CALET : Summary of the First Two-Years on Orbit

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for the CALET collaboration
Waseda University

CALET collaboration team

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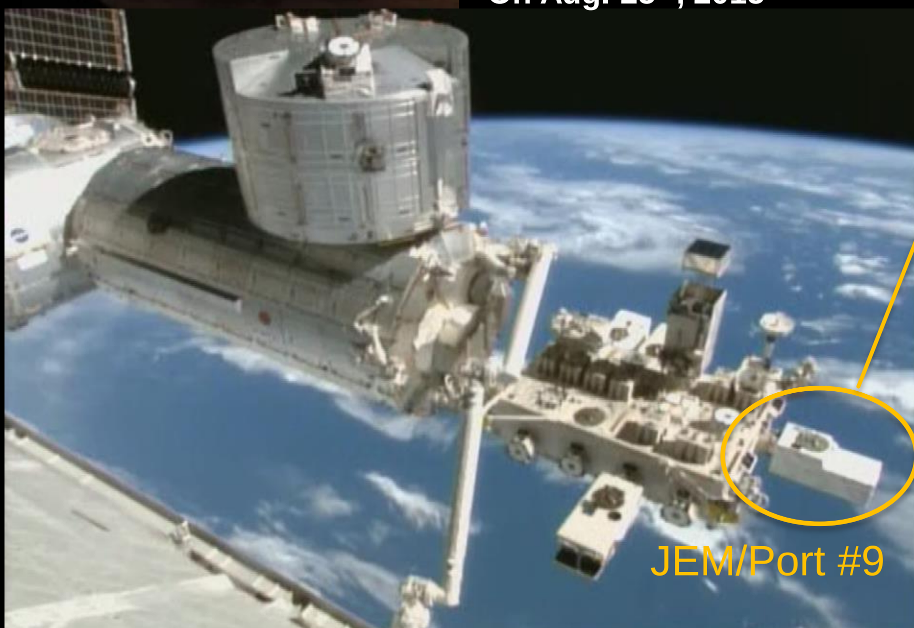
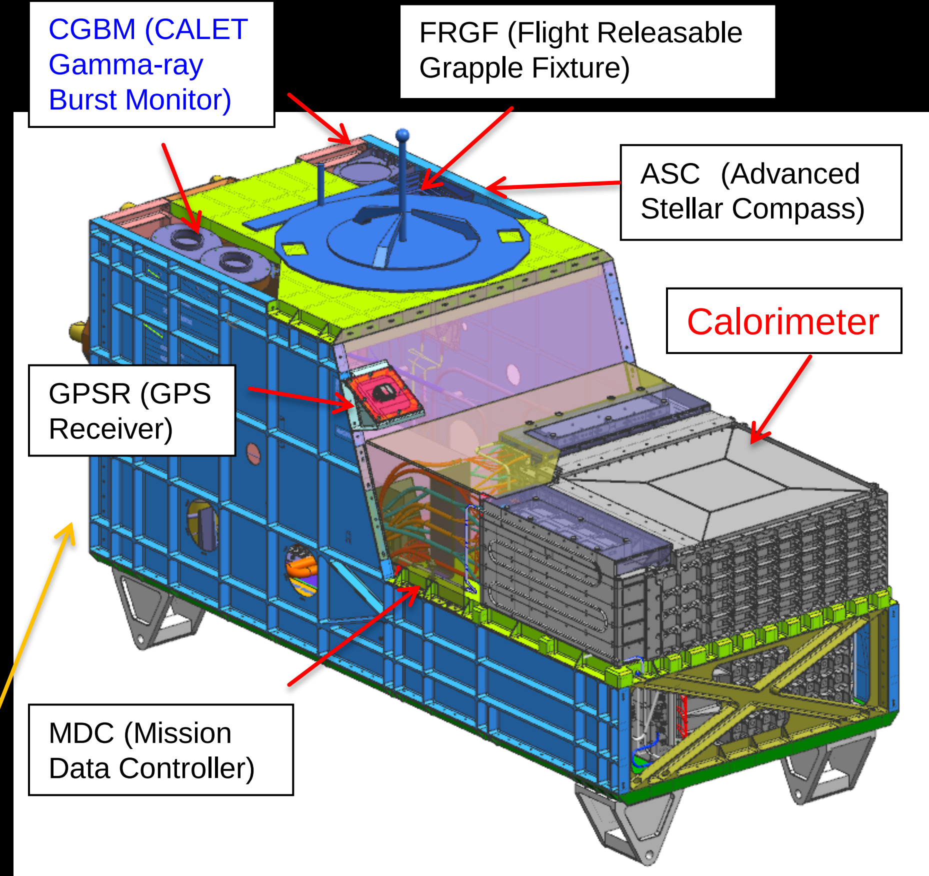
CALET Payload

Kounotori (HTV) 5

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

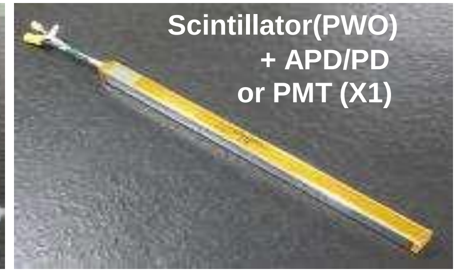
Emplaced on JEM-EF port #9
On Aug. 25th, 2015



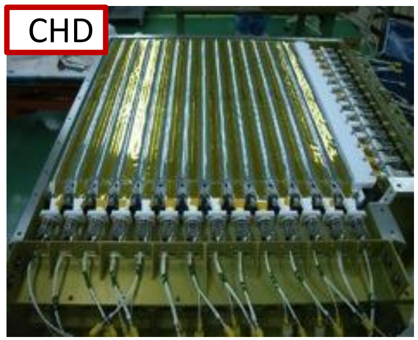


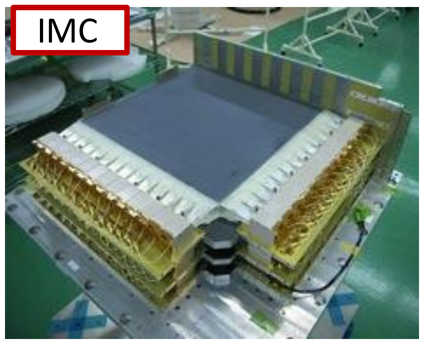
- **Mass: 612.8 kg**
- **JEM Standard Payload Size:**
  1850mm(L) × 800mm(W) × 1000mm(H)
- **Power Consumption: 507 W（max）**
- **Telemetry:**
  Medium 600 kbps (6.5GB/day) / Low 50 kbps

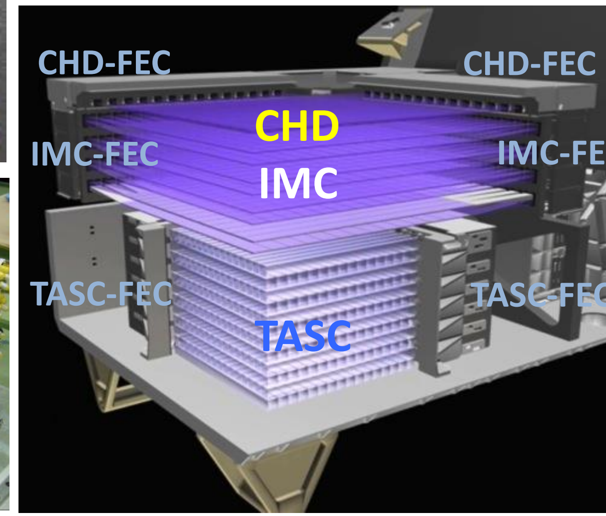
CALET Instrument



CALORIMETER







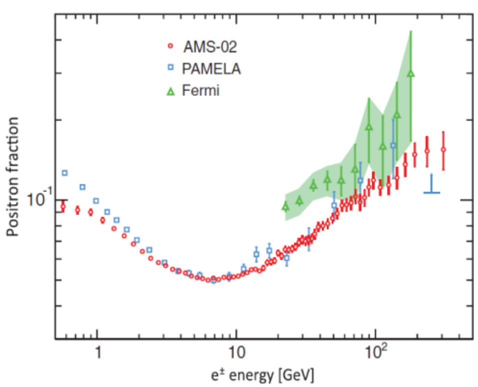
	CHD (Charge Detector)	IMC (Imaging Calorimeter)	TASC (Total Absorption Calorimeter)
Measure	**Charge (Z=1-40)**	**Tracking , Particle ID**	**Energy, e/p Separation**
Geometry (Material)	**Plastic Scintillator 14 paddles x 2 layers (X,Y): 28 paddles Paddle Size: 32 x 10 x 450 mm^3**	**448 Scifi x 16 layers (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**

Scientific Goals

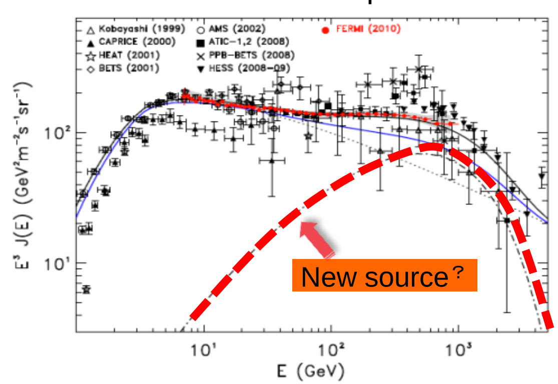
Scientific Objectives	Observation Targets	Energy Range
CR Origin and Acceleration	Electron spectrum p- - Fe individual spectra Ultra Heavy Ions (26<Z≤40) Gamma-rays (Diffuse + Point sources)	1GeV - 20 TeV 10 GeV - 1000 TeV > 600 MeV/n 1 GeV - 1 TeV
Galactic CR Propagation	B/C and sub-Fe/Fe ratios	Up to some TeV/n
Nearby CR Sources	Electron spectrum	100 GeV - 20 TeV
Dark Matter	Signatures in electron/gamma-ray spectra	100 GeV - 20 TeV
Solar Physics	Electron flux	< 10 GeV
Gamma-ray Transients	Gamma-rays and X-rays	7keV - 20 MeV

Respond to the unresolved questions from the results found by recent observations

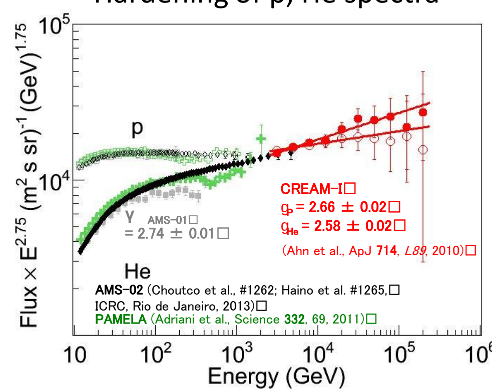
Increase of positron/electron ratio



Excess of electron+positron flux



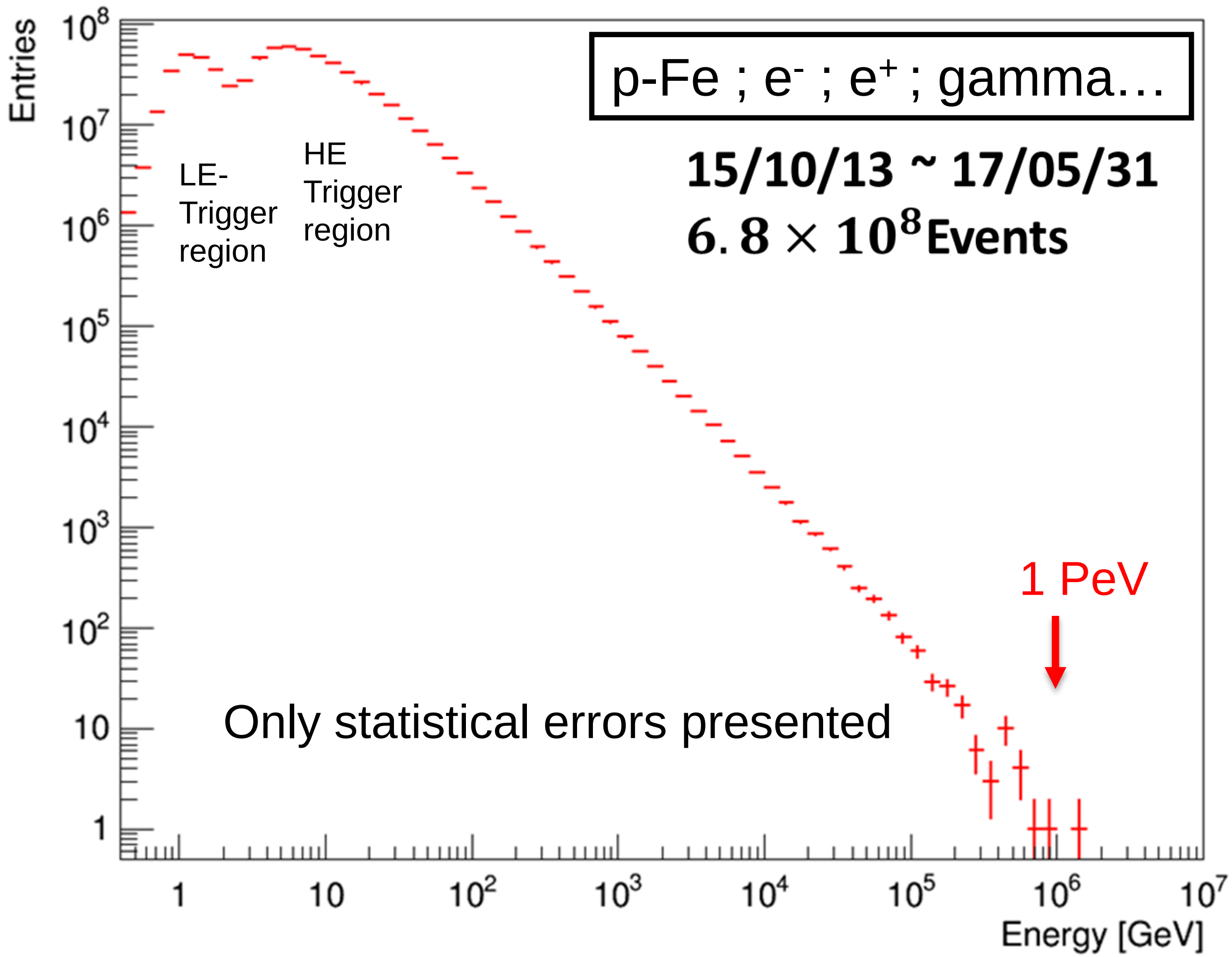
Hardening of p, He spectra



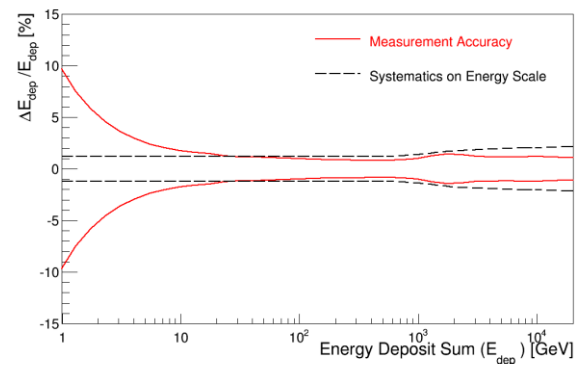
New source of electrons and positrons at 100 GeV ?

Energy Deposit Distribution of All Triggered-Events by Observation for 597 days

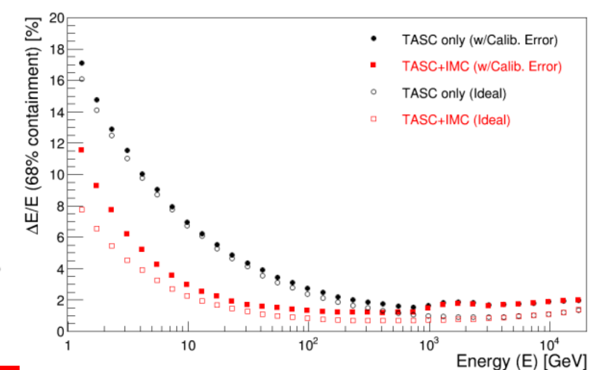
Distribution of deposit energies (ΔE) in TASC



Performance of energy measurement in 1GeV-20TeV



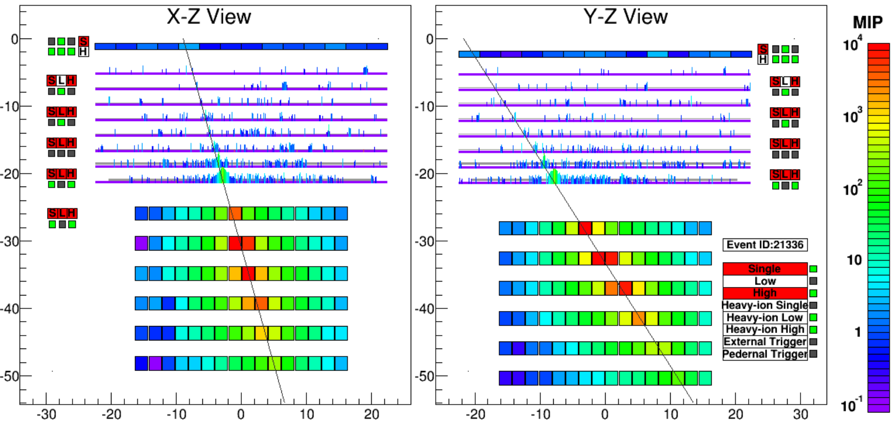
Energy resolution for electrons (TASC+IMC):
< 3% over 10 GeV; <2% over 100GeV



The TASC energy measurements have successfully been carried out in the dynamic range of 1 GeV – 1 PeV.

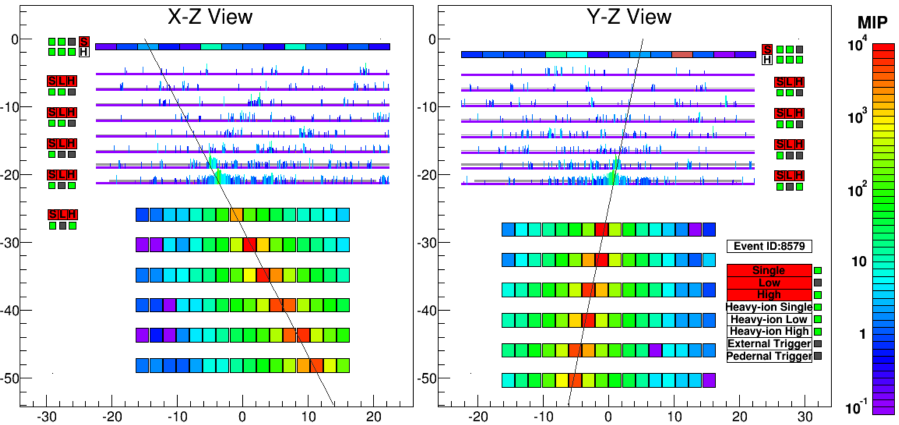
Event Examples of High-Energy Showers

Electron, E=3.05 TeV



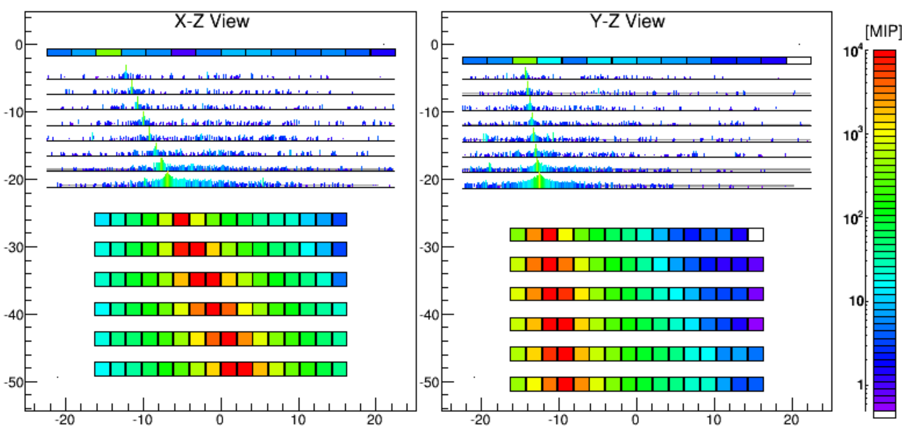
fully contained even at 3TeV

Proton, ΔE=2.89 TeV



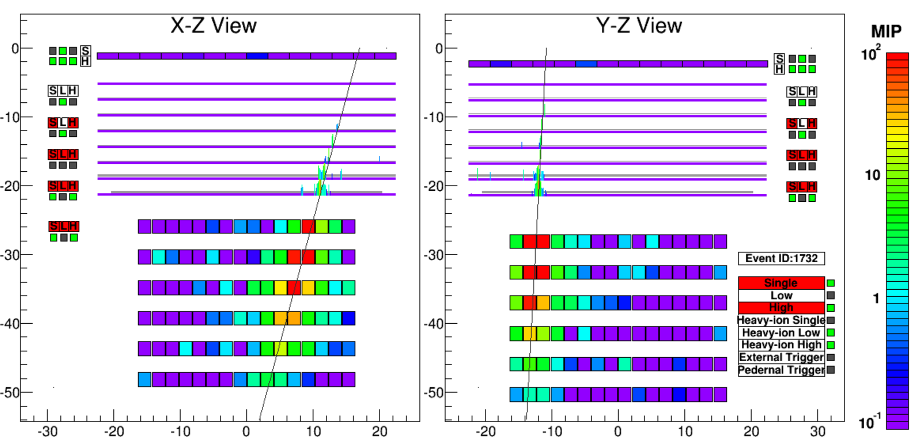
clear difference from electron shower

Fe(Z=26), ΔE=9.3 TeV



energy deposit in CHD consistent with Fe

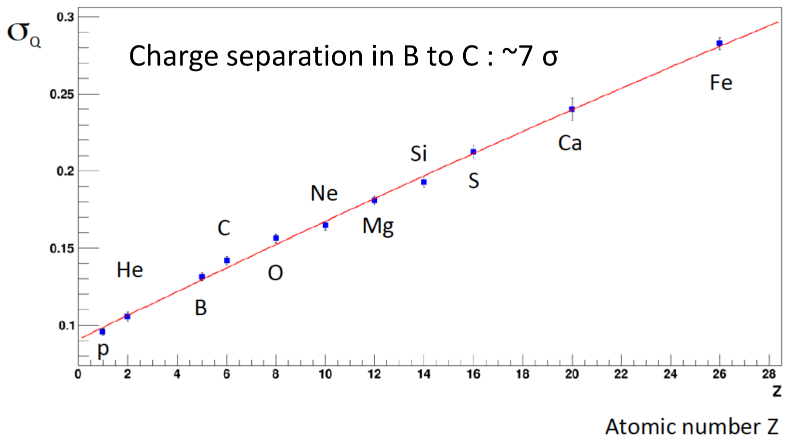
Gamma-ray, E=44.3 GeV



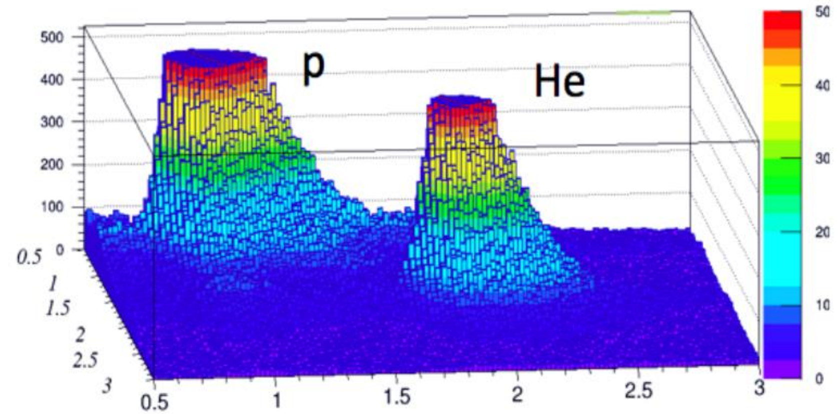
no energy deposit before pair production

Preliminary Nuclei Measurements (p, He, Z ≤ 8)

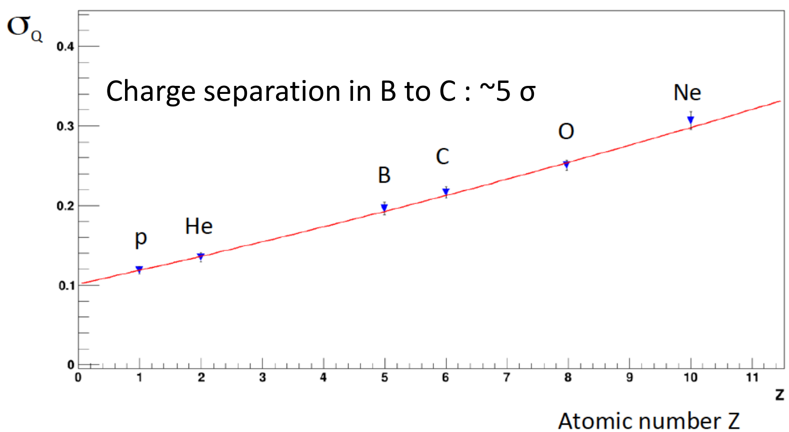
CHD charge resolution (2 layers combined) vs. Z

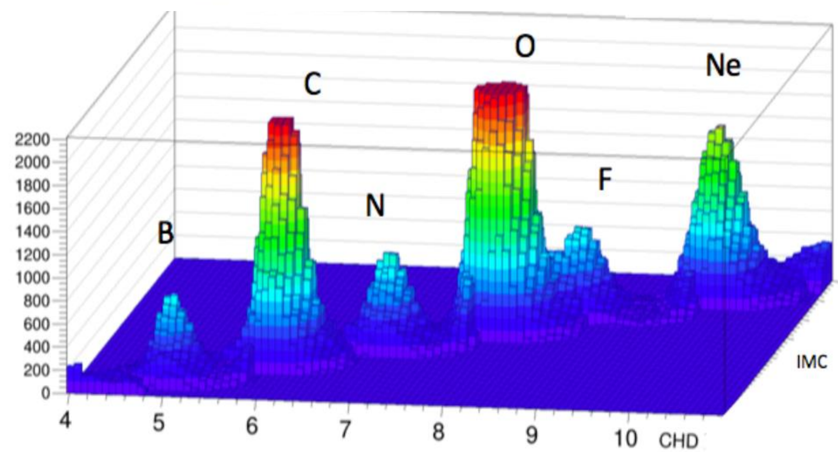


Charge resolution combined CHD+IMC



Charge resolution using multiple dE/dx measurements from the IMC scintillating fibers





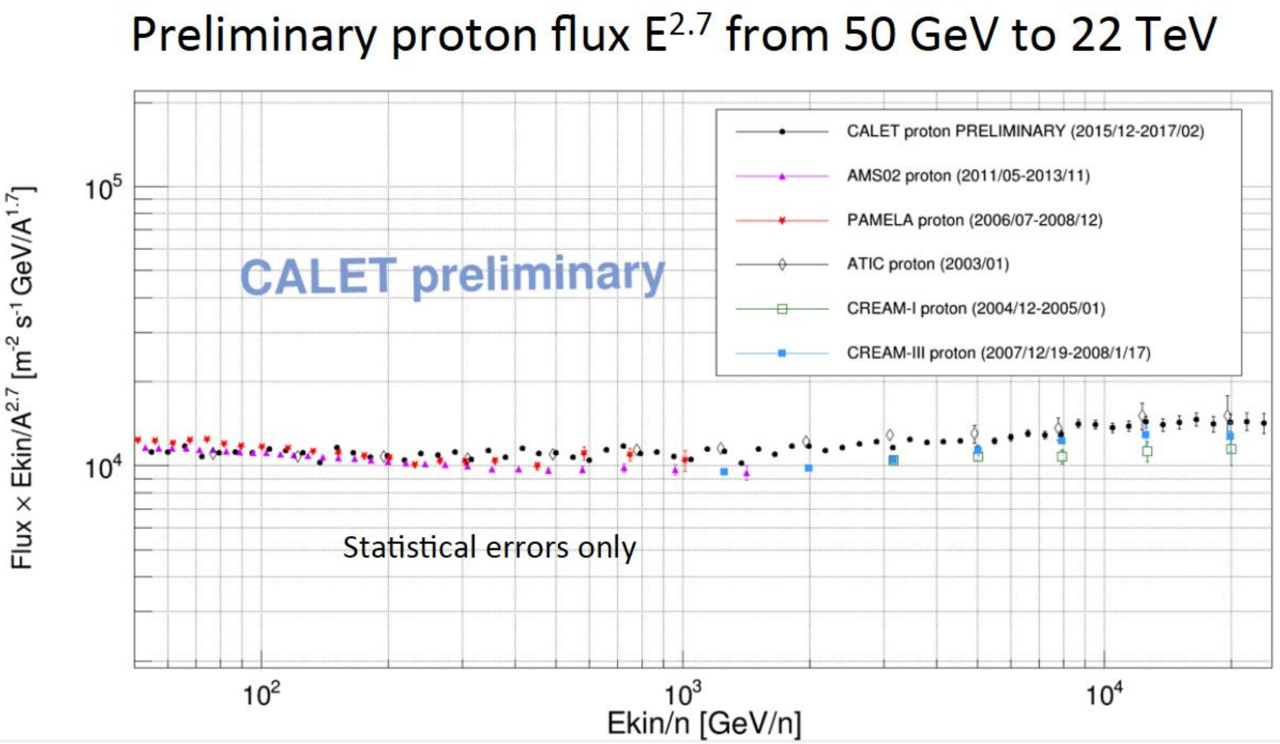
*) Plots are truncated to clearly present the separation.

Non-linear response to Z^2 is corrected both in CHD and IMC using a model.

A clear separation between p, He, up to Z=8, can be seen from CHD+IMC data analysis.

Preliminary Proton Energy Spectrum

P.S.Marrocchesi et al., ICRC 2017, PoS 205.



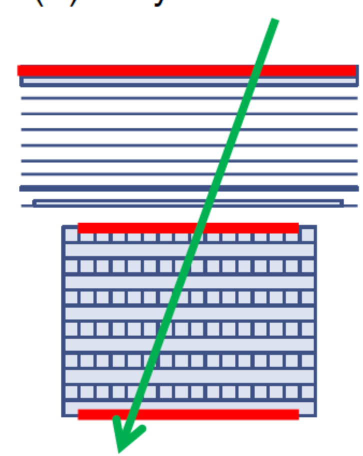
- 15 months of observation from December 1st , 2015 to February 28th, 2017
- subset of total acceptance: acceptance A (fiducial) with $S\Omega$ = 416 cm^2 sr
- Assessment of the systematic errors: IN PROGRESS

☐ Proton Event Selection

1) Fully-contained (Acceptance A) event in geometry
2) Good tracking (KF)
3) High Energy Trigger
4) Charge selection Z=1
5) Helium rejection cuts
6) Electron rejection cuts

☐ Energy Unfolding using an *energy overlap matrix* from MC data

(A) Fully-contained

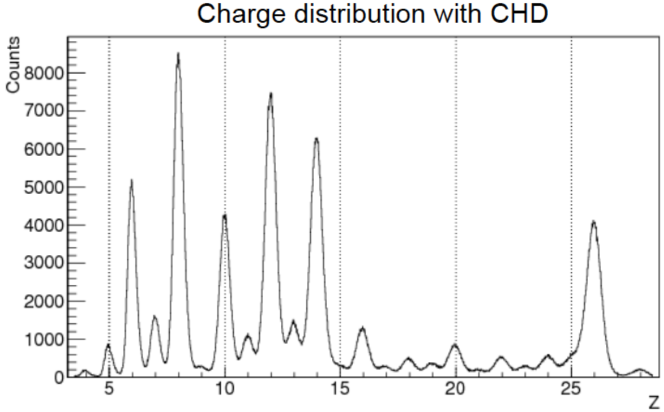


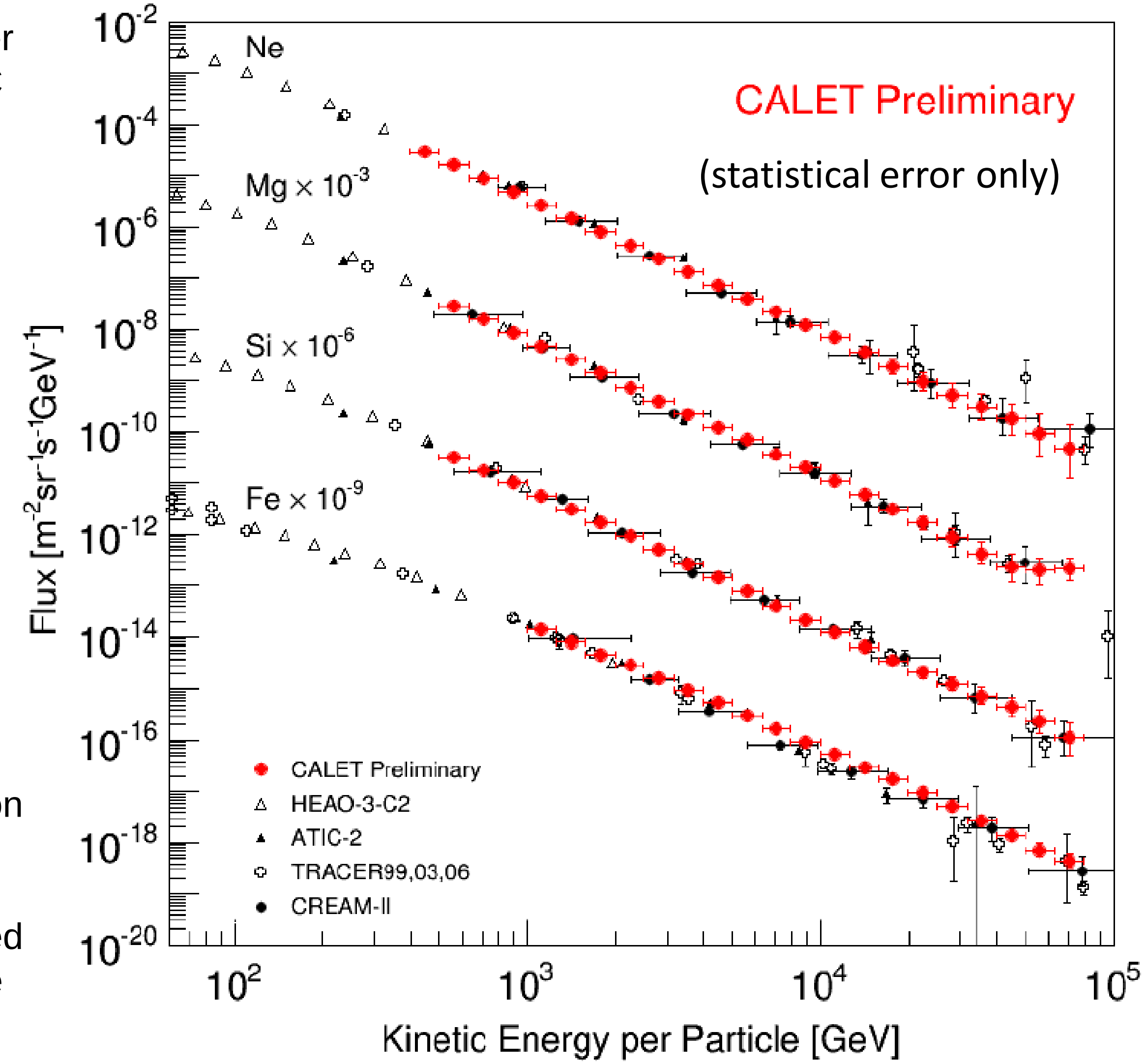
Preliminary Nuclei Measurements (Z= 8~26)

Y.Akaike et al., ICRC 2017, PoS 156.

<u>Independent analysis is carried out for heavy nuclei in Z=8-26.</u>

- Charge determination by CHD together with consistency requirement with IMC
- Consistent charge resolutions were obtained between the two analysis methods.





<u>Analysis Method (in particular for heavy nuclei)</u>

- Unfolding procedure based on *Bayes' theorem* is applied with response function from MC data.
- Charge selection efficiencies and contaminations from neighboring charged nuclei are also taken into account in the unfolding procedure.

Electron Identification

Simple Two Parameter Cut

F_E: Energy fraction of the bottom layer sum to the whole energy deposit sum in TASC

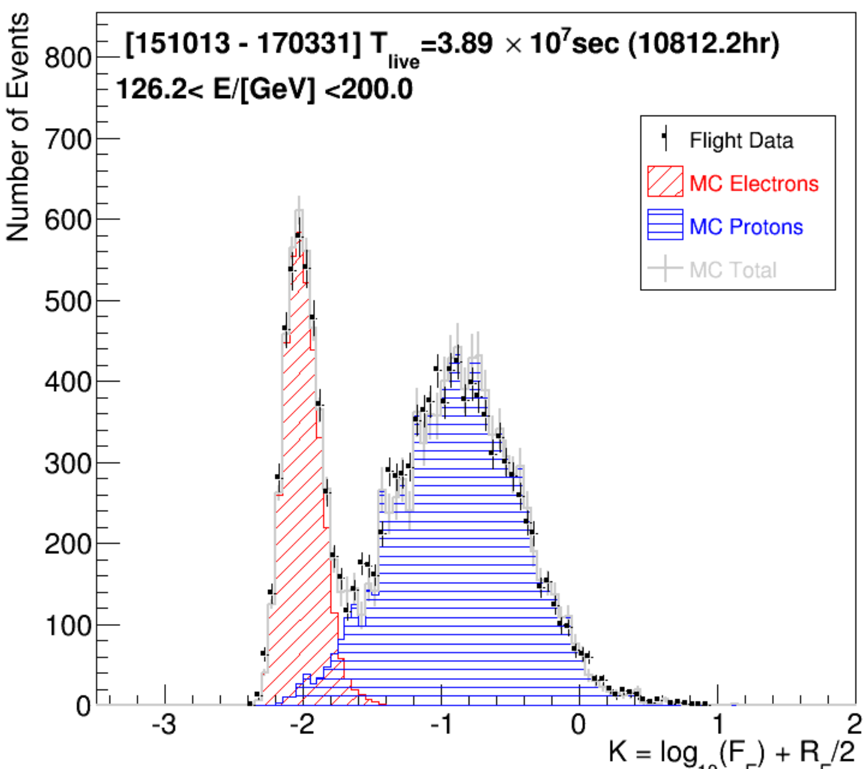
R_E: Lateral spread of energy deposit in TASC-X1

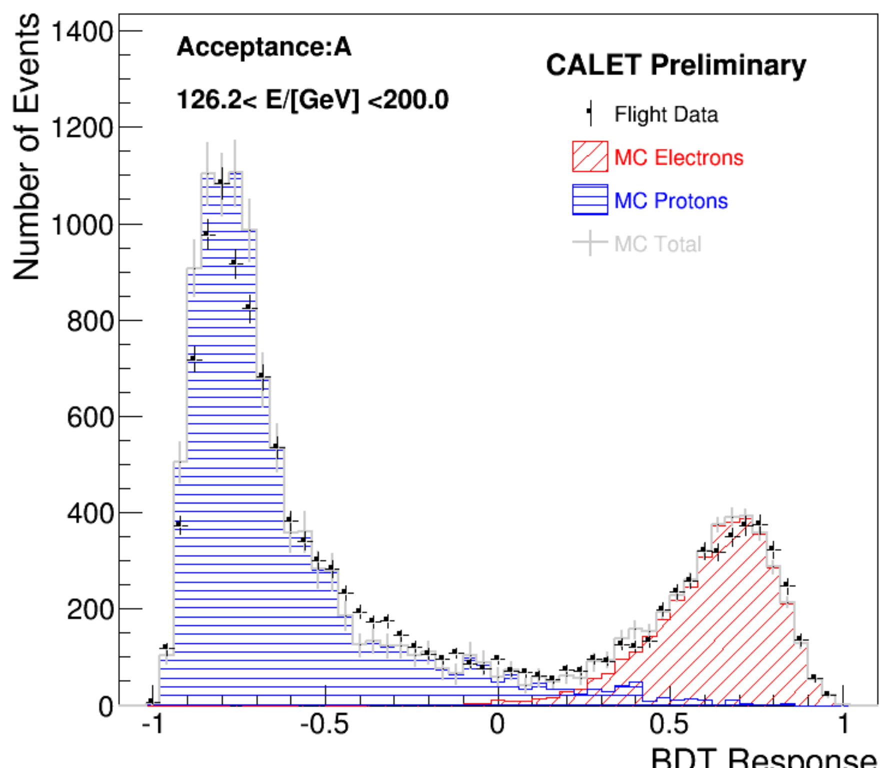
Separation Parameter K is defined as follows:

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

Boosted Decision Trees (BDT)

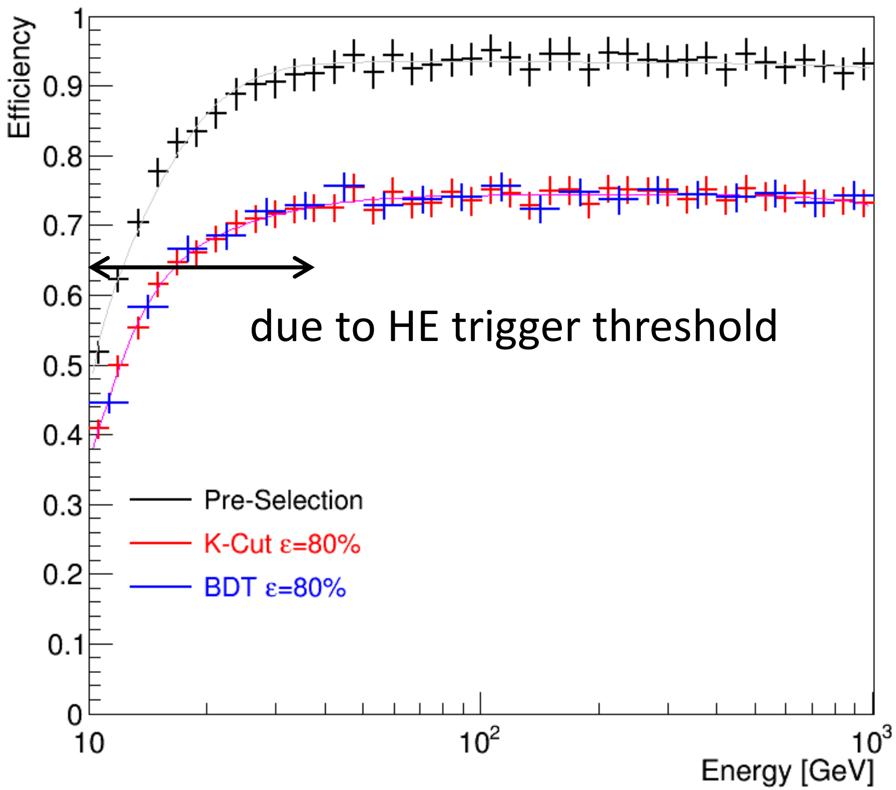
In addition to the two parameters in the left, TASC and IMC shower profile fits are used as discriminating variables.

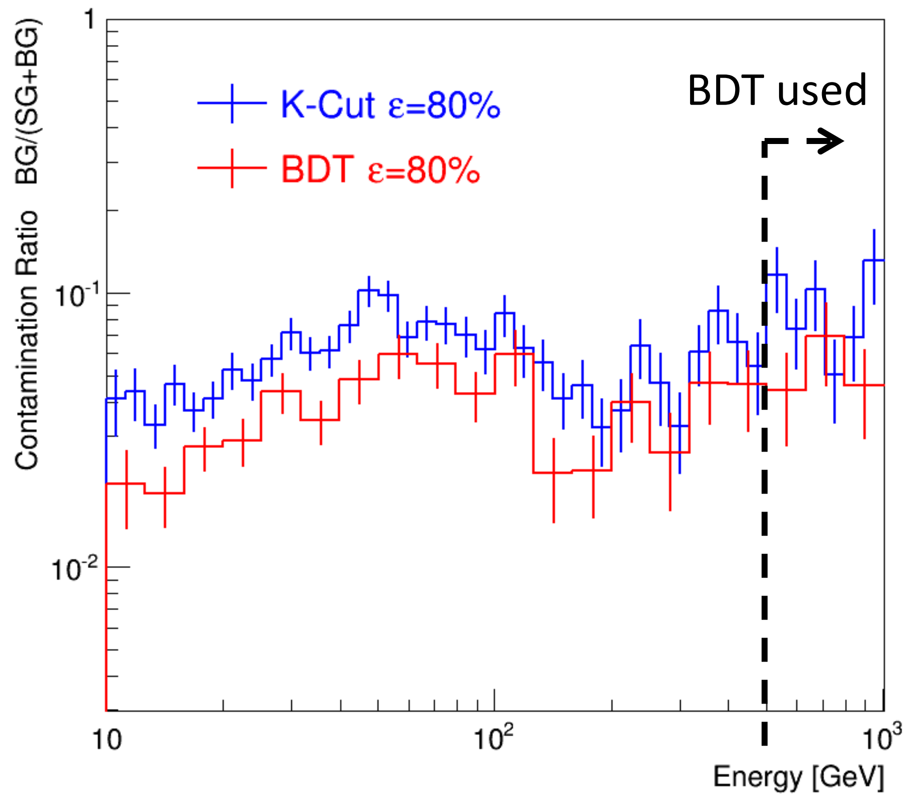




Electron Efficiency and Subtraction of Proton Contamination

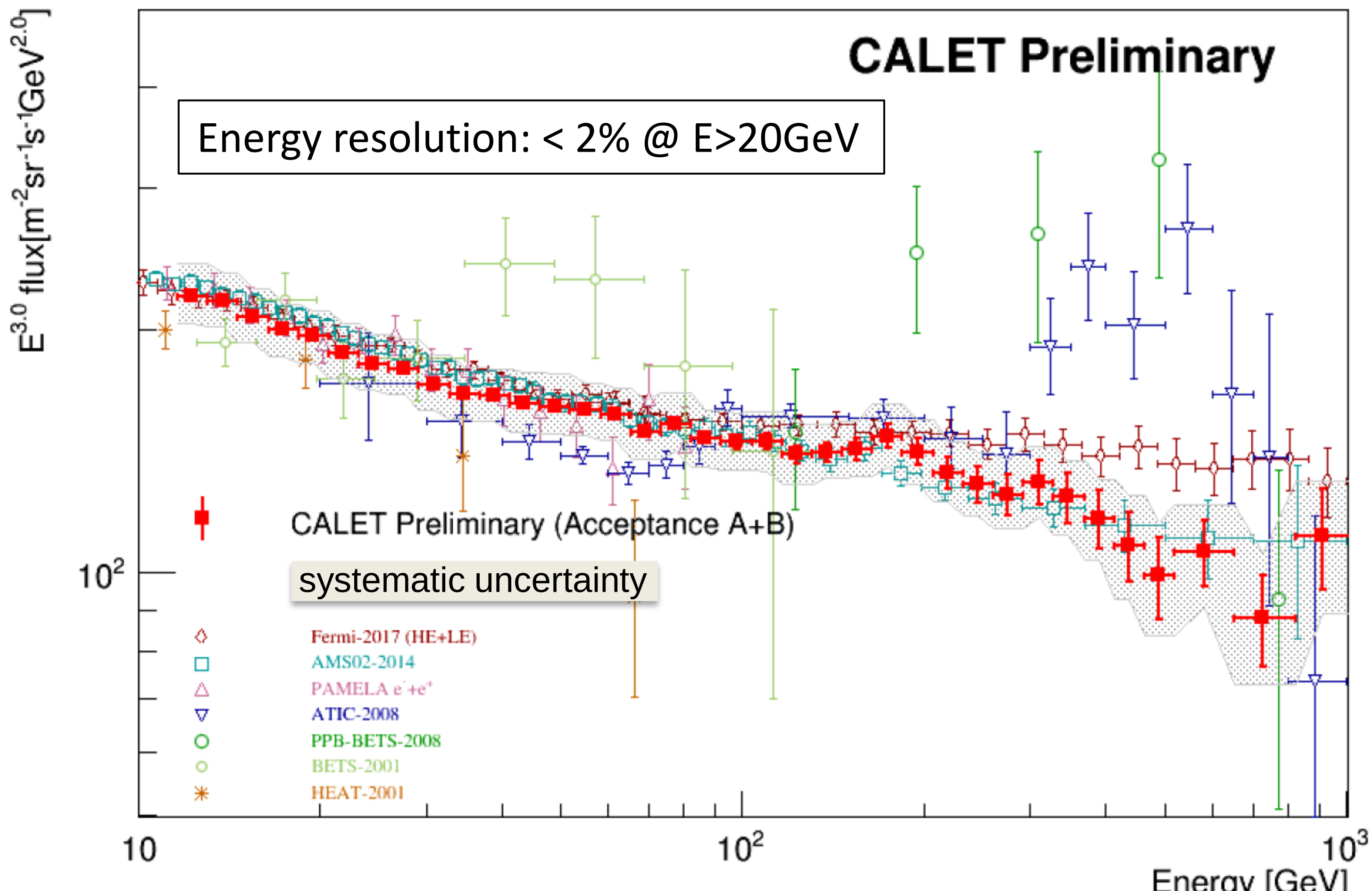
- Constant and high efficiency is the key point in our analysis.
- Simple two parameter cut is used in the low energy region while the difference in resultant spectrum are taken into account in the systematic uncertainty.





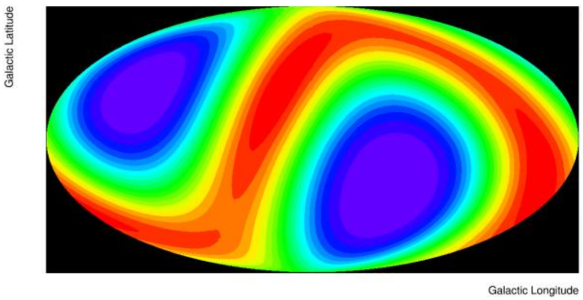
Total Electron Energy Spectrum in 10 GeV～1TeV

- Geometry Condition: SΩ= 570.3 cm²sr (55% for all acceptance)
- Live Time: 2015/10/13—2017/03/31（x 0.84)=> T= 3.89 x 10^7 sec
- Exposure: SΩT = 2.24 x 10^6 m^2 sr sec **~1/7 of full analysis for 5 years**
- Absolute energy scale determined by geomagnetic cutoff energy.



CALET γ–ray Sky in LE (>1GeV) Trigger

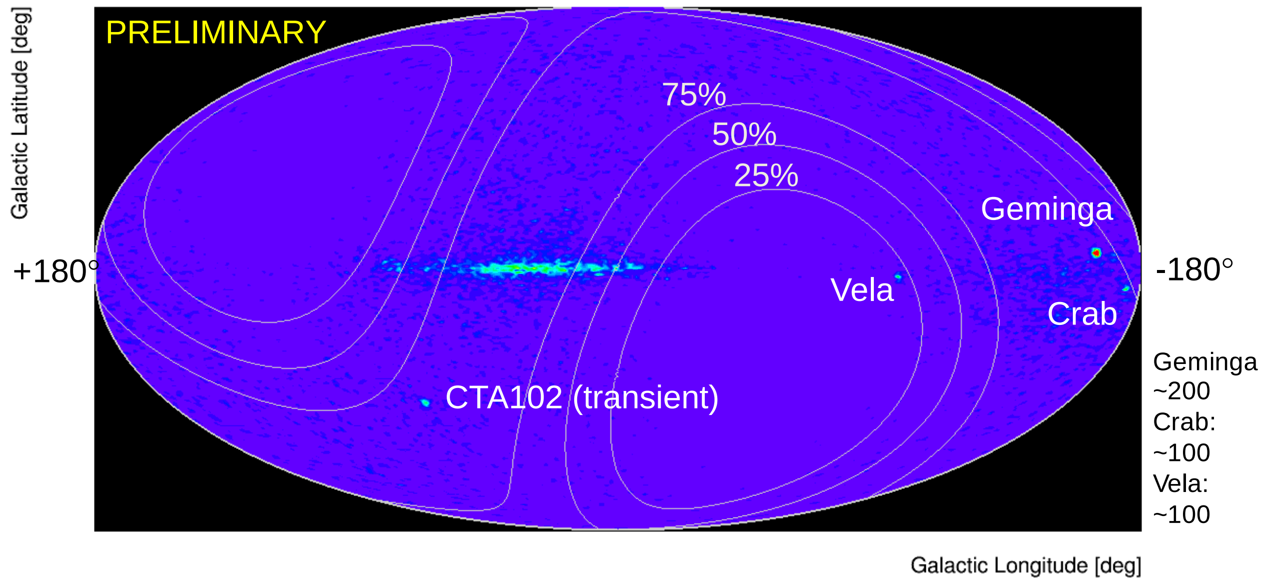
Exposore



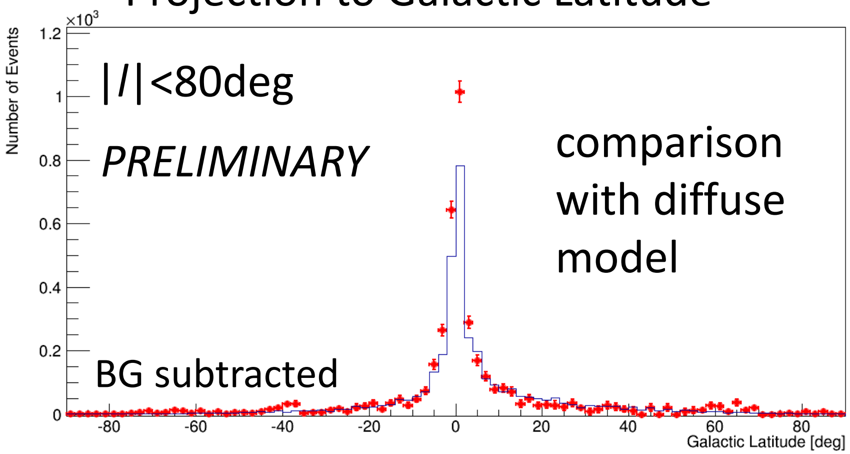
Exposure is limited to low latitude region
=> |declination| > 60 deg is hardly seen in LE gamma-ray trigger mode.

151013—170228 E>1GeV

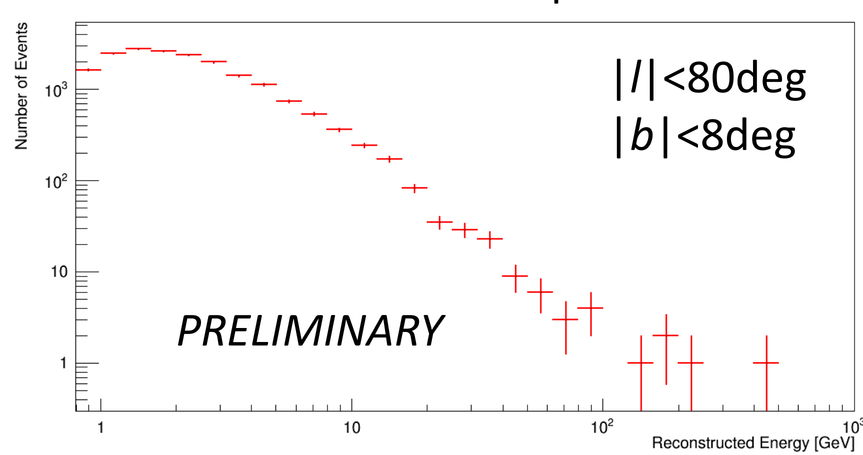
Galactic Coordinate



Projection to Galactic Latitude



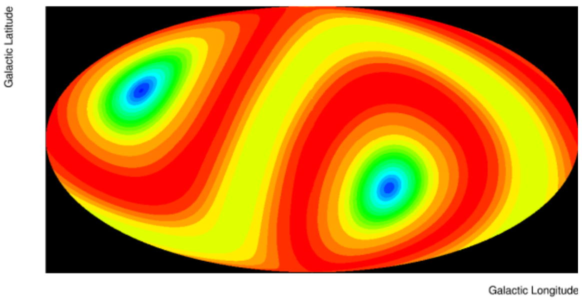
Galactic Diffuse Spectrum



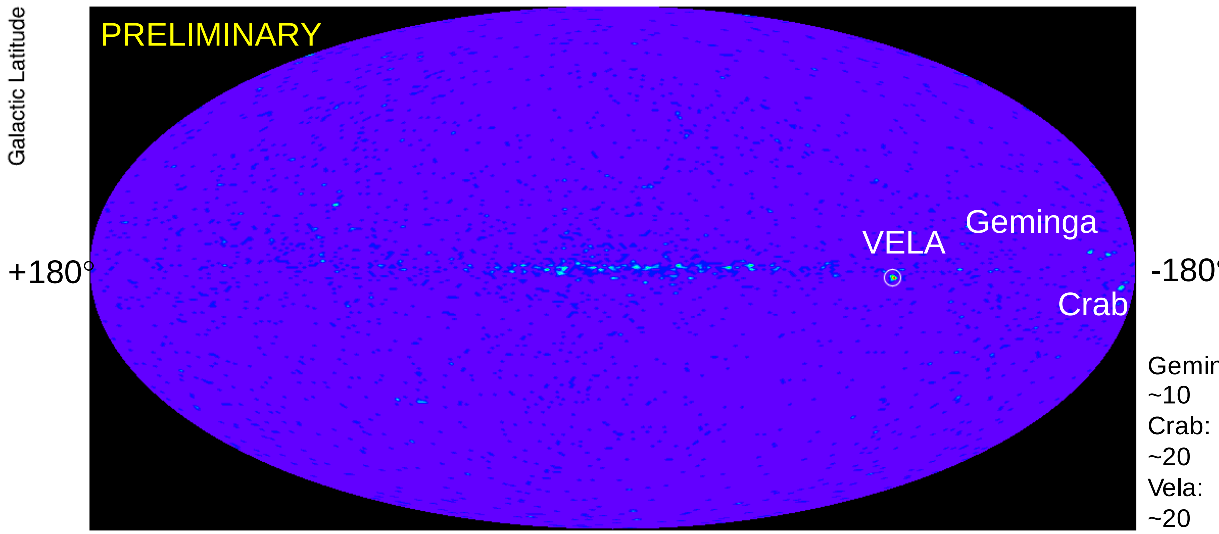
contribution from point sources is not included in the model

CALET γ–ray Sky in HE (>10GeV) Trigger

Exposure



151013—170228 E>10GeV Galactic Coordinate

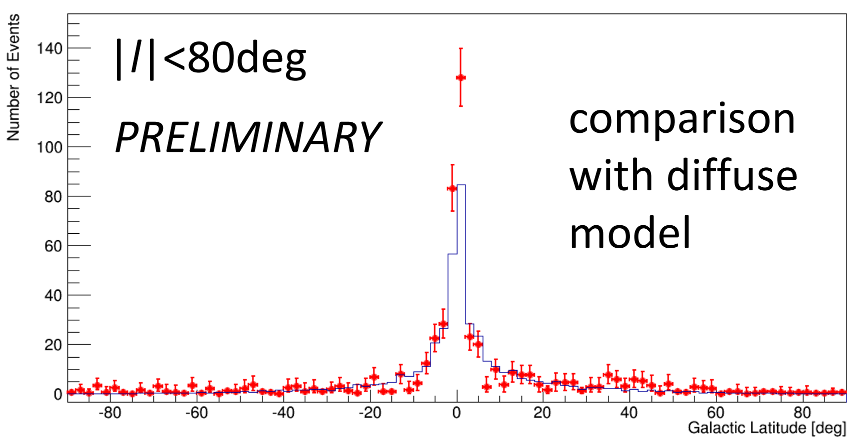


Geminga ~10
Crab: ~20
Vela: ~20

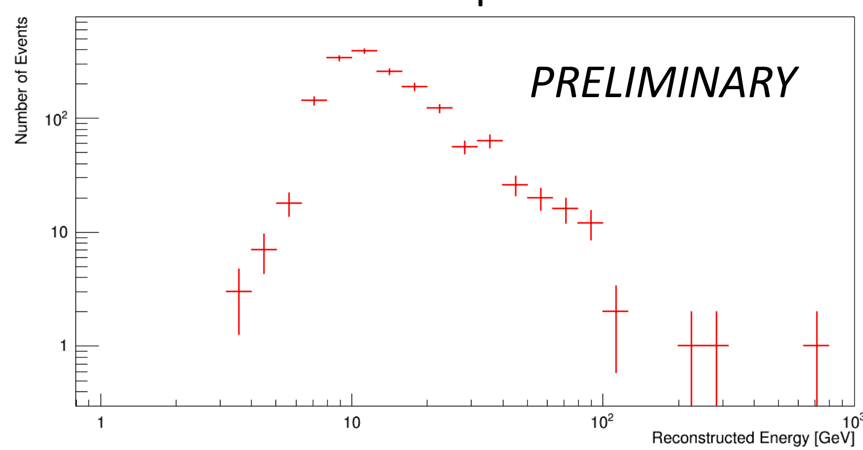
HE trigger is always ON
=> Exposure is more uniform than LE trigger.

Vela, Crab and Geminga are identified.

Projection to Galactic Latitude



Diffuse Spectrum



contribution from point sources is not included in the model

CALET UPPER LIMITS ON X-RAY AND GAMMA-RAY COUNTERPARTS OF GW 151226

Astrophysical Journal Letters 829:L20(5pp), 2016 September 20

The CGBM covered 32.5% and 49.1% of the GW 151226 sky localization probability in the 7 keV - 1 MeV and 40 keV - 20 MeV bands respectively. We place a 90% upper limit of 2×10^{-7} erg cm^{-2} s^{-1} in the 1 - 100 GeV band where CAL reaches 15% of the integrated LIGO probability (~1.1 sr). The CGBM 7 σ upper limits are 1.0×10^{-6} erg cm^{-2} s^{-1} (7-500 keV) and 1.8×10^{-6} erg cm^{-2} s^{-1} (50-1000 keV) for one second exposure. Those upper limits correspond to the luminosity of 3-5 $\times 10^{49}$ erg s^{-1} which is significantly lower than typical short GRBs.

CGBM light curve at a moment of the GW151226 event

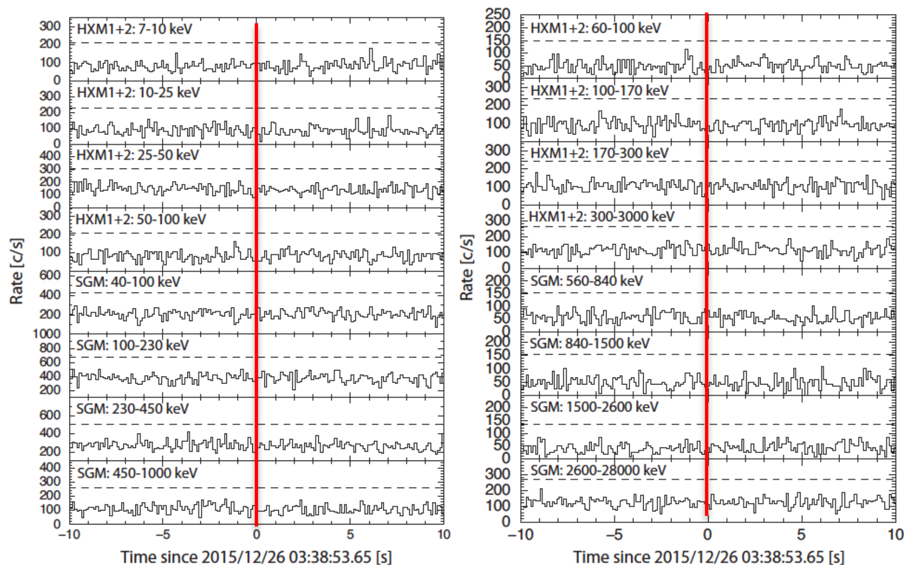


Figure 1. The CGBM light curves in 0.125 s time resolution for the high-gain data (left) and the low-gain data (right). The time is offset from the LIGO trigger time of GW 151226. The dashed-lines correspond to the 5 σ level from the mean count rate using the data of ±10 s.

Upper limit for gamma-ray burst monitors and Calorimeter

HXM: 7-500 keV

SGM: 50-1000 keV

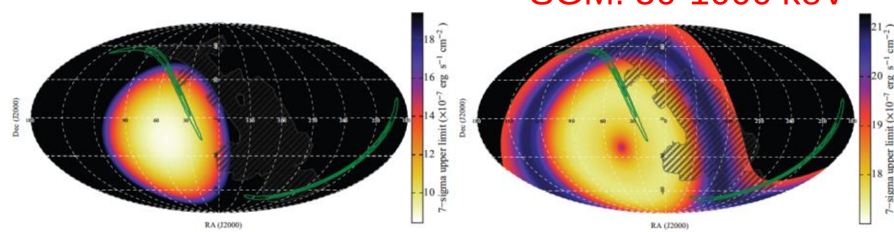


Figure 2. The sky maps of the 7 σ upper limit for HXM (left) and SGM (right). The assumed spectrum for estimating th upper limit is a typical BATSE S-GRBs (see text for details). The energy bands are 7-500 keV for HXM and 50-1000 keV fo SGM. The GW 151226 probability map is shown in green contours. The shadow of ISS is shown in black hatches.

Calorimeter: 1-100 GeV

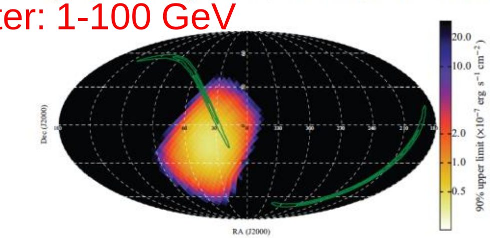


Figure 3. The sky map of the 90% upper limit for CAL in the 1-100 GeV band. A power-law model with a photon index of − is used to calculate the upper limit. The GW 151226 probability map is shown in green contours.

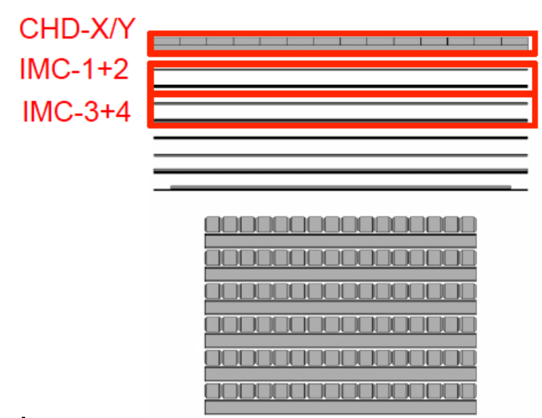
Summary and Future Prospects

- CALET was successfully launched on Aug. 19, 2015, and the detector is being very stable for observation since Oct. 13, 2015.
- As of Jun.30, 2017, total observation time is 627 days with live time fraction to total time to close 84%. Nearly 409 million events are collected with high energy (>10 GeV) trigger.
- Careful calibrations have been adopted by using "MIP" signals of the non-interacting p & He events, and the linearity in the energy measurements up to 10^6 MIPs is established by using observed events.
- Preliminary analysis of nuclei, total elections and gamma-rays have successfully been carried out to obtain the energy spectra in the energy range;
  Protons: 55 GeV~22 TeV, Ne-Fe: 500 GeV~70 TeV, Total electrons: 10 GeV~1 TeV.
- Preliminary analysis of UH cosmic-ray flux are done up to Z=40.
- CALET's CGBM detected nearly 60 GRBs (~20 % short GRB among them) per year in the energy range of 7keV-20 MeV, as expected. Follow-up observation of the GW events is carried out. (Not reported in this talk)
- The so far excellent performance of CALET and the outstanding quality of the data suggest that a 5-year observation period is likely to provide a wealth of new interesting results.

Preliminary Ultra Heavy Nuclei Measurements (26 < Z ≤ 40)

- CALET measures the relative abundances of ultra heavy nuclei through $_{40}$Zr
- Trigger for ultra heavy nuclei:
  - signals of only CHD, IMC1+2 and IMC3+4 are required
  - ➡ an expanded geometrical acceptance (4000 cm^{2}sr)
- Energy threshold depends on the geomagnetic cutoff rigidity

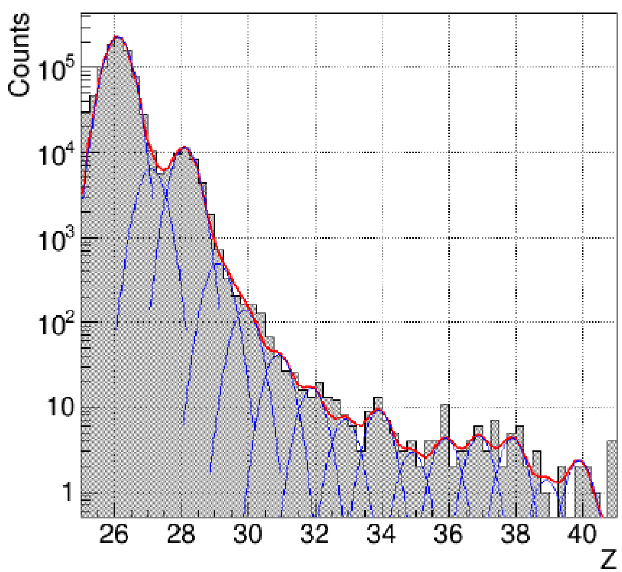
Onboard trigger for UH events



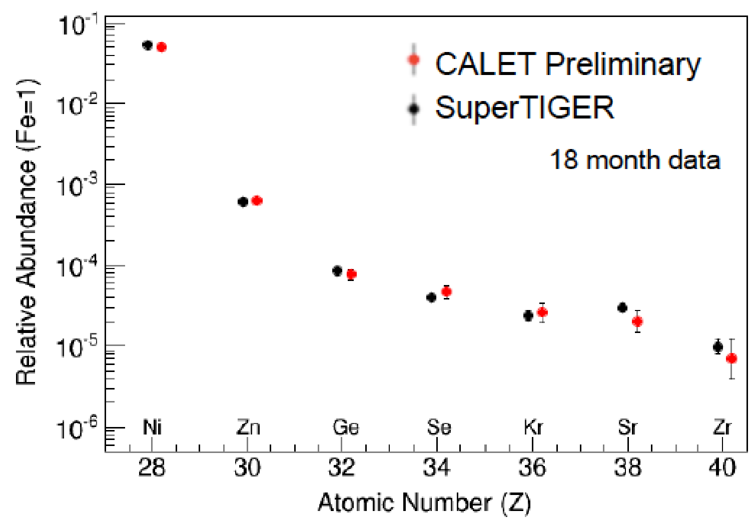
<u>Data analysis</u>

- ☐ Event Selection: Vertical cutoff rigidity > 4GV & Zenith Angle < 60 degrees
- ☐ Contamination from neighboring charge are determined by multiple-Gaussian function

Charge distribution



Relative abundance (Fe=1)



CALET's first publication NOT for Cosmic Rays

Accepted article online 25 APR 2016

Geophysical Research Letters

Relativistic electron precipitation at International Space Station: Space weather monitoring by Calorimetric Electron Telescope

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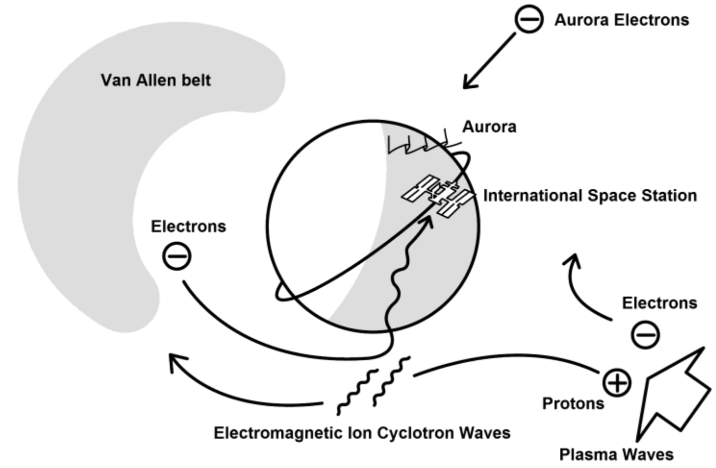
Abstract The charge detector (CHD) of the Calorimetric Electron Telescope (CALET) on board the International Space Station (ISS) has a huge geometric factor for detecting MeV electrons and is sensitive to relativistic electron precipitation (REP) events. During the first 4 months, CALET CHD observed REP events mainly at the dusk to midnight sector near the plasmapause, where the trapped radiation belt electrons can be efficiently scattered by electromagnetic ion cyclotron (EMIC) waves. Here we show that interesting 5–20 s periodicity regularly exists during the REP events at ISS, which is useful to diagnose the wave-particle interactions associated with the nonlinear wave growth of EMIC-triggered emissions.

Space Weather is now a new topic of the CALET science !!

Relativistic Electron Precipitation



CHD X and Y count rate increase by REP