First CUPID-0 results

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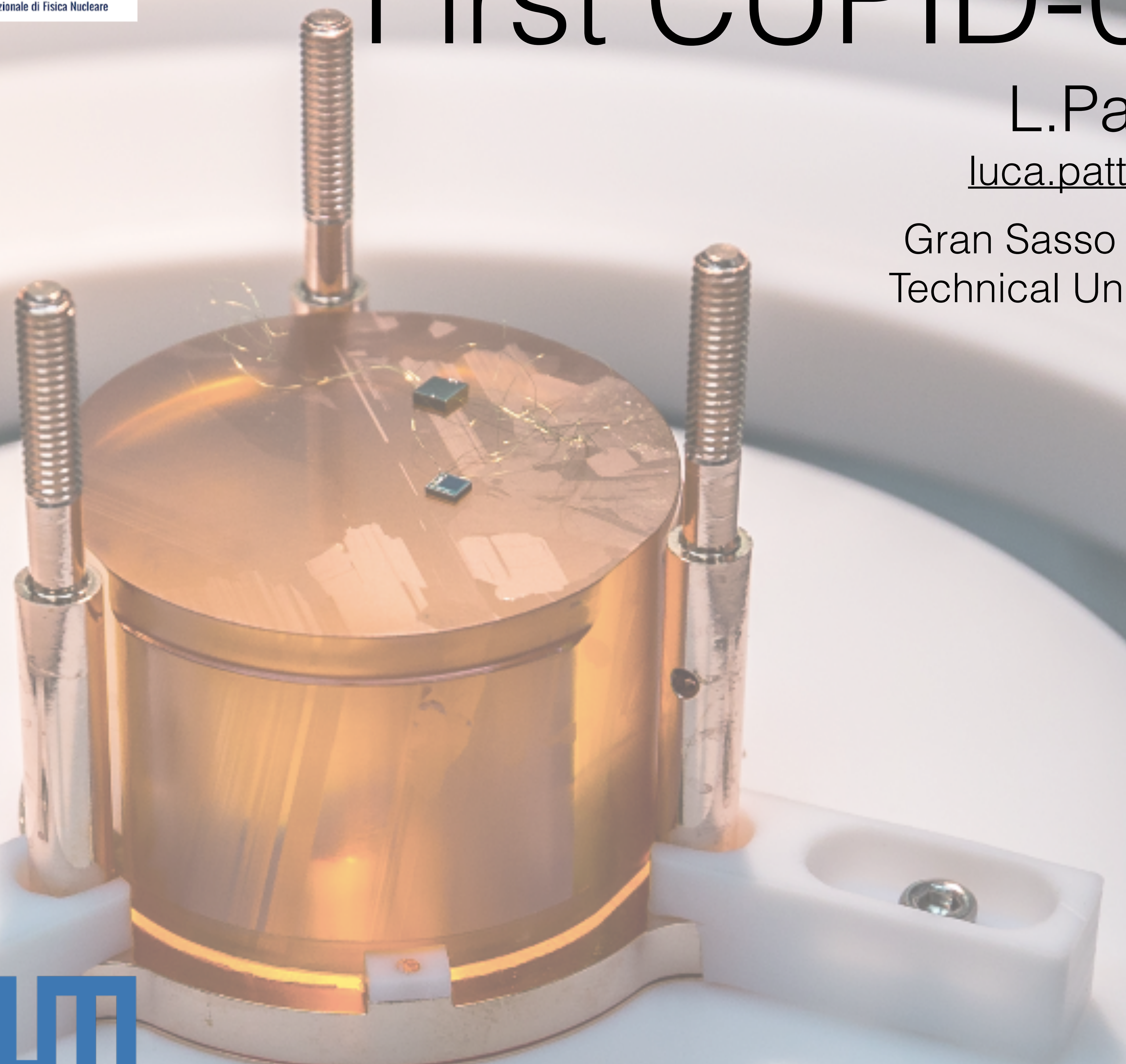


Technische Universität München

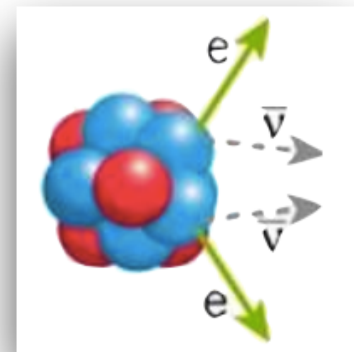
GDR Neutrino meeting June 11-12 2018

Outline

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

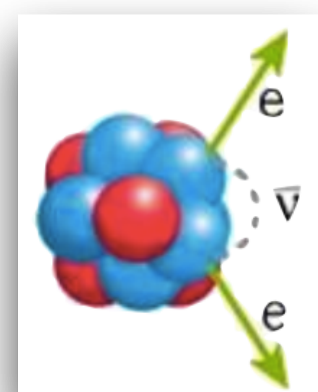
Double-beta decay

- One of the rarest observed nuclear decay is 2νββ: $(A,Z) \rightarrow (A,Z+2) + 2e^- + 2\bar{\nu}$



- ☑ 2^{nd} order transition
- ☑ even-even nuclei where the β-decay is suppressed
- ☑ Half-lives of the order of 10^{21} y

- **If** neutrino are massive Majorana particle, 0νββ may occur: $(A,Z) \rightarrow (A,Z+2) + 2e^-$



- ☐ Neutrino Majorana nature
- ☐ Lepton number violation ΔL=2
- ☐ Infos on neutrino: mass & hierarchy

Effective Majorana mass

$$m_{\beta\beta} = |\Sigma_i U_{ei}^2 m_i|$$

- By measuring the half-life of the decay:

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

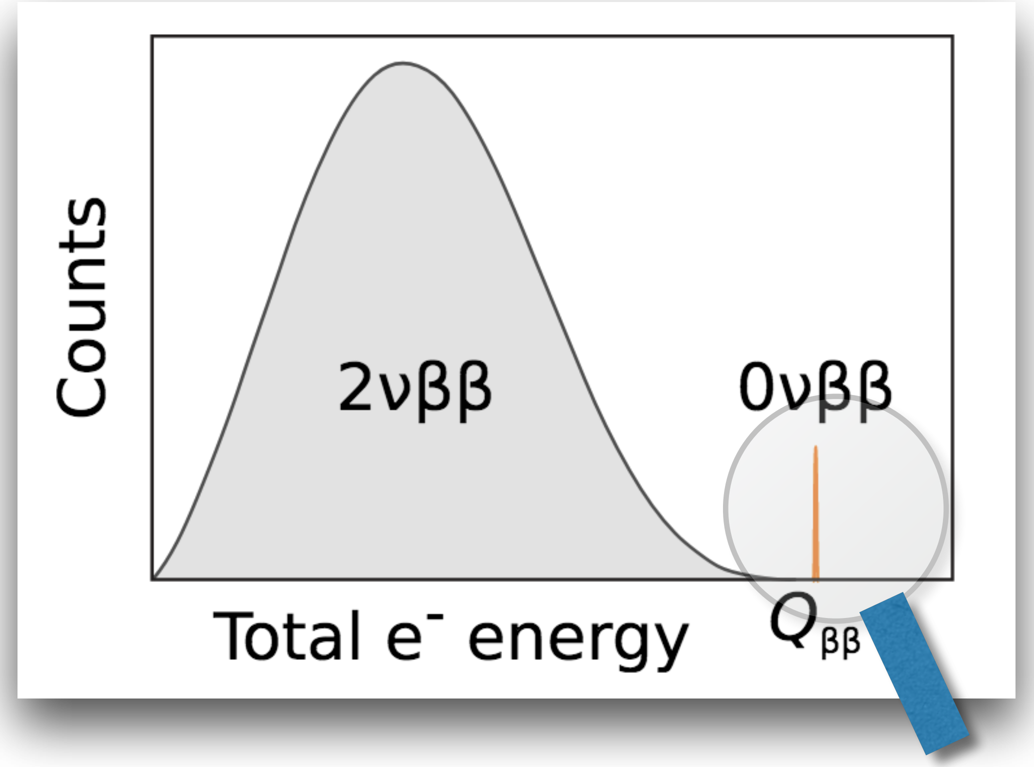
Nuclear Matrix element

Phase space

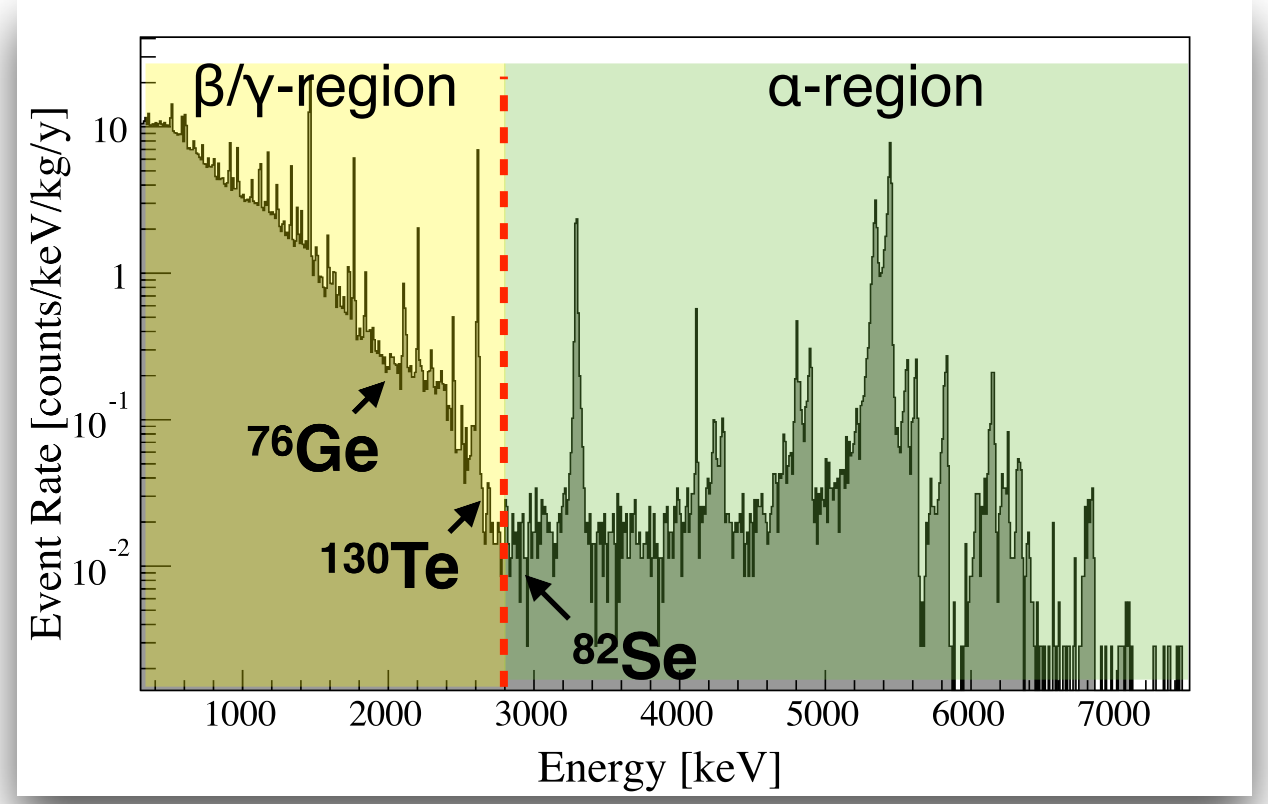
Expected signal & bkg

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

Computed energy spectrum



Energy spectrum from natural radioactivity



- Most of the β/γ events extends up to 2.6 MeV
- α events extends up to 8 MeV

High 0νββ Q-value ➜ low β/γ background

Zero-bkg ➜ sensitivity scales linearly with exposure

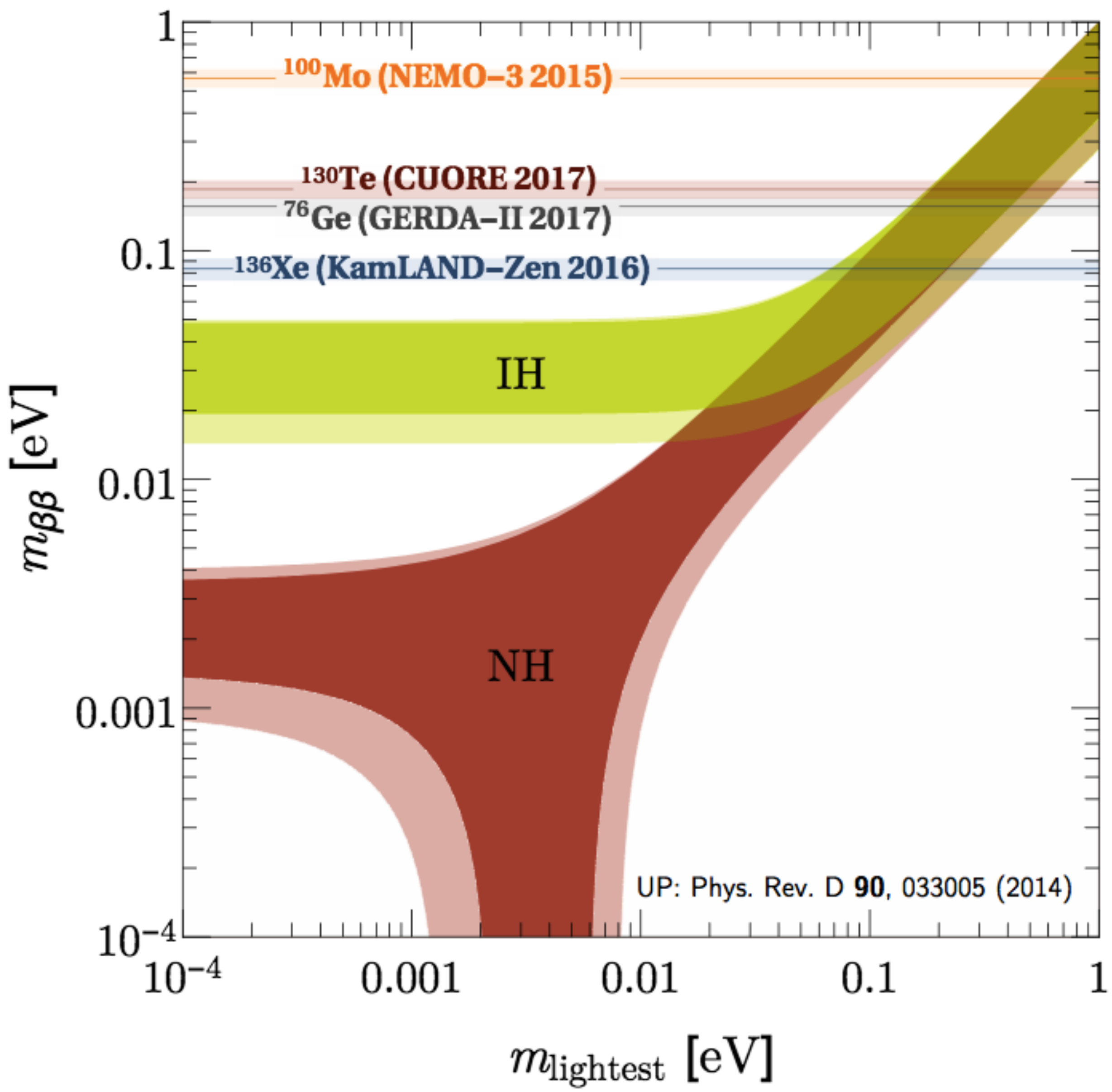
Neutrino mass sensitivity

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.



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

Tomorrow
M~100-1000 kg isotope
B~10^{-3} 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 $\times$ 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 *
- Improved material selection
- Better energy resolution
- Reduced cosmo-activation

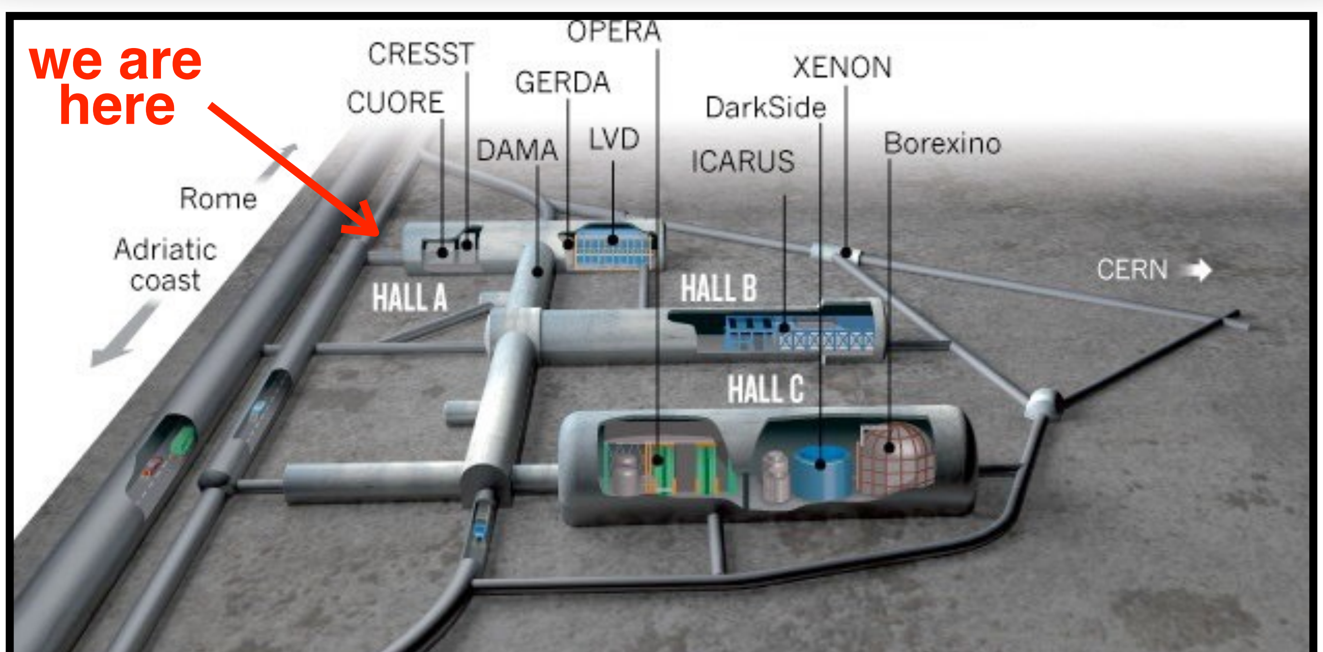
$\left.\begin{matrix}* \\ *\end{matrix}\right\}$ CUPID-0

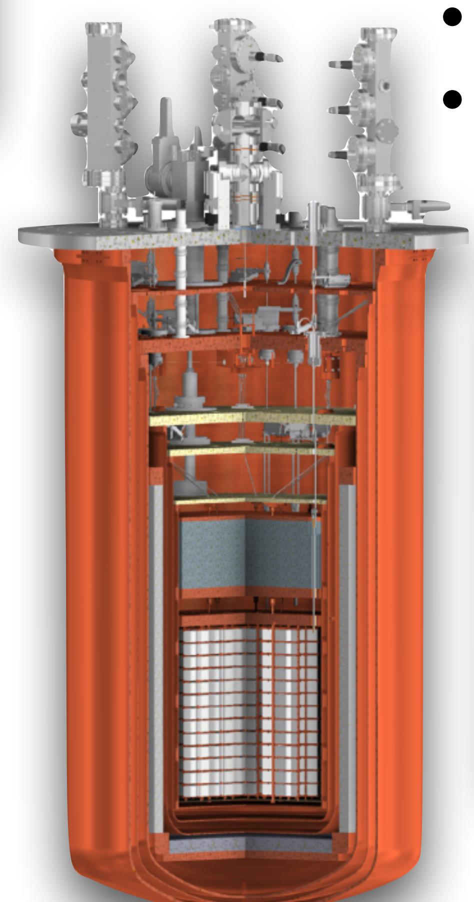
The underground facility

Experimental location:

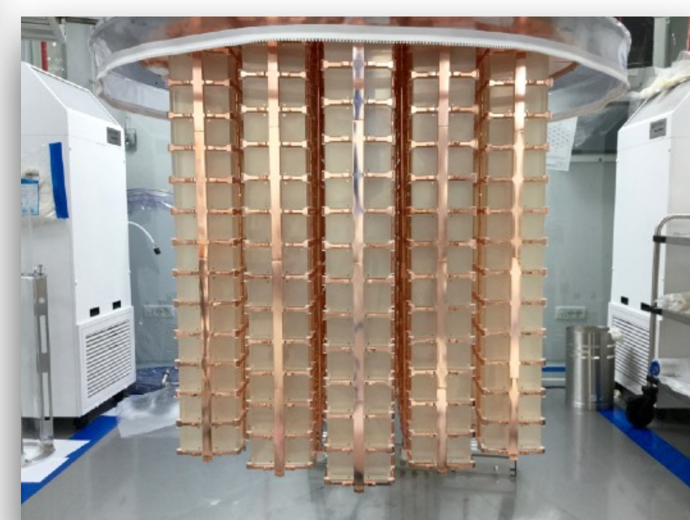
- Average depth ~ 3600 m w.e.
- Muon flux ~ 2.6×10^{-8} μ/s/cm²
- Neutrons < 10 MeV: $<10^{-6}$ n/s/cm²

CUORE: unique infrastructure for low background physics with bolometers





- 1 m³ detector @ 10 mK
- 10 ton shields @ 10 mK

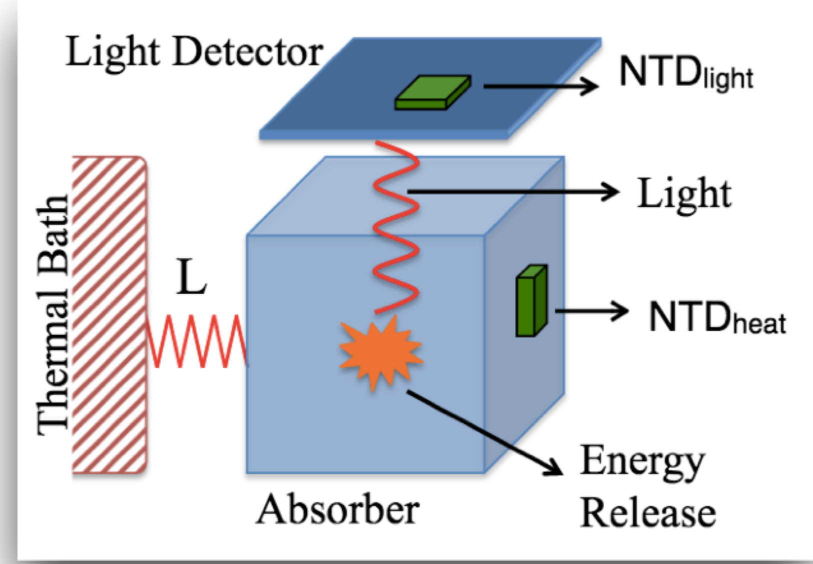


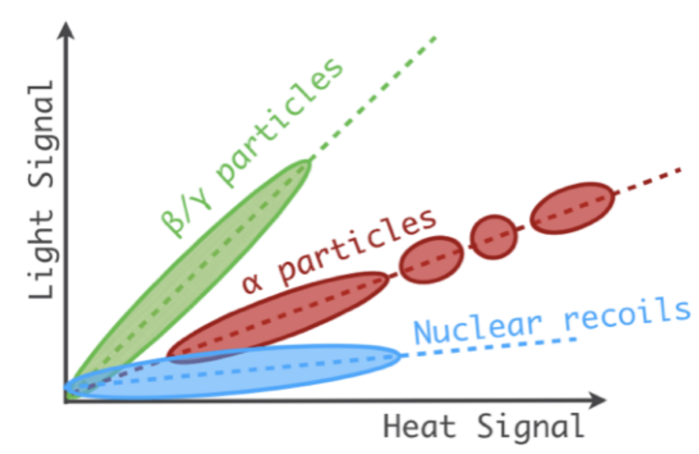
Scintillating bolometers

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:

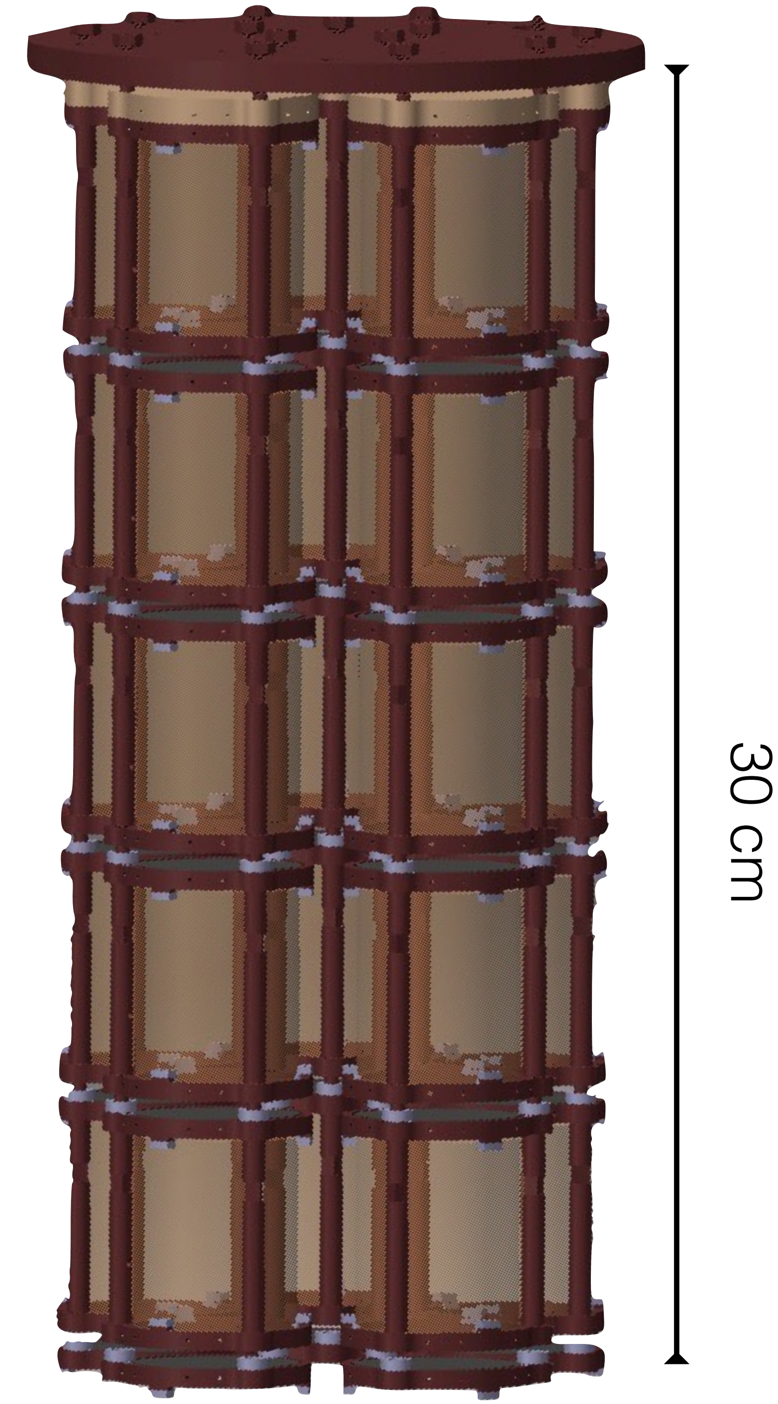
- high energy resolution O(1/1000)
- wide choice of compound $^{130}TeO_2$, $Zn/Li_2{}^{100}MoO_4$, $Zn^{82}Se$
- high detection efficiency (source = detector)
- scalable to large masses
- **particle ID**

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 $0\nu\beta\beta$

- ^{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 -> $N_{\beta\beta} = 3.8 \times 10^{25}$ $\beta\beta$ 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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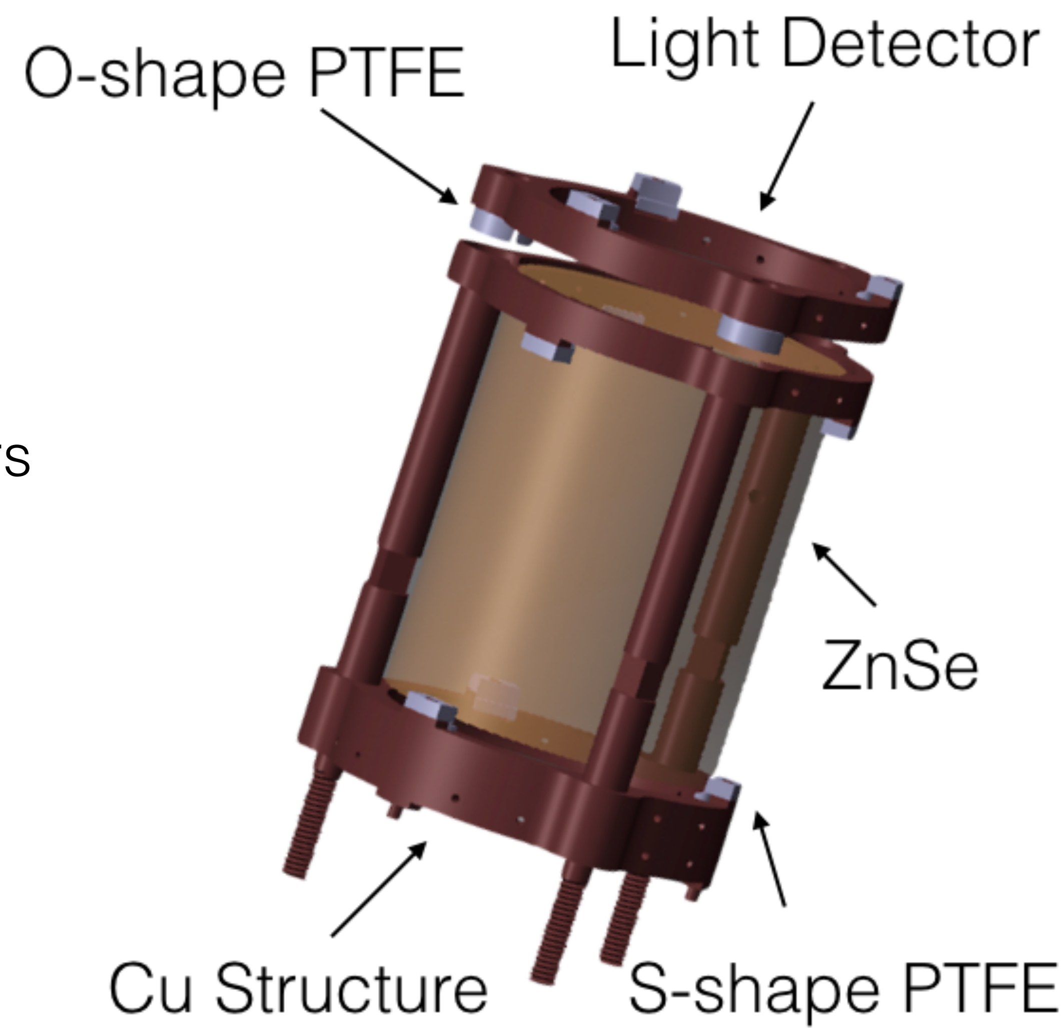


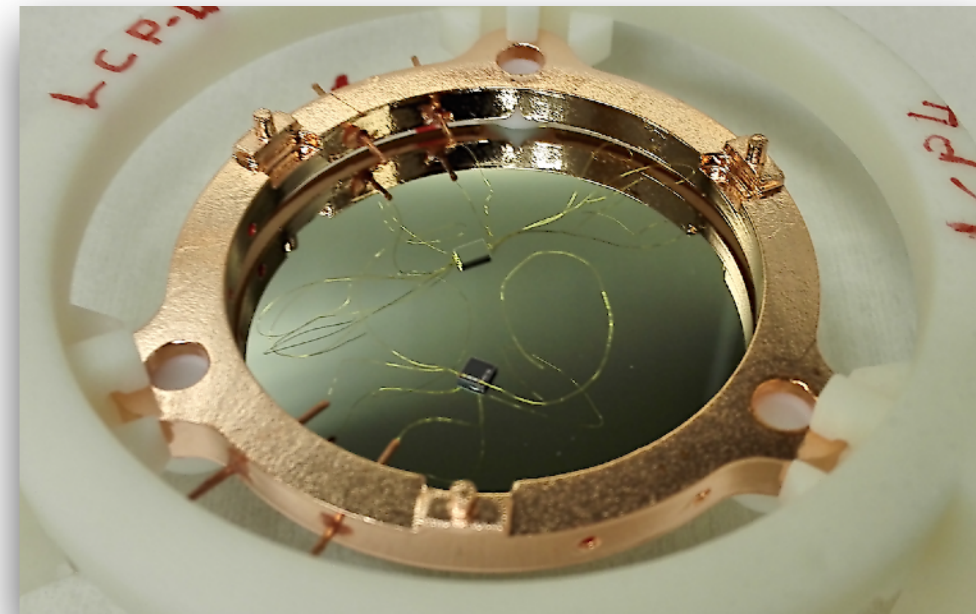
This design has the main goal of
Minimize mass of passive materials
Cu ~22% - PTFE/Vik. ~0.1% - ZnSe+Ge ~78%

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

LD for α background rejection

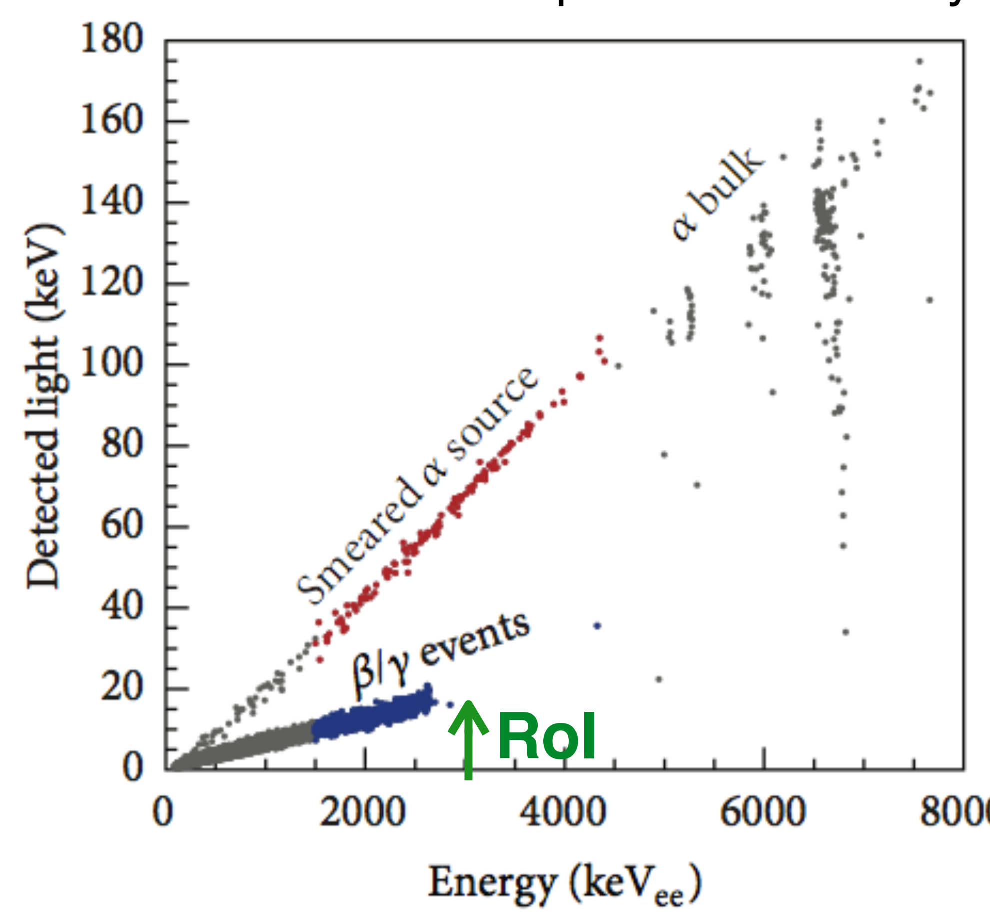
- Well established technology for bolometric LDs

	PMT	Bolometer
Quantum efficiency	✘	✔
Energy resolution efficiency	✘	✔
Intrinsic radiopurity	✘	✔
Work @ low T	✘	✔
Energy threshold	✔	✘



- LD: Ge wafer + SiO coating (60 nm) + Ge-NTD
- LD performance are crucial for background suppression
  - Light vs Heat: possible α leakage in β/γ ROI
  - Pulse Shape Analysis of Light: efficient particle-ID

Calibration scatter plot of a ZnSe crystal



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

CUPID-0 operates 31 LDs

LD for a background rejection

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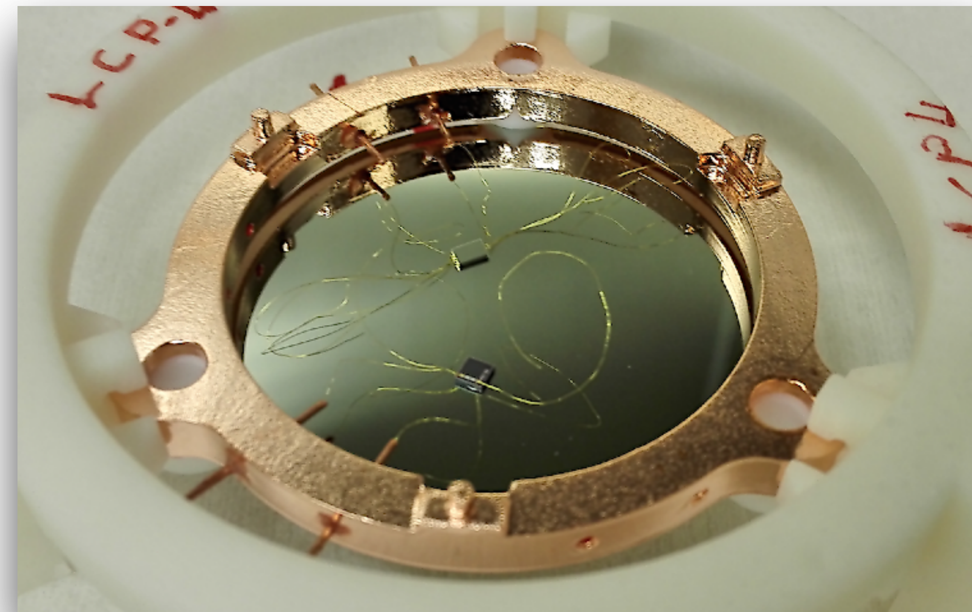

	PMT	Bolometer
Quantum efficiency	✗	✔
Energy resolution efficiency	✗	✔
Intrinsic radiopurity	✗	✔
Work @ low T	✗	✔
Energy threshold	✔	✗

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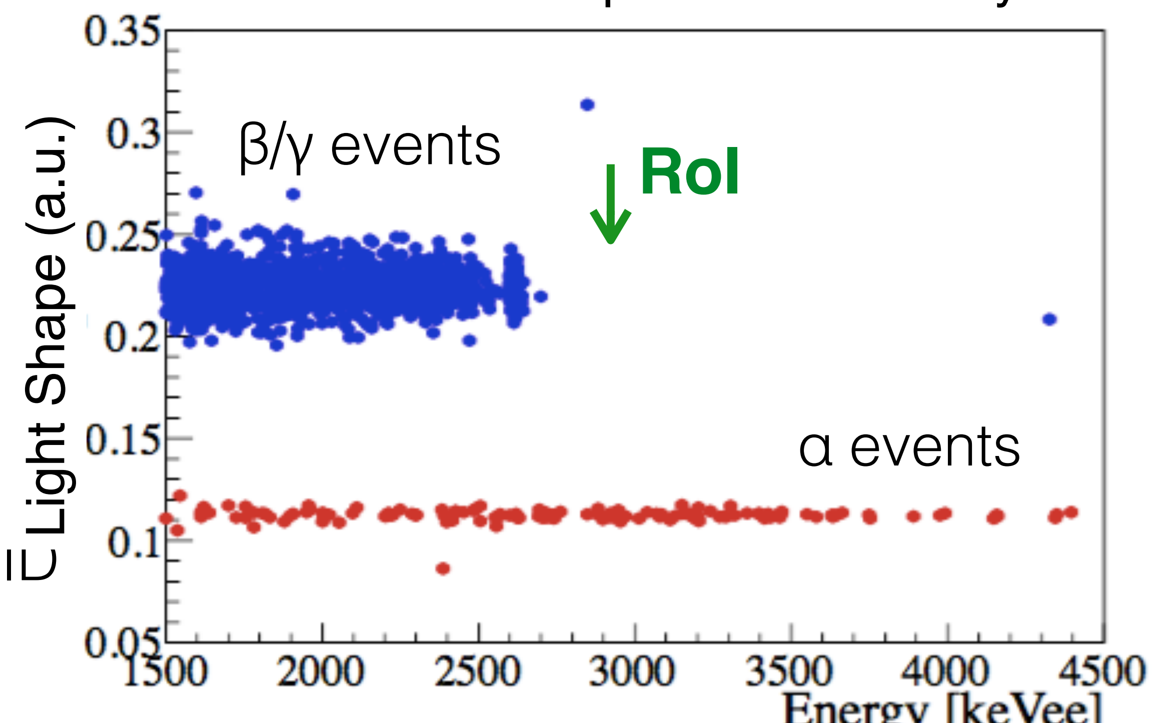

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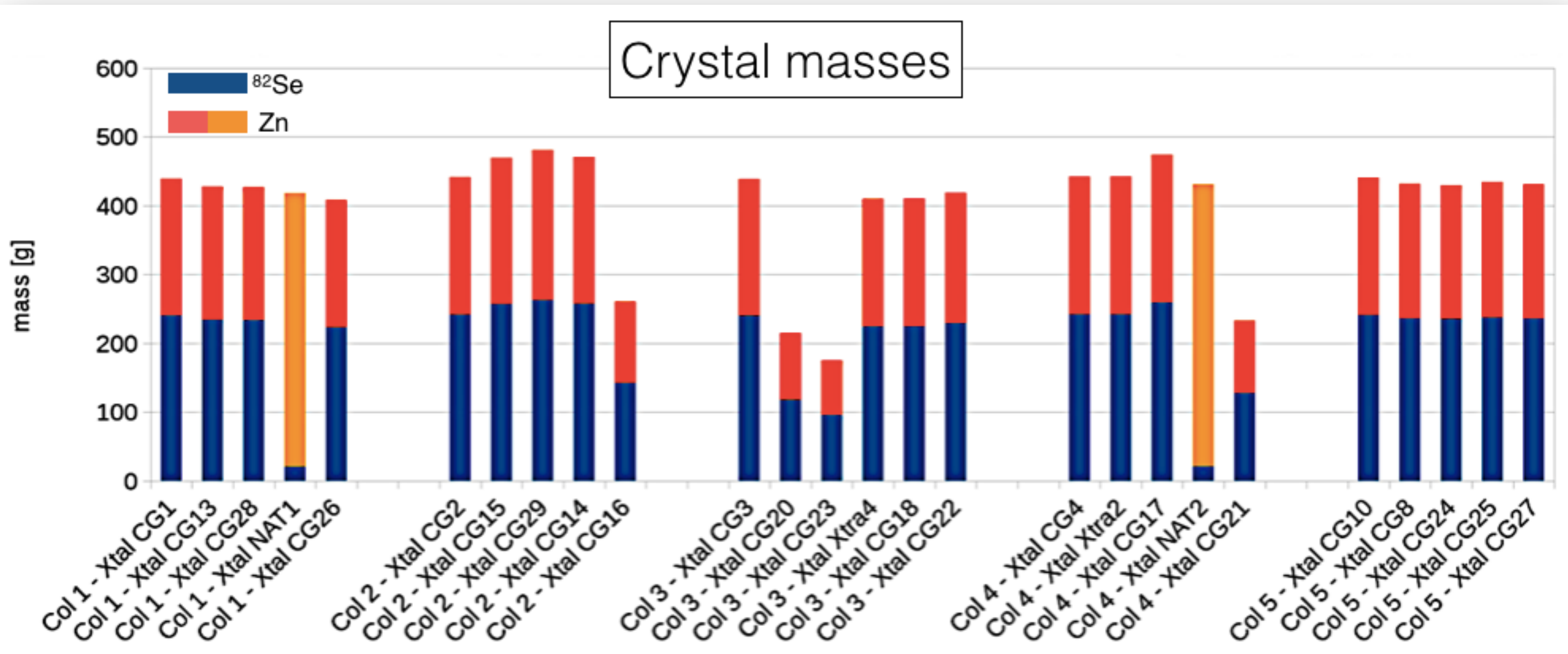
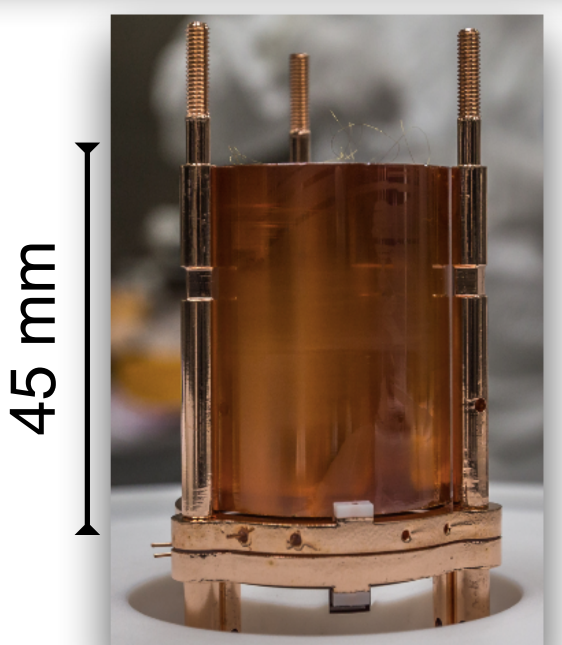
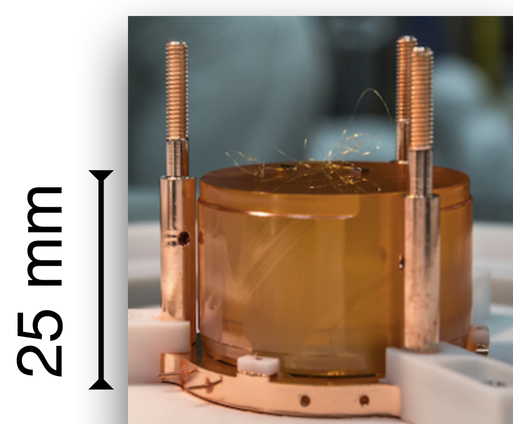
CUPID-0 operates 31 LDs

CUPID-0 assembly

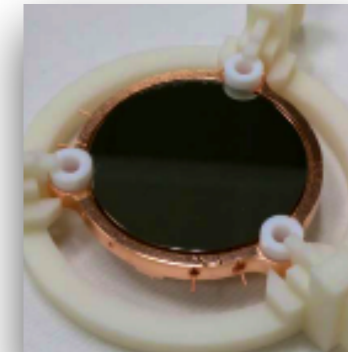
Complex detector design: CUPID-0 crystals have all different shapes and heights ranging from 21 mm to 58 mm.



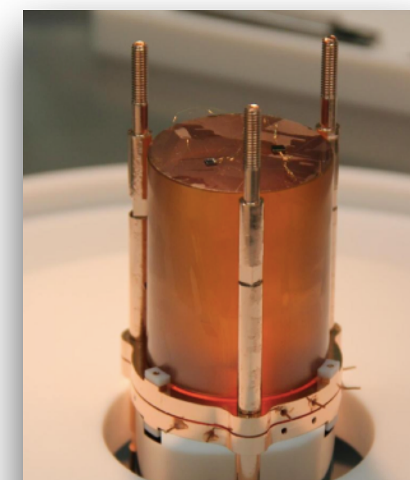




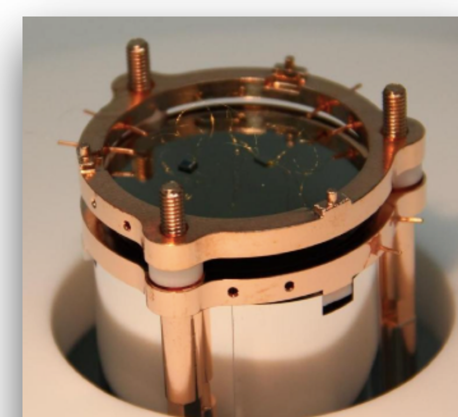
Assembly started in Oct-2016



#1 LD installation



#2 ZnSe installation

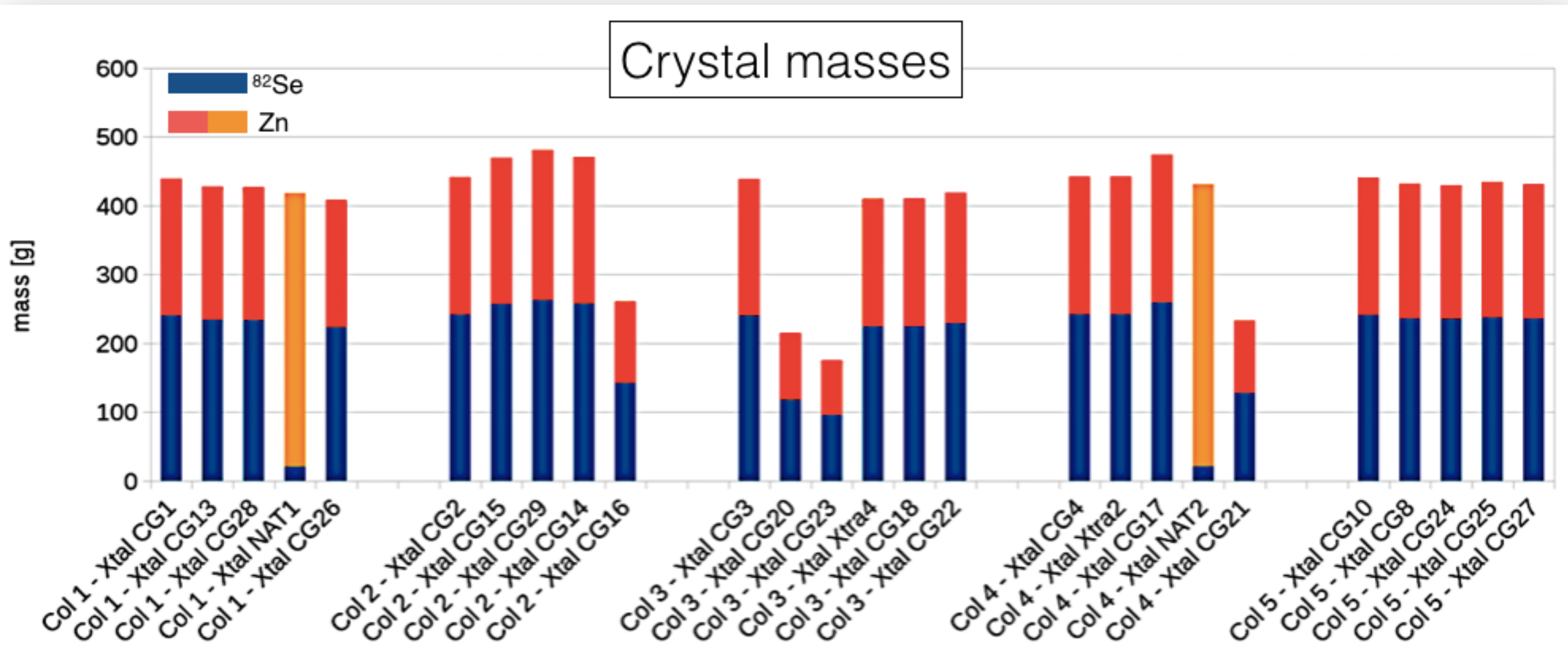


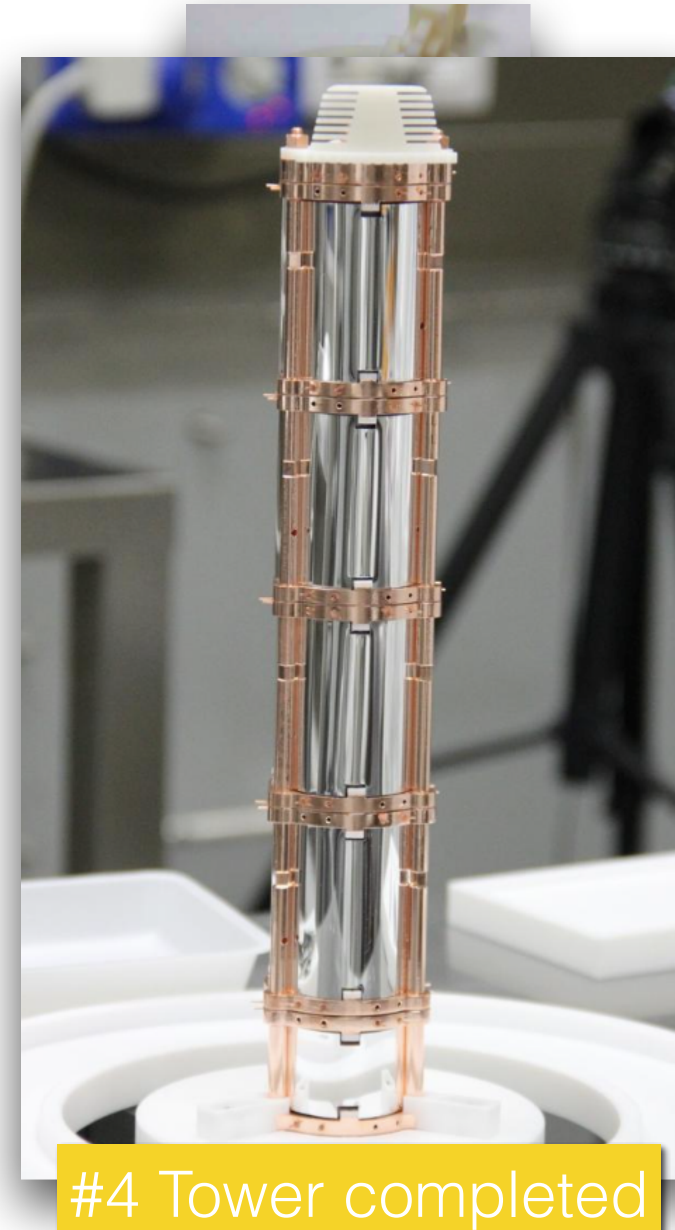
#3 LD installation

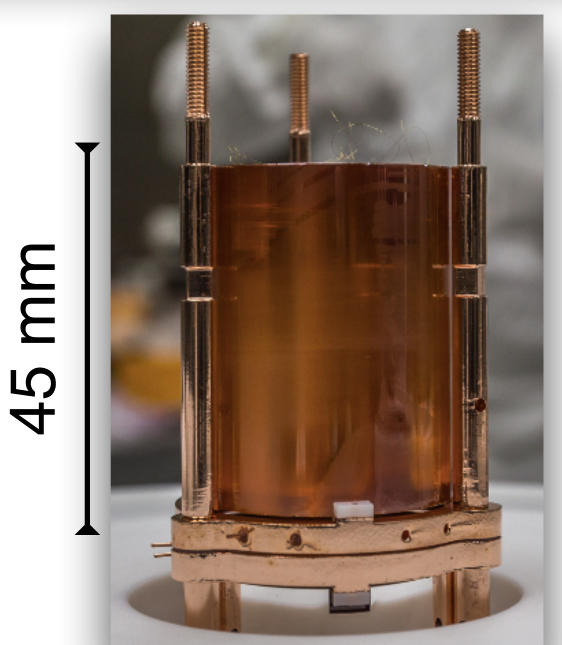
CUPID-0 assembly

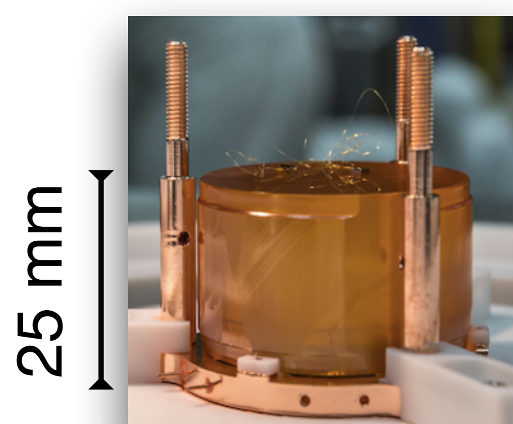
Complex detector design: CUPID-0 crystals have all different shapes and heights ranging from 21 mm to 58 mm.

Assembly started in Oct-2016







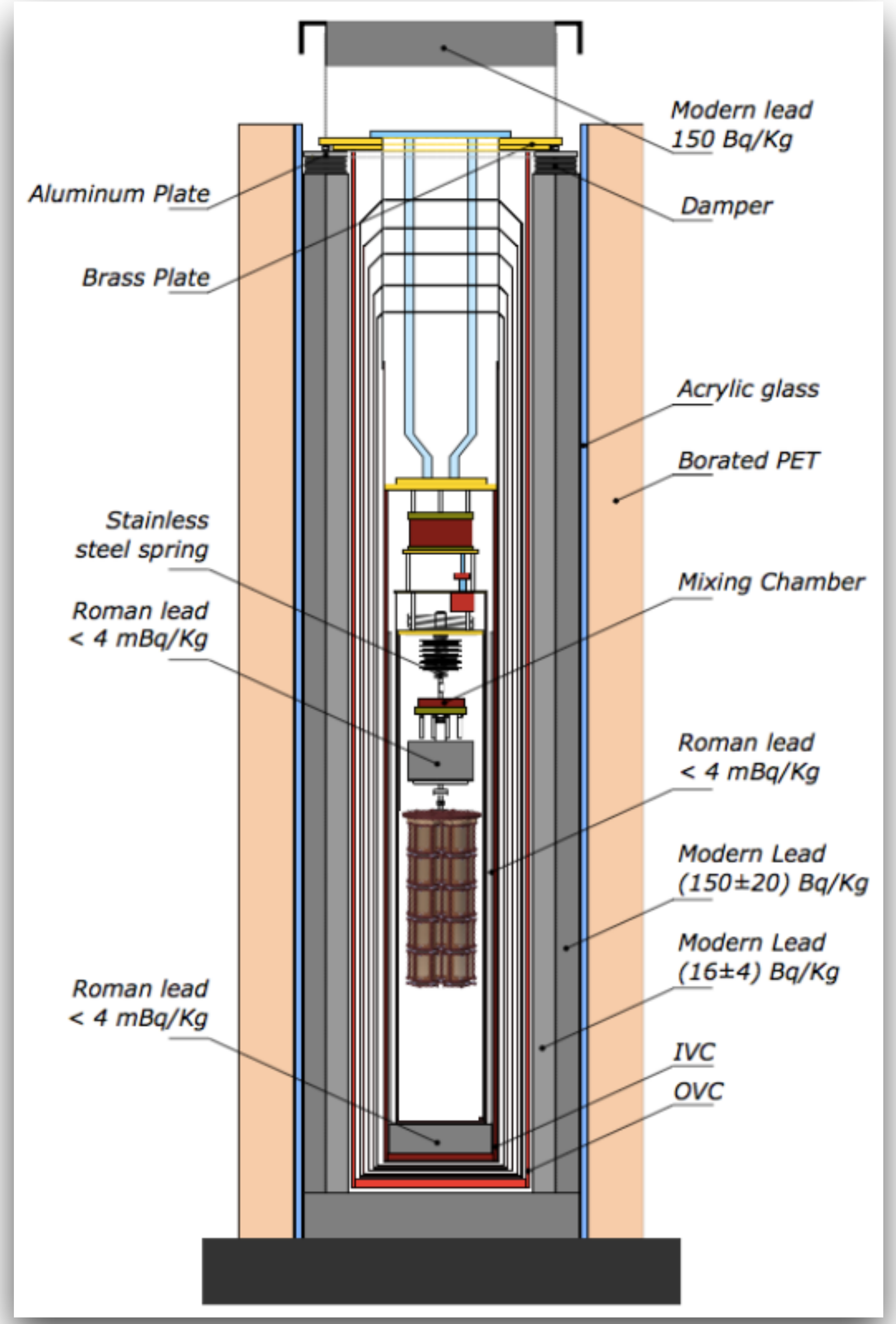


Detector installation

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

Upgrades:

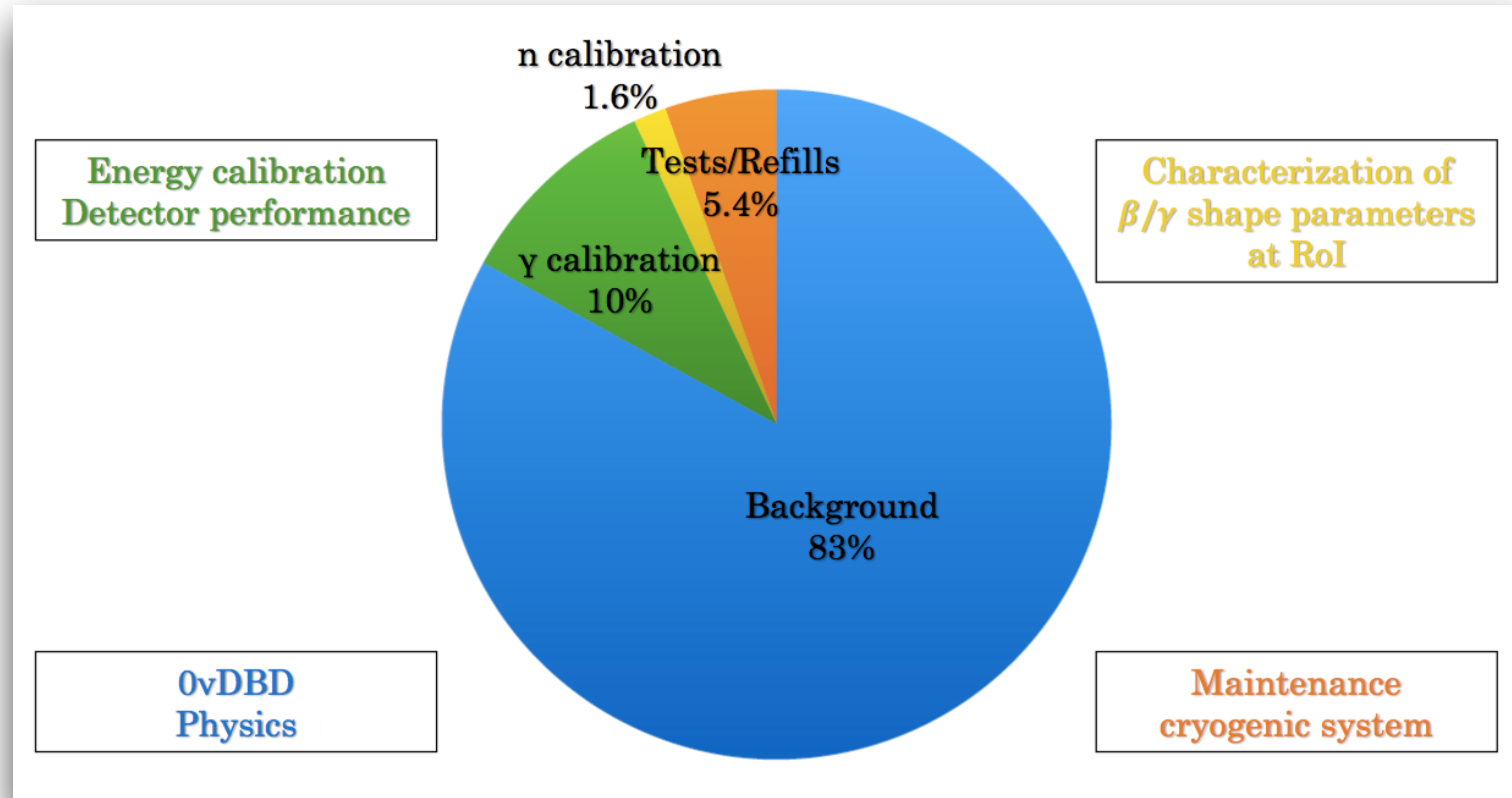
- ☐ Double stage pendulum for low vibrational noise
  - ☑ Improve LD performance
- ☐ Cryostat wiring: can host up to 120 channels
  - ☑ CUPID-0 uses more than 60 channels
  - ☑ CUPID-0/Mo next phase can be hosted
- ☐ Rn-reduction system next to the cryostat
  - ☑ Reduction and monitoring of ^{214}Bi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



Data taking

Background data presented here were collected between Jun-Dec 2017

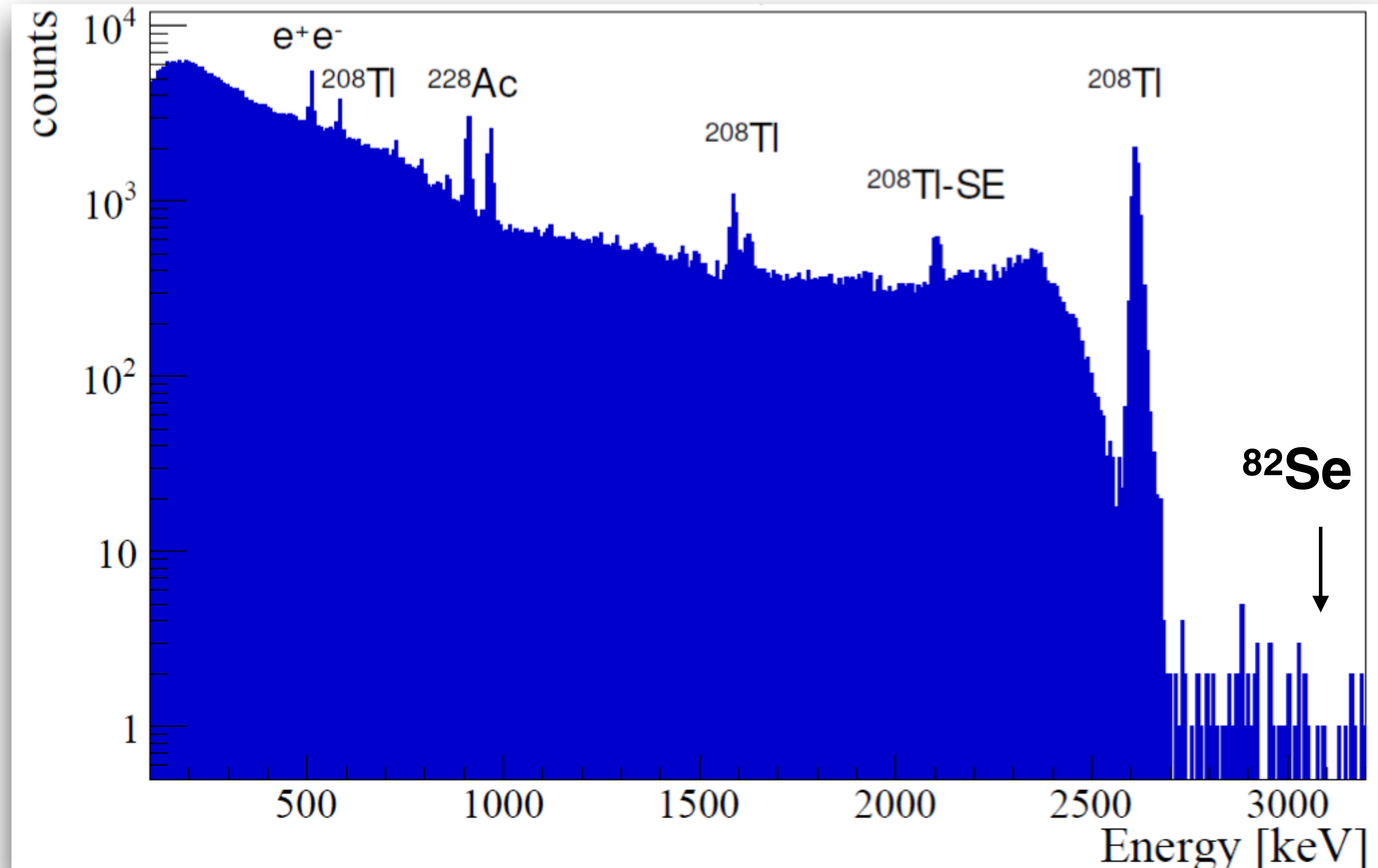
Exposure: 3.44 kg · y of ZnSe (1.83 kg · y ^{82}Se)



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

Detector performance

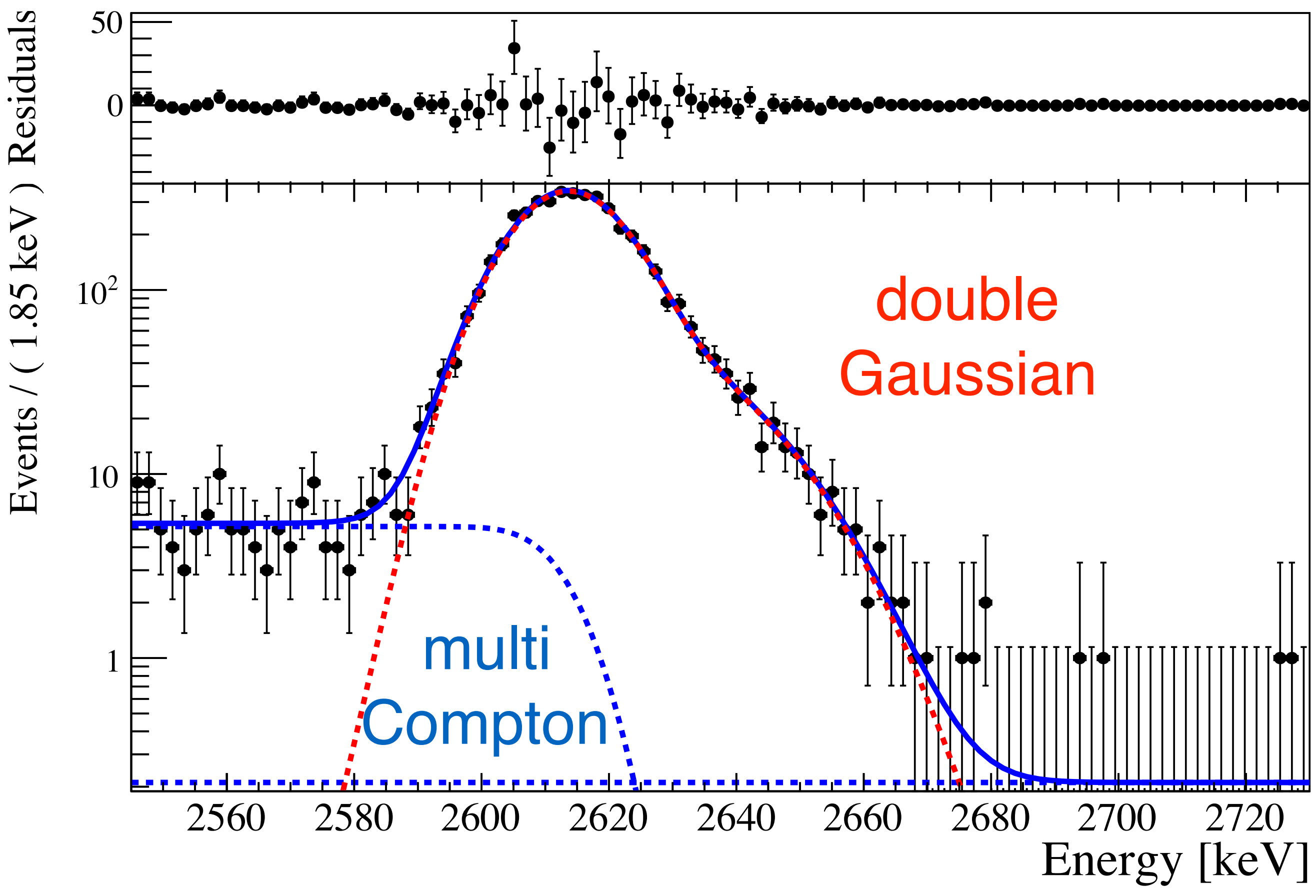
Total ^{232}Th calibration energy spectrum



Threshold is channel dependent and ranges between 10 and 110 keV

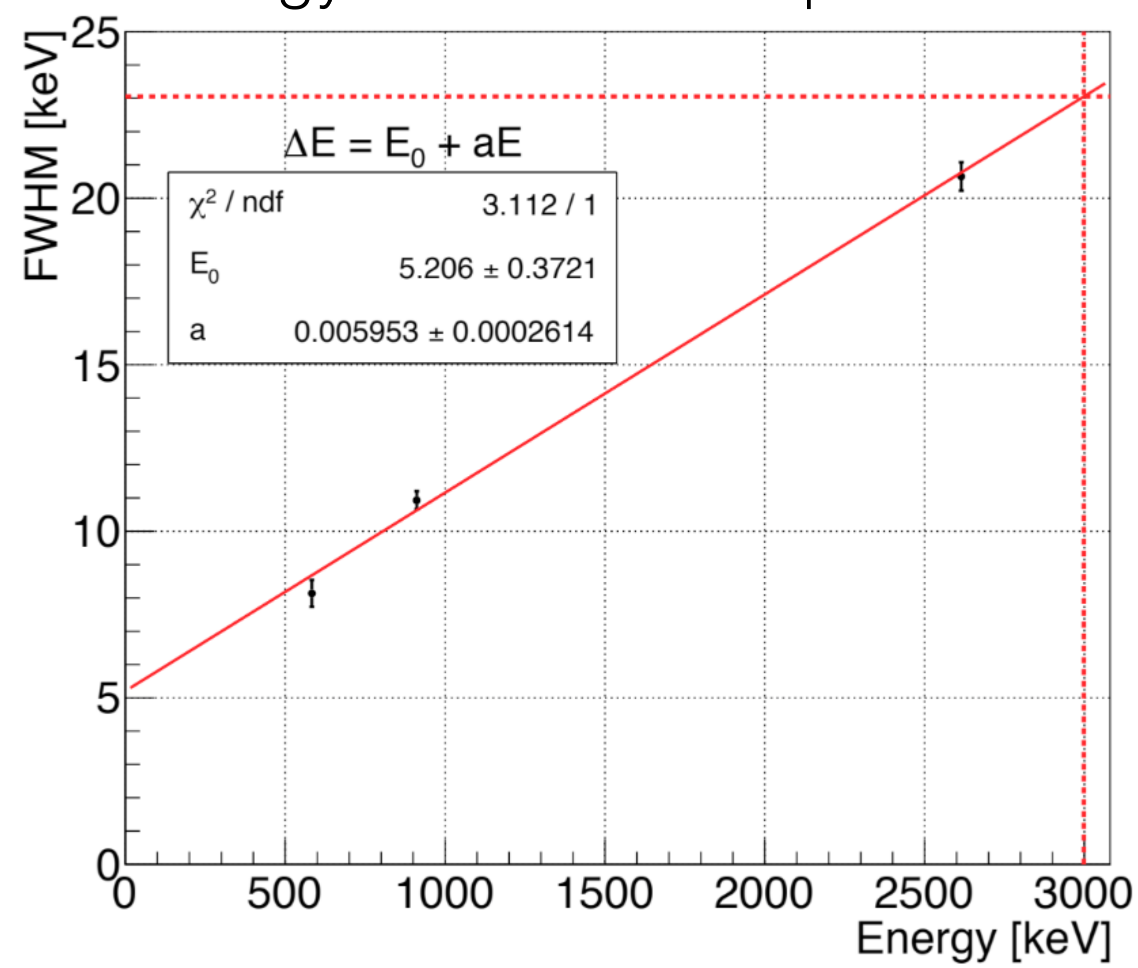
Response function

Total Background run



- ✓ Simplest model which well reproduces the detector response function over the entire spectrum
- ✓ Deviations from the single gaussian model already observed in other bolometric experiments

Energy resolution extrapolation

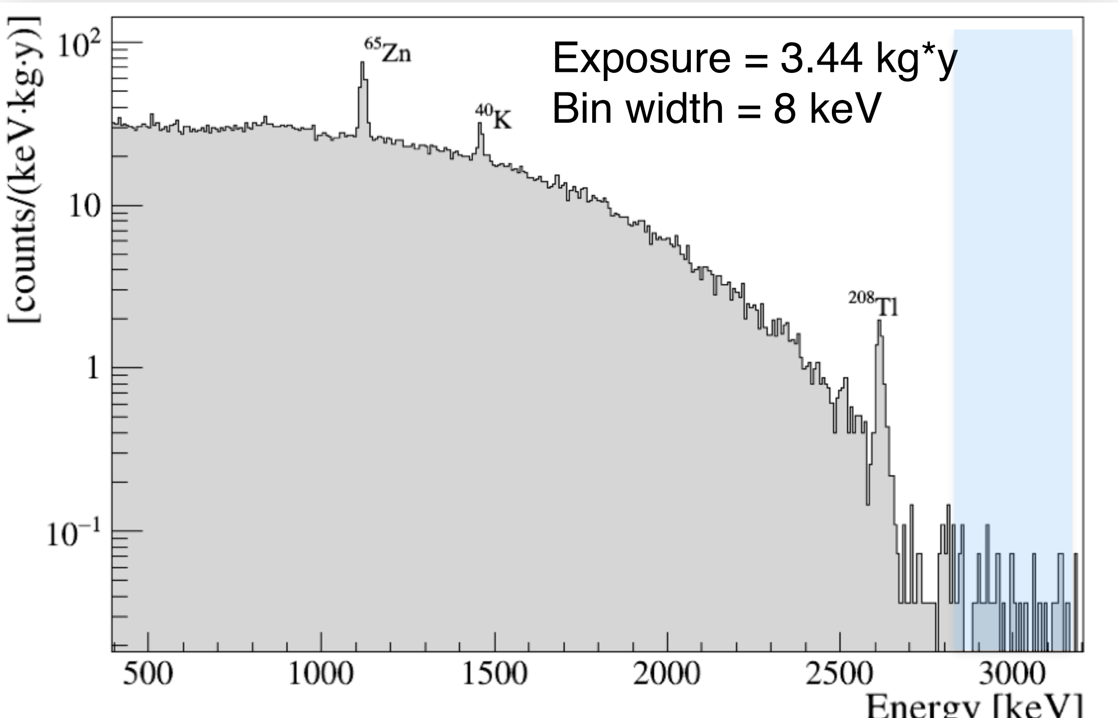


- ✓ We linearly extrapolate the width of the primary peak at $Q_{\beta\beta}$.
- ✓ The exposure-weighted harmonic mean FWHM energy resolution at the $Q_{\beta\beta}$ results to be

(23.0±0.6) keV

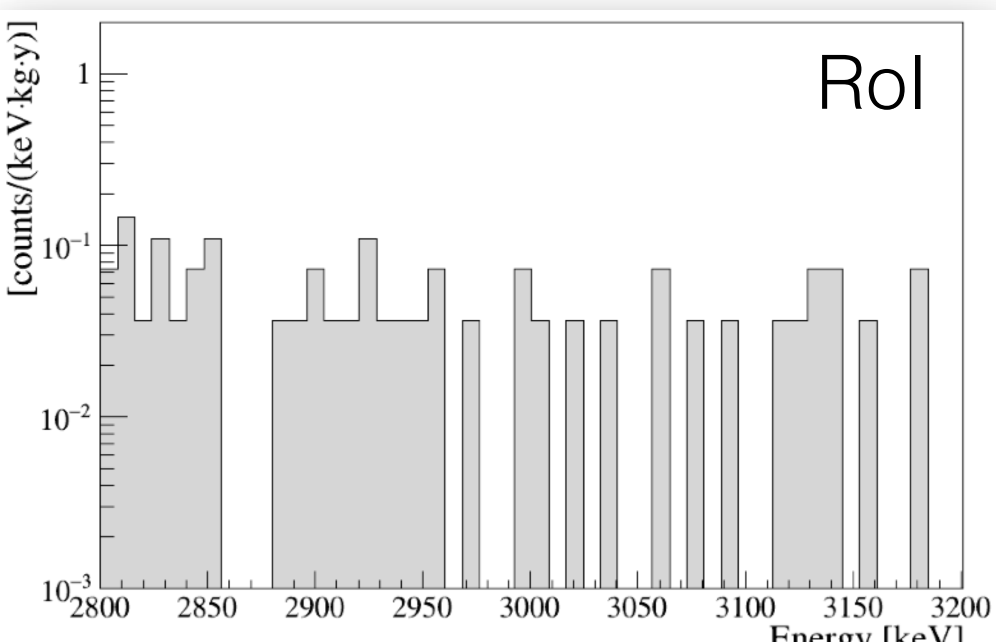
  - ✓ Validated with a dedicated ^{56}Co calibration

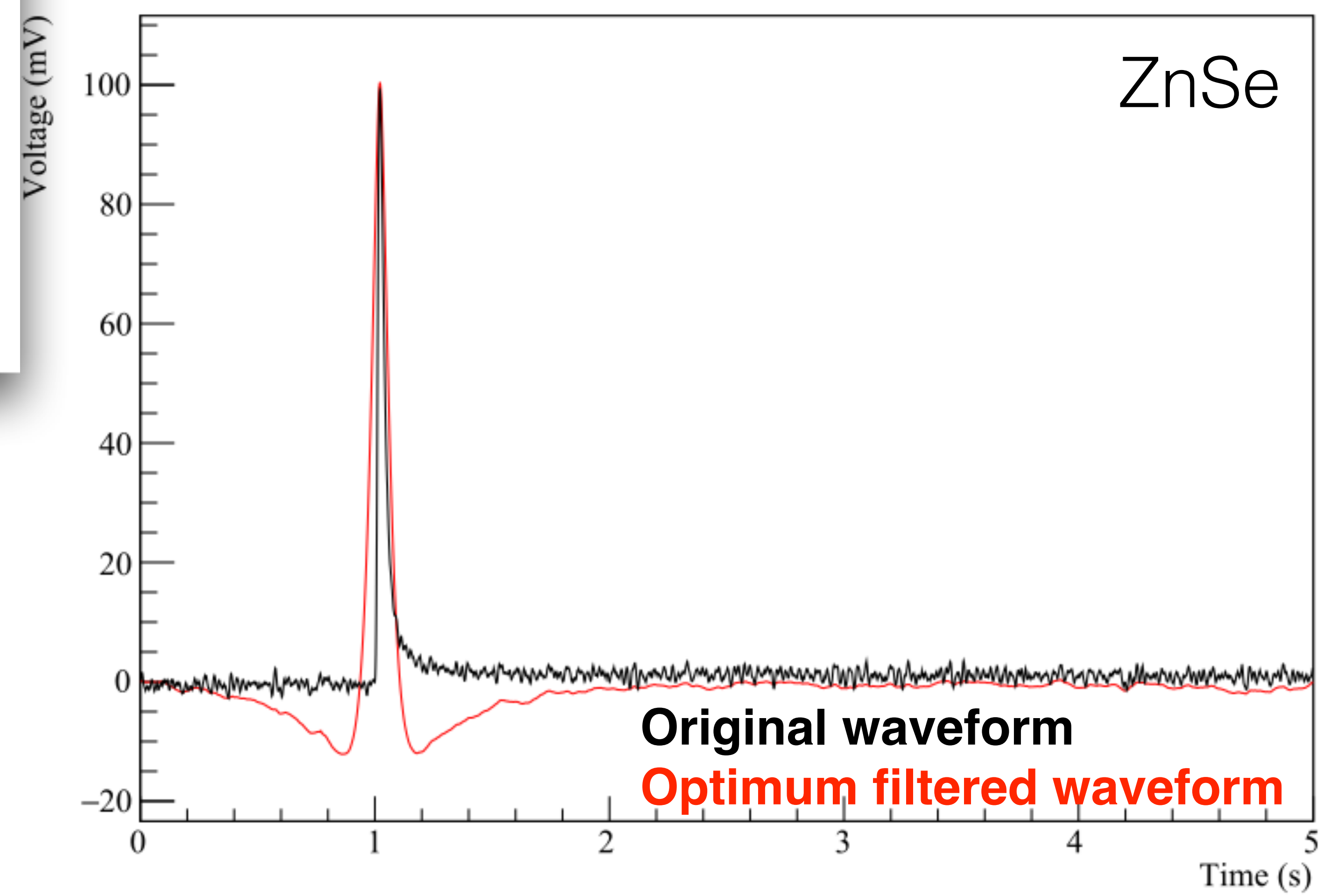
Background data selection



First level data analysis:

- Optimum filtering
- Gain stability corrections
- Synchronisation heat-light





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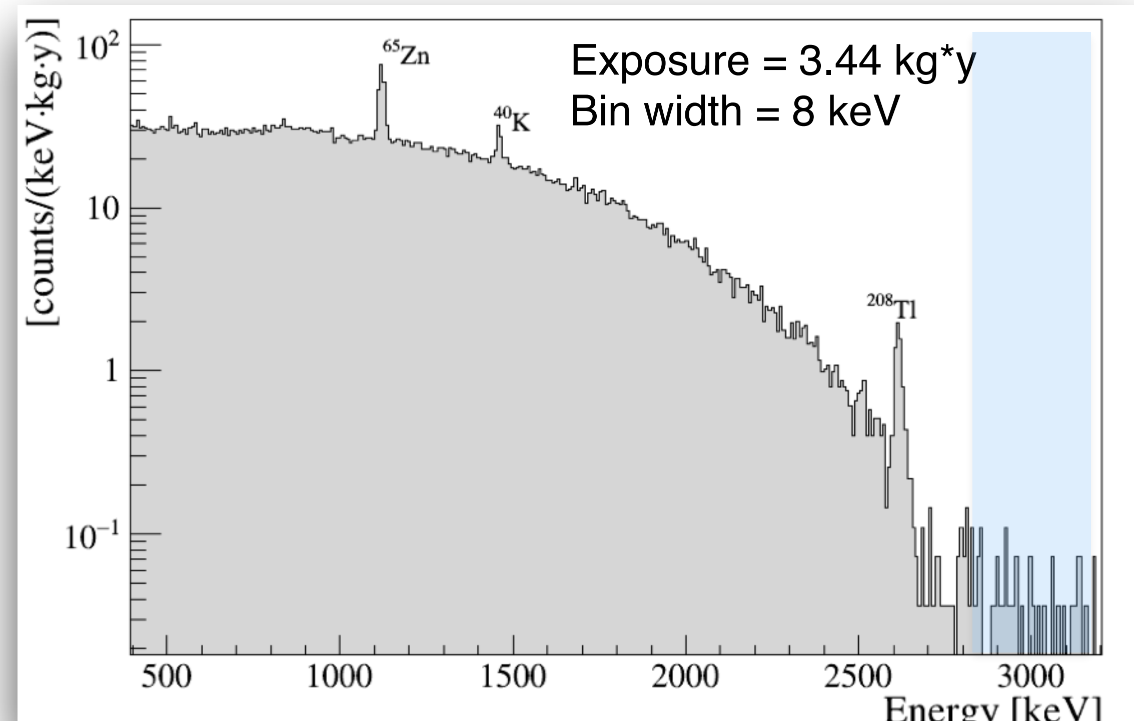

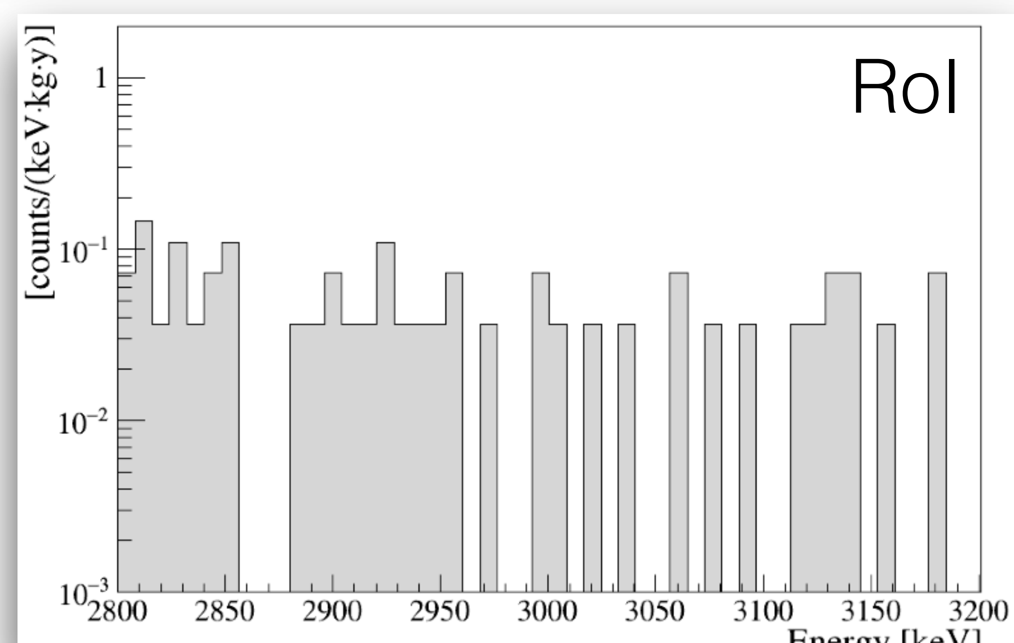

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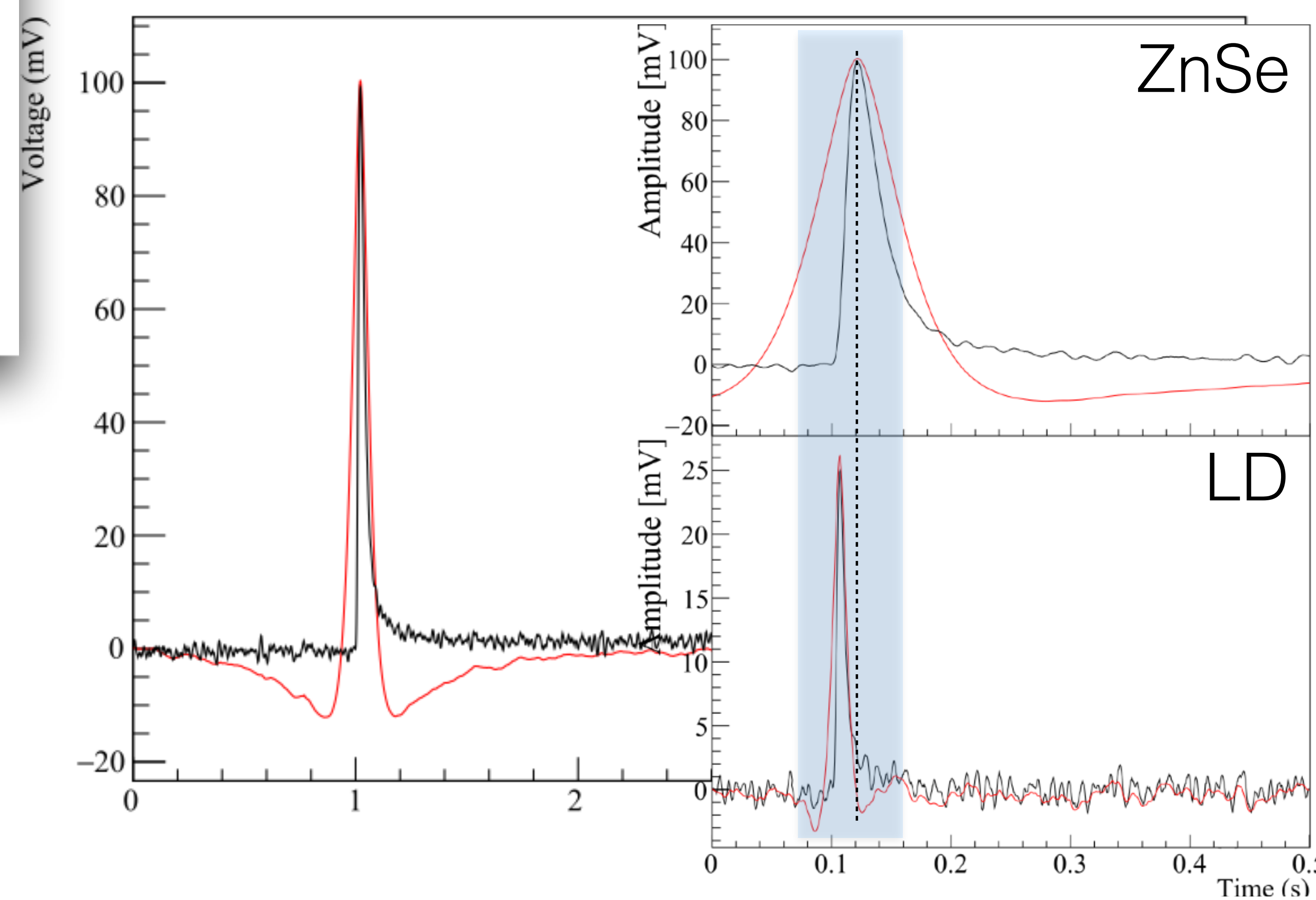

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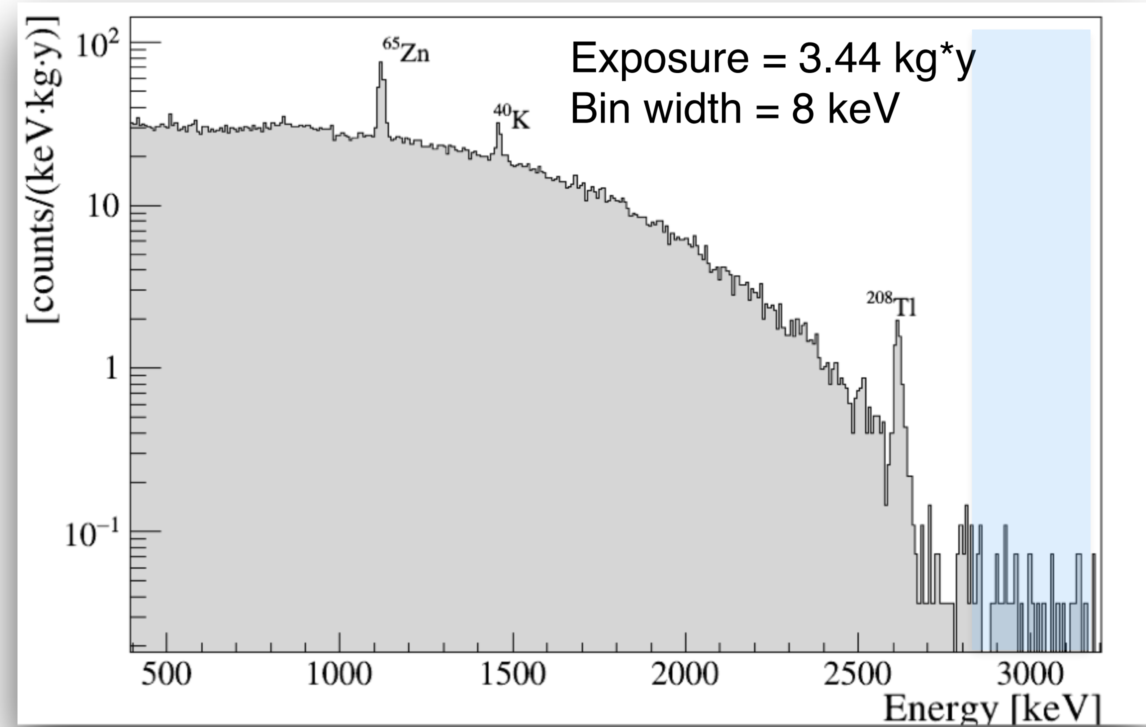

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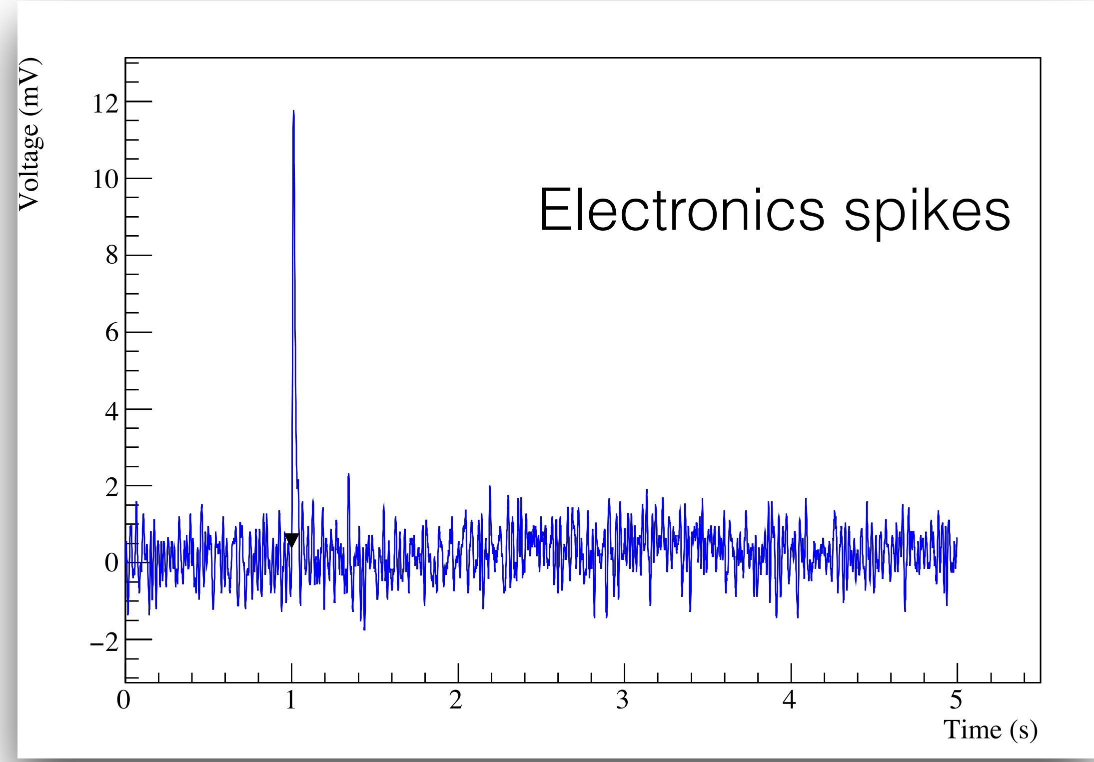
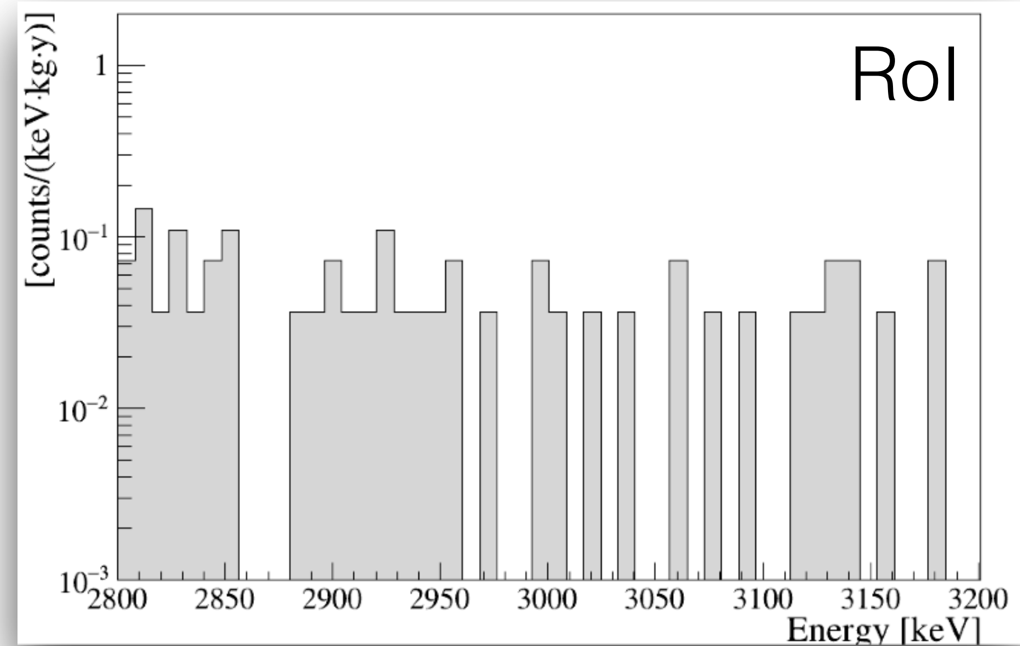
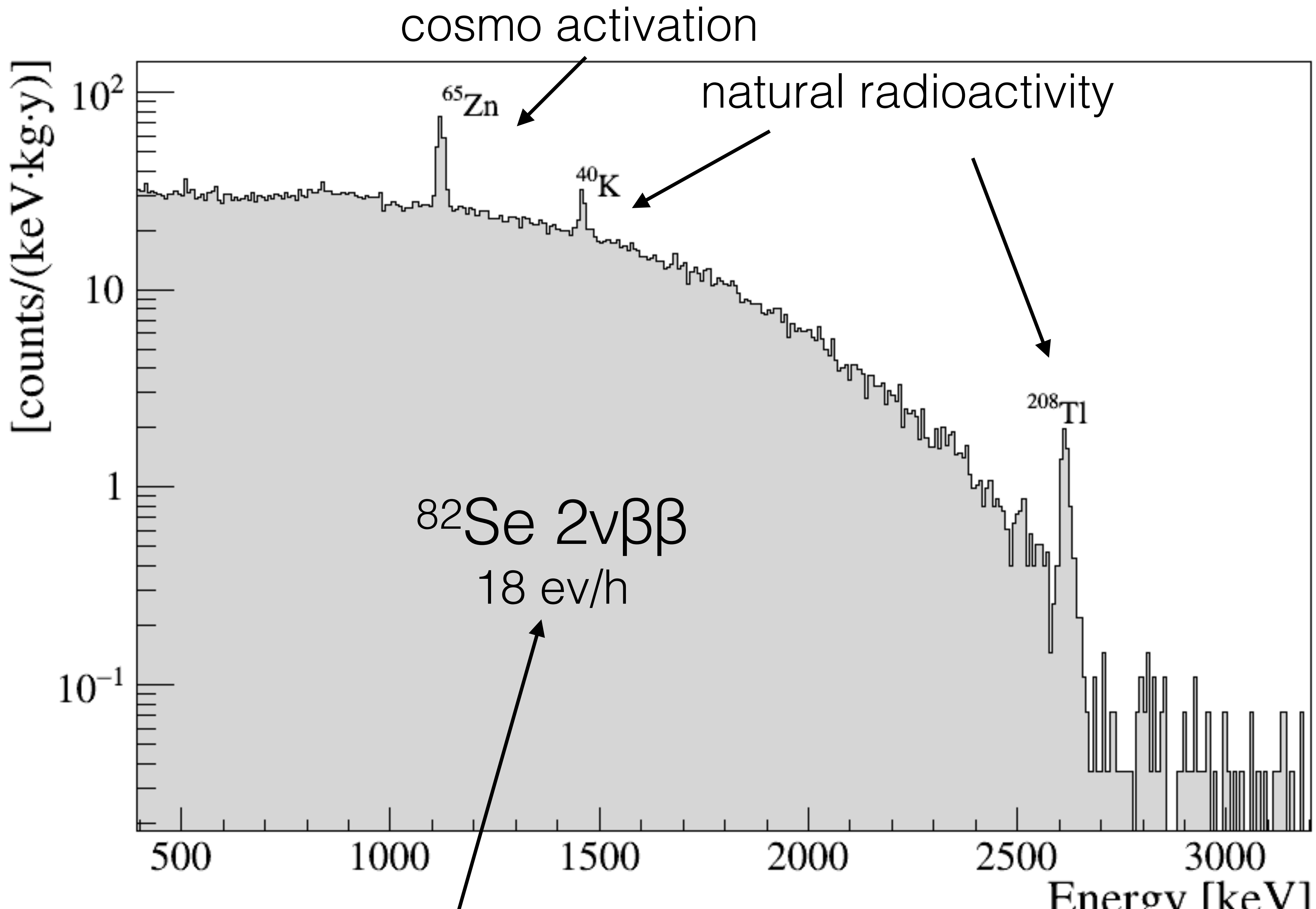




- Rejection of “non-particle” events via PSA
- Anti-coincidence cut Δ=20 msec

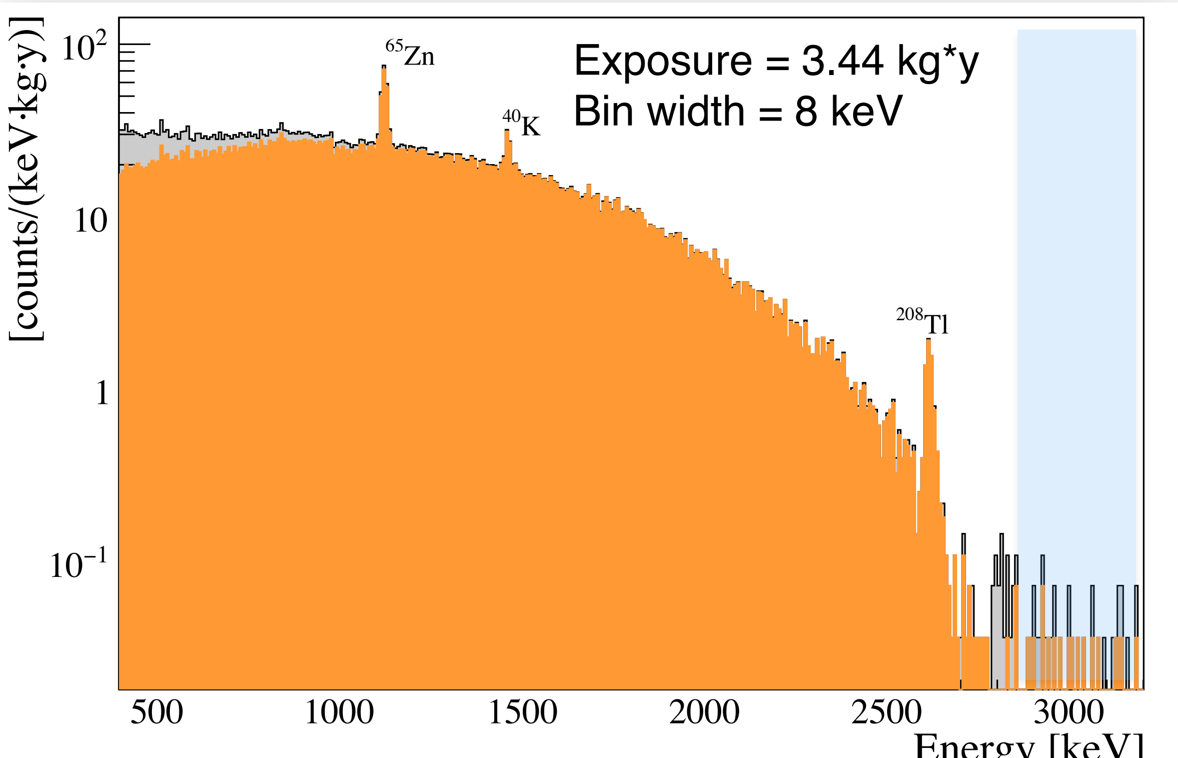
BKG ~ 3.6x10^{-2} counts/(keV kg yr)

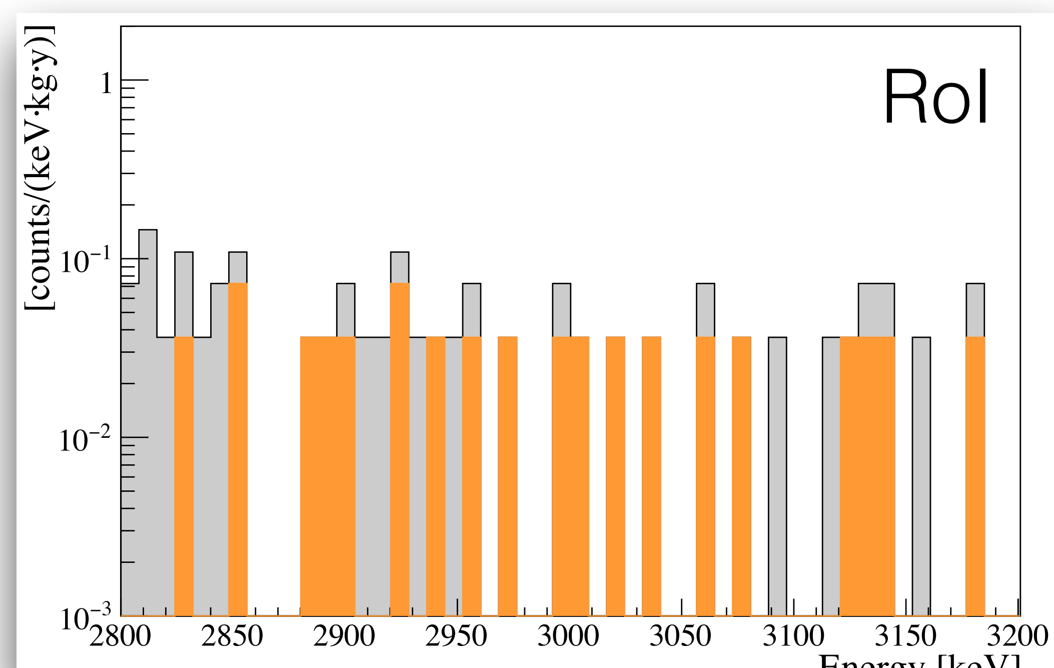
Background energy spectrum



Continuum energy spectrum: $(9.2\pm0.7)\cdot10^{19}$ y

Background data selection

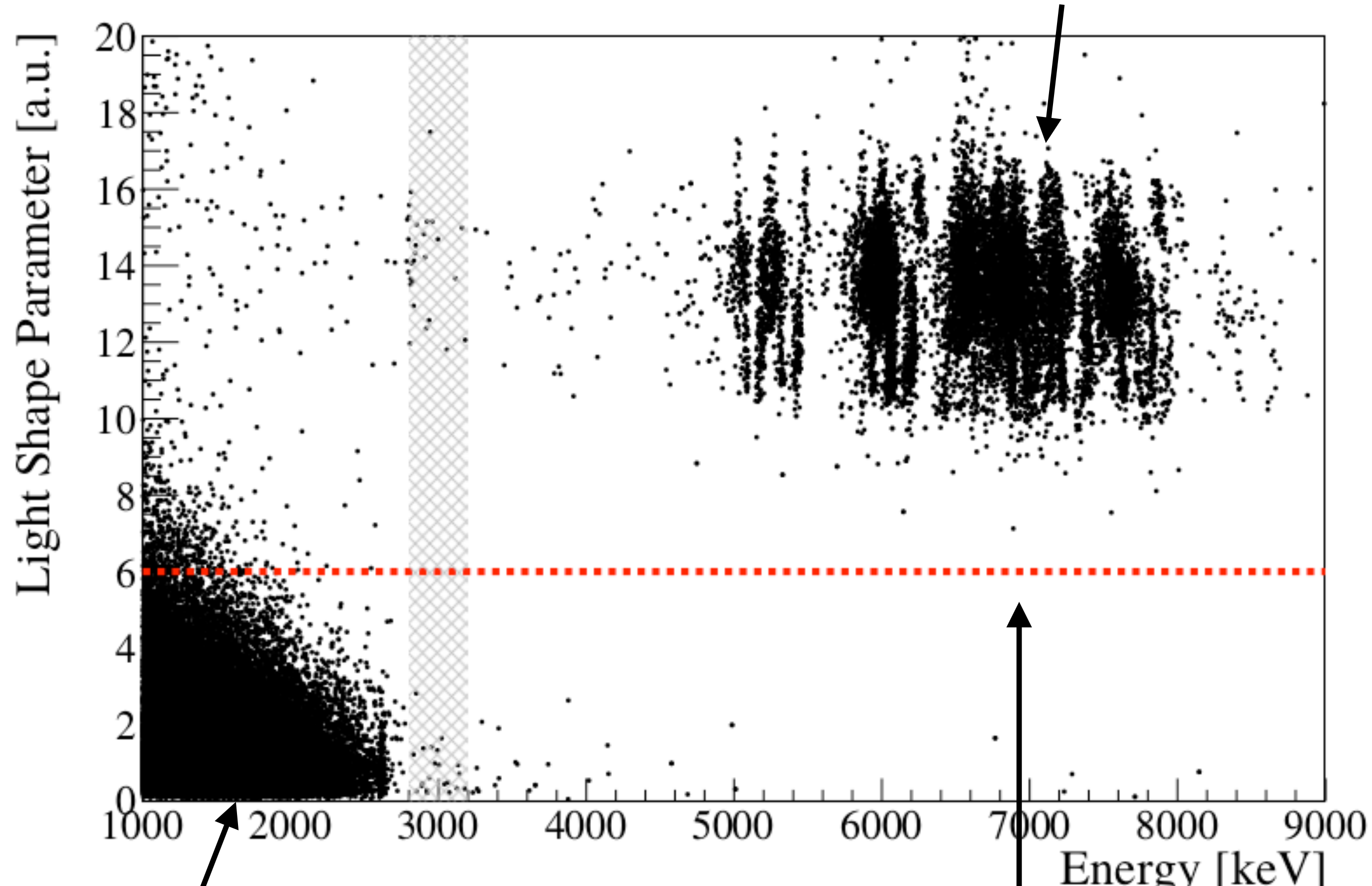




BKG ~ 1.5x10^{-2} counts/(keV kg yr)

Alpha rejection with PSA on light channel

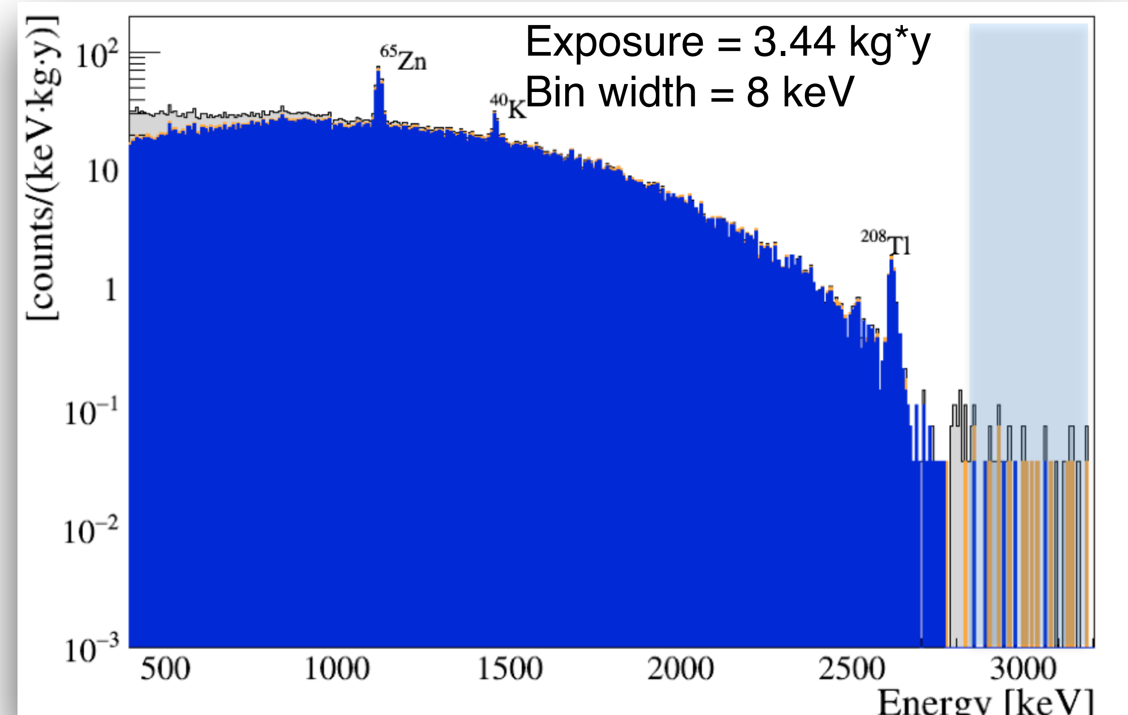
alpha events

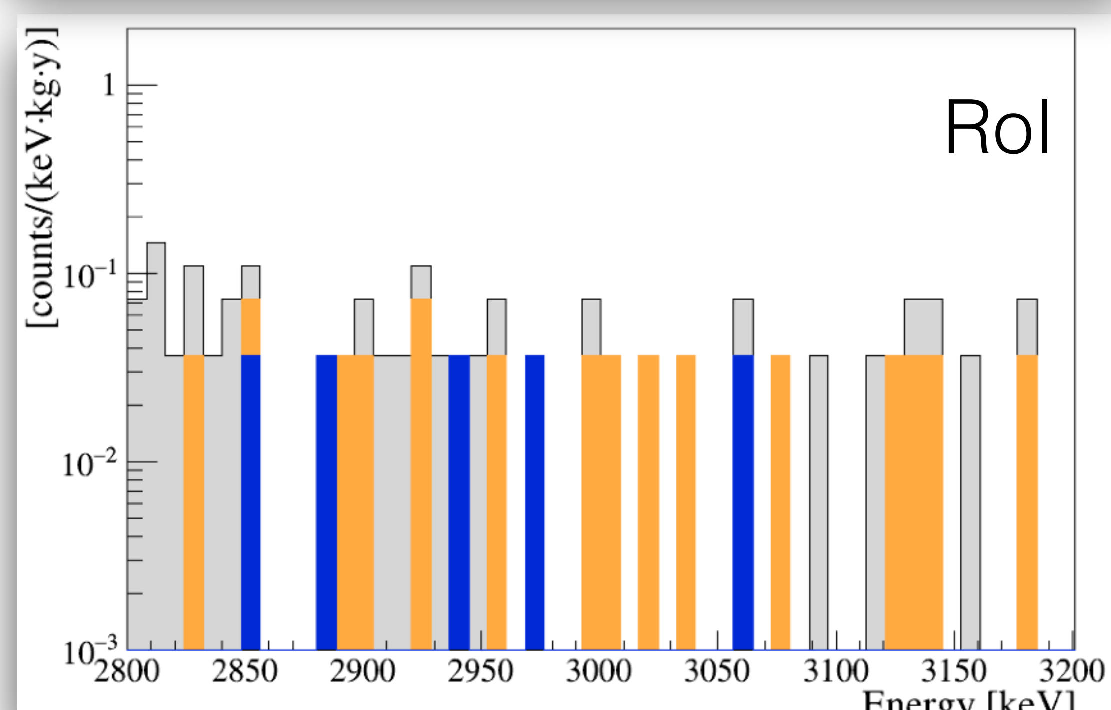


beta/gamma events

acceptance threshold
For E>4500 keV mis-identification probability <10^{-6}

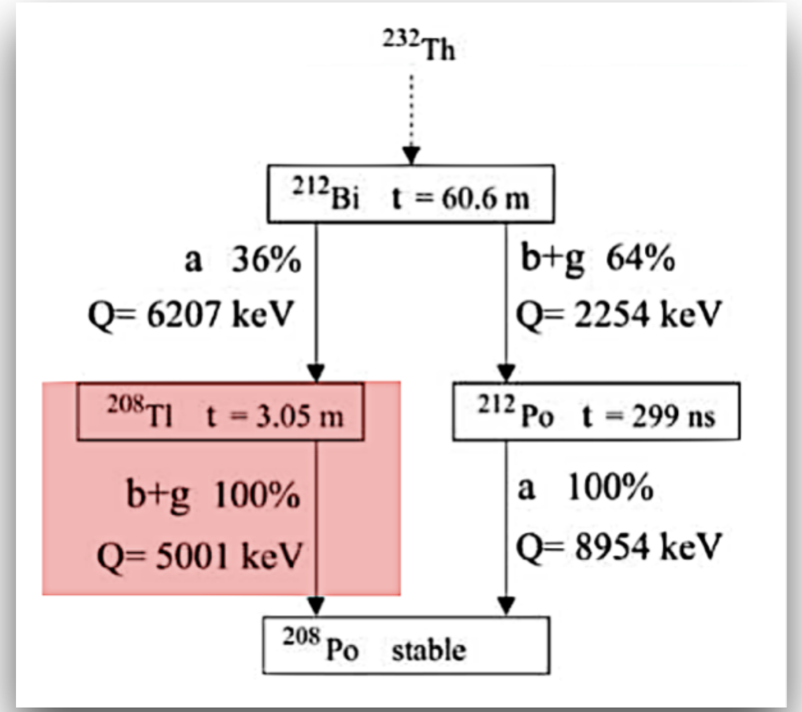
Background data selection





BKG ~ 3.6x10^{-3} counts/(keV kg yr)

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



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

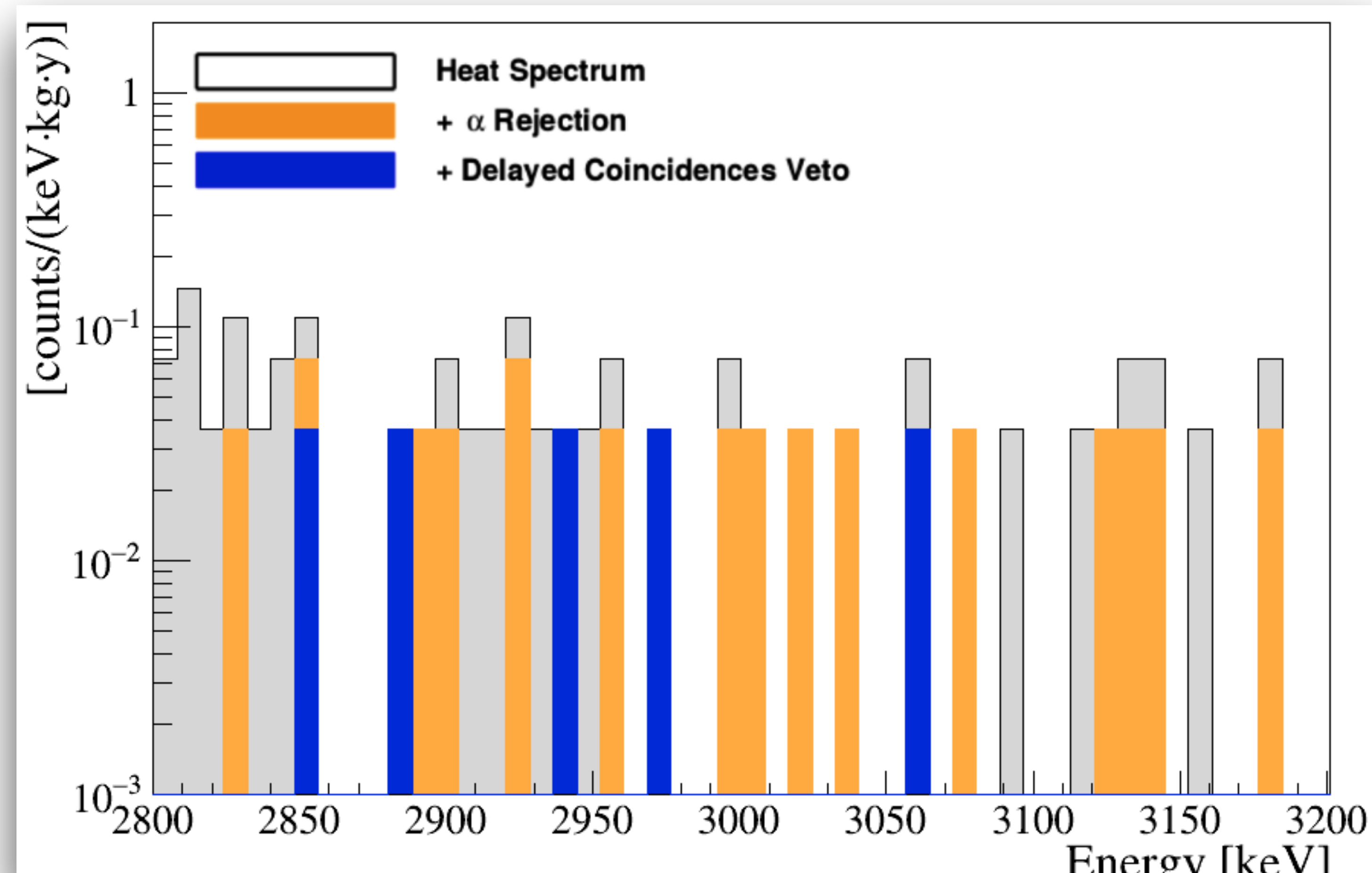
For each ^{212}Bi α event the detector is disabled for 3τ (~9min).

↓

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

All cuts efficiency 93±2%

Background data selection



Data Selection:

Anti-coincidence between ZnSe:

➜ **BI: (3.7±0.5)*10^{-2} c/keV/kg/y**

α particles rejection:

➜ **BI: (1.5±0.3)*10^{-2} c/keV/kg/y**

Delayed coincidence veto:

➜ **BI: (3.6±1.6)*10^{-3} c/keV/kg/y**

➜ **only 5 events in RoI**

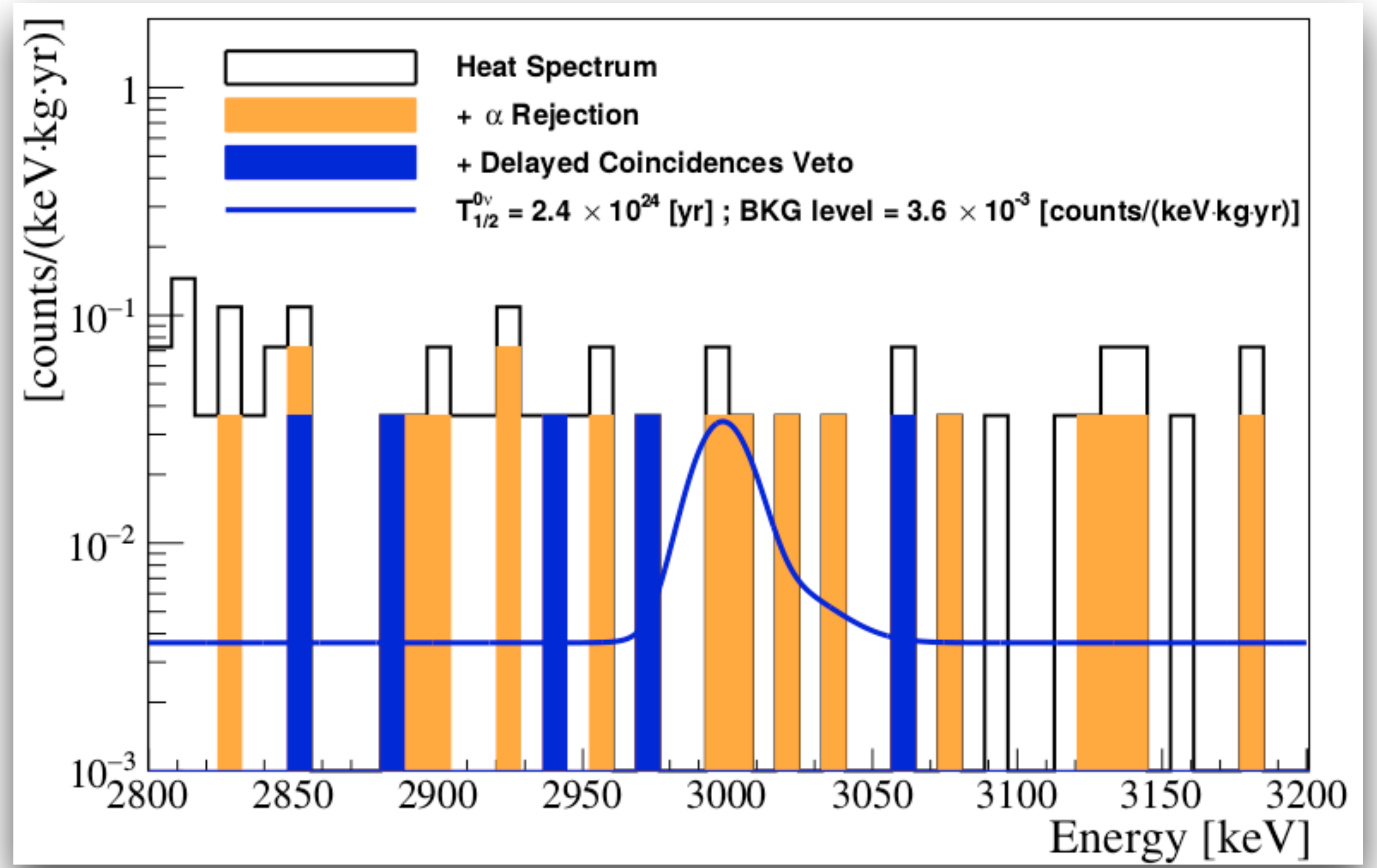
LOWEST BKG ACHIEVED WITH A BOLOMETRIC DETECTOR

UEML SIMULTANEOUS FIT OVER THE DATASETS

$$3.6^{+1.9}_{-1.4} \times 10^{-3} \text{ counts}/(\text{keV} \cdot \text{kg} \cdot \text{yr})$$

(1.5±0.3) x 10^{-3} counts/(keV kg yr) from muons (PRELIMINARY MC simulation)

Background data selection



O. Azzolini *et al.* (CUPID-0), Phys. Rev. Lett. **120**, 232502 (2018)

No evidence of 0νββ ➜ $T^{0\nu}$ > 2.4 · 10^{24} yr @ 90C.L.

$m_{\beta\beta}$ < (376-770) meV

Previous measurement 3.6 · 10^{23} yr @ 90C.L.

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

Conclusions

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

$$3.6^{+1.9}_{-1.4} \times 10^{-3}\ \mathrm{counts/(keV \cdot kg \cdot yr)}$$

- The analysis of the first data (3.44 kg y of ZnSe) allows to set the best limit on ^{82}Se $0\nu\beta\beta$ half-life

$$T^{0\nu}_{1/2} = 2.4 \times 10^{24}\ \mathrm{yr\ @\ 90\%\ C.I.}$$

$m_{\beta\beta}$<(376-770) 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 ν IH region

O. Azzolini *et al.* (CUPID-0), Phys. Rev. Lett. **120**, 232502 (2018)