observed in the cosmic ray spectrum as measured at the Earth between these energy regions. These facts suggests that the mechanism responsible for TeV gamma-ray production may be quite different than that which operates in the GeV region. Also, the measured spectral index is close to that of the cosmic ray spectral index as expected from π^0 dominant models.

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6. References

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