Heavy Dark Matter Annihilation Search Towards Dwarf Galaxies with the HAWC Observatory

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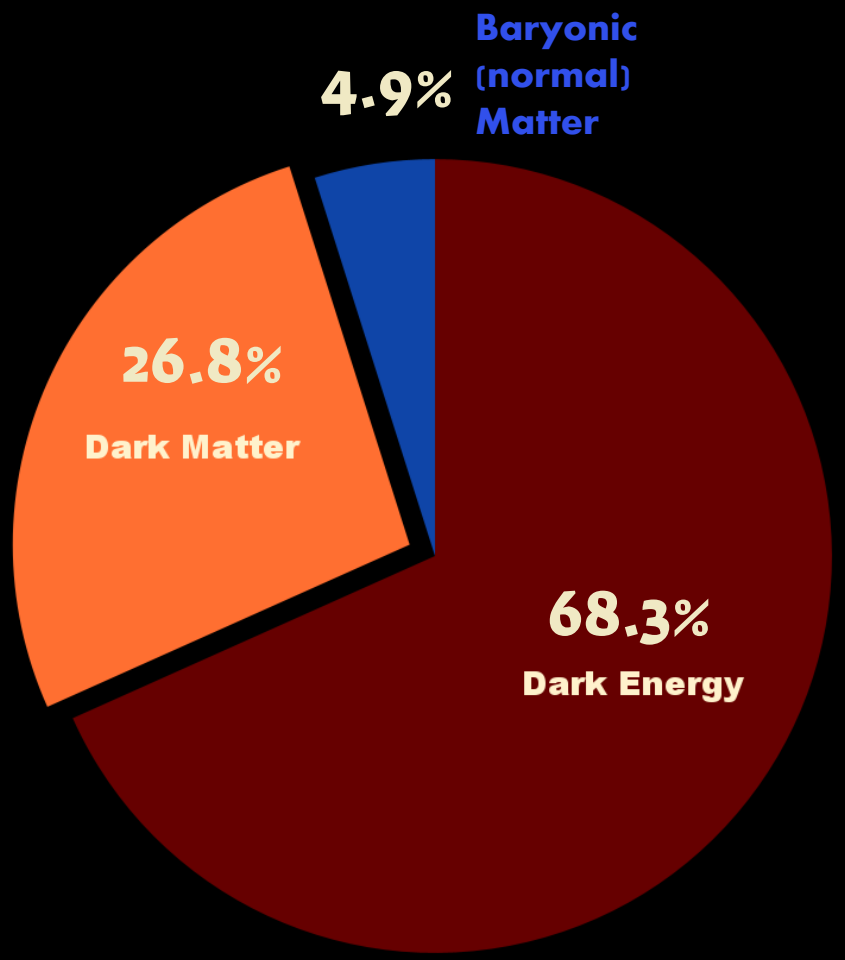
The Dark Matter Basics

What we know from astrophysical observations

ABUNDANT
- 5x more than normal (baryonic) matter
- Accounts for ~27% of the universe's energy

DARK
- Does not interact with the electromagnetic force (aka light)
- Tight limits on other Standard Model forces

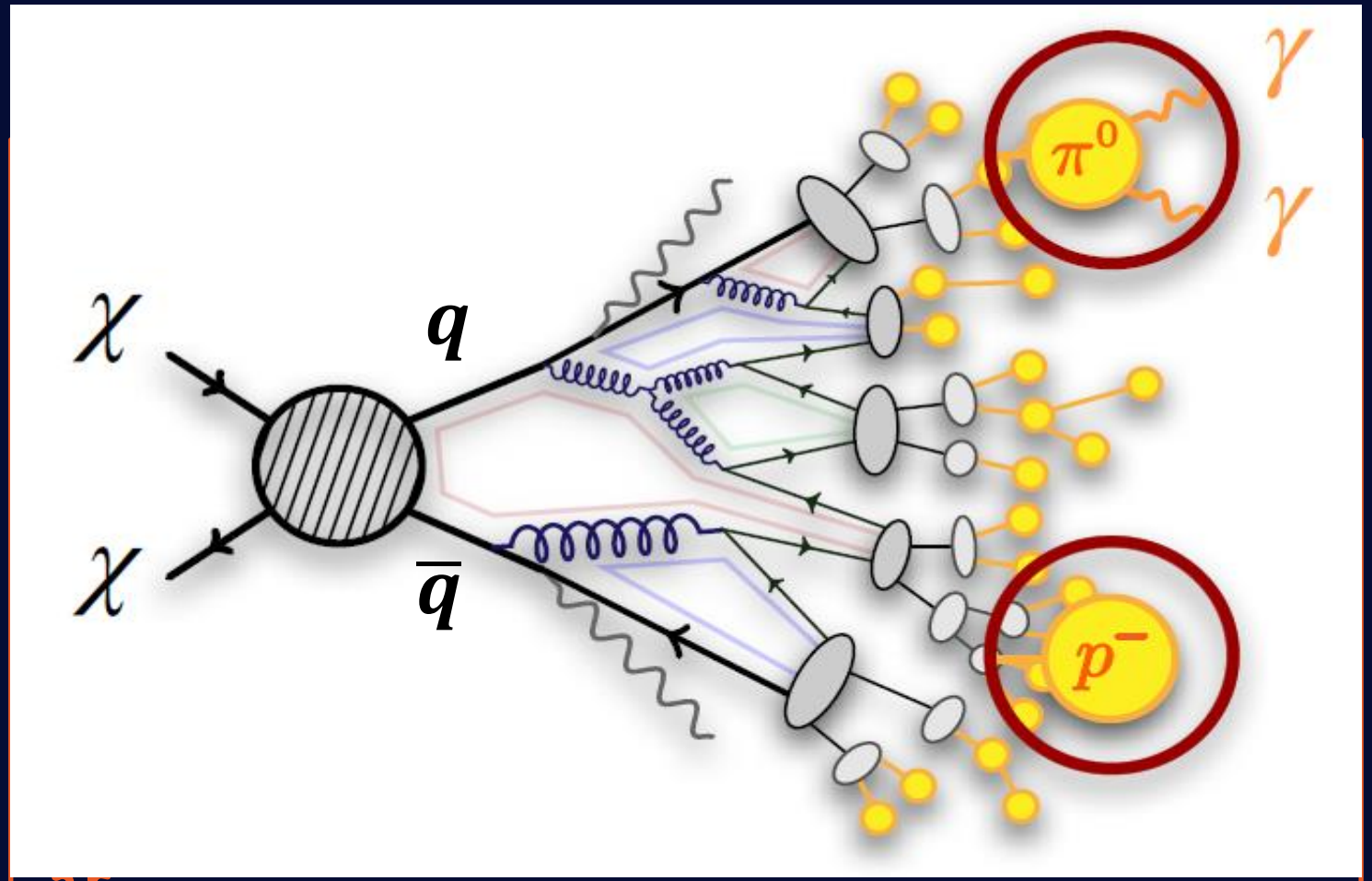
OLD
- Plays a massive role in the shape and evolution of our universe and galaxy.



Source: NASA

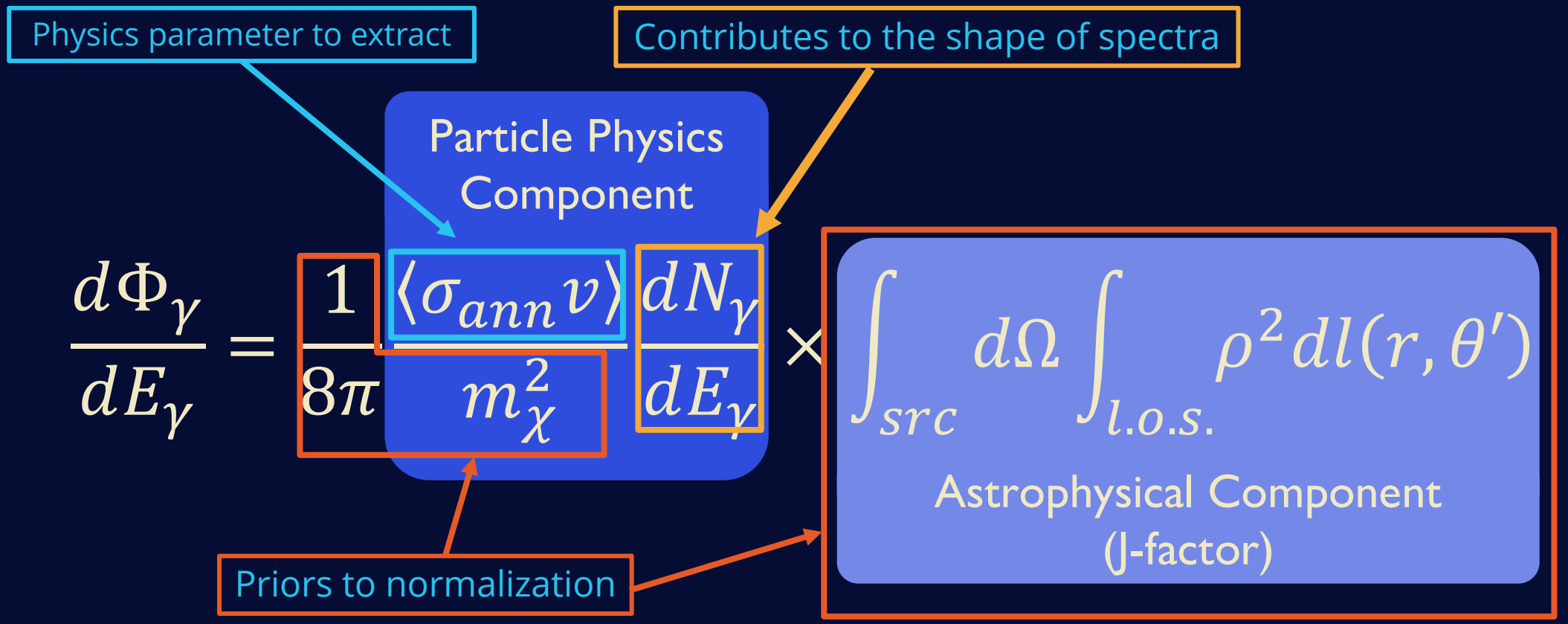
How we can begin to probe DM

Shake it



Break it

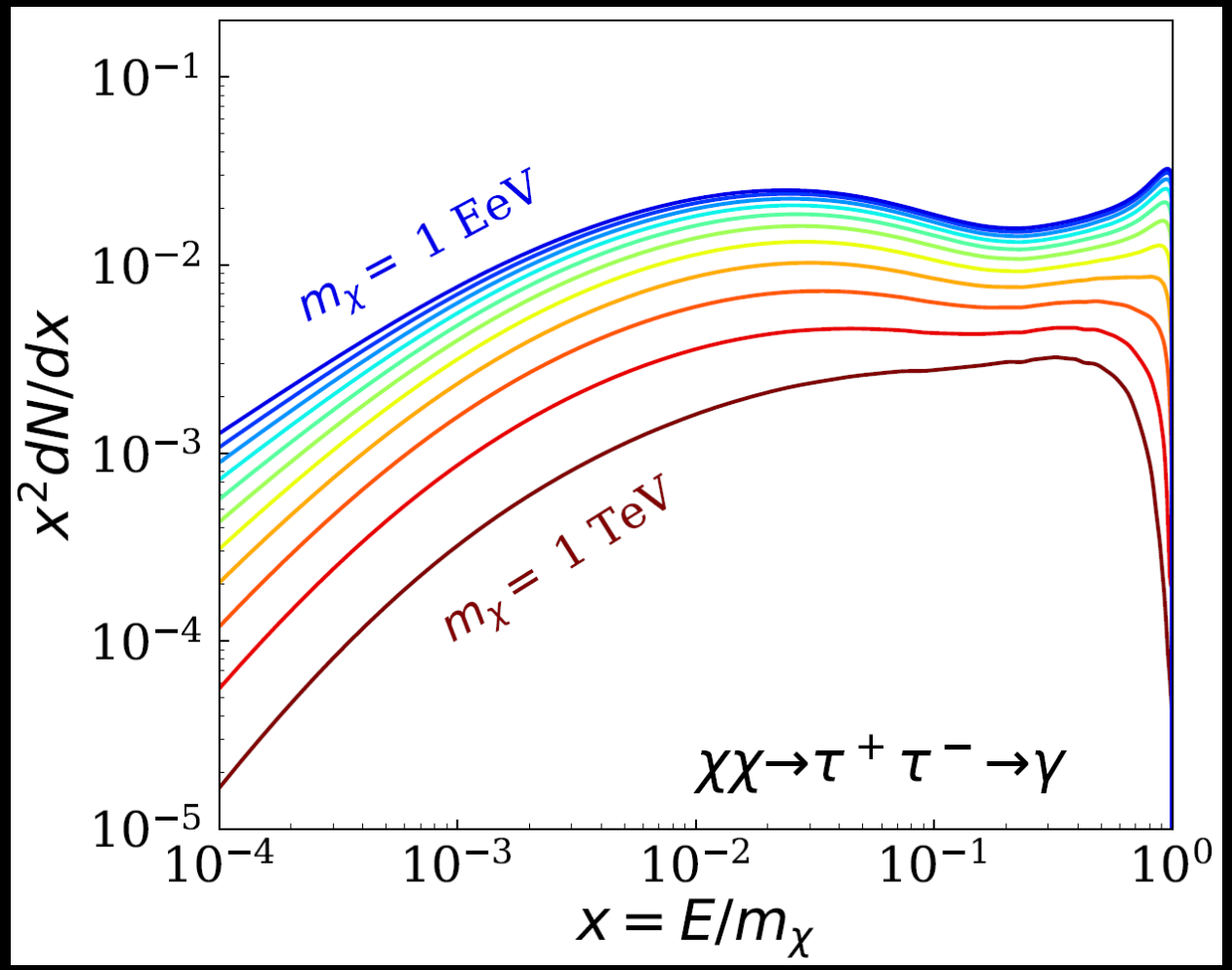
Indirect Detection of Annihilating Dark Matter



Likelihood fit over the simplified equation:

$$A \times \frac{dN_\gamma}{dE_\gamma}(M_\chi, E_\gamma, SM_{chan})$$

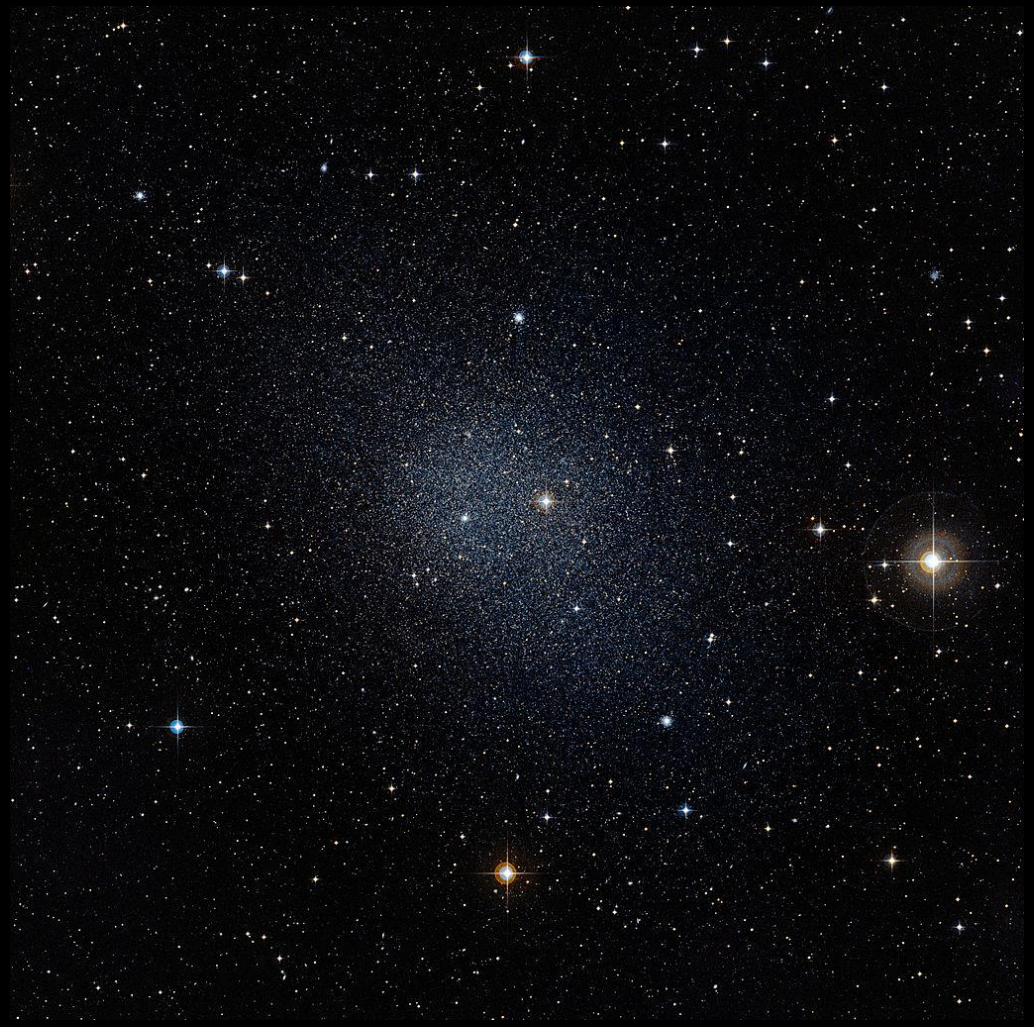
Particle Physics Component



Dark Matter Annihilation spectra from the Heavy Dark Matter Spectra (HDMSpectra)

C. Bauer et. al. , 10.1007 (2021)

Standard DM Search; Dwarf Spheroidals



ESO/Digitized Sky Survey 2

(left) Fornax Dwarf Spheroidal Galaxy (dSph)

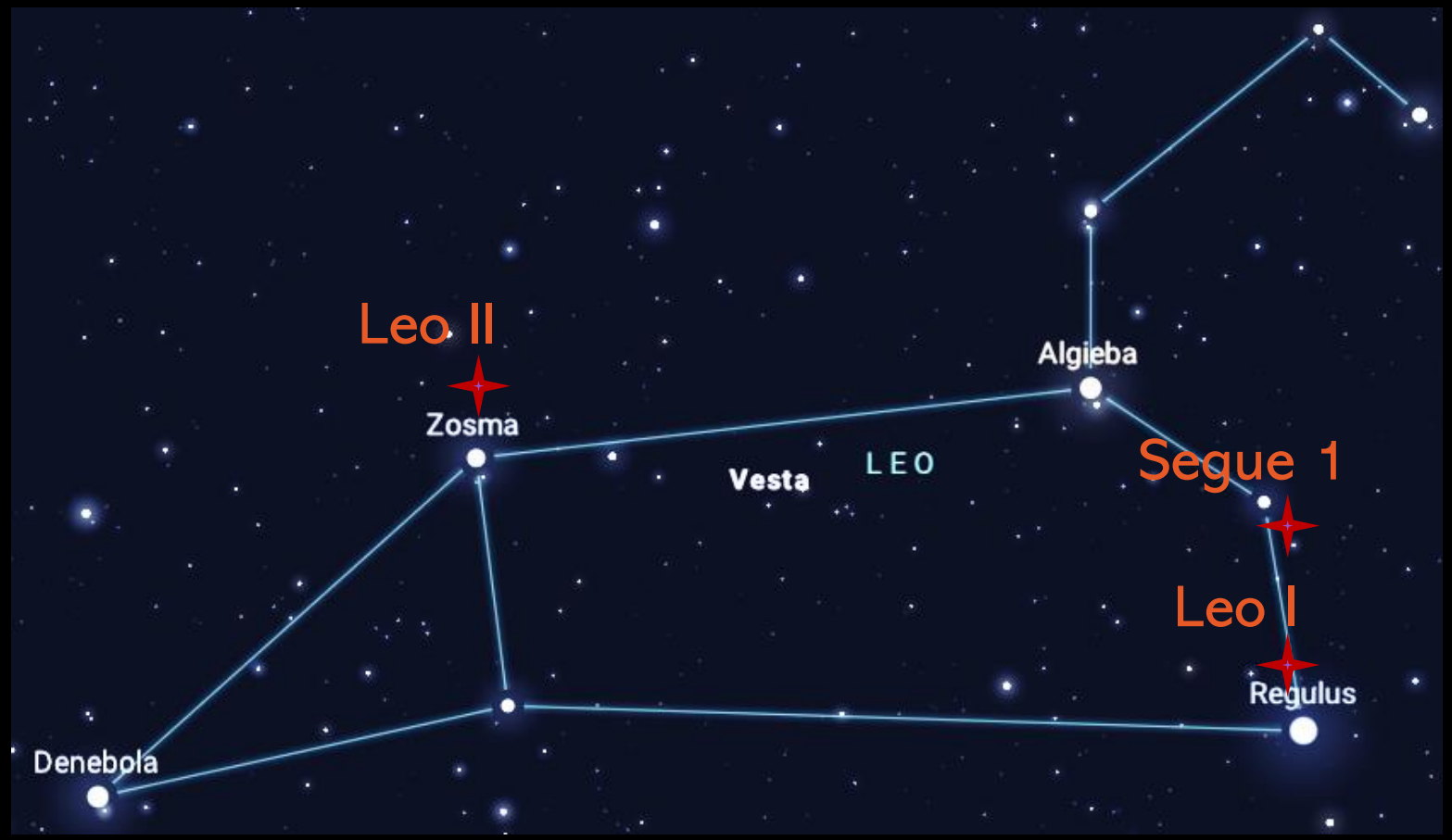
'Small' clustering of matter and stars within our galactic neighborhood

dSphs are DM dominated.

Very little astrophysical γ background or obstructive dust

Ideal sources for astrophysical Dark Matter searches

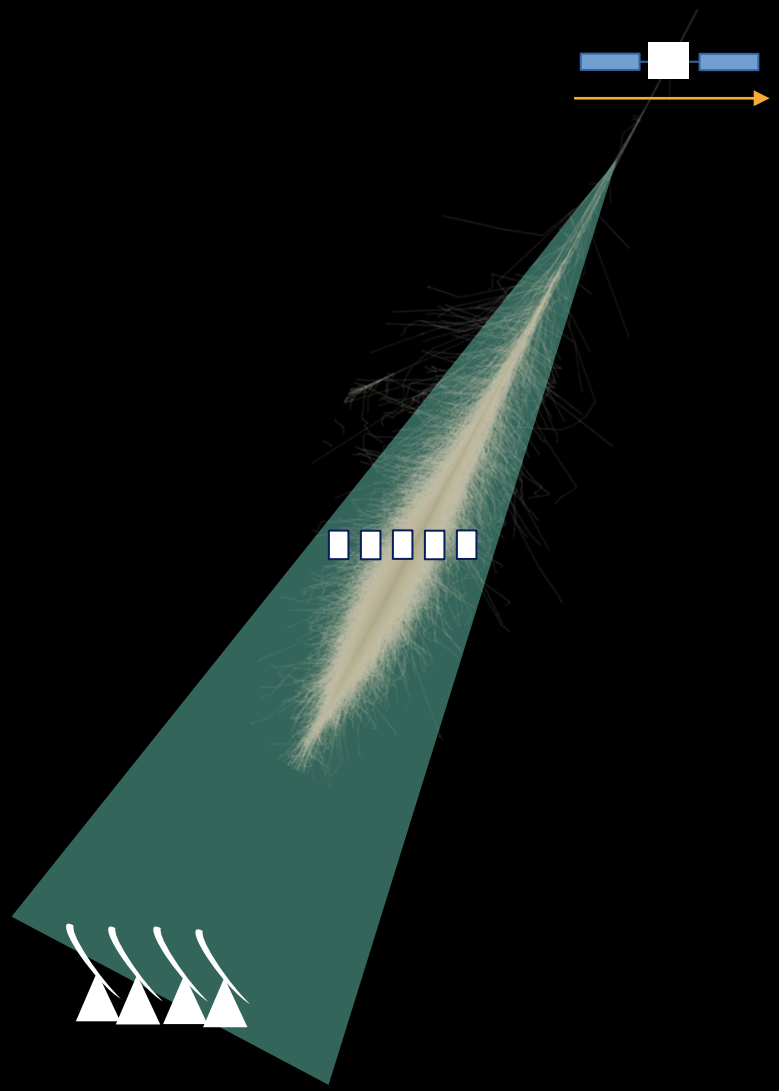
Some of the sources for real



Leo constellation with location of 3 dSph's marked

Sources pulled from Louis Strigari 2020 for HAWC's analysis

High Energy Gamma Ray Observatories



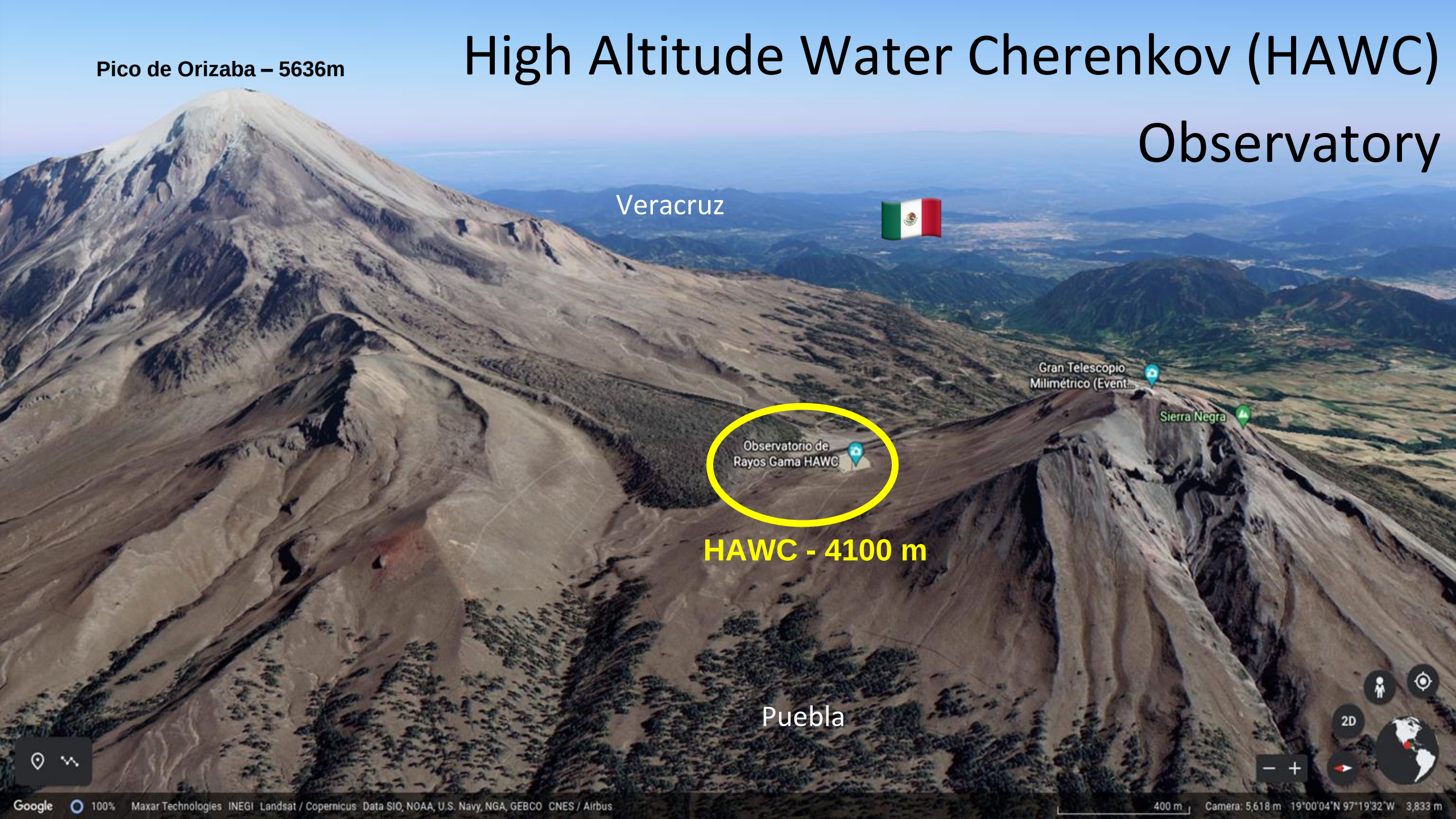
Wide Field of View,
Continuous Operations

Satellite Detectors
Fermi-LAT

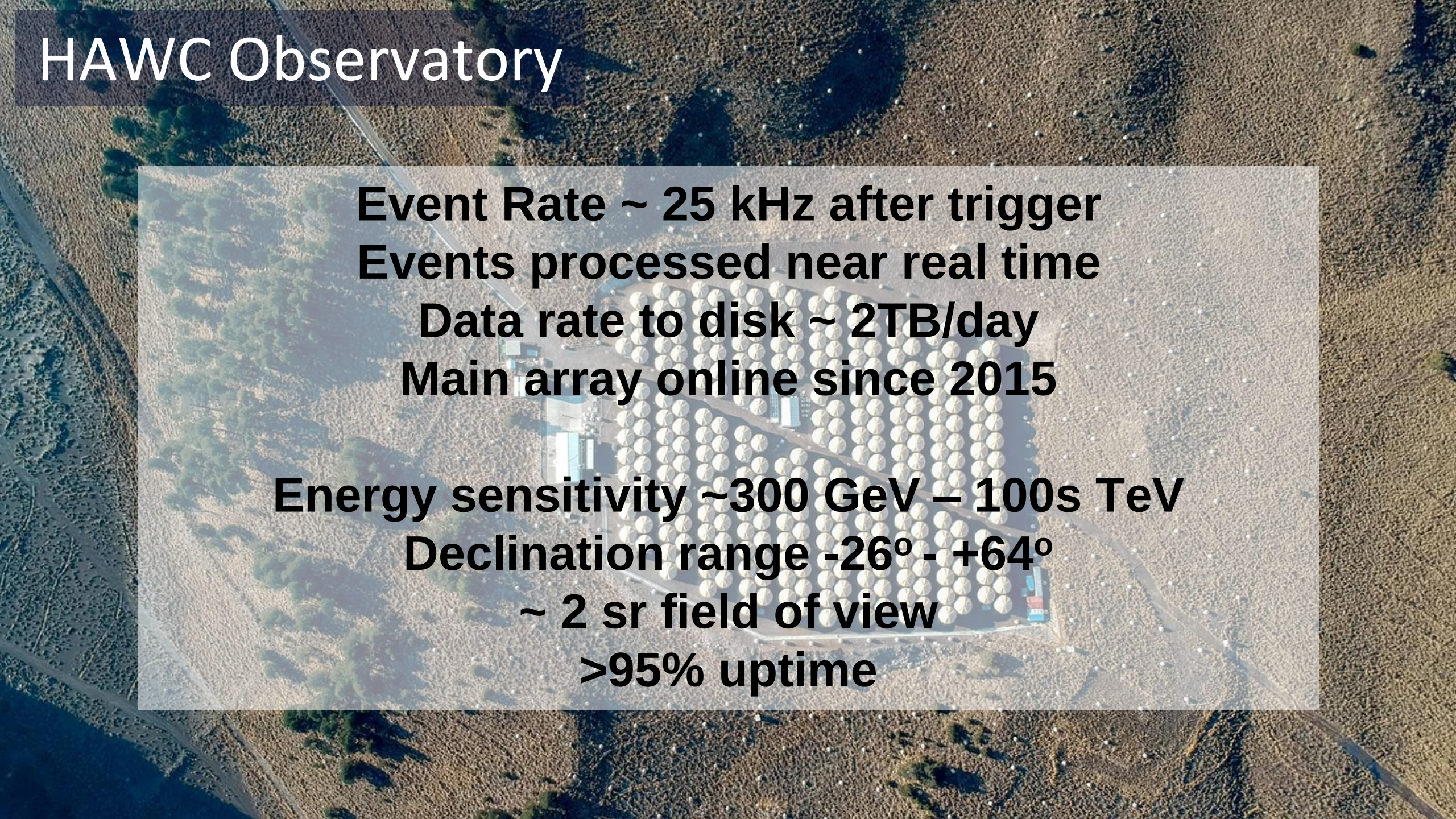
Extensive Air Shower
(EAS) Detector
HAWC, LHASO

Imaging Atmospheric
Cherenkov Telescope
VERITAS, HESS, MAGIC,
CTA

High Altitude Water Cherenkov (HAWC) Observatory



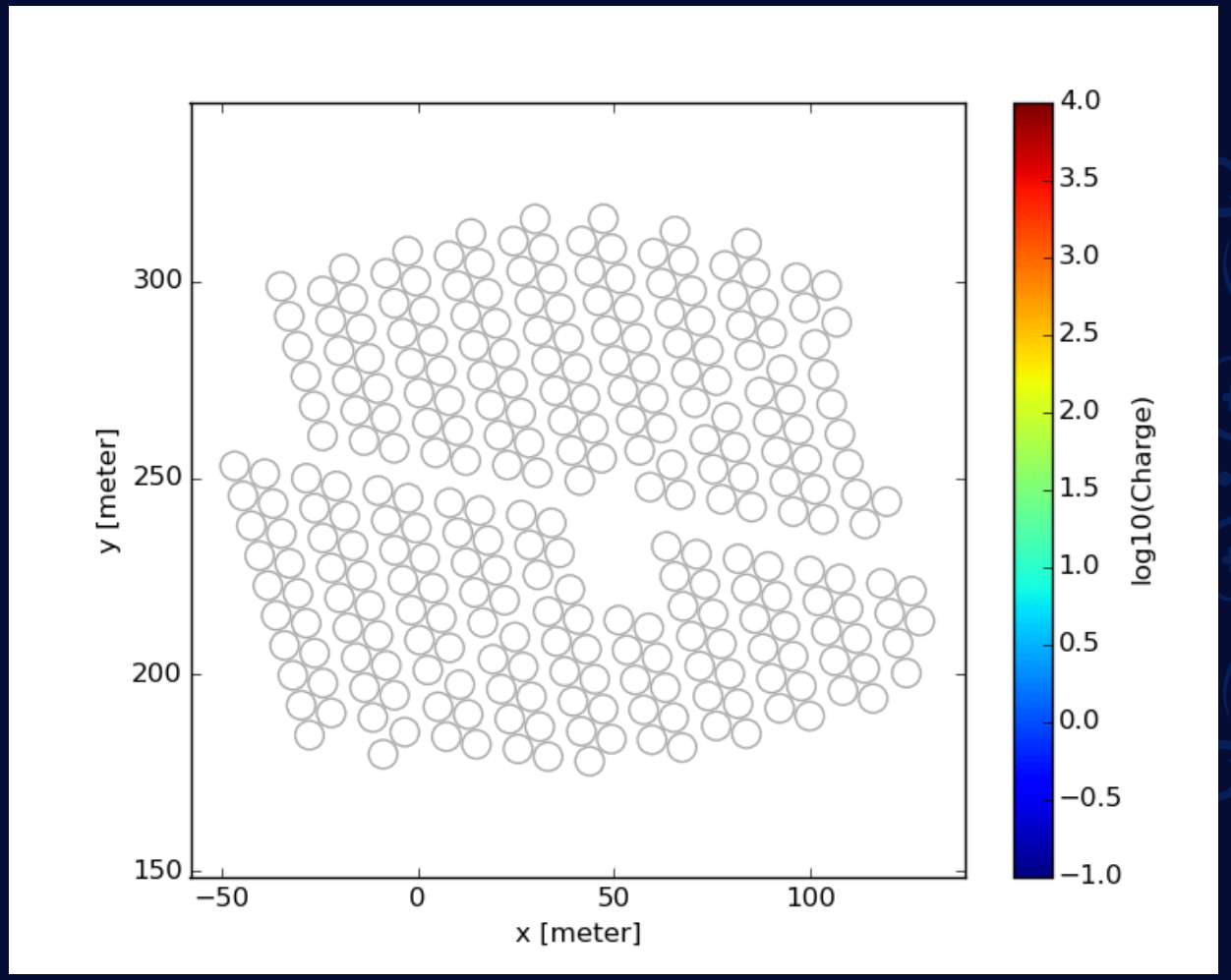
HAWC Observatory



Event Rate ~ 25 kHz after trigger
Events processed near real time
Data rate to disk ~ 2TB/day
Main array online since 2015

Energy sensitivity ~300 GeV – 100s TeV
Declination range -26° - +64°
~ 2 sr field of view
>95% uptime

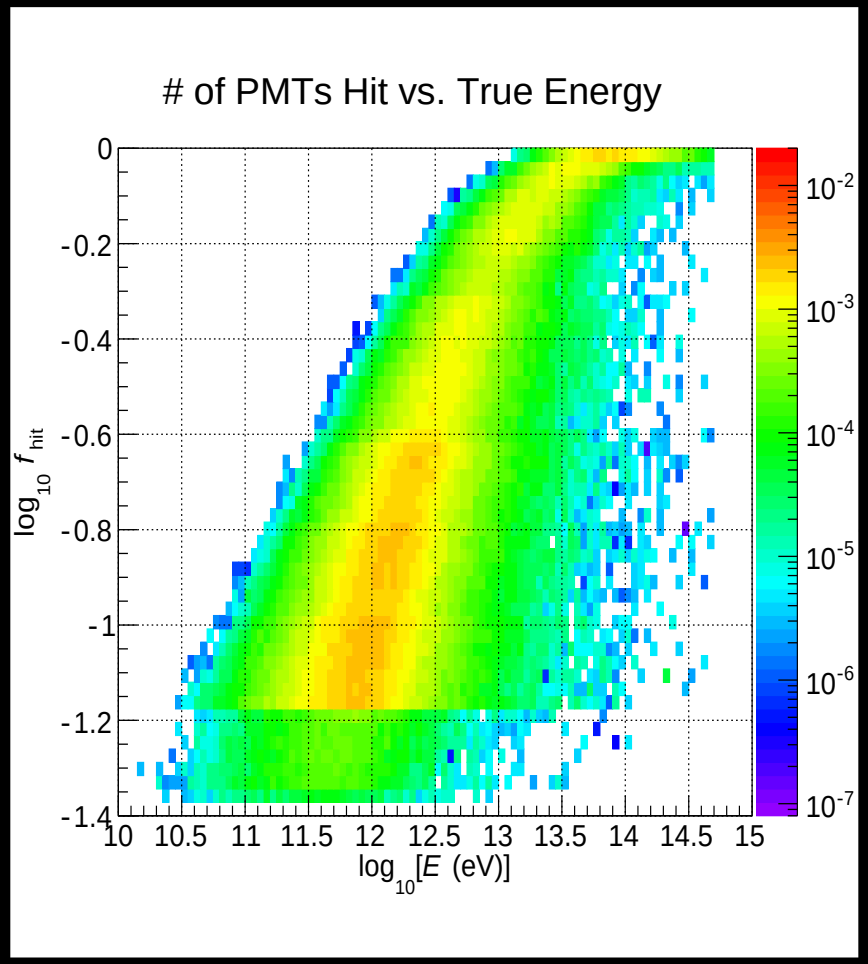
Air Shower Reconstruction with HAWC



For the 1200 PMTs we record hit time and amplitude

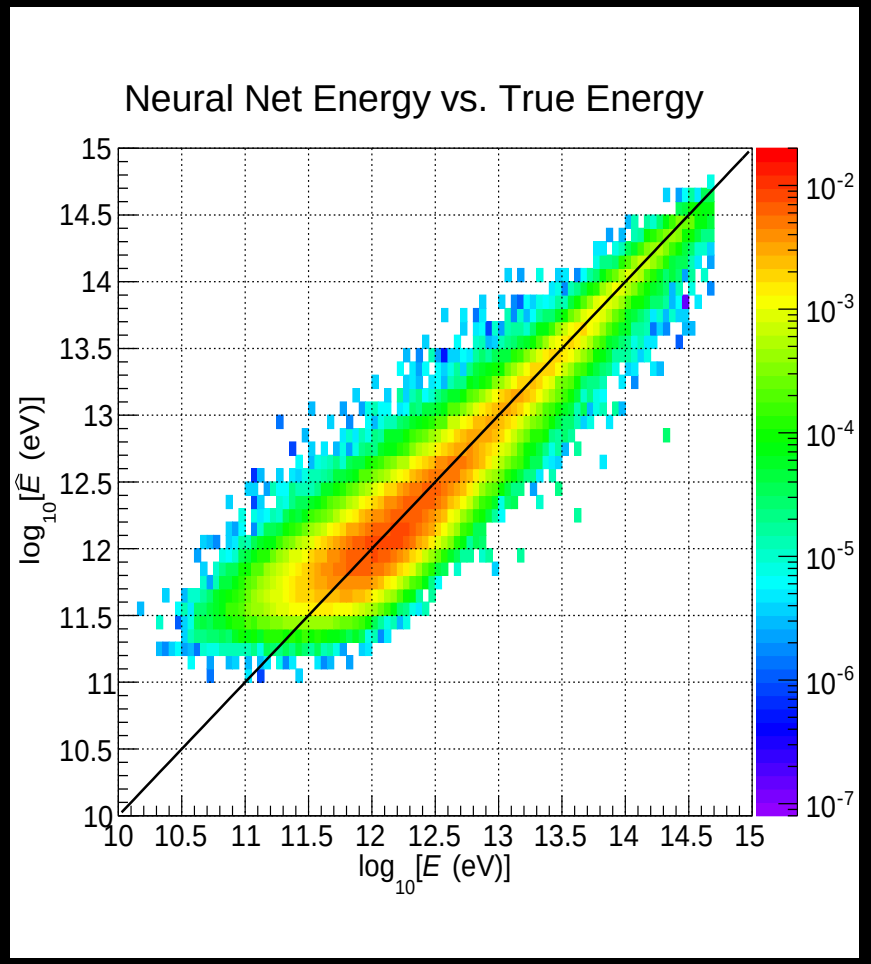
- Estimate energy – ML based or analytic methods
- Reconstruct direction of primary gamma
- Particle Discrimination (Cosmic rays vs gammas)

Improved Energy Estimation

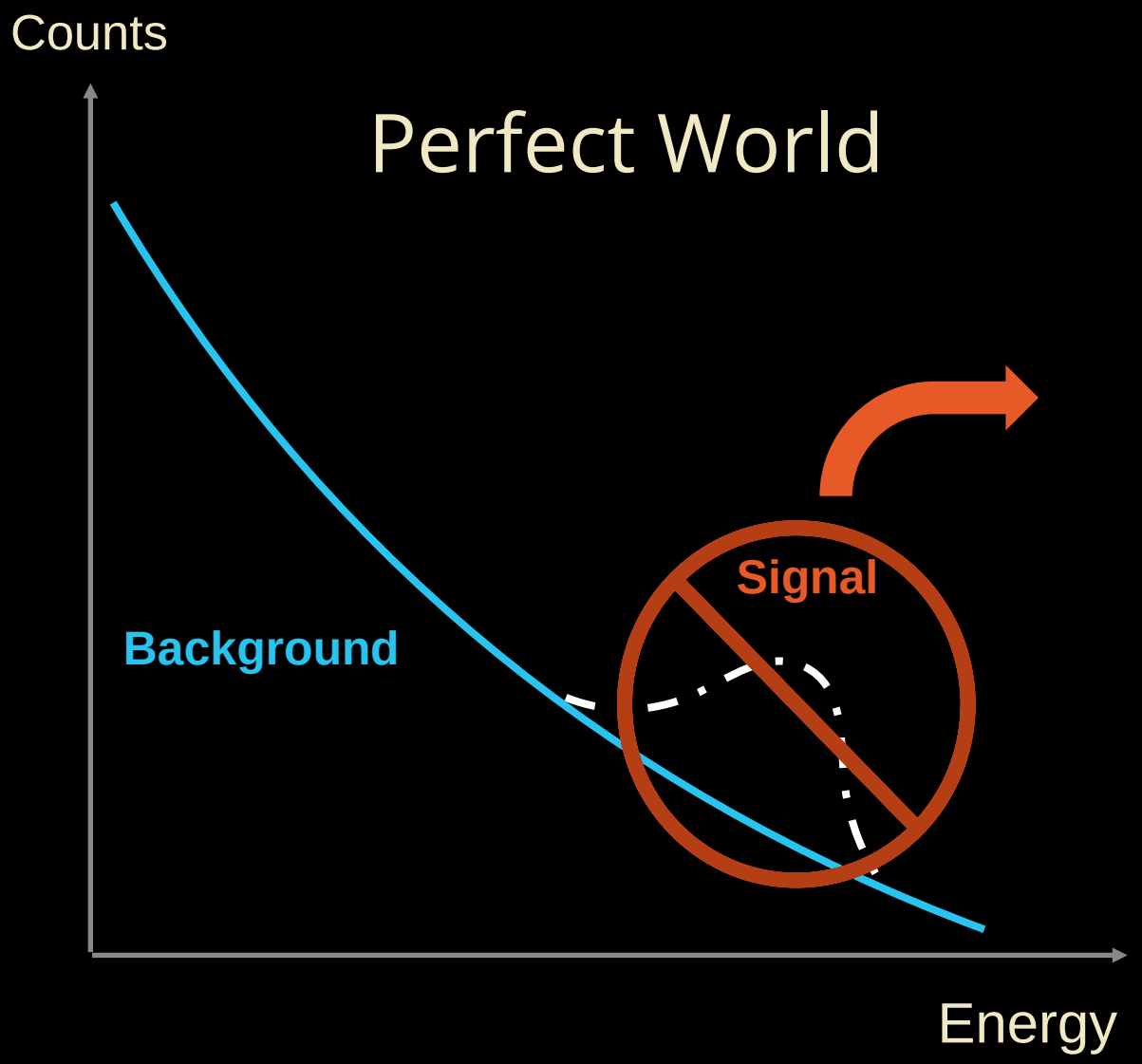


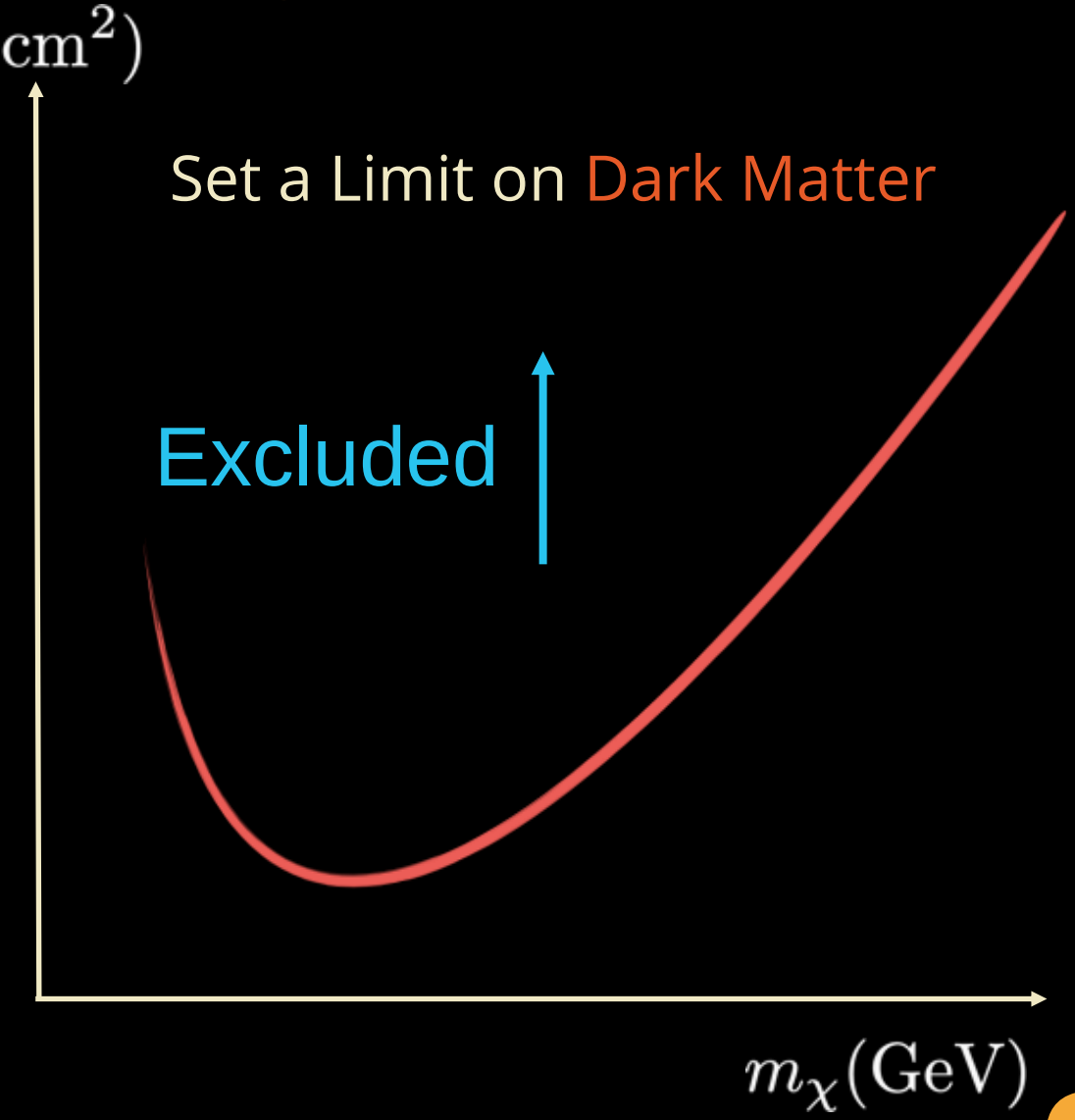
HAWC now supplements it's "n hit" gamma ray energy estimation with a neural network.

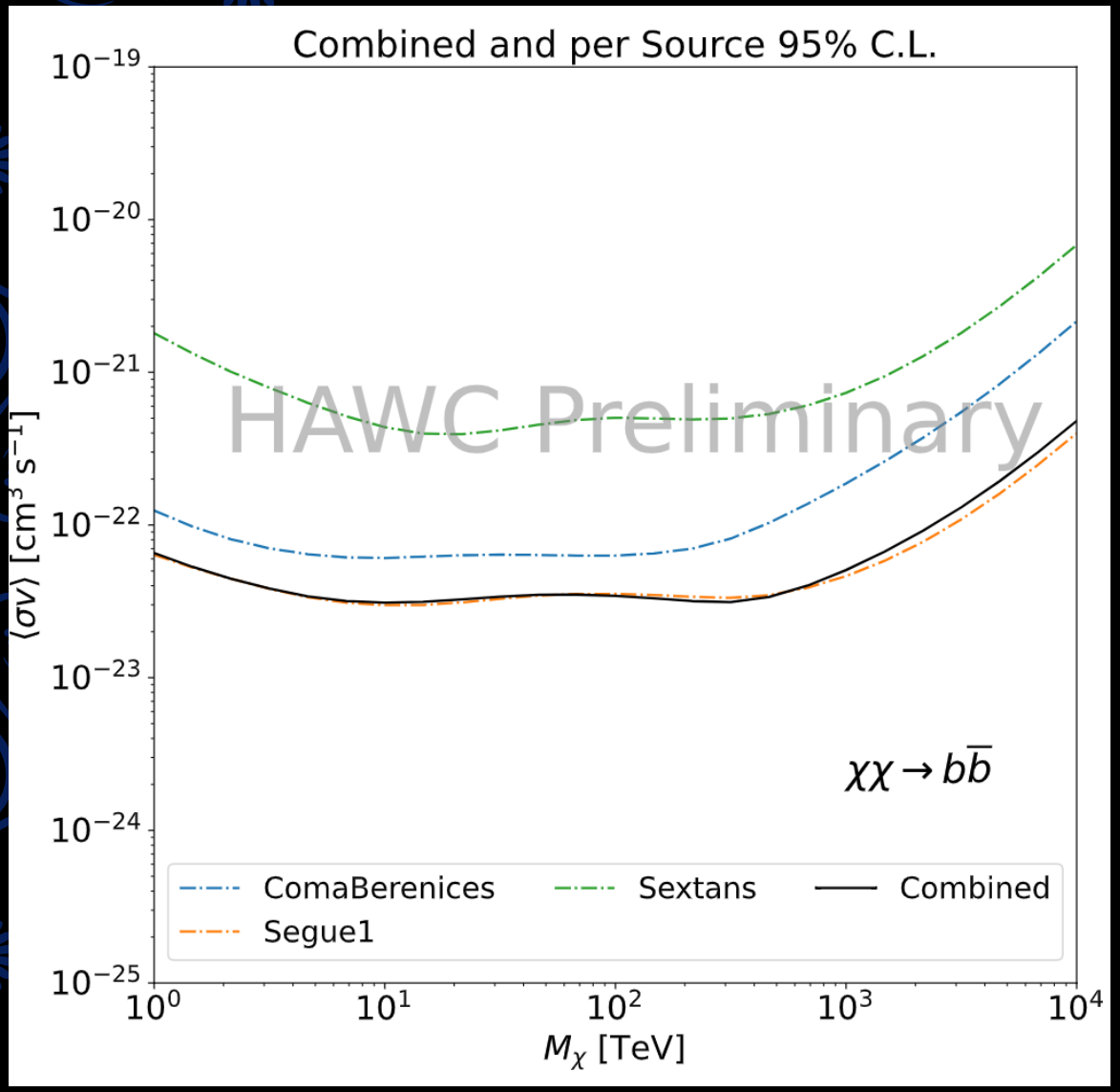
Overall this leads to better energy reconstruction at higher gamma-ray energies

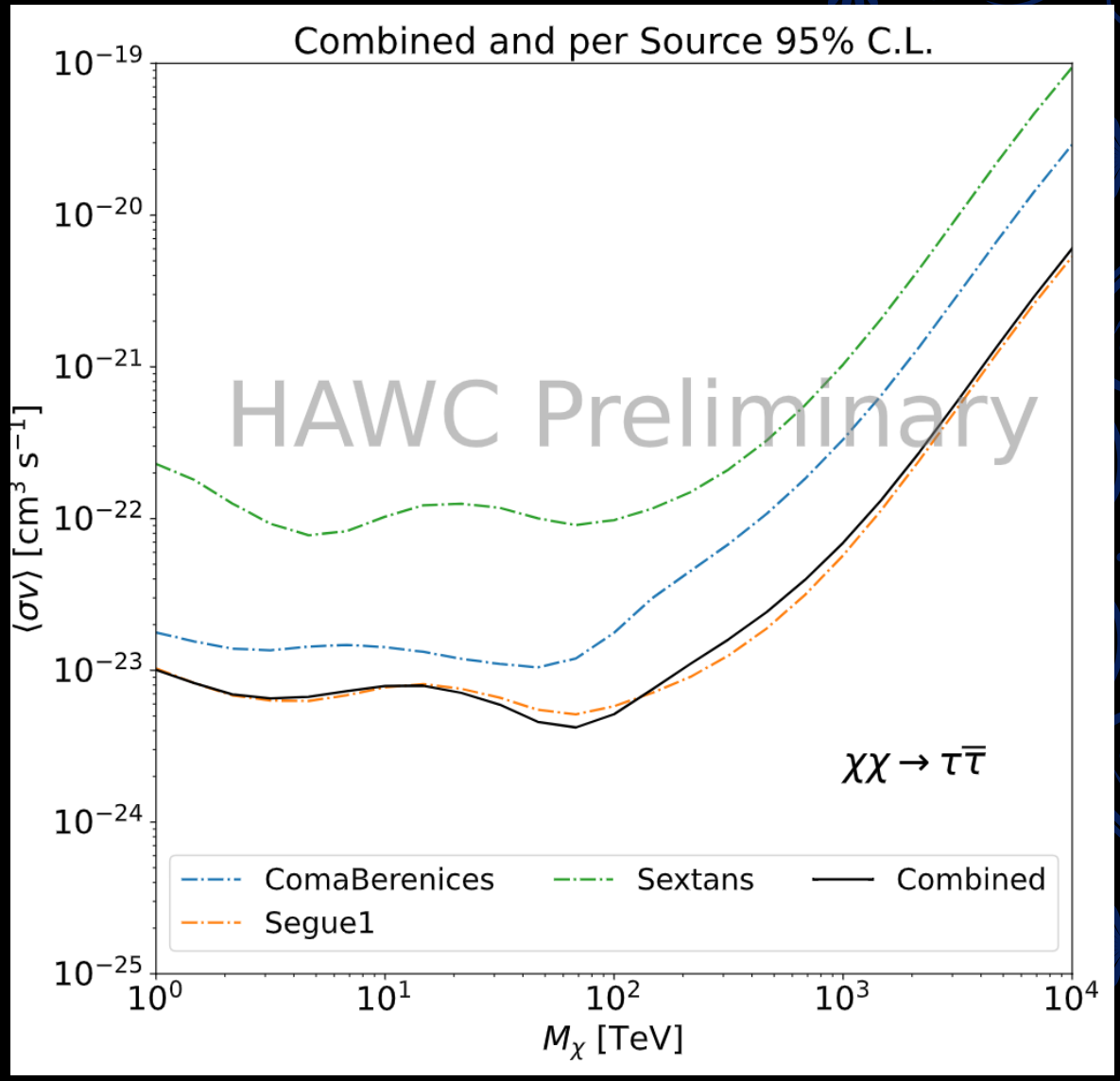


Bump Hunting






Combined and per Source 95% C.L.
HAWC Preliminary
$\chi\chi \to b\bar{b}$
ComaBerenices
Segue1
Sextans
Combined
$\langle\sigma v\rangle$ [cm^3 s^{-1}]
M_χ [TeV]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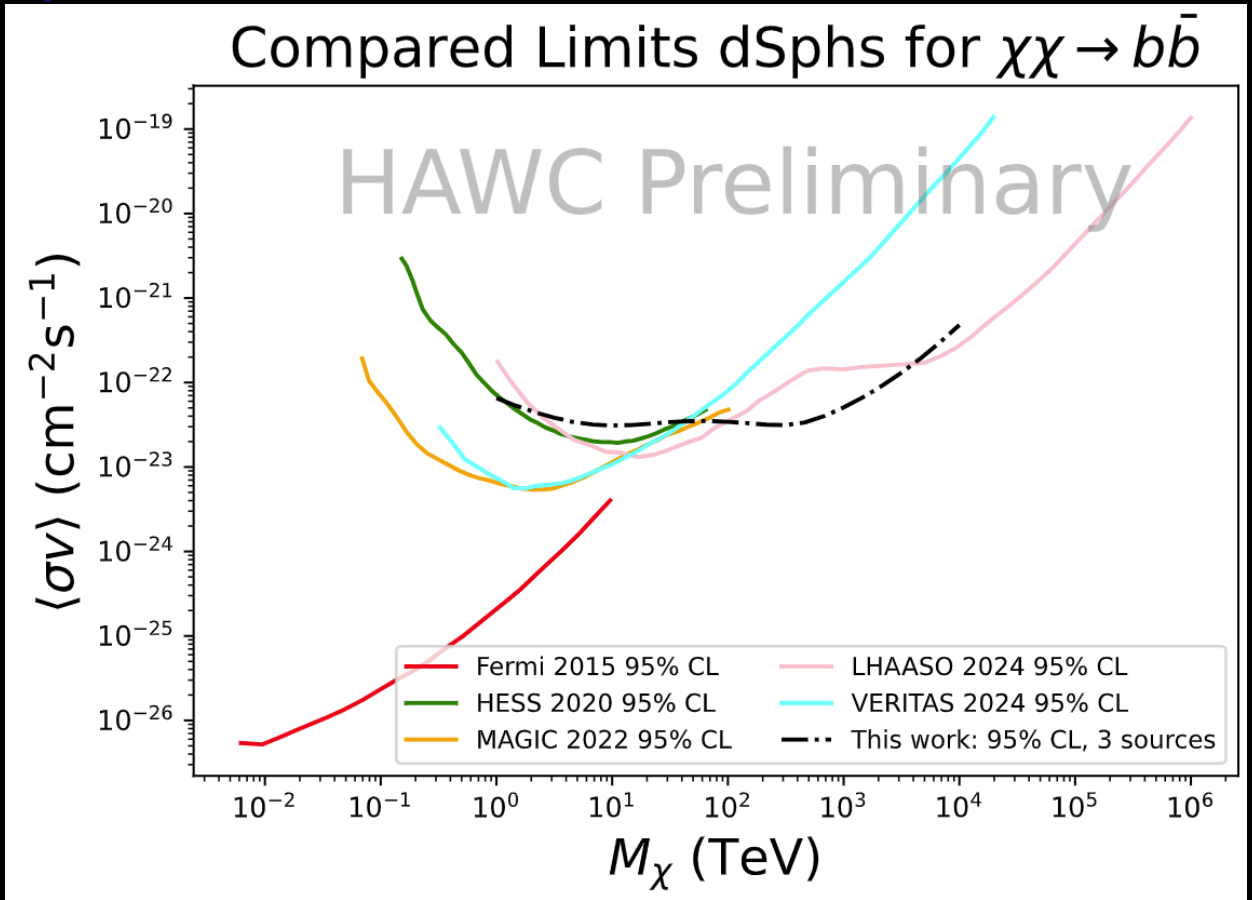
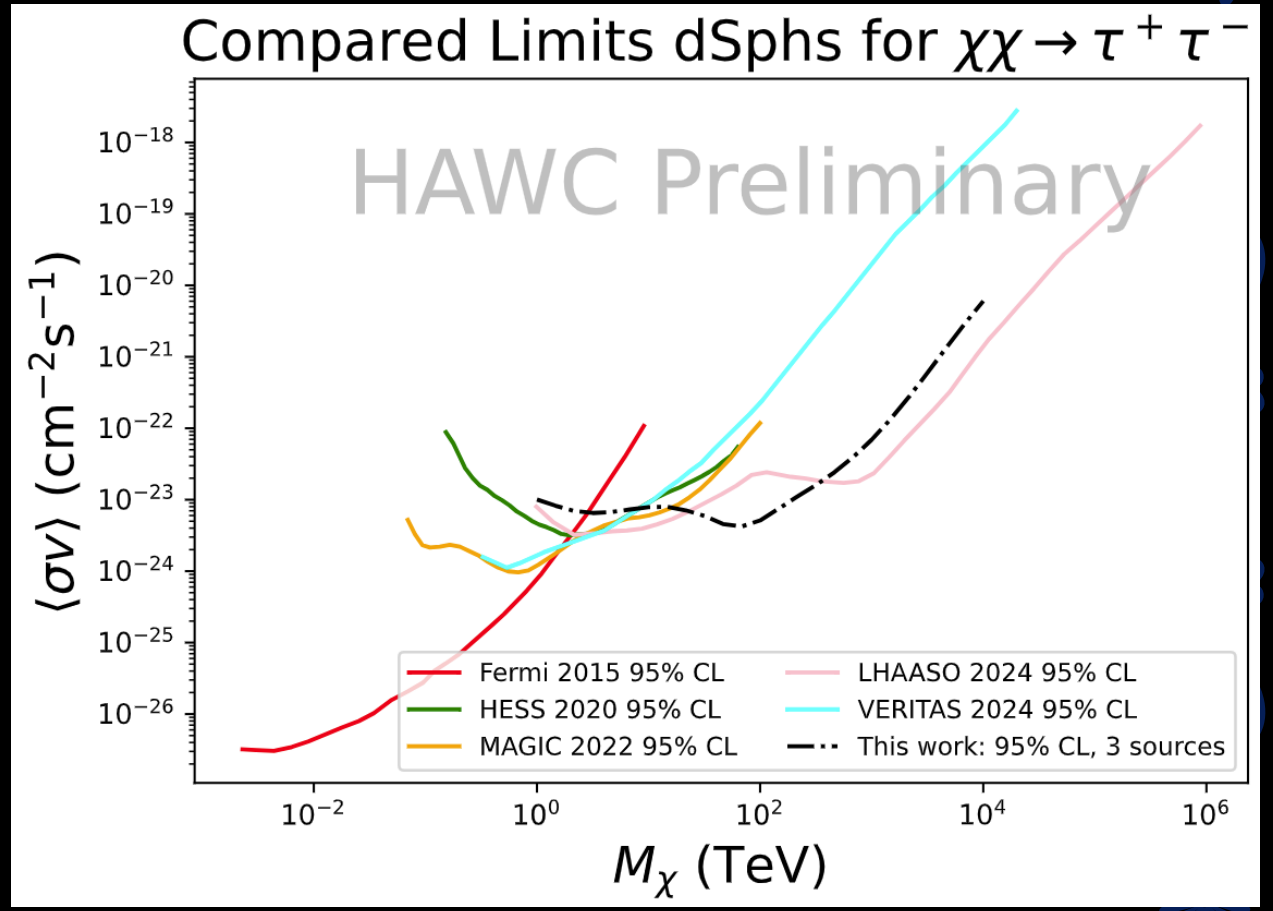
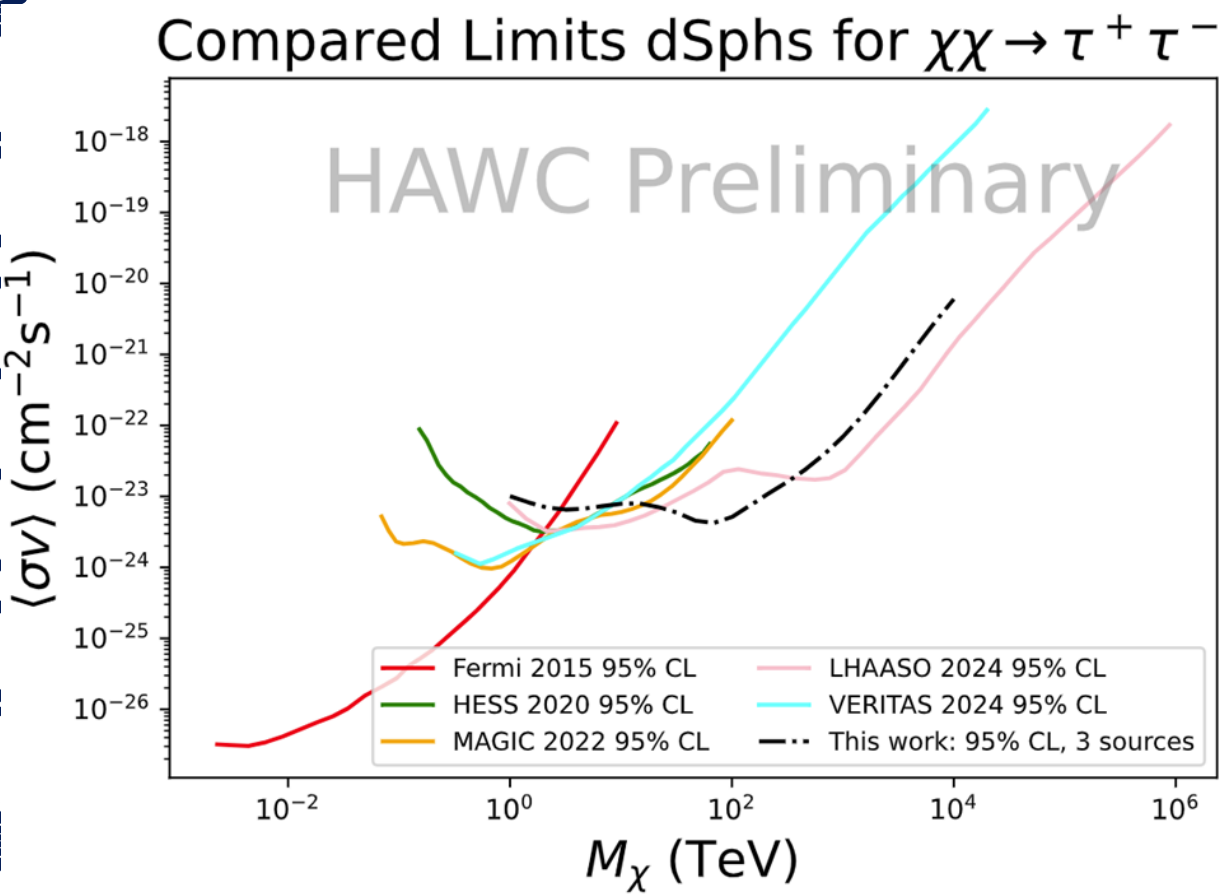
Sensitivities Compared





Avoid higher mass because of large theoretical uncertainties in the region of our energy sensitivity

HAWC Conclusions



HAWC's revised energy estimation and larger dataset improves its sensitivity to Dark Matter!

We've gained a substantial amount of sensitivity to DM annihilation from dwarf galaxies!

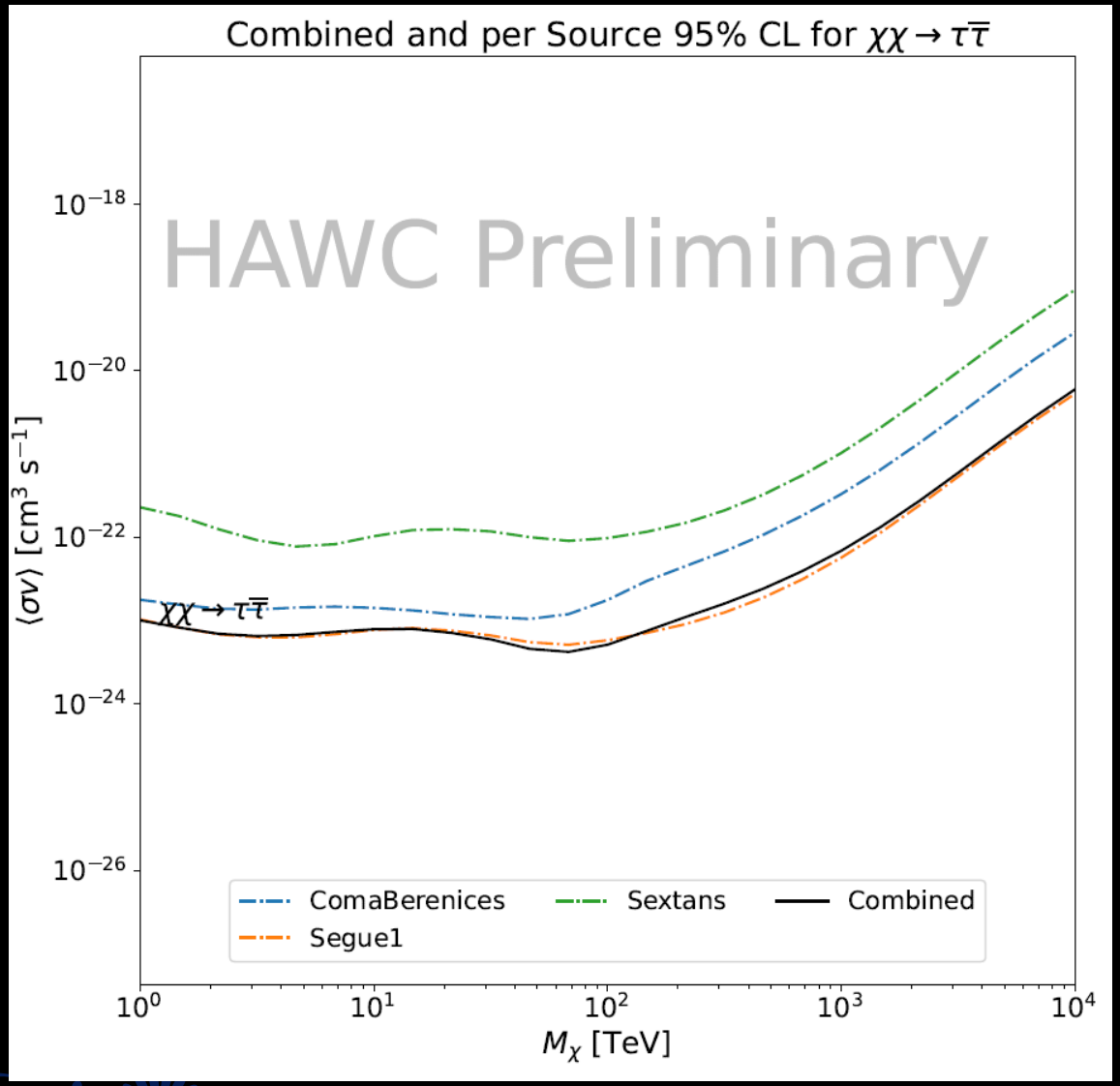
HAWC is most competitive in for 10 – 100 TeV Dark Matter.

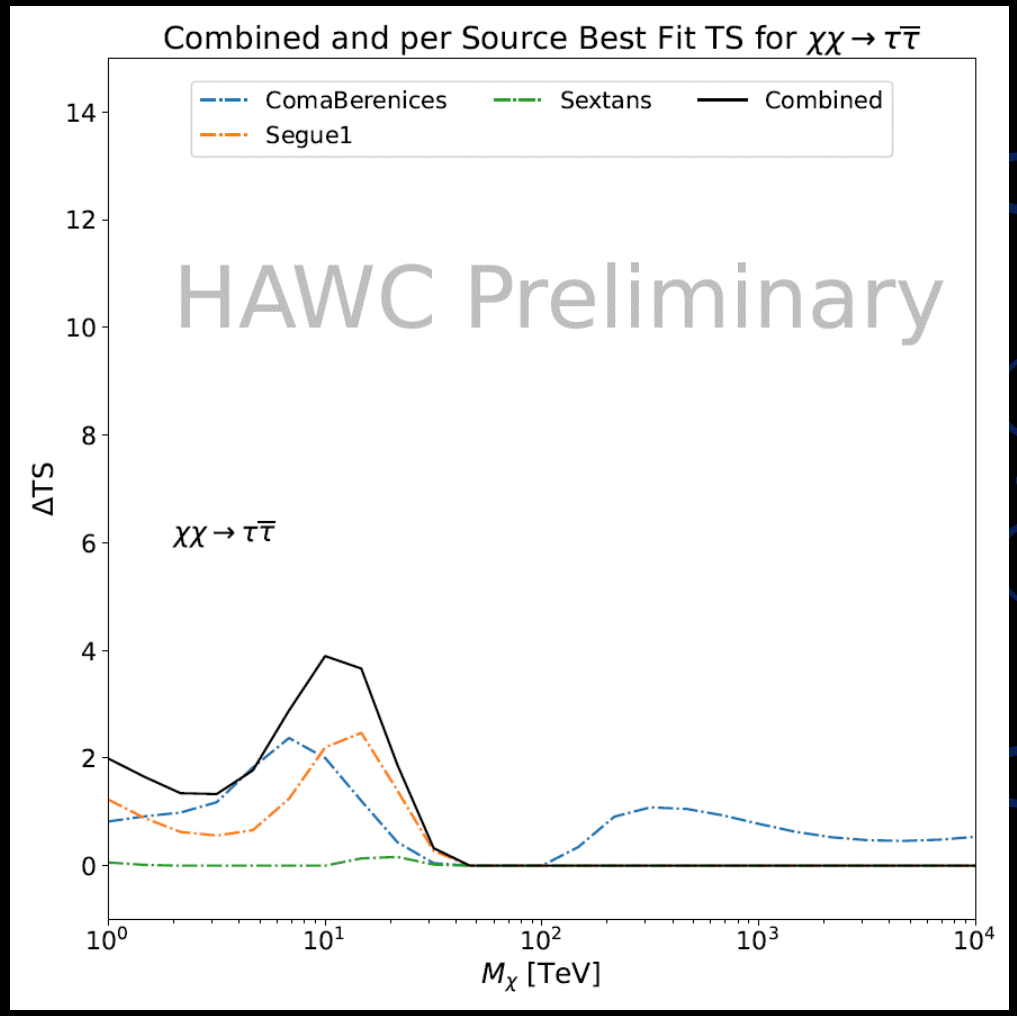
HAWC can probe very heavy Dark Matter at PeV mass scales.

Stay Tuned for a publication!

Backup

Updated Limits





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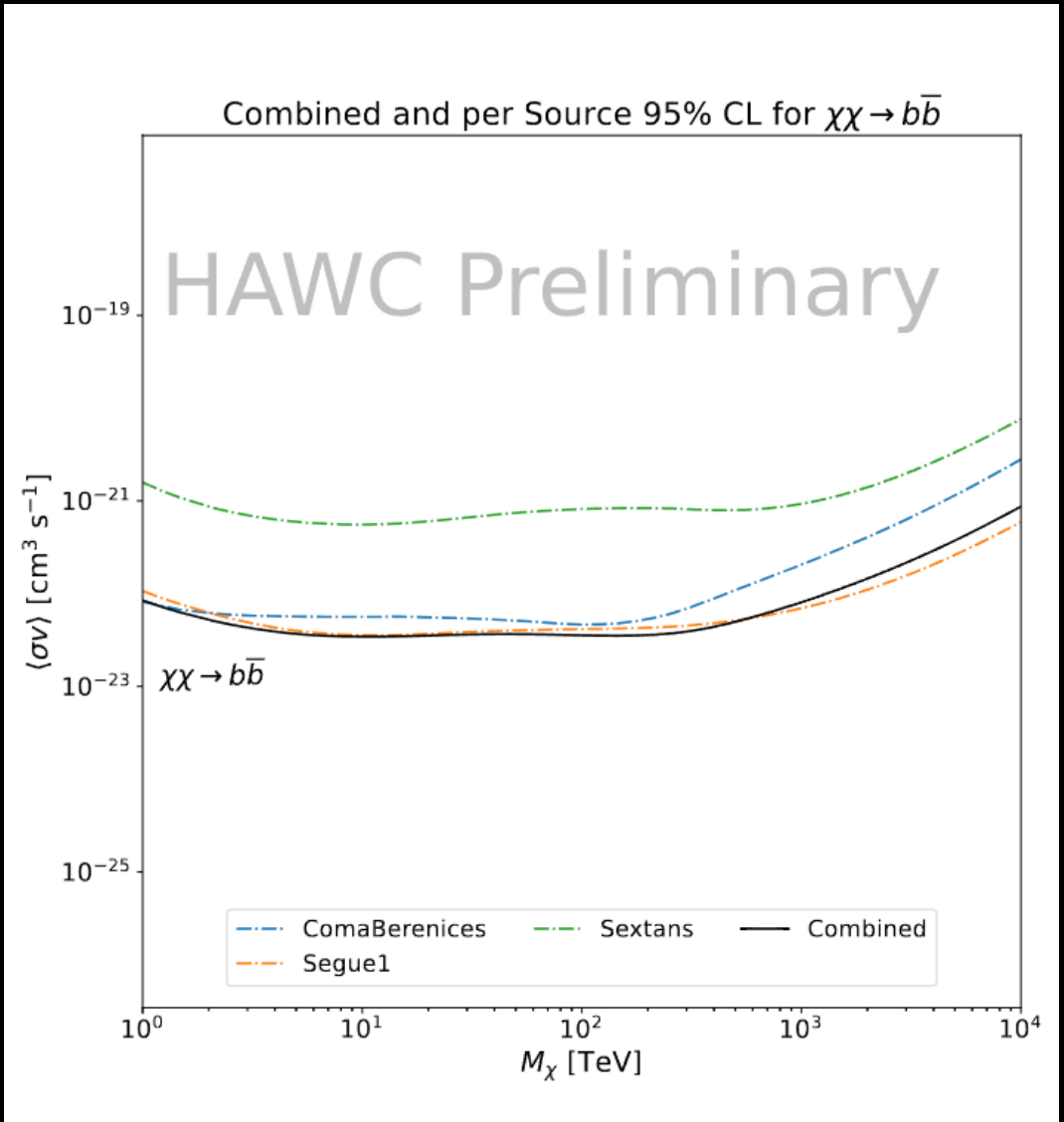
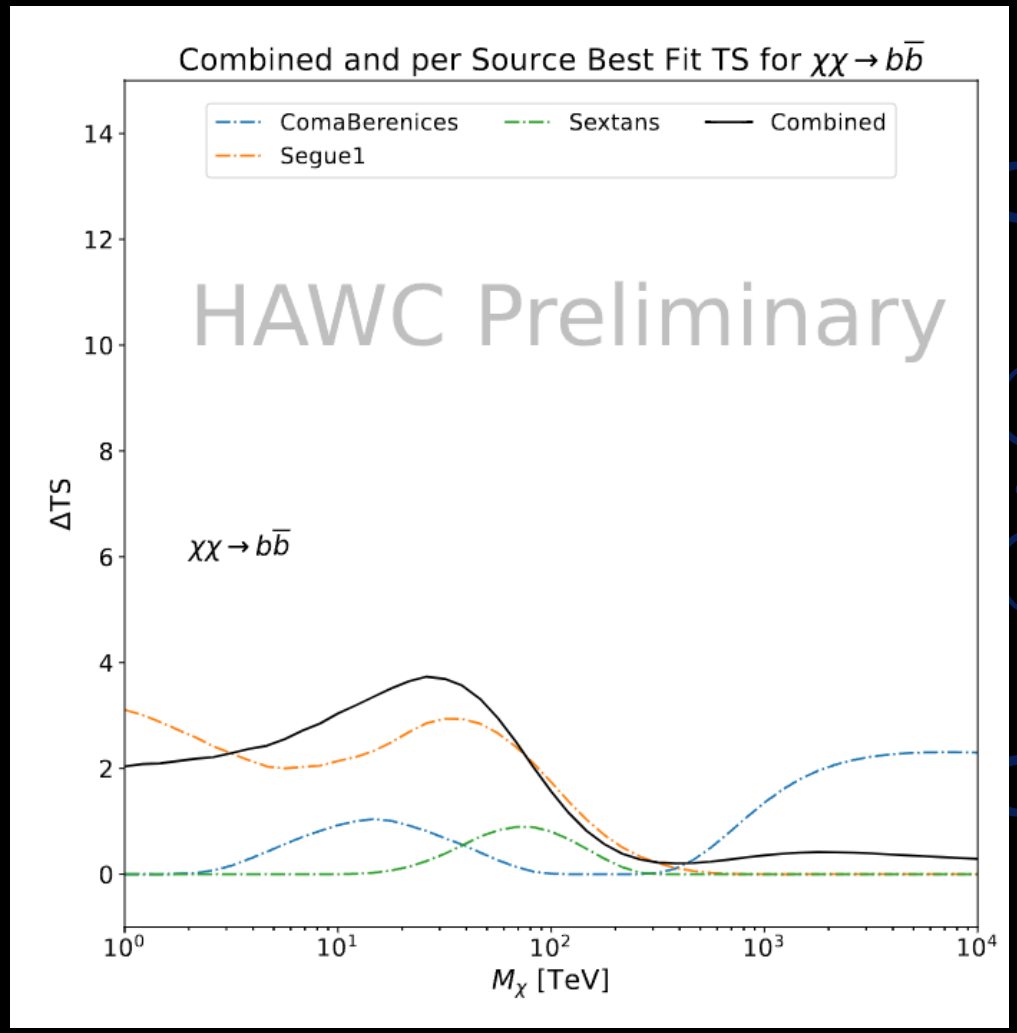
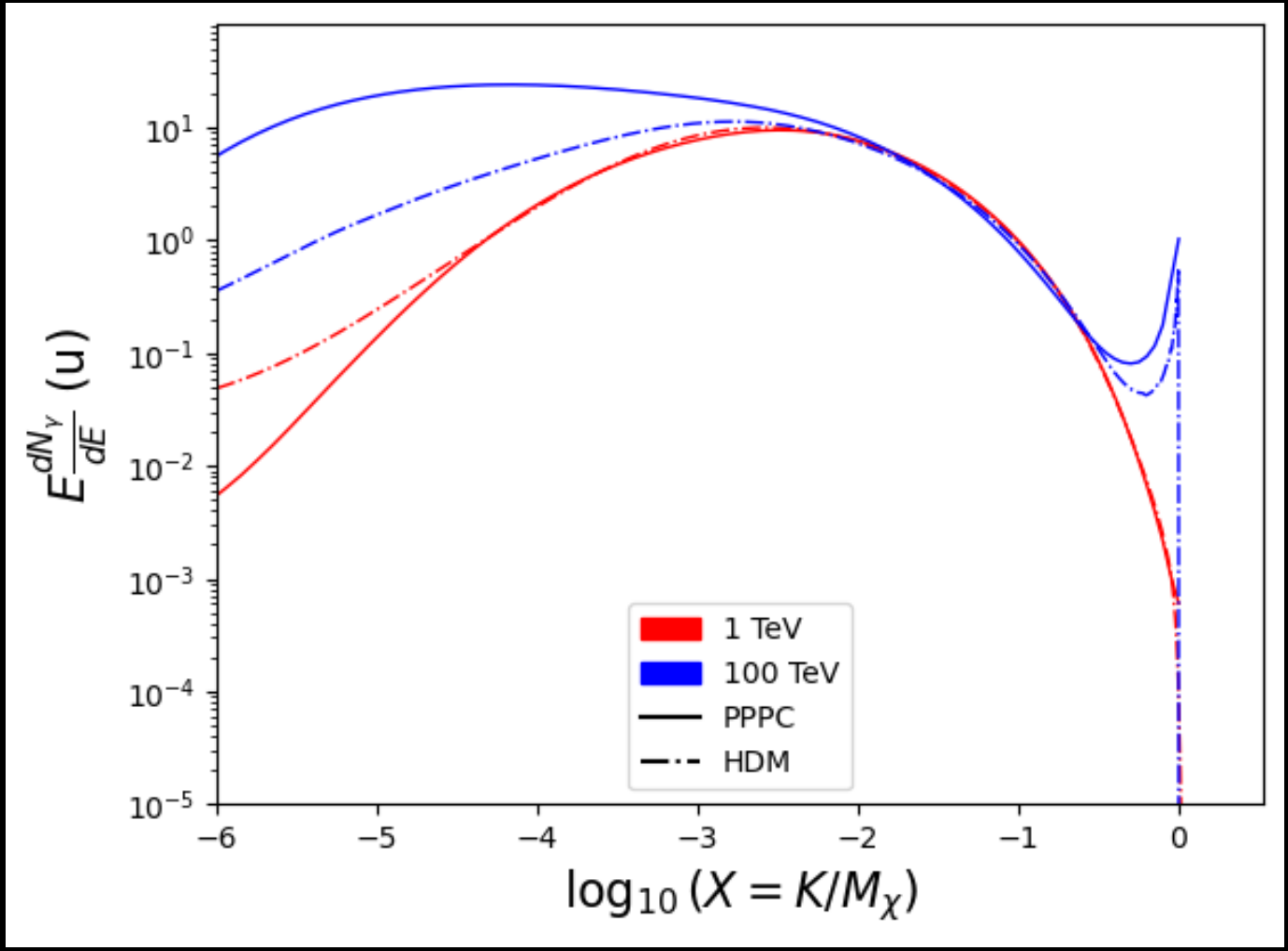




New Spectral Models (HDMSpectra)

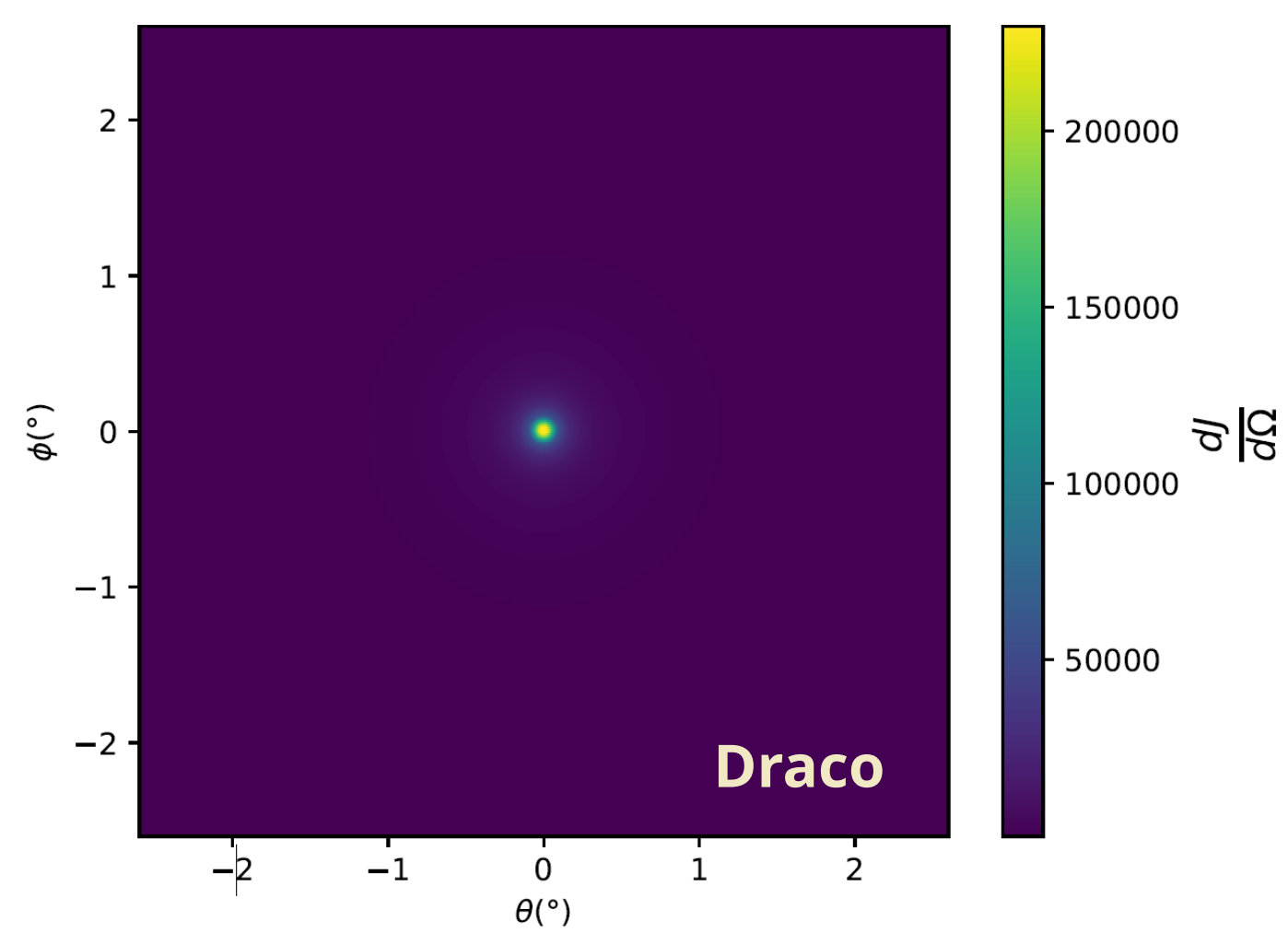


The summary is that Nick Rodd et. al. built upon the PPPC so that it better models neutrinos and the weak sector.

This changes many spectral models in all messengers including gamma. (XX -> ee being an exception)

Modeling is better for 1 TeV + dark matter masses.

New Spatial Models (Strigari 2020)



Now using an updated list of dwarf spheroidal dark matter distributions from Louis Strigari 2020.

Catalog has up to 40 sources. ~20 are in HAWC's FOV

Spatial profiles use a standard NFW profile and scales each dwarf according to distance, apparent brightness and more.

Shown left is Draco from his publication.