GRAN SASSO SCIENCE INSTITUTE
SCHOOL OF ADVANCED STUDIES
Scuola Universitaria Superiore

INFN
Istituto Nazionale di Fisica Nucleare

TAUP
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Final results of the CUPID-0 combined background model

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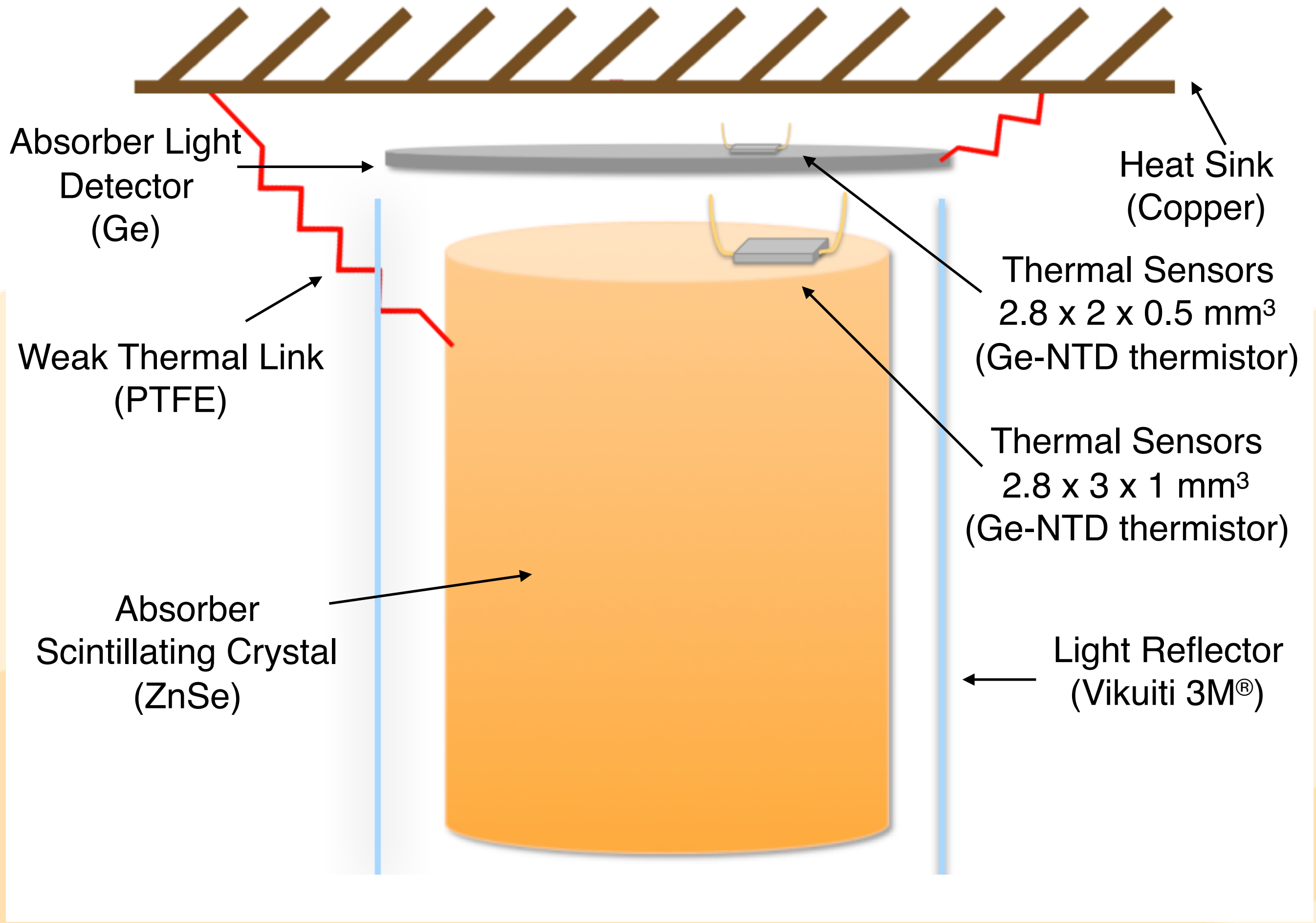
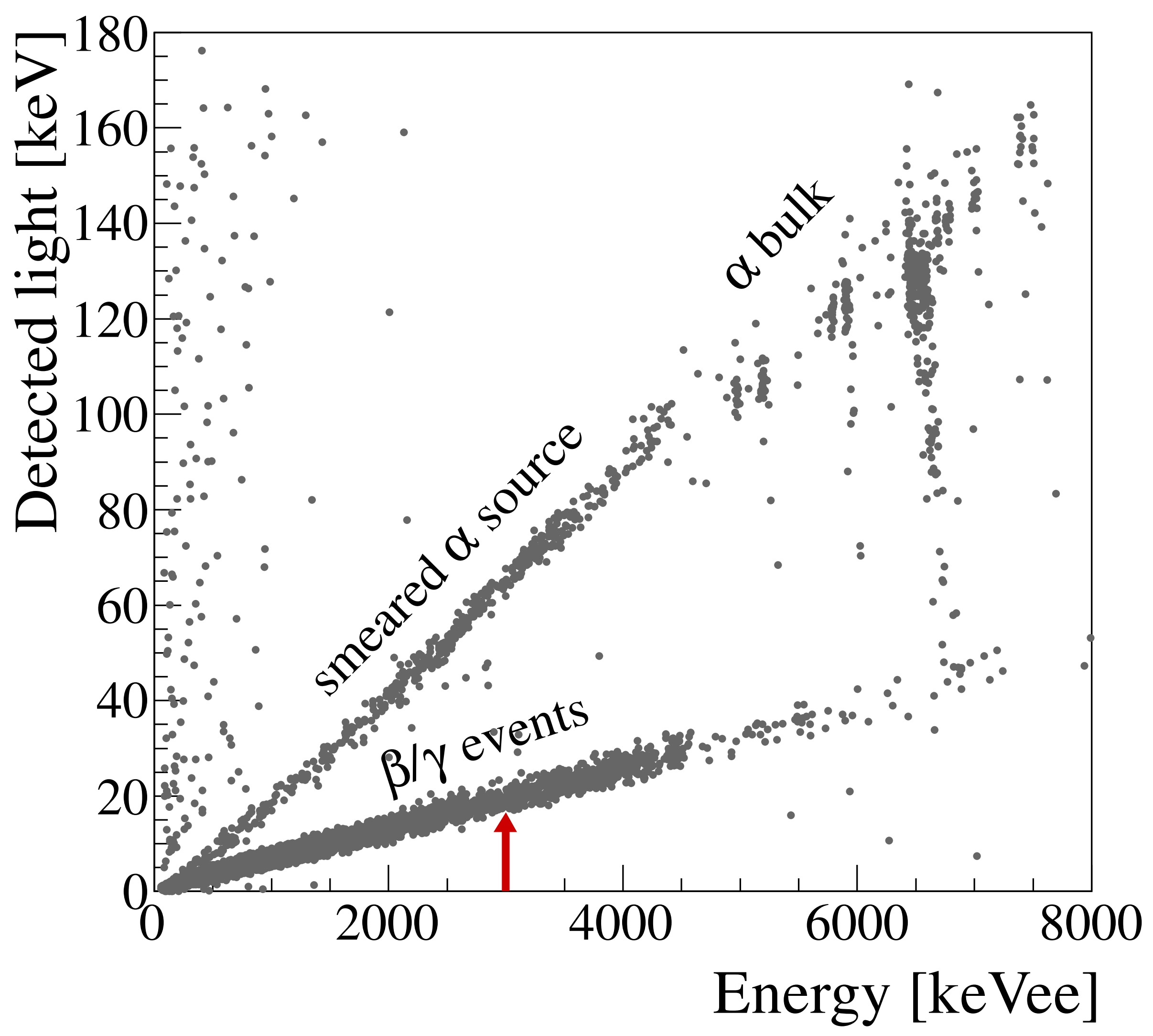
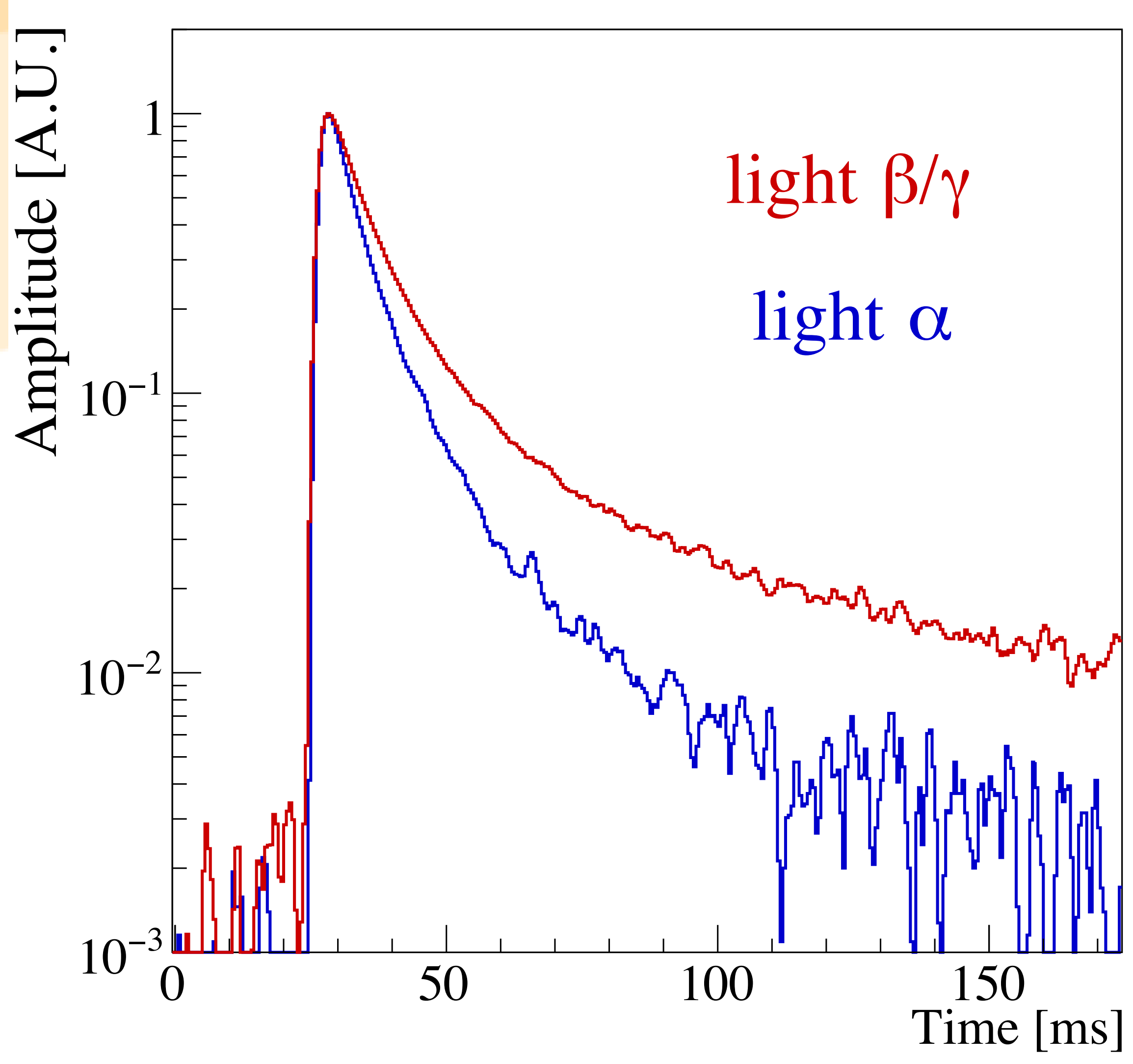
Scintillating cryogenic calorimeters

Scintillating calorimeters operating at cryogenic temperature ~10 mK → double read-out via heat & light

- Source = detector → High efficiency
- Excellent energy resolution (<1%)
- Modular design → large scalability
- Possibility to study different isotopes
- $LY_{\alpha} \neq LY_{\beta}$ and shape parameters allow Particle identification

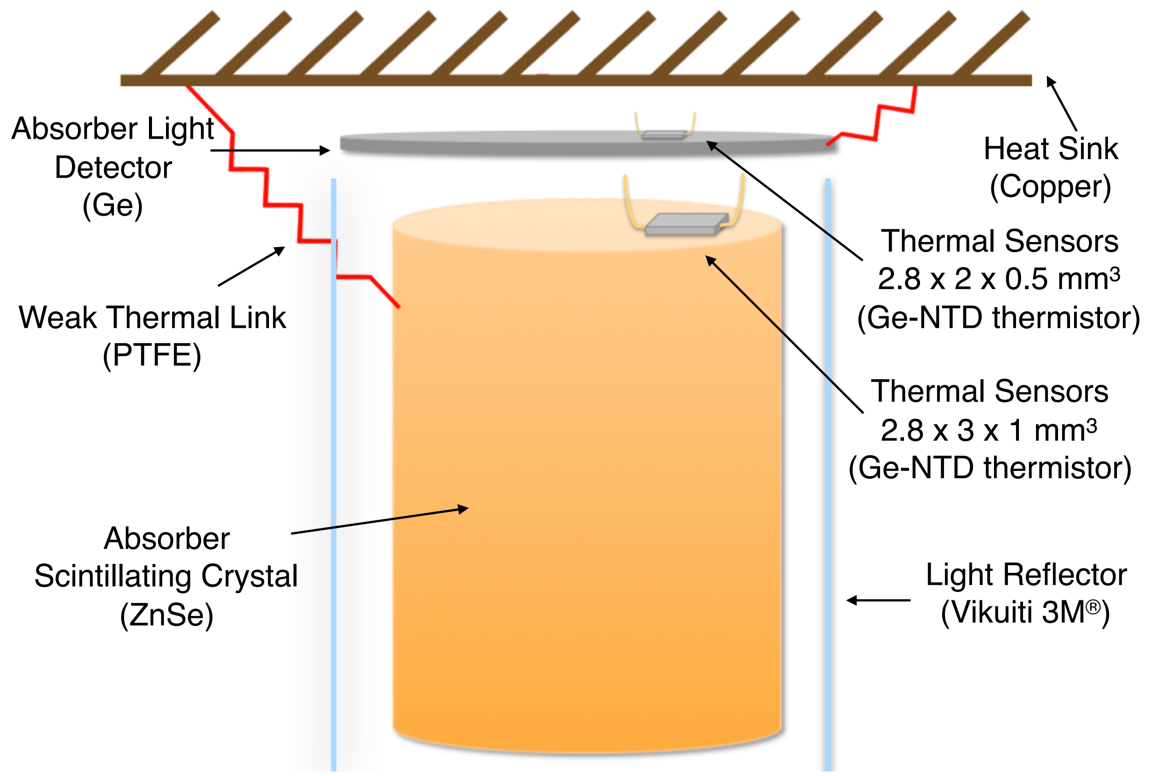




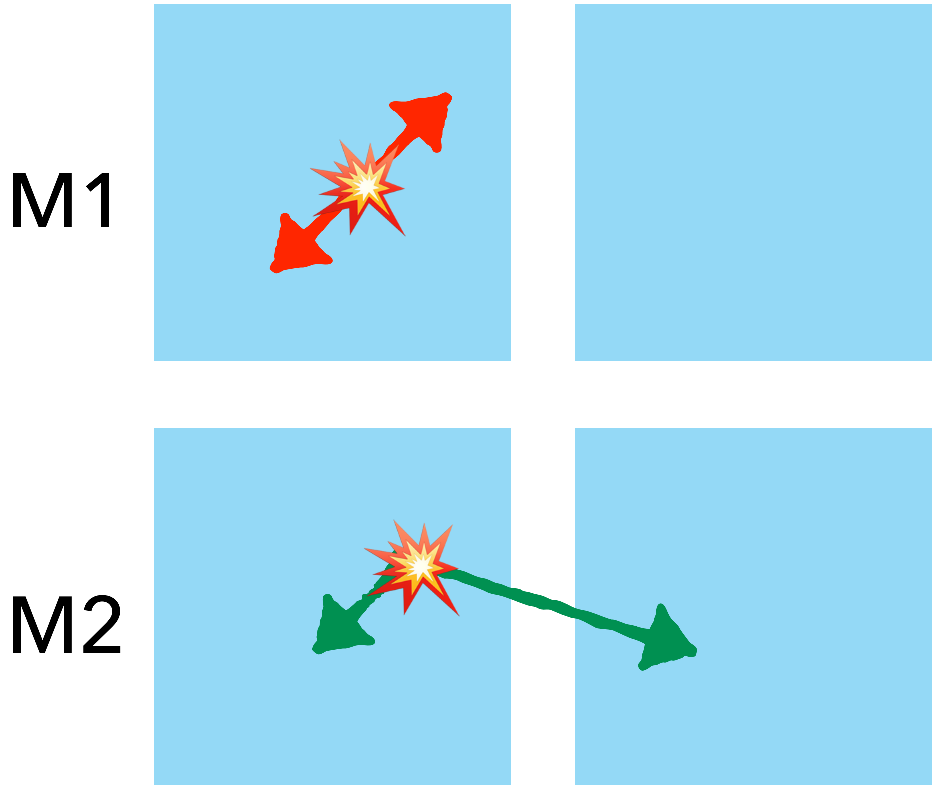


The CUPID-0 detector

- 24 ZnSe crystals enriched at >95% of ^{82}Se + two natural ones + 31 Ge Light detectors
- Located at LNGS
- $Q_{\beta\beta}(^{82}Se)$ = (2997.9 ± 0.3) keV → low background region
- Total mass: 10.5 kg ZnSe
- GeNTD thermistors as temperature sensors
- Reflective foils to increase light collection



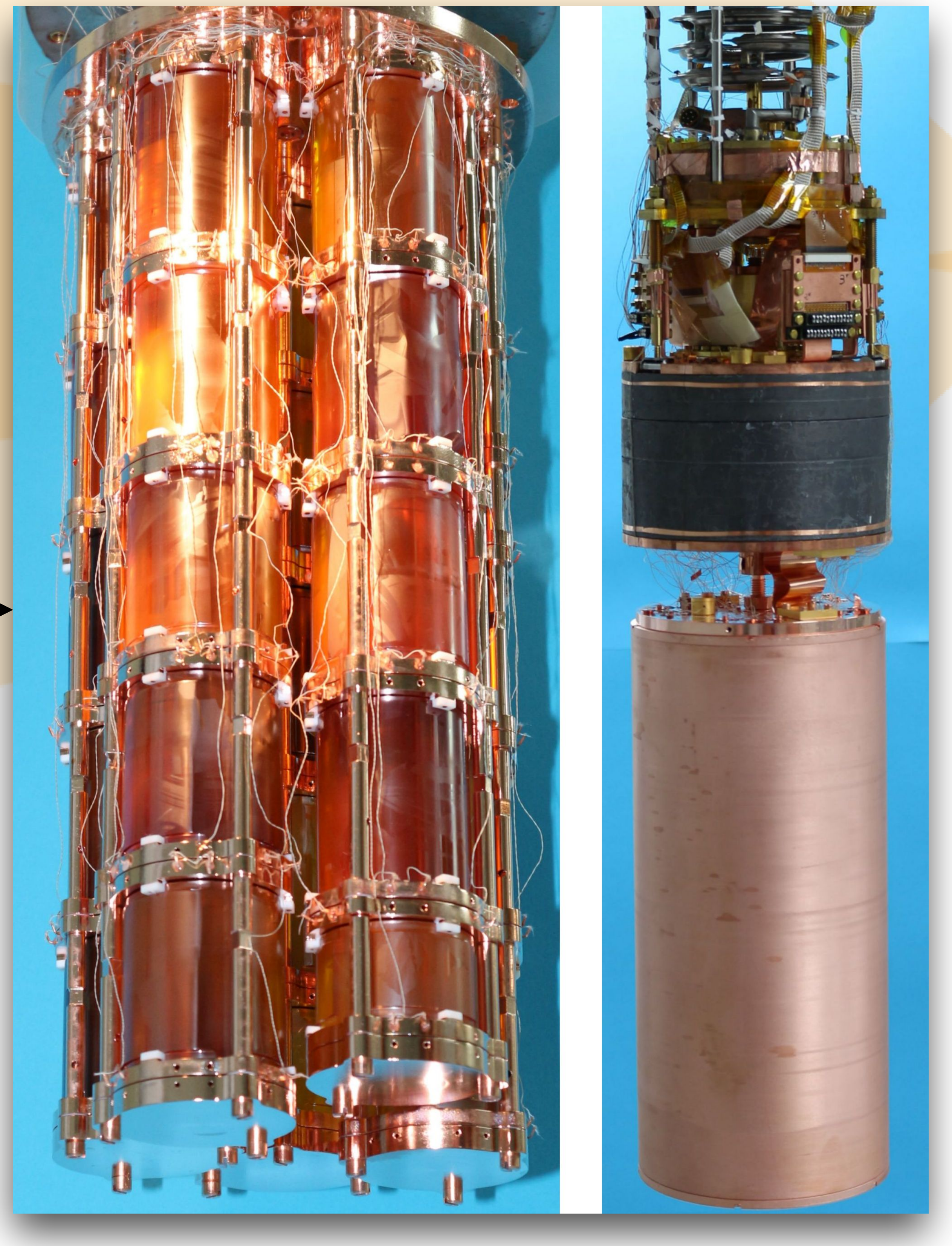
Coincidence analysis



In Jan 2019 the CUPID-0 collaboration has made an upgrade of the detector, starting the so-called "Phase II" of the experiment.

Phase I
9.99 kg×y

Phase II
5.74 kg×y



CUPID-0 results

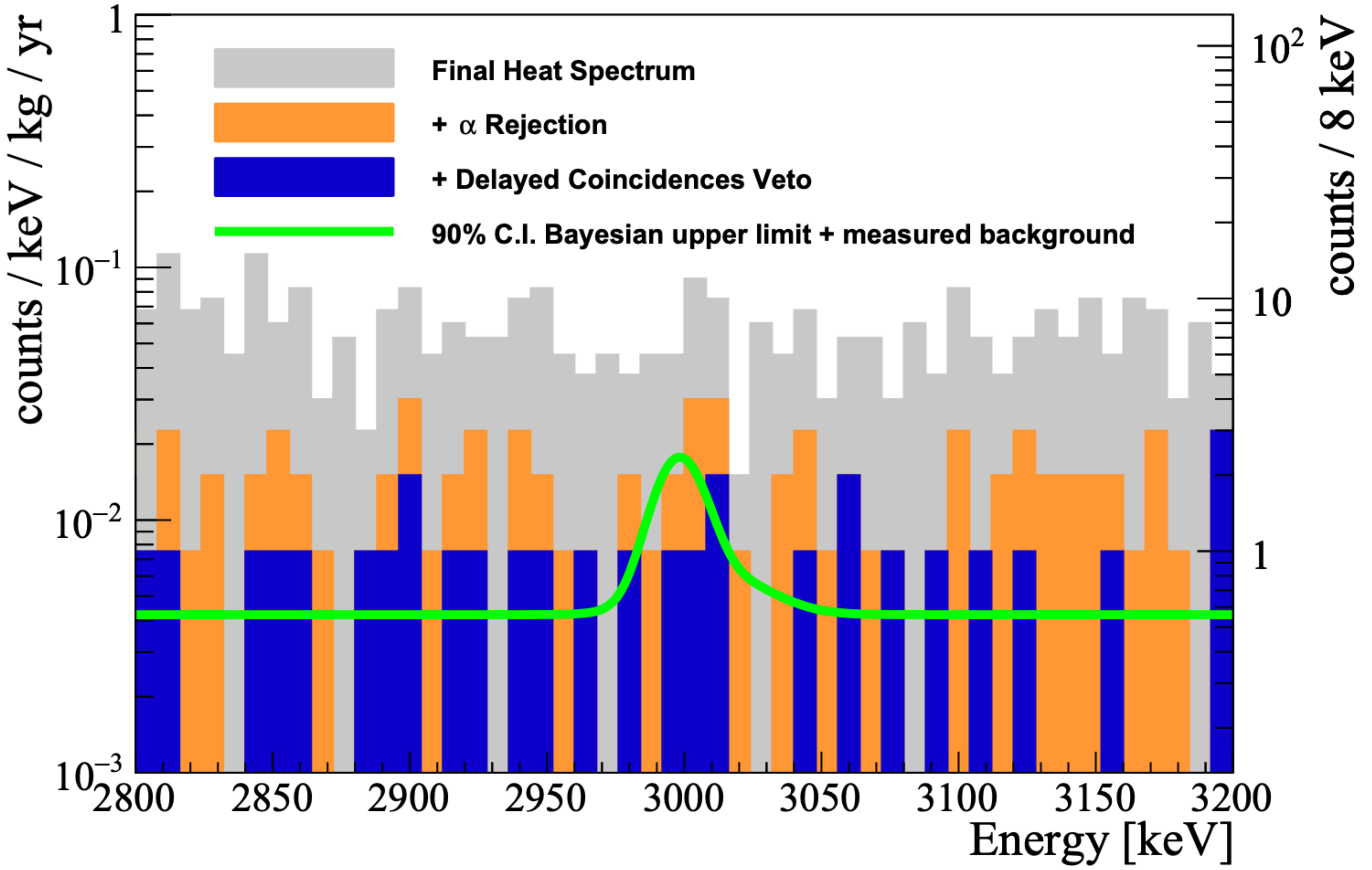
Important milestones to validate the use of scintillating cryogenic calorimeters in the search for 0νββ:

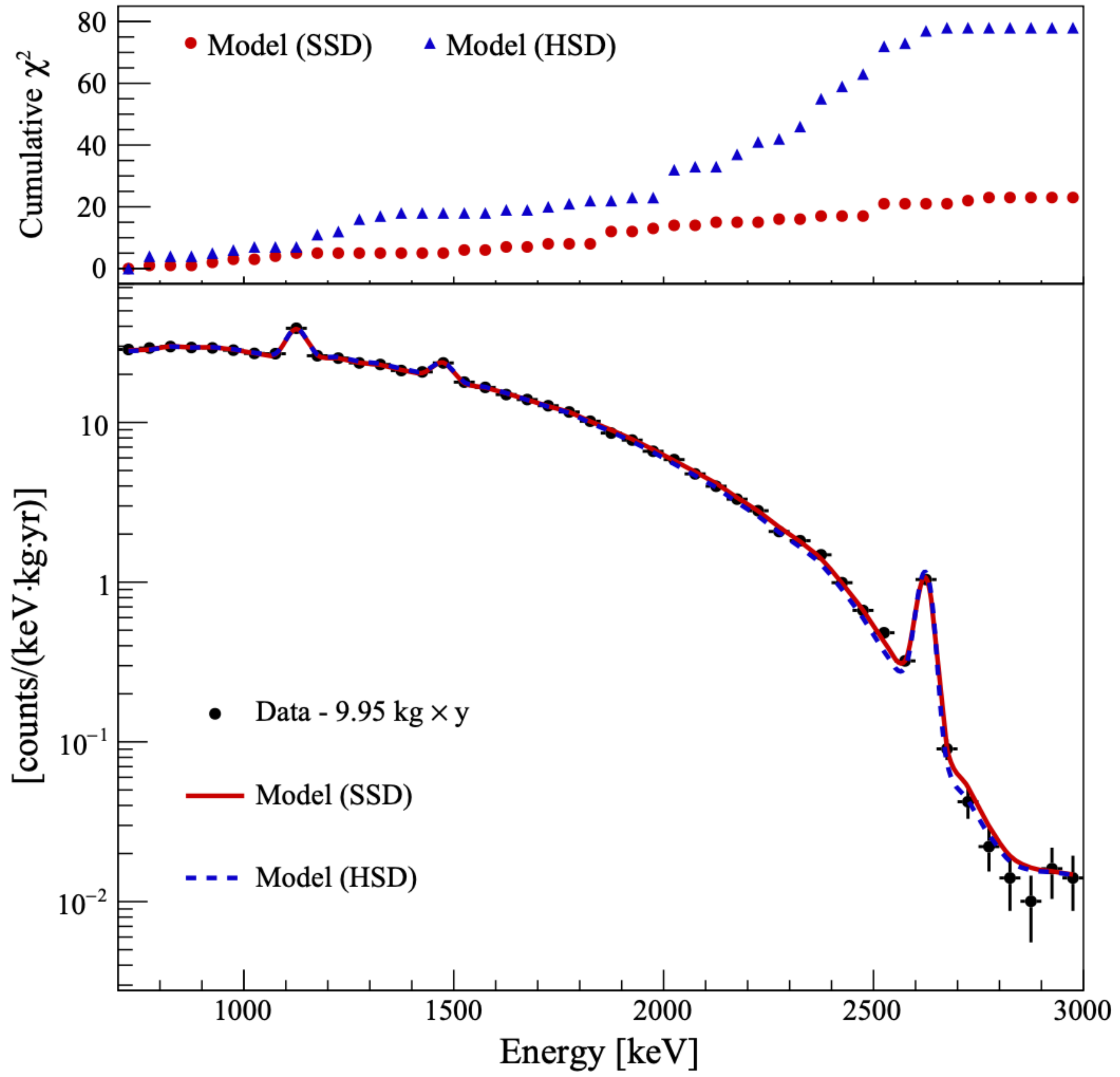
- Final Result on the Neutrinoless Double Beta Decay of Se-82 with CUPID-0

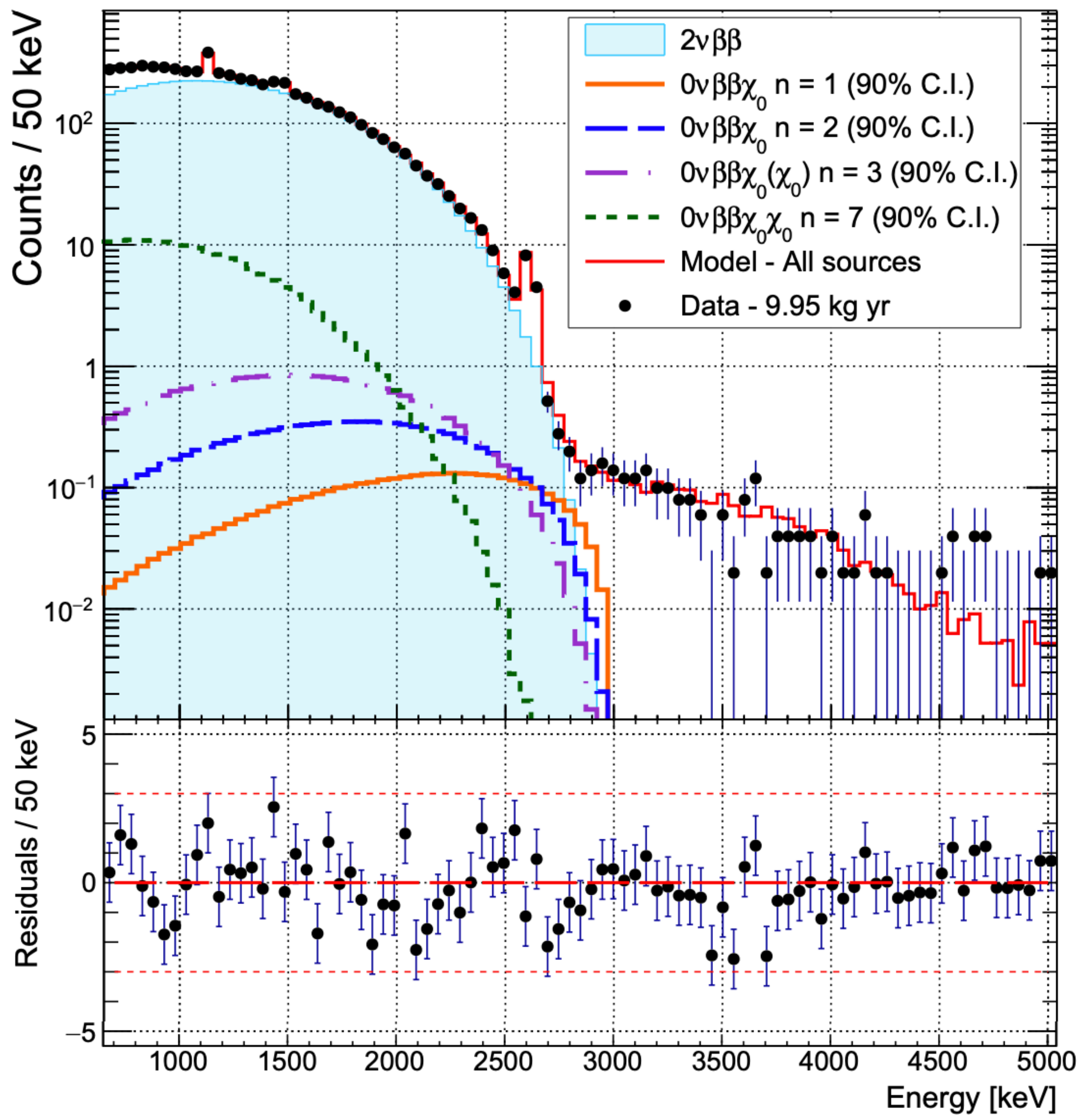
$$T^{0\nu}_{1/2}\left(^{82}\mathrm{Se}\right) > 4.6\times10^{24}\ \ \mathrm{yr}\ \ (90\,\%\ \mathrm{CI})$$

- Evidence of Single State Dominance in the Two-Neutrino Double-β Decay of Se-82 with CUPID-0
- First search for Lorentz violation in double beta decay with scintillating calorimeters
- Search for Majoron-like particles with CUPID-0

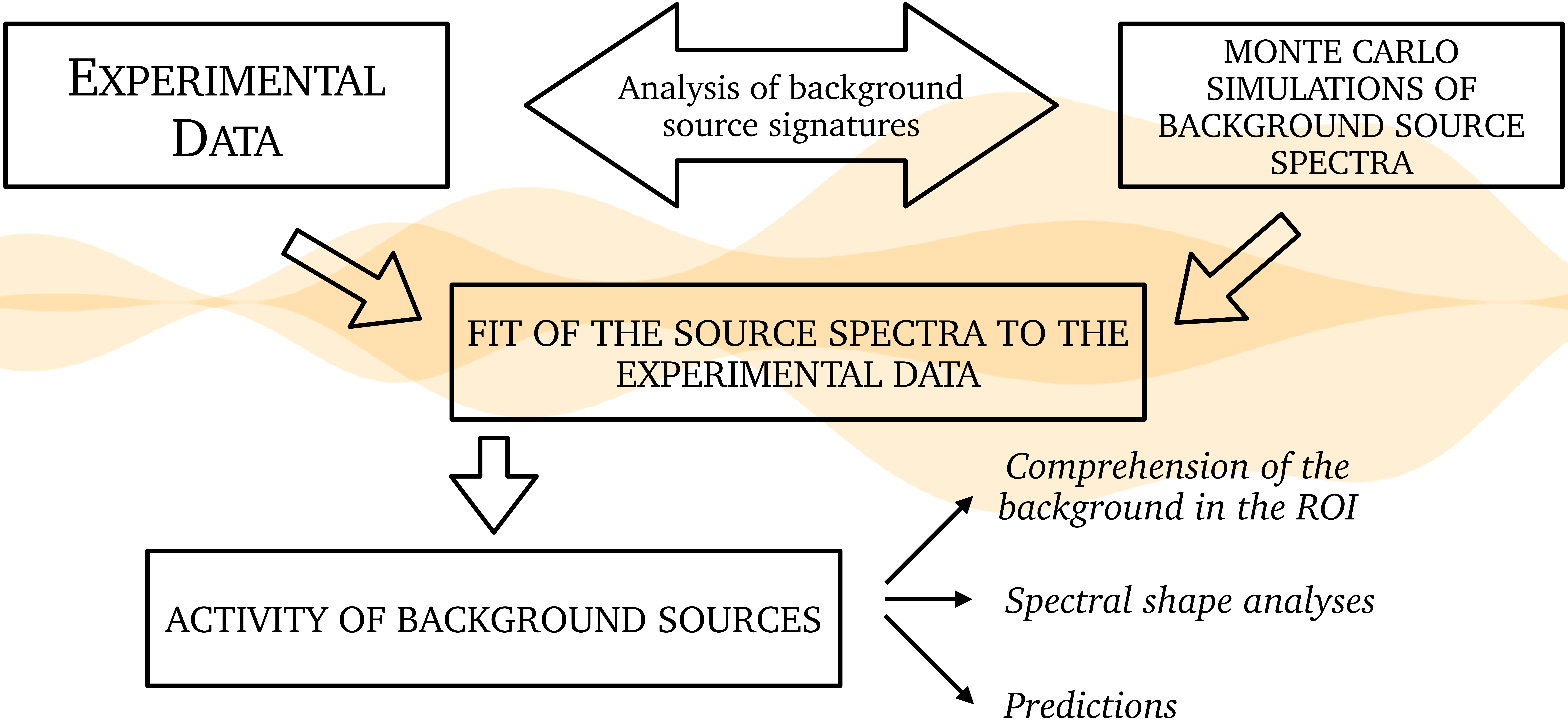
And many others…







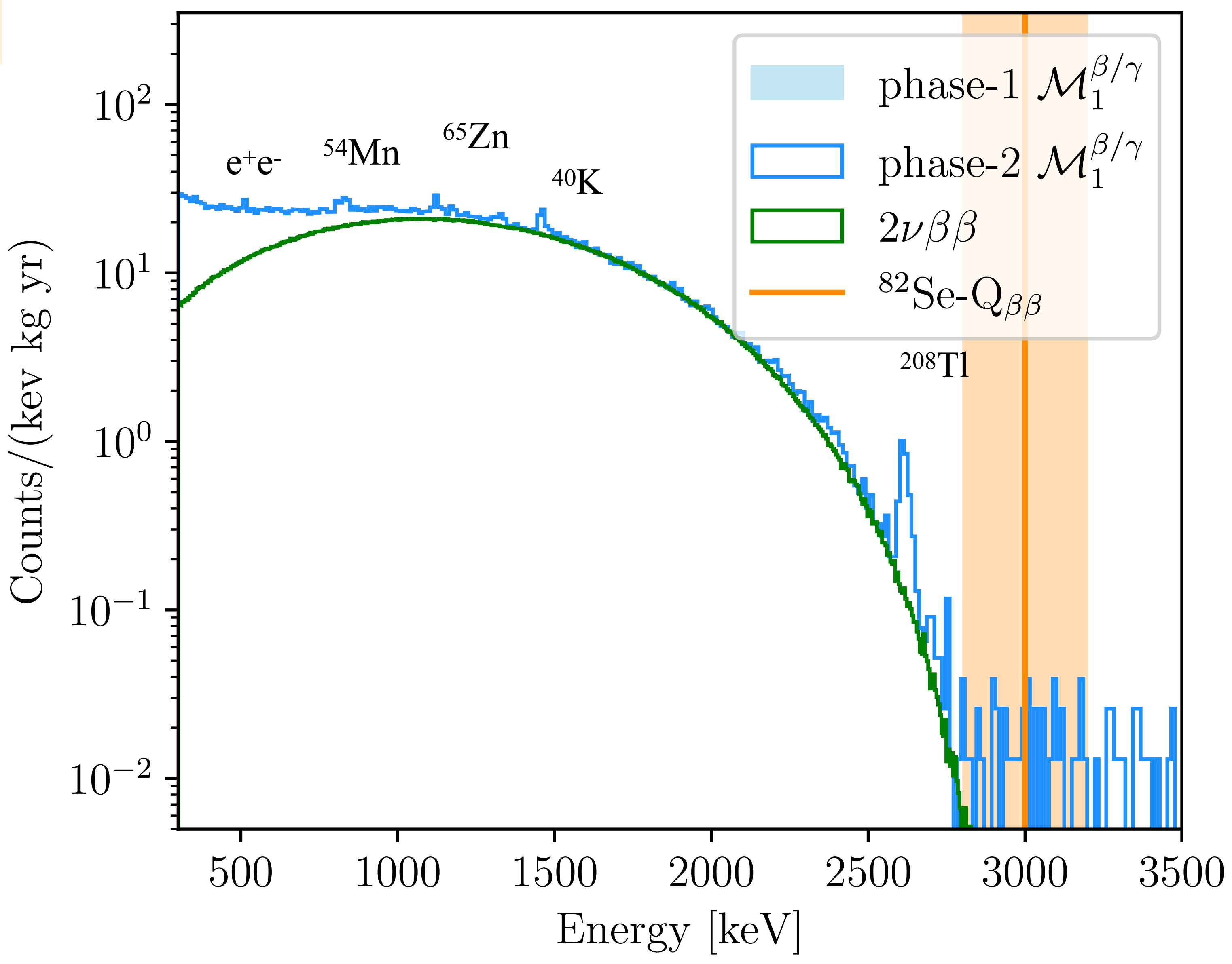
Background model

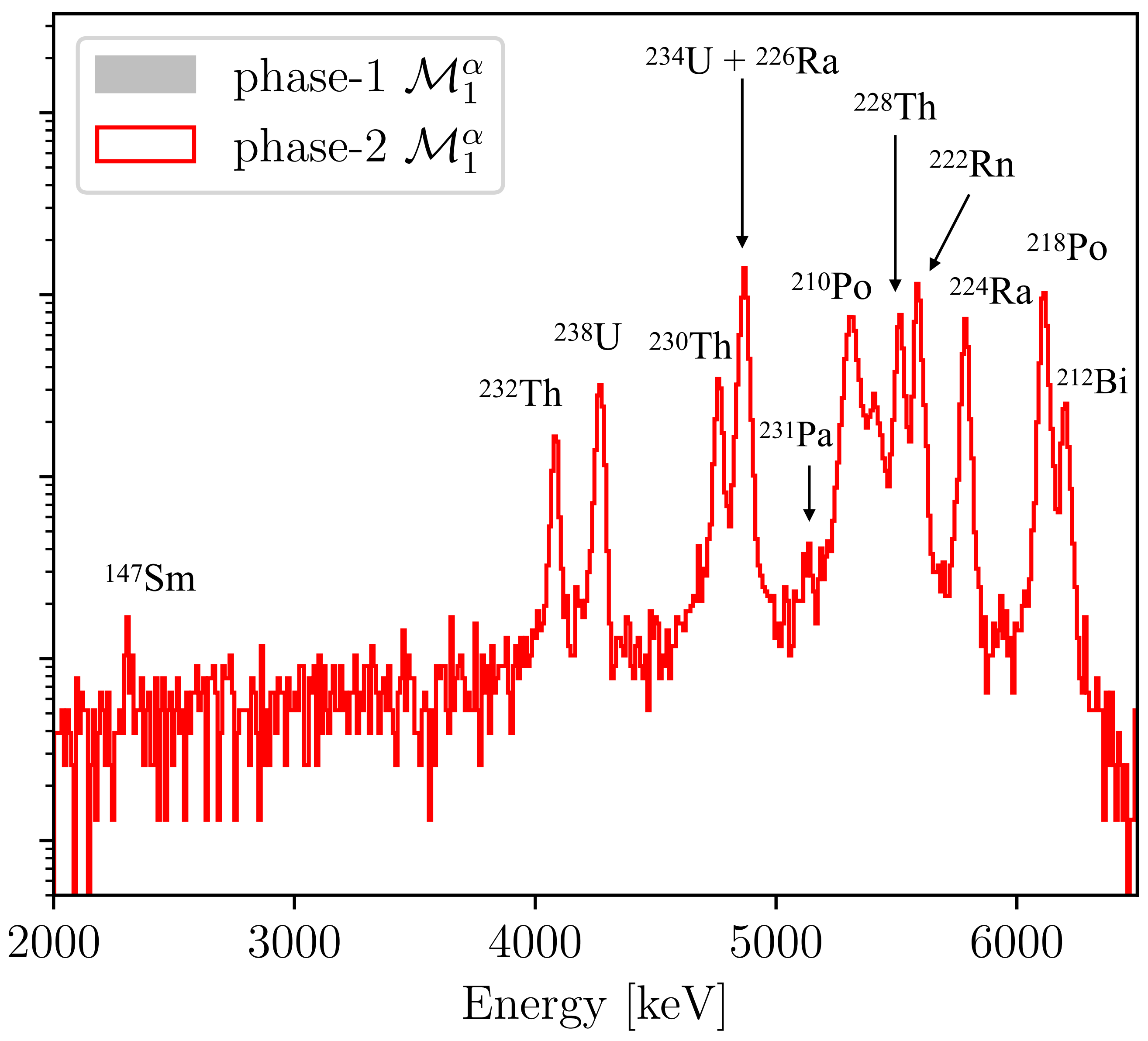


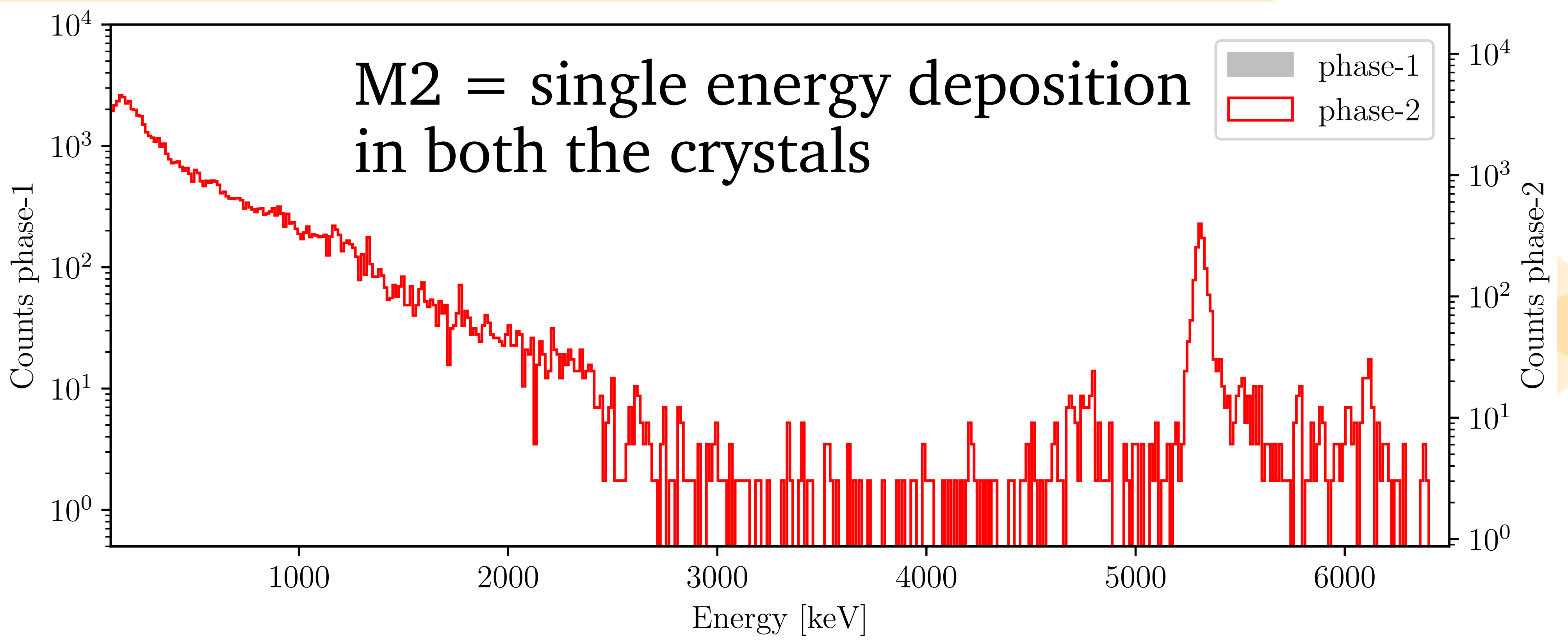
Phase I vs. Phase II - experimental spectra

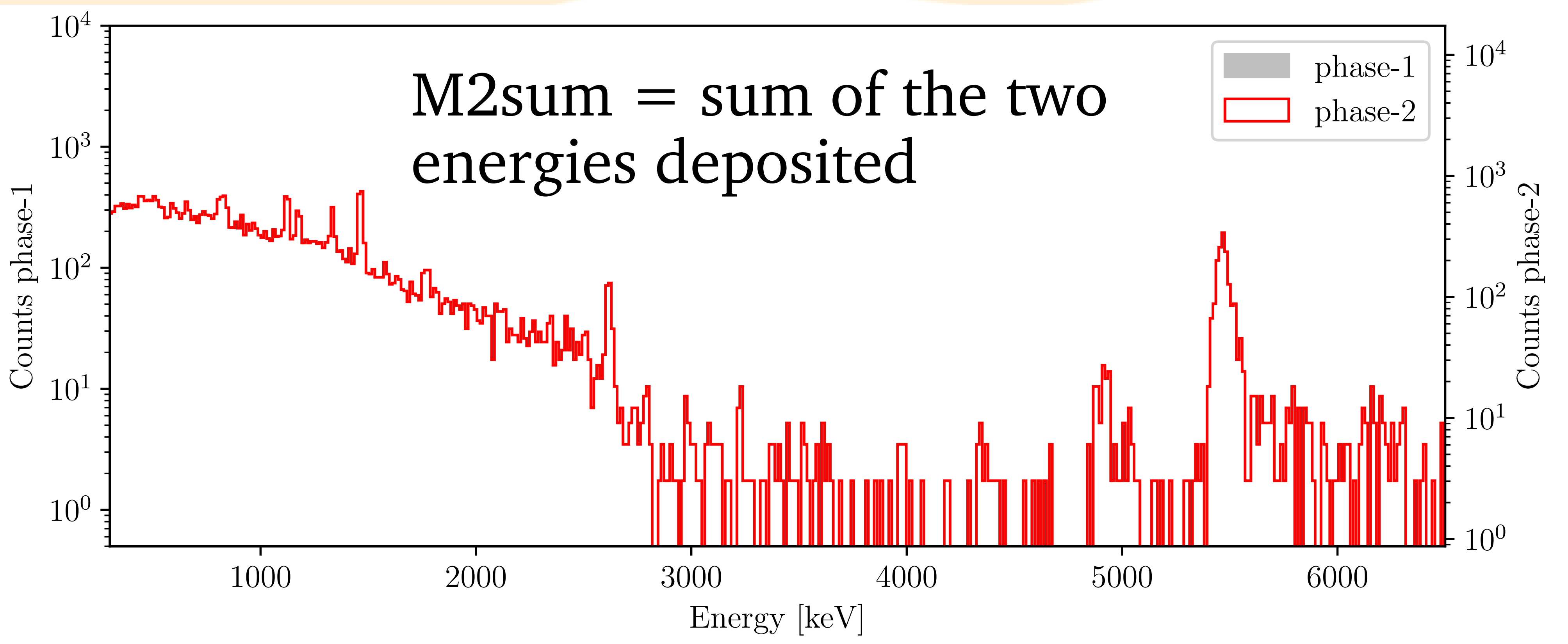
- α-contaminations have the same activity in phase-I and phase-II
- Cosmogenic activation isotopes decay
- Higher alpha continuum from close component contaminations (10 mK)
- $2\nu\beta\beta$ is dominant up to 3 MeV

Multiplicity = 2 → events hitting two crystals simultaneously



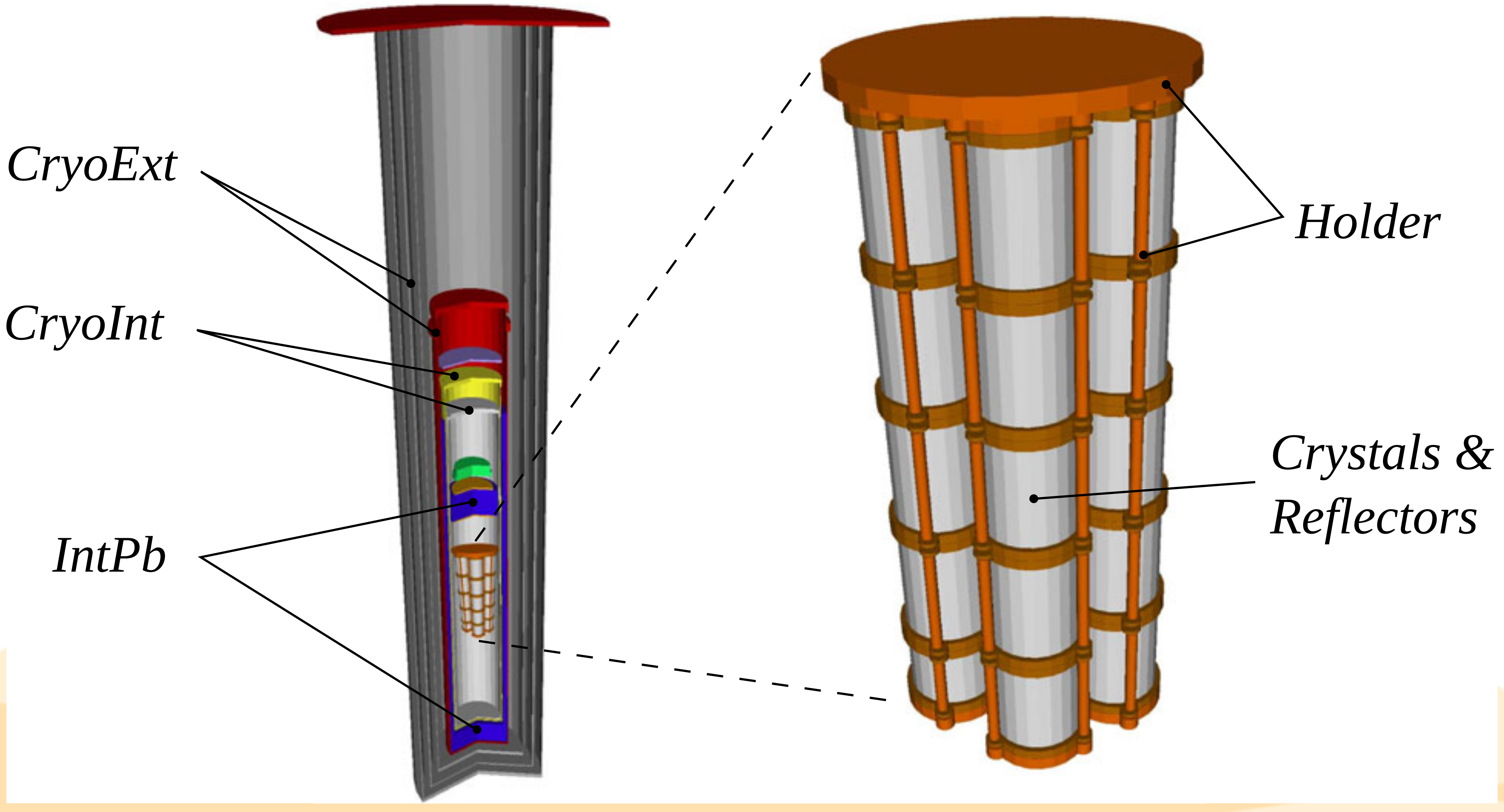






Simulations

- A GEANT4 based software taking into account the detector geometry generates a **series on Monte Carlo spectra**
- The simulations are processed with a **custom software to implement experimental features** on simulated data (energy and time resolution, coincidences, particle identification…)
- Degenerate spectra are grouped together in a single simulation



Phase-I → Reflectors + Holders
Phase-II → Holders + 10mK

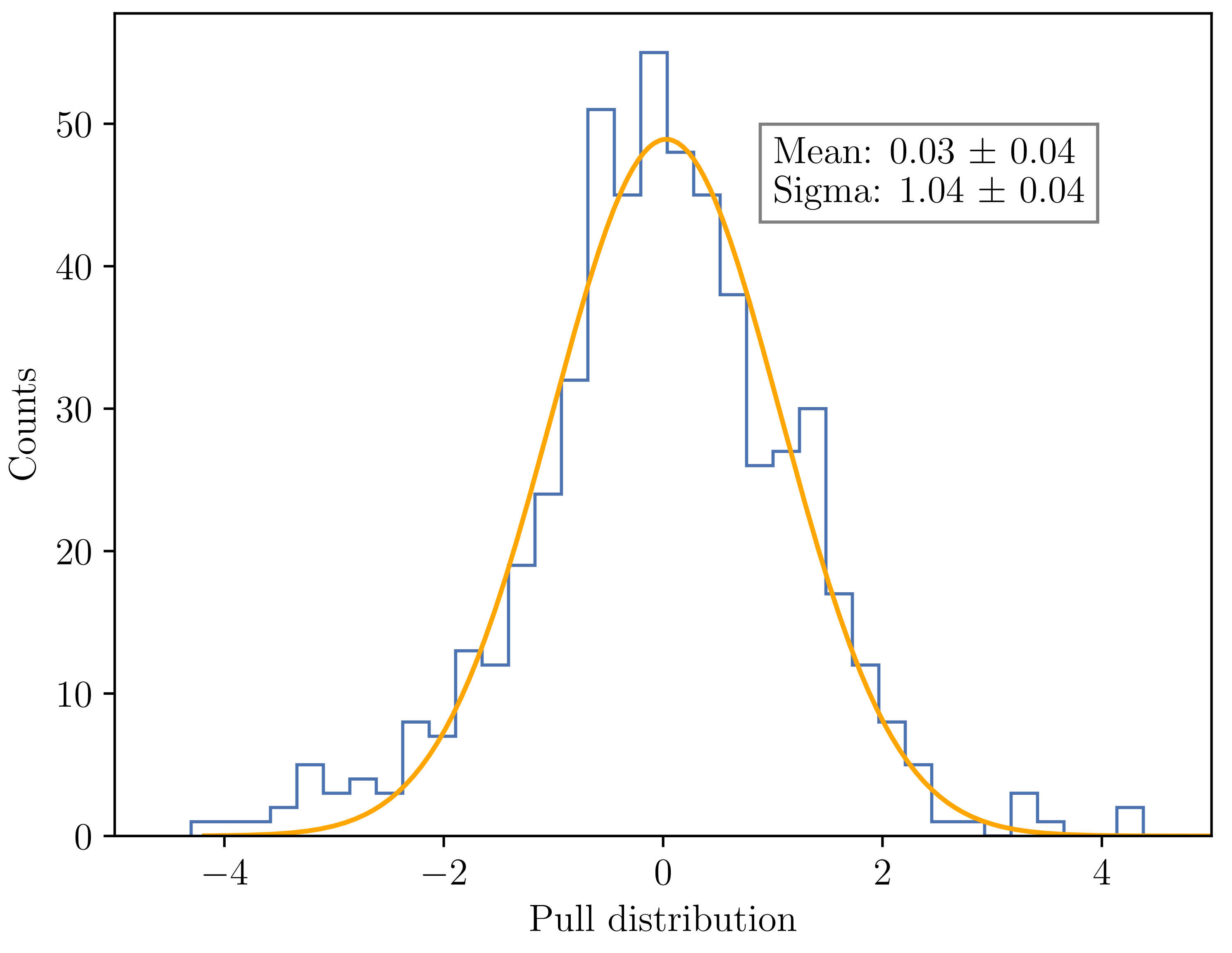
Contaminants

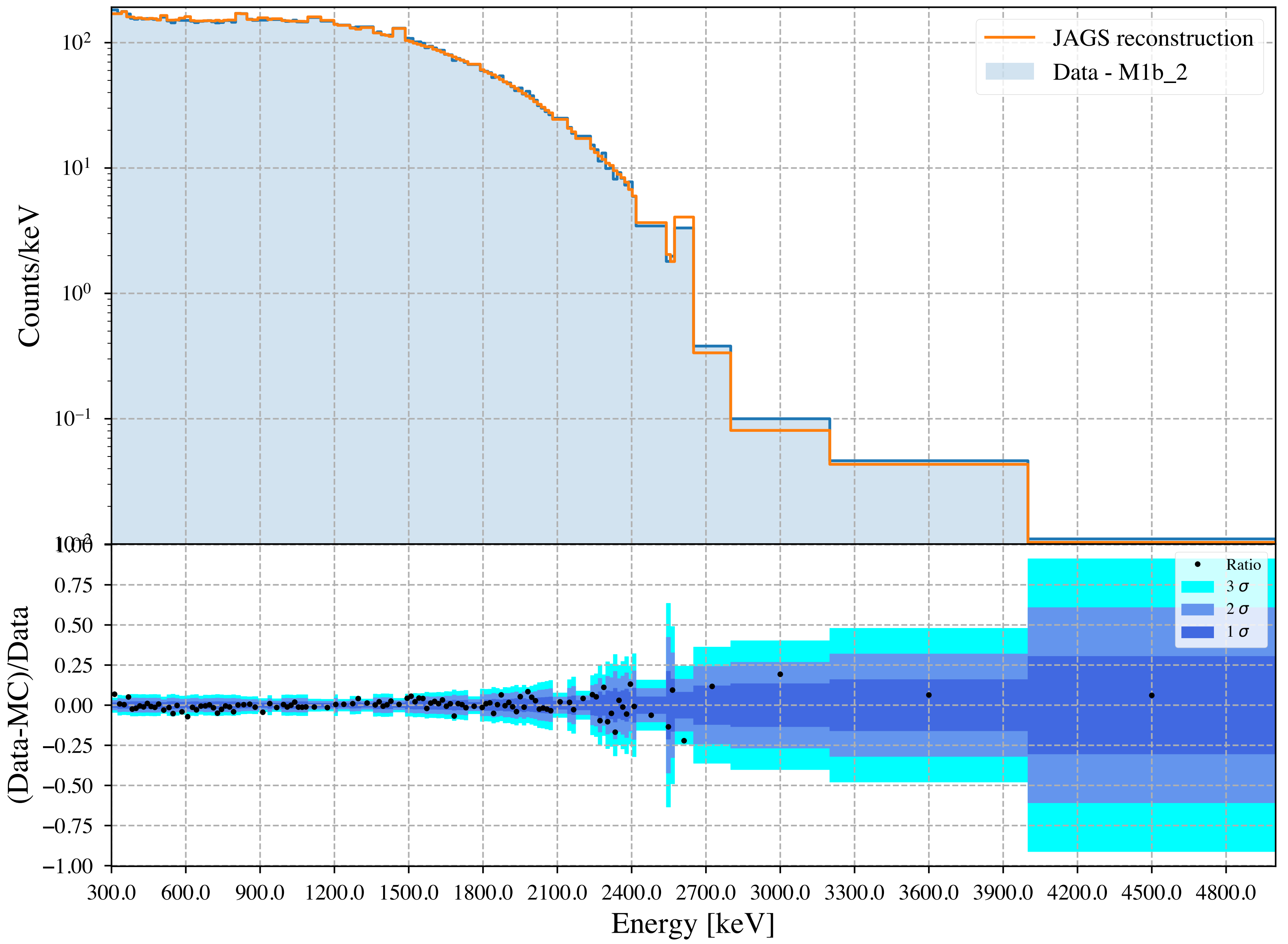
- Long-living radioisotope (^{232}Th, ^{238}U, ^{235}U, ^{40}K) with the possible breaks of the chains → Crystals, Holders and Cryostat
- Cosmogenic activation products of Copper and ZnSe (^{65}Zn, ^{60}Co, ^{54}Mn) → Crystals and Holders
- Muons → Environment
- $2\nu\beta\beta$

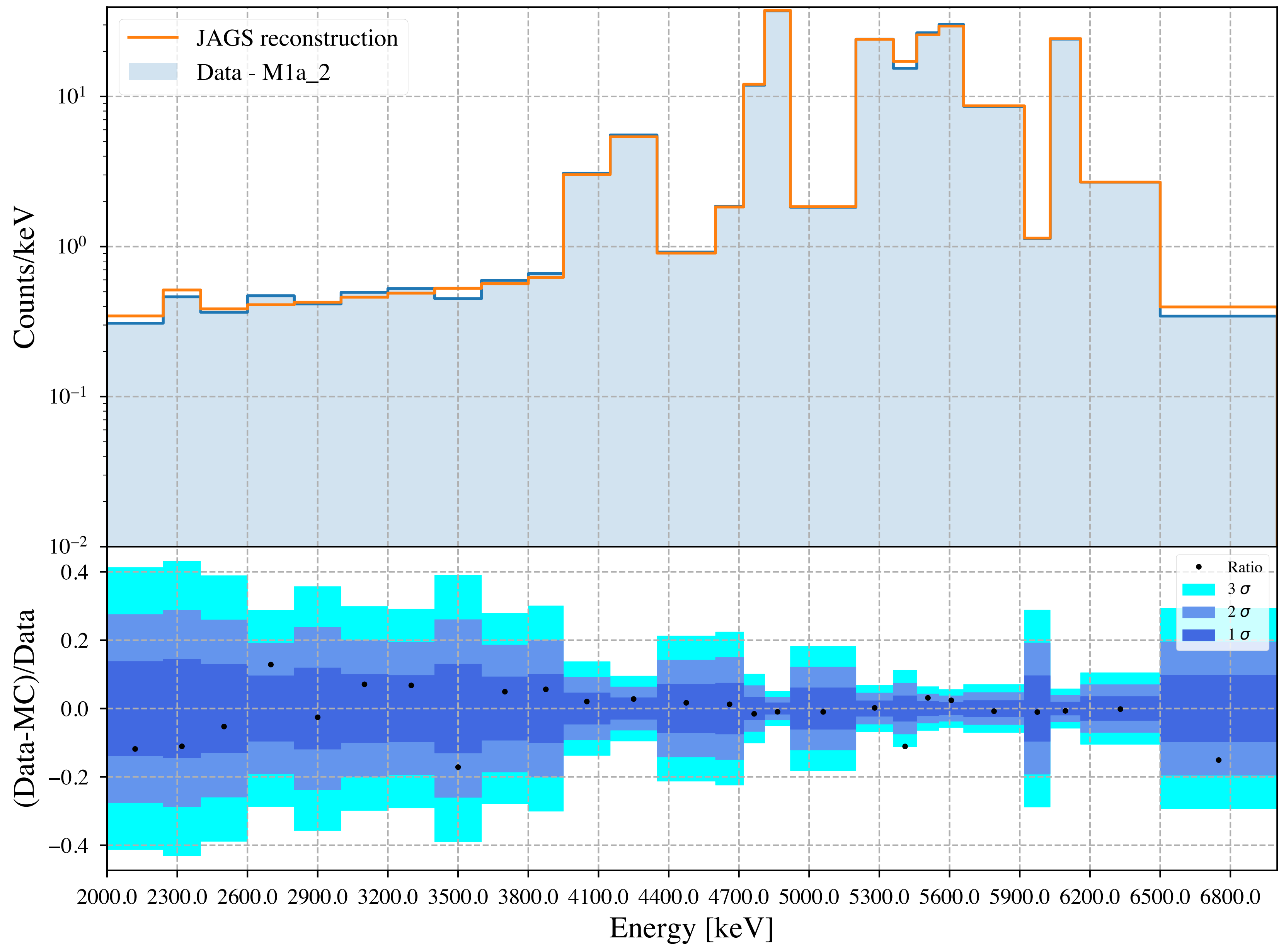
Background model fit

Combined Bayesian **fit on 8 experimental spectra [(M1a, M1b, M2, M2sum) × 2]** with the Just Another Gibbs Sample (JAGS). It uses Markov Chain Monte Carlo to sample the joint posterior pdf of the scale parameters.

Constraints on all the long living isotopes to have the same activity between phase-I and phase-II

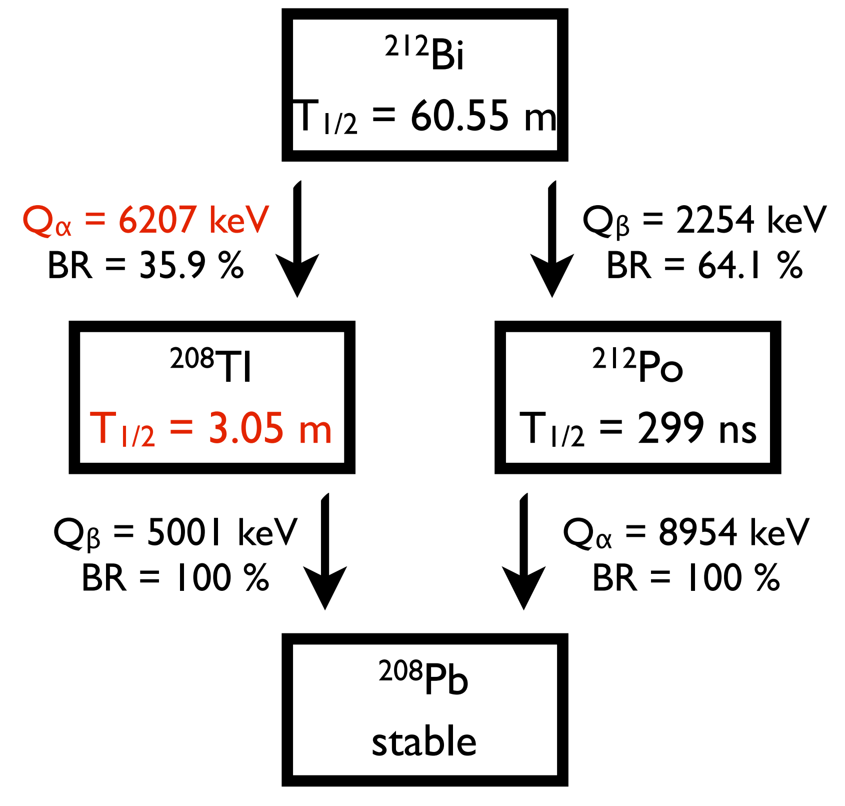




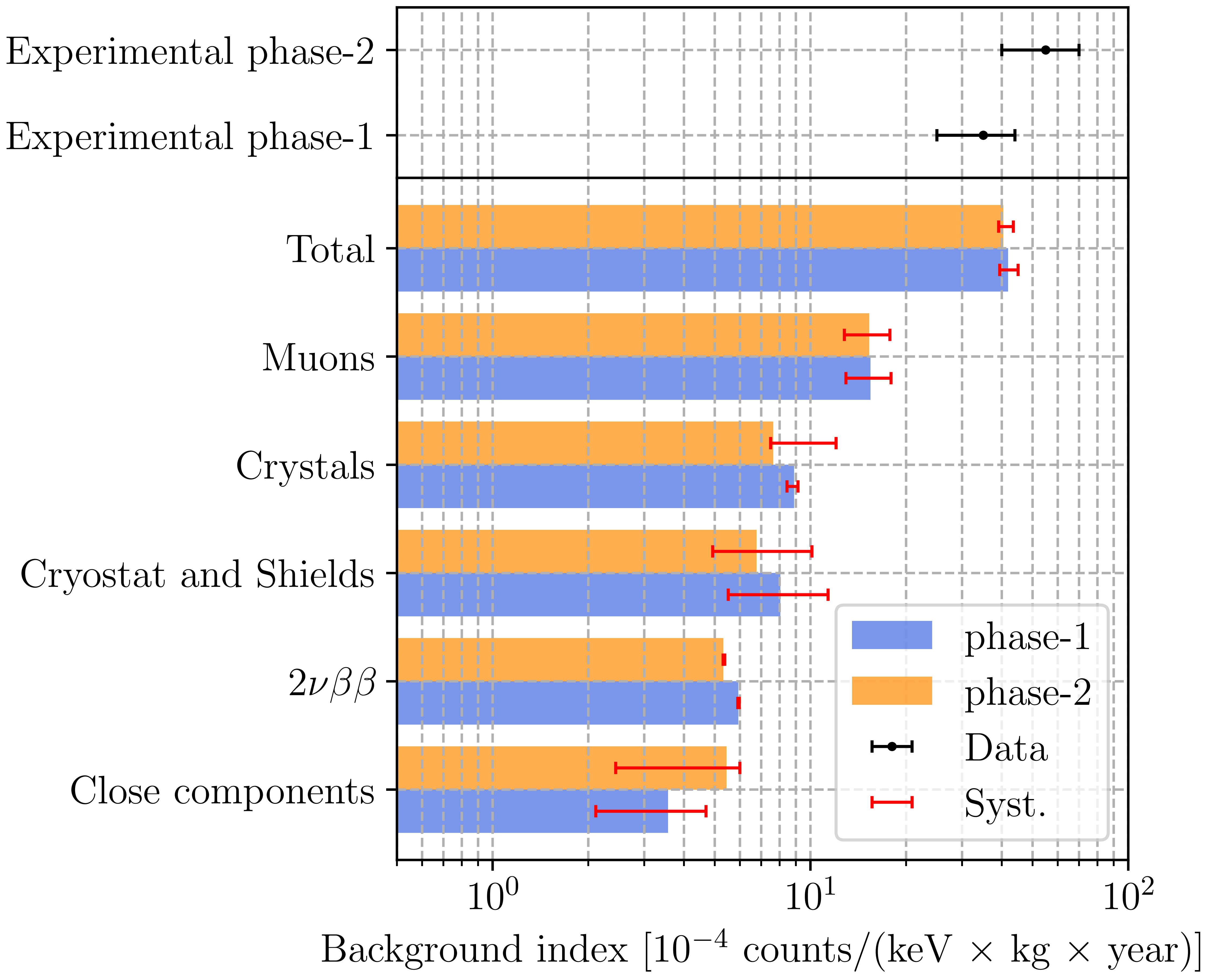


Background in the ROI

The delayed coincidence cut is applied on the data and simulations as well to reproduce the background in the region of interest.



Component	ROI$_{bkg}$ rate [10^{-4} counts/keV/kg/yr]		
	phase-I (only)	phase-I (comb.)	phase-II (comb.)
Crystals	$11.7 \pm 0.6\ ^{+1.6}_{-0.8}$	$8.9 \pm 0.5\ ^{+0.3}_{-0.4}$	$7.6 \pm 0.4\ ^{+4.4}_{-0.1}$
Near Components	$2.1 \pm 0.3\ ^{+2.2}_{-1.0}$	$3.6 \pm 0.3\ ^{+1.1}_{-1.4}$	$5.4 \pm 0.9\ ^{+0.6}_{-3.0}$
Cryostat & Shields	$5.9 \pm 1.3\ ^{+7.2}_{-2.9}$	$8.0 \pm 1.5\ ^{+3.3}_{-2.5}$	$6.8 \pm 1.0\ ^{+3.3}_{-1.8}$
Muons	$15.3 \pm 1.3 \pm 2.5$	$15.4 \pm 0.7 \pm 2.5$	$15.3 \pm 0.7 \pm 2.5$
$2\nu\beta\beta$	$6.0 \pm 0.02\ ^{+0.13}_{-0.09}$	$5.93 \pm 0.03\ ^{+0.04}_{-0.02}$	$5.31 \pm 0.03\ ^{+0.06}_{-0.04}$
Total	$41 \pm 2\ ^{+9}_{-4}$	$42 \pm 2\ ^{+4}_{-4}$	$40 \pm 2\ ^{+4}_{-2}$
Experimental	$35\ ^{+10}_{-9}$	$35\ ^{+10}_{-9}$	$55\ ^{+15}_{-15}$



Systematics: threshold, binning, energy calibration and source location

2νββ half-life measurement

PhaseI + PhaseII 2νββ Activity = [8.63 ± 0.04 (stat.)] mBq

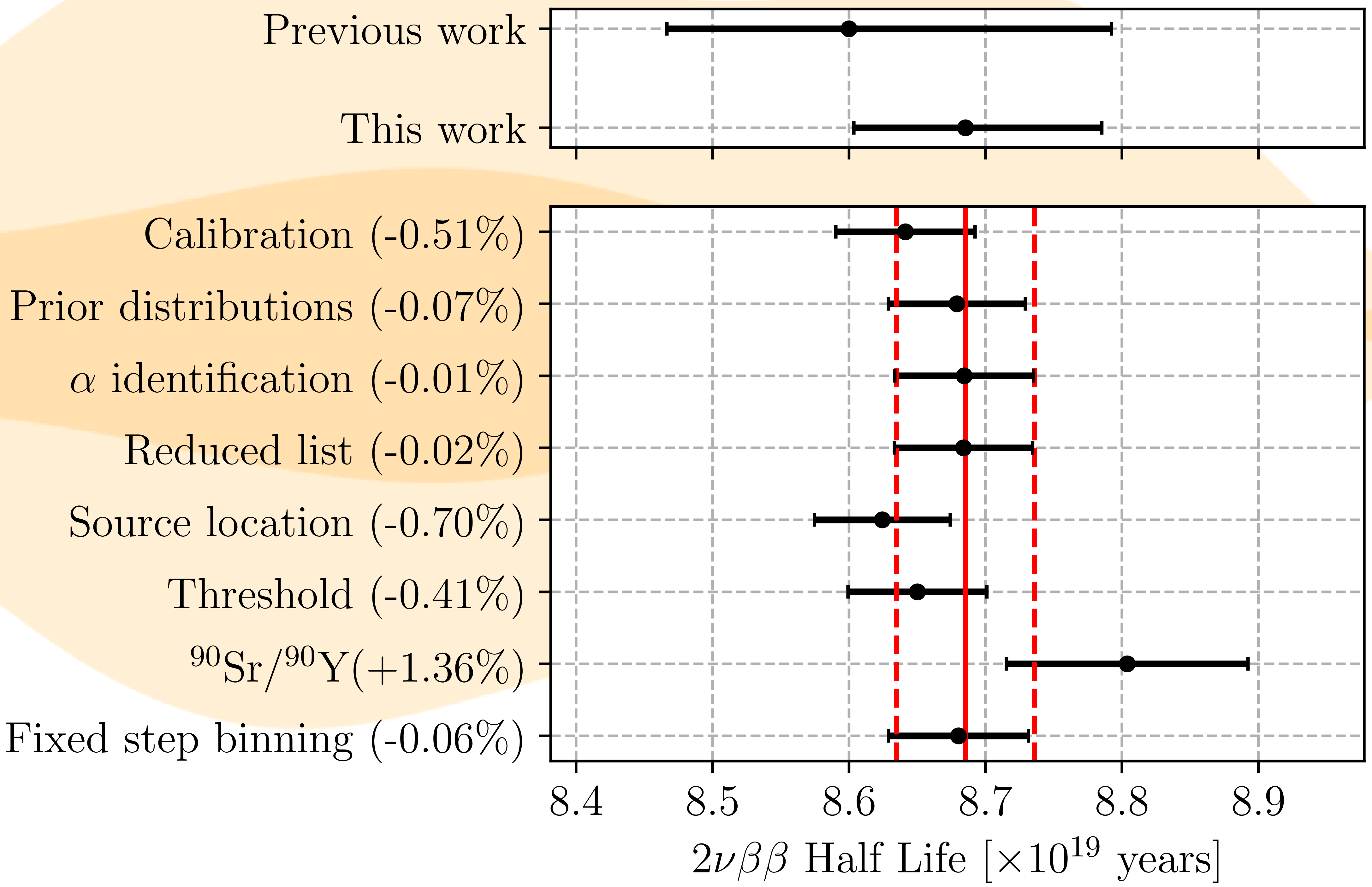
Fit systematics are combined with the sum in quadrature of the 68% difference between the *Reference*

The uncertainties on the efficiencies and the enrichment are included as nuisance parameters and marginalised in the statistical error

+Fit systematics (+1.0%)(-0.7%)
+Stat. uncertainty (±0.6%)
+Theoretical uncertainty (0.3%) (SSD vs. HSD)
= (+1.2%)(-0.9%)

Final result:

$$T_{1/2}^{2\nu} = \left[8.69 \pm 0.05(\text{stat.})^{+0.06}_{-0.09}(\text{syst.})\right] \times 10^{19}\text{yr}$$



2νββ half-life measurement

Final result

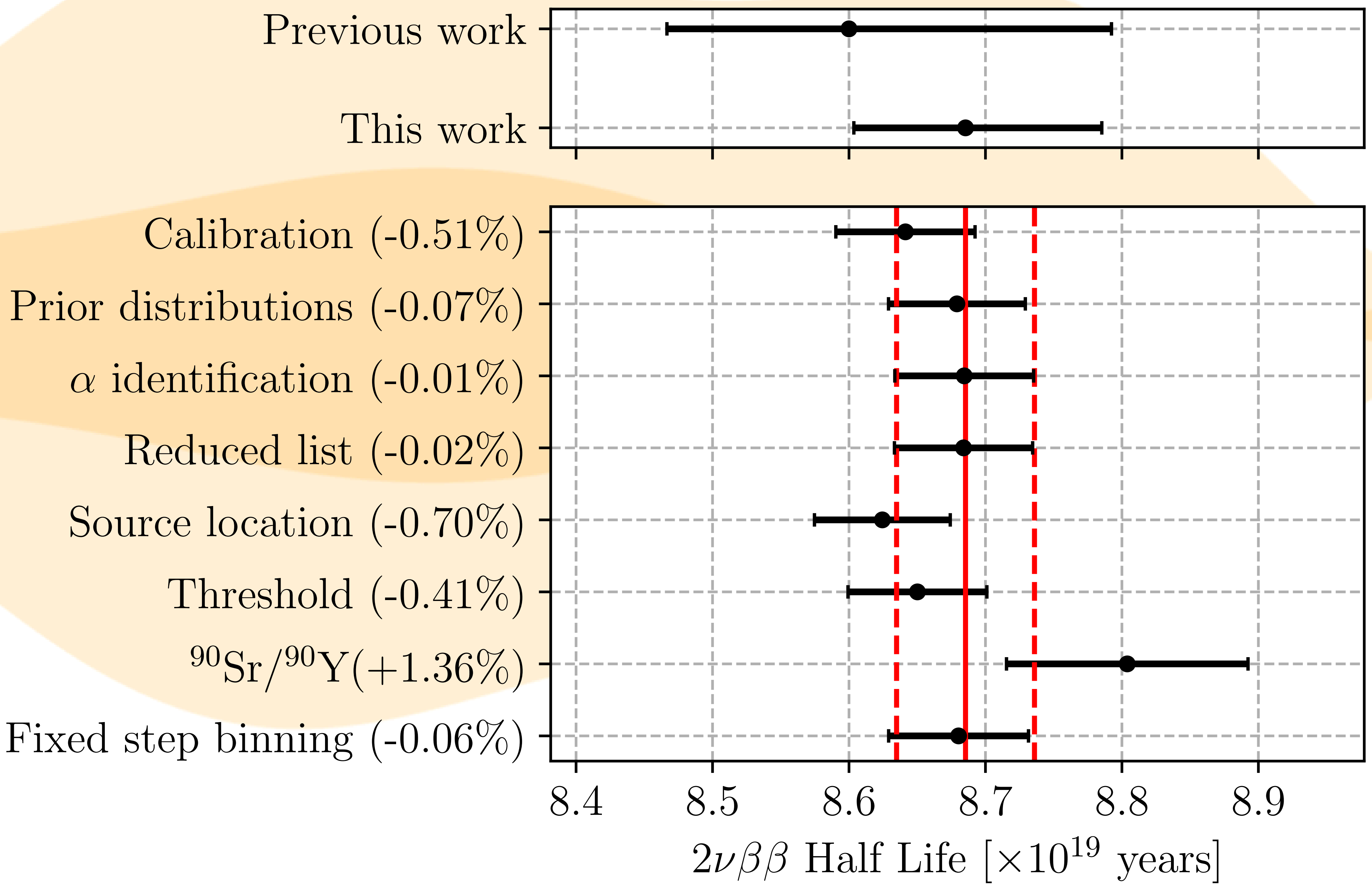
$$T_{1/2}^{2\nu} = \left[8.69 \pm 0.05(\text{stat.})^{+0.06}_{-0.09}(\text{syst.})\right] \times 10^{19}\text{yr}$$

Using as Phase Space Factor the value

$$G^{2\nu} = (1.996 \pm 0.028) \times 10^{-18}$$

The final result on the nuclear matrix element is:

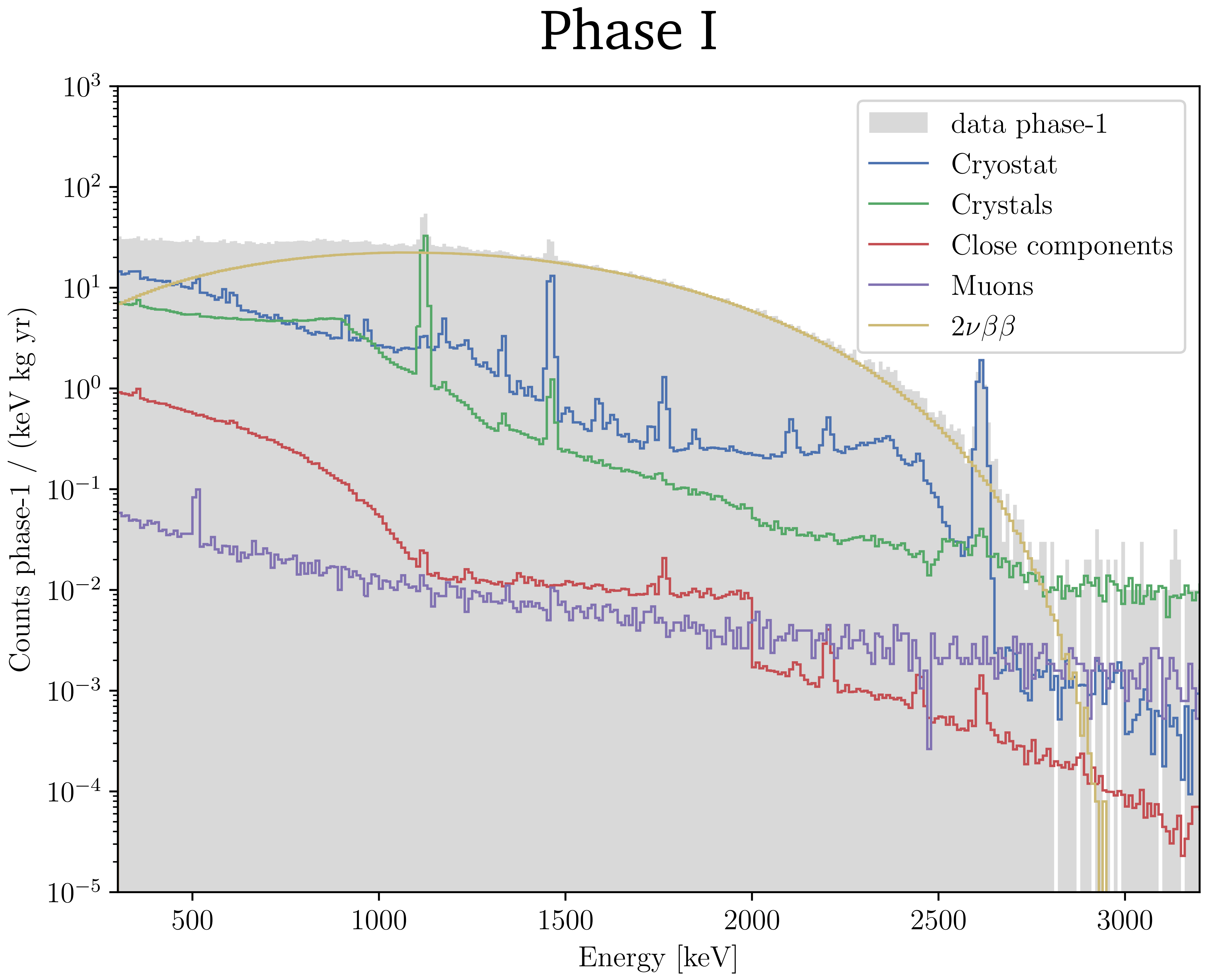
$$\mathcal{M}^{eff}_{2\nu} = 0.0760 \begin{array}{l} +\ 0.0006 \\ -\ 0.0007 \end{array}$$

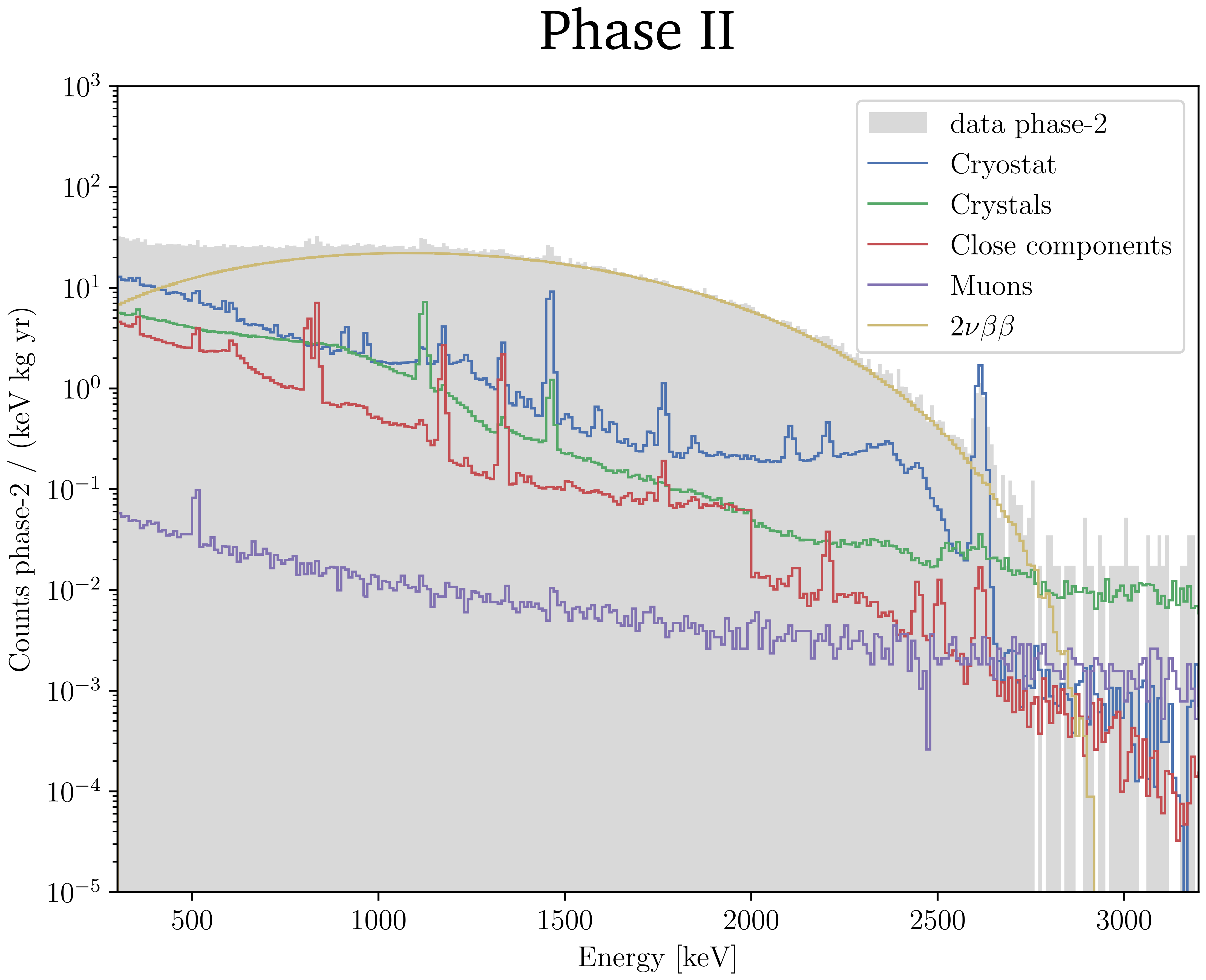



Thanks for the
attention!

Backup slides

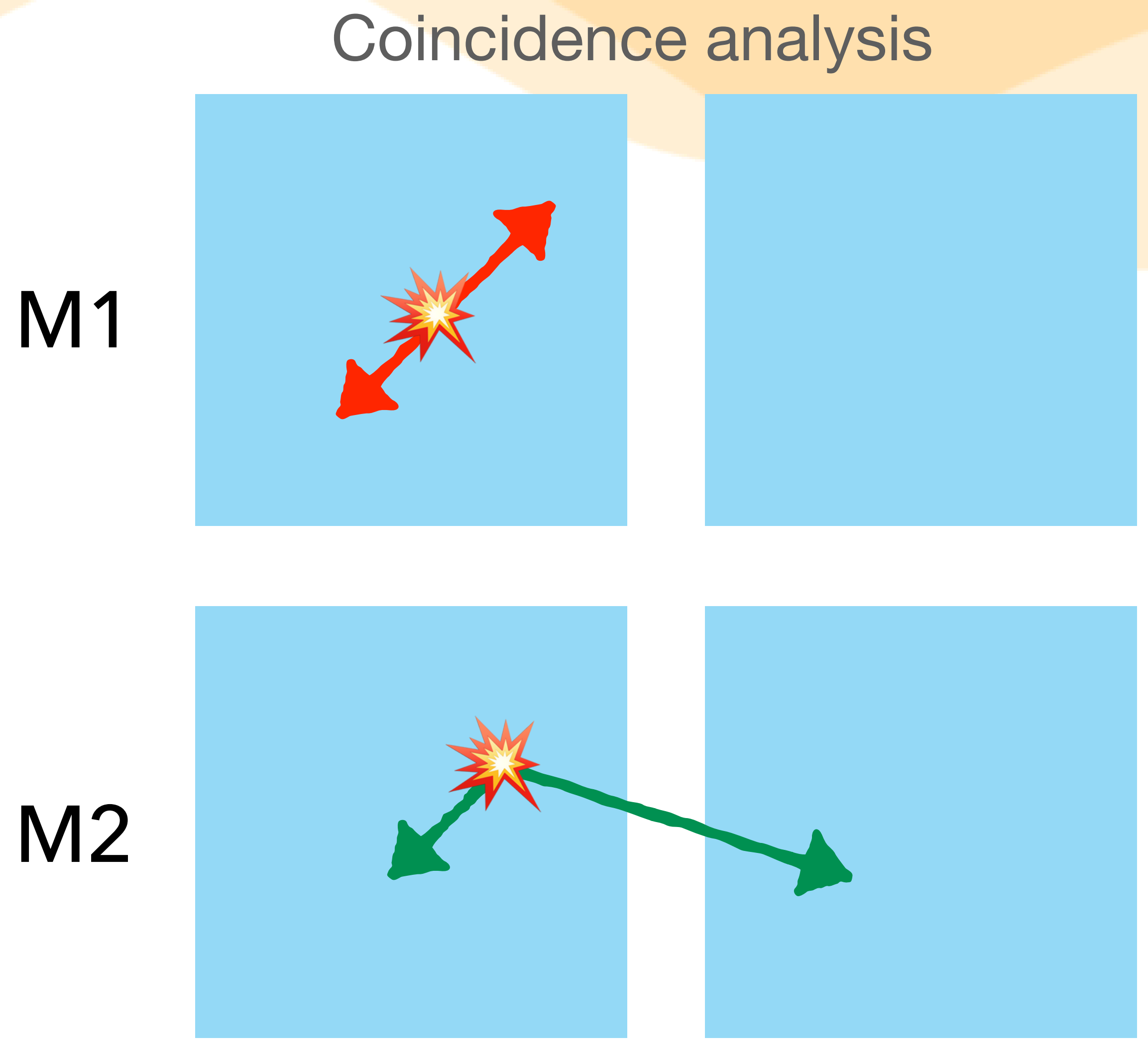
Reconstruction





Phase II setup

- The reflecting foils are removed for a better background comprehension using the coincidence analysis
- Additional shield at the 10mK stage facing directly the detectors



Contaminants

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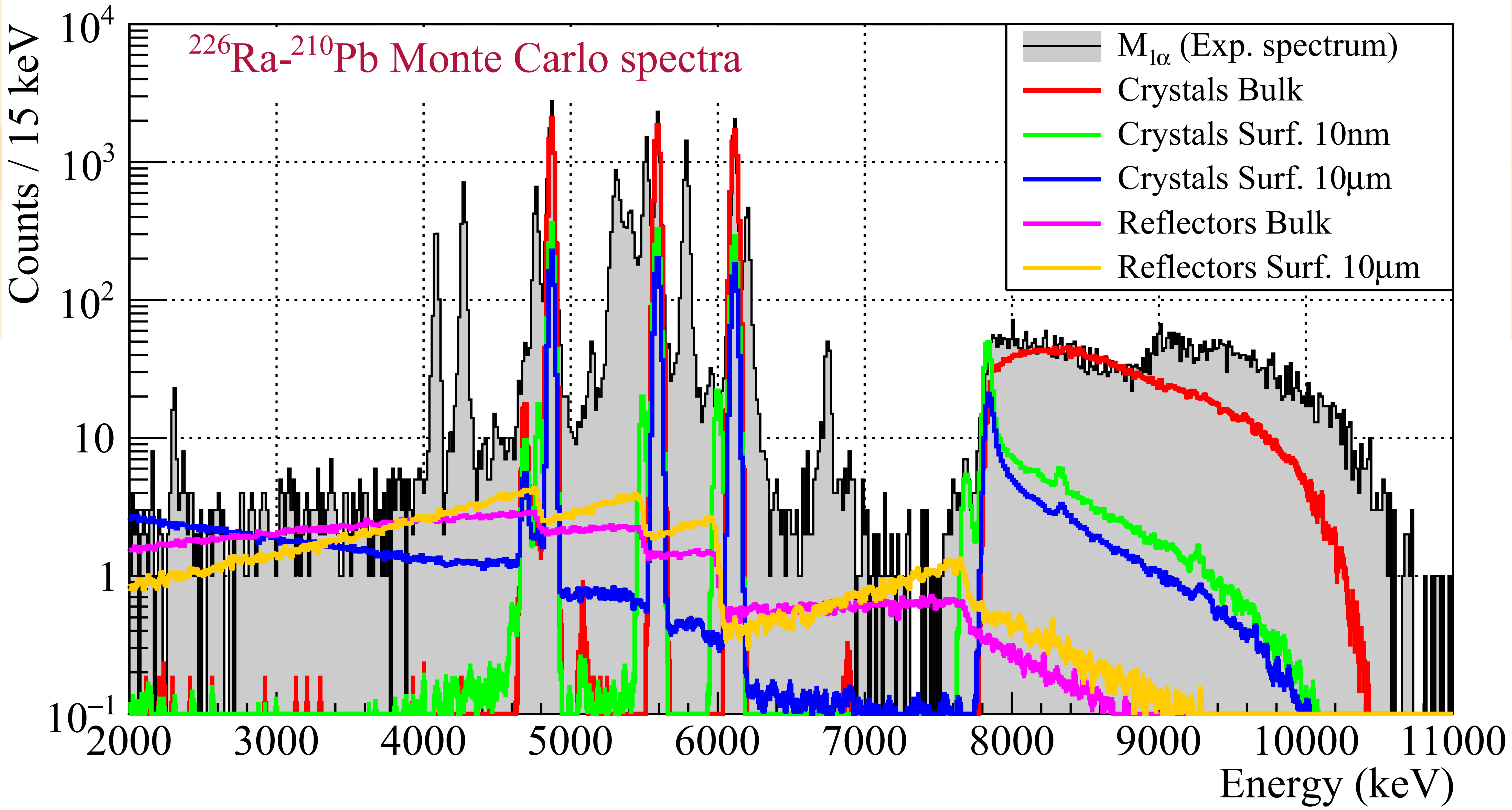
- Muons → Environment
- 2νββ

Crystal contaminants are modeled with different depth profiles:

$$e^{-x/\lambda}$$

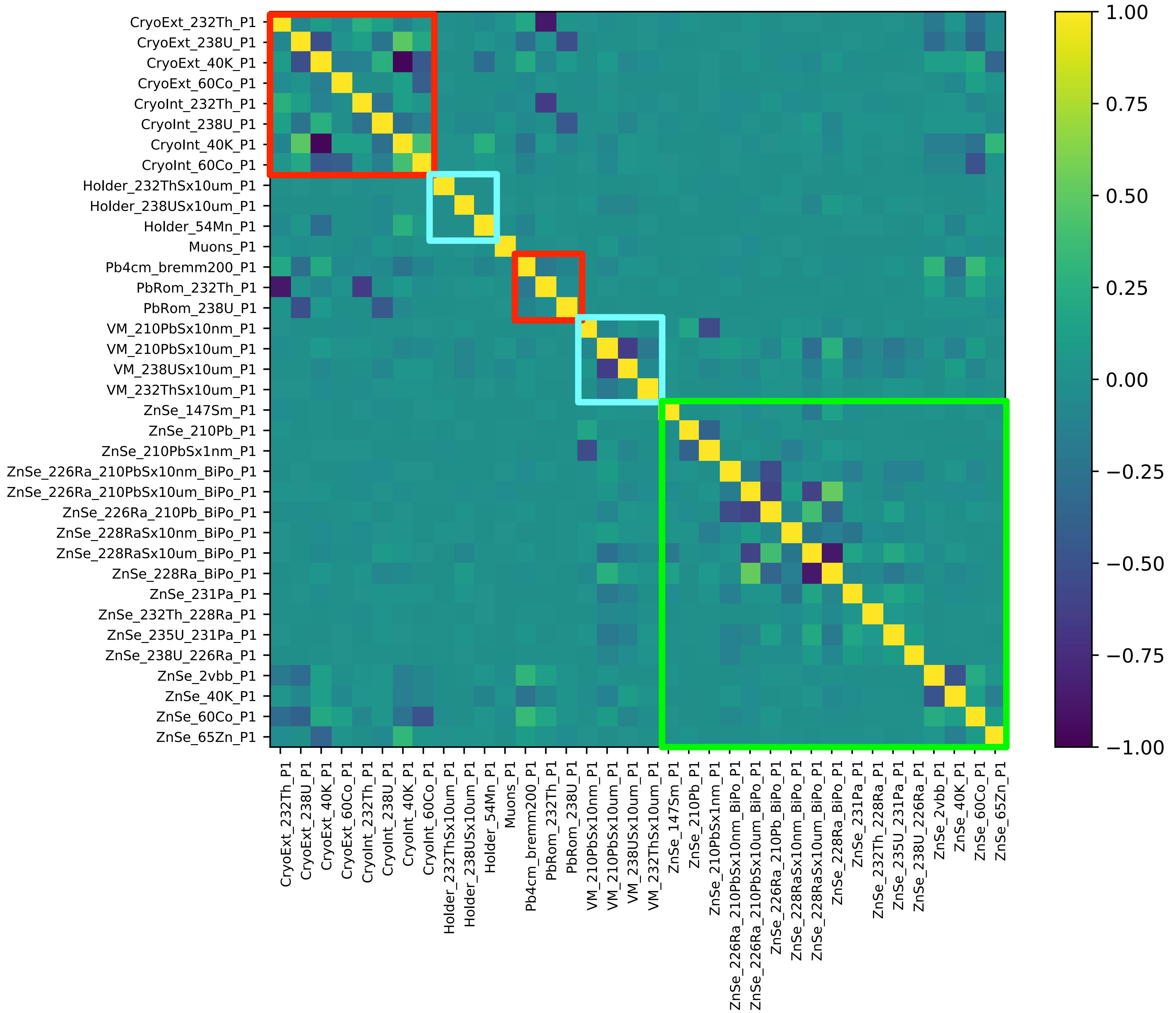
λ = depth parameter assumed to be 10nm or 10μm.



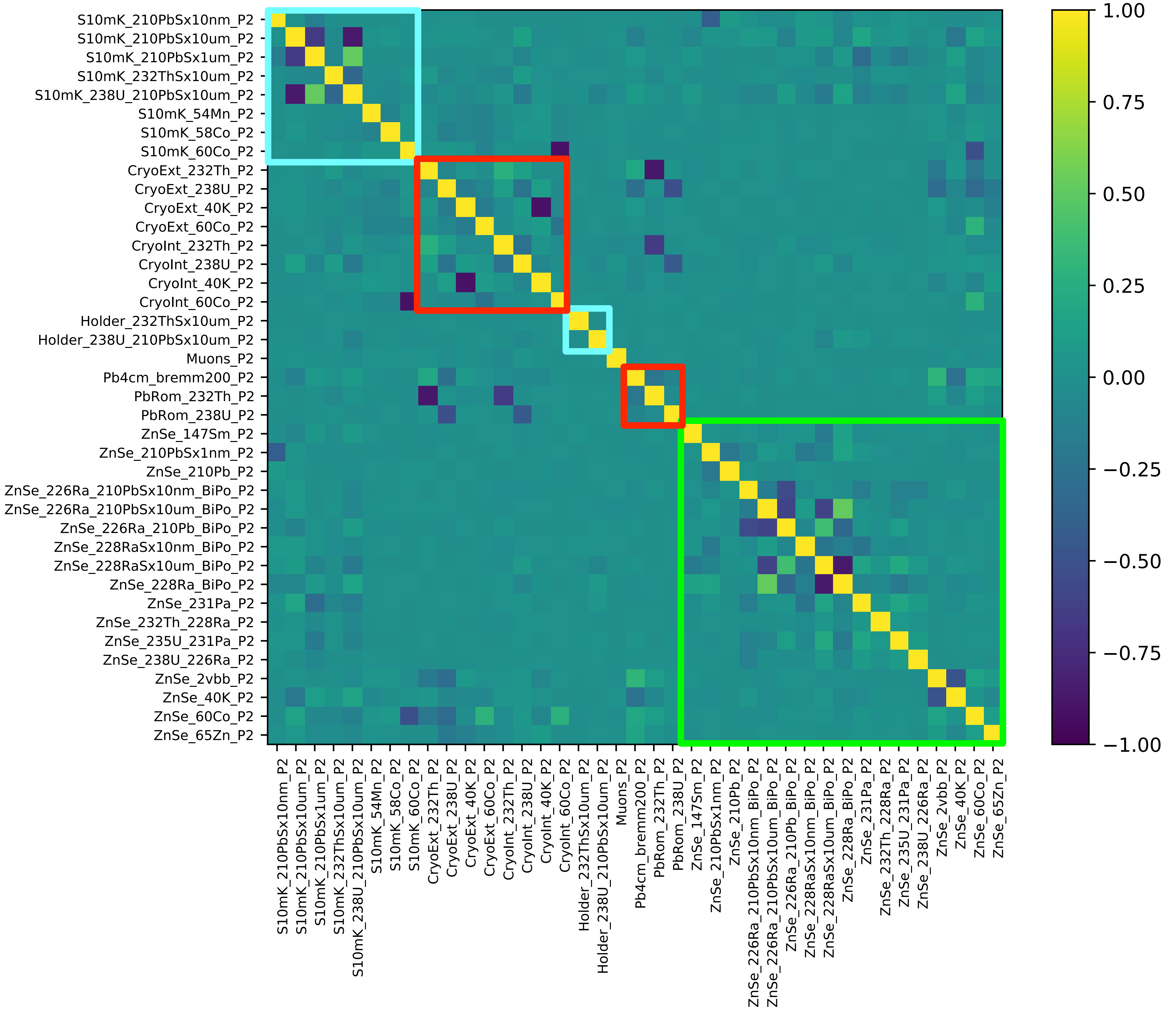
Correlation matrices

Cryostat & shields
Close components
Crystals

PhaseI



PhaseII



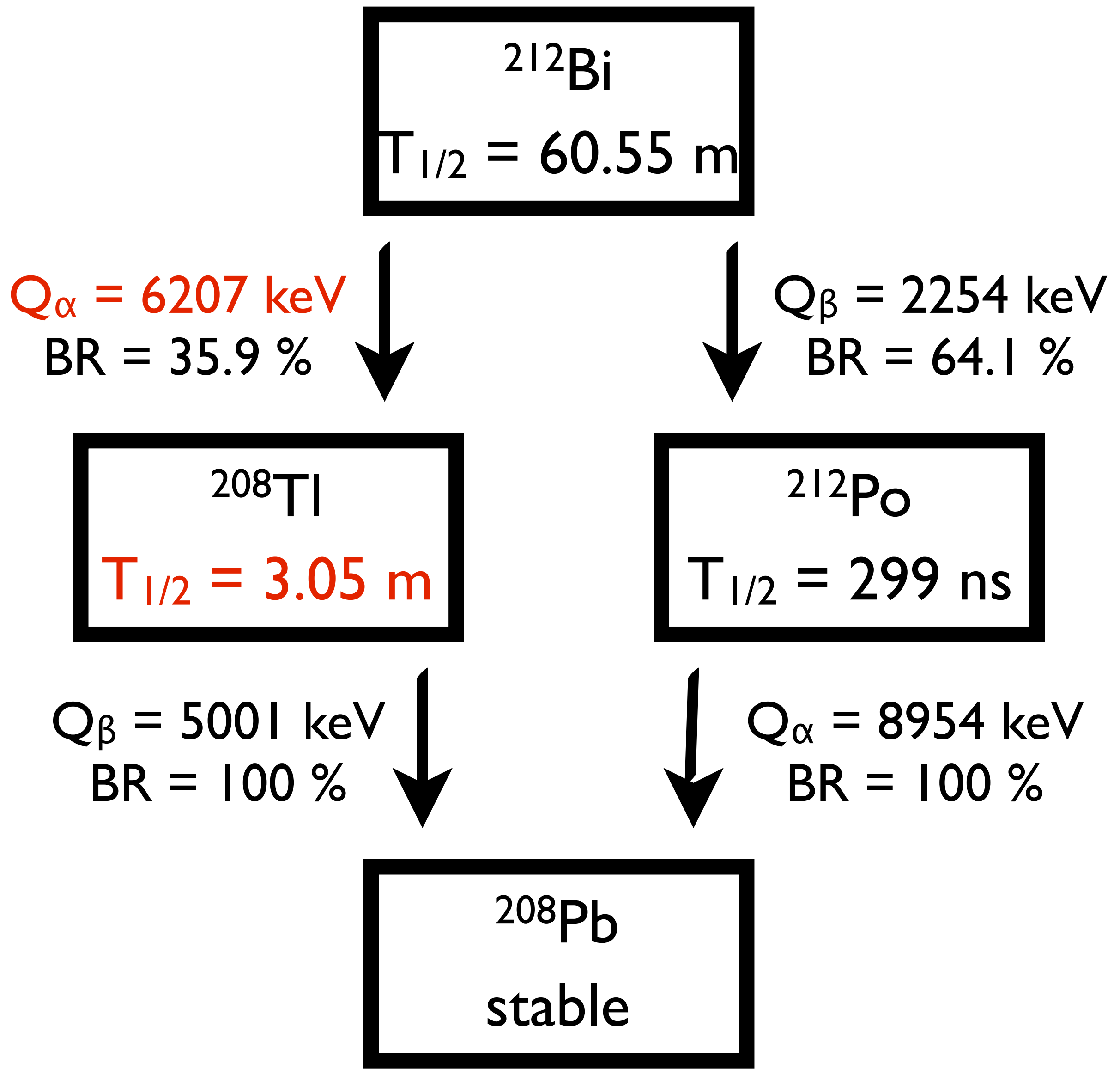
Correlation matrices

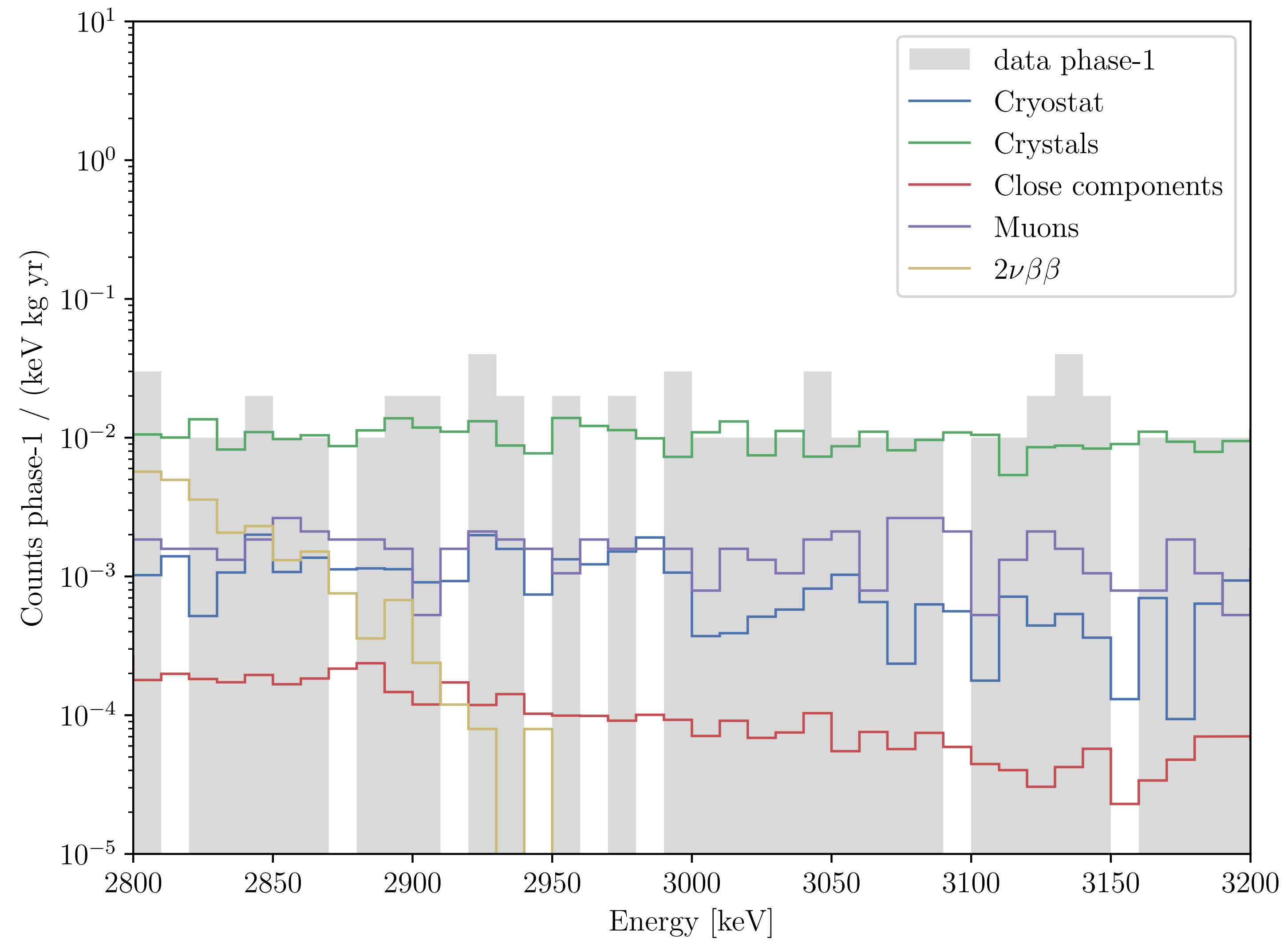
Looking at the region of interest of the $0\nu\beta\beta$ for the ^{82}Se (~3MeV) the main background come from crystals contaminations, the ^{232}Th chain in particular.

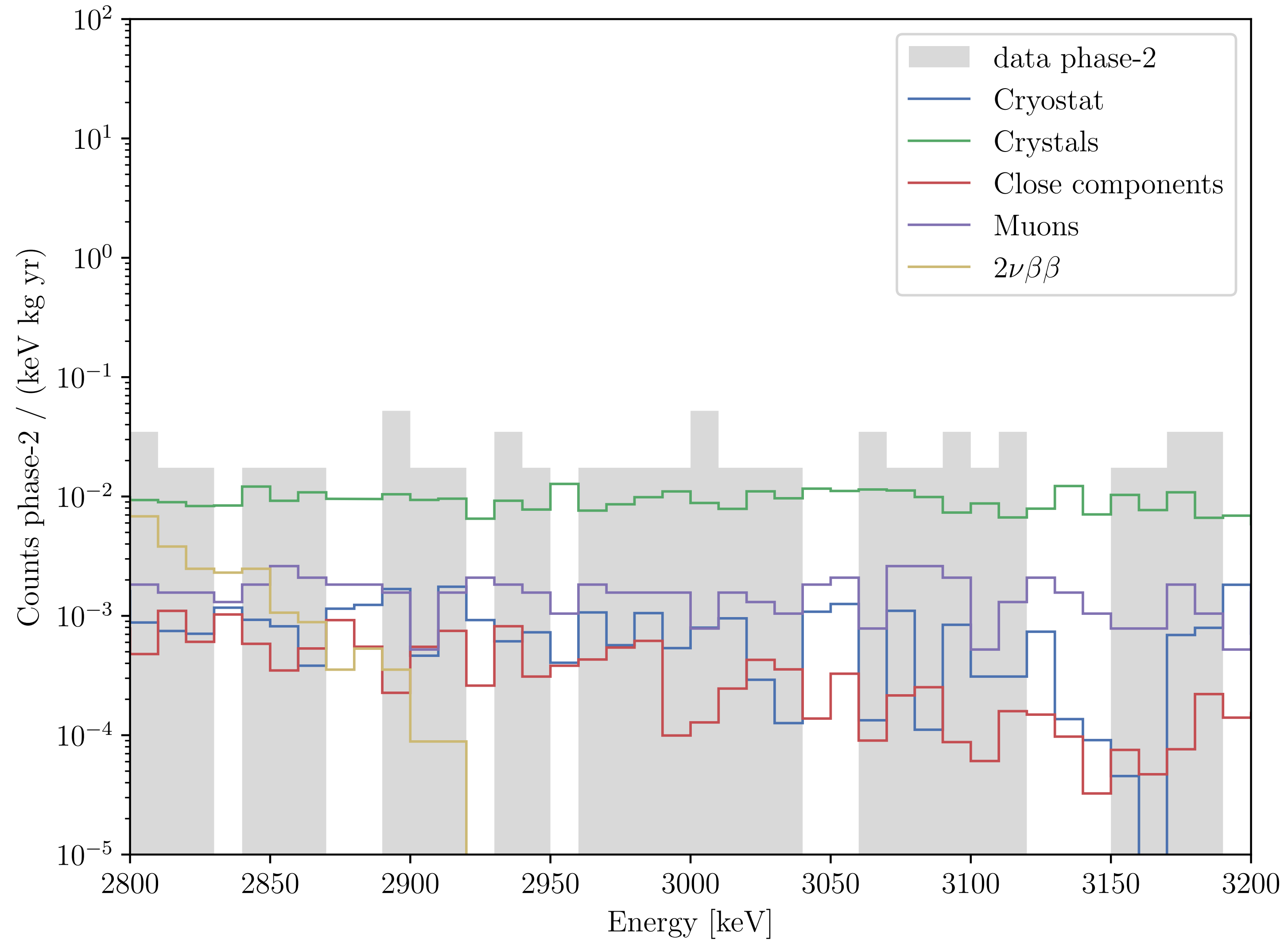
This can be reduced exploiting the delayed coincidence analysis

1. Tag the alpha decays from ^{212}Bi
2. Reject all the events occurring in forward 21mins (7 × ^{208}Tl half-life)

The same cut is applied on the simulations to reproduce the background index in the ROI



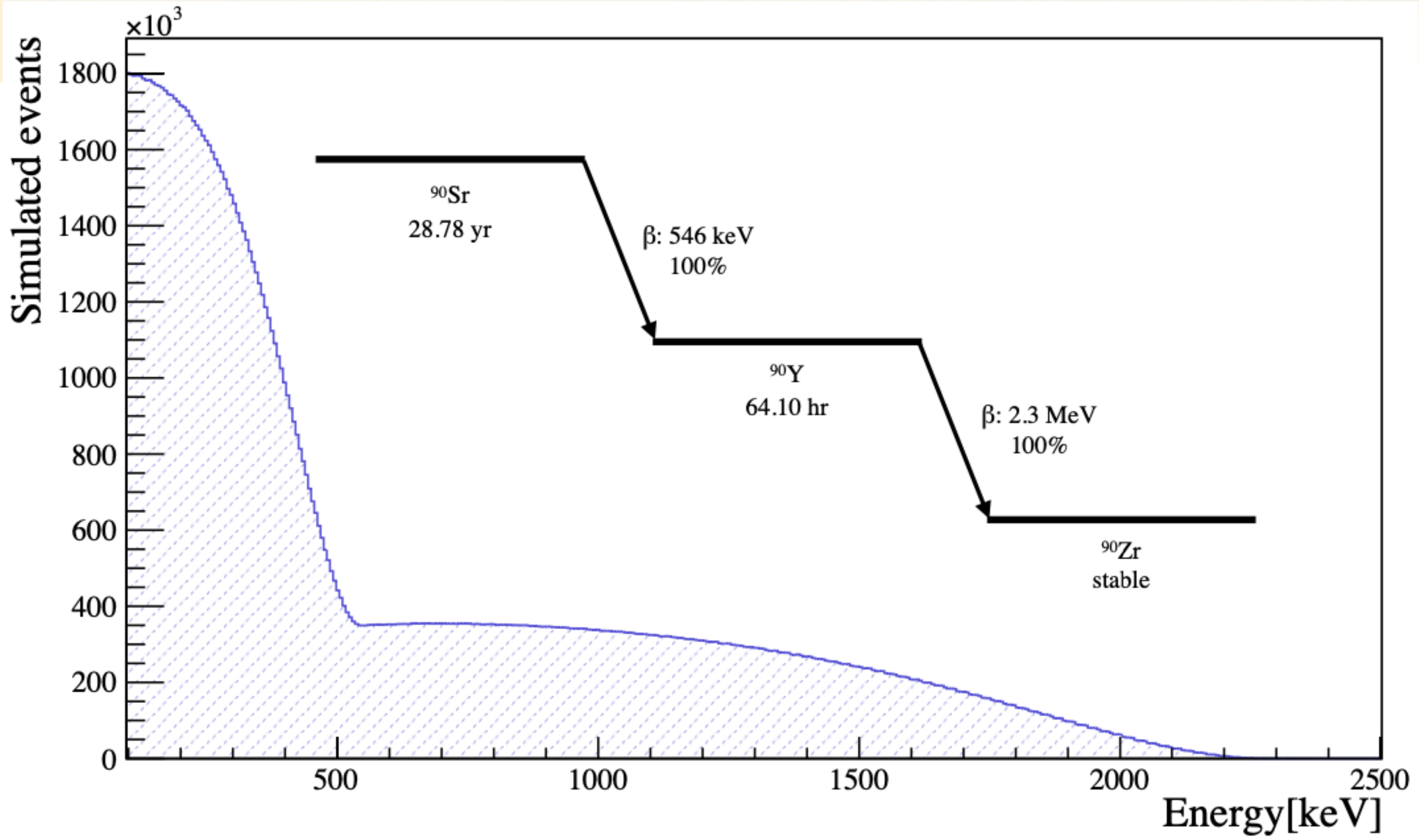


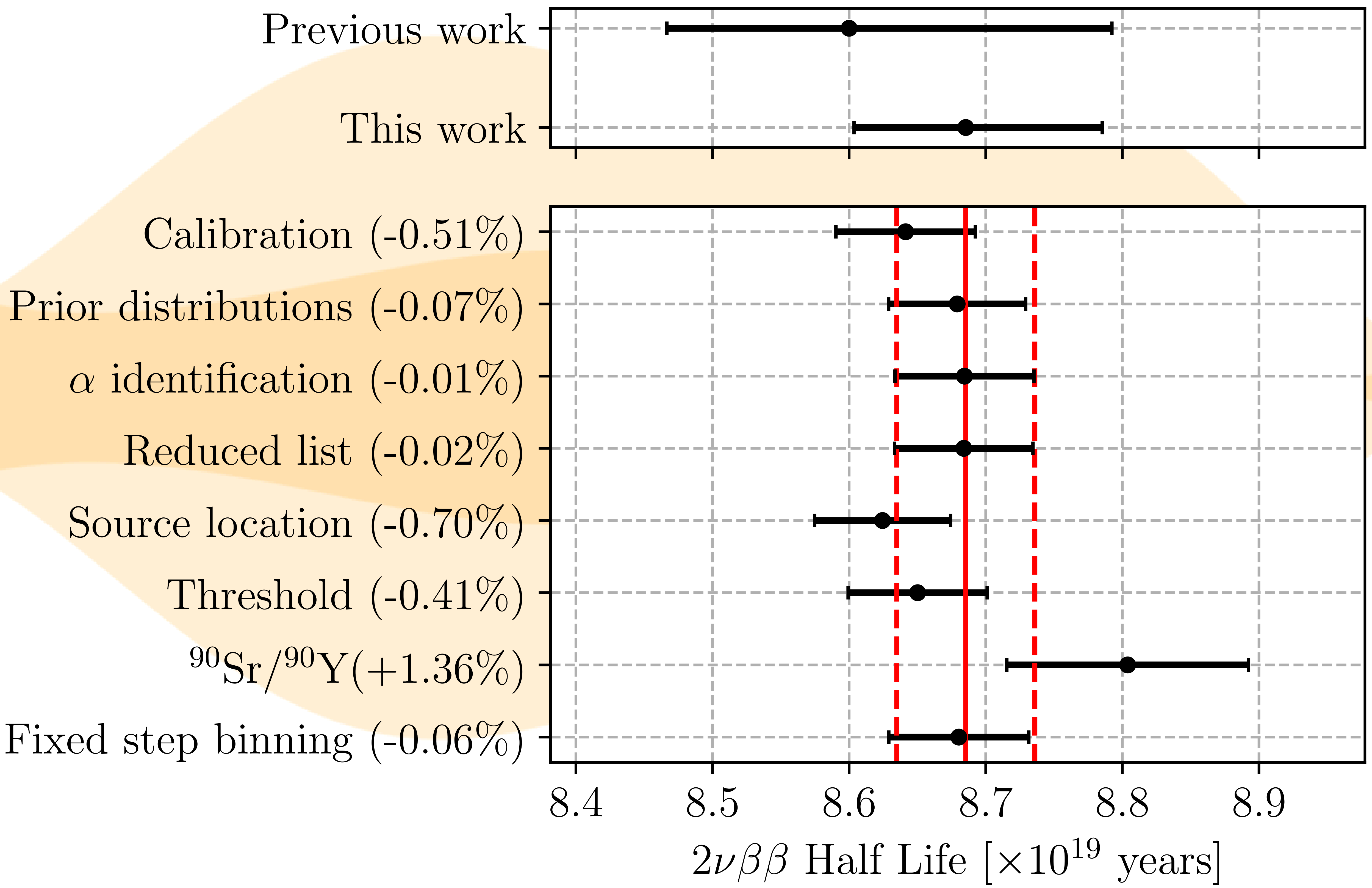


Systematics

Fit systematic uncertainties added:

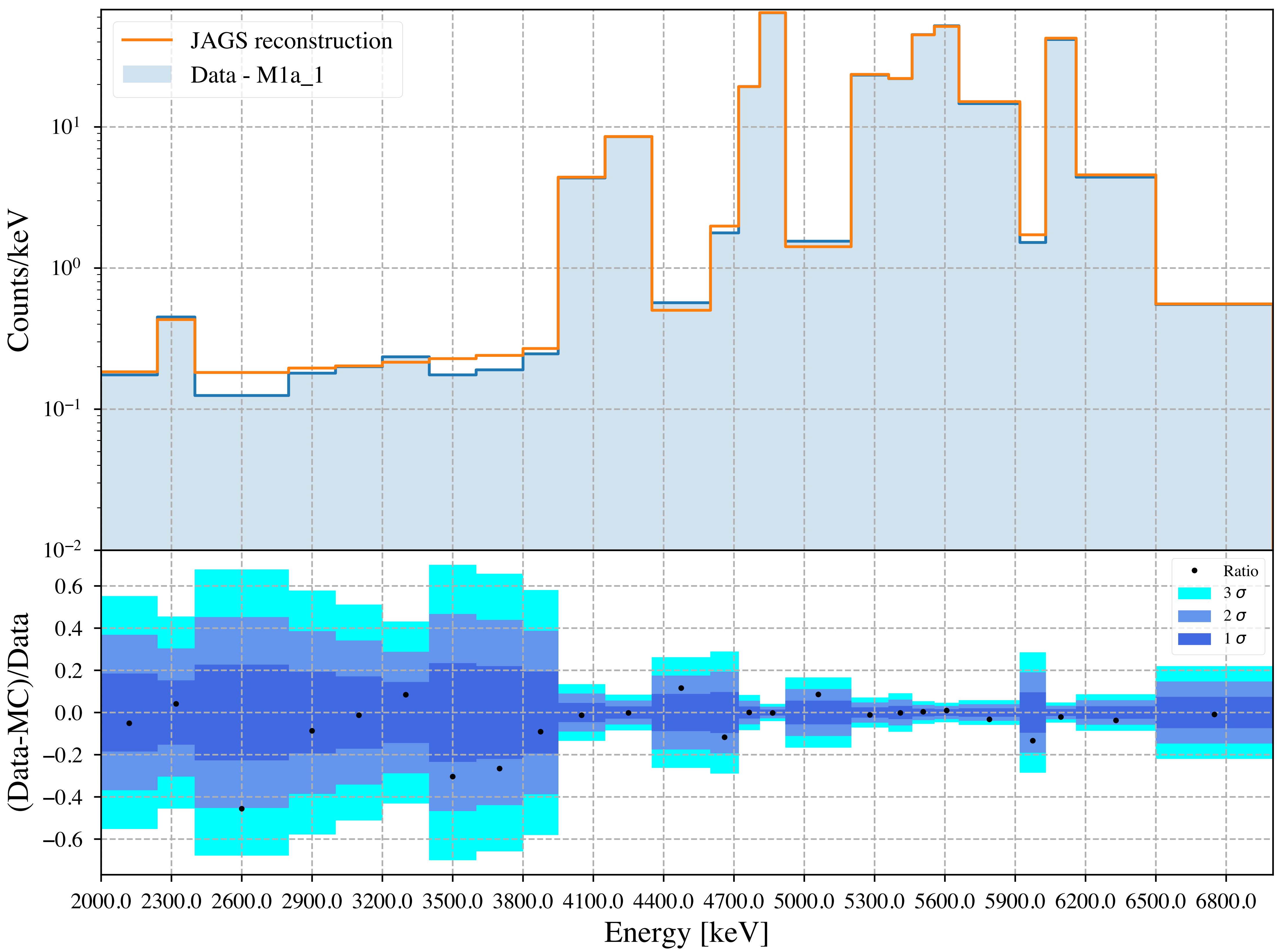
- Switch off all the priors
- No alpha identification
- phase-II efficiency
- ^{90}SrY → strongest effect



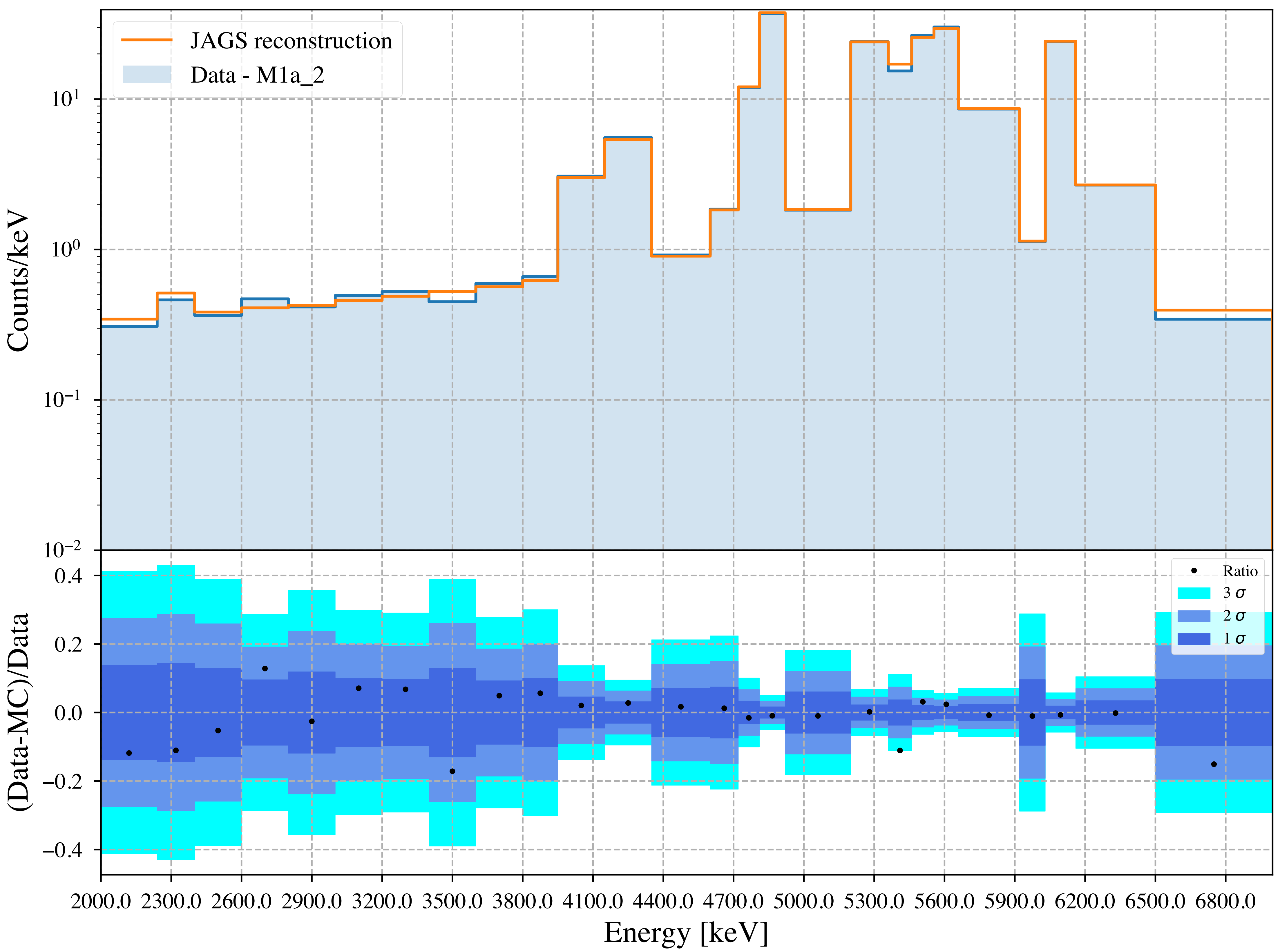


Reconstruction

PhaseI

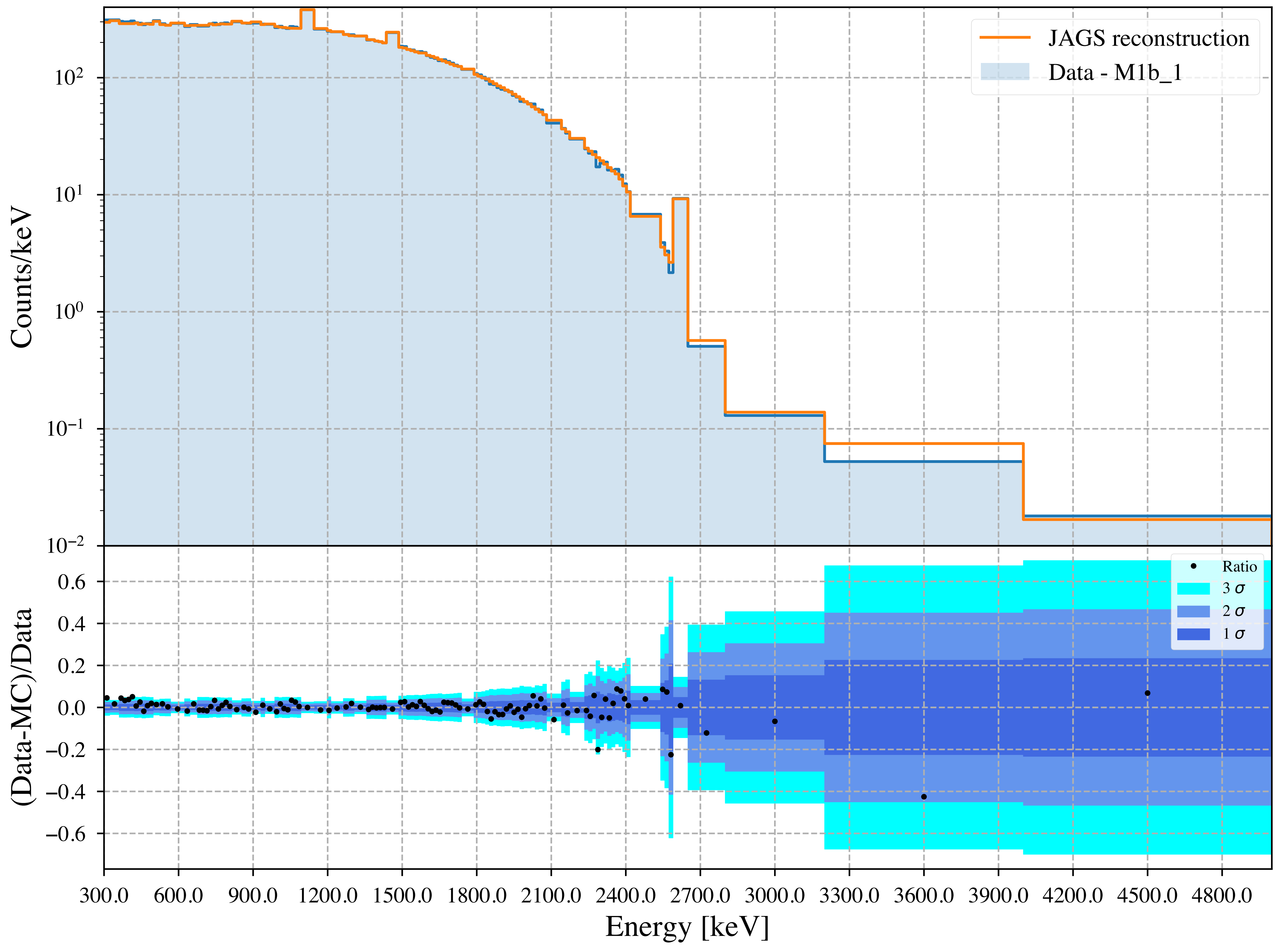


PhaseII

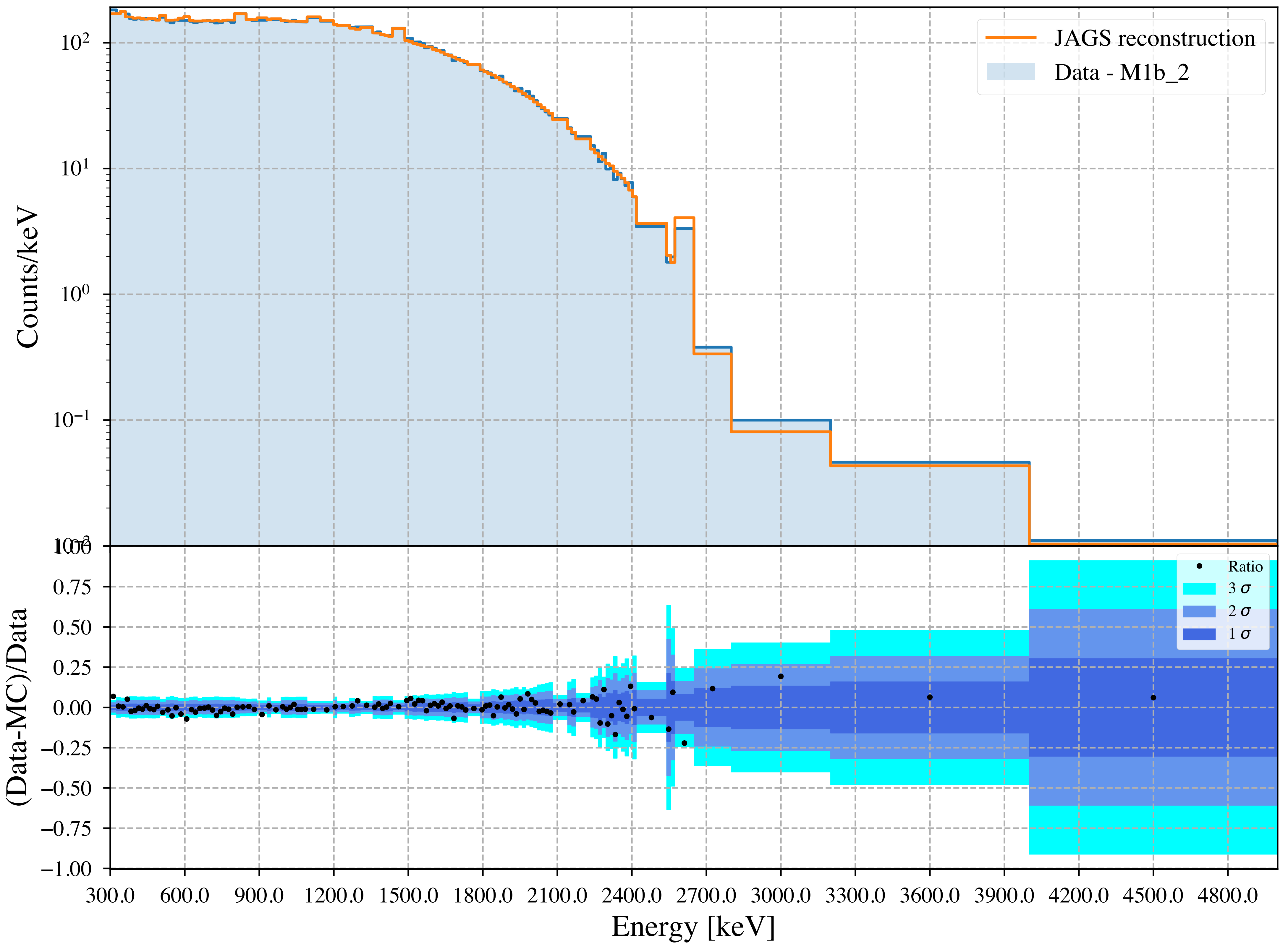


Reconstruction

PhaseI

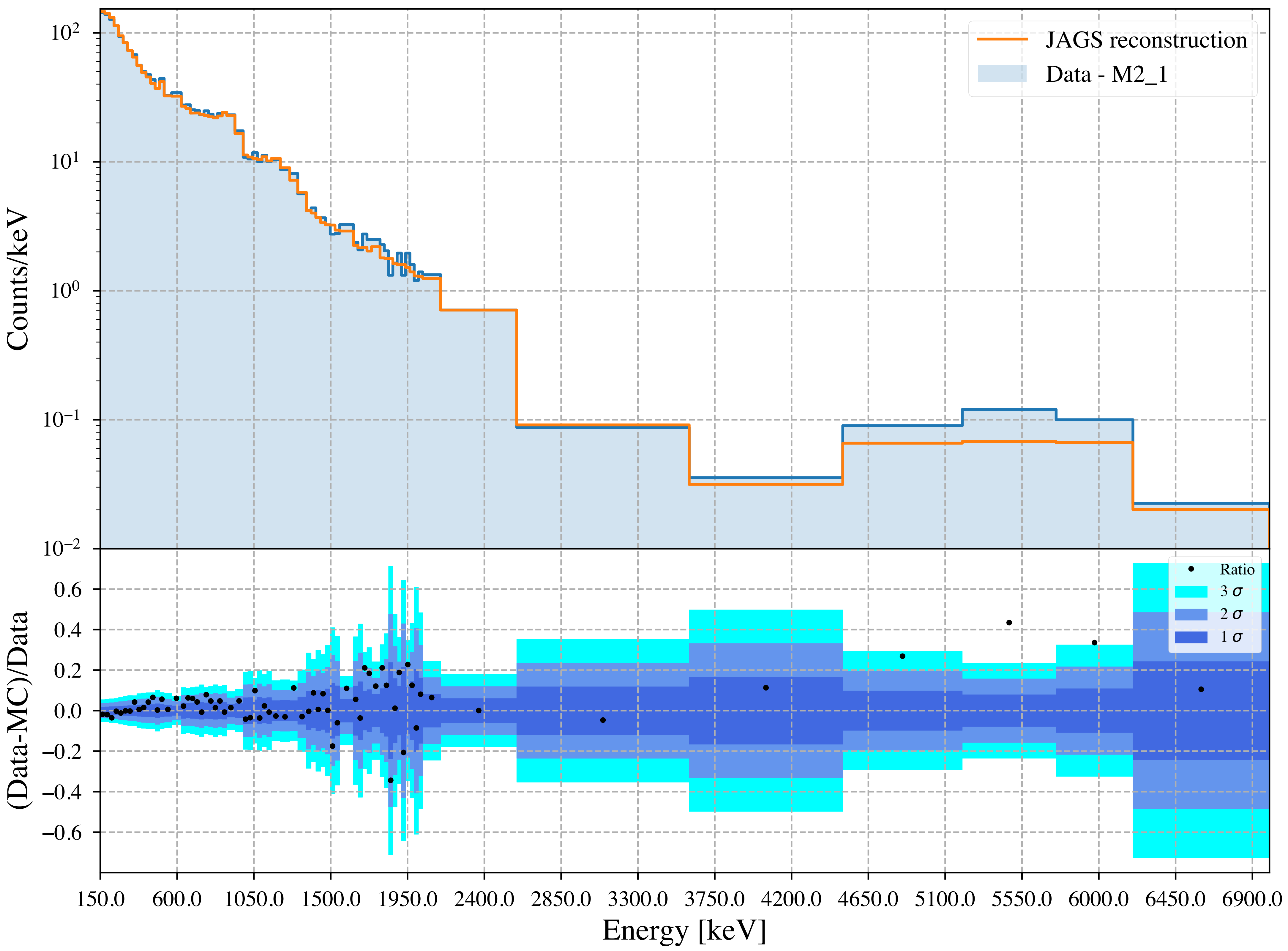


PhaseII

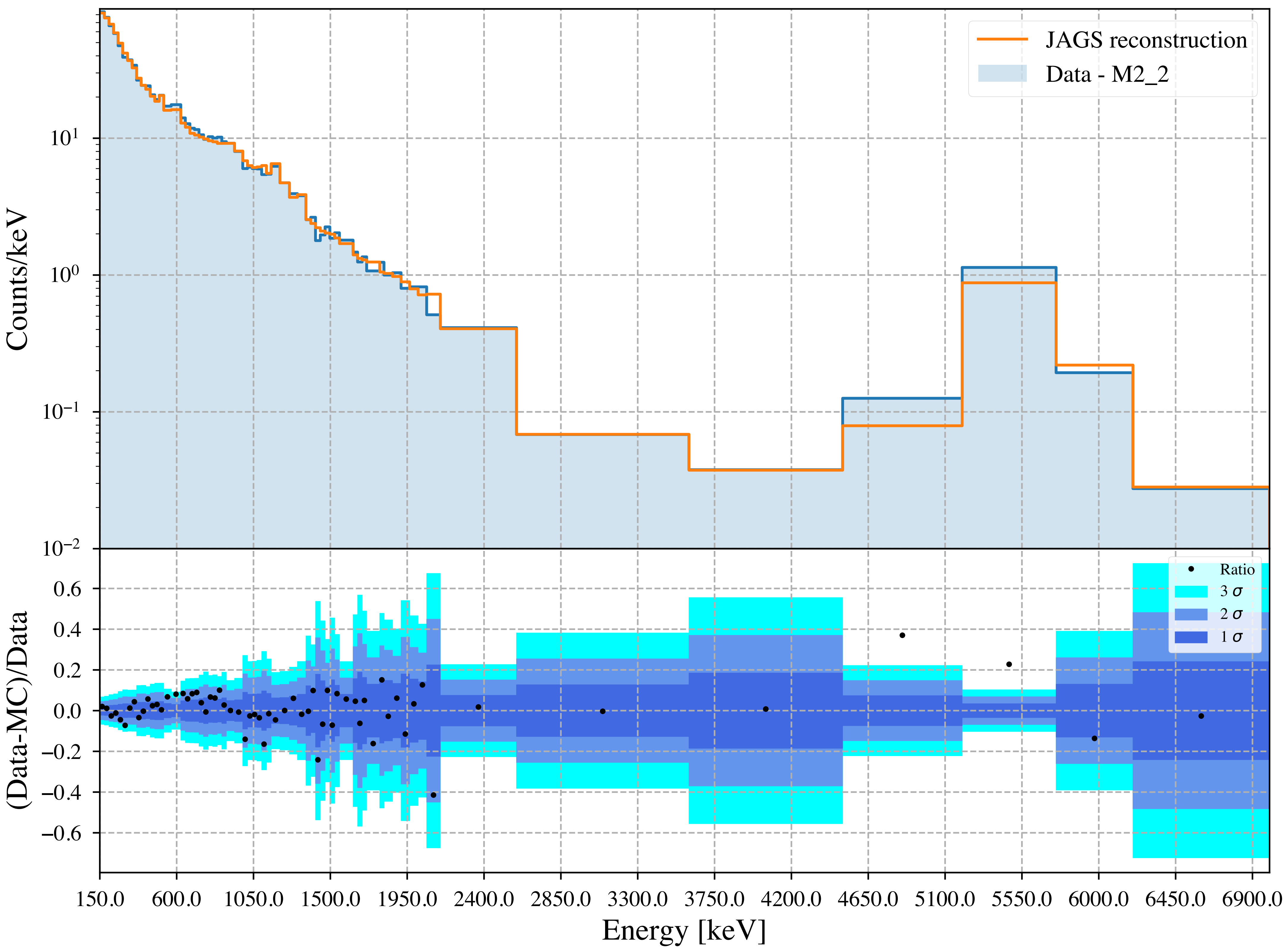


Reconstruction

PhaseI

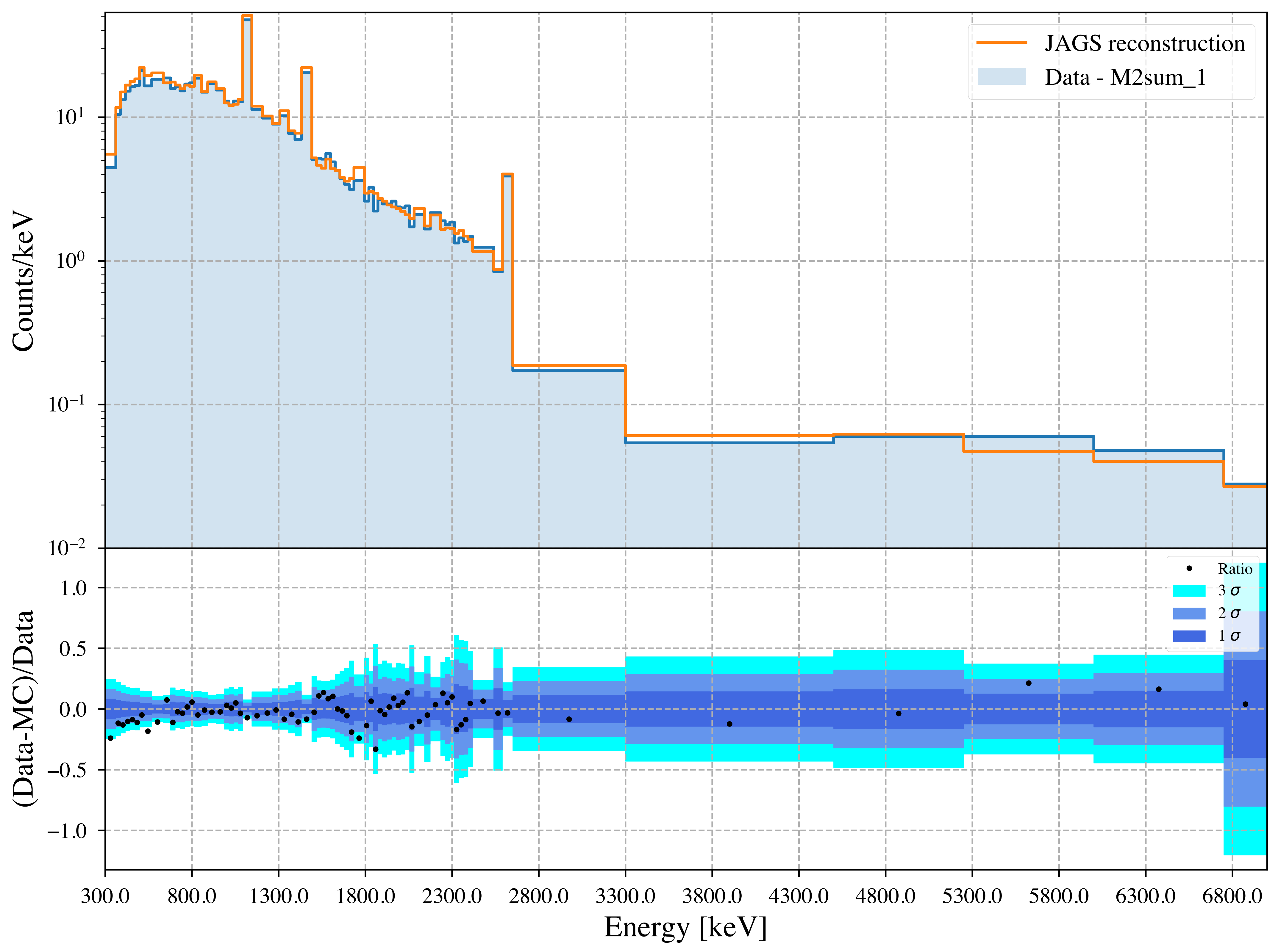


PhaseII



Reconstruction

PhaseI



PhaseII