The cosmic-ray electron and positron spectrum measured with CALET on the International Space Station

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CALORIMETRIC ELECTRON TELESCOPE
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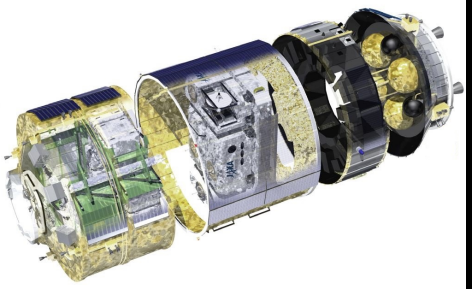
38th International Cosmic Ray Conference
The Astroparticle Physics Conference

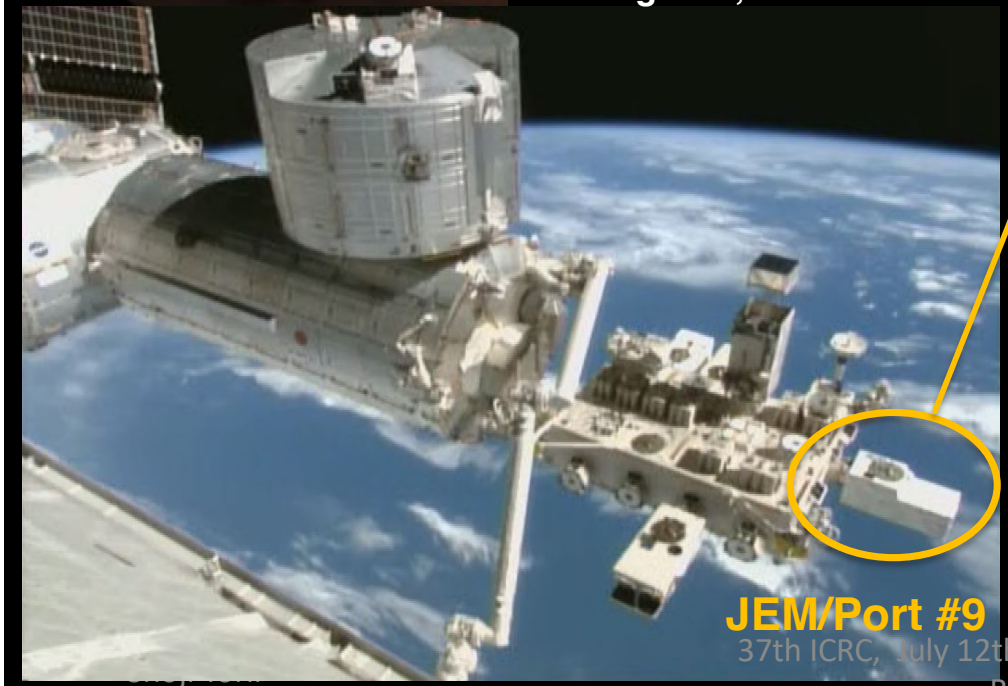
CALET Payload

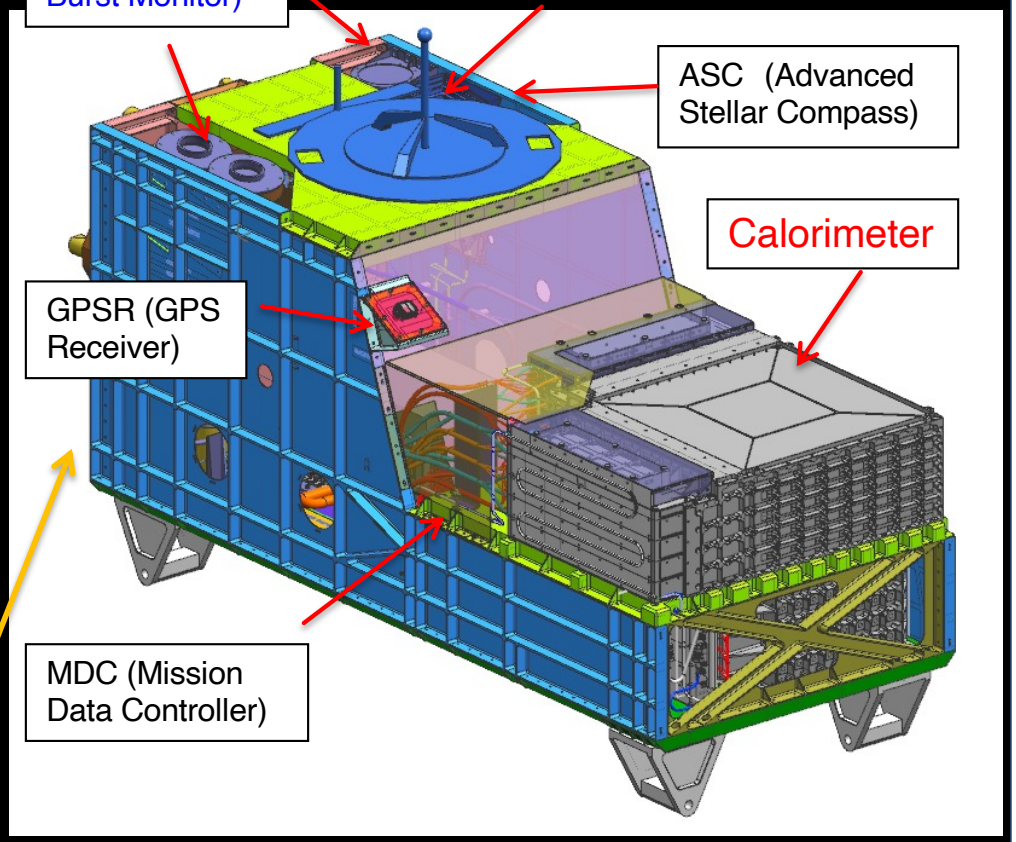
Kounotori (HTV) 5



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

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



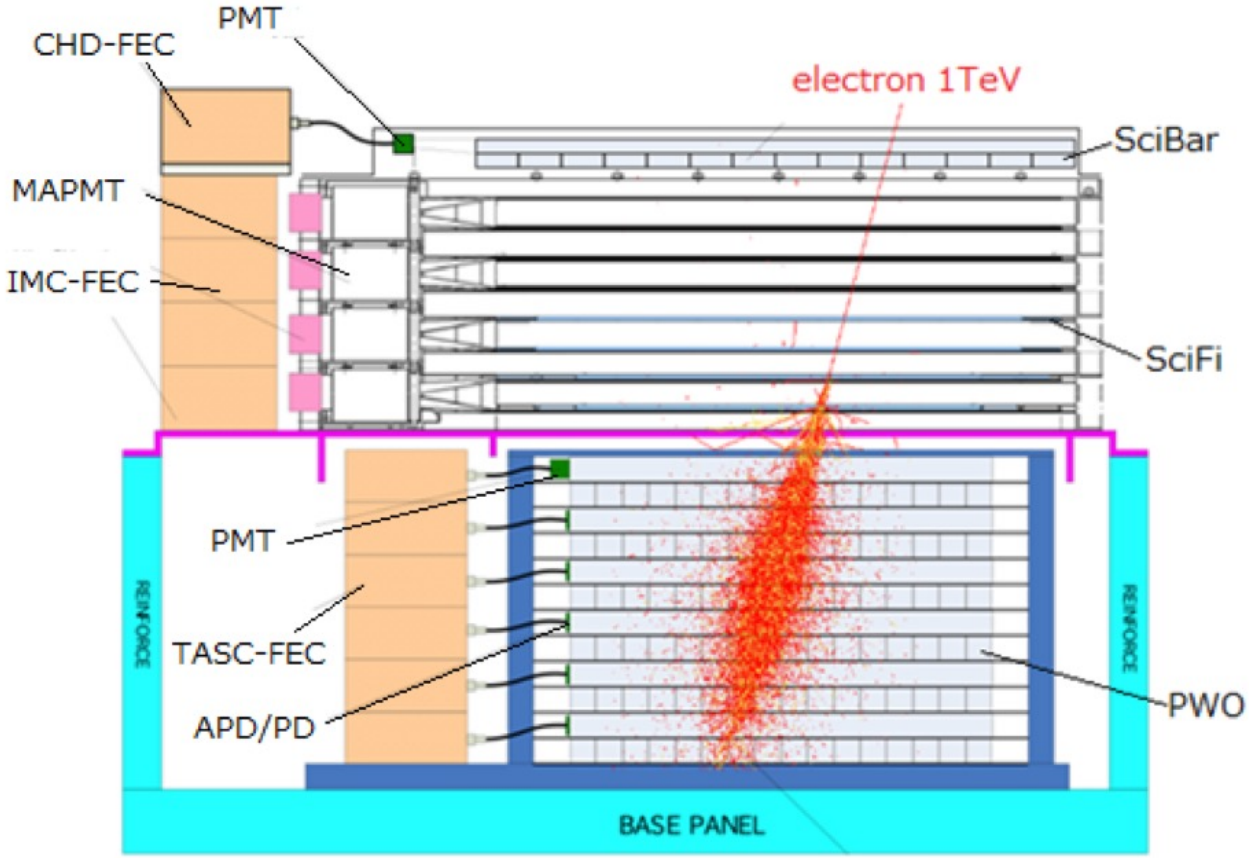


- **Mass: 612.8 kg**
- **JEM Standard Payload Size:**
  1850mm(L) × 800mm(W) × 1000mm(H)
- **Power Consumption: 507 W（max）**
- **Telemetry:**
  Medium 600 kbps (6.5GB/day) / Low 50 kbps

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

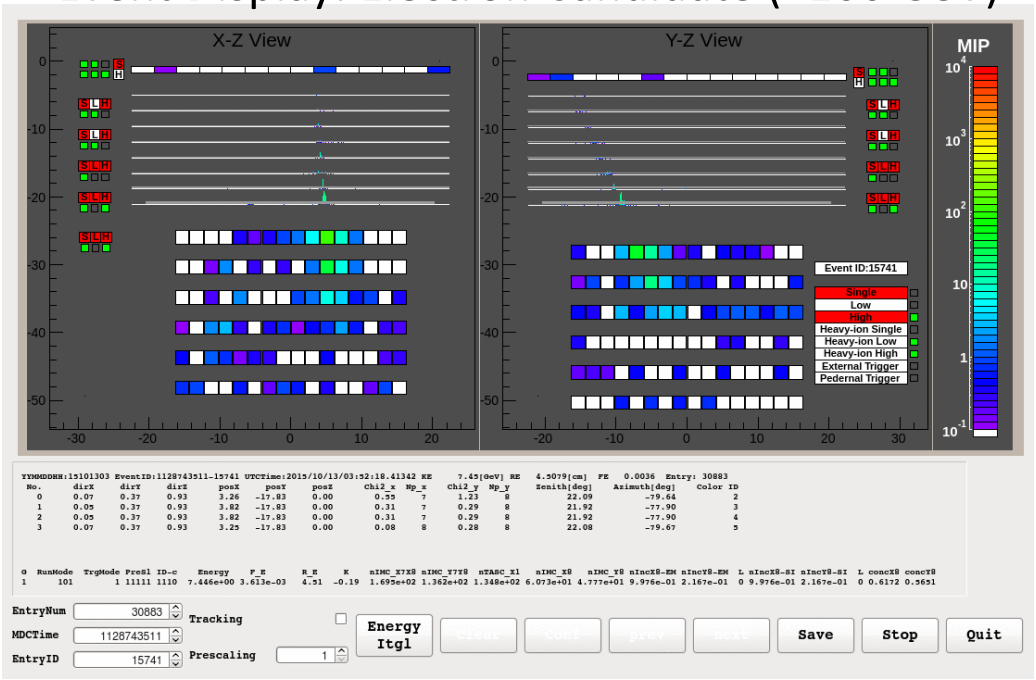
Energy measurement, Particle ID

- 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

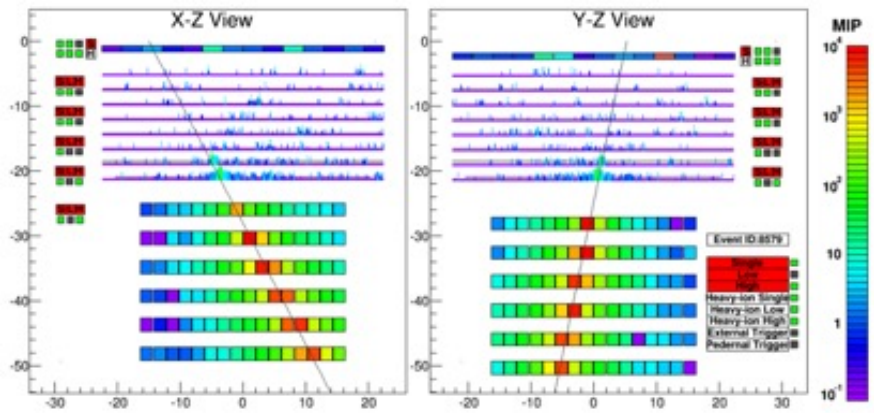
Field of view: ~45 degree (from the zenith)
Geometrical Factor: ~1040 cm^2sr for electrons

Examples of Event Display

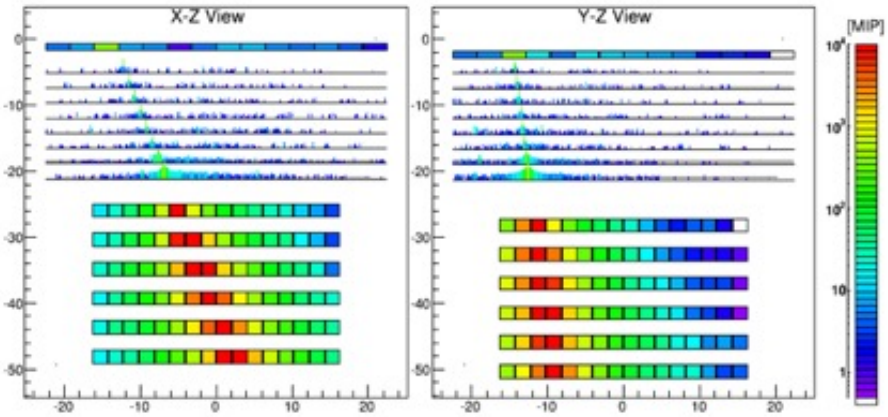
Event Display: Electron Candidate (>100 GeV)



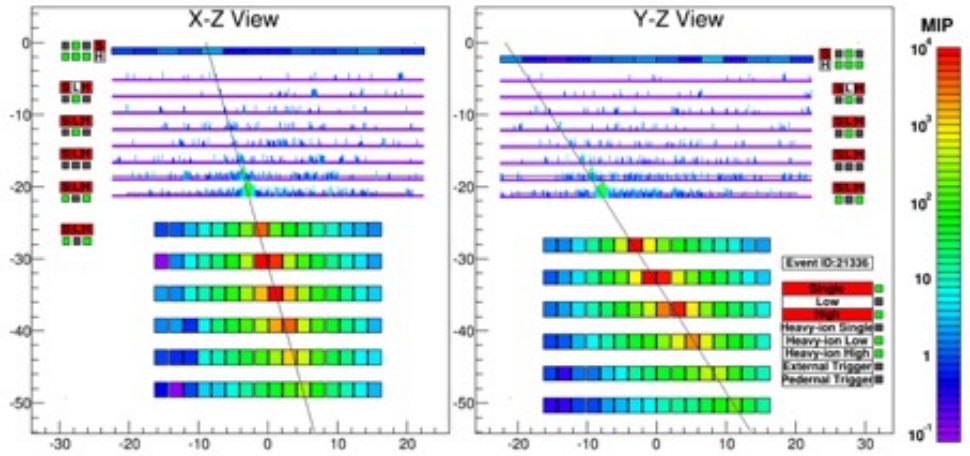
Proton, E_{TASC}=2.89 TeV



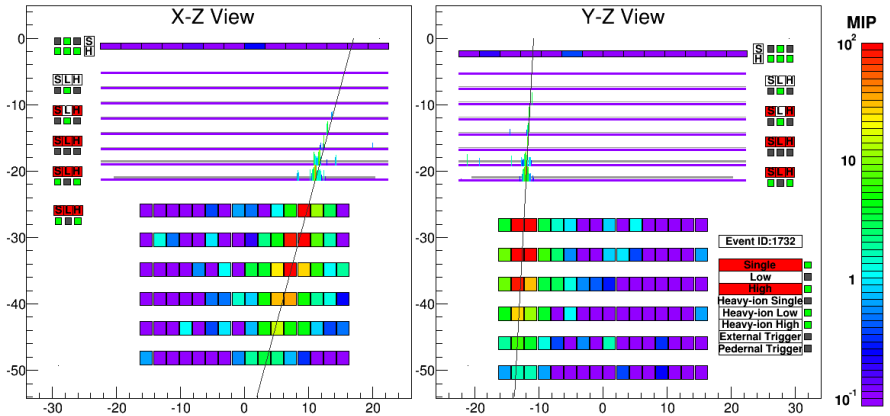
Fe, E_{TASC} =9.3 TeV



Electron, E=3.05 TeV

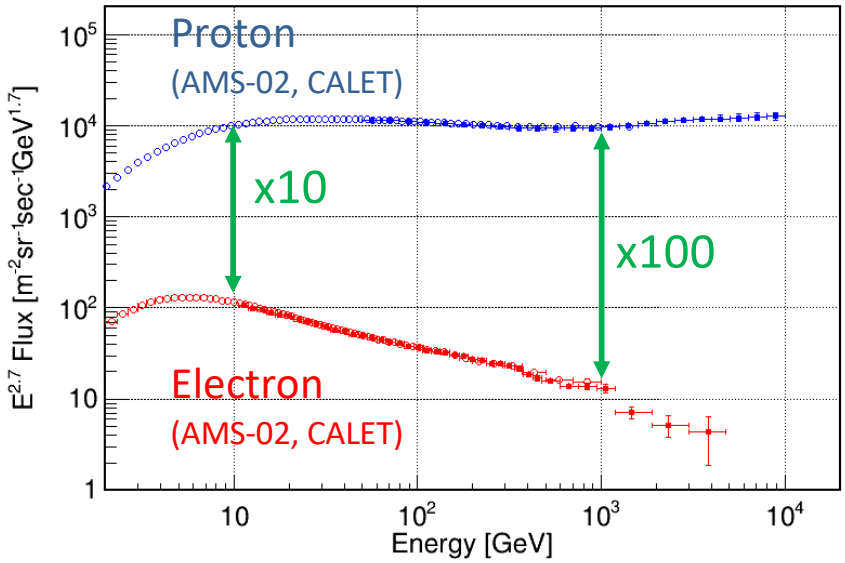


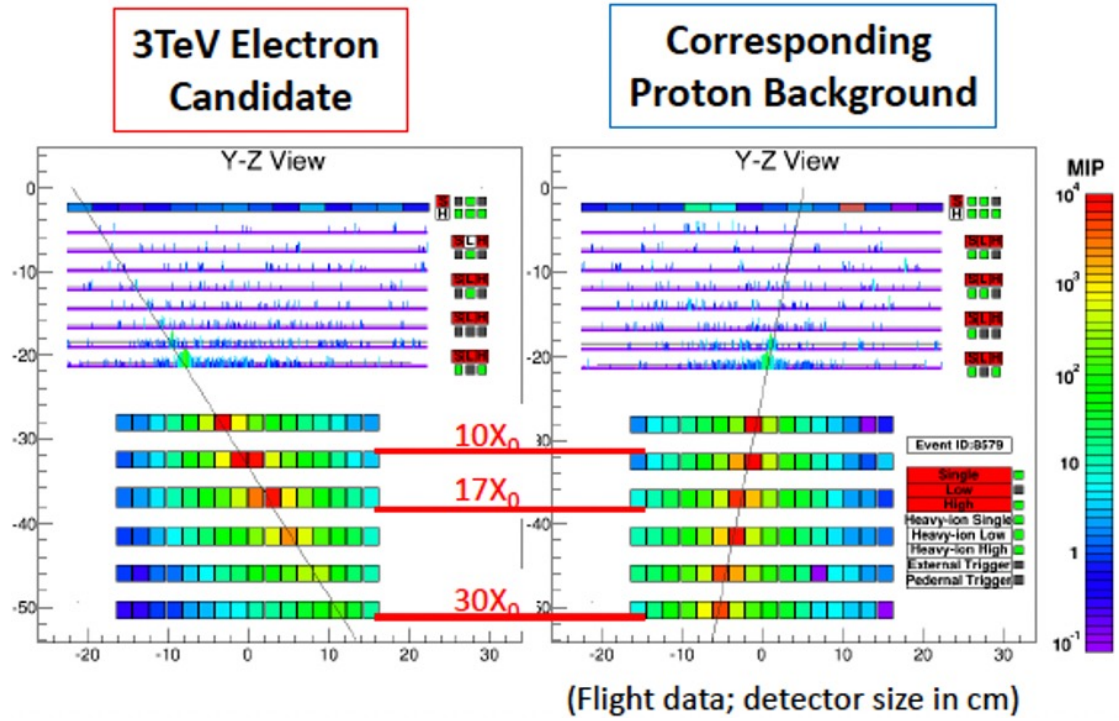
Gamma-ray, E=44.3 GeV



Electron Measurement with CALET

Proton rejection power is essential to investigate the TeV energy region





Features of CALET calorimeter:

1. Reliable tracking: well-developed shower core
2. Fine energy resolution: full contaminant 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

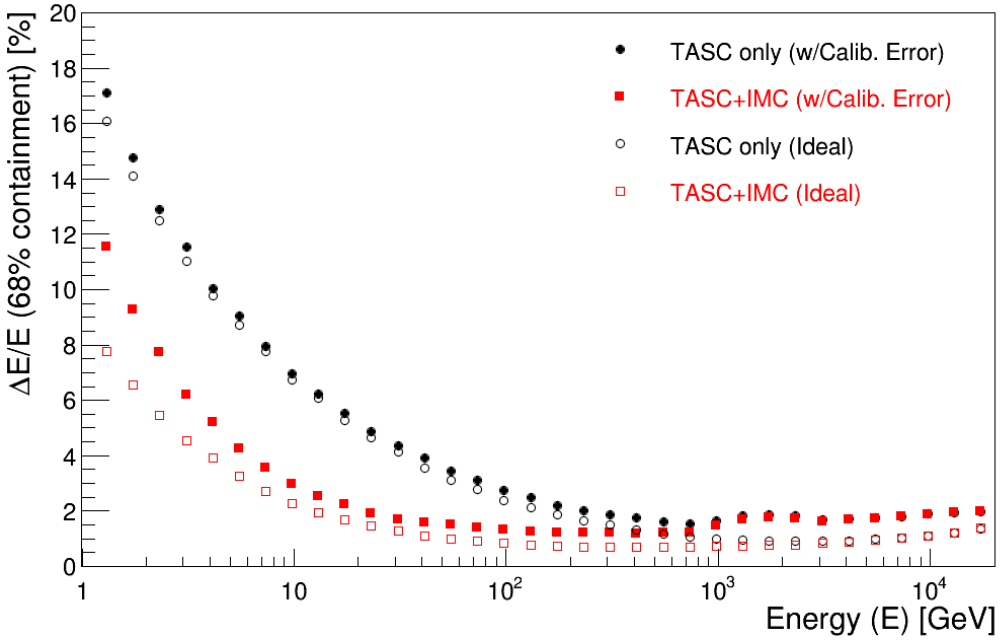
Energy calibration, resolution and energy scale

- Energy calibration in space have been done by the penetrate particle of osmic-ray protons and helium nuclei
- Very-wide range read out of energy deposited in TASC calibrated by a UV pulse laser on the ground

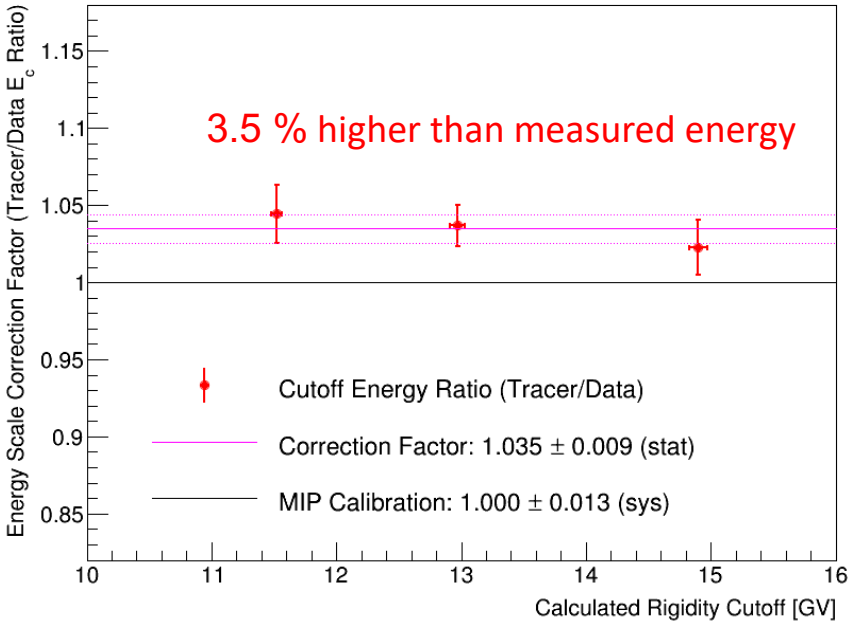
➡ The energy resolution of electrons is <2% above 20 GeV

- Absolute energy scale is calibrated by the study with the geomagnetic cutoff rigidity

Energy resolution including calibration errors



Absolute energy scale calibration by rigidity cutoff



Electron Identification

Simple Two Parameter Cut

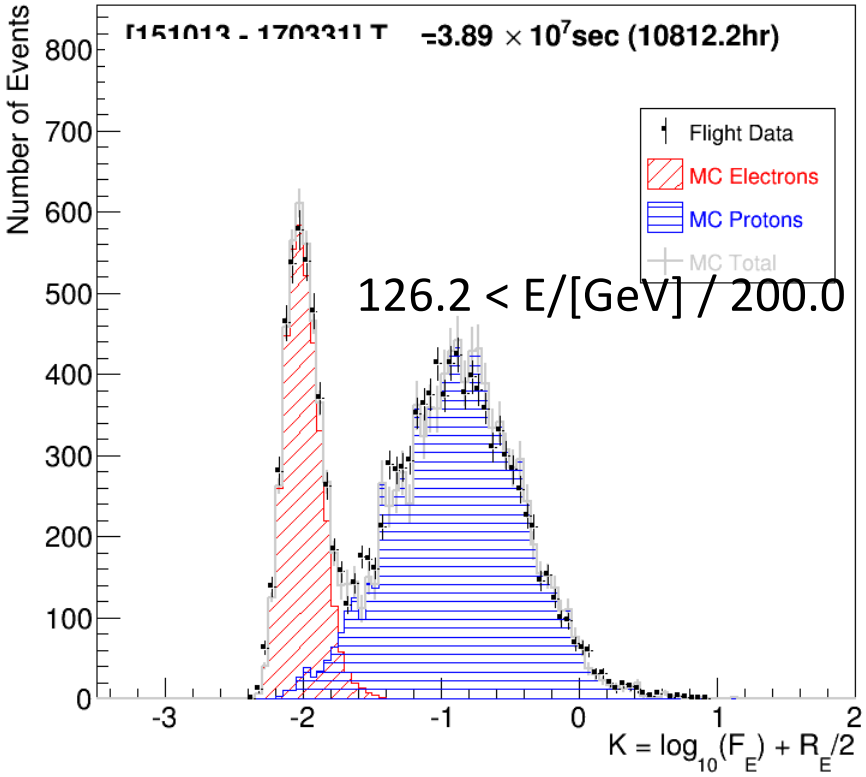
E<476GeV

$\mathbf{F_E}$: Energy fraction of the bottom layer sum to the whole energy deposit sum in TASC

$\mathbf{R_E}$: Lateral spread of energy deposit in TASC-X1

Cut Parameter K is defined as follows:

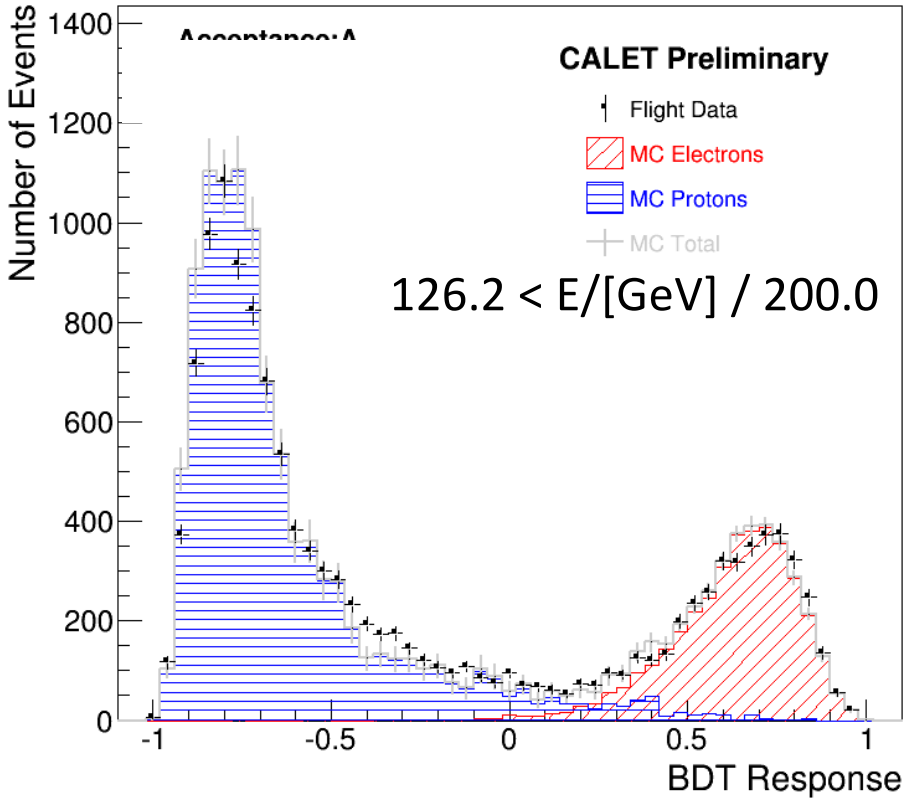
$$\mathbf{K = \log_{10}(F_E) + 0.5\ R_E\ (/cm)}$$



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. **χ²/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. **χ²/NDF**

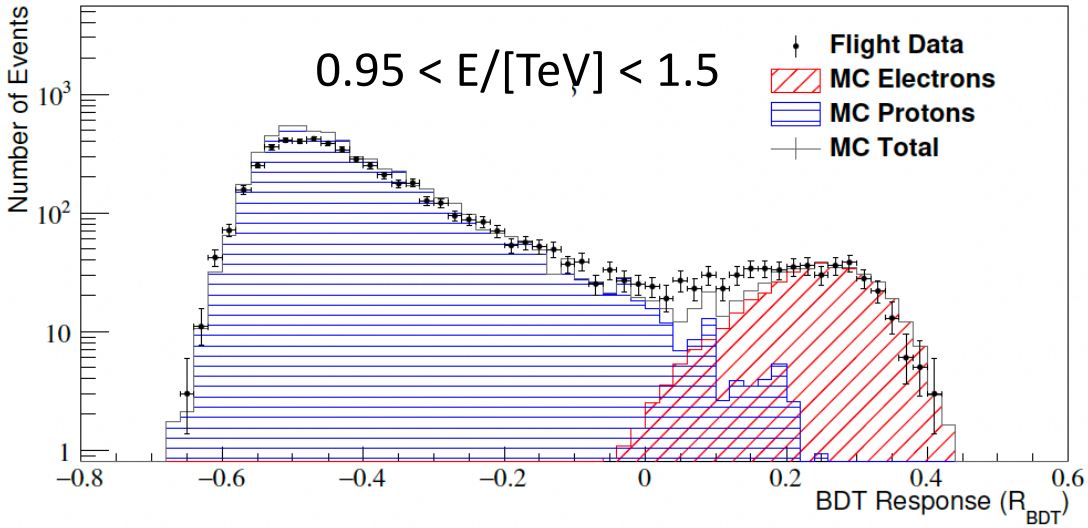
$$\frac{dE}{dt} = e^{(p_1 t + p_0)}$$

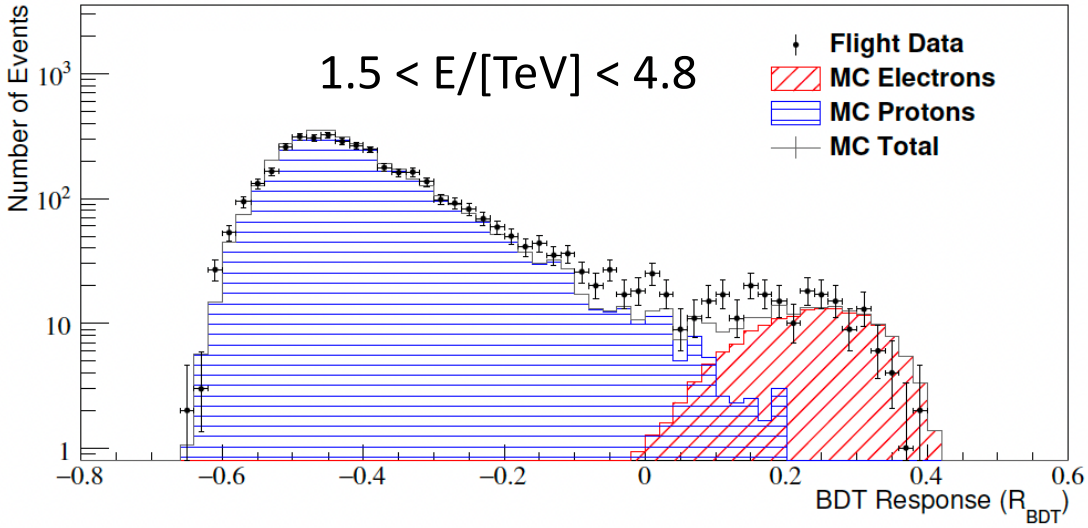
11. *The sum of CHD energy deposit : S_{CHD}

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

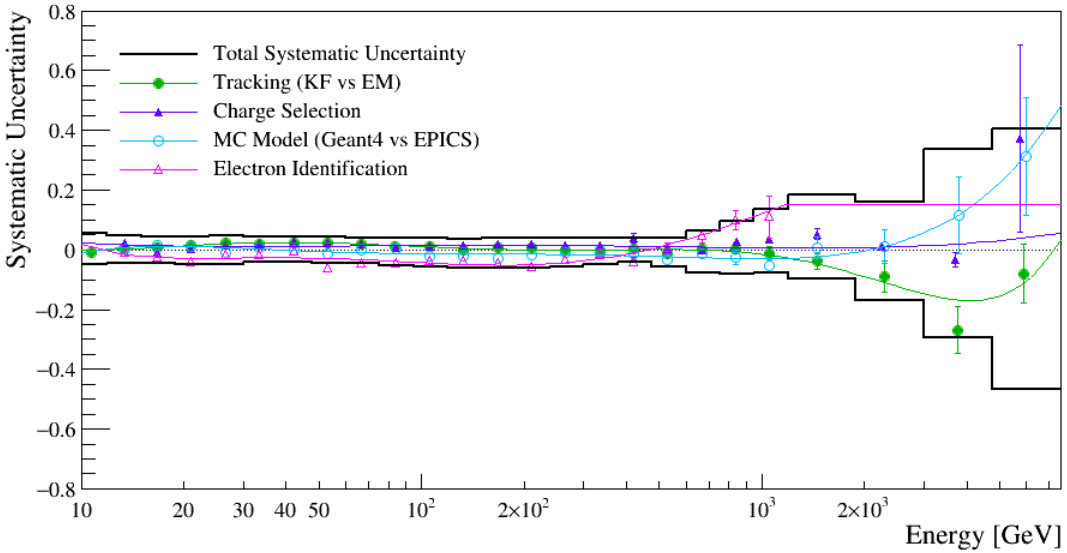
* New parameters

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

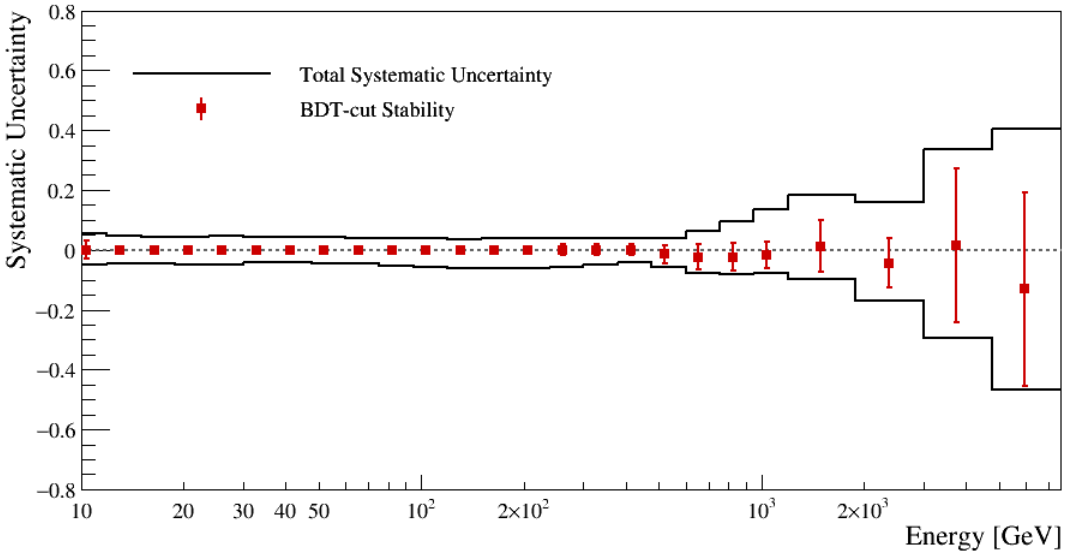




Systematic uncertainties



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



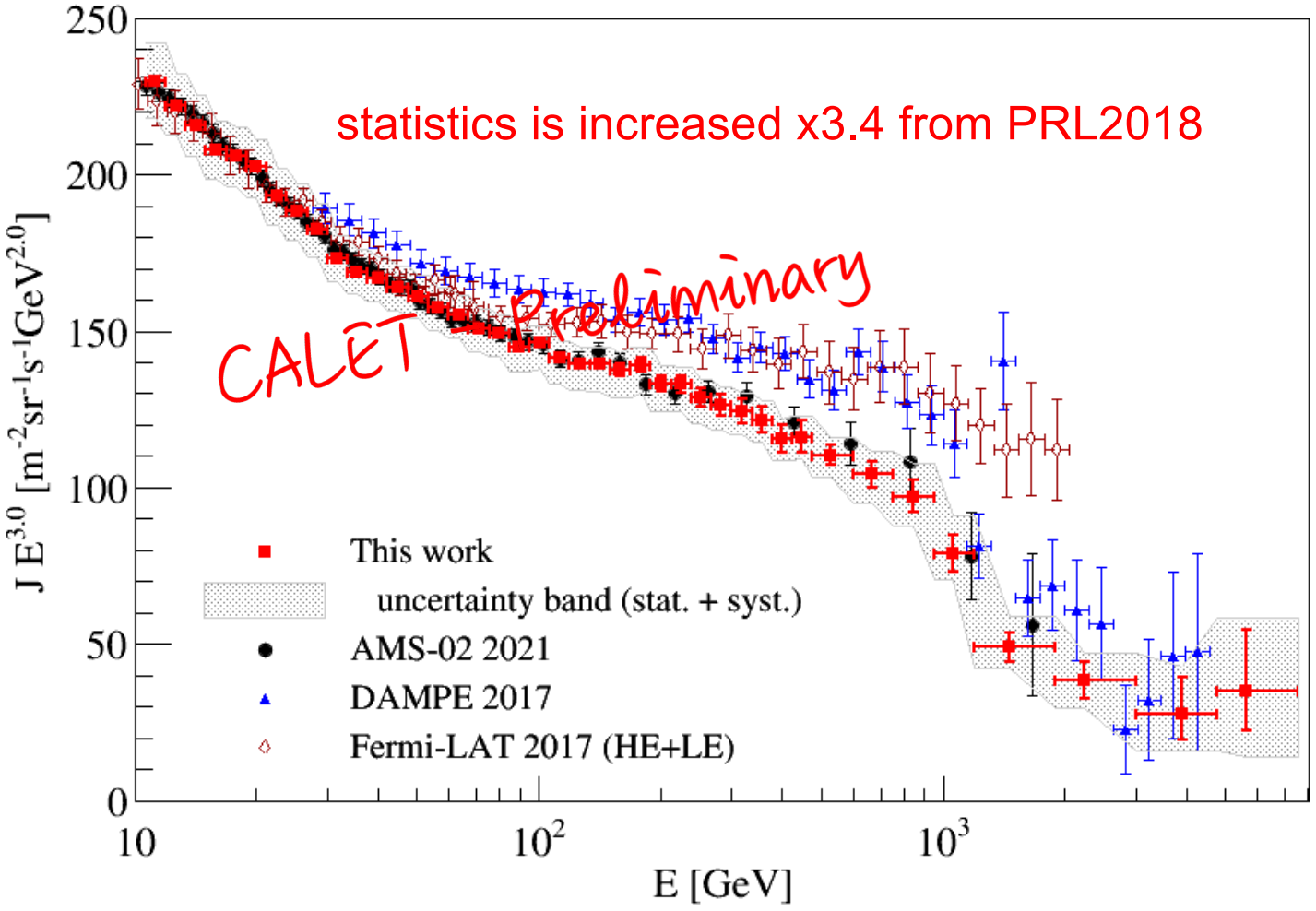
Energy in dependent sources;
- live time
- long-term stability
- track quality cut

Energy spectrum of all-electrons

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

Preliminary spectrum is especially updated in :

- 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

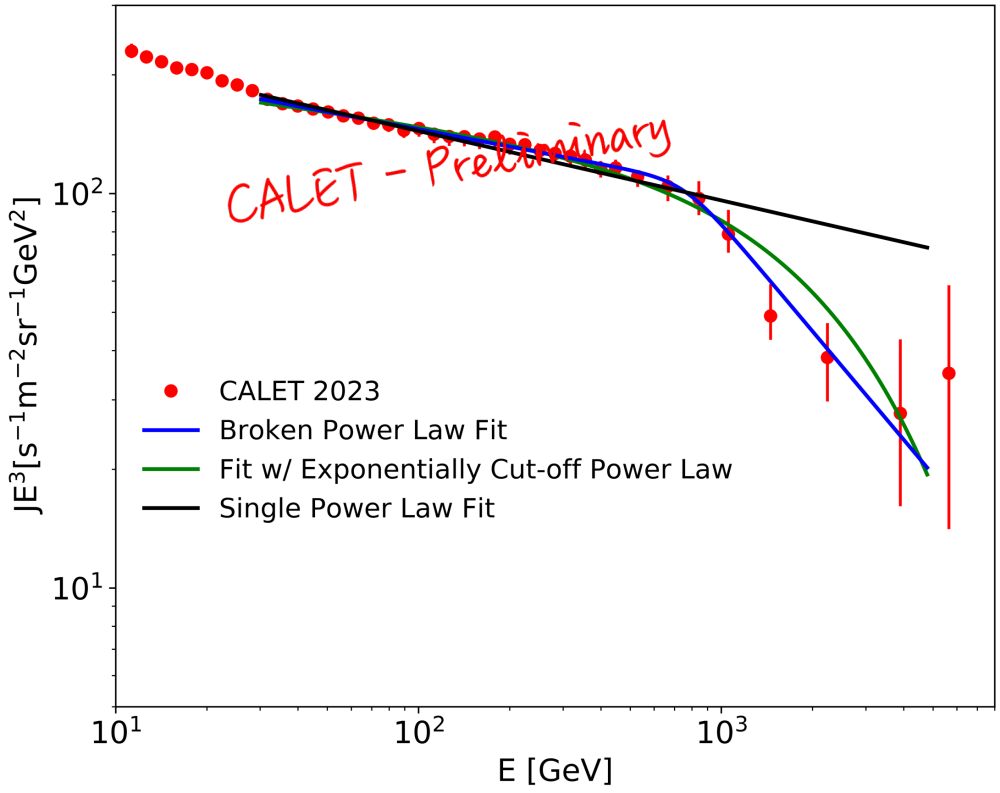
$$J(E) = C(E/100\ GeV)^{\gamma}(1+(E/E_b)^{\Delta\gamma/s})^{-s}$$

  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.



Summary

- CALET was successfully launched on August 19th, 2015, and is successfully carrying out observations 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 below 2 TeV is consistent with AMS-02 and is well.
- 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.
  (see Poster PCRD3-06)
- Further observation until Dec. 2024 (at least) are approved by JAXA, and we will improve the measurements with higher statistics and further reduction of the systematic errors, especially in the TeV region.