# CALETにおけるTeV領域電子の選別手法の改良

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

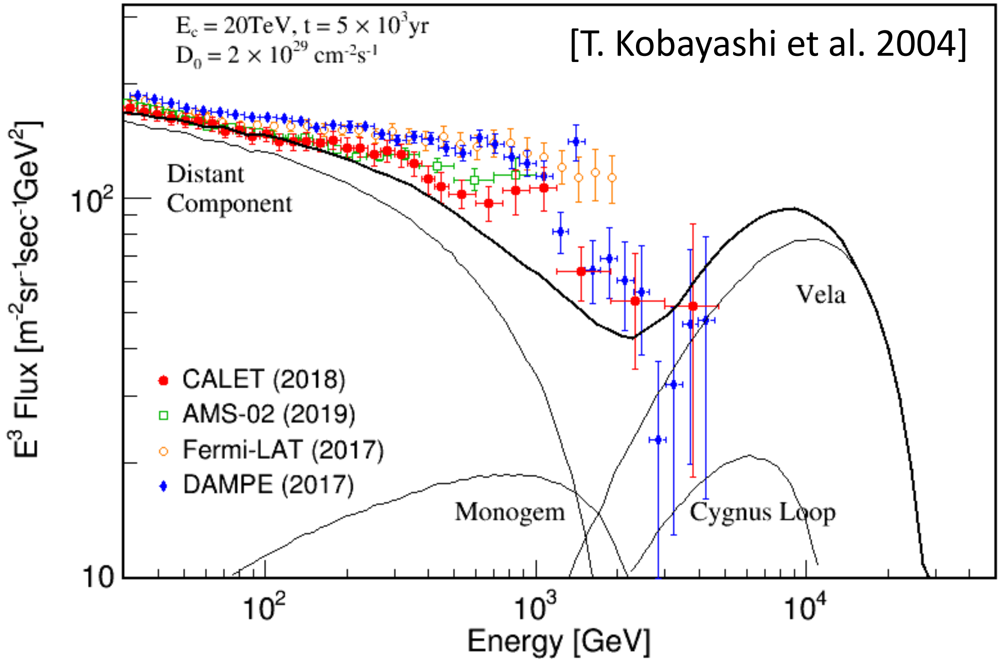
- distance: d < 1kpc
- time: T < $10^4$ yr

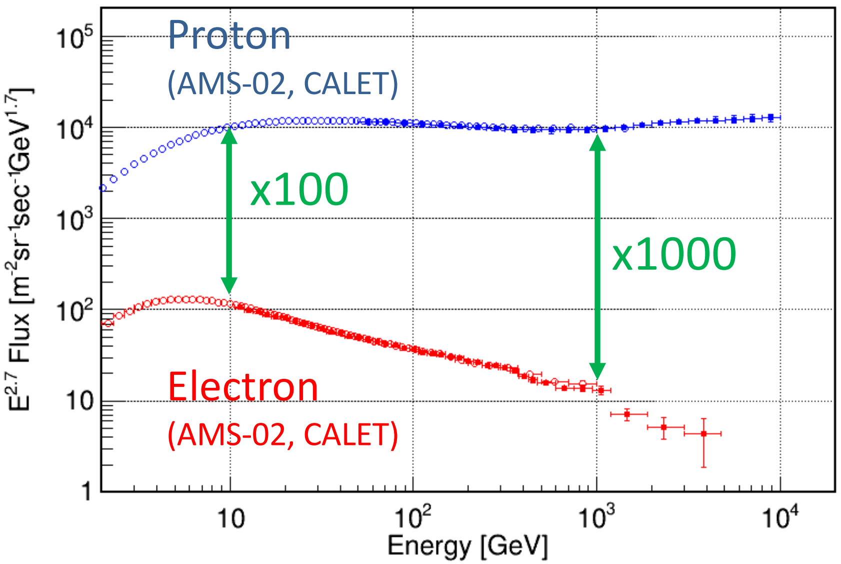
Candidate sources are very few like Vela

➡ 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

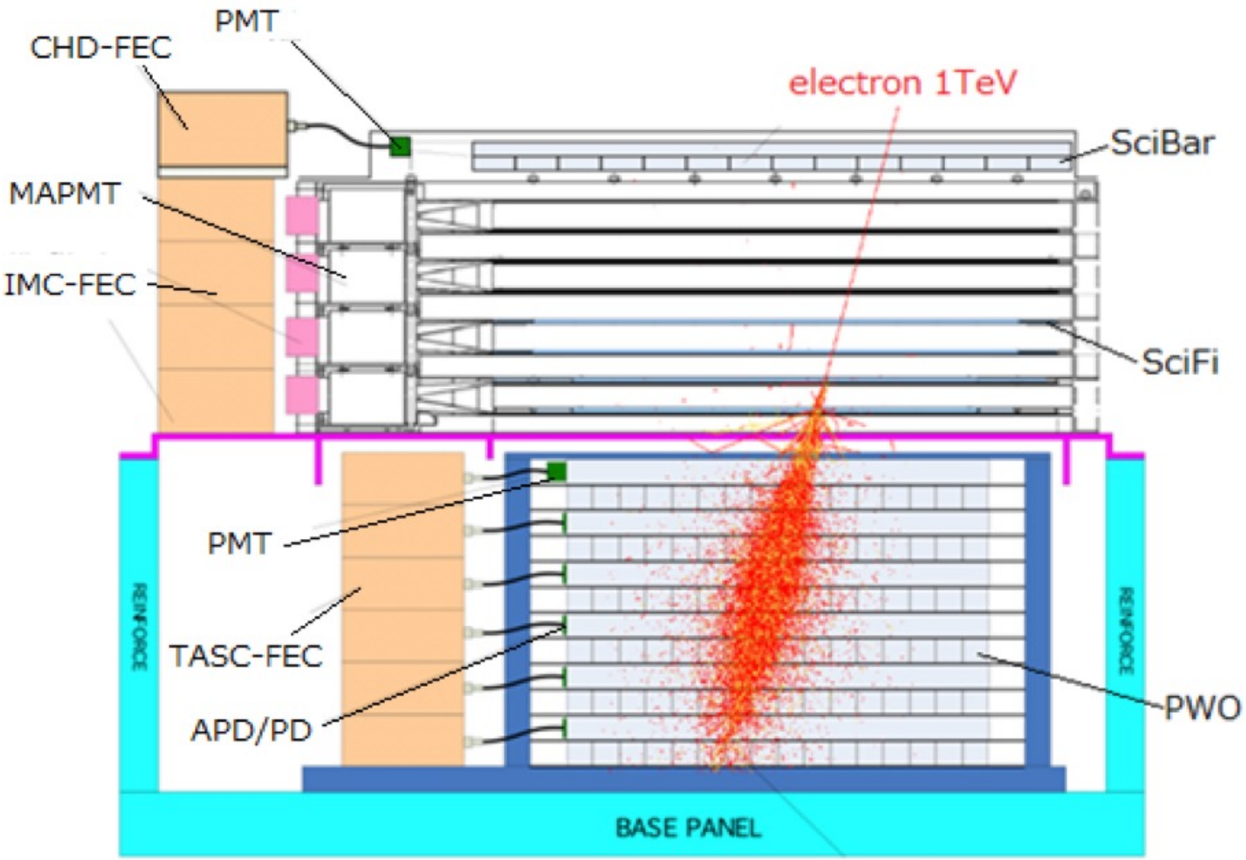
Maximum detectable rigidity of AMS-02 is 2TV

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 $X_0$x 2)

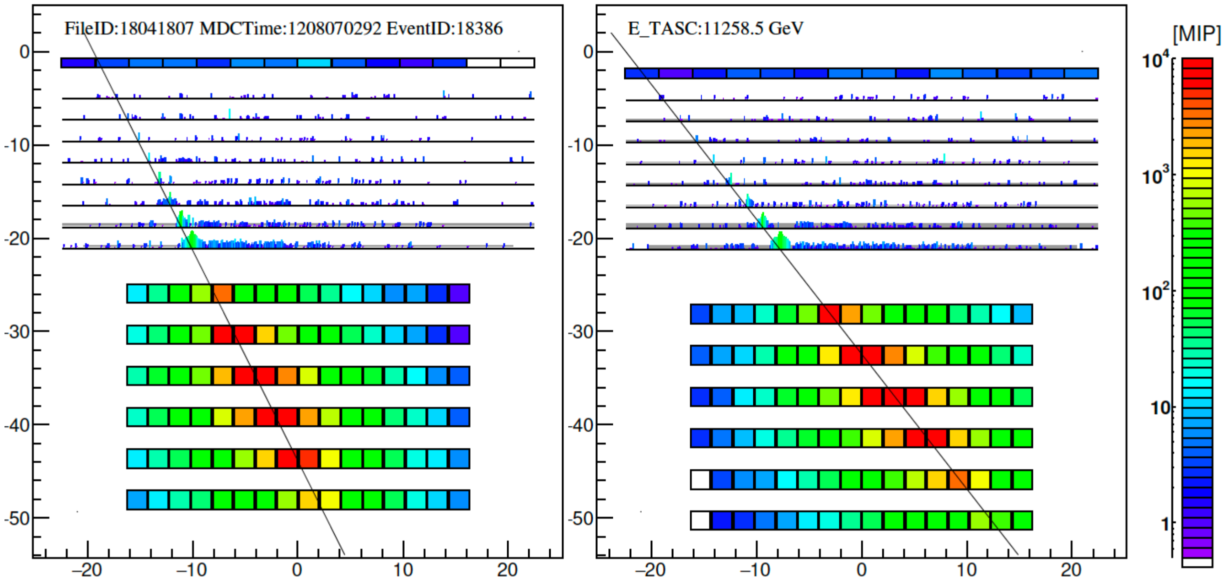
TASC: Total Absorption Calorimeter

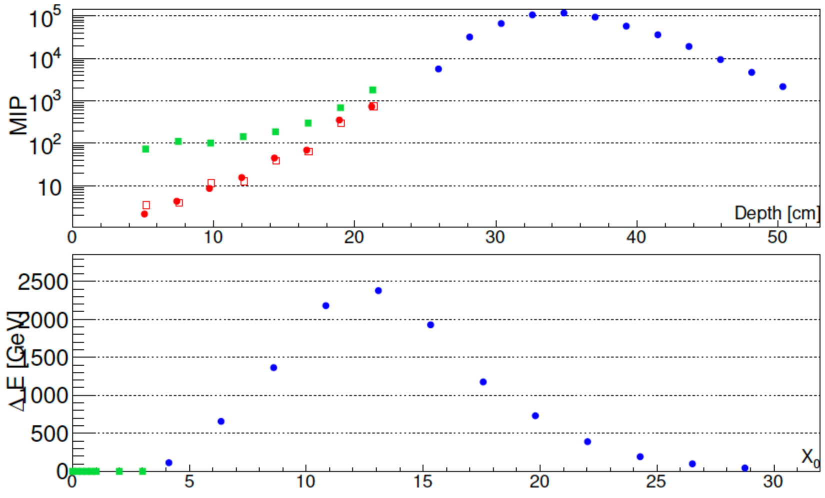
Energy measurement, Particle ID

- 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 $cm^2$sr for electrons

# Event display of electron candidates




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

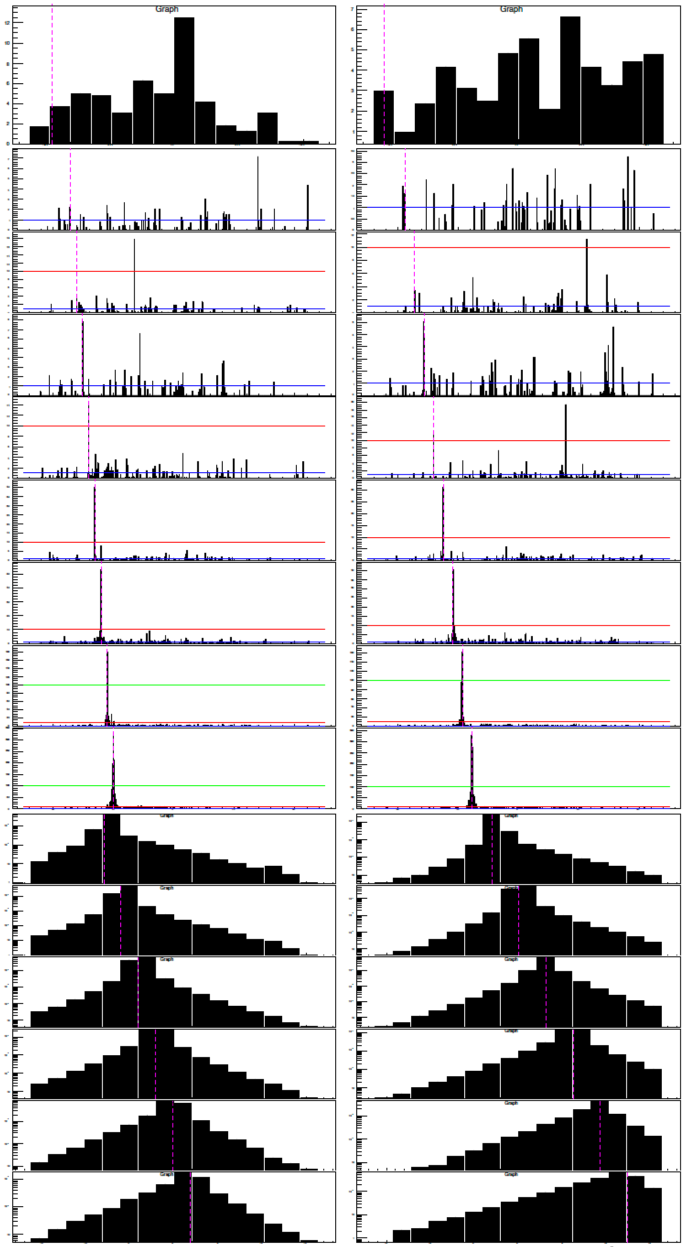
imc_p0: -0.794

Rmax: 0.476

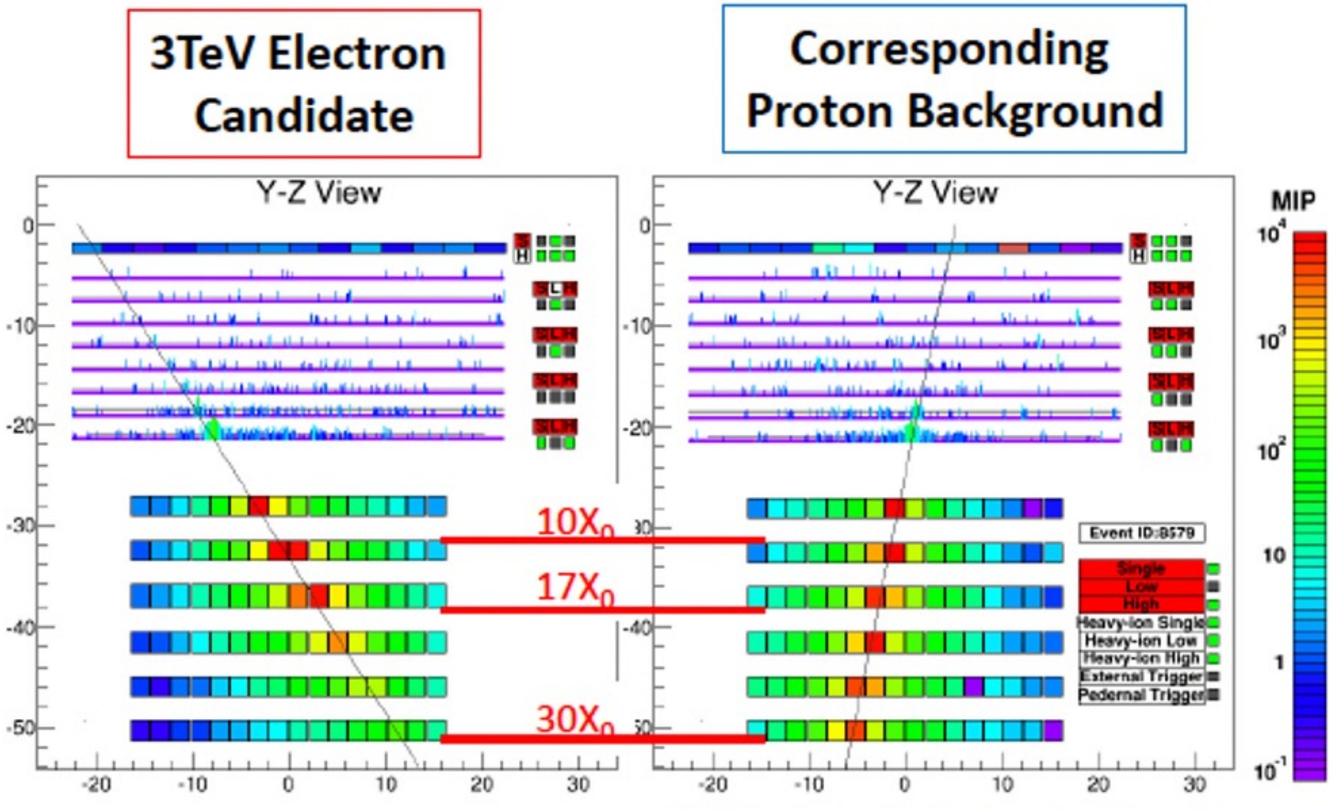
imc_p1: 1.629

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**

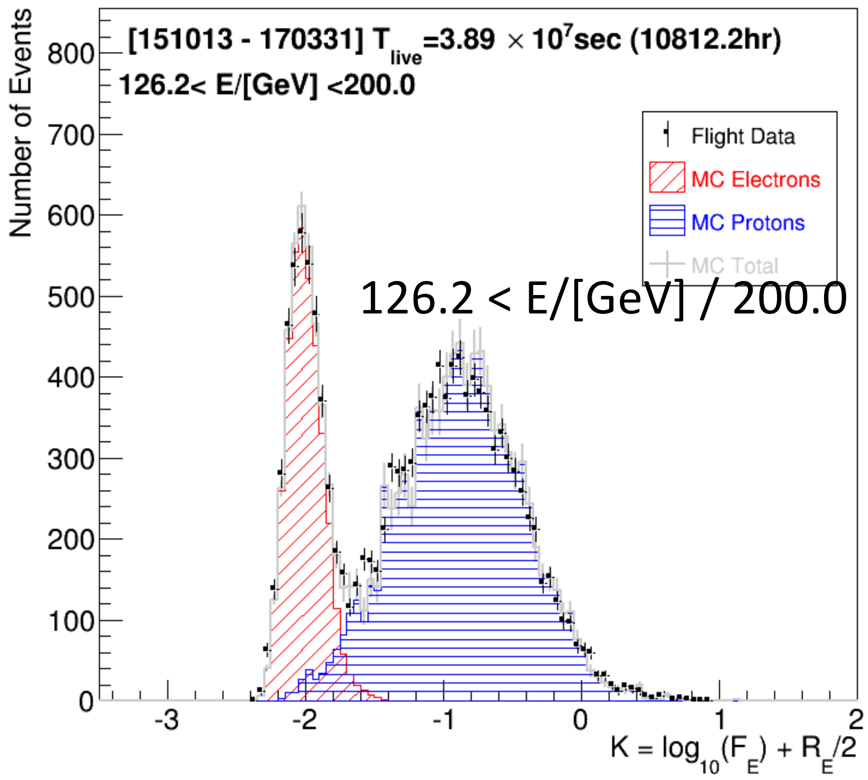
E<476GeV

**$F_E$**: 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:

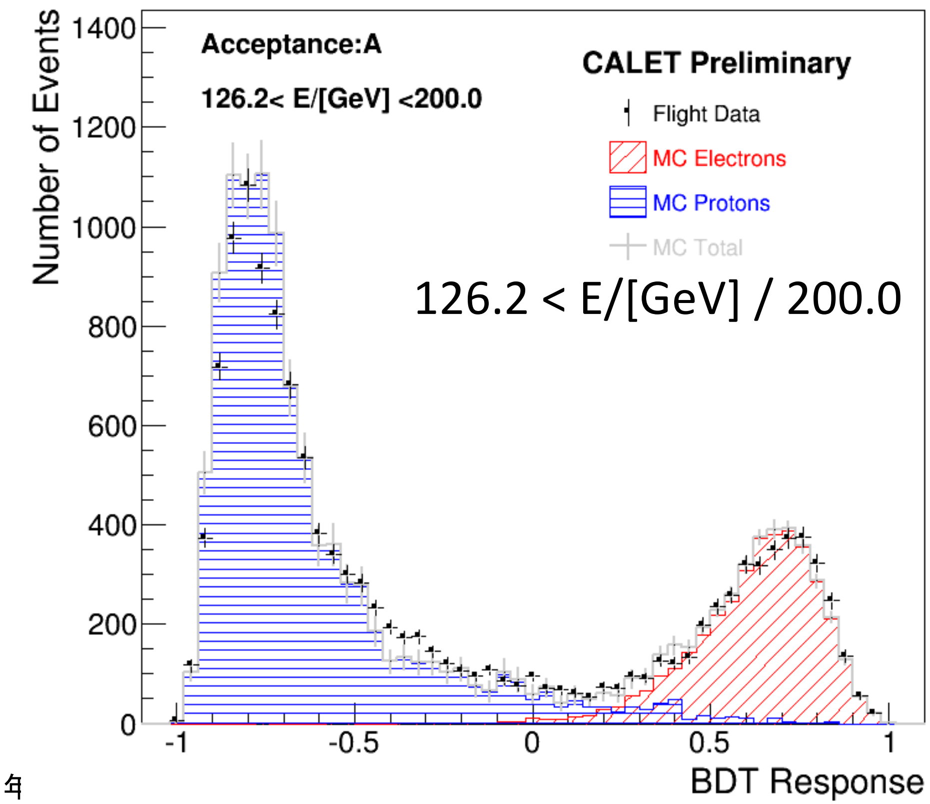
$$K = \log_{10}(F_E) + 0.5\, R_E \text{ (/cm)}$$




**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 : $\boldsymbol{R_E}$
2. Shower development : $\boldsymbol{F_E}$
3. *Shower concentration ratio on IMC Y8 : $\boldsymbol{C_E}$

- The fitting of TASC transition curve
  4. ***α/b***
  5. ***b***
  6. ***χ²/NDF***
  7. $\boldsymbol{T_{5\%}}$

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

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

- Exponential fitting of IMC transition curve
  8. ***p0***
  9. ***p1***
  10. ***χ²/NDF***

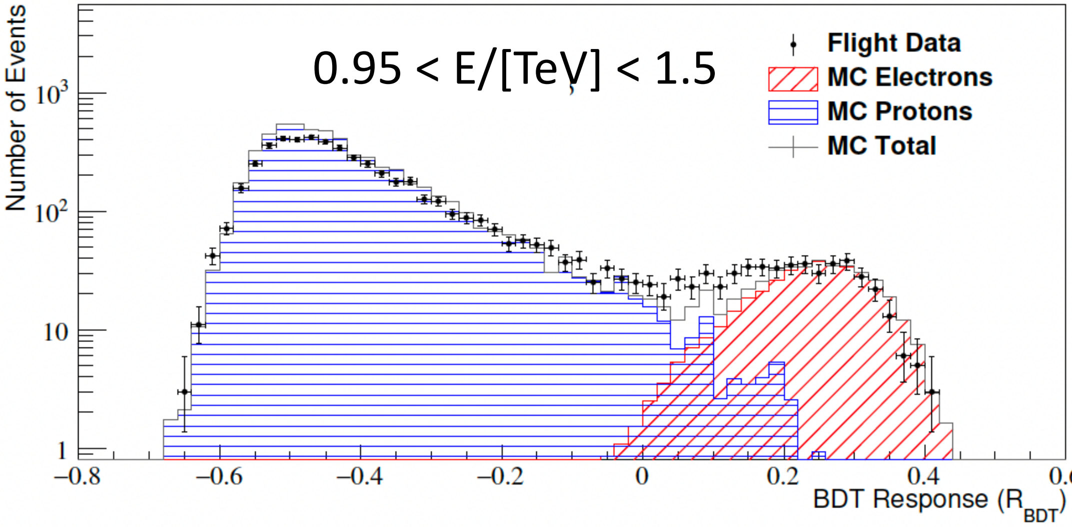
$$\frac{dE}{dt} = e^{(p_1 t + p_0)}$$

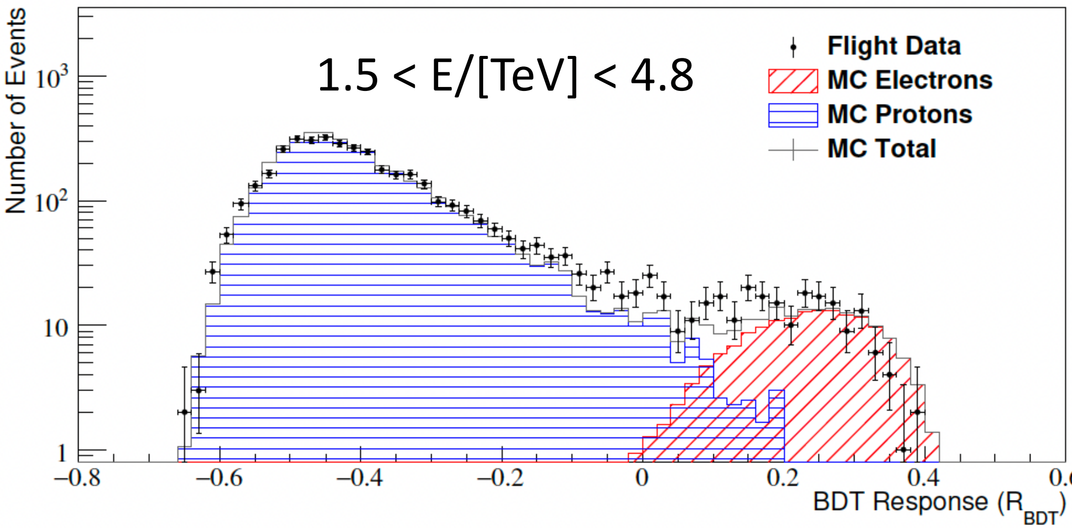
11. *The sum of CHD energy deposit : $\boldsymbol{S_{CHD}}$

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

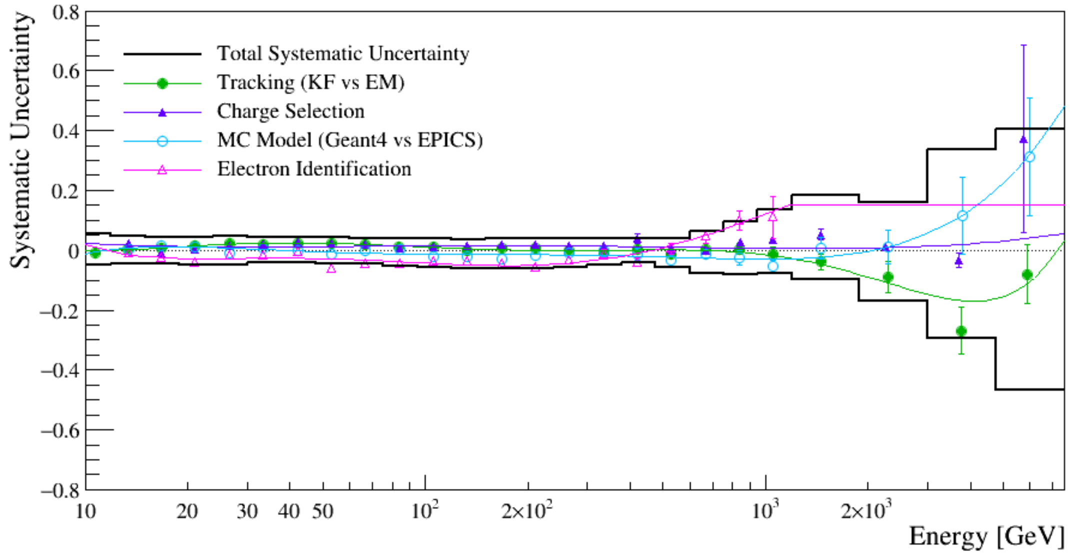
* New parameters

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

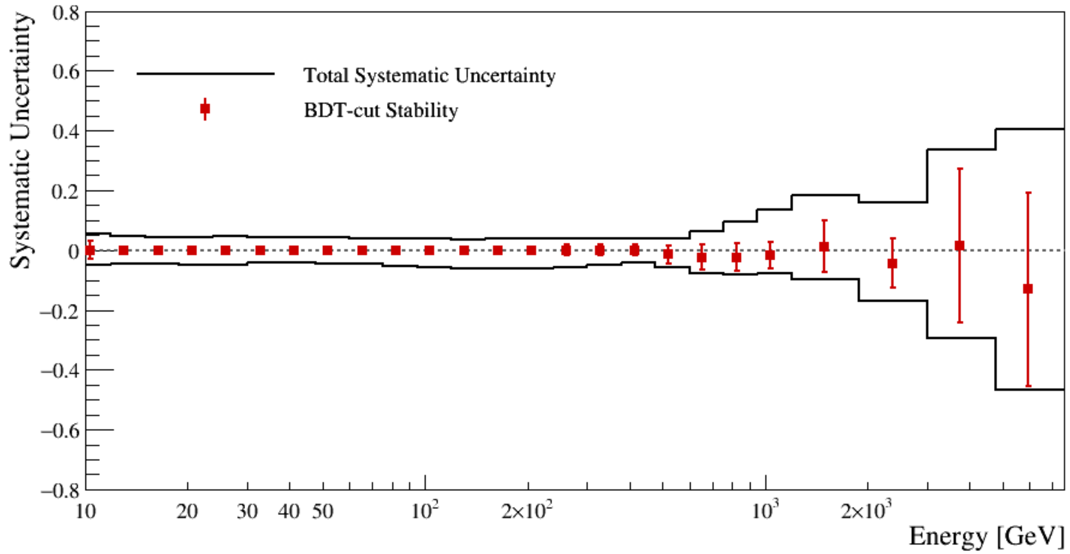


# Systematic uncertainties




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



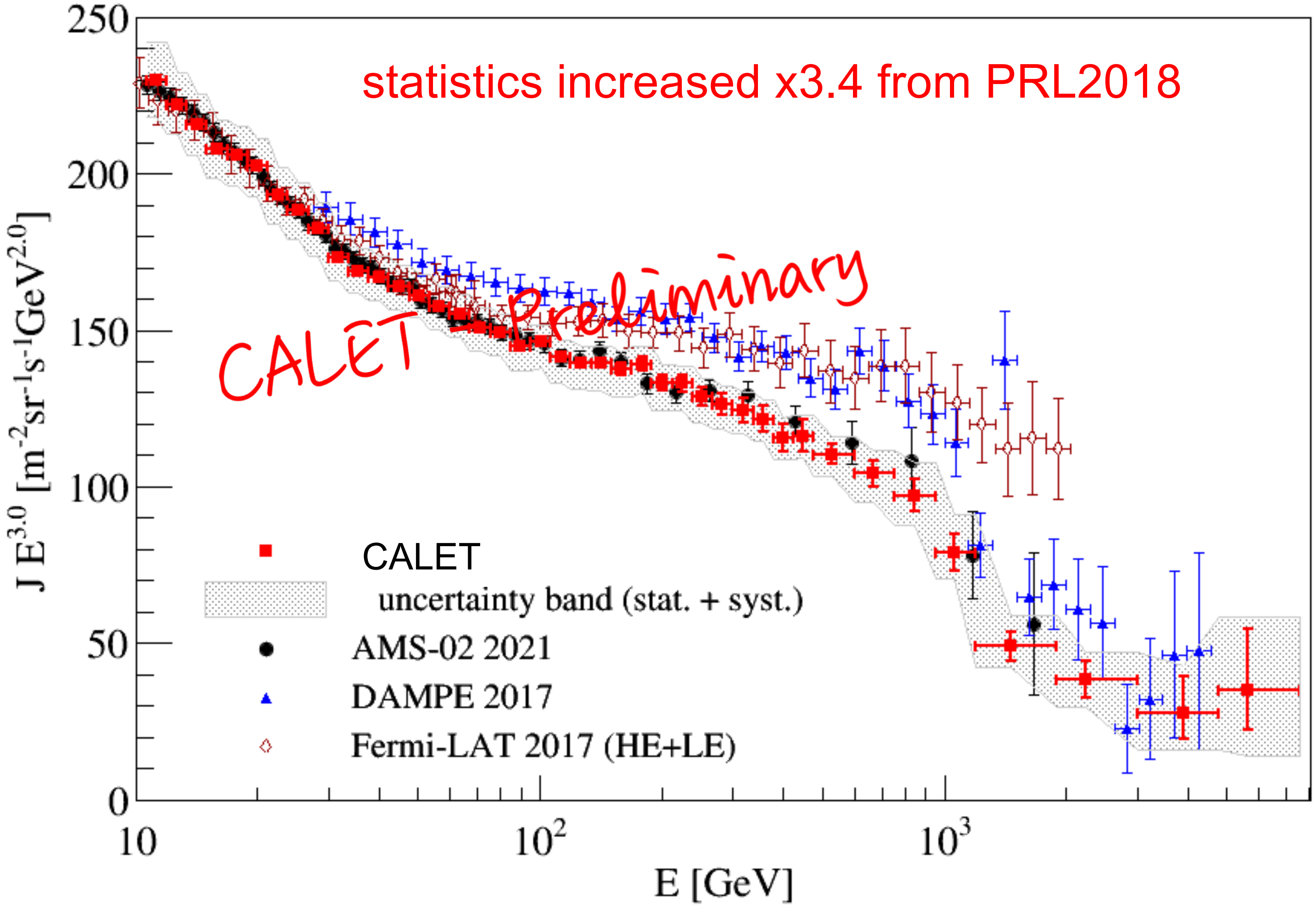

Energy independent sources;
- live time
- long-term stability
- track quality cut
- trigger efficiency (E<30GeV)
- energy scale

# 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 ($\chi^2$ /NDF=3.6/27)

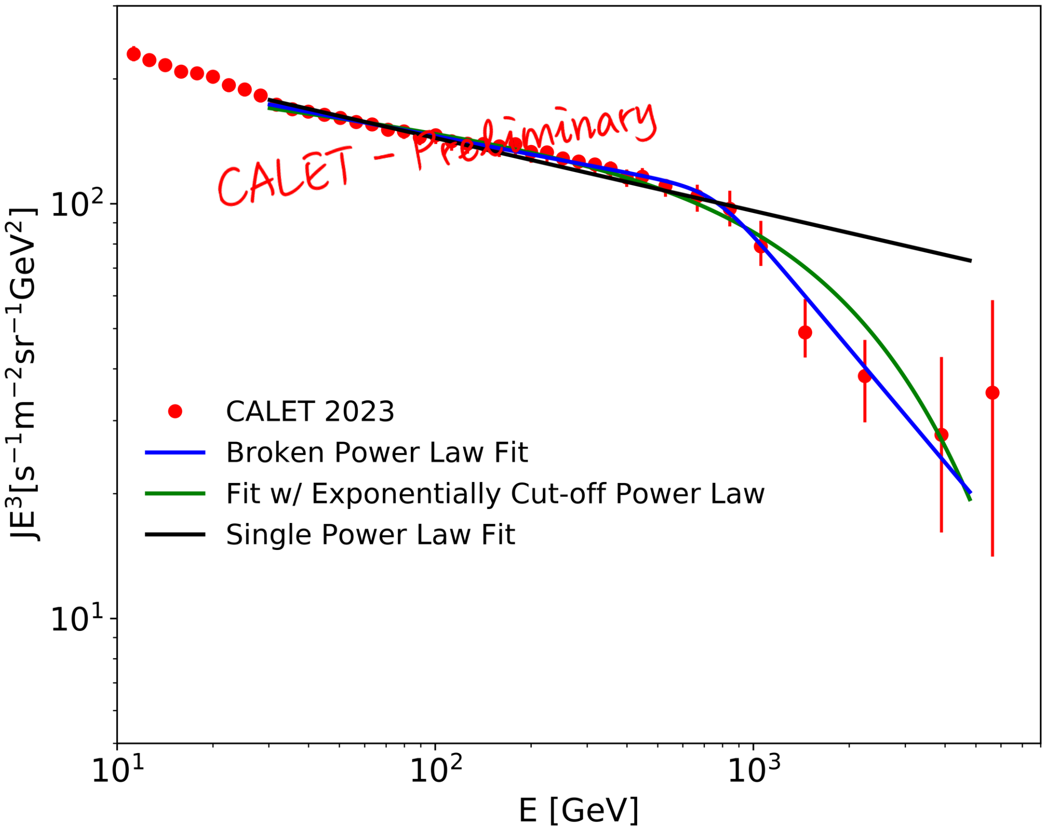
- Exponential cut-off power law [PRL, 2018]

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

- Single power law

  γ = -3.18 ± 0.01 ($\chi^2$ /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.



# Event-by-Event Analysis

- Proton contamination increases above ~5TeV
- Statistics decrease at these energies that each candidate event can be studied individually

➡ Dedicated event-by-event analysis to evaluate the likelihood of each candidate event

<u>Analysis</u>

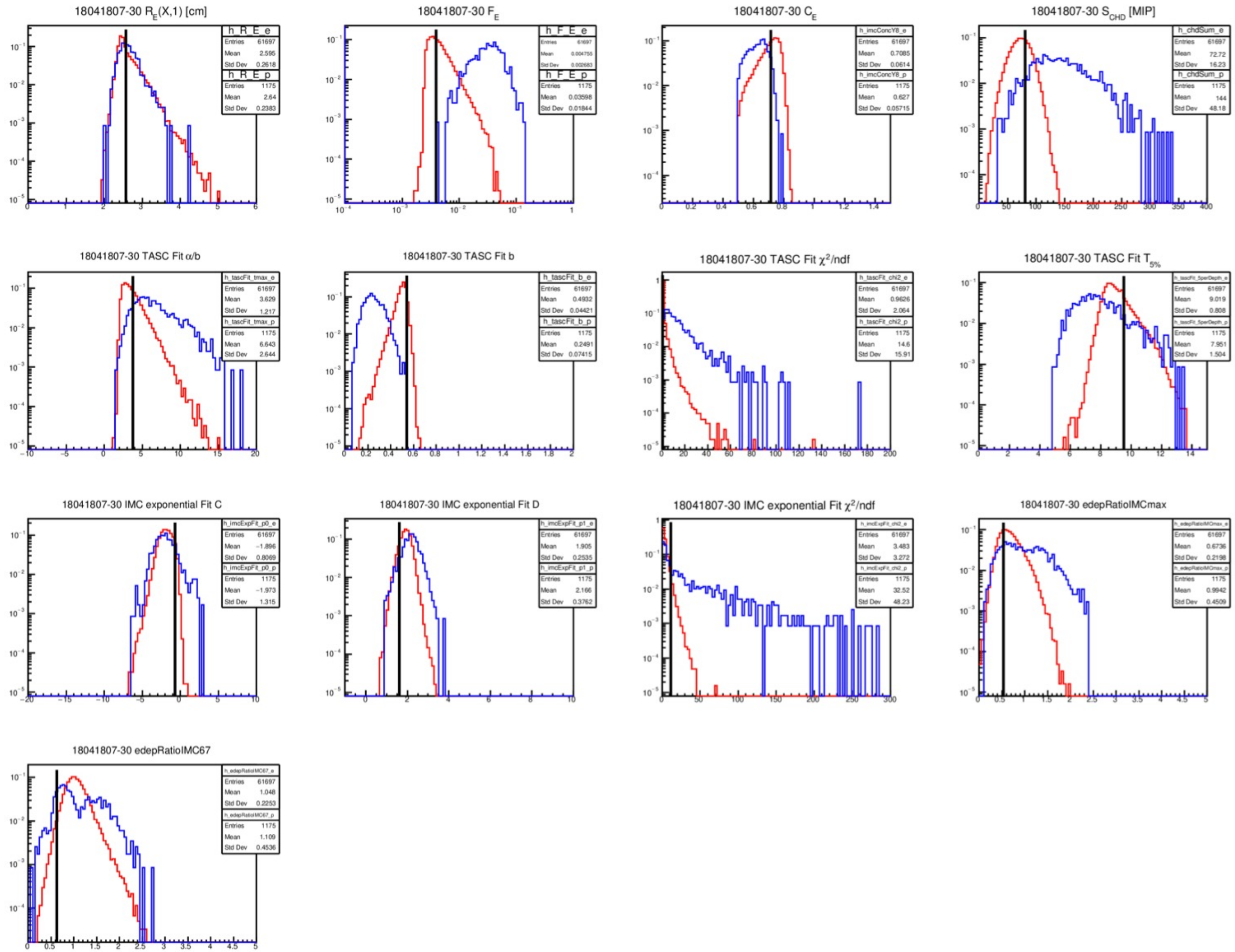
- Pickup electron candidates by standard analysis
- Generate simulation data set
- Apply the likelihood analysis using 13 parameters

<u>Simulation data</u>

- Electrons: $10^5$ events for same primary energy and incident direction as flight data candidate
- Protons: $10^6$ events with same incident direction and energy according to $E^{-2.7}$ spectrum from 1 to $10^3$ times the candidate

# Parameters for EBE analysis

- Lateral shower spread
- TASC Y6 dep. frac.
- IMC concentration
- CHD sum
- TASC fit shower max.
- TASC fit atten. Const.
- TASC fit 5% depth
- TASC fit $\chi^2$/ndf
- IMC exp. fit const.
- IMC exp. fit slope
- IMC exp. fit $\chi^2$/ndf
- IMC ratio 6-7
- IMC ratio max.



# Event-by-Event Analysis

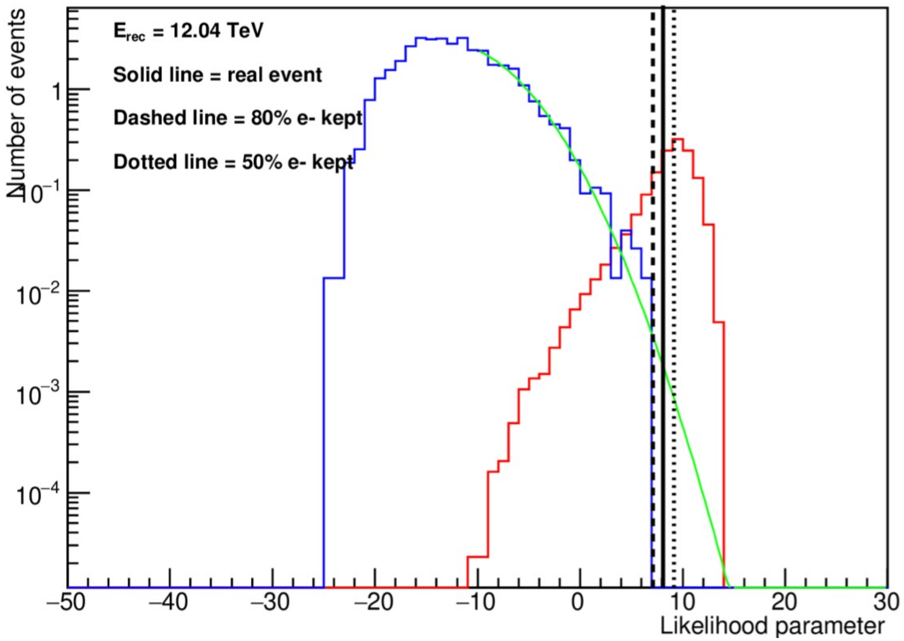
- Proton contamination increases above ~5TeV
- Statistics decrease at these energies that each candidate event can be studied individually

➡ Dedicated event-by-event analysis to evaluate the likelihood of each candidate event

## Analysis

- Pickup electron candidates by standard analysis
- Generate simulation data set
- Apply the likelihood analysis using 13 parameters

Likelihood distribution of an event




## Simulation data

- Electrons: $10^5$ events for same primary energy and incident direction as flight data candidate
- Protons: $10^6$ events with same incident direction and energy according to $E^{-2.7}$ spectrum from 1 to $10^3$ times the candidate

## Results

- 9 events are selected above 4.8 TeV which have $p_{cont} < 0.1$

# 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 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.