CCAPP Symposium 2011
Columbus, Ohio, US
April 4-6, 2011

Prospects for GRB detection and other measurements with the HAWC observatory

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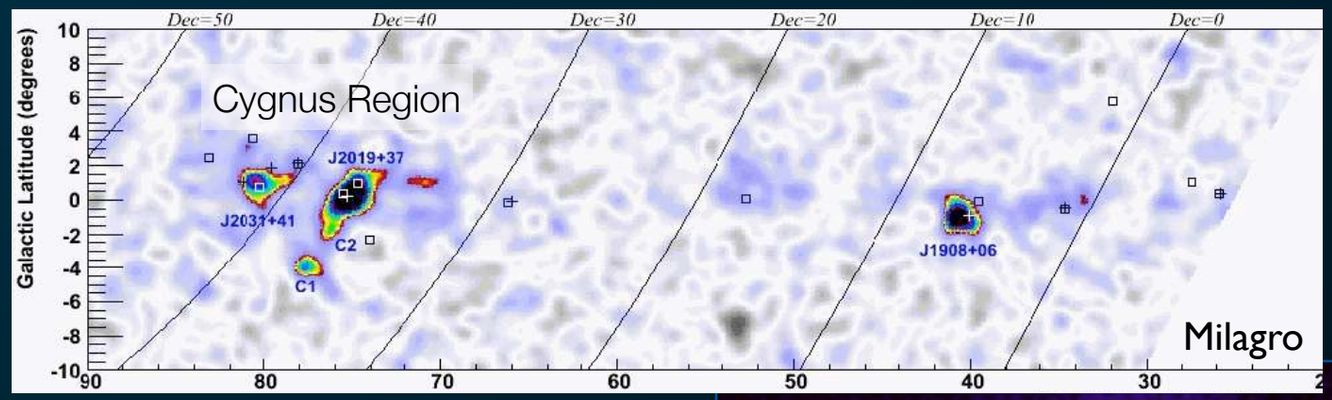
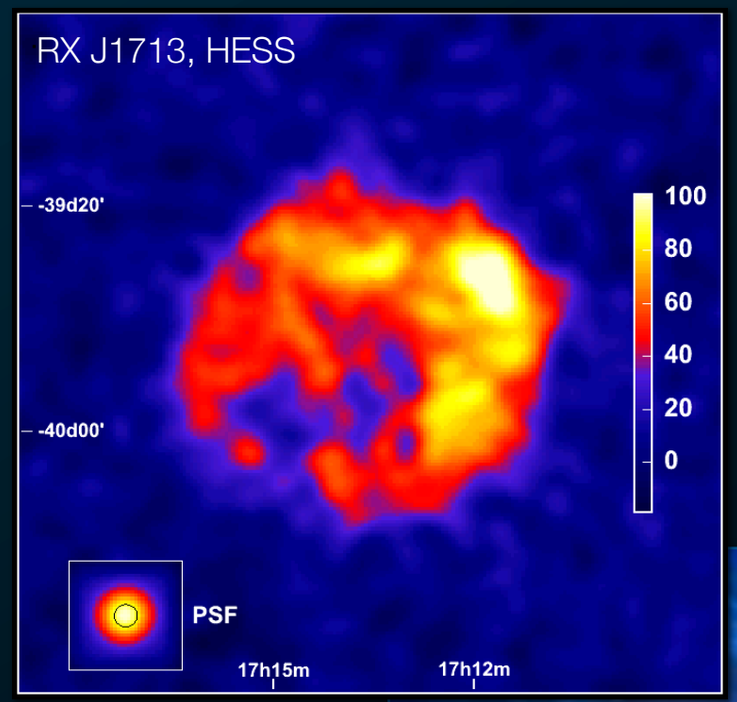
for the HAWC collaboration

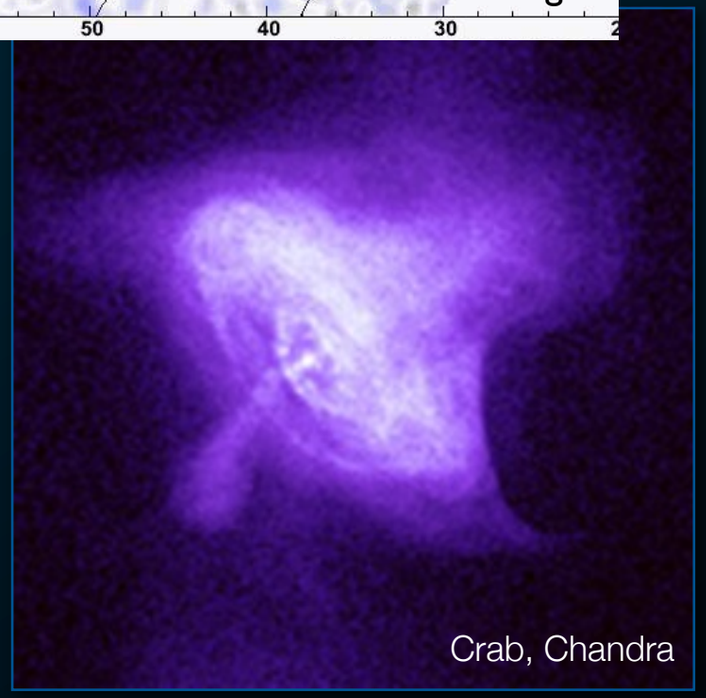
- Brief introduction to HAWC
- Sensitivity to steady sources
- Sensitivity to gamma ray bursts

Physics objectives

- Diffuse emission from galactic plane, extended sources (Cygnus, Fermi bubbles?)
- Galactic point sources (SNR, PWN)
- AGN and AGN flares
- GRB



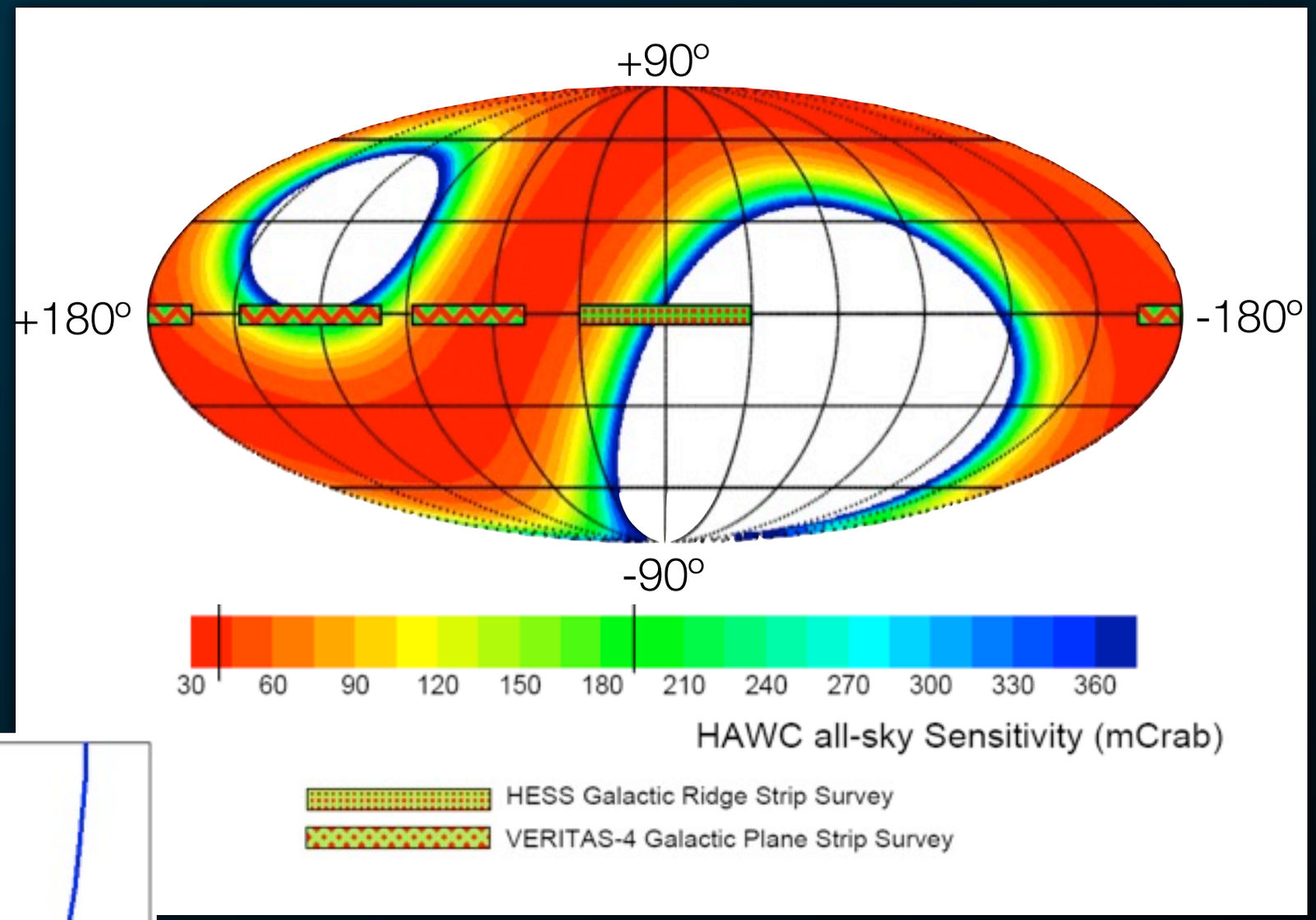


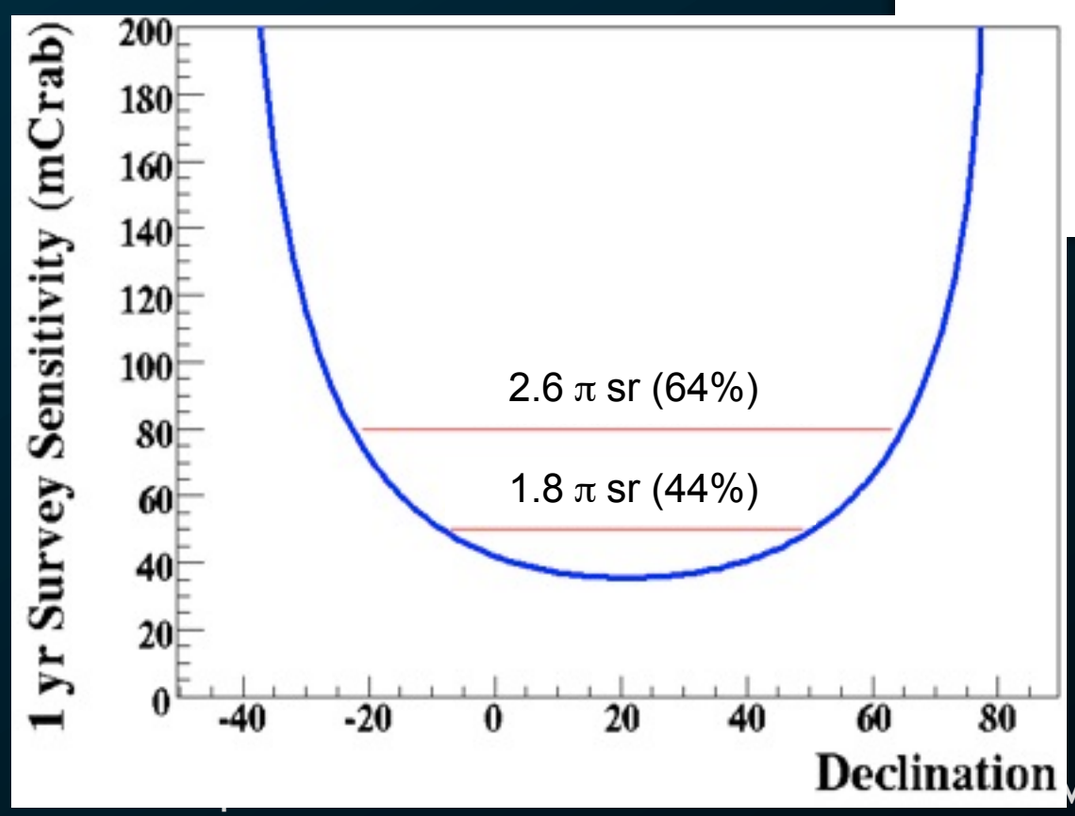


Observable sky

Wide field of view provides several advantages:

- Survey of a large fraction of the sky (look for the unknown)
- Measure the highest energy emission from astronomical objects
- Observe larger objects (nearby supernova remnants & pulsar wind nebulae, Galactic disk)
- Observe transient events (gamma ray bursts, flares from active galactic nuclei)





Wide field of view
limited by atmospheric depth
45° from zenith (Milagro standard analysis)
50 mCrab survey in 1 yr

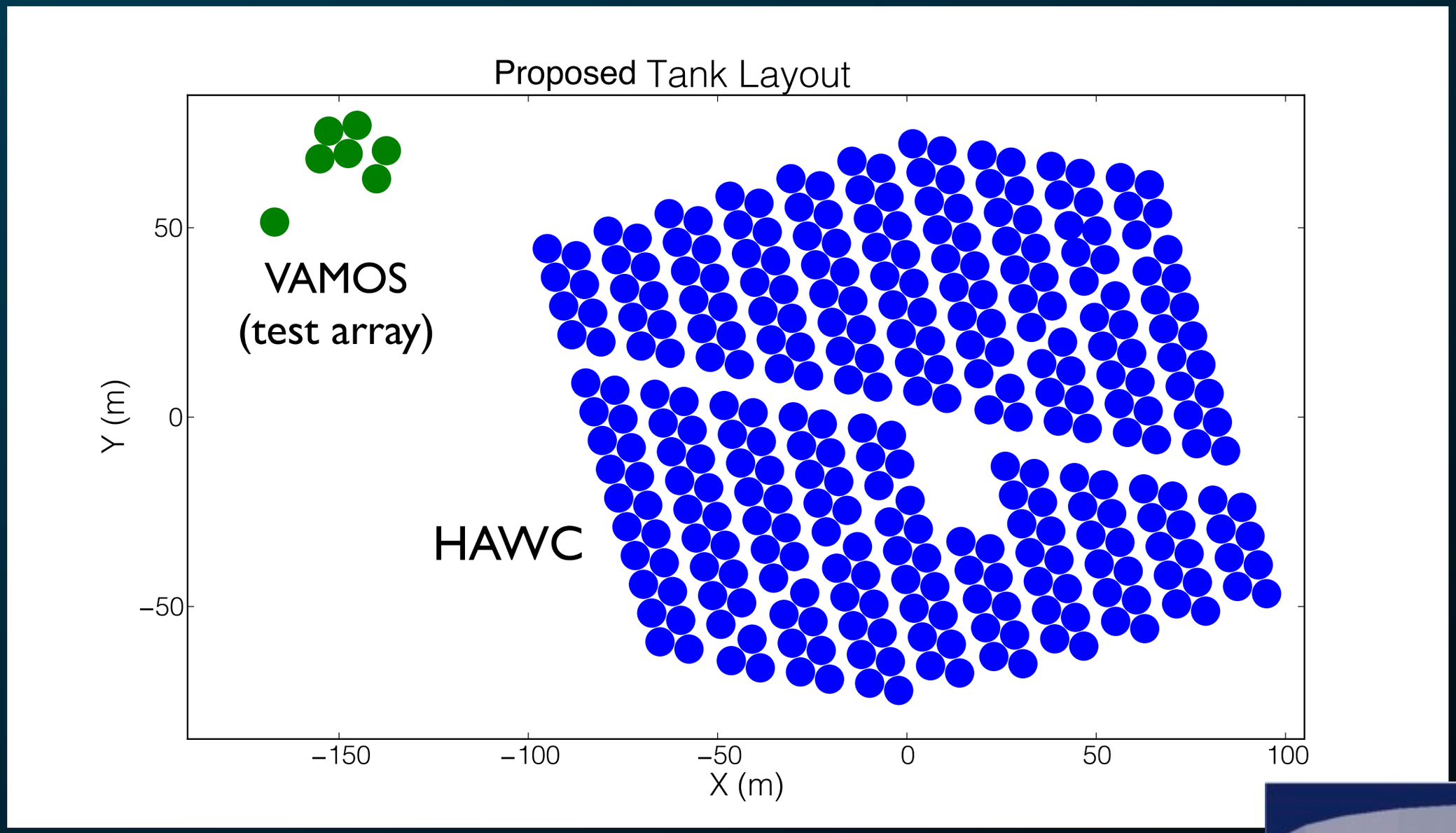
HAWC - High Altitude Water Cherenkov Observatory

(artists view)

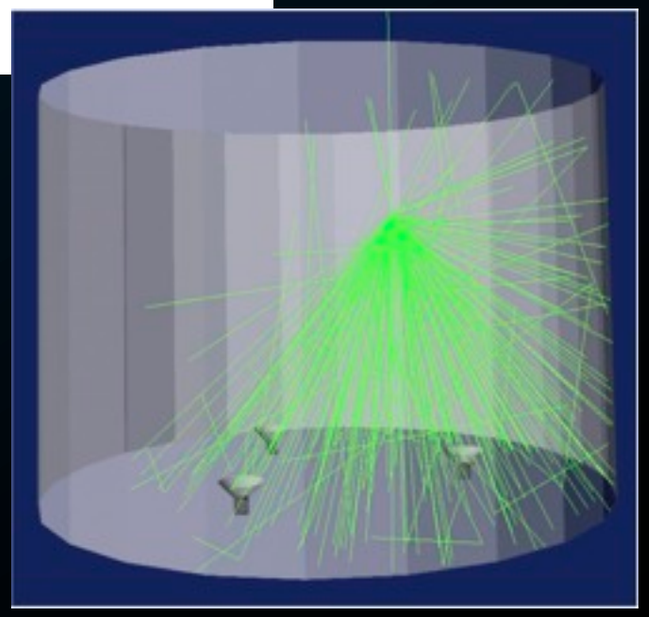
- Direct detection of gamma-induced atmospheric showers
- Successor of Milagro
- Under construction in Mexico
- Collaboration of ~100 scientists from US & Mexico

Pico de Orizaba, altitude 4100 m, latitude 18° 59' N
Two hours drive from Puebla, four from México City
Also site of Large Millimeter Telescope

Detector layout



300 water Cherenkov detectors, 7.3 m diameter x 4.5 m tall,
200,000 liters of water, 3 upward looking 8" PMTs per tank,
~20,000 m^2 area, >60% active Cherenkov volume



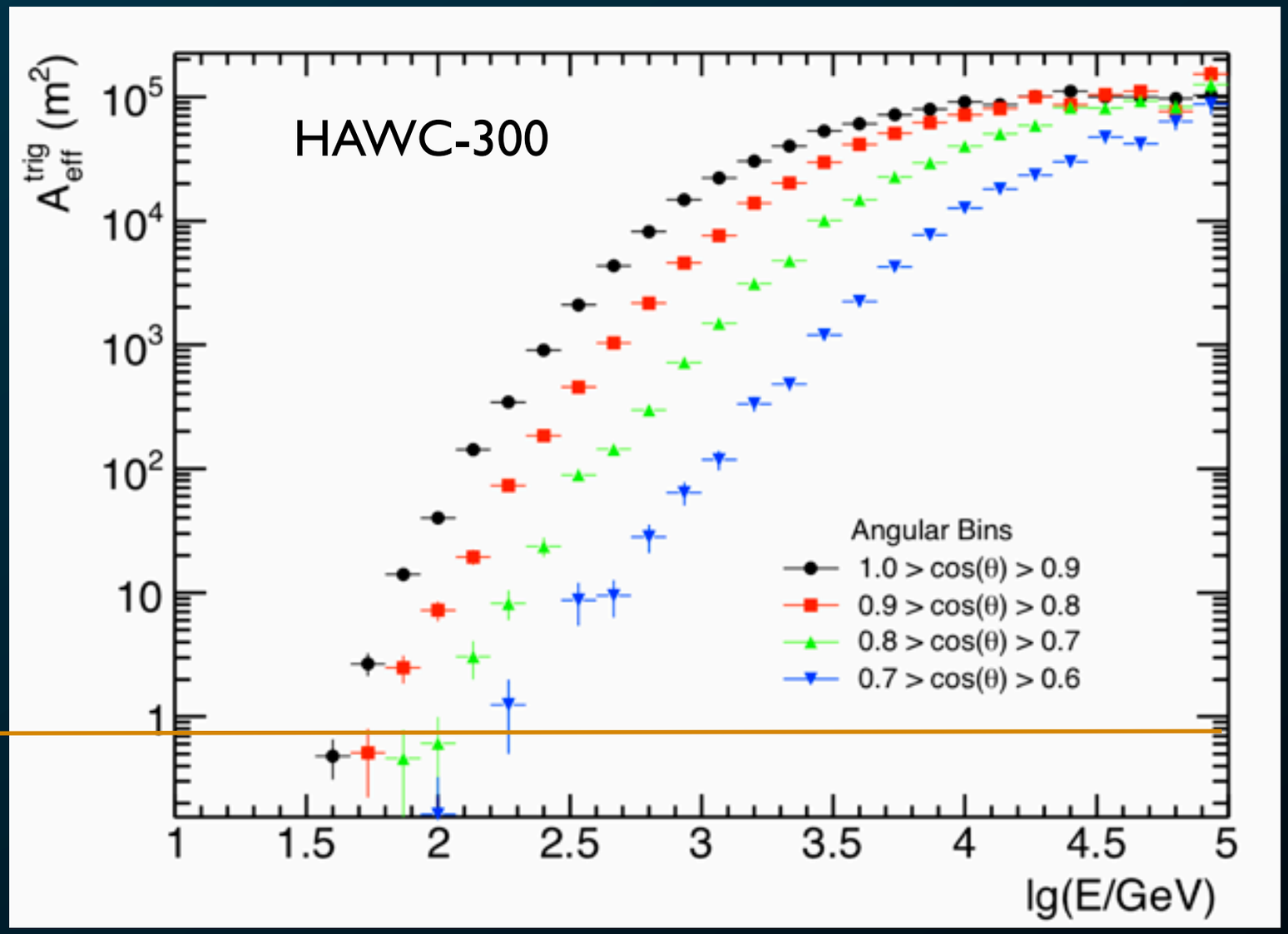
Energy threshold and effective area

Nhit > 70

Angular error < 1°

No hadron rejection cut applied

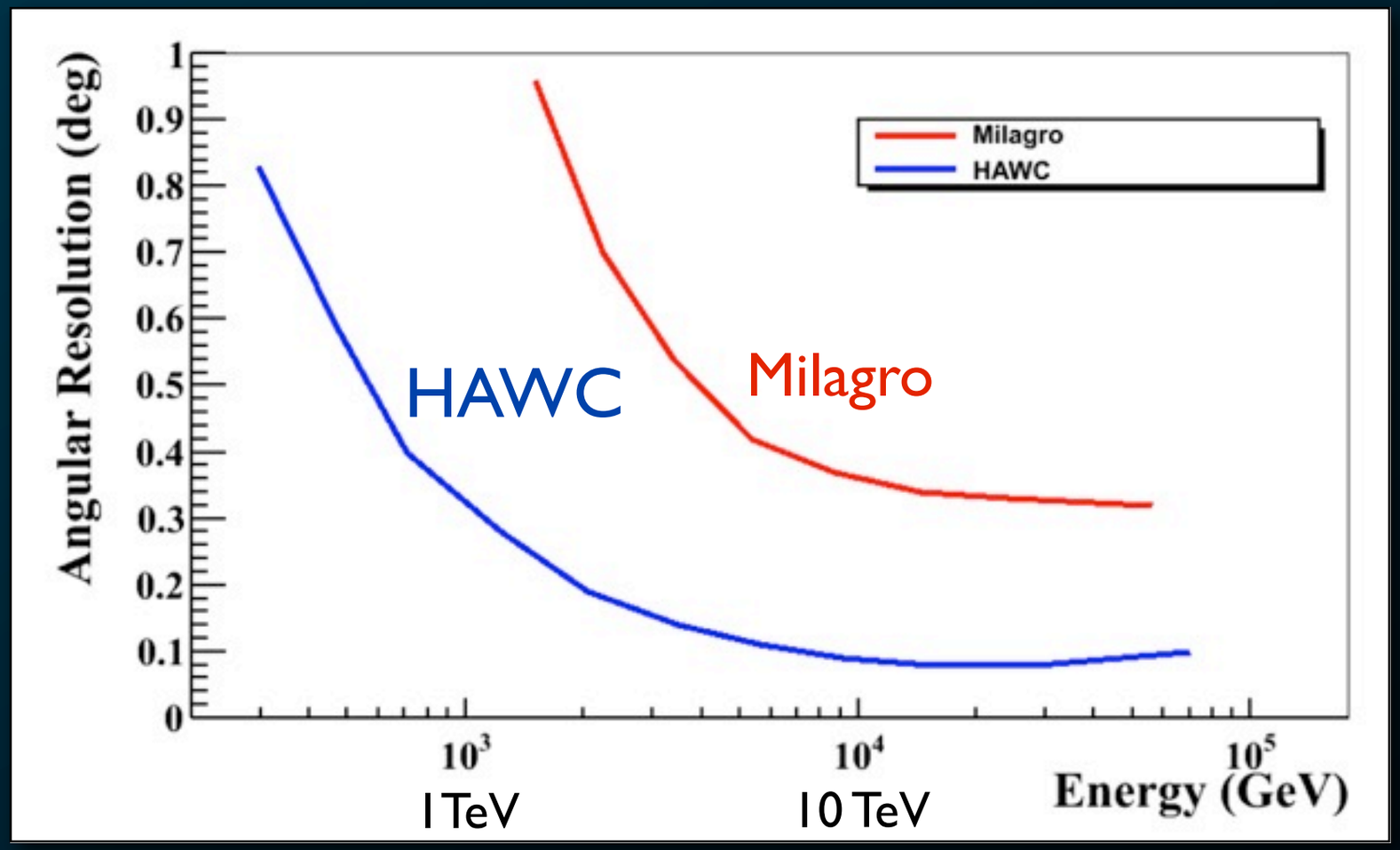
Fermi LAT ($0.8\ m^2$)



- Geometric area ~10^5 m^2 (6 x Milagro pond area)
- Energy threshold ~30 GeV, fully efficient at E > 3 TeV
- Still ~100 m^2 at E = 100 GeV

Alternative triggers which would substantially increase effective area at low energies are under investigation

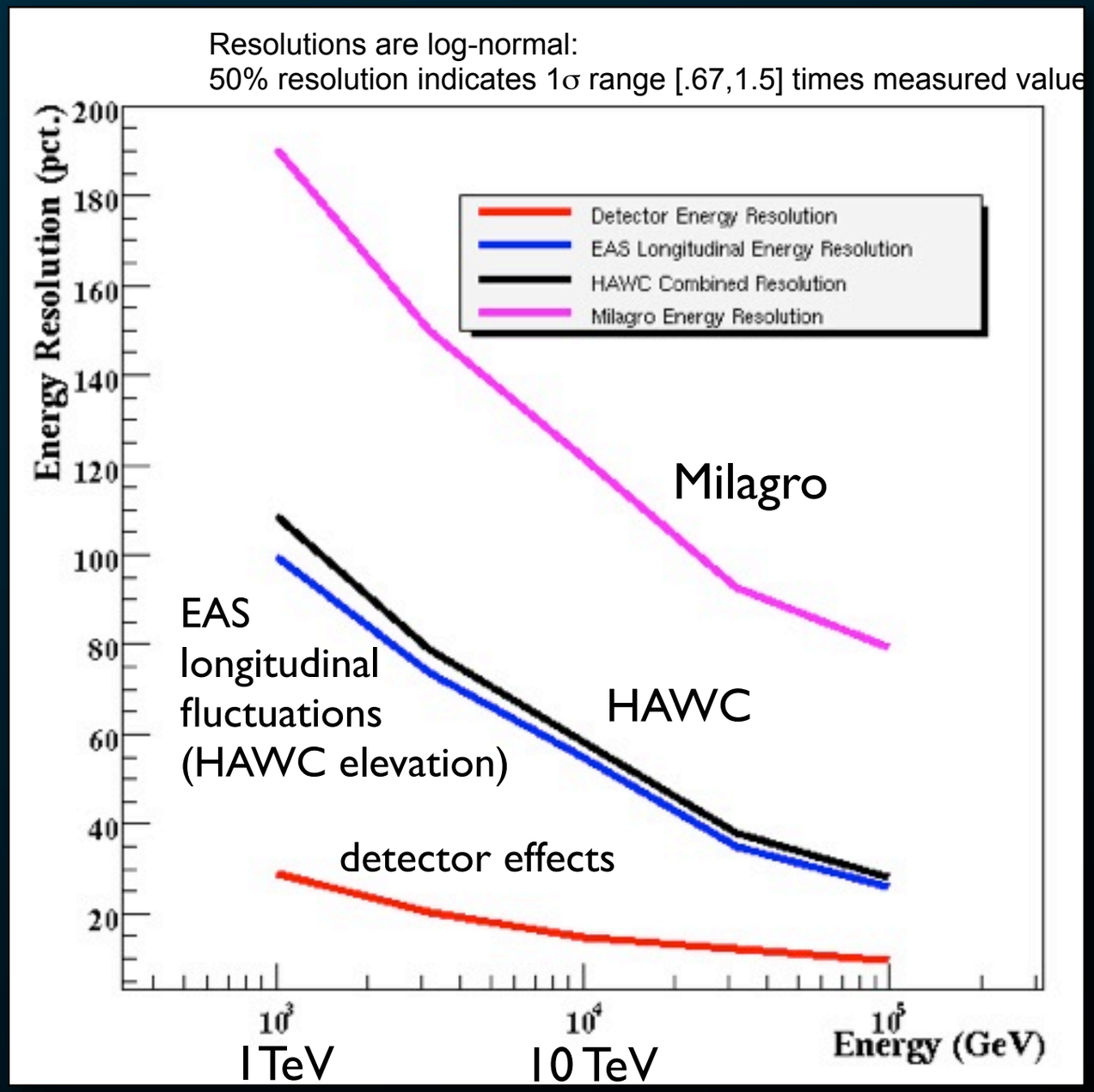
Angular resolution



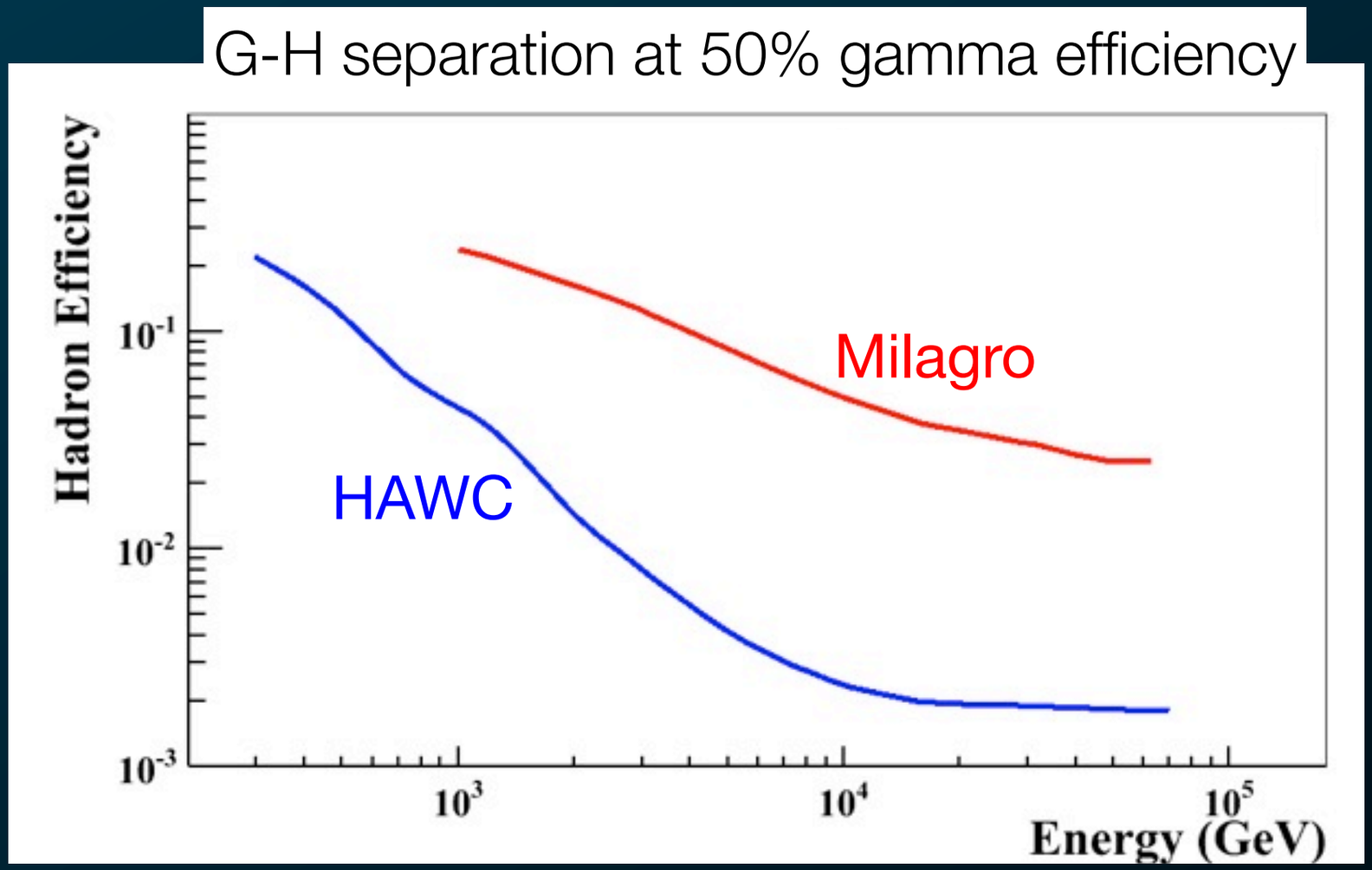
- Angular resolution up to 0.1 degree at TeV energies
- Determined by information in the particles that reach the ground

Energy resolution

- Uncertainty from two sources:
  - Measurement of energy deposited at ground level
  - Fluctuations in shower development in atmosphere (naturally log-normal)
- Higher elevation means HAWC has a big advantage over Milagro



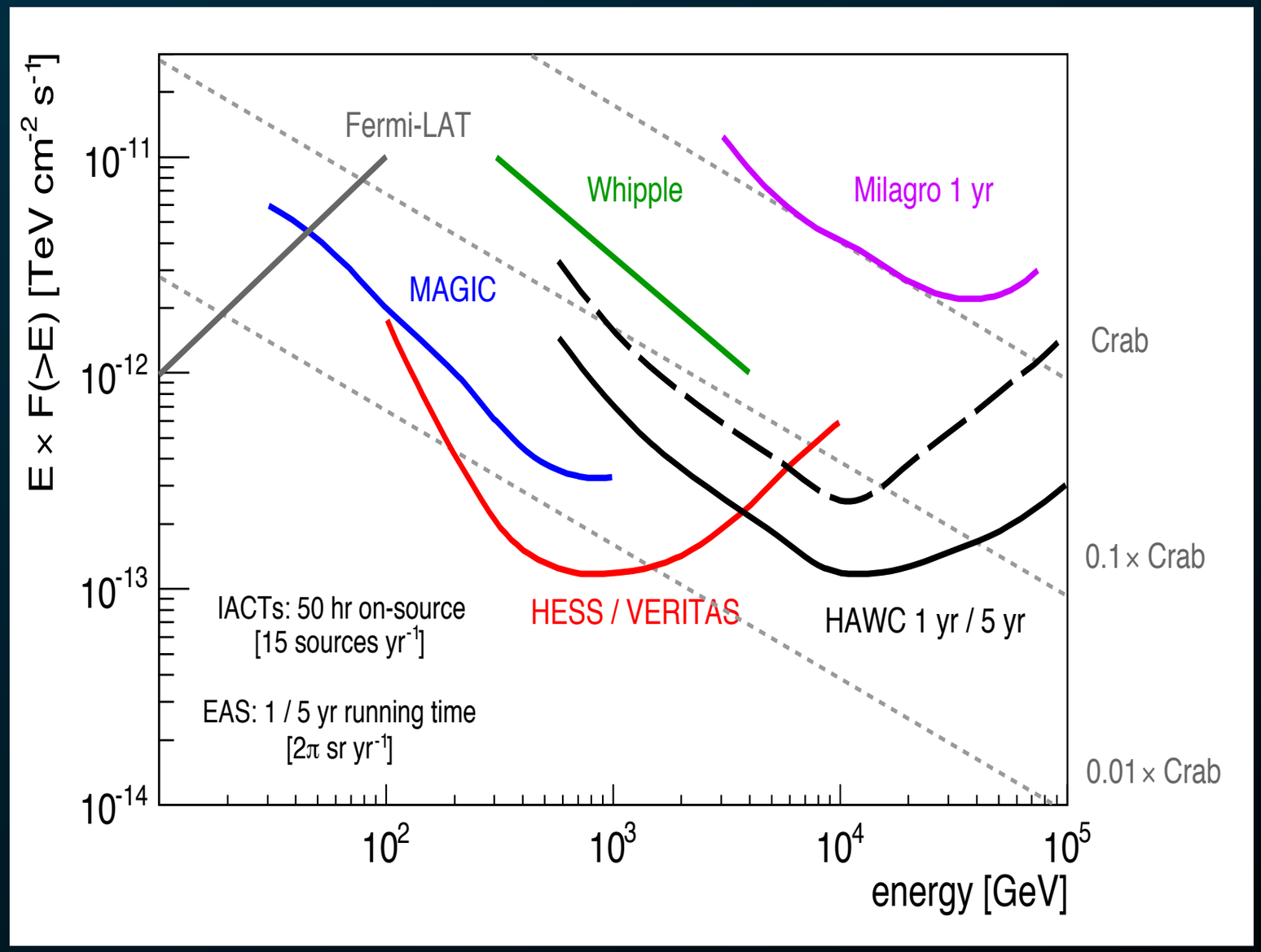
Gamma hadron separation



- Gamma-hadron separation is based on shower lateral size, clumpiness, and high amplitude pulses produced by muons
- Currently use parameter C = nHit / CxPE
  CxPE = largest hit (in PEs) > 30 m from shower core
- Already gives ~10x better rejection than Milagro for fixed energy

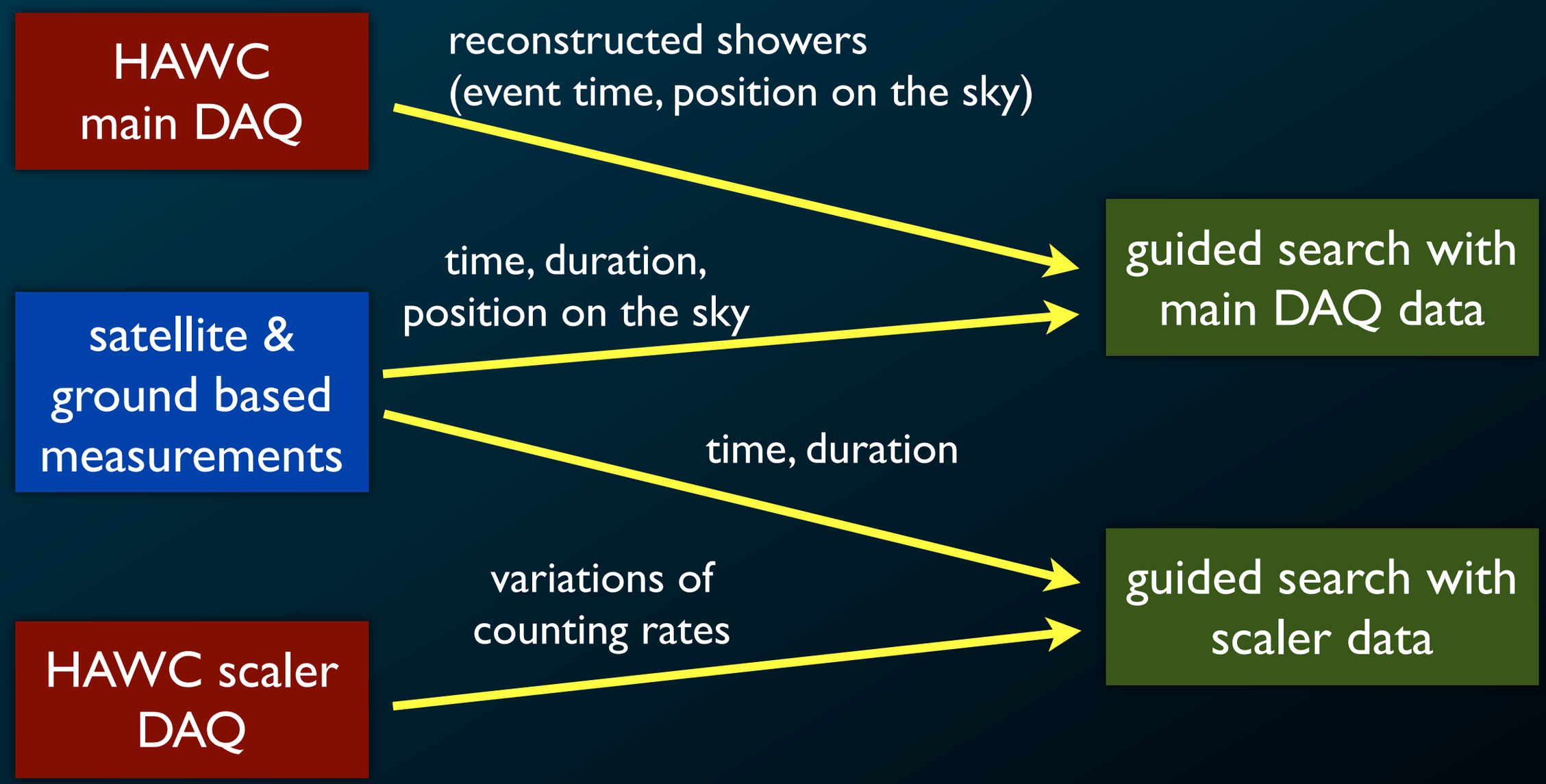
Sensitivity to Crab-like point sources

- Long integration times lead to excellent sensitivity at highest energies (> few TeV)
- 5σ sensitivity to:
  10 Crab in 3 minutes
  1 Crab in 5 hr (1 transit)
  0.1 Crab in ⅓ year
- 10-15x Milagro sensitivity
  - Lower energy threshold
  - Better angular resolution
  - Better rejection of cosmic rays



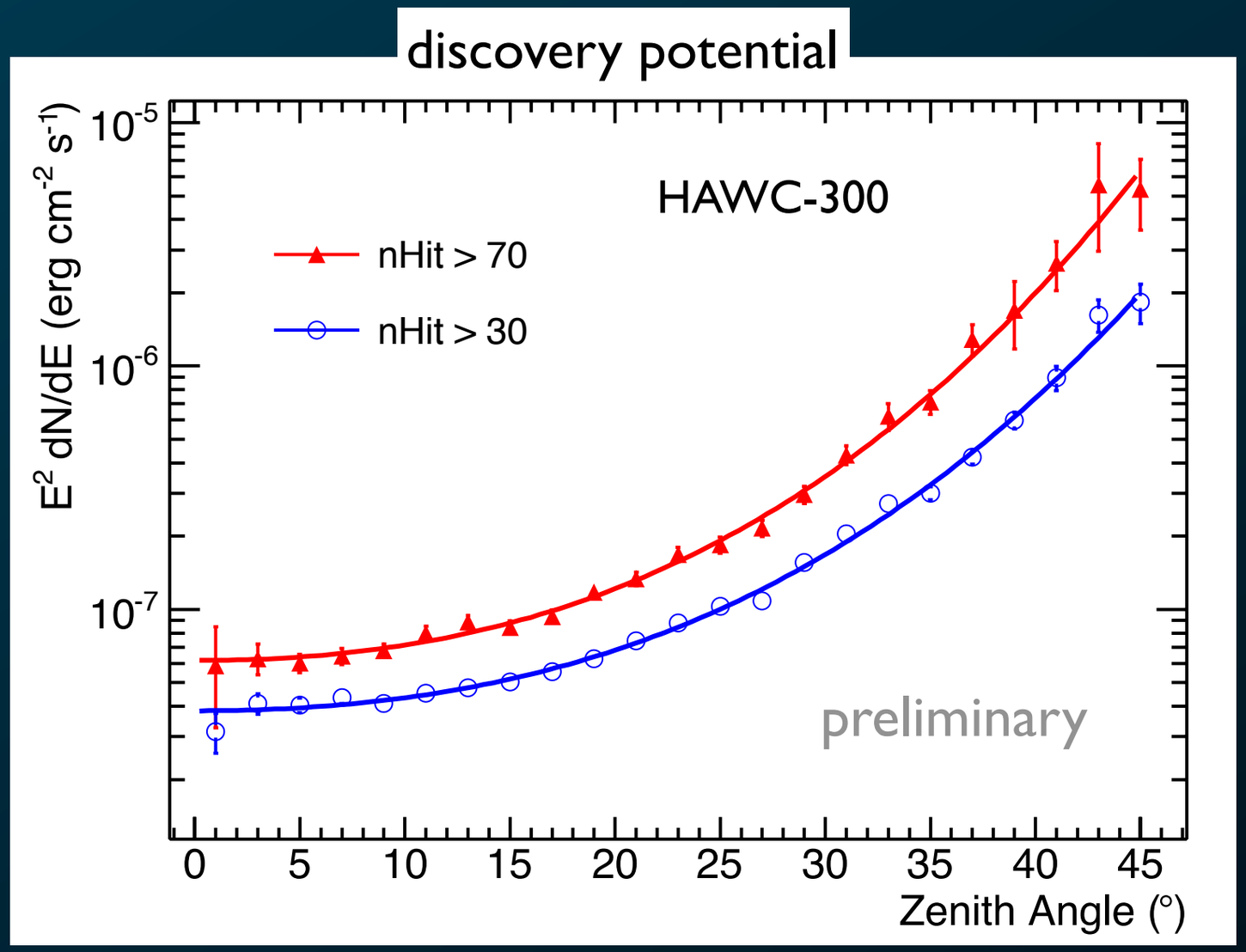
50 hr observation time assumed for IACTs,
HAWC source transit 15° off zenith

Guided search for GRB: two approaches



- Objective: extend GRB observations to high energy (E > 30 GeV)
- Both analyses, main DAQ and scalers, can be done offline

Sensitivity vs. zenith angle (main DAQ)



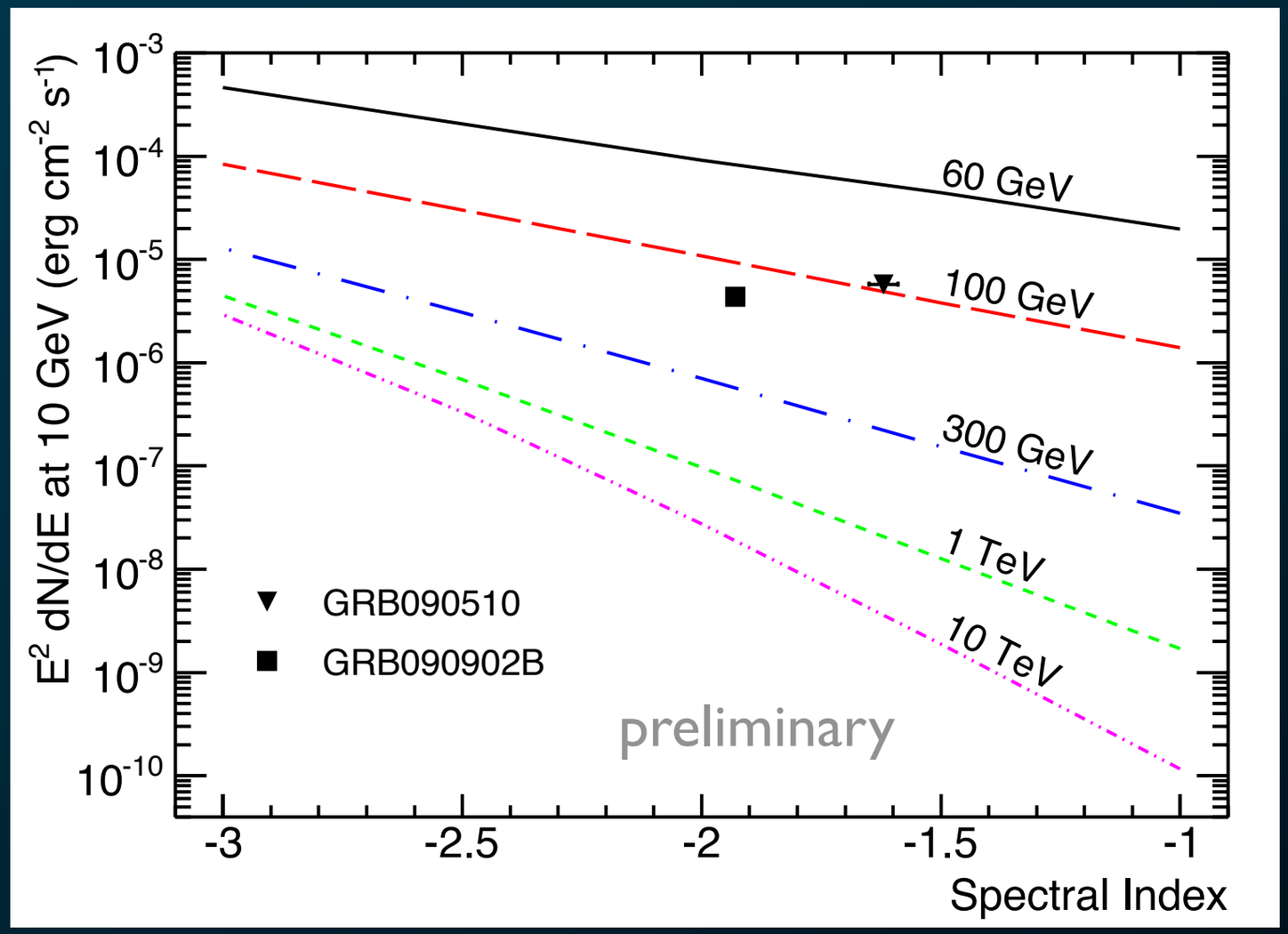
Simulated GRB:
duration = 20 seconds
spectral index = 2
redshift = 0.5 (EBL absorption following Gilmore et al.)

Number of events in the time window (20 s) is examined

Shown is the flux detectable at 5 sigma significance with 50% probability

EBL absorption removes high energy gammas from GRB spectra
--> Have to work with low energies
Relatively background-free analysis due to narrow time window (duration of GRB)
--> Angular resolution and gamma-hadron separation performance not critical
--> Easier to go to low energy
--> Low trigger threshold very useful

Sensitivity as function of spectral index and cutoff



Simulated GRB:
T = 1 s
zenith = 20 deg

Power law spectrum
with Heaviside cutoff

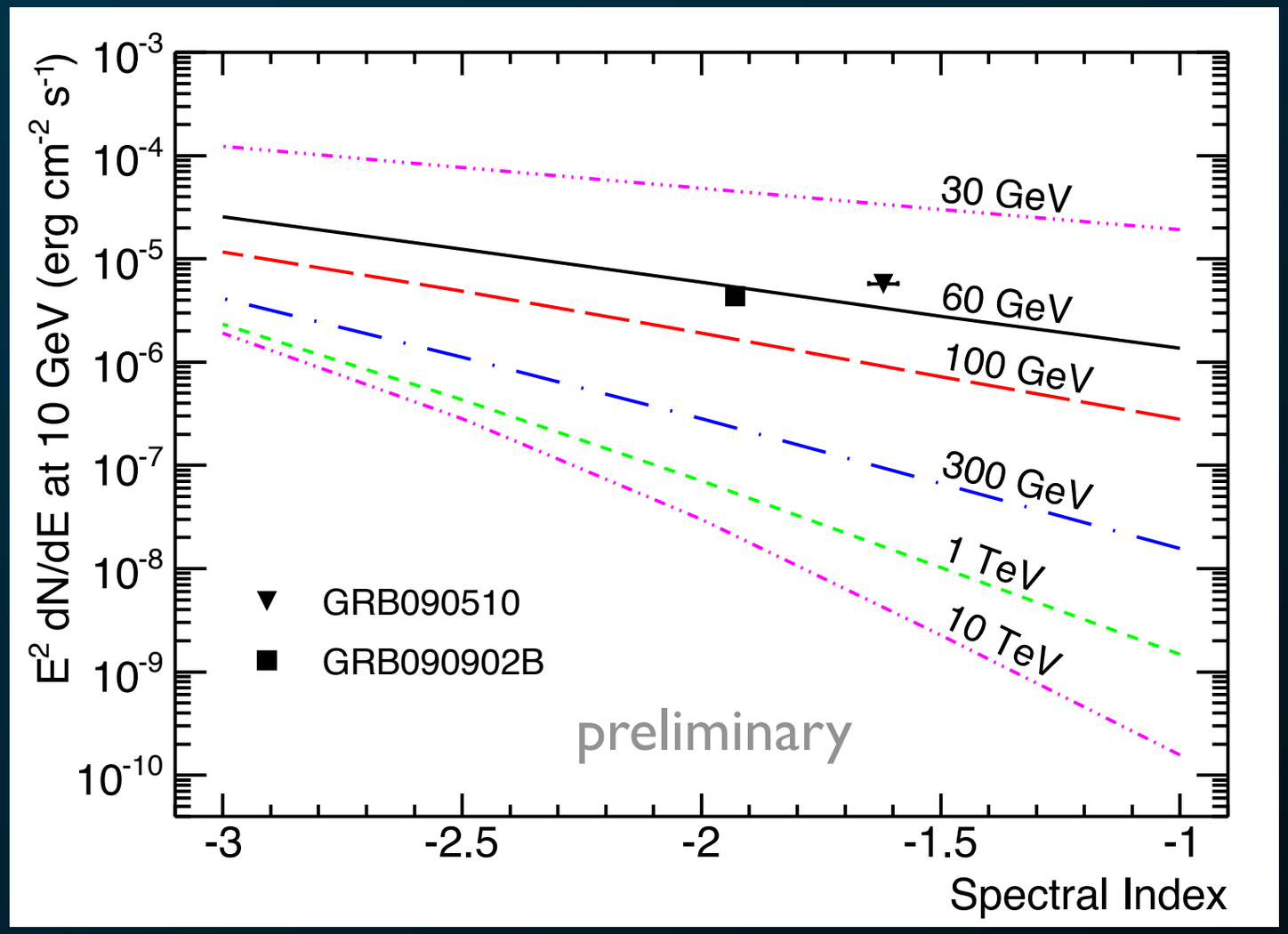
The cutoff is intended to
mimic either an intrinsic or
an EBL absorption cutoff

Nhit > 70 (5 kHz trigger)

Brightest GRBs detected by Fermi should be observable
with 5 sigma significance if cutoff is above ~100 GeV,
even without improvements in the trigger and reconstruction algorithms

Same for reduced trigger threshold

Nhit > 30 (16 kHz trigger)



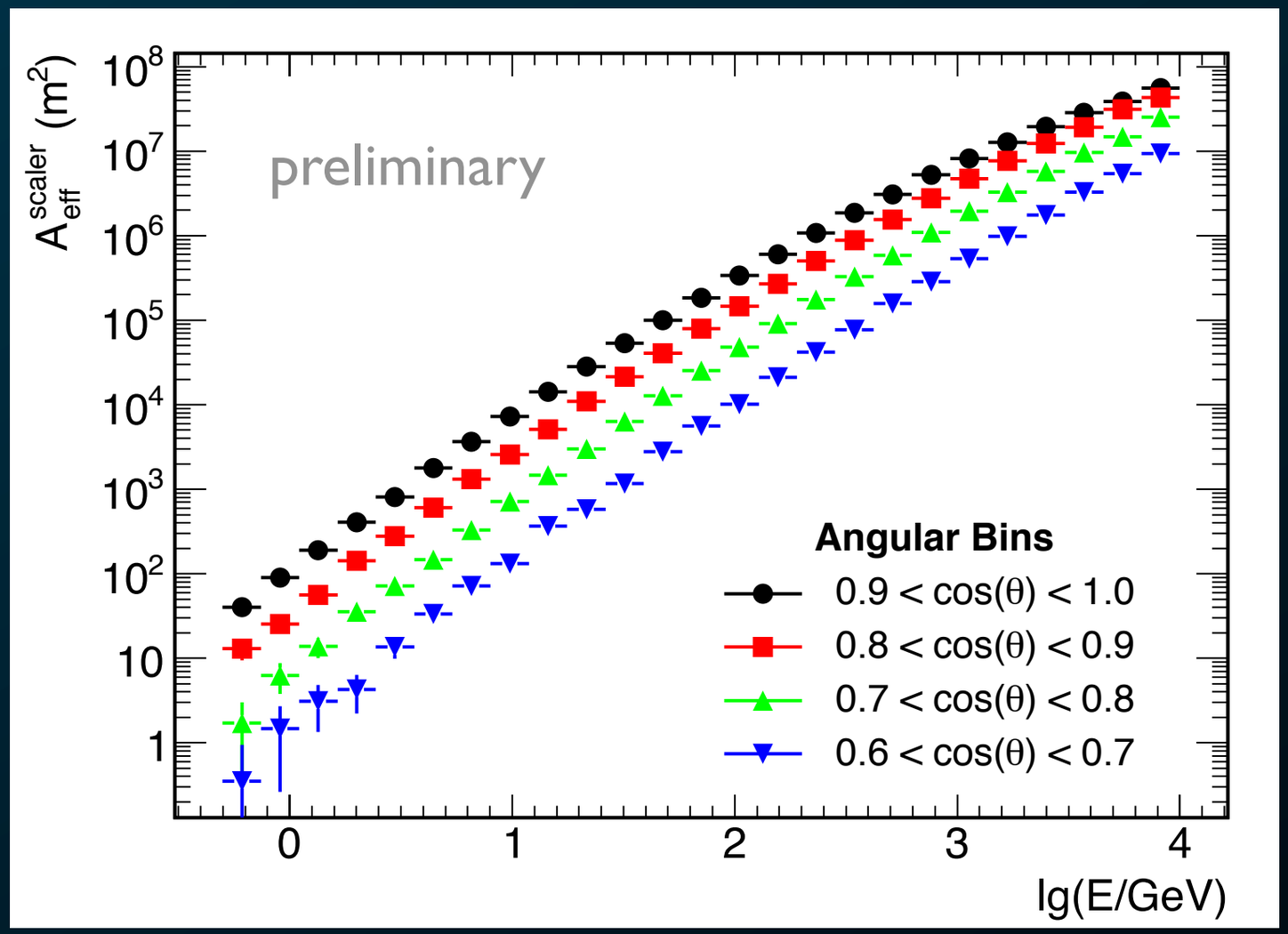
* Correlated noise from simultaneous hadronic showers not included in simulation

Accessible cutoff range extends from ~100 GeV to ~60 GeV

Final choice of trigger threshold depends on many factors
(hardware design, background rejection at low energies, etc)

Scaler DAQ "Effective area"

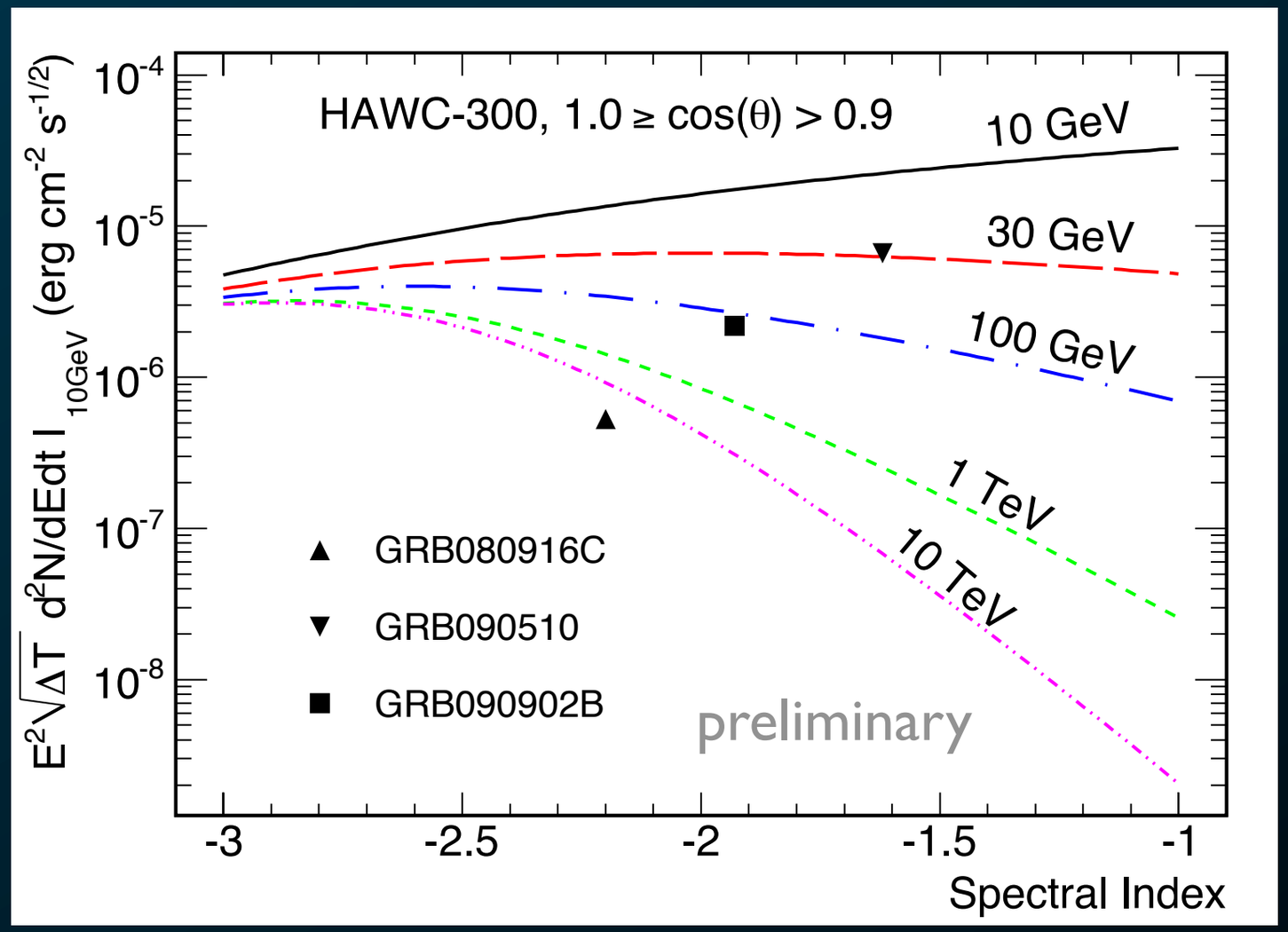
- GRB produces simultaneous increase of PMT counting rates
- Sudden increase in PMT counting rates may reveal a GRB
- Only counting rates are analyzed (no shower reconstruction)



* It is the sum of effective areas of 900 PMTs, not the usual detector effective area

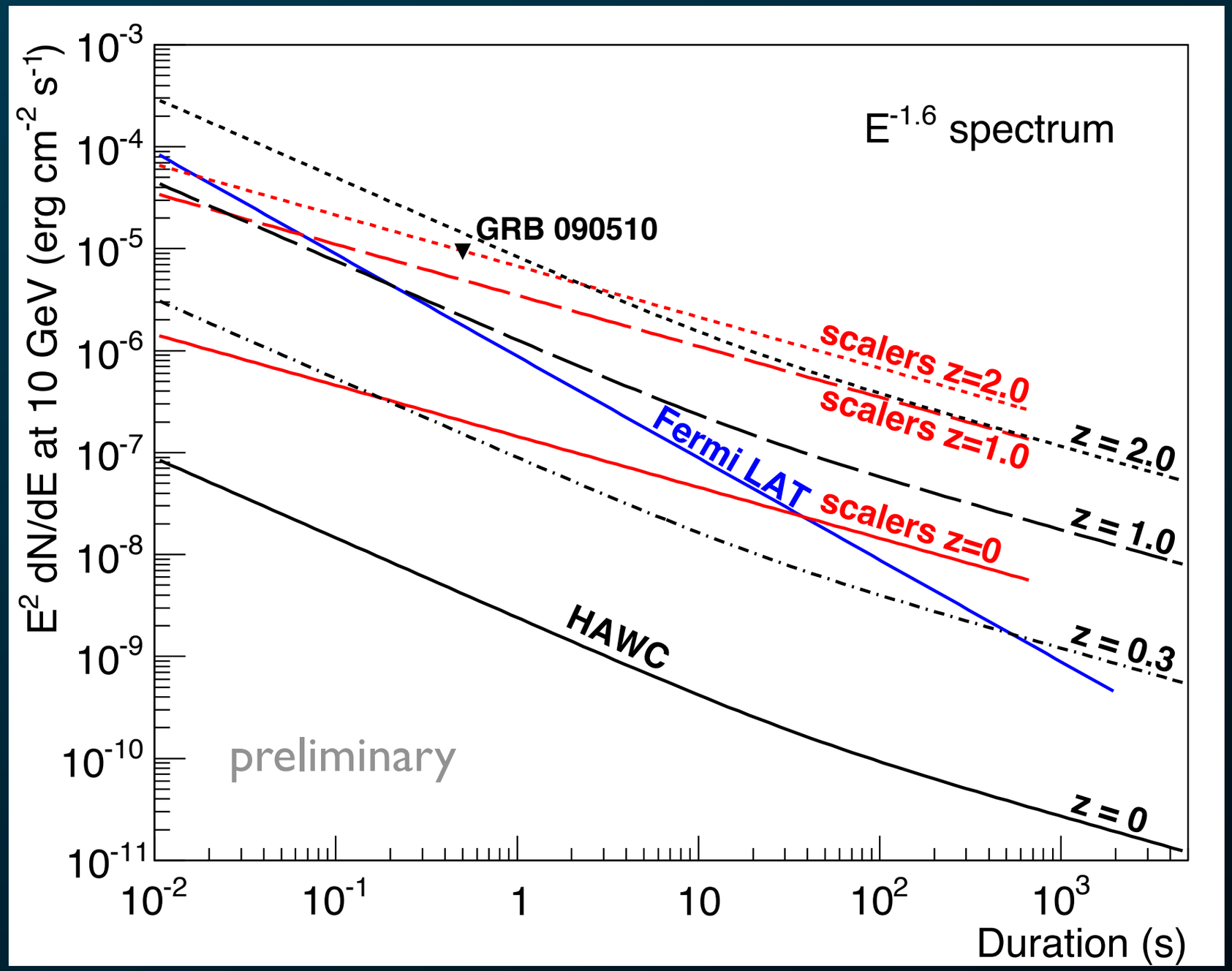
Non-negligible sensitivity down to a few GeV (much lower than for the main DAQ analysis)

Scaler DAQ sensitivity



Scaler analysis complements the main DAQ analysis,
covering short GRBs with soft spectra and cutoffs <100 GeV

Sensitivity vs. burst duration



Redshift is modeled according to Gilmore et al.

No intrinsic spectral cutoff

Fermi LAT curve: 1 photon above 10 GeV

Fermi LAT is essentially "background free" (sensitivity ~ 1 / T)

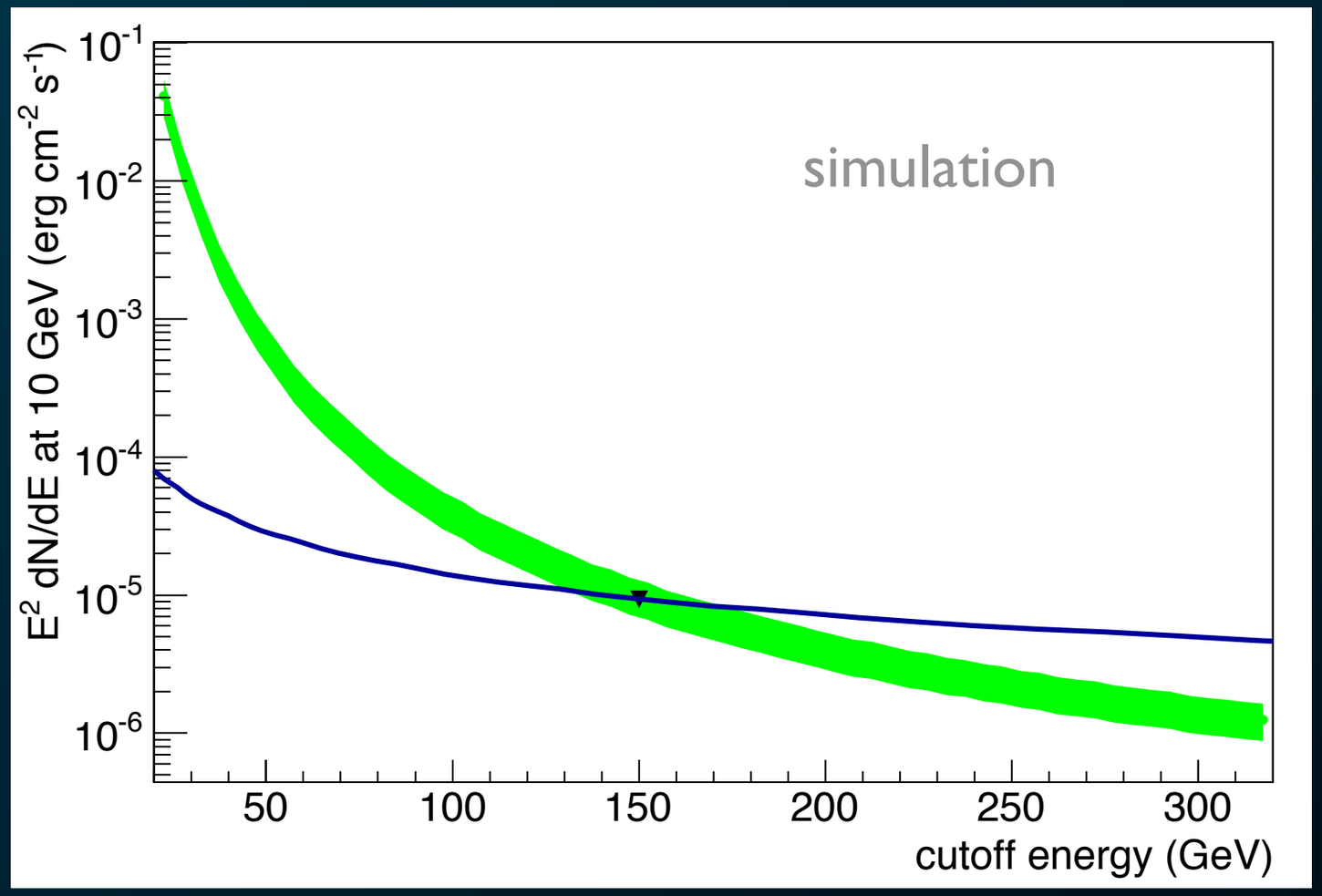
HAWC scalers are background dominated (sensitivity ~ 1 / sqrt(T))

Above 10 GeV HAWC's sensitivity will be comparable to Fermi LAT's (for short GRBs)

A possible way to measure spectral cutoff

Assumption 1: GRB is detected by both scalers and main DAQ

Assumption 2: spectral index at some reference energy (e.g. 10 GeV) is known from other observations (e.g. Fermi LAT)



Simulated GRB:
spectral index = 1.62
Sharp cutoff at 150 GeV

Green band: region compatible within 1 sigma with observation of 18 events with the main DAQ

Blue curve: line of constant significance for the scalers

Systematic errors not included

A ±30 GeV accuracy in the measurement of the effective cutoff energy might be feasible

Various approaches to combined analyses

- Use external data in offline analyses (when/where available)
  - e.g. set search time window based on Fermi LAT data, use coordinates and redshift measured by optical/infrared telescopes
- Receive GCN alerts
  - temporarily lower trigger threshold to improve efficiency
- Generate GCN alerts based on HAWC data
  - HAWC will be efficient enough to produce meaningful alerts

When?

- VAMOS (ready June 2011)
  - 7 tank test array
- HAWC-30 (6 months)
  - Implementation of all subsystems
  - Considerable sensitivity to GRBs
- HAWC-100 (18 month)
  - Science operations with 2 times Milagro's sensitivity
- HAWC-300
  - Full detector

GRB searches with HAWC greatly profit from external guidance
--> Important to run at the same time as Fermi

Summary

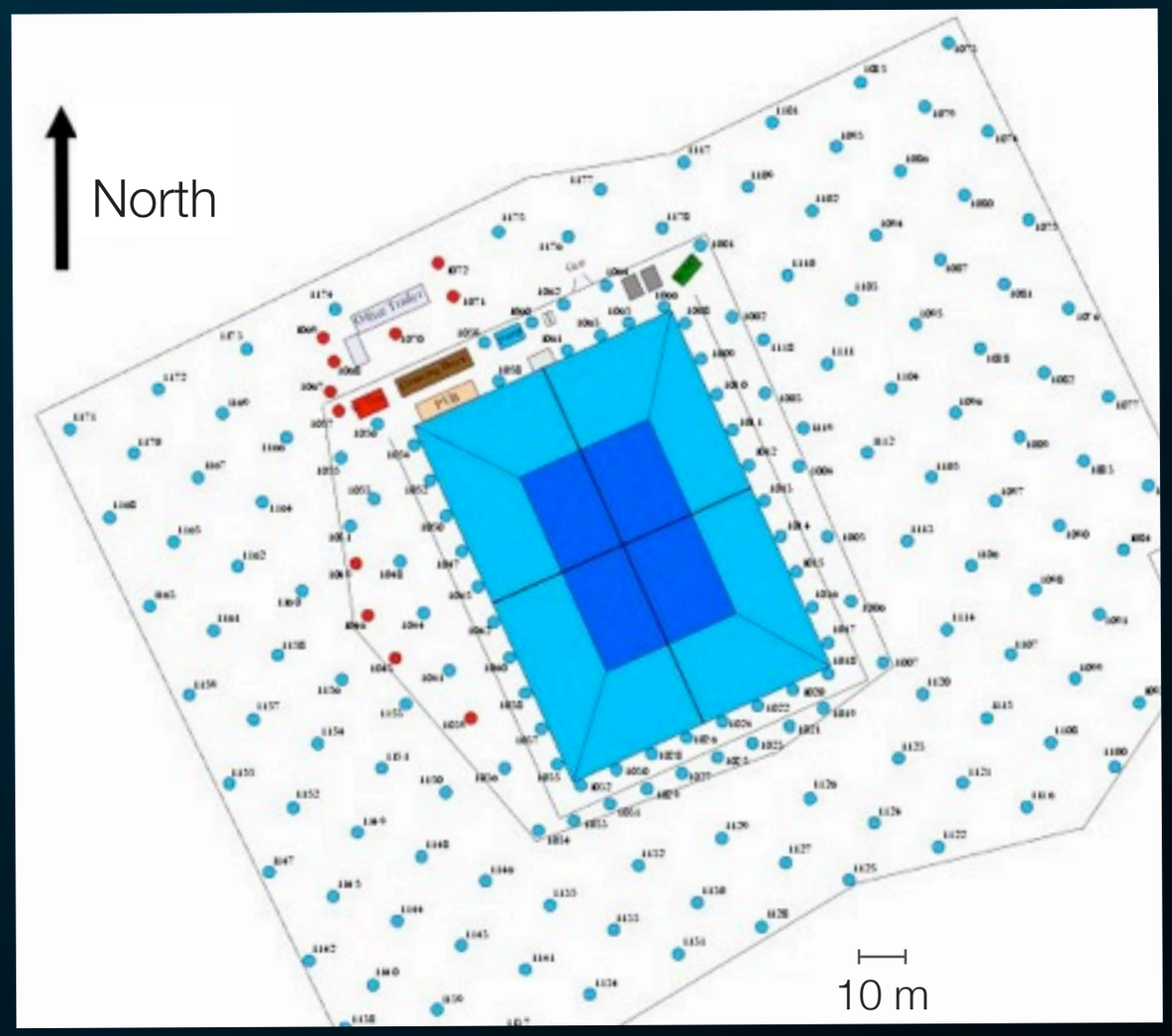
- HAWC is a new generation wide field of view gamma-ray telescope currently under construction in Mexico
- HAWC will be sensitive to gamma rays with energies down to 30 GeV
- HAWC will have effective area ~10000 m^2 and angular resolution ~0.1 degree at TeV energies
- The wide field of view and high duty cycle of HAWC offer exciting prospects for the first detection of a gamma ray burst by a ground-based experiment
- HAWC measurements could constrain high energy cutoff in GRB spectra, providing information on intrinsic spectral cutoff and/or EBL absorption

Thank you for your attention!

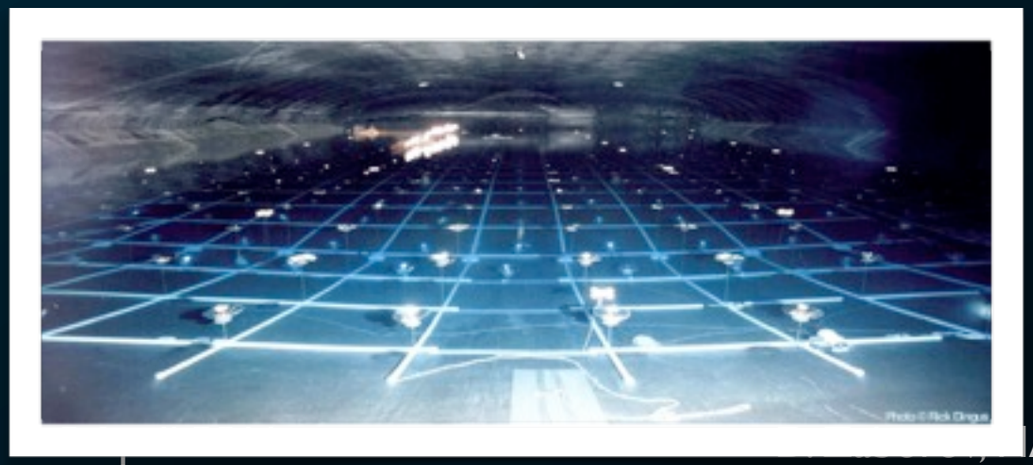
(backup slides follow)

Milagro gamma ray observatory

2650 m altitude, near Los Alamos, New Mexico

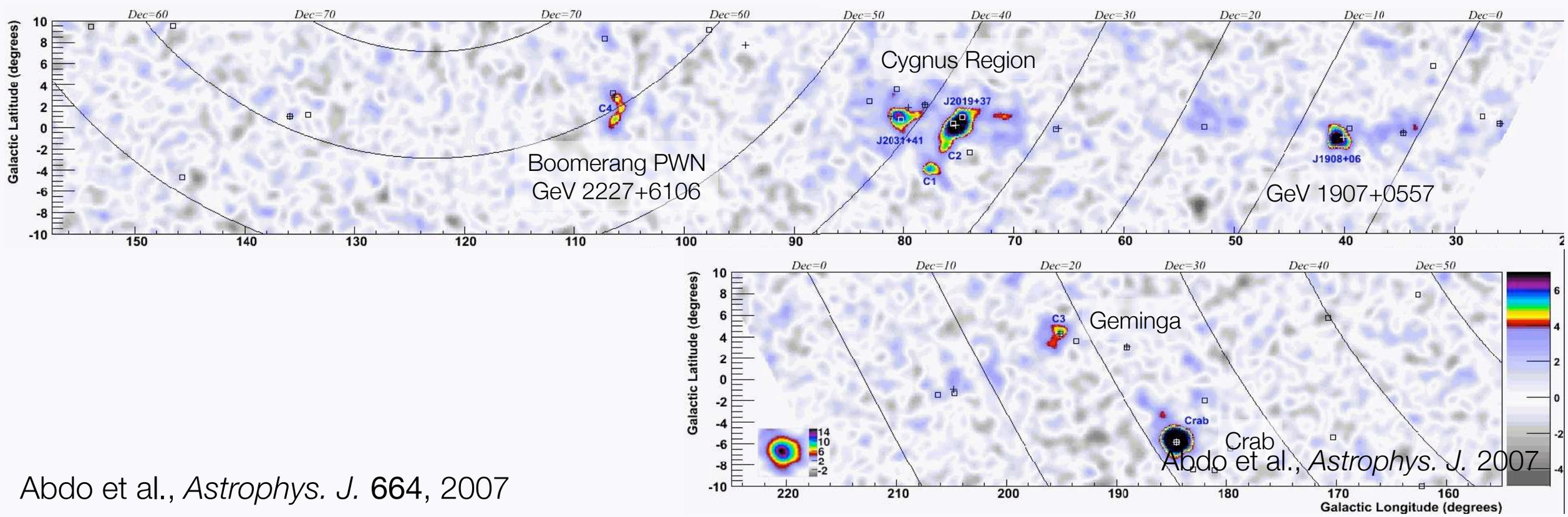


2650 m above sea level
898 photomultipliers
450 in top layer of pond
273 in bottom layer of pond
175 outrigger tanks (8' dia. x 3' deep)
3600 m^2 pond, operational Jan. 2001
34,000 m^2 outrigger array, fully operational June 2004



Optimal energy ~ 20 TeV
Effective area ~ 10^4 m^2 (pond), 10^5 m^2 (outtrigger)
Background rejection ~ 95%
Angular resolution ~ 0.7°
Energy resolution ~ 50%
95% duty cycle / ~1.8 sr aperture

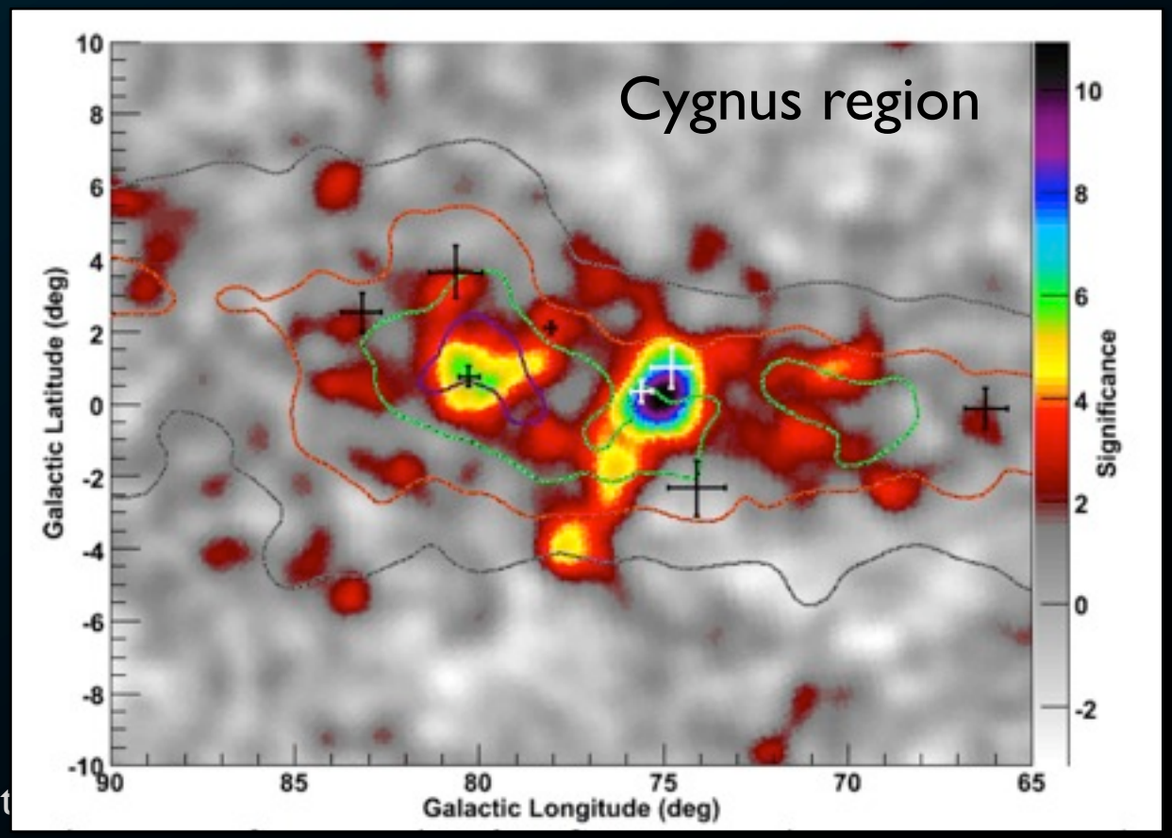
Milagro galactic survey



Abdo et al., *Astrophys. J.* 664, 2007

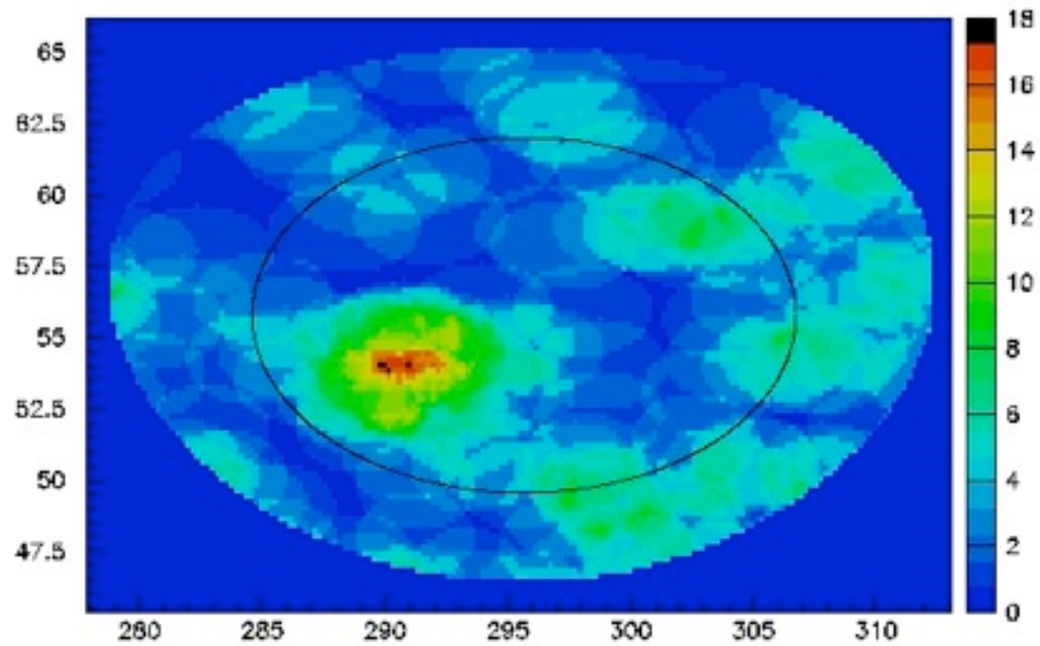
Abdo et al., *Astrophys. J.* 2007

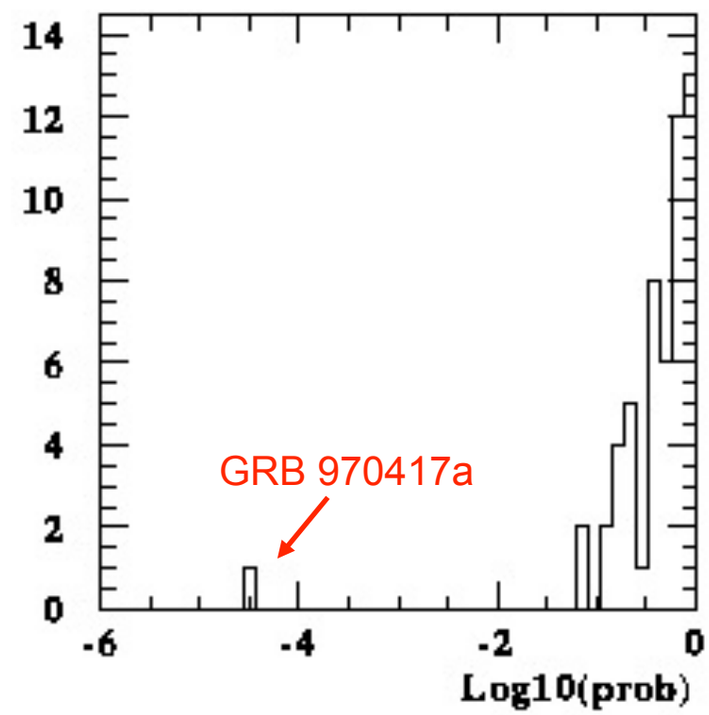
- Observations with Milagro wide-field TeV telescope, 2000–06
- 4 detected sources, additional 3-4 candidates (<5σ post-trials)
- 5/7 have EGRET GeV counterparts (13 sources in the region, p=3x10-6)
- Significant diffuse emission in the Cygnus region



Other Milagro results: CR anisotropy, Geminga, TeV diffuse emission from Galactic plane

Mialgrito's GRB





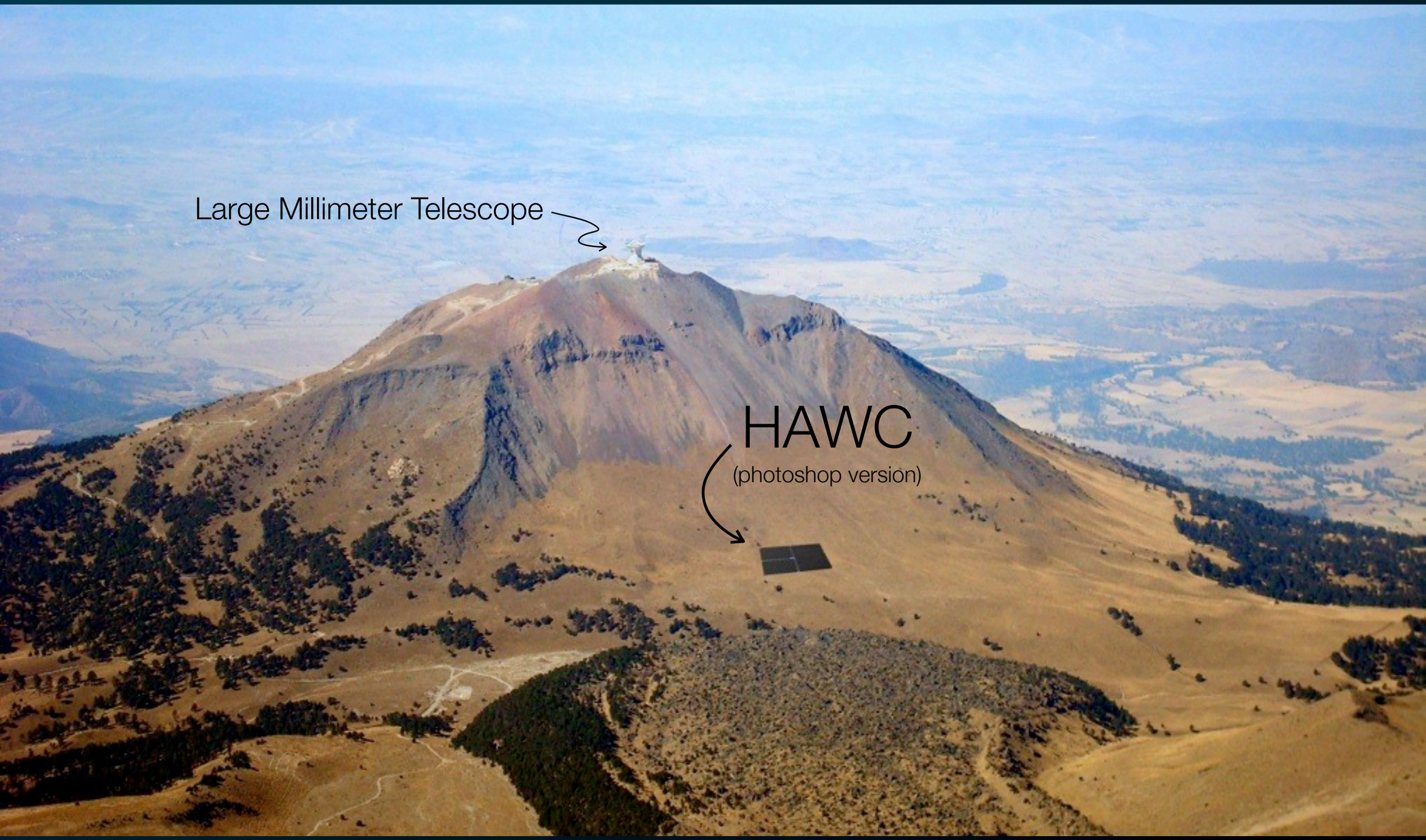
One of 54 GRBs observed by Milagrito
18 events on background of 3.3
Chance probability (post-trials) of 1.7×10^{-3} (2.9σ)
TeV fluence > 10x keV fluence

Milagro: Atkins et al., 2000

From Milagro to HAWC

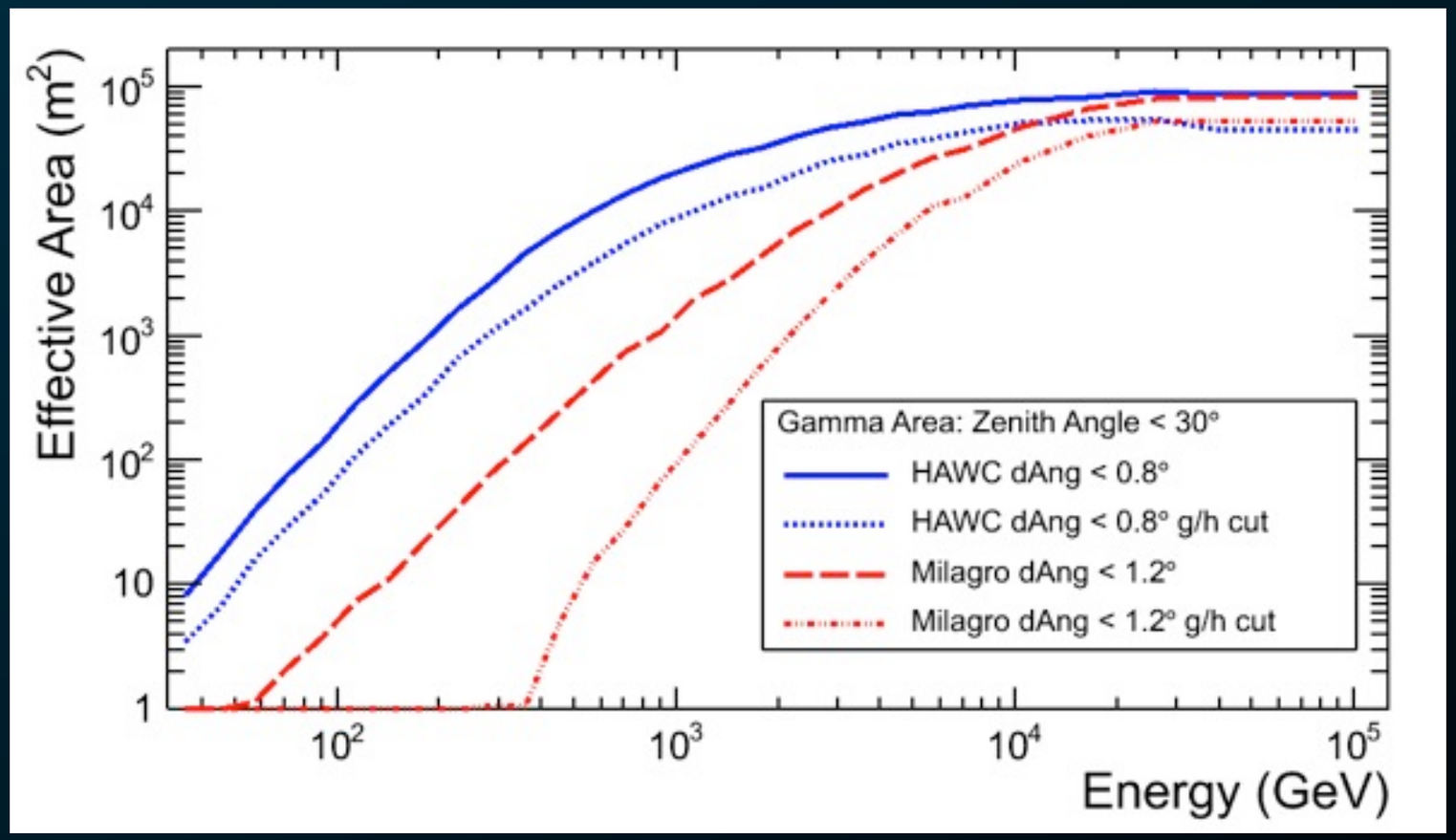
- Redeploy Milagro at Volcán Sierra Negra, México
- Increase altitude from 2650 m to 4100 m
- Increase area from 3,600 m^2 (pond) to 22,000 m^2
- Segment the Cherenkov medium: separate tanks instead of a single pond
- Better angular resolution and background rejection, lower energy threshold
- Achieve 10-15 x sensitivity of Milagro
- Detect Crab at 5σ in 6 hours instead of 3 months

HAWC site



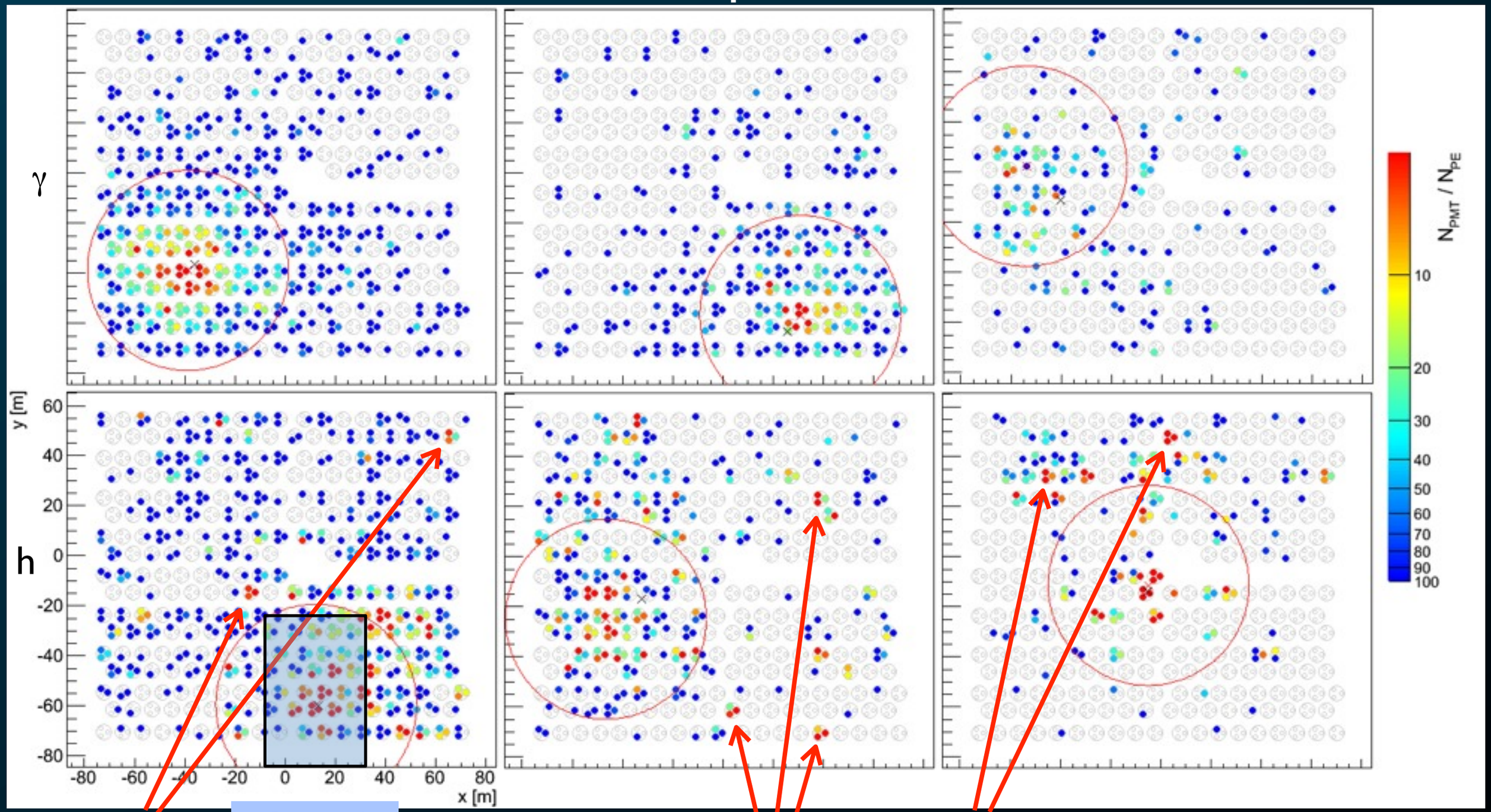
Effective area: HAWC vs. Milagro

- EAS detectors are tail-catching calorimeters
- Higher altitude means more particles survive to reach the detector
- HAWC fully efficient above ~2 TeV
- Still ~100 m2 area at 100 GeV
- ~100x Milagro after background rejection



HAWC: Nhit > 30

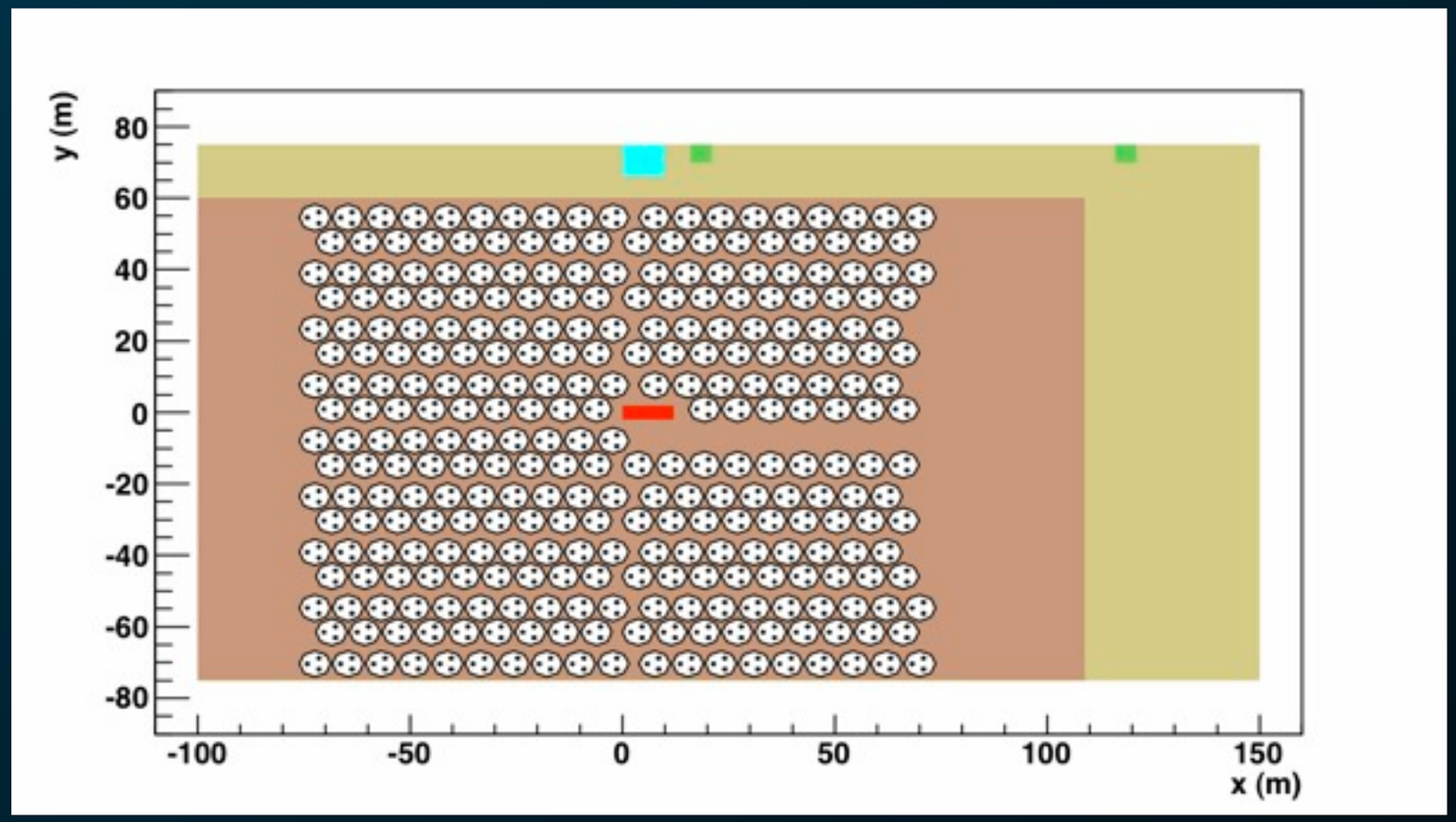
Gamma-hadron separation in HAWC



Size of Milagro

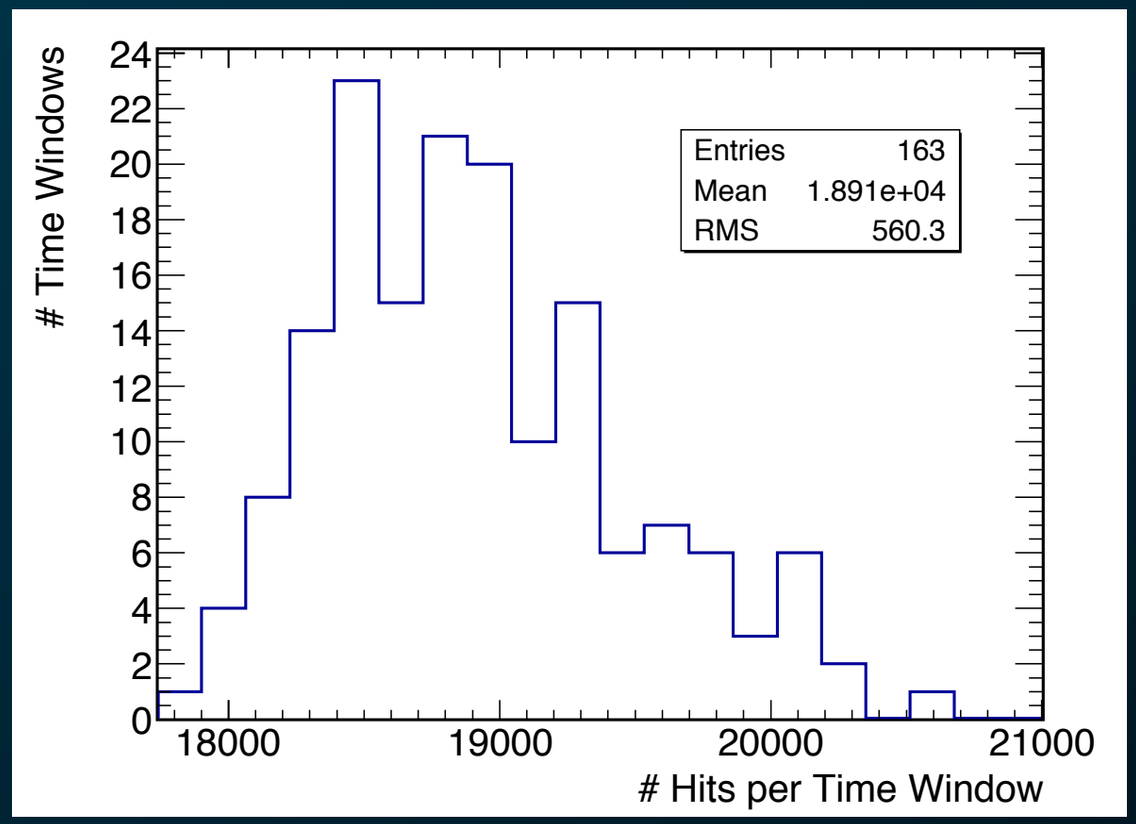
- Cosmic ray showers are clumpier than gamma rays
- Algorithm looks for high-amplitude hits more than 40 m from the reconstructed core location

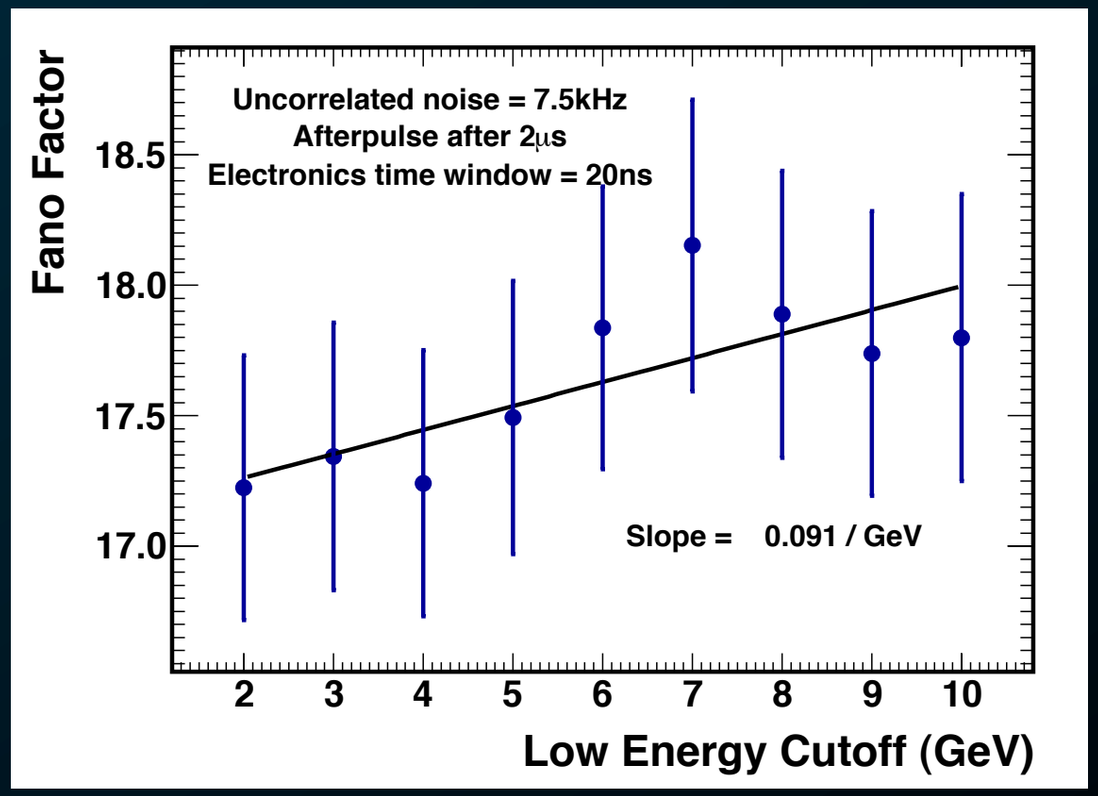
Old layout version (used in simulation)



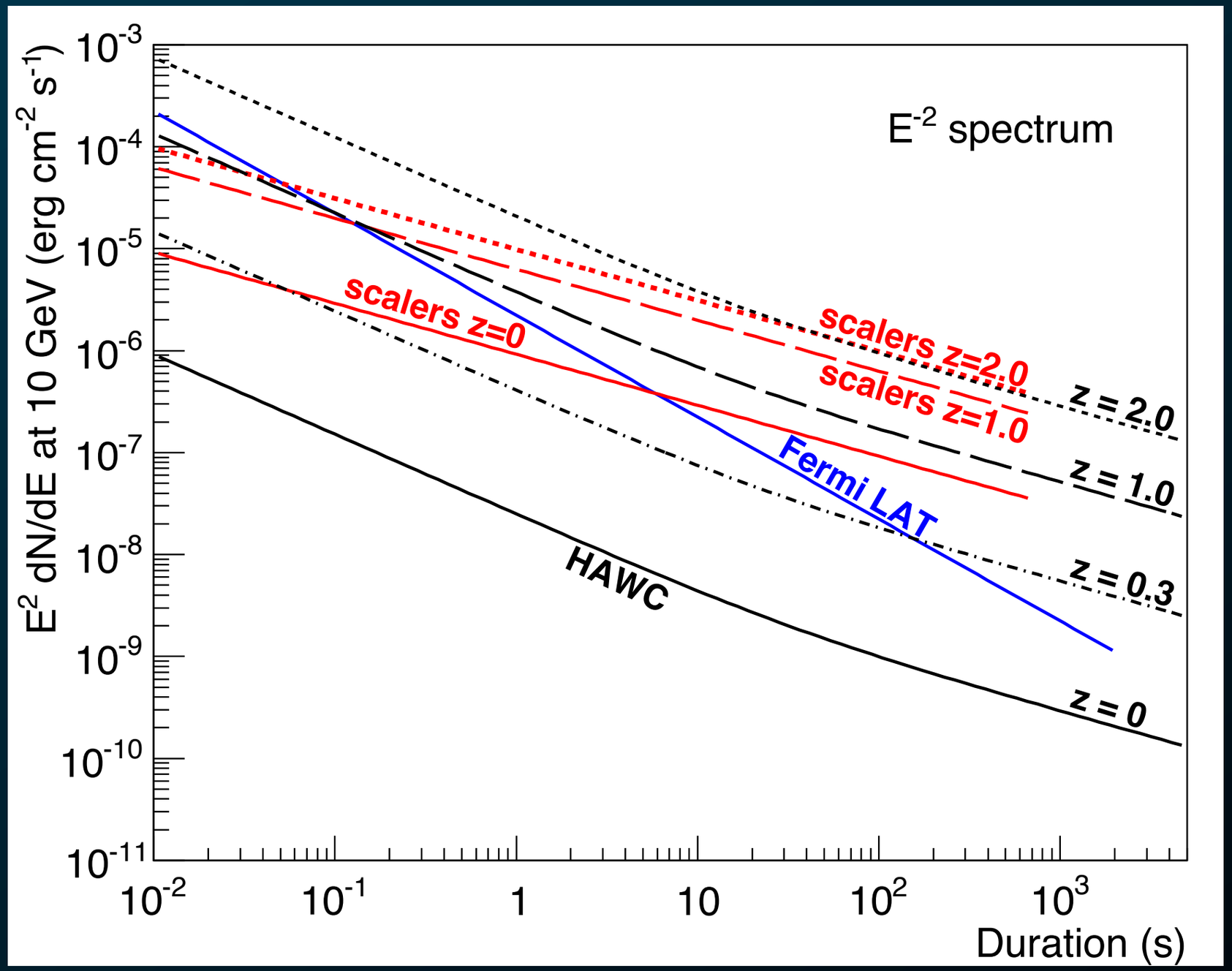
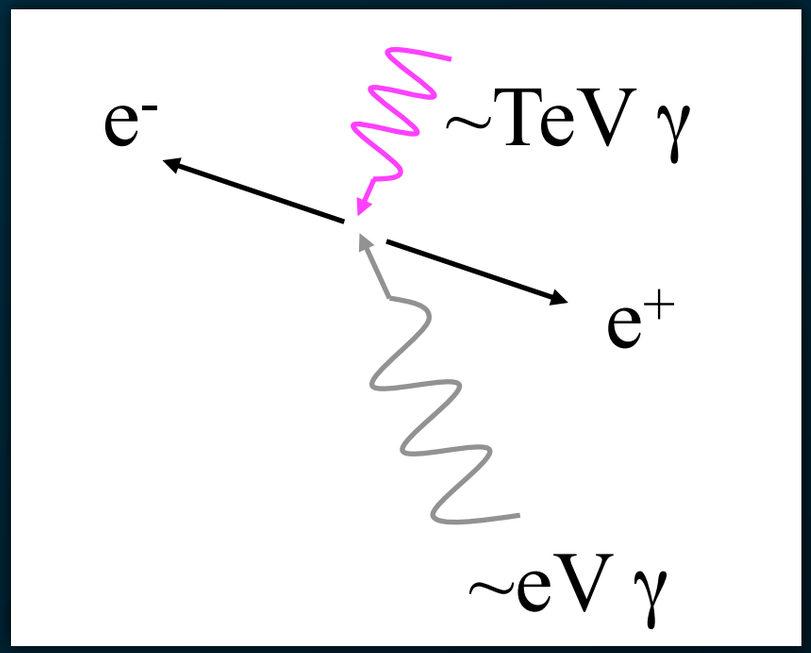
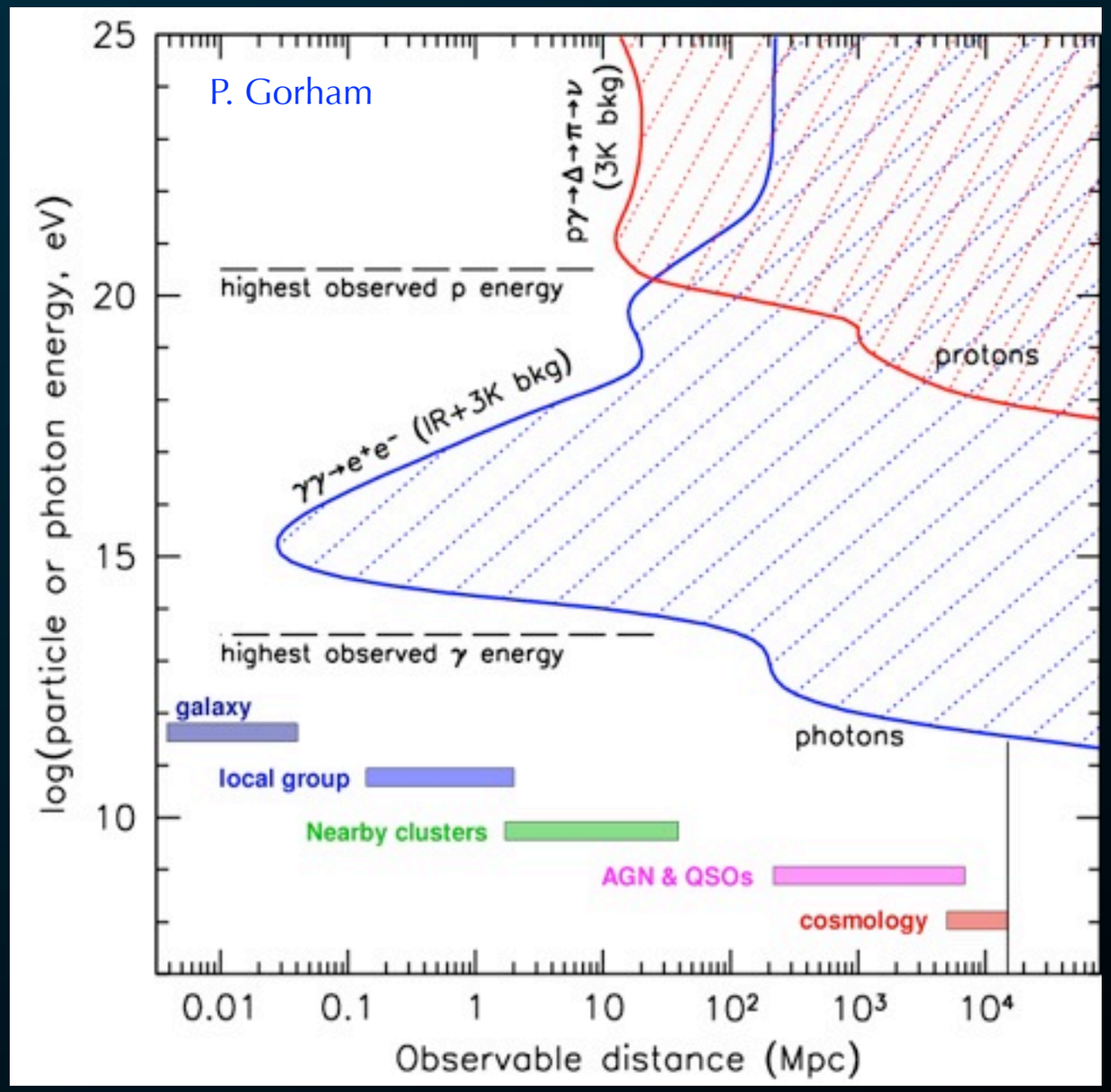
- 300 tanks in a square layout

Counting rates and Fano factor





Sensitivity for E^{-2} spectrum



EBL absorption