





Recent Results and Dark Matter Search with CALET on the ISS

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WASEDA

Dark Matter searches in the 2020s At the crossroads of the WIMP

> Symposium on next-generation collider, direct, and indirect Dark Matter searches





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Outline

- 1. Introduction
 - Objectives
 - Instrument
 - Calibration
 - Operations
- 2. Results
 - Electrons —
 - (Protons)

Y.Asaoka, Y.Akaike, Y.Komiya, R.Miyata, S.Torii et al. (CALET Collaboration), Astropart. Phys. 91 (2017) 1. Y.Asaoka, S.Ozawa, S.Torii et al.

(CALET Collaboration), Astropart. Phys. 100 (2018) 29.

O.Adriani et al. (CALET Collaboration), Phys.Rev.Lett. 119 (2017) 181101.

O.Adriani et al. (CALET Collaboration), Phys.Rev.Lett. 120 (2018) 261102.

O.Adriani et al. (CALET Collaboration), Phys.Rev.Lett. 120 (2018) 261102.

- 3. Indirect Dark Matter Searches with CALET
 - H.Motz et al. PoS (ICRC2019) 533 (as an example)
 - not a collaboration work, just uses published spectra
- 4. Summary

ISS as Cosmic Ray Observatory



AMS Launch May 16, 2011



CALET Launch August 19, 2015



ISS-CREAM Launch August 14, 2017





CALET: Cosmic Ray Detector onboard the ISS



Overview of CALET Observations

Direct cosmic ray observations in space at the highest energy region by combining:

- ✓ A large-size detector
- Long-term observation onboard the ISS (5 years or more is expected)

 Electron observation in the 1 GeV - 20 TeV energy range, with high energy resolution owing to optimization for electron detection
 Search for Dark Matter and Nearby Sources

- Observation of cosmic-ray nuclei in the 10 GeV - 1 PeV energy range.
- ➡ Unravelling the CR acceleration and propagation mechanism
- Detection of transients in space by long-term stable observations
- ➡ EM radiation from GW sources, Gamma-ray burst, Solar flare, etc.

CALET Instrument



>	Plastic	Scintillator + PMT + 64anode PMT	r Scintillator(PWO) + APD/PD or PMT (X1)	CALORIMETER
				CHD-FEC CHD-FEC MC-FEC IMC-FEC
			TASC Contraction of the second	TASC-FEC TASC FEC
3				
		CHD (Charge Detector)	IMC (Imaging Calorimeter)	IASC (Total Absorption Calorimeter)
	Measure	Charge (Z=1-40)	Tracking , Particle ID	Energy, e/p Separation
	Geometry (Material)	Plastic Scintillator 14 paddles x 2 layers (X,Y): 28 paddles Paddle Size: 32 x 10 x 450 mm ³	448 Scifi x 16 layers (X,Y) : 7168 Scifi 7 W layers (3X ₀): 0.2X ₀ x 5 + 1X ₀ x2 Scifi size : 1 x 1 x 448 mm ³	16 PWO logs x 12 layers (x,y): 192 logs log size: 19 x 20 x 326 mm ³ Total Thickness : 27 X ₀ , ~1.2 λ ₁
	Readout	PMT+CSA	64-anode PMT+ ASIC	APD/PD+CSA PMT+CSA (for Trigger)@top layer

DM searches in 2020s (CALET Y.Asaoka)



Electron, E=3.05 TeV



fully contained even at 3TeV

Fe(Z=26), ΔE=9.3 TeV

clear difference from electron shower

Gamma-ray, E=44.3 GeV



energy deposit in CHD consistent with Fe

no energy deposit before pair production



Electron, E=3.05 TeV



energy deposit in CHD consistent with Fe

no energy deposit before pair production





energy deposit in CHD consistent with Fe

no energy deposit before pair production



Electron, E=3.05 TeV





All-Electron Measurement with CALET



- 1. Reliable tracking well-developed shower core
- 2. Fine energy resolution full containment of TeV showers
- High-efficiency electron ID 30X₀ thickness, closely packed logs
- ⇒ CALET is best suited for observation of possible fine structures in the all-electron spectrum up to the trans-TeV region.















Here, we have adopted the same energy binning as DAMPE.

What happens if we shifted our energy binning...



1.4 TeV peak is disfavored with 4σ significance

We don't see any peak-like structure at around 1.4TeV even in the shifted energy binning.





DM searches in 2020s (CALET Y.Asaoka)



All Electron Spectrum: Comparison with Indirect Measurements





All Electron Spectrum: Comparison with Indirect Measurements





All Electron Spectrum: Comparison between Recent Direct Measurements







All Electron Spectrum: Comparison with the Updated AMS-02 Result



Search for "Particle" Dark Matter

Dark Matter (DM): The solid evidence for new physics

WIMP = Weakly Interacting Massive Particles

- Thermal relics (basic processes in the early universe)
- Candidate "new" particles as a byproduct of new physics frameworks



- Three complementary approaches
- Direct search made a significant progress to approach "neutrino floor"
 - Many underground detectors
- Production experiment in collider must identify dark matter as missing mass.
 - Large model dependence
 - Indirect searches directly probe the condition of dark matter to be thermal relics.
 - (downside) existence of astrophysical background

Indirect Dark Matter Search: Gamma-rays + Charged Particles (Antiparticles)

Advantage: Directly constrain the condition to be thermal relic

• Canonical cross section which matches the observed DM density: $\langle \sigma v \rangle \sim 3 \ge 10^{-26} \text{ cm}^3/\text{s}$

Challenges: To know the background of galactic cosmic rays (including secondaries)

Relatively large uncertainties

Examples: Gamma-rays, positrons, antiprotons, other cosmic rays

- Gamma-rays: can observe high density region like galactic center
- Antiprotons: only background from secondary production
- Complementary channels: hadrons and leptons

Constraints from AMS-02 antiprotons Cuoco, Kramer, Korsmeier PRL 118(2017)191102 Constraints are obtained by using the predicted antiproton flux due to hadronization of quark pairs produced by DM

annihilation.



Constrains from Fermi-LAT

PRL 115 (2015) 231301

Constraints are obtained using the gamma-ray continuum produced during hadronization. Stacking the dwarf spheroidal galaxies to achieve huge target mass. (*) uncertainties in J-factor

DM searches in 2020s (CALET Y.Asaoka)

Importance of Proton Spectrum

in the Indirect DM Searches using Antiparticles



an order of magnitude higher energy.

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DM Search with CALET All-Electron Spectrum

Leptons are complementary probes of DM.

Using excellent energy resolution and high statistics combined with positron spectrum obtained by AMS-02, CALET results can be used to search for a DM signature in the all-electron spectrum.



Modeling the Electron and Positron Spectra

H.Motz et al. PoS (ICRC2019) 533 (not a collaboration work, just uses published spectra)

- The model must reproduce the observed spectra of all-electron (CALET) and positron (AMS-02), and be compatible with numerical calculation (e.g. GALPROP).
- The variation of parameters reflects the uncertain input in numerical calculation.



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Limits on Dark Matter Annihilation as a Function of Dark Matter Mass



- We still have plenty room to be explored in lepton channel!
- CALET results better constrain annihilation to $e^+ + e^-$ pair.

DM searches in 2020s (CALET Y.Asaoka)

Φ [0.3GV,**0.5GV**,0.7GV]

s [0.03,0.05,0.1]

Fit Improvement by Modeling 350 GeV Step-like Structure with Dark Matter Signature



- χ^2 improvement compared to single pulsar case:

Full energy range (CALET & AMS-02 data) : $\Delta \chi^2 = 6.6 (33.9 \rightarrow 27.3)$ 100 GeV – 3 TeV (CALET data only) : $\Delta \chi^2 = 7.0 (13.3 \rightarrow 6.3)$



Prospects for the CALET All-Electron Spectrum

Five years or more observations \Rightarrow 3 times more statistics, reduction of systematic errors





Summary and Prospects

- □ CALET continues very stable observation since Oct. 2015, for more than 3.5 years.
- □ We have published all-electron spectrum (11 GeV 4.8 TeV) and proton spectrum (50 GeV –10 TeV) including the detailed assessment of systematic errors.
- □ There are many more results such as heavy nuclei spectra, gamma-ray observations including GW counterpart searches, and space weather.
- □ The so far excellent performance of CALET and the outstanding quality of the data suggest that a 5-year (or more) observation period is likely to provide a wealth of new interesting results.

