CALETによる10 GeVから7.5 TeVの電子のエネルギースペクトル測定結果

早大理工総研, 神奈川大工[A],
NASA/GSFC/CRESST/UMBC[B], 芝工大シエ[C]

赤池陽水, 鳥居祥二,
Holger MotzA, Nicholas Cannady[B],
笠原克昌[C], 小林兼好
他 CALET チーム

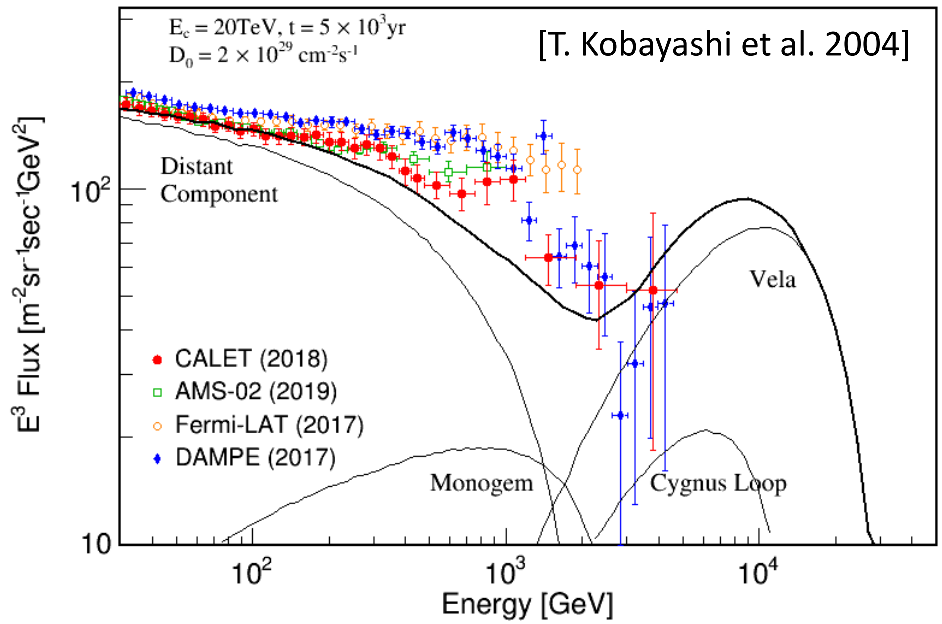
Electron measurement in the TeV region

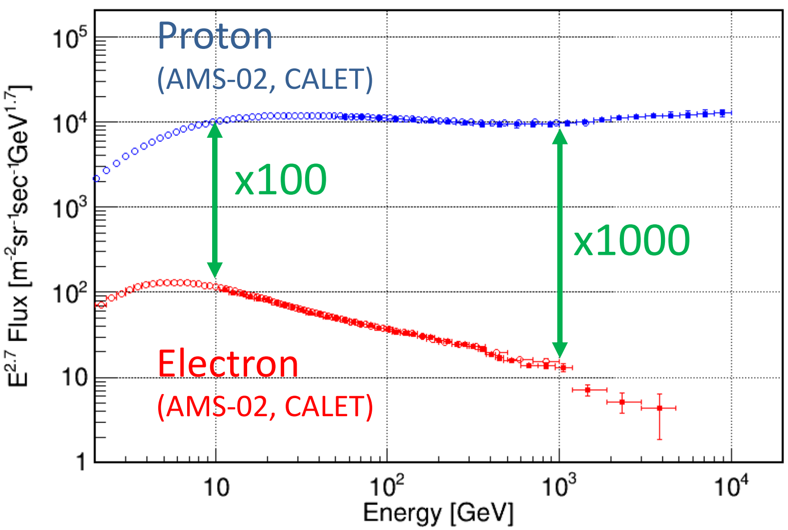
TeV electron measurements

Electrons rapidly lose their energy ($\propto E^2$)
➡ TeV electrons can arrive from
- distance: d < 1kpc
- time: T < 10^4 yr

Candidate sources are very few like Vela
➡ unique structure in TeV region
➡ identify the cosmic ray source by charged particles

electron spectrum measured in space





Difficulty of the electron measurements

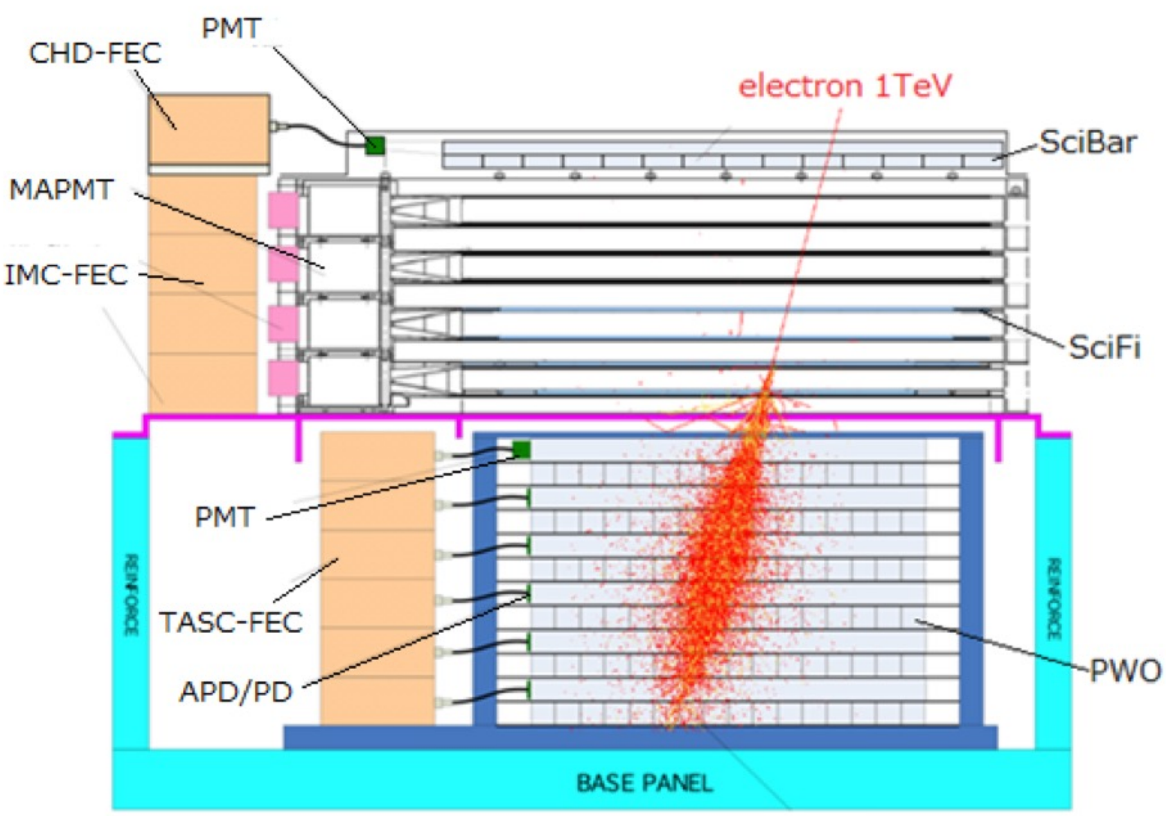
- Flux in TeV electron is very rare
- Large proton background

Maximum detectable rigidity of AMS-02 is 2TV
Calorimeter in space has unique capability to reveal TeV electrons

Instrument of CALET

A 30-radiation length deep calorimeter designed to detect electrons and gammas to 20 TeV and cosmic rays up to 1 PeV

Since the start of operation on the ISS in October 2015,
CALET has been accumulating scientific data without any major interruption



CHD: Charge Detector

Charge measurements (Z=1-40)

- Plastic scintillator paddles 14 x (X, Y)
  Unit size: 32mm x 10 mm x 450 mm

IMC: Imaging Calorimeter

Arrival direction, Particle ID

- Scintillating fiber belts 448 x 16 layers
  Unit size: 1 mm^2 x 448 mm
- Tungsten plates 7 layers
  3 X_0 (=0.2 X_0 x 5 + 1.0 X_0x 2)

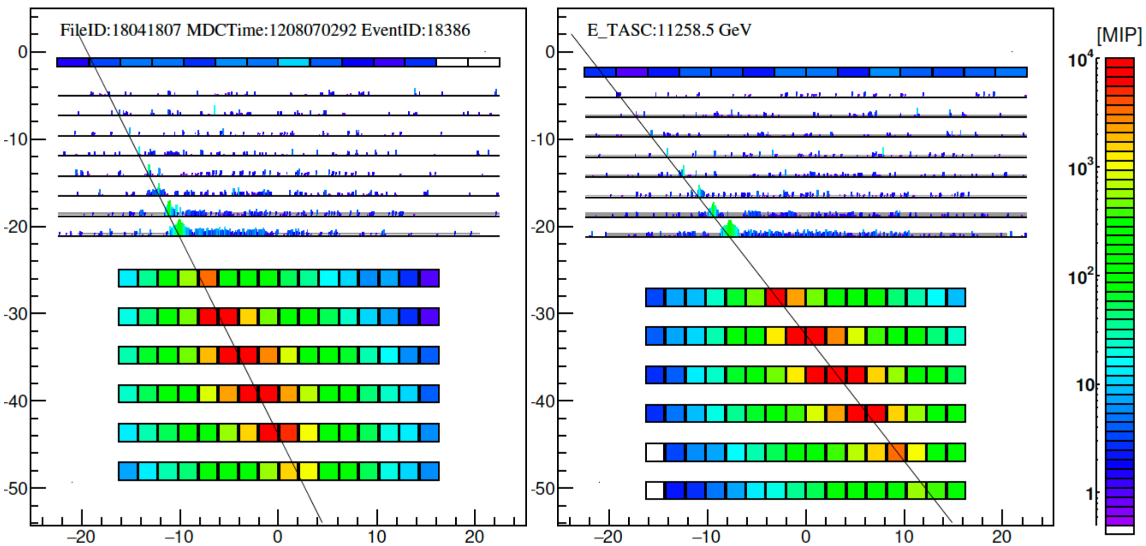
TASC: Total Absorption Calorimeter

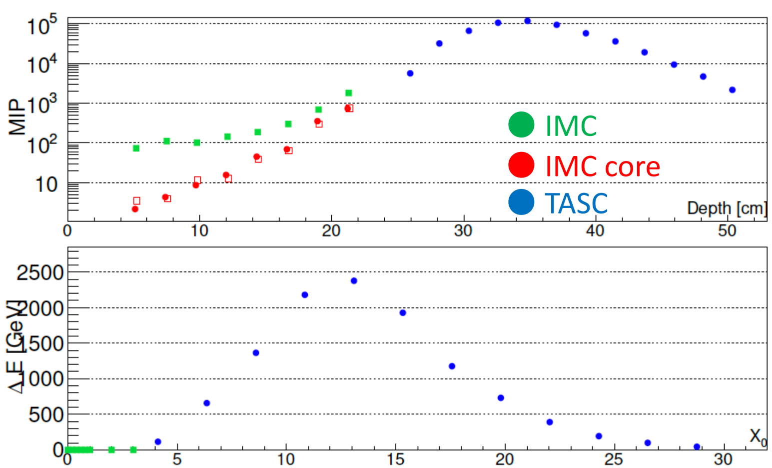
Energy measurement, Particle ID

- PWO logs 16 x 12 layers
  Unit size: 19 mm x 20 mm x 326 mm
  27 X_0 for electrons
  1.2 interaction length for protons

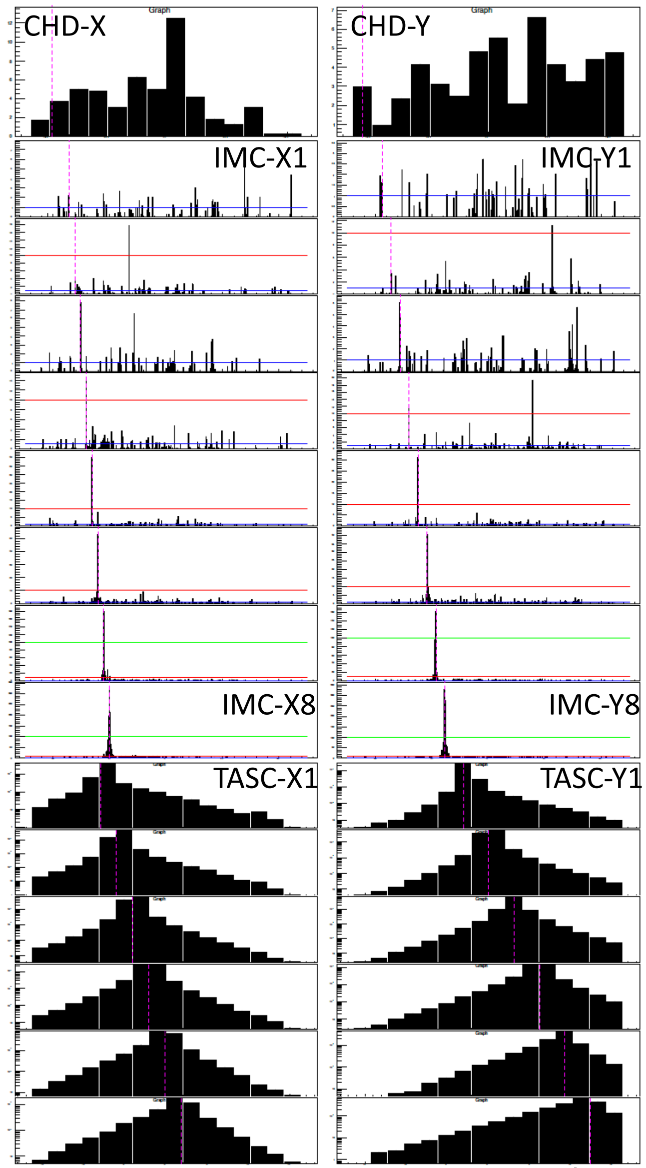
Field of view: ~45 degree (from the zenith)
Geometrical Factor: ~1040 cm^2sr for electrons

Event displays of electron candidate

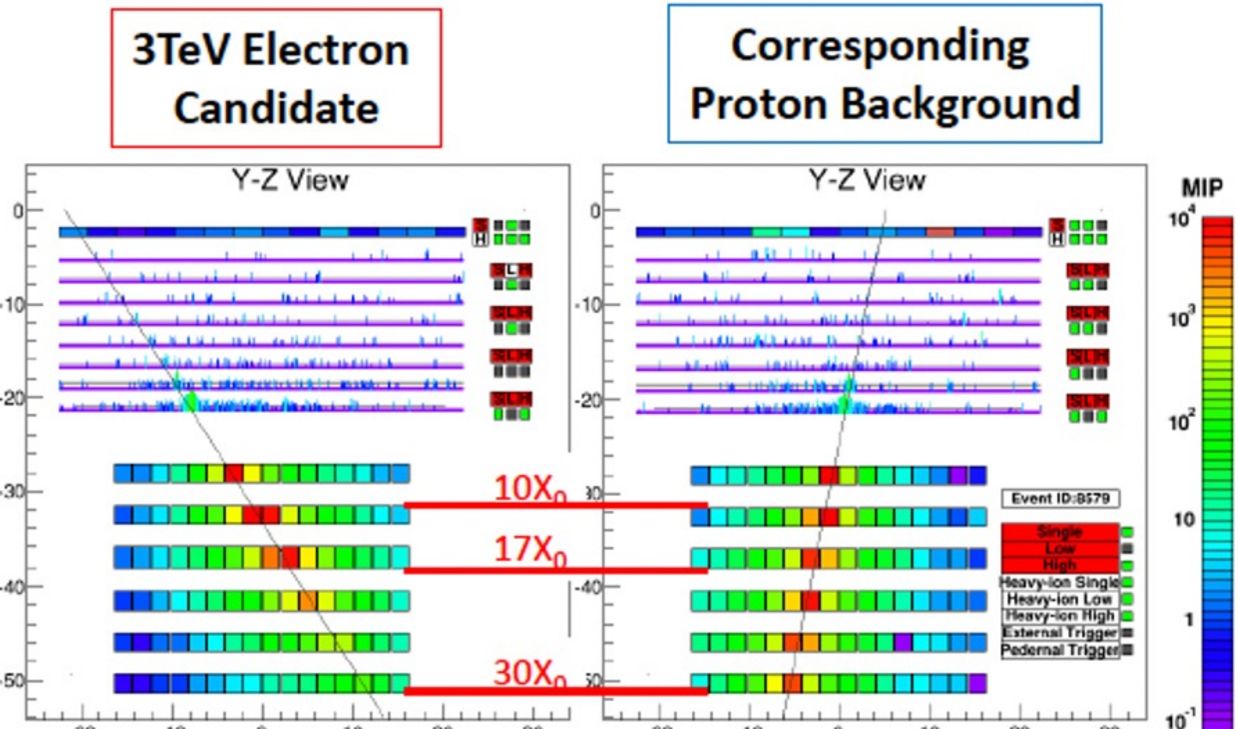




RE: 2.510	tasc_tmax: 3.790
FE: -2.408	tasc_b: 0.539
ConcIMC: 0.714	tasc_sta: 9.497
sumCHD: 80.626	tasc_chi2ndf: 0.464
imc_p0: -0.794	Rmax: 0.476
imc_p1: 1.629	R78: 0.665
imc_chi2ndf: 11.380	



Features of CALET calorimeter



(Flight data; detector size in cm)

1. Reliable tracking
   well-developed shower core

2. Fine energy resolution
   Full containment of TeV showers
   Correction factor < 5%

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

Electron Identification

Simple Two Parameter Cut

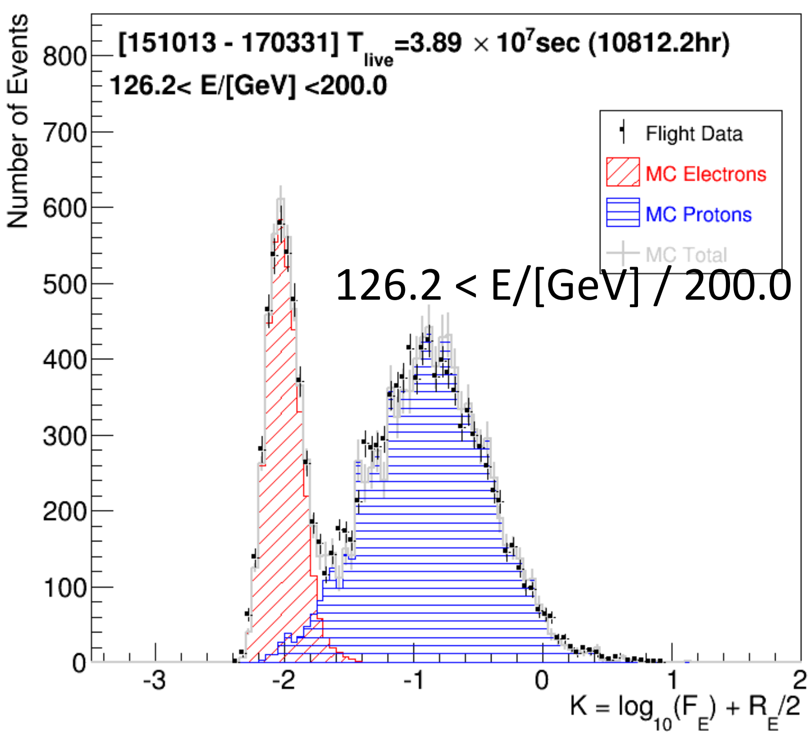
E<476GeV

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

Cut Parameter K is defined as follows:

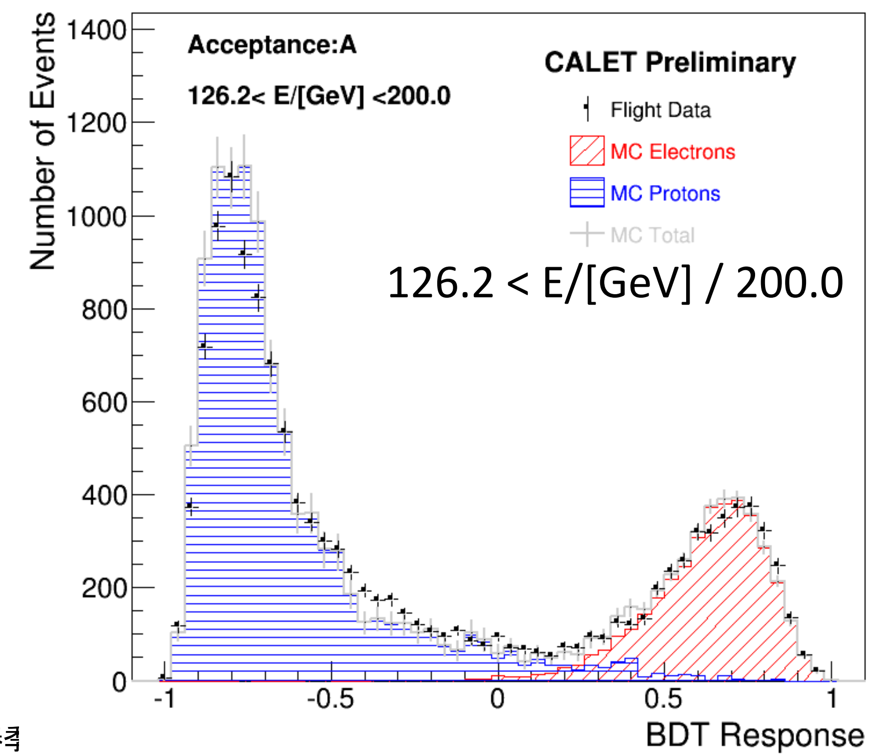
$$K = \log_{10}(F_E) + 0.5\ R_E\ (/cm)$$



Boosted Decision Trees (BDT)

E>476GeV

In addition to the two parameters in the left, TASC and IMC shower profile fits are used as discriminating variables with 9 parameters



Electron identification at high energy region

The discriminate variables for BDT are optimized;

1. Lateral spread : R_E
2. Shower development : F_E
3. *Shower concentration ratio on IMC Y8 : C_E

- The fitting of TASC transition curve
  4. α/b
  5. b
  6. χ^2/NDF
  7. $T_{5\%}$

$$\frac{dE}{dt} = E_0 \frac{b^{\alpha+1}}{\Gamma(\alpha+1)} t^{\alpha} e^{-bt}$$

($T_{5\%}$: Development the ratio of energy deposit is 5%)

- Exponential fitting of IMC transition curve
  8. $p0$
  9. $p1$
  10. χ^2/NDF

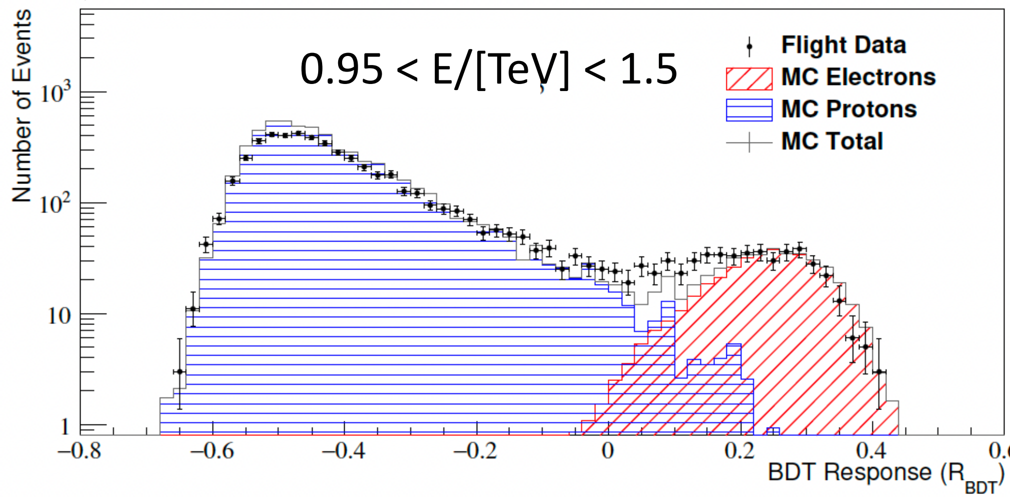
$$\frac{dE}{dt} = e^{(p_1 t + p_0)}$$

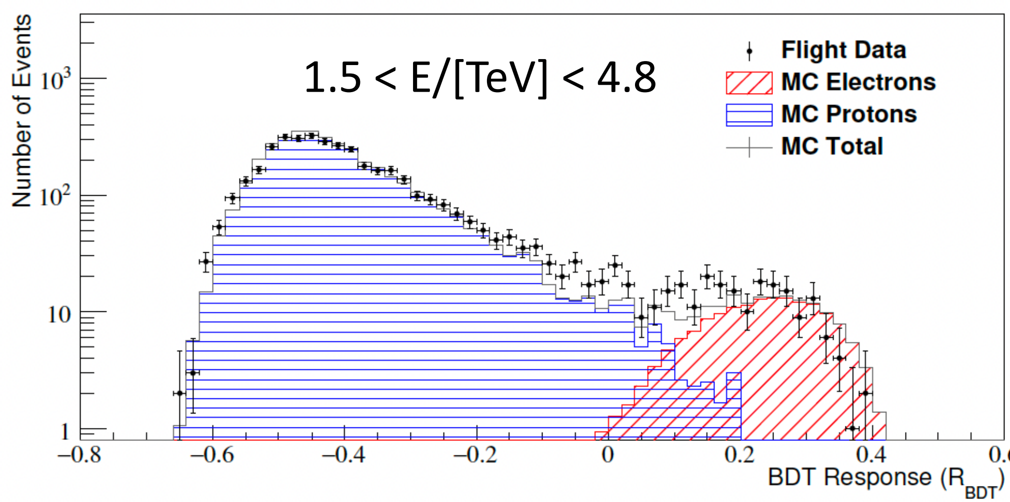
11. *The sum of CHD energy deposit : S_{CHD}

- Energy ratio between adjacent IMC layers
  12. * R_{max}
  13. * R_{67}

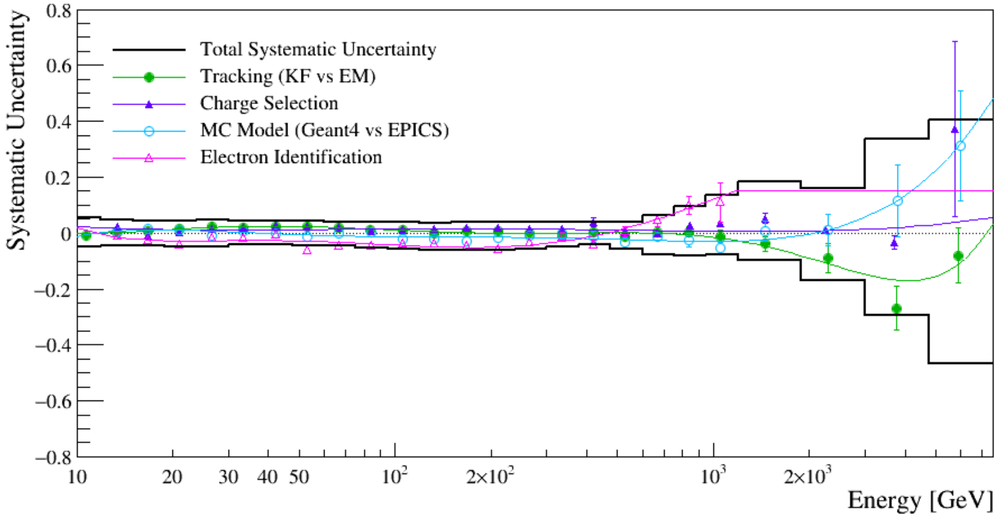
* New parameters

➡ The total BG protons are less than 10% up to 7.5 TeV with 70% electron efficiencies

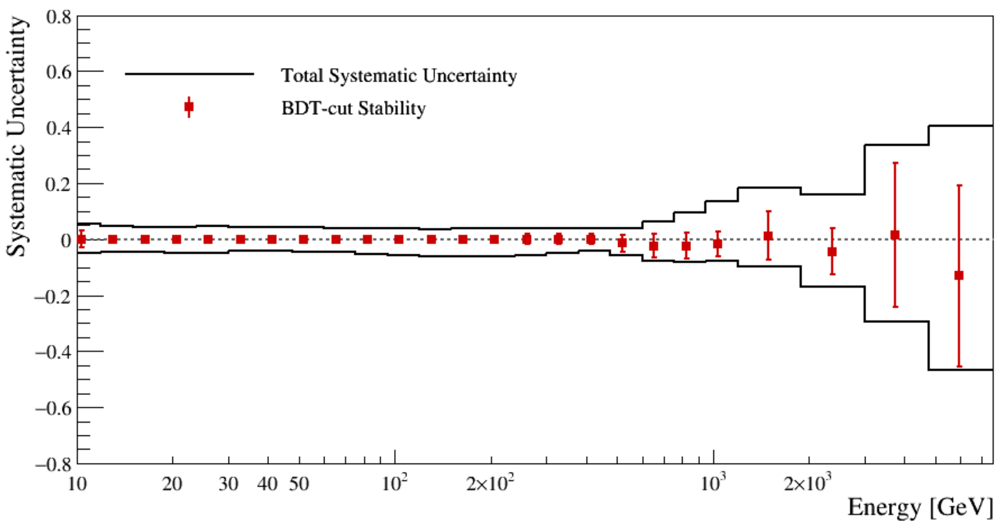




Systematic uncertainties



Energy dependent sources;
- Tracking (EM vs KF)
- Charge selection (CHD vs IMC)
- MC model (EPICS vs Gent4)
- Electron identification (K-cut vs BDT)
- BDT stability



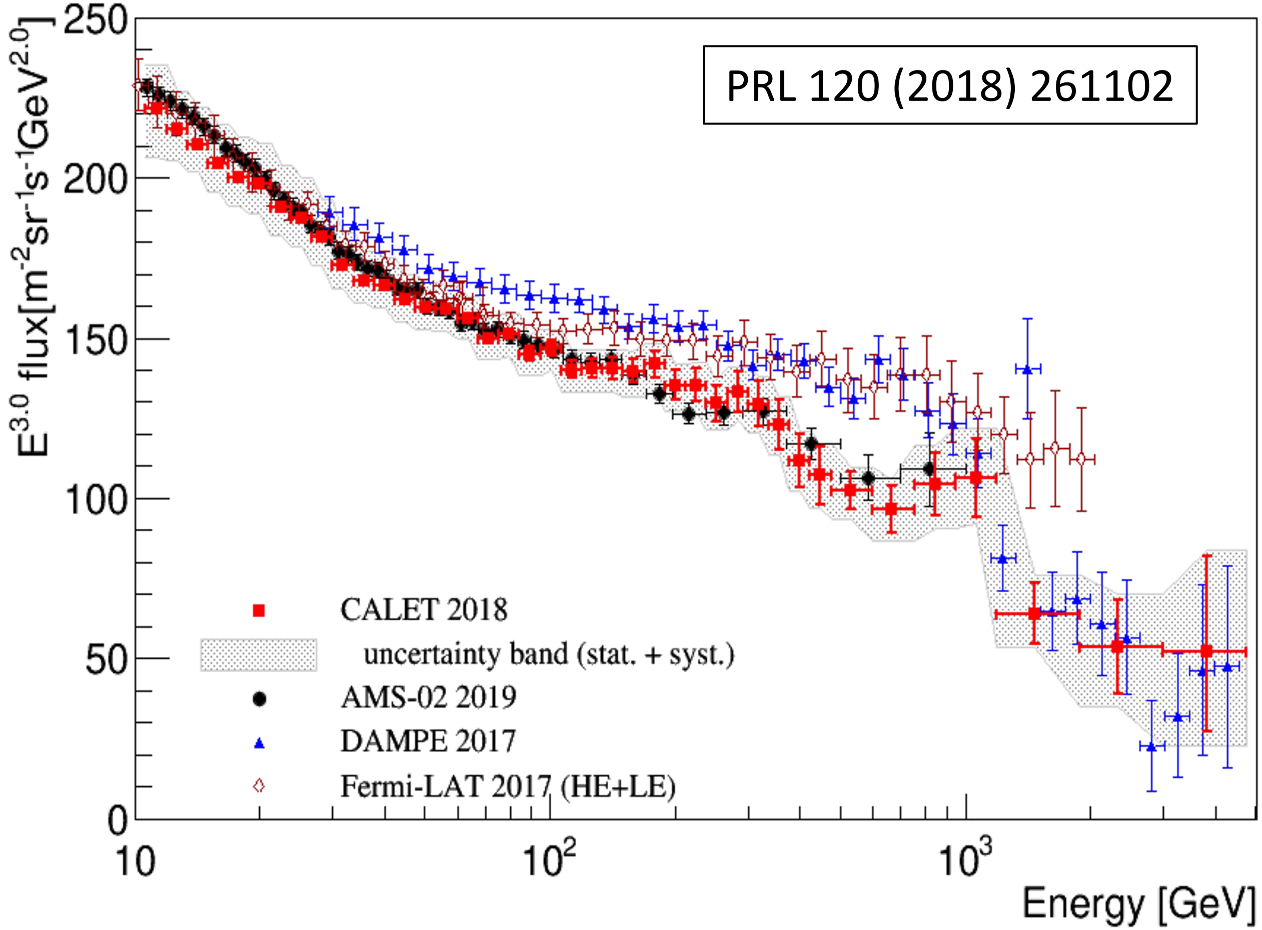
Energy independent sources;
- live time
- long-term stability
- track quality cut
- trigger efficiency (E<30GeV)

Electron spectrum

CALET Observations: Oct.13, 2015 – Nov. 30, 2017 (for 780 days)

The spectrum is especially updated in :

- Consistent with AMS-02 up to 1 TeV
- Observe flux suppression above 1 TeV consistent with DAMPE within errors



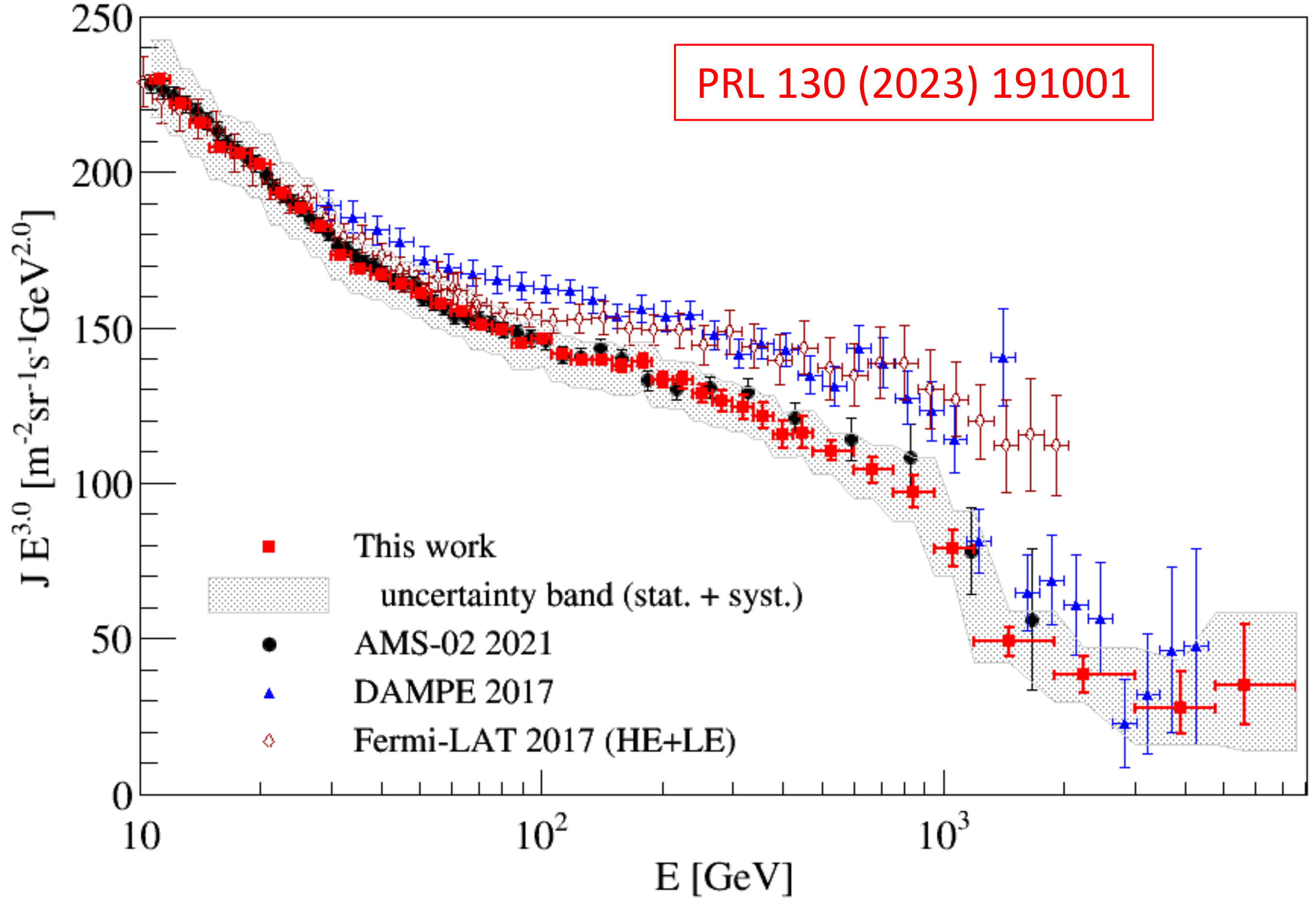
Electron spectrum

CALET Observations: Oct.13, 2015 – Dec. 31, 2022 (for 2637 days)

The spectrum is especially updated in :

statistics x3.4

- Consistent with AMS-02 up to 2 TeV
- Observe flux suppression above 1 TeV consistent with DAMPE within errors



Fitting to all-electron spectrum

- Fits of the CALET all-electron spectrum in 30 GeV – 4.8 TeV

- Broken power law

$$J(E) = C(E/100\ GeV)^{\gamma}(1+(E/E_b)^{\Delta\gamma/s})^{-s}$$

  γ = - 3.15 ± 0.01, Δγ = -0.77 ± 0.22
  Eb = 761 ± 115 GeV (χ^2 /NDF=3.6/27)

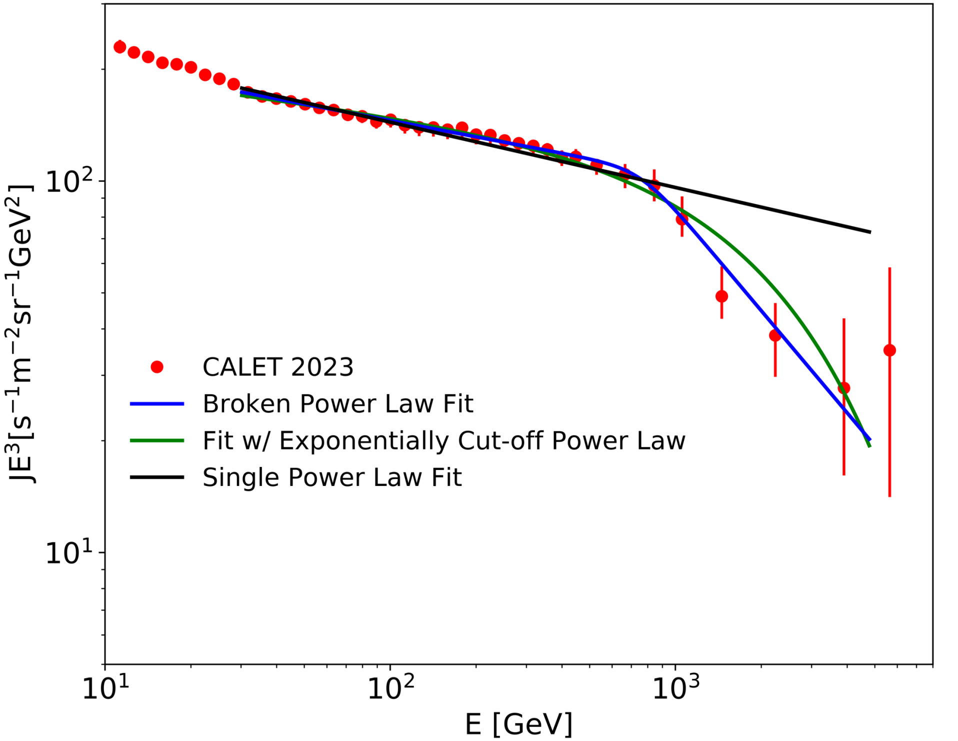
- Exponential cut-off power law [PRL, 2018]

  γ = - 3.10 ± 0.01
  Ec = 2.854± 0.305 TeV
  (χ^2 /NDF=12/28)

- Single power law

  γ = -3.18 ± 0.01 (χ^2 /NDF=56/29)

The significance of both fits of softening spectrum is more than 6 σ, which is considerably improved comparing to ~4 σ obtained in PRL2018.



Towards an interpretation of all-electron spectrum

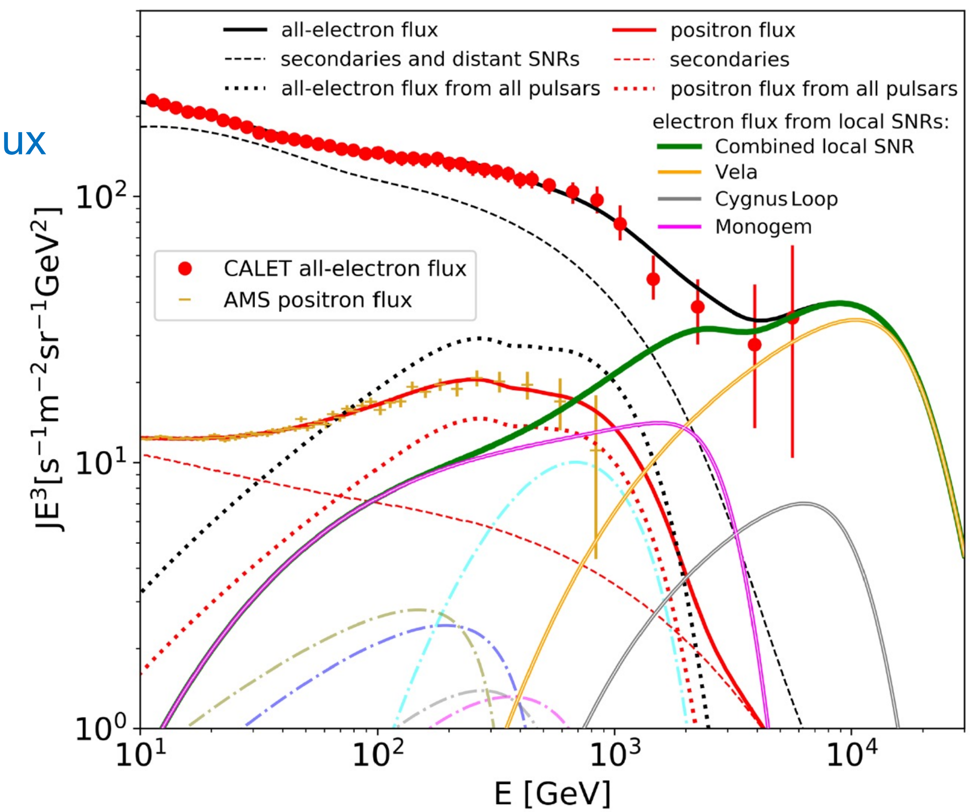
□ Possible spectral fit in whole energy region

- Positron contribution is fitted using AMS-02 flux with secondaries + pulsers

- CALET electron + positron flux is fitted with secondaries + pulsers + SNRs

- The best fit: 0.8 x 10^{48} erg in E>1TeV for nearby SNR.

- $\chi^2/NDF = 34/80$ with nearby SNRs
- $\chi^2/NDF = 32/80$ without nearby SNRs



The model fitting result predicts;

- 11.0 (4.2) events above 4.8 (7.5) TeV with nearby sources
- 4.6 (1.0) events above 4.8 (7.5) TeV without nearby sources

An excess 9 (4) events above 4.8 (7.5) TeV observed by the event-by event analysis

Summary

- Since the start of observation in October 2015, CALET has been accumulating the scientific data without any major interruption with stable instrument performance.

- The all-electron (e^++e^-) spectrum in the energy range from 10 GeV to 7.5 TeV observed by the end of Dec. 2022 is reported with statistics higher by a factor of 3.4 since the last publication in PRL2018

- The spectrum up to 2 TeV is well consistent with AMS-02.

- The results at high energies present suppression of the flux above 1 TeV with a considerable significance of more than 6σ over the single power law.

- Advanced analysis for electron candidates above 5 TeV is on going.

- Further observation until 2030 is expected to approved by JAXA, and we will improve the measurements with higher statistics and further reduction of the systematic errors, especially in the TeV region.