

# First Results on keV-Scale Sterile Neutrinos from the LiFE-SNS Project

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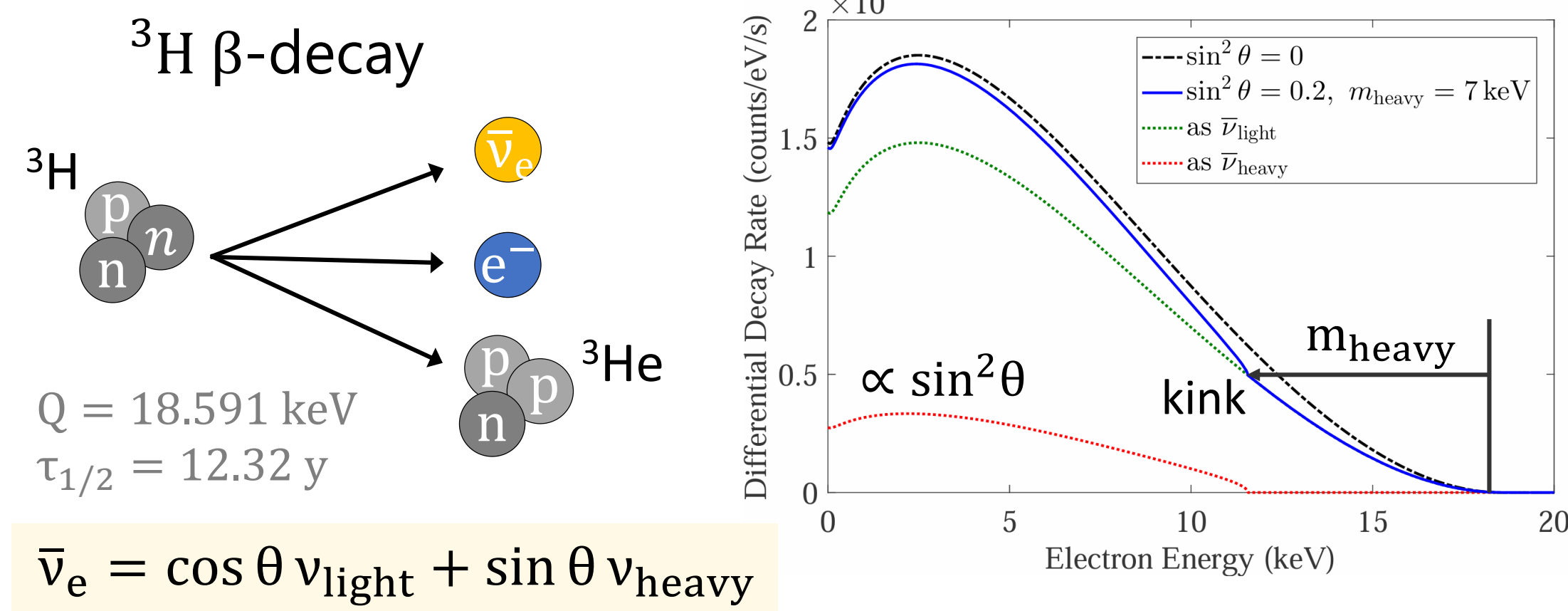
for LiFE-SNS project



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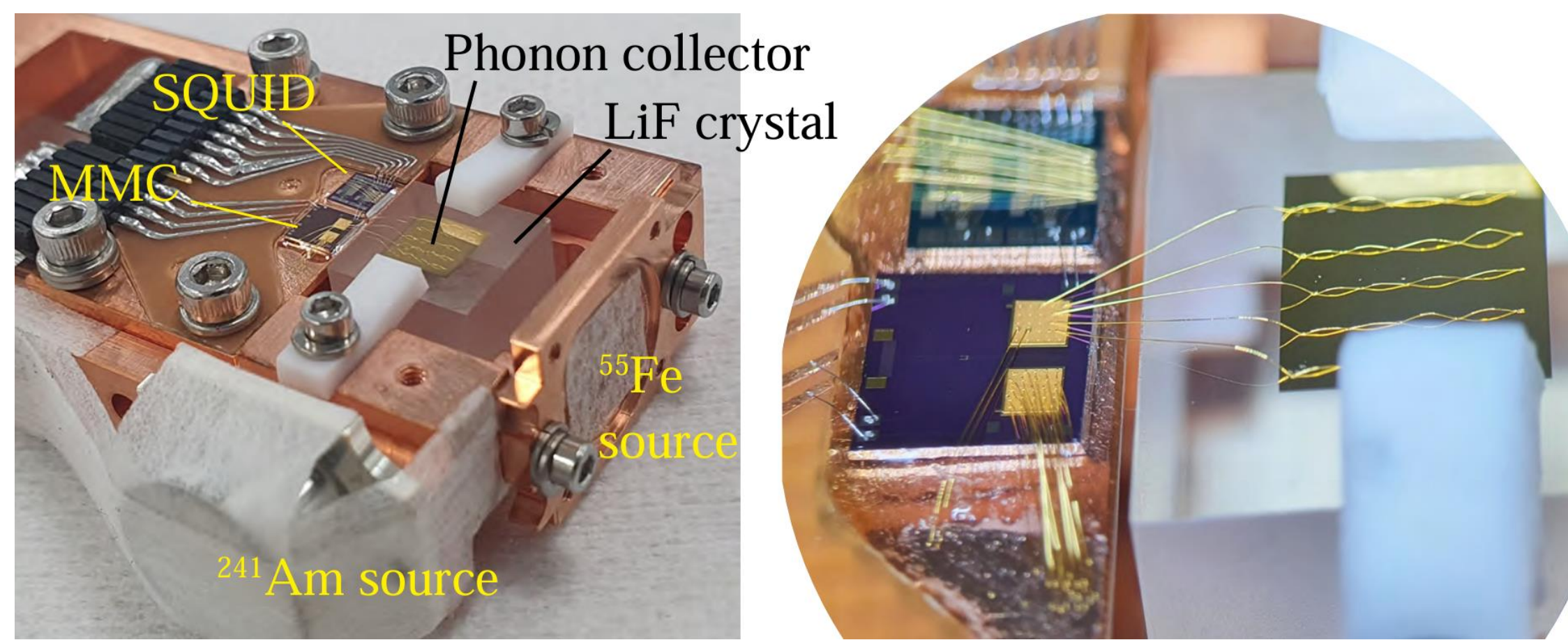
arXiv:2602.05161

## Sterile neutrino signal in $\beta$ -decay spectrum



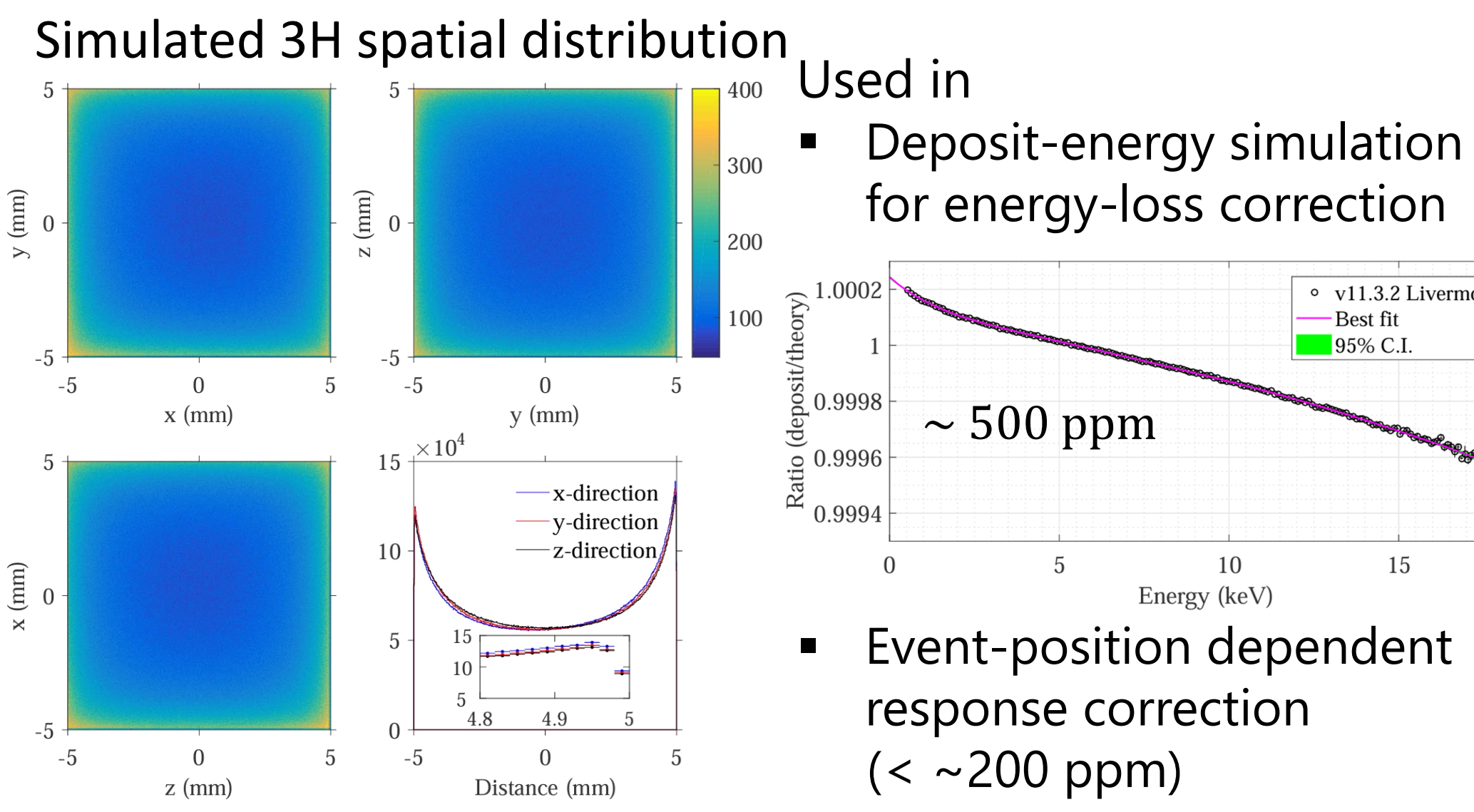
## LiFE-SNS: LiF Experiment for keV-scale Sterile Neutrino Search

- Full-spectrum measurement of  $^3\text{H}$   $\beta$  spectrum using LiF crystal
- Total decay energy measured by magnetic micro-calorimeter (MMC)
- Nearly full energy deposition ( $E_{\text{dep}} \approx Q - E_\nu$ )



## $^3\text{H}$ source embedding in LiF: thermal neutron irradiation

- $n + ^6\text{Li} \rightarrow ^3\text{H} + ^3\text{He}$
- 22day exposure at KRISS
- n-storage results in 40 Bq  $^3\text{H}$
- 2.3 mm capture length in LiF
- Before irradiation, background spectrum measured

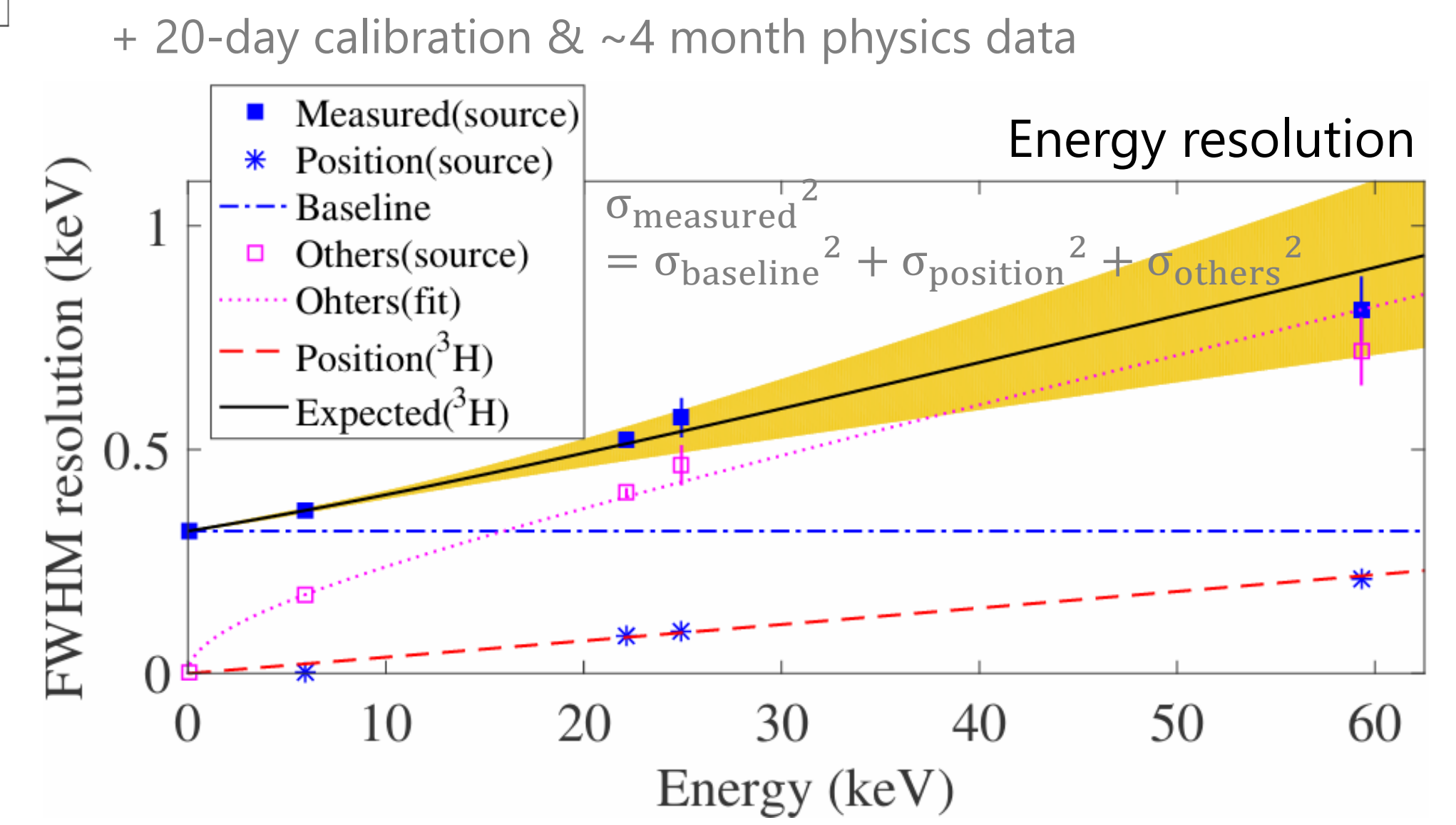
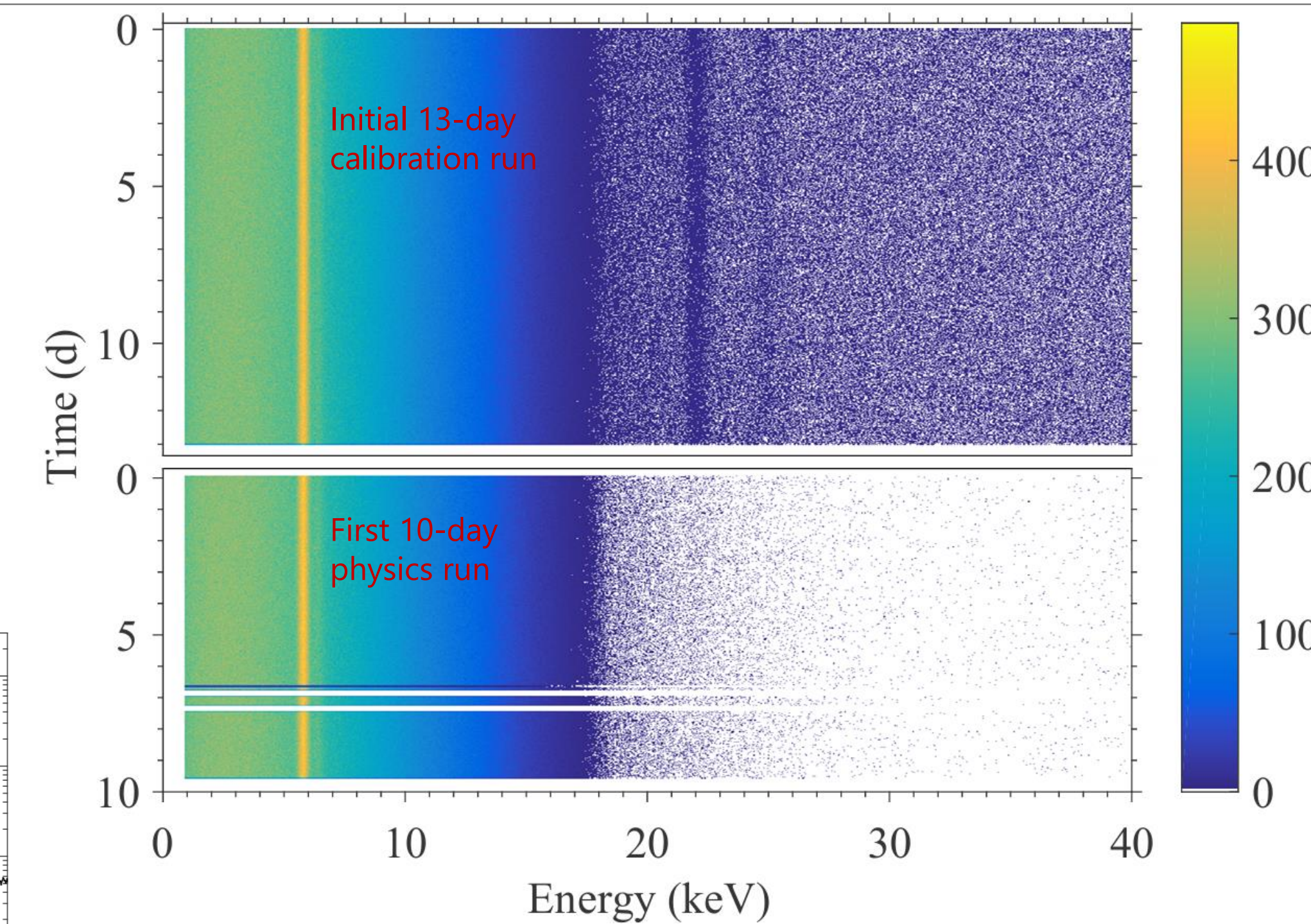
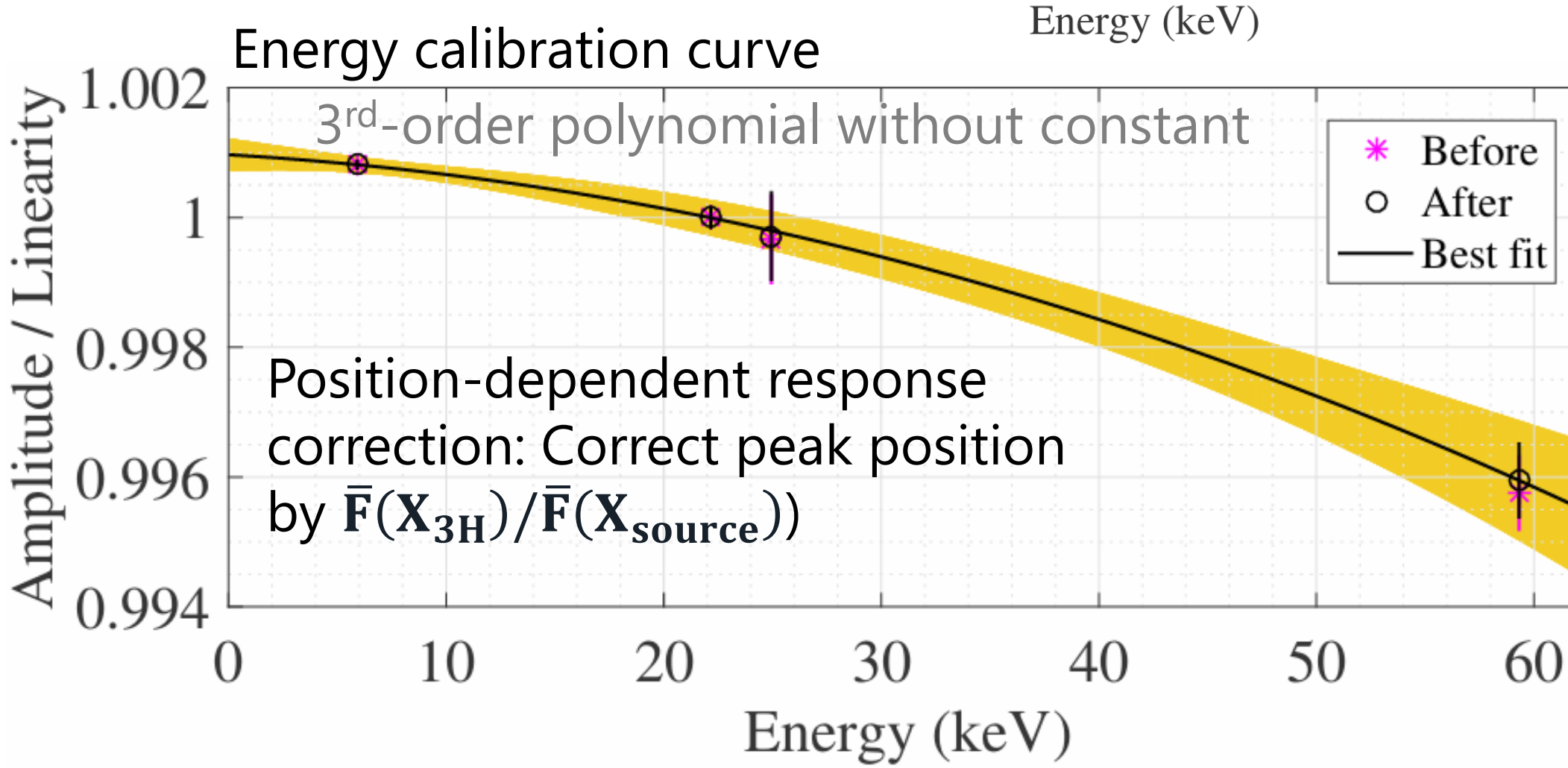
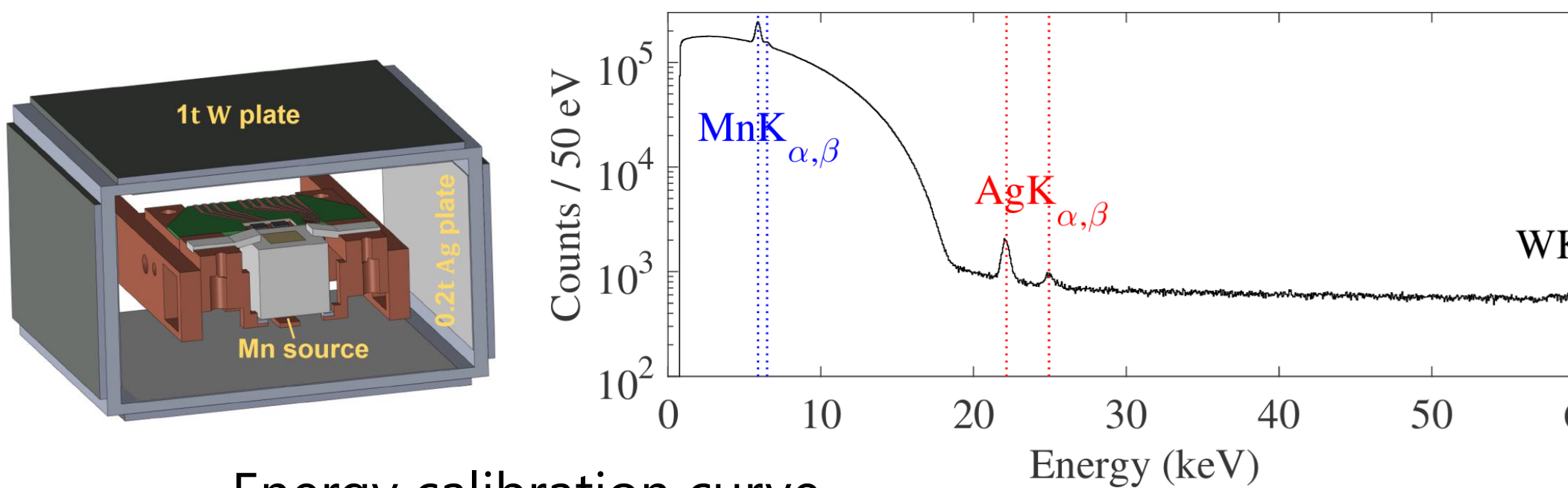


## Theoretical deposited-energy spectrum of $^3\text{H}$ $\beta$ -decay

- Energy deposit in LiF:**
  - $E_{\text{dep}} = E_e + E_{\text{recoil}} + E_{\text{deexcitation}} + E_{\text{neutralization}}$
  - Based on exact-description of 3-body decay of  $^3\text{H}$
  - Electromagnetic & atomic corrections<sup>2</sup>, final atomic states<sup>3</sup>
- 1: PRC 77, 055502 (2008), PRC 76, 045501 (2007), JHEP 06, 040 (2016)  
2: RMP 90, 015008 (2018), JCAP 02, 020 (2015), PRD 84, 014021 (2011)  
3: JHEP 03, 144 (2023)

## LiFE-SNS Phase-1

- Two  $\sim 40$  Bq detectors operated in dilution refrigerator (20mK)
  - Data taking completed:** Jun. 2024 – Dec. 2024
  - Initial 13-day calibration run
  - 4-month physics run without external source
  - Additional 20-day calibration run at Oct. 2024
- Calibration strategy
- Internal Fe55 source producing peak at 6keV region
  - Ag/W fluorescence x-rays from external thoriated tungsten rods (calibration runs only)



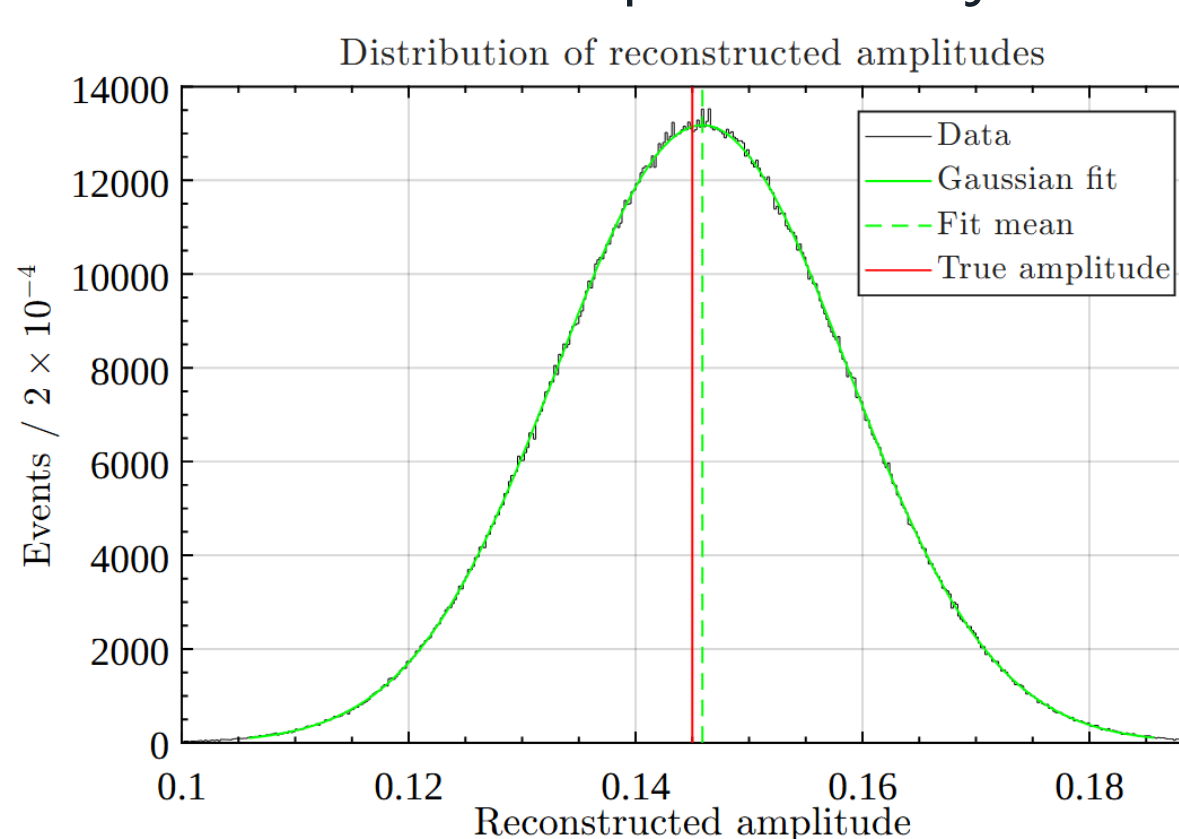
## Data analysis



- ### Injection simulation
- Inject scaled noise-free signals into raw data streams at random times
  - Same data-processing chain applied
  - Purpose
    - Event-selection efficiency
    - Bias correction

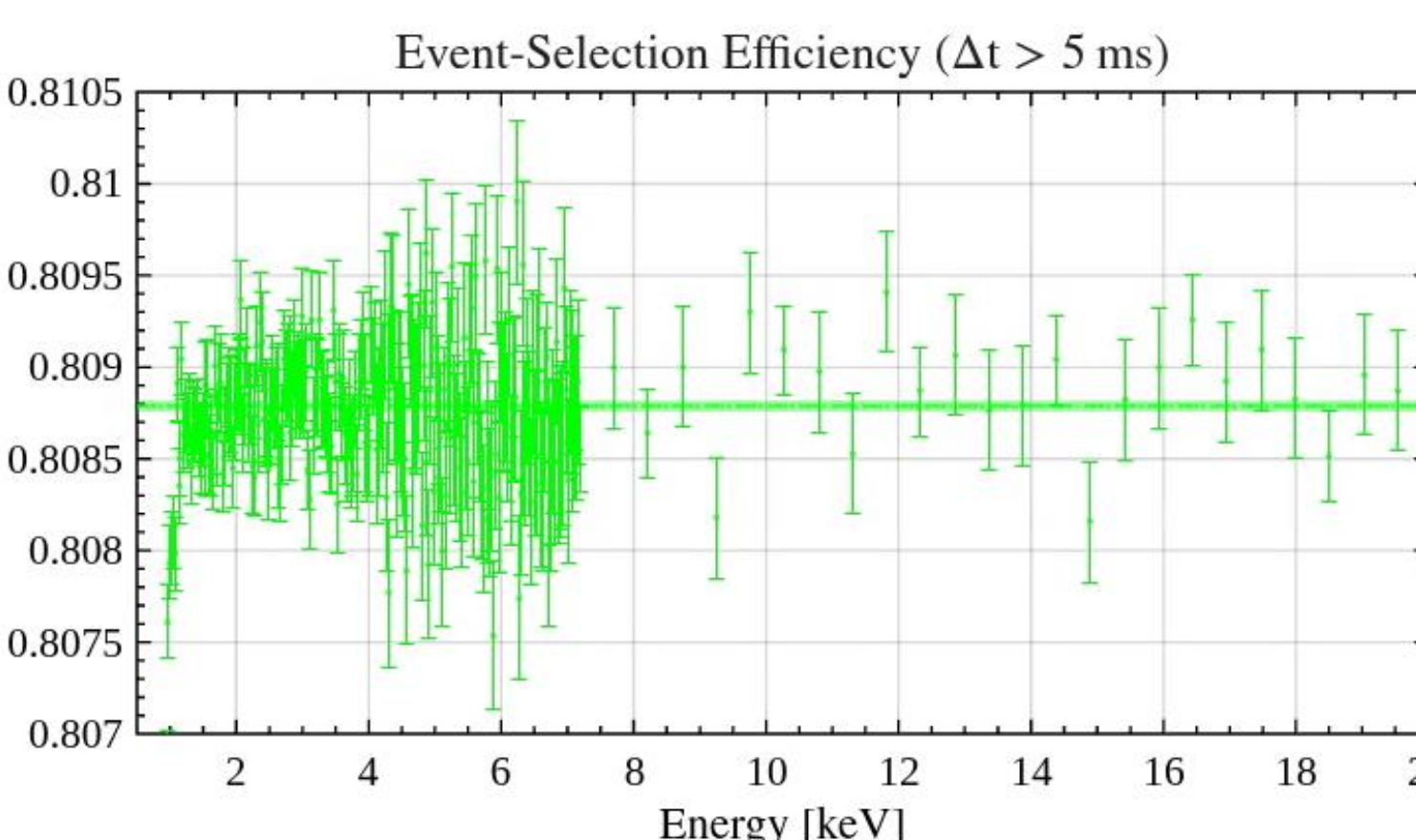
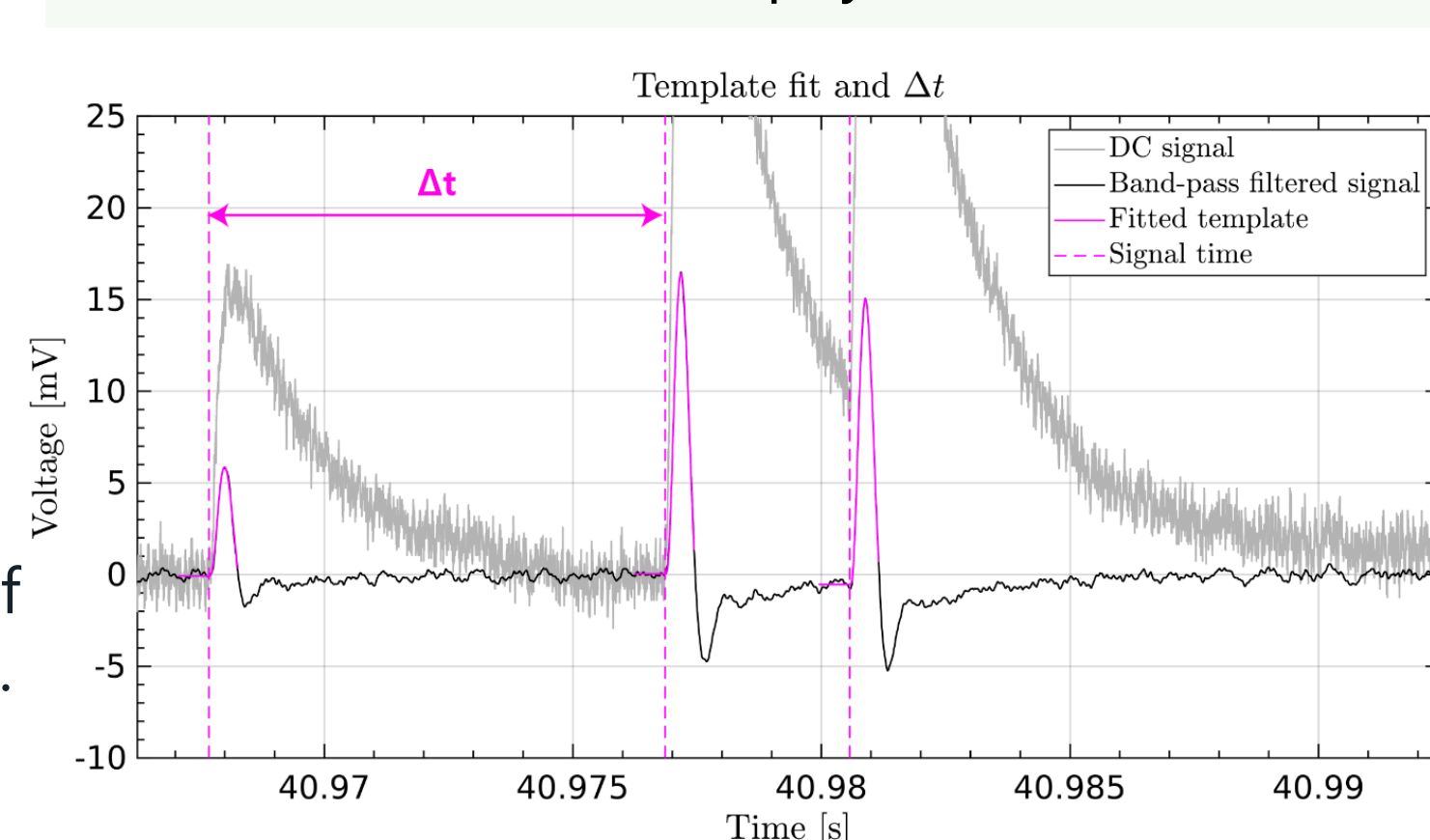
- ### Event trigger
- Fixed 5 $\sigma$  threshold trigger with 2 ms dead-time

- ### Pulse amplitude, signal time
- Least square fit using averaged signal
  - $S(t) = A \cdot T(t - t_0) + C$
  - Positive-bias are corrected using mean of reconstructed amplitude in injection Sim.



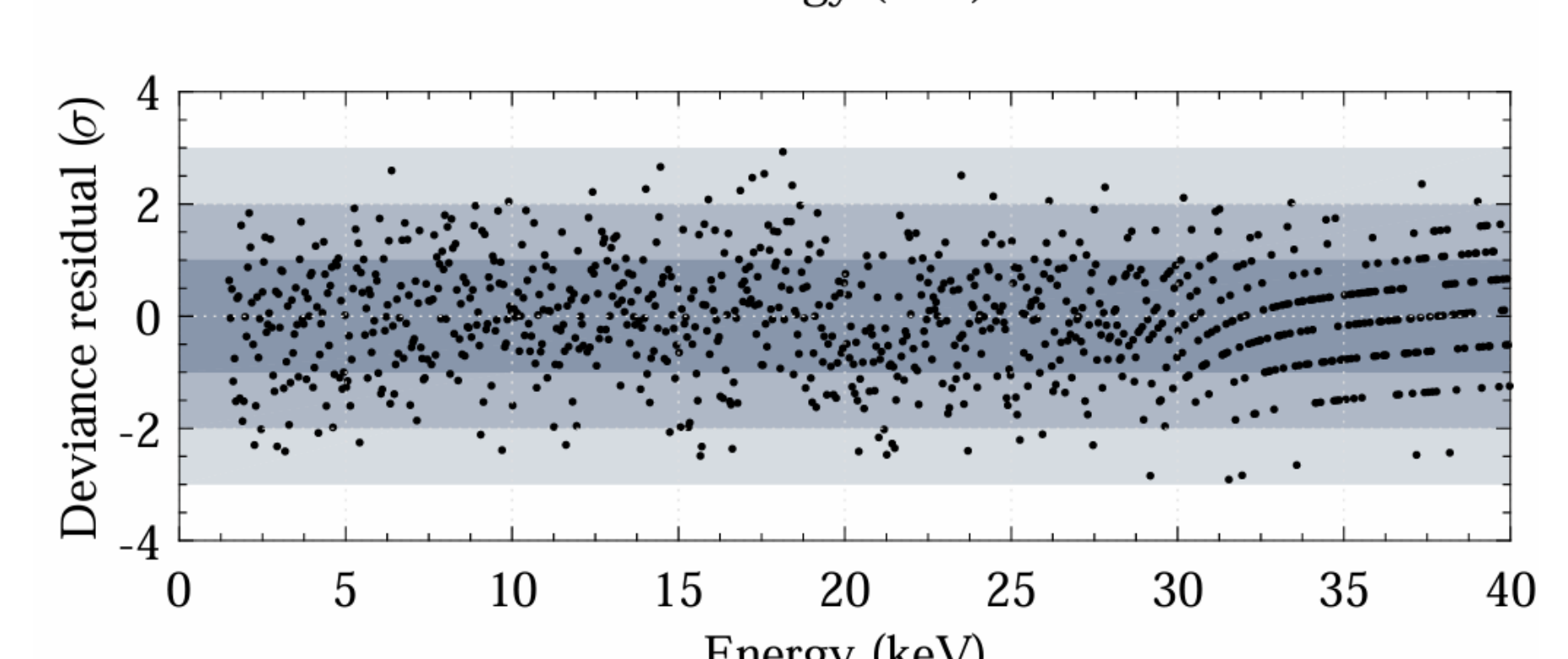
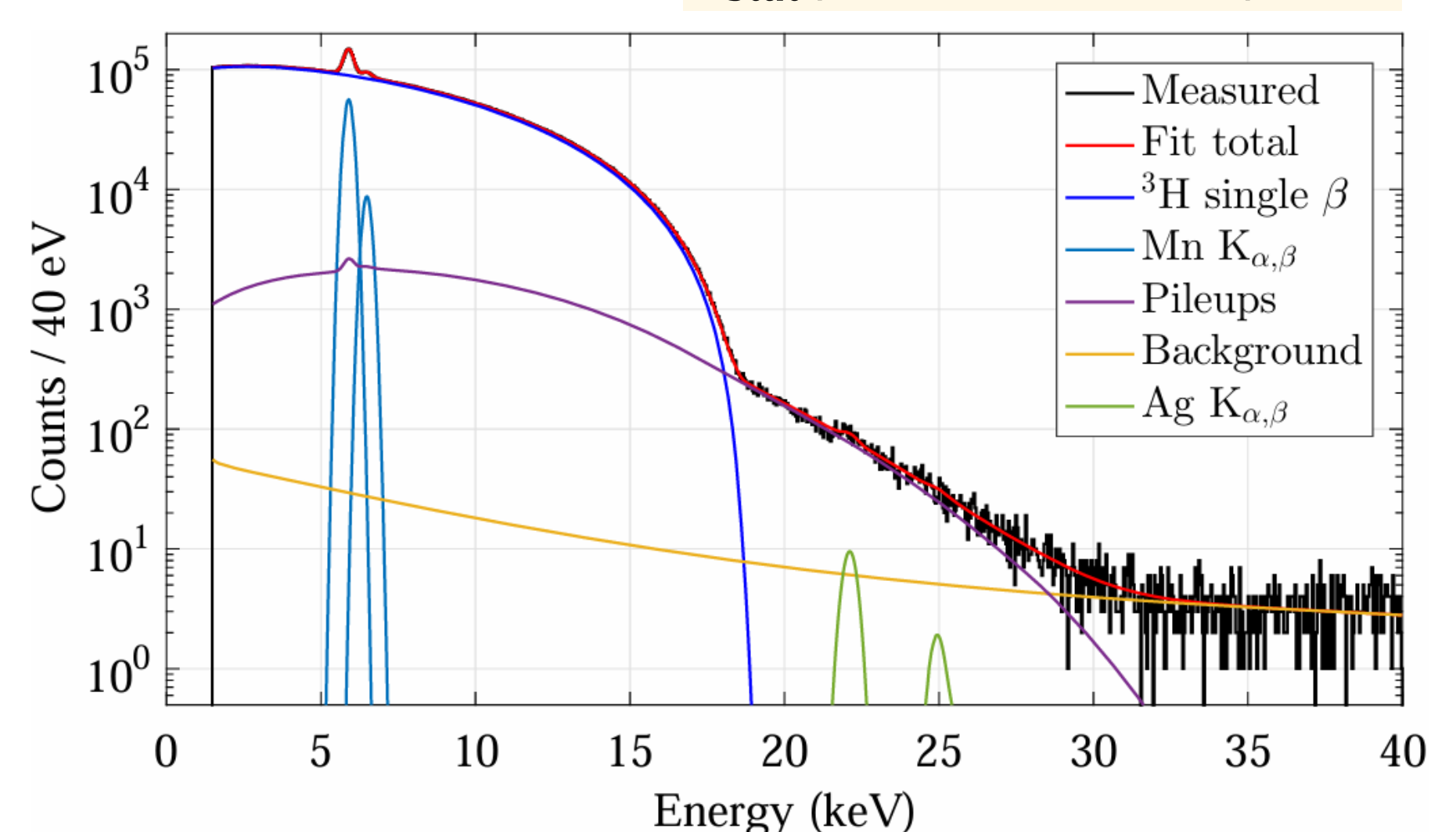
$\Delta t > 5$  ms cut ensures flat efficiency above 1.5 keV

Band-pass filtering (0.9–2 kHz) suppresses pulse overlap and mitigates changes in response nonlinearity arising from different event rates between calibration and physics data.



## Spectrum analysis with first 10-day physics data

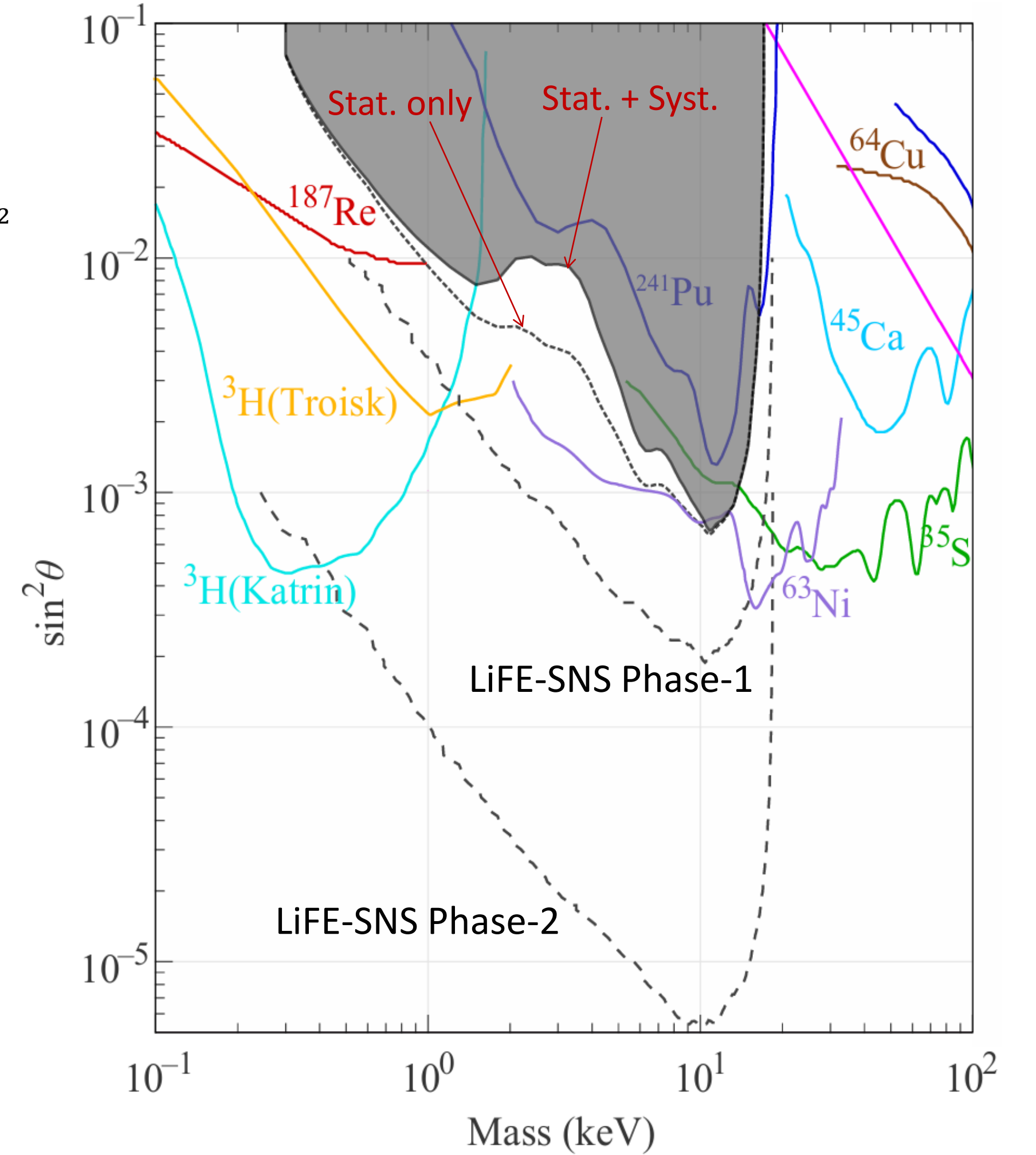
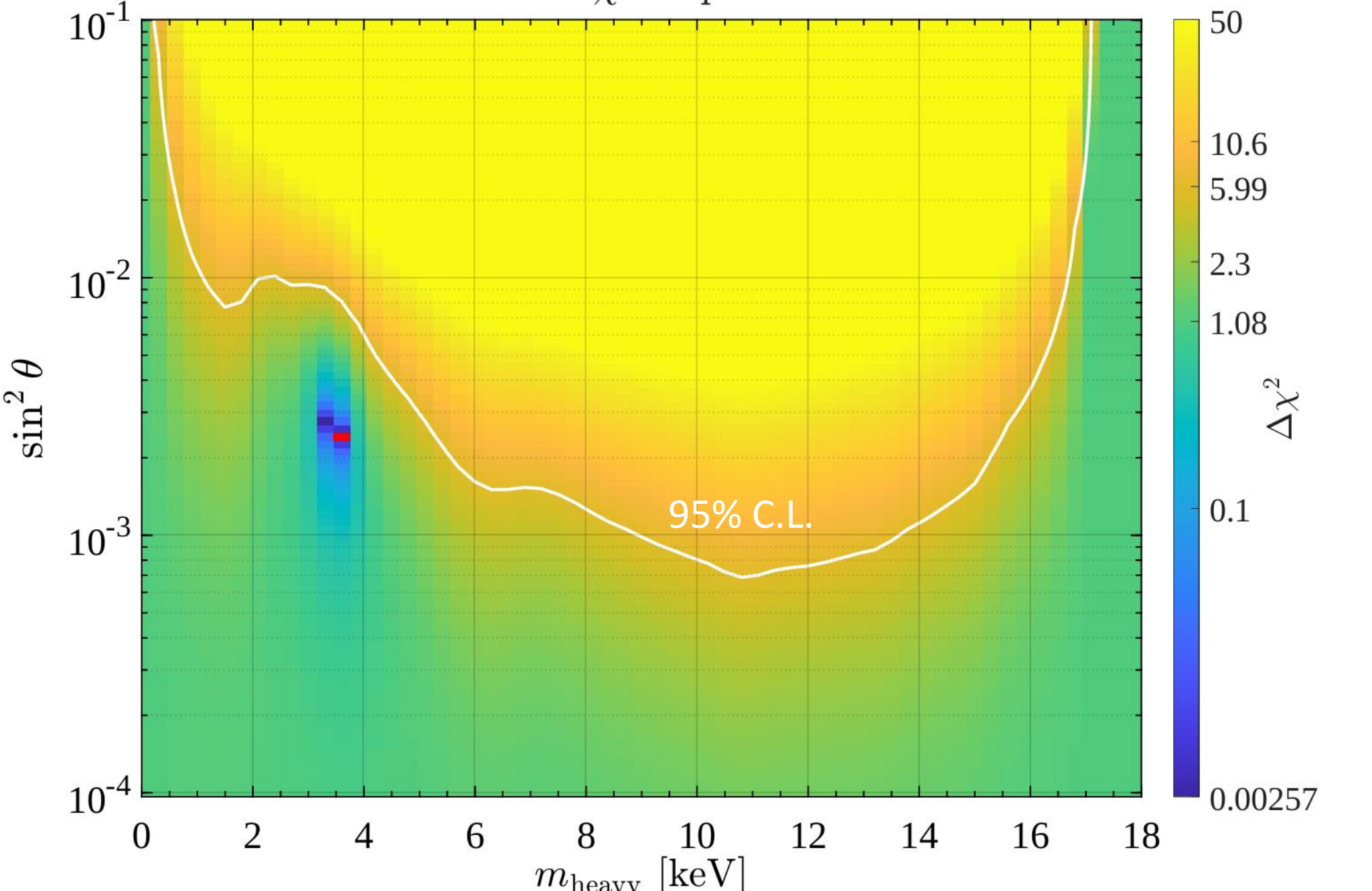
- Null-hypothesis fit:  $\chi^2_{\text{stat}} = 2 \sum_i [M_i - D_i + D_i \ln(\frac{D_i}{M_i})]$
- Measured spectrum:  $D_i$
- $2.4 \times 10^7$  events in 1.5–40 keV, binned in 40 eV intervals
- Expect spectrum:  $M_i$
- Single-event  $^3\text{H}$   $\beta$ -decay, Mn  $K_{\alpha,\beta}$  lines, Pileup spectrum, background, Ag fluorescence X-rays
  - Pileup spectrum generated from pseudo waveforms using the same reconstruction chain
  - 9 free parameters  $\chi^2_{\text{stat}} / \text{n. d. f} = 991.43 / 953$



- Main systematic sources: Gain variation, energy-calibration uncertainty, pileup-spectrum uncertainty
- Systematic uncertainties are included in the expected model through principal distortion modes with nuisance parameters
- $\chi^2_{\text{tot}} = 2 \sum_i [M_i - D_i + D_i \ln(\frac{D_i}{M_i})] + (\alpha_{\text{gain}})^2 + \sum_{k=1}^4 (\alpha_k^{\text{ecal}})^2 + \sum_{k=1}^{25} (\alpha_k^{\text{pileup}})^2$
- | $\alpha_{\text{gain}}$ | $\alpha_k^{\text{ecal}}$ | $\alpha_k^{\text{pileup}}$ |
|------------------------|--------------------------|----------------------------|
| 0.5                    | -1.1                     | -0.2                       |
|                        | -0.8                     | 0.3                        |
|                        |                          | -0.68 ~ 0.39               |
- For null-hypothesis

## keV sterile neutrino search result

- Spectral model
- $\frac{dR}{dE}(E; m_{\text{heavy}}, \sin^2\theta) = \cos^2\theta \frac{dR}{dE}(E; m_\nu = 0) + \sin^2\theta \frac{dR}{dE}(E; m_{\text{heavy}})$
- Search grid
- $m_{\text{heavy}}$ : 300 eV interval steps from 0 to 18.3 keV
  - $\sin^2\theta$ : 101 logarithmic interval from  $10^{-4}$  to  $10^{-1}$
- Global minimum:  $(m_{\text{heavy}}, \sin^2\theta) = (3.6 \text{ keV}, 0.0024)$ , with  $\chi^2_{\text{min}} = 985.7$
- Null hypothesis:  $\Delta\chi^2 = 1.1 \rightarrow$  No significant signal observed



- This work**
- First 10-day  $^3\text{H}$  data with one detector
- Phase-1**
- Data taking completed: 4 month with 2 detectors  $\rightarrow \sim 20\times$  more  $\beta$ -decay events available
  - Energy-calibration uncertainty dominates the sensitivity degradation and is expected to be reduced by including the additional 20-day calibration data
- Phase-2**
- Future high-statistics measurement with improved setup
  - $10^{12}$   $\beta$ -events: 100 detectors  $\times$  100 Bq  $\times$  3 years