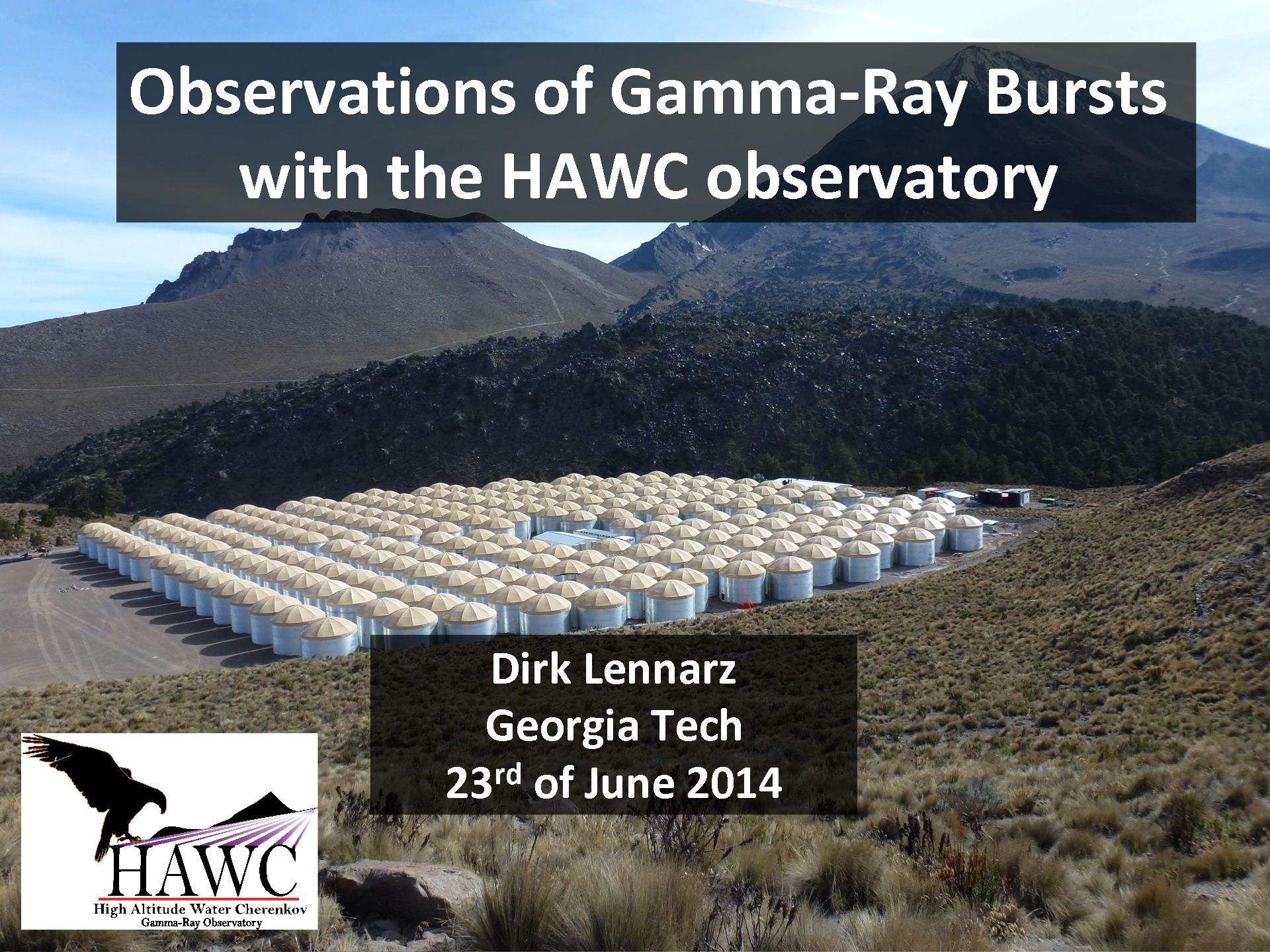
Observations of Gamma-Ray Bursts with the HAWC observatory



Dirk Lennarz
Georgia Tech
23rd of June 2014

HAWC
High Altitude Water Cherenkov
Gamma-Ray Observatory

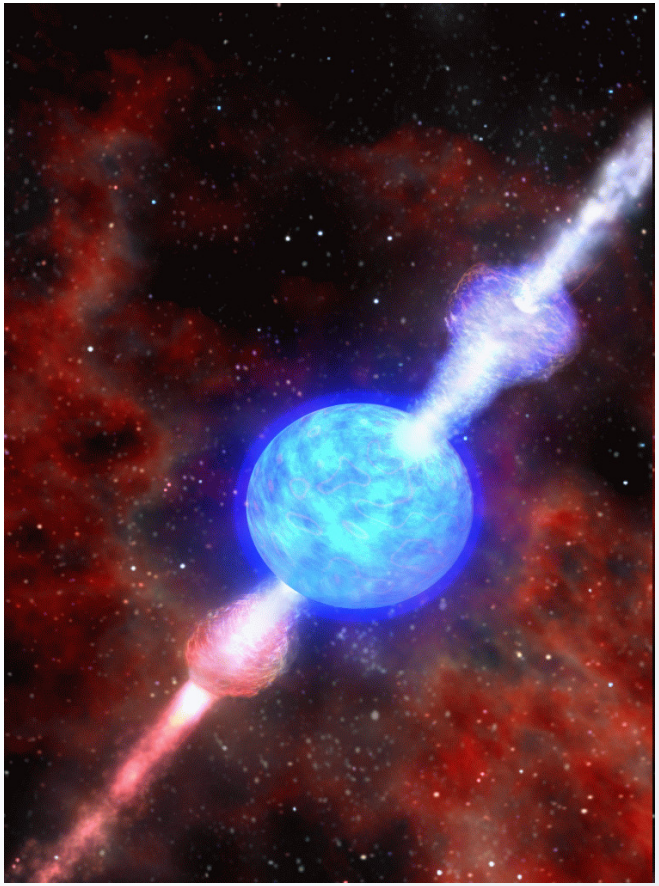
Gamma-Ray Bursts (GRBs)

- Central engine (collapse of massive star, merger of two compact stellar remnants)
- Collimated relativistic outflow
- Internal and external shocks
- Prompt keV-MeV emission
- Afterglow emission

Radiation mechanism

- Synchrotron Emission
- Inverse Compton Radiation

→ Distinguishable by emission at the highest energies

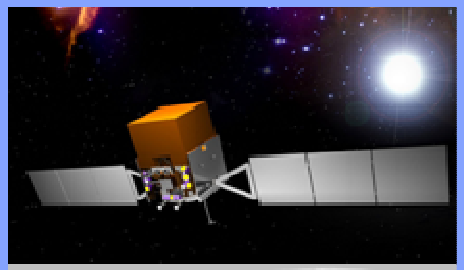


Artist impression of a GRB. Credit: NASA/Dana Berry, SkyWorks Digital

> 10 GeV Gamma-Ray Observatories

Wide Field of View

Continuous Operation



Artist impression of Fermi.
Credit: Fermi collaboration

Fermi

AGILE

EGRET

HAWC

Milagro

ARGO

Tibet AS-γ

TeV Sensitivity

H.E.S.S.

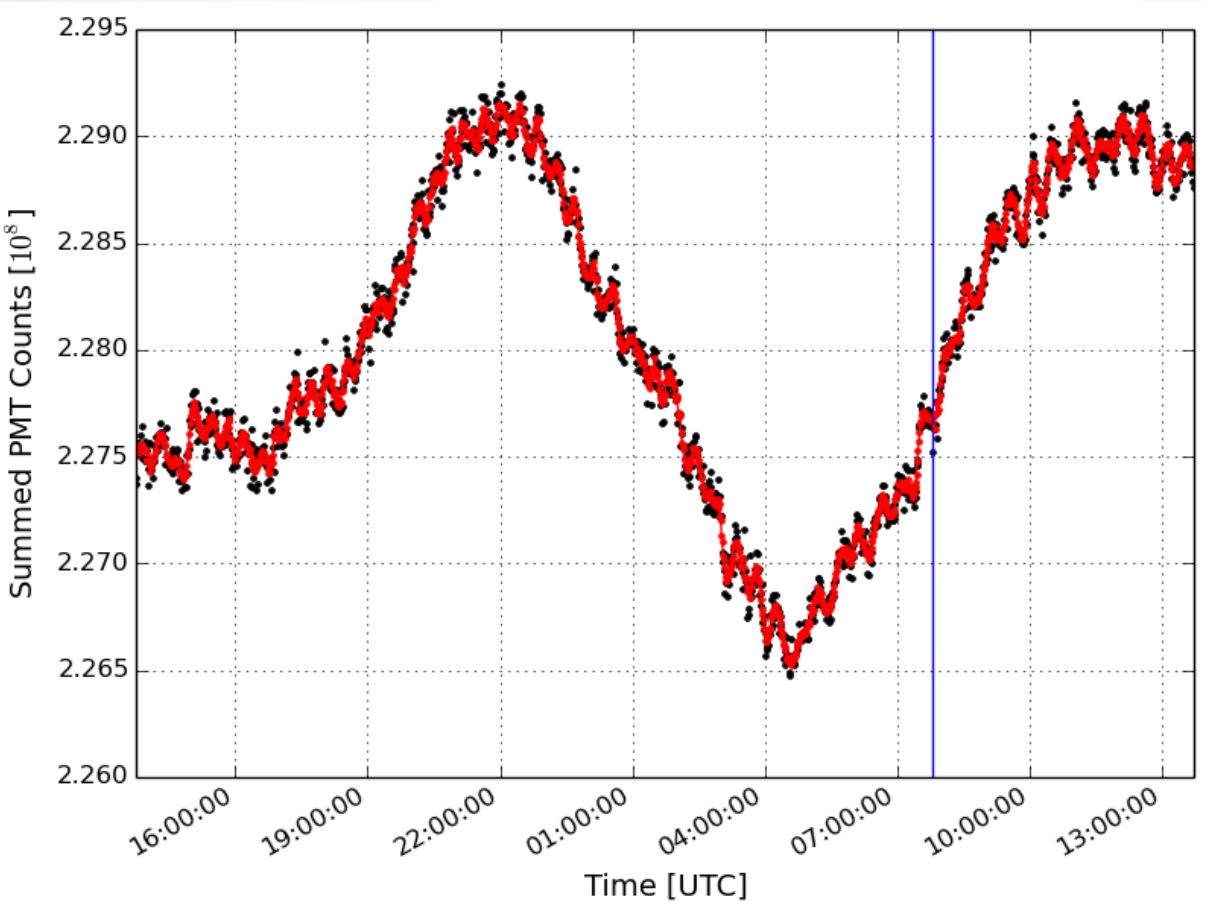
VERITAS

MAGIC

HAWC

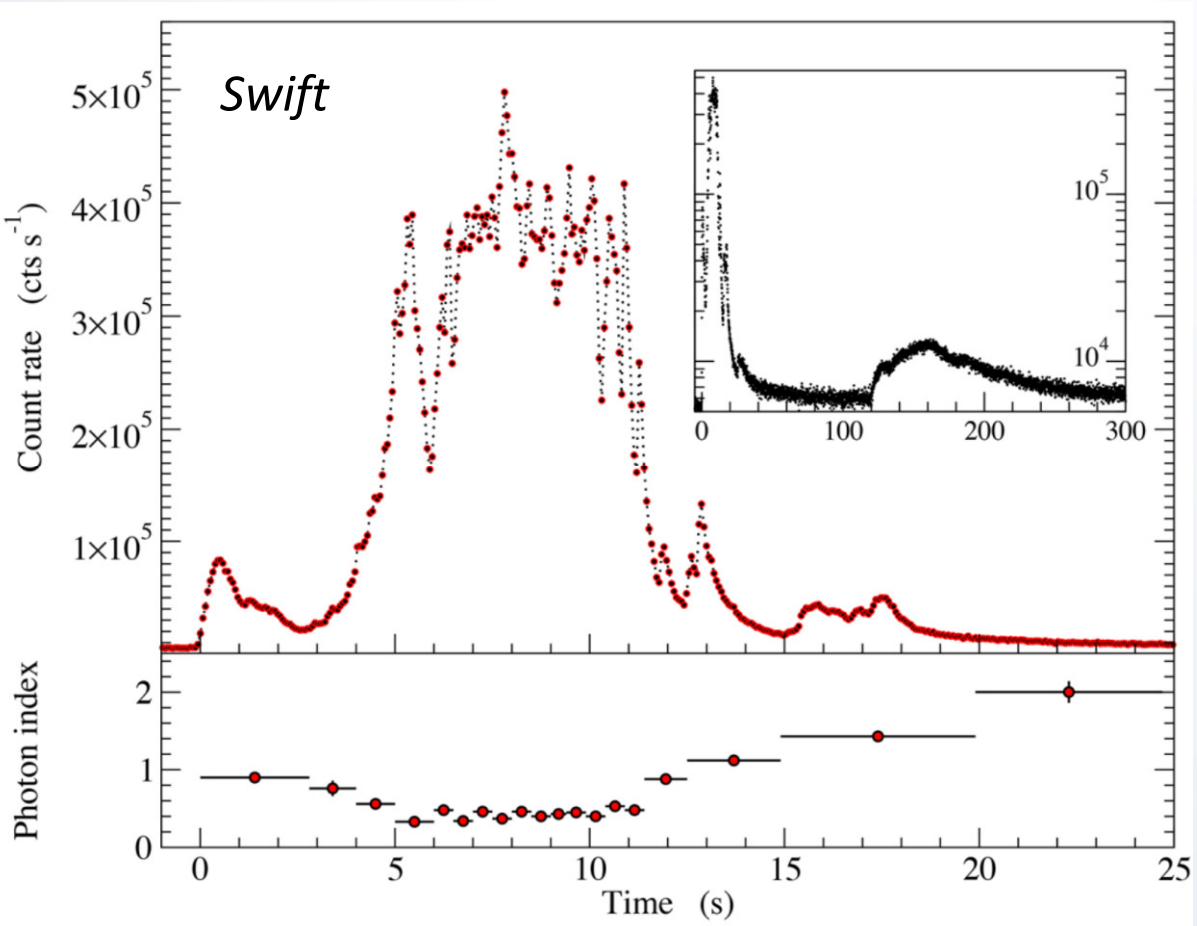
Data Acquisition Systems

- Triggered ("main") DAQ
  - Records time and charge of individual PMT pulses
  - Reconstruction of individual gamma-rays
- Scaler DAQ
  - PMT pulse counting mode
  - Detects GRBs from statistical excess over noise rate



GRB 130427A

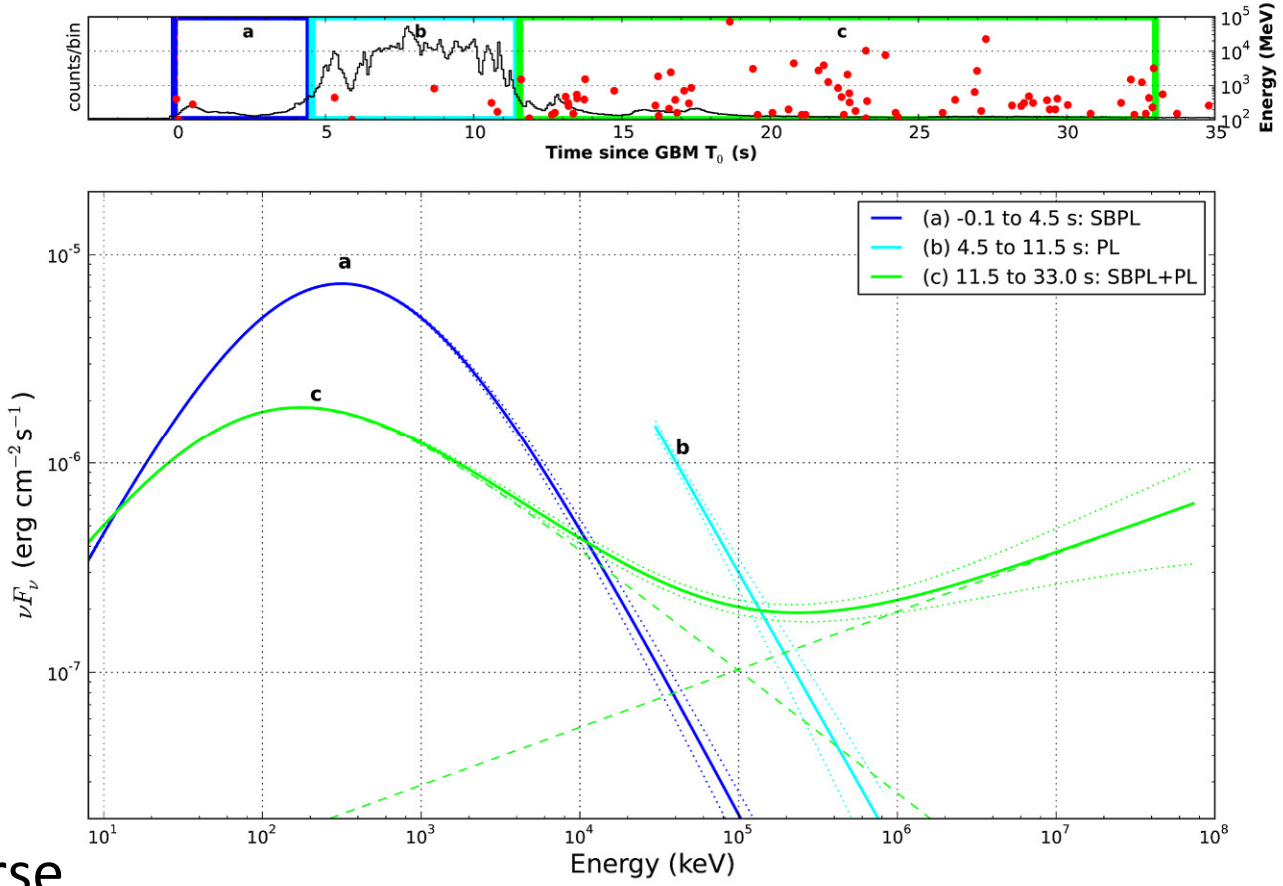
- Brightest burst ever detected by *Swift*
- Very close (z=0.34)
- Most powerful GRB detected z< 0.5



Science 343 (2014) 48-51

GRB 130427A

- Brightest burst ever detected by *Swift*
- Very close (z=0.34)
- Most powerful GRB detected z< 0.5
- Longest lasting high energy emission ever detected (~20 h)
- Most energetic photon ever detected (95.3 GeV)



Science 343 (2014) 42-47

Evidence for inverse Compton?

What did HAWC see?

Misfortune 1

- The main DAQ was offline
- Luckily, the scaler DAQ was taking data

➡ Monitoring the rate of 29 tanks (HAWC 30) with 112 PMTs

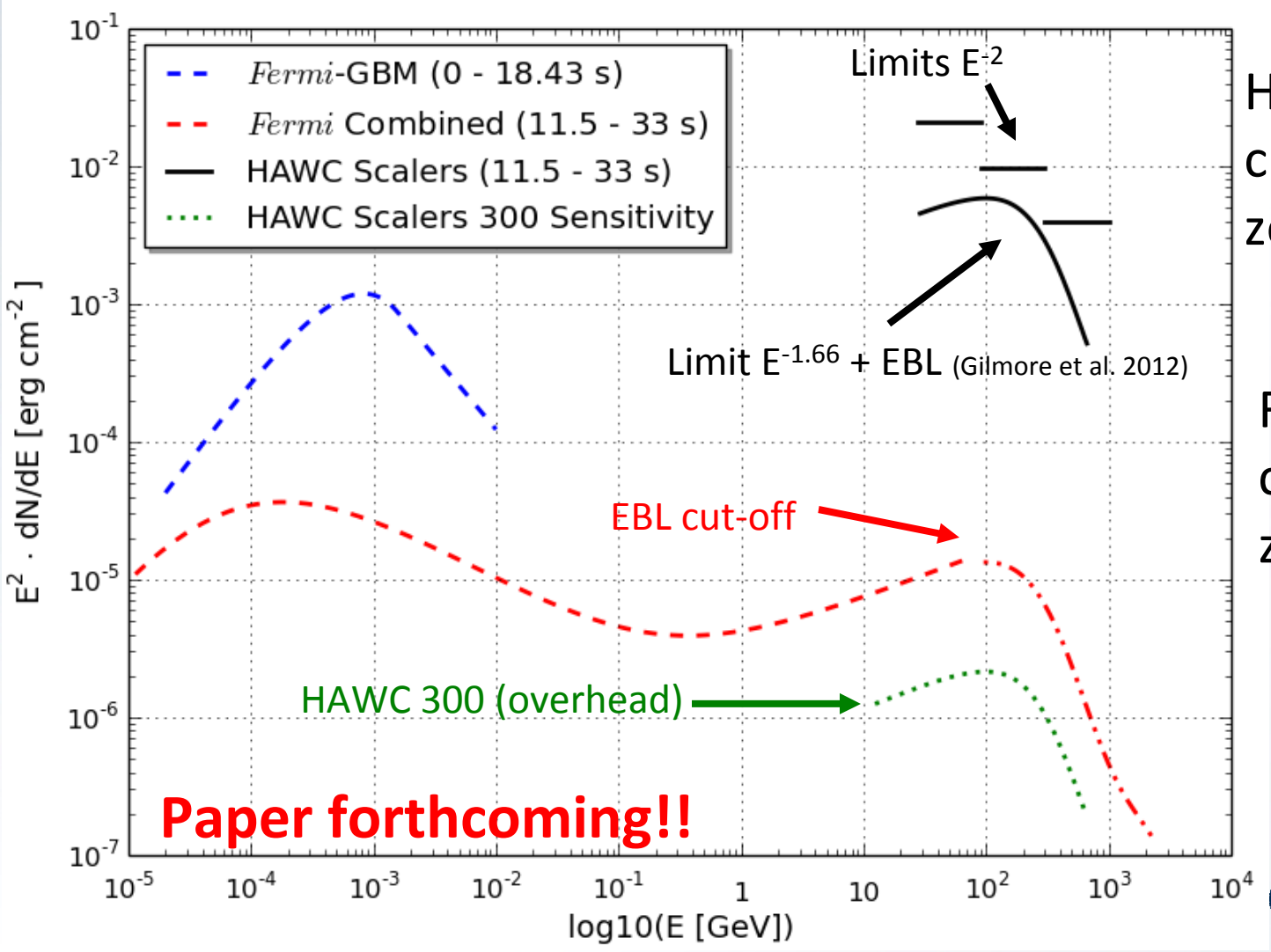
Misfortune 2

- The GRB had an elevation of only 33° in the HAWC field of view

➡ Sensitivity is about 2 orders worse than at zenith

➡ Increased energy threshold

GRB 130427A Upper Limits



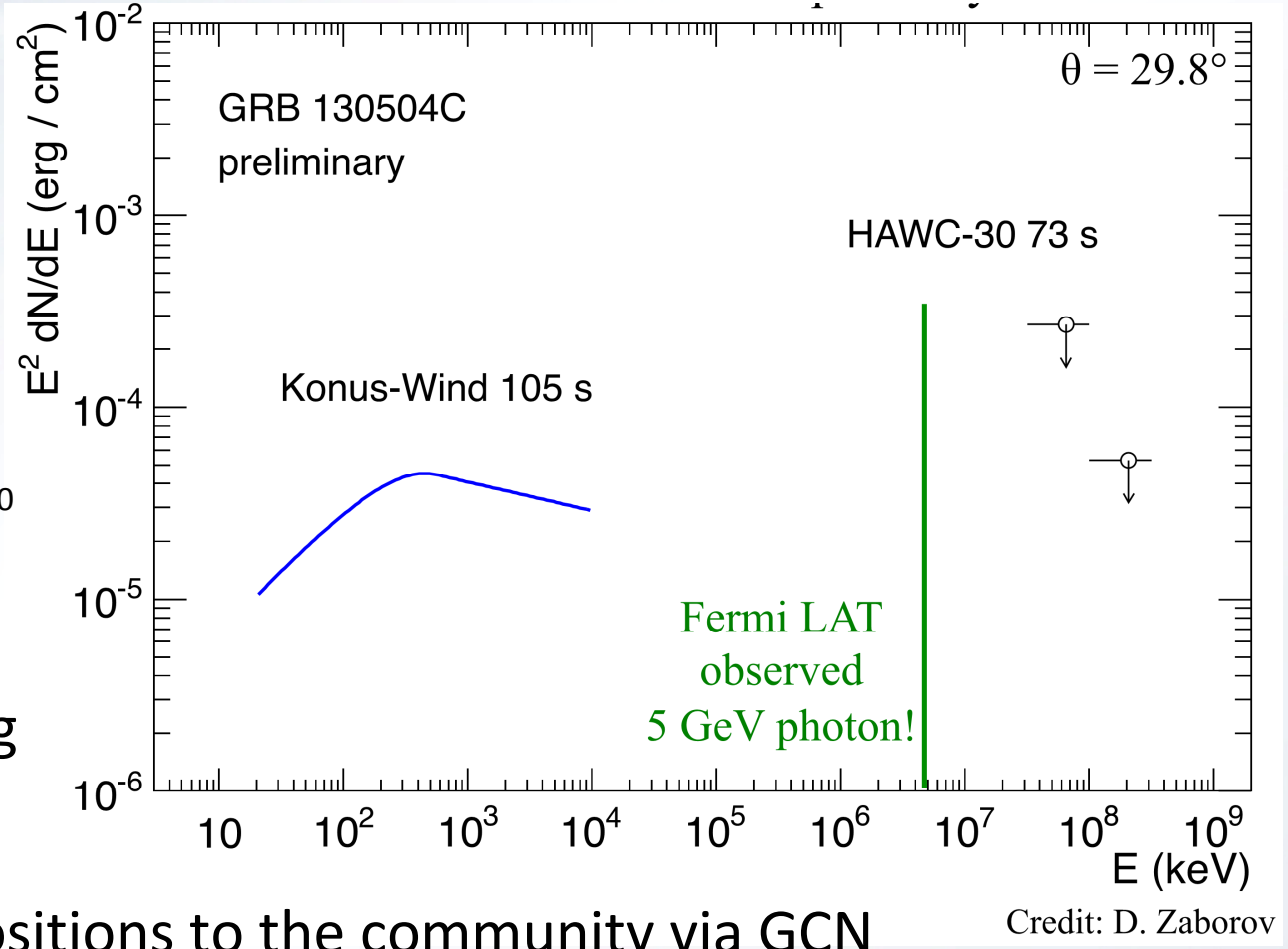
HAWC 30, close to zenith: ~2.3 σ

Full HAWC, close to zenith: > 15 σ

Main DAQ

Quick look analysis

- Single time-bin analysis
- Estimate background from off-time data
- Counts number of events in T_{90} and $3xT_{90}$
- If excess < 5σ keep data blind



Credit: D. Zaborov

➡ Currently installing at site

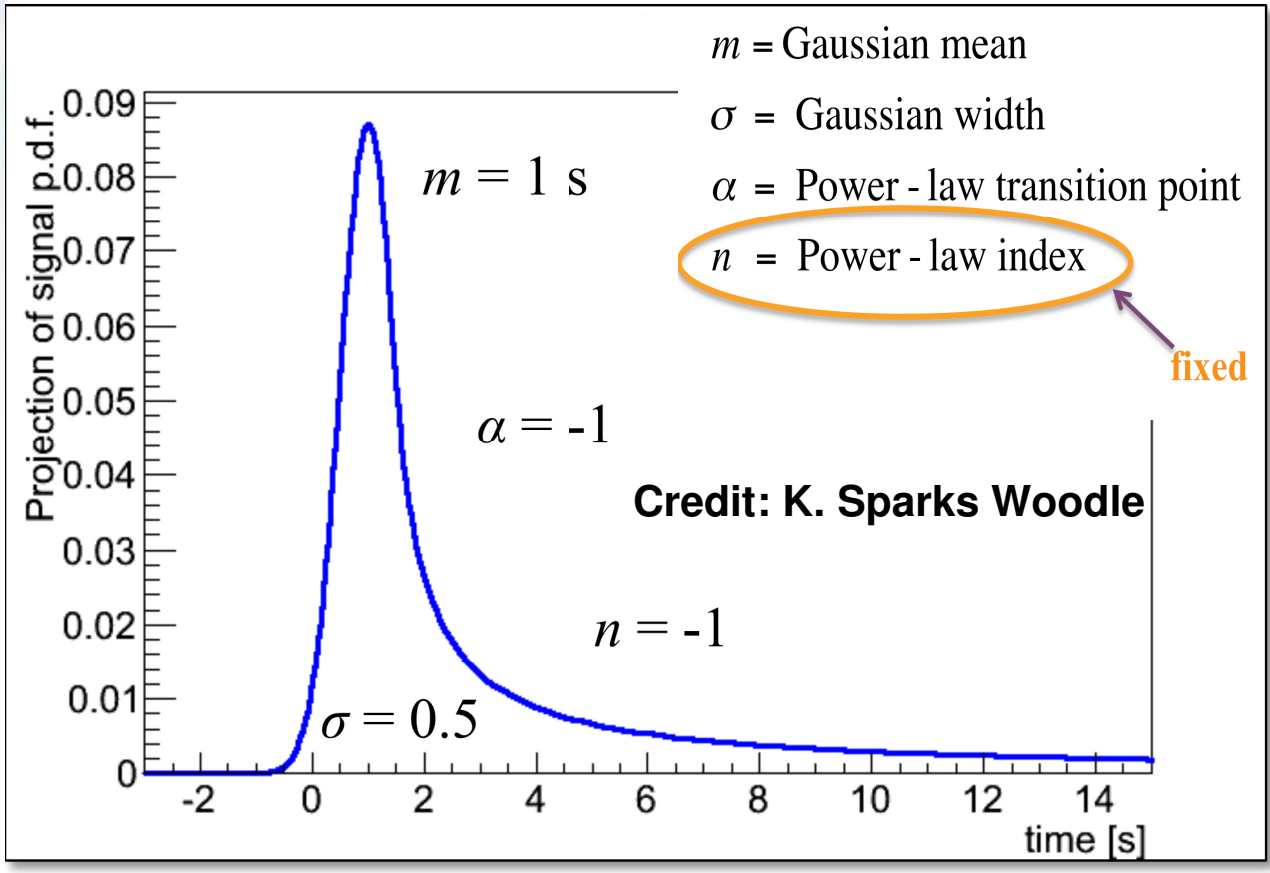
➡ Provide alerts / positions to the community via GCN

Main DAQ

Likelihood analysis

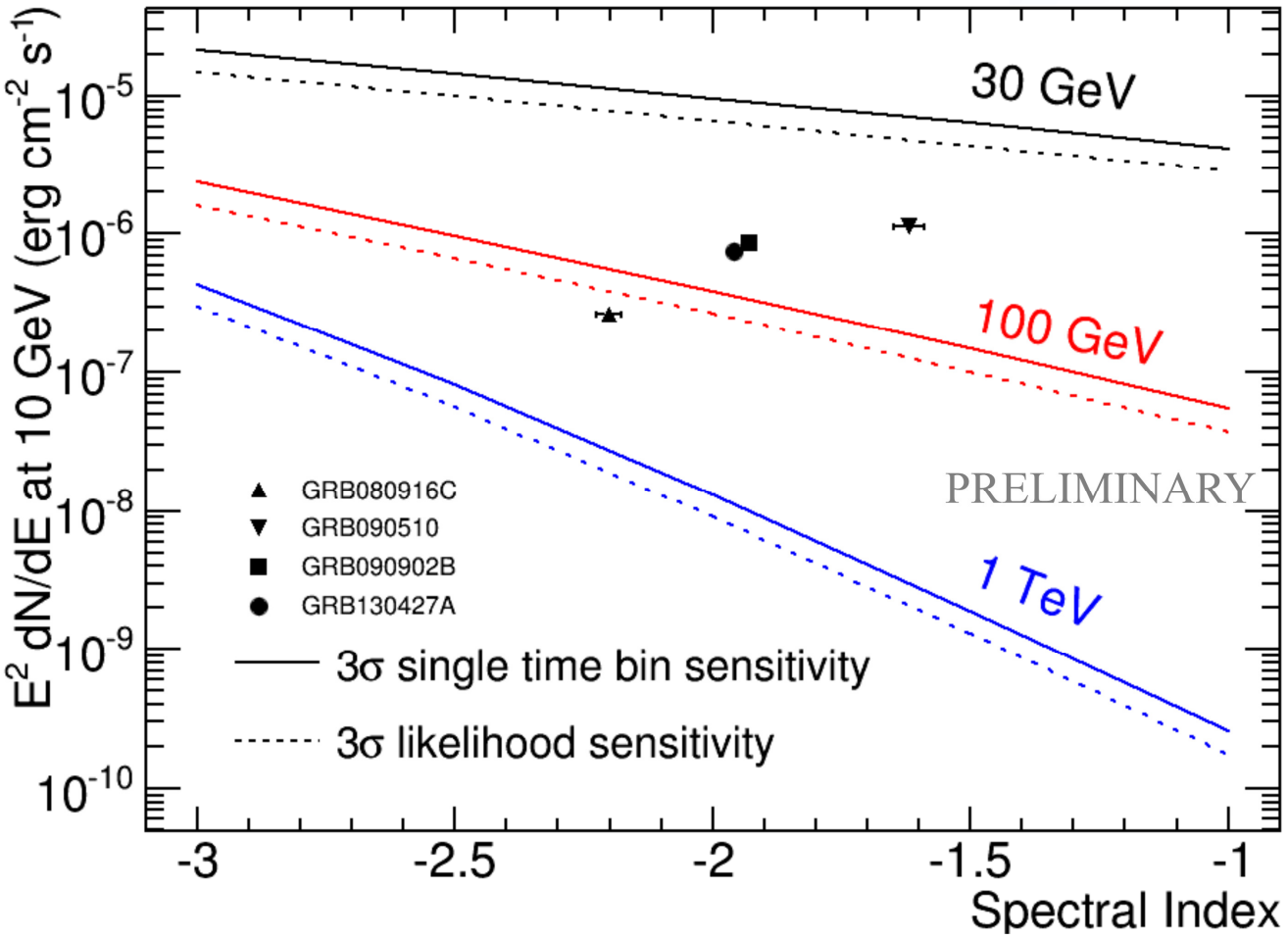
- Fermi: GeV emission delayed + temporally extended
- Add this knowledge to signal Likelihood

➡ Crystal Ball Function



Sensitivity

3σ discovery sensitivity to sources with sharp high-energy cutoffs

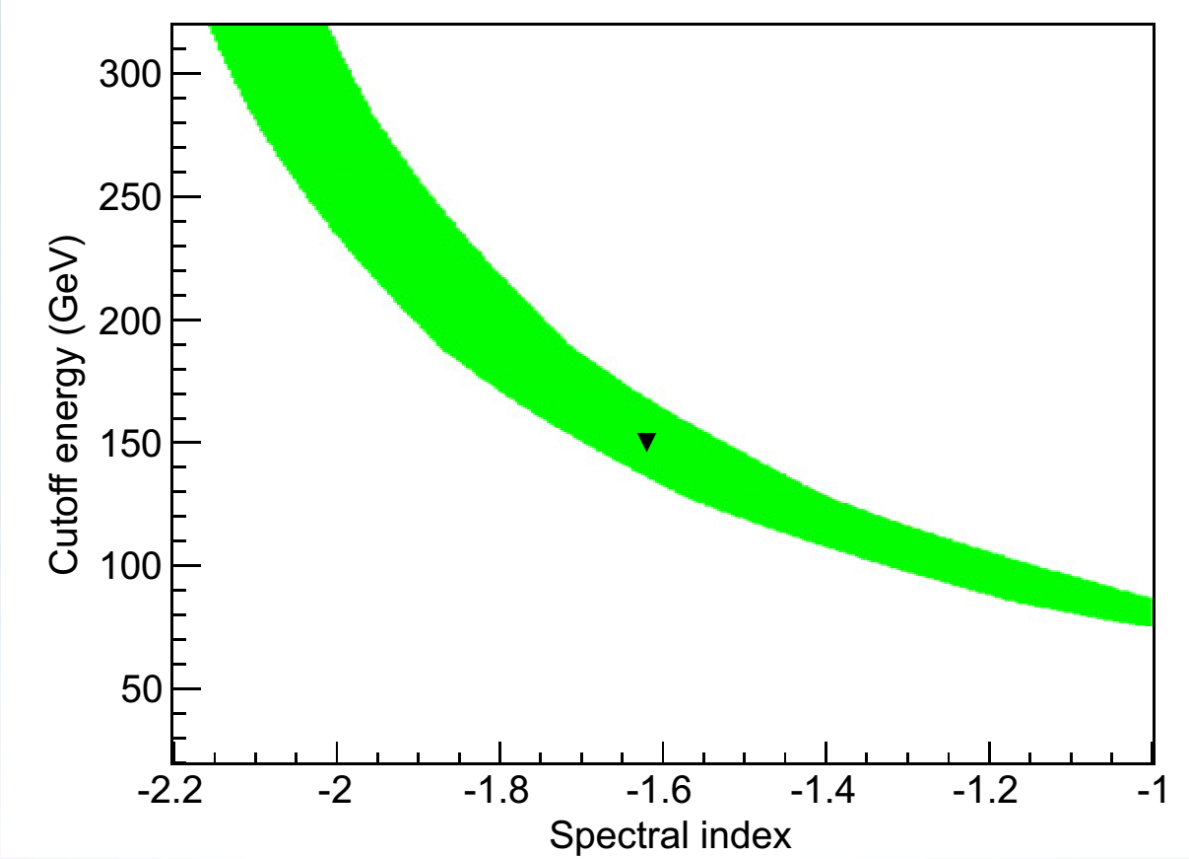


Note: Reference GRB flux is scaled according to main DAQ duration sensitivity.

- Likelihood >30% more sensitive
- **HAWC will be able to see bursts** comparable to those already observed

HAWC Combined Power

Abeysekara et al., Astropart. Phy. 35 (2012) 635



- Simulated GRB (black triangle)
- Green band: flux values from both DAQs agree within 25%

HAWC GRB Rate

Taboada & Gilmore, NIM-A (2014) 742

Assumptions

- >1 GeV emission: additional hard (long E^{-2} , short $E^{-1.66}$) power-law
- Power-law cutoff by EBL absorption
- Long GRB T_{90} fluence ratio 10%, short GRBs 100%

Cutoff	main DAQ sGRB /yr	Scaler sGRB /yr	main DAQ LGRB /yr
n/a	1.4	0.15	0.25
500 GeV	1.3	0.12	0.22
400 GeV	1.2	0.11	0.20
300 GeV	0.97	0.10	0.15
200 GeV	0.54	0.07	0.08
150 GeV	0.27	0.05	0.04
100 GeV	0.07	0.02	0.01

➡ Detection rate as high as 1.63 GRB per year!

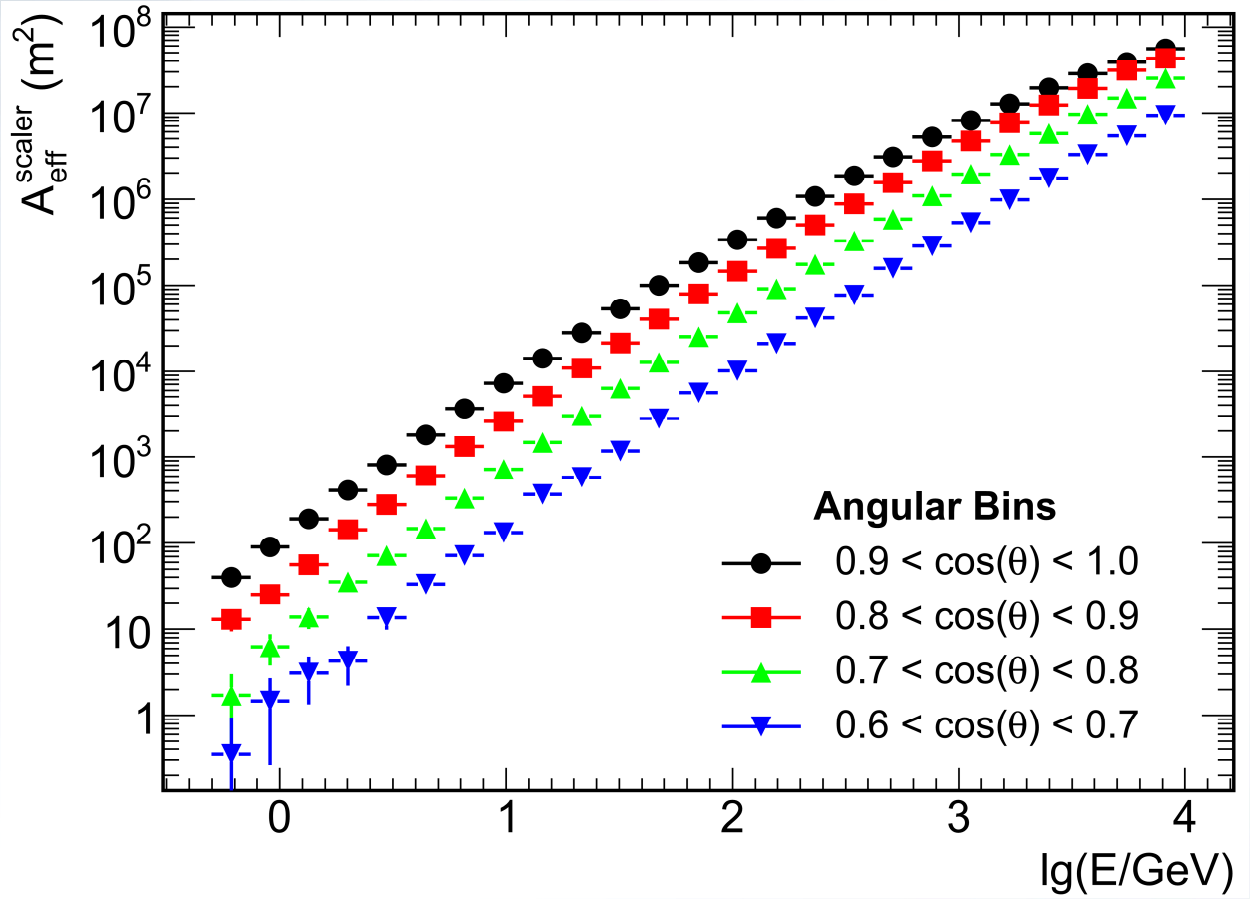
Summary

- HAWC is an exciting new gamma-ray experiment
- GRB 130427A was a very special GRB, but under unfavourable conditions for HAWC
- HAWC has the sensitivity to detect GRBs at the highest energies
- Detection rate might be as high as 1.6 GRBs per year!

Backup

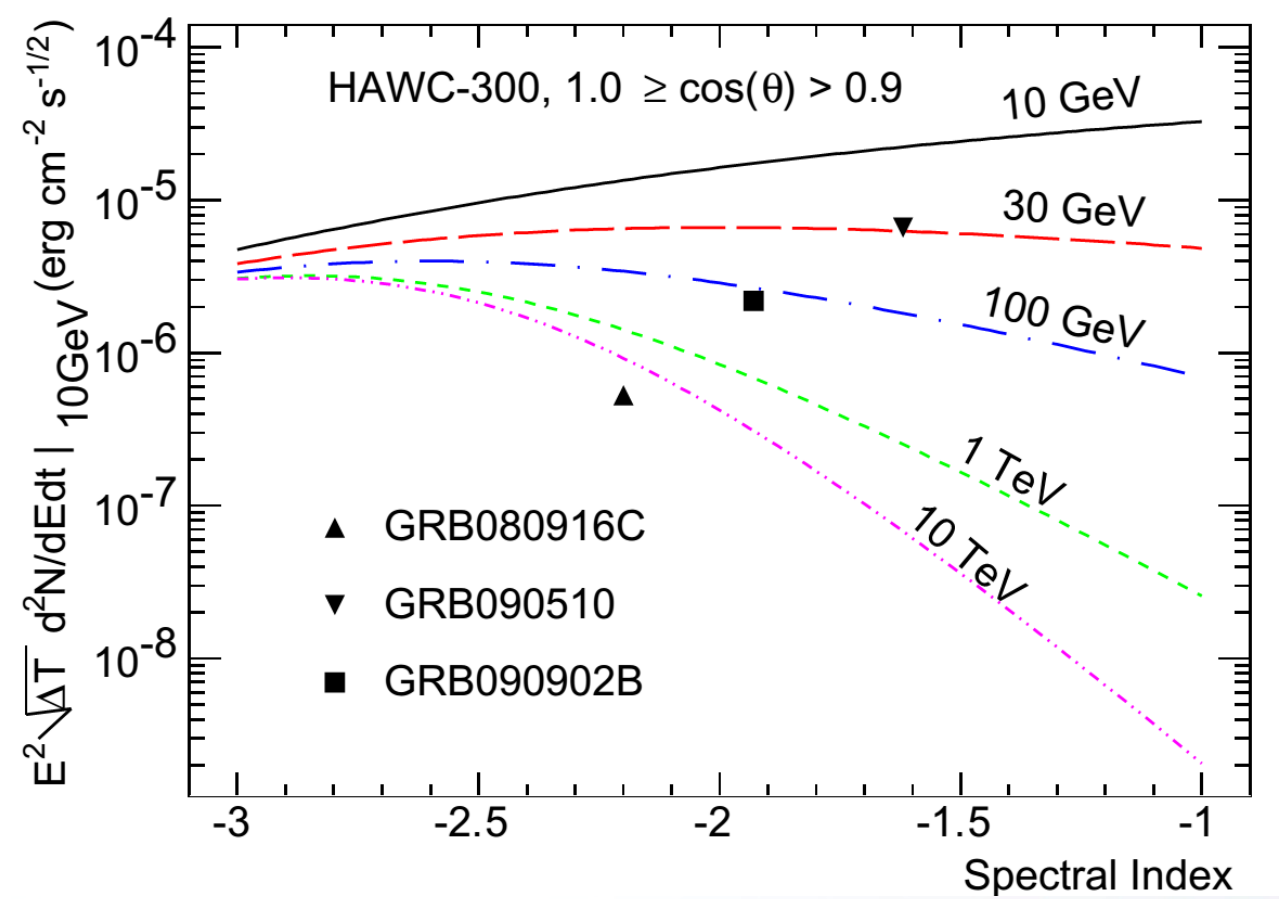
Scaler Effective Area

Abeysekara et al., Astropart. Phy. 35 (2012) 635



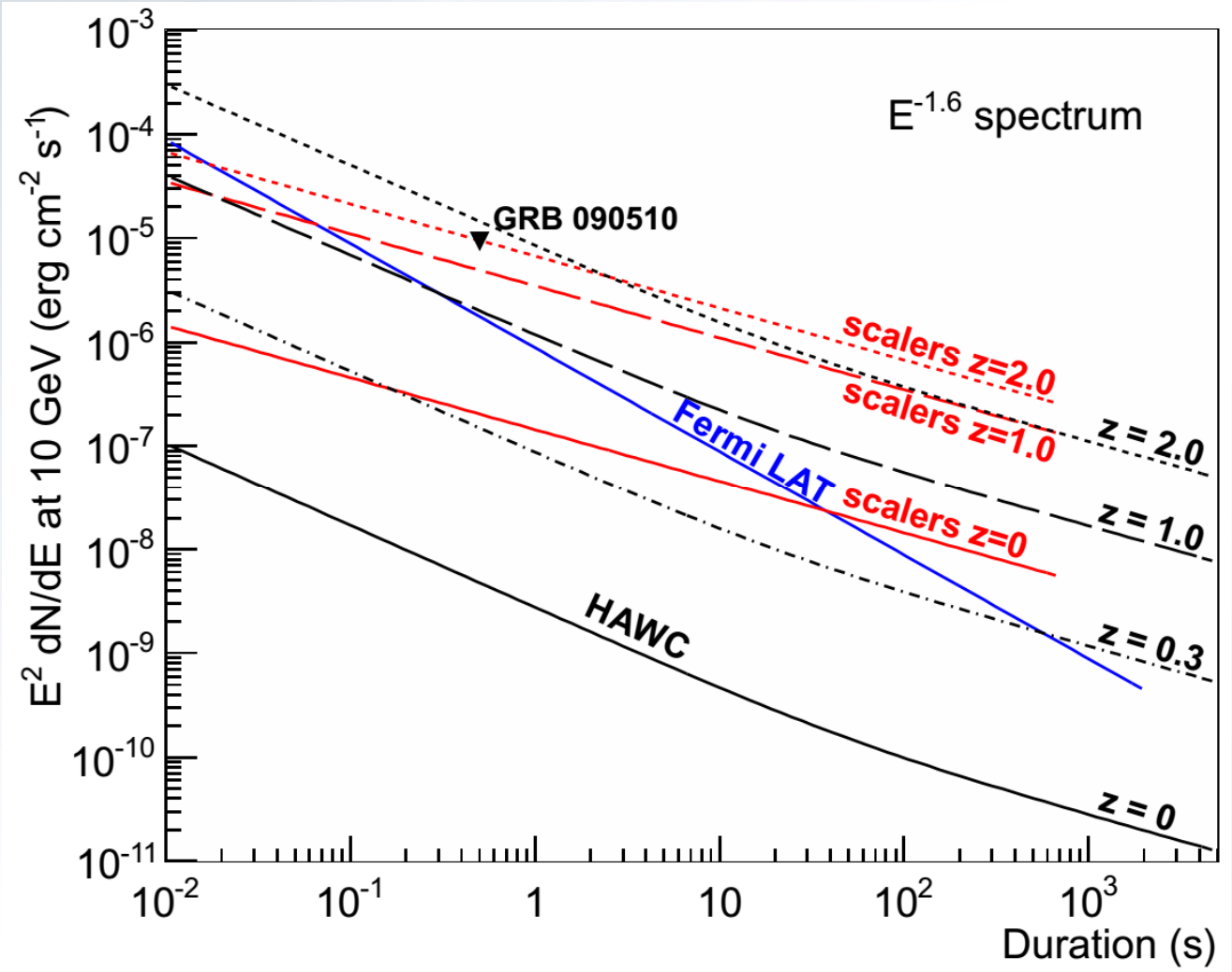
Scaler Sensitivity

Abeysekara et al., Astropart. Phy. 35 (2012) 635



GRB Sensitivity

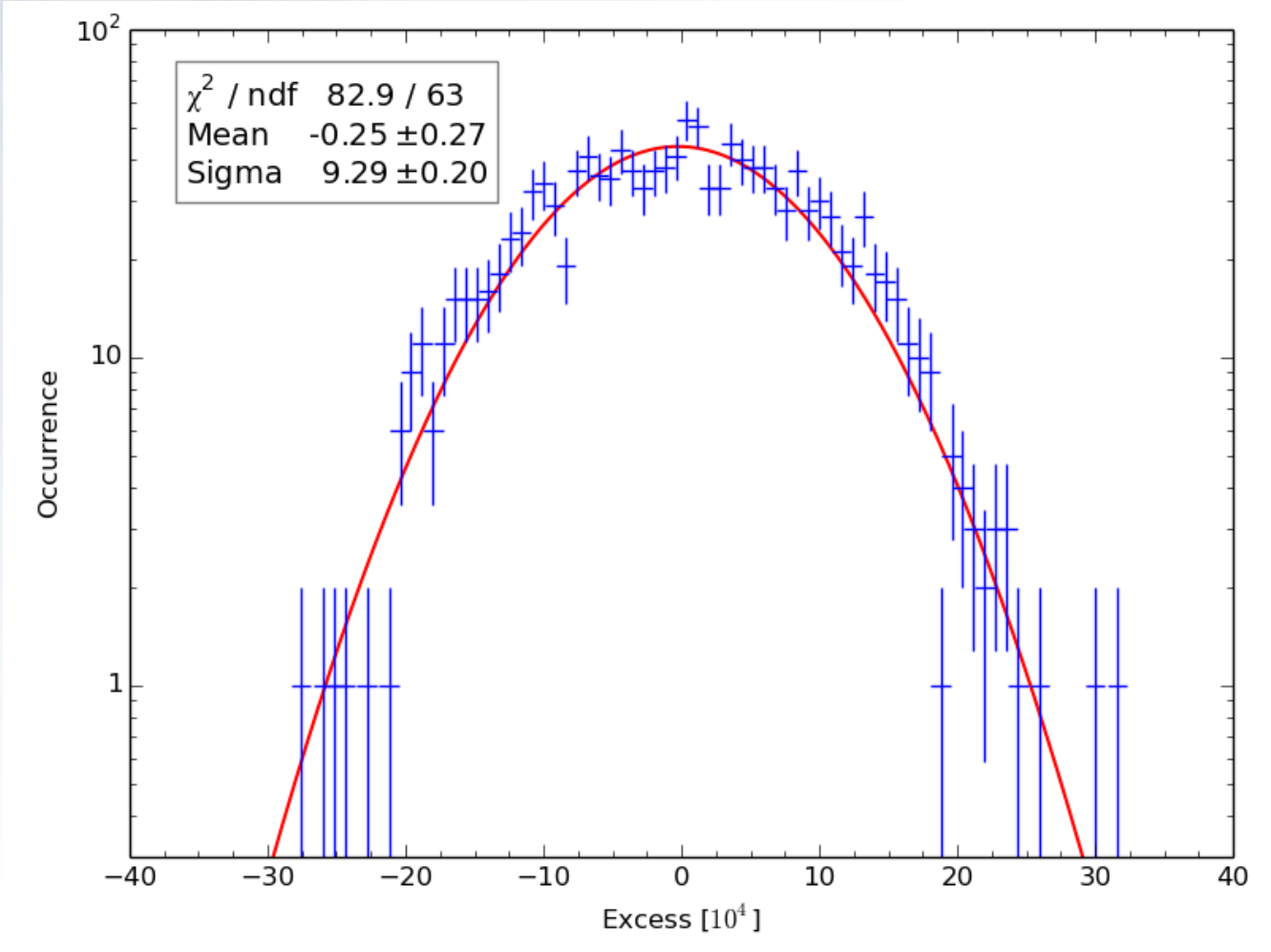
Abeysekara et al., Astropart. Phy. 35 (2012) 635



Time Windows

1. 0-20 s (first two BAT emission periods)
2. -5-55 s (extended time window)
3. -5-145 s (GBM T_{90}=138s)
4. 120-300s (third BAT emission period)
5. -10-290s (combine all three BAT emission periods)
6. -10-10s around time of highest energy LAT photon
7. 11.5-33s (Fermi-LAT extra hard power law)
8. 196-257s (Fermi-LAT power law harder then -2)

Excess Distribution



Results

Search Window [s]	0-20	-5-55	-5-145	120-300	-10-290	233-253	11.5-33	196-257
PMT Sum [10^4]	7593.0	22765.5	56899.3	68308.5	113826.7	7590.6	8161.3	23148.1
BG Est. [10^4]	7591.1	22773.6	56937.4	68326.3	113893.6	7591.1	8160.6	23153.4
Excess [10^4]	+1.9	-8.0	-38.0	-17.8	-66.9	-0.5	+0.6	-5.3
p-value	31%	79%	98%	71%	95%	54%	43%	69%