飛翔体観測（CALET）による
高エネルギー宇宙線加速天体の研究

CALET

Calorimetric
Electron
Telescope

on the International Space Station

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他CALET国際研究チーム

令和5年度東京大学宇宙線研究所共同利用研究成果発表会　2024年2月22日

共同利用研究概要（2023年度）

- 共同研究内容
  - データ解析のための大規模シミュレーショ計算
  - CALET観測結果の理論的検討（来週２月２９日に研究会を開催予定。）
- 予算
  - 旅費１１０千円+１９０千円（繰越）(２月２９日の研究会に使用予定）

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立命館大学: 森正樹
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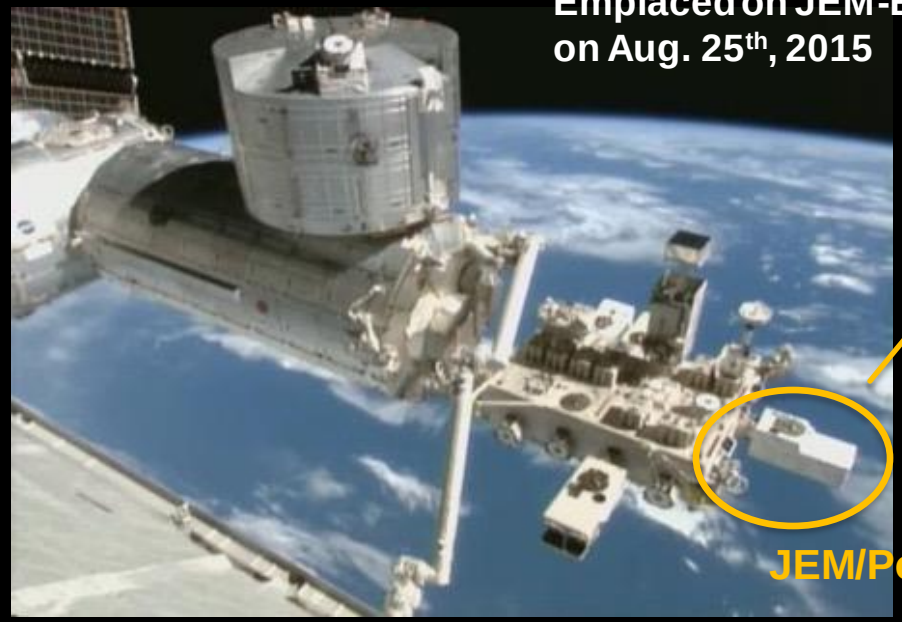
ルイジアナ州立大学: 川久保裕太
芝浦工業大学: 笠原克昌
弘前大学: 市村雅一
信州大学: 宗像一起
茨木高専: 三宅晶子
大阪公立大学: 常定芳基
NASA/GSFC : Nick Cannady
INFN-Pisa : Pier Marrocchesi

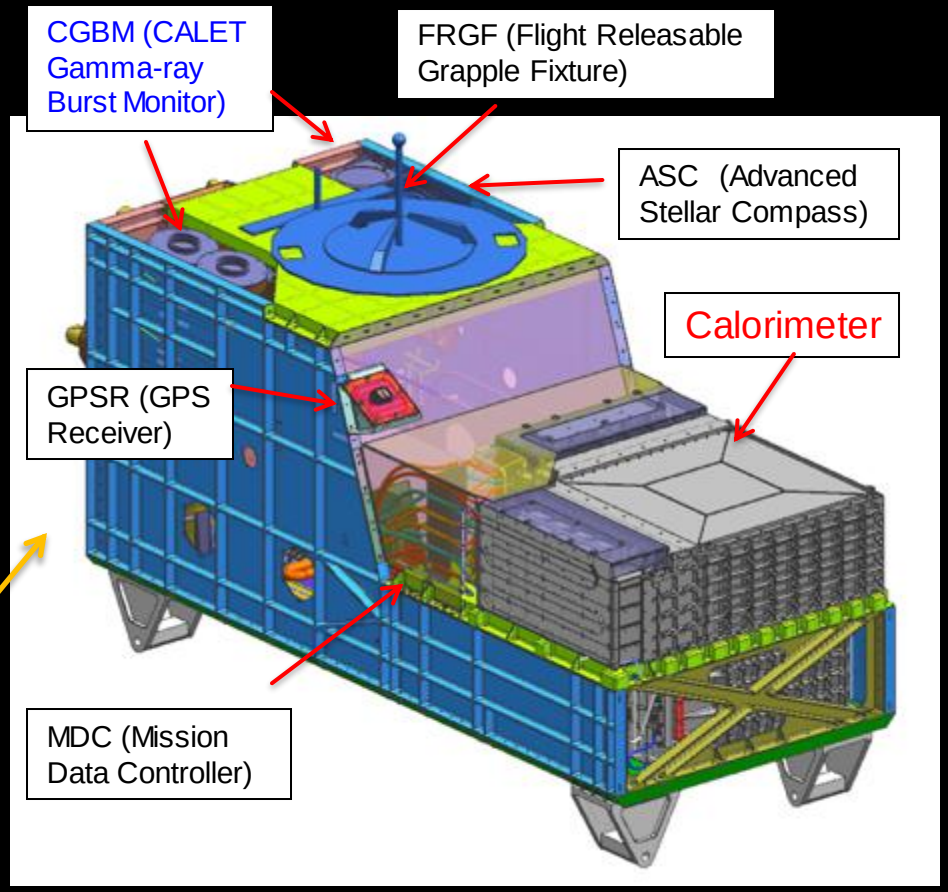
CALET Payload

Kounotori (HTV) 5

Launched on Aug. 19th, 2015 by the Japanese H2-B rocket

Emplaced on JEM-EF port #9 on Aug. 25th, 2015

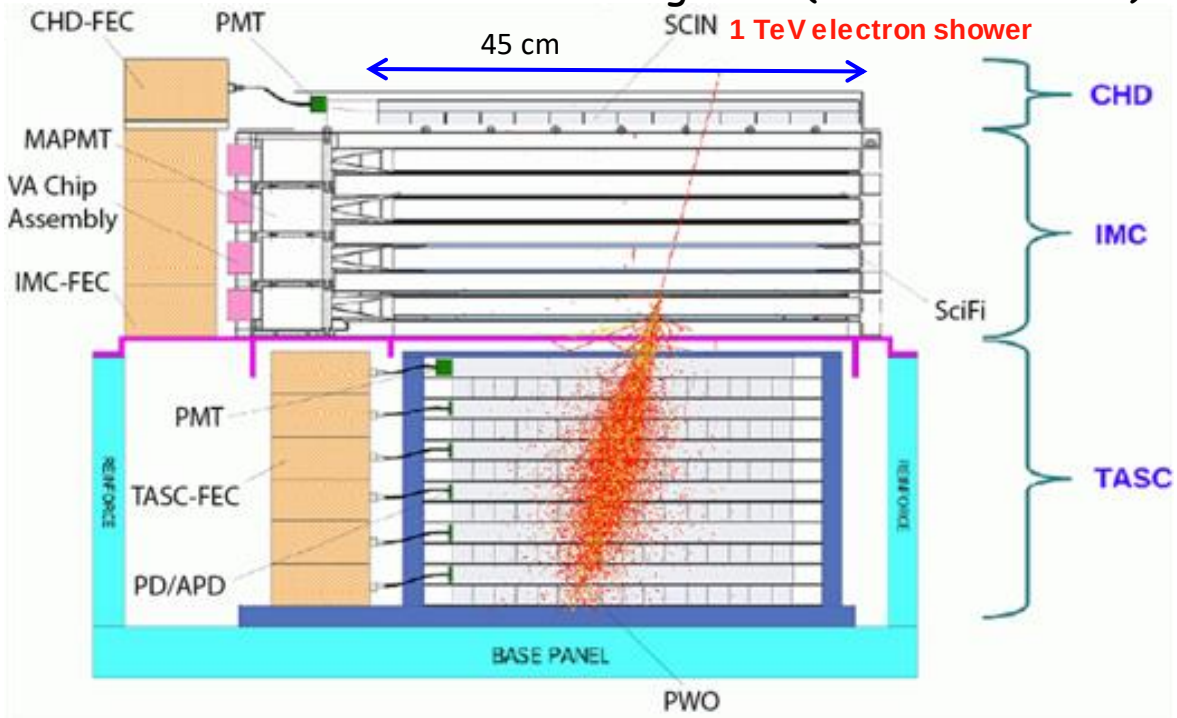




- **Mass: 612.8 kg**
- **JEM Standard Payload Size:**
  1850mm(L) × 800mm(W) × 1000mm(H)
- **Power Consumption: 507 W（max）**
- **Telemetry:**
  Medium 600 kbps (6.5GB/day) / Low 50 kbps

CALET calorimeter and capability

Field of view: ~ 45 degrees (from the zenith) Geometrical Factor: ~ 1,040 cm^{2}sr (for electrons)



CHD – Charge Detector

- 2 layers x 14 plastic scintillating paddles
- single element charge ID from p to Fe and above (Z = 40)
- charge resolution ~0.1-0.3 e

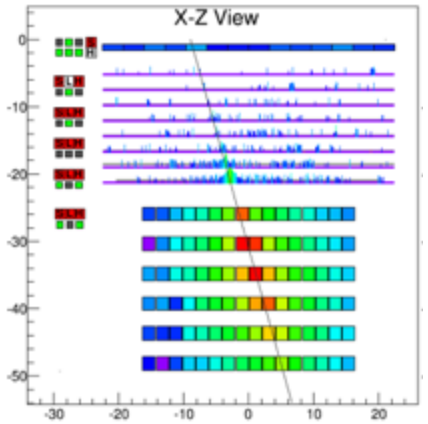
IMC – Imaging Calorimeter

- Scifi + Tungsten absorbers: 3 X_0 at normal incidence
- 8 x 2 x 448 plastic scintillating fibers (1mm) **readout individually**
- **Tracking** (~0.1° angular resolution) + **Shower imaging**

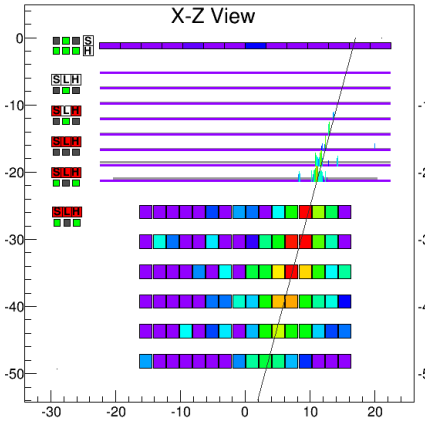
TASC – Total Absorption Calorimeter 27 X_0, 1.2 λ_I

- 6 x 2 x 16 lead tungstate ($PbWO_4$) logs
- **Energy resolution:** ~2 % (>10GeV) for e , γ ~30-35% for p, nuclei
- **e/p separation:** ~10^{-5}

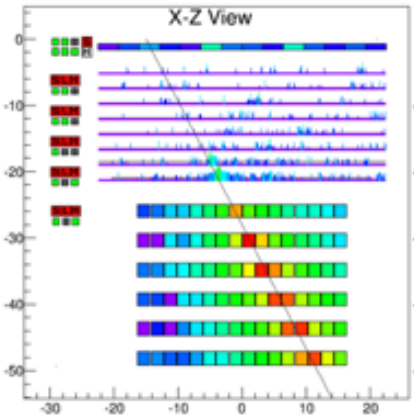
Electron, E=3.05 TeV



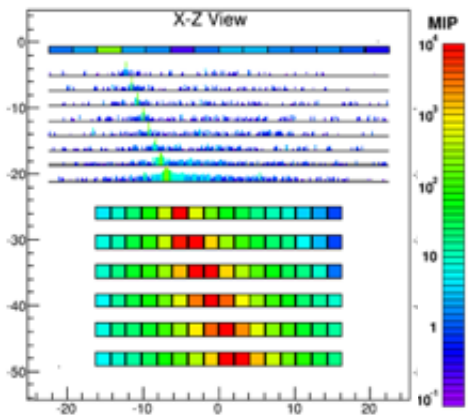
Gamma-ray, E=44.3 GeV



Proton, E_{TASC}=2.89 TeV



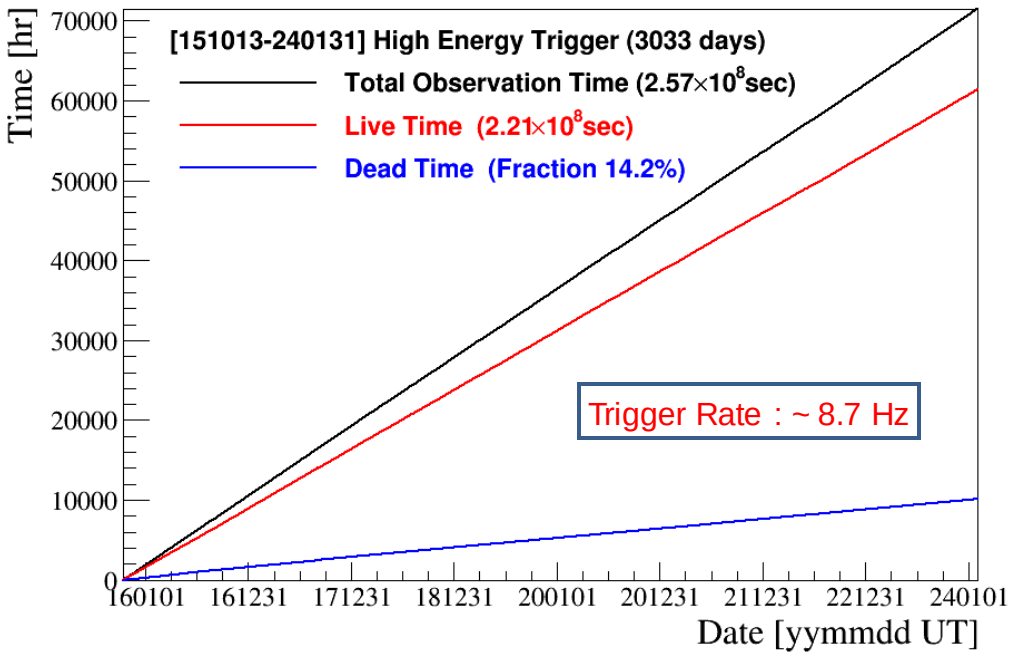
Iron, E_{TASC} =9.3 TeV



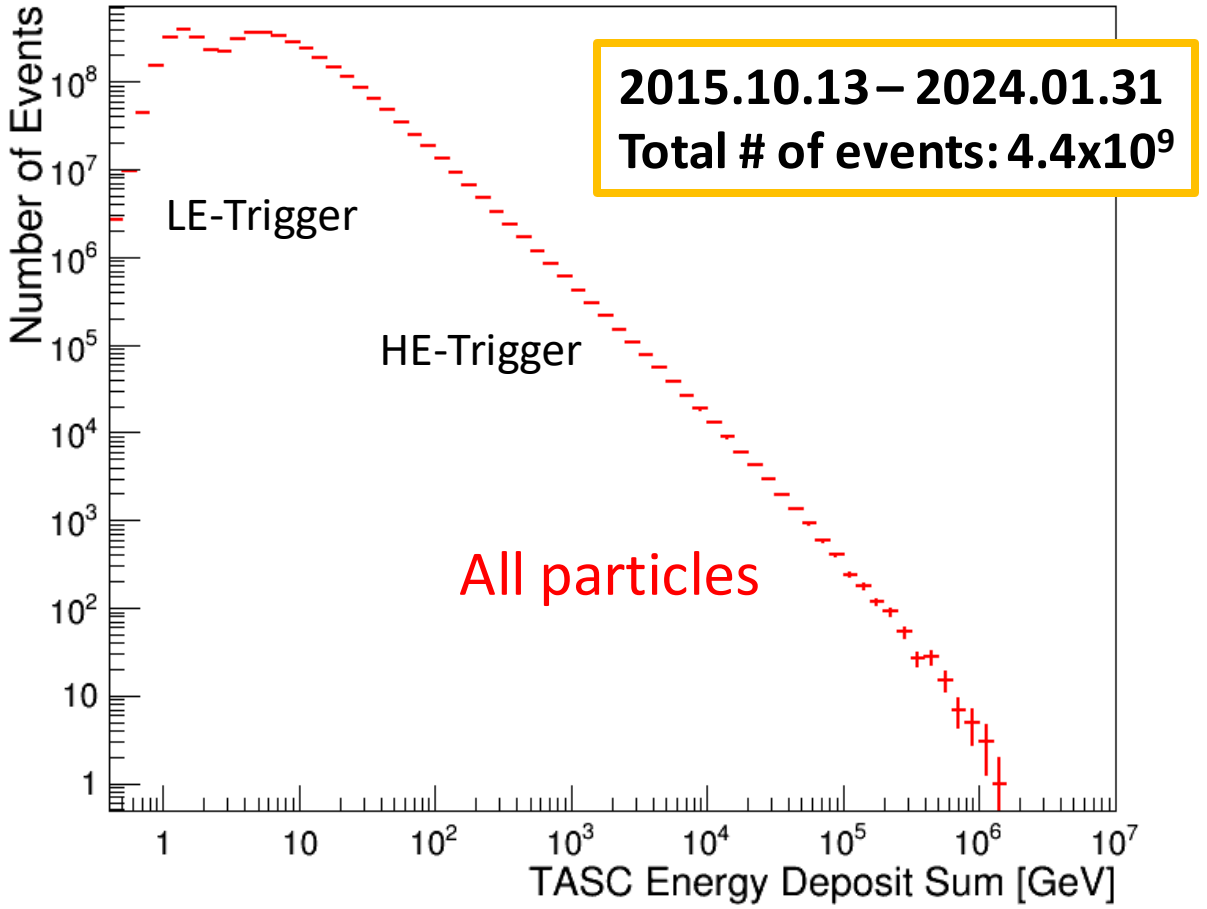
Event Display: Electron Candidate (>100 GeV)

CALET observations on the ISS

Accumulated observation time (live, dead)



Energy deposit (in TASC) spectrum: 1 GeV-1 PeV



High-energy trigger (> 10 GeV) statistics:

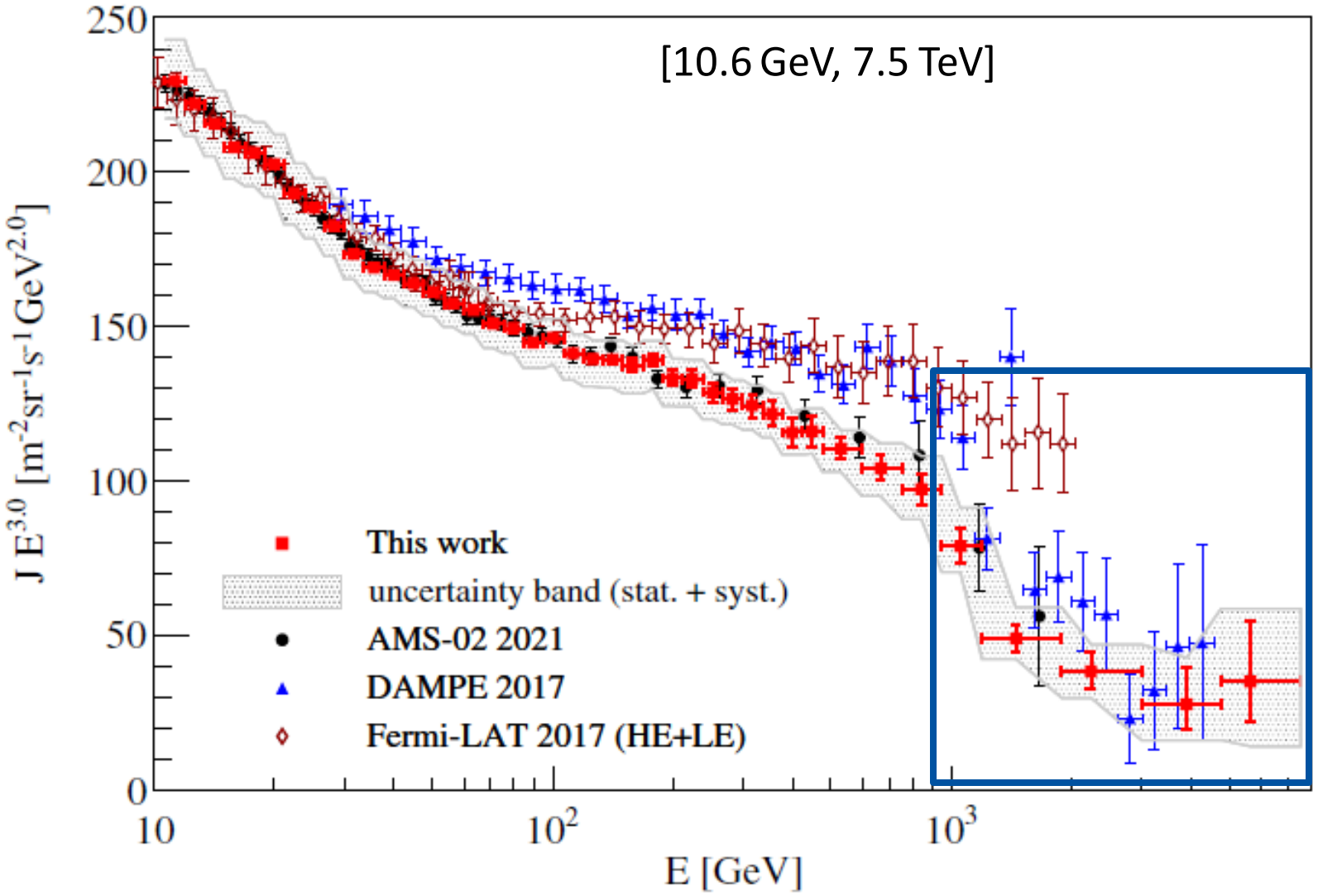
- Operational time: **3033 days** as of Jan. 31, 2024
- Live time fraction **>85%**
- Exposure of HE trigger
  ~265 m² sr day
- HE-gamma point source exposure
  ~5.2 m² day (for Crab, Geminga)

2023年の主な成果

- Direct Measurement of the Spectral Structure of Cosmic-Ray Electrons + Positrons in the TeV region with CALET on the International Space Station
  - Physical Review Letters 131, 191001, 2023
- Direct Measurement of the Cosmic-Ray Helium Spectrum from 40 GeV to 250 TeV with the Calorimetric Electron Telescope on the International Space Station
  - Physical Review Letters 130, 171002, 2023
- Charge-sign dependent cosmic-ray modulation observed with the Calorimetric Electron Telescope on the International Space Station
  - Physical Review Letters 130, 211001, 2023
- ICRC2023発表（計22件）
  - Highlight talk (invited): Highlights from the CALET observations for 7.5 years on the International Space Station (S. Torii)

Cosmic-ray all-electron spectrum (PRL 131, 191001 (2023))

Data: Oct. 2015 – Dec. 2022 (2637days)

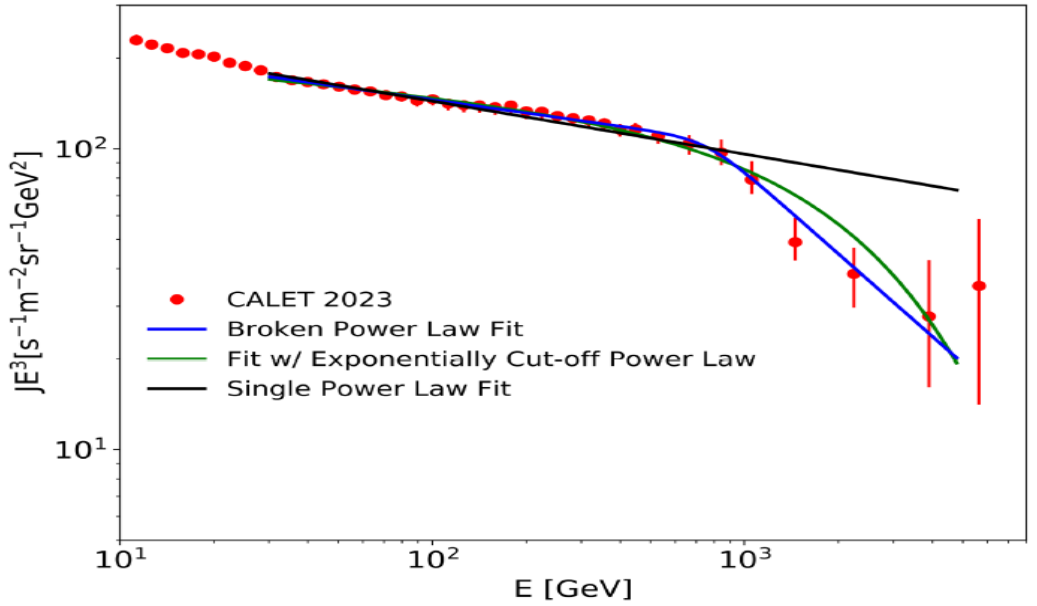


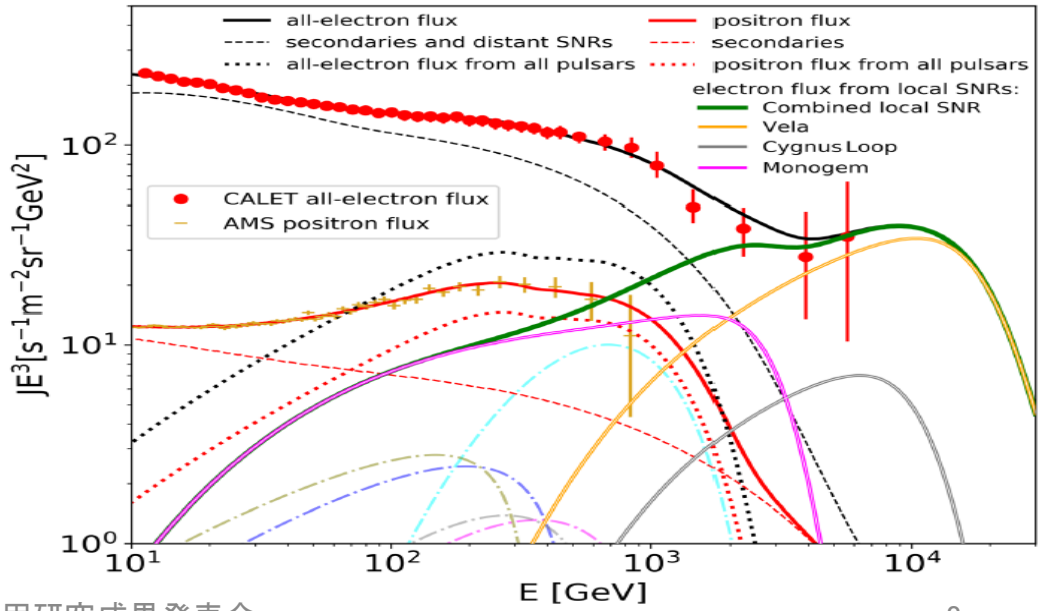
Statistics has increases by ~3.4 from PRL 2018 and also energy region has expanded up to 7.5 TeV with proton contamination <10%.

CALET observes a flux suppression above 1 TeV with a **significance of 6.9 σ**, a considerable improvement with respect to the result published in PRL2018 (~4 σ)

Towards an interpretation of the CALET all-electron spectrum

- Fit in 30-4.8TeV
  - Broken power law
    - γ= -3.15±0.01 -> 3.92 at 761±115GeV (χ^2/NDF=3.6/27)
  - Exponentially cut-off power law
    - γ= -3.10±0.01 at 2854± 304GeV (χ^2/NDF=12/28)
  - Single power law
    - γ= -3.18±0.01 (χ^2/NDF=56/29)
- Possible spectral fit in whole energy region
  - Positron contribution is fitted using AMS flux with secondaries + pulsers.
  - CALET electron+positron flux is fitted with secondaries + pulsers + SNRs.
  - The best fit: 0.8x10^{48}erg in E>1TeV for each nearby SNR.

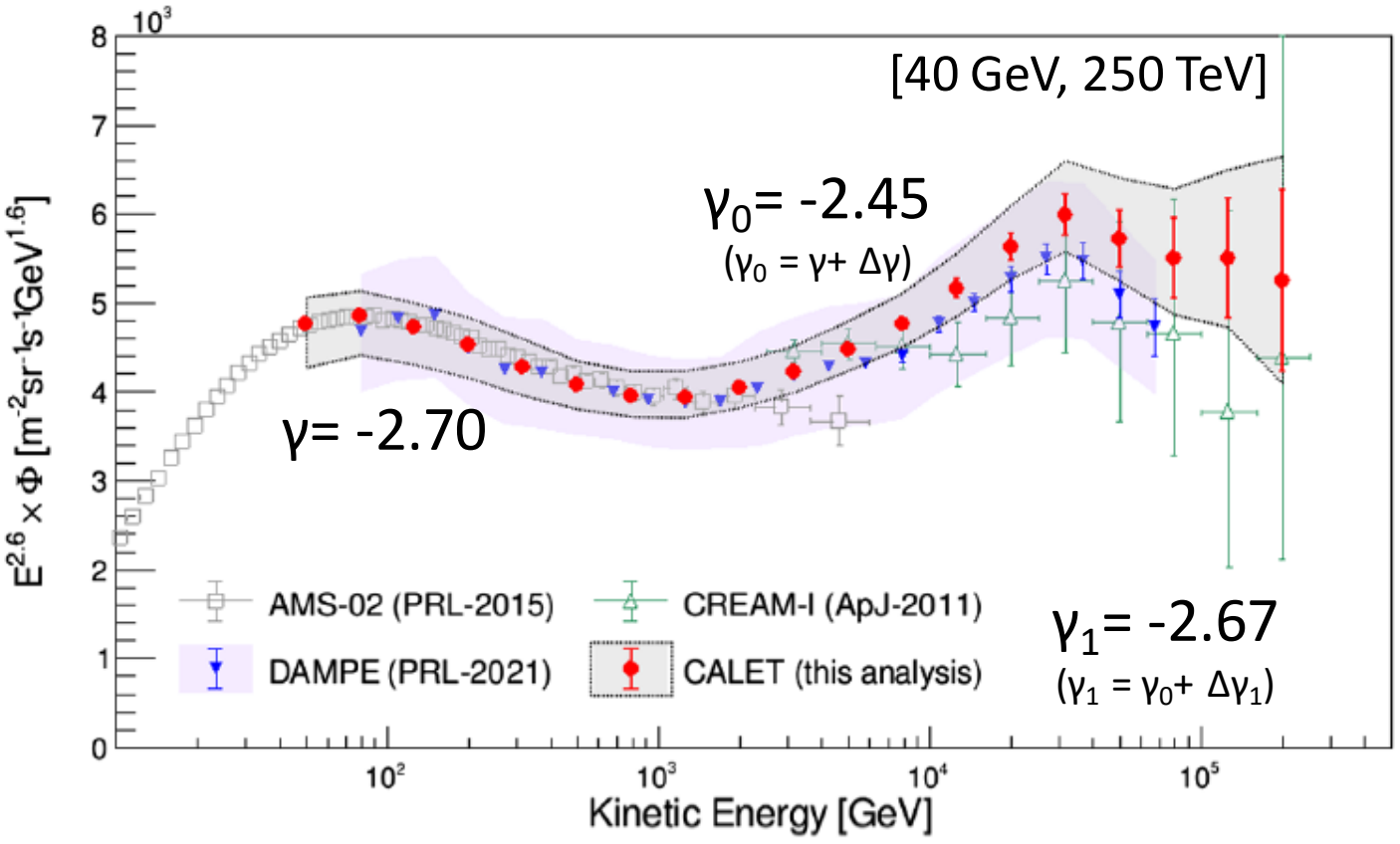




Helium energy spectrum

PRL 130, 171002 (2023)

Data: Oct. 2015 – Sep. 2020

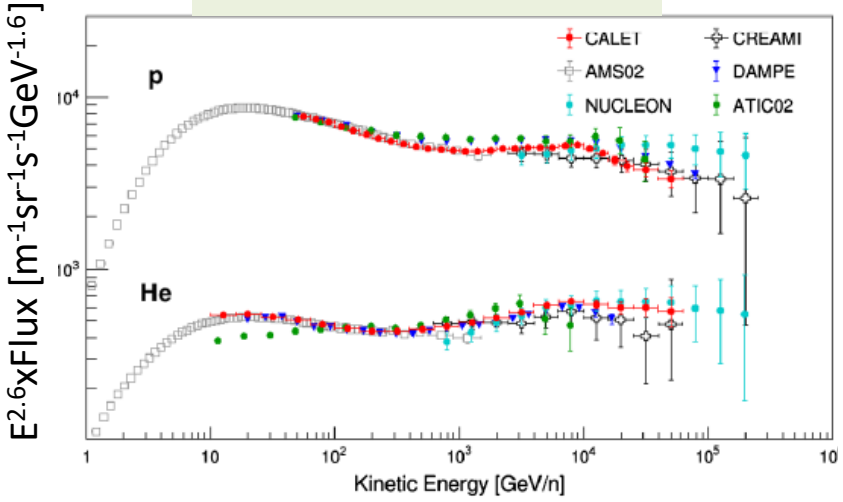


- We observe the spectral hardening starting at
  $E_0 = 1.319^{+0.113}_{-0.093}(stat)^{+0.267}_{-0.124}(sys)\mathrm{TeV}$
  This is consistent with DAMPE result (PRL 2021)
- We also observe spectral softening starting at
  $E_1 = 33.2^{+9.8}_{-6.2}(stat)^{+1.8}_{-2.3}(sys)\mathrm{TeV}$

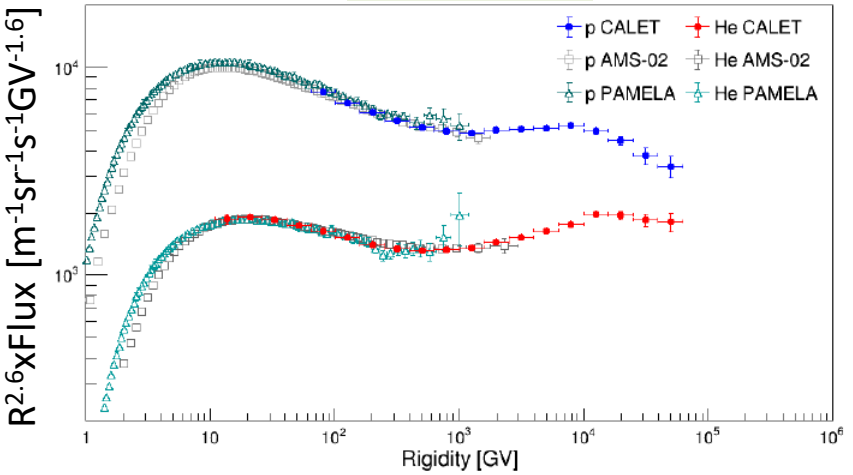
Proton/He ratio

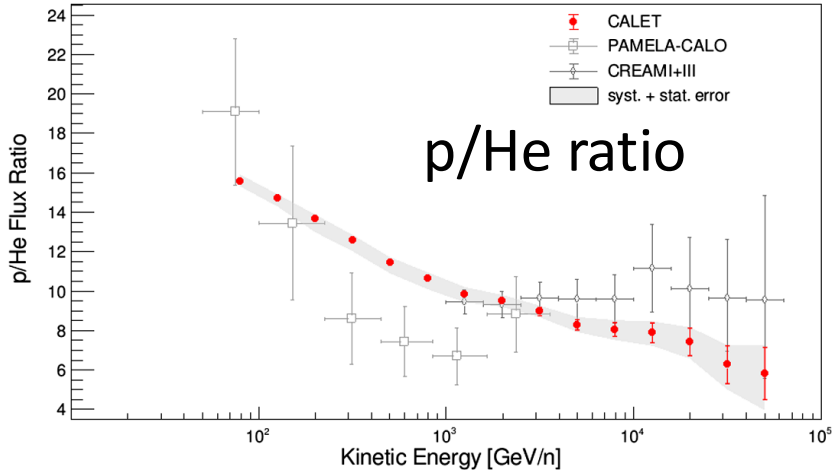
PRL 130, 171002 (2023)

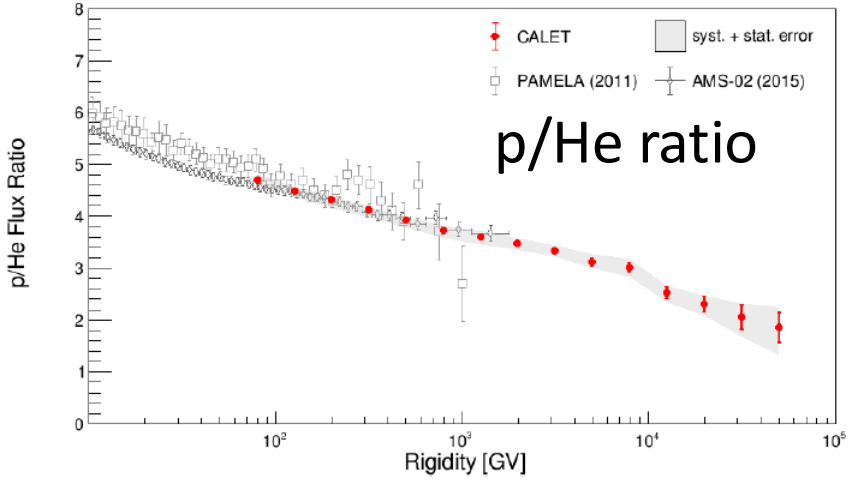
Energy/nucleon



rigidity



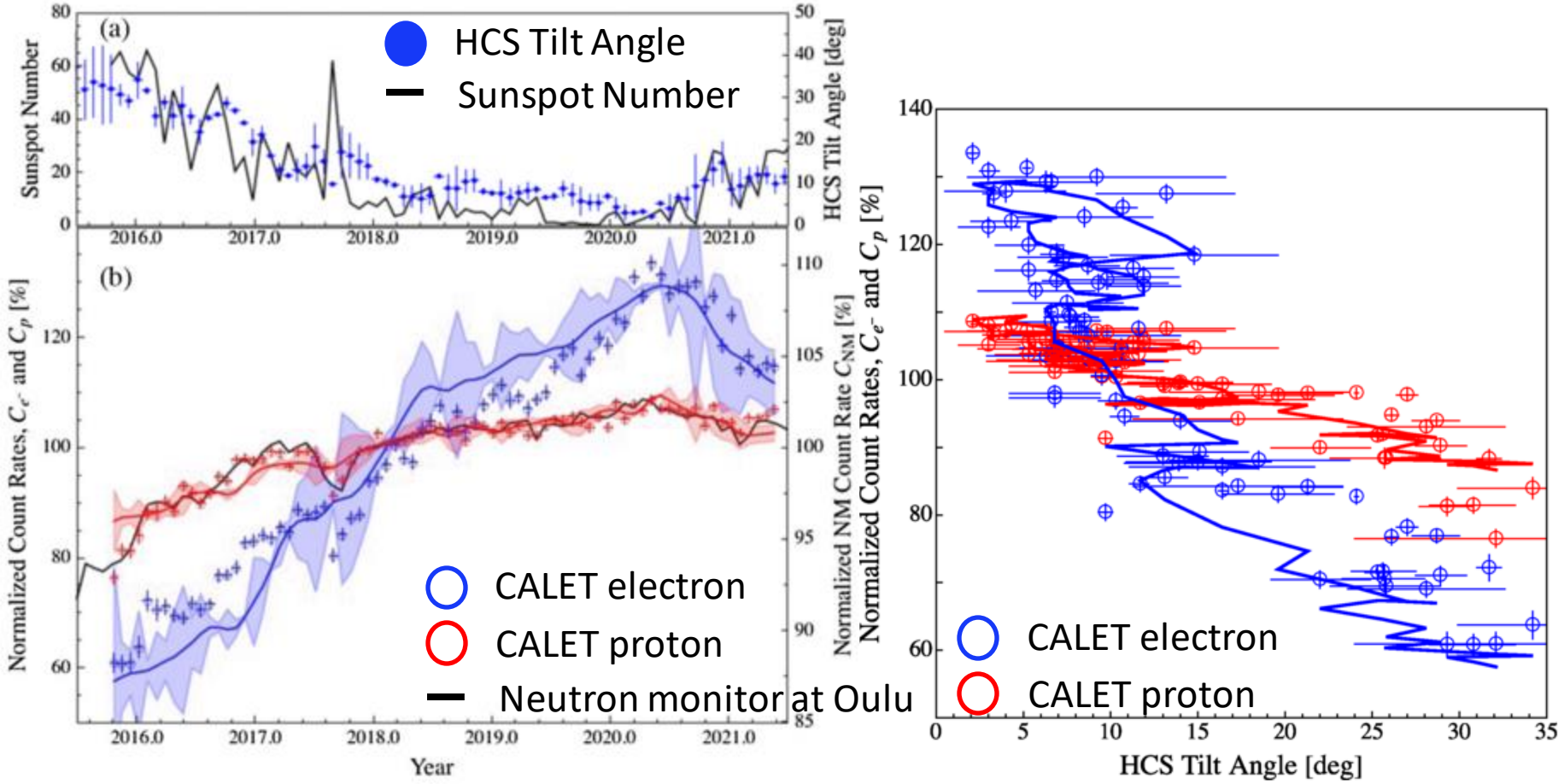




- Spectral hardening in rigidity are consistent between proton and helium.
- p/He ratio in 60GV/n<E<60TV/n is consistent to previous measurements.

	hardening (GeV)	softening (TeV)
Proton	584^{+61}_{-58}	$9.3^{+1.4}_{-1.1}$
Helium (E/Z)	$660^{+56\ +134}_{-46\ -62}$	$16.6^{+4.9\ +0.9}_{-3.1\ -1.3}$
Helium (E/n)	$330^{+28\ +67}_{-23\ -31}$	$8.3^{+2.3\ +0.5}_{-3.8\ -0.6}$

Charge-sign dependent solar modulation (PRL 130, 211001, (2023))



- CALET electron rate reached minimum 6months after the beginning of solar cycle 25 in Dec. 2019. Now the electron count rate is decreasing.
- Good correlation of neutron monitor counting rate at Oulu station (black line) with CALET proton rate.
- The count rate increase of electron is found to be larger than that of proton. This is consistent with numerical drift model (colored solid lines) which expects CHARGE SIGN dependence of the solar modulation.

CALET: Summary and Future Prospects

- CALET has taken more than 8 years of data with excellent performance and remarkable stability of the instrument since the start of data taking on Oct. 13, 2015.
- HE trigger operational for >3300 days with >85% live time fraction
- Total number of > GeV triggers ~4.4 billion
- We have achieved the following observations:
  - Cosmic ray spectra: electron/proton/He/B/C/O/Fe/Ni/more
  - Solar modulation/diffuse and point source gamma-ray/GRB/GW follow up
- New results
  - electron (PRL131, 191001 (2023))
  - Helium (PRL130, 171002 (2023))
  - Solar modulation (PRL 130, 211001 (2023))

Extended operations were approved by JAXA/NASA/ASI until the end of 2024 (at least and plan to operate until 2030).

研究会「CALETによる銀河宇宙線・ガンマ線観測の現状と展望」

- 日時：2024年2月29日（木）　10:00-17:30
- 場所：東京大学宇宙線研究所（柏）大セミナー室　（ZOOM配信あり）
- 概要：国際宇宙ステーション日本実験棟「きぼう」に搭載されたCALETは、2015年の観測開始以来これまで8年間にわたりISS上で観測を継続し、2030年のISS運用終了までの観測延長が承認される予定です。
  これまでの電子や陽子・原子核の観測からは、銀河宇宙線の加速・伝播機構について新たな解釈が必要となるスペクトル構造などが検出されています。さらに、今後の観測でKneeに迫るスペクトルの高精度観測が実現される予定です。このため、これまでのCALETの観測データの解釈や、他の実験との比較、また今後の方針を議論します。

是非、ご参加ください。