The CALET mission on the International Space Station

Paolo Maestro
University of Siena and INFN

On behalf of the CALET collaboration

VULCANO WORKSHOP 2014
Frontier Objects in Astrophysics and Particle Physics

Vulcano 18-24 May 2014

CALET collaboration

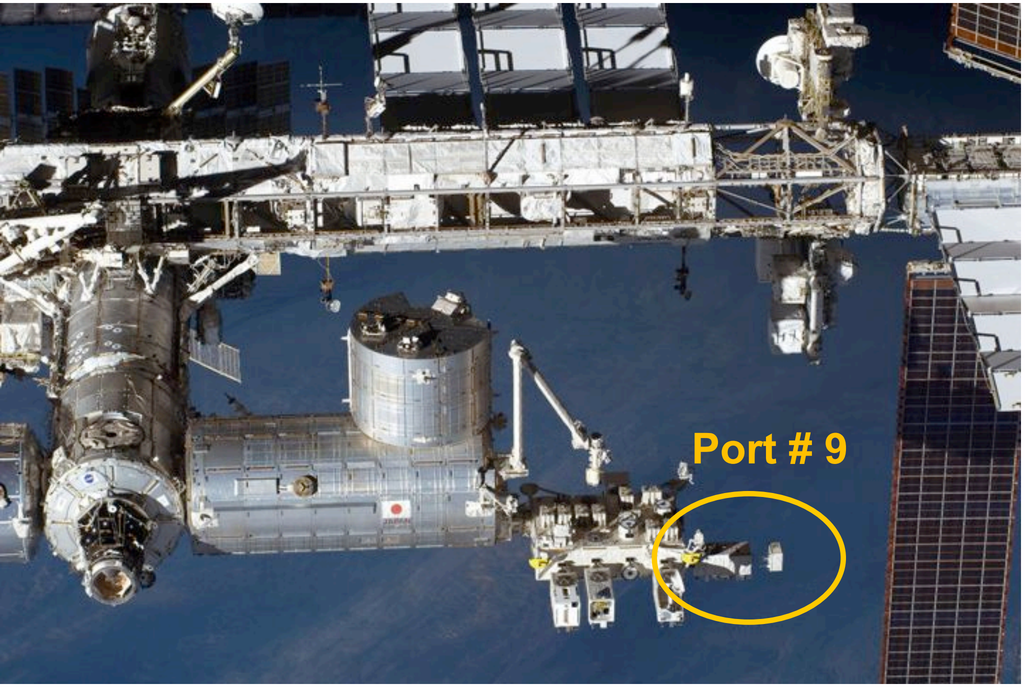
JAPAN
Waseda University
JAXA/Space Environment Utilization Center
JAXA/ Institute of Aerospace and Astronautical Sciences
Kanagawa University,
Aoyama Gakuin University
Shibaura Institute of Technology
Institute for Cosmic Ray Research , University of Tokyo
Yokohama National University
Hirosaki University
Tokyo Technology Inst.
National Inst. of Radiological Sciences
High Energy Accelerator Research Organization (KEK)
Kanagawa University of Human Services
Saitama University
Shinshu University
Nihon University
Ritsumeikan University

CALET is a Recognized Experiment

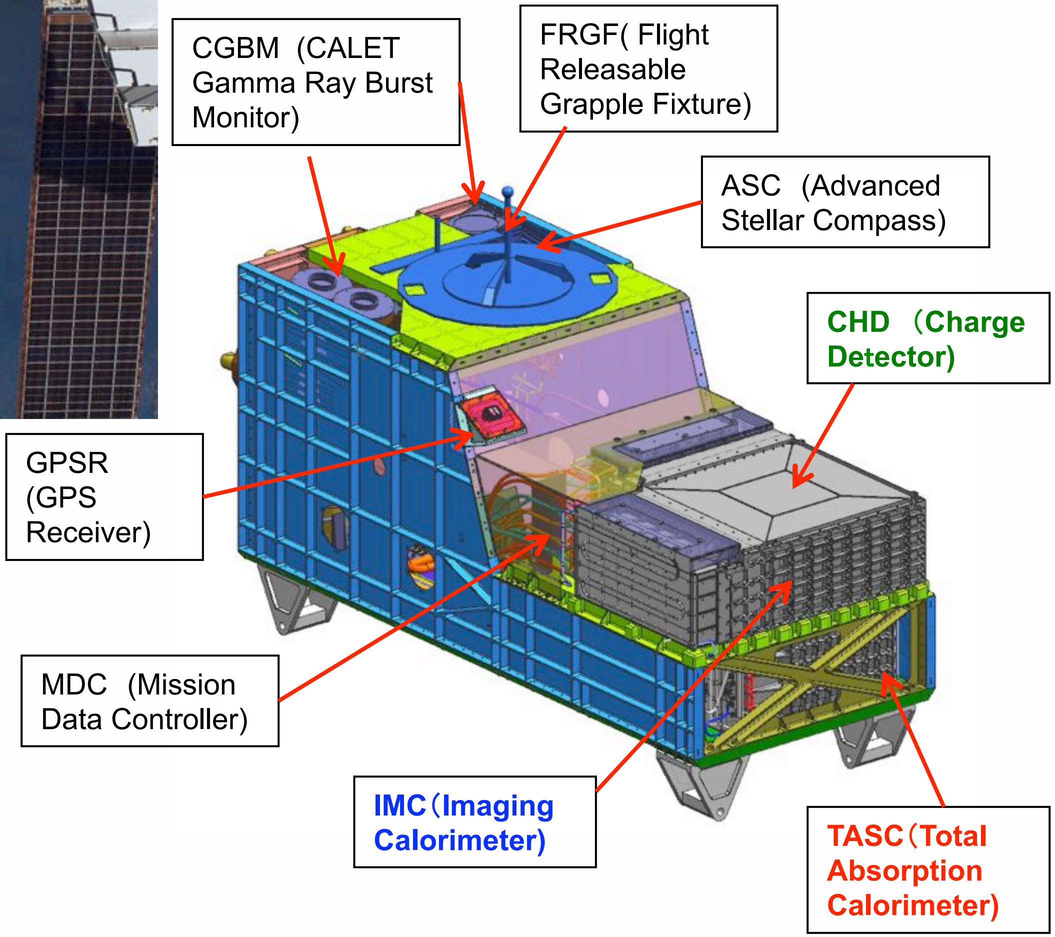
ITALY
University of Siena
University of Florence & IFAC (CNR)
University of Pisa
University of Padova
University of Roma Tor Vergata

USA
NASA/GSFC
Louisiana State University
Washington University in St Louis
University of Denver

CALET Payload



- Launch carrier : HTV-5
- Payload will be attached to JEM-EF
- Launch date: JFY 2014



- Mission period: > 2 years (5 years target)
- Mass 650 kg (max)
- JEM/EF standard payload size
- Power 650 W (Nominal)
- Data rate: Medium (Low) 600 (35) kbps

CALET science objectives

Science Objectives	Observation Targets	Energy range
Nearby CR sources	Electron spectrum	1 GeV – 10 TeV
Dark Matter	Signatures in e/γ spectra	10 GeV – 10 TeV
CR Origin and Acceleration	p-Fe individual spectra	10 GeV – 10^3 TeV
	Ultra Heavy Ions ($26<Z\leq40$)	few GeV/amu
Galactic CR Propagation	B/C sub-Fe/Fe ratios	Up to some TeV/n
Solar Physics	Electron flux	< 10 GeV
Gamma-ray Transients	Gamma and X-rays	3 keV – 30 MeV

CALET instrument

CHarge Detector (CHD)
(Charge Measurement in Z = 1 - 40)

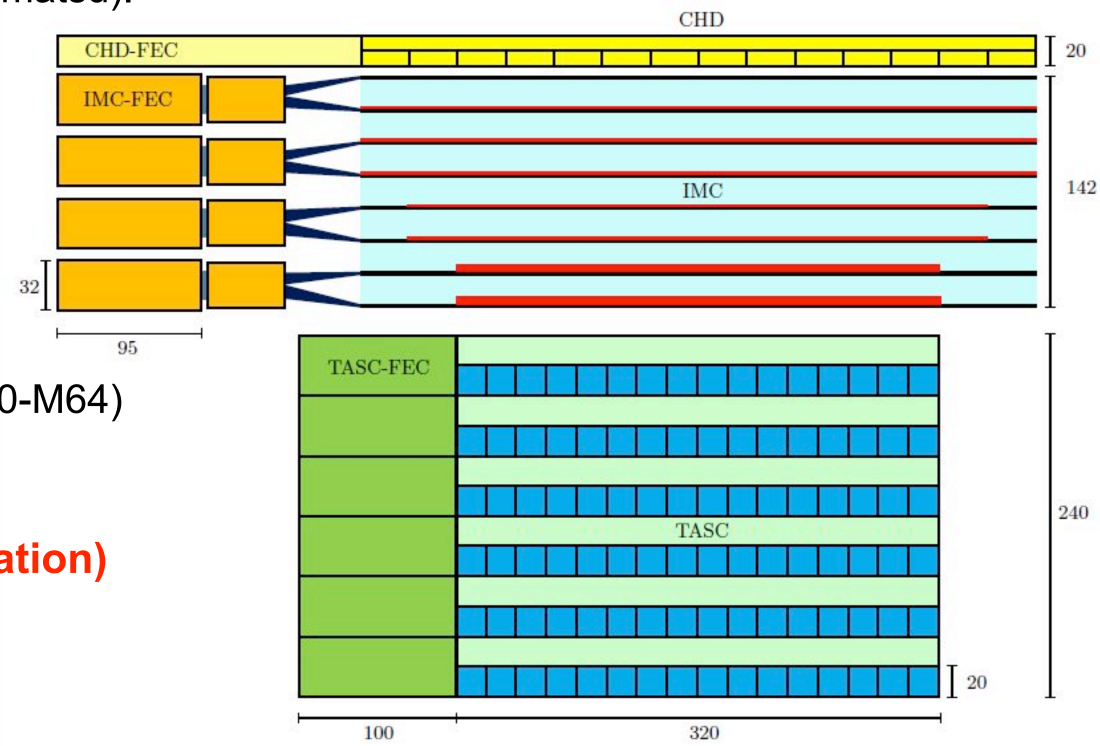
- **2 layers each made of 14 Plastic Scintillator Paddles EJ204**
- Paddle size 45 x 3.2 x 1 cm^3
- Layers orthogonally arranged
- Readout by PMTs (R7400-06 type, Hamamatsu).

Field of view: ~ 45 degrees (from the zenith)

Geometrical Factor: 0.12 m^2sr

IMaging Calorimeter (IMC)
(Tracking, Particle ID)

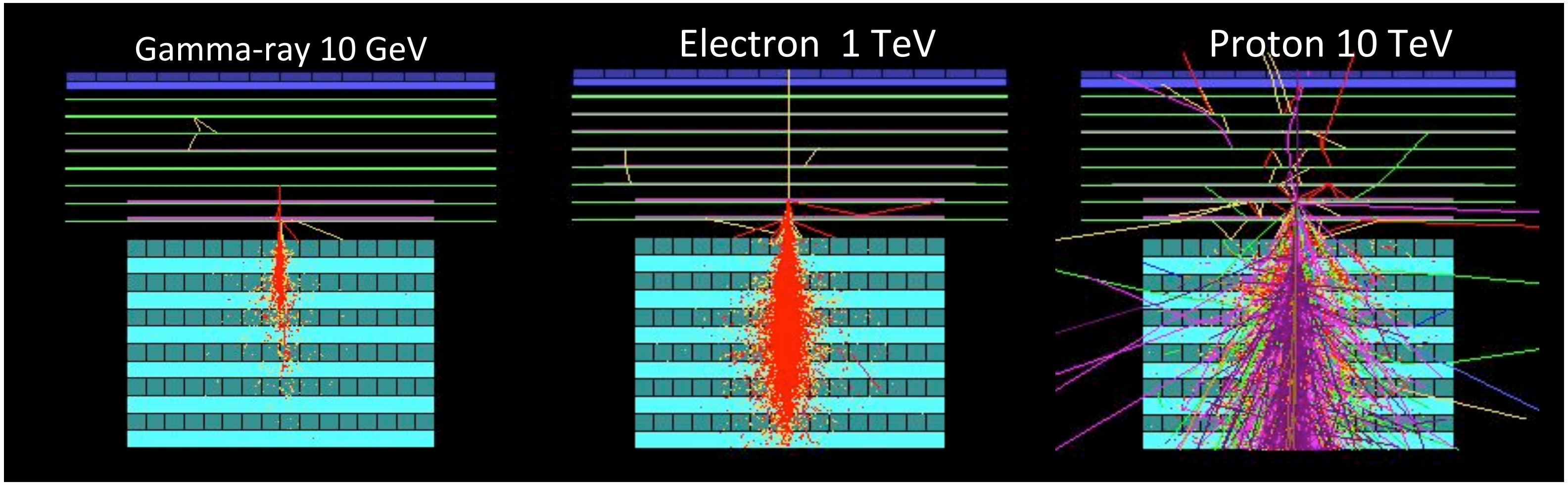
- **7 Tungsten plates total thickness: 3 X_0 , 0.11 λ_I**
- **8 Layers x 2 (X,Y) of 448 SciFi**
- SciFi size: 44.8 x 0.1 x 0.1 cm^3
- Readout MAPMTs (Hamamatsu R5900-00-M64)

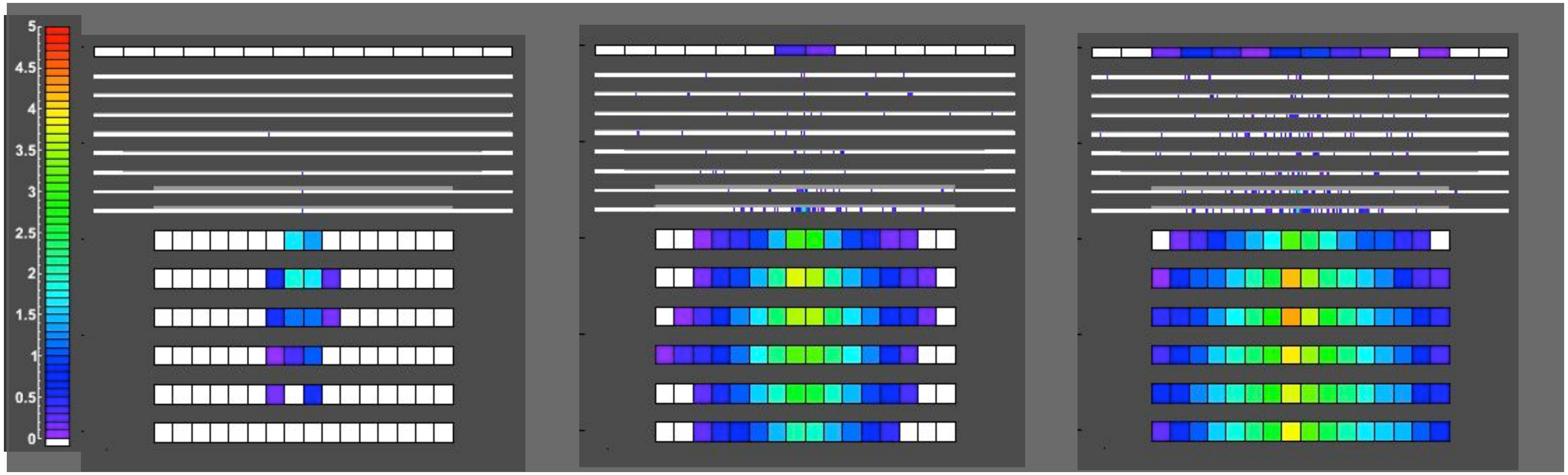


Total AbSorption Calorimeter (TASC)
(Energy Measurement, e/p discrimination)

- **12 layers each made of 16 PWO logs**
- Each log size 32.6 x 1.9 x 2.0 cm^3
- Layers orthogonally oriented;
- **Total depth of PWO: 24 cm (27 X_0 , 1.23 λ_I)**
- Readout system based on PMTs (layer 0) for trigger and Dual APD/PD (layers 1-11).

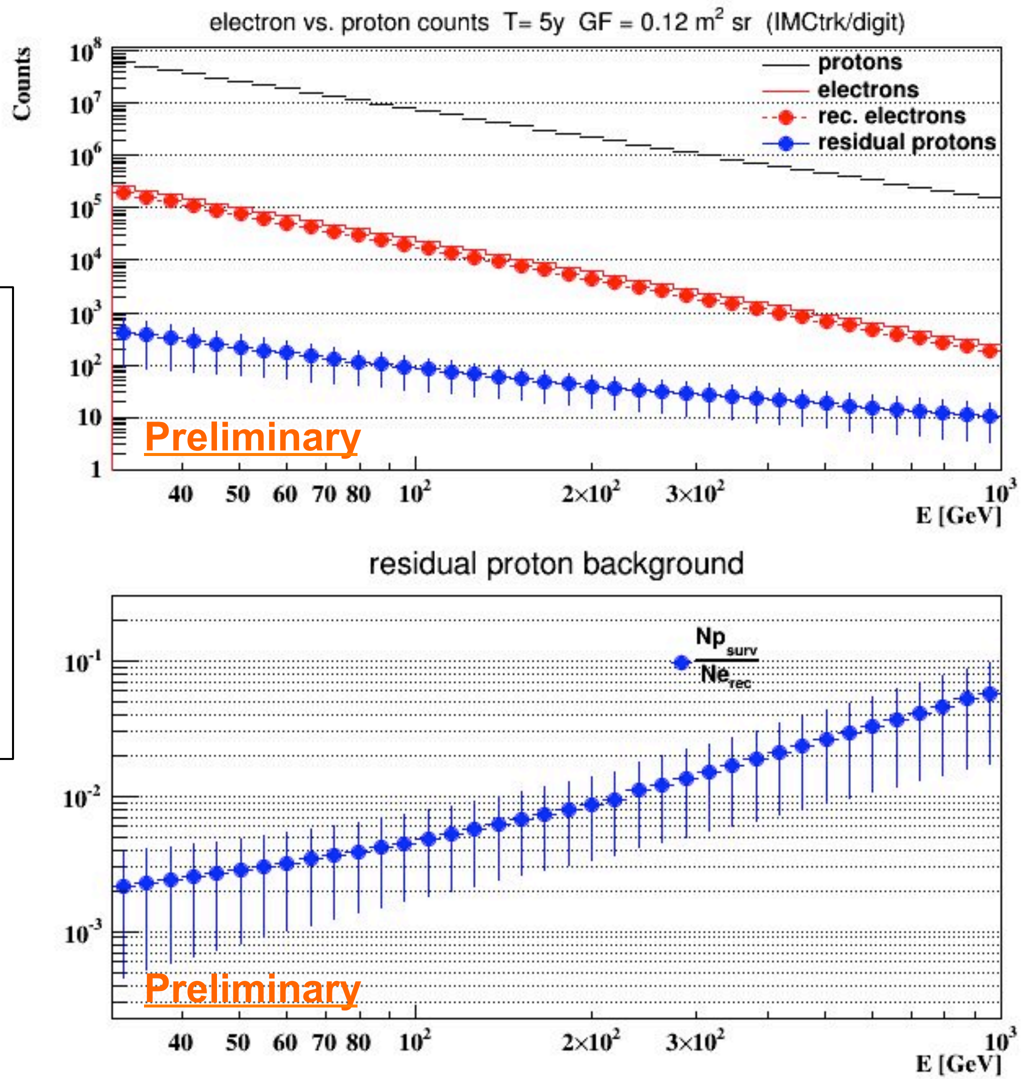
CALET Imaging capabilities





Proton rejection power >10^5 can be achieved by shower imaging with IMC/TASC

Residual proton background



Proton spectrum: broken-power law (PAMELA)
$E^{-2.79}$ @ E<235 GeV
$E^{-2.68}$ @ E>235 GeV

Electron spectrum
$E^{-3.04}$ (Fermi)
with no nearby source

Expected electrons ~200 between 0.9-1 TeV

Residual protons

Residual proton bkg ~6% @ 1 TeV

CALET will explore the electron spectrum around 1 TeV with low background and high energy resolution (2%) to search for possible spectral features of astrophysical origin or from Dark Matter annihilation/decay.

CR electrons in TeV region

- **>1 TeV electron astrophysical sources: $T<10^5$ years (young) Distance < 1 kpc (nearby)**
  Few known SNRs candidates (Monogem, Vela, Cygnus Loop..)
  Signatures in the electron spectrum: spectral features and anisotropy
- **electrons from DM annihilation/decay**

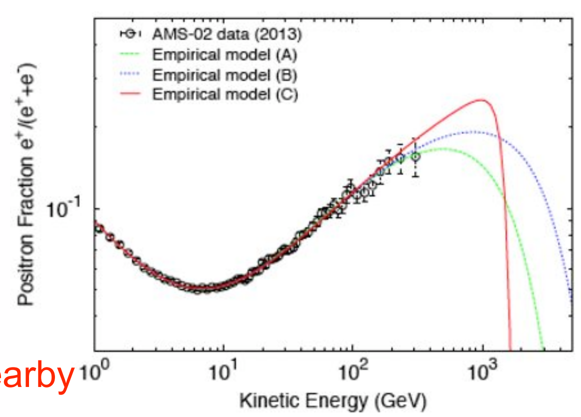
Empirical models fitting the positron fraction and e^-+e^+ spectrum

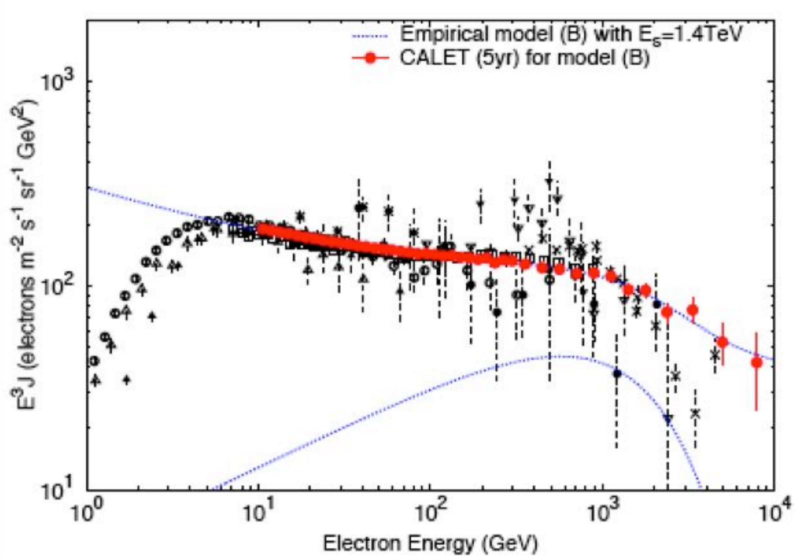
$$\Phi_{e^-} = C_{e^-}E^{-\gamma_{e^-}} + C_s E^{-\gamma_s} e^{-(E/E_s)^\alpha}$$

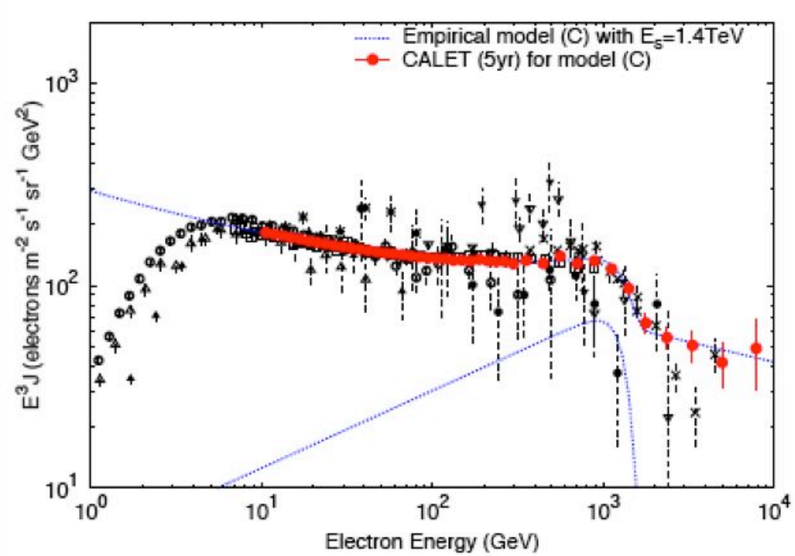
$$\Phi_{e^+} = C_{e^+}E^{-\gamma_{e^+}} + C_s E^{-\gamma_s} e^{-(E/E_s)^\alpha}$$

Power-law diffuse e^- and secondary e^+ fluxes

Common source spectrum from nearby SNR or DM.

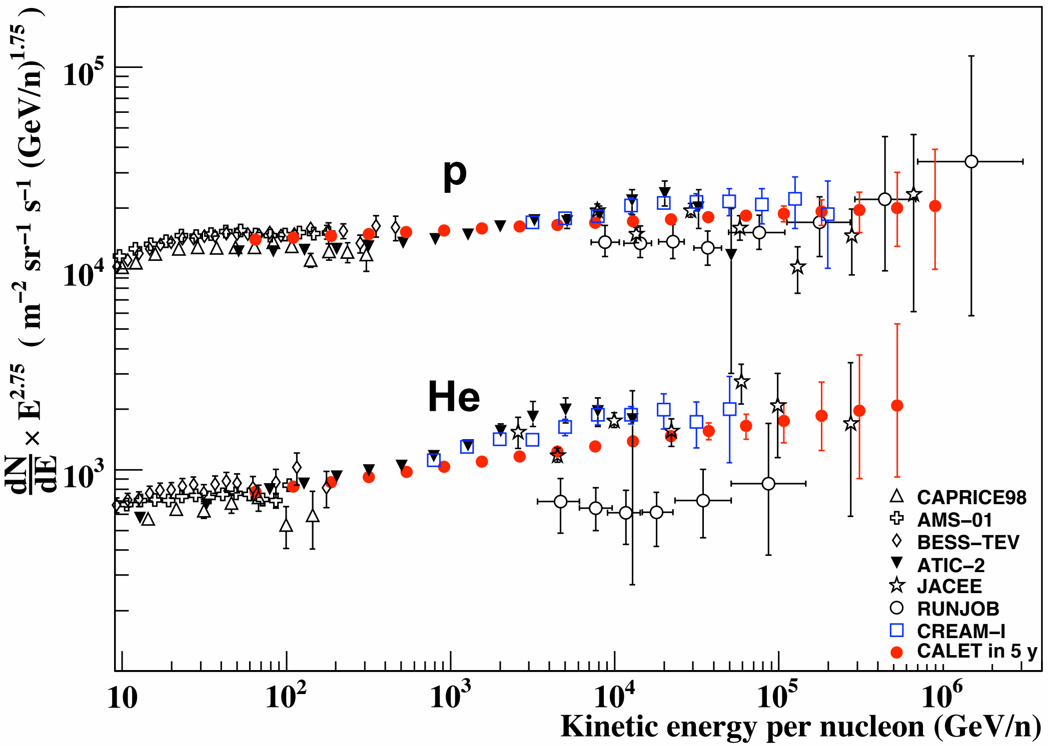






Proton and helium spectra

- p and He spectra at TeV are harder than the low-energy spectra and have different slopes in the multi TeV region (CREAM)
- Hardening in the p and He at 200 GV observed by PAMELA
  - ➔Hint of concavity due to CR interactions with the shock?
  - ➔Cutoff in the p spectrum (proton knee) ?
  - ➔Different types of sources or acceleration mechanisms?
- However AMS-02 did not observe any break or spectral features



Requirements for a space calorimeter to measure the energy of CR nuclei

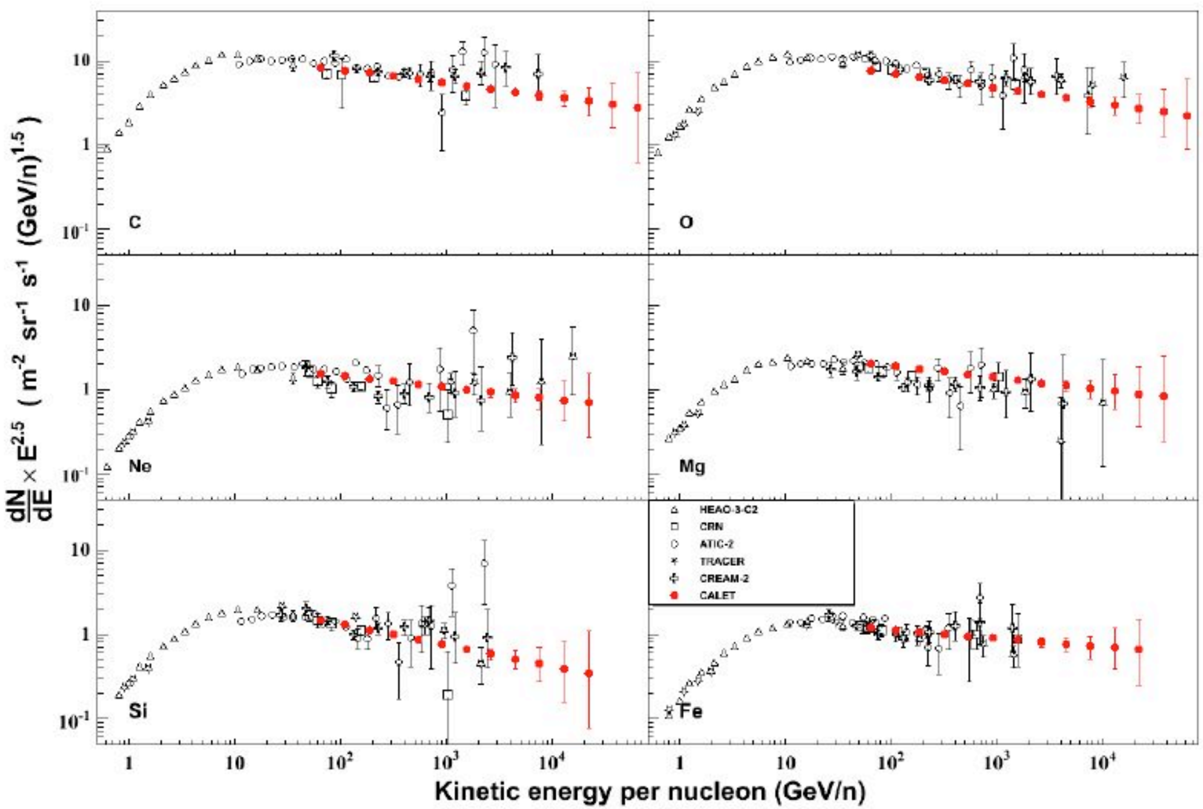
- $> 0.5\ \lambda$ to force inelastic interaction
- $> 20\ X_0$ to contain the e.m. core of the hadronic showers at 100 TeV scale

CALET expectations:

- more accurate data at >100 TeV
- data covering the energy range from tens GeV to >100 TeV
- energy reach in 5 years
  900 TeV for proton
  400 TeV for He

CR nuclei

- 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)
  - ➔ Possible features (concave spectrum) or spectral breaks?

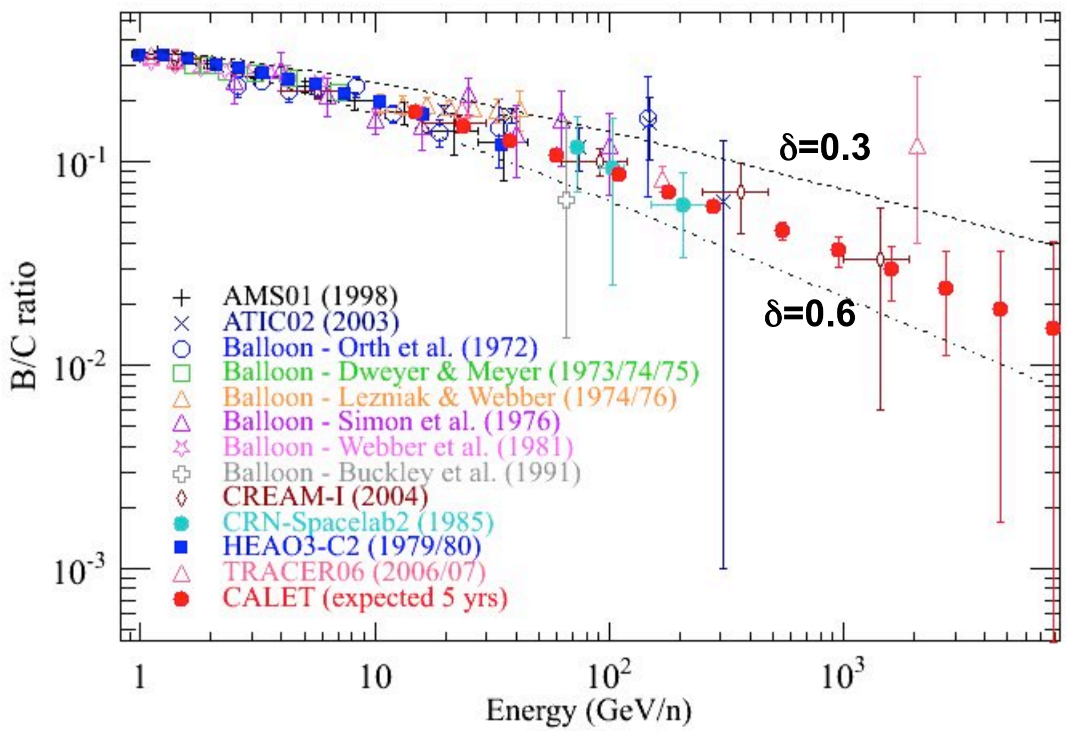


CALET energy resolution for nuclei 30÷40% independent on energy

CALET energy reach in 5 yr
~20 TeV/n C,O, Ne, Mg, Si
~10 TeV/n Fe

B/C abundance ratio

- At high energy (> 10 GeV/n) the B/C ratio measures the energy dependence of the escape path-length $\lambda \sim E^{-\delta}$ 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)
- Balloon experiments CREAM and TRACER measured the B/C ratio up to ~1 TeV/n
  But: - large statistical error (limited exposure)
  - large systematic errors due to corrections for B produced by interaction of of heavier nuclei with atmosphere



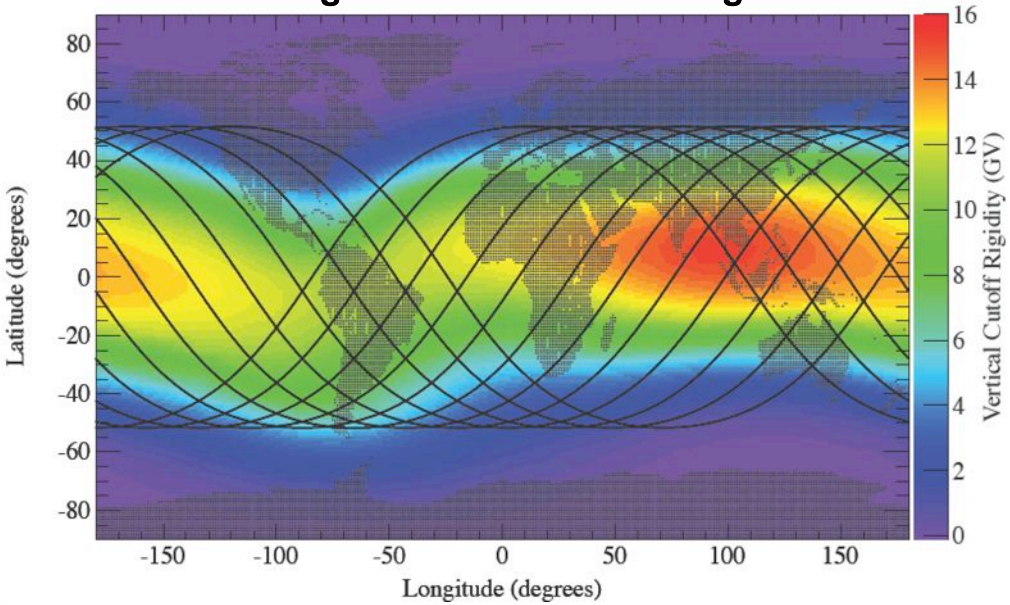
CALET can measure in 5 years the B/C ratio up to 5-6 TeV/n.

CALET measurements in orbit free from atmospheric production of boron.

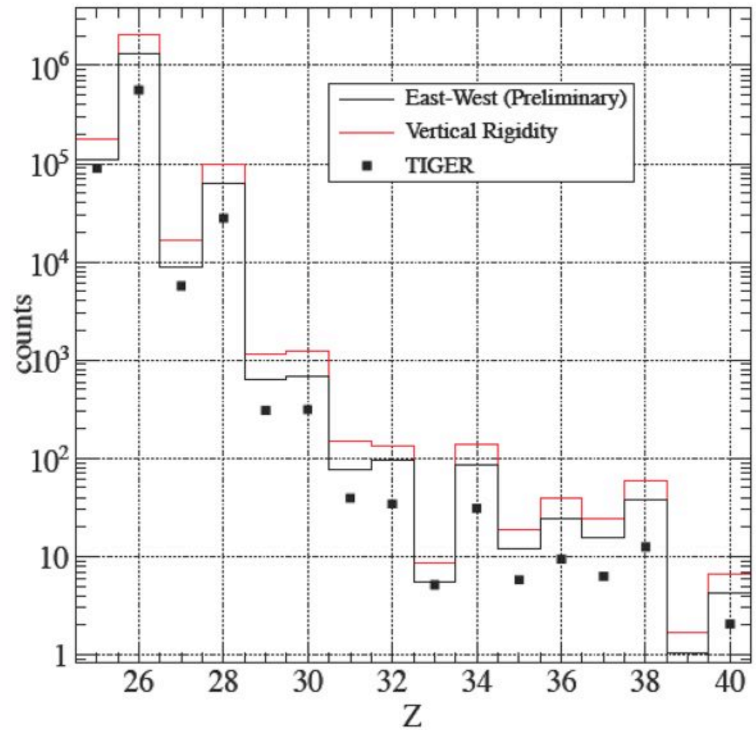
CALET can also measure the sub-Fe over Fe abundance ratio.

Ultra heavy nuclei

Geomagnetic Vertical cutoff rigidities



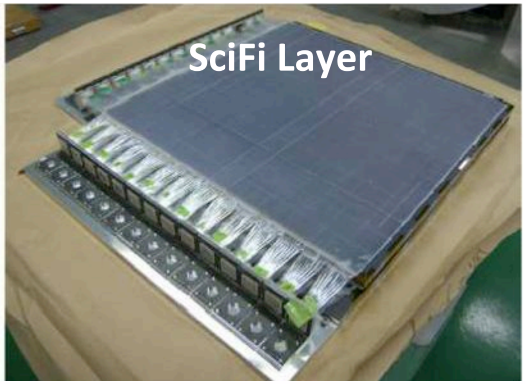
CALET (expected) vs. TIGER data



- 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 in scintillator
- 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 2-4 times the statistics of TIGER, w/o corrections for residual atmosphere overburden.

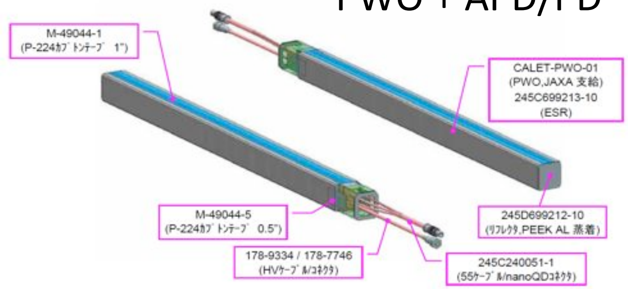
Hardware development: Structure and Thermal Model (STM)

IMC

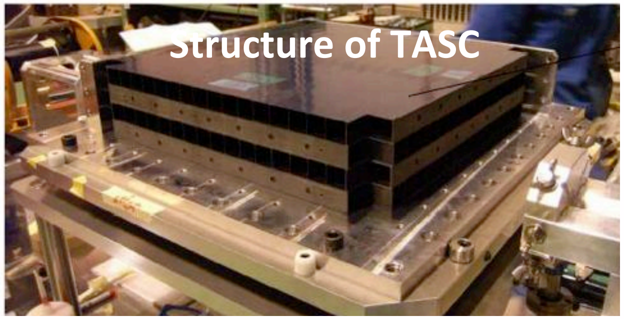


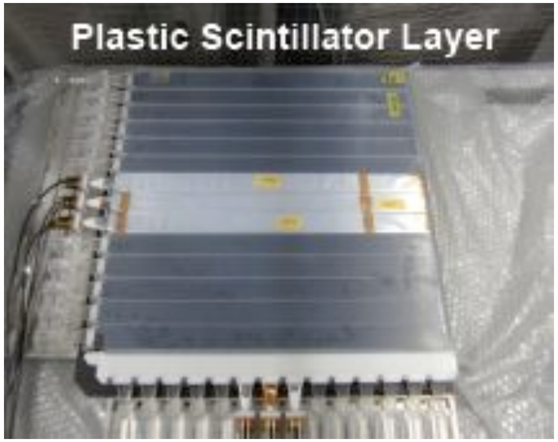
TASC

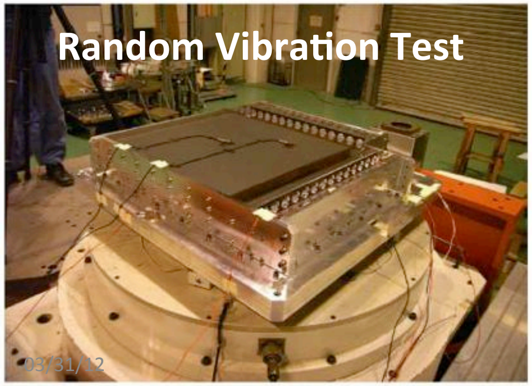
PWO + APD/PD



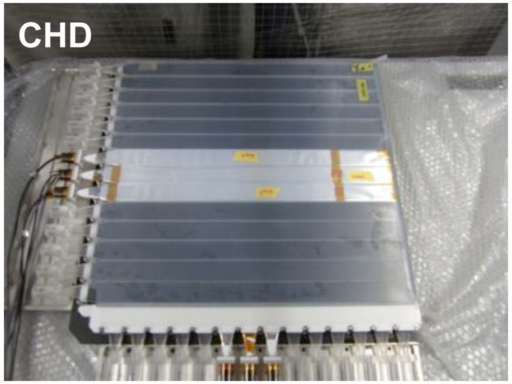
CHD

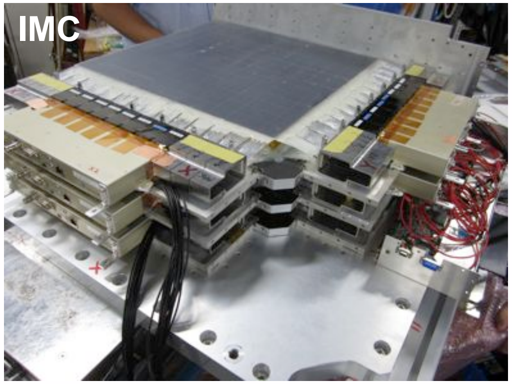


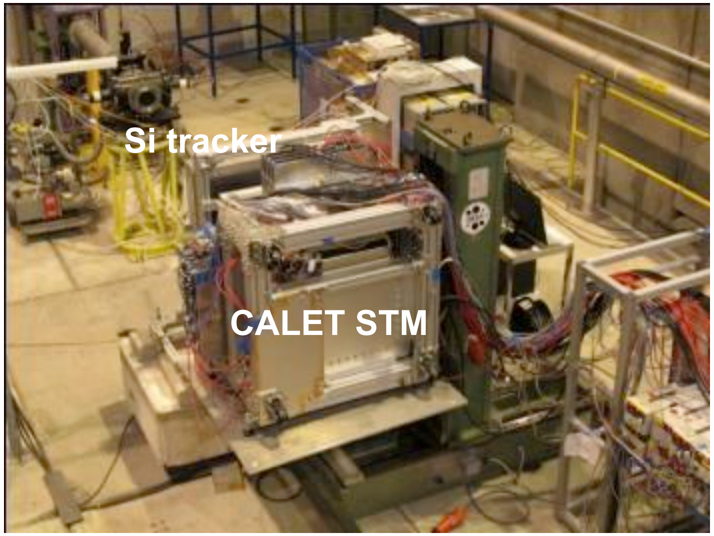


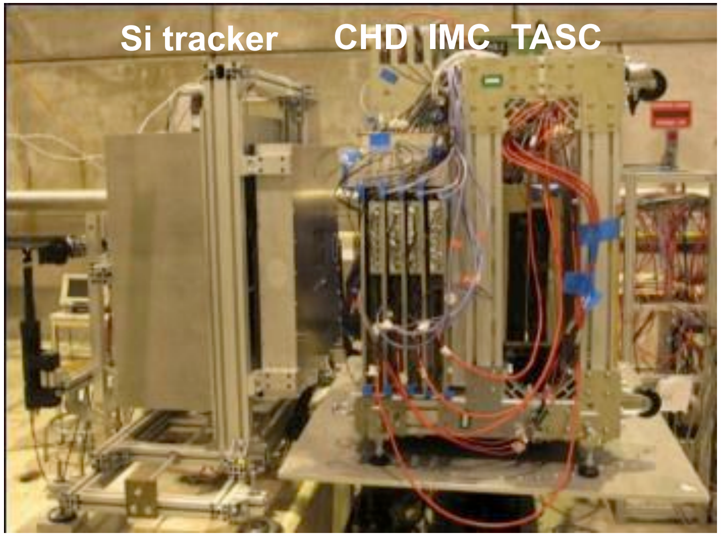


CERN beam test with CALET STM









- **SPS beams:**

  μ 150 GeV/c

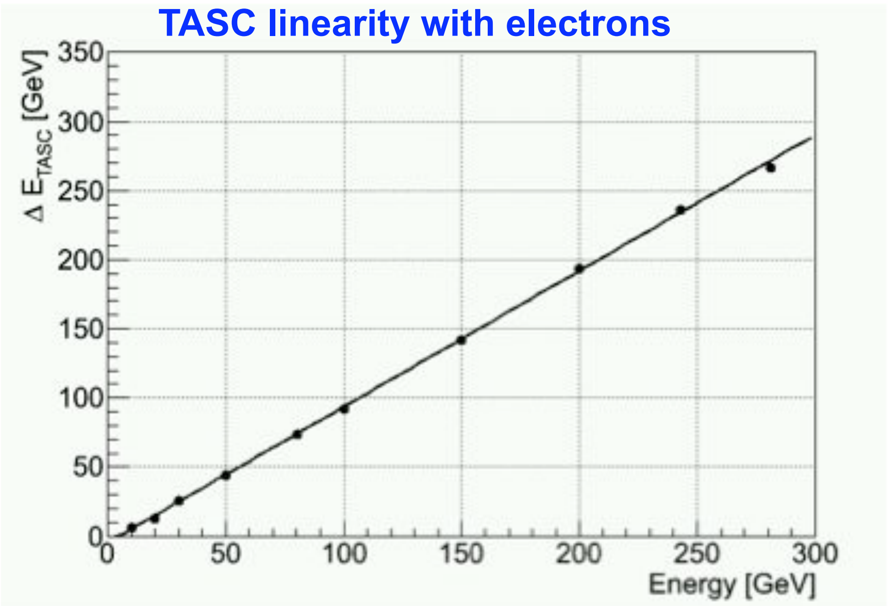
  e 10, 20, 30, 50, 80, 100, 150, 200, 250, 290 GeV/c

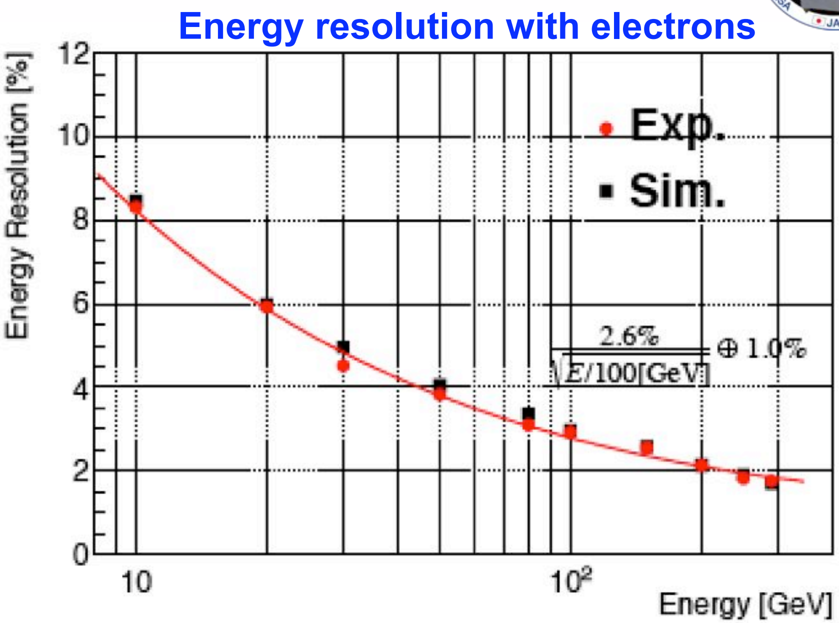
  p 30, 100, 400 GeV/c

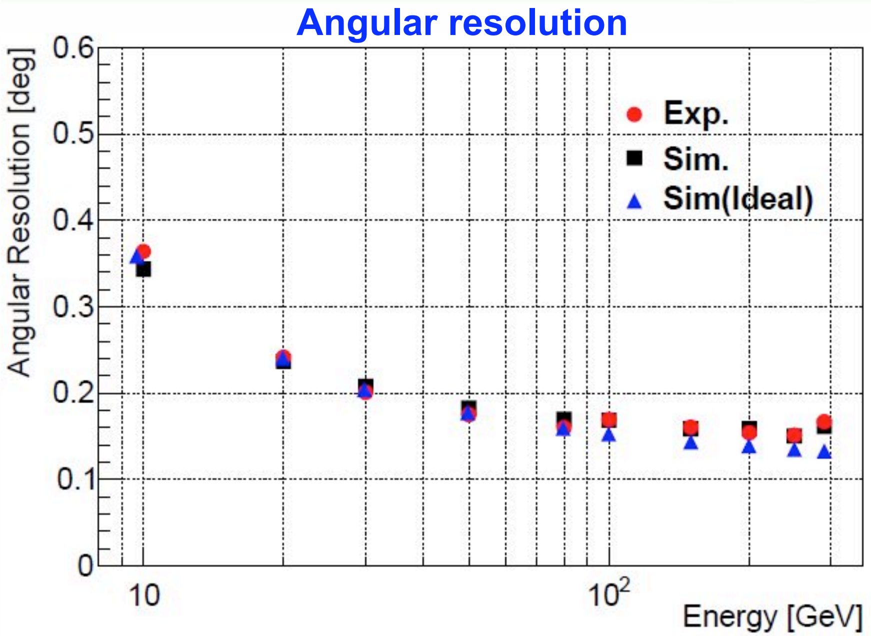
  Ion fragments (A/Z=2) from a primary Pb beam @ 30(13) GeV/n on Be target

- **Charge tagging by a dedicated Si tracker**

Beam test results

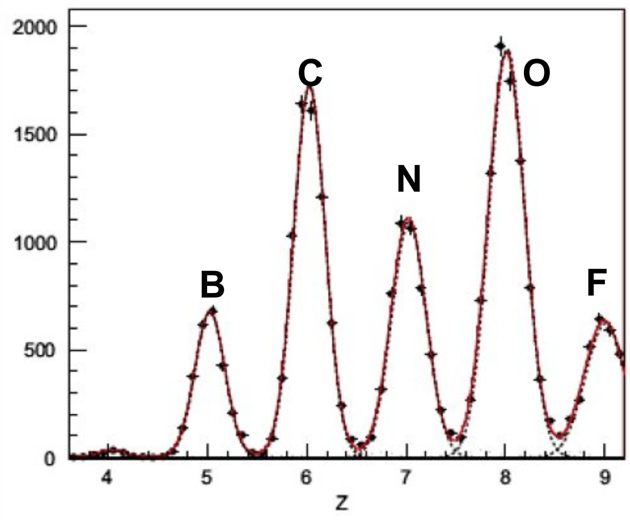


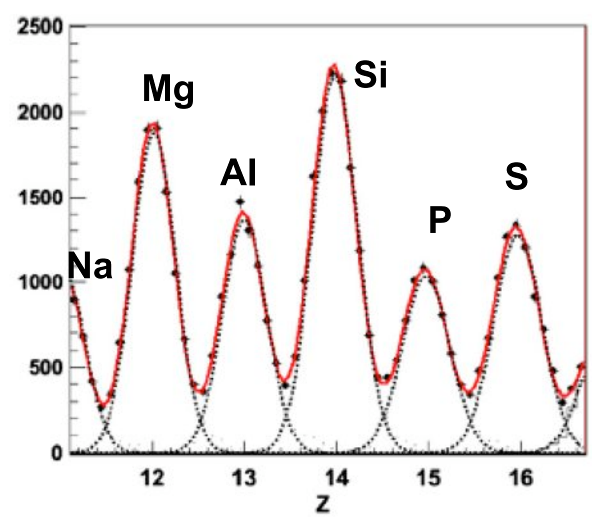


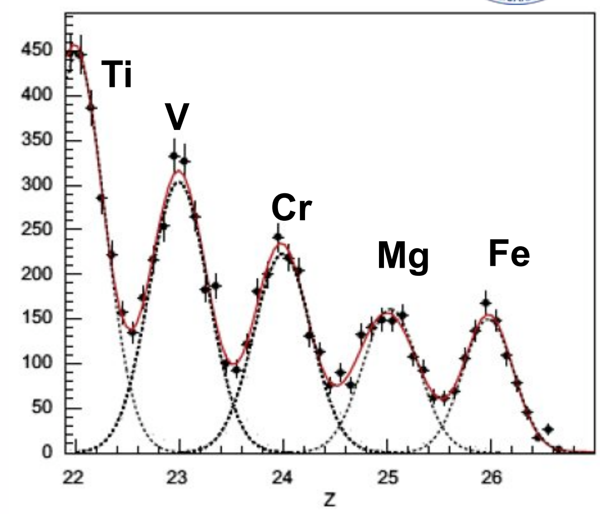


- Perfect linearity of TASC up to 290 GeV/c
- Energy resolution ~2% @ E>200 GeV/c
- Angular resolution ~0.15° @ E>100 GeV/c

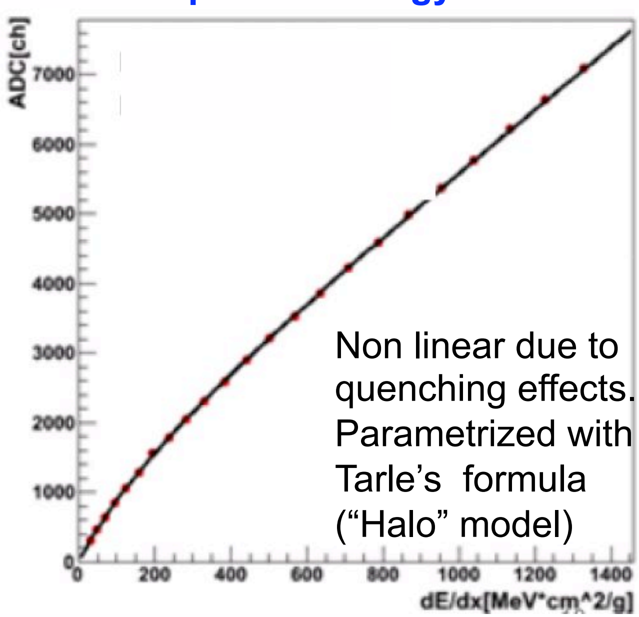
CHD performance





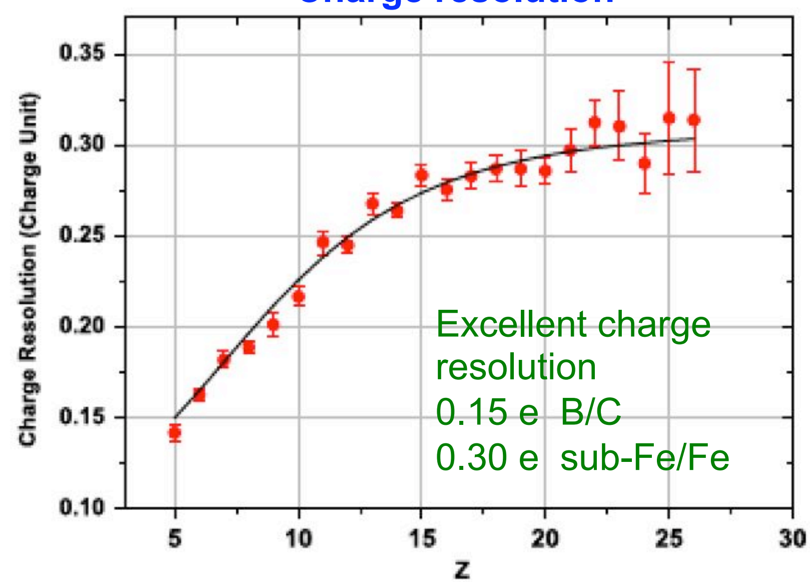


Deposited energy vs Z^2



Non linear due to quenching effects. Parametrized with Tarle's formula ("Halo" model)

Charge resolution



Excellent charge resolution
0.15 e B/C
0.30 e sub-Fe/Fe

Summary

CALET is a space-based deep (30 X_0) calorimeter designed to perform cosmic ray measurement with high energy resolution, mainly aimed at the electron component.

CALET is characterized by excellent energy resolution, excellent charge identification, 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.

Integration and test of the flight module are now underway in Tsukuba Space Center.

The CALET project has been approved for flight by HTV-5 to the Japanese Experiment Module (Kibo), to be launched by JFY 2014.

The expected mission time is 2 (approved) to 5 (possible) years.

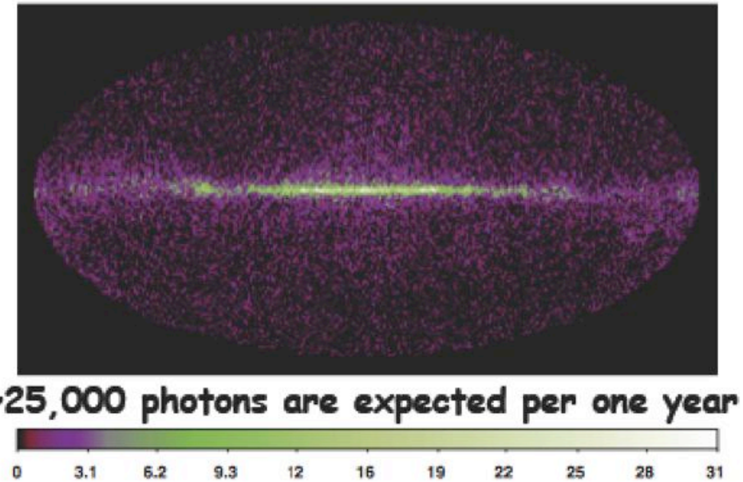
BACKUP SLIDES

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 x 10^{-9} $cm^{-2}s^{-1}$
Observation Period (planned)	2014-2019 (5 years)

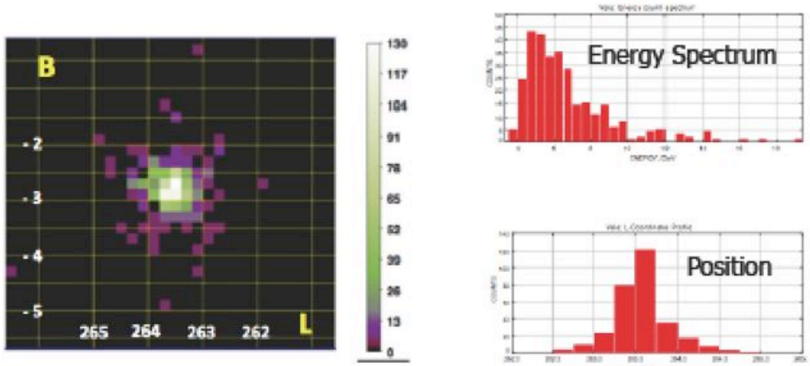
Simulation of Galactic Diffuse Radiation



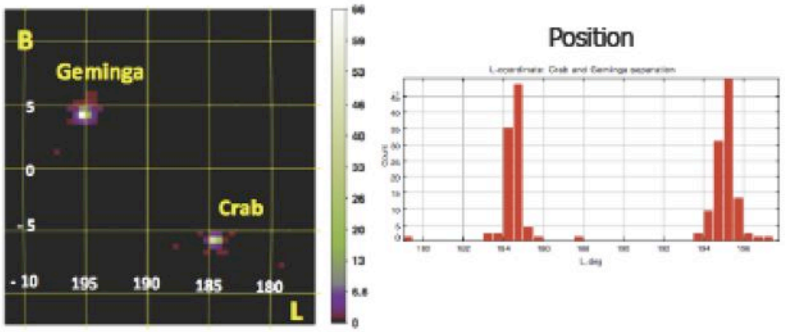
~25,000 photons are expected per one year

*) ~7,000 photons 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

CALET GRB performance

Broad energy range (from few keV X-rays to GeV-TeV gamma-rays):
long-duration GRBs, short-duration GRBs, X-ray flashes and GeV GRBs.
Sensitivity of CGBM: ~10^{-8} ergs cm^{-2} s^{-1} (1-1000 keV) for 50 s long bursts.

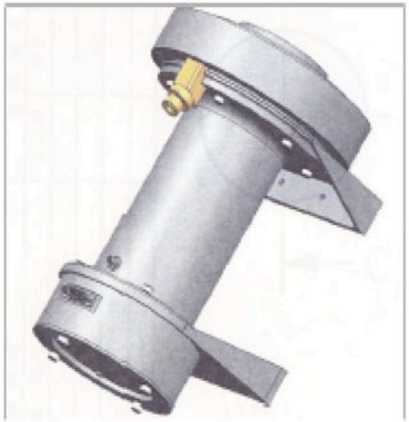
Parameters	CAL	CGBM
Energy range	1 GeV - 10 TeV (GRB trigger)	HXM: 7 keV - 1 MeV (goal 3 keV - 3 MeV) SGM: 100 keV - 20 MeV (goal 30 keV - 30 MeV)
Energy resolution	3% (10 GeV)	HXM: ~3% (662 keV) SGM: ~15% (662 keV)
Effective area	~600 cm^2 (10 GeV)	68 cm^2 (2 HXMs), 82 cm^2 (SGM)
Angular resolution	2.5° (1 GeV) 0.35° (10 GeV)	-
Field of view	~45° (~2 sr)	~3 sr (HXM), ~4π sr (SGM)
Dead time	2 ms	40 μs
Time resolution	62.5 μs	GRB trigger: 62.5 μs (event-by-event data) Normal mode: 125 ms with 8 ch, 4 s with 512 ch (histogram data)

Chracteristics of HXM and SGM in CGBM

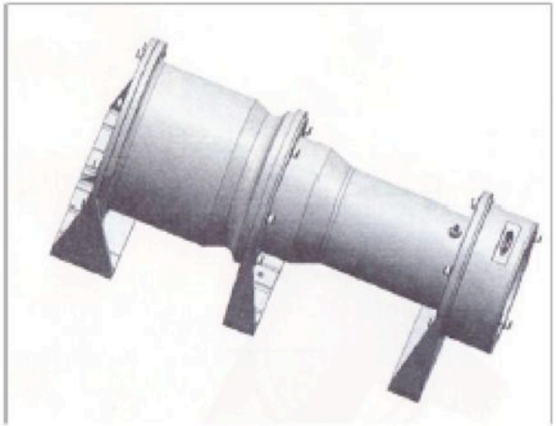
	HXM	SGM
Detector (Crystal)	$LaBr_3(Ce)$	BGO
Number of Detector	2	1
Diameter (mm)	66(front), 79(rear)	102
Thickness(mm)	12.7	76
Geometrical Area (cm^2)	68(front),97(rear)*	82
Energy Range (keV)	7–1000	100–20000
Energy Resolution@662 keV	~4%	~15%
Field of View (FOV)	$\sim \pi$ str.	$\sim 4\pi$ str.

∗ two detectors are combined.

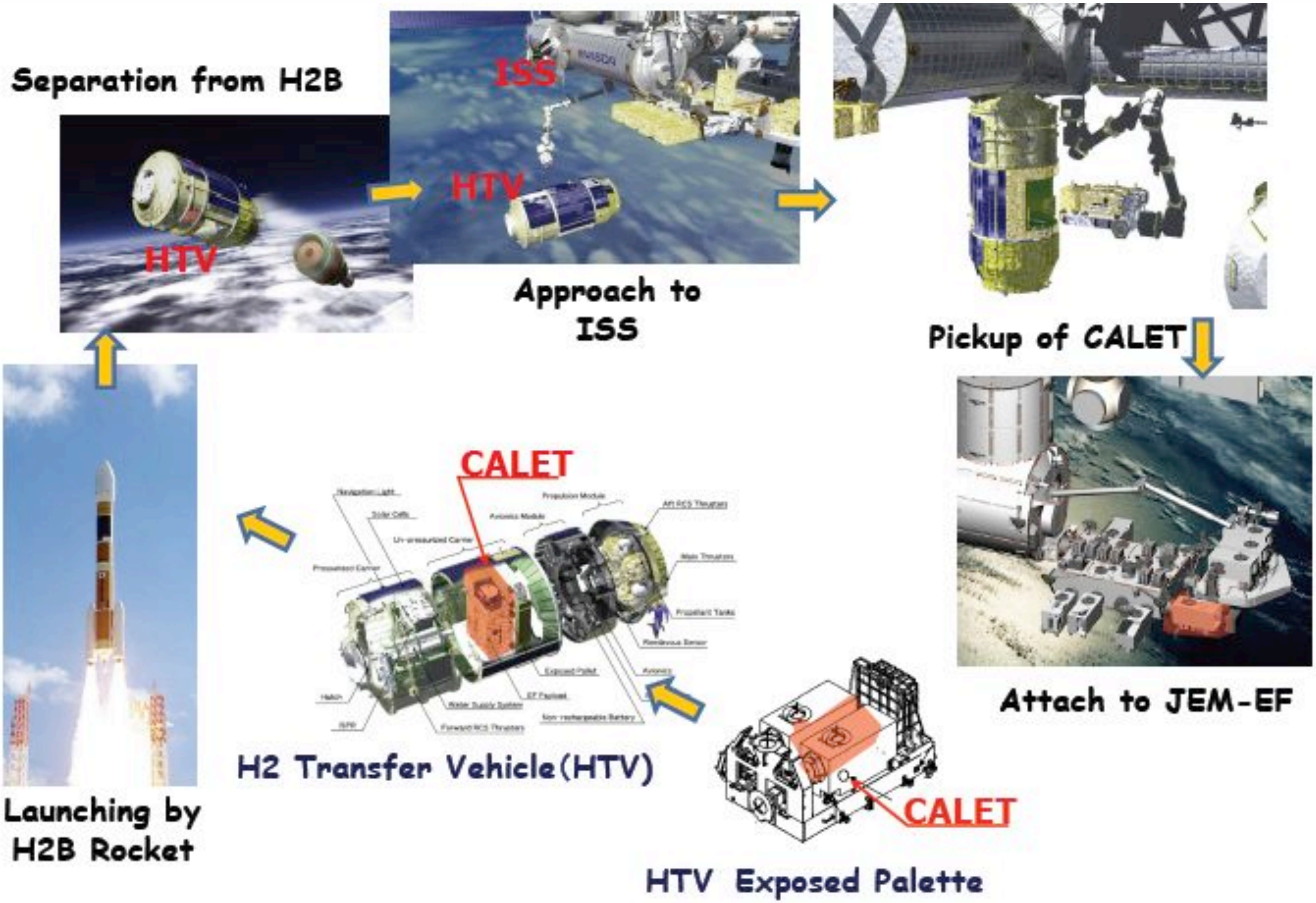
HXM



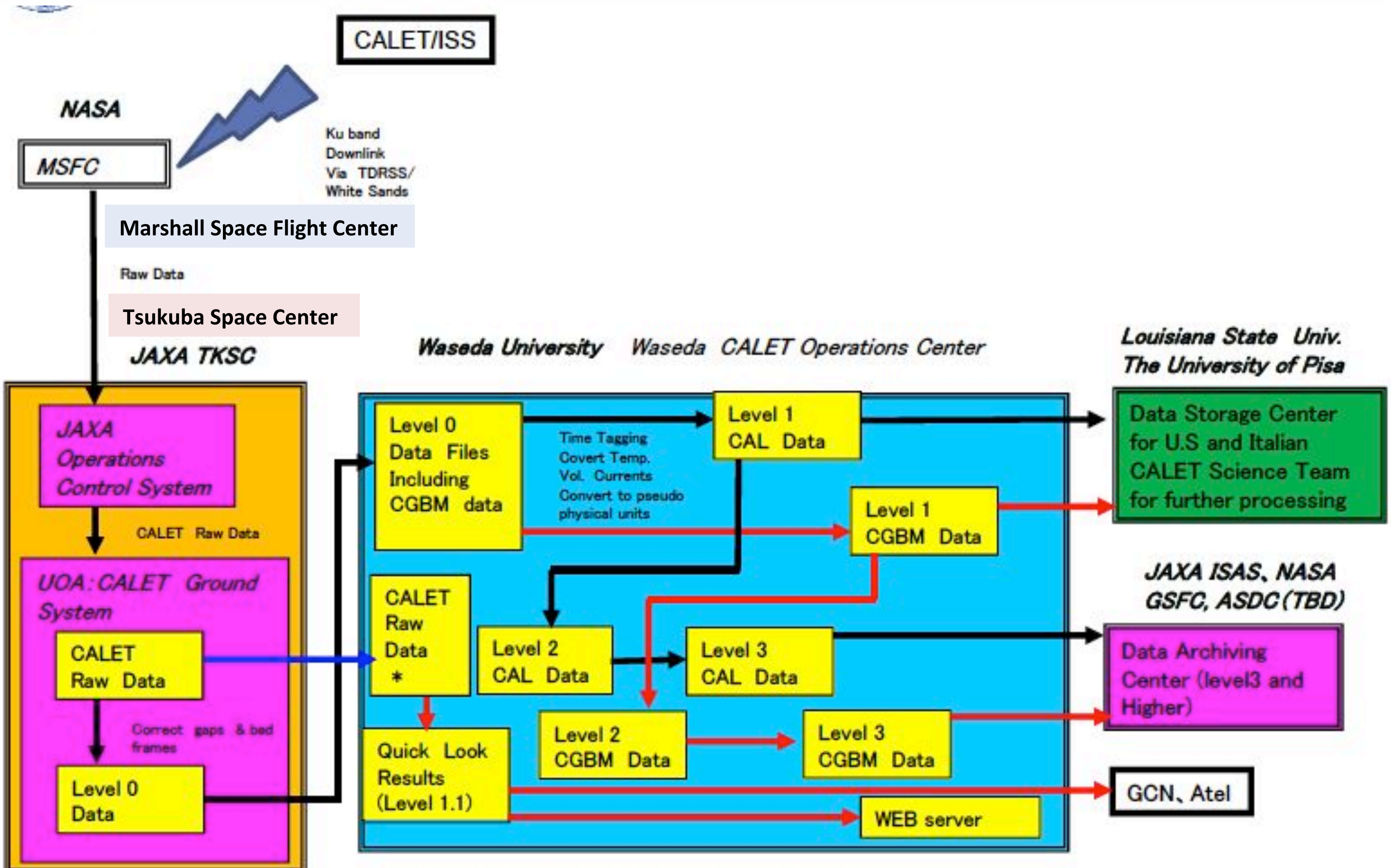
SGM



CALET launching procedure

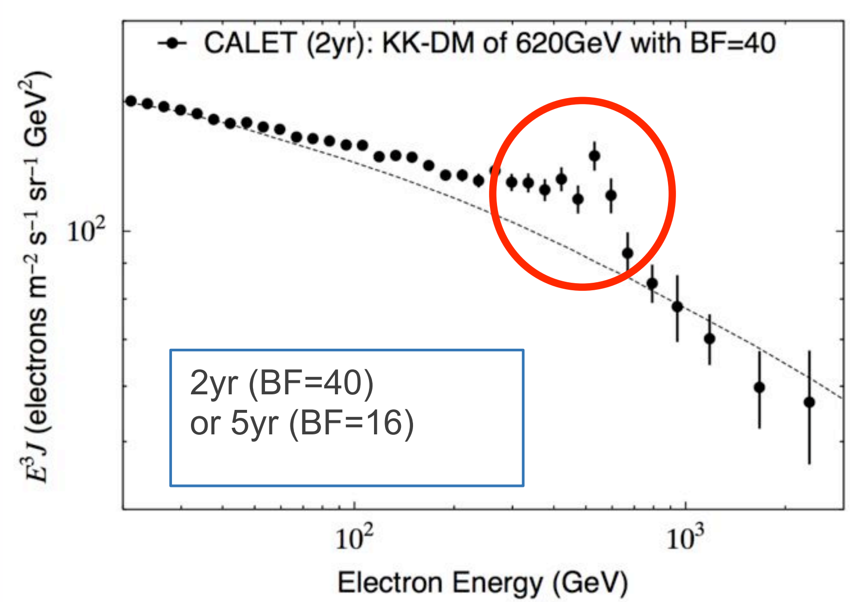


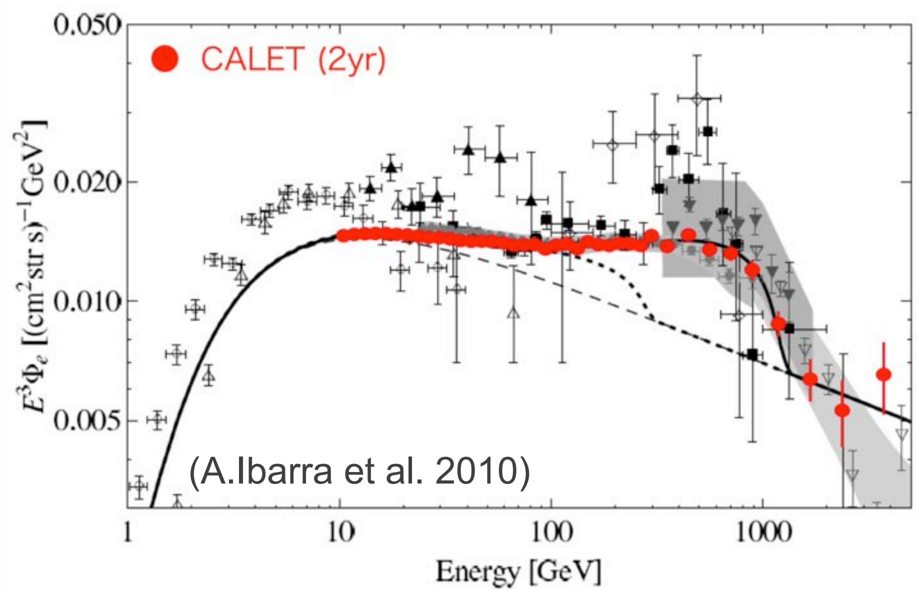
CALET Science Data Flow



Note: Level 0 data can be accessed by persons who contribute CAL FM/CGBM hardware production and calibration work in the CALET Science team
* Raw data will be provided based on the agreement between JAXA/Waseda Univ.

Indirect dark matter search by electrons



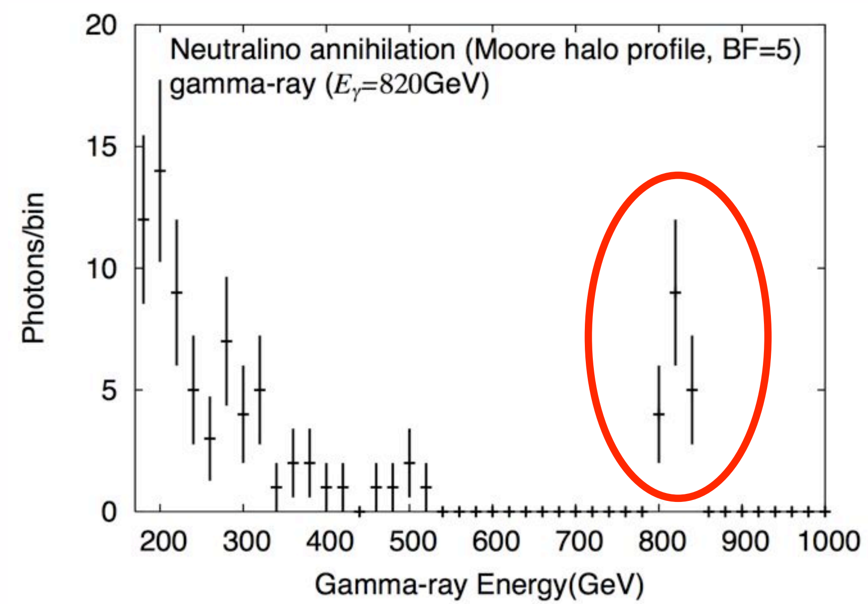


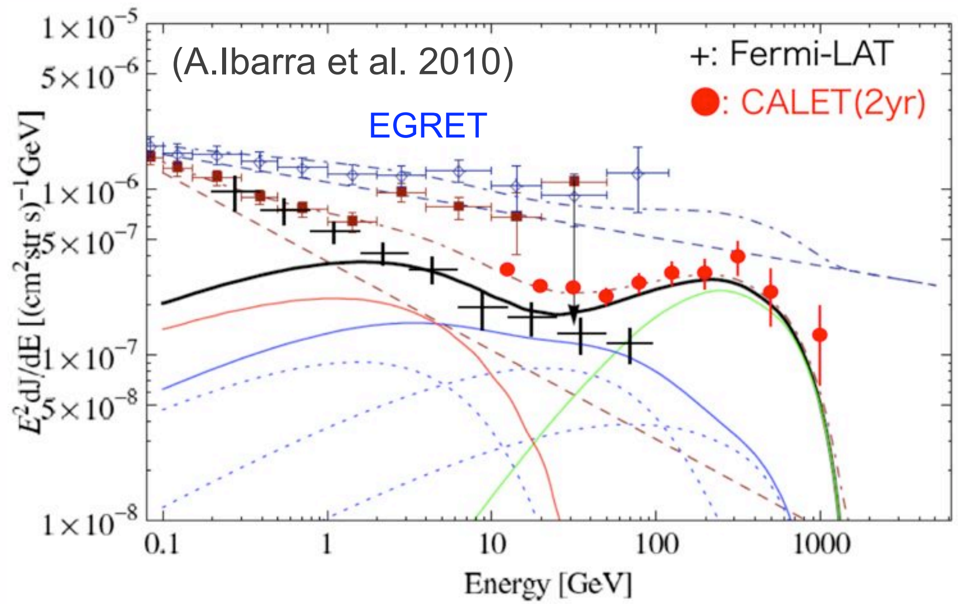
Simulated e^++e^- spectrum for 2yr from Kaluza-Klein dark matter annihilations with m=620GeV and BF=40

Simulated e^++e^- spectrum for 2yr from decaying dark matter for a decay channel of D.M.-> $l^+l^-\nu$ with m=2.5TeV and τ = 2.1x10^{26}s

=> CALET has a potential to detect electron + positron signals from dark matter annihilation/decay

Indirect dark matter search by gamma rays





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

Simulated extra-galactic gamma-ray spectrum for 2yr from decaying dark matter for a decay channel of D.M.-> $l^+l^-\nu$ with m=2.5TeV and τ = 2.1x10^{26}s

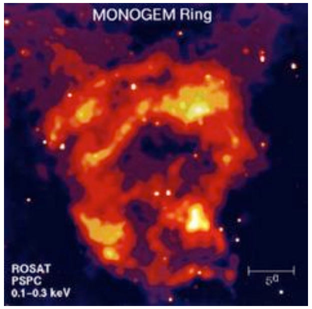
=> CALET has a potential to detect gamma-ray signals from dark matter annihilation/decay with the excellent energy resolution of 2%

Nearby sources of electrons in TeV region

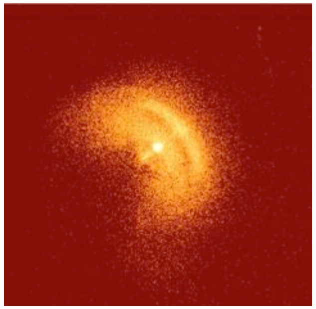
>1 TeV electron sources: **T<10^5 years (young)** **Distance < 1 kpc (nearby)**

Signatures in the electron spectrum: spectral features and anisotropy

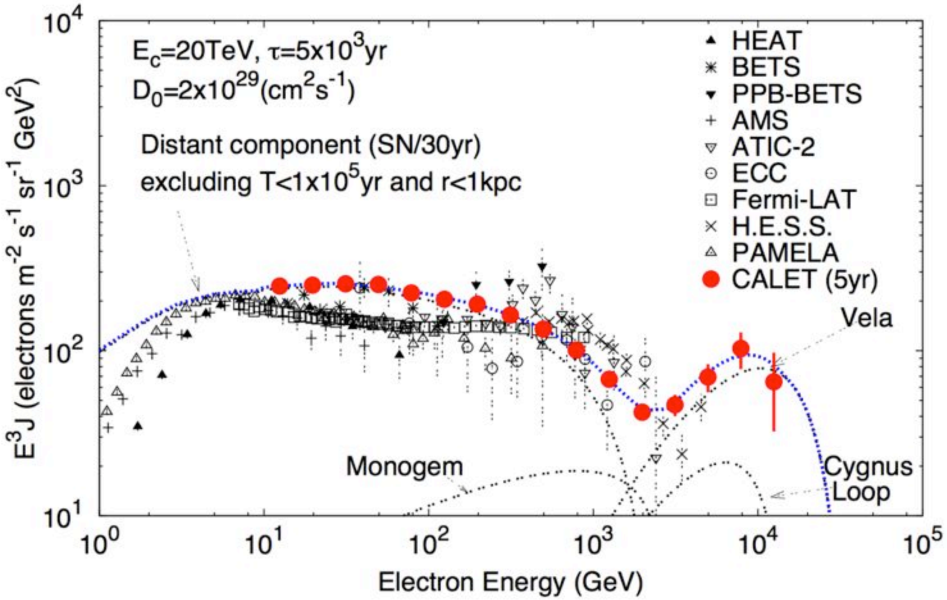
Few know SNR candidates

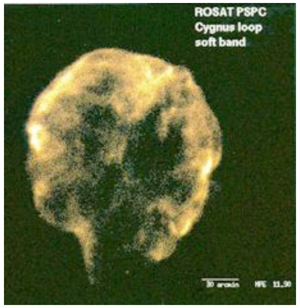


Monogem
8.6×10^4 y
1000 ly



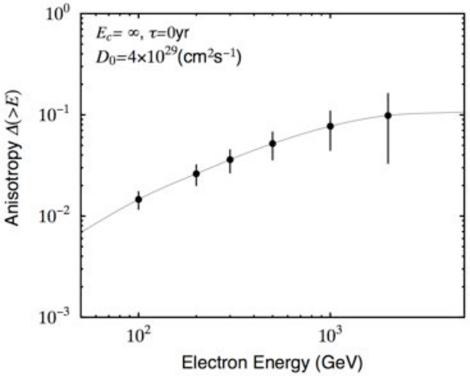
Vela
10^4 y
820 ly





Cygnus Loop
2×10^4 y
2500 ly

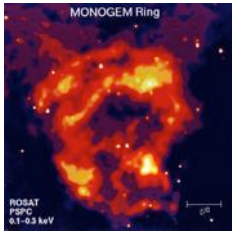
Expected Anisotropy from Vela SNR



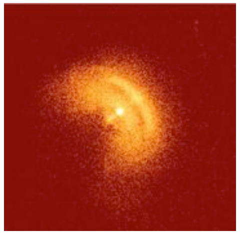
Nearby sources of electrons in TeV region

>1 TeV electron sources: **T<10^5 years (young)** **Distance < 1 kpc (nearby)**
Signatures in the electron spectrum: spectral features and anisotropy

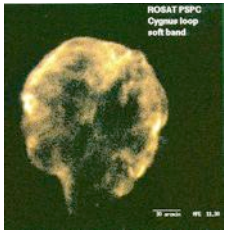
Few known SNR candidates



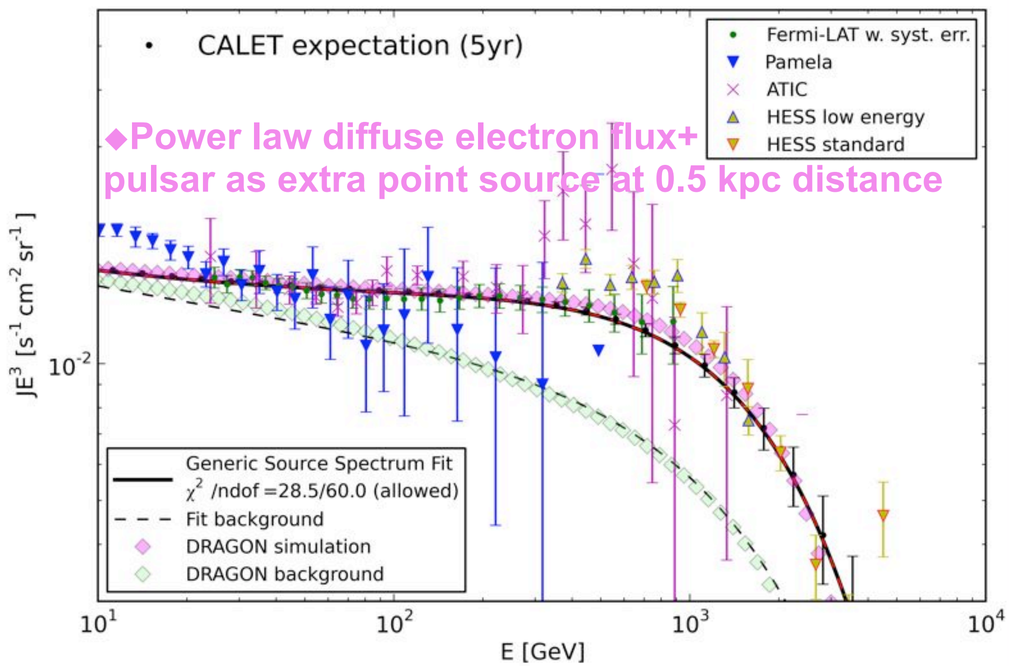
Monogem
8.6×10^4 y
1000 ly



Vela
10^4 y
820 ly



Cygnus Loop
2×10^4 y
2500 ly



Expected Anisotropy from Vela SNR