CALET on the International Space Station

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Vulcano Workshop *May 22-28, 2016*

CALET Collaboration

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17) Nihon University, Japan
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26) University of Padova and INFN, Italy
27) University of Pisa and INFN, Italy
28) University of Rome Tor Vergata and INFN, Italy
29) University of Siena and INFN, Italy
30) The University of Tokyo, Japan
31) Waseda University, Japan
32) Washington University-St. Louis, USA
33) Yokohama National University, Japan

CALET is taking data 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.

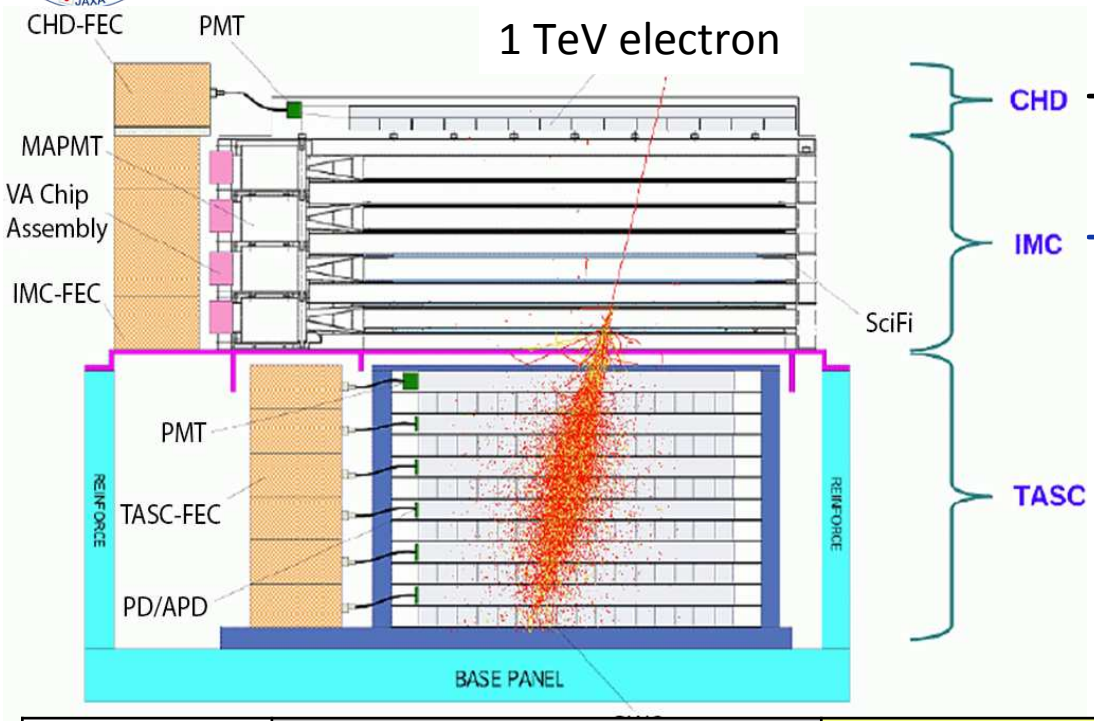
③ **August 24th:**

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.

CALorimetric Electron Telescope (CALET): **INSTRUMENT OVERVIEW**



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

IMC - Imaging Calorimeter (IMC)
(Particle ID, Direction)

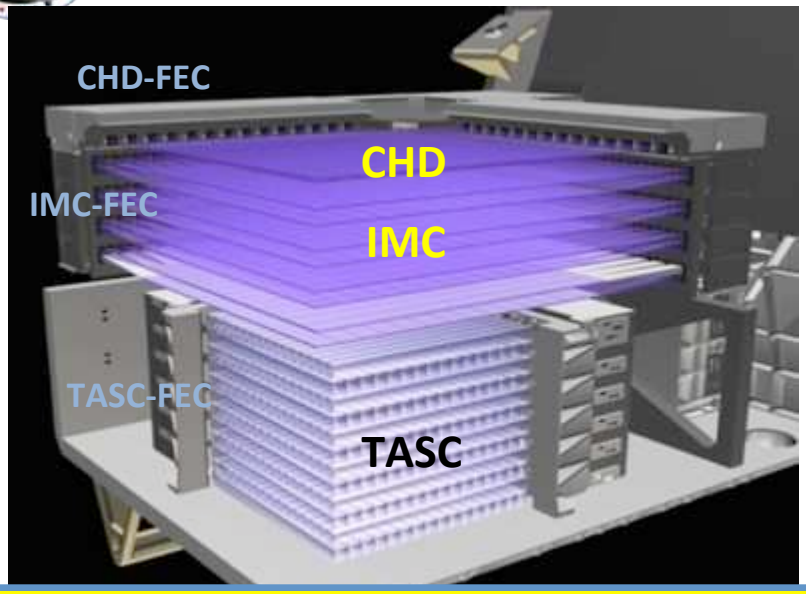
Total Thickness of Tungsten (W): 3 X_0 , 0.1 λ_I
Layer Number of Scifi Belts: 8 Layers × 2(X,Y)

TASC - Total Absorption Calorimeter (TASC)
(Energy Measurement, Particle ID)

PWO 20mm x 20mm x 320mm
Total Depth of PWO: 27 X_0 (24 cm), 1.2 λ_I

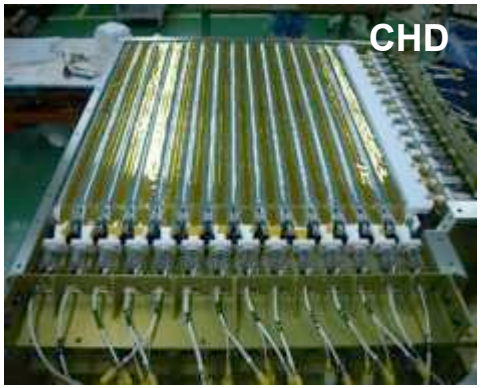
	CHD (Charge Detector)	IMC (Imaging Calorimeter)	TASC (Total Absorption Calorimeter)
Function	Charge Measurement (Z = 1 - 40)	Arrival Direction, Particle ID	Energy Measurement, PID
Sensor (+ Absorber)	Plastic Scintillators: 2 layers Unit Size: 32mm x 10mm x 450mm	Scintillating Fibers: 16 layers single readout: 1mm^2 x 448 mm Total thickness of Tungsten: 3 X_0	PWO logs: 12 layers Unit size: 19mm x 20mm x 326mm Total Thickness of PWO: 27 X_0
Readout	PMT+CSA	64-anode MAPMT+ ASIC	APD/PD+CSA PMT+CSA (for Trigger)

Main Flight Components

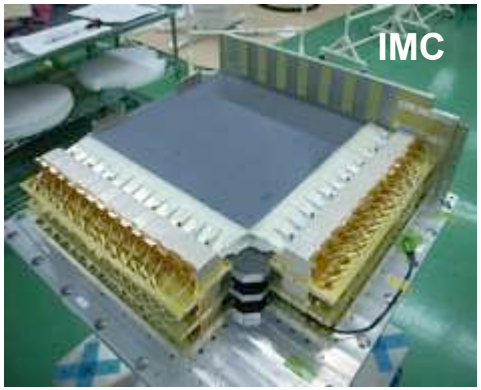


CALET: a unique set of key instruments.

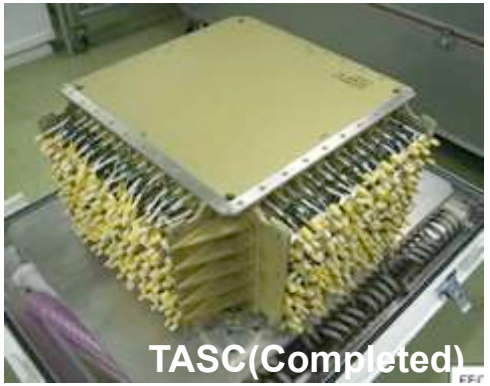
- **TASC**: a **thick, homogeneous calorimeter** allows to extend electron measurements into the TeV energy region with ~2% energy resolution.
- **IMC:** a **high granularity (1mm) imaging pre-shower with tracking capabilities** identifies the starting point of electromagnetic showers.
- TASC+IMC provide a **strong rejection power ~10^5** to separate electrons from the abundant protons.
- **CHD: a charge detector** combined with multiple dE/dx samples from IMC identifies individual elements.



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



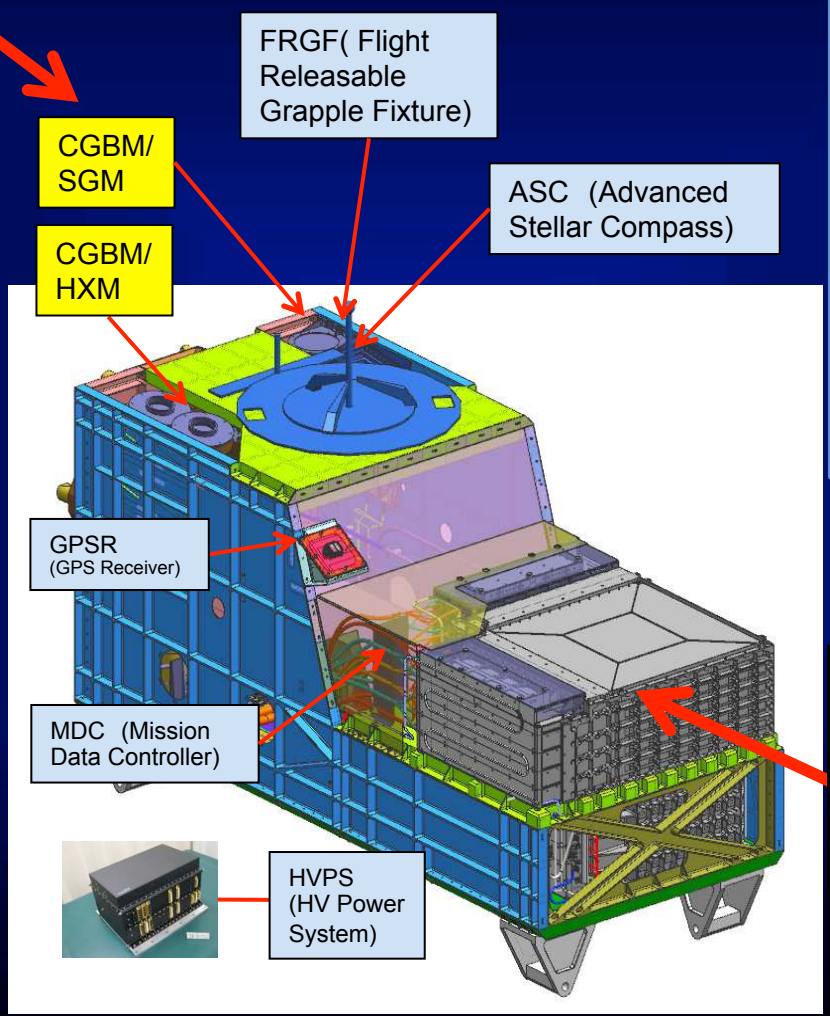
448 x 8 (x,y) layers = 7168
1mm^2 x 448 mm



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

CALET System Overview

CGBM (Calet Gamma-ray Burst Monitor)



Geometric Factor :

1200 cm^2sr for electrons, light nuclei

1000 cm^2sr for gamma-rays

4000 cm^2sr for ultra-heavy nuclei

- **ΔE/E** :

  ~2% (>10 GeV) for e, gamma

  ~30-35 % for protons, nuclei

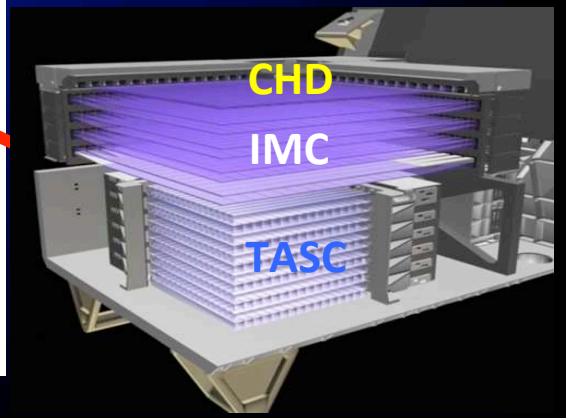
- **e/p separation** : ~10^{-5}
- **Charge resolution** : 0.15 - 0.3 e
- **Angular resolution** :

  0.2° for gamma-rays > ~50 GeV

- Standard Payload Size
- Mass: 612.8 kg
- Power: 507 W (Max)

- Telemetry:
  - Medium rate: 600 kbps
  - Low rate: 50 kbps

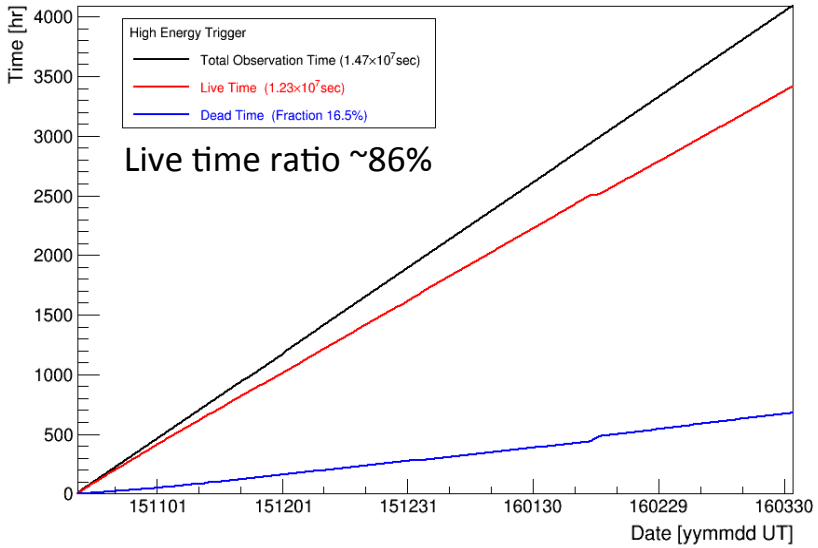
CALORIMETER MODULE



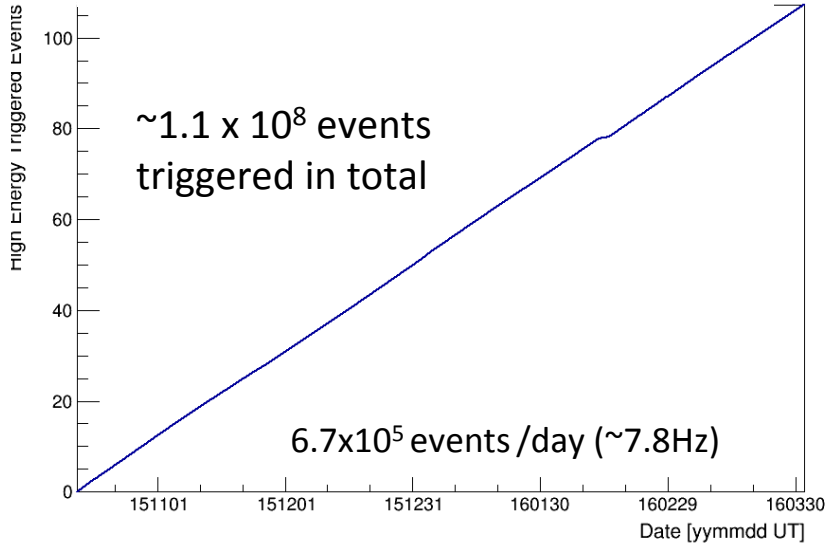
Observations with High Energy Trigger

High Energy Observation for 171 days: October 13, 2015 – March 31, 2016

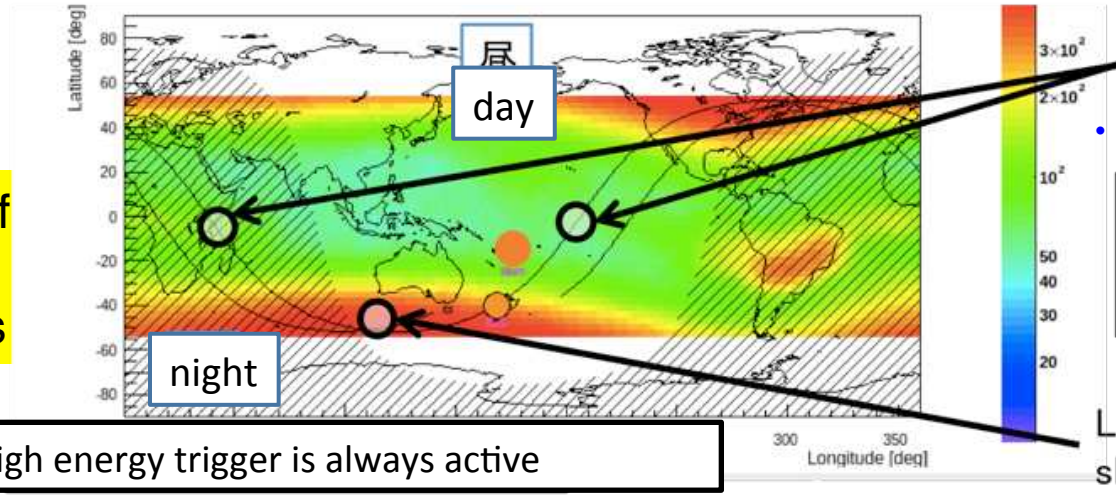
Accumulated observation time (live, dead)



Accumulated triggered event number



Concept of on-orbit operations



Pedestal data acquisition

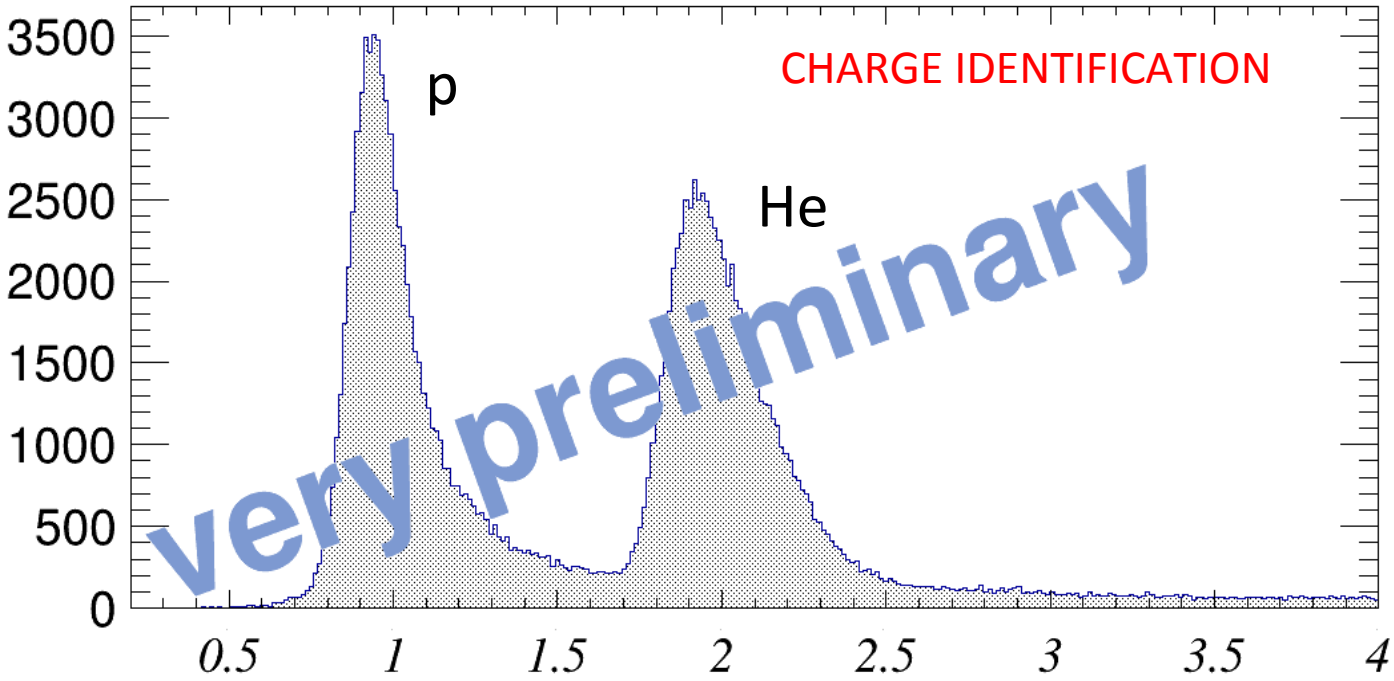
- Single He trigger (for calibration)

Schedule file: sequence of time and command

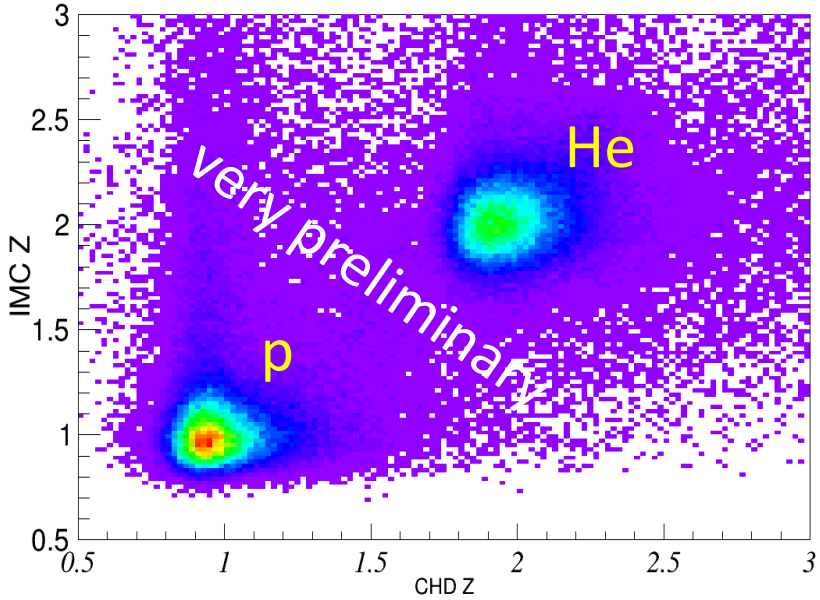
Low energy electron shower data acquisition

High energy trigger is always active

data selection is NOT representative of elemental abundances



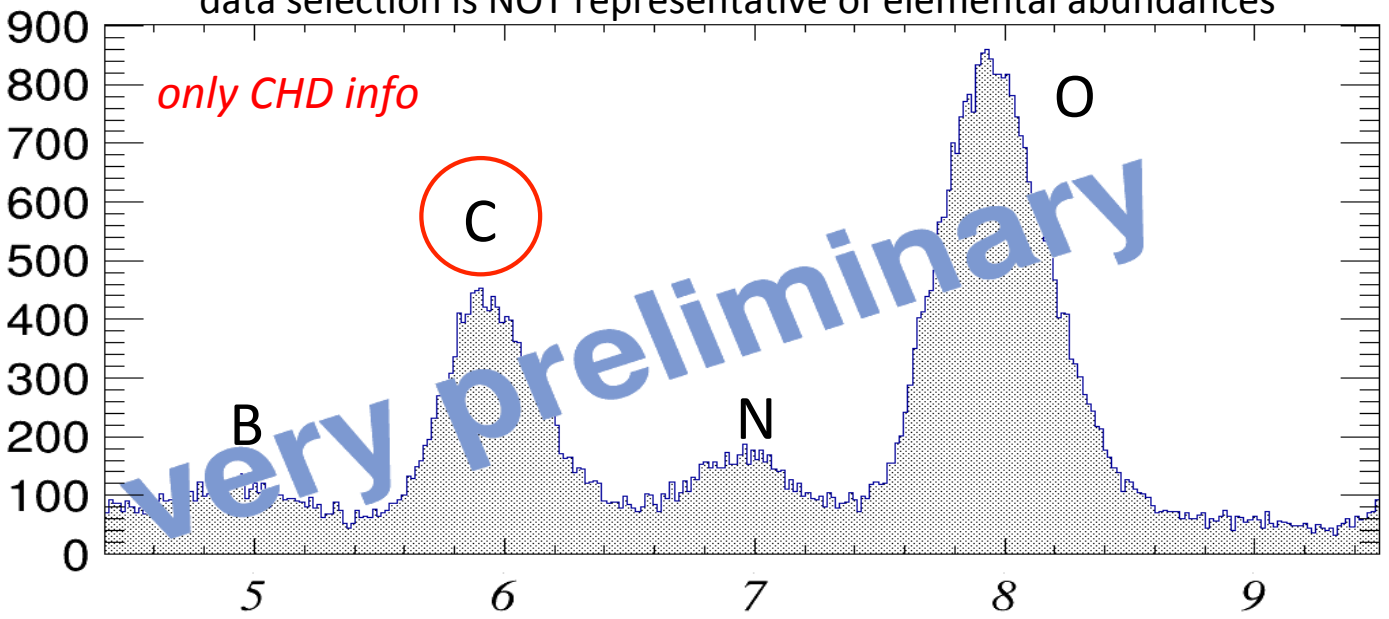
Atomic Number Z

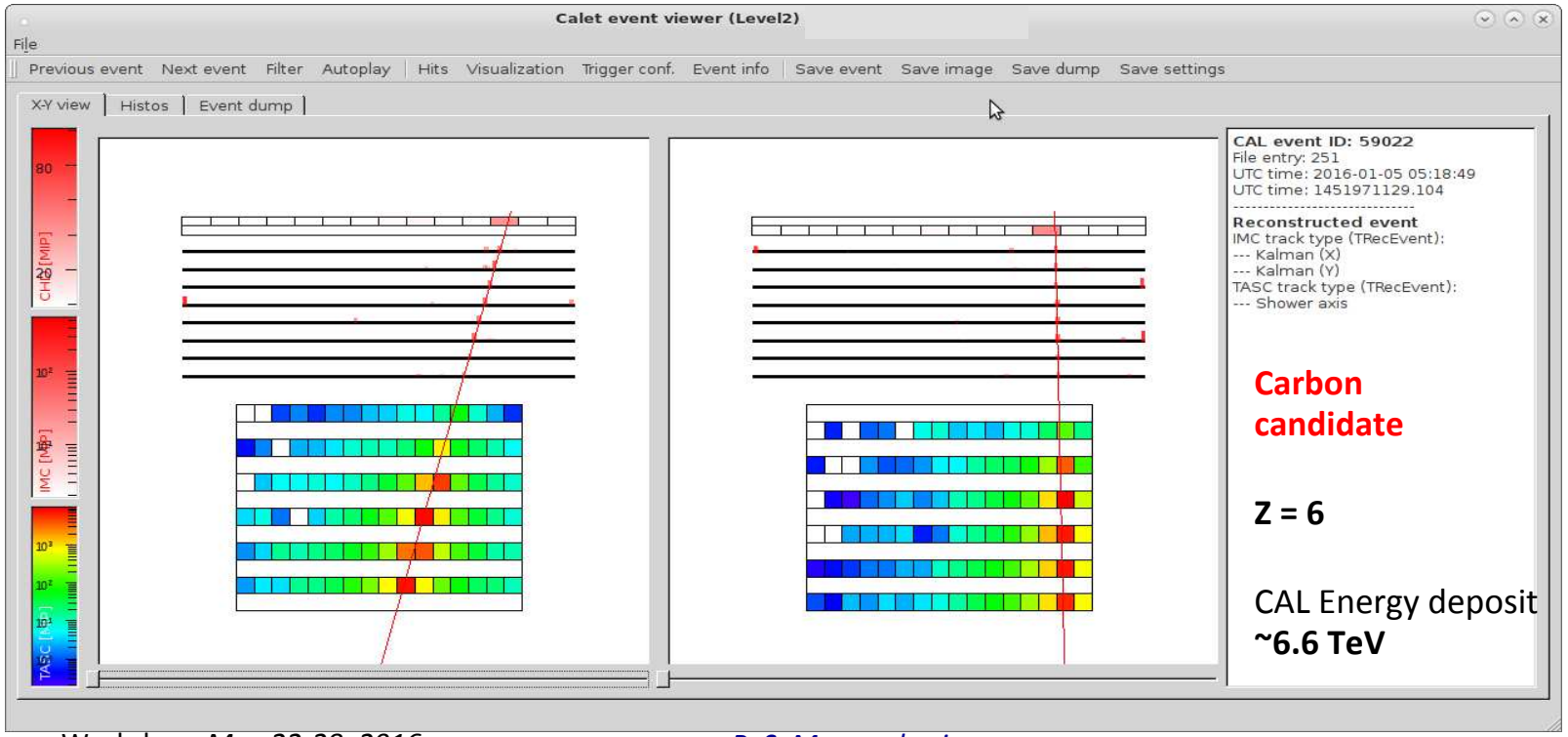


Using multiple dE/dx measurements from the IMC scintillating fibers (upstream the interaction point), a complementary charge measurement from IMC is plotted vs the CHD charge assignment (abscissa).

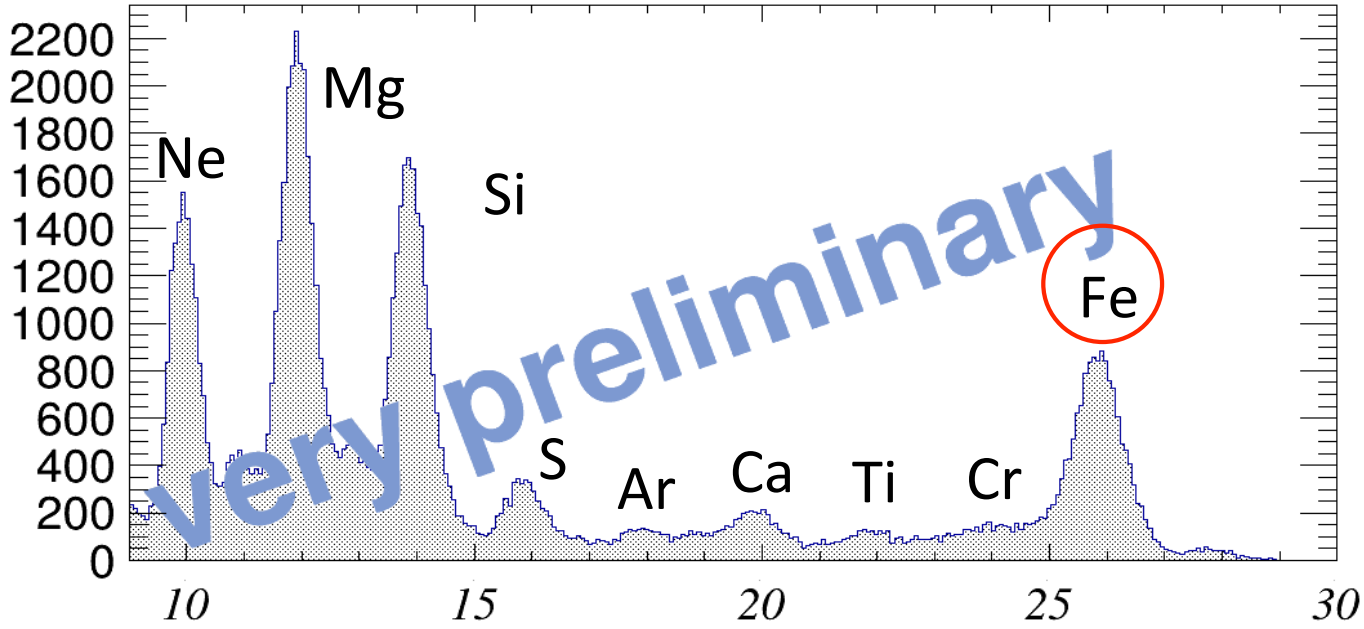
A clear separation between p and He can be seen from preliminary data analysis.

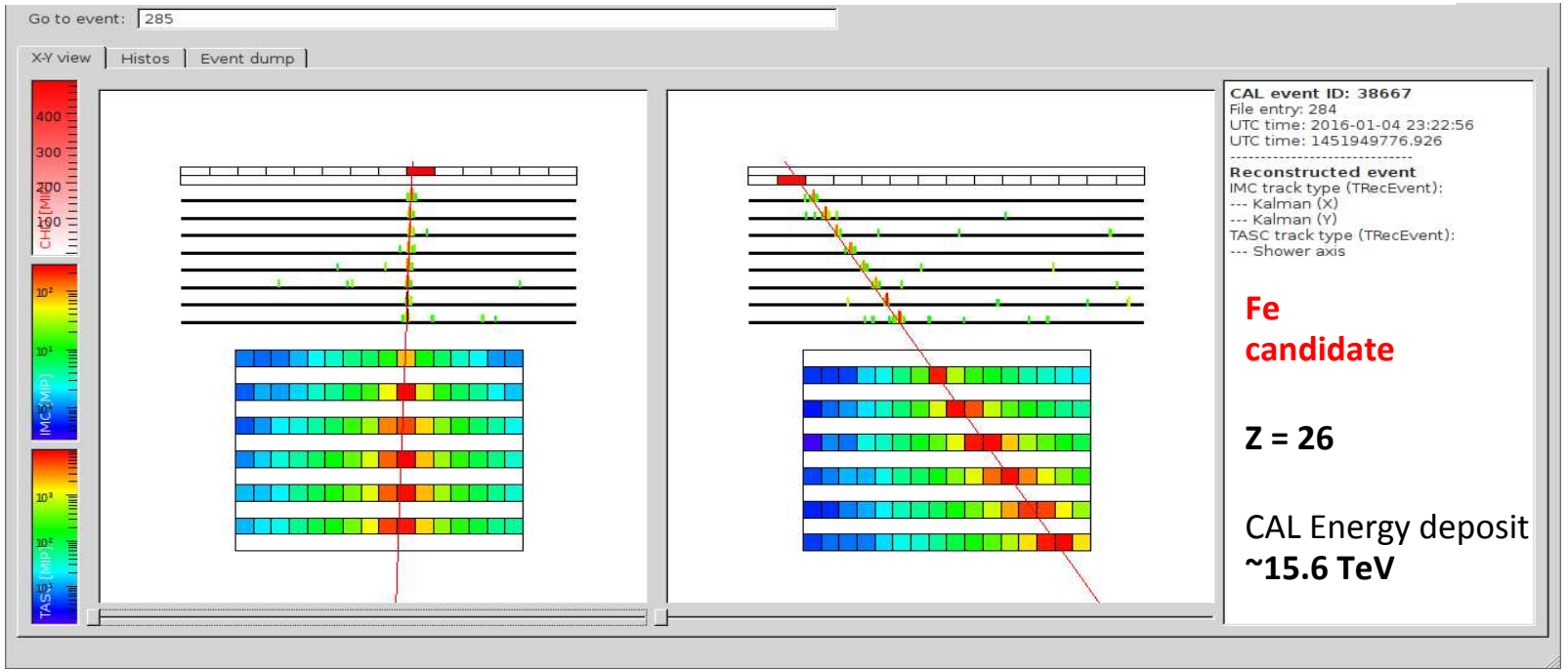
data selection is NOT representative of elemental abundances

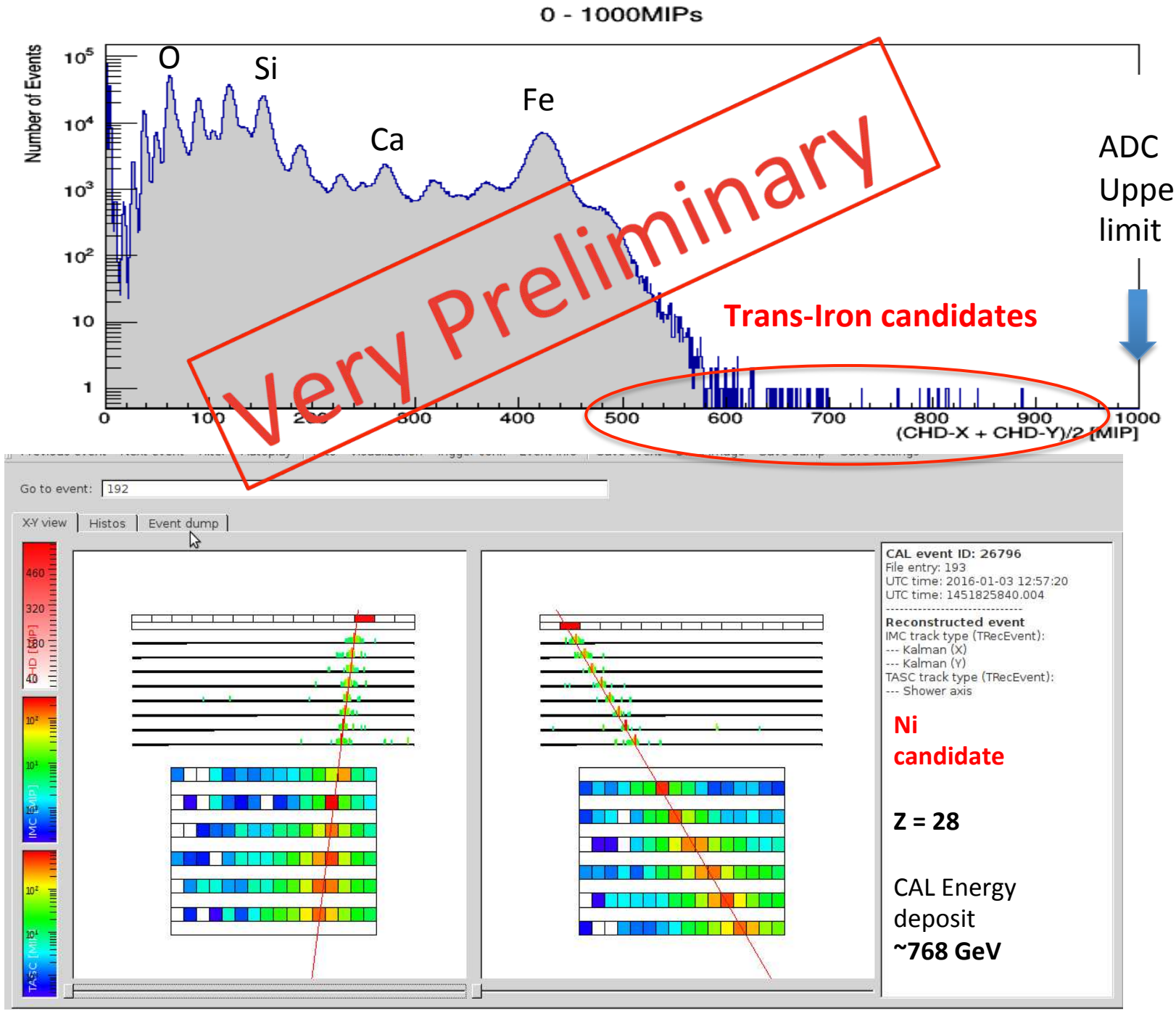




data selection is NOT representative of elemental abundances





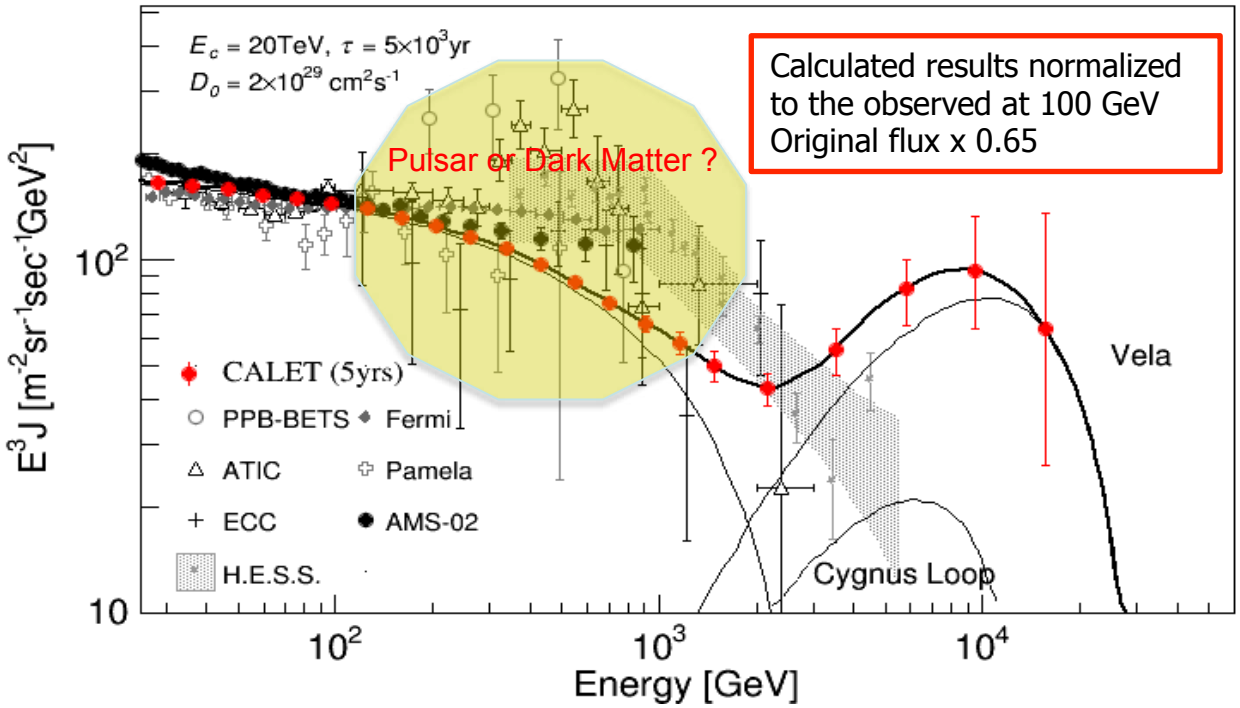

0 - 1000MIPs
Number of Events
O
Si
Ca
Fe
Very Preliminary
ADC
Upper
limit
Trans-Iron candidates
(CHD-X + CHD-Y)/2 [MIP]
Go to event: 192
X-Y view
Histos
Event dump
CAL event ID: 26796
File entry: 193
UTC time: 2016-01-03 12:57:20
UTC time: 1451825840.004
Reconstructed event
IMC track type (TRecEvent):
--- Kalman (X)
--- Kalman (Y)
TASC track type (TRecEvent):
--- Shower axis
Ni
candidate
Z = 28
CAL Energy
deposit
~768 GeV

CALET Main Target: Identification of Electron Sources

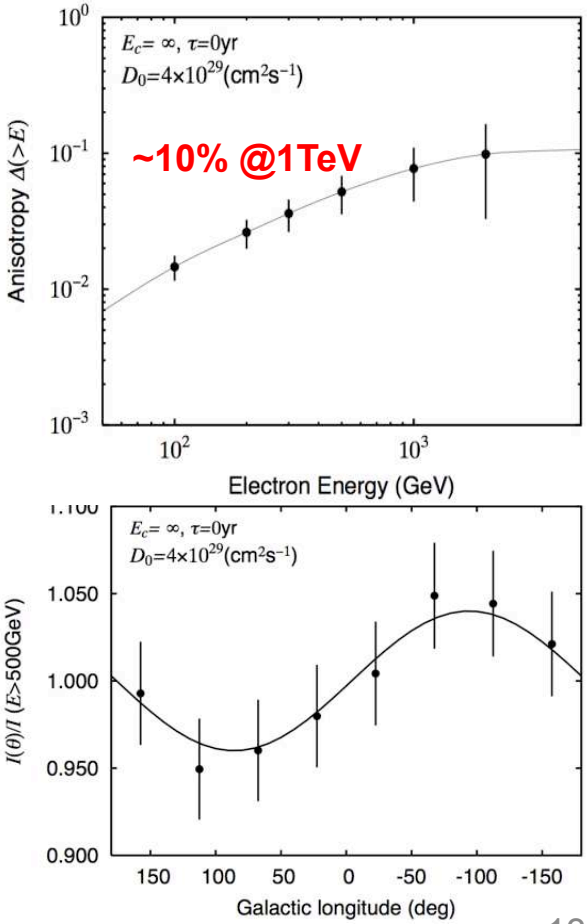
Some nearby sources, e.g. Vela SNR, might have unique signatures
in the electron energy spectrum in the TeV region (Kobayashi et al. ApJ 2004)

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



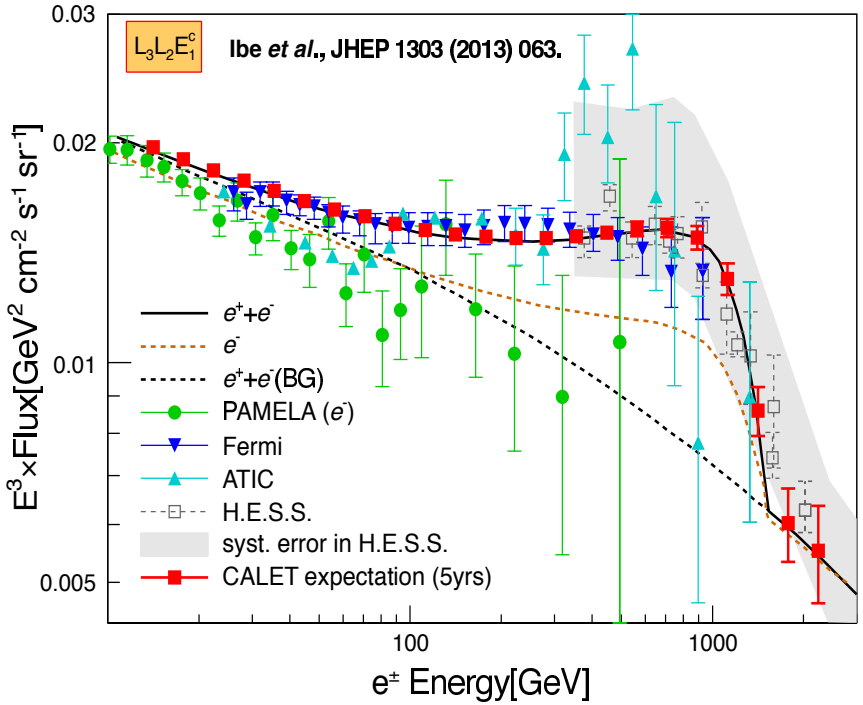
Expected Anisotropy
from Vela SNR



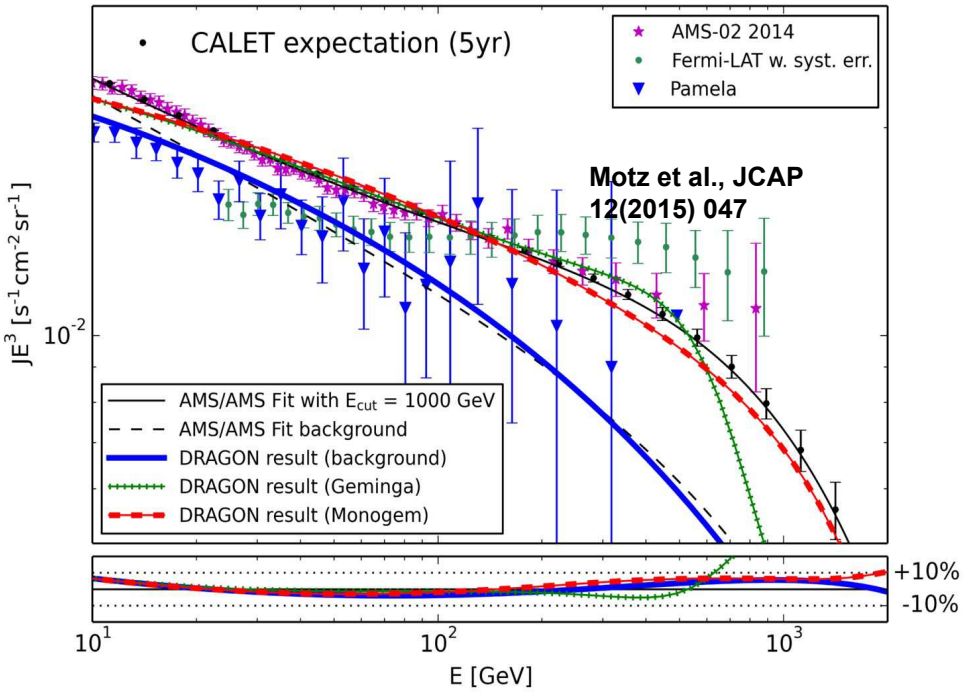
Identification of the unique signature from nearby SNRs,
such as Vela in the electron spectrum by CALET

Dark Matter or Pulsar with Electrons

Decay of Dark Matter (LSP)



Single Pulsar (Geminga or Monogem)



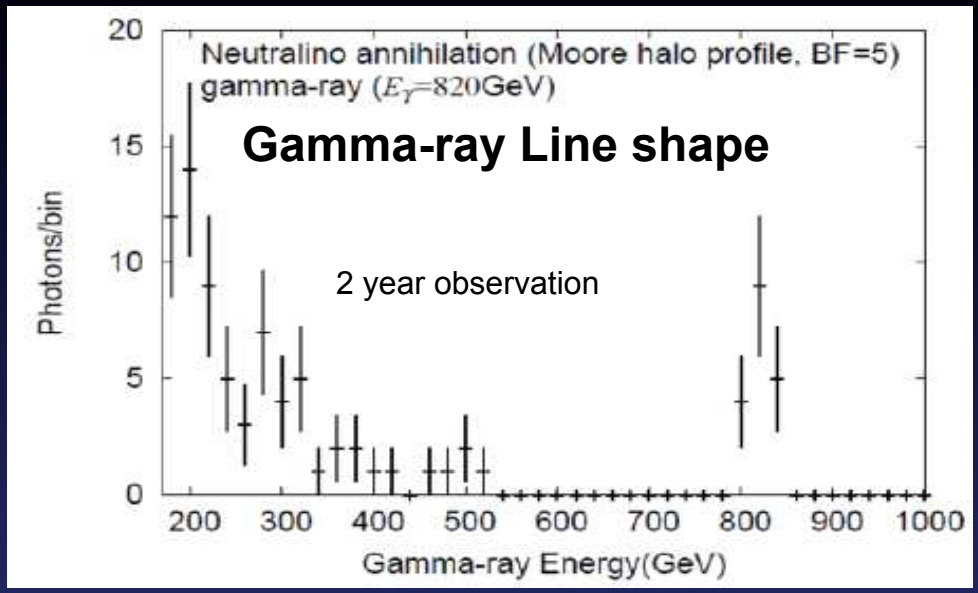
Expected $e^+ + e^-$ spectrum by **Lightest Super Symmetry Particle (LSP) (black line)** with CALET measurement after 5-year (red dots), consistent with present data of positron excess and $e^+ + e^-$ spectrum

Best fit results for the single pulsar extra source (E_{cut} = 1TeV) to AMS-02 positron fraction data and AMS-02 total flux data compared with the results of the DRAGON simulation.
In the lower panel the fractional residuals are plotted, showing an agreement better than 10%. in the most relevant energy range.

Gamma-ray Detection Performance

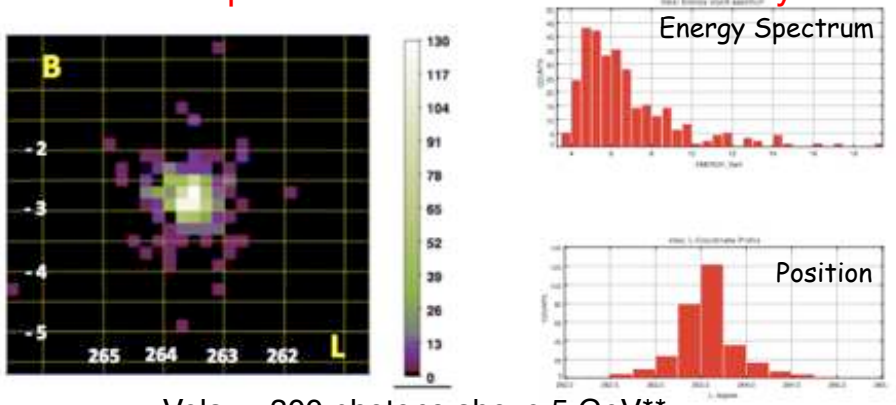
Energy Range	4 GeV-10 TeV (or > 1GeV)
Effective Area	600 cm^2 (10GeV)
Field-of-View	2 sr
Geometrical Factor	1100 $cm^2 sr$
Energy Resolution	3% (10 GeV)
Angular Resolution	0.35 ° （10GeV)
Pointing Accuracy	6′
Point Source Sensitivity	8 x 10^{-9} $cm^{-2}s^{-1}$
Observation Period (planned)	2015-2020 (5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

Indirect Dark Matter Search with Gamma rays



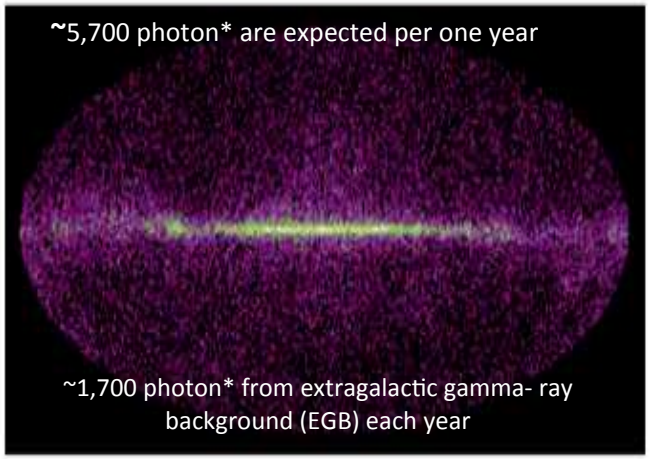
Detection of High Energy Gamma-rays

Simulation of point source observations in one year



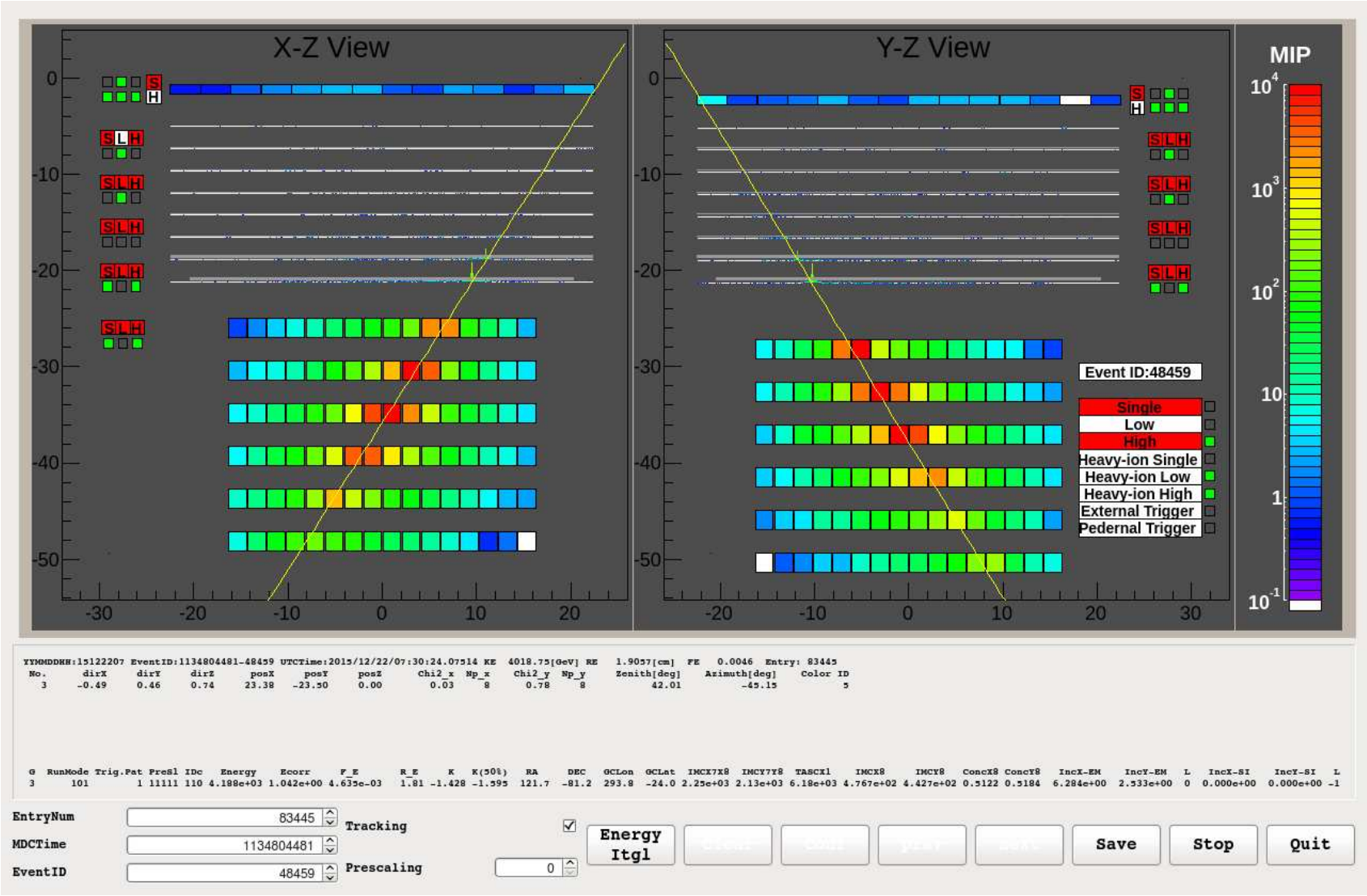
Vela: ~ 300 photons above 5 GeV**

Simulation of Galactic Diffuse Radiation



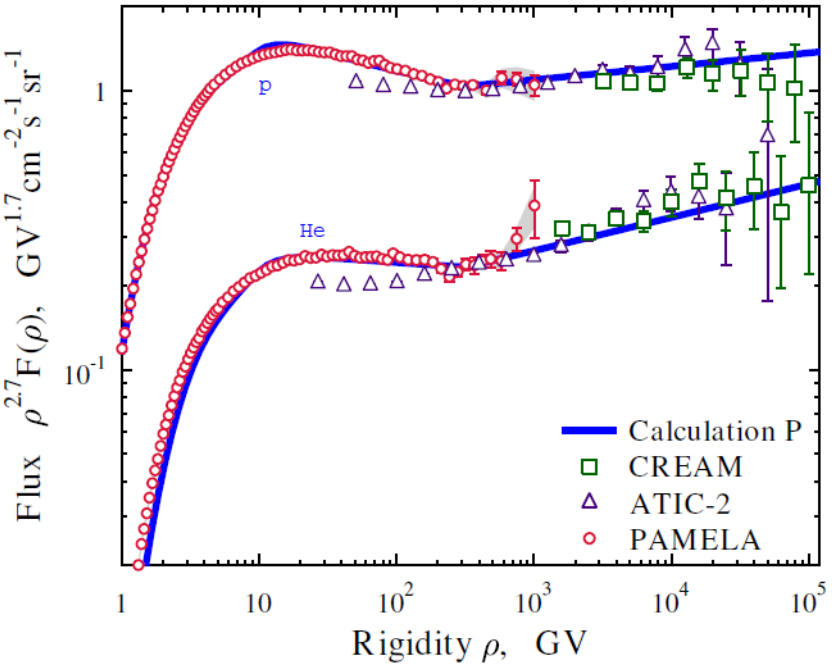
*) Trigger efficiency included below 10 GeV
**) 100 % efficiency over 5 GeV

High Energy Electron Candidate : 4.2TeV

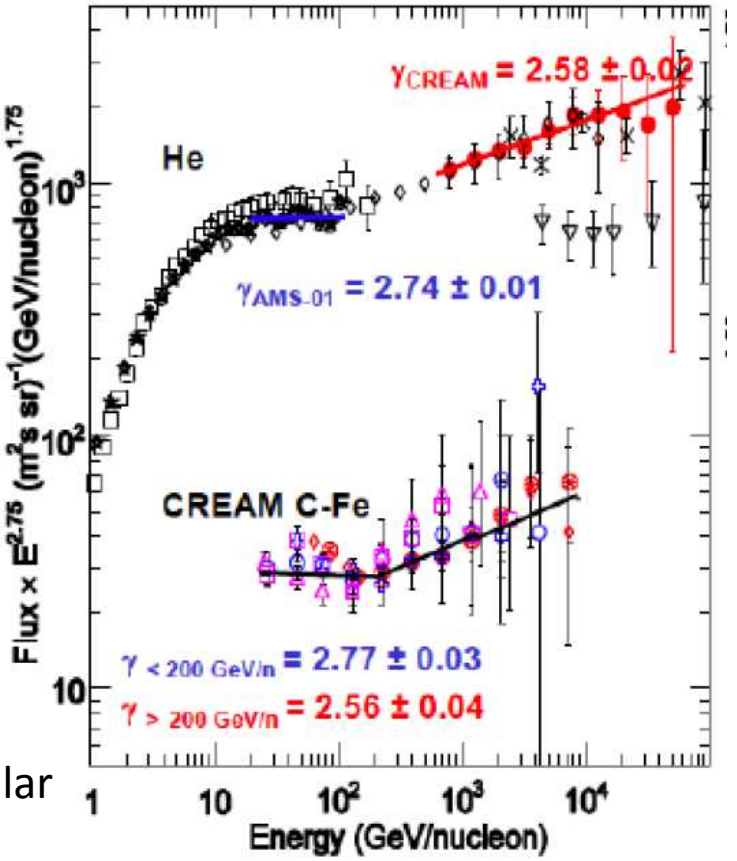


Measurements of cosmic nuclei spectra

❑ **PAMELA detected a spectral break in PROTON and HE spectra at R ~ 240 GV**



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

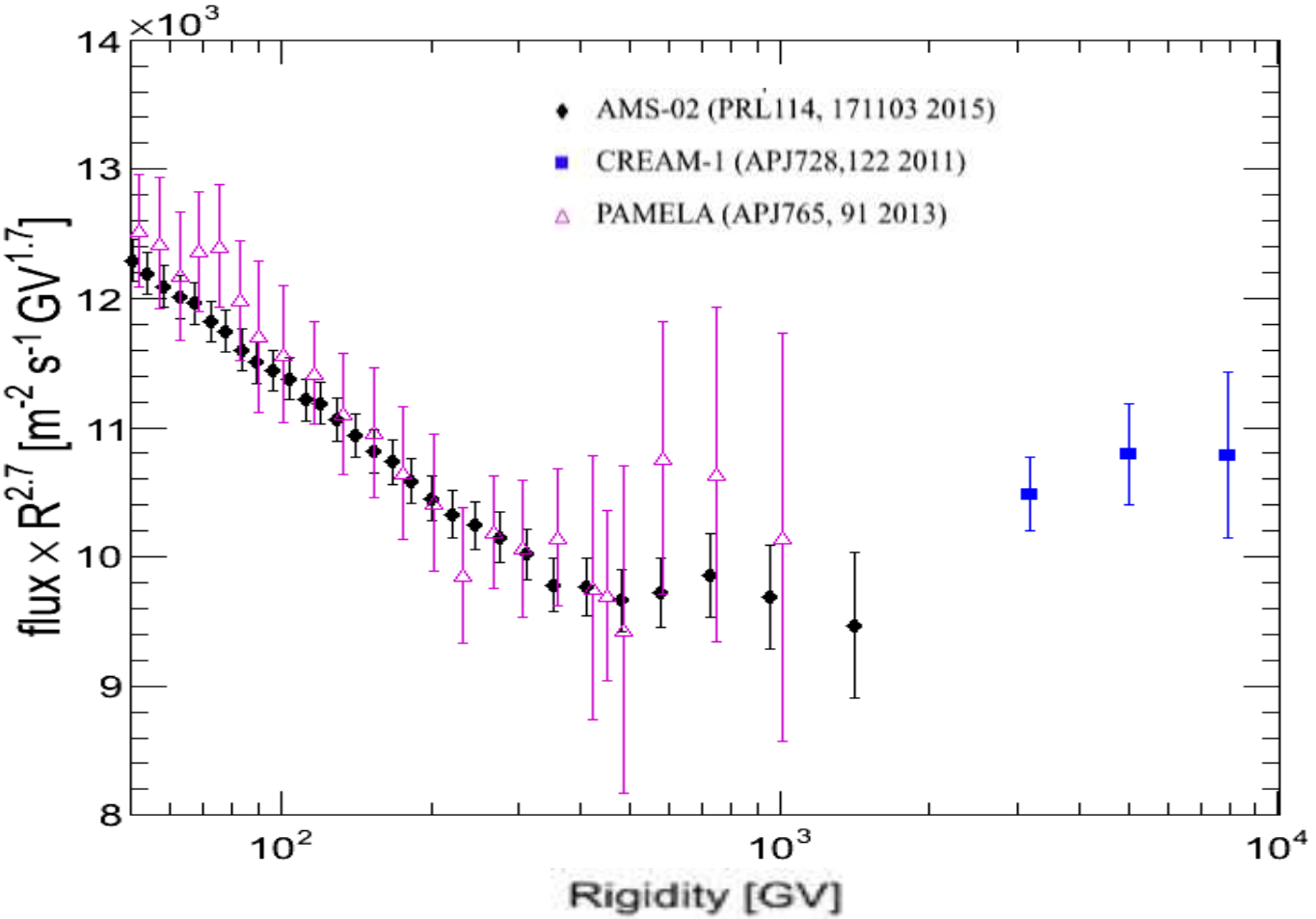


The slope of Z>2 NUCLEI at high energy looks similar to He and different from protons

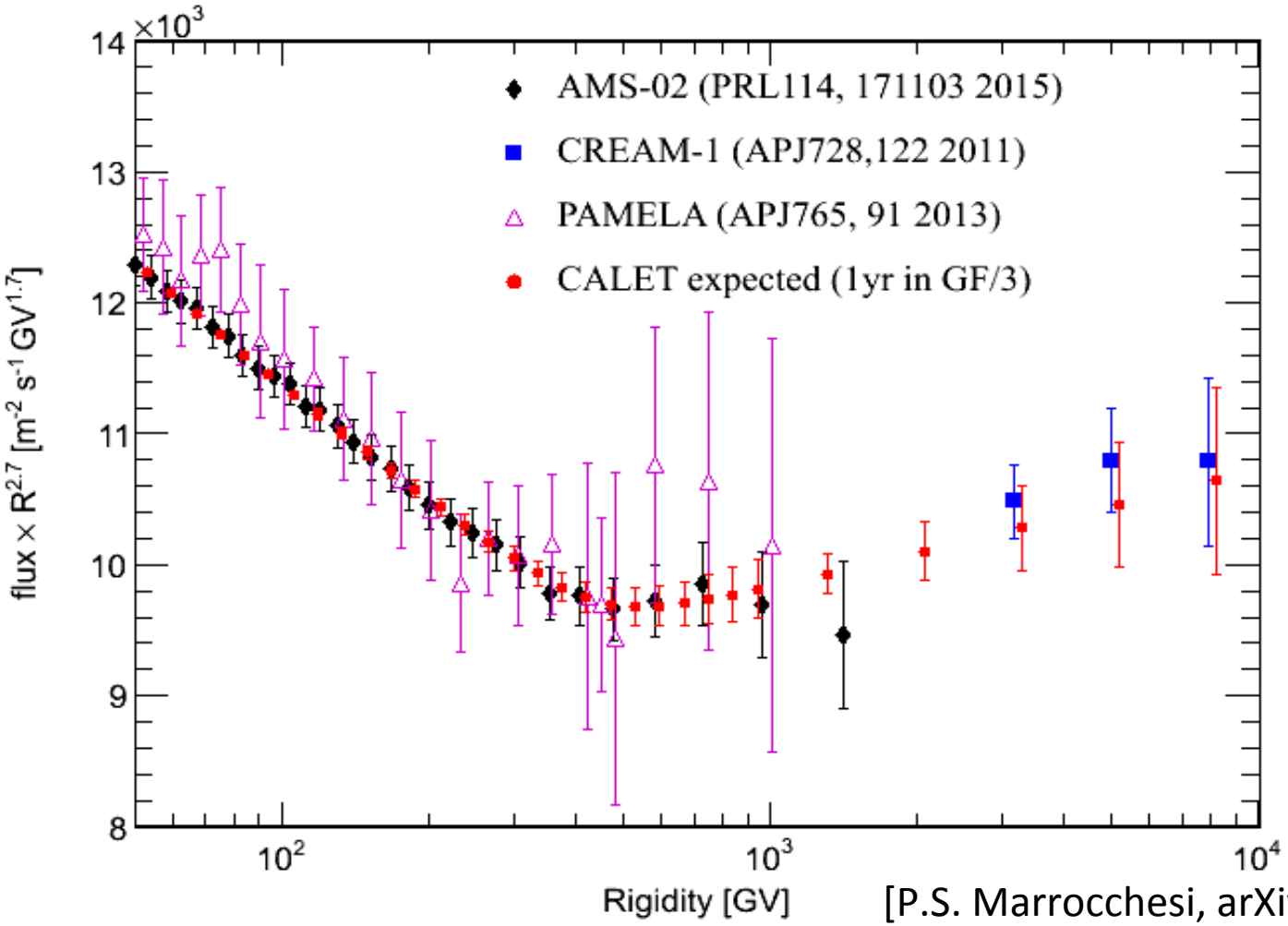
A single power-law seems inadequate to fit the spectra of nuclei

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

✧ CALET is **carrying on an accurate scan of** the energy region around the spectral break with an energy resolution ~30 – 40 % and larger GF ~ 0.12 m^2 sr



✧ After one year on the ISS, CALET is expected to close the gap between AMS02 and CREAM above 1 TV. It will also extend the investigation on the spectral shapes of proton and He to the multi-TeV region.



[P.S. Marrocchesi, arXiv:1512.08059]

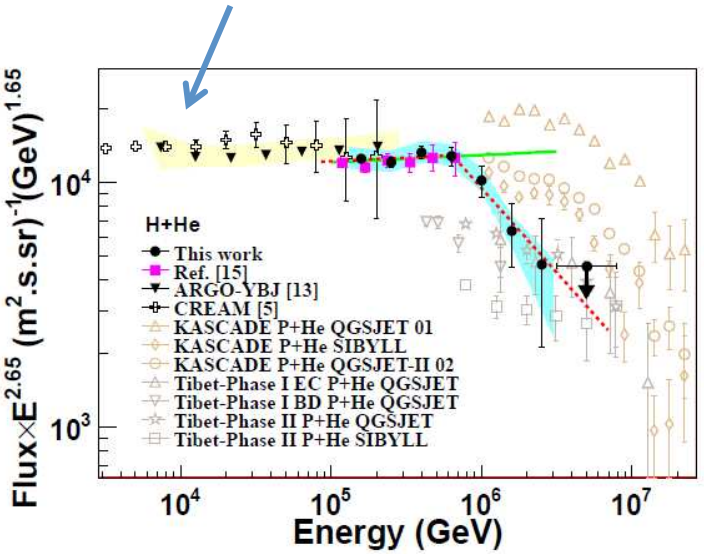
Exploration of the sub-PeV region

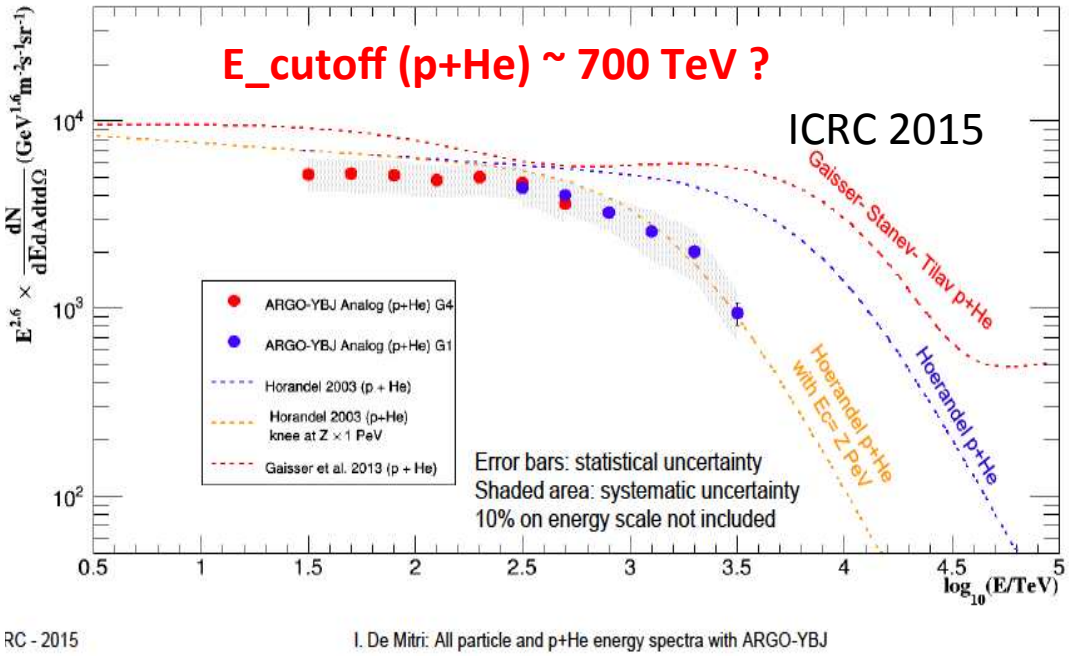
- INDIRECT MEASUREMENTS BY AIRSHOWERS: **hints of a proton cutoff below 1 PeV?**

ARGO YBJ: (P + HE) SPECTRUM

- **Gradual change of the slope starting around 700 TeV**
- **Agreement with other two ARGO-YBJ independet analyses**
- **Consistent with previous hints** (MACRO, CASA-MIA, Chacaltaya, EAS-TOP, YAC-Tibet...)
- **Overlap with direct measurements at low energy**

Superposition with CREAM direct measurements





In 5 yrs CALET can perform DIRECT measurements of p and He fluxes in the multi-TeV region.

CALET explores the Multi-TeV region

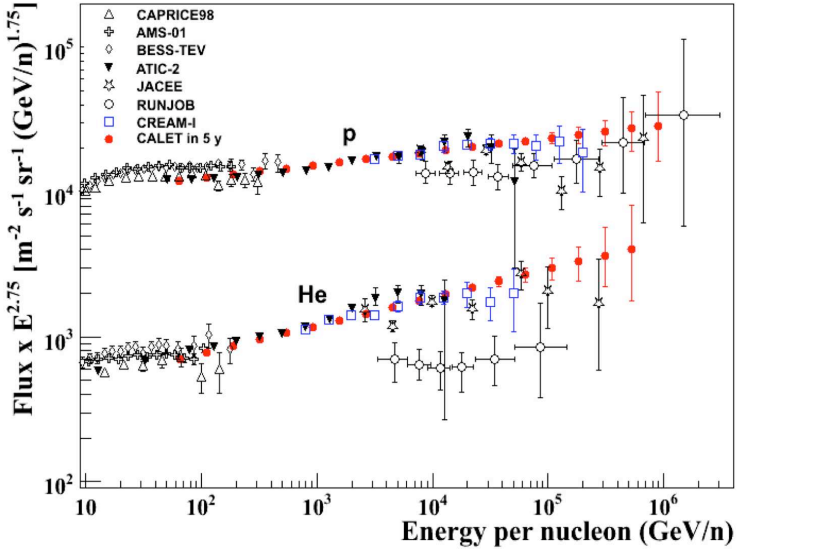
Elemental spectra

CALET Energy reach in 5 years:

- Proton spectrum to ≈ 900 TeV
- He spectrum to ≈ 400 TeV/n
- Spectra of C,O,Ne,Mg,Si to ≈ 20 TeV/n
- B/C ratio to ≈ 4 - 6 TeV/n
- Fe spectrum to ≈ 10 TeV/n

Proton and He

CALET expected in 5 yrs (red points)



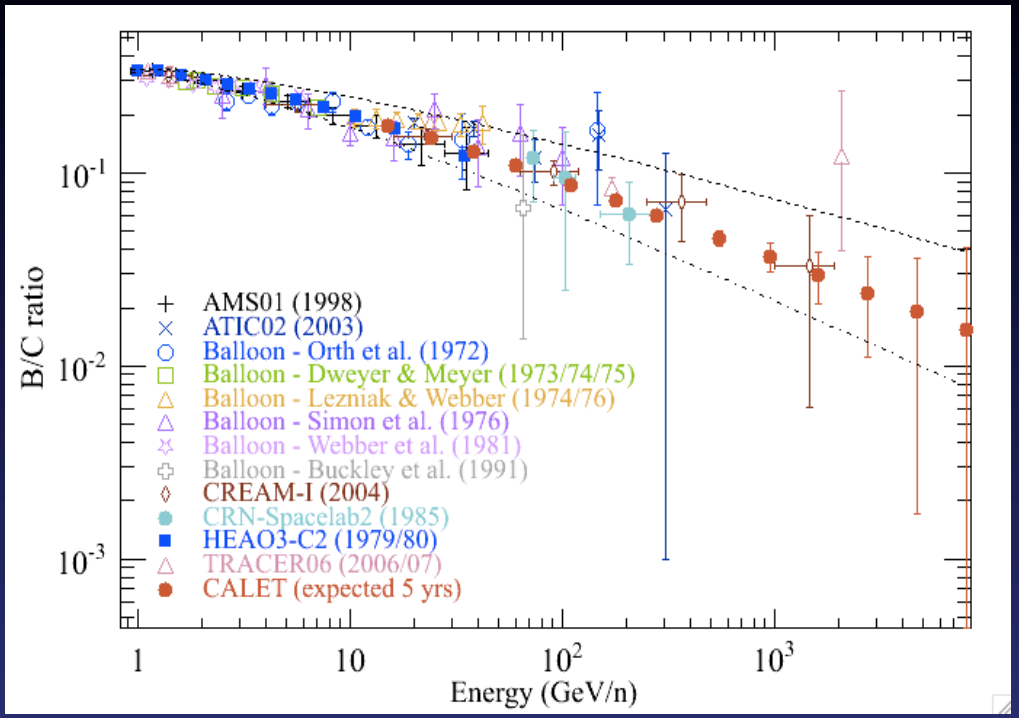
	λ_{INT}	X_0 (normal incidence)
CREAM	0.5 + 0.7	20
CALET	1.3	30
AMS-02	0.5	17

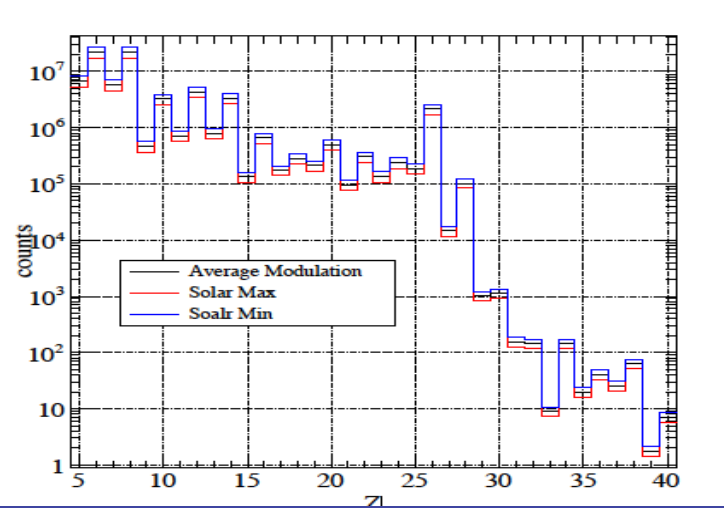
Requirements for proton calorimetry:

- proton interaction requires > 0.5 λ_{INT}
- at 100 TeV energy scale, longitudinal containment of the e.m. core of the shower requires > 20 X_0

Secondary to Primary ratio (B/C and Fe/Sub-Fe)

- Energy dependence of the diffusion constant: $D \sim E^{\delta}$
- δ~0.6 below 100 GeV/n. At higher energy the ratio is expected to flatten out (otherwise CR anisotropy should be larger than observed)
- Observation up to several TeV/n free from the atmospheric production of boron by heavier cosmic nuclei





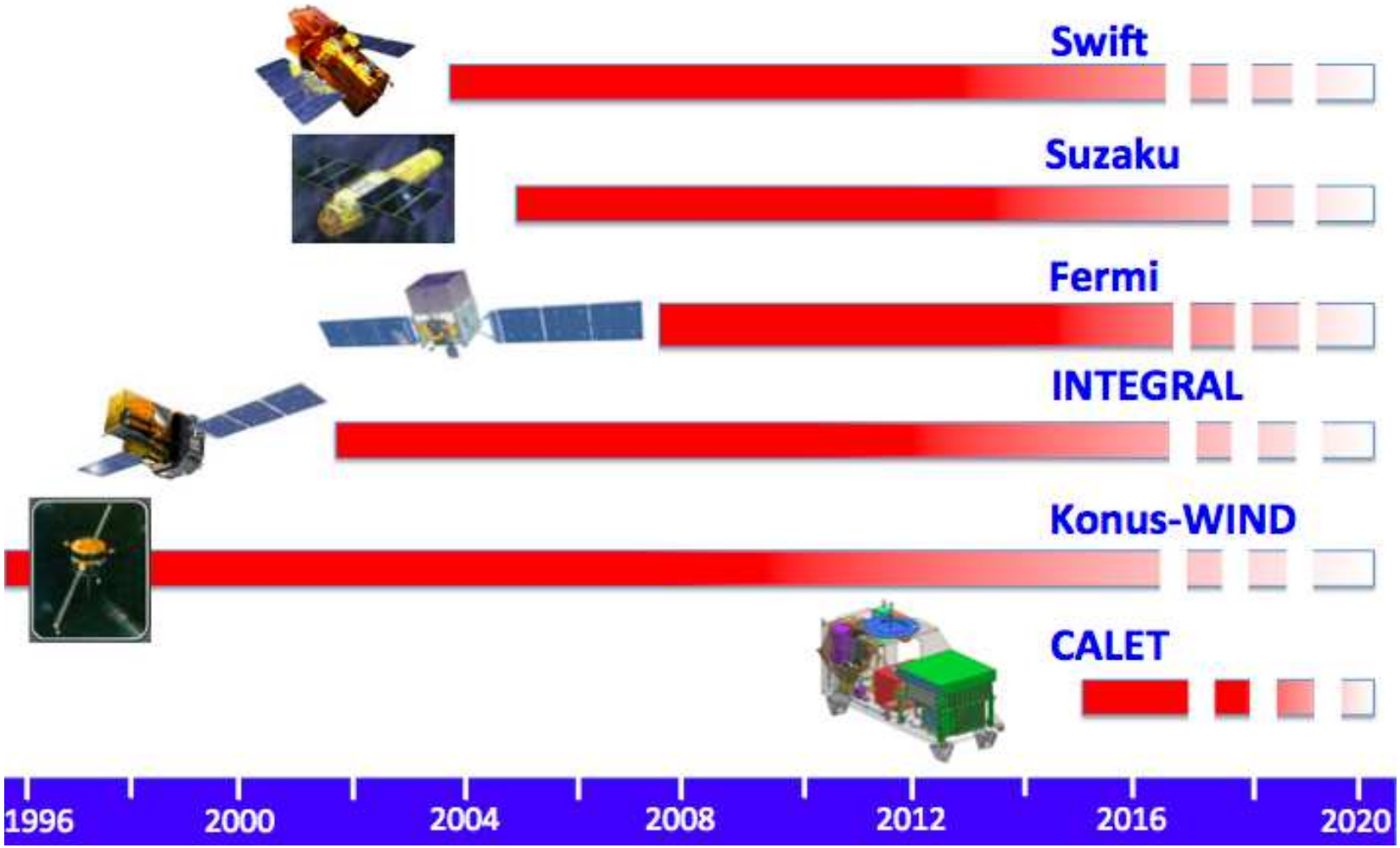
UH Composition to Z=40

Dedicated UH trigger: larger trigger acceptance
→ 0.4 m^2sr

Statistcs::
≅ 10 x TIGER (with UH trigger)
≅ 4 x TIGER (with full geometry and energy reconstruction)

Cleaner measurements (smaller corrections for hadronic interactions above atmosphere)

Currently active missions able to detect GRBs



CGBM (Calet Gamma-ray Burst Monitor)

HXM x2

7keV-1MeV

$LaBr_3(Ce)$

SGM x1

0.1-20MeV

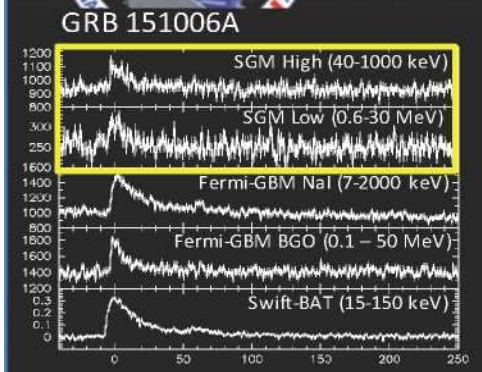
BGO

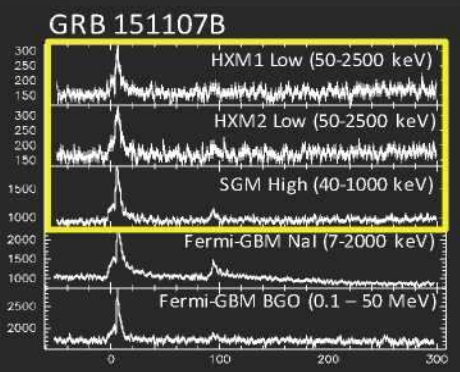
Hard X-ray Monitor (HXM)
($LaBr_3(Ce)$, 7 – 1000 keV)

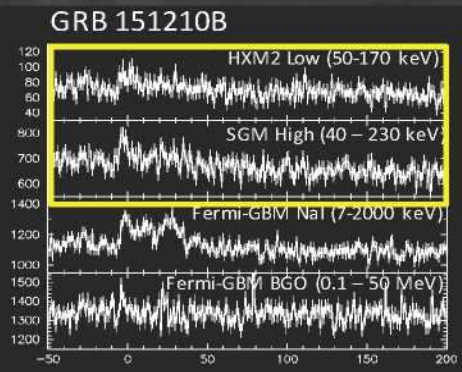
CALET's CGBM has measured the light-curves of 20 GRB's as of May 15, 2016

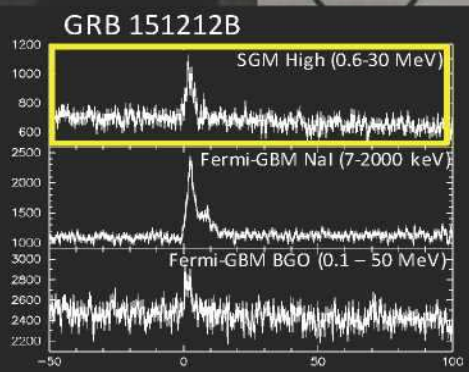
Soft γ-ray Monitor (SGM)
(BGO, 100 keV – 20 MeV)

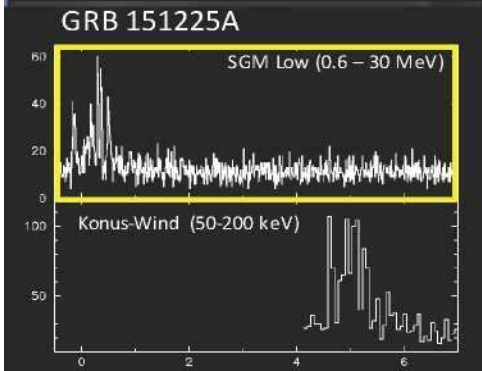
CGBM GRB light curve gallery

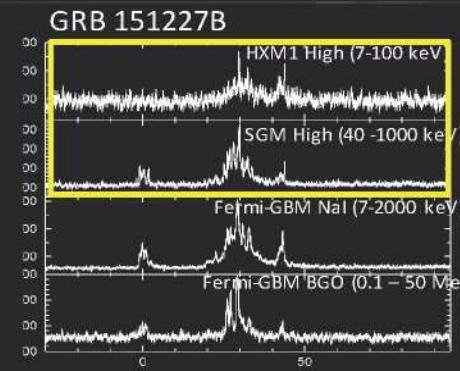


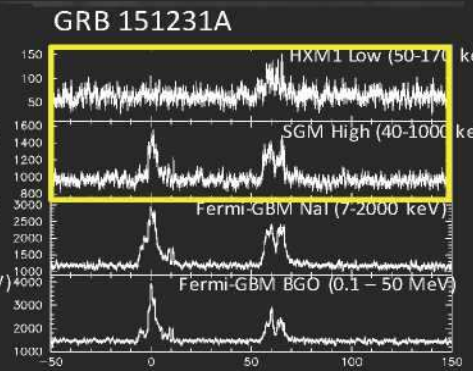


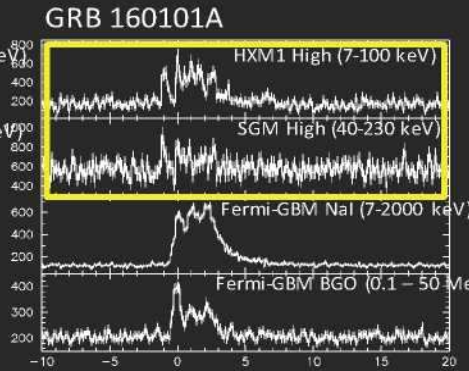


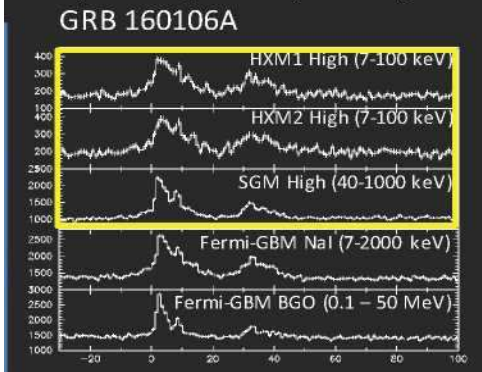


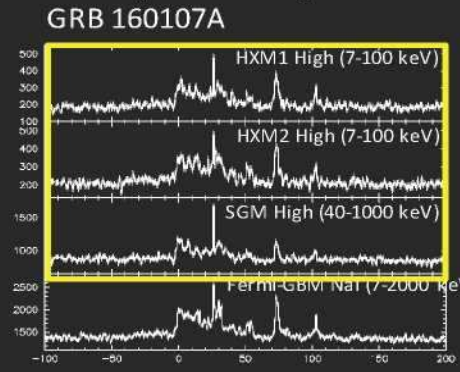


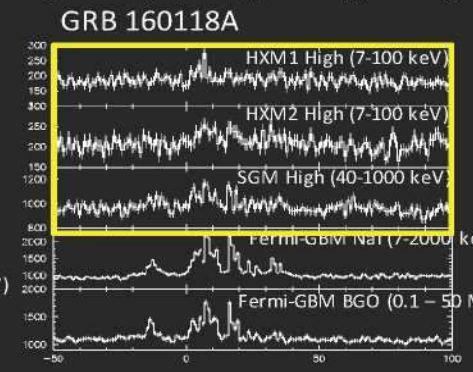












Summary

- CALET was successfully launched on HTV-5 from Tanegashima Space Center on August 19, 2015 berthing to the ISS on August 25. After functional check-out, CALET completed a calibration and initial operation phase on November 17, 2015, and standand operation mode began.

- It 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.** From Oct.13, 2015 - March 31, 2016 nearly 1.2 x 10^6 electron candidate events above 10 GeV have been observed among 1.1 x 10^8 triggered events. Electron event candidates were observed above 1 TeV.

- Cosmic rays from proton to Fe and Ultra Heavy ions ($26 < Z < 40$), as well as astrophysical gamma-rays have been observed. Energy spectra, relative elemental abundances and secondary-to-primary ratios are being measured.

- CALET's CGBM has measured the light-curves of 20 GRB's as of May 15, 2016.

- 5 year observations are planned.

Data Downlink Using TDRSS and DRTS