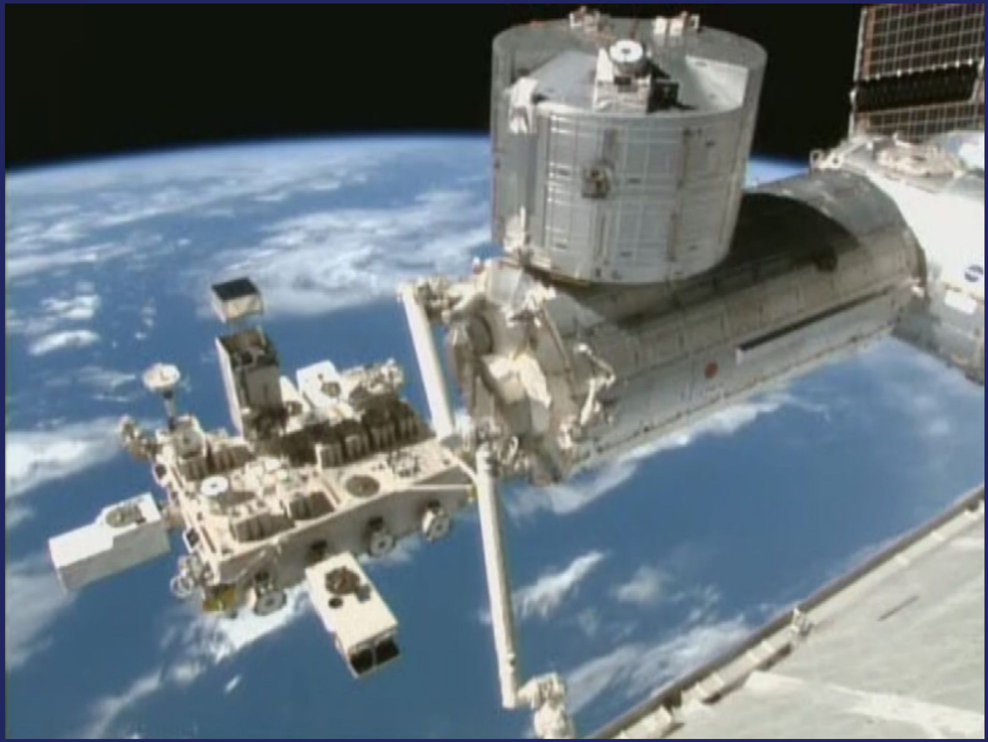
ICRC2017
35th International Cosmic Ray Conference
The Astroparticle Physics Conference



Measurements of Heavy Nuclei with the CALET Experiment

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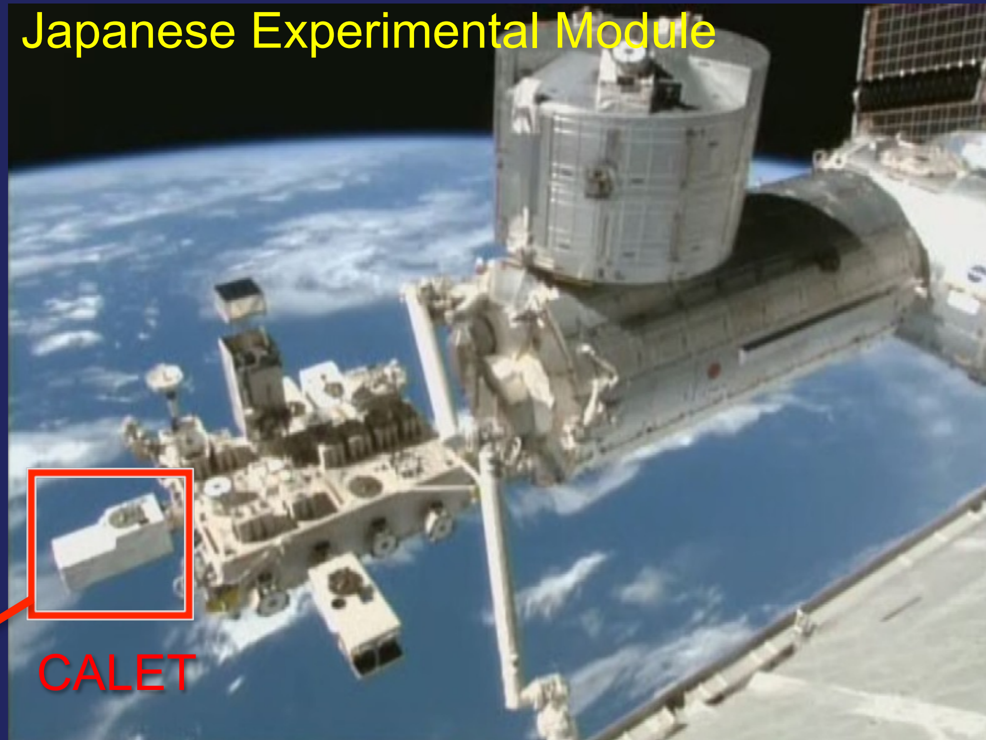
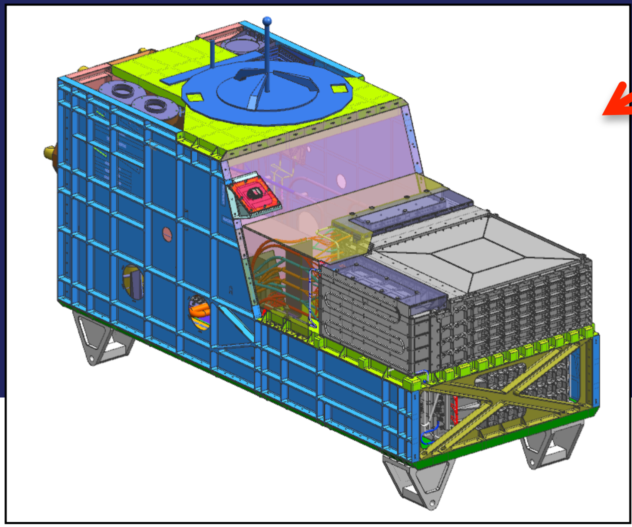
for the CALET Collaboration
University of Maryland, Baltimore County
and NASA Goddard Space Flight Center

CALET:
CALorimetric Electron Telescope

Launch: August 19, 2015
Observations: October 13, 2015





CALET Collaboration

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17) National Institute of Polar Research, Japan
18) Nihon University, Japan
19) Osaka City University, Japan
20) Ritsumeikan University, Japan
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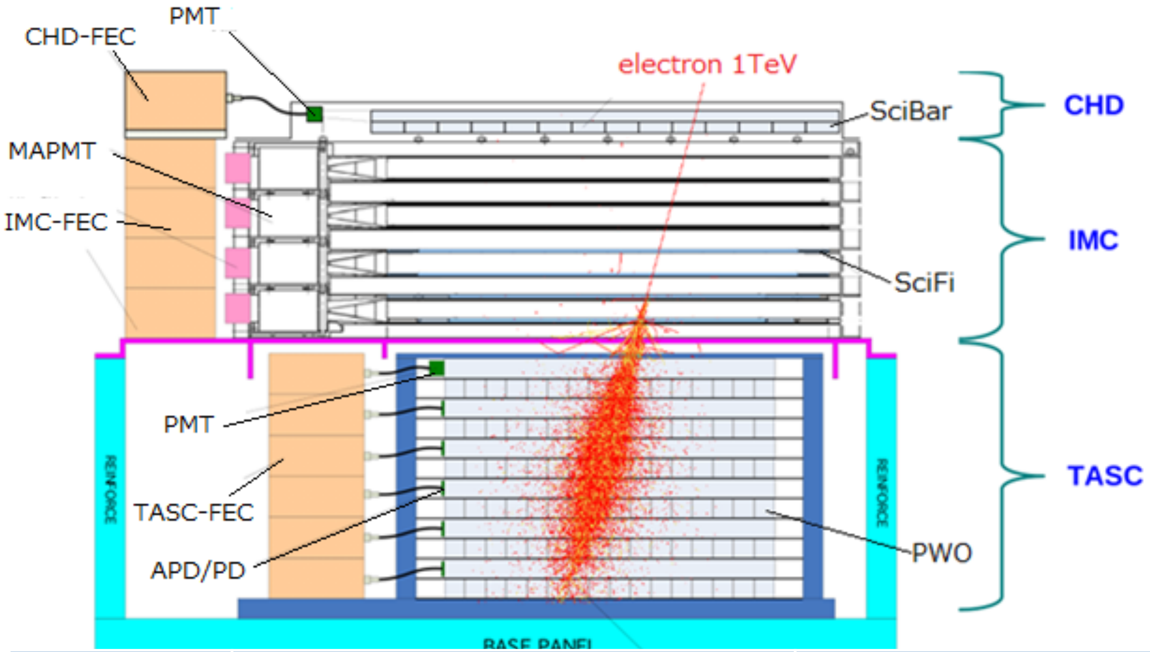
34) Yokohama National University, Japan
35) Yukawa Institute for Theoretical Physics, Kyoto University, Japan

CALET-CAL Detector

A 30 radiation length deep calorimeter designed to detect electrons and gamma-rays to 20 TeV and cosmic rays up to 1 PeV

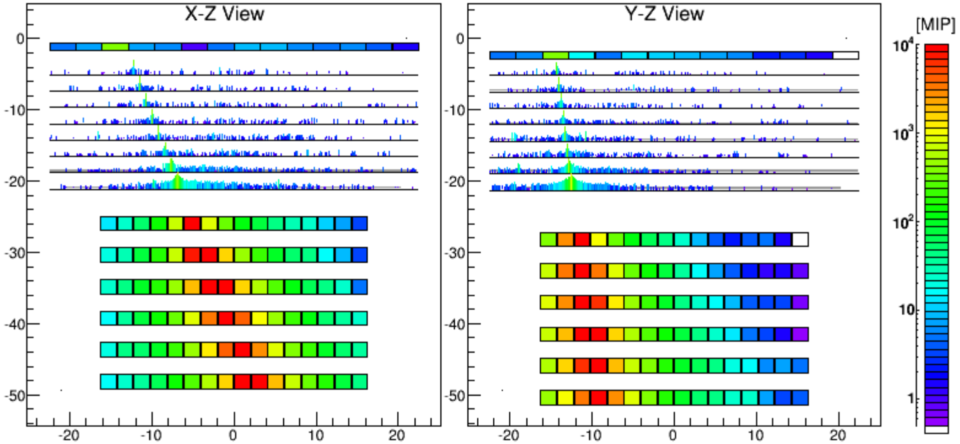


Performances
- Energy resolution
  - 2% (>100GeV) for electron, γ
  - 30~35% for protons, nuclei
- Charge resolution
  - 0.15 – 0.3*e*
- Angular resolution
  - 0.2 deg for electron, γ > ~50GeV

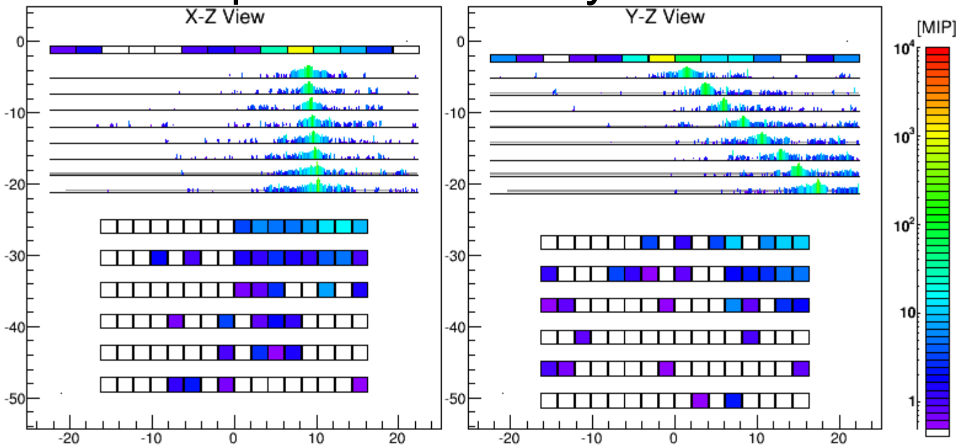
	CHD (Charge Detector)	IMC (Imaging Calorimeter)	TASC (Total Absorption Calorimeter)
Function	Charge Measurement (Z=1-40)	Arrival Direction, Particle ID	Energy Measurement, Particle ID
Sensor (+ Absorber)	**Plastic Scintillator : 14 × 2layers** Unit Size: 32mm x 10mm x 450mm	**Scintillating fibers: 448 x 16 layers** Unit size: 1mm^2 x 448 mm **Total thickness of Tungsten: 3 X_0**	**PWO log: 16 x 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)@top layer

Analysis of Heavy Nuclei and Ultra Heavy Nuclei

An example of heavy nuclei



An example of ultra heavy nuclei



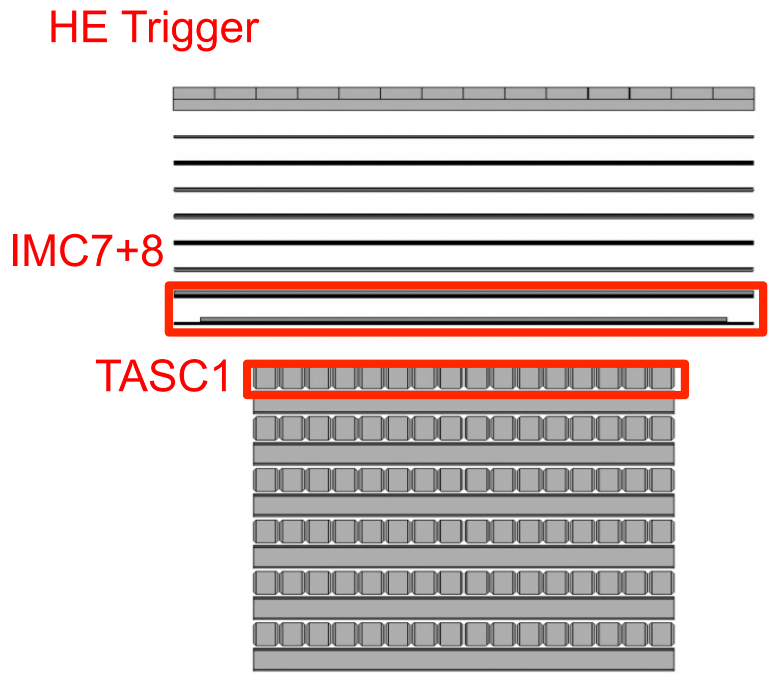
- Analysis of heavy nuclei (Z>8)
  - On-board trigger
  - Event reconstruction
    - Track reconstruction
    - Charge identification
    - Energy measurement
  - Energy unfolding
  - Spectrum of primary components

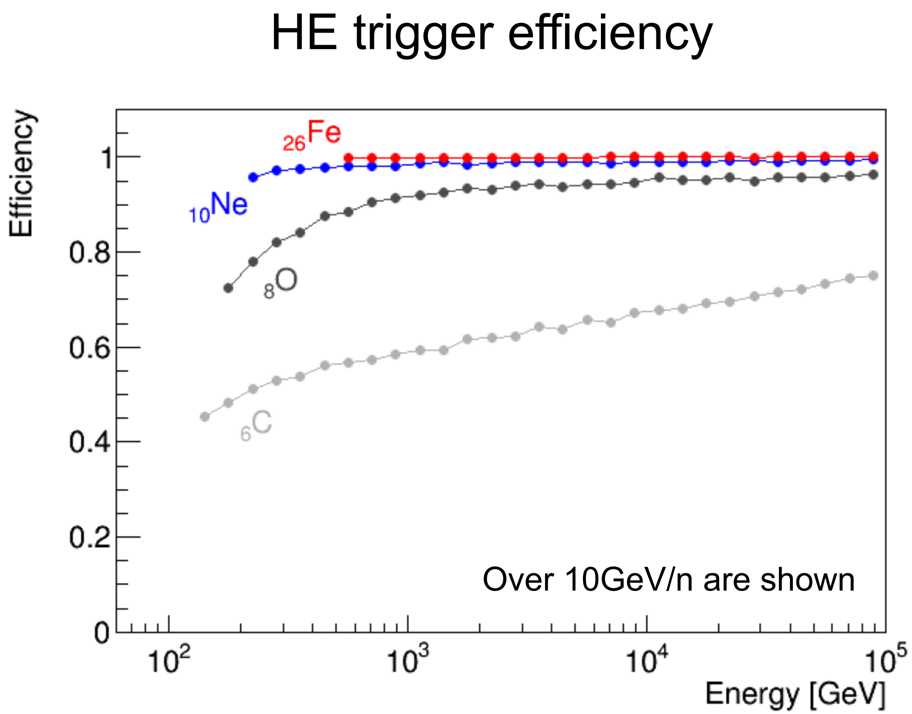
- Analysis of ultra heavy nuclei (Z≤40)
  - On-board trigger
  - Event reconstruction
    - Track reconstruction
    - Charge identification
  - Relative abundance to Fe

On-board trigger for heavy nuclei

On-board High Energy shower trigger (HE Trigger):
- The energy thresholds are set to detect shower events with energies over 10GeV

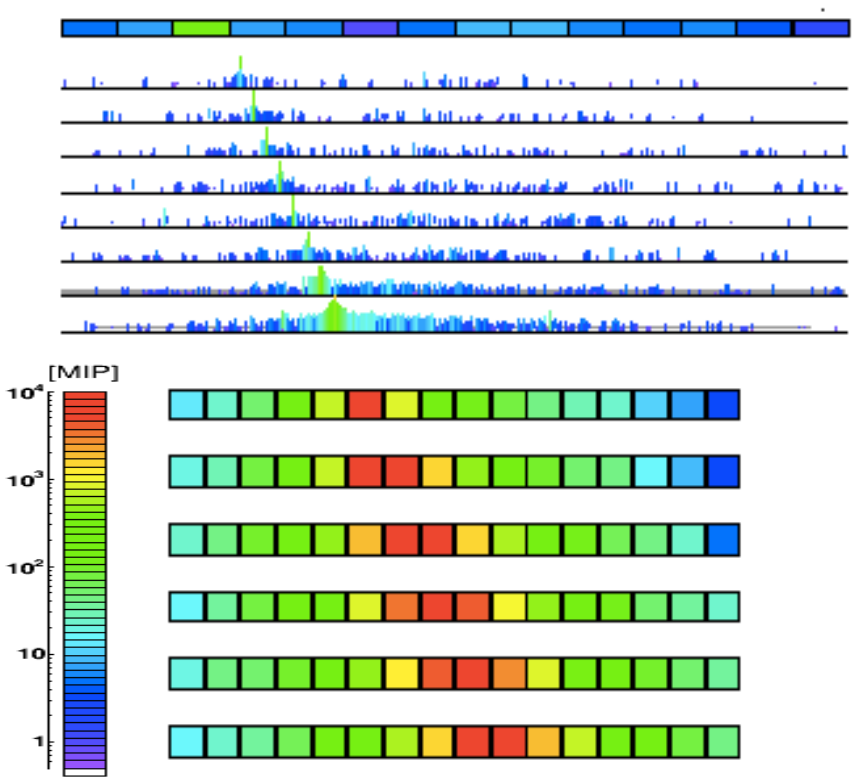
While penetrating light nuclei like protons and helium are not triggered, heavy ions with $Z > 8$ that interact in deep layers are detected thanks to its large dE/dx
⇨ Trigger efficiency for heavy nuclei with $Z > 8$ is therefore almost 100%.





Analysis procedure for heavy nuclei

shower image in X-Z view



Event reconstruction

① Tracking IMC
- Track reconstruction
  (CHD-X) 330μm, (CHD-Y) 300μm

② Charge measurement CHD
- dE/dx measurement
- consistency in CHDs and IMCs

③ Energy measurement TASC
- Sum of deposit energy in TASC

Flux measurement

- Energy unfolding
- Efficiencies, contaminants

Analysis procedure for heavy nuclei

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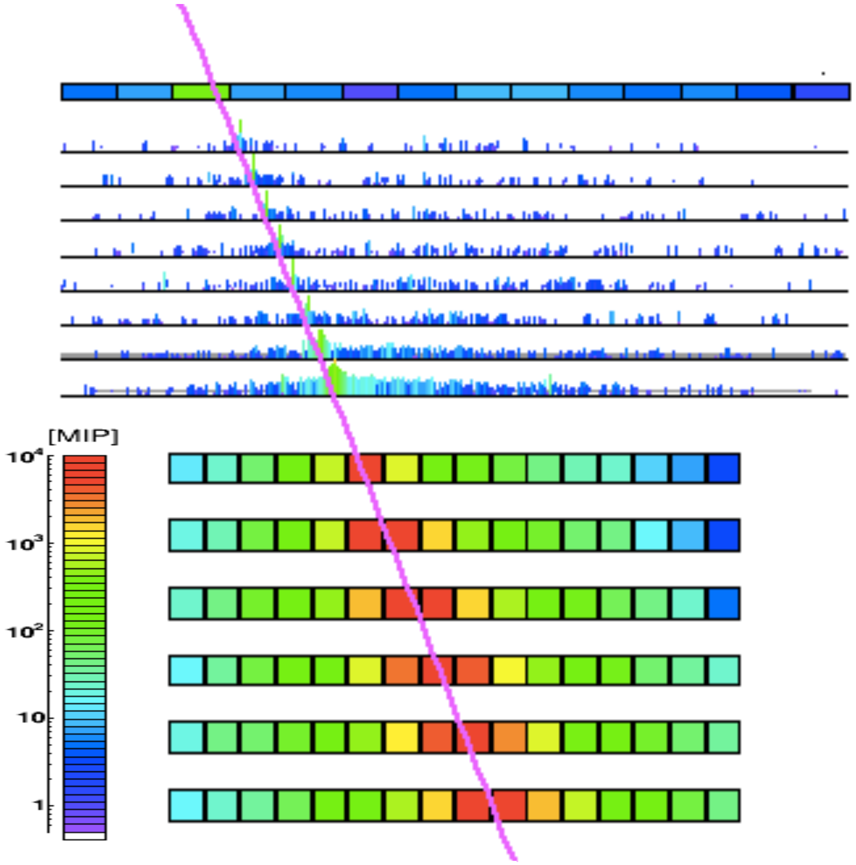

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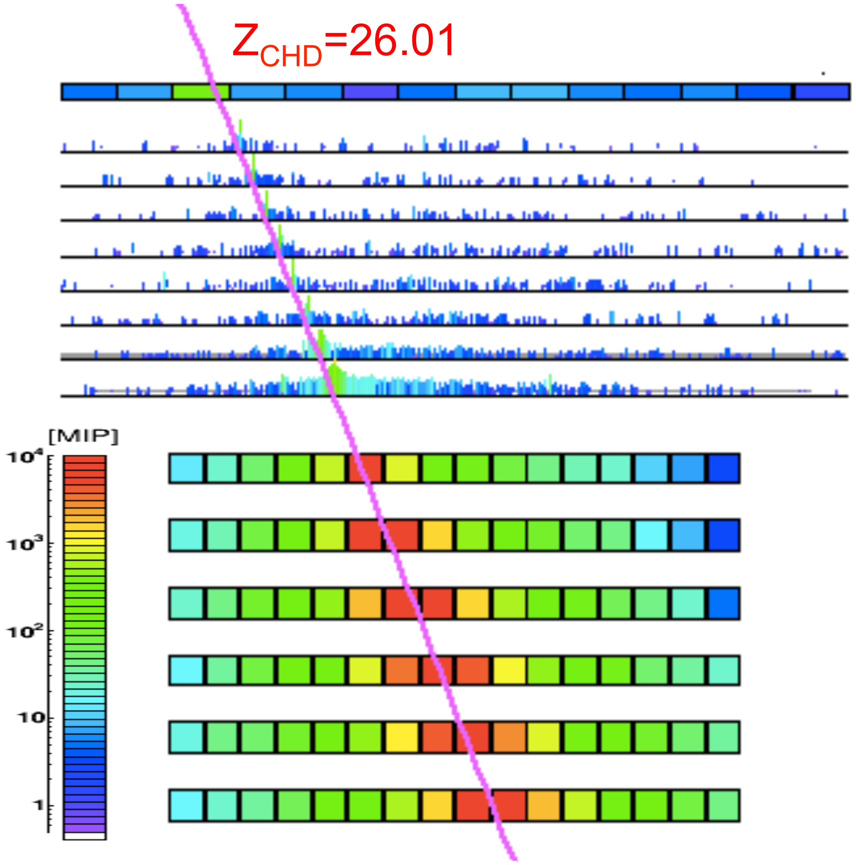

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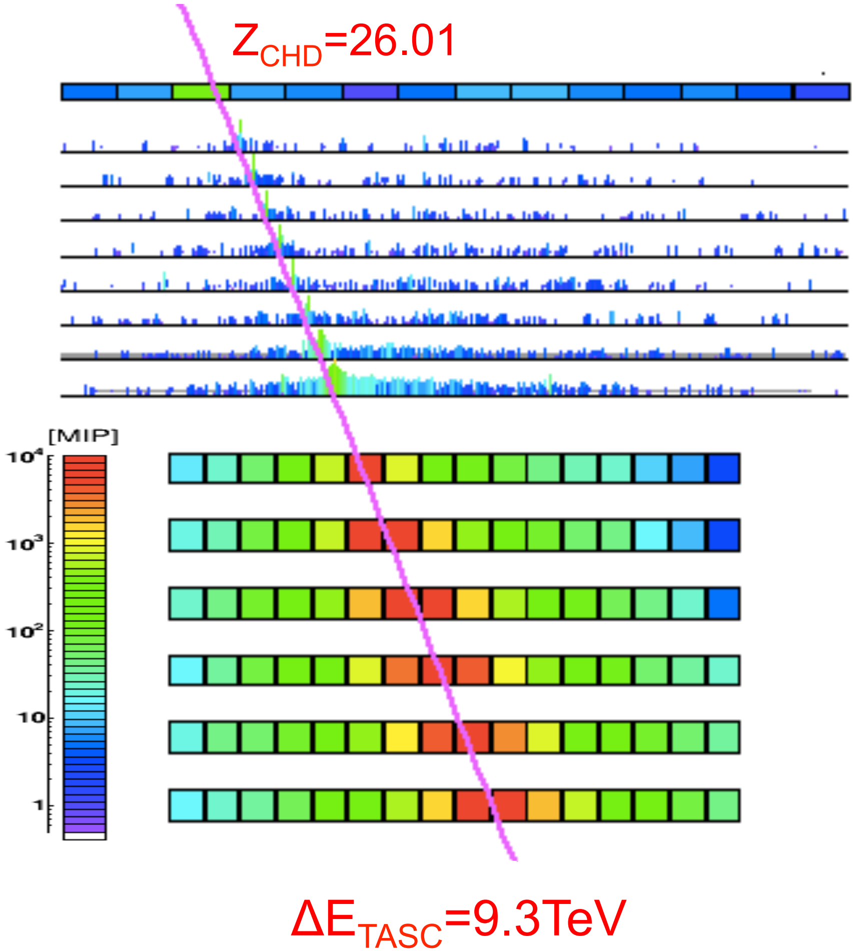

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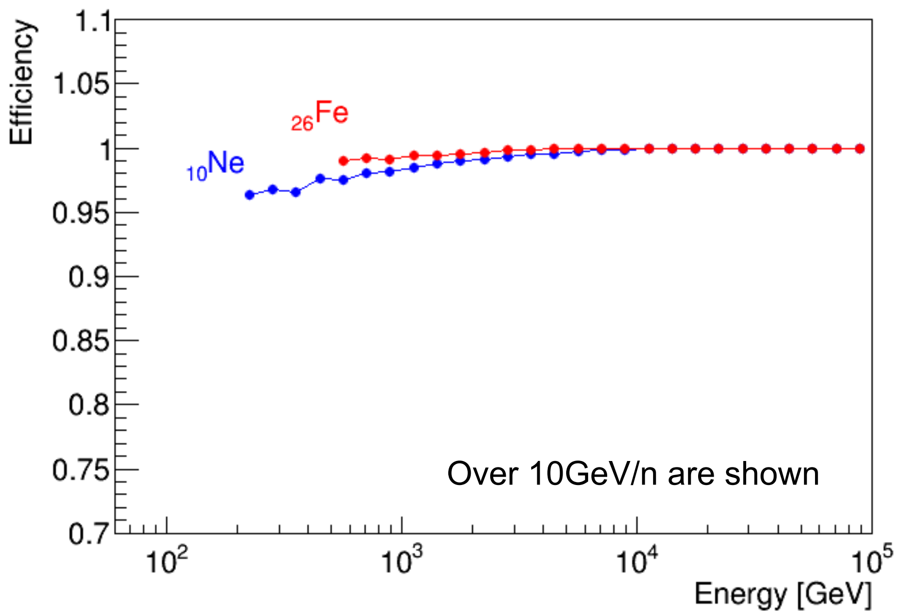
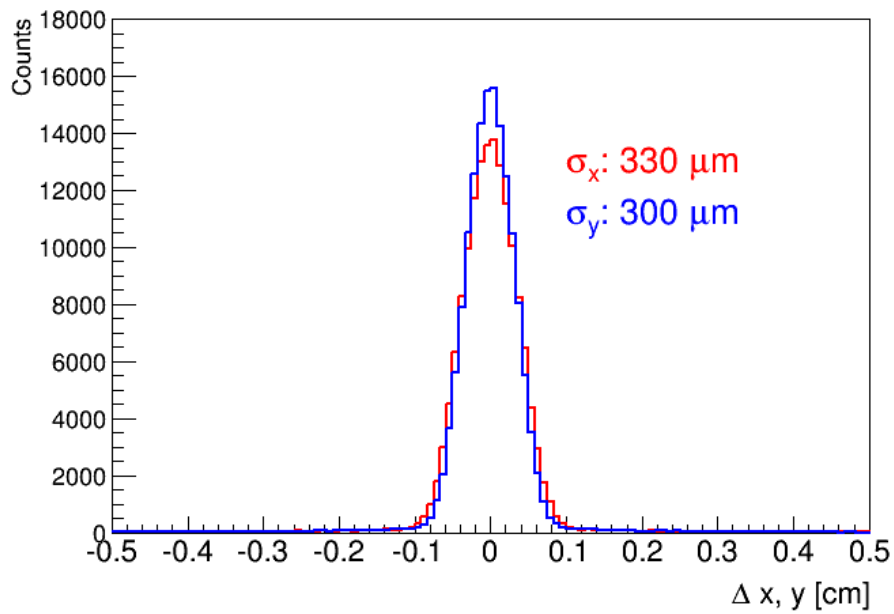
Track reconstruction

- Reconstruction of the shower axis is based on IMC signals
- Heavy nuclei can make many shower particles in IMC, which could be a large background for track reconstruction. But the signal of primary particle is commonly larger than the signals of the shower particles
  - ⇨ Simple tracking methods: Least chi-square fitting was applied for the maximum clusters in upper four IMC layers.

Tracking efficiency



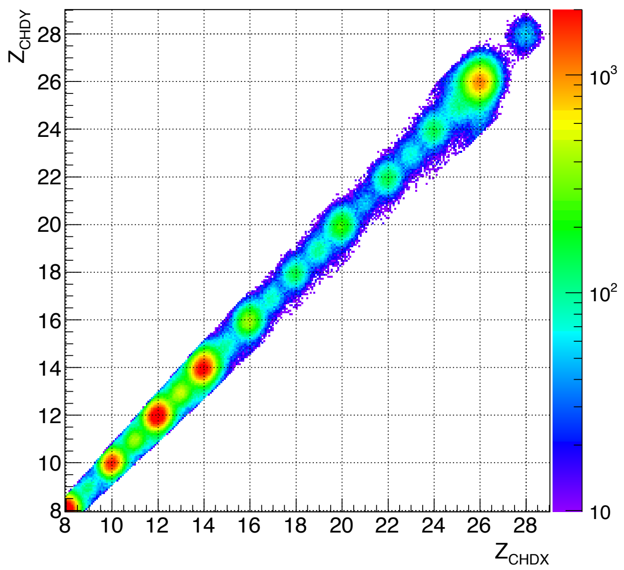
Accuracy of impact point at CHD



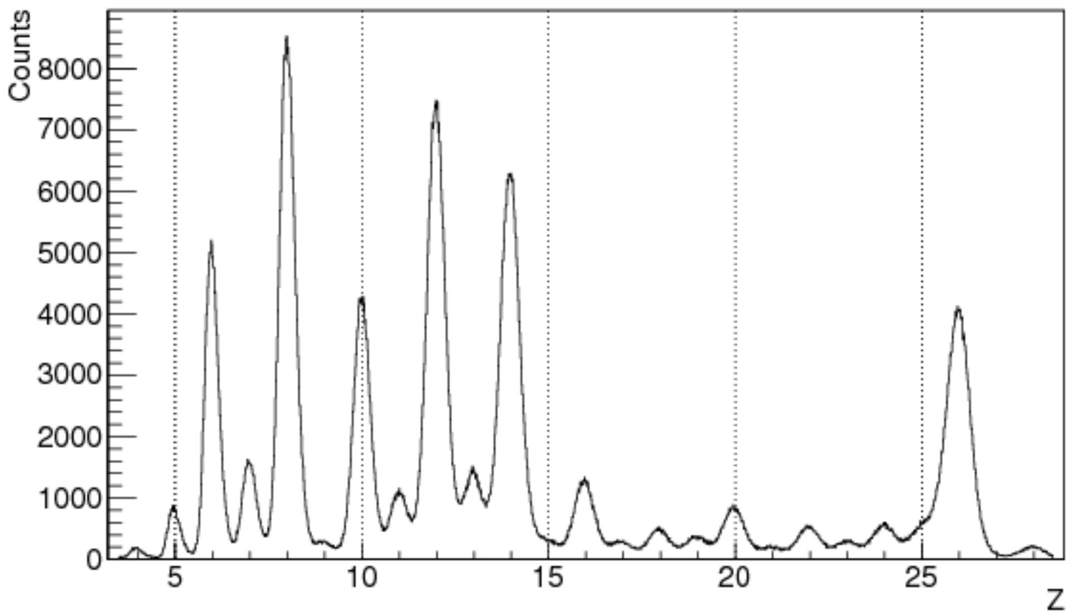
Charge identification

- Charge determinations are based on the signals from the CHD paddles
- To maintain good charge resolution and remove interact events at CHD;
  - require the charge consistency in CHD and IMC
  - Efficiency of these consistency cuts is 65~70% for heavy nuclei (Z>8) with little energy dependence

Charge correlation in CHD

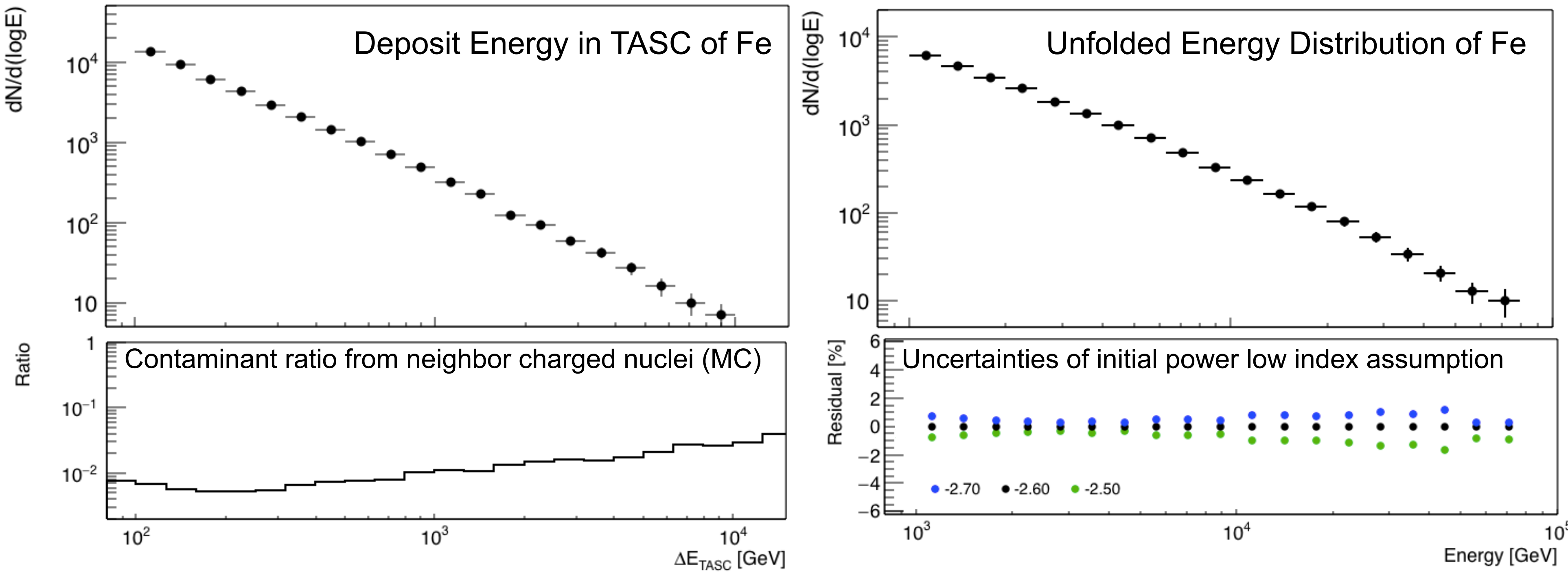


Charge distribution with CHD



Energy measurements and unfolding

- The shower energy is determined from the sum of the TASC signals
- To derive the primary energy spectrum, Bayesian unfolding procedure were applied
- Response functions were made from MC simulation;
  - EPICS v9.21, Cosmos8.01 with DPMJET-III
  - Assuming MC spectra: $dN/dE = A\,E^{-\gamma}$ γ: initial power low index (=2.60)
    A: norm. factor (determined by charge distributions)
- Charge selection efficiencies and contaminants from the neighboring charged nuclei were also taken into account in the unfolding procedures



Energy spectrum of heavy nuclei

Flux measurement:

$$\Phi(E) = \frac{N(E)}{S\Omega\varepsilon(E)T\Delta E}$$

$N(E)$	Events in unfolded energy bin
$S\Omega$	Geometrical acceptance (416 cm^{2}sr)
T	Live time (39 million seconds) (Oct.13 2015 – Mar.31 2017)
$\varepsilon(E)$	Efficiency of trigger and track reconstruction (>96%)
ΔE	Bin width

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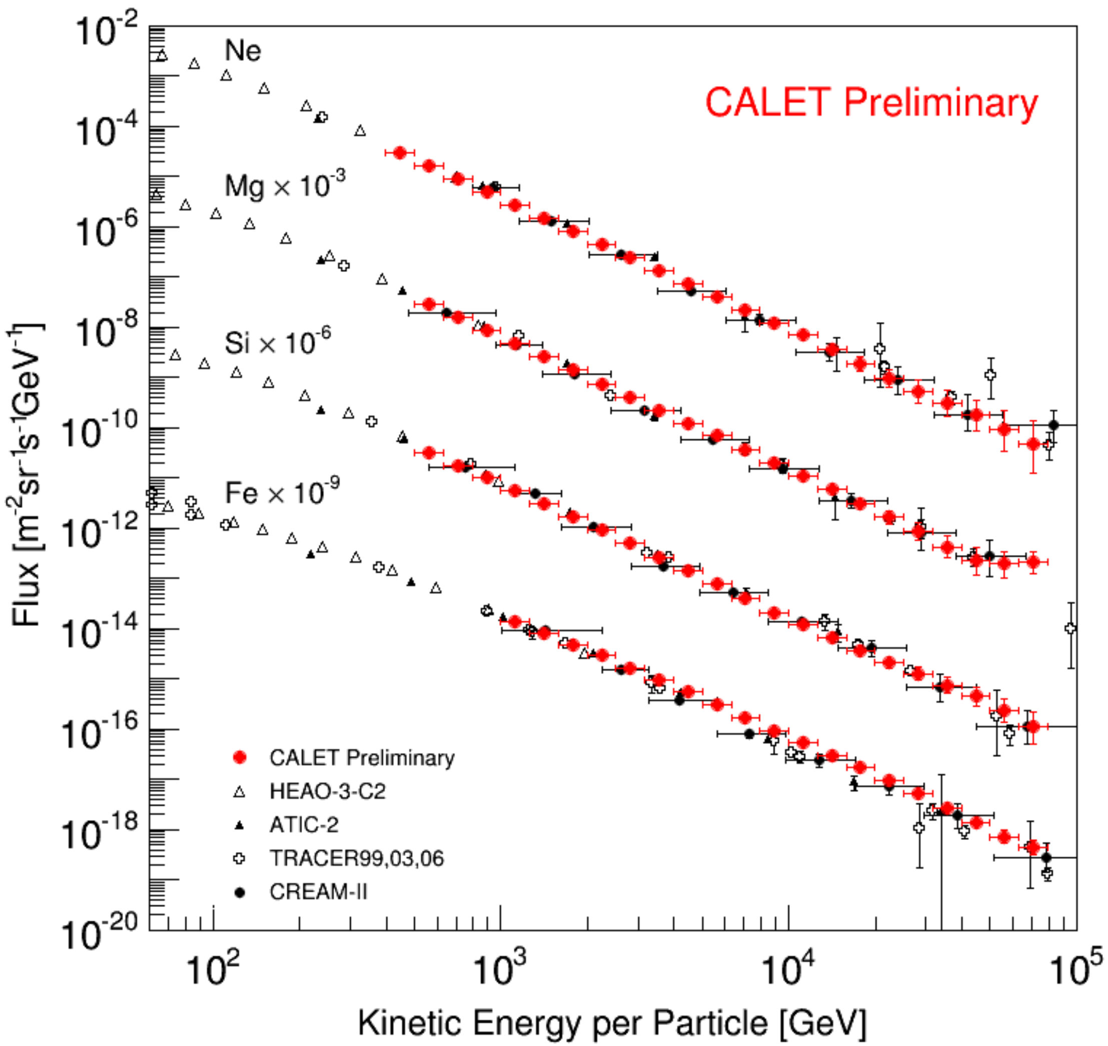
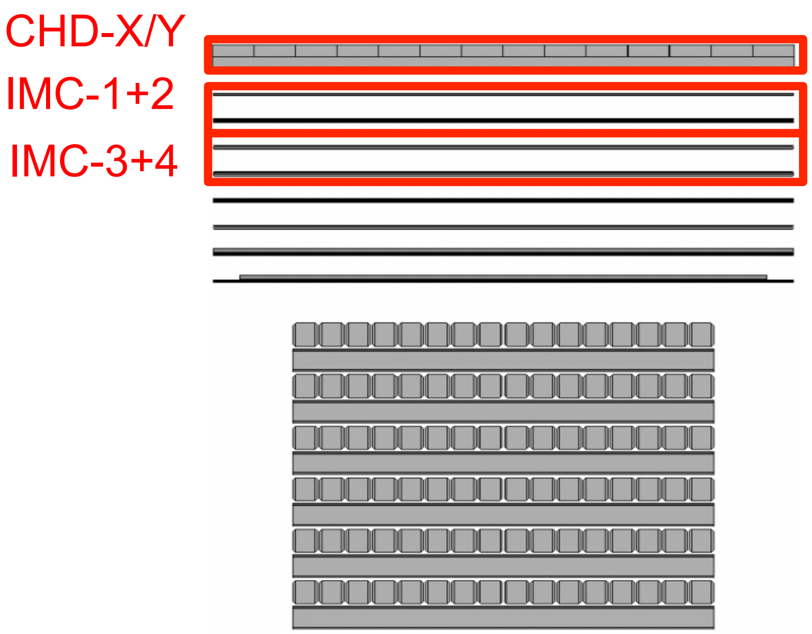
ΔE Bin width



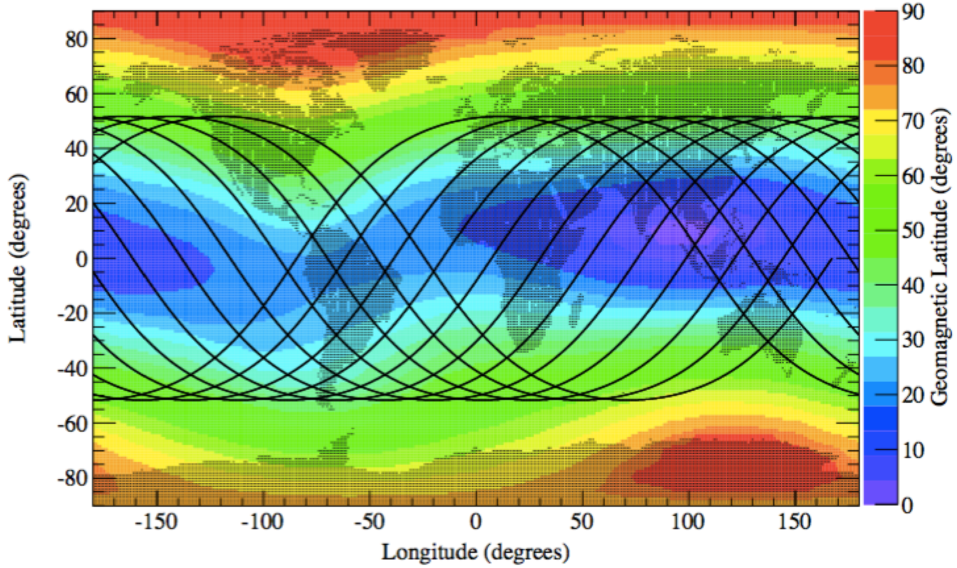
Observations of ultra heavy nuclei

- CALET measures the relative abundances of ultra heavy nuclei through $_{40}Zr$
- Onboard trigger for ultra heavy nuclei:
  - -signals of only CHD, IMC1+2 and IMC3+4 are required
  - ⇨ an expanded geometrical acceptance (4000 cm^2sr)
- Energy threshold depends on the geomagnetic cutoff rigidity

Onboard trigger for UH events



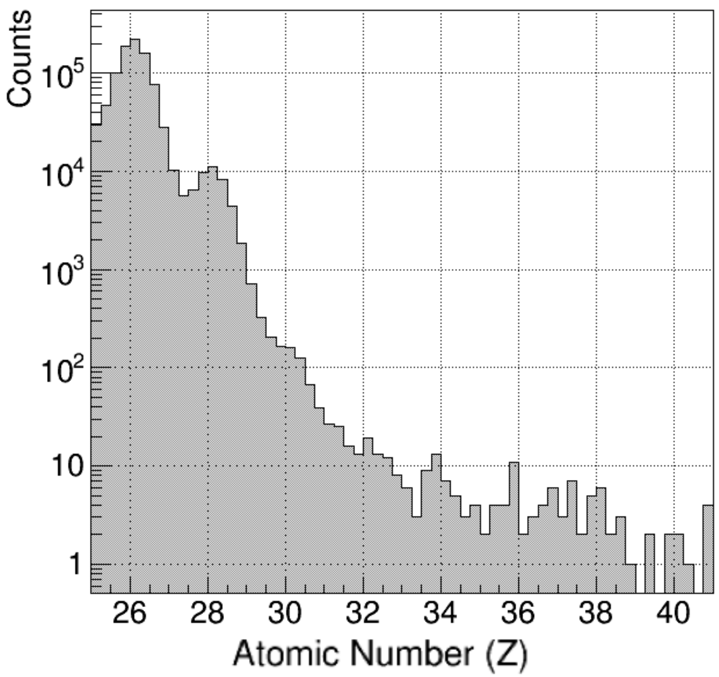
Geomagnetic Latitude



Relative abundance to Fe

- Methods of track reconstruction and charge determination are same as those for heavy nuclei analysis
- Event selection:
  - Vertical geomagnetic cutoff rigidity > 4GV
  - Zenith angle < 60 degree

Charge distribution



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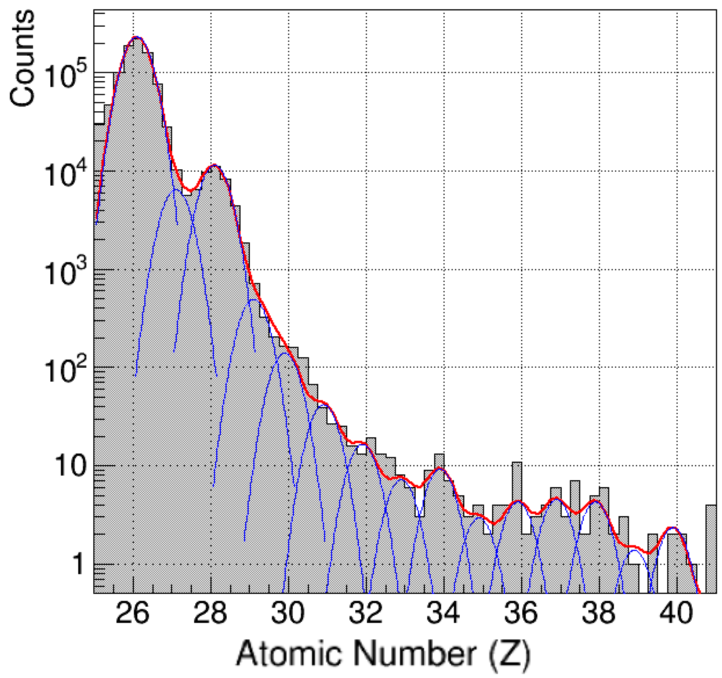
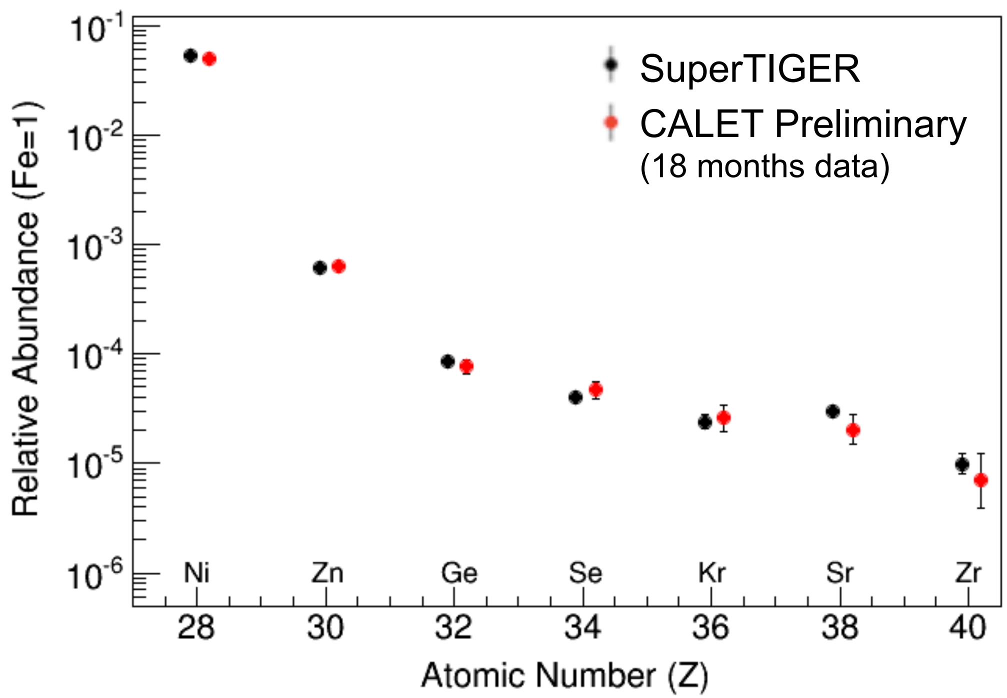
- Methods of track reconstruction and charge determination are same as those for heavy nuclei analysis
- Event selection:
  - Vertical geomagnetic cutoff rigidity > 4GV
  - Zenith angle < 60 degree
- Contaminants from neighbor charge were determined from multiple-Gaussian function

Charge distribution



Relative abundance (Fe=1)



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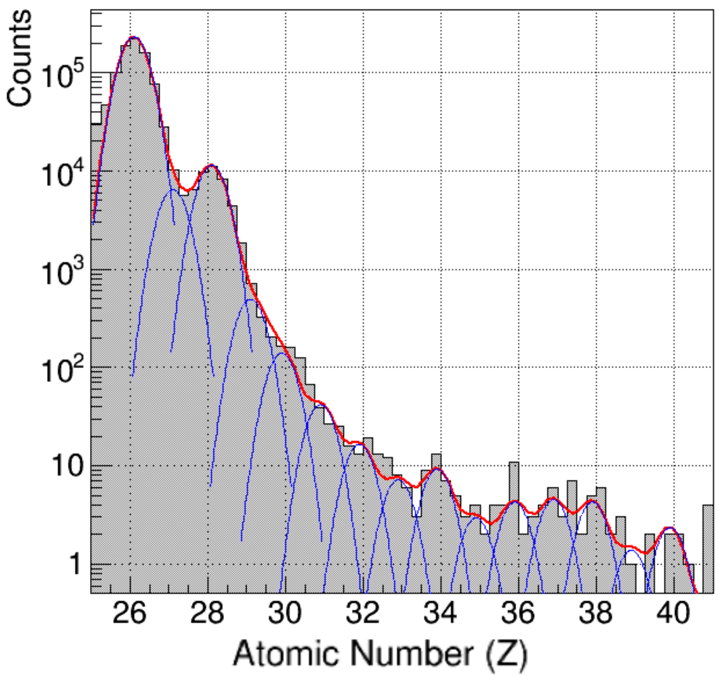

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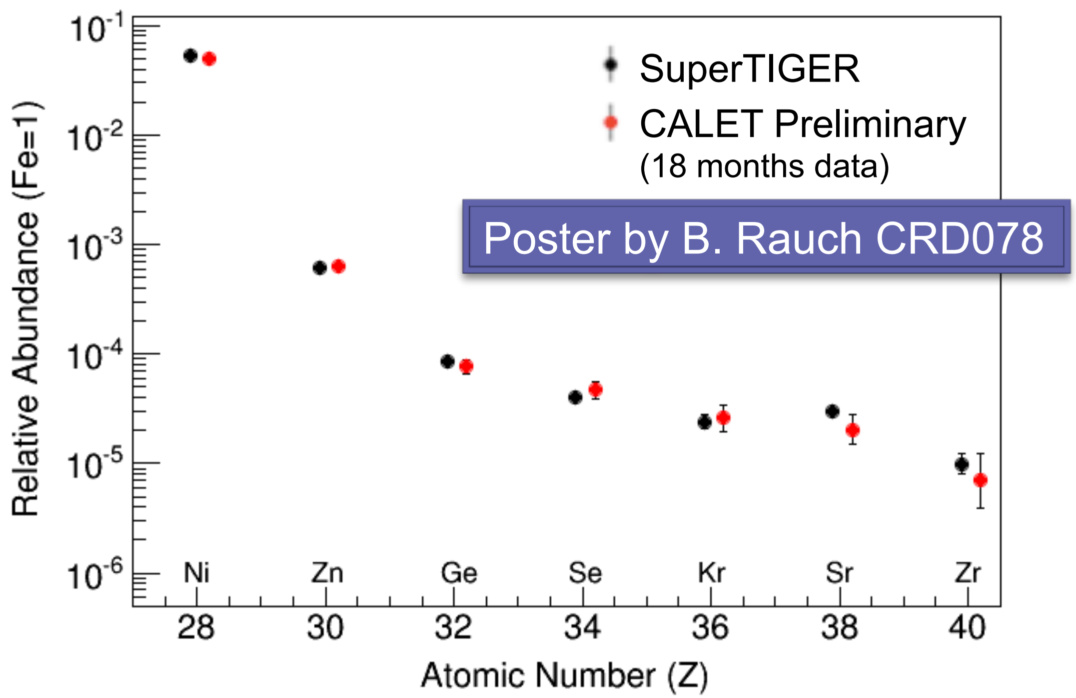

Conclusions

Energy spectrum of heavy nuclei up to 100TeV/particle

- The ability of CALET to measure heavy cosmic-ray nuclei has been successfully demonstrated, and preliminary energy spectra have derived for the primary comic ray elements up to 100TeV using data from the first 18 months of operation.
- Further studies will provide the excellent energy spectra with high statistics in a wide energy range, and reveal details spectral features.

Relative abundances of ultra heavy nuclei ($_{26}$Fe – $_{40}$Zr)

- CALET has also the capability to measure the relative abundances of the ultra heavy nuclei, and preliminary results of relative abundance to Fe were consistent with SuperTIGER within statistical uncertainties.
- Further studies will reduce the low-energy spillover from lower charges and allow us to resolve the odd-Z abundances as well.

END

Weighting for MC

- Response functions were made from MC simulation;
  - EPICS v9.21, Cosmos8.01 with DPMJET-III
  - Assuming MC spectra: $dN/dE = A\,E^{-\gamma}$

    γ: initial power low index (=2.60)

    A: norm. factor (determined by charge distributions)

Charge distribution with CHD