Ability of CALET to Identify or Constrain Dark Matter Annihilation and Decay in the Galactic Halo

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Introduction

The Calorimetric Electron Telescope (CALET) has commenced operations on the ISS and will measure the spectrum of electron+positron cosmic rays well into the TeV range. An extra source emitting an equal amount of electrons and positrons may provide an explanation for the positron excess in cosmic rays. The prime candidates for this source are nearby pulsar wind nebulae (PWN) and Dark Matter annihilation or decay. The current measurements of positron fraction and total electron+positron flux allow a wide range of scenarios of either source type or a combination. CALET data will allow for identification of the extra source or significantly constrain it's properties.

Electron/Positron Flux and Positron Fraction Parametrization

electron + positron flux:

Coefficient and slope of the electron flux

y-axis intercept and slope of positron fraction without extra source

$$\Phi(E) = 2\Phi_{extra}(E) + C_e E^{\gamma_e}\left(\frac{C_{e^+}}{C_e}\cdot E^{\gamma_{e^+}-\gamma_e} + 1\right)\cdot\exp\left(\frac{-E}{E_{cut_d}}\right)$$

Extra source emitting equal amount of electron & positron

Exponential cut-off due to energy loss during propagation

Pulsar Wind Nebula $\Phi_{PWN}(E) = C_s E^{\gamma_s}\cdot\exp\left(\frac{-E}{E_{cut_s}}\right)$

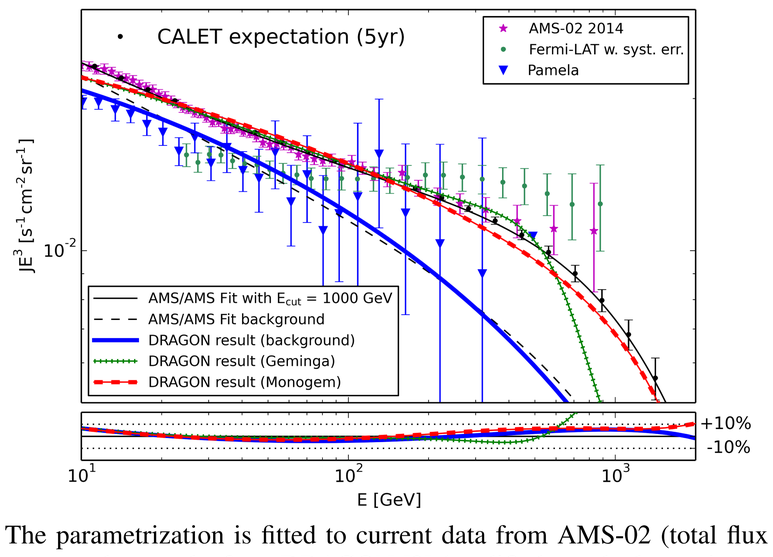
Dark Matter Annihilation $\Phi_{DM}(E) = BF\cdot\Phi_{DM_{base}}(E)$

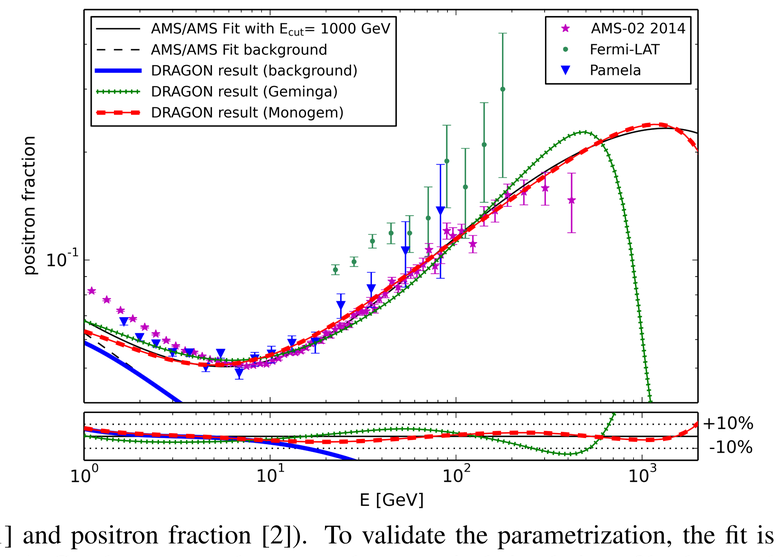
$(\Phi_{DM_{base}}$ calculated for $<\sigma v> = 3\cdot10^{-26} cm^3 s^{-1})$

Dark Matter Decay $\Phi_{DM}(E)$ proportional to $\frac{1}{\tau}$

positron flux: $\Phi_{e^+}(E) = \Phi_{extra}(E) + C_e E^{\gamma_e}\left(\frac{C_{e^+}}{C_e}\cdot E^{\gamma_{e^+}-\gamma_e}\right)\cdot\exp\left(\frac{-E}{E_{cut_d}}\right)$

positron fraction = (positron flux) / (electron + positron flux)





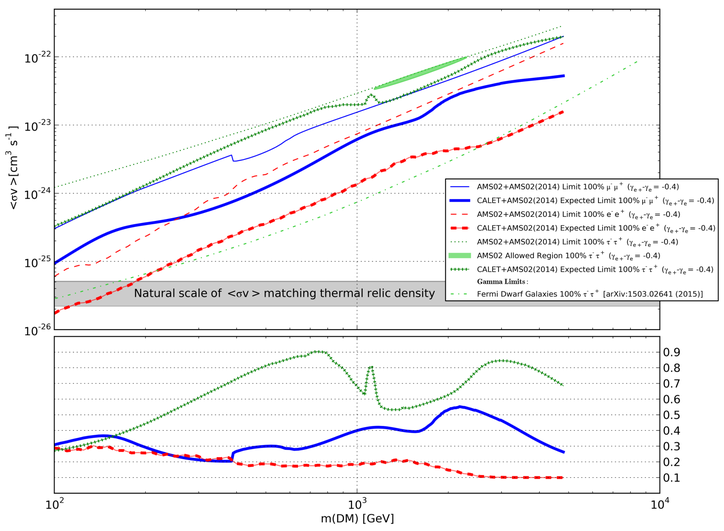
The parametrization is fitted to current data from AMS-02 (total flux [1] and positron fraction [2]). To validate the parametrization, the fit is compared to results from DRAGON [3] (modified to calculate point sources). Good agreement betweeen the numerical simulation of background and the flux from the Monogem PWN is achieved (lower panel shows percentage of difference) for $\gamma_{e^+} - \gamma_e = -\delta$ = -0.4 ($D_0 = 6.2\cdot10^{28}$ cm^2/s) and γ_{i_s} = 2.3, $E_{cut_i} = 3$ TeV for Monogem $\Rightarrow$ **A single PWN is a viable background case for Dark Matter search.**

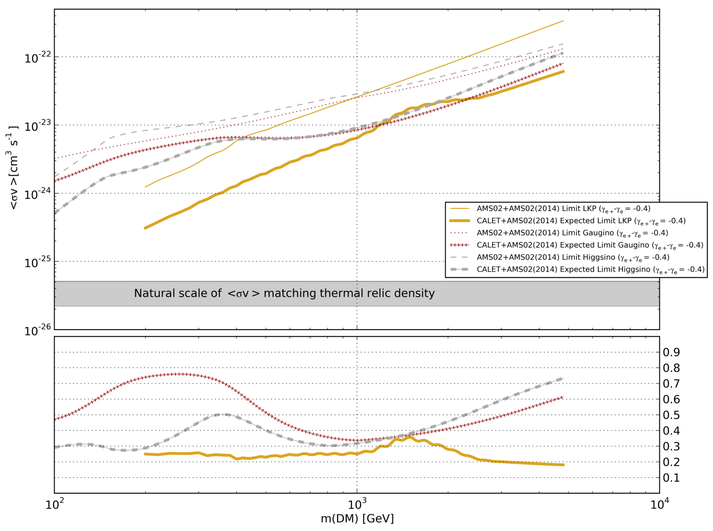
Sensitivity to Dark Matter Annihilation

Assumption: One dominating pulsar causes the positron excess, CALET measures a TeV-region spectrum which matches this case

Question: What will be the limits by CALET on Dark Matter annihilation?

Result: Improvement up to one order of magnitude over current limits from AMS-02 data for direct annihilation into $e^+ + e^-$





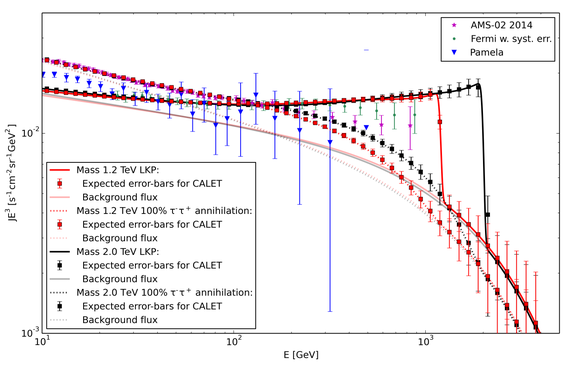
The expected limits from 5-year CALET data on Dark Matter annihilation into leptons and with the branching ratios of selected Dark Matter candidates are shown to the left. CALET data assuming a single pulsar as the extra source is simulated, and fitted with above parametrization. Starting with the pure pulsar case, the Dark Matter term (calculated with DarkSUSY [4]) is added, and the BF increased in steps until the resultant χ^2 is larger than the critical χ^2 value. With this method, the expected limits from CALET data in combination with the AMS02 positron fraction are calculated, and current limits from AMS02 positron fraction and total flux data for comparison (factor shown on lower panel). A significant improvement of the sensitivity is observed, especially for Dark Matter candidates including annhilation directly into $e^+ + e^-$-pairs, such as the LKP.
Detailed description in **JCAP12(2015)047**

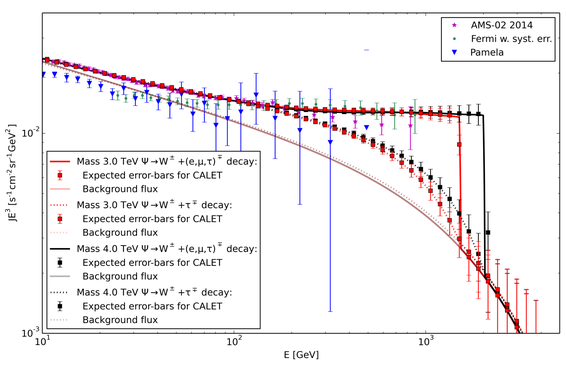
Ability to Identify Dark Matter as Source of the Positron Excess

Assumption: Dark Matter annihilation or decay causes the positron excess

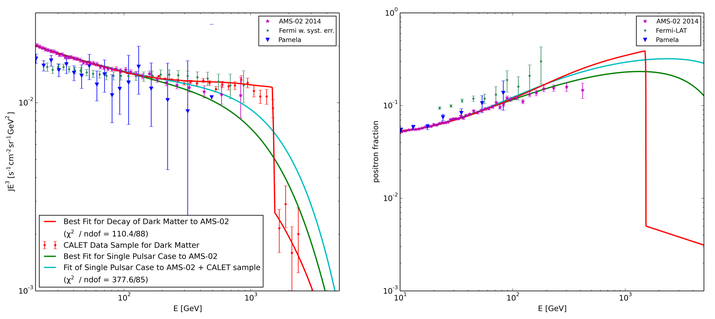
Question: Can this spectrum be distinguished from the spectrum of a nearby pulsar?

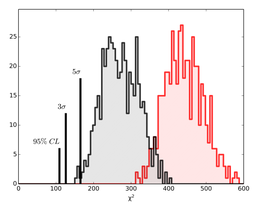
Result: If there is partial annihilation or decay directly into $e^+ + e^-$, the spectra can be clearly identified





Expected spectra from annihilation of selected Dark Matter candidates (left) and generic cases of 2-particle Dark Matter decay [5] (right) with BF or $1/\tau$ scaled to explain the positron excess and match current experimental data (AMS-02 [1] or Fermi-LAT [6] total flux and AMS-02 positron fraction [2]).
The size of the error-bars for the expected CALET measurement indicates that the Dark Matter candidates with direct annhilation or decay to electron+positron can be distinguished from a pulsar spectrum (see also χ^2 analysis on the right) and from candidates with softer spectra, and that their masses can be determined at good precision.





⇑ Example fit of a CALET data sample for $\Psi \rightarrow W^{\pm} + (e^{\mp}, \mu^{\mp}, \tau^{\mp})$ with the pure pulsar parametrization.
$\Leftarrow$ χ^2-distribution from fitting 500 statistical samples of the above type.
Red: M_{Ψ}=3 TeV, Black: M_{Ψ}=4 TeV.

References

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Conclusions

- The first time direct measurement of the TeV-region electron+positron spectrum by CALET reveals new information on Dark Matter annihilation or decay in the galactic halo.
- If data indicates that the positron excess is from a nearby PWN, the limit on Dark Matter annihilation can be improved by up to a factor 10 ($e^+ + e^-$-channel).
- A Dark Matter explanation of the positron excess can can be clearly identified for Dark Matter candidates including a significant fraction of direct annhilation to $e^+ + e^-$ or decay to $W^{\pm} + e^{\mp}$ up into the TeV-mass range.