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AMS-02 and Dark Matter

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20 Apr 2017
Alps 2017, Obergurgl Austria

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Three-body decaying Dark Matter, AMS-02 e^+ excess and indirect searches

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Based on : Cheng, WCH, Huang, Low, Tsai and Yuan: 1608.06382
Cheng, WCH, Low, Menon: 1012.5300
Cheng, WCH, Low, Shaughnessy: 1205.5270

Indirect Searches for Dark Matter
Multi-messenger approach

?

γ

Gamma rays
- Extremely simple propagation (geodesics)
- Absorption or energy losses negligible
- Point towards their sources

B-field

$\bar{p},\ e^+,\ \ldots$

Charged Cosmic rays
- Electrons/positrons, nuclei
- Propagation distorted by galactic magnetic fields
- Sizeable energy losses

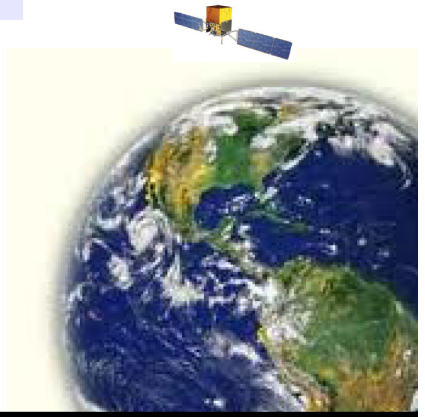
ν

Neutrinos
- Simple propagation
- But: very hard to measure

The dark matter **annihilation cross-section** today is roughly given by

$$\langle \sigma v \rangle_{\rm tot} \sim 3 \times 10^{-26} {\rm cm}^3 {\rm s}^{-1}$$

Since the conditions during freeze-out and today are very different, also the velocity averaged annihilation cross-section can differ by orders of magnitude.



Christoph Weniger's lecture 2013

AMS-02 in a nutshell

Weight 8,500 kg

Volume 64 cubic meters

Power 2,500 watts

Data downlink 9 Mbps (average)

Magnetic field intensity 0,15 Tesla (4,000 times stronger than the Earth magnetic field)

Magnetic material 1,200 kg of Neodymium alloy ($Nd_2Fe_{14}B$)

Subsystems 15 among particle detectors and supporting subsystems

Launch 16th May 2011, 08:56 am EDT

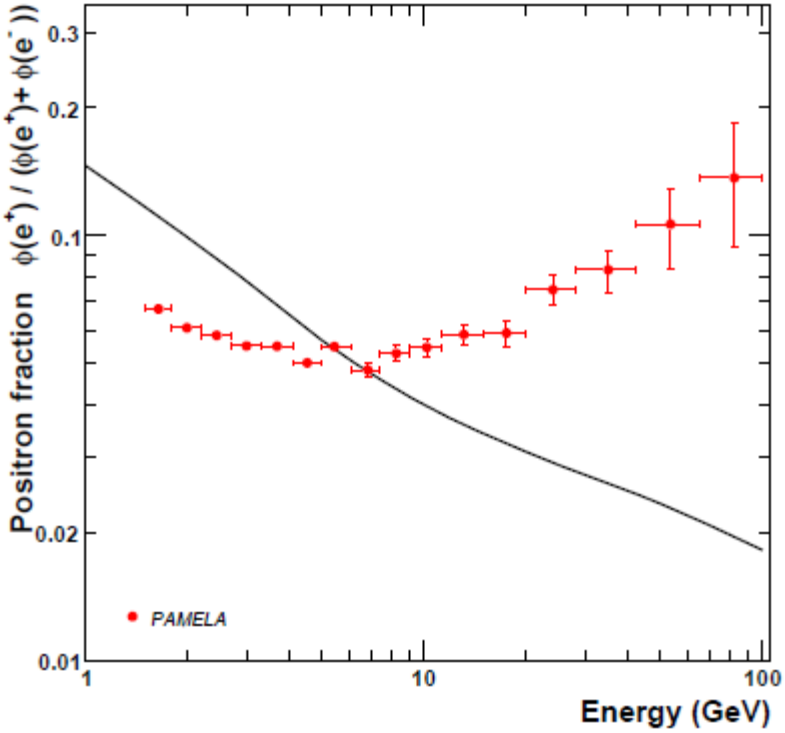
Mission duration through the lifetime of the ISS, until 2020 or longer (it will not return back to Earth)

Construction 1999-2010

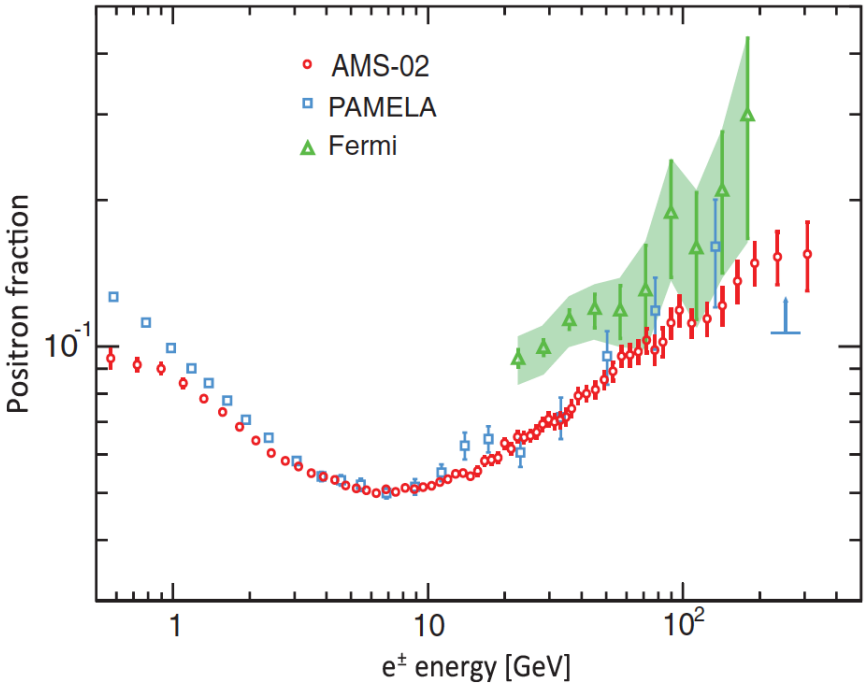
Cost $1.5 billion (estimated)

http://www.ams02.org/what-is-ams/ams-facts-figures/

Positron excess



PAMELA, 0810.4995



AMS-02, Phys. Rev. Lett. 110, 141102
April 2013

DM explanation

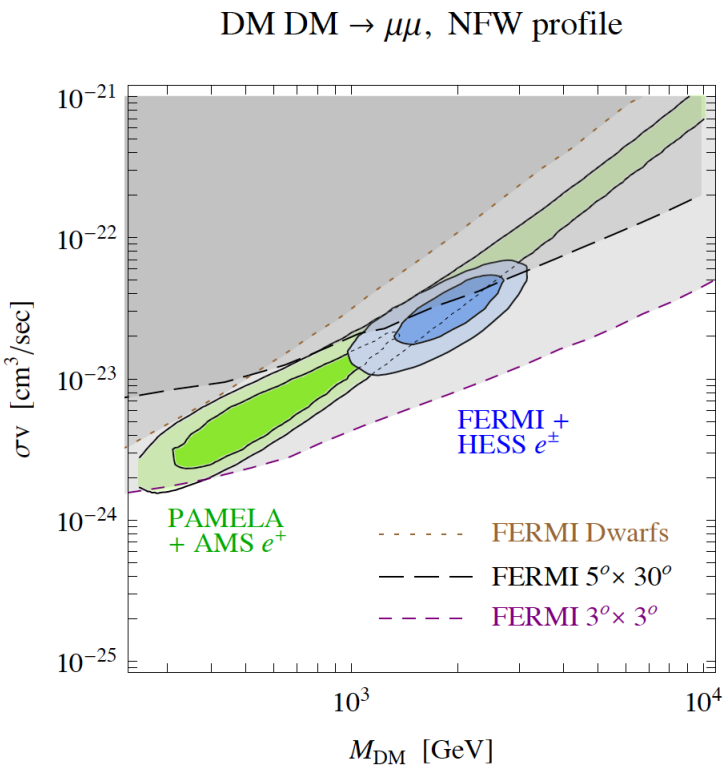
- Annihilating DM needs large booster factors of O(100) which can come from, for instance, a nearby DM clump or Sommerfeld Enhancements

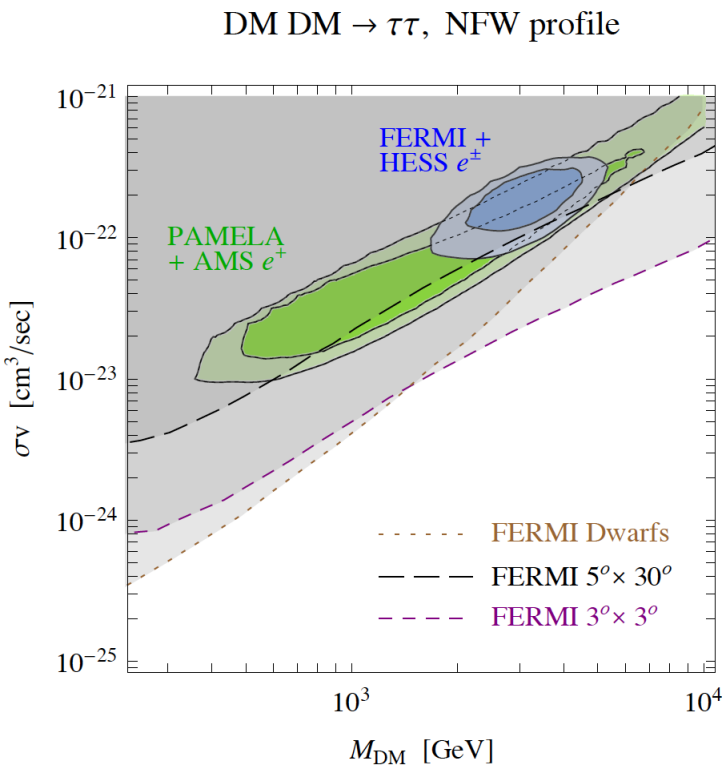
$$\langle \sigma v \rangle \gg 3 \times 10^{-26} \mathrm{cm}^3/\mathrm{sec}$$

Bergstrom et al., 0810.4995
Cirelli et al., 0809.2409 …

- Decaying DM requires a lifetime of $O(10^{26})$ sec to explain the positron excess

Constraints from Fermi-LAT





The current constraints on <σv> from dwarf spheroidal satellite galaxies will rule out the DM explanation (2→2)

Cirelli et al., 0809.2409

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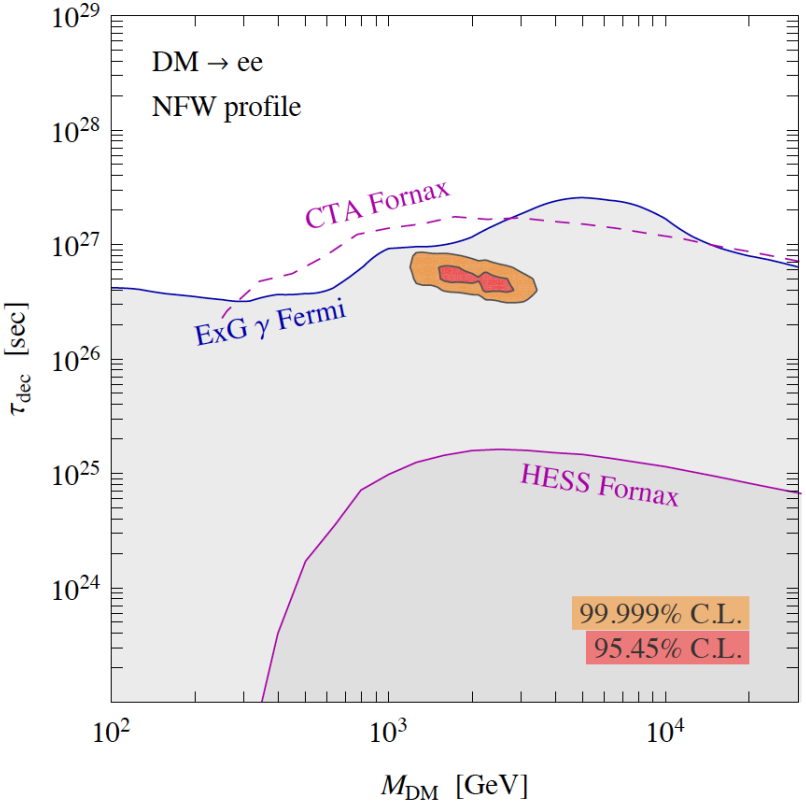
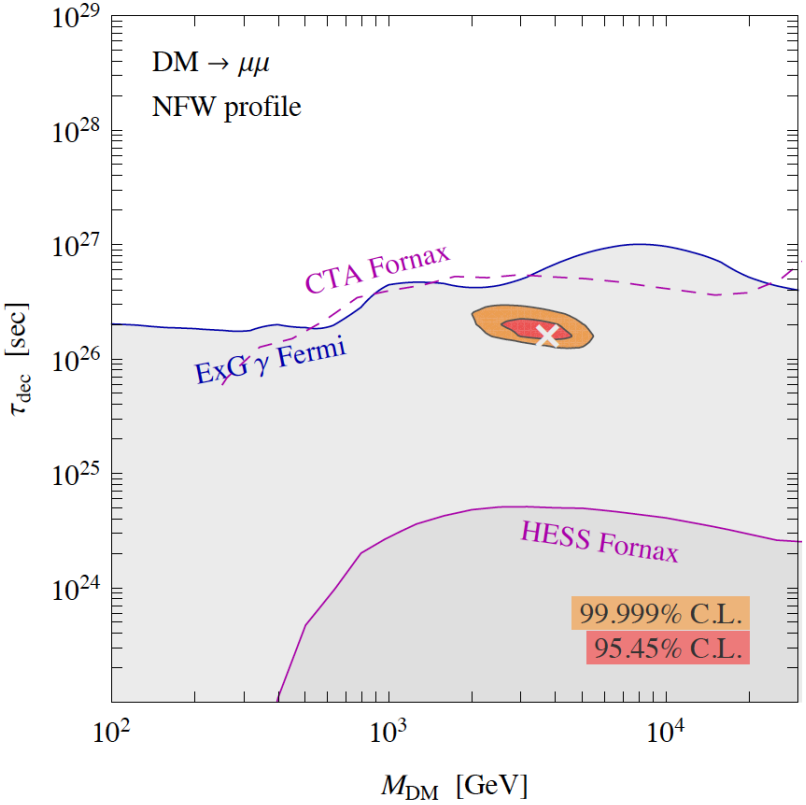
Constraints from Fermi-LAT





Cirelli et al., 1205.5283

The current constraints from isotropic extragalactic background will rule out decaying DM explanation (1→2)

3-body decaying DM

- DM decays into a stable neutral particle and a pair of SM fermions:

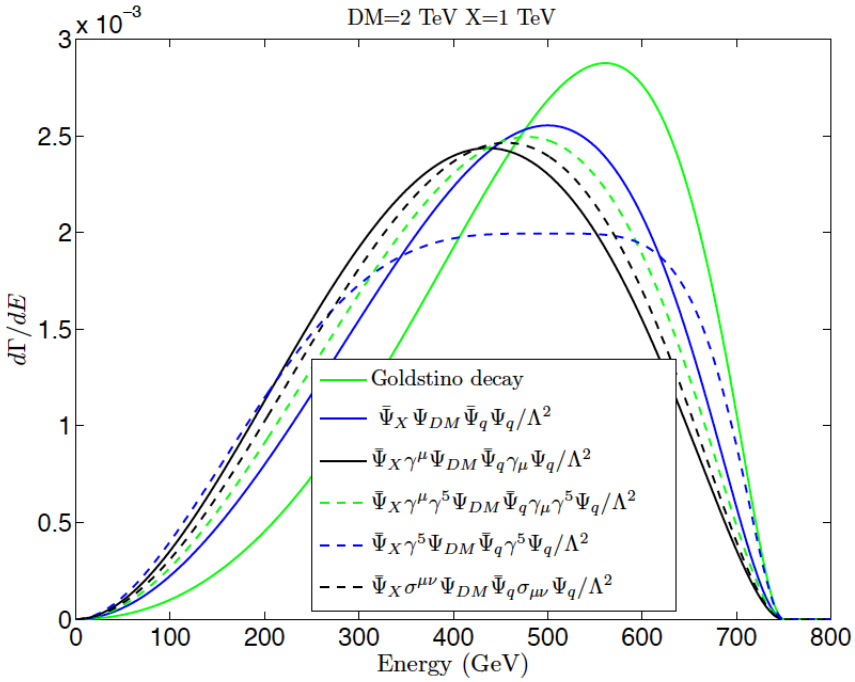
$$\chi \to \chi' \bar{f} f$$

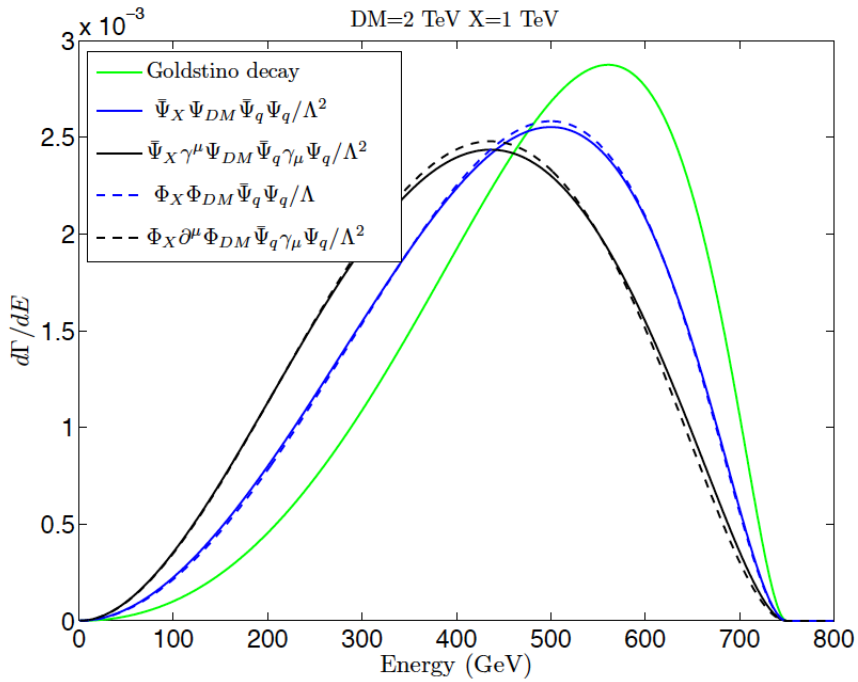
- Due to the softer energy spectrum from the three-body decay, such models can explain the AMS-02 positron excess without being excluded by gamma-ray and antiproton constraints

- Two examples: R-parity conserving super-wimp (0812.0432, 0906.3540) and multiple SUSY breaking sectors, goldstini (1002.1967)

3-body decaying DM

1205.5270





- Different types of operators behave similarly
- Scalar and fermion DM also feature similar energy spectra

3-body Decaying DM

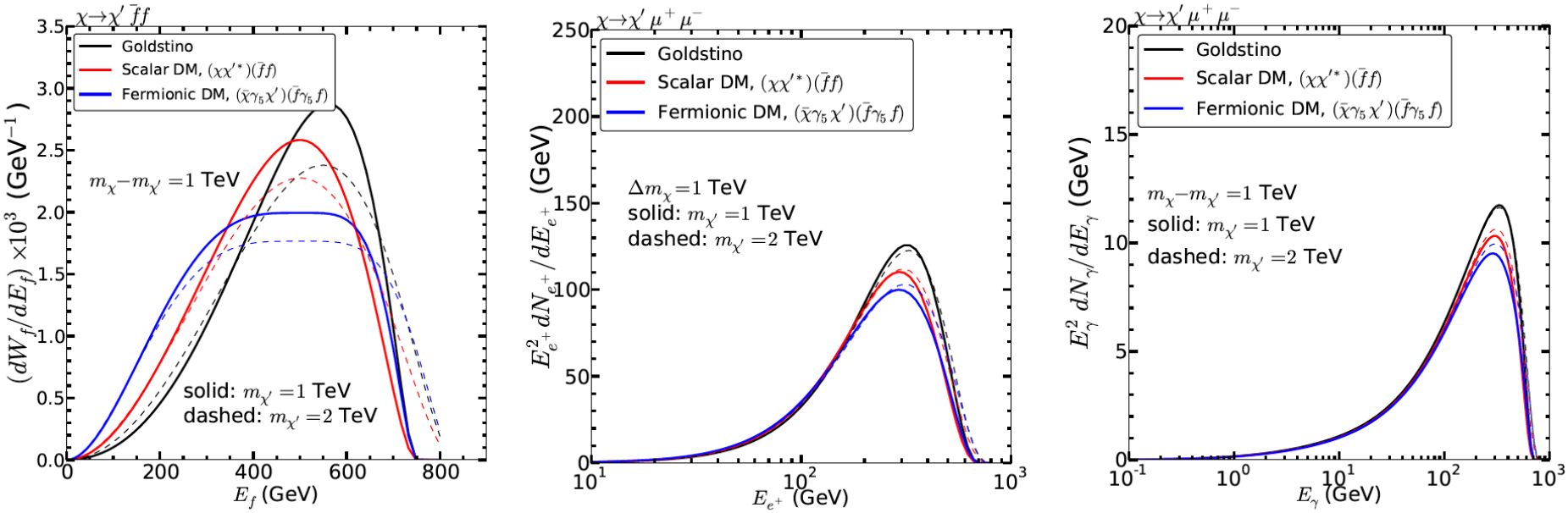


Figure 1. Primary spectrum (left), secondary electron (central) and photon (right) spectrum.

$$\frac{dN}{dE_e}\left(E'_e\right) = \int_{E'_e}^{E_\mu^{\max}} dE_\mu \underbrace{\frac{dW_\mu}{dE_\mu}\left(E_\mu\right)}_{\text{Primary spectrum}} \frac{dN_\mu}{dE_e}\left(E_\mu, E'_e\right),$$

- We use the intermediate energy spectrum, $\chi(\chi')^* \bar{f} f$, for data analysis.

Analysis in a nutshell

- NFW DM profile is employed
- We fit to the AMS e^+ fraction, (e^+ + e^-) and anti-proton spectrum
- The propagation of cosmic rays are simulated by GALPROP
- The likelihood analysis has been carried out by the tool “LikeDM” created by Huang, Tsai and Yuan (1603.07119)
- For DM-origin γ-rays, we consider inverse Compton (IC) scattering, final state radiation, bremsstrahlung, etc.

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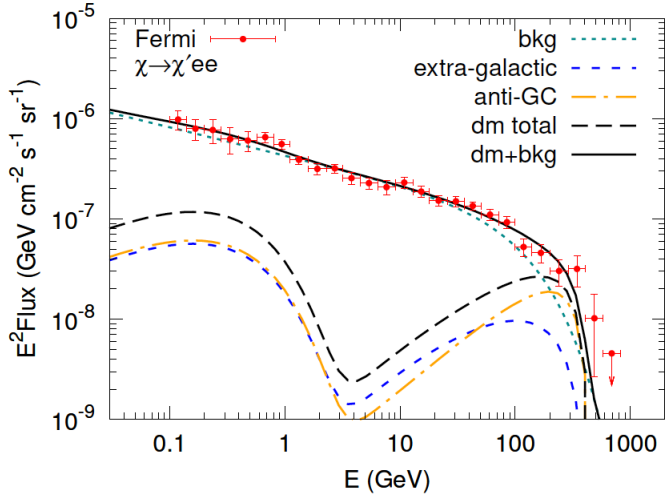
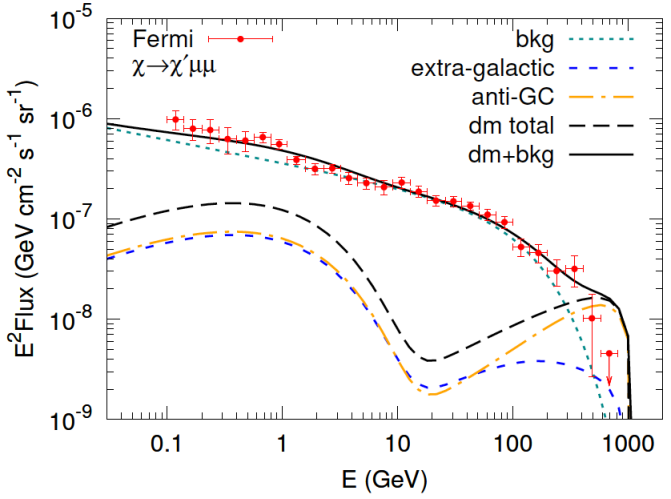
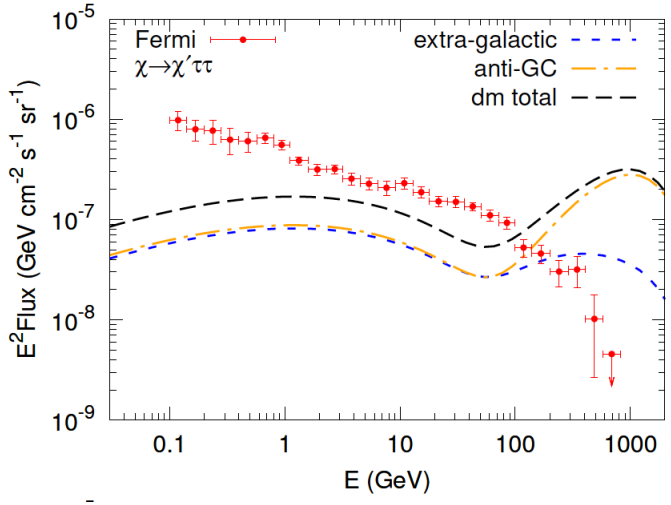
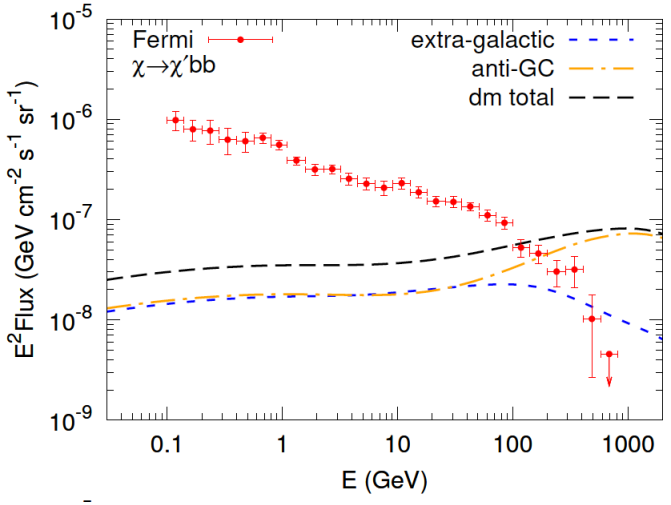
Fermi-LAT EGB constraints









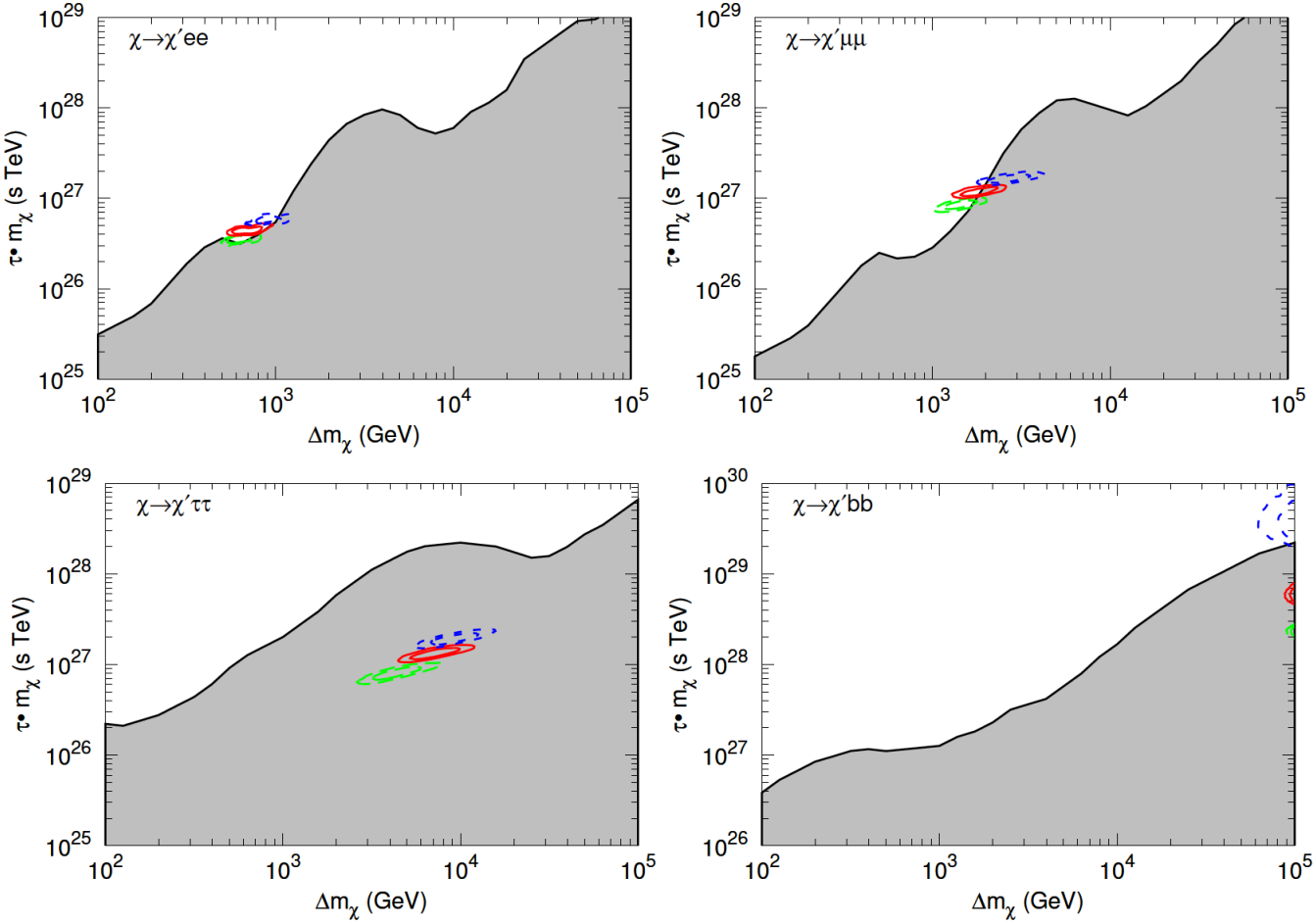
Diffuse γ-ray emission:

- Extra-galactic
- Anti-GC

which have

- IC component
- Prompt component

Fermi-LAT EGB constraints



Only e and μ can survive from the Fermi-LAT EGB constraints

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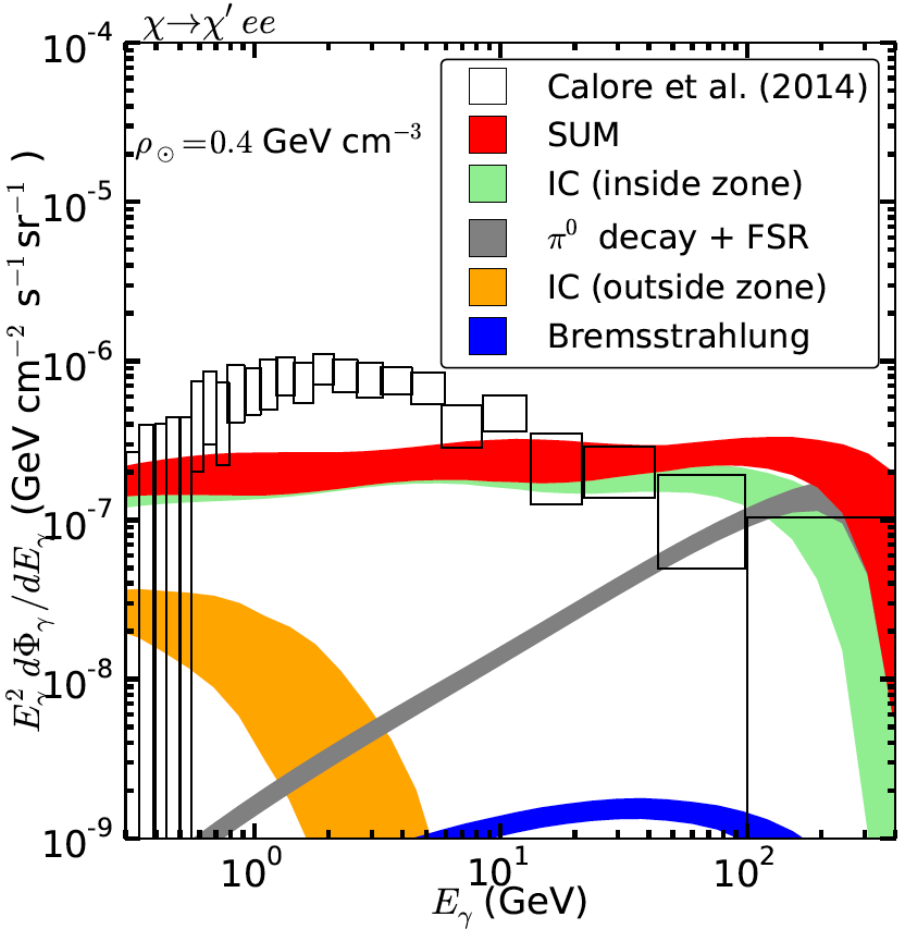
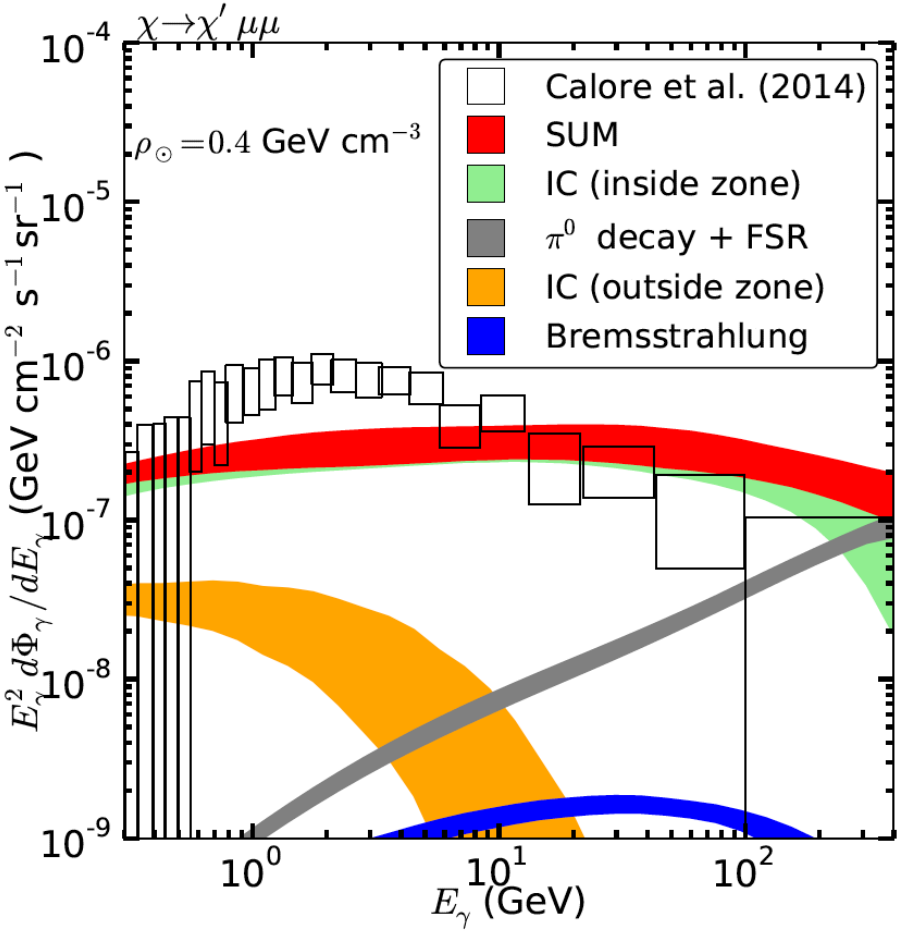
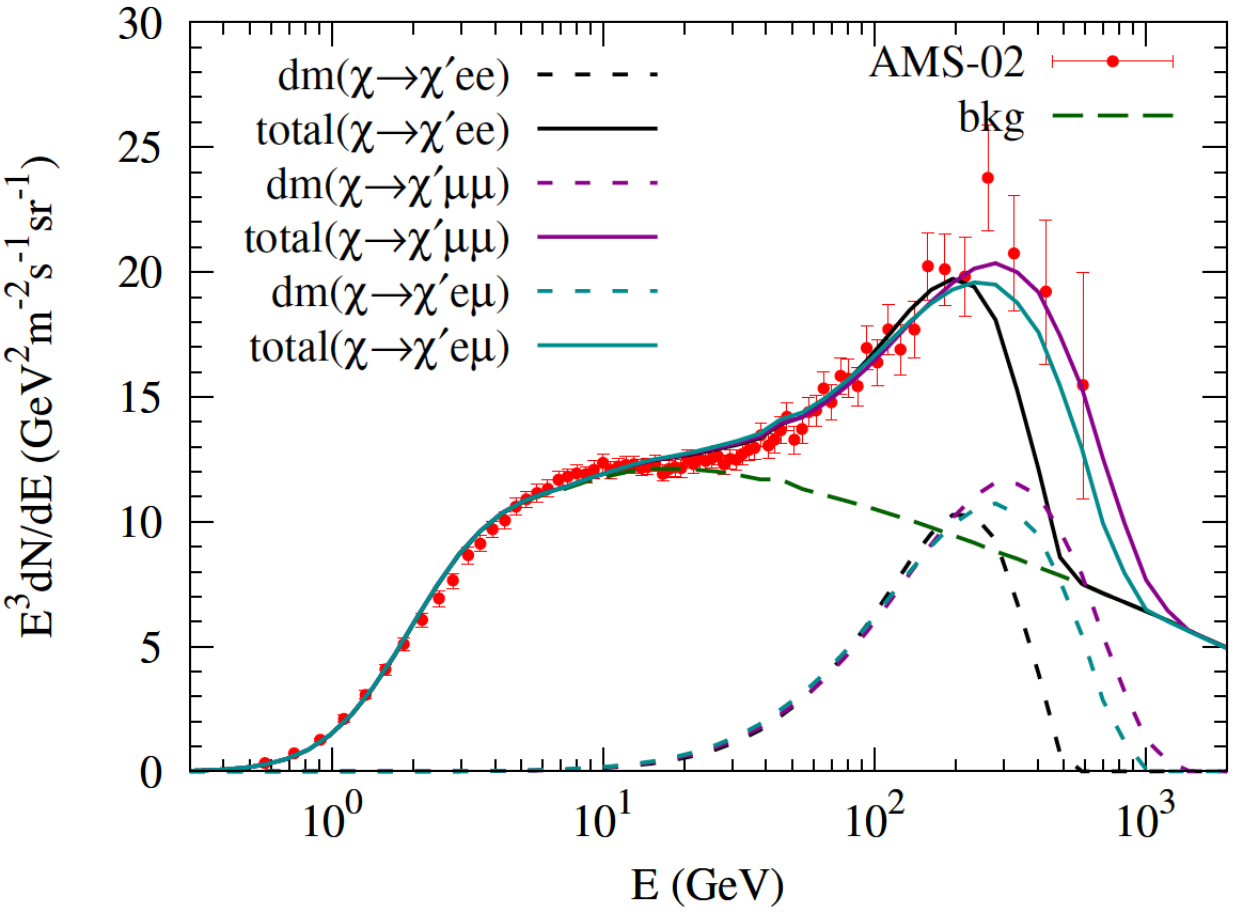
Galactic center γ-ray excess





New AMS-02 (2016) data



Conclusions

- 3-body decaying DM into a stable particle and a pair of SM fermions can account for the AMS-02 positron excess
- Channels which hadronize will overshoot the EGB data from Fermi-LAT
- Decays into electrons, muon or the mixture can survive from the EGB constraints
- Taking into account the data uncertainties, the electron and muon channels are below the observed excess in the inner Galaxy region