Precise Measurement of the Cosmic-Ray Electron and Positron Spectrum with CALET on the International Space Station

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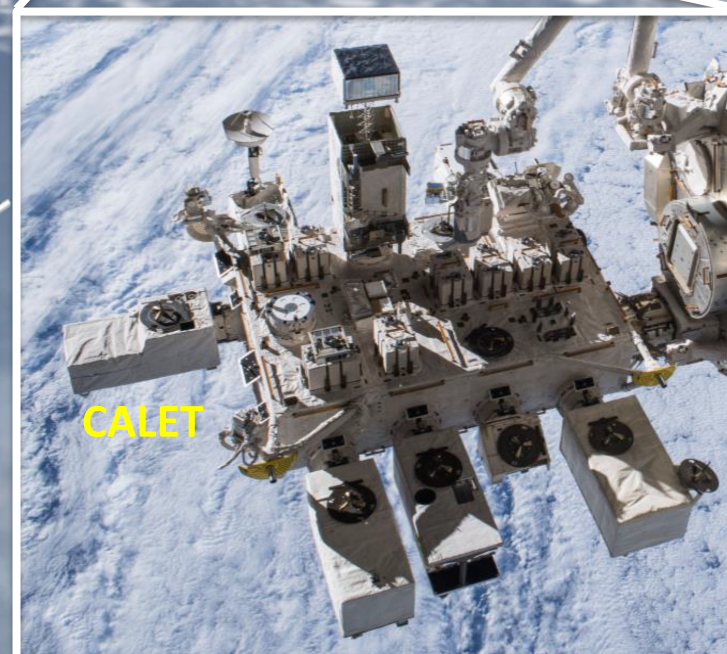
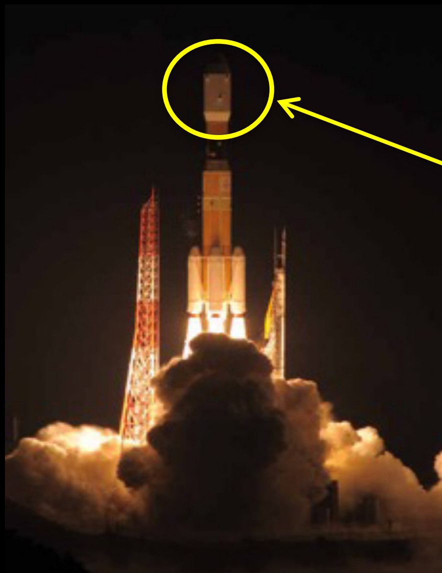
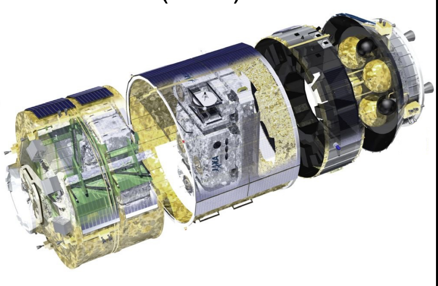


CALET Payload

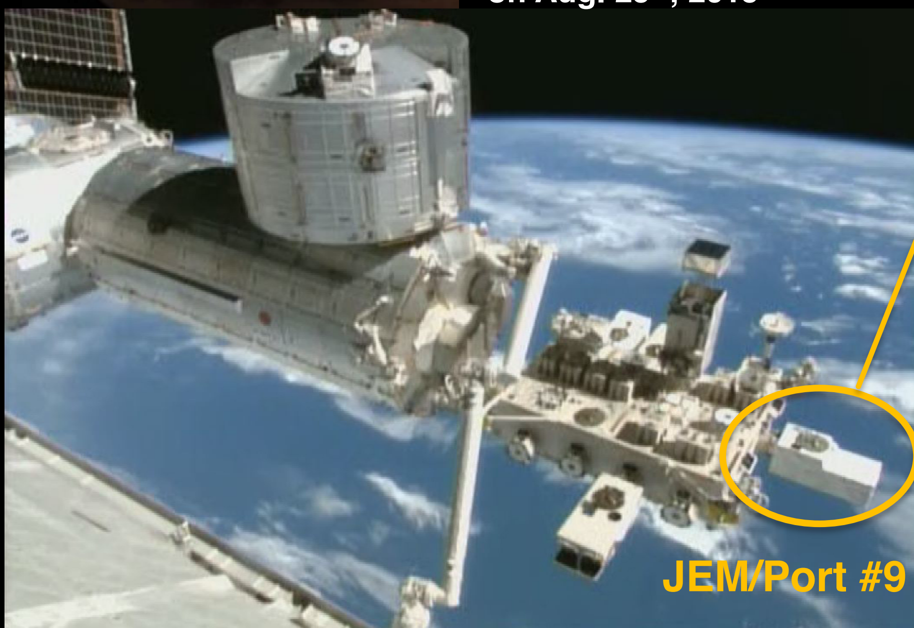


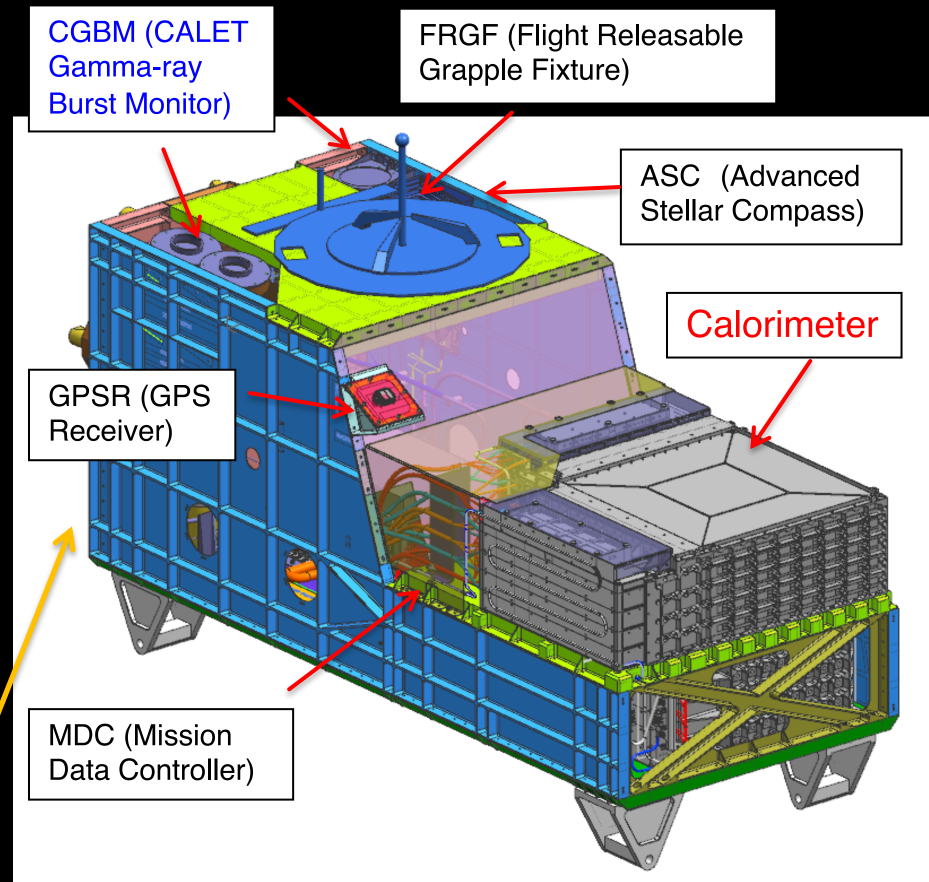
Kounotori (HTV) 5



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

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

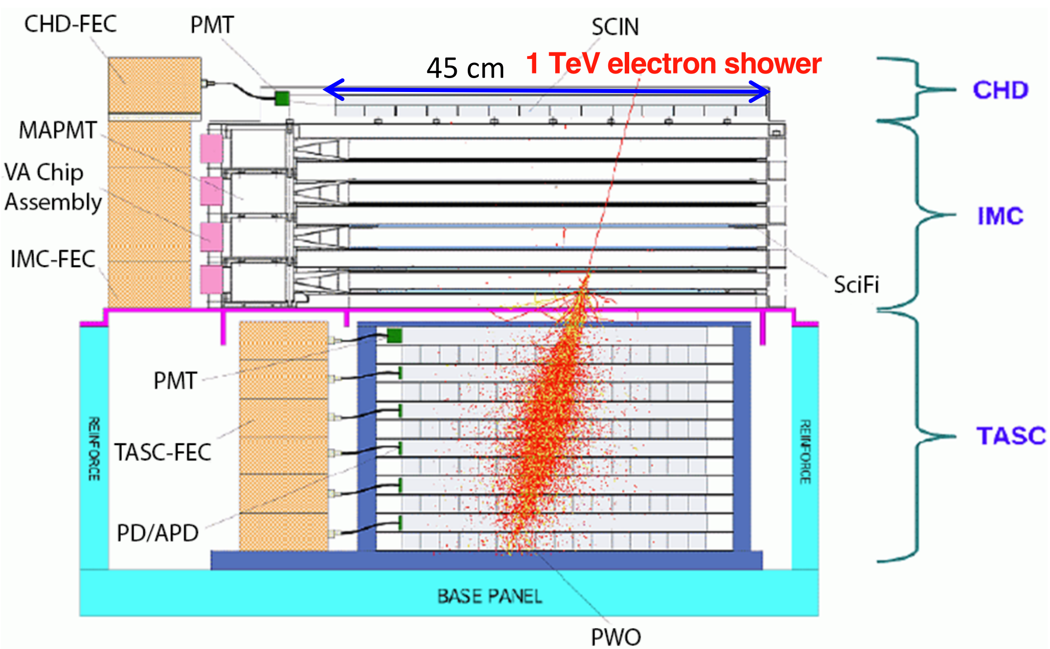




- **Mass: 612.8 kg**
- **JEM Standard Payload Size:**
  1850mm(L) × 800mm(W) × 1000mm(H)
- **Power Consumption: 507 W (max)**
- **Telemetry:**
  Medium 600 kbps (6.5GB/day) / Low 50 kbps

CALET Capability

Field of view: ~ 45 degrees (from the zenith)
Geometrical Factor: ~ 1,040 cm^2sr (for electrons)



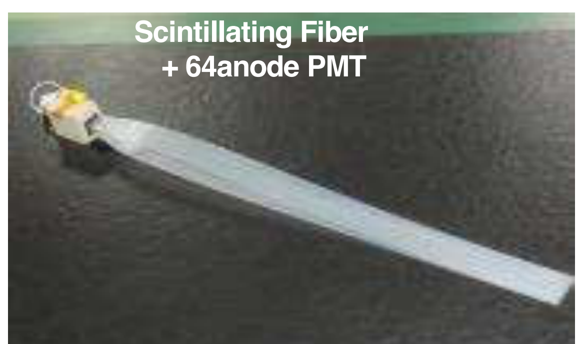
CHD – Charge Detector
- 2(X,Y) x 14 plastic scintillating paddles
- Charge measurement Z = 0 → 40+
- Charge resolution ΔZ= 0.15 - 0.3

IMC – Imaging Calorimeter
- 8 x 2(X,Y) x 448 plastic scintillating fibers
- 7 tungsten sheets
- 3 X_0 at normal incidence
- Tracking ($\Delta\theta$ ~0.1 degree) +Shower imaging

TASC – Total Absorption Calorimeter
- 6 x 2(X,Y) x 16 lead tungstate ($PbWO_4$) logs
- 27 X_0 at normal incidence
- Energy resolution:~2% (>10GeV) for e,γ
- e/p separation: ~10^5

CHD Paddle Size: 32 x 10 x 450 mm^3

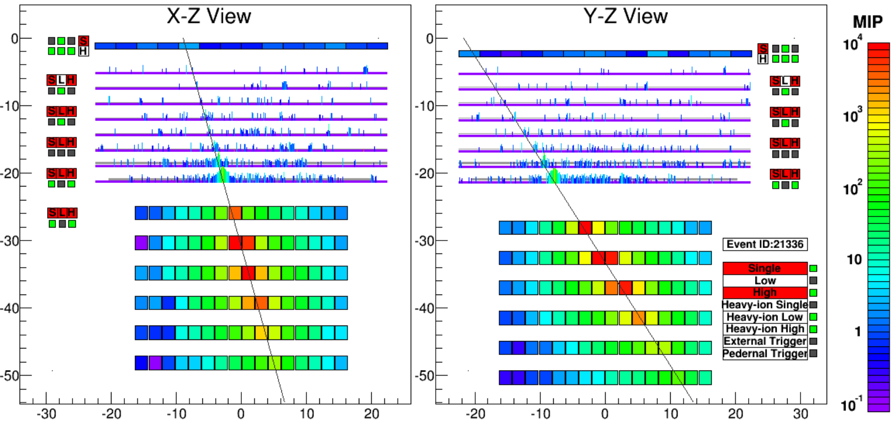
IMC Scifi size : 1 x 1 x 448 mm^3



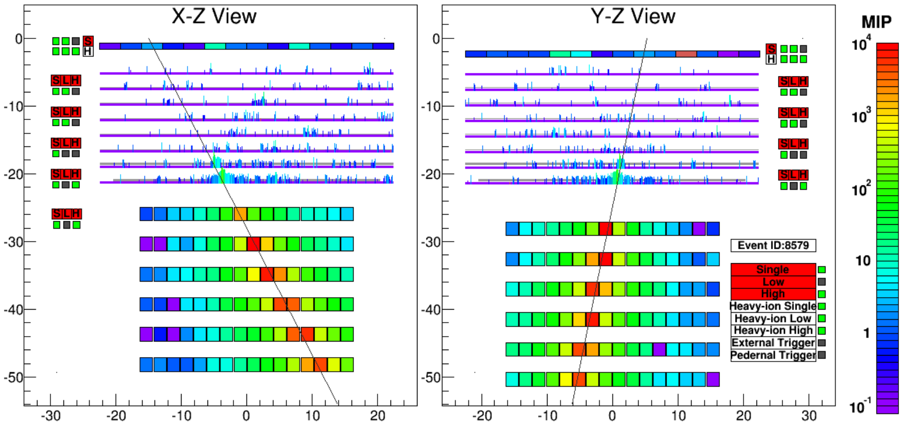
TASC Log size: 19 x 20 x 326 mm^3

Examples of Event Display

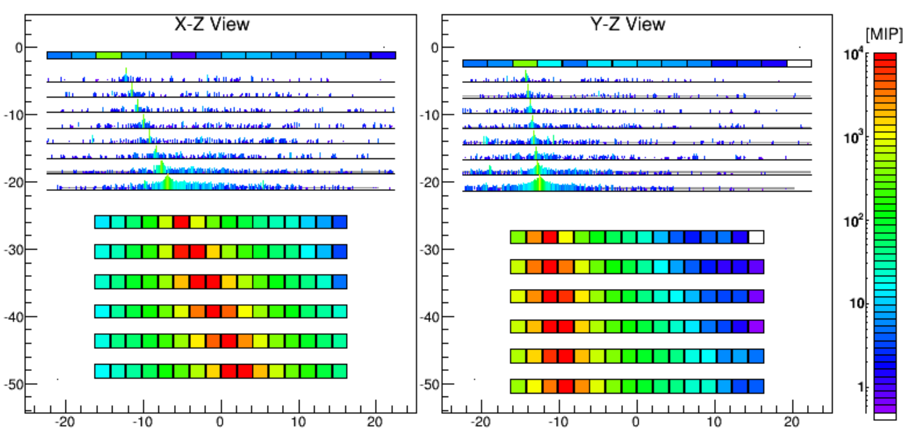
Electron, E=3.05 TeV



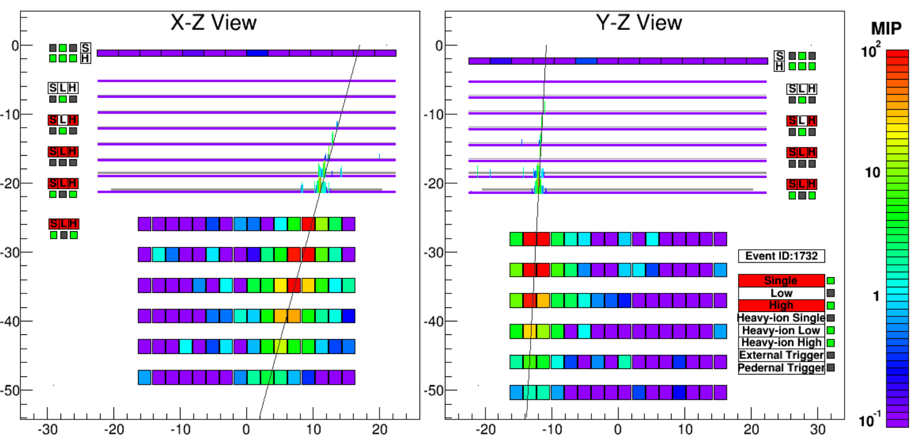
Proton, ΔE=2.89 TeV



Fe, ΔE=9.3 TeV



Gamma-ray, E=44.3 GeV



Unit in MIP

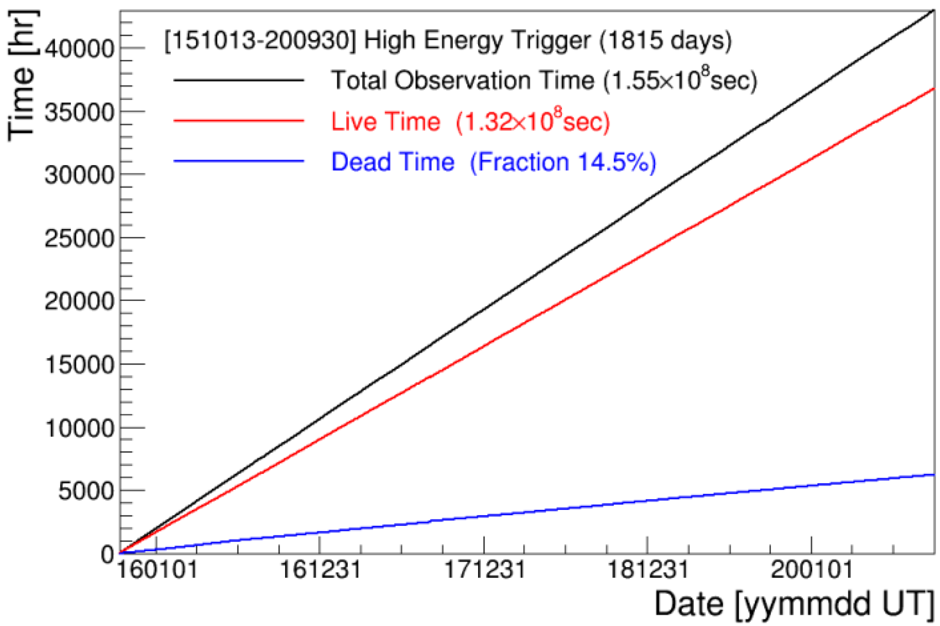
Electron Measurement with CALET: Accurate measurements constrain systematics

1. Acceptance - Geometrical factor	➡	well defined SΩ because of reliable tracking
2. Detection efficiency - Losses in the detector	➡	$\varepsilon \sim 70$ % (after electron selection, E>30 GeV) keeps mostly constant up to 5 TeV
3. Energy determination - Energy resolution - Calibration	➡	$\Delta E/E < 2\%$ (E>20 GeV) Absolute energy scale calibrated by beam tests and rigidity cutoff
4. Particle Identification - Proton contamination	➡	$P_{BG} < 5$ % (E<1 TeV) $P_{BG} \sim 10\text{-}20$ % (1 TeV<E< 5 TeV)

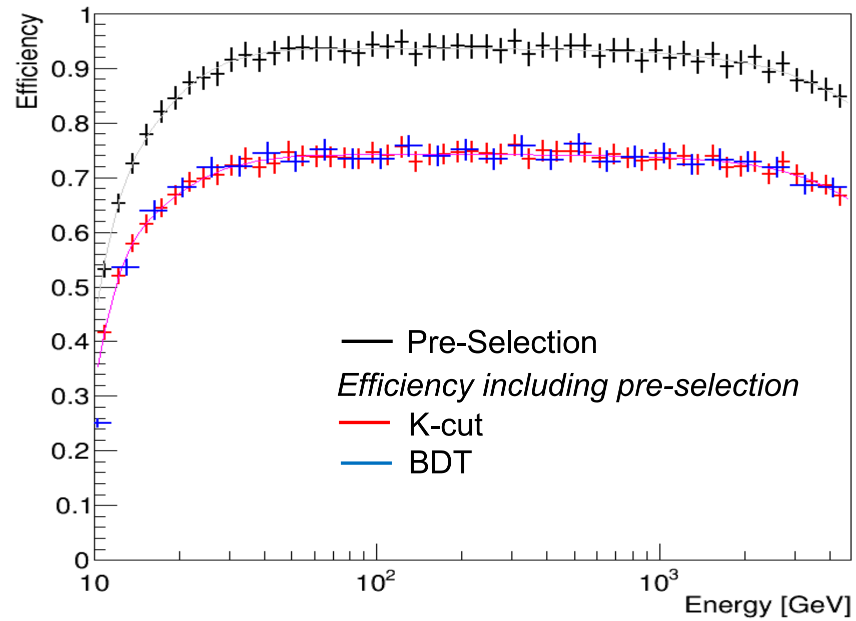
➡ **Minimize the effects of unforeseen systematics,**
combined with detailed systematic studies (see PRLs and SM)

High-quality observations and Detection efficiency

Observation time
by high-energy (>10GeV) trigger



Energy vs. Efficiency by event selection
10 GeV - 5TeV



Very stable operations more than 5 years (at present)

- Loss of the observation time due to accidents : < 1%
- Live time fraction : ~85 %
- Exposure of HE trigger for electrons : ∼160 m^2sr day (in this report)

- Detection efficiency after cut of electron selection is mostly constant (ε ~ 70 %) in 30 GeV - 5 TeV.
- The efficiency below 30 GeV decreases due to the threshold energy (> 10 GeV) although it is very well controlled by confirmation using lower threshold observations (> 1GeV).

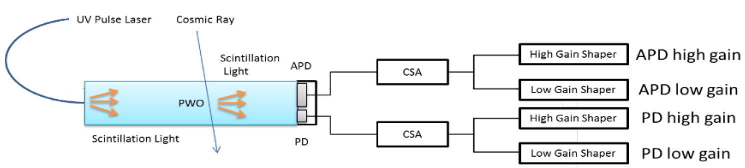
Energy Determination: Resolution and Calibration

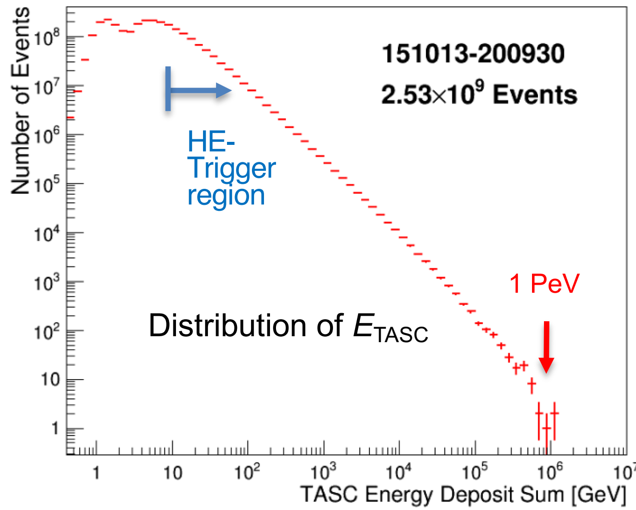
- Very-wide range readout of energy deposited in TASC calibrated by a UV pulse laser on the ground

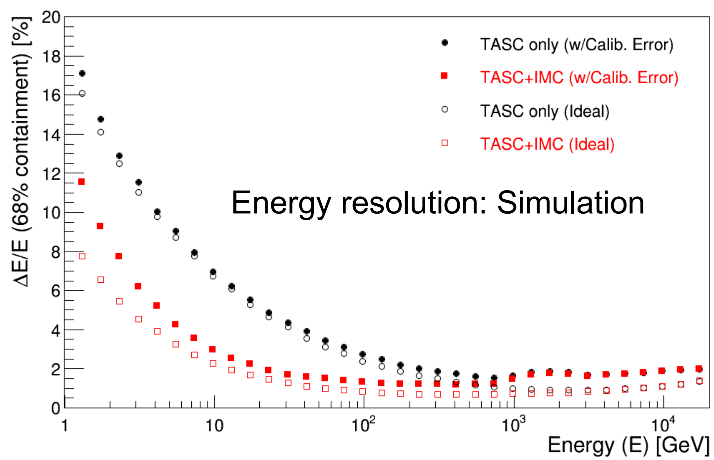
- Observed distribution of the energy deposited in TASC: Linearity of readout signals is kept up to 1 PeV

- Simulated energy dependence of the energy resolution: < 2 % above 20 GeV for energy measurements using both TASC and IMC including the calibration errors, presented by red dots

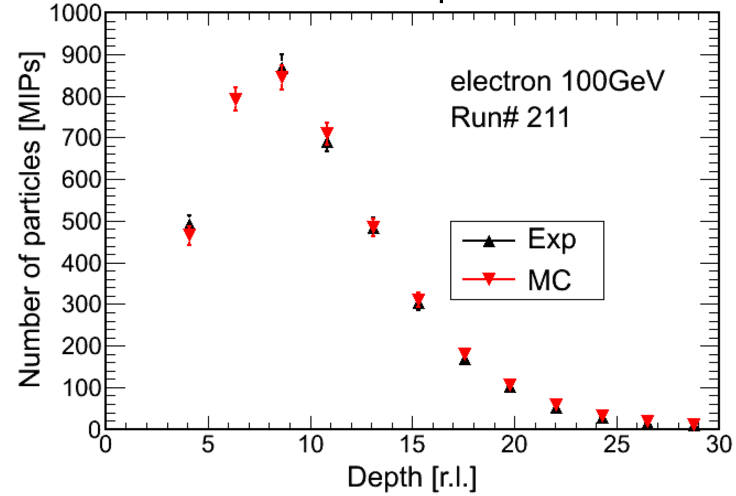
Four readout signals of PWO calibrated by UV laser



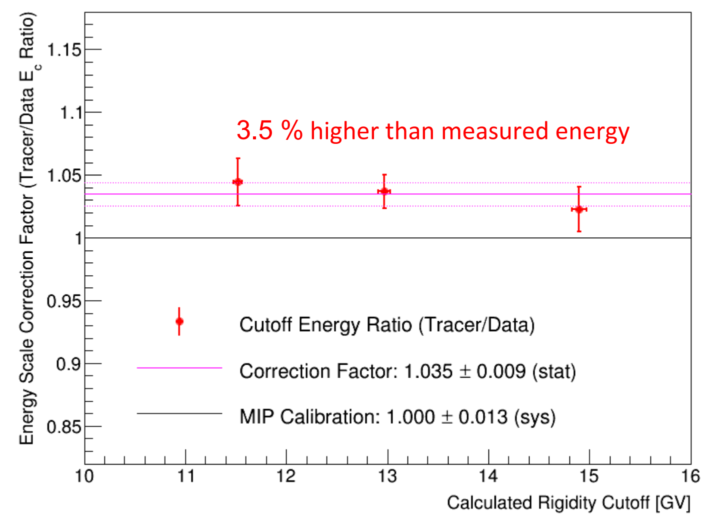




Example of beam test results of shower development in TASC



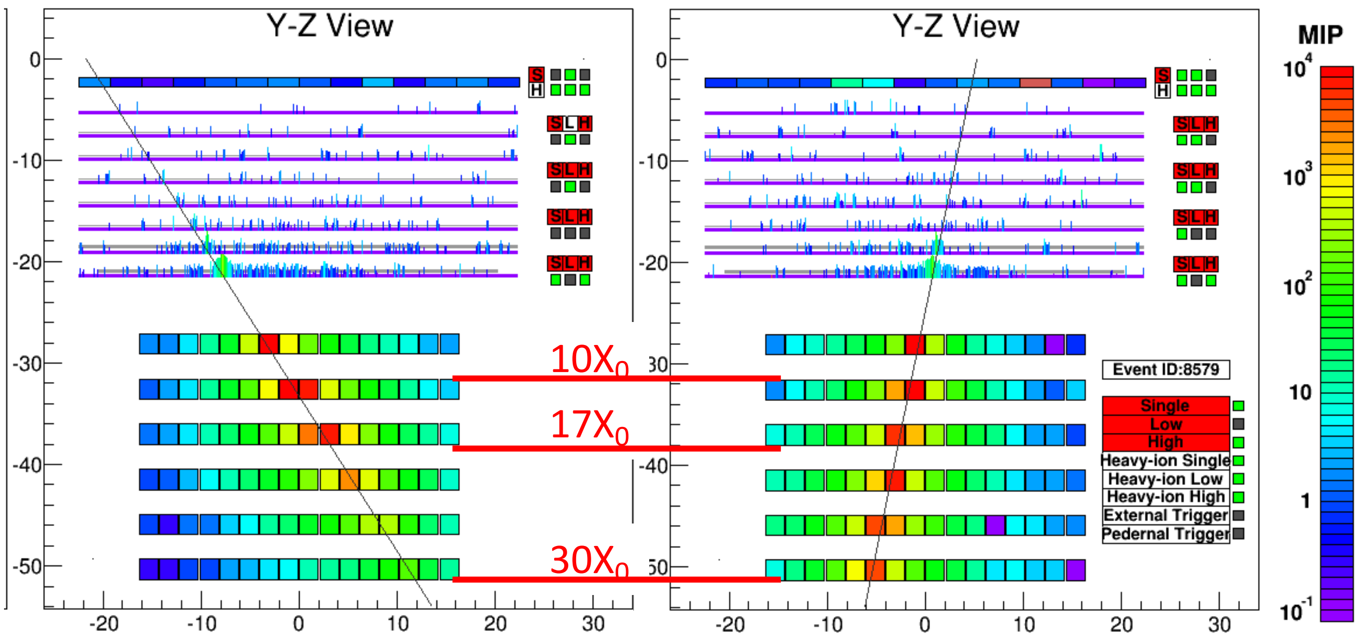
Absolute energy scale calibration by rigidity cutoff



Particle Identification

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.

Electron Identification

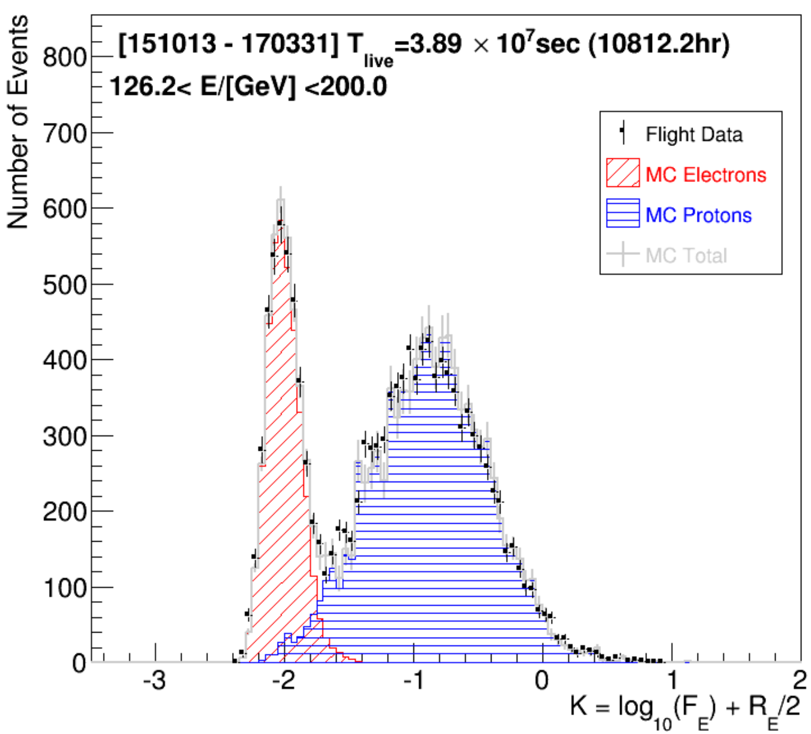
Simple Two Parameter Cut

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

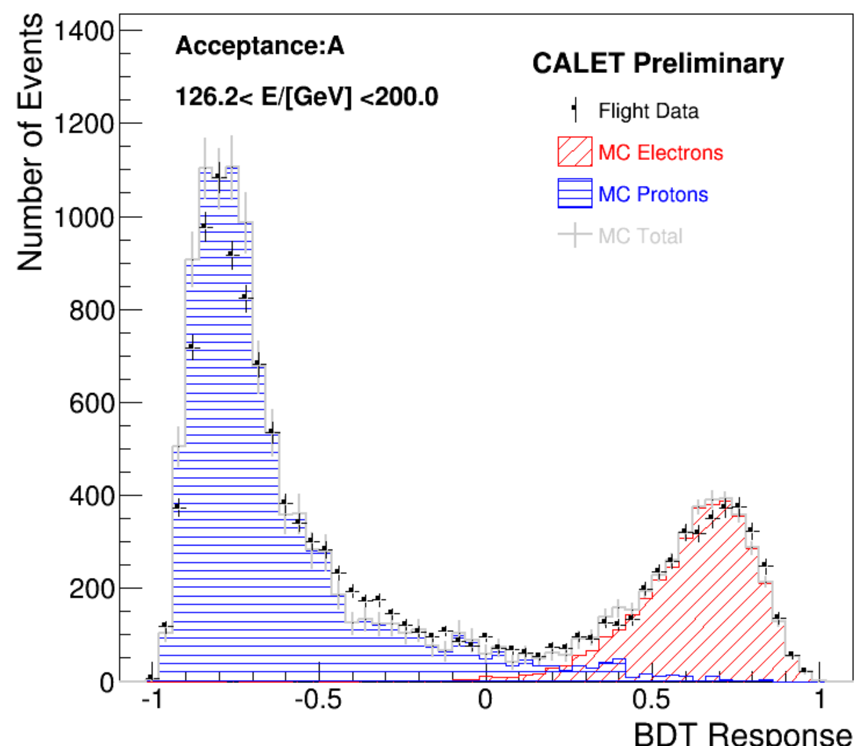
Cut Parameter K is defined as follows:

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



Boosted Decision Trees (BDT)

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



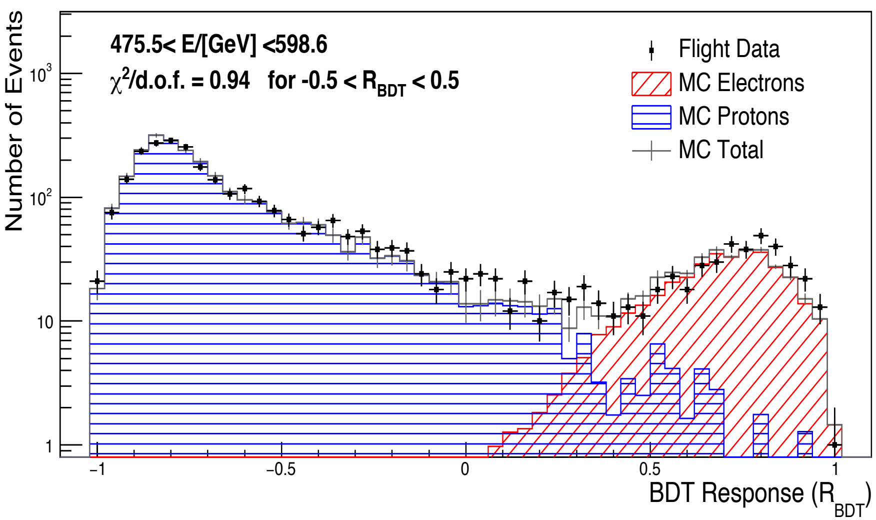
BDT Response Distribution at Higher Energies: New

In the final electron sample, the resultant contamination ratios of protons are:

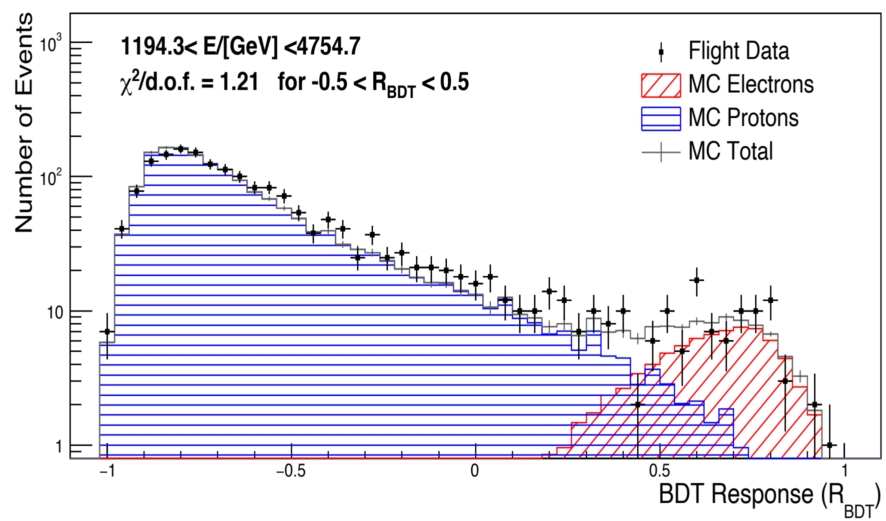
< 5 % up to 1 TeV ; 5 % - 20 % in the 1 – 5 TeV region

, while keeping a constant high efficiency of 80 % for electrons.

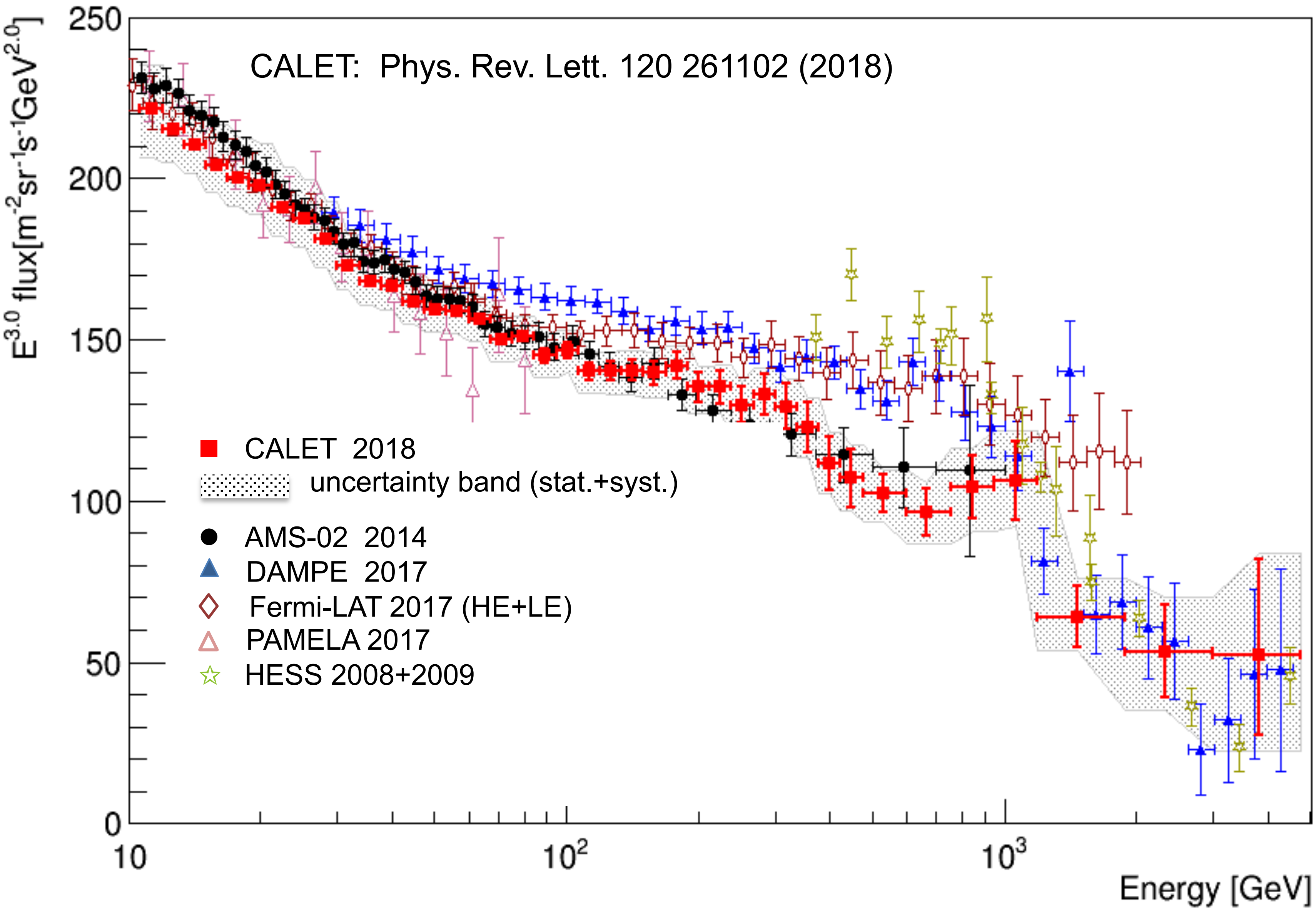
476 < E < 599 GeV



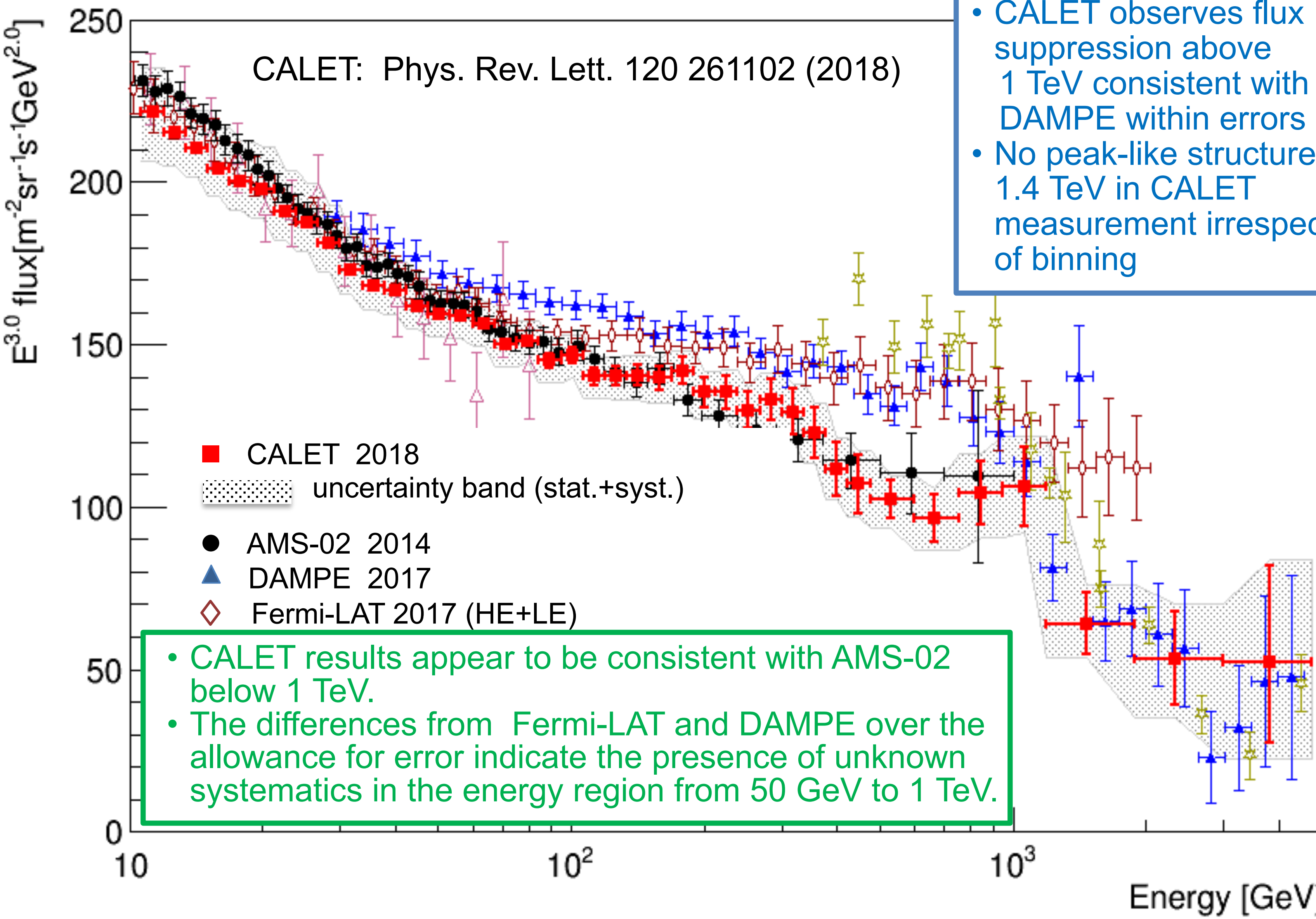
1196 < E < 4755 GeV
(highest energy bin)



Comparison of all electron spectrum as of 2018



Comparison of all electron spectrum as of 2018

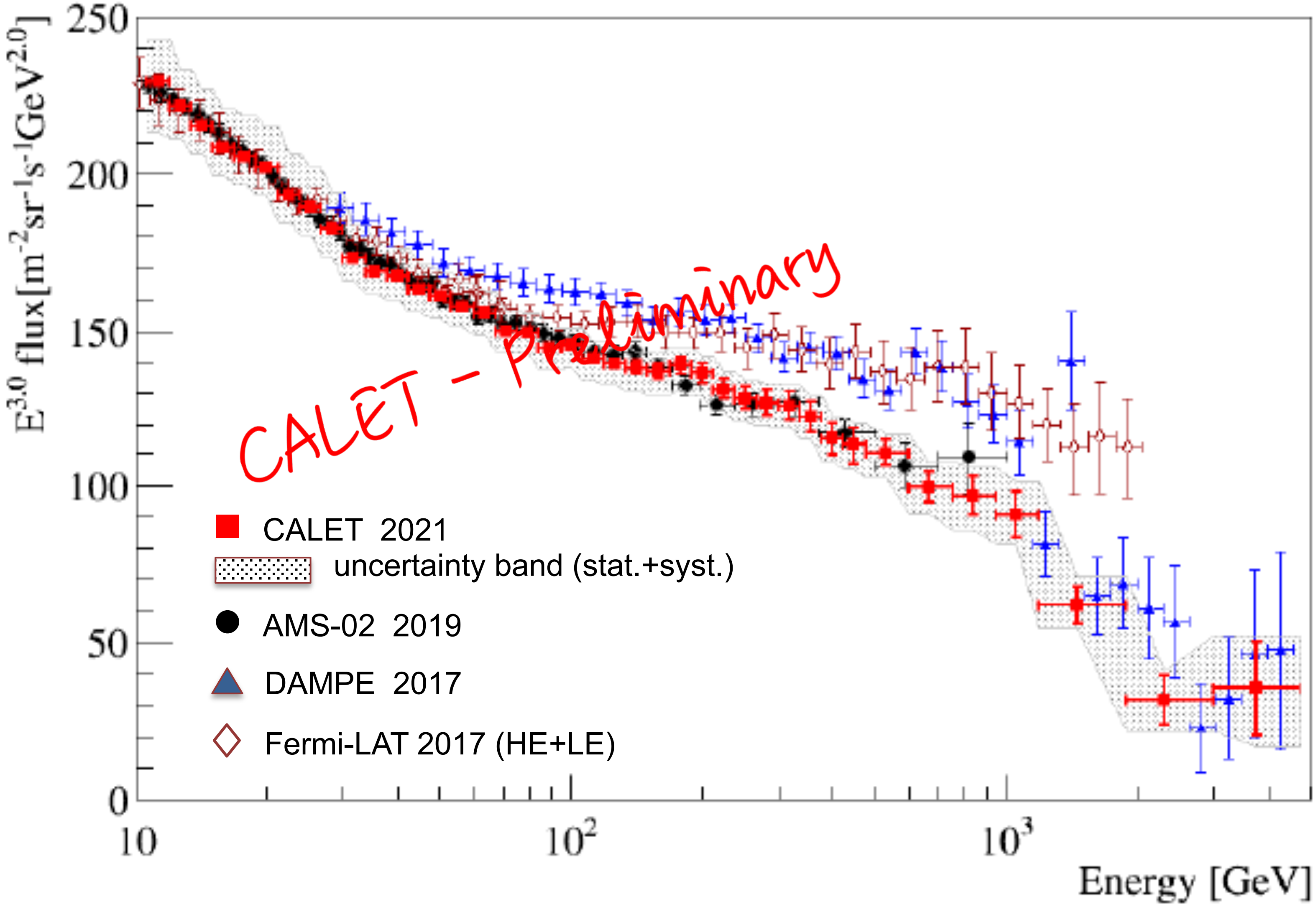


- CALET observes flux suppression above 1 TeV consistent with DAMPE within errors
- No peak-like structure at 1.4 TeV in CALET measurement irrespective of binning

- CALET results appear to be consistent with AMS-02 below 1 TeV.
- The differences from Fermi-LAT and DAMPE over the allowance for error indicate the presence of unknown systematics in the energy region from 50 GeV to 1 TeV.

All Electron Spectrum: Comparison between Recent Direct Measurements

CALET Observations: Oct.13, 2015 - Sep.30, 2020 (for 1815 days)



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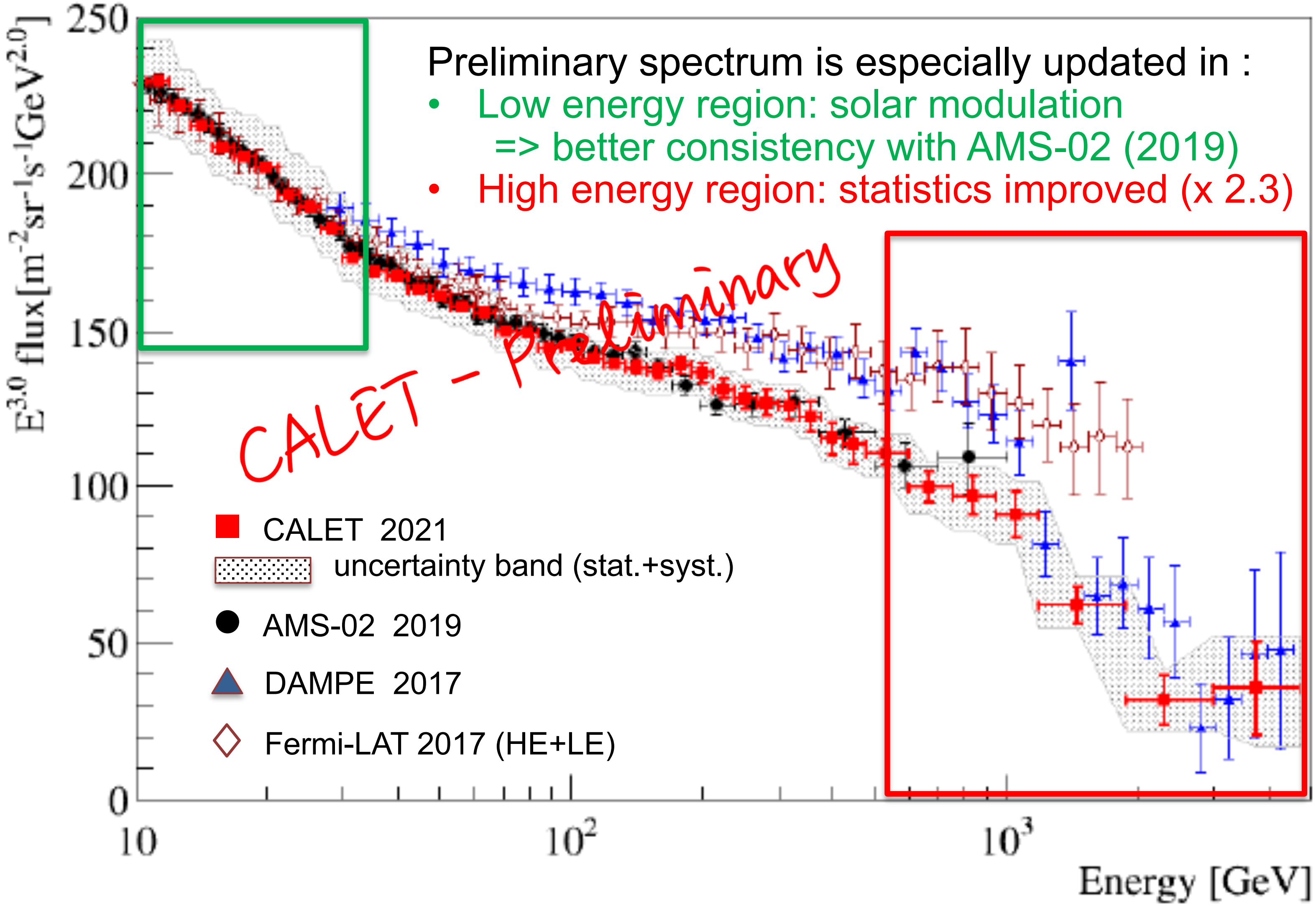
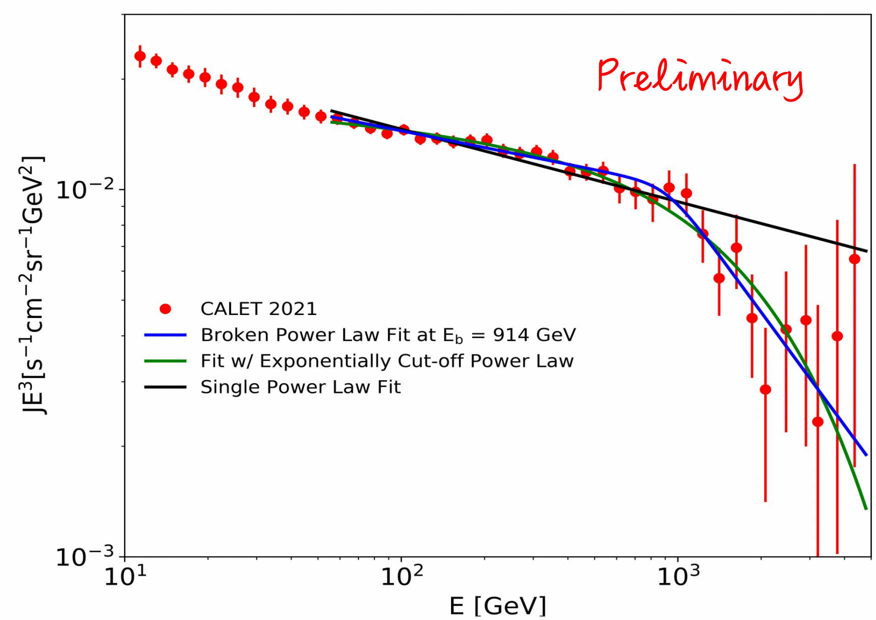


Towards an interpretation of the CALET all-electron spectrum

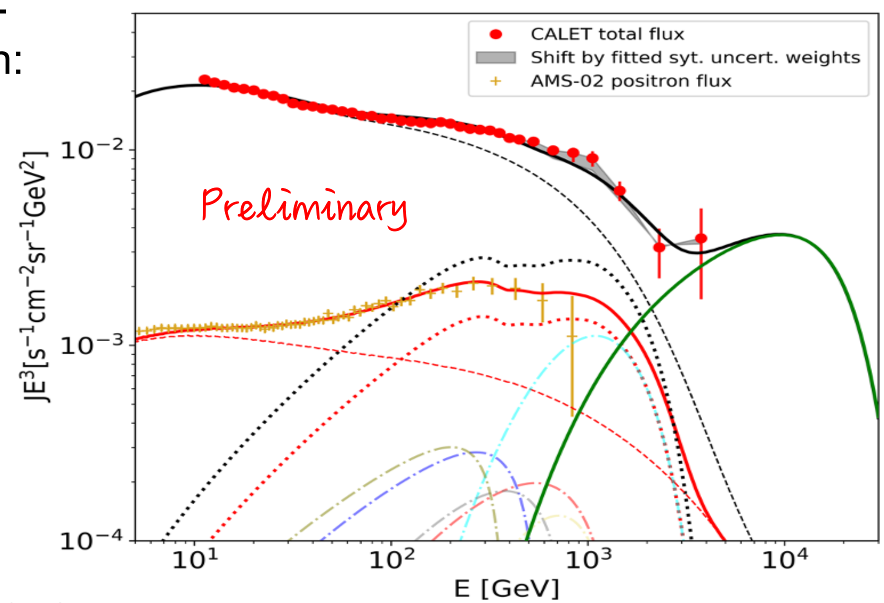
- Fits of the CALET all-electron spectrum in 55 GeV - 4.8 TeV, using the same energy binning as DAMPE [Nature, 2017]:
  - Broken power law used in DAMPE
    $\gamma = -3.151 \Rightarrow -4.024$ (χ^2 /NDF=11.64/29)
  - Exponential cut-off power law [PRL, 2018]
    $\gamma = -3.054$ with E_c= 2.17 TeV (χ^2 /NDF=11.25/29)
  - Single power law
    $\gamma = -3.197$ (χ^2 /NDF=54.50/30)

  The significance of both fits of softening spectrum is nearly 6.5 σ, which is considerably improved comparing to ~4 σ obtained in PRL2018.



- Tentative spectral fit in 11 GeV-4.8 TeV include-ing pulsars and a possible Vela SNR contribution:
  - The positron flux of AMS-02 is shown with expected contributions (red line) from secondaries (red dashed line) and sum of several pulsars (red dotted line).
  - The electron flux is shown with contribution from by secondaries + distant SNRs (black dashed line) and the Vela SNR (green line).
  - The fitted model includes a possible contribution from the Vela SNR , consistent with an energy output of 2.08 x 10^{48} erg in electron CR above 1 GeV.

  [See Poster #492 for details and other possibilities]



Summary and Future Prospects

- 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 11 GeV to 4.8 TeV observed by the end of Sep. 2020 is reported with statistics higher by a factor of 2.3 since last publication in PRL2018.
- The results at high energies present suppression of the flux above 1 TeV with a considerable significance of ~6.5 σ over the single power law, and is consistent with tentative fitting assuming the nearby supernova remnants emitting a few 10^{48} erg in electron CR above 1 GeV.
- The spectrum below 1 TeV is consistent with AMS-02, and is well reproduced by the positron flux on the assumption of astrophysical origin of the positrons.
- Further observations until Dec. 2024 (at least) are approved by JAXA, and we will improve the measurements with higher statistics and a further reduction of the systematic errors, especially in the TeV region.