CALETの初期成果観測報告

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早稲田大学　理工研/物理
JAXA　有人宇宙技術センター

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日本物理学会@宮崎大学　21pSP-1　　2016年9月21日

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CALET Observations and Science Targets

Main Telescope: Calorimeter (CAL)
- Electrons: 1 GeV – 20 TeV
- Gamma-rays: 10 GeV – 10* TeV

浅岡陽一 21pSP-2 Bursts: > 1 GeV)

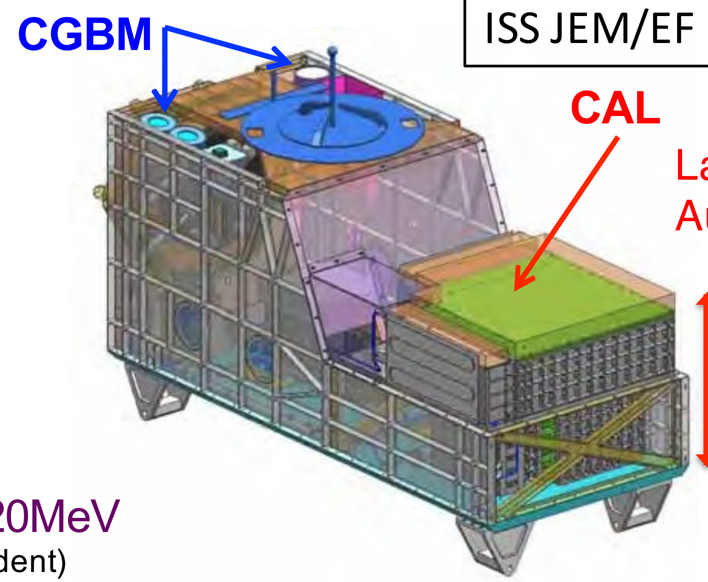
- Protons and Heavy Ions:
  10's of GeV – 1,000* TeV
- Ultra Heavy (Z>28) nuclei:
  E > 600 MeV/nucleon

Gamma-ray Burst Monitor (CGBM)
- X-rays/Soft Gamma-rays: 7keV – 20MeV

川久保雄太 23aSP-1

(* statistics dependent)

ISS JEM/EF Payload

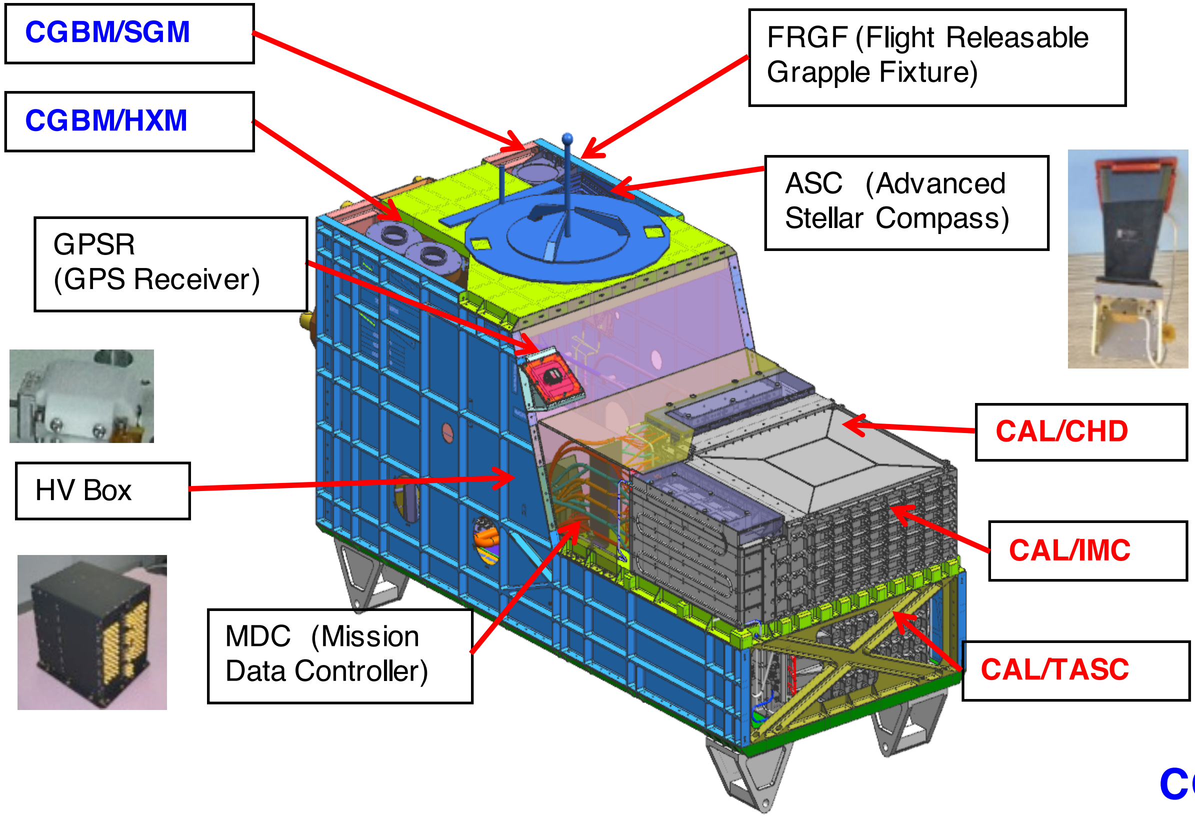


Launched on Aug.19, 2015

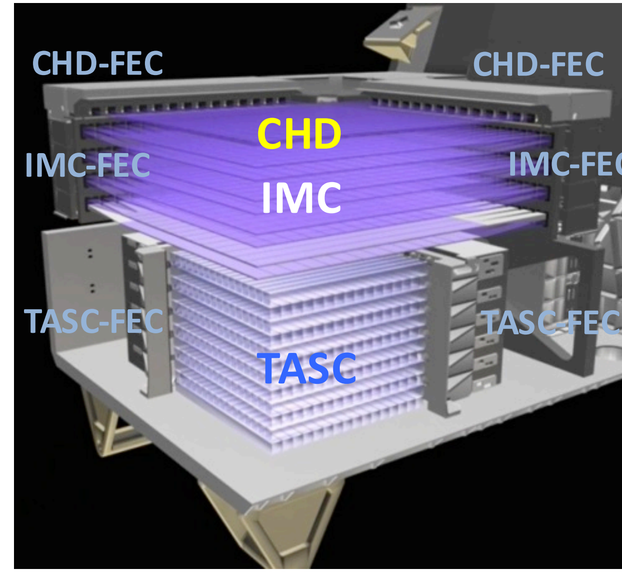
$30\ X_0$: nearly atmospheric depth

Science Objectives	Observation Targets
Nearby Cosmic-ray Sources	Electron spectrum in trans-TeV region
Dark Matter H.Motz 21pSP-9	Signatures in electron/gamma energy spectra in 10 GeV – 10 TeV region
Origin and Acceleration of Cosmic Rays	p-Fe over several tens of GeV, Ultra-Heavy Ions
Cosmic–ray Propagation in the Galaxy	B/C ratio up to several TeV /nucleon
Solar Physics	Electron flux below 10 GeV
Gamma-ray Transients	X-rays/Gamma-rays in 7 keV –20 MeV

CALET System Overview



CALORIMETER (CHD/IMC/TASC)



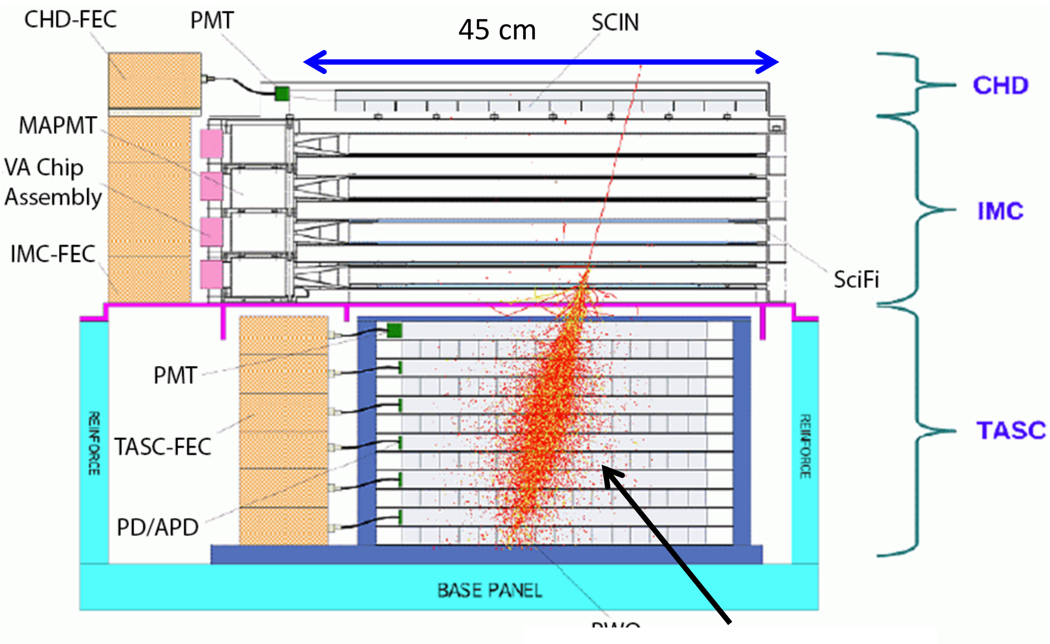
- Mass: 612.8 kg
- JEM Standard Payload Size
  1850mm(L) × 800mm(W) × 1000mm(H)
- Power Consumption: 507 W(max)
- Telemetry:
  Medium 600 kbps (6.5GB/day) / Low 50 kbps

CGBM (CALET Gamma-ray Burst Monitor)

CALET: Instrument Overview

CERN-SPS ビーム実験：
p,e　田村忠久　21pSP-6
Heavy 多田真希子　21pSP-5

Field of view: ~ 45 degrees (from the zenith)
Geometrical Factor: ~ 0.12 m^2sr (for electrons)



1 TeV electron shower

Unique features of CALET

A dedicated charge detector + multiple dE/dx track sampling in the IMC allow to identify individual nuclear species (Δz~0.15-0.35e).

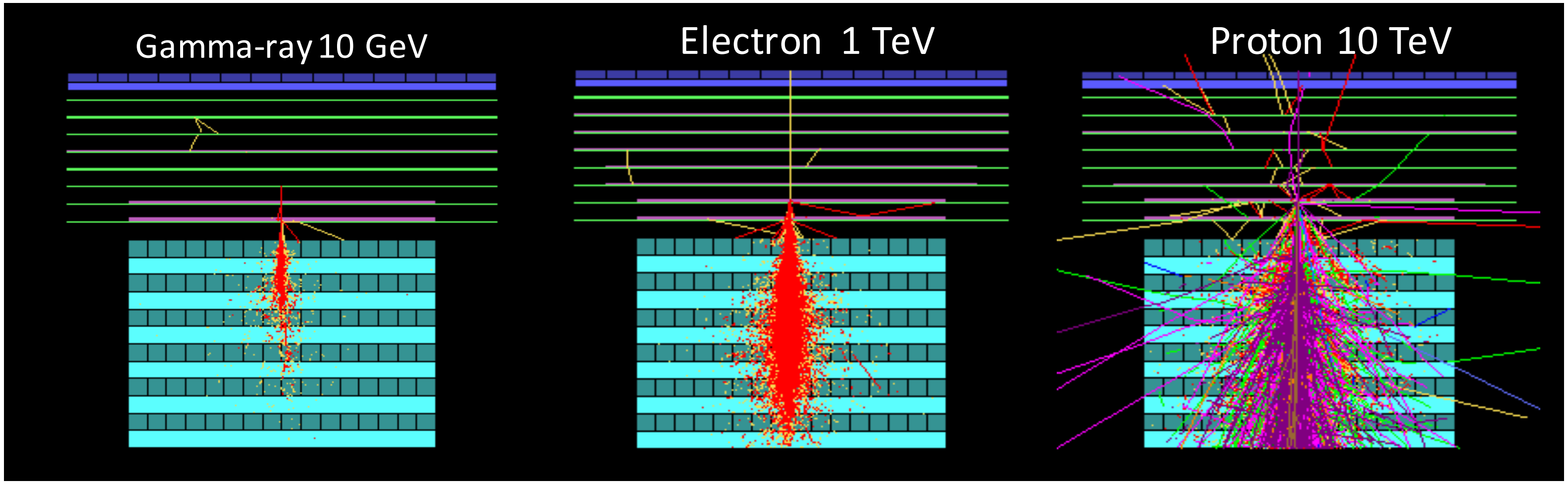
Thick(~30 X_0), fully active calorimeter allows measurements well into the TeV energy region with excellent energy resolution (~2-3%)

High granularity imaging pre-shower calorimeter accurately identify the arrival direction of incident particles (~0.2°) and the starting point of electro-magnetic showers.

Combined, they powerfully separate electrons from the abundant protons: rejection power ~10^5.

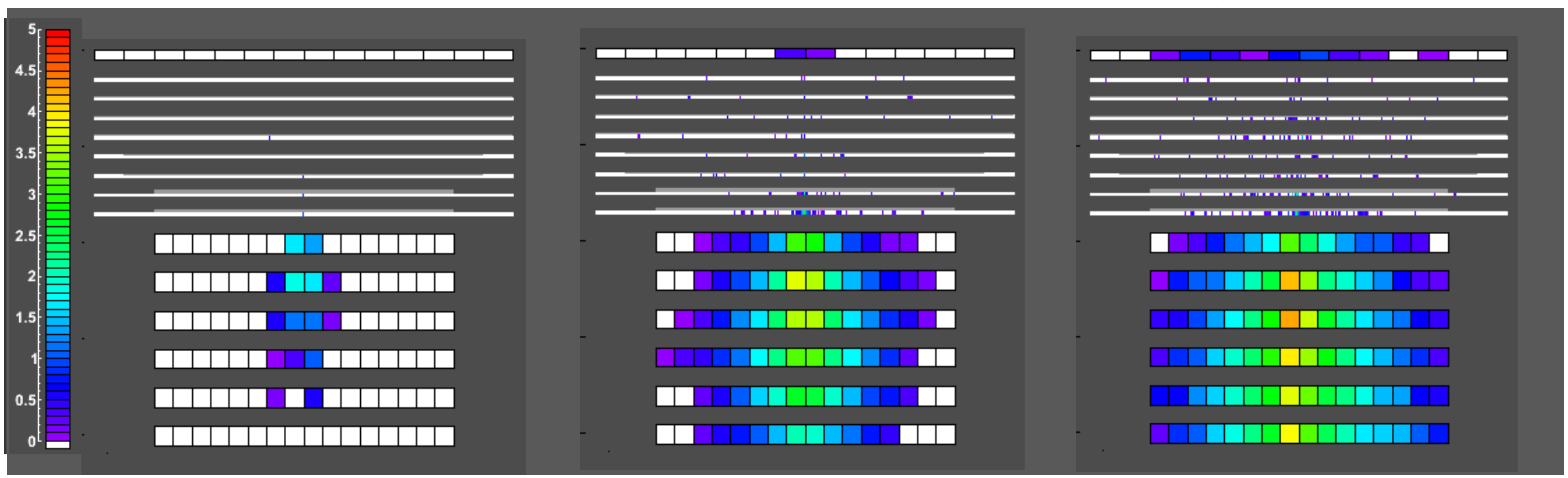
	CHD (Charge Detector)	IMC (Imaging Calorimeter)	TASC (Total Absorption Calorimeter)
Function	Charge Measurement (Z=1-40)	Arrival Direction, Particle ID	Energy Measurement, Particle ID
Sensor (+ Absorber)	**Plastic Scintillator : 14 × 1 layer (x,y)** Unit Size: 32mm x 10mm x 450mm	**SciFi : 448 x 8 layers (x,y) = 7168** Unit size: 1mm^2 x 448 mm **Total thickness of Tungsten: 3 X_0**	**PWO log: 16 x 6 layers (x,y)= 192** Unit size: 19mm x 20mm x 326mm **Total Thickness of PWO: 27 X_0**
Readout	**PMT+CSA**	**64 -anode PMT(HPK) + ASIC**	**APD/PD+CSA** PMT+CSA (for Trigger)@top layer

CALET/CAL Shower Imaging Capability (Simulation)



シャワー軸再構成方法: 市村雅一 21pSP-4

In Detector Space

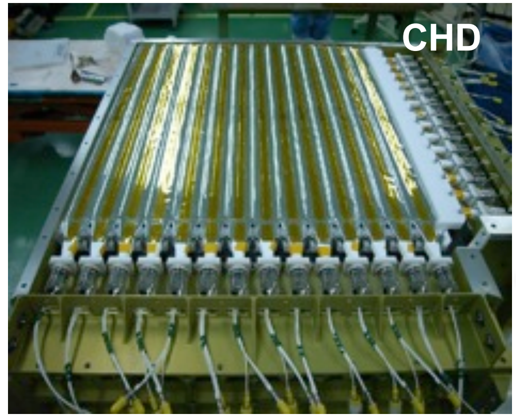


- Proton rejection power of 10^5 can be achieved with IMC and TASC shower imaging capability.
- Charge of incident particle is determined to σ_Z=0.15-0.35 with the CHD.

Calorimeter Flight Components

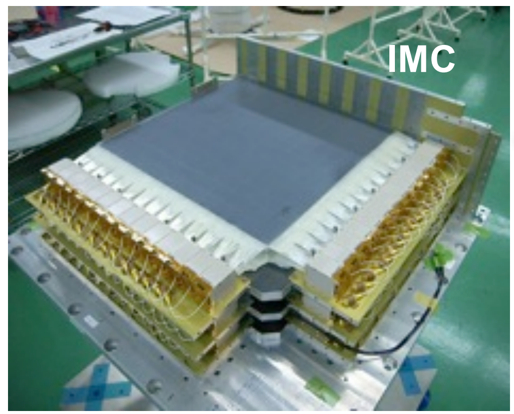
CHD

14 × 1 layer (x,y) = 28
32mm x 10mm x 450mm



IMC

448 x 8 layers (x,y) = 7168
1mm^2 x 448 mm

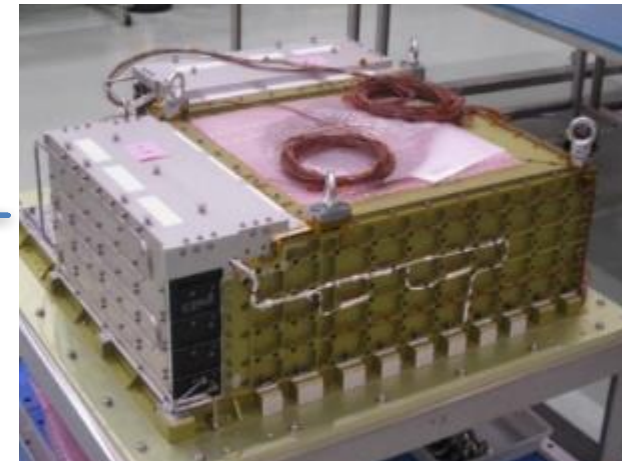


TASC

16 x 6 layers (x,y)= 192
19mm x 20mm x 326mm

Completed Component with Front End Circuit

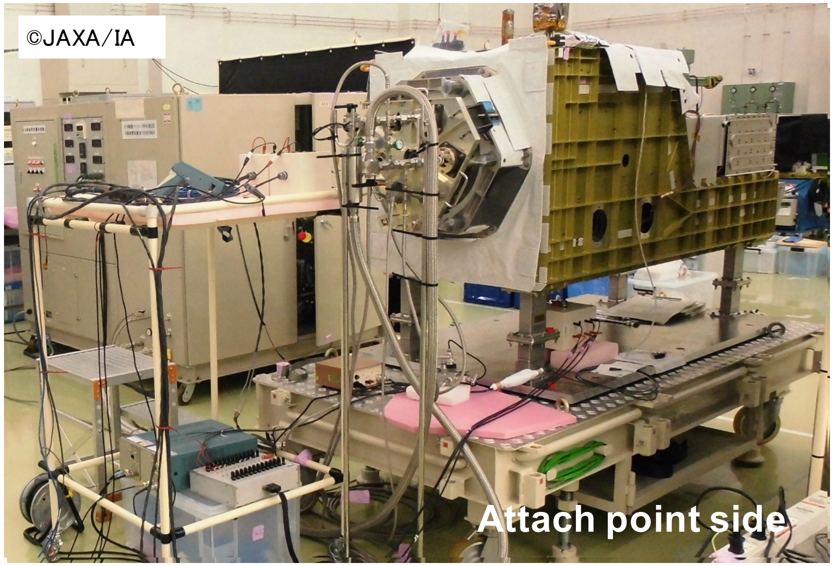
CHD/IMC

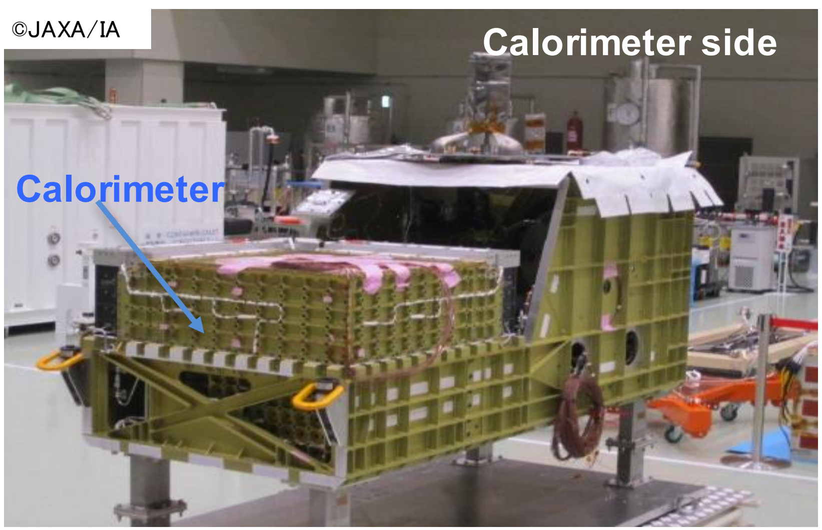


TASC

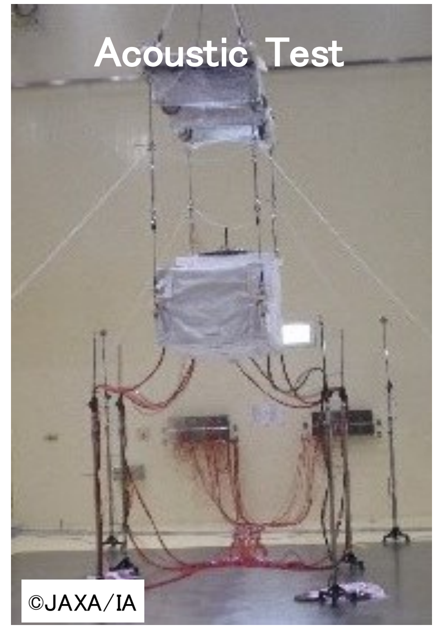
System Test of Flight Model

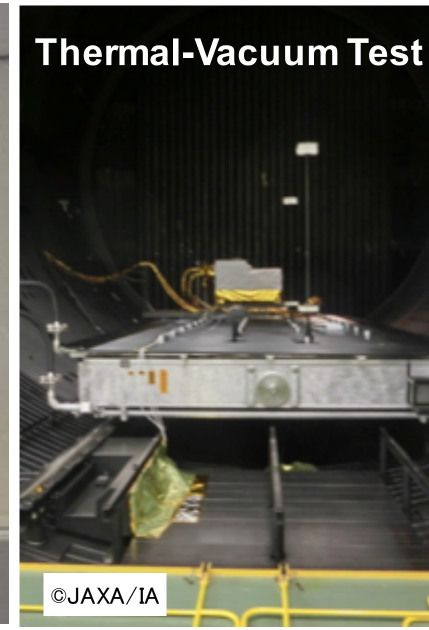
System Integration Test for Payload

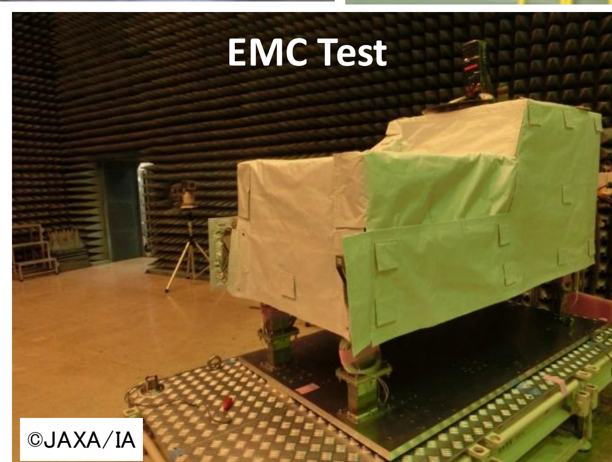




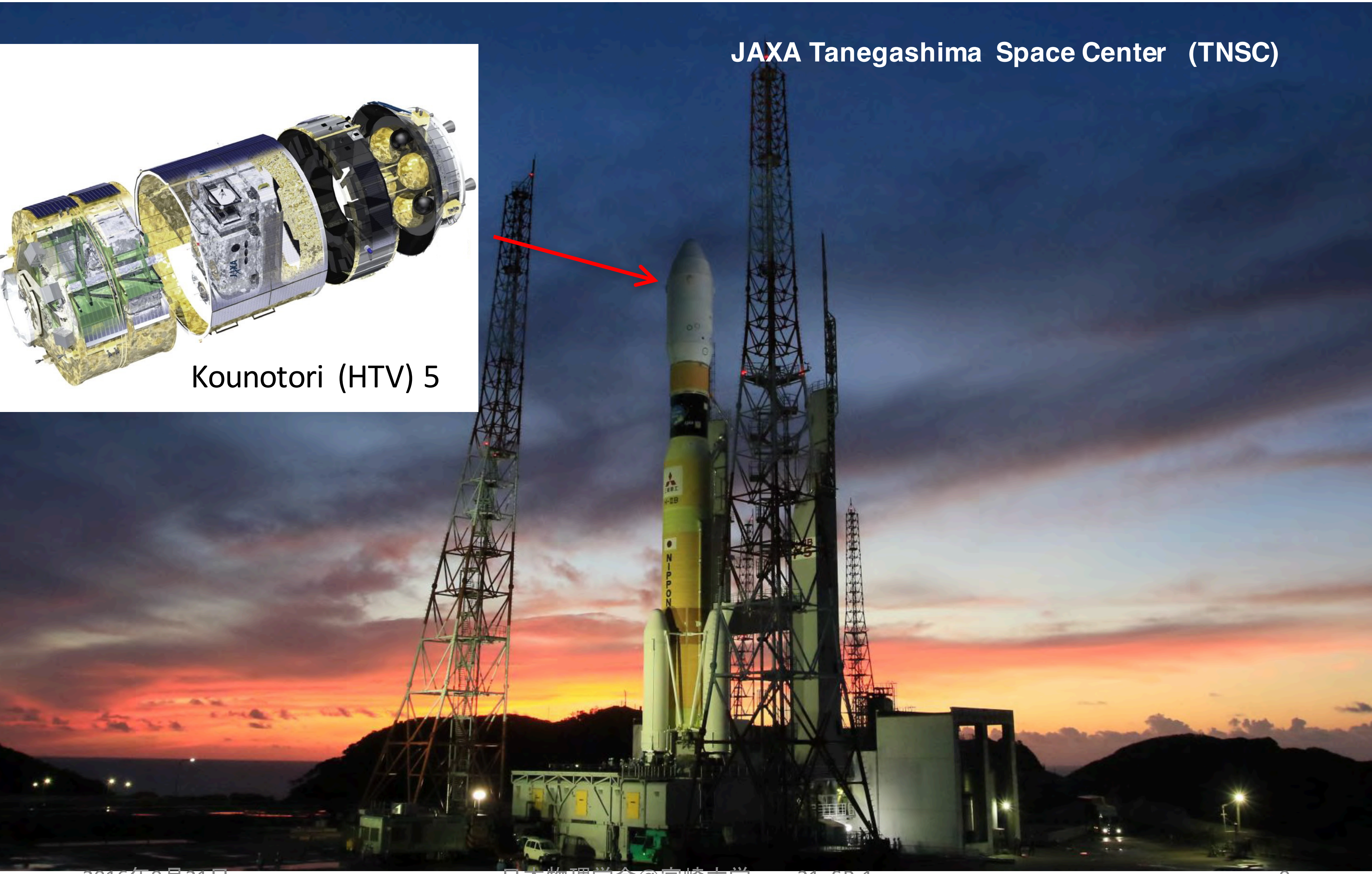
Acoustic test, Thermal–Vacuum test and EMC test at Tsukuba Space Center (JAXA)







CALET Launch: August 19, 2015 at 12:50:49 (UT)



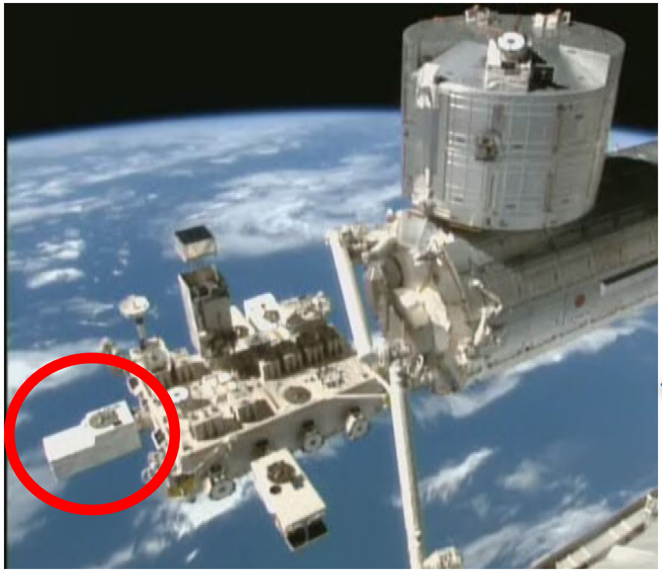
CALET is now on the ISS !

① **August 19th**: Launch of the Japanese H2-B rocket by JAXA at 20:50:49 (JST)

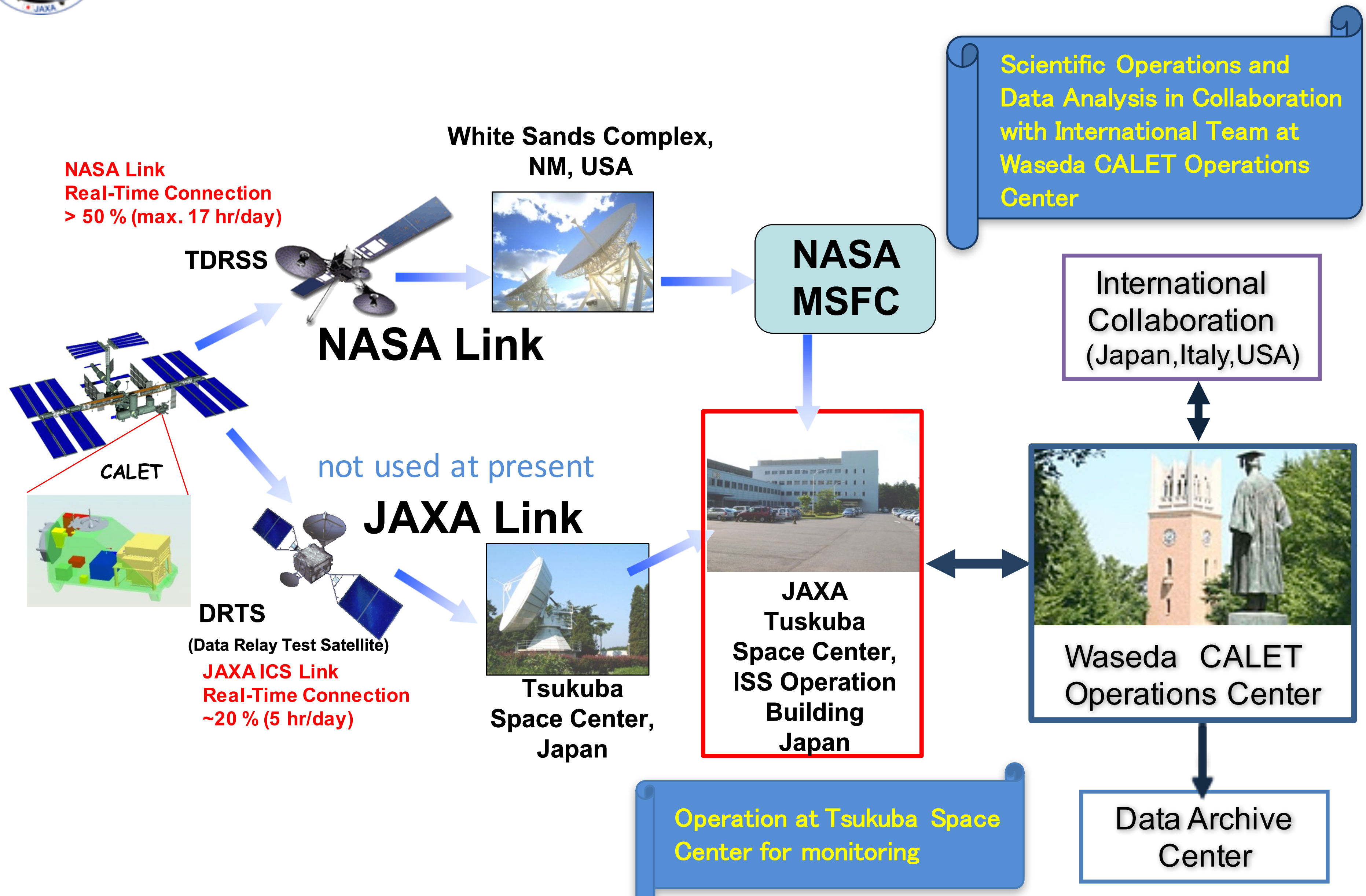
② **August 24th:** The HTV-5 Transfer Vehicle (HTV-5) is grabbed by the ISS robotic arm.

③ **August 24th:** The HTV-5 docks to the ISS at 2:28 (JST).

④ **August 25th:** CALET is emplaced on port #9 of the JEM-EF and data communication with the payload is established.



Data Downlink Using TDRSS and Operations Center



Overview of Trigger Modes for CALET

Trigger	Targets
High Energy Shower Trigger (HE)	- High energy electrons (10GeV ～20TeV) - High energy gamma rays (10GeV ～10TeV) - Nuclei (a few10GeV～1000TeV)
Low Energy Shower Trigger (LE)	- Low energy electron at high latitude (1GeV ～10GeV) - GeV gamma-rays originated from GRB (1GeV ～) - Ultra heavy nuclei (combined with heavy mode)
Single Trigger (Single)	- For detector calibration : penetrating particles (mainly non-interacting protons and heliums)

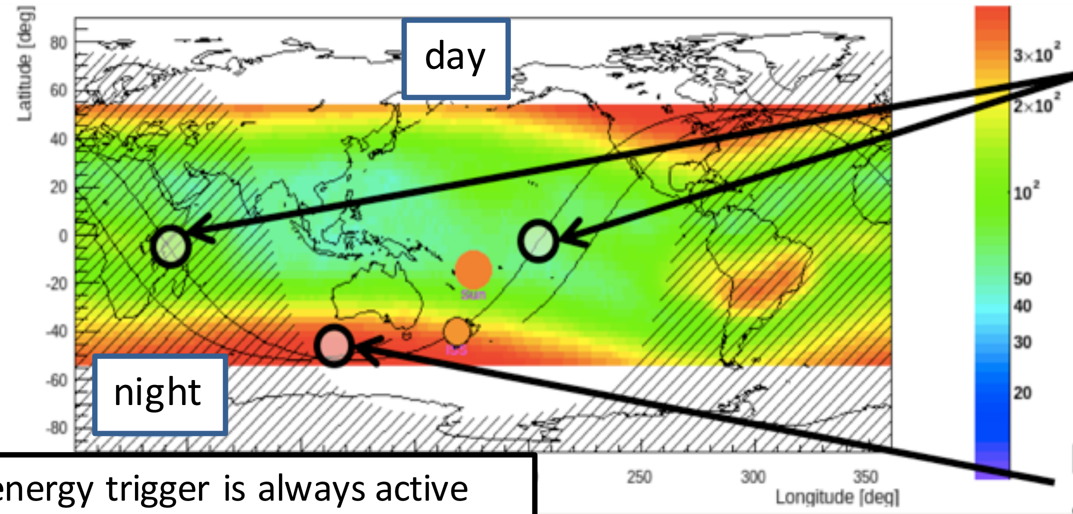
(*) In addition to above 3 trigger modes, heavy modes are defined for each of the above trigger mode. They are omitted here for simple explanation.

Trigger	Targets
Auto Trigger (Pedestal/Test Pulse)	- For calibration: ・ ADC offset measurement (Pedestal) ・ FEC's response measurement (Test pulse)

ISS Orbit and CALET On-orbit Operations

Concept of on-orbit operations

ISS orbit: inclination 51.6 degree, ~400 km

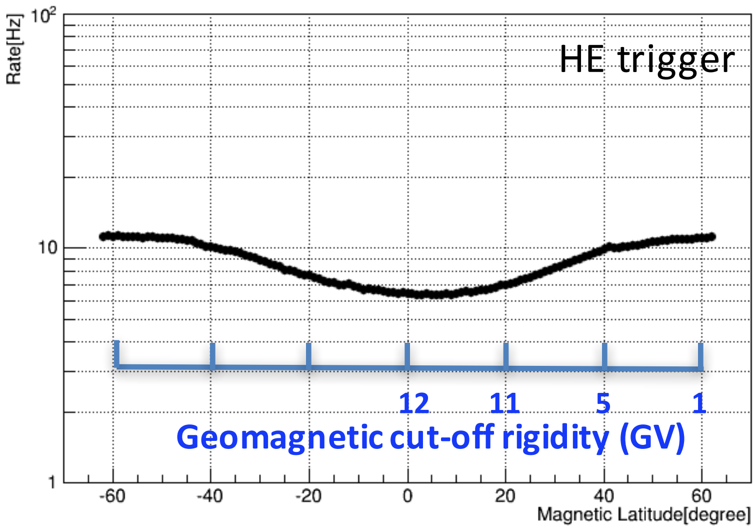


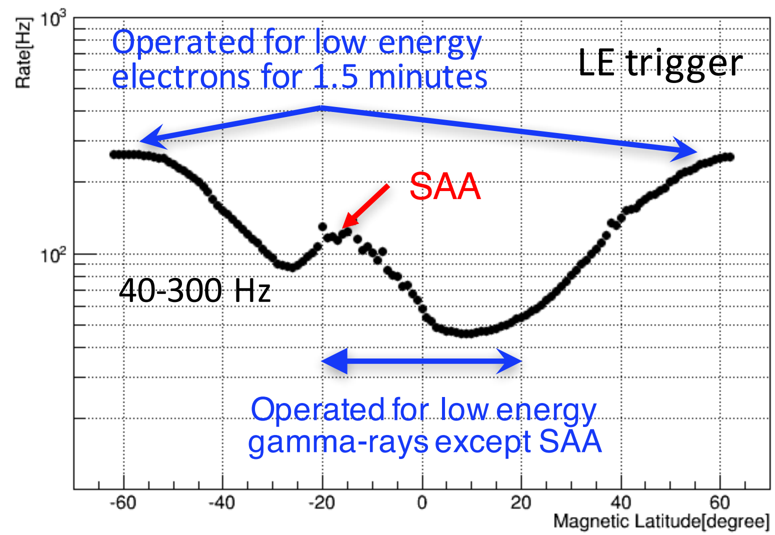
Pedestal data acquisition

Schedule file: sequence of time and command

Low energy electron shower data acquisition

Dependence of the count rate on geomagnetic latitude



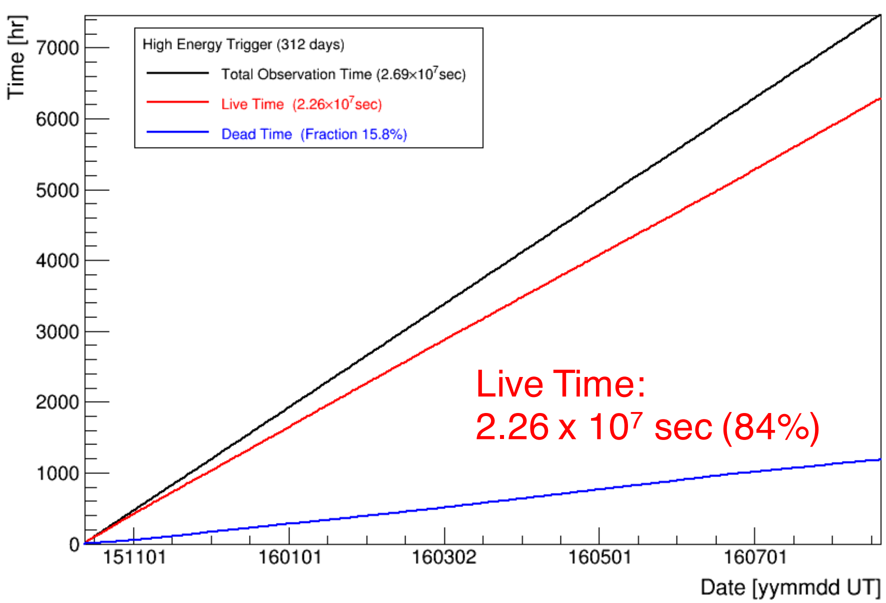


Observation by High Energy Trigger

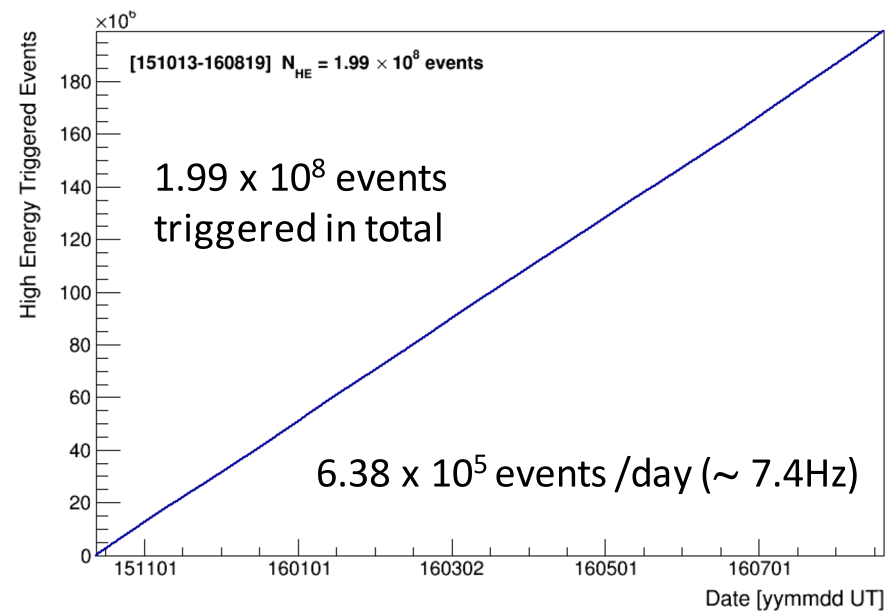
Observation by High Energy Trigger for 312 days : Oct. 13, 2015 – Aug.19, 2016

- The exposure, SΩT, has reached to ~27.1 m^2 sr day. by continuous observation.
- Total number of the triggered events is ~ 200 million with a live time of 84 %.

Accumulated observation time (live, dead)



Accumulated triggered event number



Energy Calibration Using “MIP” in Flight with Tests on Ground

Intrinsic Advantage of the CALET Instrument :

EM Shower Energy Measurement =TASC Energy Sum × “Small” Correction

- Active and thick calorimeter absorbs most of the electromagnetic energy (~95%) up to the TeV region
  - Fine energy resolution of ~ 2 %
  - Capability of measuring shower energy from 1GeV to 1000 TeV in 6 order of magnitude !

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- In principle, energy measurement with very small systematic error is possible.
- Needs to obtain the ADC unit to energy conversion factor and to calibrate the whole dynamic range channel by channel

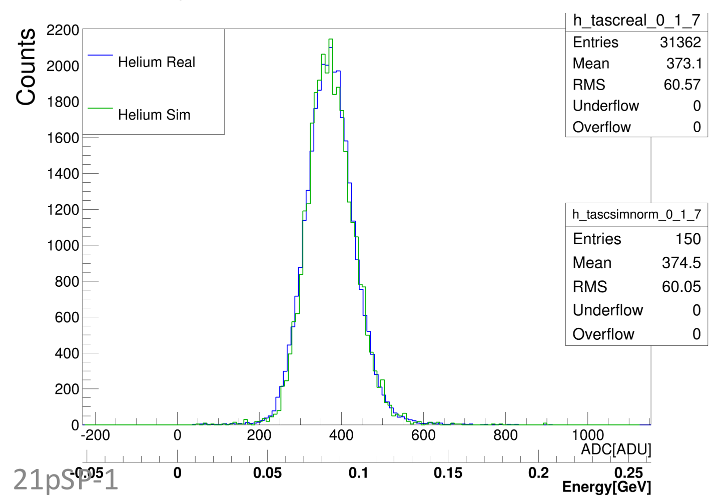
On orbit : Energy conversion factor using “MIP” of p or He

- Position and temperature dependence
- Latitude dependence due to rigidity cutoff

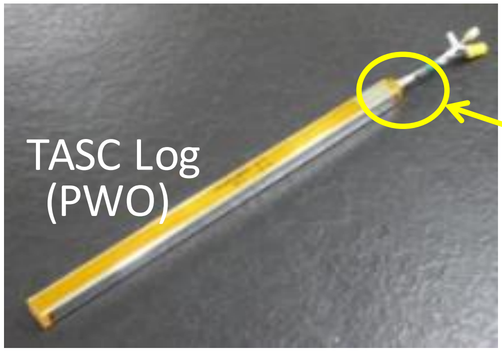
On ground: Linearity measurements for the whole dynamic range

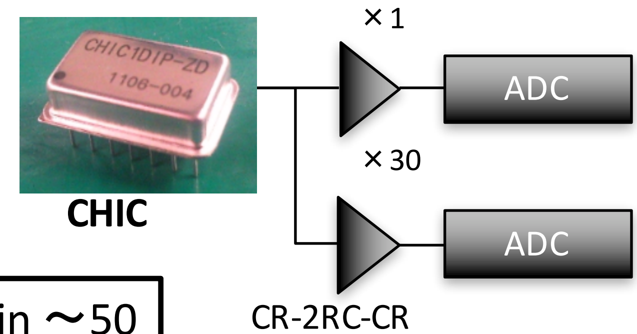
- CHD/IMC – Charge injection
- TASC – UV Laser irradiation (end-to-end)

“MIP” peak in PWO: Obs. vs. MC

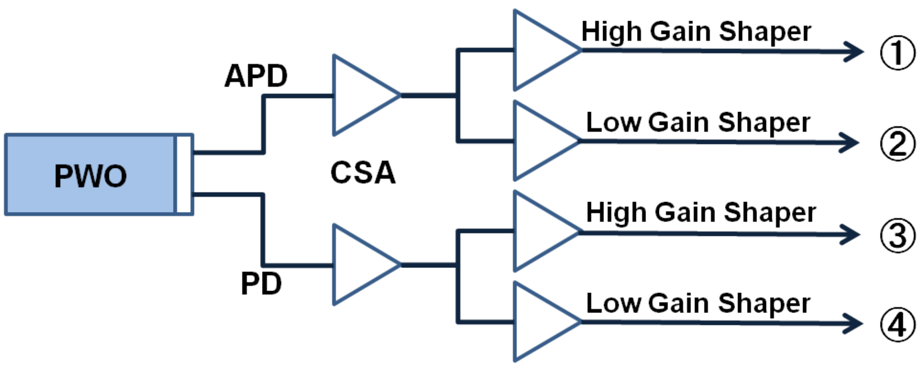


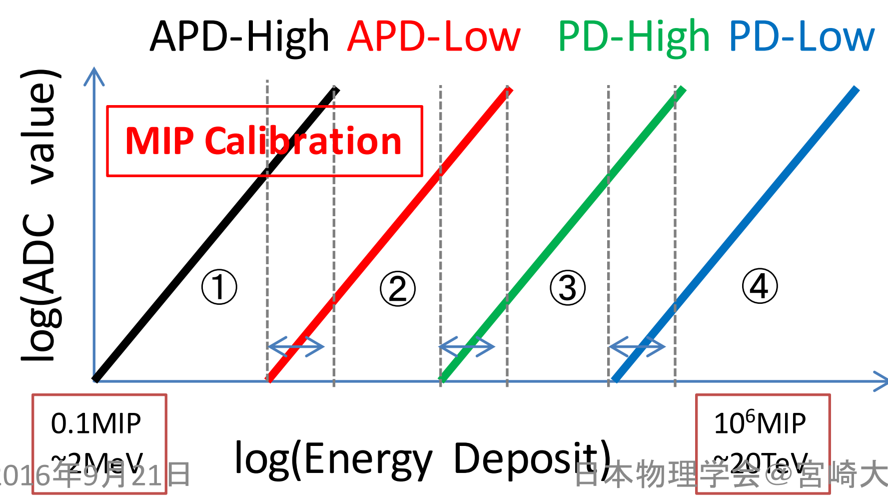
Energy Calibration in Dynamic Range of 1-10^6 MIP in TASC





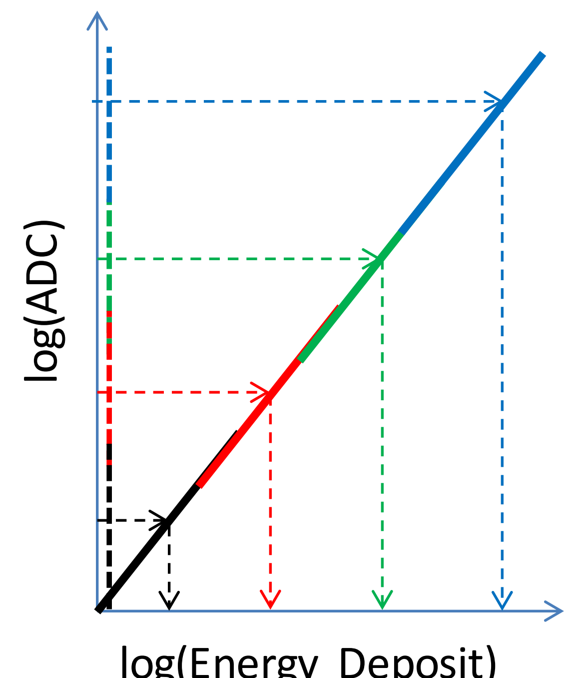
APD gain ～50





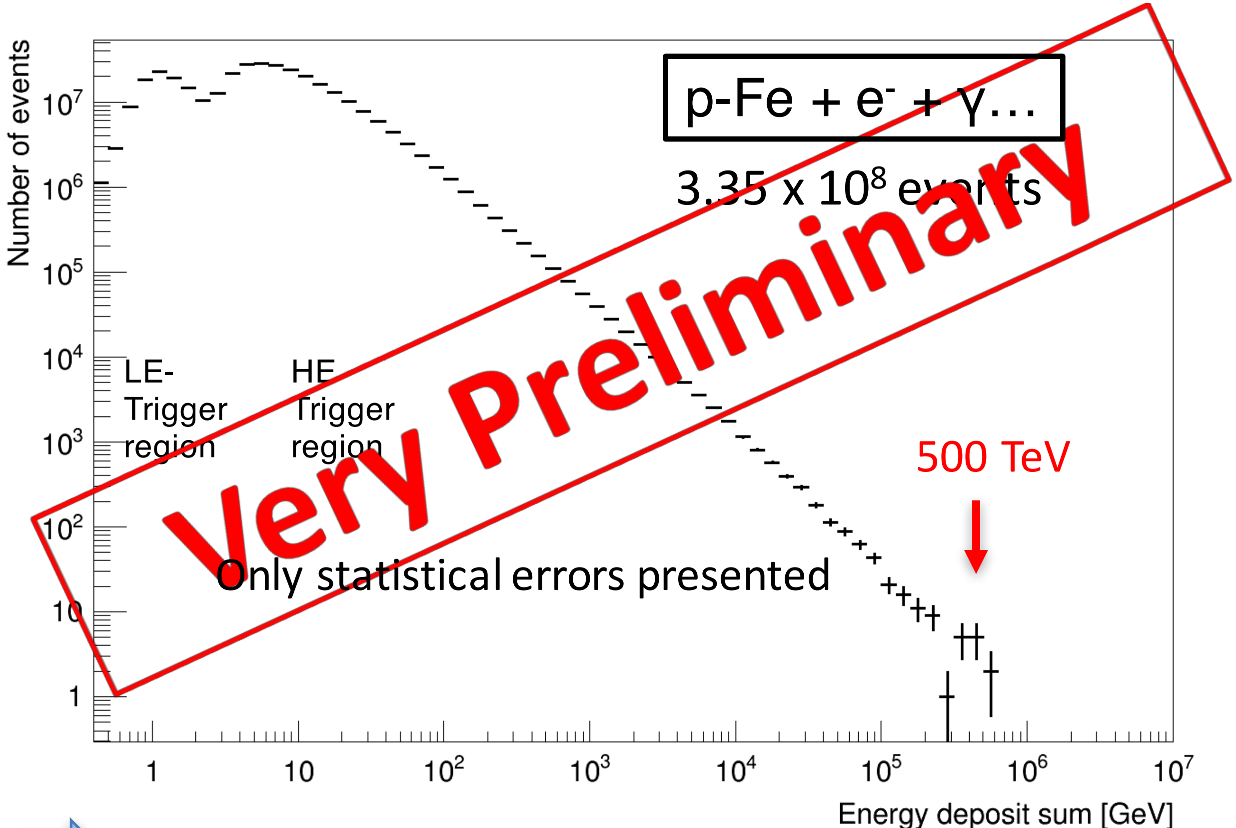
Gain Ratio Calibration Using UV Pulse Laser

Calibrating full range (6 order of magnitude) is quite a challenge !



Energy Deposit Distribution of All Triggered-Events by Observation for Nearly 10 months

Distribution of deposit energies in TASC observed in 2015.10.13—2016.08.19

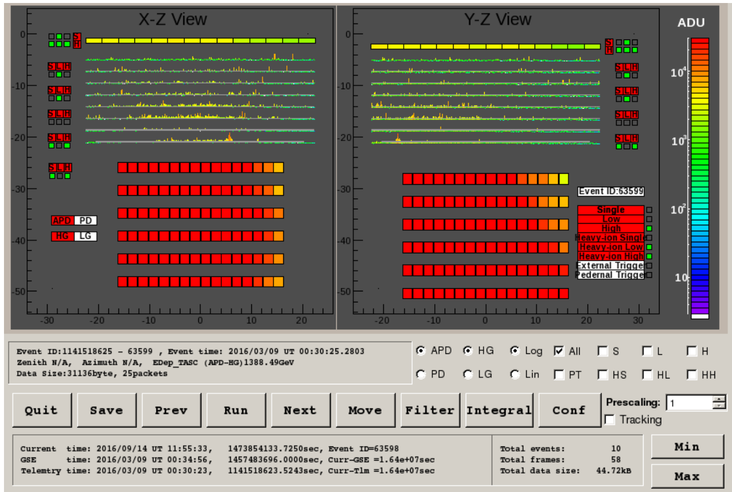


Energies are calibrated but non reconstructed

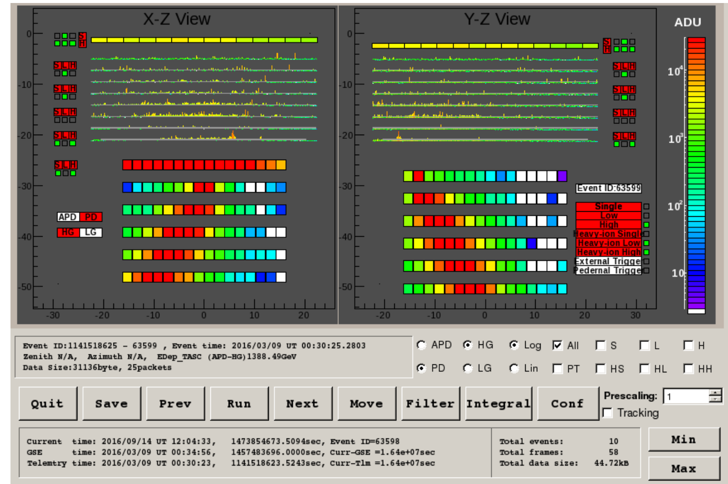
The TASC energy measurements have successfully been carried out in the dynamic range of 1 GeV – several 100 TeV.

Highest Energy Event (~500 TeV): Quick Look View

APD-H

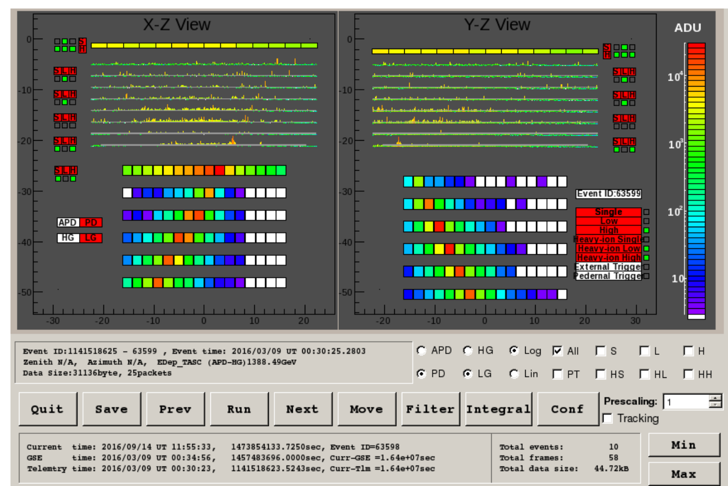


PD-H

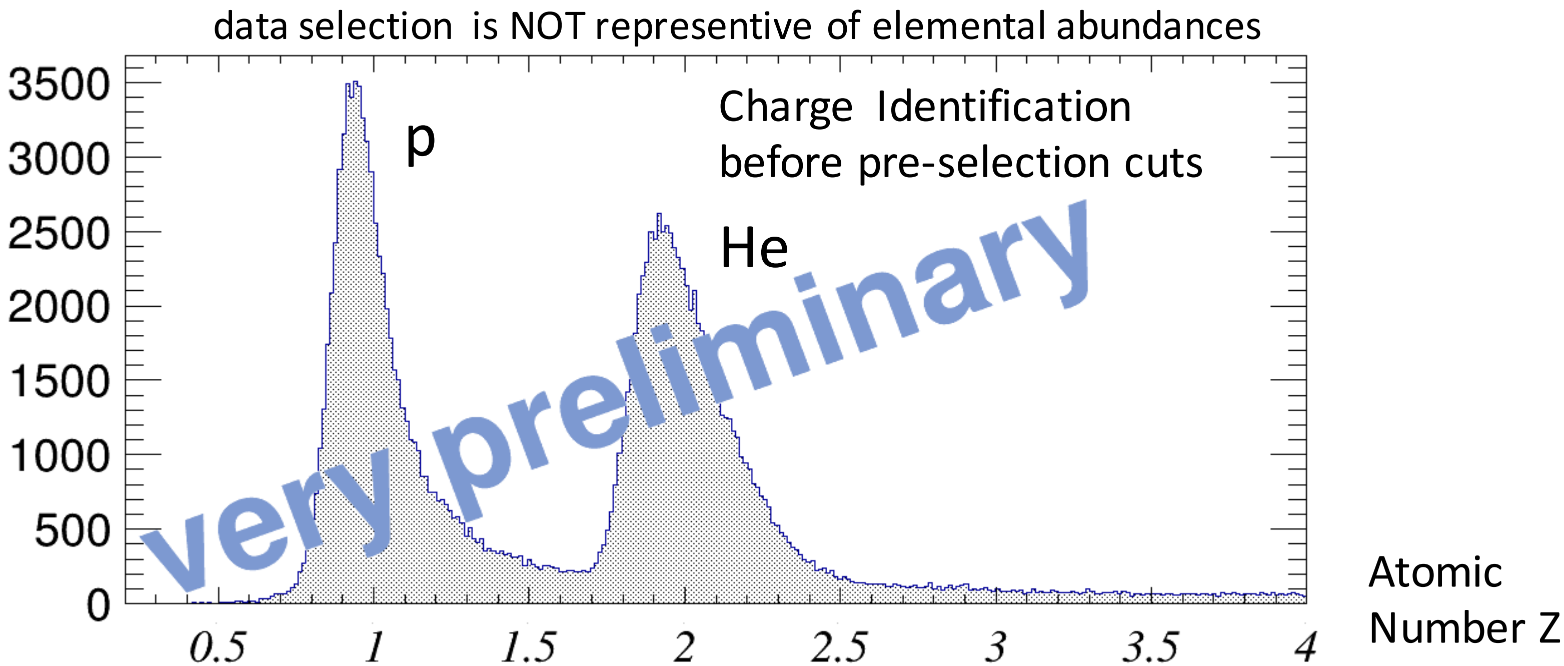


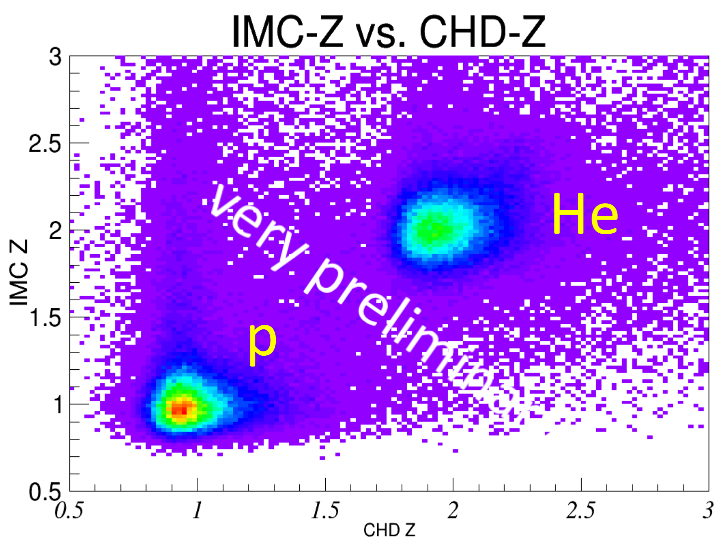
APD-L

PD-L



Preliminary Nuclei Measurements – p , He –



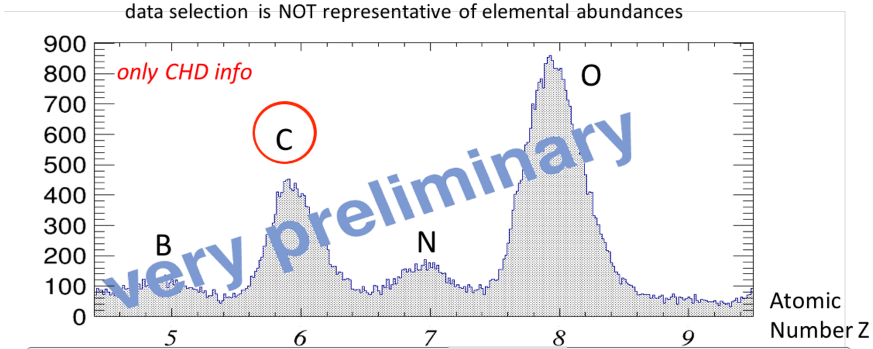


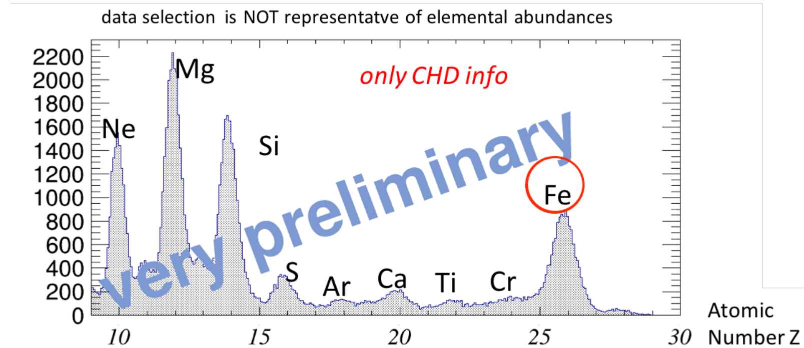
Using multiple dE/dx measurements from the IMC scin/lla/ng fibers (upstream the interaction point), a complementary charge measurement from IMC is ploted vs the CHD charge assignment (abscissa).

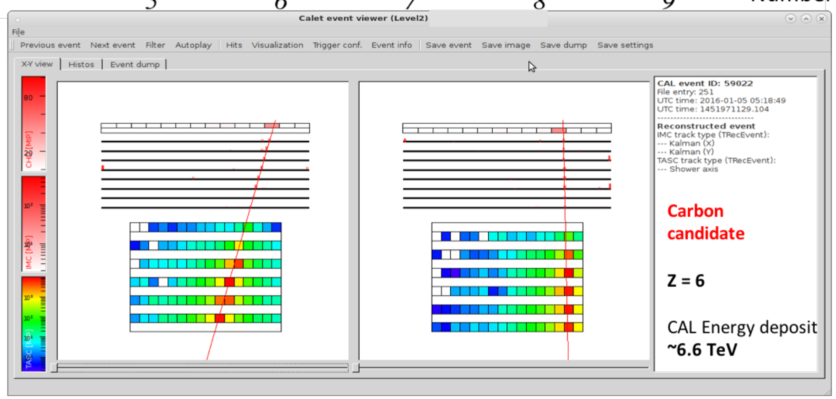
A clear separation between p and He can be seen from preliminary data analysis.

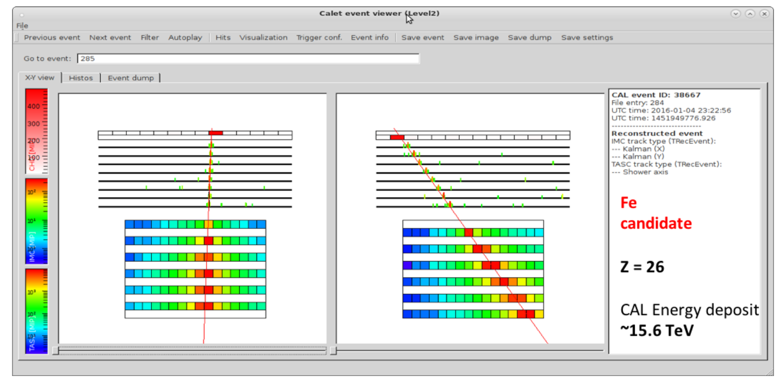
Preliminary Nuclei Measurements – Z = 3 ~ 40 –

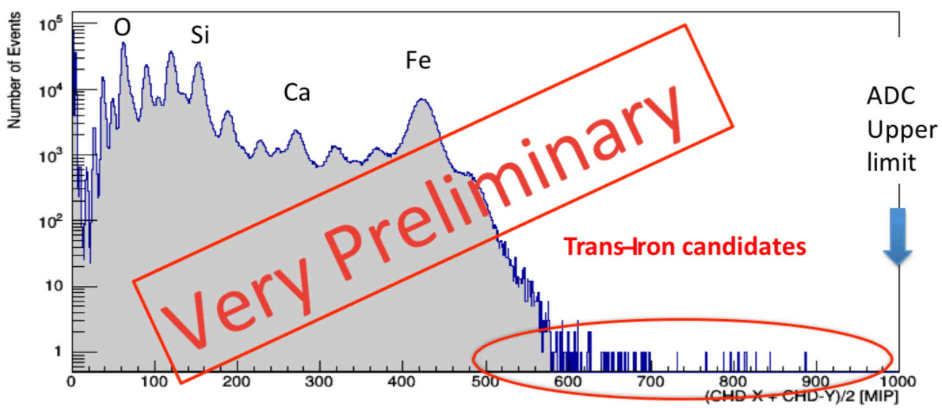
Charge Identification after pre-selection cuts

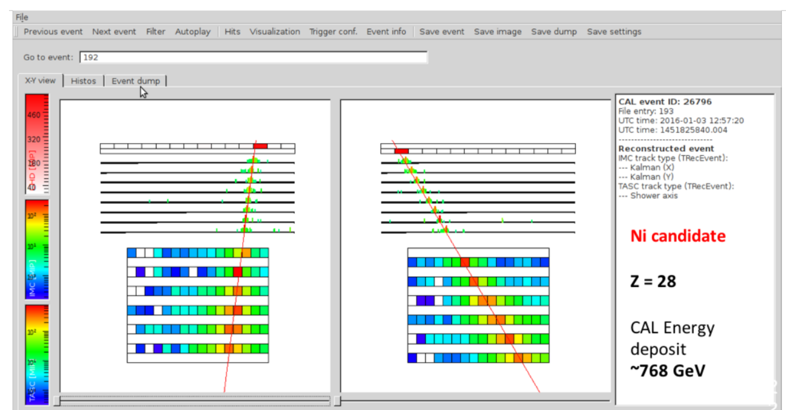








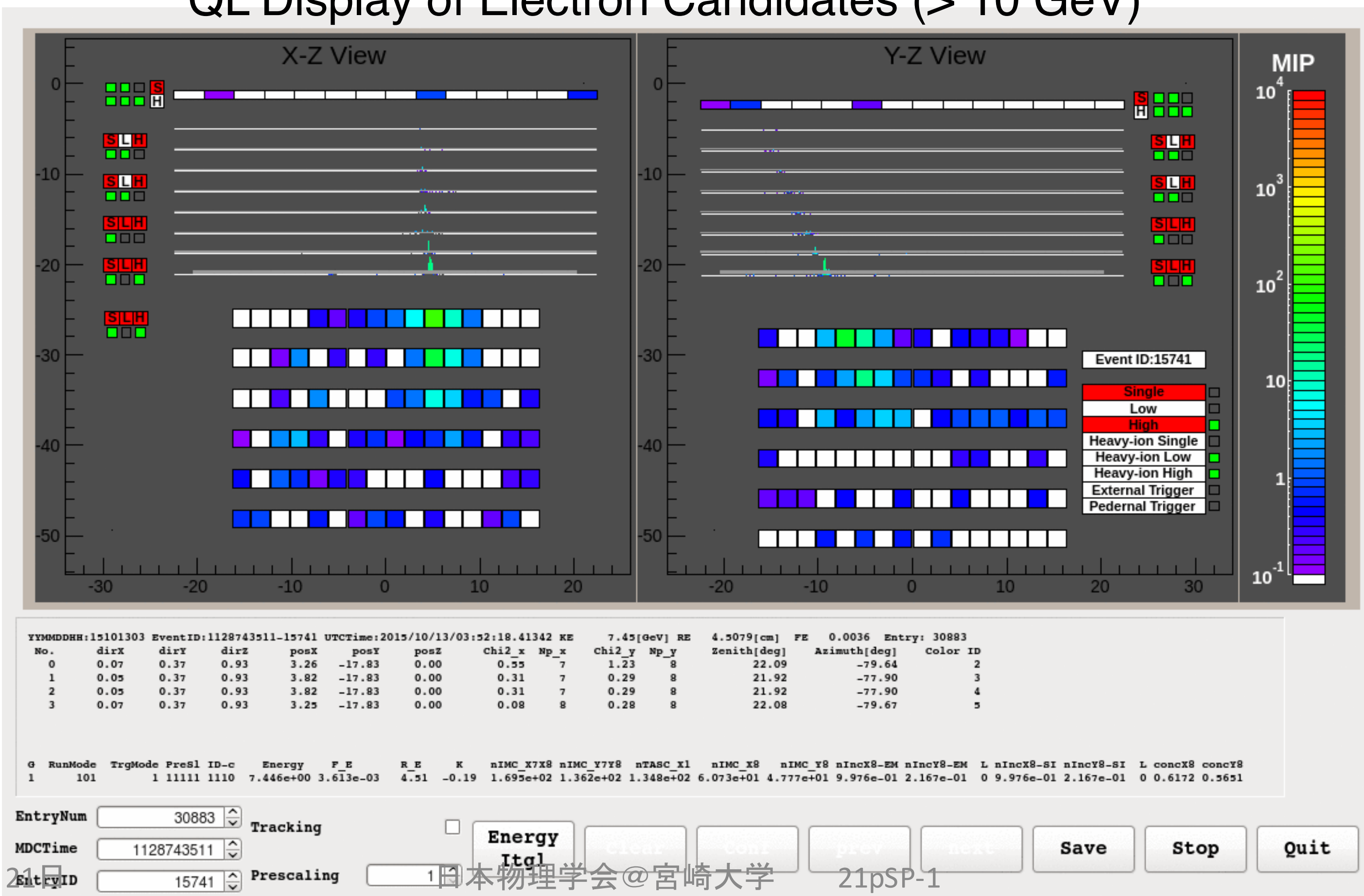




Preliminary Status of Electron Observations

For an observation for 312 days (Oct. 13, 2015 – Aug. 19, 2016), a number of the selected electron candidates is about 1.14 x 10^{6} event (>10GeV) with an efficiency cut of 90 % (without correction of proton contamination: less than several %).

QL Display of Electron Candidates (> 10 GeV)



Preliminary Simple e/p Separation

Definition of parameters

$$R_E = \sqrt{\frac{\sum_i \{\sum_j \Delta E_{i,j} \times R^2{}_i\}}{\sum_i \sum_j \Delta E_{i,j}}}$$
(Lateral Spread)

$$F_E = \frac{\sum_j \Delta E_{12,j}}{\sum_i \sum_j \Delta E_{i,j}}$$
(Shower development)

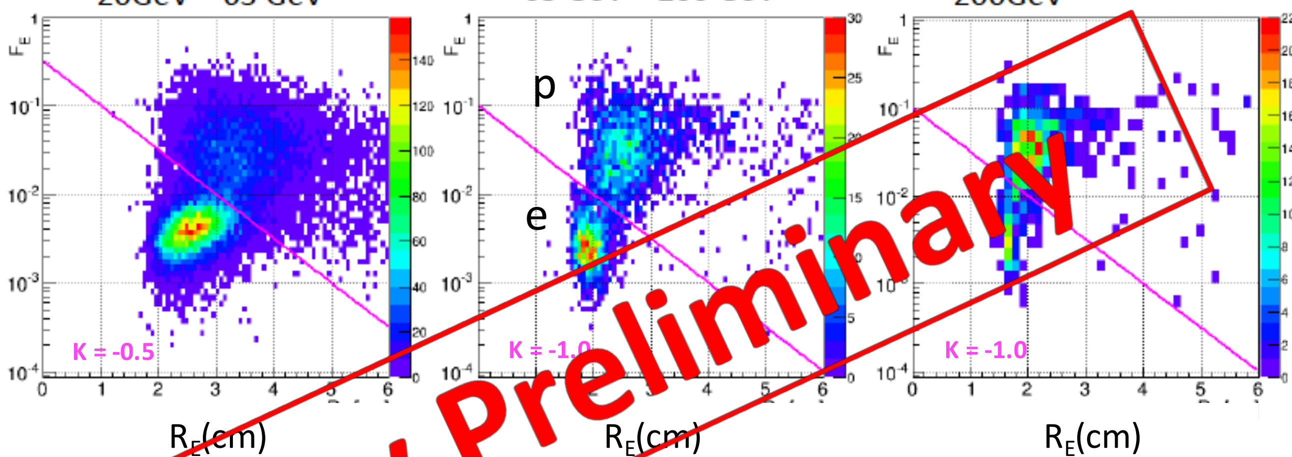
$$R_i = \sqrt{\frac{\sum_j \{\Delta E_{i,j} \times (x_j - x_c)^2\}}{\sum_j \Delta E_{i,j}}}$$

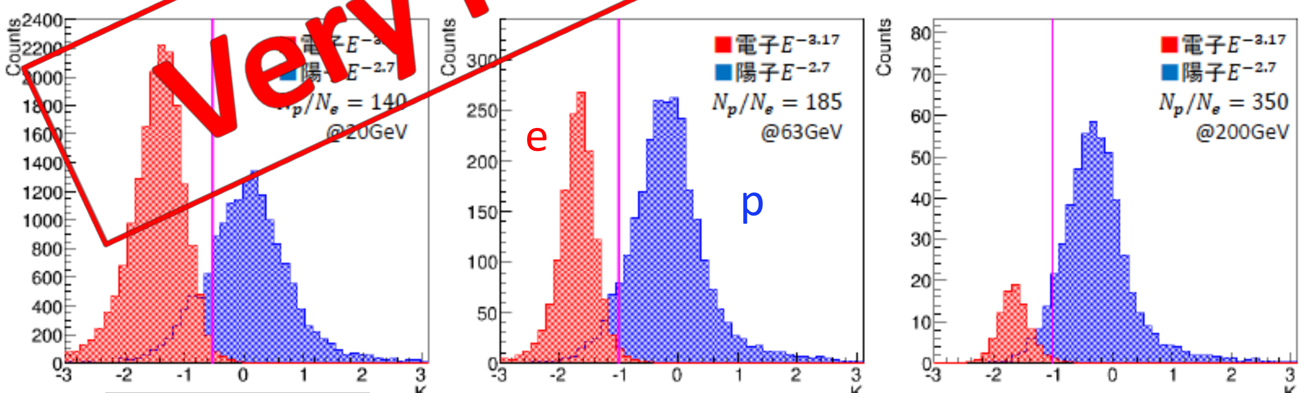
x_c : shower axis center

$\Delta E_{i,j}$: ΔE at i-th layer, j-th PWO

Observed events

(As of Nov.17, 2015 -- 90 days after launch: observation ~1 month)





Simulation

e/p separation parameter

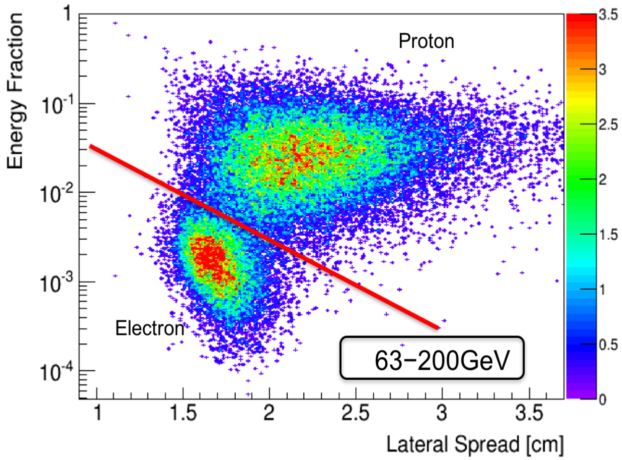
$$K = \frac{R_E}{2} + \log_{10}(F_E)$$

The K values are optimized by simulation to get a selection efficiency of 90% in each energy range.

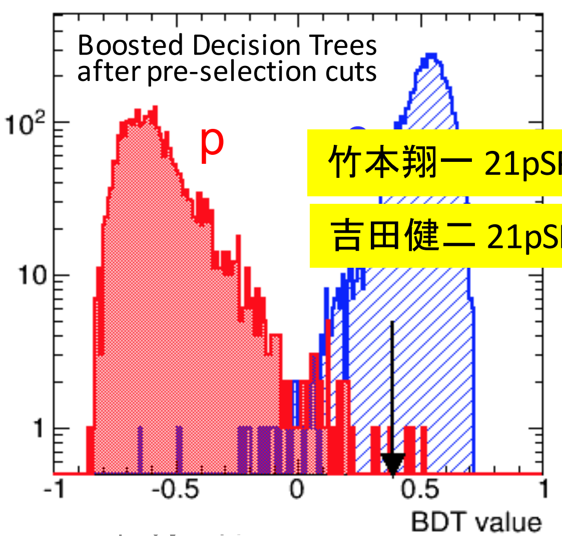
Very preliminary analysis using only two parameters. Multi parameter analysis will be applied to achieve better separation as expected from simulations.

Differential Energy Distribution of the Electron-Candidates in 10-1000 GeV by observation for nearly 10 months

Observation: e/p separation after pre-selection cuts



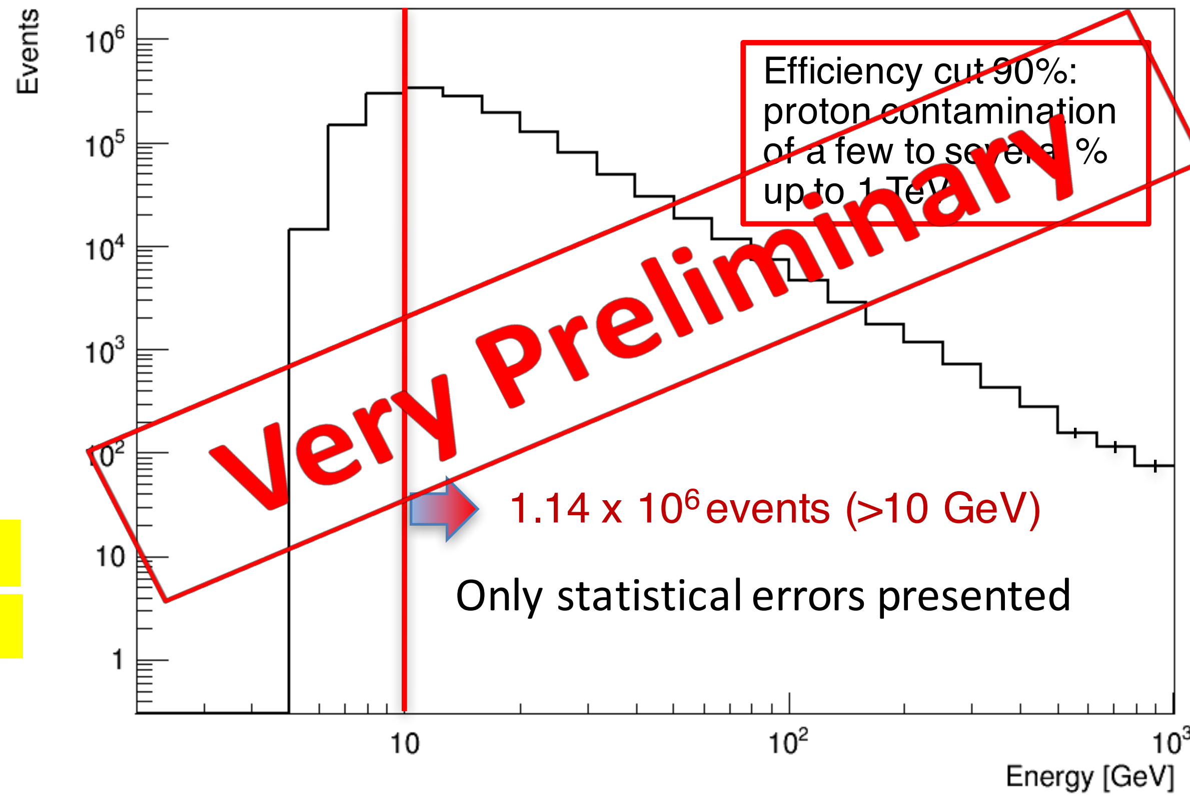
Simulation : e/p at 1TeV ~1.3 x10^5 with ~90% efficiency for electrons



竹本翔一 21pSP-7

吉田健二 21pSP-8

Differential energy distribution reconstructed by using the electron (e^++e^-) candidate events observed in 2015.10.13—2016.08.19

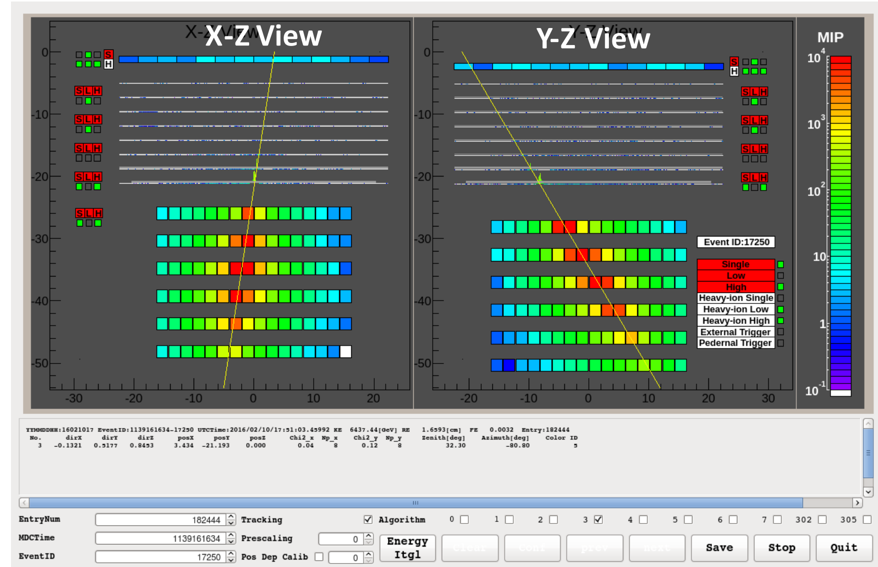


Energies are reconstructed after the calibrations.

Examples of Electron Candidates in TeV Region

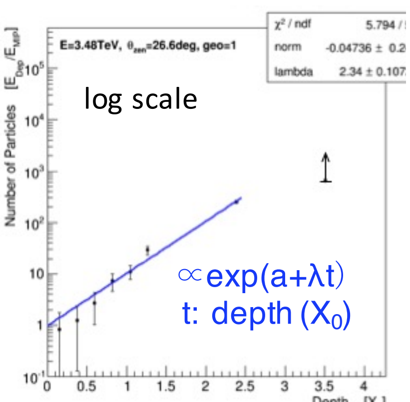
Energy: 3.62 TeV (θ=26.5°)

Energy: 6.75 TeV (θ=32.3°)

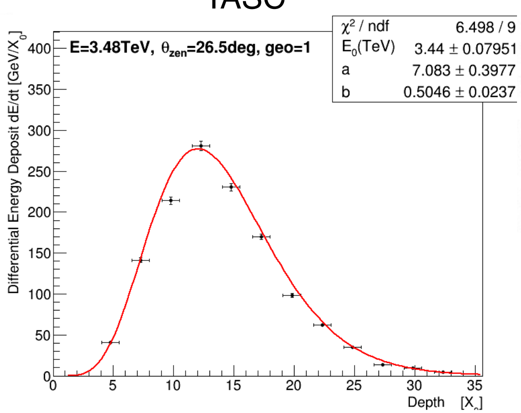


Longitudinal development of shower particles in IMC and TASC with fit of EM shower

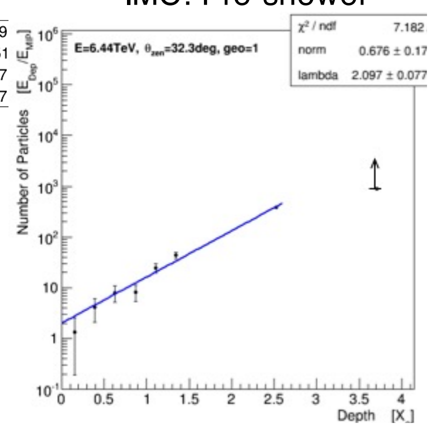
IMC: Pre-shower



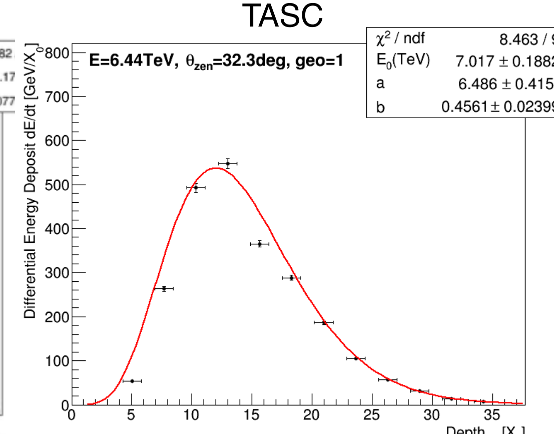
TASC



IMC: Pre-shower



TASC



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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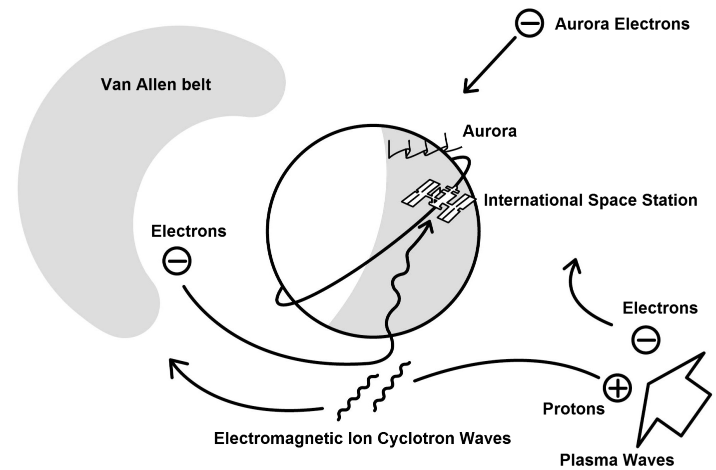
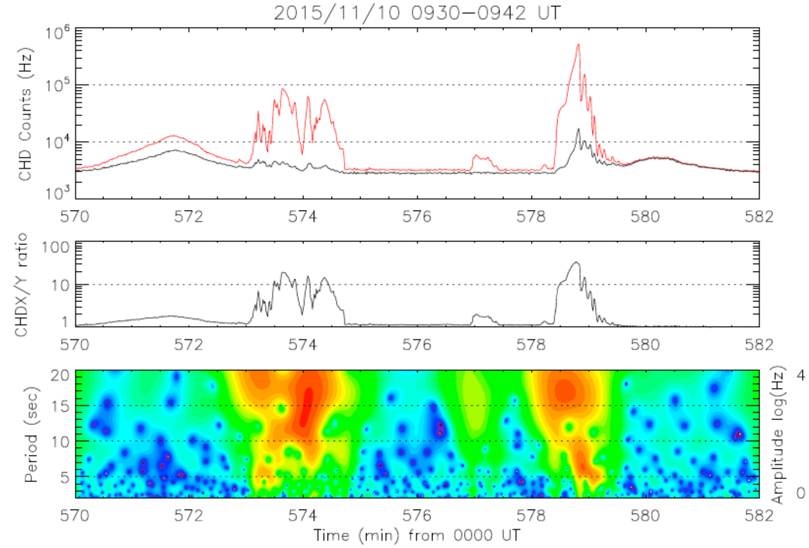
Abstract The charge detector (CHD) of the Calorimetric Electron Telescope (CALET) on board the International Space Station (ISS) has a huge geometric factor for detecting MeV electrons and is sensitive to relativistic electron precipitation (REP) events. During the first 4 months, CALET CHD observed 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



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

http://arxiv.org/abs/1607.00233v2: accepted by Astrophysical Journal Letters

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

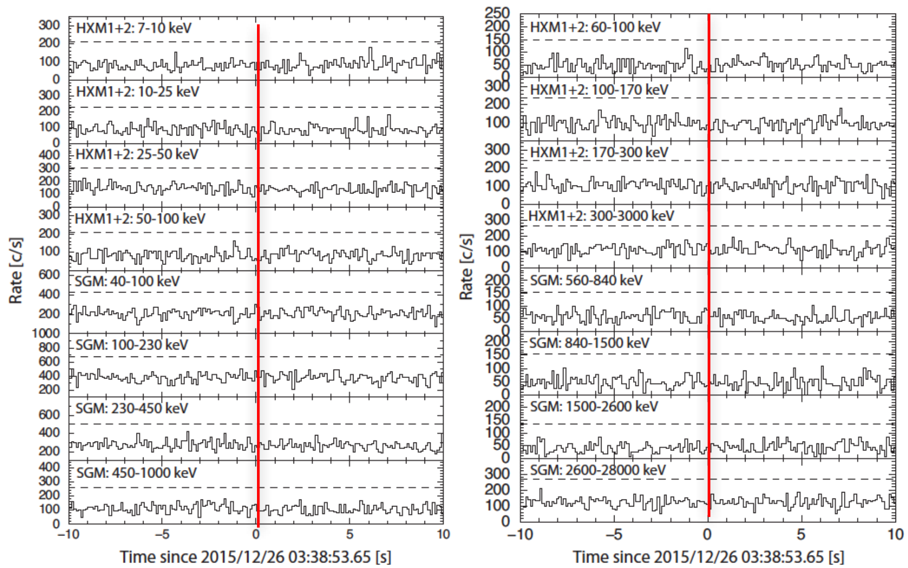


Figure 1. The CGBM light curves in 0.125 s time resolution for the high-gain data (left) and the low-gain data (right). The time is offset from the LIGO trigger time of GW 151226. The dashed-lines correspond to the 5 σ level from the mean count rate using the data of $\pm$10 s.

Upper limit for gamma-ray burst monitors and Calorimeter

HXM: 7-500 keV

SGM: 50-1000 keV

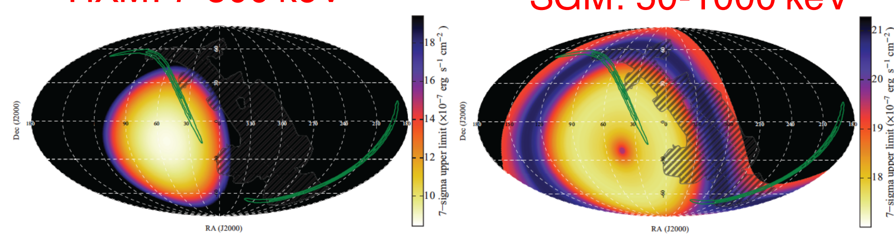


Figure 2. The sky maps of the 7 σ upper limit for HXM (left) and SGM (right). The assumed spectrum for estimating th upper limit is a typical BATSE S-GRBs (see text for details). The energy bands are 7-500 keV for HXM and 50-1000 keV fo SGM. The GW 151226 probability map is shown in green contours. The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

Calorimeter: 1-100 GeV

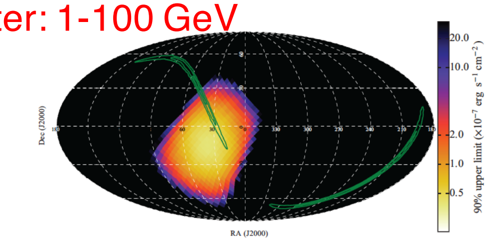
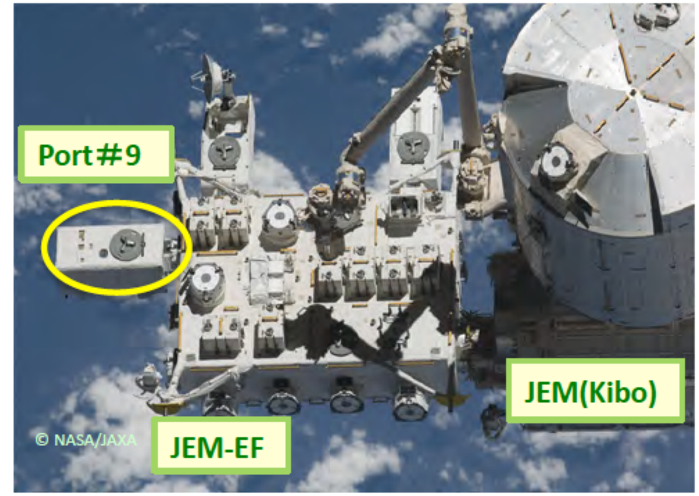


Figure 3. The sky map of the 90% upper limit for CAL in the 1-100 GeV band. A power-law model with a photon index of – is used to calculate the upper limit. The GW 151226 probability map is shown in green contours.

Summary



- CALET was successfully launched from Tanegashima Space Center (TNSC) on Aug. 19, 2015, and the detector is being very stable for observation since Oct. 13, 2015. As of Aug.19, 2016, nearly 200 million events are collected for ～10 months with high energy 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 within a few % by using observe shower events.
- Electron selection is carried out with 90% efficiency cut up to 1 TeV, and 1.14×10^6 electron candidates are selected over 10 GeV among 1.47×10^8 triggered events. Electron event candidates have been observed above 1 TeV.
- Cosmic rays from proton to Fe and Ultra Heavy ions $(26 < Z < 40)$, as well as gamma-rays have been detected. Energy spectra, relative elemental abundances and secondary-to-primary (say, B/C) ratios are being measured.
- CALET's CGBM has measured the light curves of 30 GRB's as of July, 2016.
- 5-year Observations are planned.

＊）本研究は科学研究費基盤S（#26220708）の助成を受けて行っています。