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Search for diffuse TeV gamma-ray emission from the galactic plane, using the Milagro gamma-ray telescope.

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Abstract. Diffuse high energy gamma radiation can arise from a variety of astrophysical sources, in particular from interactions between energetic cosmic rays and matter in our galaxy. Emission from the galactic plane has been detected up to GeV energies by space-based detectors. Observations at higher energies, for which the flux is too low for satellites, can be done with ground based telescopes. Milagro is a wide-aperture extensive air shower water Cerenkov detector collecting data from a solid angle of about two steradians in the overhead sky at energies near 1 TeV. We have used a 2000-2001 data set from Milagro to search for the emission of diffuse gamma rays from the galactic disk. Preliminary results of the search will be presented.

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. Indeed, such an emission was detected by the space-borne detectors SAS 2, COS B (R.C. Hartman et al. , 1979) and EGRET (S. D. Hunter et al. , 1997) at energies up to 30 GeV.

However, observations with present satellite based instruments at higher energies are not possible due to the rapidly decreasing flux of γ-rays, requiring bigger effective area of the detectors. Therefore, the use of ground-based arrays is needed to observe the diffuse Galactic radiation. Inasmuch as the Galactic cosmic ray spectrum extends beyond 10^{15} eV, the diffuse Galactic emission should extend well beyond the energy threshold of Milagro ($\sim$ 400 GeV). A number of authors have estimated the expected diffuse very high energy gamma-ray flux from the Galactic plane (see for example P. Chardonnet et al. (1995)): they generally predict a flux within $\pm 5^\circ$ of the Galactic equator in latitude that is $\sim 10^{-4} - 10^{-5}$ of the cosmic ray flux for the regions of the outer galaxy.[1] The shape of the gamma-ray spectrum is predicted by the same authors as $\frac{dN}{dE} \sim E^{-2}$. However, at TeV energies the contribution from source cosmic rays, considered by E. G. Berezhko and H. J. Völk (2000), may increase the expected diffuse γ-ray flux by almost as order of magnitude compared to π^0-decay model predictions. It is also possible that the spectrum of cosmic rays in the interstellar medium is substantially harder compared with the local one measured directly in the solar neighborhood (F. A. Aharonian and A. M. Atotan , 2000) which will lead to higher diffuse γ-ray flux as well.

At present, gamma rays from the galactic plane have not been detected above EGRET energies (only upper limits were set). The only measurements that approach the required sensitivity are above 180 TeV, performed by CASA-MIA experiment (A. Borione et al. , 1998). The best measurement in the 1 TeV region, which is two orders of magnitude less sensitive, is due to Whipple (P. T. Reynolds et al. , 1993). Milagro, the detector designed to cover the energy gap in the few TeV region between other existing instruments, should be able to detect the diffuse very high energy Galactic emission and possibly its spatial distribution and bring an enhanced understanding of Galactic cosmic rays. The sky coverage of Milagro is illustrated on Figure 1. Because Milagro is located in the northern hemisphere at latitude of 36°, the Galactic center is not in its field of view. However, a considerable portion

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[1]The outer Galaxy is defined as the region with galactic longitude l, $40^\circ < l < 320^\circ$.

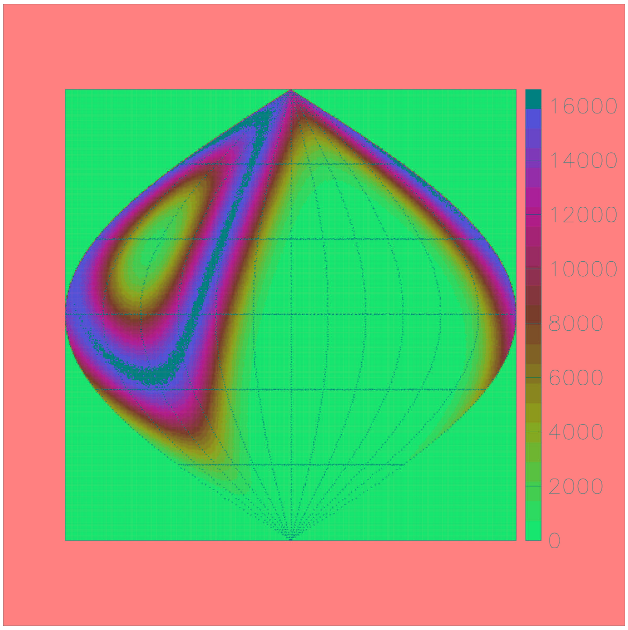

Fig. 1. The density of events from Milagro (in arbitrary units) plotted in galactic coordinate system, sine equal area projection. Grid lines are plotted every 30° in longitude and latitude. Galactic center is in the middle of the map

of the outer disk is visible to Milagro.

2 The Milagro Gamma-Ray Observatory

High energy gamma rays as well as cosmic rays do not penetrate the Earth's atmosphere, but interact at high altitude producing cascades of particles called extensive air showers. Milagro is the first detector designed to study air showers at energies near 1 TeV using water Cerenkov techniques by detecting particles in the cascade that survive to the ground level. The detector is built in the Jemez Mountains near Los Alamos, New Mexico, USA at an altitude of 2650 m. It presents a 60m x 80m x 8m pond, filled with clean water, covered with a light barrier and instrumented with 723 - 20 cm photo-multiplier tubes (PMT). The PMTs are arranged in two layers: top one of 450 tubes is used primarily to reconstruct shower direction, and the bottom one of 273 tubes is used for discrimination of gamma ray and hadron induced air showers. Milagro is currently operational. For a recent status update please see G. Sullivan et al. (2001).

The shower direction is calculated from the relative times at which the PMTs are struck after correcting for the effects of electronic slewing, sampling of particles in the shower front, and curvature of the shower front. After making these corrections, the direction of the shower plane can be determined with a χ^2 fit using the measured times and positions from the PMTs which also accounts for the tail of late light due to low-energy particles that tend to trail the shower front and nearly horizontal light in the water from the large Cerenkov angle and from scattering of particles and light in the water. Baffles have been installed around the PMTs to block the horizontal light and increase the light collection.

3 Analysis Method

Most air showers detected are produced by charged cosmic rays that form an isotropic background. Emission from a gamma ray source would appear as an excess number of events coming from the direction of the source. Therefore, when searching for weak signals the analysis must be able to predict the expected number of air shower events at each candidate position assuming there is no source which then can be compared with the observed number of events to determine the excess. There are many effects in an air shower experiment that, if not handled properly, could cause possible large systematic errors leading to artificial creation or disappearance of sources. These effects include:

– times when the experiment was not operating

– non-uniformities in the acceptance of the array to air showers due to detector geometry

– short- and long-term event rate variations due to detector upgrades or changes in the atmosphere

– short- and long-term variations in the acceptance of the detector due to atmospheric conditions and detector reconfigurations.

These effects can cause variations in effective exposure of the array to different parts of the sky.

A method has been developed that is able to determine the number of expected background events at each point in the celestial sky, even though each of the above effects exists in the data, without having to make any cuts on the data. This technique is based on widely used method presented in (D. E. Alexandreas et al. , 1993). The method takes advantage of the rotation of the Earth and is based on the assumption that the detector responds to an isotropic background of cosmic rays. Under this supposition there should be a time independent flux of particles from each direction in local coordinates. *Thus, a shower detected with particular local coordinates could have arrived with equal probability at any other time of shower detection*.

Each background event is generated from a real event by calculating new value of Right Ascension using new randomly chosen arrival time from the pool of registration times of collected events in a finite time window which is large compared to the source size convoluted with angular resolution. Inasmuch as events from the source region are used to estimate the background level, the background will be overestimated if the signal is indeed present. This leads to an underestimation of the signal strength. The time window, typically 2 hours for a point source search, is extended to 8 hours for this Galactic signal search to accommodate the 10 degree thickness of the disk.

However, the assumption of time invariance of the flux of detected cosmic rays is violated during such a long time period due to variations in the acceptance of the detector induced by atmospheric condition changes. The developed method is able to track and correct for such modulations. The extended version still possesses the advantages of the original one: background events have the correct distribution in local coordinates and it naturally compensates for event rate variations including interruptions of any length in data collection.

We are applying this analysis technique to search for a signature of gamma rays from the Galactic plane region at energies near 1 TeV in combination with the background rejection method presented at this conference (C. Sinnis et al. , 2001) for improved sensitivity to diffuse Galactic gamma rays. Preliminary results will be presented at the conference.

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