

# The TeV Cosmic-Ray Anisotropy from Local Dark Matter Annihilation



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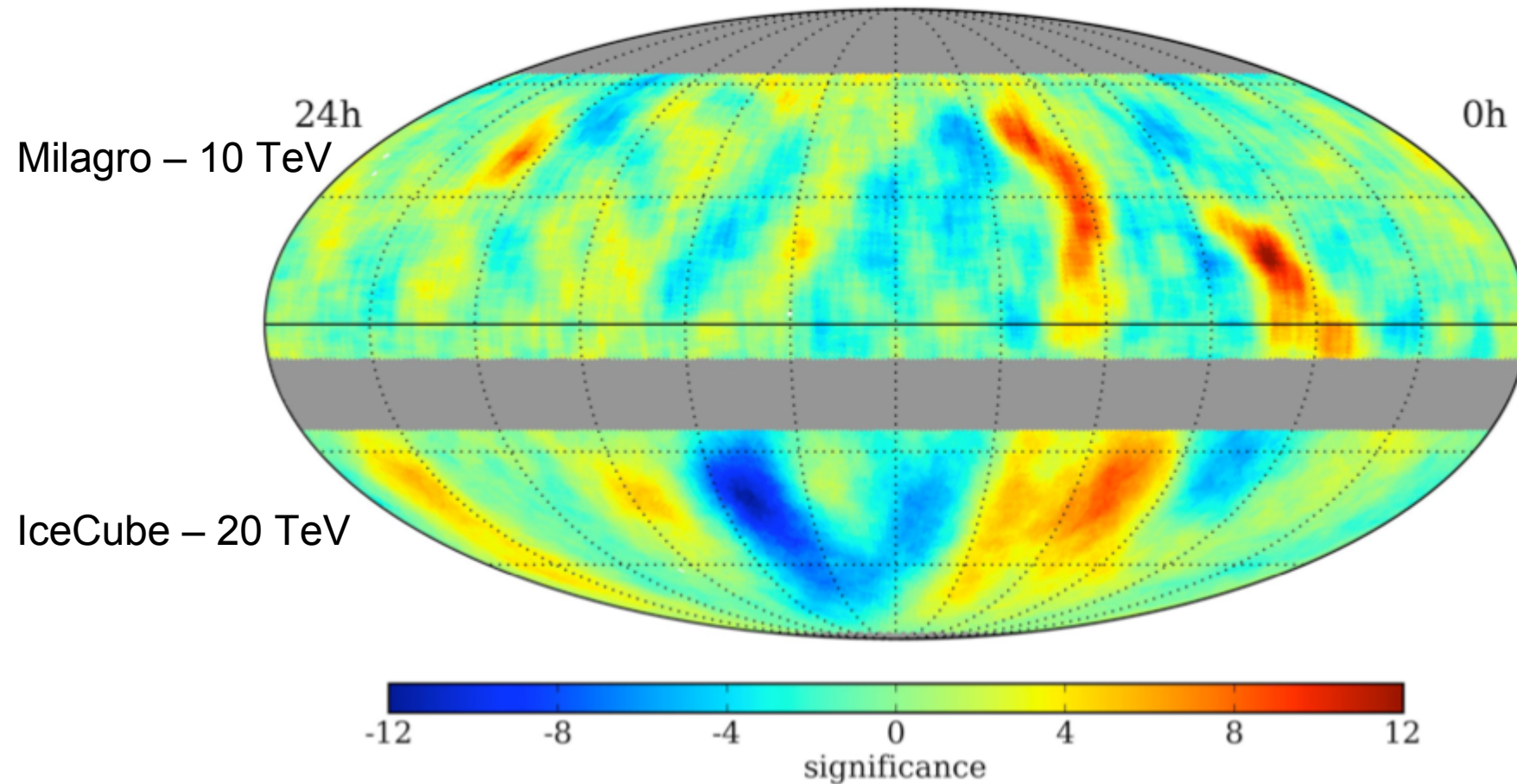
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TeVPA

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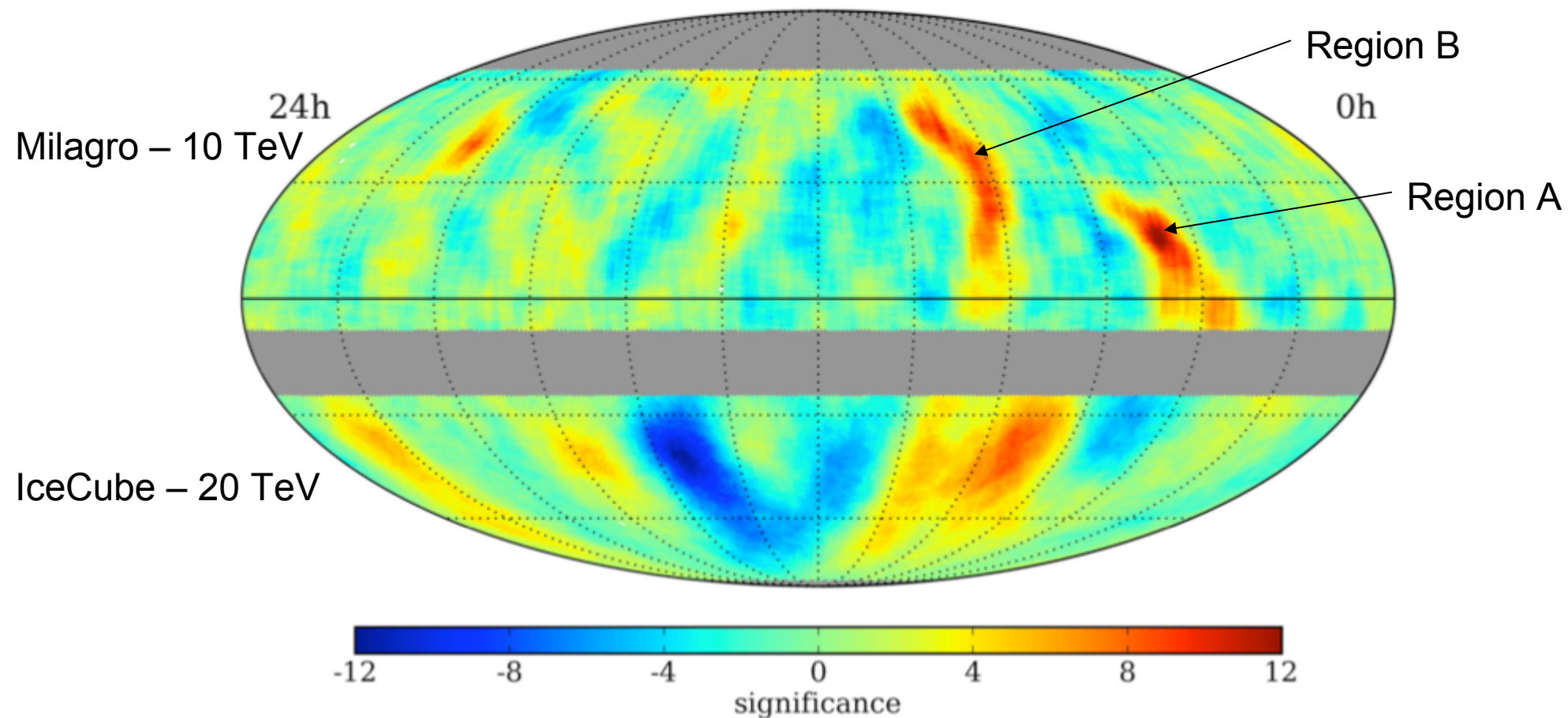
# TeV CR Anisotropy

Milagro + IceCube TeV Cosmic Ray Data ( $10^\circ$  Smoothing)



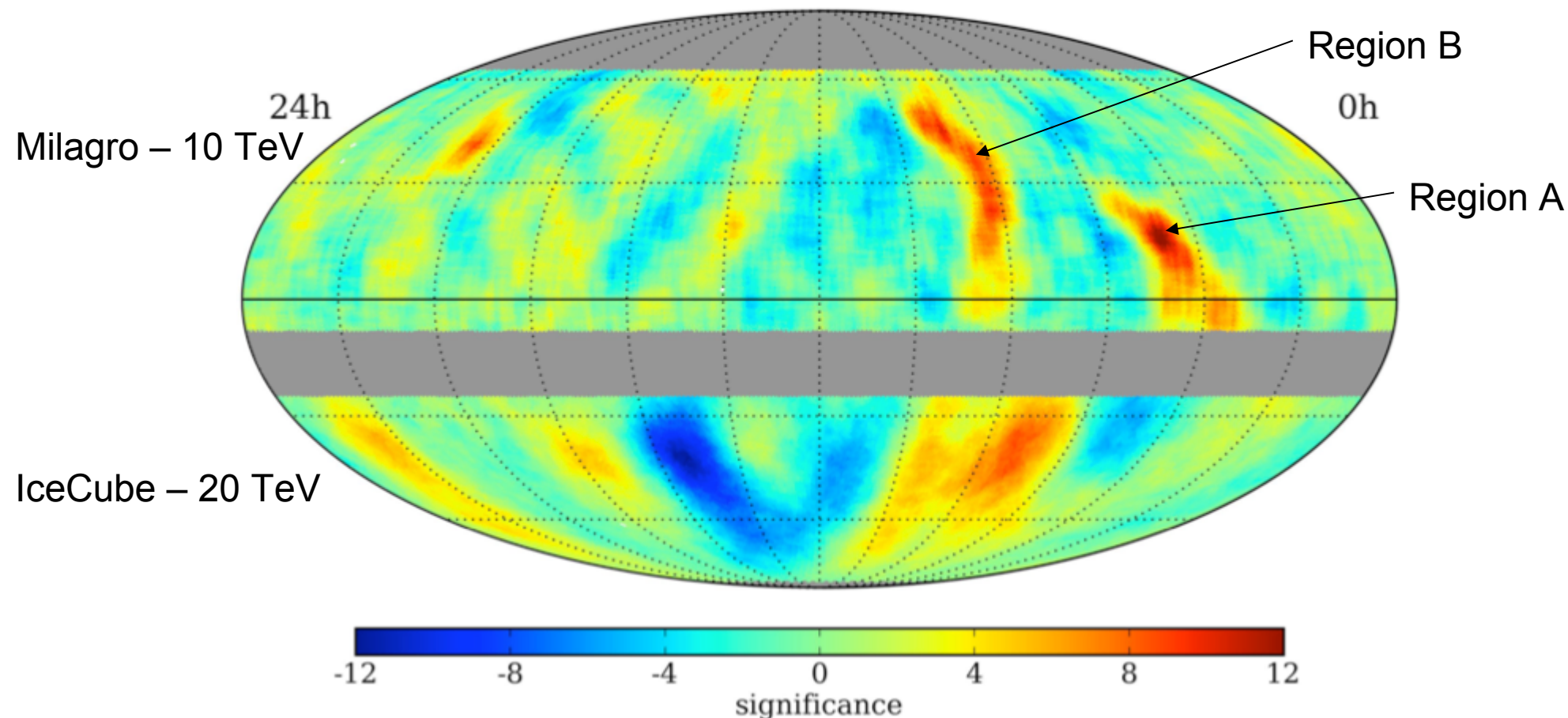
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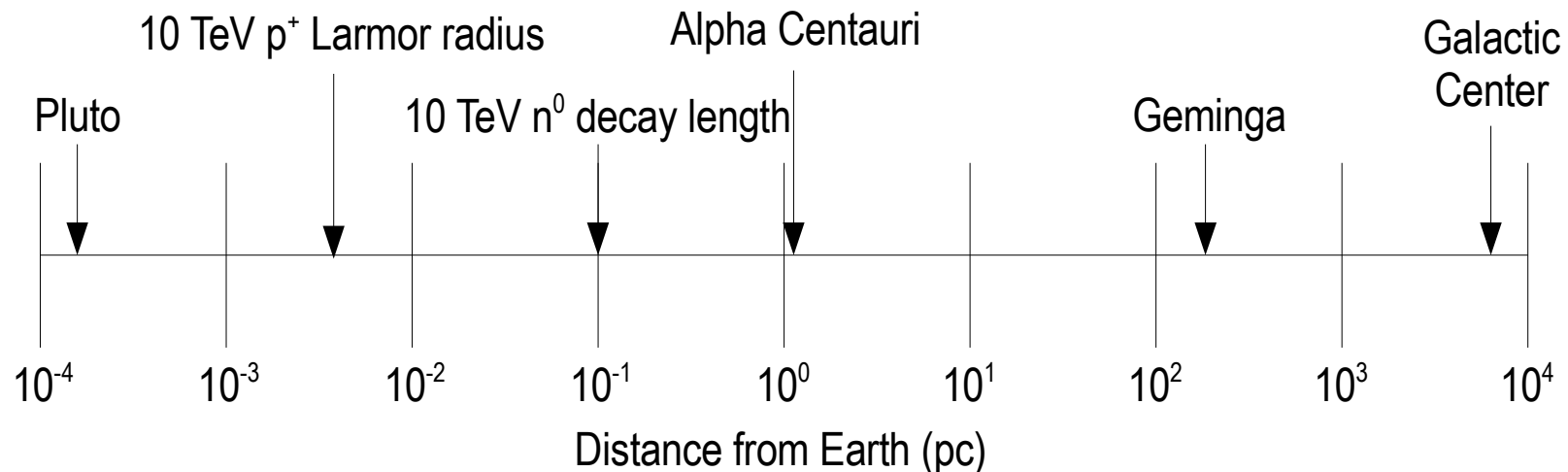
Milagro + IceCube TeV Cosmic Ray Data ( $10^\circ$  Smoothing)



- $10^{-4}$ - $10^{-3}$  excess over the isotropic intensity
- Anisotropy observed at  $10^\circ$  angular scales at tens of TeV
- Hadrons, not electrons or photons

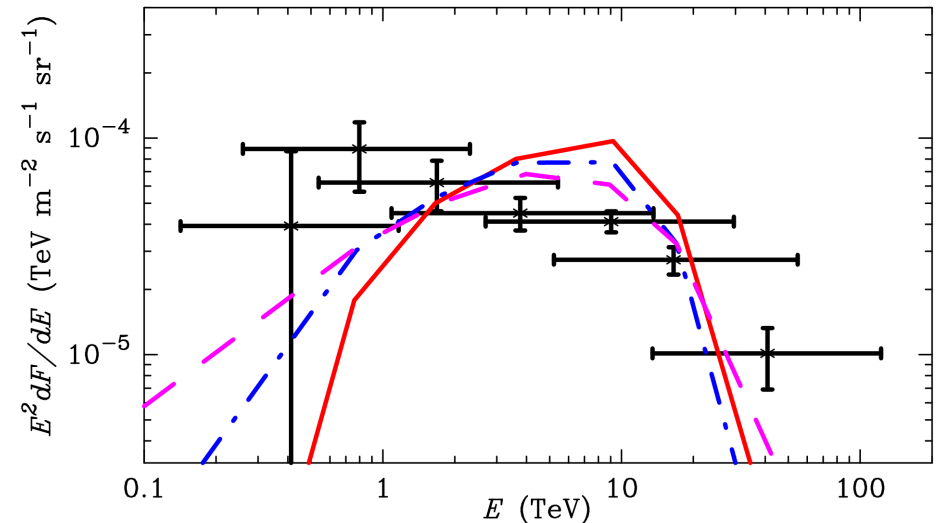
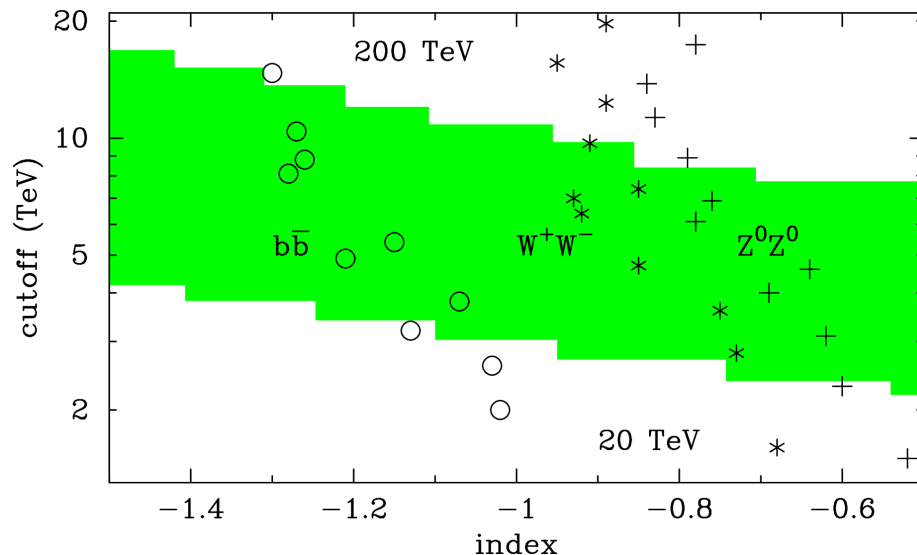
# The Impossible Signal

- From propagation over long distances, CRs should be isotropized due to diffusion in the turbulent magnetic field.
- For 10 TeV CRs, the Larmor radius in the local 2  $\mu\text{G}$  magnetic field is only 0.005 pc
- For a source of neutrons, the decay length of a 10 TeV neutron is 0.1 pc
- No source of CRs is so close to Earth
- Coherent magnetic field connecting the source to Earth can do it
  - But must be  $<100$  pc long, with shorter lengths increasingly likely
- Must have *both* non-standard propagation *and* a nearby source





# Anisotropy from DM



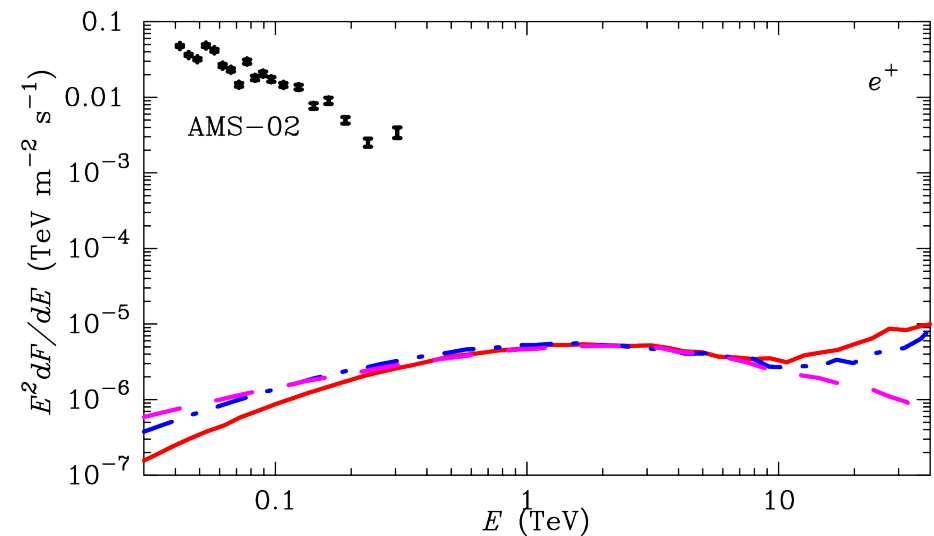
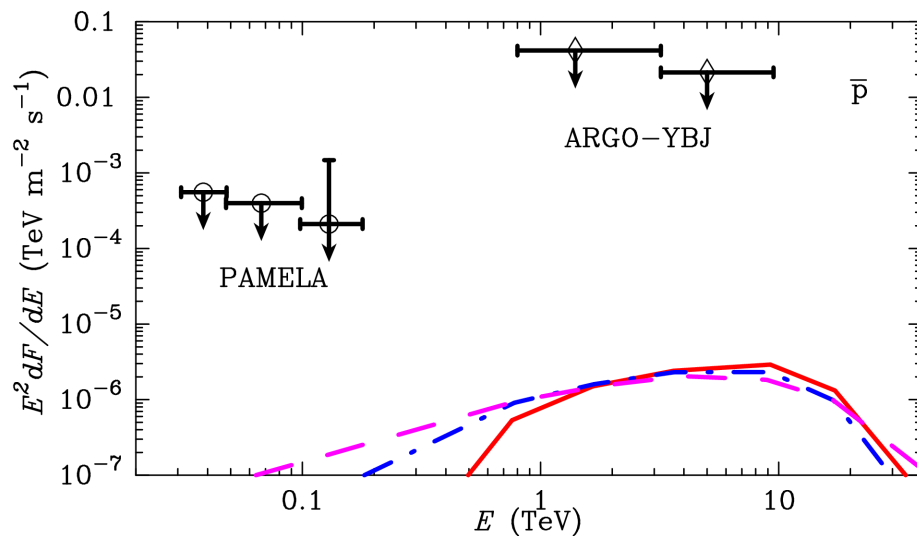
- Left: Milagro-consistent spectra (green region) vs DM spectral parameters
  - $W^+W^-$  (stars),  $Z^0Z^0$  (crosses),  $b\bar{b}$  (circles) from 20-200 TeV
- Right: 60 TeV  $W^+W^-$  (red), 50 TeV  $Z^0Z^0$  (blue), 100 TeV  $b\bar{b}$  (magenta) vs Milagro spectrum
  - Need better error bars to distinguish spectra
  - Energy losses during propagation should shift peaks to right and soften cutoffs

# Local Dark Matter Subhalo

- Expect many subhalos from DM substructure
- Minimum distance  $D_{\min}$  to a subhalo consistent with the local DM density
- Scaling with subhalo mass from Bolshoi simulation
- DM flux to source is  $\sim$  independent of subhalo mass
- DM flux to magnetic stream is highly scenario-dependent

$M_{\text{vir}}$	$D_{\min}$	$J_{\Delta\Omega}(D_{\min})$	$J_{\Delta\Omega}(D_{\min}-100 \text{ pc})$
$10^9 M_{\odot}$	933 pc	119	137
$10^8 M_{\odot}$	465 pc	114	158
$10^7 M_{\odot}$	225 pc	112	247
$10^6 M_{\odot}$	108 pc	112	2840
$10^5 M_{\odot}$	51.3 pc	111	-
$10^4 M_{\odot}$	24.1 pc	110	-
$10^3 M_{\odot}$	11.2 pc	109	-

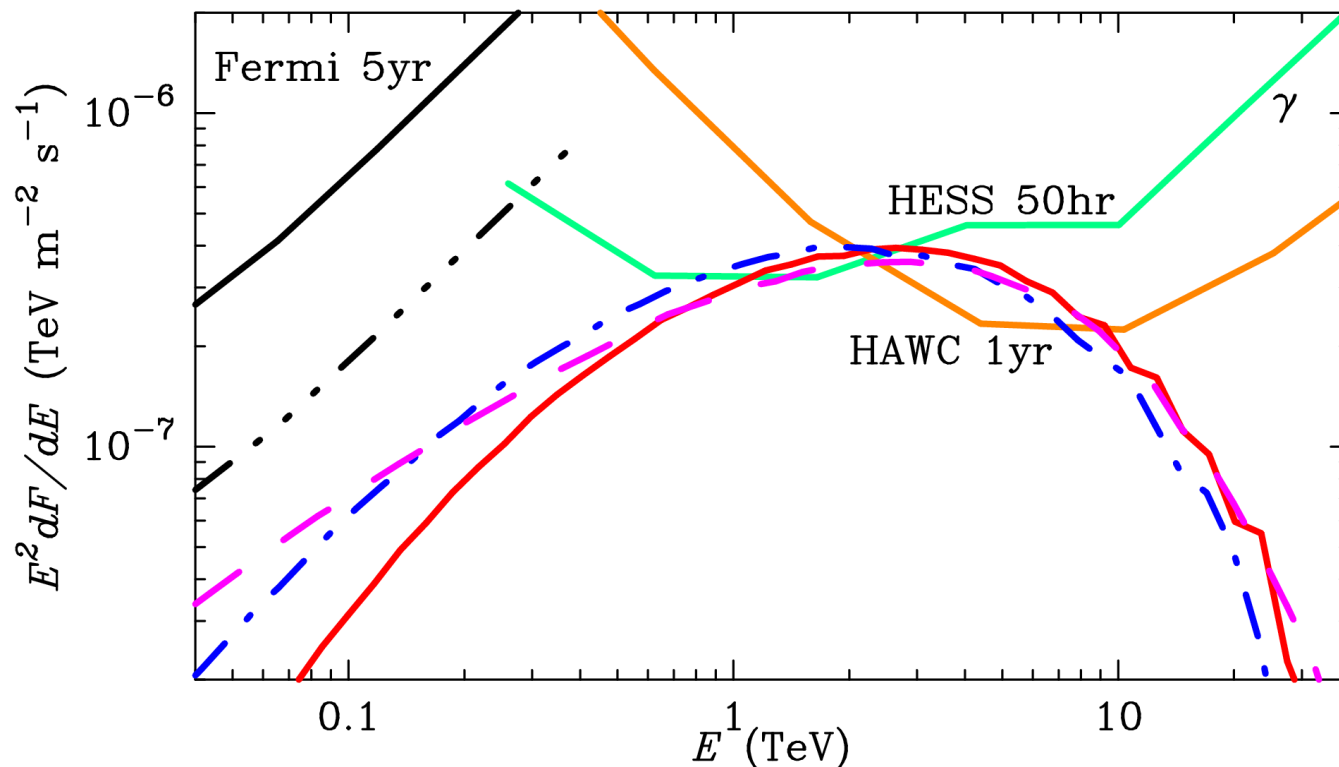
# Antiproton and Positron Constraints



- Total flux from DM subhalo compared to total isotropic flux from limits (for 0.03 sr region)
  - Should be seen at  $\sim 10^{-4}$ - $10^{-3}$  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  $5^\circ$ -extended gamma-ray sources
  - Fermi 5-year sensitivity to  $1^\circ$ -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

# Particle Constraints

- Meets all constraints:
  - Diffuse anti-protons (PAMELA, ARGO)
  - Diffuse positrons (AMS)
    - But pointed could detect it
  - All-sky gamma-rays (Fermi, Milagro)
    - For expected extended source
  - Pointed gamma-rays (HESS, VERITAS, MAGIC)
    - Would see it if they look at it for ~50 hours
  - HAWC
    - Will detect it, if dec > -30

# Discussion

- Small-scale anisotropies have been observed in the TeV cosmic rays
- Non-standard propagation and a local CR source are needed
- Local dark matter subhalos can be the source of the anisotropy
- Gamma-ray emission from the subhalo causing the Region A excess should be observable by HAWC