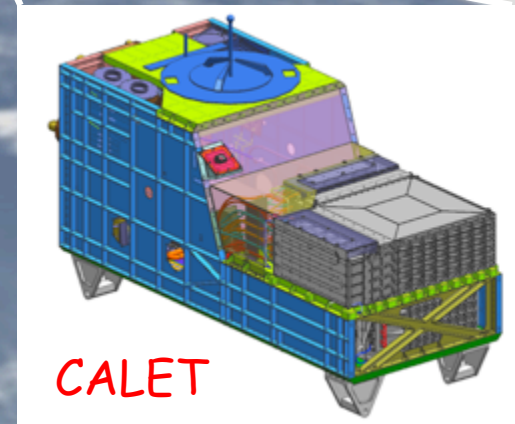




Status and Performance of the CALorimetric Electron Telescope (CALET) on the International Space Station

*Shoji Torii
for the CALET Collaboration*

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



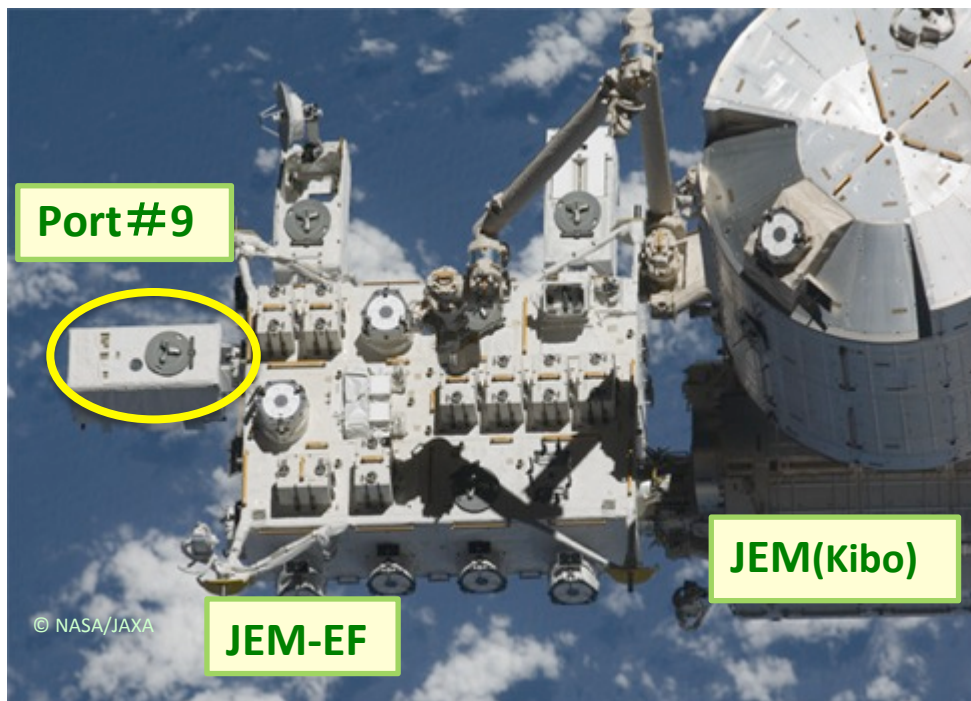
CALET Collaboration



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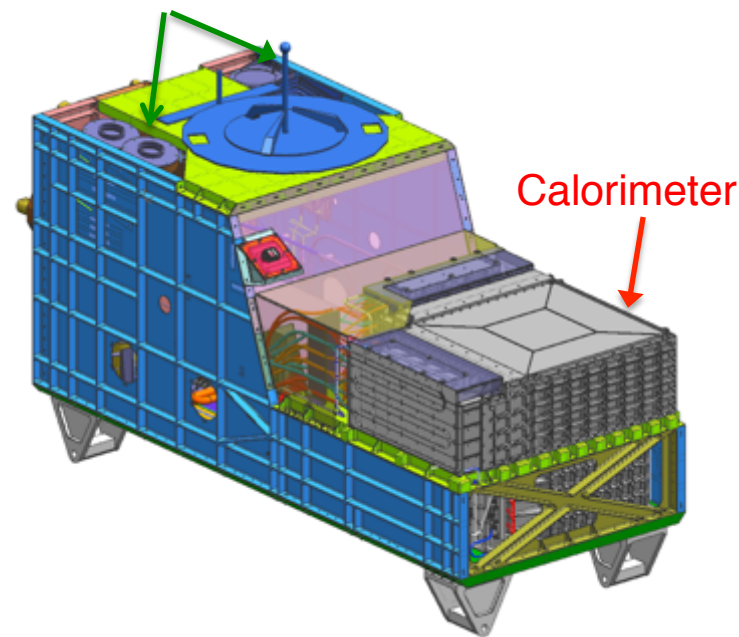
- | | |
|--|---|
| 1) Aoyama Gakuin University, Japan | 18) University of Denver, USA |
| 2) Hirosaki University, Japan | 19) University of Florence, IFAC (CNR) and INFN, Italy |
| 3) ICRR, University of Tokyo, Japan | 20) University of Pisa and INFN, Italy |
| 4) JAXA/SEUC, Japan | 21) University of Rome Tor Vergata and INFN, Italy |
| 5) JAXA/ISAS, Japan | 22) University of Siena and INFN, Italy |
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| 7) Kanagawa University, Japan | 24) Washington University-St. Louis, USA |
| 8) KEK, Japan | 25) Yokohama National University, Japan |
| 9) Louisiana State University, USA | 26) University of Padova and INFN, Italy |
| 10) NASA/GSFC, USA | 27) Ibaraki University, Japan |
| 11) National Inst. of Radiological Sciences, Japan | 28) Ibaraki National College of Technology, Japan |
| 12) Nihon University, Japan | 29) Nagoya University, Japan |
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| 14) Saitama University, Japan | 31) CRESST/NASA/GSFC and Universities Space Research Association, USA |
| 15) Shibaura Institute of Technology, Japan | 32) National Institute of Polar Research, Japan |
| 16) Shinshu University, Japan | 33) The University of Tokyo, Japan |
| 17) Tokyo Institute of Technology, Japan | |

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

Gamma - Ray Burst Monitor



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.

Calorimeter

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

Gamma-ray burst monitor (CGBM)

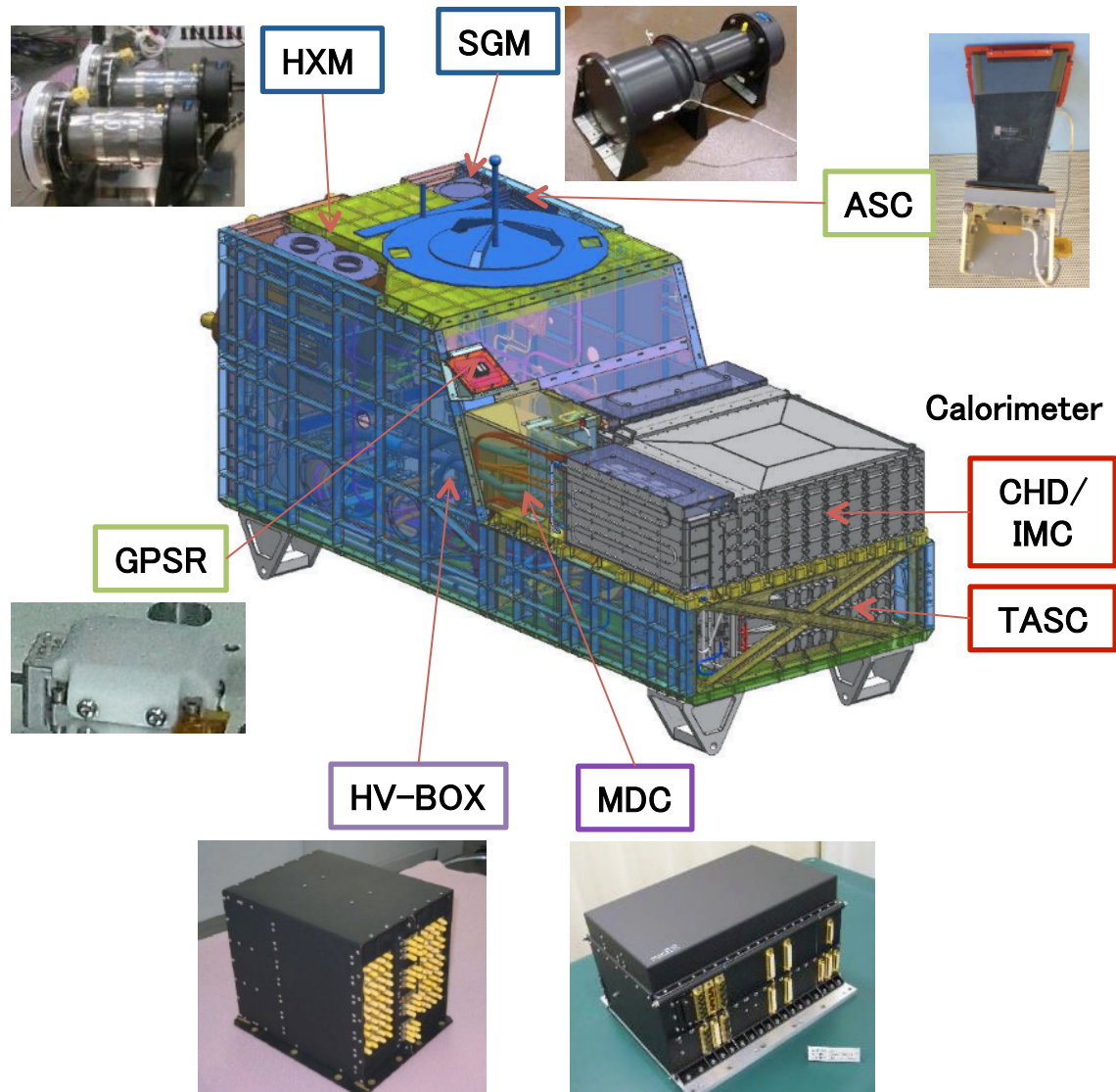
- **Hard X-ray Monitor (HXM)**
LaBr₃ : 7keV~1MeV
- **Soft γ -ray Monitor (SGM)**
BGO : 100keV~20MeV

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)



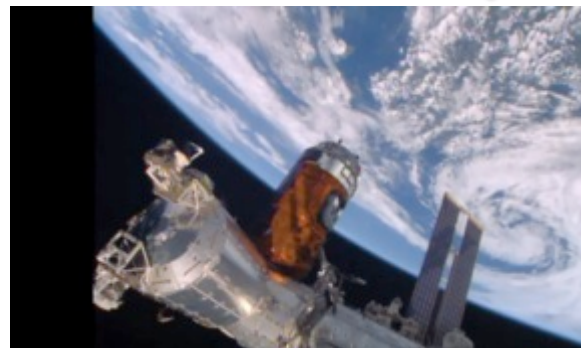
CALET is now on the ISS !



- 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.



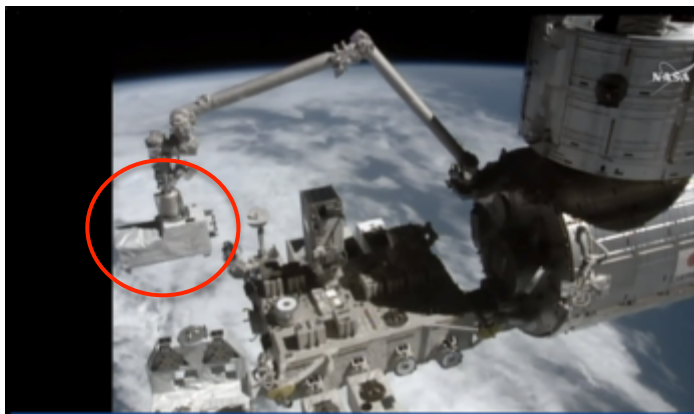
- ② **August 24th:** The HTV-5 Transfer Vehicle (HTV-5) is grabbed by the ISS robotic arm.



- 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.



2015/10/30

TeVPA2015@Kashiwa



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**.

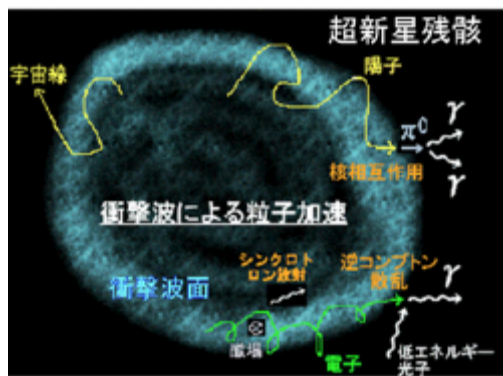
Science Objectives	Observation Targets
Nearby Cosmic-ray Sources	Electron spectrum into trans-TeV region
Dark Matter *	Signatures in electron/gamma energy spectra in the several GeV – 10 TeV range
Cosmic-ray Origin and Acceleration	p-Fe energy spectra up to 10^{15} eV and trans-iron elements ($Z=26-40$) 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.

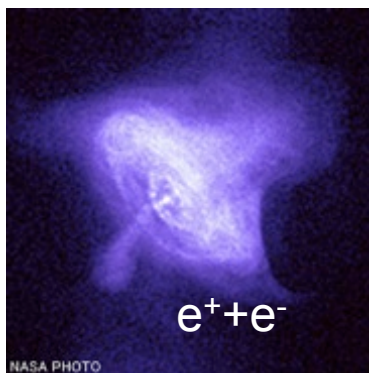
Electron & Positron Origins and Production Spectrum

Astrophysical Origin

Shock Wave Acceleration in SNR

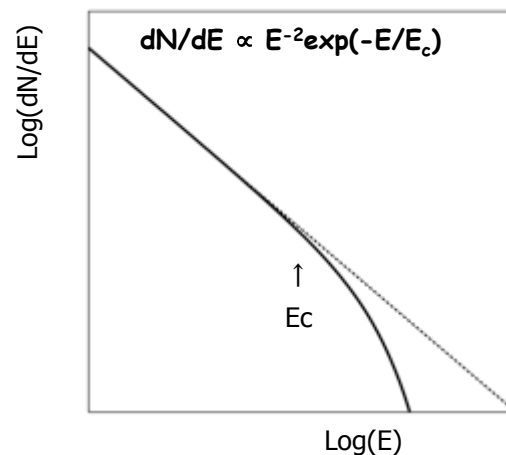


Acceleration in PWN



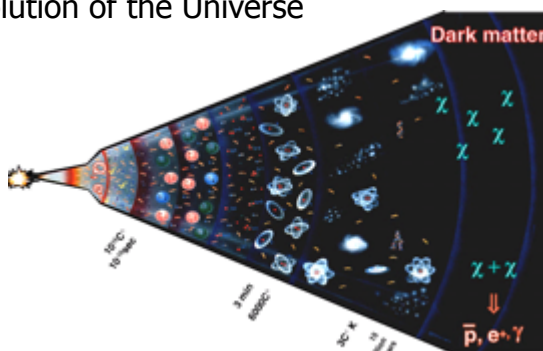
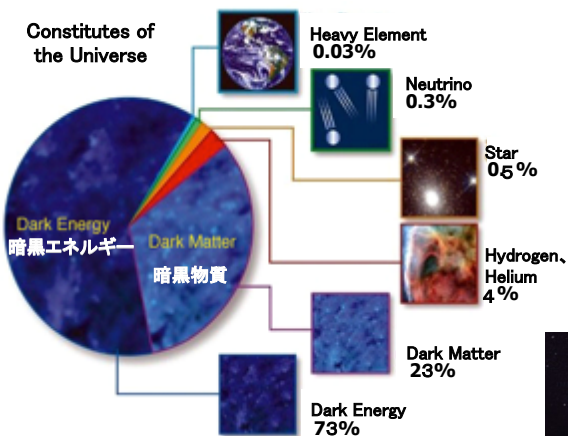
etc.

Power Law Distribution with a Cutoff

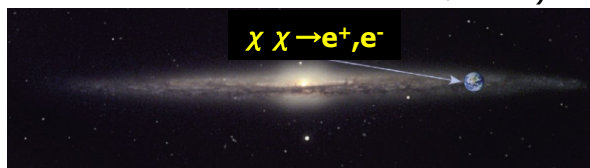


Dark Matter Origin

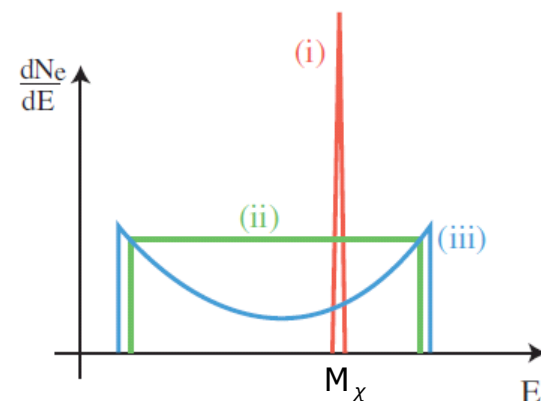
Evolution of the Universe



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

$$\frac{\partial}{\partial t} f(t, \varepsilon_e, \mathbf{r}, x) = \underbrace{D(\varepsilon_e) \nabla^2 f}_{\text{Diffusion}} + \underbrace{\frac{\partial}{\partial \varepsilon_e} [b \varepsilon_e^2 f]}_{\text{Energy loss by IC \& synchro.}} + \underbrace{q(t, \varepsilon_e, \mathbf{r}, x)}_{\text{Injection}}$$

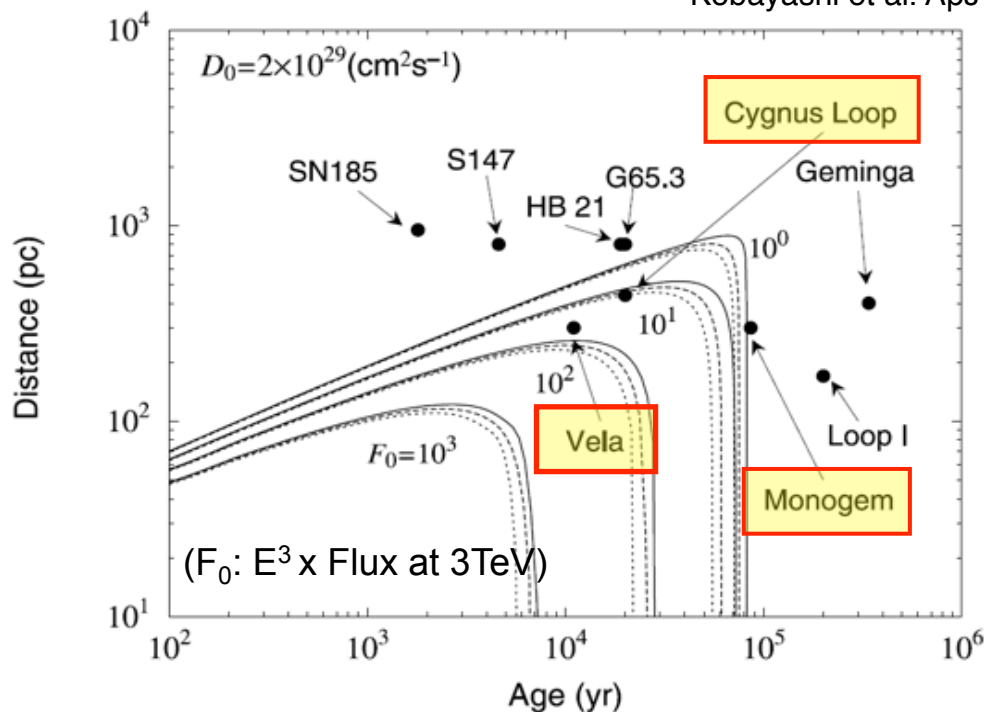
$$b \sim 10^{-16} \text{ GeV}^{-1} \text{ s}^{-1}$$

$$D(\varepsilon_e) \sim 5.8 \times 10^{28} \text{ cm}^2 \text{ s}^{-1} \left(1 + \frac{\varepsilon_e}{4 \text{ GeV}} \right)^{1/3} \leftarrow \text{B/C ratio}$$

$$T(\text{age}) = 2.5 \times 10^5 \times (\text{TeV}/E) \text{ yr}$$

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

Contribution to 3 TeV Electrons from Nearby Source Candidates
Kobayashi et al. ApJ 2004

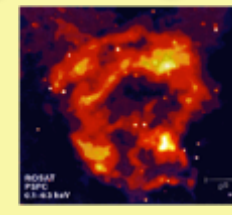
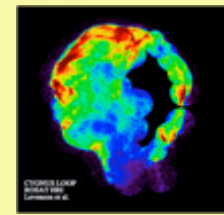
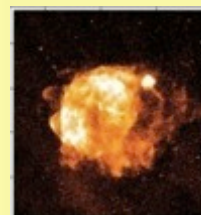


> 1 TeV Electron Source:

- Age < a few 10^5 years
very young comparing
to $\sim 10^7$ year at low energies
- Distance < 1 kpc
nearby source

Source (SNR) Candidates :

Vela Cygnus Loop Monogem



Unobserved Sources?

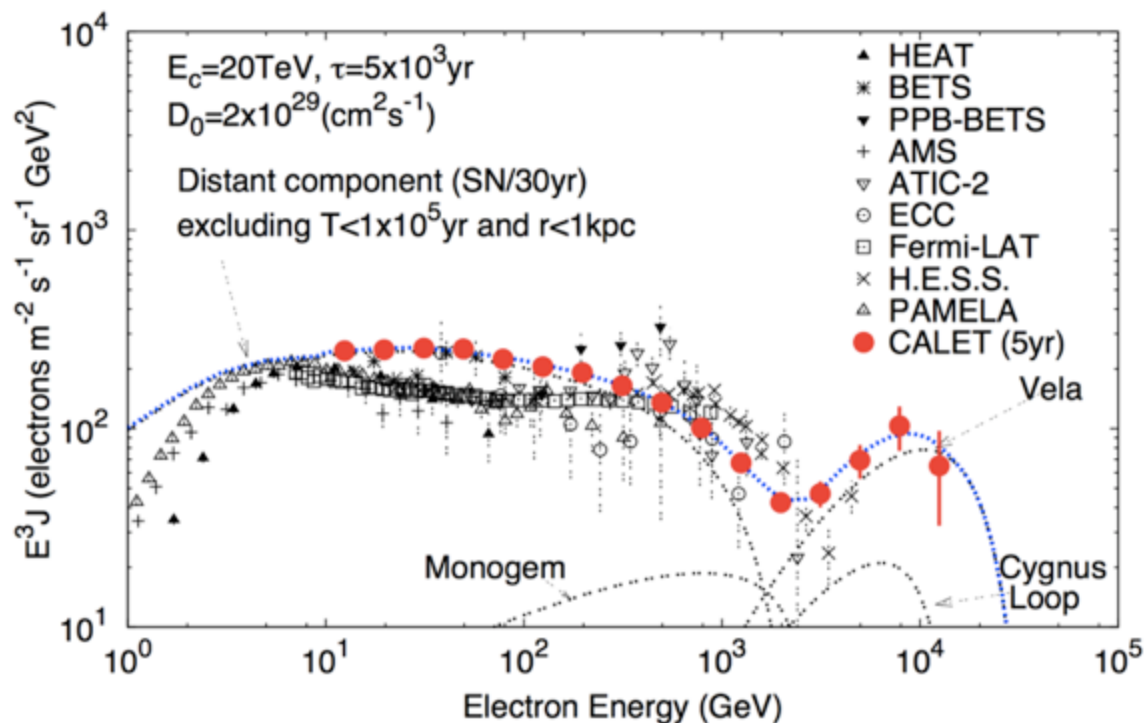


CALET Main Target: Identification of Electron Sources

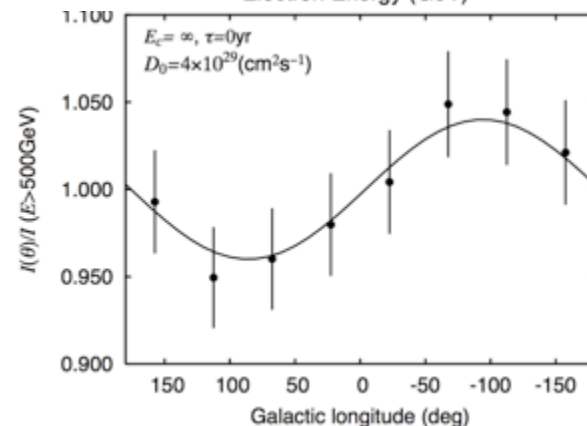
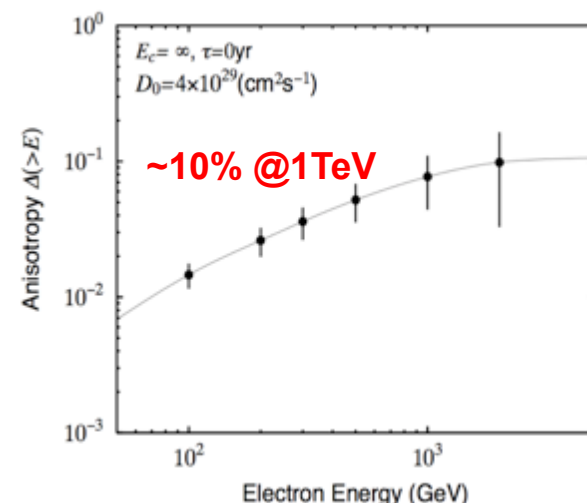
Some nearby sources, e.g. Vela SNR, might have unique signatures in the electron energy spectrum in the TeV region (Kobayashi et al. ApJ 2004)

Expected flux
for 5 year mission

> 10 GeV	$\sim 2.7 \times 10^7$
>100 GeV	$\sim 2.0 \times 10^5$
>1000 GeV	$\sim 1.0 \times 10^3$



Expected Anisotropy
from Vela SNR



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

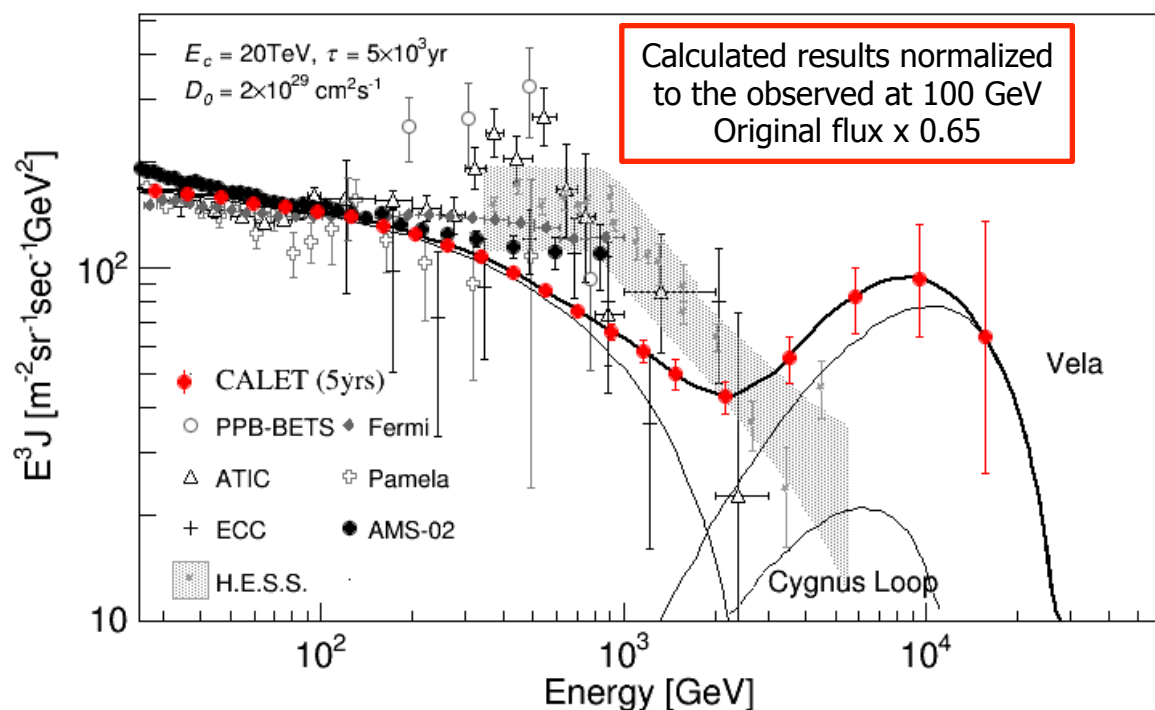


CALET Main Target: Identification of Electron Sources

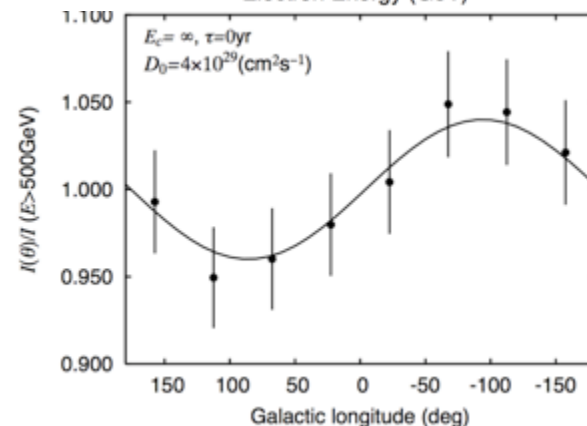
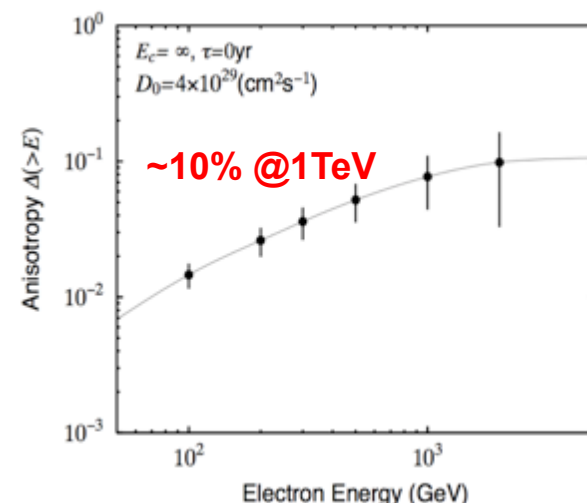
Some nearby sources, e.g. Vela SNR, might have unique signatures in the electron energy spectrum in the TeV region (Kobayashi et al. ApJ 2004)

Expected flux
for 5 year mission

> 10 GeV	$\sim 1.8 \times 10^7$
>100 GeV	$\sim 1.3 \times 10^5$
>1000 GeV	$\sim 6.5 \times 10^2$



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!

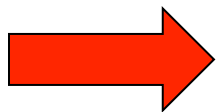
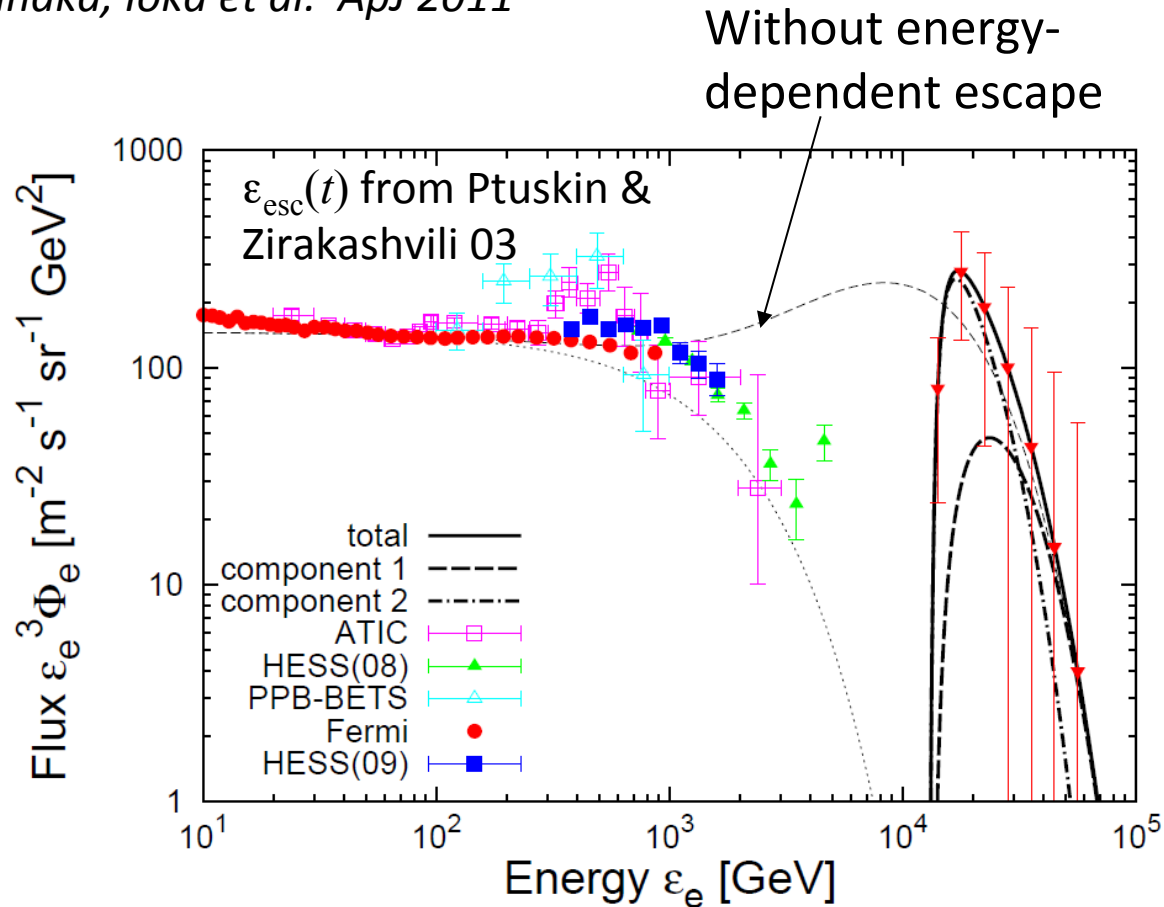
Kawanaka, Ioka et al. *ApJ* 2011

- Electron spectrum from Vela SNR/PSR ($d=290\text{pc}$, $t_{\text{age}}\sim 10^4\text{yr}$, $E_{\text{tot}}=10^{48}\text{erg}$)

- Only $e^\pm$ with $\varepsilon_e > \varepsilon_{\text{esc}}(t_{\text{age}})$ can run away from the SNR.

→ Low Energy Cutoff

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



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

Detection of High Energy Gamma-rays

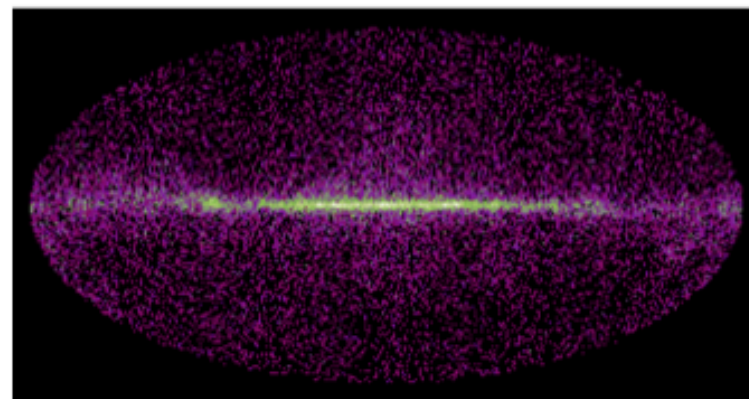
Performance for Gamma-ray Detection

Energy Range	4 GeV-10 TeV
Effective Area	600 cm ² (10GeV)
Field-of-View	2 sr
Geometrical Factor	1100 cm ² sr
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)

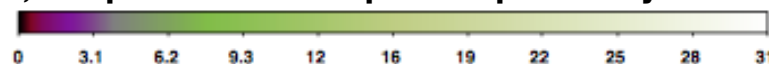
*) Trigger efficiency included below 10 GeV

**) 100 % efficiency over 5 GeV

Simulation of Galactic Diffuse Radiation

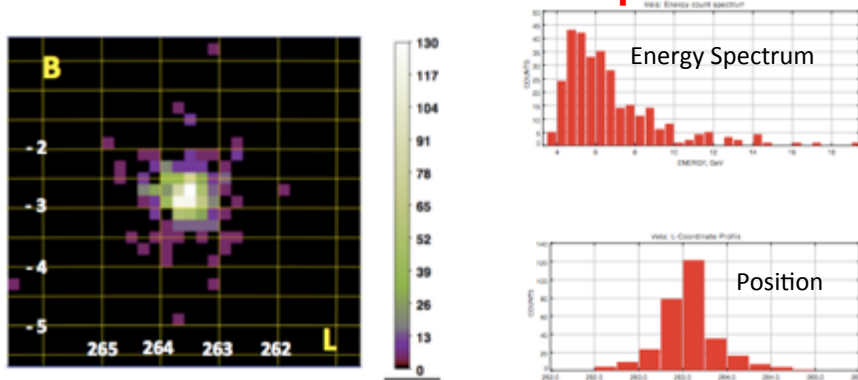


~5,700 photon* are expected per one year

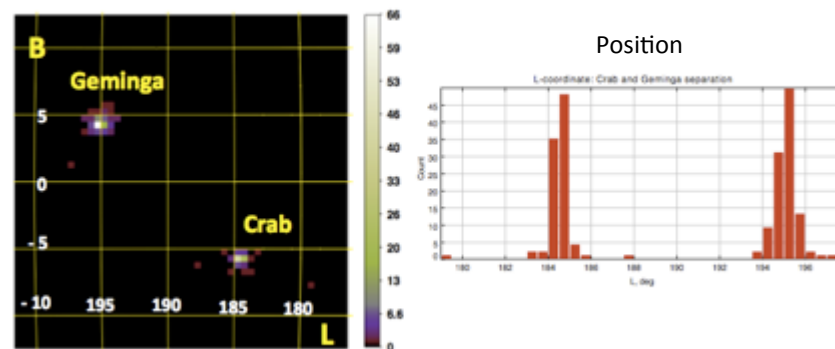


~1,700 photon* from extragalactic γ -background (EGB) each year

Simulation of point source observations in one year



Vela: ~ 300 photons above 5 GeV**



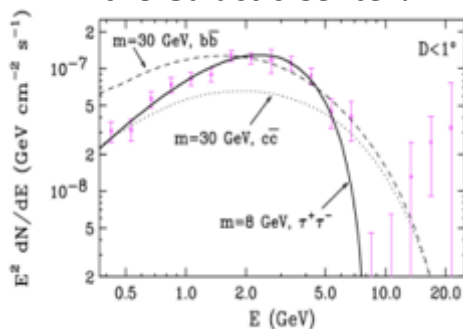
Geminga: ~150 photons above 5 GeV**

Crab: ~ 100 photons above 5 GeV**

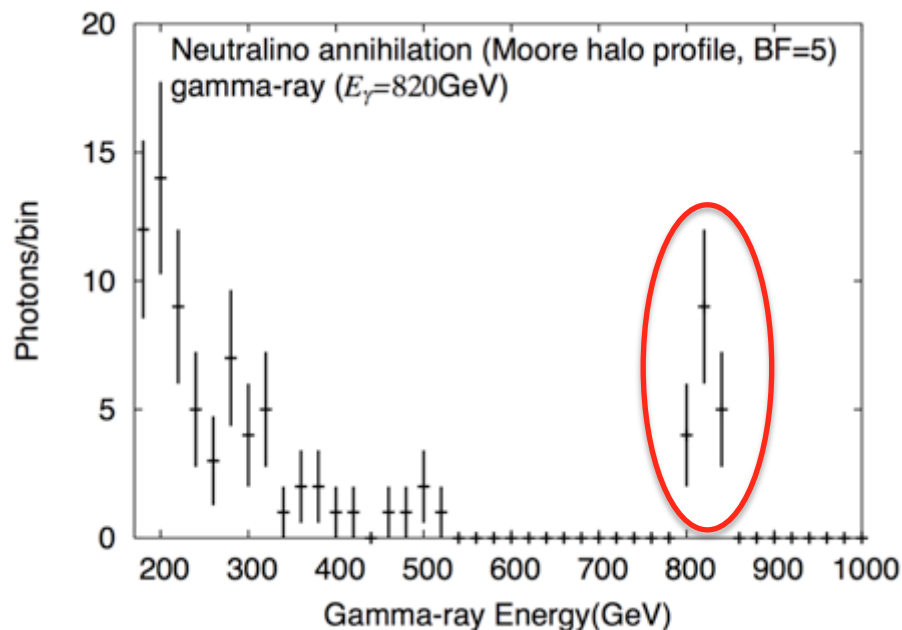
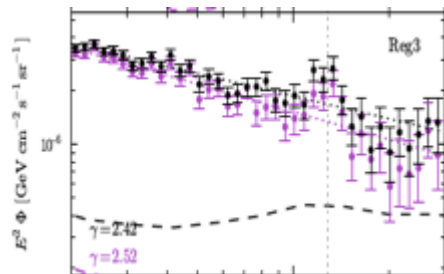
Detection Capability of Gamma-ray Lines from Dark Matter

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?



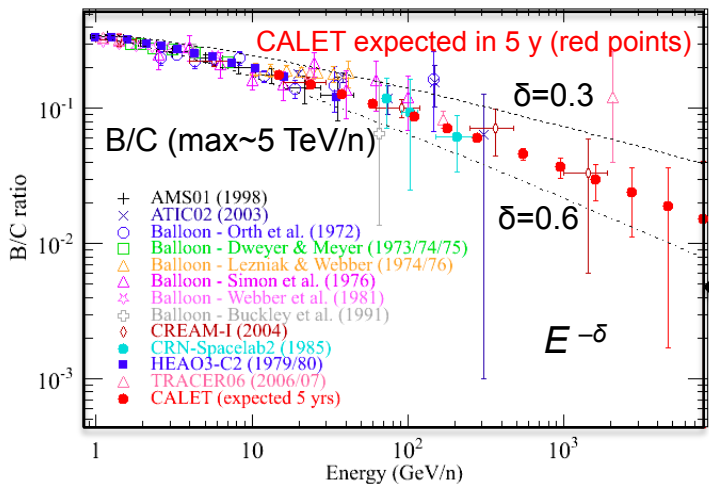
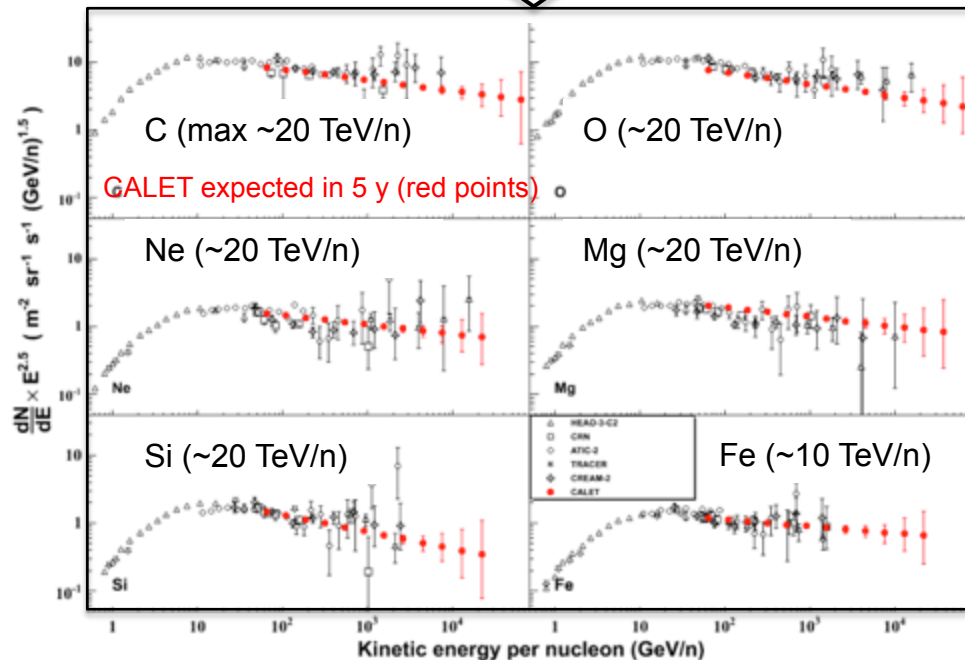
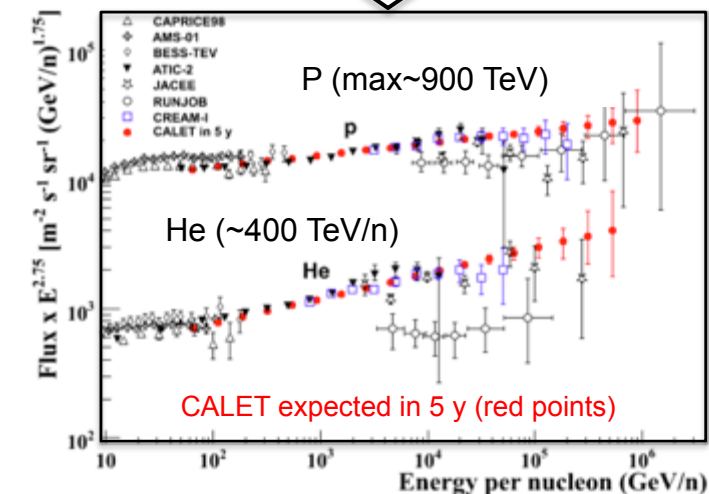
Simulated gamma-ray line spectrum for 2yr from neutralino annihilation toward the Galactic center with $m=820\text{GeV}$, a Moore halo profile, and $\text{BF}=5$



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 ?

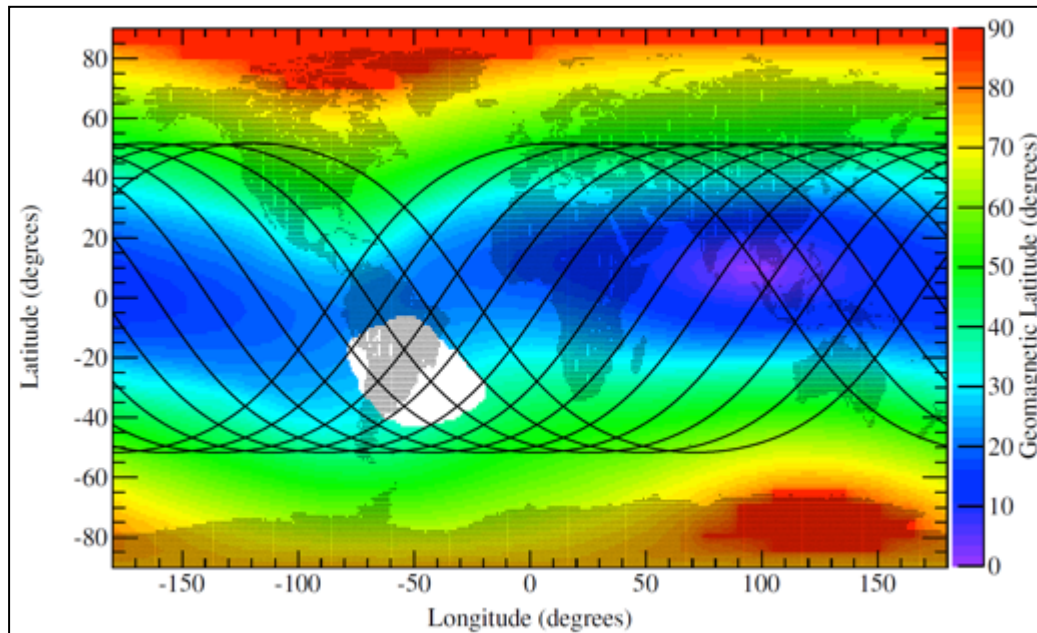
- All primary heavy nuclei spectra well fitted to single power-laws with similar spectral index (CREAM, TRACER)
- **However hint of a hardening from a combined fit to all nuclei spectra (CREAM)**



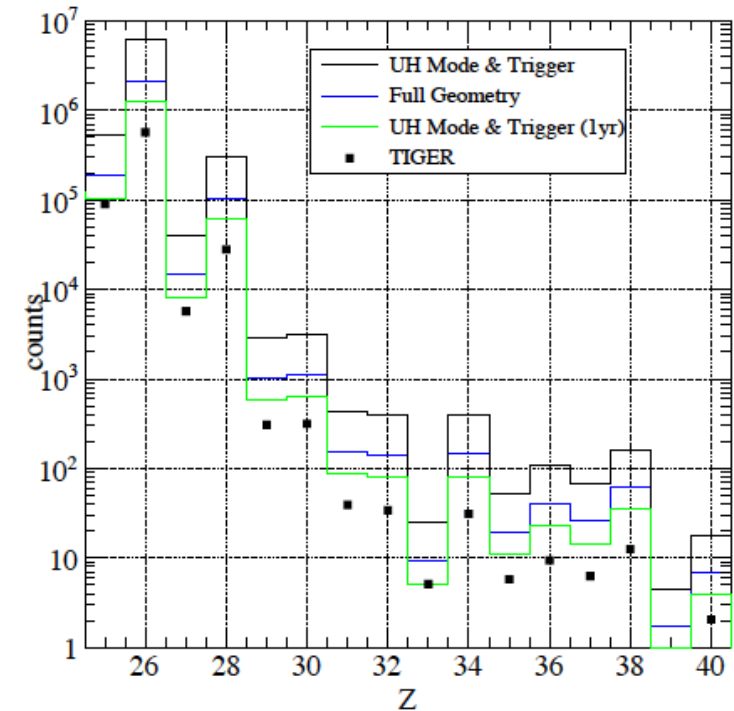
- At high energy ($> 10 \text{ GeV}/n$) the B/C ratio measures the energy dependence of the escape path-length, $\sim E^{-\delta}$, of CRs from the Galaxy
- Data below 100 GeV/n indicate $\delta \sim 0.6$. At high energy the ratio is expected to flatten out (otherwise CR anisotropy should be larger than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

Observation of Ultra Heavy Nuclei

Geomagnetic Latitude



CALET (expected) vs. TIGER data

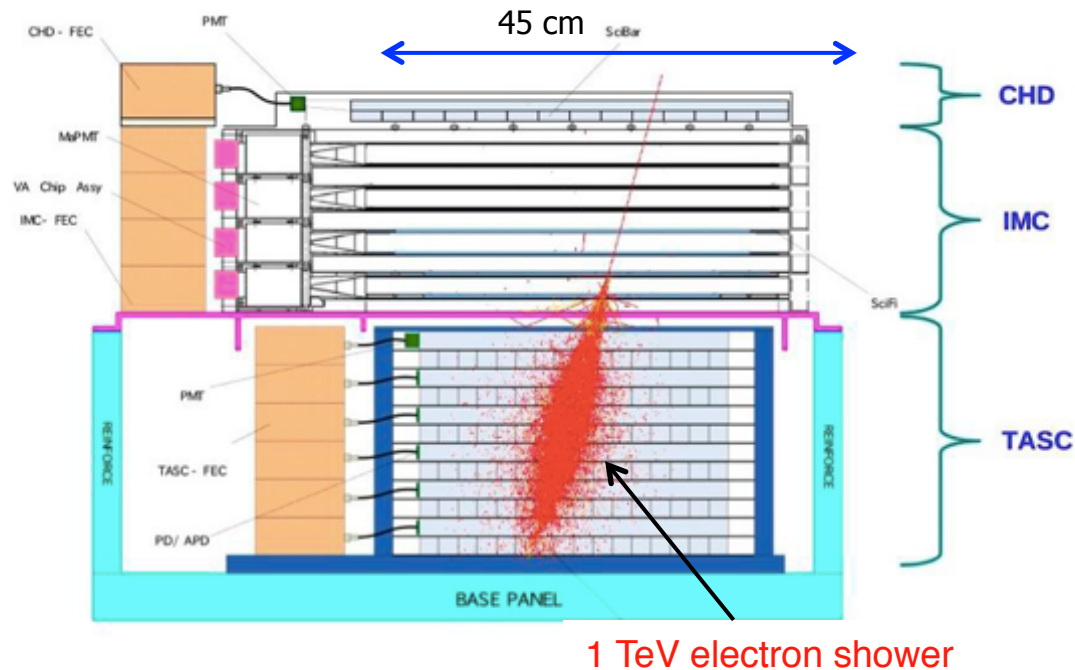


- Ultra heavy nuclei abundances provide information on CR site and acceleration mechanism
- CHD resolution is $\sim$ constant above 600 MeV/n $\rightarrow$ Charge ID from saturated dE/dx
- No need to measure energy $\rightarrow$ No passage through TASC $\rightarrow$ **Large acceptance $\sim 0.4 \text{ m}^2\text{sr}$**
- **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: $0.12 \text{ m}^2\text{sr}$ (for electrons)

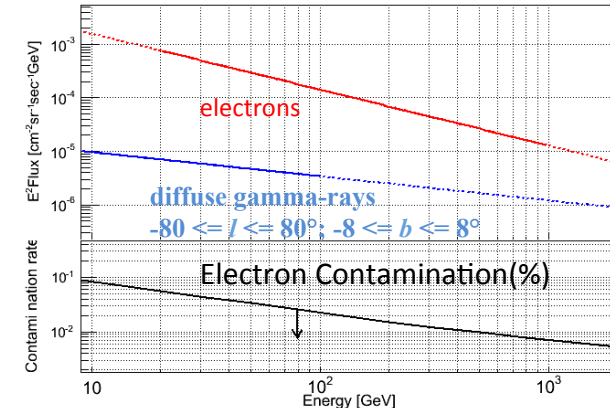
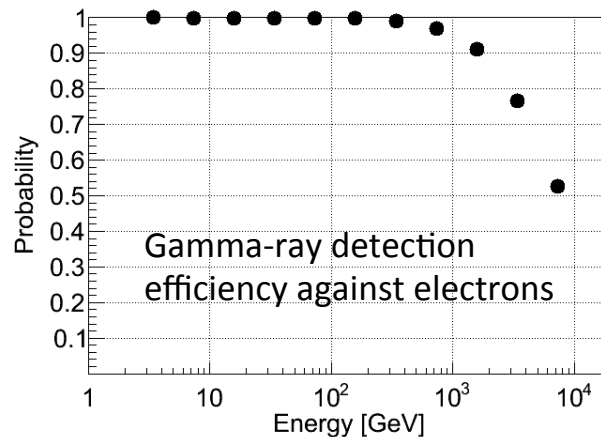
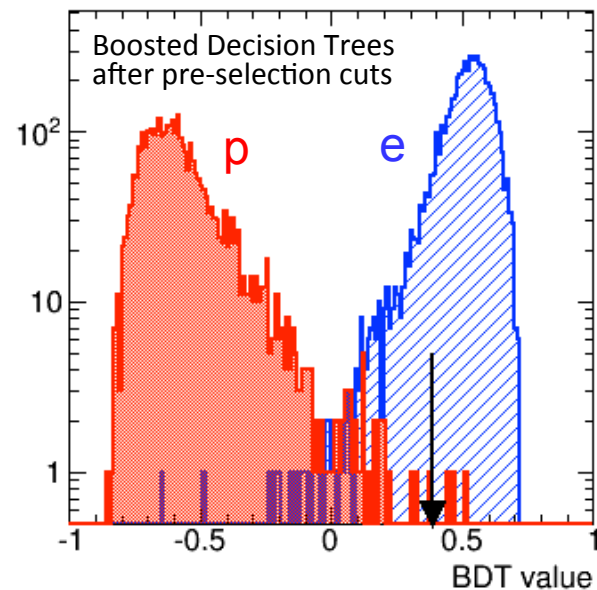
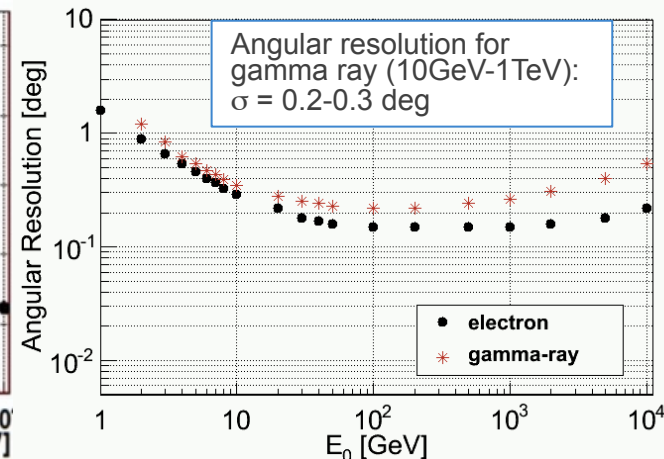
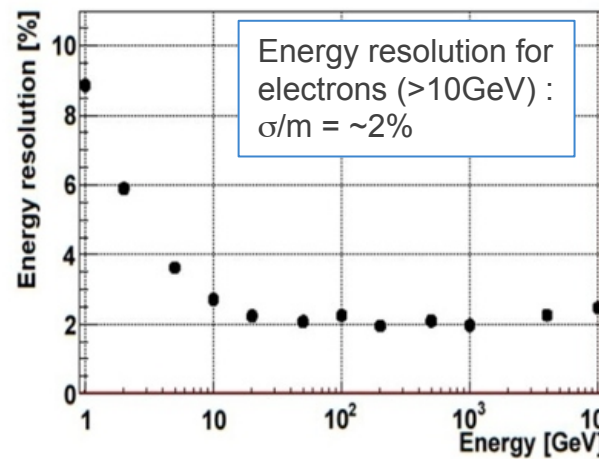
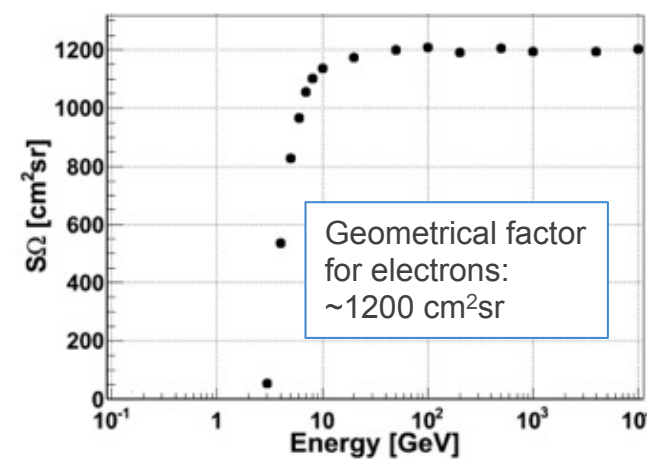


- The unique feature of CALET is its **thick($\sim 30 X_0$)**, **homogeneous calorimeter** that allows to extend electron measurements into the TeV energy region with **excellent energy resolution($\sim 2\text{-}3\%$)**, coupled with a **high granularity imaging pre-shower calorimeter** to accurately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

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



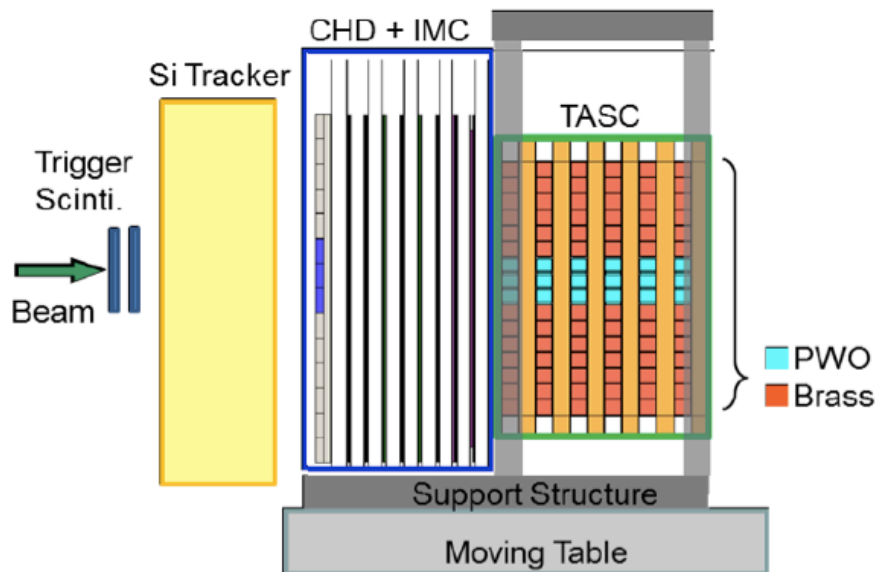
CALET Expected Performance by Simulations –electrons & gamma-ray–



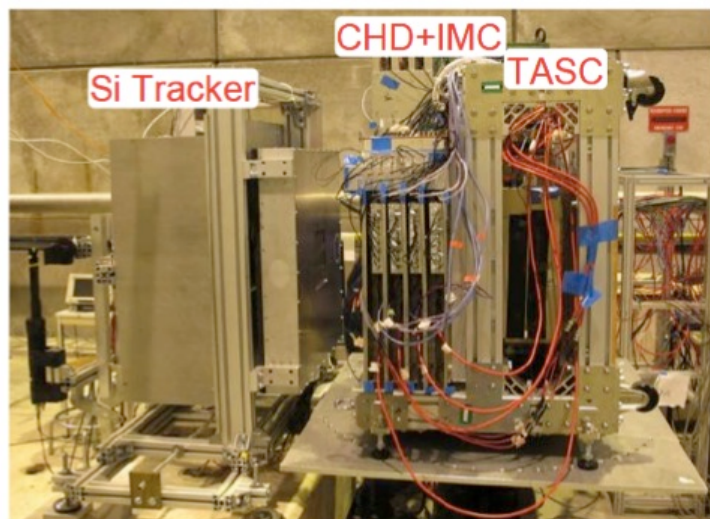
Left: detection efficiency of gamma-rays with electron discrimination power 3.54×10^{-4} (90% CL): >95% in 10-900 GeV
Right: electron contamination in galactic diffuse gamma-rays : 10% @10GeV – 1% @TeV

CERN Beam Test using the STM

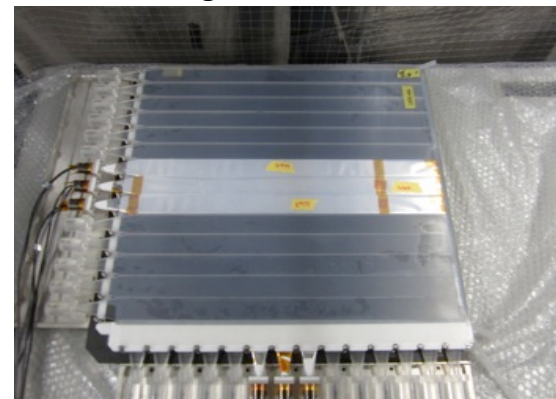
Schematic Side View of the Beam Test Model



The Beam Test Model at CERN SPS H8 Beam Line



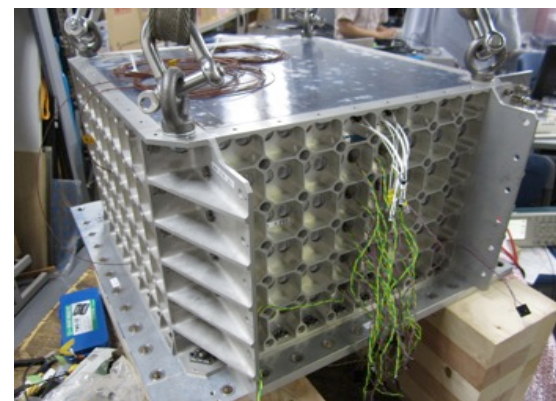
Charge Detector: CHD



Imaging Calorimeter: IMC

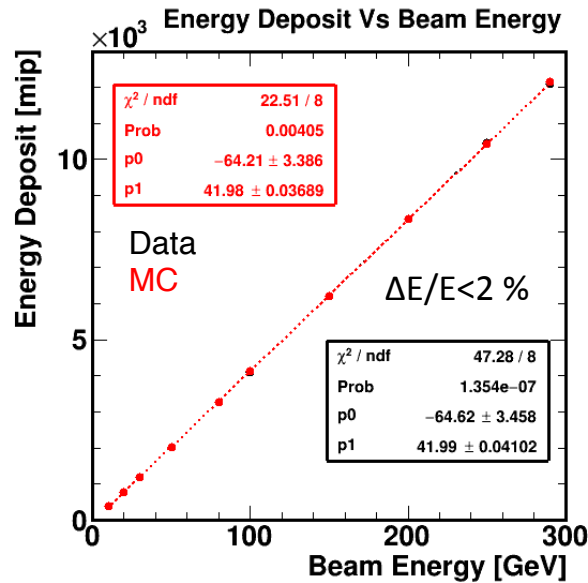


Total Absorption Calorimeter: TASC

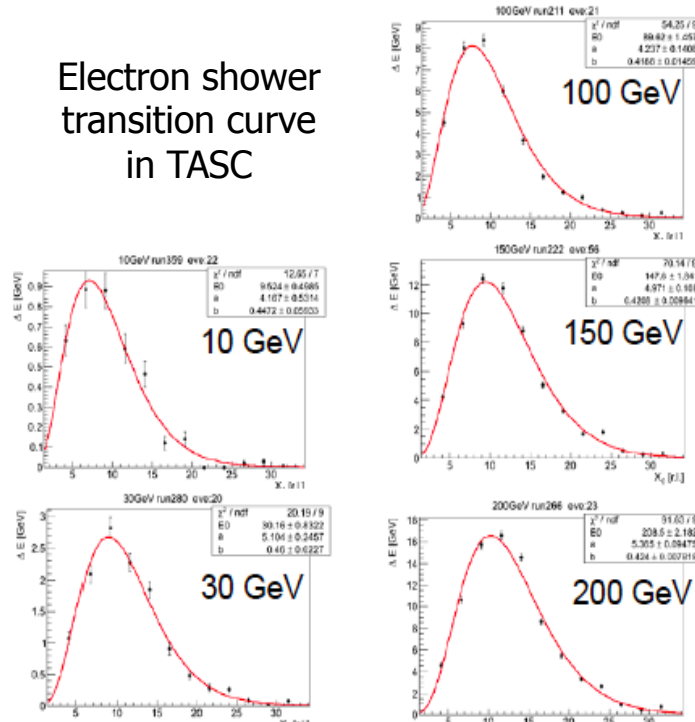




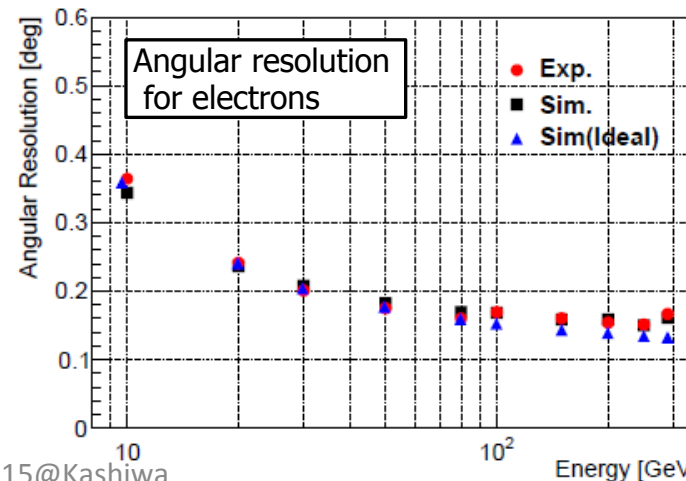
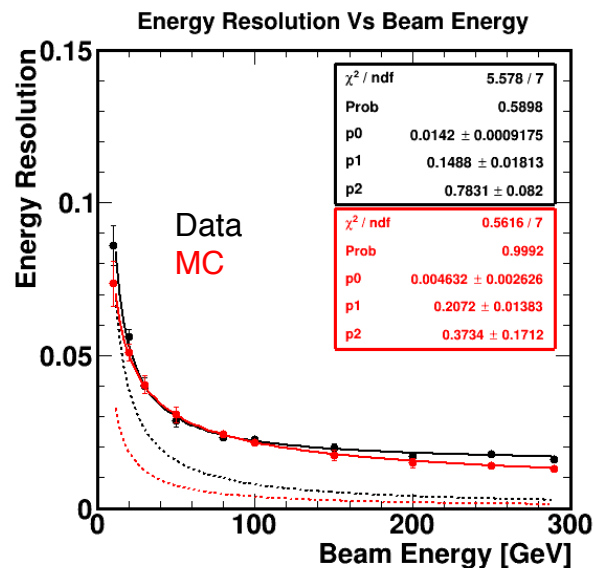
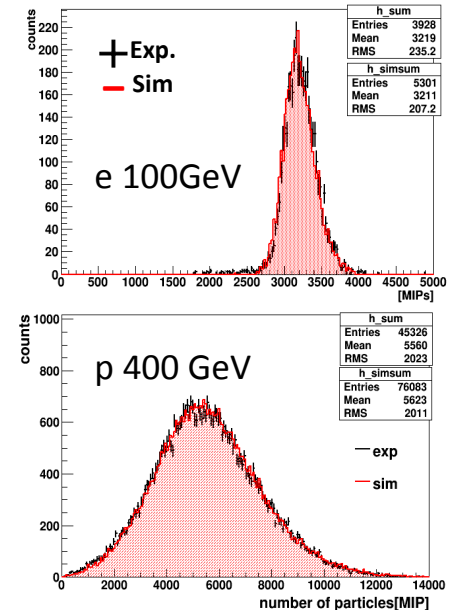
CERN-SPS beam tests



Electron shower transition curve in TASC

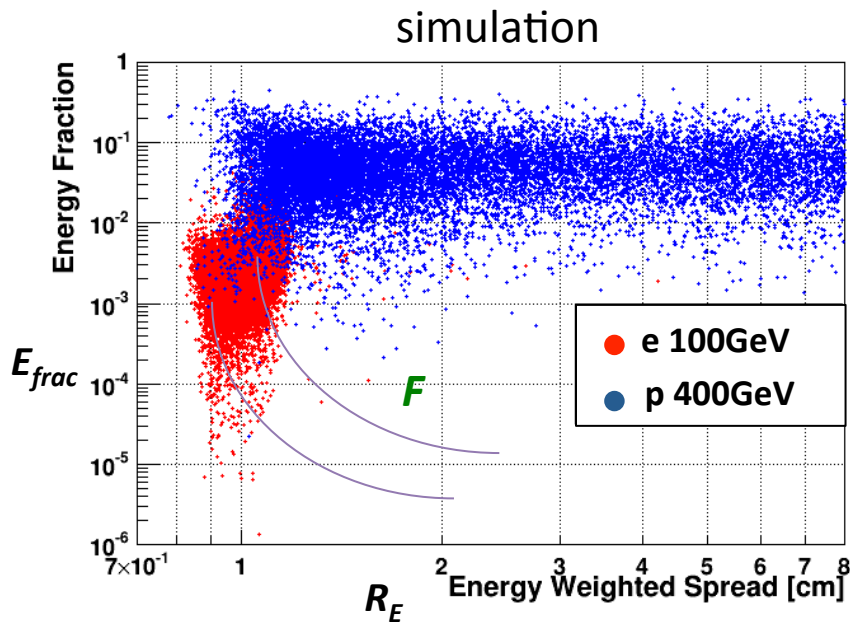


Energy distribution





electron/proton discrimination power by beam tests



Proton rejection power for 85 % survival
probability of electrons

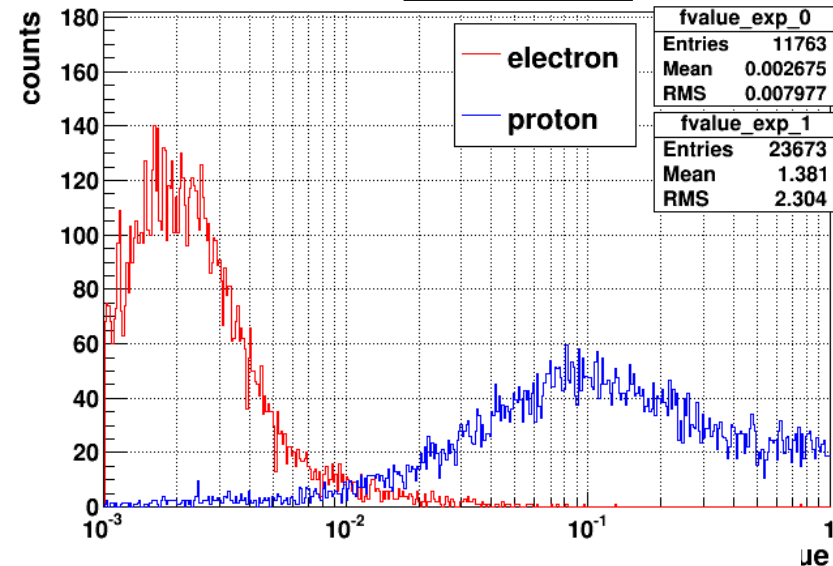
- beam test: 6.45×10^{-4}
- simulation: 4.88×10^{-4}

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

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

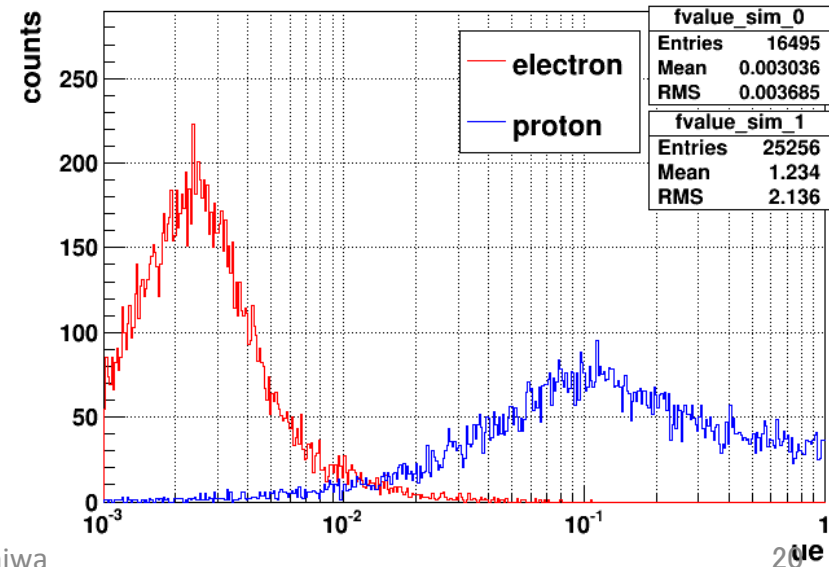
Shower development

Beam test



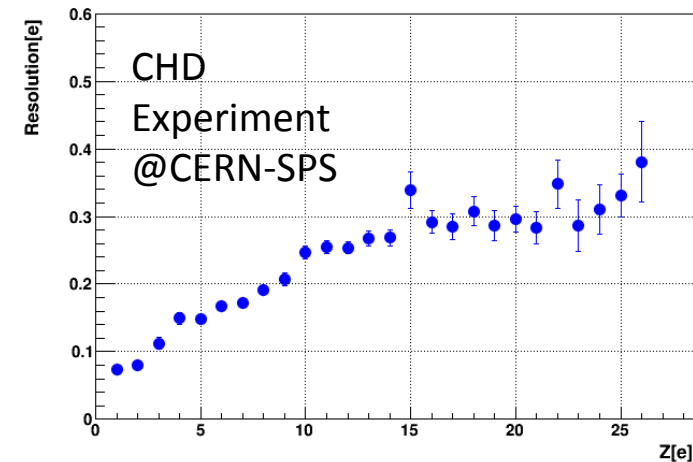
Shower development

Simulation



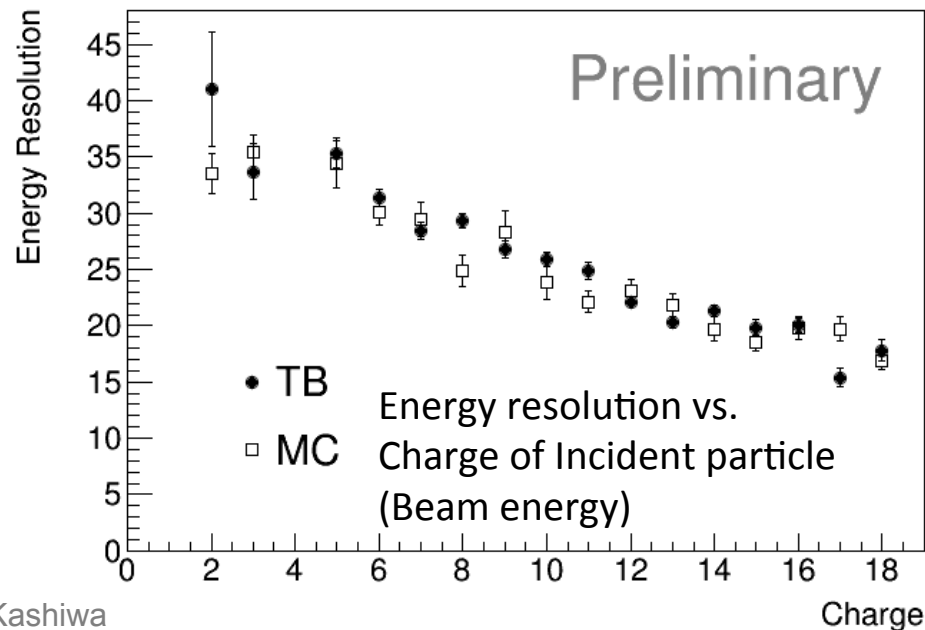
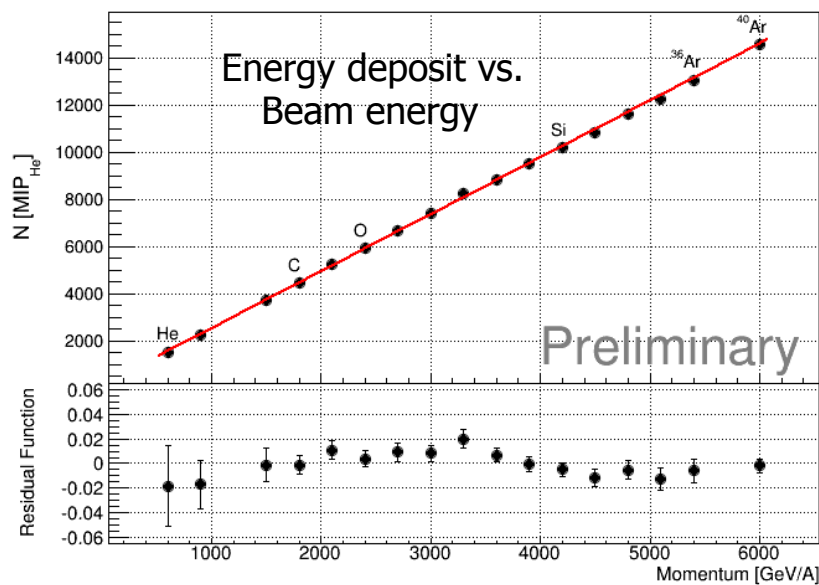
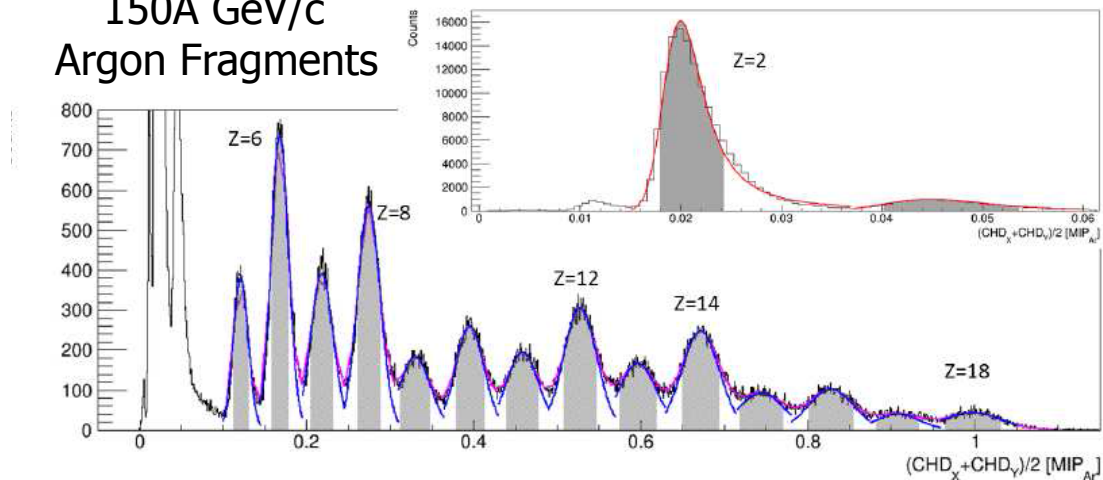


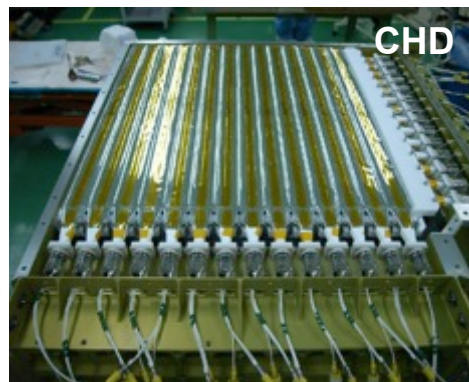
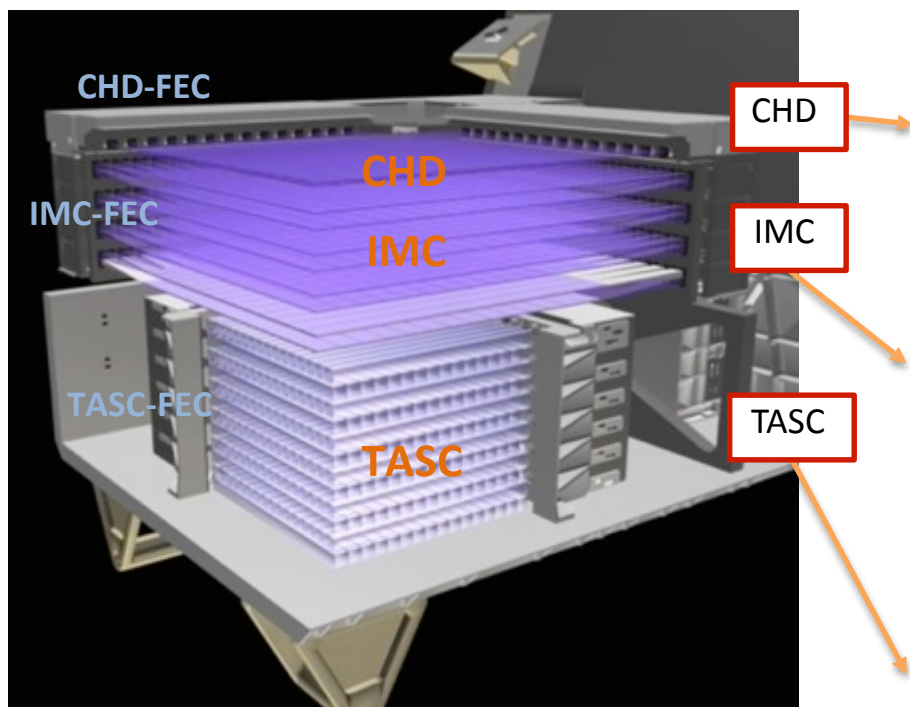
Heavy Ion Beam Test @ CERN 2014 & 2015



Charge resolution:
 $\sigma_Z = 0.15e(@B) - 0.30e(@Fe)$

150A GeV/c
Argon Fragments

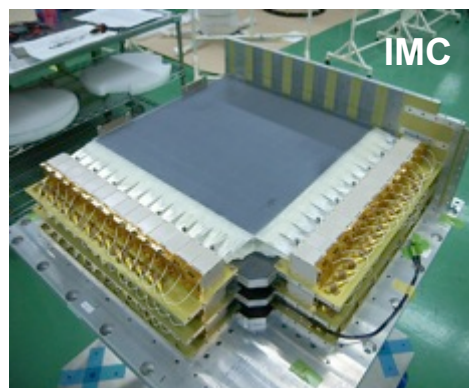




CHD

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

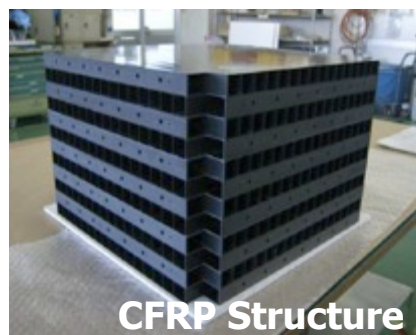
Plastic Scintillator



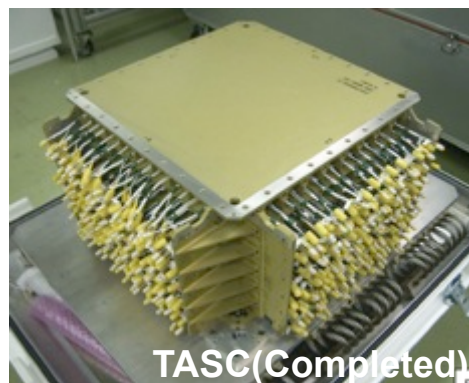
IMC

448 × 8 layers (x,y) = 7168
1mm² x 448 mm

Scintillating Fiber



CFRP Structure



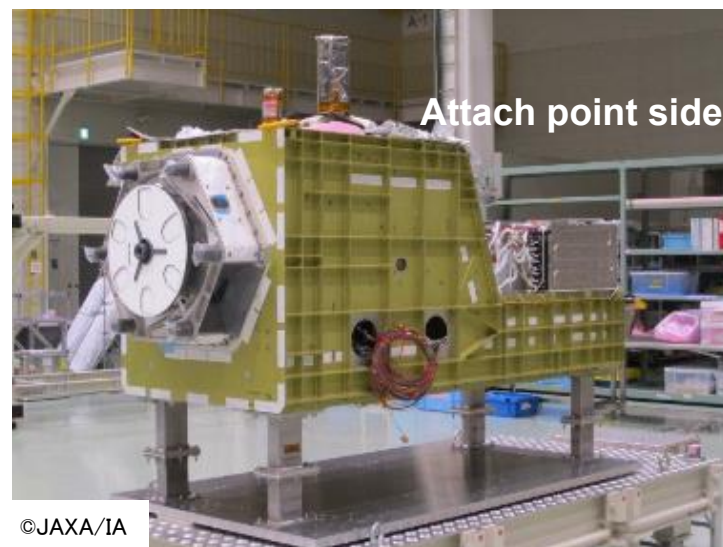
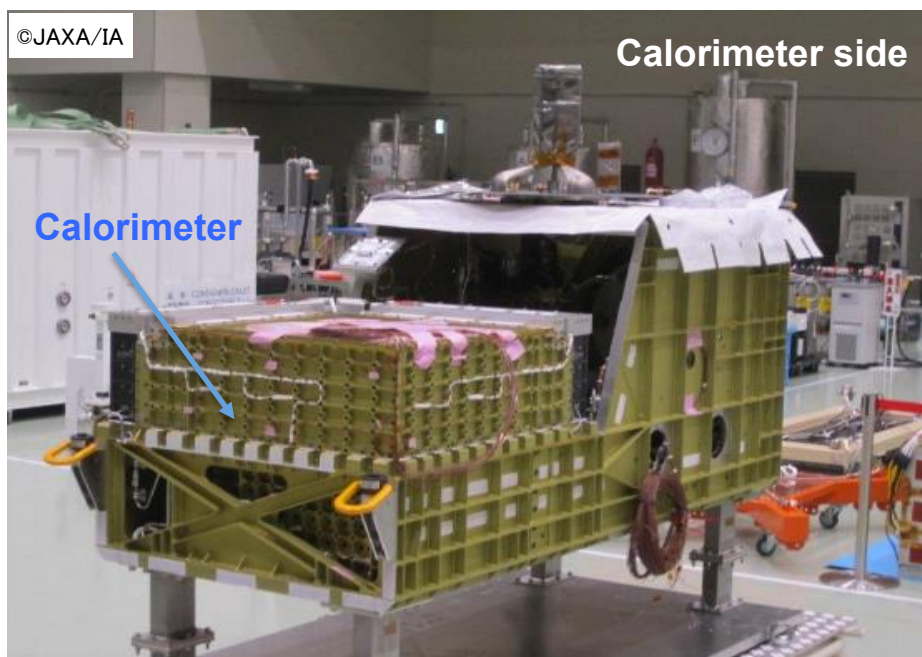
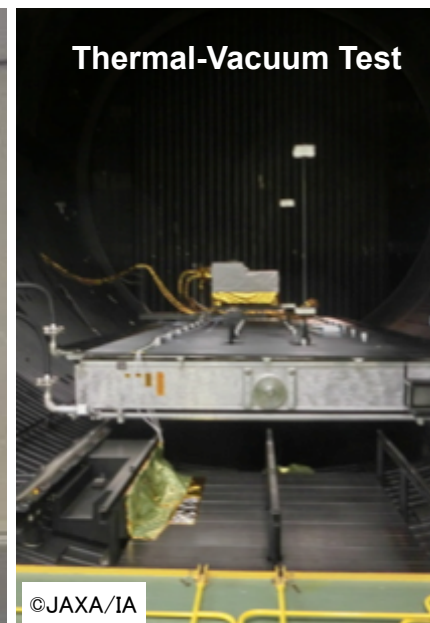
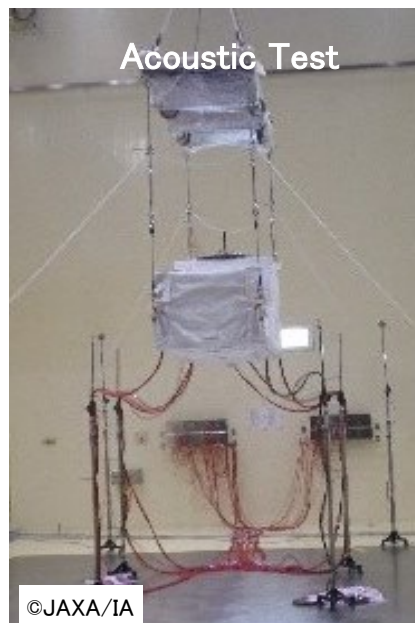
TASC(Completed)

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

Scintillator(PWO)

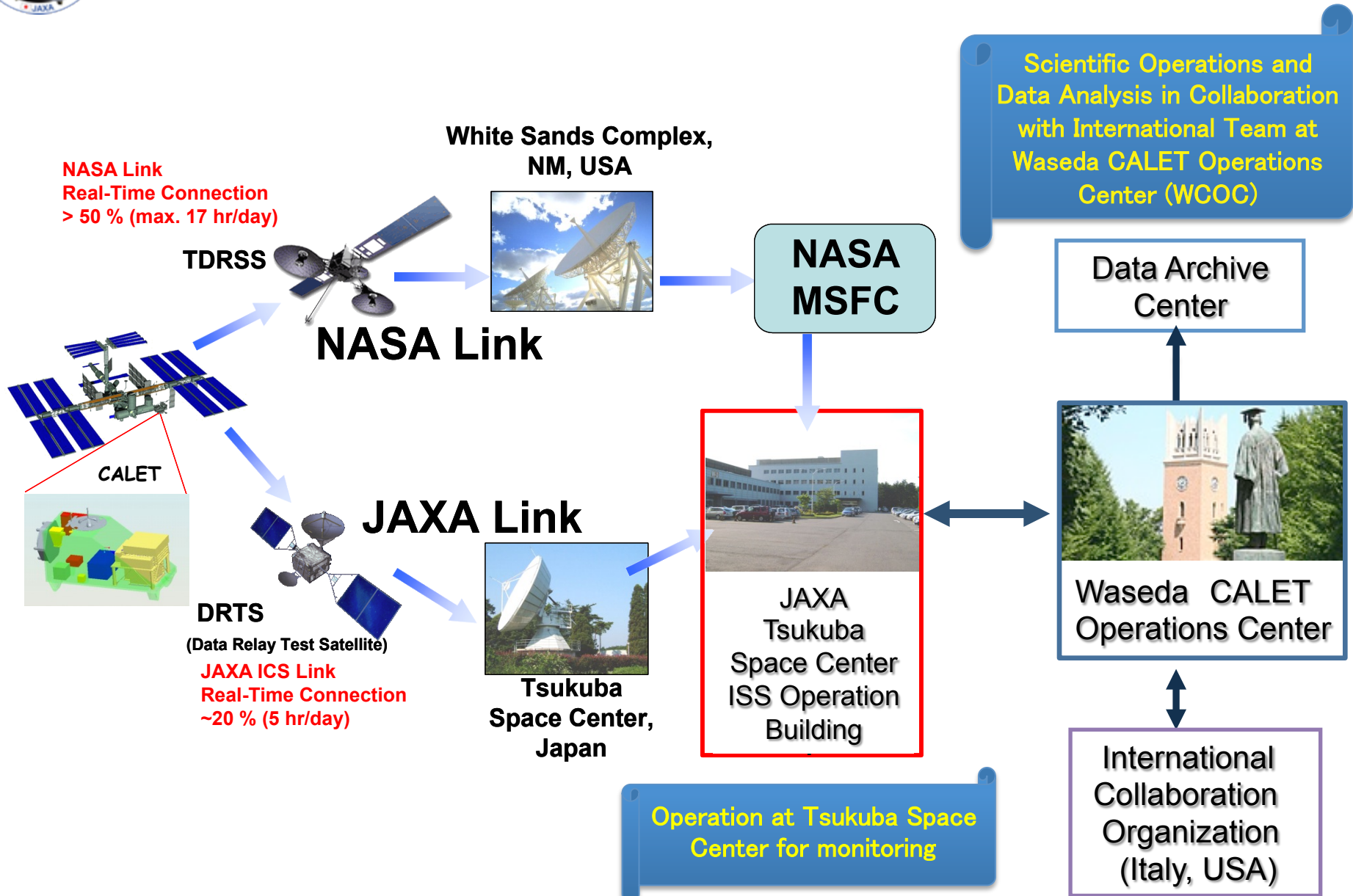


- ❑ Acoustic test, Thermal-Vacuum test and EMC test were successfully carried out at Tsukuba Space Center (JAXA)
- ❑ After final system function test, the payload was transferred to the launching site , Tanaegashima Space Center, for launch with HTV5.



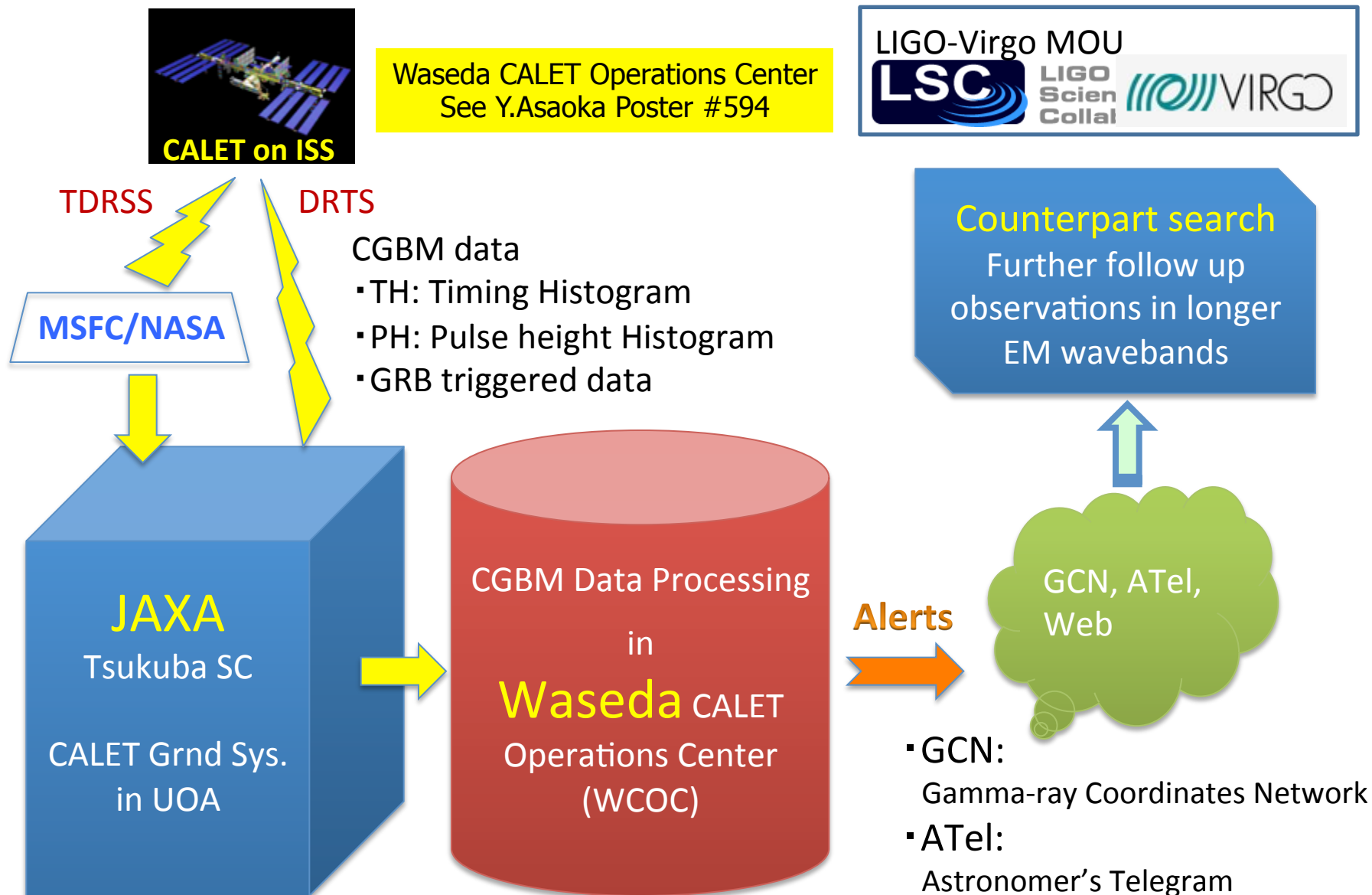


Data Downlink Using TDRSS and DRTS





General Alerts of Transients by CGBM





CGBM: Gamma-ray burst GRB 151006A detected !

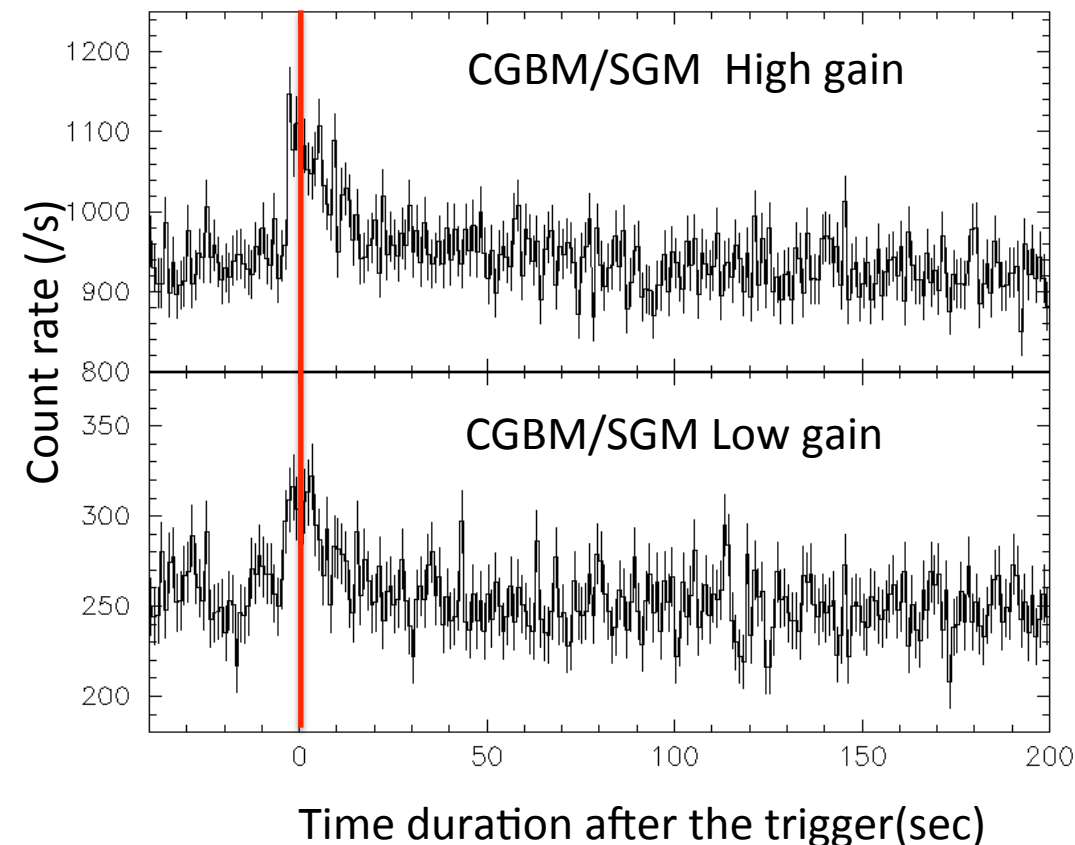


GCN Circular #18475 (27.10.2015)

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 T_0-2s and T_0+2s , and the emission ending around $T_0+\sim 60s$. The T90 duration measured by the SGM data is 63 ± 5 s (30 - 1000 keV).

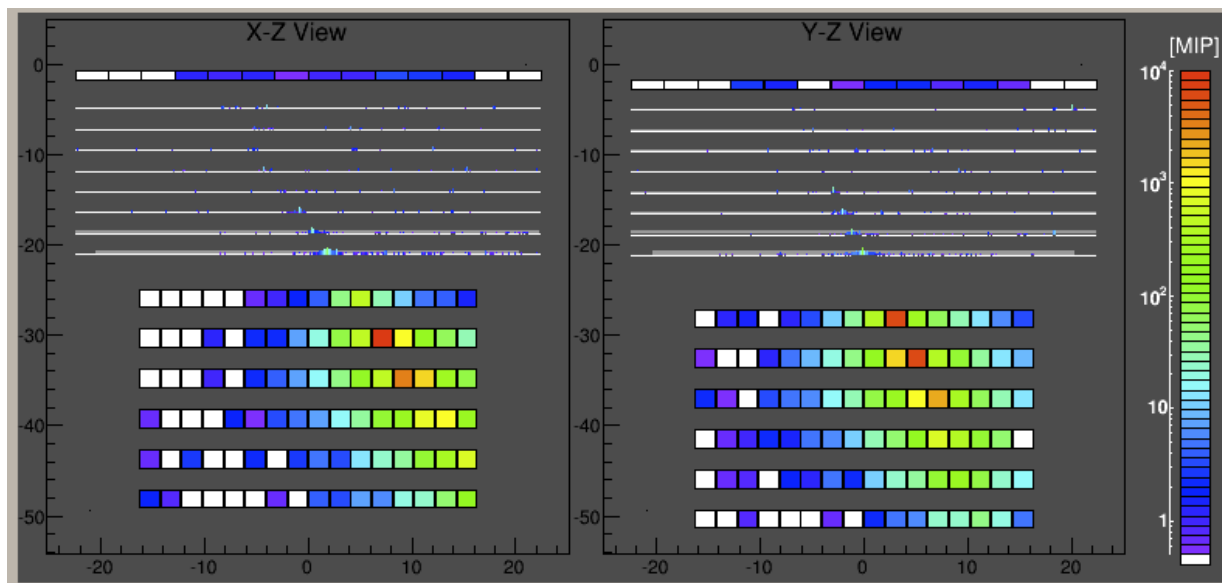
Currently, CALET is in the commissioning phase.



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

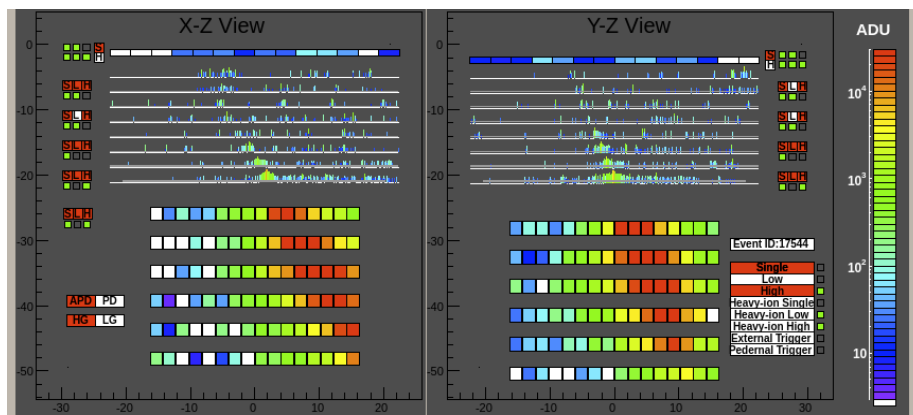
~1TeV electron (candidate) observed !

(converted to MIP by calibration on ground)

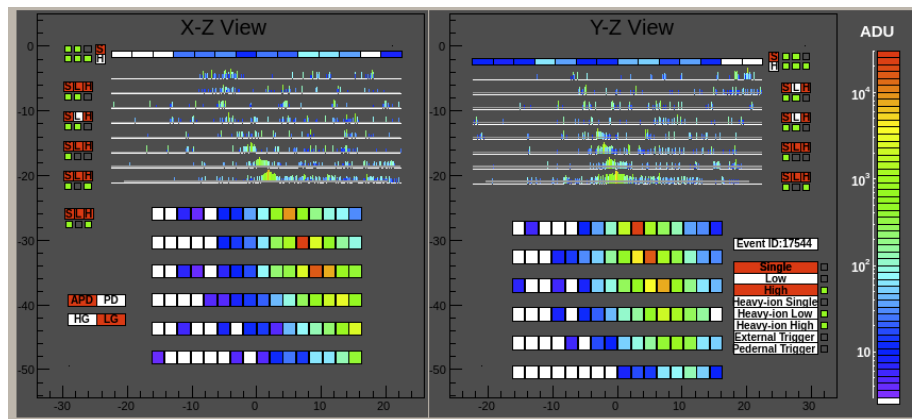


1 event per
a few days
expected

Raw Data -APD High gain-



Raw Data -APD Low gain-



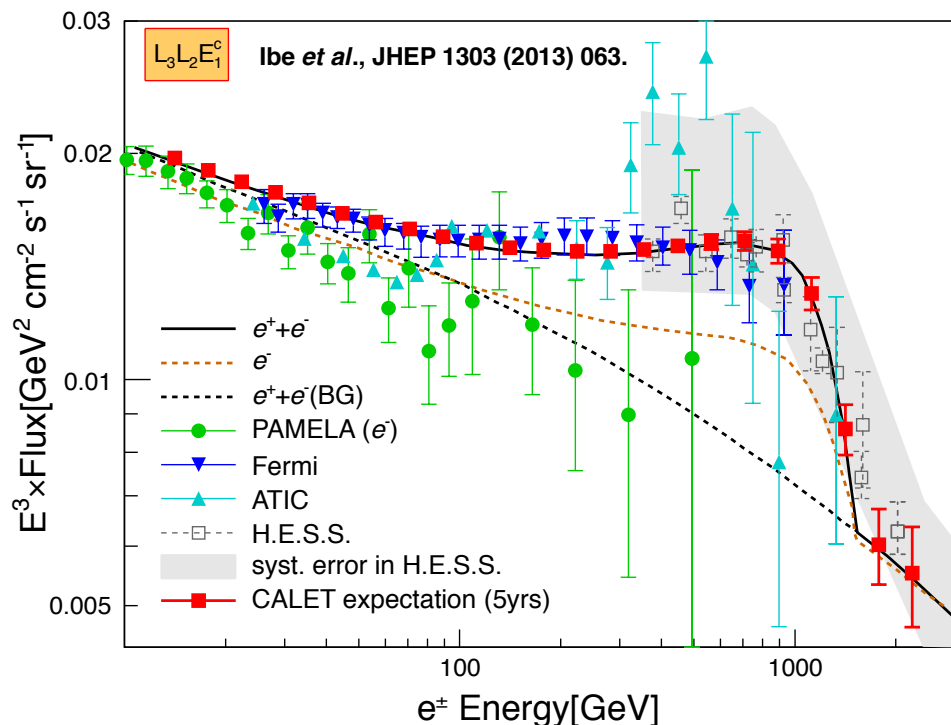
Conclusions and Summary

- ✧ 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 ($3 X_0$), 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, commissioning of each component was being carried on, and the science operation has started from Oct. 5.

Stay tuned !!!

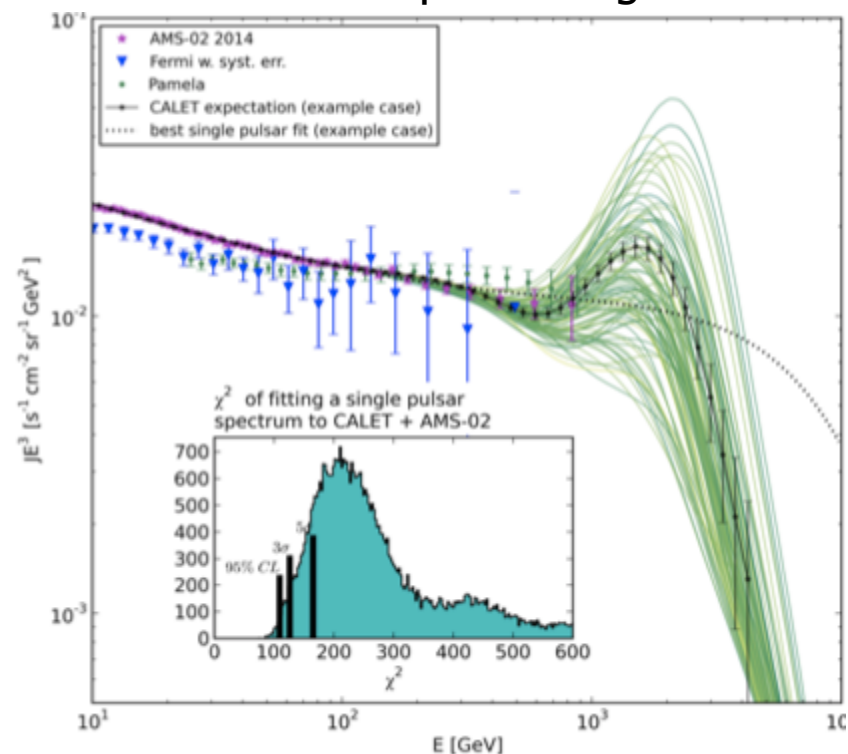
Dark Matter or Pulsar by CALET Observation

Decay of Dark Matter (LSP)



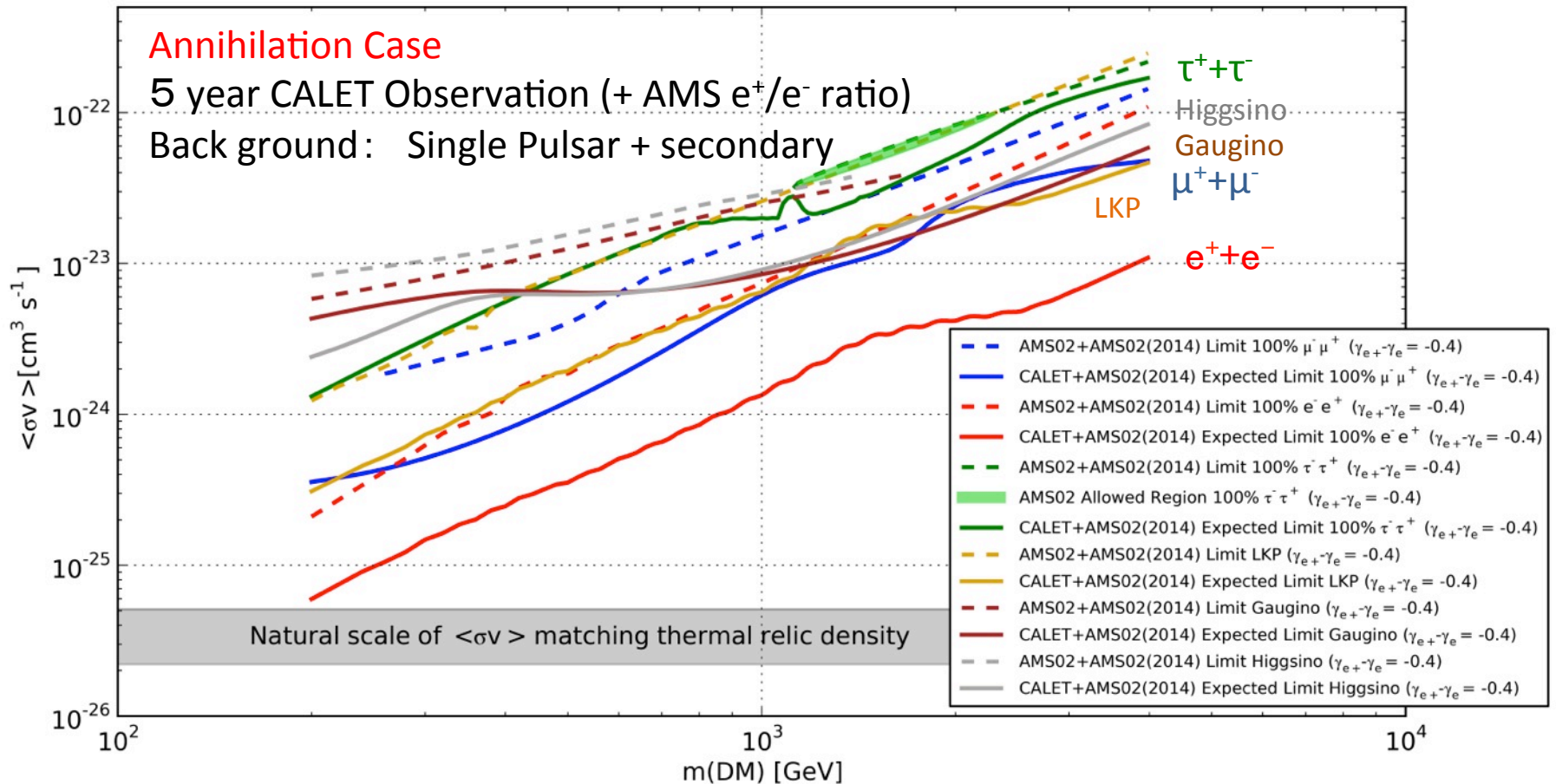
Expected e^+e^- spectrum by **Lightest Super Symmetry Particle (LSP) (black line)** after **5-year CALET measurement (red dots)**, which is consistent with present data of positron excess and e^+e^- spectrum

Pulsar: multiple or single



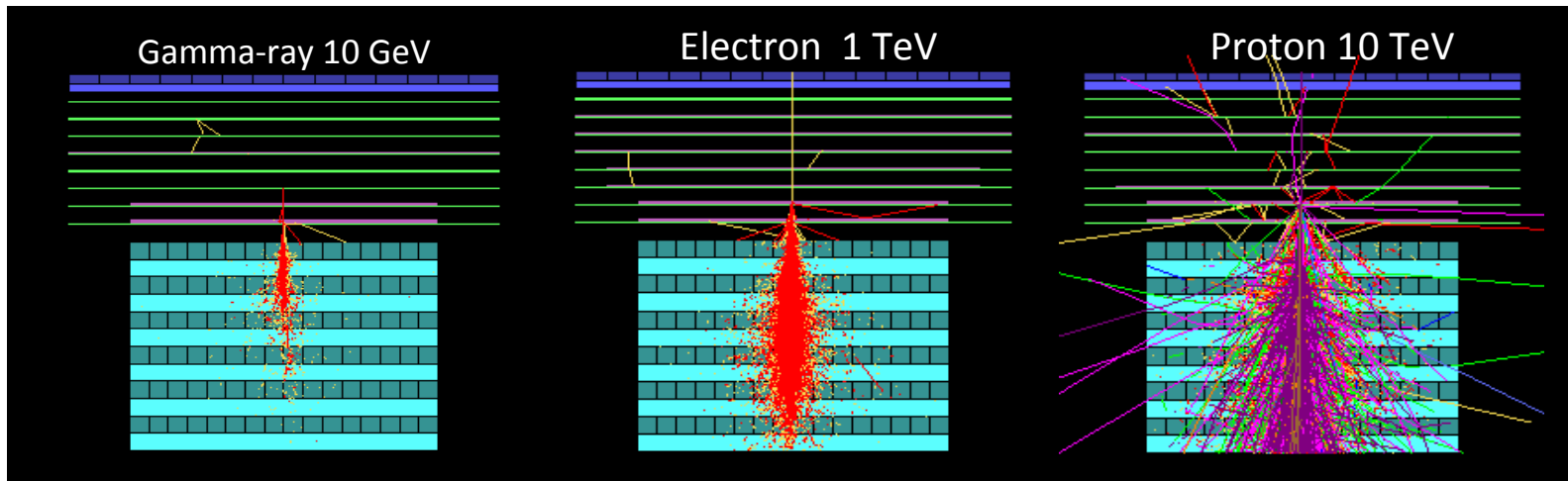
- ❖ Parameters assigned to PWN in random walk to match AMS-02 data => 100 cases
 - ATNF : $R < 2$ kpc, Age $< 10^6$ year (40 pulsars)
 - Spectra of nearby PWN simulated with DRAGON
- ❖ By using 500 CALET 5-yr samples:
 - **The fine structure (e.g black line)** is observable by CALET thanks to the high 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

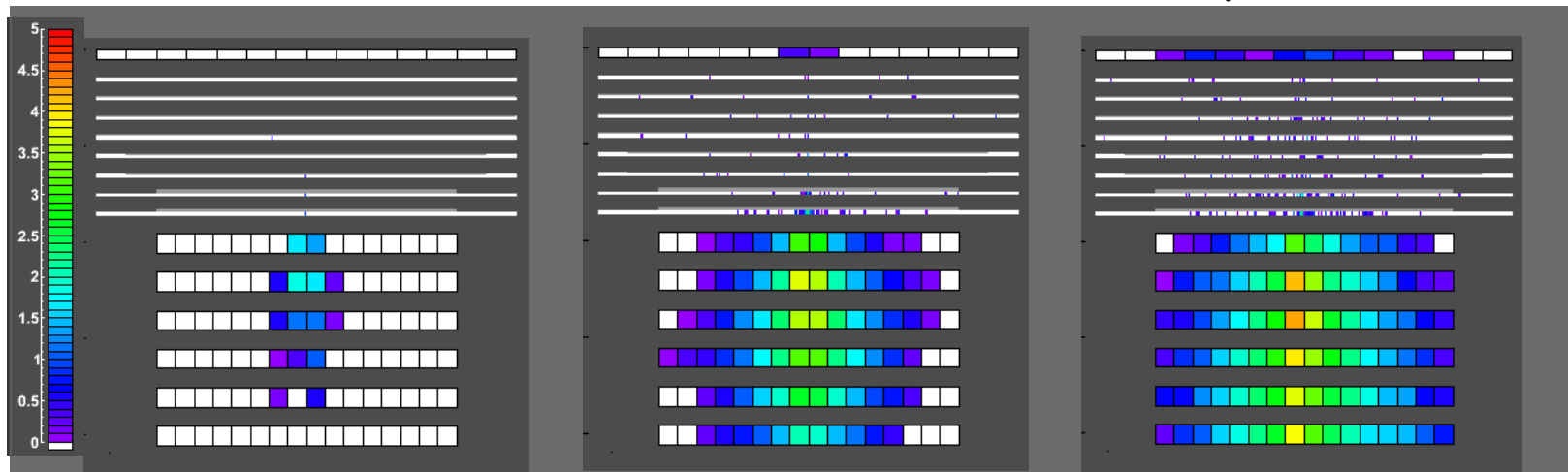


- Largest improvement (up to factor 10) for **e^+e^- - channel** and (up to factor 5) for **LKP** – hard drop in spectrum at mass of Dark Matter particle – well detectable by CALET due to high statistics in TeV region
- $\tau^+\tau^-$ - channel** spectrum most similar to pulsar - **could so far explain 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)



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 $\sigma_Z=0.15-0.3$ with the CHD.



Overview of Trigger modes for CALET

High Energy Shower Trigger (HE)

- High energy electrons (10GeV $\sim$ 20TeV)
- High energy gamma rays (10GeV $\sim$ 10TeV)
- Nuclei (a few 10GeV $\sim$ 000TeV)

Low Energy Shower Trigger (LE)

- Low energy electron at high latitude (1GeV $\sim$ 10GeV)
- GeV gamma-rays originated from GRB (1GeV $\sim$)
- 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.

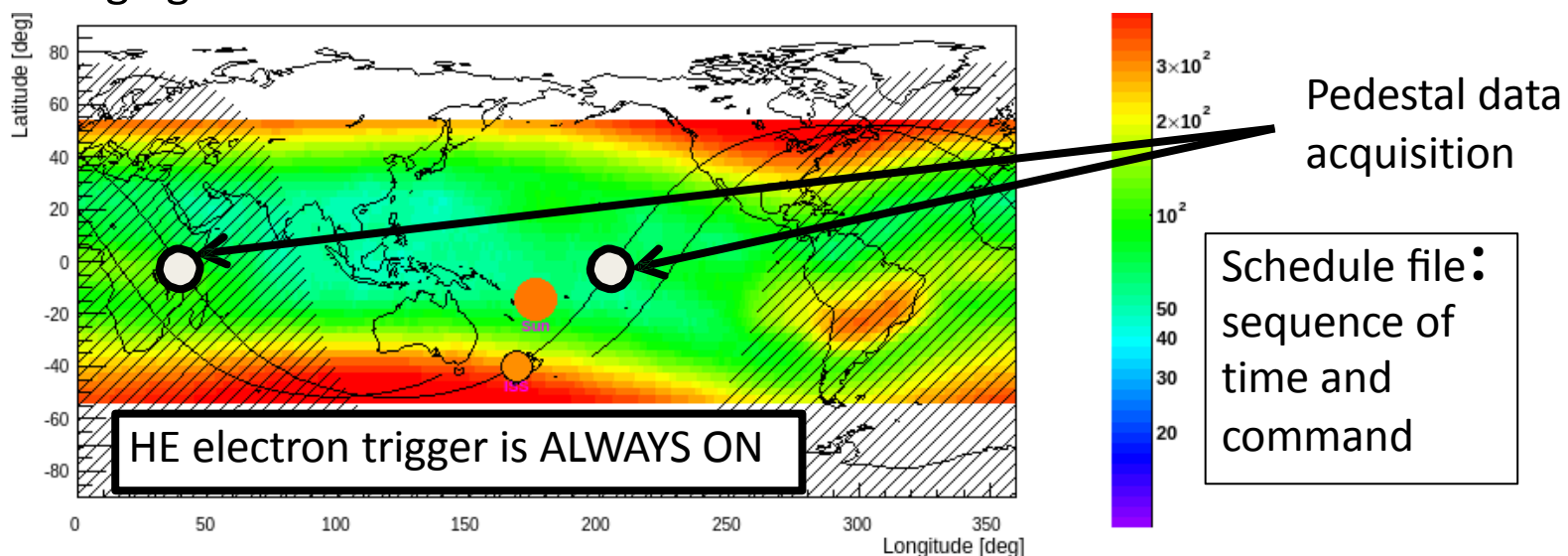
Auto Trigger (Pedestal/Test Pulse)

- 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

