Searching for Dark Matter Signatures in Cosmic Rays with CALET

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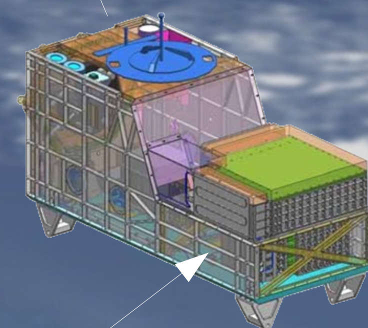
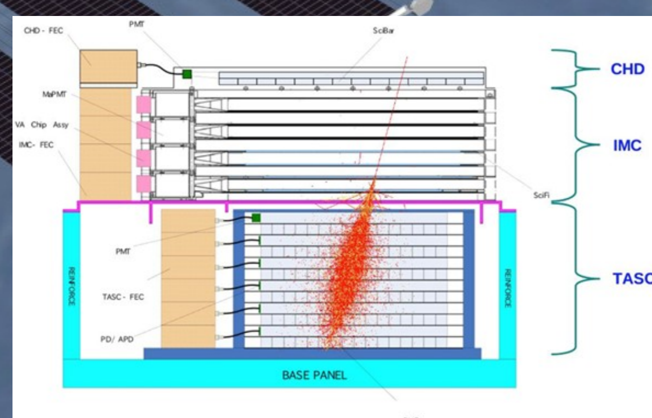
CALET
(Calorimetric Electron Telescope)

- Collaboration with groups from Japan, USA, Italy

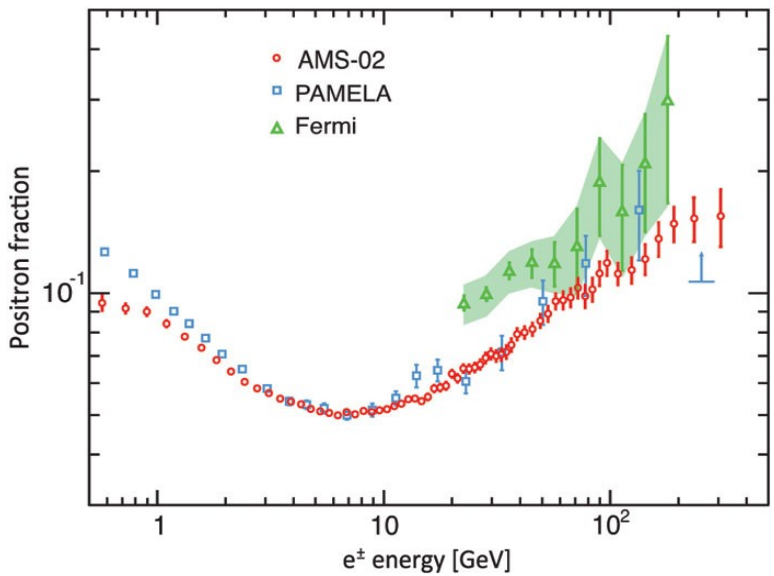
- Launch planned until 3/2015
- 5 year mission time
- 2% energy resolution
- 1200 cm²×sr aperture
- Proton rejection 10^{-5}





- Charge Detector
- Imaging Calorimeter
- Total Absorption Calorimeter
- 30 RL in total

Cosmic Ray Positron Excess



- Confirmed by several experiments in measurement of positron fraction
- Most precise measurement by AMS-02
- CALET will measure total electron + positron flux with 2% energy resolution up to several TeV energy => complementary information

- Nearby astrophysical accelerator(s)
  - Default scenario: Pulsar
  - **Investigated Question 1:** What limits can be set on Dark Matter Annihilation on top of nearby pulsar source
- Dark Matter Annihilation
  - Requires large boost factor and lepton dominated annihilation
  - **Investigated Question 2:** How well can CALET constrain mass and boost factor

Parameterization

Φ_e = total flux of electron+positron Φ_{e^+} = positron only flux

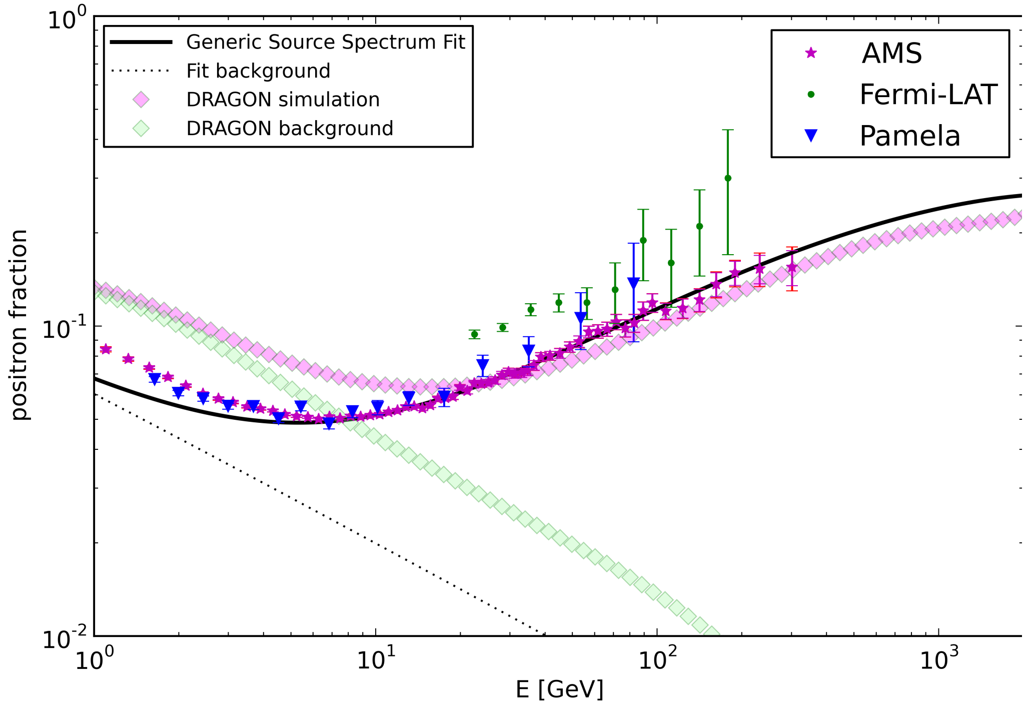
$$\Phi_e(E) = 2\Phi_{DM}(E)\cdot BF + C_e E^{\gamma_e}\left(2\frac{C_s}{C_e}E^{\gamma_s-\gamma_e}\cdot\exp\left(\frac{-E}{E_{cut_s}}\right) + \left(\frac{C_{e^+}}{C_e}\cdot E^{\gamma_{e^+}-\gamma_e}+1\right)\cdot\exp\left(\frac{-E}{E_{cut_d}}\right)\right)$$

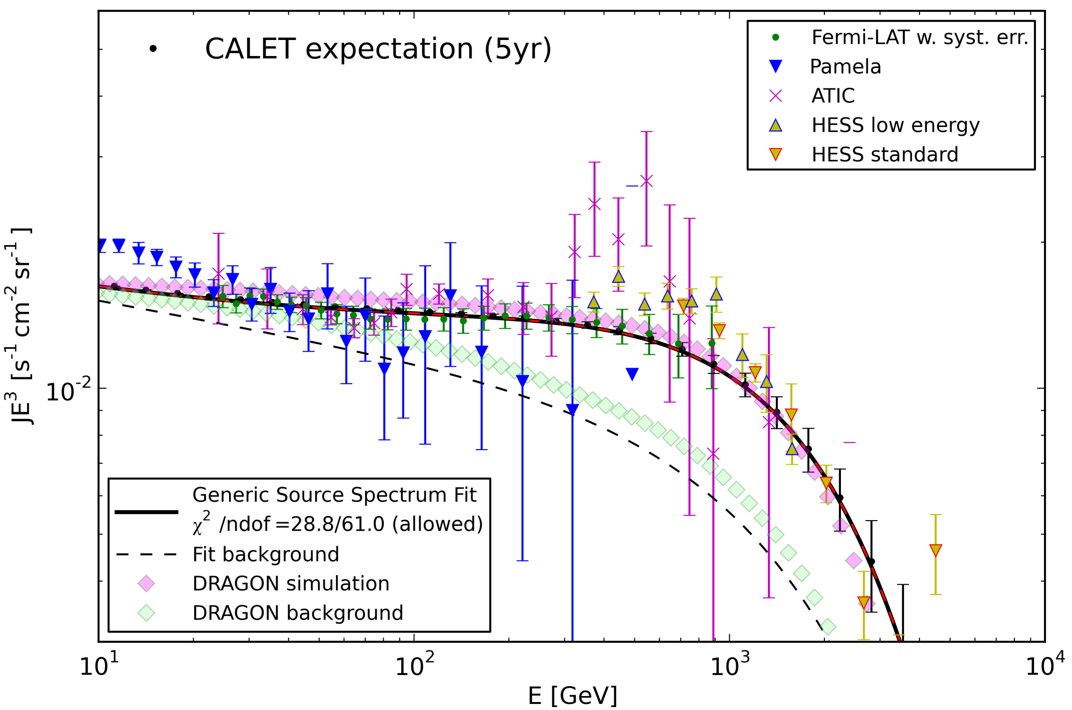
Positron Fraction Coefficient	C_{e+}/C_e
Total Flux Coefficient	C_e
Power Law Index of Total Flux	γ_e
Power Lax Index Difference e^+-total	$\gamma_{e+}-\gamma_e$
Power law index Generic Source	$\gamma_s-\gamma_e$
Coefficient of Generic Source	C_s/C_e
Generic Source Cutoff Energy	E_{cuts}
Boost Factor of Dark Matter	BF
Cutoff of Diffuse Flux	E_{cutd}

- Power law diffuse background flux with different index for total and secondary positron flux and exponential cutoff from propagation
- Power law spectrum of local accelerator (pulsar) with exponential cutoff and with same coefficient and index for electron and positron flux
- Dark Matter Flux Φ_{DM} calculated with DarkSUSY (**and Micromegas to compare**) for NFW profile and annihilation x-section $\langle\sigma v\rangle = 3 \times 10^{-26}$ cm^{3}s^{-1}

$$\frac{\Phi_{e^+}(E)}{\Phi_e(E)} = \frac{\frac{\Phi_{DM}(E)\cdot BF}{C_e E^{\gamma_e}} + \frac{C_s}{C_e}E^{\gamma_e-\gamma_s}\cdot\exp\left(\frac{-E}{E_{cut_s}}\right) + \frac{C_{e^+}}{C_e}\cdot E^{\gamma_{e^+}-\gamma_e}\cdot\exp\left(\frac{-E}{E_{cut_d}}\right)}{\frac{2\cdot\Phi_{DM}(E)\cdot BF}{C_e E^{\gamma_e}} + 2\frac{C_s}{C_e}E^{\gamma_e-\gamma_s}\cdot\exp\left(\frac{-E}{E_{cut_s}}\right) + \left(\frac{C_{e^+}}{C_e}\cdot E^{\gamma_{e^+}-\gamma_e}+1\right)\cdot\exp\left(\frac{-E}{E_{cut_d}}\right)}$$

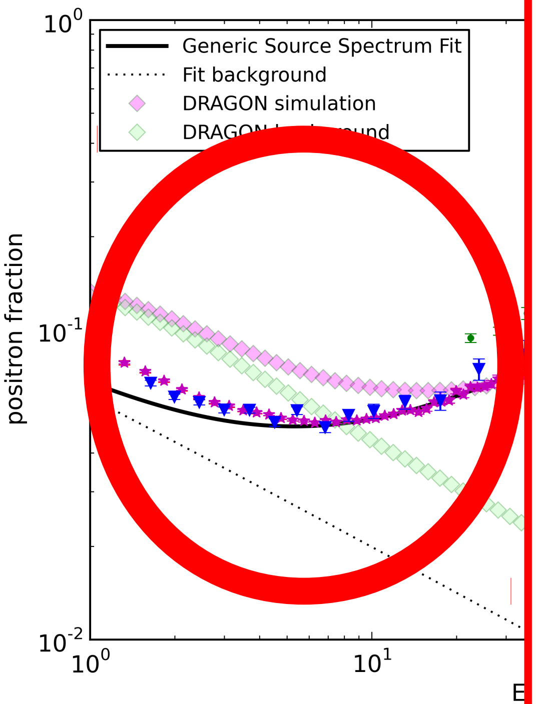
Pulsar Solution Fitted to AMS-02 + Fermi-LAT Data

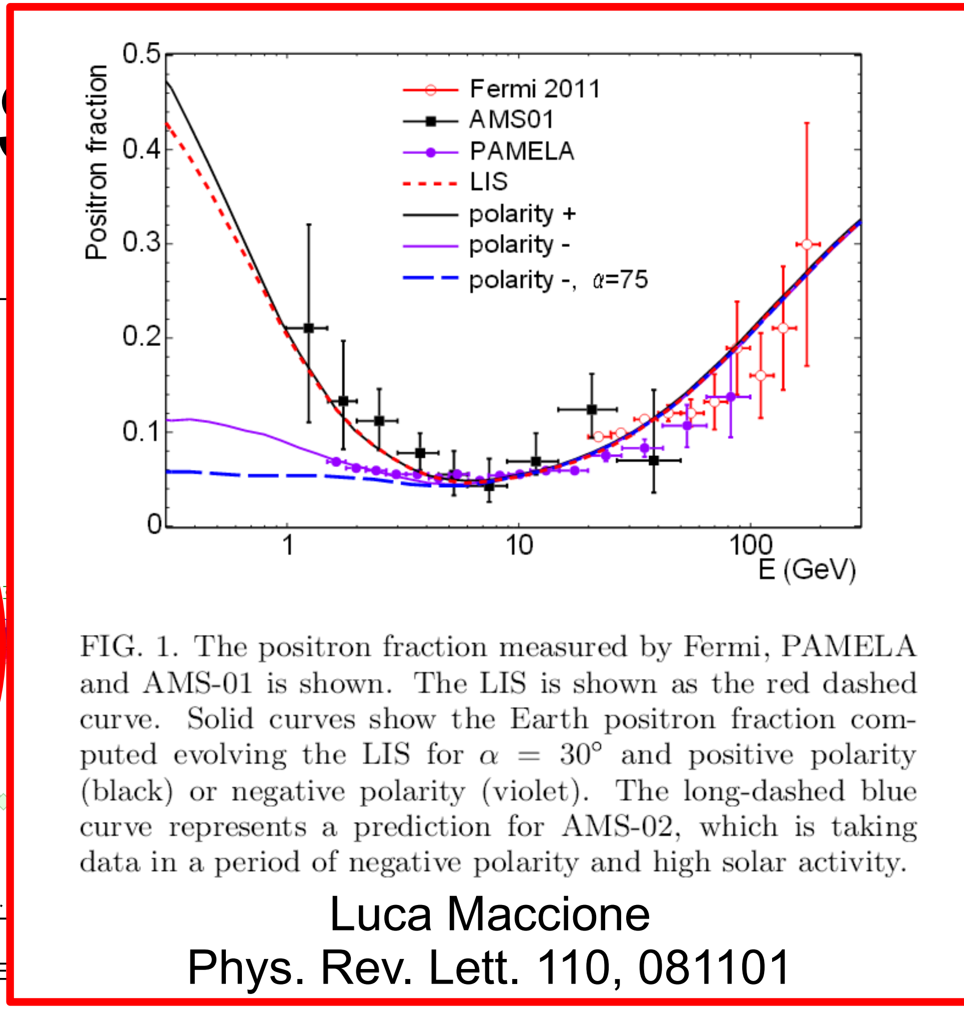


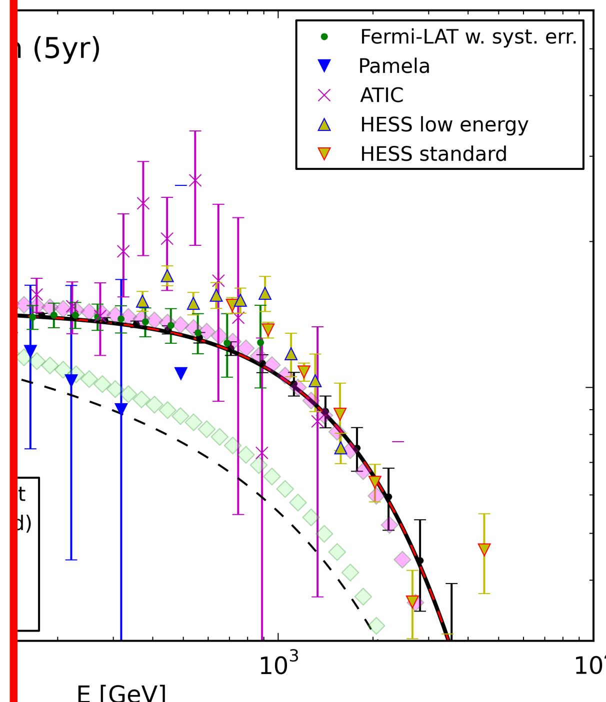


- Positron fraction from AMS-02 and total flux data from Fermi used to determine parameters **initially without the Dark Matter term**
- Fraction and total flux reproduced with 3D DRAGON propagation simulation code to validate the parameterization (around 20% level)
  - one pulsar as extra point source at 0.3 kpc distance
  - Cutoff energy parameter fixed: E_{cut_d} = 2 TeV

Pulsar MS-02 +







- Positron fraction at low energy is significantly influenced by charge dependent solar modulation
  - Data-points below 10 GeV energy are not used in the fit
  - Physically meaningful value needed for γ_{e+}-γ_e : using relation to δ
  - Simulation with δ = 0.6 indicates γ_{e+}-γ_e = - 0.5 => fixed to this value

Dark Matter Limit Calculation Method

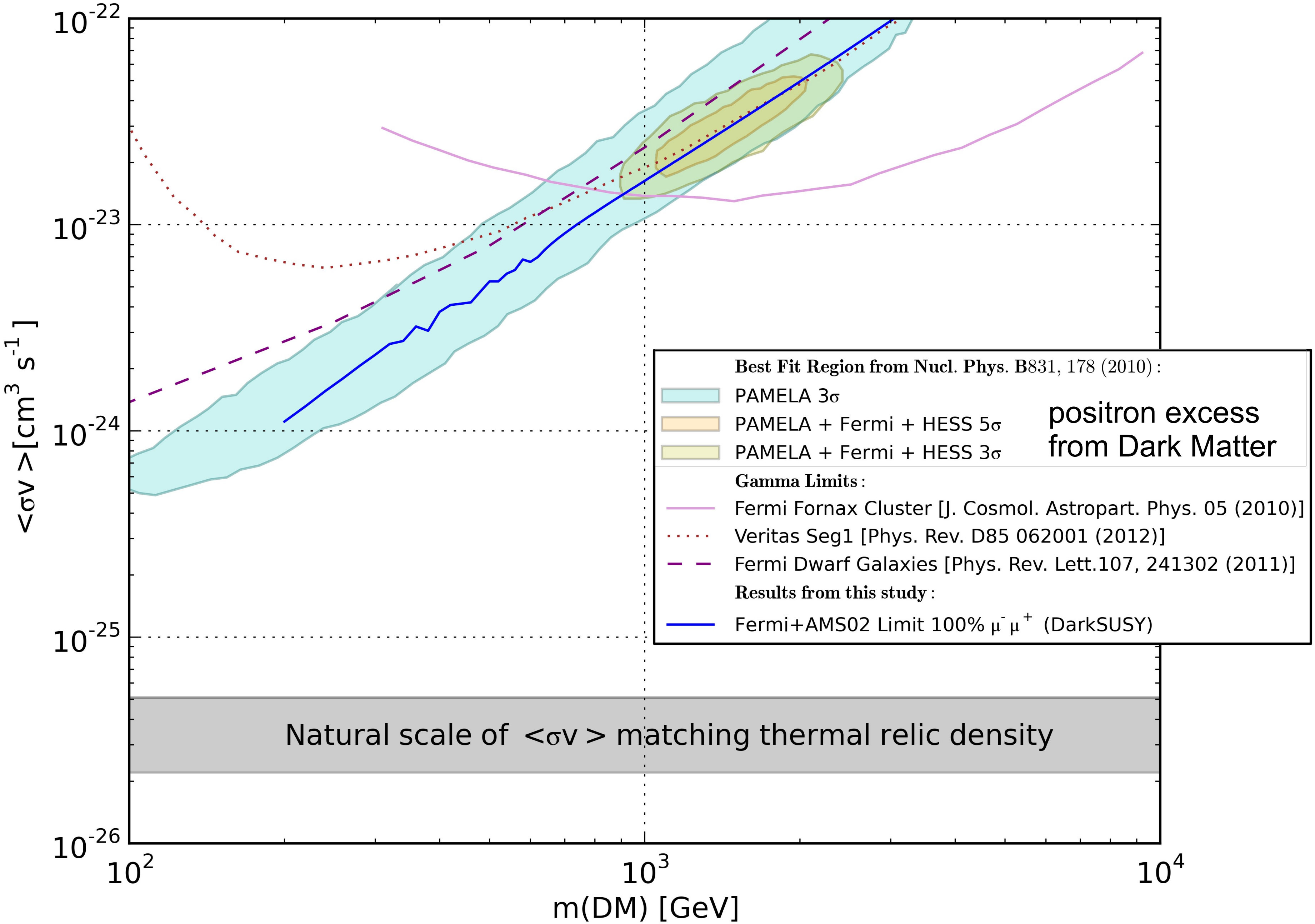
- Assumption that a nearby pulsar is the reason for the excess
- **Investigated Question 1:** What limits can be set on Dark Matter Annihilation on top of nearby pulsar source

- **Starting from the best pulsar fit, the Dark Matter term is added and the boost factor increased, until 95%CL exclusion limit reached**
- **The fit is repeated in each step to optimize pulsar and background parameters**

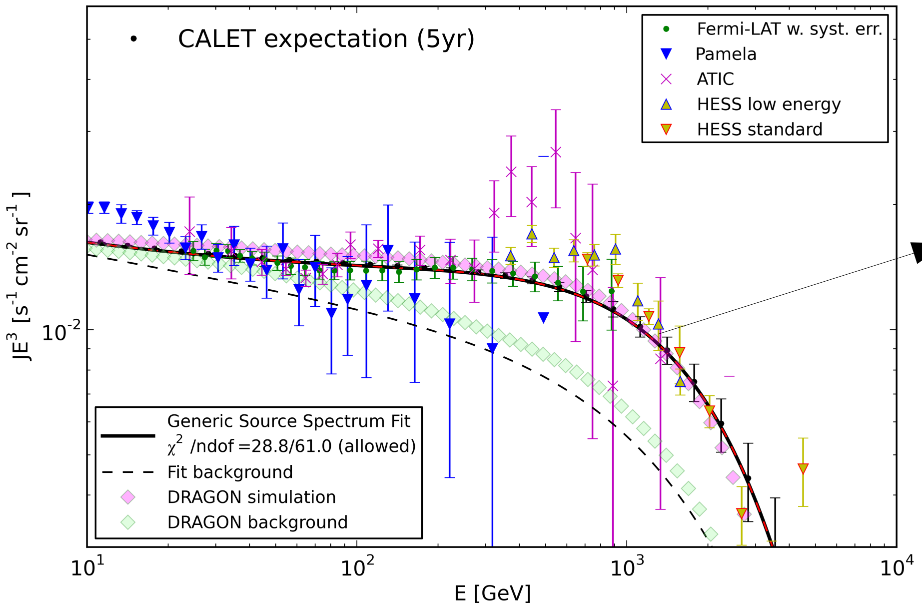
- Boost factor limit translated into effective annihilation cross-section by multiplication with $\langle\sigma v\rangle = 3 \times 10^{-26}\ cm^3 s^{-1}$

=> Initially calculated limit for Fermi + AMS-02

Fermi+AMS02 Limit on Dark Matter Annihilation for 100% $\mu^+\mu^-$-channel DM



Dark Matter Sensitivity of CALET



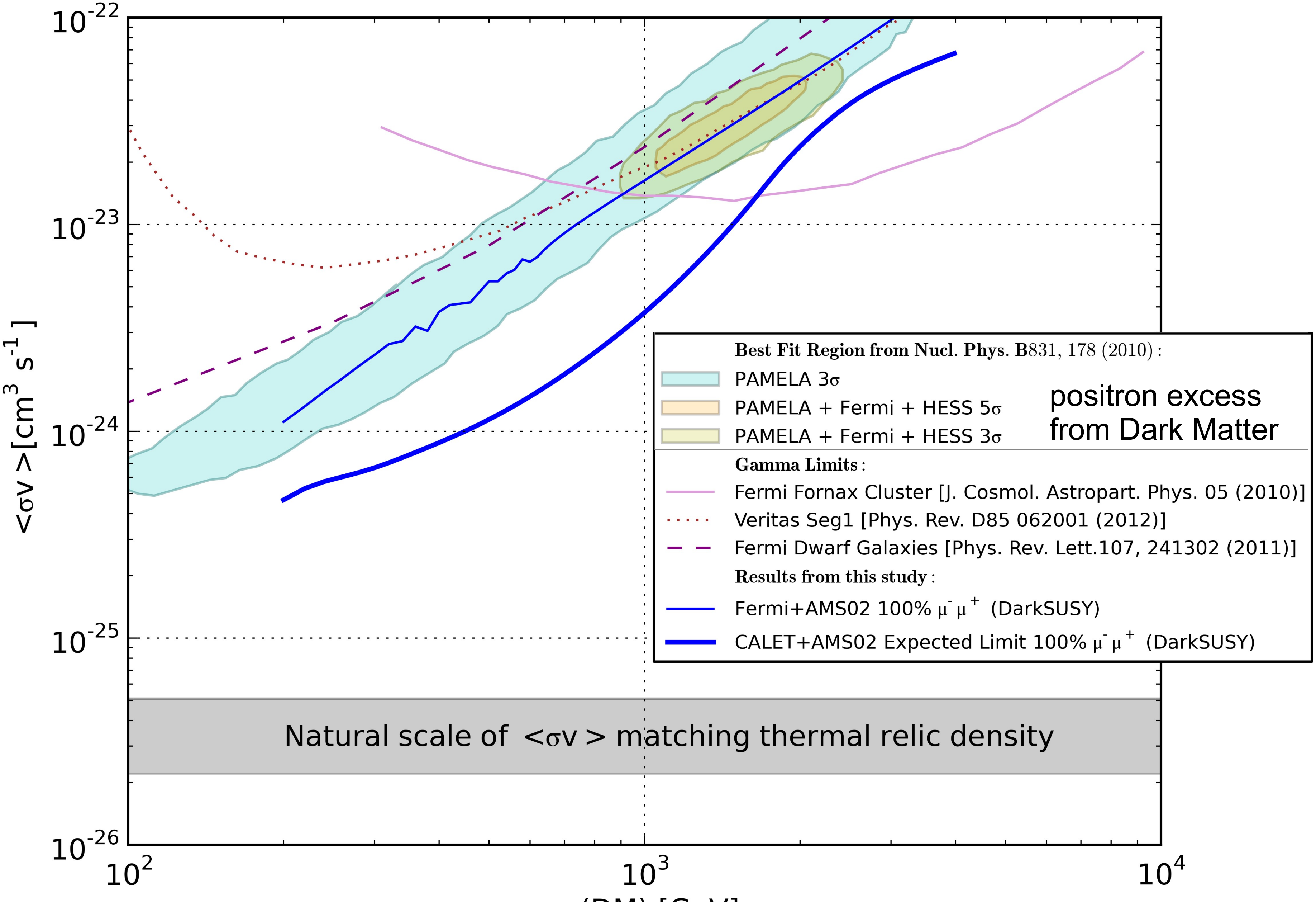
- randomized
- 5 year measurement
- 2% energy resolution
- 1200 cm²×sr aperture
- 90 % reconstruction efficiency

Expected Signal Samples

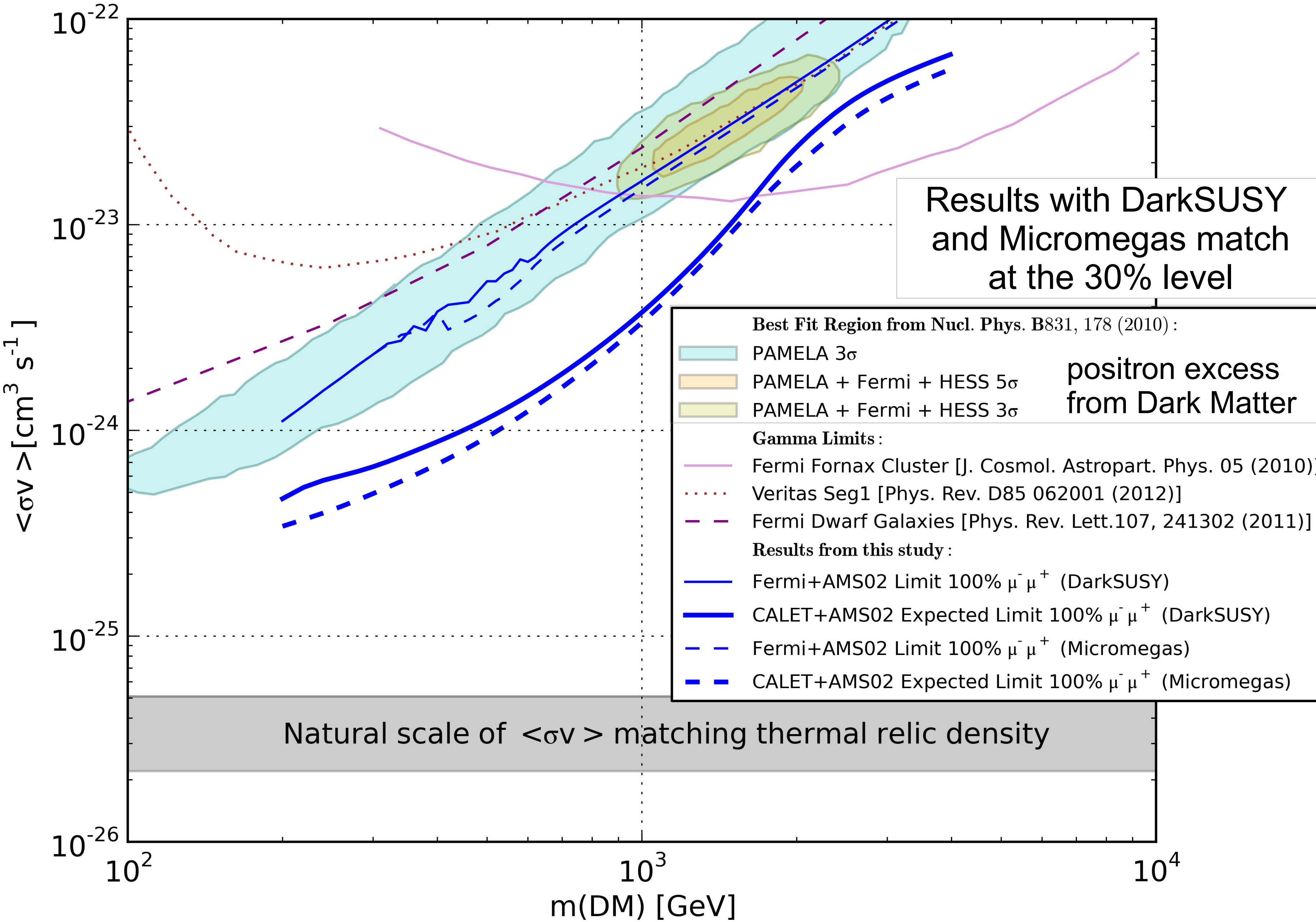
- 100 samples of 5-yr CALET data according to best fit prediction of AMS-02 + Fermi-LAT were simulated
- Same analysis method as for Fermi-LAT + AMS-02 results applied to 100 CALET samples + AMS-02 data
- sensitivity = average value of final allowed boost factor

(multiplied with $\langle\sigma v\rangle = 3 \times 10^{-26}$ cm^{3}s^{-1})

Expected Limit on Dark Matter Annihilation for 100% $\mu^+\mu^-$-channel DM



Expected Limit on Dark Matter Annihilation for 100% $\mu^+\mu^-$-channel DM



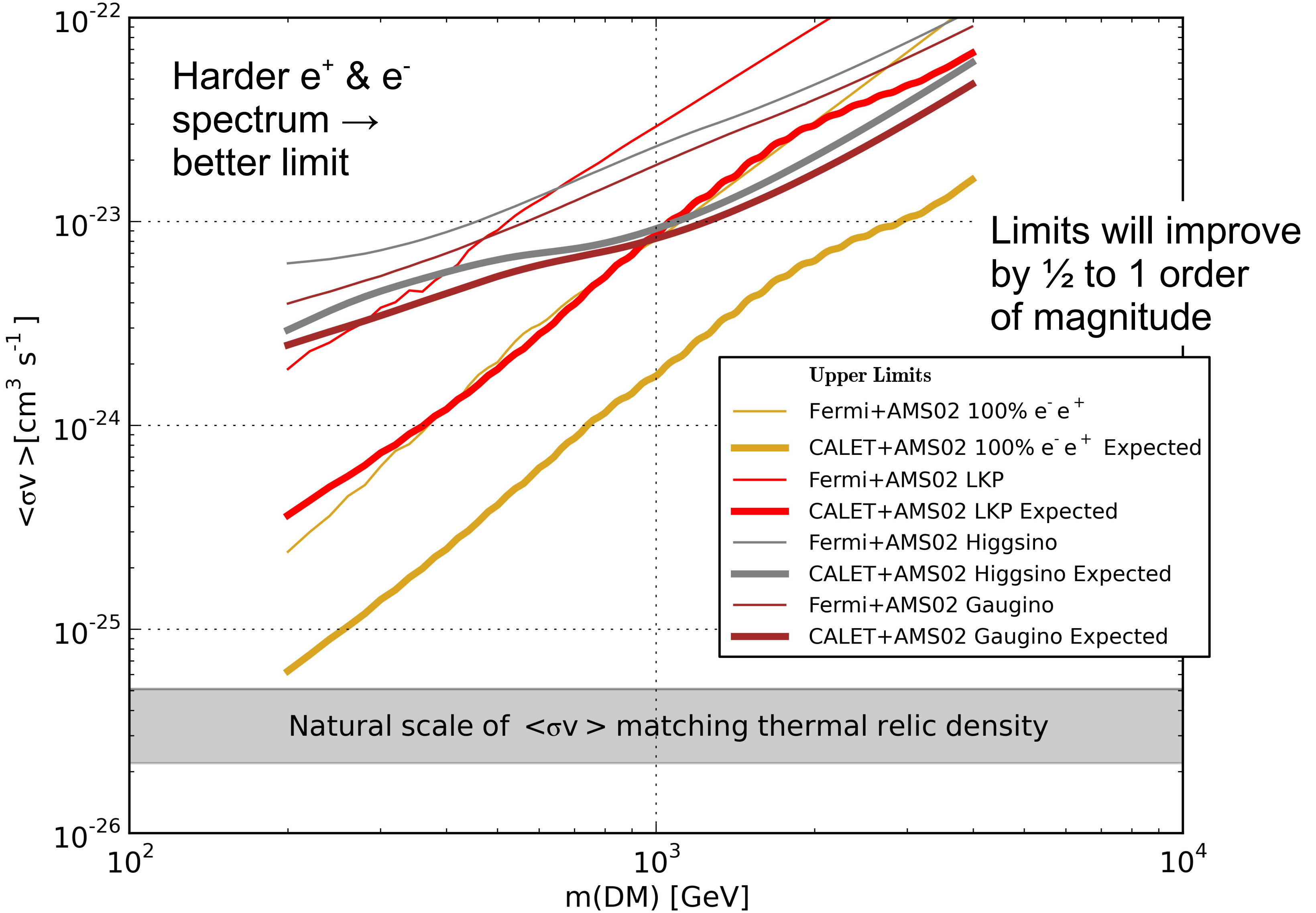
Overview of Expected Limits on Dark Matter Annihilation

Branching Ratios

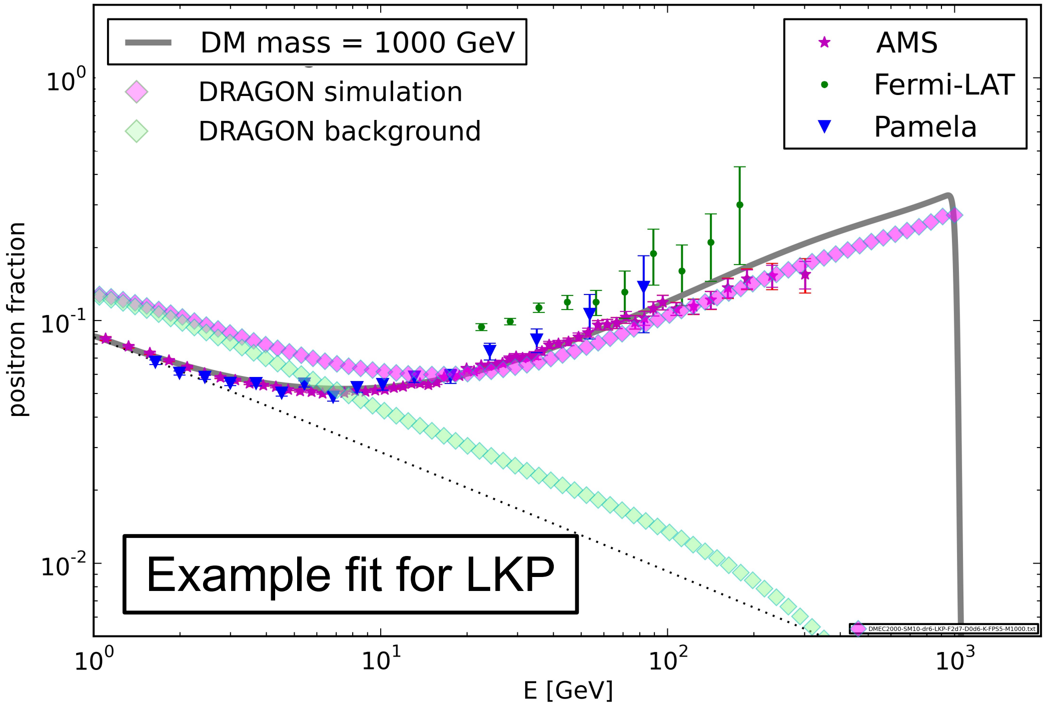
LKP (Lightest Kaluza-Klein Particle):
20% e^+e^-,
20% $\mu^+\mu^-$,
20% $\tau^+\tau^-$,
11% $u\bar{u}$,
11% $c\bar{c}$,
11% $t\bar{t}$,
2% hh

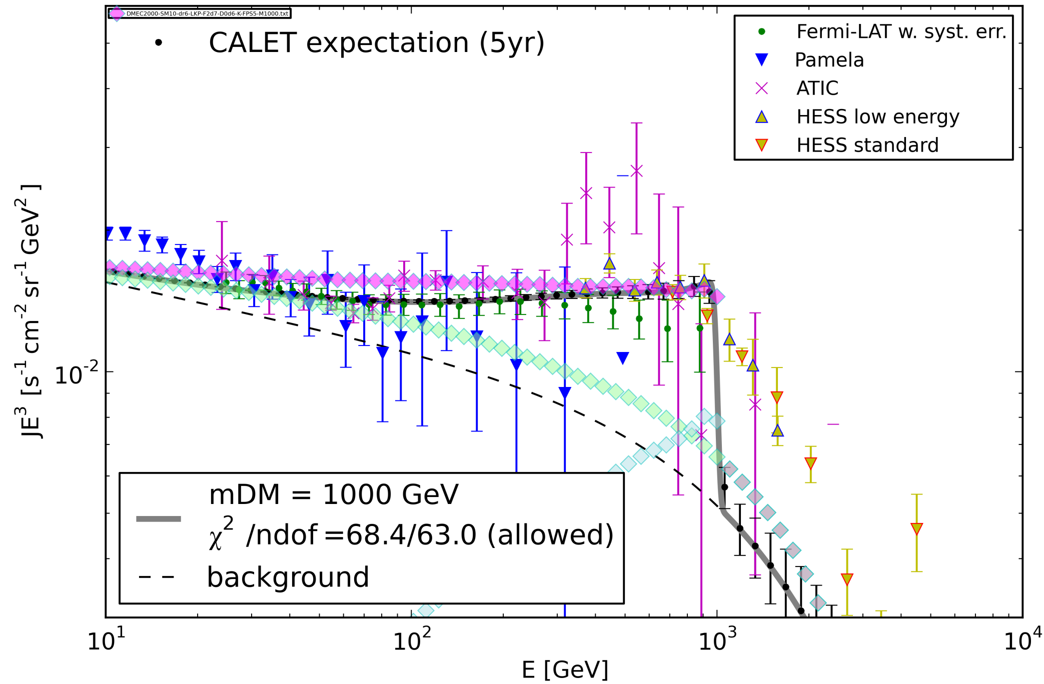
Higgsino:
85% $b\bar{b}$,
15% $\tau^+\tau^-$

Gaugino:
50% ZZ,
50% W^+W^-



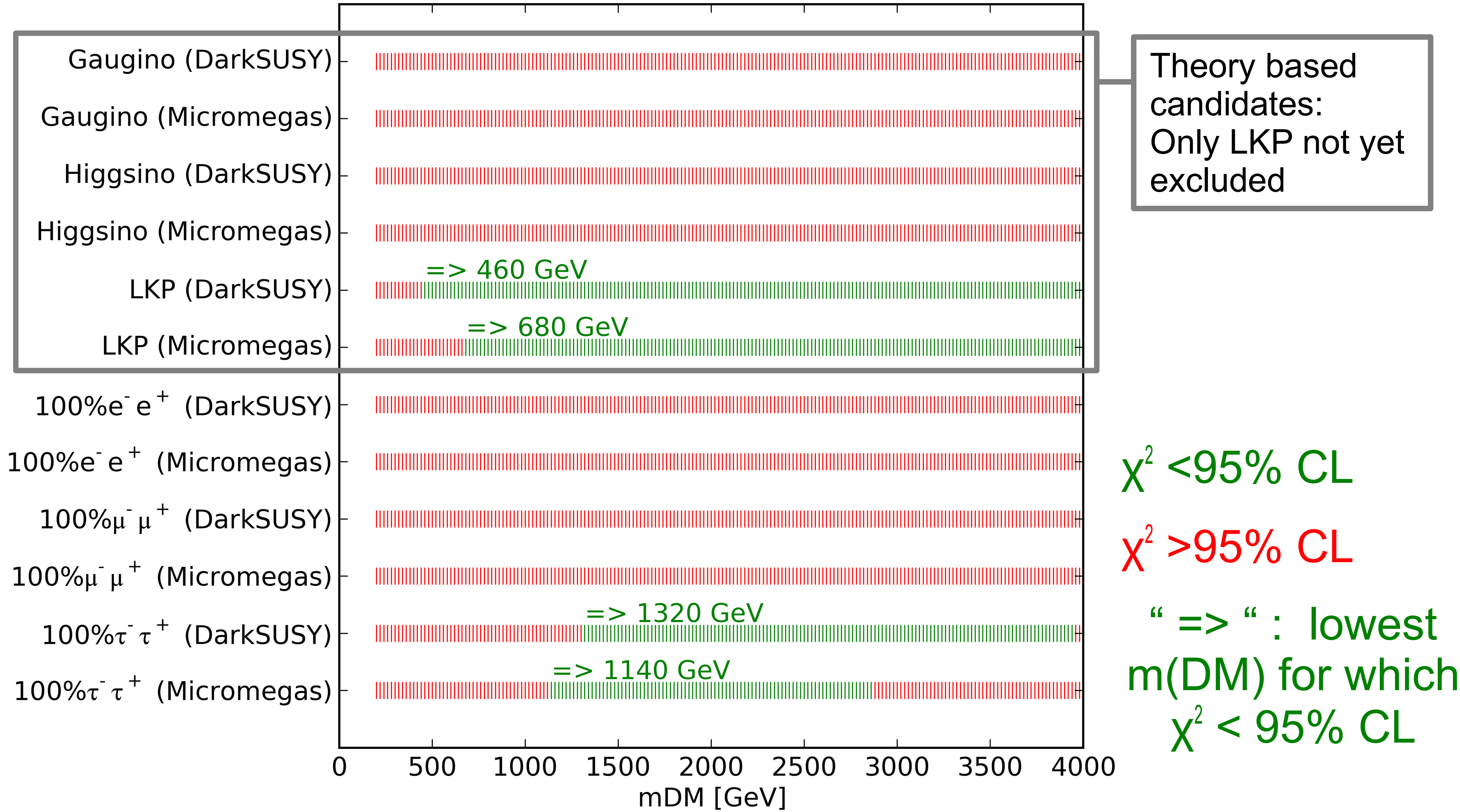
Which Type of Dark Matter Could Explain the Positron Excess ?





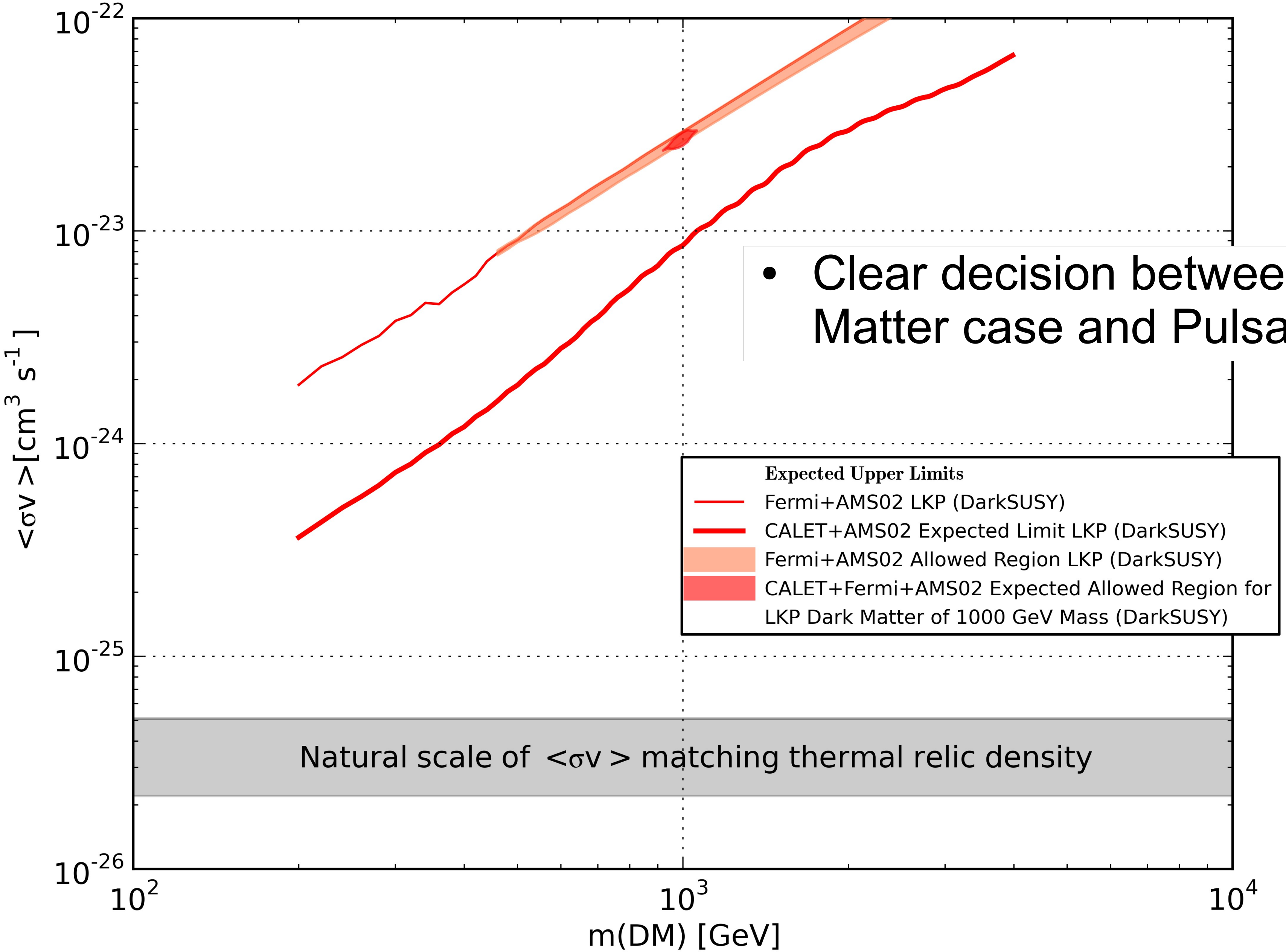
- Tested several Dark Matter candidate particles scanning the mass from 200 GeV to 4 TeV for ability to **explain positron excess only by emission from annihilation – given a sufficiently high boost factor**
- Fit of parameterization **without pulsar term** to AMS-02 and Fermi-LAT data => χ^2 <95% CL: allowed model

Allowed Mass Ranges



For allowed DM candidates => **Investigated Question 2:**
Allowed region in m(DM) vs. <σv> expected with 5-year CALET data calculated with method analogous to Dark Matter sensitivity calculation

Expected Allowed Region for LKP



- Clear decision between Dark Matter case and Pulsar for LKP

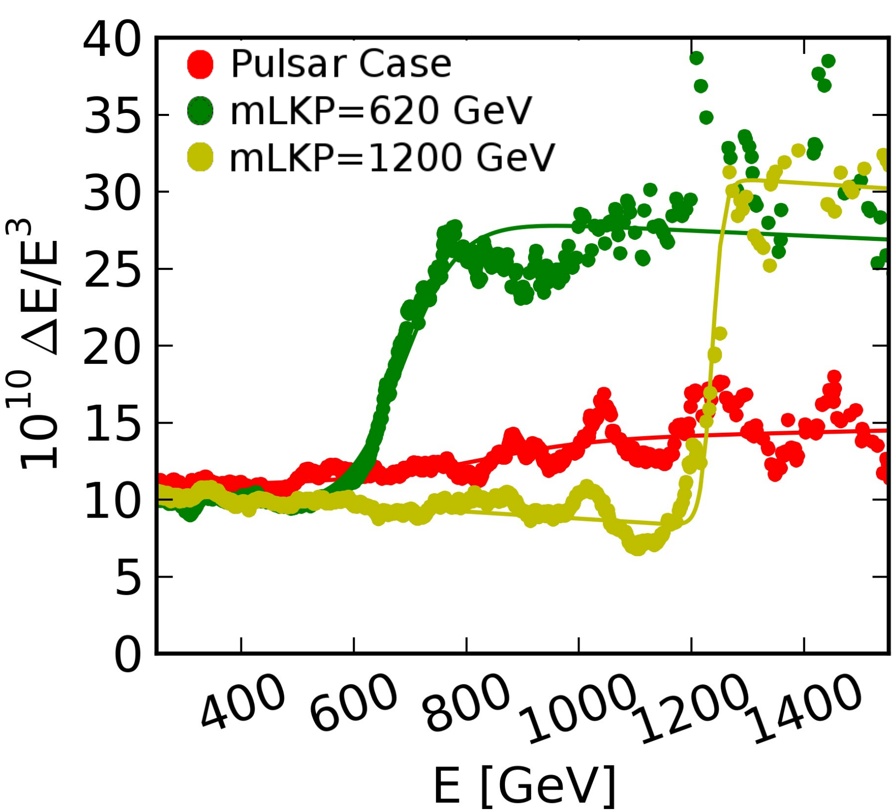
Reconstruction of Dark Matter Mass with Unbinned Analysis

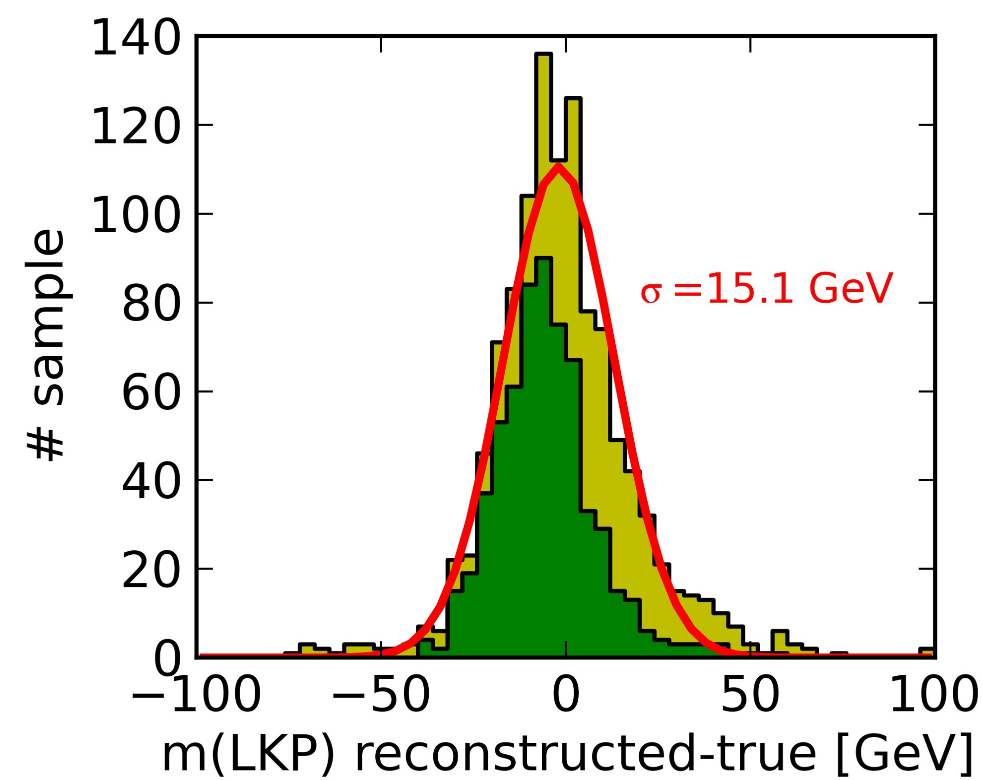
- CALET's good energy resolution not used in binned analysis
- ΔE(E): Energy difference between energy ordered events (inversely proportional to density of events at energy E)

$$10^{10}\,\Delta E / E^3 = p_1 + p_2 \cdot E + p_3 / \left(e^{(p_4 - E)/p_5} + 1\right)$$

χ^2 fit

step at m(LKP)
m(LKP) = p_4-p_5-20 GeV





Conclusion

- The Calorimetric Electron Telescope (CALET) is going to be launched and installed at the ISS
- With 5 years of CALET data
  - it will be possible to put strong limits on Dark Matter Annihilation in the Galactic Halo, about ½ to one order of magnitude better than current limits
  - LKP Dark Matter as source of the positron excess will be either excluded or its mass and annihilation cross-section can be determined at high precision
- Unbinned Analysis methods promise better results by taking full advantage of CALET's excellent 2% energy resolution and will be further developed