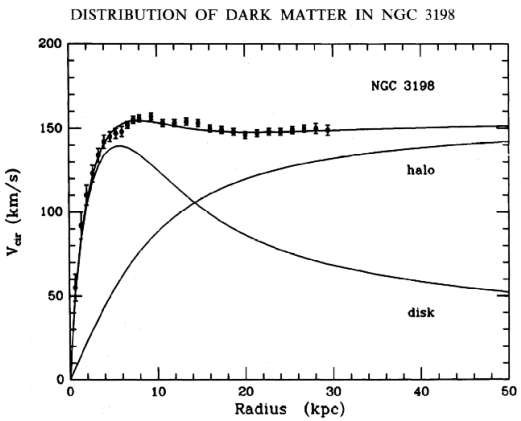
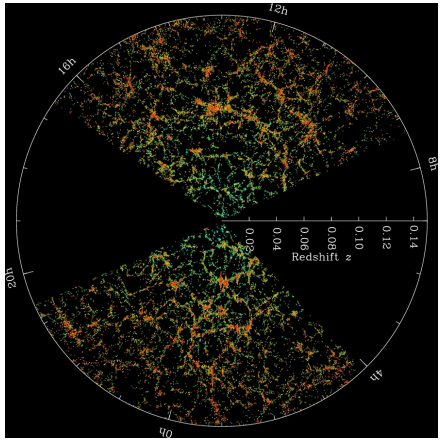
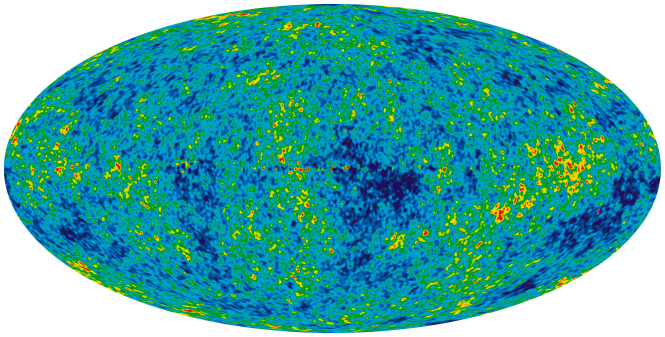
The Search for Dark Matter with the HAWC Observatory



J. Patrick Harding
LANL
12 September 2013

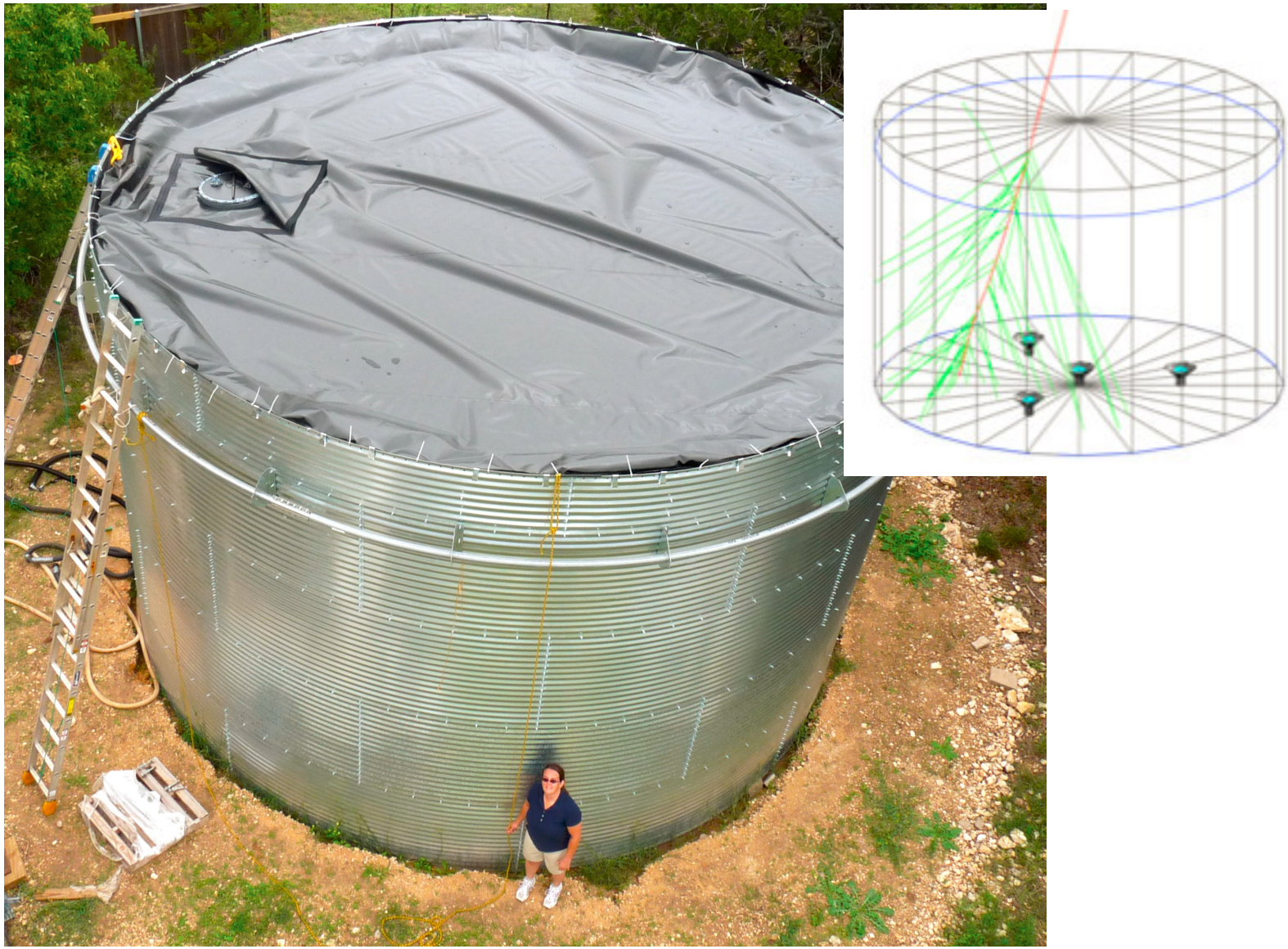




HAWC

Altitude: 4100 m (13000 ft) Latitude: 19° N

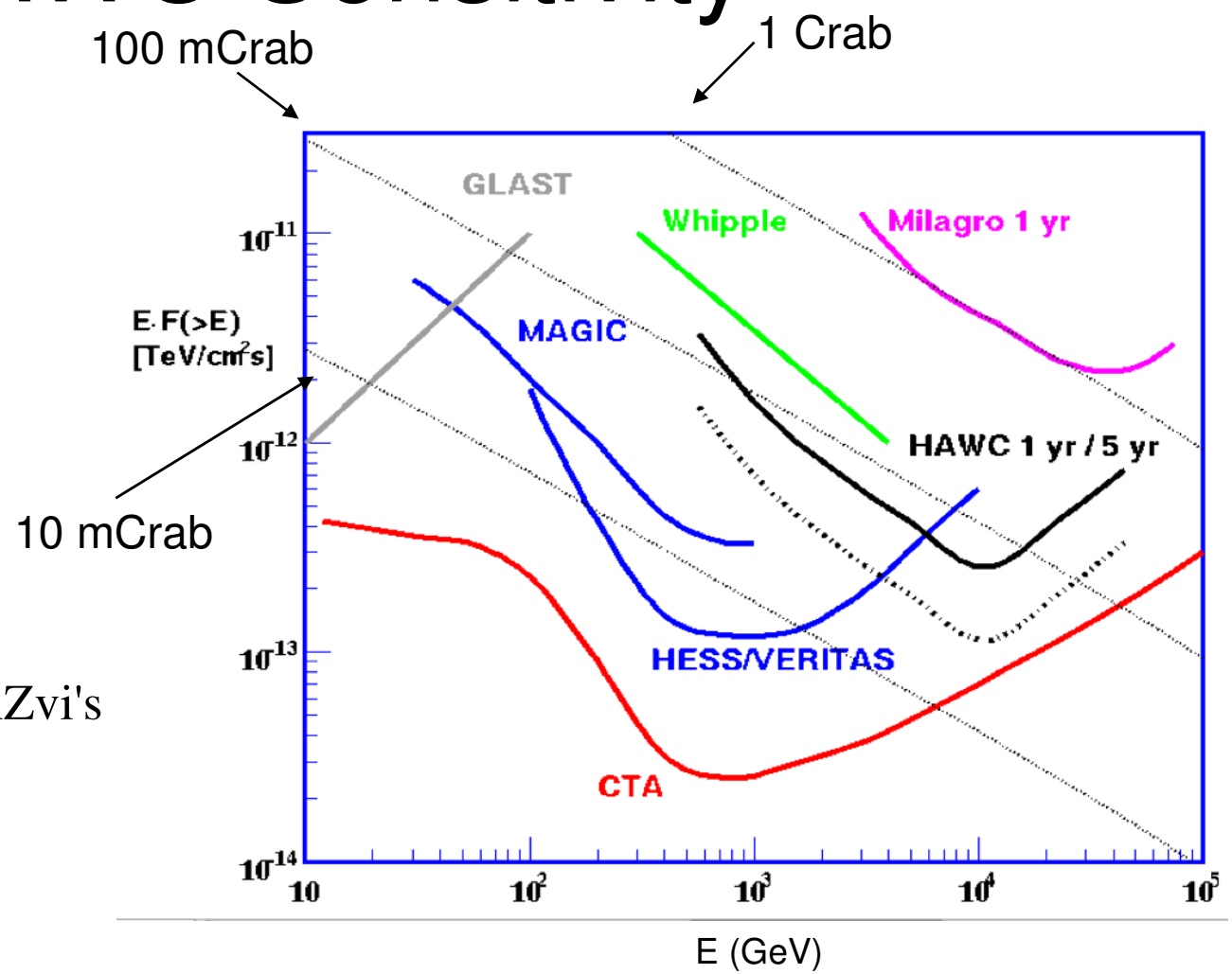
Water Cherenkov Detectors



Slide: J. Pretz

HAWC Sensitivity

- Angular Resolution:
  ~0.1º – 1.0º
- Field-of-view:
  2 sr (2/3 sky each day)
- Effective Area:
  22500 m^2
- Sensitivity:
  ~ Crab @ 5σ each day
- For more details, see S. BenZvi's talk (16:20 Today)



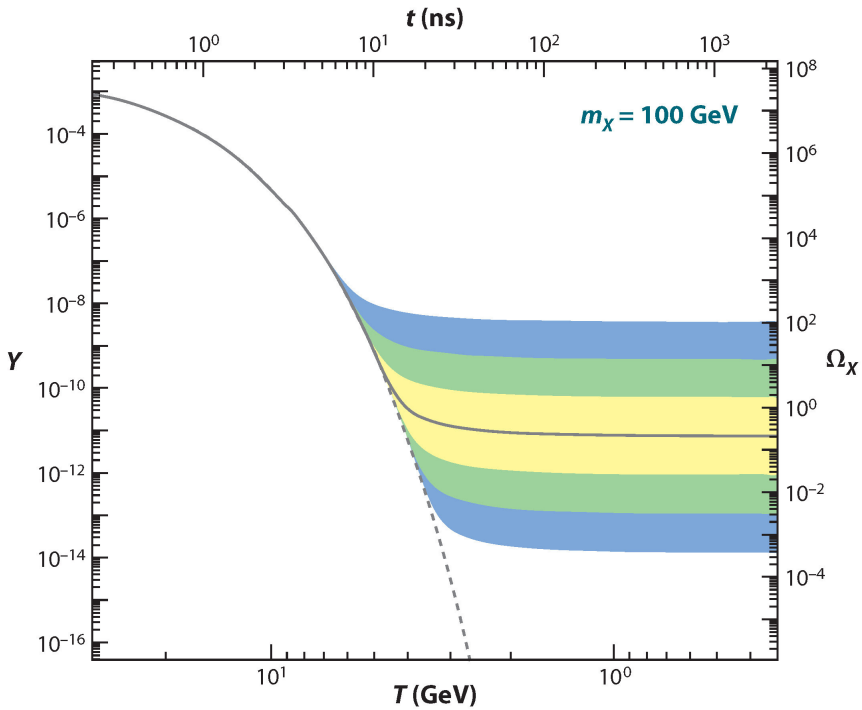
Annihilating WIMP Dark Matter

For s - wave thermal relic cold dark matter :

$$\Omega_{\mathrm{CDM}} h^2 \approx \frac{3\times10^{-25}\ \mathrm{cm^3 s^{-1}}}{\langle \sigma v \rangle}$$

$$\Omega_{\mathrm{CDM}} h^2 = 0.1196 \pm 0.0031 \ \text{(Ade et al. 2013)}$$

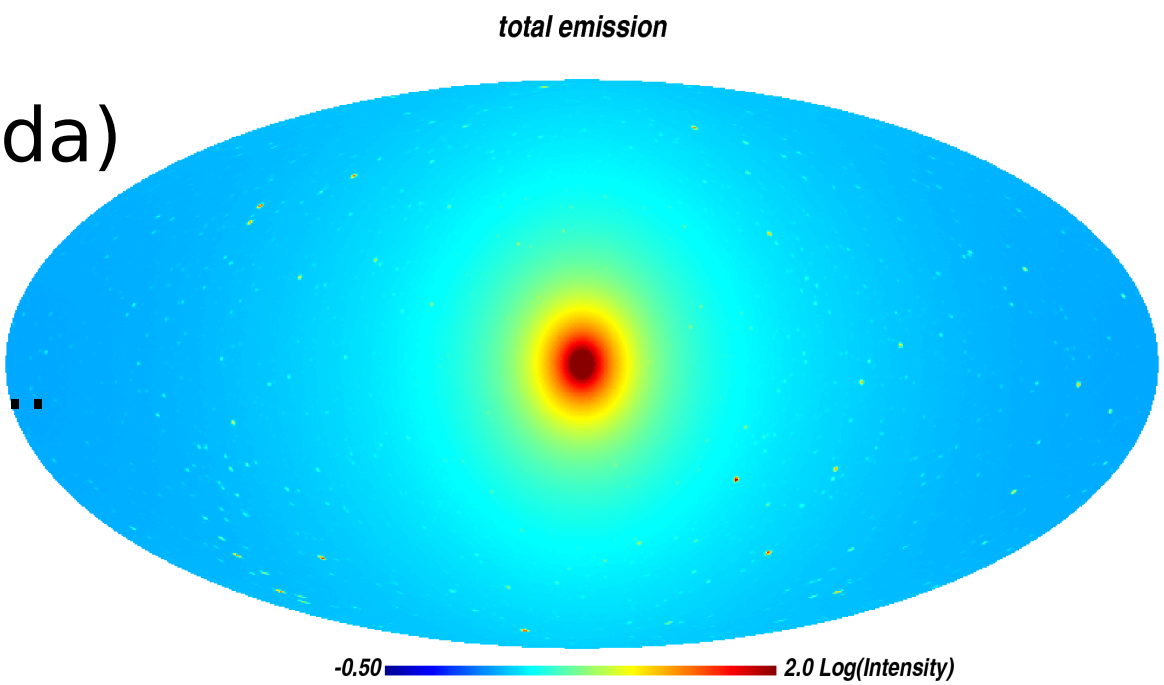
$$\langle \sigma v \rangle \approx 3\times10^{-26}\ \mathrm{cm^3 s^{-1}}$$



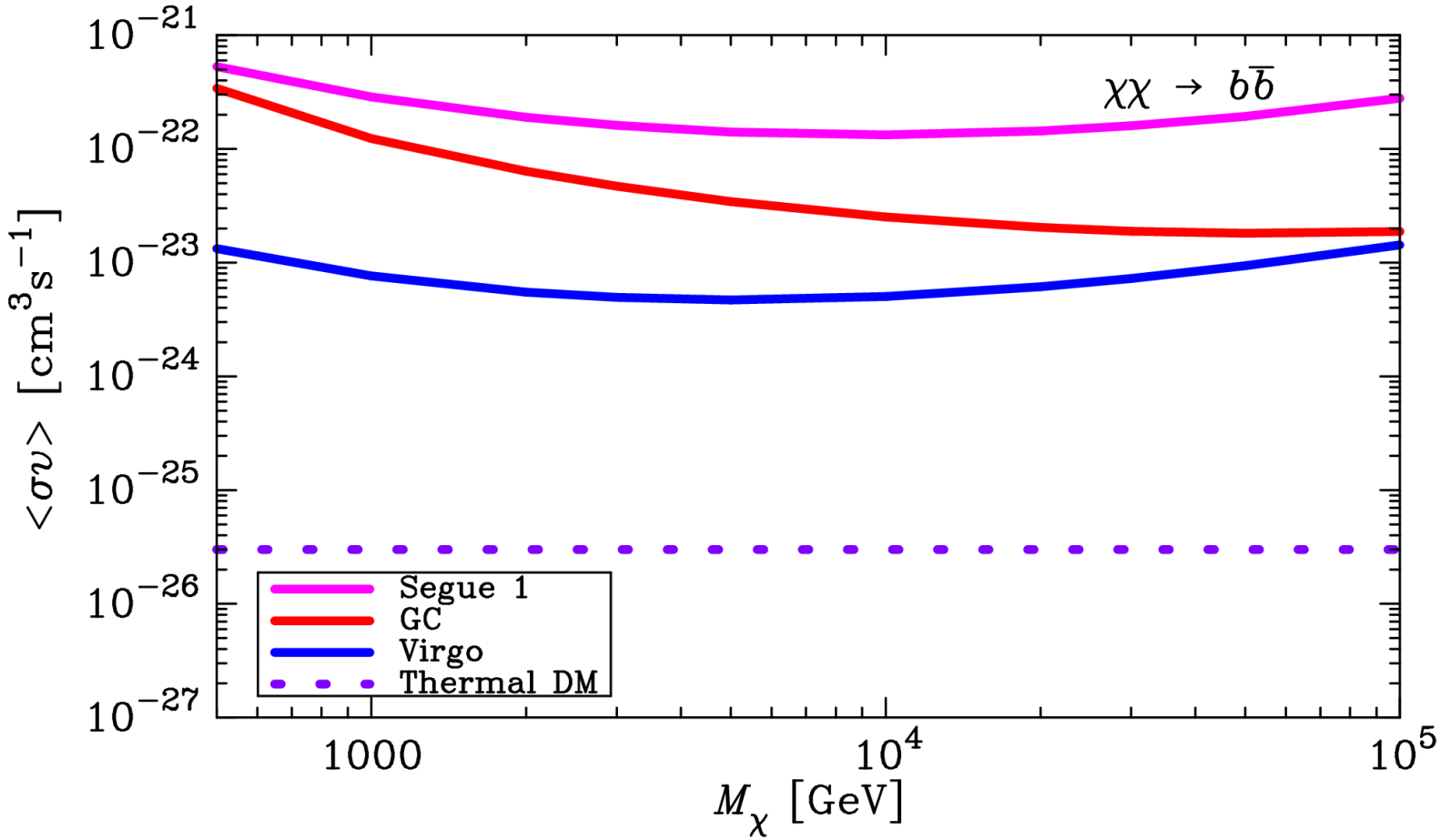
- Expected thermal cross-section is nearly independent of dark matter mass
- Is the weak-scale cross-section σ ~ 1 pb
- Weak-scale cross-section + weak-scale mass = Weakly Interacting Massive Particle dark matter

HAWC DM Sources

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

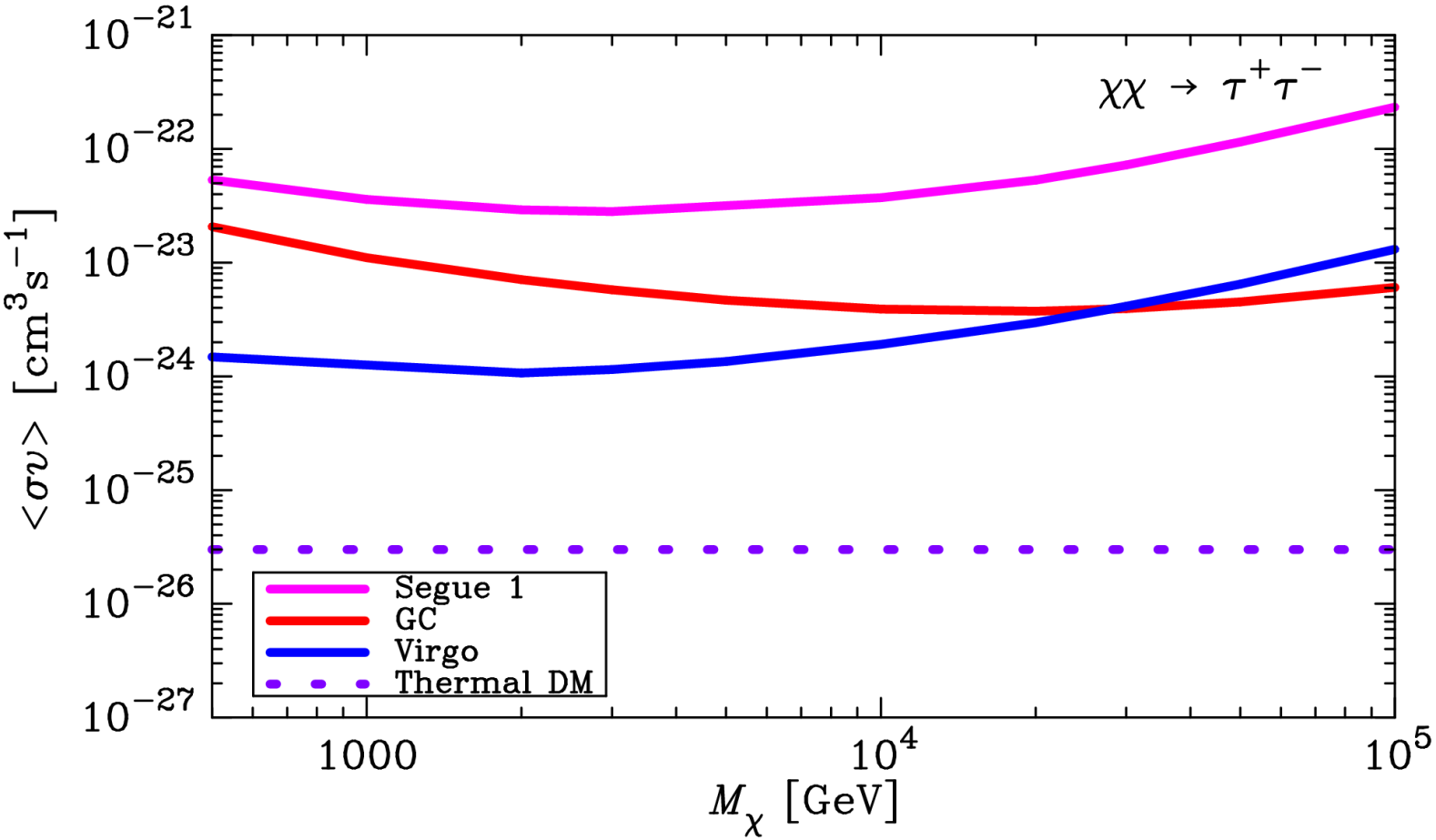


HAWC $b\bar{b}$



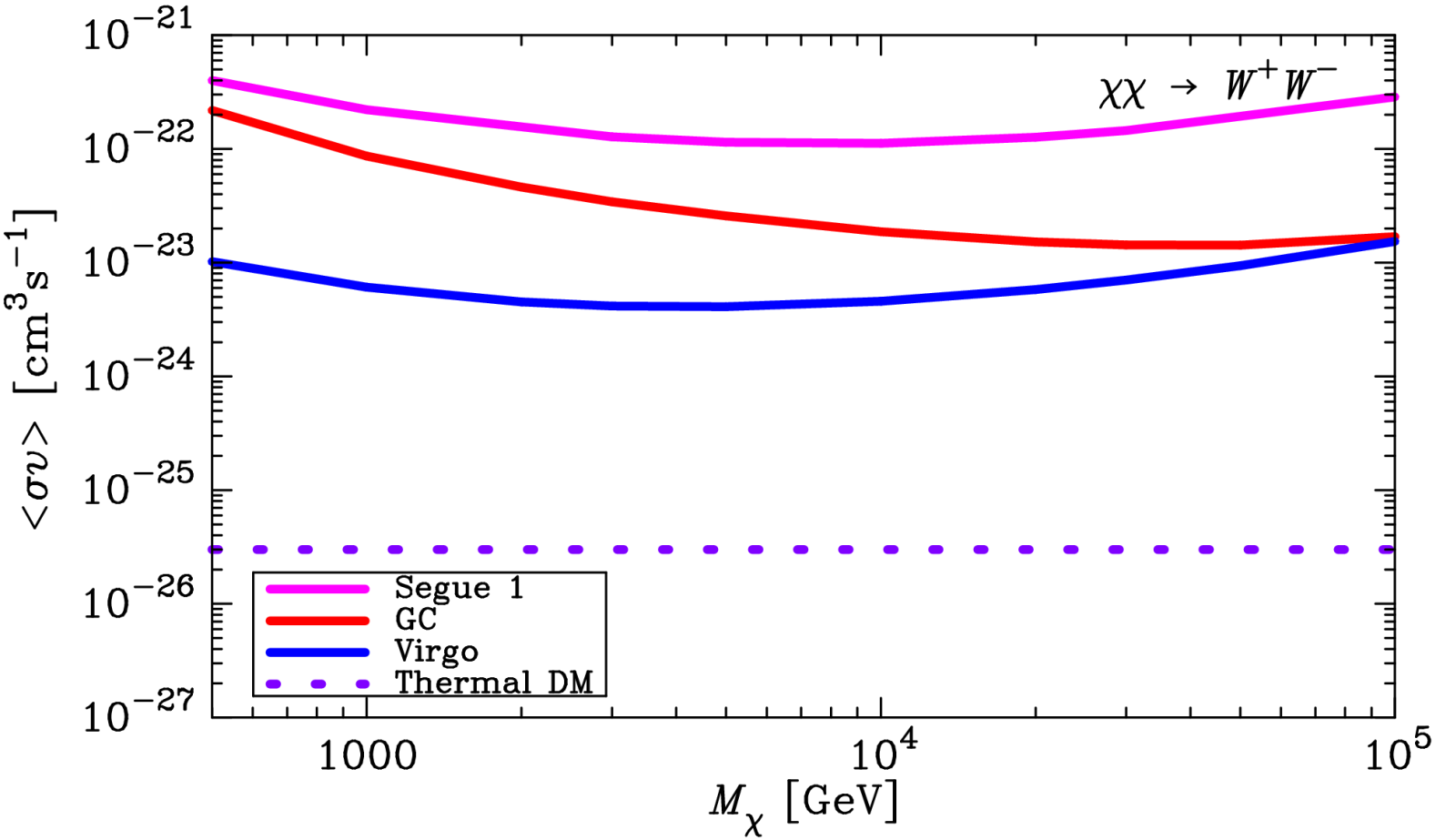
The expected HAWC 5-year limits for the $b\bar{b}$ channel for the Segue 1 dwarf galaxy, Galactic center with an Einasto profile, and Virgo cluster.

HAWC $\tau^+\tau^-$



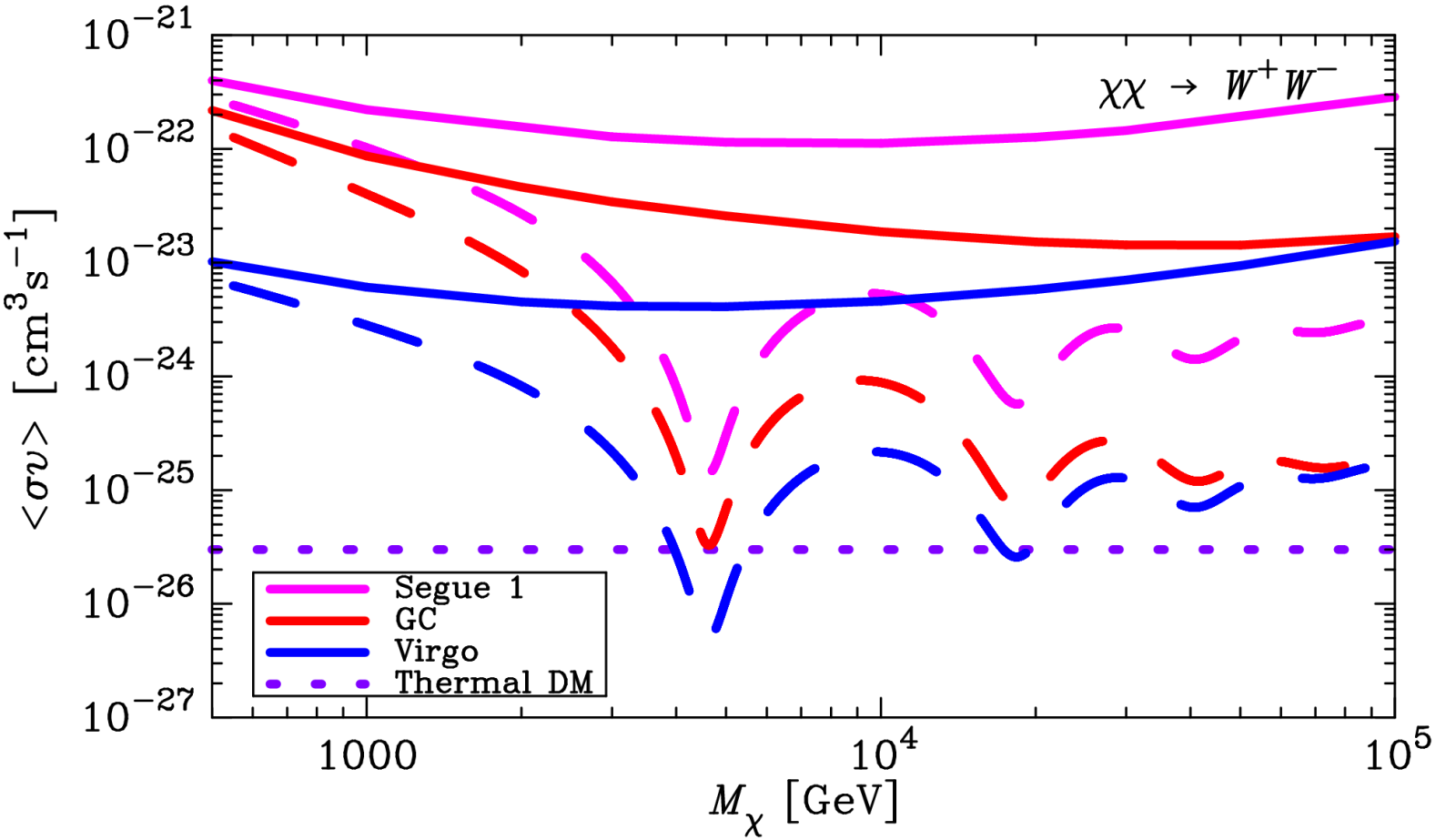
The expected HAWC 5-year limits for the $\tau^+\tau^-$ channel for the Segue 1 dwarf galaxy, Galactic center with an Einasto profile, and Virgo cluster.

HAWC W^+W^-



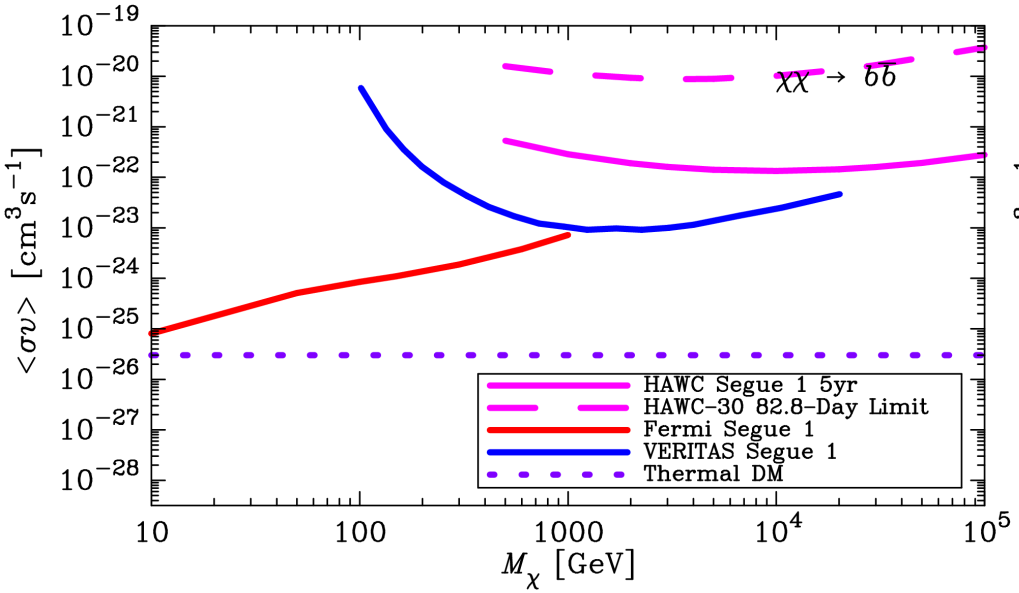
The expected HAWC 5-year limits for the W^+W^- channel for the Segue 1 dwarf galaxy, Galactic center with an Einasto profile, and Virgo cluster.

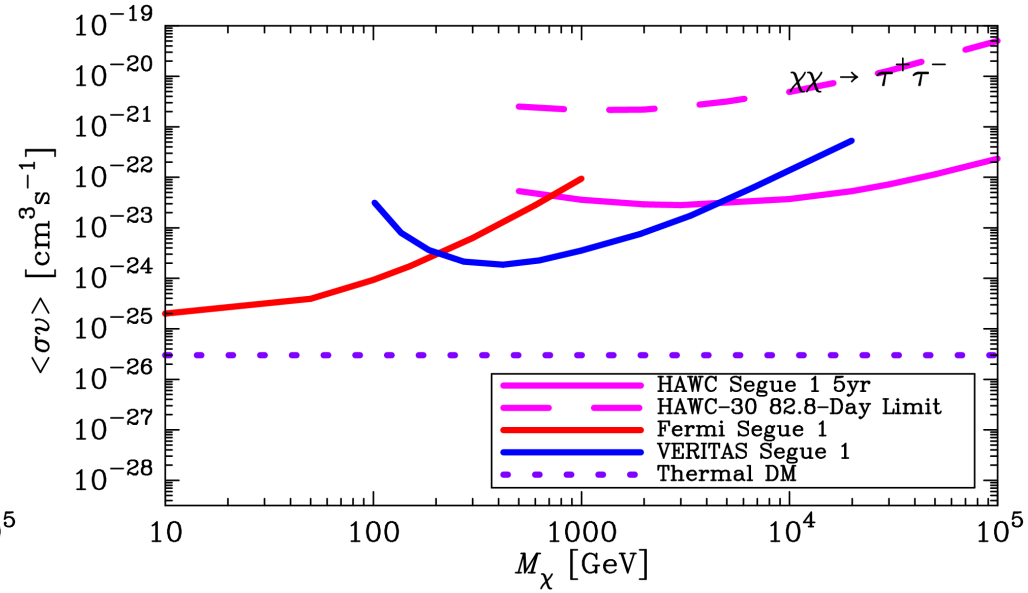
HAWC W^+W^-



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.

Limits Comparison



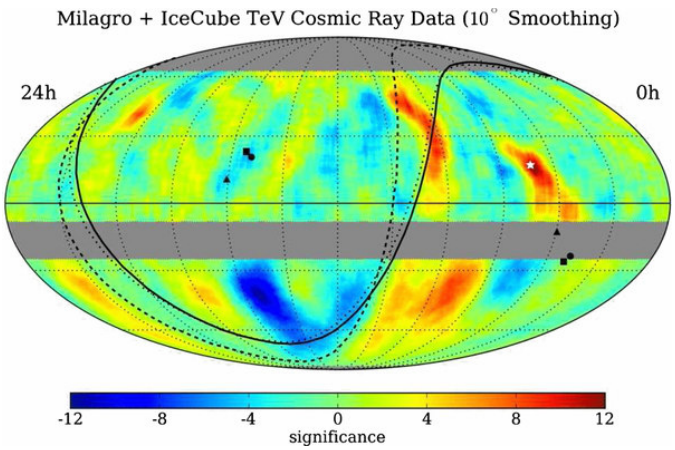


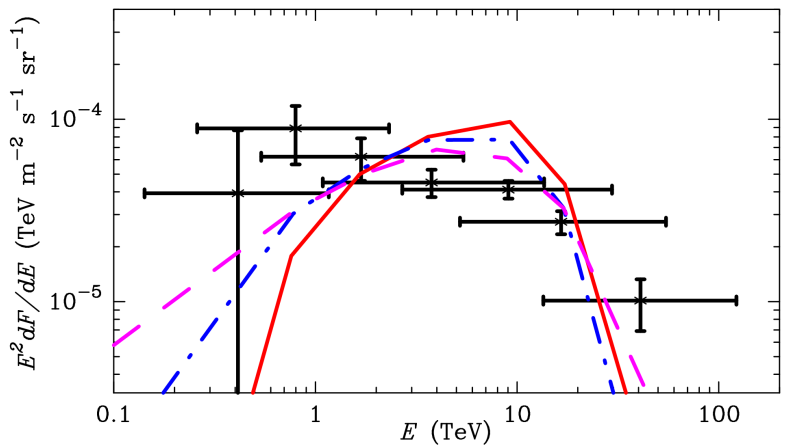
- HAWC $b\bar{b}$ will be best above ~50 TeV
- HAWC $\tau^+\tau^-$ will be best above ~5 TeV
- HAWC is already searching for the dark matter

Additional HAWC 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

Cosmic Ray Anisotropy from Dark Matter





- CR anisotropy may be from a nearby dark matter subhalo (Harding 2013)
- Detailed HAWC measurements of the spectrum should constrain the dark matter model
- Consistent with current antiproton, positron, and gamma-ray constraints
- Explained by similar masses to the HESS GC anomaly
- HAWC should see the gamma-ray counterpart after 1 year

Discussion

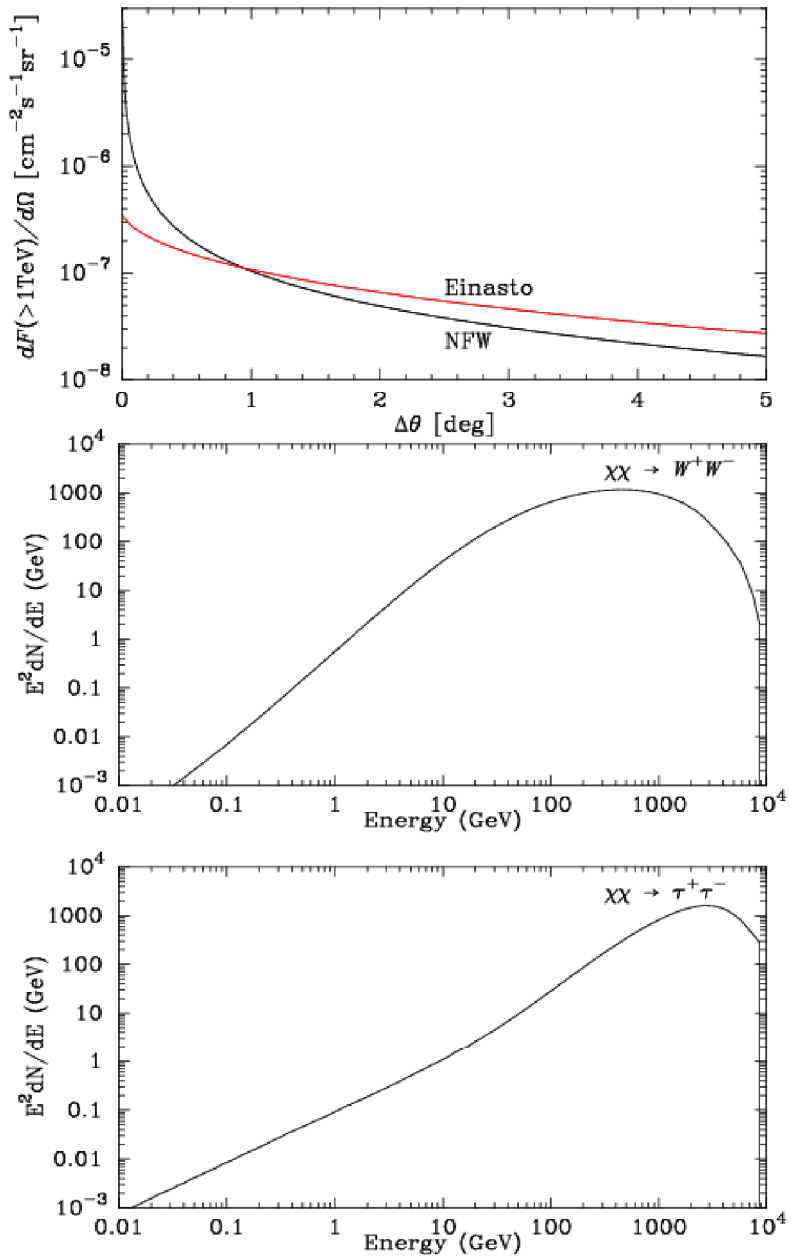
- HAWC is sensitive to high-mass annihilating dark matter
- HAWC can search in many sources simultaneously
- HAWC limits are better than comparable IACT limits above ~5TeV (~100TeV) for leptonic (hadronic) channels
- TeV cosmic ray anisotropy may be from dark matter – HAWC can verify

Backup Slides

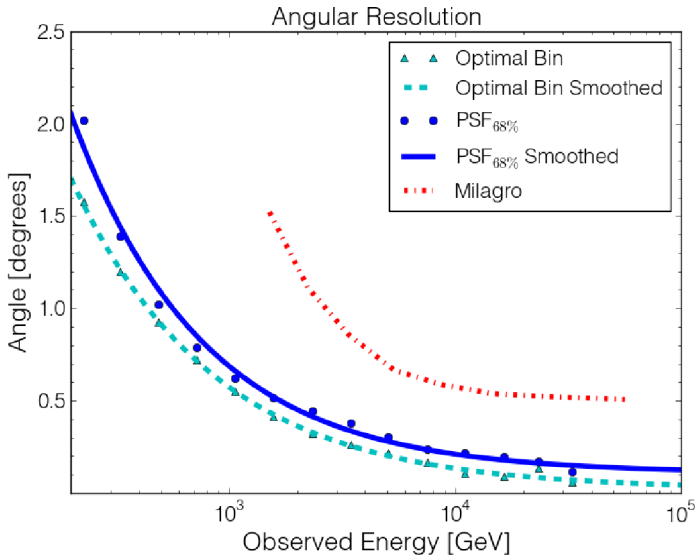
Dark Matter Flux

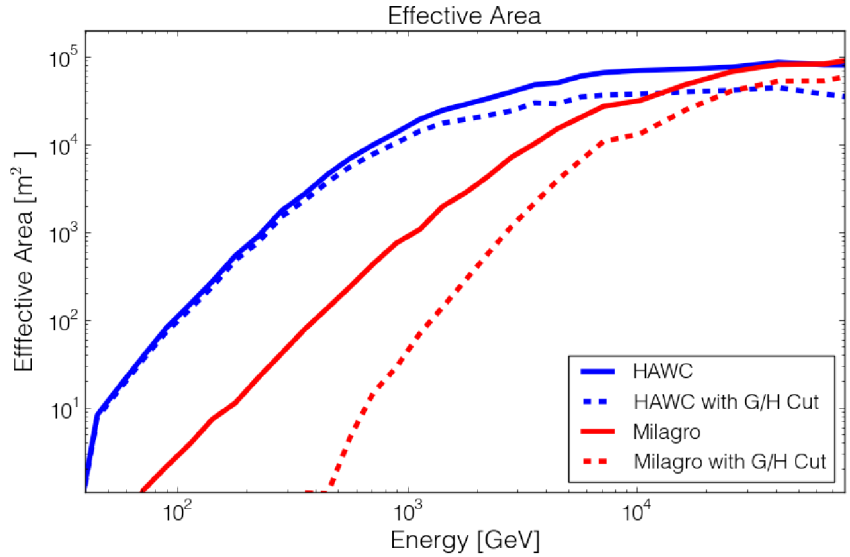
$$\text{Flux} \propto \frac{\langle \sigma v \rangle}{M_\chi^2} \frac{dN_\gamma}{dE} \int_{\text{l.o.s.}} dx\, \rho^2(r)$$

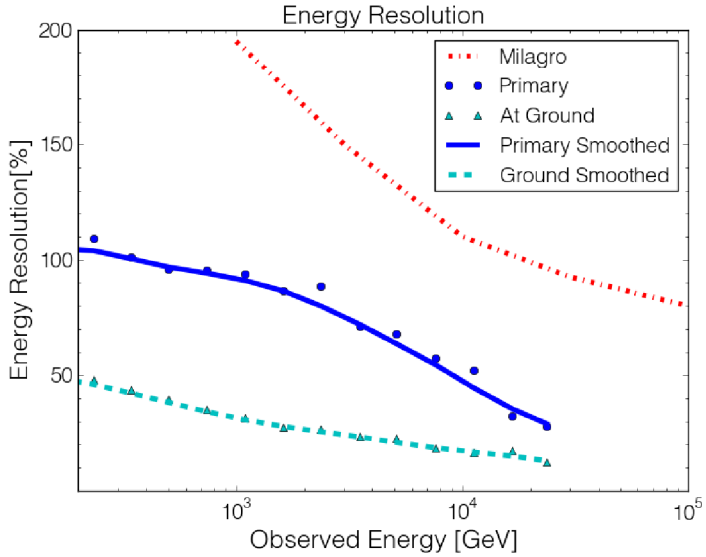
- For GC, optimal bin depends strongly on DM profile
- For dwarf galaxies, flux is not very sensitive to DM profile
- Flux peaks sharply, dependent on DM channel

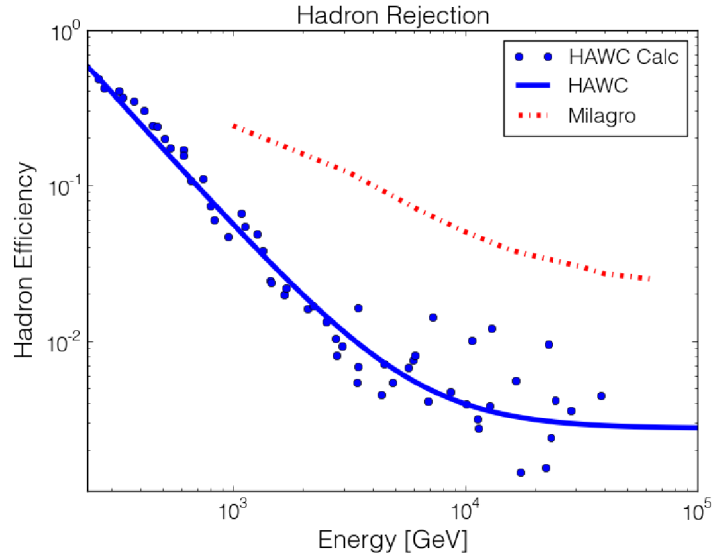


HAWC Performance

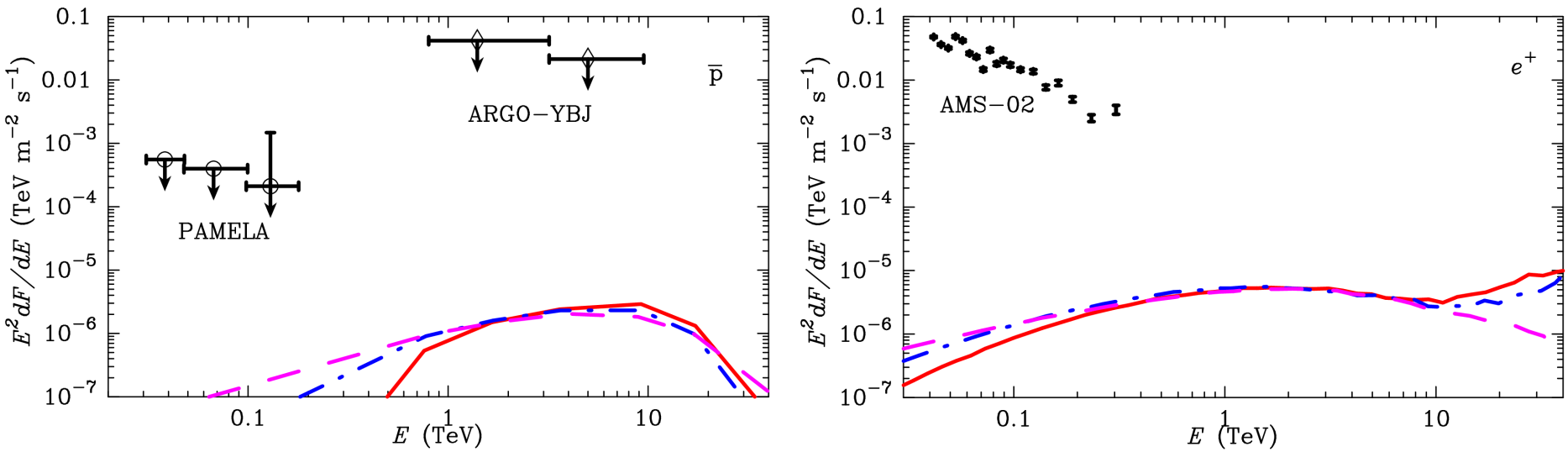






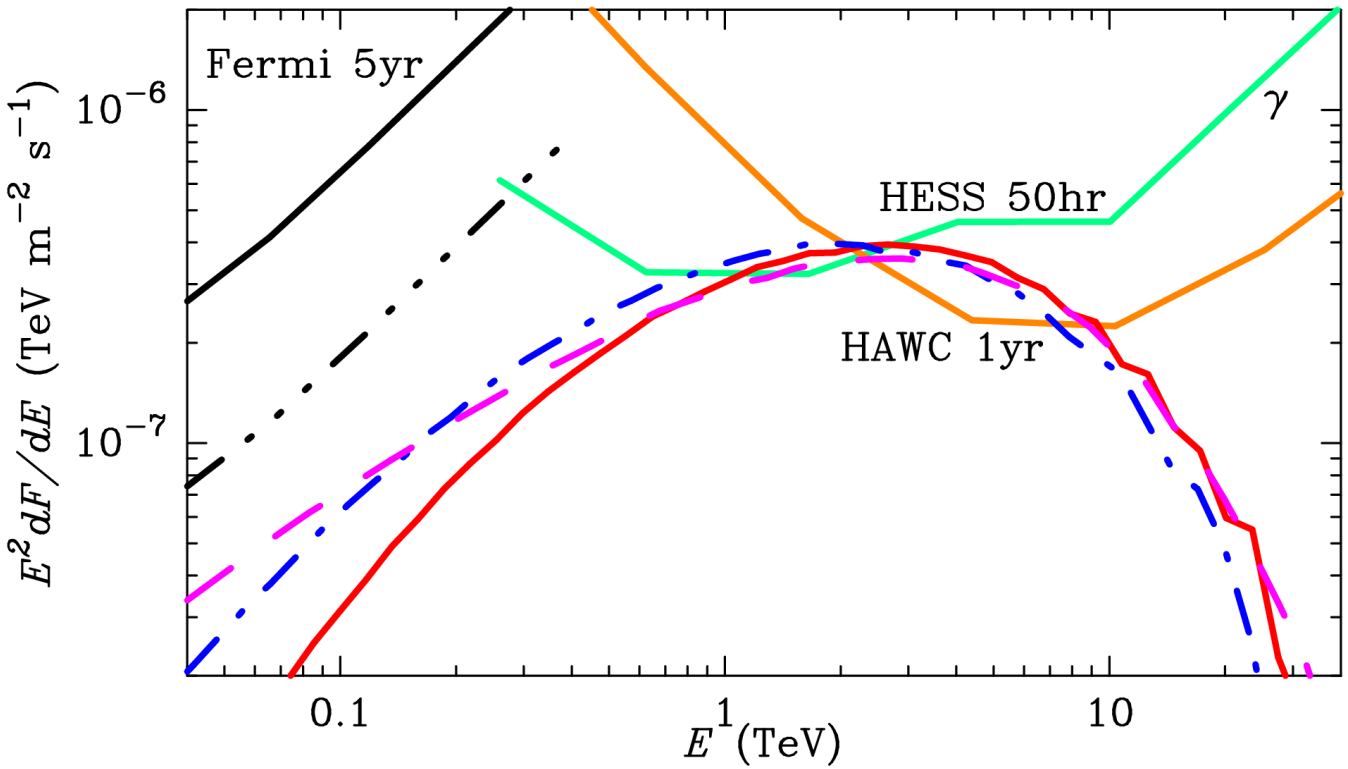


Antiproton and Positron Constraints



- Total flux from DM subhalo compared to total isotropic flux from limits (for 0.03 sr region)
  - Should be seen at ~10^{-4}-10^{-3} small-scale anisotropy in 100s of GeV
- Shown: 60 TeV W^+W^- (red), 50 TeV Z^0Z^0 (blue), 100 TeV $b\bar{b}$ (magenta)

Gamma-Ray Constraints



- Experimental sensitivities to 5°-extended gamma-ray sources
  - Fermi 5-year sensitivity to 1°-extended gamma-ray source shown as well
- Shown: 60 TeV W^+W^- (red), 50 TeV Z^0Z^0 (blue), 100 TeV $b\bar{b}$ (magenta) DM fluxes