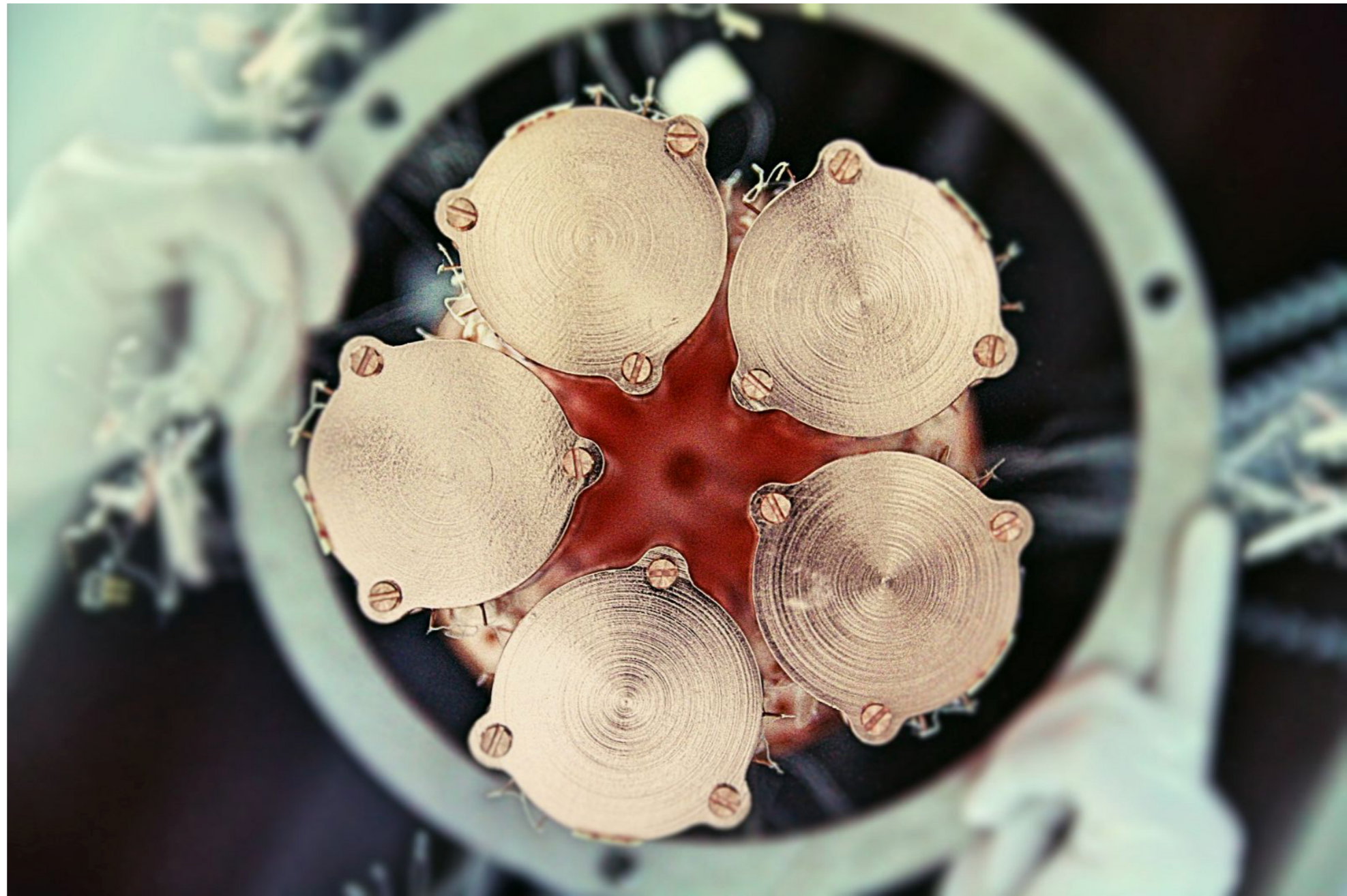


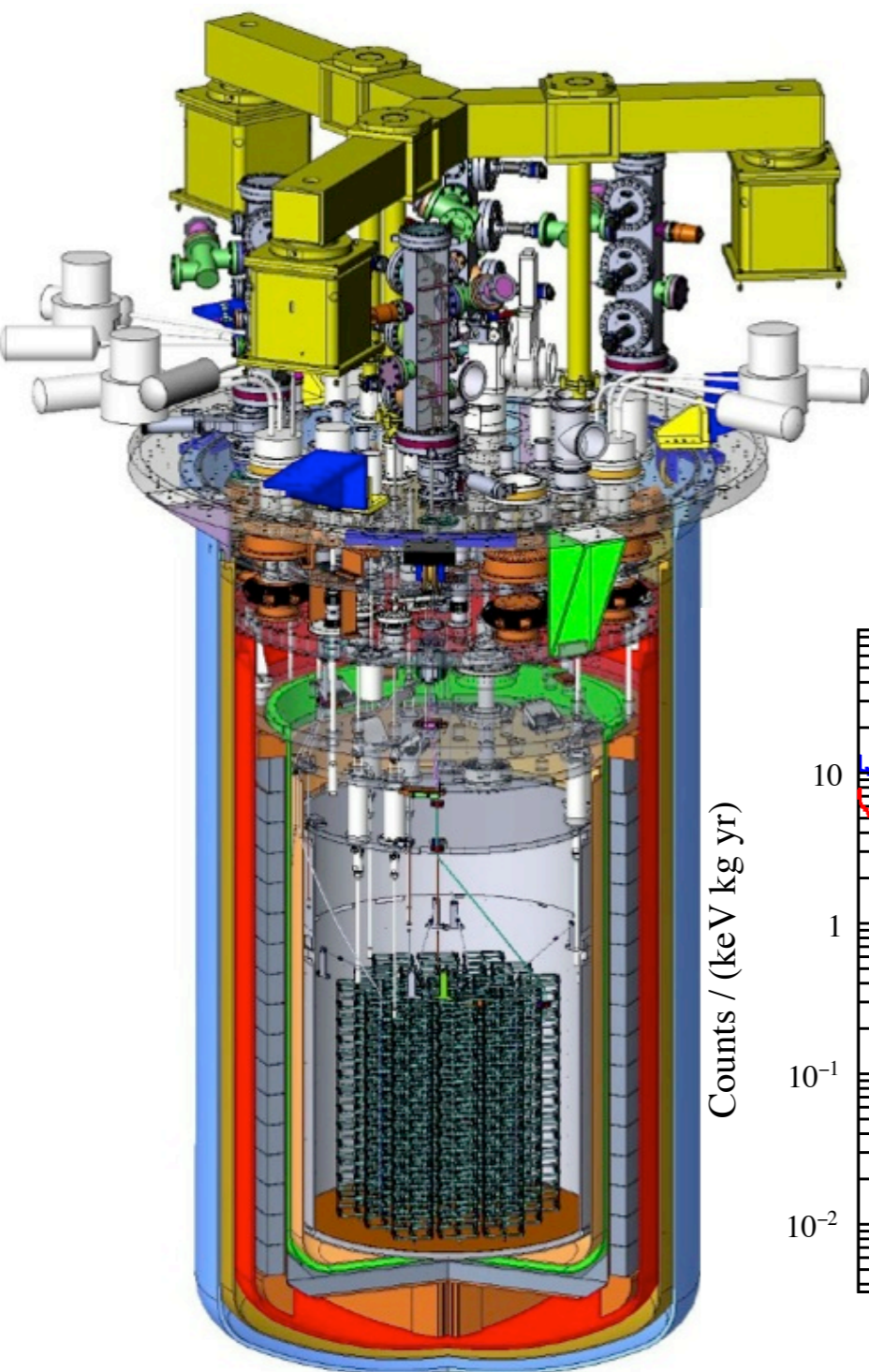
CUPID-0: cryogenic calorimeters with light and heat read-out for $0\nu\beta\beta$ searches



*Nicola Casali for the CUPID-0 collaboration. Neutrino Oscillation Workshop,
Rosa Marina, Ostuni, Italy, 9-16 September 2018*

CUORE Experiment

P. Gorla's Talk

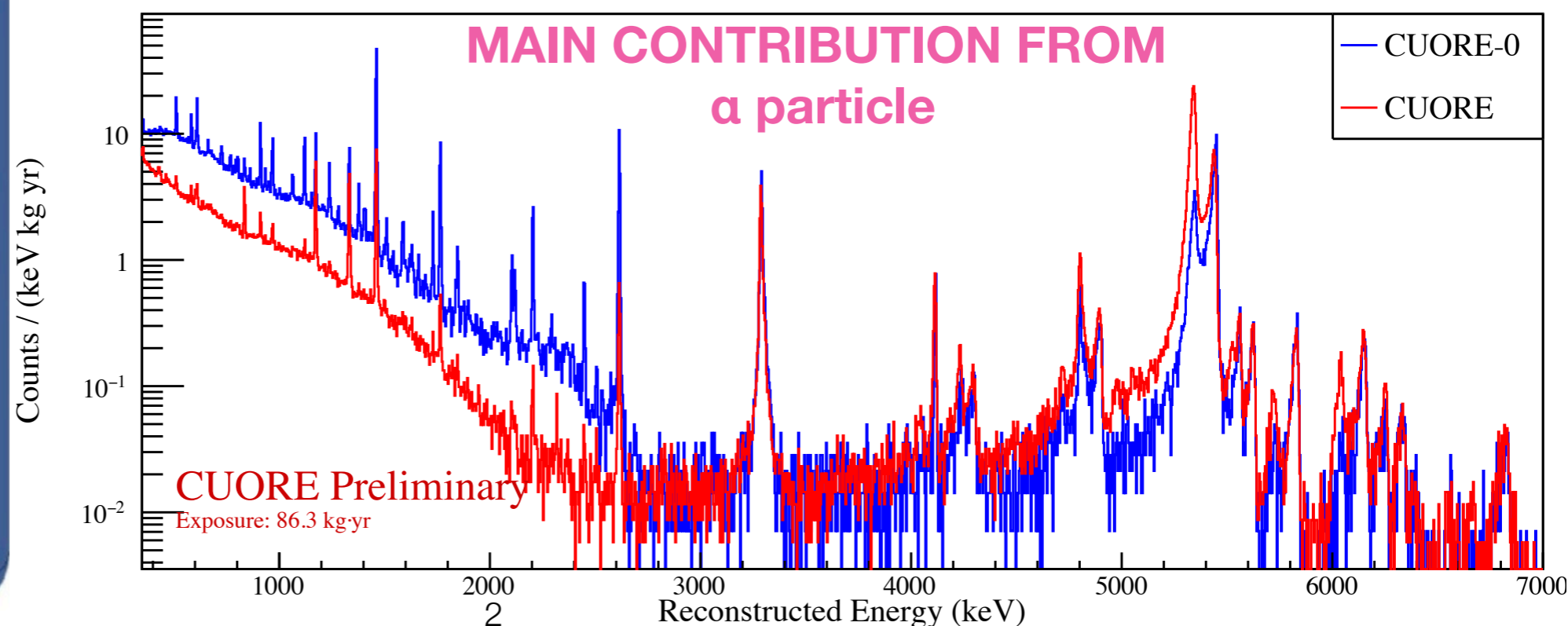


- The new standard for the cryogenic calorimeters searching for neutrino-less double beta decay:

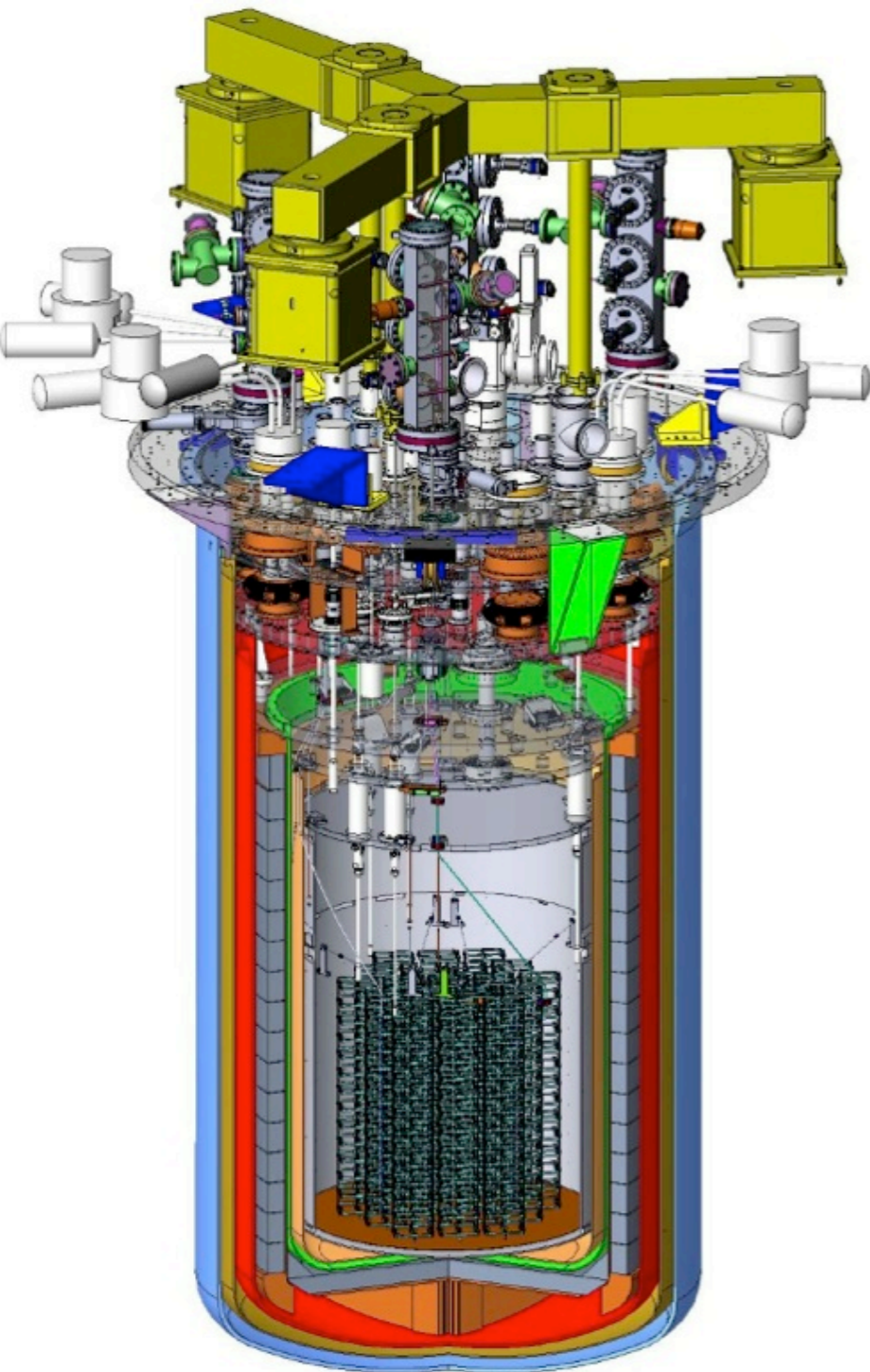
1. One ton of active detectors with hundreds of kg of $\beta\beta$ emitting isotope

2. Energy resolution $\sim 0.1\%$

3. BKG in the RoI ~ 250 counts/ton in 5 y data taking



CUPID: CUORE Upgrade with Particle Identification



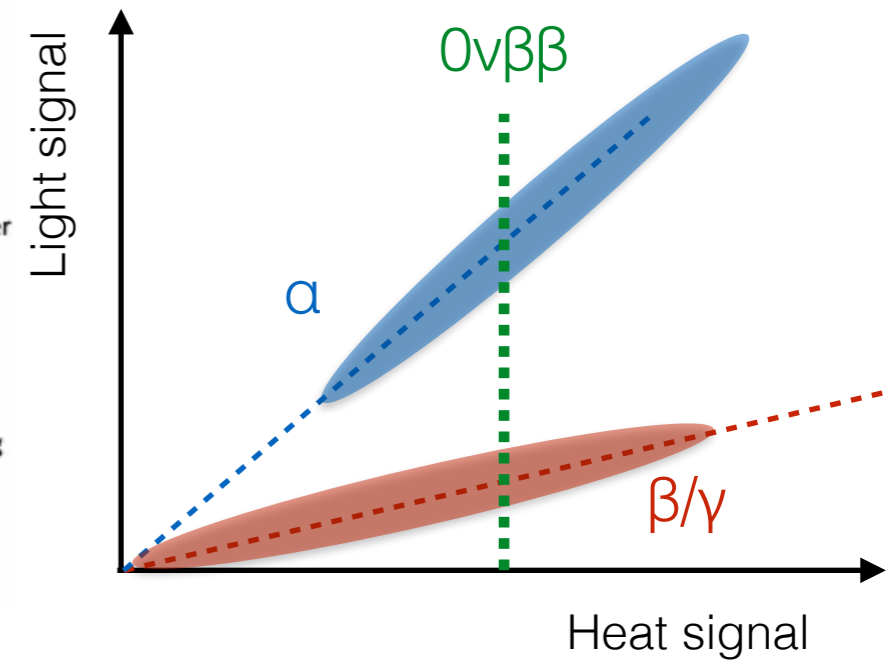
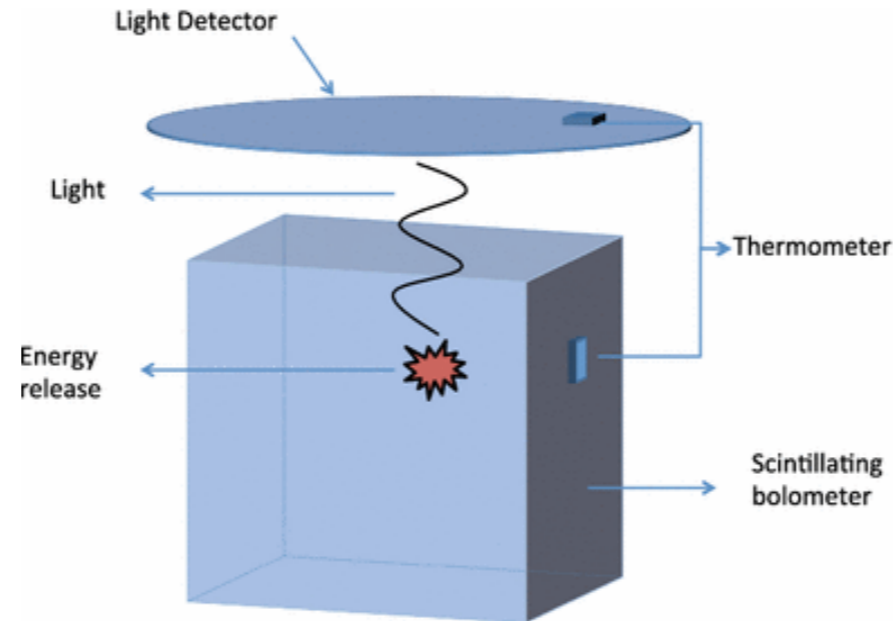
CUPID Interest Group [arXiv:1504.03612v1](https://arxiv.org/abs/1504.03612v1)

- Possibility to use the CUORE infrastructure for a future ton-scale $0\nu\beta\beta$ experiment with a sensitivity on $m_{\beta\beta} \sim 10$ meV:
 1. **One ton of emitting isotope (isotopic enrichment)**
 2. **BKG in the RoI ~ 1 counts/ton (to be demonstrated)**

The first certain step is the active α particle rejection

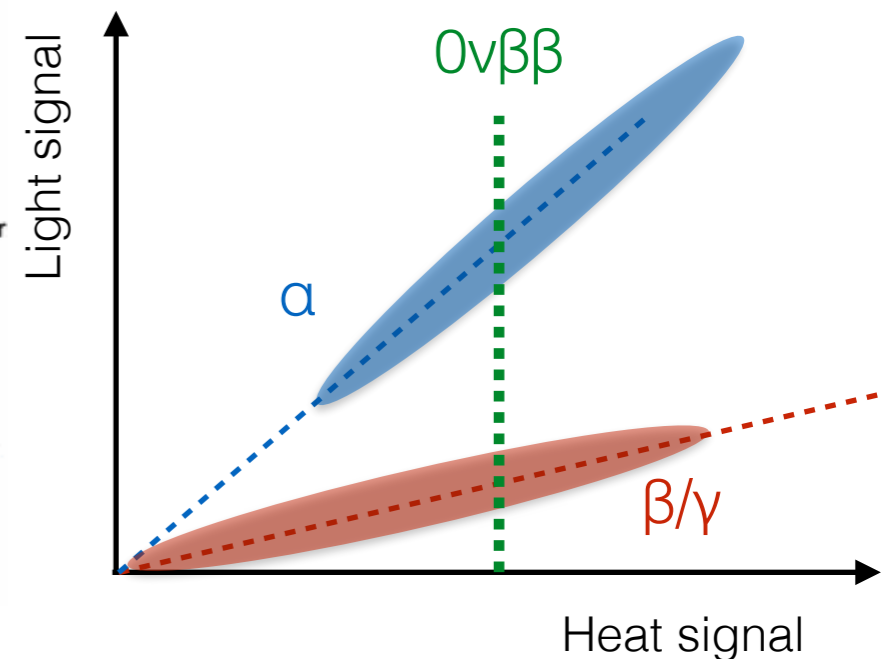
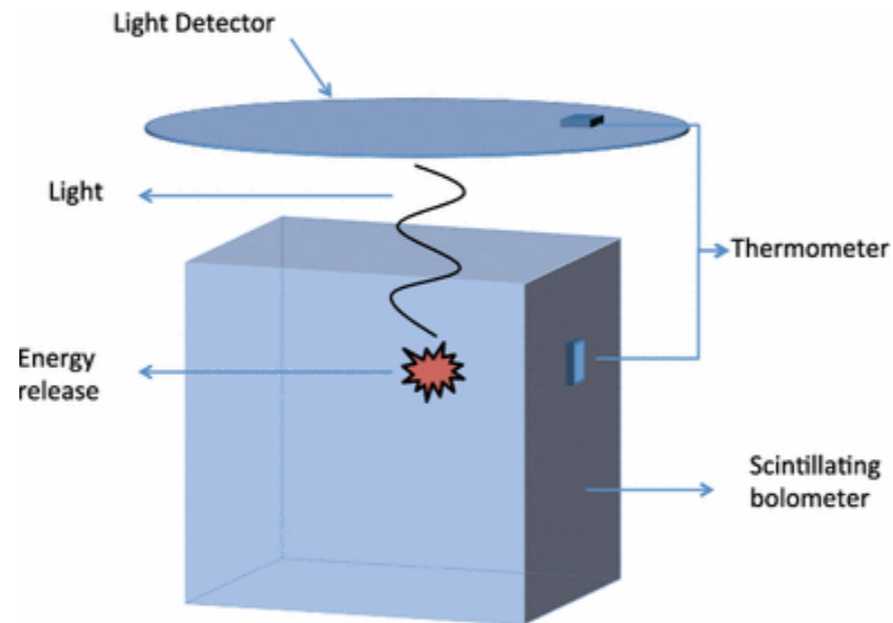
Particle Identification techniques

- Couple to each bolometer a light detector
- Exploit differences in the LY between α and β/γ interactions



Particle Identification techniques

- Couple to each bolometer a light detector
- Exploit differences in the LY between α and β/γ interactions



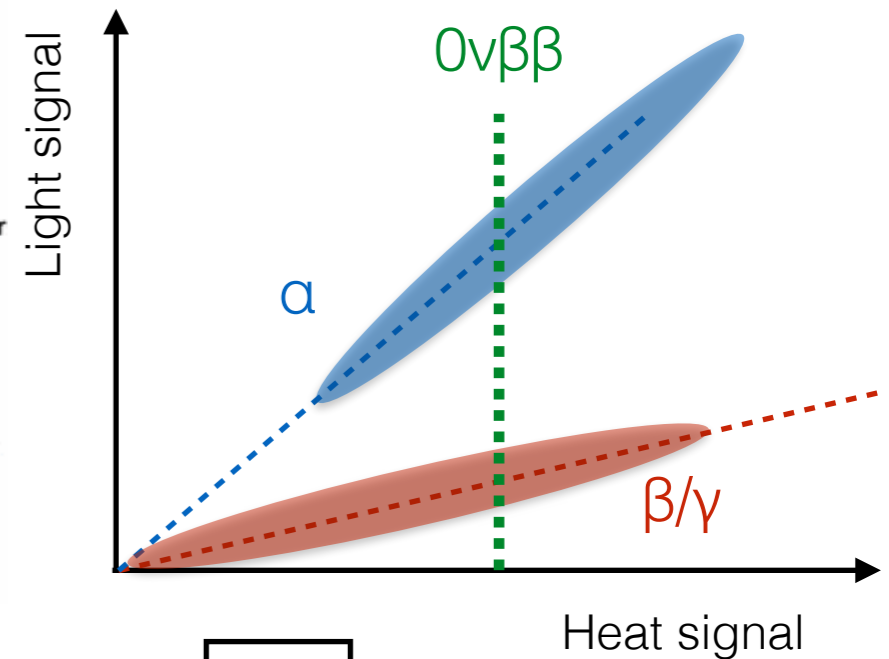
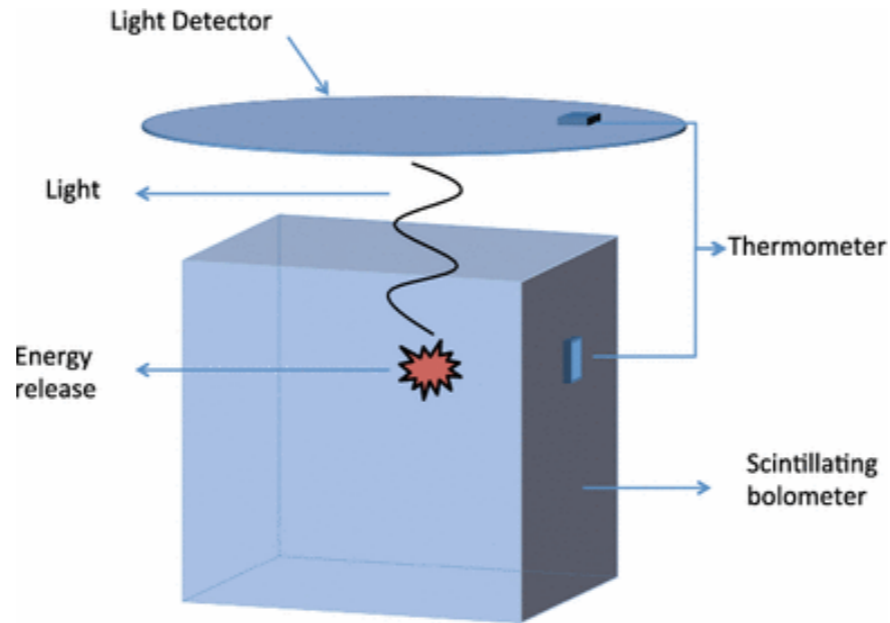
With TeO_2 crystal also ~ 100 eV signal
too low for the sensitivity of the current light detectors

Intense R&D activities exploiting TES, KID, NTD-Ge, + Neganov-Luke effect technologies.. but none is ready for such application

N.Casali et al. Eur.Phys.J. C 75 (2015) 1, 12
 L. Cardani et al. Appl.Phys.Lett. 107 (2015) 093508
 M. Biassoni et al. Eur.Phys.J. C75 (2015) no.10, 480
 L. Pattavina et al., Journal of Low Temp Phys 1-6 (2015)
 K.Schaeffner et. al, Astropart.Phys. 69 (2015) 30-36
 M. Willers et al., JINST 10 P03003 (2015)
 L. Pattavina et al. J.Low.Temp.Phys. 184 (2016) no.1-2, 286-29
 L. Gironi et al. Phys.Rev. C94 (2016) no.5, 054608
 F. Bellini et al. Appl.Phys.Lett. 110 (2017) 033504
 L. Cardani et al. Supercond.Sci.Technol. 31 (2018) 075002
 V. Novati et al. Nucl.Instrum.Meth. (2018)
 L. Bergé Phys.Rev. C97 (2018) no.3, 032501

Particle Identification techniques

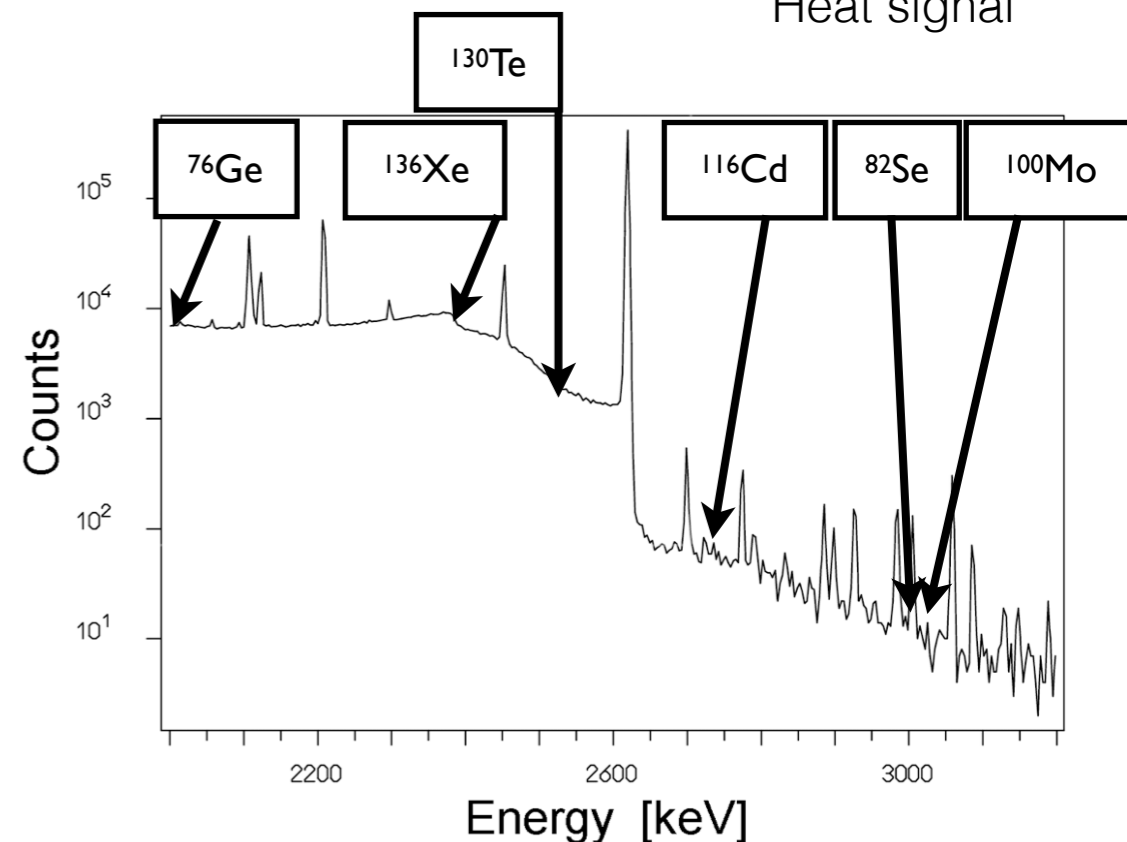
- Couple to each bolometer a light detector
- Exploit differences in the LY between α and β/γ interactions



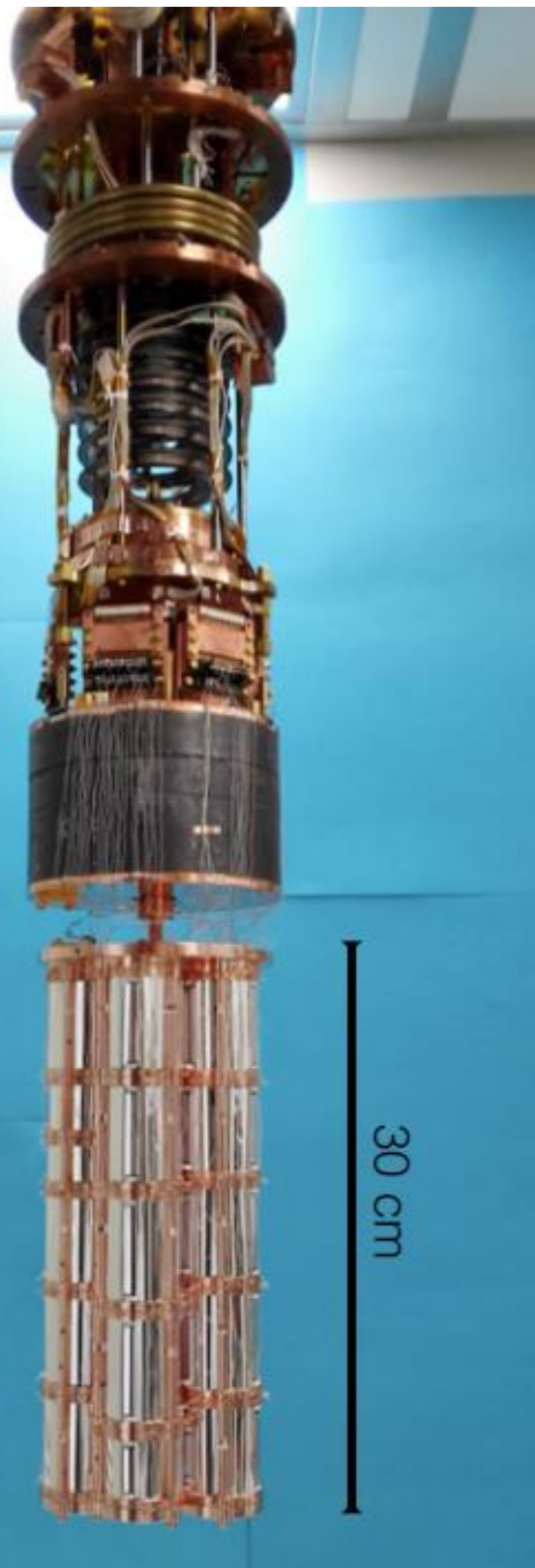
But for scintillating crystal like ZnSe or Li_2MoO_4 the LY is $\sim \text{keV/MeV}$

Furthermore the higher Q-Value ensures a lower β/γ background

CUPID-0 -> Zn^{82}Se scintillating crystals

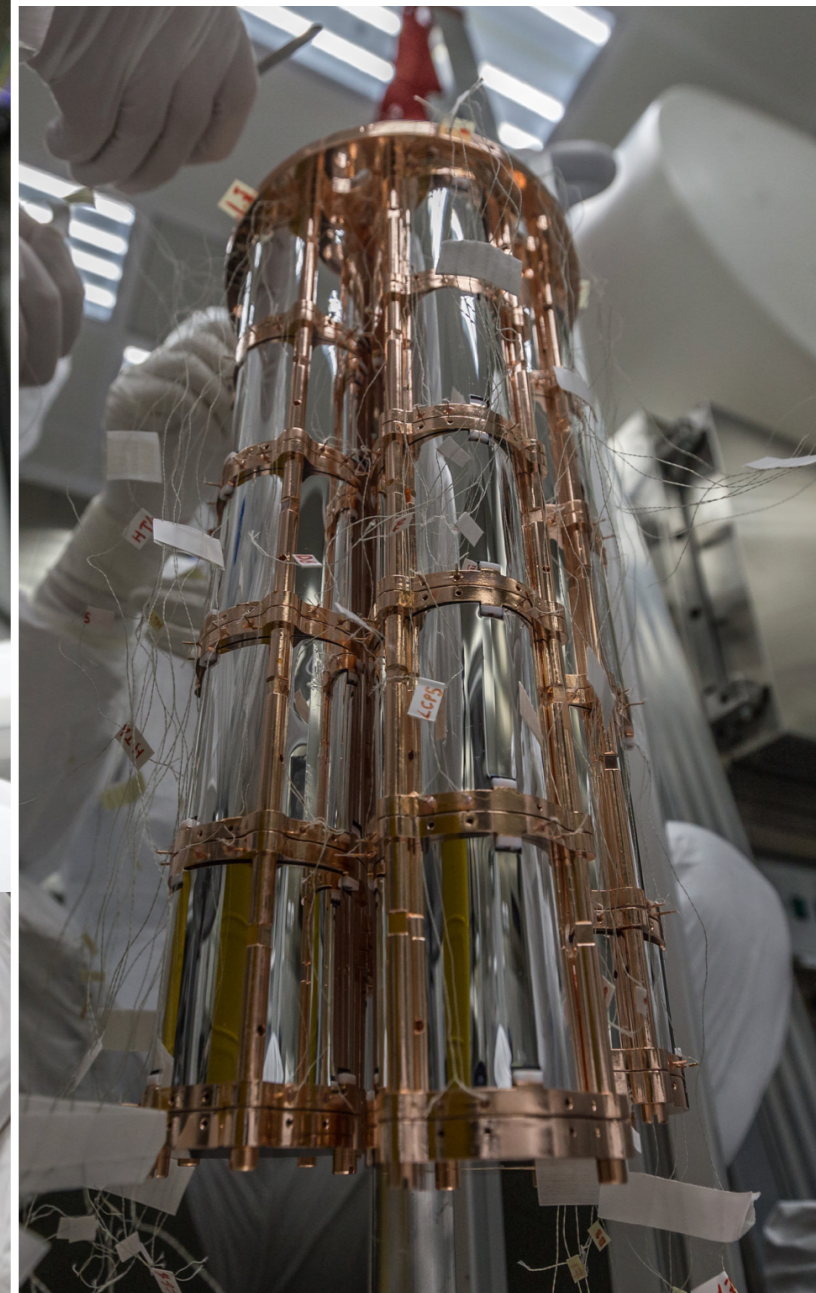
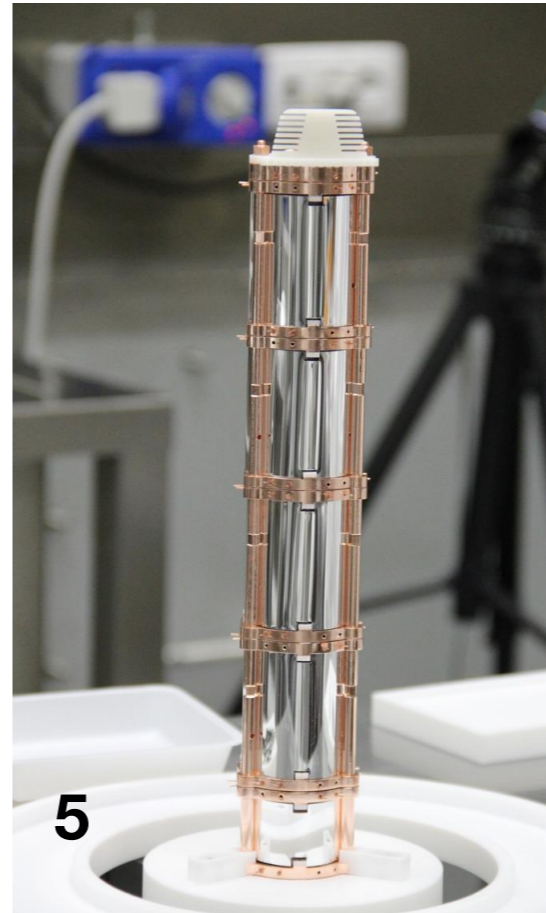
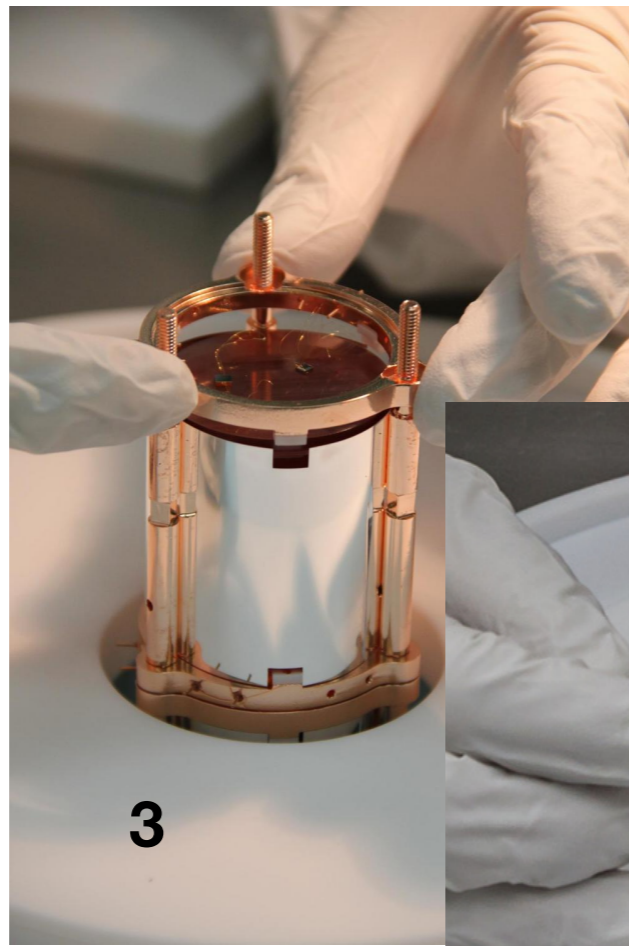
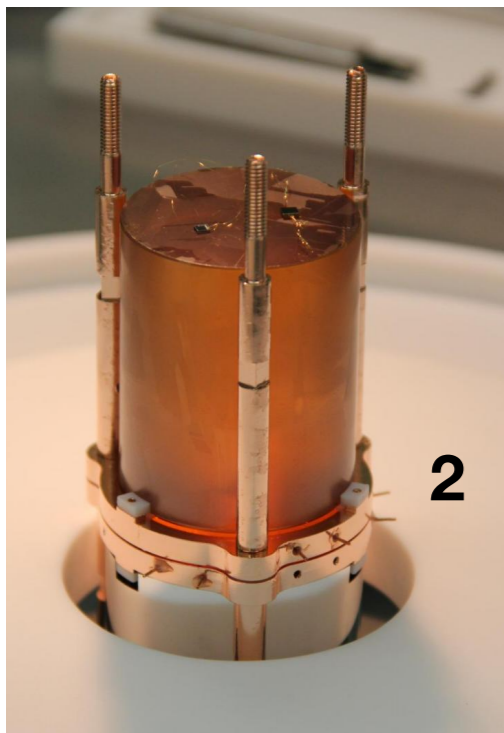
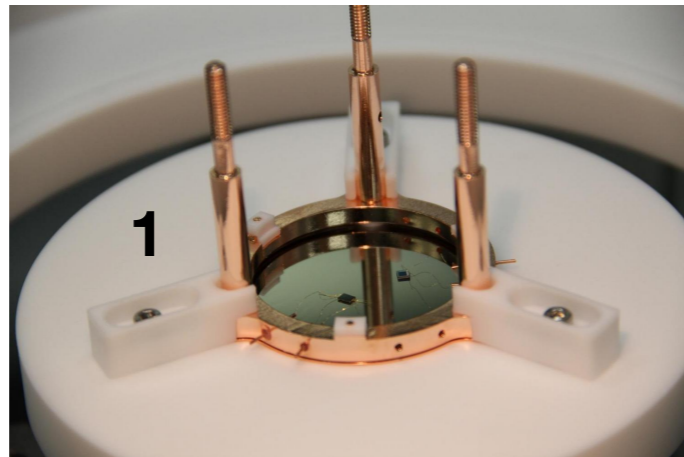
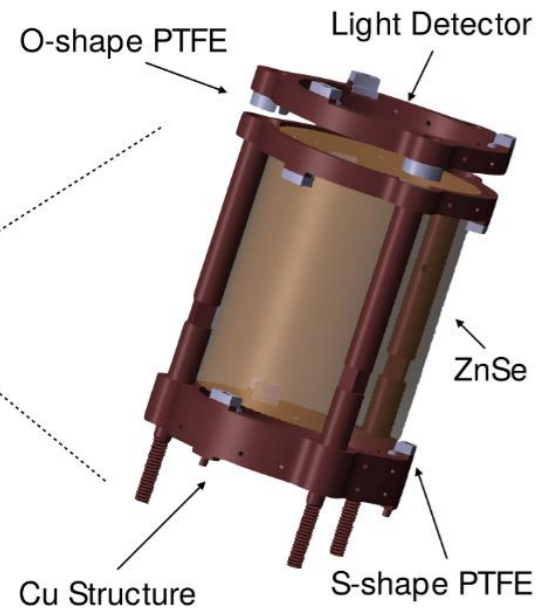


CUPID-0: the first demonstrator



- ^{82}Se $0\nu\beta\beta$ decay Q-Value: 2998 keV
- 26 ZnSe (24 95% enriched + 2 natural) \rightarrow 10.5 kg of ZnSe (3.8×10^{25} ^{82}Se nuclei)
- 31 Ge slabs (Light Detector)
- Arranged in 5 towers
- Assembled in an underground radon free clean-room @ LNGS
- Hosted in the same CUORE-0 dilution refrigerator (Hall A)
- BKG goal in the RoI $\sim 10^{-3}$ counts/(keV kg y)

CUPID-0: towers assembly



CUPID-0 time-line

First Result on the Neutrino-less Double Beta Decay of ^{82}Se with CUPID-0,
<https://doi.org/10.1103/PhysRevLett.120.232502>

Reached base temperature

physics (PRL 2018)
3.44 kg x y

physics
2.02 kg x y

phys.

2017

2018

Commissioning

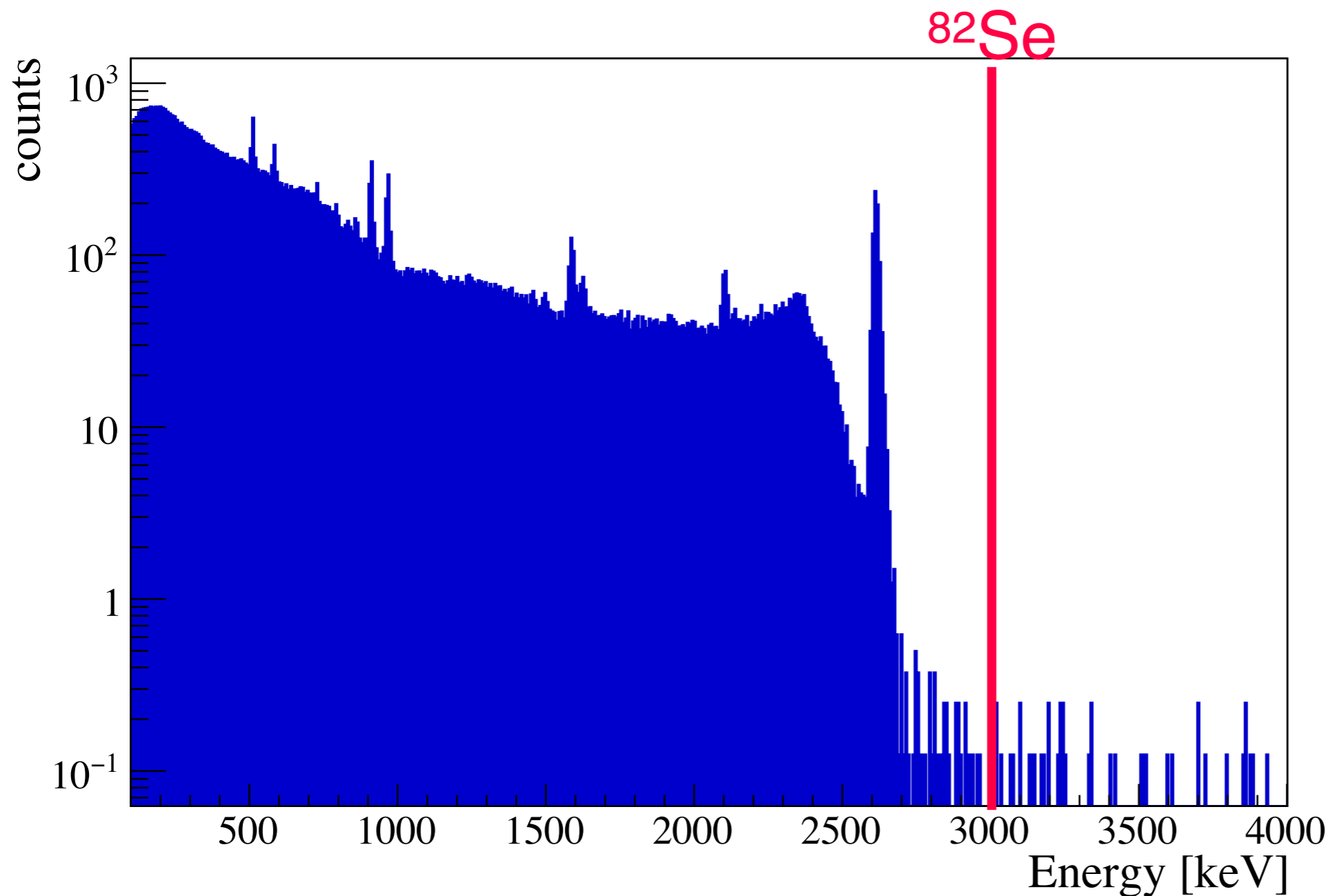
^{56}Co calibration

Start cool-down

This talk: full statistics acquired until the end of April: 5.46 kg x y
CUPID-0 continues data-taking.

Energy calibration to β/γ interactions

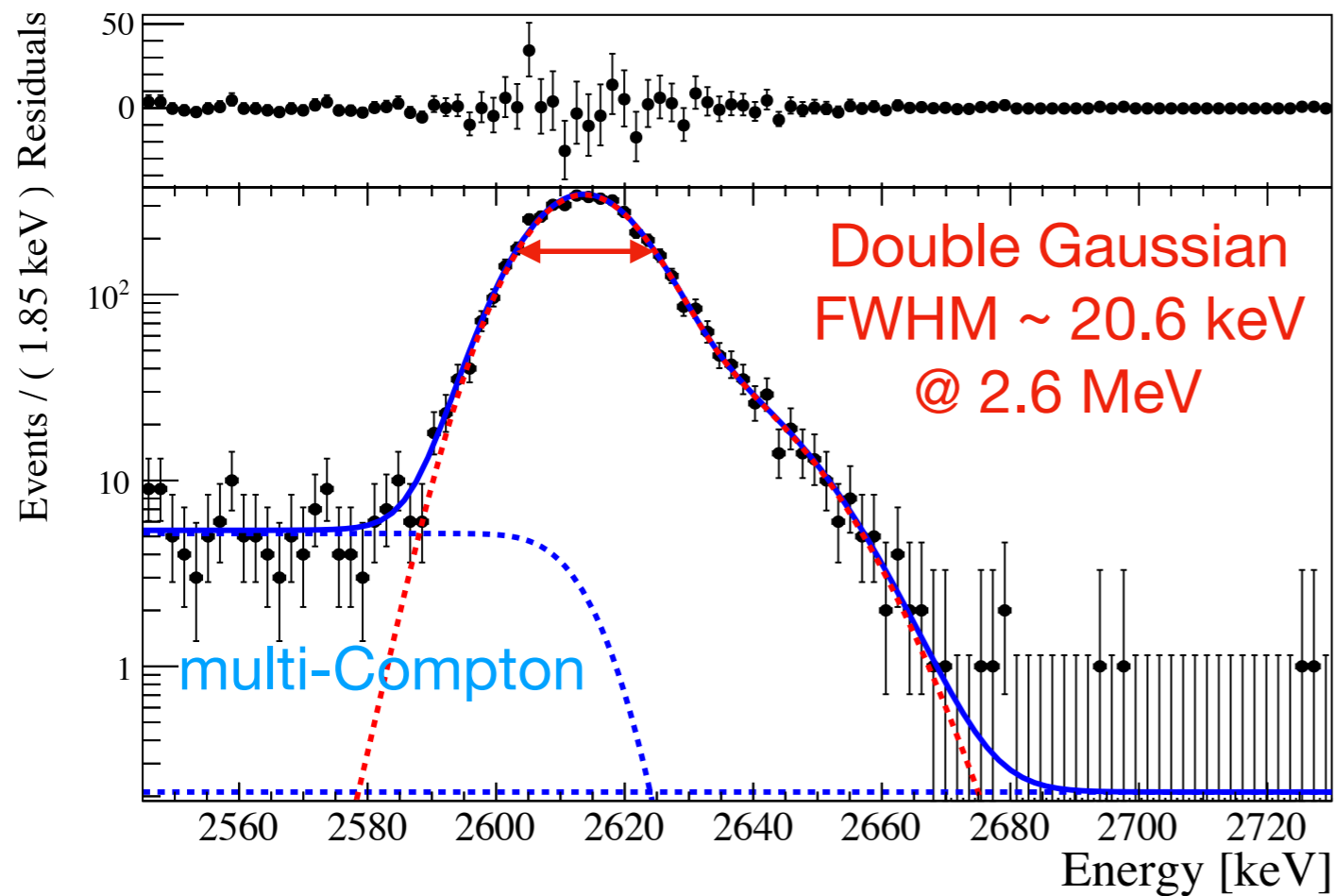
Example of energy spectrum in periodical calibration runs (all Channels)



γ lines from thoriated wires used for energy calibration

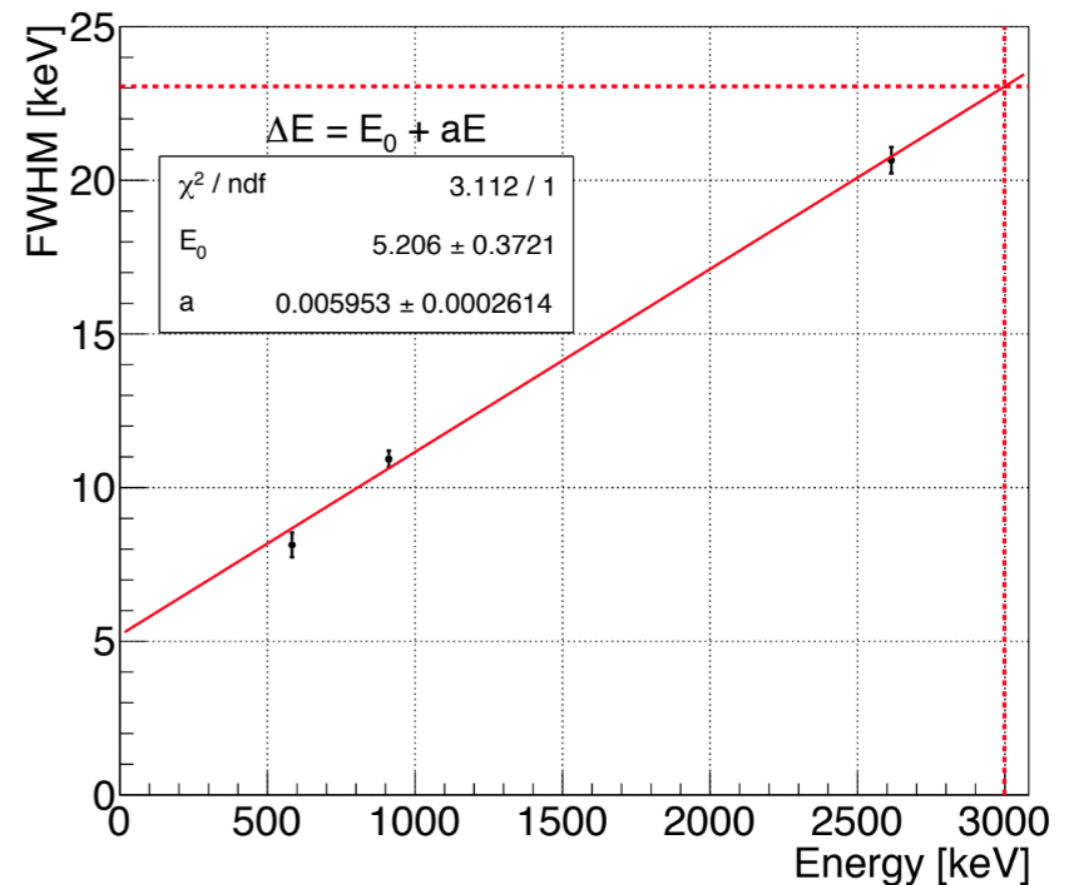
Detector response function

Response to monochromatic energy release (^{208}Tl γ line)



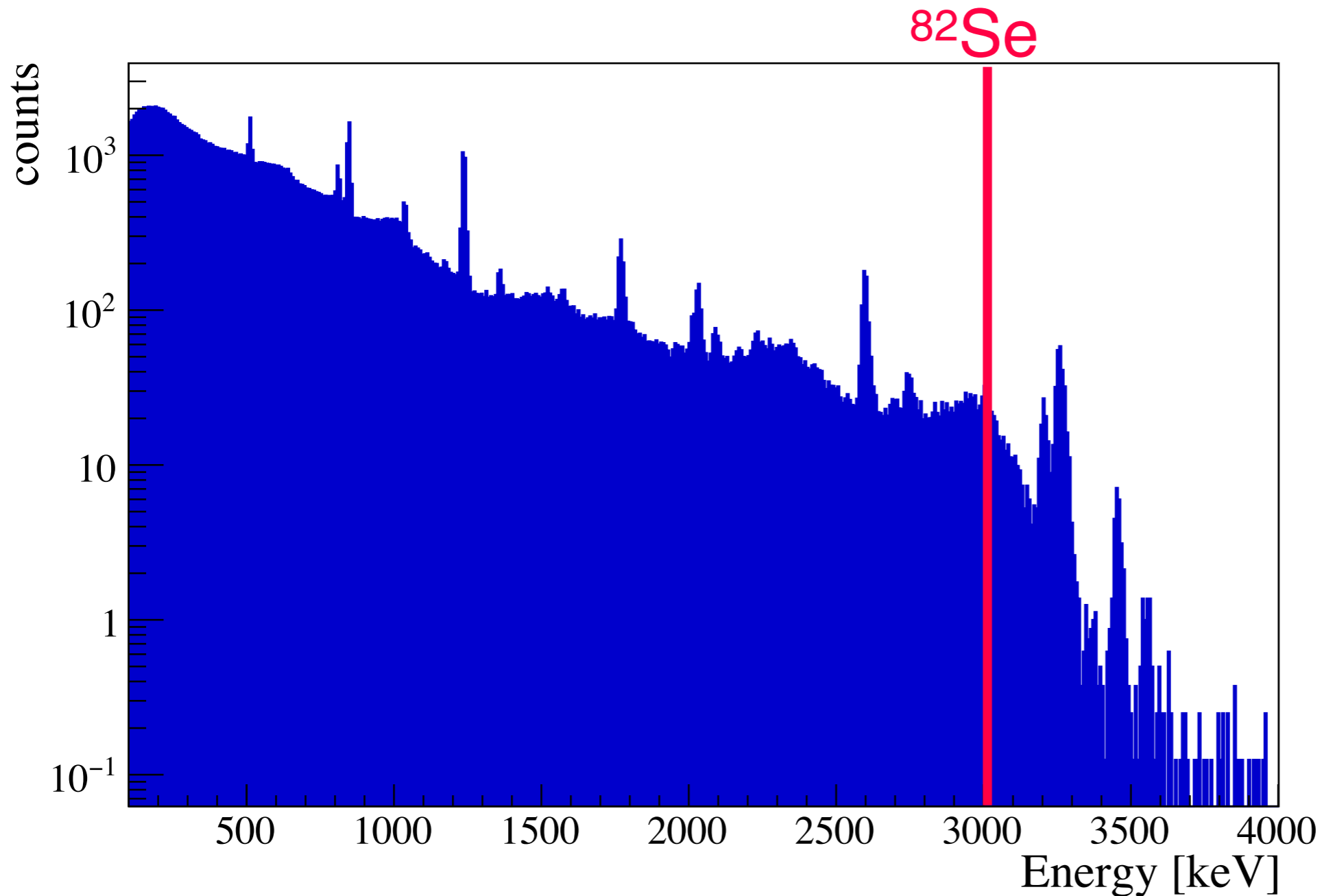
Deviation from single gaussian commonly measured on bolometric experiments

The exposure-weighted harmonic mean FWHM energy resolution at the Q-value is (23.0 ± 0.6) keV

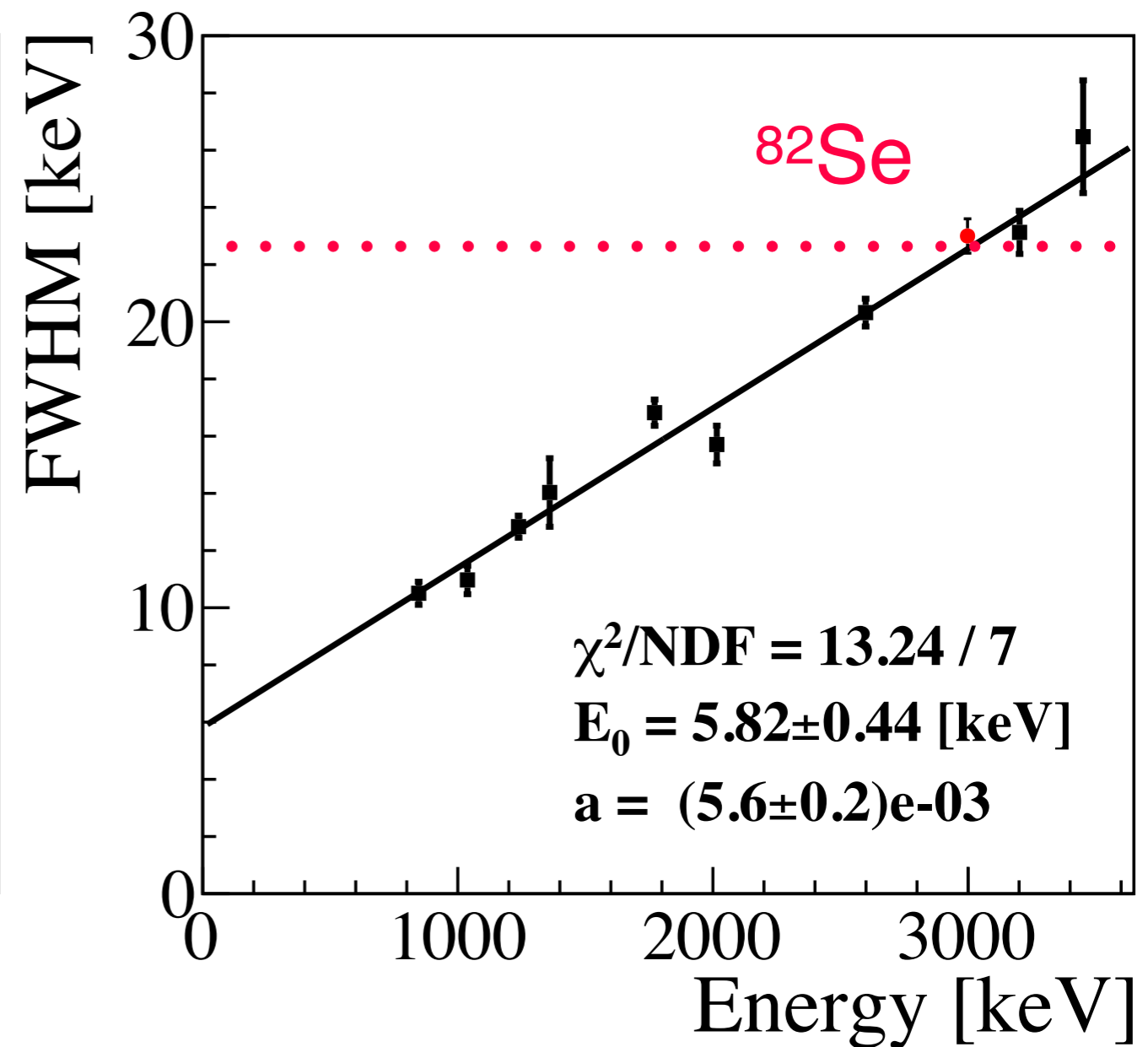
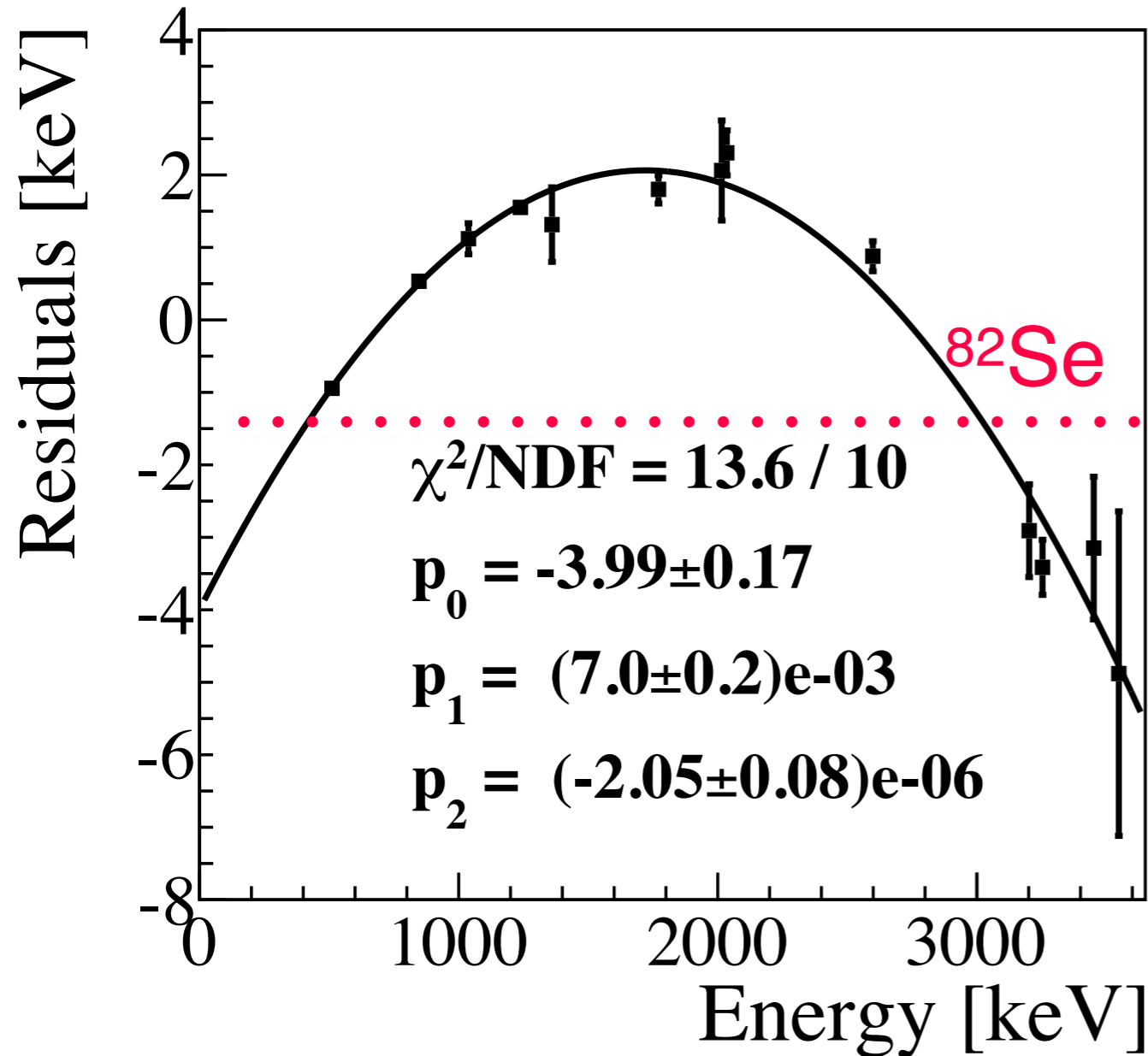


Energy calibration to β/γ interactions

Cross-check with ^{56}Co calibration (Q-value ~ 4.57 MeV, T1/2 ~ 77 days)



Cross-check result

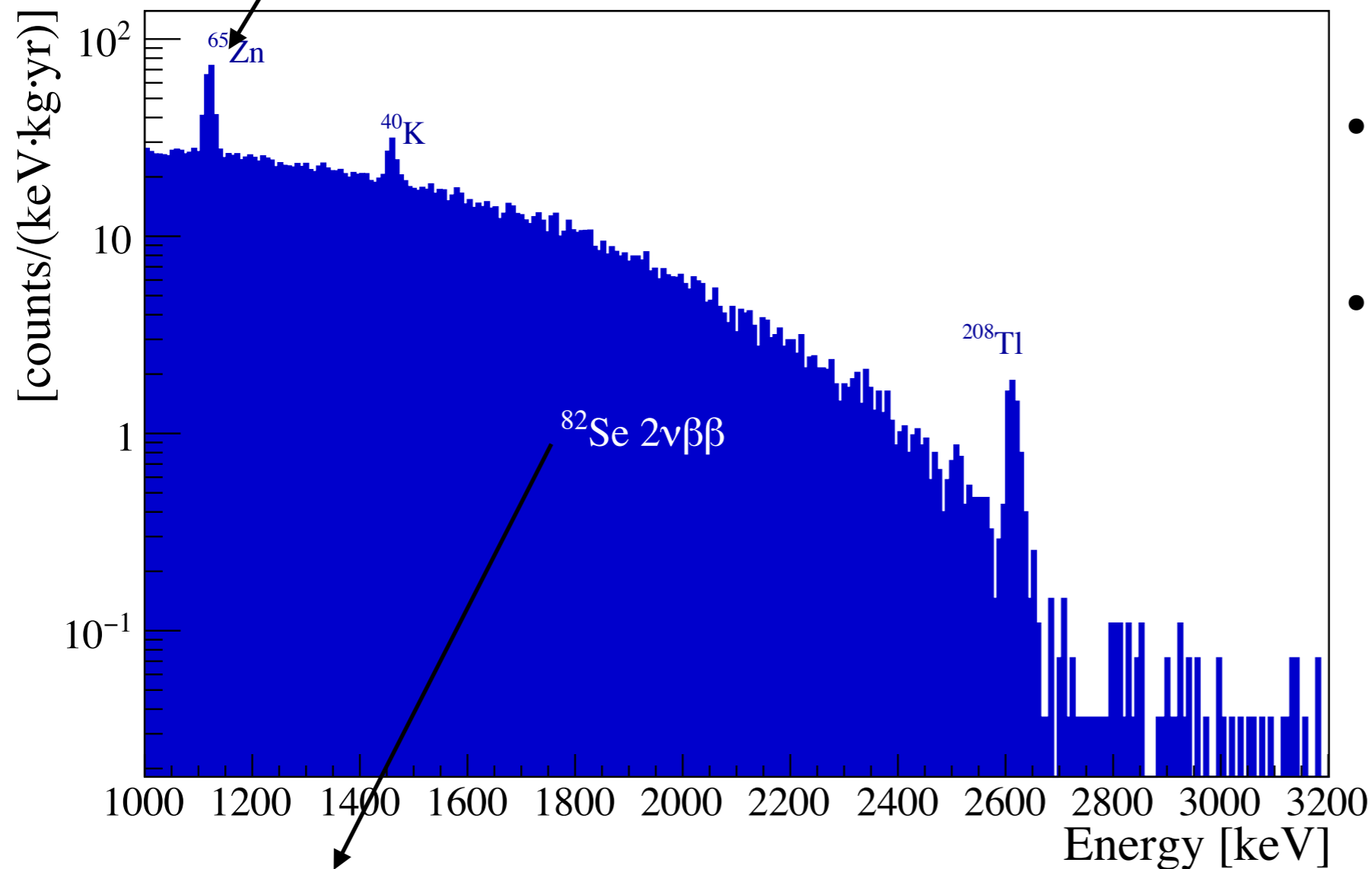


Energy resolution in ROI = (22.5 ± 1.2) keV FWHM

Consistent with (23.0 ± 0.6) keV extracted from ^{232}Th calibration, used for PRL analysis

Physics spectrum 5.46 kg·y ZnSe

Cosmogenic activation



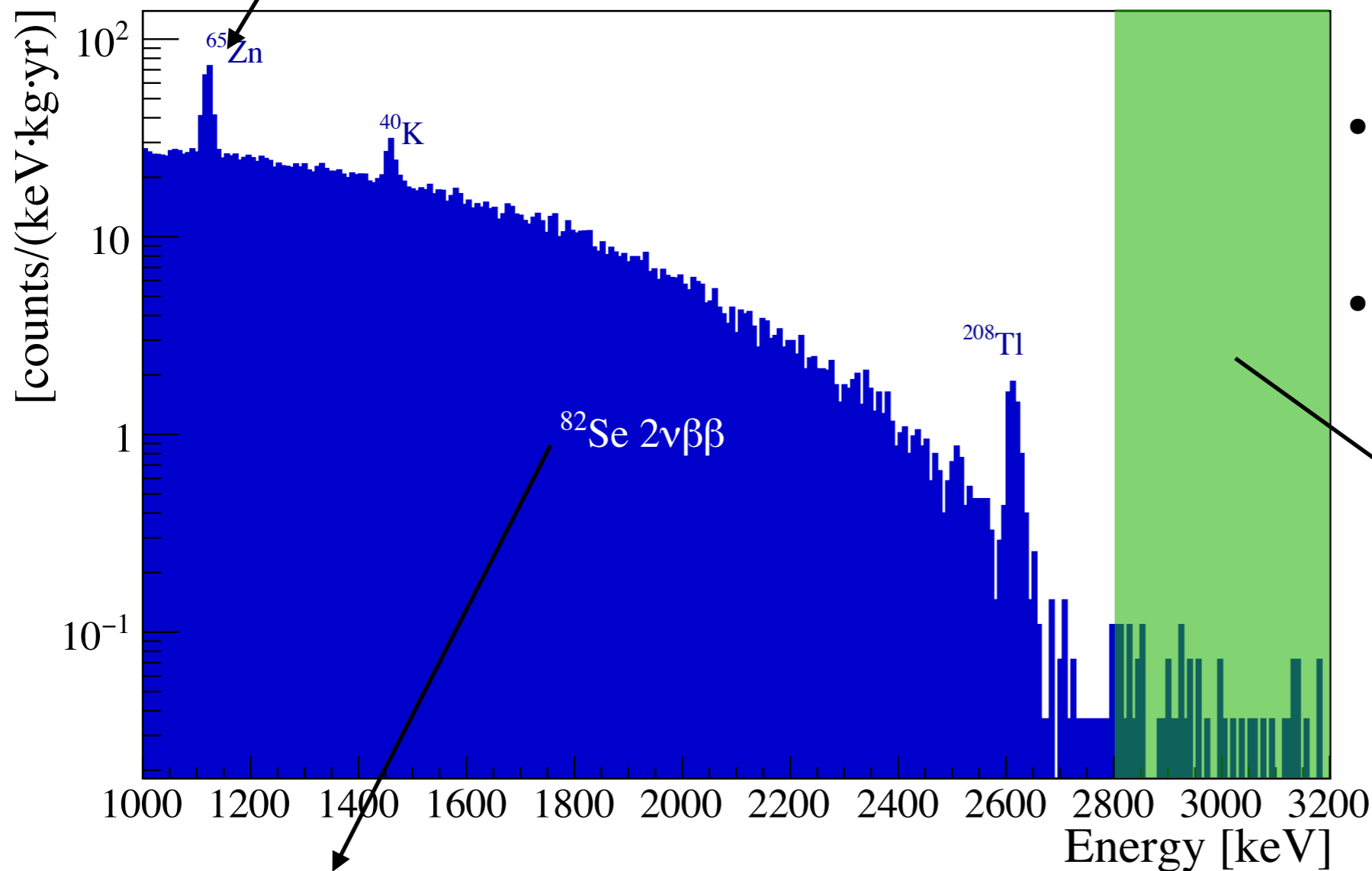
- Rejection of “non-particle-like” events through pulse shape on thermal pulses.
- Anti-coincidence between ZnSe crystals

$$T_{1/2} = (9.2 \pm 0.7) \cdot 10^{19} \text{ yr}$$

A. S. Barabash, <https://doi.org/10.1016/j.nuclphysa.2015.01.001>

Physics spectrum 5.46 kg×y ZnSe

Cosmogenic activation



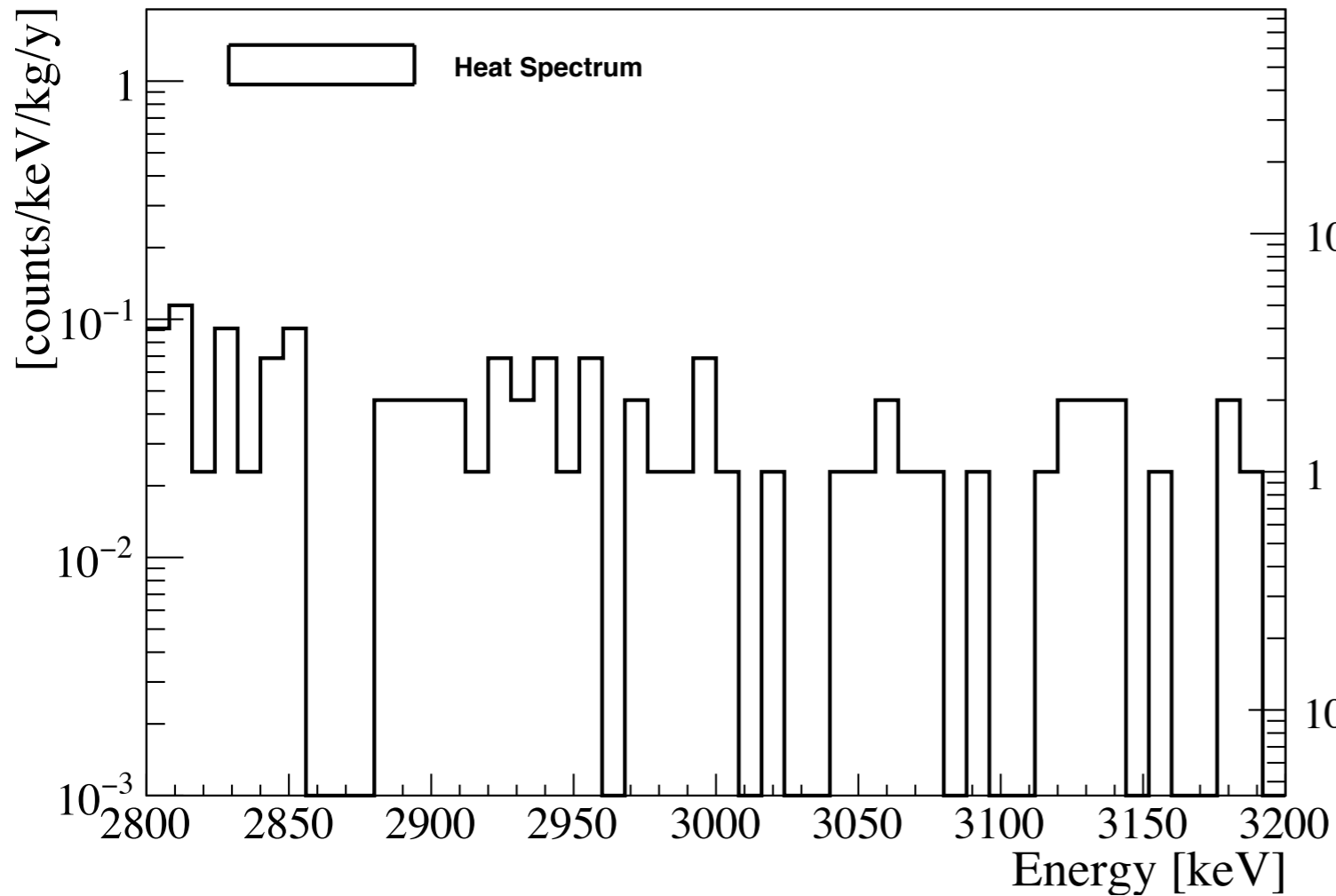
- Rejection of “non-particle-like” events through pulse shape on thermal pulses.
- Anti-coincidence between ZnSe crystals

approximately symmetric around $Q_{\beta\beta}$ (2800-3200 keV)

$T_{1/2} = (9.2 \pm 0.7) \cdot 10^{19} \text{ yr}$

A. S. Barabash, <https://doi.org/10.1016/j.nuclphysa.2015.01.001>

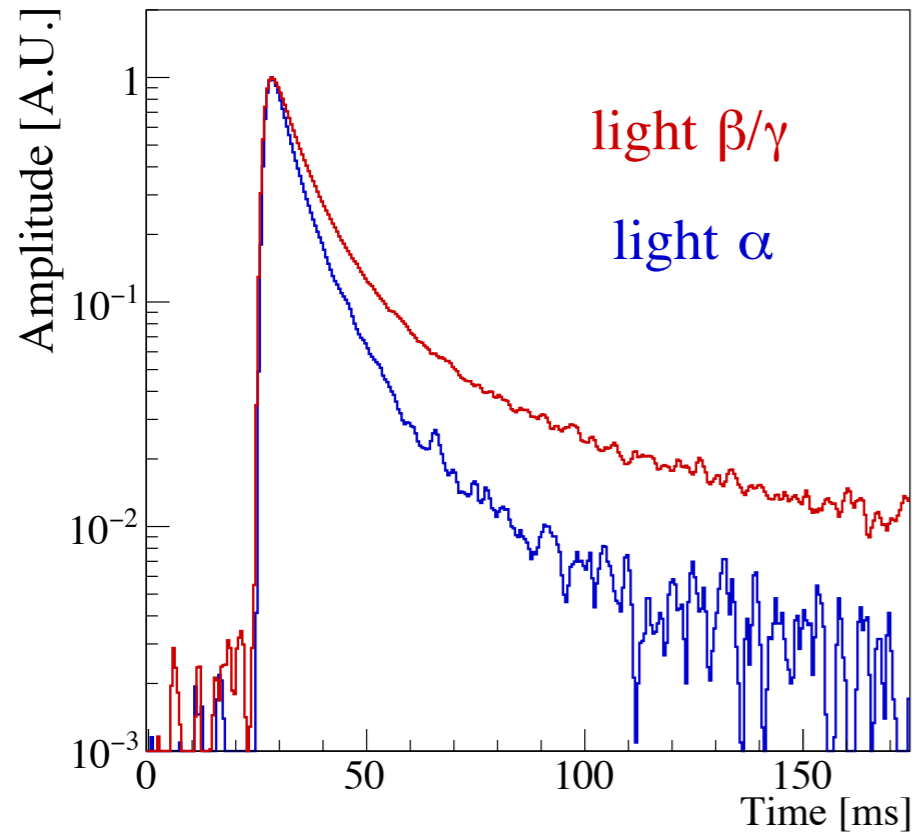
Rol energy spectrum



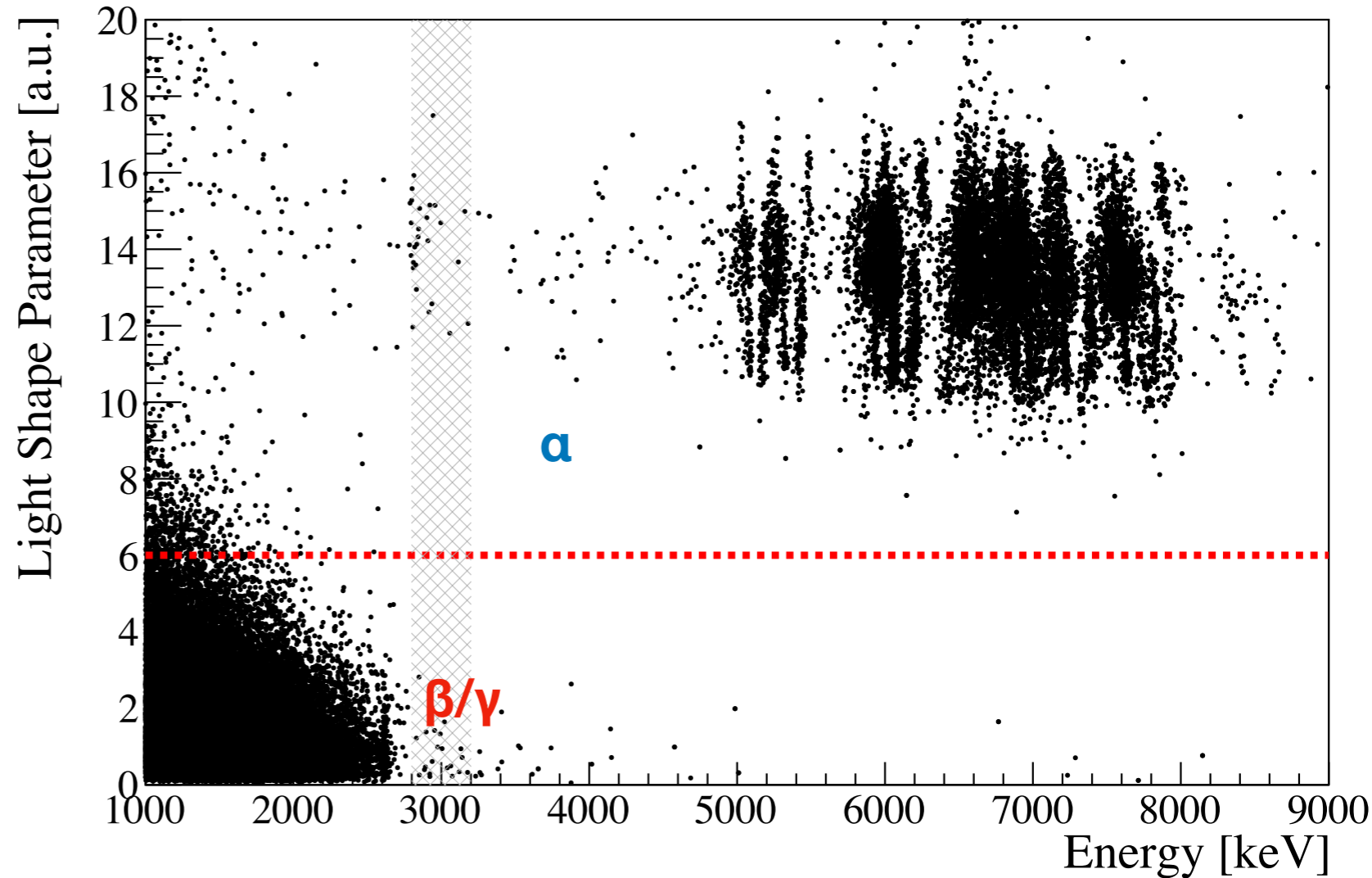
- Rejection of “non-particle-like” events through pulse shape on thermal pulses.
- Anti-coincidence between ZnSe crystals

$$\text{BKG} = (3.2 \pm 0.4) \times 10^{-2} \text{ counts}/(\text{keV kg yr})$$

α rejection with light shape

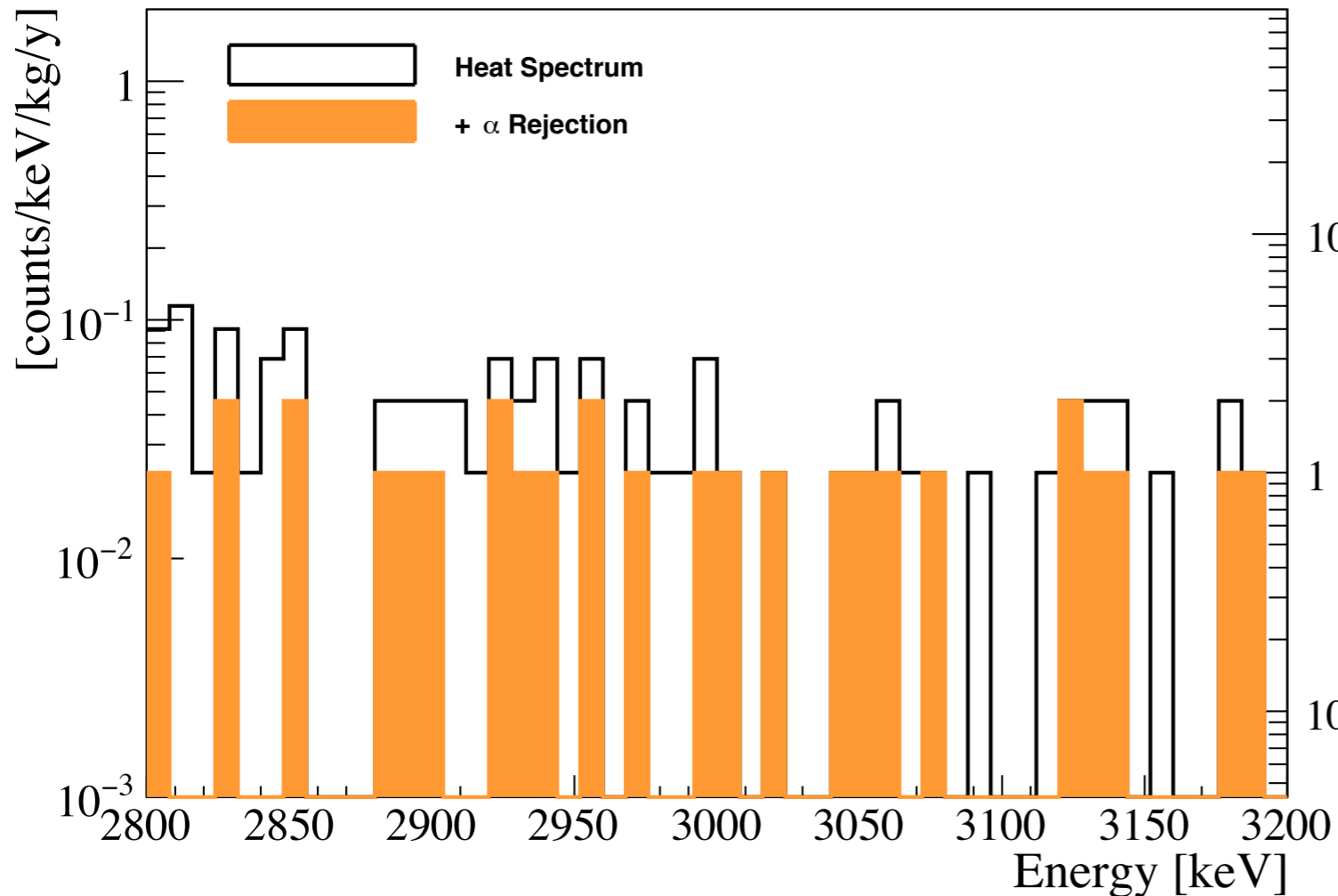


The light signal shape depends on particle type



Cut optimized in the RoI with a pure β/γ sample \rightarrow conservative at high energy

Rol energy spectrum + α rejection

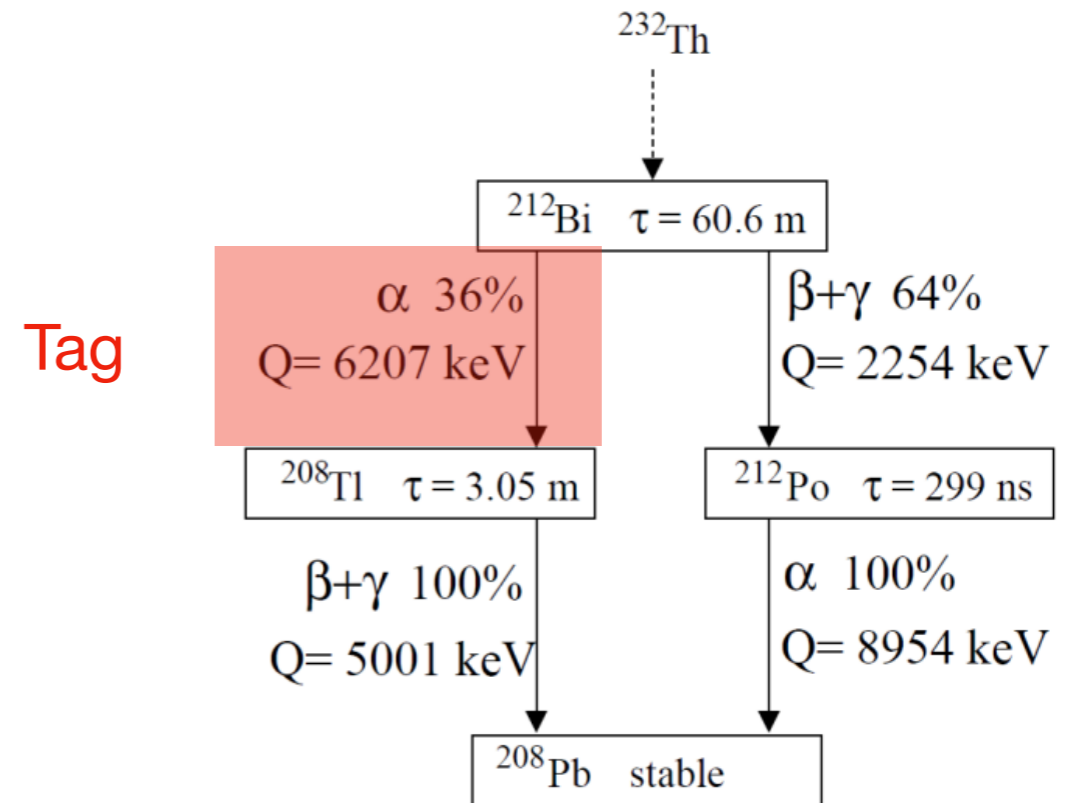
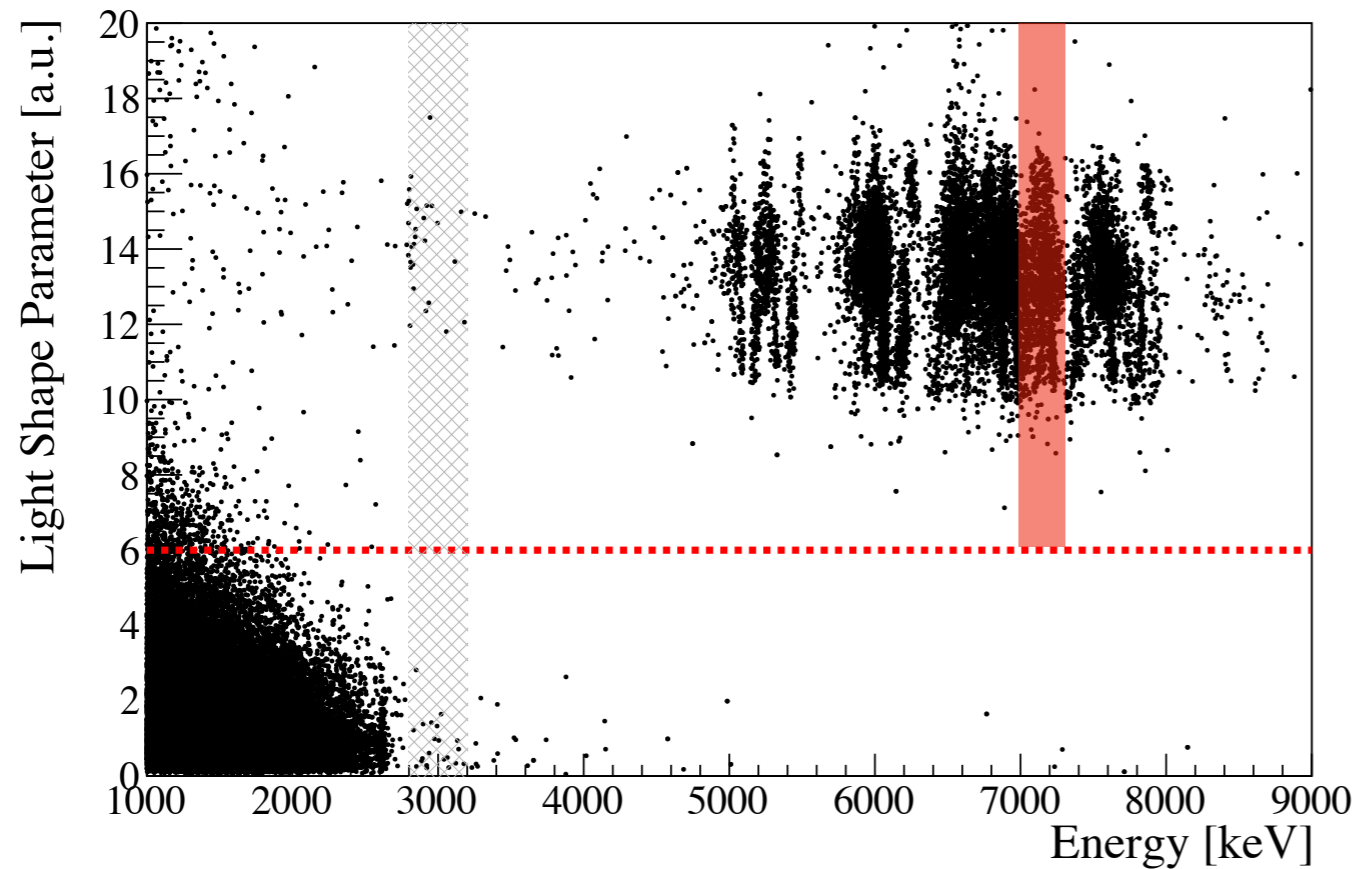


- Rejection of “non-particle-like” events through pulse shape on thermal pulses.
 - Anti-coincidence between ZnSe crystals
- +
- α particles rejection

BKG = $(3.2 \pm 0.4) \times 10^{-2}$ counts/(keV kg yr)

BKG = $(1.3 \pm 0.2) \times 10^{-2}$ counts/(keV kg yr)

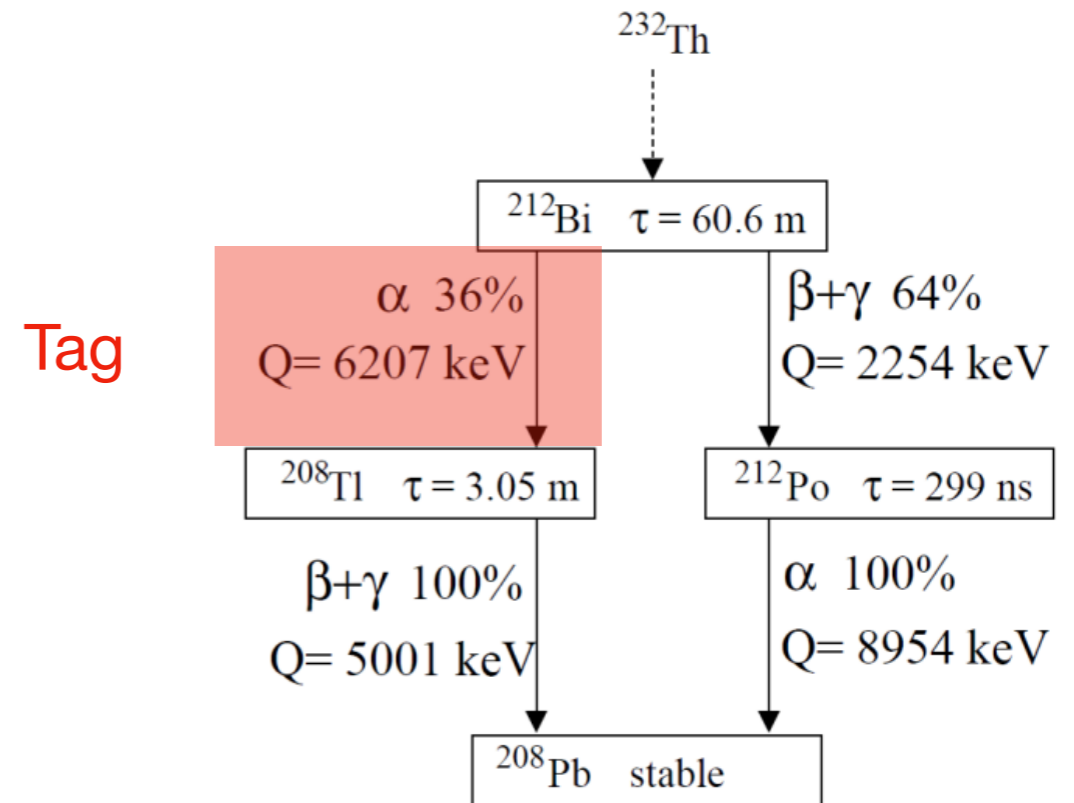
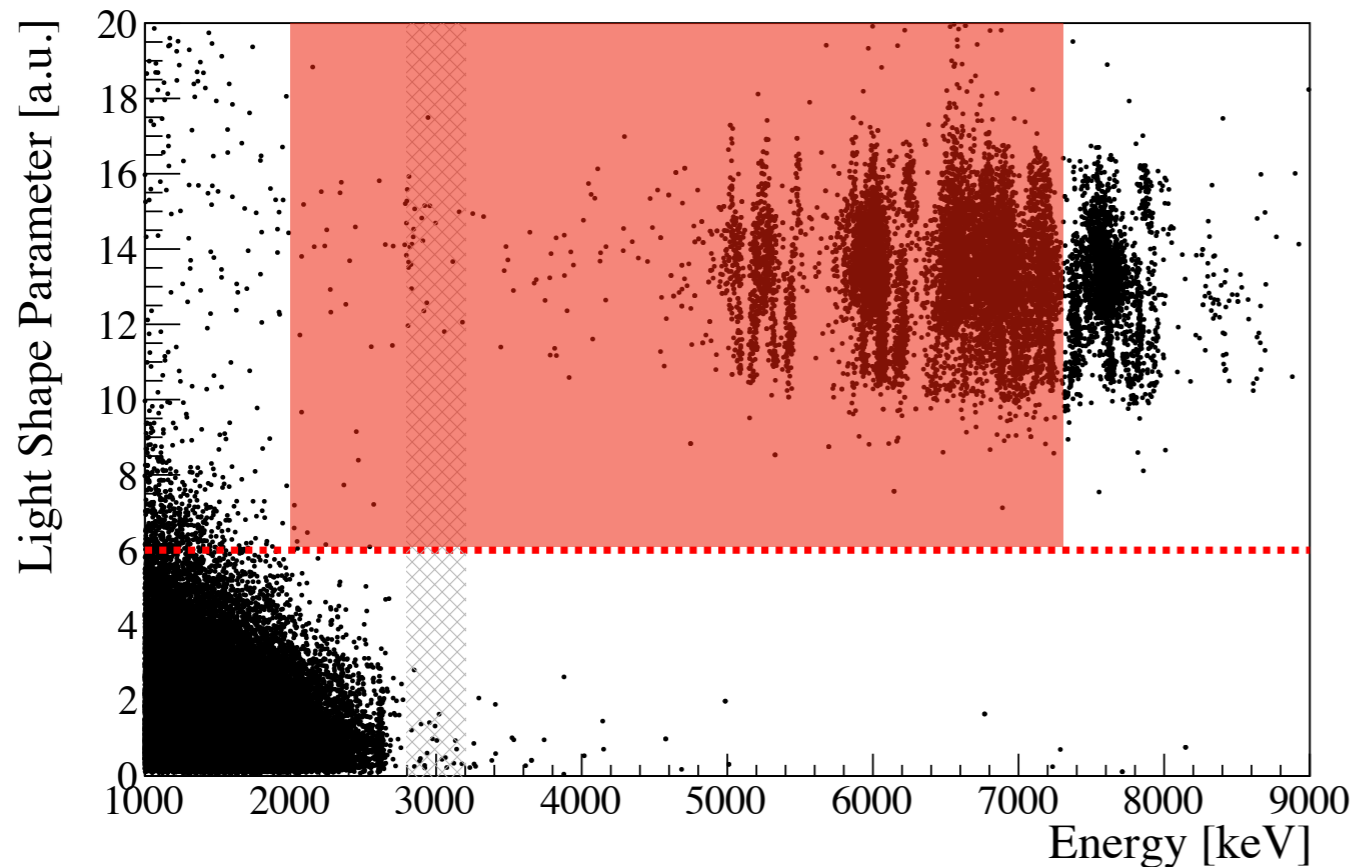
β/γ background from internal contaminations



We apply a 3 half-life time veto after all ^{212}Bi α events

Rejection of the ^{208}Tl induced background (internal crystal contamination)

β/γ background from internal&surface contaminations

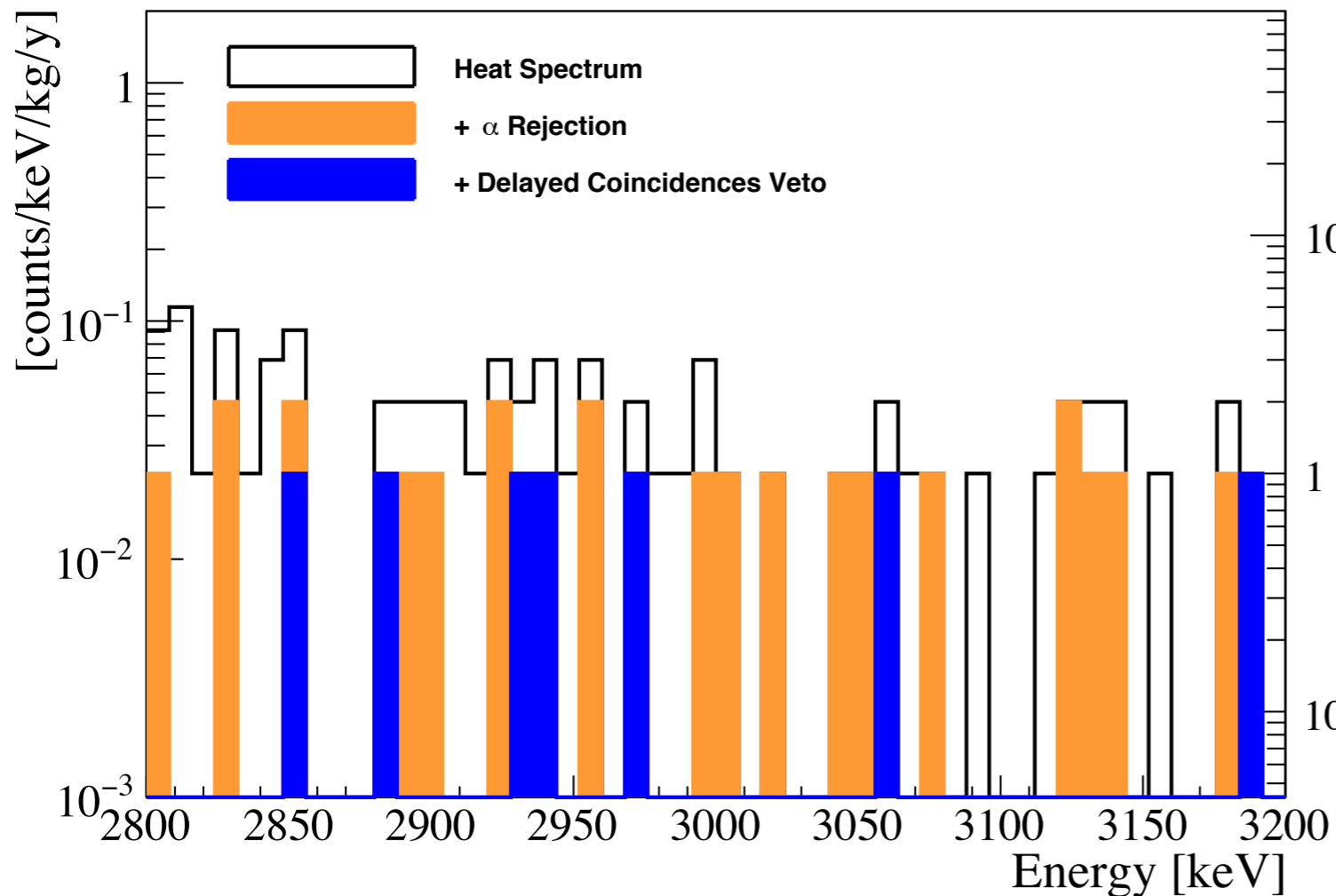


We apply a 3 half-life time veto after all ^{212}Bi α events

Rejection of the ^{208}Tl induced background (internal crystal contamination)

Surface crystal contamination -> we veto after all α interactions with energy between 2 and 6.5 MeV

RoI energy spectrum + α rejection + Delayed coincidences veto

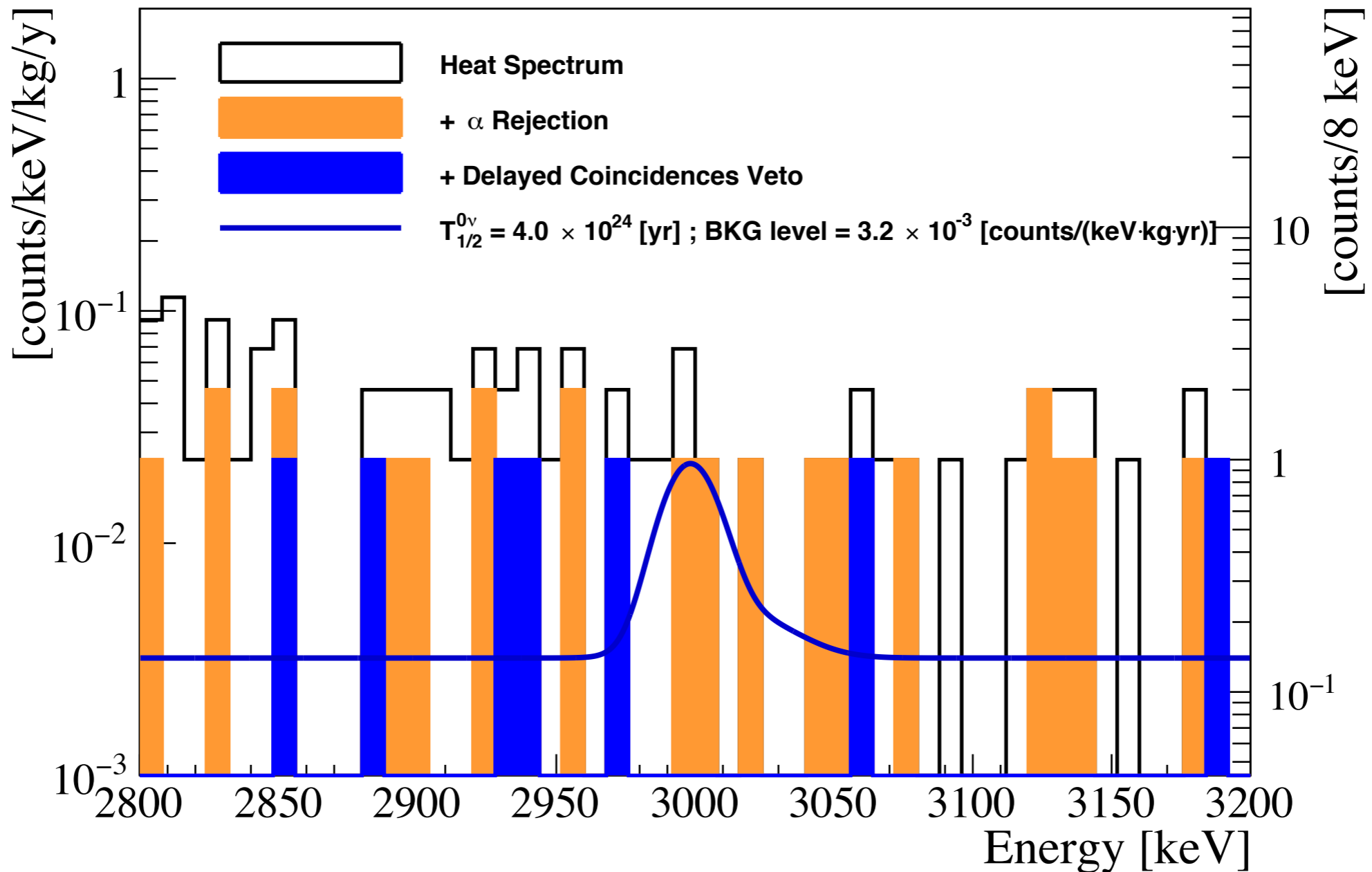


- Rejection of “non-particle-like” events through pulse shape on thermal pulses.
 - Anti-coincidence between ZnSe crystals
- +
- α particles rejection
 - Delayed coincidence veto
- All cuts efficiency $93 \pm 2\%$**
- 7 events survive all cuts**

UEML SIMULTANEOUS FIT OVER THE DATASETS

$$BKG = 3.2_{-1.1}^{+1.3} \times 10^{-3} \text{ counts}/(\text{keV} \cdot \text{kg} \cdot \text{y})$$

Results

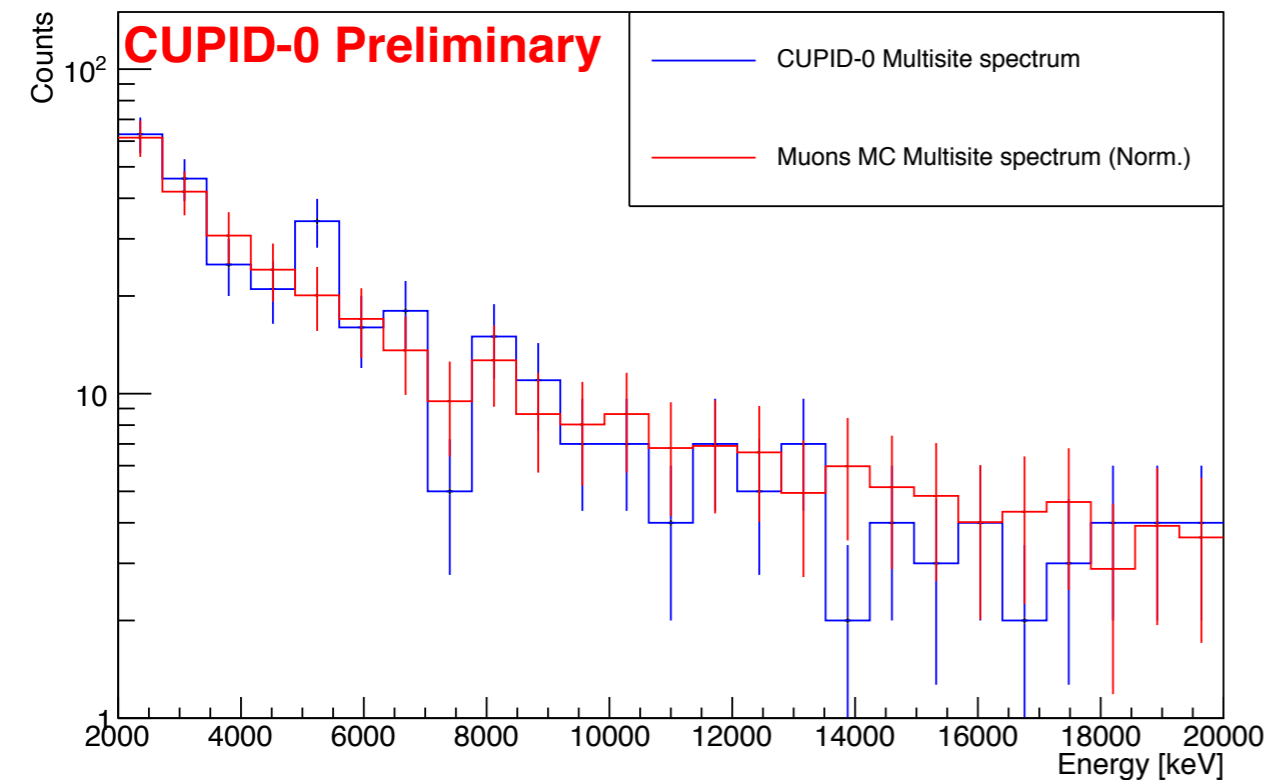


No evidence of $0\nu\beta\beta$ signal -> Bayesian Lower Limit $T_{1/2}^{0\nu} = 4.0 \times 10^{24}$ yr @ 90% C.I

Previous value from Nemo 3.6×10^{23} yr

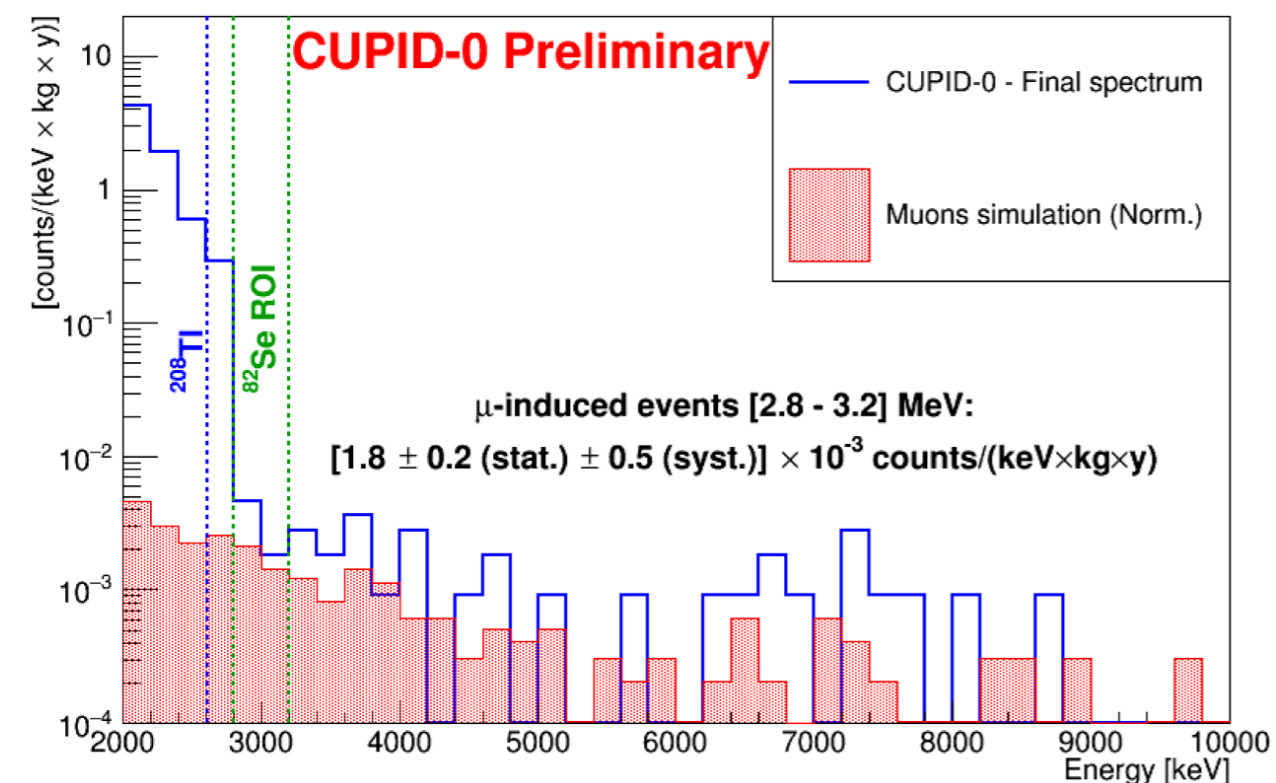
A. S. Barabash and V. B. Brudanin (NEMO), Phys. Atom. Nucl. 74, 312 (2011), arXiv:1002.2862.

Background budget



- Events triggered by many ZnSe to derive normalization for μ interactions
- Comparison simulation/data in ROI
- Muon's interactions give important contribution to the ROI

$$[1.8 \pm 0.2 \pm 0.5] \times 10^{-3} \text{ counts}/(\text{keV} \cdot \text{kg} \cdot \text{y})$$



- Easily suppressed: more packed (CUORE-like) array or muon-veto
- Now increase statistics to investigate other background contributions

Conclusions

- The first next generation $0\nu\beta\beta$ demonstrator is smoothly in data taking from June 2017
- The complete α background rejection was demonstrated and allows to reach an unprecedented BKG level for a bolometric experiment

$$BKG = 3.2_{-1.1}^{+1.3} \times 10^{-3} \text{ counts}/(\text{keV} \cdot \text{kg} \cdot \text{y})$$

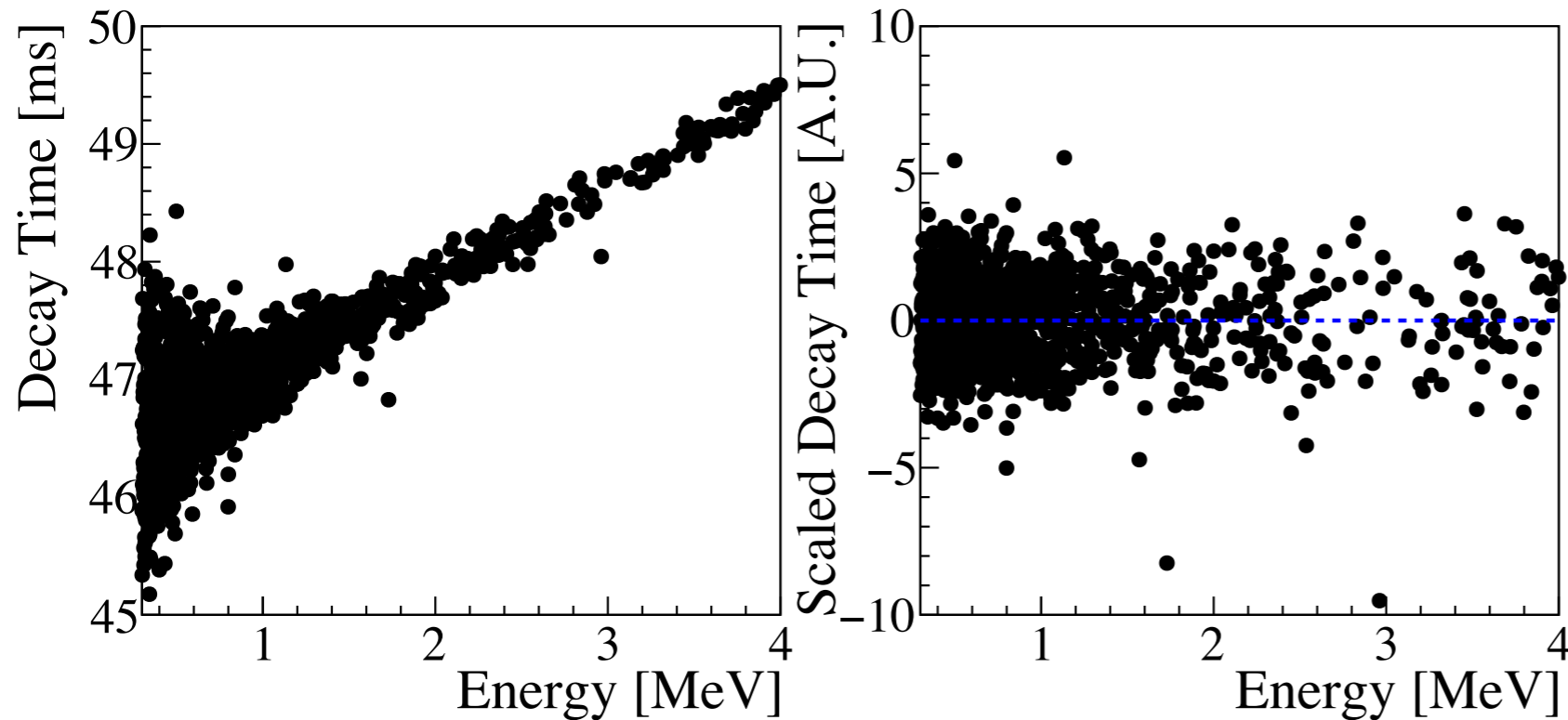
- The analysis of the first data (5.46 kg y of ZnSe) allows to put the best limits on ^{82}Se $0\nu\beta\beta$ half-life

$$T_{1/2}^{0\nu} = 4.0 \times 10^{24} \text{ yr @ 90\% C.I}$$

- We plan to reach an exposure of 10 kg y of ZnSe in order to obtain a reliable background model

Backup

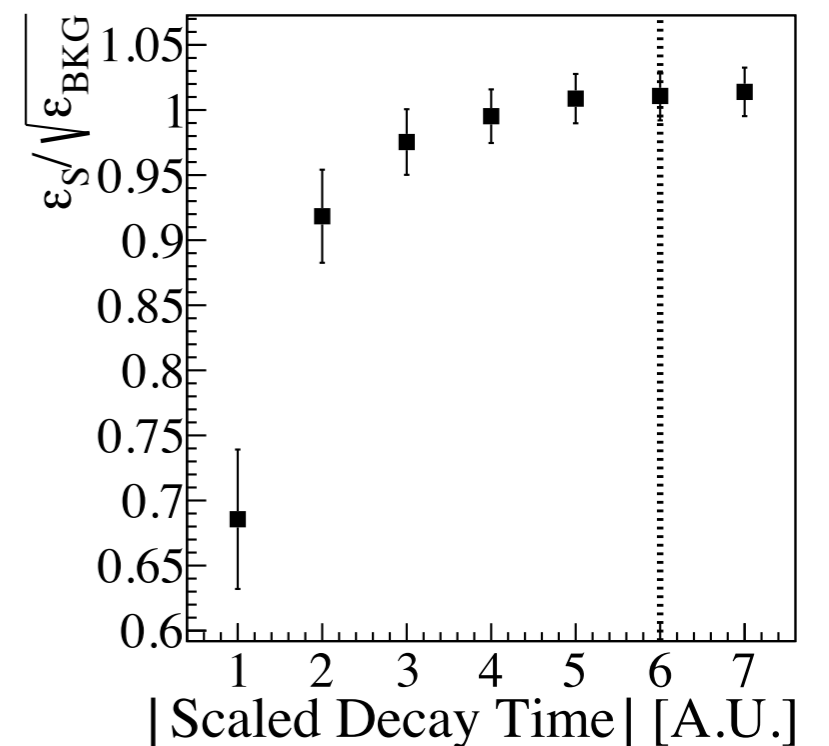
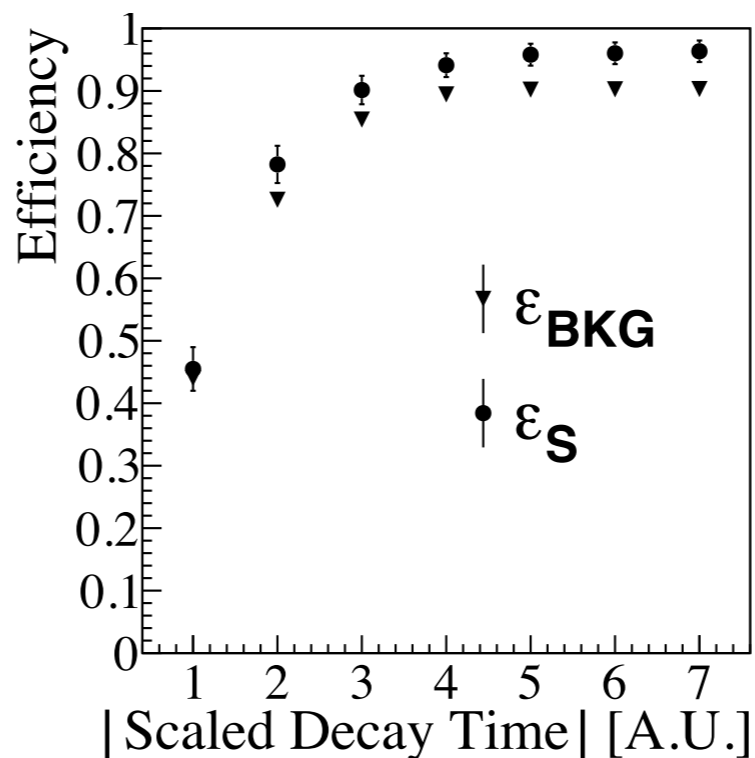
Cut optimization



Remove energy-dependency of the shape parameters for energy-independent cuts

Study the efficiency of signal and background as a function of the cut

Chose the cut value that optimizes the signal-to-background ratio



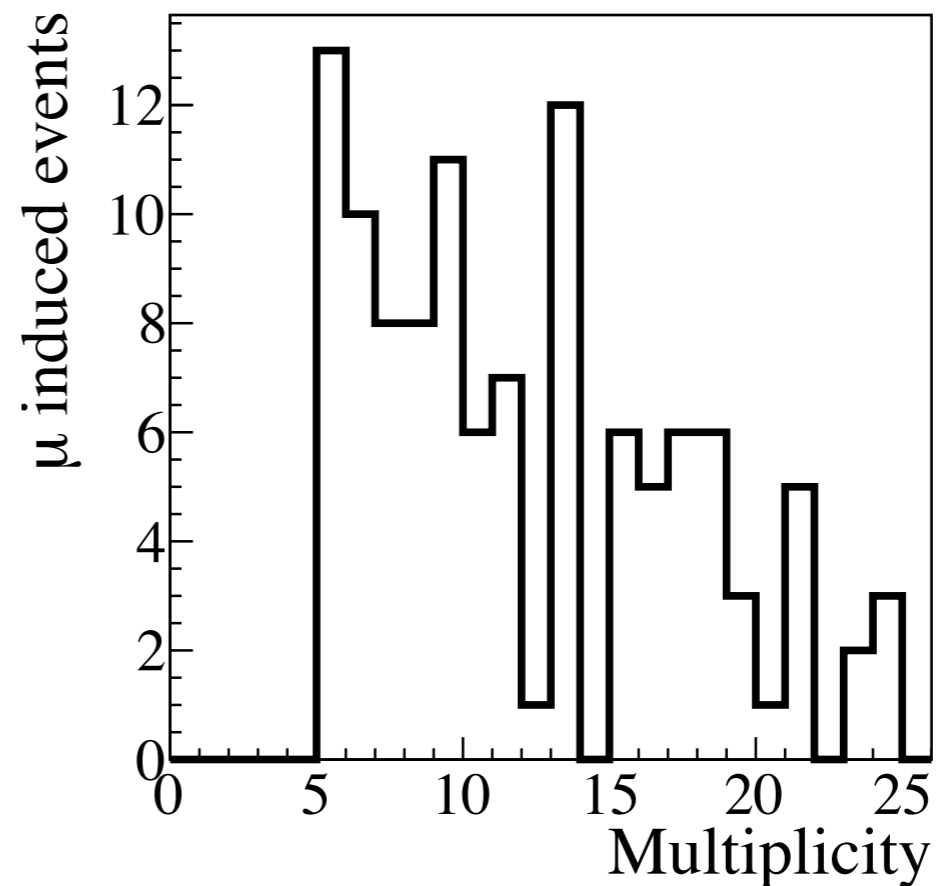
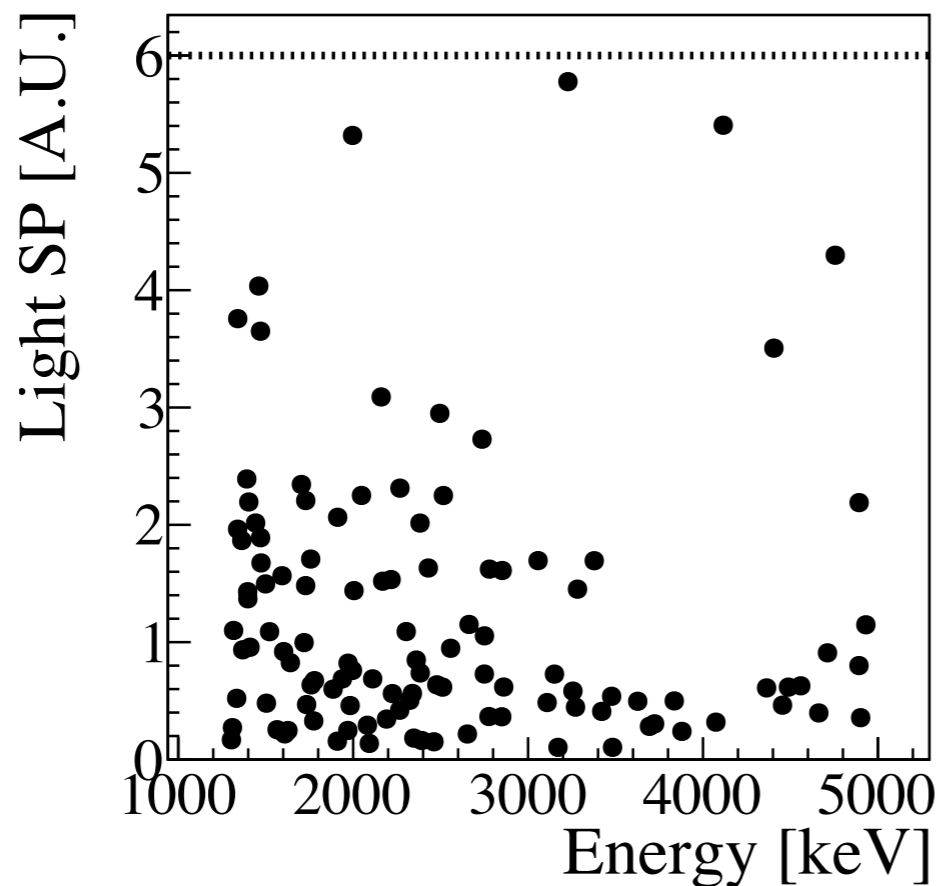
Light detector efficiency

Choose events with $M > 5$ (electromagnetic showers induced by muons interactions)

almost pure β/γ sample

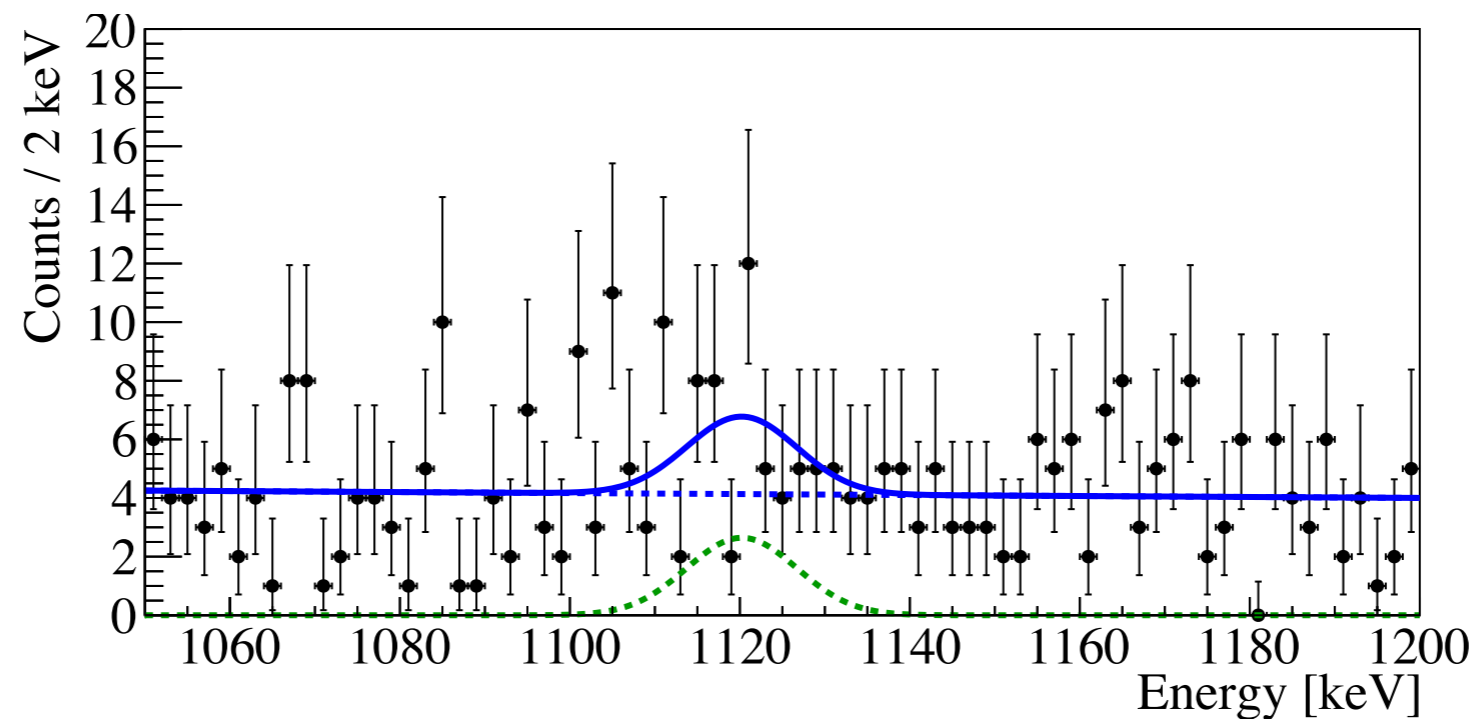
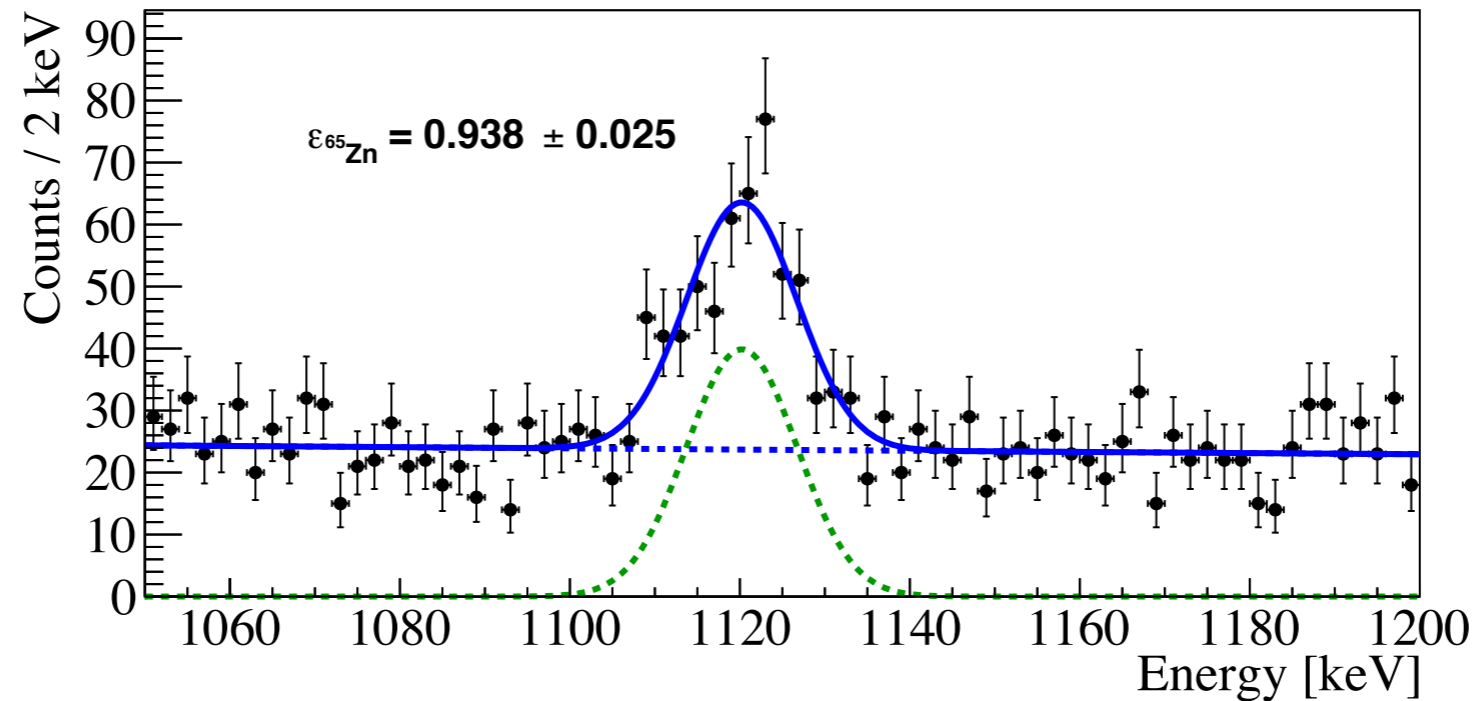
Study the distribution of the light shape parameter

Set the cut to have 100% efficiency on these events



Heat detector efficiency

Fit of the most prominent peak (^{65}Zn) validated on ^{40}K peak and M2 events



$2\nu\beta\beta$

- 2×10^5 events of $2\nu\beta\beta$ collected
- Now analysis of half-life

