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.

- 2% energy resolution
- 1200 cm²×sr aperture
- Proton rejection $10^{-5}$

Japanese Experiment Module Exposed Facility Port 9

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

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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. $\delta$ from B/C ratio)
- Search for signatures of Dark Matter annihilation or decay
- Investigate the cause of the positron excess

Focus of this talk:
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

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

\[
\Phi_e = \text{total flux of electron+positron} \quad \Phi_{e^+} = \text{positron only flux}
\]

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positron Fraction Coefficient</td>
<td>(\frac{C_{e^+}}{C_e})</td>
</tr>
<tr>
<td>Total Flux Coefficient</td>
<td>(C_e)</td>
</tr>
<tr>
<td>Power Law Index of Total Flux</td>
<td>(\gamma_e)</td>
</tr>
<tr>
<td>Power Lax Index Positron Flux</td>
<td>(\gamma_{e^+} - \gamma_e)</td>
</tr>
<tr>
<td>Cutoff of Diffuse Flux</td>
<td>(E_{cutd})</td>
</tr>
<tr>
<td>Power law Index Pulsar Source</td>
<td>(\gamma_s - \gamma_e)</td>
</tr>
<tr>
<td>Coefficient of Pulsar Source</td>
<td>(\frac{C_s}{C_e})</td>
</tr>
<tr>
<td>Pulsar Source Cut-off Energy</td>
<td>(E_{cuts})</td>
</tr>
<tr>
<td>Boost Factor of Dark Matter</td>
<td>(BF)</td>
</tr>
</tbody>
</table>

- **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 \(\Phi_{DM}\) calculated with DarkSUSY for annihilation x-section \(<\sigma v> = 3 \times 10^{-26} \text{ cm}^3\text{s}^{-1}\)**
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 $\gamma_{e^+} - \gamma_e$, $E_{\text{cut}_d}$ and $E_{\text{cut}_s}$ on $\chi^2 \rightarrow$ 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

$\rightarrow$ 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 $\chi^2$ 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 $\chi^2$ reaches the 95%CL exclusion limit
- Boost factor limit translated into effective annihilation cross-section by multiplication with $<\sigma v> = 3 \times 10^{-26} \text{ cm}^3\text{s}^{-1}$
- 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 $\gamma_{e^+} - \gamma_{e^-}$ and $E_{\text{cut}}$

- No significant dependence on choice of $\gamma_{e^+} - \gamma_{e^-}$ (range from -0.3 to -0.7 calculated)
- Pulsar cut-off energy $E_{\text{cut}}$ 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

Natural scale of $<\sigma v>$ matching thermal relic density

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% $\tau^+ + \tau^-$

$\tau^+ + \tau^- - \text{channel}$ spectrum most similar to pulsar → could explain the positron excess also without pulsar.
Selected Dark Matter Candidates

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% $t\bar{t}$
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

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
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, ???