Searching for ^{123}Te Electron Capture with CUORE

Maya Moore

Yale University

June 23, 2025

^{123}Te Electron Capture

^{123}Te is foreseen to EC to ^{123}Sb

- Second-order unique forbidden process
- Q-value = 51.9 keV
- High daughter nucleus angular momentum ($J^p = \frac{7}{2}^+$)
- Would be the first measurement made in these limits

Process has been unobserved thus far:

Limit on half-life*, $T_{1/2}$ > 9.2 • 10^{16} years

*Phys. Rev. D 67, 014323 (2003)

^{123}Te Electron Capture

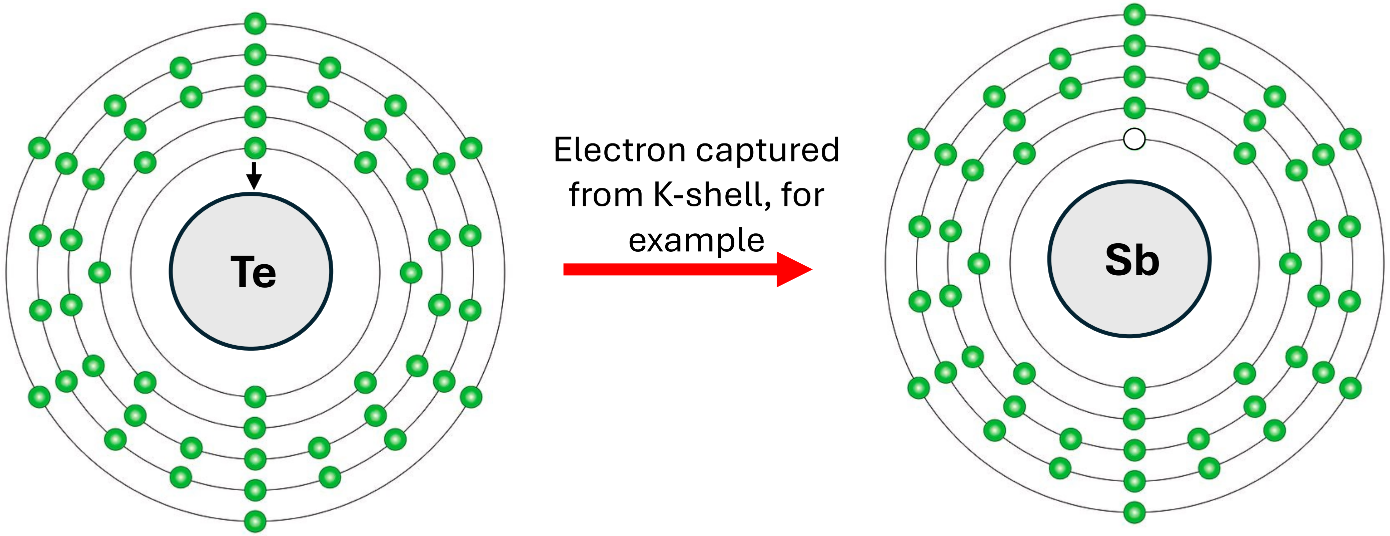
^{123}Te is foreseen to EC to ^{123}Sb

- Second-order unique forbidden process
- Q-value = 51.9 keV
- High daughter nucleus angular momentum ($J^p = \frac{7}{2}^+$)
- Would be the first measurement made in these limits

Process has been unobserved thus far:

Limit on half-life*, $T_{1/2}$ > 9.2 • 10^{16} years

*Phys. Rev. D 67, 014323 (2003)



^{123}Te Electron Capture

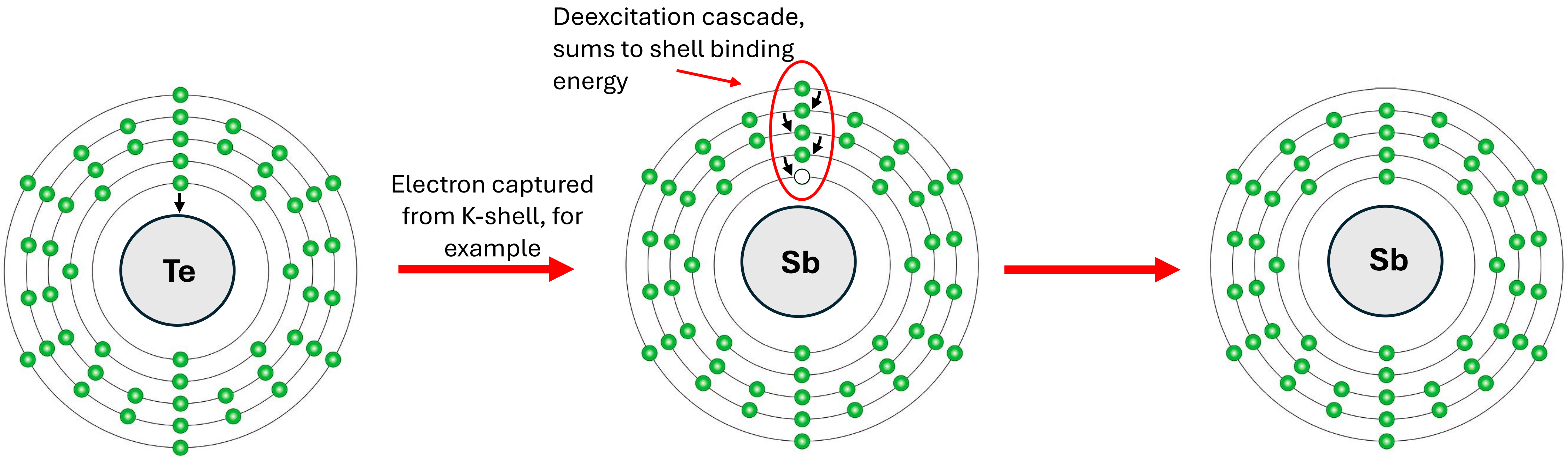
^{123}Te is foreseen to EC to ^{123}Sb

- Second-order unique forbidden process
- Q-value = 51.9 keV
- High daughter nucleus angular momentum ($J^p = \frac{7}{2}^+$)
- Would be the first measurement made in these limits

Process has been unobserved thus far:

Limit on half-life*, $T_{1/2} > 9.2 \bullet 10^{16}$ years

*Phys. Rev. D 67, 014323 (2003)



New Calculations for ^{123}Te EC

- Updated theoretical calculations completed for ^{123}Te EC ratios by O. Nitescu
  - Probability of captures from different shells tells us relative intensities of lines to expect to see in data
  - Confirm previous calculations that L3 line ($2p_{3/2}$ shell) would be the most intense line

Sb Binding Energies:

K shell = 30.5 keV

L1 shell = 4.7 keV

L2 shell = 4.4 keV

L3 shell = 4.1 keV

Capture Fraction	
L1/K	14.42
L2/K	0.38
L3/K	338.65
L/K	**353.45**

How do we look for this process?

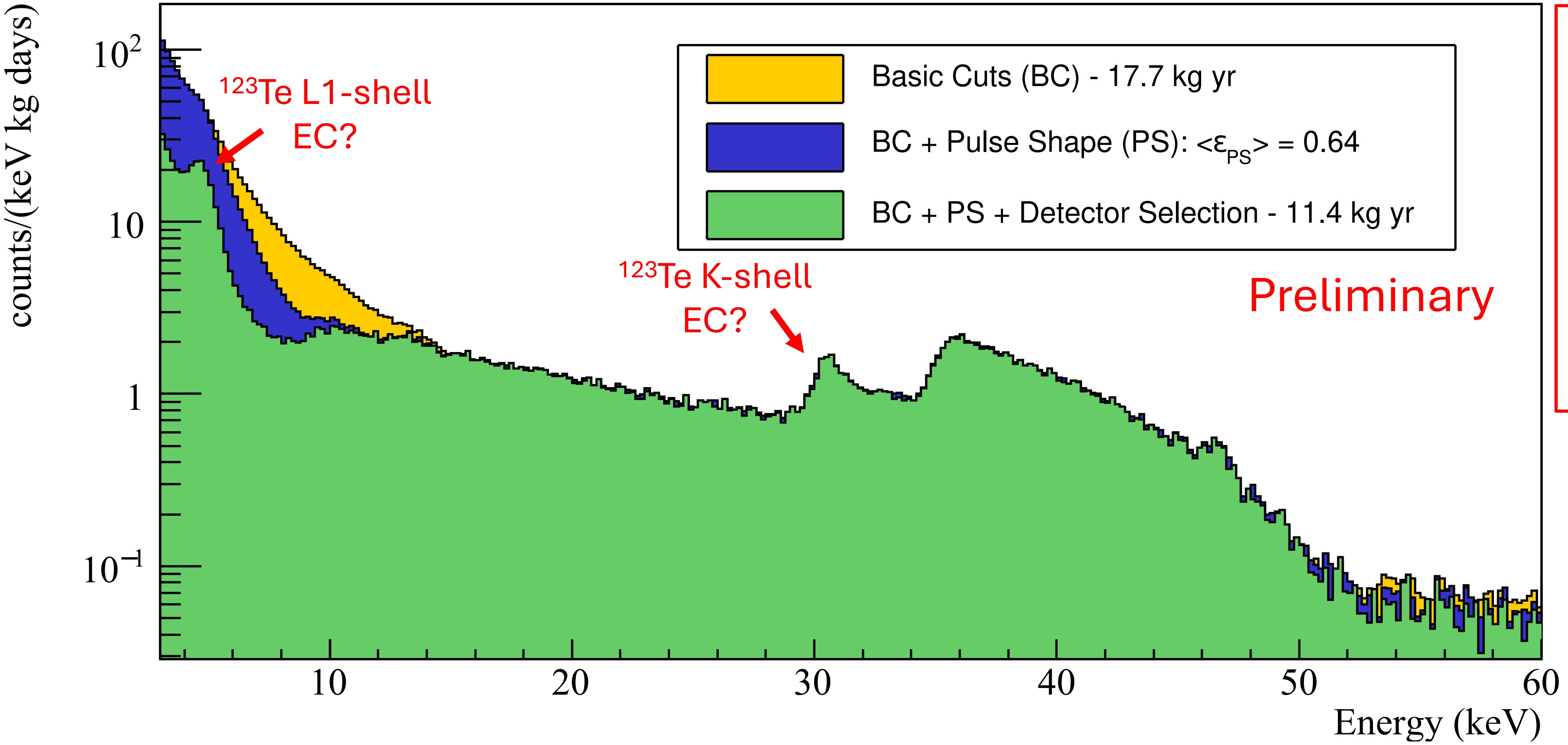
Cryogenic **U**nderground **O**bservatory for **R**are **E**vents

https://www.google.com/maps/place/Laboratori+Nazionali+del+Gran+Sasso+-+INFN

- Located at Gran Sasso National Laboratory
- 988 **natural** TeO_2 crystals (detectors) operated at ~10 mK
  - ^{123}Te isotopic abundance ~0.9%
- Searching for $0\nu\beta\beta$ of ^{130}Te ($Q_{\beta\beta}$ ~ 2528 keV)
- Low backgrounds, large exposure, and good energy resolution enables broad physics program beyond $0\nu\beta\beta$
  - New analysis chain has allowed access to data down to 3 keV [arXiv:2505.23955]

CUORE Low Energy Spectrum

M1 spectrum of detector with OT threshold lower than 3 keV



Sb Binding Energies:

K shell = 30.5 keV

L1 shell = 4.7 keV

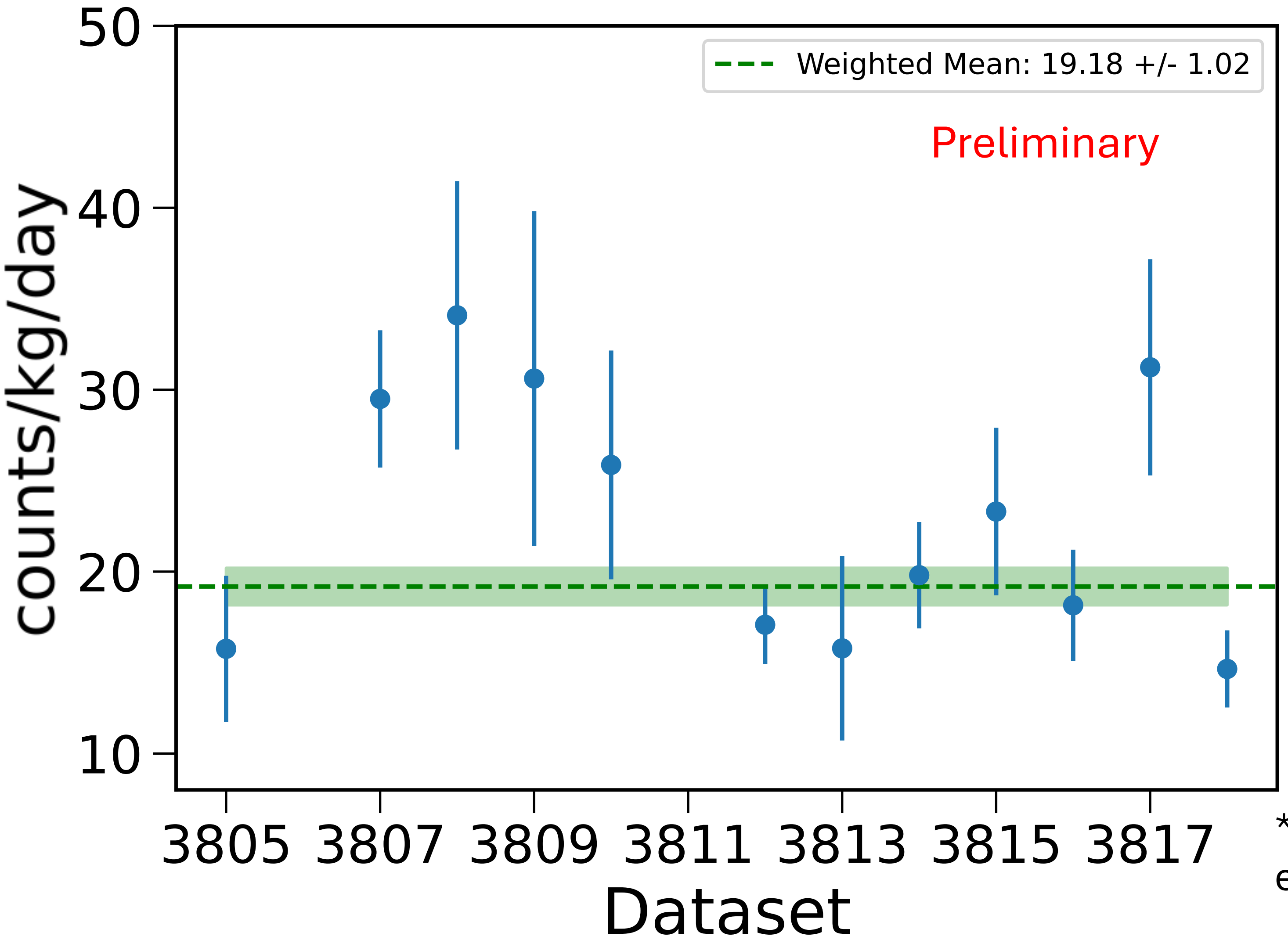
L2 shell = 4.4 keV

L3 shell = 4.1 keV

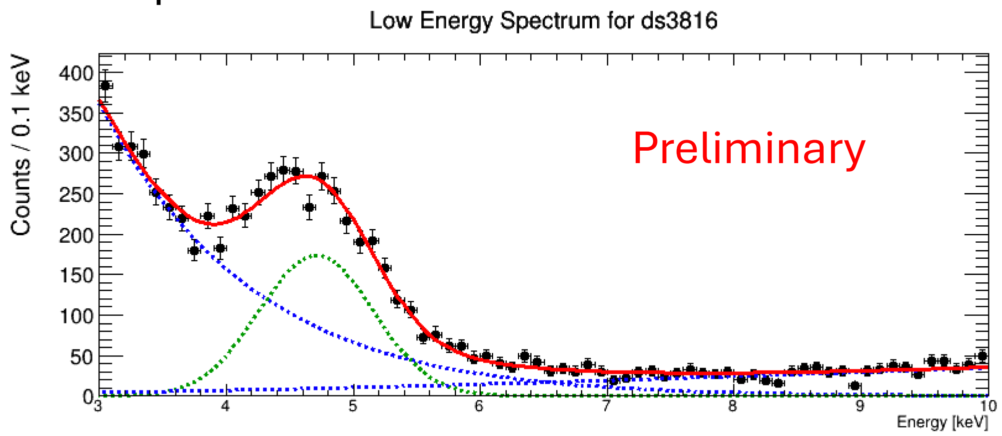
Experimental Results

1. 4.7 keV Signal Rate
2. 30.5 keV Signal Rate
3. L1/K Ratio

4.7 keV (L1-shell) Signal Rate

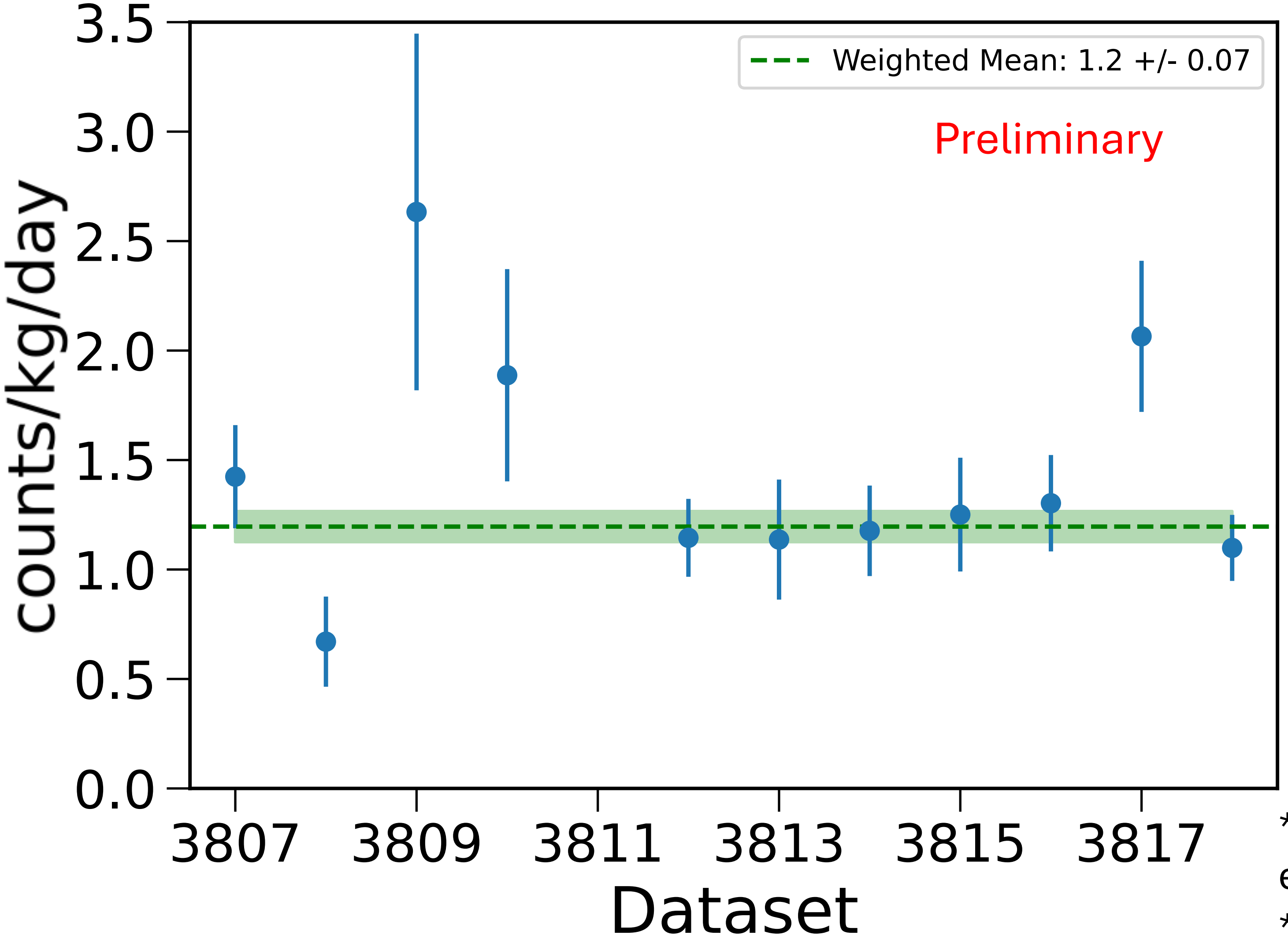


Example Fit:

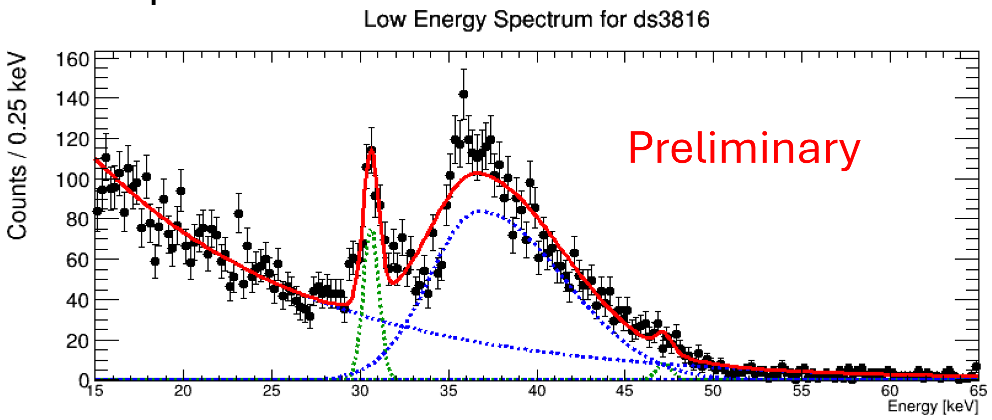


* Error bars include statistical errors on all efficiencies and number of signal events

30.5 keV (K-shell) Signal Rate



Example Fit:



* Error bars include statistical errors on all efficiencies and number of signal events

* ds3805 excluded due to small exposure

L1/K Ratio

$$\frac{L1}{K} = \frac{avg.rate\ of\ 4.7\ keV\ peak}{avg.rate\ of\ 30.5\ keV\ peak} = \frac{19.42 \pm 1.05^{*} cpd/kg}{1.22 \pm 0.03^{*} cpd/kg} = 15.9\ \pm\ 0.9\ ^{stat}\ {}^{+\,4.5}_{-\,2.4}\ ^{sys}$$

* Rates are excluding ds3805

L1/K Ratio

$$\frac{L1}{K} = \frac{avg.rate\ of\ 4.7\ keV\ peak}{avg.rate\ of\ 30.5\ keV\ peak} = \frac{19.42 \pm 1.05^{*} cpd/kg}{1.22 \pm 0.03^{*} cpd/kg} = 15.9\ \pm\ 0.9\ ^{stat}\ {}^{+\,4.5}_{-\,2.4}\ ^{sys}$$

* Rates are excluding ds3805

- Ratio is compatible with theoretical calculations **$L1/K_{th}$ = 14.42**

Missing L3 Shell?

A very intense line at 4.1 keV predicted from theoretical models which is not present in experimental data

1. Is this an issue with experiment? Miscalibration?
2. Peaks are due to other processes?
3. Is this an issue with theoretical models?

Capture Fraction	
L1/K	14.42
L2/K	0.38
L3/K	338.65
L/K	**353.45**

Remaining Mystery: Is L3 (4.1 keV) somehow suppressed?

Thank you!

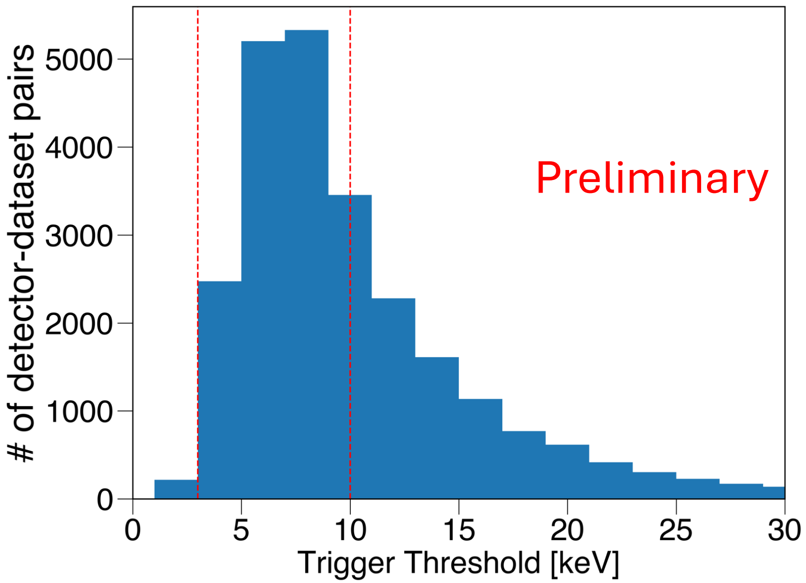
This work is supported by the INFN, the US DOE Office of Nuclear Physics, the US NSF, and internal investments at all institutions.

Backup Slides

Low Energy Analysis Methods Overview

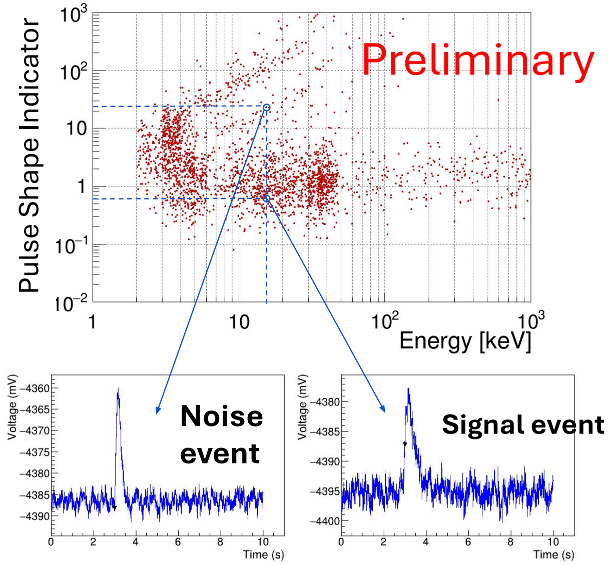
1. Optimized Detector Selection

- Energy thresholds determined for each detector
- Threshold = energy at which detector has detection efficiency of ~90% for injected pulses



2. Event Level Cuts

- Pulse shape cut determined for each detector



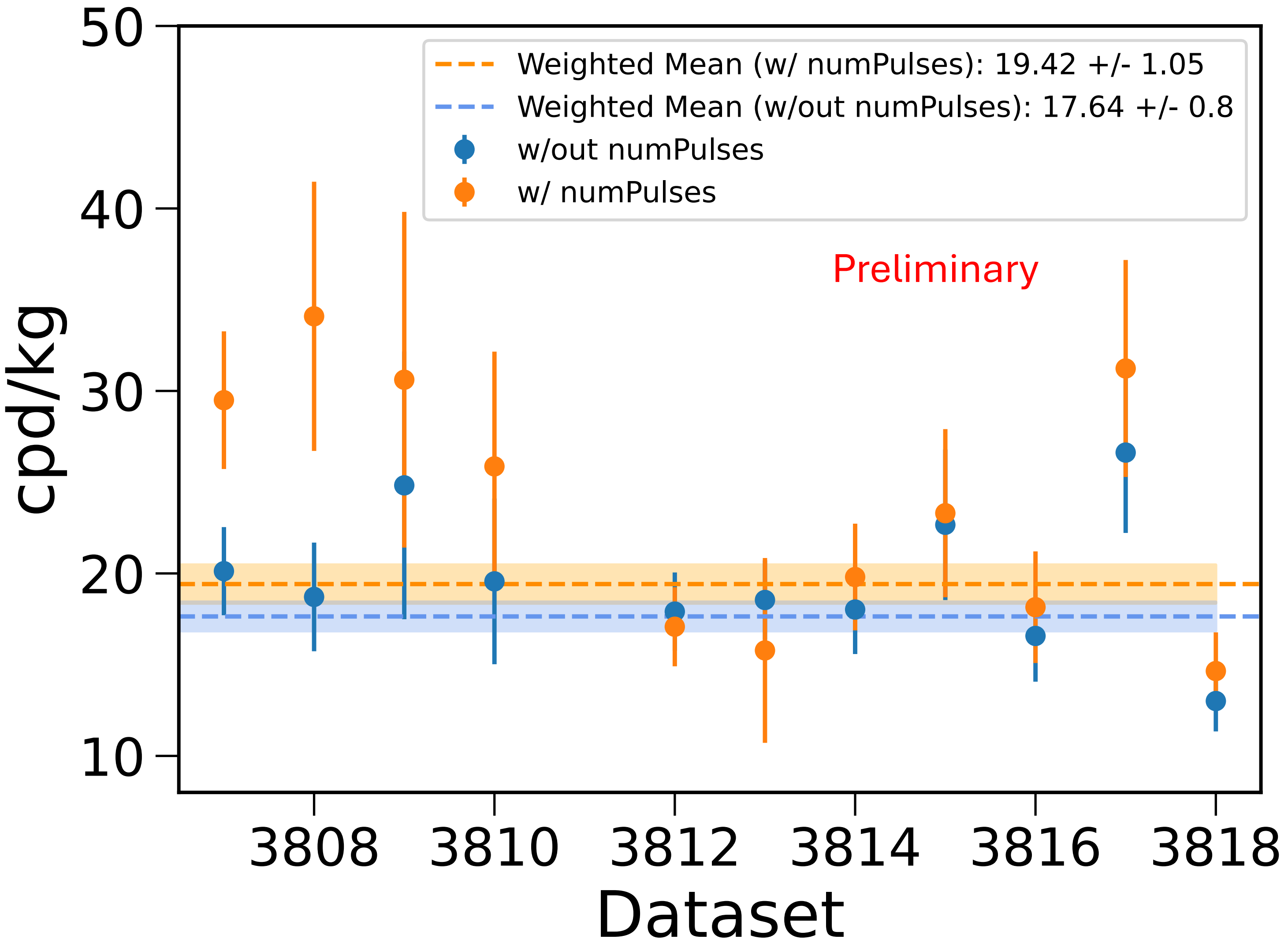
Paper now on arXiv!
arXiv:2505.23955

3. Denoising

4. Calibration & Efficiencies

- Thermal pulses at low energies

4.7 keV Signal Rate - No Pile Up Cut



- Took out NumPulses == 1 cut and then didn't weight by pile up efficiency
  - Signal rate is much more constant
- Likely due to change in timing window of pulsers
  - Before ds3813 the timing window was shorter which likely worsened the efficiency estimate

* Error bars include statistical errors on all efficiencies and number of signal events

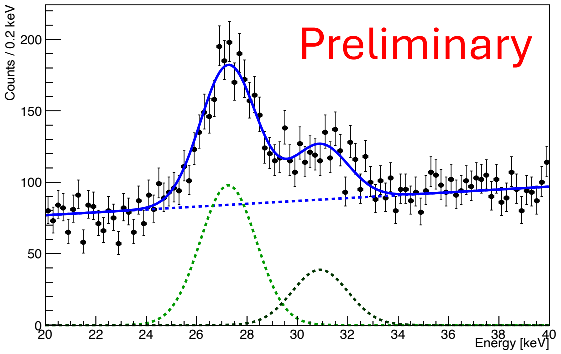
Low Energy Calibration Checks

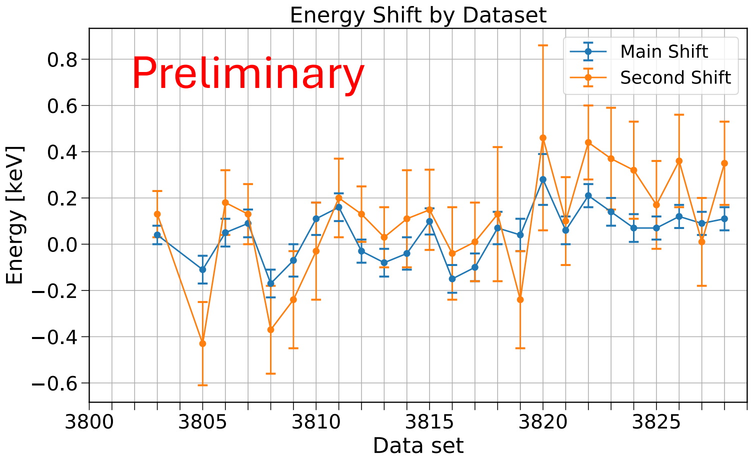
- Calibration checked at low energies on Te x-rays (~27/31 keV) and ^{40}K x-ray at 3.2 keV

Te x-rays:

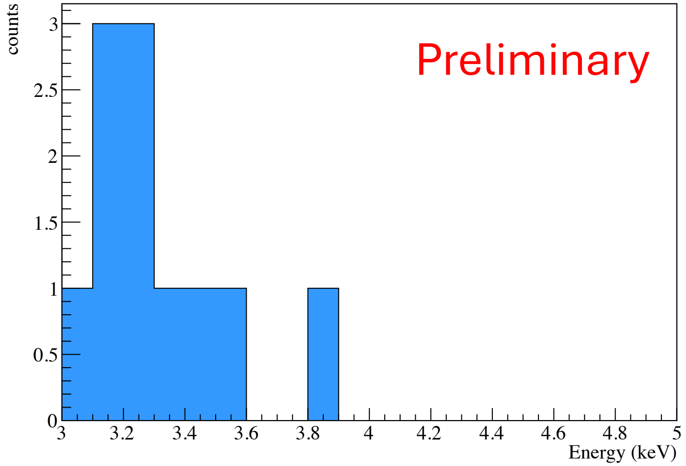
- Te x-rays are present in calibration data from excitation due to calibration sources

Line	Energy [keV]	Intensity [%]
$K\alpha1$	27.472	47.1
$K\alpha2$	27.202	25.3
$K\alpha3$	26.875	0.00202
$K\beta1$	30.995	8.19
$K\beta2$	31.704	2.37
$K\beta3$	30.944	4.25
$K\beta4$	31.774	0.363
$K\beta5$	31.237	0.075





^{40}K x-ray:



- In coincidence with the main gamma emission at 1460 keV, a low intensity, low energy x-ray can be emitted
- The existence of this 3.2 keV x-ray was confirmed in coincidence with the 1460 keV gamma peak with the 3 keV channels