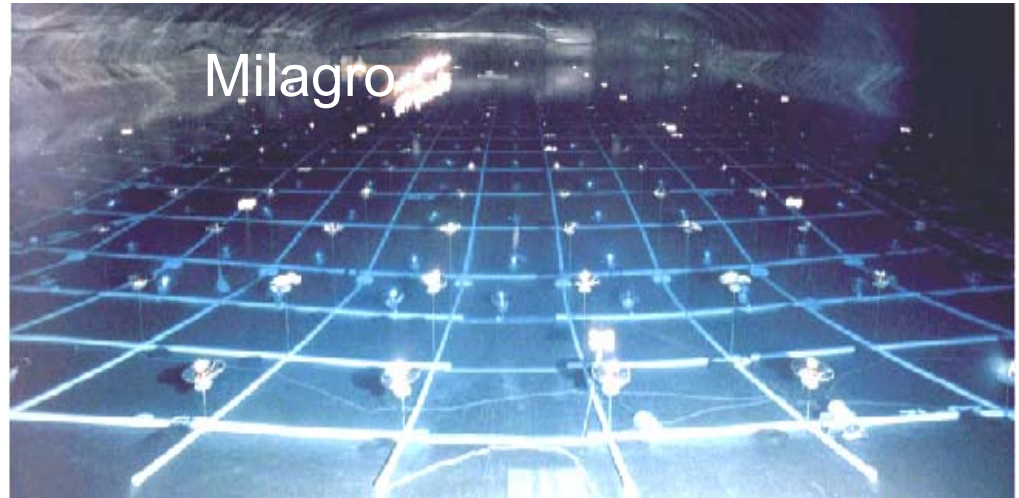


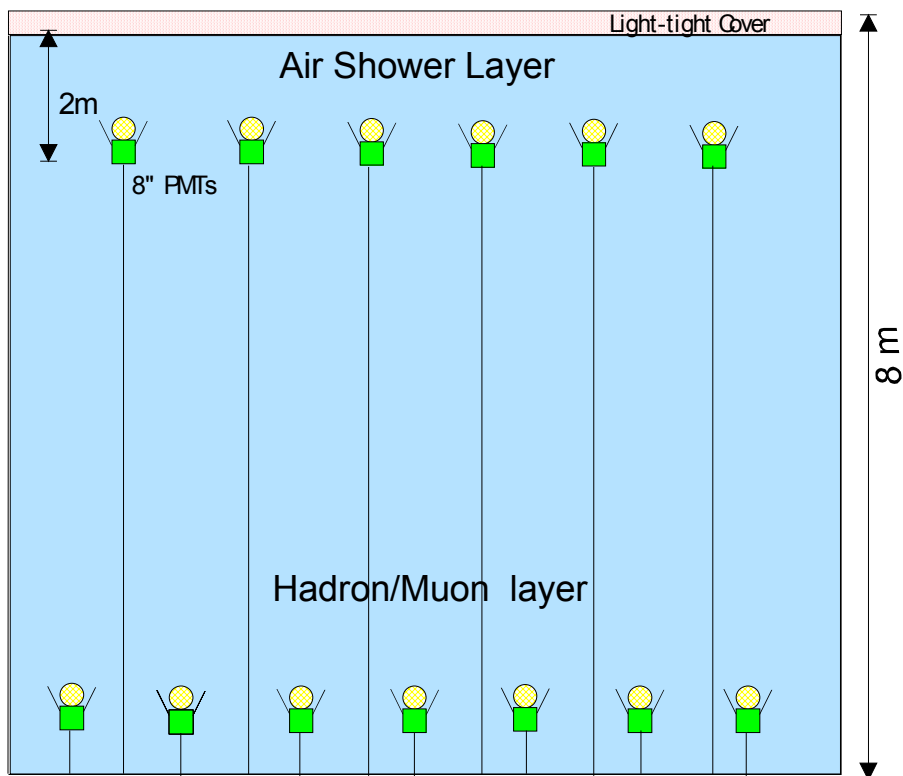
# Milagro Status

## Outline

- Detector Status
  - Intro to Milagro
  - Operations
- Physics Analysis
  - Point Sources
    - All Sky Survey
  - Effect of Outriggers
    - Angular Resolution
  - Galactic Plane Result
  - GRBs
- Milagro in the Swift era
- Recent and future papers

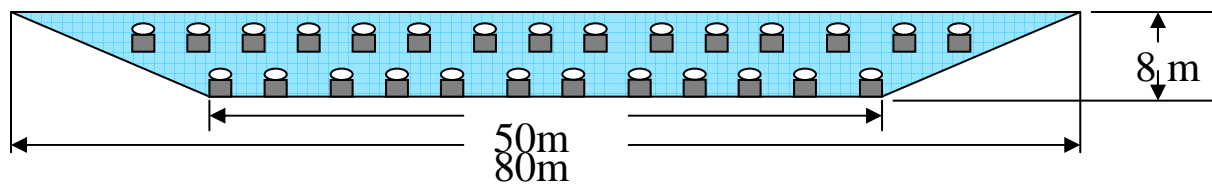


# Milagro

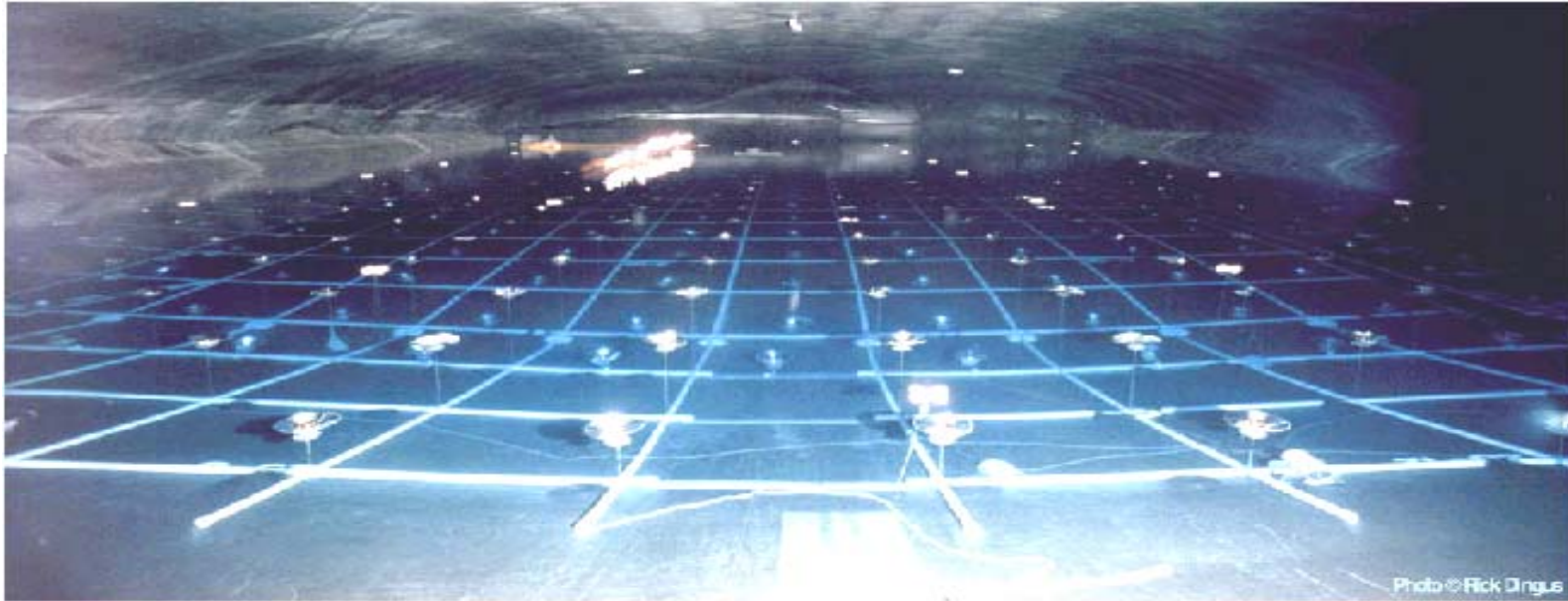


450 Top Layer  
8" PMTs

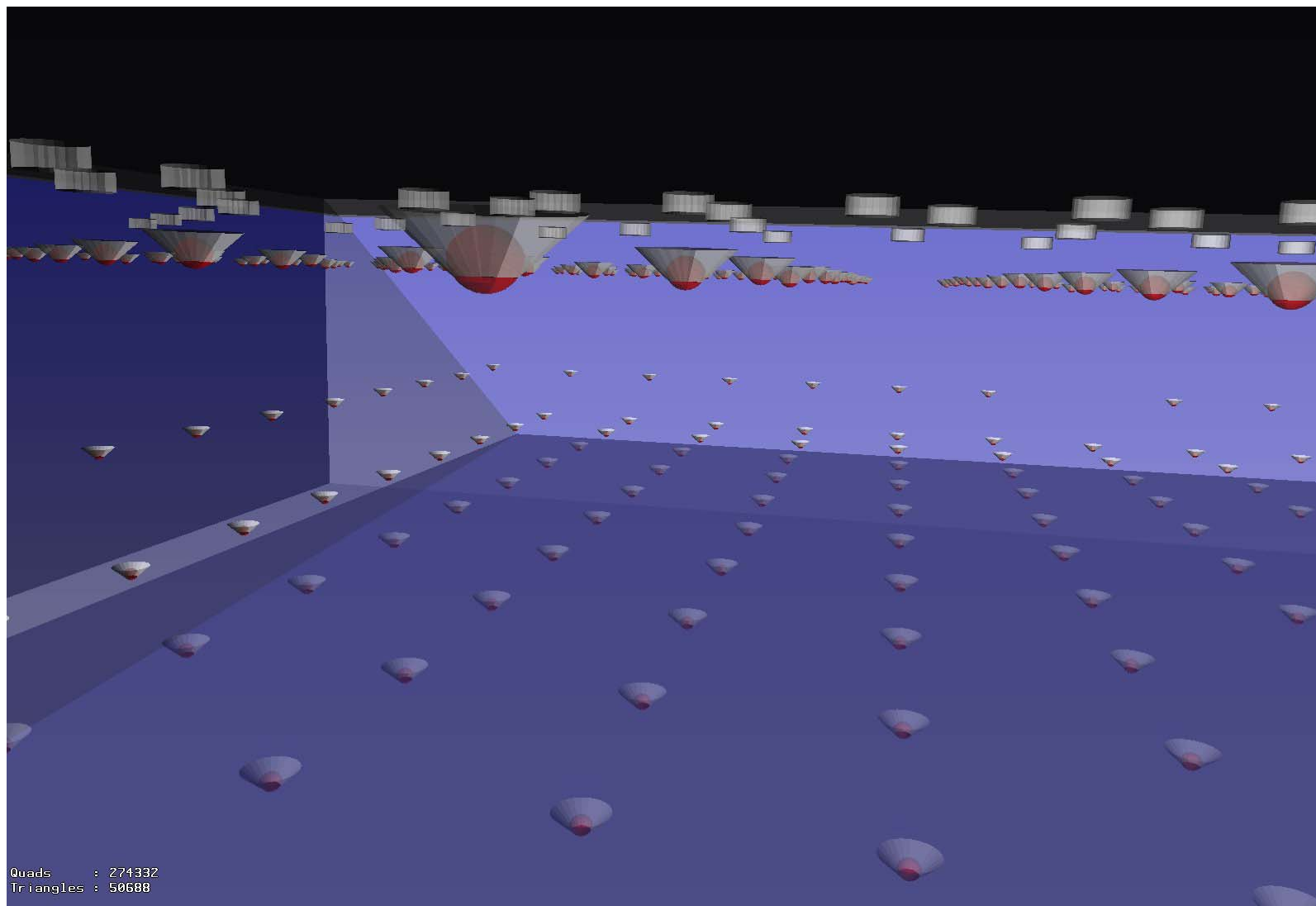
273 Bottom Layer  
8" PMTs



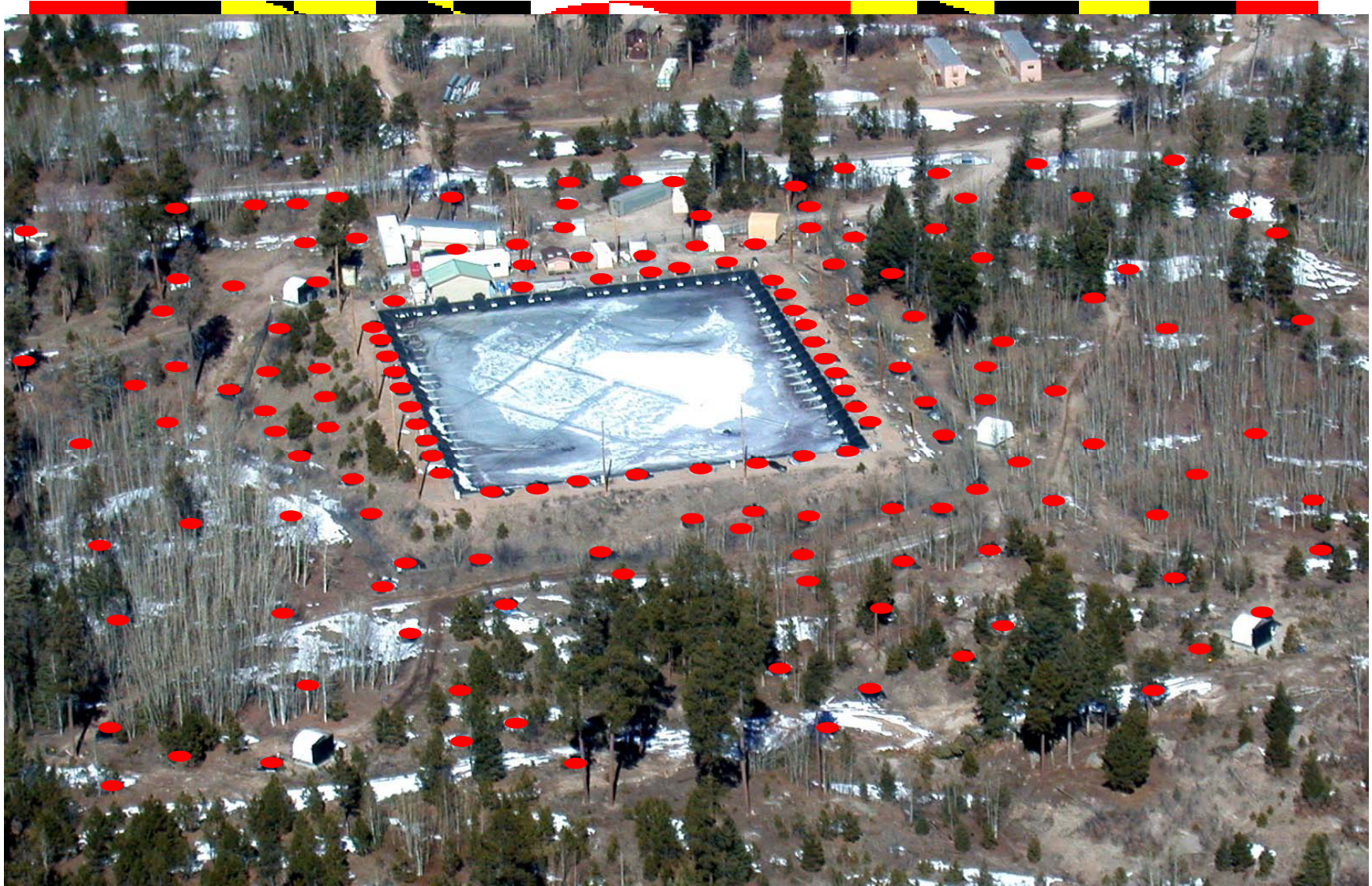
# Milagro



# Inside Milagro



# Milagro Outriggers

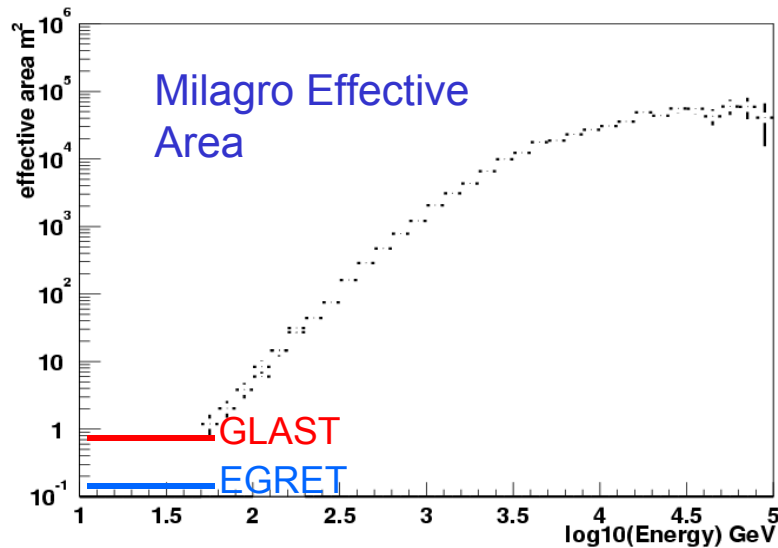
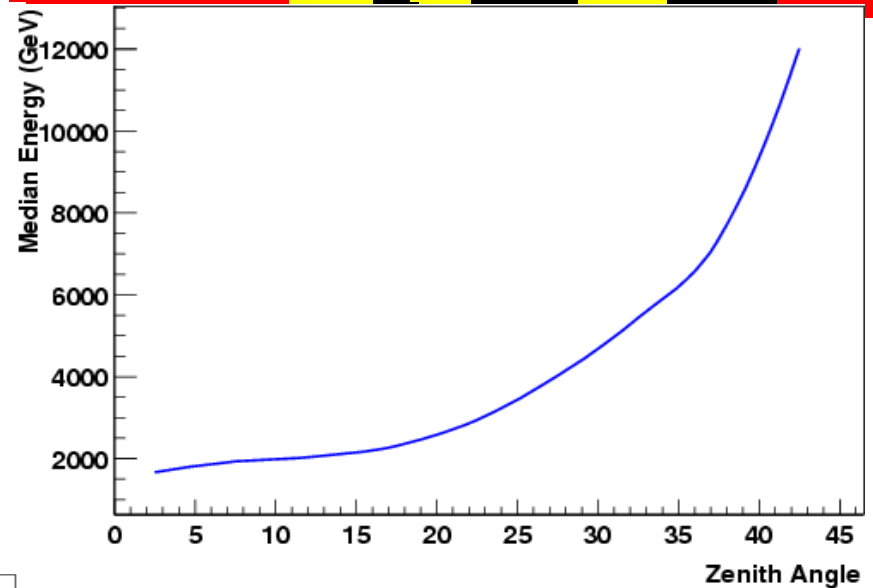


# Operations

- Milagro has been operating since 2000
  - 0.208 Trillion Events
- Outriggers were finished in 2003
- We run with ~96% on-time
- Data rate is ~ 1700 Hz
  - 8-9% downtime
- We reconstruct in real-time
  - We look for GRBs and send out alerts
  - One month of raw data saved for archival analysis
- Data is sent via network to LANL & UMD
- Nearly total remote capability

# Milagro Sensitivity

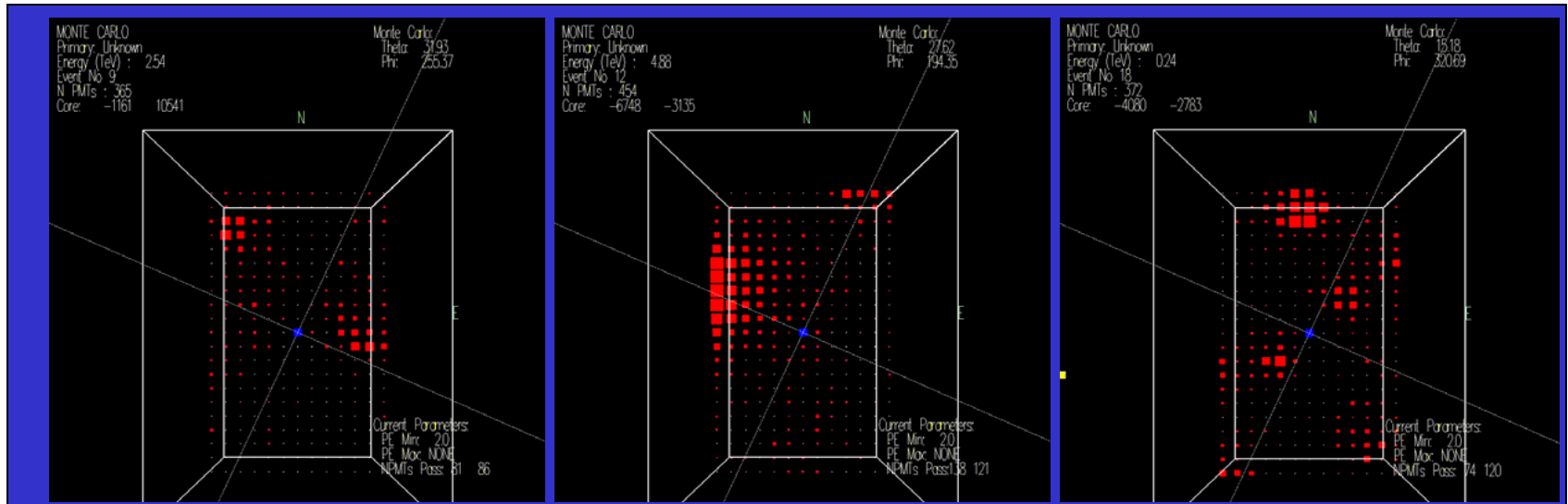
Our energy threshold increases with the zenith angle.



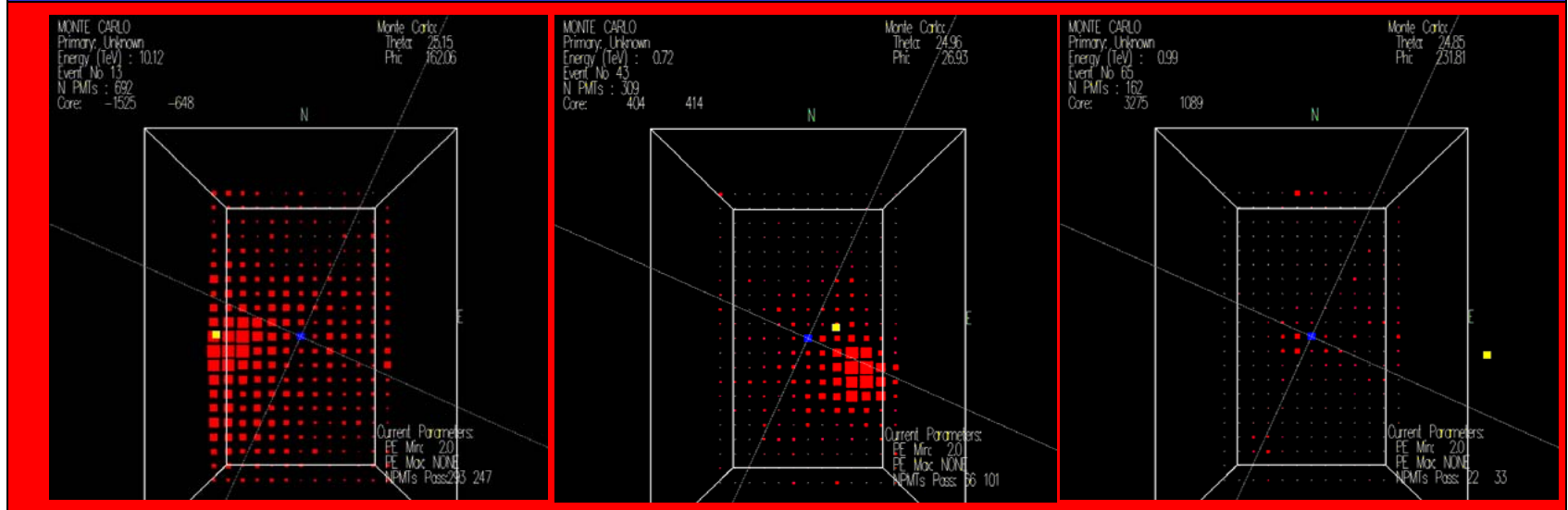
Energy threshold is not well defined. Even though our peak sensitivity is at a few TeV, we have substantial sensitivity at lower energies.

# Gamma – Hadron Separation

P



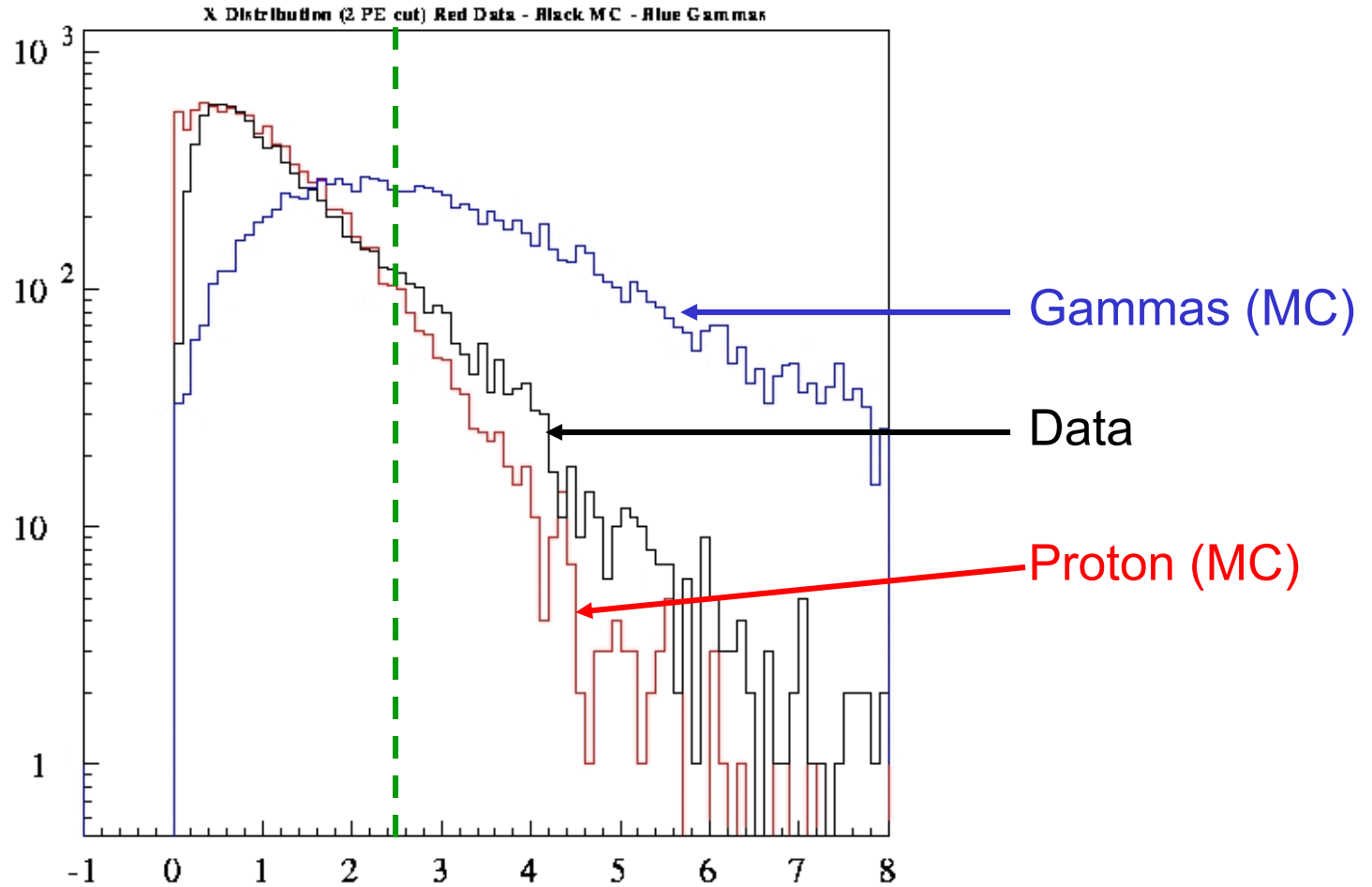
$\gamma$



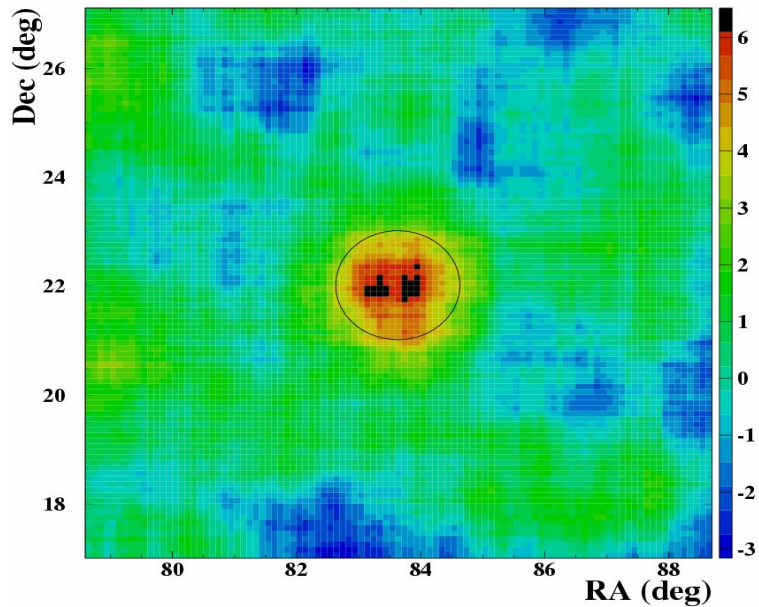
# Gamma / Hadron Separation in Milagro



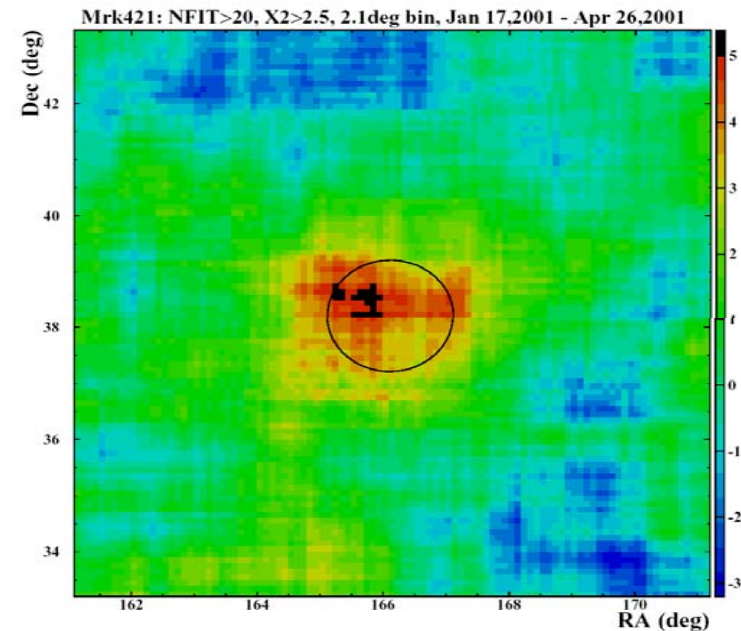
This cut removes 90% of the protons and keeps 50% of the gammas



# Milagro Point Sources

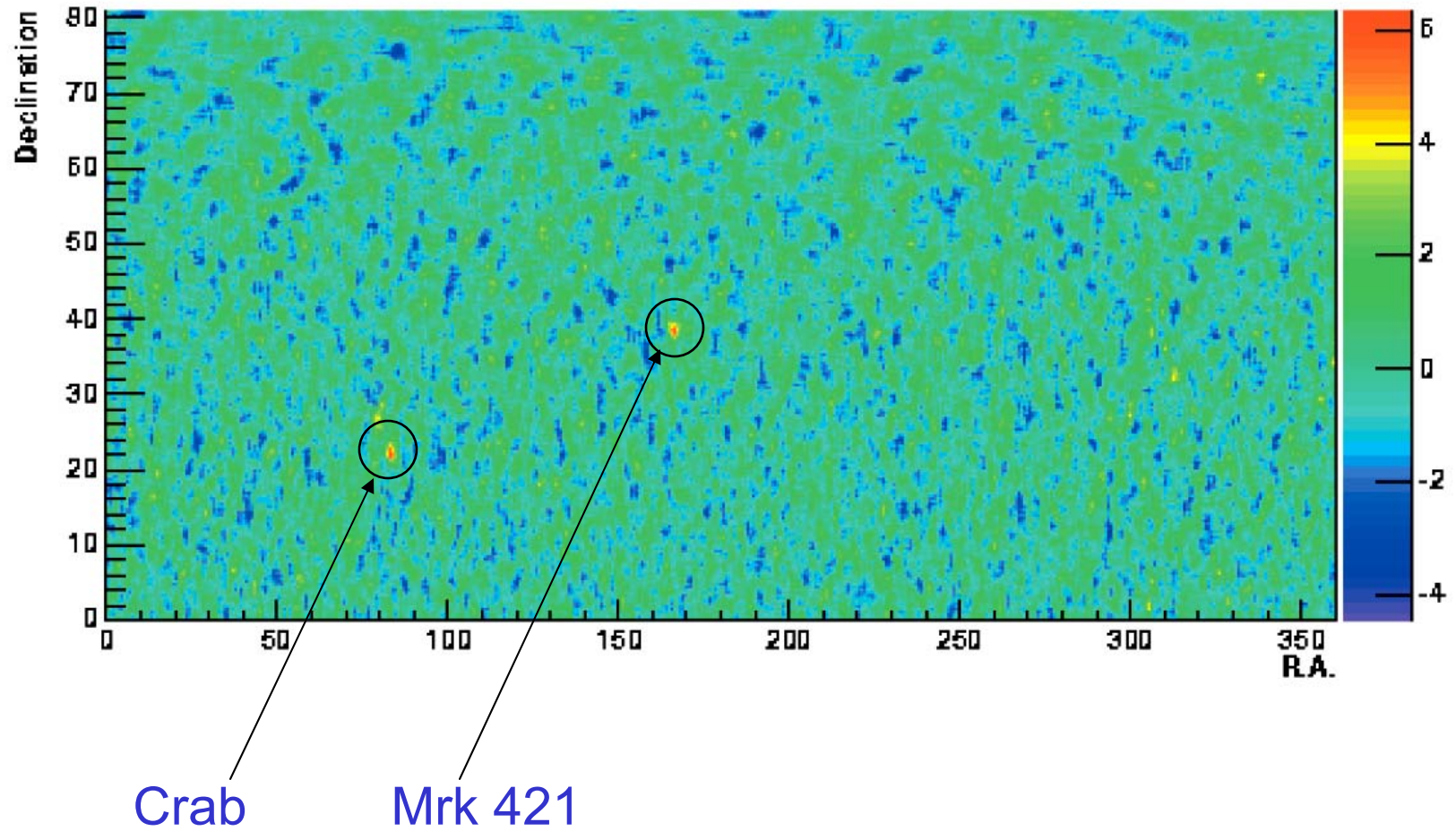


Data taken in the Crab Nebula region with  $6.4\sigma$  at the position of the Crab (2000-2002)



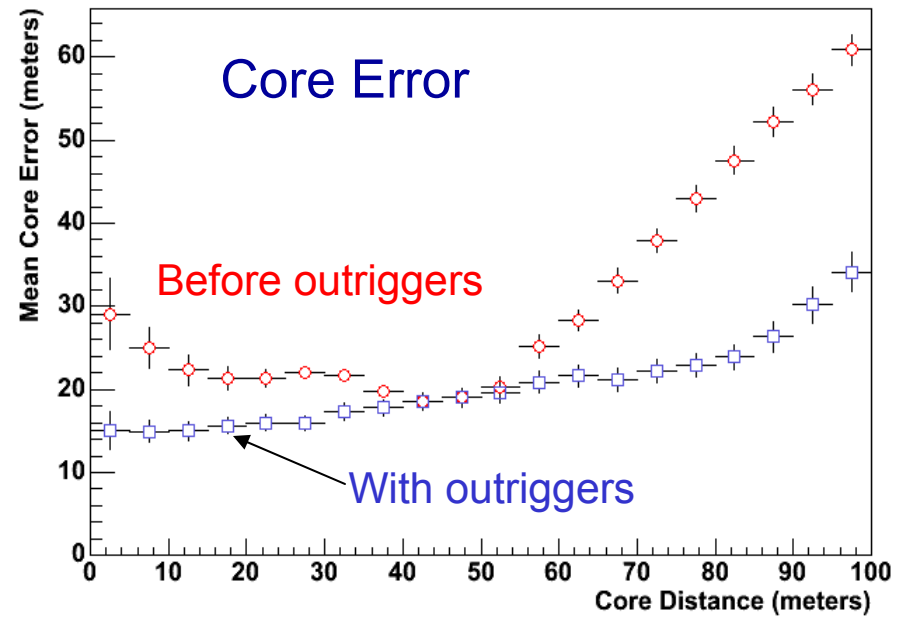
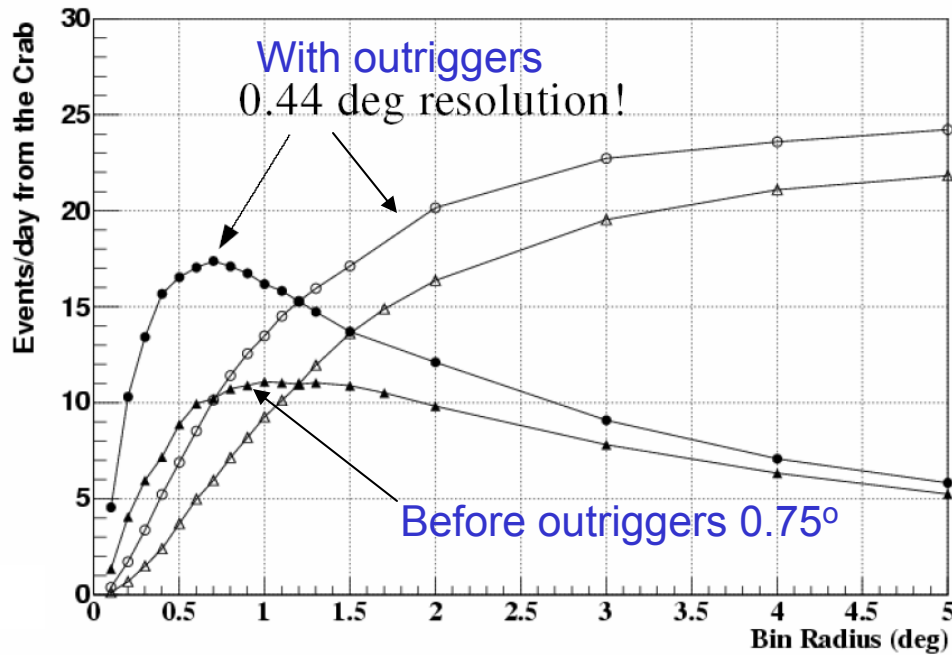
Signal map of Mrk 421 during the 2001 flare (1/17/01-4/26/01). The circle shows the position of Mrk 421 with our angular bin. The center corresponds to  $\sim 5\sigma$

# Milagro All Sky Survey



# Effect of the Outriggers

All VME Trigger bits, NFIT>20, X2>2.5



This improved ang. resolution give us an increase in Q factor of  $\sim 1.7$

This means we see the same signal  $\sim 3$  times faster!

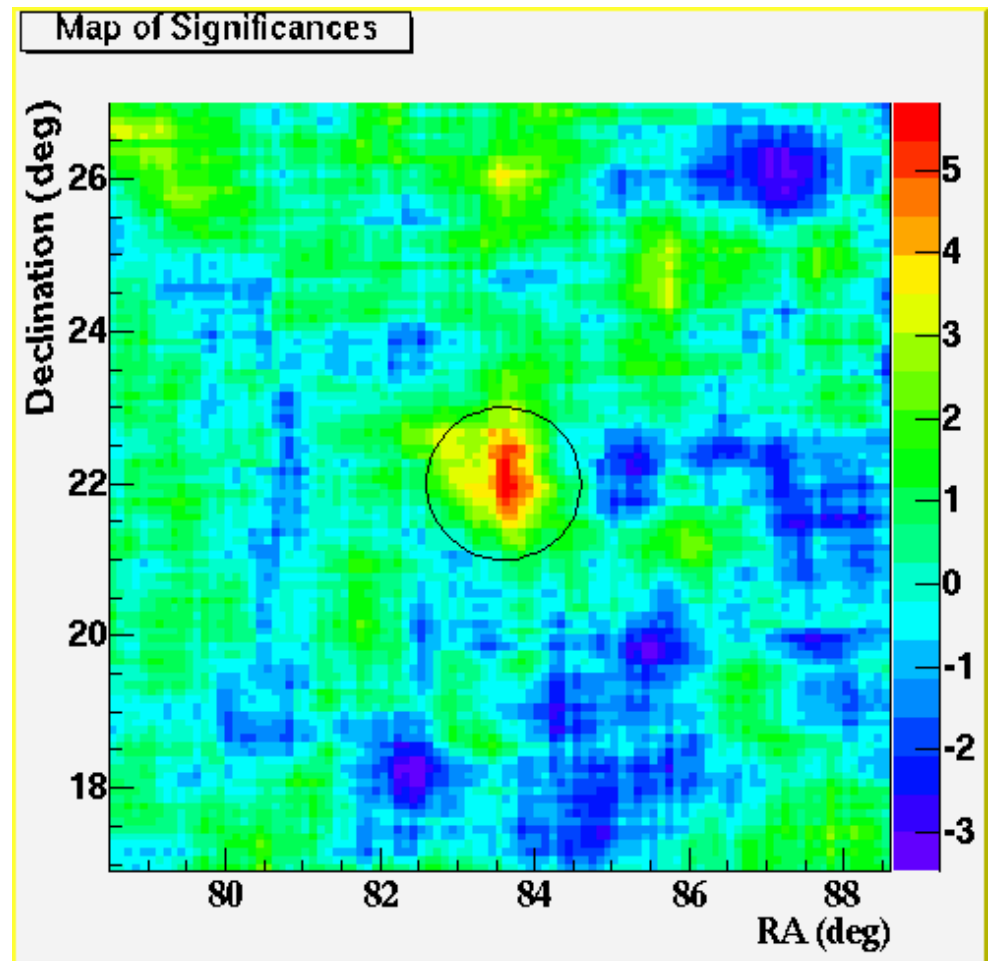
More improvement ( $\sim 1.5 - 2$  in Q) is expected with better  $\gamma/h$  separation

# Effect of the Outriggers

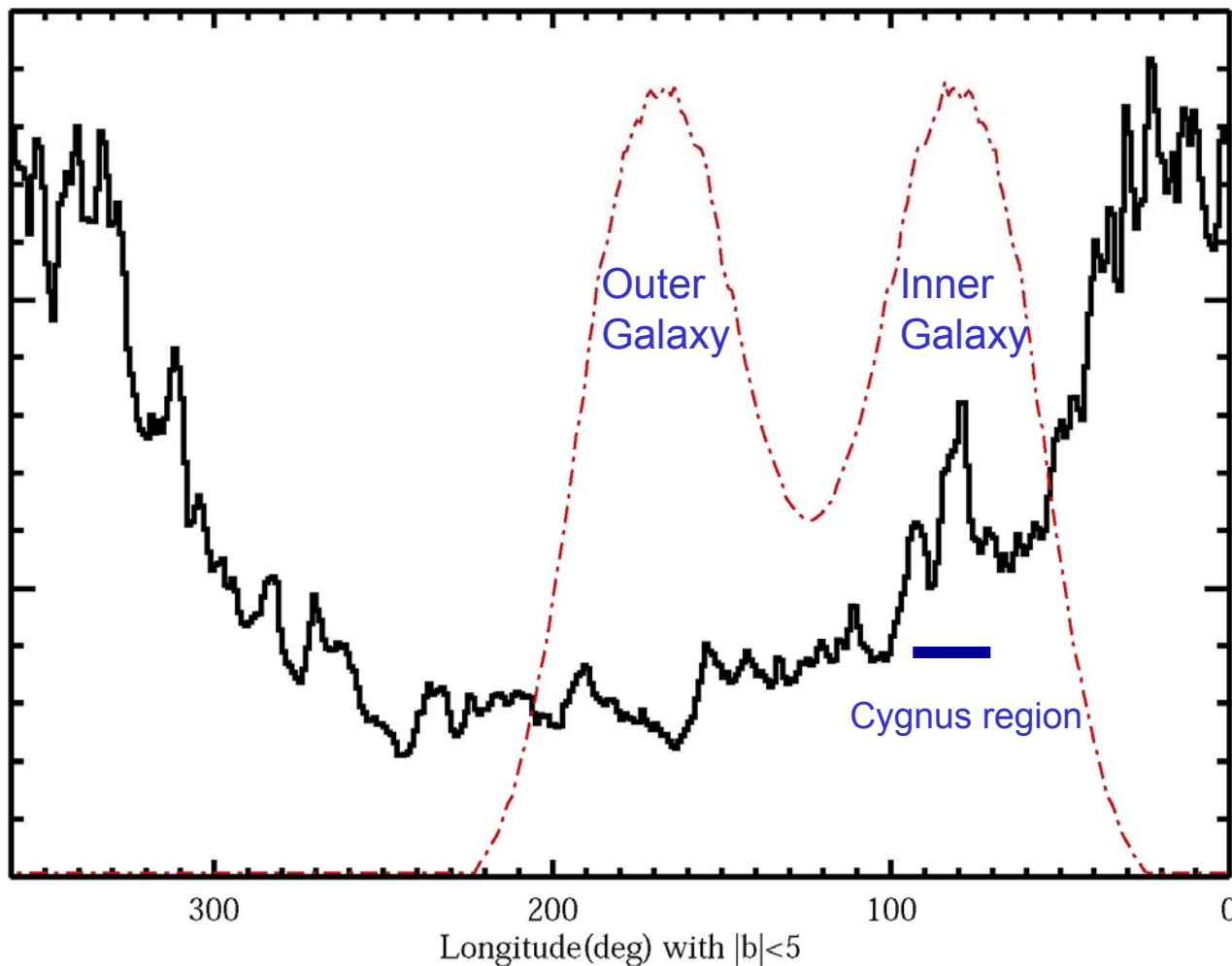
12 months of recent data  
on the Crab

~3 times faster to get same  
signal

Another factor of ~1.5 - 2 is  
expected from  $\gamma/h$  sep



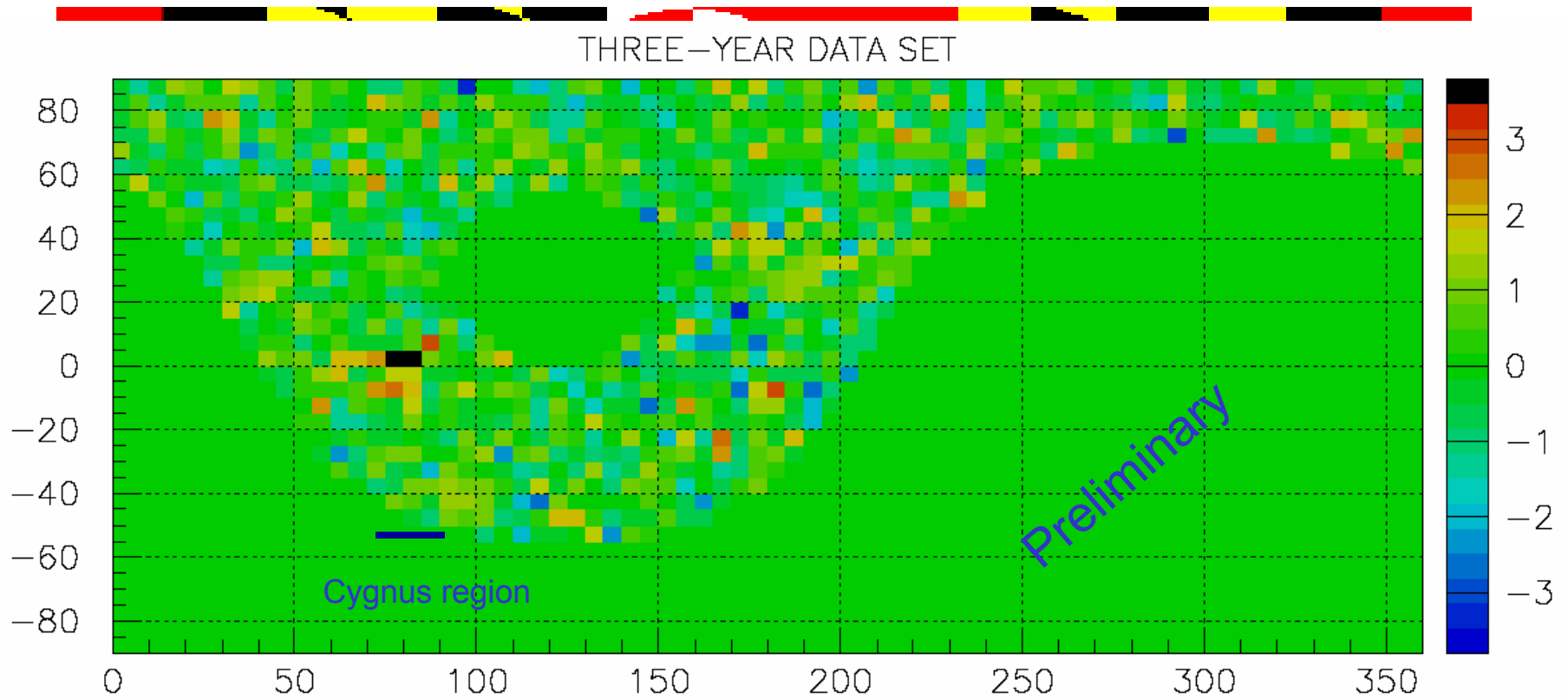
# EGRET Observation of the Galactic Plane



- Black is EGRET Diffuse Flux > GeV
- Red is Milagro Exposure (TeV)

Note that their coordinates run opposite from ours...

# Milagro Galactic Plane

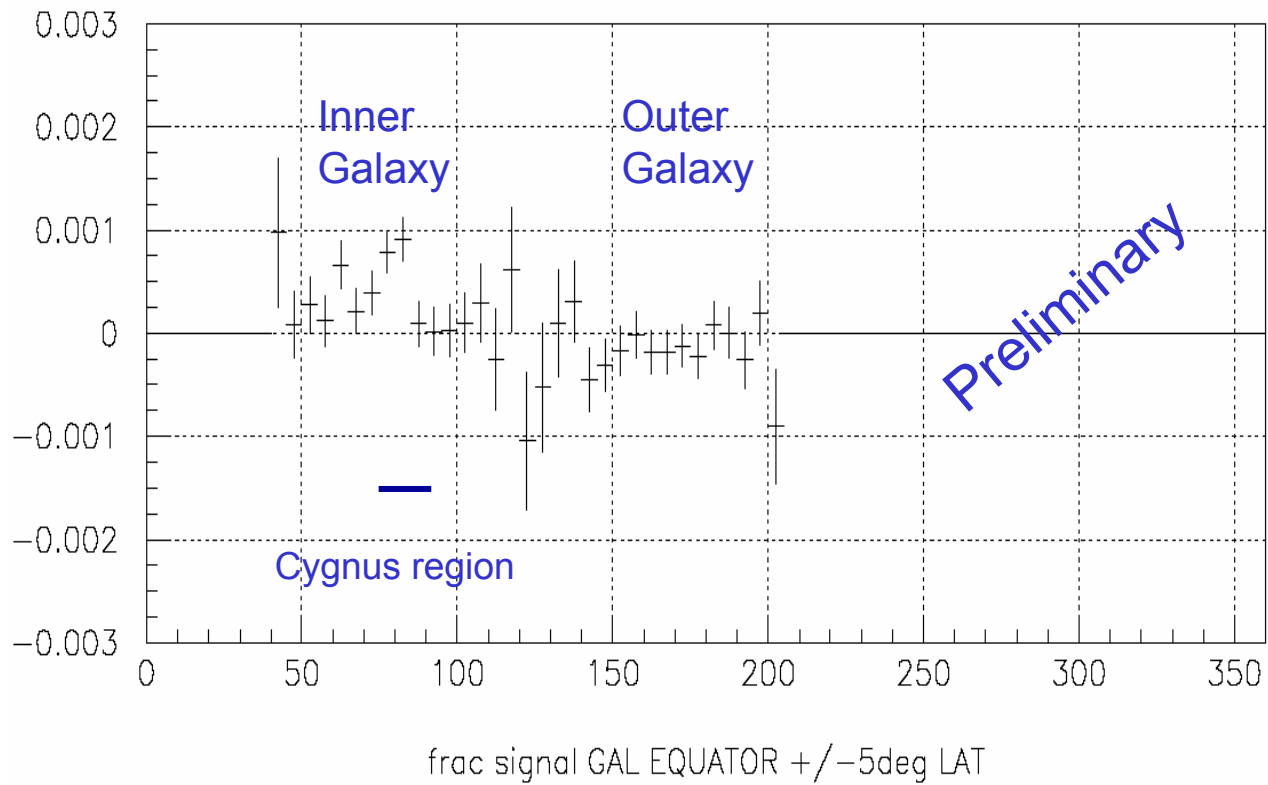


frac signal GAL COORD . Significance.

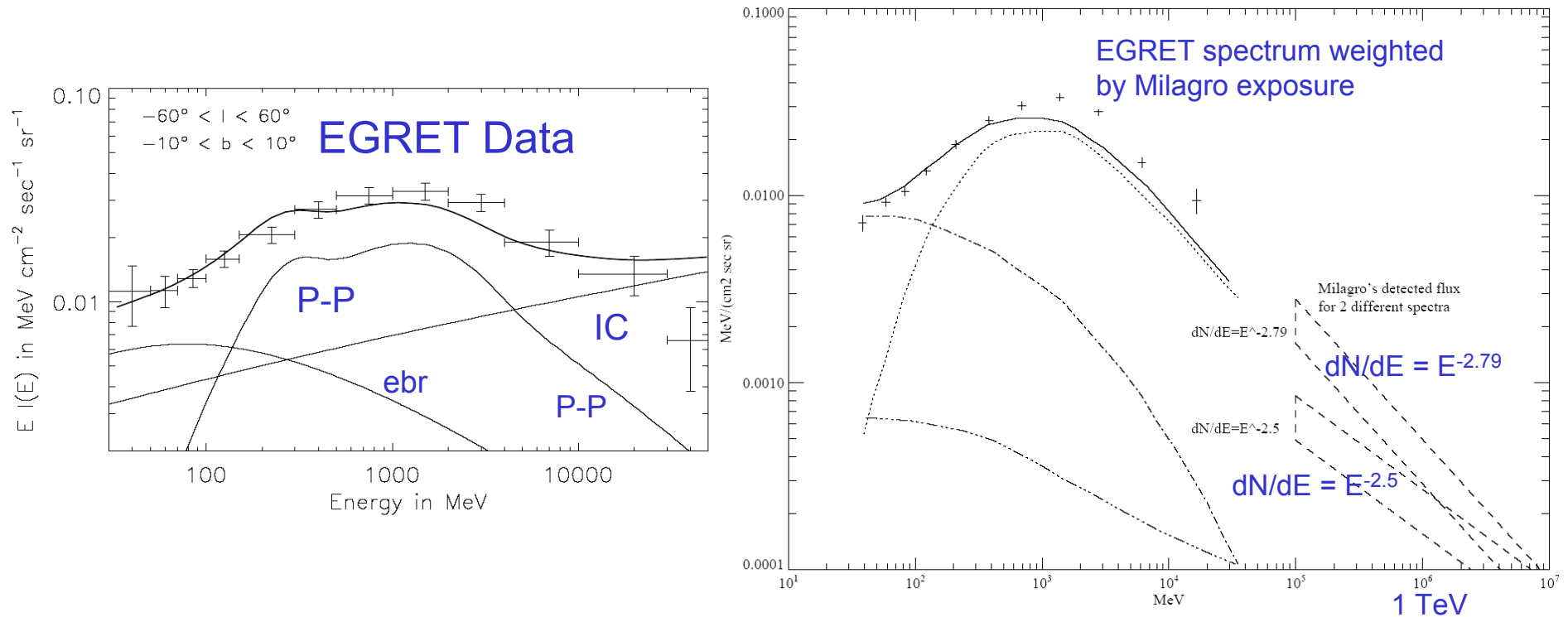
5  $\sigma$  excess for the “inner galaxy” - Flux fraction  $\sim 8 \times 10^{-5}$  of CR

This is the first detection of the galactic plane at these energies ( $\sim$ TeV)

# Milagro Galactic Plane

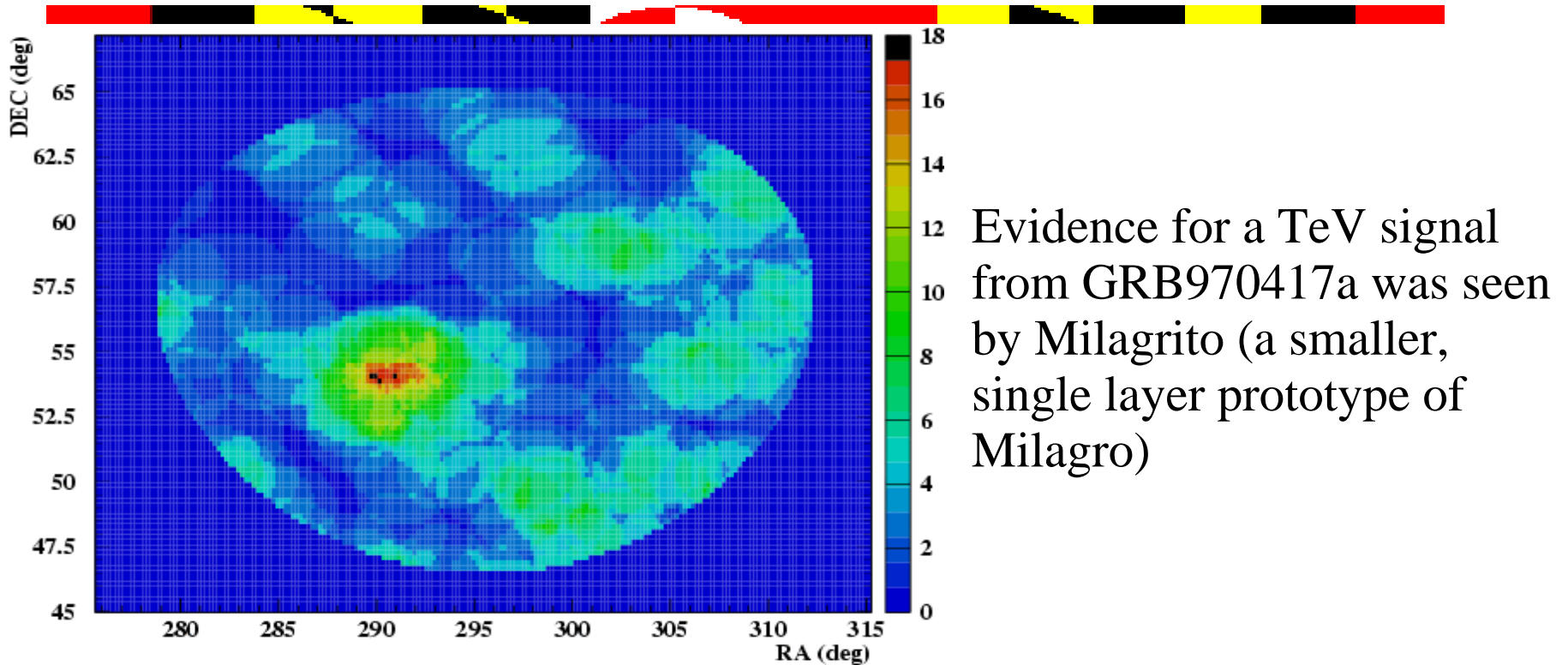


# A (Preliminary) Comparison of Milagro & EGRET Data



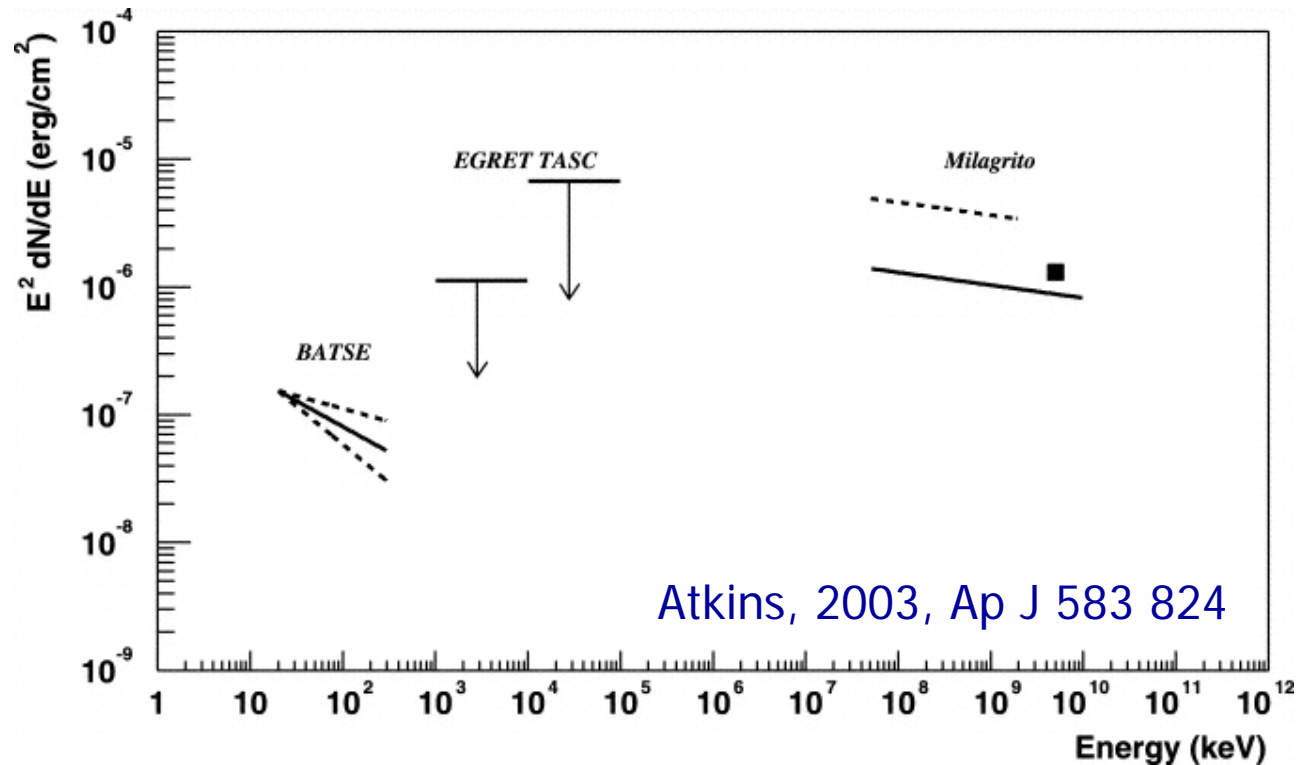
This has potential to distinguish whether it's P-P or inverse Compton at the highest energies as well as pin down the spectrum.

# GRB970417a



- 18 signal events with an expected background of 3.46 -> Poisson prob.  $2.9e-8$  ( $5.2\sigma$ ).  
Prob. after correcting for size of search area:  $2.8e-5$  ( $4\sigma$ ).  
Chance prob. of this excess in any of the 54 GRB examined for TeV emission by Milagrito:  $54 \times 2.8e-5 = 1.5e-3$  ( $3\sigma$ ).

# Luminosity of GRB970417a



More luminosity at TeV energies than MeV energies.  
But the GRB must be close due to TeV-IR absorption,  
so the total energy released is not unusually large.

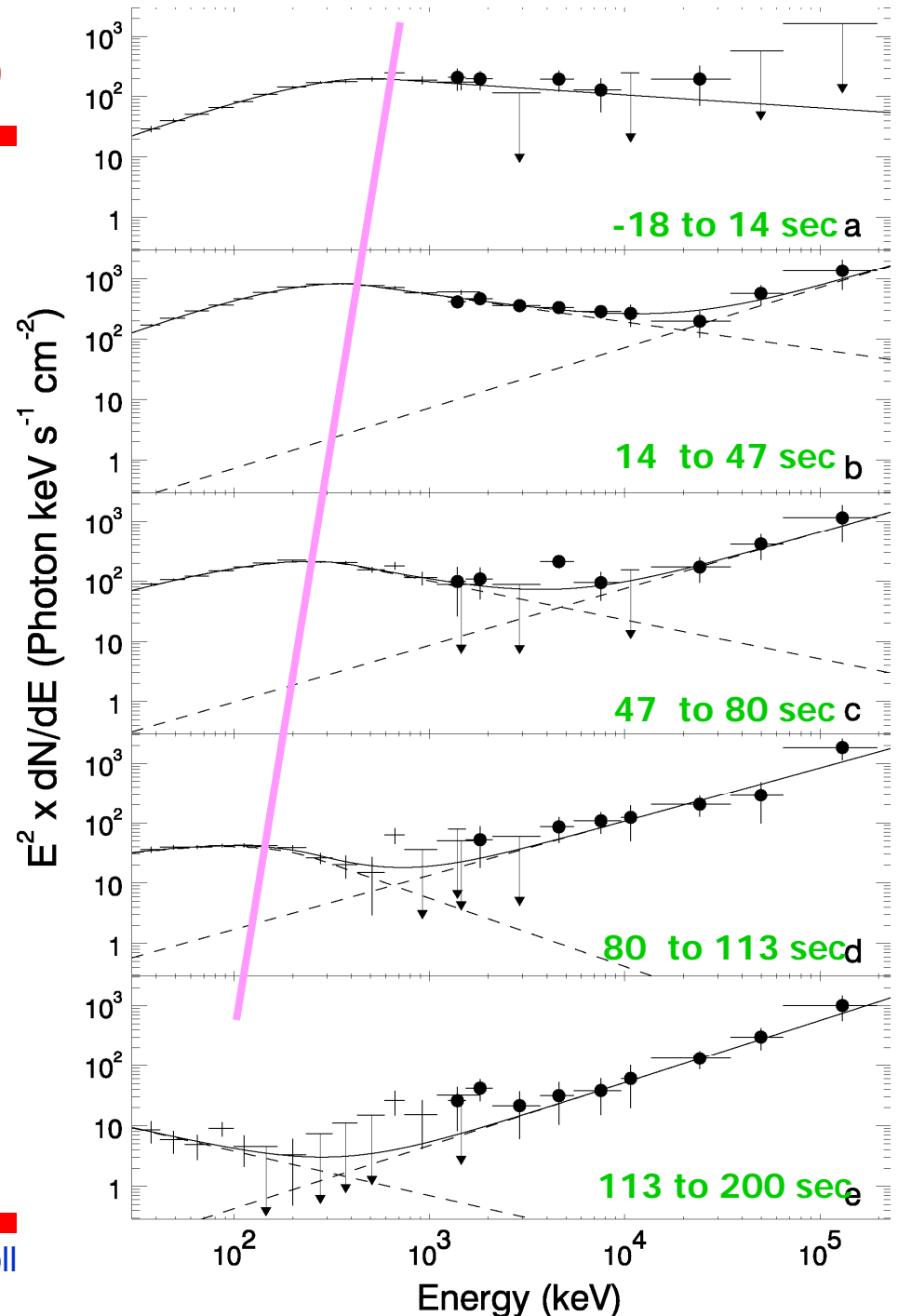
If  $z \sim 0.1 \Rightarrow E_\gamma < 700 \text{ GeV}$  so  $L < 5 \times 10^{51} \text{ ergs}$

If  $z \sim 0.03 \Rightarrow E_\gamma < 10 \text{ TeV}$  so  $L < 1 \times 10^{49} \text{ ergs}$

# GRB 941017 (pre-Milagro)

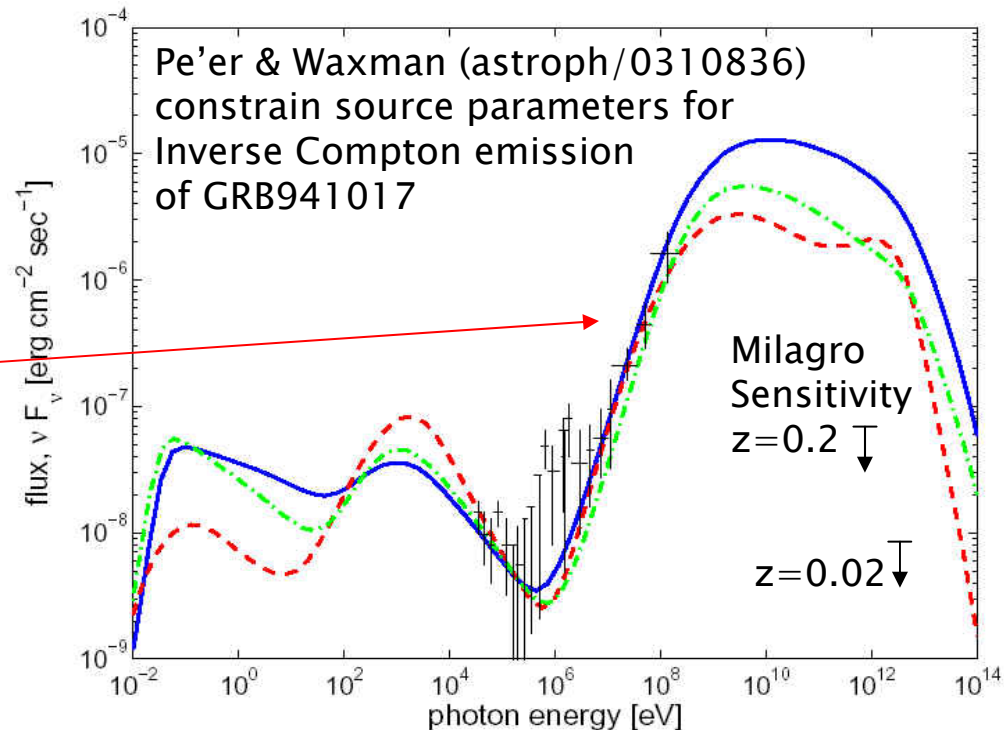


- M.M. González, B.L. Dingus, Y. Kaneko, R.D. Preece, C.D. Dermer and M.S. Briggs, Nature, 424, 749 (14 Aug 2003)
- This burst is the first observation of a distinct higher energy spectral component in a GRB
- Lower energy component decays faster than higher energy component
- Peak of higher energy component is above the energy range of the detector
- Power released in higher energy component is more than twice the lower energy component

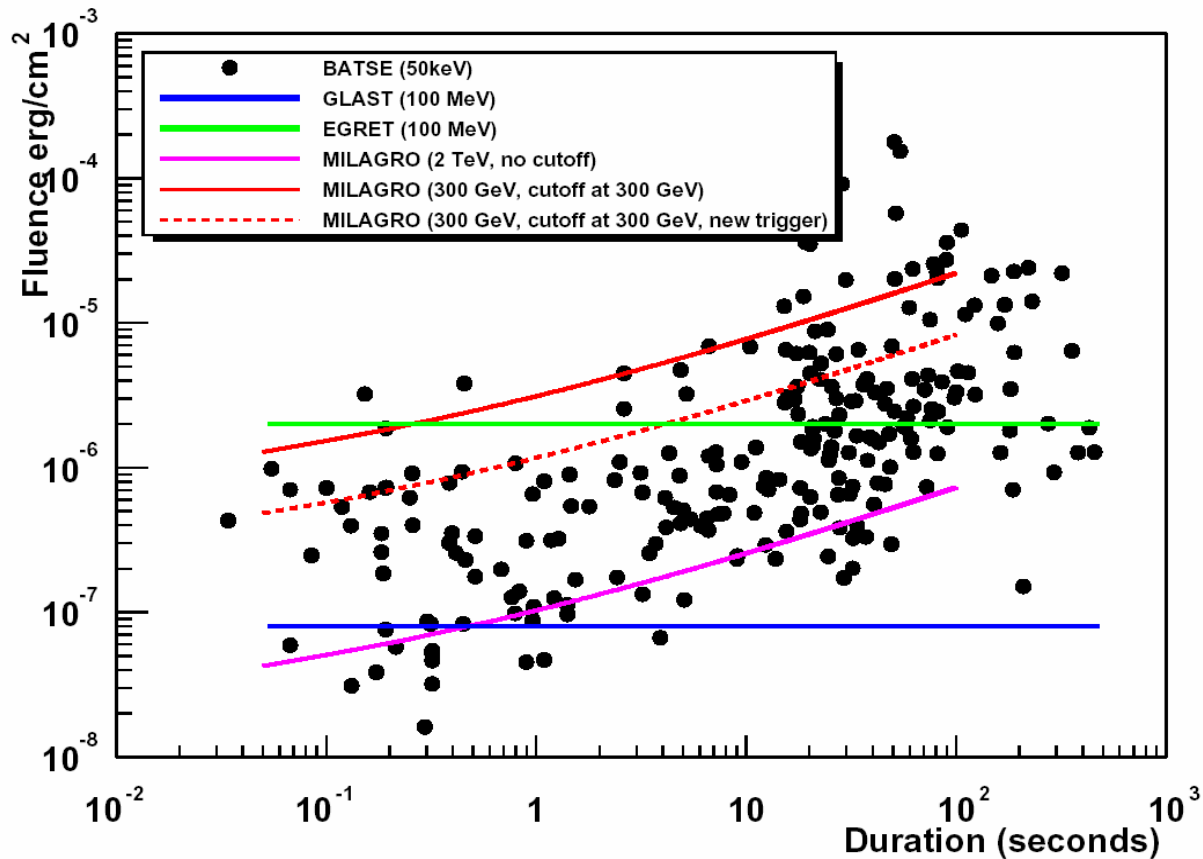


# Theories of the High Energy Component of GRB941017

- Requires GRBs to more energetic phenomena
- Different timescale of low and high energy implies an **evolving source environment** or **different high energy particles**
- **Shape of high energy component applies tight constraints to ambient densities and magnetic fields**
- Or evidence of origin of **Ultra High Energy Cosmic Rays**
- More and Higher Energy observations are needed



# VHE Instrument Sensitivity

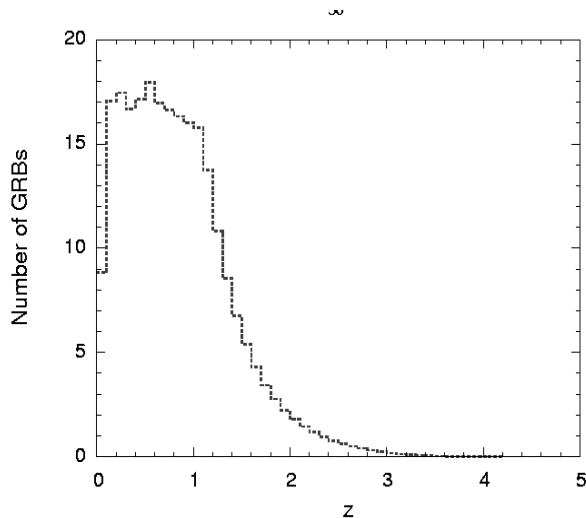


For observations of the prompt phase of GRB, current and future high energy gamma-ray instruments (GLAST and Milagro) are very complementary.

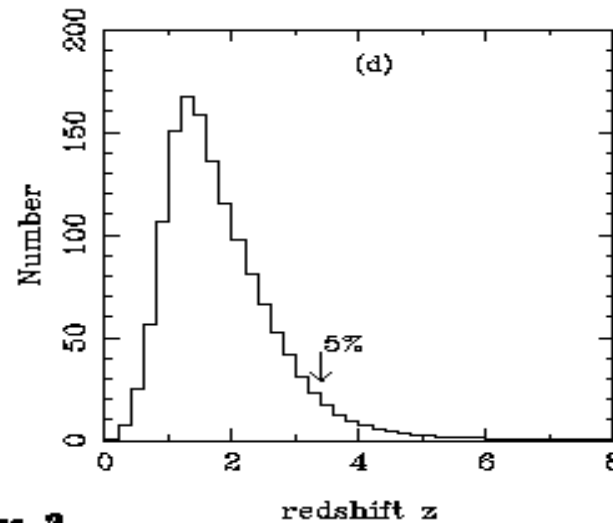
# How many GRB will we see at TeV energies?

Luminosity function at these energies is unknown!

However, assuming that all are bright at TeV energies then the distance distribution of GRB will determine how many we see.



(Boettcher and Dermer 1998)  
9% with  $z < 0.3$  - 9/year



(Schmidt 1999)  
0.6% with  $z < 0.3$  - 0.6/year

These predictions are only for long duration bursts and are very uncertain at low redshifts.

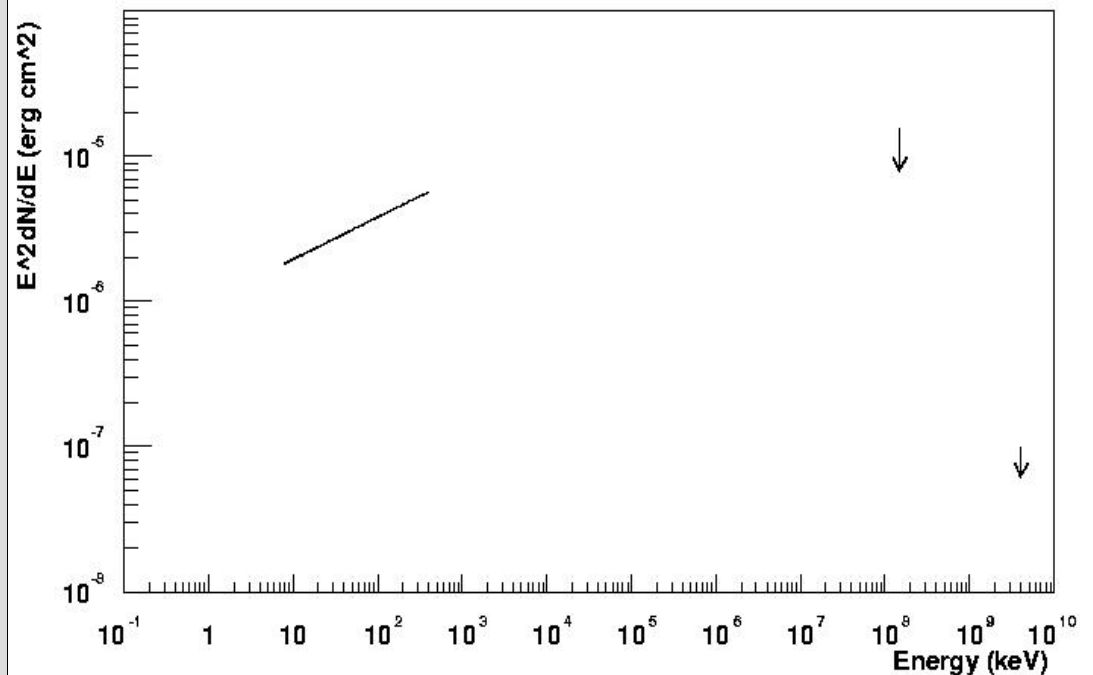
Evidence that there may be a population of soft (Schmidt2001) and/or weak (Norris 2002) which are very close.

# Milagro GRB Observations (triggered)

- ~30 satellite detected GRBs have been within Milagro's field of view of 45 degrees from zenith
- No high energy emission is detected from any of the 30 bursts
- One of the bursts is in a Galaxy of redshift of 0.45

GRB010921,  $z = 0.45$

- HETE detected burst  
Fluence (8-400 keV)  
 $= 1.5 \times 10^{-5} \text{ ergs/cm}^2$
- Milagro 99% confidence upper limits  
Fluence ( $> 4 \text{ TeV}$ )  
 $< 2 \times 10^{-7} \text{ ergs/cm}^2$   
Fluence (100-150 GeV)  
 $< 4 \times 10^{-5} \text{ ergs/cm}^2$

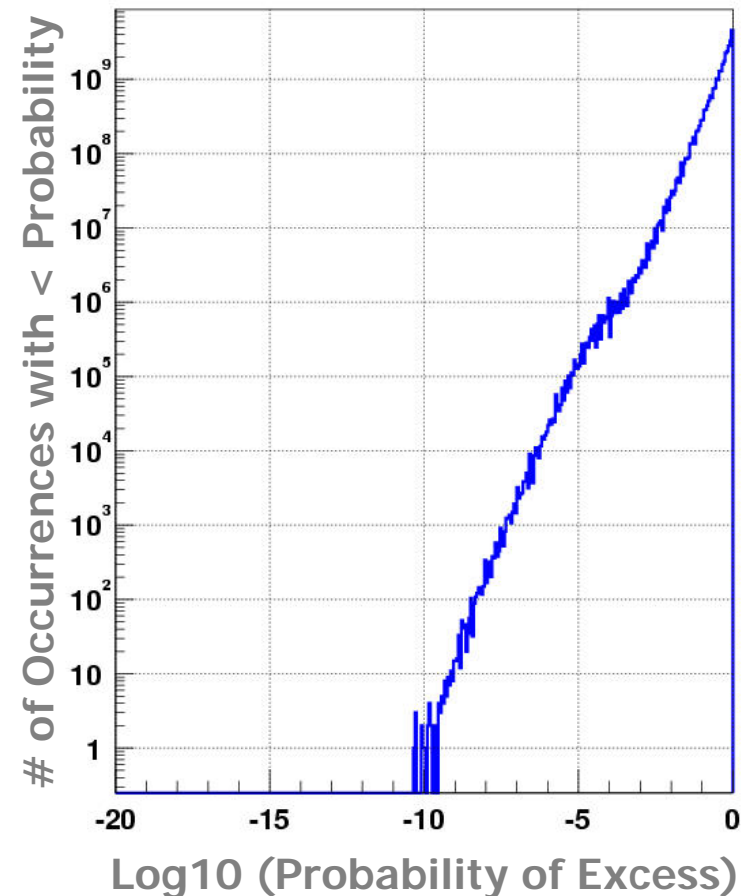


# Search of Milagro Data for Bursts (untriggered)

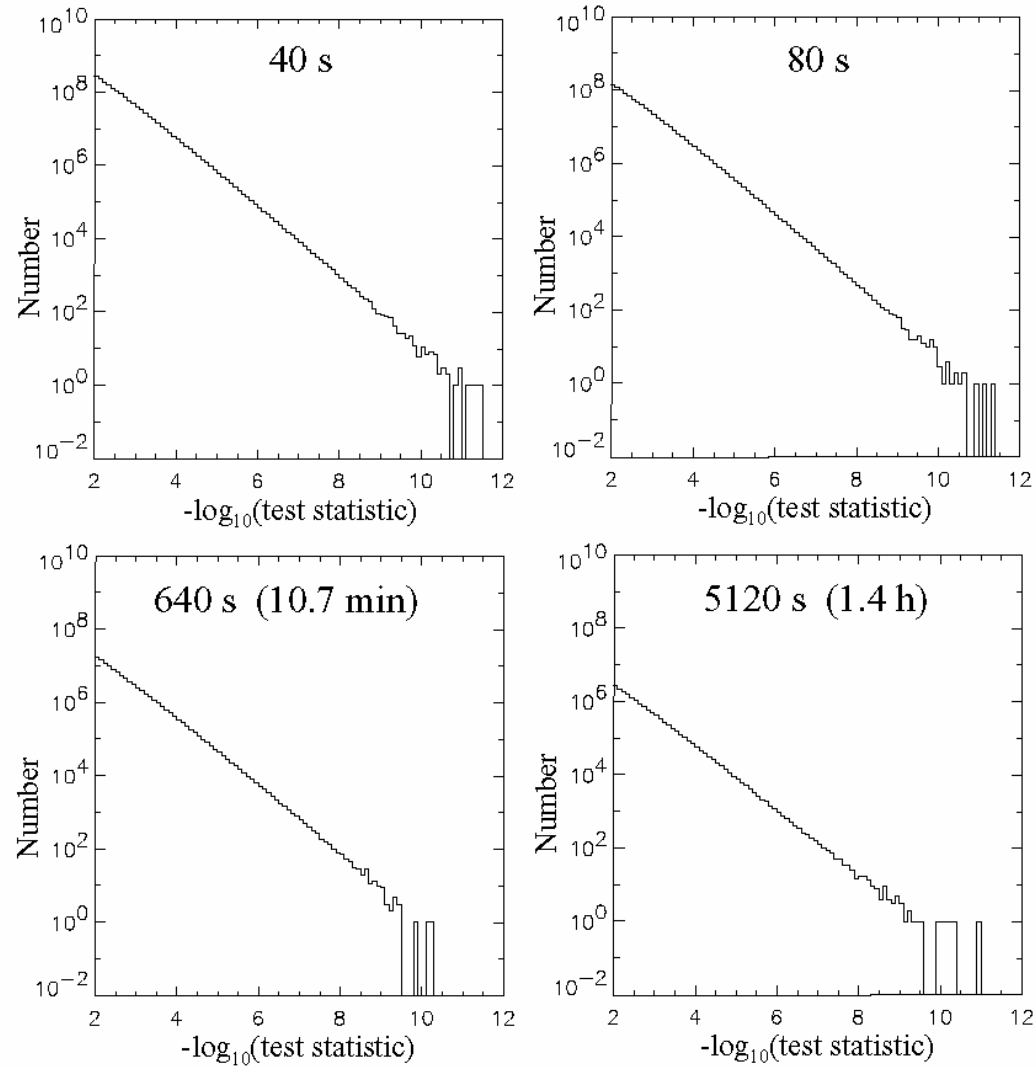
- Online search performed within 4 sec of data taking
- Search for transients of 1 msec to 2 hours duration
- Email notifications sent to anyone interested. To join contact [dnoyes@umdgrb.umd.edu](mailto:dnoyes@umdgrb.umd.edu).
- No significant detection gives 90% confidence upper limit of fewer than 2.3 GRB within fov
- This implies  $< 5.8$  GRB/year occur within the volume of space and with fluence to which Milagro is sensitive in untriggered mode

[http://umdgrb.umd.edu/cosmic/milagro\\_grb\\_main.html](http://umdgrb.umd.edu/cosmic/milagro_grb_main.html)

Distribution of probabilities for a typical day's observations



# Milagro Results (untriggered)



# Operations in the Swift era



Swift will be launched in September 2004

It will detect ~100-150 bursts per year **with redshift information**

Milagro observes ~ 1/6 the sky with some reasonable efficiency

Therefore we should expect ~20 GRBs per year in our FOV with redshift information

This will improve our sensitivity by ~ factor of 3

And allow us to put limits on bursts we don't detect

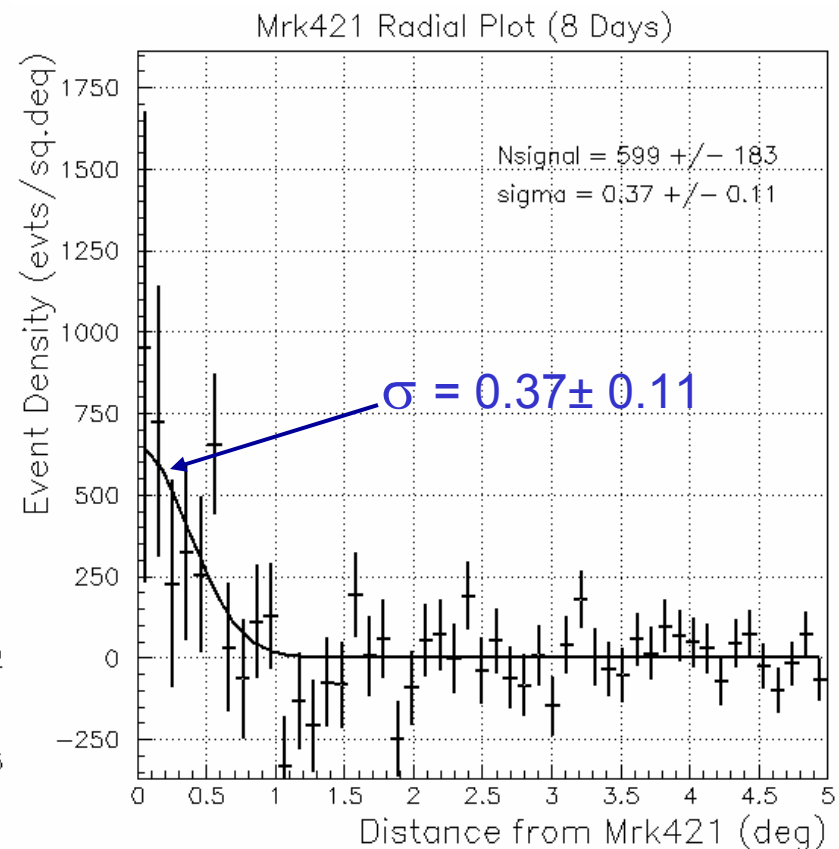
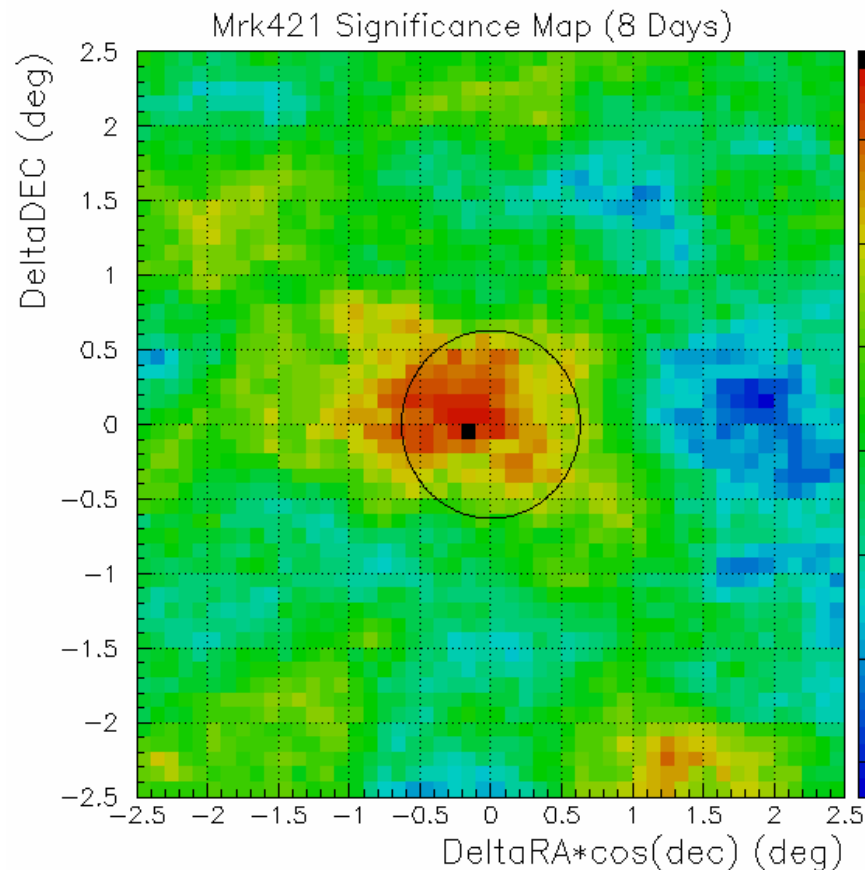
Note: EGRET saw 6 bursts in 9 years!

## Future for Milagro

- Pond is now well understood
- Outriggers are just completed
  - Already yielding a 70% improvement in Q
  - Still there is more to do with  $\gamma$ -h separation
    - We expect this to yield another factor or 1.5 – 2
- 3 years of operation will allow us to:
  - Further improve sensitivity (w/outriggers)
  - Nail down galactic plane result
  - Monitor the sky w/ improved sensitivity to AGN flare states (MRK501 quiet since Milagrato)
  - Search for/discover VHE counterparts to GRBs with SWIFT.

# Breaking Results on Mrk 421 (Preliminary)

- Mrk421 is flaring now – ( $\sim 3$  crab)
- With just 8 days of data  $\sim 3.3 \sigma$  (more coming)



# Recent Milagro Journal Articles



*TeV Gamma-Ray Survey of the Northern Hemisphere Sky Using the Milagro Observatory*

Accepted for publication in the *Astrophysical Journal*; astro-ph/0403097

*Limits on Very High Energy Emission from Gamma-Ray Bursts with the Milagro Observatory*

*Astrophysical Journal Letters* 604 (2004) L25-L28

*Observation of TeV Gamma Rays from the Crab Nebula with Milagro Using a New Background Rejection Technique*

*Astrophysical Journal* 595 (2003) 803-811

*Observation of GeV Solar Energetic Particles from the 1997 November 6 Event Using Milagrato*

*Astrophysical Journal* 588 (2003) 557-565

*The High-Energy Gamma-Ray Fluence and Energy Spectrum of GRB 970417a from Observations with Milagrato*

*Astrophysical Journal* 583 (2003) 824-832

# Milagro Journal Articles in Preparation

*Observation of TeV Gamma Rays from the Galactic Plane*

*Observation of a Forbush Decrease at High Energies  
from the Solar Event of 29 October 2003*

*First Constraints on Very High Energy Emission from Galaxy Clusters*

*Constraints on Very High Energy Emission from  
a  $z=0.45$  Gamma-Ray Burst and 29 Others*

*Search for TeV Gamma Rays from Short Duration Gamma-Ray Bursts  
and Evaporating Primordial Black Holes*

*Detection of the Moon's Cosmic Ray Shadow  
to Determine the Energy Scale of Milagro*

*Search for Very High Energy Emission from Nearby Blazars*

*Search for Very High Energy Gamma-Rays from WIMP annihilations  
near the Sun with the Milagro Detector*

*Observation of a Large Scale Cosmic Ray Anisotropy at TeV Energies*