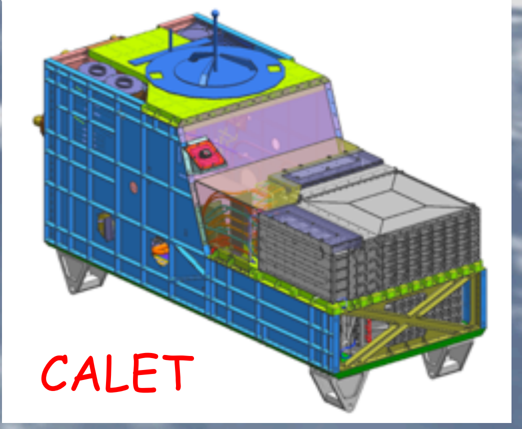
Status and Performance of the CALorimetric Electron Telescope (CALET) on the International Space Station

Shoji Torii
for the CALET Collaboration

Waseda University &
Japan Aerospace Exploration Agency (JAXA/SEUC)



CALET Collaboration

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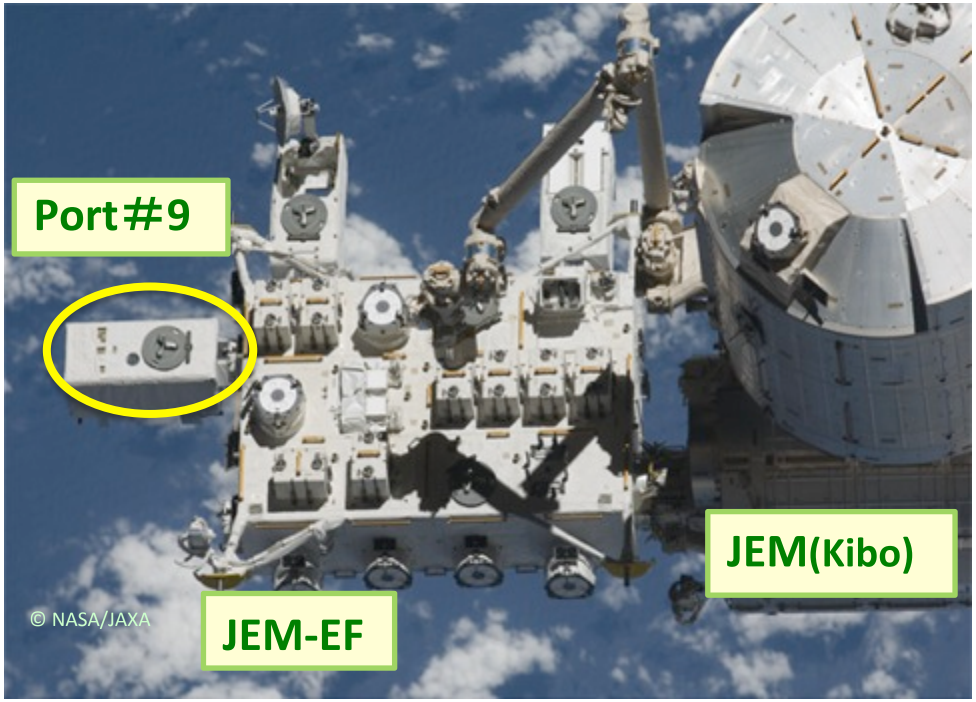
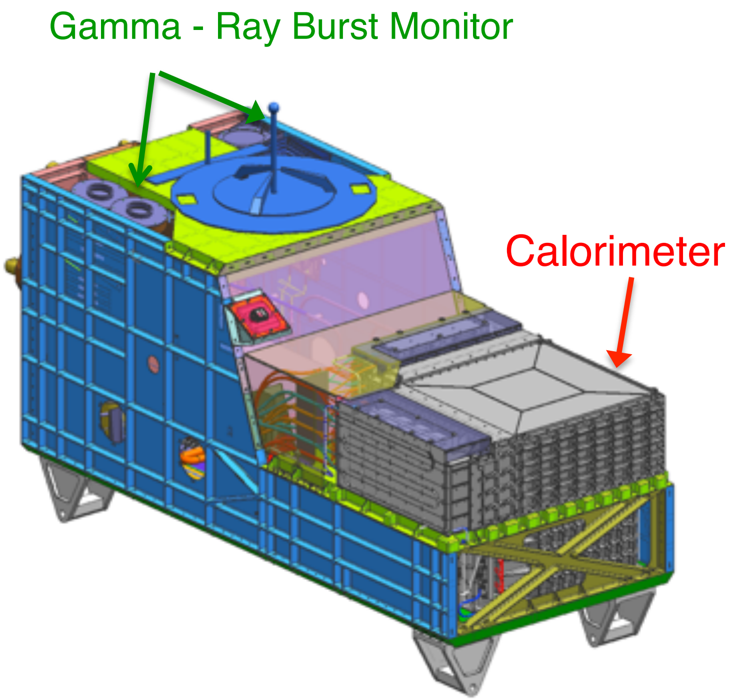
31) CRESST/NASA/GSFC and Universities Space Research Association, USA
32) National Institute of Polar Research, Japan
33) The University of Tokyo, Japan

CALorimetric Electron Telescope Payload

The CALorimetric Electron Telescope, CALET, project is a Japan-led international mission for the International Space Station, ISS, in collaboration with Italy and the United States.



Mission Life (Target) : 5 years
Launch Date: Aug.19,2015



The CALET payload is launched by the Japanese carrier, H-II Transfer Vehicle 5 (HTV5) and robotically attached to the port #9 of the Japanese Experiment Module – Exposed Facility (JEM-EF) on the International Space Station.

CALET Overview

Calorimeter

- Charge Detector (CHD)
- Imaging Calorimeter (IMC)
- Total Absorption Calorimeter (TASC)

Gamma-ray burst monitor (CGBM)

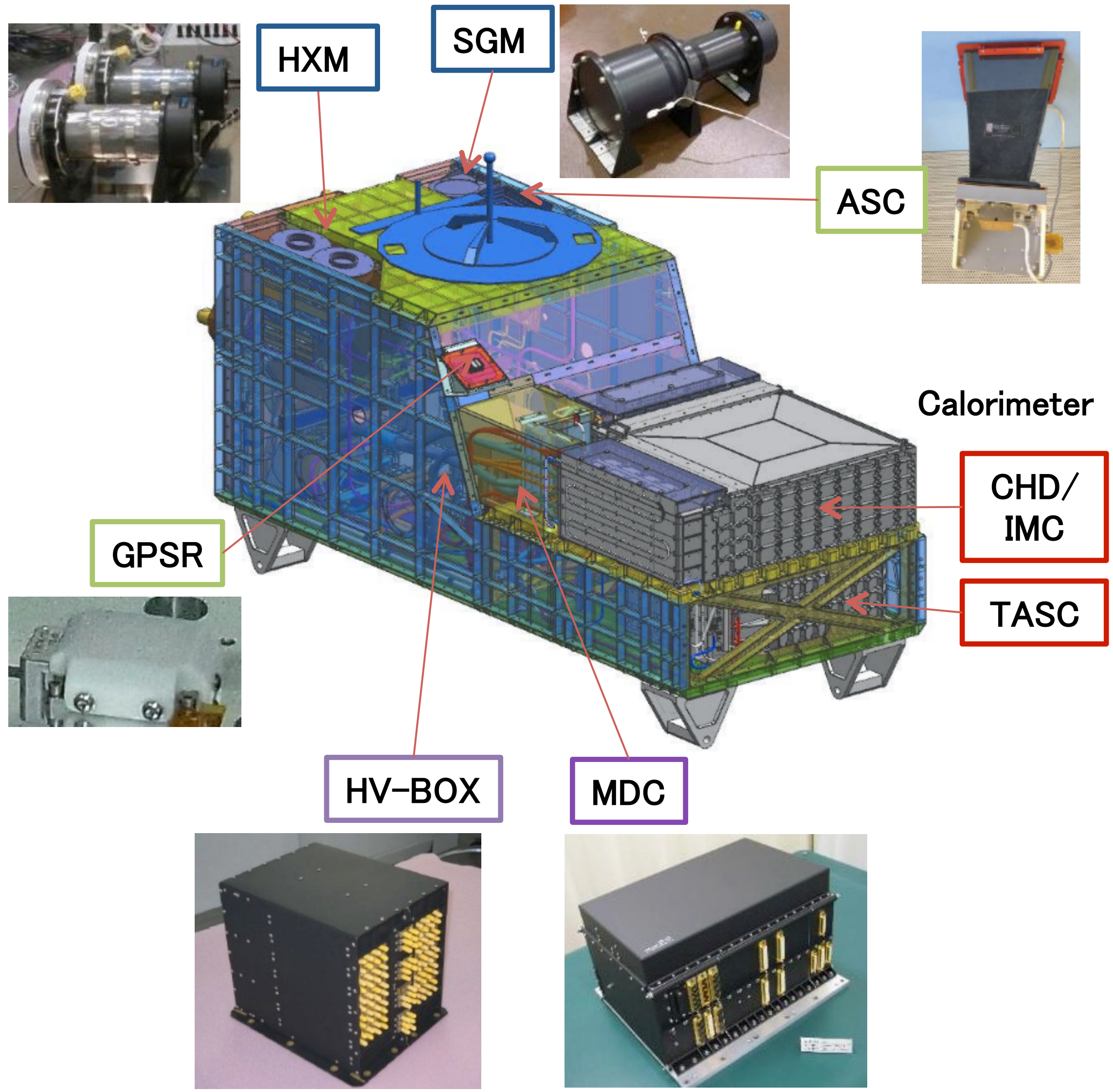
- Hard X-ray Monitor (HXM)
  $LaBr_3$: 7keV～1MeV
- Soft γ-ray Monitor (SGM)
  BGO : 100keV～20MeV

Data process and Telemetry

- Mission Data Controller (MDC)
  Data process, Telemetry, Trigger
- HV-BOX (by Italian Contribution)
  High voltage power supply
  (PMT:68ch, APD:22ch)

Support sensors

- Advanced Stellar Compass (ASC)
  Directional measurement
- GPS Receiver (GPSR)
  Time stamp on events (<1ms)



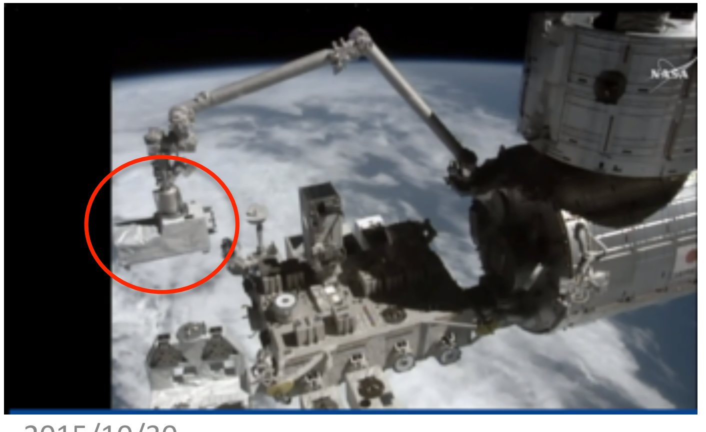
CALET is now on the ISS !

① **August 19th**: After a successful launch of the Japanese H2-B rocket by the Japan Aerospace Exploration Agency (JAXA) at 20:50:49 (local time), CALET started its journey from Tanegashima Space Center to the ISS.

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 6:28 (EDT).

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



CALET Science Goals

The CALET mission will address many of the outstanding questions of High Energy Astrophysics, such as the origin of cosmic rays, the mechanism of CR acceleration and galactic propagation, the existence of dark matter and nearby CR sources.

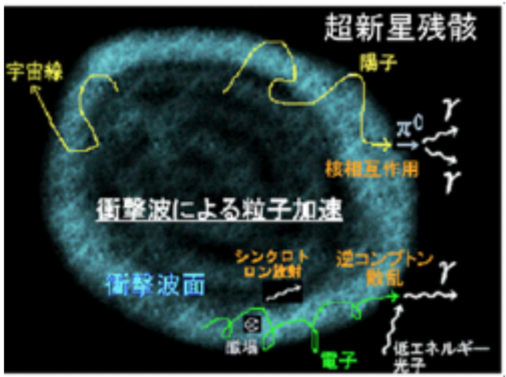
Science Objectives	Observation Targets
Nearby Cosmic-ray Sources	Electron spectrum into trans-TeV region
Dark Matter *	Signatures in electron/gamma energy spectra in the several GeV – 10 TeV range
Cosmic-ray Origin and Acceleration	p-Fe energy spectra up to 10^{15} eV and trans-iron elements (Z=26-40) at a few GeV
Cosmic–ray Propagation in the Galaxy	B/C ratio above TeV/nucleon
Solar Physics	Electron flux below 10 GeV
Gamma-ray Transients	Gamma-rays and X-rays in the 7 keV - 20 MeV range

*) See e.g. H.Motz "Dark matter sensitivity of CALET" talk at DM session on 27 Oct.

Electron & Positron Origins and Production Spectrum

Astrophysical Origin

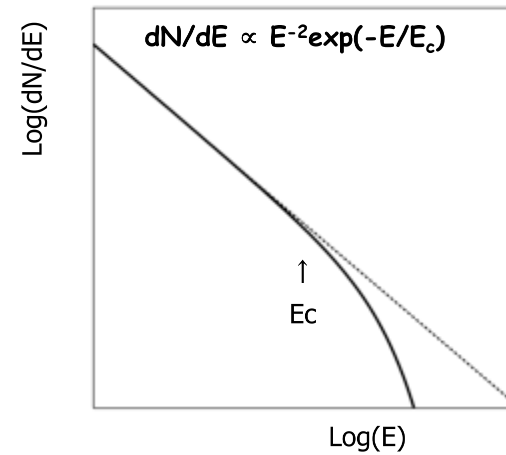
Shock Wave Acceleration in SNR



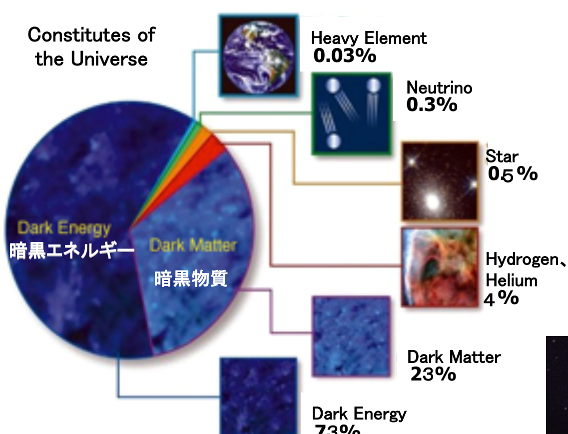
Acceleration in PWN

etc.

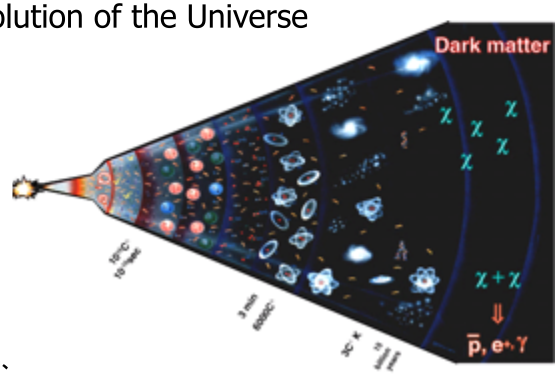
Power Law Distribution with a Cutoff



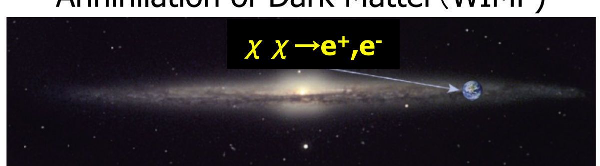
Dark Matter Origin



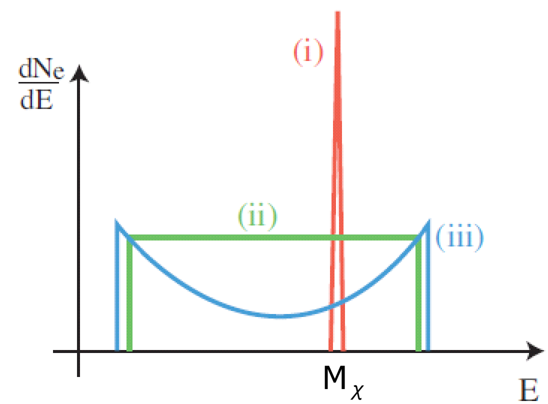
Evolution of the Universe



Annihilation of Dark Matter（WIMP)



Typical Distribution Depending on the Mass and Type of DM



(i) Monoenergetic: Direct Production of e+e- pair
（ii）Uniform：Production via Intermediate Particles
（iii）Double Peak：Production by Dipole Distribution via Intermediate Particles

Nearby Sources of Electrons in the TeV region

$$\frac{\partial}{\partial t} f\left(t,\varepsilon_e,\vec{x}\right) = D\left(\varepsilon_e\right)\nabla^2 f + \frac{\partial}{\partial \varepsilon_e}\left[b\varepsilon_e^2 f\right] + q\left(t,\varepsilon_e,\vec{x}\right)$$

Diffusion | Energy loss by IC & synchro. | Injection

$$b \sim 10^{-16}\,\mathrm{GeV^{-1}s^{-1}}$$

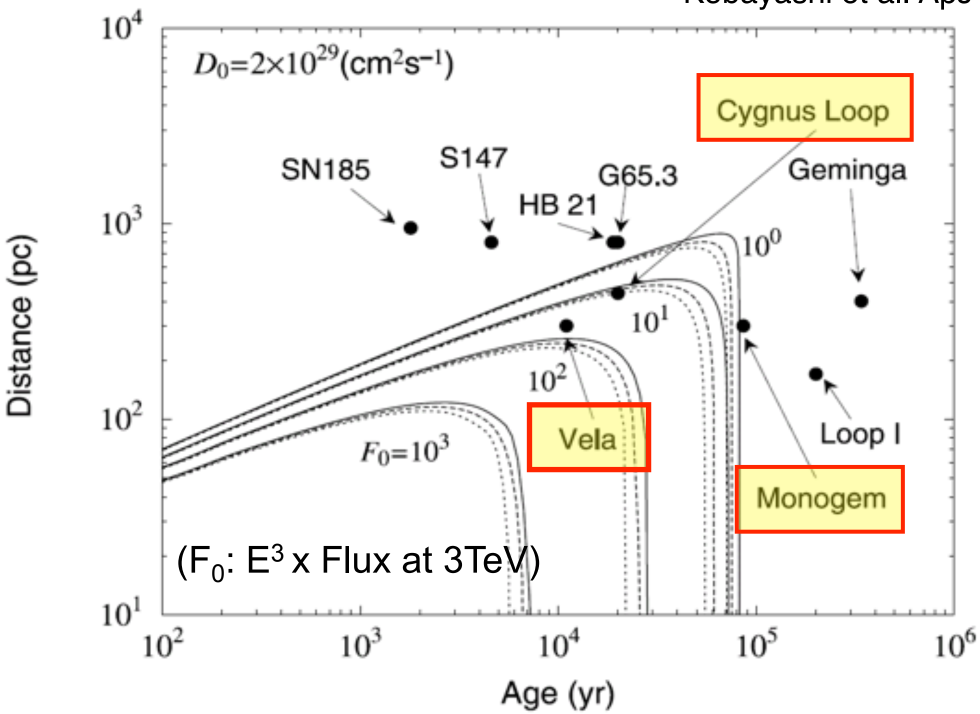
$$D\left(\varepsilon_e\right) \sim 5.8\times10^{28}\,\mathrm{cm^2s^{-1}}\left(1+\frac{\varepsilon_e}{4\mathrm{GeV}}\right)^{1/3}$$ ← B/C ratio

T (age) = 2.5 ×10^5 × (TeV/E) yr

R (distance) = 600 × $(\mathrm{TeV/E})^{1/2}$ pc

Contribution to 3 TeV Electrons from Nearby Source Candidates

Kobayashi et al. ApJ 2004

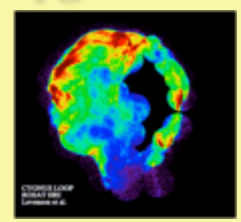


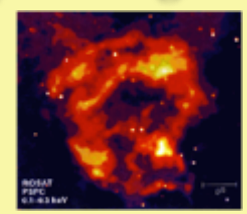
> 1 TeV Electron Source:

- **Age < a few10^5 years**
  very young comparing to ~10^7 year at low energies
- **Distance < 1 kpc**
  nearby source

Source (SNR) Candidates :

Vela Cygnus Loop Monogem





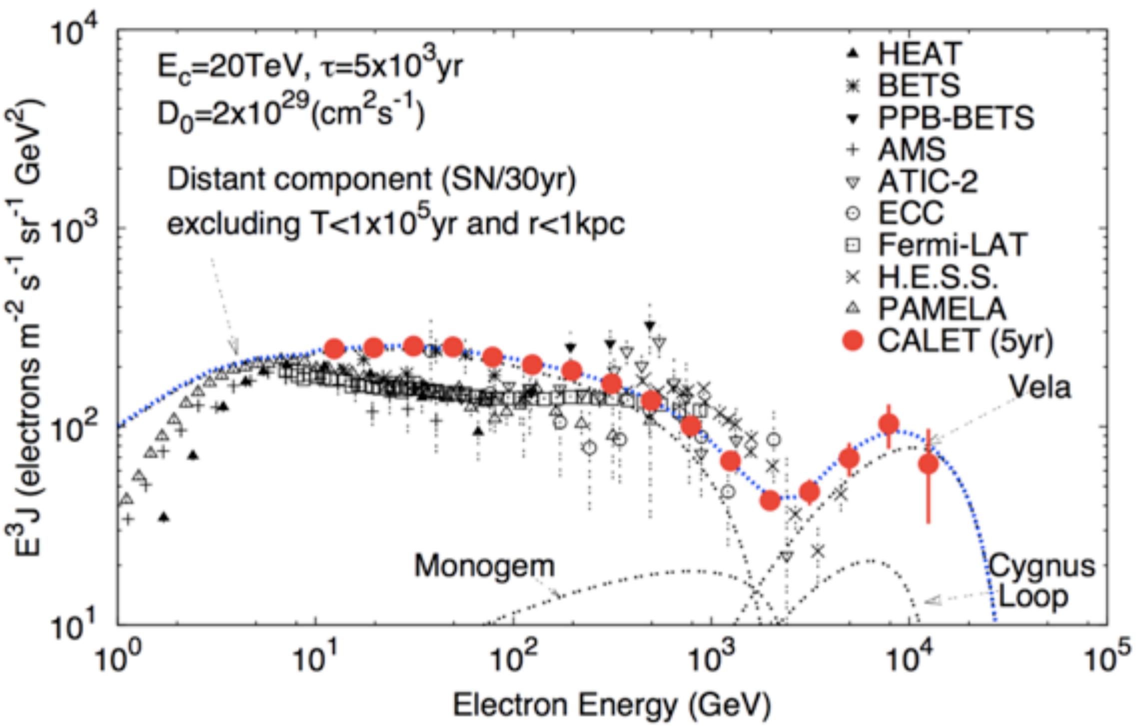
Unobserved Sources?

CALET Main Target: Identification of Electron Sources

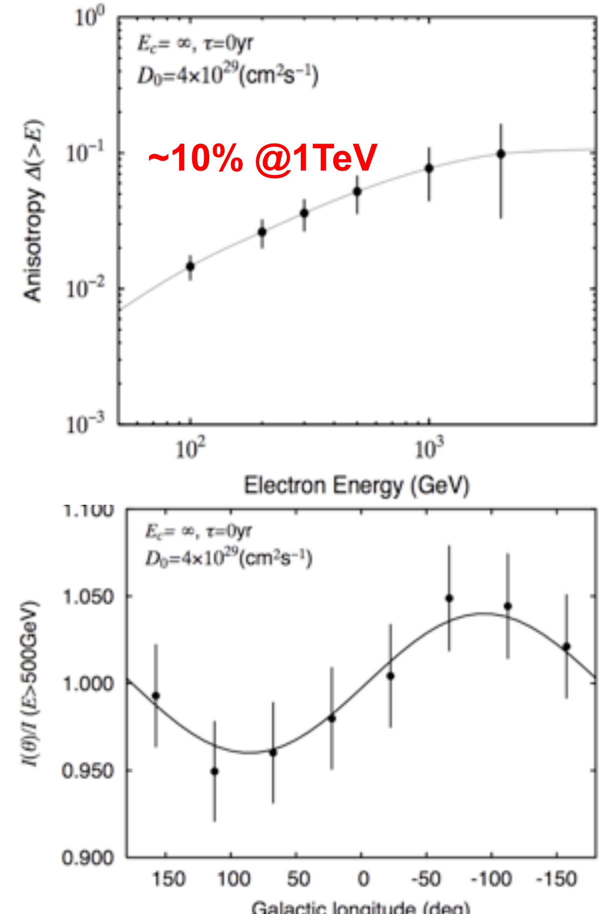
Some nearby sources, e.g. Vela SNR, might have unique signatures in the electron energy spectrum in the TeV region (Kobayashi et al. ApJ 2004)

Expected flux for 5 year mission

> 10 GeV	~ 2.7 x 10^7
>100 GeV	~ 2.0 x 10^5
>1000 GeV	~ 1.0 x 10^3



Expected Anisotropy from Vela SNR



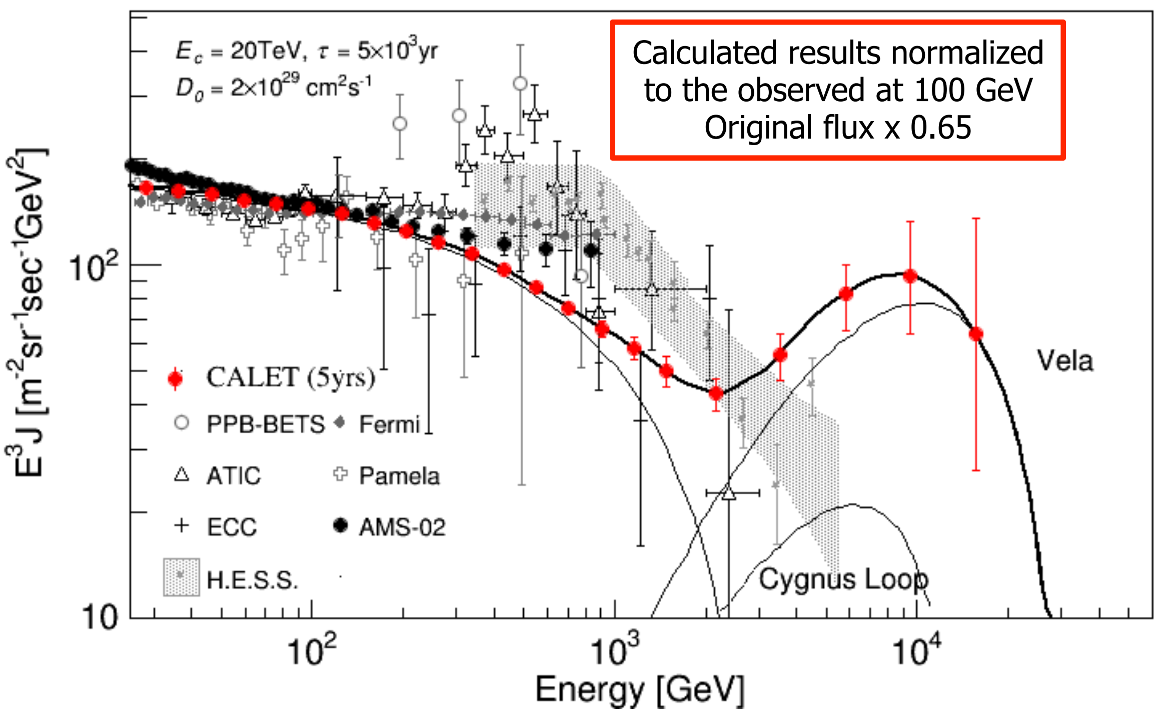
► Identification of the unique signature from nearby SRNs, such as Vela in the electron spectrum by CALET

CALET Main Target: Identification of Electron Sources

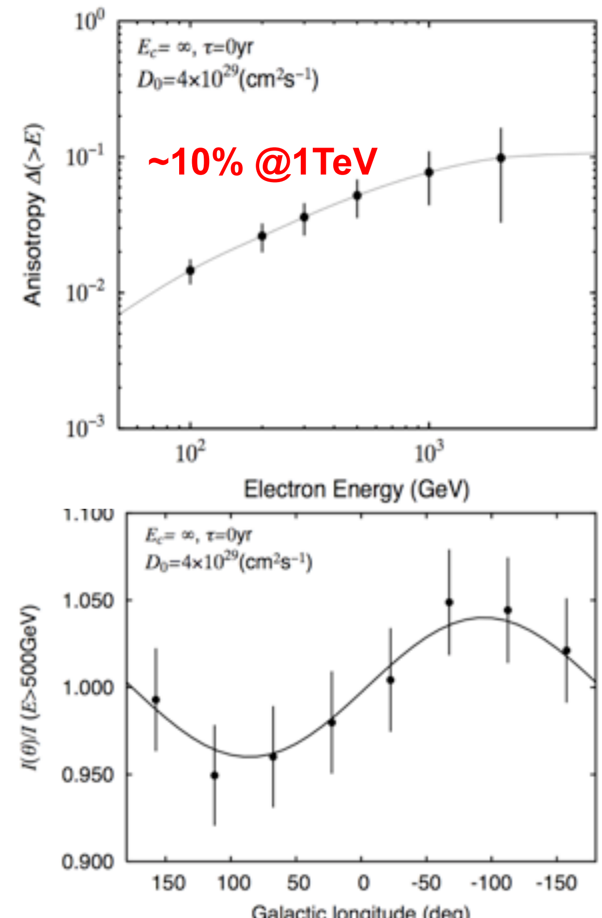
Some nearby sources, e.g. Vela SNR, might have unique signatures in the electron energy spectrum in the TeV region (Kobayashi et al. ApJ 2004)

Expected flux for 5 year mission

> 10 GeV	~ 1.8×10^7
>100 GeV	~ 1.3×10^5
>1000 GeV	~ 6.5×10^2



Expected Anisotropy from Vela SNR



Identification of the unique signature from nearby SRNs, such as Vela in the electron spectrum by CALET

TeV $e^{\pm}$ spectrum can prove the CR escape!

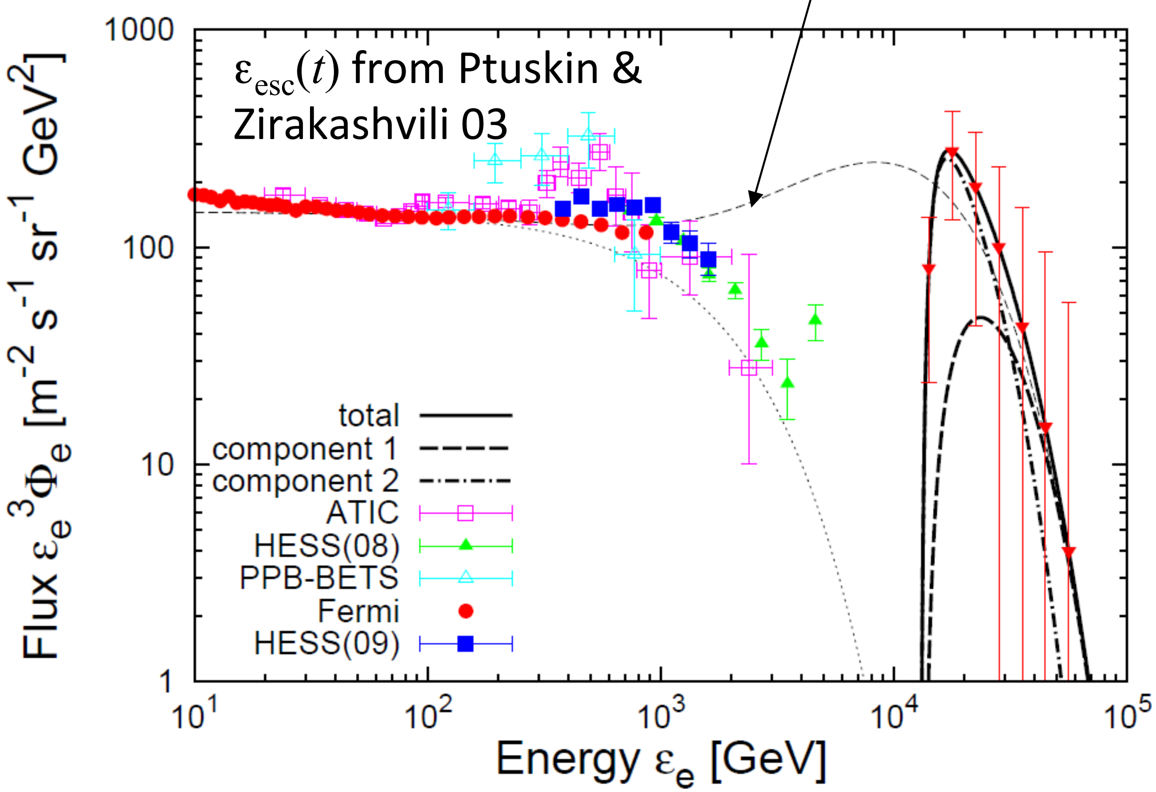
Kawanaka, Ioka et al. ApJ 2011

- Electron spectrum from Vela SNR/PSR (d=290pc, t_{age}~10^4yr, E_{tot}=10^{48}erg)
- Only $e^{\pm}$ with $\varepsilon_e > \varepsilon_{esc}(t_{age})$ can run away from the SNR.

→ Low Energy Cutoff

- 5yr obs. by CALET ($S\Omega T$=220m^{2}sr days) may detect it.

Without energy-dependent escape



→ Direct Evidence of Escape-Limited Model for CR accelerators (=SNR)!

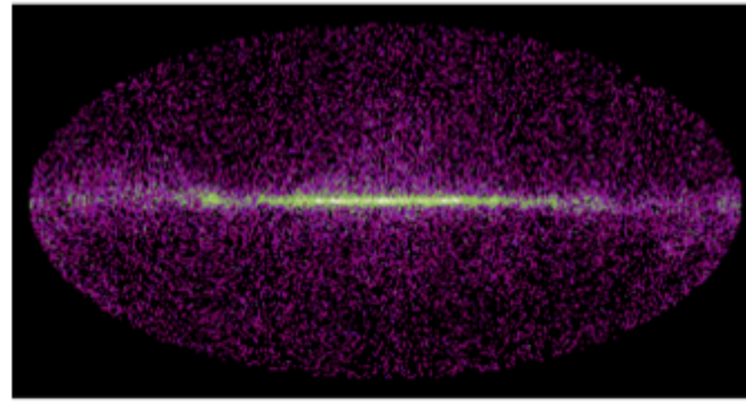
Detection of High Energy Gamma-rays

Performance for Gamma-ray Detection

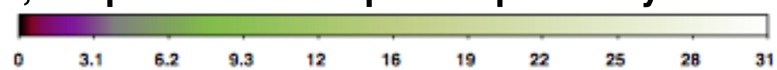
Energy Range	4 GeV-10 TeV
Effective Area	600 cm^2 (10GeV)
Field-of-View	2 sr
Geometrical Factor	1100 cm^2sr
Energy Resolution	3% (10 GeV)
Angular Resolution	0.35 ° (10GeV)
Pointing Accuracy	6′
Point Source Sensitivity	8×10^{-9} $cm^{-2}s^{-1}$
Observation Period (planned)	2015-2020 (5 years)

*) Trigger efficiency included below 10 GeV
**) 100 % efficiency over 5 GeV

Simulation of Galactic Diffuse Radiation

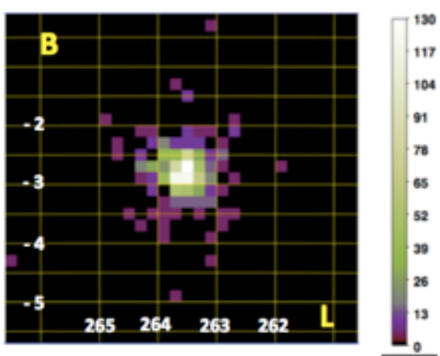


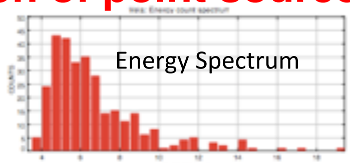
~5,700 photon* are expected per one year

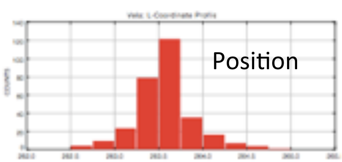


~1,700 photon* from extragalactic γ-background (EGB) each year

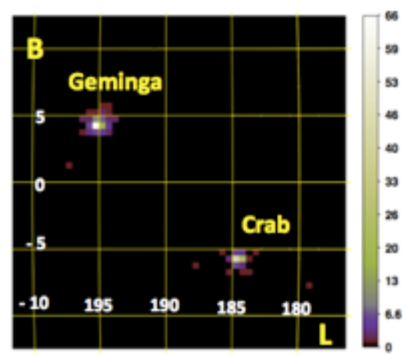
Simulation of point source observations in one year

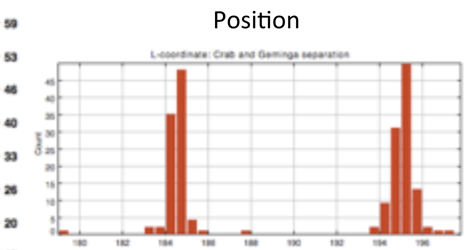






Vela: ~ 300 photons above 5 GeV**



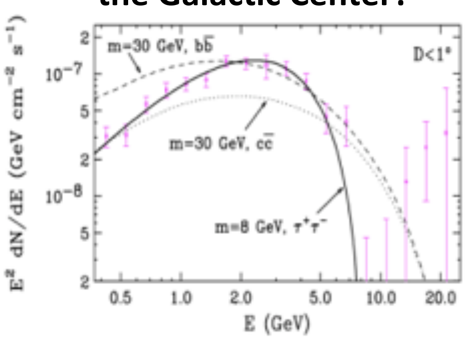


Geminga: ~150 photons above 5 GeV**
Crab: ~ 100 photons above 5 GeV**

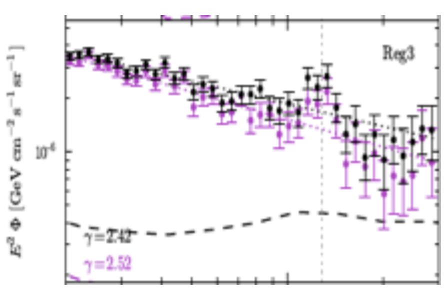
Detection Capability of Gamma-ray Lines from Dark Matter

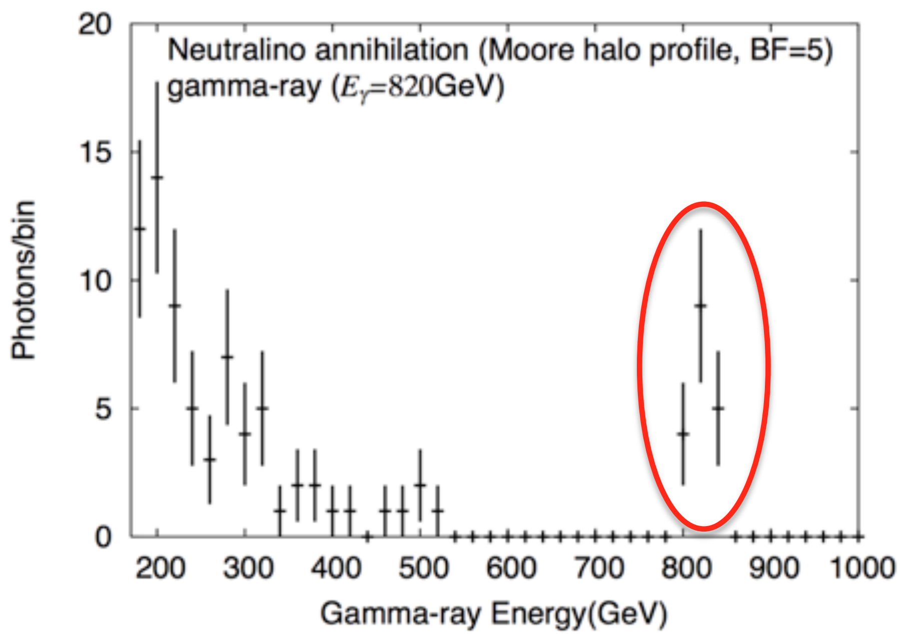
Monochromatic gamma-ray signals from WIMP dark matter annihilation would provide a distinctive signature of dark matter, if detected. Since gamma-ray line signatures are expected in the sub-TeV to TeV region, due to annihilation or decay of dark matter particles, CALET, with an excellent energy resolution of 2 - 3 % above 100 GeV, is a suitable instrument to detect these signatures .

Gamma-ray excess in the Galactic Center?



A 130 GeV line?

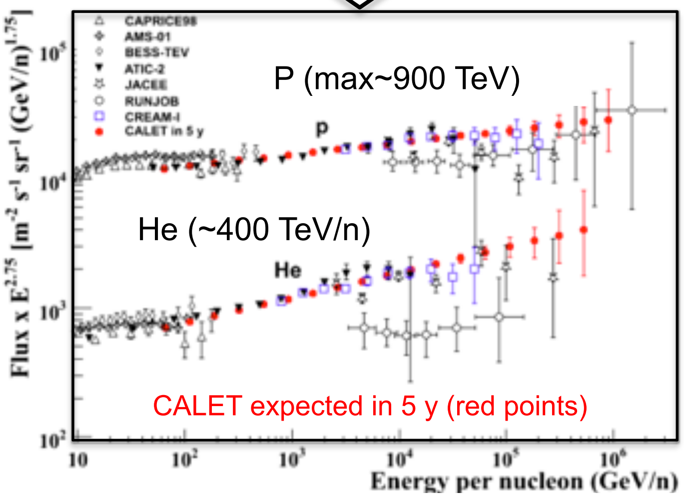




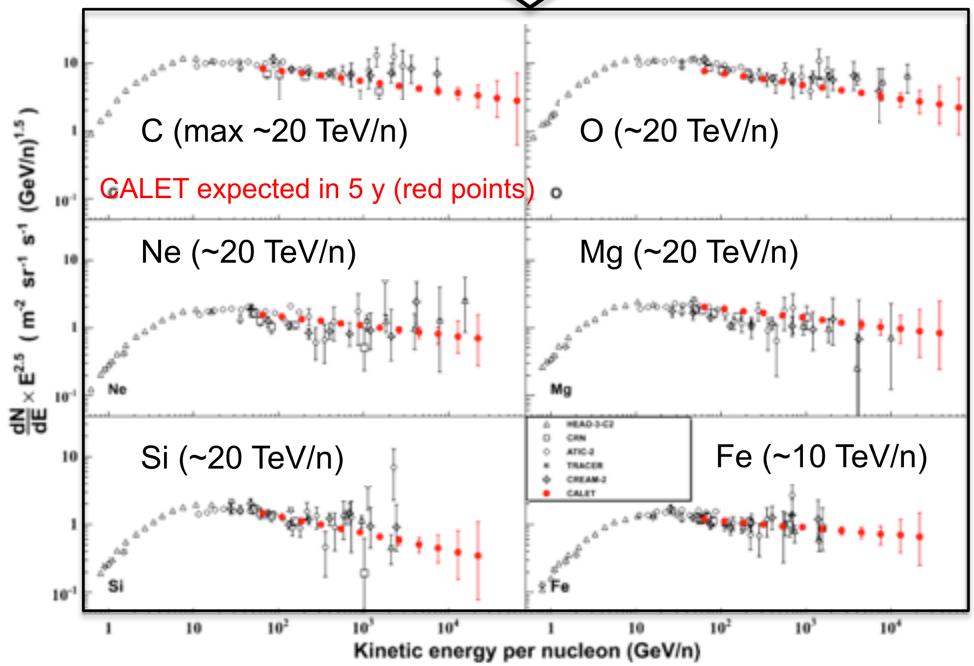
Simulated gamma-ray line spectrum for 2yr from neutralino annihilation toward the Galactic center with m=820GeV, a Moore halo profile, and BF=5

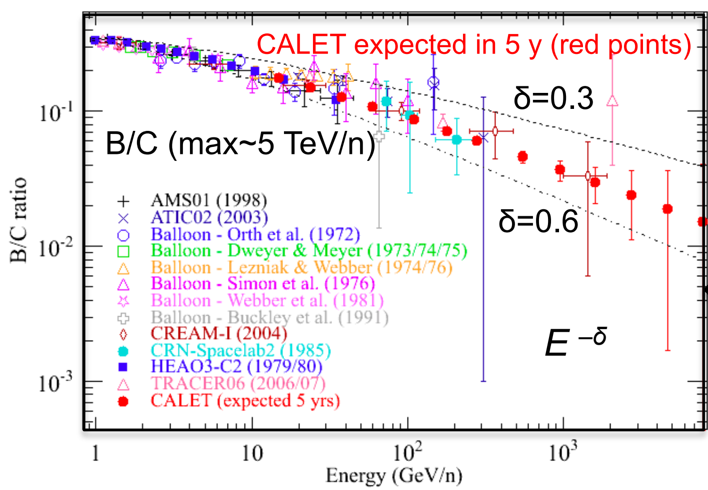
p-Fe Observations

- Hardening in the p and He at 200 GV observed by PAMELA
- p and He spectra have different slopes in the multi TeV region (CREAM)
- Acceleration limit by SNR shock wave around 100 TeV/Z ?



- All primary heavy nuclei spectra well fitted to single power-laws with similar spectral index (CREAM, TRACER)
- However hint of a hardening from a combined fit to all nuclei spectra (CREAM)

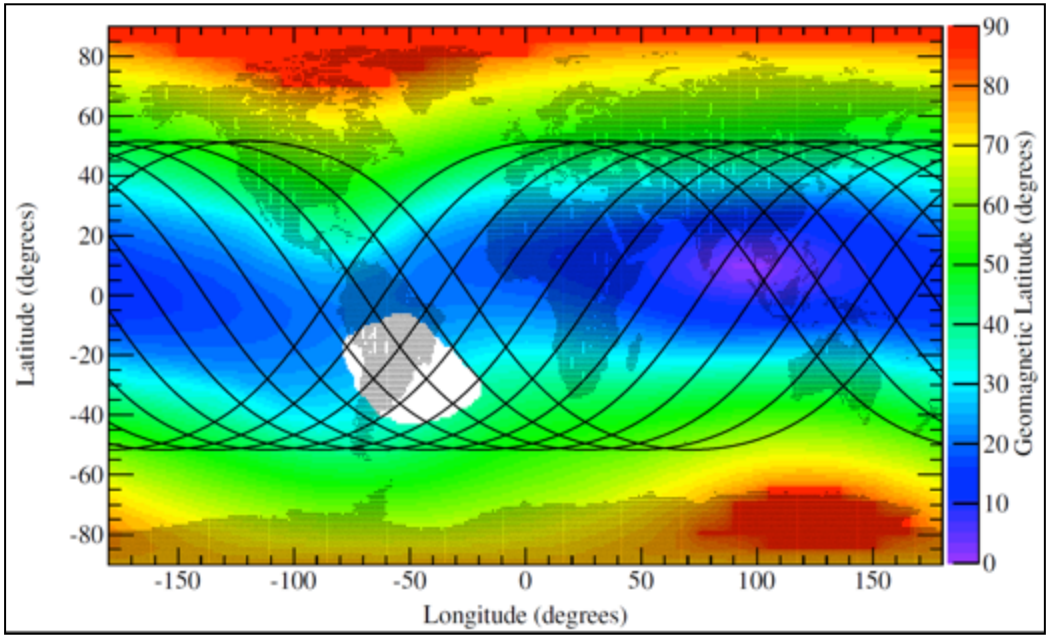




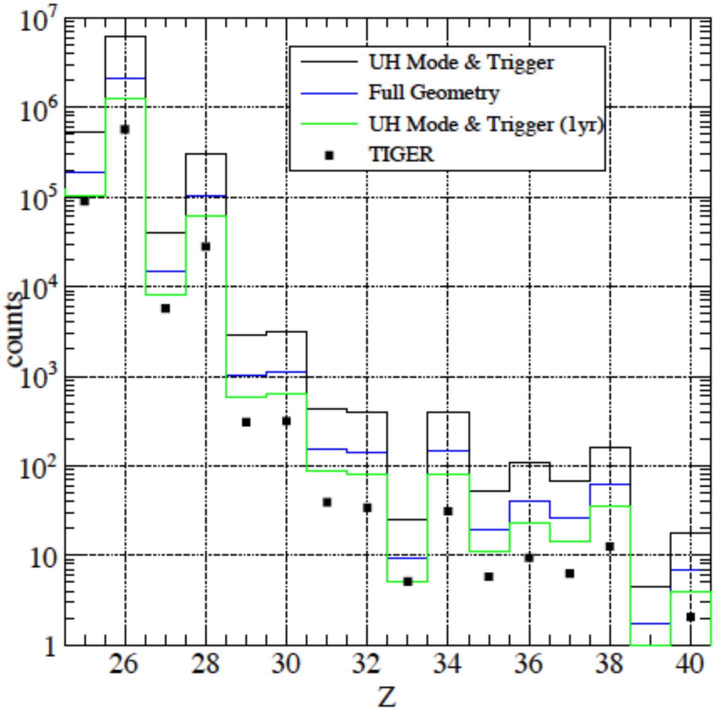
- At high energy (> 10 GeV/n) the B/C ratio measures the energy dependence of the escape path-length, $\sim E^{-\delta}$, of CRs from the Galaxy
- Data below 100 GeV/n indicate δ~0.6. At high energy the ratio is expected to flatten out (otherwise CR anisotropy should be larger than that observed)

Observation of Ultra Heavy Nuclei

Geomagnetic Latitude



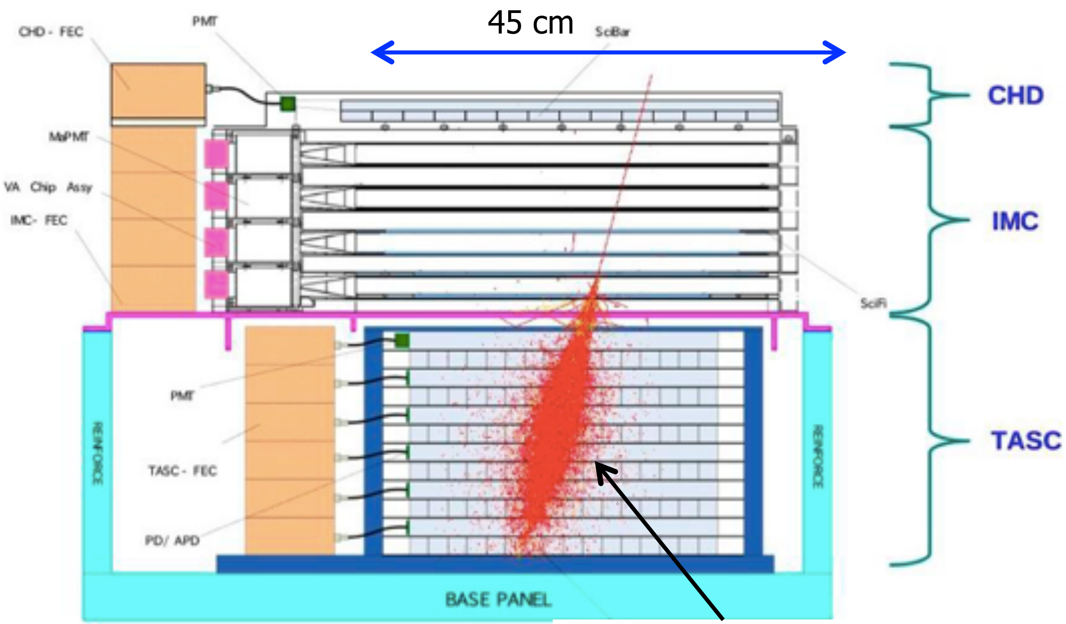
CALET (expected) vs. TIGER data



- Ultra heavy nuclei abundances provide information on CR site and acceleration mechanism
- CHD resolution is ~constant above 600 MeV/n ➔Charge ID from saturated dE/dx
- No need to measure energy ➔ No passage through TASC ➔ **Large acceptance ~0.4 m^2sr**
- **The energy threshold cut is based on the vertical cutoff rigidities seen in orbit**
- CALET should collect in 5 years ~10 times the statistics of TIGER, w/o corrections for residual atmosphere overburden

CALET Instrument Characteristics

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

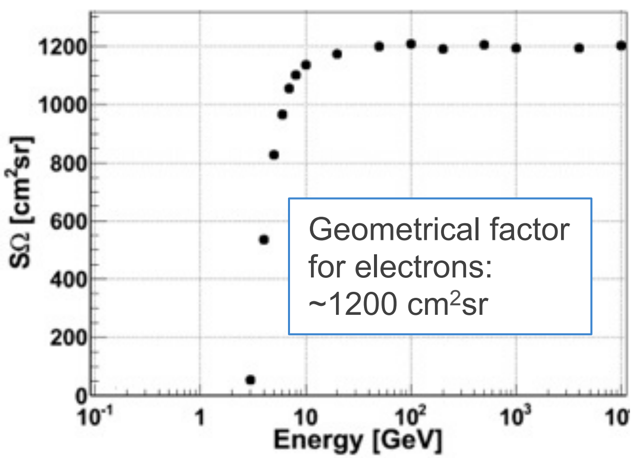


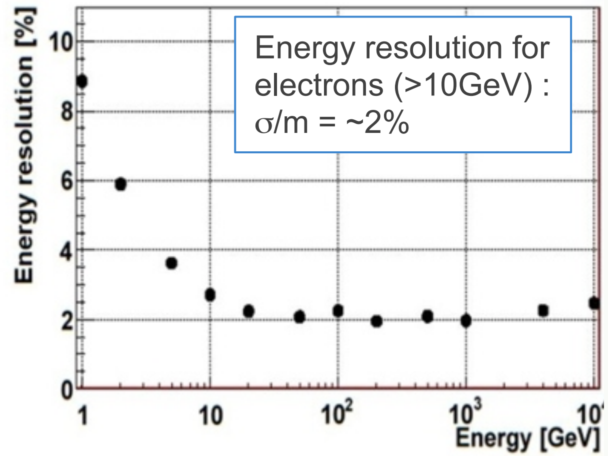
1 TeV electron shower

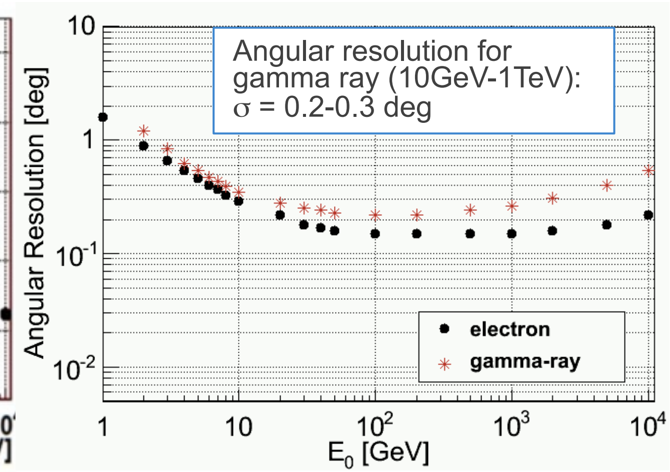
- The unique feature of CALET is its thick(~30 X_0), homogeneous calorimeter that allows to extend electron measurements into the TeV energy region with excellent energy resolution(~2-3%), coupled with a high granularity imaging pre-shower calorimeter to accurately identify the arrival direction of incident particles (~0.1°) the starting point of electro-magnetic showers. Combined, they powerfully separate electrons from the abundant protons: rejection power (~10^5).
- A dedicated charge detector + multiple dE/dx track sampling in the IMC allow to identify individual nuclear species (Δz~0.15-0.3).

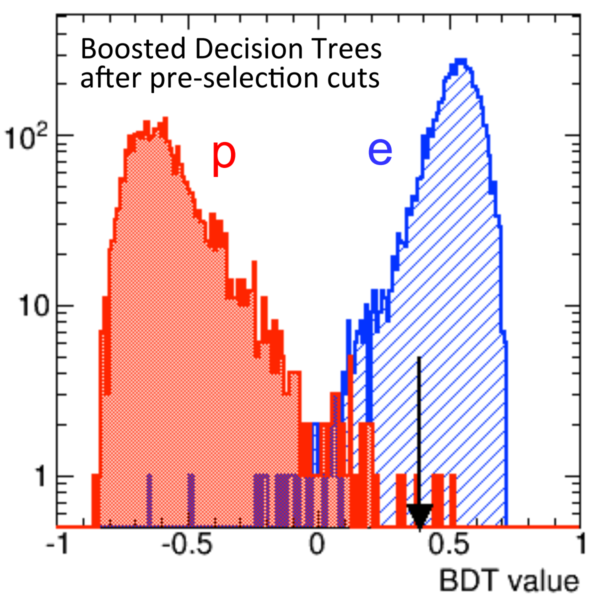
	CHD (Charge Detector)	IMC (Imaging Calorimeter)	TASC (Total Absorption Calorimeter)
Function	Charge Measurement (Z=1-40)	Arrival Direction, Particle ID	Energy Measurement, Particle ID
Sensor (+ Absorber)	**Plastic Scintillator : 14 × 1 layer (x,y)** Unit Size: 32mm x 10mm x 450mm	**SciFi : 448 x 8 layers (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

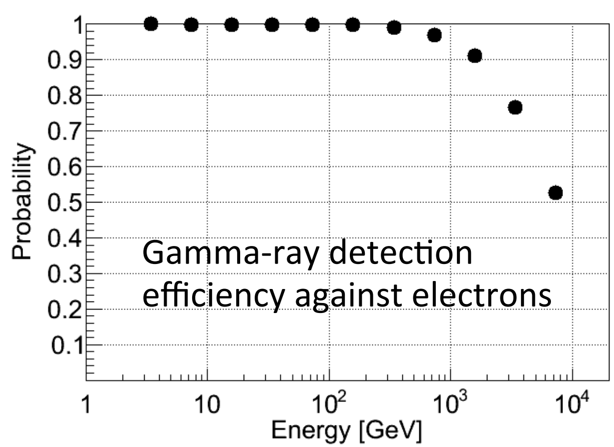
CALET Expected Performance by Simulations –electrons & gamma-ray –

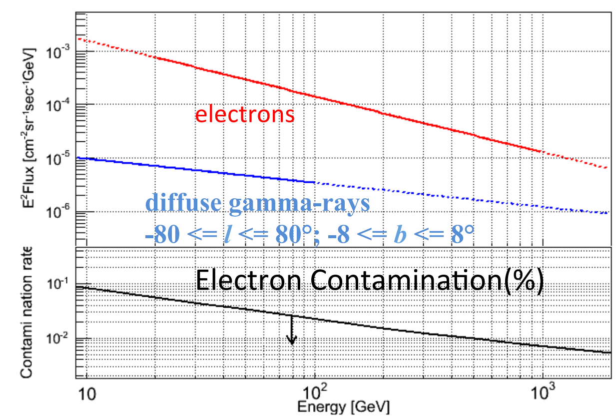










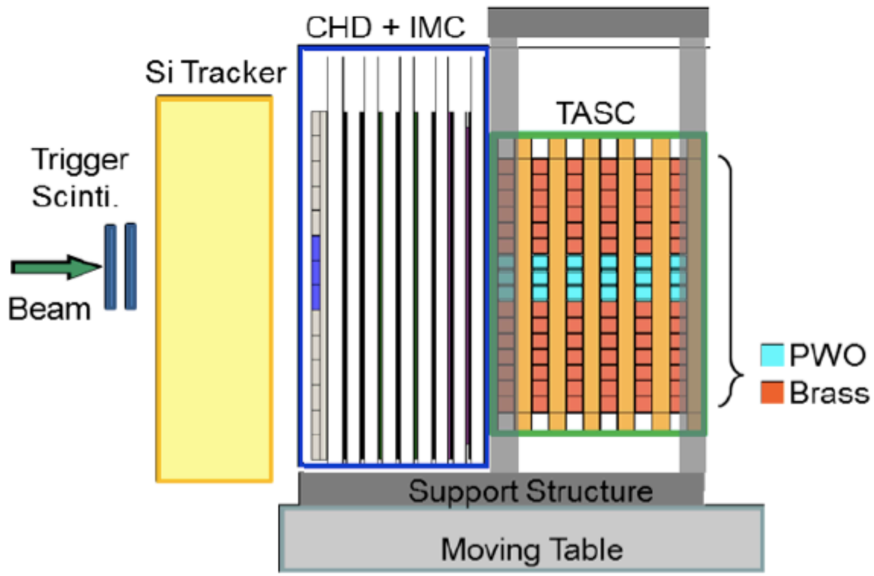


Proton rejection power at 1TeV : ≈1.3×10^5 with 88% efficiency for electrons

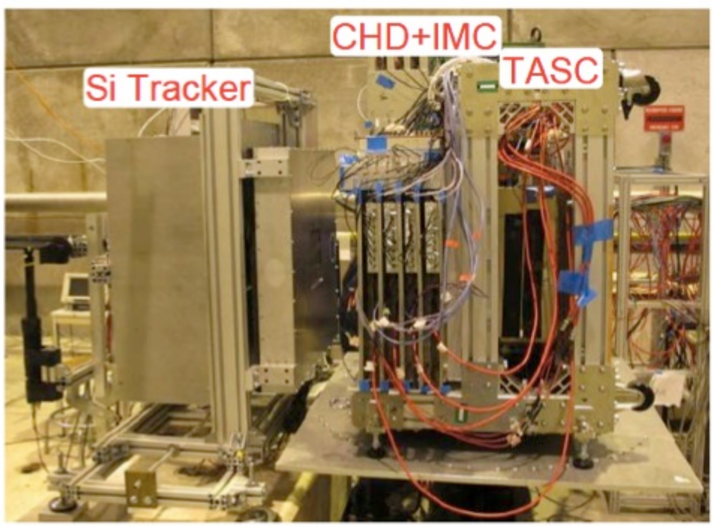
Left: detection efficiency of gamma-rays with electron discrimination power 3.54×10^{-4} (90% CL): >95% in 10-900 GeV
Right: electron contamination in galactic diffuse gamma-rays : 10% @10GeV – 1%@TeV

CERN Beam Test using the STM

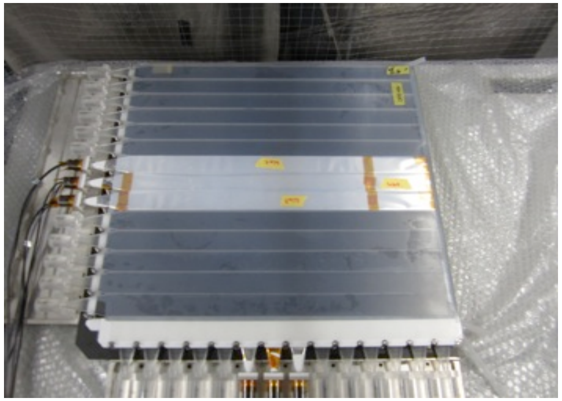
Schematic Side View of the Beam Test Model



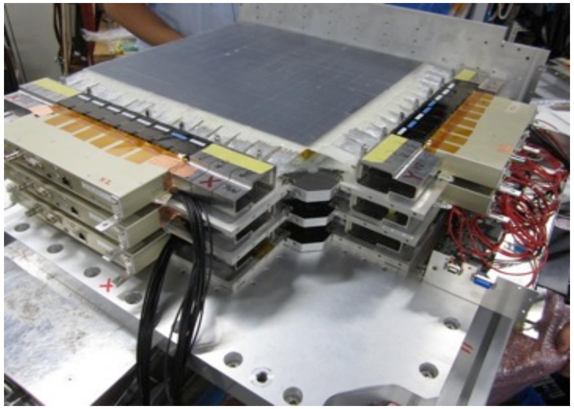
The Beam Test Model at CERN SPS H8 Beam Line



Charge Detector: CHD

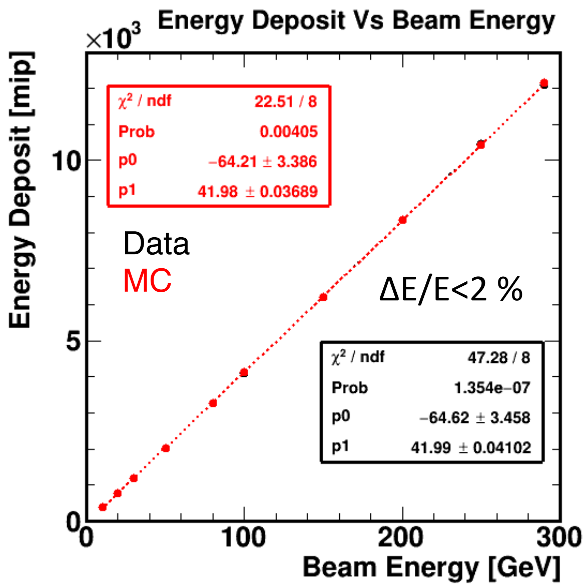


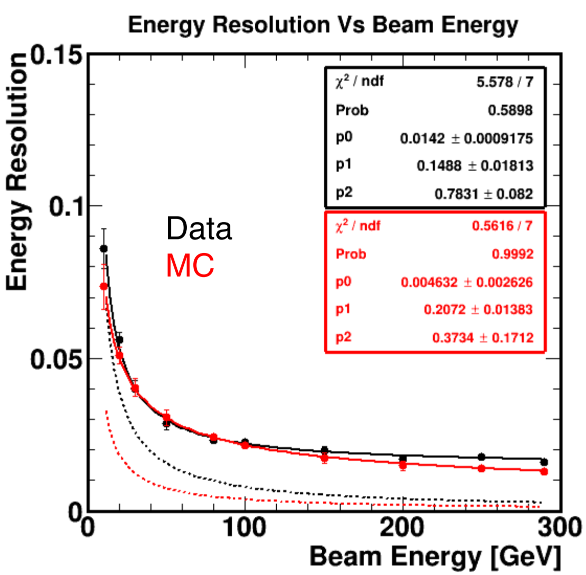
Imaging Calorimeter: IMC



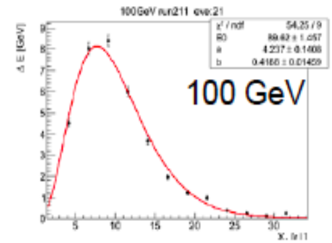
Total Absorption Calorimeter: TASC

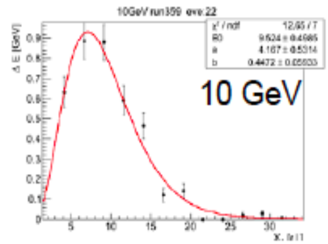
CERN-SPS beam tests

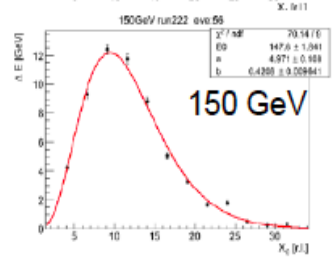


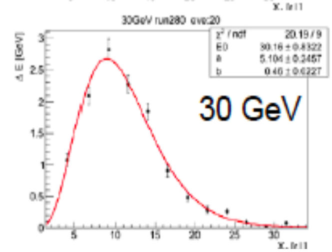


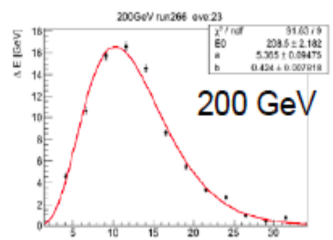
Electron shower transition curve in TASC



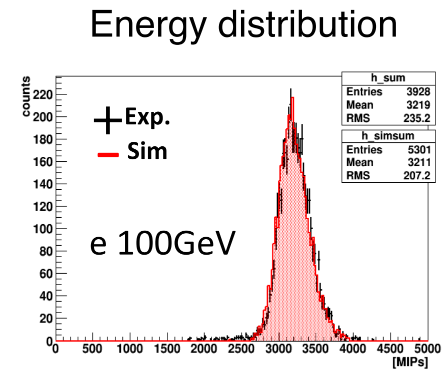


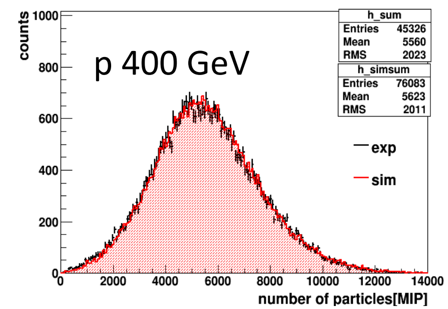


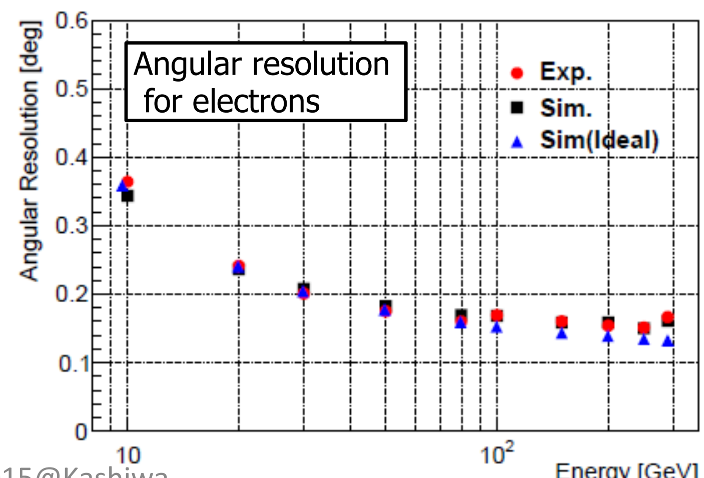




Energy distribution



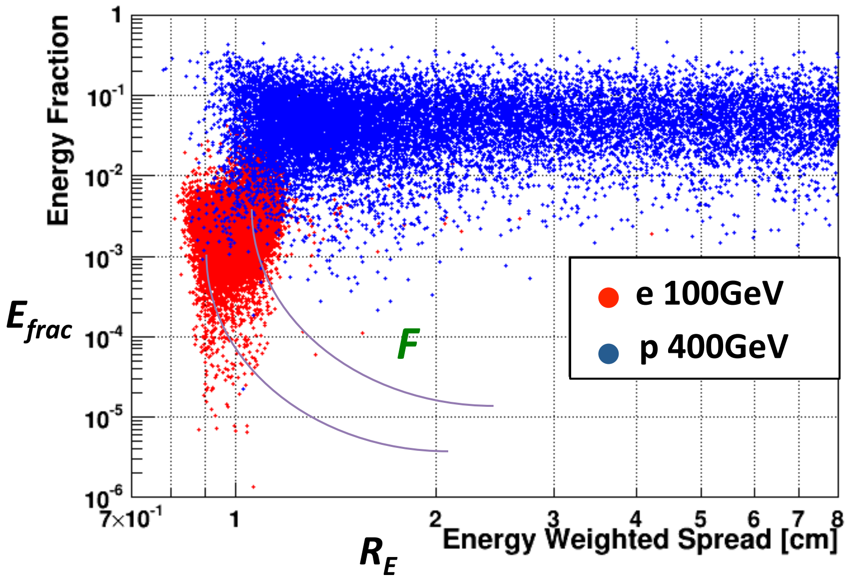


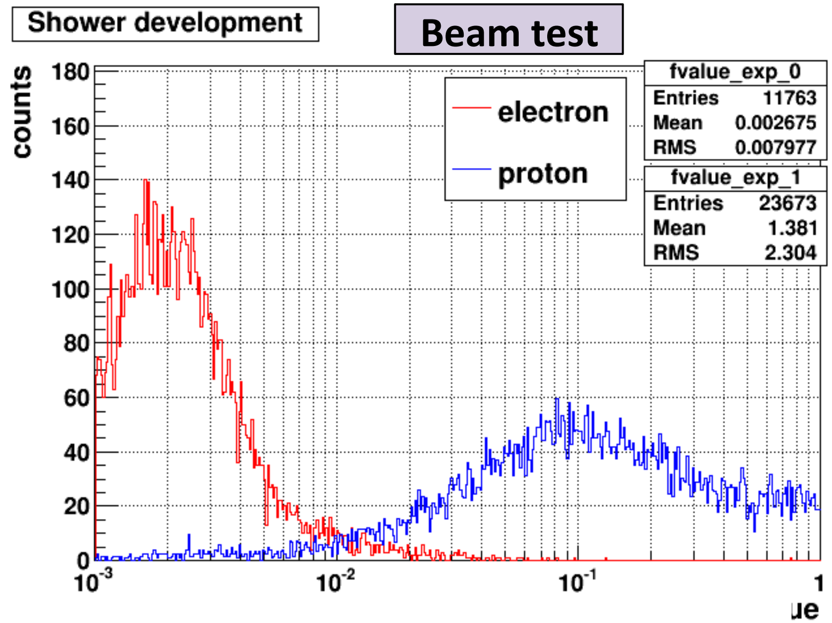


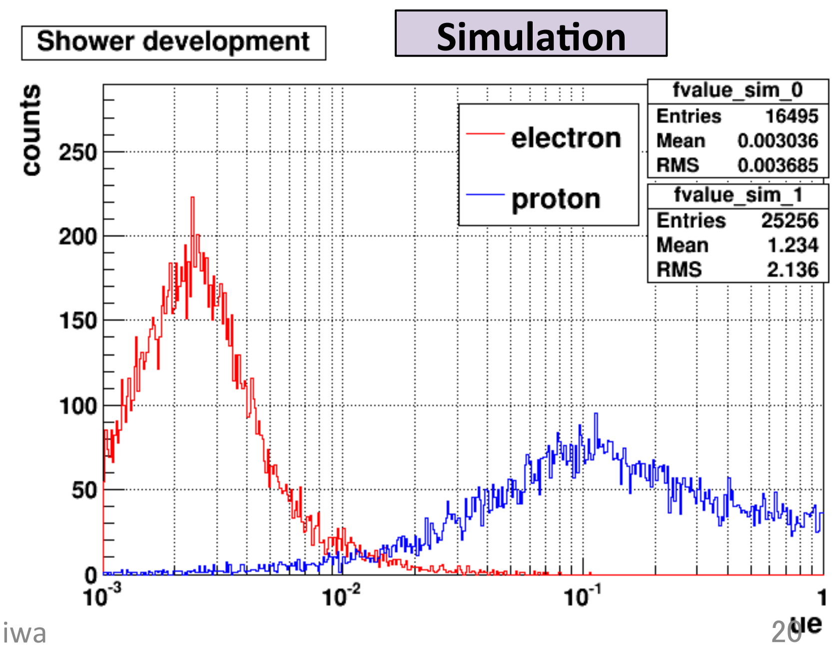
electron/proton discrimination power by beam tests

one dimensional parameter: $F = E_{frac} \times R_E^2$

simulation





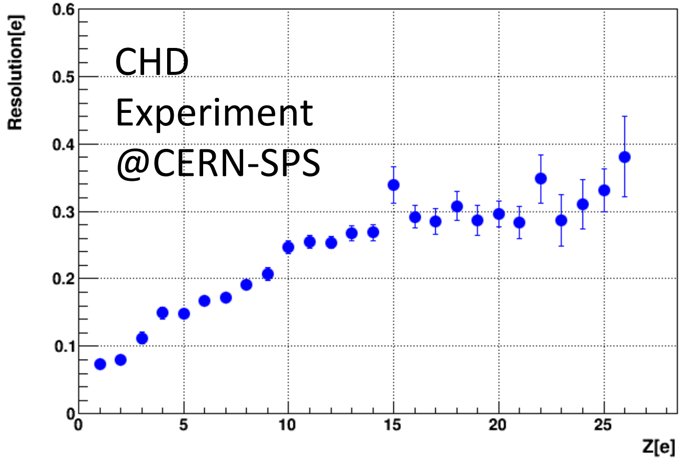


Proton rejection power for 85 % survival probability of electrons

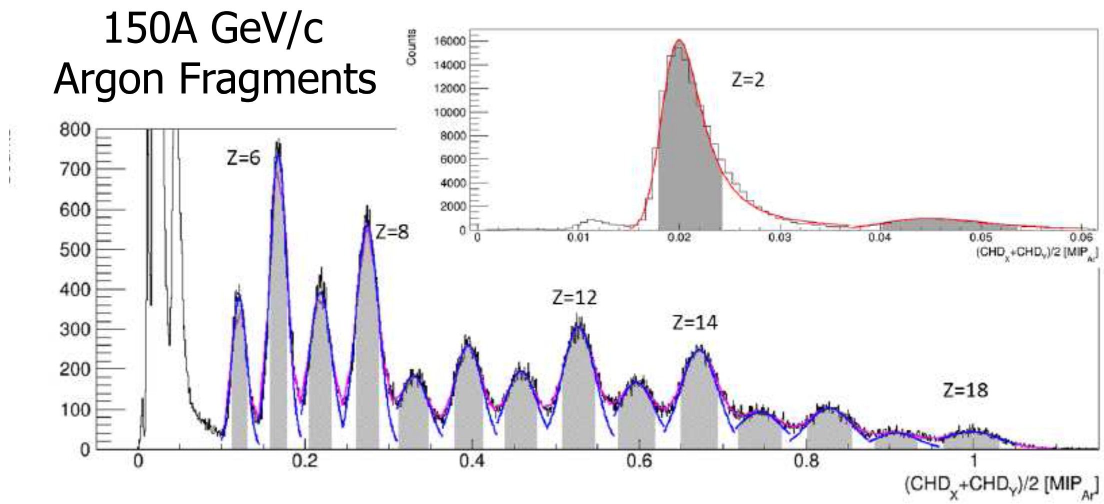
- beam test: 6.45×10^{-4}
- simulation: 4.88×10^{-4}

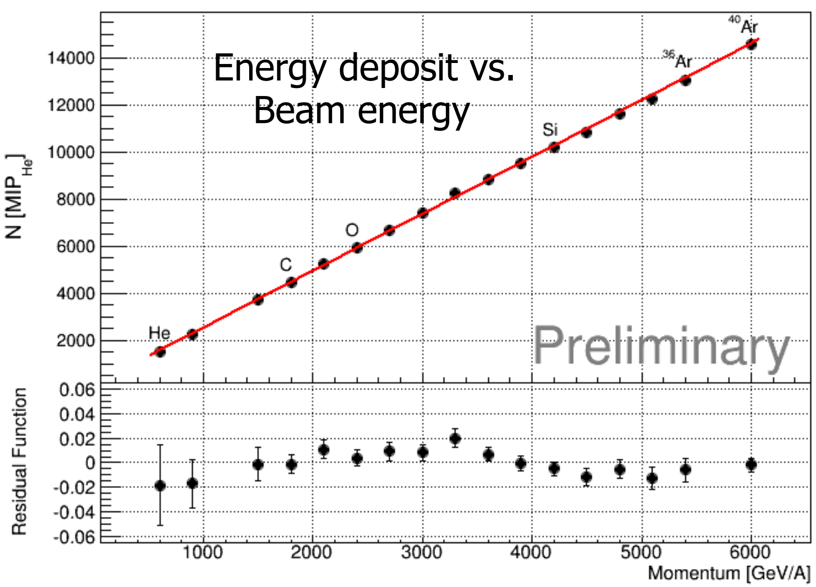
The beam test results are consistent with simulation within statistical errors.

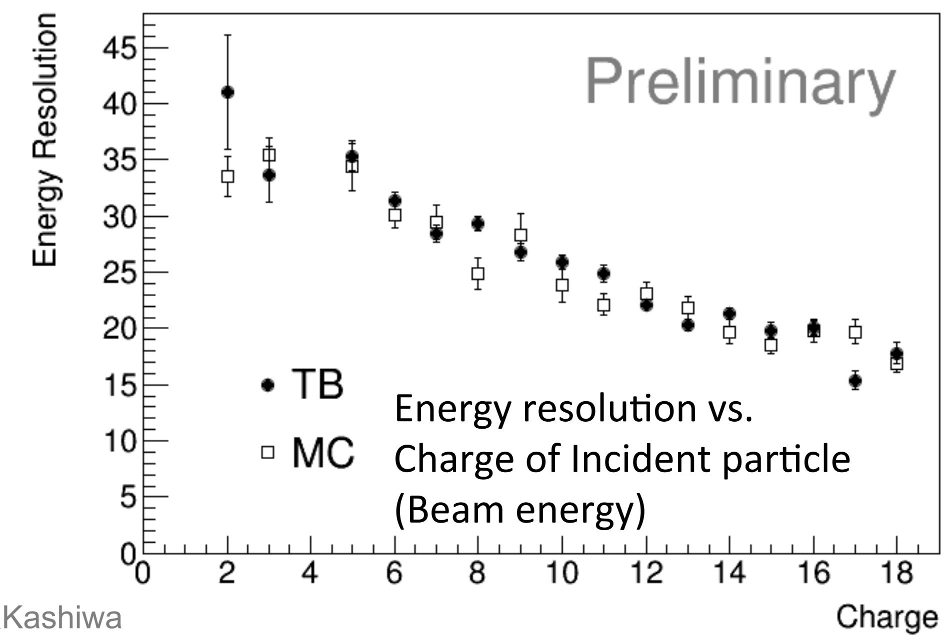
Heavy Ion Beam Test @ CERN 2014 & 2015



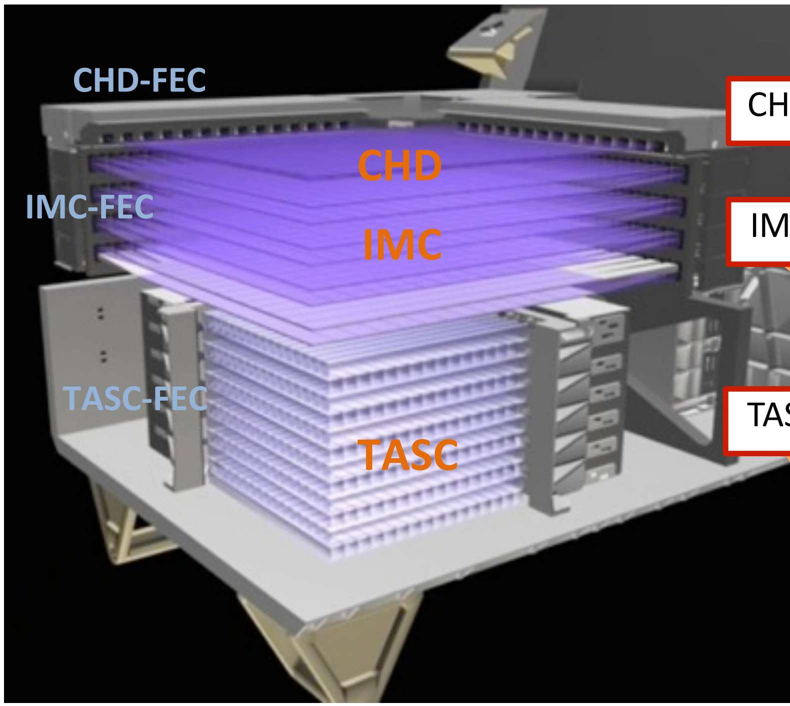
Charge resolution:
σ_Z = 0.15e(@B) – 0.30e(@Fe)







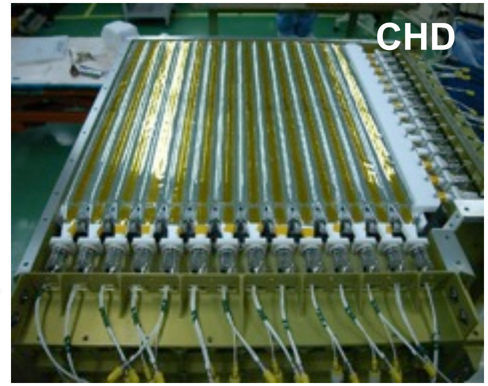
Calorimeter Flight Components



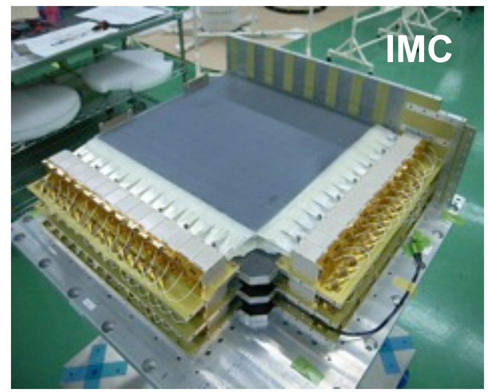
CHD

IMC

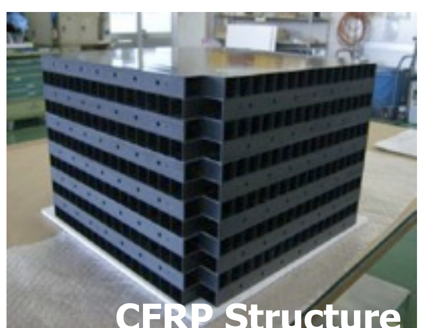
TASC



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



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

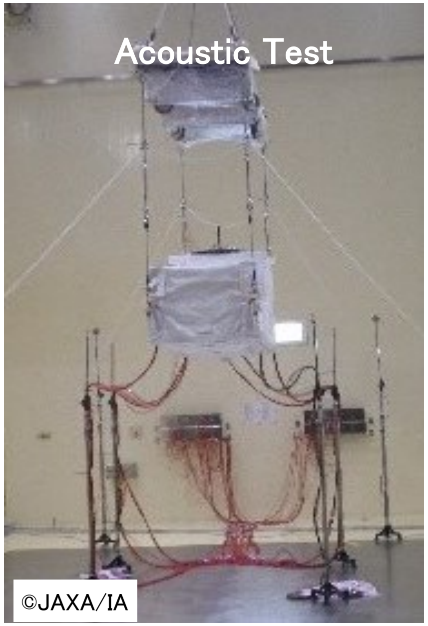


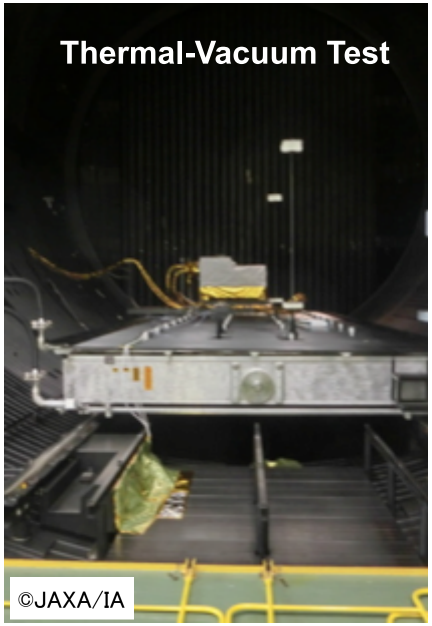
16 x 6 layers (x,y)= 192
19mm x 20mm x 326mm

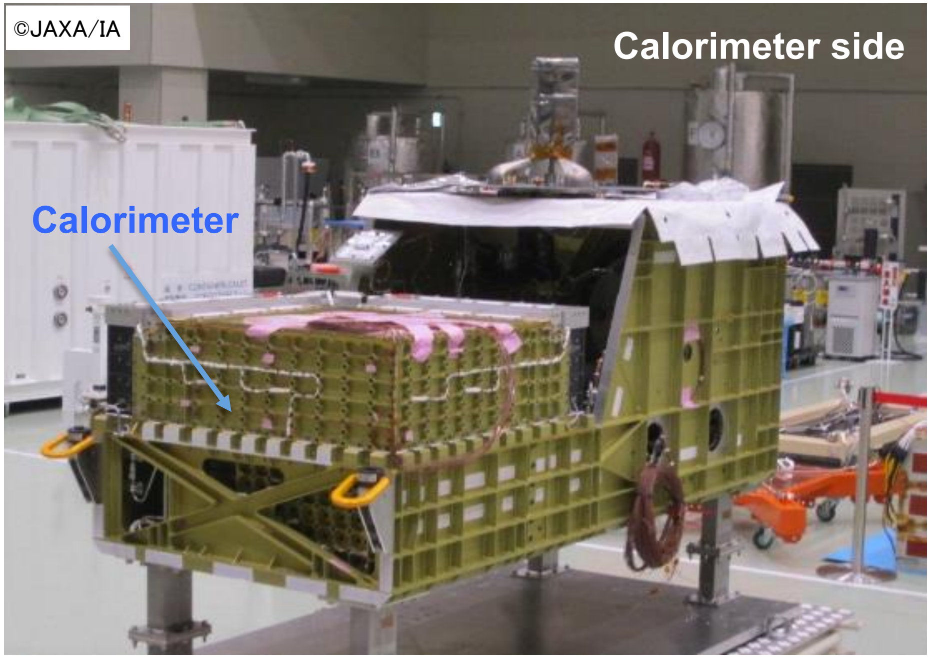
System Test of Proto-Flight Model

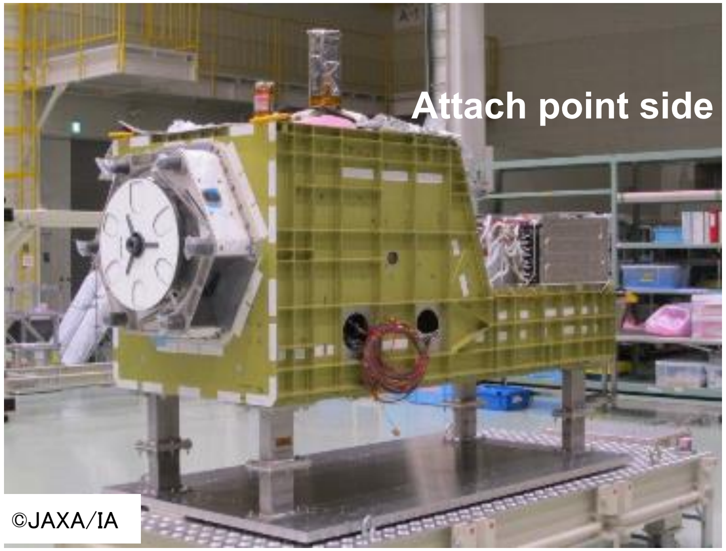
- Acoustic test, Thermal–Vacuum test and EMC test were successfully carried out at Tsukuba Space Center (JAXA)

- After final system function test, the payload was transferred to the launching site , Tanaegashima Space Center, for launch with HTV5.

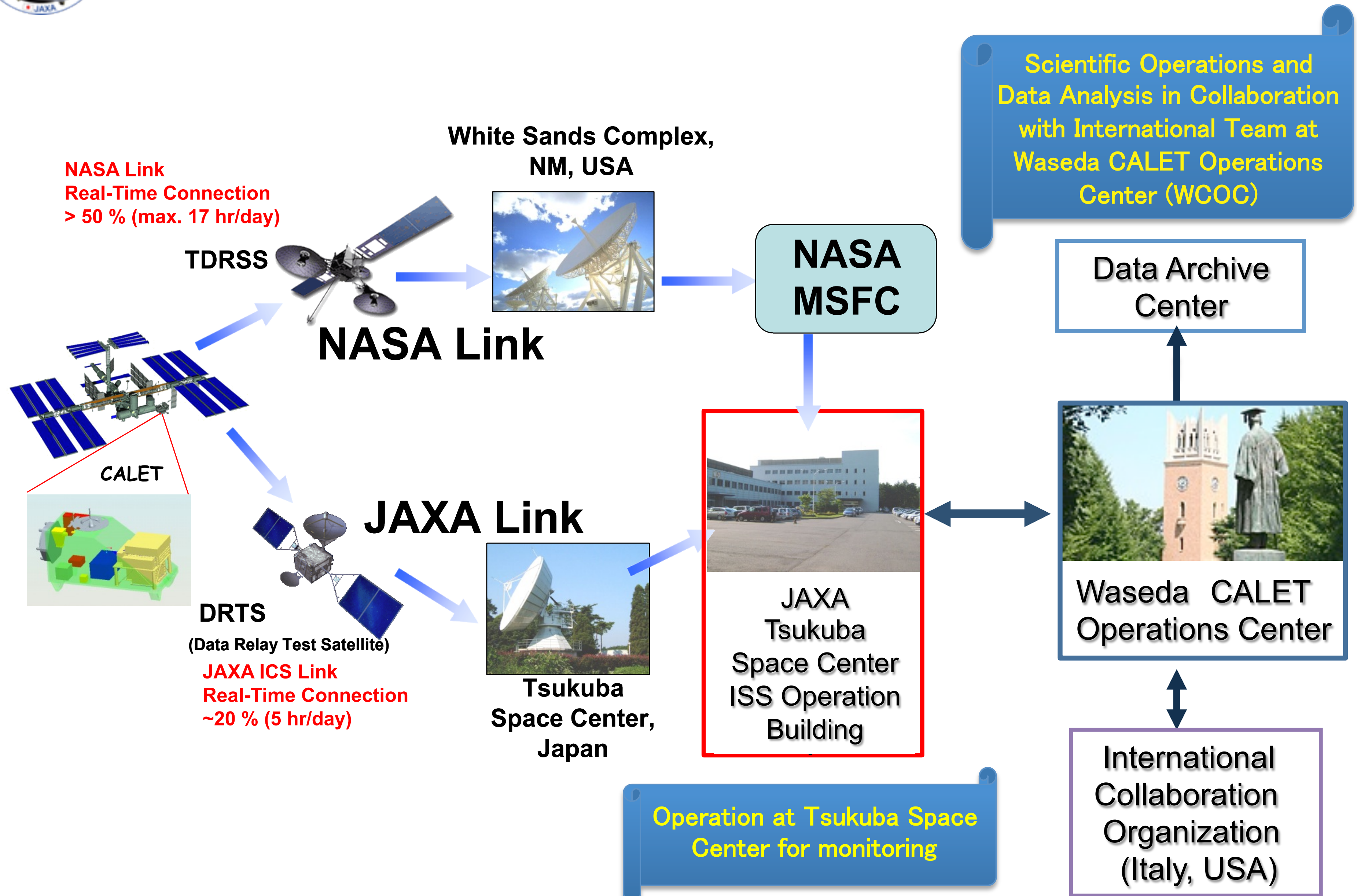




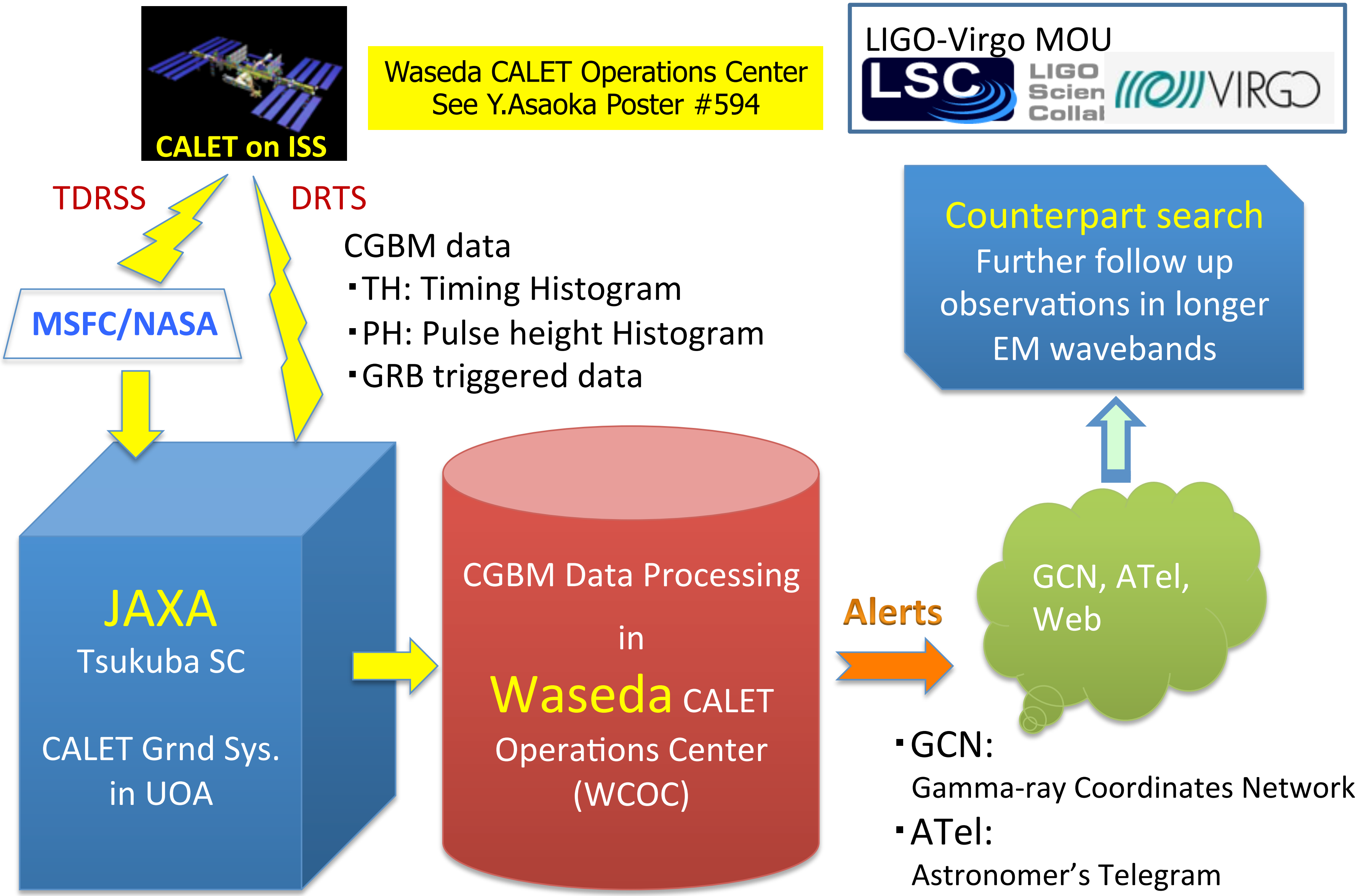




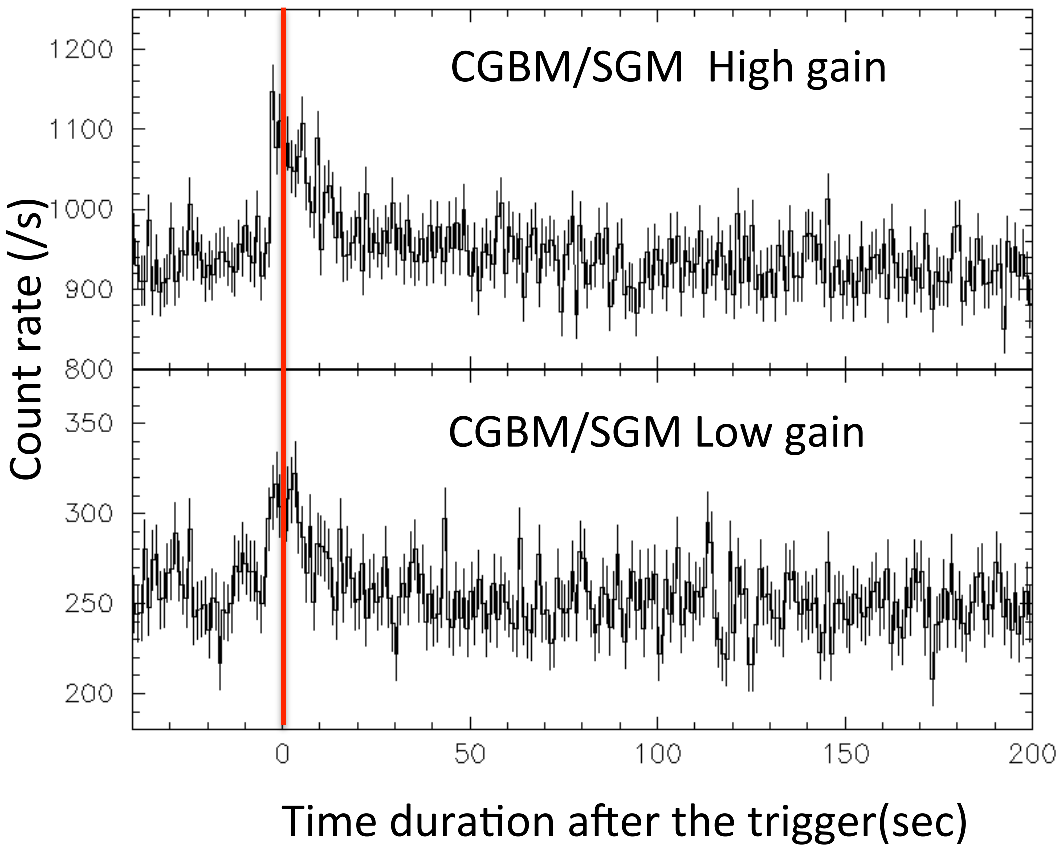
Data Downlink Using TDRSS and DRTS



General Alerts of Transients by CGBM



CGBM: Gamma-ray burst GRB 151006A detected !



GCN Circular #18475 (27.10.2015)

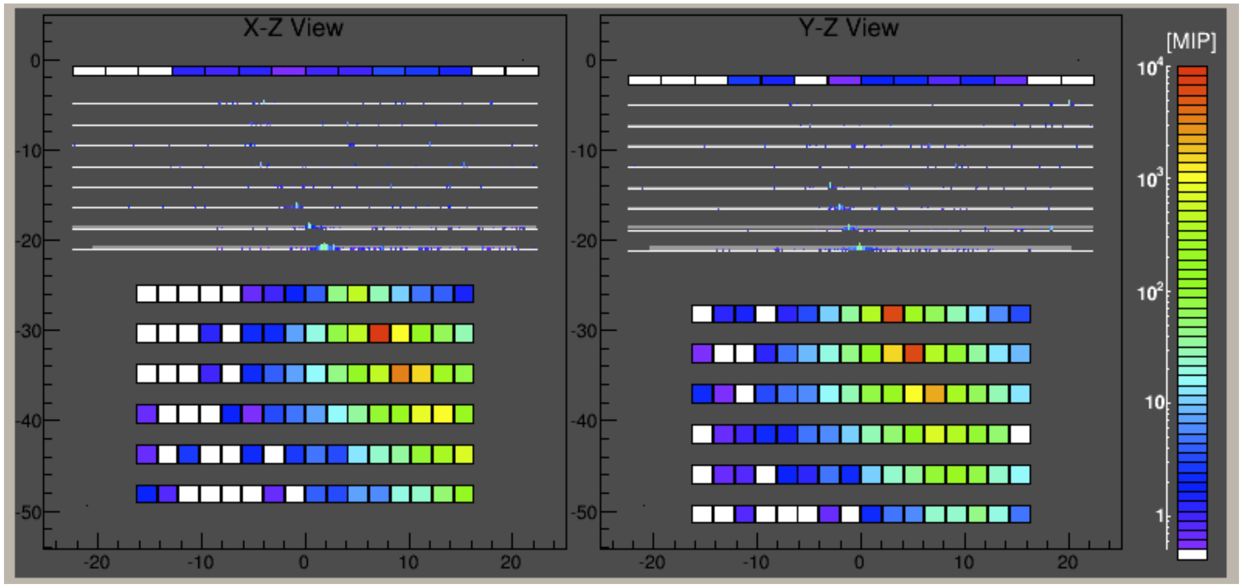
The long-duration GRB 151006A (Kocevski et al., GCN Circ. 18398; Cummings et al., GCN Circ. 18409; Roberts & Meegan, GCN Circ. 18404; Golenetskii et al., GCN Circ. 18413;Bhalerao et al.,GCN Circ.18422) triggered the CALET Gamma-Ray Burst Monitor (CGBM) at 09:54:59.97 UT on 6 October 2015. The clear burst signal was detected by the Soft Gamma-ray Monitor (SGM; 30 keV - 20 MeV) which is a scintillation detector utilized a BGO crystal. Due to a large incident angle of the event, no signal was detected by the Hard X-ray Monitor (HXM; 7 keV - 1 MeV) which is a scintillation detector composed of a LaBr3(Ce) crystal.

The SGM light curve shows two spikes peaking at T0-2s and T0+2s, and the emission ending around T0+~60s. The T90 duration measured by the SGM data is 63 +- 5 s (30 - 1000 keV). Currently, CALET is in the commissioning phase.

We predict two-three GRB events per month, and the detection coincident with CALET-Calorimeter and MAXI on JEM are expected.

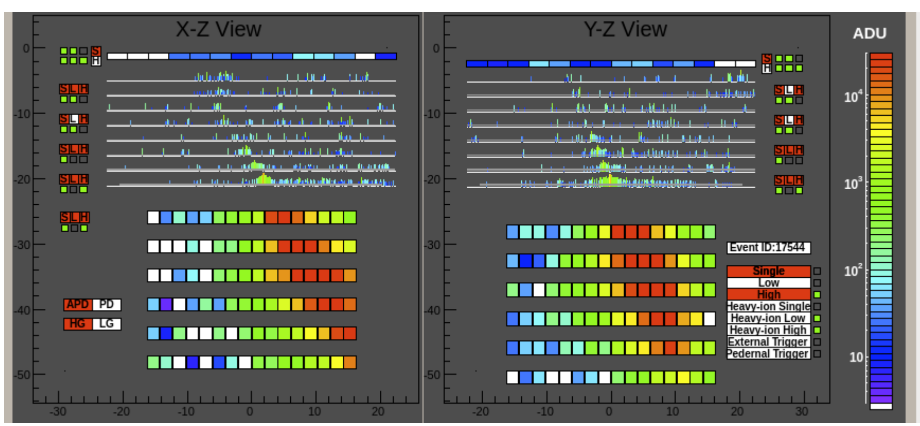
~1TeV electron (candidate) observed !

（converted to MIP by calibration on ground)

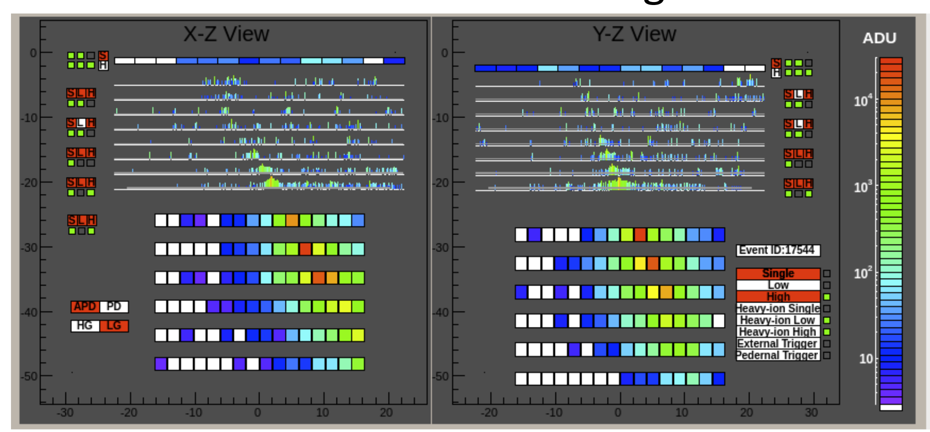


1 event per a few days expected

Raw Data -APD High gain-



Raw Data -APD Low gain-



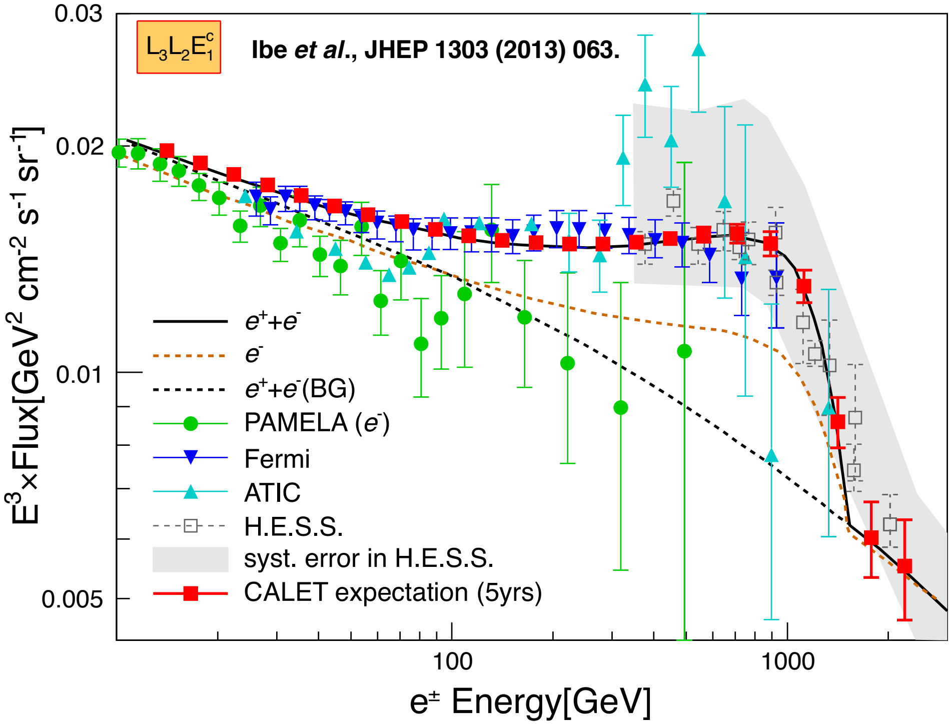
Conclusions and Summary

- ✧ **CALET is a space-based calorimeter designed to perform cosmic ray measurement, mainly aimed at the electron component.**
- ✧ Its main instrument is a deep (27 X_0), homogeneous, segmented PWO calorimeter and a fine imaging calorimeter (3 X_o) , which provides both an excellent energy resolution and a high e/p rejection power.
- ✧ **CALET will investigate the spectrum of many cosmic ray species in a broad energy range, providing valuable information for indirect DM search, and study acceleration and propagation mechanisms.**
- ✧ The CALET was launched by the Japanese carrier, HTV-5, to the Japanese Experiment Module (Kibo) on the ISS on Aug. 19, 2015 for 5-year observation. At present, commisioning of each component was being carried on, and the science operation has started from Oct. 5.

Stay tuned !!!

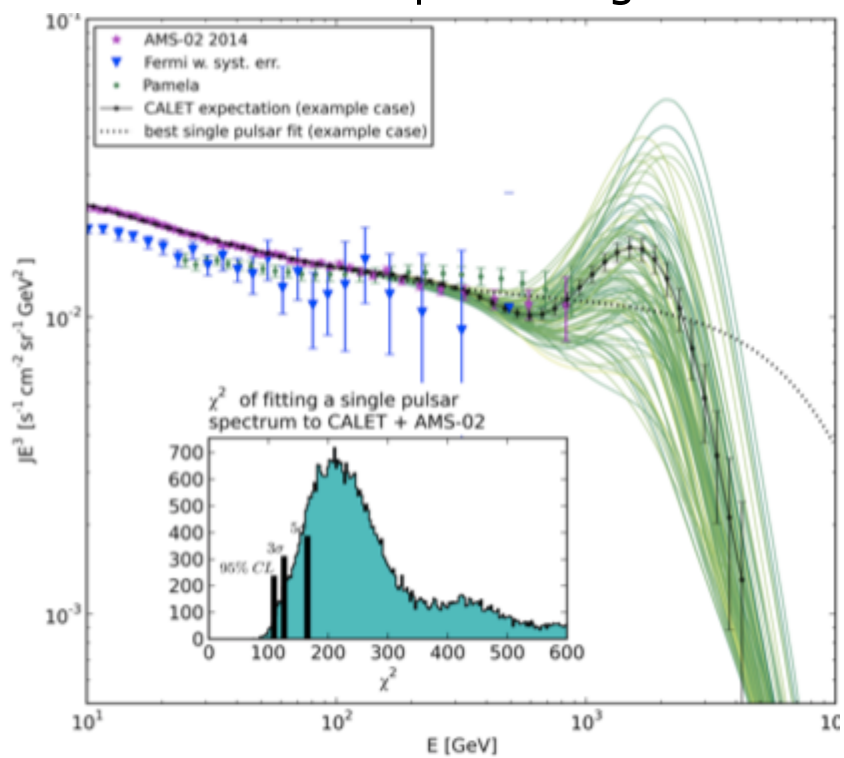
Dark Matter or Pulsar by CALET Observation

Decay of Dark Matter (LSP)



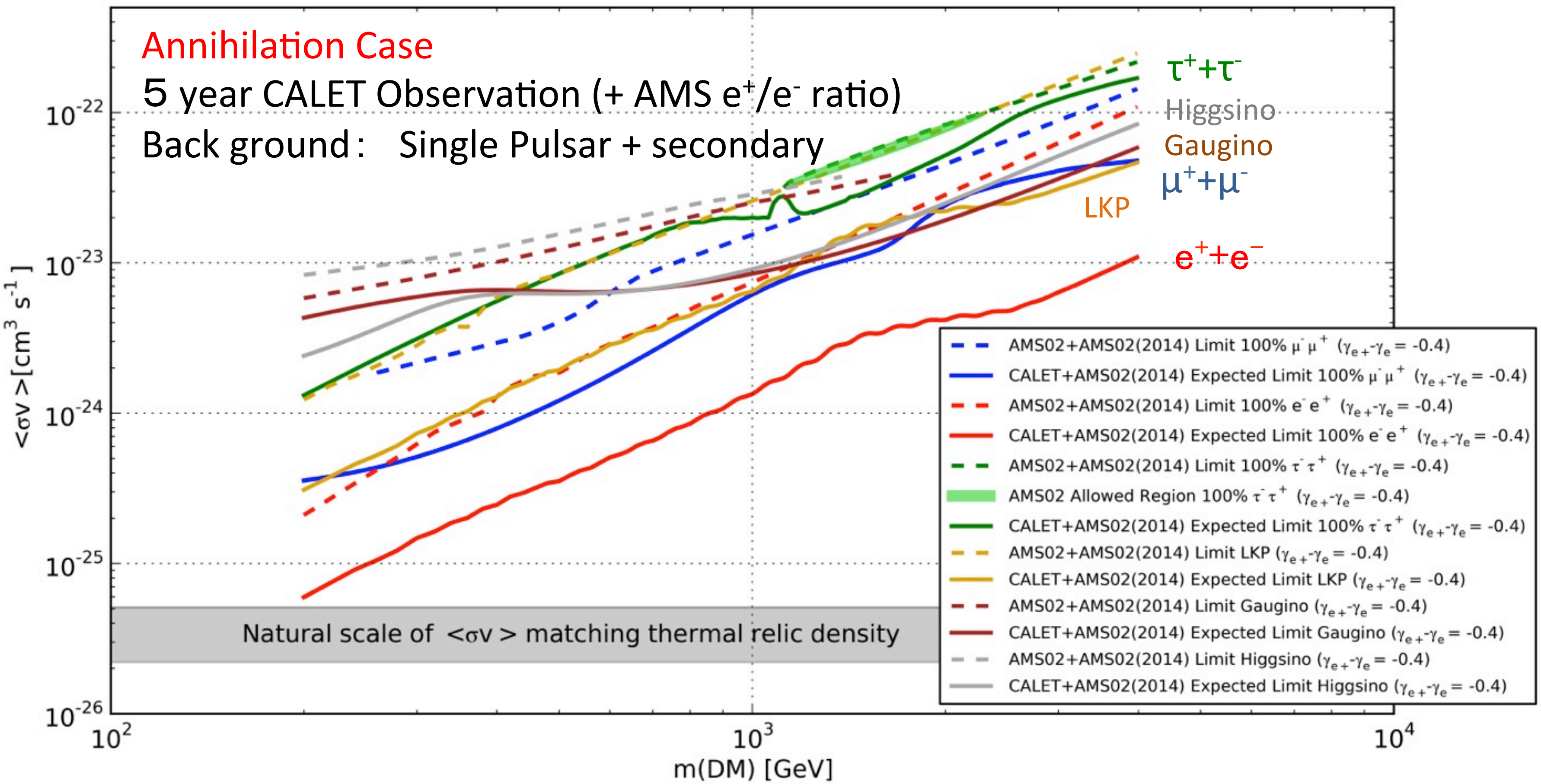
Expected e^++e^- spectrum by **Lightest Super Symmetry Particle (LSP) (black line)** after 5-year CALET measurement (red dots), which is consistent with present data of positron excess and e^++e^- spectrum

Pulsar: multiple or single



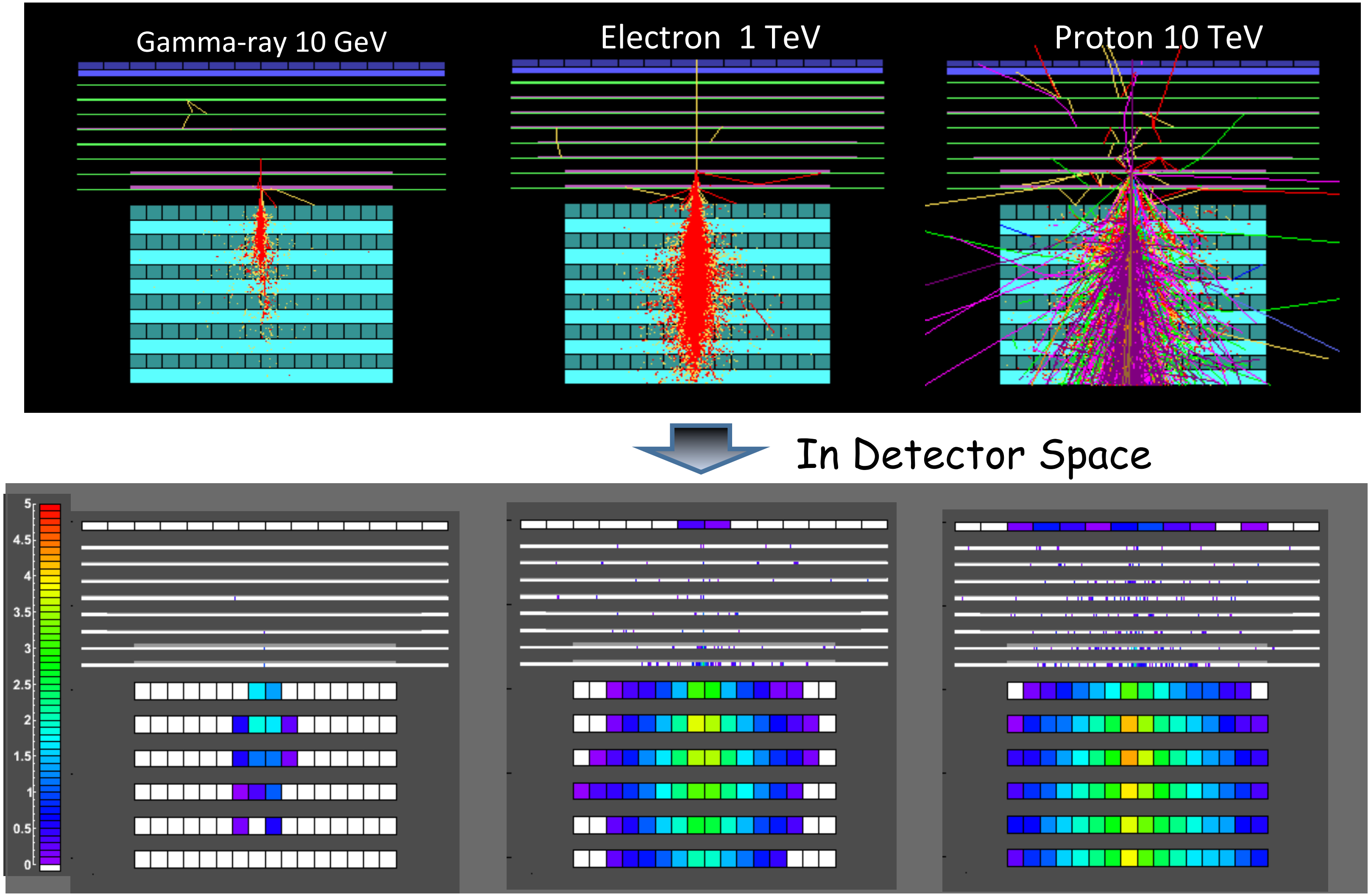
- Parameters assigned to PWN in random walk to match AMS-02 data => 100 cases
  - ATNF : R< 2 kpc, Age < 10^6 year (40 pulsars)
  - Spectra of nearby PWN simulated with DRAGON
- By using 500 CALET 5-yr samples:
  - **The fine structure (e.g black line)** is observable by CALET thanks to the high energy resolution
  - **Single pulsar hypothesis (dotted line)** can be rejected by more than 5σ for most cases

Overview of Expected Limits for Selected Dark Matter Candidates



- Largest improvement (up to factor 10) for **$e^+ + e^-$ - channel** and (up to factor 5) for LKP – hard drop in spectrum at mass of Dark Matter particle – well detectable by CALET due to high statistics in TeV region
- **$\tau^+ + \tau^-$ - channel** spectrum most similar to pulsar - could so far explain all the positron excess – weaker limit than for $\mu^+ + \mu^-$ and dent where pulsar and Dark Matter annihilation spectrum together give best fit.

CALET/CAL Shower Imaging Capability (Simulation)



- 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=0.15-0.3 with the CHD.

Overview of Trigger modes for CALET

High Energy Shower Trigger (HE)	- High energy electrons (10GeV ～20TeV) - High energy gamma rays (10GeV ～10TeV) - Nuclei (a few10GeV～000TeV)
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 particle (mainly protons and heliums)

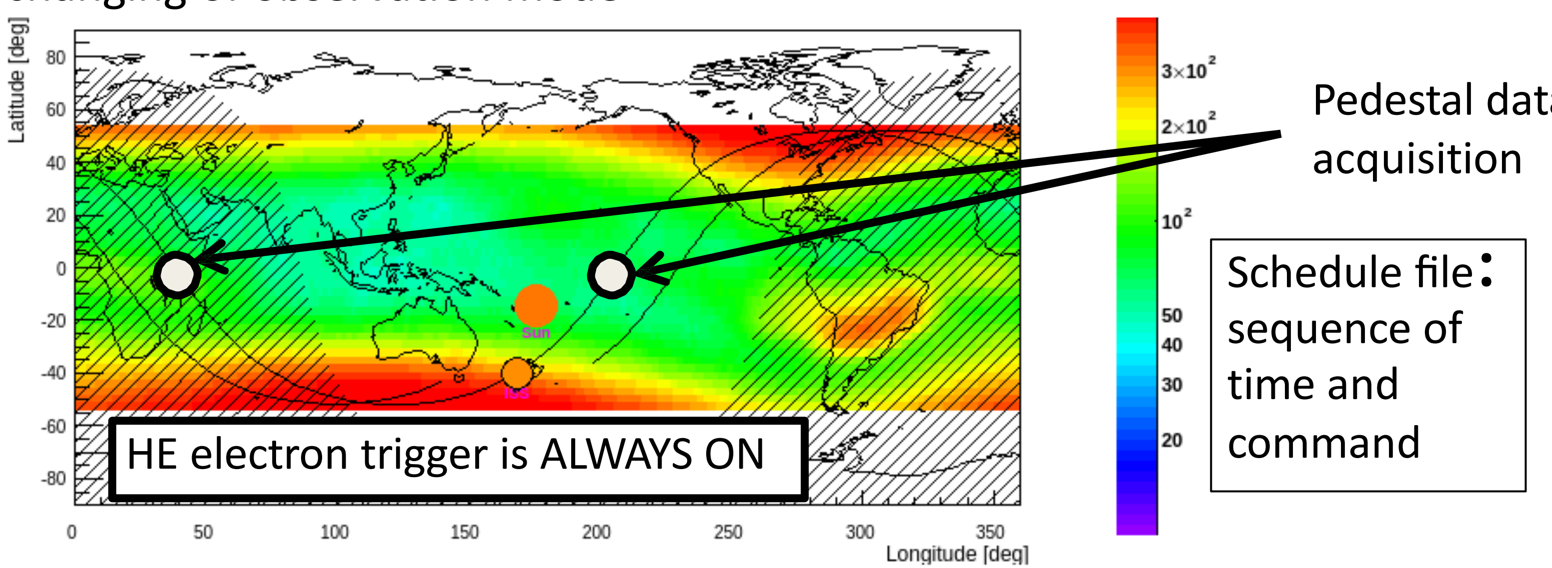
(*) In addition to above 3 trigger modes, heavy modes are defined for each of the above trigger mode. They are omitted here for simple explanation.

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

Predominantly, timestamped changes of trigger setting are described in schedule command file. It makes possible to take pedestals, penetrating particles, low energy electrons at high latitude, and other dedicated data in addition to the most important high energy shower data.

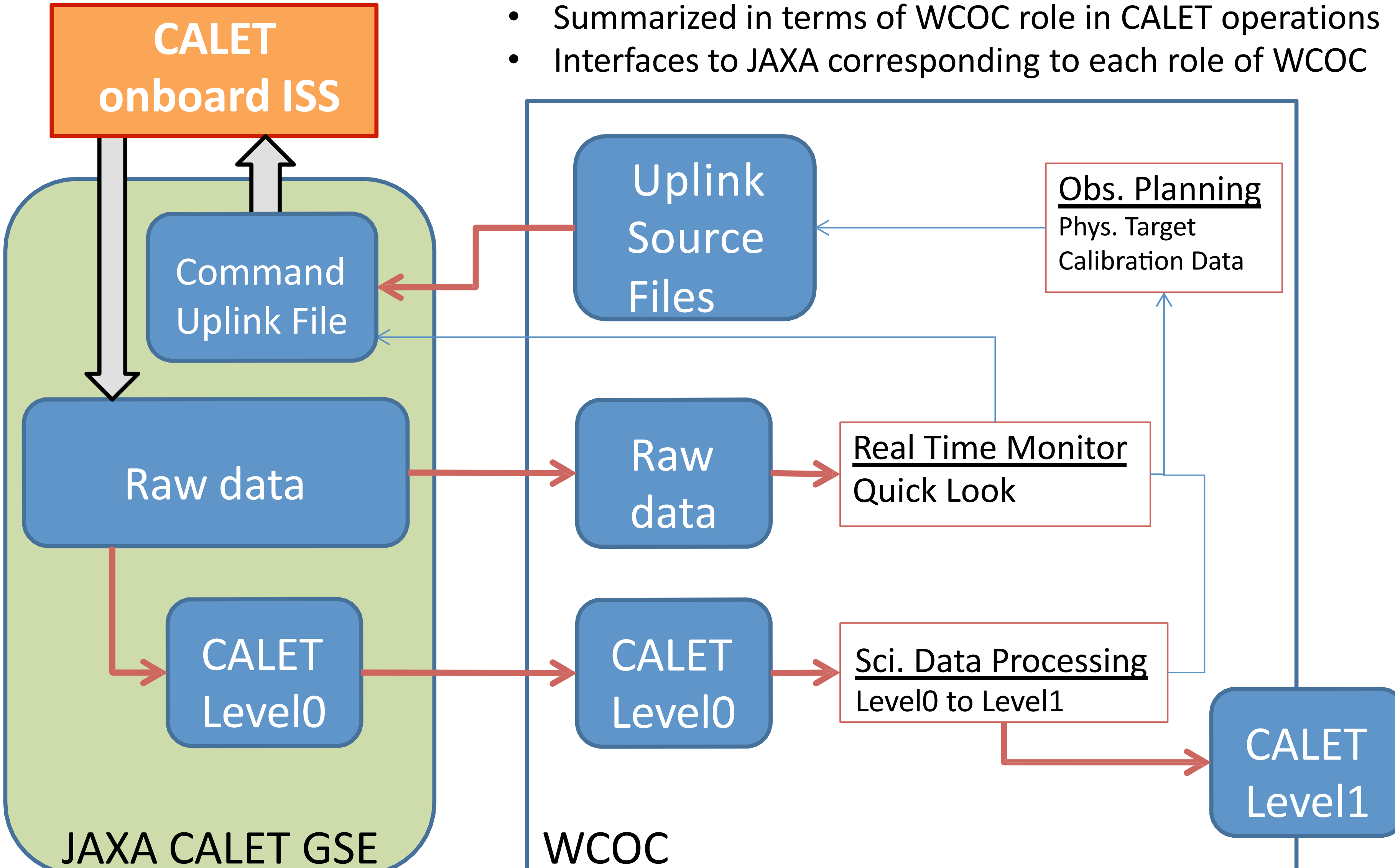
Operation Procedure

- Optimization of observation condition
  - Stable and continuous data taking to accumulate HE electron events is the primary and the most important task of the nominal operation.
  - Need to schedule calibrations runs (pedestal, penetrating p/He)
  - We can think of other trigger mode as long as it does not affect high energy electron data statistics to maximize the outcome
- Every day observation plan
  - realization with schedule command file
    - changing of observation mode



CALET Ground System Data-flow Summary

- Summarized in terms of WCOC role in CALET operations
- Interfaces to JAXA corresponding to each role of WCOC



GSE: Ground Support Equipment