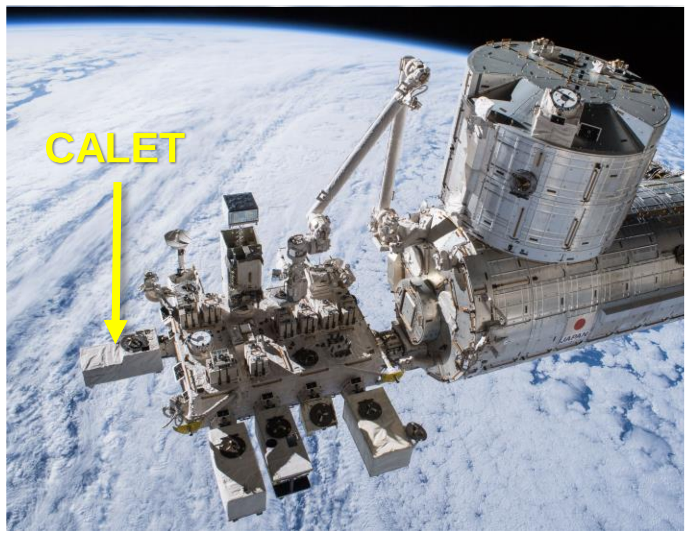
The CALorimetric Electron Telescope (CALET) Status and Initial Results

T. Gregory Guzik
for the CALET Collaboration
Louisiana State University



Many thanks to Yoichi Asaoka of Waseda University for the slides in this presentation.

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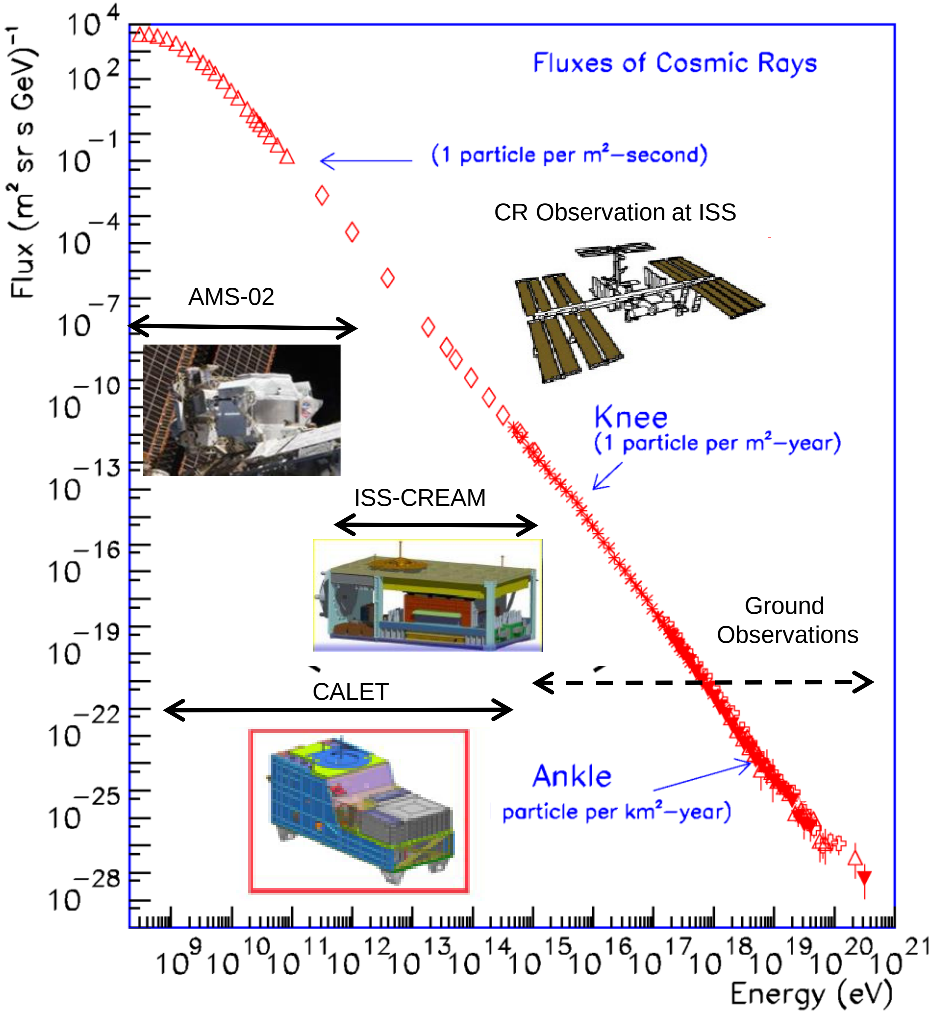
Cosmic Ray Observations at the ISS and CALET



Overview of CALET Observations

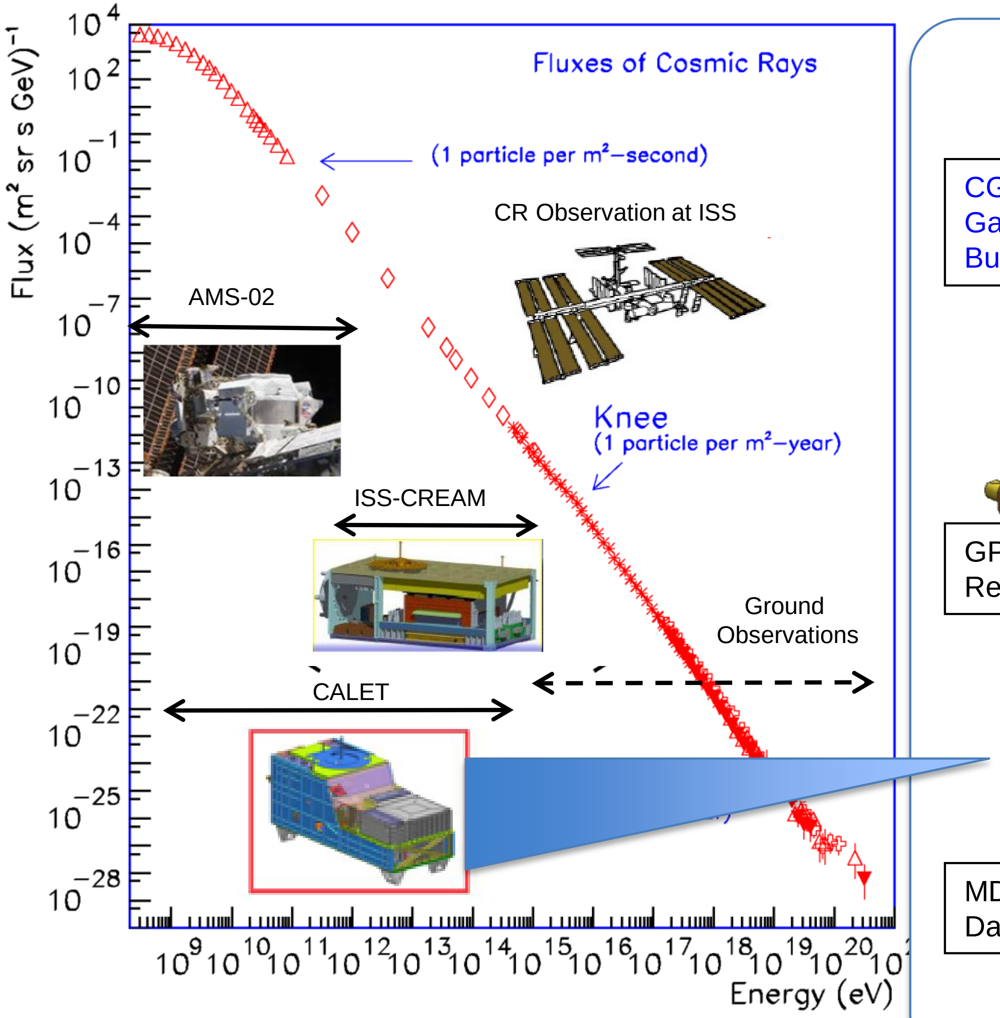
- ☐ Direct cosmic ray observations in space at the highest energy region by combining:
  - ✓ A large-size detector
  - ✓ Long-term observation onboard the ISS (5 years or more is expected)
- ☐ Electron observation in 1 GeV - 20 TeV will be achieved with high energy resolution due to optimization for 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

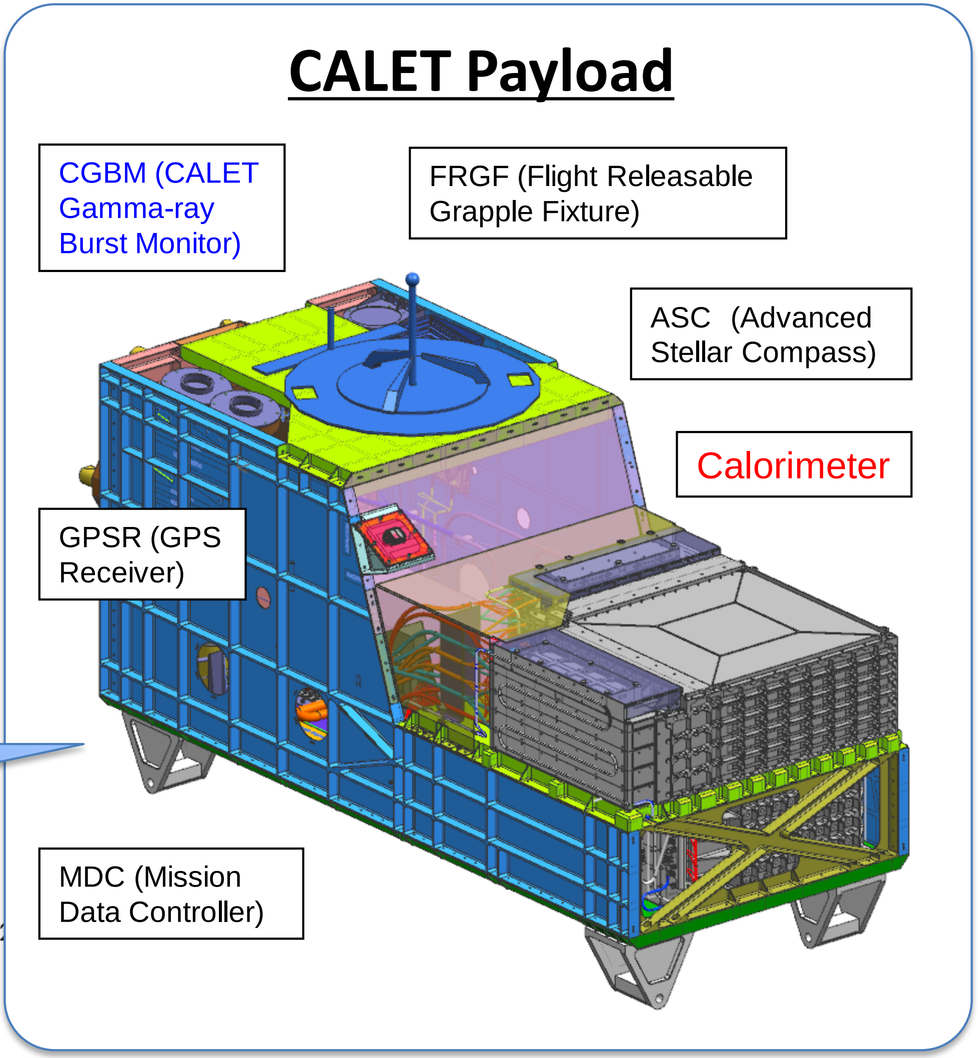
  ⇨ Unravelling the CR acceleration and propagation mechanism
- ☐ Detection of transient phenomena is expected in space by long-term stable observations

  ⇨ EM radiation from GW sources, Gamma-ray burst, Solar flare, etc.

Cosmic Ray Observations at the ISS and CALET

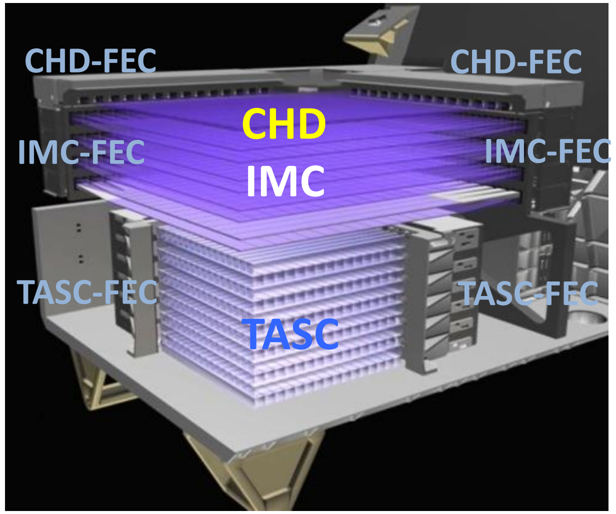


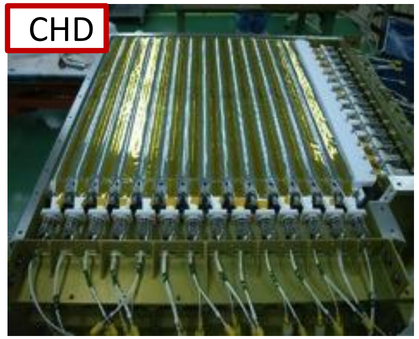
Overview of CALET Observations

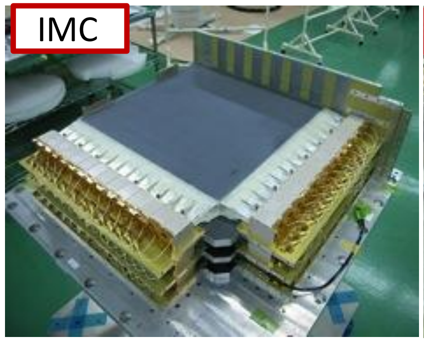


CALET Instrument

CALORIMETER



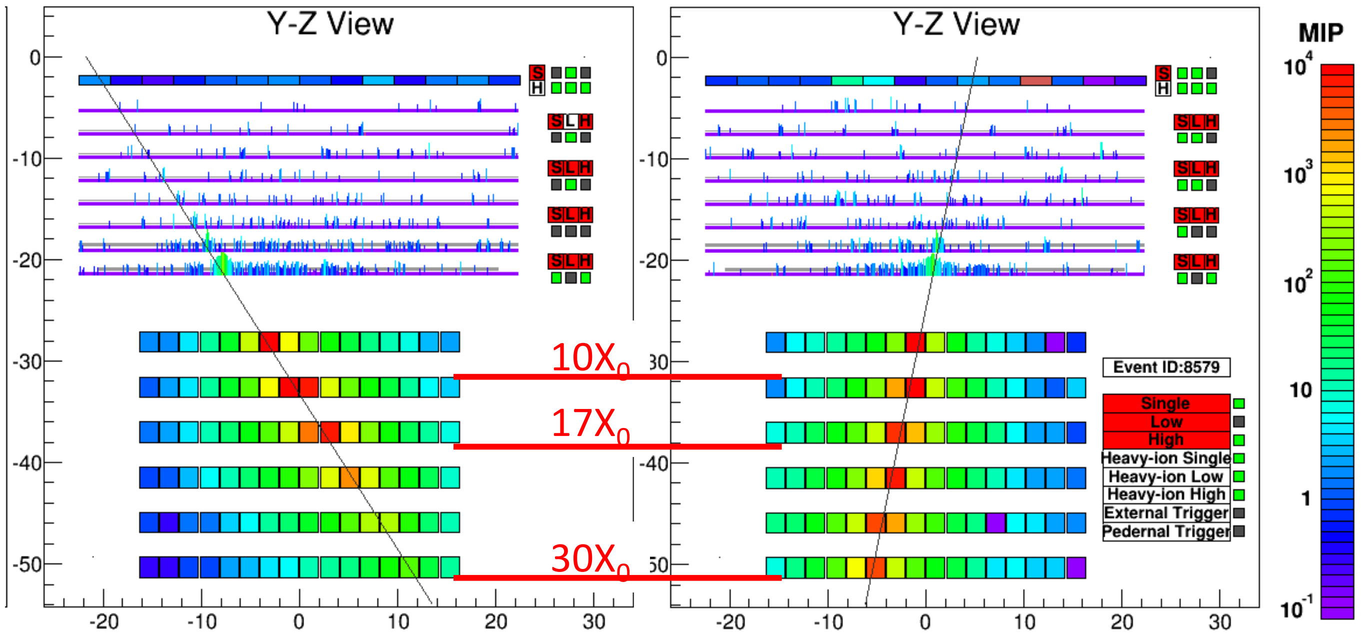




	CHD (Charge Detector)	IMC (Imaging Calorimeter)	TASC (Total Absorption Calorimeter)
Measure	**Charge (Z=1-40)**	**Tracking , Particle ID**	**Energy, e/p Separation**
Geometry (Material)	**Plastic Scintillator 14 paddles x 2 layers (X,Y): 28 paddles Paddle Size: 32 x 10 x 450 mm^3**	**448 Scifi x 16 layers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

All-Electron (electron + positron) Analysis

3TeV Electron Candidate | **Corresponding Proton Background**



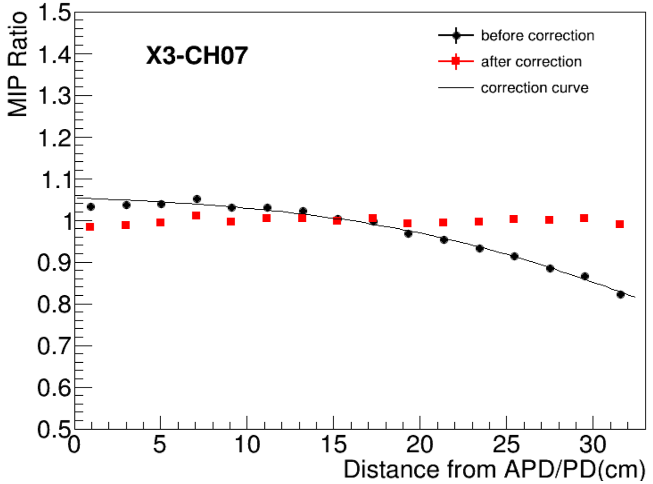
(Flight data; detector size in cm)

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

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

Position and Temperature Calibration, and Long-term Stability

Example of position dependence correction



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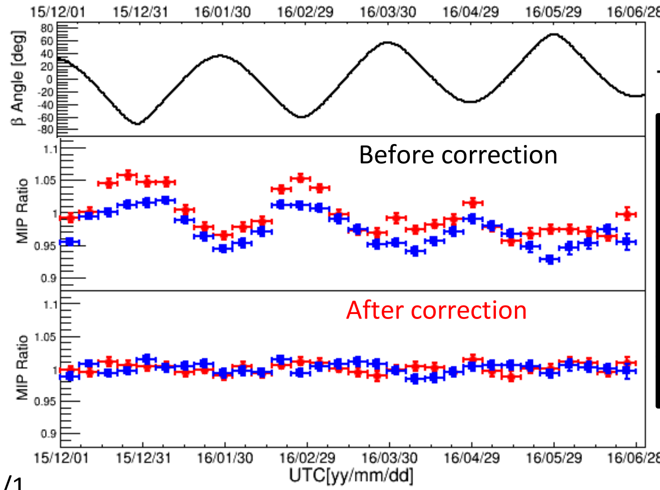
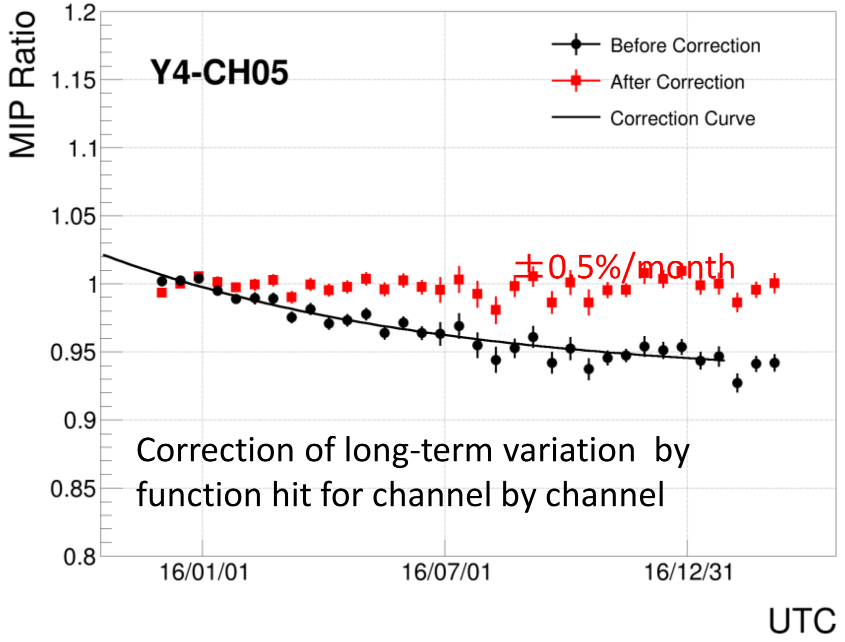
Examples of temperature change correction



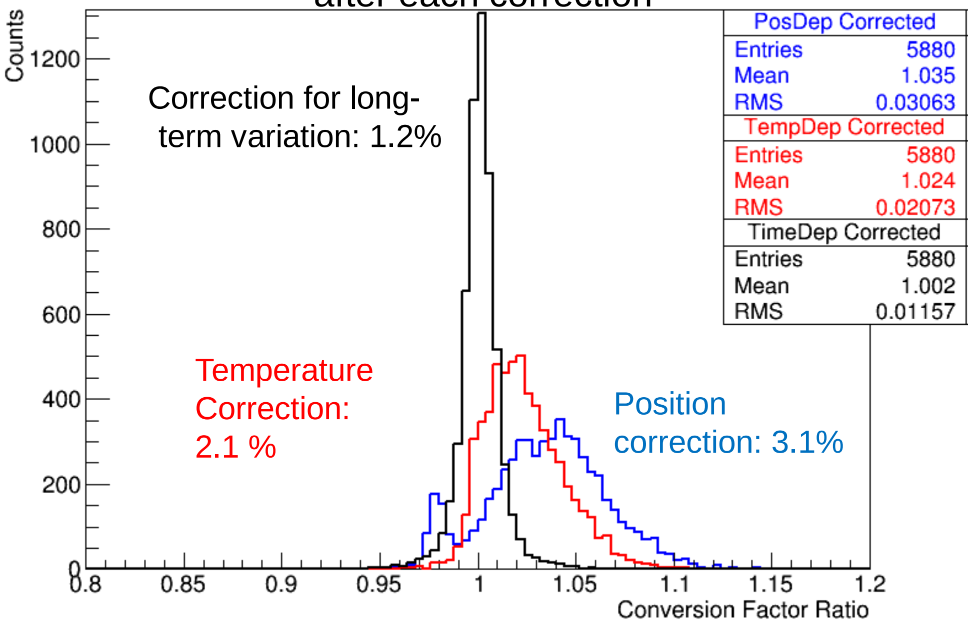
Active Thermal Control System (ATCS) on ISS can provide very stable thermal condition during observations:
Δt ~ a few degrees

16/6/28

Example of long-tem variation correction

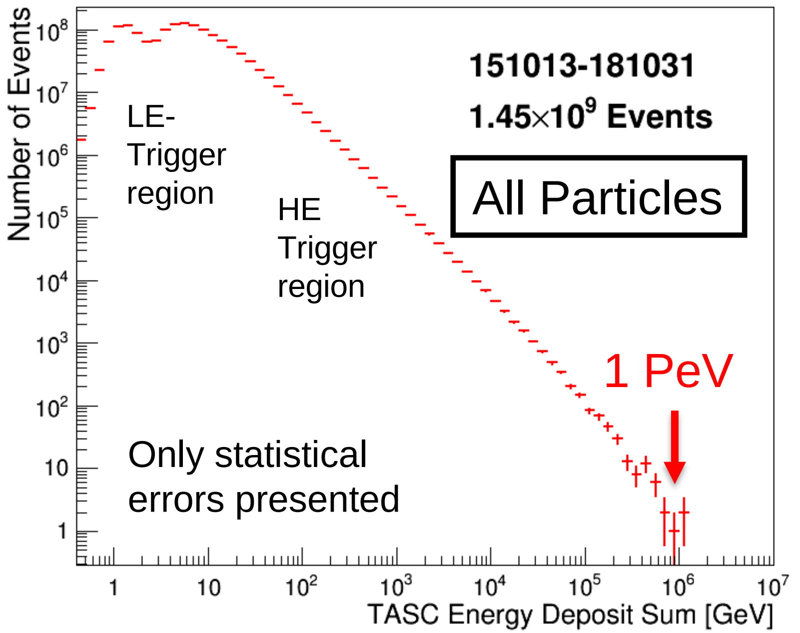


Distribution of MIPs for 192 ch x 16 segmented positions after each correction

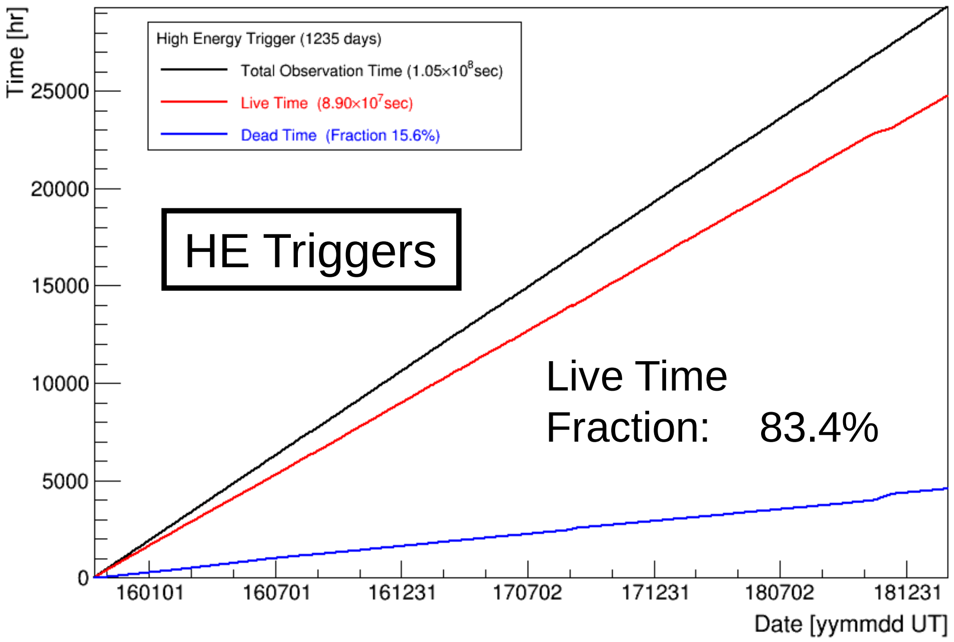


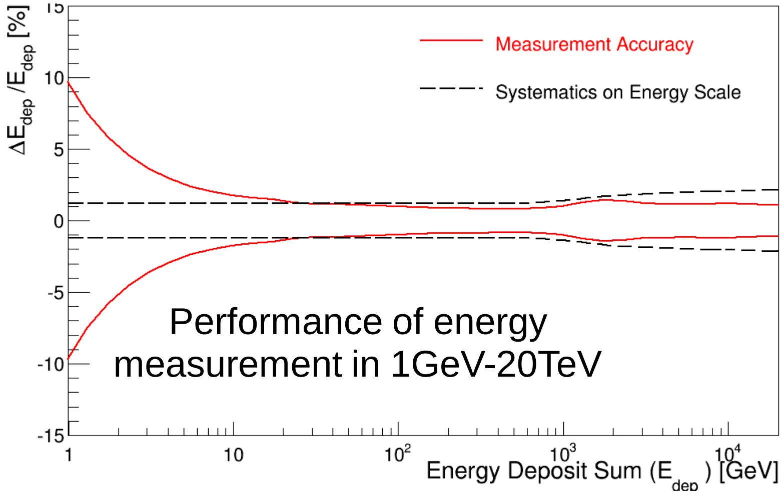
All Particle & High Energy Triggered Events

Distribution of deposit energies (ΔE) in TASC



Accumulated observation time (live, dead)





High Energy Trigger Period: 10/13/15 – 2/28/19 - 1235 days

Exposure: SΩT ~107.0 m^2 sr day

Total number of triggered events: ~730 million

Live Time Fraction: 83.4%

Electron Identification

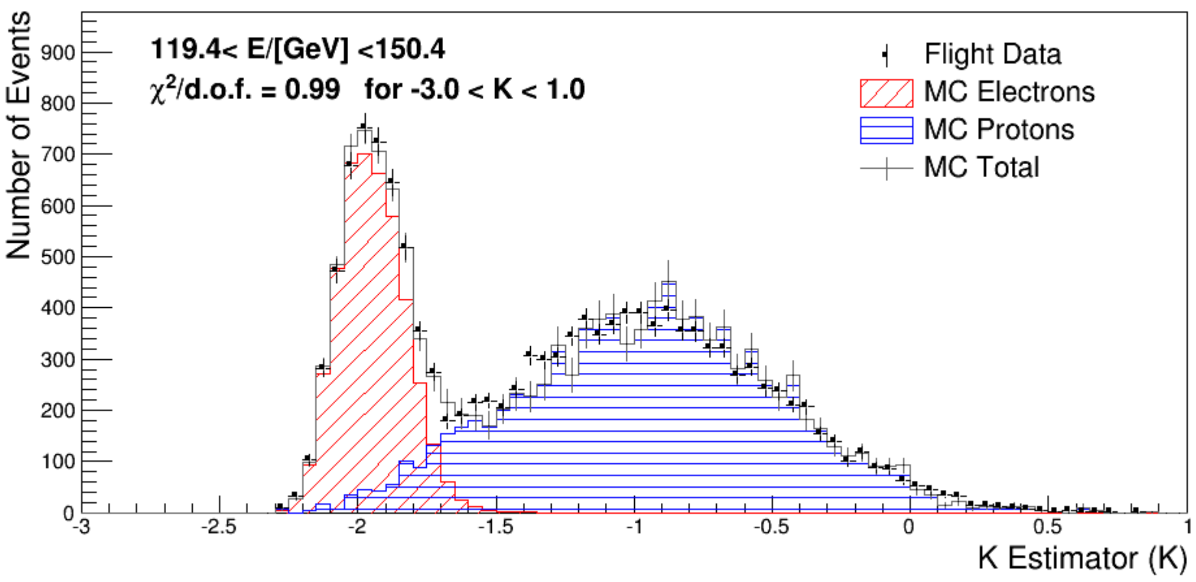
Simple Two Parameter Cut

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

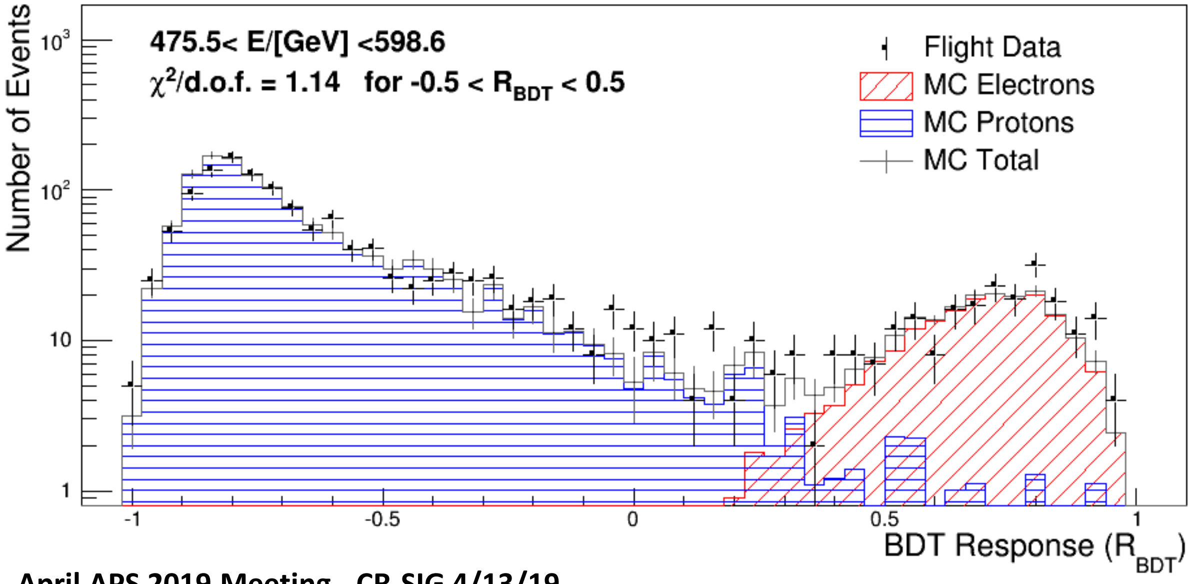
Separation Parameter K is defined as follows:

$$K = \log_{10}(F_E) + 0.5\, R_E\ (/\mathrm{cm})$$

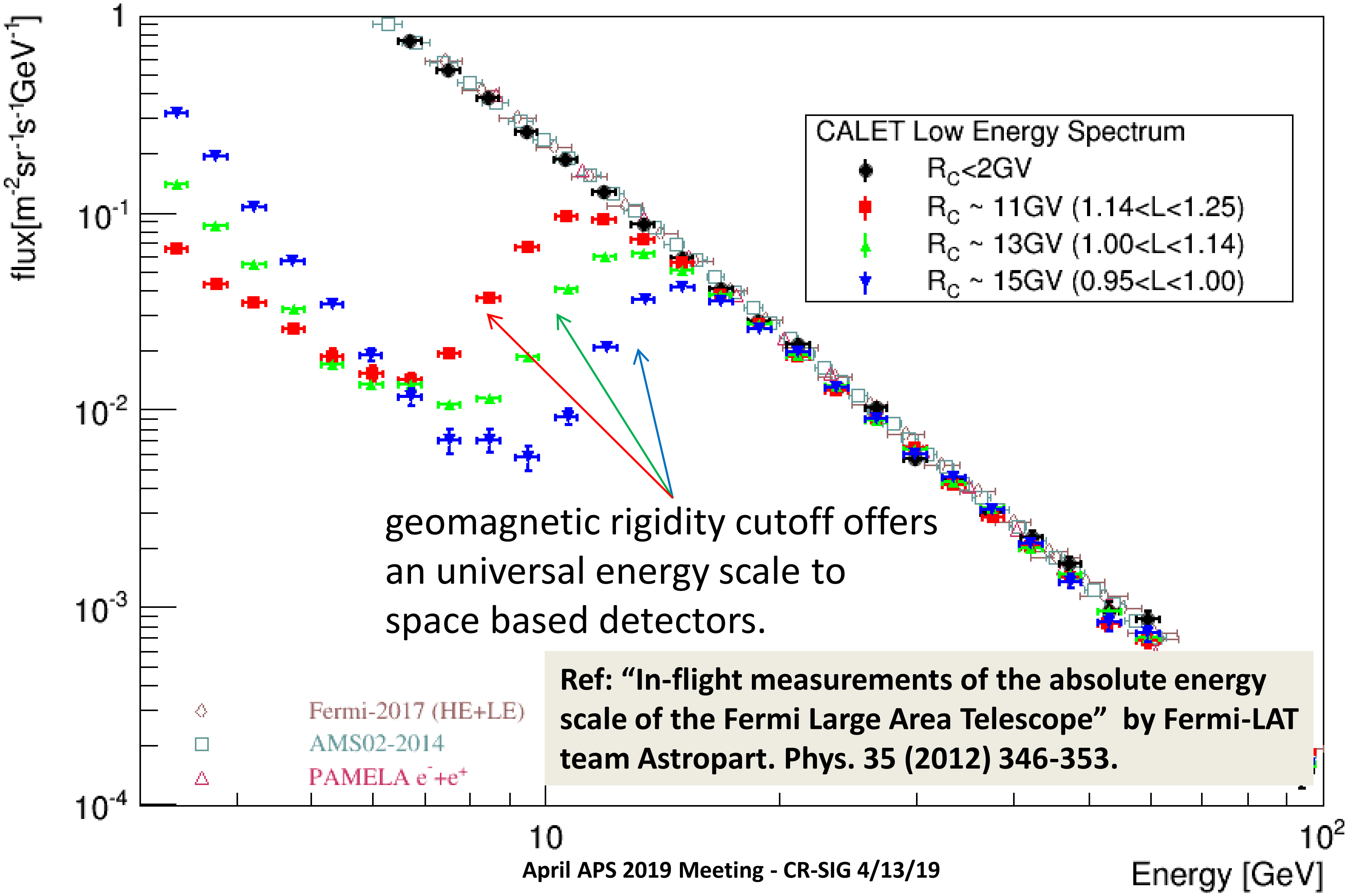


Boosted Decision Trees

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



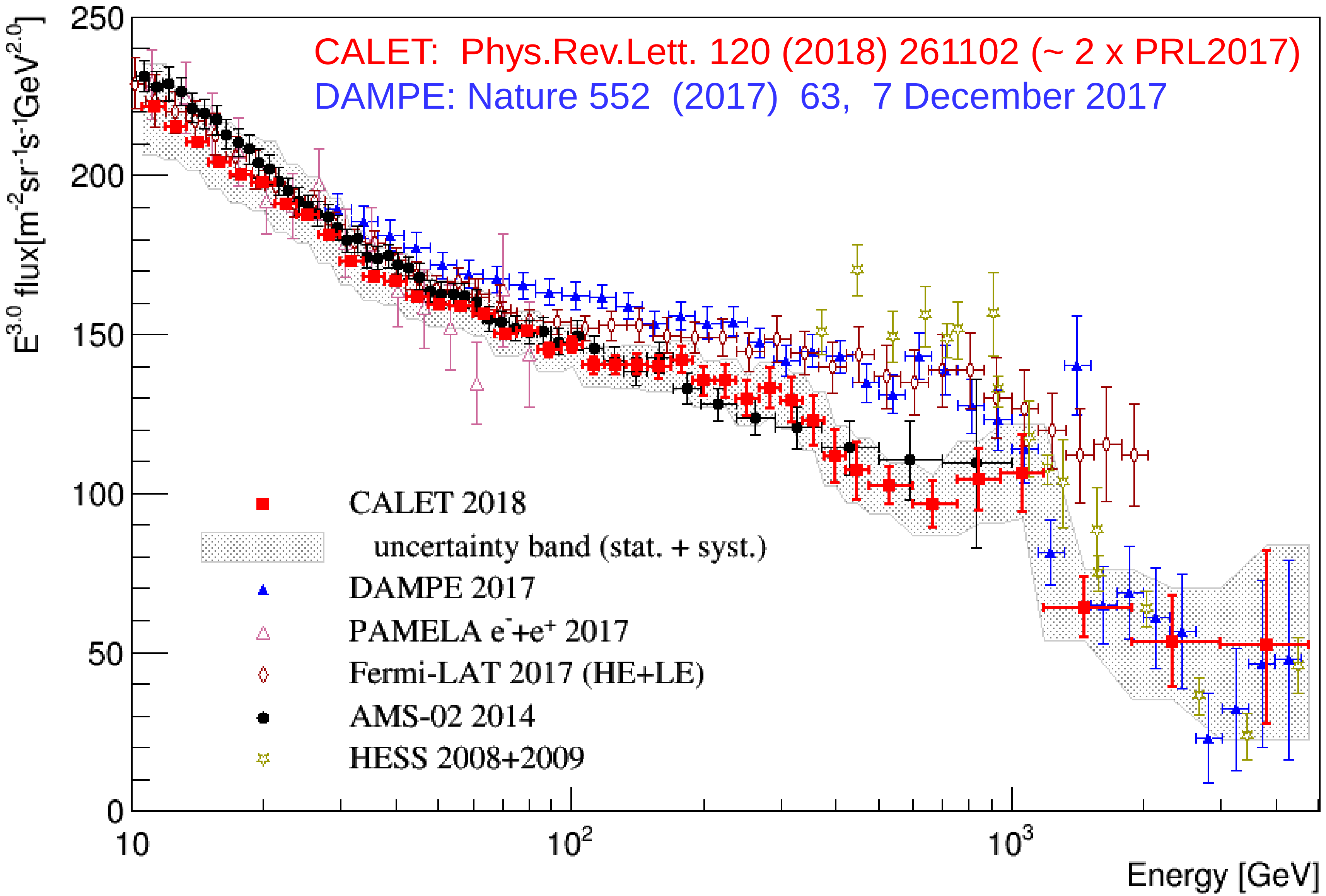
Absolute Calibration of Energy Scale using Geomagnetic Rigidity Cutoff



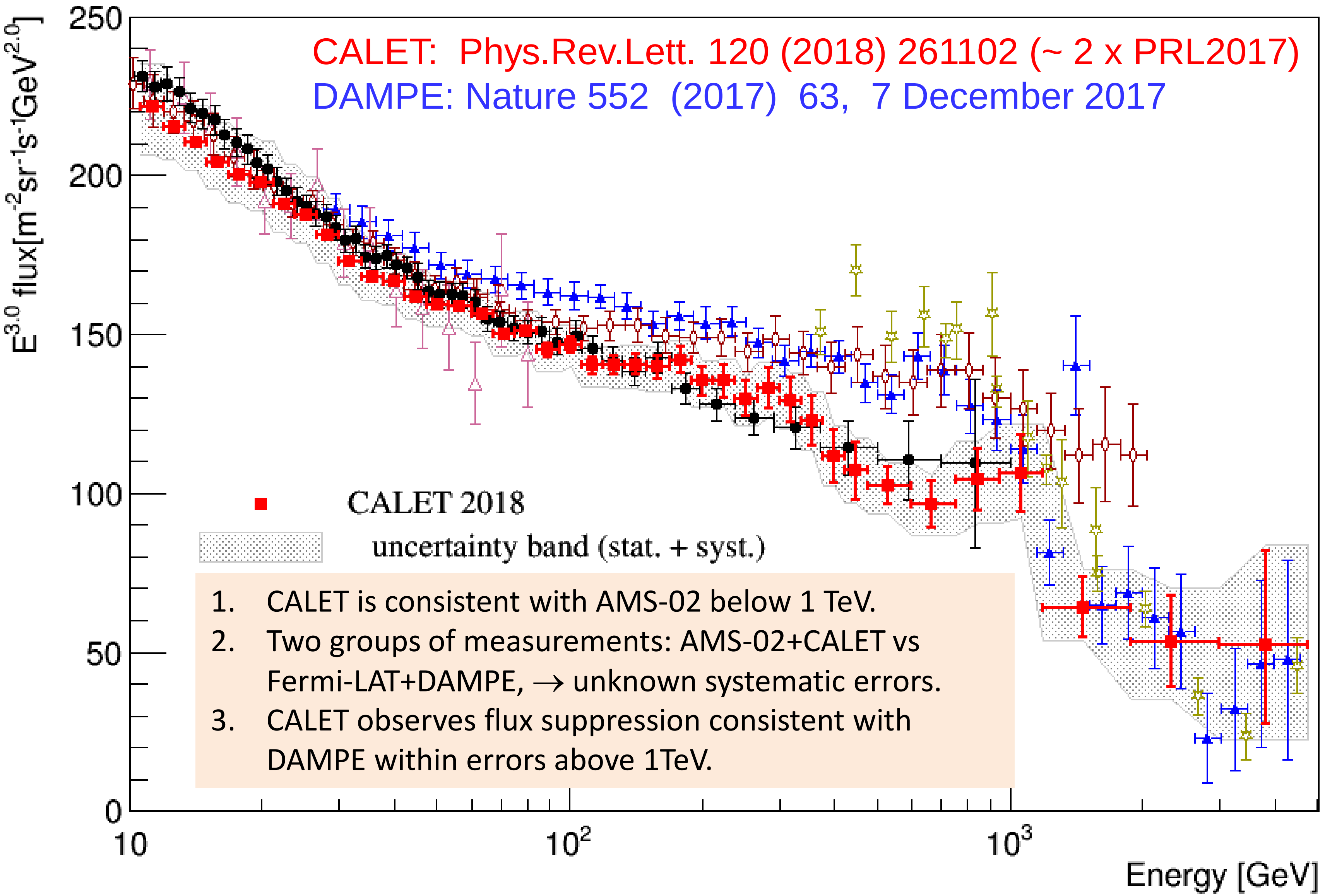
geomagnetic rigidity cutoff offers an universal energy scale to space based detectors.

Ref: "In-flight measurements of the absolute energy scale of the Fermi Large Area Telescope" by Fermi-LAT team Astropart. Phys. 35 (2012) 346-353.

Electron Measurement by CALET



Electron Measurement by CALET

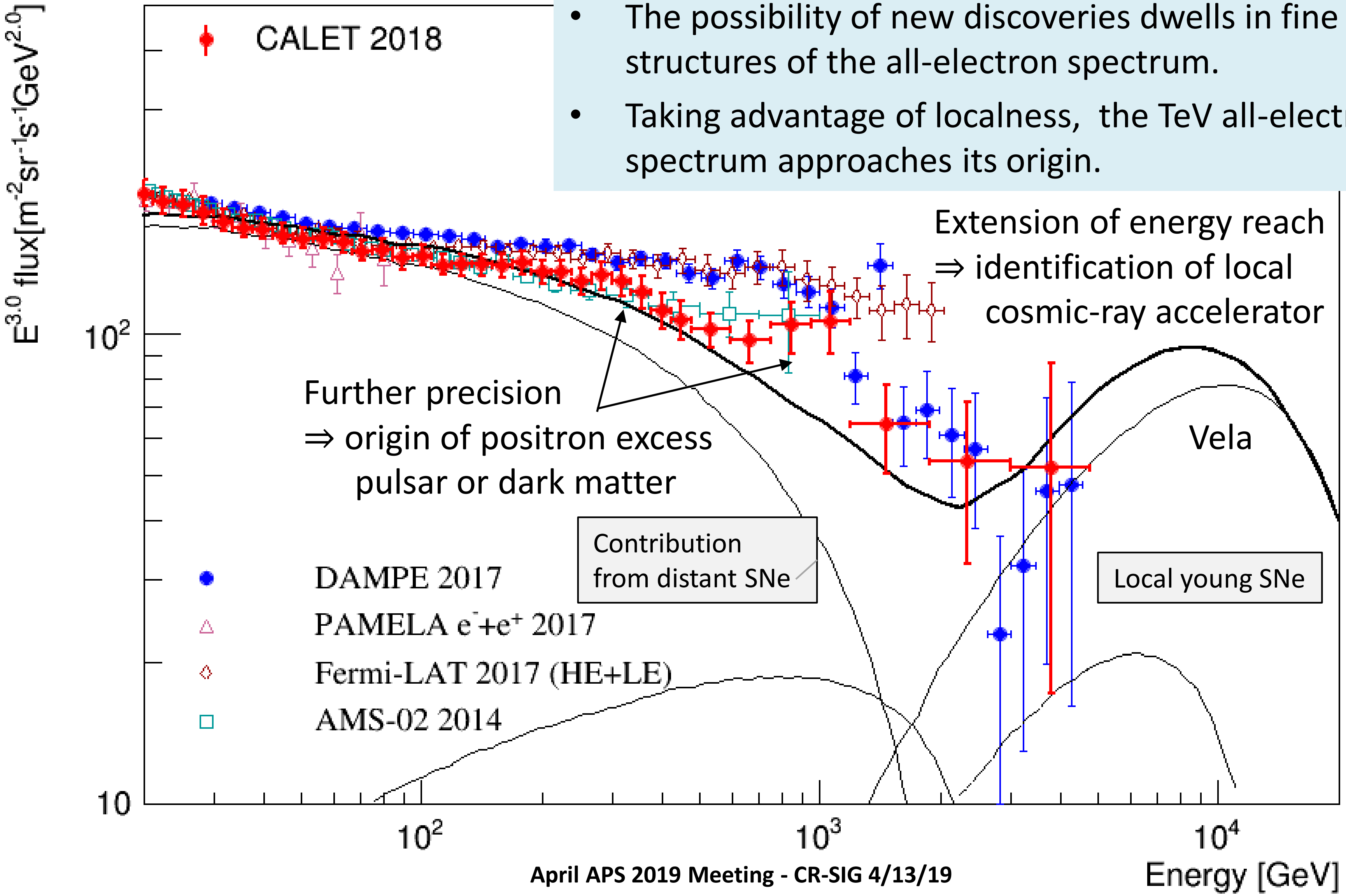


1. CALET is consistent with AMS-02 below 1 TeV.
2. Two groups of measurements: AMS-02+CALET vs Fermi-LAT+DAMPE, → unknown systematic errors.
3. CALET observes flux suppression consistent with DAMPE within errors above 1TeV.

Prospects for CALET All-Electron Spectrum

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

- The possibility of new discoveries dwells in fine structures of the all-electron spectrum.
- Taking advantage of localness, the TeV all-electron spectrum approaches its origin.



Preliminary Flux of Primary Components

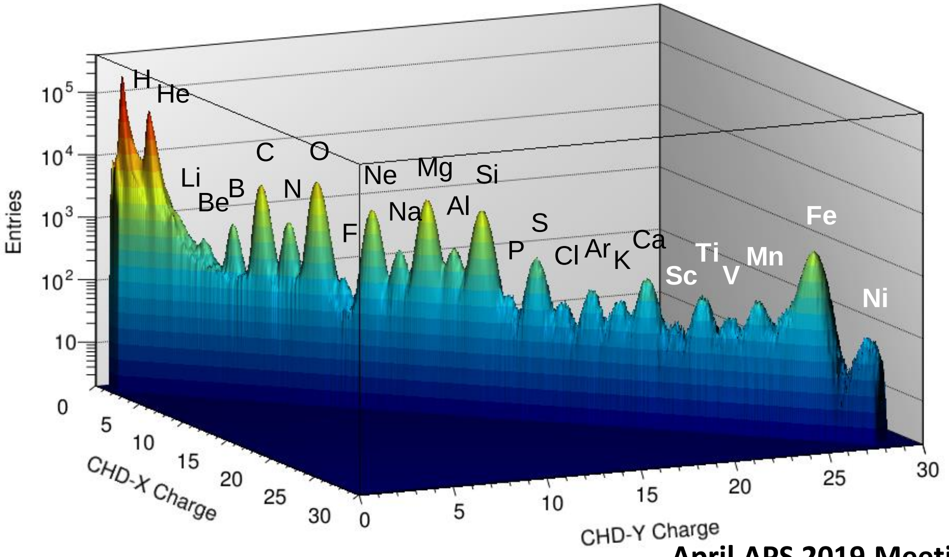
Y. Akaike et al., E+CRS 2018

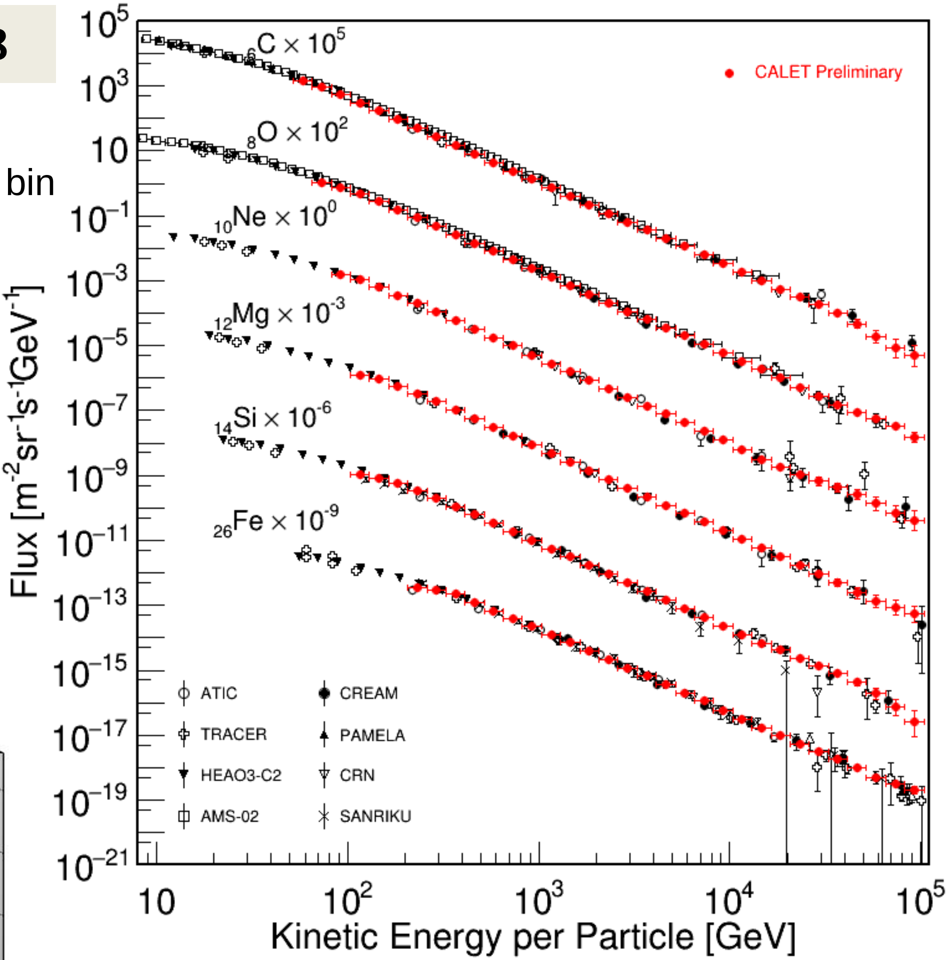
Flux measurement:

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

N(*E*): Events in unfolded energy bin
SΩ : Geometrical acceptance
T : Live time
ε(*E*) : Efficiency
ΔE : Energy bin width

Observation period:
2015.10.13 – 2018.5.31 (962 days)
Selected events: ~5.6 million for C-Fe





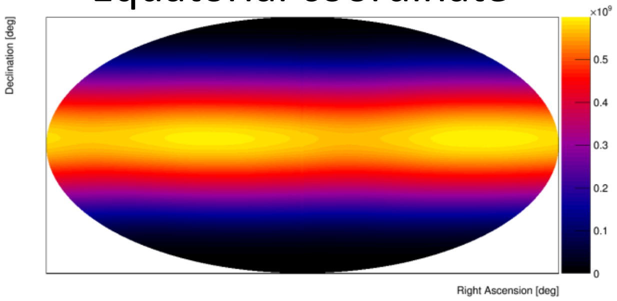
Charge Separation only with CHD

Clear separation of protons, helium to iron and nickel (up to Z=40).

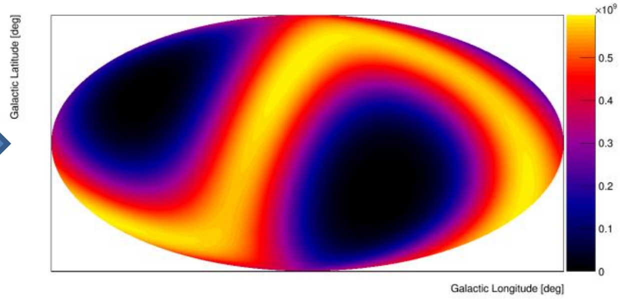
CALET Sky Map w/ LE-γ Trigger (E>1GeV)

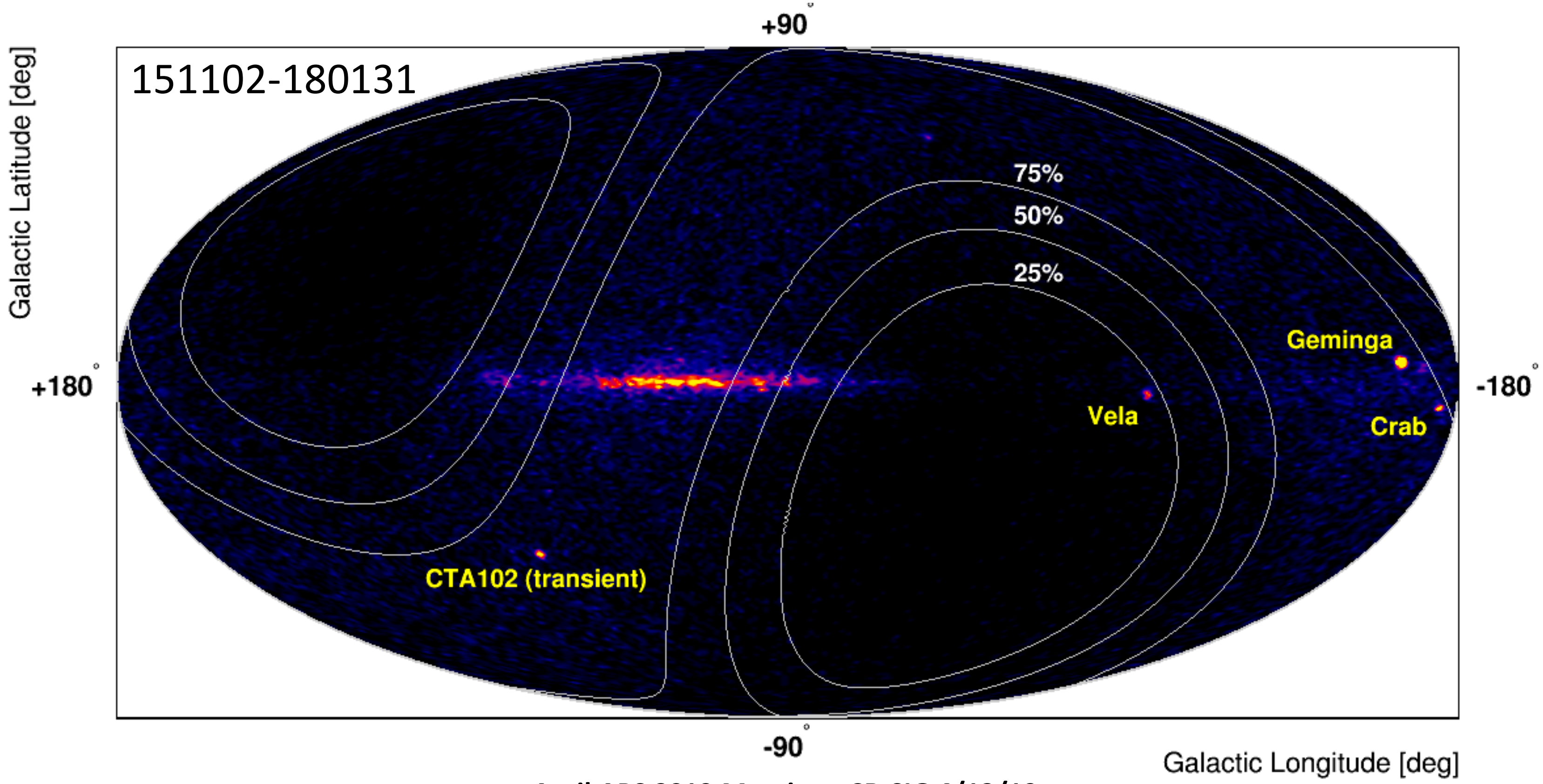
While exposure is not uniform, we have clearly identified the galactic plane and bright GeV sources.

Equatorial coordinate

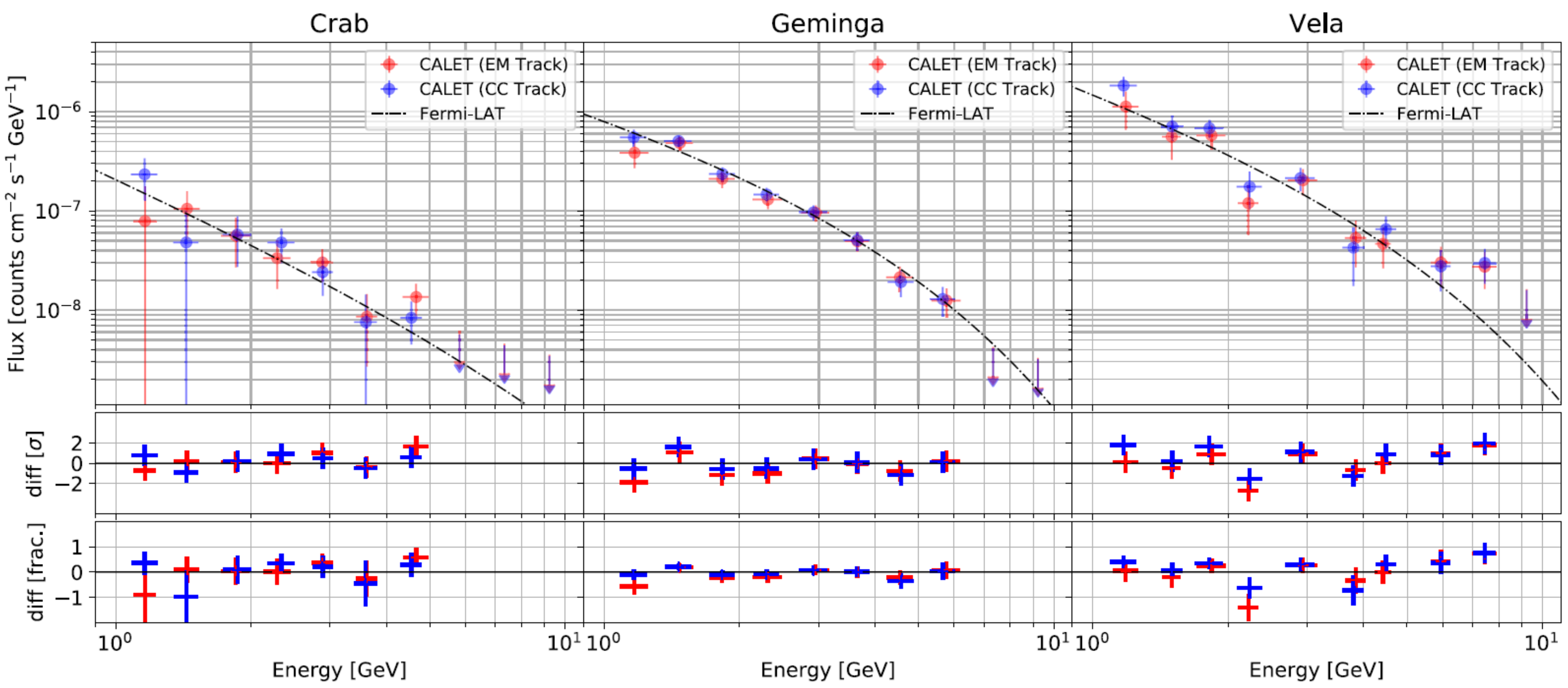


Galactic coordinate



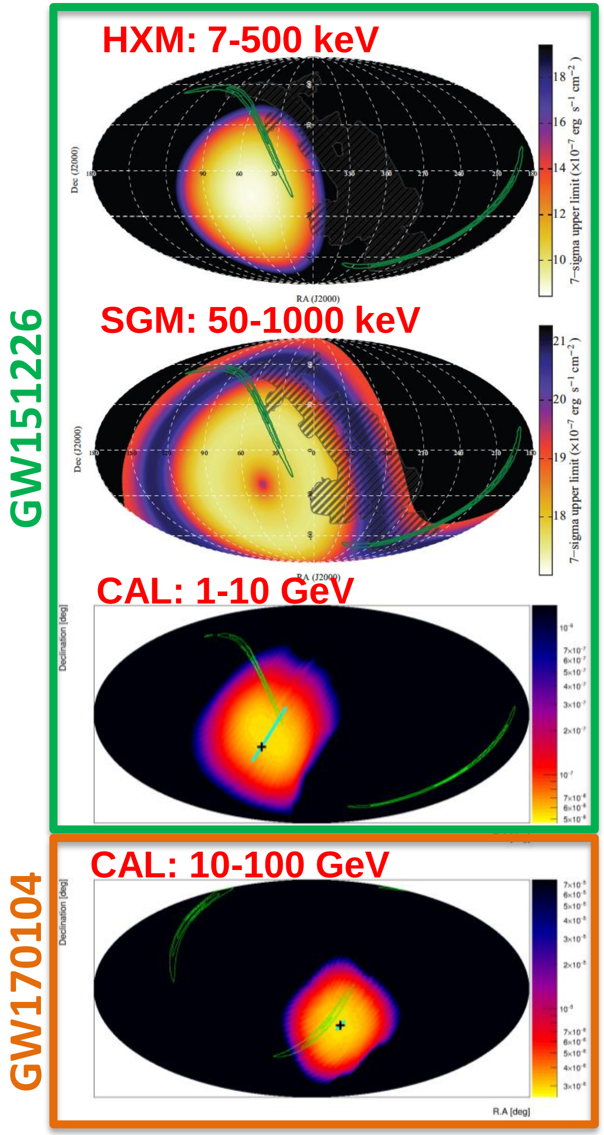


Bright Point-Source Spectra



- The observed point source spectra are well consistent with Fermi-LAT's parameterizations.
- Point Spread Function (PSF) and absolute pointing accuracy (~0.1deg) were validated, too, using bright point source data.

Complete Search Results for GW Events during O1&O2



GW151226: O. Adriani et al. (CALET Collaboration), ApJL 829:L20 (2016).
All O1 & O2: O. Adriani et al. (CALET Collaboration), ApJ 863 (2018) 160.

Event	Type	Mode	Sum. LIGO prob.	Obs. time	Upper limits	
					Ene. Flux erg cm^{-2} s^{-1}	Lum. erg s^{-1}
GW150914	BH-BH	Before operation				
GW151226	BH-BH	LE HXM SGM	15%	T_0-525 – T_0+211	9.3 x 10^{-8} 1.0 x 10^{-6} 1.8 x 10^{-6}	2.3 x 10^{48} 3-5 x 10^{49}
GW170104	BH-BH	HE	30%	T_0-60 – T_0+60	6.4 x 10^{-6}	6.2 x 10^{50}
GW170608	BH-BH	HE	0%	T_0-60 – T_0+60	Out of FOV	
GW170814	BH-BH	HE	0%	T_0-60 – T_0+60	Out of FOV	
GW170817	NS-NS	HE	0%	T_0-60 – T_0+60	Out of FOV	

- CALET can search for EM counterparts to LIGO/Virgo triggers
- All O1 and O2 triggers checked – no signal in CGBM or CAL
- Upper limits set for GW151226 for CGBM+CAL in 2016 paper
- Upper limits for the CAL set using refined LE selection for triggers to-date in the 2018 paper

Summary and Future Prospects

- **CALET has been observationally very stable and scientifically productive since Oct. 13, 2015**
  - High energy trigger exposure of more that 107 m^2 sr days as of 2/28/2019
  - 10 peer-reviewed journal manuscripts have been published since 2016
  - One peer-reviewed journal article has been accepted and another is in preparation
  - Close to 30 conference publications on flight results.
- **Major scientific results have been published or reported**
  - All electron spectrum from 11 GeV to 4.8 TeV published in PRL in June 2018.
  - CALET GBM detected more than 40 GRBs per year in energy range 7 keV – 20 MeV
  - CAL provides extended gamma-ray observation for E > 1 GeV (ApJS September 2018)
  - CALET GW counterpart searches for LIGO/Virgo O2 run published in ApJ in August 2018
  - Proton energy spectrum paper has been accepted and should be published soon.
- **Presentations here at the April 2019 APS meeting include the following:**
  - **"Three Years of CALET Ultra Heavy Cosmic Ray Observations"**, B.F. Rauch,
    G08.00007, 4/14/2019, 08:30 am
  - **"Measurements of Nuclei Fluxes in Cosmic Rays with CALET",** Y. Akaike,
    G08.00008, 4/14/2019, 08:30 am
  - **"Observations of the Sun in GeV Gamma Rays by CALET on the ISS",** N.W. Cannady,
    Q09.00003, 4/15/2019, 10:45 am
  - **"On-orbit operation and gamma-ray burst observations with the CALET Gamma-ray Burst Monitor",** Y. Kawakubo,
    T08.00001, 4/15/2019, 03:30 pm
- **Future prospects**
  - Instrument is in excellent health and flight data analysis involves the entire collaboration
  - Expect CALET flight operations to continue at least until March 31, 2021 and possibly longer