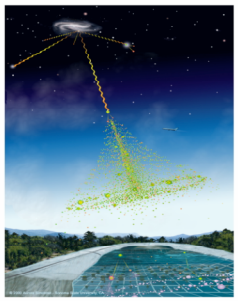
TeV γ-Ray Astrophysics @ LANL

Brenda Dingus, P-23

Milagro Observatory

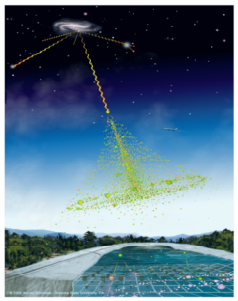
- Scientific Objective
- The Milagro Detector
- Recent results

Future Directions



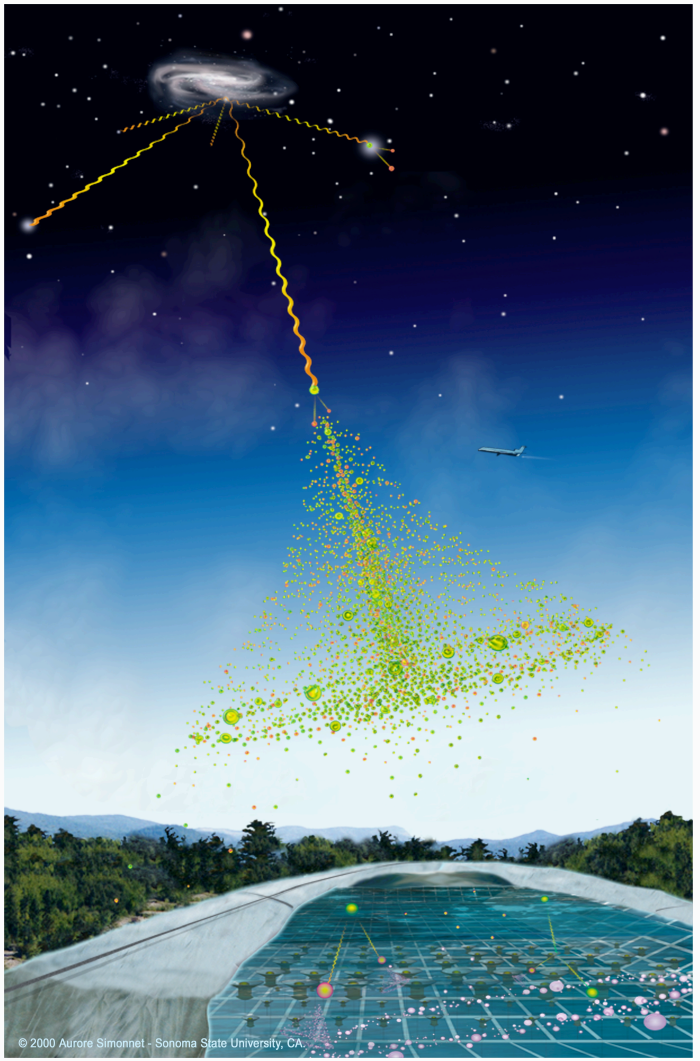
The Milagro Collaboration

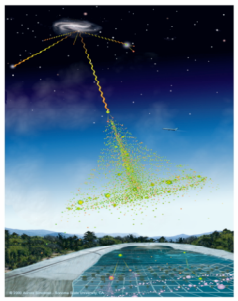
- LANL
  - Sinnis (PI/co-spokesman), Dingus (TSM), Walker, Casanova, Spaulding (UGS)
- U. Maryland
  - Goodman (PI/co-spokesman), Smith, Lansdell (at LANL), Vasilios (GRA), Noyes (GRA)
- U.C. Irvine
  - Yodh, Shoup, Allen (GRA), Amarotto (UGS), Delay (tech at LANL)
- U.C. Santa Cruz
  - Williams, Saz-Parkinson, Schneider (tech)
- Michigan State University
  - Linnemann, Aous Abdo (GRA), Iris Gebauer (GRA)
- New York University
  - Nemethy, Mincer
- George Mason University
  - Ellsworth



Milagro: A Tera-Volt Astrophysical Observatory

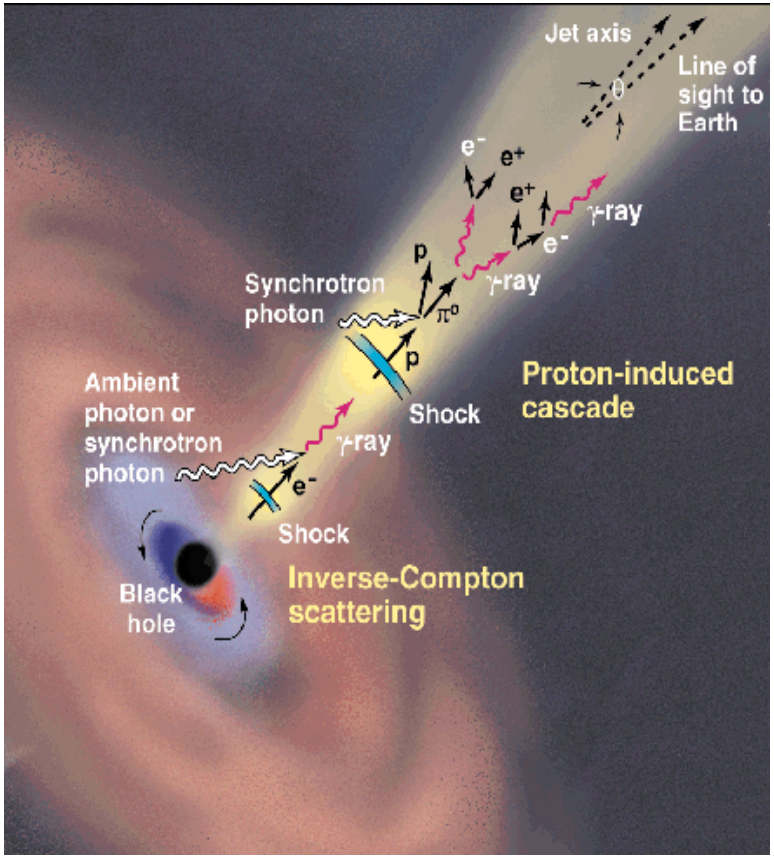
- Physics Goals
  - Particle acceleration
  - Astrophysical shocks
  - Black hole environments
  - Neutron star environments
- Astrophysical Sources
  - Active Galactic Nuclei
  - Gamma-ray bursts
  - Supernova Remnants
  - Sun
- Open aperture/continuous observation
  - Monitoring of variable sources
  - Study large-scale structure of sources
  - Discovery potential

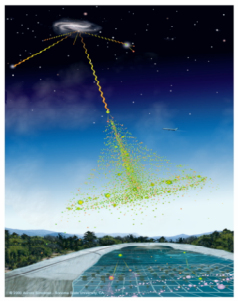




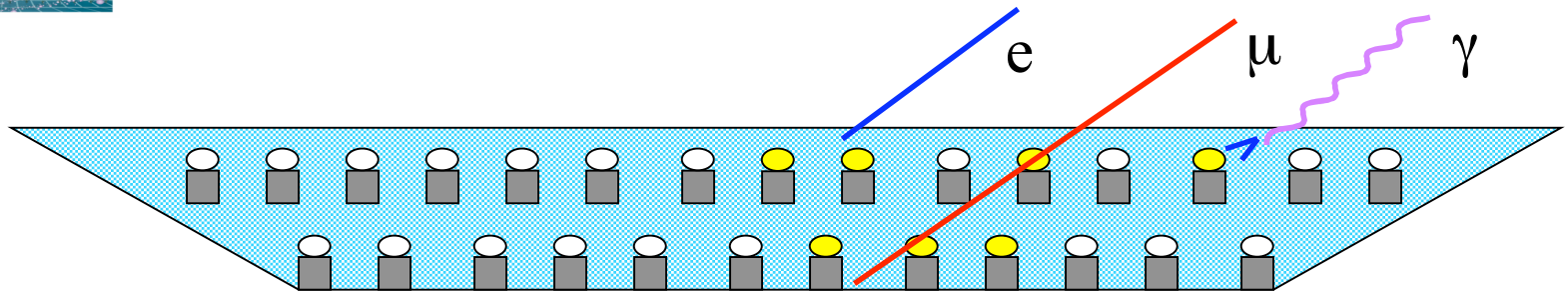
Active Galactic Nuclei

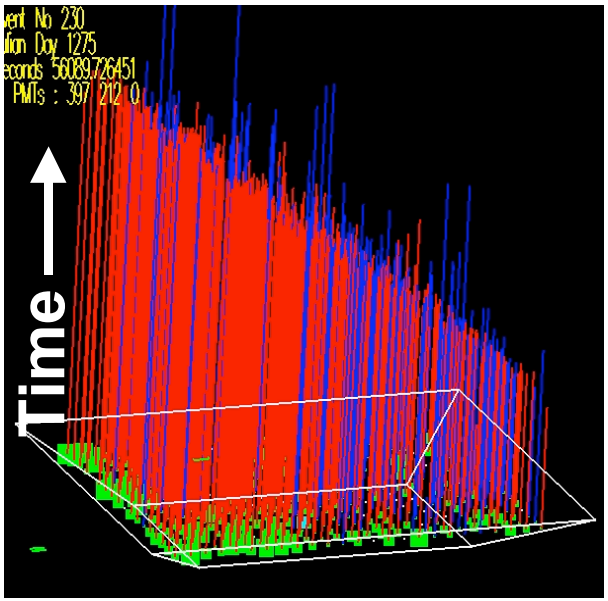
- ~10^8 M_{sun} black hole
- Relativistic particle jets
- 10^{48} ergs/sec
- TeV emission is along jet
- Highly variable
- Open questions
  - what is being accelerated?
  - how large is the bulk Lorentz factor of shock?
  - B-field in shock?
- Need multi-wavelength observations
  - many objects
  - many flares
  - long-term monitoring





Water Cherenkov Technology

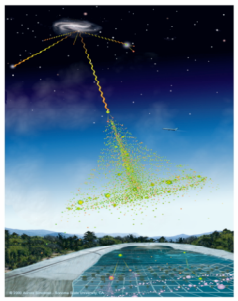




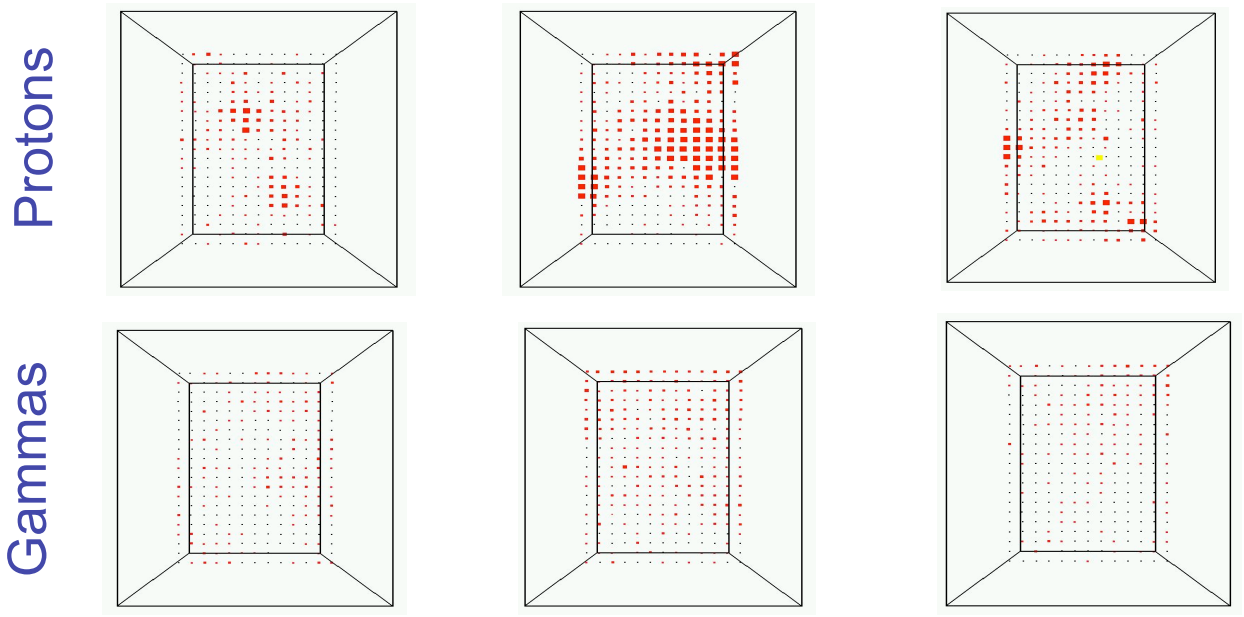
Top layer detects 50% of particles that enters the pond (γ, e^+, e^-)

Measure relative timing across pond (~1ns)

Reconstruct direction ~0.5^o

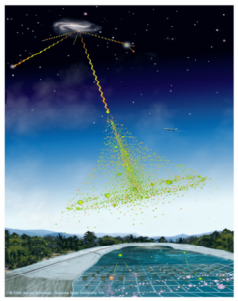


Background Rejection in Milagro

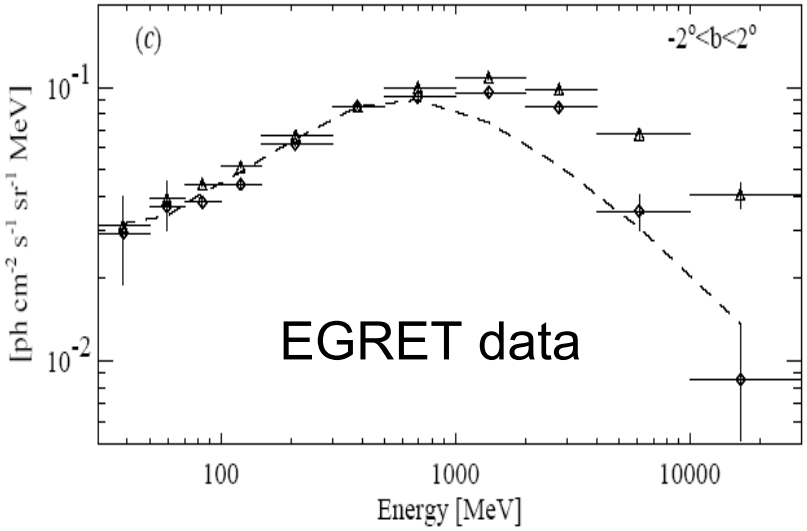


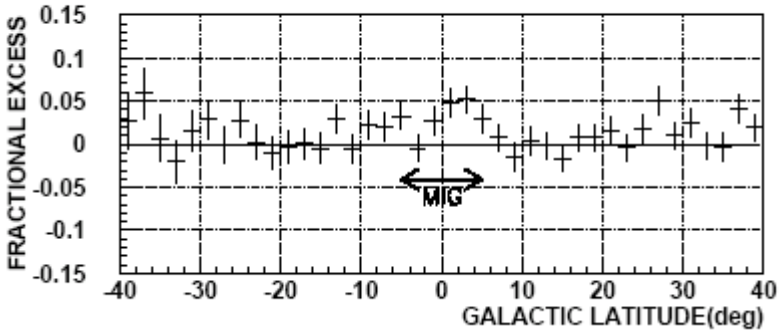
Reject 90% of proton background

Retain 50% of γ-ray signal



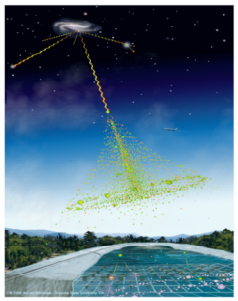
Galactic Plane in TeV Gamma Rays





- Cosmic rays interacting with matter in Galaxy produce π's that decay into γ rays
- Gamma ray spectrum is sensitive to cosmic ray source models
  - inverse Compton component
  - point sources
- EGRET observations up to 20 GeV indicated an excess > 1 GeV
- Higher energy observations have proven elusive despite 20 years of effort

- Milagro has made the first detection of TeV gamma rays from the Galactic plane
- S/B level ~3x10^{-4} – a very difficult analysis
- Submitted to PRL



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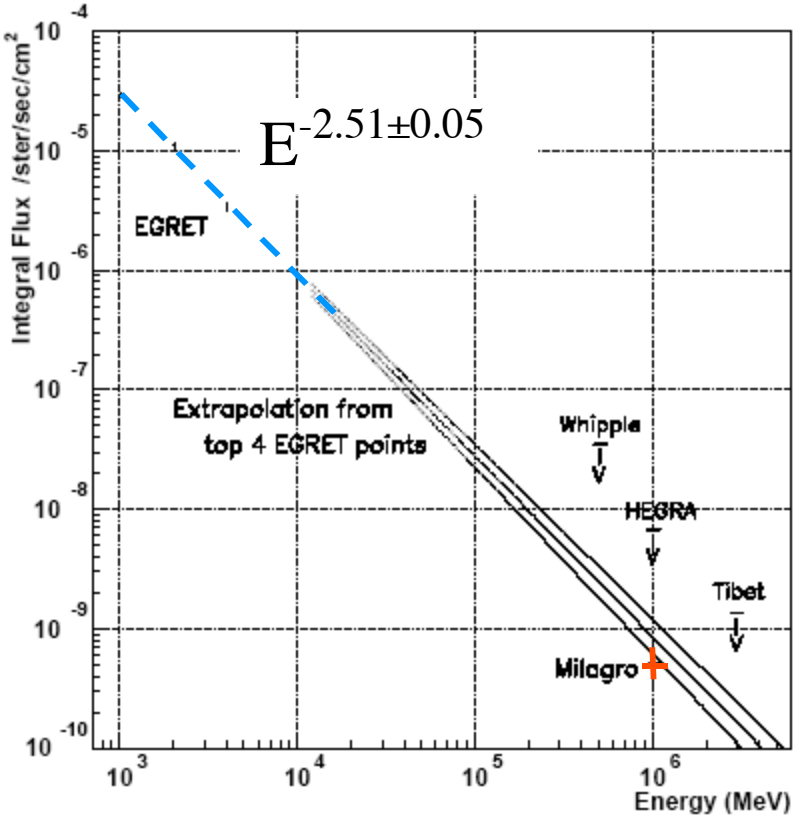
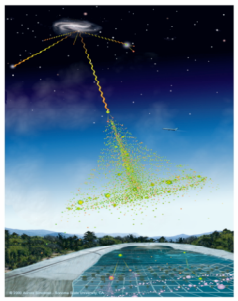
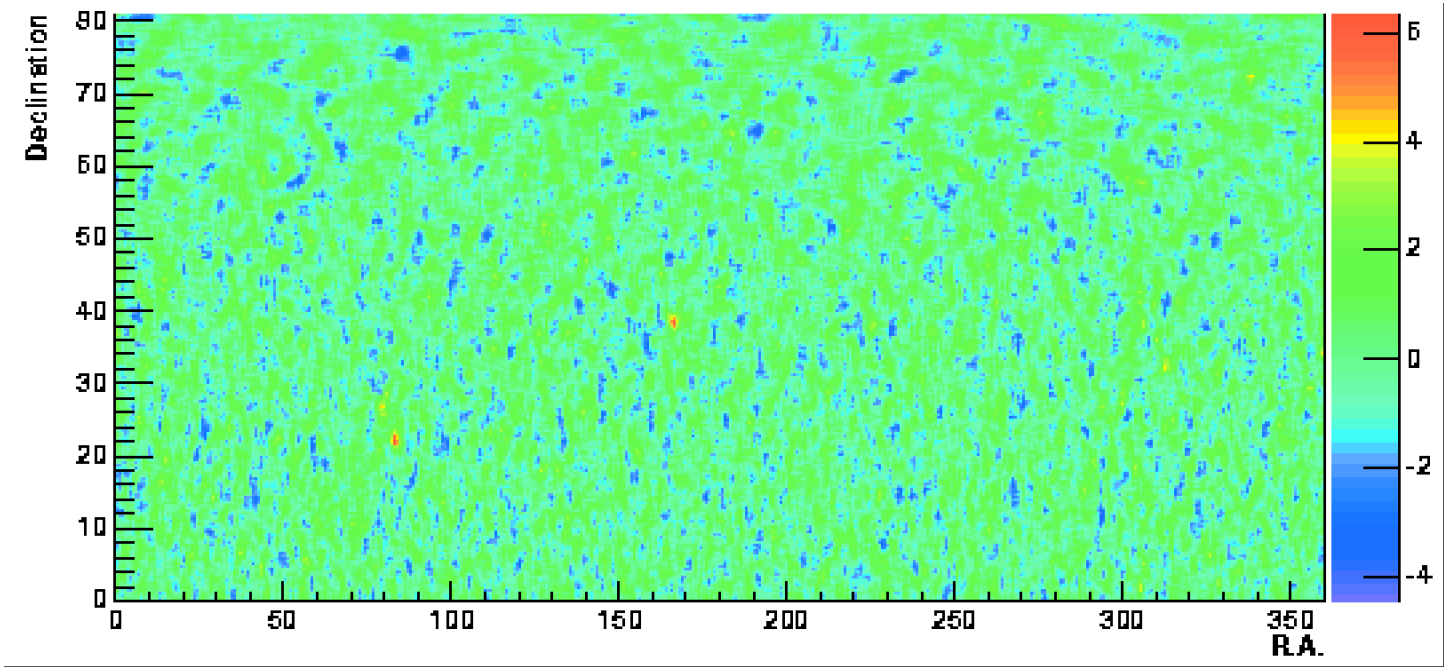


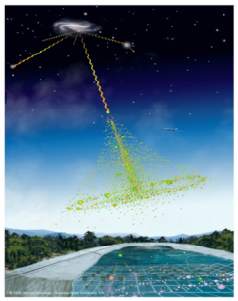
- Demonstrates the strength of Milagro in finding diffuse and extended sources
  - Due to good "inherent" background rejection
  - ACTs get most of their rejection from angular resolution
  - Large observation time
  - Large field of view
- Our flux measurement is ~1/10 of previous upper limits



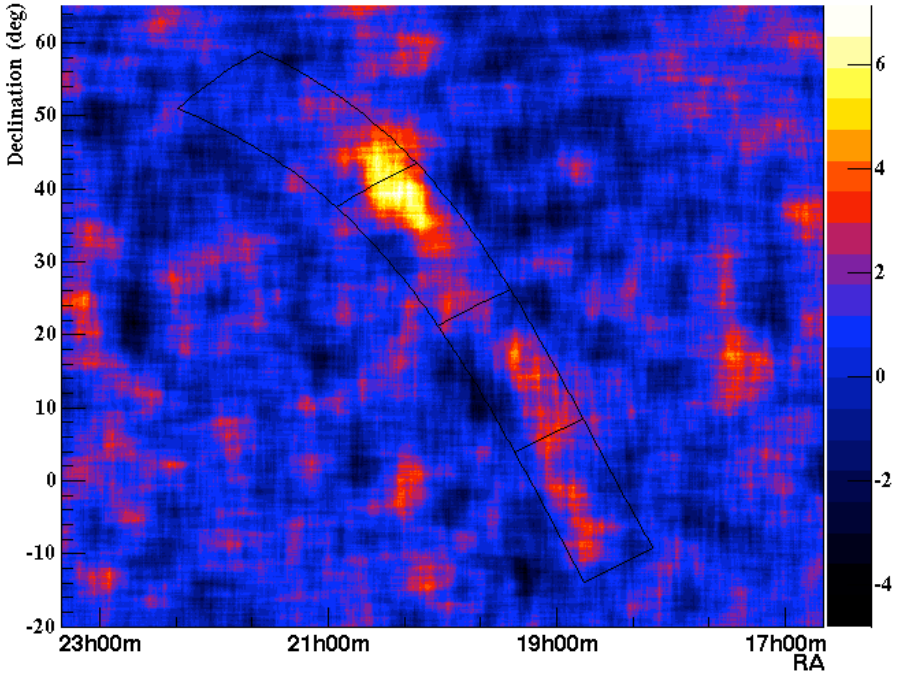
TeV Point-Source Survey of the Northern Hemisphere



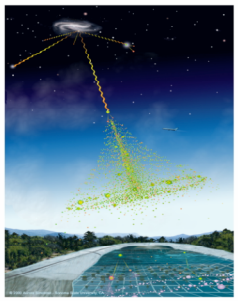
- Crab Nebula and active galaxy Mrk421 detected
- 9 regions of interest identified (>4σ) – 3 coincident with “roi’s” from Tibet array (Walker et al. ApJ)



Extended Source Survey

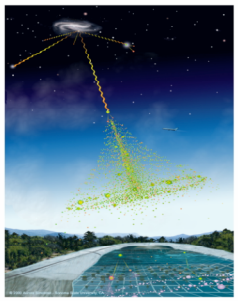


- Two of the regions of interest are actually extended sources
- ~6 degree source in Cygnus region of Galaxy
- ~3 degree source near the Crab Nebula
- HESS telescope now performing follow-up observations



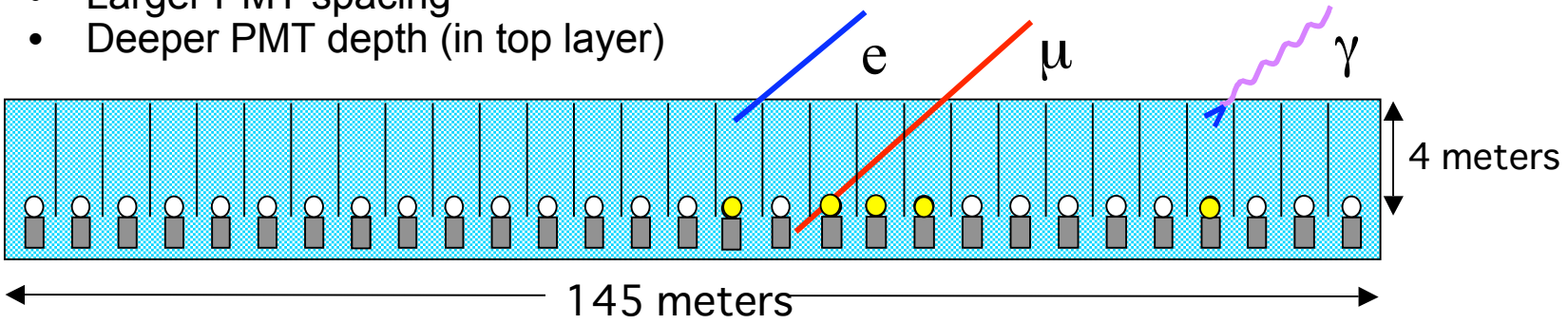
Milagro Status and Future

- Milagro is running in stable mode
- We are discovering new source of TeV gamma rays
  - Galactic plane
  - Extended sources (not anticipated)
- Online GRB analysis continuing
  - Tied into global alert network (GCN)
- Several exciting solar events detected
- NSF anticipates 2 more years of operations

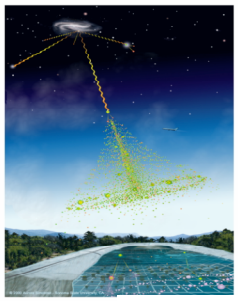


Future Plans: miniHAWC

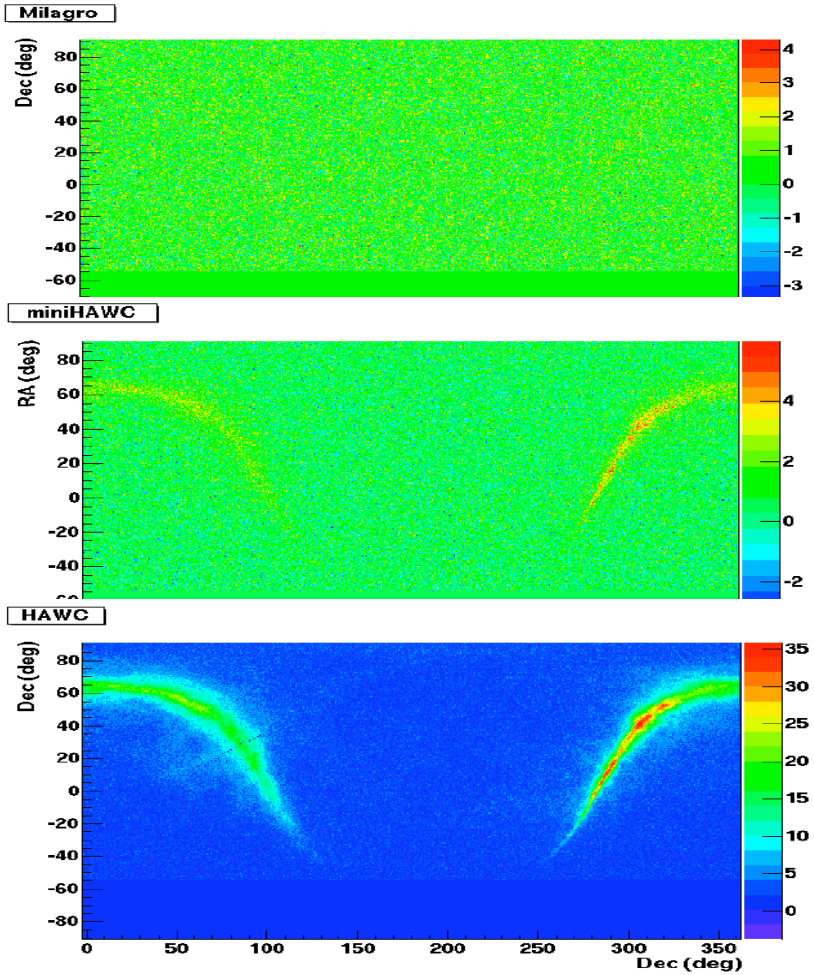
- Reuse Milagro PMTs and electronics
- Build pond at extreme altitude (Tibet – 4300m asl)
- Incorporate new design
  - Optical isolation between PMTs
  - Larger PMT spacing
  - Deeper PMT depth (in top layer)



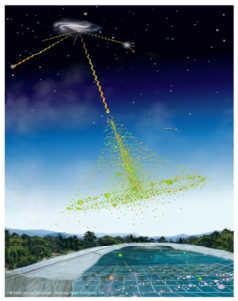
- Increase collaboration
  - Added IHEP (Beijing), MSU, UNM, and Utah
- $2-3M for complete detector
- >15x sensitivity of Milagro
  - Crab Nebula in 2-3 days (now 1 year)
  - GRBs to redshift of >1 (now 0.4)



miniHAWC Sensitivity: Galactic Emission

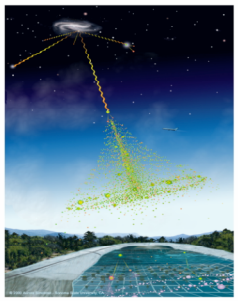


- Extrapolate from Milagro detection of Galactic plane
- Use neutral H map to predict TeV intensity
- Maps on left show 1-year of data from Milagro, miniHAWC and HAWC



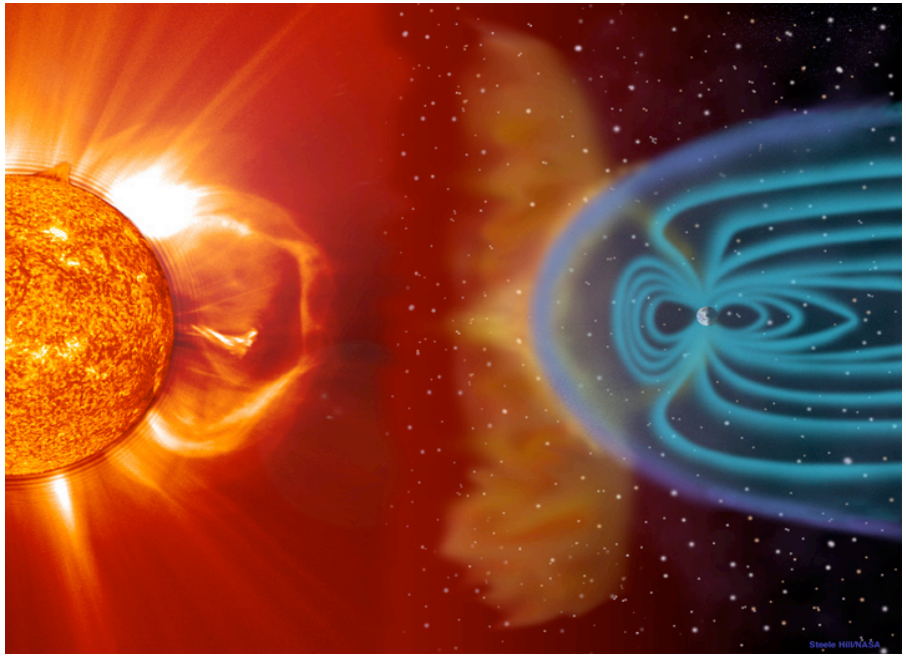
Conclusion

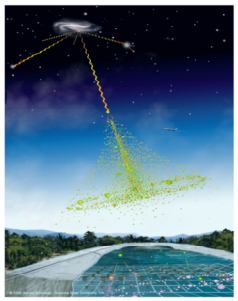
- Milagro has made several discoveries
  - TeV emission from the Galactic plane
  - 2 extended sources of TeV gamma rays
- Milagro is a completely new technique and we are still learning. The best days lie ahead.
- Design of next generation instrument in progress
- For modest cost (~$2-3M) we can build an instrument >15x more sensitive than Milagro
- Needed for monitoring of GLAST sources, ICECUBE sources, and discovery of new phenomena



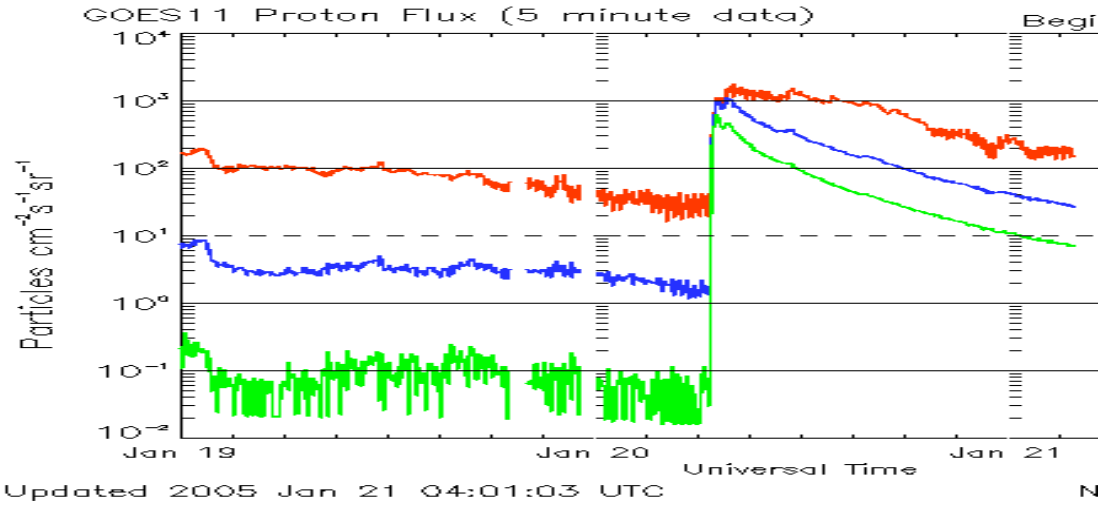
Solar Physics

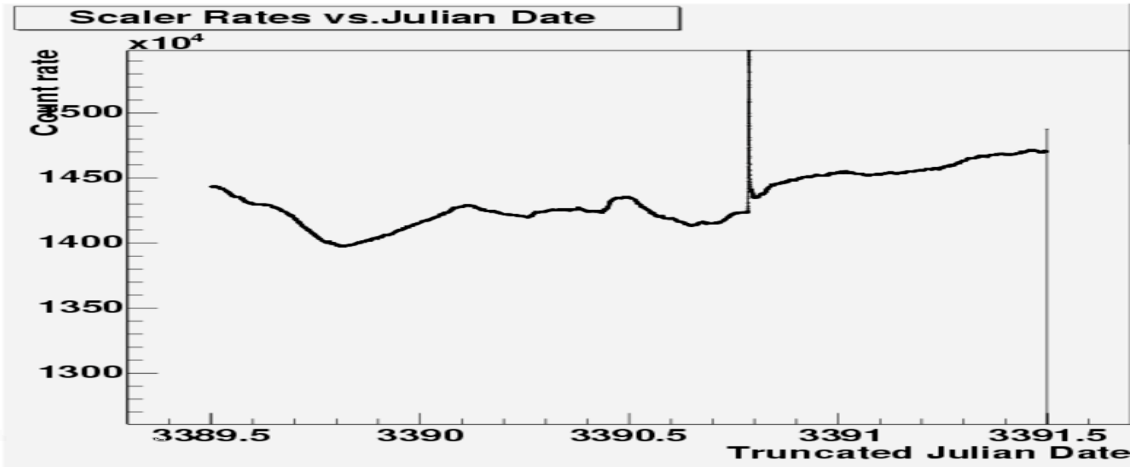
- Coronal mass ejections are an ideal laboratory to study particle acceleration in the cosmos
- By monitoring the singles rates in all PMTs we are sensitive to “low”-energy particles (>10 GeV)
- Milagro has detected 4 events from the Sun with >10 GeV particles



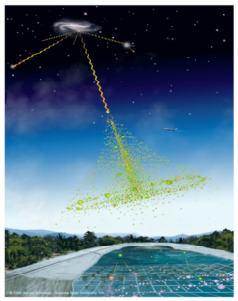


X7-Class flare Jan. 20, 2005



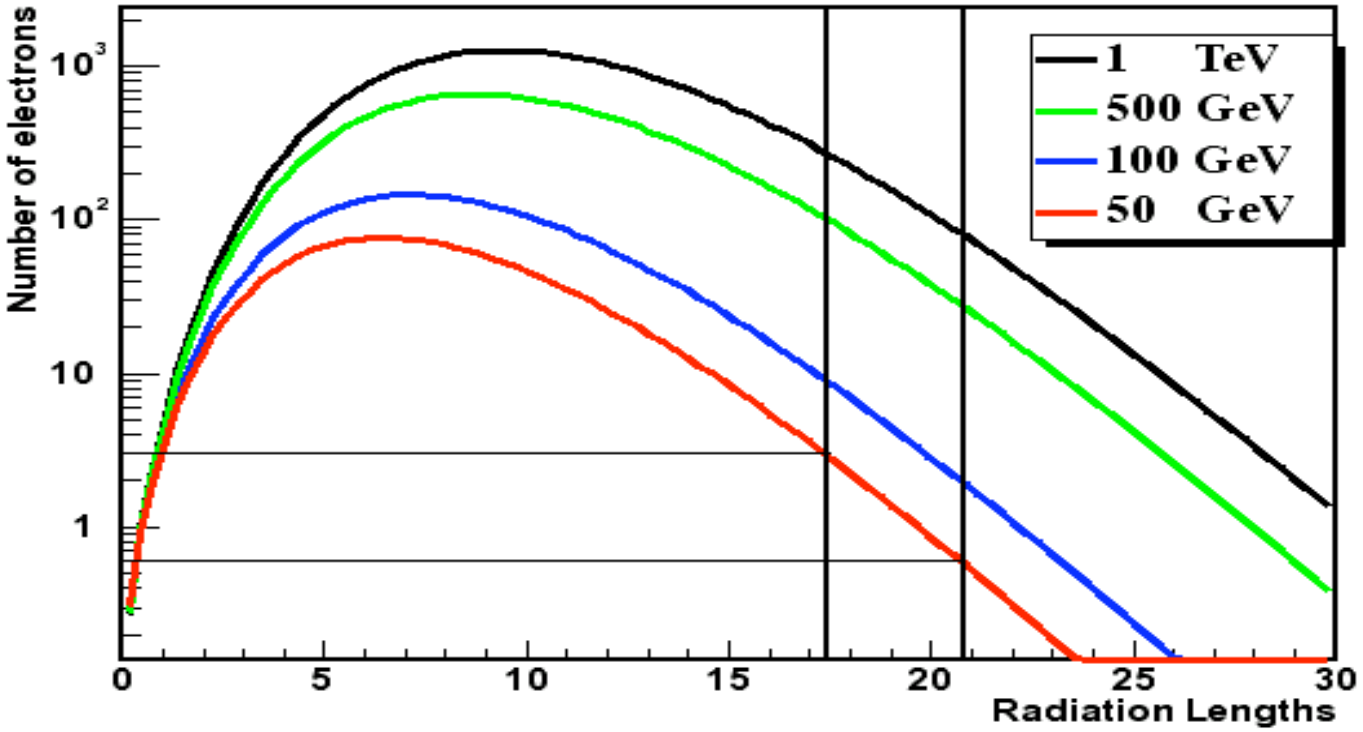


- GOES proton data
  - >10 MeV
  - >50 MeV
  - >100 MeV
- Milagro scaler data
  - > 10 GeV protons
  - ~1 min rise-time
  - ~5 min duration

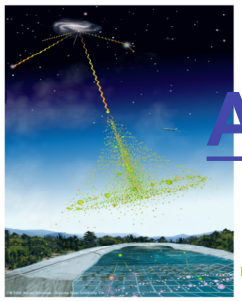


Effect of Altitude

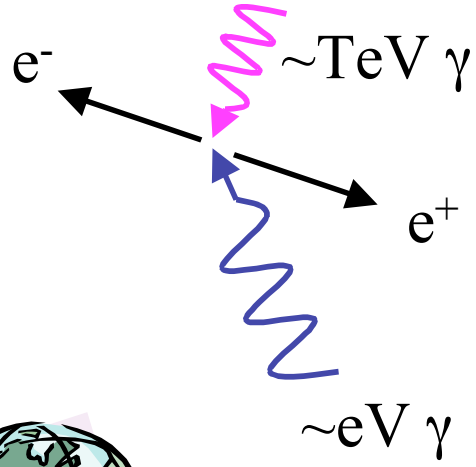
Approximation B

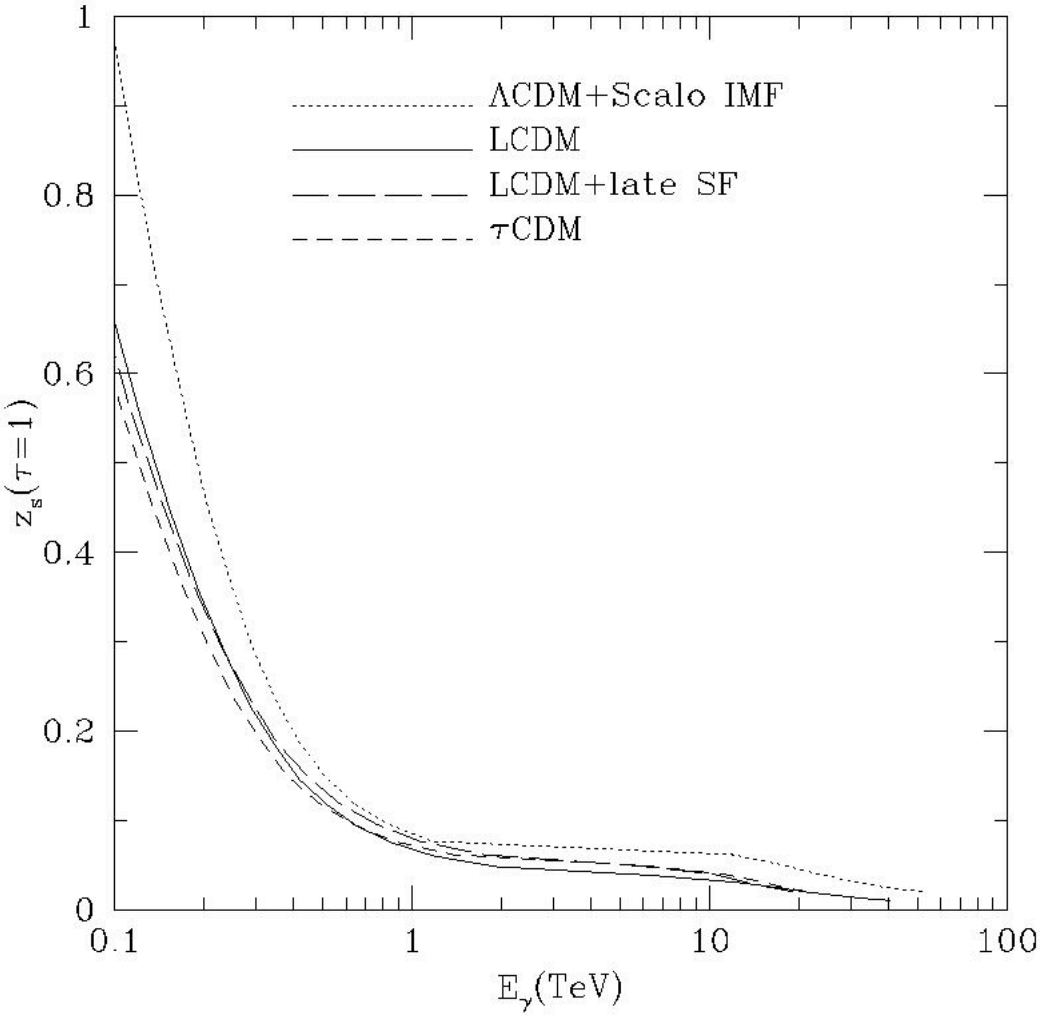


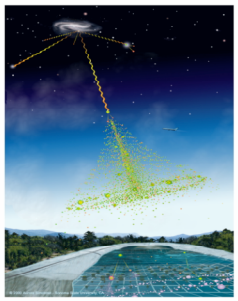
Low Energy Threshold Requires High Altitude



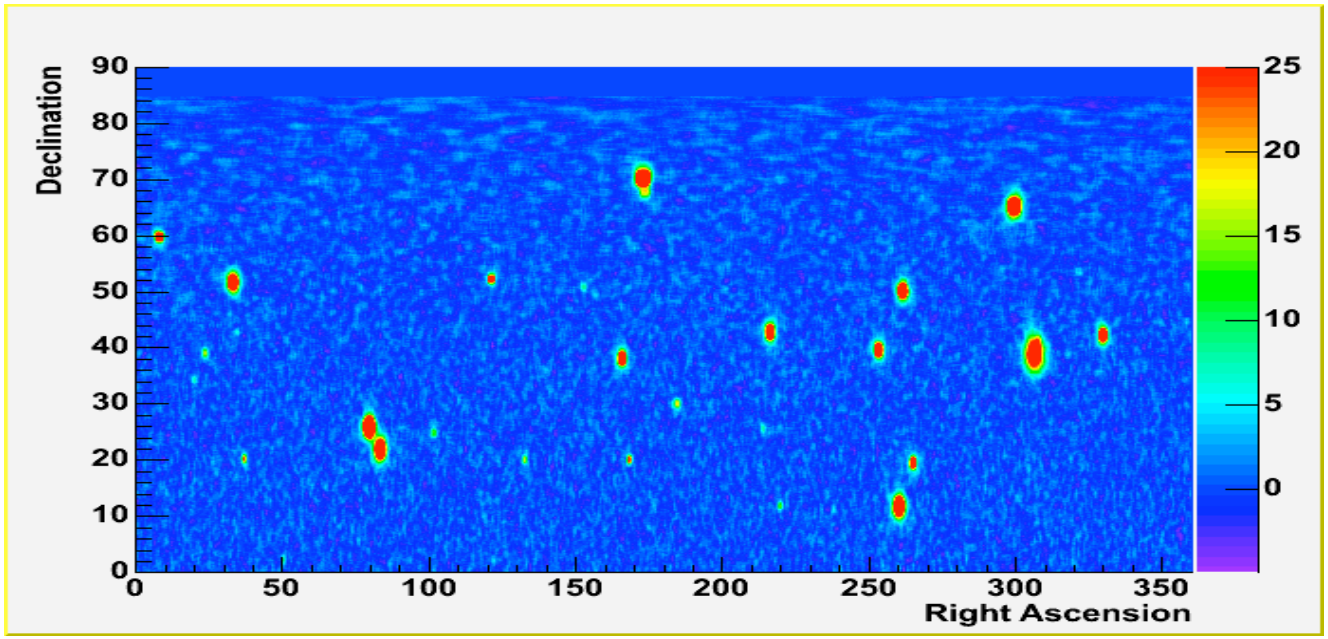
Absorption of TeV Photons



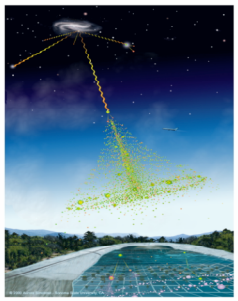




HAWC Sensitivity: Active Galaxies



- Assume theoretical model of 27 AGN
- Account for IR absorption
- Add in 5 known TeV sources



Forbush Decreases – The interplanetary field