New 0νββ results from CUPID-0

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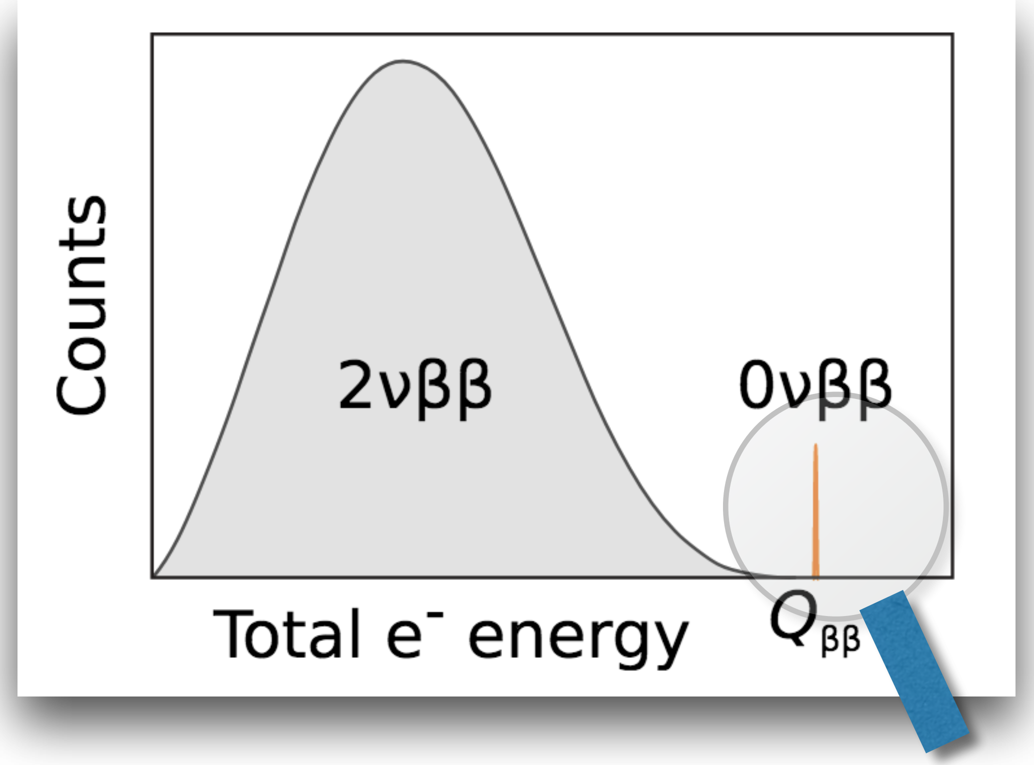
Outline

- $0\nu\beta\beta$ physics
- The cryogenic calorimetric technique
- CUPID-0
  - Detector design and construction
  - Detector performance
- Results

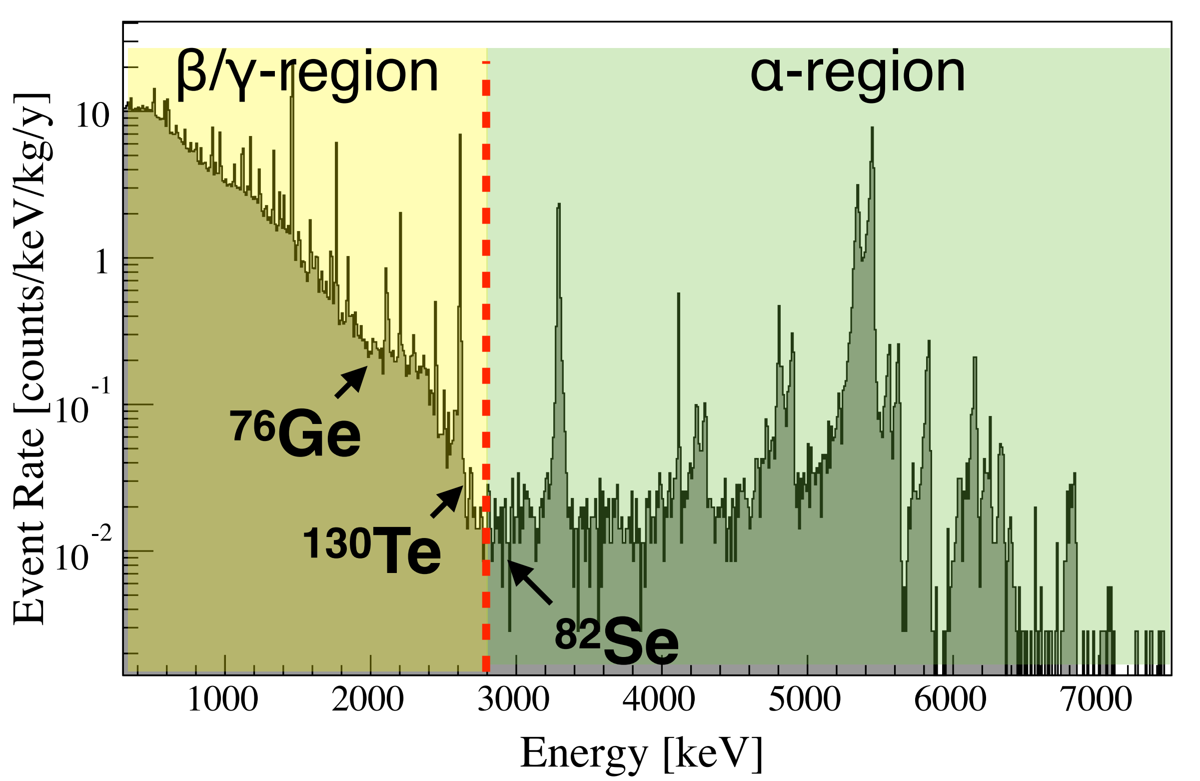
Expected signal & bkg

Signature: peak at the sum-energy (Q) of the two electrons (2-3 MeV).

Computed energy spectrum



Energy spectrum from natural radioactivity



High **0νββ** Q-value ➔ **low** β/γ **background**

+

α bkg **suppression ➔ close to zero-bkg**

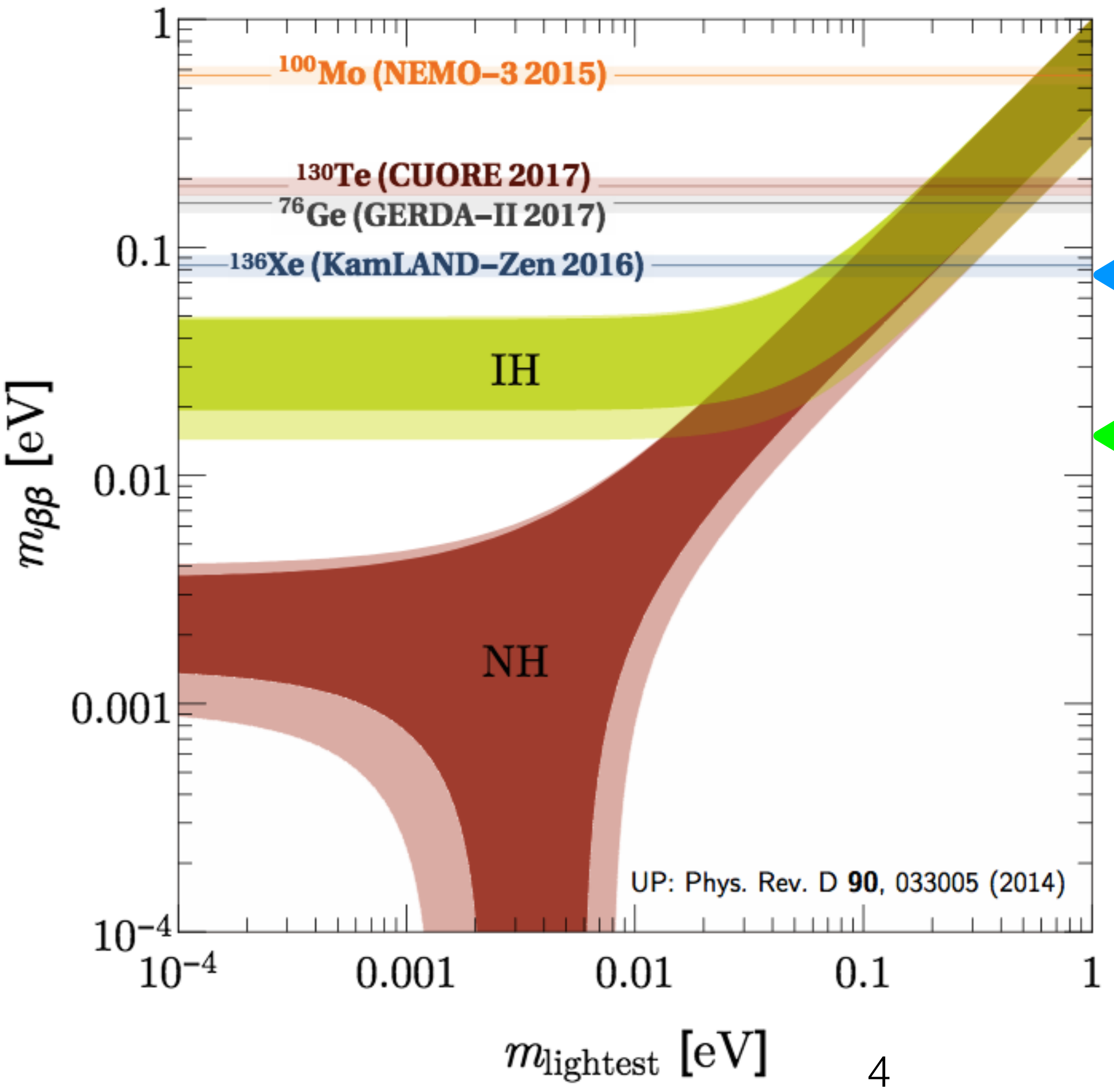
Neutrino mass sensitivity

Current limit on neutrino mass are set at the level of ~100 meV

To probe lower mass region higher sensitivity is needed: ↑ mass and ↓ background

$$(t^{0\nu}_{1/2})^{-1} = |\mathcal{M}^2_{0\nu}| \cdot G_{0\nu} \cdot m^2_{\beta\beta}$$

The main goal of next-generation experiment is to span the entire IH region of neutrino mass.



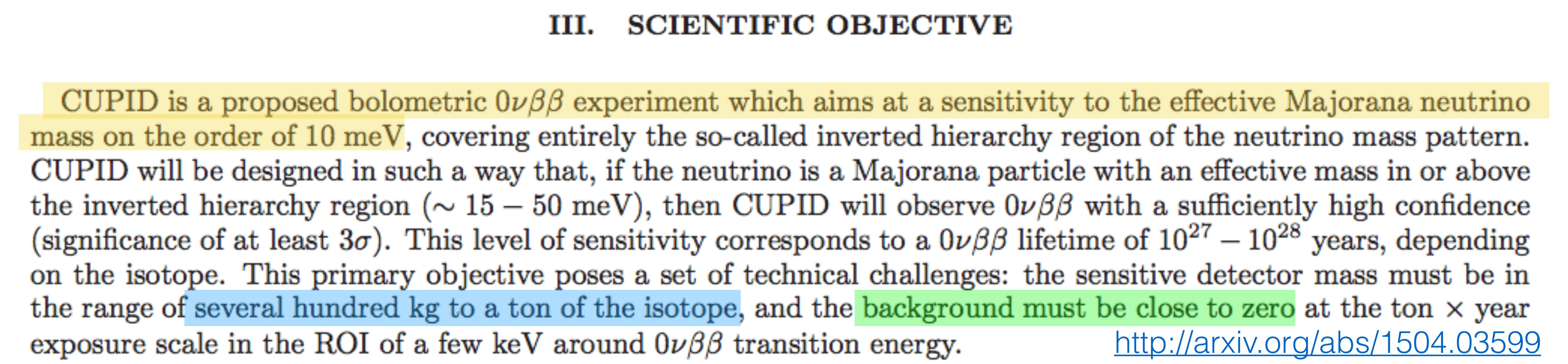
UP: Phys. Rev. D **90**, 033005 (2014)

Today
M~10-100 kg isotope
B~10^{-2} c/keV/kg/y

Tomorrow
M~100-1000 kg isotope
B~10^{-4} c/keV/kg/y

CUPID

Cuore Upgrade with Particle ID



III. SCIENTIFIC OBJECTIVE

CUPID is a proposed bolometric $0\nu\beta\beta$ experiment which aims at a sensitivity to the effective Majorana neutrino mass on the order of 10 meV, covering entirely the so-called inverted hierarchy region of the neutrino mass pattern. CUPID will be designed in such a way that, if the neutrino is a Majorana particle with an effective mass in or above the inverted hierarchy region ($\sim 15-50$ meV), then CUPID will observe $0\nu\beta\beta$ with a sufficiently high confidence (significance of at least 3σ). This level of sensitivity corresponds to a $0\nu\beta\beta$ lifetime of $10^{27}-10^{28}$ years, depending on the isotope. This primary objective poses a set of technical challenges: the sensitive detector mass must be in the range of several hundred kg to a ton of the isotope, and the background must be close to zero at the ton × year exposure scale in the ROI of a few keV around $0\nu\beta\beta$ transition energy.

http://arxiv.org/abs/1504.03599

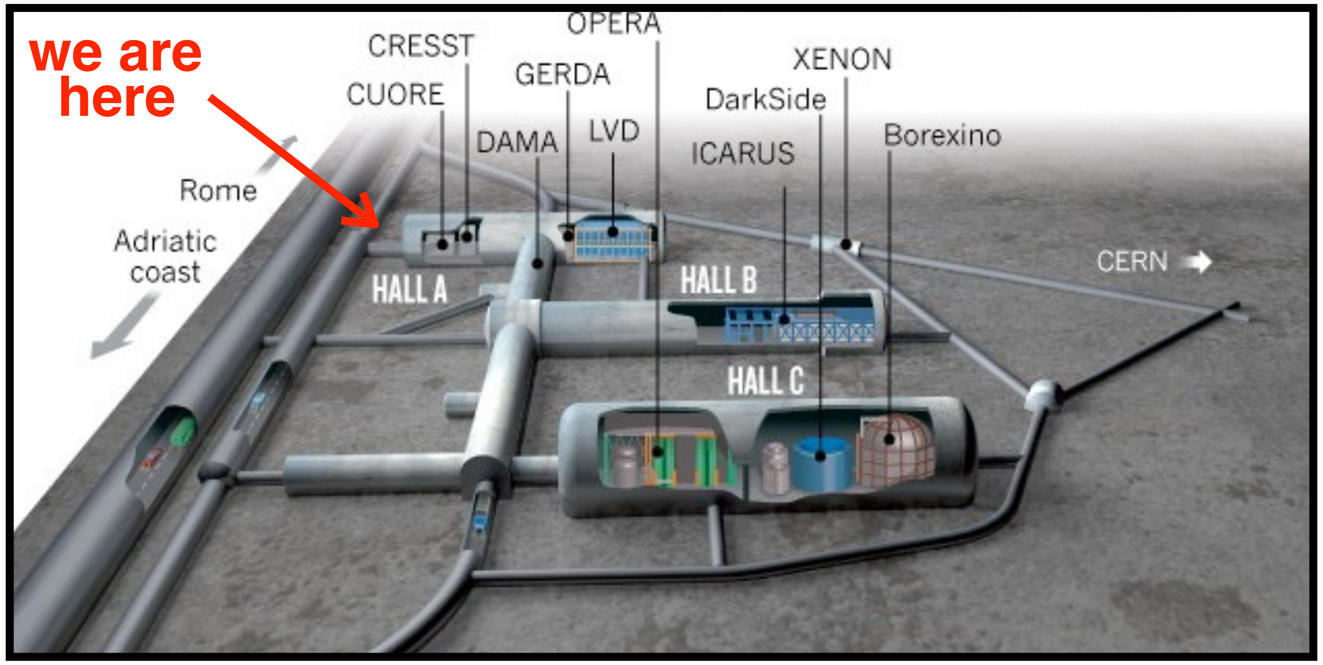
a ton of isotope + **bkg close to zero** = **m_ν Majorana probe**

Five steps beyond the present technology are required:

- Isotopic enrichment *
- Active bkg rejection * } CUPID-0
- Improved material selection
- Better energy resolution
- Reduced cosmo-activation

The underground facility

Laboratori Nazionali
del Gran Sasso
INFN, Italy



Unique site for low background physics with cryogenic detectors

Experimental location:

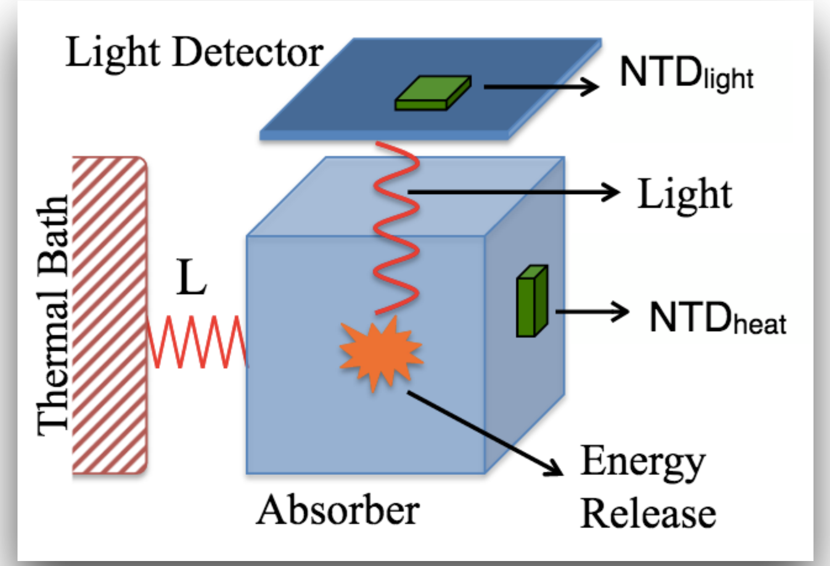
- Average depth ~ 3600 m w.e.
- Muon flux ~ 2.6×10^{-8} μ/s/cm^2
- Neutrons < 10 MeV: $<10^{-6}$ n/s/cm^2

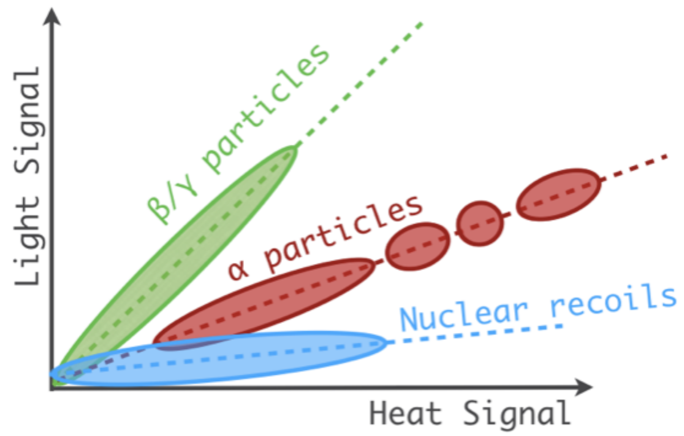
Scintillating bolometers

A bolometer is a highly sensitive **calorimeter** operated @ cryogenic temperature (~10 mK).

Energy deposits are measured as **temperature** variations of the absorber.

If the absorber is also an **efficient scintillator** the energy is converted into **heat** + **light**





The simultaneous read-out of **HEAT** and **LIGHT** allows particle identification

Bolometer features:

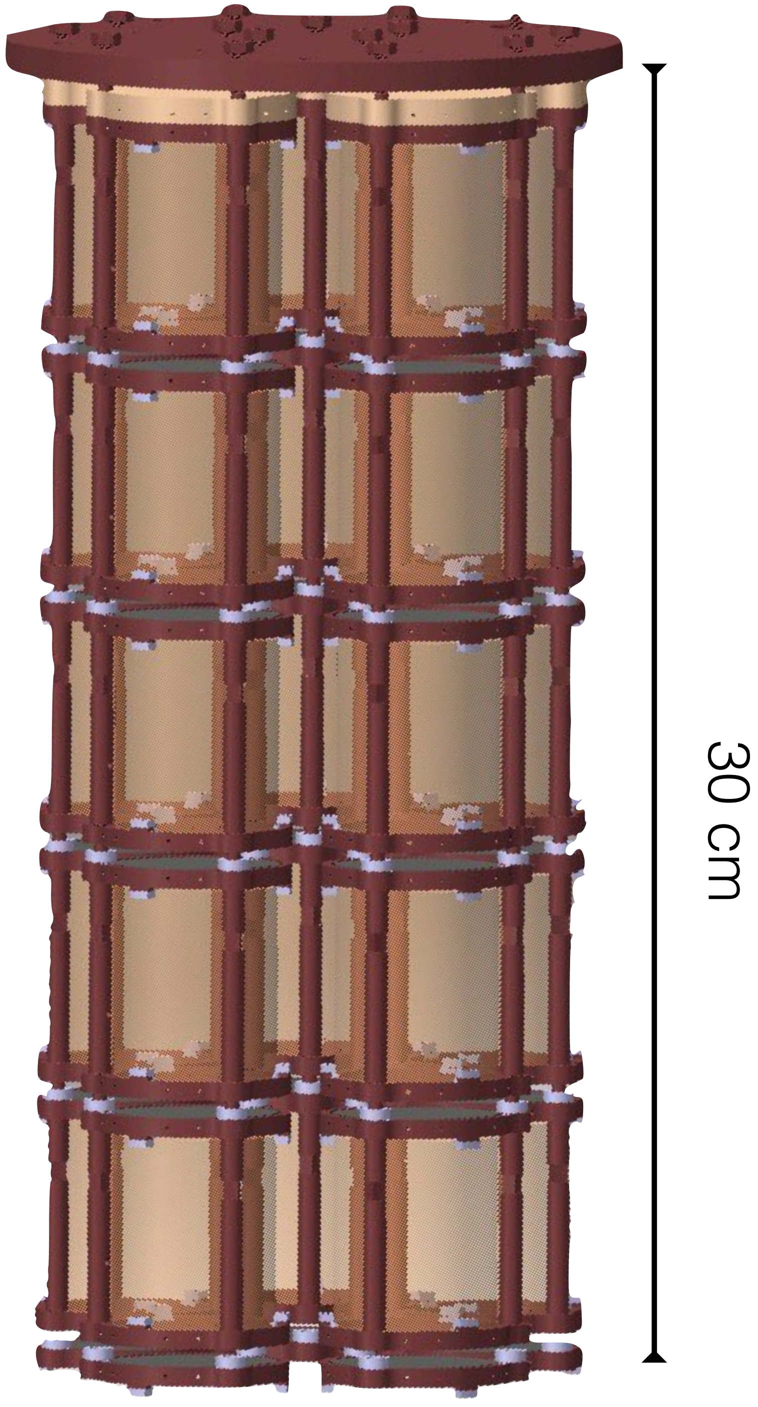
- high energy resolution O(1/1000)
- wide choice of compound $^{130}TeO_2$, $Li_2{}^{100}MoO_4$, $Zn^{82}Se$
- high detection efficiency (source = detector)
- scalable to large masses
- **particle ID**

A **background-free experiment** is possible:
α-background: identification and rejection
β/γ-background: ββ isotope with large Q-value

CUPID-0

CUPID-0 is the first array of scintillating bolometers
for the investigation of ^{82}Se 0νββ

- ^{82}Se Q-value 2998 keV
- 95% enriched Zn^{82}Se bolometers
- 26 bolometers (24 enr + 2 nat) arranged in 5 towers
  - 10.5 kg of ZnSe
  - 5.17 kg of ^{82}Se -> $N_{\beta\beta} = 3.8\text{x}10^{25}$ ββ nuclei
- LD: Ge wafer operated as bolometer
- Simplest modular detector ➜ scale up
  - Copper structure (ElectroToughPitch)
  - PTFE holders
  - Light Reflector (VIKUITI 3M)



CUPID-0 Coll., Eur. Phys. J. C (2018) 78:428.

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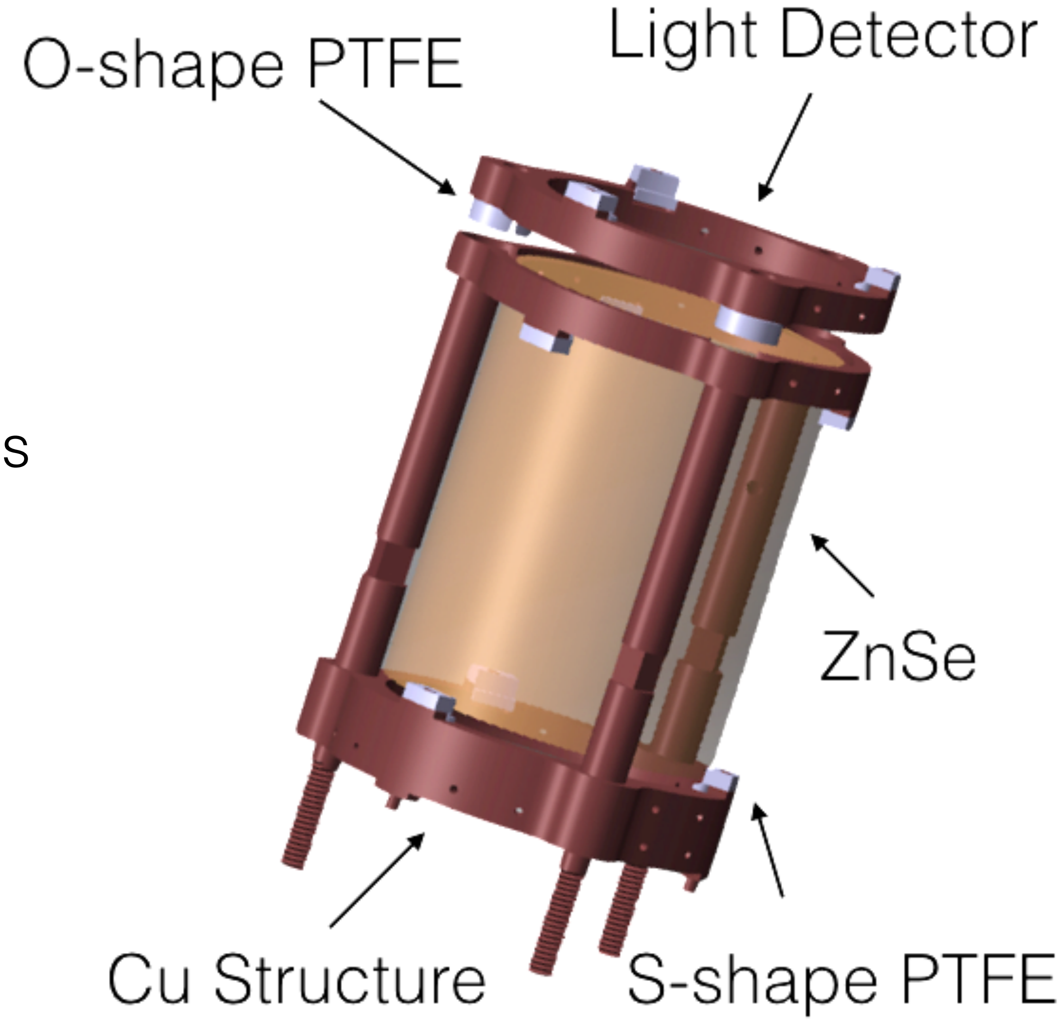


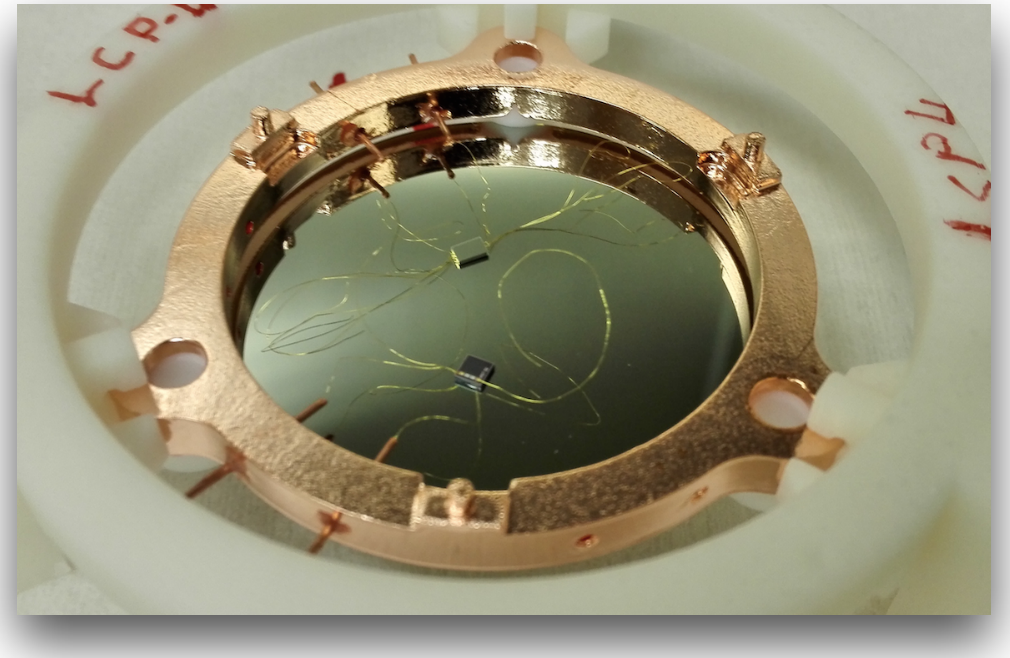
This design has the main goal of
Minimize mass of passive materials
Cu ~22% - PTFE/Vik. ~0.1% - ZnSe+Ge ~78%

CUPID-0 Coll., Eur. Phys. J. C (2018) 78:428.

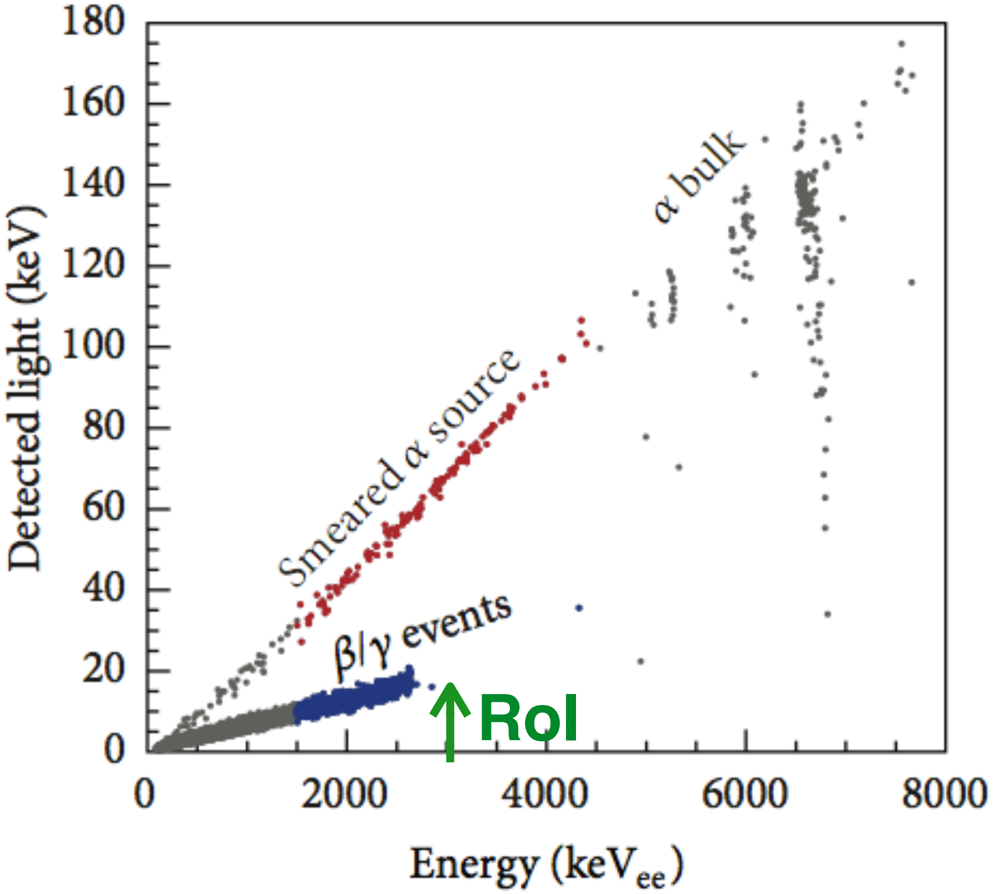
CUPID-0 Light Detectors

- Well established technology for bolometric LDs
  - Ge disk 44.5 x 0.17 mm
  - Ge-NTD thermal sensor 2x1.5x3 mm^3
  - Si-heater for gain drift corrections
- One face coated with 60 nm SiO_2
  - Light collection enhancement ~50%
- Performance are crucial for background suppression
  - Light vs Heat: α leakage in β/γ ROI band
  - PSA of Light: highly efficient PID

CUPID-0 has 31 LDs



Calibration scatter plot of a ZnSe crystal



J.W. Beeman et al., J. Instrum. 8 (2013) P05021.

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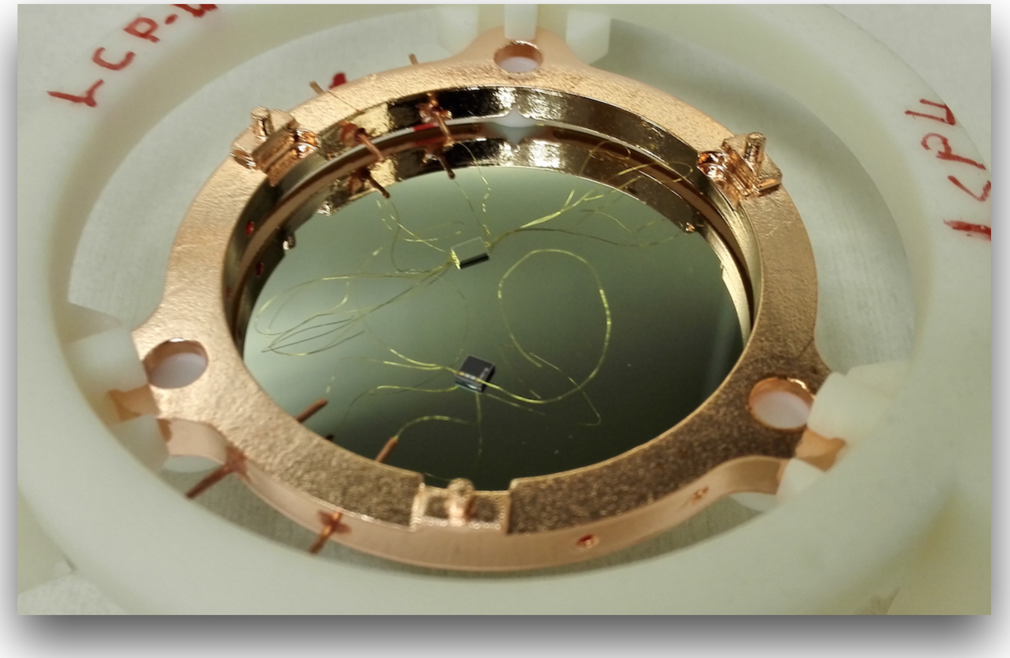

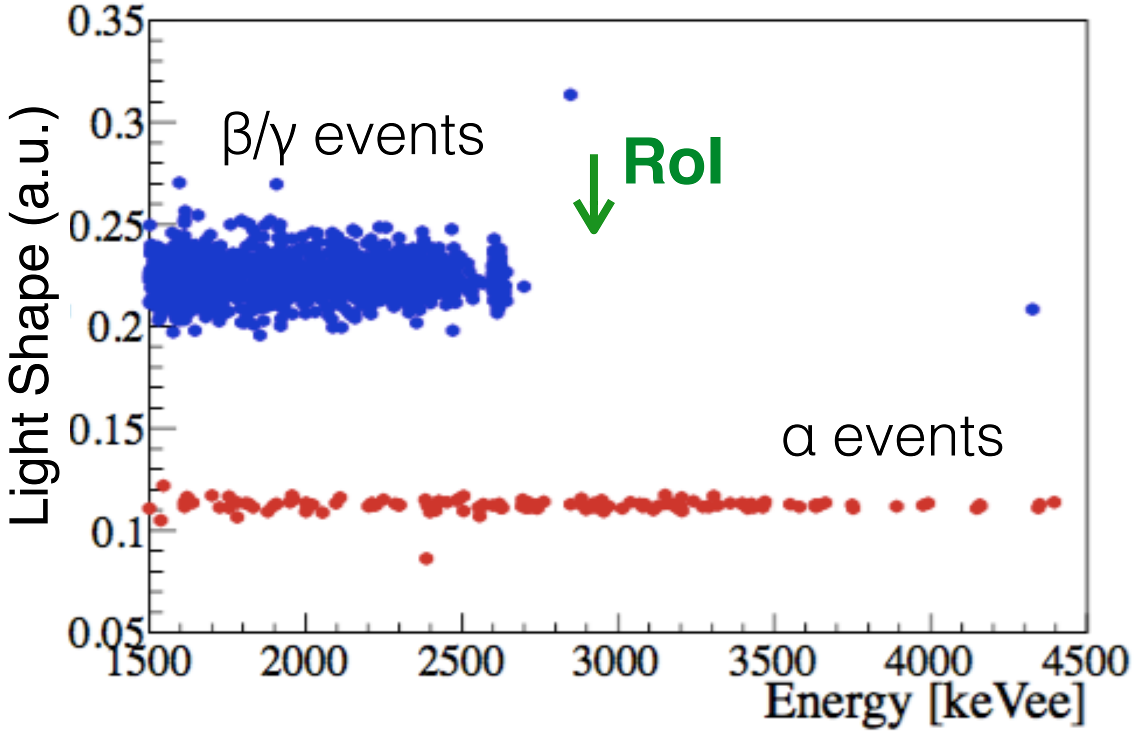
Calibration scatter plot of a ZnSe crystal

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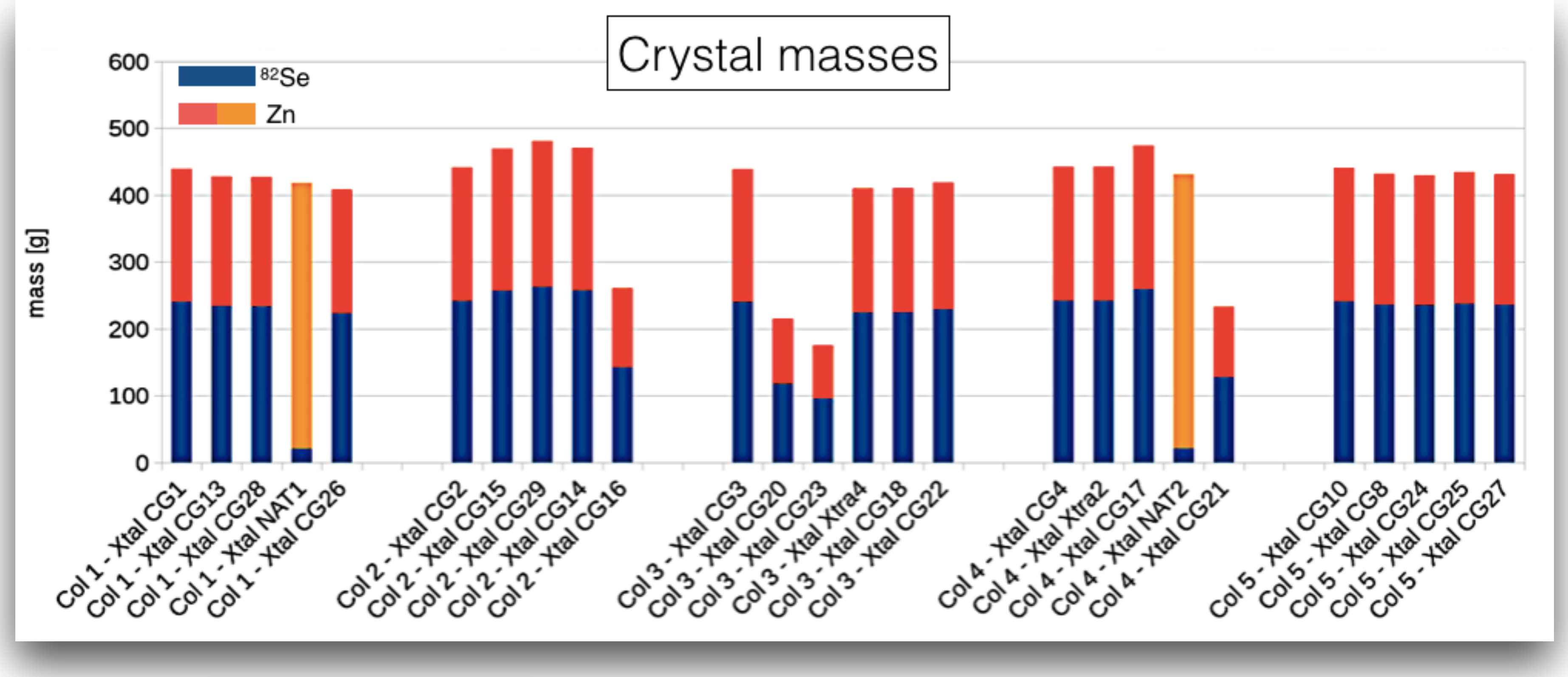
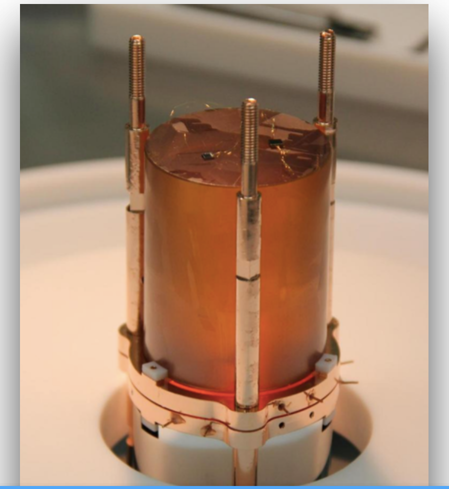
CUPID-0 assembly

Complex detector design: CUPID-0 crystals have all different shapes and heights ranging from 21 mm to 58 mm.

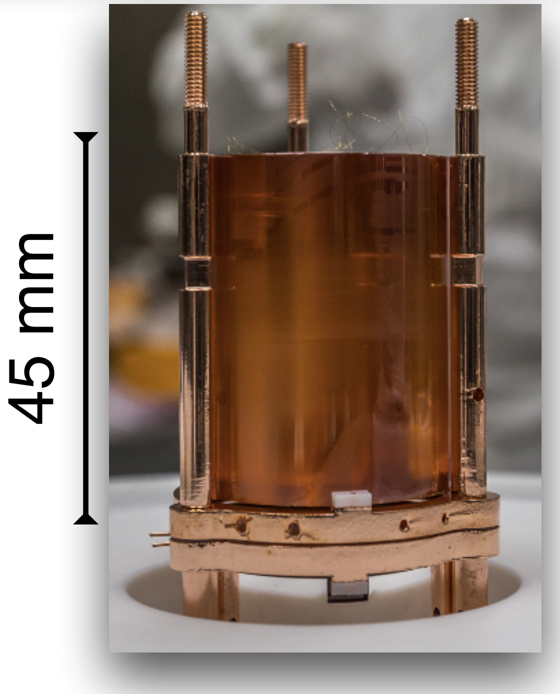
Assembly started in Oct-2016

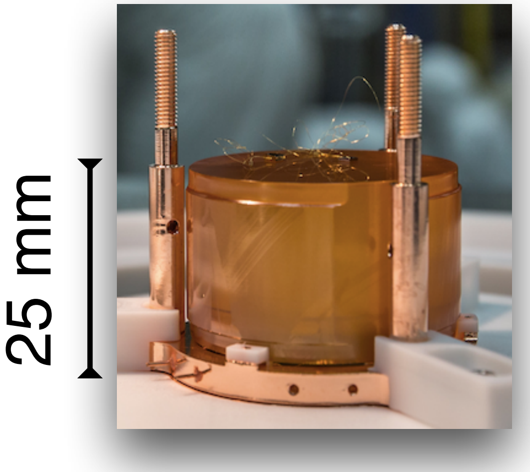


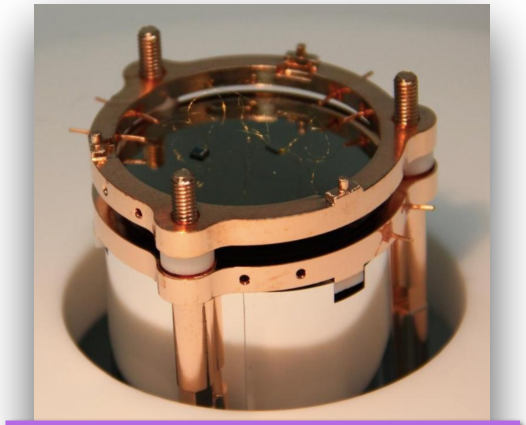
#1 LD installation



#2 ZnSe installation





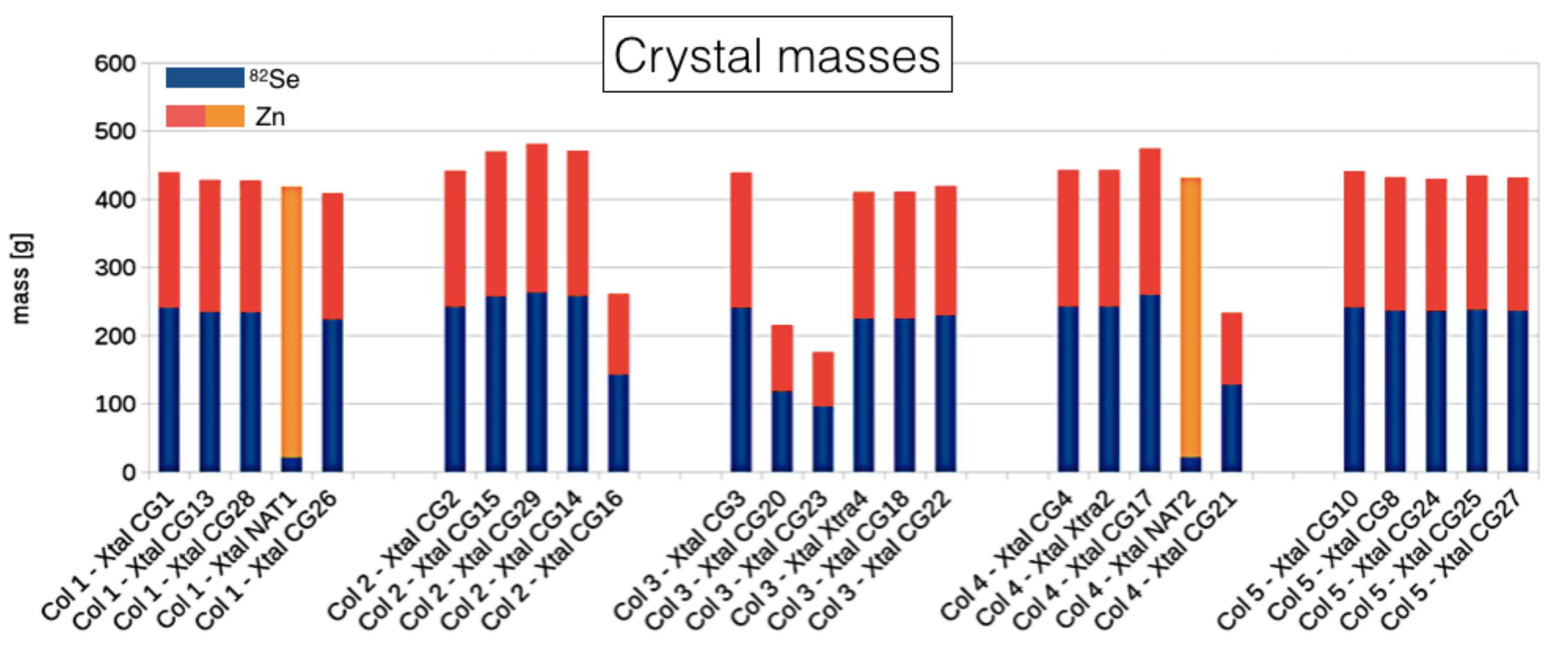


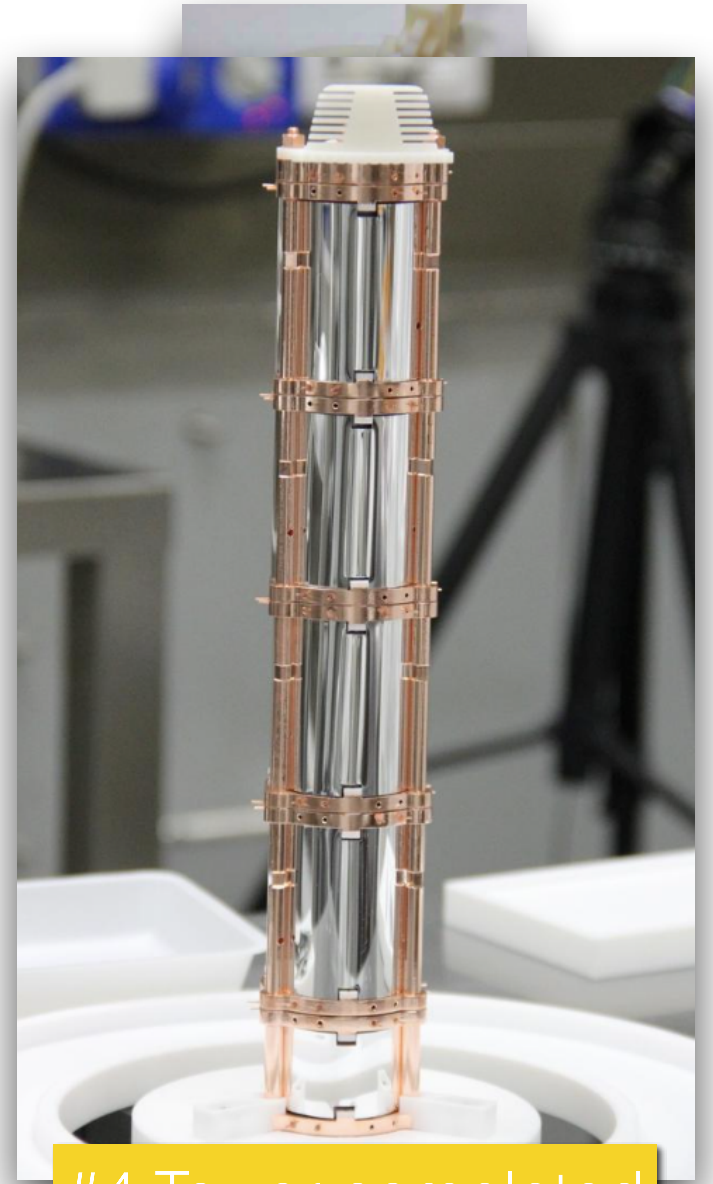
#3 LD installation

CUPID-0 assembly

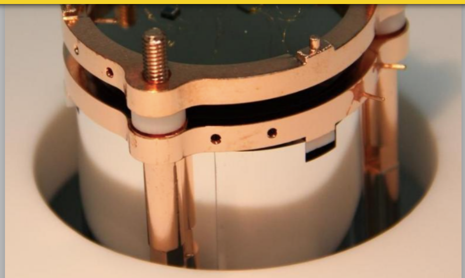
Complex detector design: CUPID-0 crystals have all different shapes and heights ranging from 21 mm to 58 mm.

Assembly started in Oct-2016

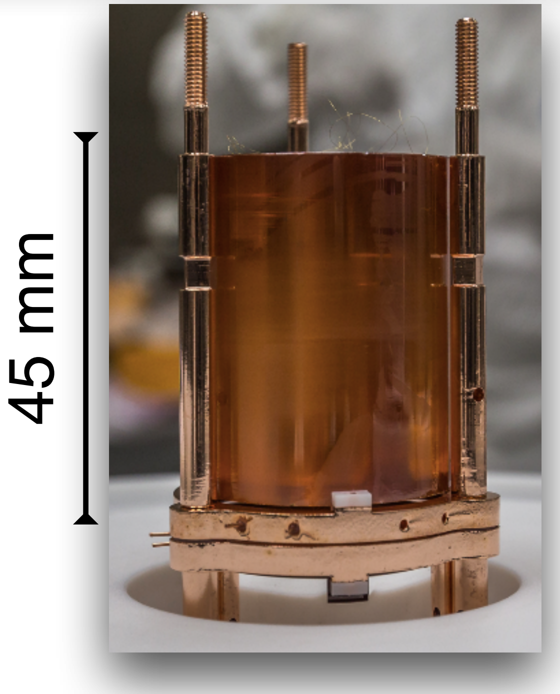


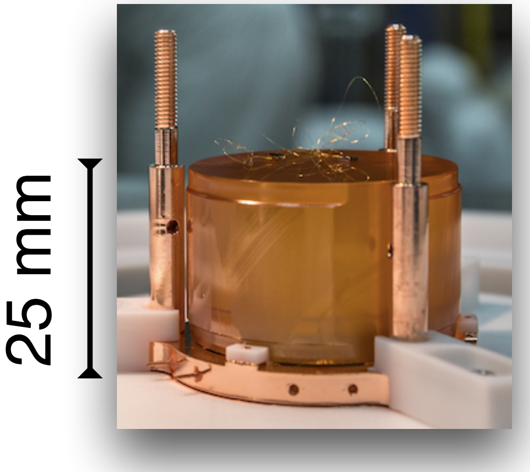


#4 Tower completed



#3 LD installation



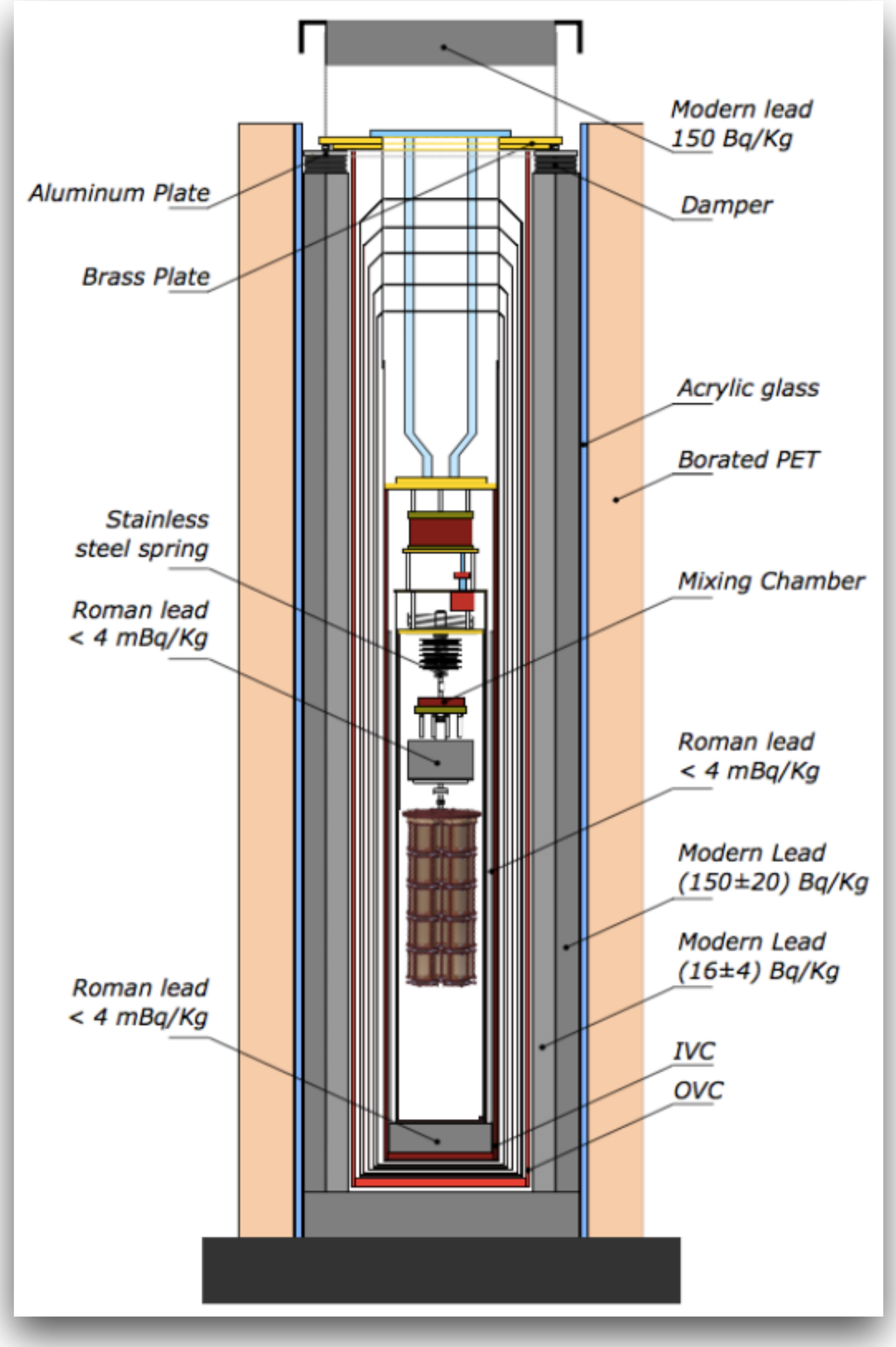


Detector installation

Detector installed in the former CUORICINO/CUORE-0 cryostat (80's).

Upgrades:

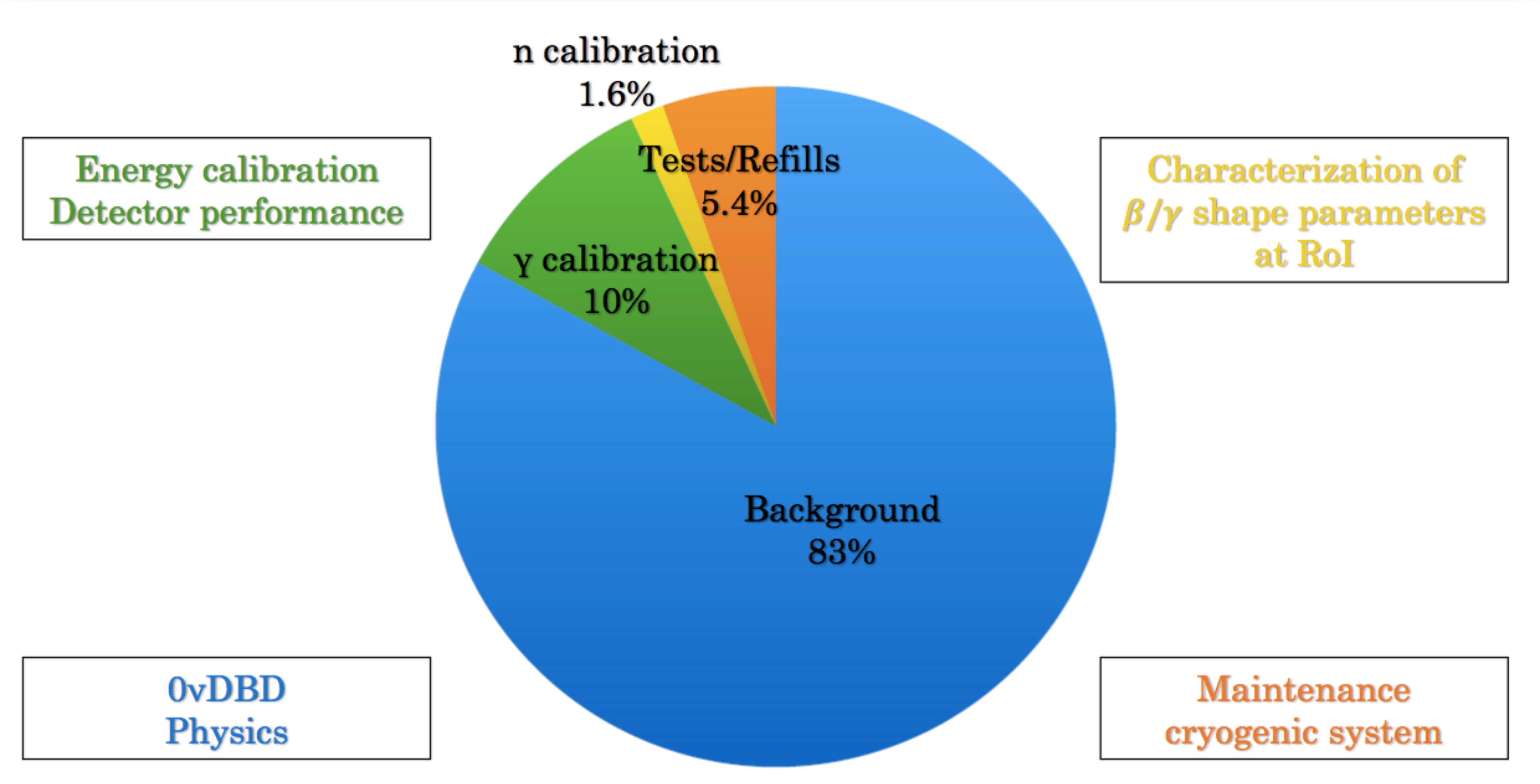
- ☐ Double stage pendulum for low vibrational noise
  - ☑ Improve LD performance
- ☐ Cryostat wiring: can host up to 120 channels
  - ☑ CUPID-0 uses more than 60 channels
  - ☑ CUPID-0/Mo next phase can be hosted
- ☐ Rn-reduction system next to the cryostat
  - ☑ Reduction and monitoring of ^{214}Bi (high energy γ's)



Data taking

Background data presented here were collected between Jun 2017-Apr 2018

Exposure: 5.46 kg · y of ZnSe (2.90 kg · y ^{82}Se)

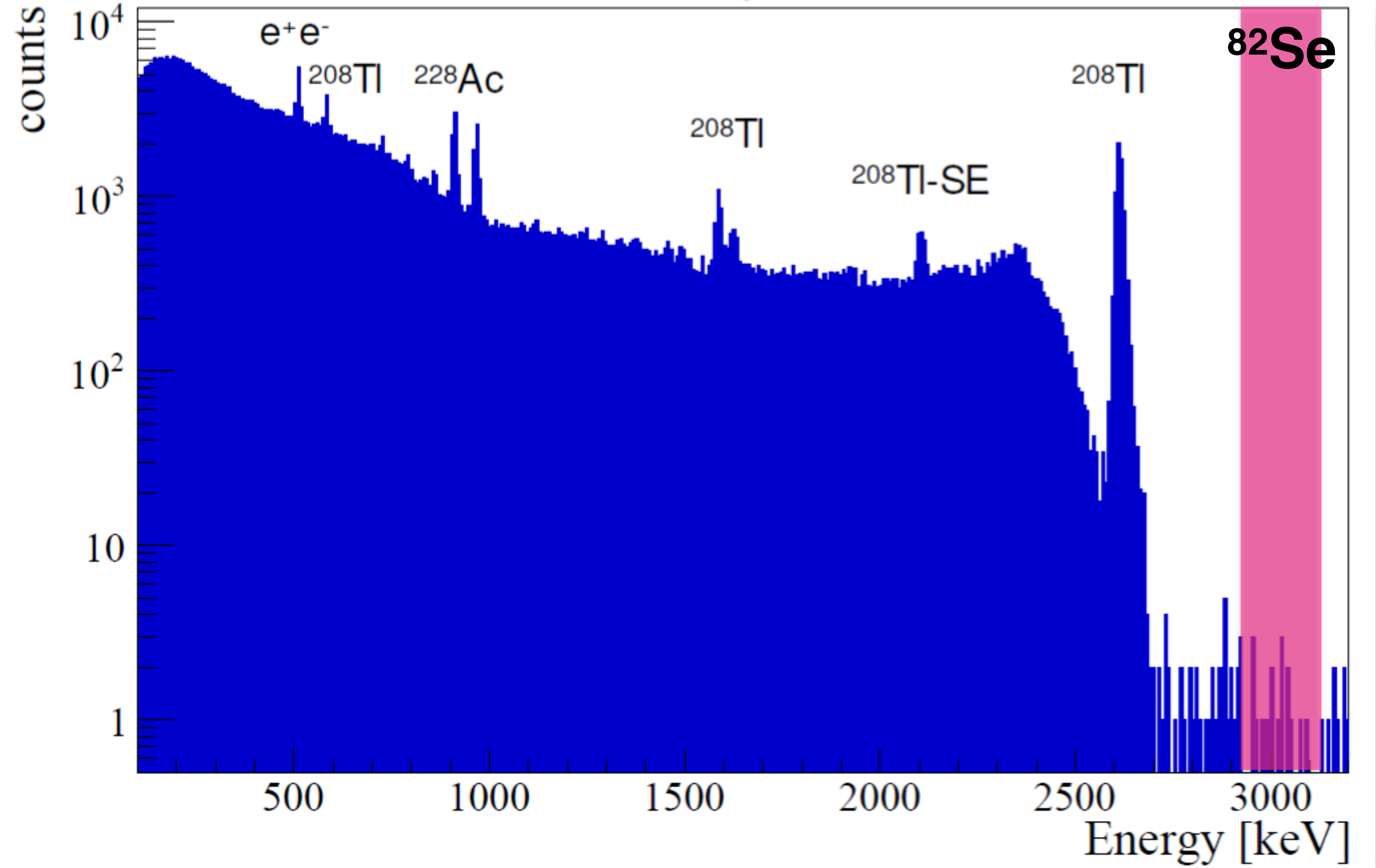


CUPID-0 Coll., Phys. Rev. Lett. 120, 232502 (2018)

+ 2.02 kg · y of ZnSe

Energy calibration

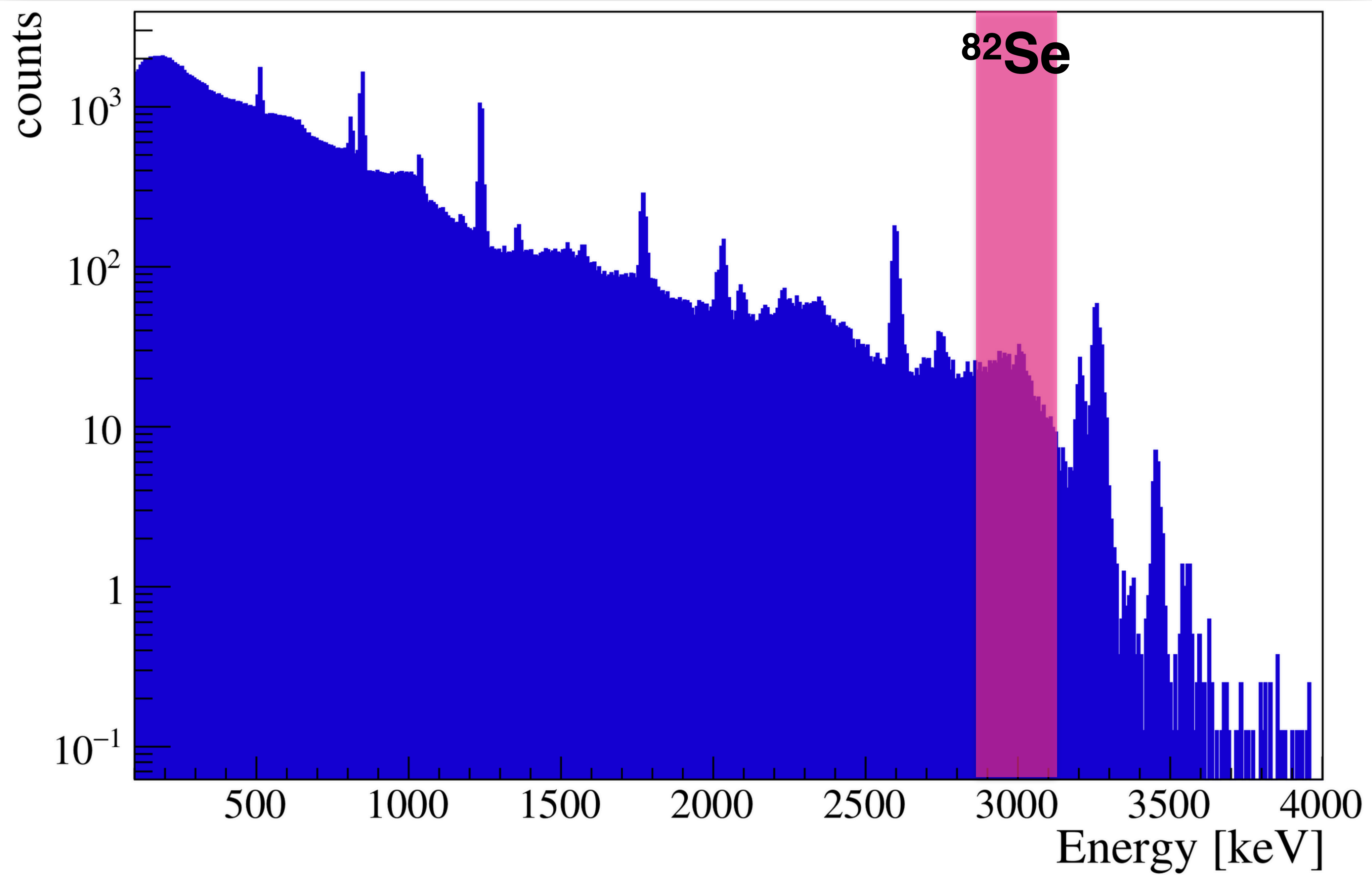
Total ^{232}Th calibration energy spectrum



Periodical (~4 days every month) calibration with ^{232}Th external source.

Energy calibration

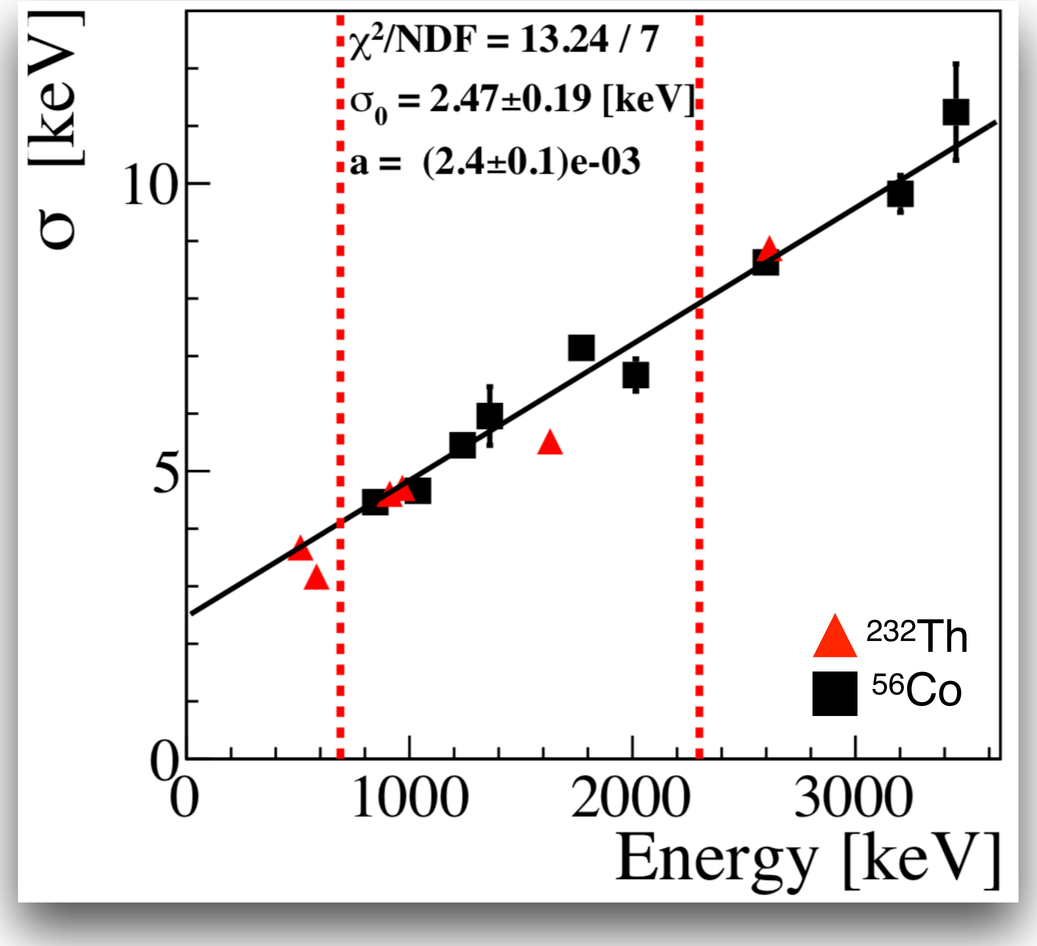
Total ^{56}Co calibration energy spectrum

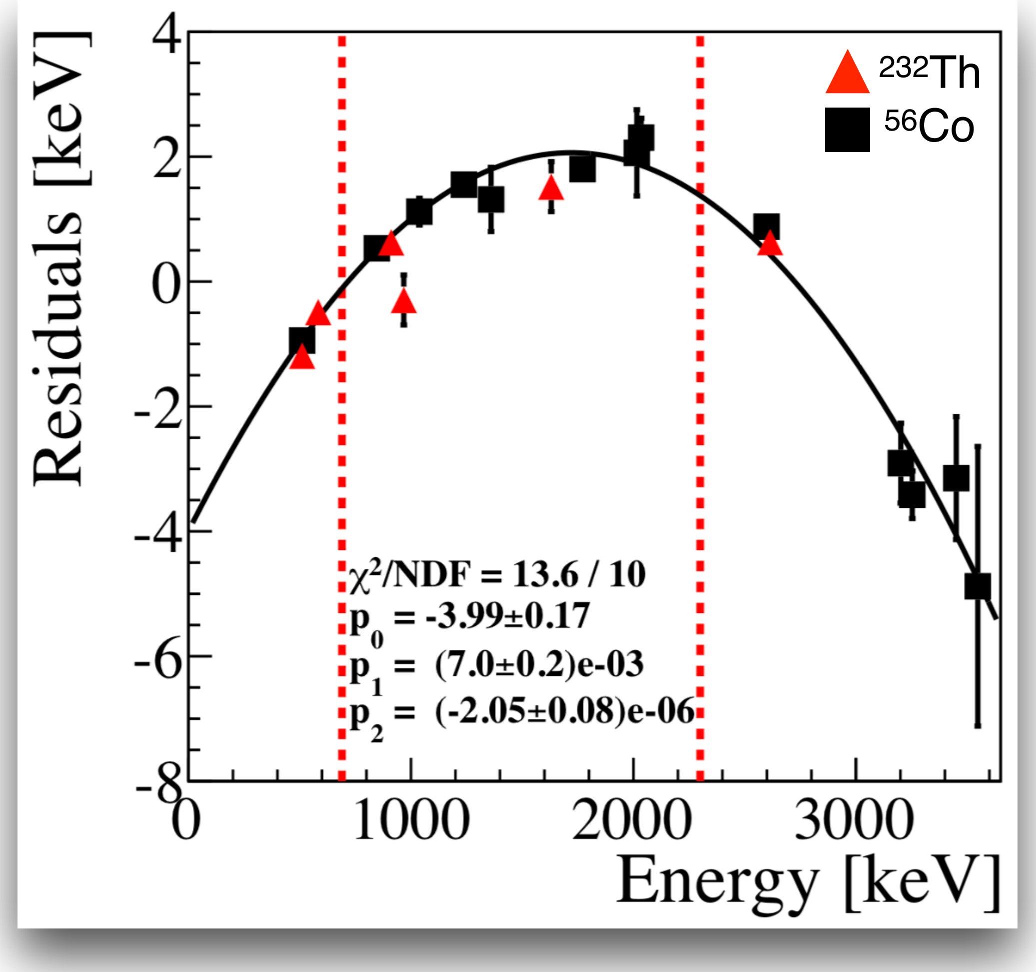


Calibration cross check:

^{56}Co: Q-value: 4.57 MeV, $T_{1/2}$: 77 days

Energy calibration



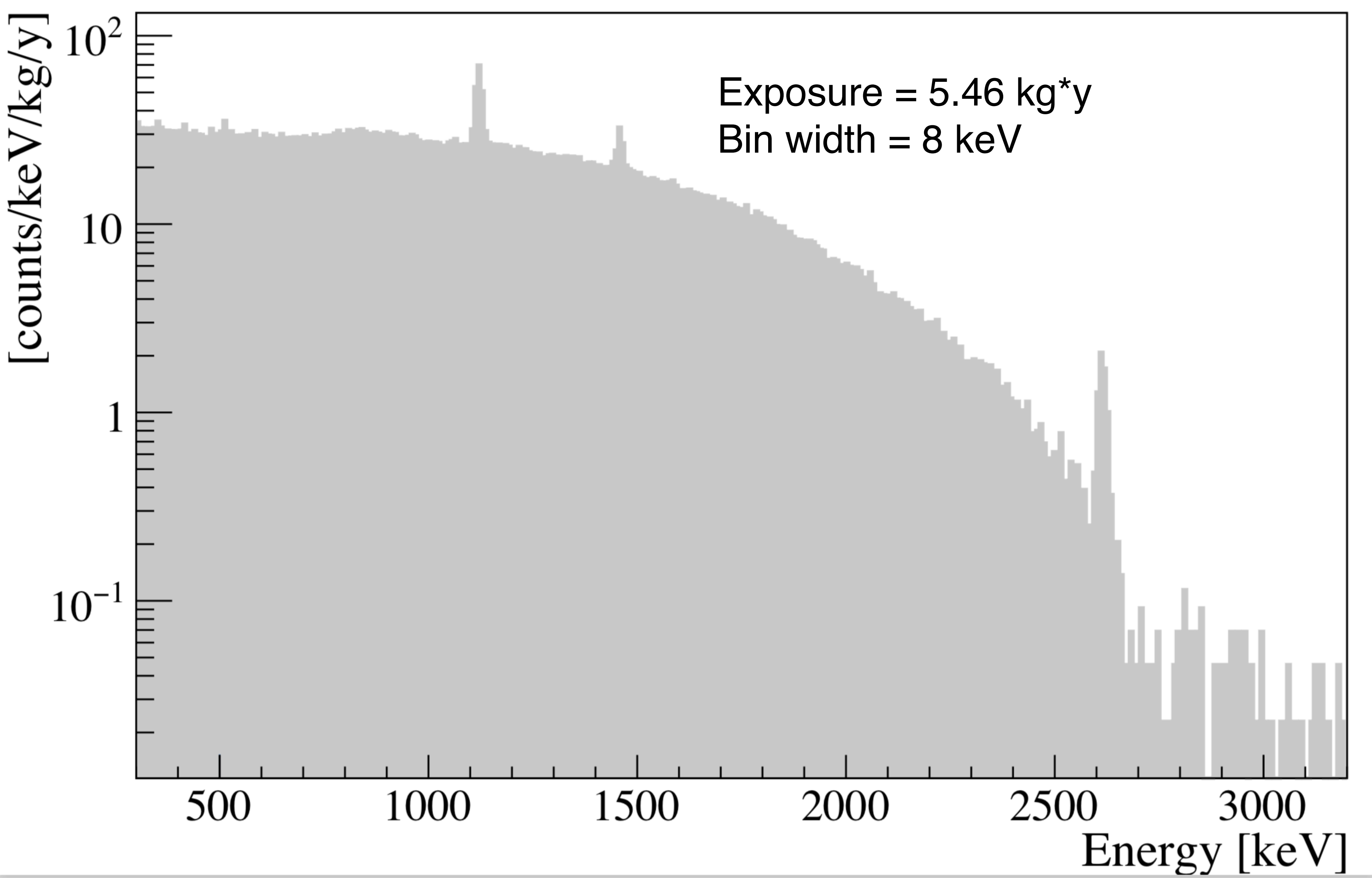


We linearly extrapolate the width of the primary peak at $Q_{\beta\beta}$.

Energy resolution in the ROI FWHM(^{56}Co): (22.5±1.2) keV.

Consistent with (23.0±0.6) keV extracted from ^{232}Th calibration.

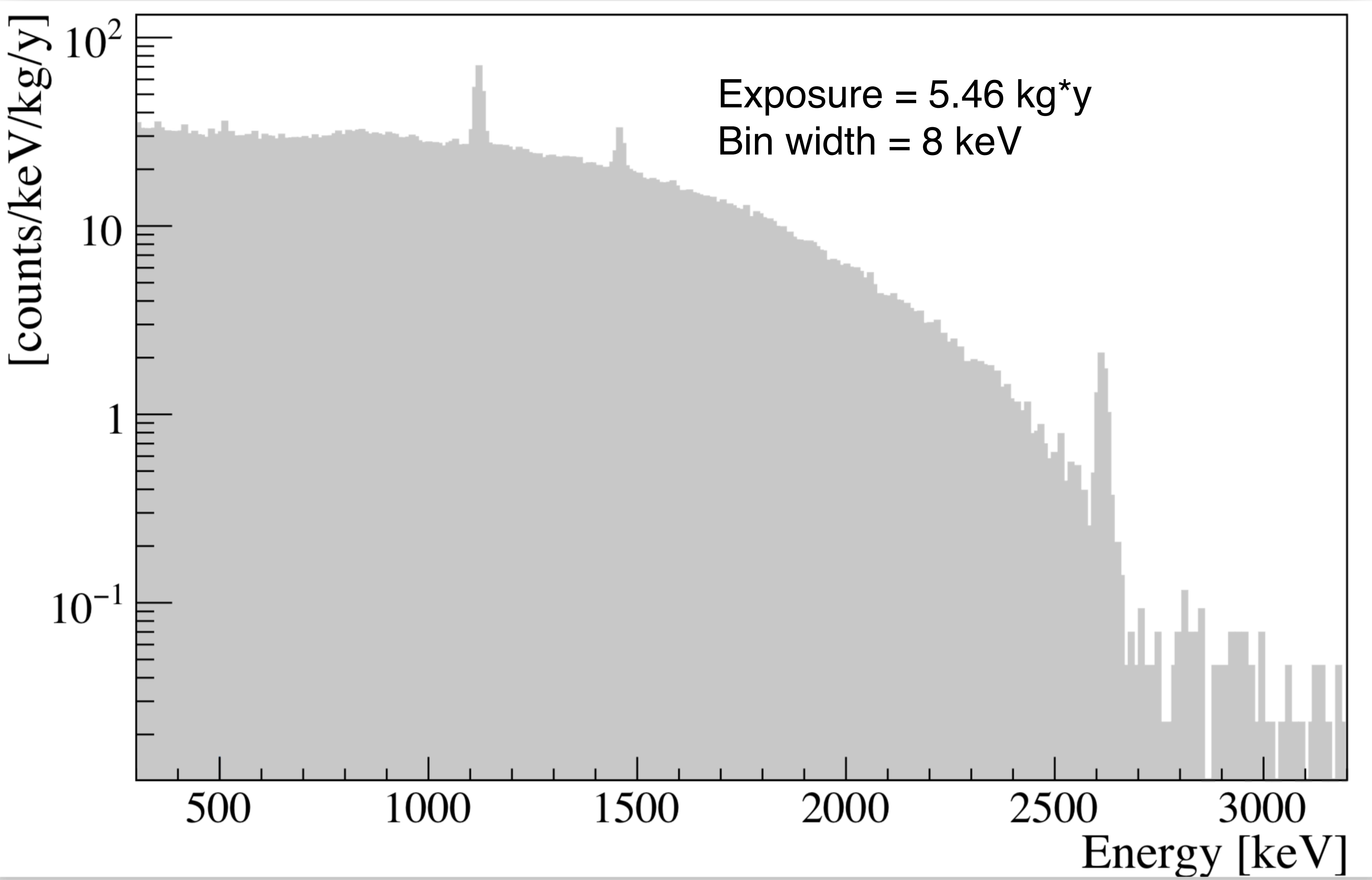
Background data selection



First level data analysis:

1. Optimum filtering
2. Gain stability corrections
3. Synchronisation heat-light

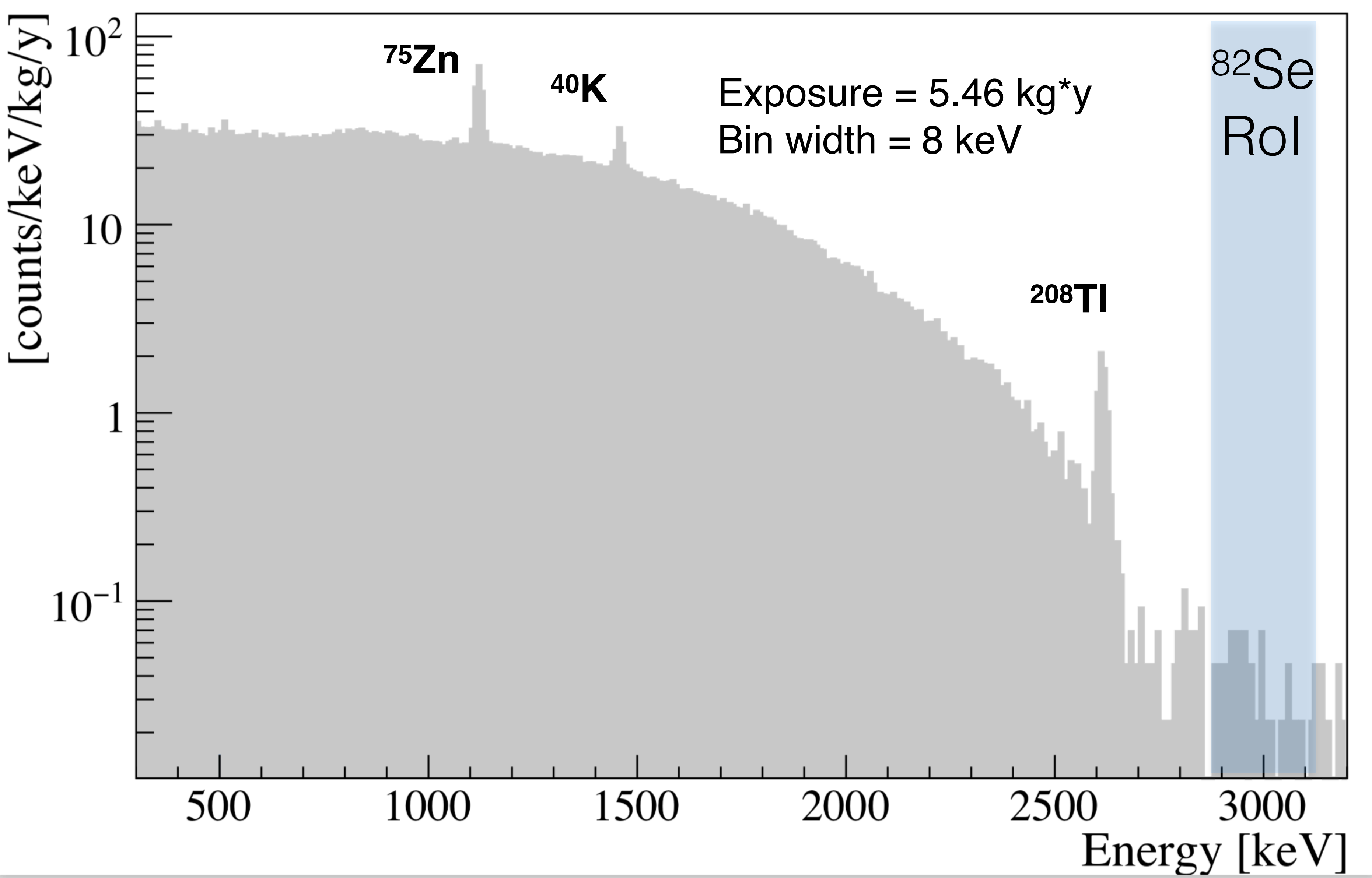
Background data selection



First level data analysis:

1. Optimum filtering ➜ Maximise S/N ratio in the frequency domain
2. Gain stability corrections ➜ Off-line gain correction with artificial pulses
3. Synchronisation heat-light ➜ To each event is associated 1 light & 1 Heat event

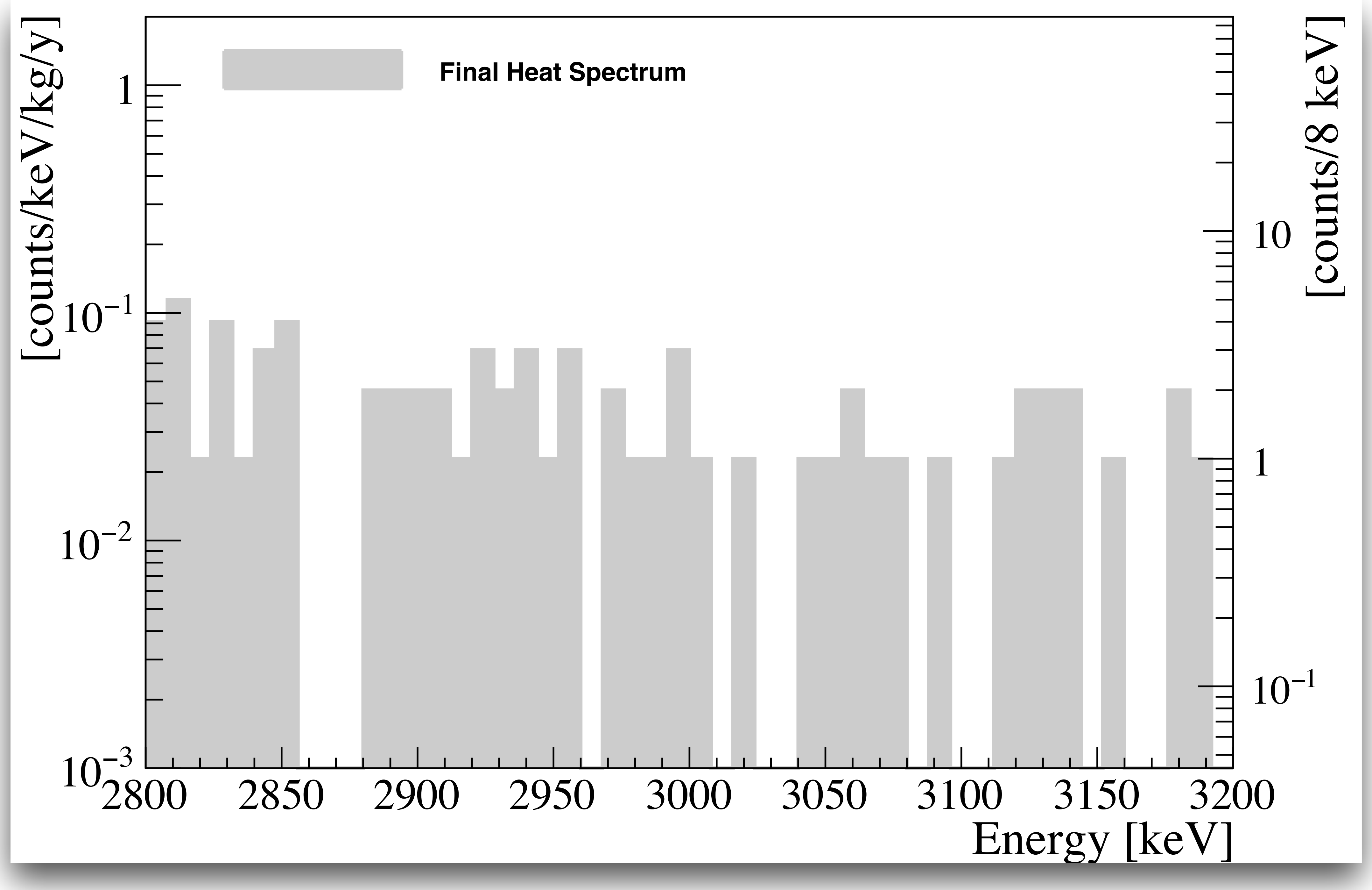
Background data selection



Second level data analysis:

- Rejection of “non-particle” events via Pulse Shape Analysis
- Anti-coincidence cut Δ=20 msec

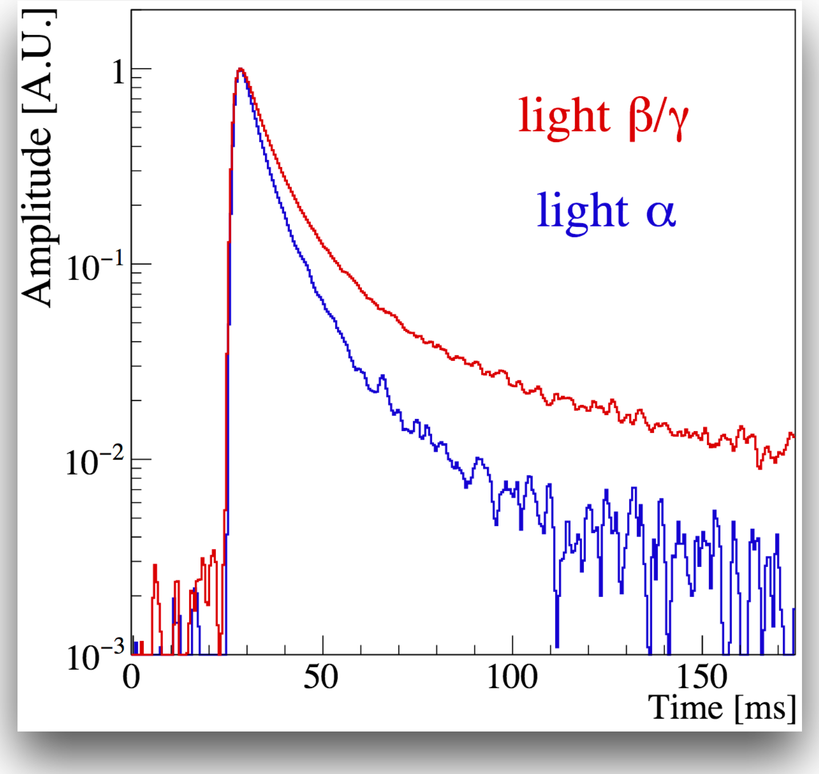
Total bkg energy spectrum

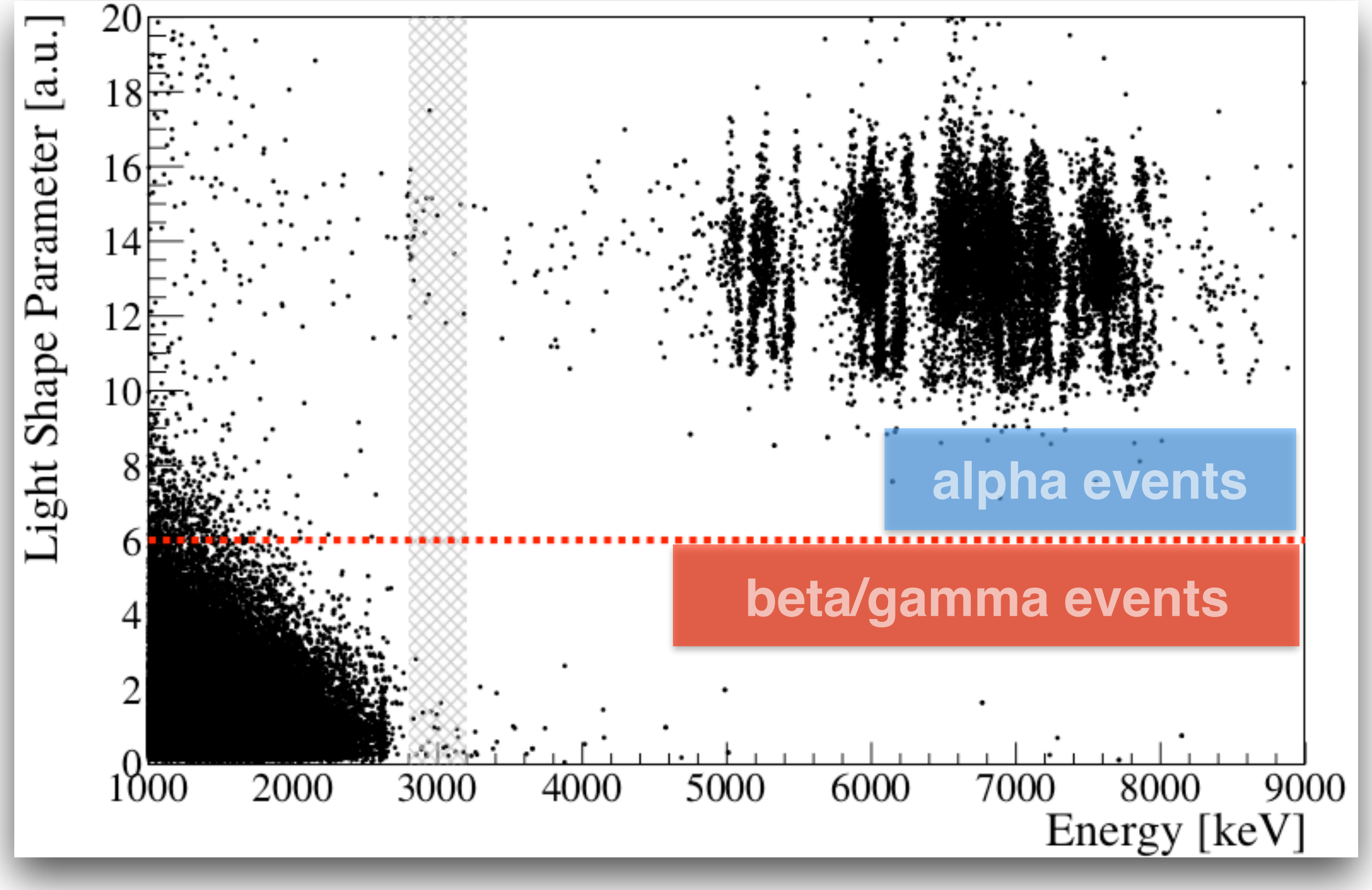


➜ **Background Index in the ROI: (3.2±0.4)*10^{-2} c/keV/kg/y**

Background data selection

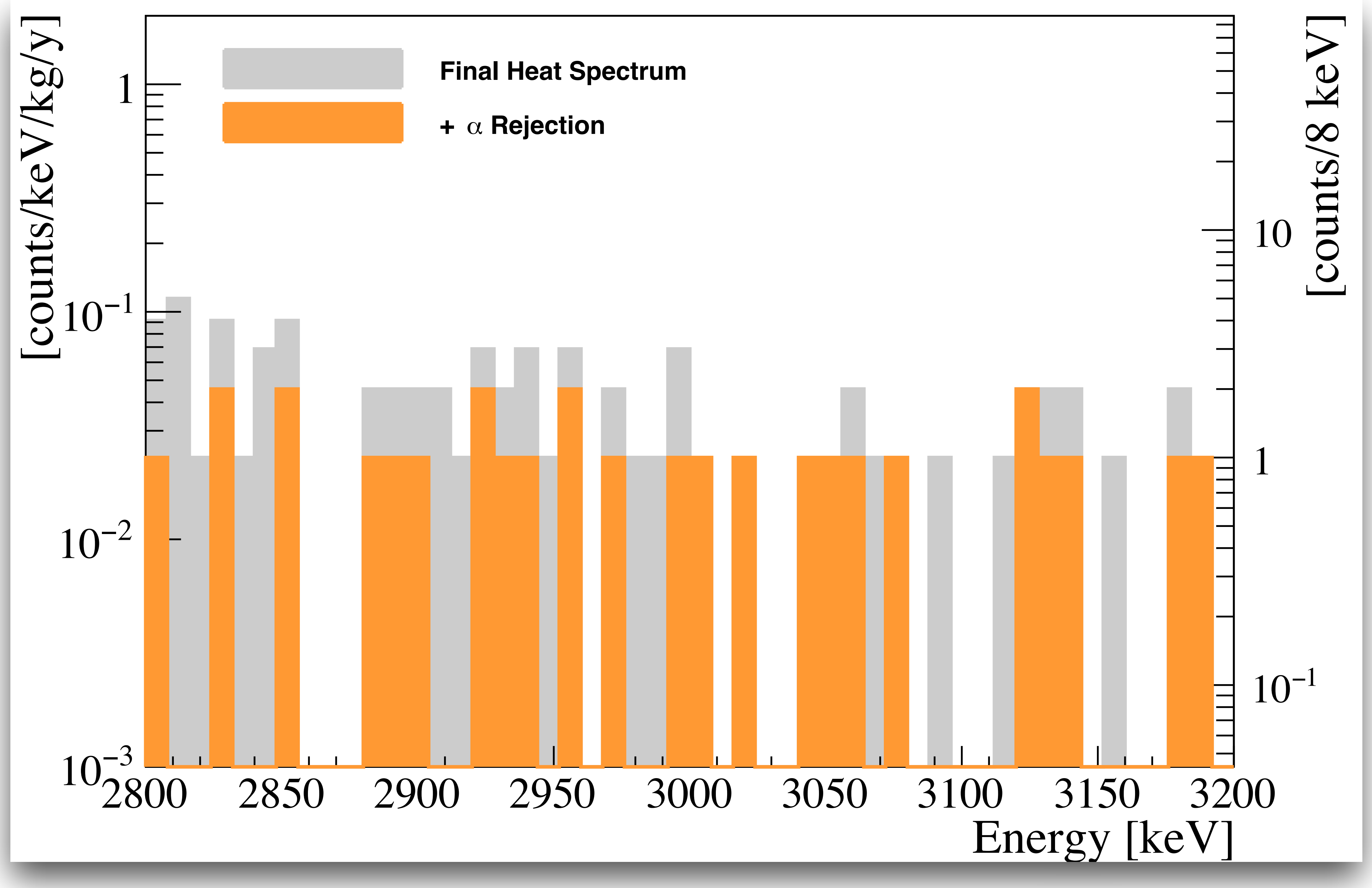
Turn **ON** the Light Detector:





- Rejection of α's with PSA on light channel
- Cut optimized with a pure β/γ sample in order to have ε_{signal} ~100%

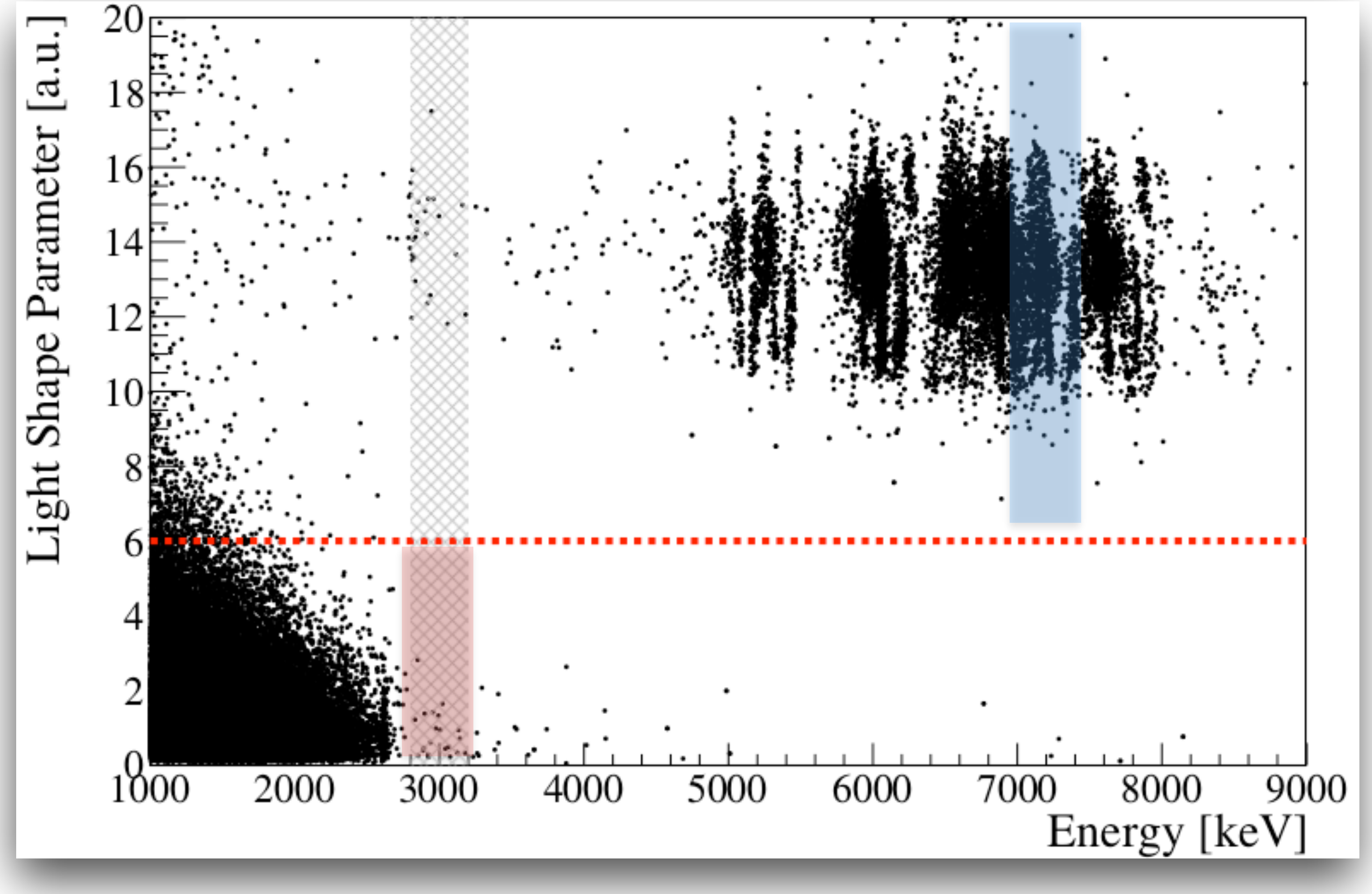
Background data selection



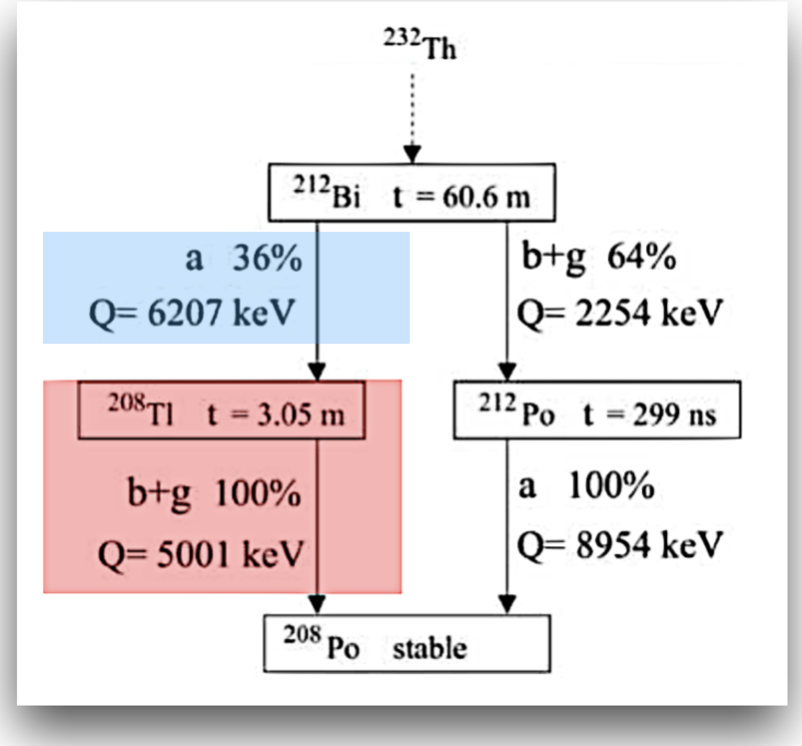
➜ Background Index in the ROI: (1.3±0.2)*10^{-2} c/keV/kg/y

Background data selection

Rejection of **α-related events** (high energy γ):



Delayed alpha coincidence ^{212}Bi-^{208}Tl



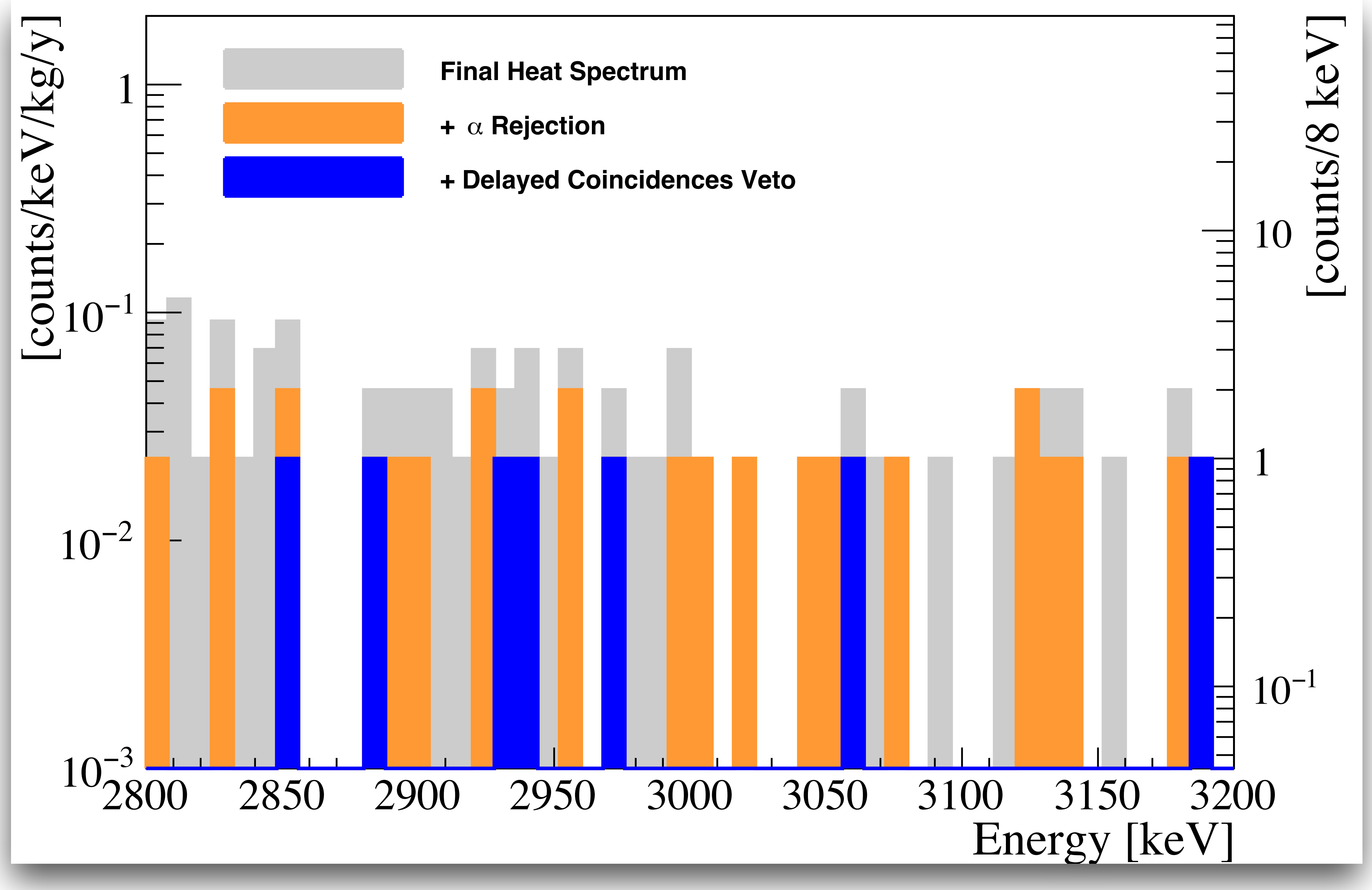
^{212}Bi α event are selected in a range of (2.5-6)MeV

For each ^{212}Bi α event the detector is disabled for 3τ (~9min).

↓

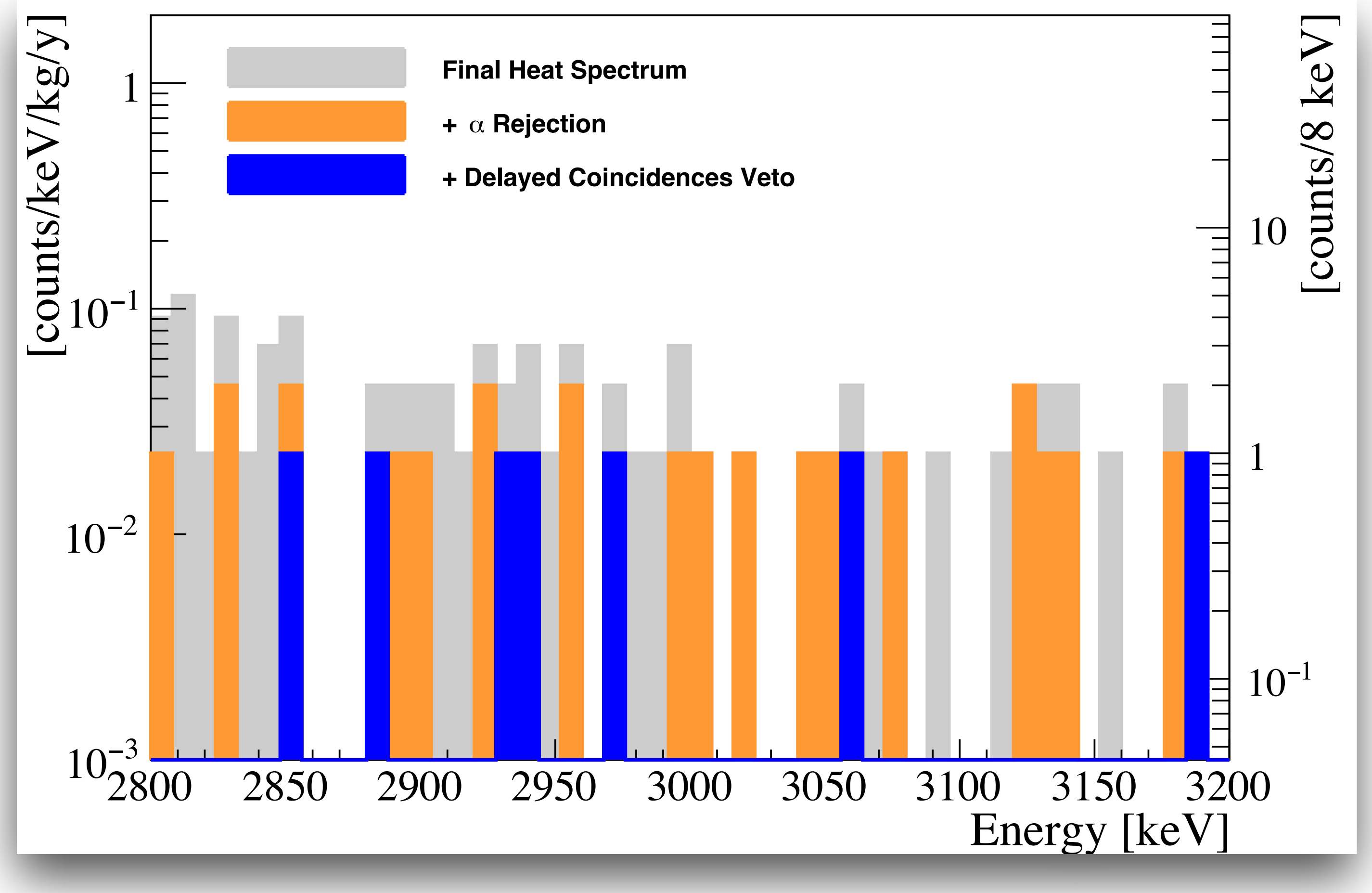
Rejection of high energy γ from ^{208}Tl.

Background data selection



➜ Background Index in the ROI: (3.2±1.3)*10^{-3} c/keV/kg/y

Background data selection



Data Selection:

Anti-coincidence between ZnSe:

→ **BI: (3.2±0.4)*10^{-2} c/keV/kg/y**

α particles rejection:

→ **BI: (1.3±0.2)*10^{-2} c/keV/kg/y**

Delayed coincidence veto:

→ **BI: (3.2±1.3)*10^{-3} c/keV/kg/y**

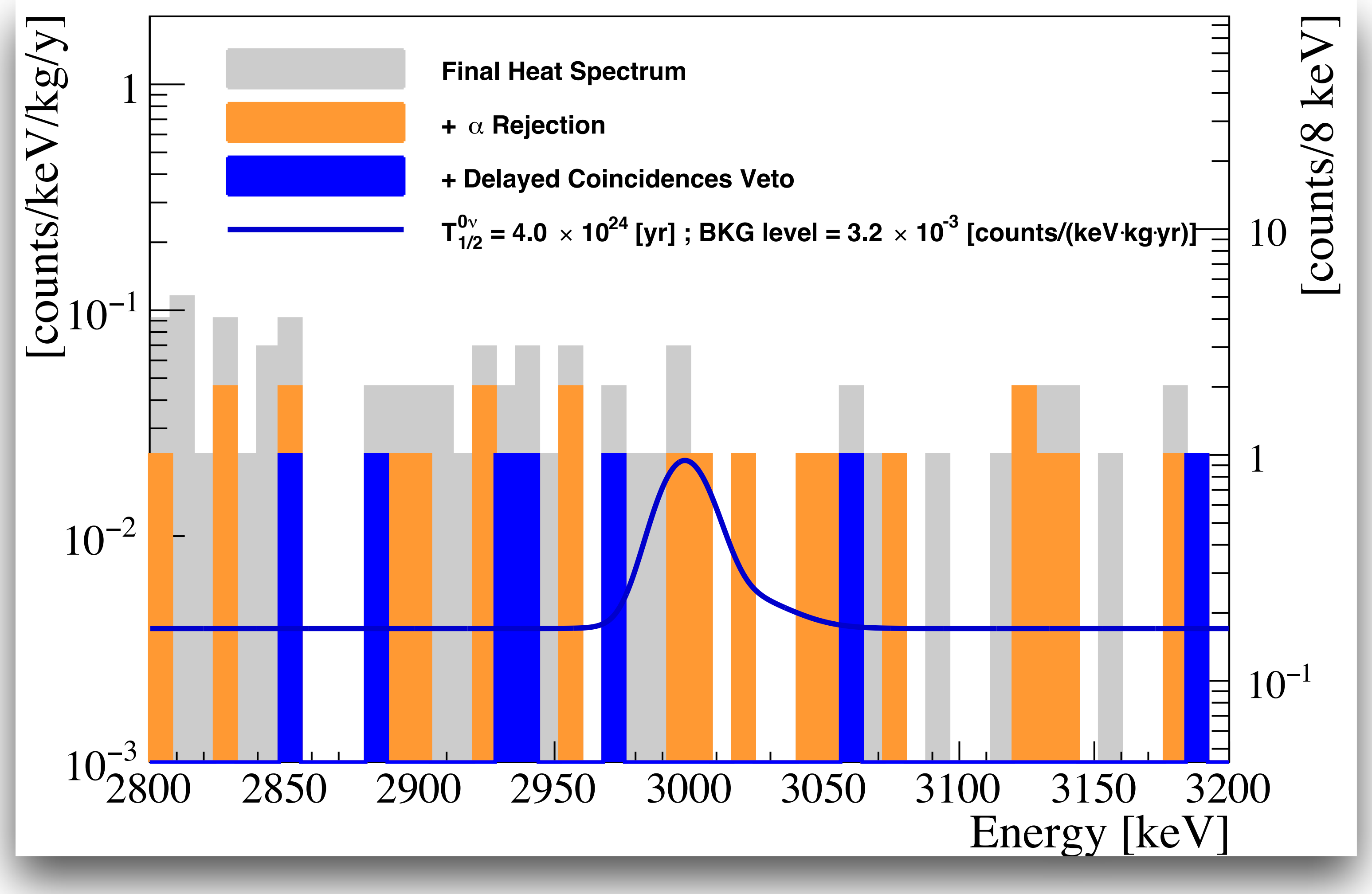
→ **only 7 events in RoI**

Global data selection efficiency (exposure weighted harmonic mean over data-set): 93±2%

Lowest background ever achieved with a cryogenic detector

Background data selection

UEML Simultaneous fit over the datasets



Exposure: **5.46 kg · y of ZnSe**

Energy resolution in ROI: **23.0±0.6 keV**

Total signal efficiency: **75±2%**

$(\varepsilon_{ntrigger} + \varepsilon_{signal} + \varepsilon_{\beta\beta})$

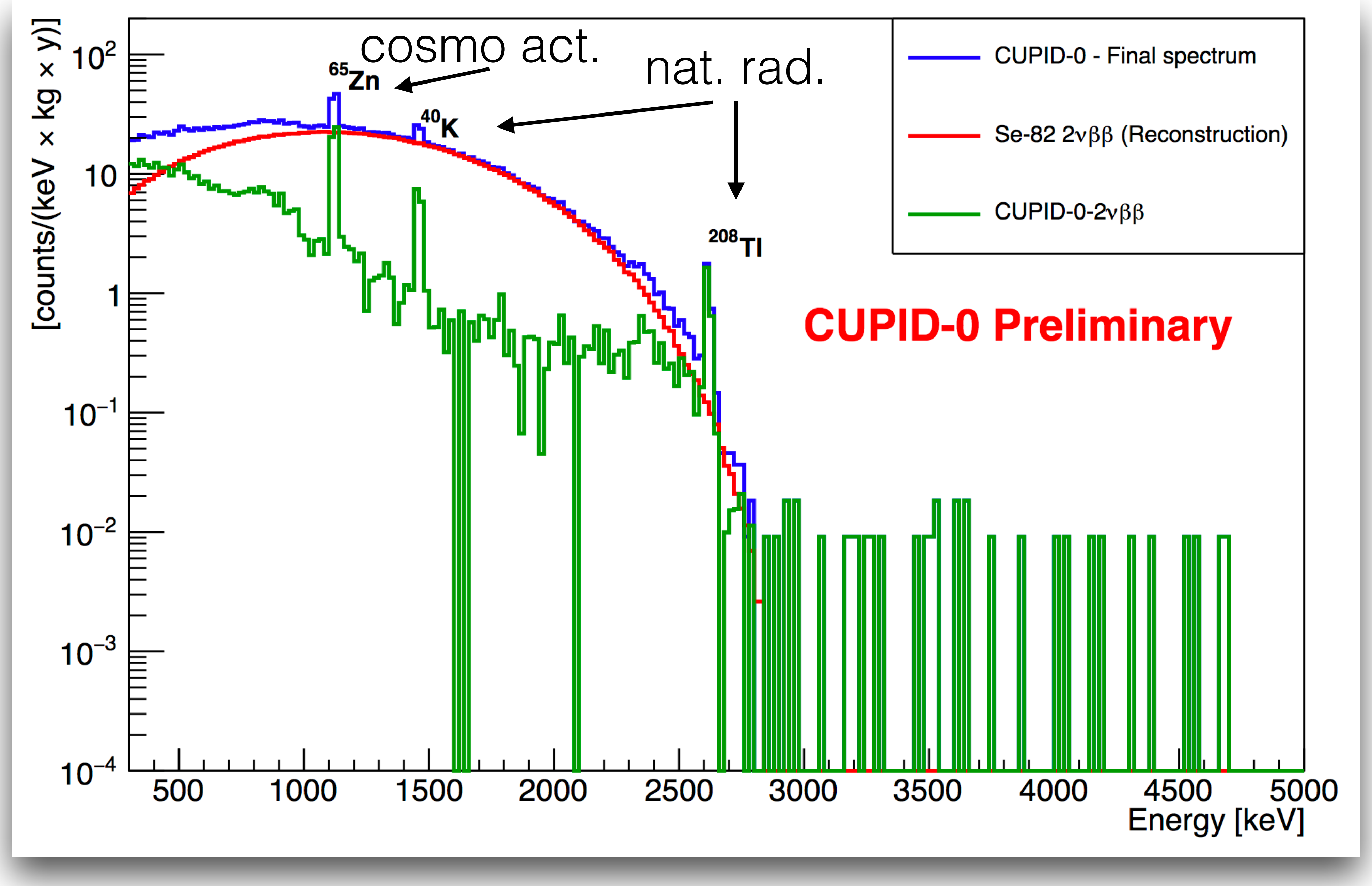
$T_{1/2}(^{82}Se \rightarrow {}^{82}Kr) > 4.0 \cdot 10^{24}$ yr @ 90C.L.

$m_{\beta\beta}$ < (290-596)[1] meV

NEMO3 measurement $3.6 \cdot 10^{23}$ yr @ 90C.L.

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

Background model (1)



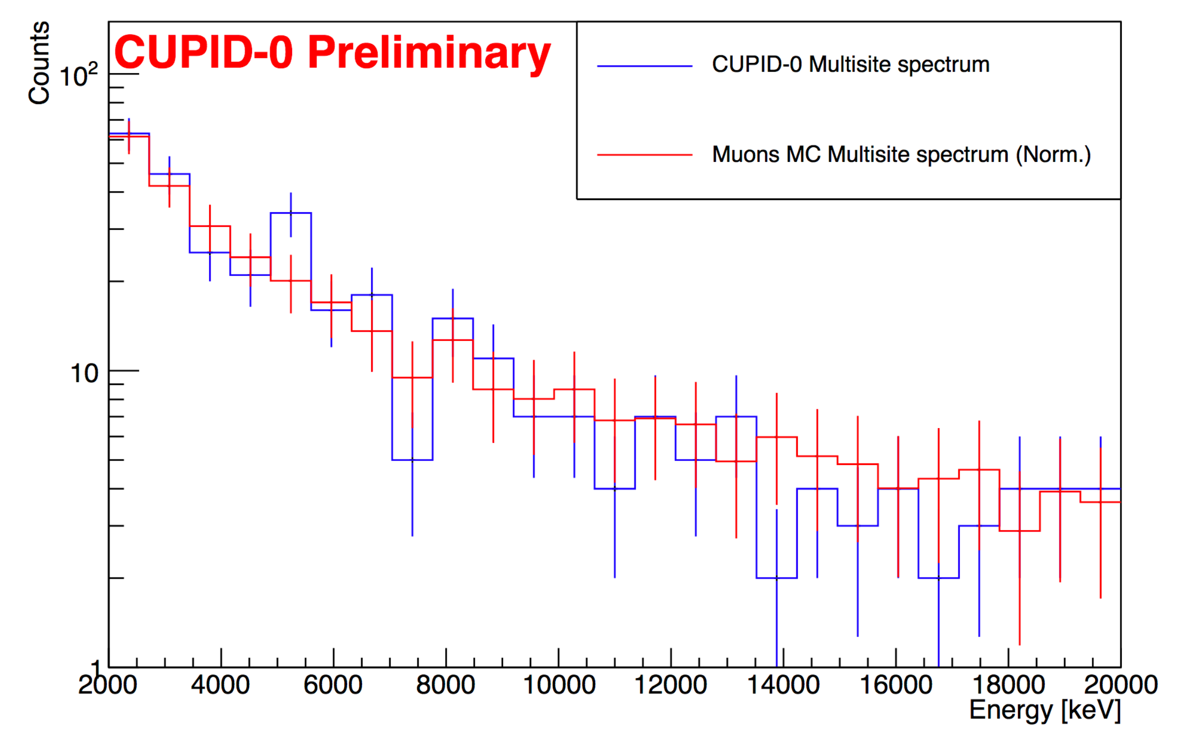
^{82}Se(2νββ): Continuum energy spectrum: $(9.2 \pm 0.7) \cdot 10^{19}$ y

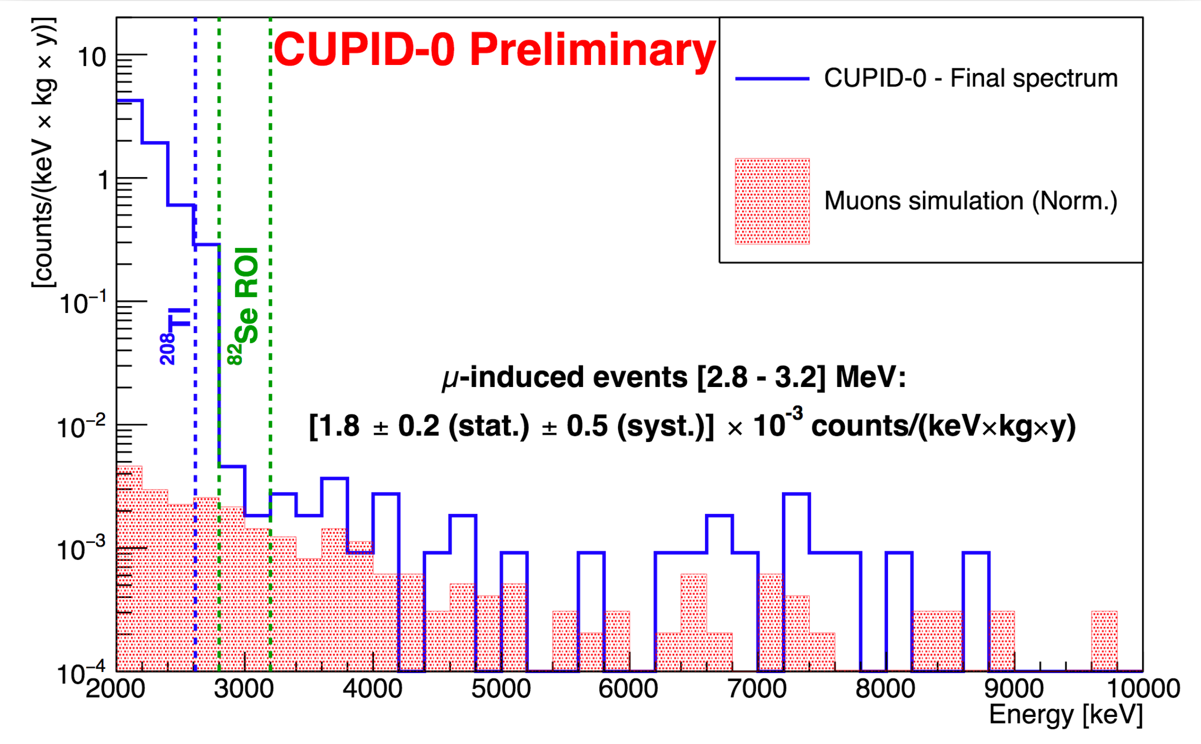
NEMO3: $(9.39 \pm 0.17\,stat \pm 0.58\,sys) \cdot 10^{19}$ y

A. S. Barabash, https://arxiv.org/pdf/1806.05553.pdf

Background model (2)

Total background energy spectrum





- The small volume of the detector prevents an efficient identification of μ events.
  - High multiplicity events for μ norm. factor
  - Comparison data vs. MC
  - Relevant μ contribution in the ROI (~50%)

(1.8 ± 0.2*stat* ± 0.5*sys*)*10^{-3} c/keV/kg/y

- Full-comprehensive background model is on-going
  - Hard because of the extremely low statistics
  - High decay rate of ^{82}Se 2νββ

Conclusions

- The first next generation 0vββ demonstrator is smoothly taking data.
- The efficient α-background rejection was demonstrated and allows to reach an unprecedented BKG level for a bolometric experiment

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

- The analysis of the first data (5.46 kg y of ZnSe) allows to set the best limit on ^{82}Se 0vββ half-life

$T^{0v} > 4.0 \cdot 10^{24}$ yr @ 90C.L. **$m_{\beta\beta} < (290\text{-}596)^{1}$ meV**

- We plan to reach an exposure of 10 kg y of ZnSe in order to obtain a reliable background model
- The scintillating bolometric technique is suitable for investigating the v IH rmass region

1

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