CALET Ultra Heavy Cosmic Ray Observations on the ISS

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for the CALET Collaboration
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CALET Collaboration

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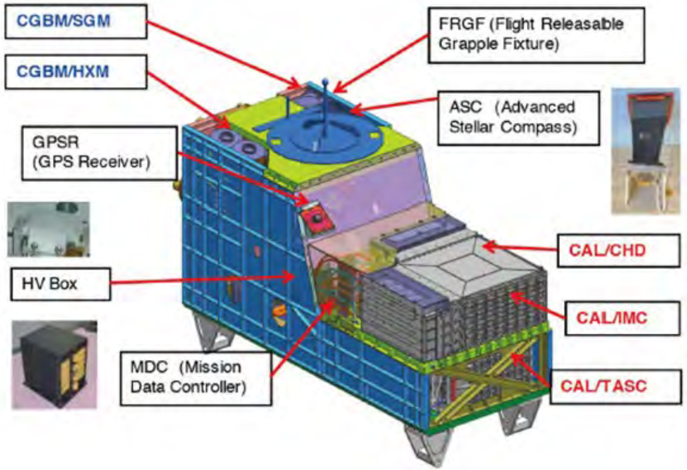
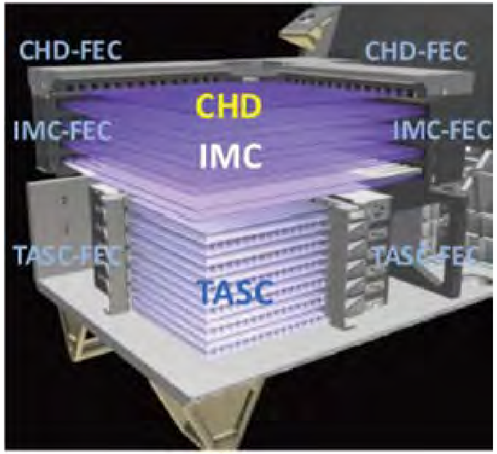
CALET System Overview



CALorimetric Electron Telescope

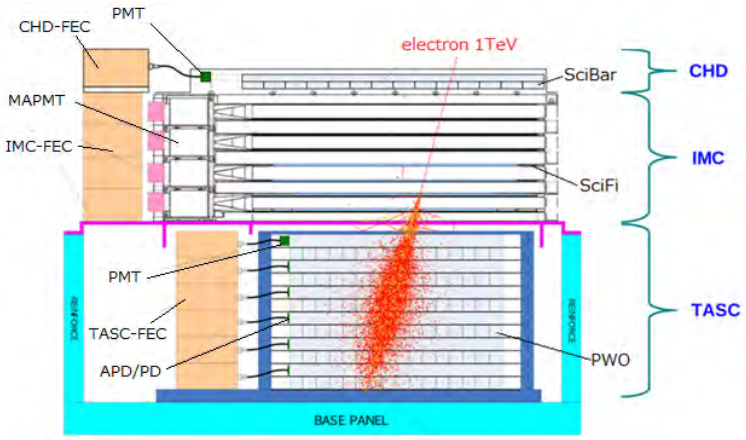
■CALorimeter (CAL)



- Mass: 612.8 kg
- JEM Standard Payload Size
  1850mm(L) x 800mm(W) x 1000mm(H)
- Power Consumption: 507 W(max)
- Telemetry:
  Medium 500 kbps (6.5GB/day)
  Low 50 kbps

■CALET Gamma-ray Burst Monitor (CGBM)

CALET-CAL Detector



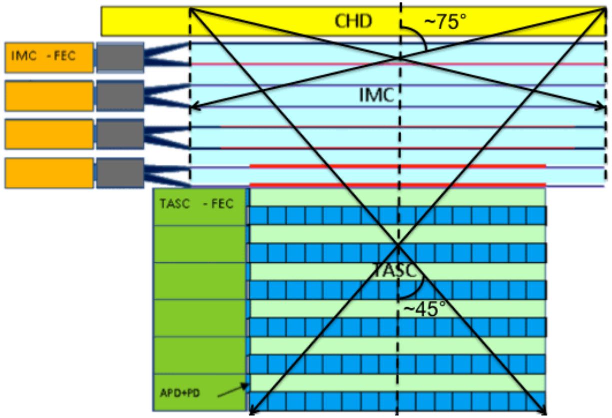
A 30 radiation length deep calorimeter designed to detect electrons and gamma-rays to 20 TeV and cosmic rays up to 1 PeV

- 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% (>100GeV) 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 > ~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

Ultra Heavy Cosmic Ray Analysis

- CALET has a special UH CR trigger utilizing the CHD and the top 4 layers of the IMC that:
  - has an expanded geometry factor of ~4000 cm^2sr
  - has a very high duty cycle due to low event rate
  - ISS obstructions in FOV reduce benefit and complicate analysis
- Analysis presented here uses data with UH triggers and good trajectories
- Relative abundances of elements below ${}_{14}Si$ impacted as they only trigger at higher incidence angles
- UH analysis requires specialized data corrections and selections optimized for UH range using ${}_{26}Fe$

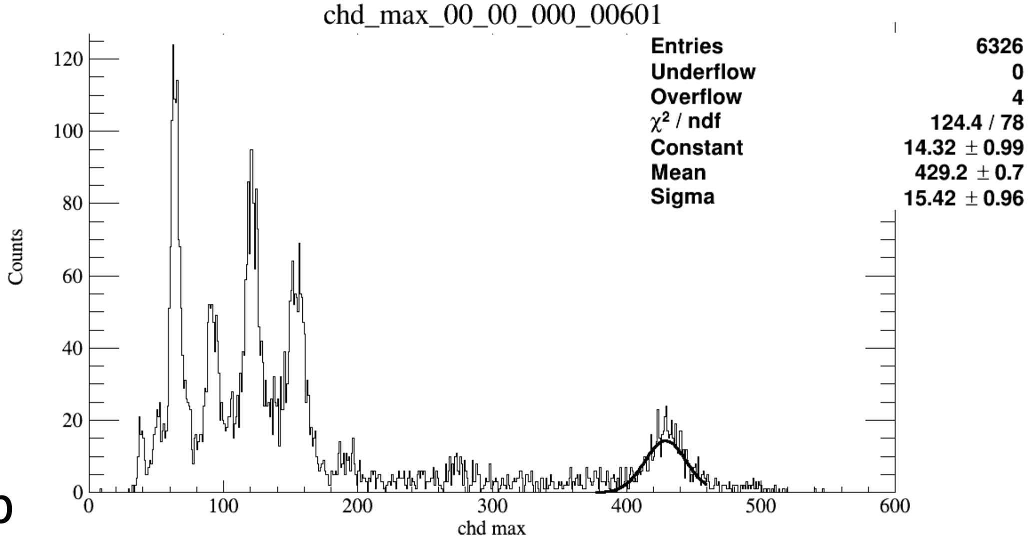


CALET UH Analysis Status

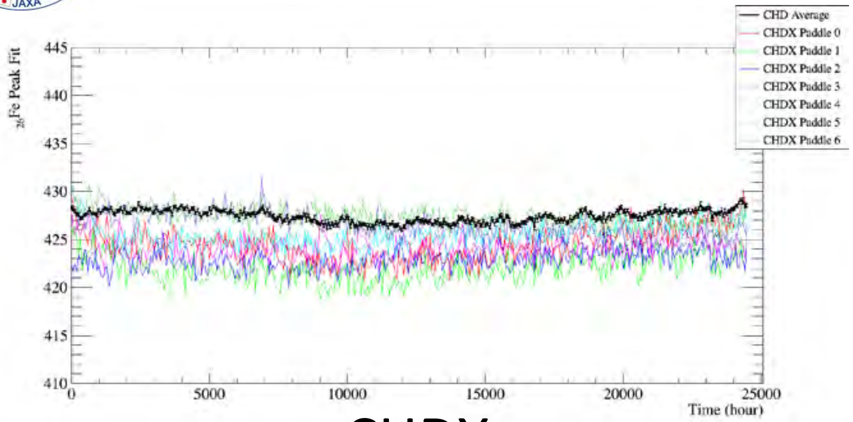
- Using ~3 years of CALET Level 2 PASS03.1 UH data
  - Analysis developed on previous 17 month data set applied
  - UH analysis CHD paddle time corrections
  - UH analysis CHD paddle position dependent corrections
  - Data selections for incidence angle, vertical cutoff rigidity, charge consistency, etc. applied
- Abundances fit for previous data sets agree within statistics with other UH measurements (SuperTIGER and ACE-CRIS)
- Work continues on trajectory dependent rigidity thresholds and ISS obstruction identification
- Analysis planned for CALET HE trigger data set with energy reconstruction in TASC

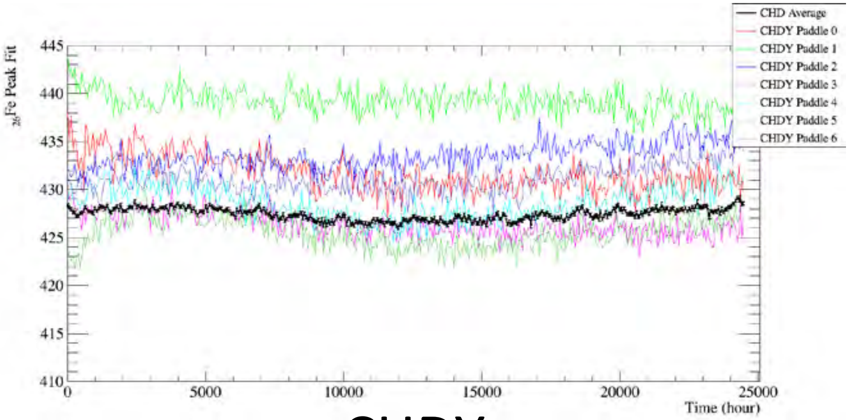
CHD $_{26}$Fe Time Corrections

- CHD time step histograms filled until at least 500 $_{26}$Fe range events in each CHD paddle
- In each time step $_{26}$Fe peaks fit with a Gaussian for each paddle and paddle average time steps calculated
- CHD paddle signals multiplied by the ratio of the mean of both layers over the full dataset to the paddle time step mean



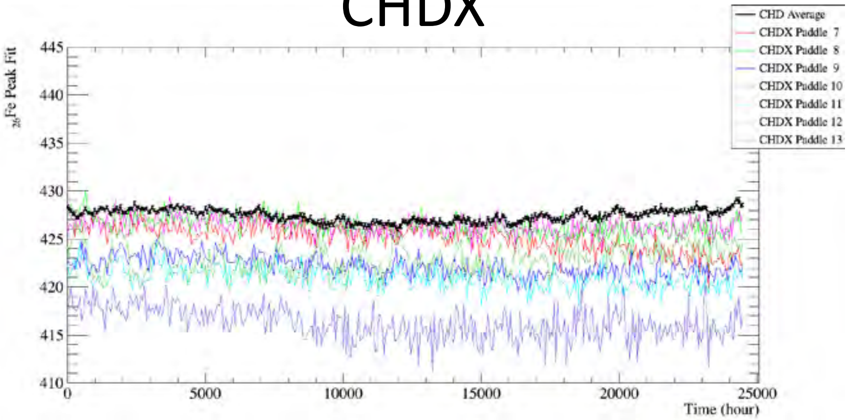
CHD $_{26}$Fe Time Contours

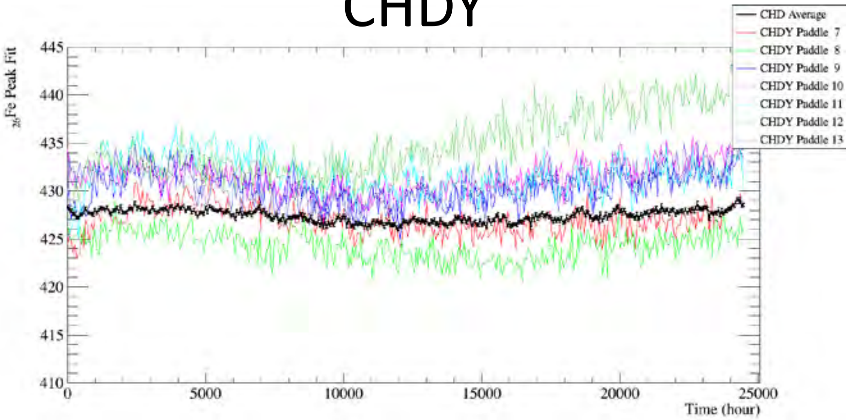




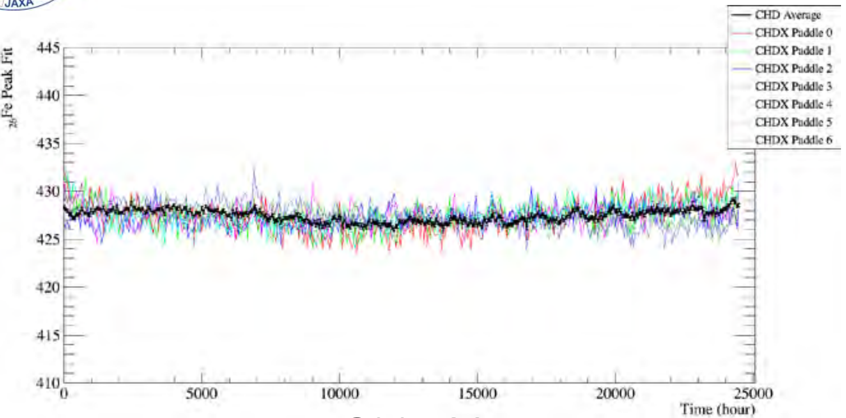
CHDX

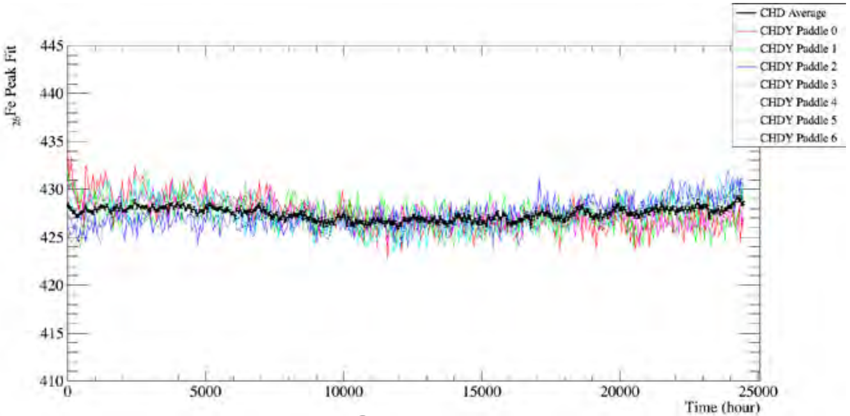
CHDY





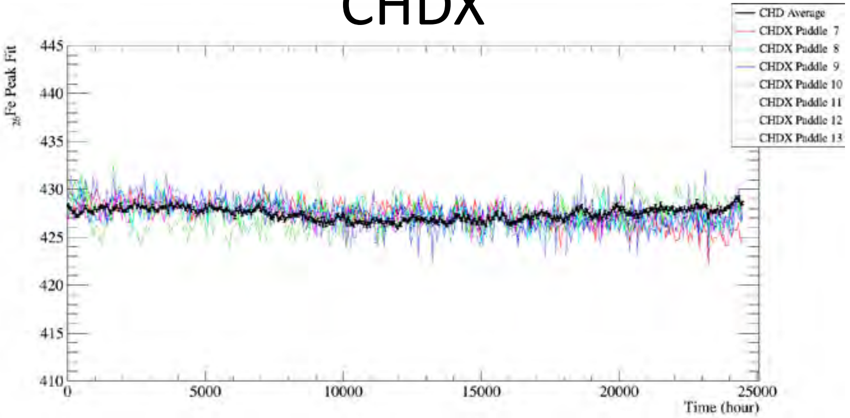
Corrected Time Contours

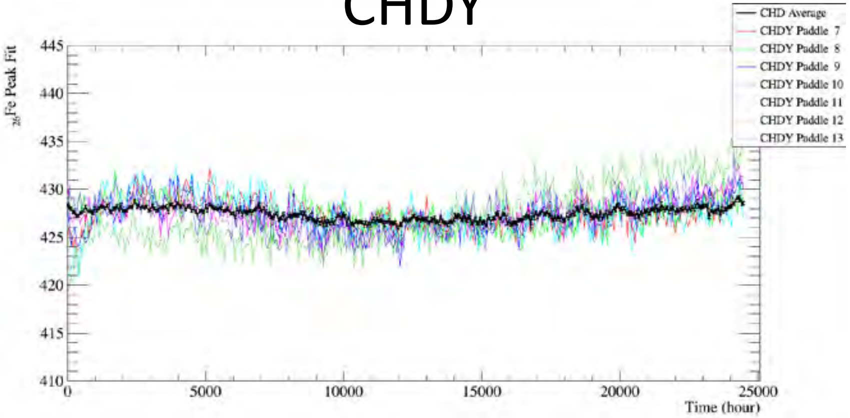




CHDX

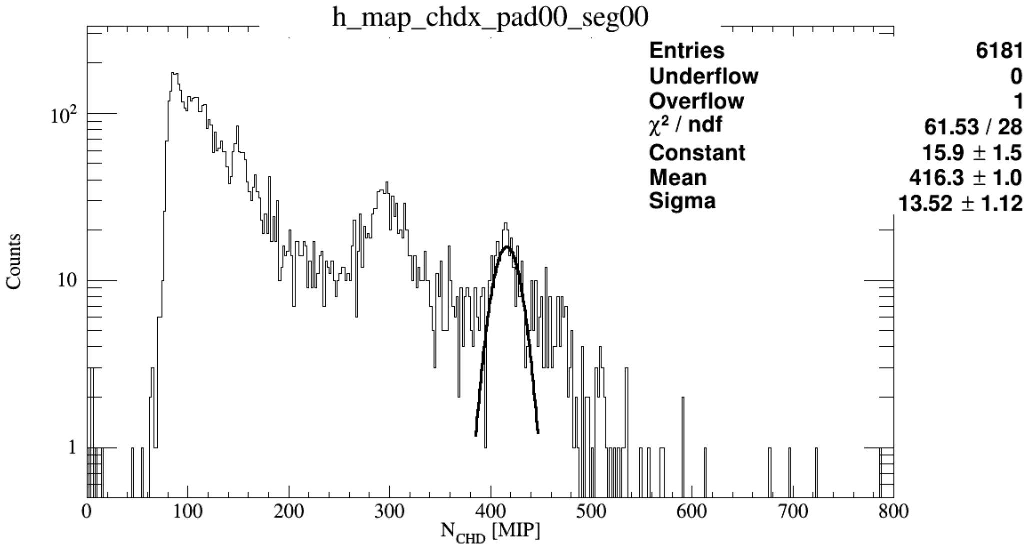
CHDY





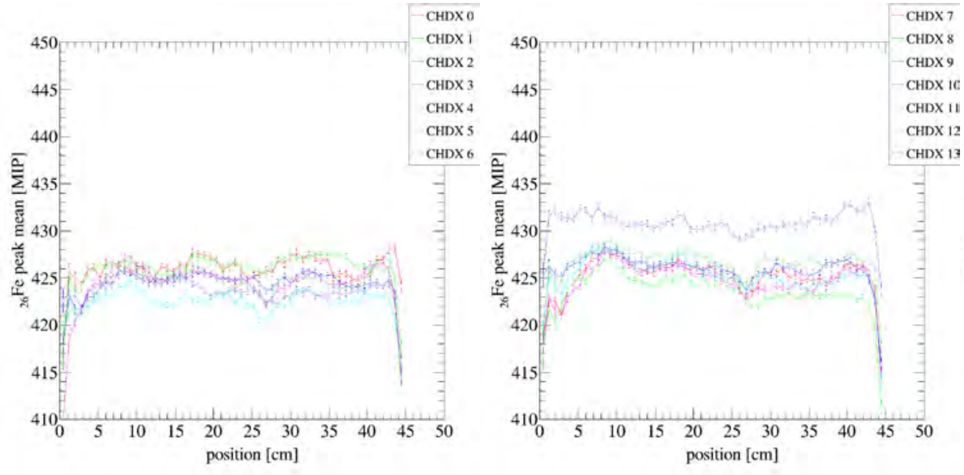
CHD Position Correction Method

- CHD paddles divided into thirds of the paddle width (1.07 cm) segments
- $_{14}$Si and $_{26}$Fe peaks fit with Gaussian for each segment
- CHD paddle signal multiplied by the ratio of each layer mean to the segment mean

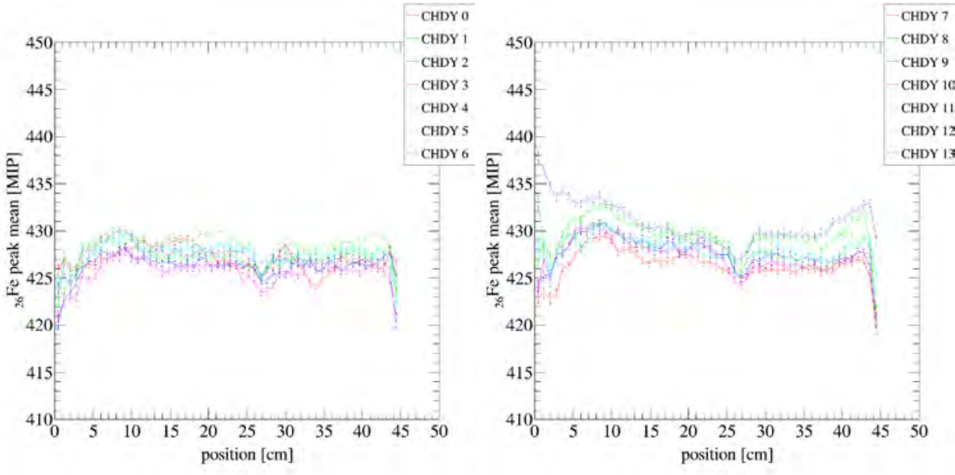


CHD $_{26}$Fe Position Dependence

CHDX

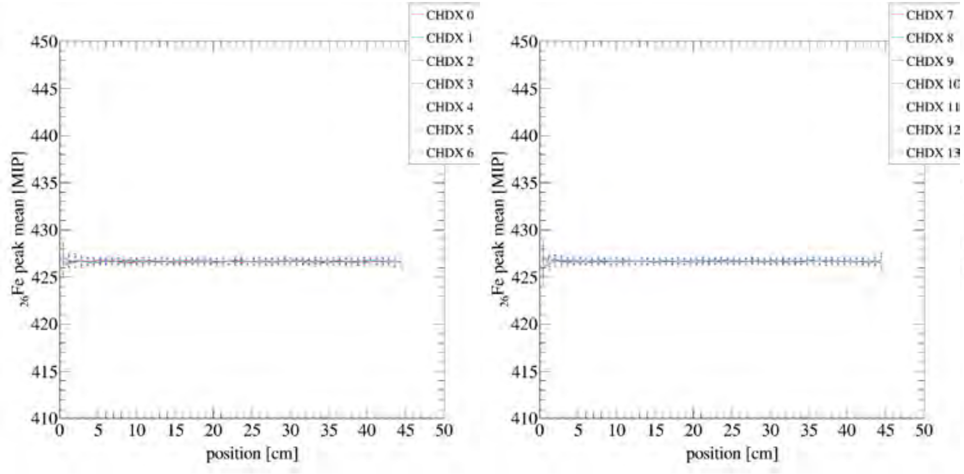


CHDY

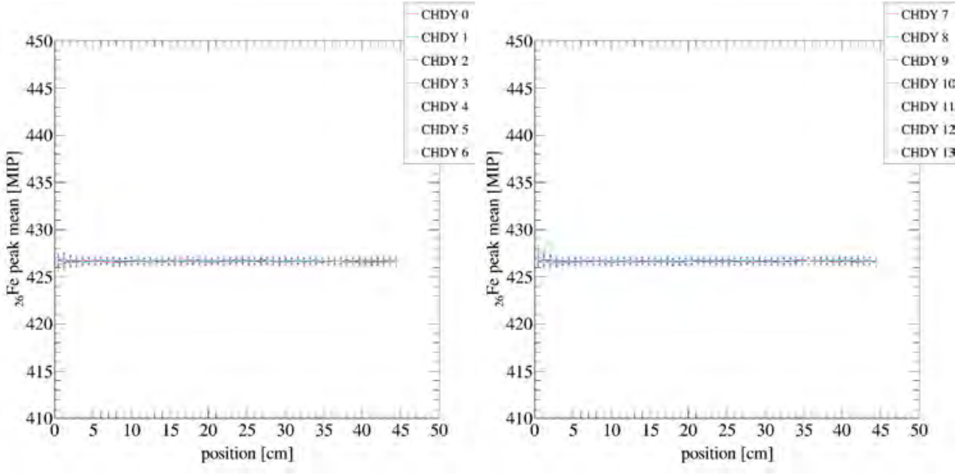


CHD $_{26}$Fe After Position Correction

CHDX

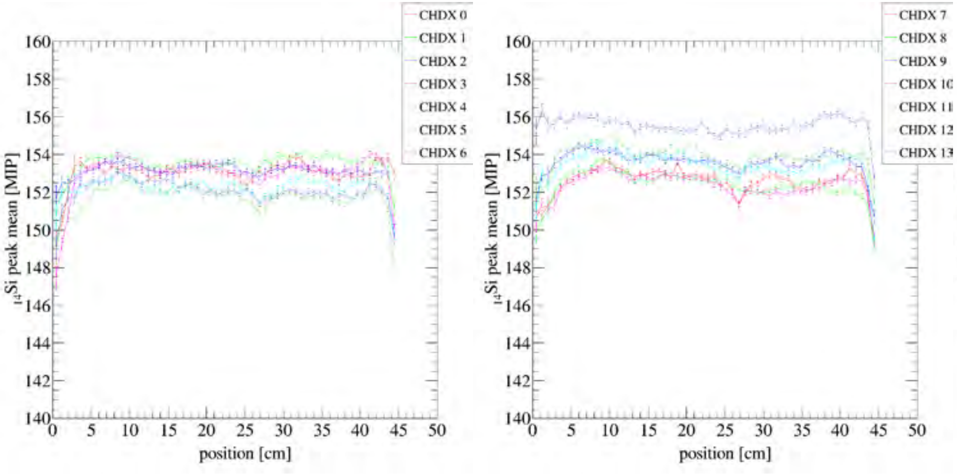


CHDY

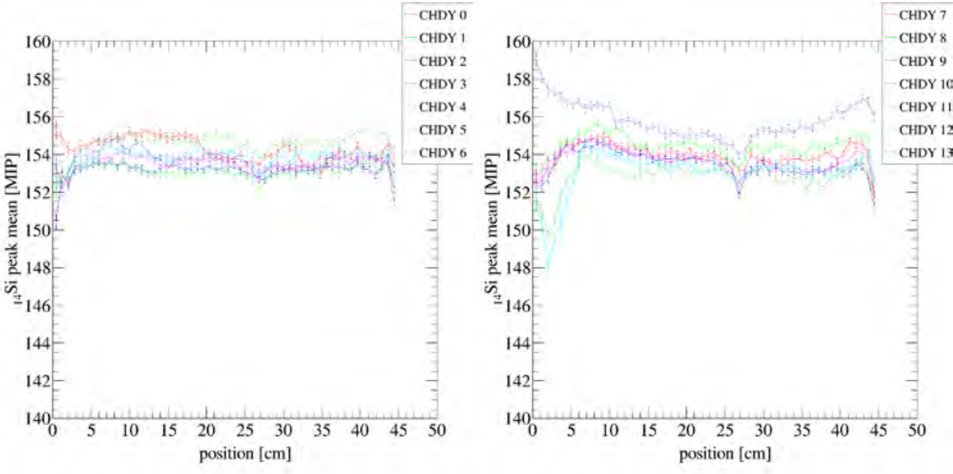


CHD $_{14}$Si Position Dependence

CHDX

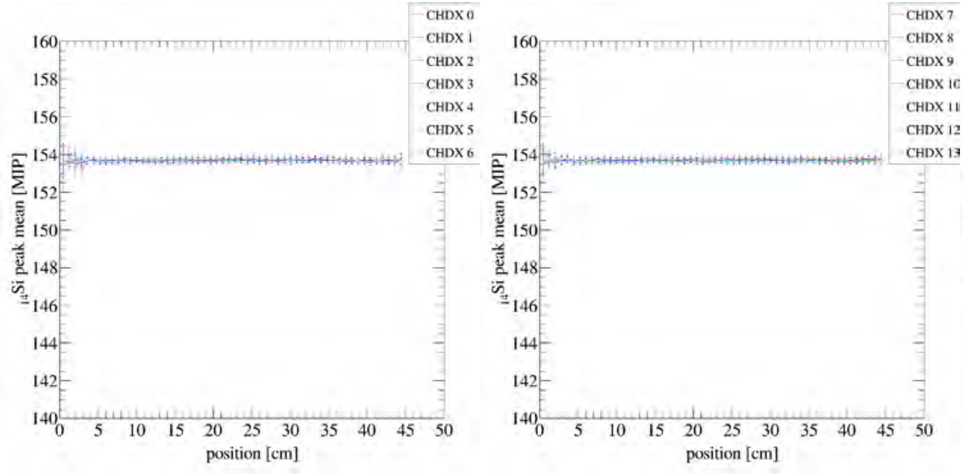


CHDY

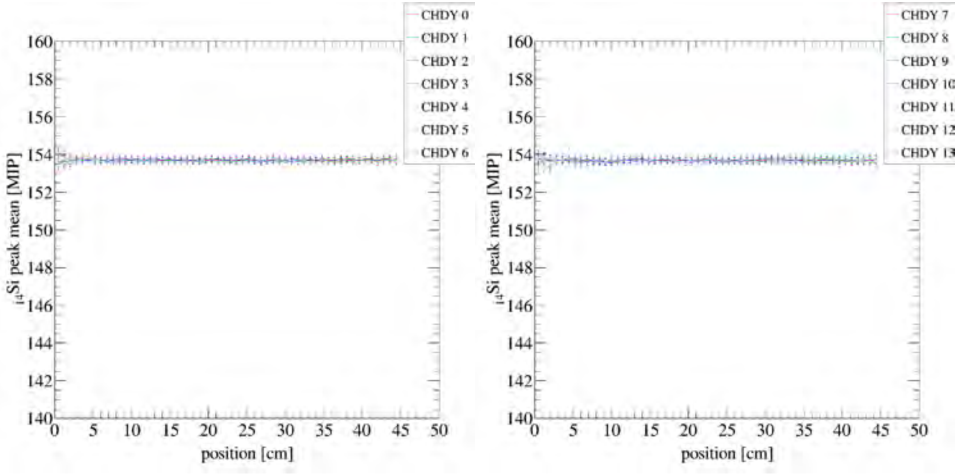


CHD $_{14}$Si After Position Correction

CHDX

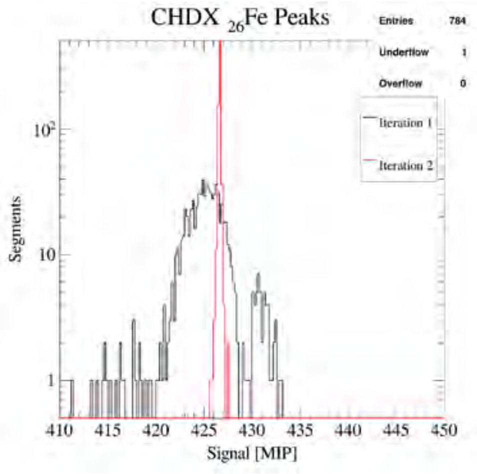


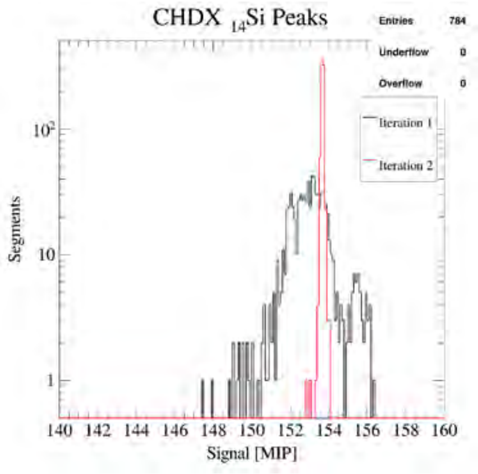
CHDY



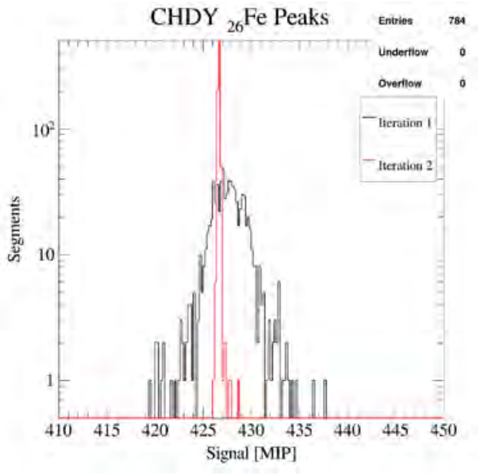
CHD $_{14}$Si and $_{26}$Fe Peak Means

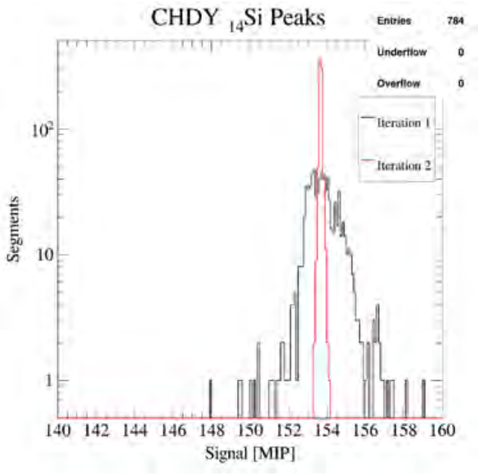
CHDX





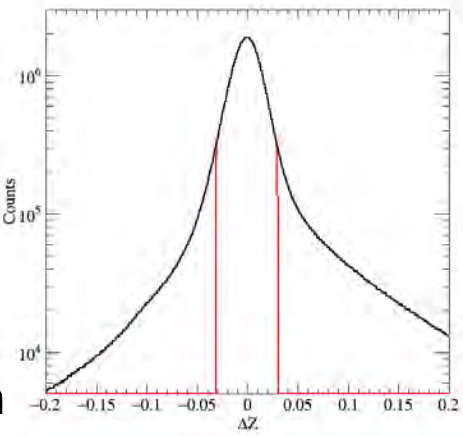
CHDY

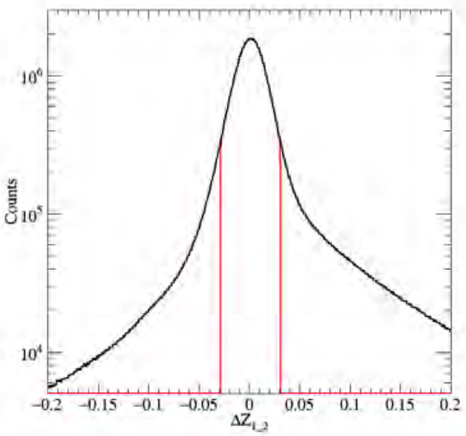




Charge Consistency Selections

- Selection cut is made for charge estimate consistency between CHDX and CHDY
- $Z_{est} \propto \mathrm{CHD}^{1/1.7}$
- $\Delta Z=(Z_{CHDX}-Z_{CHDY})/(Z_{CHDX}+Z_{CHDY})$ for Z_{CHDX} and Z_{CHDY} total layer signals
- ΔZ_{1_2} uses Z_{CHDX} and Z_{CHDY} for sum of signals from two highest layer paddles
- ±2σ selections applied



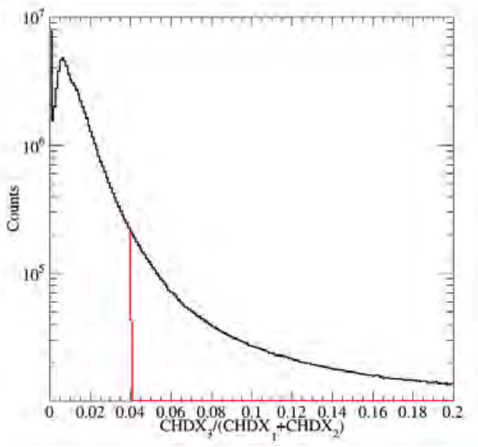


ΔZ selection Includes more signal from backscatter
ΔZ_{1_2} selection focused on primary particle track

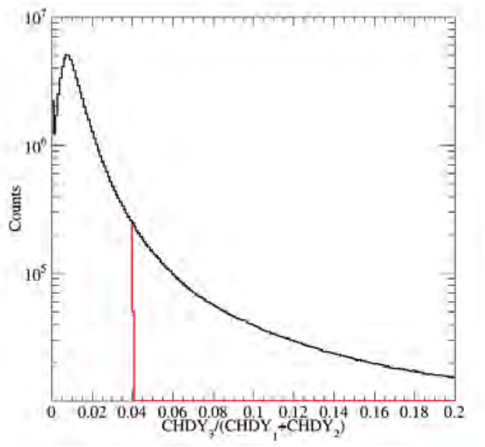
Paddle Dominance Selections

- Best charge estimate uses CHDX and CHDY signals from the two highest paddles
- Events with disproportionately high third paddle signals are selected
- $CHDX_3/(CHDX_1+CHDX_2) < 0.04$
- $CHDY_3/(CHDY_1+CHDY_2) < 0.04$

CHDX

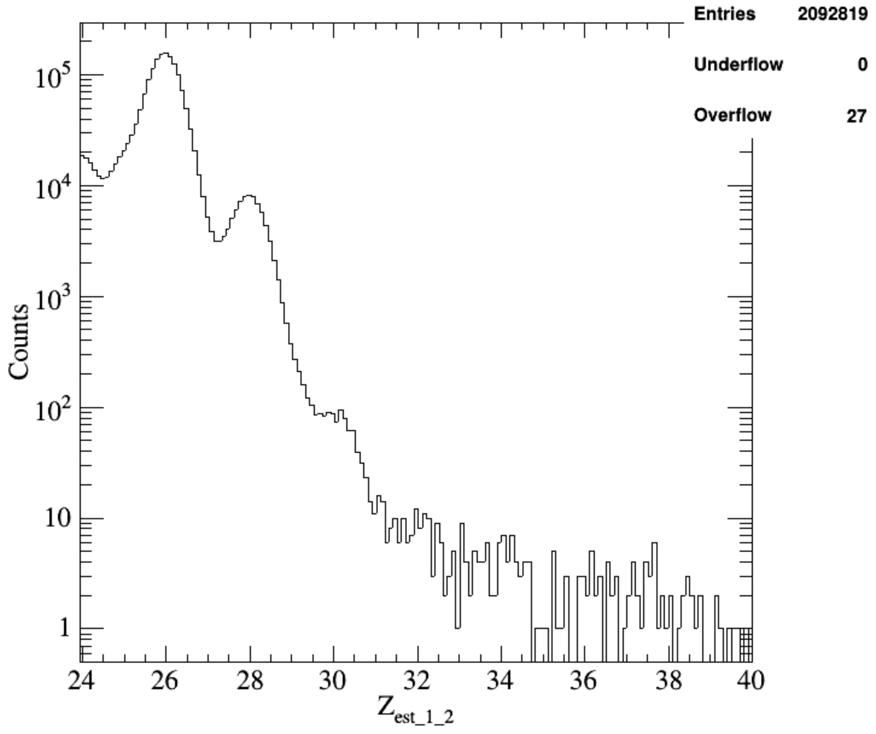


CHDY



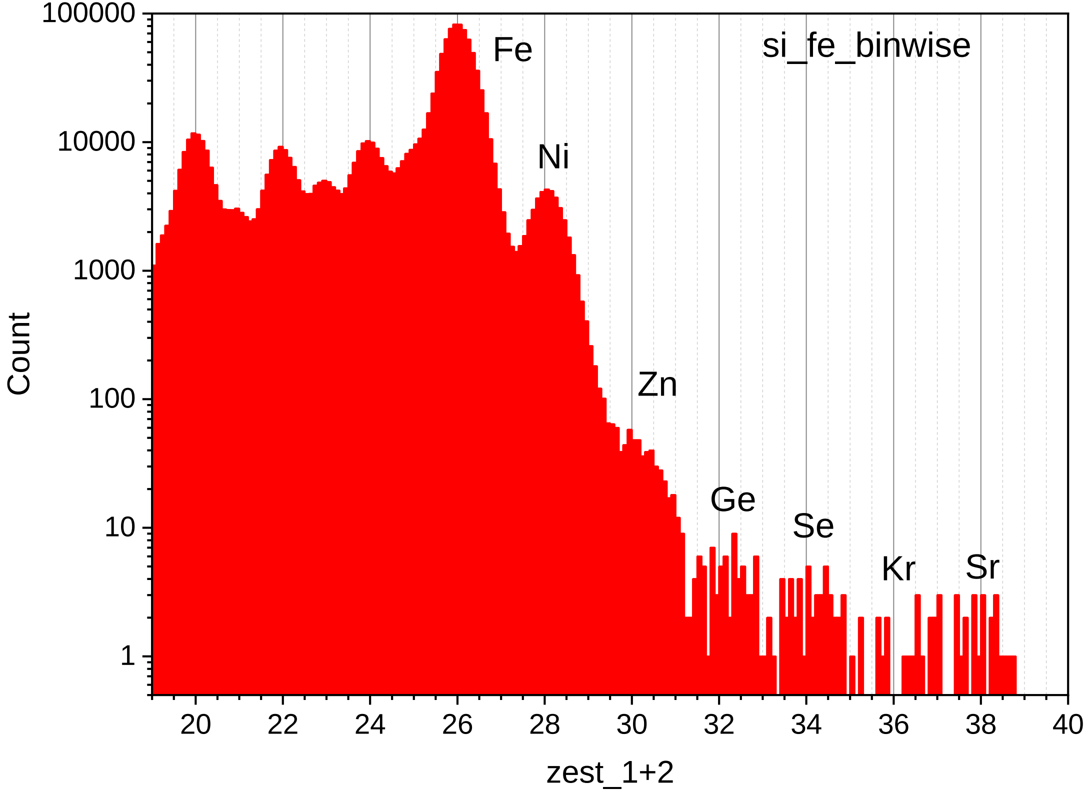
Current Analysis Charge Histogram

- Selections on ~3 year dataset:
  - Zest > 24
  - Theta < 45 deg
  - STRM > 4.0 GV
  - Z Consistency
  - Paddle dominance
  - IMC minimum
- We can clearly see well resolved peaks for $_{32}$Ge, $_{34}$Se, and $_{38}$Sr.
- $_{30}$Zn is more than a shoulder, but is not clearly resolved. Even a small improvement in resolution would help a lot here.
- More statistics should be a major help in better defining the peaks
- Geomagnetic cutoff for each trajectory should help in rejecting low energy particles that are very likely broadening the distributions.



Reduced Dataset Charge Histogram

- Selections on 17 month dataset:
  - Zest > 19
  - Theta < 45 deg
  - STRM > 4.5 GV
  - Z Consistency
  - IMC Energy Correction
- We can clearly see well resolved peaks for $_{32}$Ge, $_{34}$Se, and $_{38}$Sr.
- $_{30}$Zn is more than a shoulder, but is not clearly resolved. Even a small improvement in resolution would help a lot here.
- More statistics should be a major help in better defining the peaks
- Geomagnetic cutoff for each trajectory should help in rejecting low energy particles that are very likely broadening the distributions.



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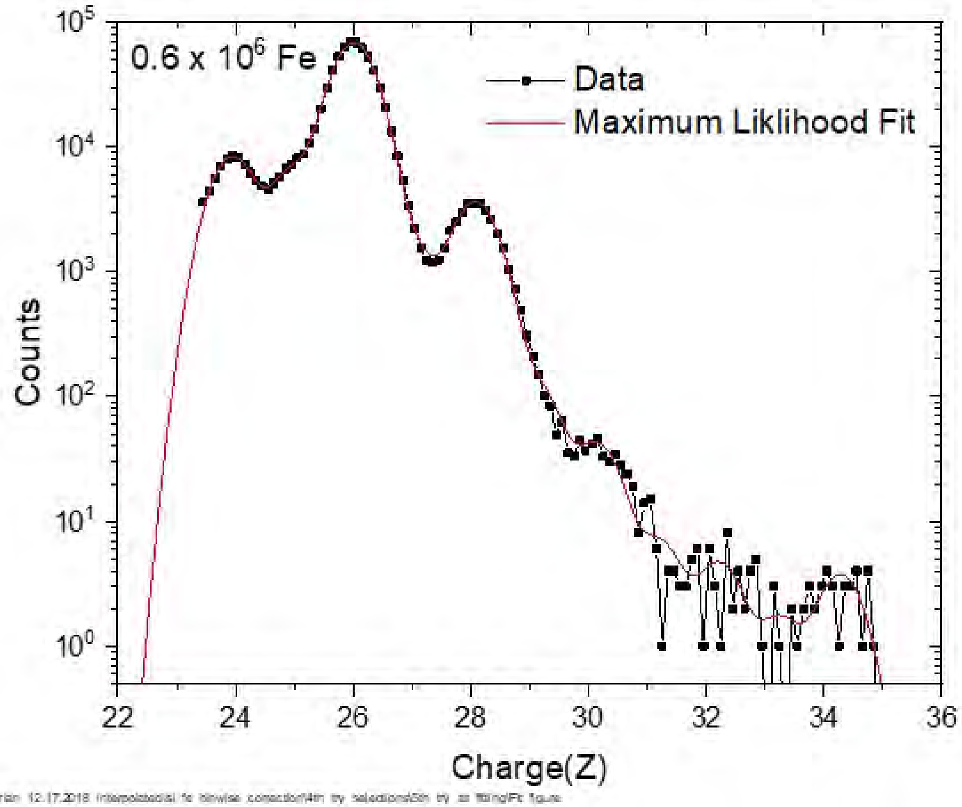
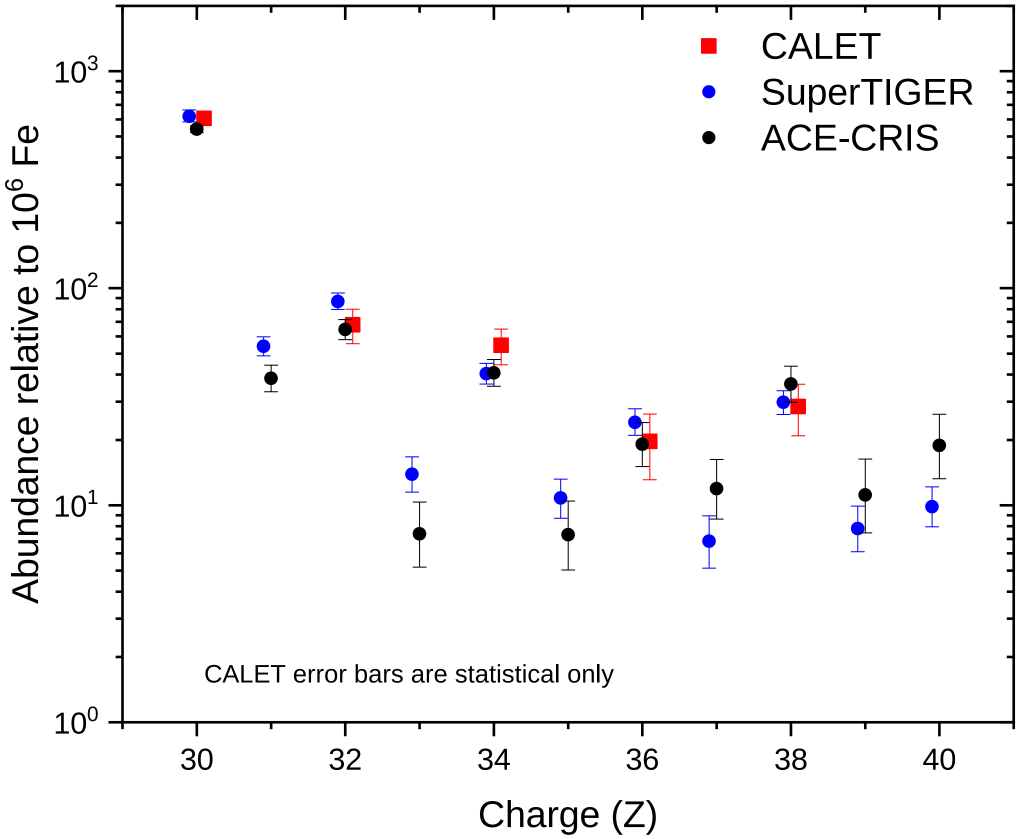
Event Distribution

- To estimate the abundances detected, we used a maximum likelihood fitting routine to fit the data.
- Fits reasonably good up to $_{34}$Se.
- For higher charges, the low statistics resulted in poor fits.
- For even-Zs above $_{34}$Se ($_{36}$Kr & $_{38}$Sr) the abundances were initially estimated by taking cuts in the valleys.
- Using SuperTIGER abundances, half of the odd-Zs on either side of the even-Z charge was subtracted off of the $_{36}$Kr & $_{38}$Sr numbers to estimate their abundances.



Comparing Relative Abundances

- The ACE and ST data are "in-space" abundances.
- The CALET data have not yet been corrected to the top of the instrument.
  - Those corrections will be small, so they will not change things materially.
- The agreement with ST and ACE-CRIS appears to be quite good.
- Additional data and anticipated improved resolution should result in reduced error bars.



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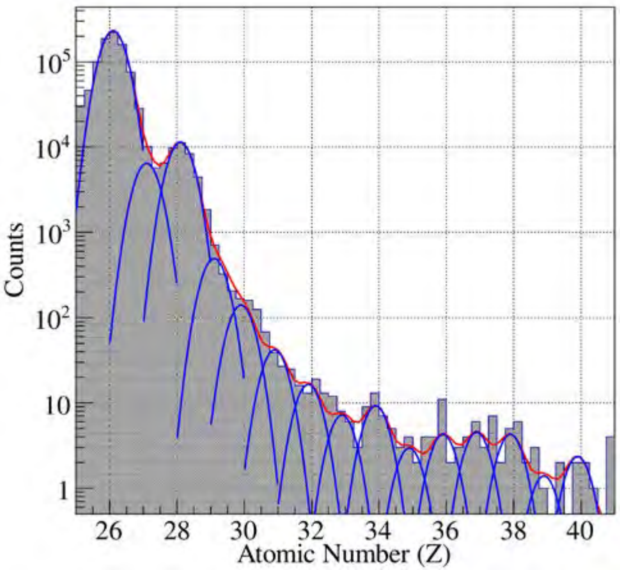
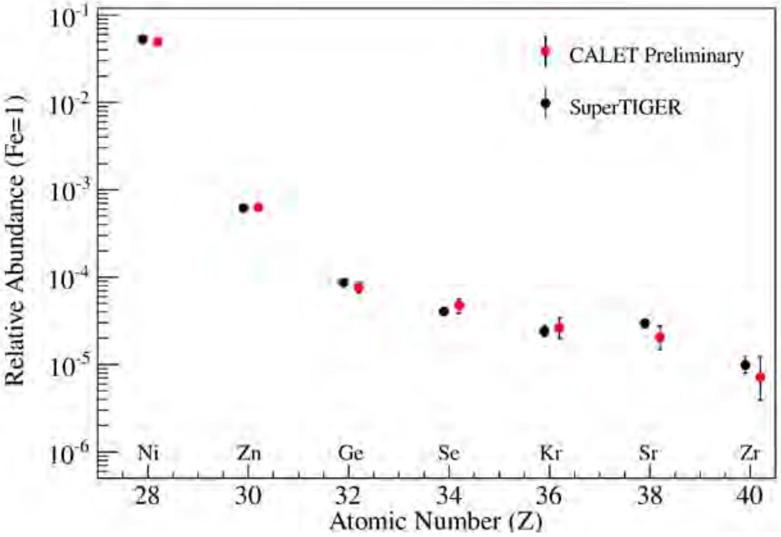
2017 CALET UH ICRC Results

Selections on ~13 month dataset:

- Zest > 24
- Theta < 60 deg
- STRM > 4.0 GV
- Z Consistency

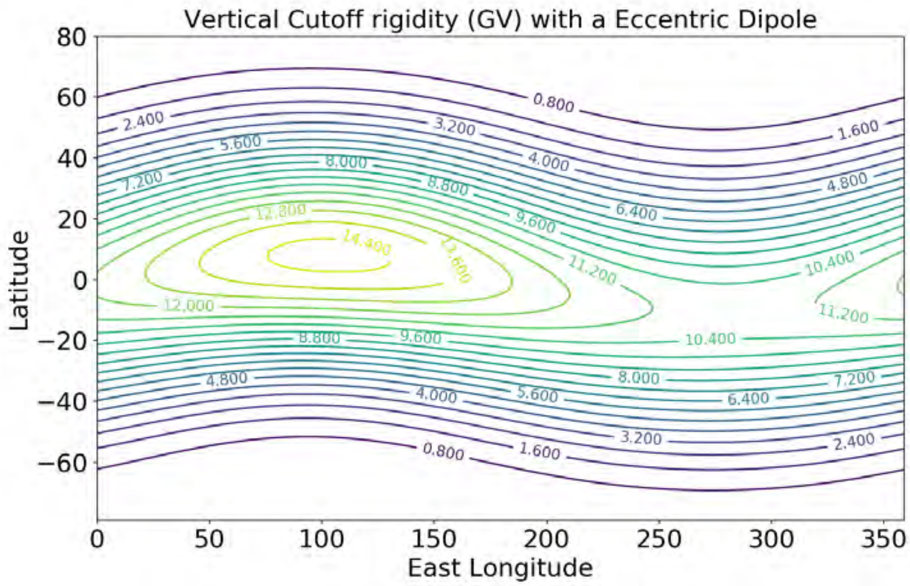
Abundances fit to integer centered charges with fixed σ = 0.35

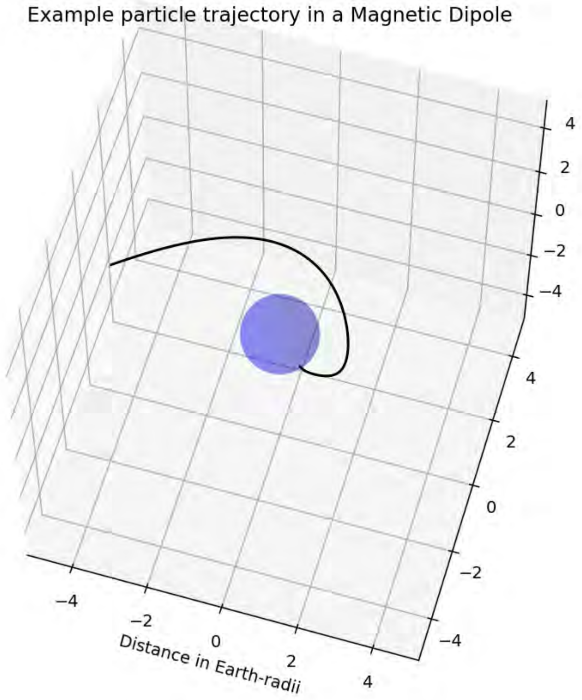




Trajectory Based Rigidity Threshold

Work is ongoing on determining event trajectory based geomagnetic rigidity cutoffs. These will allow a more targeted energy threshold selection that will maximize statistics.





Summary

- Work in progress on ~3 year dataset that should help considerably in clearly defining the low-statistics peaks.
- CALET UH analysis results on 13 and 17 months worth of data have relative abundances in good agreement with SuperTIGER and ACE-CRIS.
- At present we are able to resolve even-Z elements ${}_{30}$Zn, ${}_{32}$Ge, ${}_{34}$ Se, and it looks like we have a low-statistics peak at ${}_{38}$Sr.
- ${}_{30}$Zn peak is heavily overlapped by the ${}_{28}$Ni and ${}_{26}$Fe tails, but fit abundance agrees with other measurements.
- Work that graduate student Wolfgang Zober is doing on cutoff rigidity for every event is expected to improve our resolution in charge by eliminating low energy particles which presently contribute to broadening our resolution in Z.