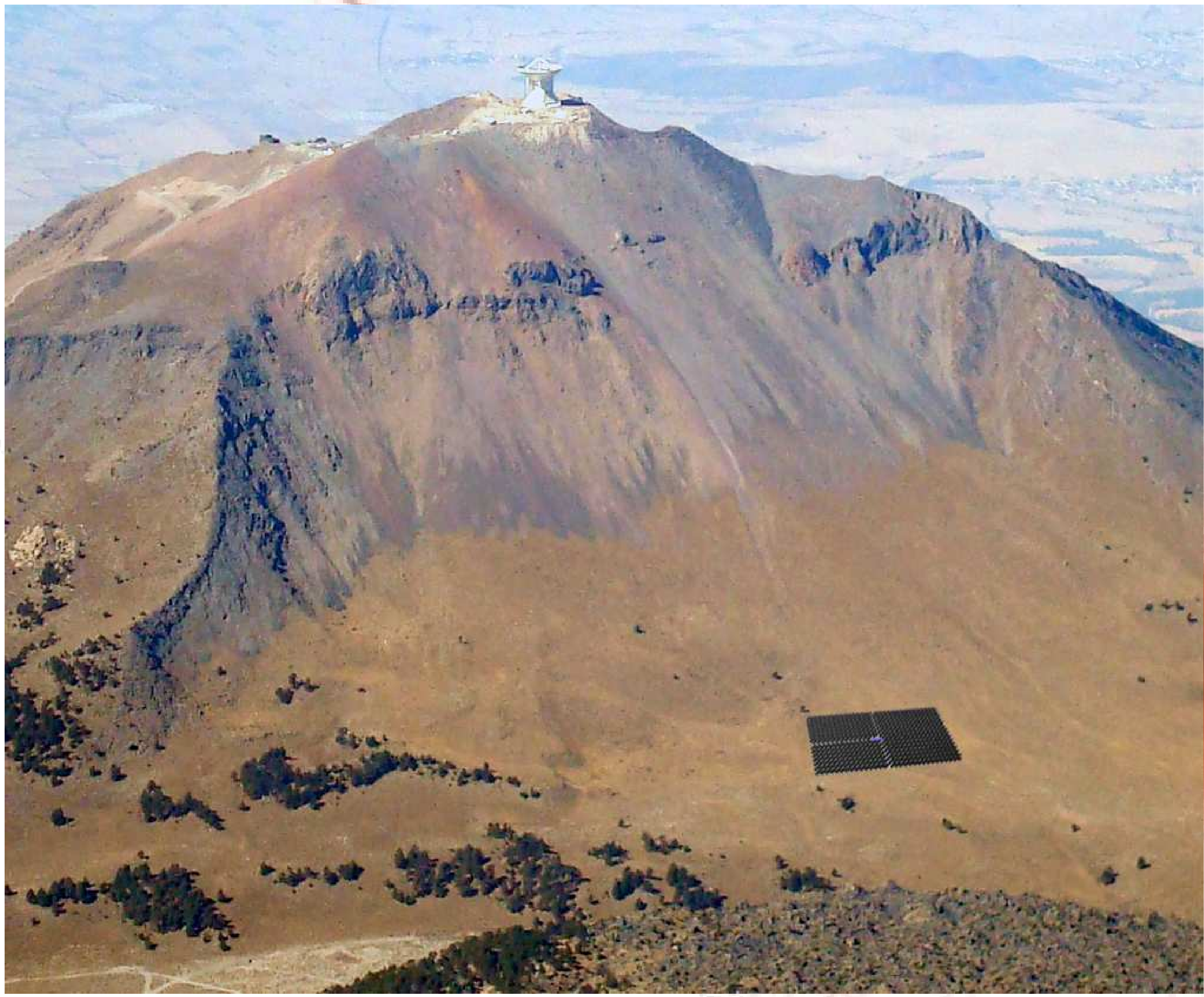
The HAWC Observatory
(High Altitude Water Cherenkov)



Andrew Smith
University of Maryland, College Park

SciNeGHE 2009
Gamma Ray Physics in the LHC Era

The Answer....

HAWC will be ~15x more sensitive than Milagro to a like spectrum

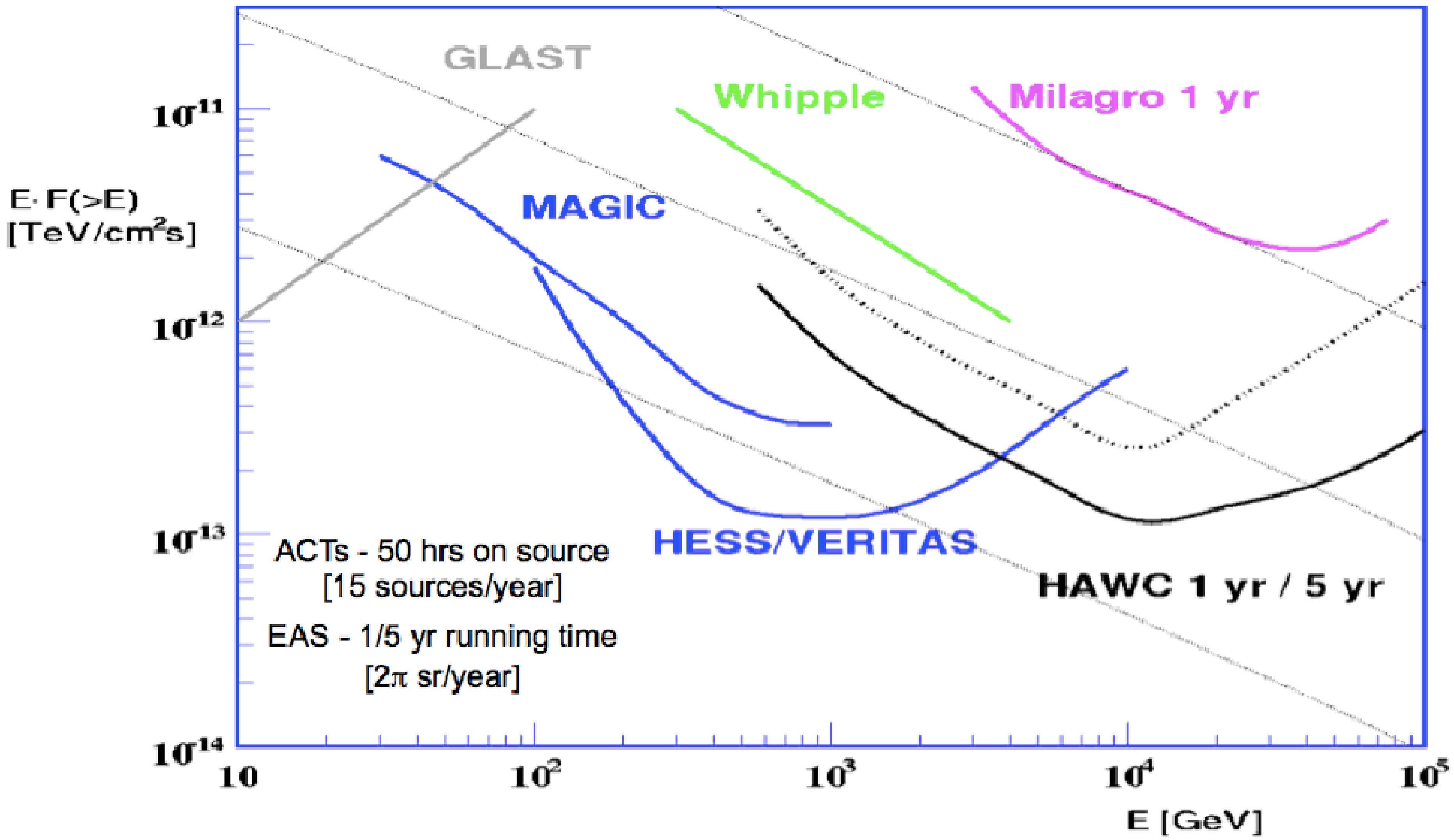
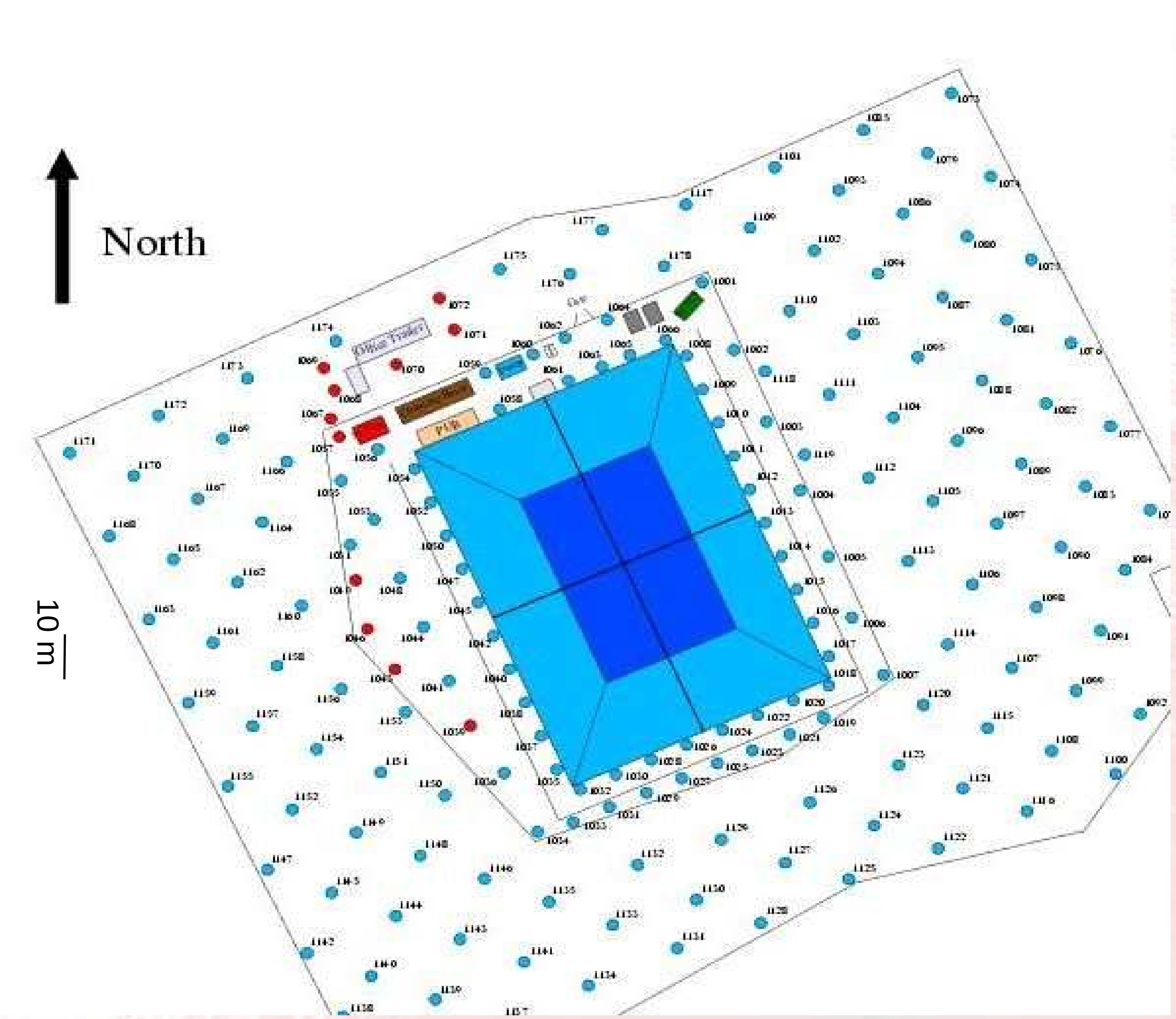


Image from Johannes Knapp

Outline-
How, Why , Where, When...

Milagro Detector

- Water Cherenkov Detector
- 2640m (8640') elevation
- 898 photomultiplier tubes
  - 450 in top layer in pond
  - 273 in bottom layer in pond
  - 175 water tank outriggers
- Pond Area is 3600 m^2
  - Operational in January 2001
- Outrigger Array area is ~ 30000 m^2
  - Operational in June 2004
- Shutdown June 2008
- 10x the trigger rate as Tibet AS-Gamma
- 0.5x the trigger rate of ARGO



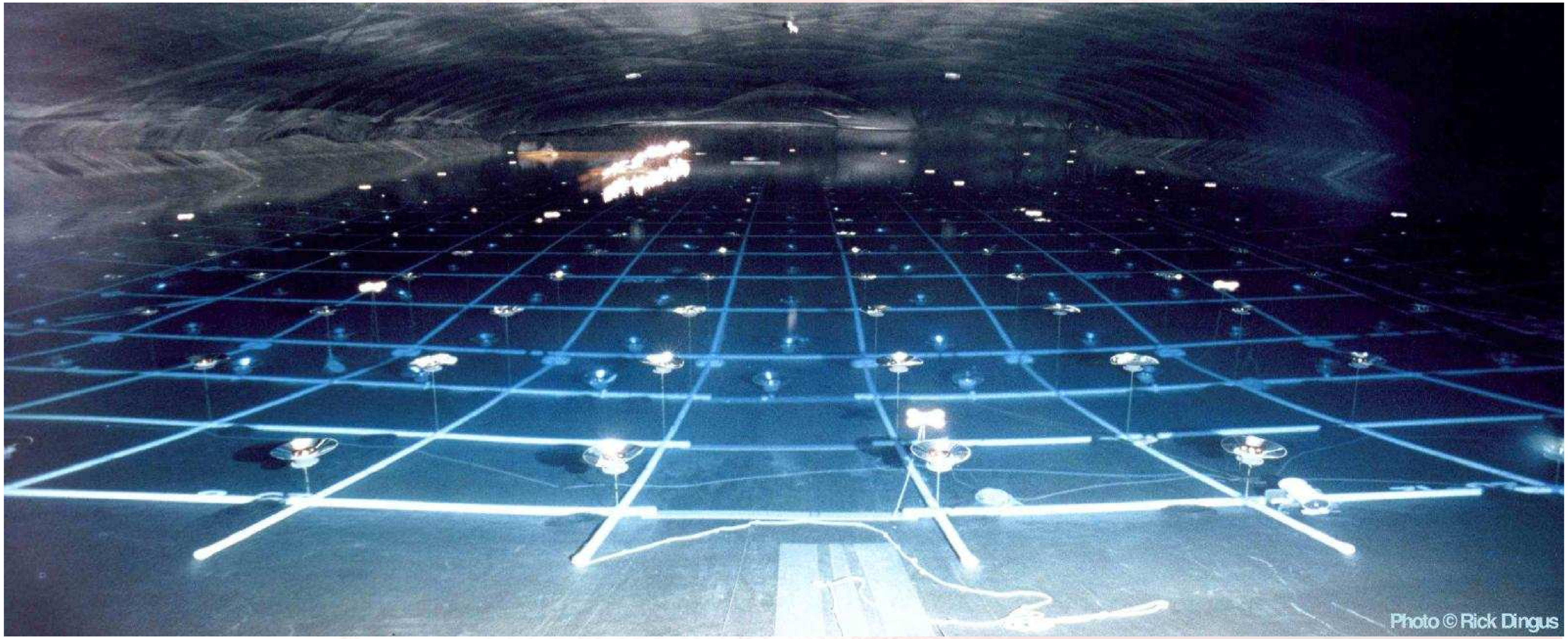
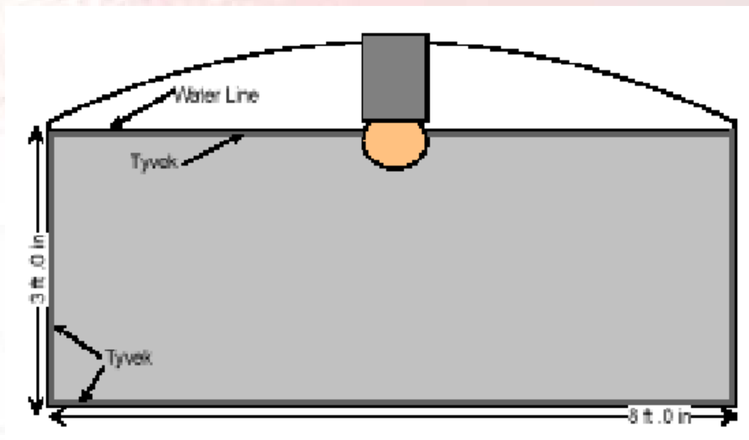


Photo © Rick Dingus


Water Line
Tyvek
3 ft. 0 in
Tyvek
8 ft. 0 in

Trigger: ~60 PMTs hit within 180ns window

Event Rate ~1700 Hz with 8% dead time. Due almost entirely to CR p(70%) He(25%) C,O, Ne, Mg,Si,Fe(5%)

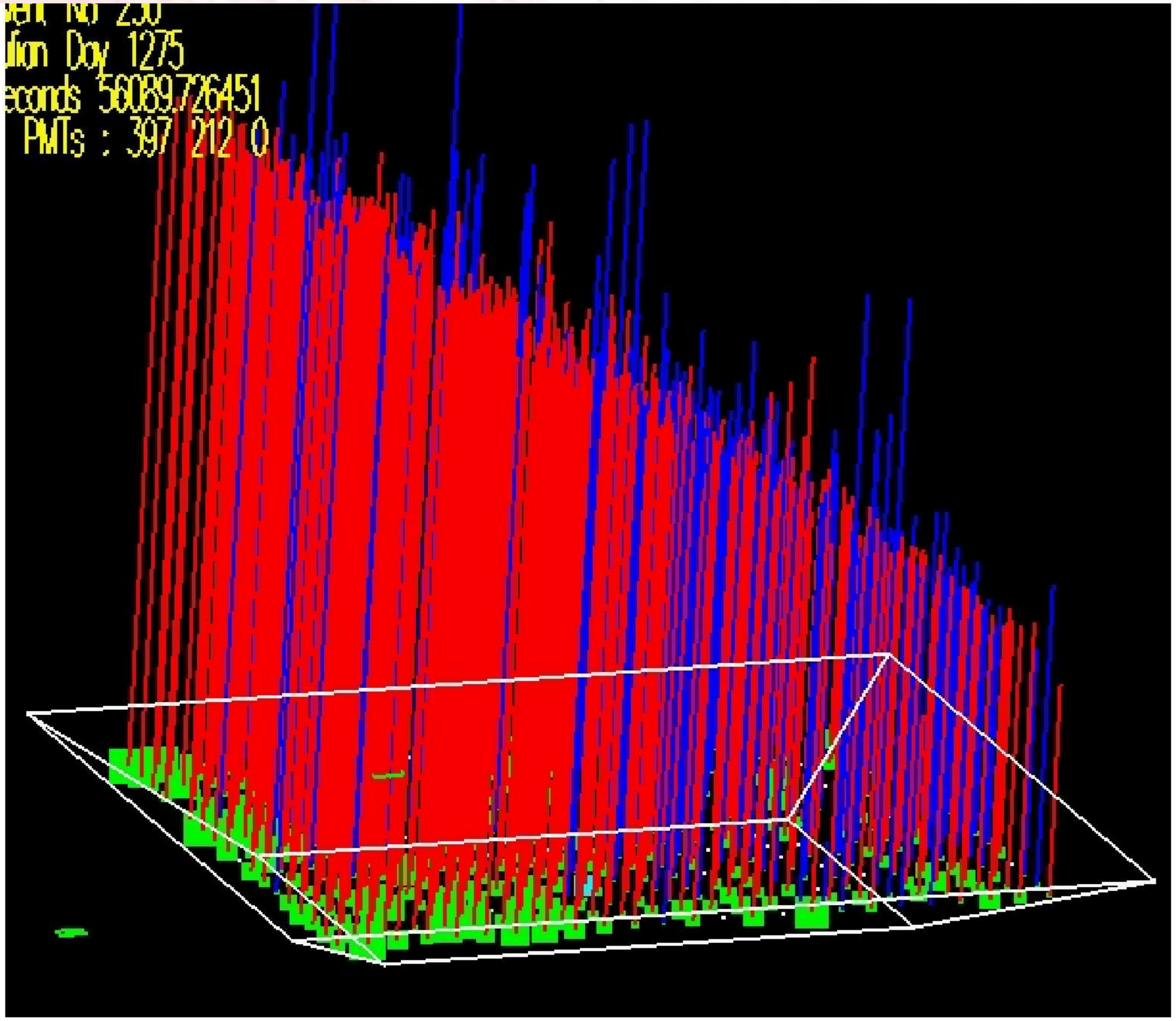
Operational for 7 years, 4 years with outrigger array.

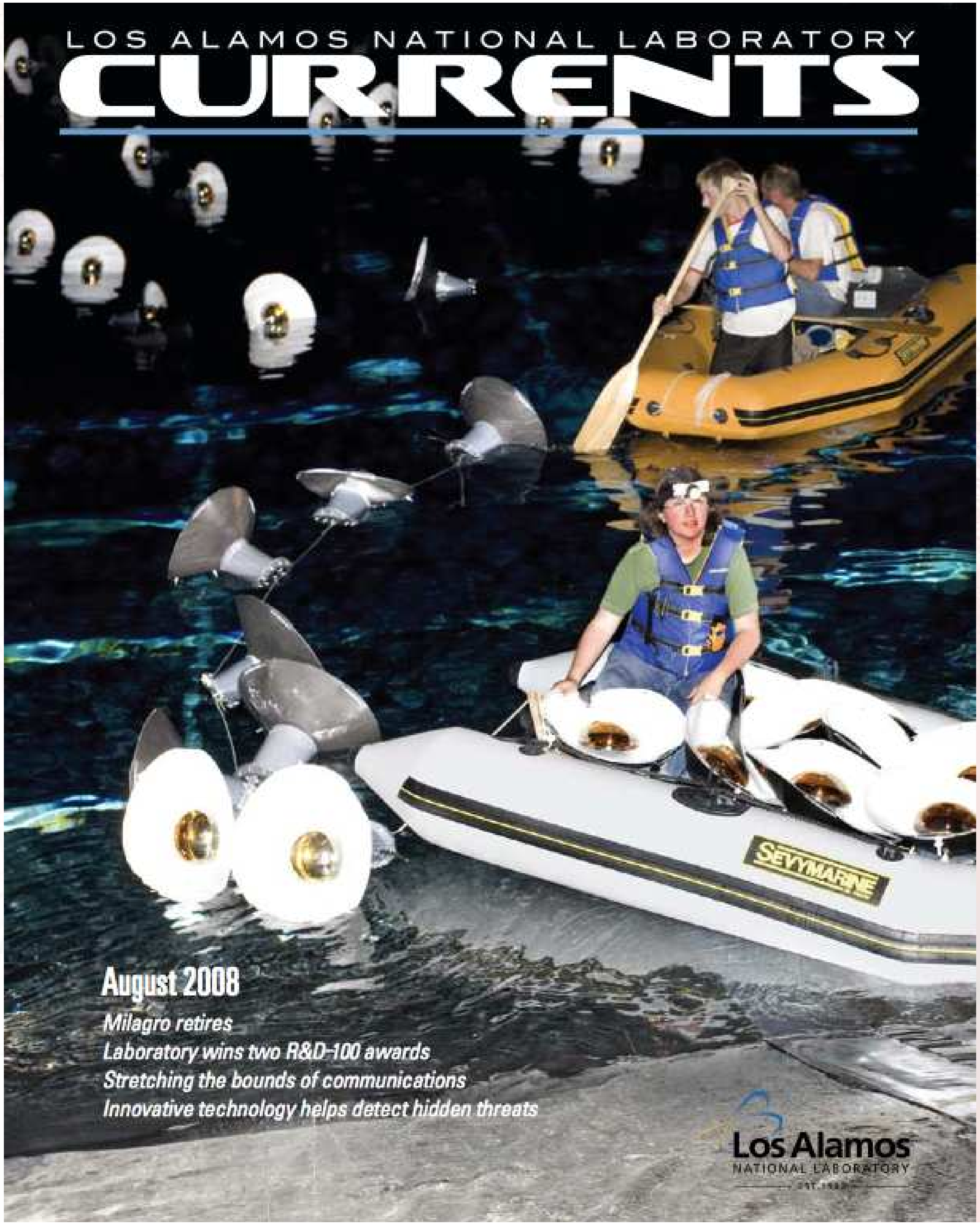
>90% on-time

Online reconstruction only, “raw” data not recorded.

Angular resolution <1°

>300 x 10^9 events logged.




LOS ALAMOS NATIONAL LABORATORY
CURRENTS
August 2008
Milagro retires
Laboratory wins two R&D-100 awards
Stretching the bounds of communications
Innovative technology helps detect hidden threats
Los Alamos
NATIONAL LABORATORY

Simulation Details -

- Corsika - EPOS,QGSJet-II
- GEANT4 detector simulation
- Scattering, Absorption
- PMT model
- Simulate 8 hadron species: P,He,C,O,Ne,Mg,Si,Fe (ATIC spectra)
- Verified with Milagro
- Simulation predicts well the sensitivity of Milagro and CR background rates
- Simulate backgrounds: SPE and shower overlaps
- Simulate electronics and trigger: Multiplicity within ~100ns window
- Full reconstruction.

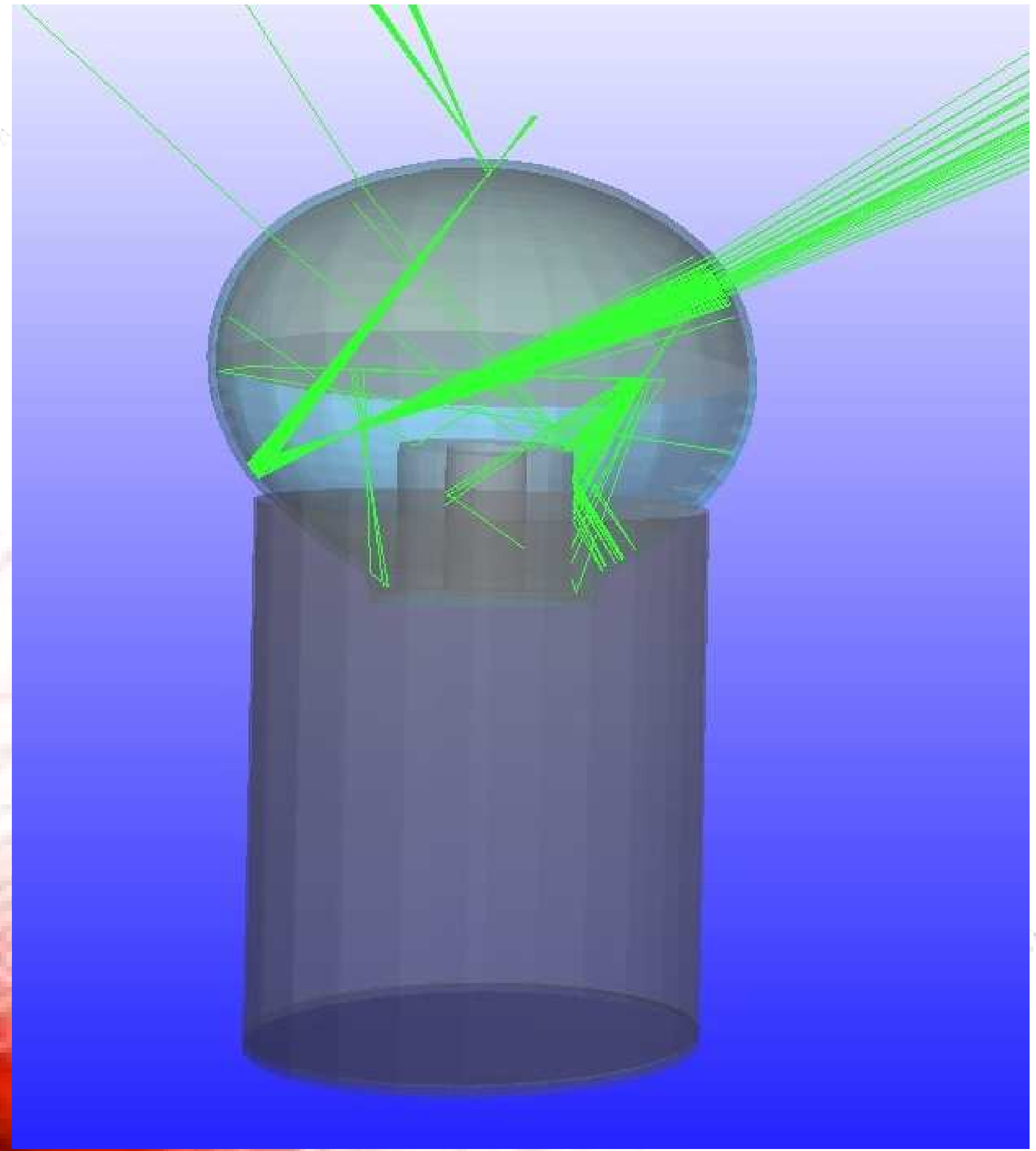
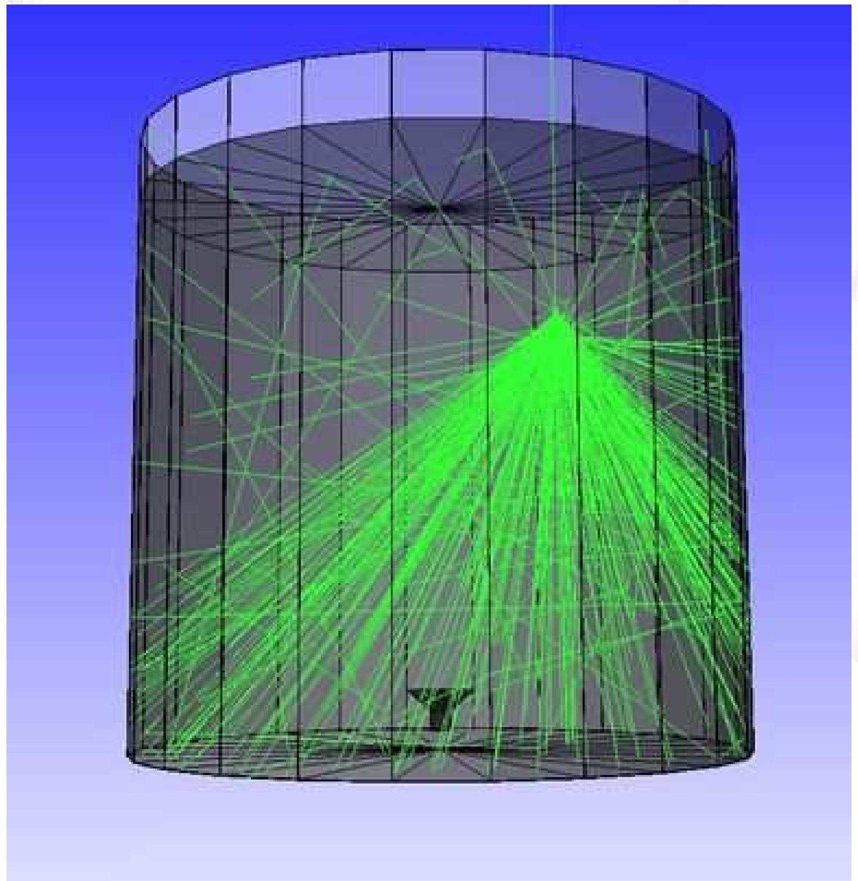


Image from Johannes Knapp

Water Depth Optimization

Want good calorimetry:
=> PMT is far from source of light



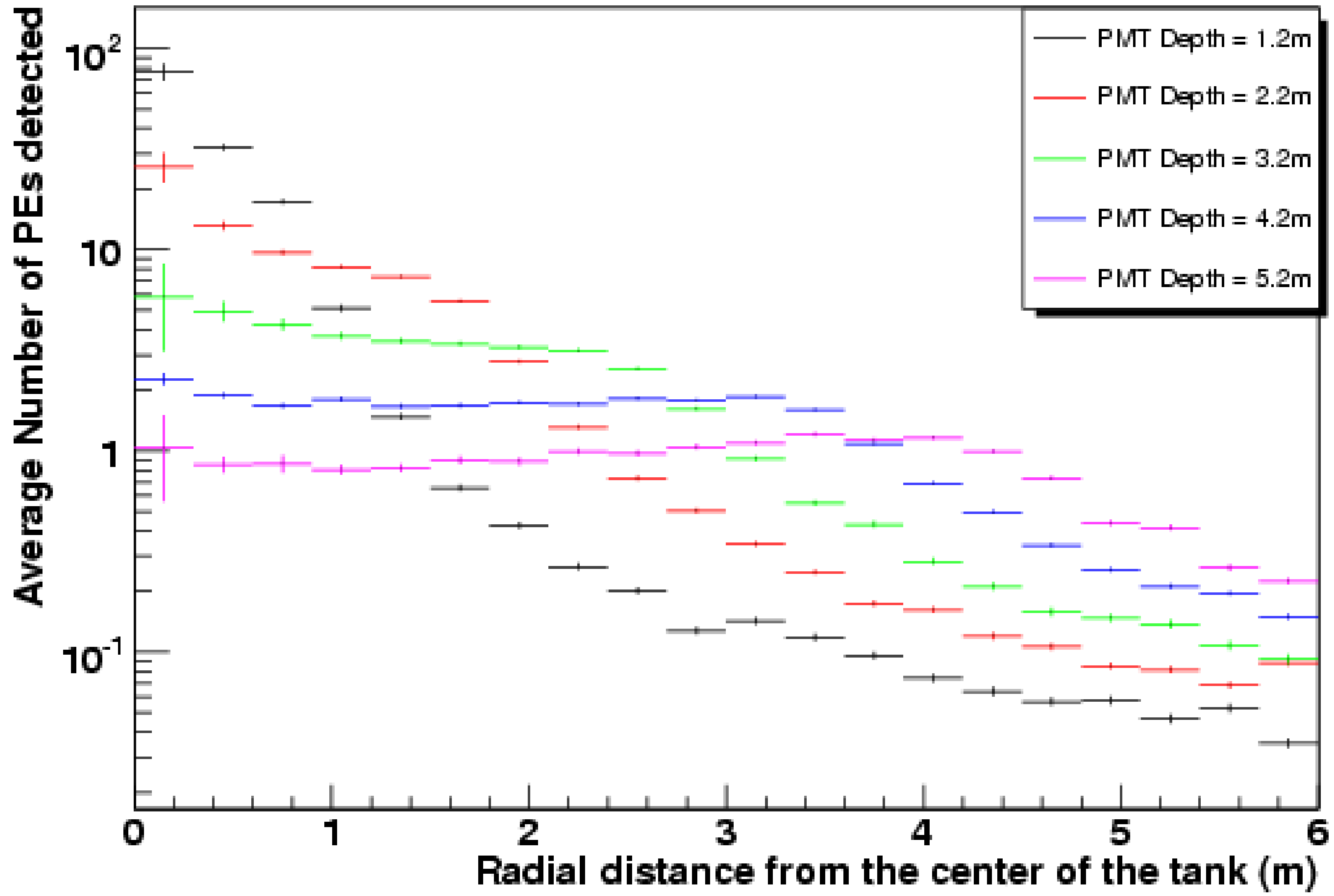


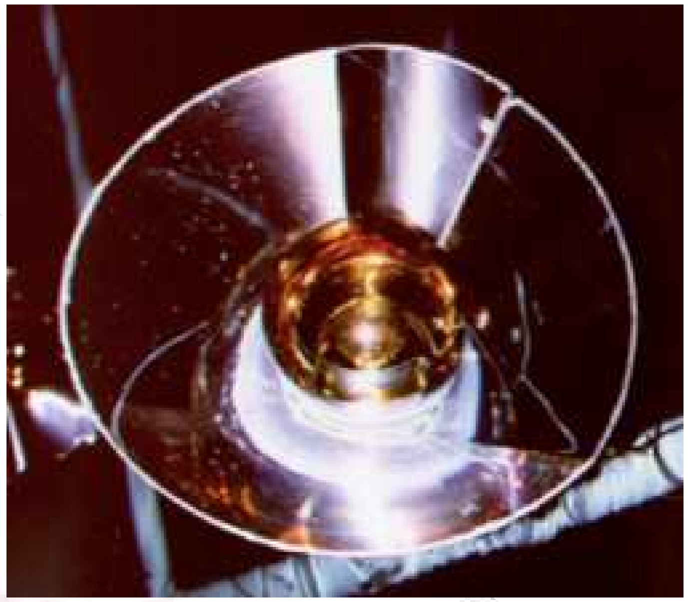
Image from Johannes Knapp

At depths greater than 3.5-4.0m the response curve is roughly flat vs shower position.

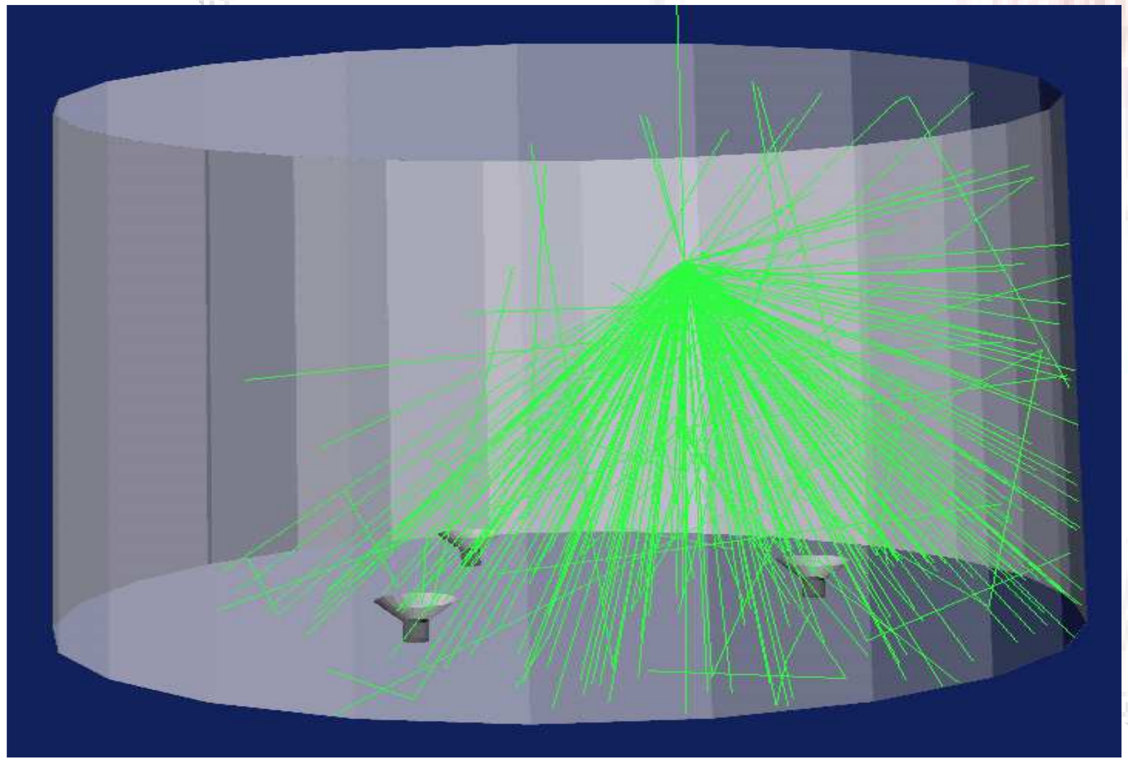
Get about 1 PE/50MeV at 4m depth where a single PMT can monitor ~30m^2 of water.

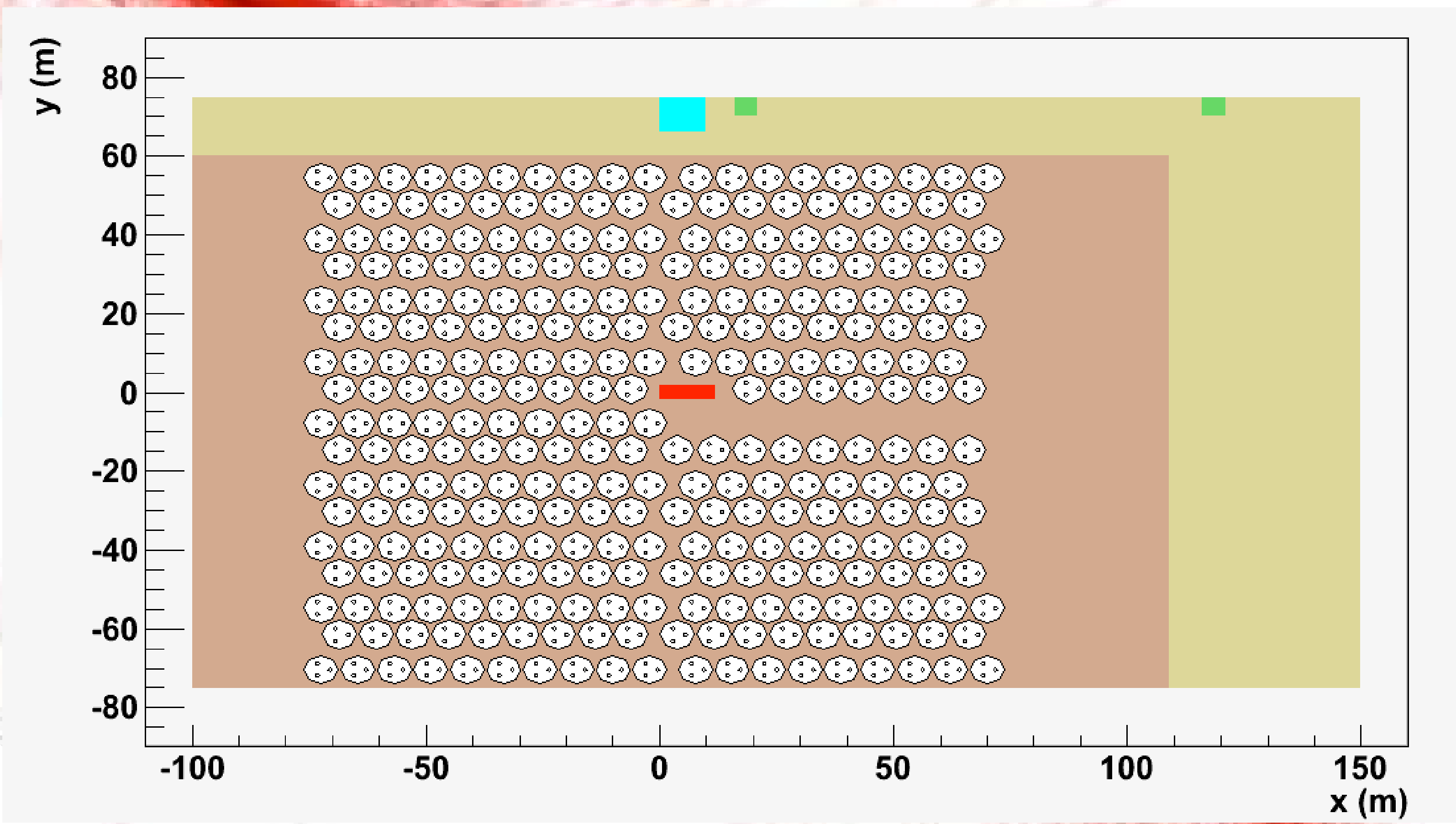
HAWC Design -

- 300 7.3m diameter, 4.3m tall water tanks.
- 180000 liters/tank
- Each tank has 3 upward facing PMT 4.0m below the surface of the water.
- Tanks densely packed over 135m x 150m region (>70%coverage)
- Reuse Milagro analog electronics and PMTs
- Readout with VME multi-hit TDCs.
- Time-over-threshold for 5 decade pulse amplitude scale (0.1-10^4 PEs)



Milagro PMT





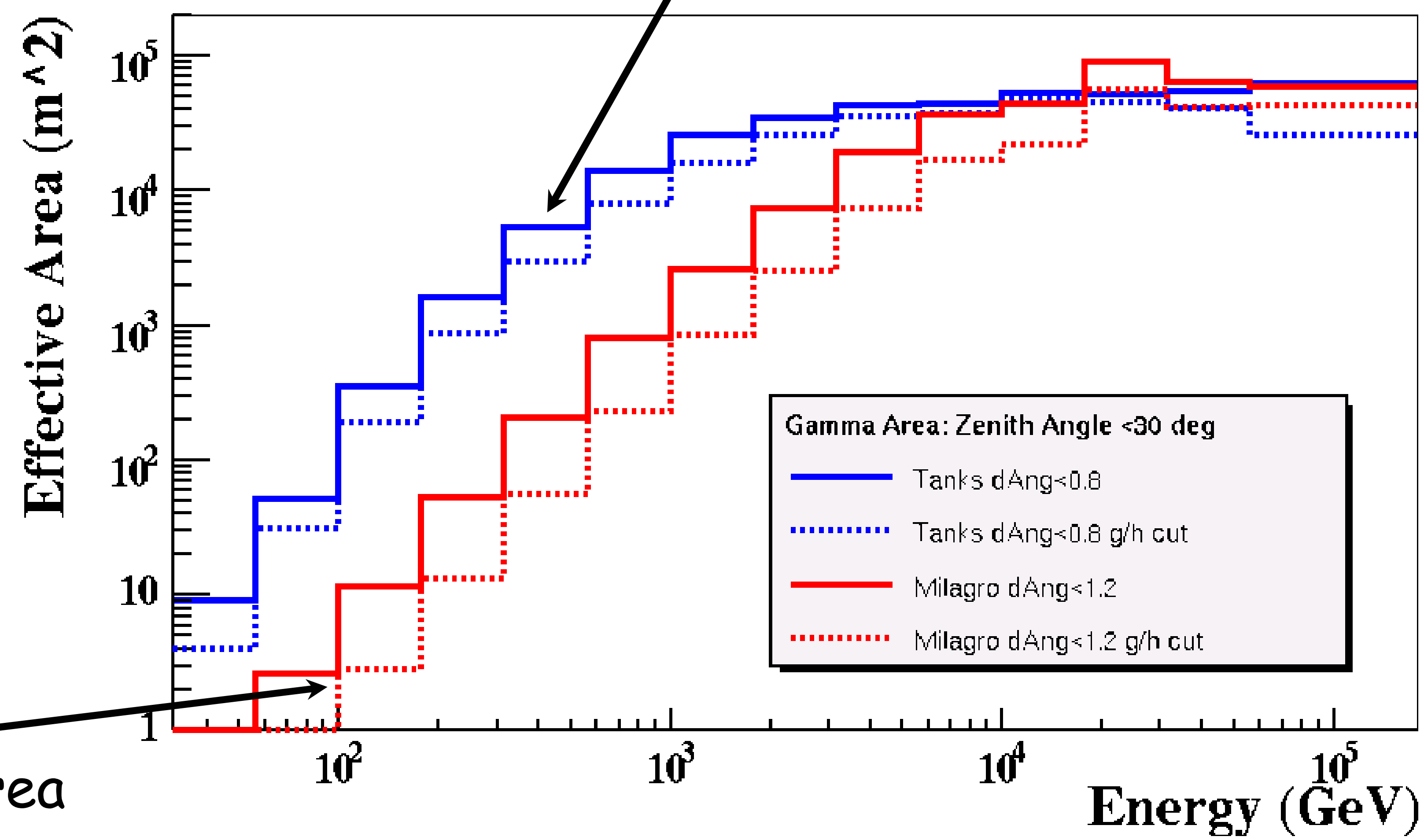
Triggering, Reconstruction and Effective Area

- Trigger threshold of 30PMTs hit (150ns) window 15-20 kHz (Milagro 2kHz,ARGO 3.6kHz)
- Fit core using Gaussian profile - 2-3m position accuracy for cores on array.
- Fit shower front times to plane after correcting for shower front curvature.

Increasing elevation from 2650m (Milagro) to 4100m (HAWC) increases the energy reaching the detector level increases by a factor of ~4x.

HAWC Area (--- gamma/hadron cut)

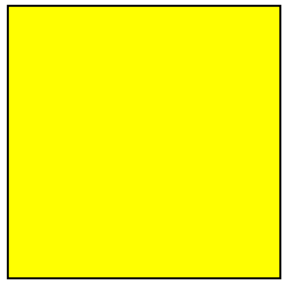
HAWC will have nearly 100x the area of Milagro below 1 TeV



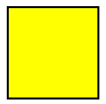
Milagro Area

Gamma/Hadron Separation

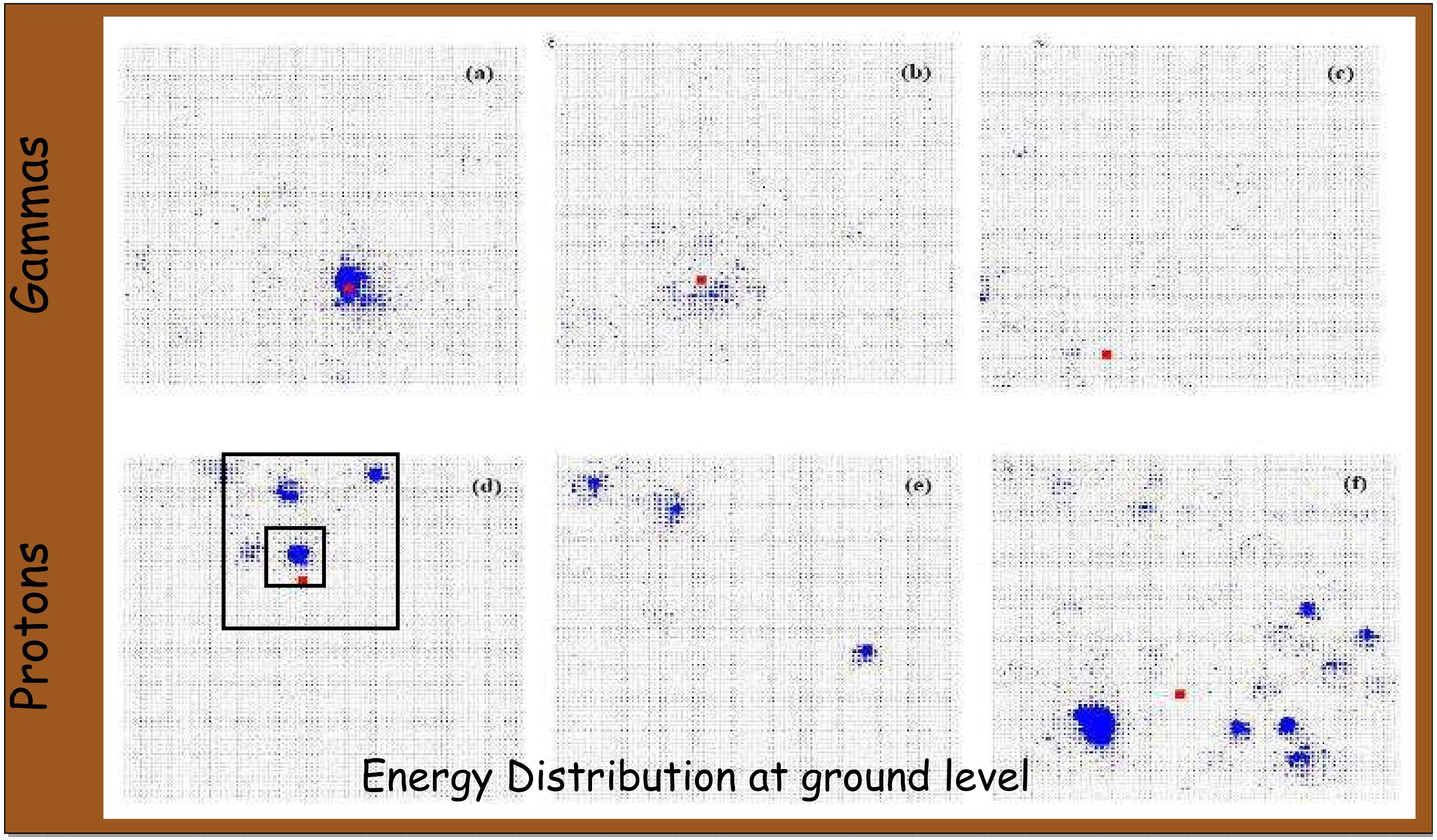
Rejection factor ~ $e^{-\langle\mu\rangle}$



Size of HAWC

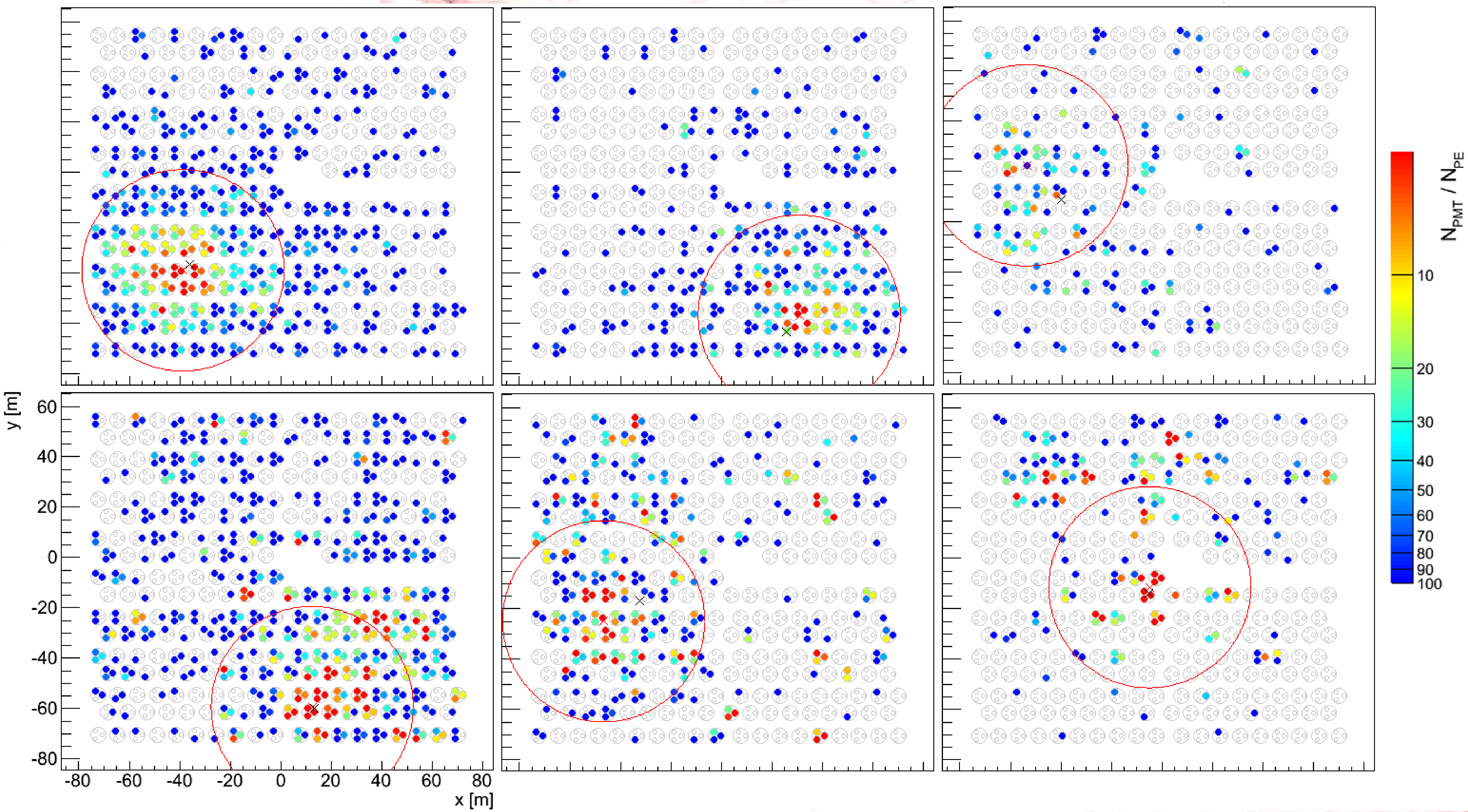


Size of Milagro deep layer

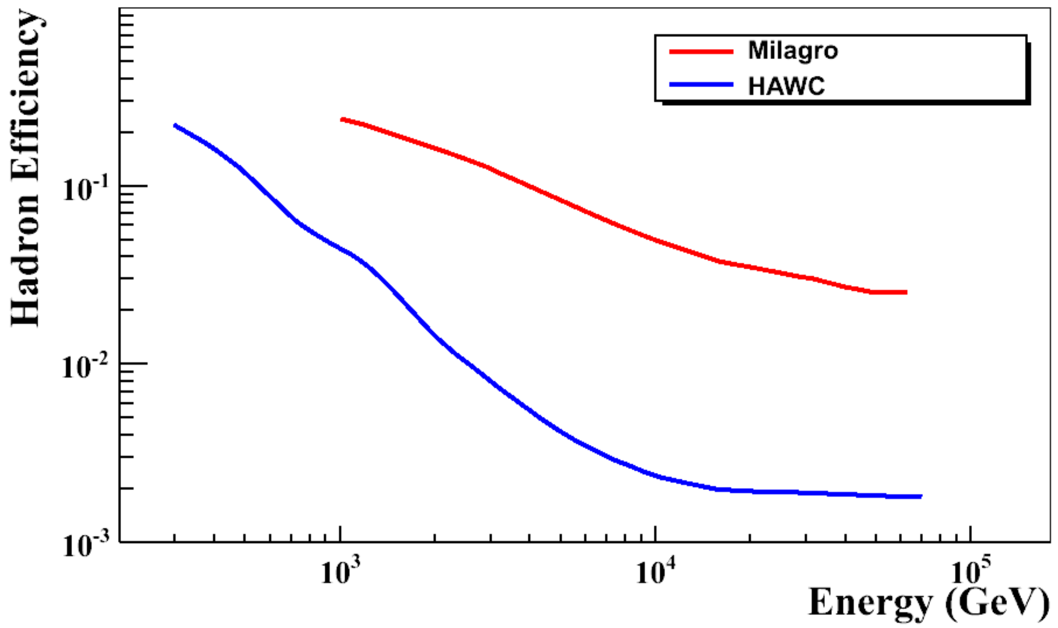


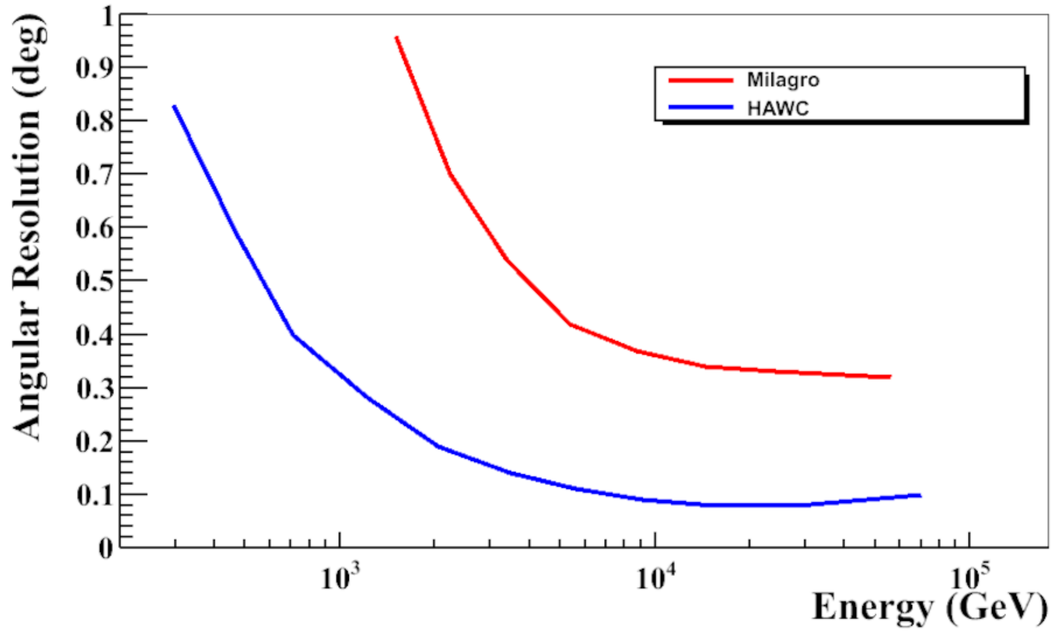
Gamma/Hadron Separation -

Hadron events are characterized by the presence of muons and large energy deposits far from the shower core.
Gamma event have large energy deposits only at the core.
Devise simple discriminant:
ntop/cxpe: ntop=number of hits, cxpe=largest hit >40m from shower core.



Gamma/Hadron Separation and Angular Resolution

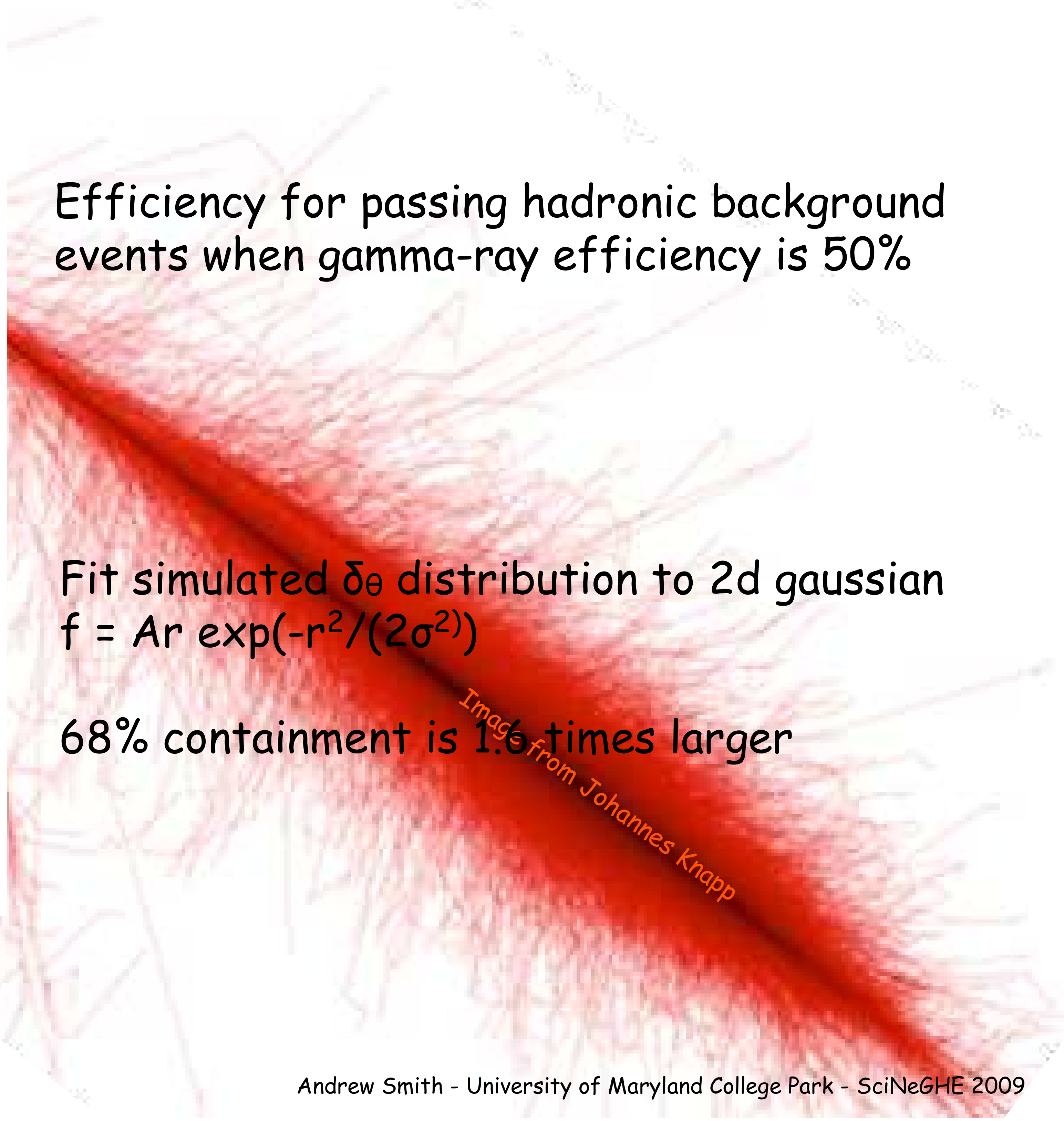




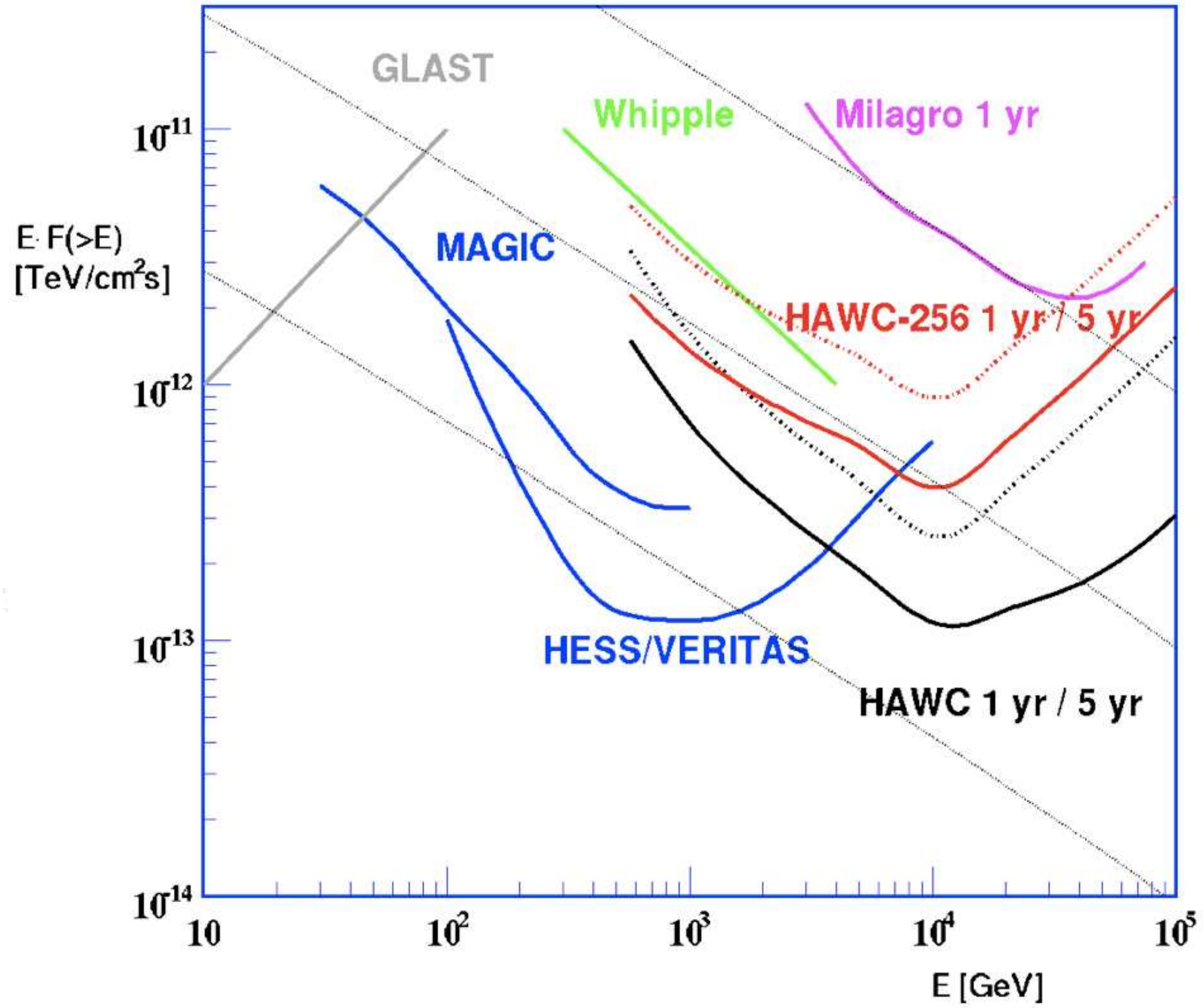
Efficiency for passing hadronic background events when gamma-ray efficiency is 50%

Fit simulated δ_θ distribution to 2d gaussian
$f = Ar\exp(-r^2/(2\sigma^2))$

68% containment is 1.6 times larger



Detector Sensitivity



1 year

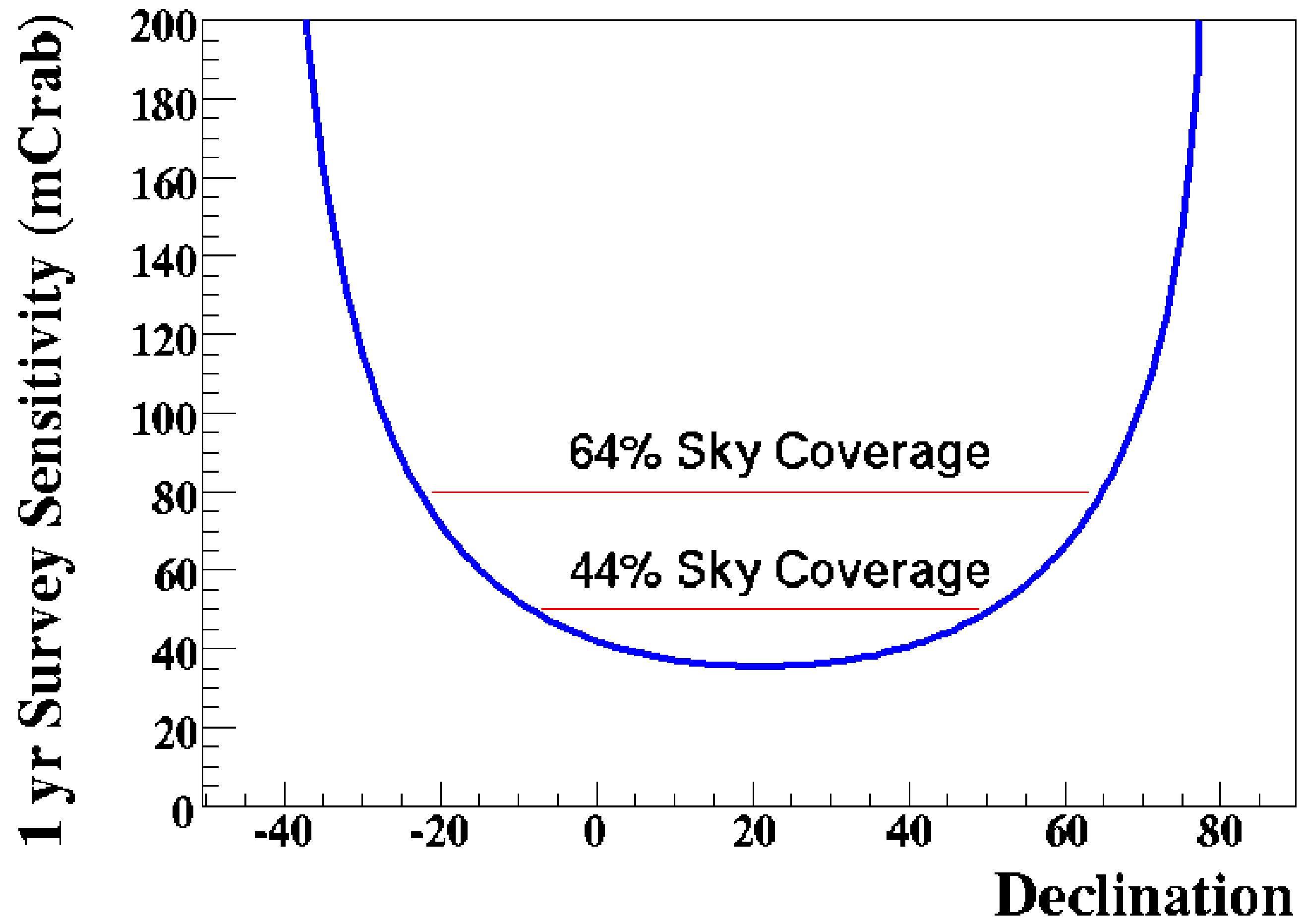


Image from Johannes Knapp

HAWC will survey the northern sky to <50 mCrab
~15 time the sensitivity of Milagro. (1 week of HAWC data ~= Entire Milagro data set)
~6 sigma/day on the Crab, 120 sigma/year
Peak sensitivity ~10x higher than ACTs. (favorable for hard spectra)

HAWC Galactic Source Sensitivity

Milagro detects many northern-hemisphere Fermi Galactic sources with a test statistic (significance in σ's) that is 2.5-5 times less than that of Fermi

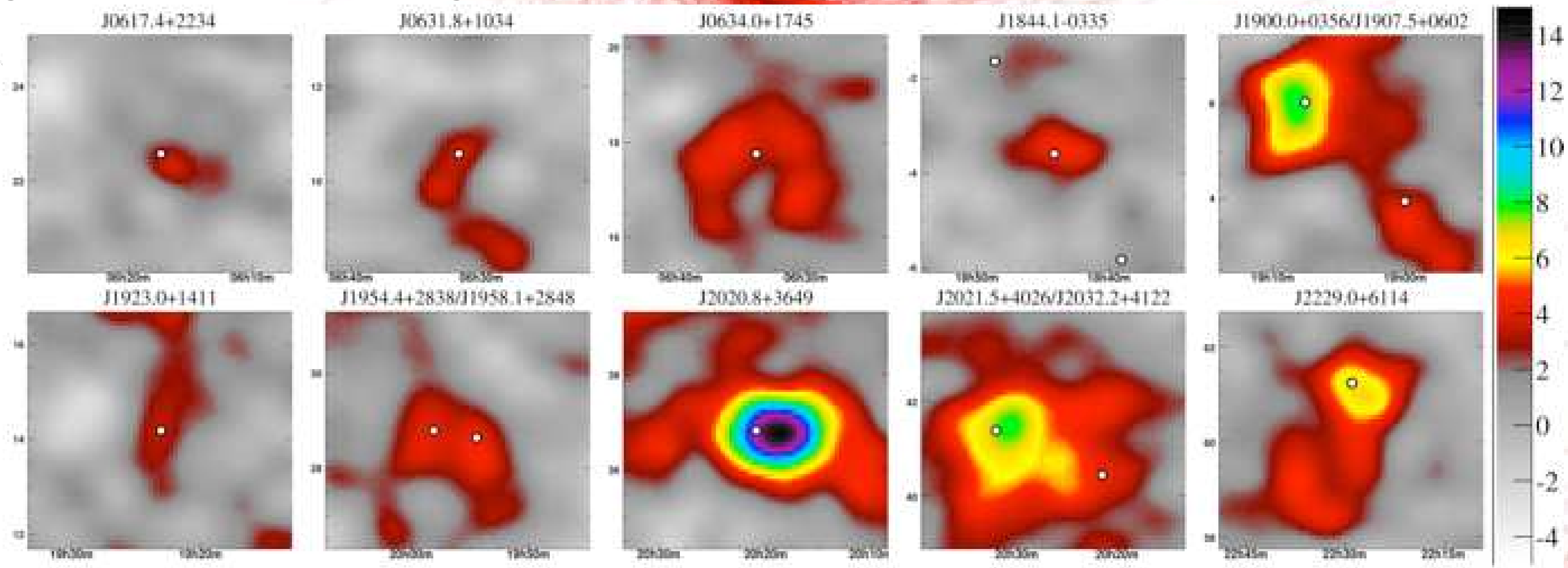
2.5-5 x signif(Milagro in 5 years) ~ signif(Fermi in 3 months)

Sensitivity time factor =sqrt(Exposure time ratio M:F) = sqrt(5/0.25) = 4.5

<u>Fermi is 11-22 x more sensitive than Milagro</u>   <u>HAWC is 15x more sensitive than Milagro</u>

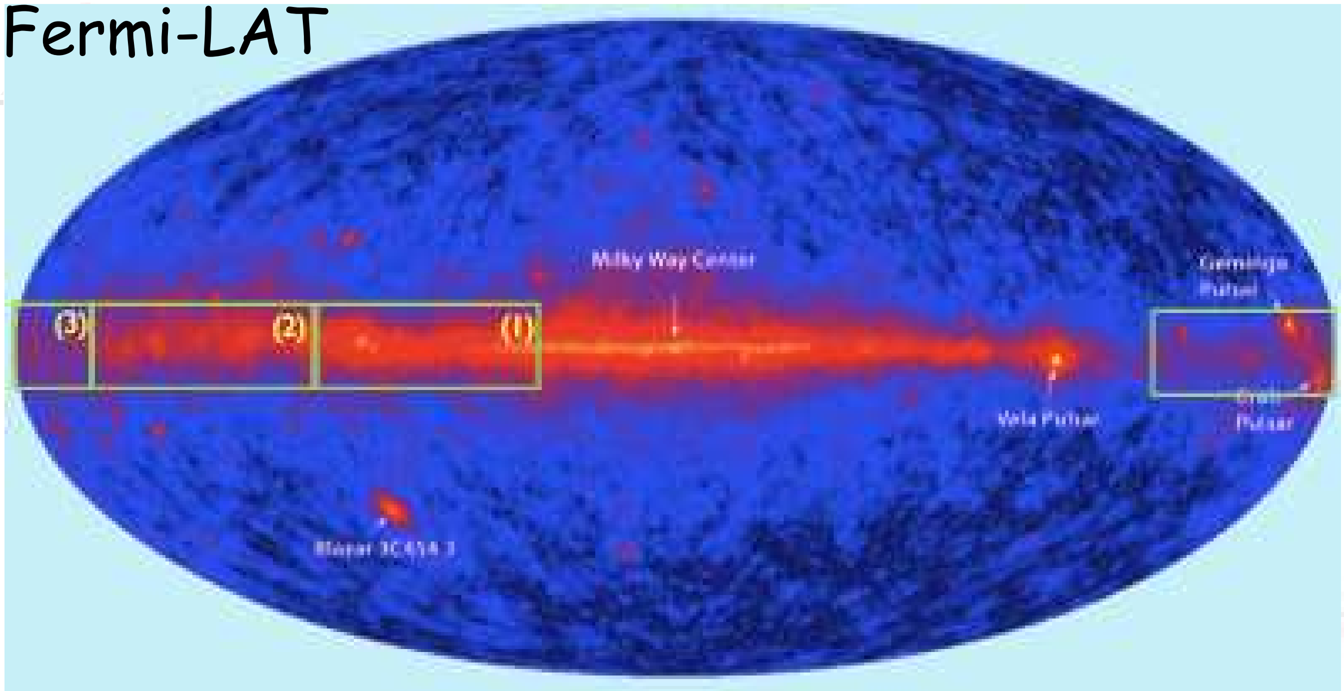
HAWC and Fermi are well matched for an important class of Galactic sources

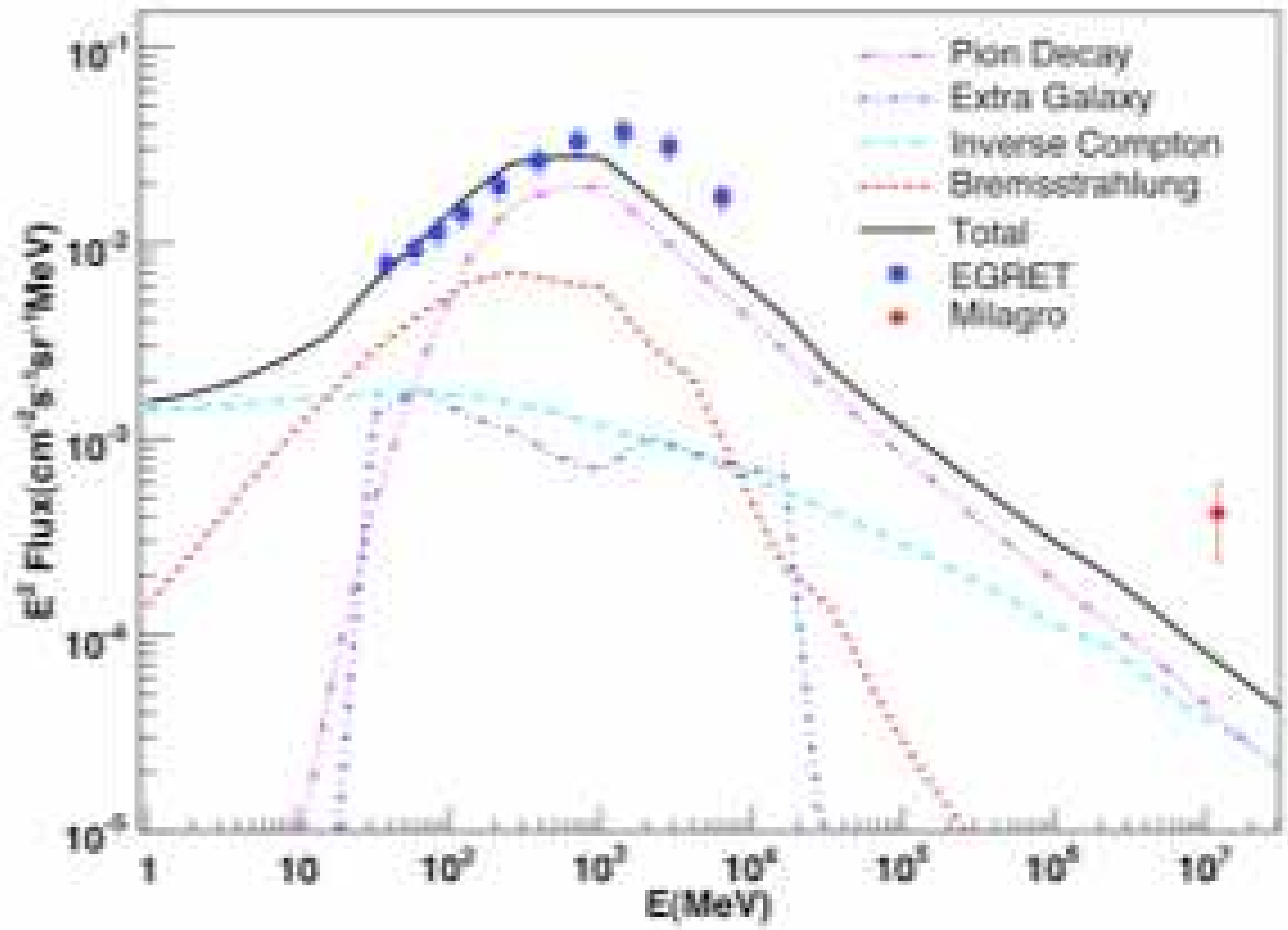
Milagro correlations with Fermi Bright Source List (BSL)

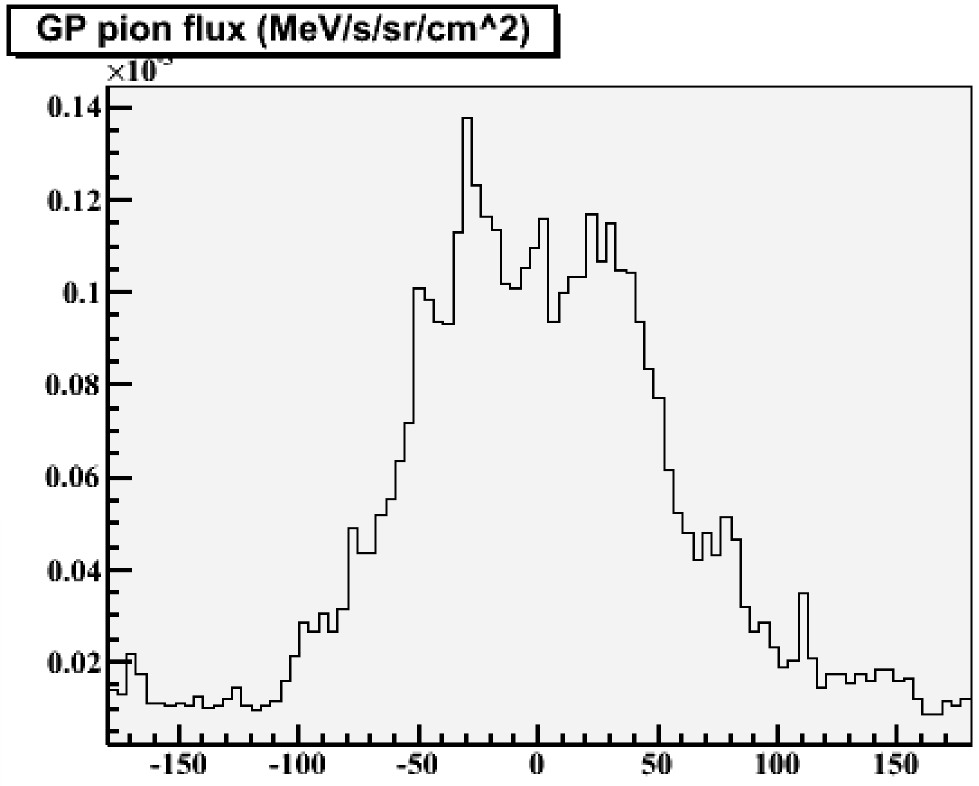


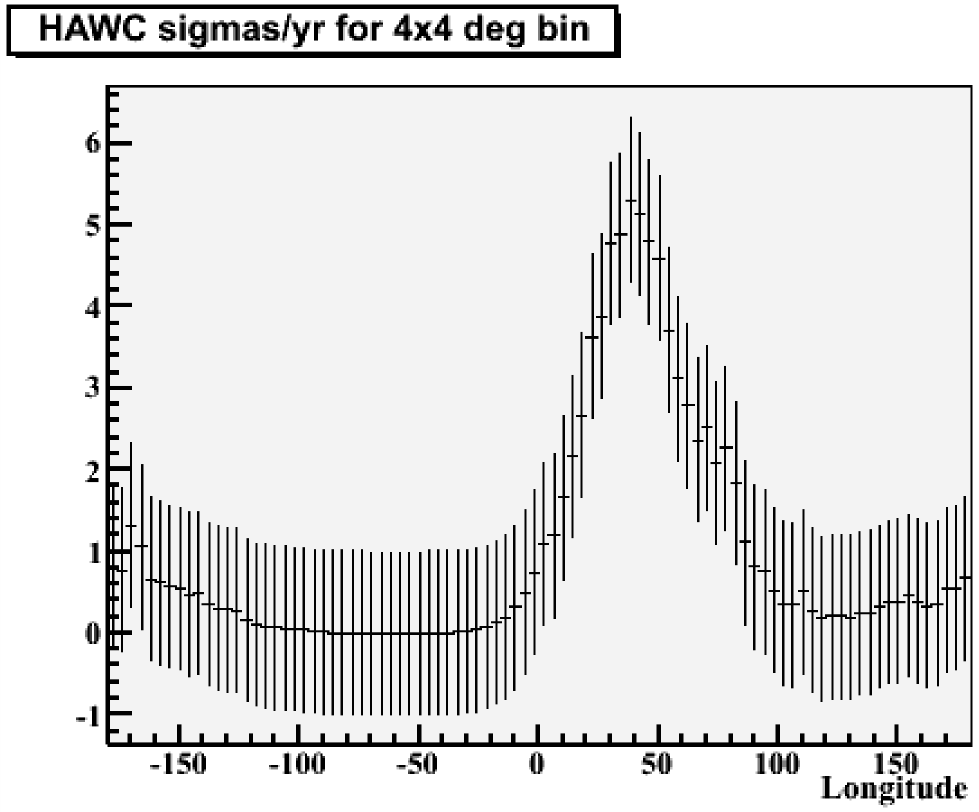
Galactic Diffuse Emission

Fermi-LAT

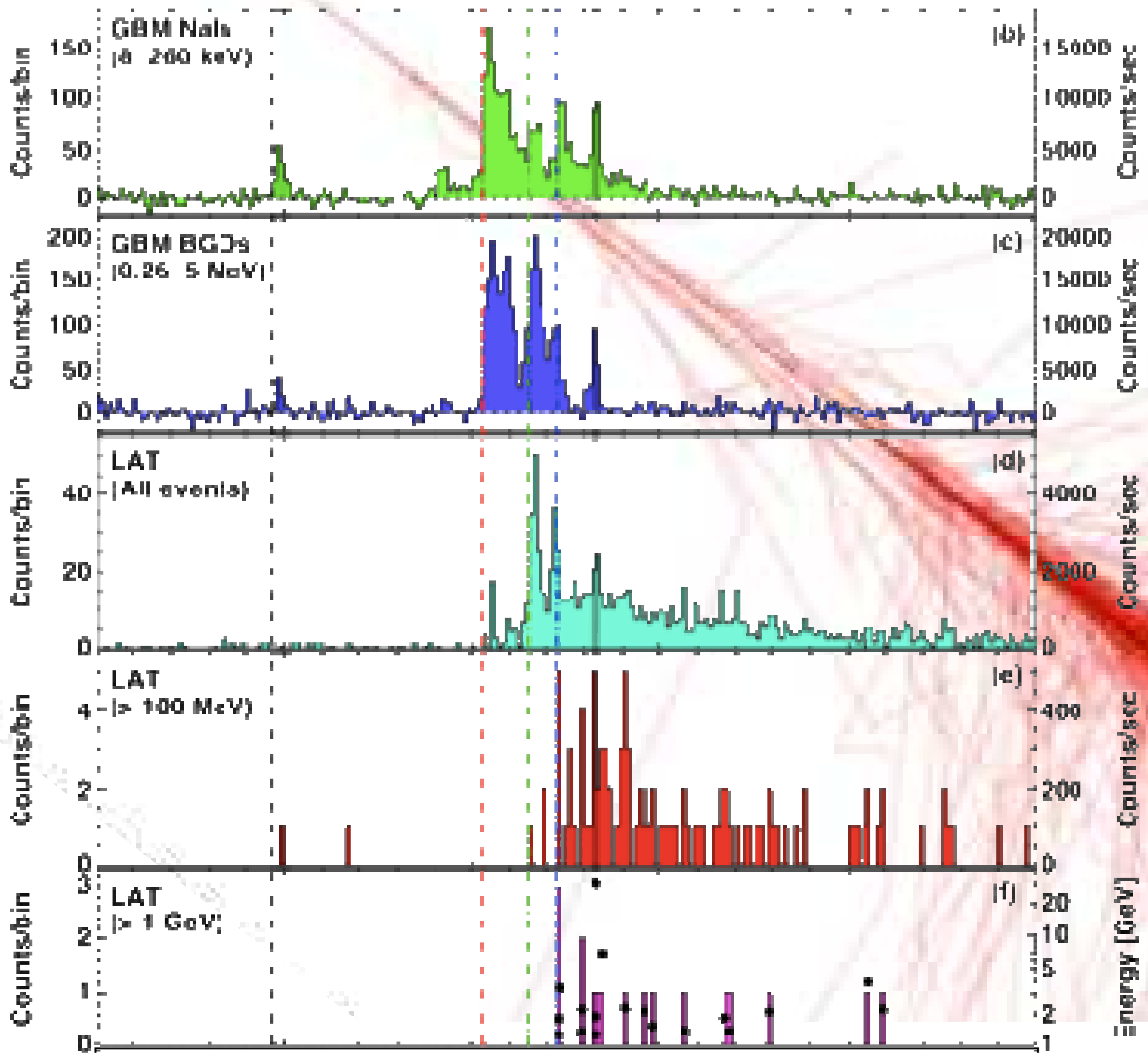




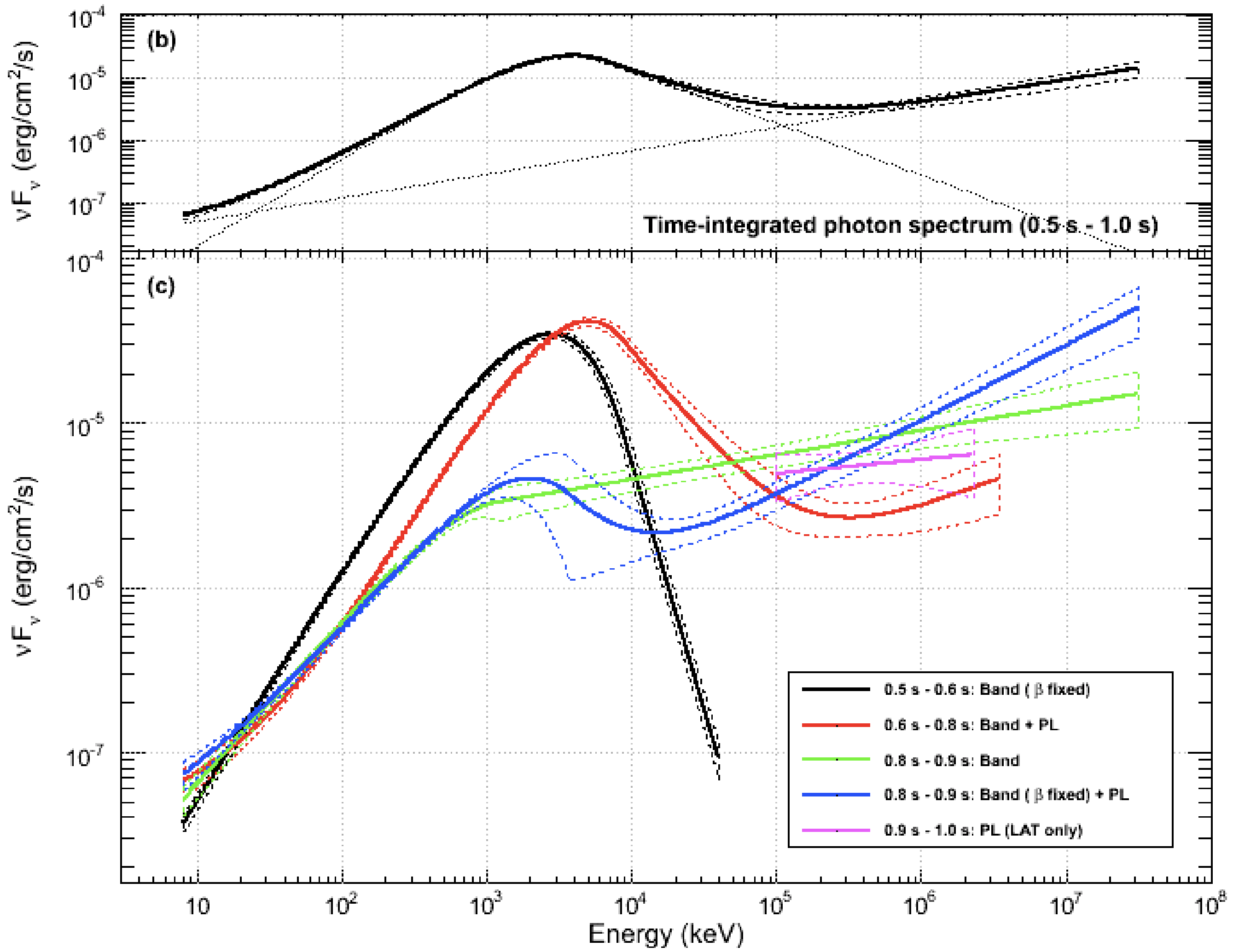




Fermi GRB090510



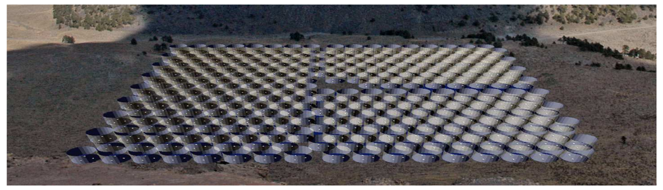
Fermi detected a GRB with a second VHE component



LAT GRB 090902 also has additional hard component

Image from Johannes Knapp

HAWC will see a 200 event excess with only a few background, even with a 125 GeV internal hard cutoff with Gilmore EBL model (Z=0.903)!



The HAWC Collaboration

- **University of Maryland:** Jordan Goodman, Andrew Smith, Greg Sullivan
- **Los Alamos National Laboratory**: Gus Sinnis, Brenda Dingus, John Pretz
- **University of Wisconsin:** Teresa Montaruli, Stefan Westerhoff, Segev BenZvi, J.A. Aguilar
- **University of Utah:** Dave Kieda
- **Univ. of California, Irvine:** Gaurang Yodh
- **Michigan State University:** Jim Linnemann, Kirsten Tollefson
- **George Mason University:** Robert Ellsworth
- **University of New Hampshire:** James Ryan
- **Pennsylvania State University**: Tyce DeYoung, Patrick Toale, Kathryne Sparks
- **University of New Mexico:** John Matthews, William Miller
- **Michigan Technical University:** Petra Hüntemeyer
- **NASA/GSFC:** Julie McEnery, Vlasios Vasileiou, Liz Hays
- **Georgia Institute of Technology:** Ignacio Taboada
- **Harvey Mudd College:** Richard Haskill, Ann Esin, Pat Little and Greg Lyzenga

USA

Instituto Nacional de Astrofísica Óptica y Electrónica (INAOE): Alberto Carramiñana, Eduardo Mendoza, Janina Nava, Luis Carrasco, William Wall, Daniel Rosa, Guillermo Tenorio Tagle, Sergey Silich

Universidad Nacional Autónoma de México (UNAM): Instituto de Astronomía: Octavio Valenzuela, V ladimir Avila-Reese, Marco Martos, Maria Magdalena Gonzalez, Sergio Mendoza, Dany Page, William Lee, Hector Hernández, Deborah Dultzin, Erika Benitez **Instituto de Física:** Arturo Menchaca, Rubén Alfaro, Varlen Grabski, Andres Sandoval, Ernesto Belmont. Arnulfo Matinez-Davalos **Instituto de Ciencias Nucleares:** Lukas Nellen, Gustavo Medina-Tanco, Juan Carlos D'Olivo **Instituto de Geofísica:** José Valdés Galicia, Alejandro Lara, Rogelio Caballero

Benemérita Universidad Autónoma de Puebla: Humberto Salazar, Arturo Fernández, Caupatitzio Ramirez, Oscar Martínez, Eduardo Moreno, Lorenzo Diaz, Alfonso Rosado,

Universidad Autónoma de Chiapas: Cesar Álvarez, Eli Santos Rodriguez, Omar Pedraza

Universidad de Guadalajara: Eduardo de la Fuente

Universidad Michoacana de San Nicolás de Hidalgo: Luis Villaseñor, Umberto Cotti, Ibrahim Torres, Juan Carlos Arteaga Velazquez

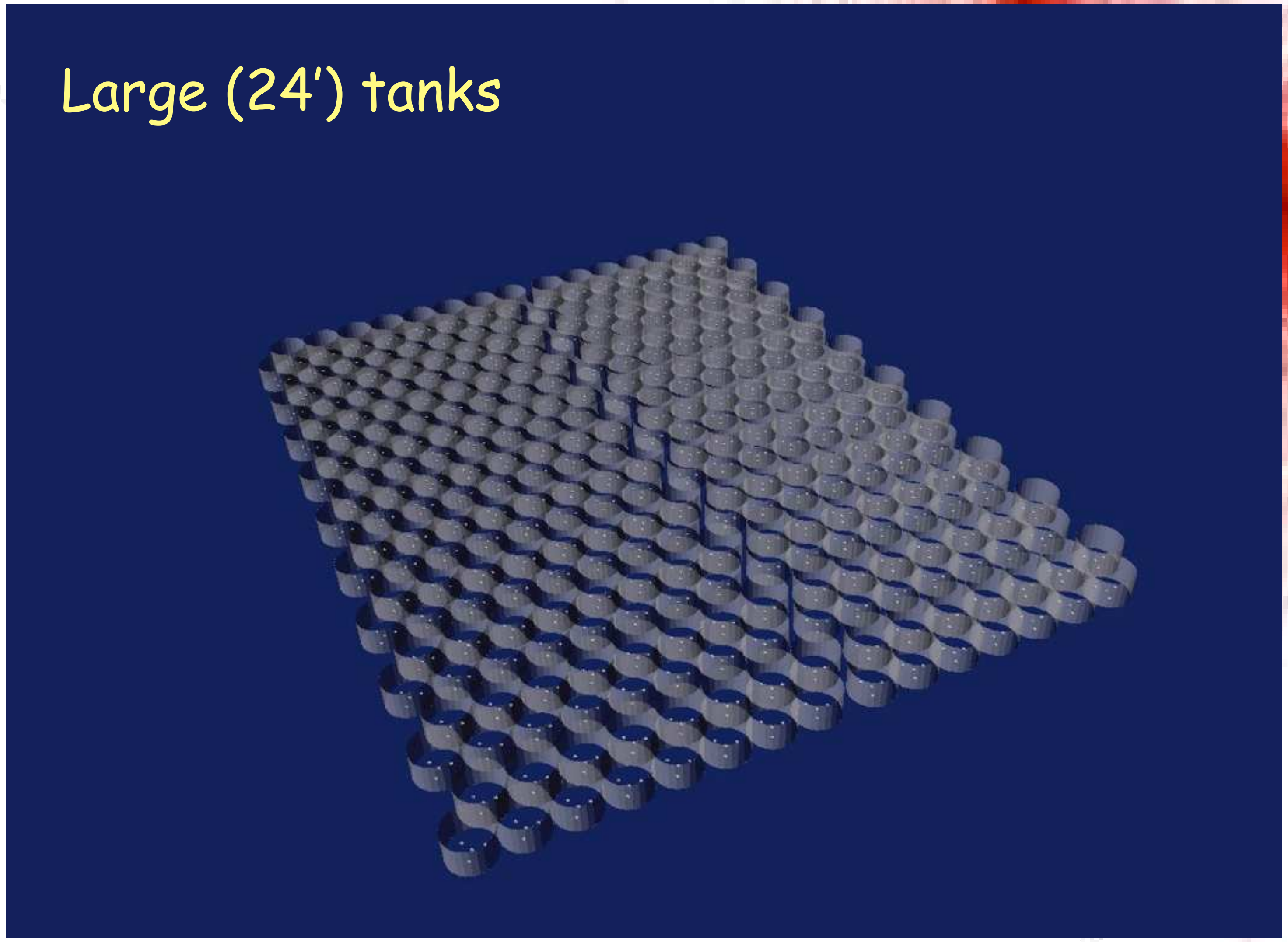
Centrode Investigacion y de Estudios Avanzados: Arnulfo Zepeda

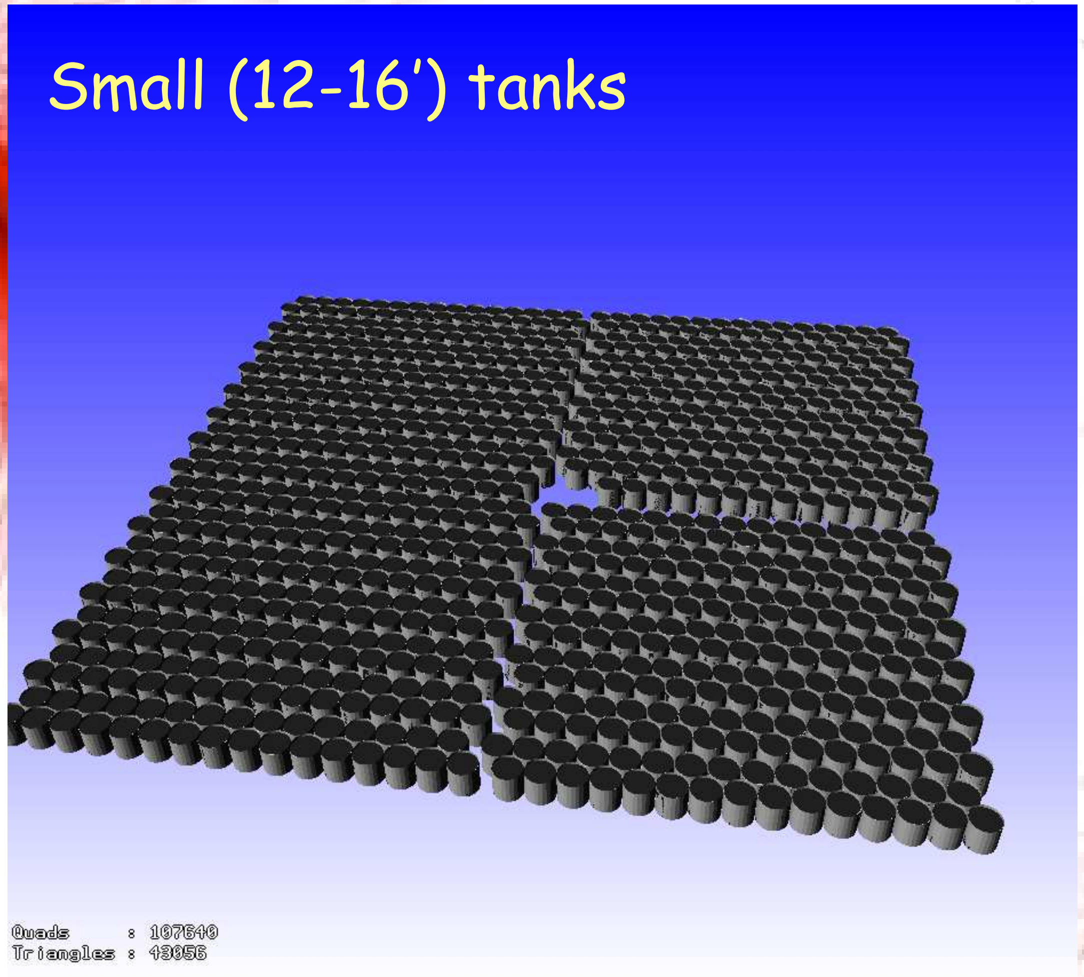
Universidad de Guanajuato: David Delepine, Gerardo Moreno, Edgar Casimiro Linares, Marco Reyes, Luis Ureña, Mauro Napsuciale, Victor Migenes

Mexico

HAWC Design concepts

The configuration largely does not matter.





Plastic Tanks -

Purchase off the shelf in sizes up to 3.6m diameter

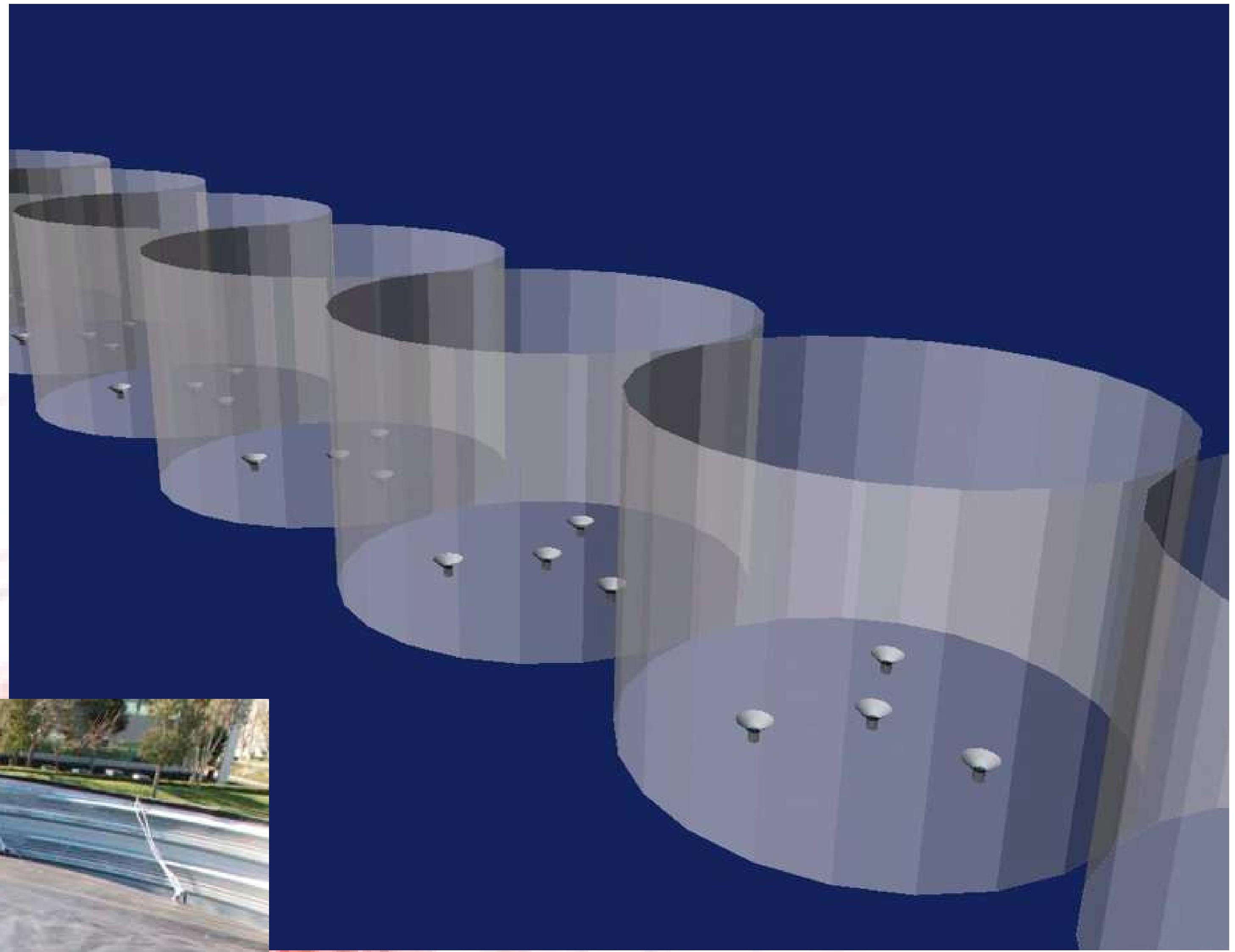
Custom molded tanks up to 5.0m diameter.

Lots of experience with plastic tanks. Milagro "outriggers"

Tank Design - Metal Spiral

Spiral construction corrugated pipe diameters up to 24′ (7.3m)

Mobile construction platform can manufacture tanks at remote site.



Metal tank provides structural support. Water is contained within a flexible bladder.

Larger tanks can accommodate multiple PMTs.

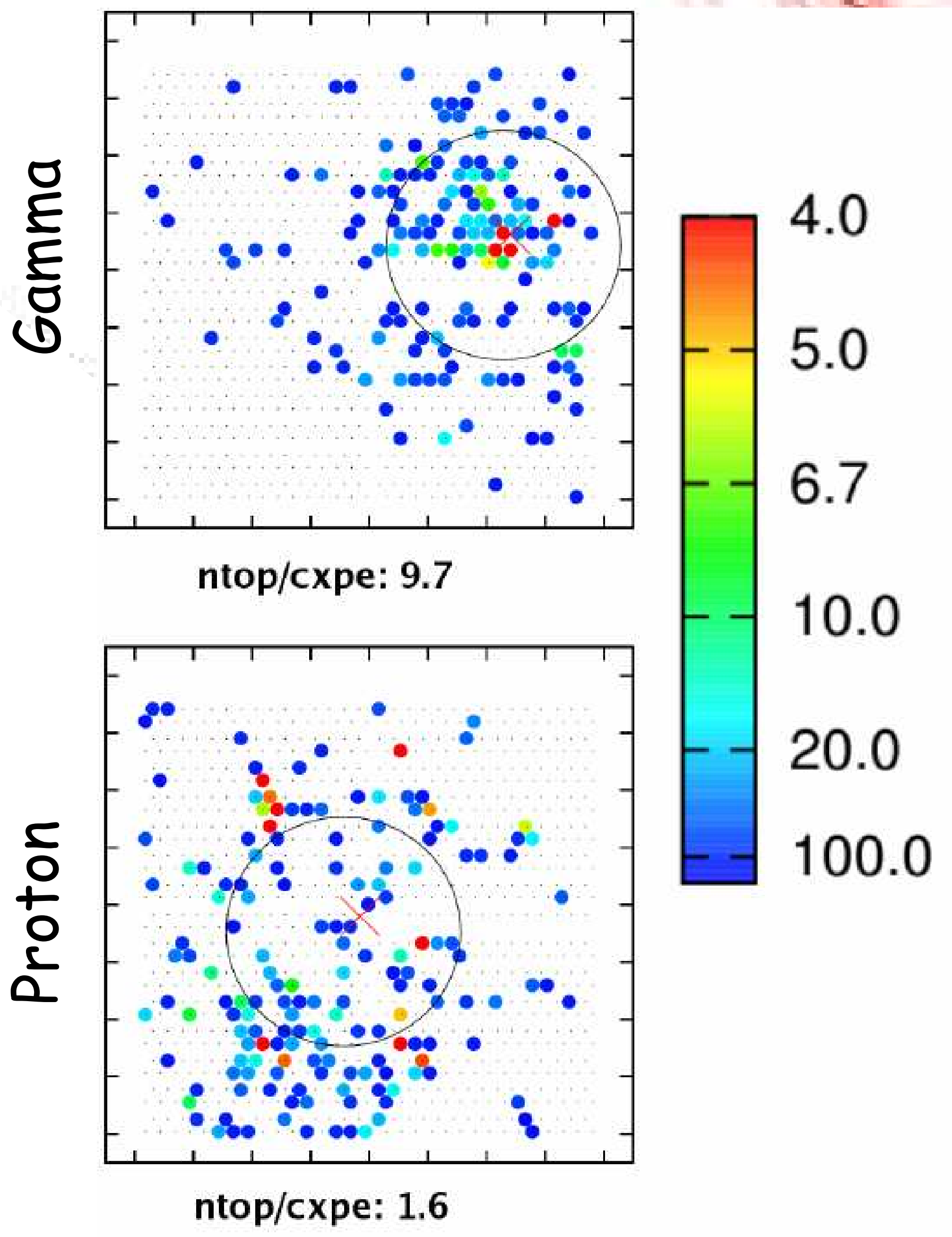
Image from Johannes Knapp

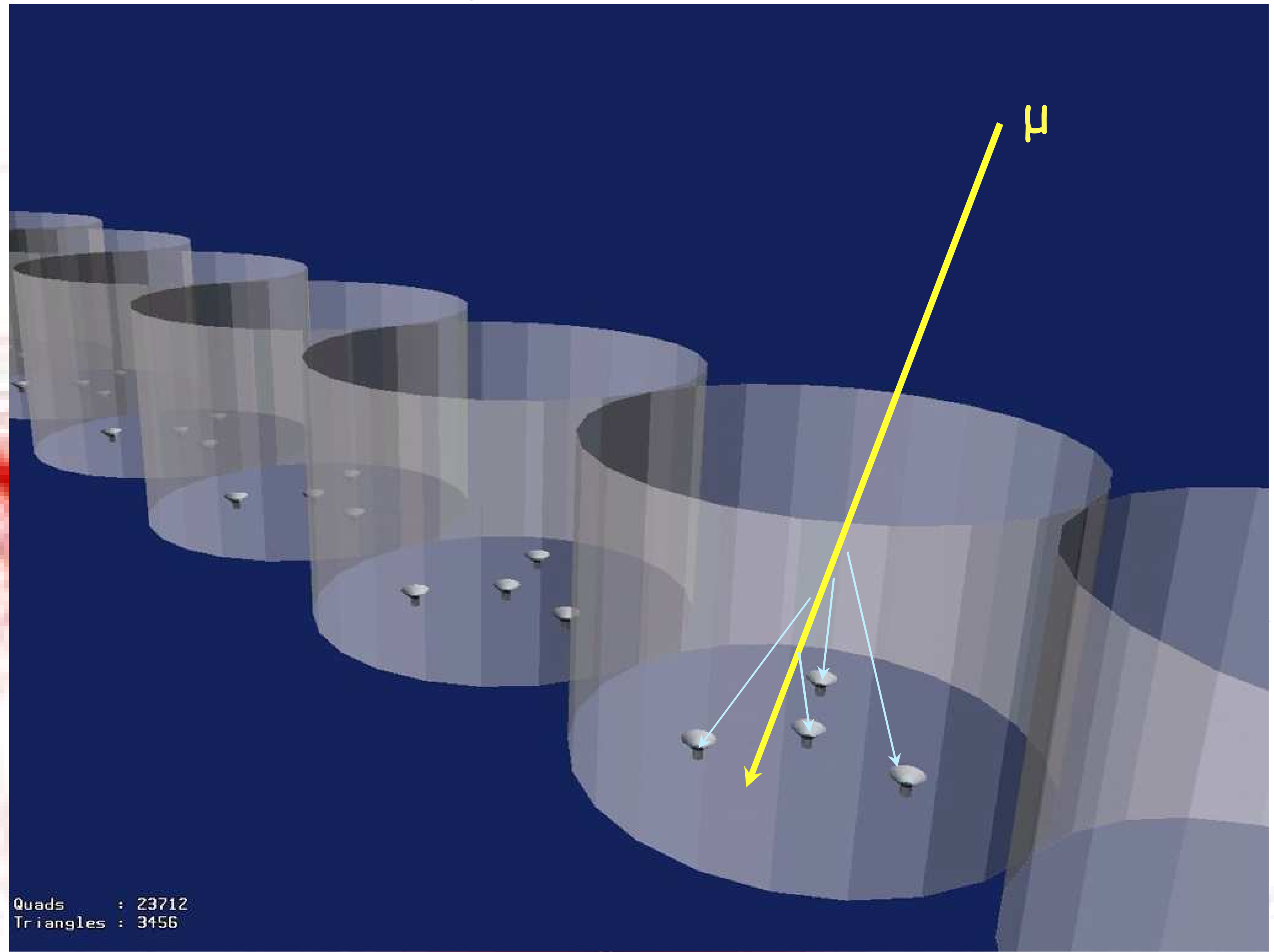
Steel Tank - Assembled

Prefabricated
Delivered in easily shippable containers
Bladder/metal structure from same vendor

Single Tank Muon Reconstruction -

With multiple PMTs in large tanks, reconstruction of individual thru-going muons is possible.





Record 4 pulse amplitudes and 4 times, 8 measurements. Perform 3 parameter fit to single muon track hypothesis.

Search for muon signatures near low energy cores.

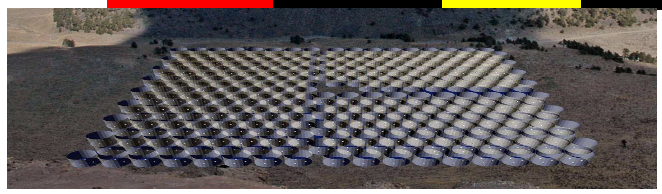
Conclusion/Status

- Development MRI from
- NSF + Support from
- Mexico/Maryland
  - Total $850k
  - Site Development
  - Tank Development
  - Electronics Development

- Constructed development array near HAWC site (protoHAWC).
- Final approval for site in hand.

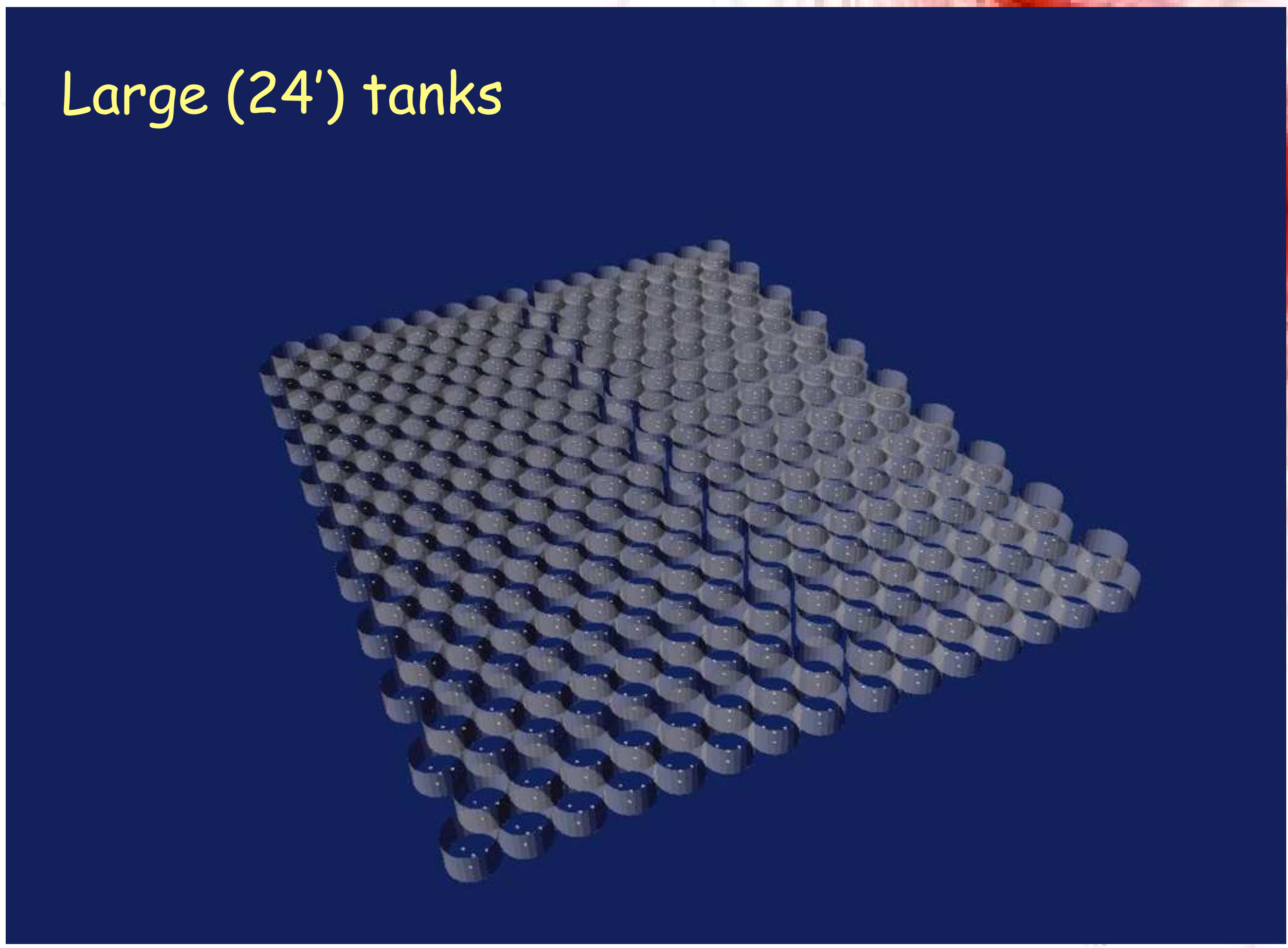
Image from Johannes Knapp

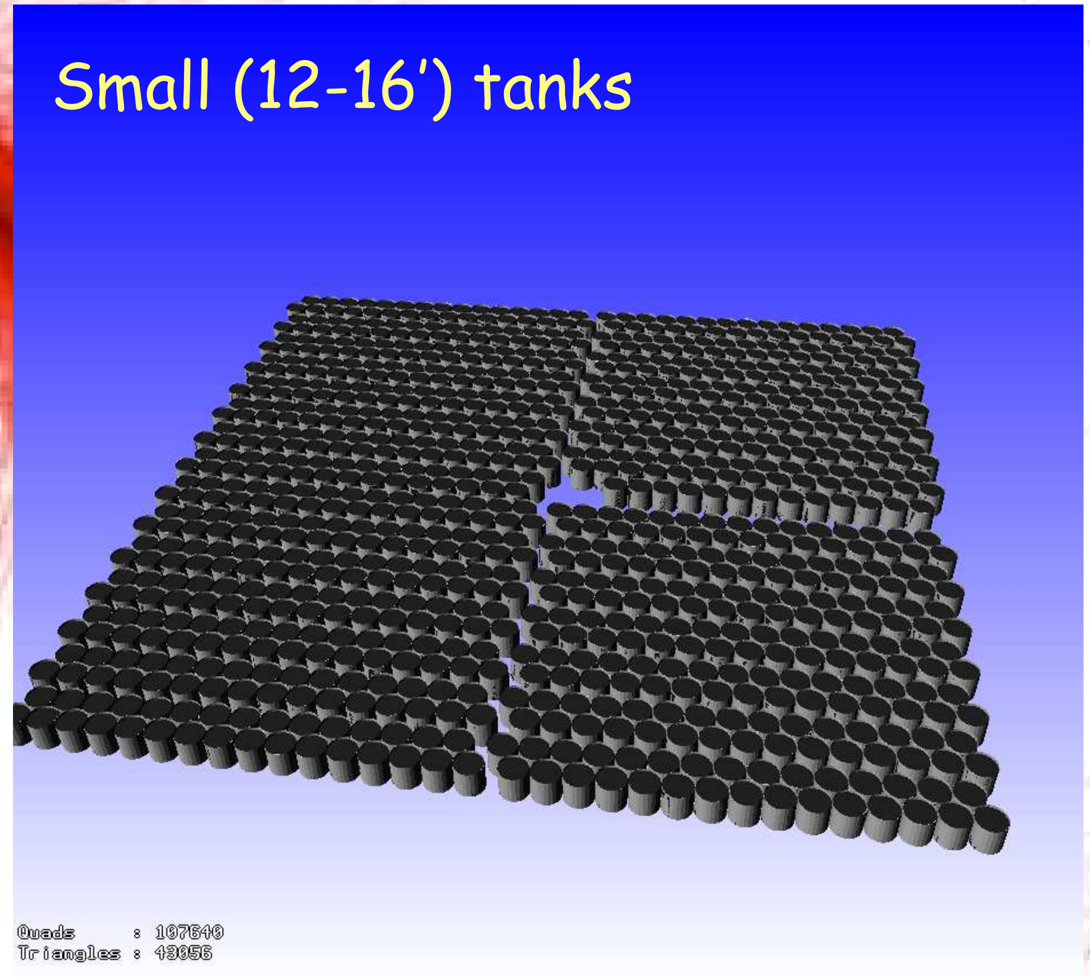
Tank Design – steel pipe with bag



HAWC Design concepts

The configuration largely does not matter.





Plastic Tanks -

Purchase off the shelf in sizes up to 3.6m diameter

Custom molded tanks up to 5.0m diameter.

Lots of experience with plastic tanks.
Milagro "outriggers"

Tank Design – steel pipe with bag

Commercial Water Storage Tanks

Full Scale Prototype Tank

Upgrade Electronics

Reuse Milagro -
- PMTs
- Bases
- Encapsulations
- Front-End Electronics

Replace -
- TDCs - CAEN multihit
- Trigger - FPGA for fast logic

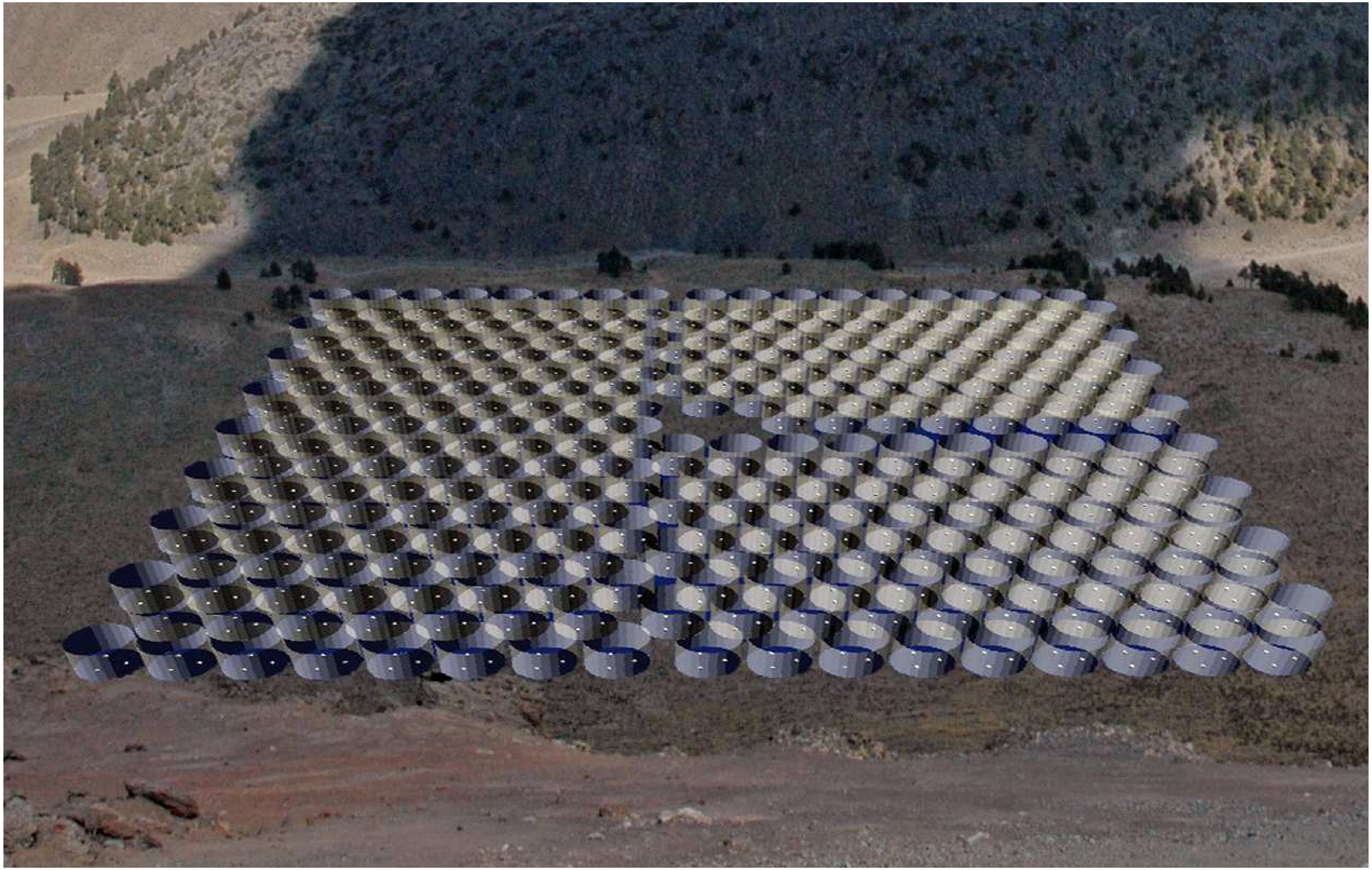
Rates -
- 15-20kHz trigger rate (30 PMT threshold)
- ~10-20MB/s raw data rate

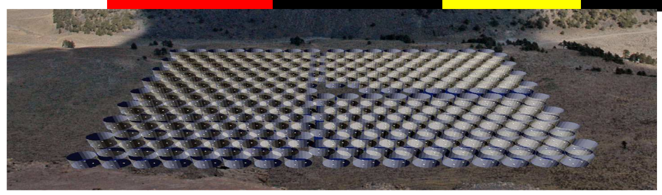
Image from Johannes Knapp

Sierra Negra Mexico Site

- 4100 m elevation
- Latitude of 19 deg N
- Easy Access
- Existing Infrastructure & Excellent Mexican Collaborators

HAWC Site - Sierra Negra Mexico





HAWC Collaboration

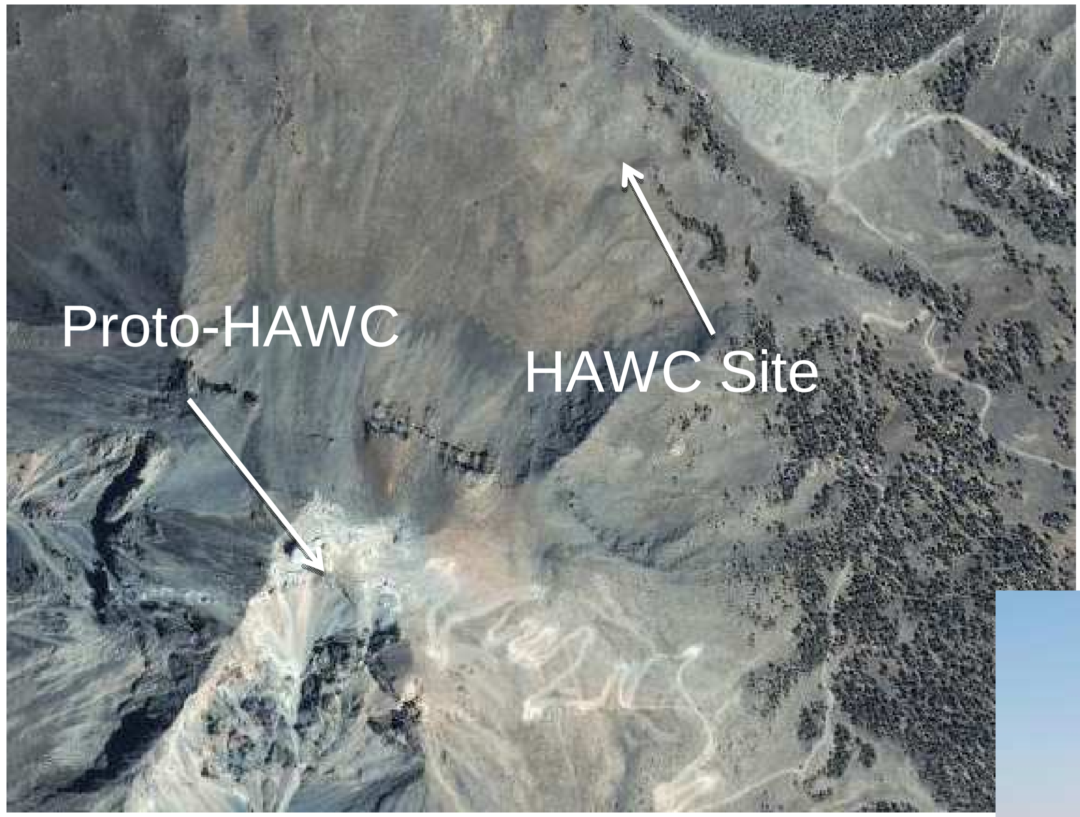
July 2009

Existing Infrastructure - Mexico

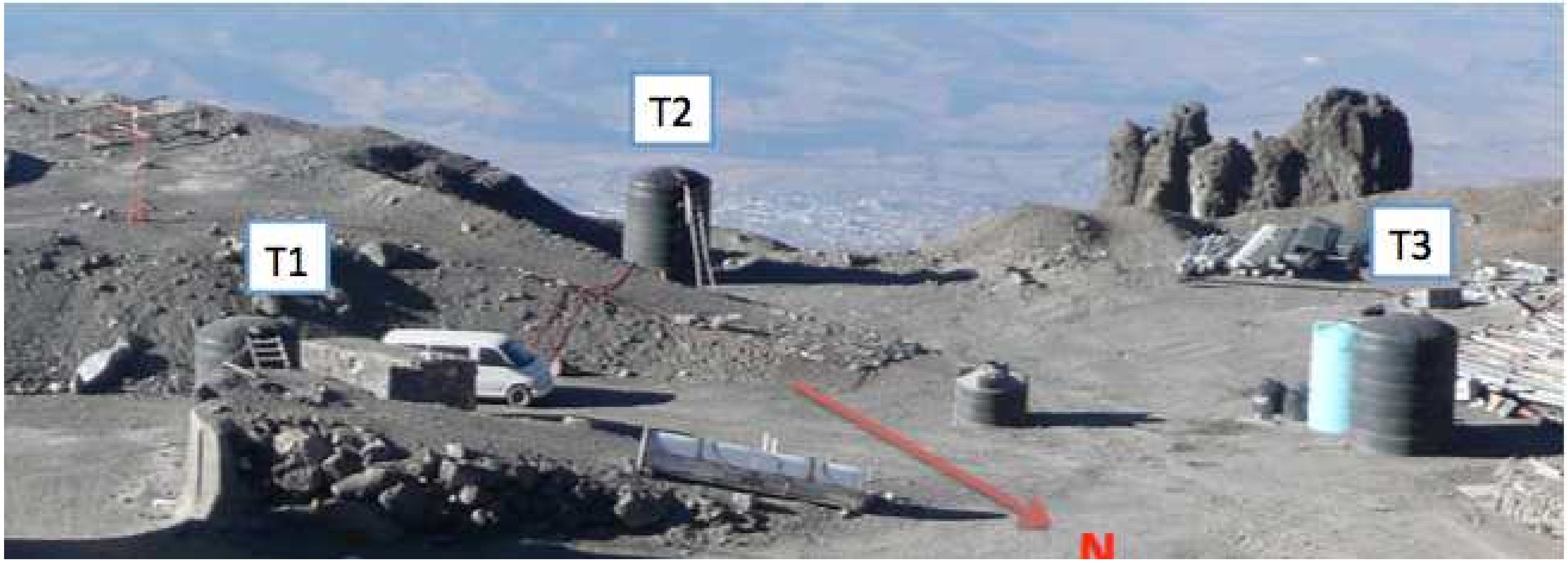
- LMT - Large Millimeter Telescope
- Provides foundational infrastrucure
- "Sierra Negra Consortium" formed to support many projects

HAWC Road

Proto-HAWC



- Test array at the LMT site
- 3 - 3.0–meter black plastic water tanks at the LMT site (4530 meters)
- Built by our Mexican Colleagues
- Study rates etc.


T2
T1
T3
N

Conclusions...

- HAWC can complement Fermi and ACTs
•High Sensitivity Survey, Energy spectra to 100 TeV scale
•Diffuse Emission
•CR anisotropy
•GRBs, AGN and other Transients

- HAWC can be built fast (3 years) and can take data prior to completion and in conjunction with Fermi.
- Status: Waiting for report from "Particle Astrophysics Scientific Assessment Group (PASAG), due Oct 23.

Milestones (assuming NSF approval by Jan. 2010)	Date
Road to the Site. Power to the Site. Temporary Electronics Trailer delivered to the site. (using MRI funding)	January 2010
Deployment and shakedown operation of the first 6 tanks	June 2010
30 Tank/90 Channel array deployed.	Oct 2010
100 Tank/300 Channel array deployed.	Oct 2011
Physics running with 100 Tanks.	Dec 2011
300 Tank/900 Channel array deployed/operational	Jan 2013

Why Now? What's the Rush?

- The idea is:
- We have the *people* and a *site* so that we can rebuild Milagro at high altitude, in a different configuration quickly and inexpensively by reusing exiting parts and Milagro developed technology.
- We can build a detector more than an order of magnitude more sensitive than Milagro.
- We can maximize the science impact by getting it running quickly, so that it can operate coincidentally with Fermi, Veritas, LIGO and IceCube.