TeVPA 2013
Irvine, CA
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Search for high energy emission from GRBs with the HAWC Observatory

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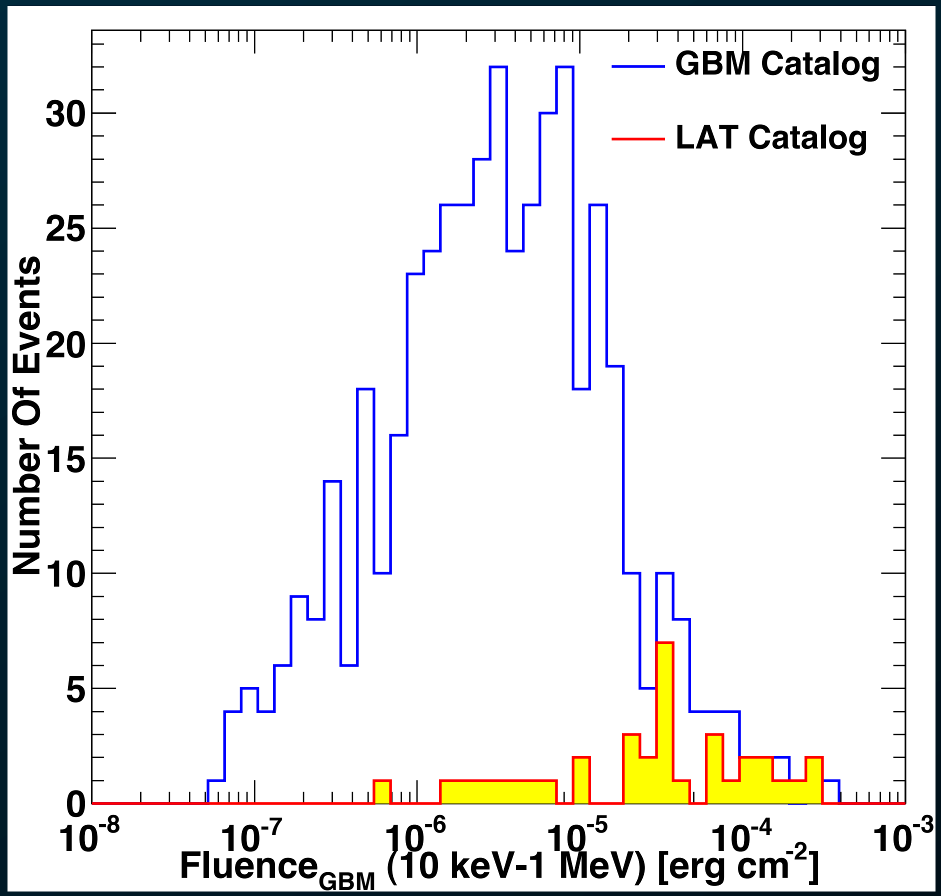
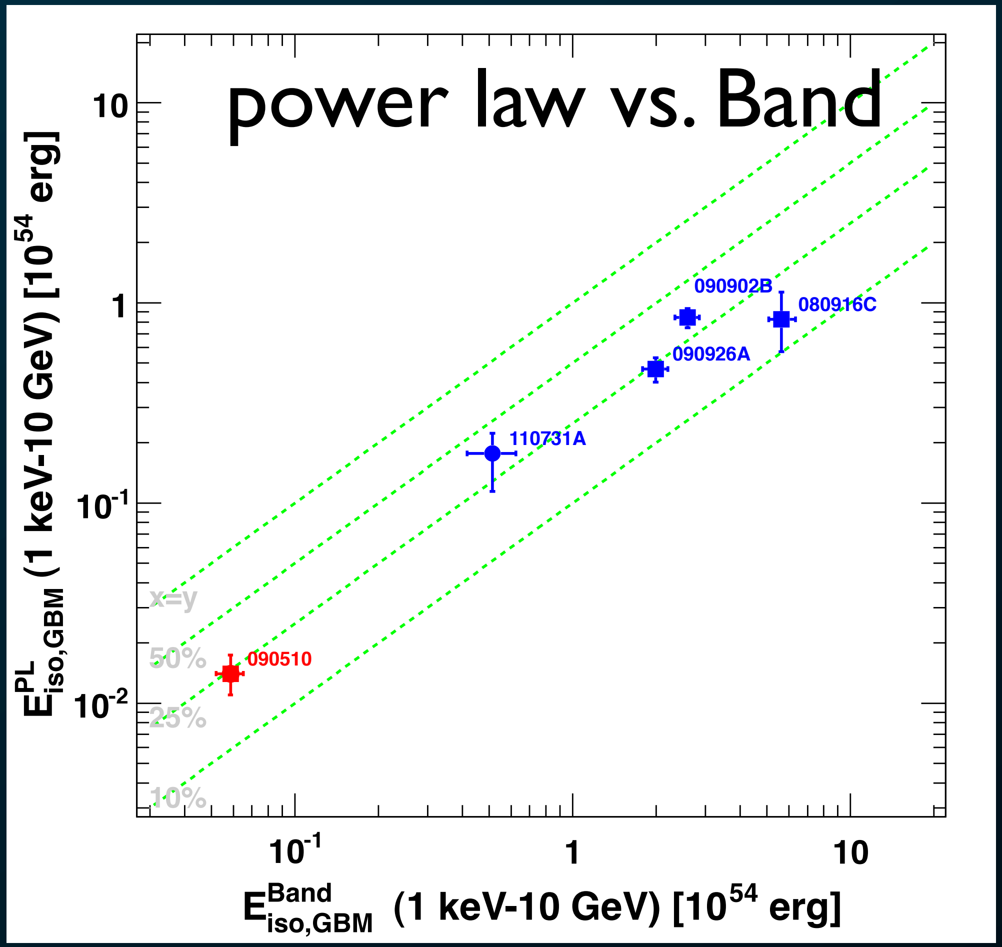
for the HAWC collaboration

- Prospects for the detection of high energy emission from GRBs by HAWC
- First results from partially built array

Fermi LAT heritage

- Most of well measured (high fluence) gamma-ray bursts are detectable at high energy (> 100 MeV)
- Joint GBM-LAT spectral fits require an additional power-law component in all bright LAT bursts, indicating that the Band function alone is inadequate to fit the spectra of these bursts

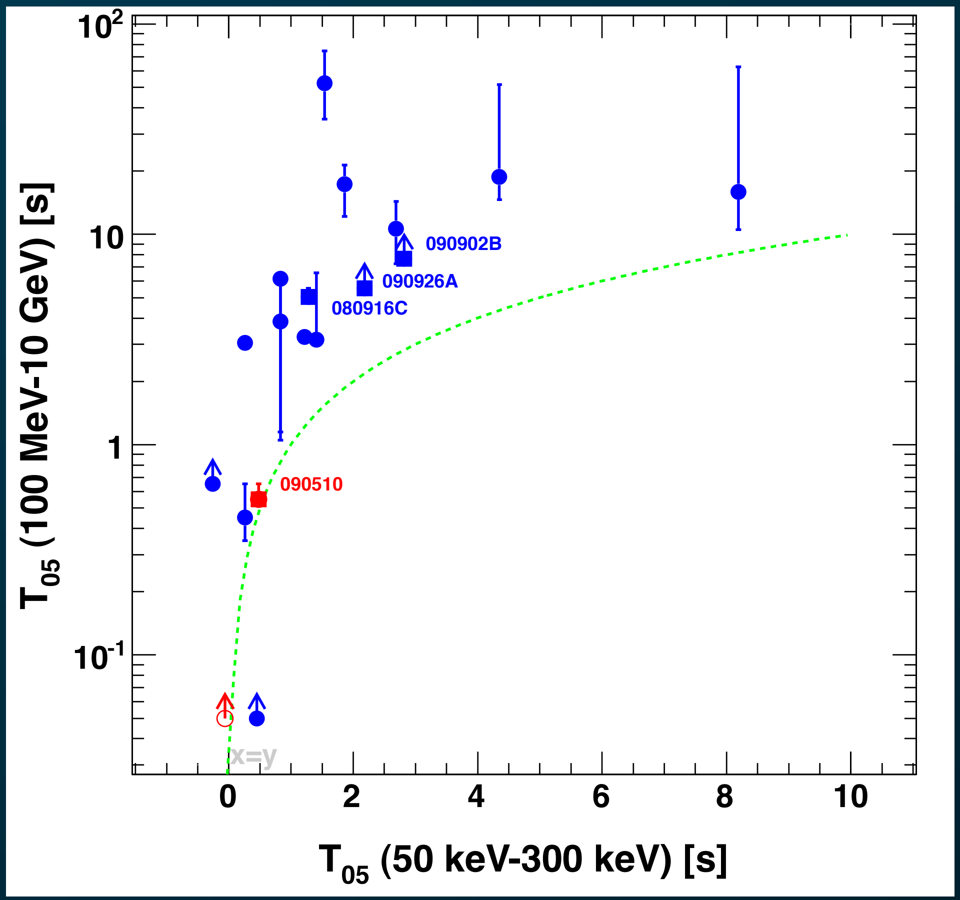




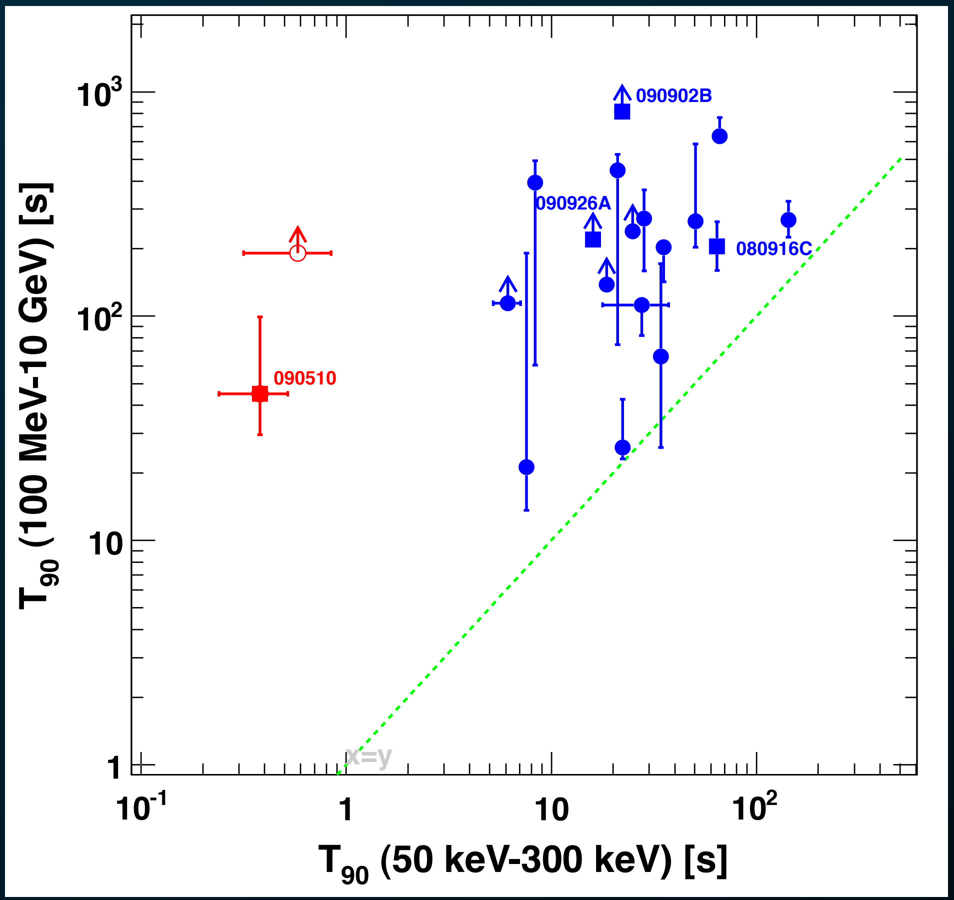
- Typical spectral index of the power-law component is -2.0 (-1.6 for GRB 090510)
- There appears to be correlation between the power-law and Band component fluxes

Source: Fermi LAT GRB catalog
http://arxiv.org/abs/1303.2908

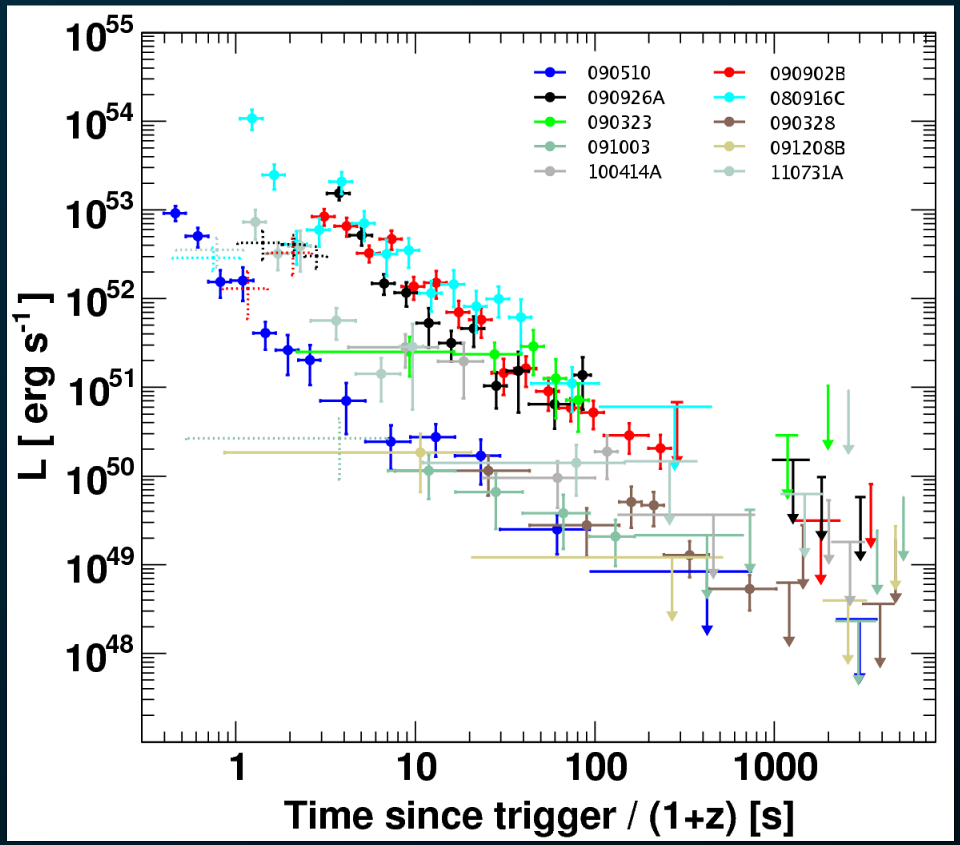
Distinct properties of high energy emission



delayed onset



longer duration (compared to low energy)

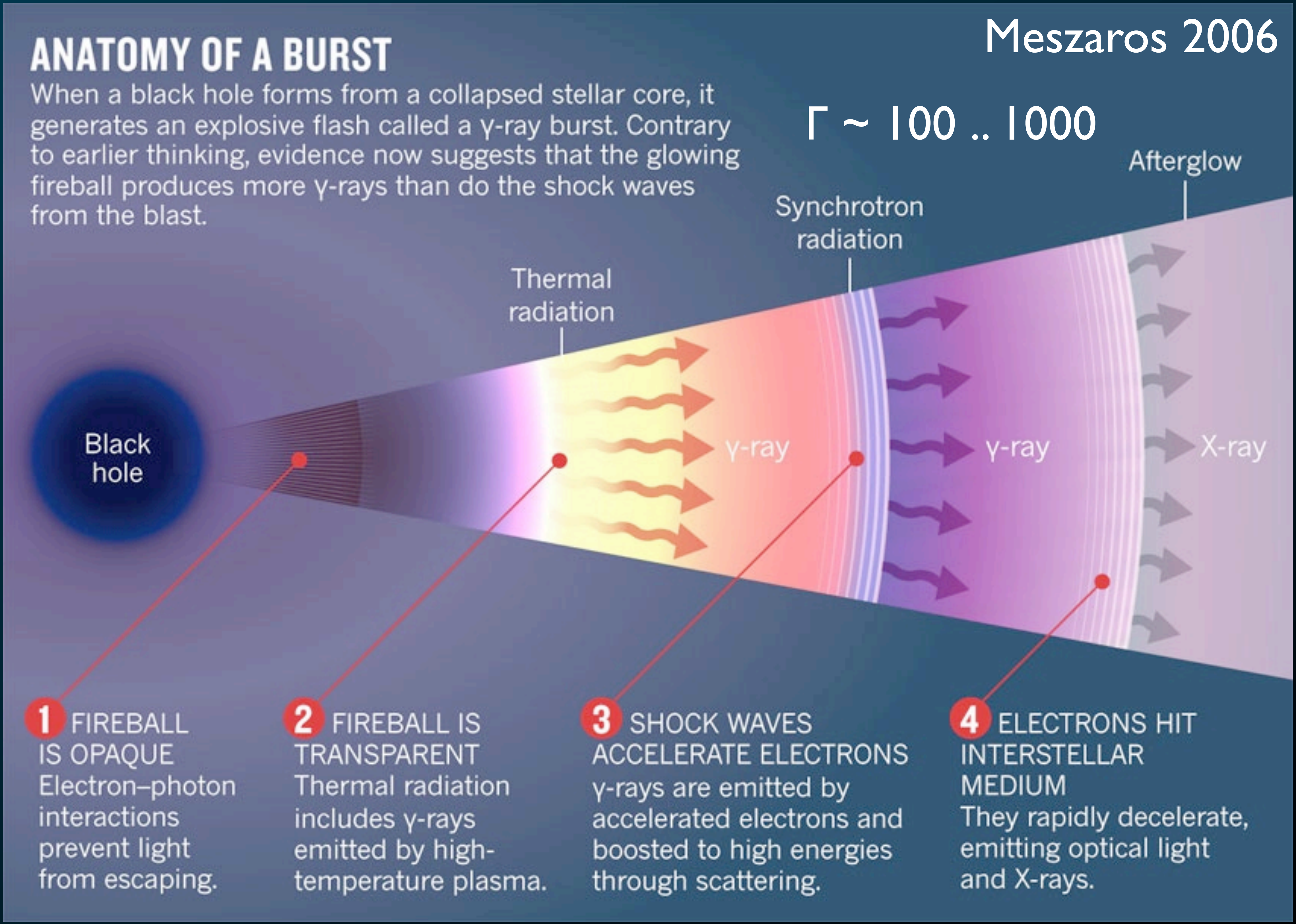


afterglow-like smooth power-law temporal decay

Distinct properties imply distinct physics

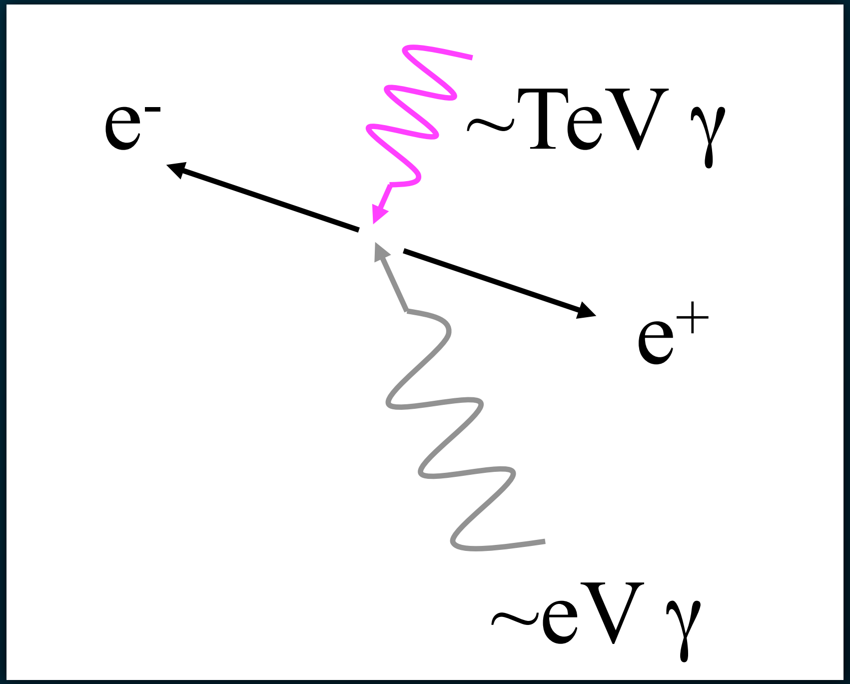
* Plots are from Fermi LAT GRB catalog

GRB emission mechanisms

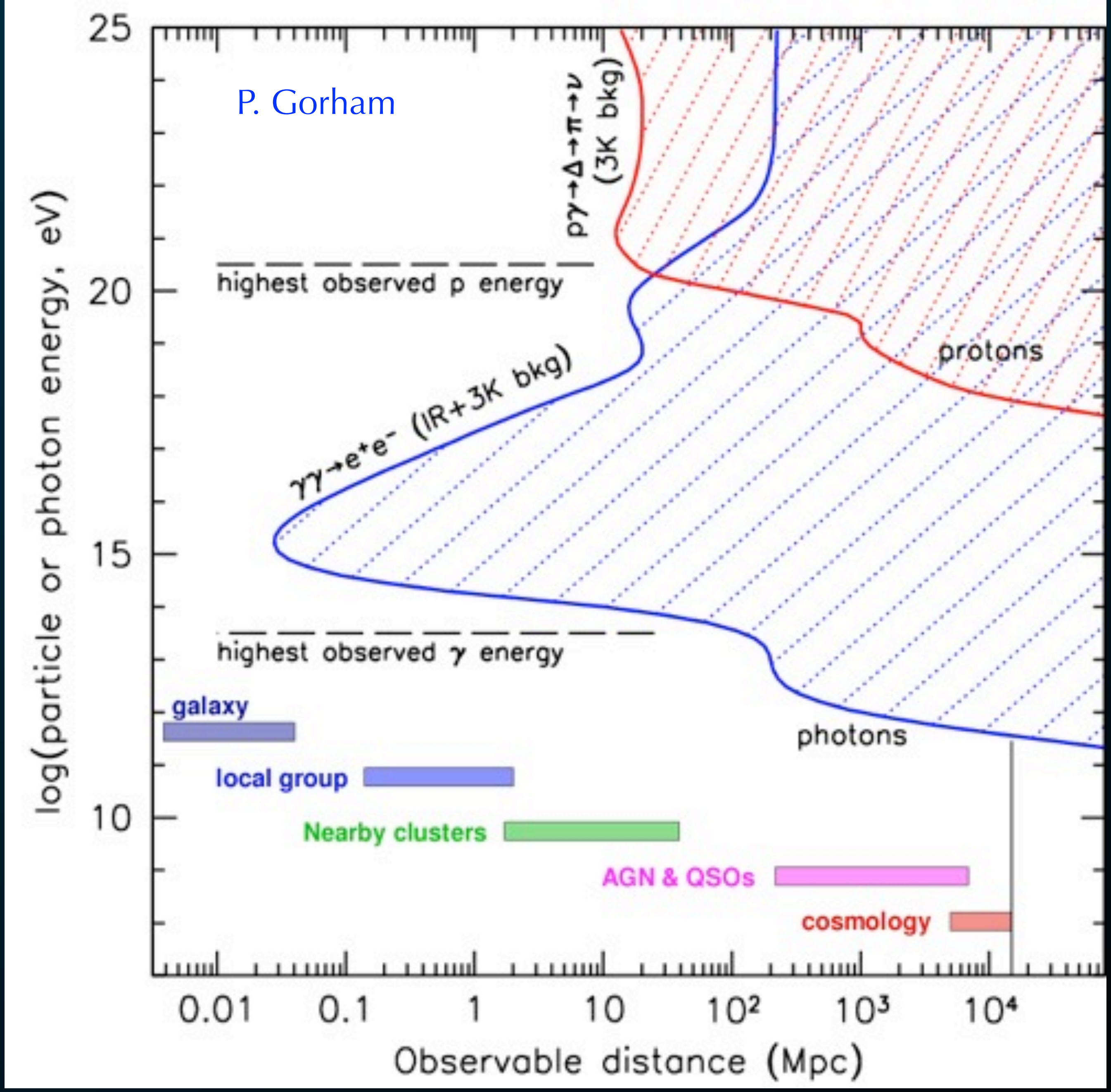


EBL absorption

Extragalactic background light (EBL) = integrated luminosity of the universe at UV, optical and IR frequencies (star formation history, dust, ...)



interactions with EBL define gamma ray horizon



gamma rays from GRBs (z ~ 1) probe near-IR, visible and UV EBL

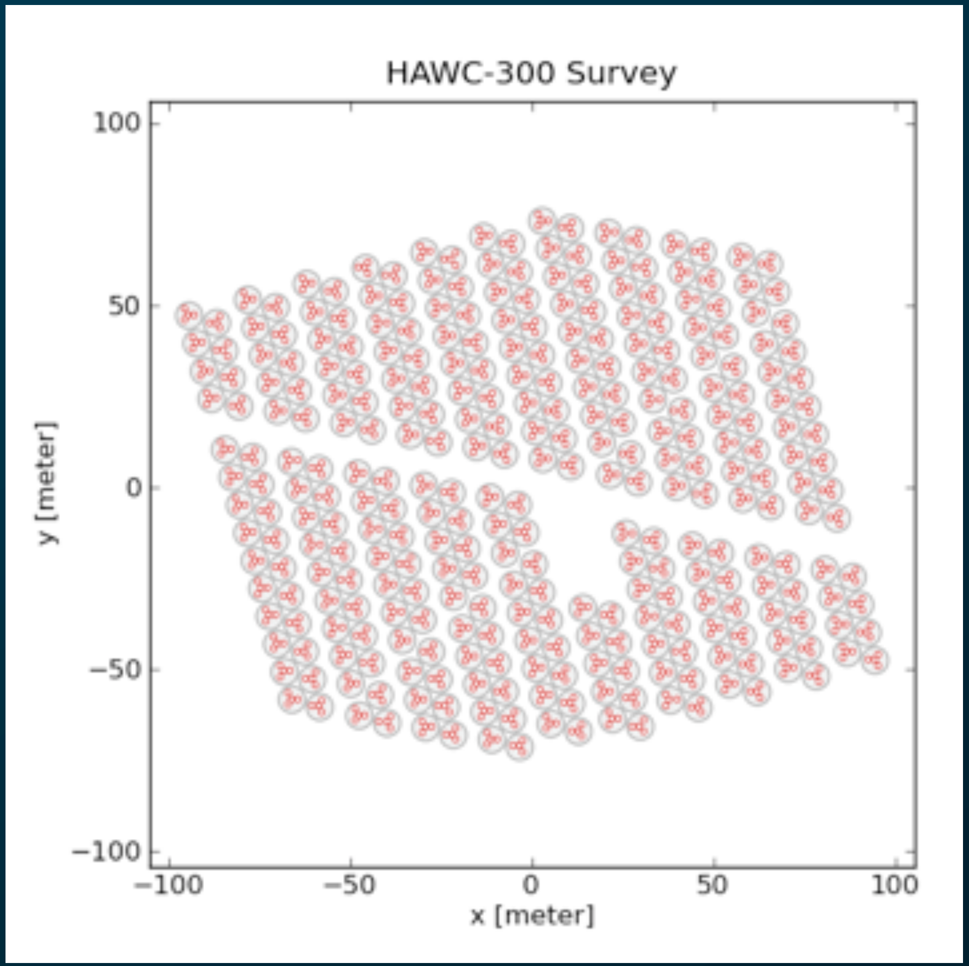
HAWC - High Altitude Water Cherenkov Observatory

location: saddle point between Volcán Sierra Negra (also site of Large Millimeter Telescope) and Pico de Orizaba

Collaboration of ~100 scientists from US & Mexico

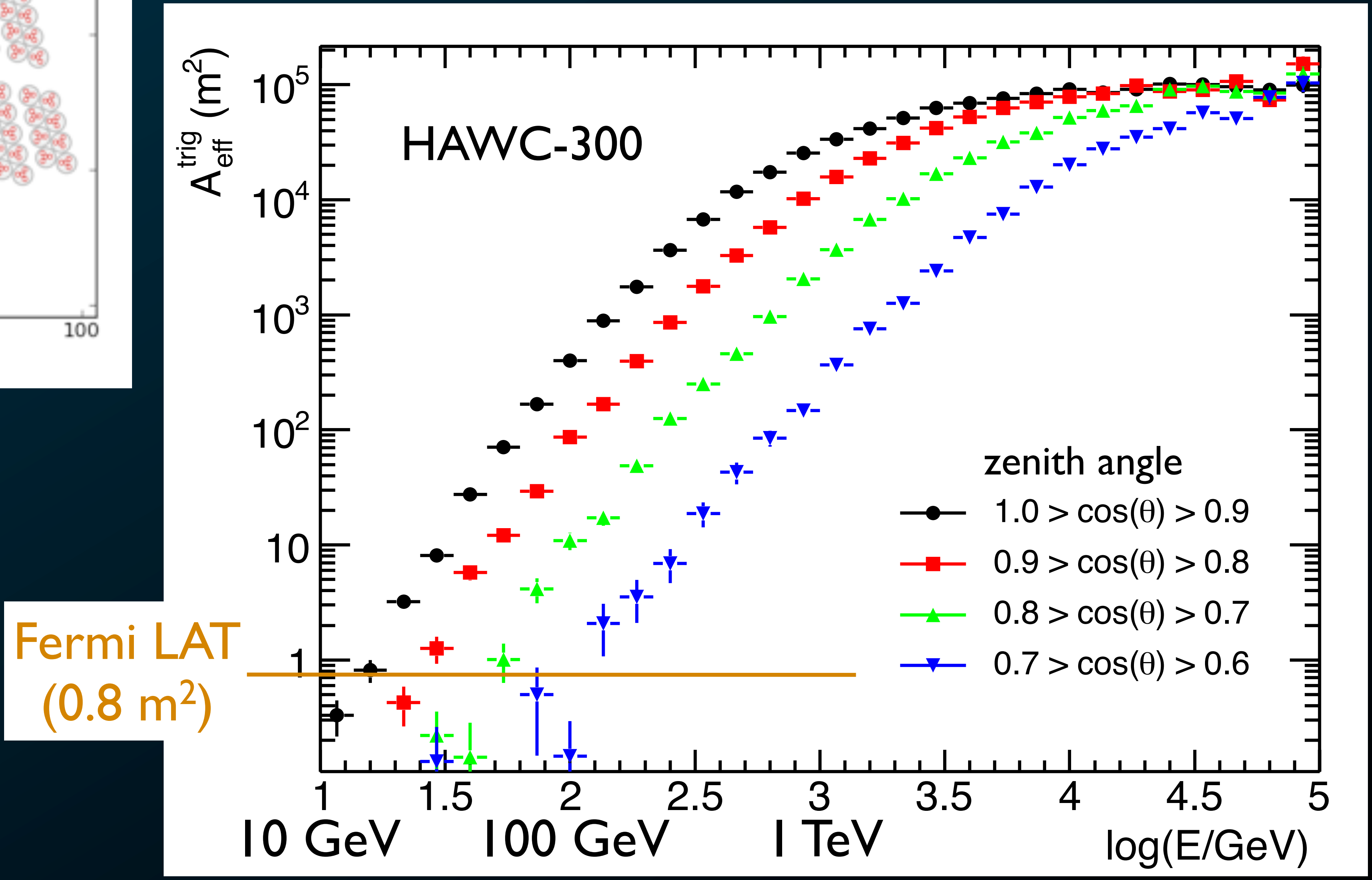
7.3 m dia x 4.5 m tall

Detector layout and effective area



- 300 water Cherenkov detectors (“tanks”)
- ~20,000 m² area
- >60% active Cherenkov volume

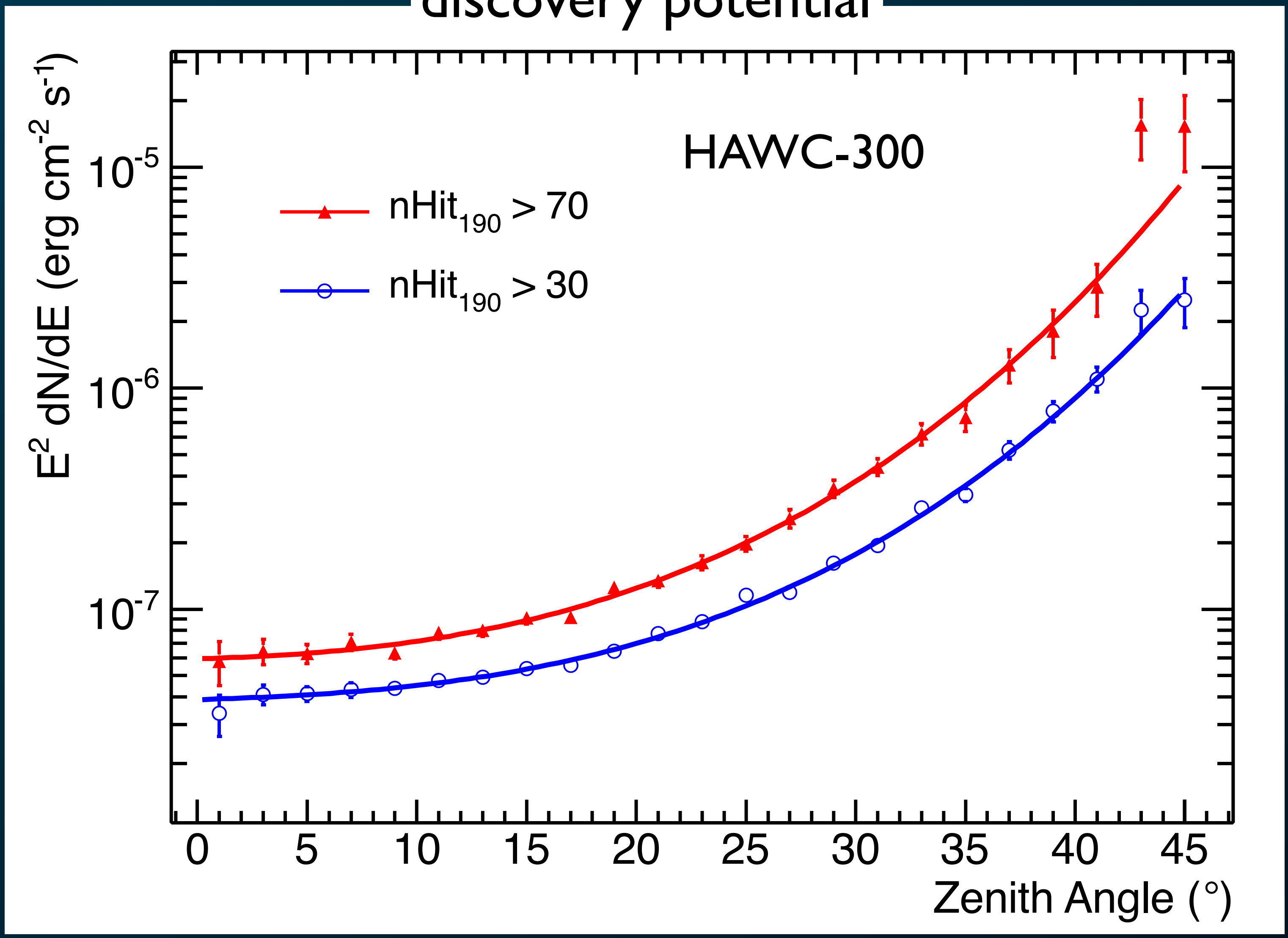
- Effective area up to ~10^5 m² in multi-TeV regime
- Energy threshold ~30 GeV
- >100 m² at 100 GeV



Nhit > 30; Angular error < 1.1°; No hadron rejection cut applied

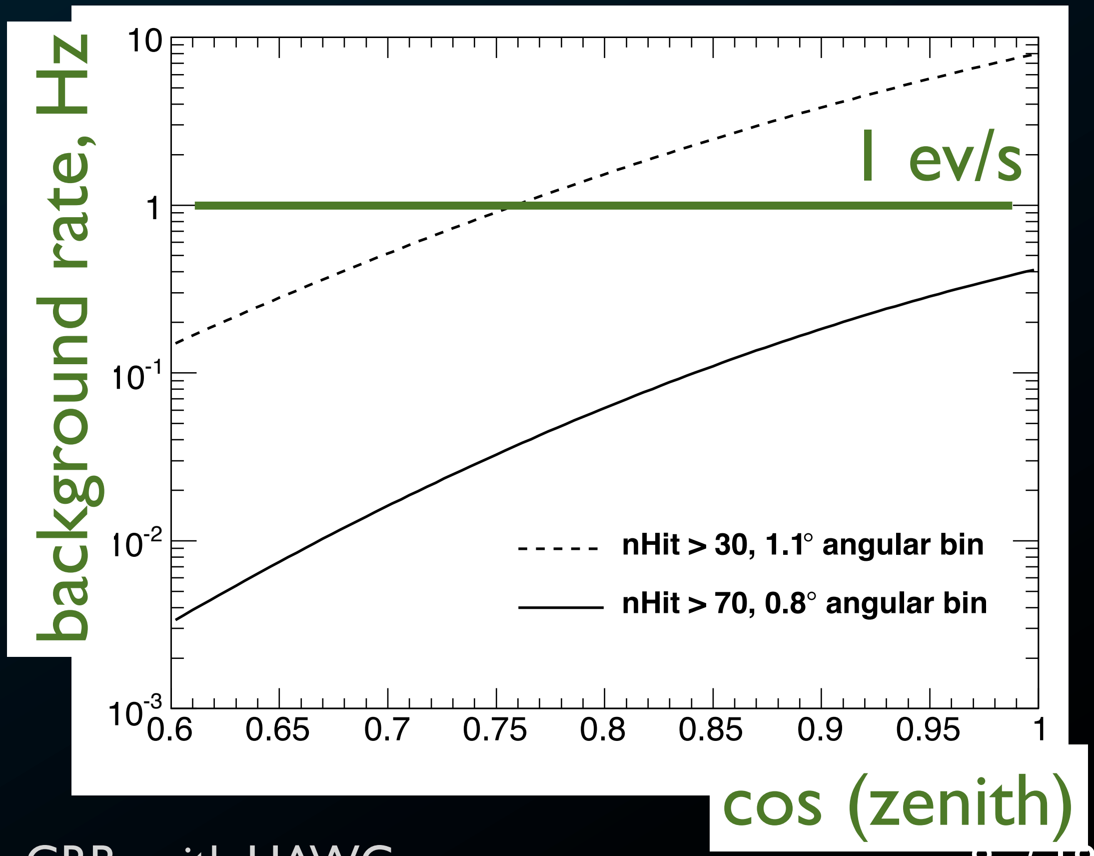
Sensitivity to GRBs vs zenith angle (main DAQ)

discovery potential



field of view limited by atmospheric depth (~45° from zenith)

Narrow time window (duration of GRB) compensates for poor gamma-hadron separation and angular resolution at low energy (~ 1° at 100 GeV)

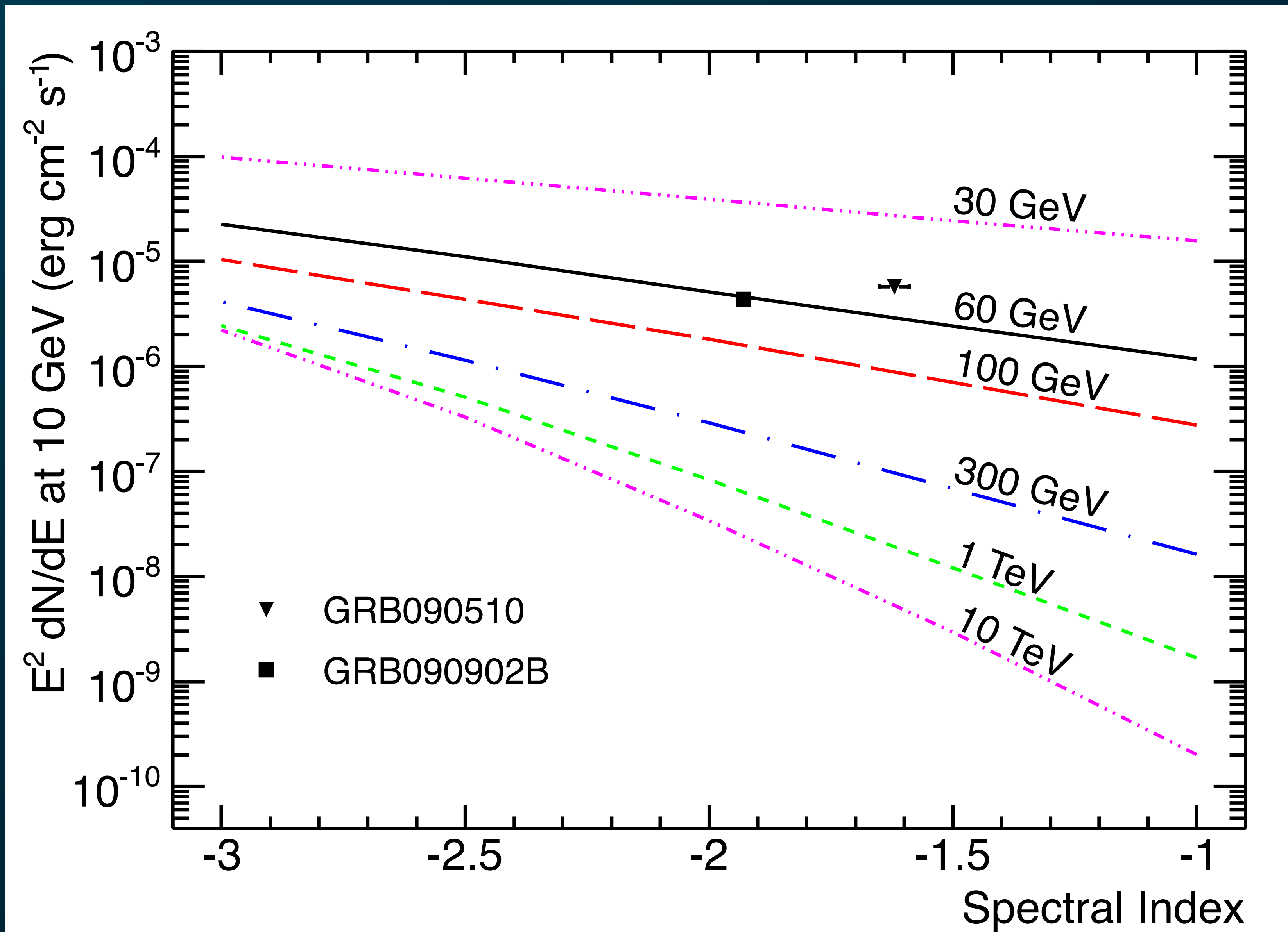


Shown is the flux level detectable at 5 sigma significance with 50% probability

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

wide field of view provides advantage over IACTs

Sensitivity to transients (standard main DAQ analysis)



Simulated GRB:
T = 1 s
zenith = 20°

Power law spectrum
with Heaviside cutoff

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

trigger: Nhit > 30

* Correlated noise from simultaneous hadronic showers not included in simulation

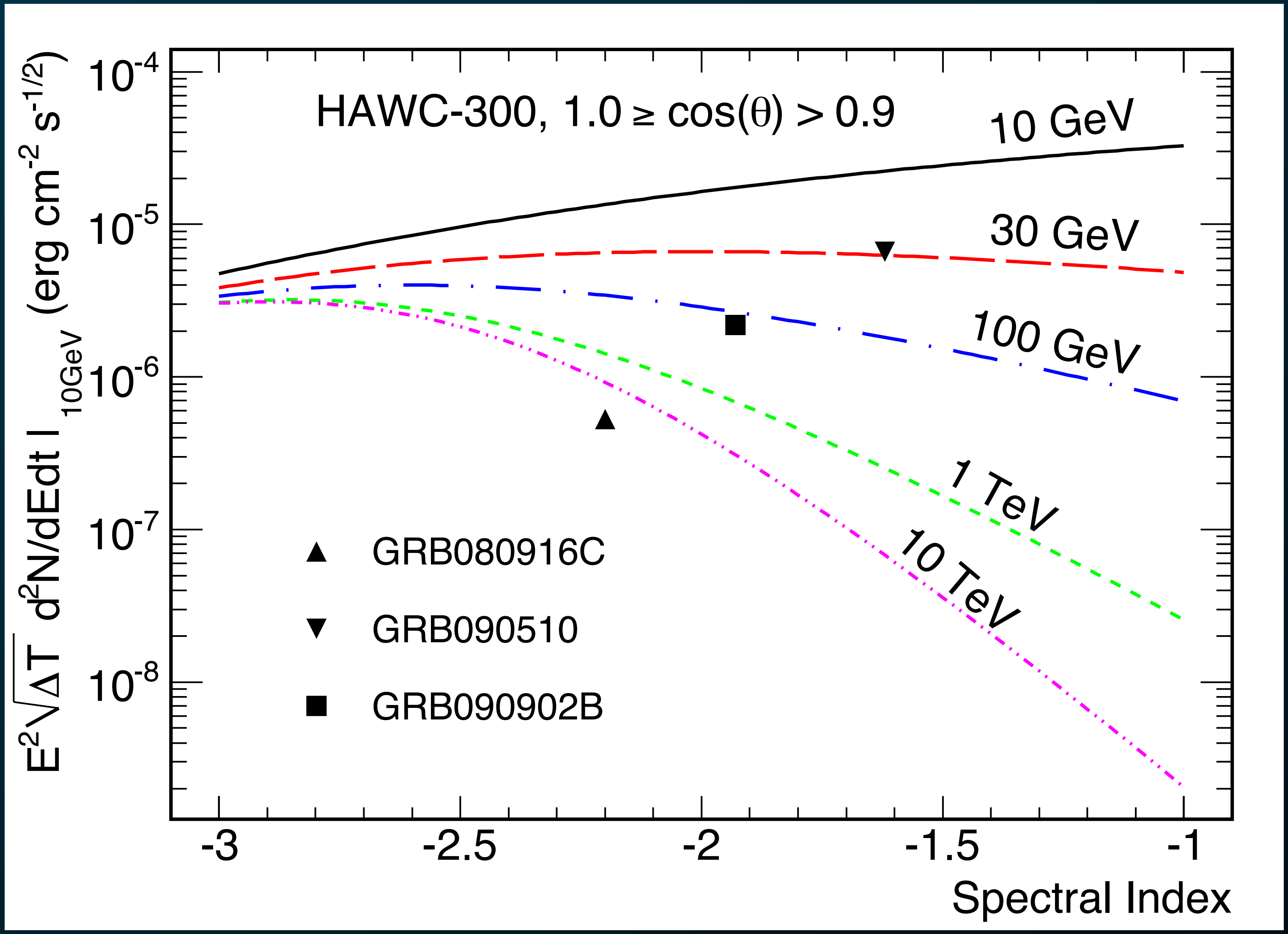
Brightest GRBs detected by Fermi should be observable with 5 sigma significance if cutoff is above ~50 GeV

For details see Astropart. Phys. 35 (2012) 641-650.

Also see I. Taboada, R.C. Gilmore, Prospects for the detection of GRBs with HAWC, arXiv:1306.1127

Sensitivity to transients (Scaler DAQ)

- Scaler DAQ measures PMT rates
- GRB produces simultaneous increase of counting rates in all PMTs
- Sudden increase in rates may reveal a GRB

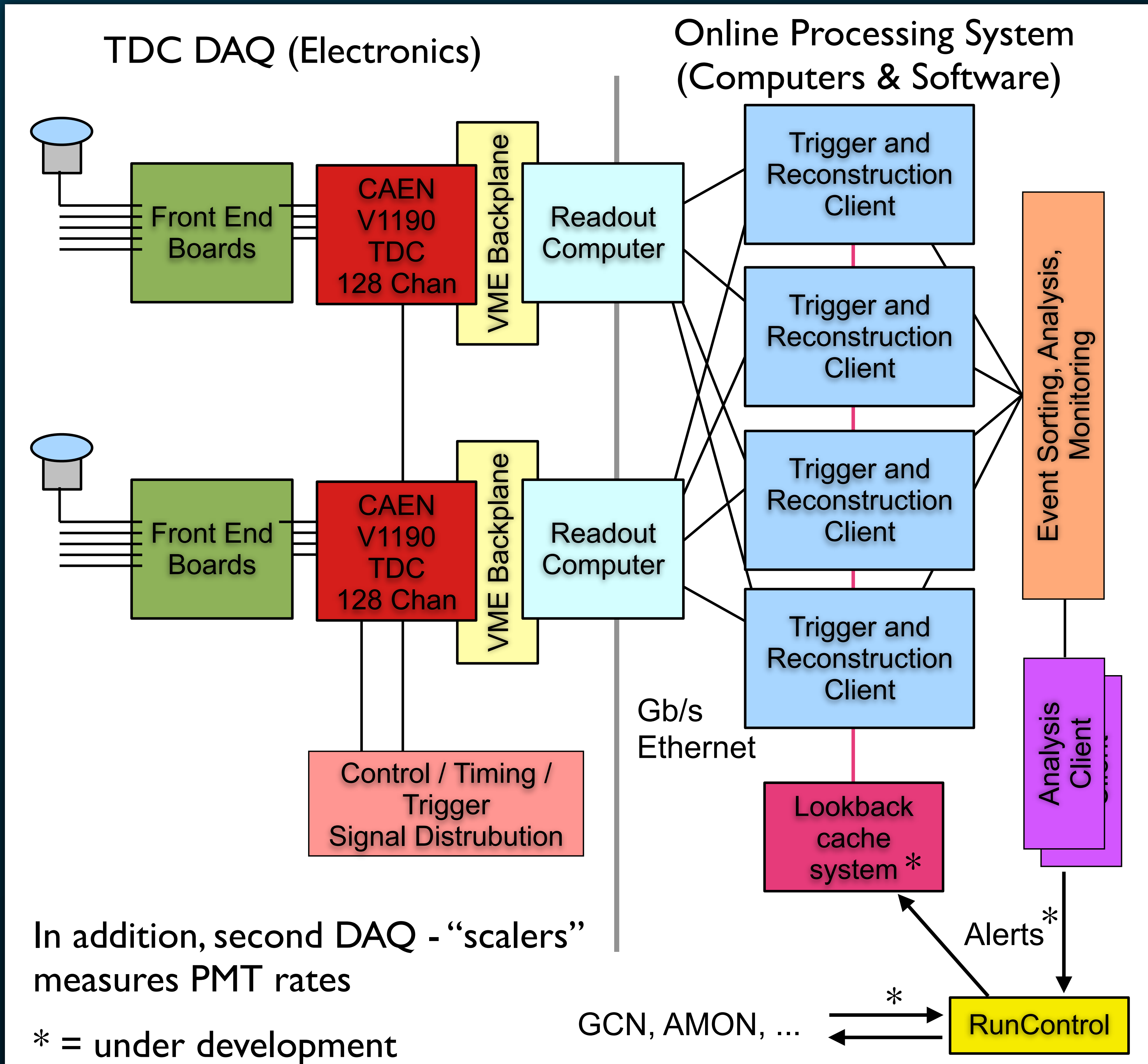


Scaler DAQ provides sensitivity down to a few GeV

For details see *On the sensitivity of the HAWC observatory to gamma-ray bursts, by HAWC Collaboration, Astropart.Phys. 35 (2012) 641-650. Also arXiv: 1108.6034 [astro-ph.HE].*

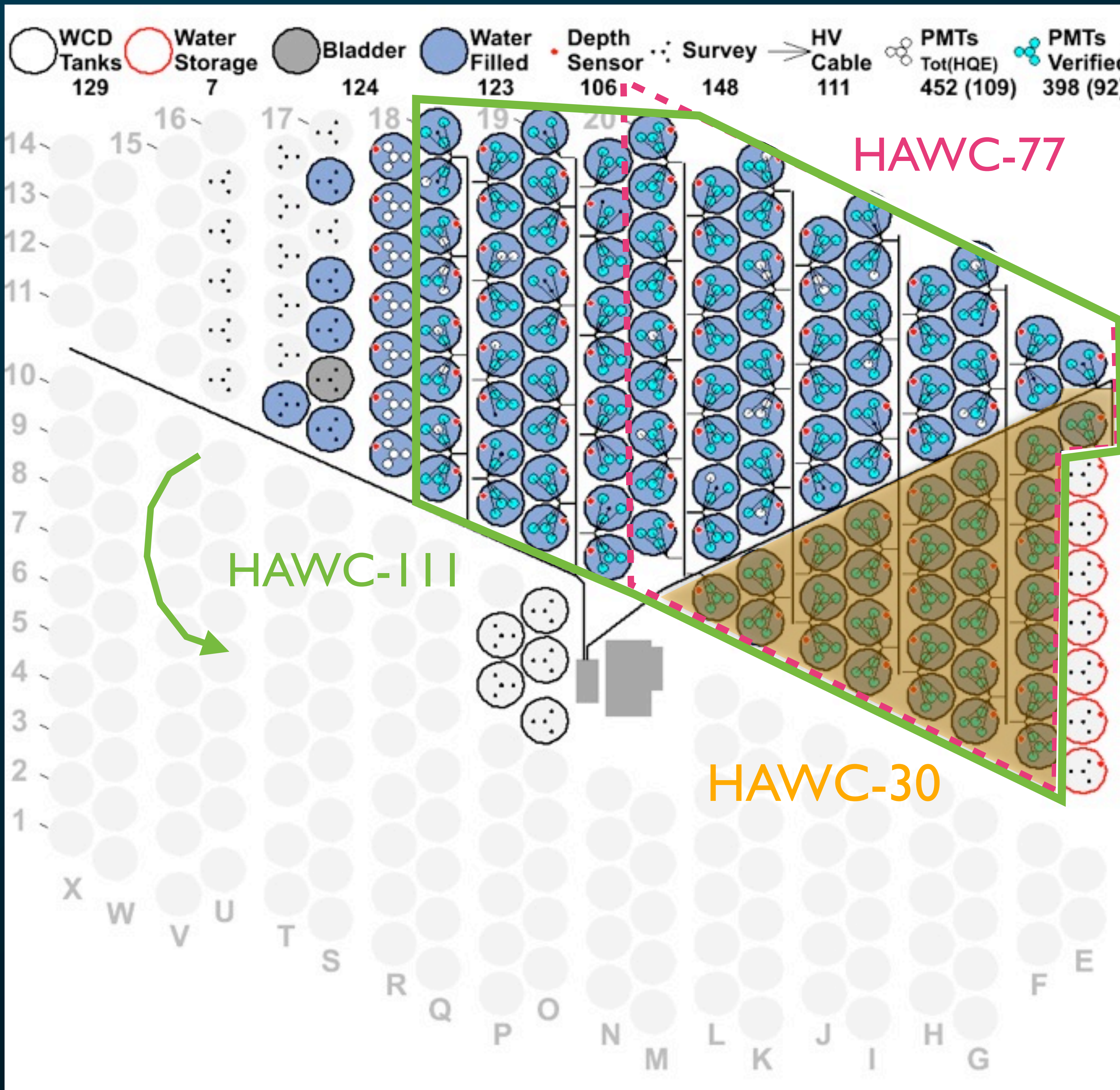
Scaler analysis complements the main DAQ analysis, covering short GRBs with soft spectra and cutoffs <100 GeV

"Triggerless" DAQ



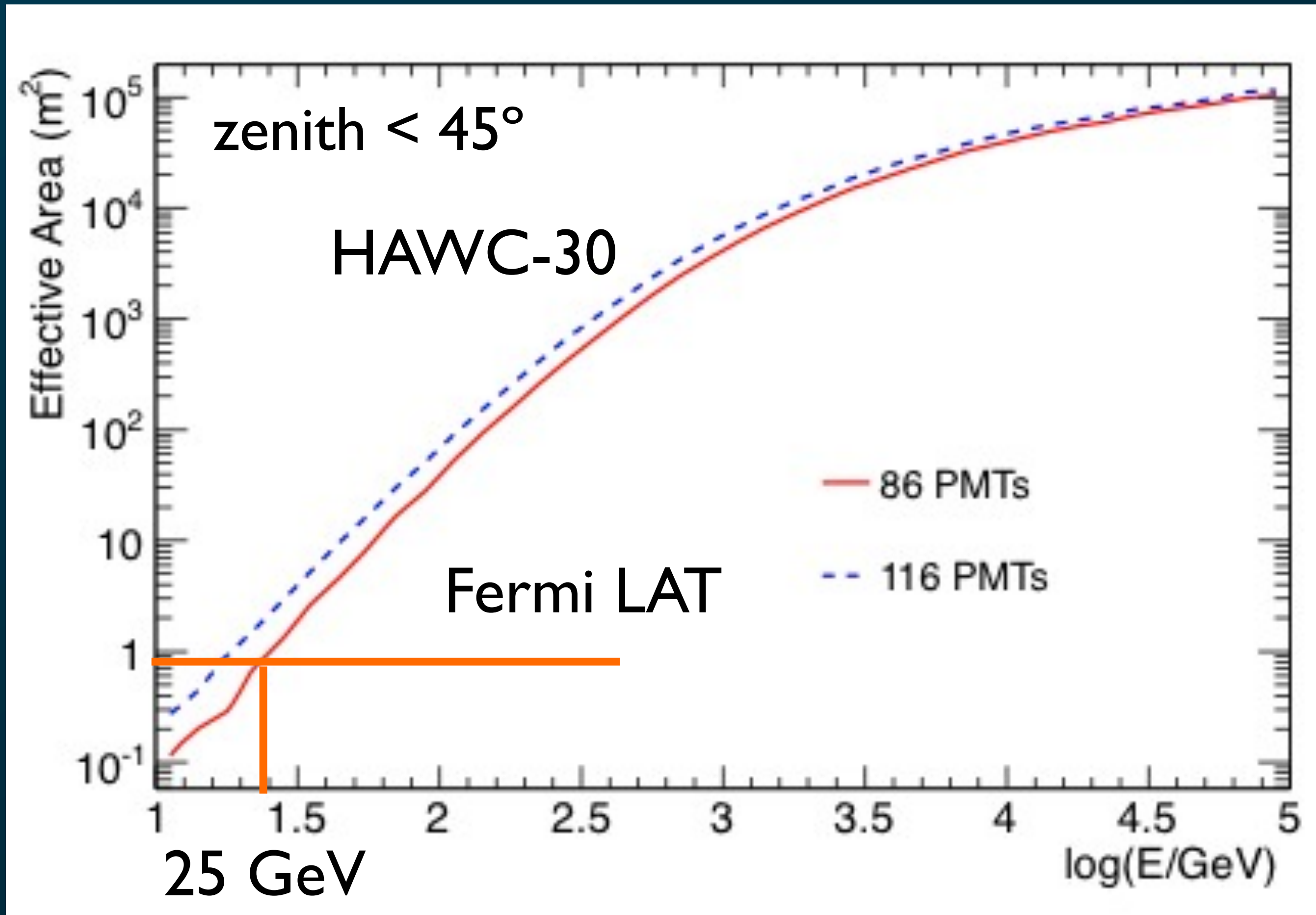
- TDCs synchronized by common 40 MHz clock
- Continuous acquisition with common 40 kHz trigger (25 μs data blocks)
- Each TDC is read out by a VME single-board computer (SBC)
- DAQ records ALL photoelectrons from ALL 1200 PMTs = 500 MB/sec
- Sets of 1000 data blocks pushed to processing clients over Ethernet and merged with those from other TDCs
- Triggering is done entirely in software (requires ~10% of ~200 CPU cores on-site)
- Software Trigger reduces data to 20 MB/sec (600 TB/yr)

HAWC construction progress



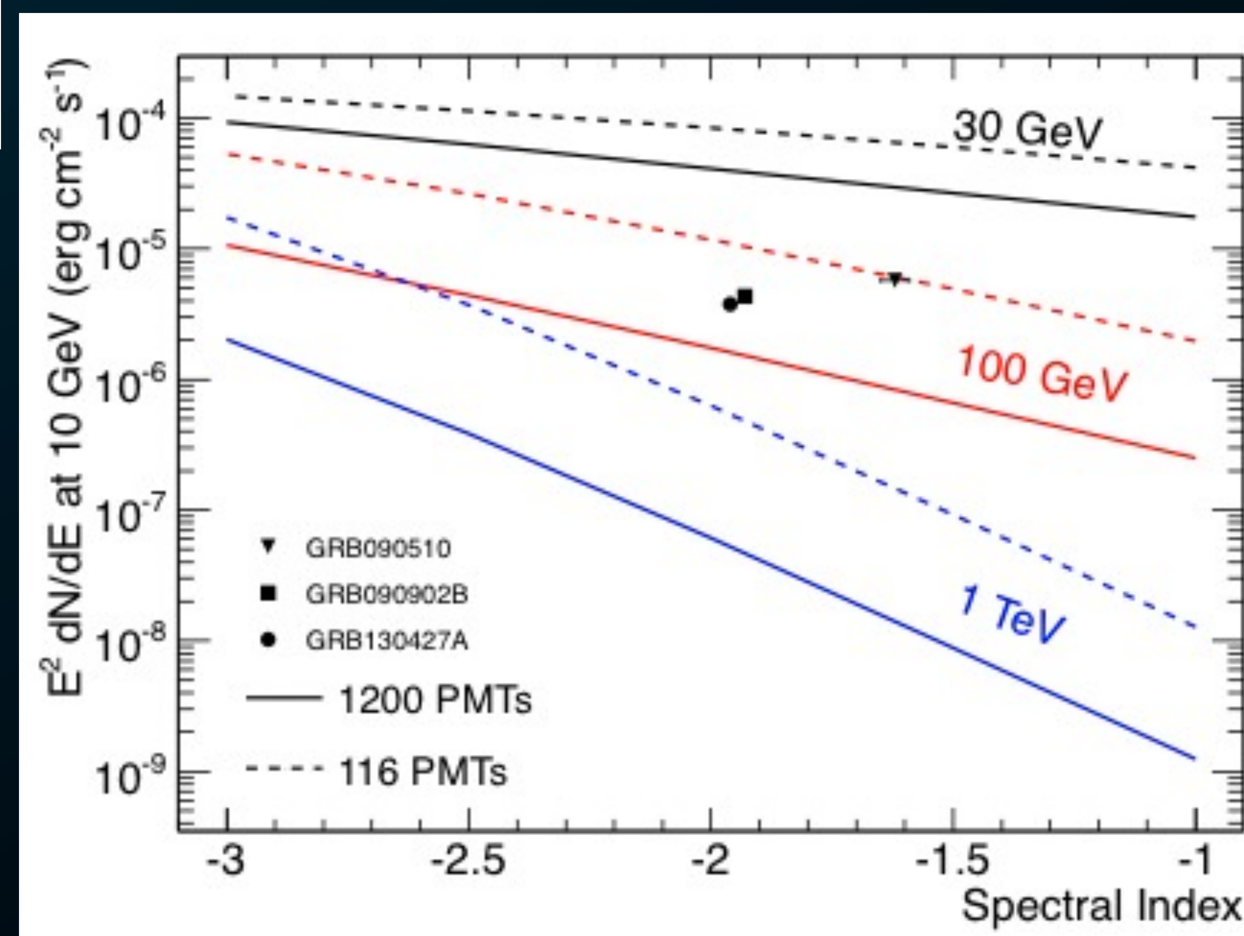
- Sep 2012: first 29 tanks completed; regular data taking begins
- January-March 2013: high QE PMTs added
- mid-May: 77 tanks operational
- June: >90% uptime reached (automatic running)
- Now: operating with 111 tanks / 400 PMTs
- summer 2014: expect complete detector

Science with partially built HAWC array



Thanks to low trigger threshold, the partially built array already provides > 1 m^2 effective area at E > 25 GeV

Angular resolution with 30 tanks is ~ 3° (for E ~ 100 GeV)



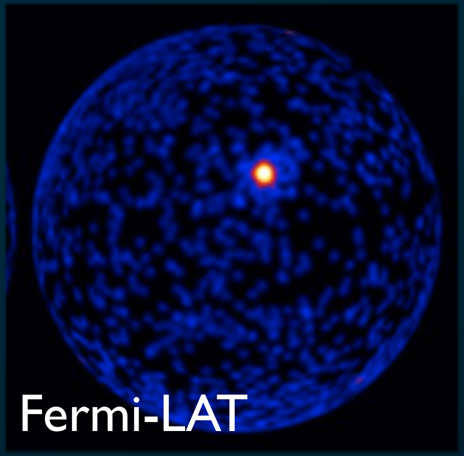
Caveat: gamma-hadron separation is very poor at low energy

HAWC-30 is ~10x less sensitive to GRBs than HAWC-300

HAWC is already capable of detecting GRBs

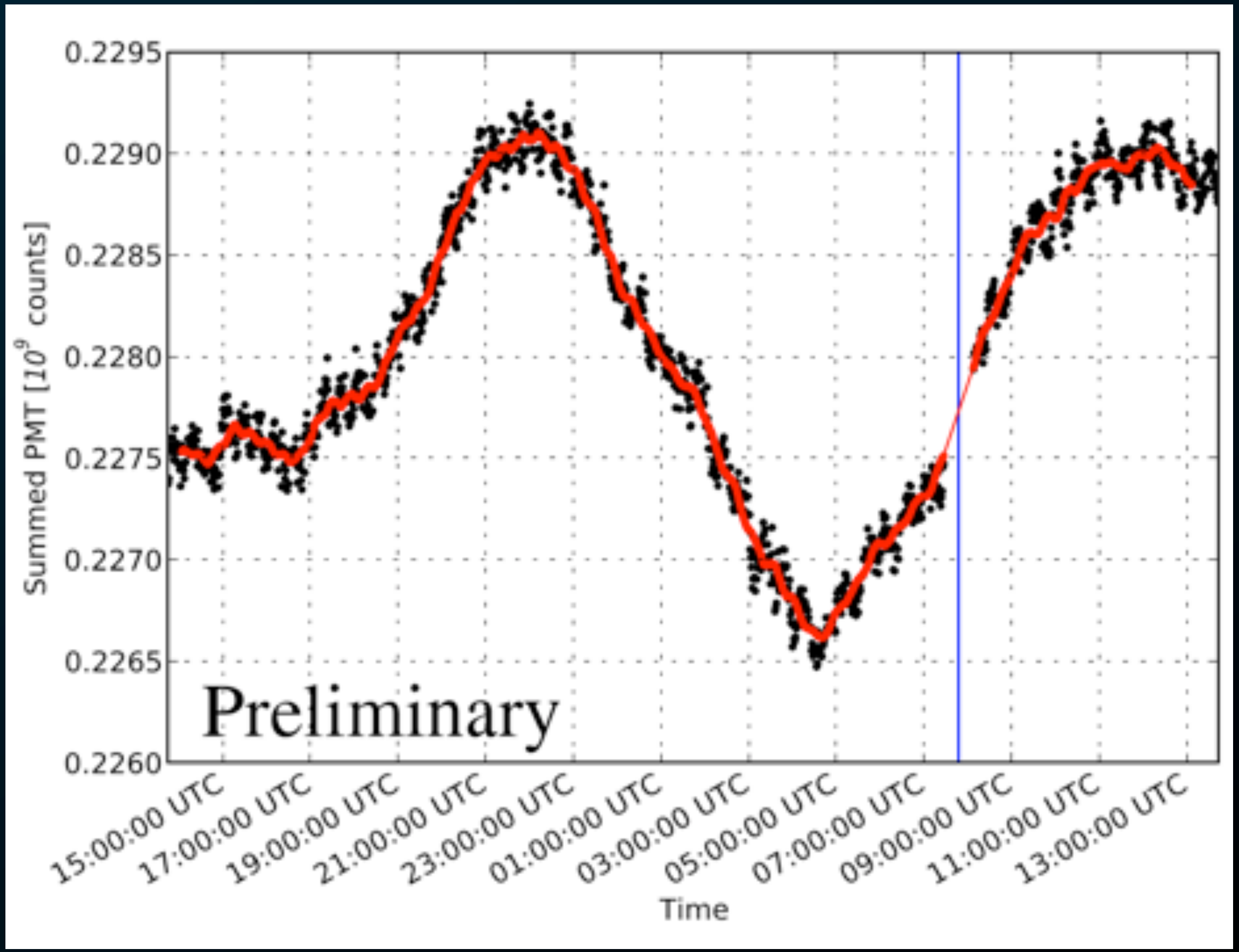
GRB 130427A

- Brightest GRB detected in 30 years (2×10^{-3} erg/cm^2)
- Highest energy photon ever recorded from a GRB - 94 GeV
- low redshift z = 0.34
- zenith angle at HAWC = 57º and setting (very bad)
- HAWC main DAQ was off, but PMT rates were recorded by the scalers DAQ



? →

summed PMT rate and moving average



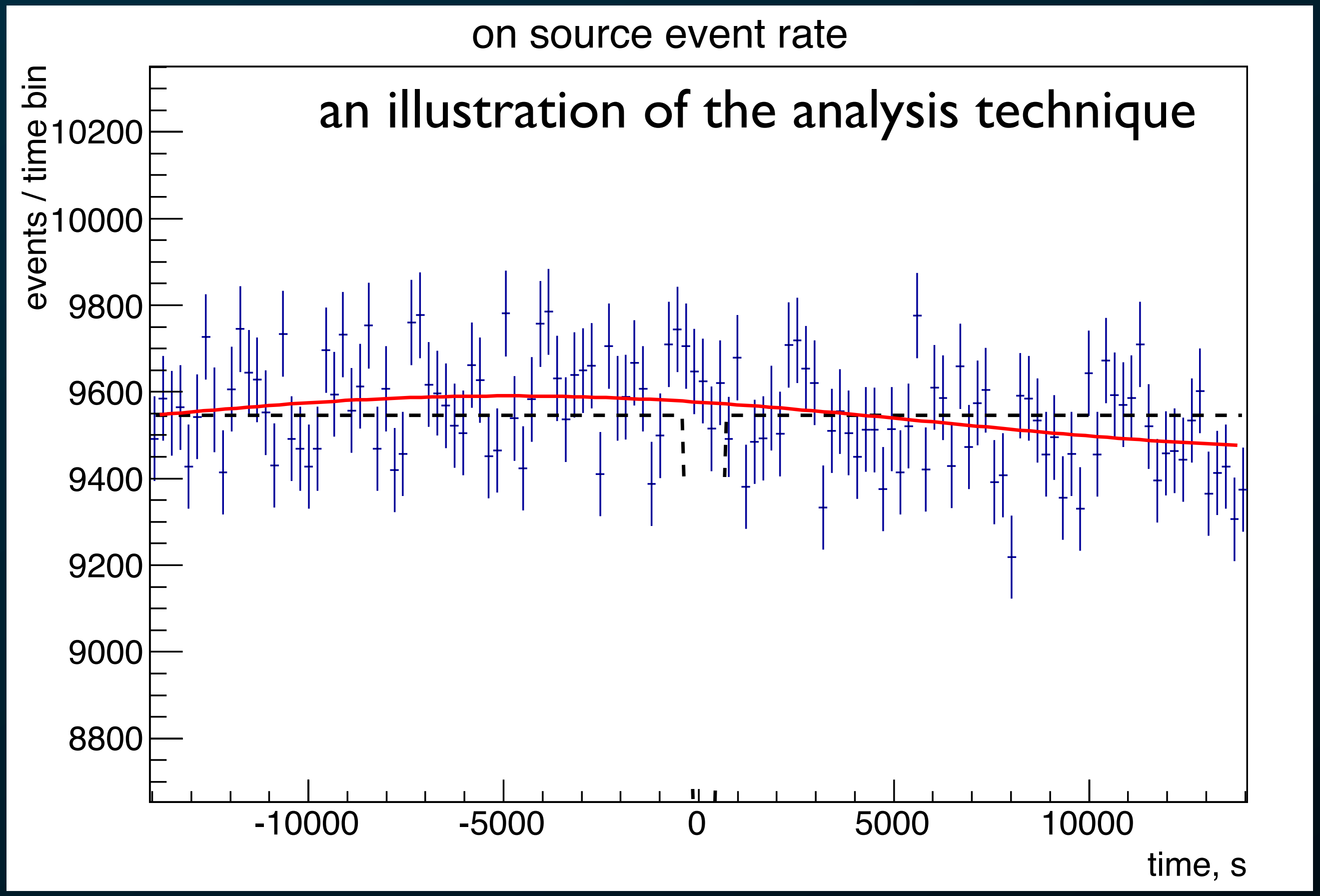
6 different time windows examined, no excess found (GCN circular 14549)

would be seen at ~5σ if it happened near zenith

For details see
D. Lennarz et al., Sensitivity of the HAWC Observatory to Gamma-ray Bursts Using the Scaler System, ICRC 2013

GRB search using reconstructed air shower data

- Search for high energy counterparts of Fermi, Swift and IPN GRBs
- Compare event count in a circular angular bin around the known position of GRB with a background estimate obtained from off-time data (3° radius circle for HAWC-95 and HAWC-111; 4° for earlier configurations)
- Time windows: T90 from the low energy instrument and 3×T90
- No gamma-hadron separation
- Keep light curve blinded unless a > 5 σ excess is found

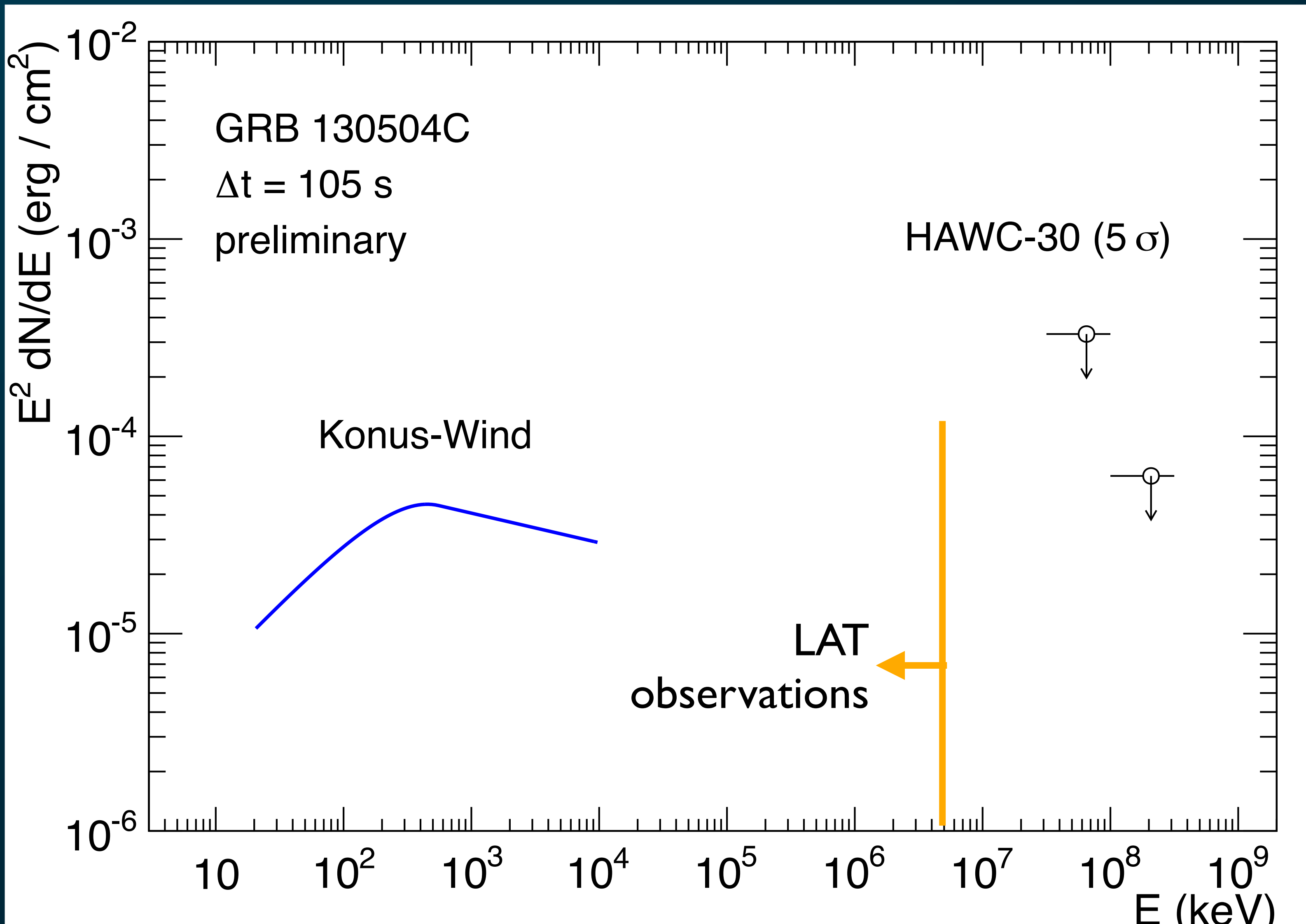


23 GRBs in HAWC FoV analyzed so far

No excess found

More sensitive analyses are being developed: a model-dependent likelihood analysis and a model-independent scanning time window analysis (K Sparks, ICRC 2013)

GRB 130504C



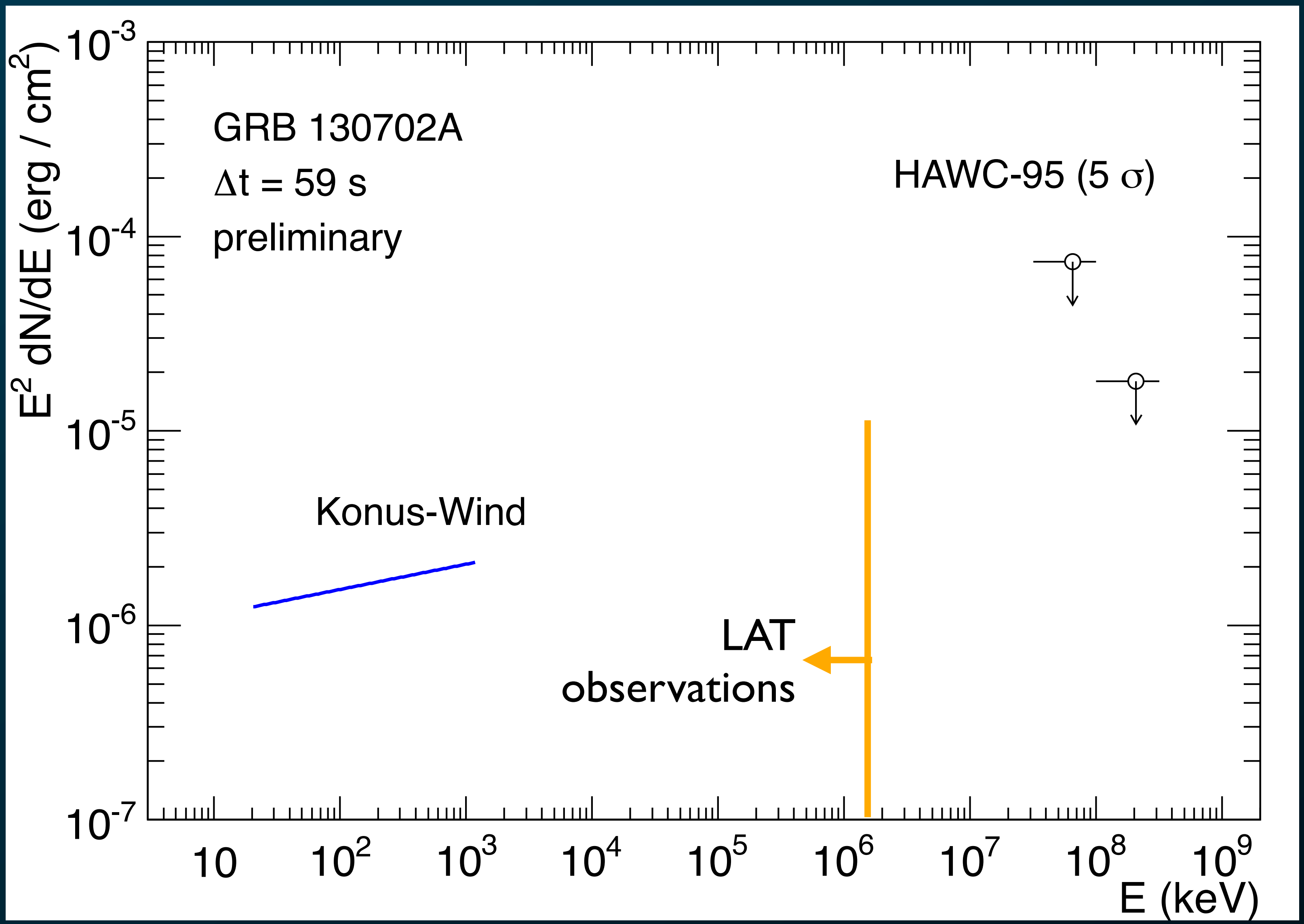
- A high fluence GRB detected by Fermi LAT (also by Fermi GBM and Swift XRT)
- LAT detected > 70 photons above 100 MeV (GCN circular 14574)
- highest energy LAT photon ~ 5 GeV
- Zenith angle at HAWC: 30º
- HAWC was taking data with 28 tanks

* HAWC limit shows the flux level corresponding to 50% probability of 5 σ detection
* Fermi LAT spectral analysis was not available at this time

No excess observed in HAWC (upper limit set)

All upper limits are preliminary
A factor 2 improvement is expected with the final analysis

GRB 130702A



- Fermi LAT observed > 5 photons at E > 100 MeV (GCN circular 14971)
- Highest energy photon observed by LAT ~1.5 GeV
- Low energy instrument suggest hard power law index = -1.65
- Optical afterglow observed
- Redshift = 0.145
- HAWC was taking data with 95 tanks

No excess observed in HAWC

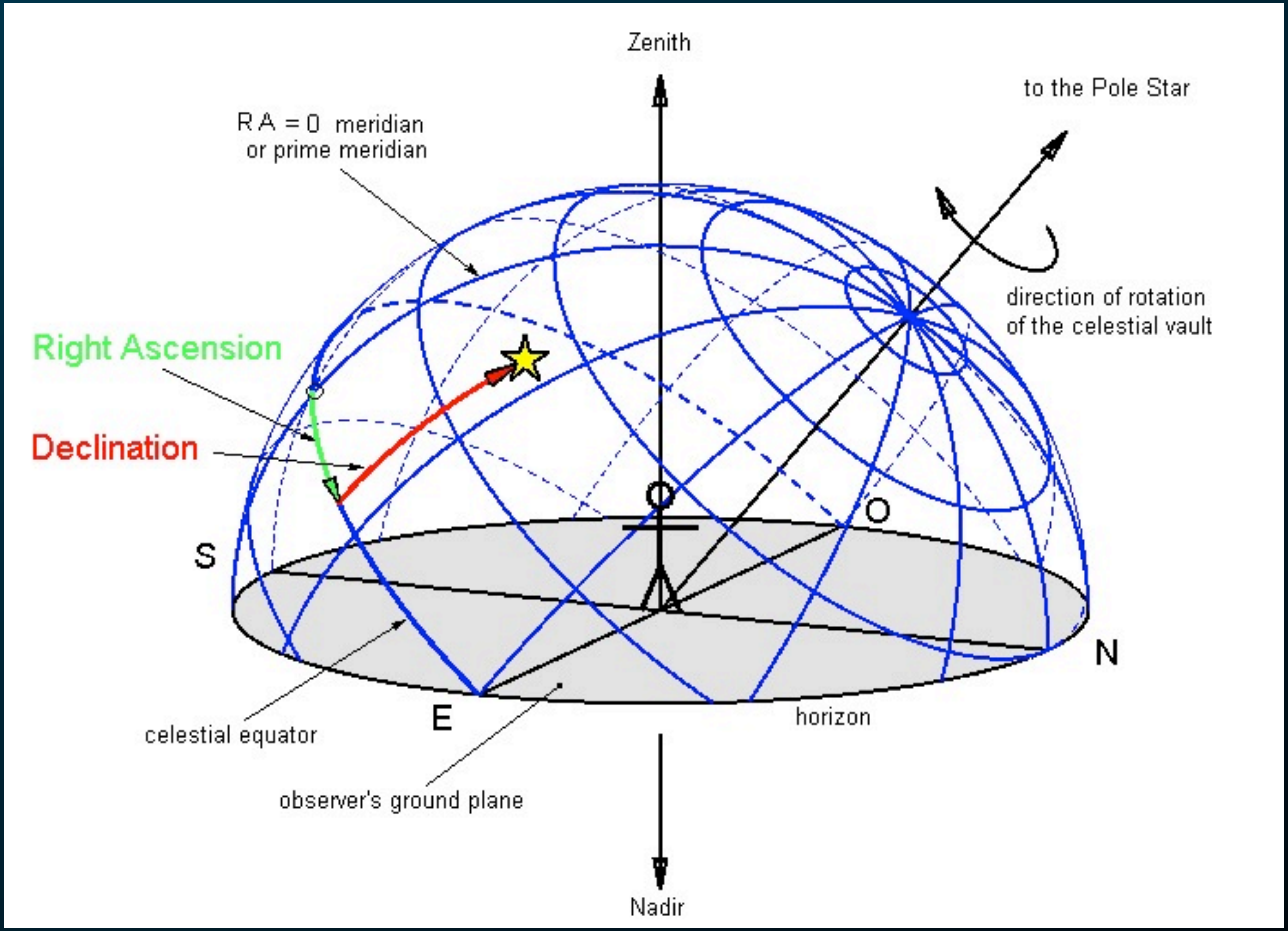
All upper limits are preliminary
A factor 2 improvement is expected with the final analysis

Summary

- The high altitude, high duty cycle and large field of view make HAWC a suitable detector of gamma-ray bursts
- HAWC is able to observe the high-energy power law components of GRBs that extend at least up to 30 GeV
- HAWC measurements will provide valuable information on the high-energy cutoff in the intrinsic GRB spectra and/or EBL absorption cutoff, as well as temporal behavior of HE emission
- A search for high energy counterparts of known GRBs has been conducted using data from the partially built array (23 bursts analyzed). Within 5σ, the data for all bursts is consistent with the background-only hypothesis. Preliminary upper limits were presented for a subset of bursts
- HAWC is on watch for gamma-ray transients and will send alerts to the community


Thank you for your attention!
(backup slides follow)

Background estimation



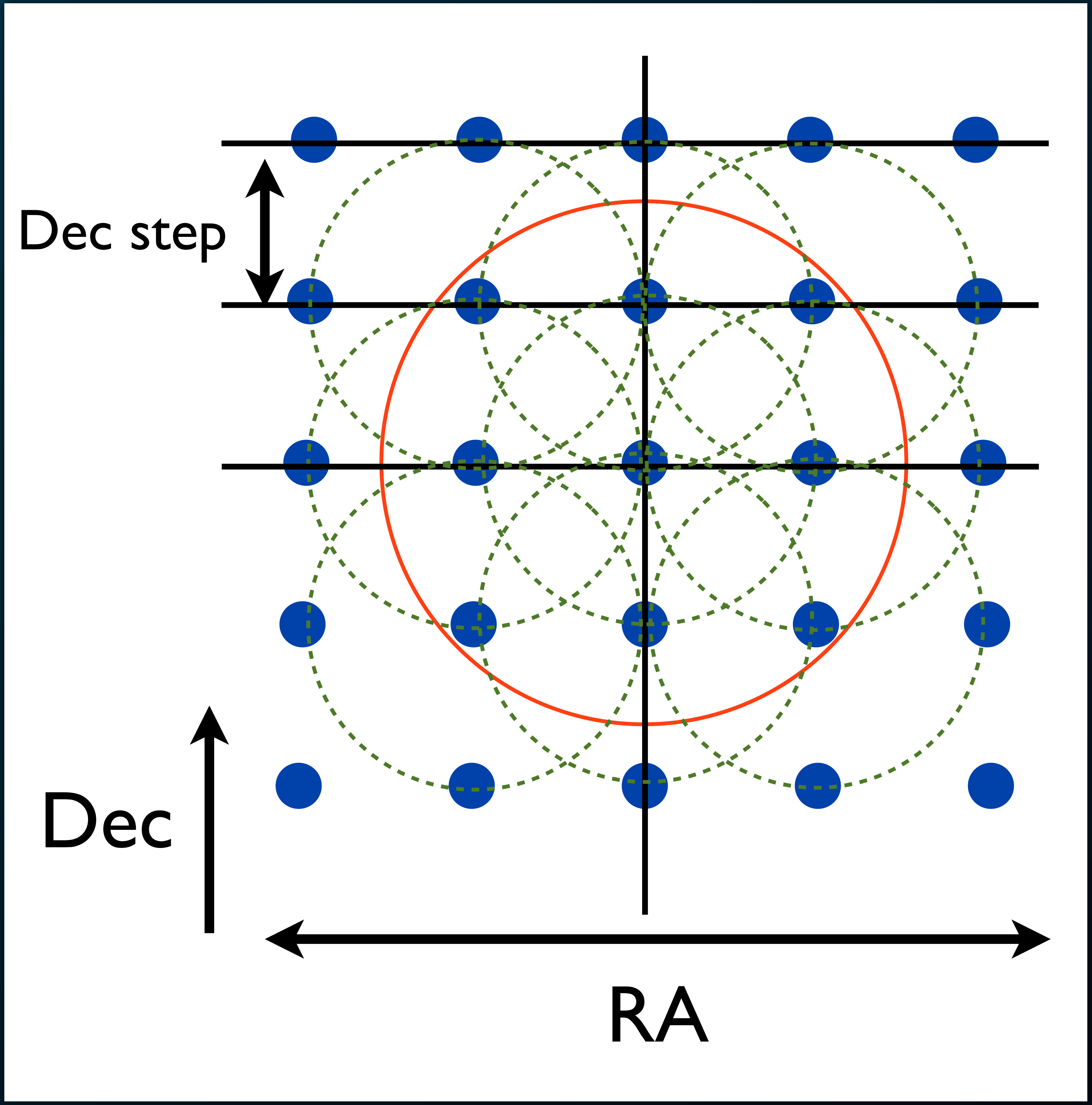
During time interval (0, T) follow the source at RA, Dec

During time interval (T, 2T) follow imaginary source at RA+T, Dec

Due to difference between solar day and

time interval of 60 s corresponds to 60 * 24 / 23.9344699 = 60.0164 angular seconds

Tiled analysis



Tiling grid is centered at the assumed RA, Dec of the source

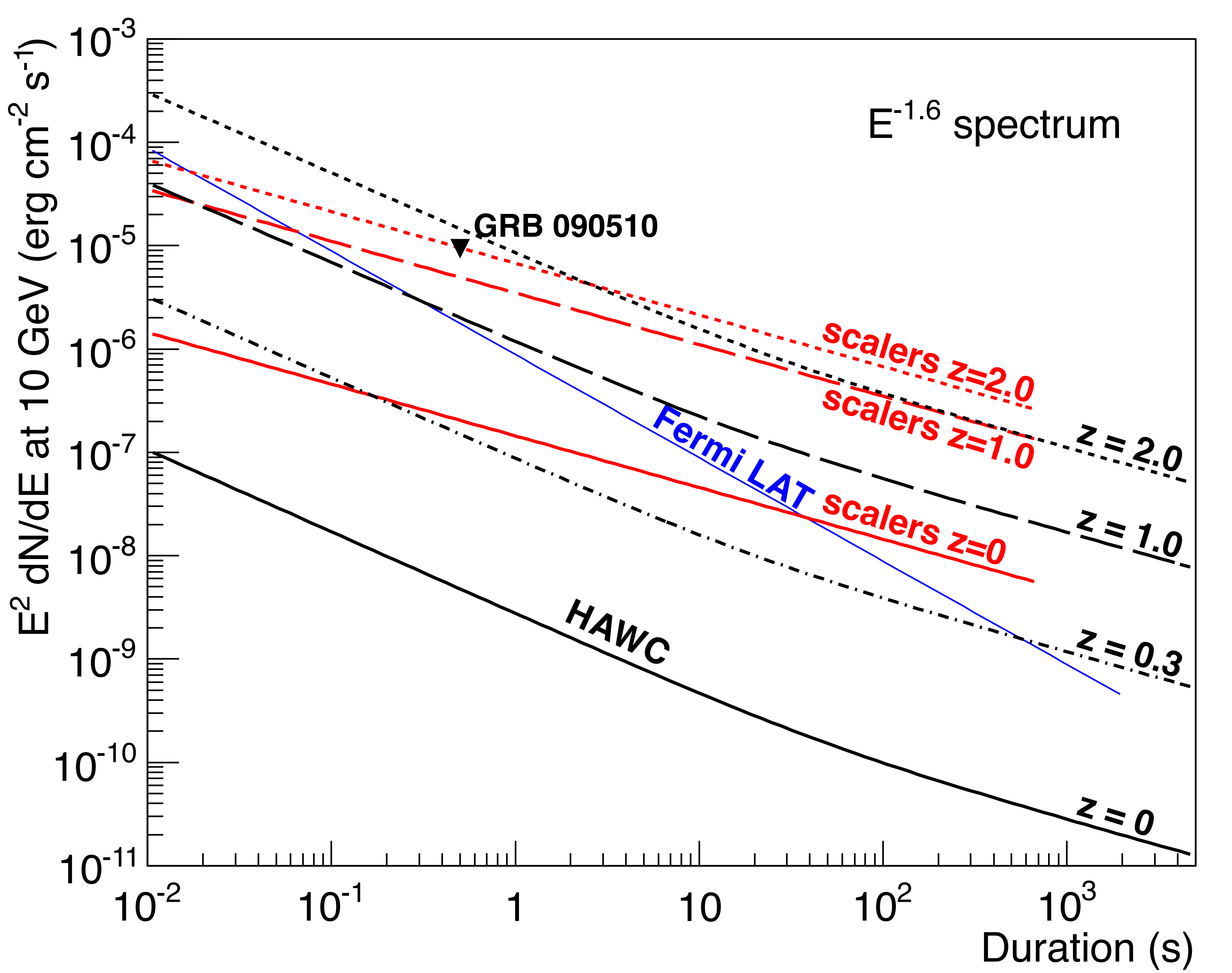
equal declination rings are added every 3 degree in both directions

each ring is tiled with a step = Dec_step * cos(Dec)

The GRB search is executed for each tiling grid node that falls within the accept radius

For GBM burst with statistical localization error **r**, we define the “accept” radius as
$R = \mathrm{sqrt}((4\ \mathrm{deg})^2 + r^2) + 1\ \mathrm{deg}$

Sensitivity vs. 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)

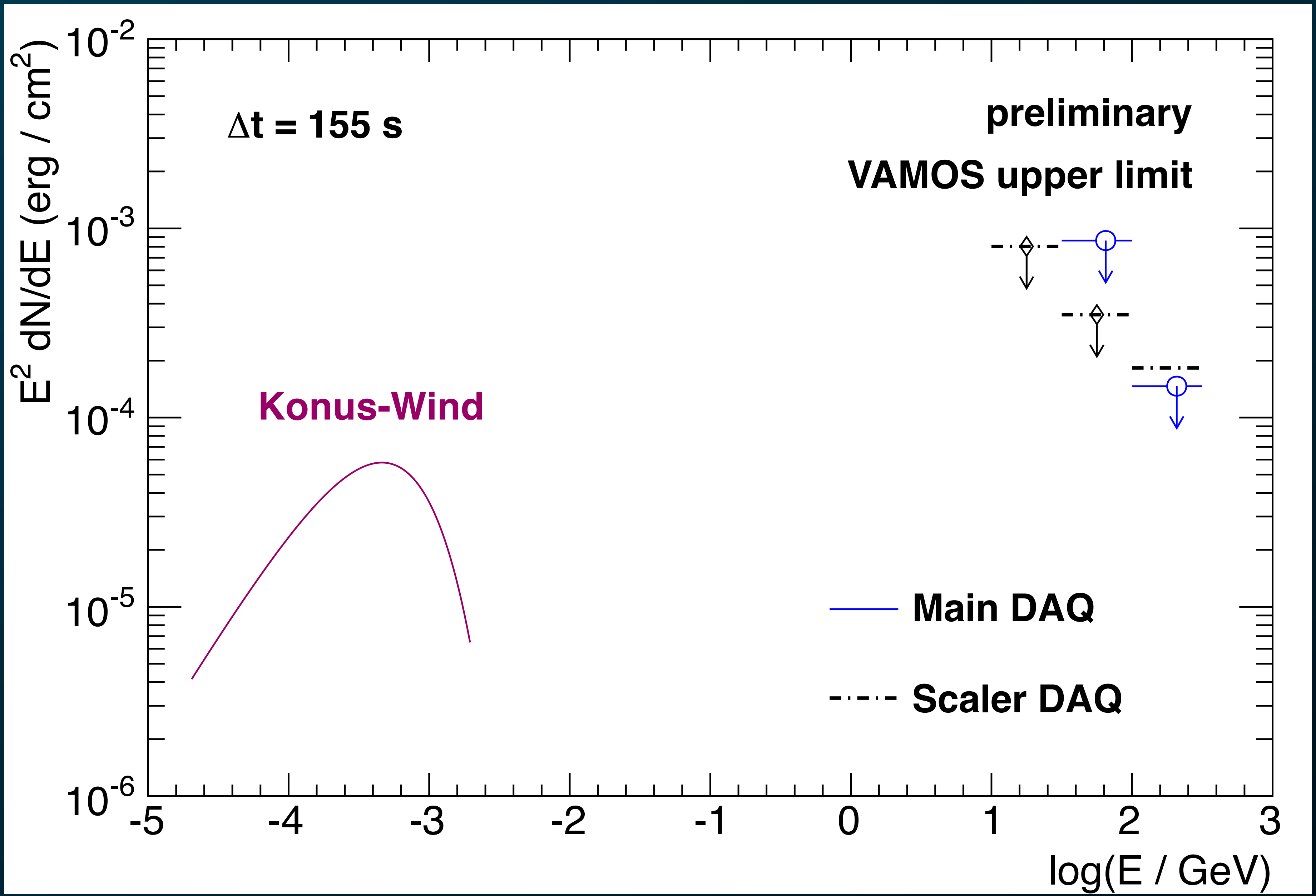
HAWC scalers are background dominated (sensitivity ~ 1 / sqrt(T))

high energy GRB detections would provide information on the acceleration mechanism of GRB or probe the extra-galactic background light

Above 10 GeV HAWC's sensitivity will be comparable to Fermi LAT's

For details see Astropart. Phys. 35 (2012) 641-650. Also arXiv:1108.6034 [astro-ph.HE]

Upper limits on GRB 111016B

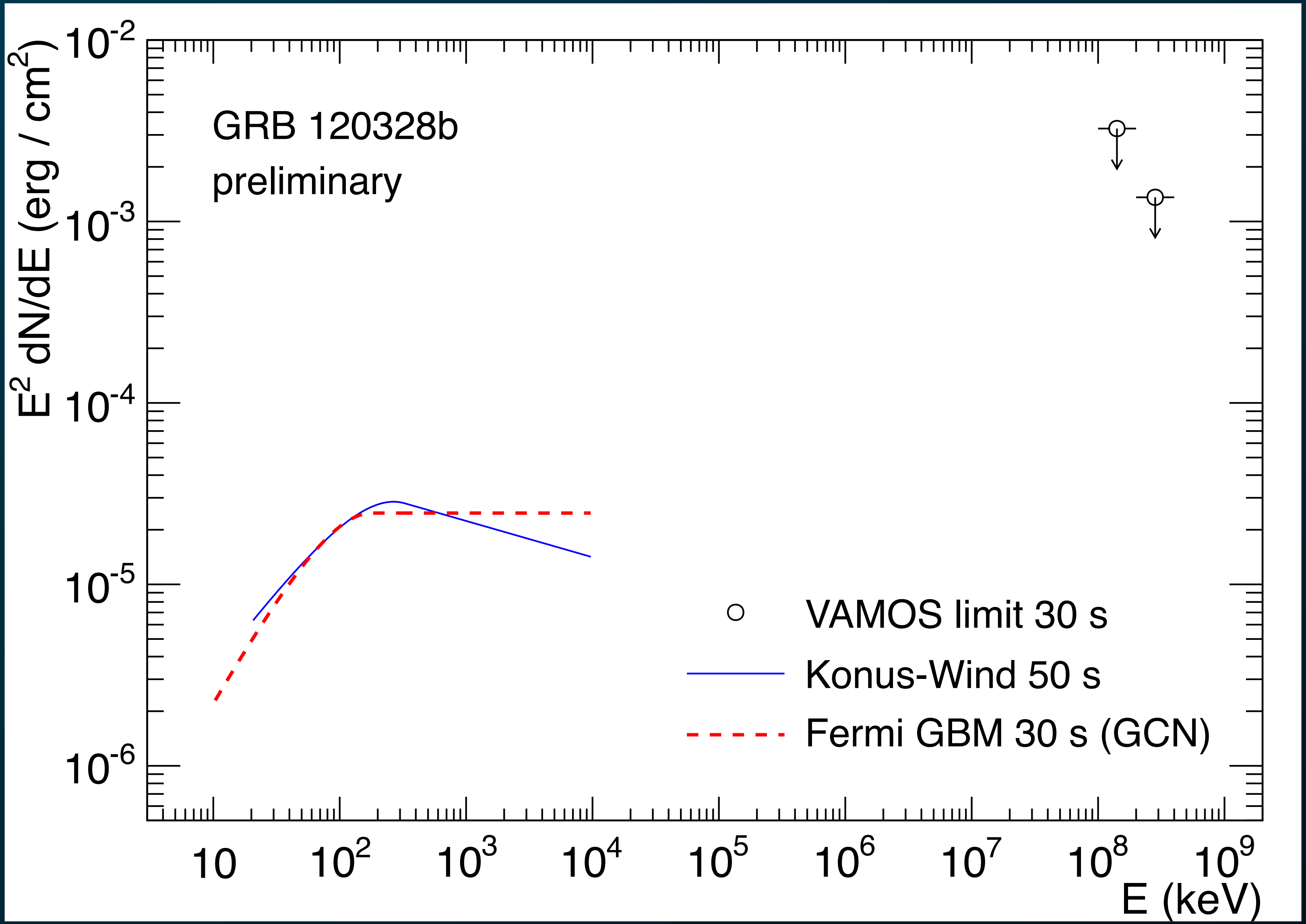


- A high fluence GRB discovered by IPN
- VAMOS zenith angle = 32 deg
- 3 time windows examined, no excess found
- Cuts used: number of hits >= 14; 6 degree radius circle around GRB position
- 90% C.L. limit in two energy bands are reported
- Results from scalers analysis are also shown (three energy bands)

First GRB limit from VAMOS!

D. Zaborov for the HAWC collaboration, The HAWC observatory as a GRB detector, proceedings of the 4th Fermi symposium, Monterey, CA, 28 Oct - 2 Nov 2012, arXiv:1303.1564 [astro-ph.HE]

Upper limits on GRB 120328B



Weak limits due to unfavorable zenith angle (41 deg) and a positive fluctuation observed

- Very bright (1.2 x 10^{-4} erg/cm^2) GRB discovered by IPN
- Observed by Fermi, Konus-Wind, MESSENGER (GRNS), INTEGRAL (SPI-ACS), Swift-BAT (outside coded field of view) and AGILE (MCAL)
- Emission was seen up to ~8 MeV by Konus-Wind
- Fermi LAT reported 8 sigma excess using non-standard analysis (burst was 66 degrees off axis and zenith angle was 105 deg meaning high Earth limb background)
- VAMOS zenith angle 41 deg
- 7 time windows examined, no significant excess found

List of bursts analyzed so far

GRB name	start time	T90, s	zenith, deg	comment
121209A	21:59:11	42.7	**31.1**	
121211A	13:47:02	183.0	**12.2**	
130102A	18:10:54	77.5	40.7	
130131511	12:15:17	147.5	43.2	
130215A	01:31:27	65.7	**26.8**	z = 0.597
130216A	22:15:21	6.5	42.5	
130219A	18:35:52.4	96.1	**32.3**	
130224370	08:52:26.5	70.9	42.2	
130307126	03:01:44.4	0.4	40.1	
130327A	01:47:30	9.0	40.4	
130504C	23:29:06	73.2	29.8	LAT detection
130507545	13:04:38	60.2	39.8	

List of bursts (continued)

GRB name	start time	T90, s	zenith, deg	comment
130612A	03:22:20.8	7.4	43.6	
130623130	03:06:36.6	29.4	28.4	
130623790	18:57:51.2	42.4	18.5	
130626596	14:17:14.3	28.2	**15.7**	
130628531	12:44:01.9	21.5	24.4	
130702A	00:05:23.8	58.9	31.7	LAT detection
130708A	11:43:04.3	14.1	22.6	
130716352	08:26:15.9	91.1	33.6	
130720116	02:46:40.5	48.6	**4.2**	
130723092	02:12:33.4	8.2	40.4	
130725527	12:38:40.4	6.7	46.1	