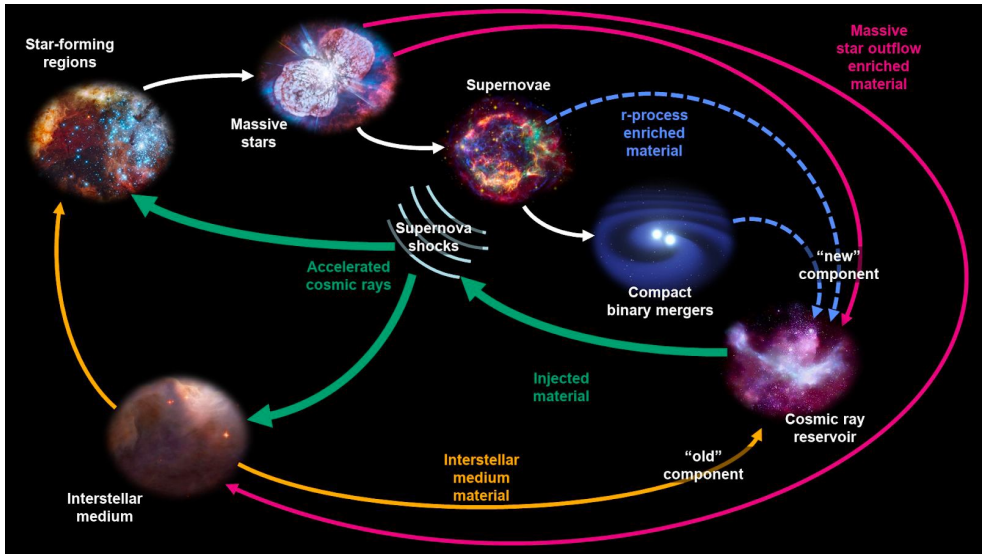
CALETによる宇宙線超重核の観測

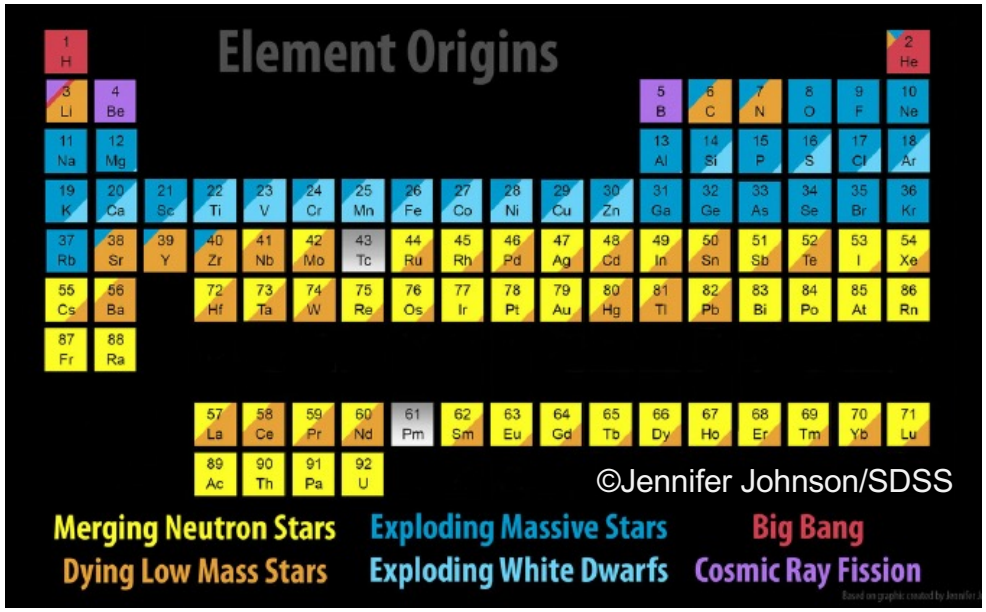
早大理工総研, WUSTL[A], 芝工大シエ[B]

赤池陽水, Wolfgang Zober[A], Brian Rauch[A],
鳥居祥二, 小林兼好, 笠原克昌[B]
他 CALET チーム

Objectives of Ultra-heavy nuclei measurements (Z≦44)

- Perform new tests of the origins of galactic cosmic rays
  - ➡ strengthen evidence pointing to OB associations as a major source of cosmic rays
- Test mass dependence and refractory/volatile fractionation
- Begin to sample the charge range where r-process production resulting from binary neutron star mergers (NSM) may become important
  - r-process from massive stars and BNSM
  - s-process from massive stars only





https://www.ligo.caltech.edu/news/ligo20180817

Observations of Ultra Heavy Cosmic Rays

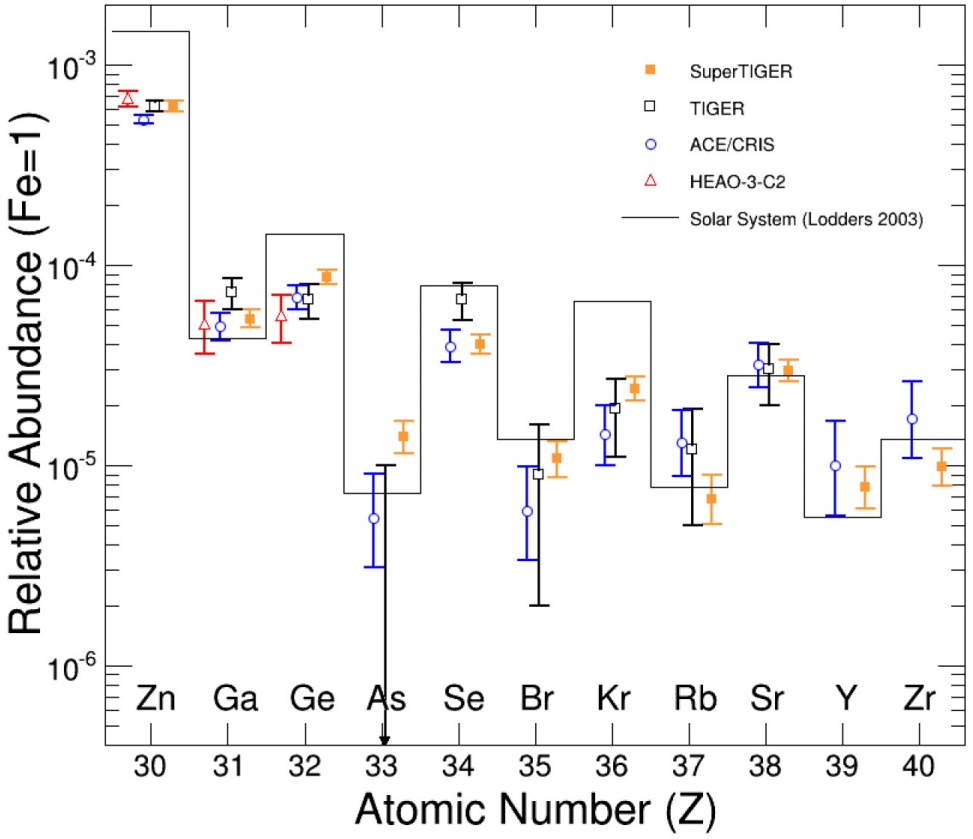
☐ UHCR is very rare (<10^{-4} of Fe)

◆ ACE-CRIS: satellite (1997~)
L1 Lagrange point
E = ~100 – 500 MeV/n
SΩ~0.025 m^2sr

◆ SuperTIGER: balloon
Antarctica
E > 350 MeV/n
SΩ~8.3 m^2sr ($SΩ_{eff}$~ 3.9 m^2sr)
- ST-1: 55days, ST-2: 32days
- need atmospheric corrections

◆ CALET: (2015~)
ISS within earth's magnetosphere
E > (Cutoff rigidity)
SΩ~0.4 m^2sr
- not need atmospheric corrections
- long observation on the ISS

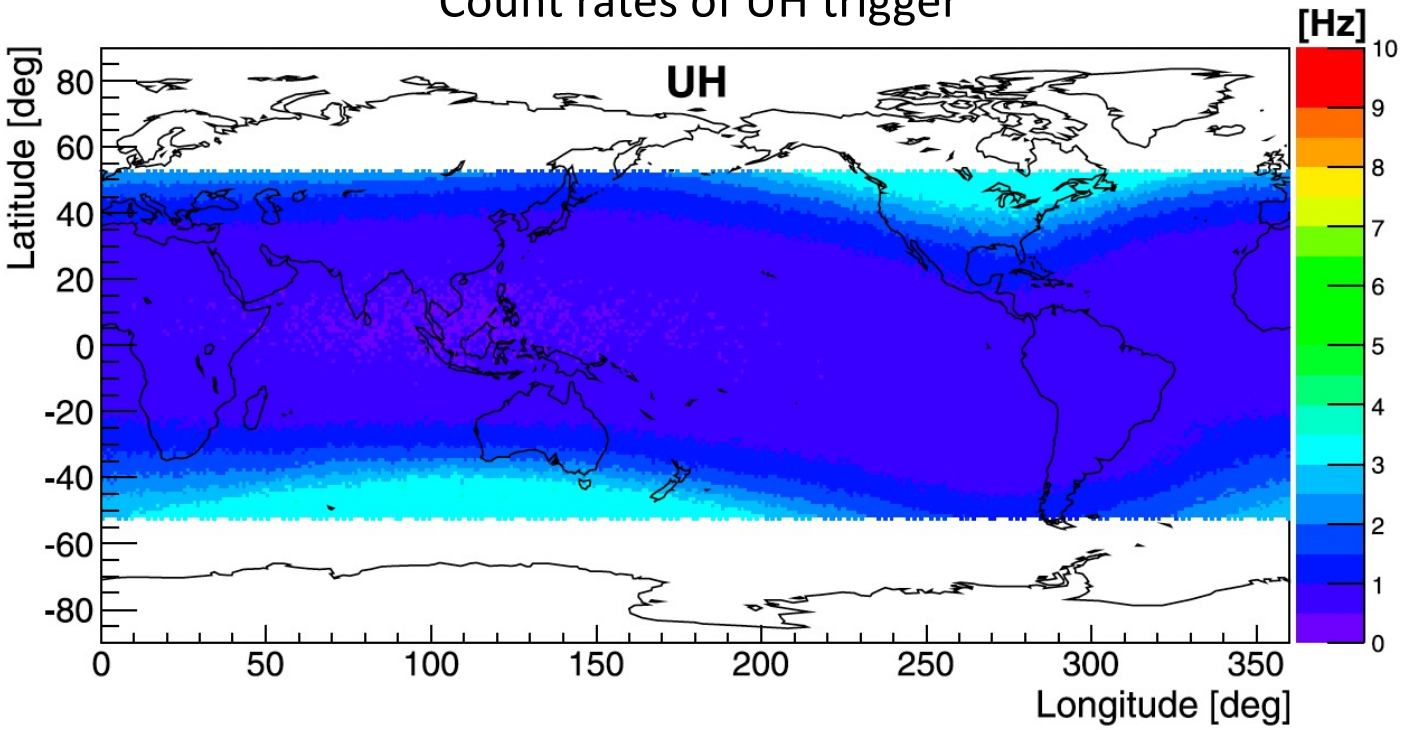
Murphy et al. Apj **831** 148 (2016)



UH measurements with CALET

- CALET-CHD can measure the charge with Z≦44
- Ultra-Heavy (UH) trigger always operates together with the high-energy (HE) trigger.
- The threshold of UH trigger is set to be detect particles
  with Z ≧ 12 (until Dec. 2023),
  Z ≧ 8 (from Dec. 2023)

Count rates of UH trigger



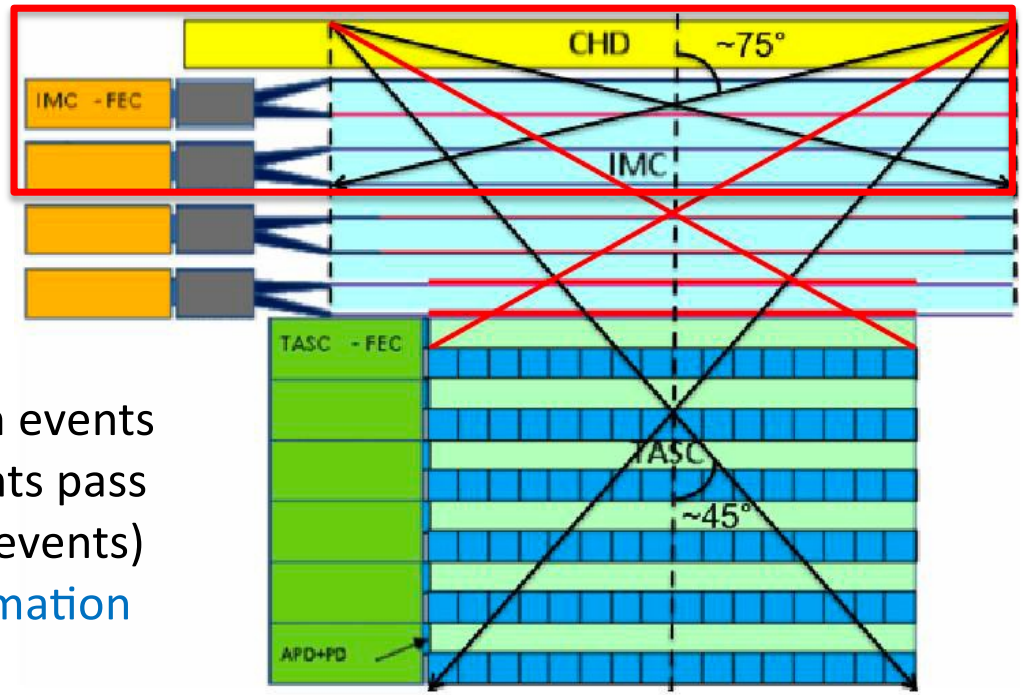
UH measurements with CALET

UH trigger

- UH Trigger by the coincidence of
  - CHD-X & CHD-Y
  - IMC-1X and -1Y
  - IMC-2X and -2Y

➡ wide acceptance angle (~75°)
~0.4 m^2 sr

UH Trigger



Analysis:

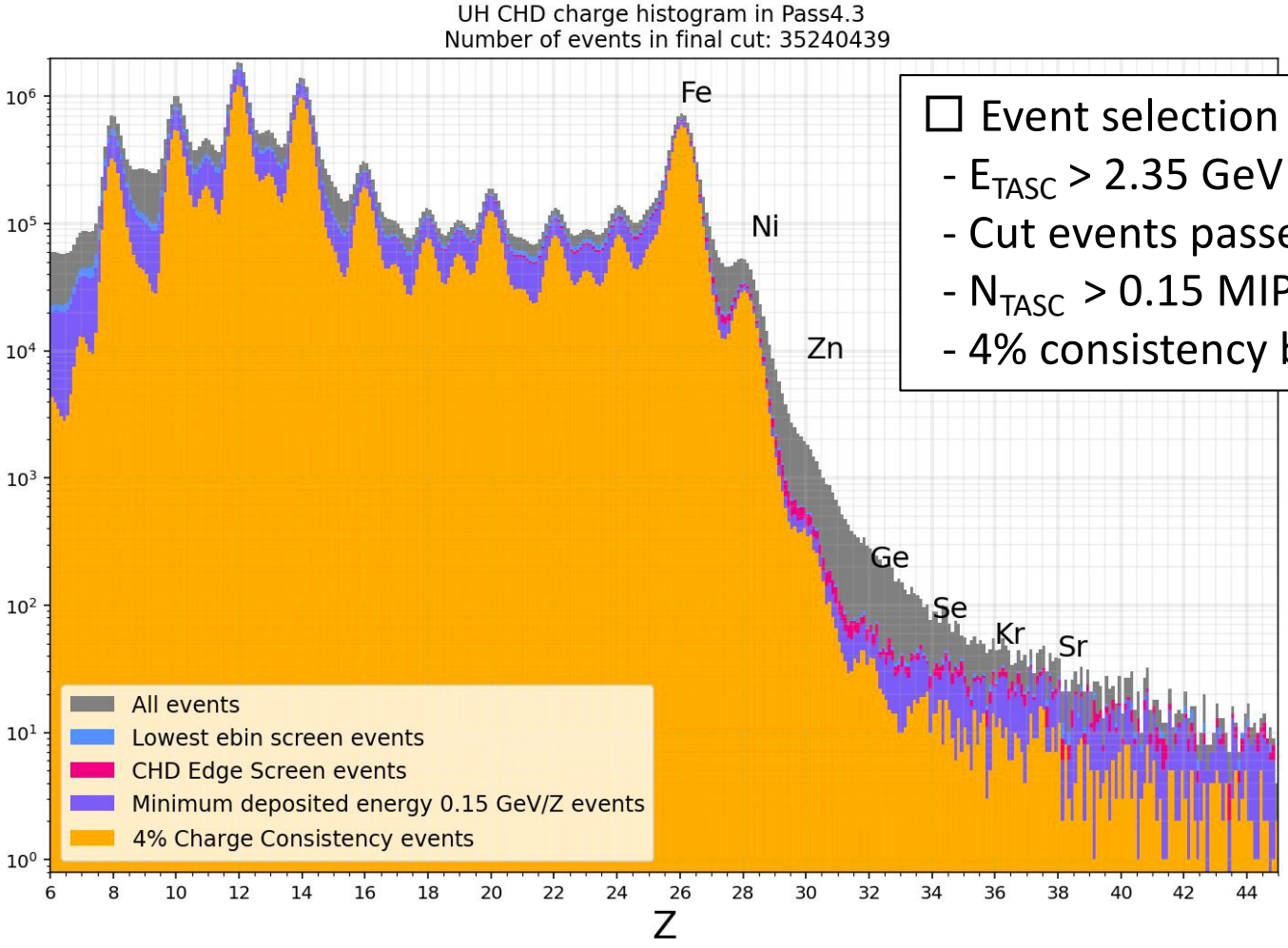
- 151013 – 230630 (>7 years): ~280 million events
- Add a constraint to the analysis that events pass through the top of the TASC (~70 million events)

This reduces statistics but the energy information allows for an improved charge assignment.

- MIP calibration with Fe ions
  - position dependence
  - time variation

➡ achieved to 0.1% resolution

Event selection



☐ Event selection
- E_{TASC} > 2.35 GeV
- Cut events passes through the edge of CHD
- N_{TASC} > 0.15 MIP/Z
- 4% consistency between Z_{CHDX} and Z_{CHDY}

Determination of Abbundances

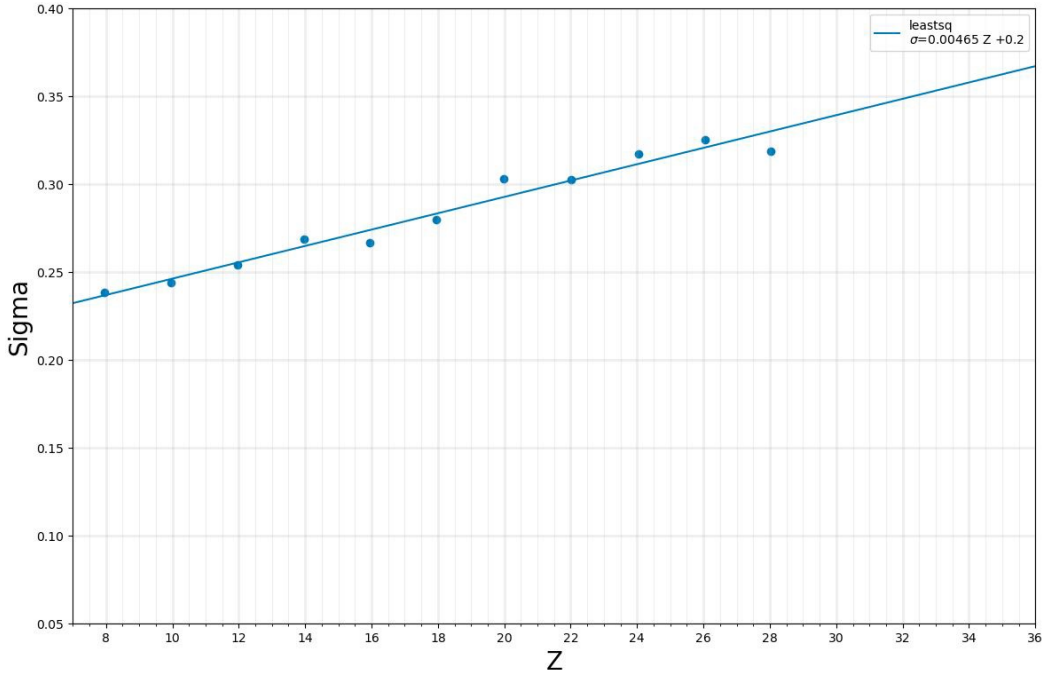
Peak fitting is done over multiple steps

1. The sigmas from the even peaks over 8≦Z≦28 are then linearly fit to extrapolate a sigma for all peaks

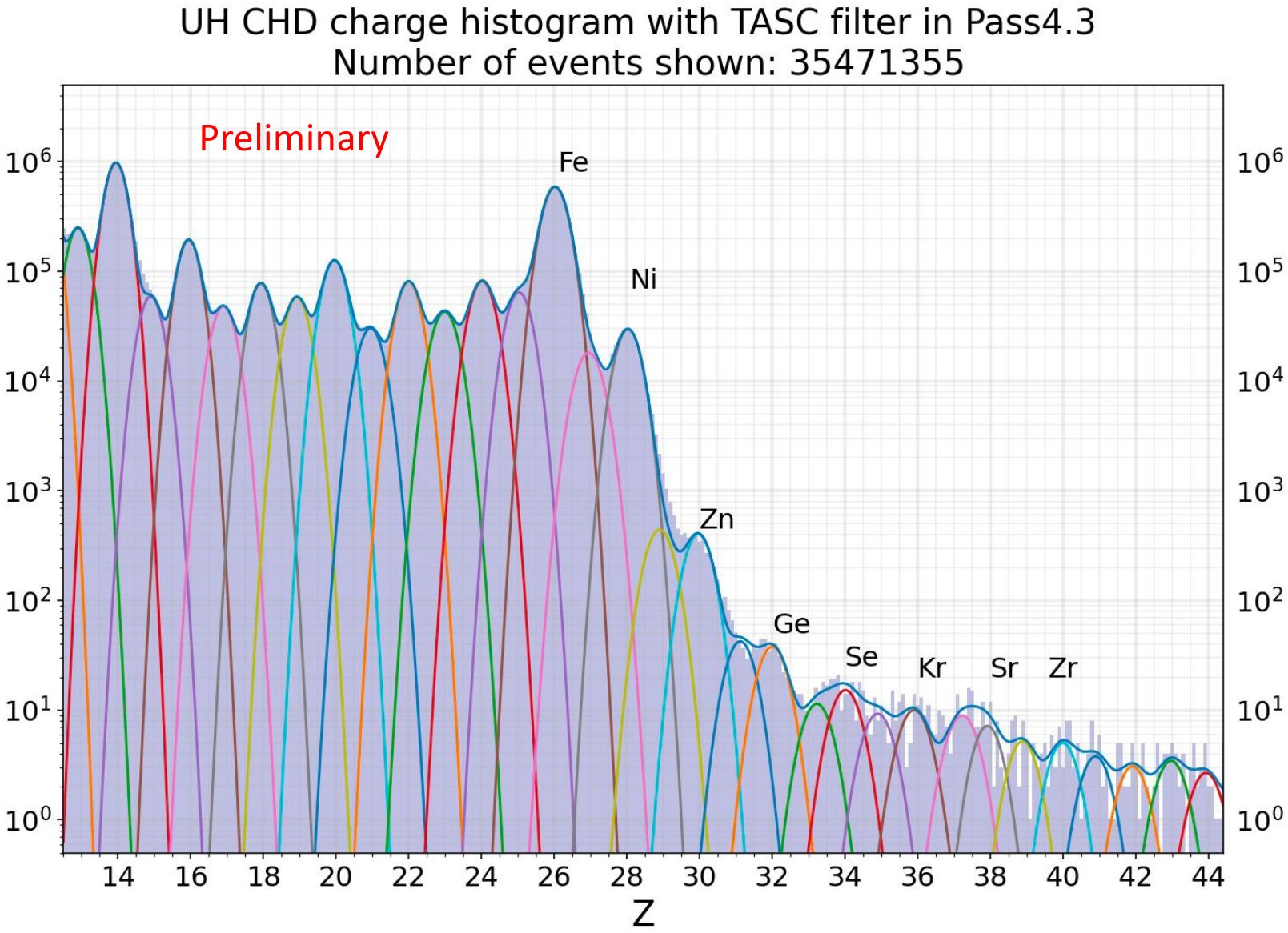
2. Multi-gaussian uses that linearized sigma equation with a maximum-likelihood multiple-Gaussian fit for all elements

3. Final fit uses a fixed position and sigma from the second fit to determine error bars on the abundances

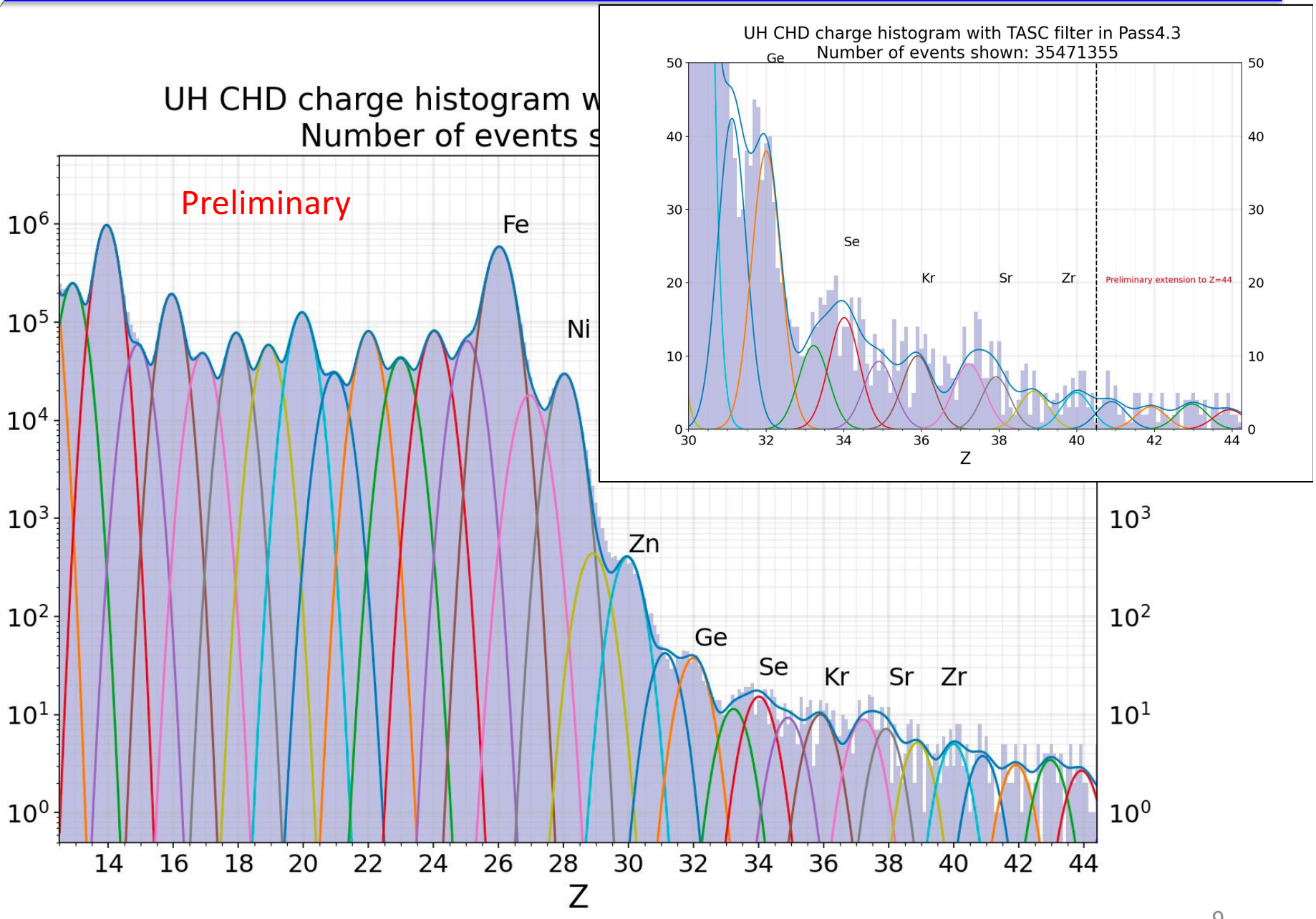
Sigma of each gaussian fit



UH CHD charge histogram



UH CHD charge histogram



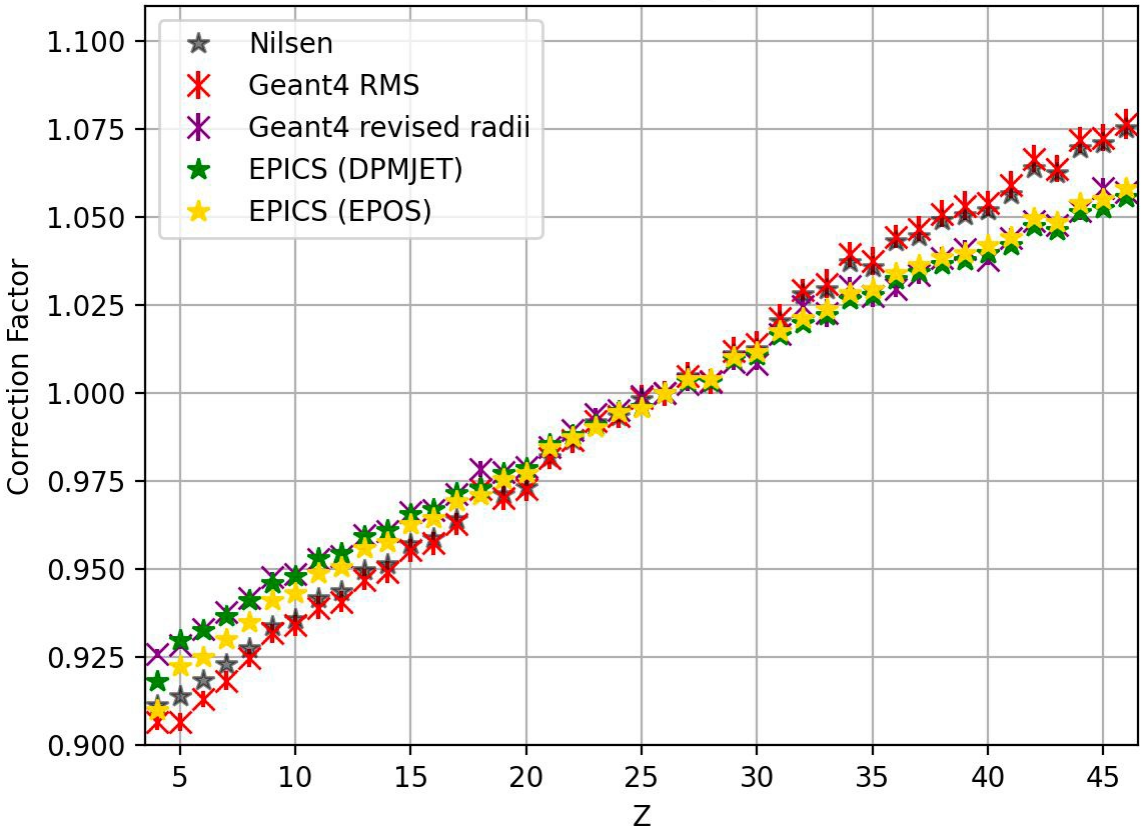
Correction factors

- Events interacting in CHD lose the charge information
- Survival probability are corrected based on the cross-section calculated by EPICS, Geant4 and Nilsen (1995)

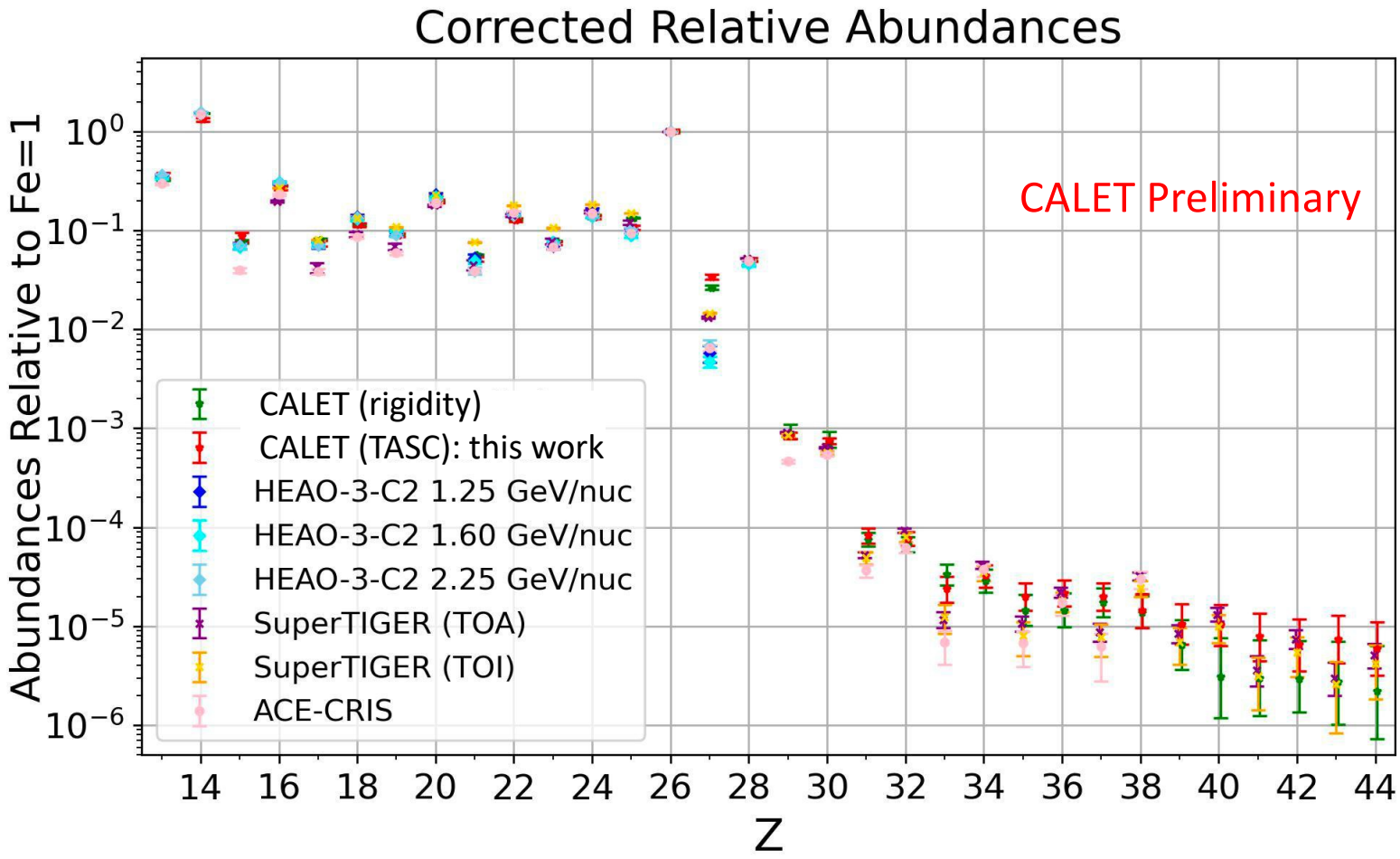
Geant4 simulations do not use the default nuclear radii function as the default function is a piecewise function that has a large discrepancy at A>50.
Two different radii in Geant4 are used to adjust EPICS results.

In the following analysis EPICS(EPOS) is selected, and others are included into the systematic errors

Correction factor for the abundance ratio to Fe (Avg. incident angle)



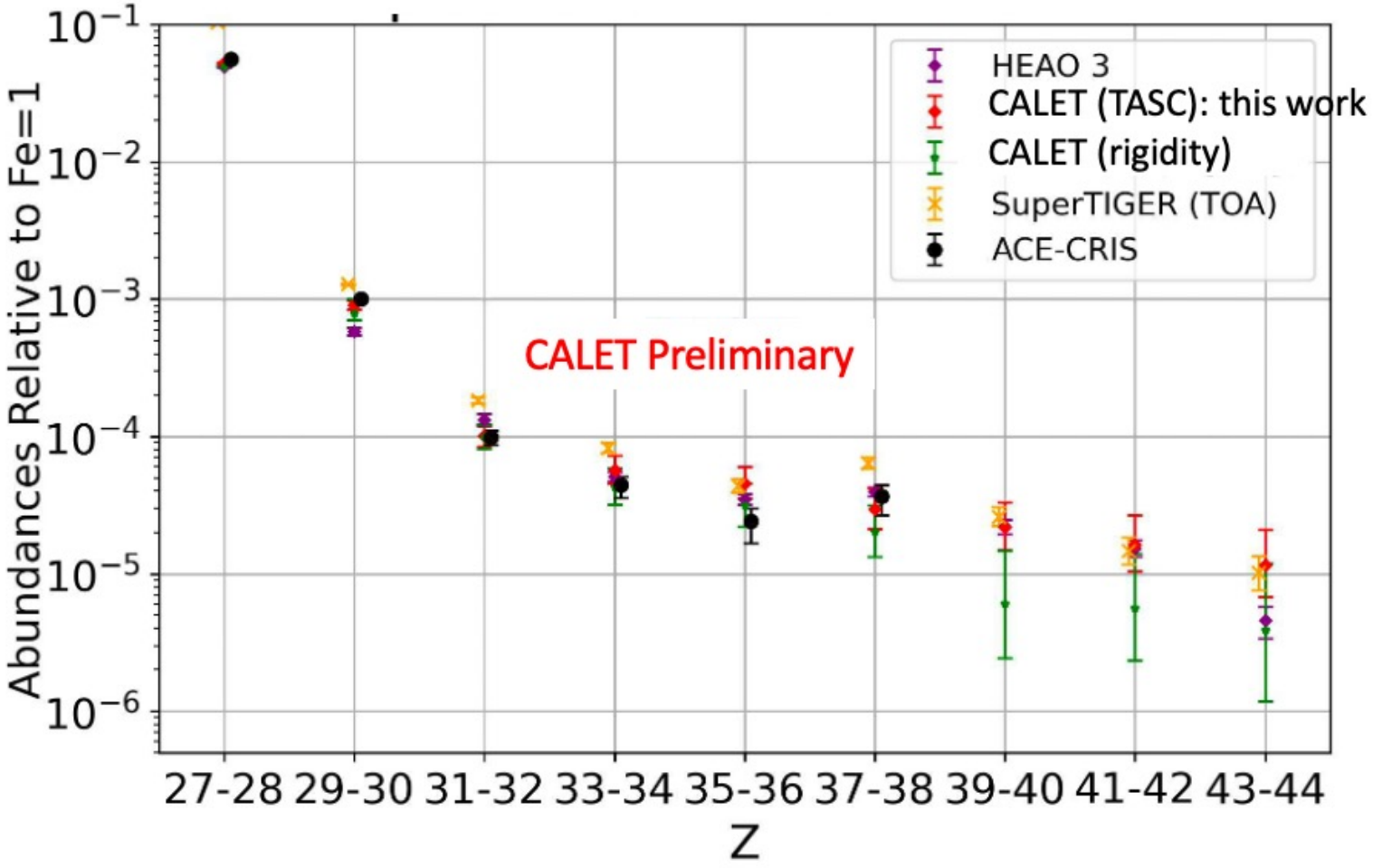
Results related abundances to Iron



CALET (rigidity): without using TASC energy information, cutoff rigidity (Rc>4GV) is required

- CALET (TASC) results are almost consistent with previous analysis
- Odd nuclei with CALET are slightly higher than SuperTIGER and ACE-CRIS

Relative abundances of even-odd pairs for 27<Z<44



CALET (rigidity): without using TASC energy information, cutoff rigidity (Rc>4GV) is required

・CALET (TASC) results are almost consistent with previous analysis

Summary

- CALET has a dedicated trigger mode to measure the ultra-heavy nuclei, which is always on during the operations.
- CALET has a capability to measure the charge up to $Z \leqq 44$.
- Preliminary results based on over 7 years of operation provides almost consistent with previous results including SuperTIGER and ACE-CRIS.
  - Some odd nuclei are larger, which might be due to the charge resolution
- We will expand the geometrical acceptance to improve the statistics.