Distinguishing between Dark Matter and pulsar interpretations

of cosmic ray positrons with multi-messenger signals

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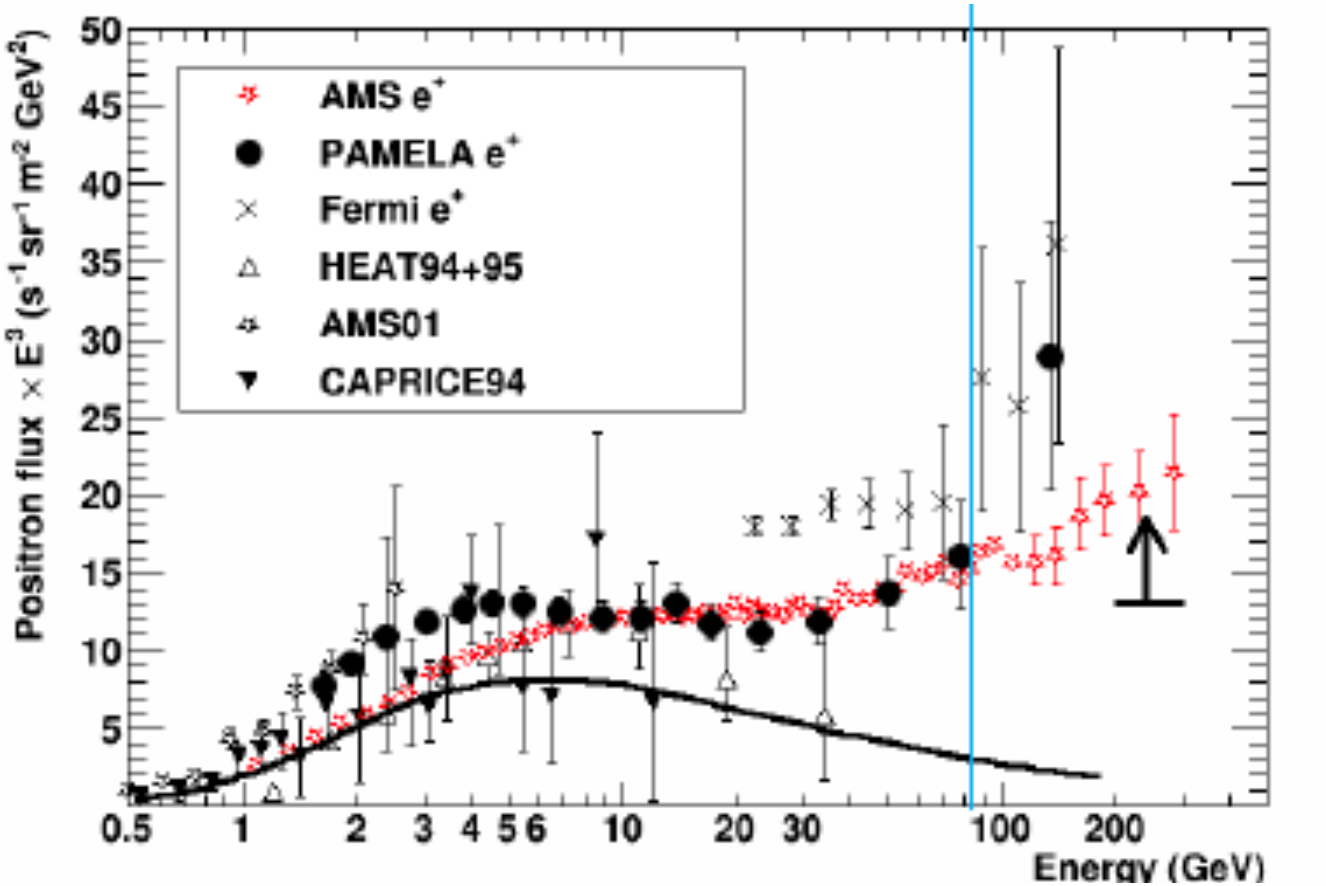
Searching for Dark Matter with cosmic ray e^+

Our task:

Imagine that the positron flux is measured with 10 % accuracy up to 5 TeV. A cut-off is measured with an exponential feature, whose characteristic energy is 2 TeV. Is that measurement sufficient to distinguish between a annihilating dark matter origin and a remnant star source? Would other measurements be helpful in the discrimination analysis?

Current measurements...

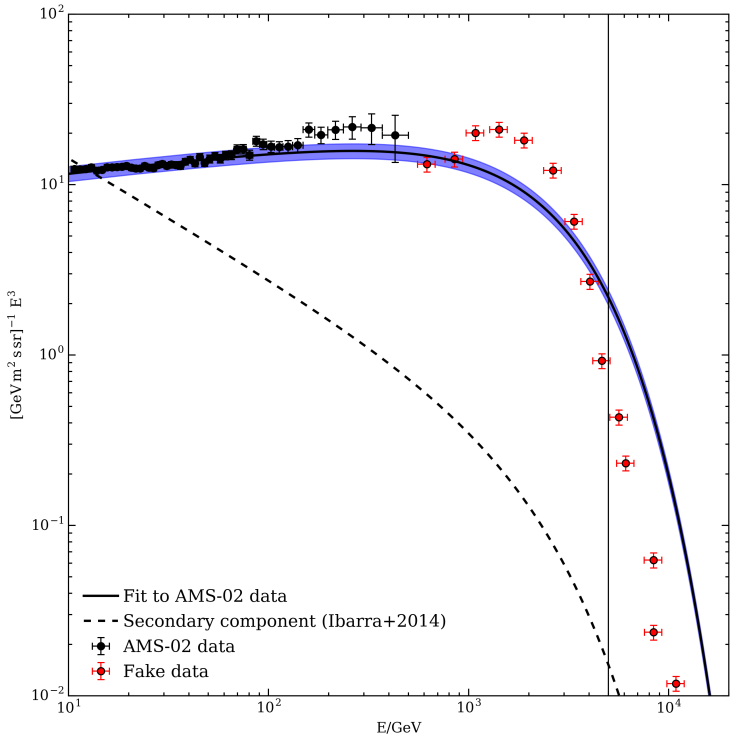


Marrocchesi, ISAPP 2017 Texel

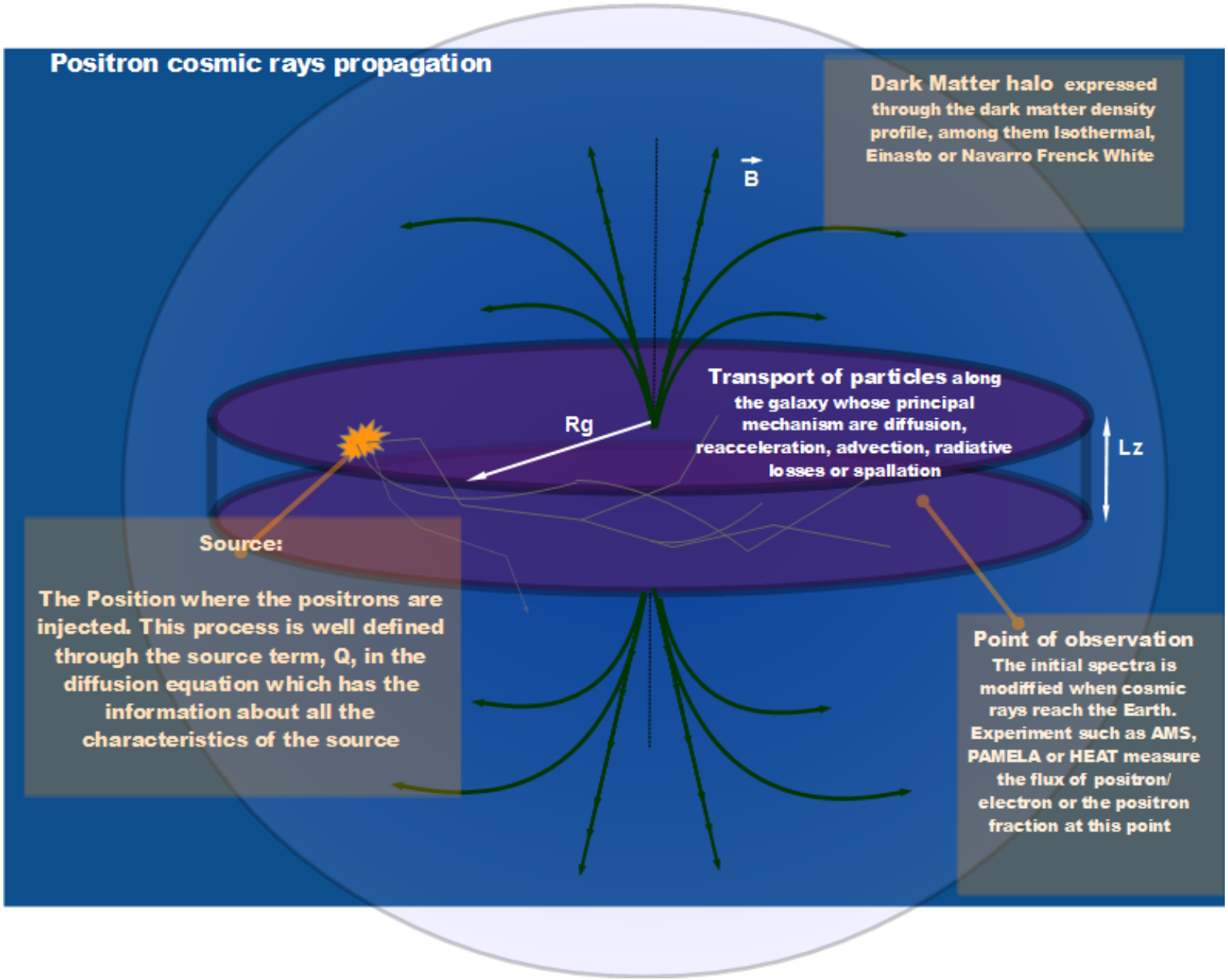
- AMS-02: e^+ flux measured up to $\sim 600\,\text{GeV}$
- $\phi_{e^+} \sim E^{-2.97}$ for $E < 31.8\,\text{GeV}$ $(\sim E^{-2.75}$ for $E > 49.3\,\text{GeV})$

...and what we might see in the future

- Upcoming data up to $\mathcal{O}(10\,\mathrm{TeV})$ by DAMPE and CALET $(e^+ + e^-)$
  arXiv:1706.08453 [astro-ph.IM]
  Nucl. Instrum. Meth. A **692**, 240 (2012)
- To reach $10\,\%$ accuracy, e^+/p discrimination power at $\mathcal{O}(10^5)$ needed
- Potential scenario: e^+ excess with cutoff at $\mathcal{O}(1\,\mathrm{TeV})$ measured

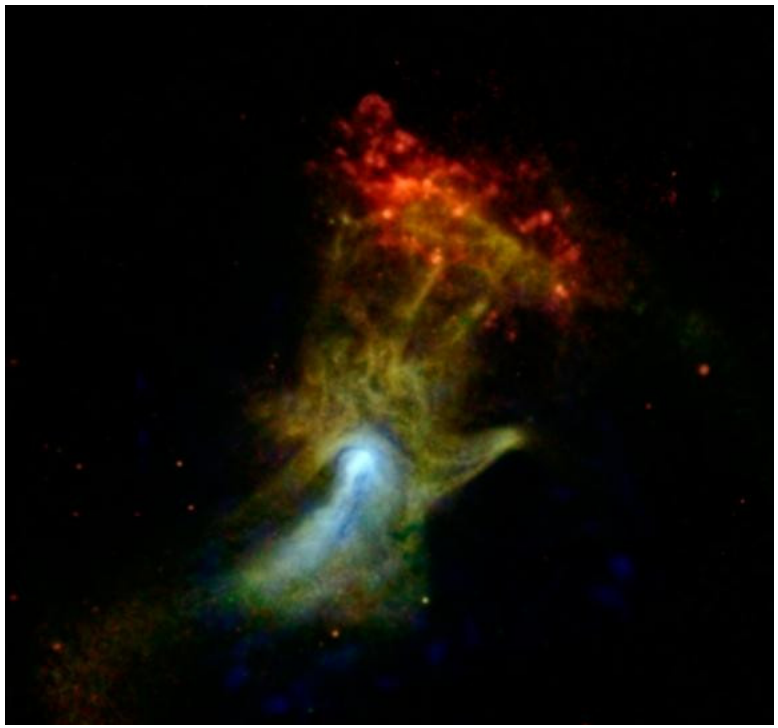


e^+ production and propagation



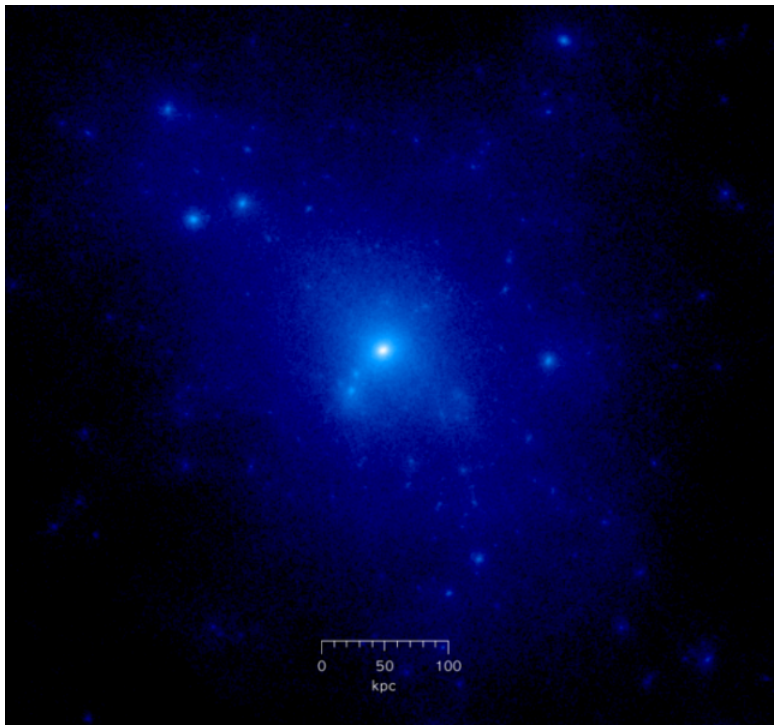
Pulsar wind nebula and Dark Matter source terms

Pulsar wind nebula (PWN):



$$Q(E) = Q_0^{PSR} \left(\frac{E}{E_0}\right)^{-\gamma_{PSR}} \exp\left(-\frac{E}{E_c^{PSR}}\right)$$

Dark Matter (DM):



$$Q(\vec{x}, E) = \kappa \langle \sigma v \rangle \left(\frac{\rho(\vec{x})}{M_{\mathrm{DM}}}\right)^2 \sum_i \beta_j \frac{dN_e^j}{dE}$$

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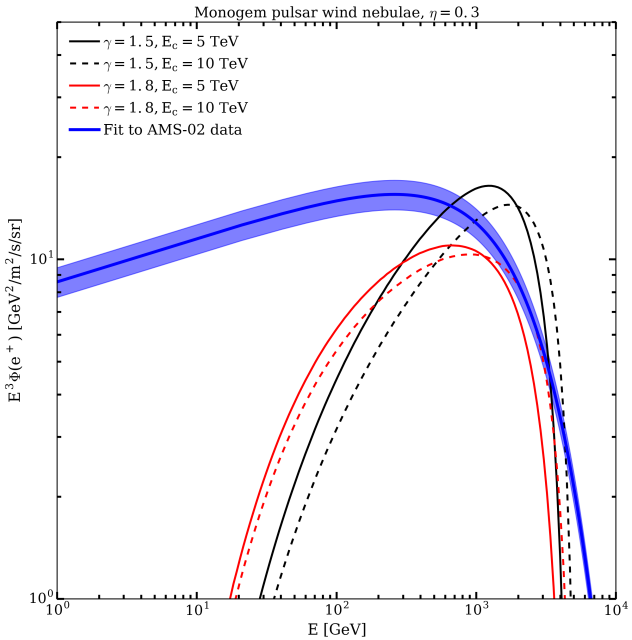

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- Single PWN sufficient to describe spectrum

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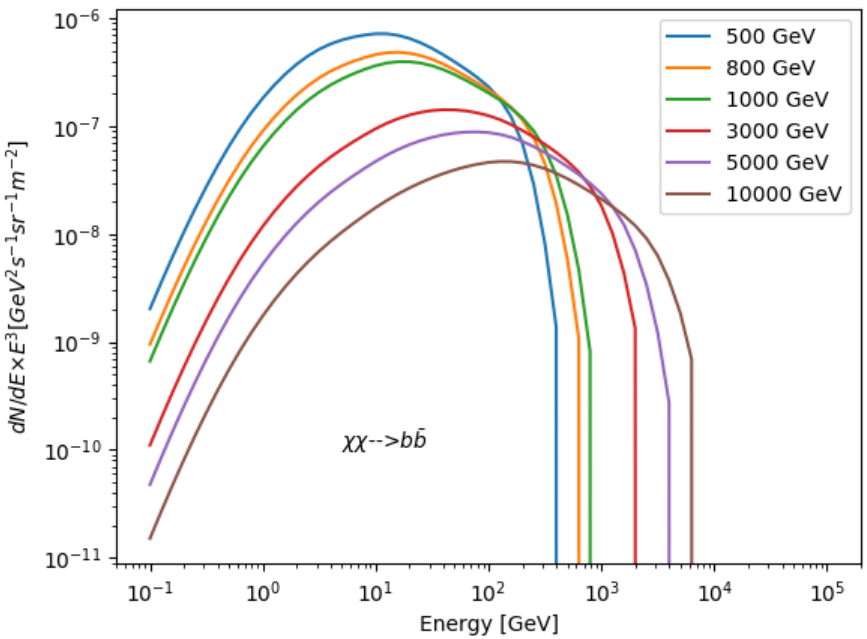

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- Fluxes from Cirelli *et al.* (PPPC 4 DM ID)

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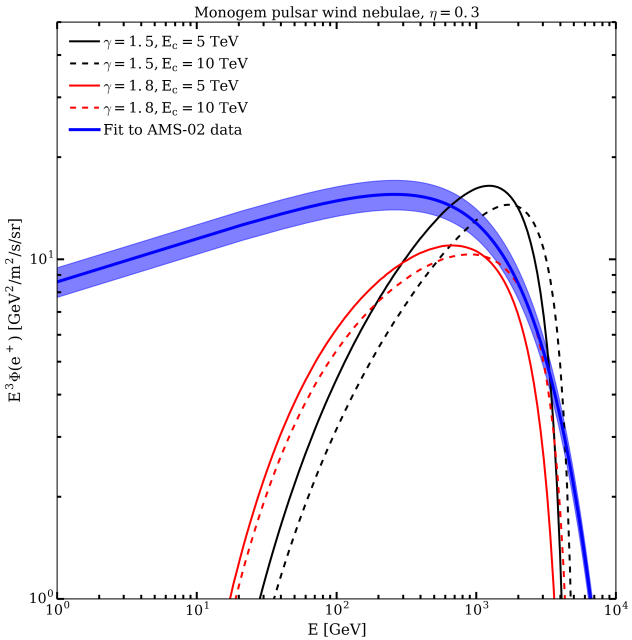

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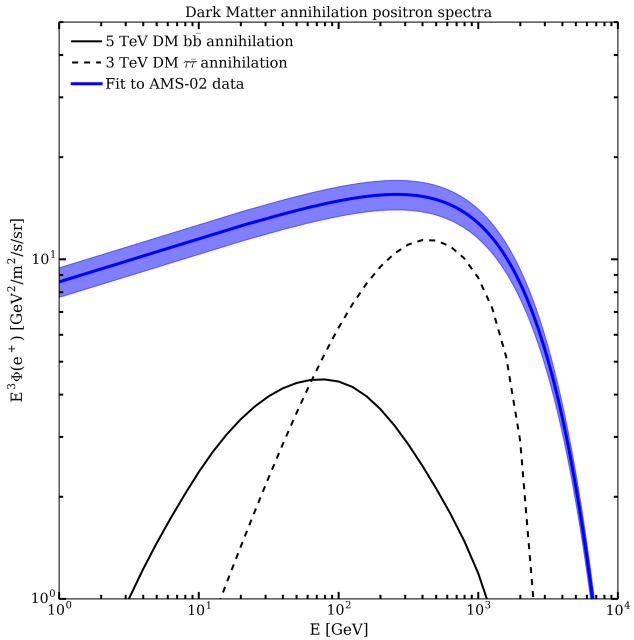

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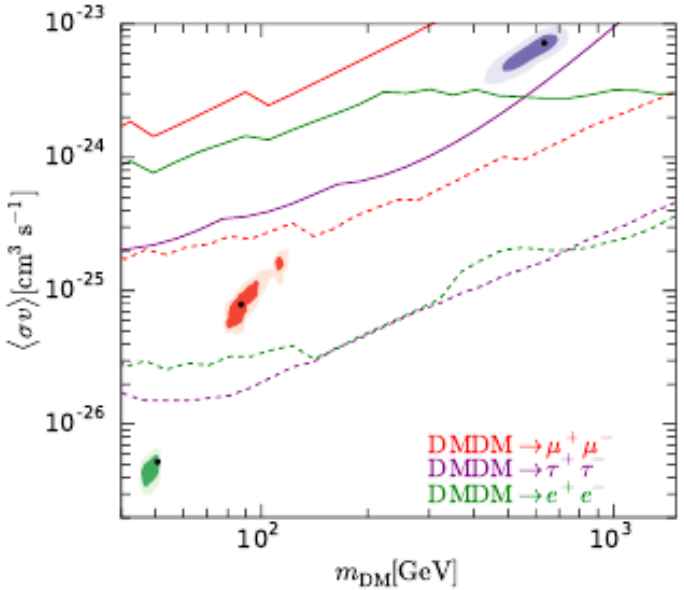
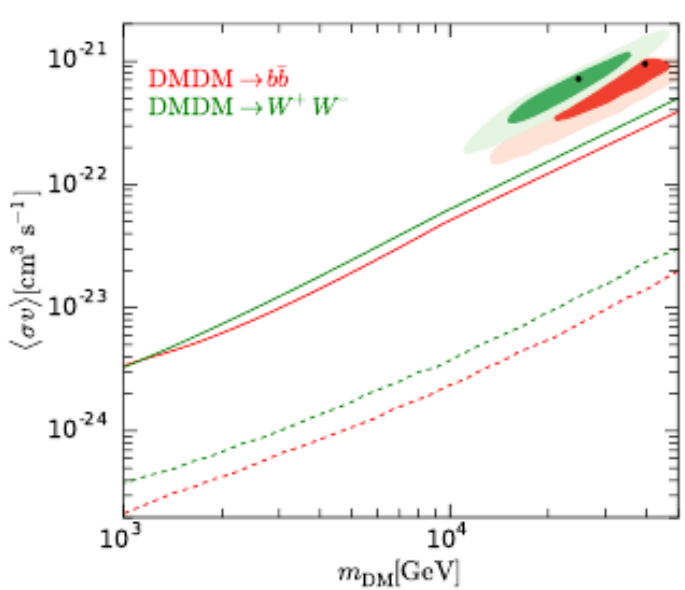
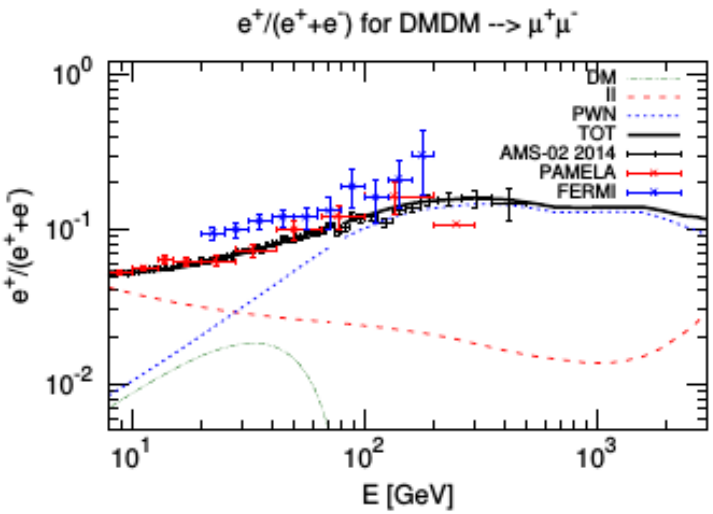
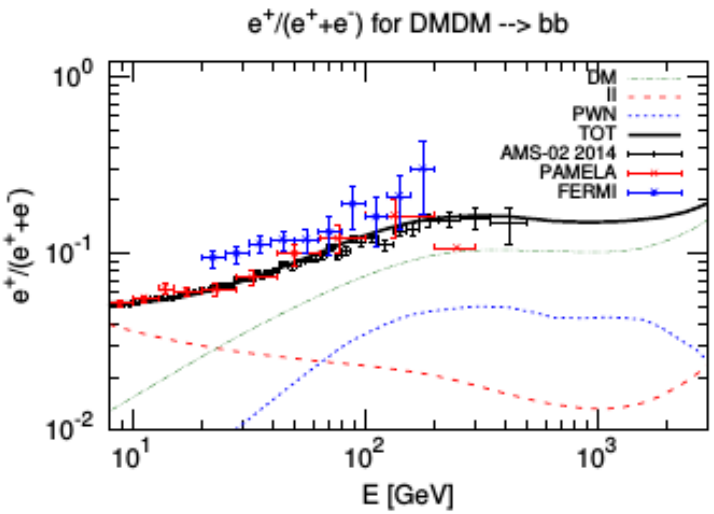
- DM annihilation on its own cannot describe spectrum

Mixed model







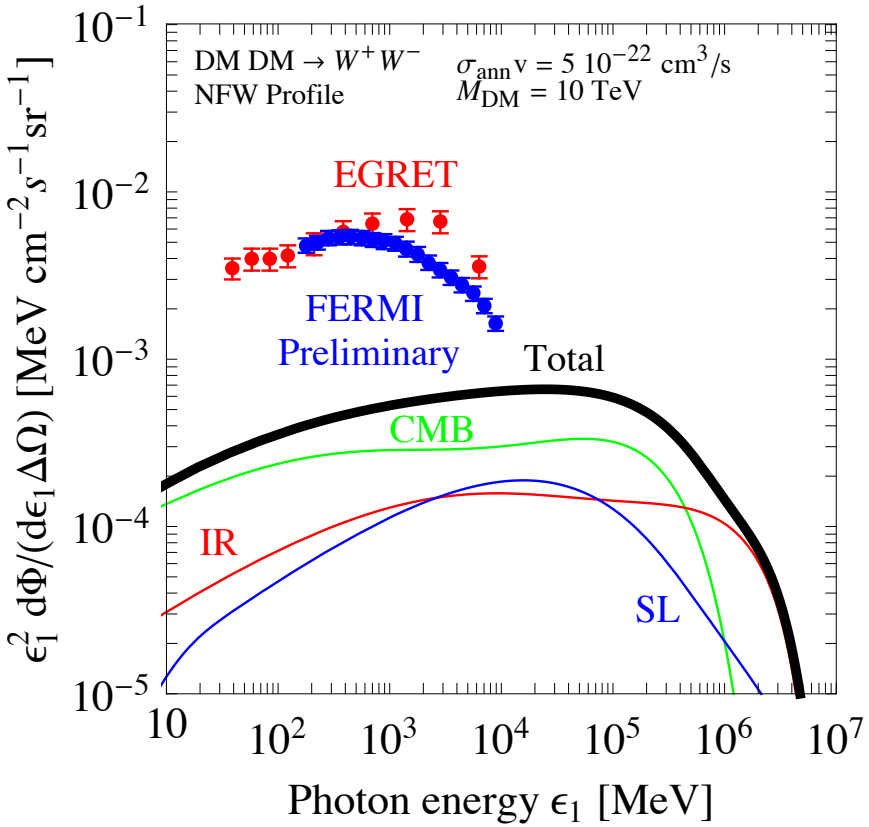


JCAP **1605** (2016) no.05, 031

How to test the Dark Matter hypothesis

- Check for compatibility of extracted DM properties with other measurements
- Measure γ-rays from inverse Compton (IC) scattering and synchrotron radiation
- Look at other potential DM annihilation channels
- Search for possible anisotropies from PWN or dense DM clumps

Correlations with γ-ray measurements

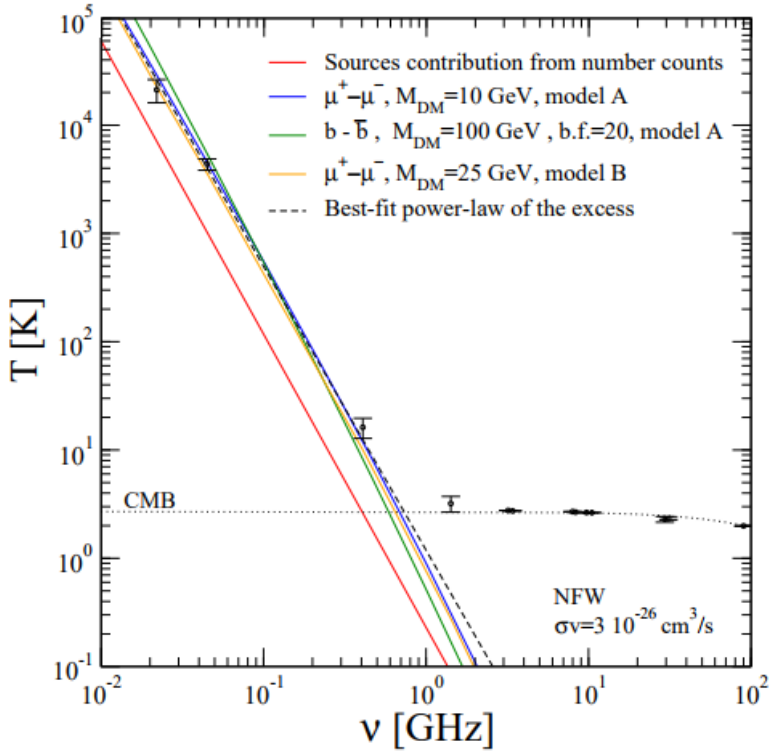


Nucl. Phys. B **821** (2009) 399

- Observed diffuse IC emission from nearby PWN
- Consistent with production efficiency $< 50\,\%$

  arXiv:1702.08436 [astro-ph.HE]

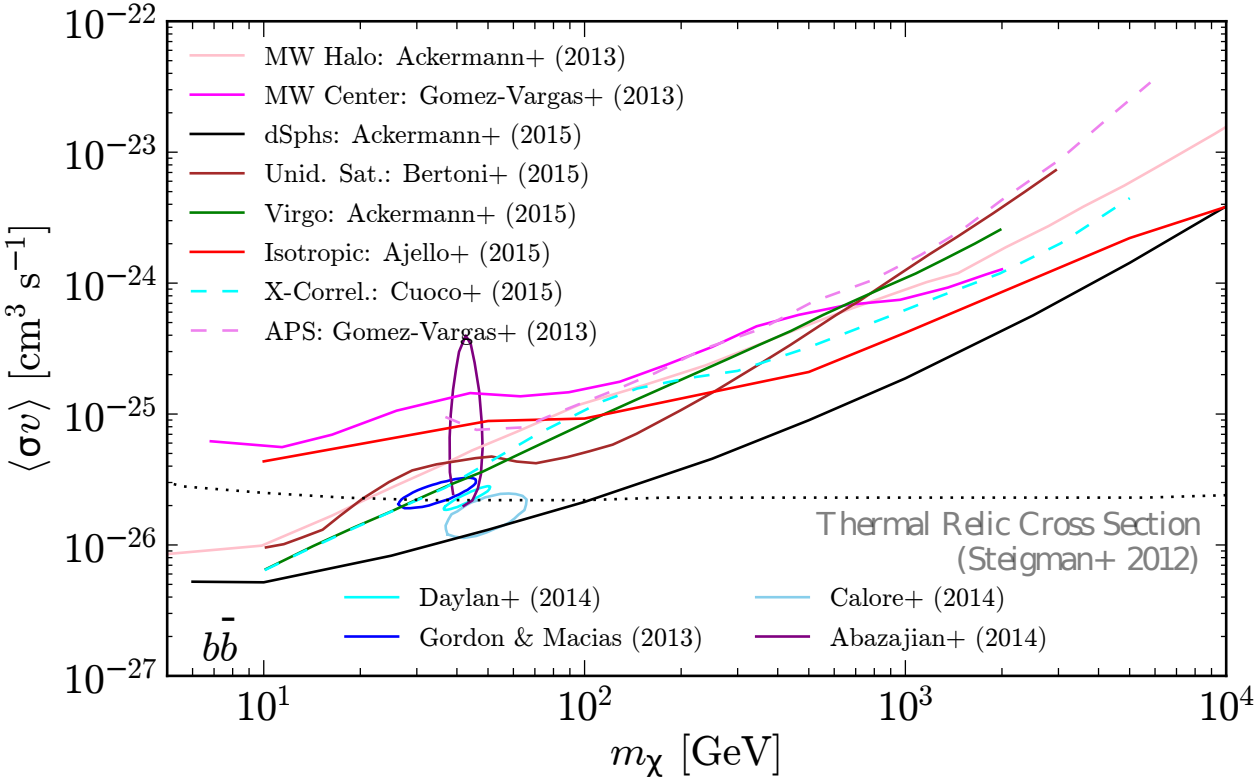
Correlations with synchrotron radiation



Phys. Rev. Lett. **107** (2011) 271302

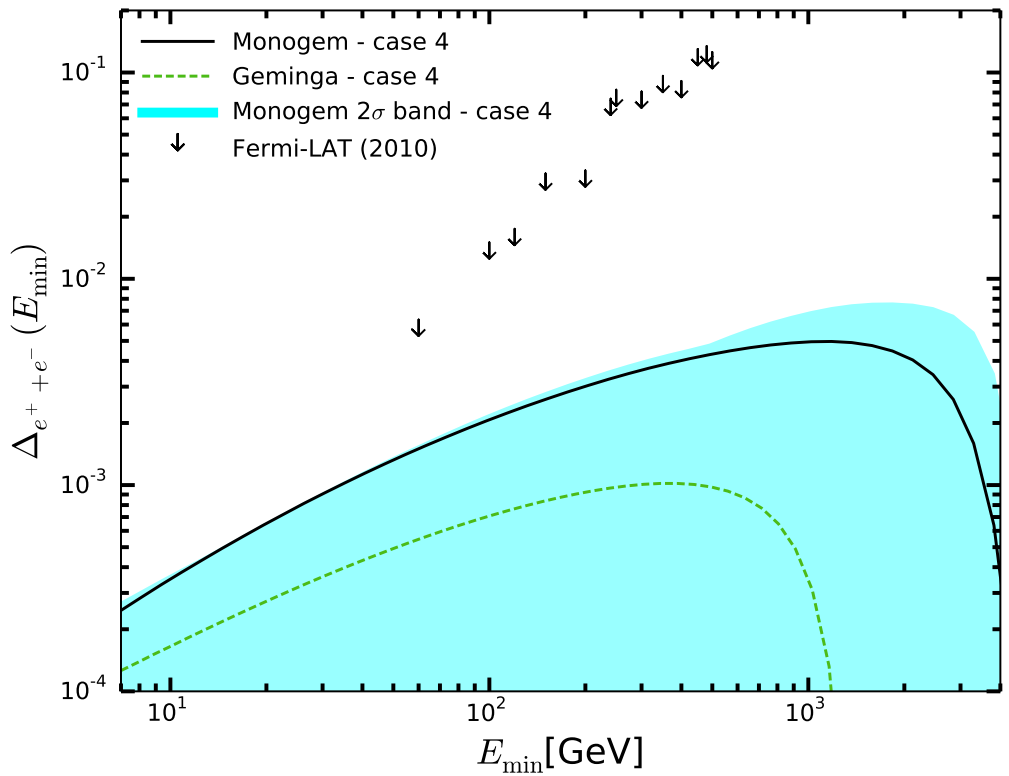
- Example: ARCADE 2 measurement of isotropic radio emission excess
- DM interpretation ruled out when combining with AMS e^+ data
  Phys. Rev. D **90** (2014) no.12, 127302

Consistency of measured annihilation cross-section



Phys. Rept. **636** (2016) 1

Looking for anisotropies



JCAP **1701** (2017) no.01, 006

- Experiments like FermiLAT sensitive to arrival direction of cosmic rays
- Searching for anisotropy to confirm PWN interpretation
- Observed anisotropy would rule out DM interpretation
  JCAP **1502** (2015) no.02, 043

Summary and conclusions

- e^+ production in astrophysical sources rules out DM as sole source
- e^+ spectrum alone insufficient to determine relative contributions from DM and PWN
- Other messengers needed to discriminate between both cases