A First Look at the Northern Fermi Bubble with HAWC

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HAWC
High Altitude Water Cherenkov
Gamma-Ray Observatory

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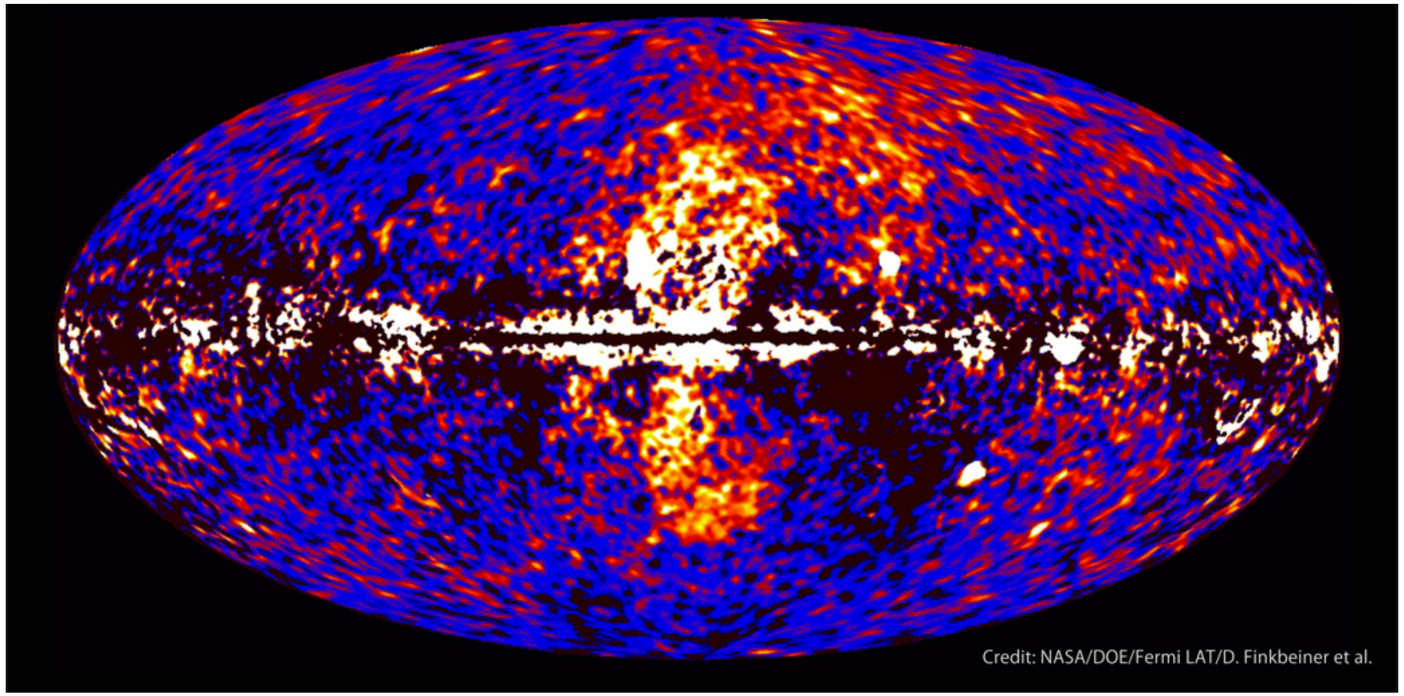
Michigan Tech

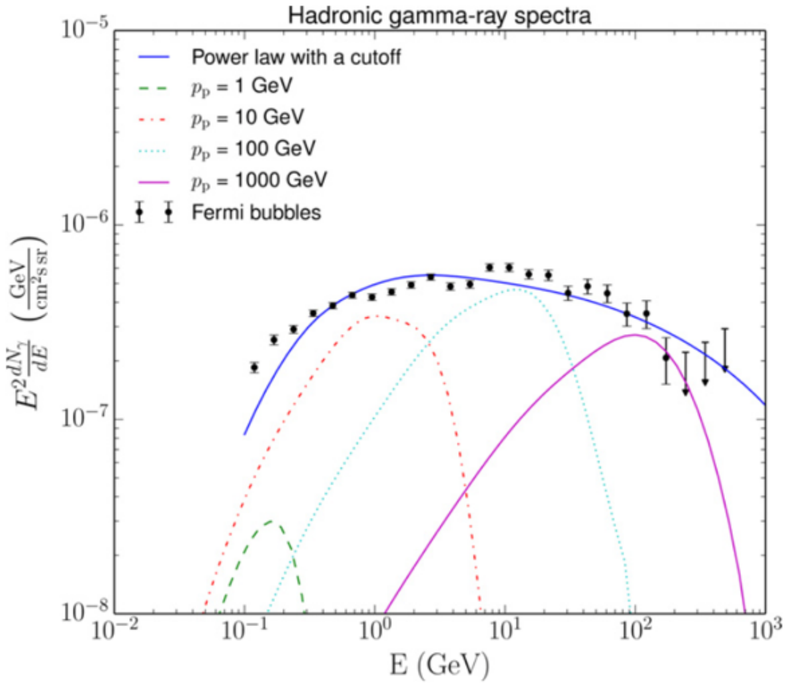
Fermi Bubbles

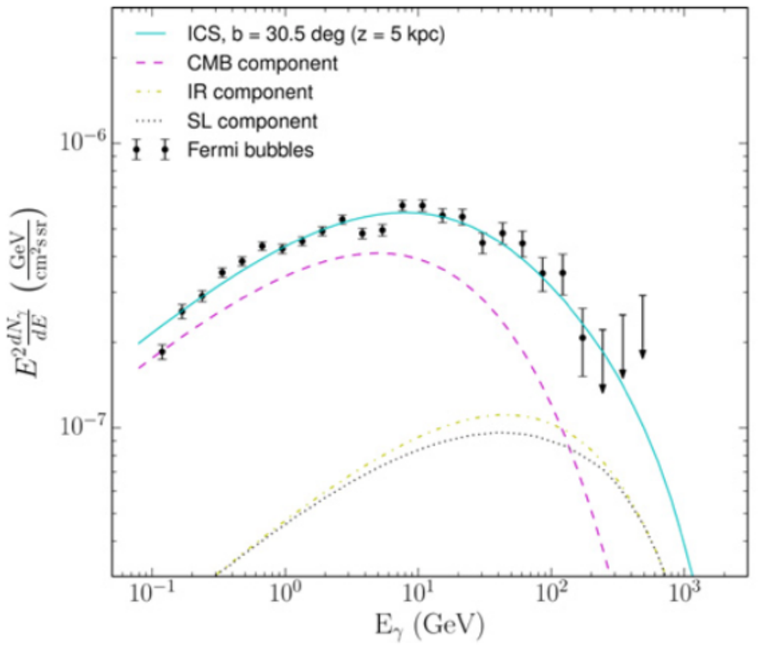
- Large structures of ***spectrally hard gamma-ray emission*** above 100MeV discovered in data from the ***Fermi Telescope***. *(Su et al. ApJ 724 2010 and Dobler et al. ApJ 717 2010)*



Spectrum of the Fermi Bubbles

- Both, ***hadronic and leptonic*** mechanisms possible explanations for the measured spectrum (Ackermann et al. 2014 ApJ 793 64)





- ***High energy gamma-ray data*** (>500GeV) desirable to constrain the spectrum and hence to shed more light on *the origin* of the Fermi bubbles.

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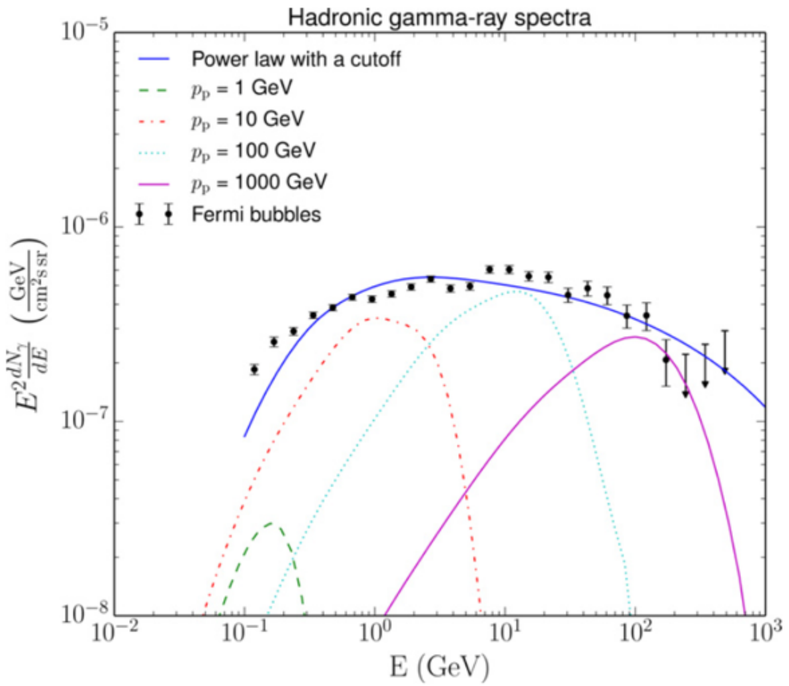

- Hadronic Model:
  - CR interacting with Interstellar Matter in the bubble region
  - Experimental evidence (or lack of): very-hard gamma rays, neutrinos(Adrian-Martinez, S. et al. 2014)
    - Hard to explain microwave haze

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Spectrum of the Fermi Bubbles

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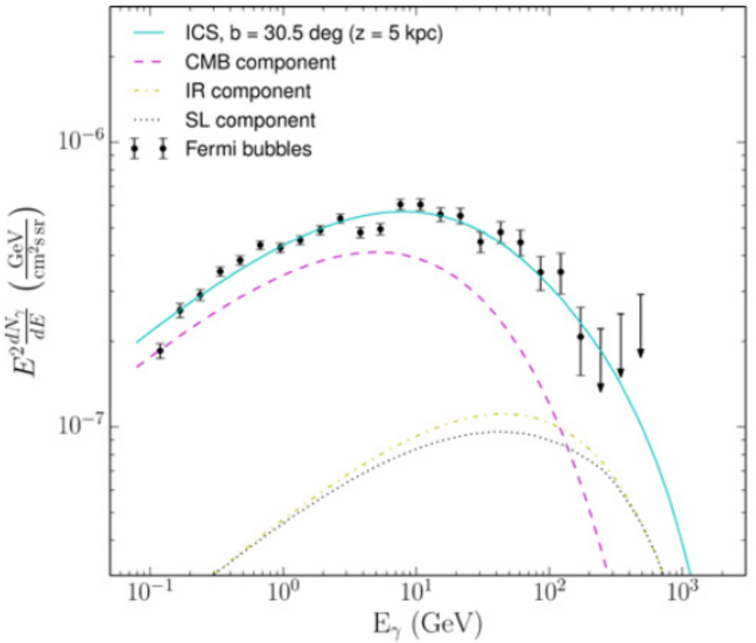
- Leptonic Model:
  - Electron population produce by outflow from the galactic center, or reacceleration inside the Bubbles
  - Can ***explain the microwave haze*** seen by WMap (Pietrobon et al. 2012;Dobler 2012) and Planck (Ade et al. 2013)



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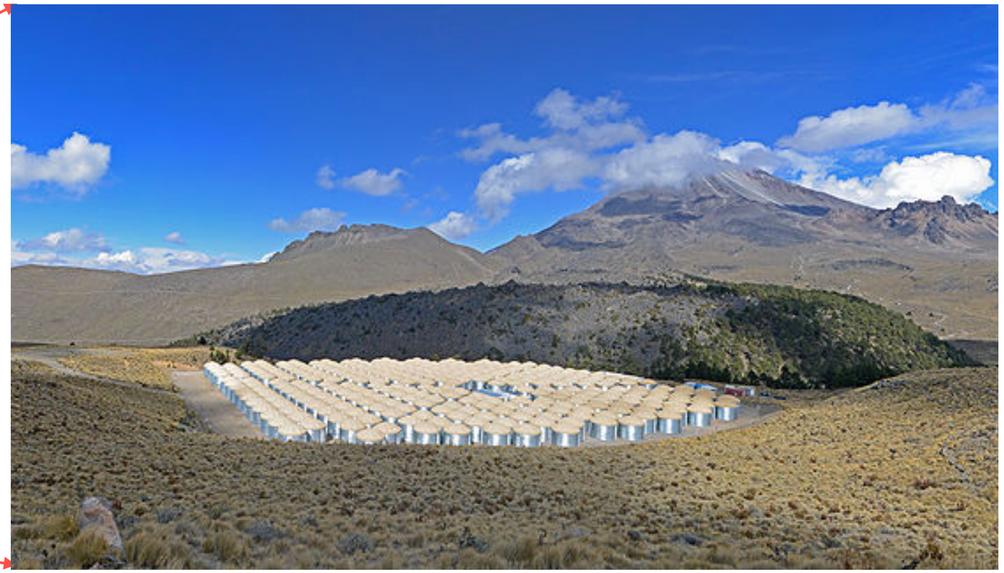
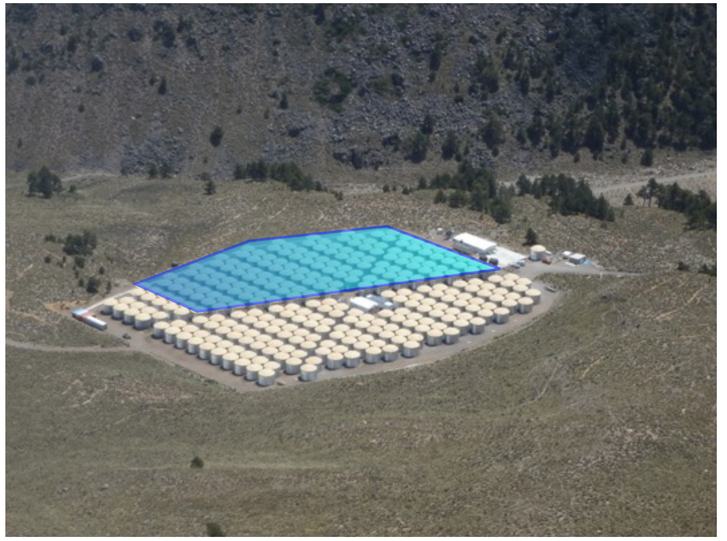
The HAWC Observatory

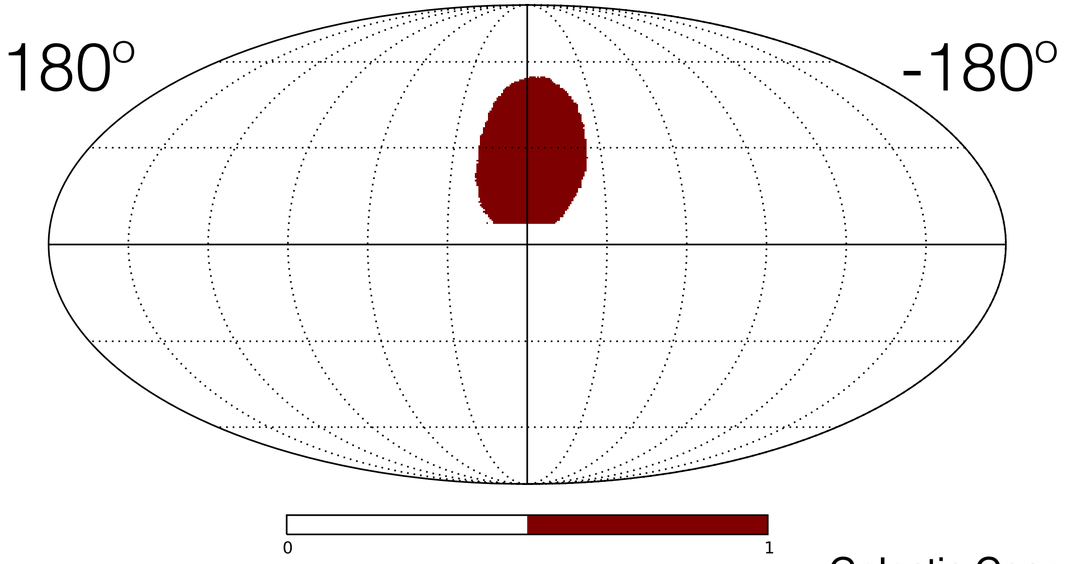


- Located at **4100 m** a.s.l. in Mexico near Pico de Orizaba at 19°N
- Effective Area: **~22,000 m²**
- Instantaneous field of view **2 sr**; daily coverage of **2/3** of the sky.
- 300 Water Cherenkov Detectors (WCDs)
- Declinations from **-26° to 64°** (***Part of Northern Fermi Bubble visible***)
- Inaugurated in **March 2015**, taking science data since **2013**.

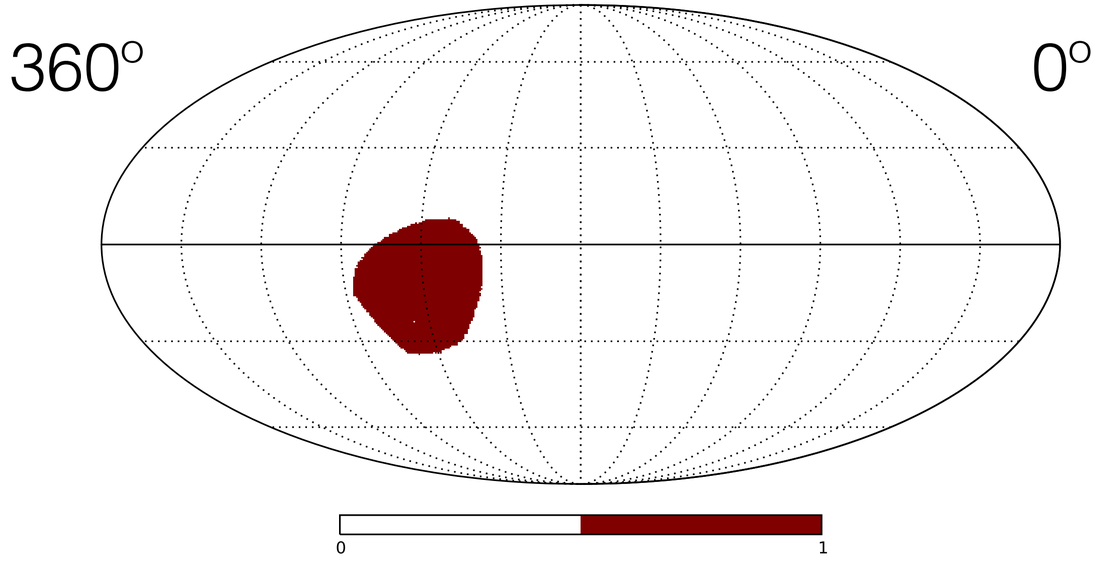
Data Set and Analysis



- ***HAWC Pass 1*** Data
  - *Partial* array: ***108 -134 WCDs***
  - ~159 days live-time between August 2, 2013 to July 8, 2014
  - ***Live-time is stricter*** for this analysis compared to other HAWC Pass 1 analyses
- Studying Northern bubble region as defined by the Fermi Diffuse Model from 2013.
  - Declinations between *-26° and 10°*
  - ***Caveat: the shape of the Fermi Bubbles at TeV energies (if they exist) is unknown***

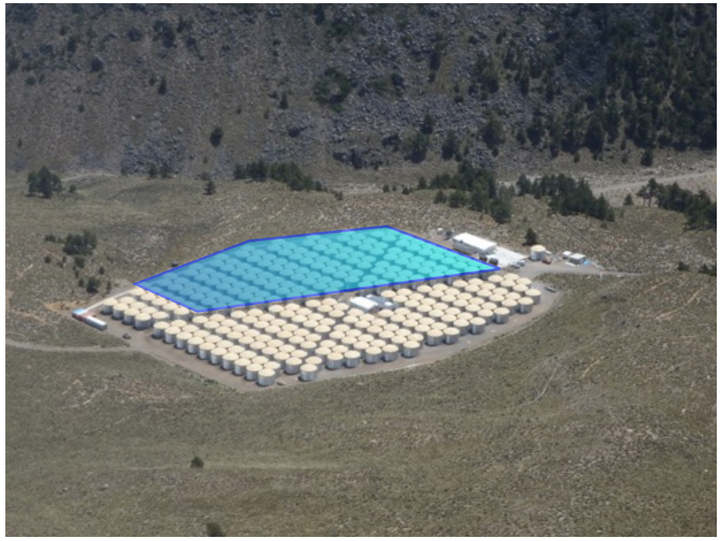


Galactic Coordinates



Equatorial Coordinates

Data Set and Analysis



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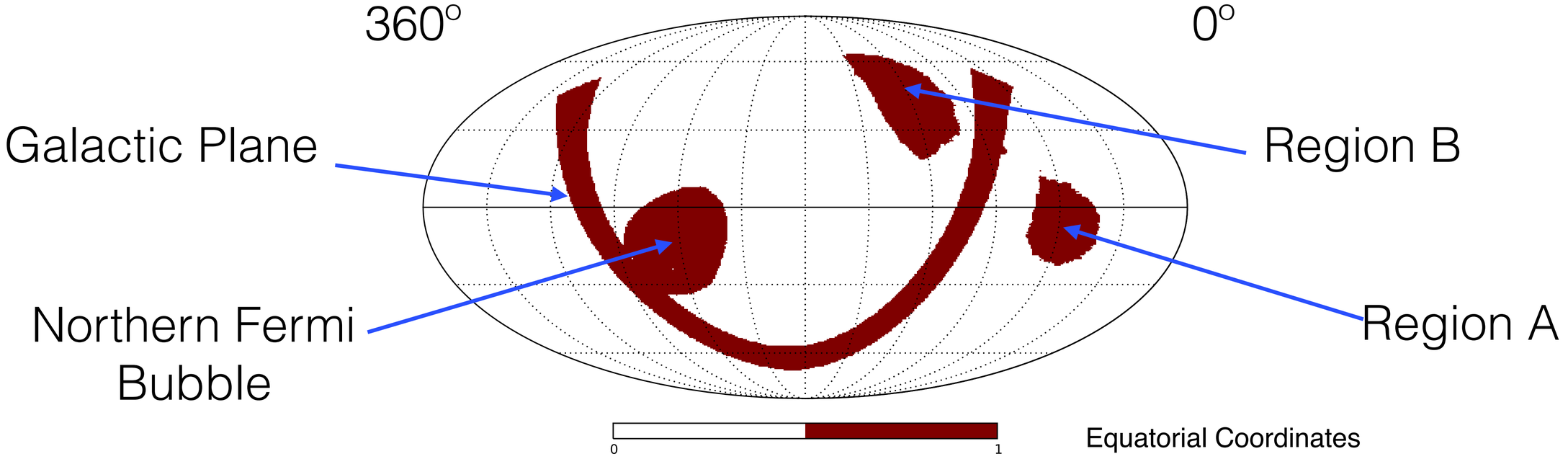
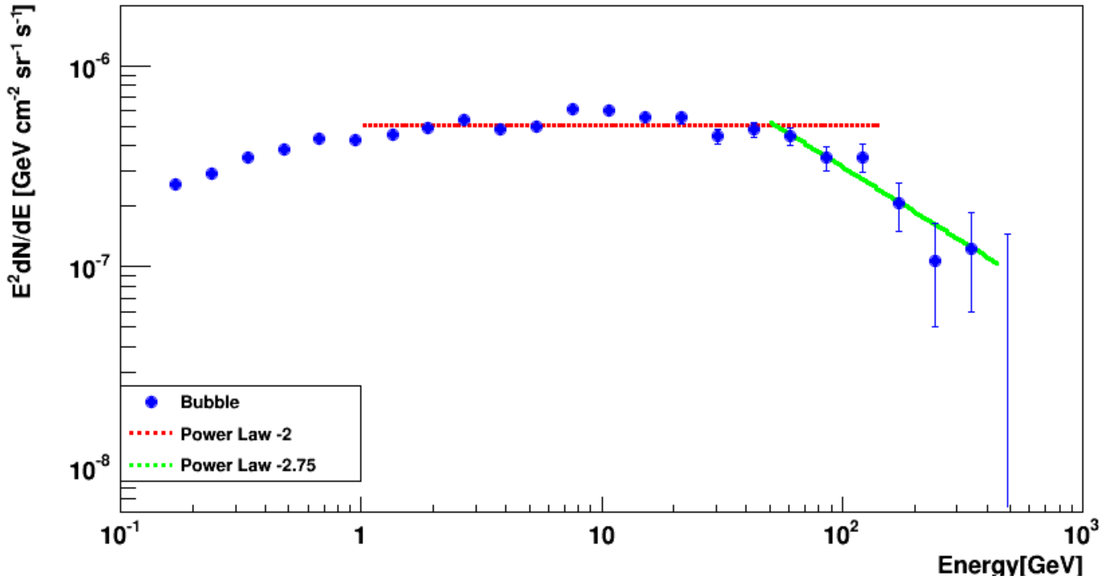
  - *Partial* array: ***108 -134 WCDs***
  - ~159 days live-time between August 2, 2013 to July 8, 2014
  - ***Live-time is stricter*** for this analysis compared to other HAWC Pass 1 analyses
- ***Direct Integration method to estimate background***
  - Integration time of ***6 hours and 24 hours*** used in this analysis. (For systematic studies)
  - Region of interest used to estimate the background. ***Avoids contamination of known/bright sources to the background***

$$R \leq (1/3)\,(\Delta t)\,(15^\circ / 1\ \mathrm{hr})$$



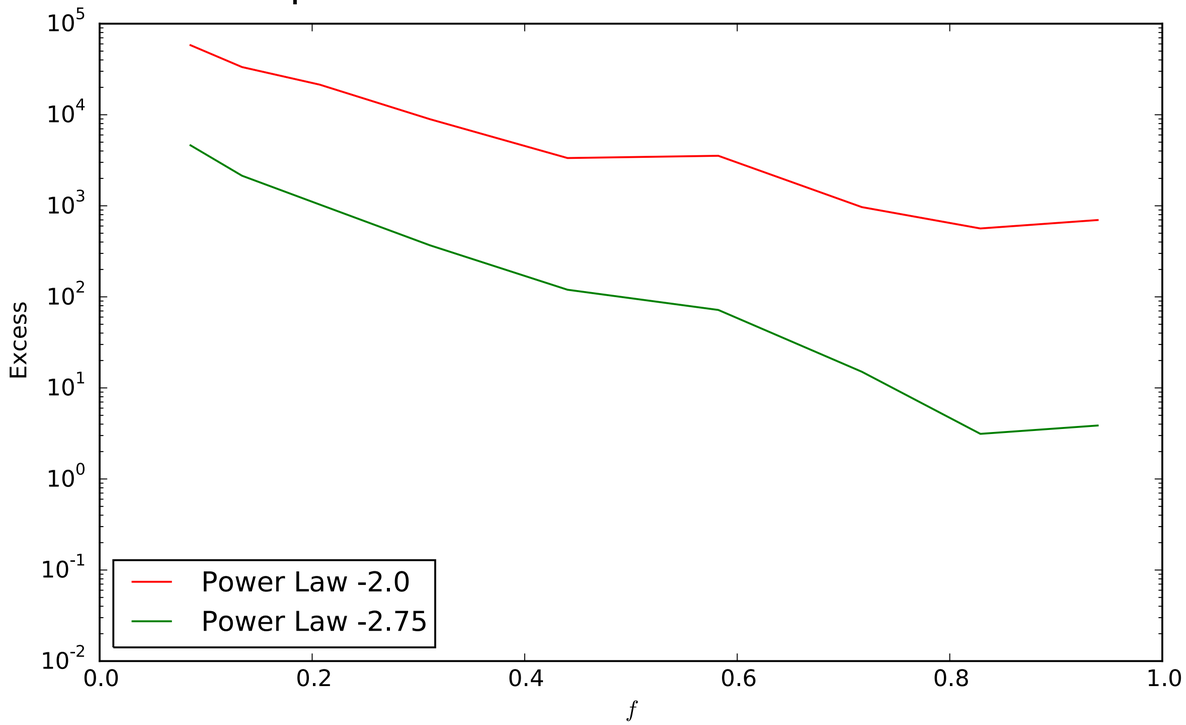
HAWC Response to Fermi Bubble Spectrum

- Data points from Ackermann et al. 2014 ApJ 793 64



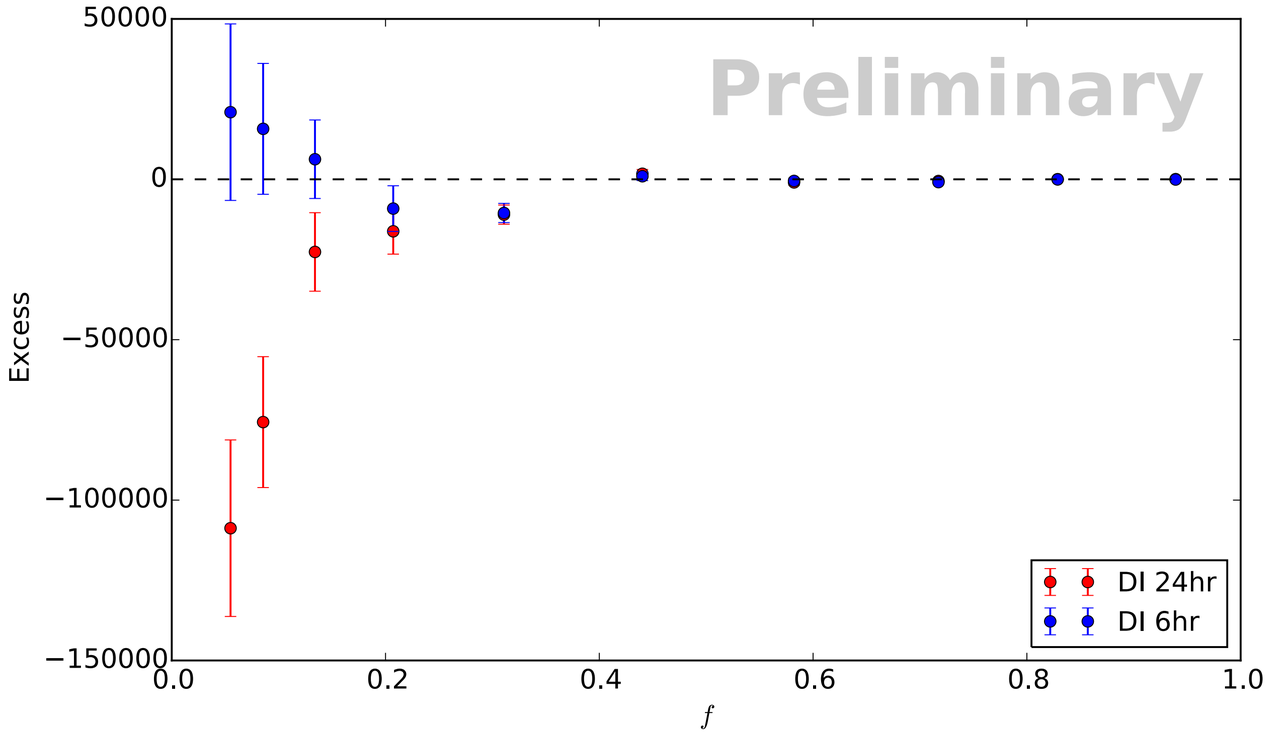
	N_o (x10^{-7} GeV cm^{-2} s^{-1} sr^{-1})	α
Power Law	5.03	-2
Power Law (50 GeV - 450 Gev)	97.8	-2.75

- ***Expectation*** for HAWC Pass 1 during ~159 days using the spectral assumptions



- ***f*** *:* fraction of PMTs participating in a shower event.

HAWC Data: Challenges



CR Anisotropy impacts background estimate

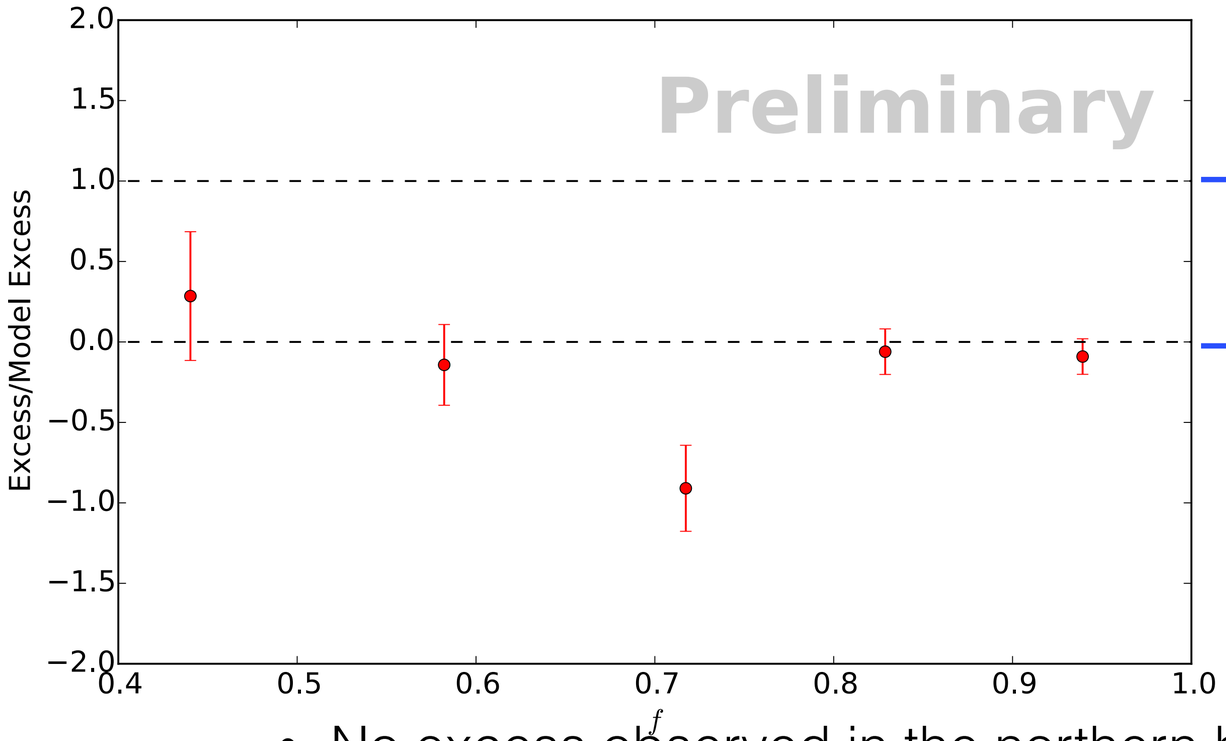
CR Anisotropy is subdominant

- HAWC Excess:
  - 24hr DI shows a deficit at lower values of f
  - Deficit disappear due to the use of a lower DI value time (6hr).
  - ***Contamination*** of large scale anisotropy at lower values of f.

Using only the last five f bins

HAWC Data: Excess

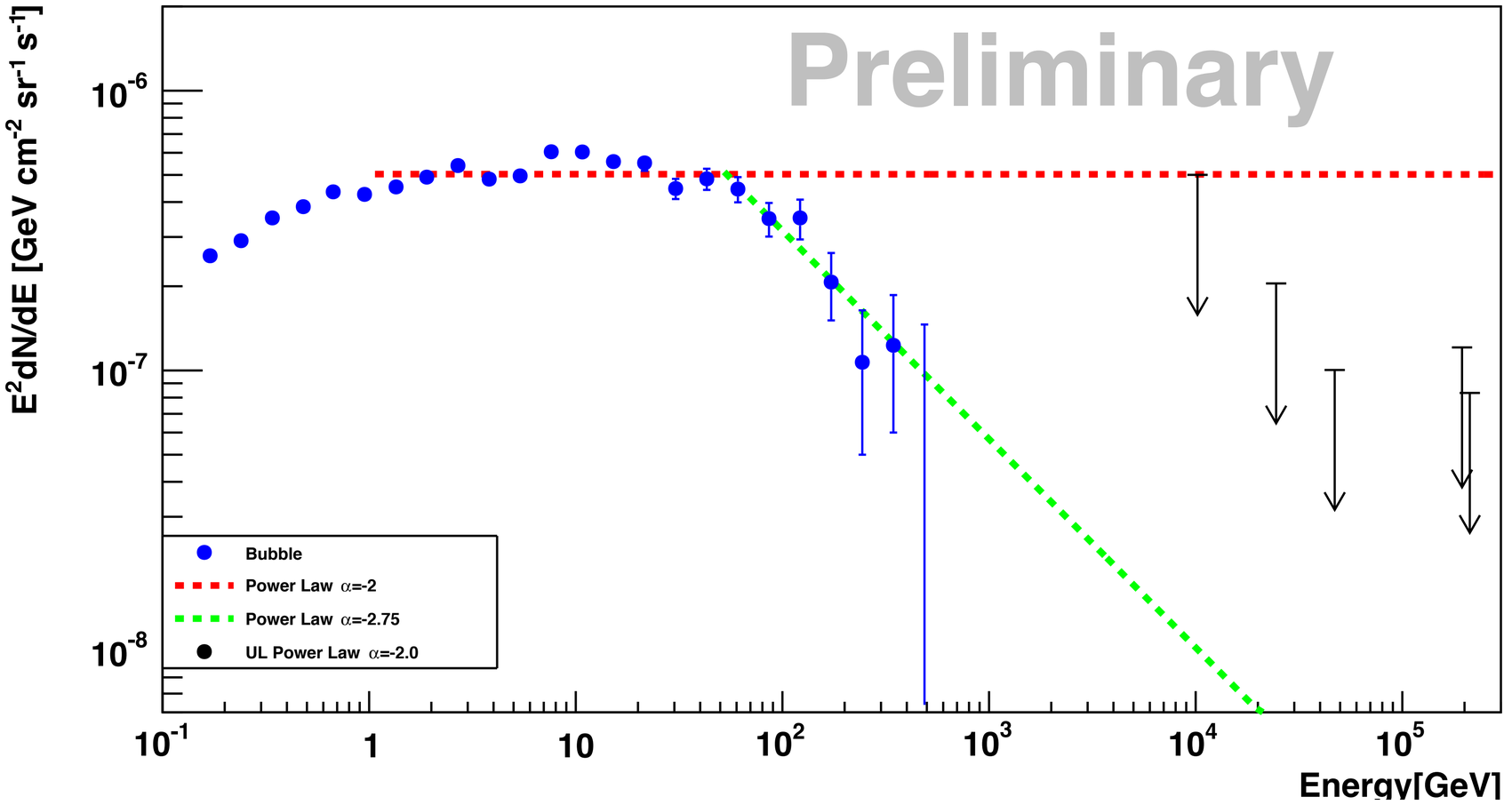
- Looking at values of ***f between 0.37 and 1*** only. Using ***6hr DI***
- Ratio of the excess in HAWC Pass 1 data and the expected excess for a power-law spectrum with index of -2



- Expectation for a power-law spectrum with index of -2
- HAWC Pass 1 data excess is consistent with zero, except for $f \sim 0.7$
  - ***Systematic effect in background estimation?***

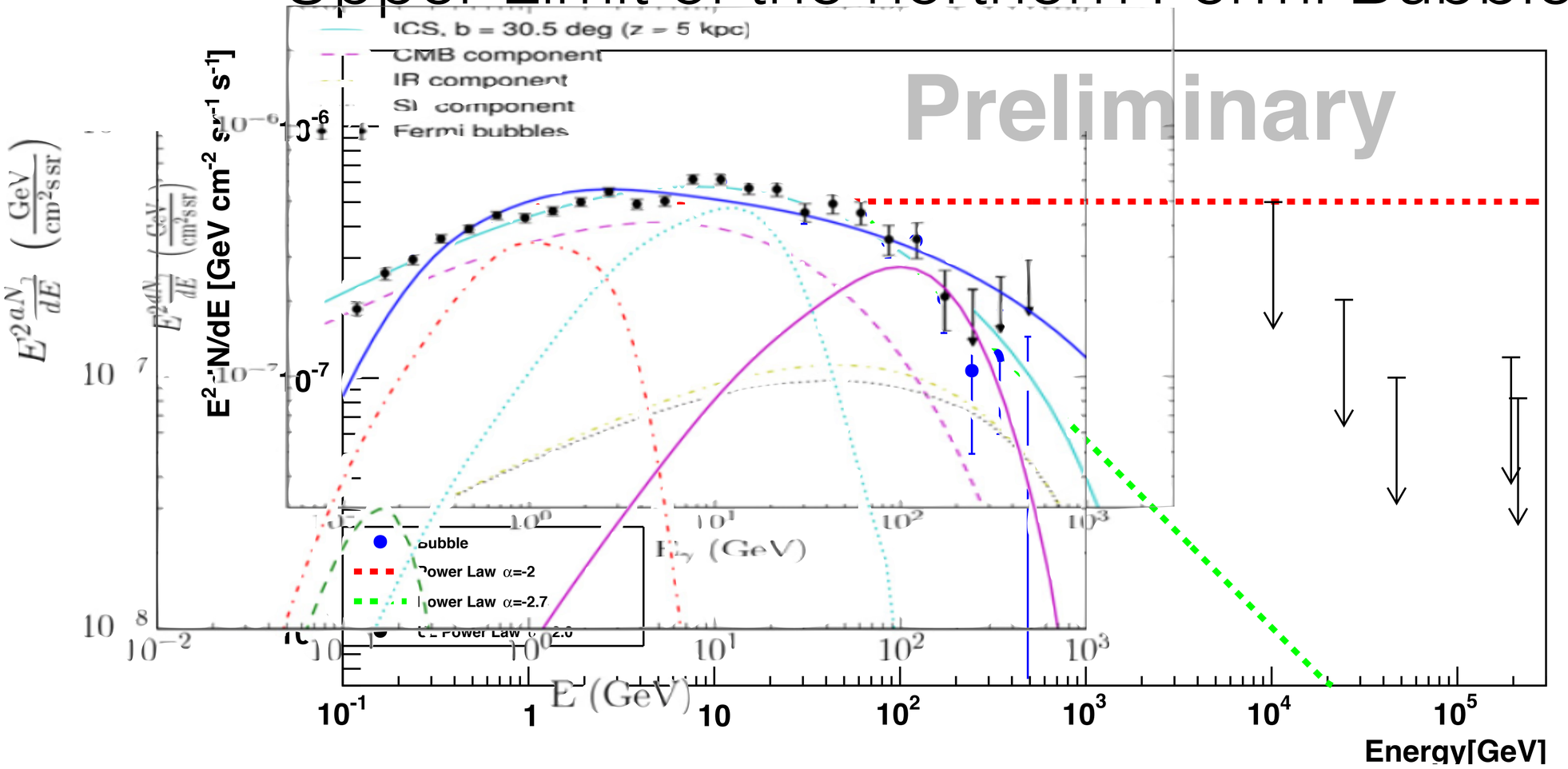
- No excess observed in the northern bubble region for high values of fraction of PMTs participating in a shower event.
- Calculate upper limit

Upper Limit of the northern Fermi Bubble



- Median energy obtained from HAWC Pass 1 simulations for a power law spectrum with index of -2
- Upper limit only uses statistical uncertainties. Need to include systematics

Upper Limit of the northern Fermi Bubble



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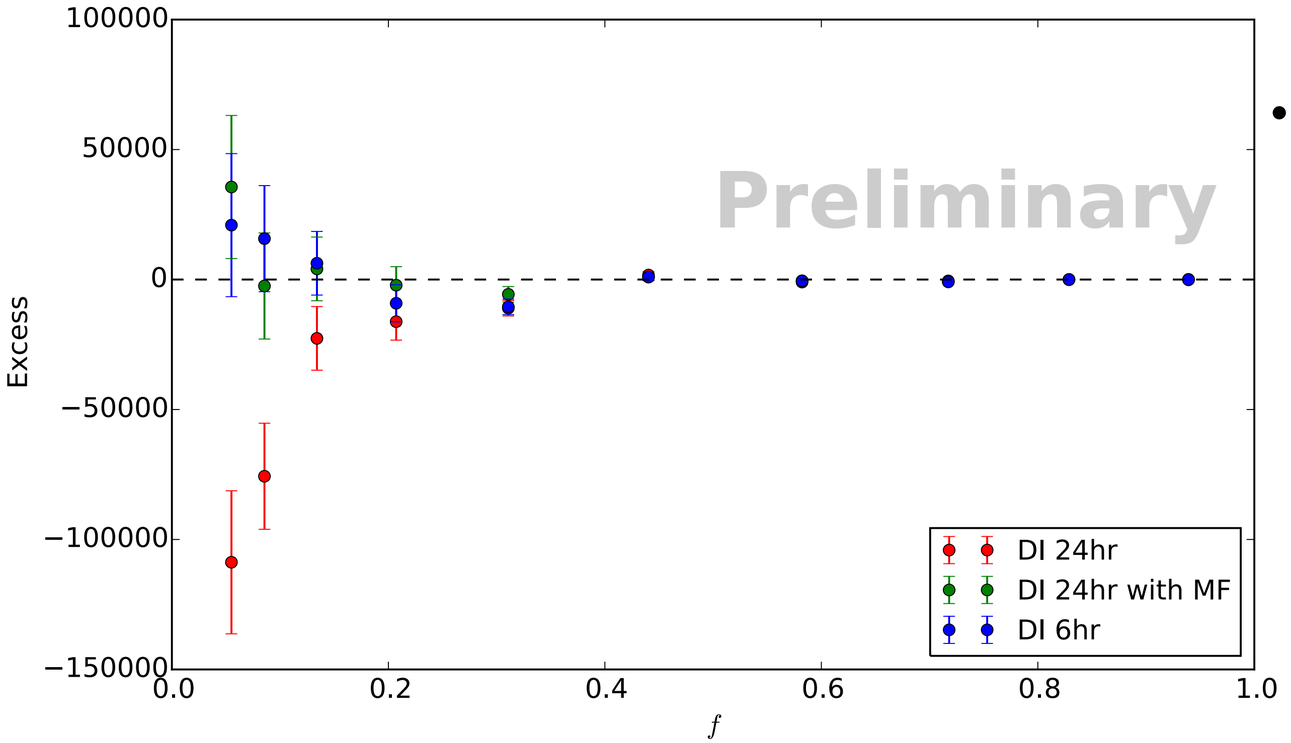
Summary

- Origin of ***Fermi Bubbles*** still uncertain. Information of high TeV gamma-rays will help constrain their origin.
- First study of the Northern Fermi Bubble region as detected by Fermi at GeV energies using data from HAWC Pass 1
- No excess observed in HAWC Pass 1 data in the range of ***0.37<f<1.0***. Lower range under observation.
- Work in progress:
  - Analyze lower ***smaller showers*** corresponding to smaller fraction of PMTs in the event.
  - Improve understanding of ***systematic uncertainties***
  - Analysis of full detector data with improved reconstruction
- HAWC data size is increasing, improving the search sensitivity. Stay tuned.

HAWC Data: Work in Progress



- HAWC Excess:
  - Smaller value of ***6hr DI*** does not use the whole sky to find the background -> No large scale anisotropy
  - Use of ***multipole fit*** to the sky to ***subtract large scale anisotropy***.
    - Working on simulations to make sure the subtraction in data works as expected
  - Need to compare both 6hr and Multipole fit procedure