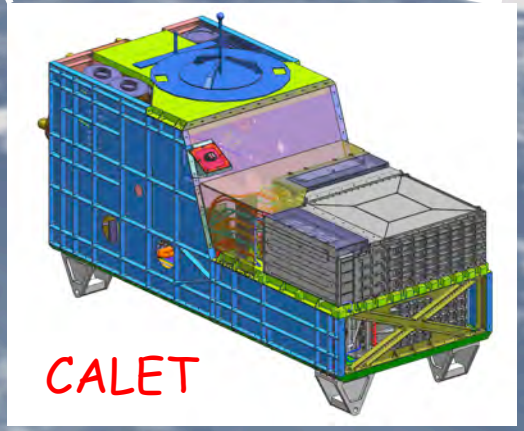
# The CALorimetric Electron Telescope (CALET): High-Energy Astroparticle Physics Observatory on the International Space Station

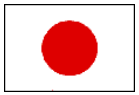
Shoji Torii
for the CALET Collaboration

Waseda University &
Japan Aerospace Exploration Agency
(JAXA)




ICRC2015@ The Hague August 5, 2015

# CALET International Collaboration



## JAPAN — 22 institutions

Aoyama Gakuin University
Hirosaki University
Ibaraki University
Institute for Cosmic Ray Research, University of Tokyo
JAXA/Space Environment Utilization Center
JAXA/ Institute of Aerospace and Astronautical Sciences
St. Marianna University, School of Medicine
Kanagawa University
High Energy Accelerator Research Organization (KEK)
Nagoya University
National Institute of Radiological Sciences
National Institute of Polar Research
Nihon University
Ritsumeikan University
Saitama University
Shibaura Institute of Technology
Shinshu University
Tokiwa University
Tokyo Institute of Technology
University of Tokyo
Waseda University (PI Institute)
Yokohama National University

## ITALY — 5 institutions

University of Siena
University of Florence & IFAC (CNR)
University of Pisa
University of Roma Tor Vergata
University of Padova

## USA — 6 institutions

NASA/GSFC
CRESST/NASA/GSFC and University of Maryland
CRESST/NASA/GSFC and Universities Space Research Association
Louisiana State University
Washington University - St Louis
University of Denver

JAXA 宇宙航空研究開発機構 Japan Aerospace Exploration Agency

Waseda University

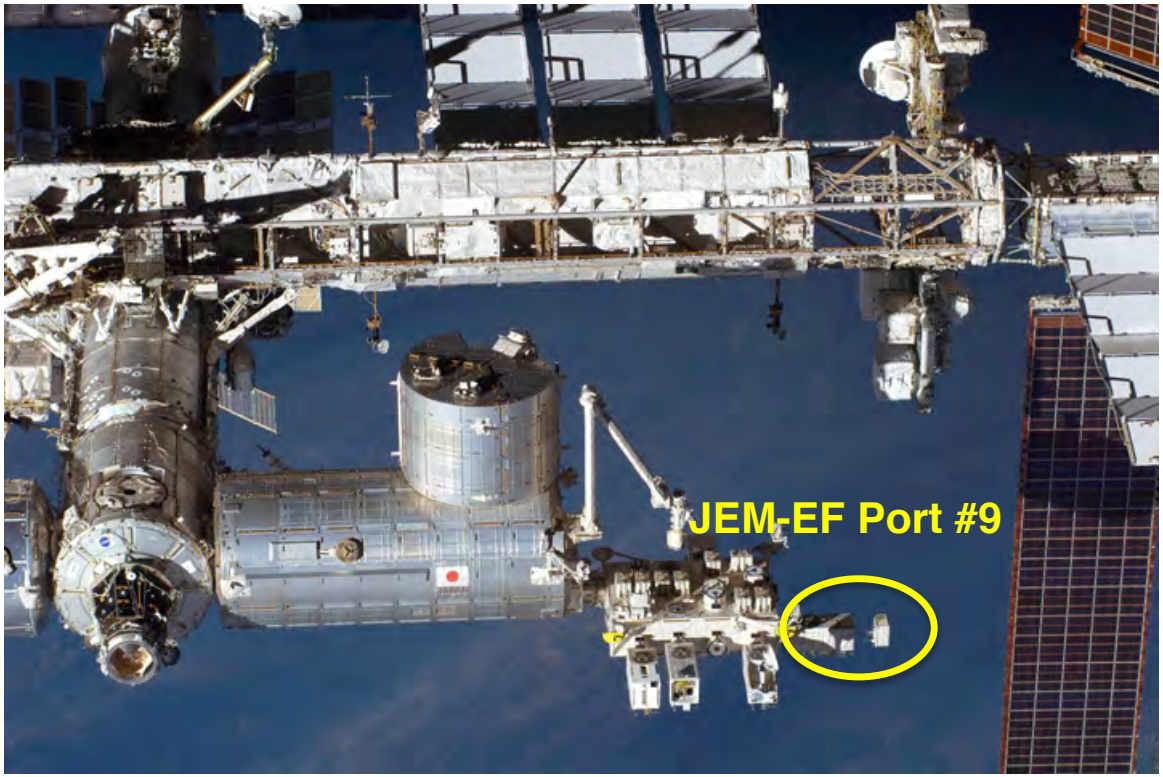
CALET is a Recognized Experiment

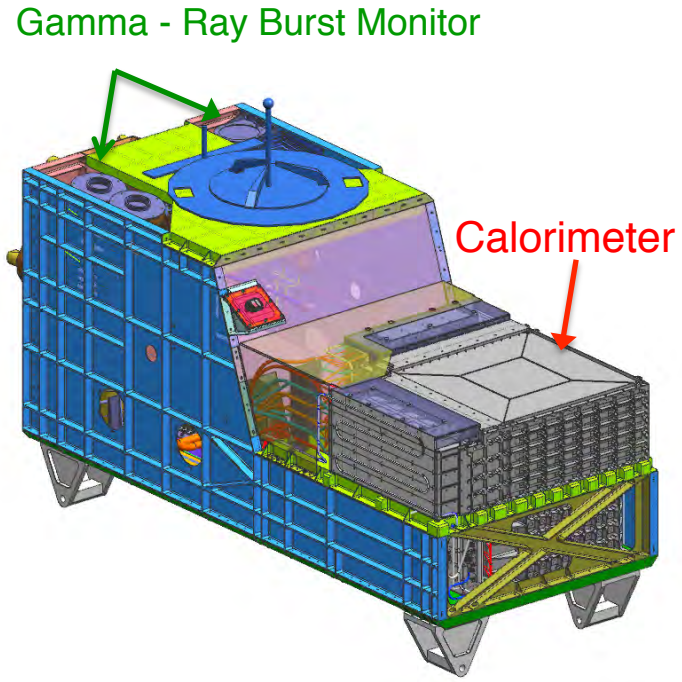
ASI

NASA

# CALorimetric Electron Telescope (CALET) Payload

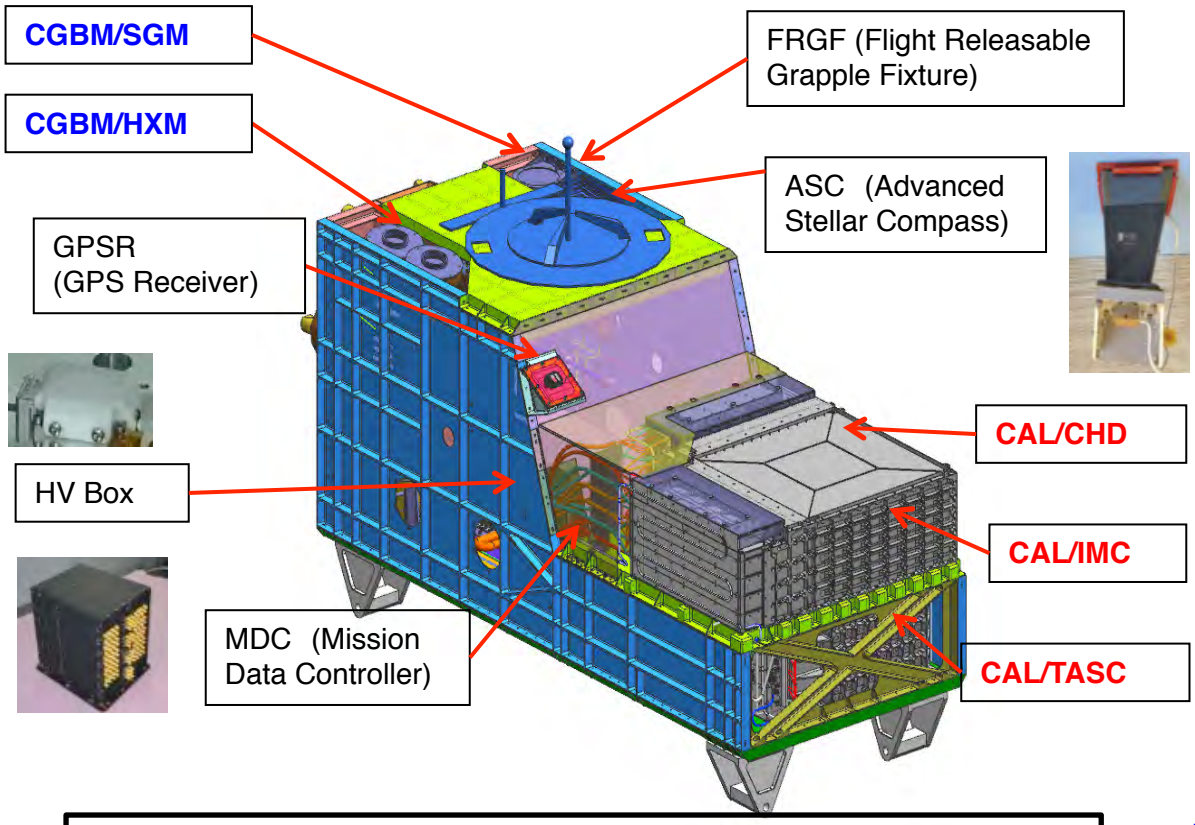
The CALorimetric Electron Telescope, CALET, project is a Japan-led international mission for the International Space Station, ISS, in collaboration with Italy and the United States.



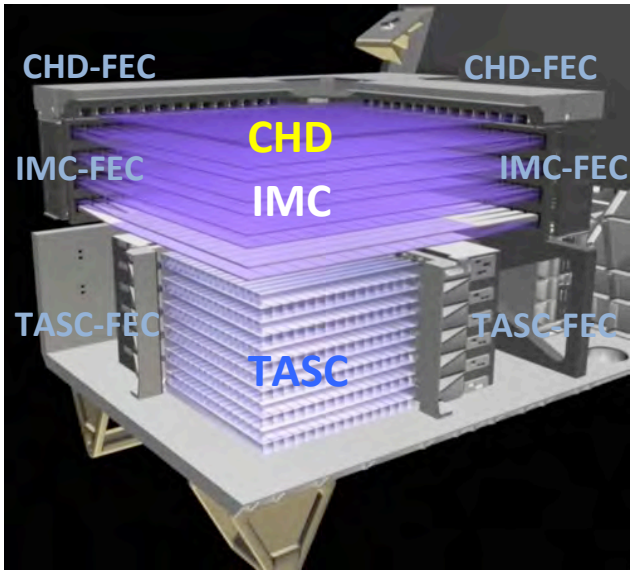




The CALET payload will be launched by the Japanese carrier, H-II Transfer Vehicle 5 (HTV-5) and robotically attached to the port #9 of the Japanese Experiment Module – Exposed Facility (JEM-EF) on the International Space Station.

# CALET System Overview (Final)




## CALORIMETER (CHD/IMC/TASC)



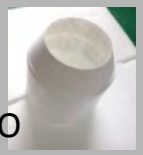

- Mass: 612.8 kg
- JEM Standard Payload Size
  1850mm(L) × 800mm(W) × 1000mm(H)
- Power Consumption: 507 W (max)
- Telemetry:
  Medium 600 kbps (6.5GB/day) / Low 50 kbps

**CGBM (CALET Gamma-ray Burst Monitor)**

HXM x2
7keV-1MeV

$LaBr_3(Ce)$

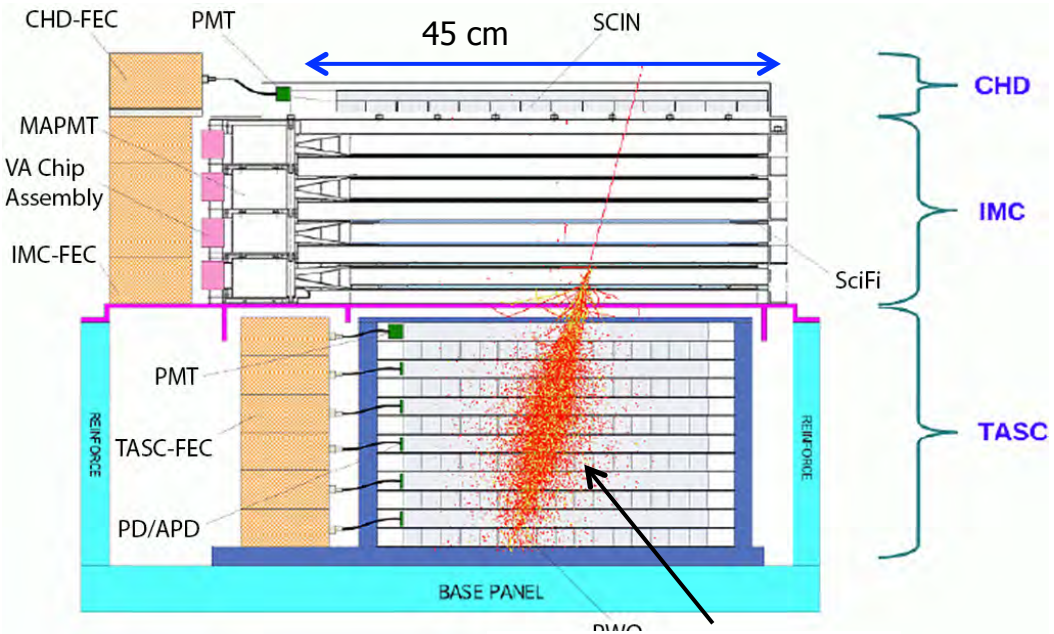
SGM x1
0.1-20MeV



BGO

# CALET: Instrument Overview

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




1 TeV electron shower

## Unique features of CALET

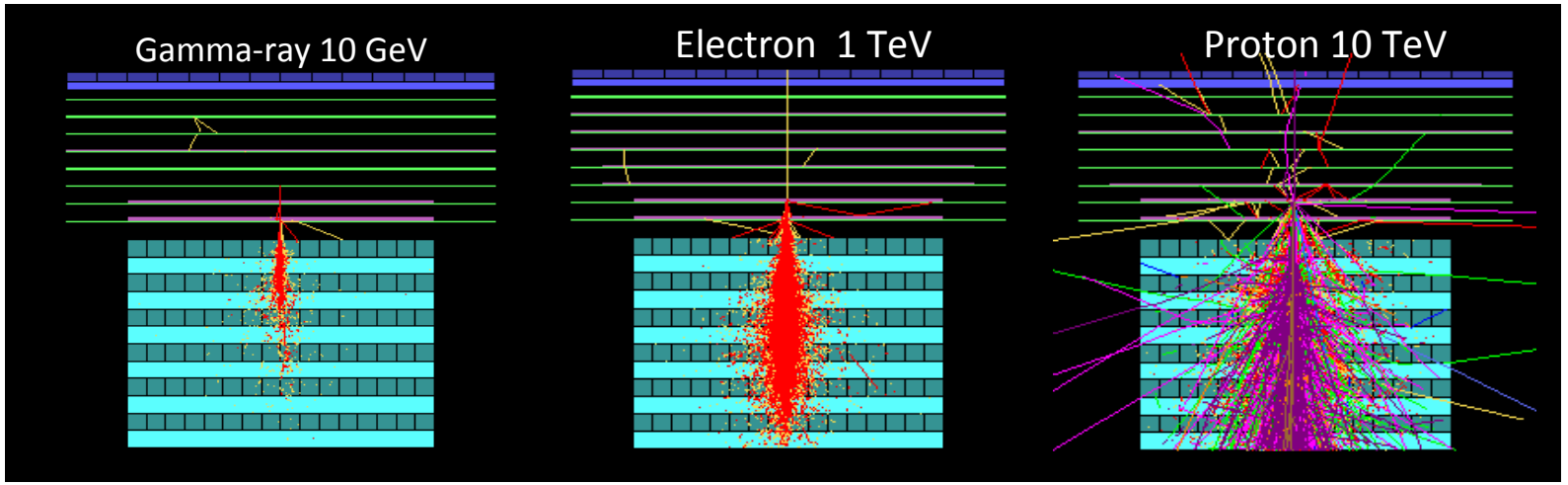
**Thick, fully active calorimeter:**
Allows measurements well into the TeV energy region with excellent energy resolution

**Fine imaging upper calorimeter:**
Accurately identify the starting point of electromagnetic showers.

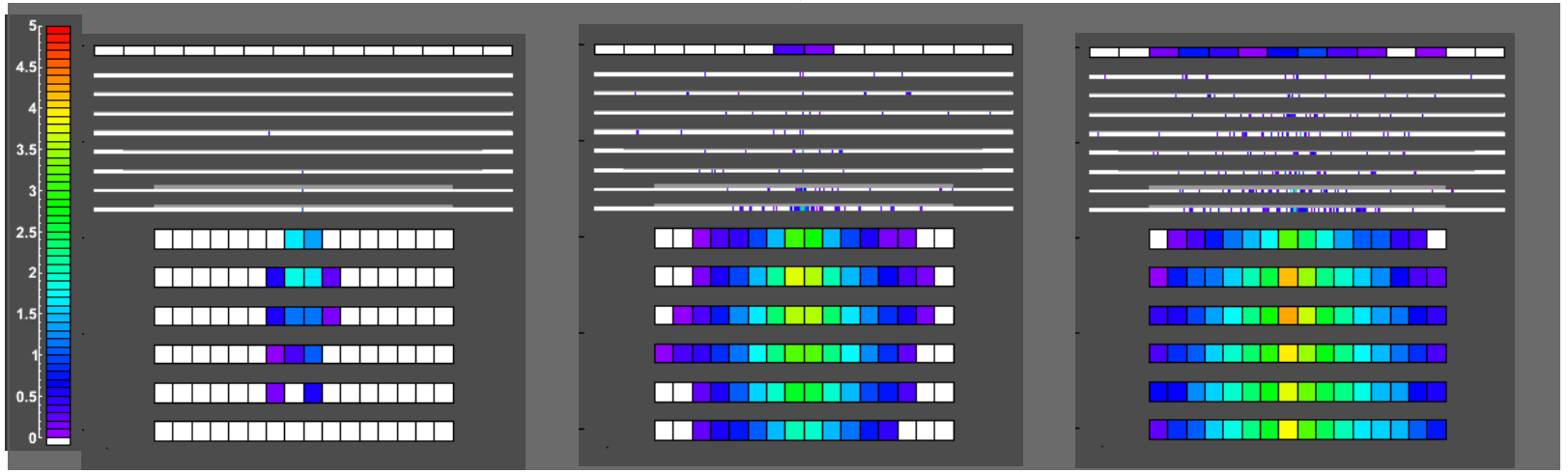
**Detailed shower characterization:**
Lateral and longitudinal development of showers enables electrons and abundant protons to be powerfully separated.

| | 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)**<br>Unit Size: 32mm x 10mm x 450mm | **SciFi : 448 x 8 layers (x,y) = 7168**<br>Unit size: 1mm² x 448 mm<br>**Total thickness of Tungsten: 3 $X_0$** | **PWO log: 16 x 6 layers (x,y)= 192**<br>Unit size: 19mm x 20mm x 326mm<br>**Total Thickness of PWO: 27 $X_0$** |
| Readout | **PMT+CSA** | **64 -anode PMT(HPK) + ASIC** | **APD/PD+CSA**<br>PMT+CSA ( for Trigger)@top layer |

# CALET/CAL Shower Imaging Capability (Simulation)

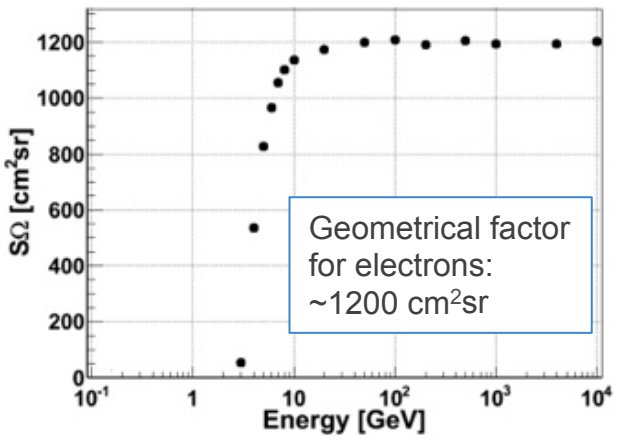


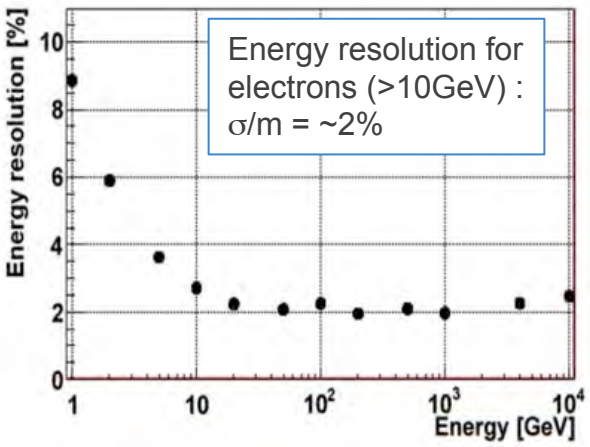

In Detector Space

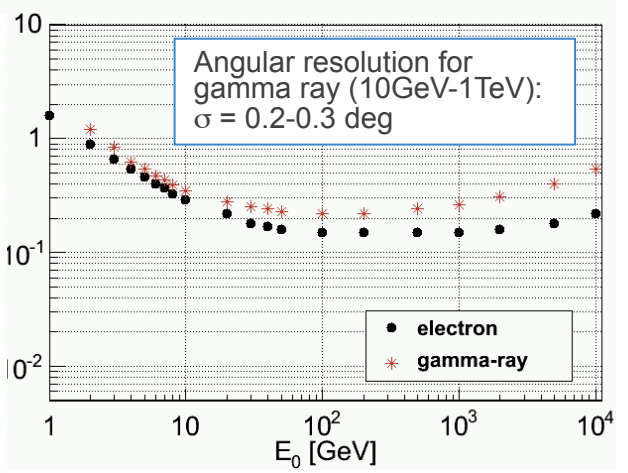


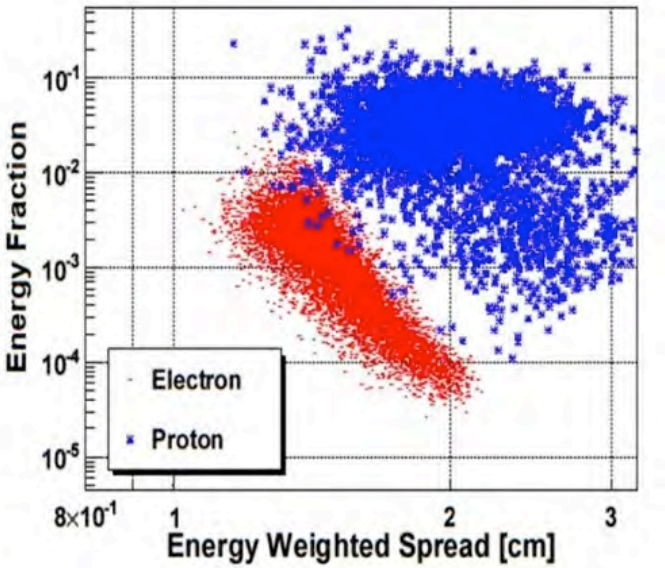

- Proton rejection power of $10^5$ can be achieved with IMC and TASC shower imaging capability.
- Charge of incident particle is determined to $\sigma_Z$=0.15-0.3 with the CHD.

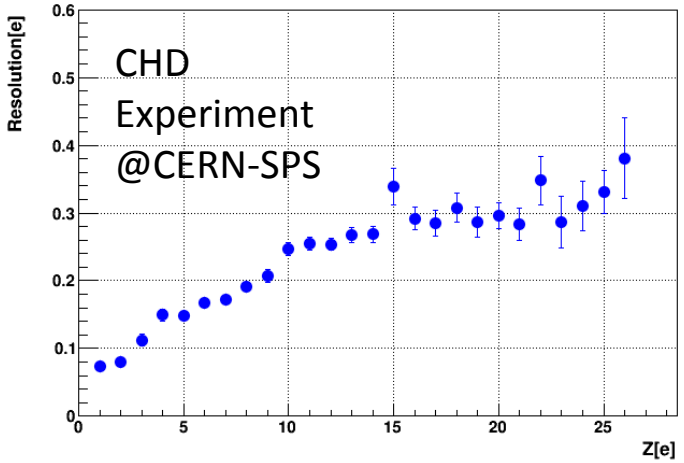
# CALET Expected Performance by Simulations and Beam Tests




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

Proton rejection power at 1TeV :
≈$10^5$ with 95% efficiency for electrons

- Beam tests @ CERN-SPS
  - Tamura Poster#487
  - Akaike Poster#594
  - Bigongiari Poster#501
- e/p separation
  - Palma Poster#481
- CHD performance
  - Brogi Poster#510

# CALET Science Targets

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.

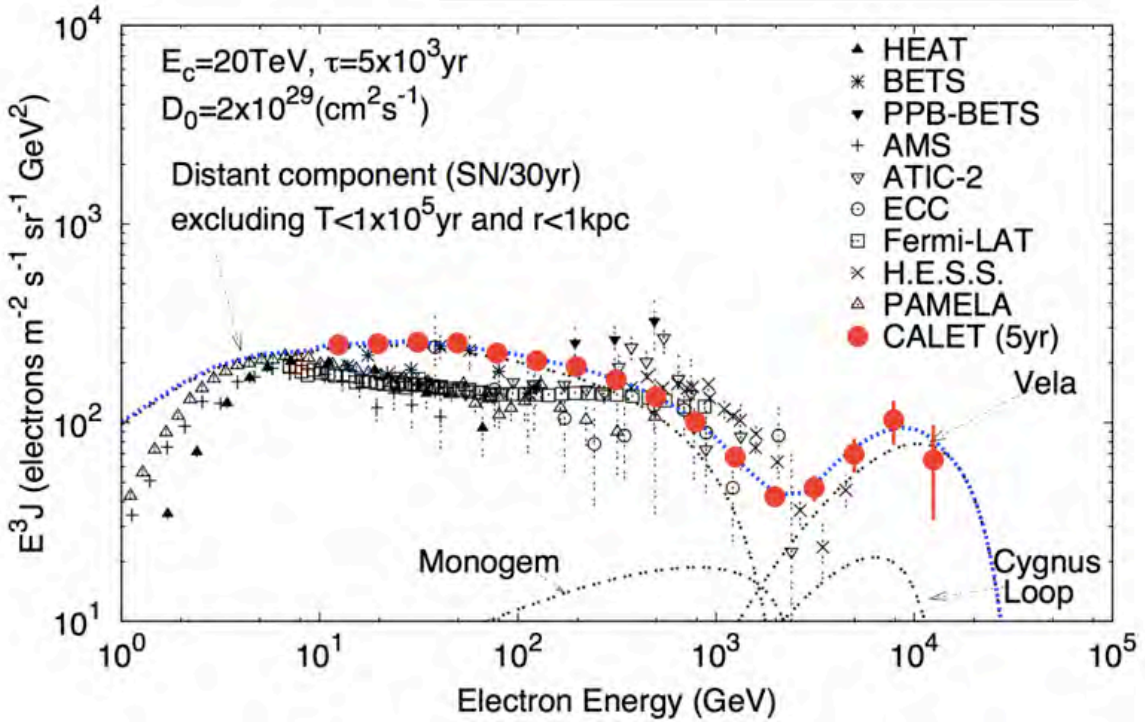
| Science Objectives | Observation |
|---|---|
| Nearby Cosmic-ray Sources | **Electron spectrum** in trans-TeV region |
| Dark Matter | Signatures in **electron/gamma** energy spectra in the 10 GeV – 10 TeV region |
| Origin and Acceleration of Cosmic Rays | **p-Fe** up to the multi-TeV region, Ultra Heavy Nuclei |
| Cosmic–ray Propagation in the Galaxy | **B/C** ratio up to a few TeV /n |
| Solar Physics | **Electron flux** below 10 GeV |
| Gamma-ray Transients | Gamma-rays and X-rays in 7 keV - 20 MeV |

# CALET Main Target: Identification of Electron Sources

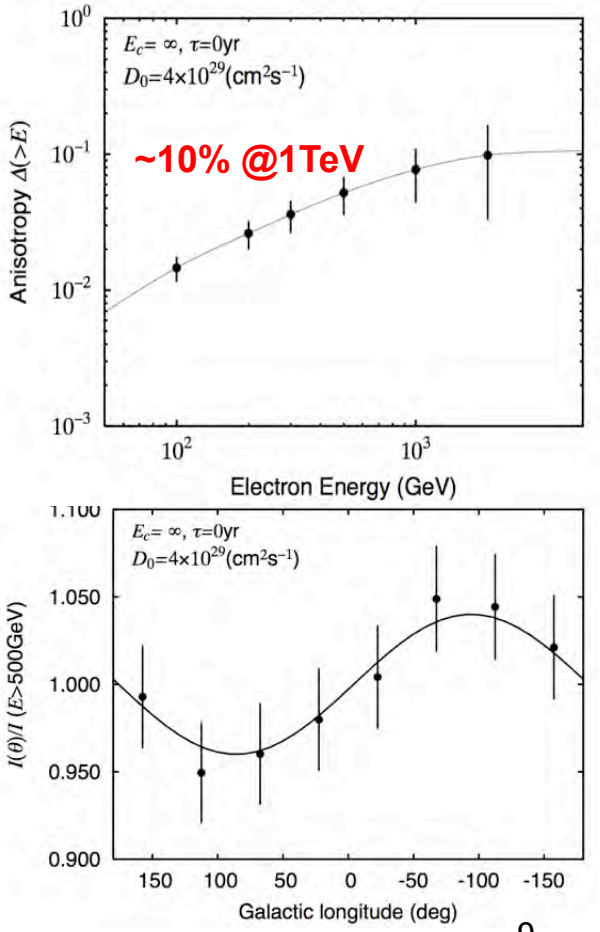
Some nearby sources, e.g. Vela SNR, might have unique signatures in the electron energy spectrum in the TeV region (Kobayashi et al. ApJ 2004)

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

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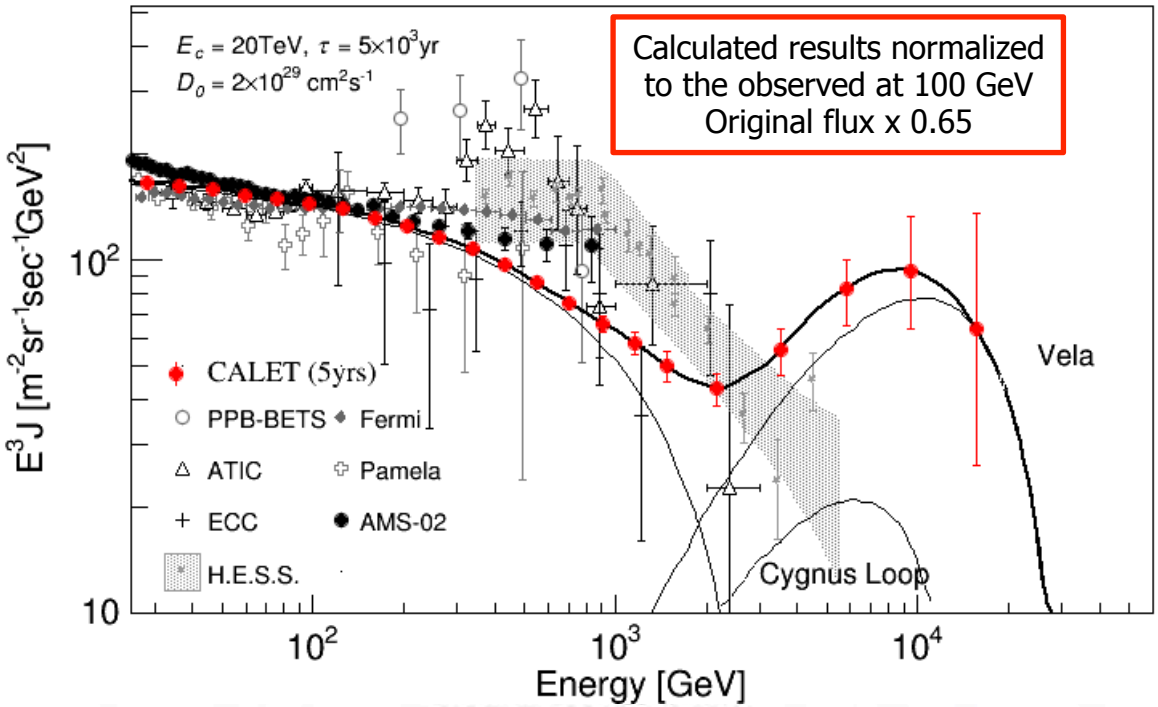
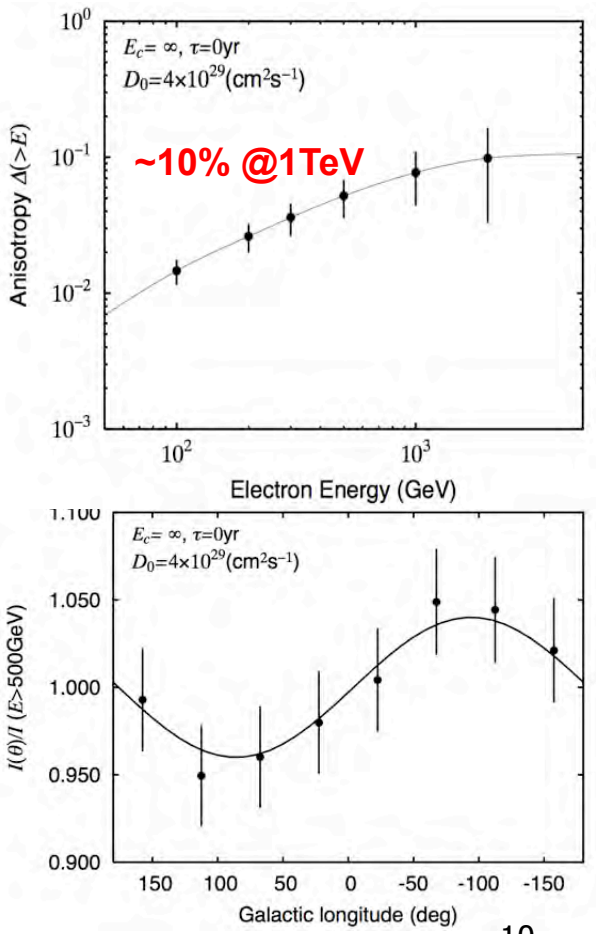


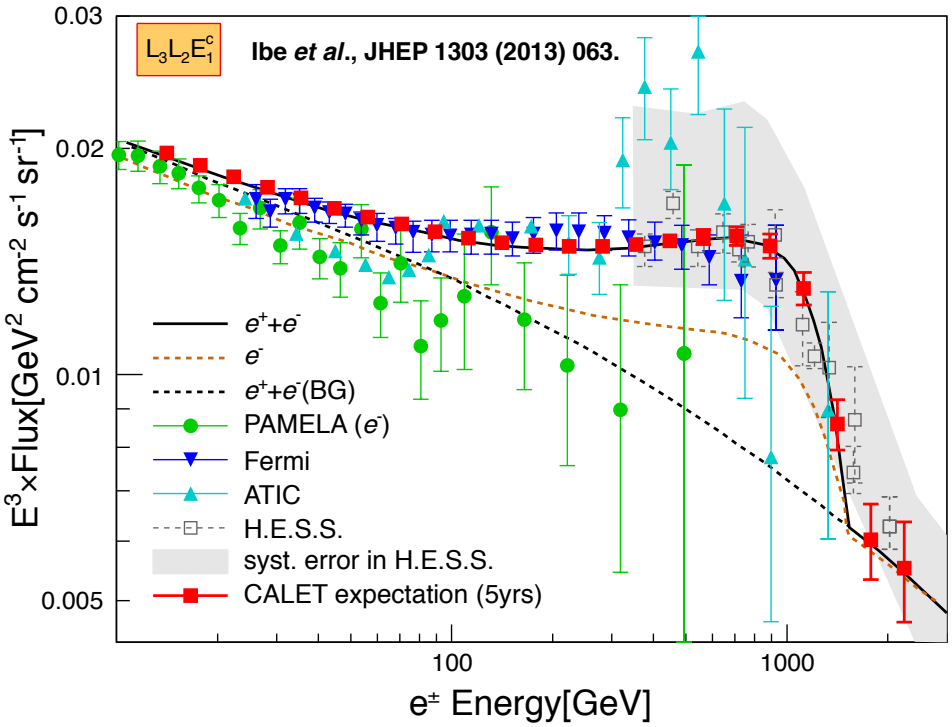

Expected Anisotropy from Vela SNR




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

# Dark Matter or Pulsar with Electrons

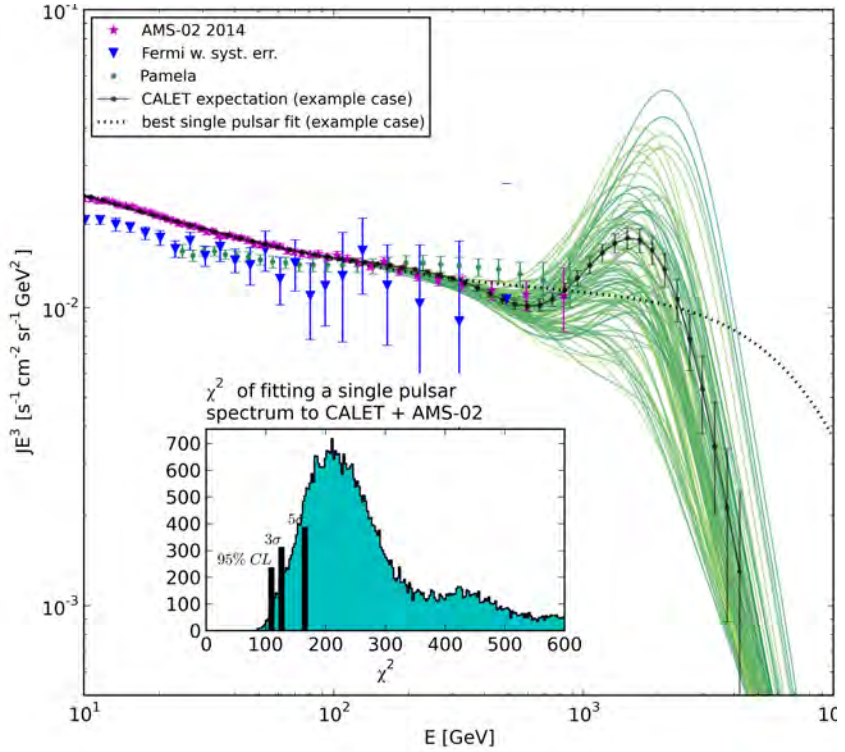
## Decay of Dark Matter (LSP)




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

Motz Oral #438

## 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

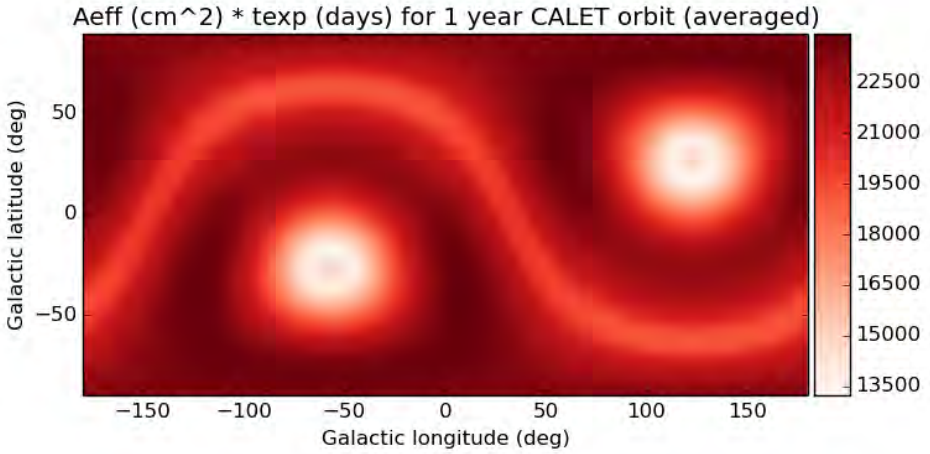
# Detection of High Energy Gamma-rays

Moissev, Mori ICRC2013
Cannady Oral #727

## Performance for Gamma-ray Detection

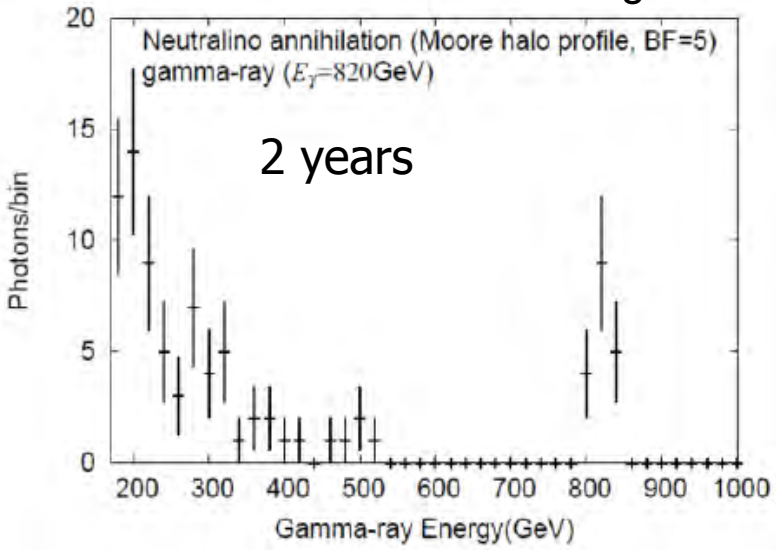
| | |
|---|---|
| Energy Range | 4 GeV-10 TeV |
| Effective Area | 600 $cm^2$ (10GeV) |
| Field-of-View | 2 sr |
| Geometrical Factor | 1100 $cm^2 sr$ |
| Energy Resolution | 3% (10 GeV) |
| Angular Resolution | 0.35 ° (10GeV) |
| Pointing Accuracy | 6′ |
| Point Source Sensitivity | 8 x $10^{-9}$ $cm^{-2}s^{-1}$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

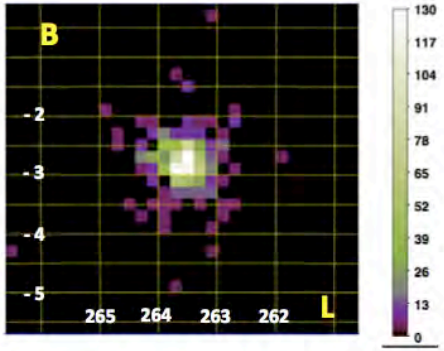
## Exposure Map

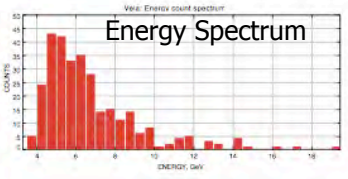


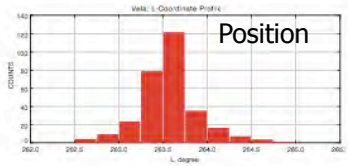

- Expected diffuse gamma-ray flux for one year*
  - Galactic: ~5,700 photons
  - Extragalactic background (EGB): ~1700
- Point source observations for one year**
  - Vela: ~ 300 photons above 5 GeV

## Indirect Dark Matter Search: Line gamma-ray



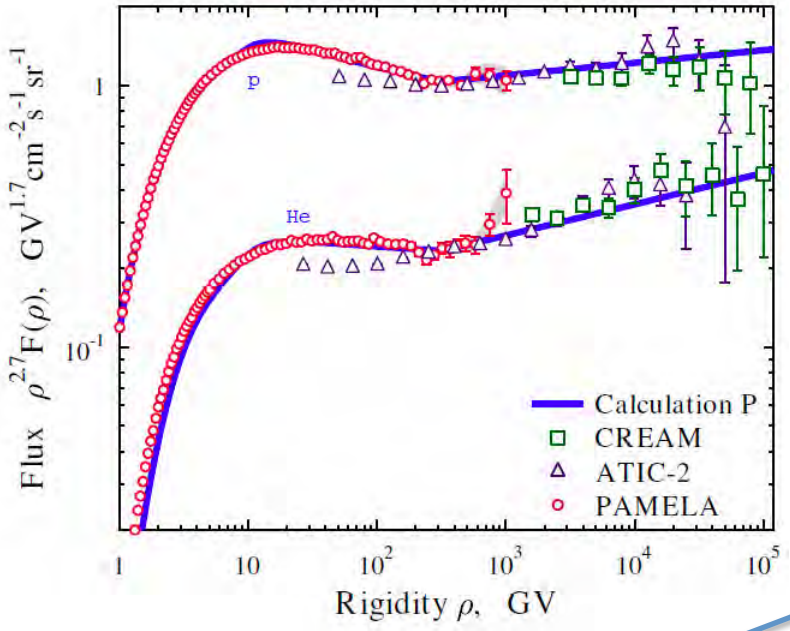



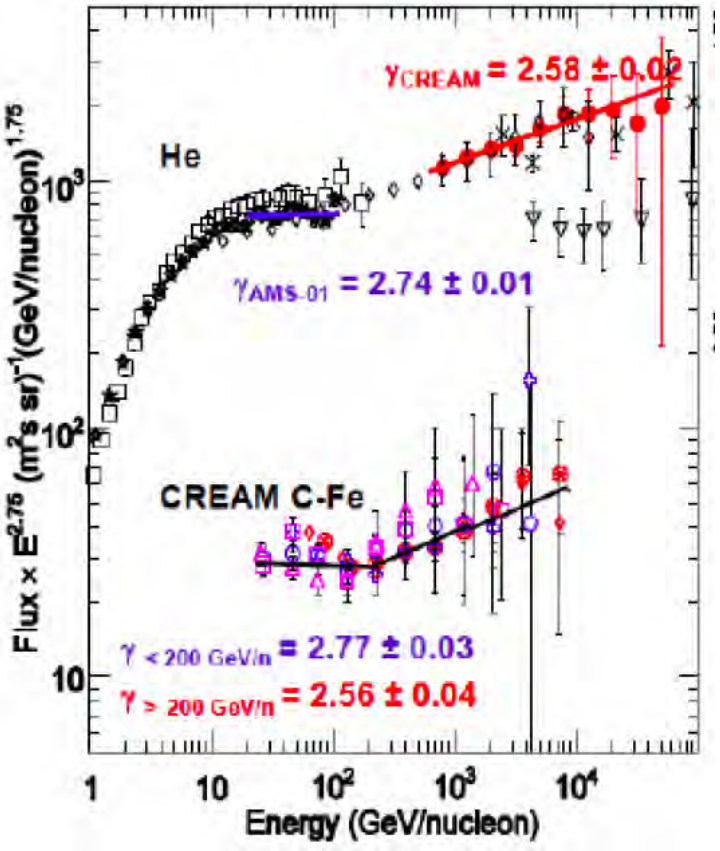

*) Trigger efficiency included below 10 GeV
**) 100 % efficiency over 5 GeV

# Measurements of Cosmic Nuclei Spectra-I

- **PAMELA detected a spectral break in Proton and He spectra at R~240GV**




- The break also appears in the spectra of NUCLEI measured by CREAM up to several TeV/n




The slope of Z>2 at high energy looks similar to He and different from protons

A single power-law seems inadequate to fit the spectra of nuclei

# Measurements of Cosmic Nuclei Spectra-II

## Proton and He

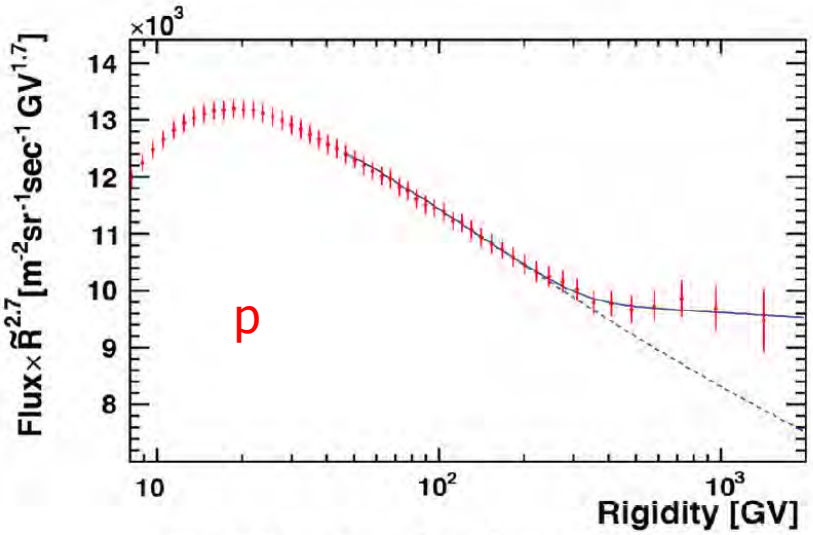



*Figure 2. Measured proton flux as a function of rigidity.*

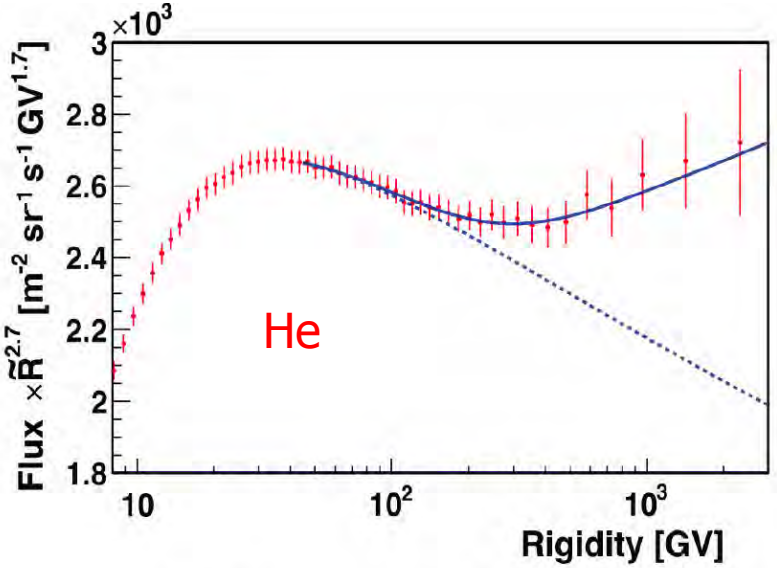


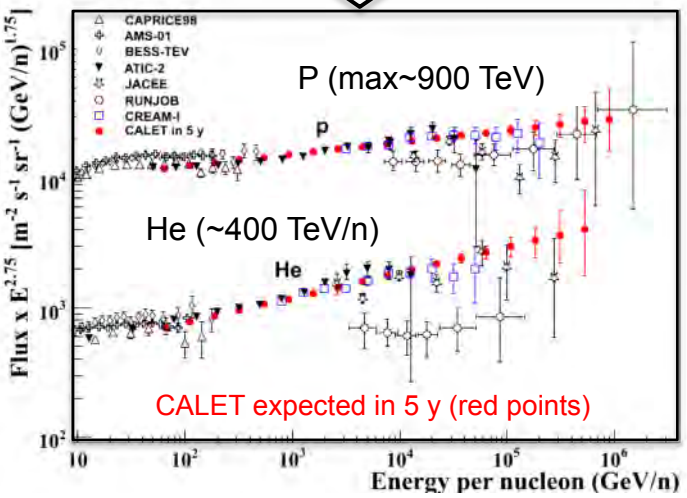

*Figure 3. Measured helium flux as a function of rigidity.*

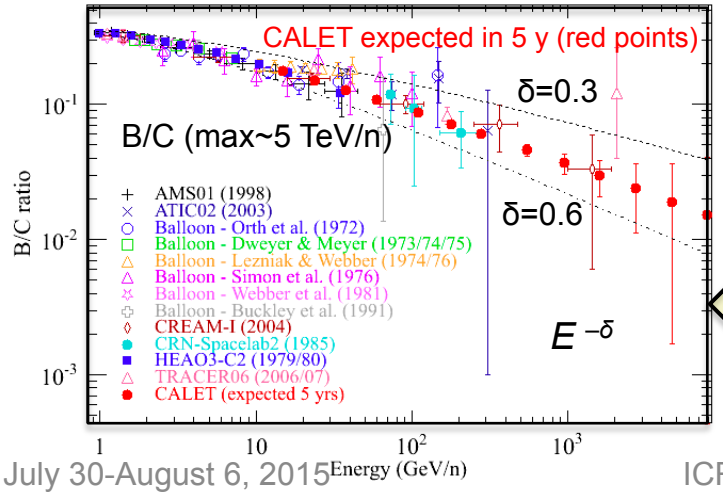
Recent measurements by AMS-02 with p and He below MDR~2 TV seems to confirm the presence of a spectral break in the same region as reported by PAMELA and CREAM

CALET willl be able to perform an accurate scan of the energy region around the spectral break with an energy resolution ~30% and a large GF~0.1 $m^2sr$

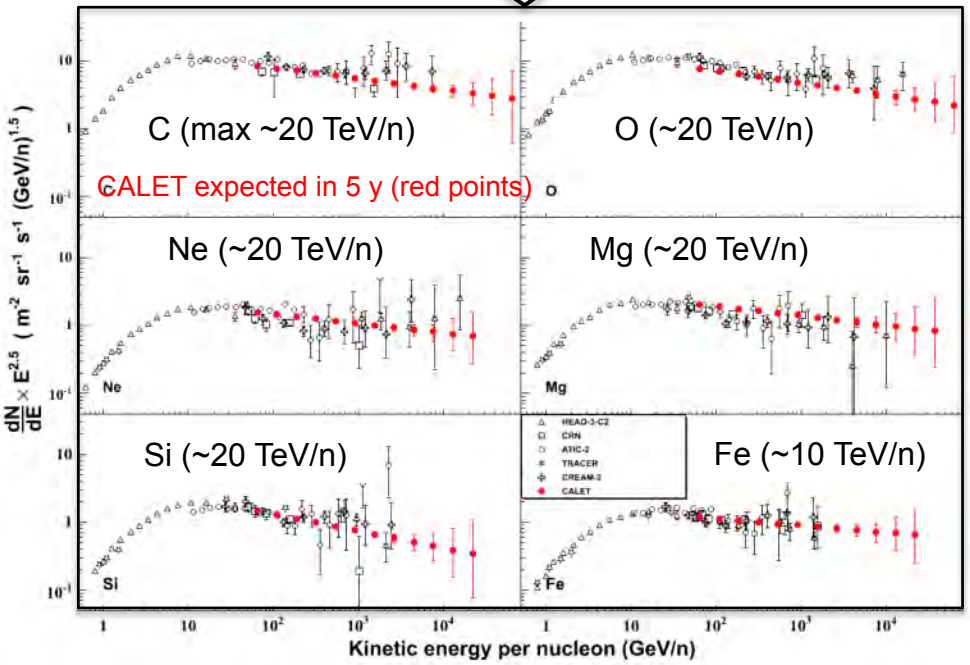
# Measurements of Cosmic Nuclei Spectra with CALET

- 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 ?



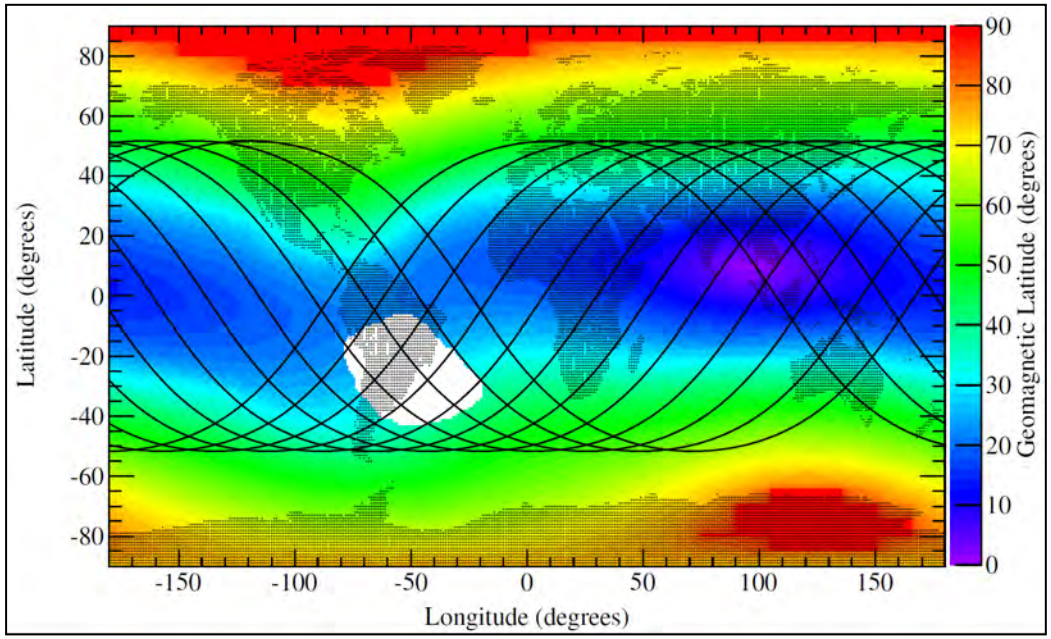

- All primary heavy nuclei spectra well fitted to single power-laws with similar spectral index (CREAM, TRACER)
- However hint of a hardening from a combined fit to all nuclei spectra (CREAM)



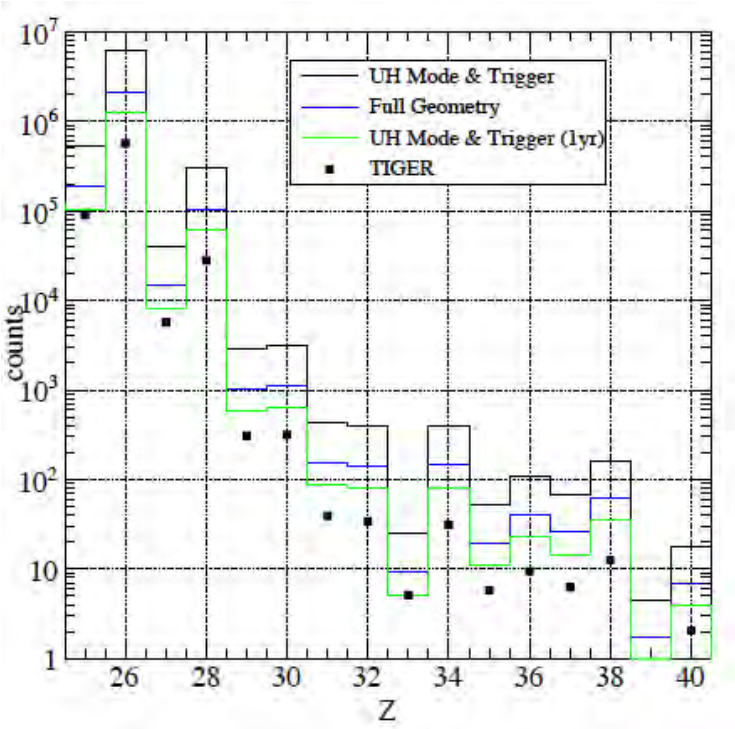

- At high energy (> 10 GeV/n) the B/C ratio measures the energy dependence of the escape path-length, $\sim E^{-\delta}$, of CRs from the Galaxy
- Data below 100 GeV/n indicate $\delta \sim 0.6$. At high energy the ratio is expected to flatten out (otherwise CR anisotropy should be larger than that observed)

# Observation of Ultra Heavy Nuclei with CALET

**Geomagnetic Latitude**




**CALET (expected) vs. TIGER data**

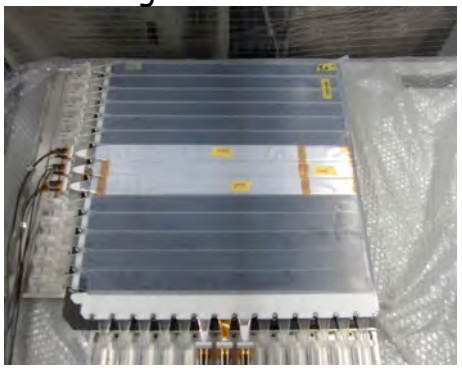



- Ultra heavy nuclei abundances provide information on CR site and acceleration mechanism
- CHD resolution is ~constant above 600 MeV/n ➔Charge ID from saturated dE/dx
- No need to measure energy ➔ No passage through TASC ➔ **Large acceptance ~0.4 m$^2$sr**
- **The energy threshold cut is based on the 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

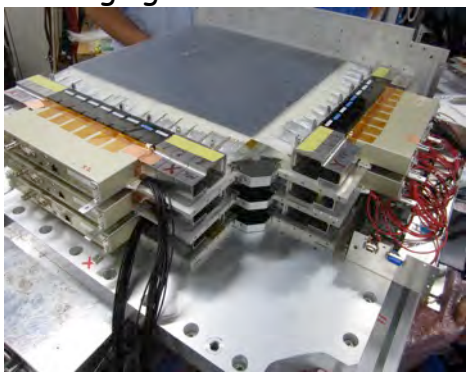
Rauch Poster #790

# CERN Beam Test using the STM

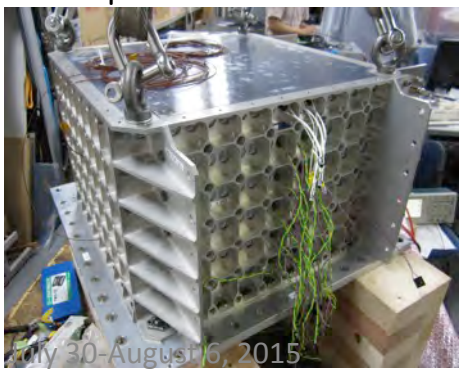
Charge Detector: CHD



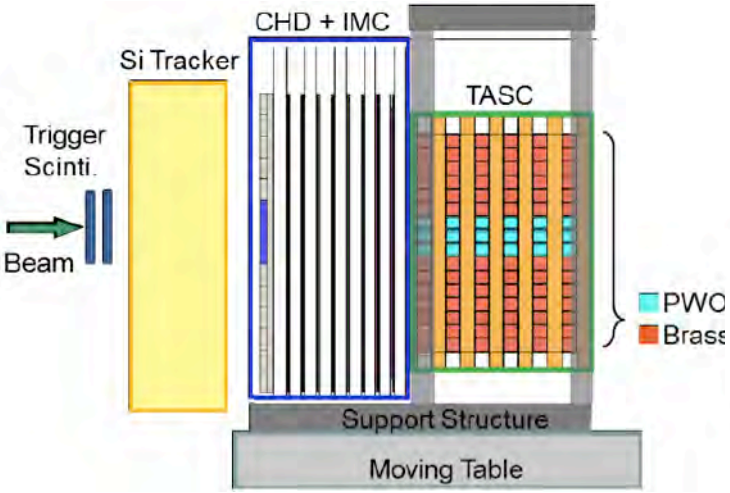
Imaging Calorimeter: IMC



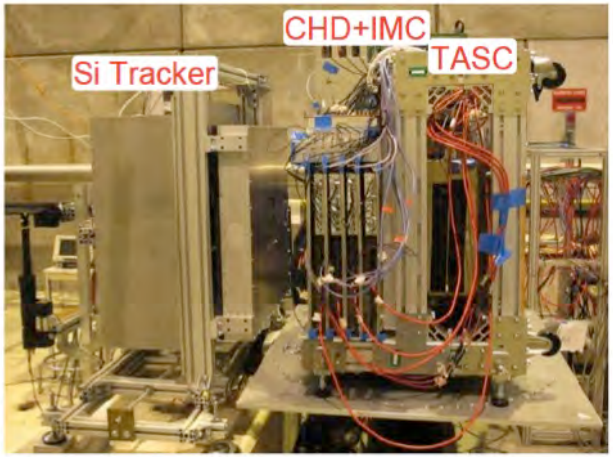
Total Absorption Calorimeter: TASC



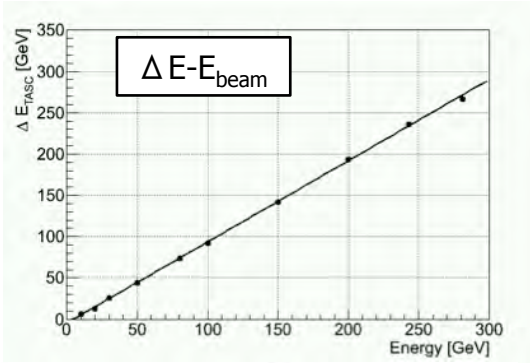
Schematic Side View of the Beam Test Model



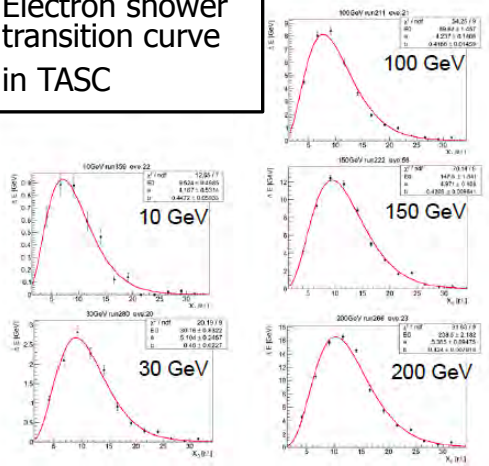

The Beam Test Model at CERN SPS H8 Beam Line

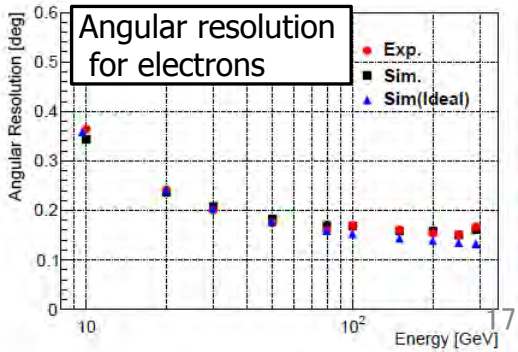



Beam Test Results




Electron shower transition curve in TASC

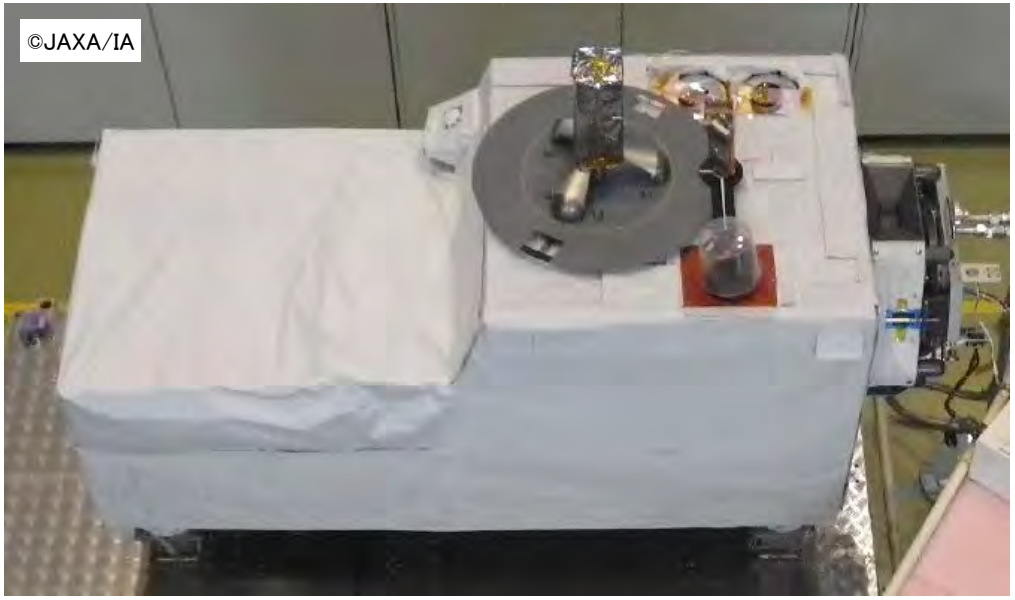


# Tests at Tsukuba Space Center


13m diameter thermal vacuum chamber

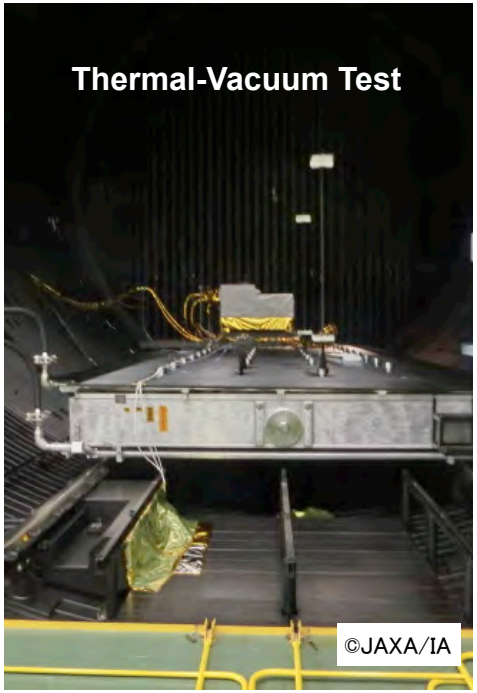

## CALET Flight Model

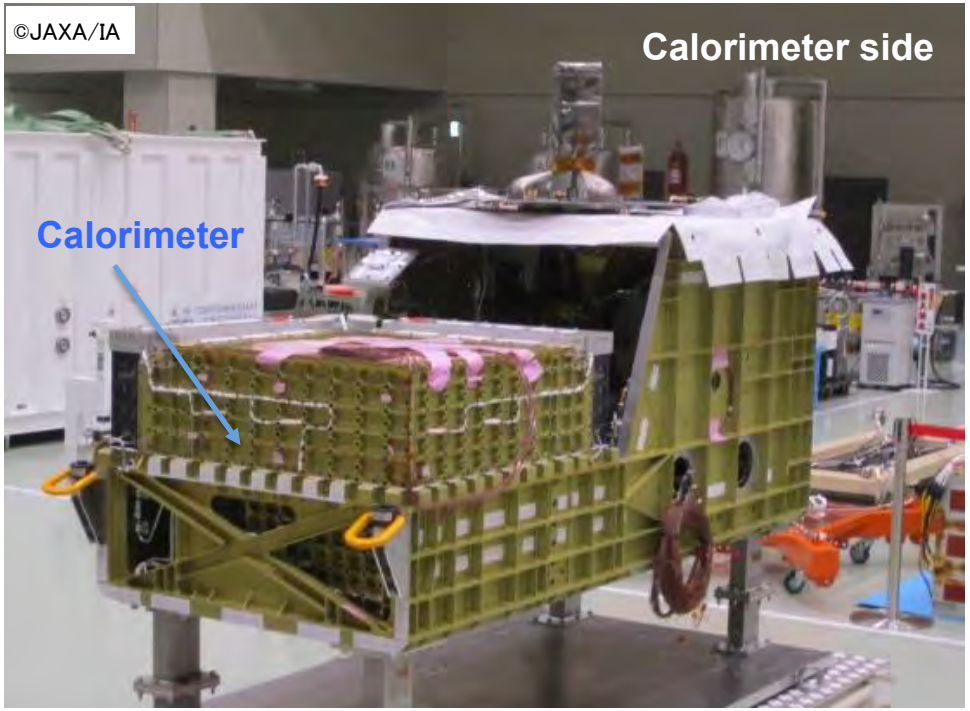


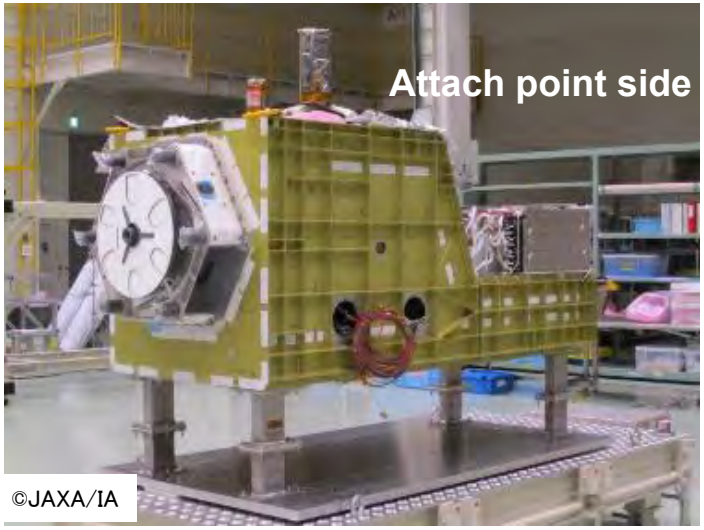

- System Function Test
- Muon Test
- Geometry Measurement
- Environmental Tests
  - Thermal Vacuum
  - Acoustic
  - EMC

# 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) in preparation for a launch with HTV-5.



# CALET Launch Date Schedule with HTV5

It is officially announced by JAXA that the HTV-5 launch is scheduled at 10:01pm on Aug. 16(Sun) in JST.


## Details

- Scheduled date of launch:
  August 16 (Sunday), 2015 (Japan Standard Time, JST)
- Launch time:
  around 10:01 p.m. (JST)*1
- Launch windows:
  Aug. 17 (Mon.) through Sept. 30 (Wed.), 2015 (JST)*2
- Launch Site:
  Yoshinobu Launch Complex at the Tanegashima Space Center (TNSC) in southern Japan.

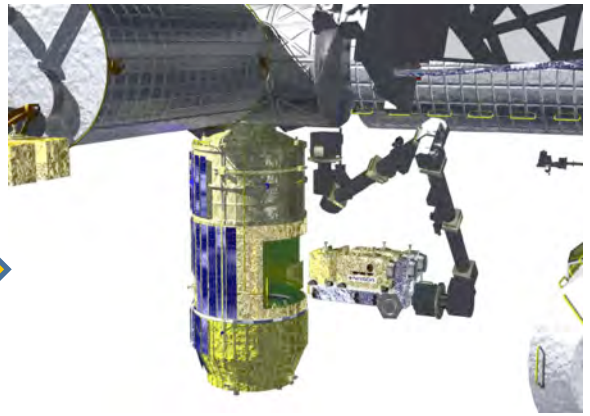
(*1) Time will be determined by the updated orbit of the International Space Station (ISS).
(*2) The launch day and time during the launch windows shall be decided by the international coordination for ISS operations.

# Launching Procedure of CALET

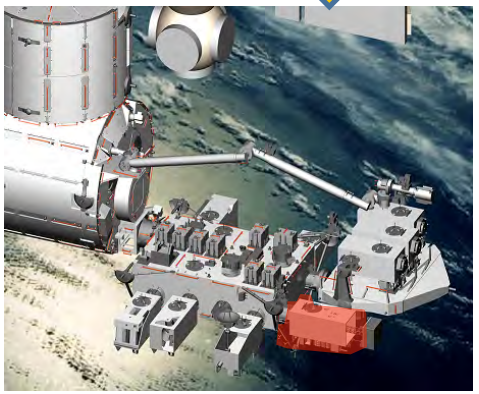
Separation from H2B



Approach to ISS

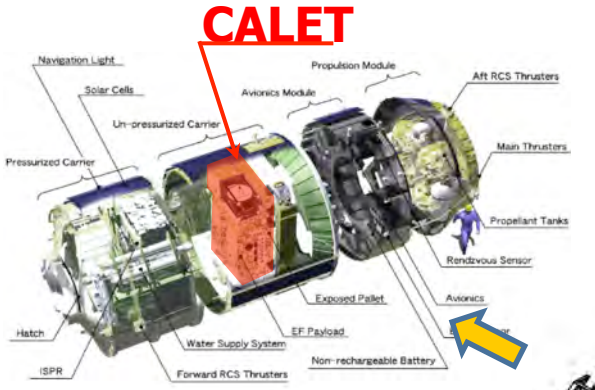


Pickup of CALET

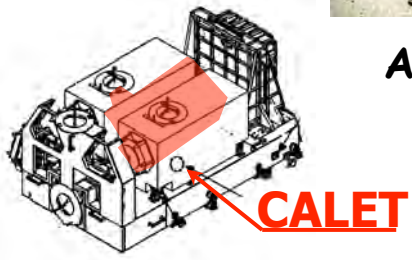


Attach to JEM-EF

Launching by H2B Rocket




H2 Transfer Vehicle(HTV)




HTV Exposed Palette

# Data Downlink Using TDRSS and DRTS

Scientific Operations and Data Analysis in Collaboration with International Team at Waseda CALET Operations Center

NASA Link
Real-Time Connection
> 50 % (max. 17 hr/day)

White Sands Complex, NM, USA

TDRSS

NASA Link

NASA MSFC

Data Archive Center

CALET

JAXA Link

DRTS
(Data Relay Test Satellite)

JAXA ICS Link
Real-Time Connection
~20 % (5 hr/day)

Tsukuba Space Center, Japan

JAXA Tsukuba Space Center, ISS Operation Building Japan

Waseda CALET Operations Center

International Collaboration Organization (Italy, USA)

Operation at Tsukuba Space Center for monitoring

Asaoka Poster#594

# Conclusions and Summary

- CALET is an instrument primarily dedicated to the observation of electrons in the TeV region to provide crucial information on nearby sources and valuable information for indirect DM searches.
- It will also study cosmic rays from proton to Fe and Ultra Heavy ions ($26<Z<40$). Energy spectra, relative elemental abundances and secondary-to-primary ratios will be measured.
- The CALET flight hardware is now integrated with the Japanese carrier HTV-5 for a flight to the Japanese Experiment Module (Kibo) on the ISS scheduled on Aug. 16, 2015 NET.
- 5-years of observations are planned.

# Other Contributions from the CALET Collaboration

1) Heavy ion beam test at CERN-SPS with the CALET Structure Thermal Model
   Tadahisa Tamura  Poster ID#487

2) CALET energy calibration using CERN-SPS beam tests
   Yosui Akaike  Poster ID#487

3) CALET's Sensitivity to Dark Matter and Astrophysical Sources
   Holger Motz  Oral  ID#438

4) Development of the Waseda CALET Operations Center (WOC) for Scientific Operations
   Yoichi Asaoka  Poster  ID#594

5) CALET measurements with cosmic nuclei: expected performance of tracking and charge identification
   Paolo Brogi  and Pier Simone Marrocchesi  Poster  ID#510

6) CALET perspectives for calorimetric measurements of high energy electrons based on beam test results
   Gabriele Bigongiari  Poster  ID#501

7) Simulation studies of the expected proton rejection capabilities of CALET
   Francesco Palma  Poster  ID#481

8) Predicted CALET Measurements of Heavy and Ultra-Heavy Cosmic Ray Nuclei
   Brian Flint Rauch  Poster  ID#790

9) Gamma-Ray Observations with CALET: Exposure Map, Response Functions, and Simulated Results
   N. W. Cannady and M. L. Cherry  Oral  ID#727

# General Alerts of Transients by CGBM


Waseda CALET Operations Center
See Y.Asaoka Poster #594

LIGO-Virgo MOU

LSC LIGO Scien Collal VIRGO

TDRSS

DRTS

MSFC/NASA

CGBM data
- TH: Timing Histogram
- PH: Pulse height Histogram
- GRB triggered data

JAXA
Tsukuba SC

CALET Grnd Sys.
in UOA

CGBM Data Processing
in
Waseda CALET
Operations Center
(WCOC)

Alerts

GCN, ATel,
Web

Counterpart search
Further follow up
observations in longer
EM wavebands

- GCN:
  Gamma-ray Coordinates Network
- ATel:
  Astronomer's Telegram