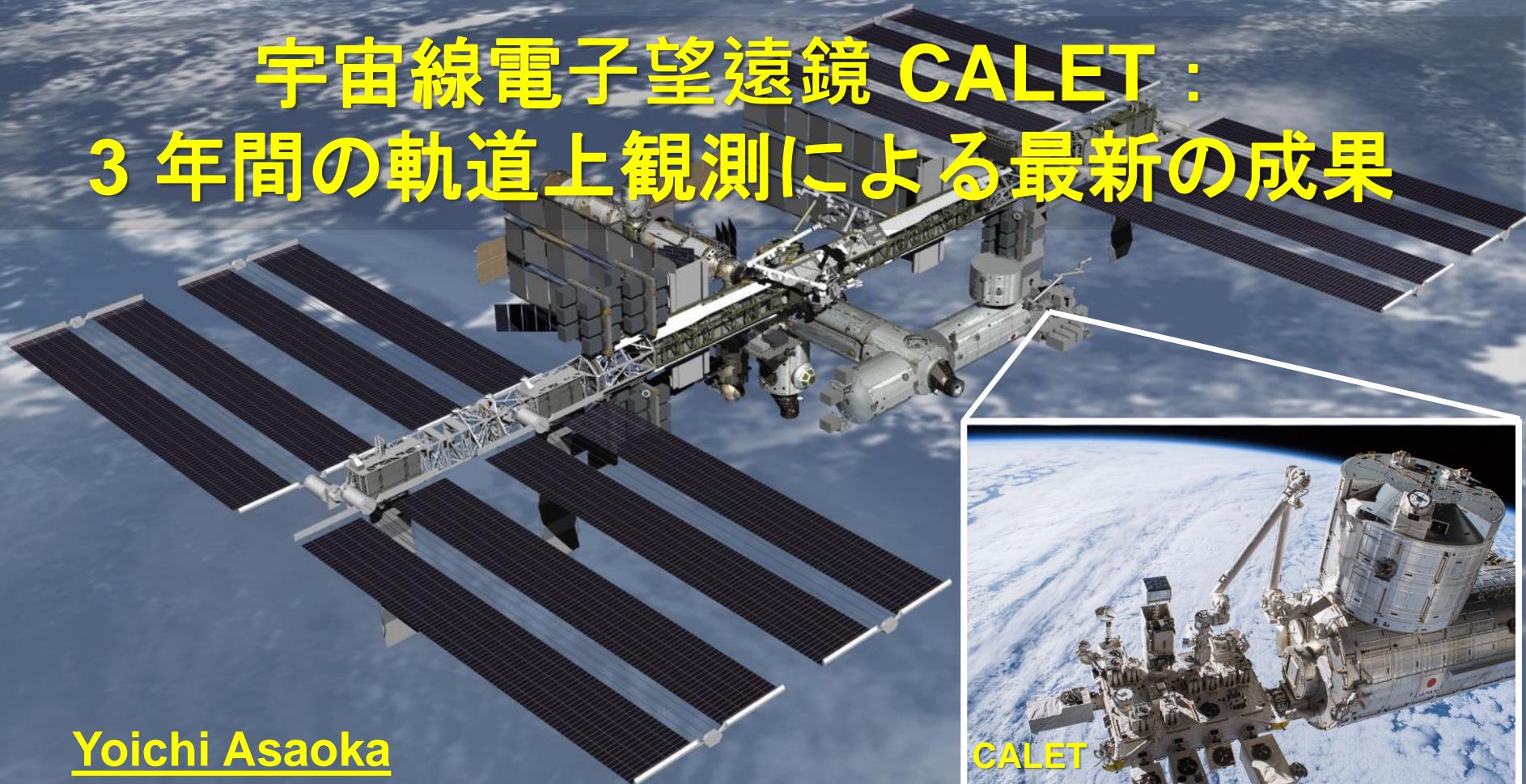
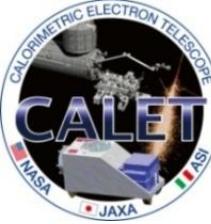




宇宙線電子望遠鏡 CALET： 3 年間の軌道上観測による最新の成果



Yoichi Asaoka
for the CALET collaboration
WISE, Waseda University



CALET Collaboration Team



O. Adriani²⁵, Y. Akaike², K. Asano⁷, Y. Asaoka^{9,31}, M.G. Bagliesi²⁹, E. Berti²⁵, G. Bigongiari²⁹, W.R. Binns³², S. Bonechi²⁹, M. Bongi²⁵, P. Brogi²⁹, A. Bruno¹⁵, J.H. Buckley³², N. Cannady¹³, G. Castellini²⁵, C. Checchia²⁶, M.L. Cherry¹³, G. Collazuol²⁶, V. Di Felice²⁸, K. Ebisawa⁸, H. Fuke⁸, T.G. Guzik¹³, T. Hams³, N. Hasebe³¹, K. Hibino¹⁰, M. Ichimura⁴, K. Ioka³⁴, W. Ishizaki⁷, M.H. Israel³², K. Kasahara³¹, J. Kataoka³¹, R. Kataoka¹⁷, Y. Katayose³³, C. Kato²³, Y. Kawakubo¹, N. Kawanaka³⁰, K. Kohri¹², H.S. Krawczynski³², J.F. Krizmanic², T. Lomtadze²⁷, P. Maestro²⁹, P.S. Marrocchesi²⁹, A.M. Messineo²⁷, J.W. Mitchell¹⁵, S. Miyake⁵, A.A. Moiseev³, K. Mori^{9,31}, M. Mori²⁰, N. Mori²⁵, H.M. Motz³¹, K. Munakata²³, H. Murakami³¹, S. Nakahira⁹, J. Nishimura⁸, G.A. De Nolfo¹⁵, S. Okuno¹⁰, J.F. Ormes²⁵, S. Ozawa³¹, L. Pacini²⁵, F. Palma²⁸, V. Pal'shin¹, P. Papini²⁵, A.V. Penacchioni²⁹, B.F. Rauch³², S.B. Ricciarini²⁵, K. Sakai³, T. Sakamoto¹, M. Sasaki³, Y. Shimizu¹⁰, A. Shiomi¹⁸, R. Sparvoli²⁸, P. Spillantini²⁵, F. Stolzi²⁹, S. Sugita¹, J.E. Suh²⁹, A. Sulaj²⁹, I. Takahashi¹¹, M. Takayanagi⁸, M. Takita⁷, T. Tamura¹⁰, N. Tateyama¹⁰, T. Terasawa⁷, H. Tomida⁸, S. Torii³¹, Y. Tunesada¹⁹, Y. Uchihori¹⁶, S. Ueno⁸, E. Vannuccini²⁵, J.P. Wefel¹³, K. Yamaoka¹⁴, S. Yanagita⁶, A. Yoshida¹, and K. Yoshida²²

1) Aoyama Gakuin University, Japan

2) CRESST/NASA/GSFC and

Universities Space Research Association, USA

3) CRESST/NASA/GSFC and University of Maryland, USA

4) Hirosaki University, Japan

5) Ibaraki National College of Technology, Japan

6) Ibaraki University, Japan

7) ICRR, University of Tokyo, Japan

8) ISAS/JAXA Japan

9) JAXA, Japan

10) Kanagawa University, Japan

11) Kavli IPMU, University of Tokyo, Japan

12) KEK, Japan

13) Louisiana State University, USA

14) Nagoya University, Japan

15) NASA/GSFC, USA

16) National Inst. of Radiological Sciences, Japan

17) National Institute of Polar Research, Japan

18) Nihon University, Japan

19) Osaka City University, Japan

20) Ritsumeikan University, Japan

21) Saitama University, Japan

22) Shibaura Institute of Technology, Japan

23) Shinshu University, Japan

24) University of Denver, USA

25) University of Florence, IFAC (CNR) and INFN, Italy

26) University of Padova and INFN, Italy

27) University of Pisa and INFN, Italy

28) University of Rome Tor Vergata and INFN, Italy

29) University of Siena and INFN, Italy

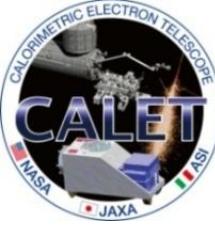
30) University of Tokyo, Japan

31) Waseda University, Japan

32) Washington University-St. Louis, USA

33) Yokohama National University, Japan

34) Yukawa Institute for Theoretical Physics,
Kyoto University, Japan



CALET Collaboration Team



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Outline

1. Introduction 2. Calibration 3. Operations 4. Results

- Electrons
- Hadrons
- Gamma-Rays
- Space Weather

- 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 Collab.), ApJL 829 (2016) L20.
- O.Adriani et al. (CALET Collab.), ApJ 863 (2018) 160.
- N.Cannady, Y.Asaoka et al. (CALET Collab.),
ApJS in press.
- R.Kataoka et al., JGR,
10.1002/2016GL068930 (2016).

5. Summary

ISS as Cosmic Ray Observatory



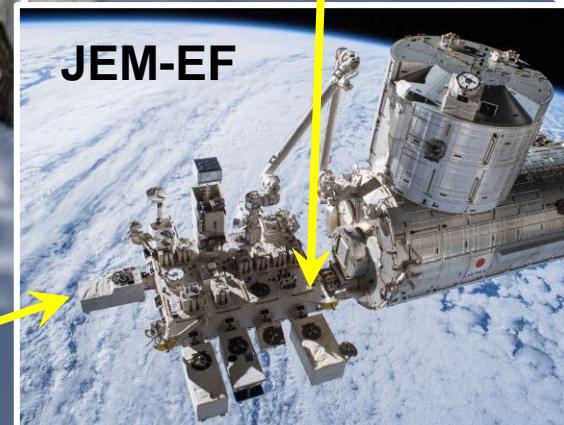
AMS Launch
May 16, 2011



ISS-CREAM Launch
August 14, 2017



CALET Launch
August 19, 2015



JEM-EF

ISS as Cosmic Ray Observatory



AMS Launch
May 16, 2011

Magnet Spectrometer

- Various PID
- Anti-particles
- $E \leq \text{TeV}$

Calorimeter

- Carbon target
- Hadrons
- Including TeV region



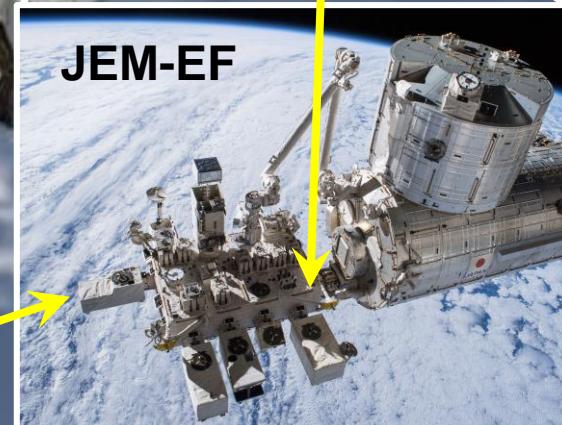
ISS-CREAM Launch
August 14, 2017

Calorimeter

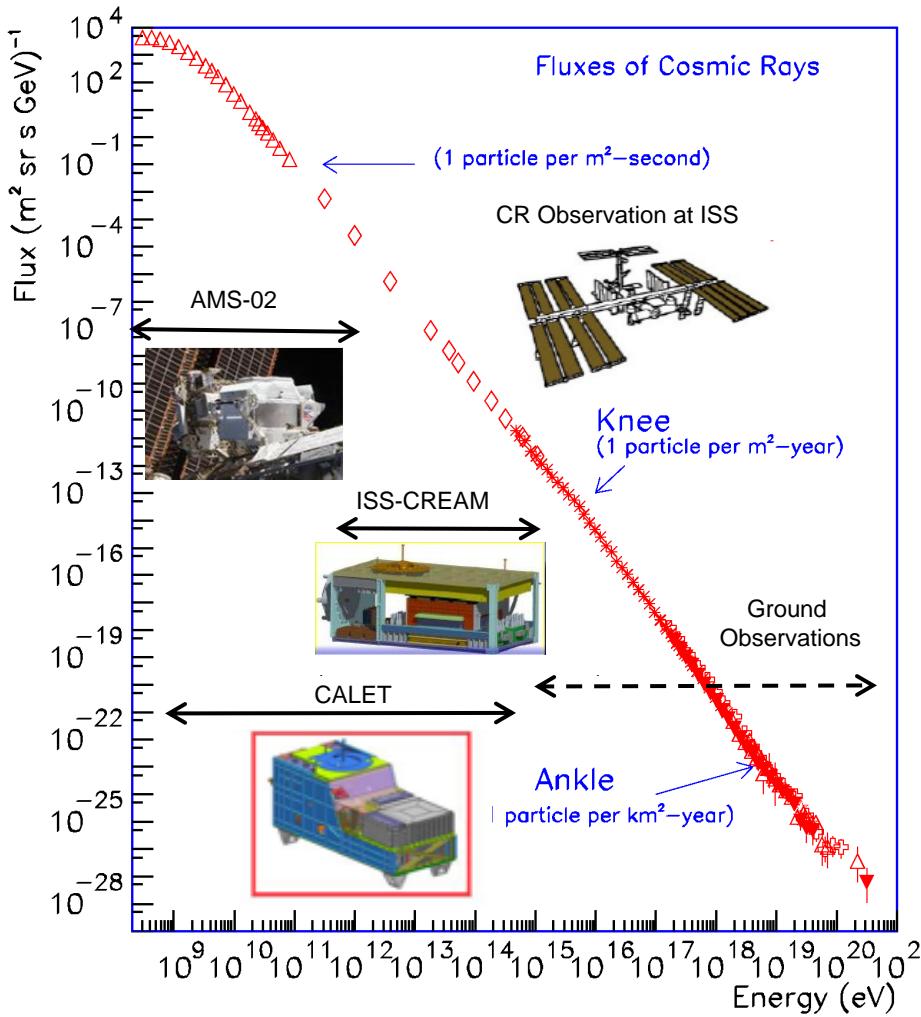
- Fully active
- Electrons
- Including TeV region



CALET Launch
August 19, 2015



Cosmic Ray Observations at the ISS and CALET

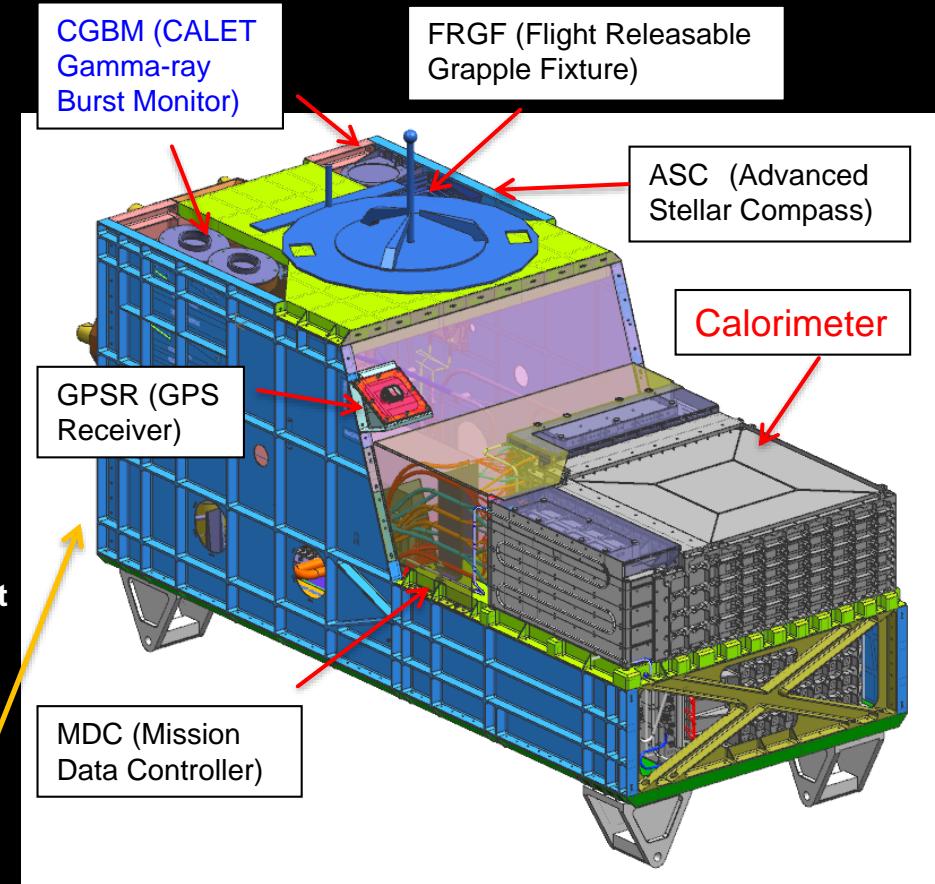
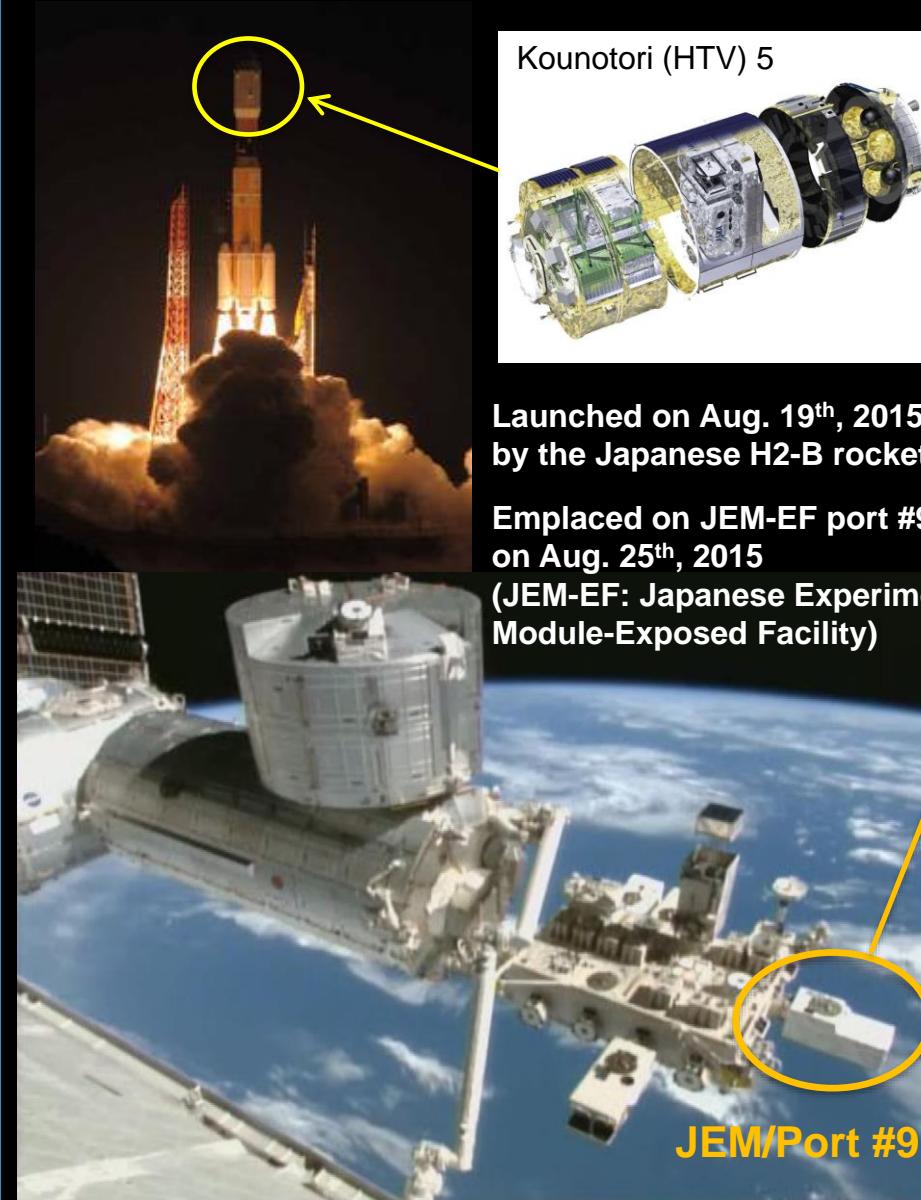


Overview of CALET Observations

- 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 1 GeV - 20 TeV will be achieved with high energy resolution due to optimization for electron detection
 - ⇒ **Search for Dark Matter and Nearby Sources**
- Observation of cosmic-ray nuclei will be performed in energy region from 10 GeV to 1 PeV
 - ⇒ **Unravelling the CR acceleration and propagation mechanism**
- Detection of transient phenomena is expected in space by long-term stable observations
 - ⇒ **EM radiation from GW sources, Gamma-ray burst, Solar flare, etc.**



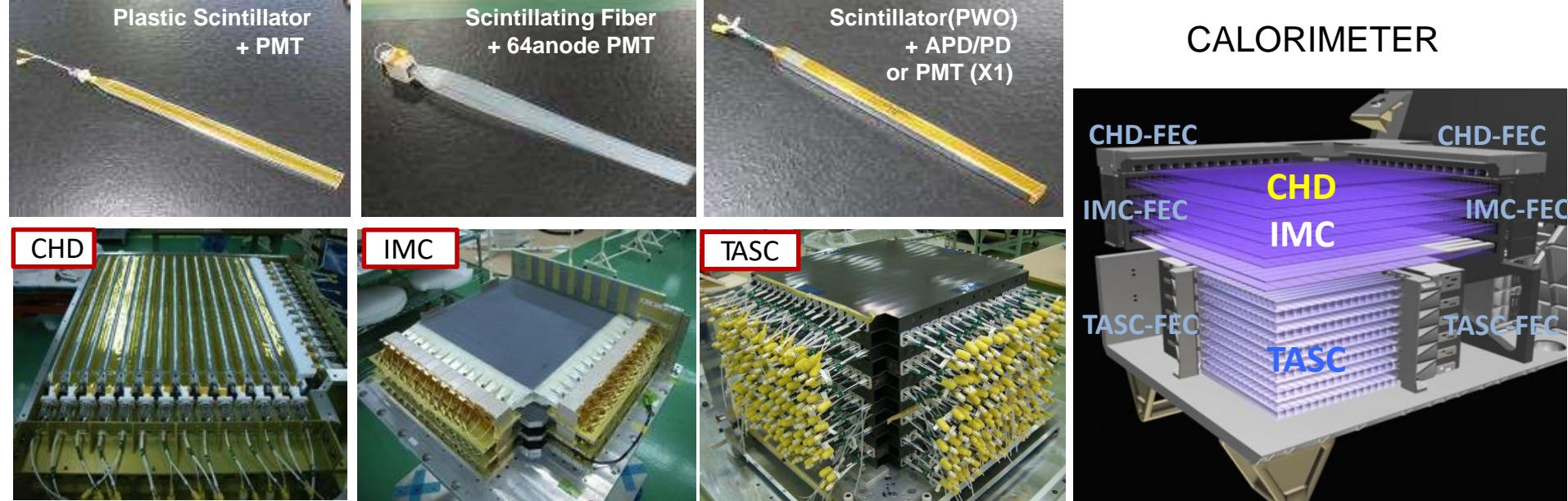
CALET Payload



- 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 Instrument

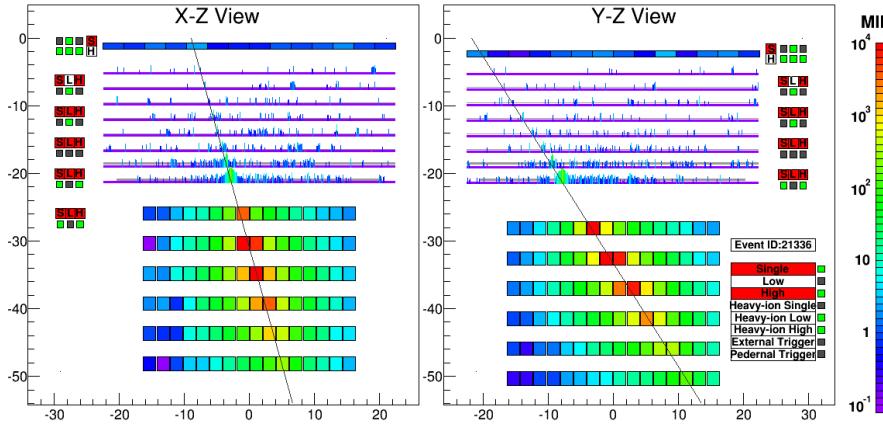


	CHD (Charge Detector)	IMC (Imaging Calorimeter)	TASC (Total Absorption Calorimeter)
Measure	Charge (Z=1-40)	Tracking , Particle ID	Energy, e/p Separation
Geometry (Material)	Plastic Scintillator 14 paddles x 2 layers (X,Y): 28 paddles Paddle Size: 32 x 10 x 450 mm ³	448 Scifi x 16 layers (X,Y) : 7168 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 _l
Readout	PMT+CSA	64-anode PMT+ ASIC	APD/PD+CSA PMT+CSA (for Trigger)@top layer



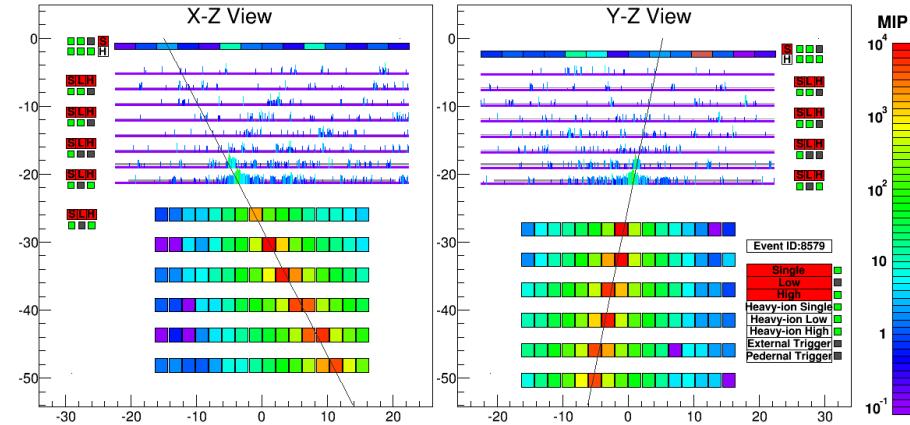
Event Examples of High-Energy Showers

Electron, E=3.05 TeV



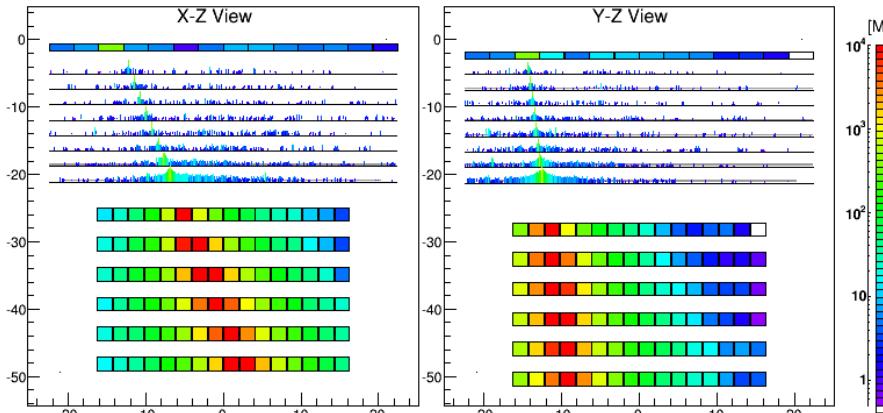
fully contained even at 3TeV

Proton, ΔE=2.89 TeV



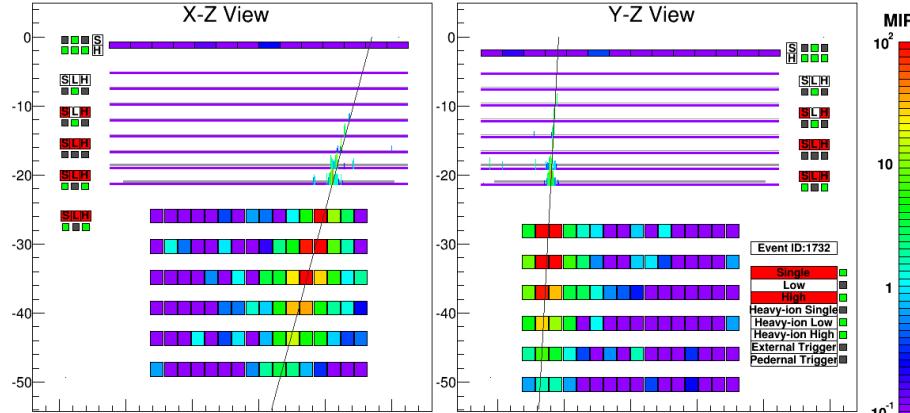
clear difference from electron shower

Fe(Z=26), ΔE=9.3 TeV



energy deposit in CHD consistent with Fe

Gamma-ray, E=44.3 GeV



no energy deposit before pair production

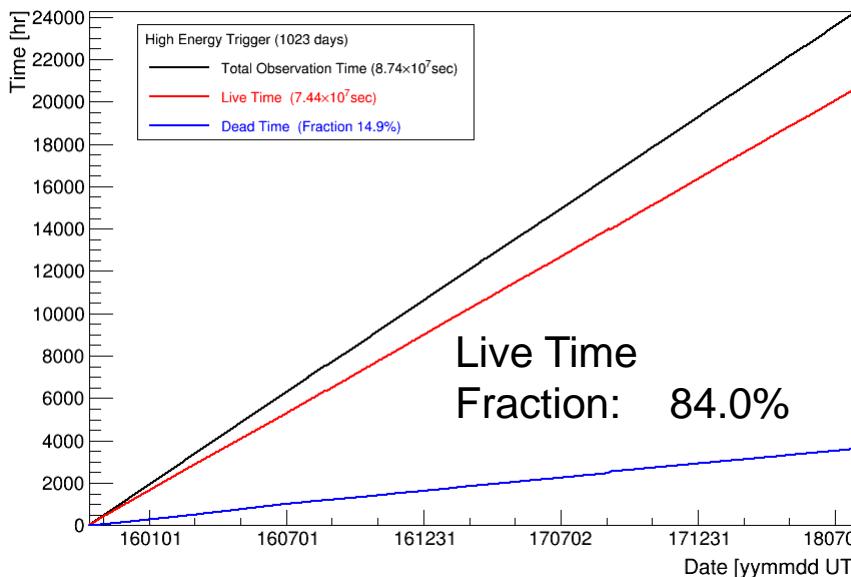
Observation with High Energy Trigger (>10GeV)

Y.Asaoka, S.Ozawa, S.Torii et al. (CALET Collaboration), Astropart. Phys. 100 (2018) 29.

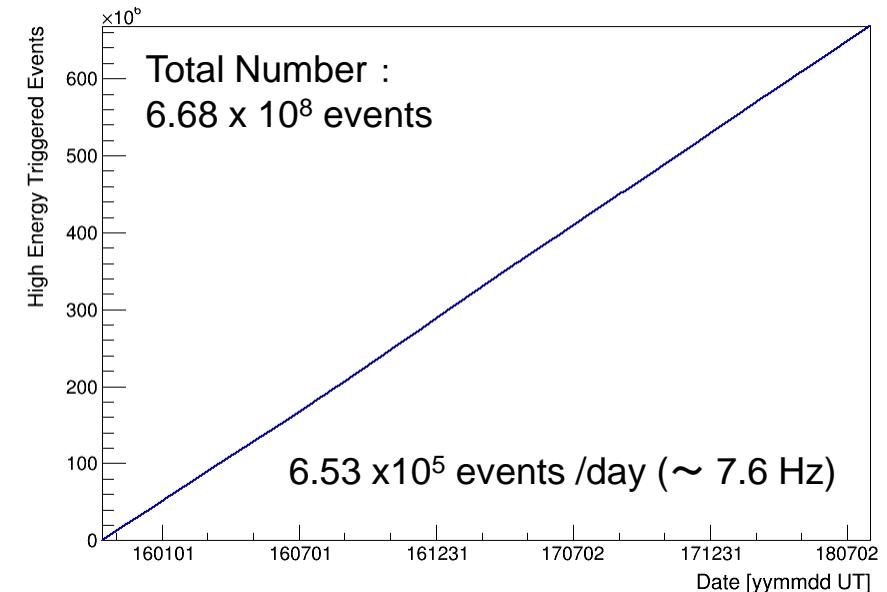
Observation by High Energy Trigger for 1023 days : Oct.13, 2015 – Jul. 31, 2018

- ❑ The exposure, **S Ω T**, has reached to ~89.6 m² sr day for electron observations by continuous and stable operations.
- ❑ Total number of triggered events is ~670 million with a live time fraction of 84.0 %.

Accumulated observation time (live, dead)



Accumulated triggered event number



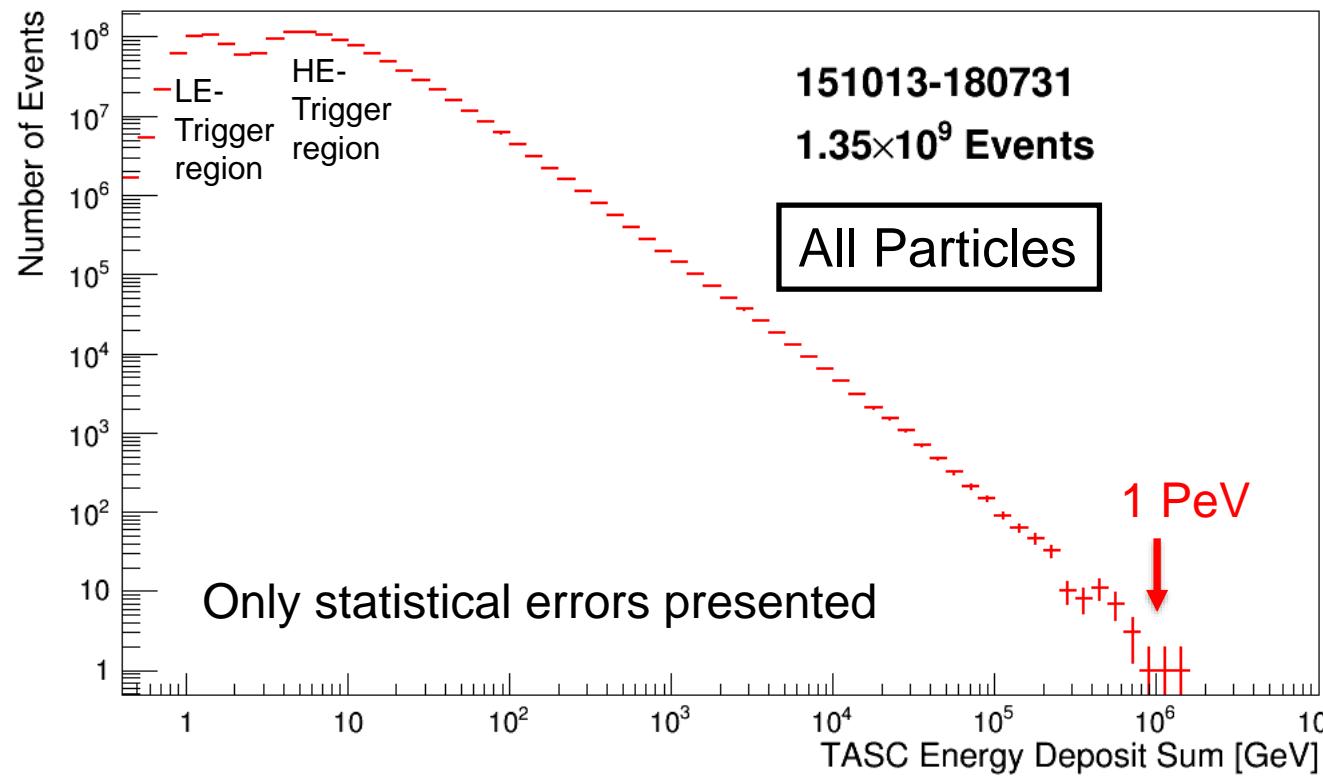


TASC Energy Deposit Distribution of All Triggered-Events by Observation for 1023 days

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

Distribution of deposit energies in TASC observed in 2015.10.13—2018.7.31

→ Energies are calibrated but non-reconstructed



The TASC energy measurements have successfully been carried out in the dynamic range of 1 GeV – 1 PeV.

All-Electron ($e^+ + e^-$)

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

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

Electron Identification

Simple Two Parameter Cut

F_E : Energy fraction of the bottom layer sum to the whole energy deposit sum in TASC

R_E : Lateral spread of energy deposit in TASC-X1

Separation Parameter K is defined as follows:

$$K = \log_{10}(F_E) + 0.5 R_E (\text{cm})$$

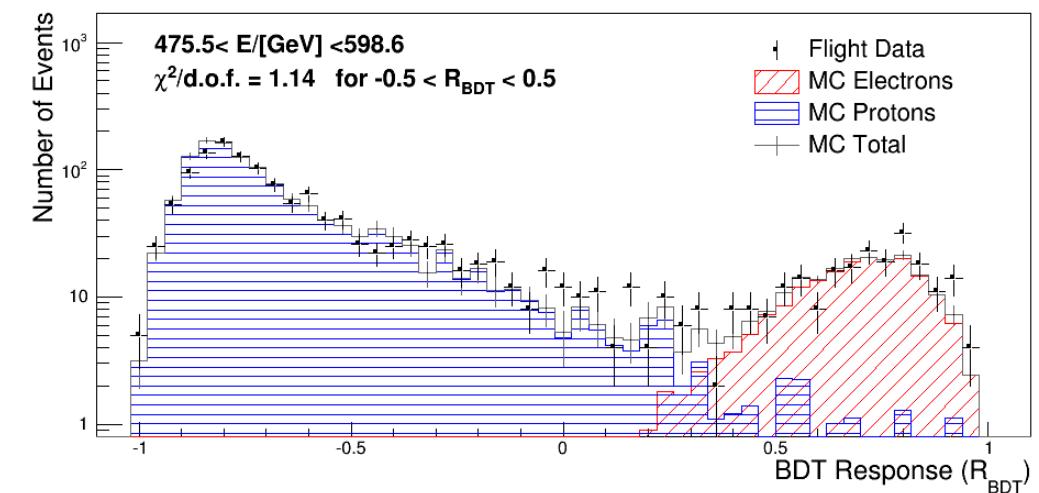
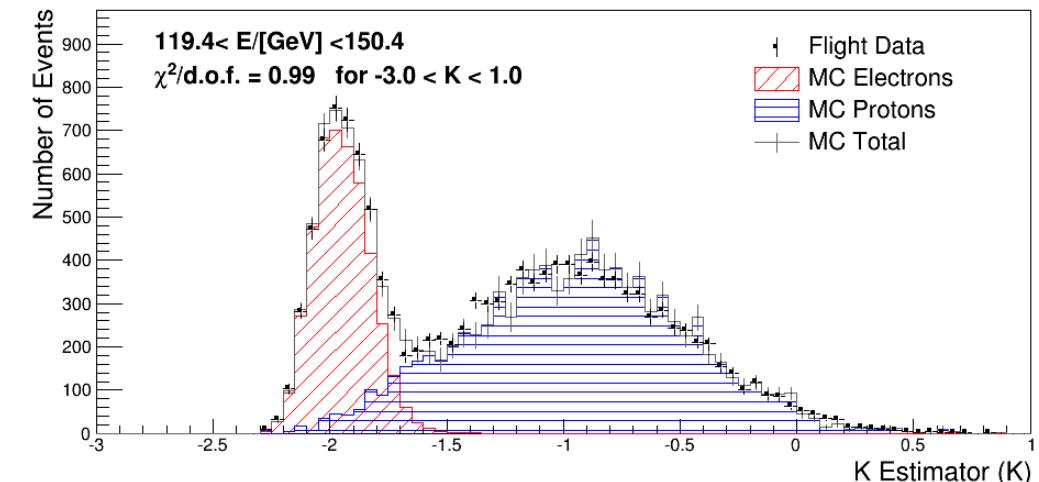
Boosted Decision Trees

In addition to the two parameters making up K, TASC and IMC shower profile fits are used as discriminating variables.

$E < 475 \text{ GeV}$: Simple two parameter cut

$E > 475 \text{ GeV}$: BDT cut

\Rightarrow Contamination is $\sim 5\%$ up to 1 TeV , and $10\text{--}15\%$ in the $1\text{--}3 \text{ TeV}$ region.

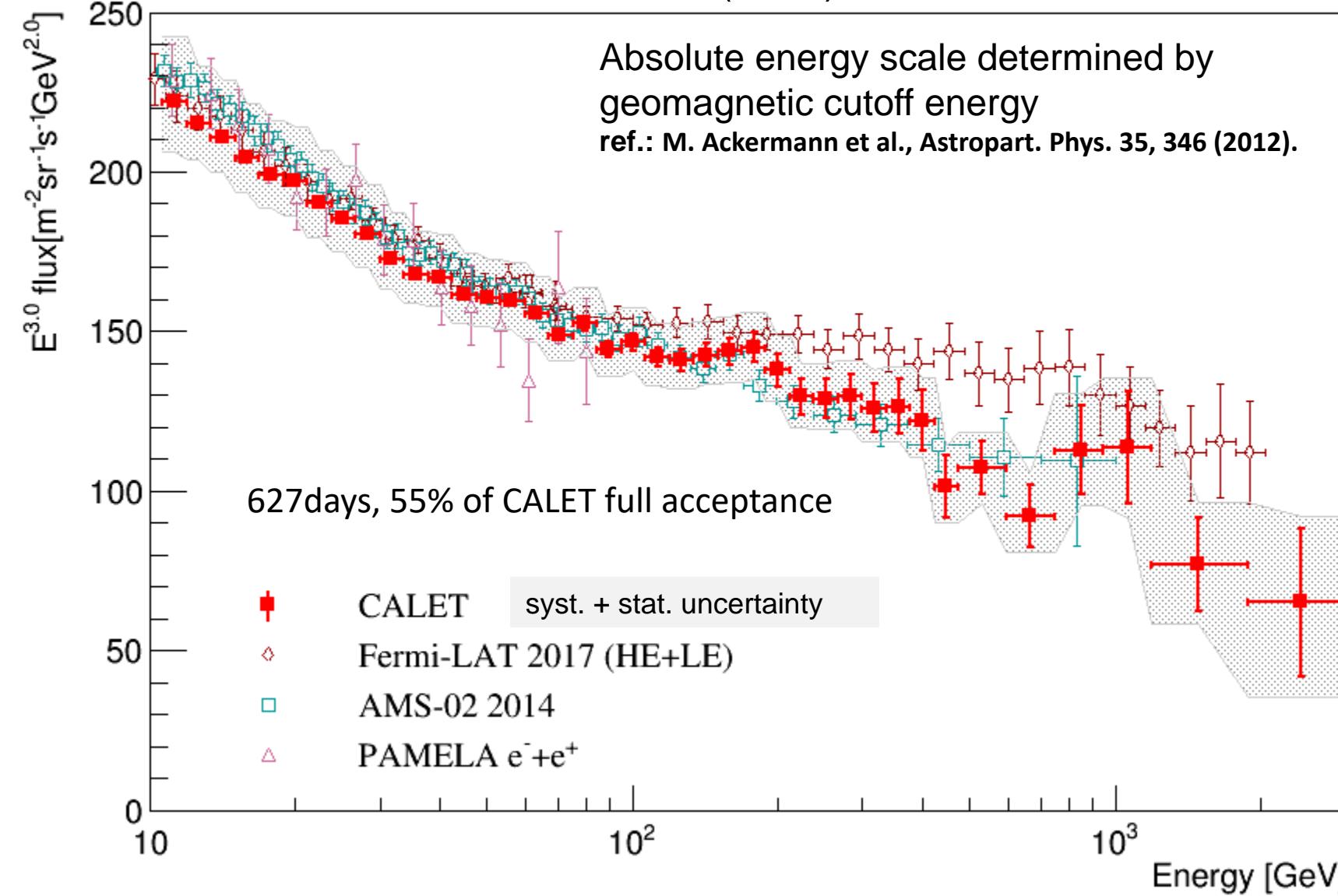


} the small difference in resultant spectrum between two methods are taken into account in the systematic error.



All-Electron Spectrum Measured with CALET from 10 GeV to 3 TeV

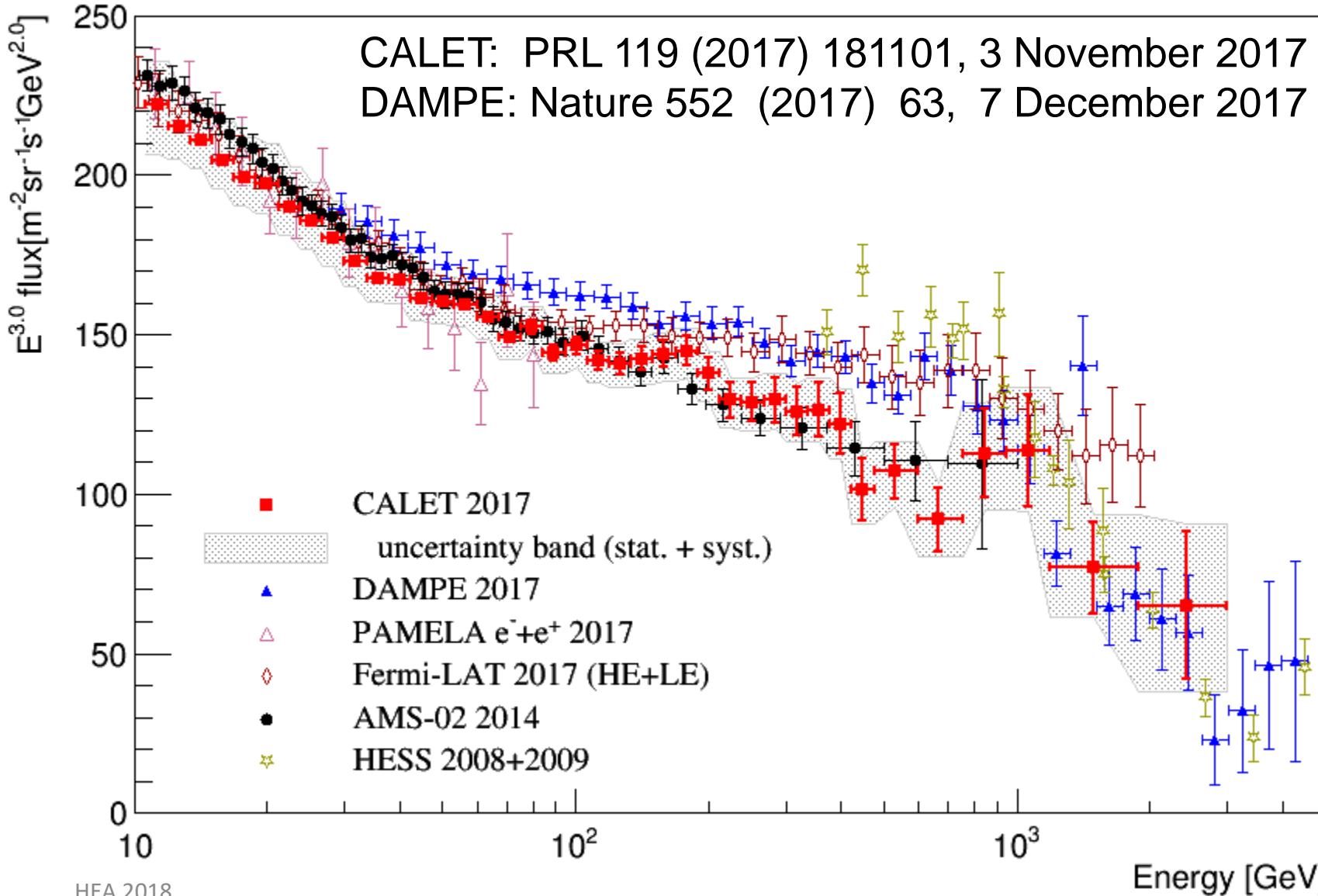
CALET: PRL 119 (2017) 181101, 3 November 2017





All-Electron Spectrum Comparison w/ DAMPE

and other space based experiments





All-Electron Spectrum Comparison w/ DAMPE and other space based experiments

arXiv:1711.10995

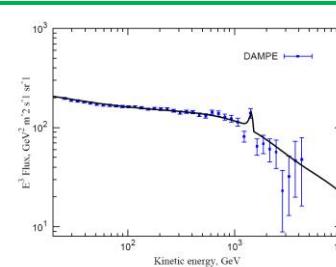
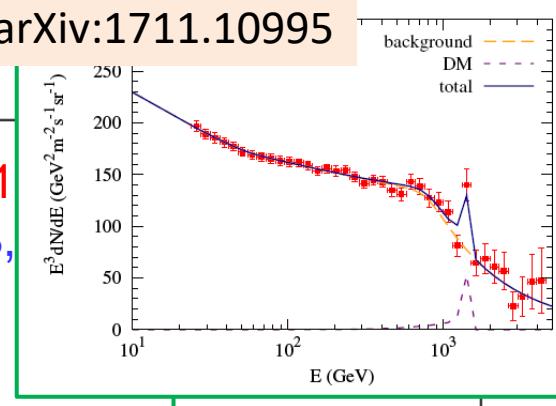


FIG. 3: Total e^- flux. $e : \mu : \tau = 1 : 1 : 1$ as $1 \times 10^8 m_\odot$ with branching ratio do is assumed

arXiv:1711.11579

$E^{3.0}$ flux [$m^{-2} \text{sr}^{-1} \text{GeV}^{2.0}$]

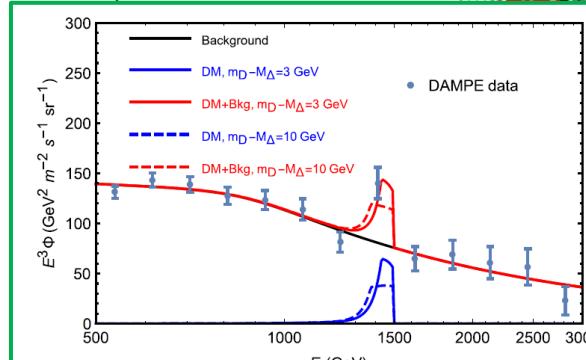


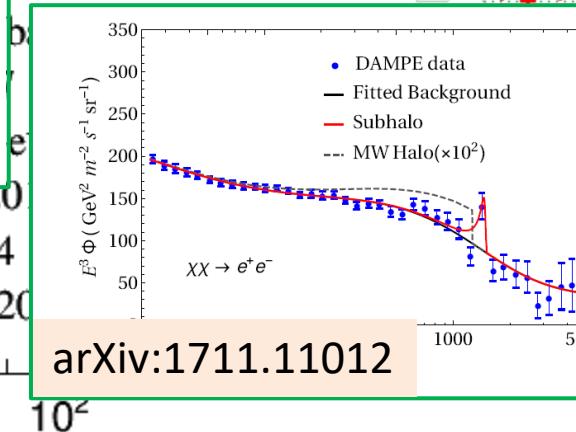
Fig. 2. The DAMPE $e^+e^-e^-e^-$ with $\Delta^{++}\Delta^{--} \rightarrow \pi^+\pi^-$ and 10 GeV . The fitted backgroun

arXiv:1712.00869

Fermi-LAT 20

AMS-02 2014

HESS 2008+20



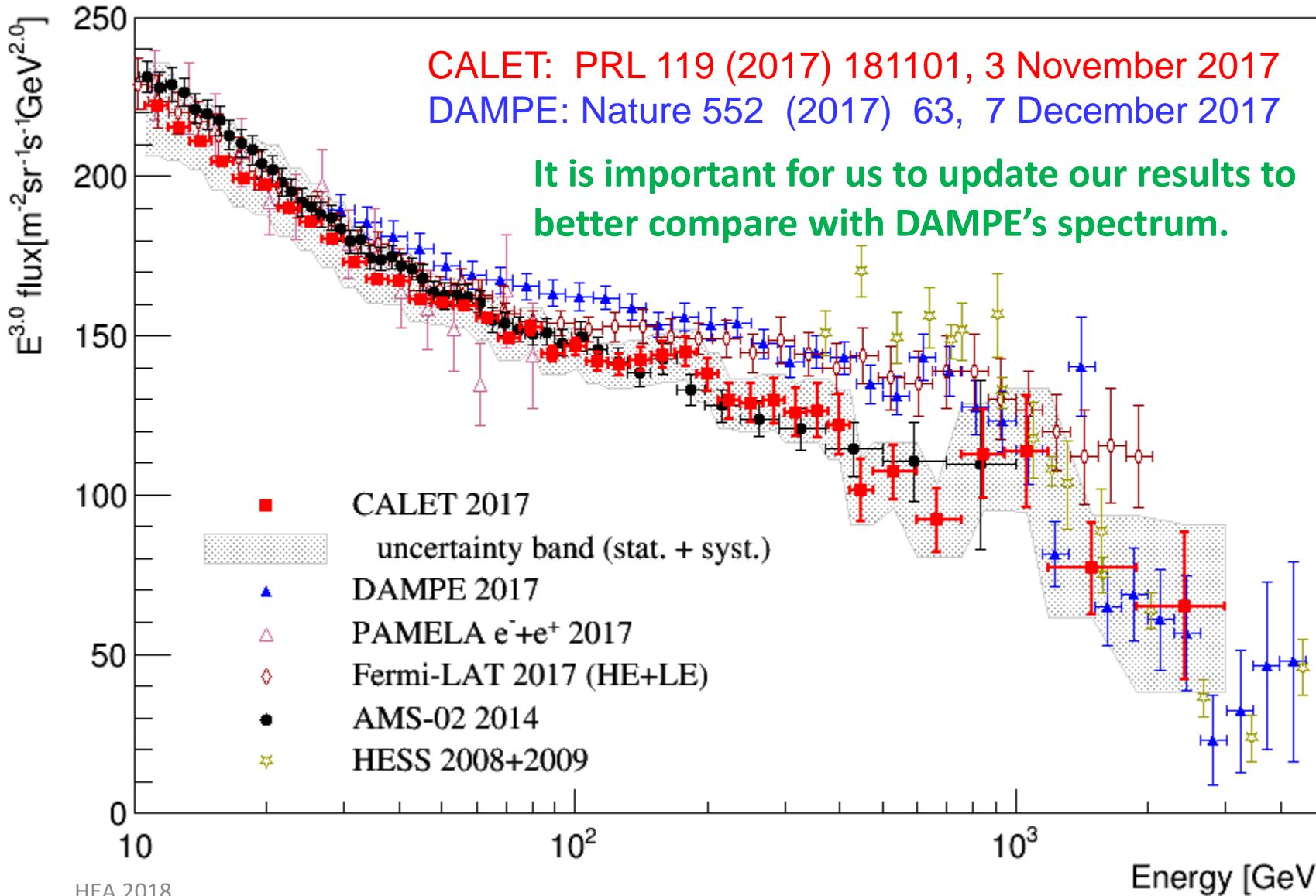
arXiv:1711.11012

Many papers
speculating about
the tentative peak
which is not
mentioned in the
original paper



All-Electron Spectrum Comparison w/ DAMPE

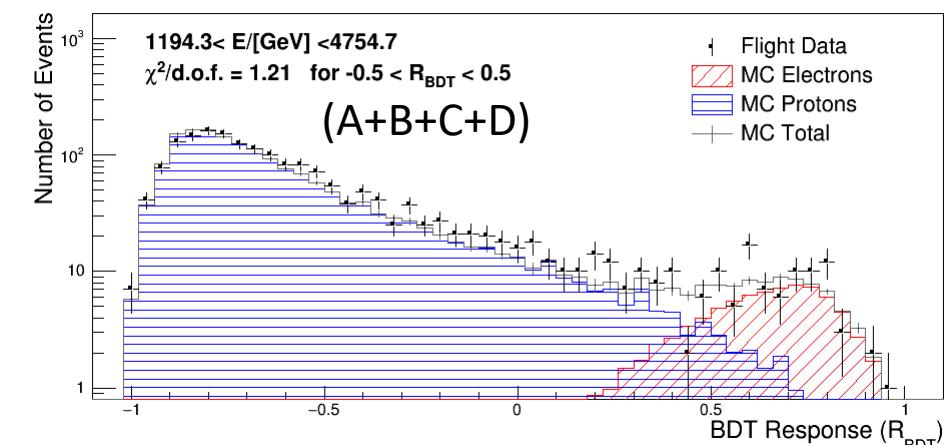
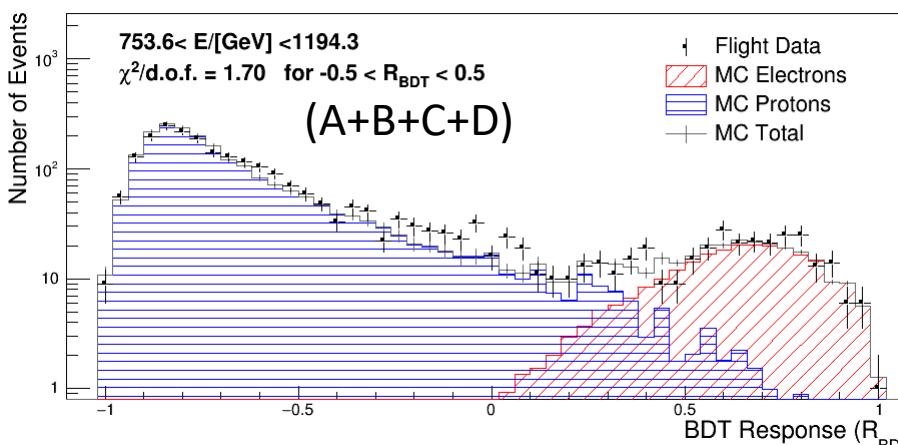
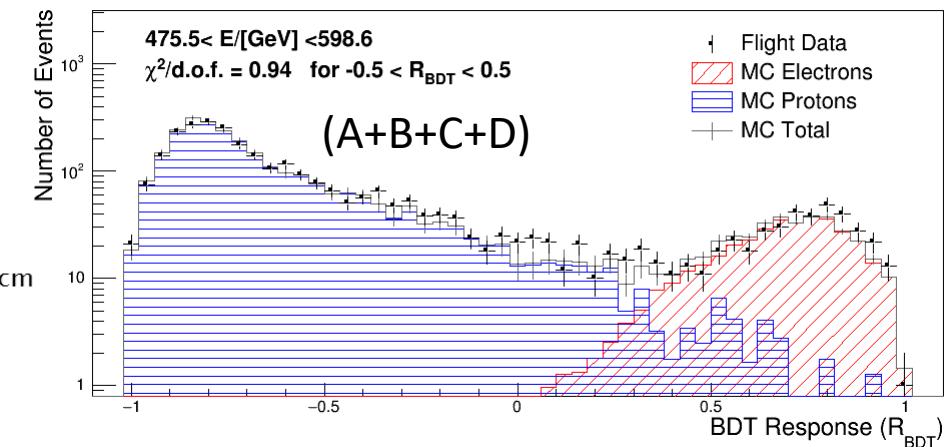
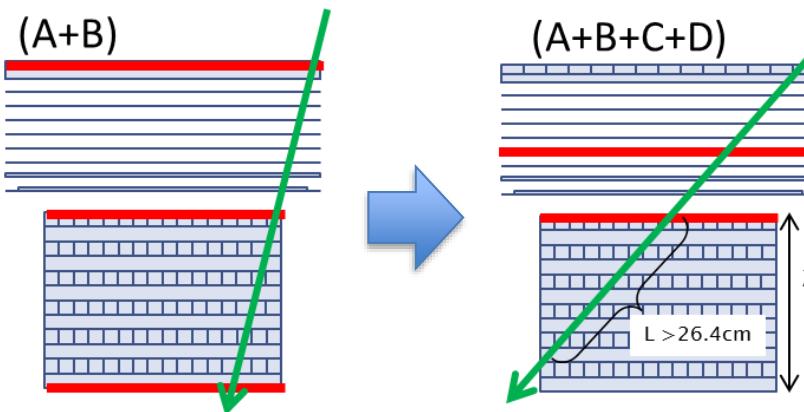
and other space based experiments



Extending the Analysis to Full Acceptance

Analyzed Flight Data:

- 780 days (October 13, 2015 to November 30, 2017)
- **Full CALET acceptance at the high energy region** (Acceptance A+B+C+D; $1040\text{cm}^2\text{sr}$).
In the low energy region fully contained events are used (A+B; $550\text{cm}^2\text{sr}$)



Systematic Uncertainties

(other than energy scale uncertainty)

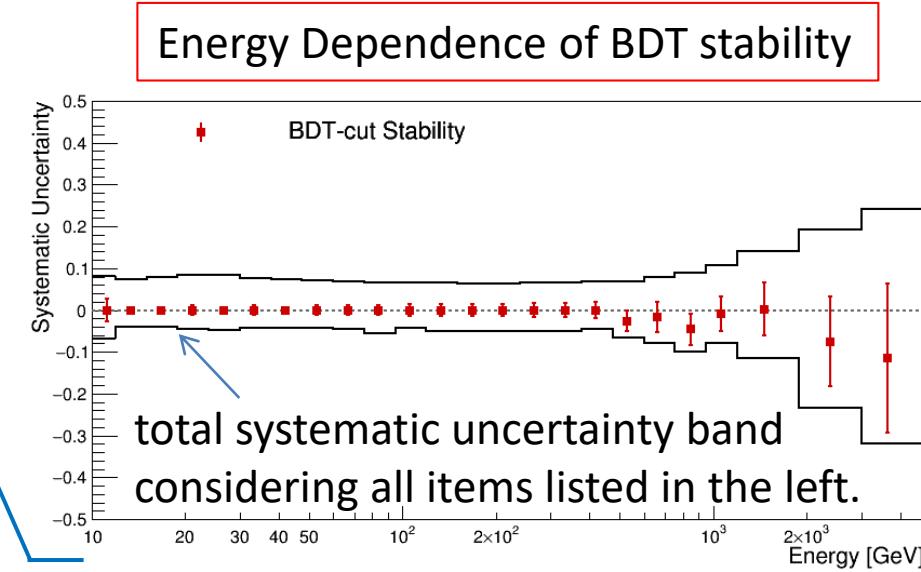
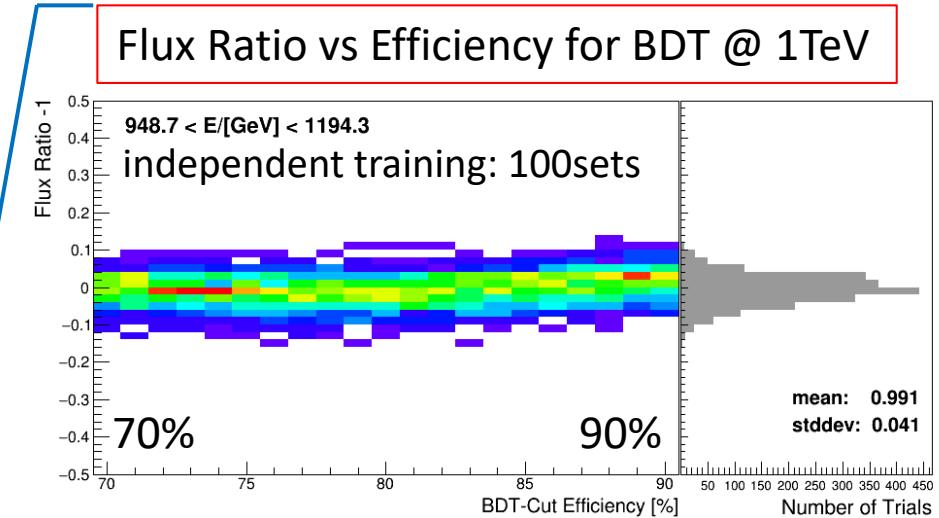
Stability of resultant flux are analyzed by scanning parameter space

Normalization:

- Live time
- Radiation environment
- Long-term stability
- Quality cuts

• Energy dependent:

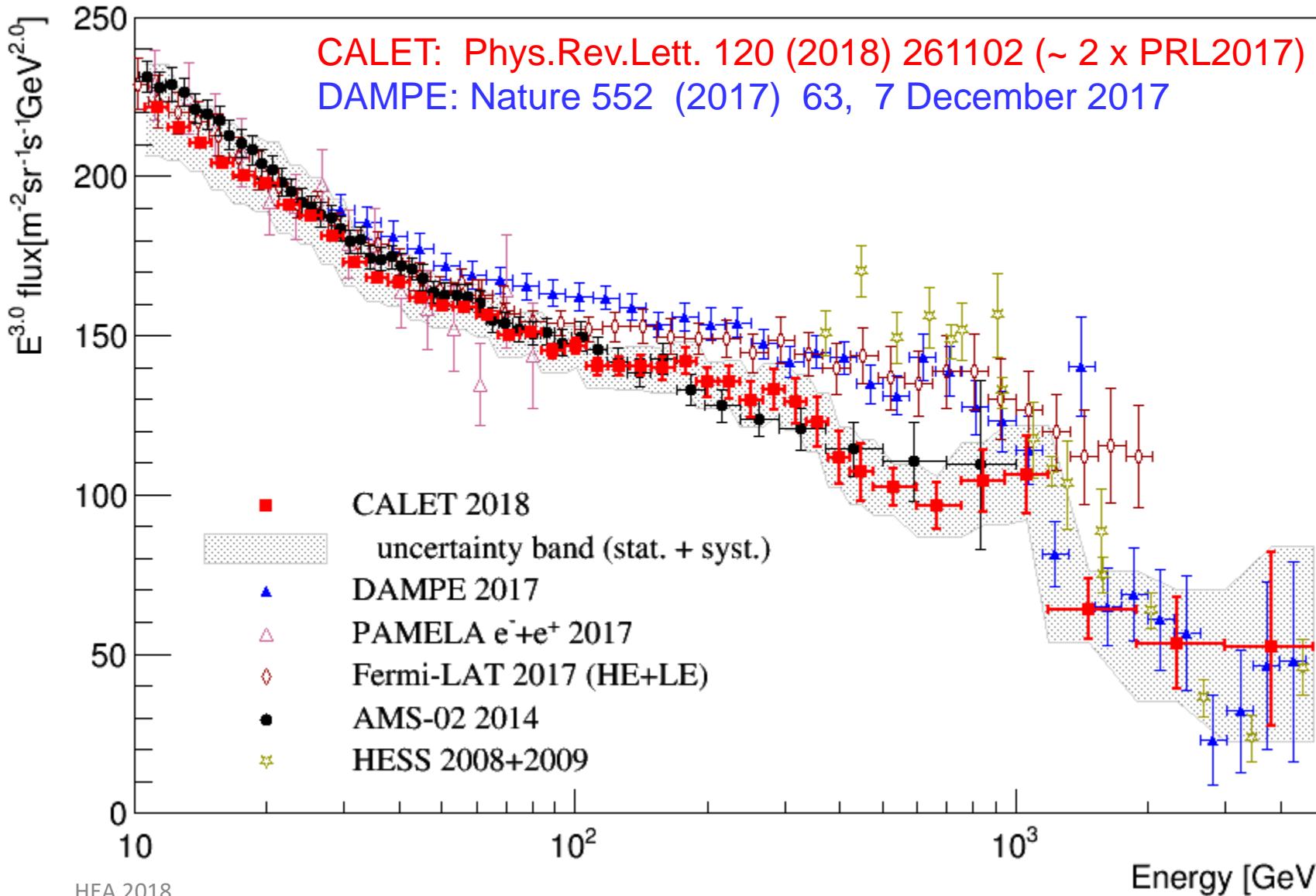
- 2 independent tracking
- charge ID
- electron ID (K-Cut vs BDT)
- **BDT stability** (vs efficiency & training)
- MC model (EPICS vs Geant4)





Extended Measurement by CALET

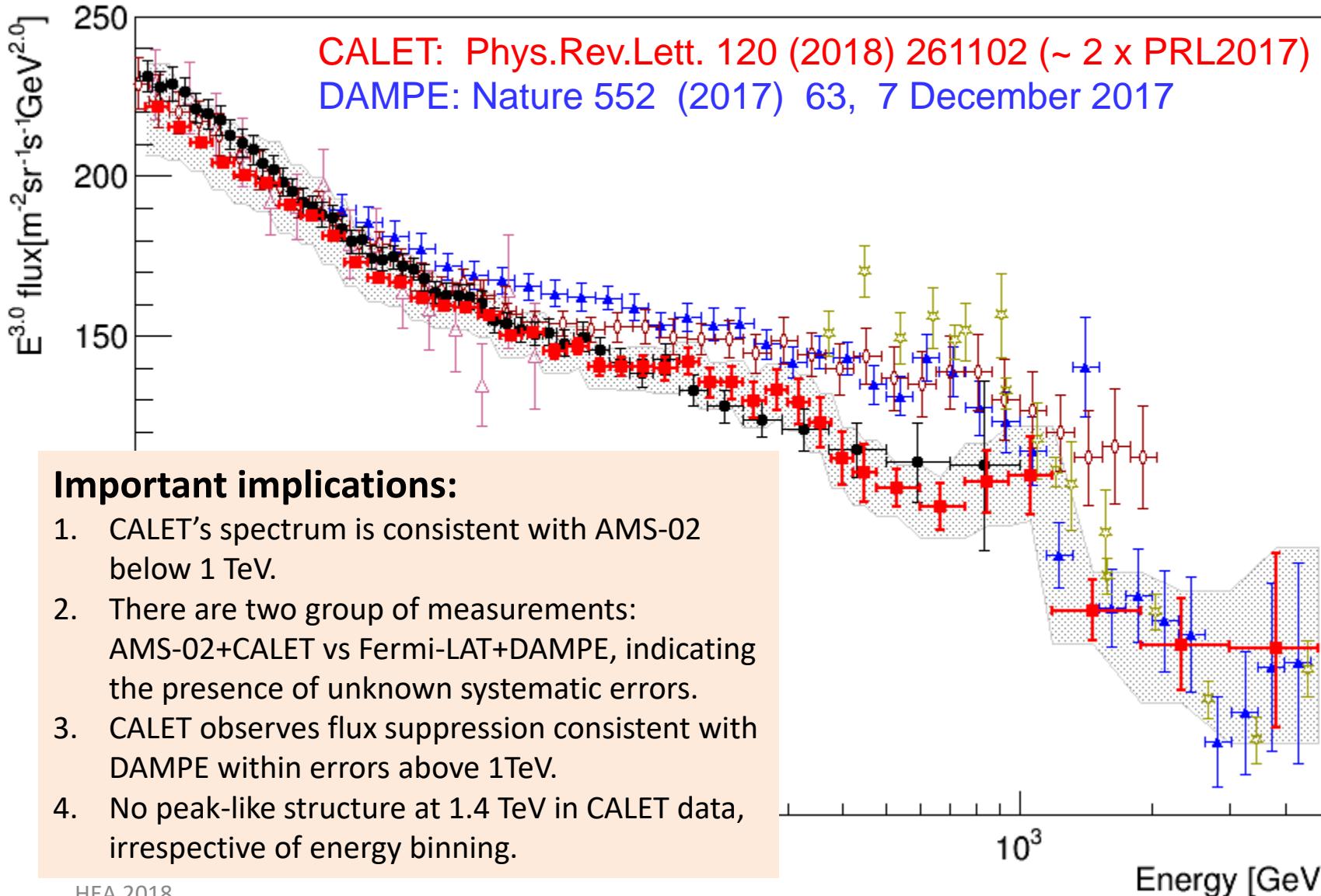
Approximately doubled statistics above 500GeV by using full acceptance of CALET





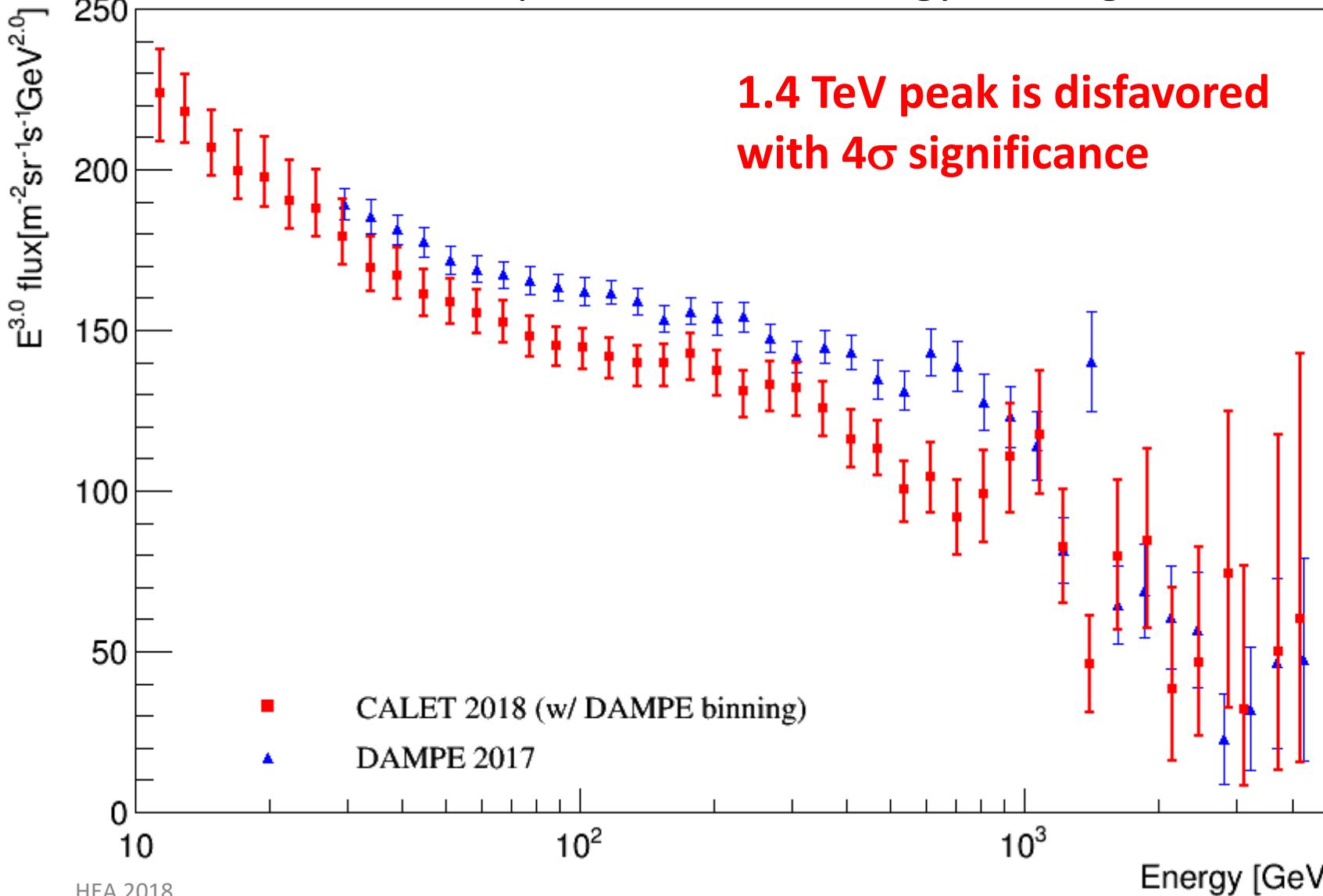
Extended Measurement by CALET

Approximately doubled statistics above 500GeV by using full acceptance of CALET



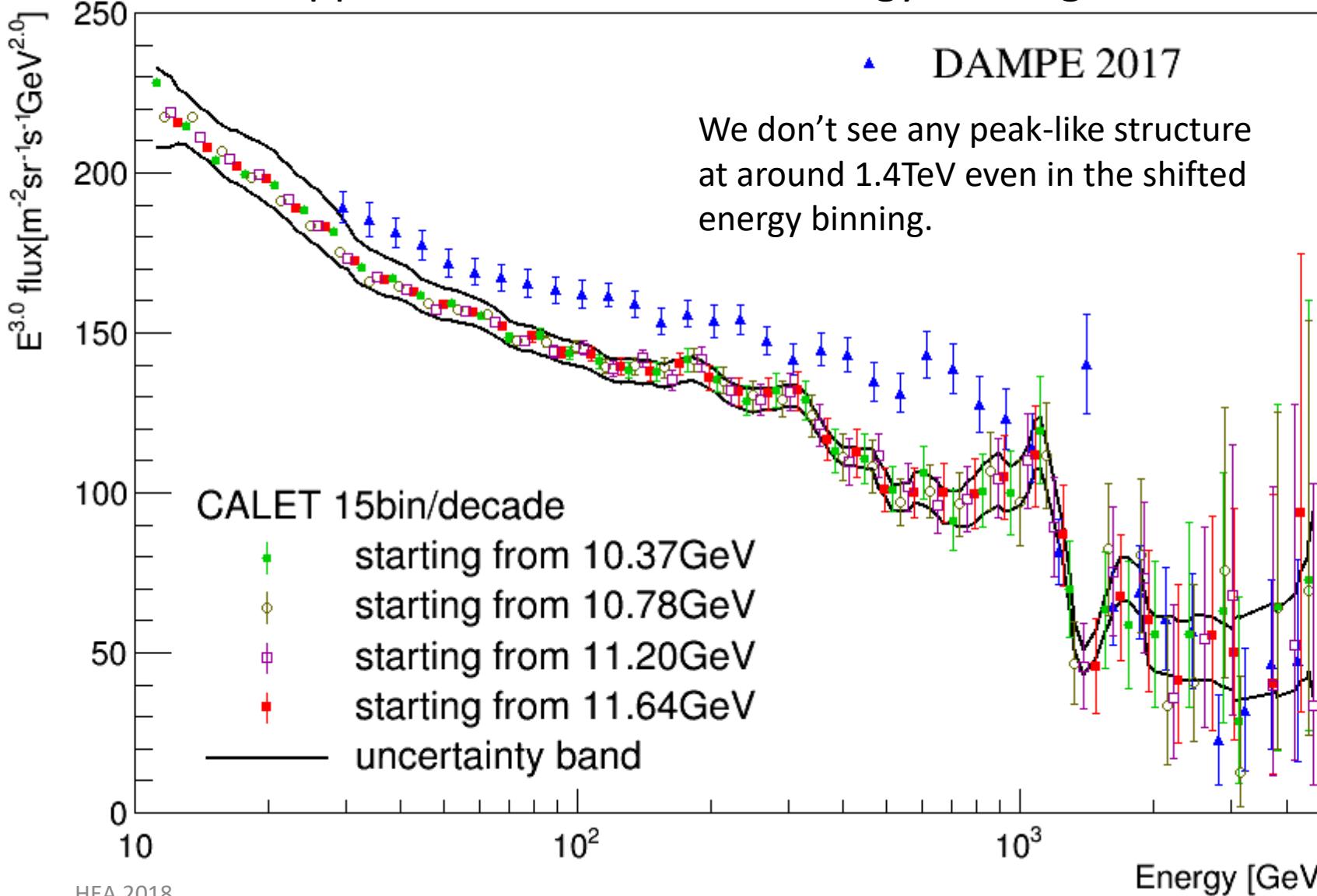
Comparison with DAMPE's result

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



Comparison with DAMPE's result

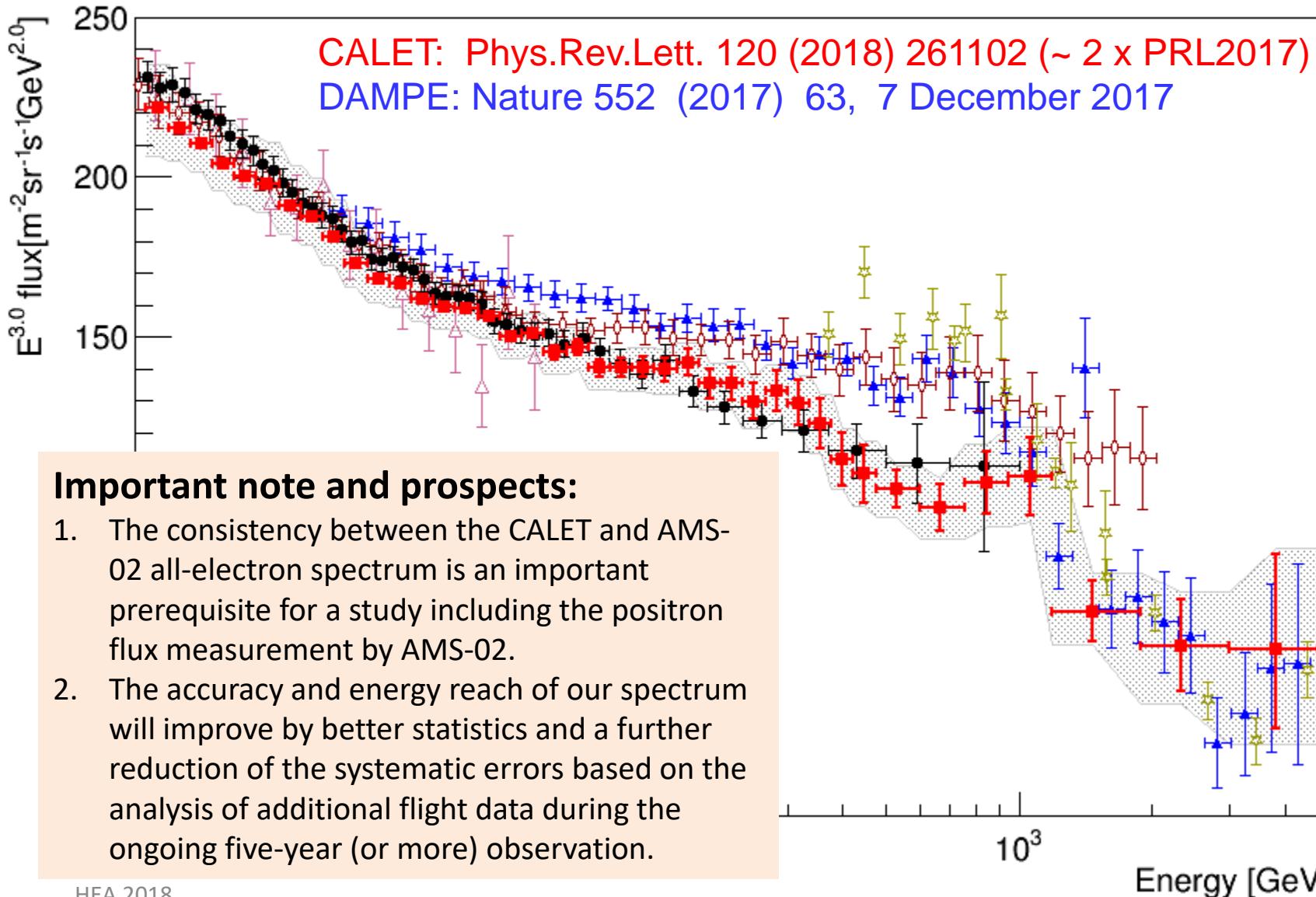
What happens if we shifted our energy binning...





Extended Measurement by CALET

Approximately doubled statistics above 500GeV by using full acceptance of CALET



Hadrons & Gamma-Rays

O.Adriani et al. (CALET Collab.), ApJL 829 (2016) L20.

O.Adriani et al. (CALET Collab.), ApJ 863 (2018) 160.

N.Cannady, Y.Asaoka et al. (CALET Collab.),
ApJS in press.

Preliminary Flux of Primary Components

Flux measurement:

$$\Phi(E) = \frac{N(E)}{S\Omega\varepsilon(E)T\Delta E}$$

$N(E)$: Events in unfolded energy bin

$S\Omega$: Geometrical acceptance

T : Live time

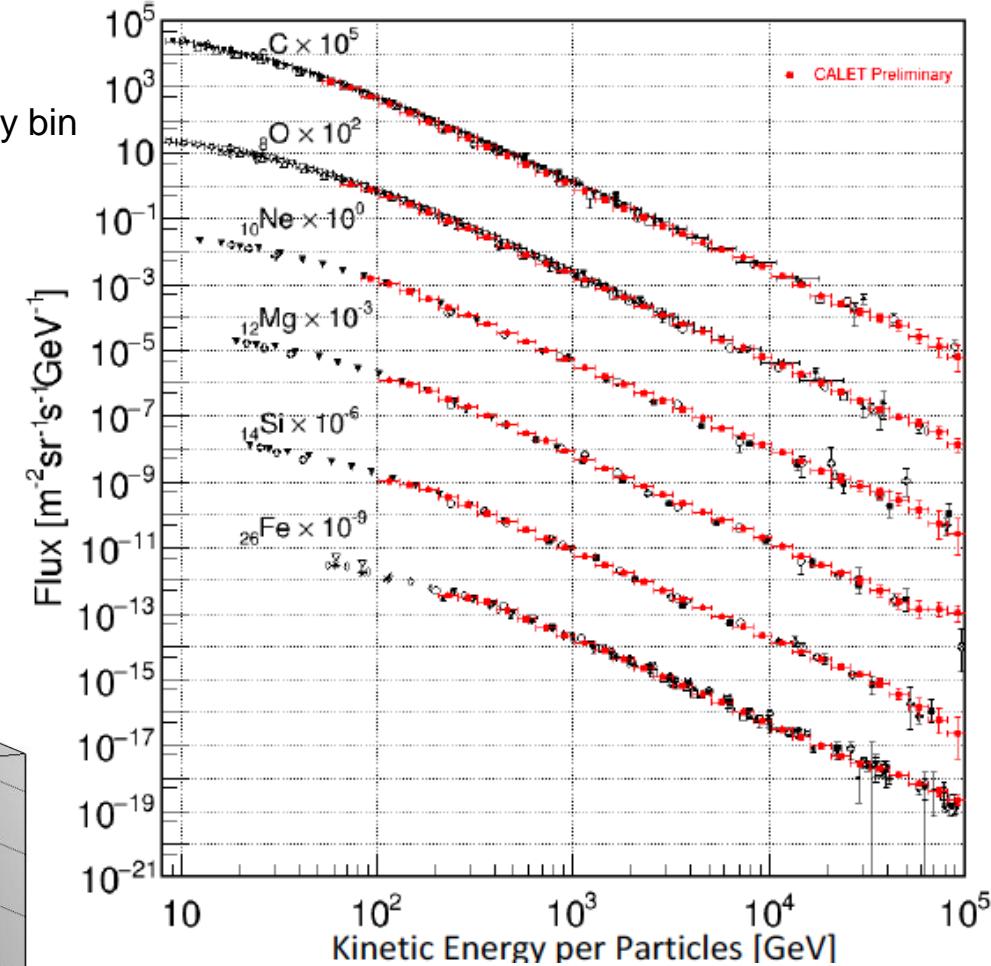
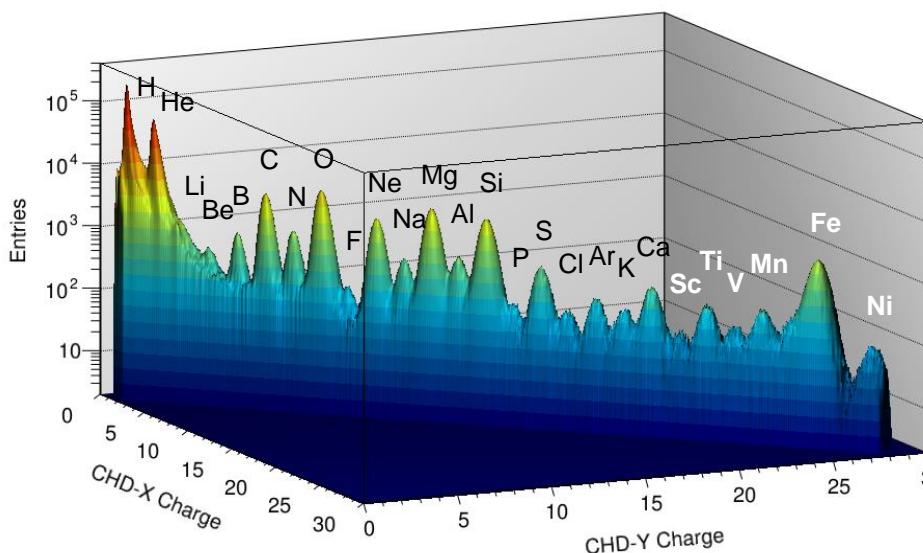
$\varepsilon(E)$: Efficiency

ΔE : Energy bin width

Observation period:

2015.10.13 – 2017.10.31 (750 days)

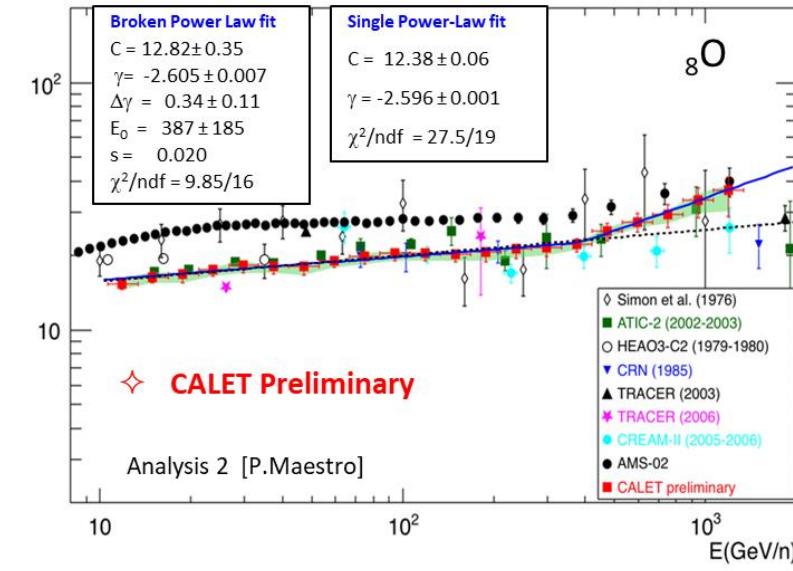
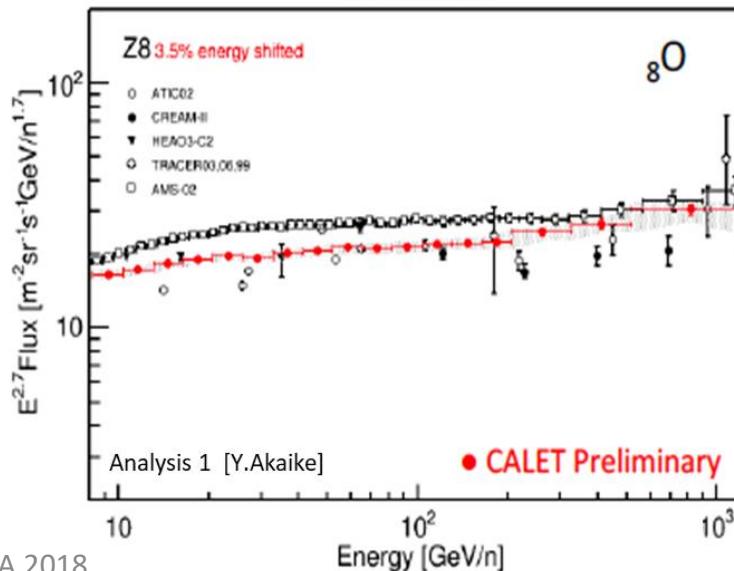
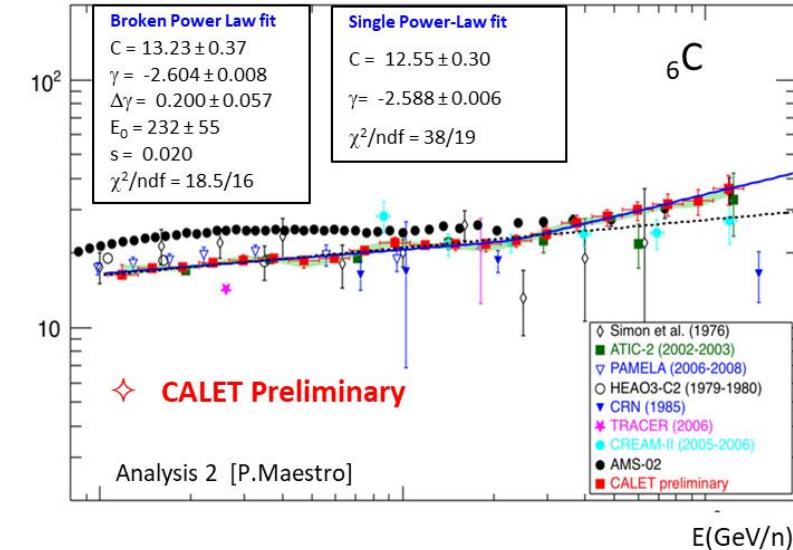
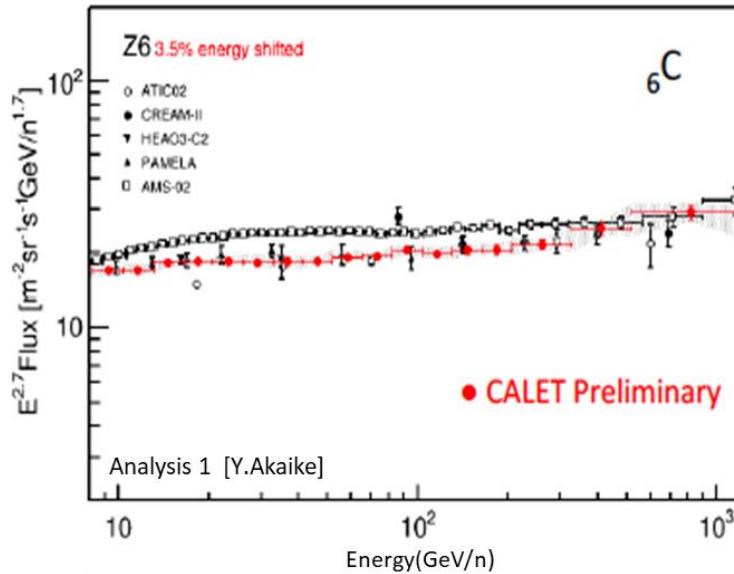
Selected events: ~13 million



Charge Separation only with CHD
 Clear separation of protons, helium to iron and nickel (up to Z=40).

Preliminary Energy Spectra of Carbon and Oxygen

(2 independent CALET analyses)

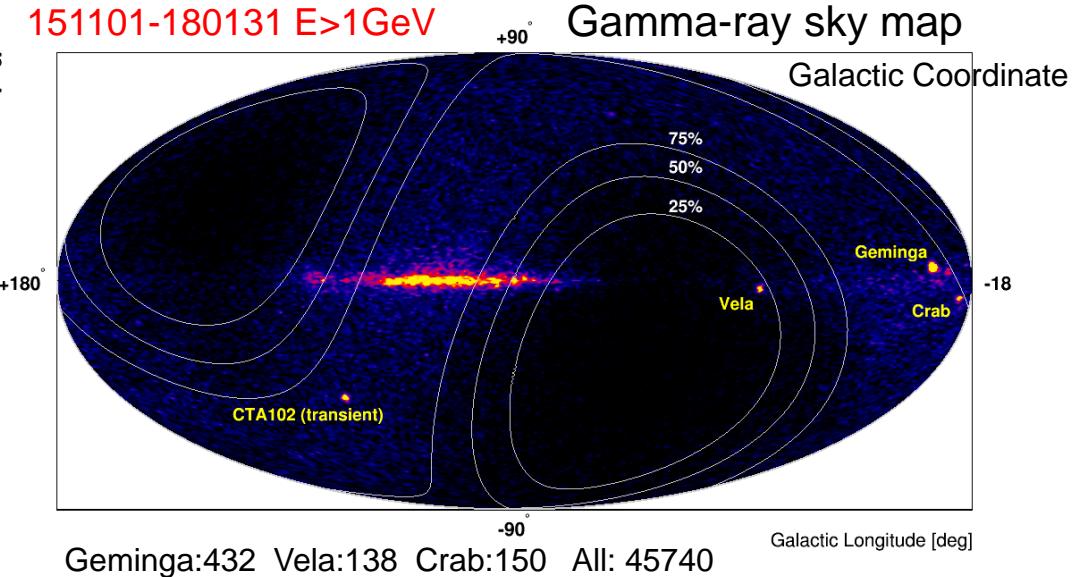
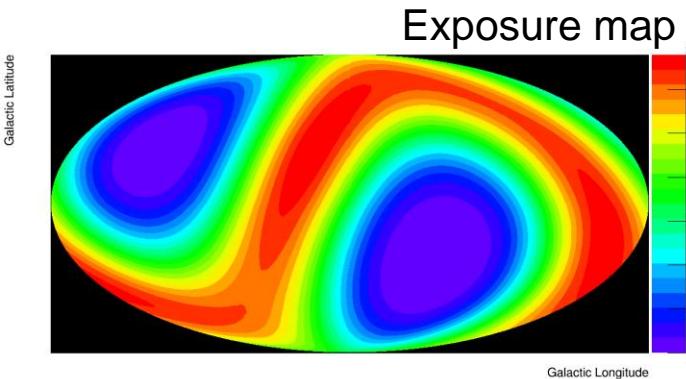




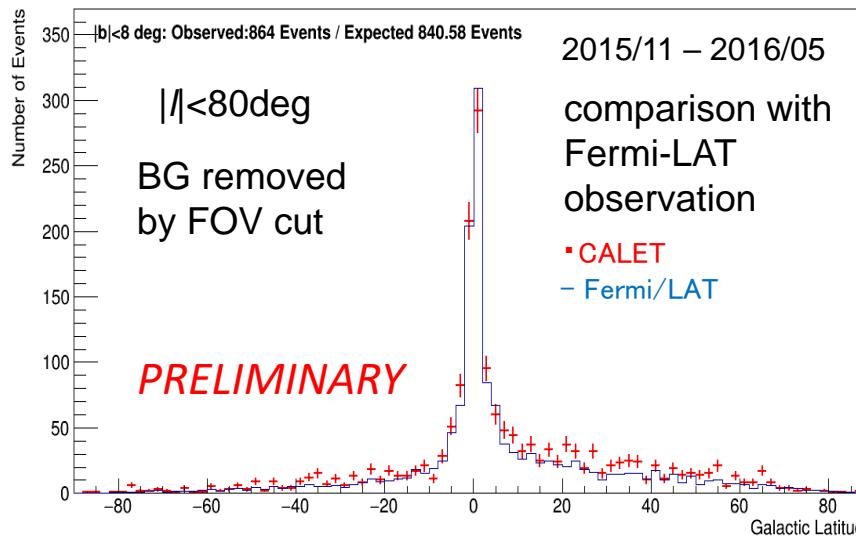
CALET γ -ray Sky in LE (>1GeV) Trigger

Analysis methodology:

N.Cannady, Y.Asaoka et al.
(CALET Collab.), ApJS in press.

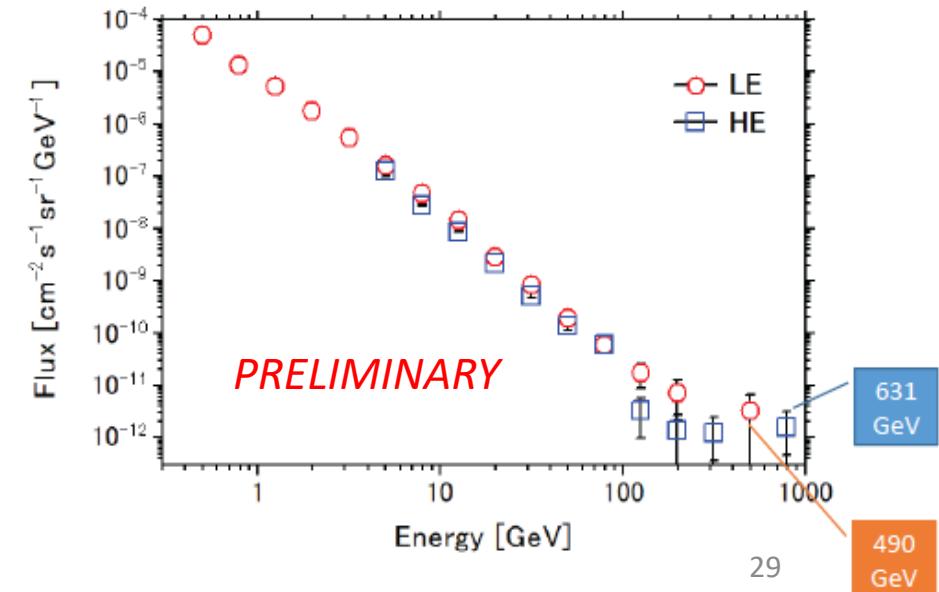


Galactic diffuse gamma-rays



HEA 2018

Gamma-ray energy spectrum



CALET UPPER LIMITS ON X-RAY AND GAMMA-RAY COUNTERPARTS OF GW 151226

Astrophysical Journal Letters 829:L20(5pp), 2016 September 20

The CGBM covered 32.5% and 49.1% of the GW 151226 sky localization probability in the 7 keV - 1 MeV and 40 keV - 20 MeV bands respectively. We place a 90% upper limit of 2×10^{-7} erg cm⁻² s⁻¹ in the 1 - 100 GeV band where CAL reaches 15% of the integrated LIGO probability (~1.1 sr). The CGBM 7 σ upper limits are 1.0×10^{-6} erg cm⁻² s⁻¹ (7-500 keV) and 1.8×10^{-6} erg cm⁻² s⁻¹ (50-1000 keV) for one second exposure. Those upper limits correspond to the luminosity of $3\text{-}5 \times 10^{49}$ erg s⁻¹ which is significantly lower than typical short GRBs.

CGBM light curve at the moment of the GW151226 event

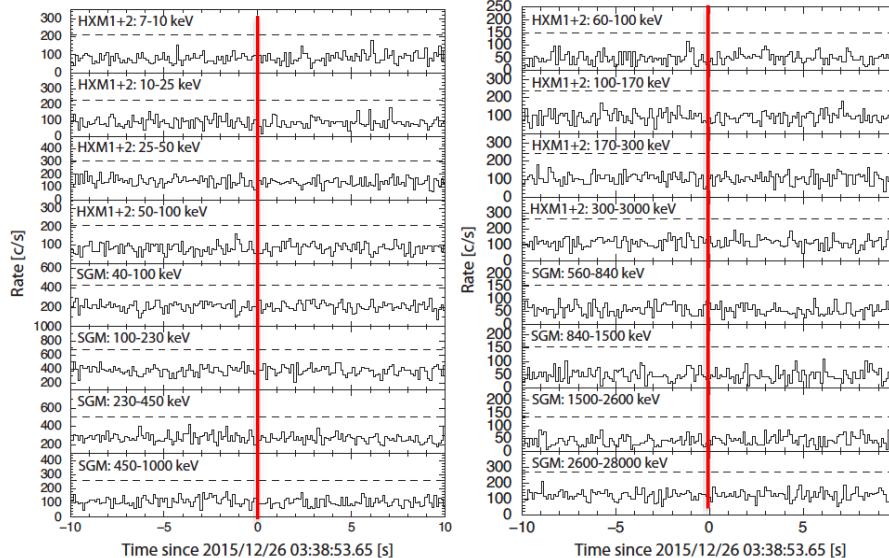


Figure 1. The CGBM light curves in 0.125 s time resolution for the high-gain data (left) and the low-gain data (right). The time is offset from the LIGO trigger time of GW 151226. The dashed-lines correspond to the 5 σ level from the mean count rate using the data of ± 10 s.

Upper limit for gamma-ray burst monitors and Calorimeter

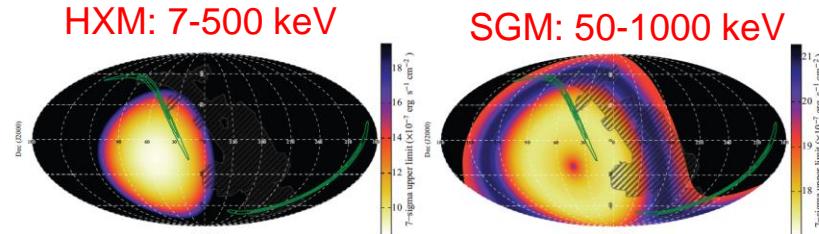


Figure 2. The sky maps of the 7 σ upper limit for HXM (left) and SGM (right). The assumed spectrum for estimating the upper limit is a typical BATSE S-GRBs (see text for details). The energy bands are 7-500 keV for HXM and 50-1000 keV for SGM. The GW 151226 probability map is shown in green contours. The shadow of ISS is shown in black hatches.

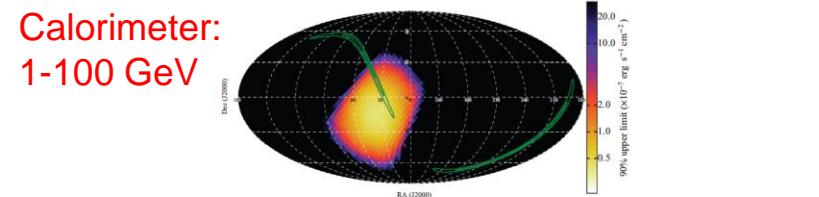


Figure 3. The sky map of the 90% upper limit for CAL in the 1-100 GeV band. A power-law model with a photon index of -2 is used to calculate the upper limit. The GW 151226 probability map is shown in green contours.

Updated analysis incl. all GW candidates in O2:
O.Adriani et al. (CALET Collab.), ApJ 863 (2018) 160.



Summary and Future Prospects

- CALET was successfully launched on Aug. 19, 2015, and the detector is being very stable for observation since Oct. 13, 2015.
- As of July 31, 2018, total observation time is 1023 days with live time fraction to total time close to 84%. Nearly 670 million events are collected with high energy trigger ($E > 10$ GeV)
- Careful calibrations have been adopted by using “MIP” signals of the non-interacting p & He events, and the linearity in the energy measurements up to 10^6 MIPs is established by using observed events.
- All electron spectrum has been extended in statistics and in the energy range up to 4.8 TeV. This result is published in PRL again on June 2018.
- Preliminary analysis of nuclei have successfully been carried out to obtain the energy spectra in the energy range: Protons in 55 GeV~22 TeV, Ne-Fe in 500 GeV~100 TeV.
- CALET’s CGBM detected nearly 60 GRBs (~20 % short GRB among them) per year in the energy range of 7keV-20 MeV, as expected (not included in this talk). Follow-up observation of the GW events is carried out and published in ApJL.
- GW counterpart searches with CALET calorimeter were extended to cover the whole LIGO/Virgo O2 and published in ApJ. In addition, onboard performance of gamma-ray observation will be published in ApJS (currently in press).
- The so far excellent performance of CALET and the outstanding quality of the data suggest that a 5-year observation period is likely to provide a wealth of new interesting results.