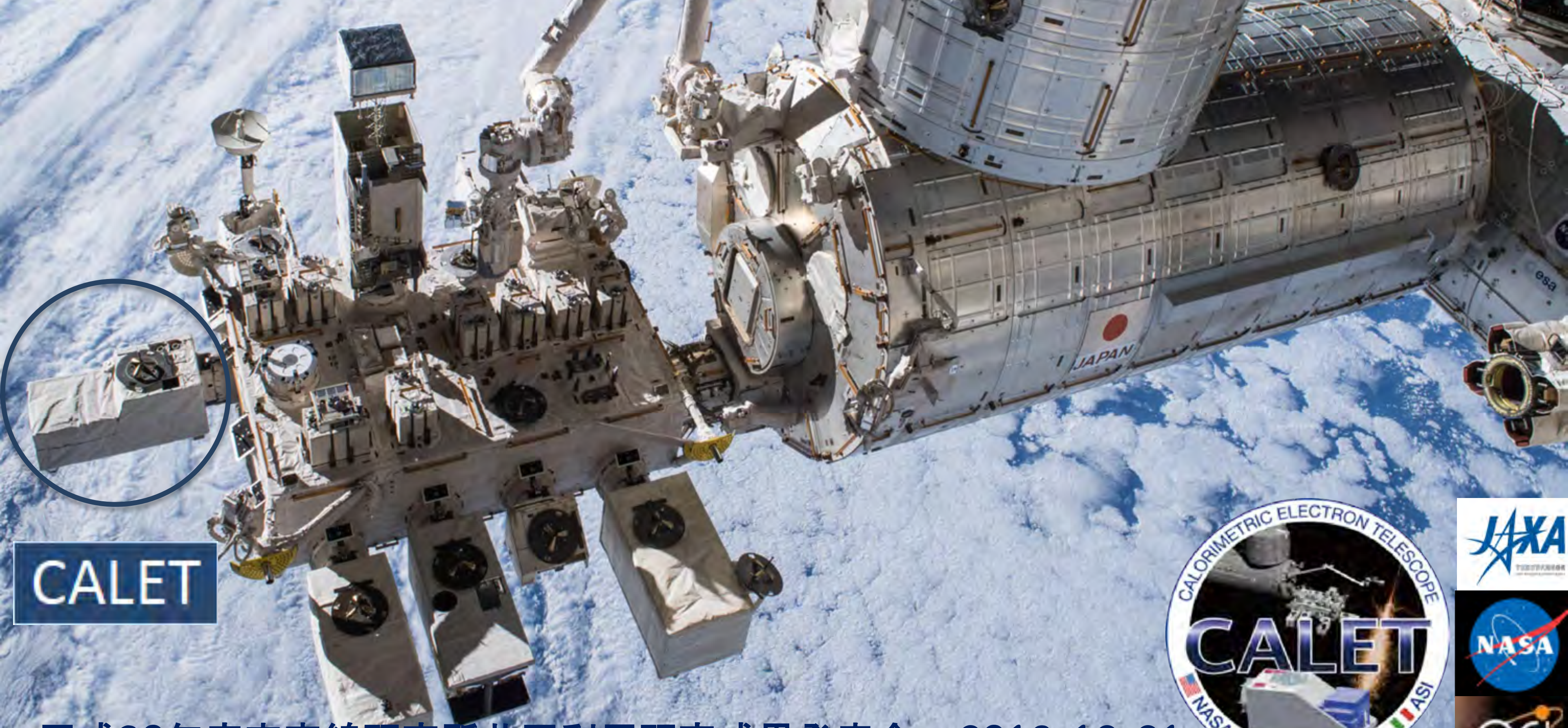
飛翔体観測(CALET)による
高エネルギー宇宙線加速天体の研究
～CALET3年間の軌道上観測成果～

研究代表者:鳥居祥二
早稲田大学　理工研/物理



平成30年度宇宙線研究所共同利用研究成果発表会　2018.12.21

共同利用研究概要(2018)

- 共同研究内容
  - CALET観測最適化のためのシミュレーション計算及びデータ解析
- 発表概要
  - CALET観測目的･装置
  - 観測現状
  - 観測データ解析
  - まとめと展望
- 予算 旅費　200千円
  支出(予定)内容: 研究打ち合わせ、小研究会
- 共同利用　計算機(シミュレーション計算)

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芝浦工業大学　吉田健二
弘前大学　市村雅一
茨城大学　柳田昭平

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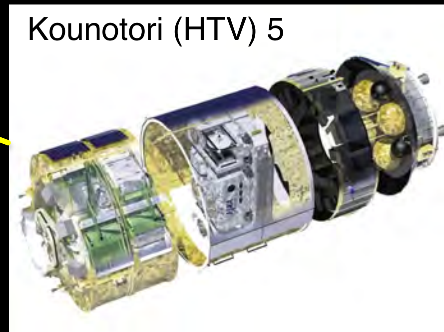
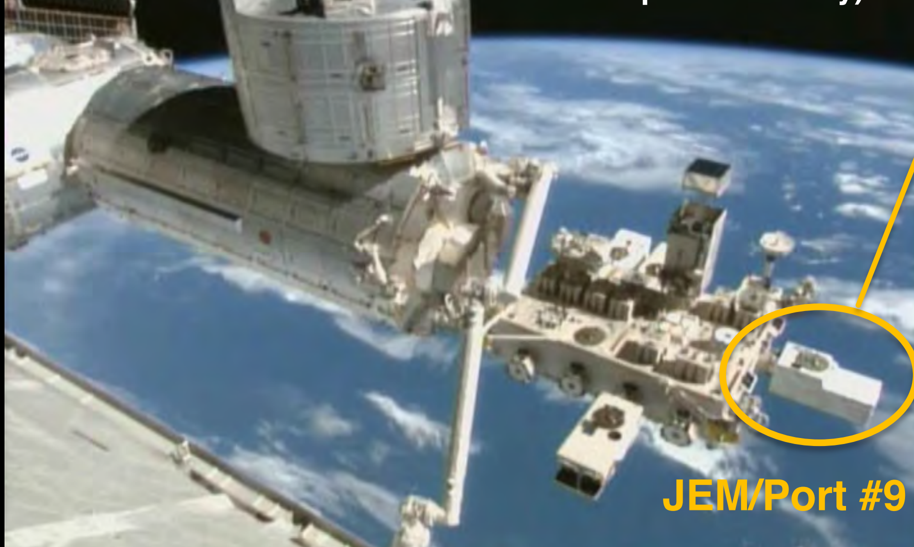
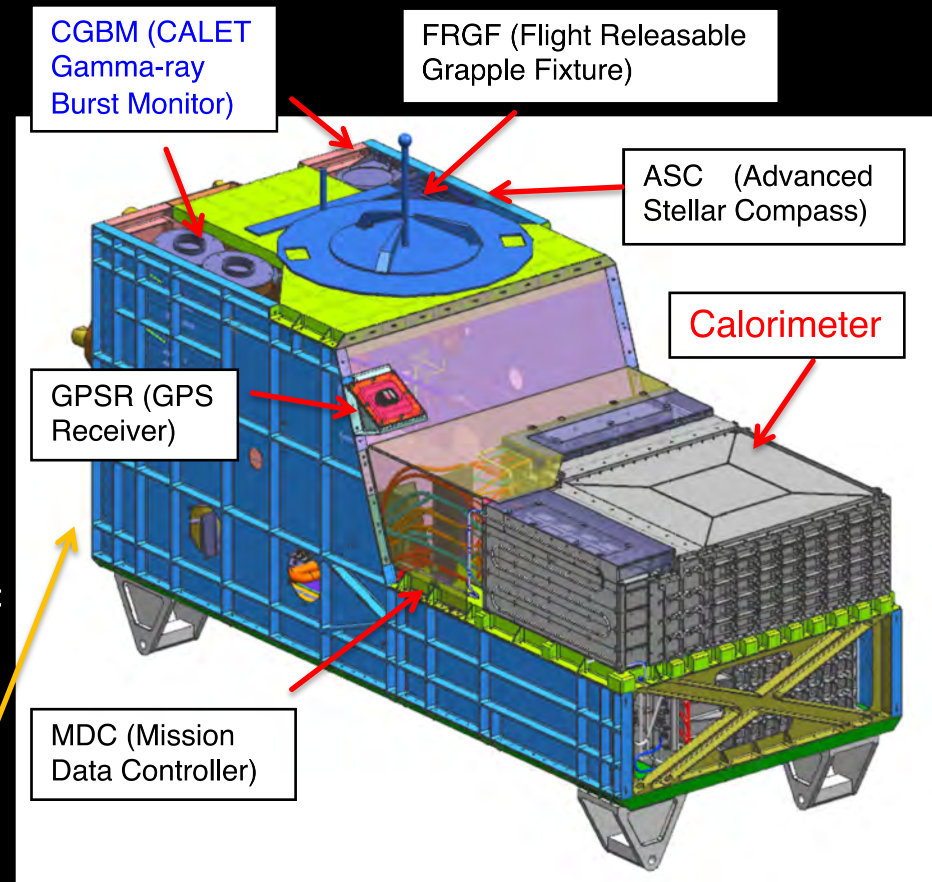
CALET Payload



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

Emplaced on JEM-EF port #9 on Aug. 25th, 2015 (JEM-EF: Japanese Experiment Module-Exposed Facility)





- **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

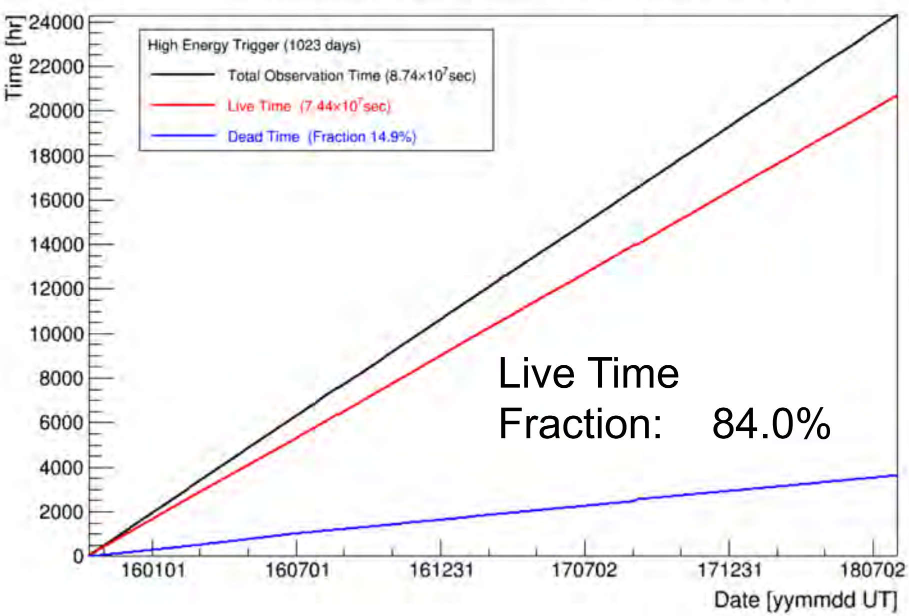
Observation with High Energy Trigger (>10GeV)

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

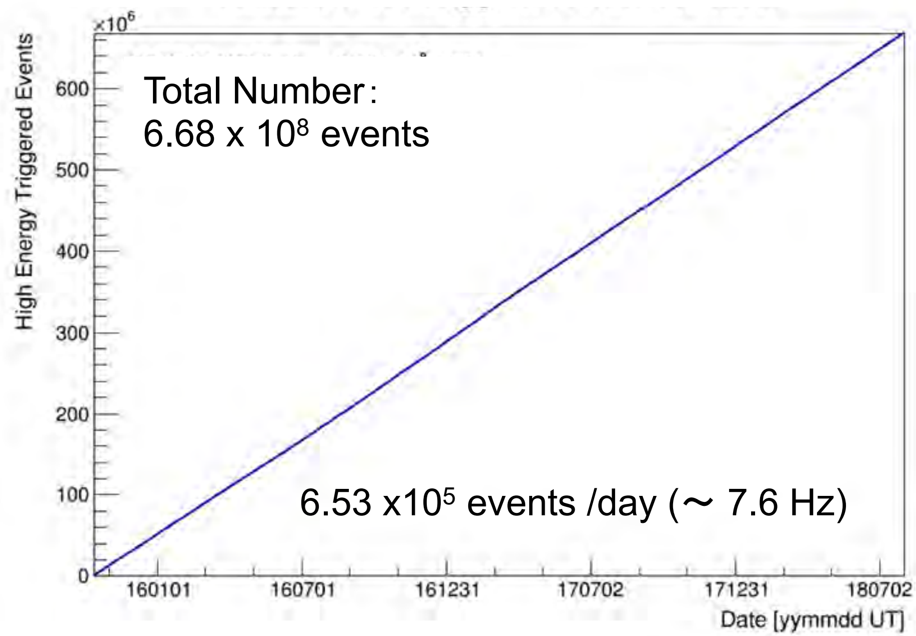
Observation by High Energy Trigger for 1032 days : Oct.13, 2015 – July 31, 2018

- The exposure, SΩT, has reached to ~ 89.6 m^2 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)

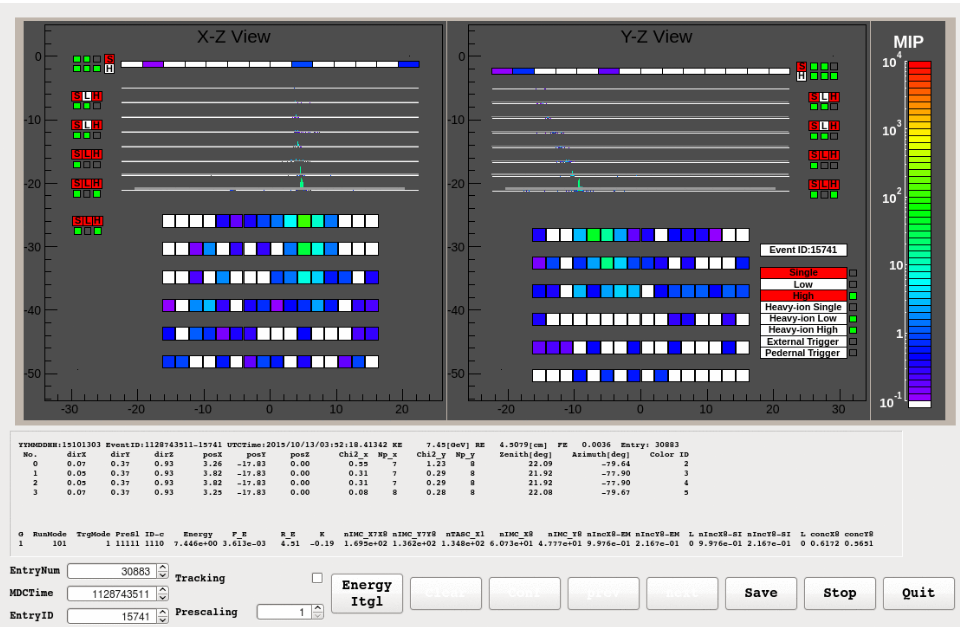


Accumulated triggered event number

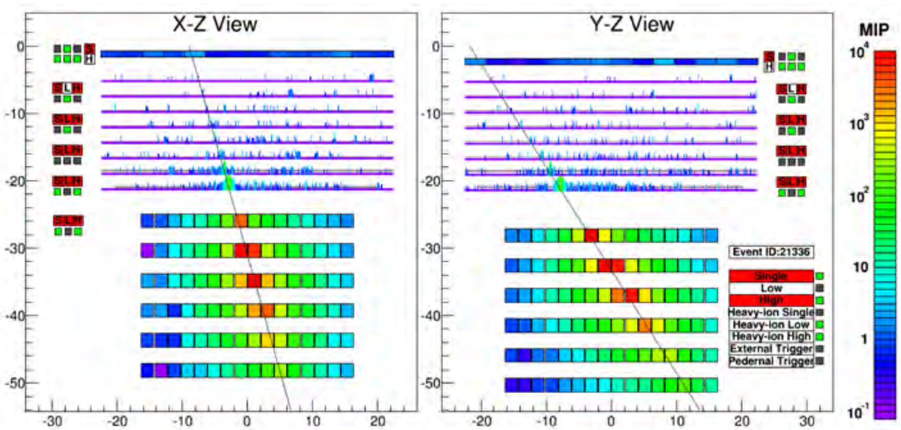


Examples of Observed Events

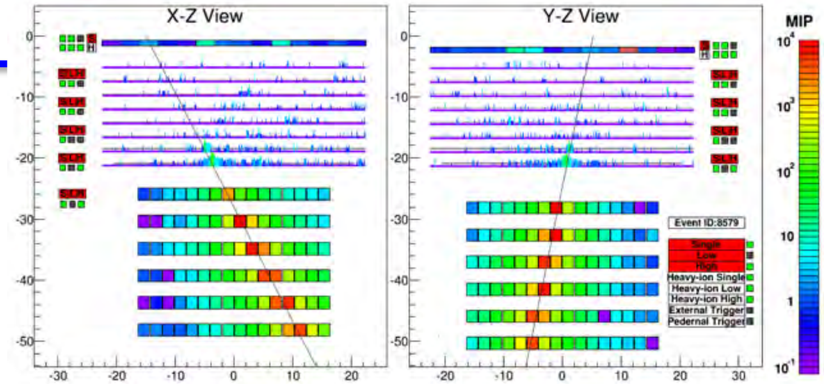
Event Display: Electron Candidate (>100 GeV)



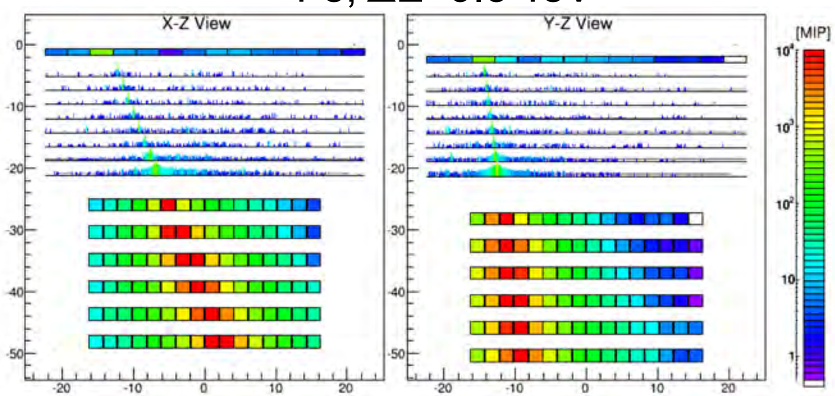
Electron, E=3.05 TeV



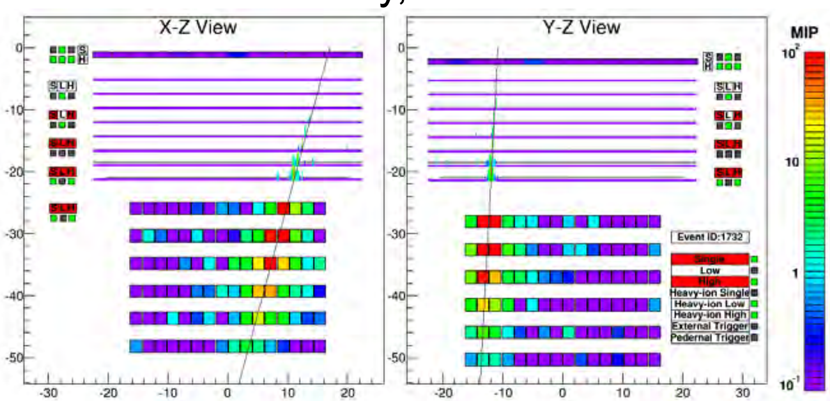
Proton, ΔE=2.89 TeV



Fe, ΔE=9.3 TeV



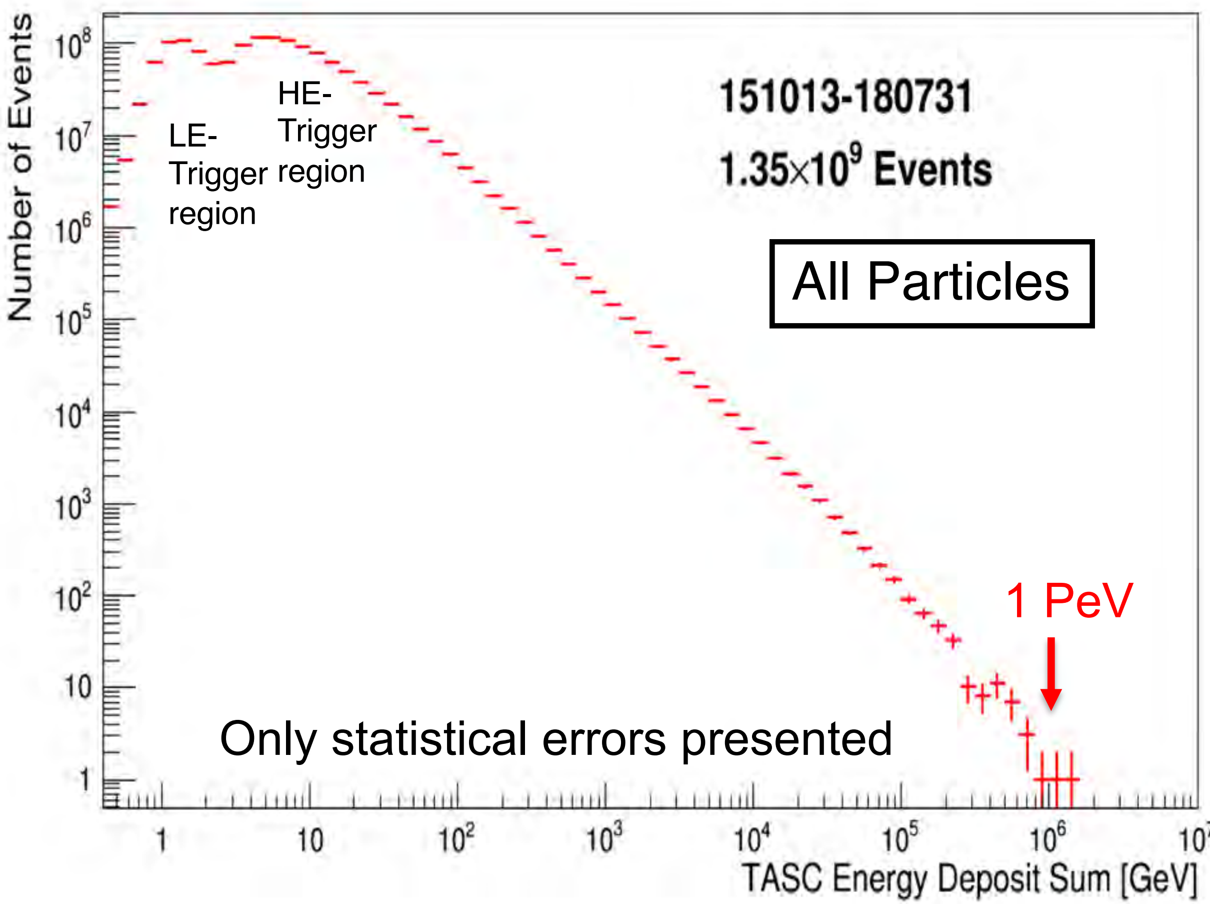
Gamma-ray, E=44.3 GeV



Unit in MIP

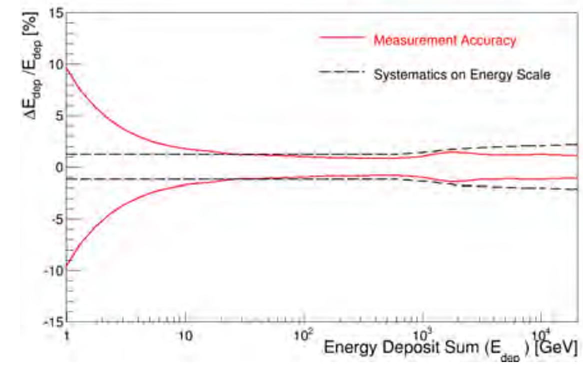
TASC Energy Deposit Distribution of All Triggered-Events by Observations for 1023 days

Distribution of deposit energies (ΔE) in TASC

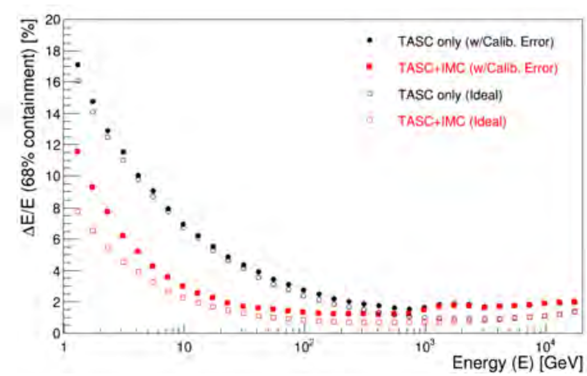


Y.Asaoka, et al. (CALET Collaboration), Astroparticle Physics 91 (2017) 1.

Performance of electron energy measurement in 1GeV-20TeV



Energy resolution for electrons (TASC+IMC):
< 3% over 10 GeV; <2% over 20GeV



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

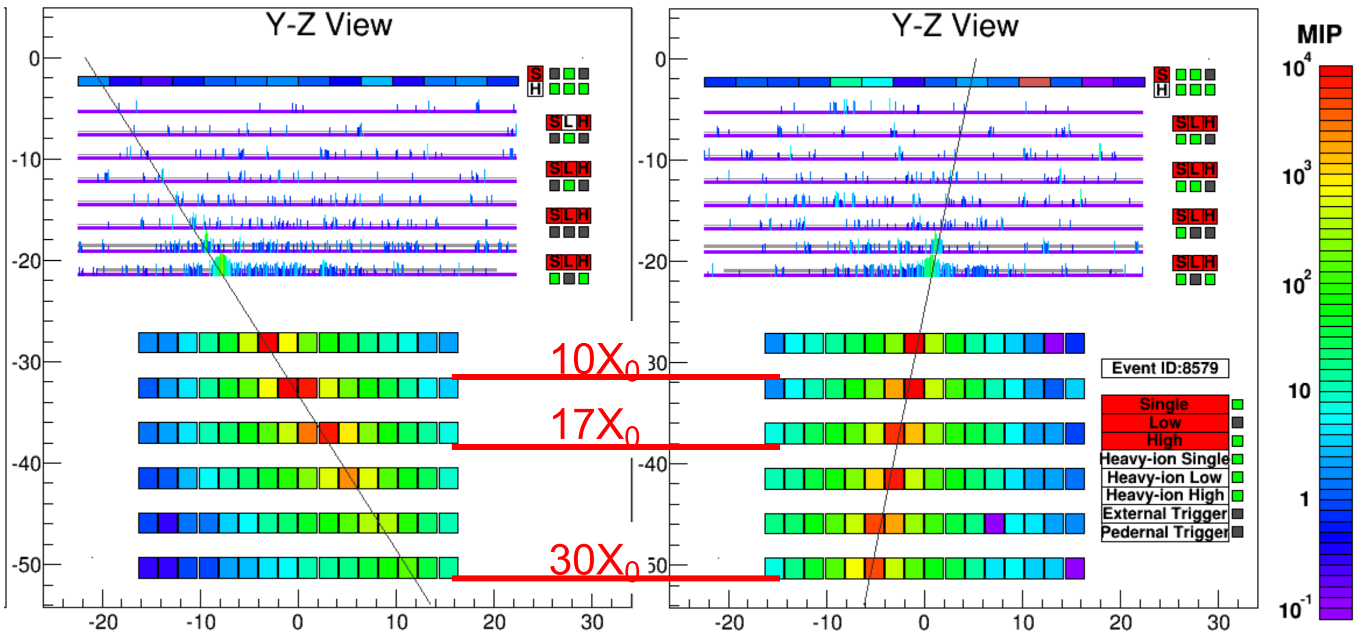
All-Electron (electron + positron) Analysis

CALET is an instrument optimized
for all-electron spectrum measurements.

⇒ CALET is best suited for observation of possible fine structures in the all-electron spectrum up to the trans-TeV region.

3TeV Electron Candidate

Corresponding Proton Background



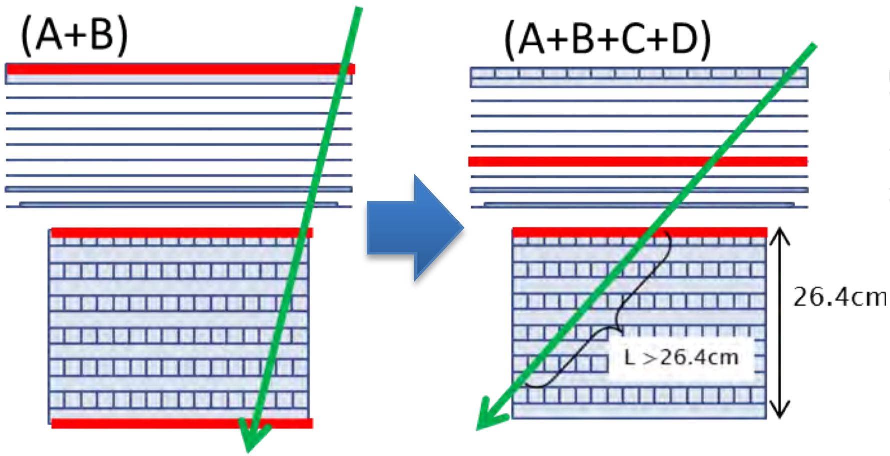
(Flight data; detector size in cm)

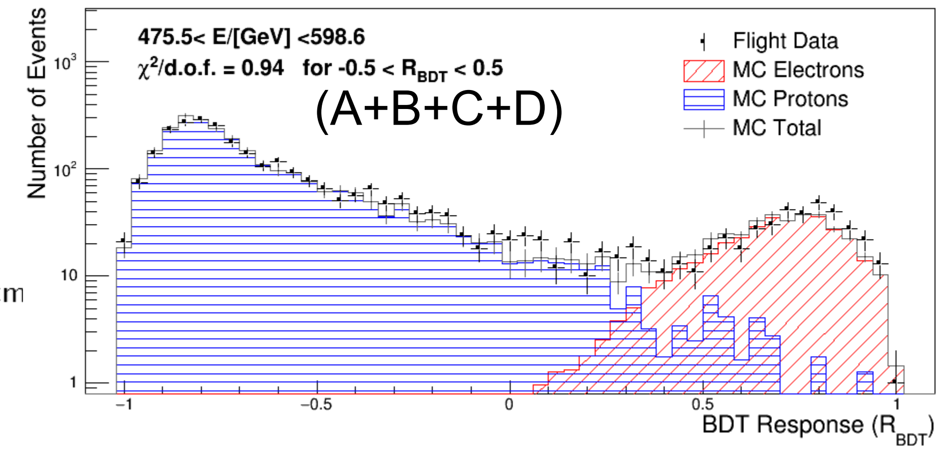
1. **Reliable tracking**
   well-developed shower core
2. **Fine energy resolution**
   full containment of TeV showers
3. **High-efficiency electron ID**
   $30X_0$ thickness, closely packed logs

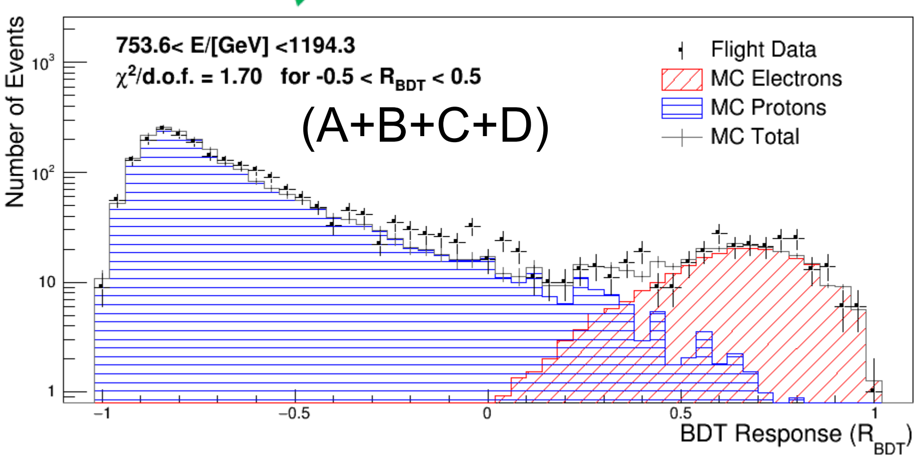
Extended Analysis of e/p Separation to Full Acceptance

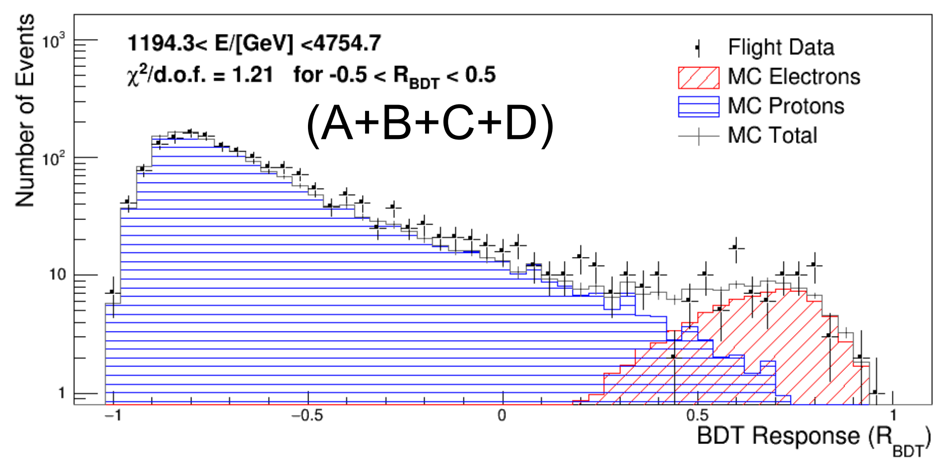
Analyzed Flight Data:

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

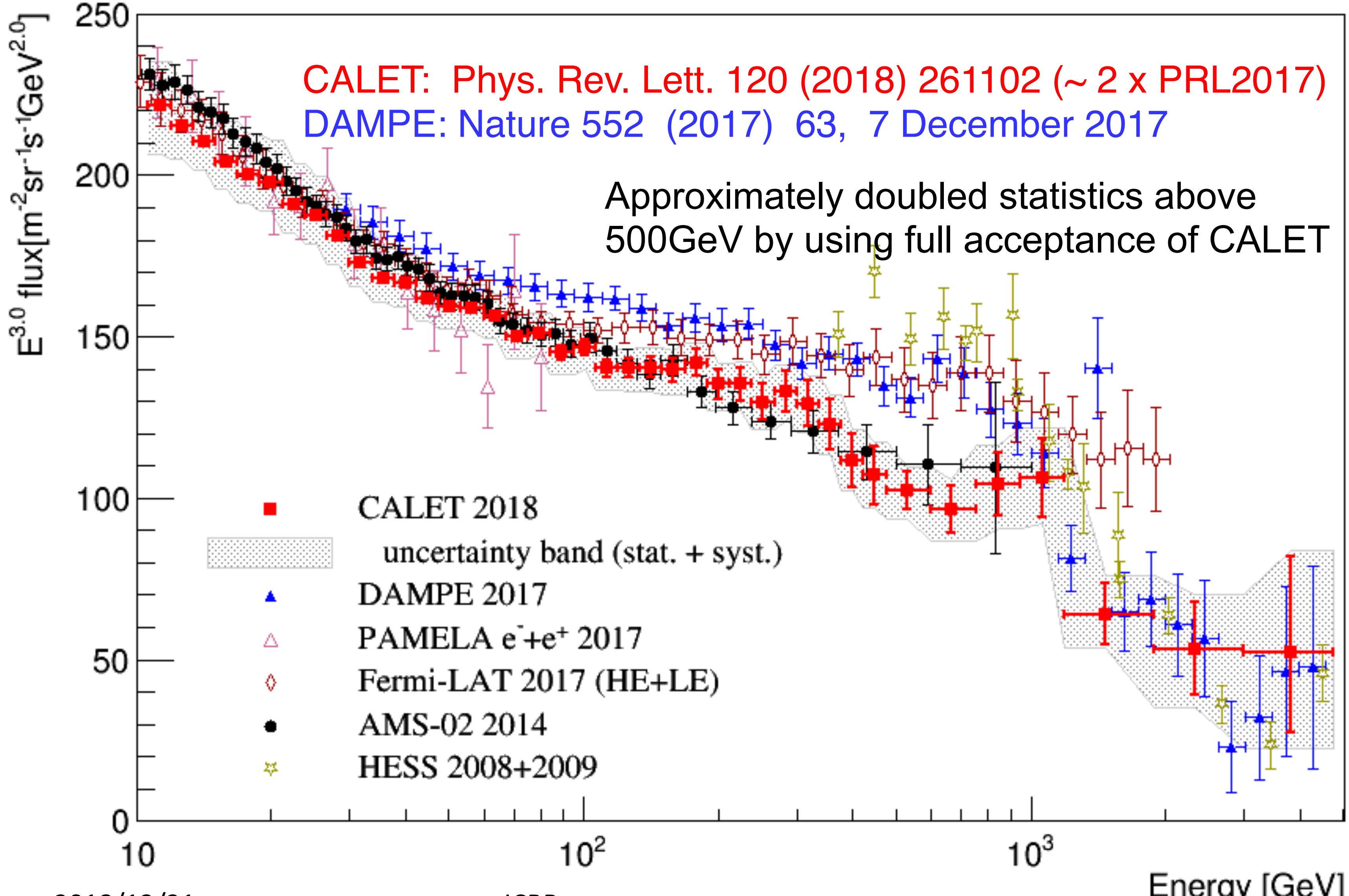




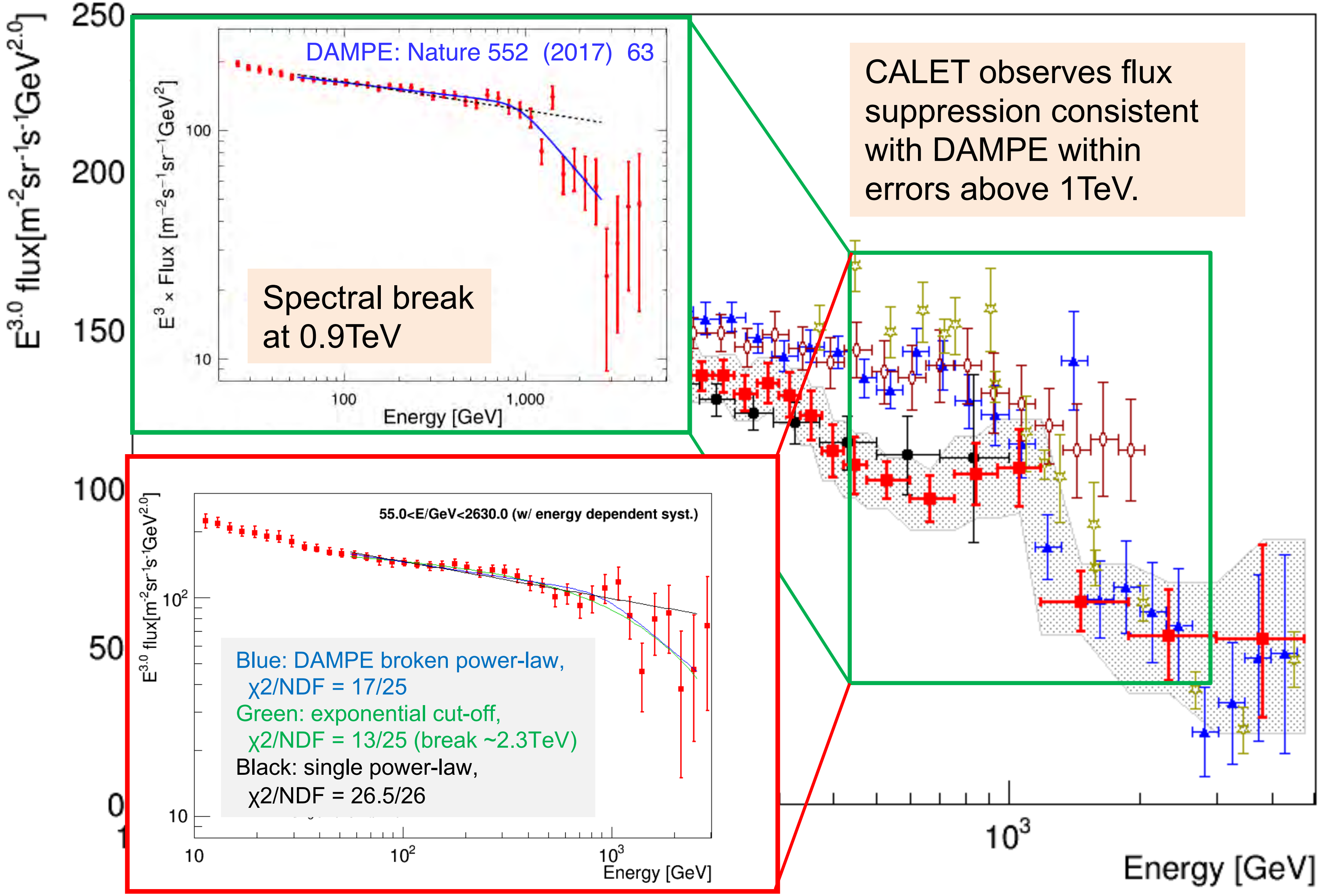




All-Electron Spectrum Measured with CALET from 11 GeV to 4.8TeV

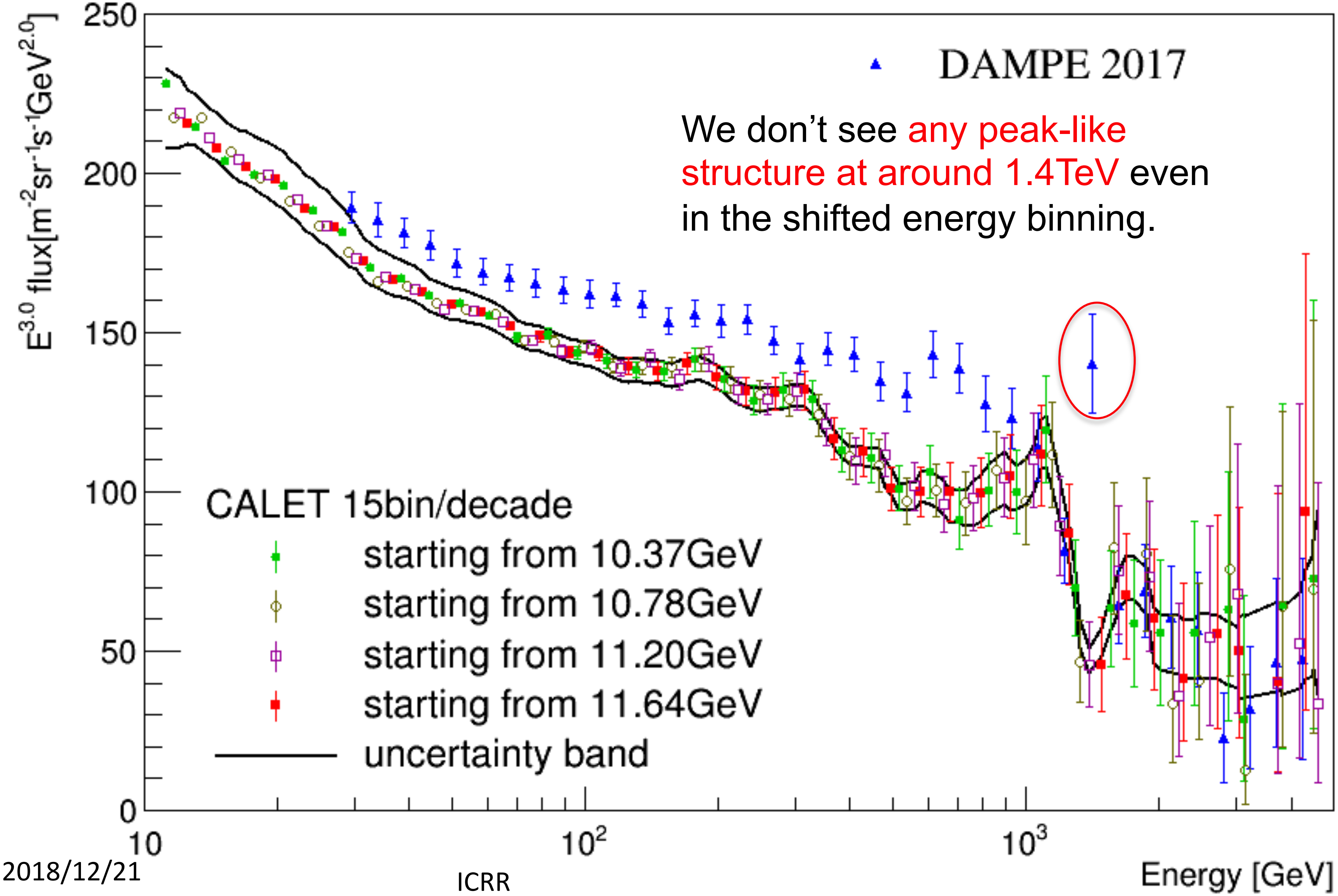


CALET All-Electron Spectrum in sub-TeV to TeV region



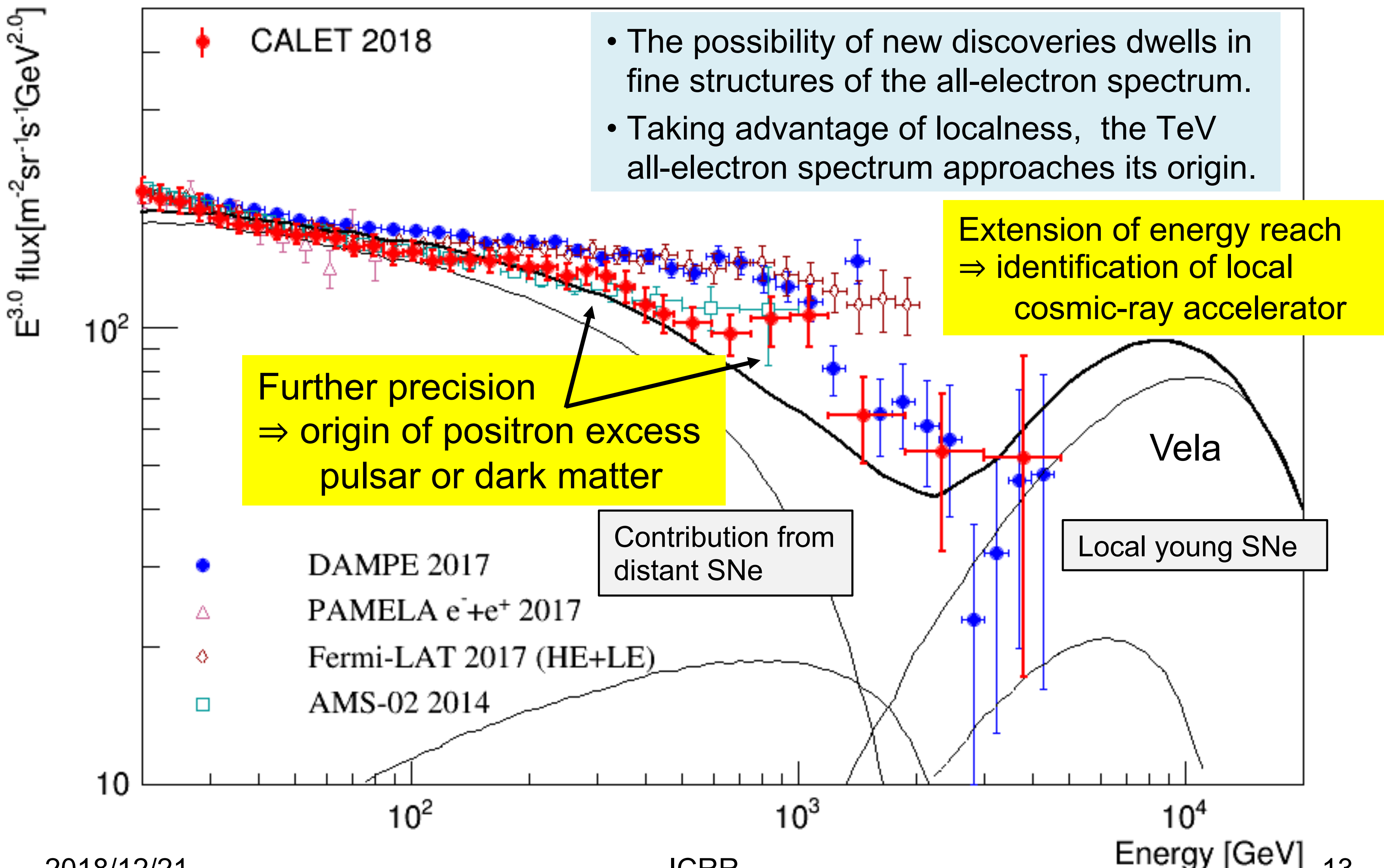
Comparison with DAMPE's result

What happens if we shifted our energy binning…



Prospects for CALET All-Electron Spectrum

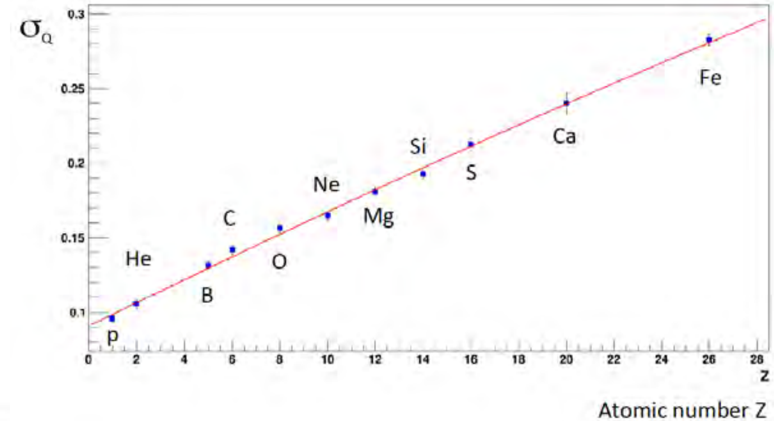
Five years or more observations ⇒ 3 times more statistics, reduction of systematic errors

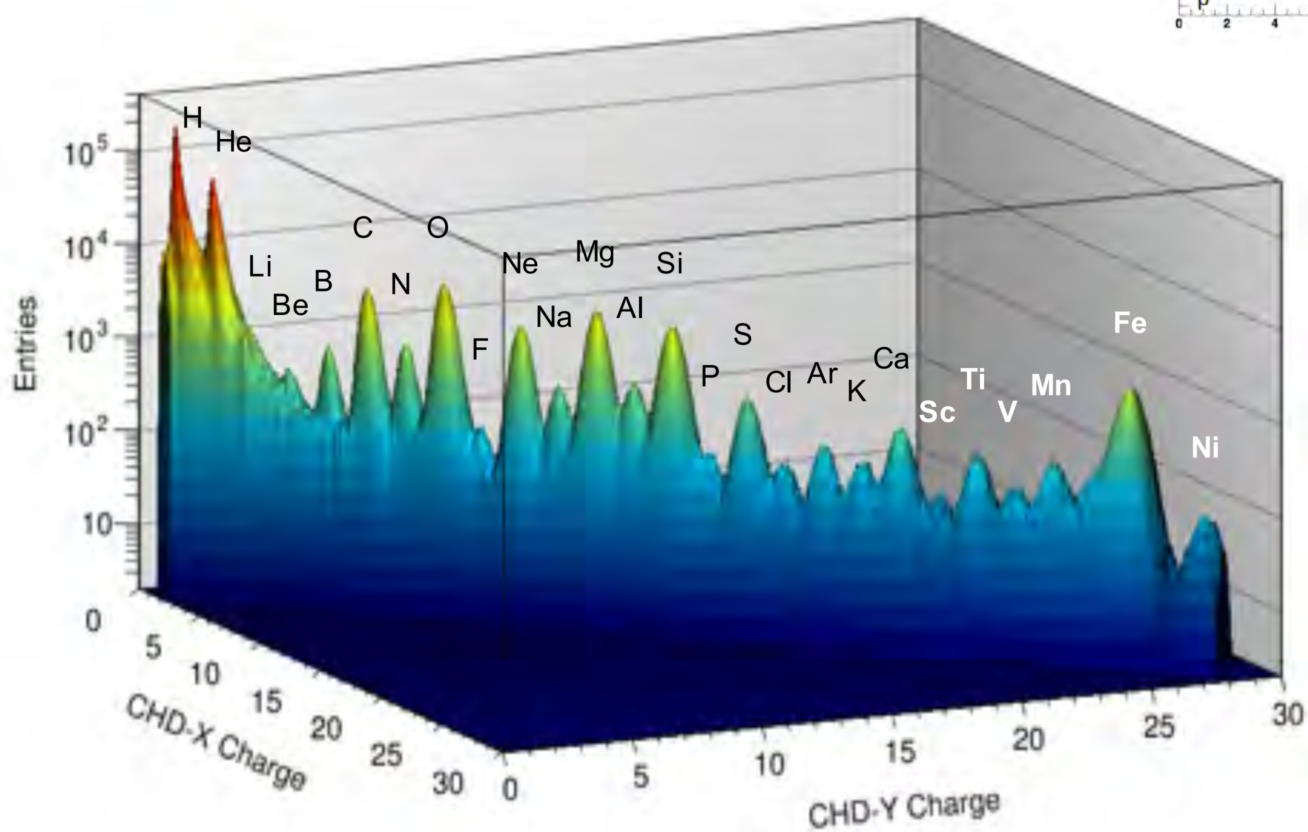


Charge Identification of Nuclei with CHD

CHD charge resolution(2 layers combined) vs. Z

- ΔZ= 0.1e (p)~ 0.28e (Fe)
- Charge separation in B to C : ~7 σ





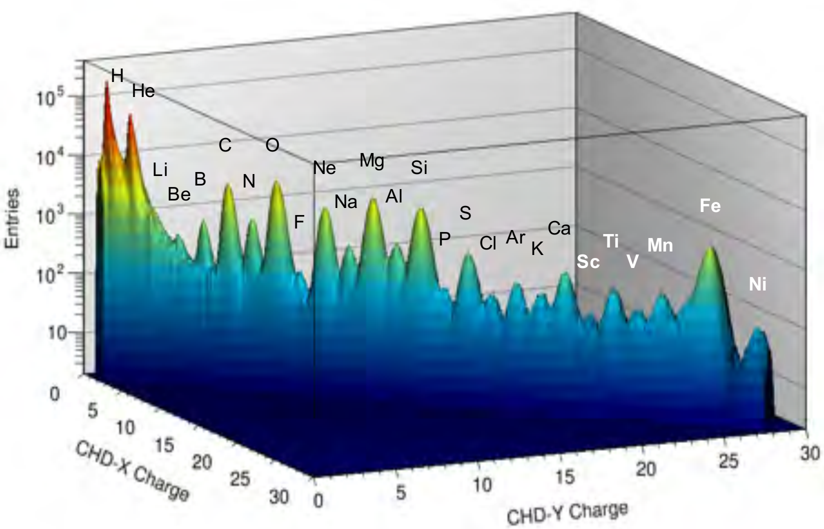
Non-linear response to Z^2 is corrected in CHD using a model.

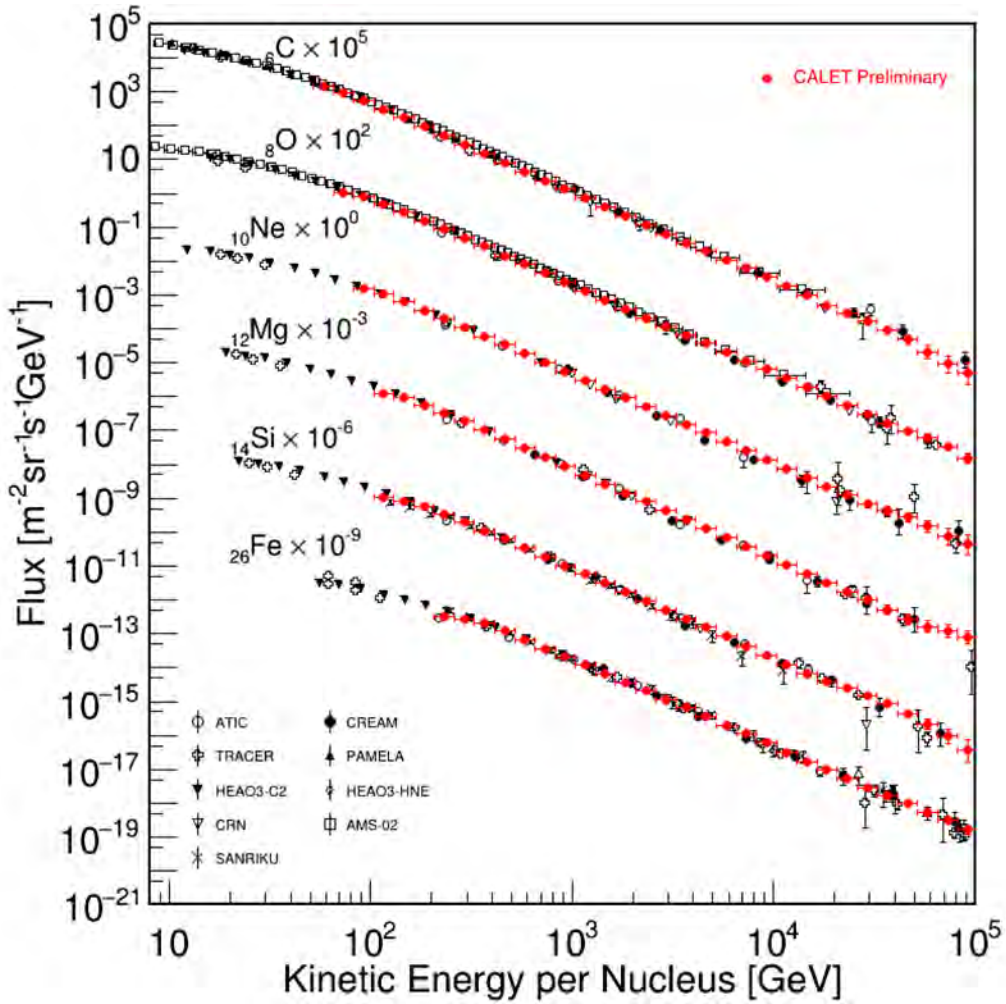
Preliminary Flux of Primary Nuclei Components

Observation period:
2015.10.13 – 2017.5.31 (962 days)
Selected events: ~17 million

Flux measurement: $\Phi(E) = \dfrac{N(E)}{S\Omega\varepsilon(E)T\Delta E}$

- N(E): Events in unfolded energy bin
- $S\Omega$: Geometrical acceptance
- T : Live time
- $\varepsilon(E)$: Efficiency
- ΔE : Energy bin width





CALET Gamma-ray Sky (>1GeV)

Instrument characterized using EPICS simulations

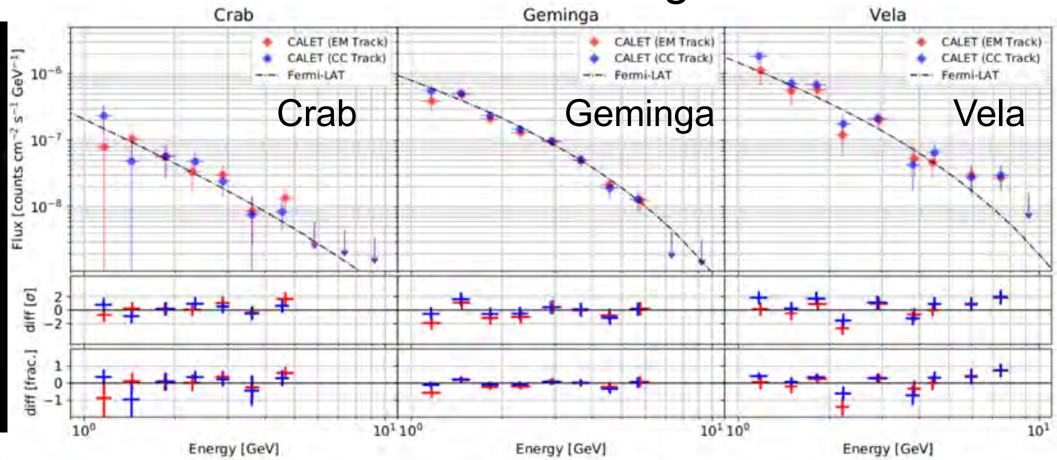
- Effective area ~400 cm² above 2 GeV
- Angular resolution < 2° above 1 GeV (< 0.2° above 10 GeV)
- Energy resolution ~12% at 1 GeV (~5% at 10 GeV)

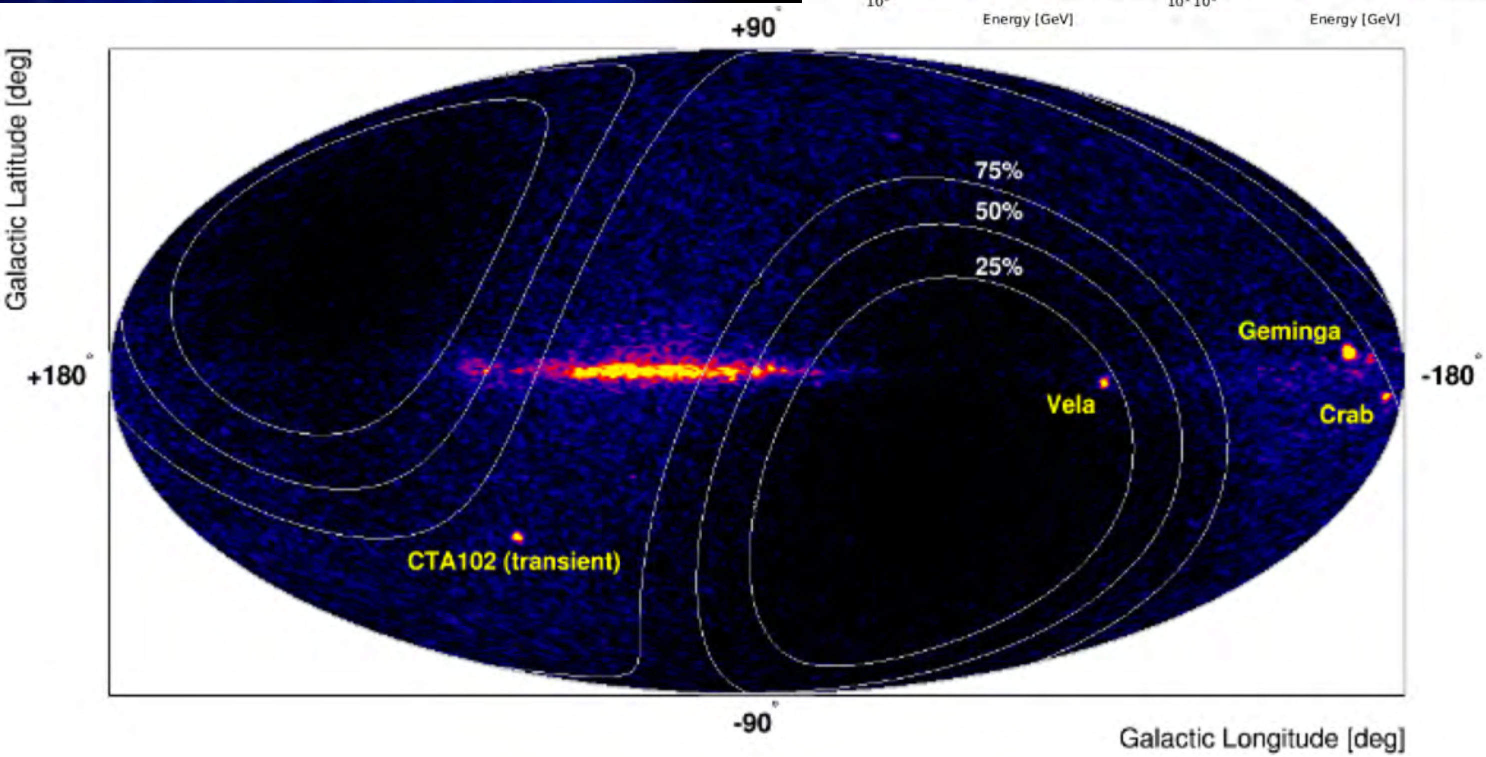
Simulated IRFs consistent with 2 years of flight data

Consistency in signal-dominated regions with Fermi-LAT

Residual background in low-signal regions

Flux validation with bright sources





Geminga:432
Vela:138
Crab:150
All: 45740
(As of 180131)

Electromagnetic Emission from Gravitational Wave Events ?

Yes

- NS-NS binary mergers
- NS-BH binary mergers?

(e.g. Phinney 2009, Rosswog 2016, Fernández&Metzger 2016)

GW170817 (~$1.5M_{\odot}$+~$1.3M_{\odot}$)
+ EM emission + GRB 170817A

No?

- BH-BH binary mergers

(e.g. De Mink&King 2017)

GW150914 ($36M_{\odot}+29M_{\odot}$)
GW151226 ($14M_{\odot}+7.5M_{\odot}$)
GW170104 ($31M_{\odot}+19M_{\odot}$)
GW170608 ($12M_{\odot}+7M_{\odot}$)
GW170814 ($31M_{\odot}+25M_{\odot}$)

CALET

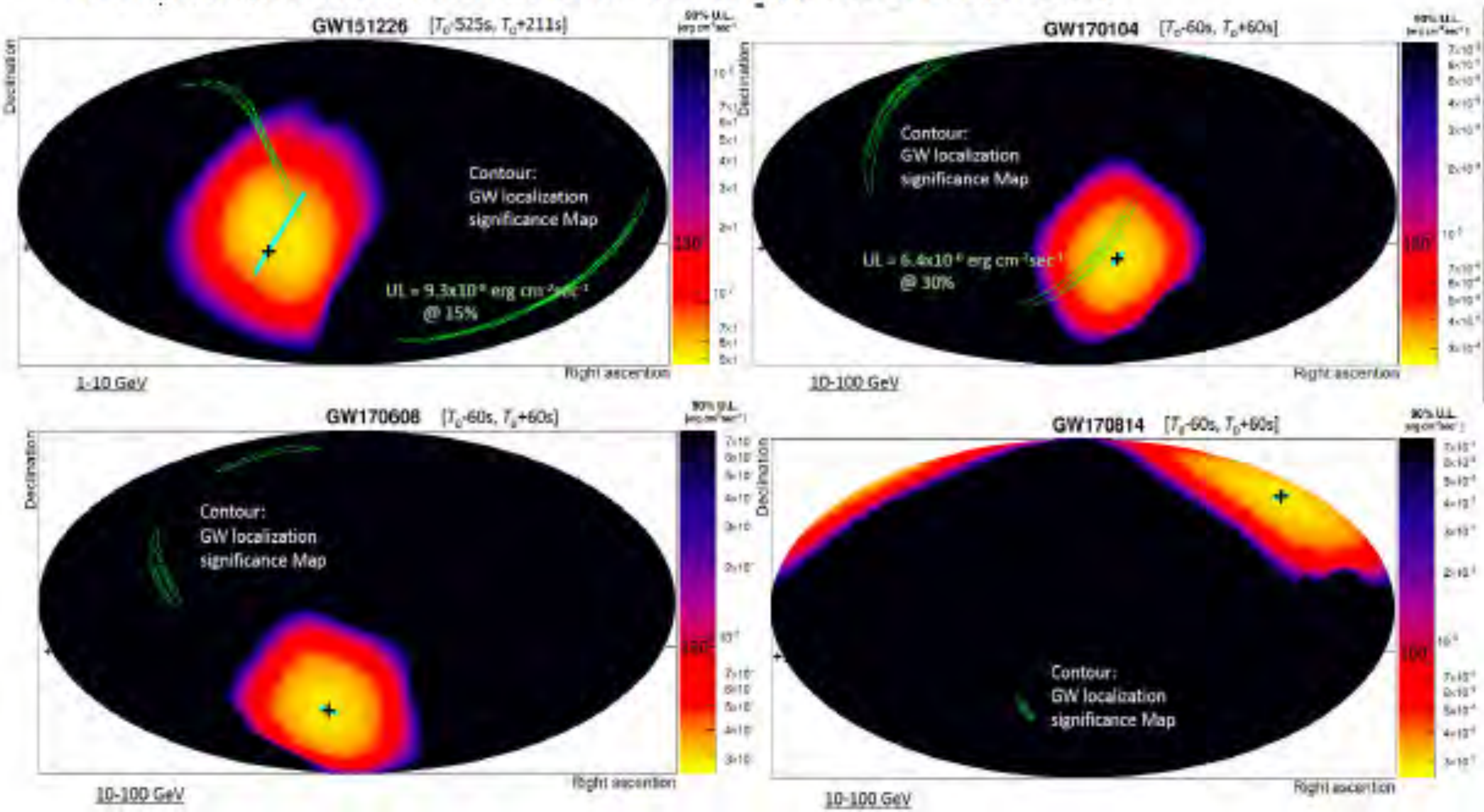
Wide field-of-view monitors are necessary to detect prompt EM emission

CALET/CAL is watching for ~1/6 of the whole sky!

90 % CL Upper Limits for GW Counterpart Search

No event survived. Backgrounds are negligible.

- For GW151226 CALET-CAL observation constrains 15% of LIGO localization map by 90% upper limit flux of 9.3x10-8erg cm-2sec-1(1-10GeV)
- For GW170104, GW170608, GW170814 no constrain on any portion of LIGO probability



Publication List in FY 2017-2018（refereed)

1) “Characteristics and Performance of the CALorimetric Electron Telescope (CALET) Calorimeter for Gamma-Ray Observations”, *N.Cannady, *Y.Asaoka, et al. (CALET Collaboration), The Astrophysical Journal Supplement Series 238:5 (16pp), 2018.

2) “Search for GeV Gamma- Ray Counterparts of Gravitational Wave Events by CALET", O.Adriani, *Y.Asaoka, *M.Mori, et al. (CALET Collaboration), The Astrophysical Journal, 863:160 (9pp), 2018.

3) “Extended Measurements of Cosmic-ray Electron and Positron Spectrum from 11 GeV to 4.8 TeV with the Calorimetric Electron Telescope on the International Space Station”,
O. Adriani, *Y. Asaoka , *S.Torii, et al. (CALET Collaboration), Phys. Rev. Lett. 120, 261102 (7pp) (2018).

4) “Detection of the thermal component in GRB 160107A”,
*Kawakubo Yuta, Sakamoto Takanori, et al. (CALET collaboration), Publication of the Astronomical Society of Japan, 70(1) p.61

5) “Energy Spectrum of Cosmic-Ray Electron and Positron from 10 GeV to 3 TeV Observed with the Calorimetric Electron Telescope on the International Space Station”,
O. Adriani, *Y. Asaoka , * S. Torii, et al. (CALET Collaboration), Phys. Rev. Lett. 119, 181101(6pp) (2017).

6) “On-orbit Operations and Offline Data Processing of CALET onboard the ISS”,
*Y. Asaoka, S.Ozawa, S. Torii, et al. (CALET Collaboration), Astroparticle Physics, 100 (2018) 29-37

7) “Energy calibration of CALET onboard the International Space Station”,
*Y. Asaoka, et al. (CALET Collaboration), Astroparticle Physics, 91 (2017) 1-10.

国際宇宙ステーションの「きぼう」で行われたCALETの実験成果が2018 ISS Award for Compelling Resultsを受賞

受賞案件概要	
受賞案件	Compelling Results in Physical Sciences and Materials Development “Direct Measurement of High Energy Cosmic-Ray Electron and Positron to the TeV region”
受賞者	鳥居祥二氏（早稲田大学）、CALET開発チーム（JAXA、NASA、ASI）、CALET国際サイエンスチーム （Waseda University/Louisiana State University/ University of Siena and INFN）
受賞理由	

- 国際協力によるISS利用成果創出

＜解説＞
日米のみならず、イタリアを含む国際協力で、ISSから他では得られない高精度なデータを取得し、宇宙物理学の発展に大きく貢献したことが評価され受賞しました。

http://iss.jaxa.jp/kiboexp/news/180727_iss_awards.html

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 1032 days with live time fraction to total time close to 84%. Nearly 670 million events are collected with high energy (>10 GeV) trigger.
- Accurate calibrations have been performed with non--interacting p & He events + linearity in the energy measurements established up to 10^6 MIP.
- All electron spectrum has been extended in statistics and in the energy range from 11 GeV to 4.8TeV.
- Preliminary analysis of nuclei and gamma-rays have successfully been carried out and spectra are obtained in the energy range:
  - proton: 50 GeV ~ 100 TeV, helium: 10 GeV/n ~ 20 TeV/n, C-Fe: 50 (200) GeV ~ 100 TeV.
  - B/C ratio: 20 GeV/n ~ 1 TeV/n
- Preliminary analysis of UH cosmic rays up to Z=40 was achieved.
- CALET's CGBM detected nearly 60 GRBs (~20 % short GRB among them) per year in the energy range of 7keV-20 MeV. Follow-up observations of the GW events were carried out .
- 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.