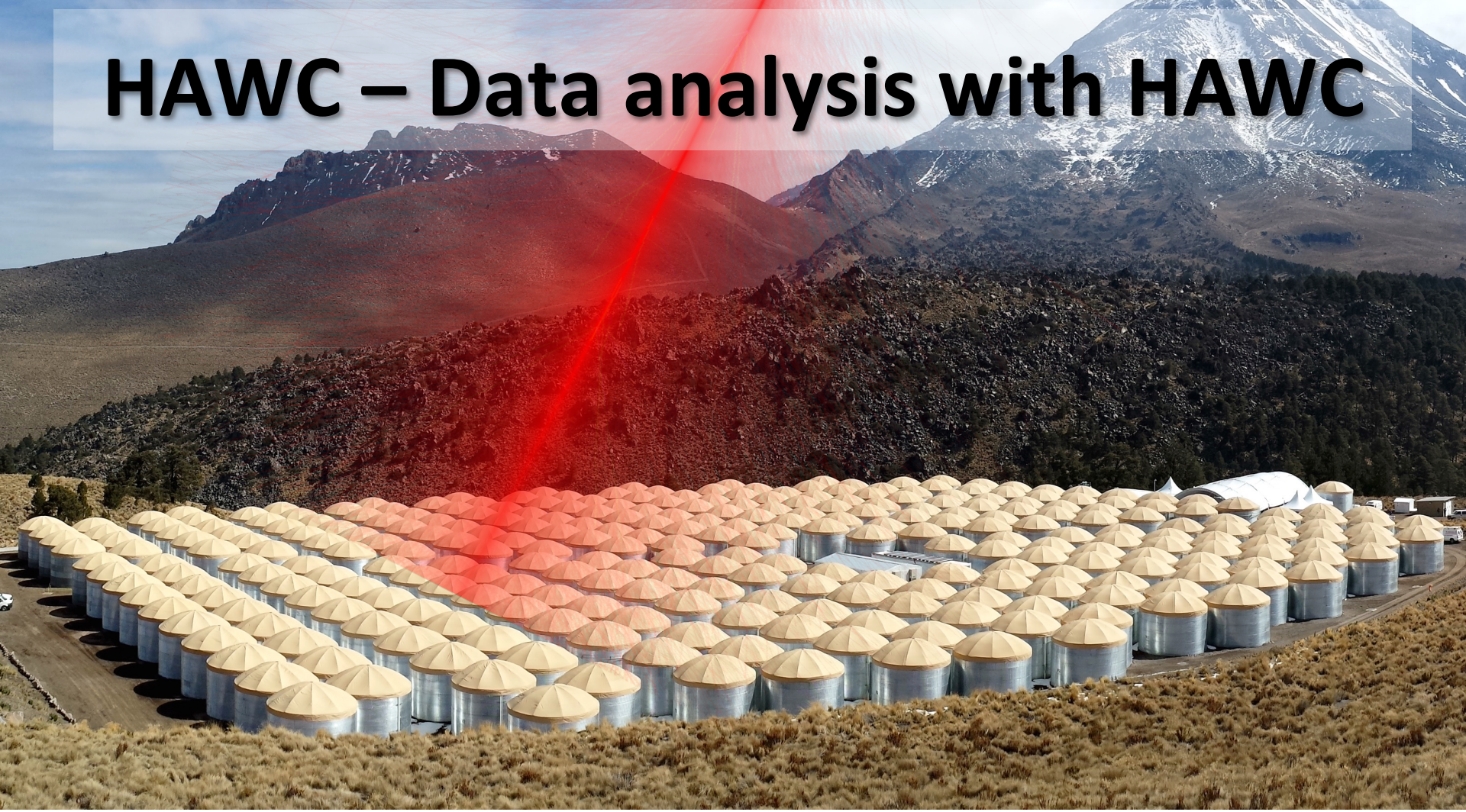
HAWC – Data analysis with HAWC



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HAWC
High Altitude Water Cherenkov
Gamma-Ray Observatory

The HAWC Collaboration

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Georgia Institute of Technology
Los Alamos National Laboratory
Michigan State University
Michigan Technological University
NASA/Goddard Space Flight Center
Pennsylvania State University
Univ. of California, Irvine
University of California, Santa Cruz
University of Maryland
University of New Hampshire
University of Rochester
University of Utah
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Universidad Autónoma del Estado de Hidalgo
Universidad de Guadalajara

Universidad Michoacana de San Nicolás de Hidalgo
Universidad Nacional Autónoma de México (UNAM)
- Instituto de Física
- Instituto de Astronomía
- Instituto de Geofísica
- Instituto de Ciencias Nucleares

Universidad Politécnica de Pachuca

Outline

Detector Performance

- Effective area
- Angular Resolution
- g/H separation

Signal and background for a fake Crab

Cosmic Ray Background

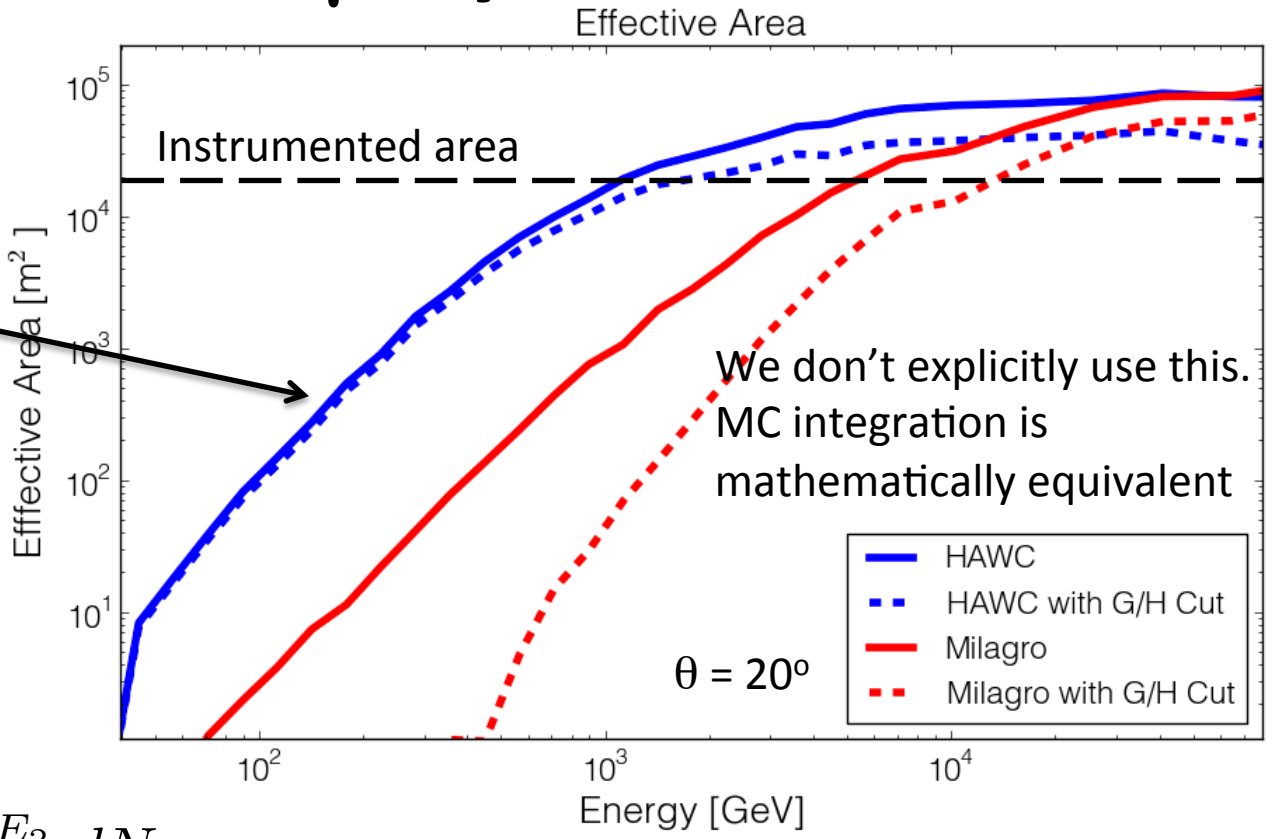
Simulated HAWC sensitivity

Direct integration – measuring background

A slide left over from yesterday.

Effective area for γ-rays

Trigger, shower development fluctuations

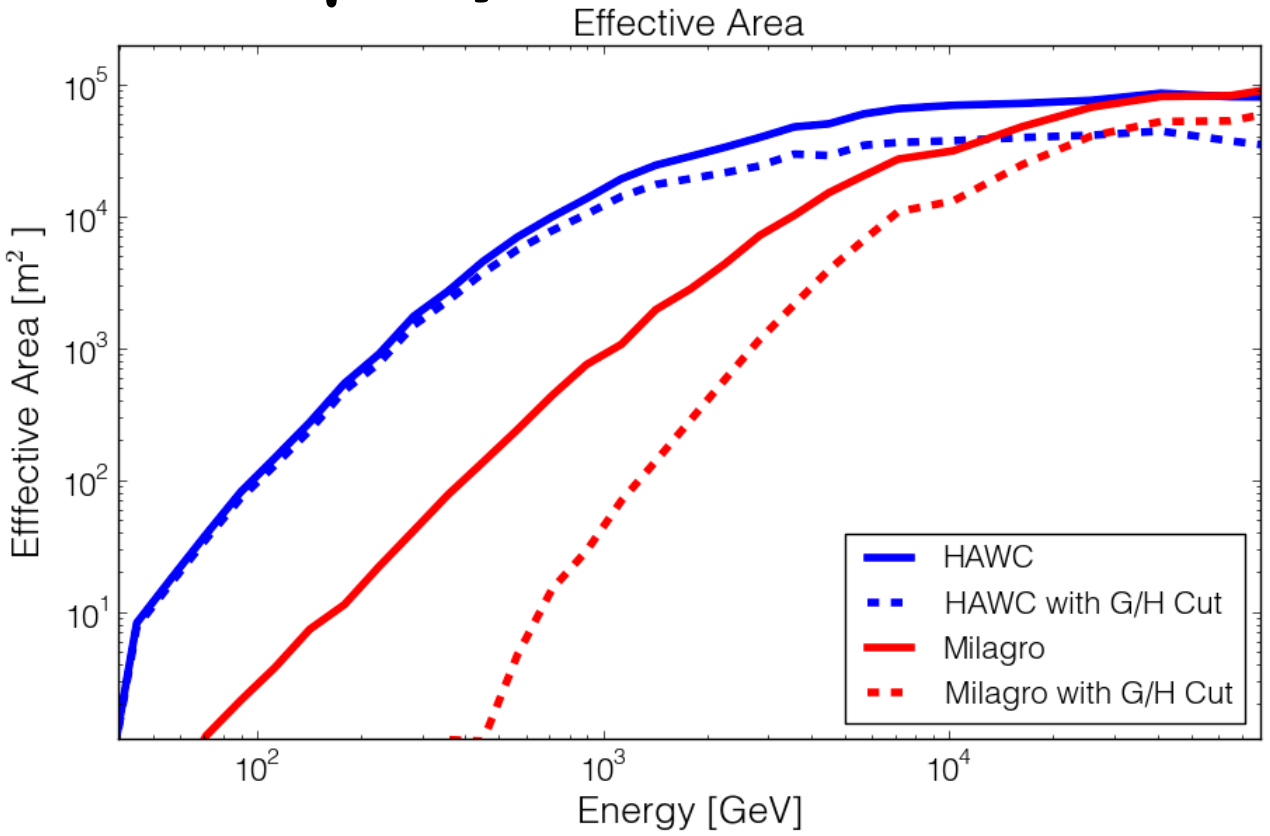


$$R = \int_{E_1}^{E_2} \frac{dN}{dE} A_{eff}(E) dE$$

No well defined threshold – IACTs have a better defined threshold

No explicit "core on the array selection"

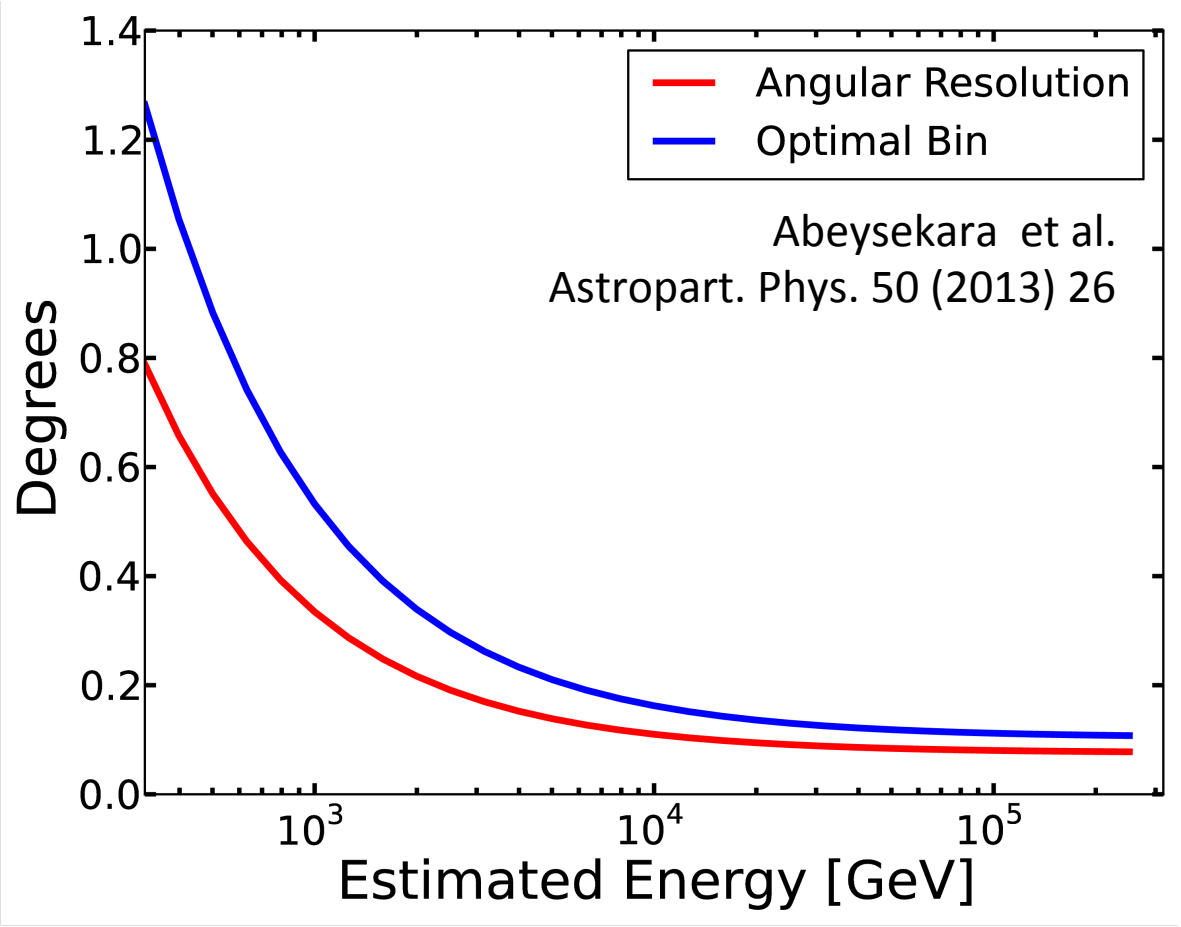
Effective area for γ-rays



Similar (but not equal) for cosmic rays

Effective area depends (strongly) on zenith angle. Sources, transit. Effective areas are a complicated way of doing things.

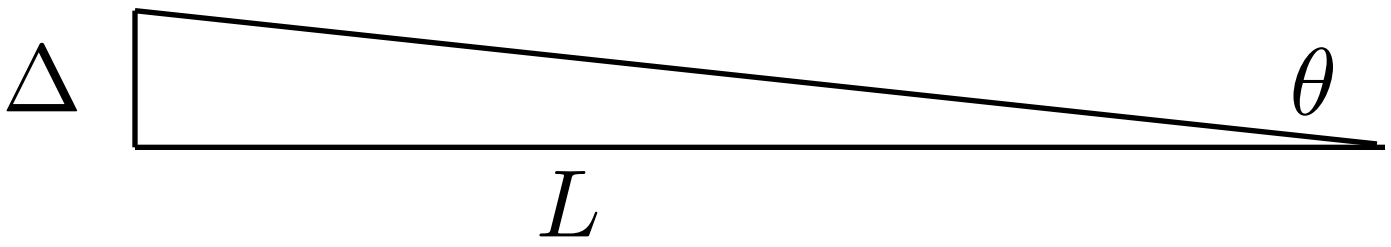
Angular resolution



Optimal bin: Maximize sensitivity

For HAWC-111 we use Crab data to measure our point spread function vs. event size

Angular resolution & Calibration
Order of magnitude argument

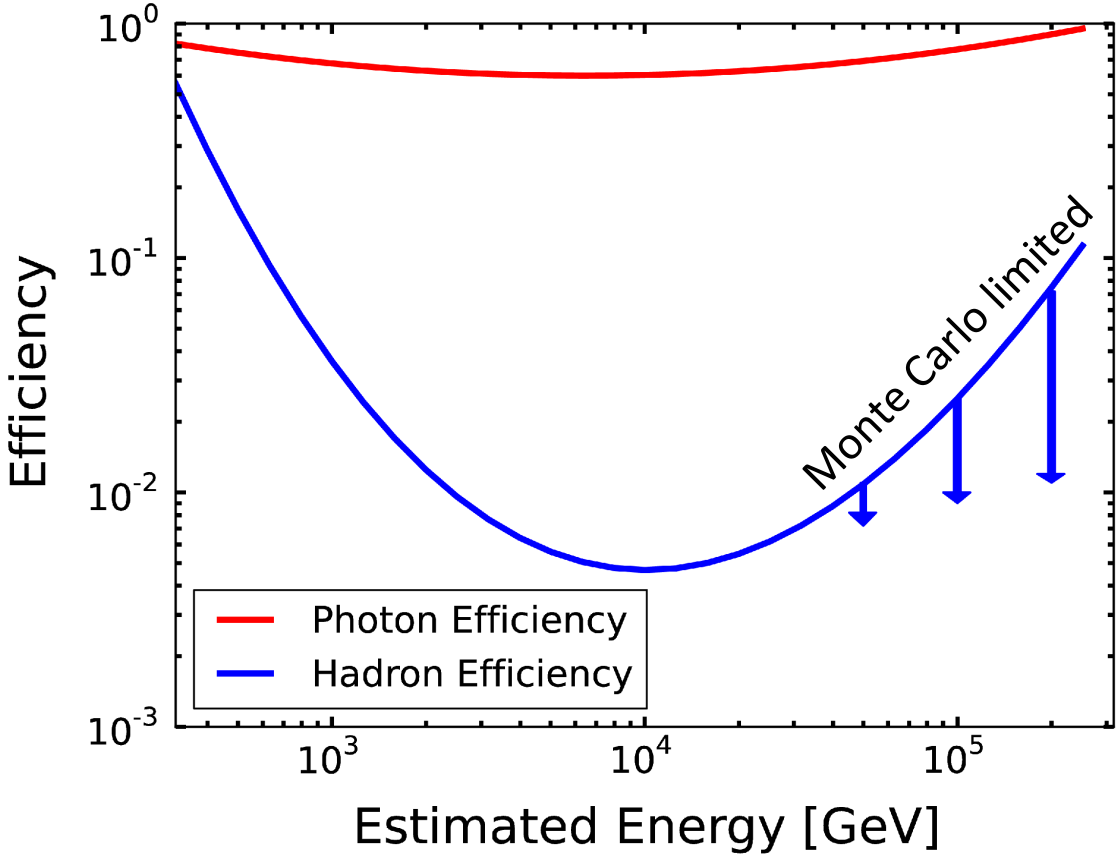


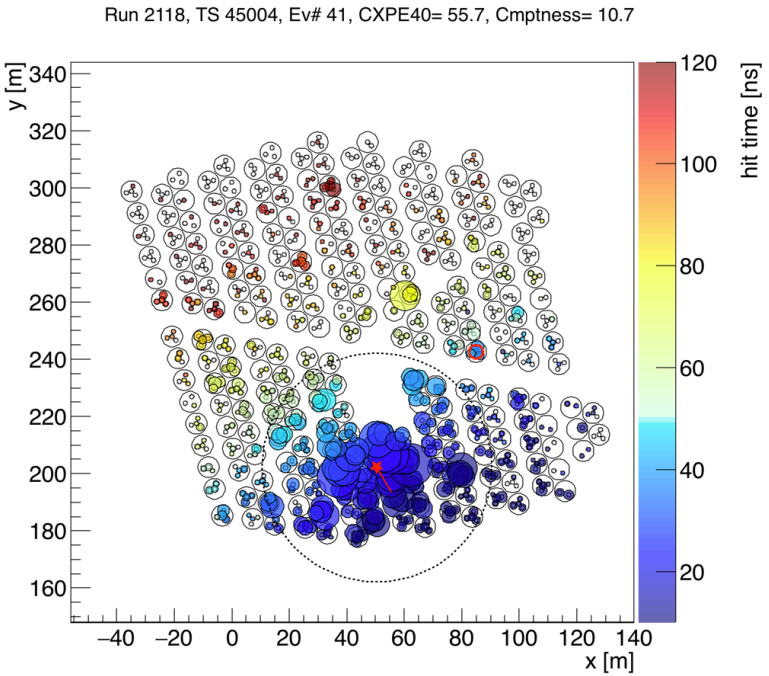
0.1º = 1.75 mrad $\Delta = L \tan\theta \sim L\theta$

L = 150 m. Δ = 0.26 m. c = 0.30 m/ns

PMT time signals need to be known with a relative time of 1 ns

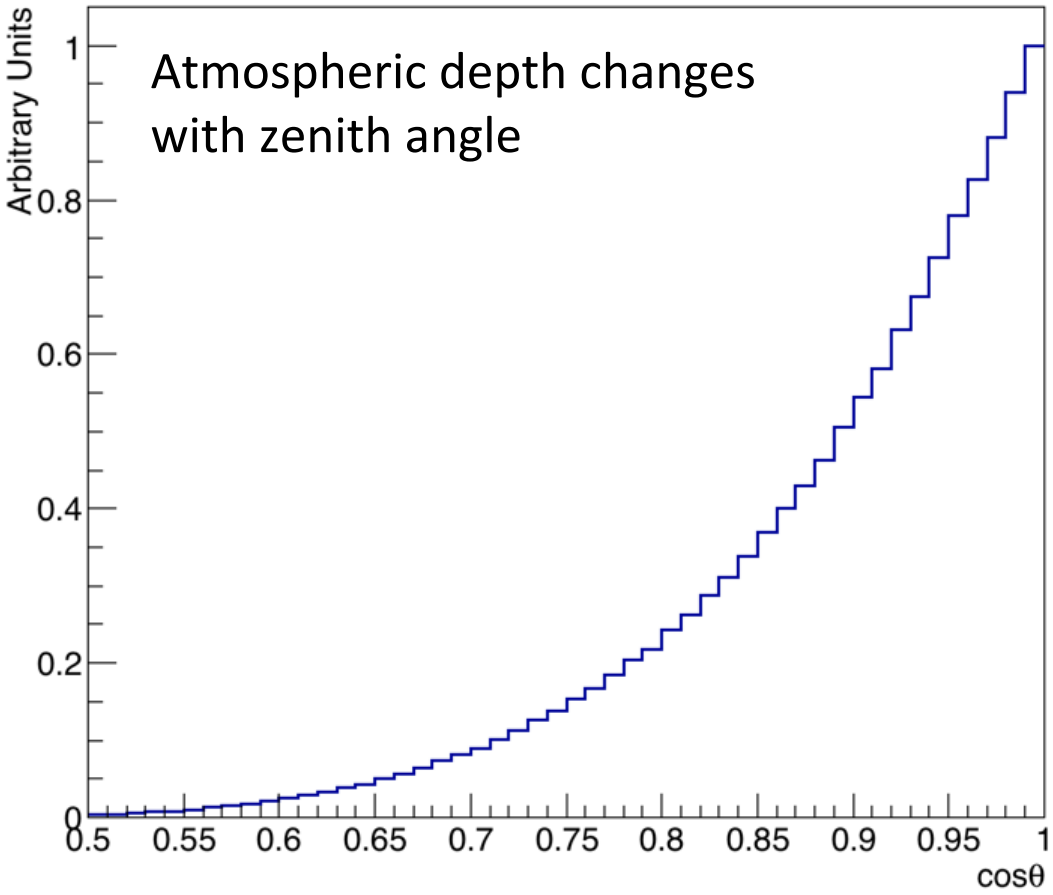
Gamma Hadron separation





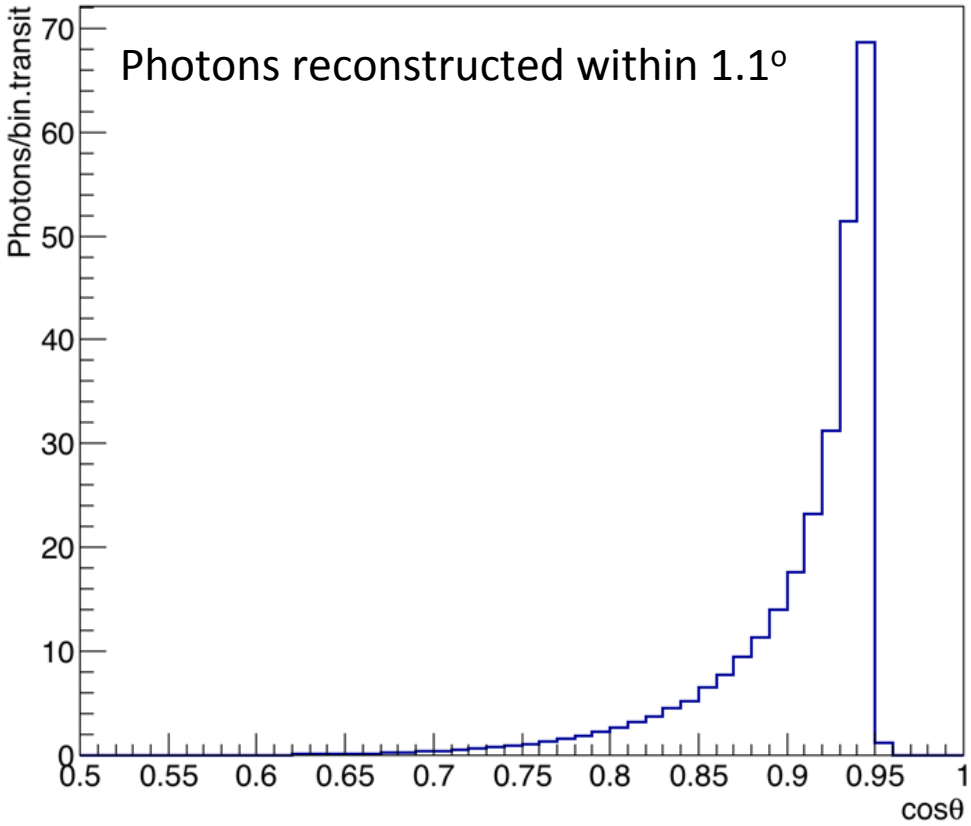
Compactness: Nhit/cxPE40
Nhit: Number of hits
cxPE40: number of photoelectrons in highest charge PMT >40 m from reconstructed core.

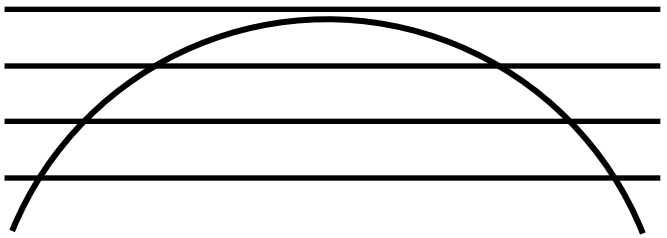
Signal simulation – Isotropic flux



Source of "One Crab": $\frac{dN}{dE} = 3.45 \times 10^{-11} (E/1\mathrm{TeV})^{-2.63}$ TeV^{-1}.cm^{-2}.s^{-1}

Signal simulation – transiting steady source



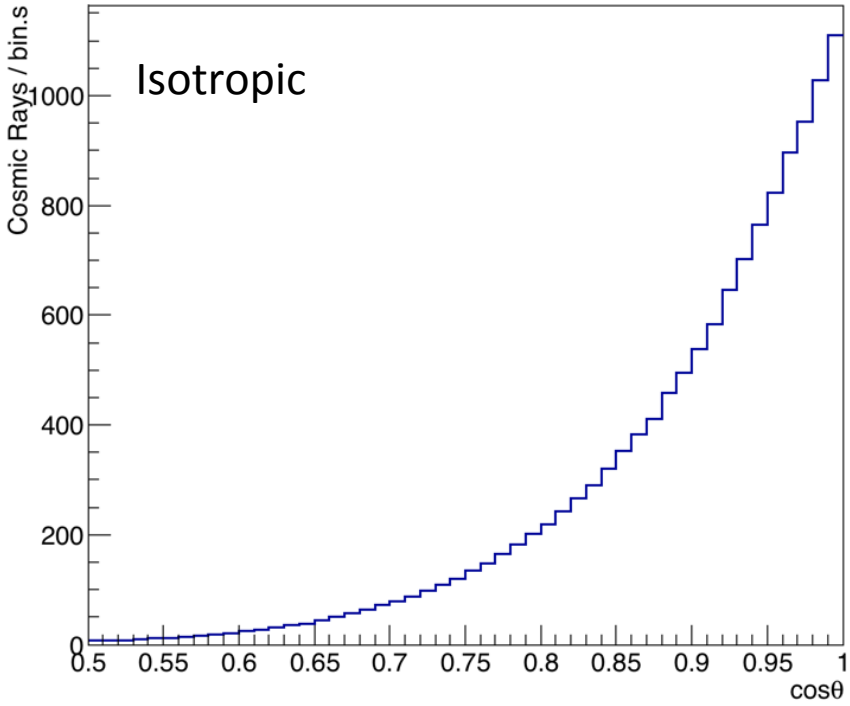


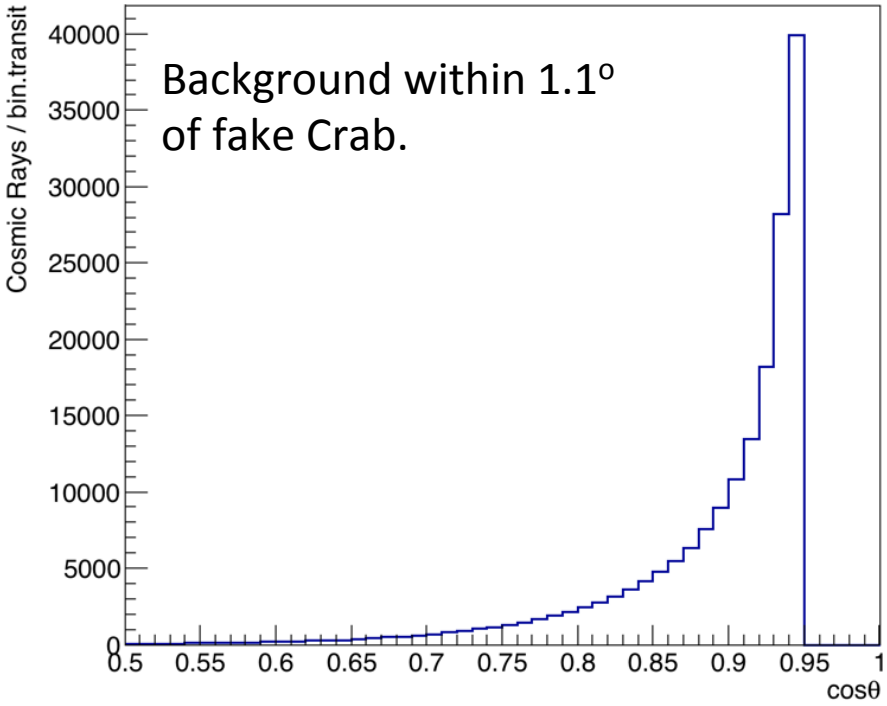
Visibility time of a source depends on declination.

For the Crab, the time above 45° is ~6 hours.

Fake Crab at declination 0°. Trigger level for this fake Crab: 275 γ / transit

Background simulation





Trigger rate: 13 kHz.

177,000 CR/transit

Sensitivity

At trigger level sensitivity to this fake Crab is:

$$S/\sqrt{B} = 275/\sqrt{177,000} = 0.65\sigma/\mathrm{transit}$$

Both signal and background scale linearly with time. Time for 5 sigma: ~59 days.

We should apply cuts …

Follow Abeysekara et al. Astropart. Phys. 50 (2013) 26

But we have better analyses options now.

Event selection

Bin	N_{chan} Bin	$\log_{10}(N_{PE})$ Bin	Angular Bin (deg.)	Compact. cut (PE^{-1})	Signal S_i	Weight w_i	E_{log} (GeV)	$\sigma_{E_{log}}$
1	39–59	1.0–7.0	1.30	3.1	5.7×10^4	2.8×10^{-3}	2.5	0.46
2	60–69	1.0–7.0	1.00	5.2	1.4×10^4	9.6×10^{-3}	2.6	0.47
3	70–90	1.0–7.0	0.88	5.3	1.8×10^4	1.3×10^{-2}	2.7	0.44
4	91–147	1.0–7.0	0.68	8.1	1.8×10^4	4.4×10^{-2}	2.9	0.40
5	148–231	1.0–7.0	0.50	11.7	7.9×10^3	1.7×10^{-1}	3.0	0.35
6	232–349	1.0–7.0	0.36	13.4	3.7×10^3	4.9×10^{-1}	3.2	0.32
7	350–495	1.0–7.0	0.30	17.2	1.4×10^3	2.0	3.5	0.28
8	496–655	1.0–7.0	0.22	17.7	6.0×10^2	4.7	3.7	0.24
9	656–789	1.0–7.0	0.20	17.1	2.4×10^2	9.8	3.8	0.21
10	790–1200	4.0–4.5	0.16	14.4	1.4×10^2	1.6×10^1	4.0	0.18
11	790–1200	4.5–4.9	0.14	11.5	1.2×10^2	1.2×10^1	4.2	0.18
12	790–1200	4.9–5.3	0.12	7.2	2.5×10^1	1.2×10^1	4.6	0.07
13	790–1200	5.3–5.7	0.12	1.9	3.4	1.8×10^{-1}	5.1	0.13
14	790–1200	5.7–6.4	0.08	0.9	3.2×10^{-1}	3.6×10^{-1}	5.5	0.10

Bin in number of PMT hit and total charge seen by PMTs

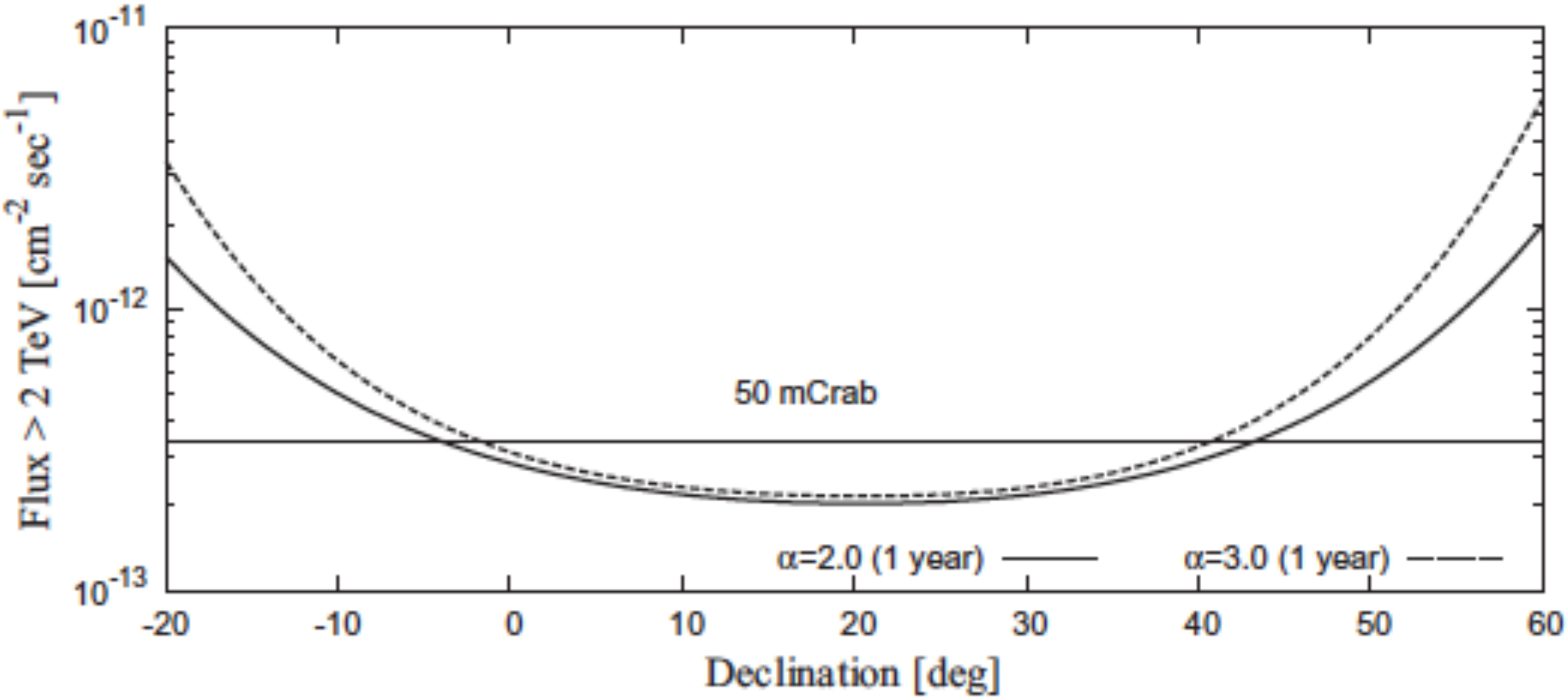
Optimize for a Crab-like spectrum for each bin

Combined significances with weights:

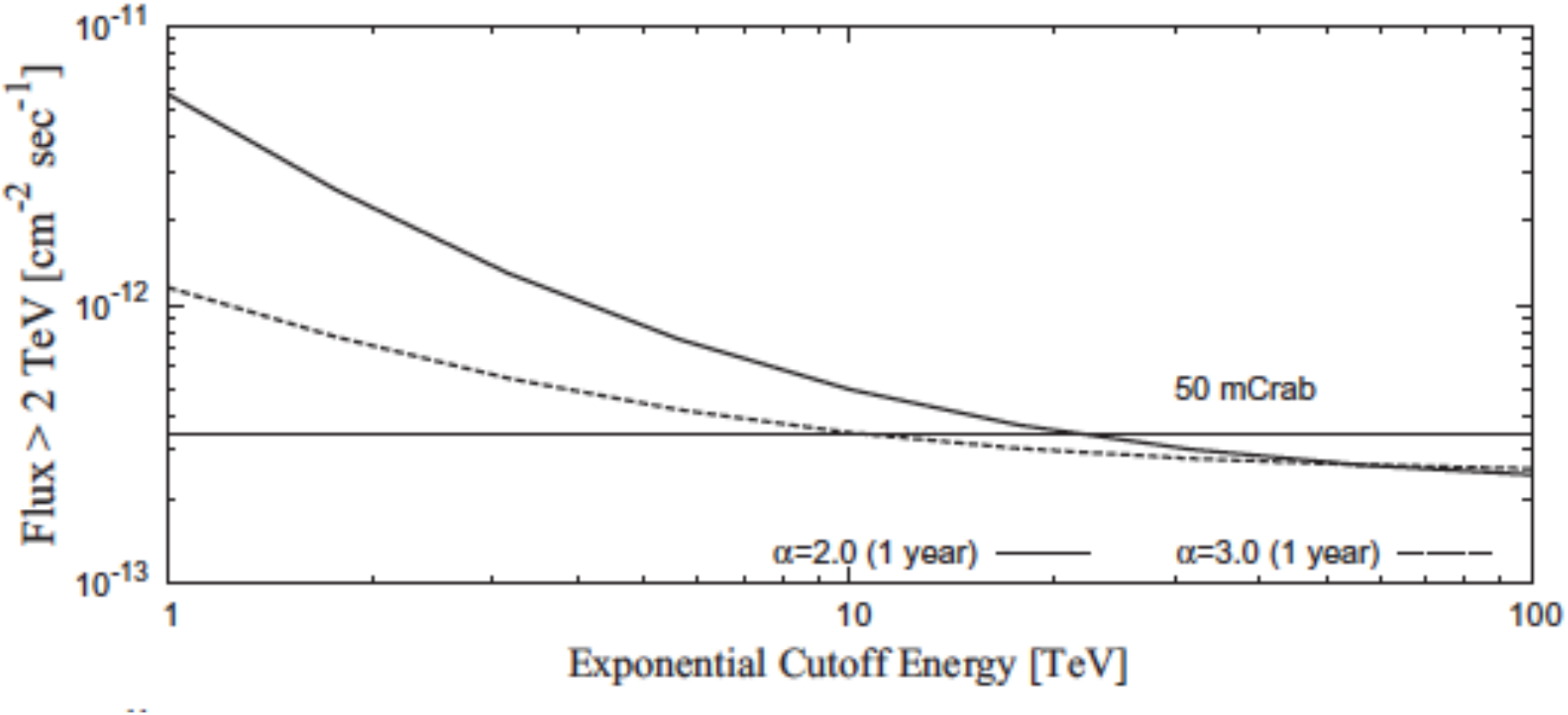
$$w_i = \frac{S_i^{opt}}{B_i^{opt}} \qquad \sigma = \frac{\sum_i w_i S_i}{\sum_i w_i^2 B_i}$$

With cuts ~5 sigma / transit on the simulated Crab

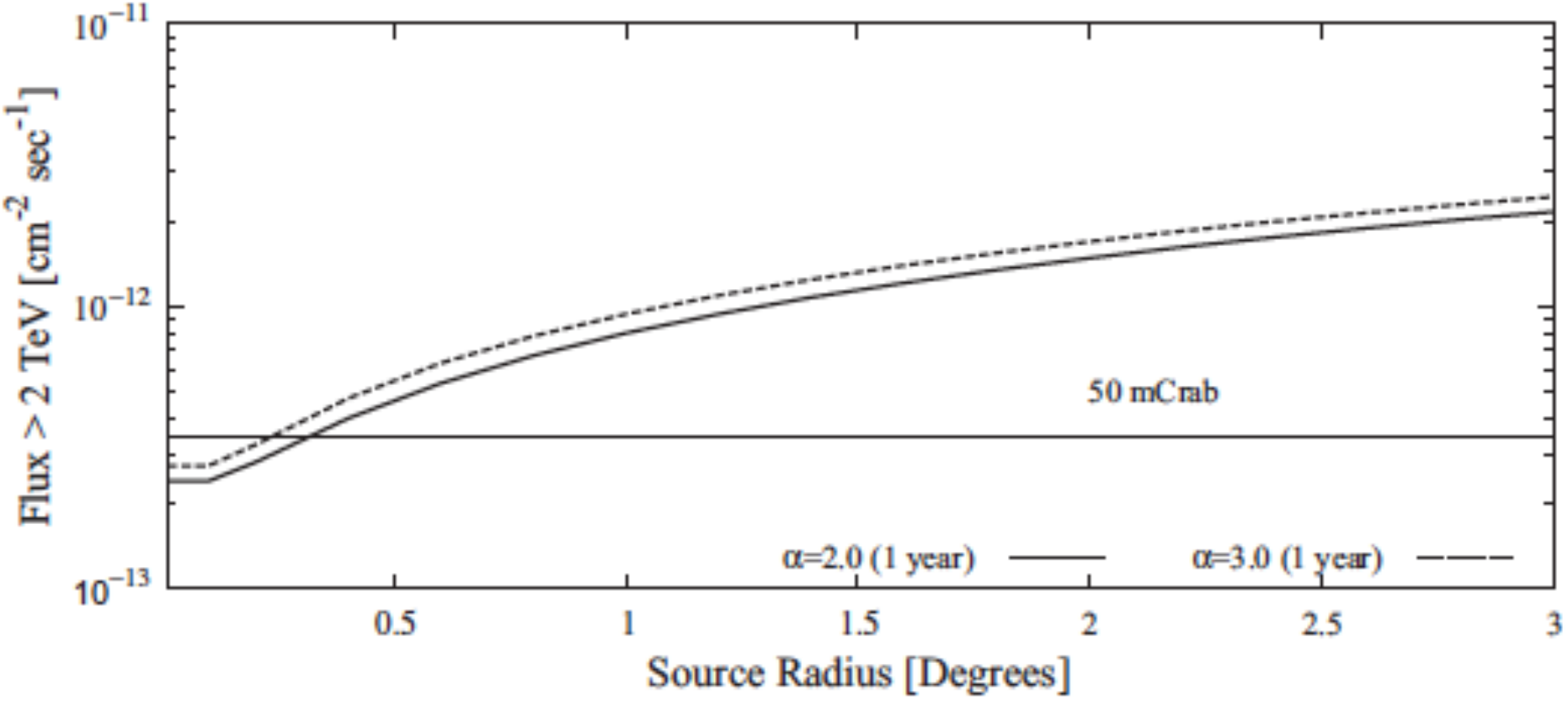
Sensitivity – One year



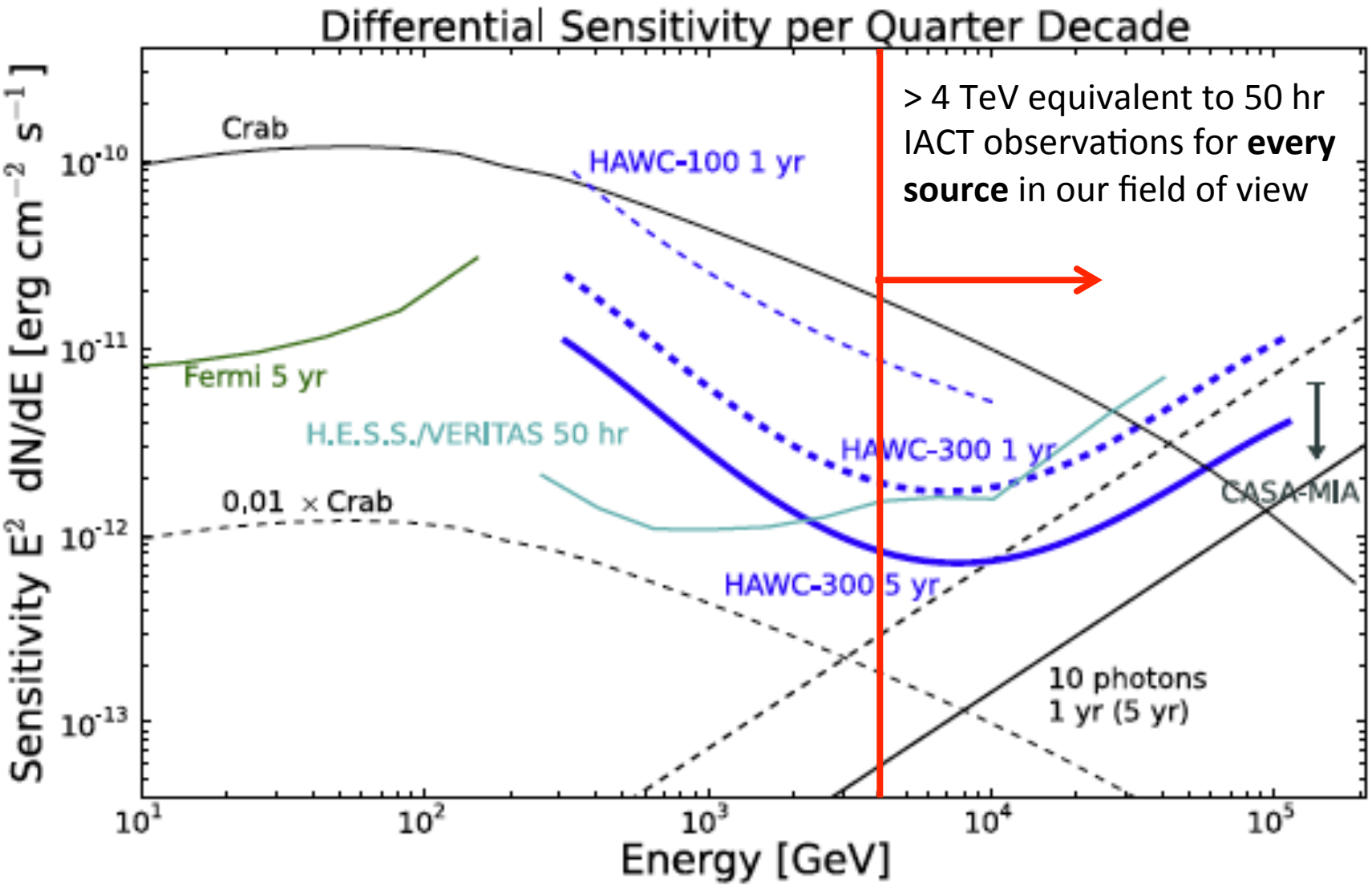
Sensitivity – One year



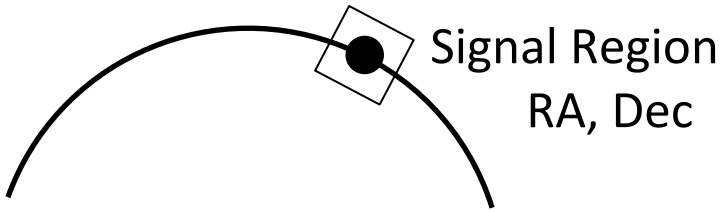
Sensitivity – One year

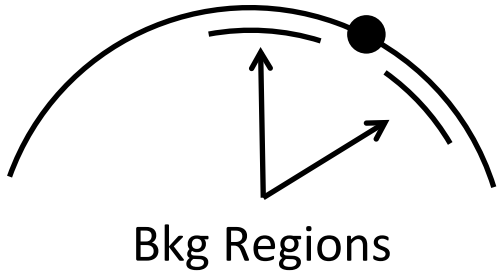


HAWC performance



Direct Integration – Measuring background





$$bkg(RA,\delta) = \int\int \epsilon(HA,\delta) R(t) E(HA,RA,t) dt d\Omega$$

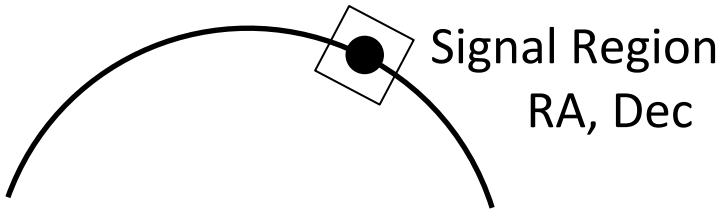
R(t): total detector rate (after cuts)

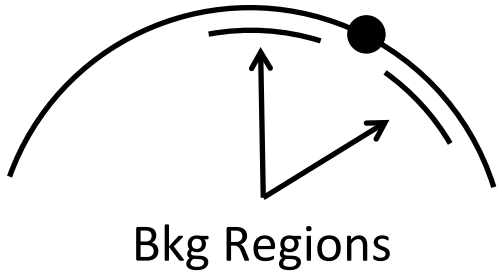
ε(HA,δ): detection probability within [δ,d+dδ] and [HA,HA+dHA]

E(HA,RA,t) = 1 if RA,HA fall in the bckg region for a time t. 0 otherwise

- with or without Signal Region masking -

Direct Integration – Measuring background





Direct integration is insensitive to sources larger than ~Δtx15^{o}/hr

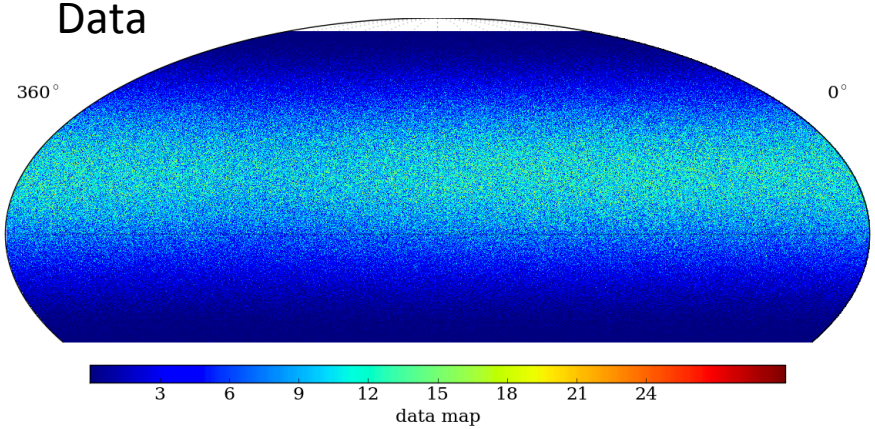
Assumes detector response doesn't vary significantly over Δt

Li & Ma alpha is about ~1/11 for 2 hour integration

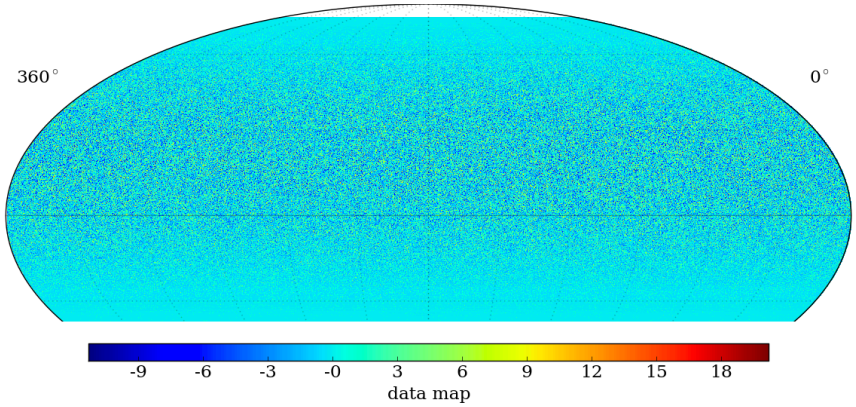
Direct integration – Example

One nHit bin / 2 months

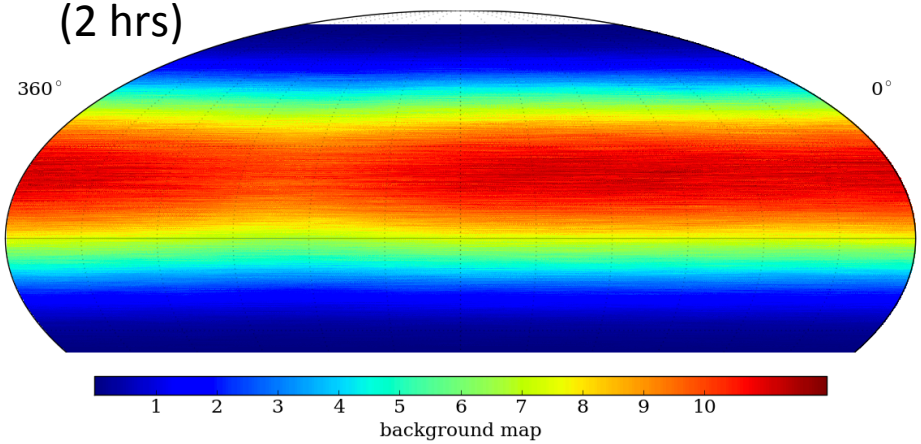
Data



Data minus Bkg

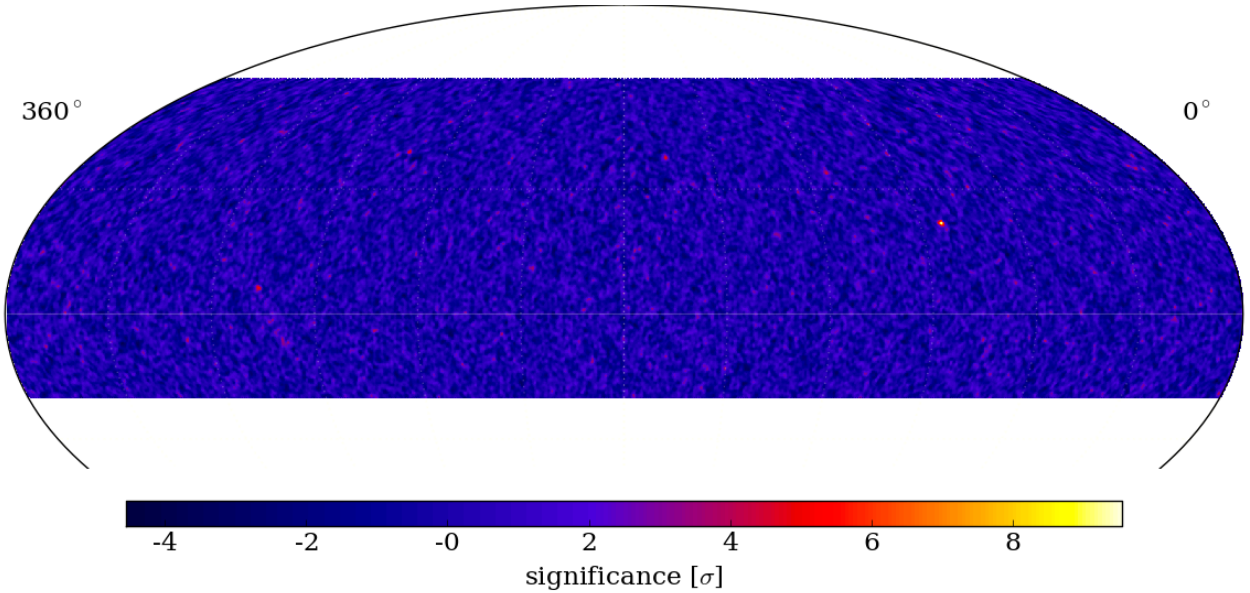


Direct integration
(2 hrs)



Direct integration - Example

One nHit bin / 2 months



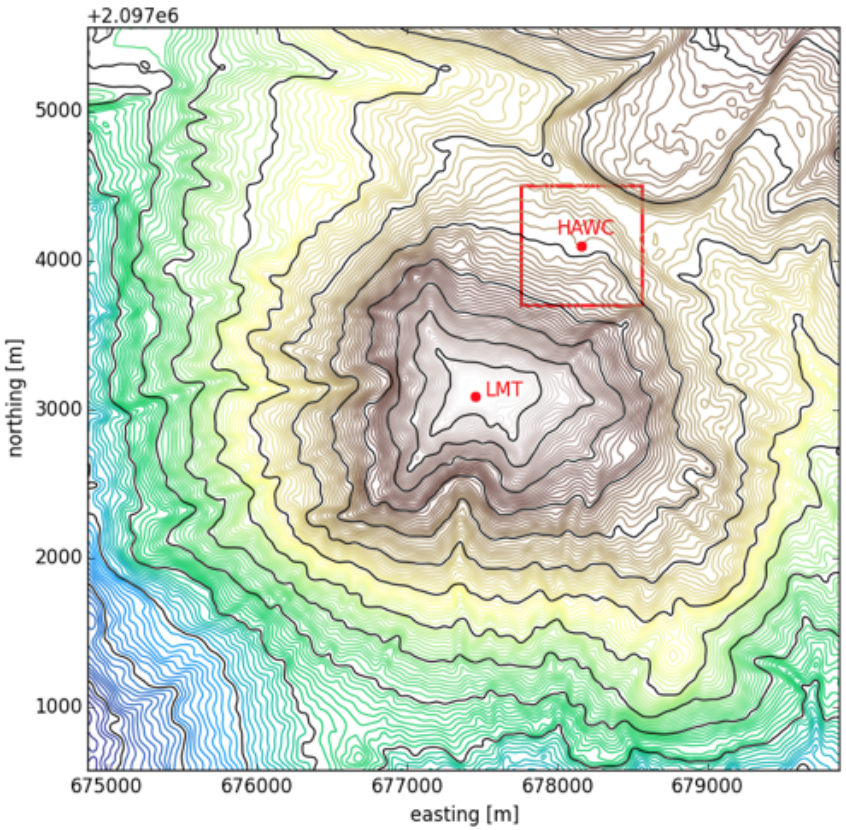
Smoothing by PSF for given nHit bin

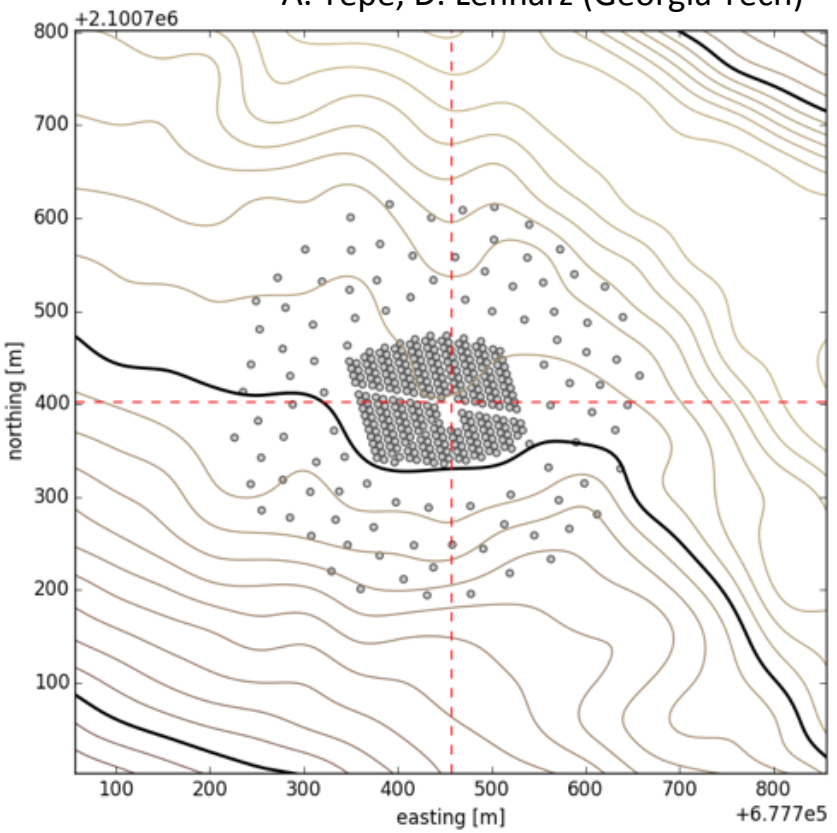
Li & Ma significance

Then we combined nHit bins (with weights)

Five/ten years from now

A. Tepe, D. Lennarz (Georgia Tech)





High-energy extension for Galactic sources (outriggers)

A Southern (higher elevation) site?

Collaborating with HAWC