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The Milagro gamma-ray observatory

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The Milagro Gamma-Ray Observatory

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Abstract. The Milagro water Cherenkov detector began full operation in January 2000. This detector is capable of monitoring the Northern sky at energies above 500 GeV for sources of equivalent strength to the Crab Nebula over one year of integration. We report on the current performance and sensitivity of Milagro.

I THE MILAGRO DETECTOR

Milagro, a new type of TeV γ-ray observatory sensitive at energies around 1 TeV, with a large field of view (>two steradian) and a high duty cycle (90%), began full operation in January 2000, near Los Alamos, NM. Milagro consists of 723 photomultiplier tubes (PMTs), submerged below the surface of a large, covered pool of water. The PMTs are placed on a grid with 2.8 m spacing in each of two

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layers, at 1.5 m and 7 m below the surface. An extensive air shower is detected by observing the particles which reach ground level. The relativistic particles in the shower which reach ground level radiate Cherenkov light in the water. An event is recorded when ~60 PMTs sense light within a ~200ns of one another. The resulting trigger rate is around 1500 Hz. The relative arrival times of the shower front at photomultiplier tubes on the top layer are used to determine the origin (on the sky) of the particle or gamma ray initiating the shower. The lower layer of photomultiplier tubes is used to identify and reject hadron-induced showers which dominate the data.

II BACKGROUND REJECTION

The data recorded by Milagro is dominated by a background of hadronic showers. In order to enhance a gamma-ray signal, techniques to reject hadronicly generated showers need to be applied to the data. Milagro samples showers which survive to observation level. The lateral distributions of the shower particles for gamma-ray initiated showers are expected to be relatively smooth over the detector, while nuclear showers can be clumpy due to the presence of muons, high-energy gammas and hadrons.

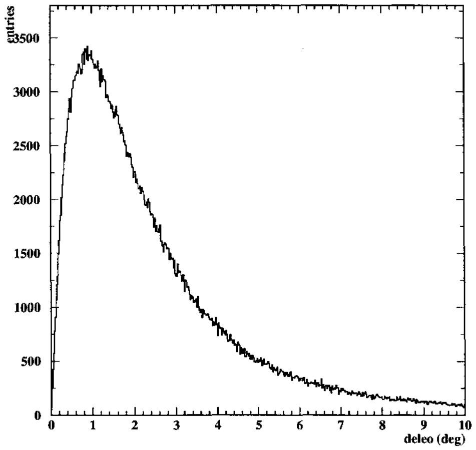

FIGURE 1. The angular resolution is estimated by dividing the array into two smaller arrays, plotted is the space angle difference between the incident shower reconstructed by the two independent detectors

The raggedness expected for nuclear showers is obscured by the general illumination of shower particles in the top layer of PMTs, but their presence should show up in the bottom layer of PMTs. This is because most of the particles are quickly absorbed in the water, and the Cherenkov light pool produced by each particle has become broad and diffuse by the time it reaches the lower level of PMTs. Penetrating particles, expected to be more prevalent in hadronic induced showers, show up as a cluster of brightly lit tubes in the bottom layer.

The ratio of the number of tubes in the muon layer hit to the pulse height in the brightest PMT has been found to be an efficient measure of "clumpiness." Simulations indicate that cutting on this parameter can reject 91% of the proton induced showers while retaining 54% of the gamma-ray signal, improving the sensitivity of the Milagro detector by a factor of 1.8.

III PERFORMANCE AND SENSITIVITY

For an event to be included in the analysis a cut is made requiring that the number of hits included in the angle fit be greater than 20. The statistical error in the reconstructed shower angle can be estimated by dividing the PMT grid into two overlapping arrays of equal size. The space angle difference between the two arrays is twice as large as the point spread function of the entire detector. This distribution, shown in Figure 1, peaks at 1.5 degrees, corresponding to a detector resolution of 0.75 degrees.

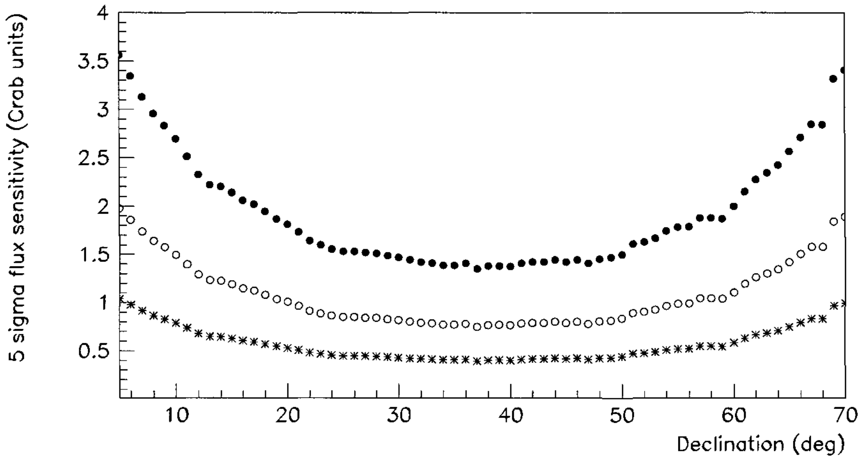

FIGURE 2. The 5 sigma flux sensitivity of Milagro in Crab units for one year of observations using a simple binned analysis with no background rejection (filled circles), with background rejection (open circles) and using an array of 120 water tanks to improve angular resolution (stars).

The expected performance of the Milagro detector has been simulated using CORSIKA to model air-shower development in the atmosphere, and GEANT to model the detector response [1]. For a rudimentary analysis with a cut that the number of PMTs in the fit must be greater than 20 and binning the data into 1.2 degree bins, the median triggered energy for a gamma-ray source with the same declination and spectrum as the Crab Nebula [2] is 2.6 TeV with 90% of the events falling in the range from 300 GeV to 25 TeV.

Figure 2 shows the expected 5 sigma flux sensitivity for one years of observation with Milagro. This is shown in units of Crab flux as a function of declination. The filled circles illustrate the sensitivity for the basic analysis described above, the open circles show the improvement obtained by applying background rejection. The angular resolution of Milagro varies strongly as a function of the number of tubes included in the angular fit. A "one binsize fits all" approach to the analysis is not optimal, so the sensitivities shown in figure 2 should be considered lower limits.

IV CONCLUSION AND FUTURE PROSPECTS

Milagro is currently capable of monitoring the northern sky at declinations from 5 to 70 degrees for sources of equivalent intensity to that of the Crab Nebula, over one year of observation. The sensitivity of Milagro will almost certainly improve as we refine our background rejection algorithms, and when we develop more sophisticated analysis methods.

An array of 120 water tanks each instrumented with a single PMT is currently being deployed over 40000 m^2 surrounding the Milagro pond. Because the pond is small compared with the lateral extent of typical air-showers, the additional detector array will allow for the identification of core positions, dramatically improving the angular and energy resolution of the instrument. The predicted improvement in the sensitivity of Milagro is illustrated by the stars in Figure 2.

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