Results from the Milagro All-Sky TeV Gamma-Ray Telescope

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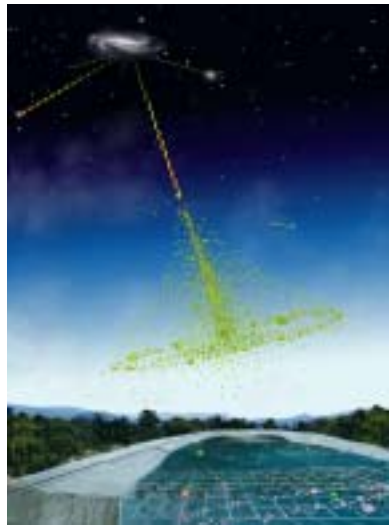
- Milagro Overview
- Background Rejection in Milagro
- Recent Results
  - Crab nebula
  - All-sky survey
  - Galactic Plane
  - GRB searches
- Upgrades



The Universe Viewed in Gamma Rays
Tokyo, Sept. 2002

Collaboration List

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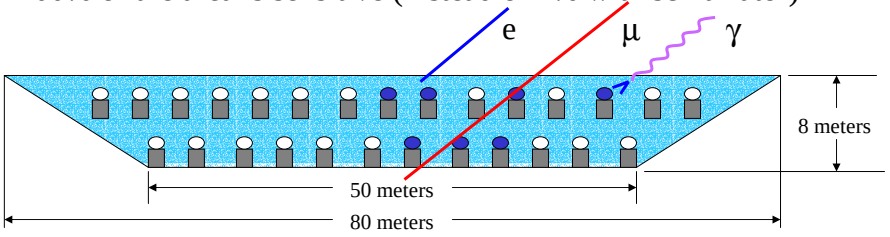
**Spokesmen* *Technicians* *Students*

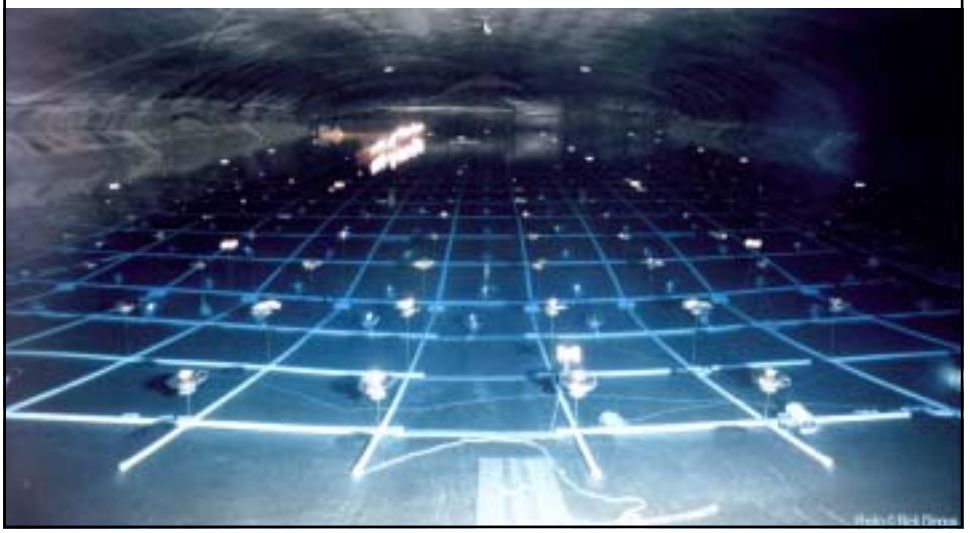
Milagro Schematic

Use water instead of scintillators to detect EAS particles
100% of the area is sensitive (instead of 1% with scintillator)

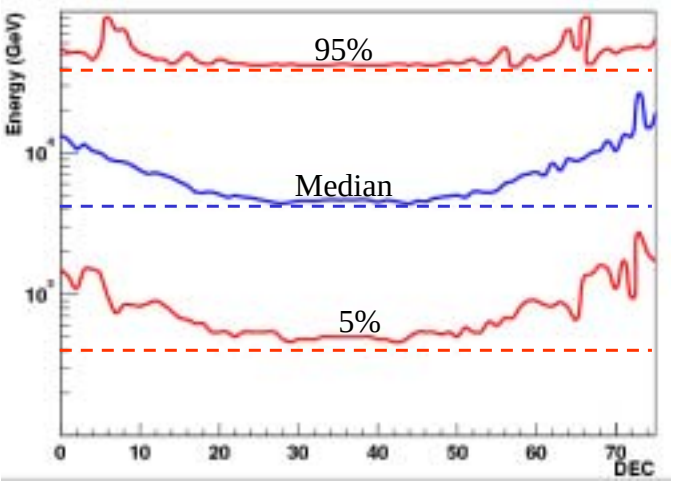


Low energy threshold (100 GeV)
Median energy ~4 TeV
High duty cycle (~95%)
Large field of view (~2 sr)
Good background rejection (~90%)
Trigger Rate 1.7 kHz

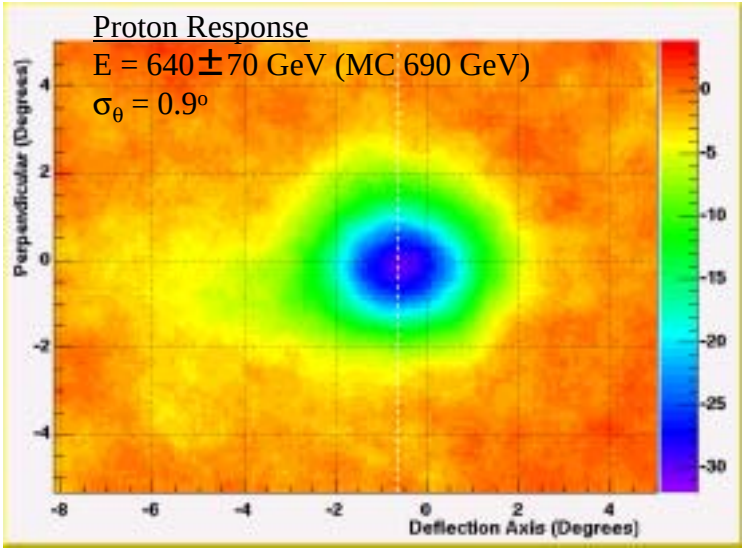
Milagro Detector



Milagro Energy Response: Gamma Rays

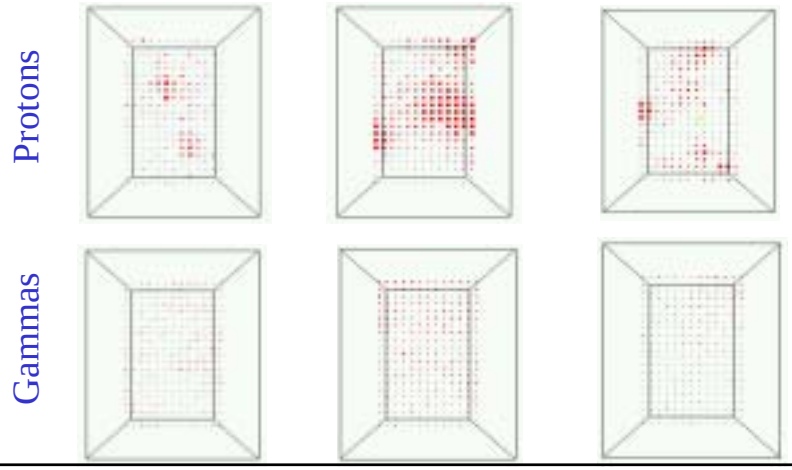


Moon Shadow: Energy Scale Calibration



Background Rejection in Milagro

- Hadronic cosmic ray showers contain penetrating particles
  - Muons and hadrons
- Deposit energy deep in Milagro – use bottom layer



Background Rejection: *C*

Search for large pulses in small number of tubes

$$C = \frac{NBottom(>2Pes)}{PE_{Max}(Bottom)}$$

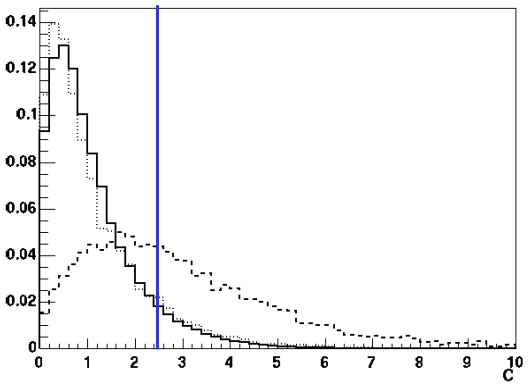
Demand C > 2.5

Retain:

53% of Gammas

11% of Protons/Data

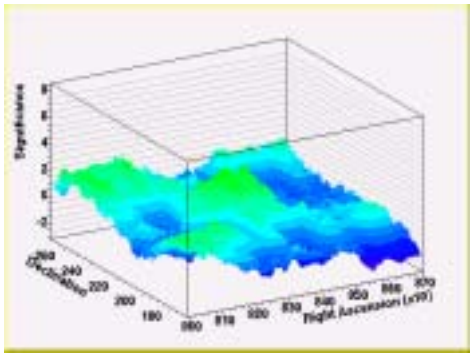
Q = 1.7

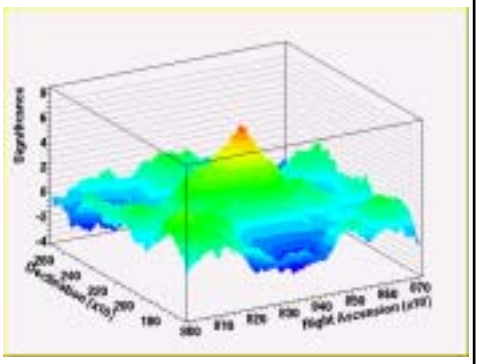


The Crab Nebula

Raw Data
On: 16,987,703
Off: 16,981,520
Significance: 1.4 σ

Cut Data
On: 1,952,917
Off: 1,945,109
Excess: 7,808 (~10/day)
Significance: 5.4 σ



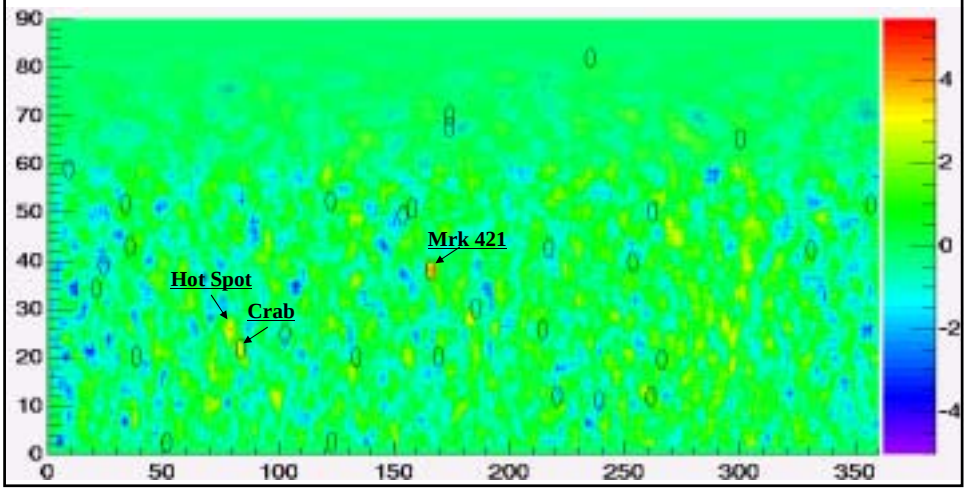


Flux from the Crab

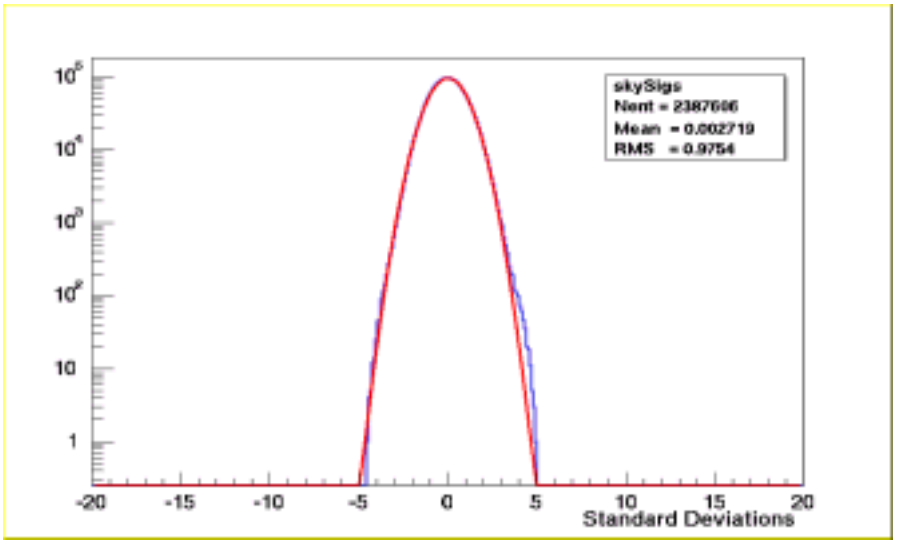
Use spectral index derived by ACTs
Determine differential flux coefficient (I_0)

Energy Spectrum	$E^{-2.44-0.15\log 10E}$ **(Whipple)**	$E^{-2.59}$ **(HEGRA)**
$I_0 \times 10^{-7}$ (m^{-2} s^{-1} TeV^{-1}) Milagro	$2.39 \pm 0.44^{stat} \pm 0.7^{sys}$	$2.3 \pm 0.42^{stat} \pm 0.7^{sys}$
$I_0 \times 10^{-7}$ (m^{-2} s^{-1} TeV^{-1}) *ACT*	$3.25 \pm 0.14^{stat} \pm 0.6^{sys}$ *Whipple*	$2.79 \pm 0.022^{stat} \pm 0.5^{sys}$ *HEGRA*

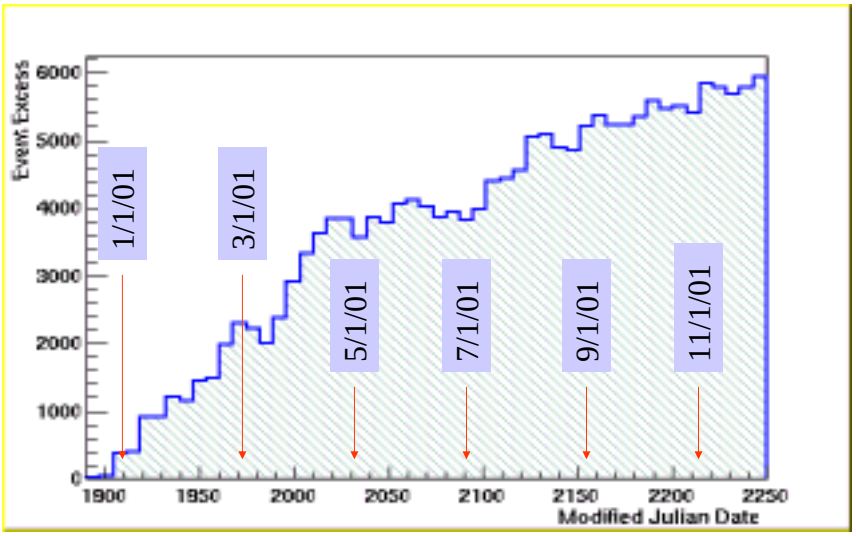
The Northern Hemisphere in TeV Gamma Rays: 12/00-12/01



Northern Hemisphere: 12 Months



Mrk 421 Excess

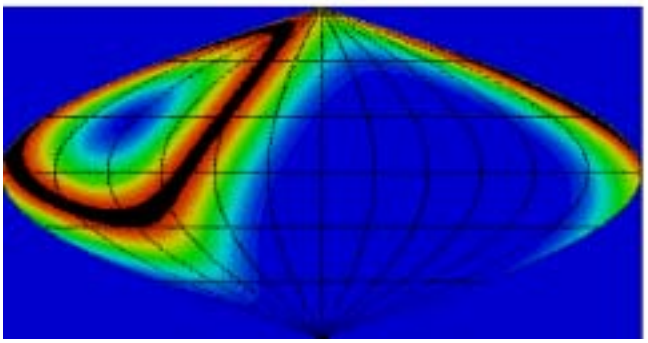


Sky Survey

- 12/00-12/01 Mrk 421 brightest object in TeV sky (Northern hemisphere)
  - Mrk 421 was bright (>2*x* Crab) 1-5/01
  - Mrk 421 ~3/4 Crab 7/11/01 – 12/5/01
- Next brightest region consistent with statistics
  - 4.7 σ
  - RA 79.6 Dec 25.8
  - 0.5 degrees from 3EG J0520+2556 (unidentified).

Diffuse Emission from The Galaxy

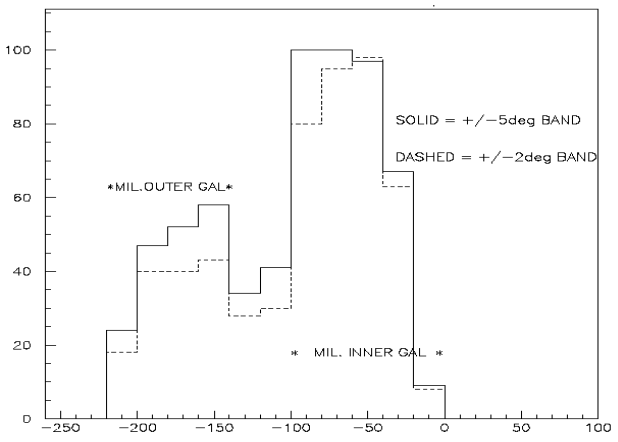
1 Year of Data: 12/00-12/01
Milagro Exposure to Galaxy



Inner galaxy: 20-100 degrees
Outer galaxy: 140-220 degrees
Gamma-ray cut applied to data

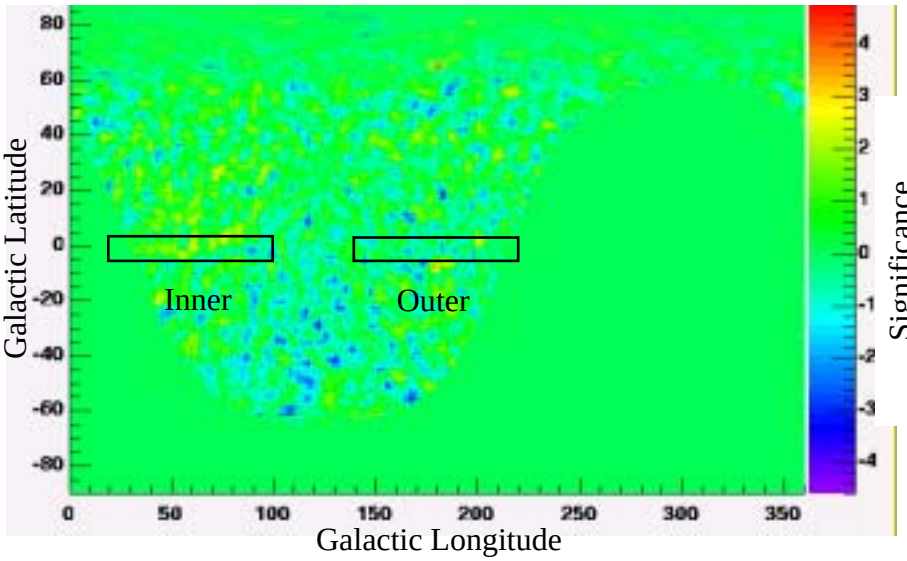
R. Fleysher/NYU

Expected Signal from EGRET

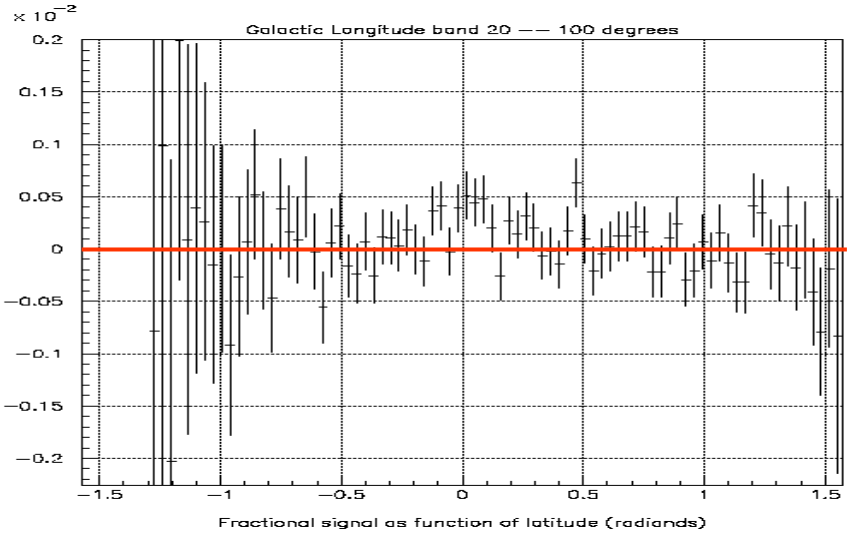


Galactic Longitude (-)

Galactic Plane: Results



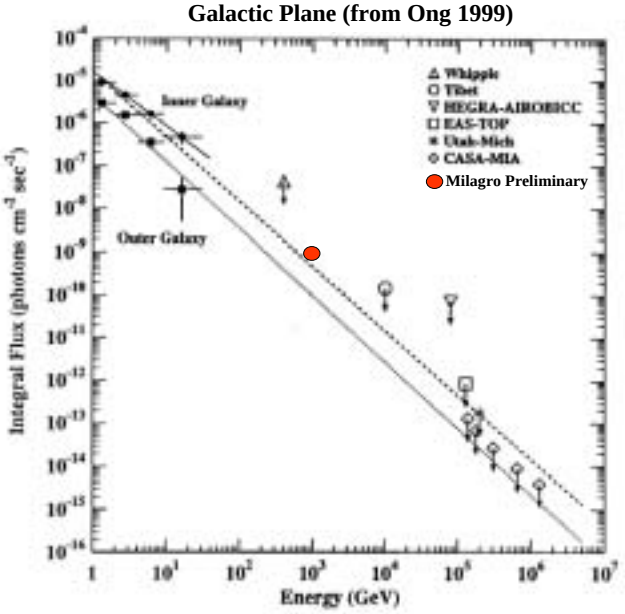
Inner Galaxy Latitude Scan



Galactic Plane Results: **Preliminary**

	Inner Galaxy		Outer Galaxy	
Thickness	$\pm 2^o$	$\pm 5^o$	$\pm 2^o$	$\pm 5^o$
Excess/ Bkg	17,800/ 4.35×10^7 2.7σ	36,460/ 1.08×10^8 3.5σ	-4,086/ 4.64×10^7 -0.6σ	-13,979/ 1.15×10^8 -1.3σ
F_γ/F_{cr} $\times 10^{-5}$	11.2 ± 4.1	9.4 ± 2.7	< 9.7 (3σ UL)	< 7.1 (3σ UL)
$F_\gamma(>1$ TeV) 10^{-10} cm^{-2}sec^{-1}sr^{-1}	11.2 ± 4.1	9.4 ± 2.7	< 9.7 (3σ UL)	< 7.1 (3σ UL)

Galactic Plane (from Ong 1999)

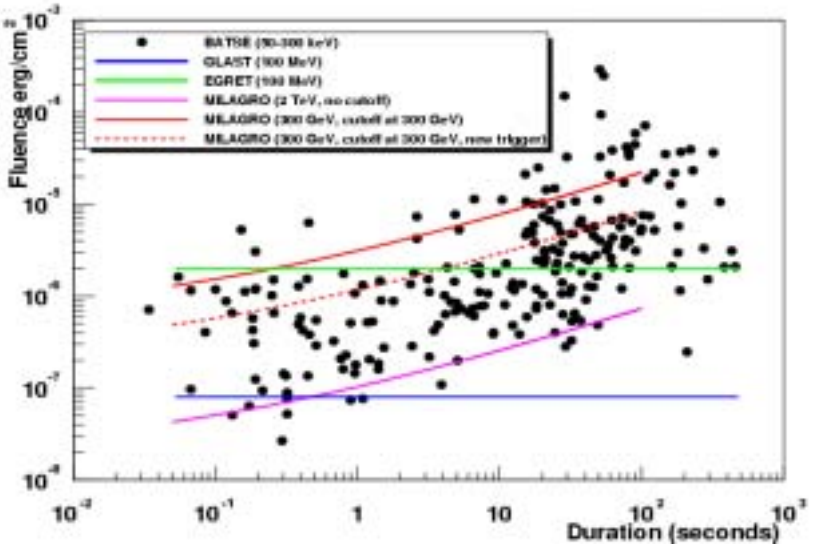


Caveats/Problems

Systematics difficult
~1 part in 10^4
Compton-Getting?

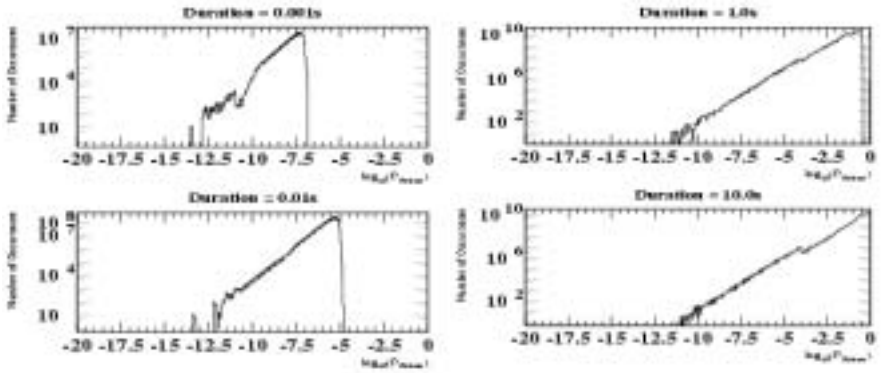
Under investigation

Gamma Ray Burst Sensitivity



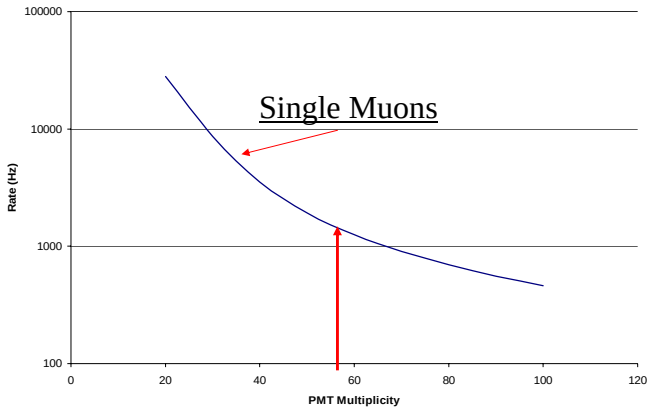
Milagro Burst Results (untriggered)

- Now running real-time burst search (10 second delay)
- Anywhere in sky
- Timescales from 250μs to 3 hours
- No signals observed in past year



Trigger Upgrade

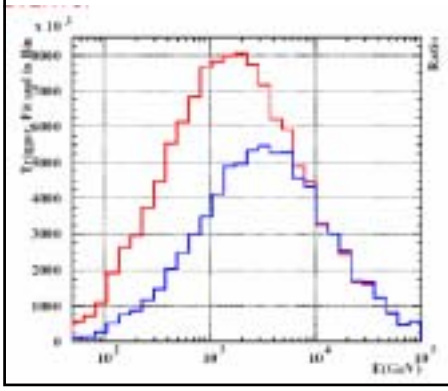
- Simple multiplicity trigger fails below ~60 PMTs
- Single muons dominate trigger rate
- Need intelligent trigger

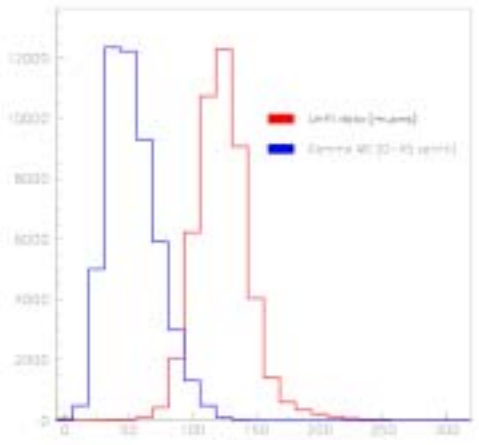


Trigger: Risetime Cut

Can remove muons by cutting on rise-time of trigger (right)

Large increase is area (below) at low energies





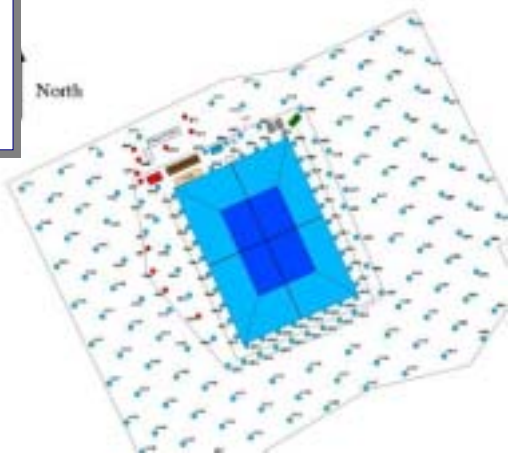
Risetime (ns)

The Outrigger Array

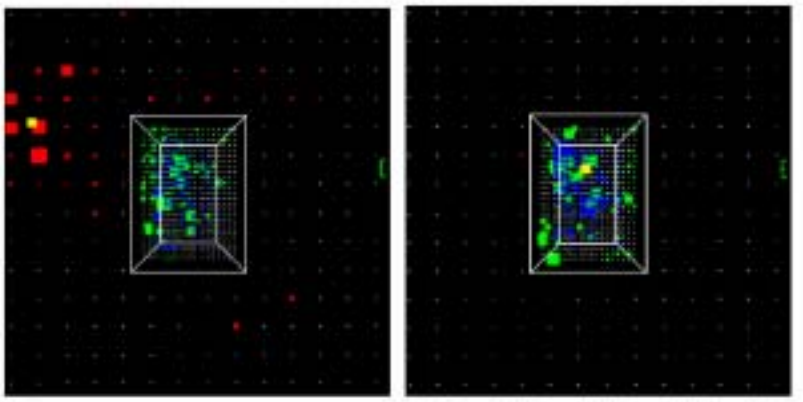
- Without knowledge of core location
  - Energy & angular resolution suffer
  - Background rejection suffers
- Solution
  - An array of 170 water tanks around the pond
  - Energy resolution ~50%
  - Angular resolution improves by ~25% (core & timing)
  - Background rejection improves ~4*x* (sensitivity by 2*x*)

The "Outrigger" Array

170 tanks (500 gallons)
Dispersed over 8 acres
Pond is ~1 acre
Improves:
Energy & Ang. Resolution
Backgnd. Rejection



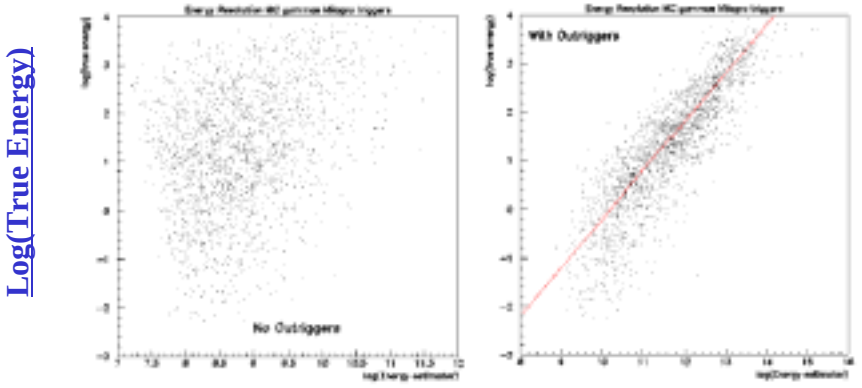
Energy Resolution



9.75 TeV γ shower

1.1 Tev γ shower

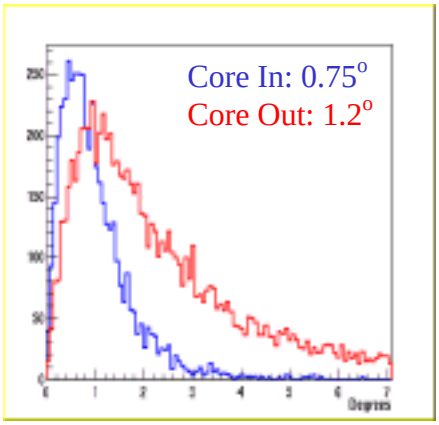
Energy Resolution



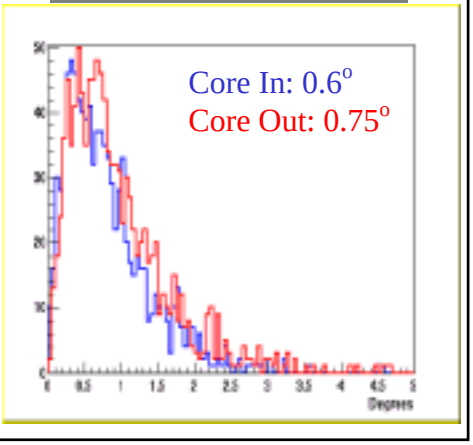
Sensitivity Improvements

Angular Resolution

No Outriggers



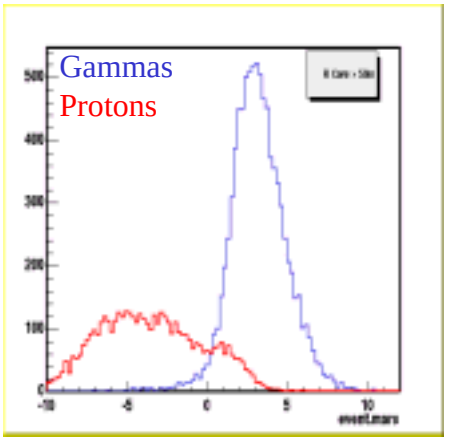
With Outriggers



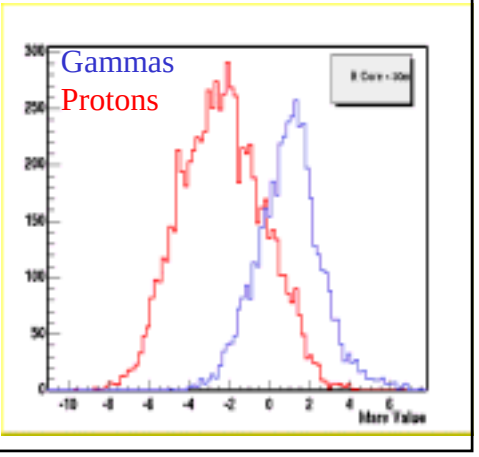
Sensitivity Improvements

Background Rejection

Core Outside

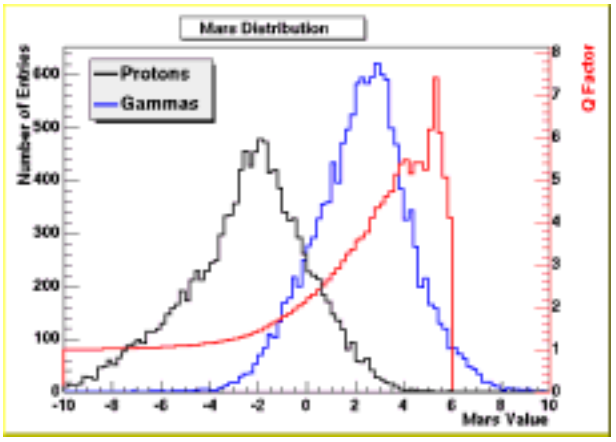


Core Inside



Background Rejection with Outriggers

All events



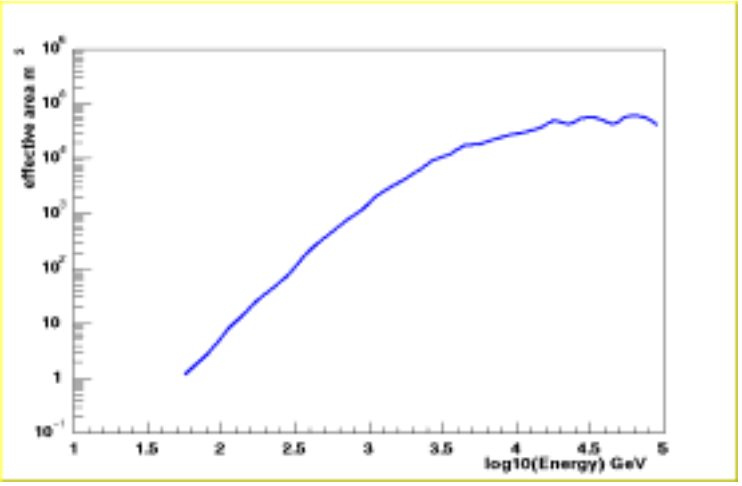
With outriggers we can reconstruct direction of exterior events as well as current interior events.

Shown is rejection for all events assuming *current* angular resolution.

Conclusions

- Moon shadow determines energy scale to ~10%
- Background Rejection Demonstrated (90%)
- Detected 2 known sources
  - Crab nebula
  - Mrk 421
- Surveying the TeV Sky
- Preliminary detection of galactic diffuse emission
- Trigger upgrade complete (5/2002)
- Real-time GRB search
- Outriggers will improve (winter 2002):
  - sensitivity ~2-fold
  - energy resolution to ~50%

Milagro Effective Area

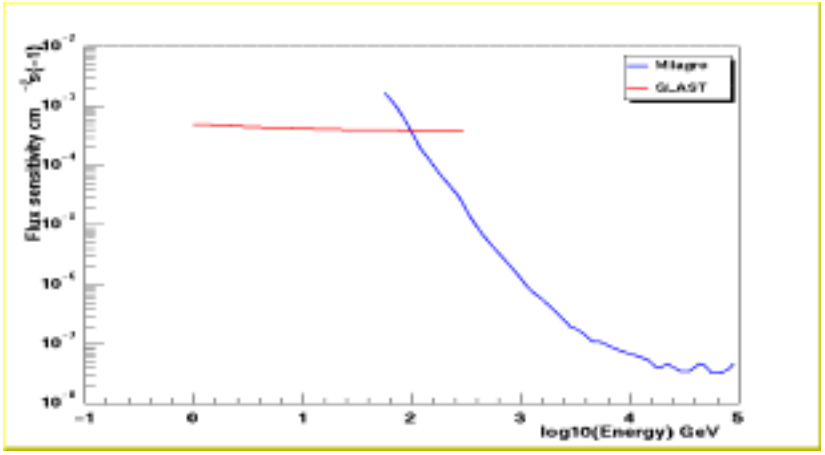


Differential Sensitivity

1 second burst

10^{-18} probability in Milagro

Assume no background in GLAST



Milagro Sensitivity