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MILAGRO: A LOW THRESHOLD WATER ČERENKOV AIR SHOWER ARRAY

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ABSTRACT

MILAGRO is a proposed 5000 m^2 water Čerenkov air shower array. Čerenkov photons are detected by 400 fast PMT's, giving MILAGRO an almost fully active surface area. Because of the large active area, MILAGRO will be sensitive to air showers down to 500 GeV, a threshold comparable to air Čerenkov telescopes. The bottom of the MILAGRO pond will be a 1500 m^2 muon detector. The 208 existing CYGNUS counters will be deployed around MILAGRO, increasing the active area.

To test the water Čerenkov concept, CYGNUS has built five 3.7 meter radius swimming pool counters, each instrumented with seven fast 10" PMT's. Based on preliminary estimates, the pools have an angular resolution of 0.3-0.4^o, matching Monte Carlo predictions.

1. MILAGRO

Existing air shower arrays have thresholds in the 10-100 TeV region. Because of their sparse coverage, typically a 0.5% active surface, they are insensitive at lower energies. Their data collection rates are typically 5-25 Hz, giving them the ability to collect about 10^8 events per year. Although a number of large counter arrays have operated for many years, no steady sources have been confirmed.[1] A few bursts have been observed, but at a significance that has generated controversy.

Air shower detector sensitivity can be improved by increasing the angular resolution, by rejecting hadronic showers, or by increasing the rate, either by increasing the effective area, or by decreasing the threshold. MILAGRO[2] has emphasized the last strategy, aiming for a 500 GeV threshold, which should result in a 1 kHz data rate. This threshold is comparable to that of air Čerenkov telescopes which, however, have a low duty cycle, and point at a single object at a time. At the same time, because of its large active area, MILAGROs averaged (over detected events)

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directional accuracy will be equal to or better than existing arrays, even at low energies. For identical-energy events, it should be much better. For a photon source spectrum that matches the cosmic ray spectrum, MILAGRO should be about 10 times more sensitive than existing arrays. For spectra that are cut off in the 10-100 TeV range, as suggested by recent studies of γ absorption by starlight[3] MILAGRO may be the only detector capable of continuous observations. The higher rate is especially helpful for detecting bursts, where the number of events is limited, and Poisson statistics can limit the significance of signals. MILAGRO will also have 1500 m^2 of muon coverage, providing substantial hadronic rejection above a TeV.

The baseline design places PMT's on a 3 meter grid, 1 meter below the surface. A trigger will require 50 hit PMT's; this yields an energy threshold in the 500 GeV region. Due to the large fluctuations in the number of shower particles reaching the ground, the effective area (a measure of sensitivity) increase substantially between 500 GeV and 10 TeV, as a larger fraction of events trigger the detector. The Čerenkov radiation is detected by large (8" - 10") PMTs with single photoelectron timing resolutions of a few nsec. This design yields a calculated angular resolution of 0.7^0 at 1 TeV, decreasing to better than 0.5^0 above 10 TeV.

One advantage of a low threshold is that the Crab Nebula can serve as a constant source for calibration. We expect to observe the Crab with a significance of 5σ in 1 year without muon cuts. If the photon showers are muon poor, as expected, then a muon cut will boost the significance to 7σ. While this sensitivity is less than that of air Čerenkov detectors, it must be emphasized that most X-ray and gamma sources are time-varying, and for episodic phenomena MILAGRO's constant observation of is of great advantage compared to pointing instruments. Because of its low energy threshold compared to current air shower arrays, it is capable of expanding the search for intermittent sources to a new energy range. Figure 1 shows the MILAGRO sensitivity to steady and episodic sources.

2. The Pool Detectors.

To gain experience with water Čerenkov detectors, the CYGNUS collaboration has built five pool detectors[4] to augment the existing array[5] They are arranged in a cross, with a spacing of about 60 meters. The pools are commercially available home swimming pools, 7.4 meters in diameter and about 2.5 meters deep. The filtration system is likewise commercial. Each pool is instrumented with seven 10" diameter Burle PMT's, arranged as a hexagon surrounding a central tube, with a 1.5 m intertube spacing. The large area of the pools gives them a high sensitivity; 72% of CYGNUS-I triggers satisfy a software pool trigger requiring at least 15 PMTs spread among 4 pools to fire.

The pools angular resolution has been studied in a number of ways, both internally and in association with CYGNUS I. The initial tests looked at pool PMT timing residuals with respect to the shower front found from CYGNUS. For large (at least 15 photoelectrons) signals, the measured width was 1.9-2.3 nsec, depending on the PMT. When the measured widths, parameterized by amplitude, are folded

into a simple Monte Carlo, the results indicate an angular resolution of 0.35°, a factor of two better than CYGNUS-I. In triggered events, there appears to be little time or amplitude correlation between adjacent PMTs in a pool.

Another measure of angular resolution comes from the space angle difference between the CYGNUS array and the pools. This is shown in Figure 2, again requiring 15 PMTs in 4 pools to be hit. When the known CYGNUS resolution is subtracted in quadrature, the implied pool resolution is 0.3-0.4°. It is worth mentioning that this matches Monte Carlo predictions, giving confidence that the MILAGRO design will perform as expected. Studies of the resolution using the shadows of the sun and the moon are in progress.

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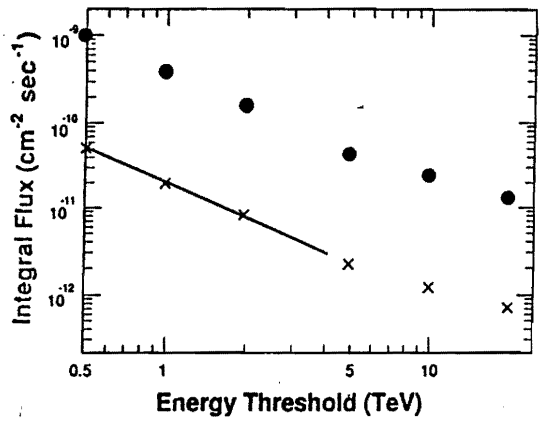

Fig. 1 MILAGRO sensitivity to continuous (X) and burst (circle) sources, for a 5σ detection, without muon rejection.

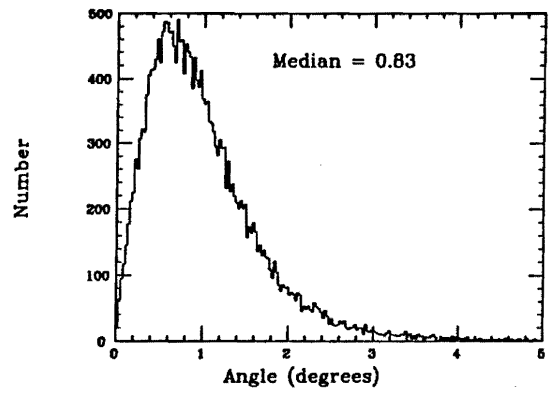

Fig. 2. The distribution of space angles between the CYGNUS fit and the pool fit.

3. References

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