Dark Matter and Multiwavelength Gamma-Rays

Fermi/HAWC/VERITAS Workshop

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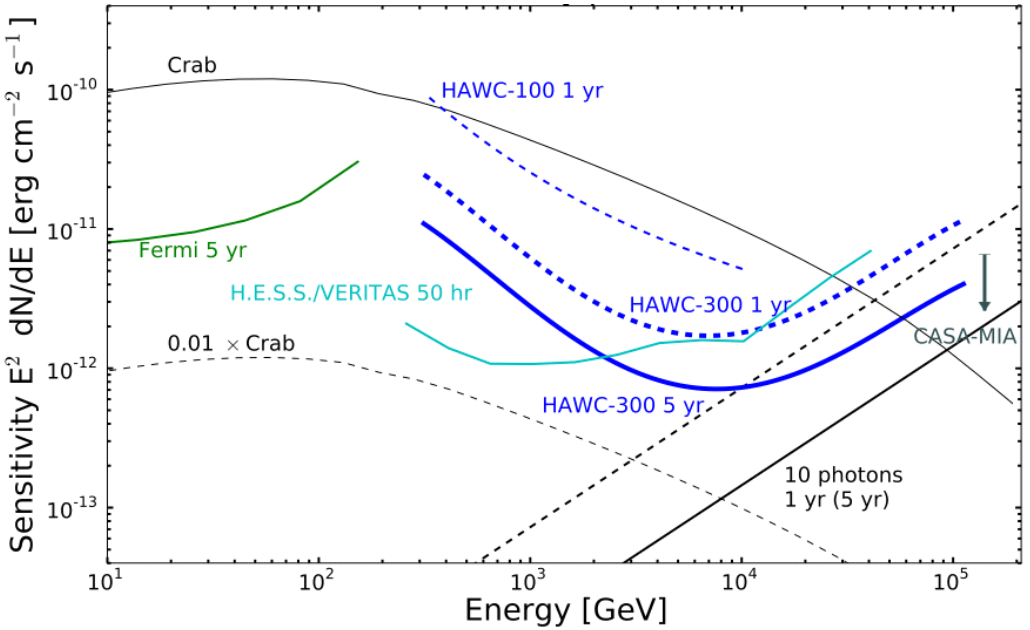
Complementary Observatories

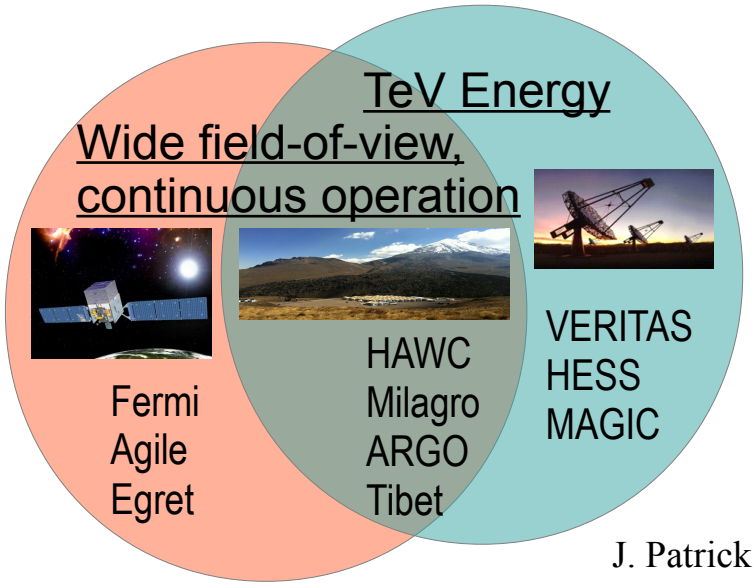


1) Combined Limits

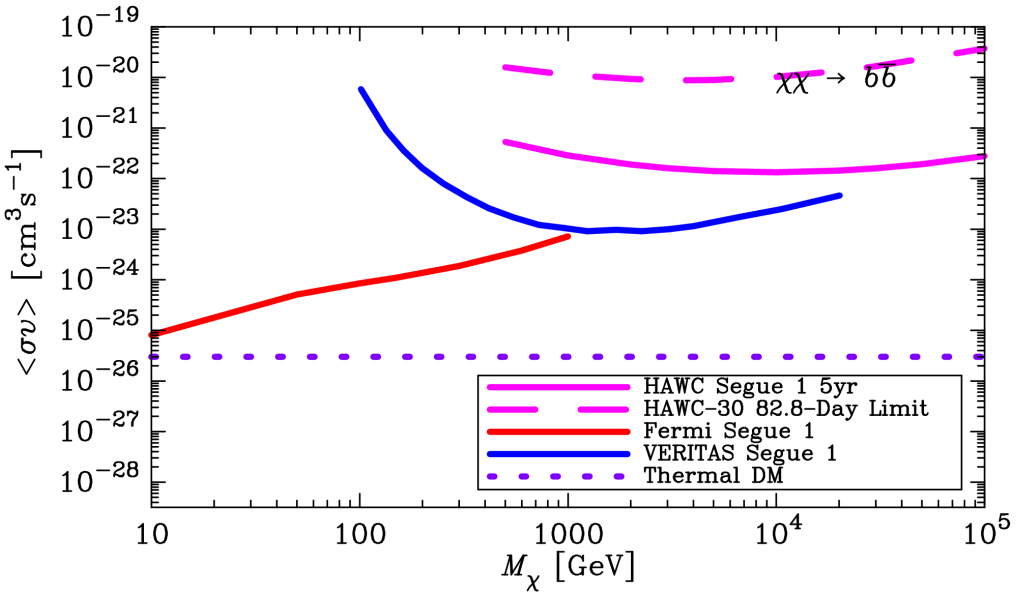
2) Combined Detections

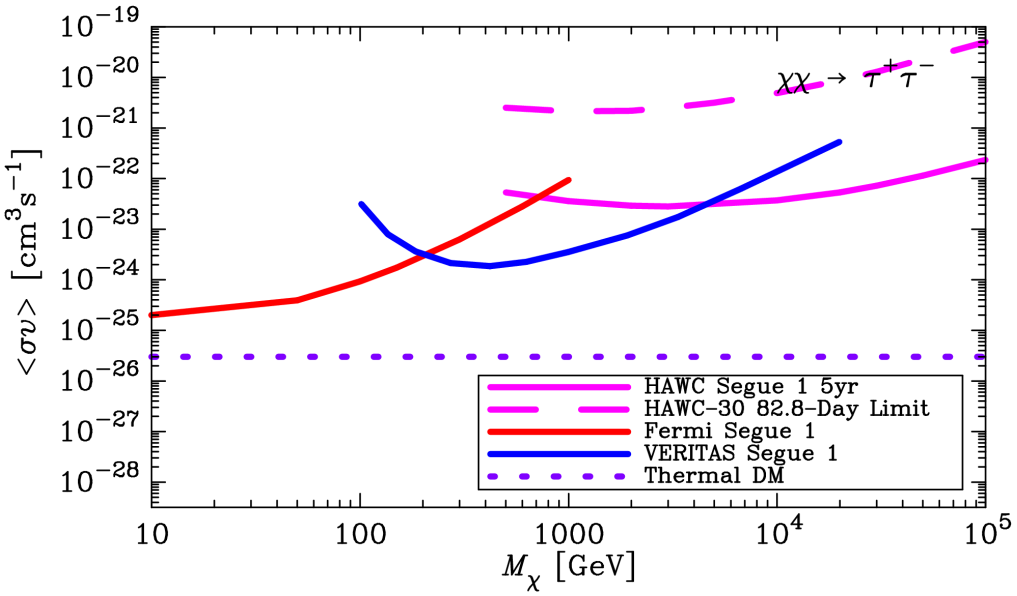
a) Spectral

b) Spatial



Comparison of the Limits on Segue 1

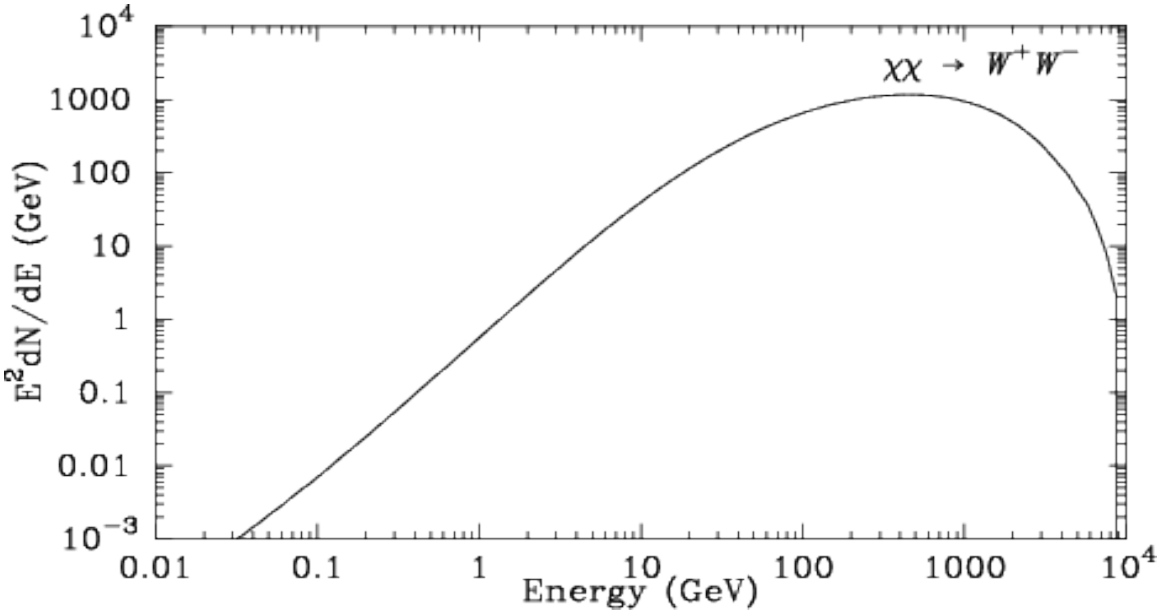




Independently, each experiment is sensitive to a few orders of magnitude in DM mass

Combined Limits 1: DM has a Flat Spectrum

- Bosonic and hadronic DM channels have a flat spectrum
- Flux greater than 1% of peak over 3 orders of magnitude



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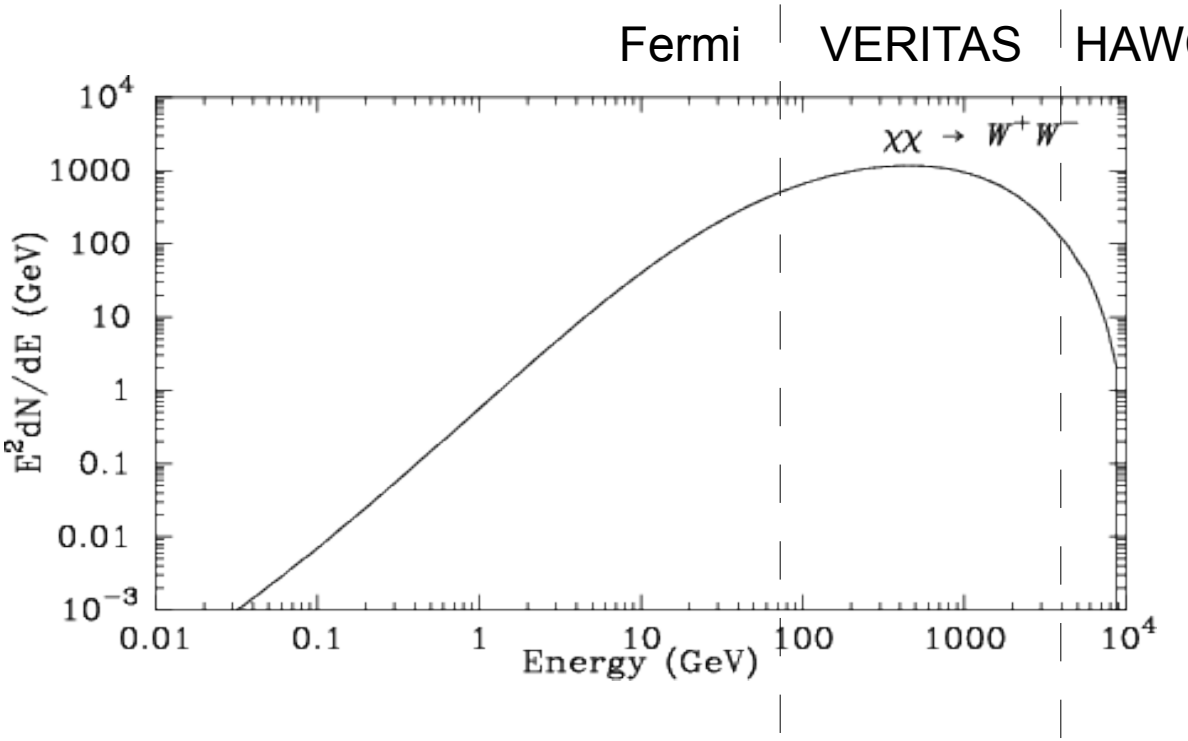
- Spans all 3 experiments' optimal energies



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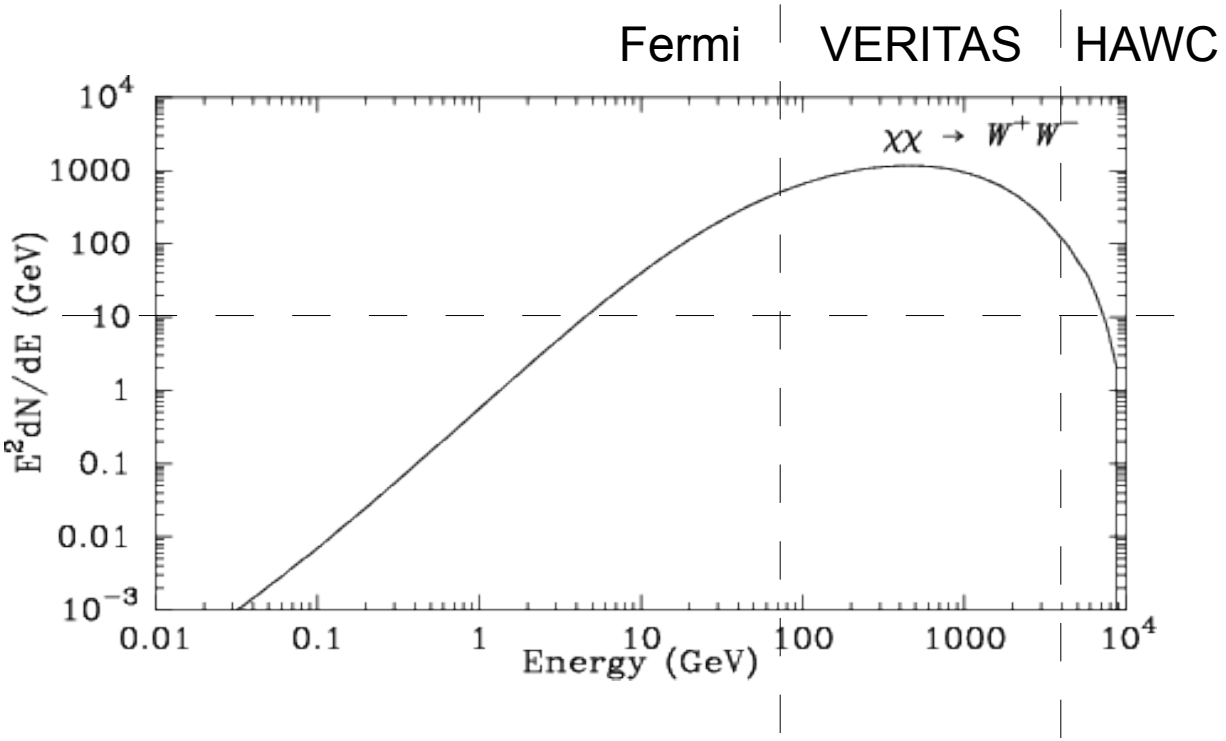
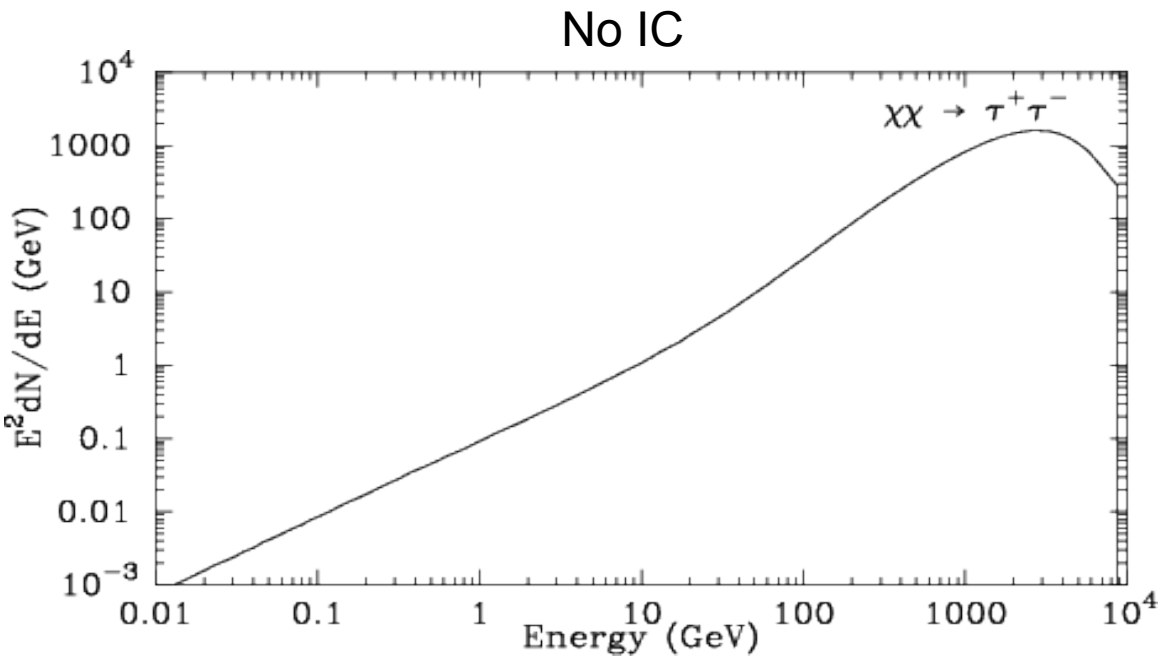


Together, we can improve our DM sensitivity

Combined Limits 2: IC Flattens the Spectrum

- Electrons, positrons, etc scatter off low-E photons to give secondary gammas
- Makes the spectra even flatter in energy
  - All the better for multi-wavelength



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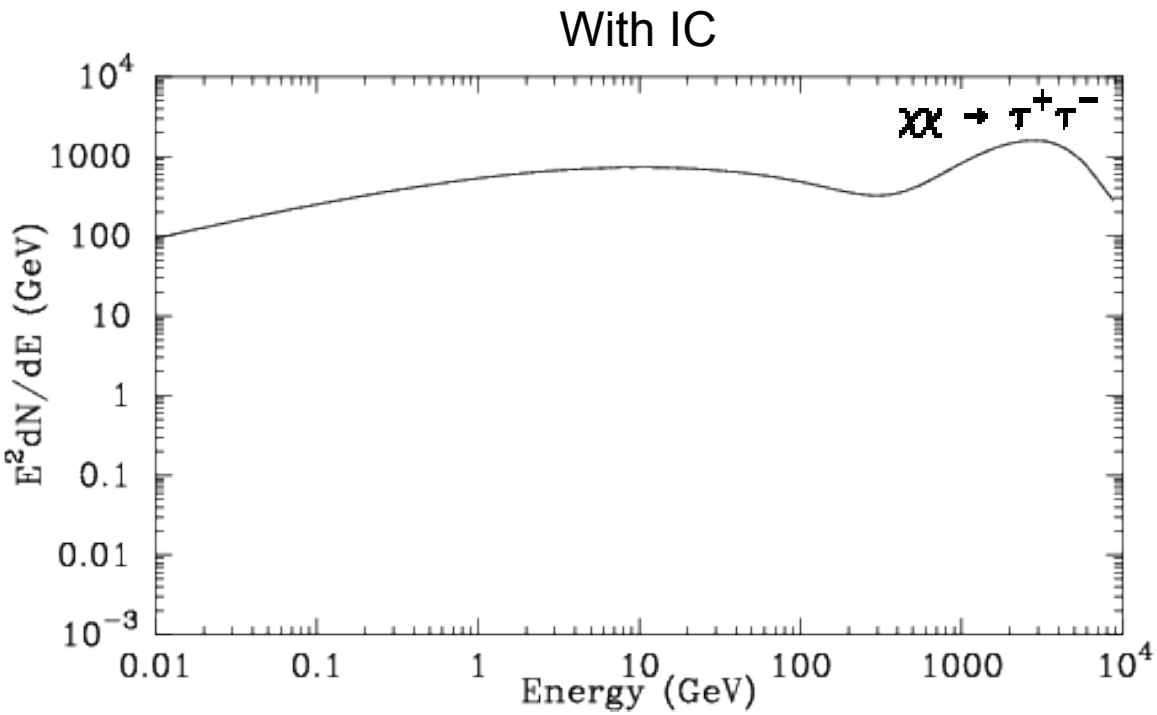


Searching for DM 1: The Case for TeV WIMPs

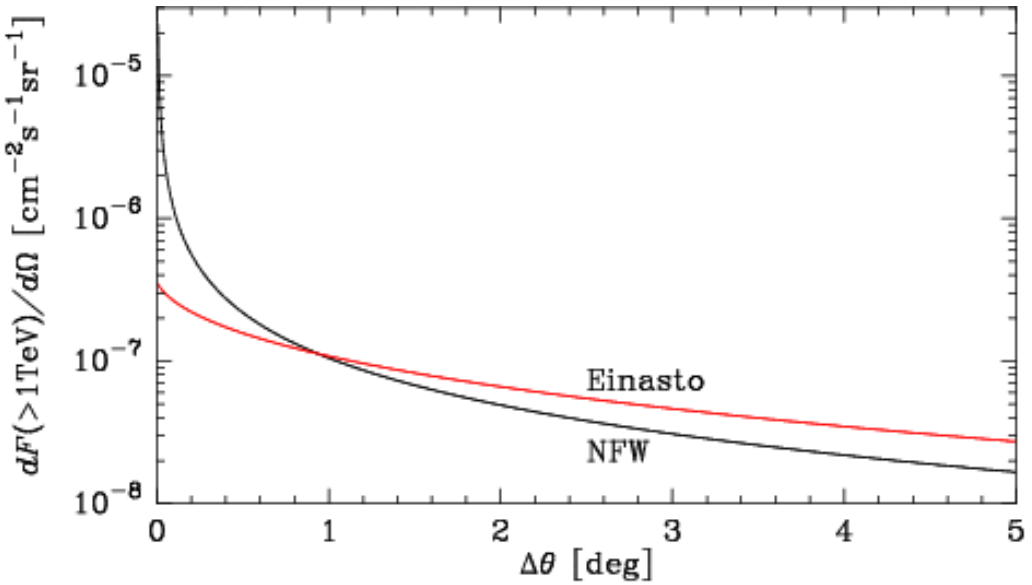
- As the LHC keeps ruling out GeV-mass WIMPs and liquid xenon detectors have no detections, higher masses become more favorable
- Kaluza-Klein extra-dimensional theories naturally have a stable multi-TeV WIMP DM candidate
- Indications of a possible multi-TeV WIMP signature in HESS Galactic-center data (Horns, 2004)
- Nearby annihilation of TeV WIMPs could be the cause of the observed small-scale cosmic-ray anisotropy (JPH, 2013)

Searching for DM 2: Spectra

- Dark matter spectra have distinct features
- If Fermi sees the dark matter as a power law, higher-energy follow-ups are needed to determine cutoff and spectral features
- Detailed spectra are the best way to verify that a signal is consistent with dark matter, and the only way to determine the WIMP mass

Searching for DM 3: Spatial Signatures

- Currently, there is great uncertainty in the details of how dark matter forms halos
- If Fermi or HAWC sees a likely WIMP signature, greater spatial resolution is required to understand the morphology of the dark matter halo
- VERITAS observations of a discovered source of DM annihilation will answer many questions about the particle nature of the DM and its interaction with baryons



Searching for DM 4: Paving the Way for the Future

As A.W. Smith said yesterday, through greater understanding of the astrophysical foregrounds, we are doing a part in the discovery of the dark matter as well.

Common Framework

One of the most important things we can do to further multiwavelength studies of WIMPs is to use a common analysis framework

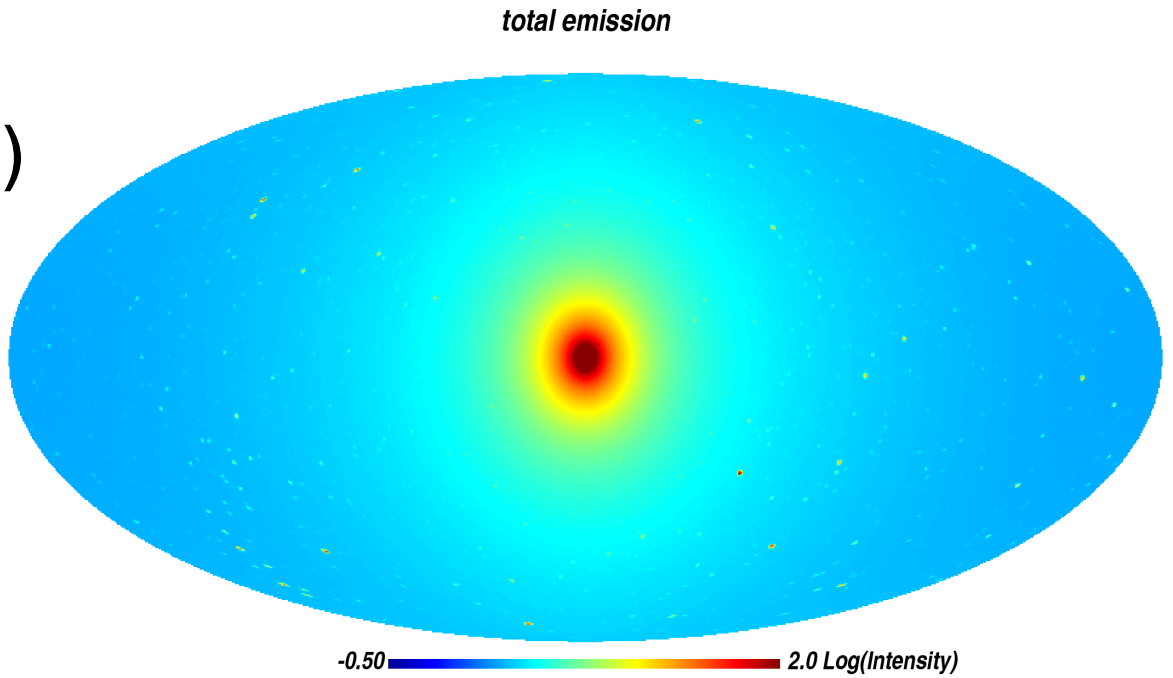
- Same DM channels
- Same spectra for each channel
- Same spatial profiles for each source
- Consistent use of DM substructure

With a common framework, all these experiments will benefit from each other.

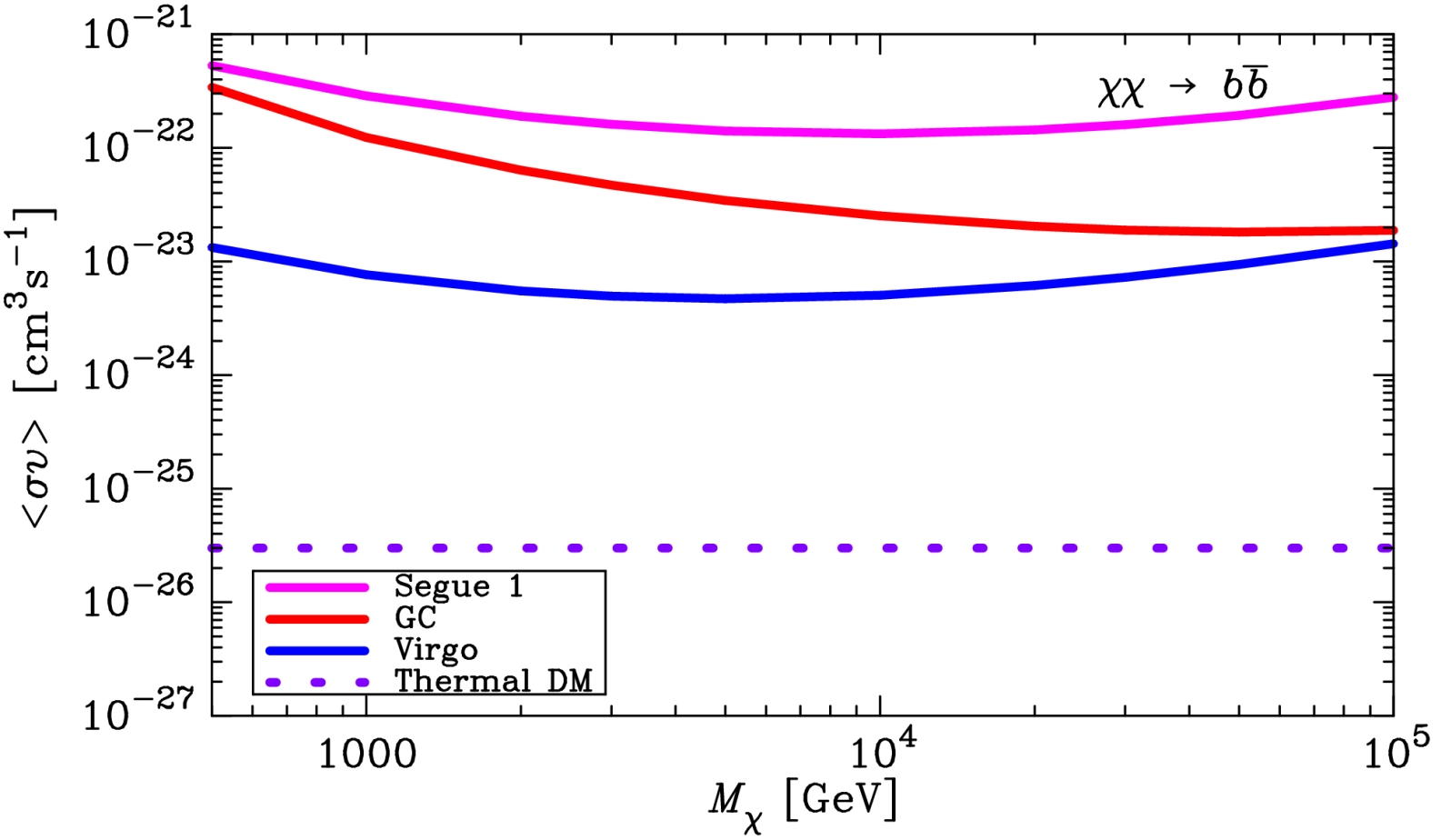
HAWC DM
What Does HAWC Bring to the Party?

HAWC DM Sources

- Dwarf Galaxies
  - Draco, Coma Berenices, Segue 1, ...
- Galaxies
  - M31 (Andromeda)
- Galaxy Clusters
  - Virgo Cluster, ...
- Galactic Center
  - NFW profile
  - Einasto profile

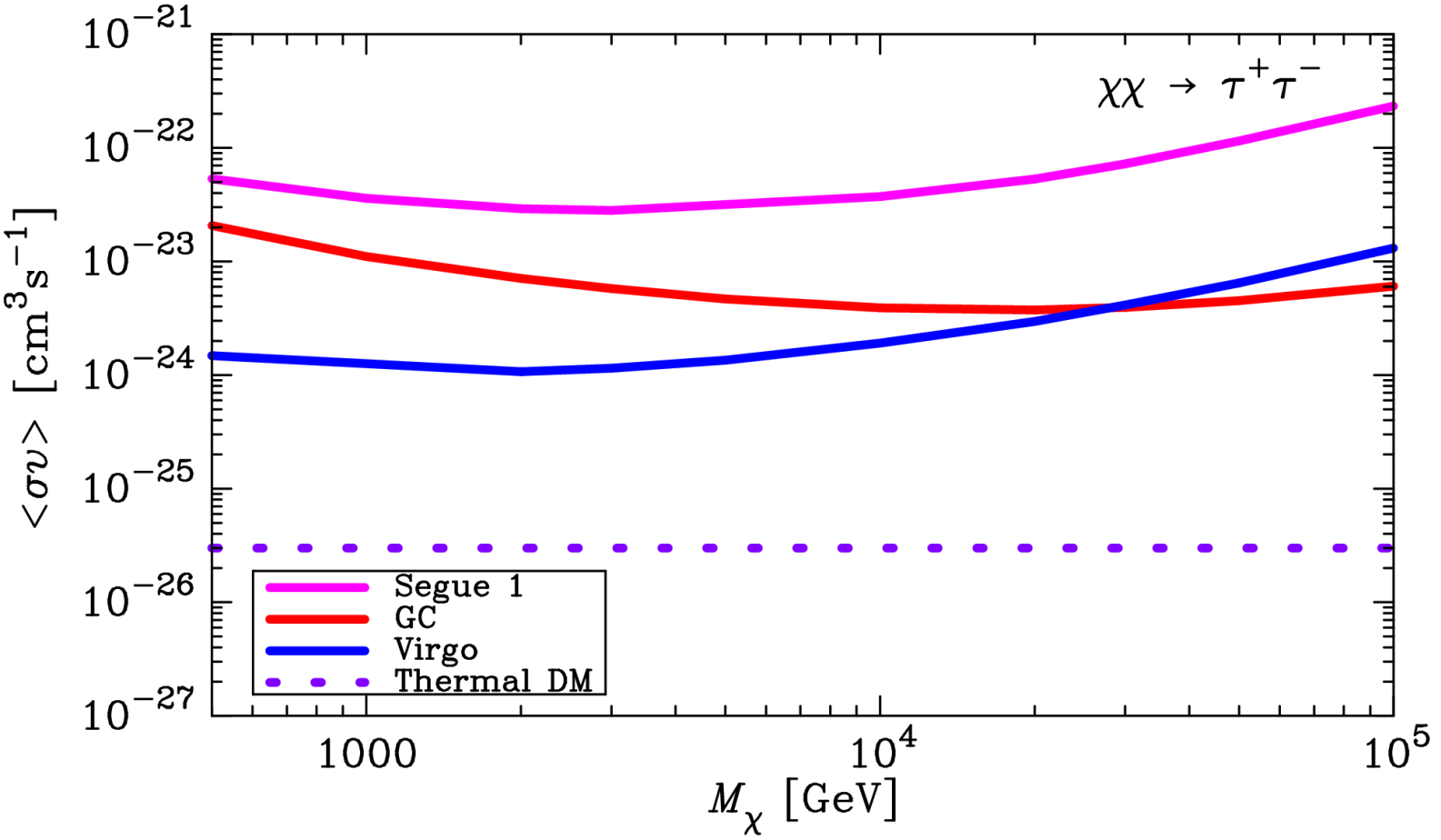


HAWC $b\bar{b}$



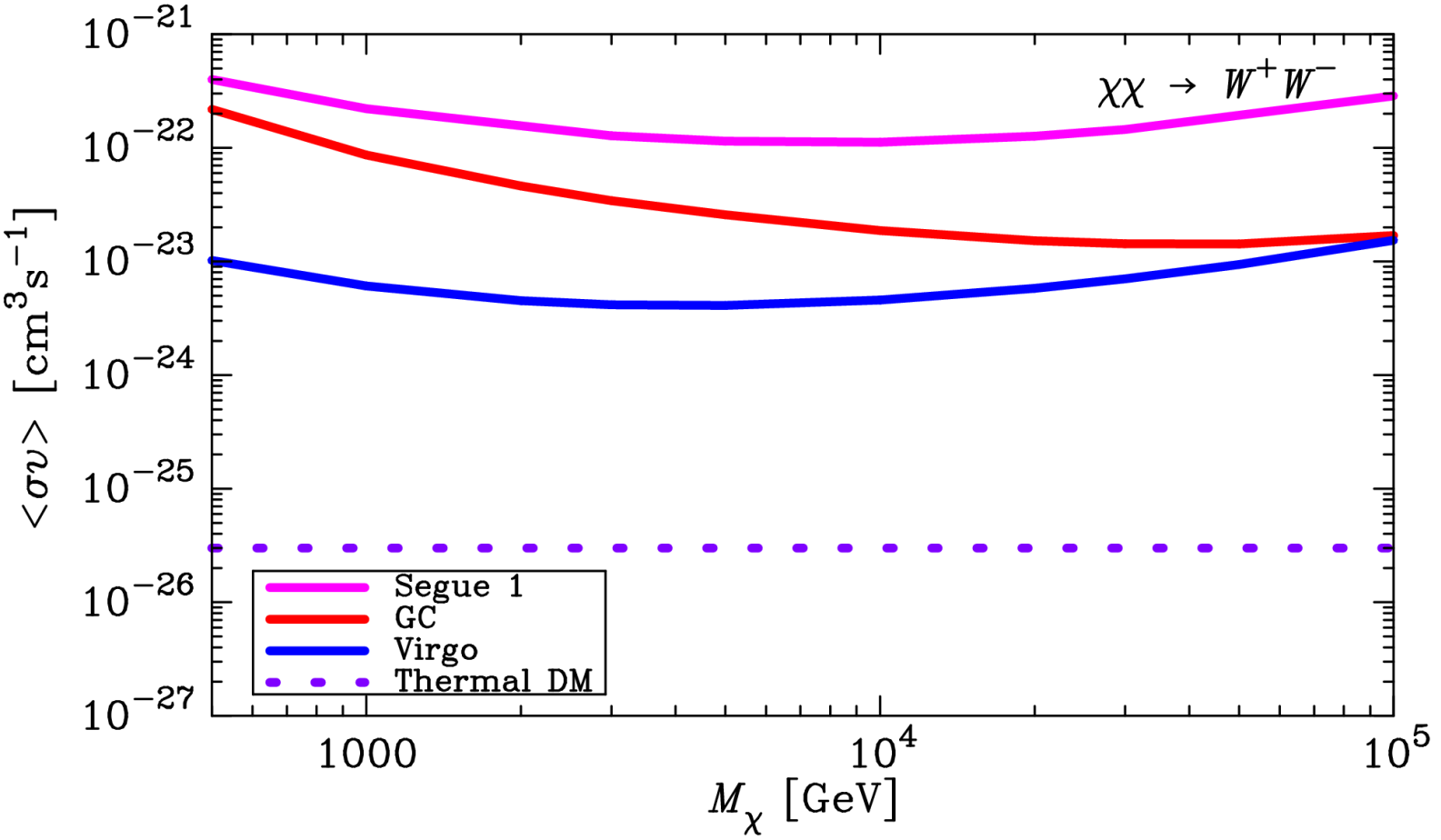
The expected HAWC 5-year limits for the $b\bar{b}$ channel for the Segue 1 dwarf galaxy, Galactic center with an Einasto profile, and Virgo cluster.

HAWC $\tau^+\tau^-$



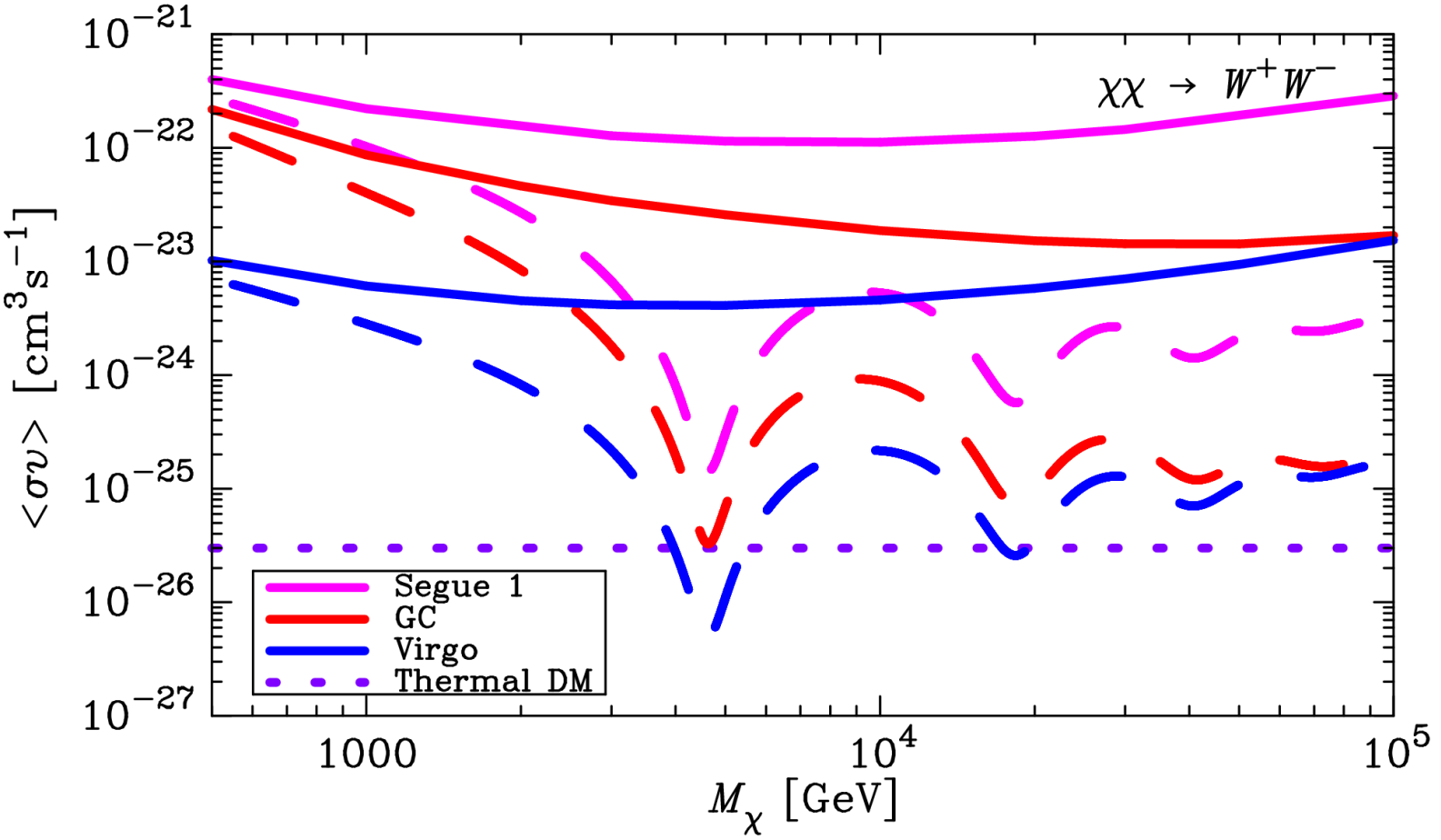
The expected HAWC 5-year limits for the $\tau^+\tau^-$ channel for the Segue 1 dwarf galaxy, Galactic center with an Einasto profile, and Virgo cluster.

HAWC W^+W^-



The expected HAWC 5-year limits for the W^+W^- channel for the Segue 1 dwarf galaxy, Galactic center with an Einasto profile, and Virgo cluster.

HAWC W^+W^-



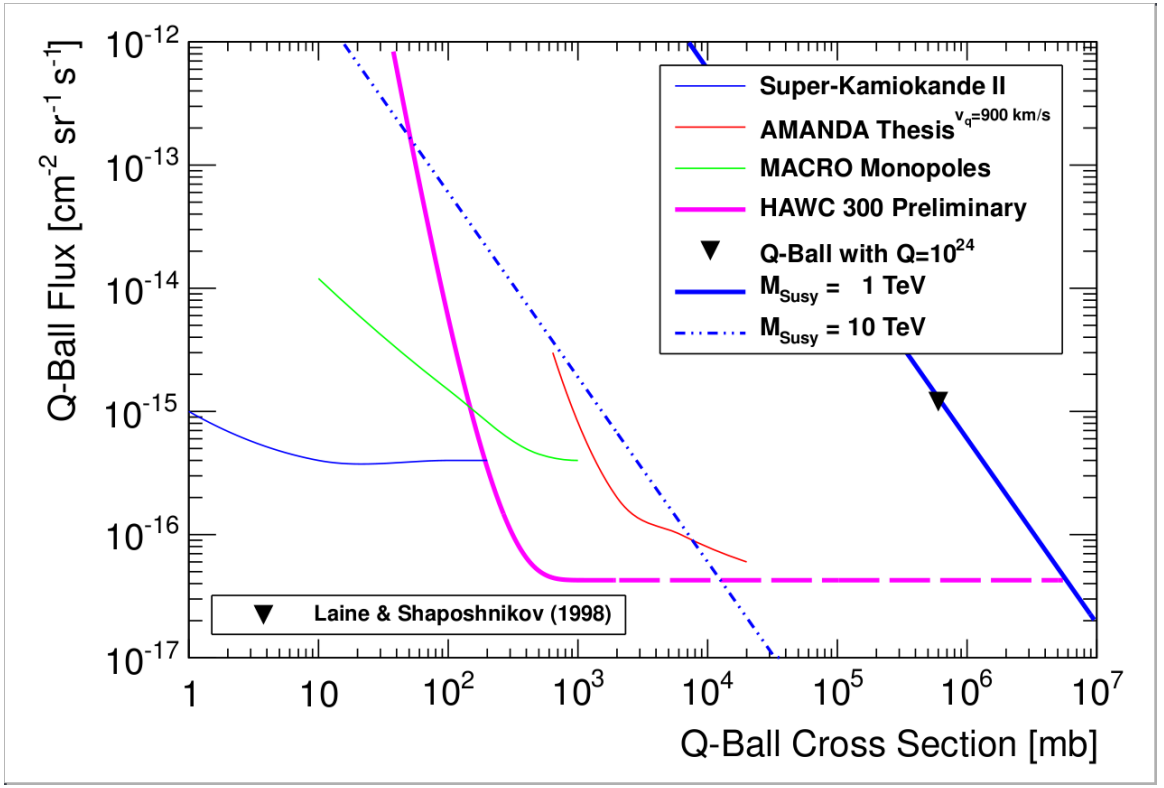
The expected HAWC 5-year limits for the W^+W^- channel for the Segue 1 dwarf galaxy, Galactic center with an Einasto profile, and Virgo cluster, including the natural Sommerfeld enhancement from DM exchange of SM gauge bosons.

Additional HAWC WIMP DM Searches

- Stacked dwarf spectra
- Stacked cluster spectra
- Diffuse gamma-ray background
- Search for DM source of AMS-02 anomaly (in $\mu^+\mu^-$ channel)
- Search for inverse Compton emission from charged products of DM annihilation
- Dark matter decay
- Undetected dwarf galaxies
- Cosmic-ray channels

HAWC Non-WIMP DM Searches – Q-Balls

- Relic DM from the early universe
- Predicted in SUSY
- Slow-moving, massive, strong interacting
- HAWC can be used as direct DM detector



HAWC Non-WIMP DM Searches – PBHs