Real-Time GRB Searches with HAWC

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for the HAWC Collaboration

HAWC
High Altitude Water Cherenkov
Gamma-Ray Observatory

UNIVERSITY OF MARYLAND
18 56

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Outline

- What can the HAWC observatory contribute to GRB Science
  - Real-time triggered GRB search
  - Real-time untriggered GRB search

HAWC and GRBs

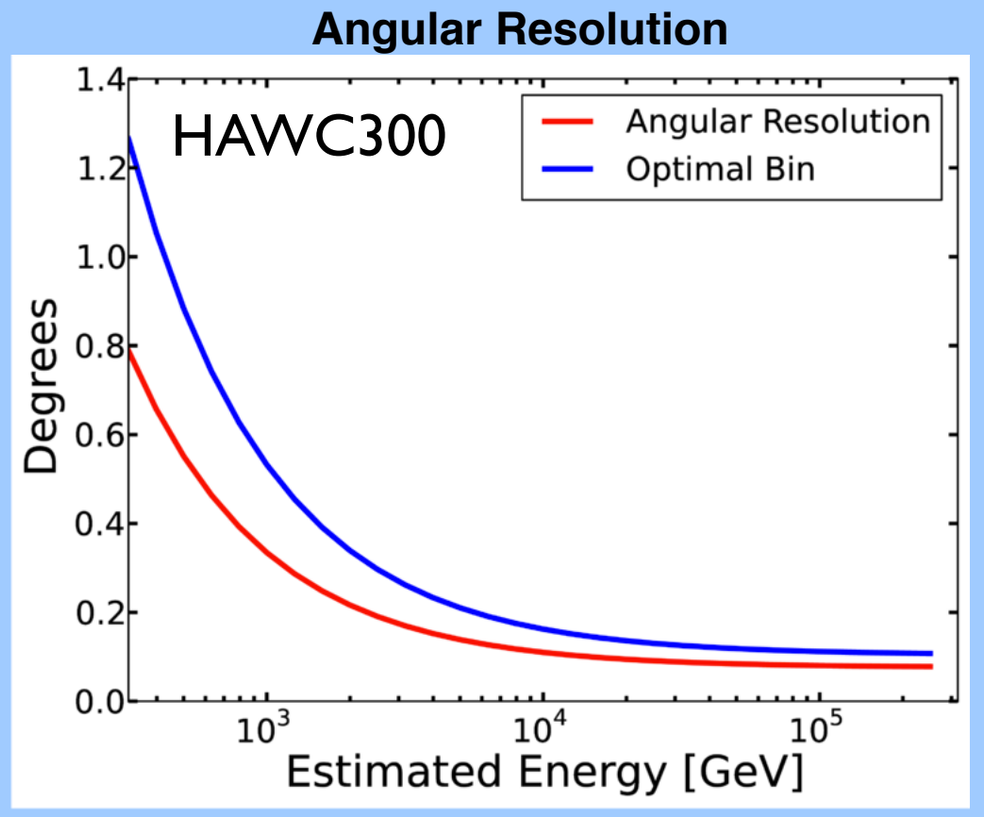
- HAWC has some nice features for observing short transients

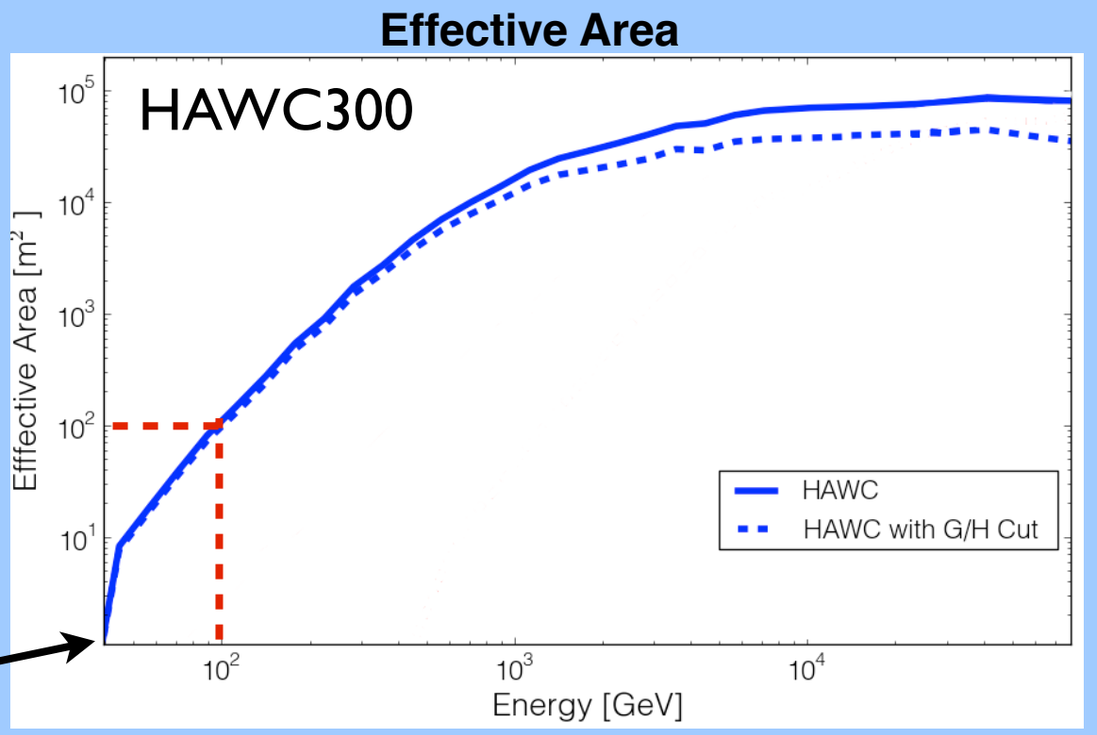
angular resolution < 1.0°

> 95% duty cycle

2 sr FoV (no need for pointing)

~100 times size of FERMI @ 100 GeV



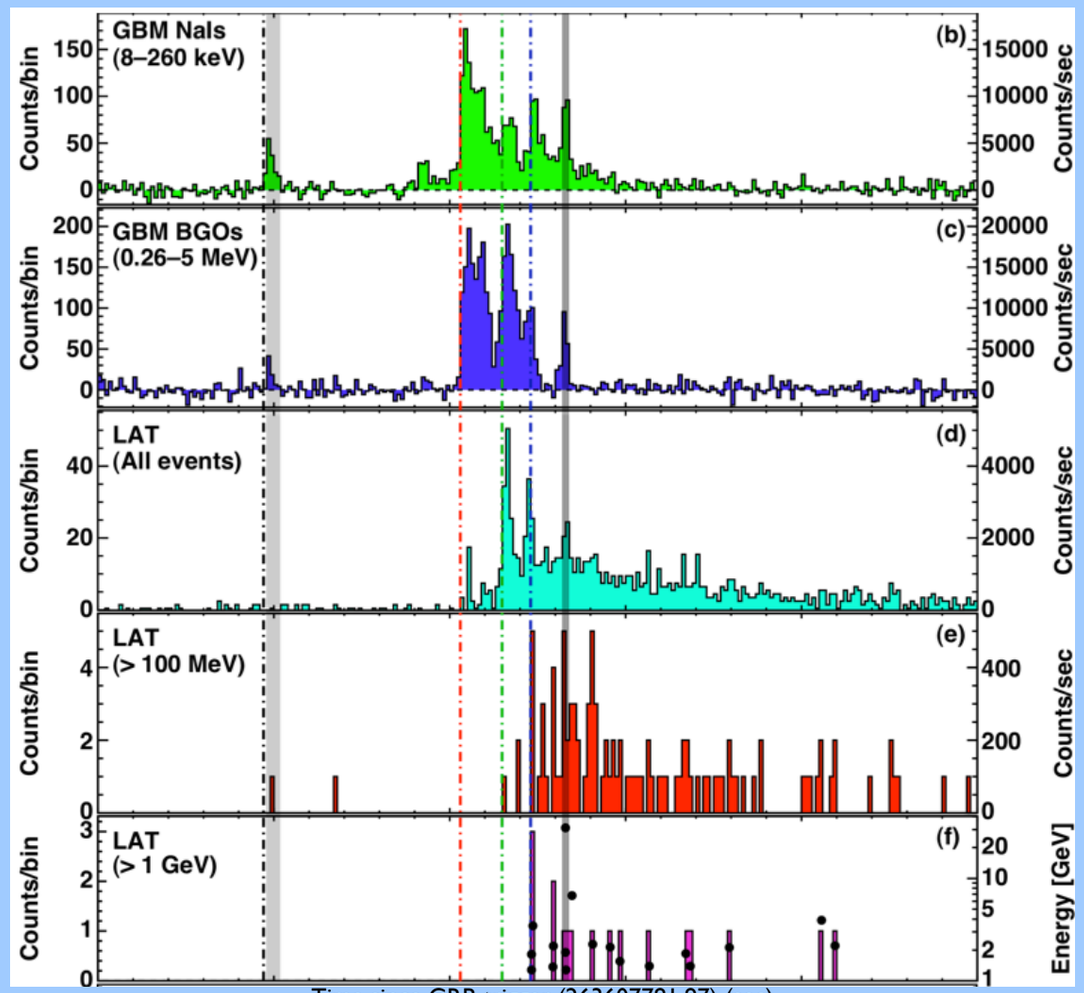


FERMI-LAT ~1m^2

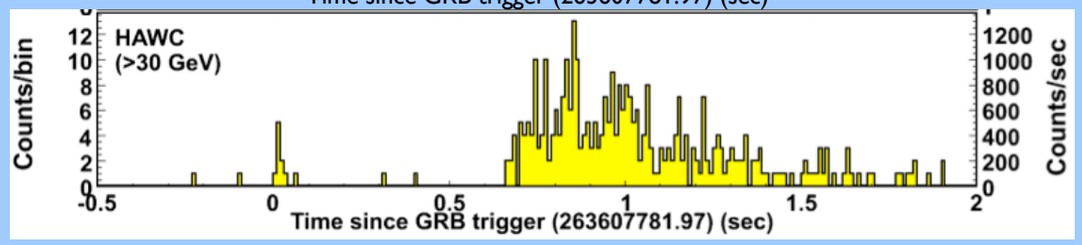
HAWC and GRB090510

GRB090510 Light Curves

FERMI



Simulated HAWC

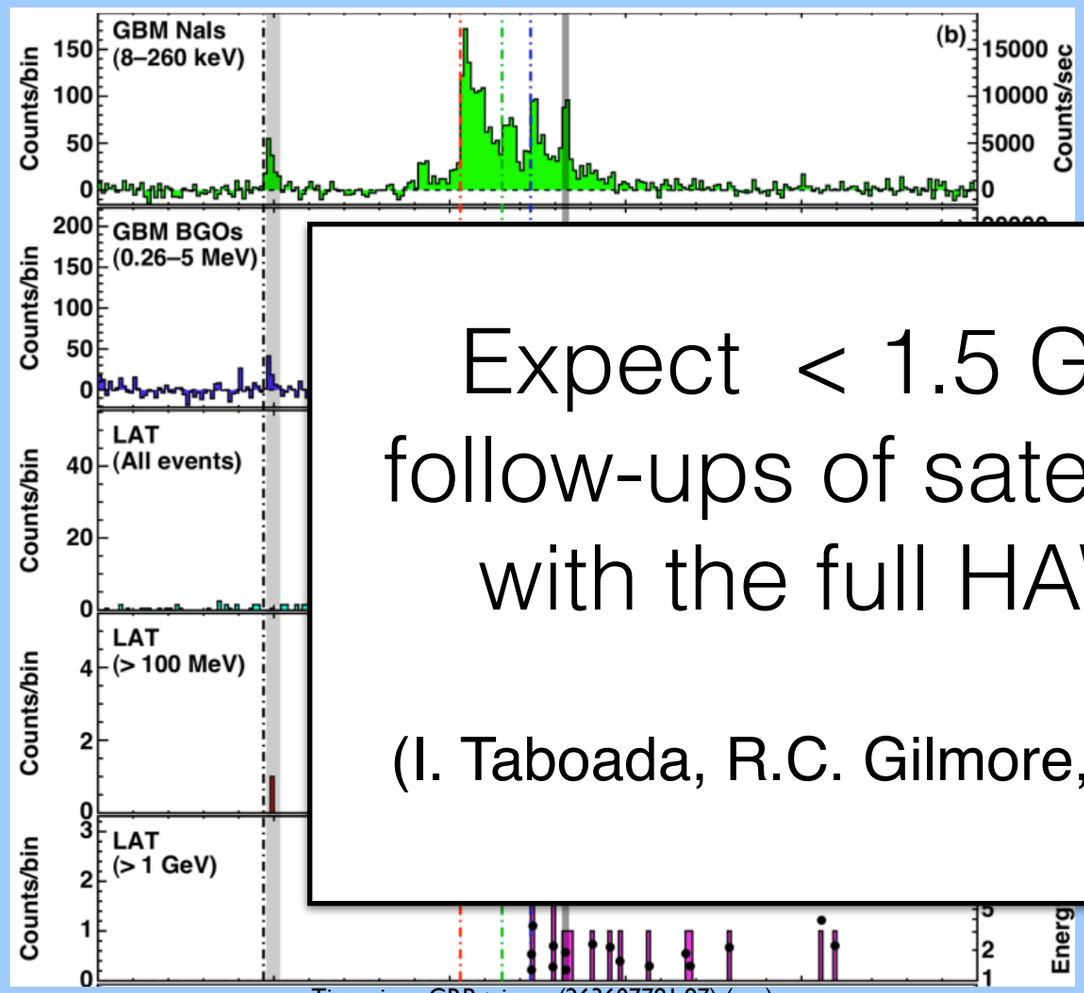


- Simulate HAWC response to GRB090510
  - extrapolate FERMI SED with abrupt 125 GeV cutoff
  - z = 1
  - cos(Θ) = 0.9
  - 200 signal photons
- HAWC can see full high energy time structure before, during & after a GRB

HAWC and GRB090510

GRB090510 Light Curves

FERMI



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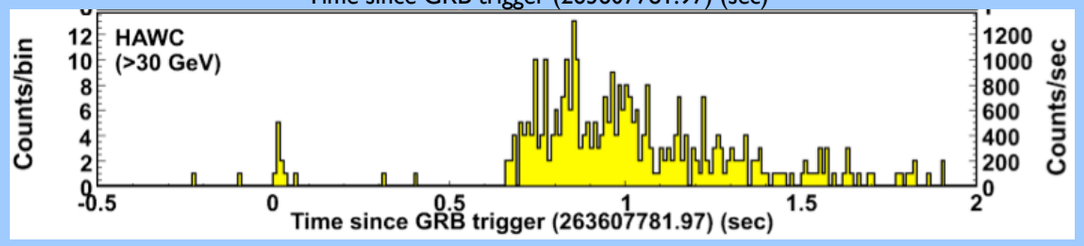


- Simulate HAWC response to GRB090510

ED
cutoff

Expect < 1.5 GRB per year from follow-ups of satellite reported GRBs with the full HAWC-300 detector

(I. Taboada, R.C. Gilmore, NIM A 742 (2014), 276-277)

- HAWC can see full high energy time structure before, during & after a GRB

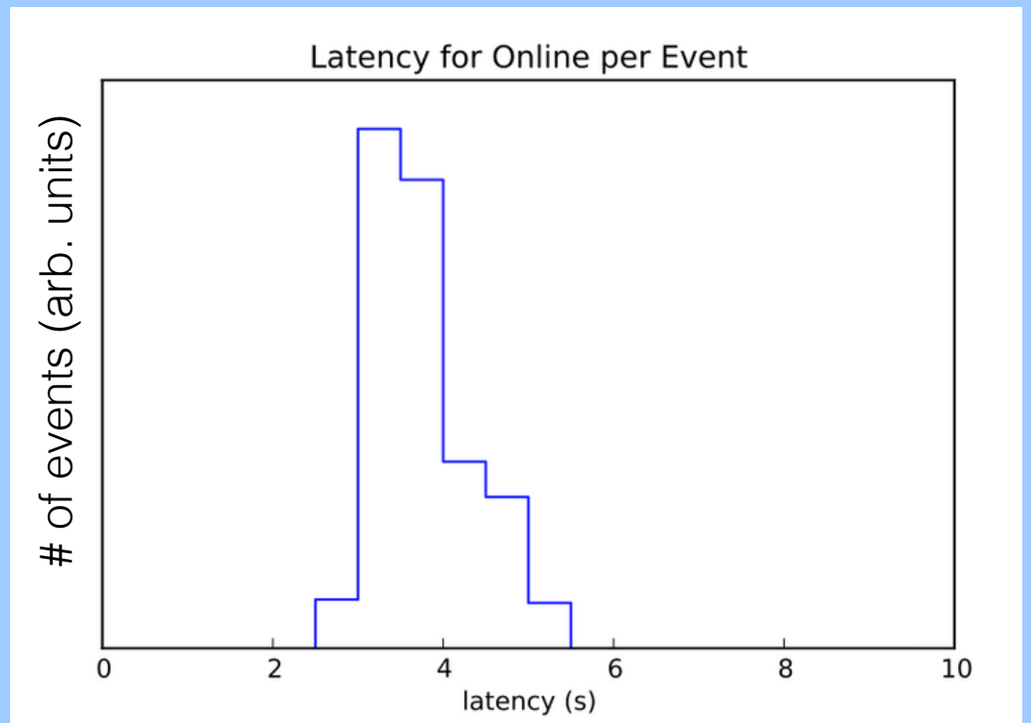
Science Take-aways

- Measuring E ≥ 100 GeV well is important for understanding cutoffs. Cutoffs could be intrinsic to the GRB or from EBL absorption.
- Time variability + a cutoff can be used to estimate bulk Lorentz factor of prompt emission region (if we know the redshift)

  (Briggs *Science* **323** 5922 pp. 1688-1693)
- Timing of low energy photons compared to VHE gives constraints on the violation of Lorentz invariance

Real-Time GRB Searches

- HAWC triggers and reconstructs showers in real-time (~ 4 sec), → all day, every day



- Currently running two search methods on real-time data:

Triggered: Follow-ups of GCN notices with ~30 min latency on 3 timescales (1, 20, 300 sec)

Untriggered: Search of the full overhead sky on 4 timescales (0.1, 1, 10, 100 sec) with ~4 sec latency

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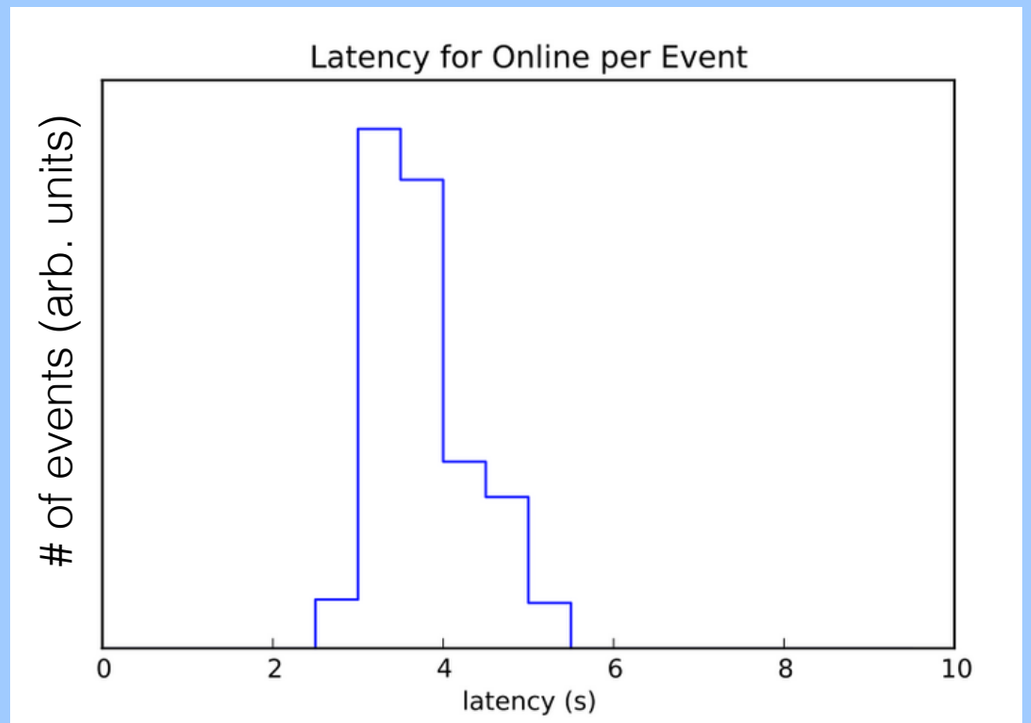

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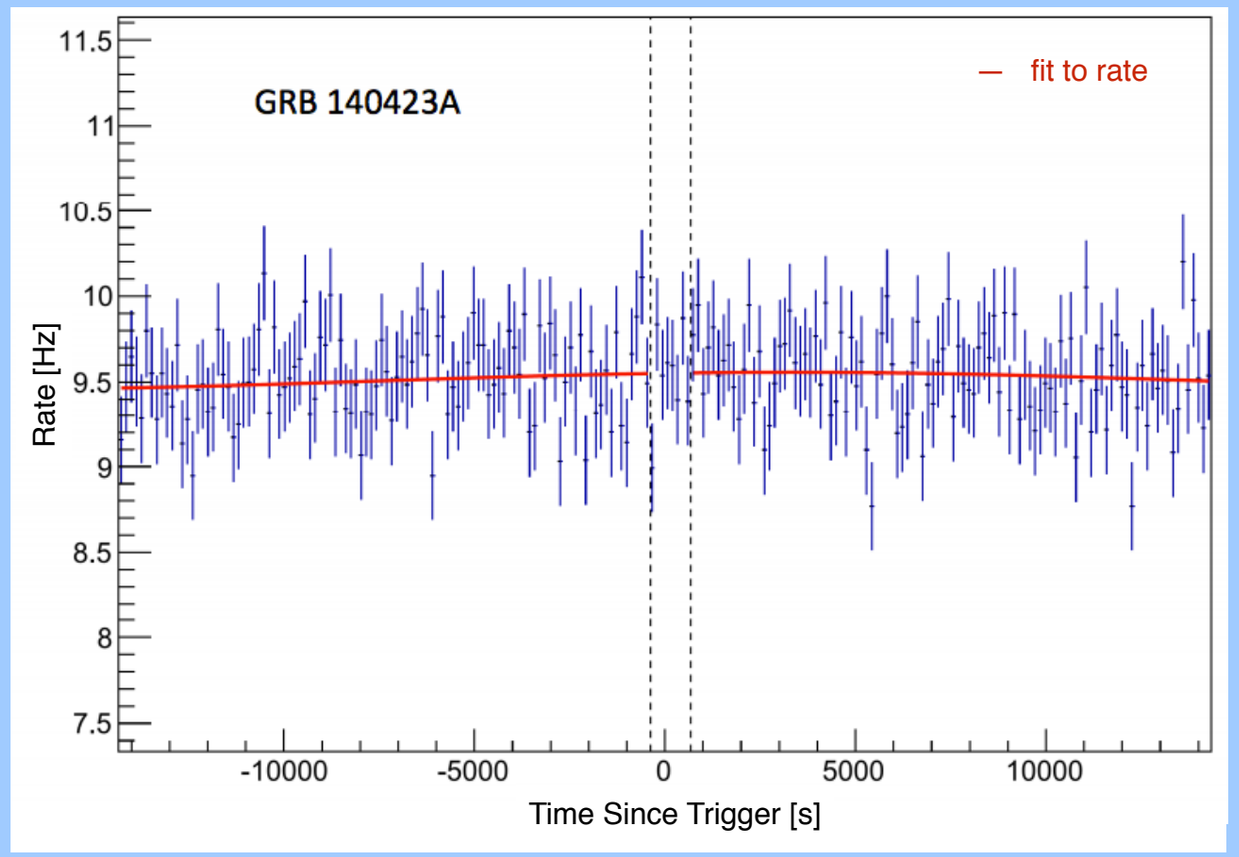
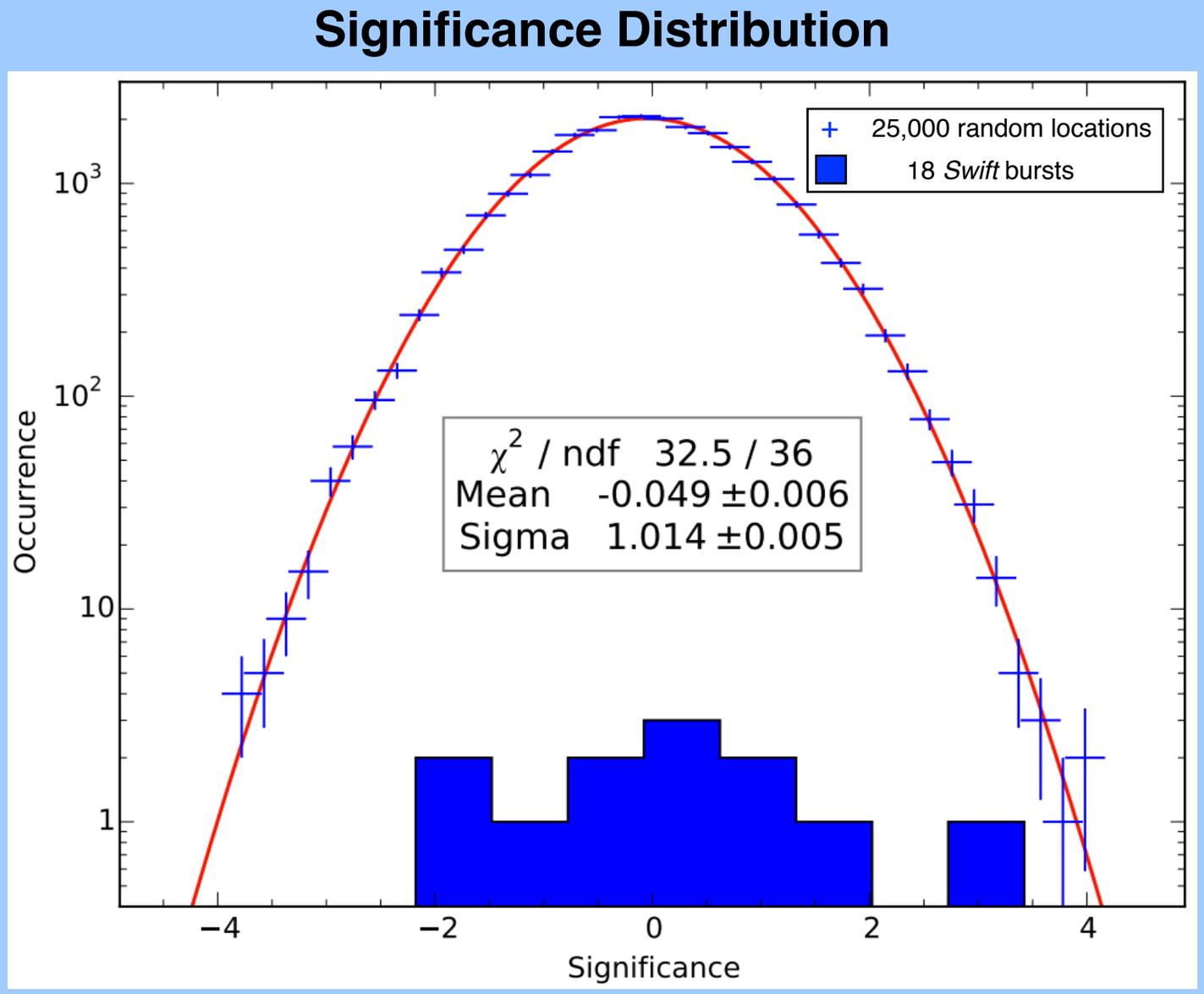
GCN Triggered Follow-ups

- Following *Swift*, *Integral*, MAXI, & Fermi LAT (well localized) GCNs
- Count the number of air showers arriving in 2˚ radius bin at reported location within 3 timescales: 1s, 20s, 300s
- Compare to expected counts from rate at that location in local coordinates →
- Obtain p-value from Poisson statistics and convert to σ



Some *Swift* Follow-ups



- Tested follow-up method offline during HAWC-111
- No >5σ detections
- Most significant result is GRB140607A
  3.4σ pre-trials,
  2.5σ post-trials
- Performing the follow-up method on 25,000 random locations across the sky throughout HAWC-111 period yields μ = 0, σ = 1

Full list of analyzed GRBs:

D. Lennarz, I. Taboada. Proceedings of the 34th ICRC
http://arxiv.org/abs/1508.07325

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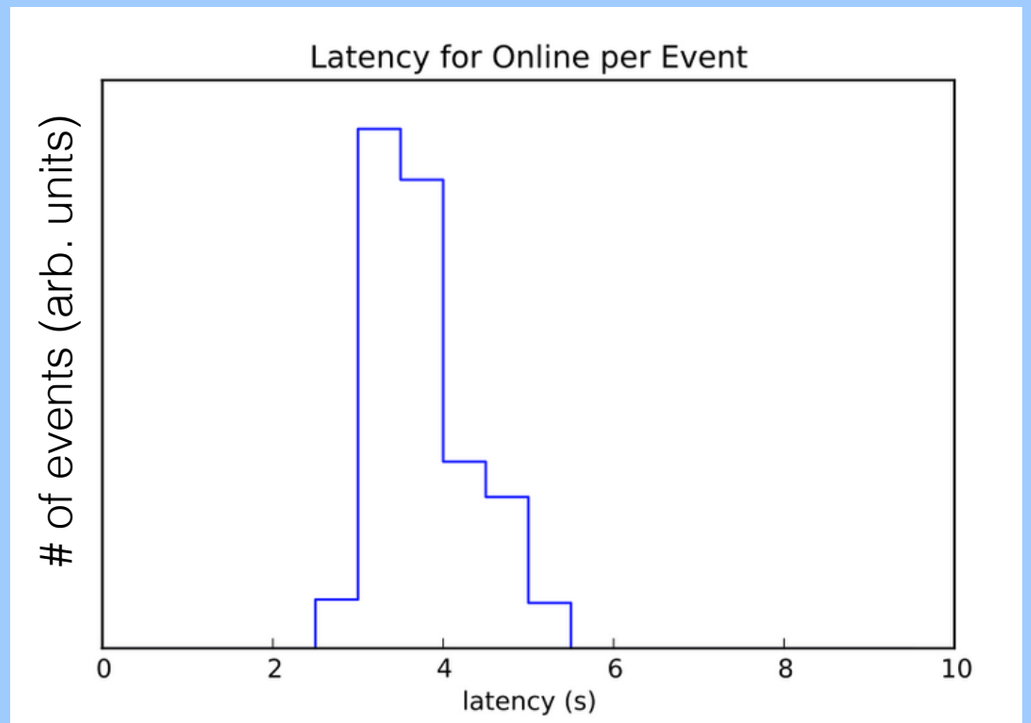

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Untriggered, All-Sky Search

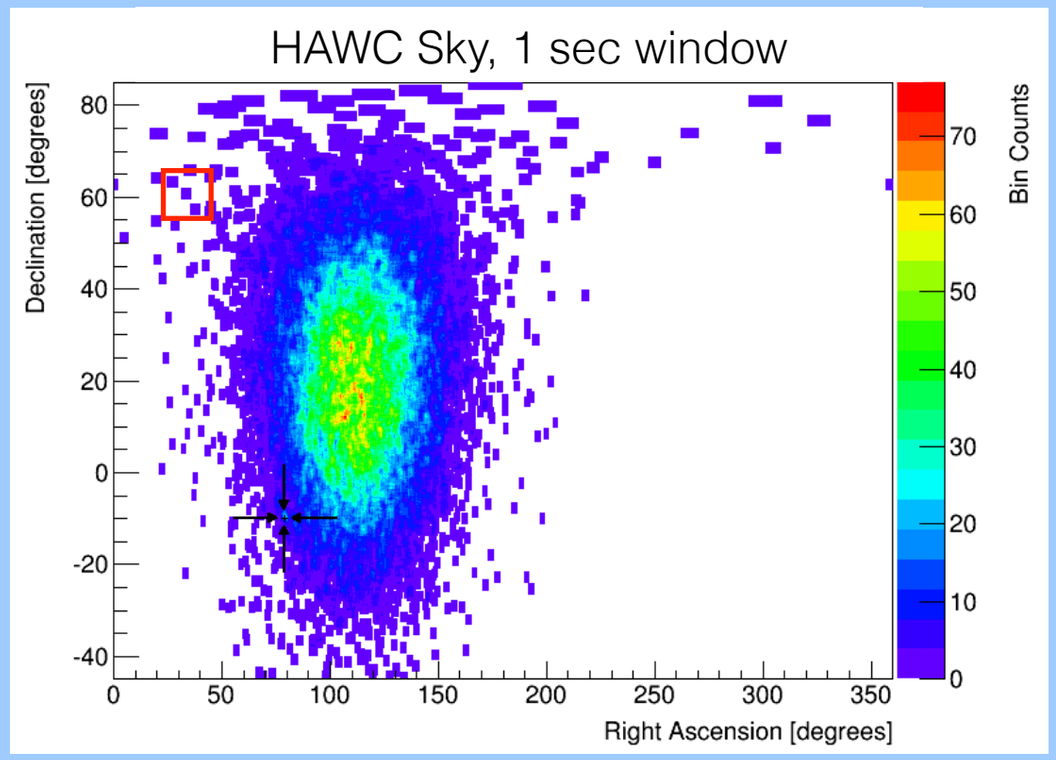
- Full search over FOV (0-60 deg zenith) using 2.3 x 2.3 deg bins separated by 0.11°

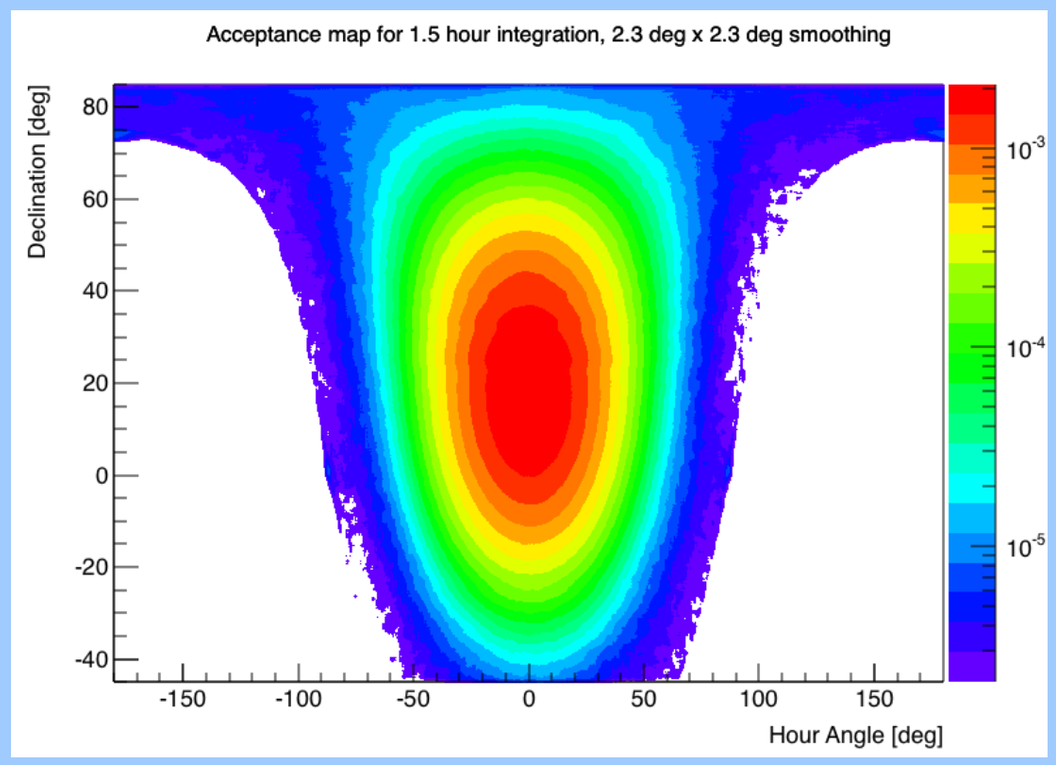
- 0.1, 1, 10, 100 sec timescales shifted by 10%

- background from poisson statistics using direct int. →

N_{BG} = Acceptance x Trigger Rate x Timescale (24 kHz)

Full details: J. Wood. Proceedings of the 34th ICRC http://arxiv.org/abs/1508.04120





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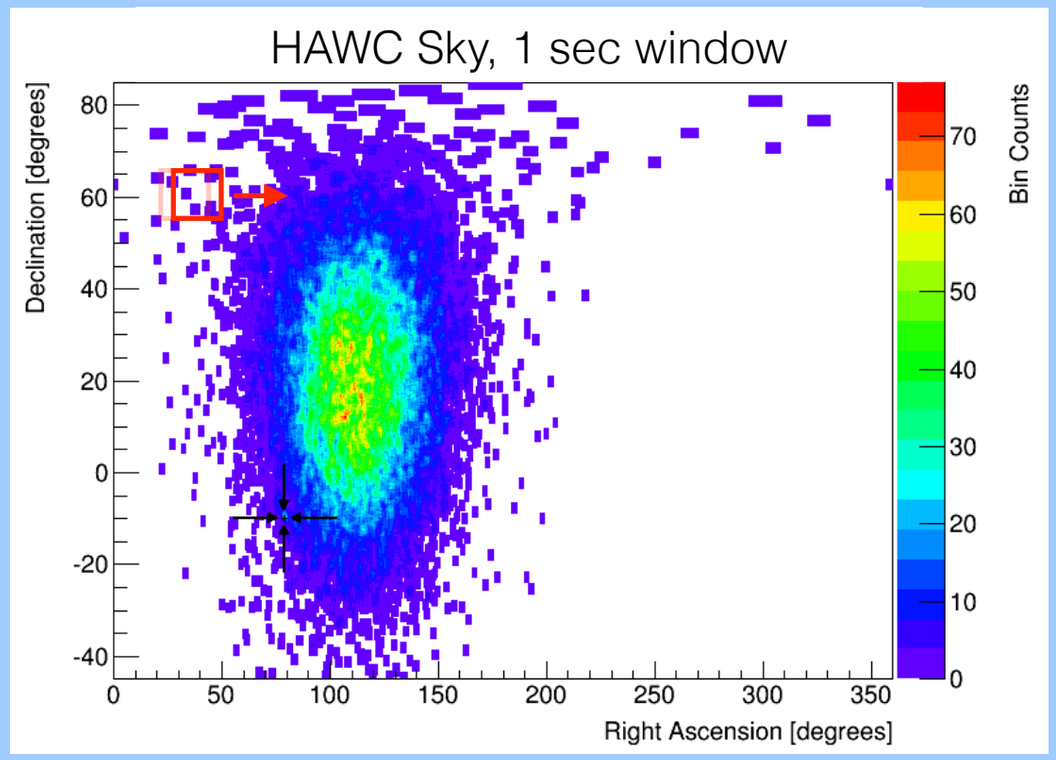

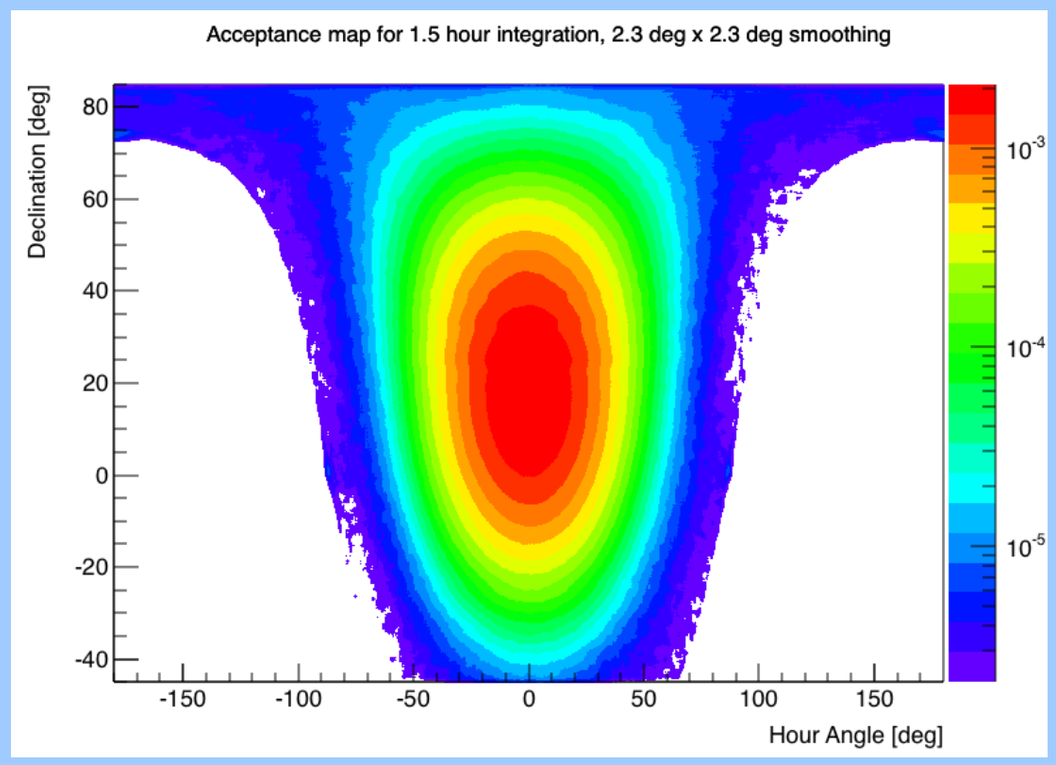

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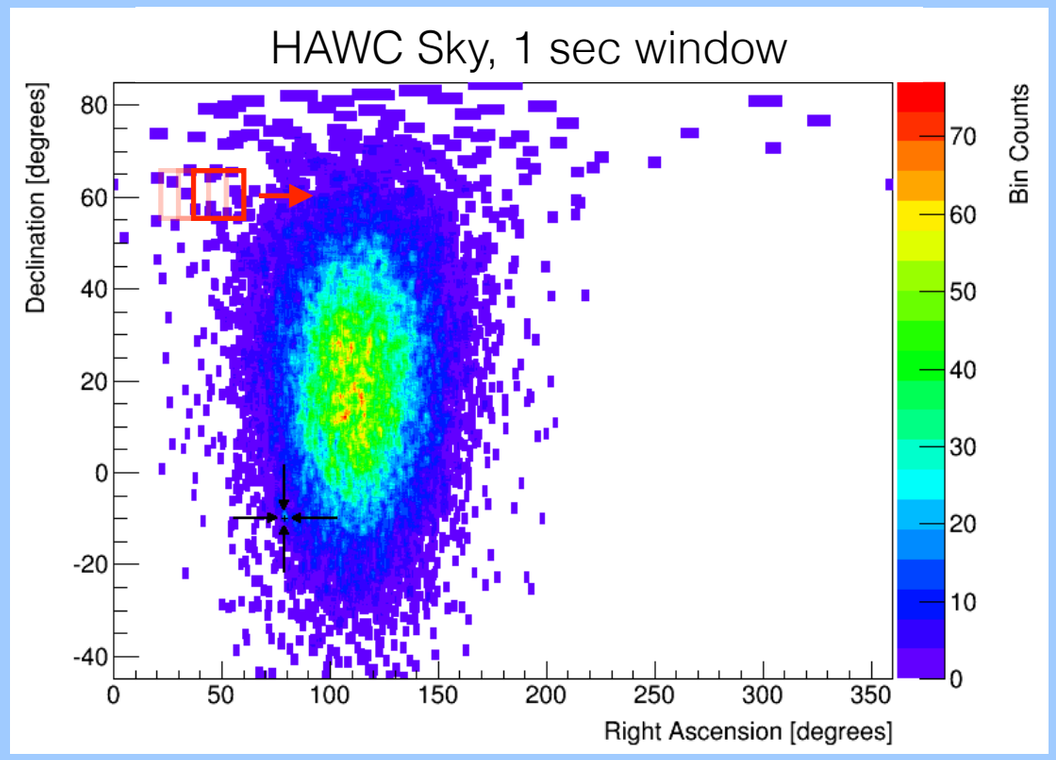

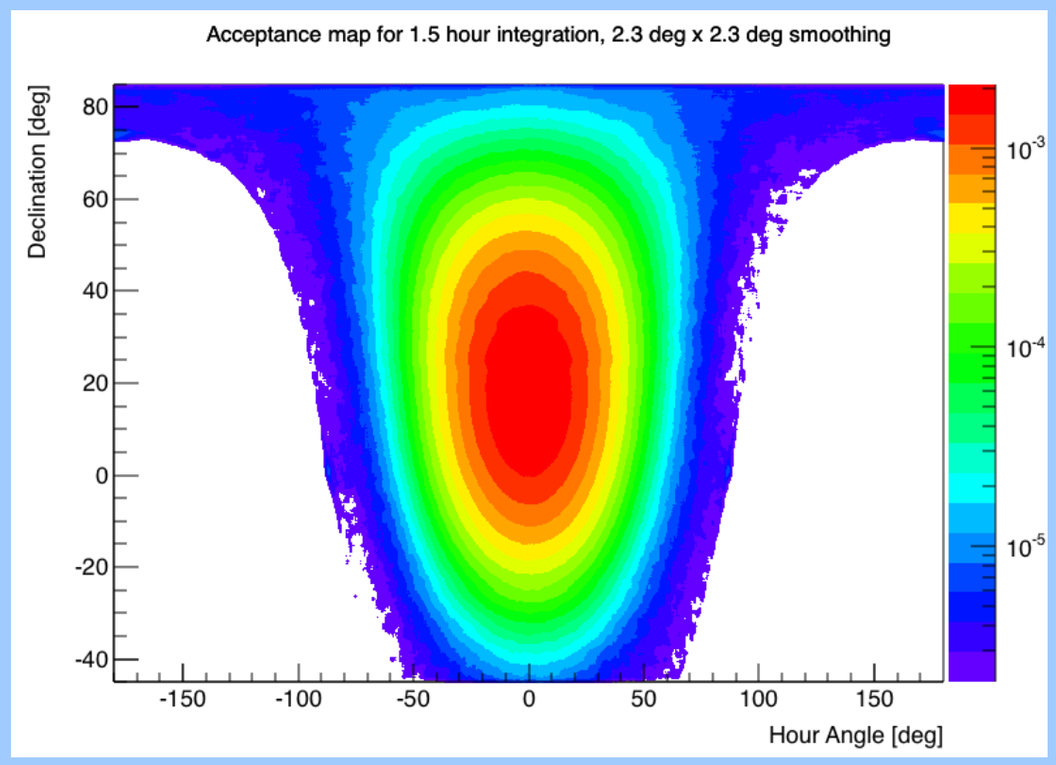

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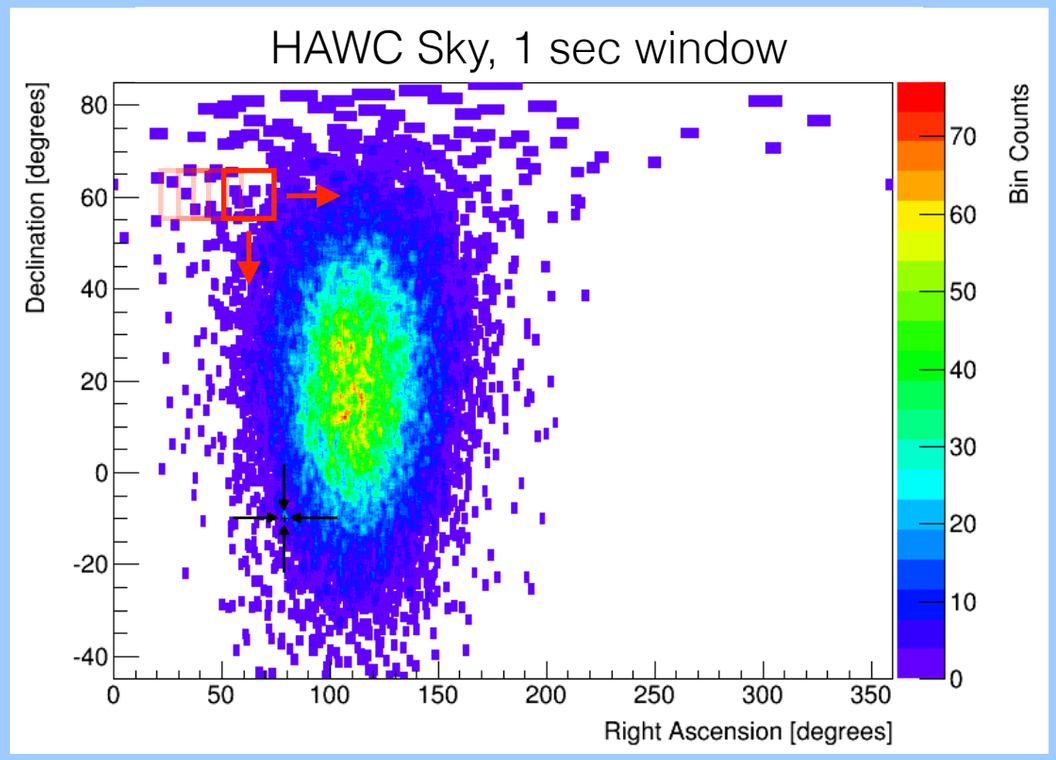
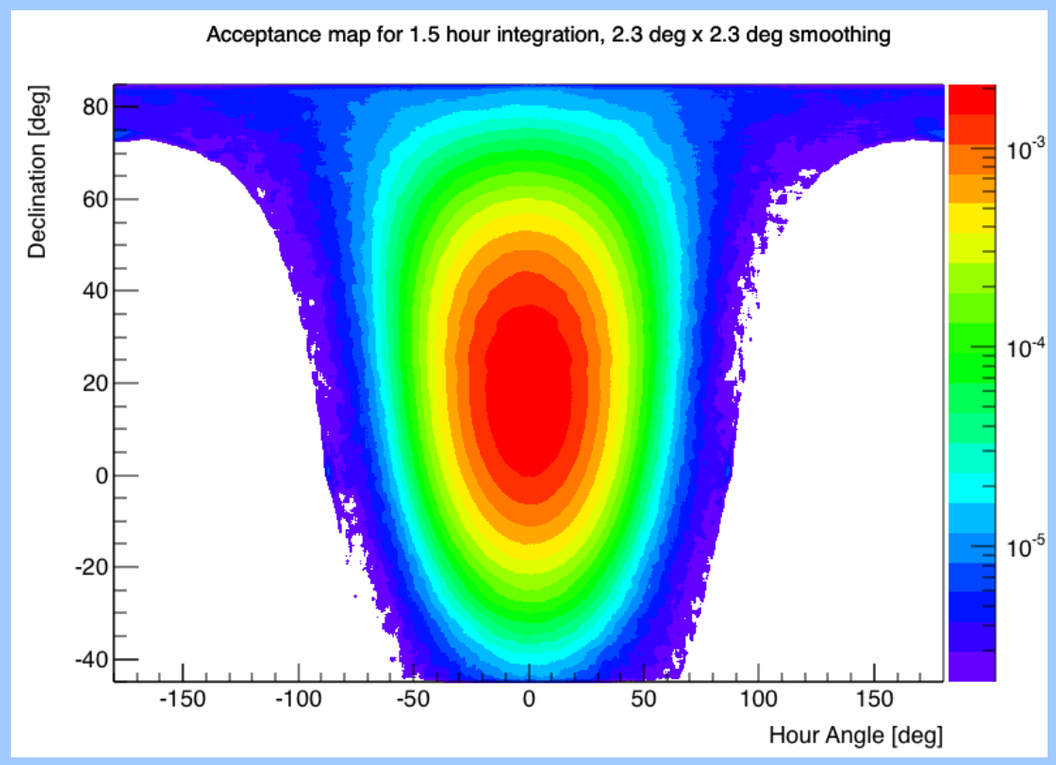
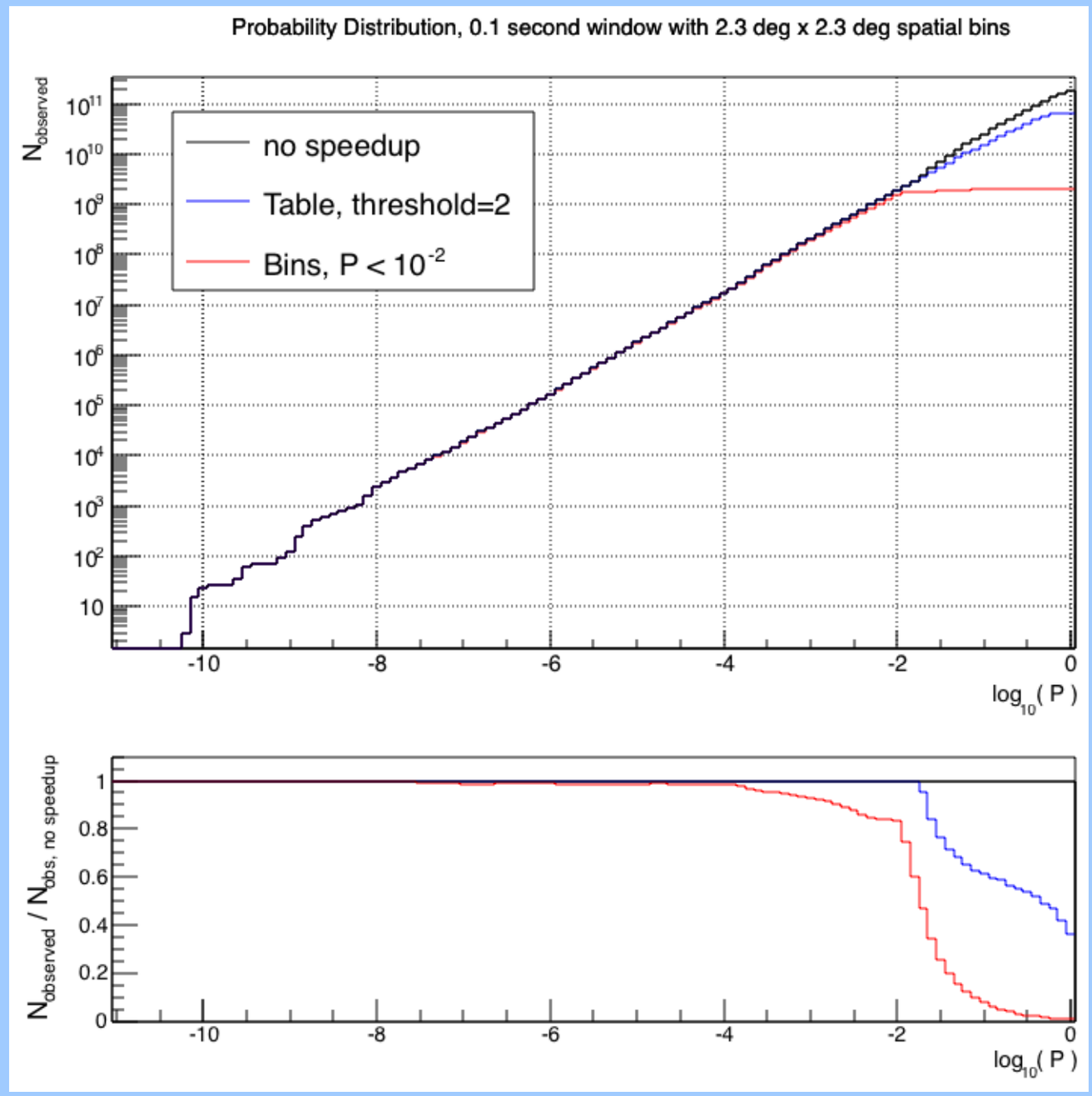




Untriggered, All-Sky Search

- Histogramming p-values collected during the search yields what we expect (falls off logarithmically with each decade in prob.)

- Background is well modeled



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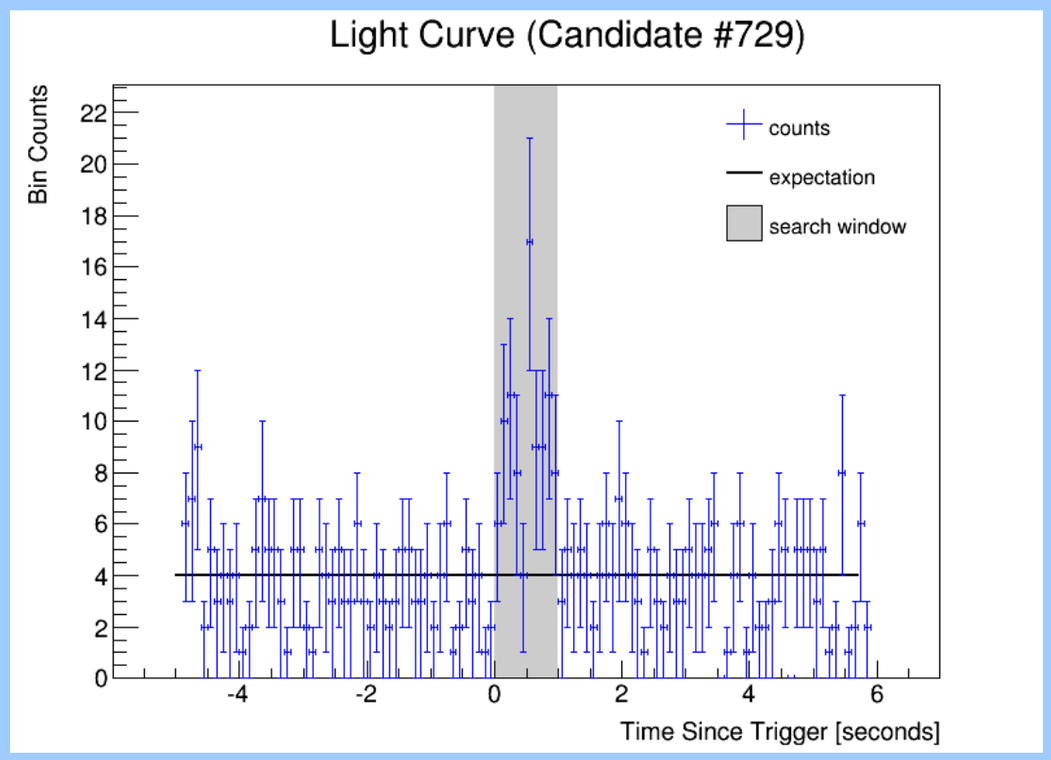
Untriggered, All-Sky Search

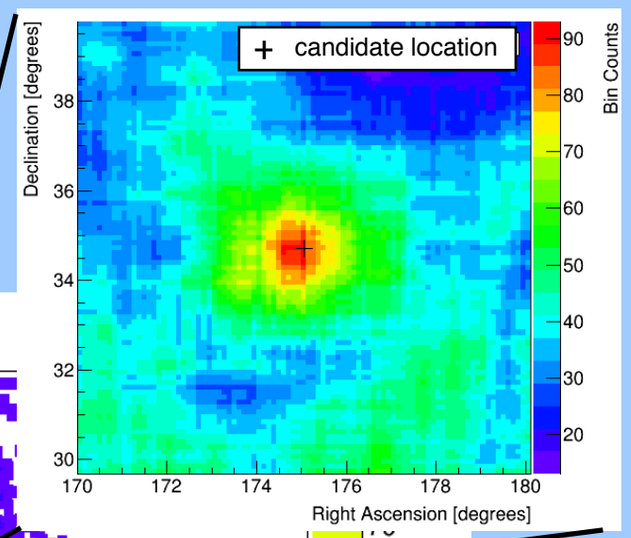
- 1 second duration, shifted by 10% over the course of a full day with spatial bins shifted by 10% over the full sky yields ~10^{12} trials

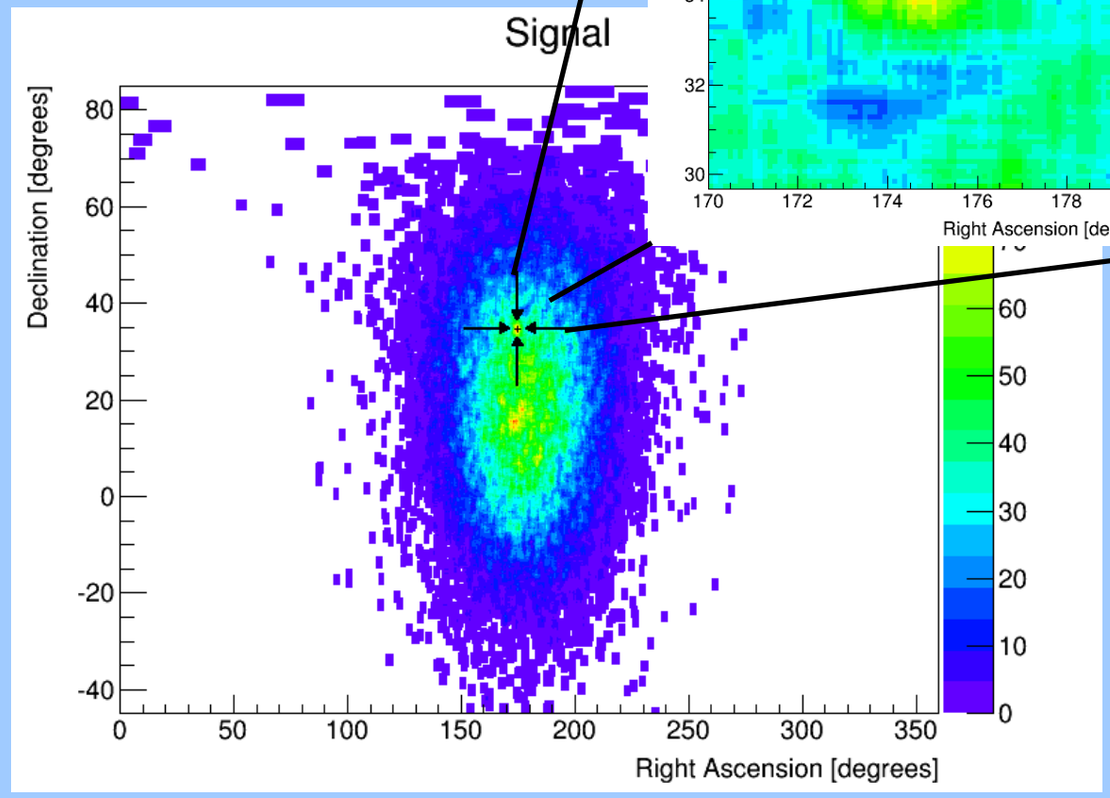
- Only requires 2x flux increase over triggered search, opens up sky where satellites are not overhead

- Let's you see really cool background fluctuations!

$P_{pre} = 6 \times 10^{-13}$, $P_{post} = 4 \times 10^{-2}$







Real-time GRB Data Products

Type	Frequency	Latency	Status
Triggered Follow-up	1 per GCN notice	30 min (can be improved)	Most vetted, probably first to go public when we finish our real-time alerts manager
Untriggered Candidates	Goal: 1 per month	4 sec + ~2 min	Still working on vetting of analysis. (trials correction). Not ready to go public just yet,but willing to work privately with MUOs (recently approached by iPFT)
Untriggered Sub-threshold	*o* (1000) per day	probably depends on internet at HAWC (~150 KB/s steady state right now, should improve)	Some work by PSU undergraduate trying to get sub-threshold events from older un-triggered search results into AMON. Will continue

Summary

- HAWC should be able to detect ~1 GRB per year, providing temporal and spectral information at ~100 GeV

- Sensitive enough to detect several historical bursts (GRB090510 shown here, GRB130427A as well)

- Running both triggered and untriggered GRB searches in real-time (4 sec analysis latency using all our tricks + 2 min for sending alert)

- Still fine tuning and trying to catch up with the rest of the community in terms of real-time abilities but we're making great strides!

Backup

18 *Swift*-detected GRBs

GRB	Trigger Number	Time UTC	RA J2000	DEC J2000	Zenith Angle deg	BAT T90 s	Significance σ
140628A	602803	13:35:37	02h42m39.88s	-0d23m05.7s	26.0	10.5	-0.74
140622A	602278	09:36:04	21h08m41.56s	-14d25m09.5s	33.4	0.13	-0.93
140607A	601051	17:13:31	05h45m29.52s	18d54m14.4s	27.9	109.9	3.42
140518A	599287	09:17:46	15h09m00.60s	42d25m05.6s	48.6	60.5	-0.61
140430A	597722	20:33:36	06h51m44.61s	23d01m25.2s	31.3	173.6	-1.75
140423A	596901	08:31:53	13h09m08.54s	49d50m29.4s	46.9	134	0.21
140419A	596426	04:06:51	08h27m57.56s	46d14m25.3s	45.3	94.7	1.35
140414A	GA	06:06:29	13h01m14.40s	56d54m07.2s	37.8	0.7	-0.18
140408A	595141	13:15:54	19h22m51.83s	-12d35m42.5s	32.4	4.00	-0.02
140331A	594081	05:49:48	08h59m27.46s	02d43m02.3s	45.7	209	-2.18
140215A	586680	04:07:10	06h56m35.81s	41d47m11.7s	23.2	84.2	0.30
140206A	585834	07:17:20	09h41m20.26s	66d45m38.6s	47.7	93.6	-1.86
140129A	585128	03:23:59	02h31m33.78s	-01d35m43.4s	47.8	2.99	1.65
140114A	583861	11:57:40	12h34m05.16s	27d57m02.6s	11.1	139.7	0.29
131229A	582374	06:39:24	05h40m55.61s	-04d23m46.7s	27.7	13.86	1.23
131227A	582184	04:44:51	04h29m30.78s	28d52m58.9s	10.1	18.0	-0.48
131117A	577968	00:34:04	22h09m19.36s	-31d45m44.3s	50.9	11.00	0.27
131001A	GA	05:37:24	00h33m12.96s	25d33m25.2s	12.4	4.9	0.96