CALET Ultra-Heavy Cosmic-Ray Analysis

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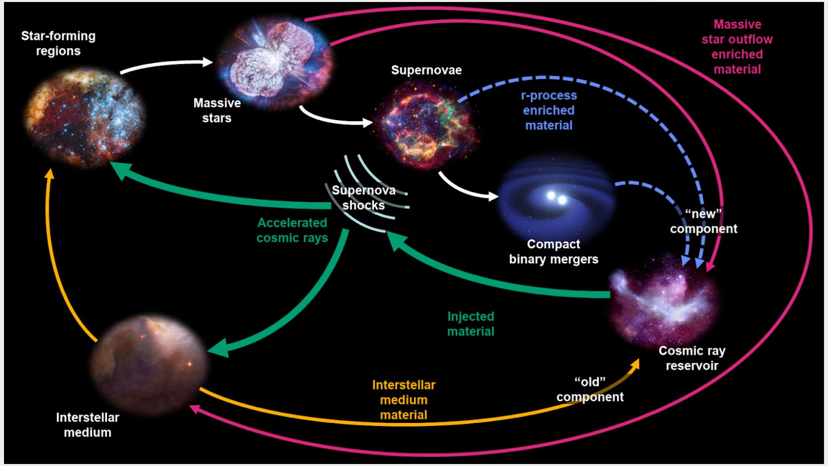
On behalf the CALET Collaboration

Ultra-Heavy Cosmic Ray Science

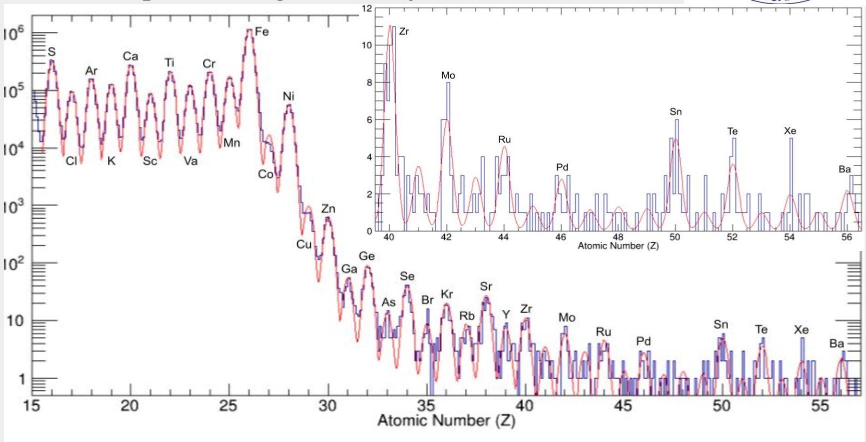
- Ultra-heavy cosmic rays (UHCR) provide clues into the source of all cosmic rays, their acceleration mechanism, and nucleosynthetic sources, which include the most energetic processes in the universe: supernova, binary neutron star mergers, etc.
- Instruments that can do UHCR measurements for $30 \leq Z \leq 40$ with single element resolution:
    - CALET on ISS within earth's magnetosphere with an energy range, E > 1 GeV/nucleon
    - SuperTIGER which measures at similar energies to CALET.
        - Note as stratospheric balloon payload it has different systematics such as requiring atmospheric corrections.
    - ACE-CRIS at the L1 Lagrange point outside Earth's magnetosphere and an energy range ~100 – 500 MeV/nucleon.

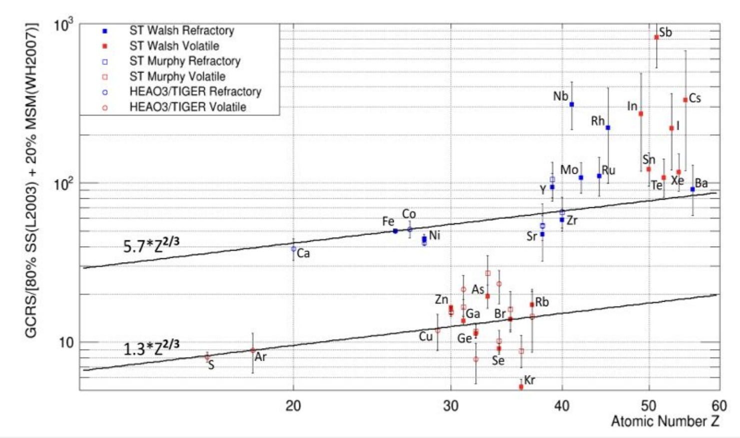


A brief word on SuperTIGER

For more info see
Walsh et al in ICRC2021 and
https://doi.org/10.1016/j.asr.2022.04.063

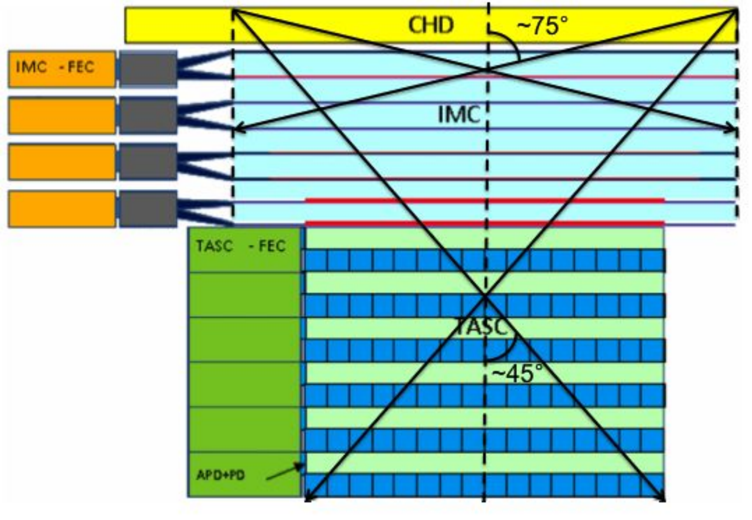
- SuperTIGER can perform single element resolution measurements over $14 \le Z \le 56$.
- Our results see a breakdown in the model of r-process production in the OB association origin and SN shock wave acceleration models after Z=40. This might imply the addition of a new r-process reservoir such as binary neutron star mergers.
- While CALET may only measure UH abundances up to Z=40, CALET's validation of SuperTIGER's results over that range gives further confidence in the determined abundances of elements with higher Z.





Ultra-Heavy Cosmic Ray Science

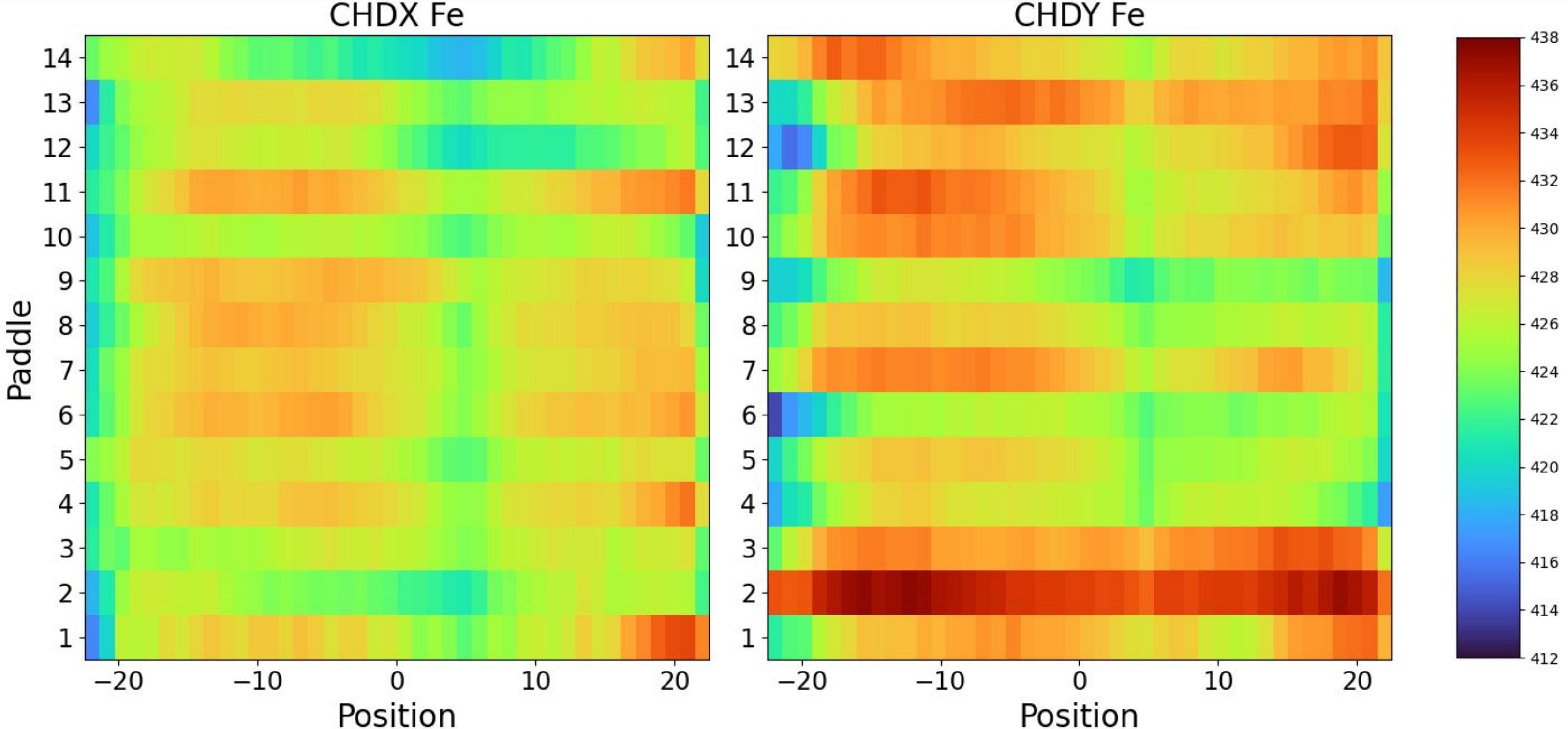
- This analysis uses ~6.5 years of CALET UH-trigger data from 10/2015 through 02/2022. This UH-trigger dataset has ~4× the geometry factor of the standard nuclei trigger. (~230 million events)
- We constrain the analysis to events that pass through the TASC. (~38 million events)
- This reduces statistics but the energy information allows for an improved charge assignment. Allowing us to trade statistics for better resolution.



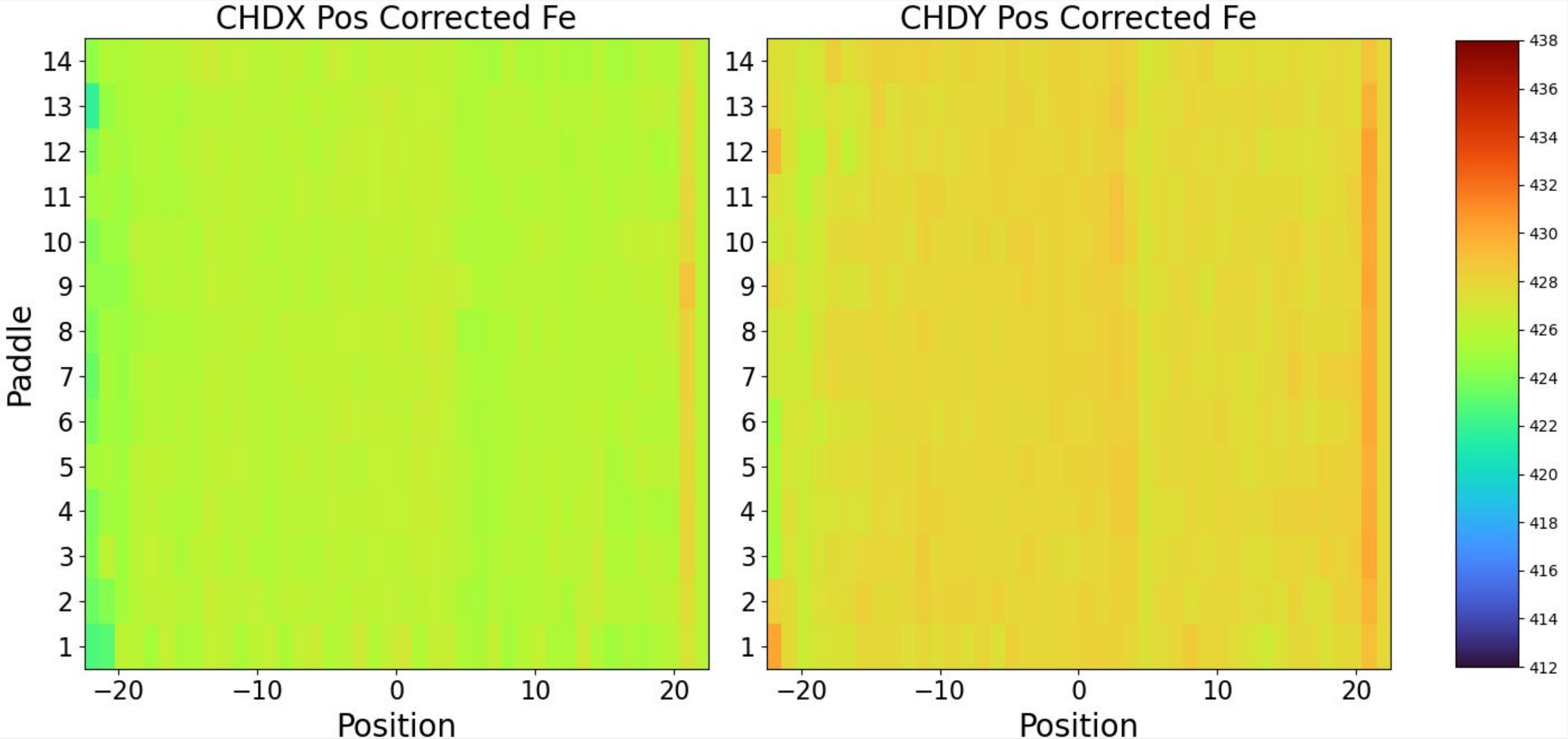
CHD Corrections

- This analysis has three corrections for optimizing the CHD signal for UH events:
- Position
  - Each CHD paddle is divided into 42 subsections, which are then normalized to the full layer mean for both the $_{14}$Si and $_{26}$Fe peaks.
- Time
  - Using the position corrected signal, the CHD paddles are normalized to the full layer $_{26}$Fe peak over time increments that have 300 events occur in each individual paddle.
- Energy
  - UH events are divided into energy bins of ~40000 $_{26}$Fe events, we then peak fit over each energy bin for charge assignment.

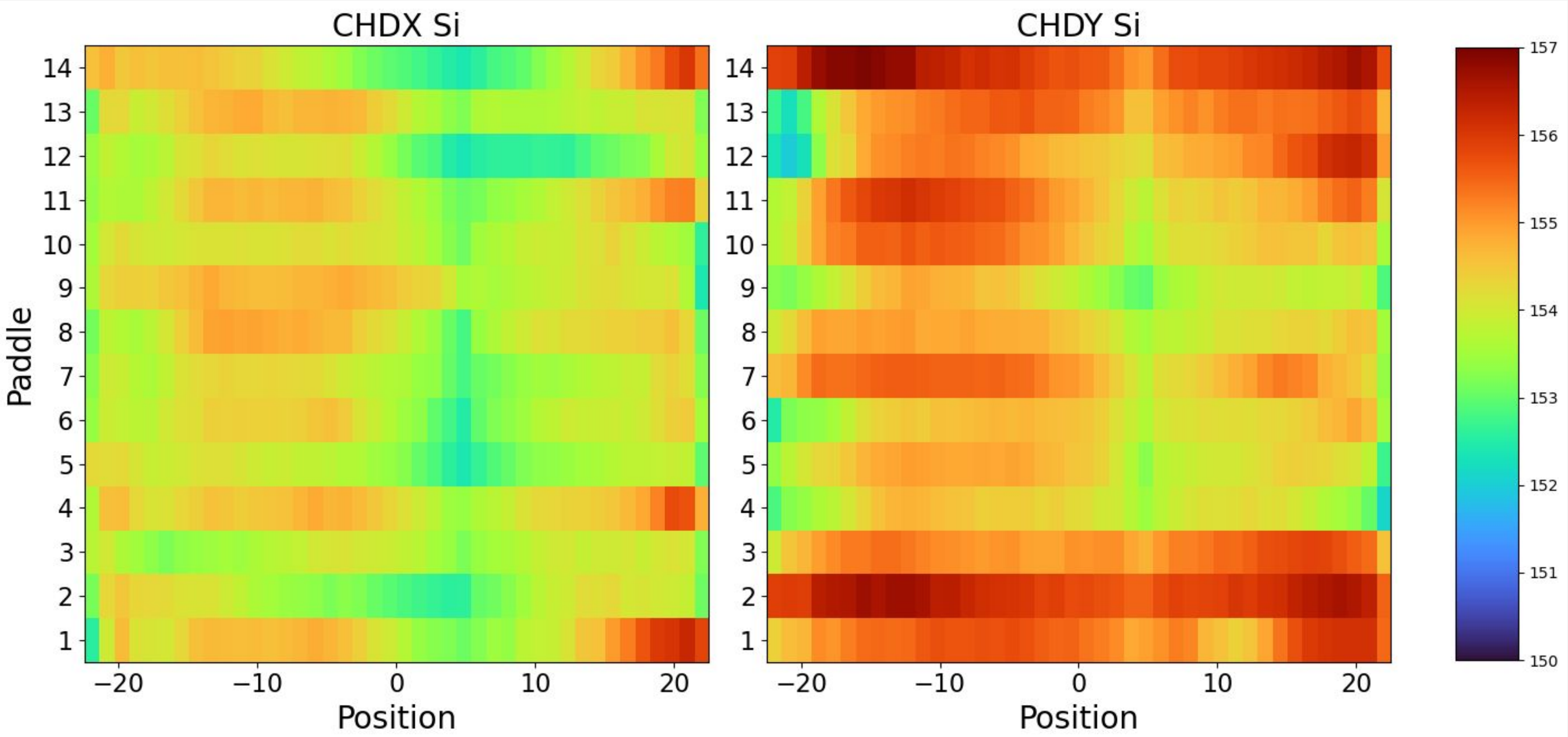
CHD $_{26}$Fe Signal Before Position Corrections



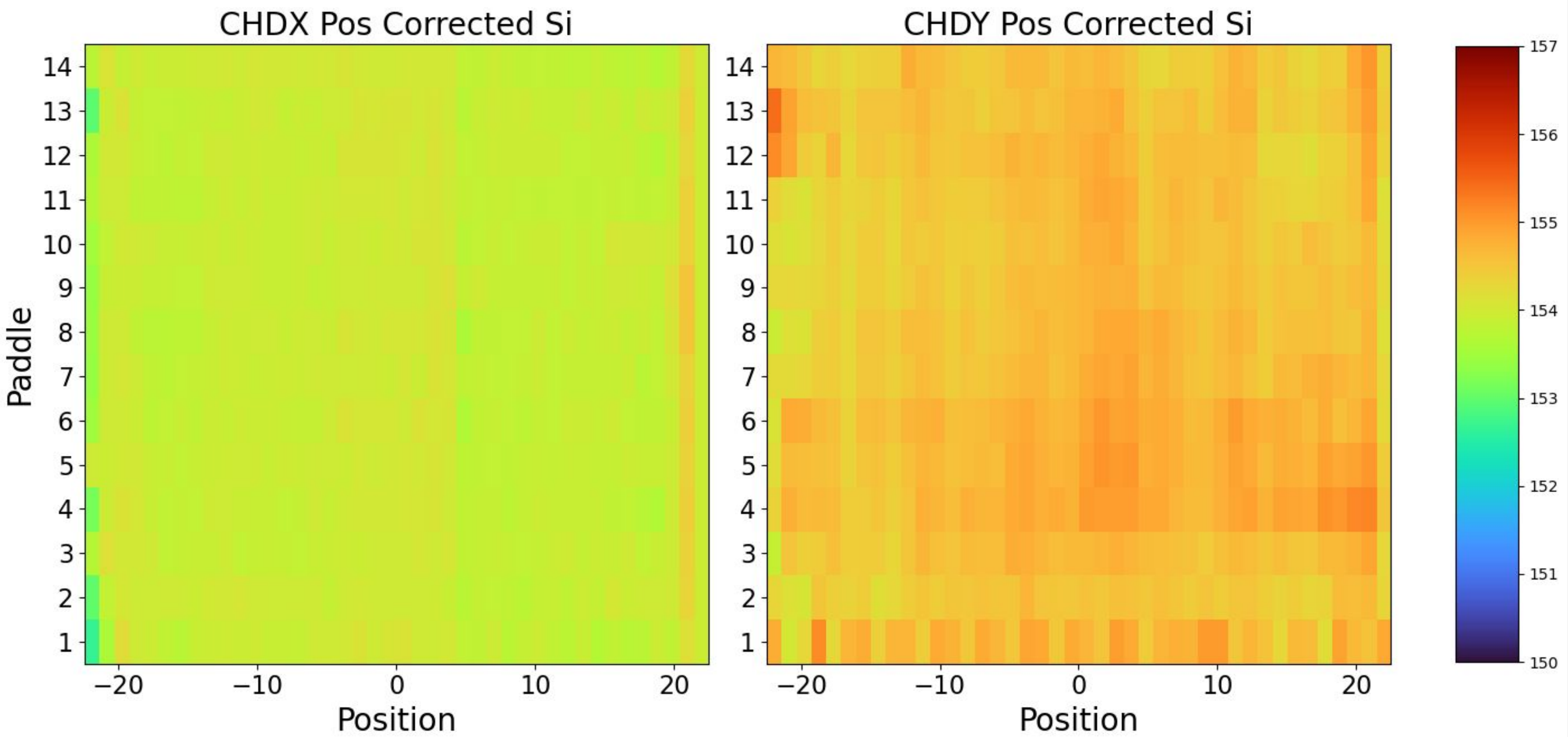
CHD $_{26}$Fe Signal After Position Corrections



CHD $_{14}$Si Signal Before Position Corrections

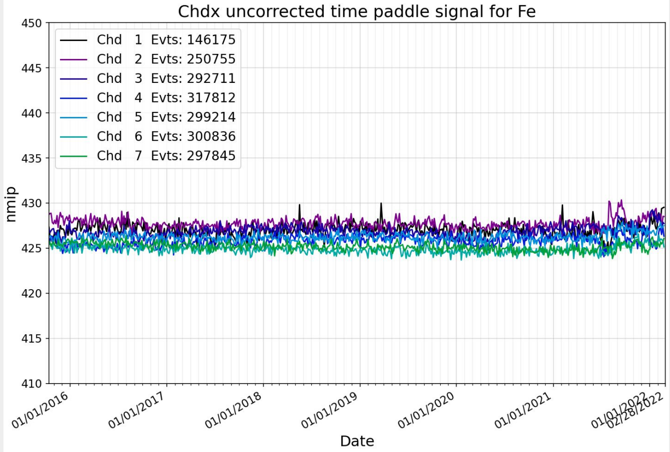


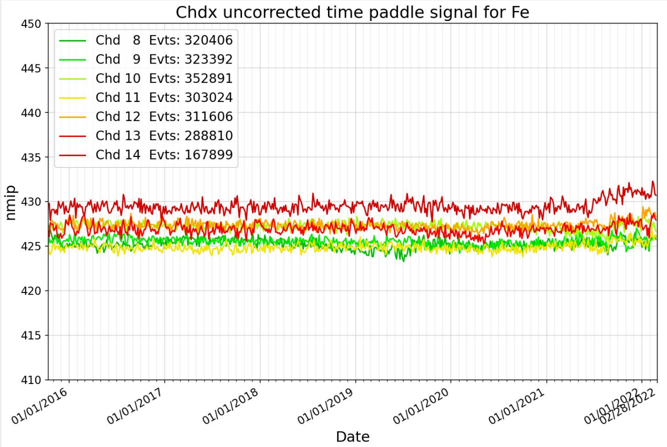
CHD $_{14}$Si Signal After Position Corrections



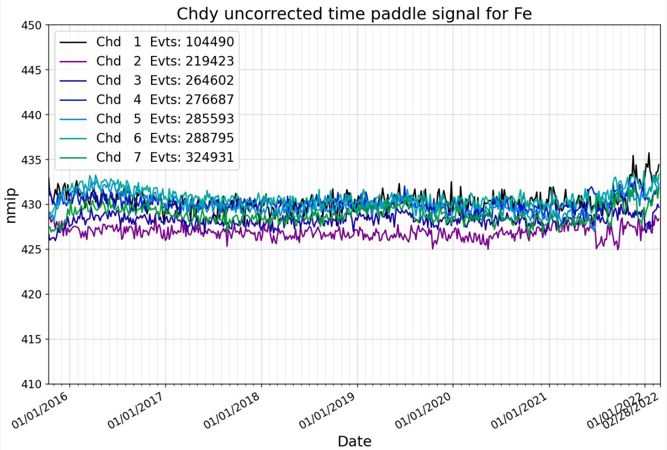
CHD $_{26}$Fe Signal Before Time Corrections

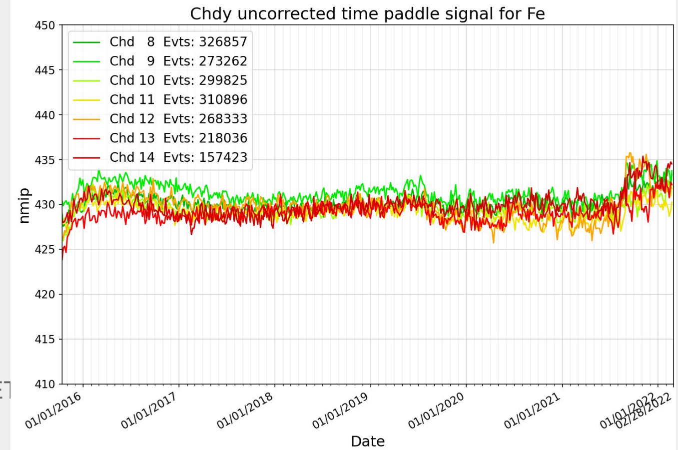
CHDX





CHDY



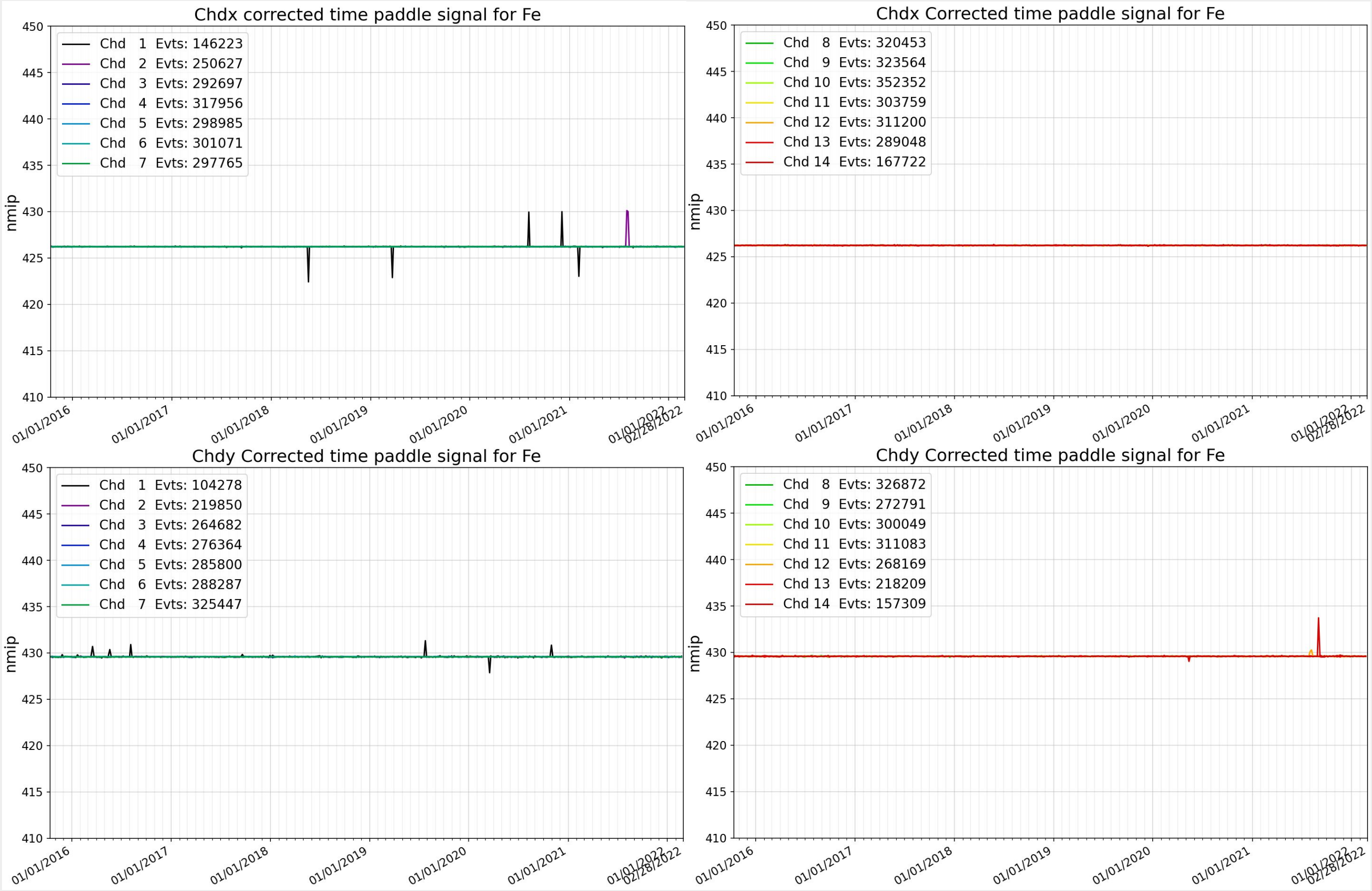


Each timestep is ~3 days

CHD $_{26}$Fe Signal After Time Corrections

CHDX

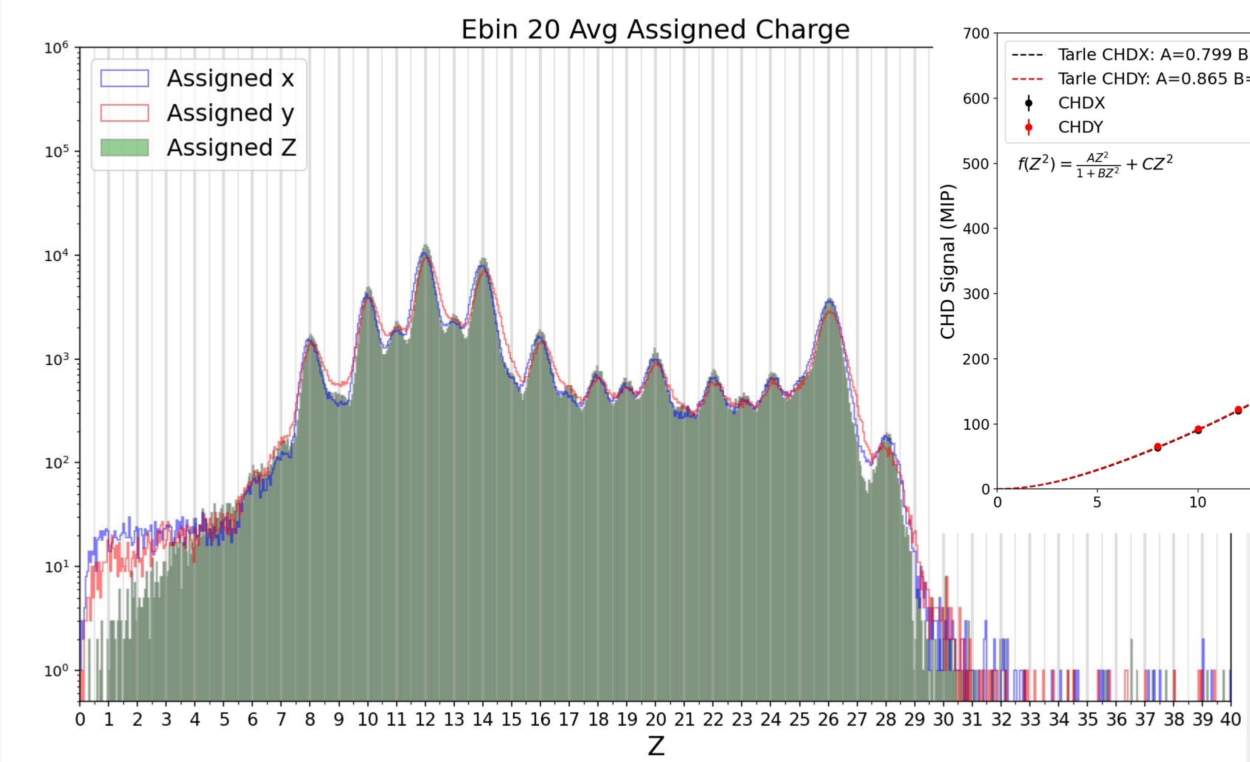
CHDY

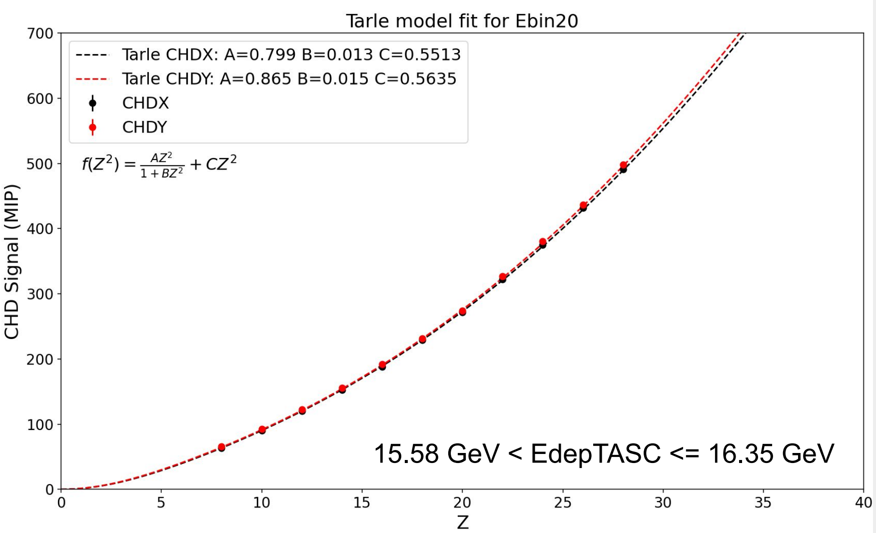


Each timestep is ~3 days

CHD Energy Corrections

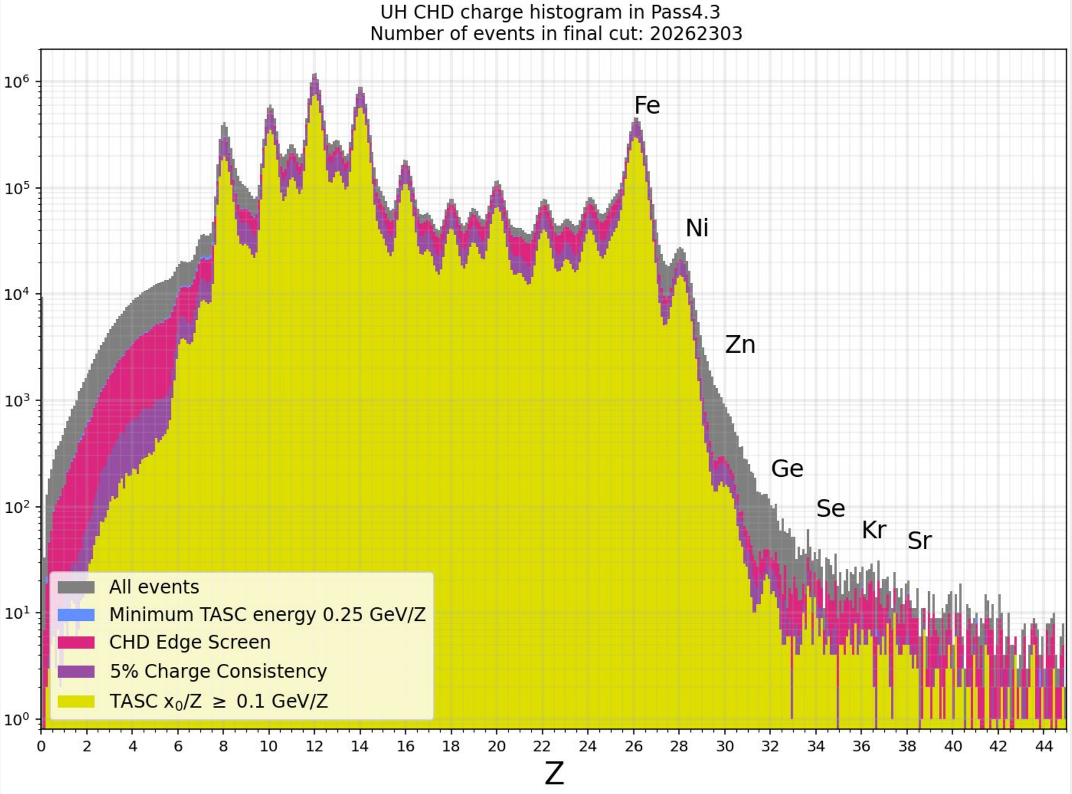
As an example, this one of 65 energy bins.





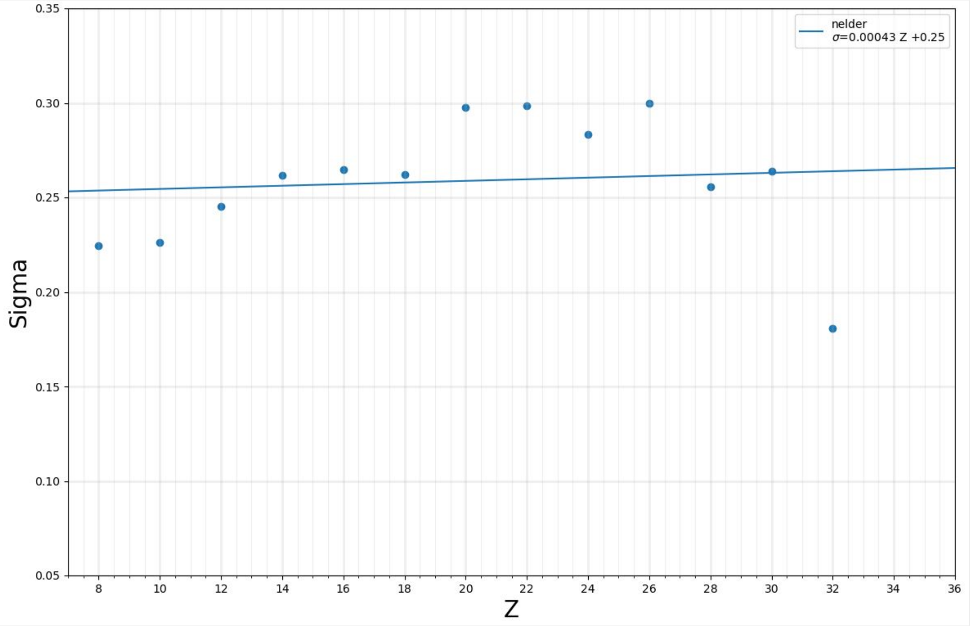
Event Screening

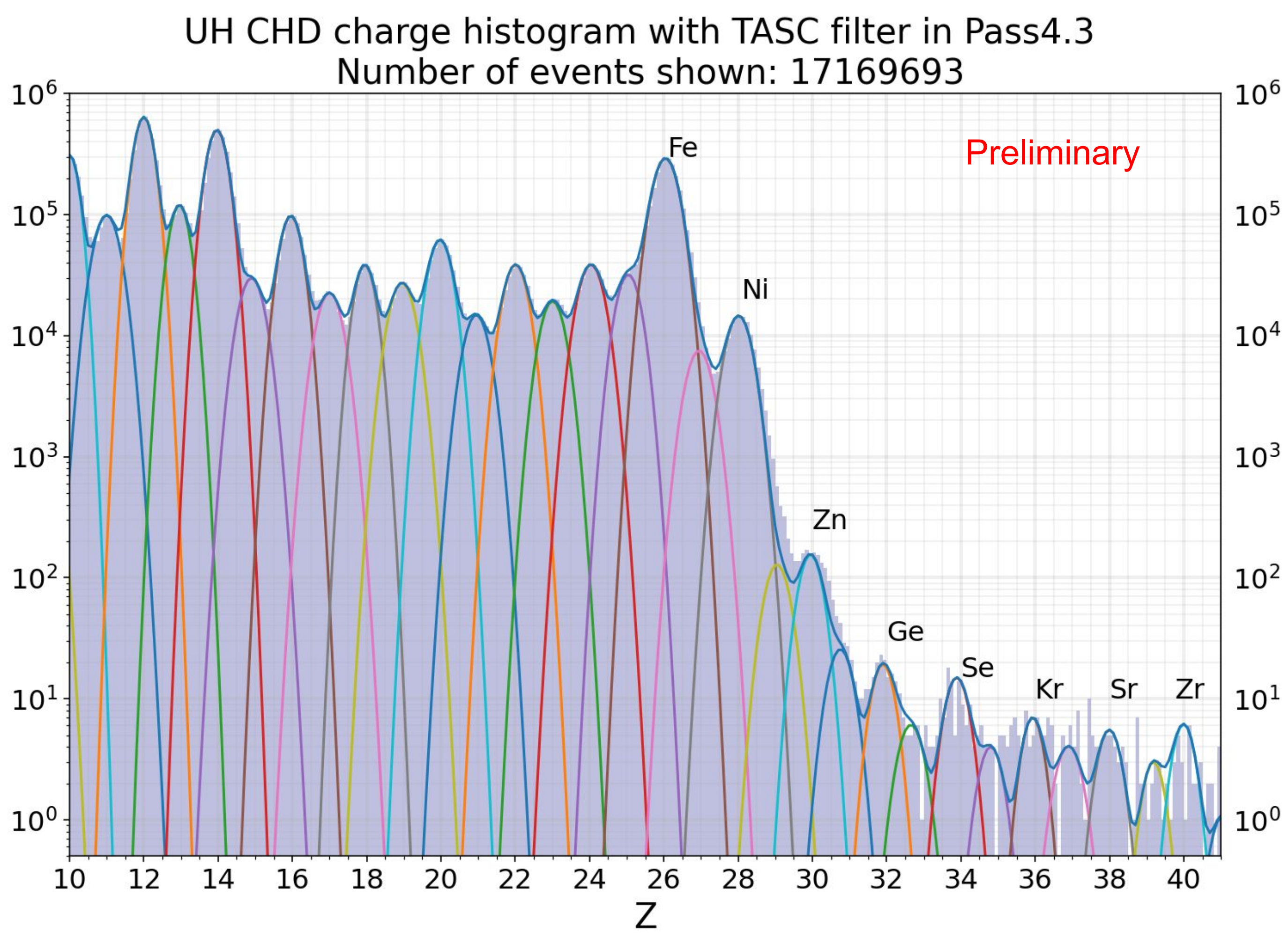
- For consistency the following events are screened in the analysis
  - Events with a deposited energy less than 0.25 GeV/Z. These energy bins were the most smeared, and a reliable peak fitting could not be done.
  - A position screen to account for the lack of statistics in the edge cases of the individual paddles.
  - A consistency screen that requires CHDX and CHDY to be within a 5% percent difference.
  - A minimum deposited energy in the first layer of the TASC, to account for fragmentation and splashback.



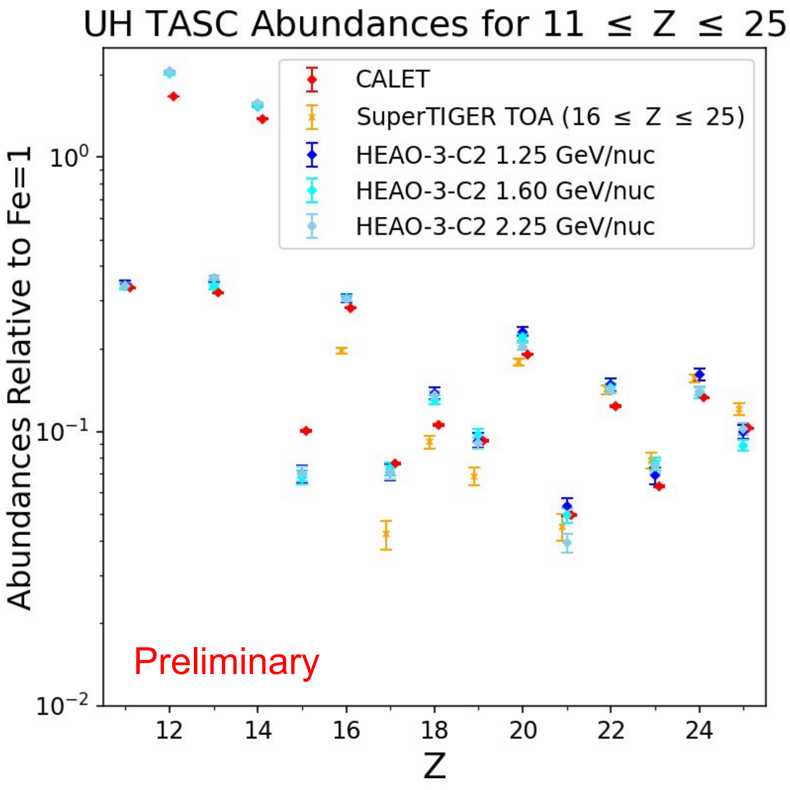
Determination of Abundances

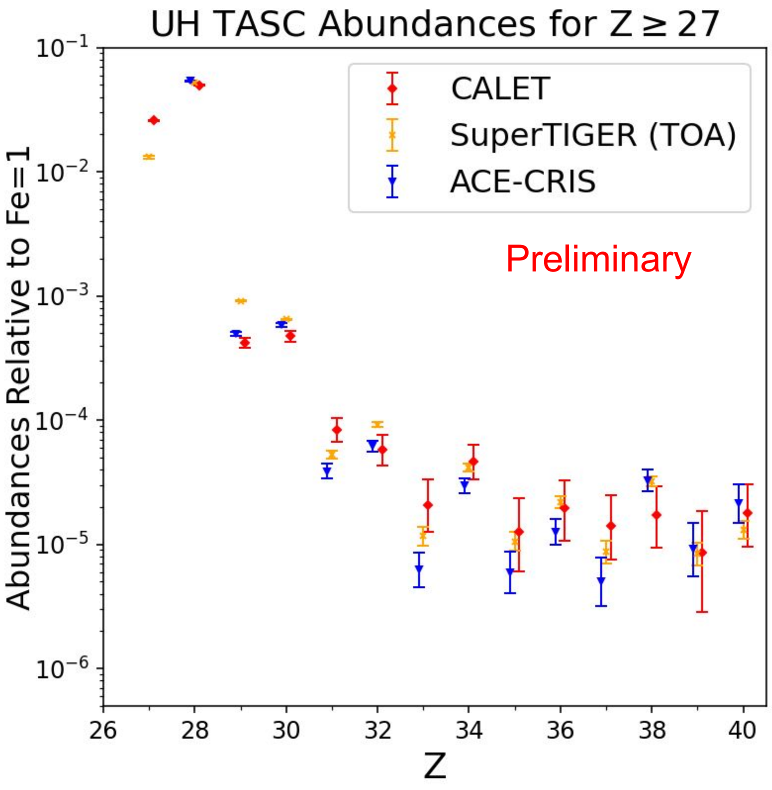
- Peak fitting is done over multiple steps
    - Iteration one has constraints on peak position to determine sigmas for each peak.
- The sigmas from the even peaks over 8 ≤ Z ≤ 32 are then linearly fit to extrapolate a sigma for all peaks up to Z=40 (Shown on right)
- Second peak fit uses that linearized sigma equation with a maximum-likelihood multiple-Gaussian fit for all elements in CALET's charge range.




UH CHD charge histogram with TASC filter in Pass4.3
Number of events shown: 17169693
Preliminary
Fe
Ni
Zn
Ge
Se
Kr
Sr
Zr
Z
10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40
10^0 10^1 10^2 10^3 10^4 10^5 10^6

Relative Abundances





CALET errors are statistical only

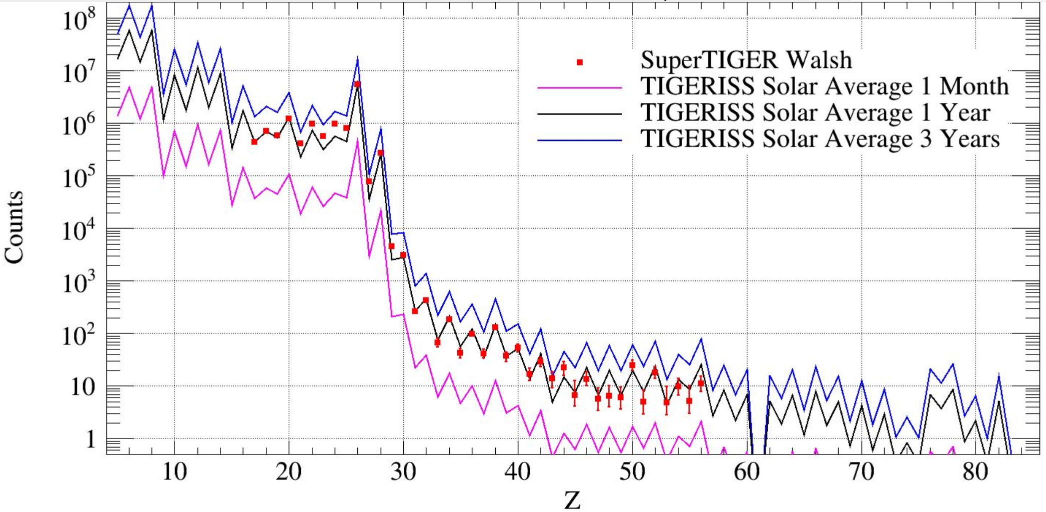
Future Work for CALET UH

- Determine energy dependent relative abundances for comparison with non-UH abundances from HEAO-3-C2.
- Use simulations to estimate or determine the systematic errors from charge misidentification, fragmentation, etc.
  - One example that is on the small amount of material above CALET on the JEM mounting structure.
- With CALET planned to operate until at least 2024, statistics will to continue improve.

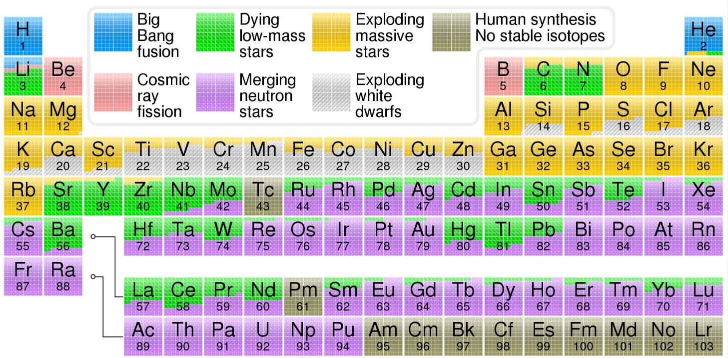
Going beyond CALET for UHCRs

- We are planning a new instrument in space built for UH observations.
- We have proposed TIGERISS which would be capable of single element resolution all the way up to $_{82}$Pb.
- Further details of this experiment and SuperTIGER will be given by Mitchell tomorrow.
- Any questions?

Rauch et al, ICRC 2021

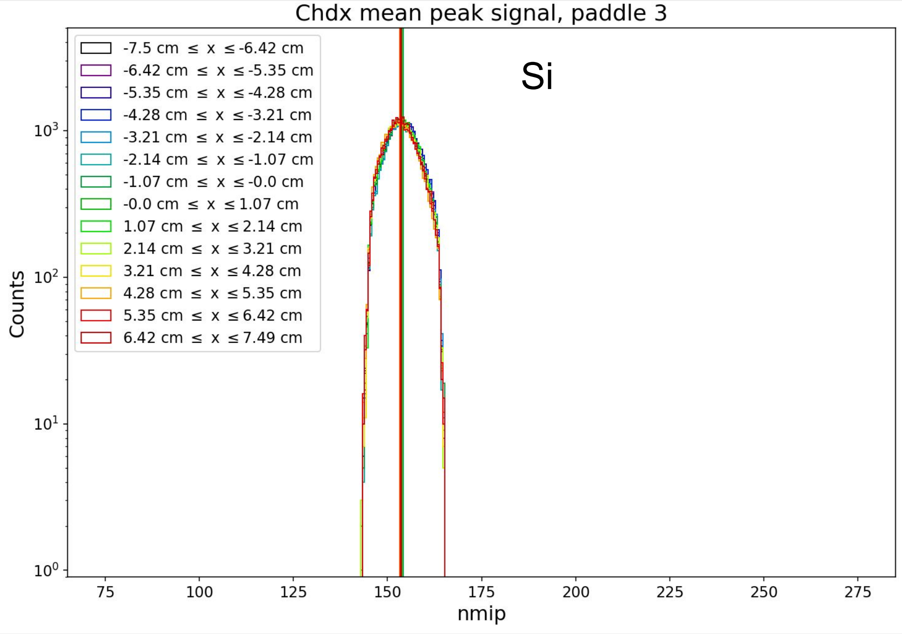


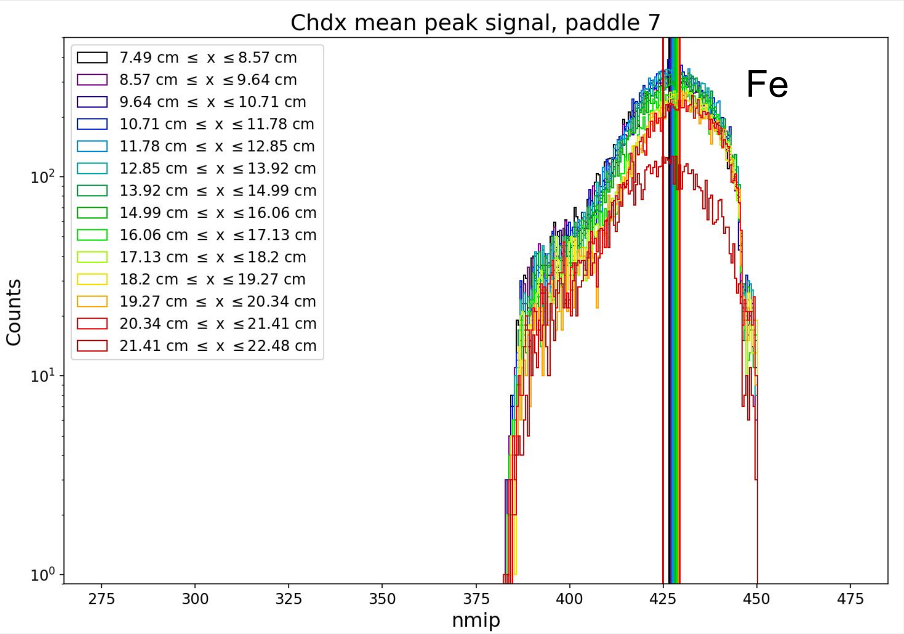
Credit:
J Johnson,
OSU



Backup

Example paddle segment signals seen for in the position Corrections





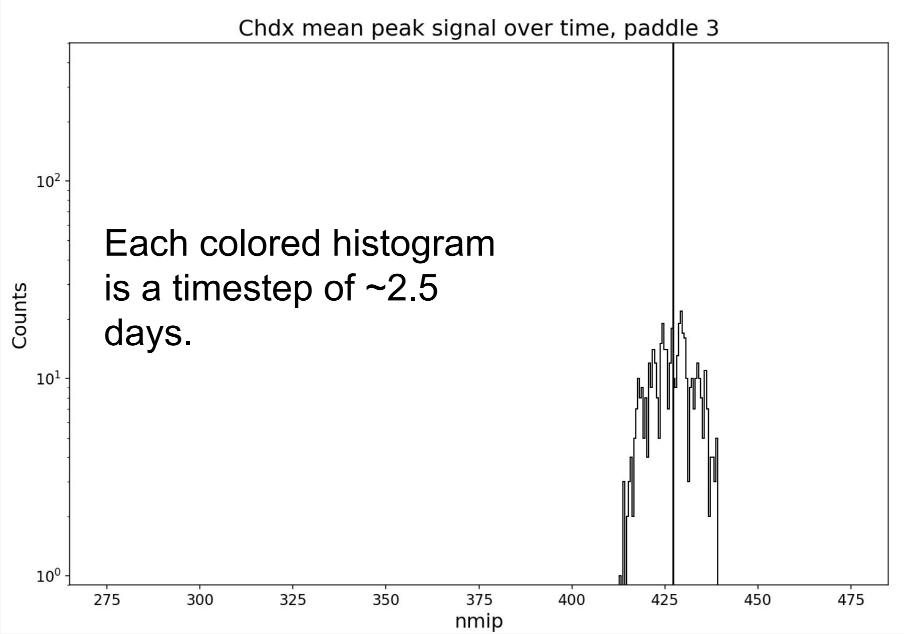
Each histogram represents one paddle segment of the larger paddle

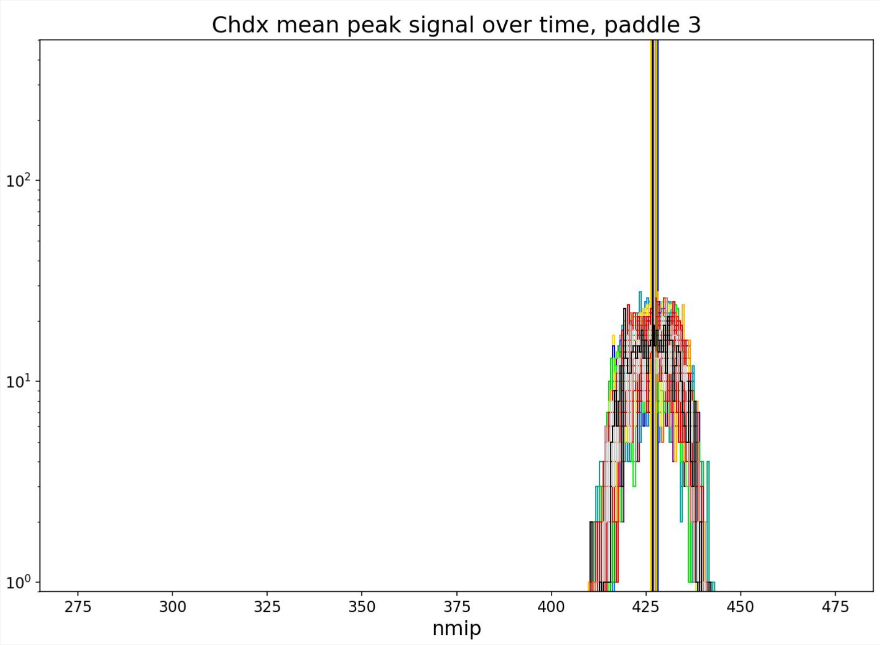
On the Iron paddle segment you can see how the peak shifts and is contaminated by Mn

Time Correction Peaks

Example peaks from the time correction process

Each colored histogram is a timestep of ~2.5 days.





Charge Smearing

Charge smearing at lower energy is shown on top
Lower plot shows a higher energy bin.

Red lines show peak fitting routine’s attempt at finding peak position for Tarle charge assignment.

Very noticeable differences in resolving peaks.