Dark Matter Sensitivity of CALET

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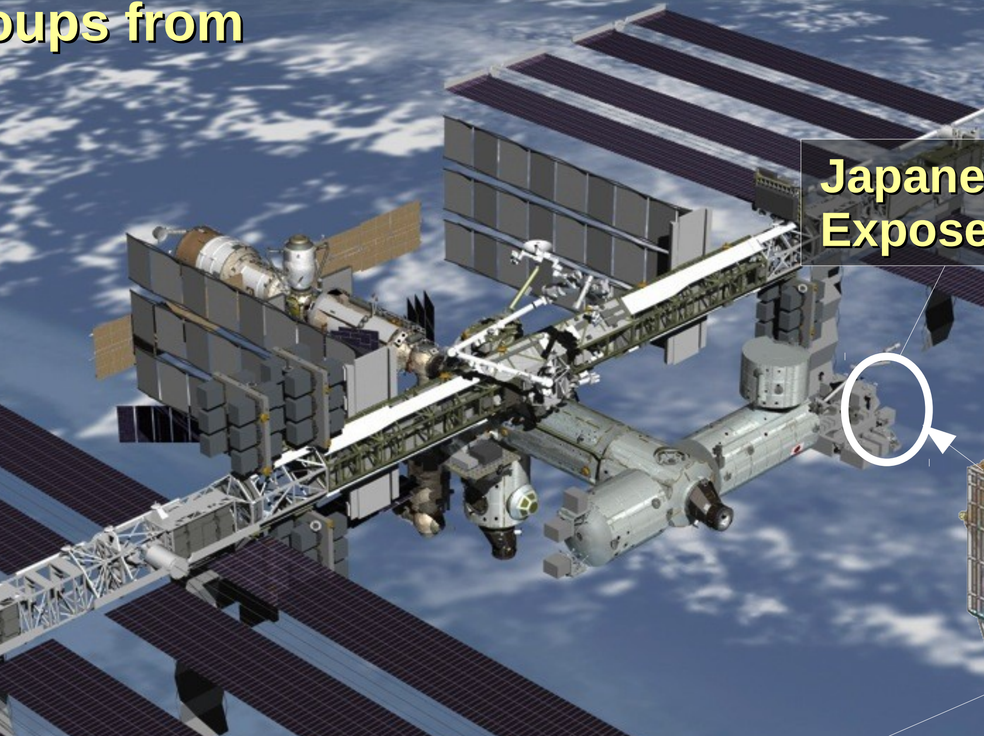
CALET

CALorimetric Electron Telescope

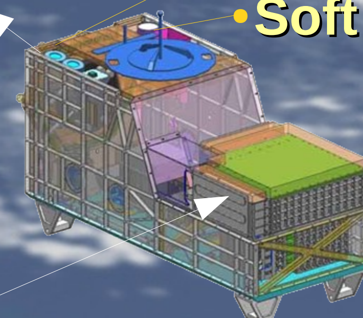
- Collaboration with groups from

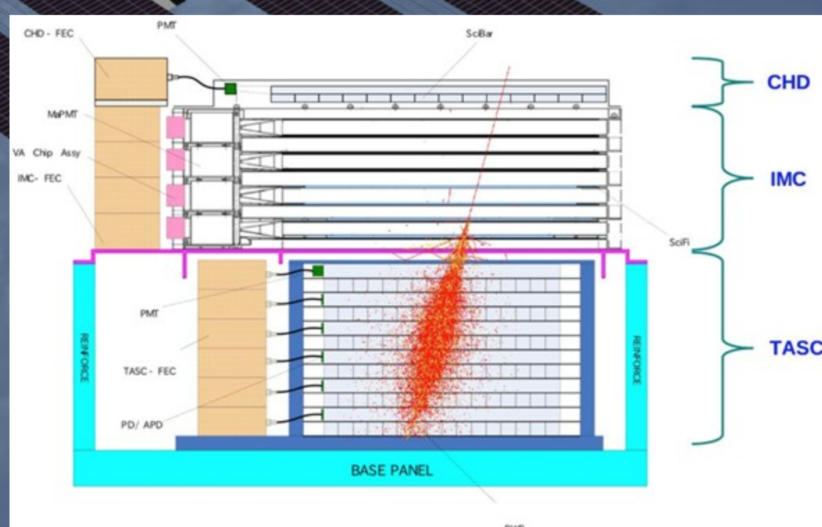
  Japan , USA , Italy

CALET was launched on August 20 aboard HTV-5 and has now been installed on the ISS for 5-years of observation



GRB Monitor:
- Hard X-Ray
- Soft γ-Ray





Calorimeter:
- Charge Detector
- Imaging Calorimeter
- Total Absorption Calorimeter
- 30 radiation length thickness in total for fully contained events

- 2% energy resolution
- 1200 $cm^2 \times sr$ aperture
- Proton rejection 10^{-5}

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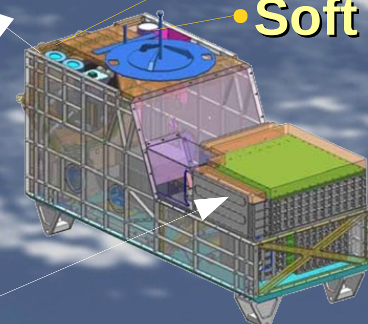
More information about CALET in plenary talk by Shoji Torii on Friday at 11:45

Japanese Experiment Module Exposed Facility Port 9



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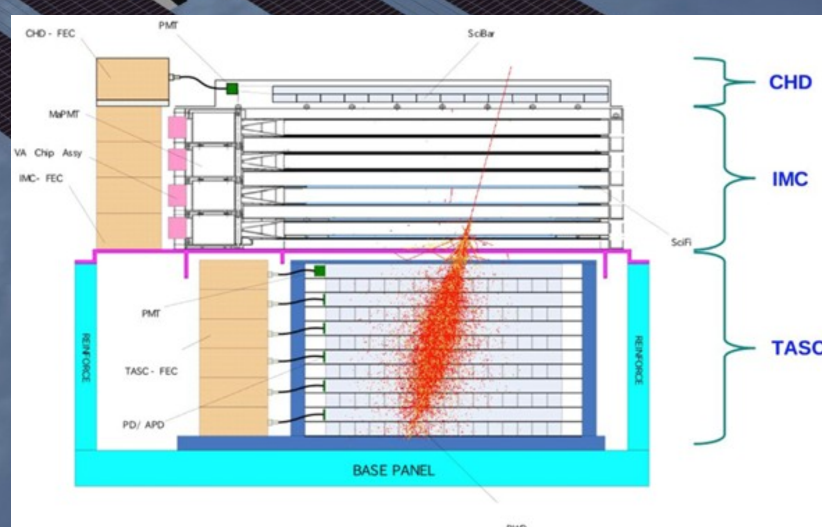

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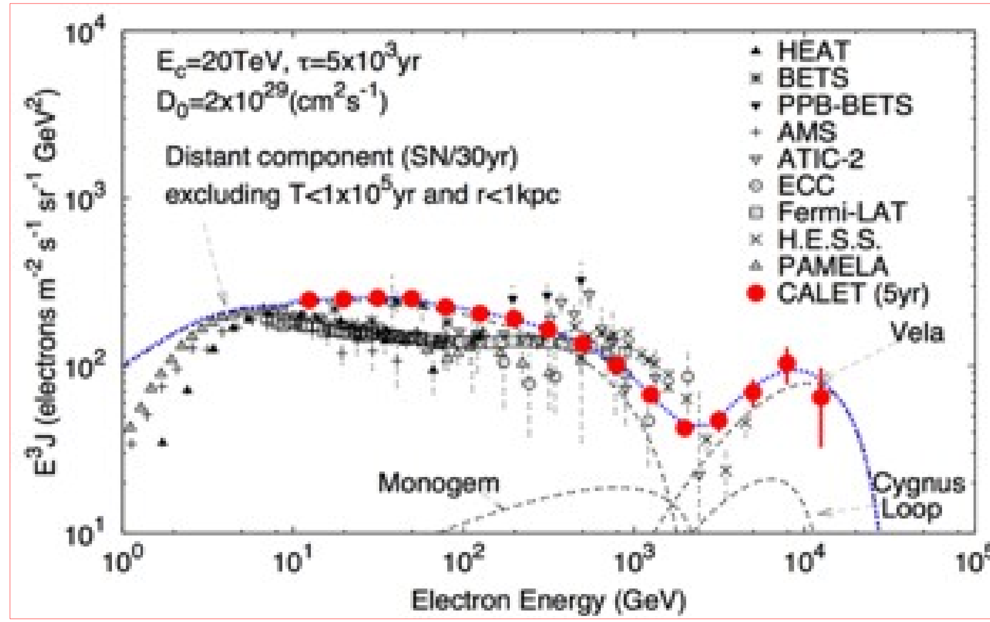
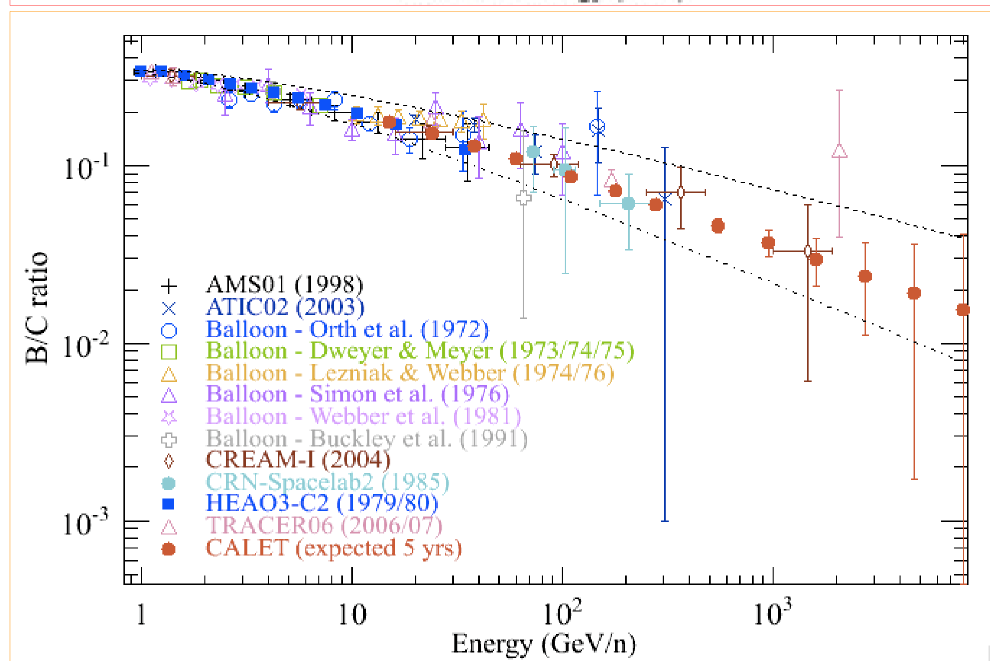
CALET's Main Science Objectives

- **Measure the e⁺ + e⁻ spectrum up to 20 TeV**
- Identify Nearby SNR
- Study Cosmic-Ray propagation through heavy nuclei spectra (e.g. δ from B/C ratio)

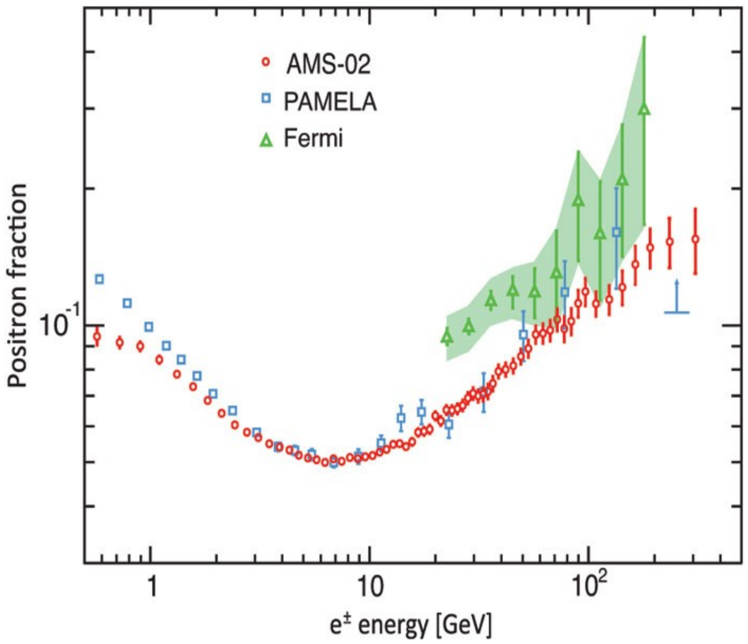




Focus of this talk:

- Search for signatures of Dark Matter annihilation or decay
- Investigate the cause of the positron excess

Origin of the Positron Excess



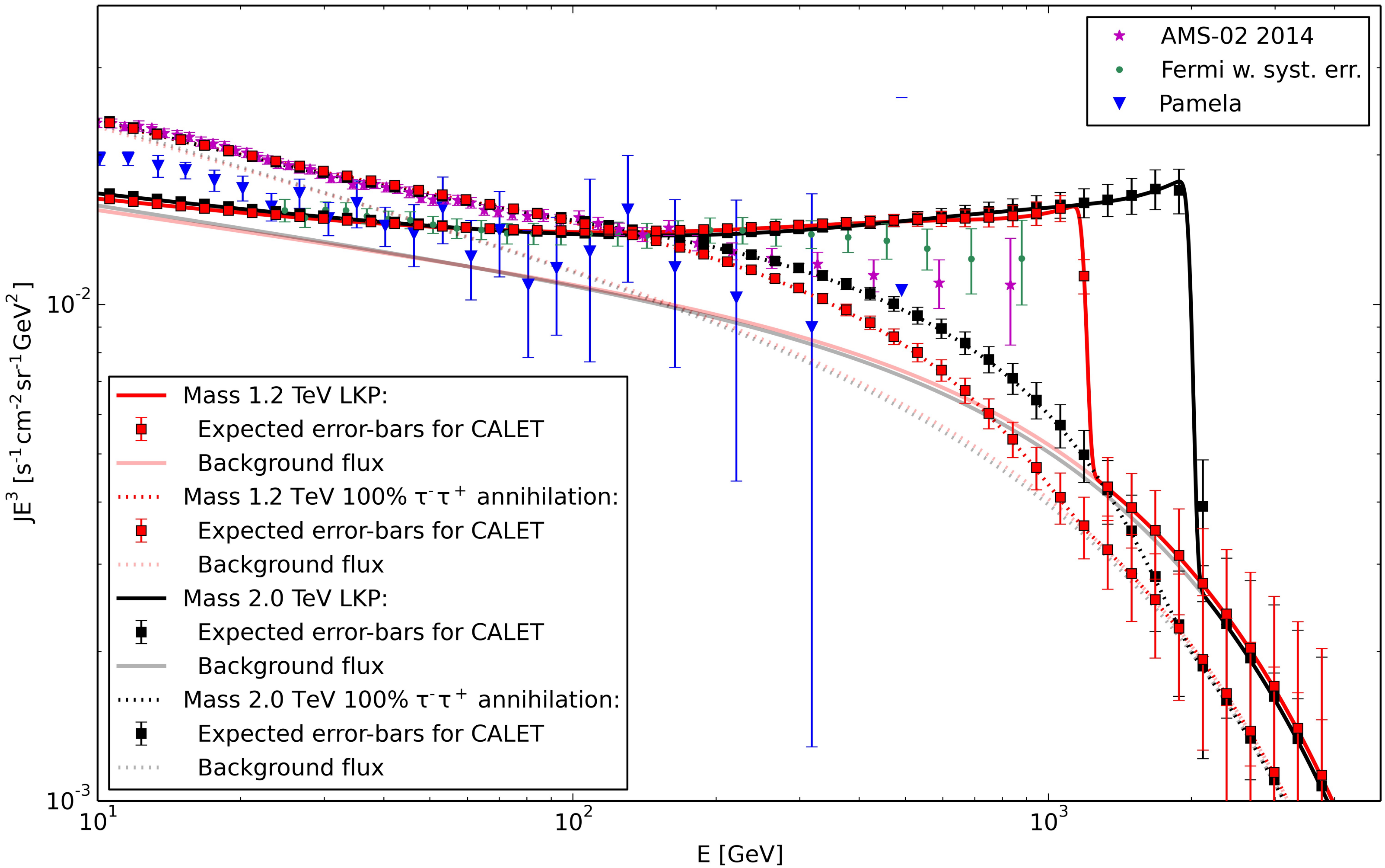
- Common power law with cut-off source proposed by AMS-02 to explain positron excess
- Possibly caused by nearby pulsar(s) emitting an equal amount of electrons and positrons **(Pulsar Case)**
- Or by Dark Matter annihilation or decay **(Dark Matter Case)**

- Investigated Questions:

  Dark Matter Case: *Could CALET identify the signatures of Dark Matter that explains the positron excess ?*

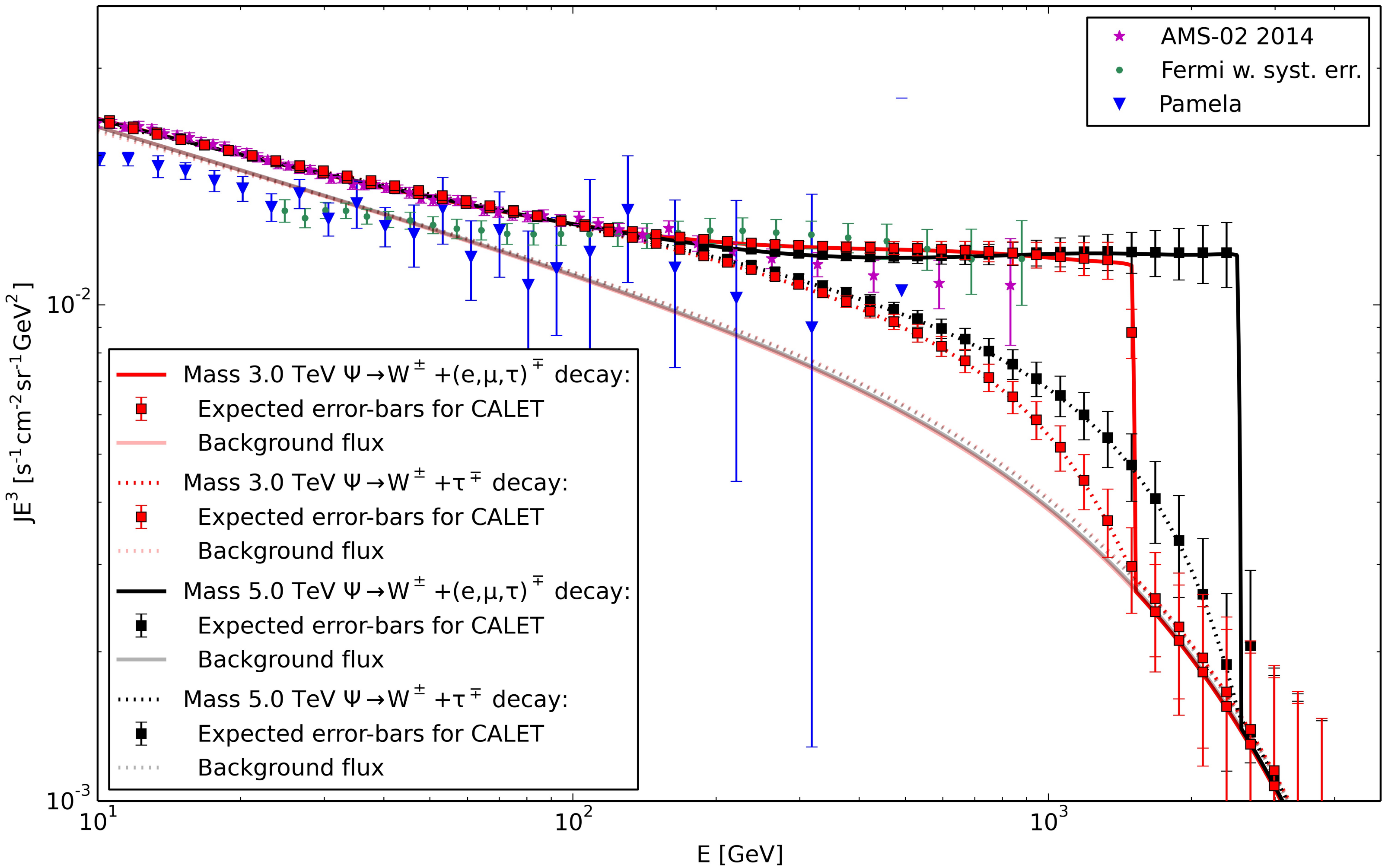
  Pulsar Case: *What limits can be set from CALET data on Dark Matter Annihilation on top of this nearby pulsar source if taking into account the shape of the Dark Matter spectrum?*

Spectra and CALET Expectation for Annihilation of Dark Matter



- CALET can distinguish different candidates and their masses for Dark Matter annihilation explaining the positron excess

Spectra and CALET Expectation for Decay of Dark Matter



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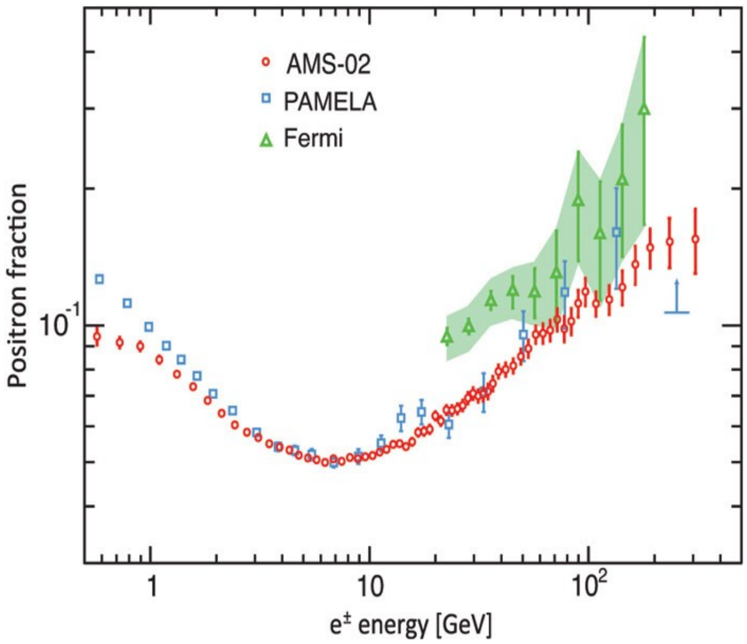

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Parametrization

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

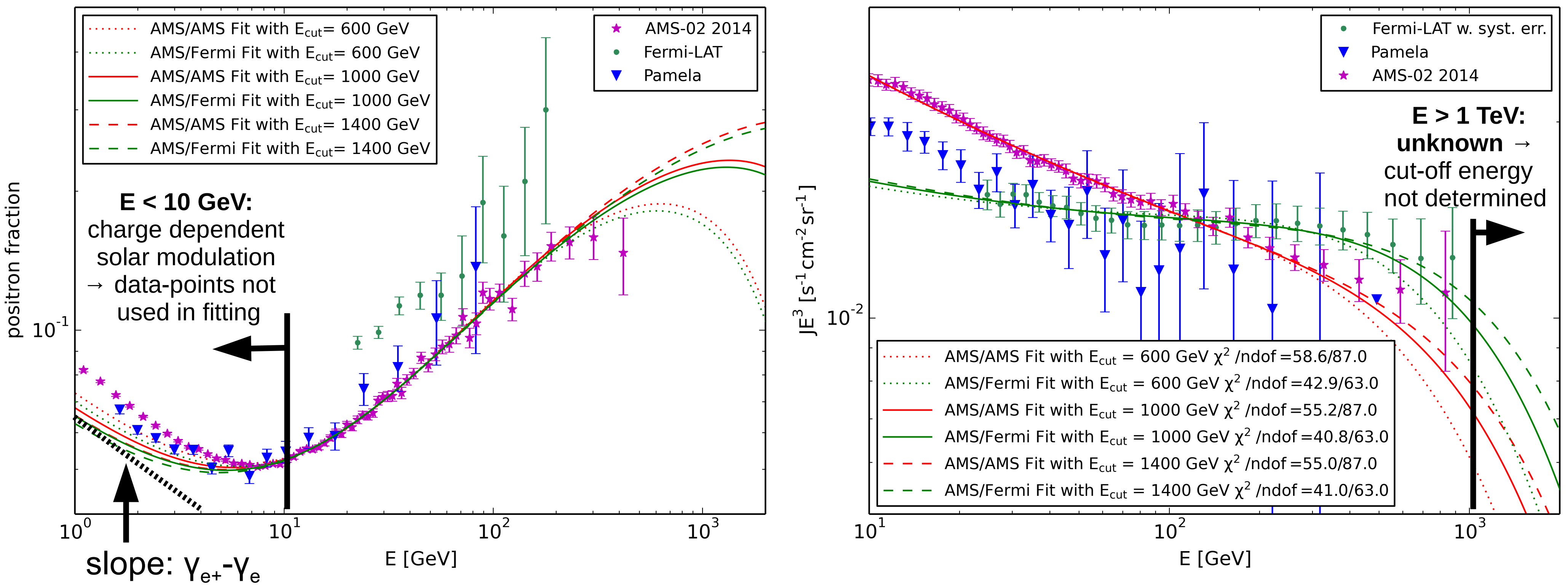
$$\Phi_e(E) = 2\Phi_{DM}(E)\cdot BF + C_e E^{\gamma_e}\left(2\frac{C_s}{C_e}E^{\gamma_s-\gamma_e}\cdot\exp\left(\frac{-E}{E_{cut_s}}\right) + \left(\frac{C_{e^+}}{C_e}\cdot E^{\gamma_{e^+}-\gamma_e}+1\right)\cdot\exp\left(\frac{-E}{E_{cut_d}}\right)\right)$$

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

- Power law diffuse background flux with different index for total and secondary positron flux and exponential cut-off from propagation
- Power law spectrum of pulsar with exponential cut-off and with same coefficient and index for electron and positron flux
- Dark Matter Flux Φ_{DM} calculated with DarkSUSY for annihilation x-section $\langle\sigma v\rangle = 3 \times 10^{-26}\ cm^3 s^{-1}$

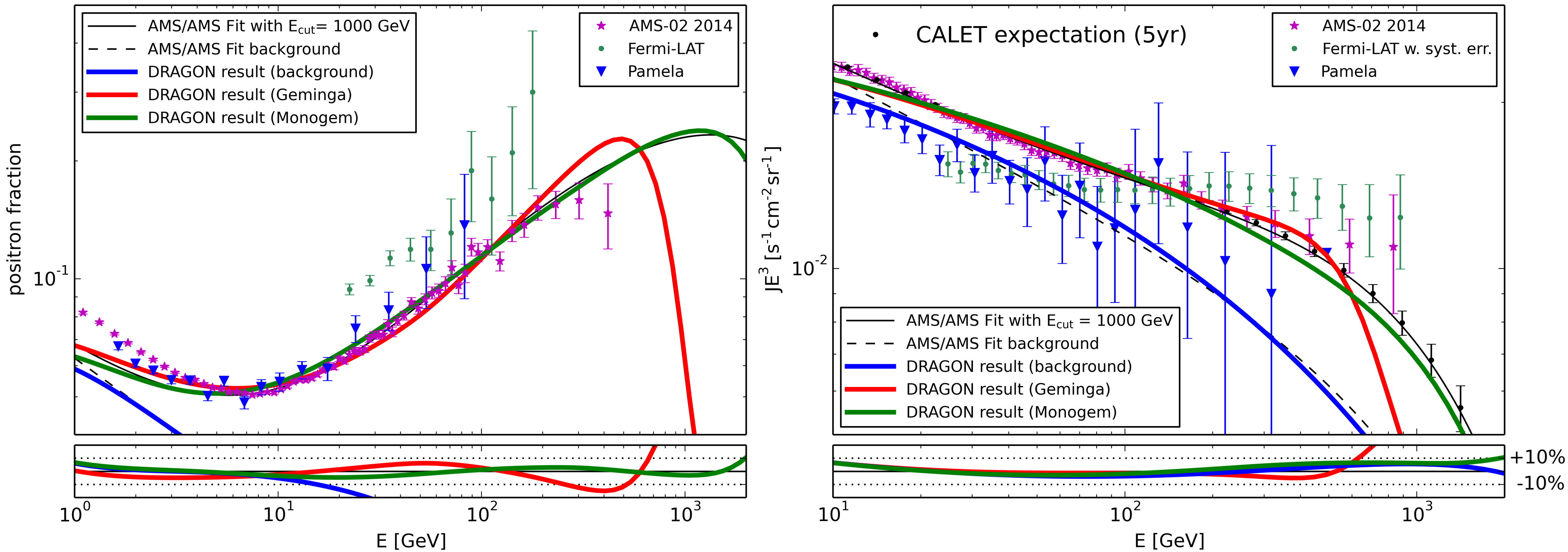
$$\frac{\Phi_{e^+}(E)}{\Phi_e(E)} = \frac{\frac{\Phi_{DM}(E)\cdot BF}{C_e E^{\gamma_e}} + \frac{C_s}{C_e}E^{\gamma_s-\gamma_e}\cdot\exp\left(\frac{-E}{E_{cut_s}}\right) + \frac{C_{e^+}}{C_e}\cdot E^{\gamma_{e^+}-\gamma_e}\cdot\exp\left(\frac{-E}{E_{cut_d}}\right)}{\frac{2\cdot\Phi_{DM}(E)\cdot BF}{C_e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

Single Pulsar Fit



- Assumed background case for Dark Matter sensitivity
- Extrapolation to TeV region to predict CALET data for this case
- Only small influence of γ_{e+}-γ_e, E_{cut_d} and E_{cut_s} on χ^2 → fixed values
- Distinct background cases for using AMS positron fraction with AMS total flux (AMS/AMS-Fit) and Fermi total flux (AMS/Fermi-Fit)

Confirmation by Numerical Simulation



- Confirmation that the parametrization is in agreement with numerical simulation results for reasonable input parameters
- Background and extra source (Geminga/Monogem) simulated with numerical propagation simulation code DRAGON (Gaggero et al. PRL(2013)111)
- Best match (difference < 10%) for background with $\gamma_{e+}-\gamma_e = -\delta = -0.4$ and Monogem with $\gamma_i = -2.3$ and source spectrum cut-off at 3 TeV

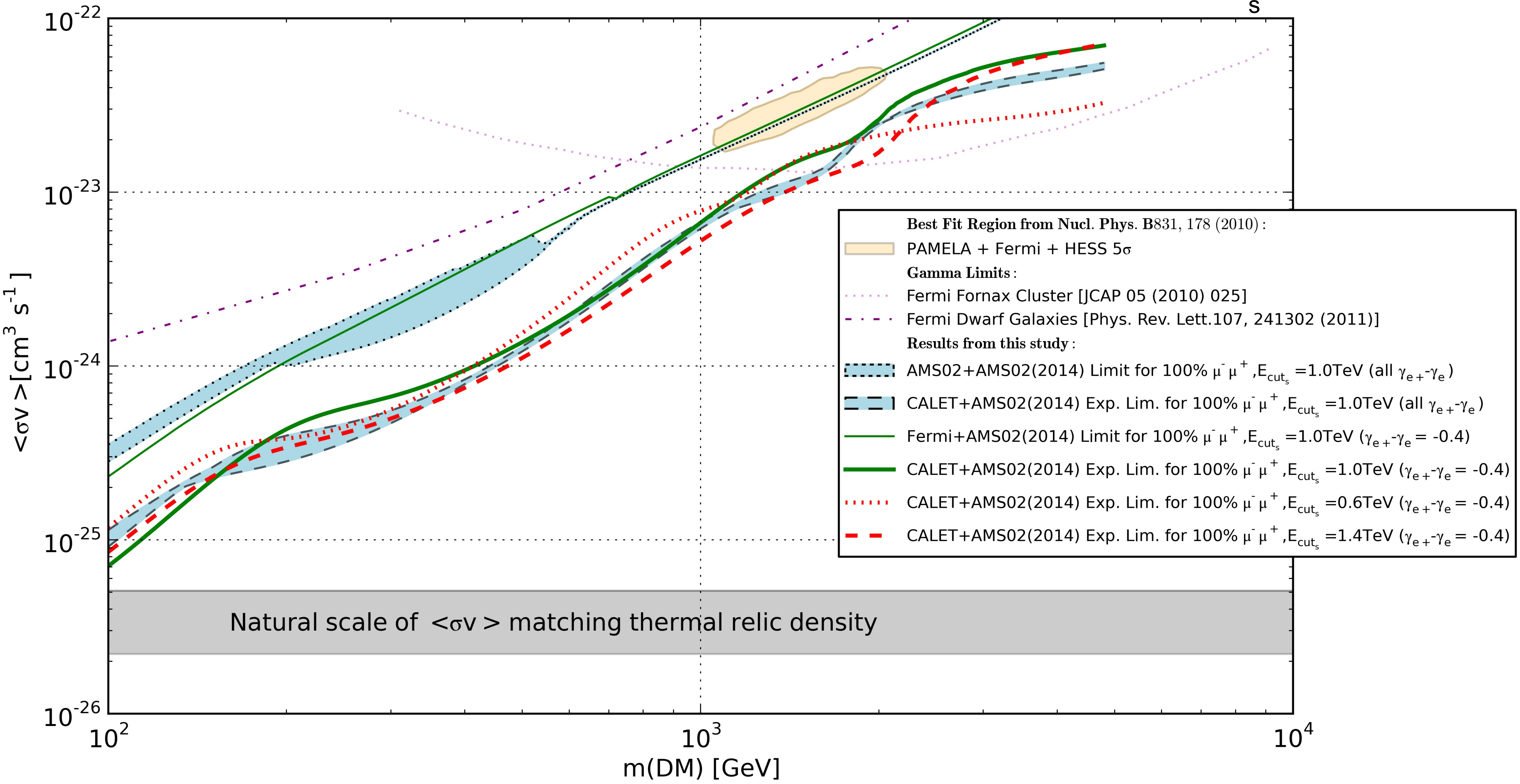
→ Parametrized single pulsar case is a viable scenario

Sensitivity Calculation

- 100 statistical samples of 5-year CALET data were simulated for each background case
- Binned χ^2 analysis of the 100 CALET samples together with current AMS-02 positron fraction
- Starting from the best pulsar fit, the Dark Matter term is added and the Boost Factor increased while repeating the fit each time to adapt all other parameters until χ^2 reaches the 95%CL exclusion limit
- Boost factor limit translated into effective annihilation cross-section by multiplication with $\langle\sigma v\rangle = 3 \times 10^{-26}\ cm^3 s^{-1}$
- Sensitivity = average value of final fit's boost factor
- Current limits: AMS-02 total flux instead of CALET sample

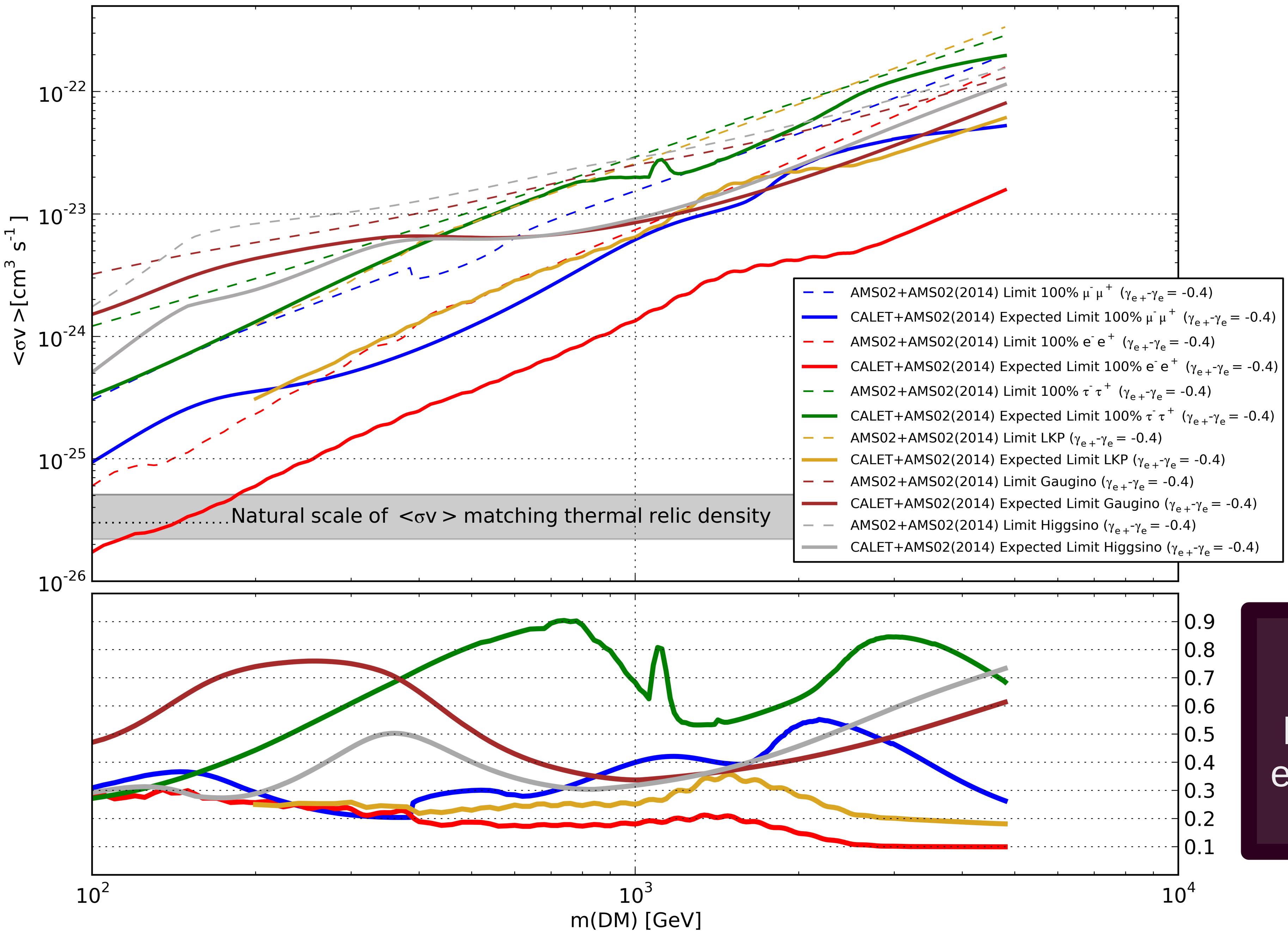
100% $\mu^+ + \mu^-$ - Channel Limits

Influence of Nuisance Parameters γ_{e+}-γ_e and E_{cut_s}



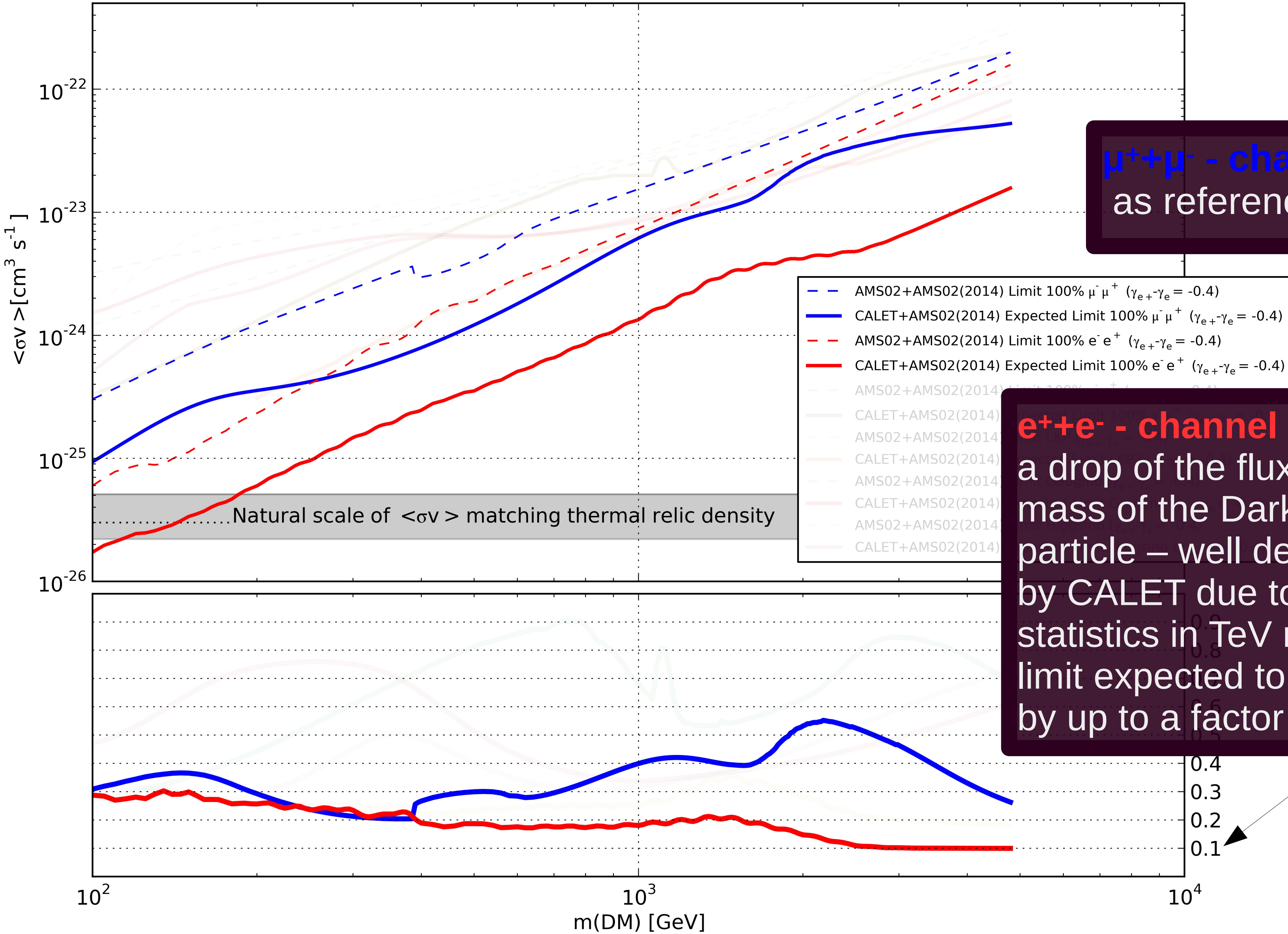
- No significant dependence on choice of γ_{e+}-γ_e (range from -0.3 to -0.7 calculated)
- Pulsar cut-off energy E_{cut_s} influences shape – changes mass of Dark Matter particle where the annihilation spectrum most resembles the assumed pulsar spectrum
- Sensitivity based on AMS/AMS and Fermi/AMS background cases comparable

Overview of Expected Limits



ratio of current limits to expected limits

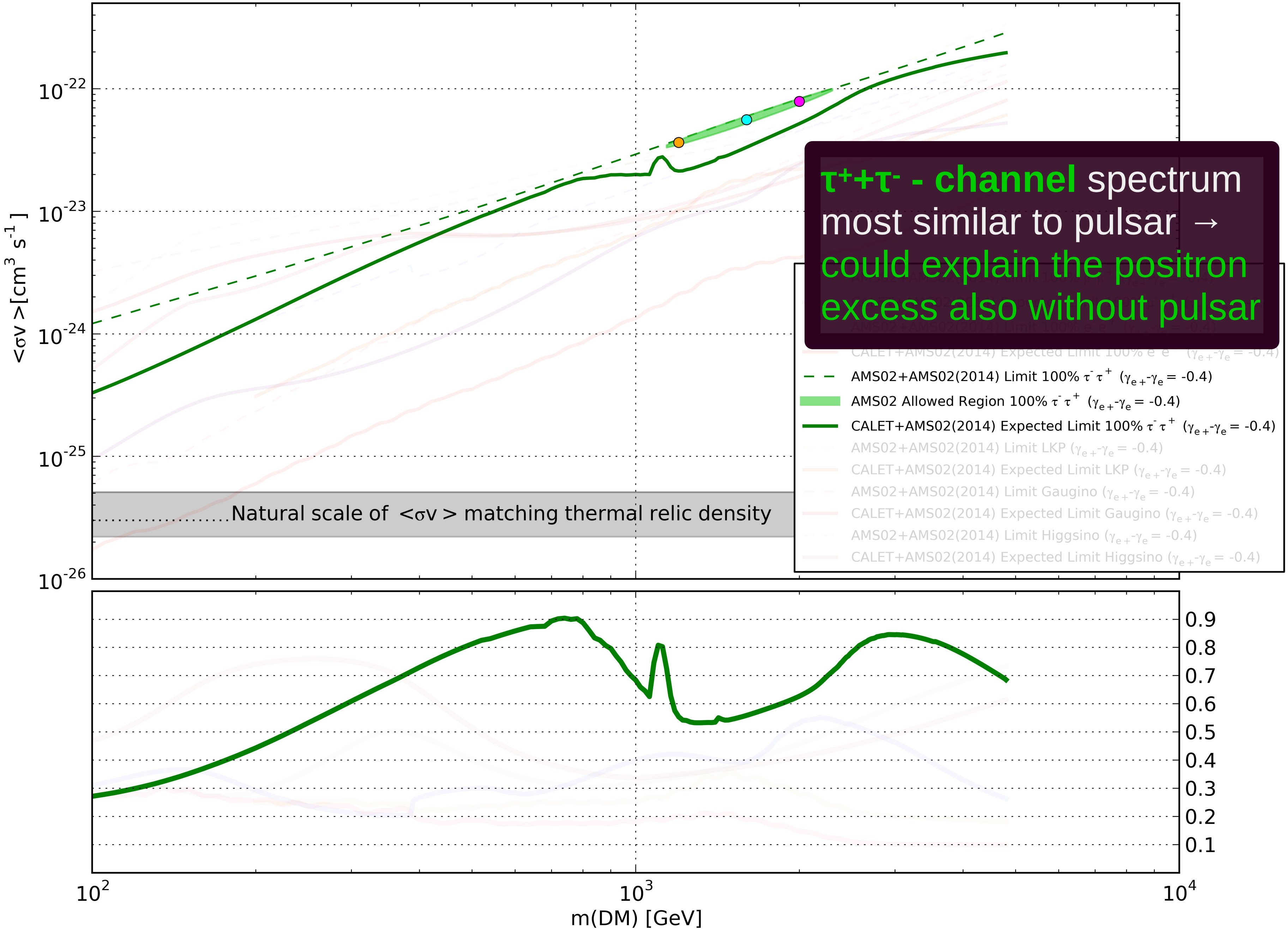
Annihilation to 100% $e^+ + e^-$



$\mu^+ + \mu^-$ - channel as reference

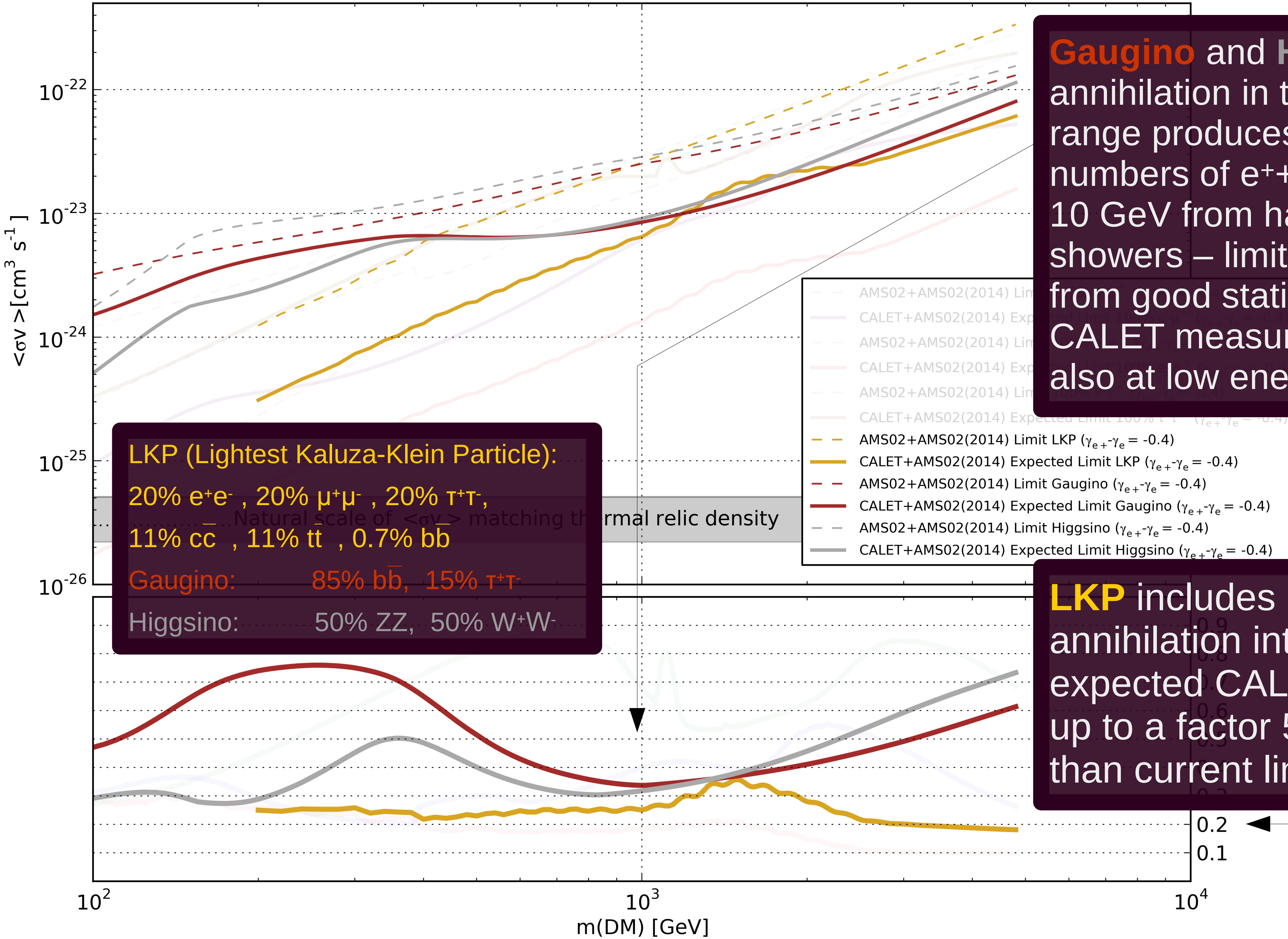
$e^+ + e^-$ - channel features a drop of the flux at the mass of the Dark Matter particle – well detectable by CALET due to high statistics in TeV region – limit expected to improve by up to a factor of 10

Annihilation to 100% $\tau^+ + \tau^-$



$\tau^+ + \tau^-$ - channel spectrum most similar to pulsar → could explain the positron excess also without pulsar

Selected Dark Matter Candidates



Gaugino and **Higgsino** annihilation in the TeV range produces large numbers of e^++e^- around 10 GeV from hadronic showers – limits improve from good statistics of CALET measurement also at low energy

LKP (Lightest Kaluza-Klein Particle):
20% e^+e^- , 20% $\mu^+\mu^-$, 20% $\tau^+\tau^-$,
11% $c\bar{c}$, 11% $t\bar{t}$, 0.7% $b\bar{b}$
Gaugino: 85% $b\bar{b}$, 15% $\tau^+\tau^-$
Higgsino: 50% ZZ, 50% W^+W^-

LKP includes 20% annihilation into **e^++e^-** expected CALET limits up to a factor 5 better than current limits

Conclusion

- CALET data will provide good statistics at high energy, making it possible to identify Dark Matter annihilation or decay explaining the cosmic ray positron excess.
- If CALET measures a spectrum matching the single pulsar case, we can set more stringent limits on Dark Matter annihilation especially for LKP Dark Matter or any candidate with large fraction of direct annihilation to $e^+ + e^-$.
- CALET has recently started operation on the ISS and will take the first direct measurement of the $e^+ + e^-$ - spectrum in the TeV – region → **we are exploring a mostly unknown region with many possibilities: SNRs, pulsars, Dark Matter, ???**