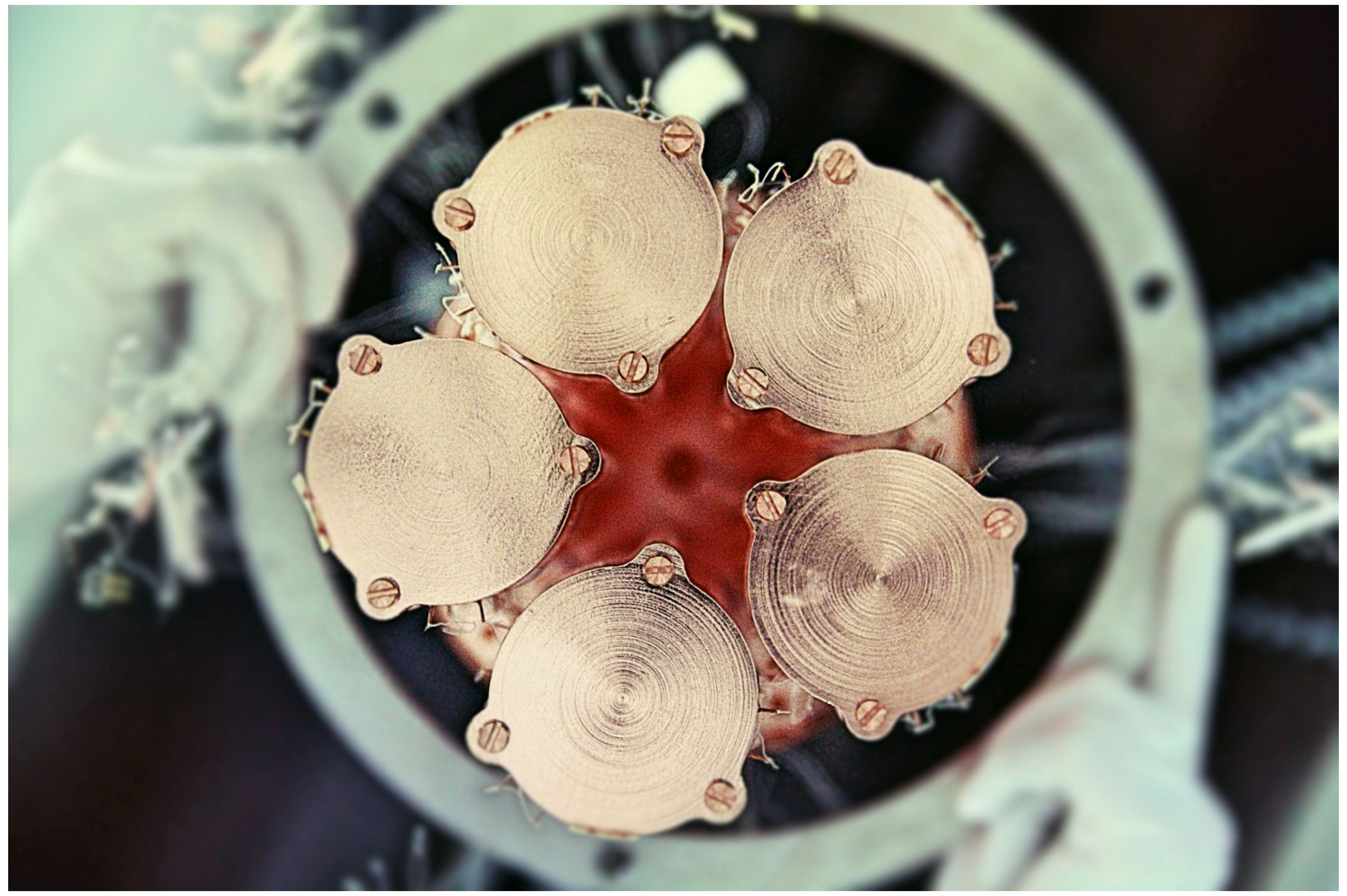
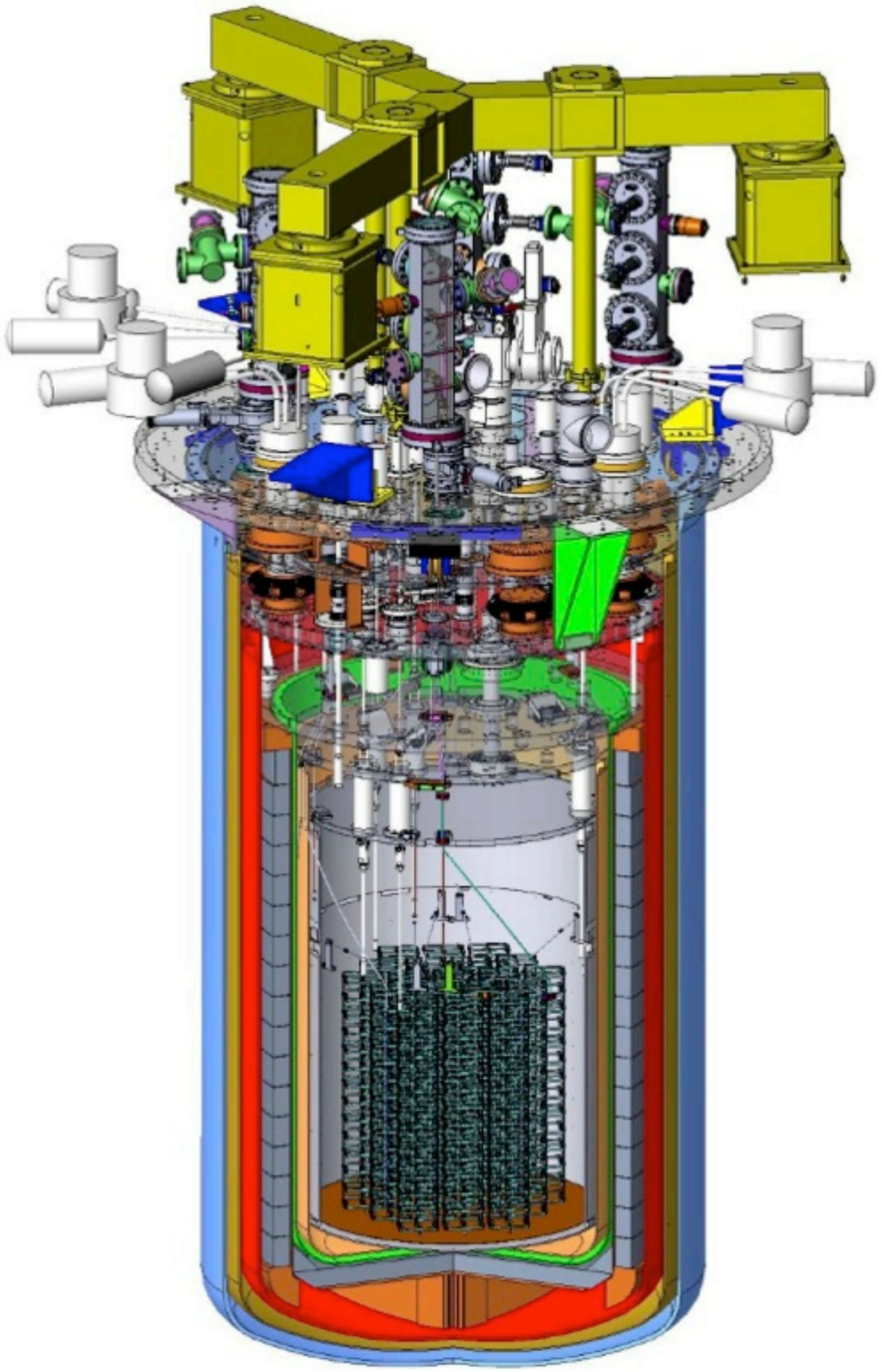
Final Results of CUPID-0 Phase I



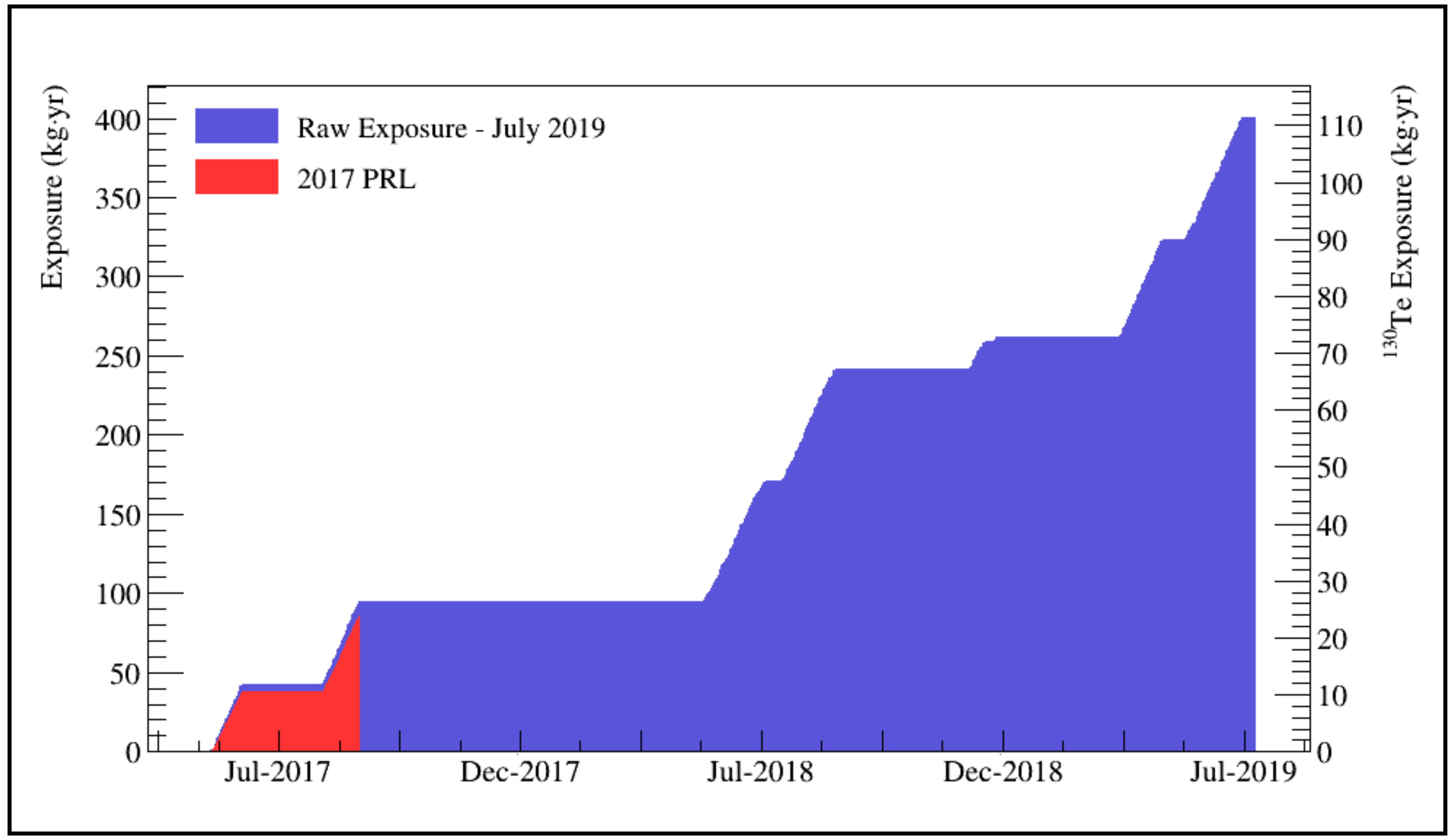
Laura Cardani on behalf of the CUPID-0 collaboration
INFN-Roma

22-26 JULY 2019
MILANO
LTD 18
LOW TEMPERATURE DETECTORS

The Lesson of CUORE

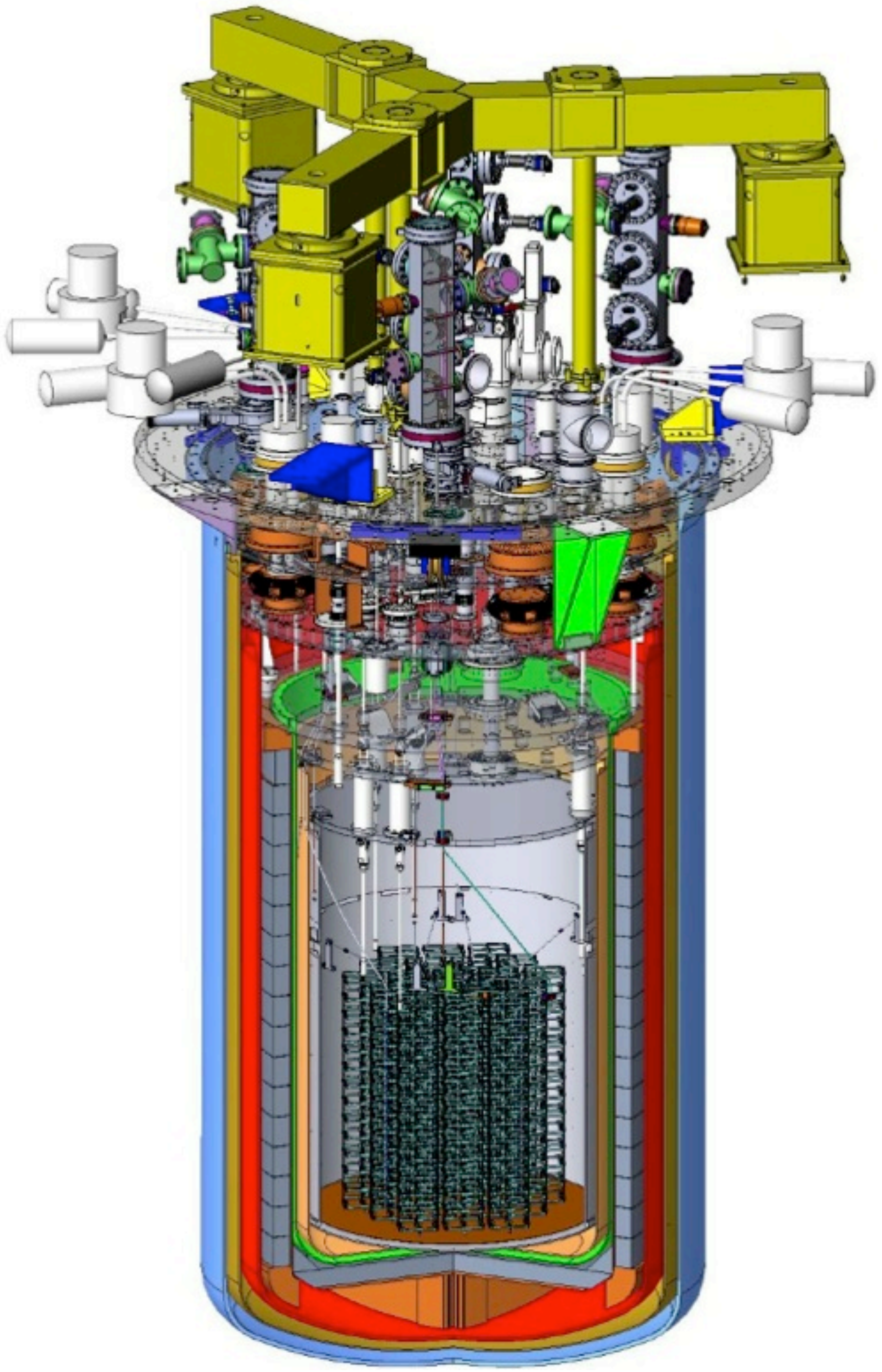


- Proved the feasibility of a tonne-scale experiment
- Excellent energy resolution (0.3%)



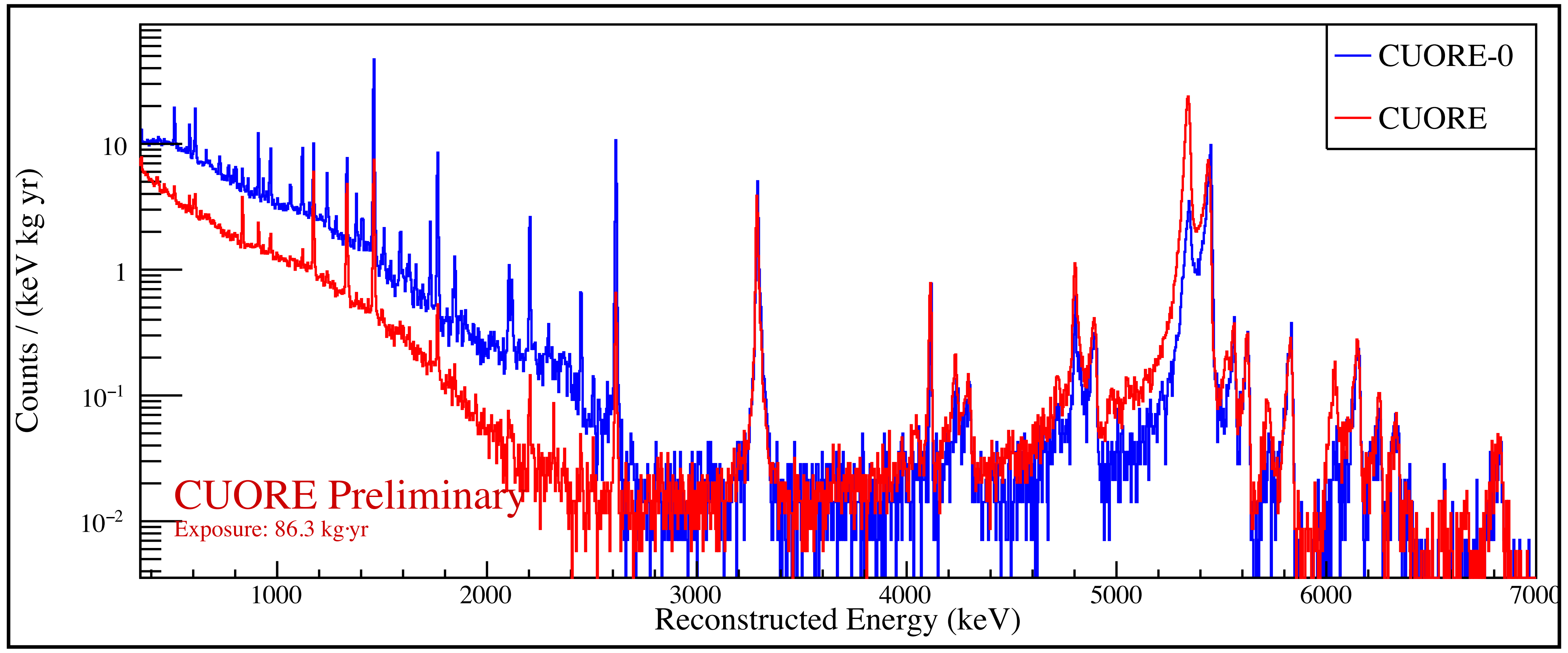
Talks: I. Nutini and V. Singh
Posters: A. Campani (319), G. Fantini (330), I. Nutini (316), S. Copello (326), V. Dompè (310)

From CUORE to CUPID

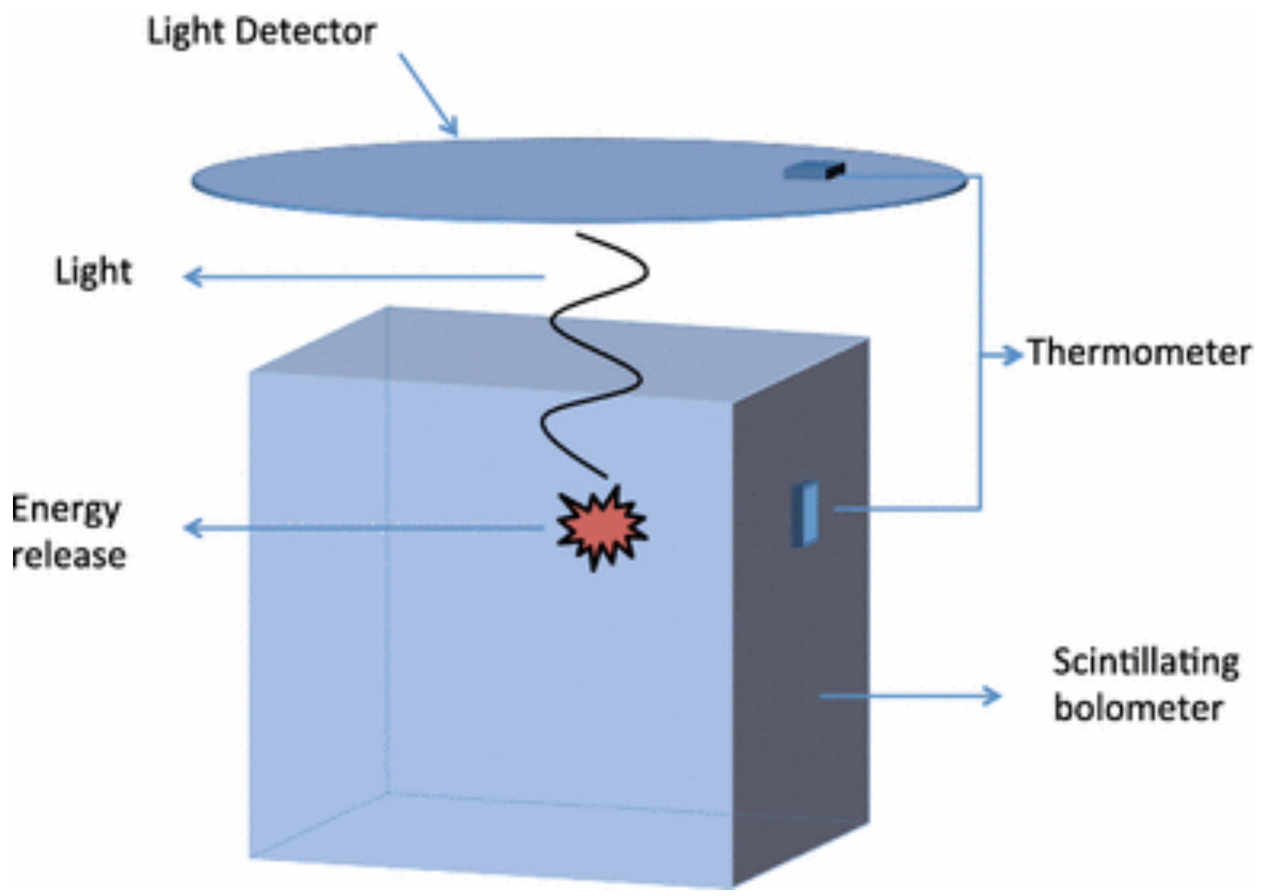


CUORE Upgrade with Particle IDentification

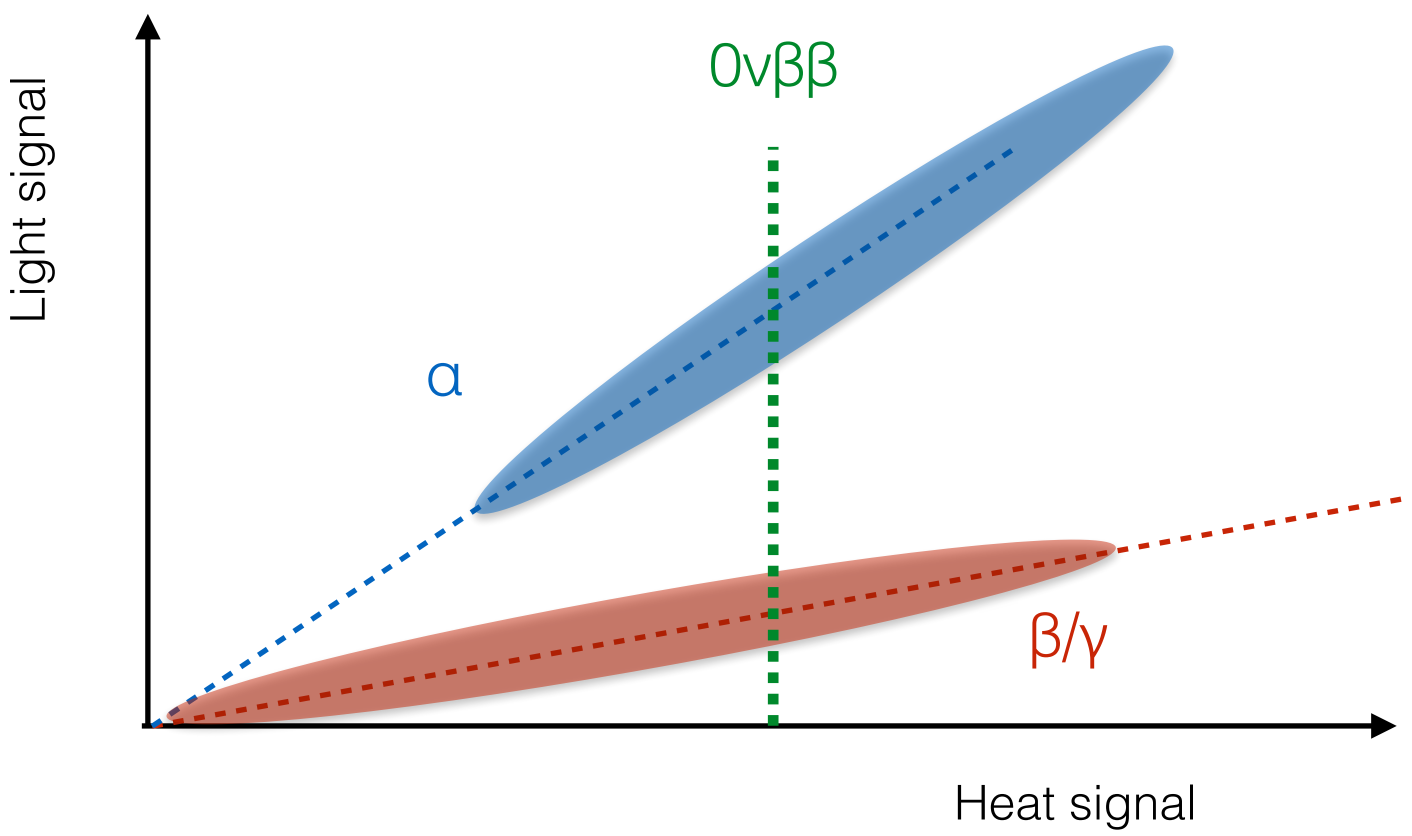
- Same CUORE infrastructure at LNGS
- Isotopic Enrichment (increase emitters without increasing volume)
- Background suppression by x100 wrt CUORE 10^{-2} counts/keV/kg/yr
  - background of CUORE dominated by α particles —> particle ID



Particle ID in cryogenic calorimeters



- Couple each calorimeter to a light detector
- Different light yield enables particle identification
- Reject the (dominant) α background
- R&D of many years to identify the best technology



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E. Armengaud, et al., JINST 10 (05), P05007 (2015).
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G.B Kim et al, Astropart. Phys 91, 105-112 (2017).
G. Buse et al., Nucl. Instr. Meth. A 891 87 (2018)
O. Azzolini et al. Eur. Phys. J. C 78 428 (2018)
A. Barabash et al, Eur. Phys. J. C 76 487 (2018)

an many many others…

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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)
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M. Willers et al., JINST 10 P03003 (2015)
L. Pattavina et al. J.Low.Temp.Phys. 184 (2016) no.1-2, 286-291
L. Gironi et al. Phys.Rev. C94 (2016) no.5, 054608
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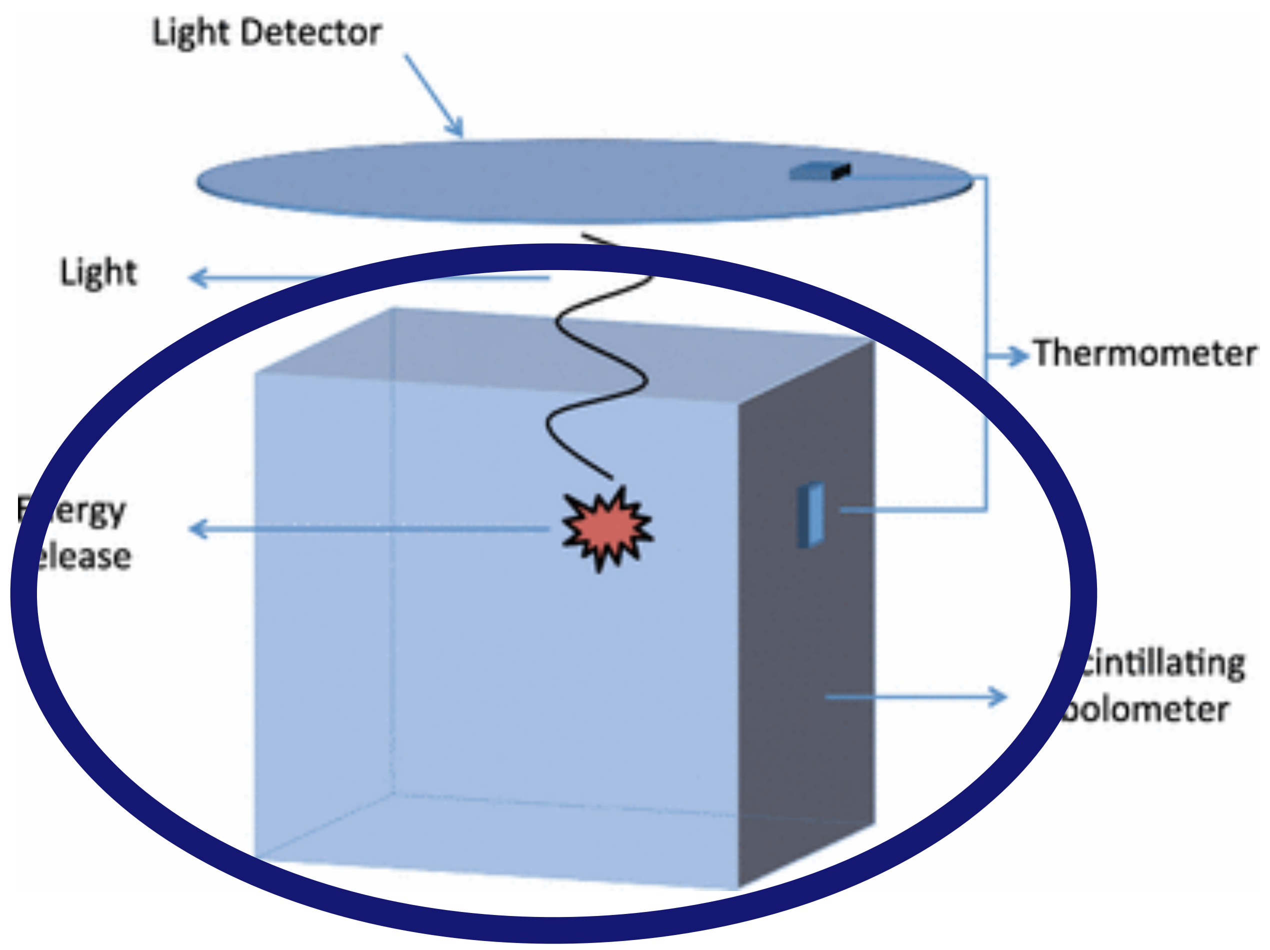
V. Novati et al. Nucl.Instrum.Meth. (2018)
M.Barucci et al NIM A. 935 (2019) 150

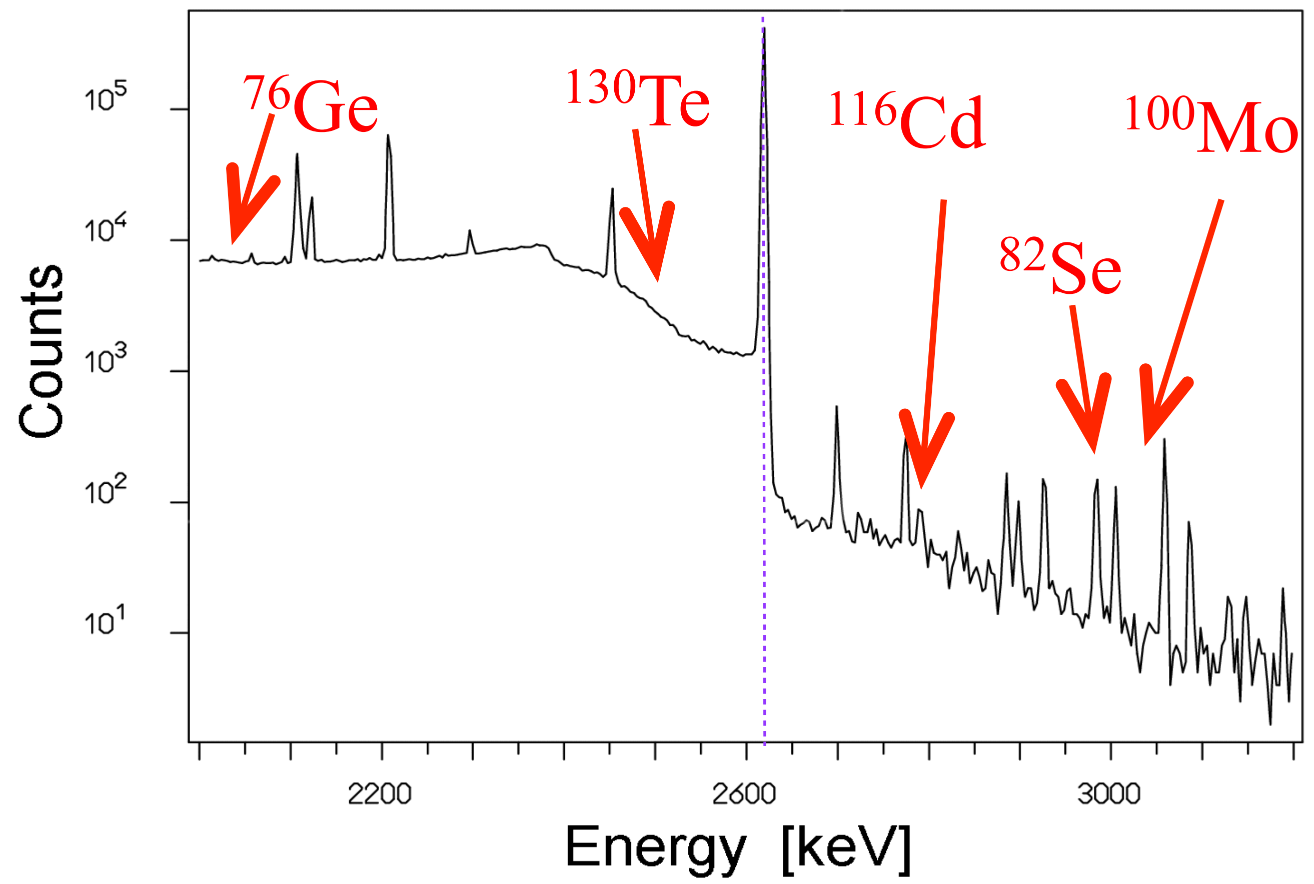
and many others…

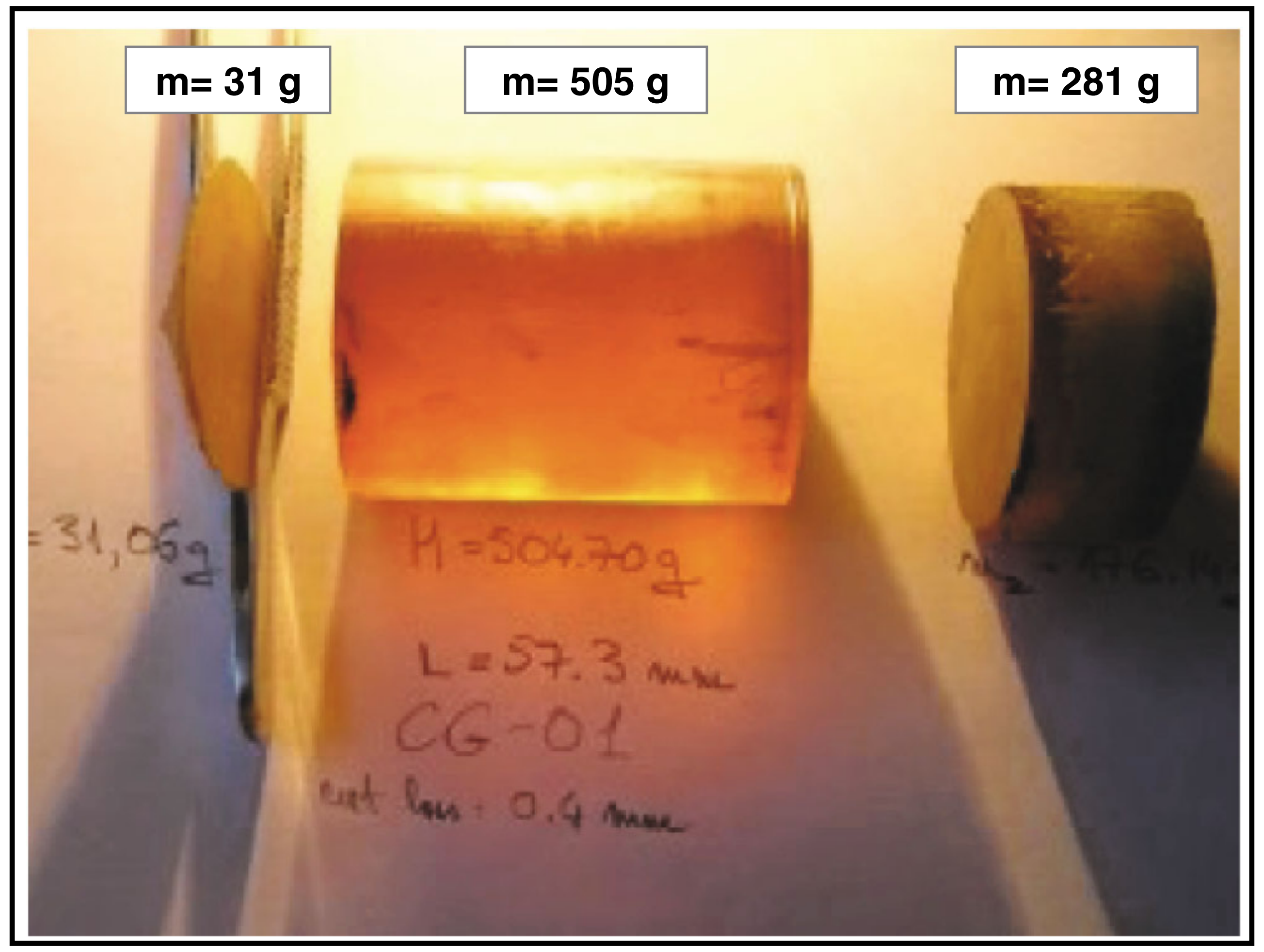
CUPID-0: absorber



Cryogenic Calorimeter for $0\nu\beta\beta$:

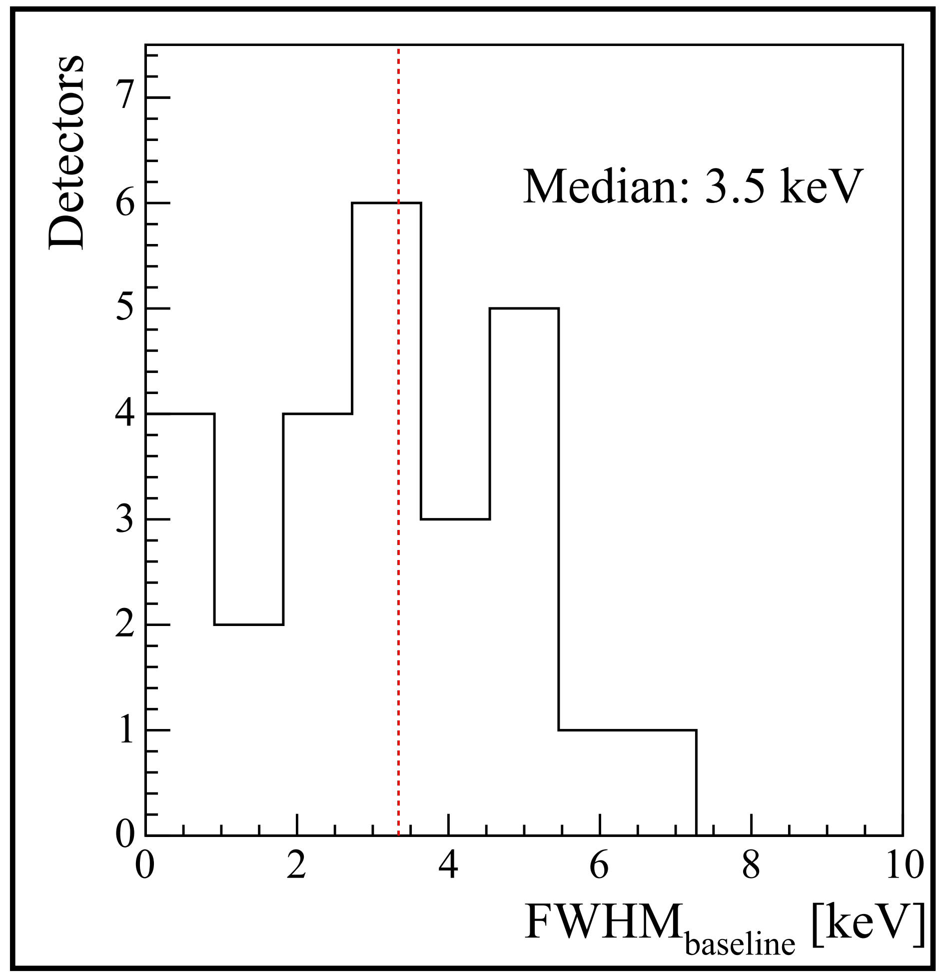
- Good bolometric performance
- Emission of scintillation light at 10 mK
- Grown from high Q-value emitter



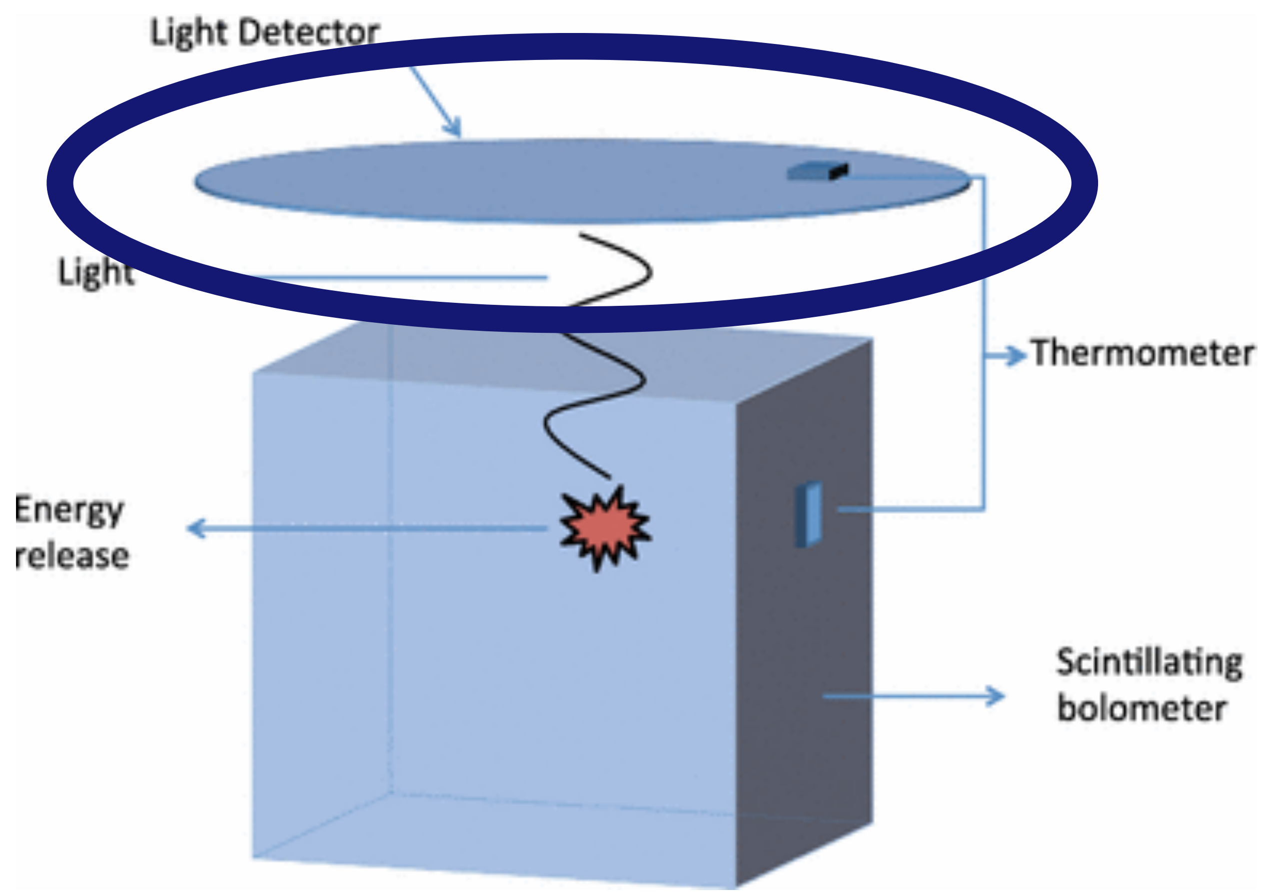


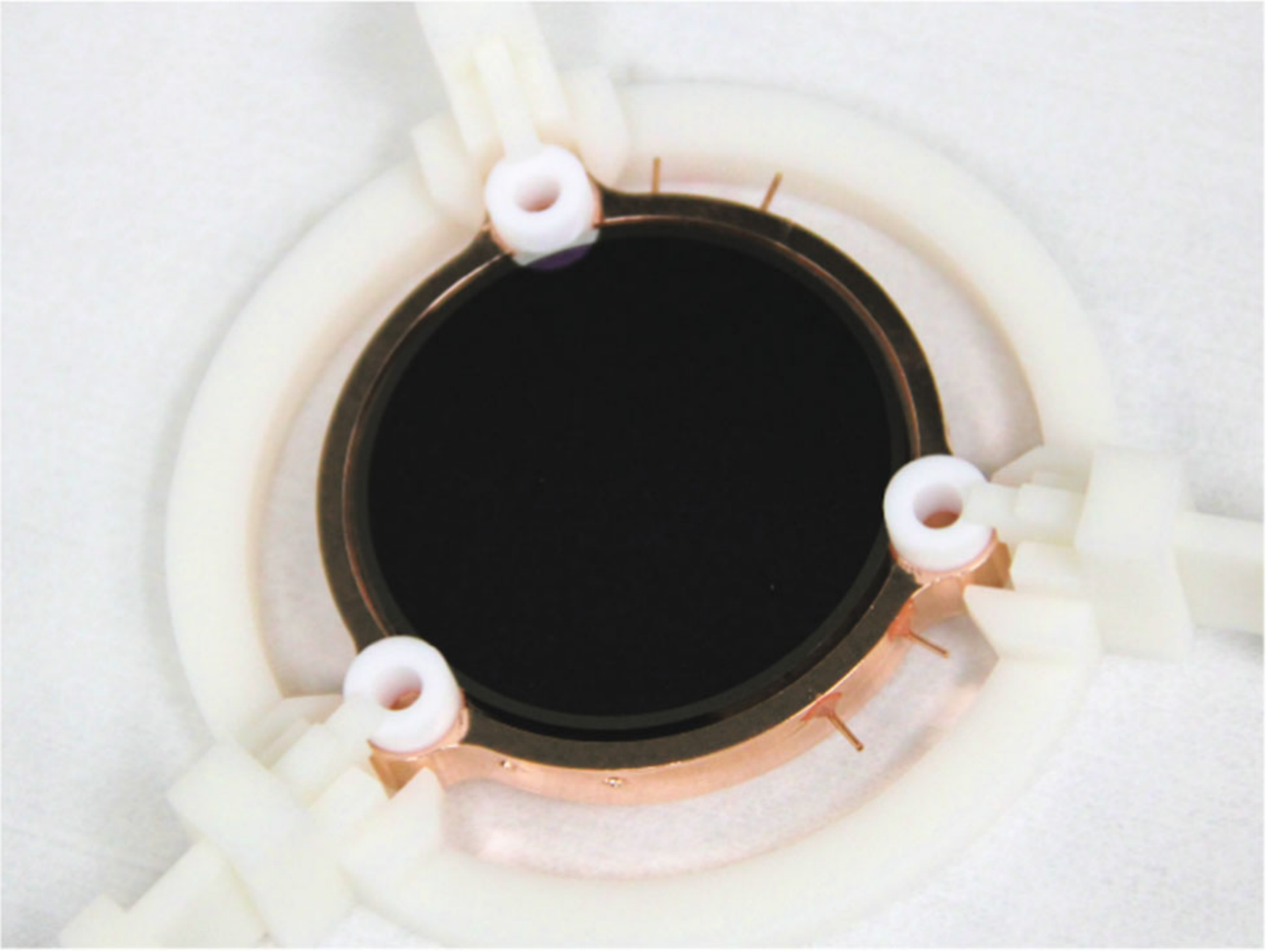
CUPID-0: $Zn^{82}Se$

- Enrichment of Se at 96.3% in ^{82}Se
- Non-standard crystal (R&D to purify powder, grow large size crystals)
- Equipped with 3 x 2.8 x 1 mm³ NTD Ge thermistor



CUPID-0: light detector





Light Detector:

- ``Standard" LD: not satisfactory at 10 mK
- Use a second calorimeter
- Light emitted by ZnSe: tens-hundreds of keV —> smaller capacitance

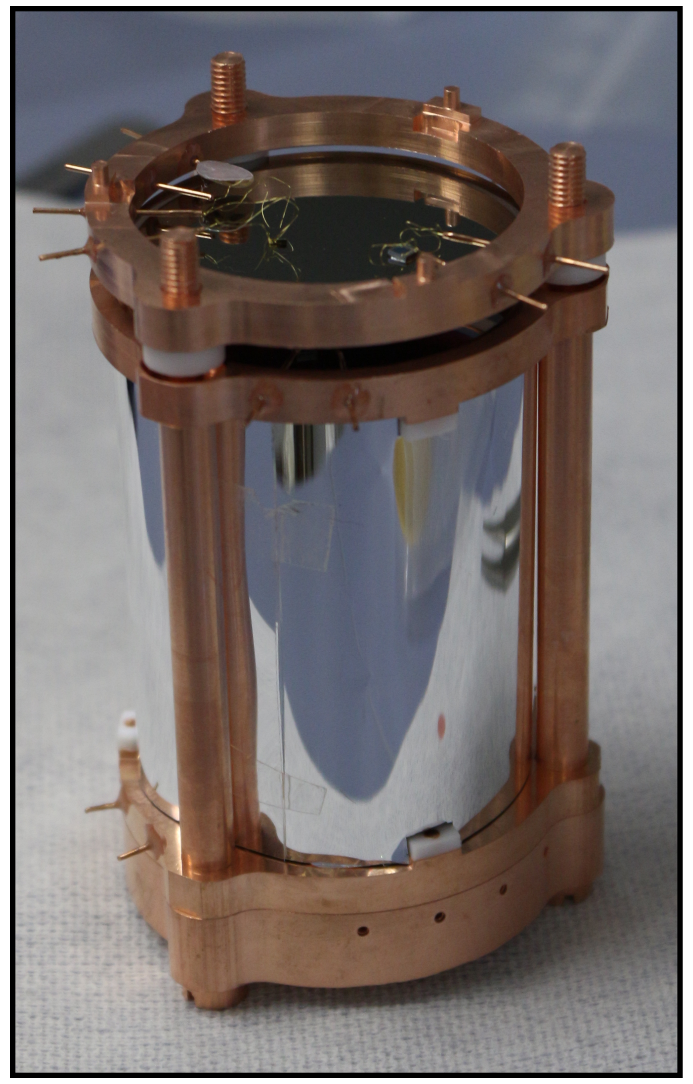
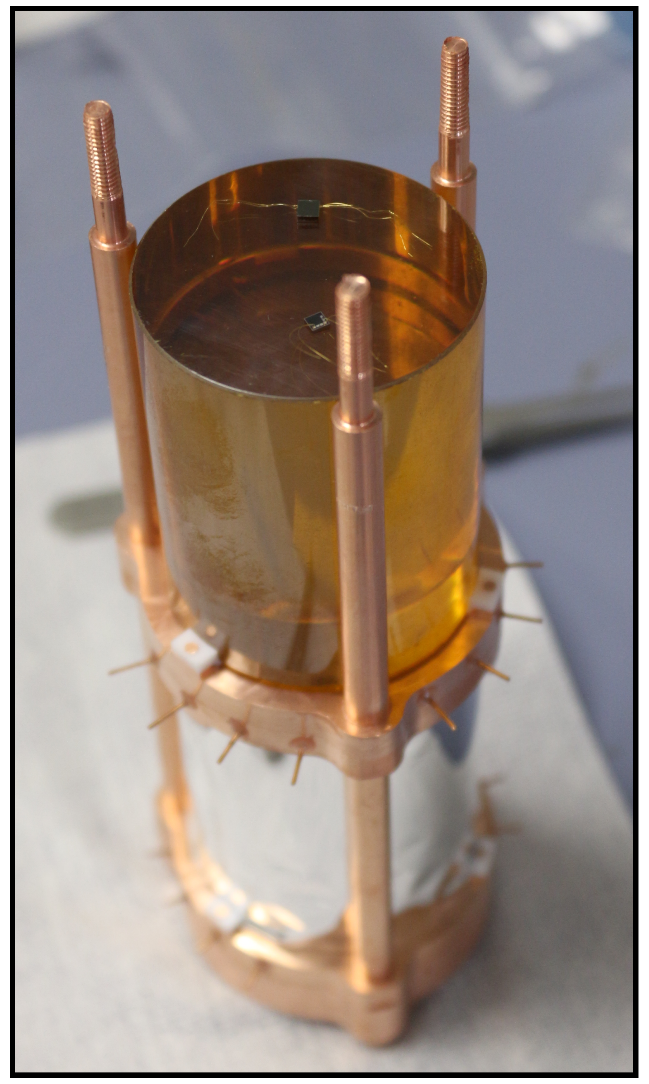
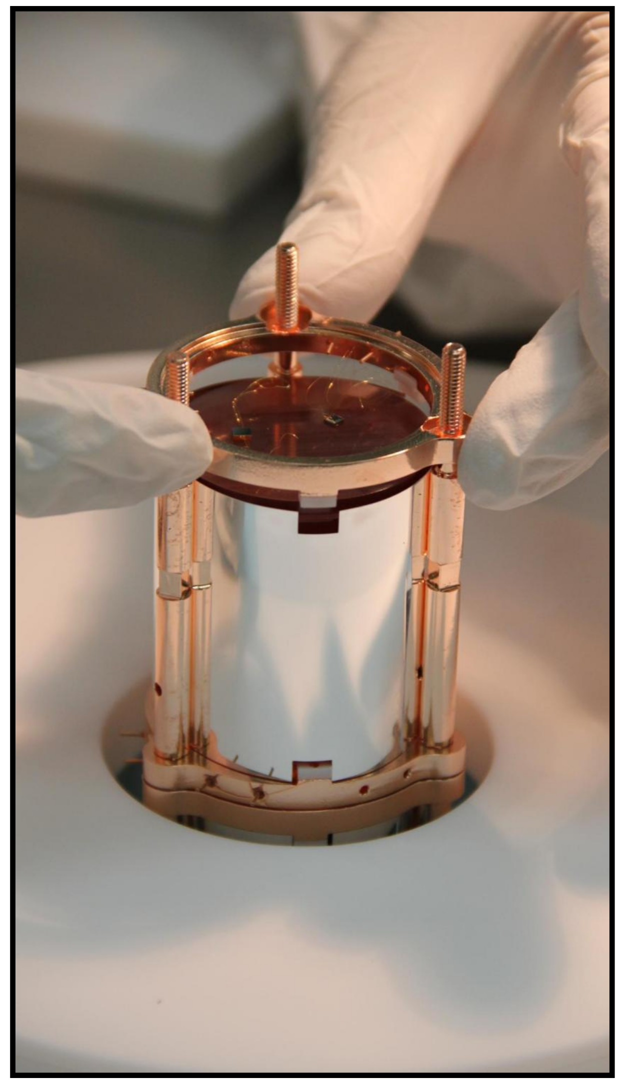
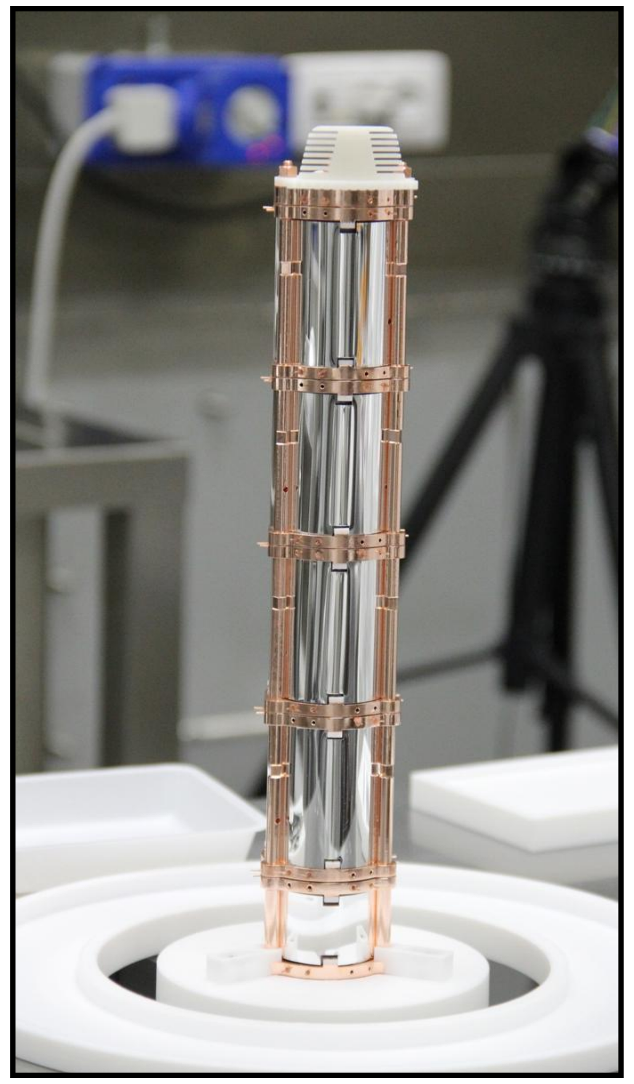
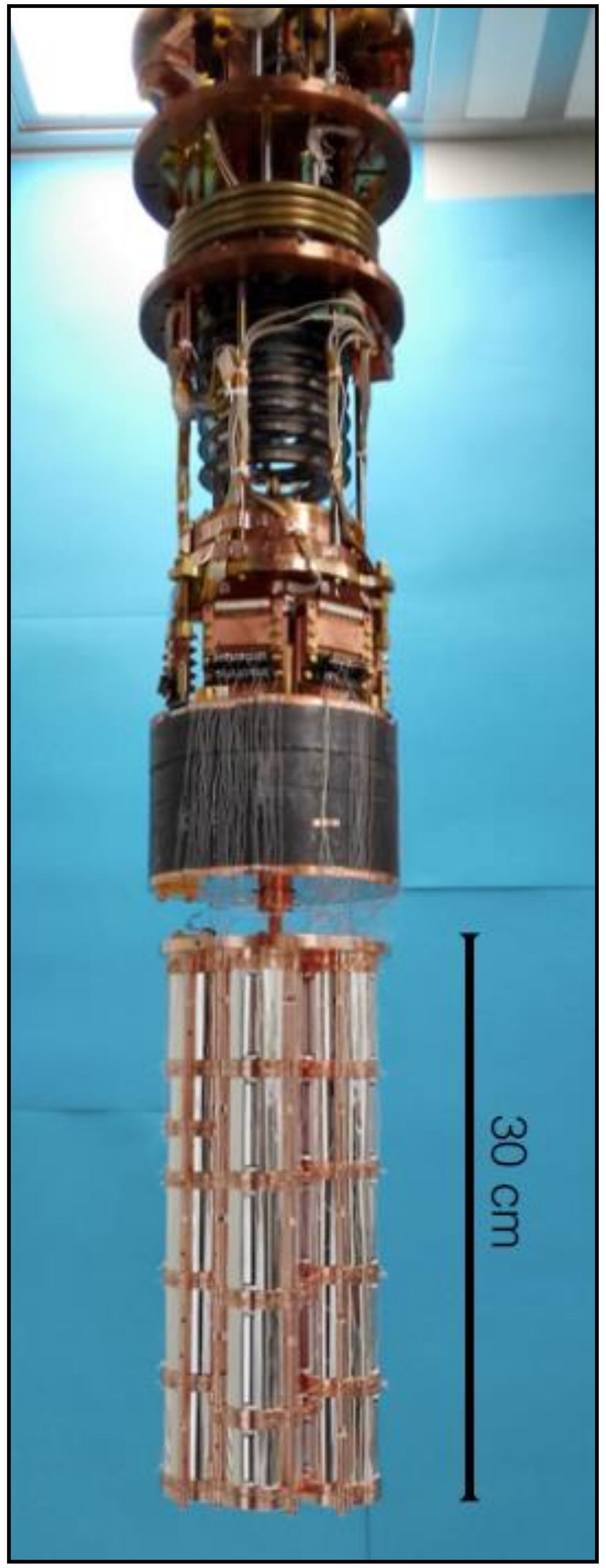
CUPID-0: Ge wafer (produced by UMICORE)

- 4.4 cm x 170 μm
- Coated with SiO on a single face
- Equipped with 2 x 2.8 x 0.5 mm^3 NTD Ge thermistor
- In previous test ~40 eV RMS, 1.8 ms rise-time, reproducible

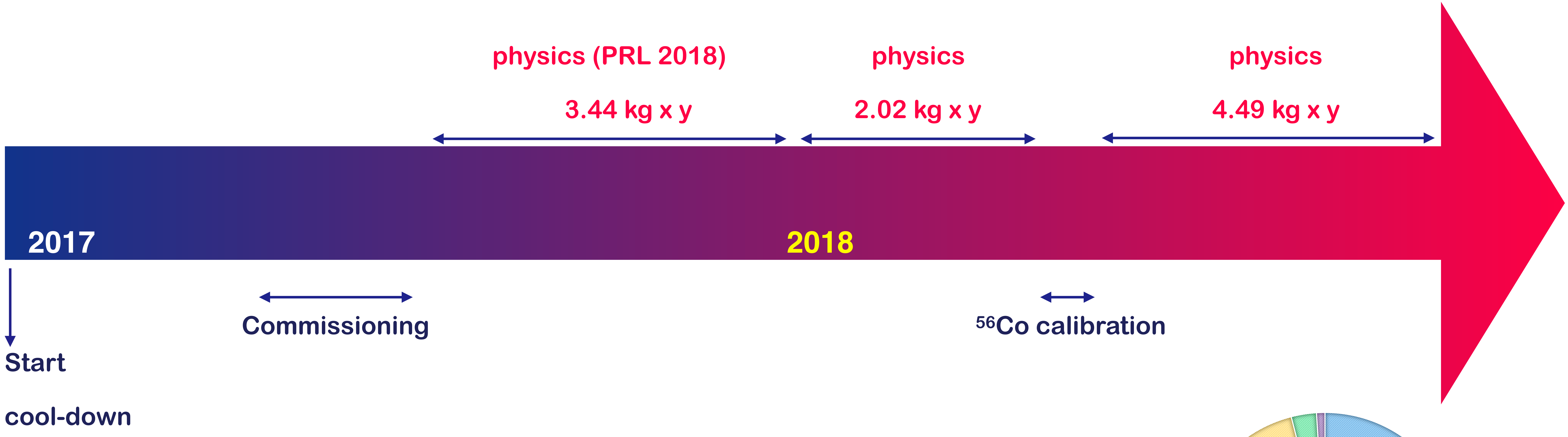
The CUPID-0 Demonstrator

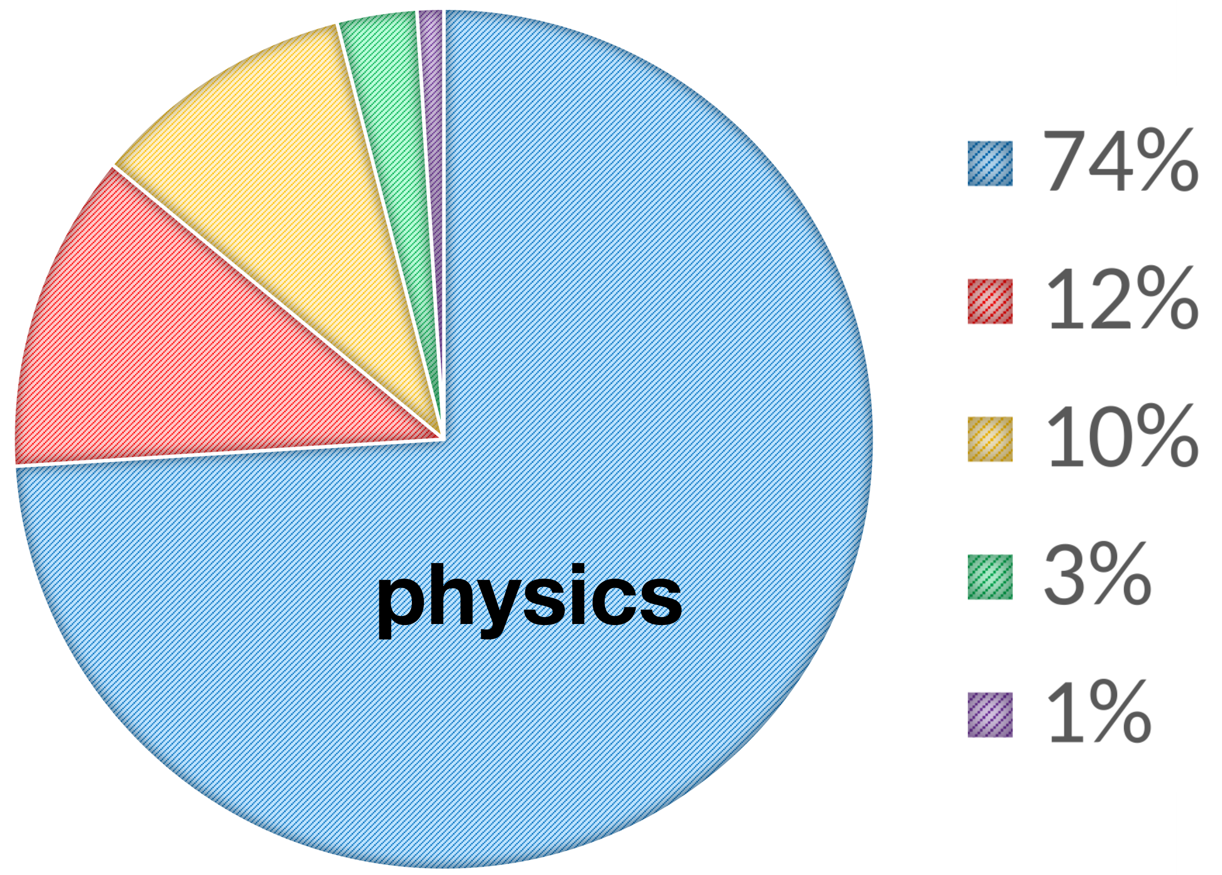
First medium-scale demonstrator of CUPID

- 24 ZnSe crystals enriched (95%) in ^{82}Se
- 2 natural ZnSe crystals
- 10.5 kg of ZnSe (3.8×10^{25} nuclei)
- Hosted in the same CUORE-0 cryogenic facility (LNGS, Italy)

The CUPID-0 time-line





This talk: full statistics acquired in ~1.5 years (phase-I): 9.95 kg x yr of ZnSe

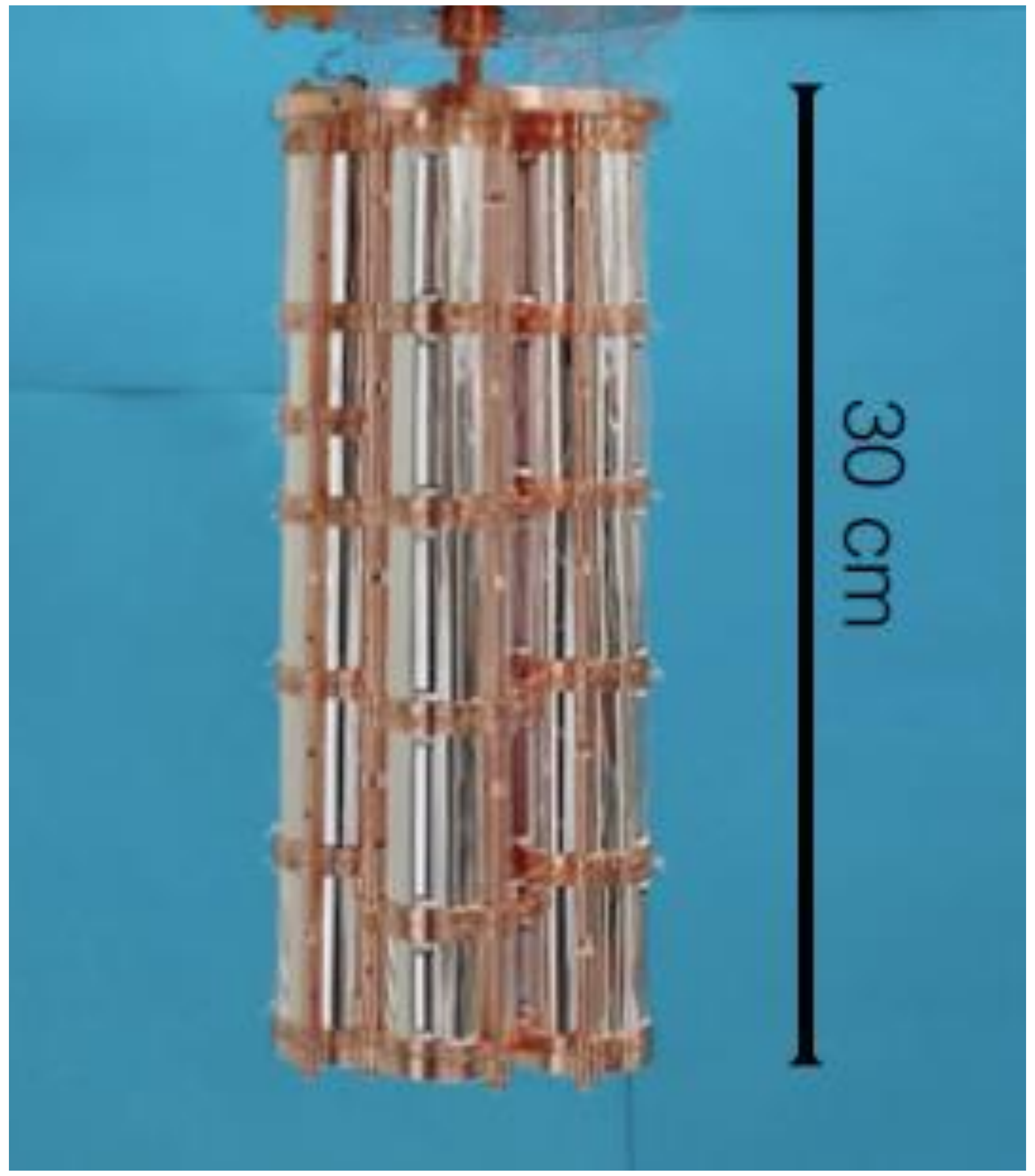
At the end of 2018 detector warm-up and upgrade

June 2019: start phase-II

Data Selection (1)

Reject non-physics events

(earthquakes, electronics noise…)

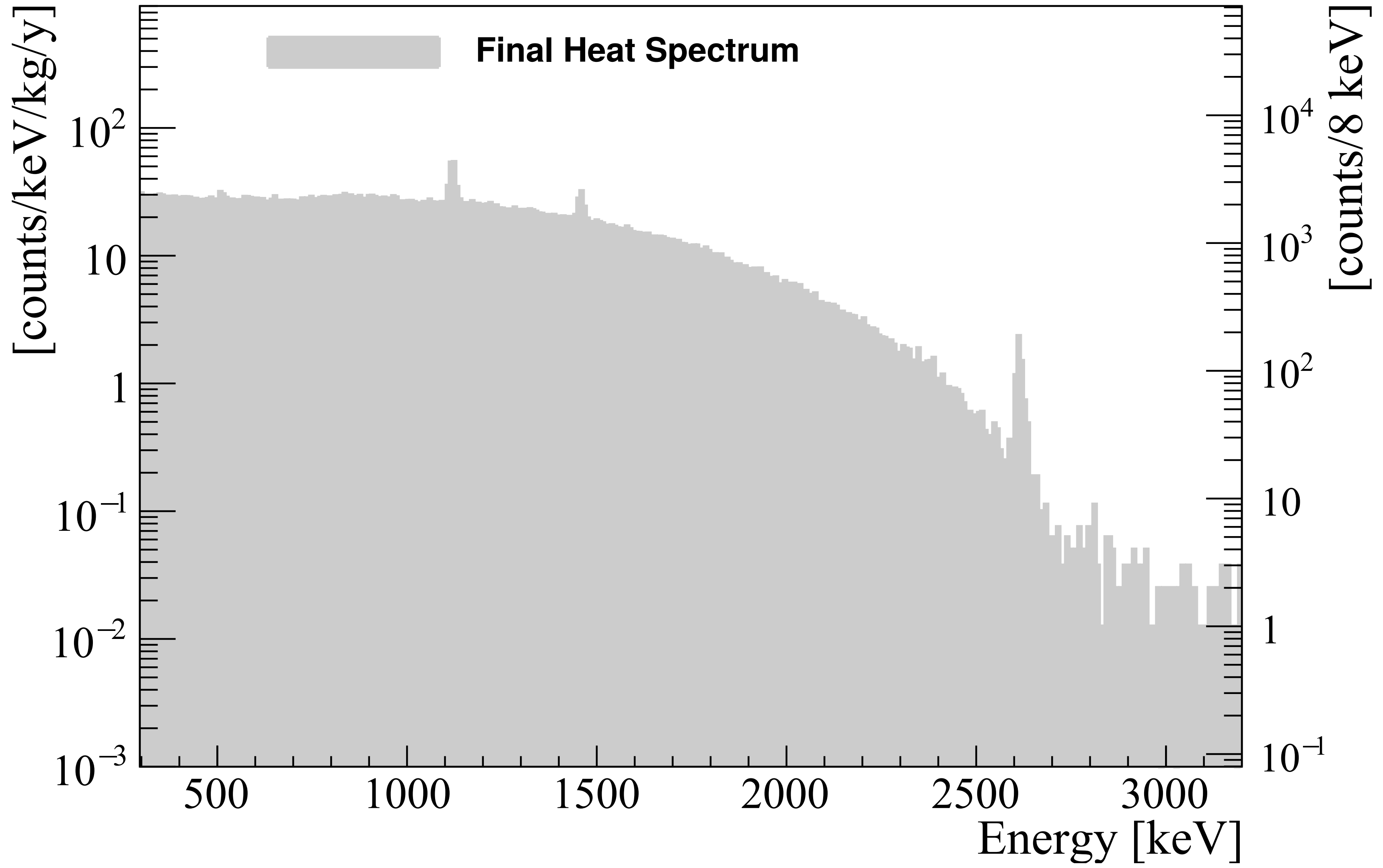


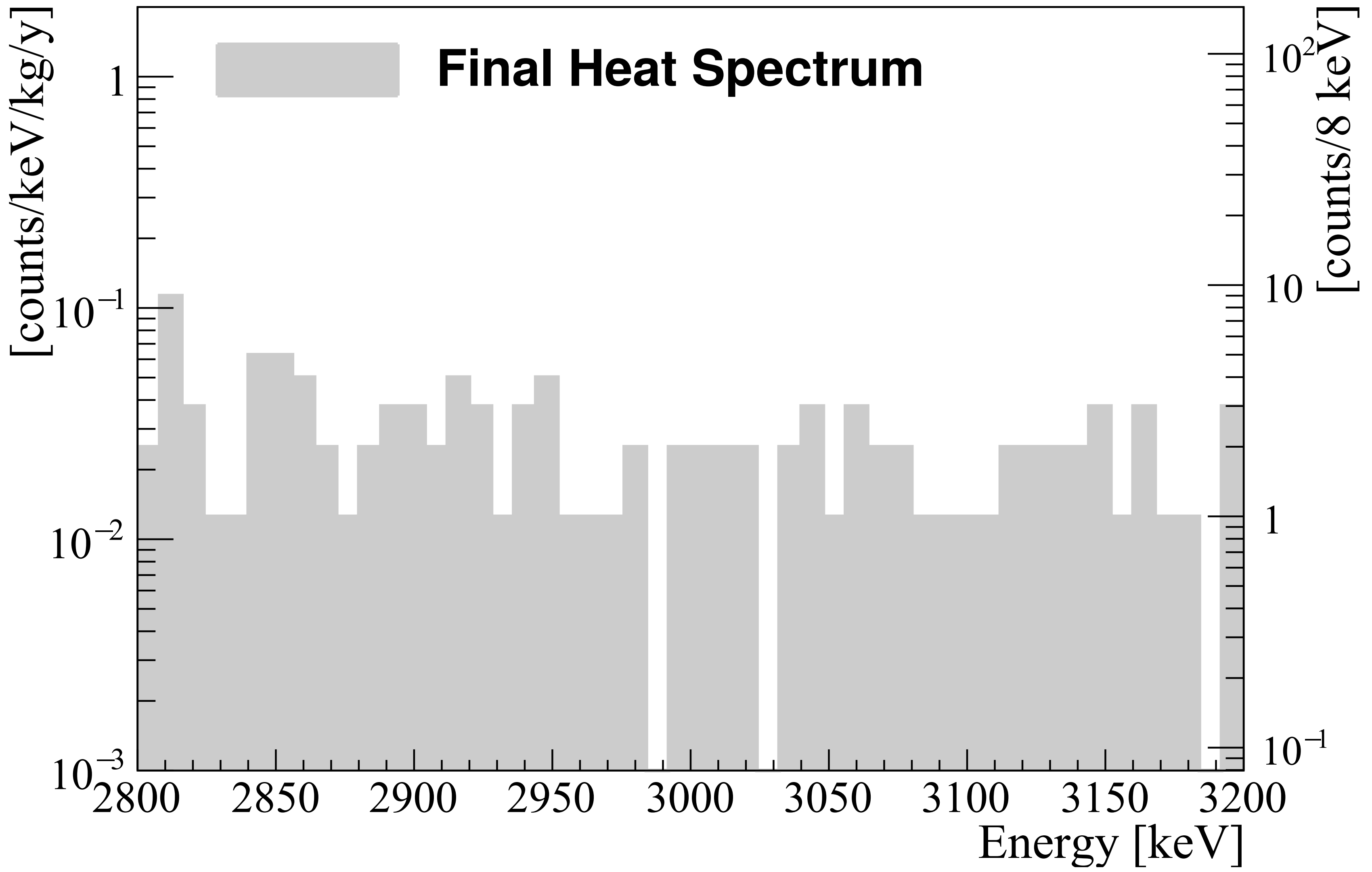
Select number of triggering crystals

(1 for 0νββ searches)

Background in ROI (2800-3200 keV):

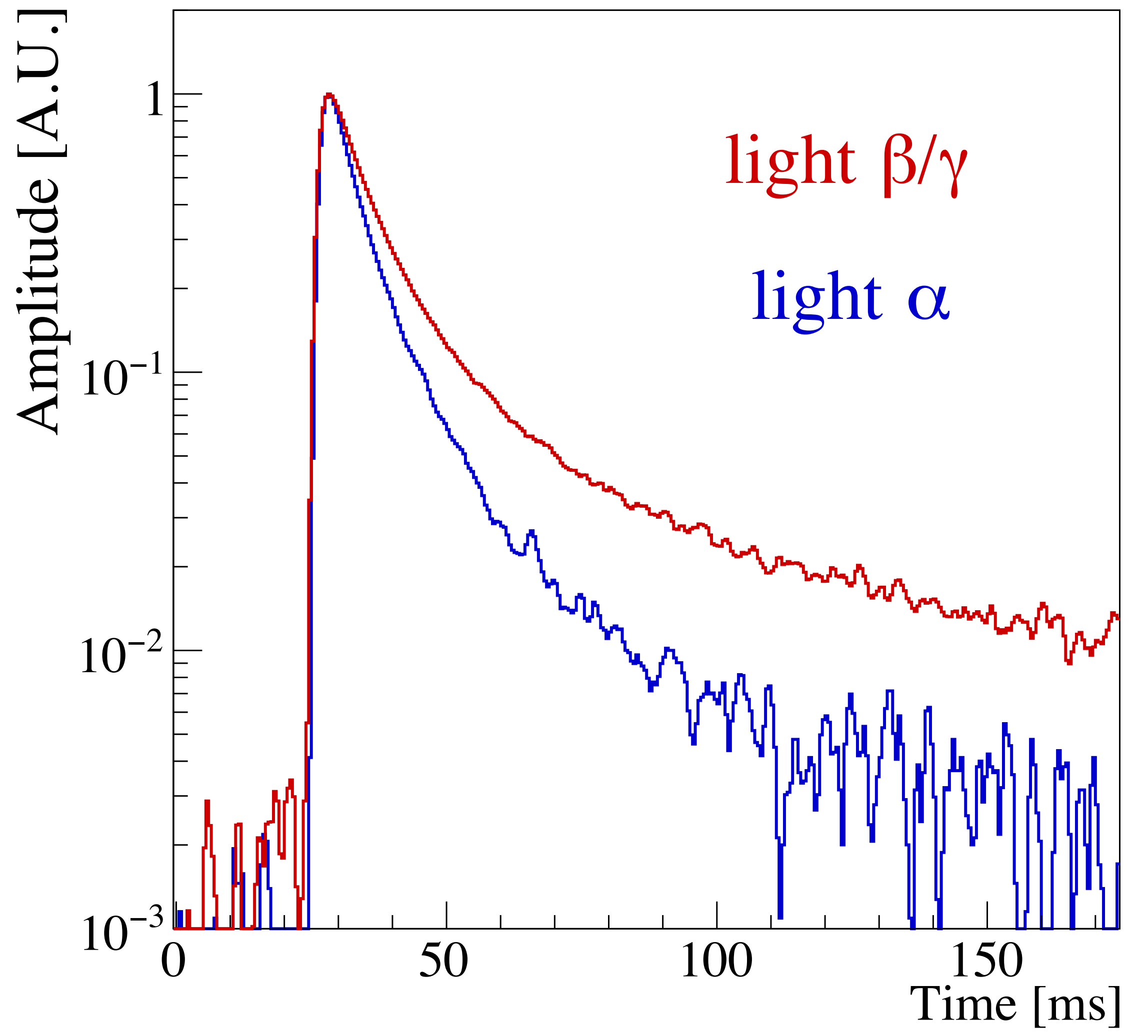
3.2×10^{-2} counts/keV/kg/yr

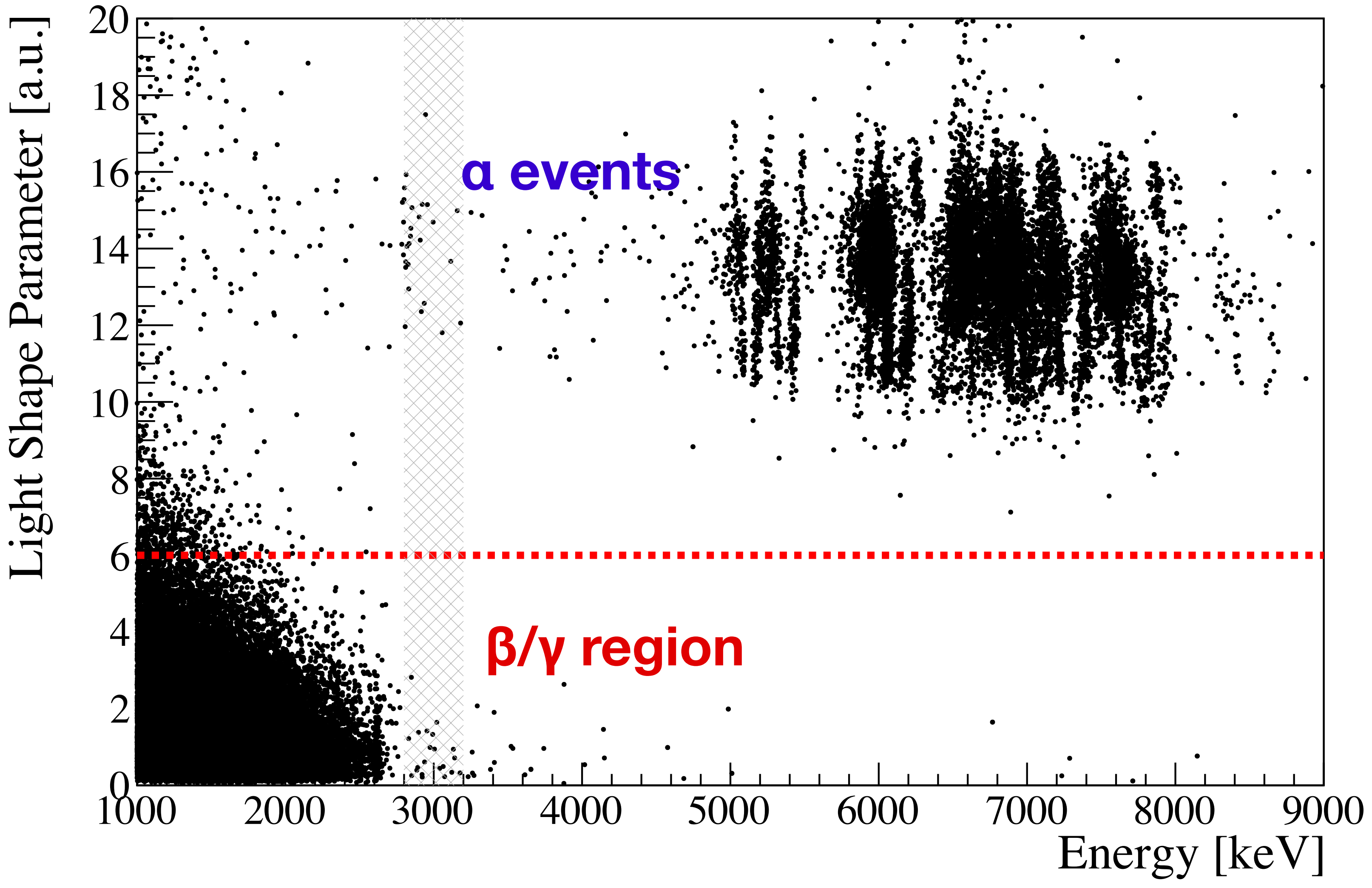




Data Selection (2)

Add information of light detectors

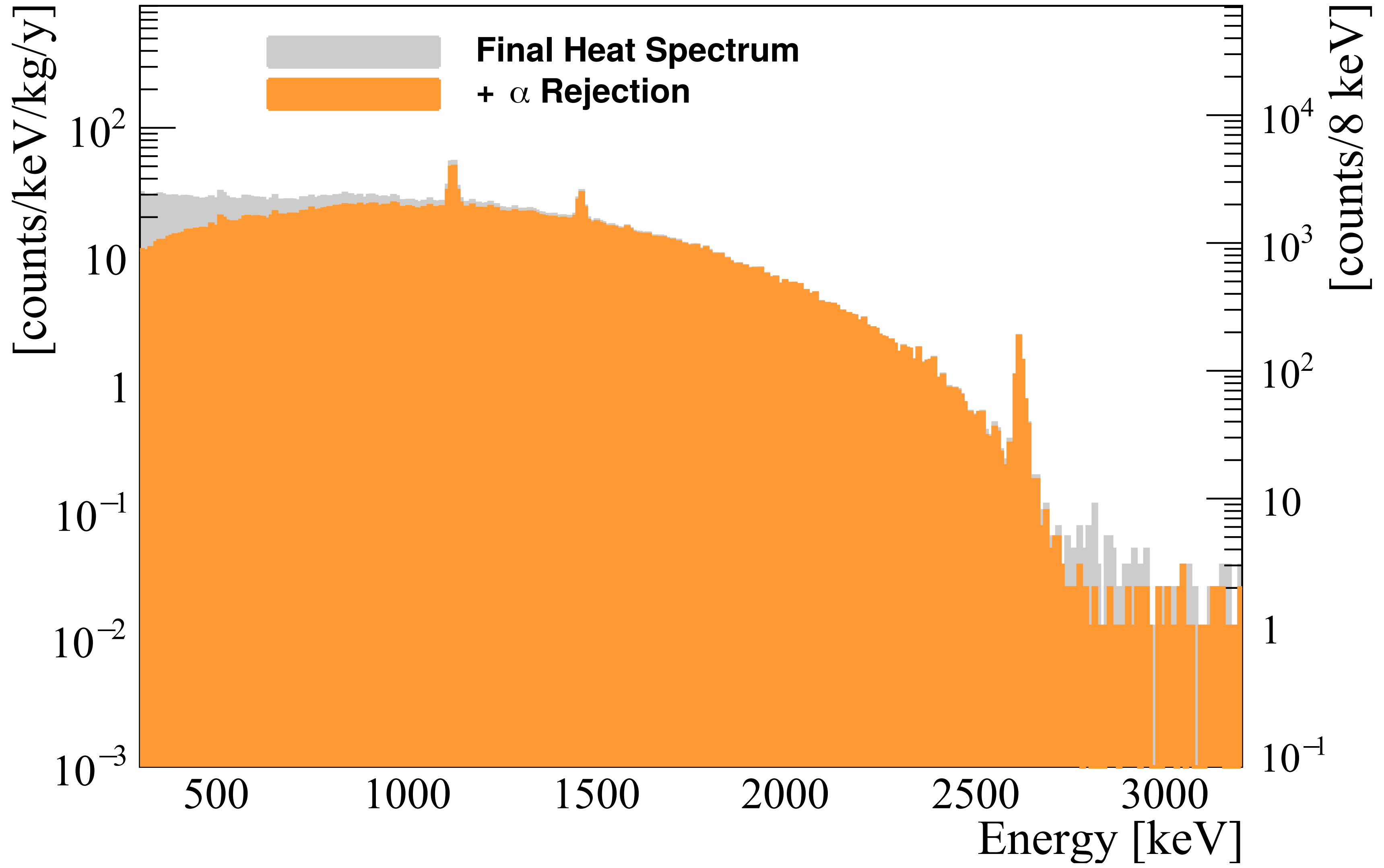


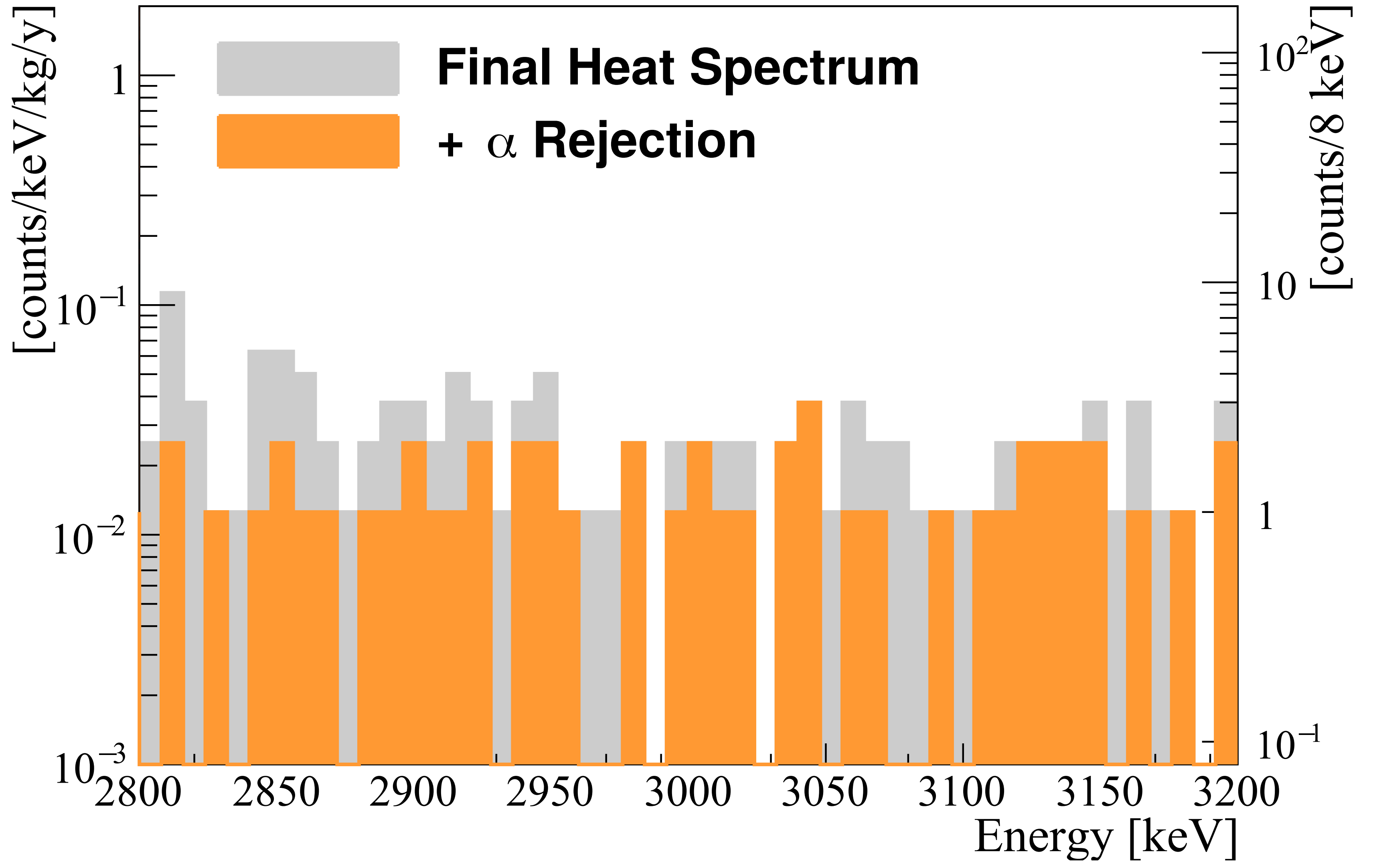


Background in ROI (2800-3200 keV):

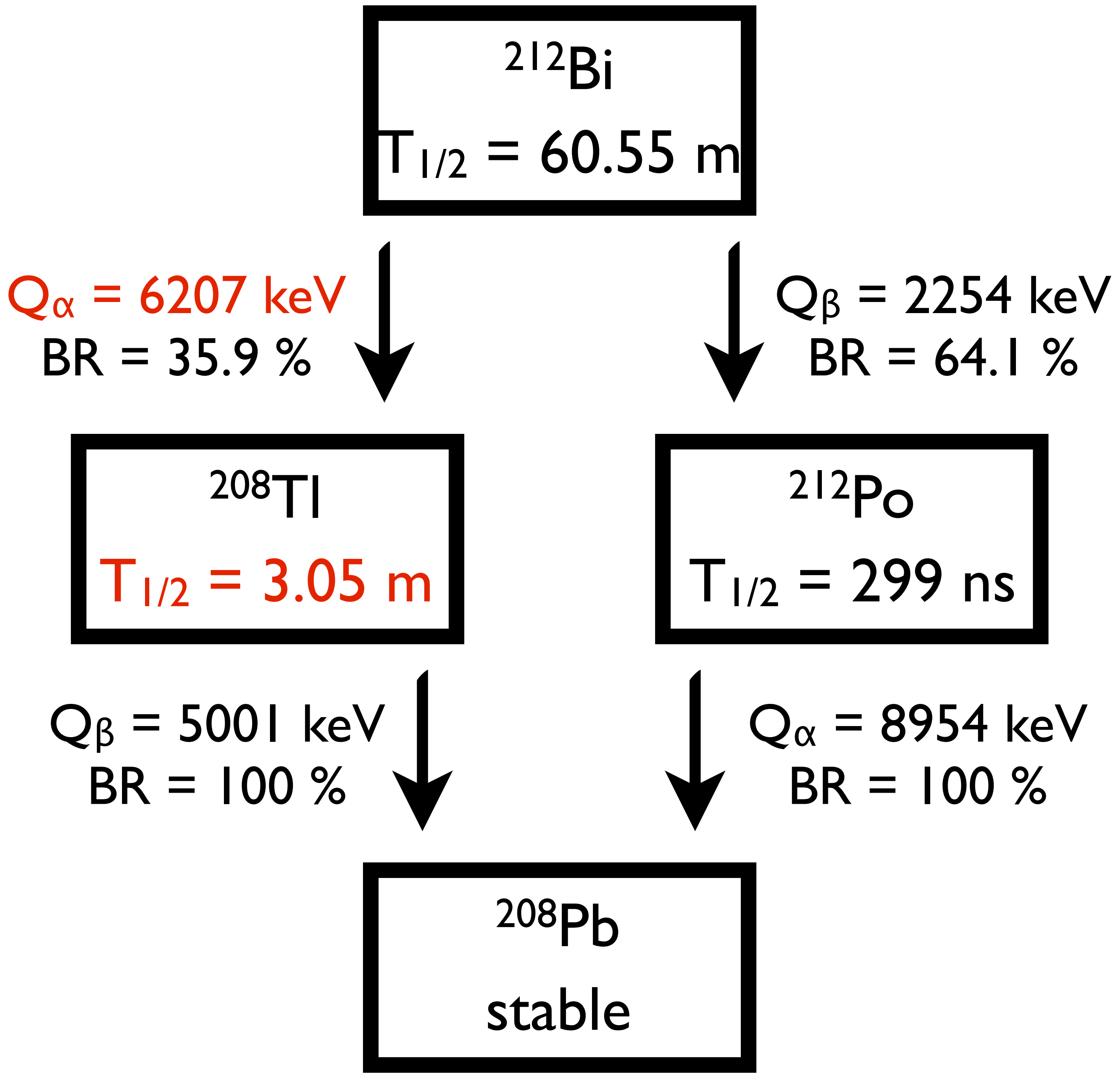
1.3×10^{-2} counts/keV/kg/yr

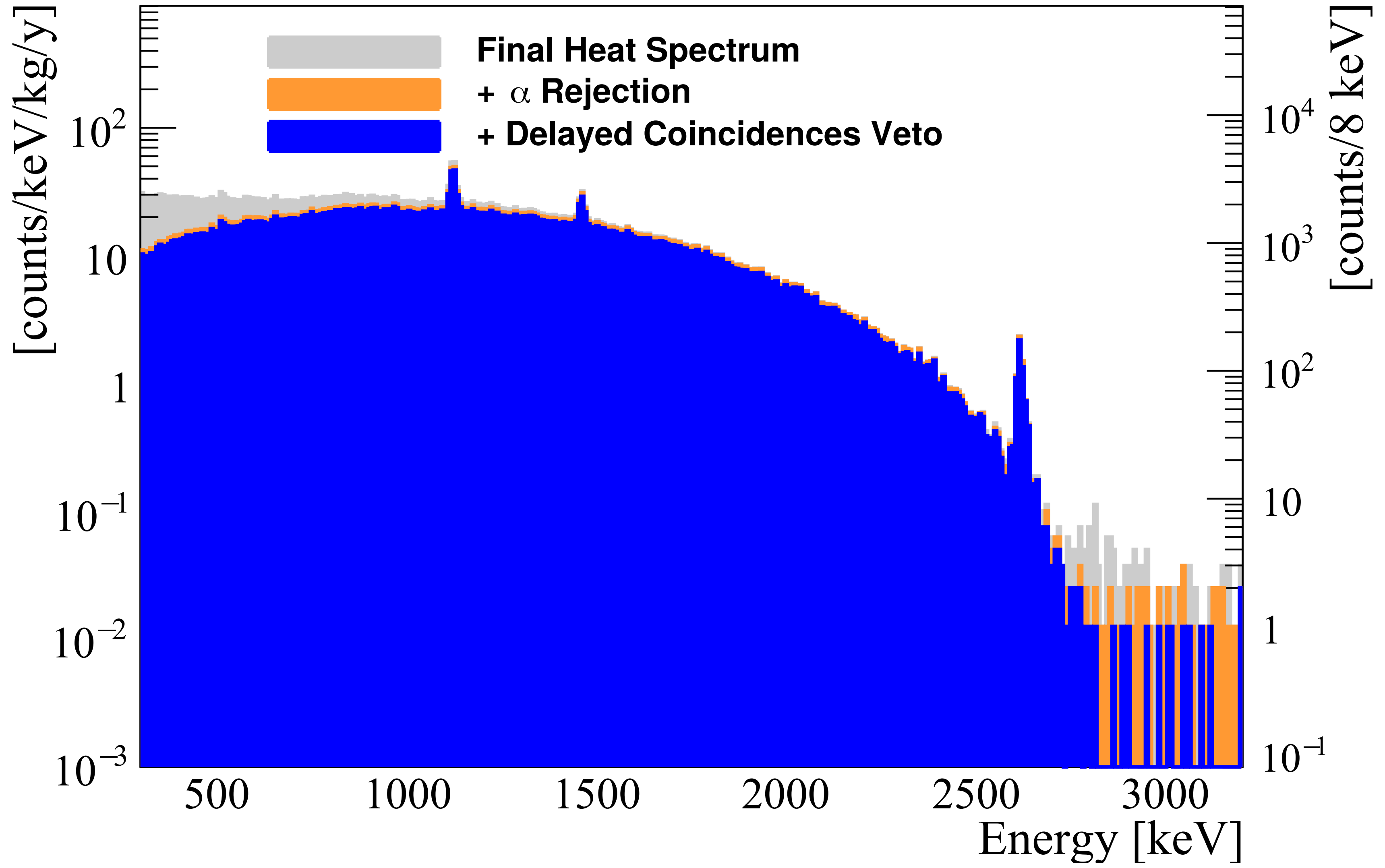
Particle ID provides x3 suppression

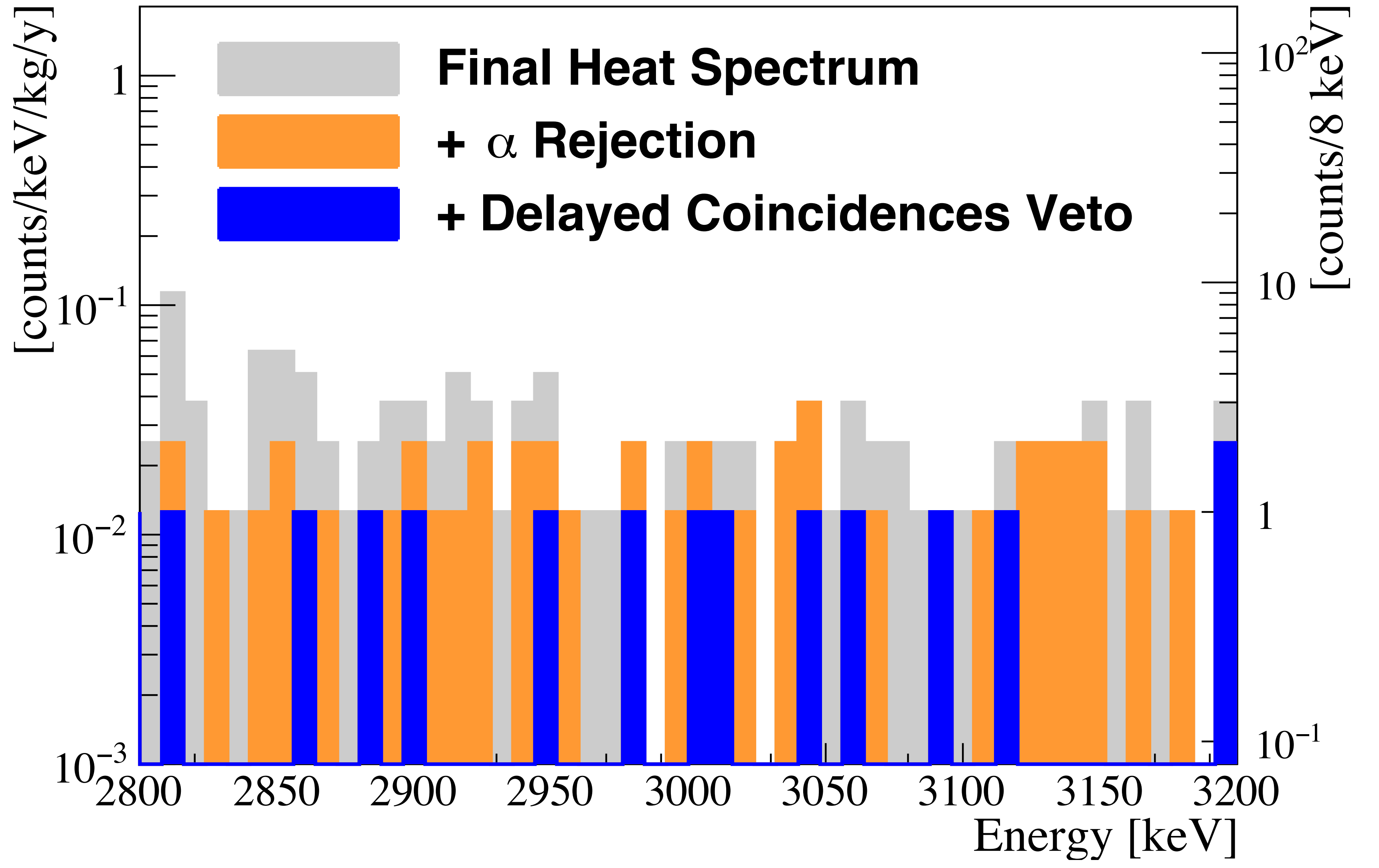




Data Selection (3)







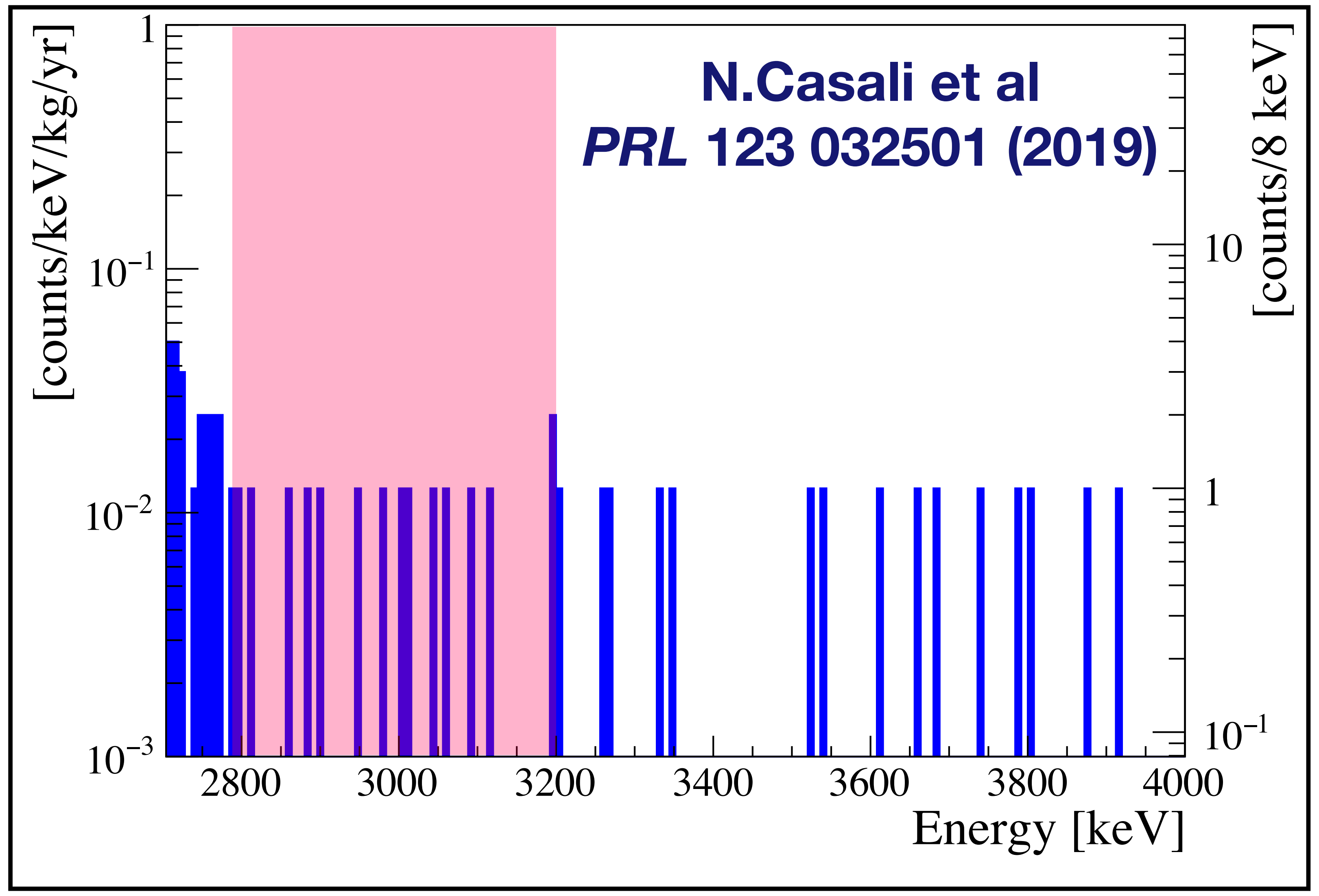
Background in ROI (2800-3200 keV):

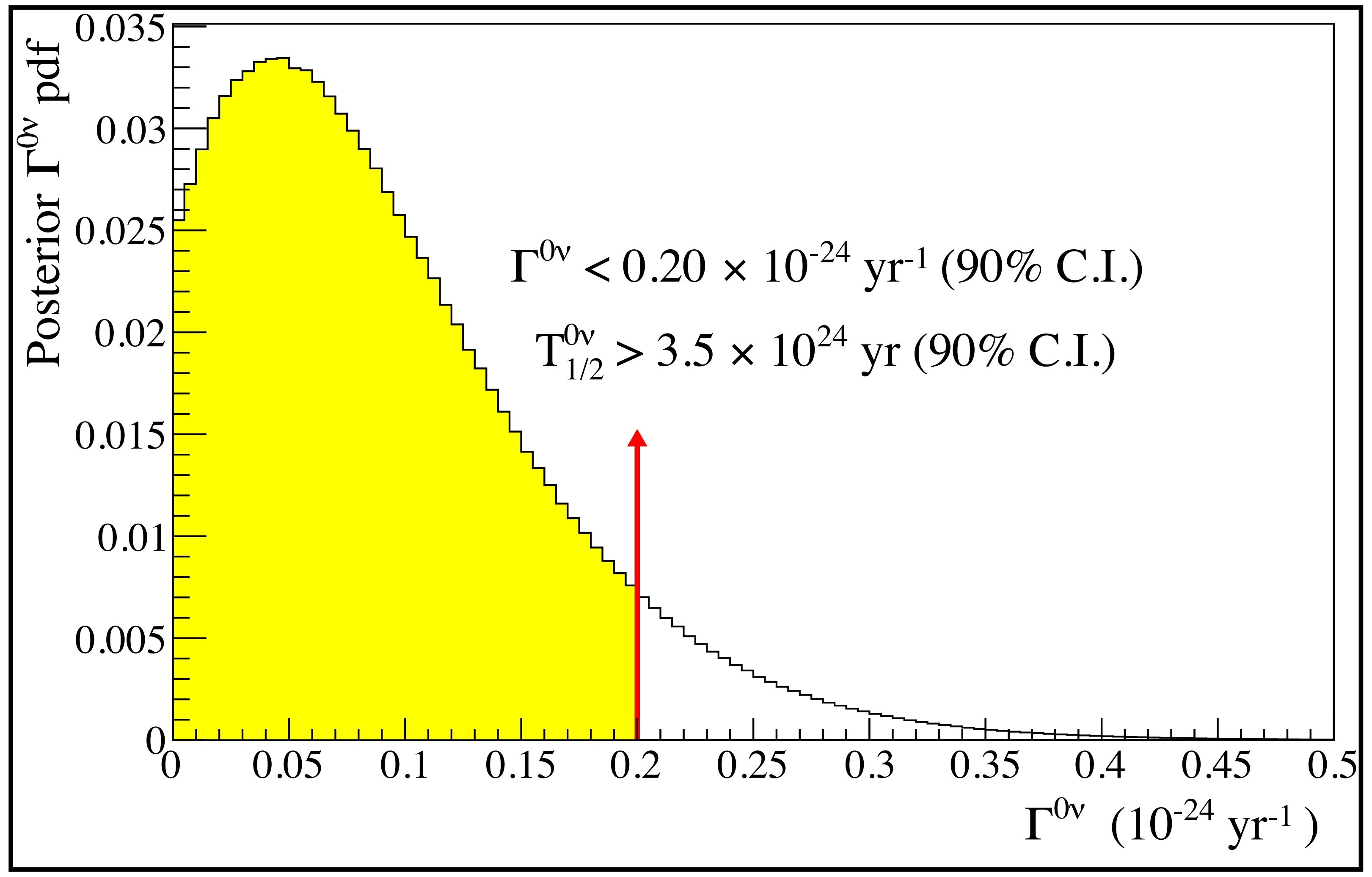
3.5×10^{-3} counts/keV/kg/yr

Lowest Background
For cryogenic calorimeters

$0\nu\beta\beta$ decay of ^{82}Se

- Total exposure:
  - 5.29 (kg x yr) of ^{82}Se
  - 3.88×10^{25} (emitters x yr) of ^{82}Se
- Final efficiency: (70 ± 1) %
  - Probability of $0\nu\beta\beta$ electrons containment (81.0 ± 0.2) %
  - Trigger and energy reconstruction 99.5 %
  - Selection on heat (shape + time veto) 88%
  - Electrons selection: 98%
- Energy resolution in ROI: (20.05 ± 0.34) keV

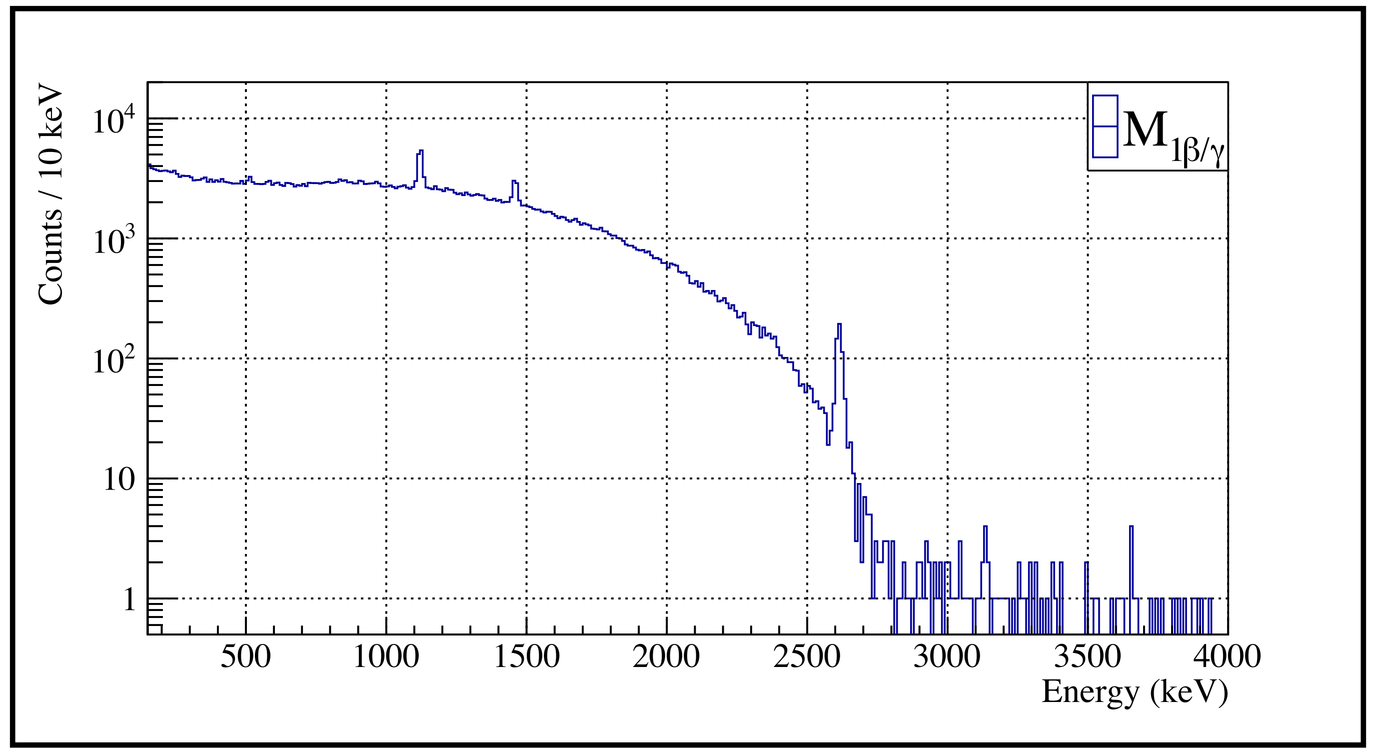


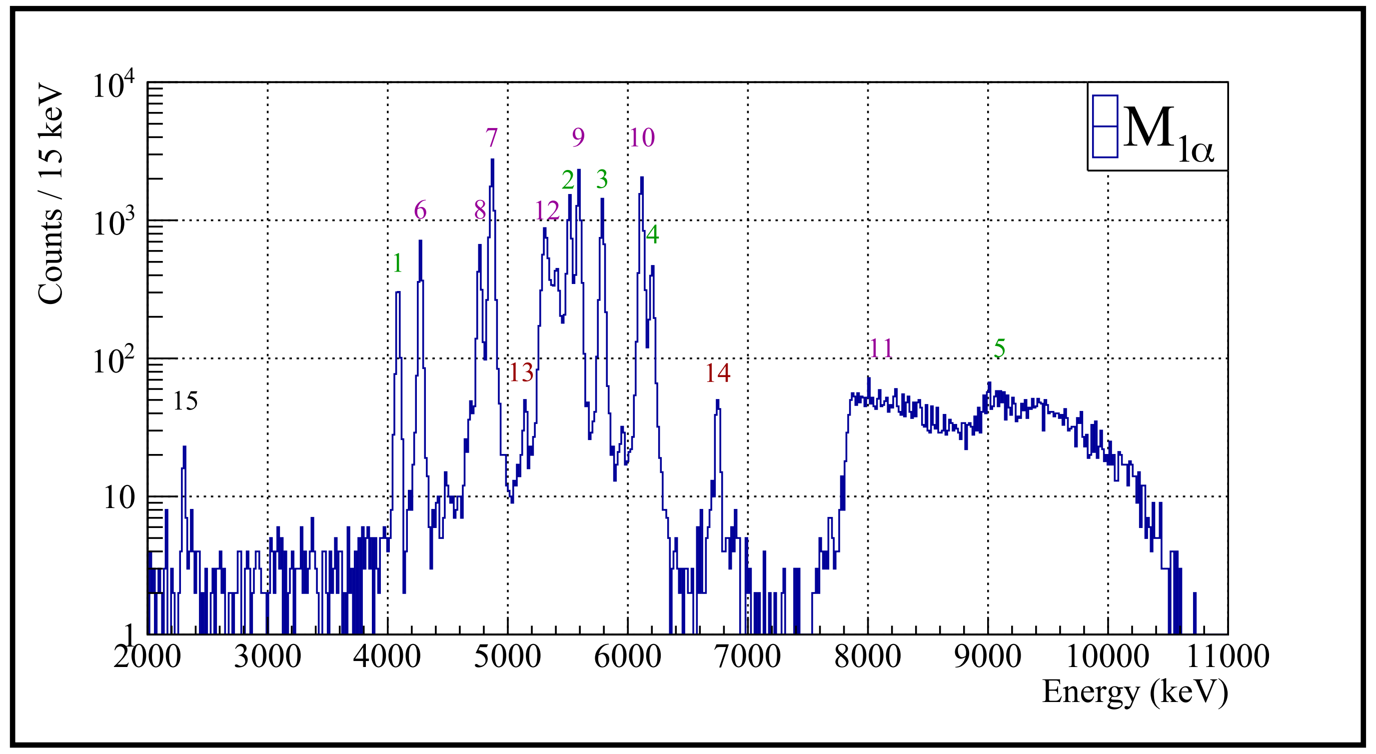


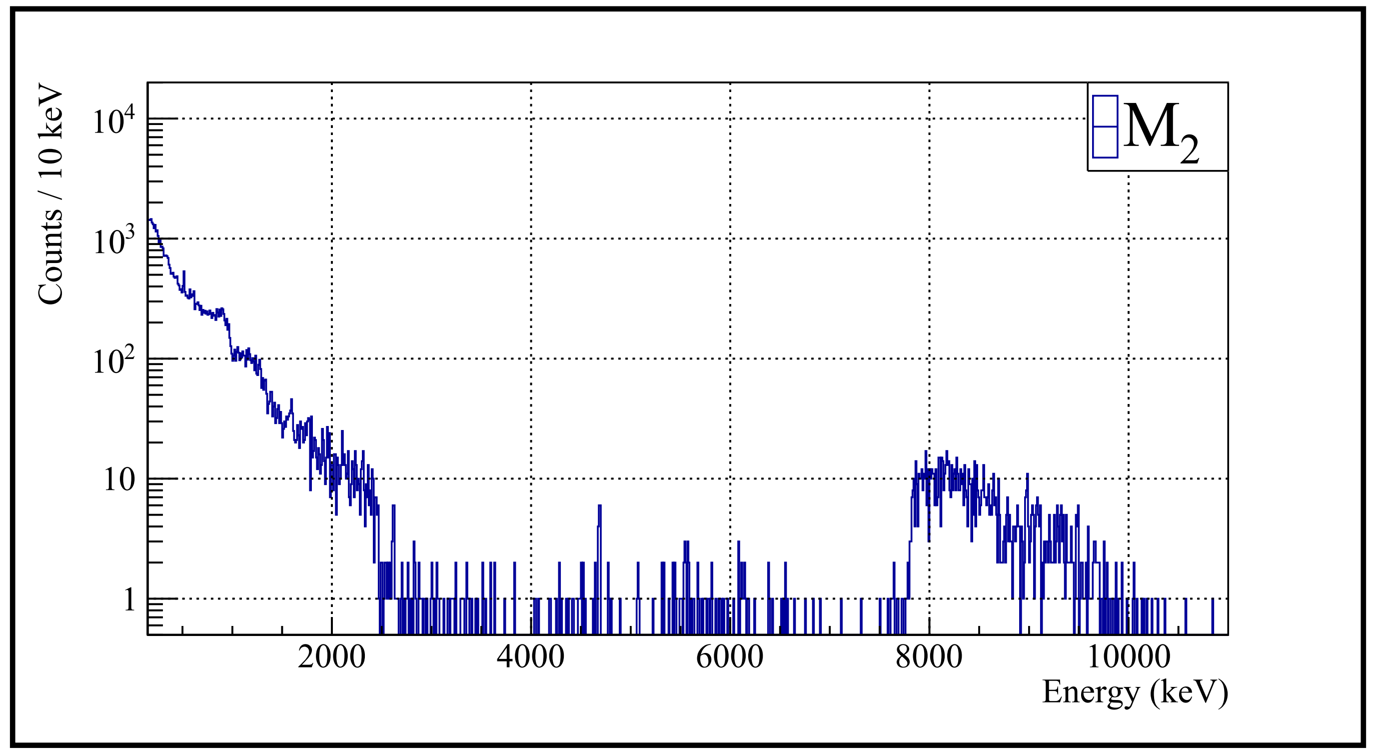
$T_{1/2} > 3.5 \times 10^{24}$ yr (90% C.I.)
Sensitivity on $T_{1/2} > 5.0 \times 10^{24}$ yr (90% C.I.)
Surpasses by more than x 10 previous limits

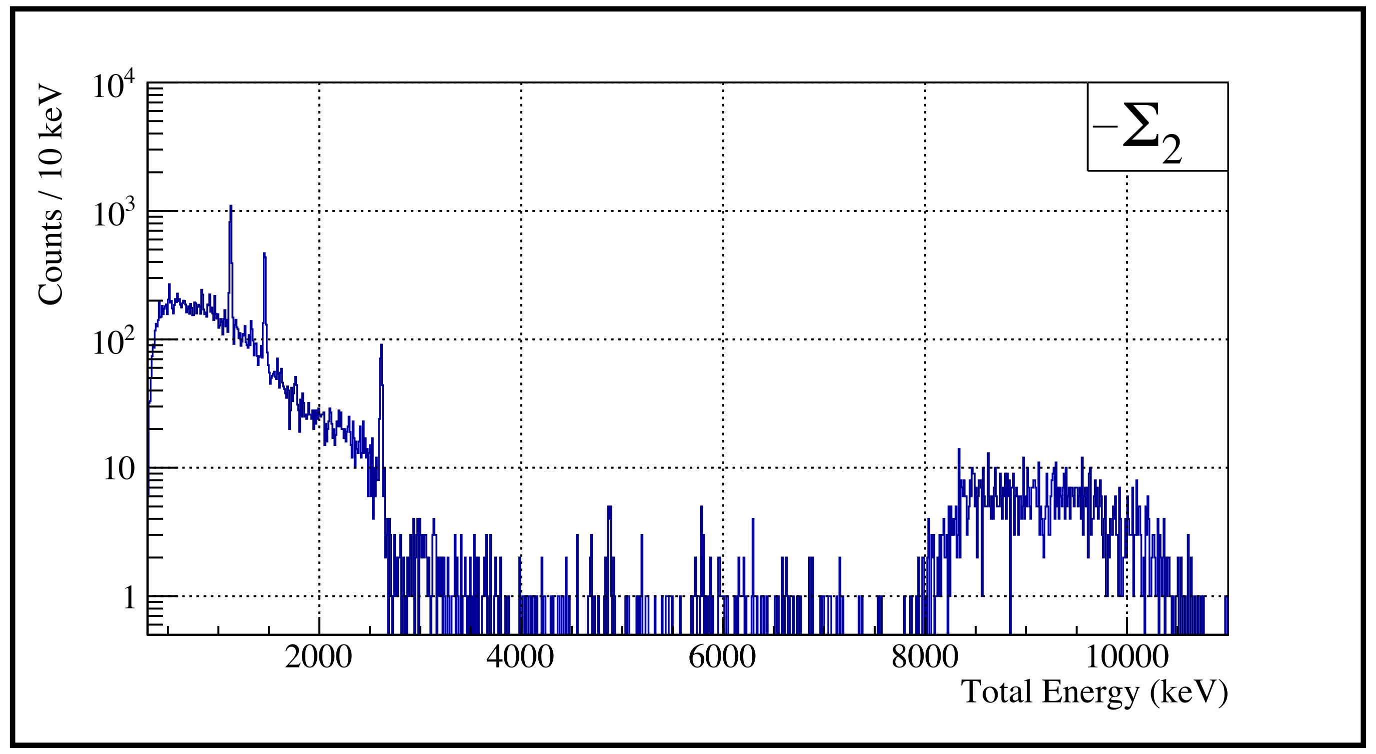
Background Model

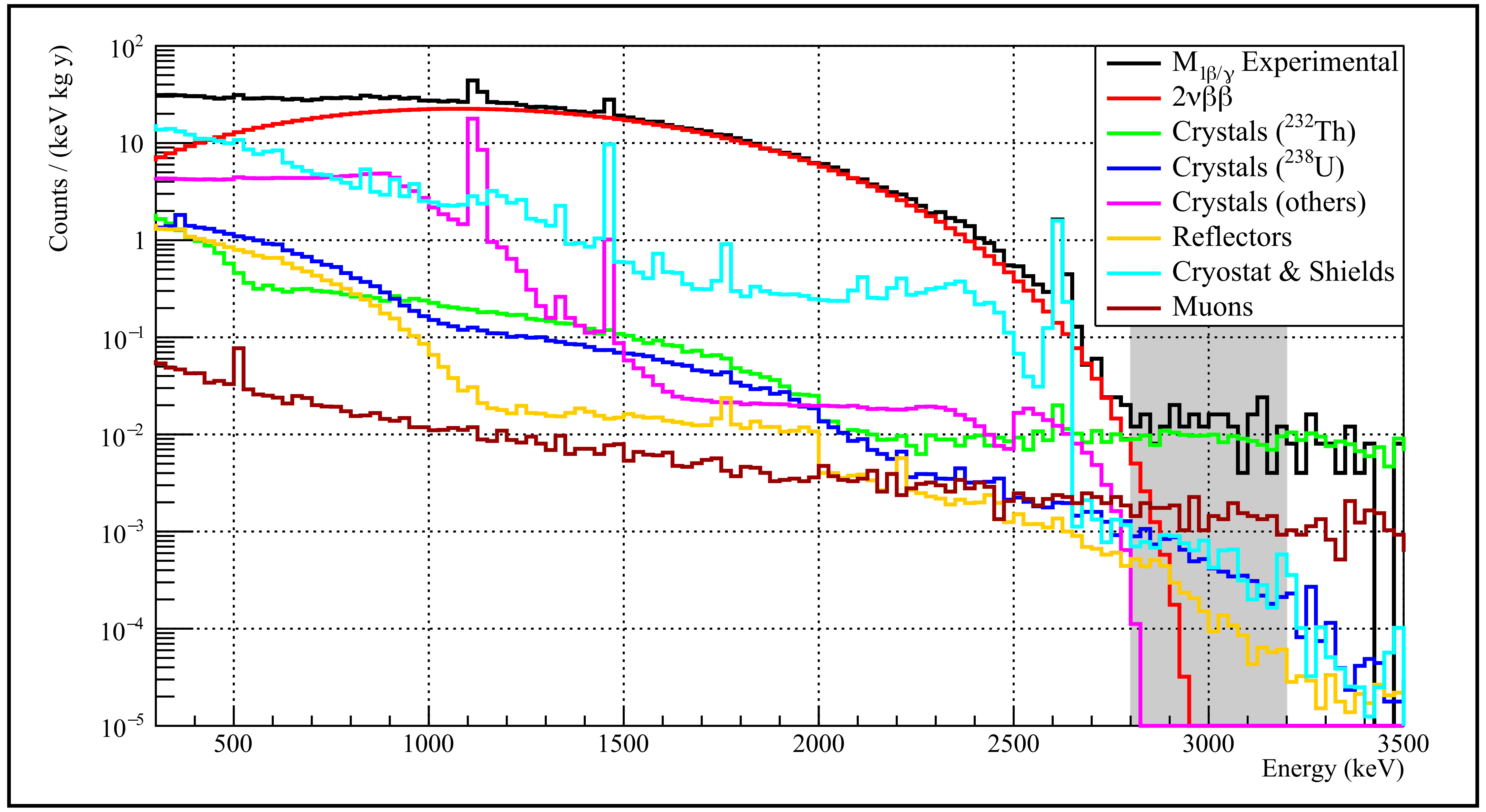
Where does the residual ($3.5x10^{-3}$ counts/keV/kg/yr) background come from?











+ higher multiplicity spectra to normalise cosmic rays

- ~44% muons
- ~33% contaminations ZnSe crystals
- ~17% cryostat
- ~6% reflecting foil and holders

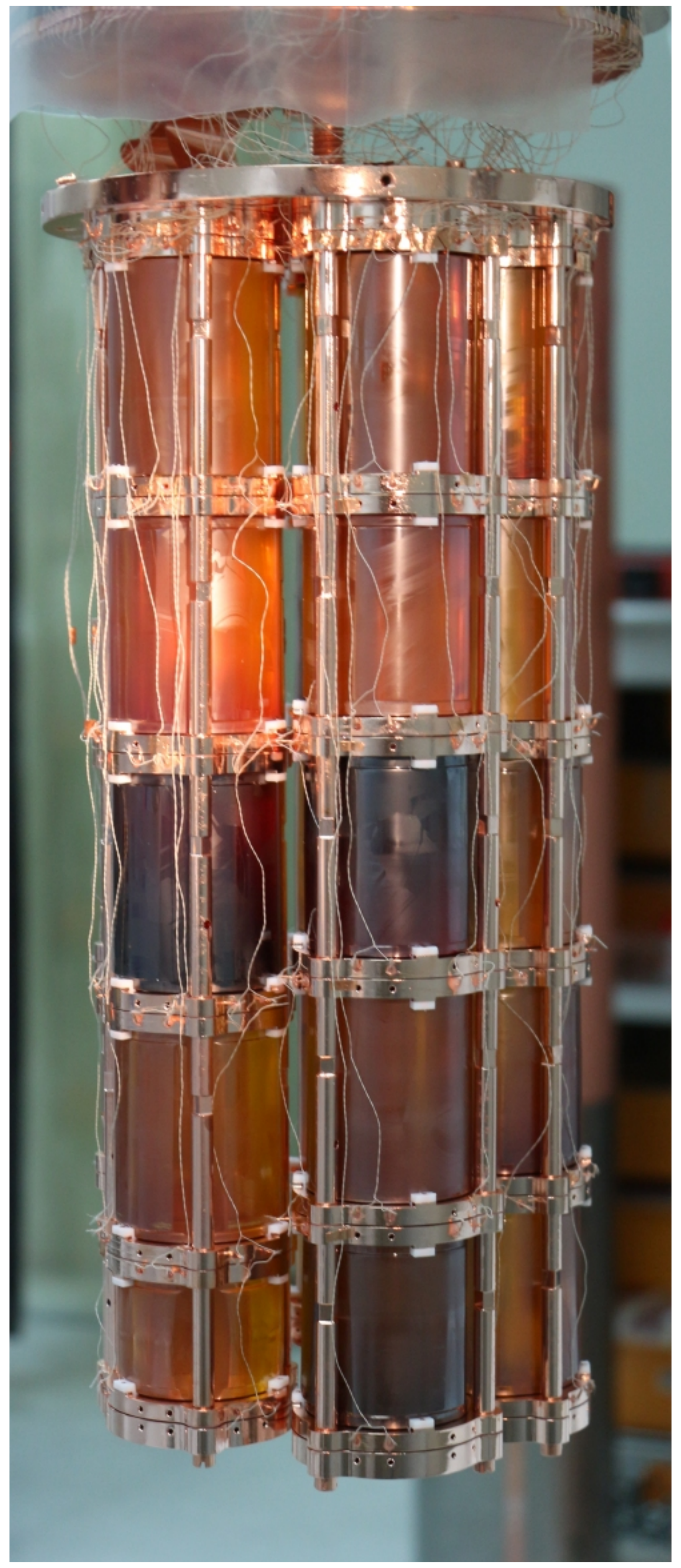
D. Chiesa et al
Eur. Phys. J. C 79 583 (2019)

What Next

- ~44% muons
- ~33% contaminations ZnSe crystals
- ~17% cryostat
- ~6% reflecting foil and holders

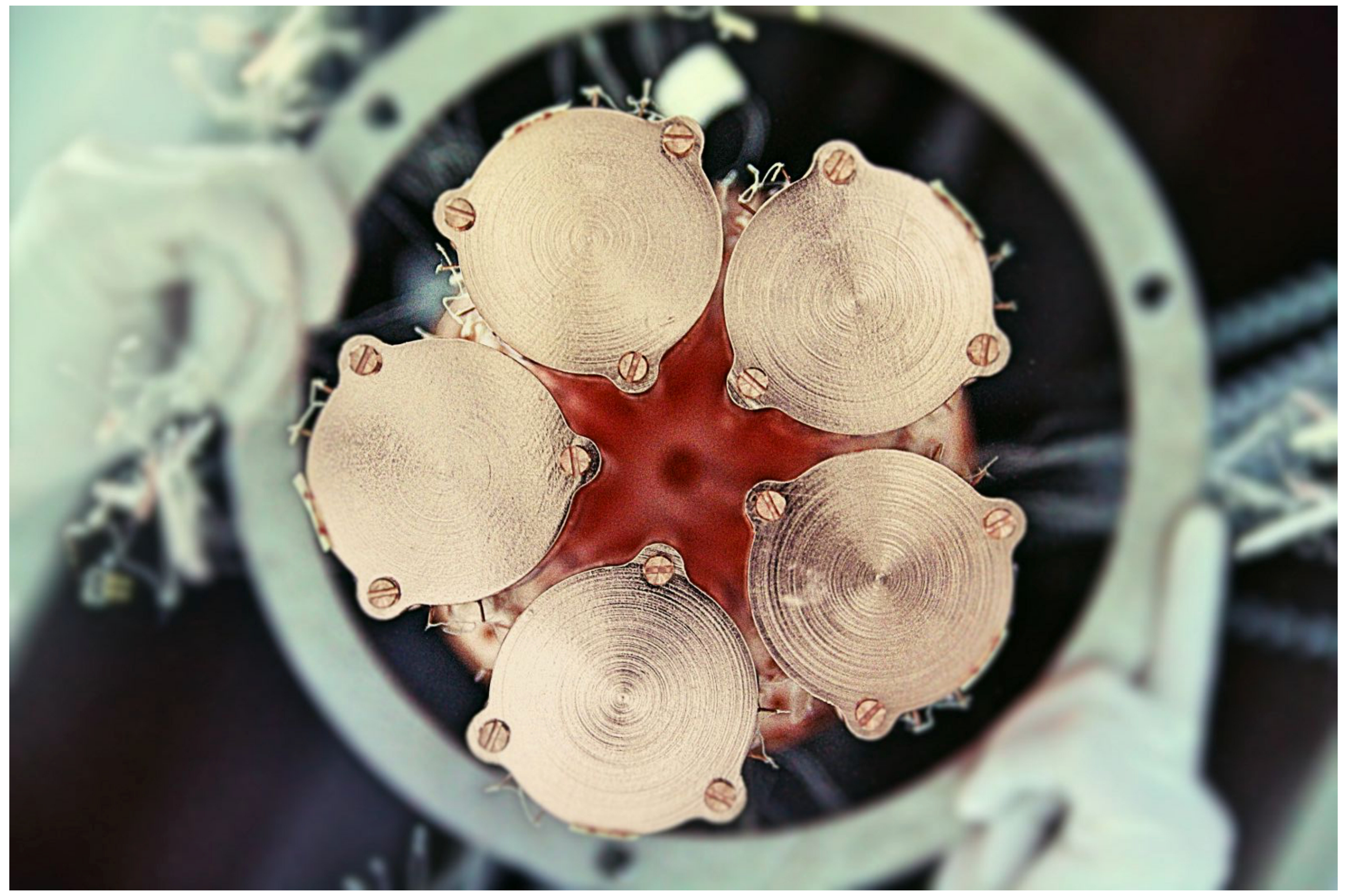
Upgrade (January-May 2019)

- Muon-veto surrounding the cryostat (lateral +top)
- Removal of reflecting foils (coincidences)
- Addition of internal copper shield



CUPID-0 is now back in data-taking for its II scientific run

Conclusions and Perspectives



- First scientific run (June 2017 — December 2018) concluded
- Most stringent limit on ^{82}Se 0νββ decay to fundamental and excited states of ^{82}Kr
- Lowest background for cryogenic calorimeters 3.5×10^{-3} counts/keV/kg/yr
- Upgrade for second scientific run concluded

Reached the sensitivity to:

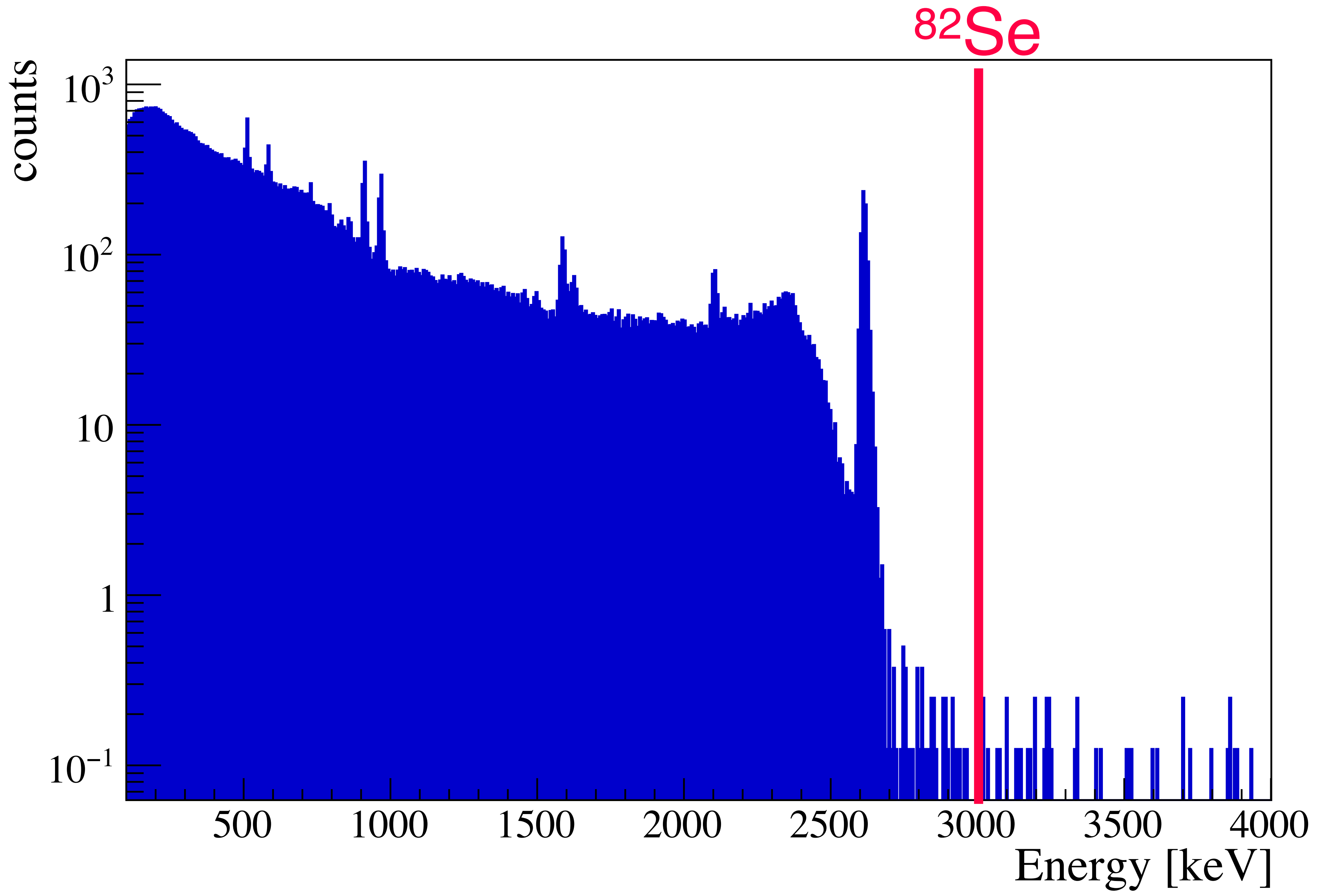
- Study the ^{82}Se 2νββ with unprecedented precision (HSD vs SSD)
- Improve sensitivity on 0νββ decay of ^{64}Zn and ^{70}Zn (by x100)
- Search for Lorentz violations in the 2νββ spectrum
- ….

https://cupid-0.lngs.infn.it

Calibration of Energy Scale

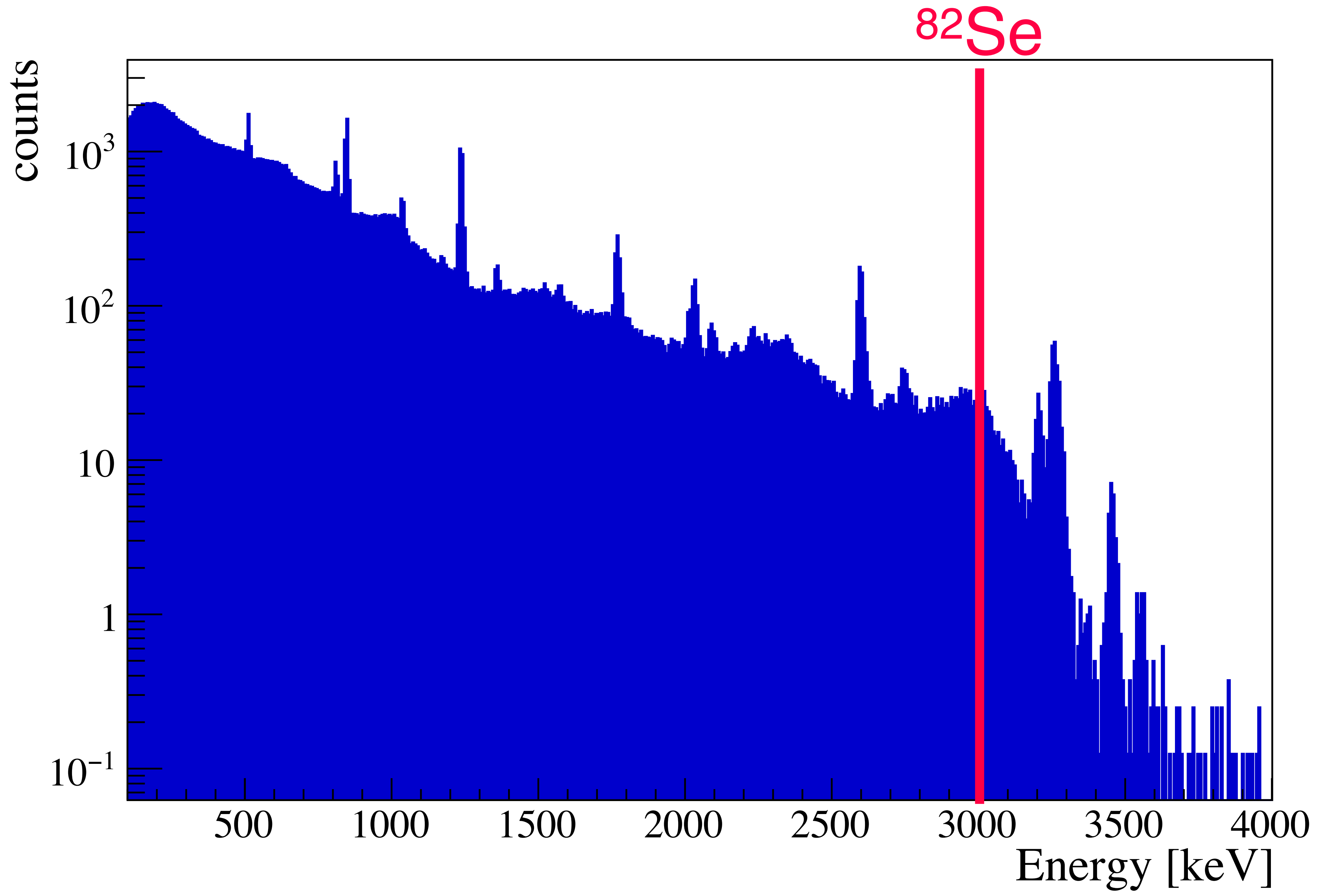
Periodical (~ 4 days every month) calibration

with ^{232}Th sources



Cross-check with ^{56}Co calibration

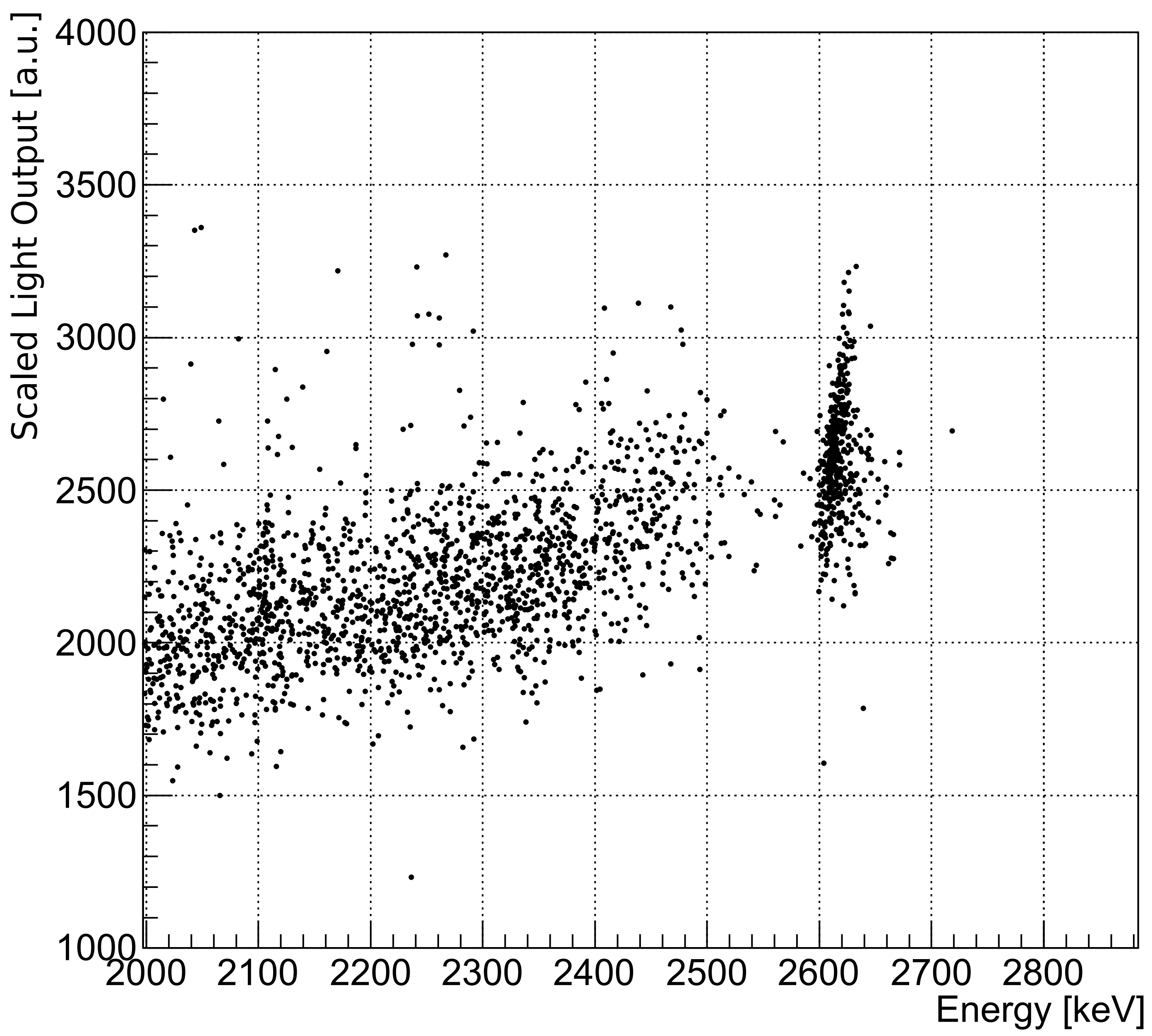
(Q-value ~ 4.57 MeV, $T_{1/2}$ ~ 77 days)

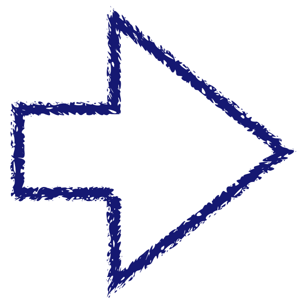


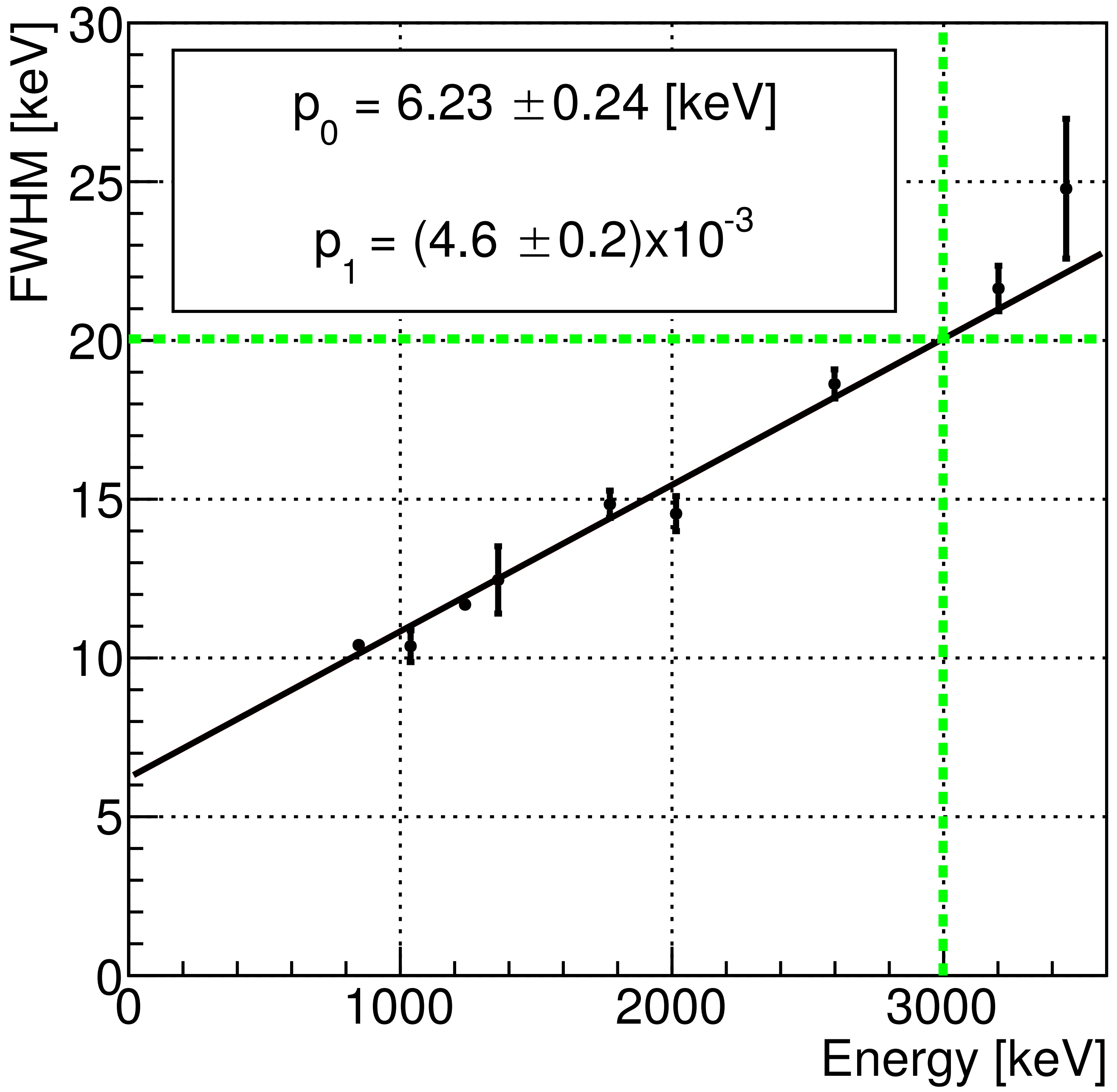
Energy Resolution

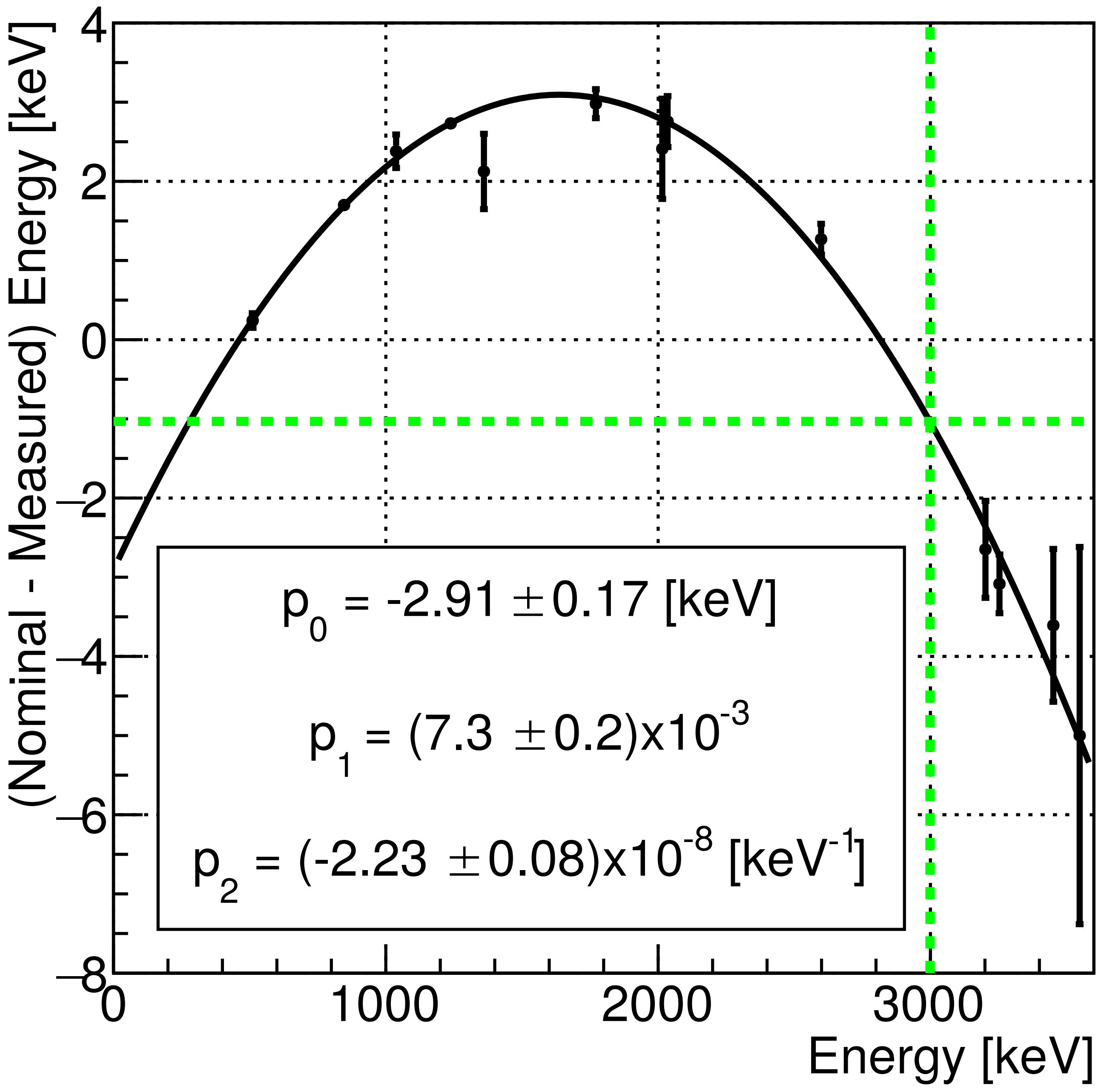
Removed light - heat correlation to improve resolution

(M.Beretta et al, arXiv:1901.10434)



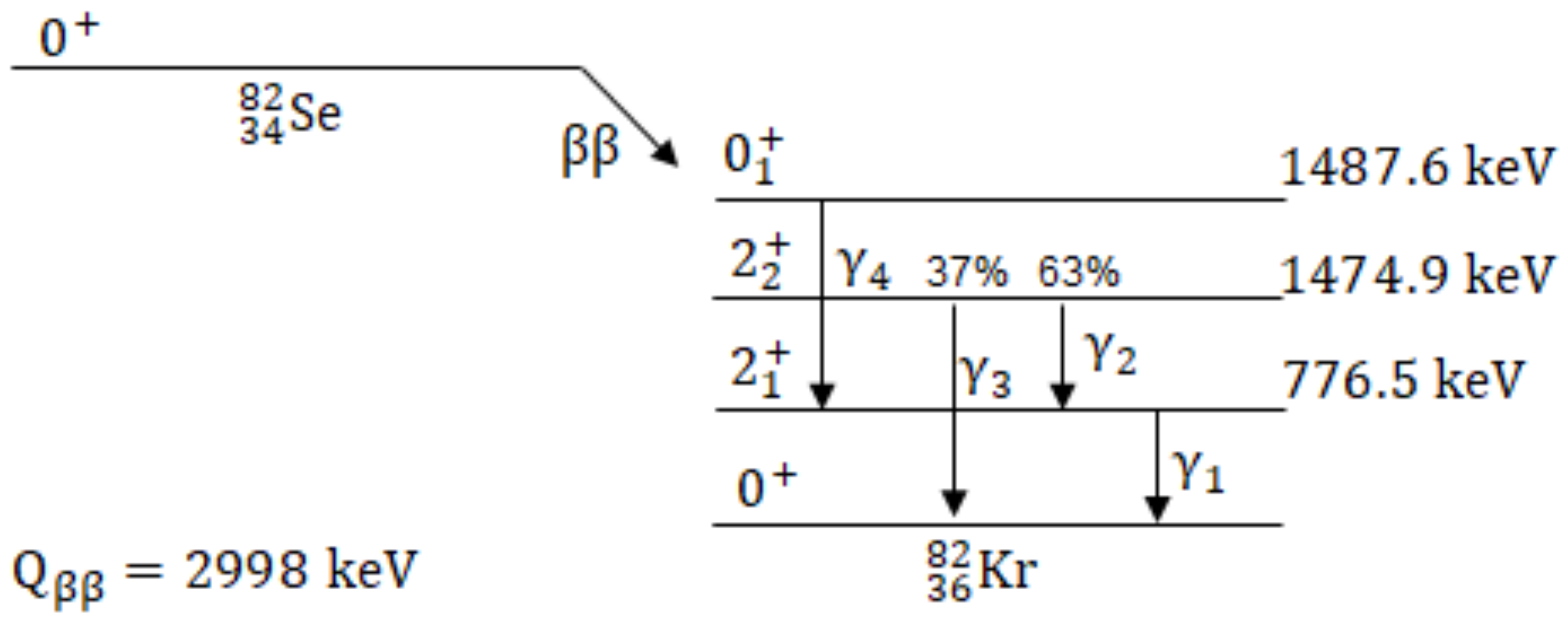






Final resolution at ^{82}Se Q-value: 20.0 ± 0.3 keV FWHM

$0\nu\beta\beta$ decay of ^{82}Se to excited states



Studied first with Ge spectroscopy of ^{82}Se powder [L. Pattavina et al. Eur.Phys.J. C75 (2015) no.12, 591]

Analysis repeated with CUPID-0 [L. Cardani et al. Eur.Phys.J. C78 (2018) no.11, 888]

$$\Gamma(^{82}Se \rightarrow ^{82}Kr_{0_1^+}) < 8.55 \times 10^{-24} yr^{-1}$$
$$\Gamma(^{82}Se \rightarrow ^{82}Kr_{2_1^+}) < 6.25 \times 10^{-24} yr^{-1}$$
$$\Gamma(^{82}Se \rightarrow ^{82}Kr_{2_2^+}) < 8.25 \times 10^{-24} yr^{-1}$$