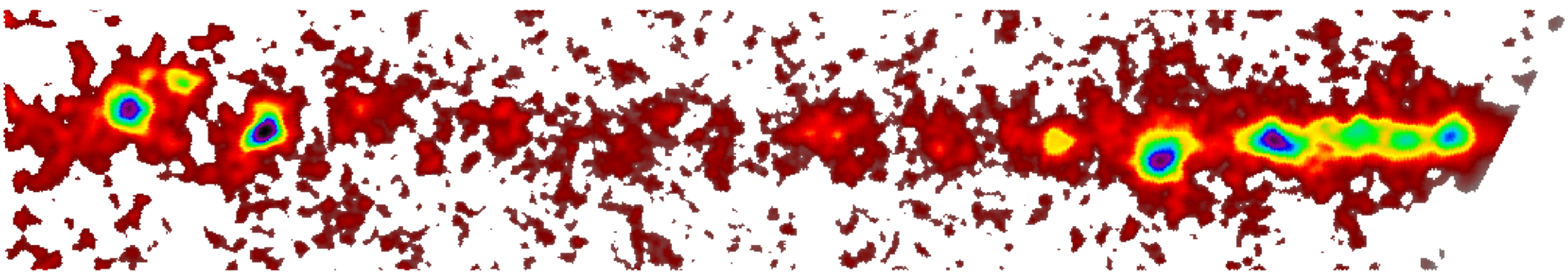
IceCube Search for Galactic Neutrino Sources using the HAWC 2HWC Catalog



IceCube

HAWC
High Altitude Water Cherenkov
Gamma-Ray Observatory

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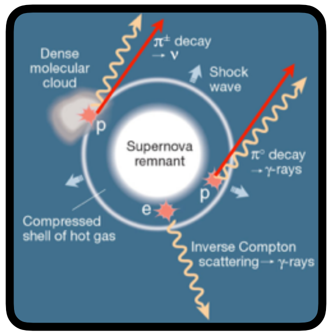
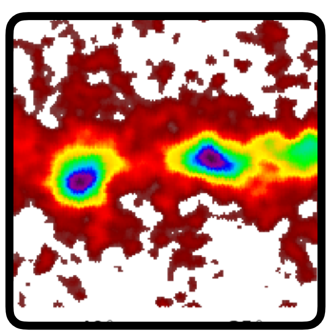
Overview



Basic Idea

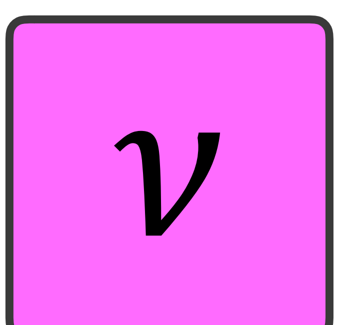
Detectors & Datasets



Analyses

(1) Stacked point source

(2) Spatial Template



Summary

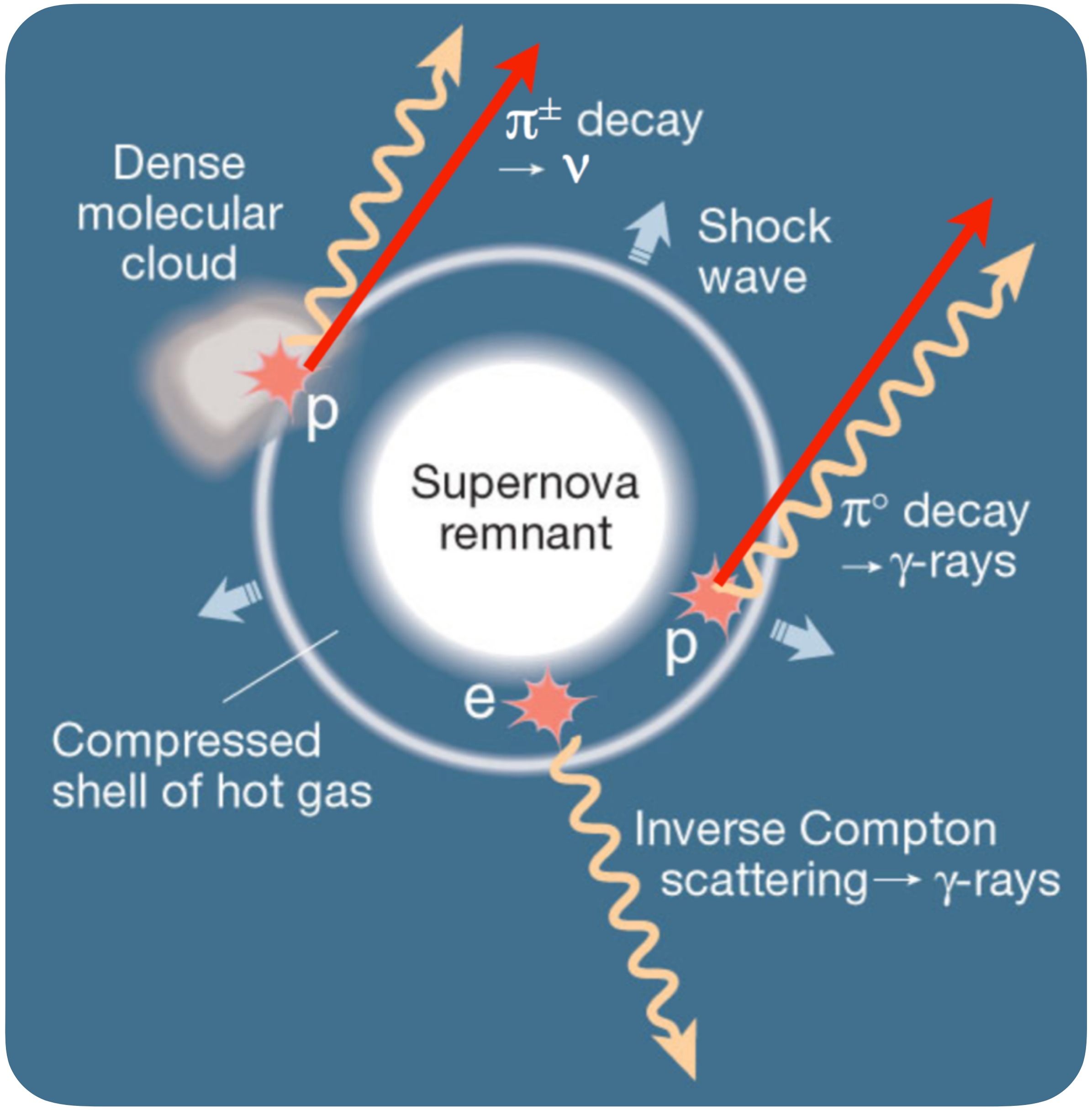
Basic Idea

- Looking for Galactic neutrino sources through **“Pevatrons”** which satisfy energetics to produce cosmic rays up to knee in the cosmic-ray spectrum

- Supernova remnants meet this condition

- **“Pevatrons”** will produce pionic gamma-rays whose spectrum extends to ~300 TeV

- Pionic TeV gamma-rays should come with neutrinos observable in IceCube



Detectors & Datasets

- HAWC is a TeV gamma-ray observatory located at 19° N

  Energy Range: **0.5-100 TeV**

  PSF: **~0.2° at high energy**

  FOV: **~2 sr**

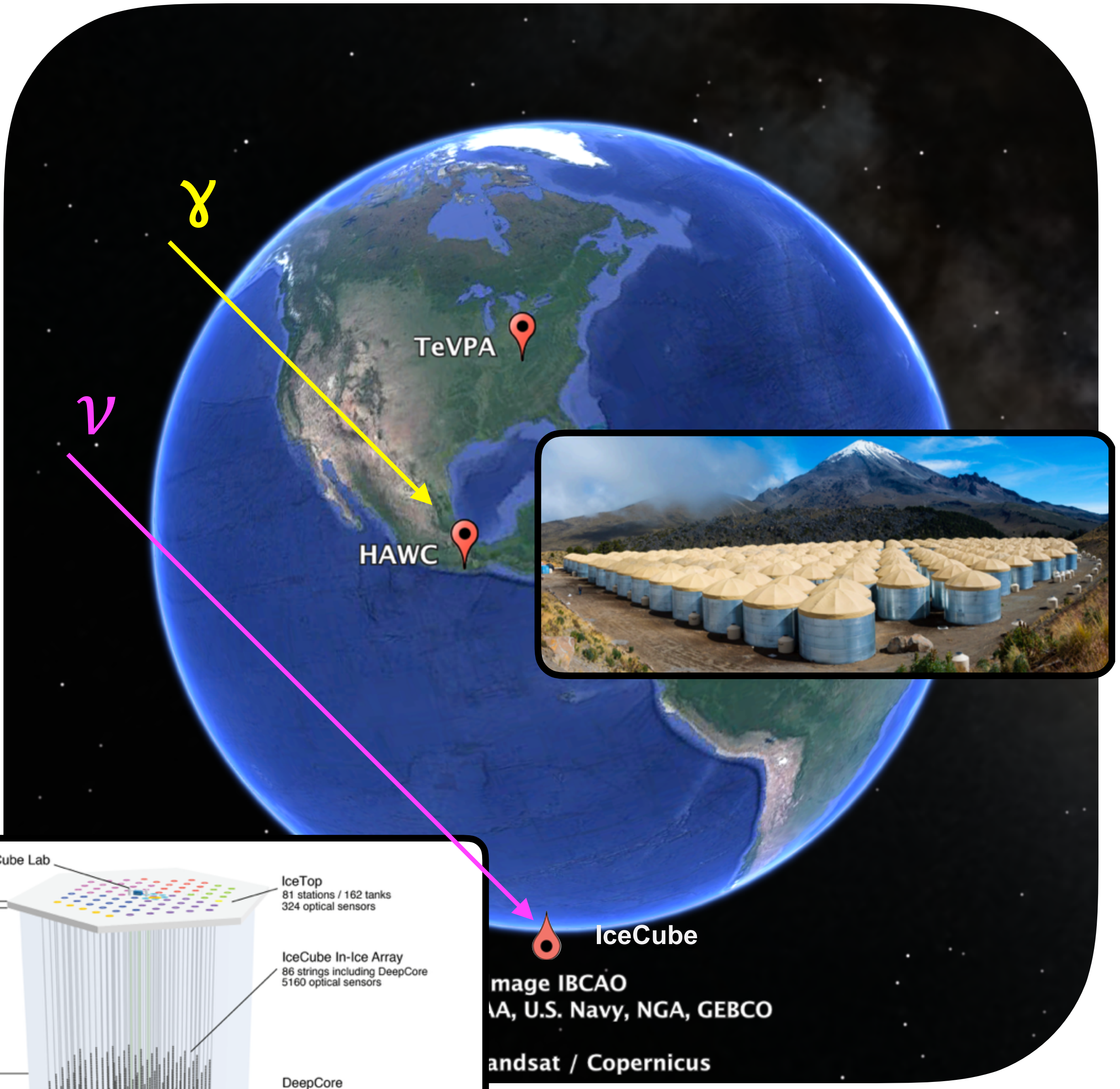
- IceCube is a TeV neutrino observatory at South Pole

  Energy Range: **0.1 TeV - 1 EeV**

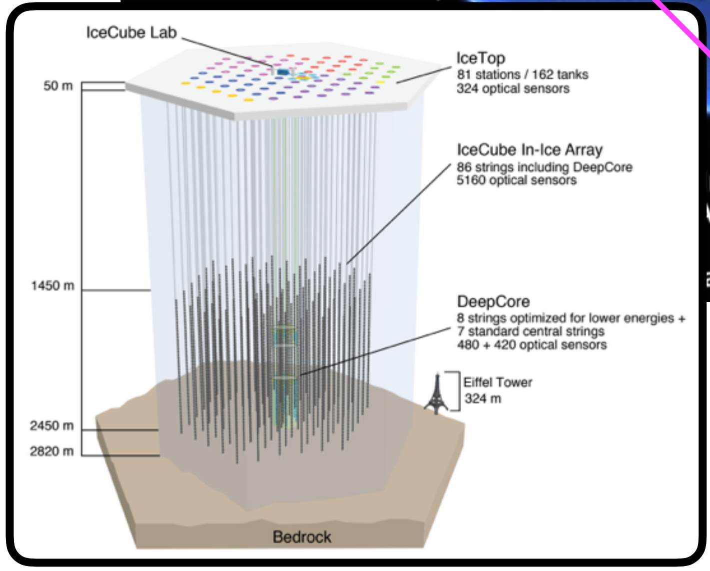
  PSF: **~0.5° median (tracks)**

  FOV: **4π sr**, most sensitive to Northern hemisphere

using Northern ν_μ track sample

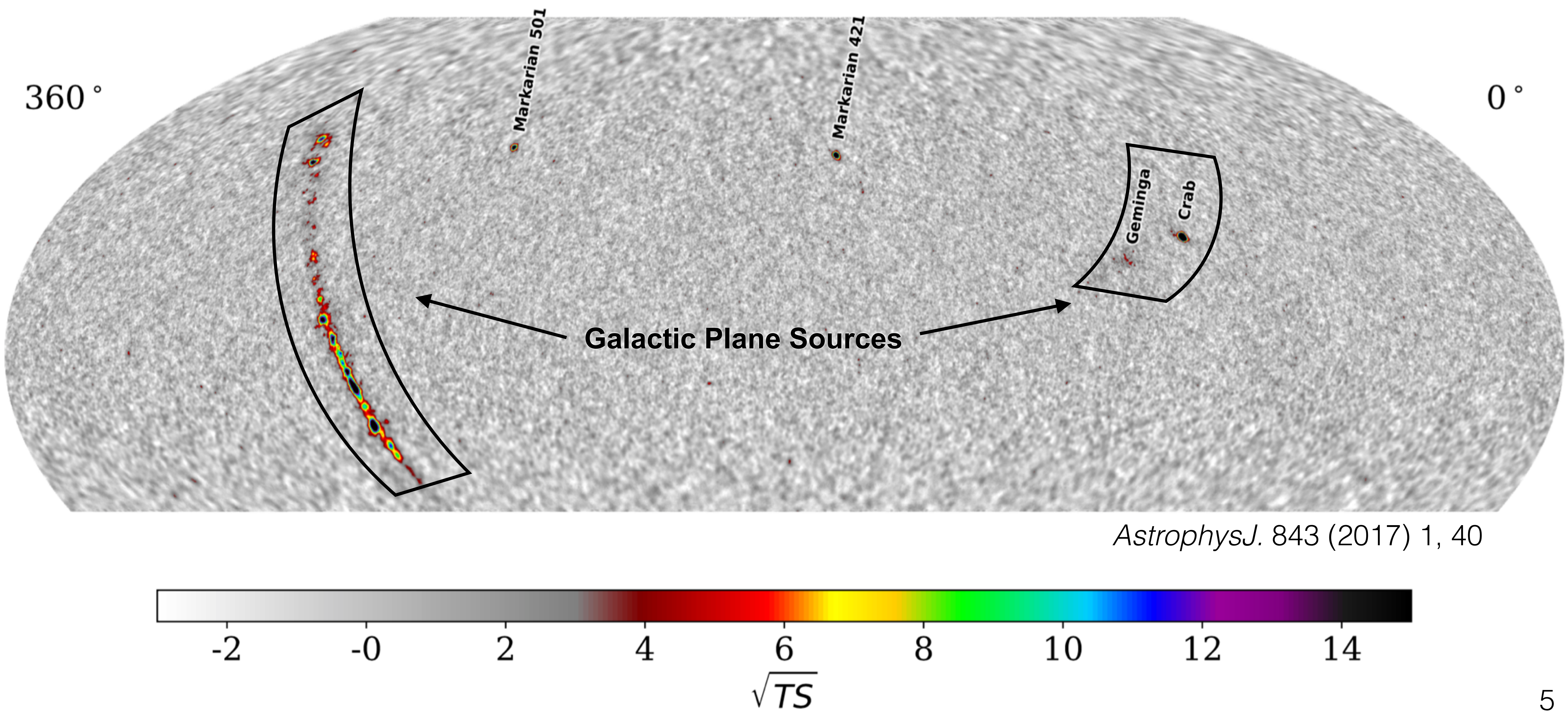


Google Earth



HAWC's 2HWC Catalog

- 17 Month dataset, ~5-10% Crab sensitivity
- 39 Detected sources, expect 0.5 false detections
- 19 new sources >0.5° from known TeV sources



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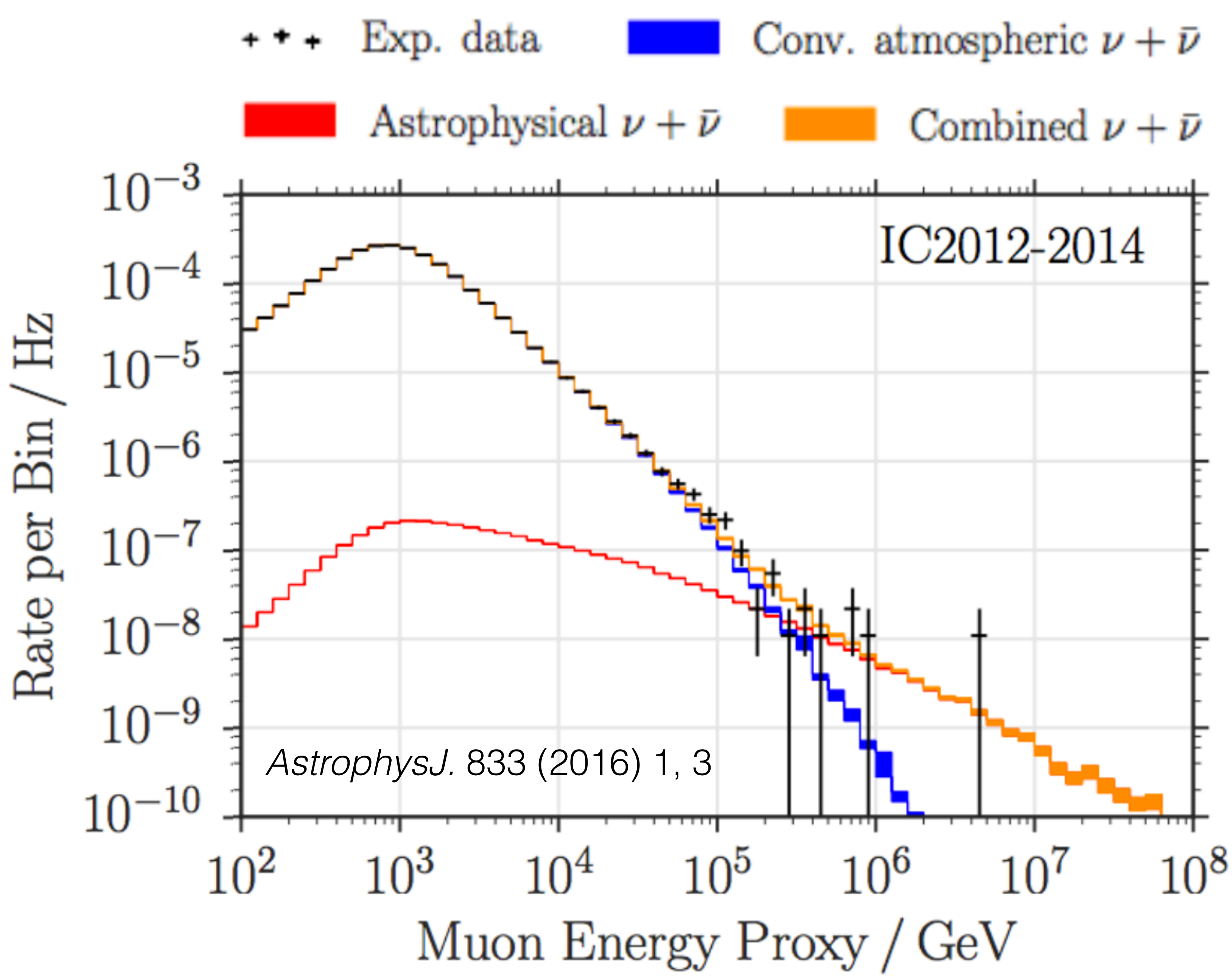
Northern Track Sample

- Up going & horizontal tracks = Earth filtered
- Estimated 99.7% pure ν_μ sample
- 350,000 events in 6 yr, this work is 4 yrs of IC86 for now
- Well modeled with MC, **use MC to develop likelihood analyses for Galactic neutrinos**

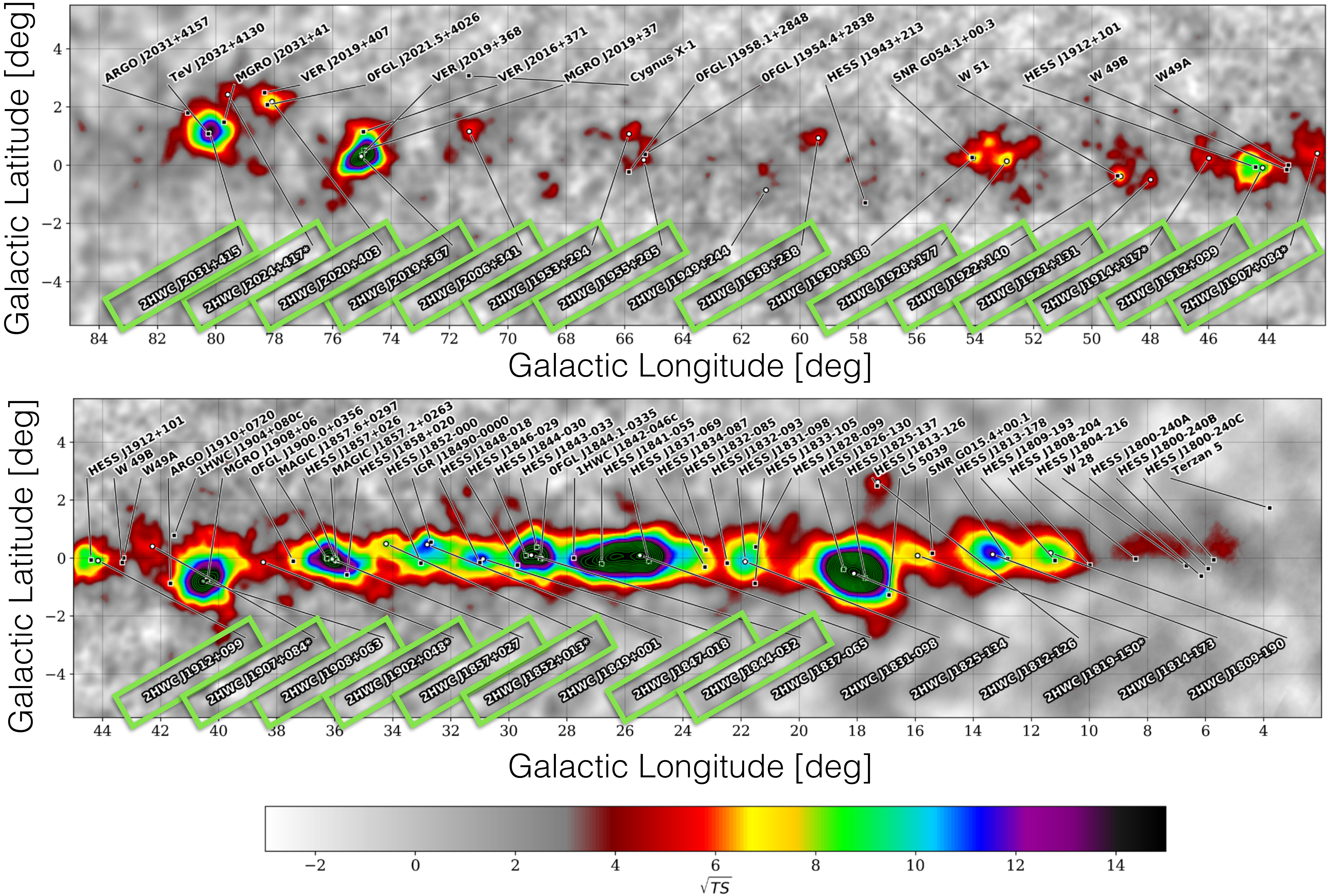


Stacked Analysis

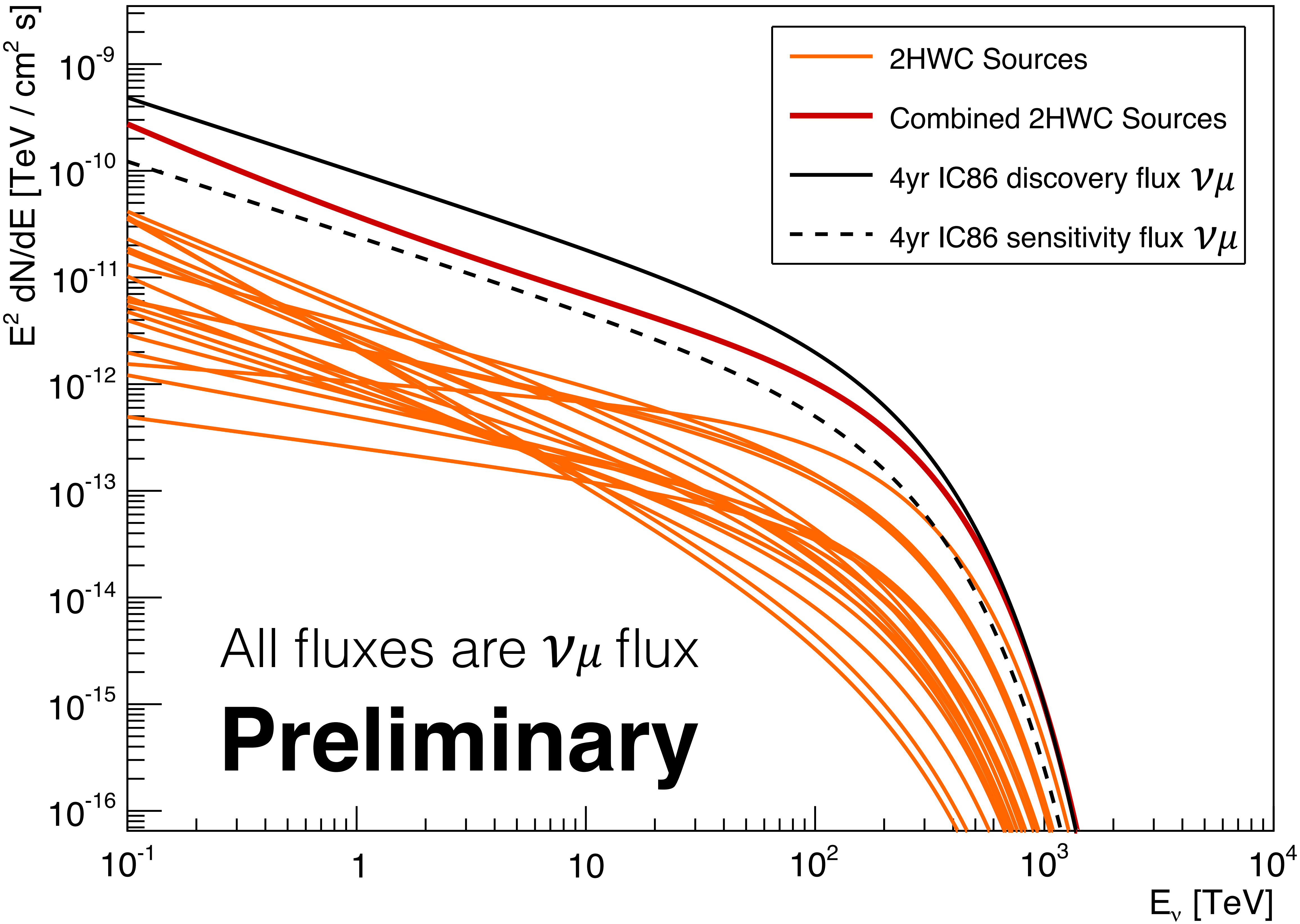
- **Goal:** Test for ν made directly at 2HWC Galactic TeV sources
- Exclude PWN because most seem to be dominantly leptonic
- Standard stacked ν point source likelihood technique with conv. atm. ν background
- Signal energy weights are $E^{-2.7}$ power law w/exponential cutoff
- Relative source weights based on integral ν flux expected under p-p interactions

Source	RA [°]	Dec [°]
1. 2HWC J1844−032	281.07	-3.25
2. 2HWC J1847−018	281.95	-1.83
3. 2HWC J1852+013*	283.01	1.38
4. 2HWC J1857+027	284.33	2.80
5. 2HWC J1902+048*	285.51	4.86
6. 2HWC J1907+084*	286.79	8.50
7. 2HWC J1908+063	287.05	6.39
8. 2HWC J1912+099	288.11	9.93
9. 2HWC J1914+117*	288.68	11.72
10. 2HWC J1921+131	290.30	13.13
11. 2HWC J1922+140	290.70	14.09
12. 2HWC J1928+177	292.15	17.78
13. 2HWC J1938+238	294.74	23.81
14. 2HWC J1953+294	298.26	29.48
15. 2HWC J1955+285	298.83	28.59
16. 2HWC J2006+341	301.55	34.18
17. 2HWC J2019+367	304.94	36.80
18. 2HWC J2020+403	305.16	40.37
19. 2HWC J2024+417*	306.04	41.76
20. 2HWC J2031+415	307.93	41.51

Stacked Analysis

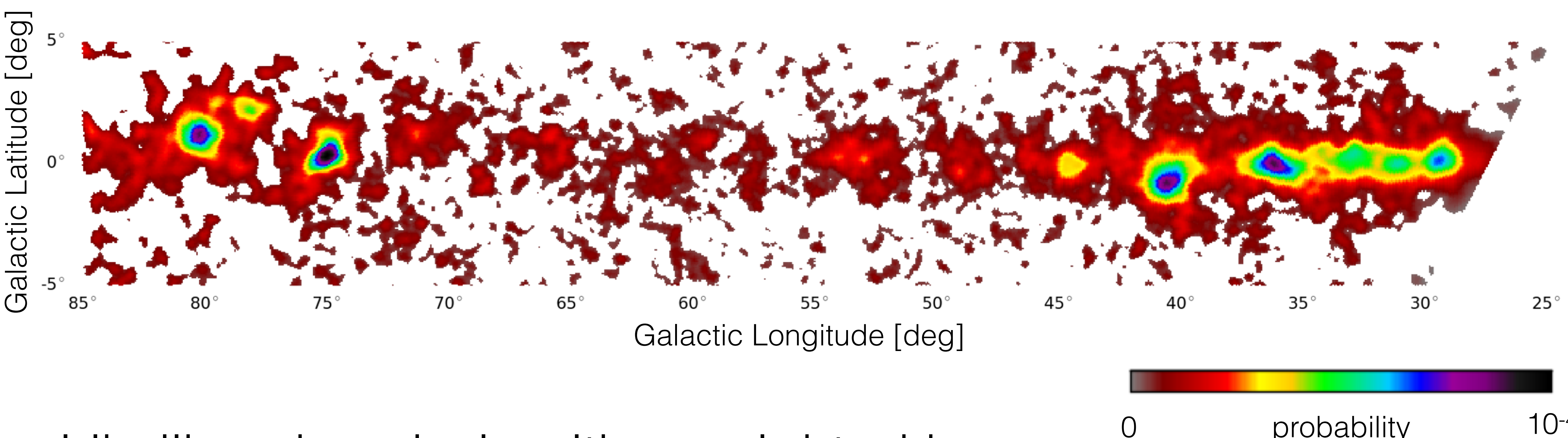


Stacked Analysis



Template Analysis

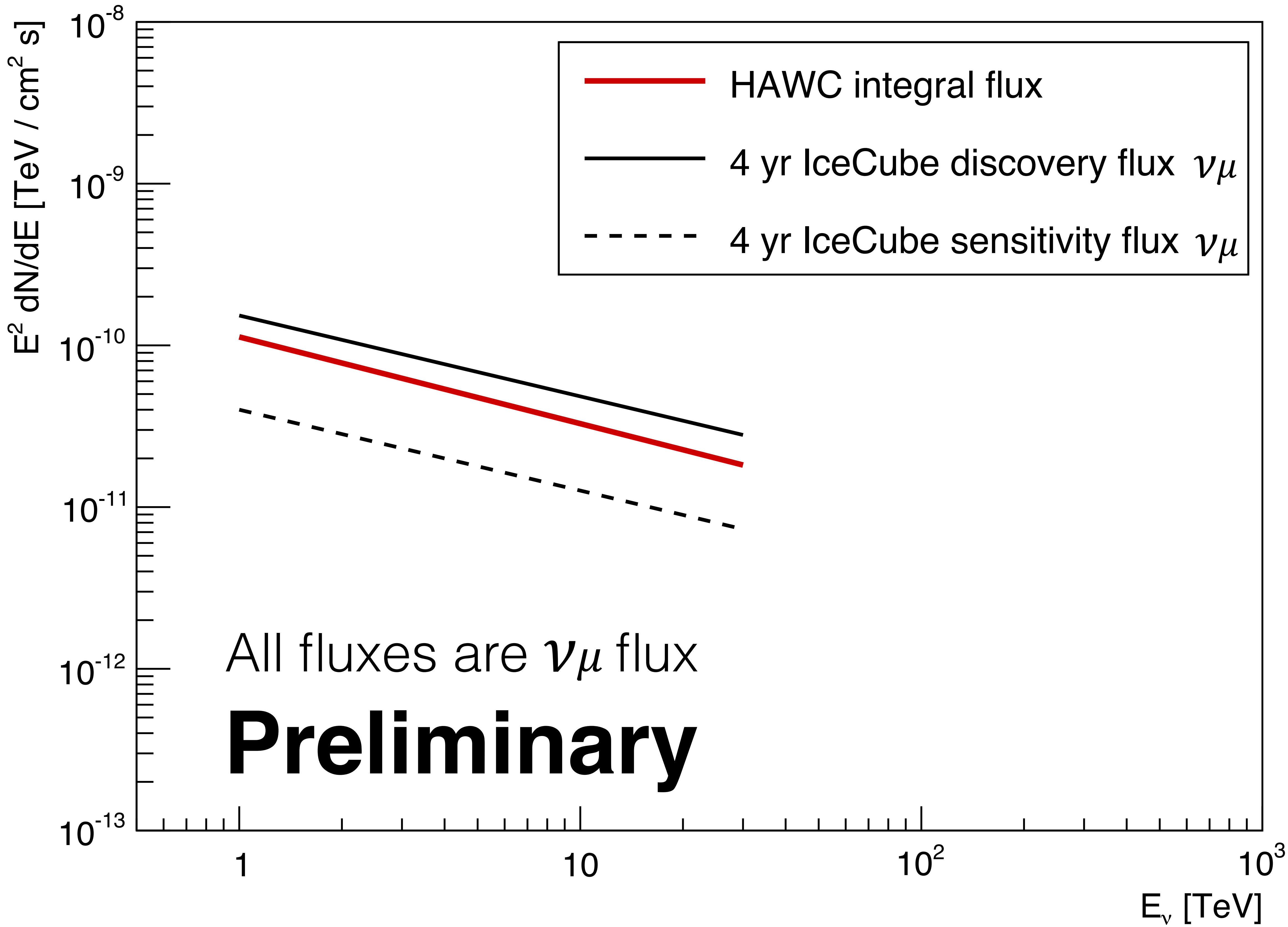
- **Goal:** Test for ν made in "stuff" around Galactic 2HWC sources
- Replace stacked source list with HAWC's flux map of Galactic plane morphology. Convolve w/IceCube acceptance, norm to 1.



- Likelihood analysis with ν weighted by $E^{-2.5}$ power law with exponential cutoff

Integral HAWC Galactic plane flux (J. Pretz, APS 2017)

Template Analysis



Summary

- Used MC to model 4 years of IC86 and produce preliminary sensitivities to two Galactic neutrino source search strategies
- Good sensitivity expected, will improve with additional years
- Even a null detection is interesting because we could place a limit on the fraction of hadronically produced photons seen by HAWC
- Future: Our understanding of gamma-ray sources > 50 TeV will only improve with more data, better energy analyses, and outriggers in HAWC (K. Malone - Monday, S. Maranelli - Wednesday) and also CTA when it comes online.

Thanks!

Stacked Likelihood

$$\mathcal{L}(n_s, \gamma, E_{cut}) = \prod_{i=1}^{N} \left(\frac{n_s}{N} S(\boldsymbol{x}_i, \sigma_i, E_i; \gamma, E_{cut}) + (1 - \frac{n_s}{N}) B(\sin\delta_i, E_i) \right)$$

- n_s is the number of neutrino events from the source
- γ is the spectral index of the source
- E_{cut} is the exponential cutoff energy of the source (optional - used in our analysis)
- N is the total number of neutrino events in the sample being tested
- $\boldsymbol{x}_i$ are the right ascension and declination coordinates of an event
- σ_i is the per event angular uncertainty
- E_i is the reconstructed energy of an event
- $\sin\delta_i$ is the sine of the event declination
- S is the signal probability density function (PDF)
- B is the background probability density function (PDF)

$$S(\boldsymbol{x}_i, \sigma_i, E_i; \gamma, E_{cut}) = \sum_{j=1}^{M} w_j \, S_S(\boldsymbol{x}_{src,j}, \boldsymbol{x}_i, \sigma_i) \times S_E(\sin\delta_i, E_i; \gamma, E_{cut})$$

$$S_S(\boldsymbol{x}_{src,j}, \boldsymbol{x}_i, \sigma_i) = \frac{1}{2\pi\sigma_i^2} e^{-|\boldsymbol{x}_i - \boldsymbol{x}_{src,j}|^2/2\,\sigma_i^2} \qquad w_j = \frac{m_j\, a_j}{w_{tot}}, \quad w_{tot} = \sum_{j=1}^{M} m_j\, a_j$$

model weight

eff. area

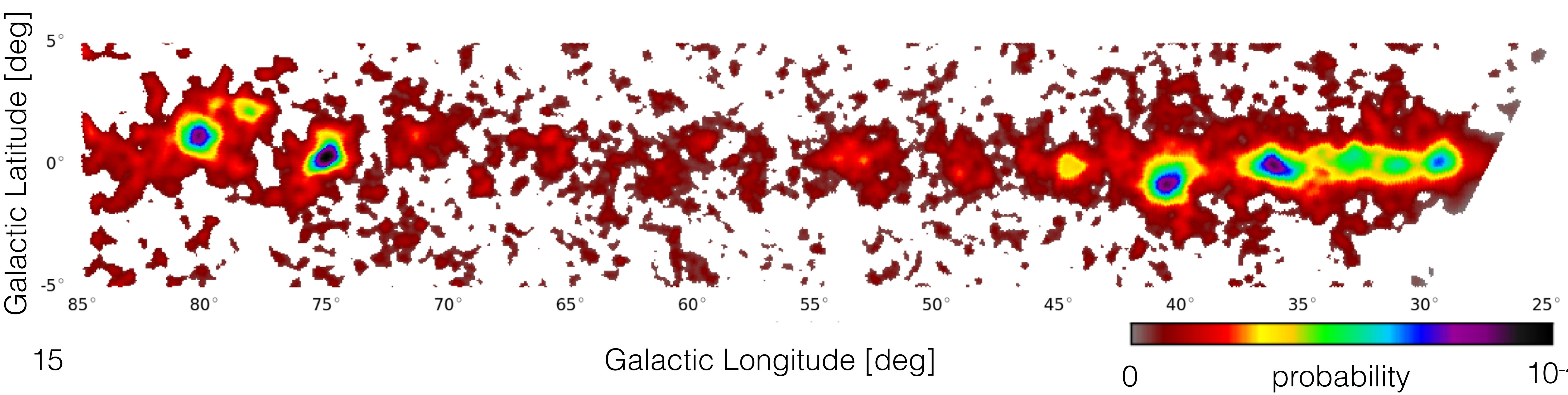
Template Likelihood

$$\mathcal{L}(n_s, \gamma, E_{cut}) = \prod_{i=1}^{N} \left(\frac{n_s}{N} S(\boldsymbol{x}_i, \sigma_i, E_i; \gamma, E_{cut}) + (1 - \frac{n_s}{N}) B(\sin\delta_i, E_i) \right)$$

Same form as stacked likelihood on slide 9, difference is signal term

$$S(\boldsymbol{x}_i, \sigma_i, E_i; \gamma, E_{cut}) = S_S(\boldsymbol{x}_i, \sigma_i) \times S_E(\sin\delta_i, E_i; \gamma, E_{cut})$$

value of healpix pixel from HAWC map convolved with acceptance and smoothed with σ_i



Template Construction

Step 1 - Select pixels from HAWC map with > 1σ detections. Each pixel is HAWC photon flux at 1 TeV

Step 2 - Convolve with IceCube $\nu\mu$ acceptance for $E^{-2.5}$ w/exponential cutoff

Step 3 - Apply IceCube PSF as gaussian smoothing with σ_{PSF}

Step 4 - Normalize map to 1 so we can treat as a probability