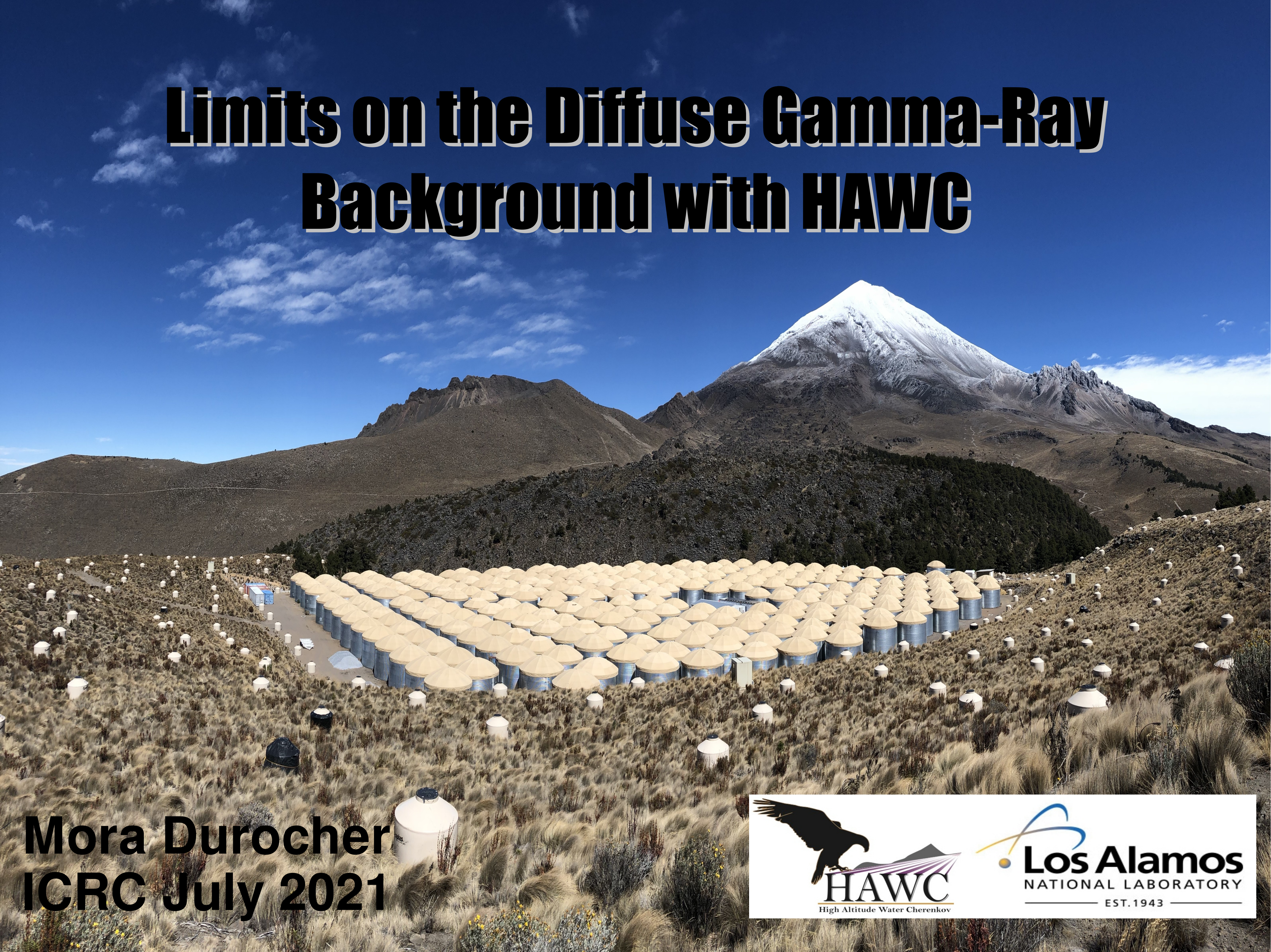
Limits on the Diffuse Gamma-Ray Background with HAWC



Mora Durocher
ICRC July 2021

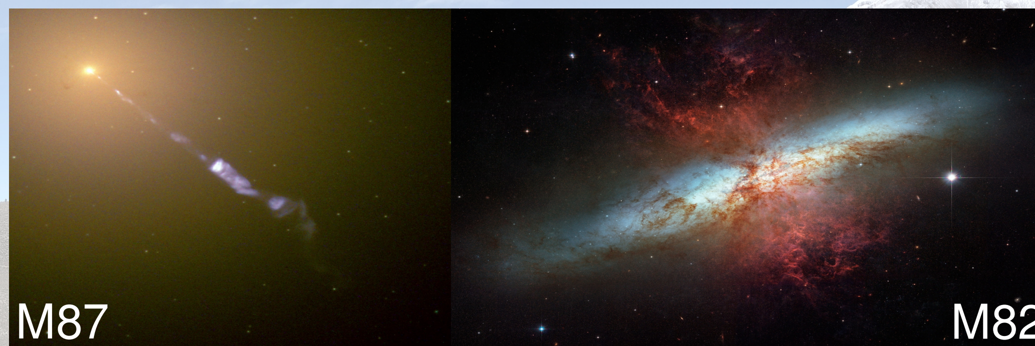
HAWC
High Altitude Water Cherenkov

Los Alamos
NATIONAL LABORATORY
EST. 1943

Diffuse Gamma-Ray Background

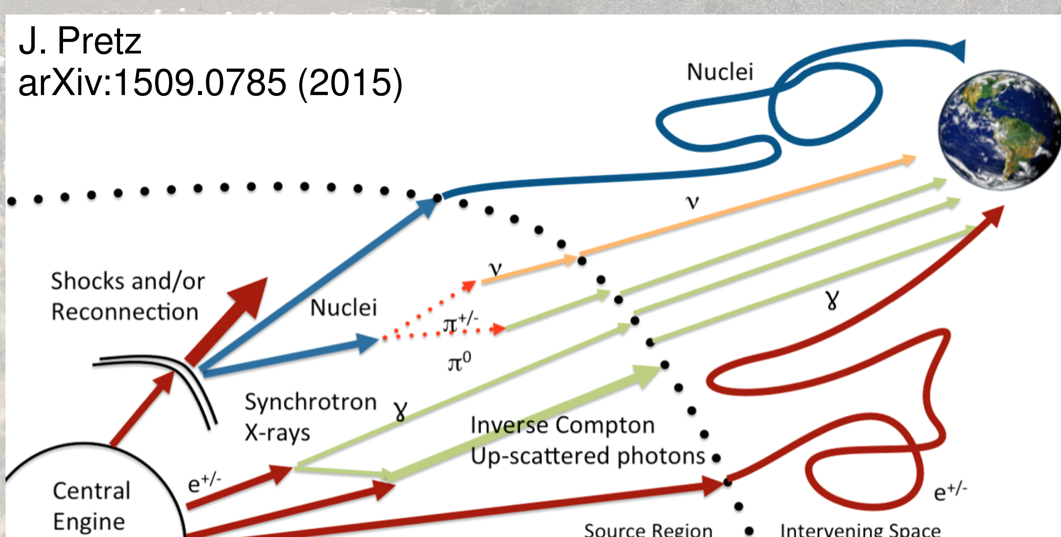
The Diffuse Gamma-Ray Background (DGRB) is expected to be produced by:

- unresolved extragalactic objects, such as AGNs and starburst galaxies
- isotropic Galactic gamma rays, emitted by the interaction of high-energy cosmic rays with matter and radiation in our Galaxy
- dark matter annihilations or decays in Galactic or extragalactic structures



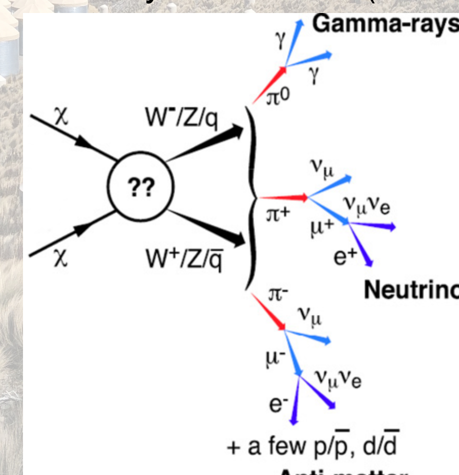
Credits: NASA, ESA and the Hubble Heritage Team (STScI/AURA)

J. Pretz
arXiv:1509.0785 (2015)



Astrophysical pion production and dark matter annihilations are likely to produce neutrinos in conjunction with gamma rays.

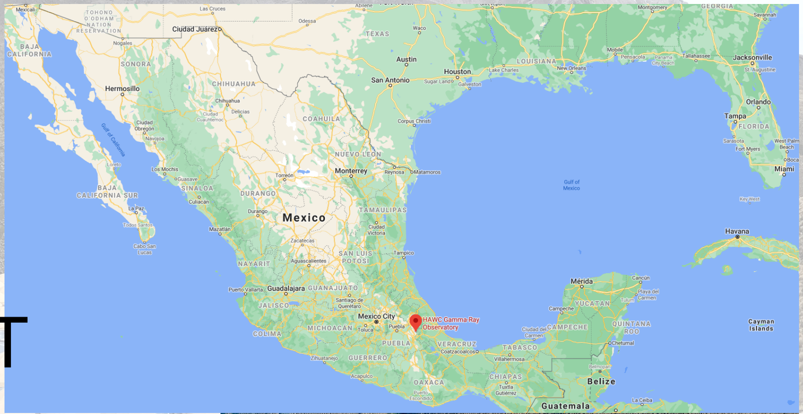
E A Baltz *et al*
J. Cosmol. Astropart. Phys. **0807** 013 (2008)

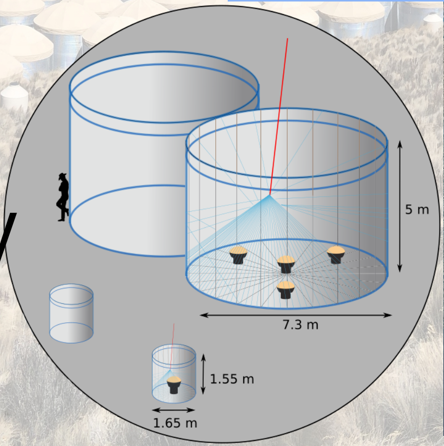


High-Altitude Water Cherenkov Gamma-Ray Observatory

- **Location:** Volcán Sierra Negra (Puebla, Mexico)
- **Elevation:** 4,100 m
- **Instrumented area:** 22,000 m^2
- **WCDs:** 300, each filled with 200 kℓ of purified water
- **PMTs:** 1 central 10-inch PMT
  3 lateral 8-inch PMTs
- **Outriggers:** 350 WCDs with 1 PMT
- **Duty cycle:** >95%
- **Field of View:** 2 sr
- **Energy range:** 300 GeV to >100 TeV
- **Declination range:** -26° to +64°

Pico de Orizaba





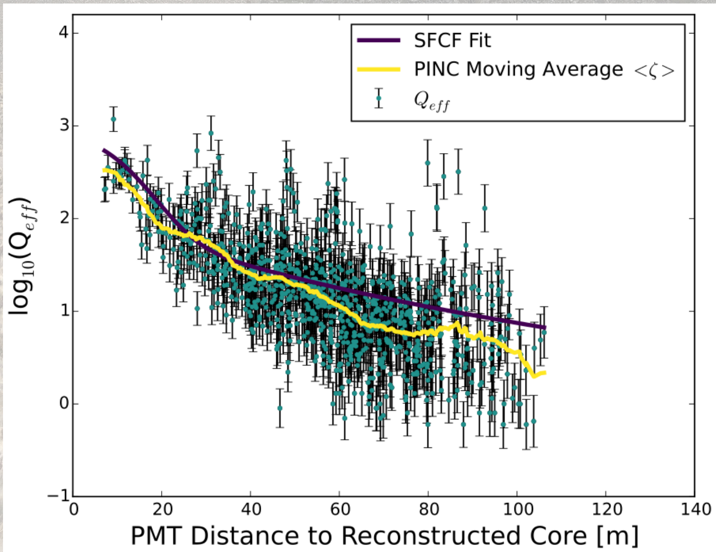
Data Selection

- This analysis uses 535 days of HAWC data from November 2014 to June 2016
- Standard HAWC quality cuts were applied and so was a preliminary gamma/hadron separation cut on Compactness, which is a parameter designed to identify muons in air showers.
- PINCness measures the “smoothness” of the lateral charge distribution function of air showers to distinguish between gamma-ray showers from charged cosmic-ray showers.
- A 2D binning scheme was implemented focusing on events with reconstructed energies above 10 TeV (bins g to l) and where more than 61.8% of the PMTs available were hit (bins 7 to 9).
- The simulation of gamma-rays follows the best-fit HAWC Crab spectrum

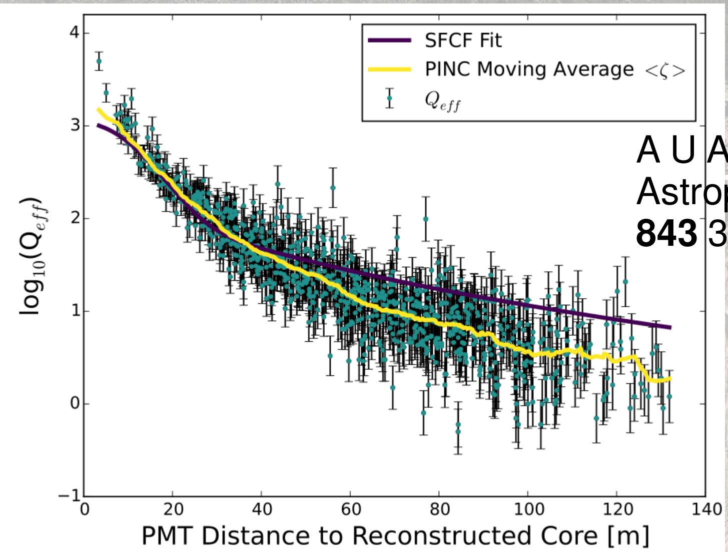
$$\left(\frac{dN}{dE}\right)_{\mathrm{Crab}} = 2.35 \times 10^{-13} \left(\frac{E}{7\ \mathrm{TeV}}\right)^{-2.79-0.10\ln(E/7\ \mathrm{TeV})} [\ \mathrm{TeV\ cm^2\ s}\ ]^{-1}$$

A U Abeysekara *et al*
Astrophysical Journal
881 (2) 134 (2019)

- Only bins with reliable data/simulation agreement were considered, as verified using the Crab Nebula



Lateral charge distribution function of a cosmic ray



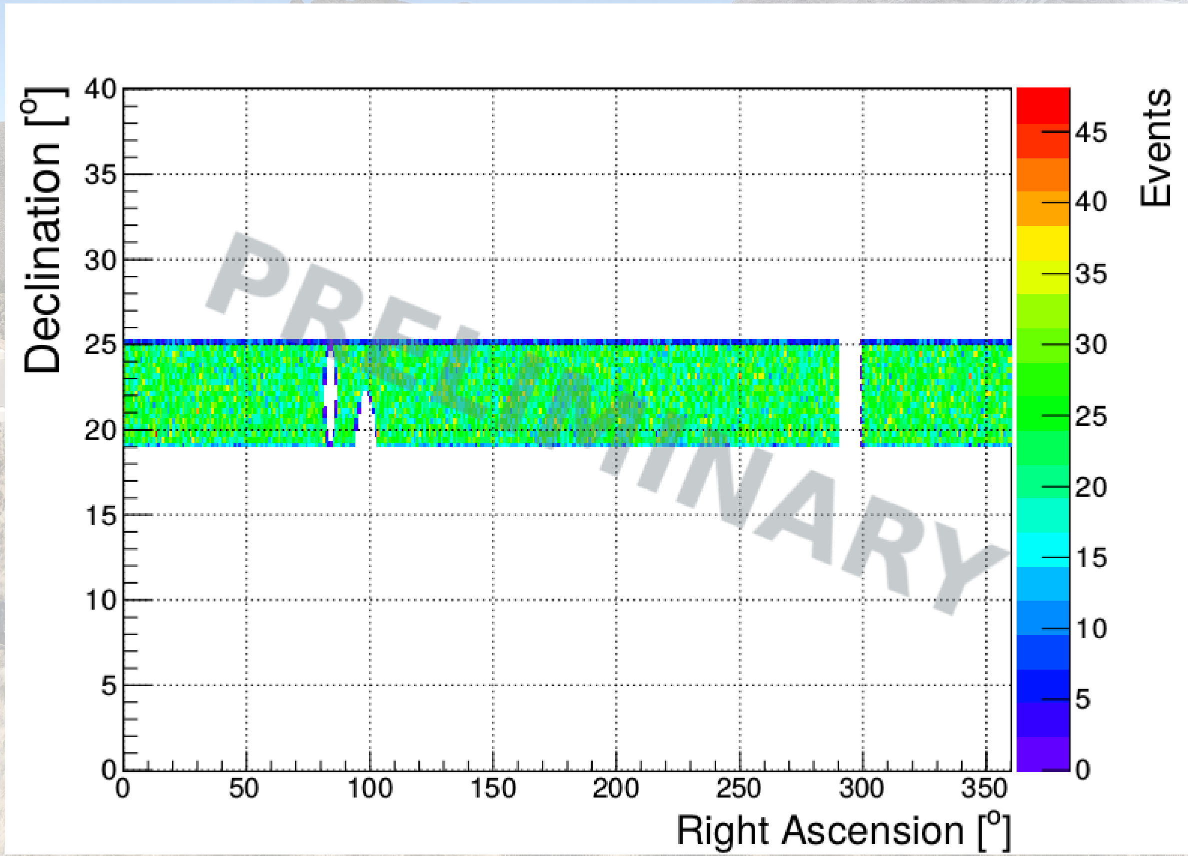
A U Abeysekara *et al*
Astrophysical Journal
843 39 (2017)

Lateral charge distribution function of a photon candidate from the Crab Nebula

DGRB Data Strip

The DGRB data strip $(0.57\,\mathrm{sr})$ is centered on the Crab location and contains:

- 6^{o} declination around Crab location by 360^{o} right ascension
- 3^{o} mask around Crab location
- 5^{o} mask around Geminga location
- 10^{o} right ascension mask around Galactic Plane location
- unresolved cosmic rays, in addition to gamma rays



Overall Scale of the Spectrum

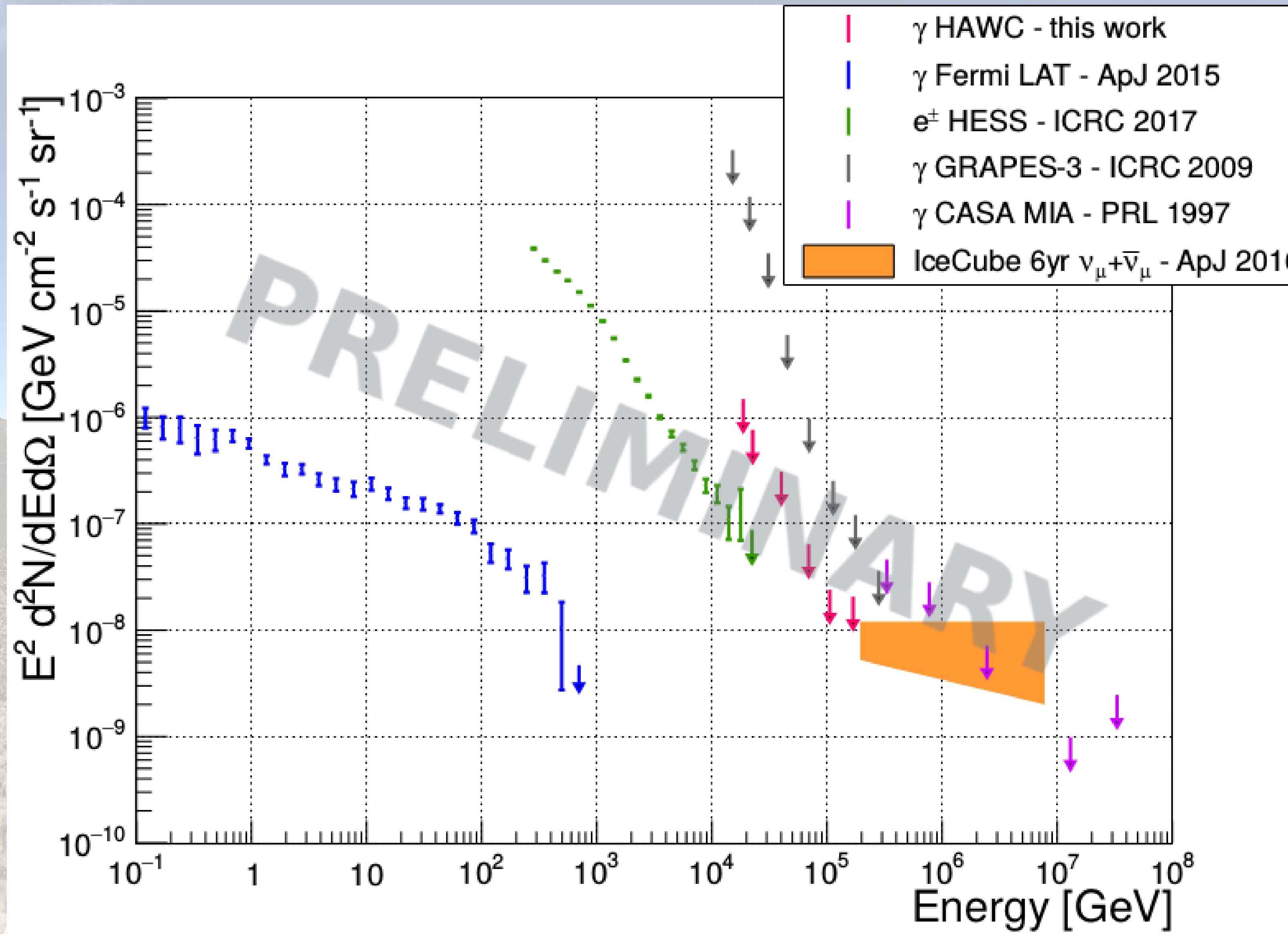
As tighter PINCness cuts are applied, few events remain and Poisson statistics can be implemented on data and MC simulation. A binned maximum likelihood analysis was performed in which bins are not summed but treated as separate independent "experiments". Therefore, for a given energy bin, the 95% one-sided upper limit of each corresponding fraction hit bin is calculated and the one with the lowest value is selected, as it would be the one with most expansive limit.

Accounting for the 0.57 sr solid angle of the DGRB strip, the 95% containment level of the overall scale of the spectrum is referred to as $\beta_{95\%}$ Assuming the Crab-like spectrum,

$$\left(\frac{d^2 N}{dE d\Omega}\right)_{95\%} = \beta_{95\%} \times \left(\frac{dN}{dE}\right)_{\text{Crab}}$$

Energy bin	Fraction hit bin	$\beta_{95\%}$	Simulation median energy (TeV)
g	7	308	19
h	8	192	23
i	9	145	40
j	9	57.8	69
k	9	37.1	106
l	9	61.0	168

HAWC 535-Day DGRB Upper-Limits



Model Testing

- The gamma-ray flux corresponding to the best fit of the IceCube unbroken power-law model for the $\nu_\mu + \bar{\nu}_\mu$ astrophysical flux

$$\left(\frac{d^2 N}{dE d\Omega}\right)_{\mathrm{IC}} = 0.9 \times 10^{-15} \left(\frac{E}{100\ \mathrm{TeV}}\right)^{-2.13} [\mathrm{TeV\ cm^2\ s\ sr}]^{-1}$$

M G Aartsen *et al*
Astrophysical Journal
833 (1) 3 (2016)

- The best fit for the H.E.S.S. electron/positron flux with a smooth broken power law

$$\left(\frac{d^2 N}{dE d\Omega}\right)_{\mathrm{H.E.S.S.}} = 1.05 \times 10^{-8} \left(\frac{E}{1\ \mathrm{TeV}}\right)^{-3.04} \left(1+\left(\frac{E}{0.94\ \mathrm{TeV}}\right)^{\frac{1}{0.12}}\right)^{0.12\times(3.04-3.78)} [\mathrm{TeV\ cm^2\ s\ sr}]^{-1}$$

D Kerszberg *et al*
ICRC BEXCO Seoul
CRI215 (2017)

$$\left(\frac{d^2 N}{dE d\Omega}\right)_{95\%} = \beta_{95\%} \times \left(\frac{d^2 N}{dE d\Omega}\right)_{\mathrm{model}}$$

	$\beta_{95\%}$	β_{best}
IceCube spectrum	2.13	1.32
H.E.S.S. spectrum	9.60	6.94

Conclusion

We implement gamma/hadron separation methods and optimize the data/simulation agreement in order to calculate 95% upper limits on the DGRB. In addition to DGRB events, the flux observed by HAWC may also include other isotropic events such as:

- misreconstructed hadrons due to their gamma-like appearance
- cosmic-ray $e^{\pm}$ whose air showers are similar to those induced by gamma rays

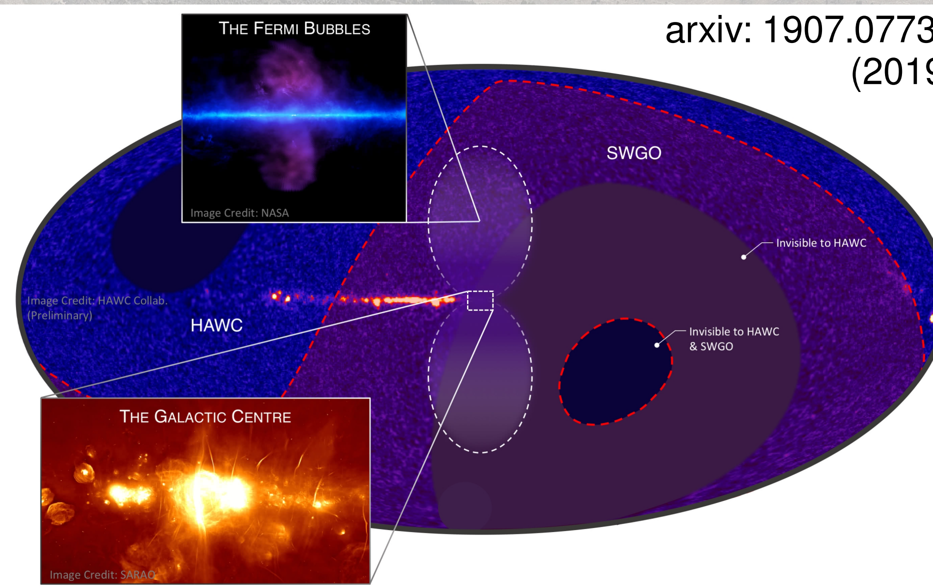
Astrophysical pion production emit neutrinos, and so might dark matter annihilations. Interestingly, the best estimate of the overall scale of the spectrum is only 1.32 times the IceCube flux. This value is likely to include a fair amount of CR background and should definitely not be considered as a measurement of the DGRB. Nonetheless, despite being ambiguous, this value is fairly consistent with the IceCube flux itself. Better characterization of residual CRs is underway and could verify the consistency between gamma-ray and neutrino flux.

Outlook

With the addition of more years of data, upcoming improvements to the HAWC reconstruction algorithms and analytical methods, and the deployment of the outrigger array in August 2018, stronger results are expected.

Furthermore, a next-generation Southern Wide-field Gamma-ray Observatory (SWGO) is being considered for the Southern Hemisphere which will extend sensitivity to energies above the tens of PeV.

arxiv: 1907.07737 (2019)



HAWC & SWGO sky coverage