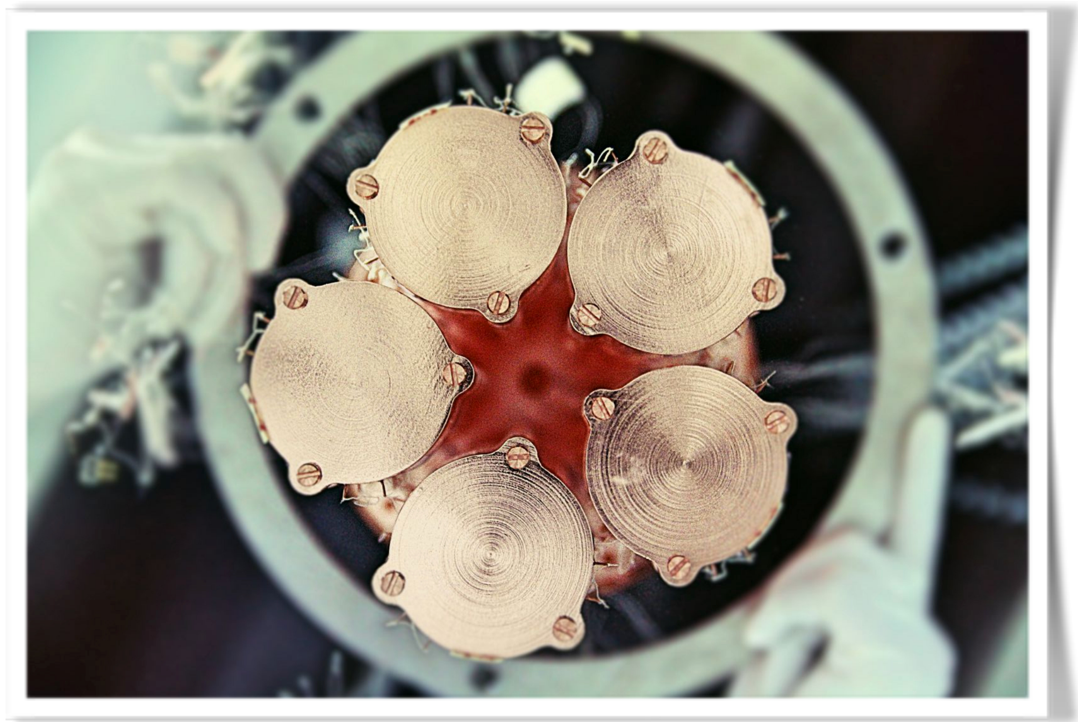
Double Beta Decay with CUPID0: Results and Perspectives

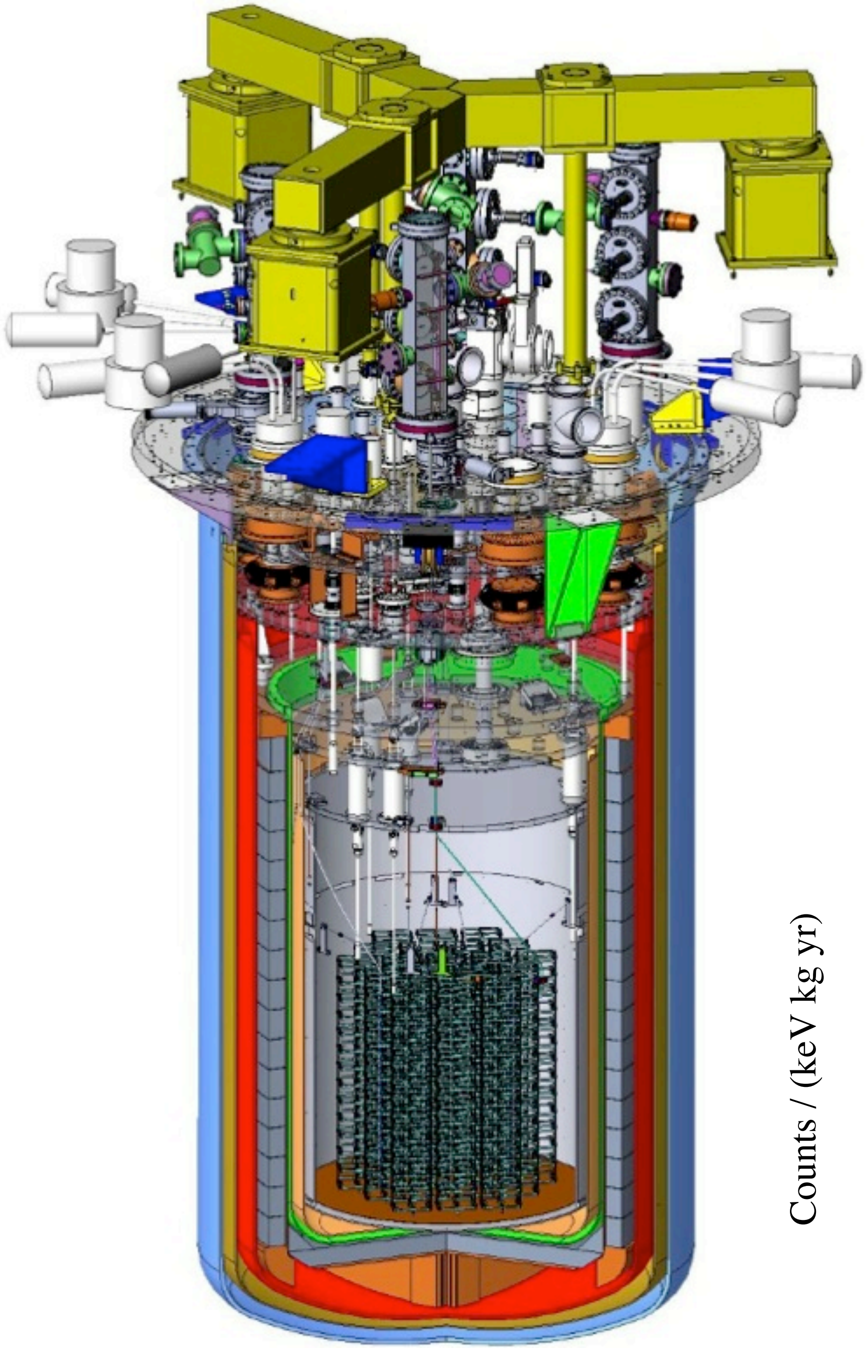


Laura Cardani for the CUPID-0 collaboration
INFN - Roma

ICHEP2018 SEOUL
XXXIX INTERNATIONAL CONFERENCE ON high Energy PHYSICS

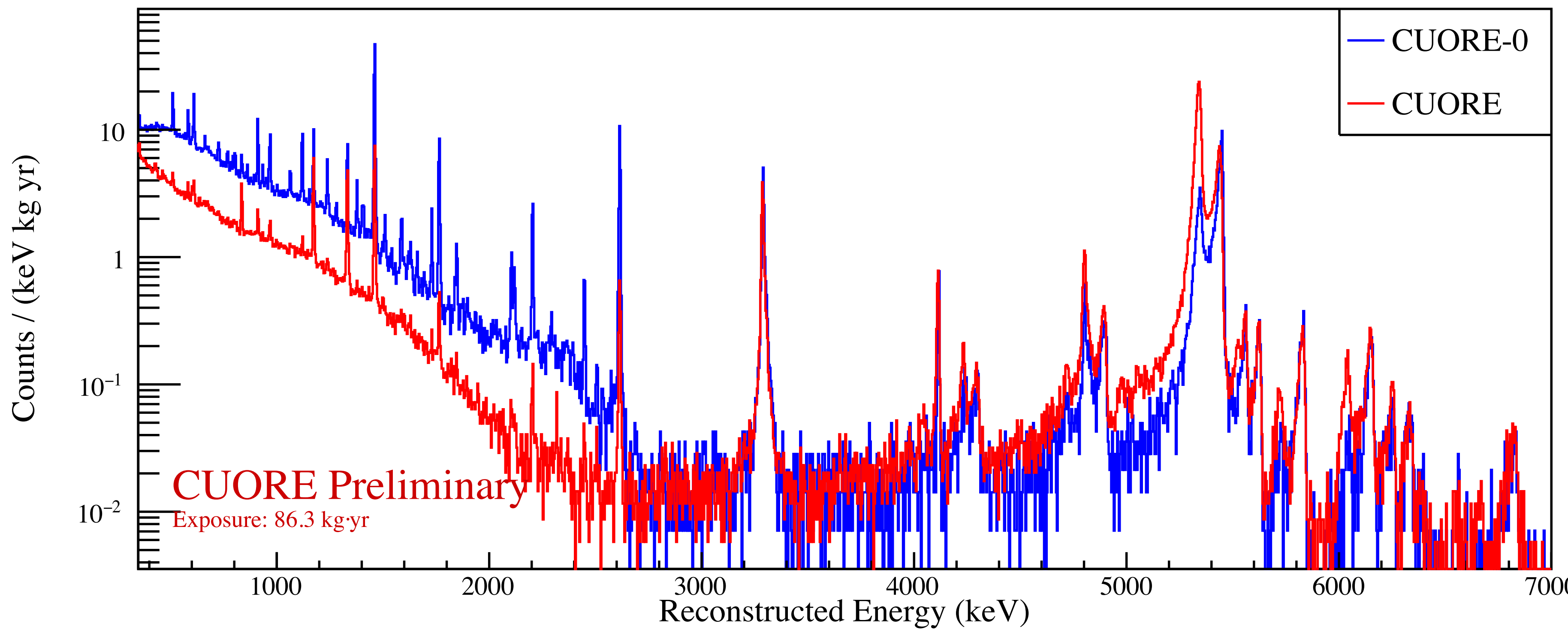
The CUORE Experience

S. Pozzi's talk



Sets the standard for next generation experiments based on cryogenic calorimeters

- Hundreds of kg of source ➪ Proved
- Energy Resolution ➪ ~0.1% in CUORE cryostat
- BUT background of 10^{-2} c/keV/kg/y in ROI



The CUORE Experience

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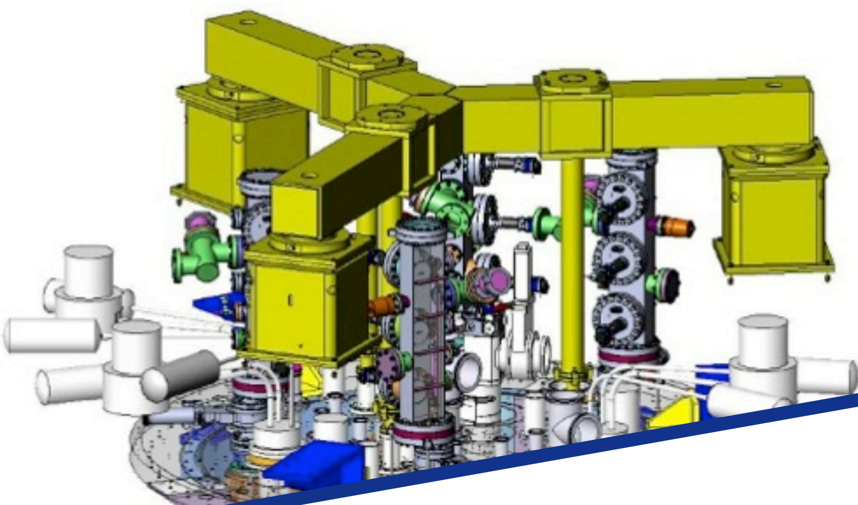


Sets the standard for next generation experiments based on cryogenic calorimeters

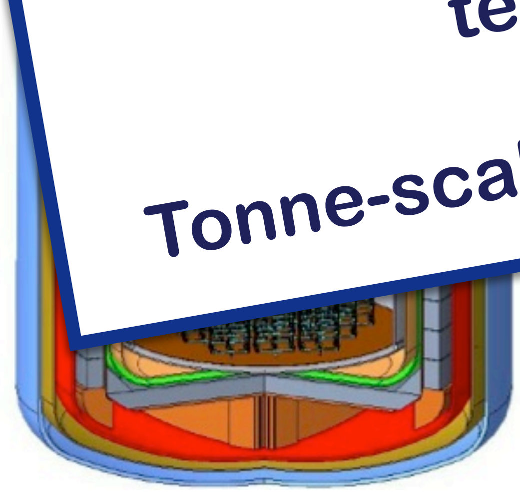
- Hundreds of kg of ...

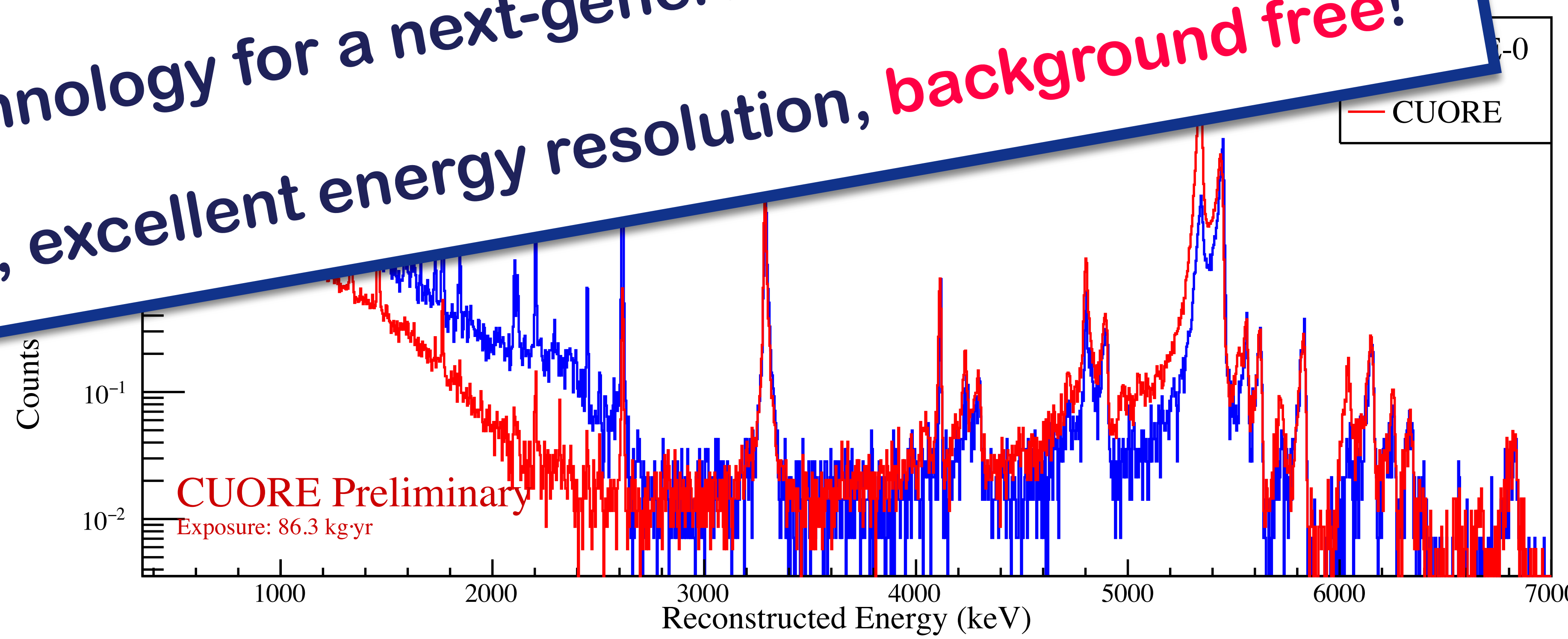
CUPID

(Cuore Upgrade with Particle IDentification)

technology for a next-generation project

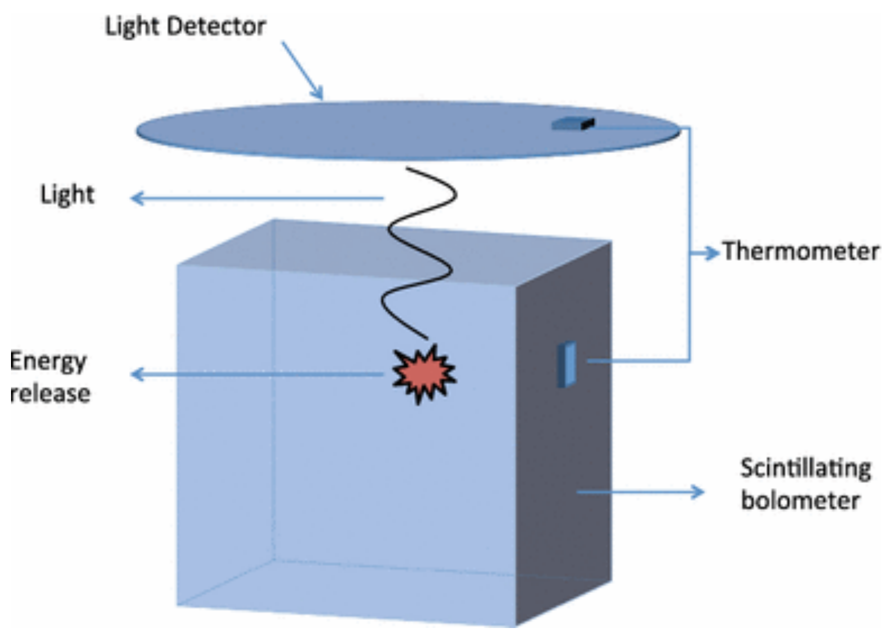
Tonne-scale, excellent energy resolution, background free!



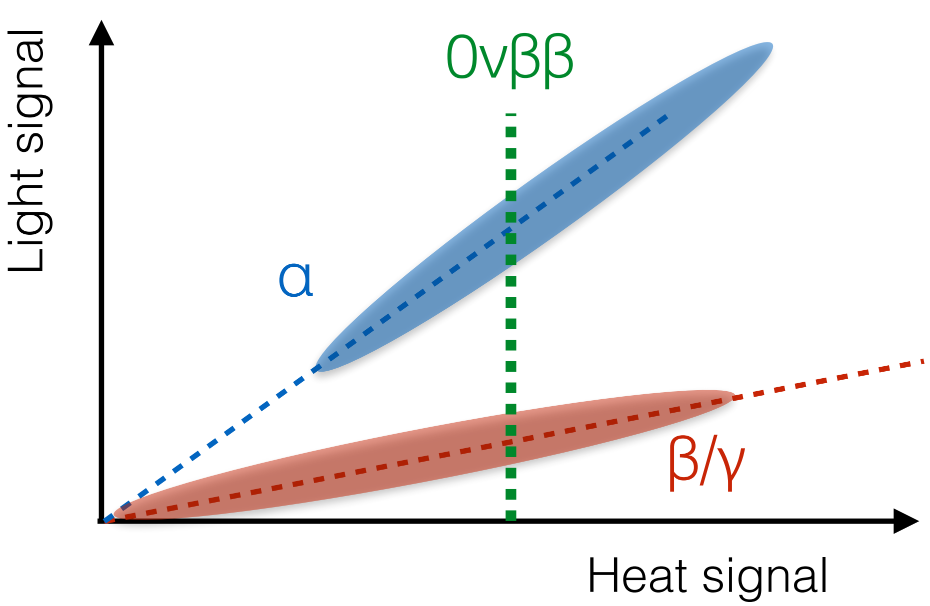


CUORE + Particle ID

The background can not be suppressed by x100 using only "passive" techniques



- **Couple each calorimeter to a light detector**
- **Different light yield enables particle identification**
- **Reject the (dominant) α background**

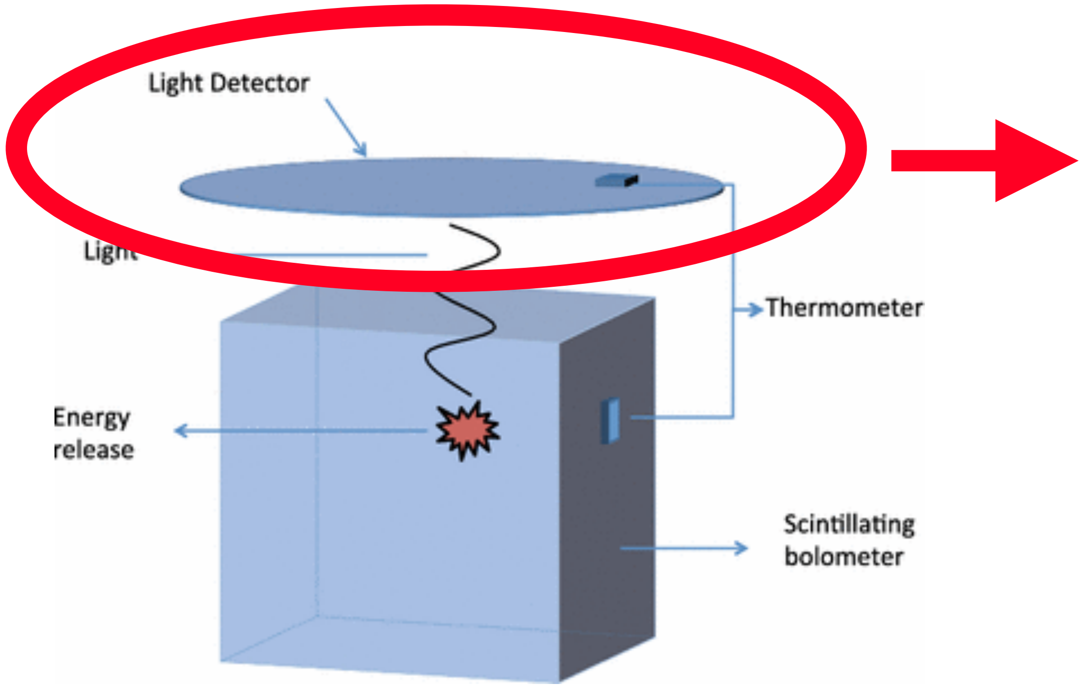


Problem:

electrons with 0νββ energy in TeO_2 emit only ~100 eV of light

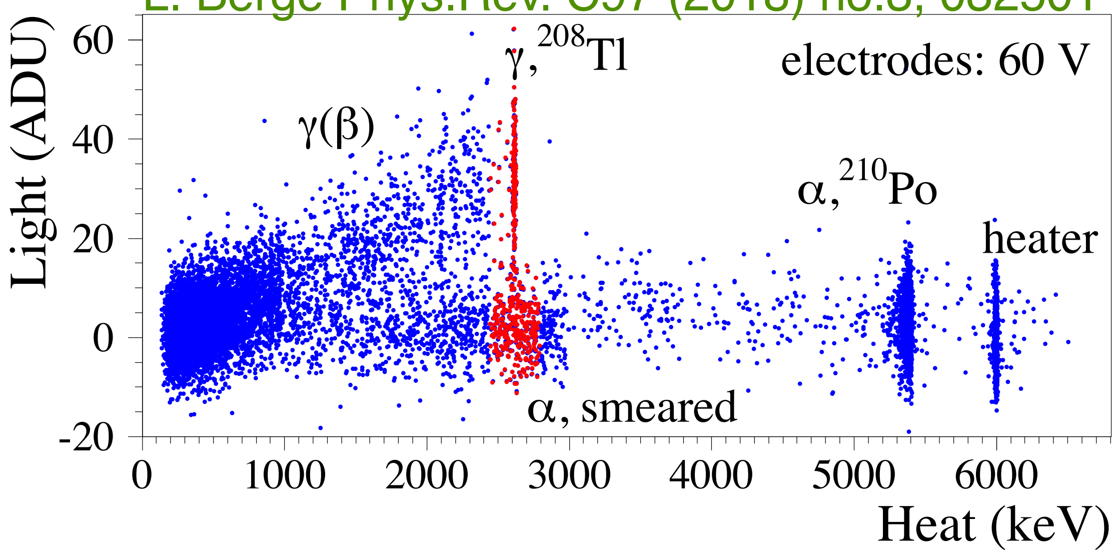
CUORE + Particle ID

Sensitive LDs to measure 100 eV (TES, KID, NTD-Ge, + Neganov-Luke effect)



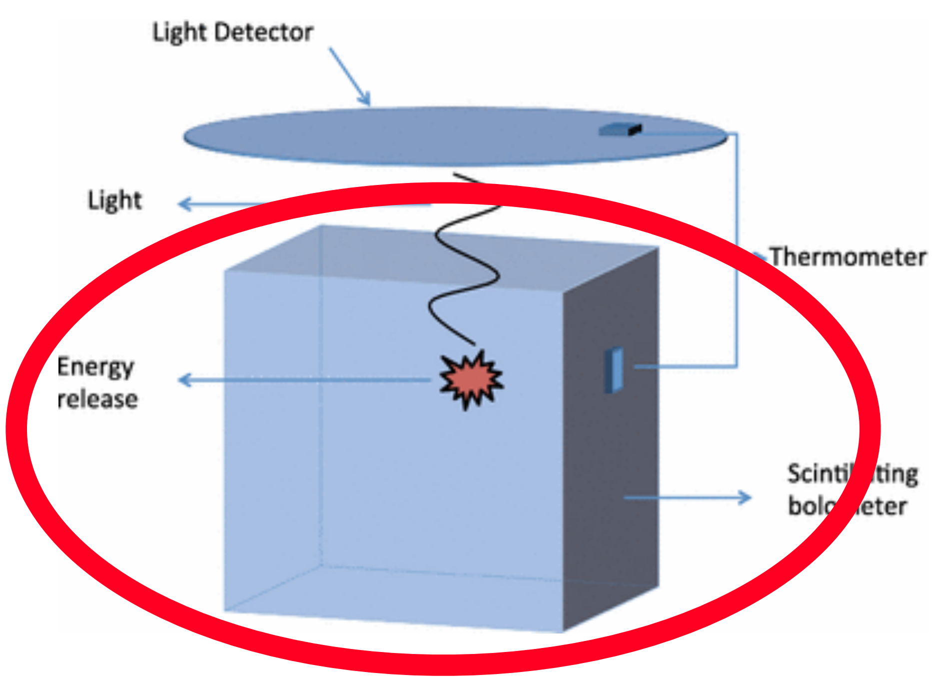
J.W. Beeman et al. JINST 8 (2013) P07021
L. Cardani et al. Appl.Phys.Lett. 107 (2015) 093508
M. Biassoni et al. Eur.Phys.J. C75 (2015) no.10, 480
L. Pattavina et al., Journal of Low Temp Phys 1-6 (2015)
K.Schaeffner et. al, Astropart.Phys. 69 (2015) 30-36
M. Willers et al., JINST 10 P03003 (2015)
L. Pattavina et al. J.Low.Temp.Phys. 184 (2016) no.1-2, 286-291
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)
and many others…

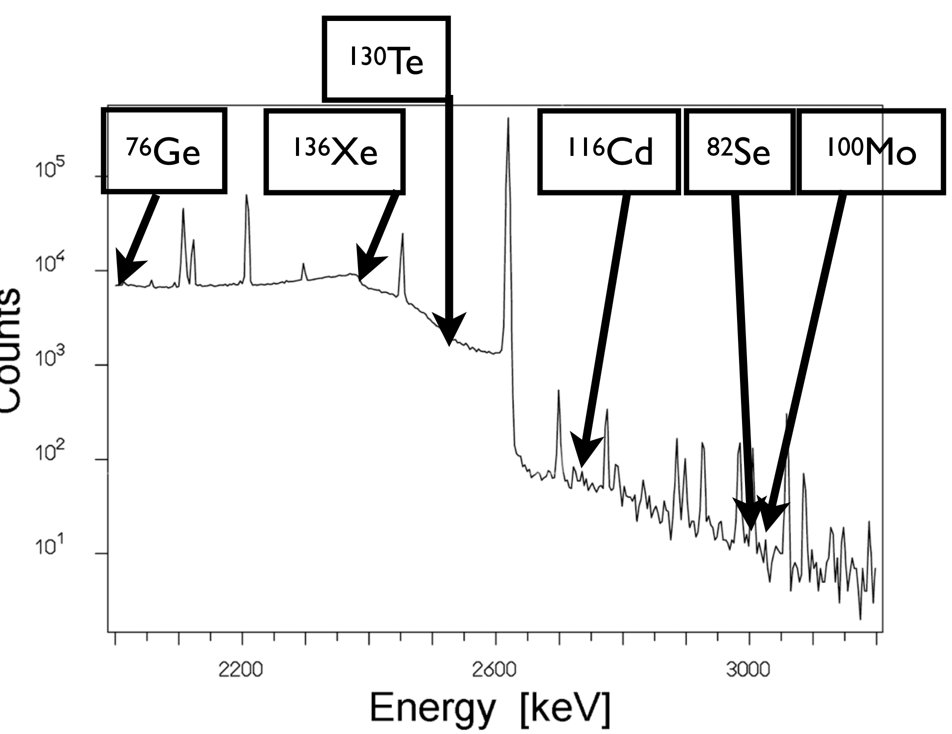
L. Bergé Phys.Rev. C97 (2018) no.3, 032501



CUORE + Particle ID

Instead of TeO_2, use crystals emitting light at cryogenic temperatures (keV vs 100 eV)





Further advantage: choose high Q-value emitters

Grow crystals based on ^{116}Cd, ^{82}Se, ^{100}Mo

C. Arnaboldi et al Astropart.Phys. 34 (2011) 344-353
C. Arnaboldi et al, Astropart.Phys. 34 (2010) 143-150
J.W. Beeman et al JINST 8 (2013) P05021
L. Cardani, et al., JINST 8, P10002 (2013).
L. Cardani, et al., J. Phys. G 41, 075204 (2014).
E. Armengaud, et al., JINST 10 (05), P05007 (2015).
L. Berge, et al., JINST 9 P06004 (2014).
. Bekker, et al., Astropart. Phys. 72, 38 (2016).
D. R. Artusa et al., Eur. Phys. J. C 76 no.7, 364 (2016).
E. Armengaud et al., Eur. Phys. J. C 77 no.11, 785 (2017).
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…

Y. Soo Yoon's talk

CUORE + Particle ID

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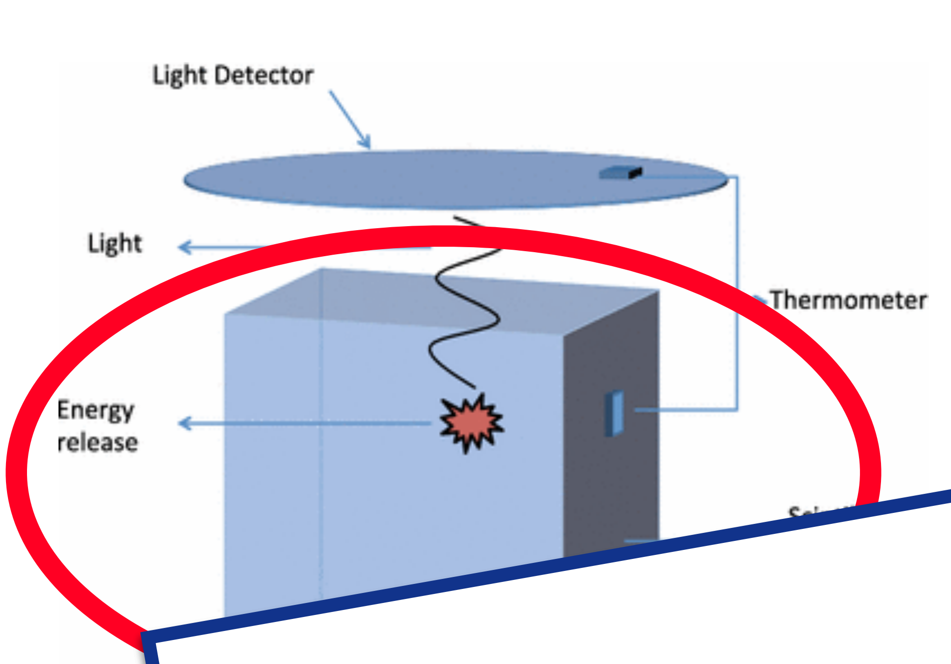

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C. Ar…

…(2018)

…ys. J. C 76 487 (2018)

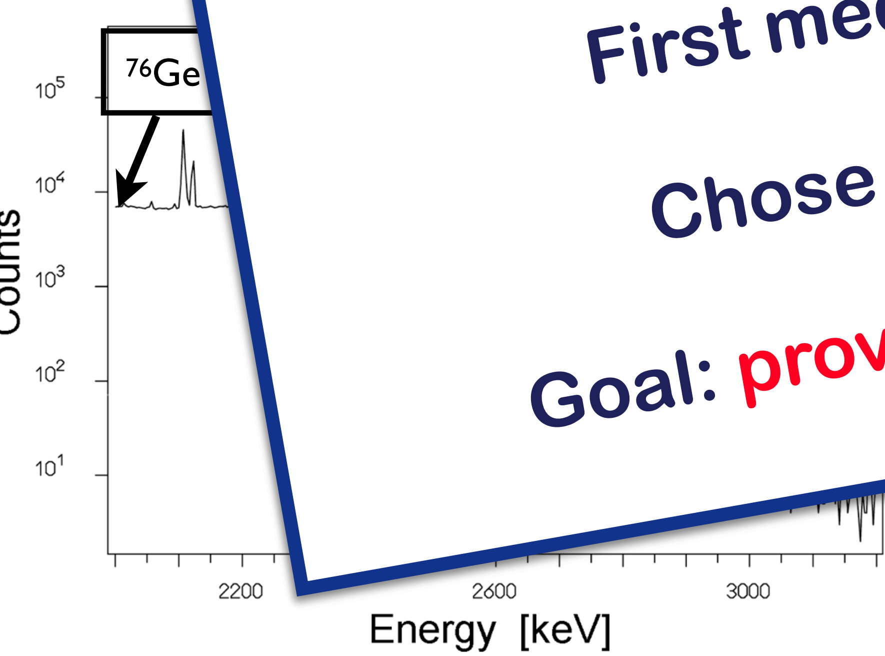
an many many others…

CUPID-0

First medium-scale demonstrator of CUPID

Chose ^{82}Se, embedded in $Zn^{82}Se$ crystals

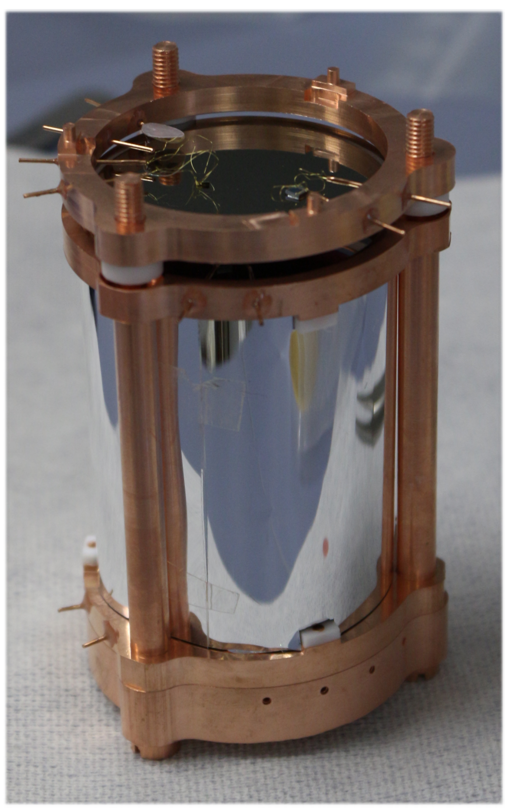
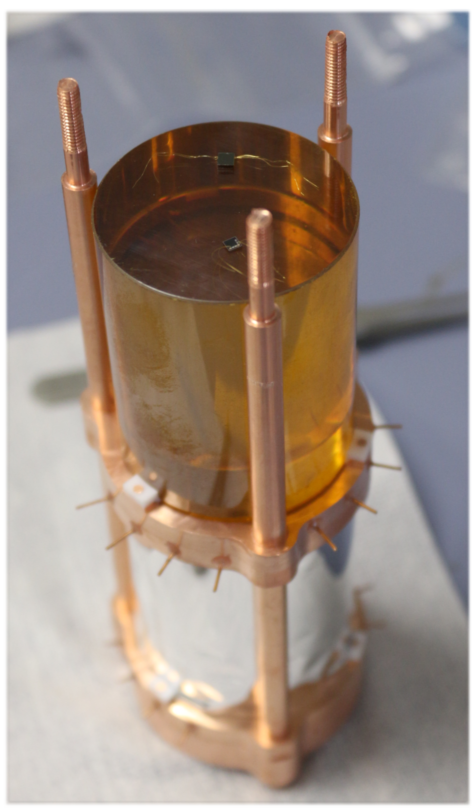
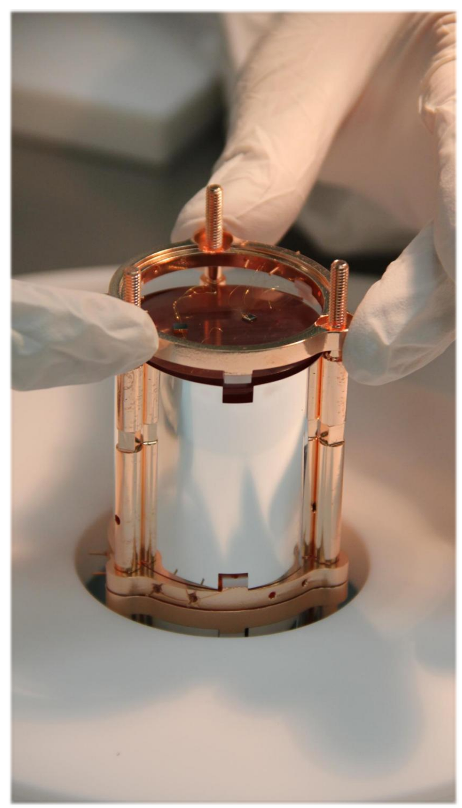
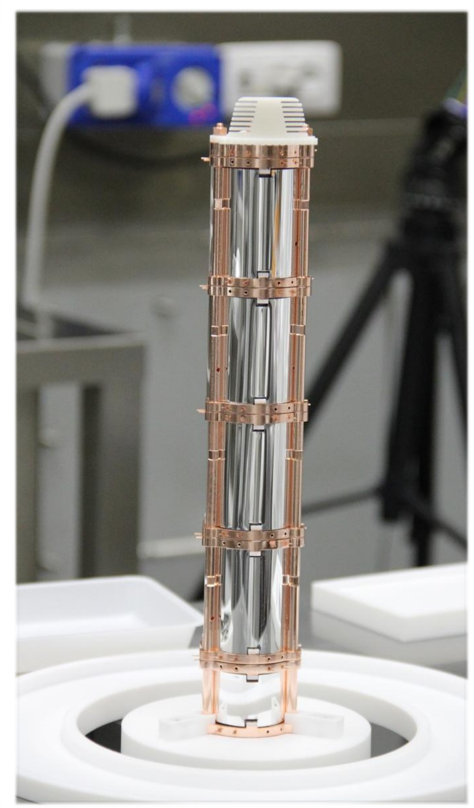
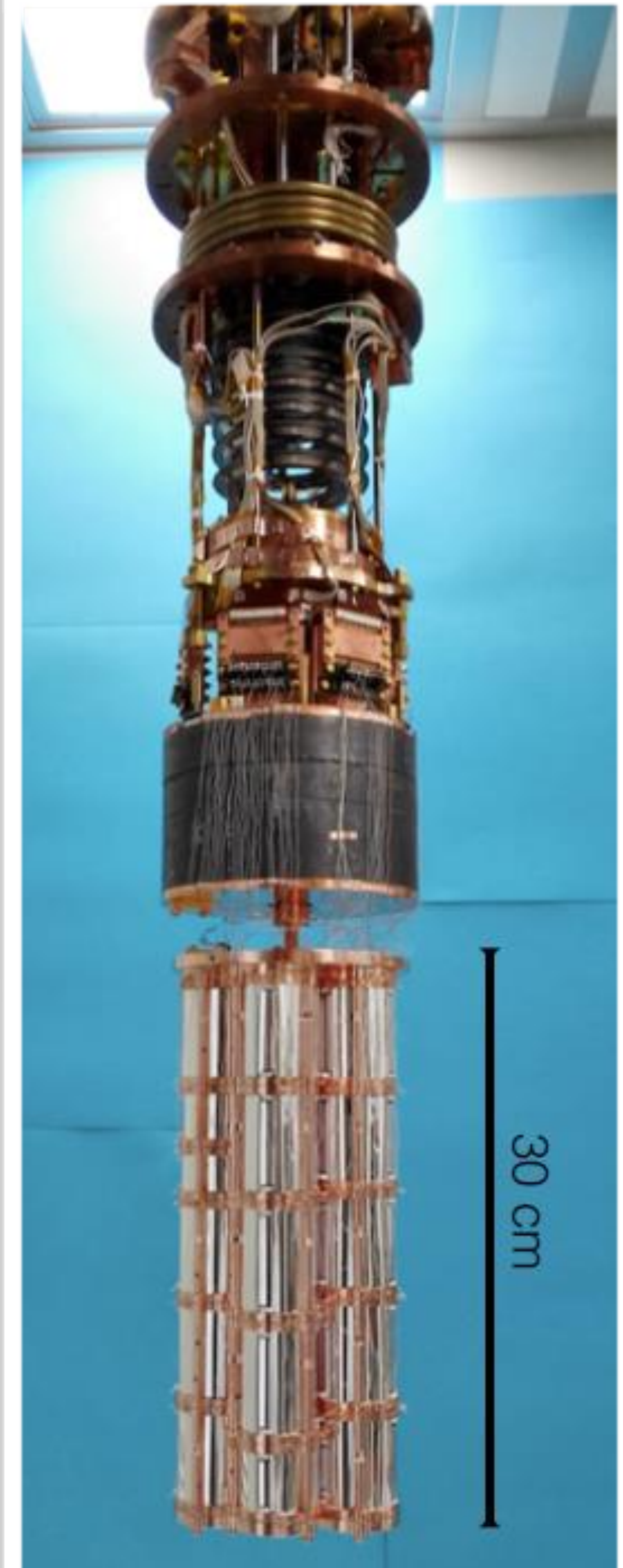
Goal: prove Particle ID for cryogenic calorimeters



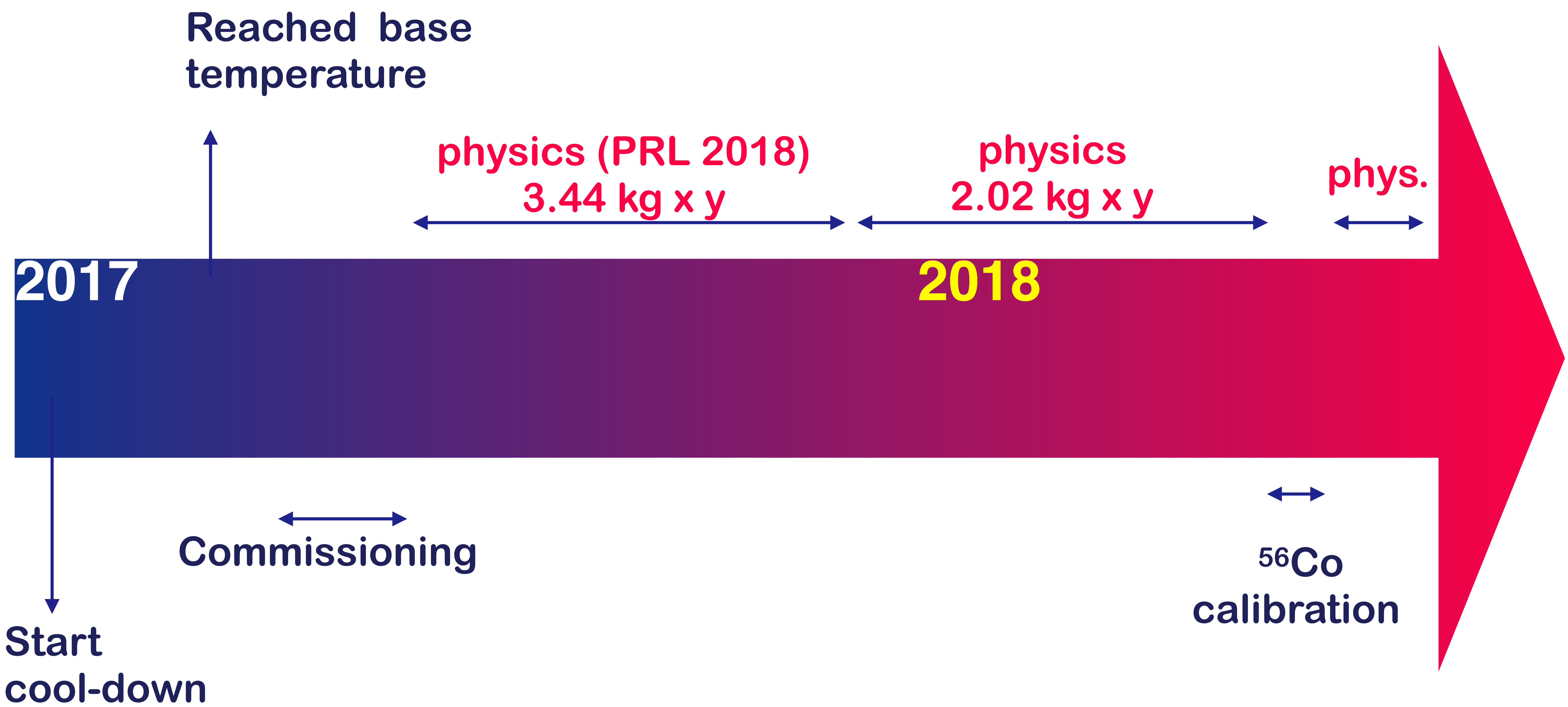
CUPID-0

First 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)

CUPID-0: time-line

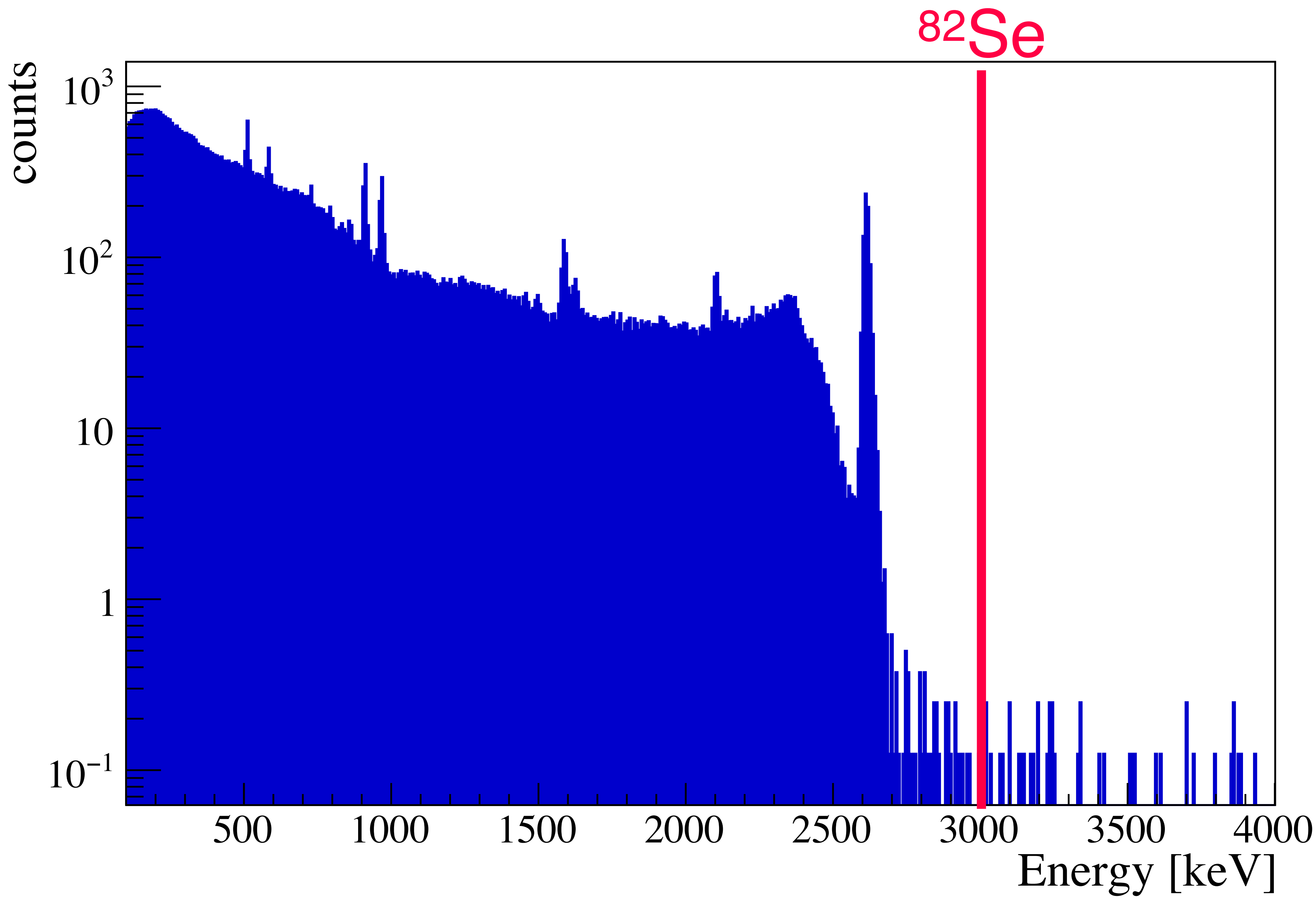


This talk: full statistics acquired until the end of April: 5.46 kg x y

CUPID-0 continues data-taking.

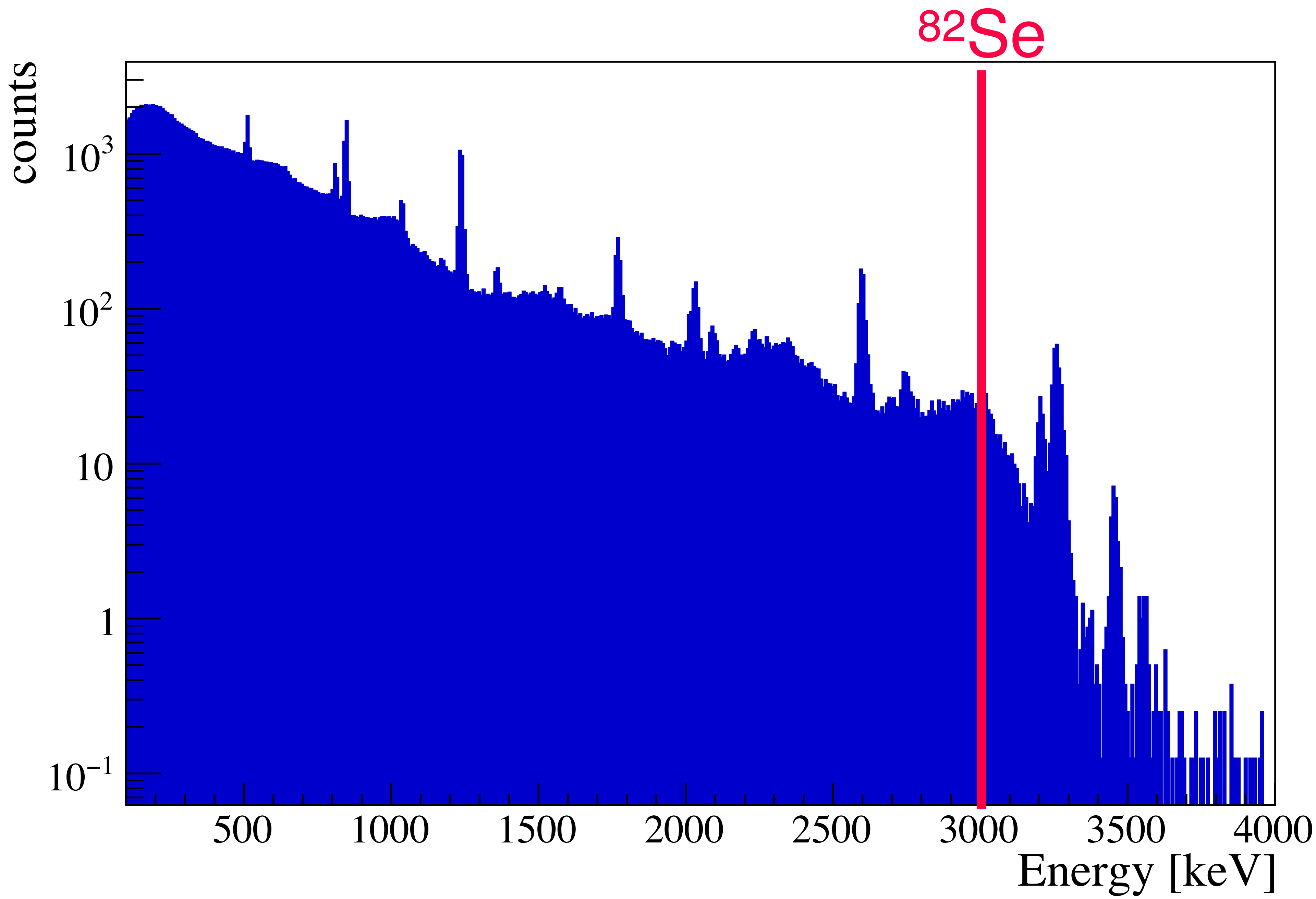
Energy Calibration

Periodical (~ 4 days every month) calibration with ^{232}Th sources

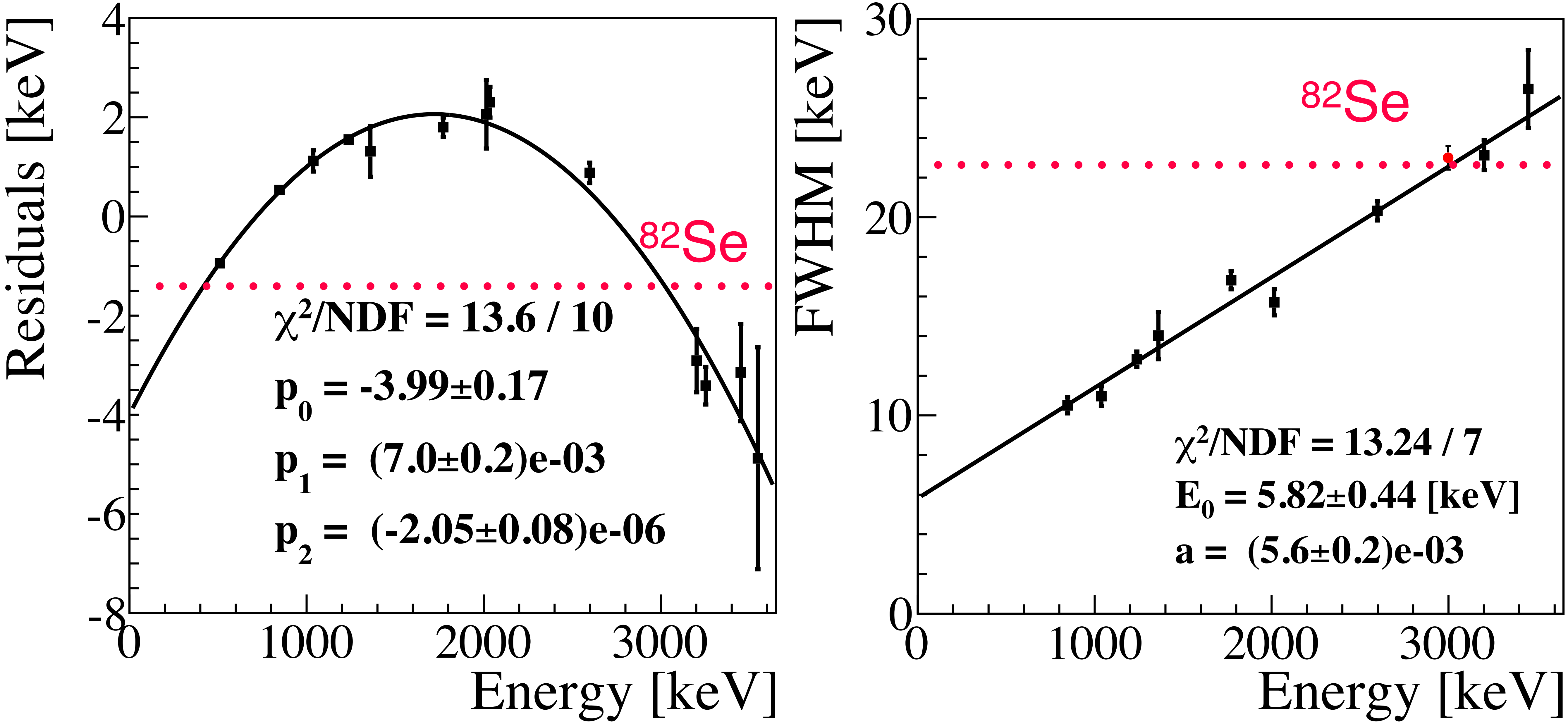


Energy Calibration (2)

Cross-check with ^{56}Co calibration (Q-value ~ 4.57 MeV, $T_{1/2}$ ~ 77 days)



Results

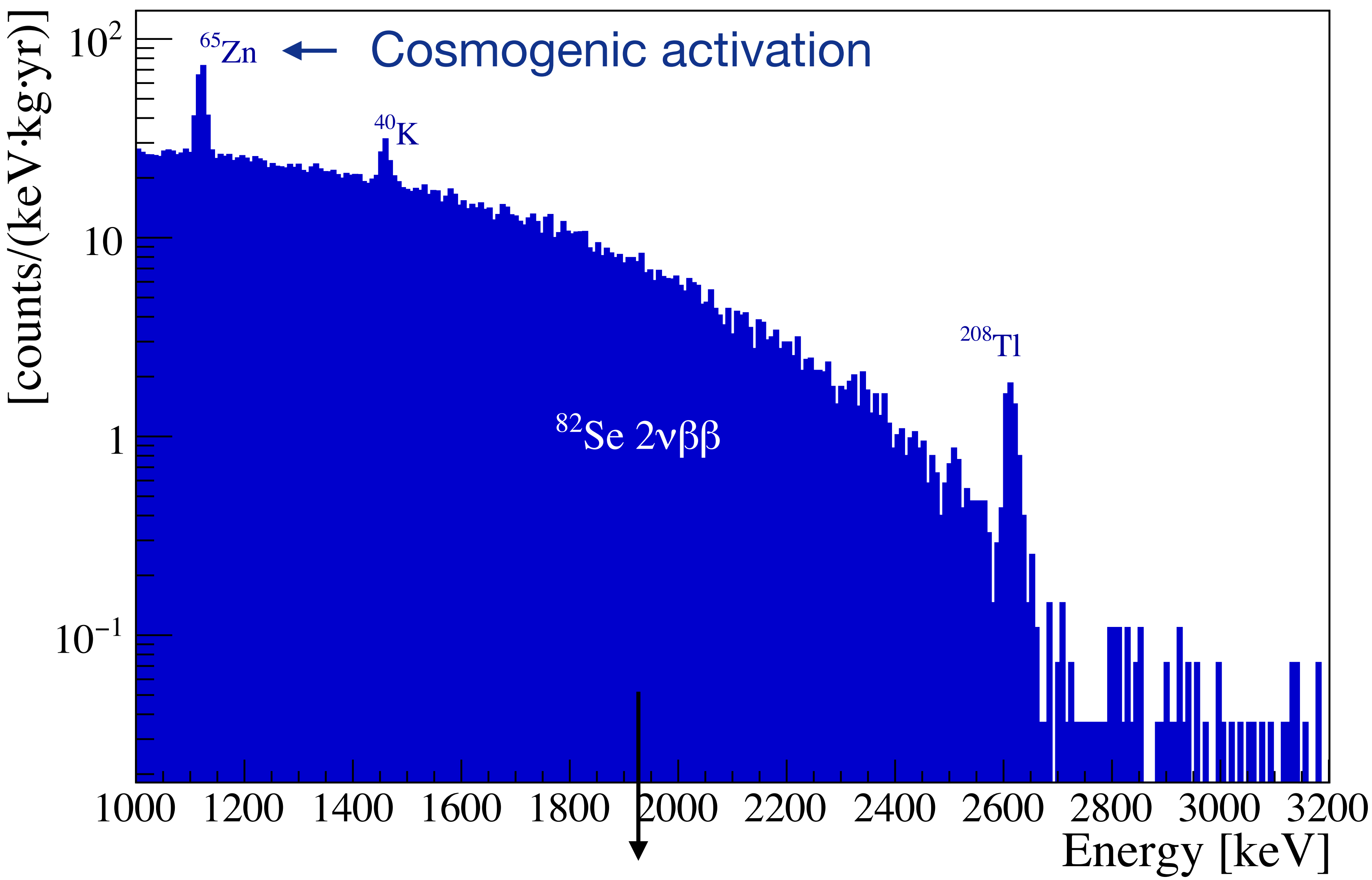


Energy resolution in ROI = (22.5 ± 1.2) keV FWHM

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

Data Selection (1)

- Rejection of “non-particle-like” events through pulse shape of thermal pulses.
- (81.0 ± 0.2)% probability for 0nββ to be fully contained in a ZnSe —> anti-coincidence



$$[9.39 \pm 0.17(stat.) \pm 0.58(syst.)] \times 10^{19} yr$$

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

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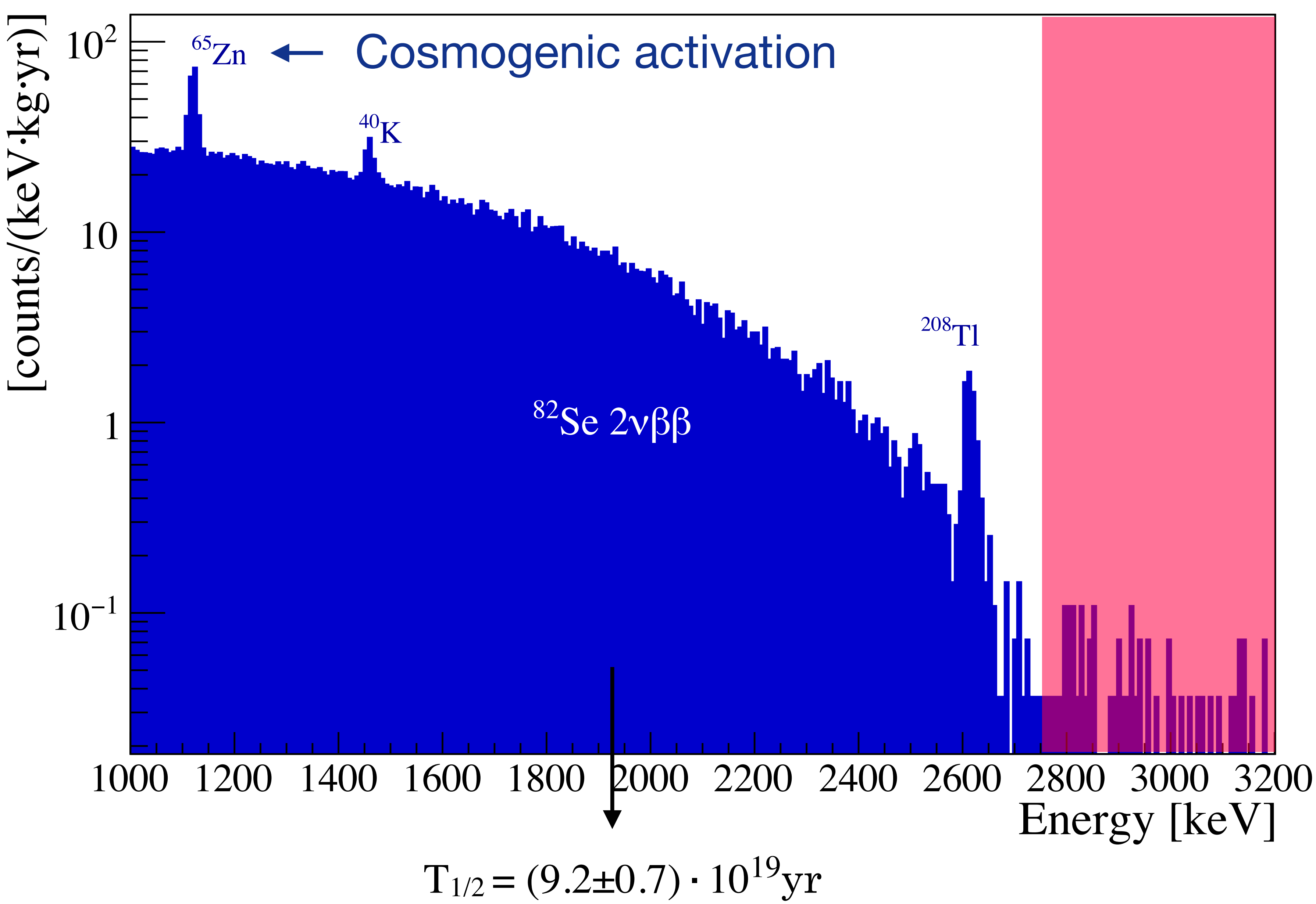

A. S. Barabash, https://doi.org/10.1016/j.nuclphysa.2015.01.001

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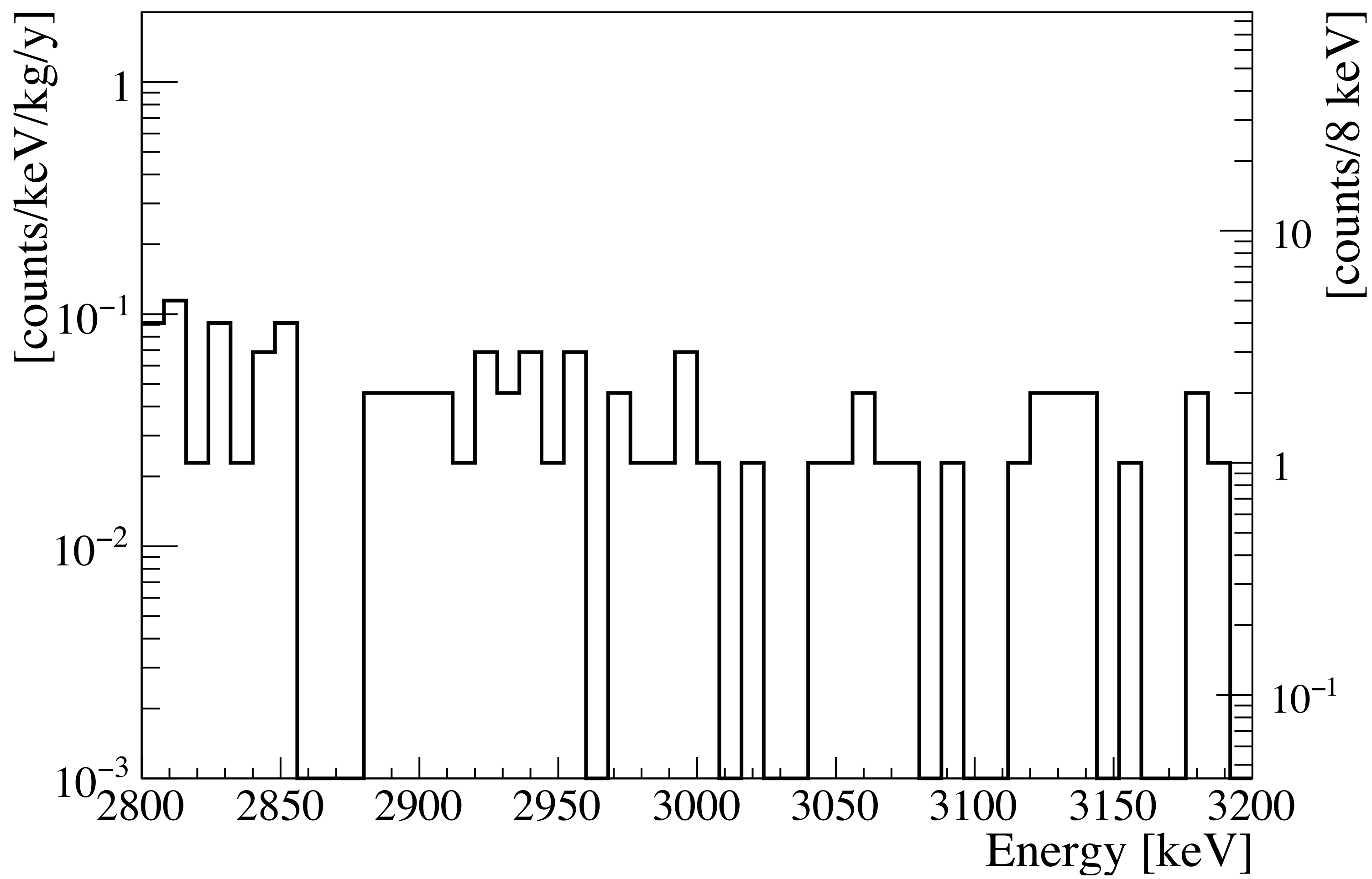
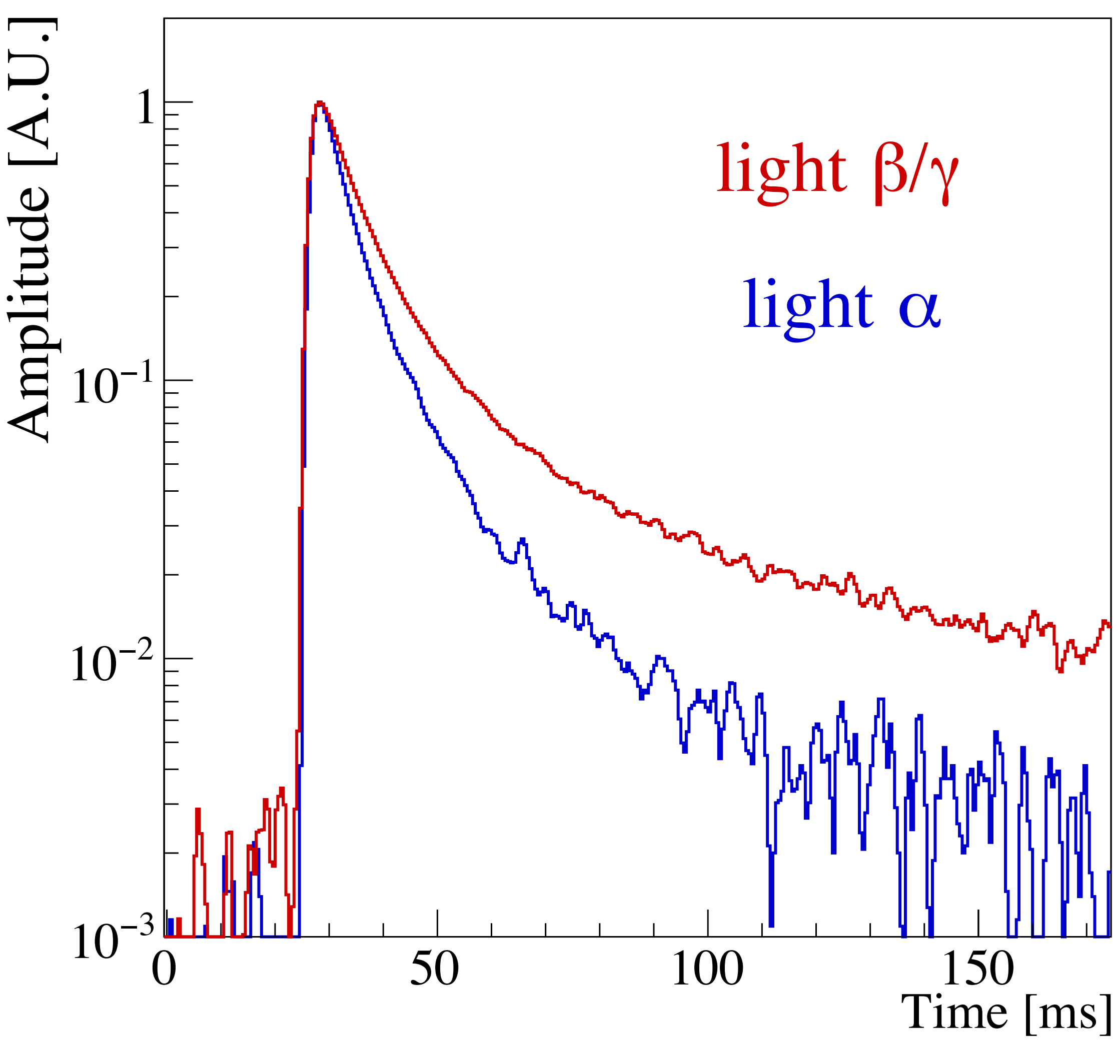
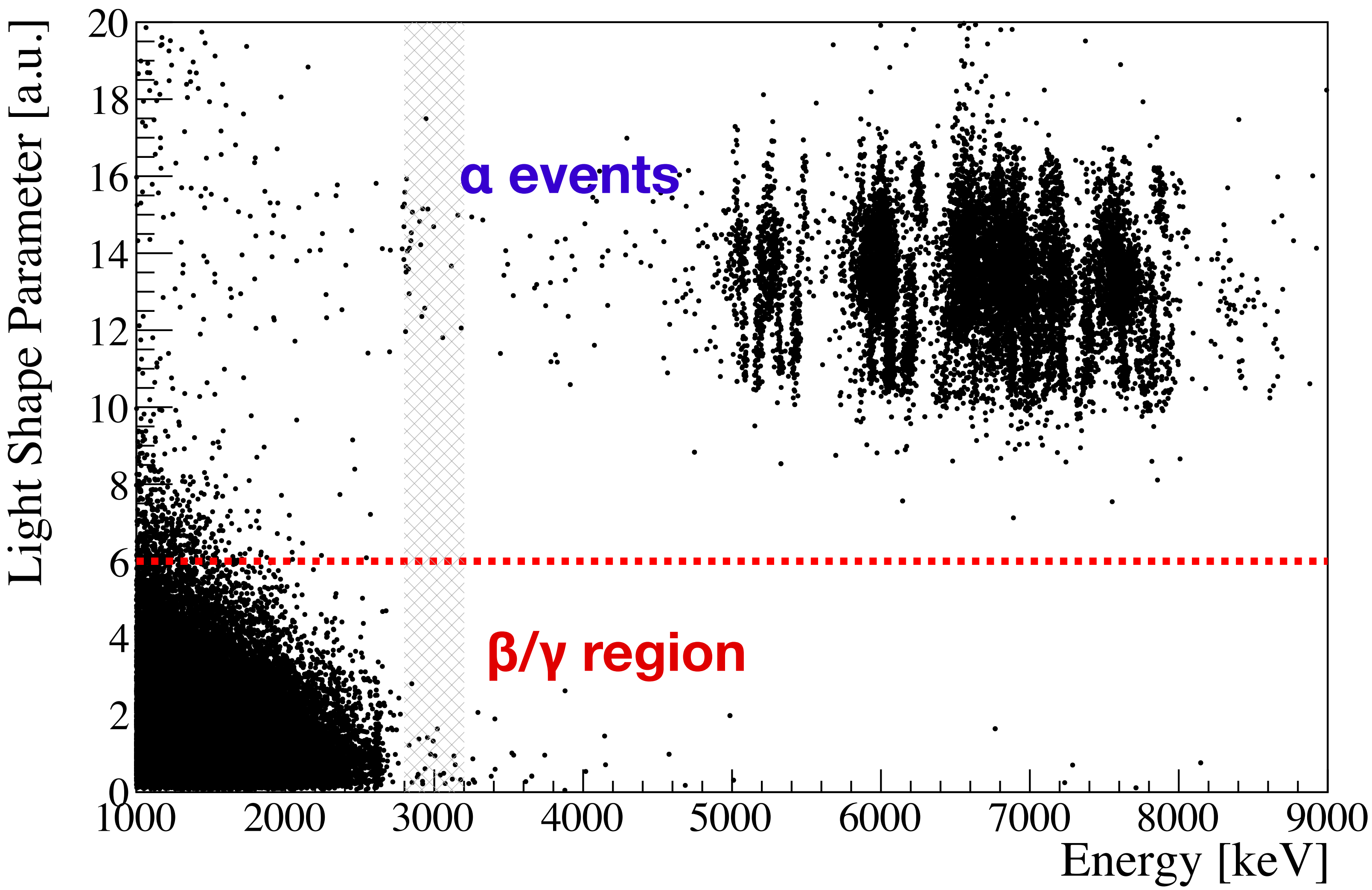


BKG = (3.2 ± 0.4)x10^{-2} counts/(keV kg yr)

Data Selection (2)

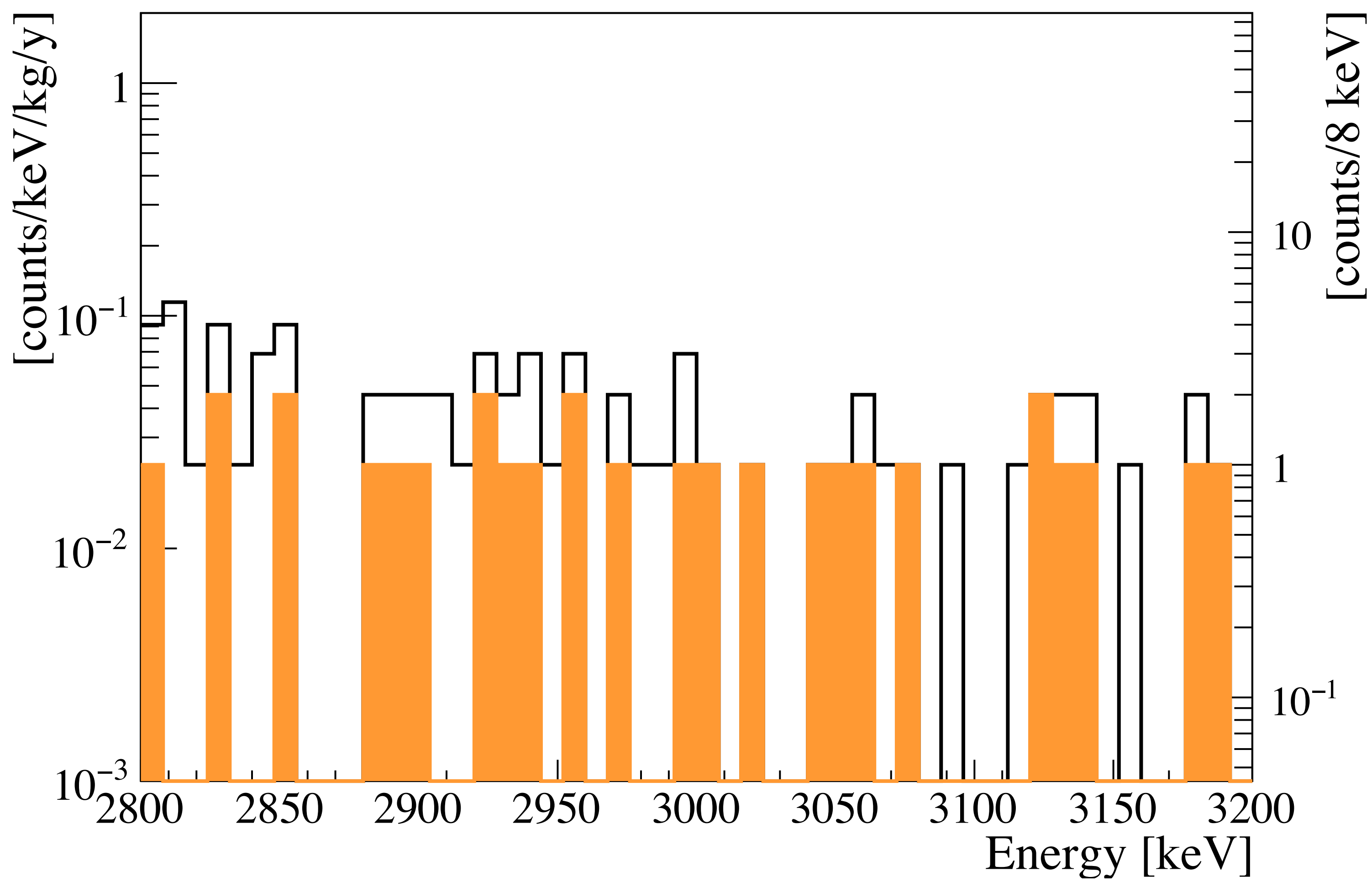
- Reject α interactions through light pulses (shape analysis)
- The cut was optimized with a pure β/γ sample to have a signal efficiency ~100%





Data Selection (2)

- Rejection of “non-particle-like” events through pulse shape of thermal pulses.
- (81.0 ± 0.2)% probability for 0nββ to be fully contained in a ZnSe —> anti-coincidence
- Rejection of α particles

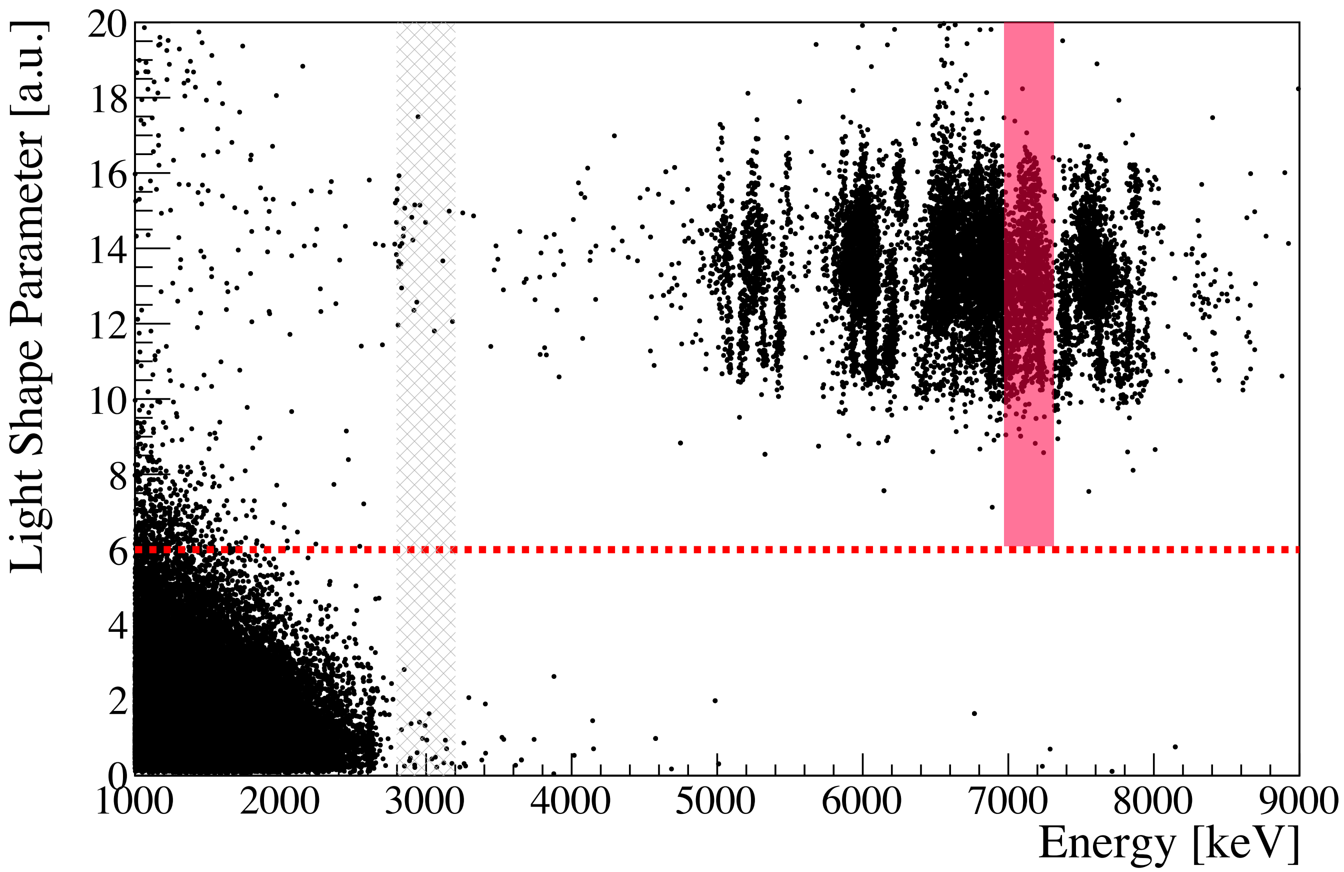


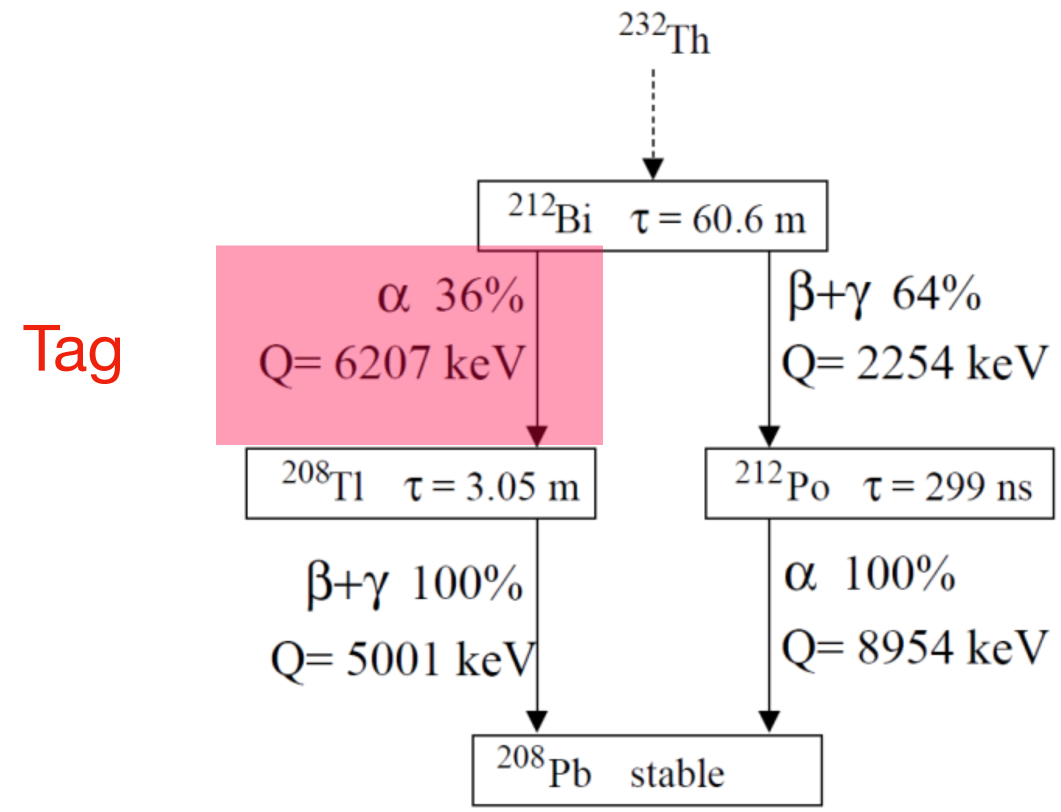
BKG = (3.2 ± 0.4)x10^{-2} counts/(keV kg yr)

BKG = (1.3 ± 0.2)x10^{-2} counts/(keV kg yr)

Data Selection (3)

- ^{208}Tl (Q-value ~5 MeV) can produce a sizable background
- It decays with short half-life (3 min) after a ^{212}Bi decay
- We can veto all event occurring after a ^{212}Bi decay (3 half-lives ~ 9 minutes)





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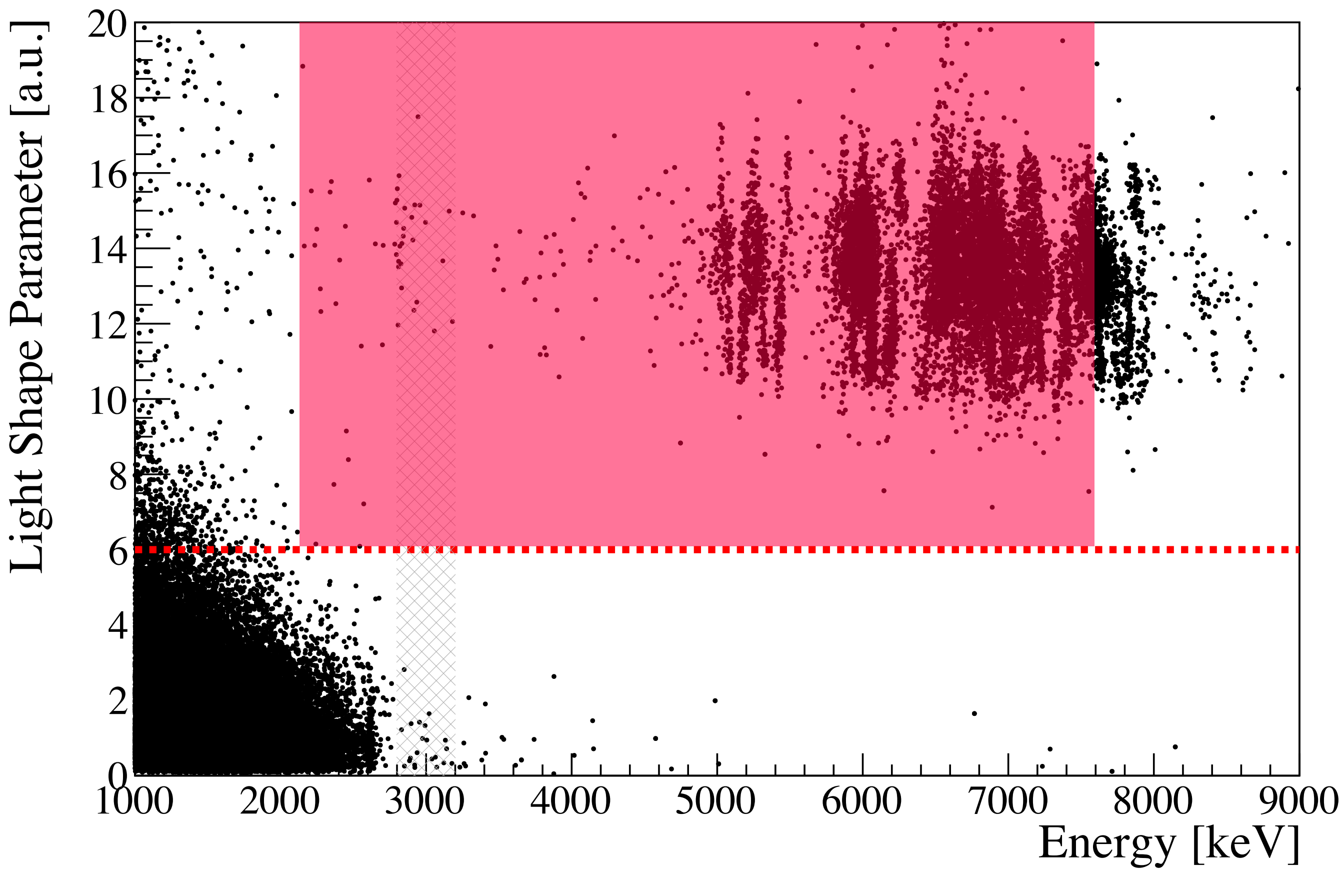
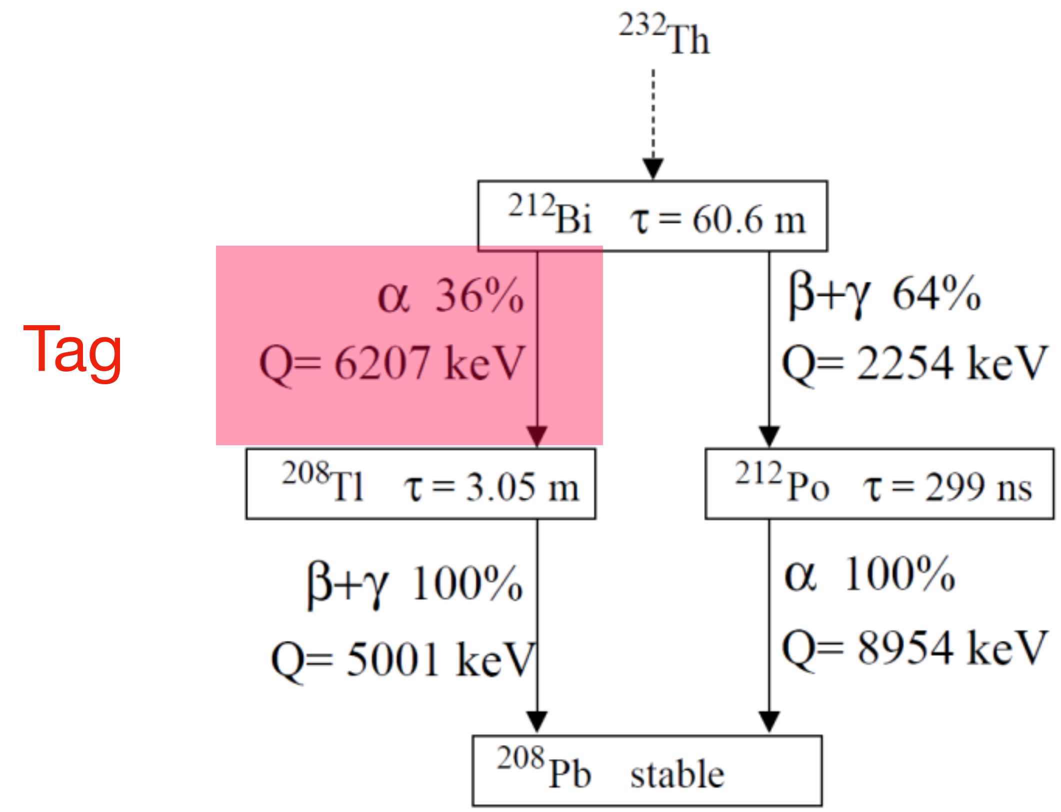
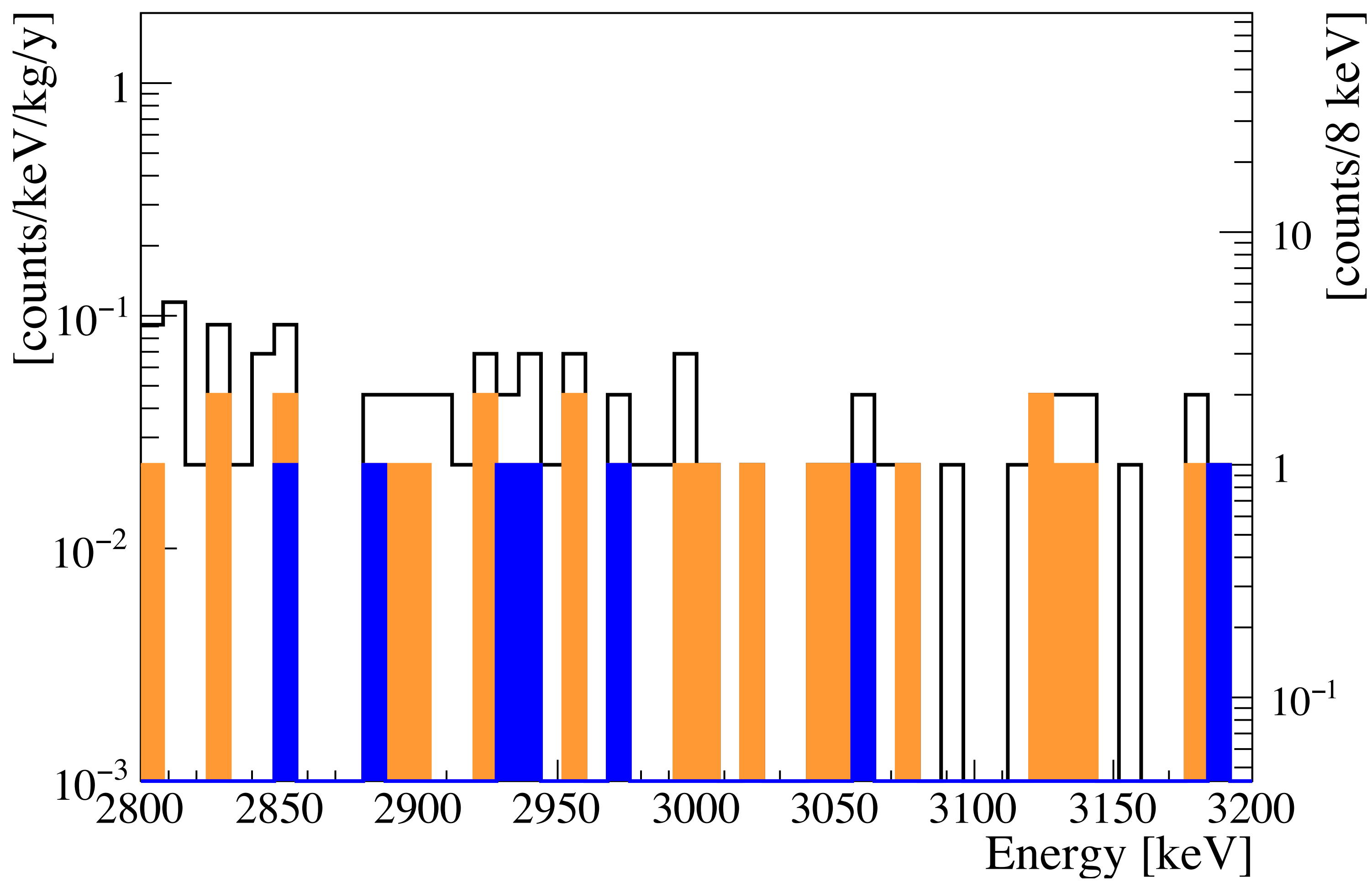




- In CUPID-0 we can tag both internal and surface ^{212}Bi thanks to the Particle ID
- Global Data Selection Efficiency (averaged on data-set): 93 ± 2 %

Data Selection (3)

- Rejection of "non-particle-like" events through pulse shape of thermal pulses.
- (81.0 ± 0.2)% probability for 0nββ to be contained in a ZnSe —> anti-coincidence
- Rejection of α particles
- Time veto

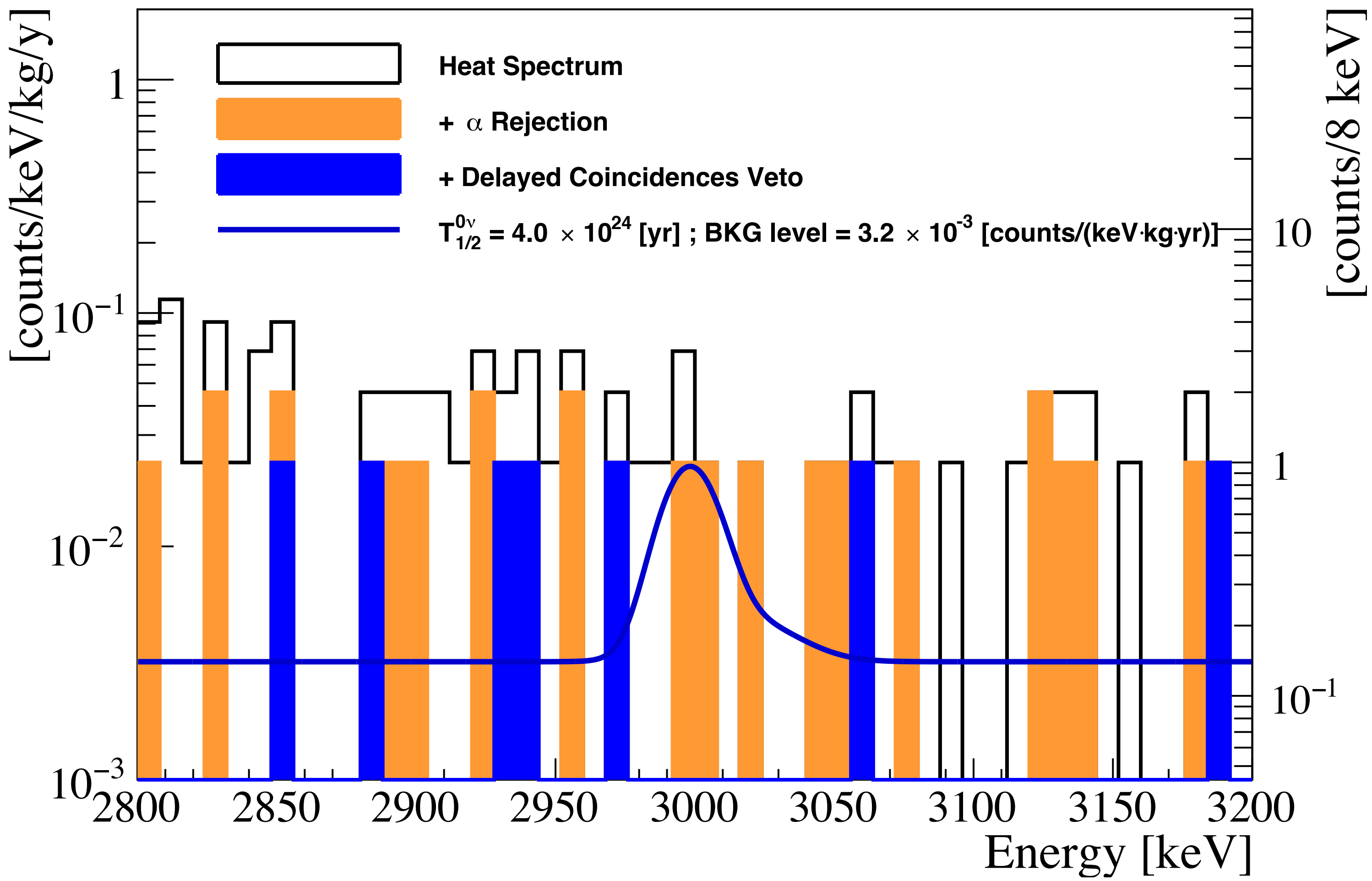


$$BKG = 3.2^{+1.3}_{-1.1} \times 10^{-3} counts/(keV \cdot kg \cdot y)$$

0νββ Result

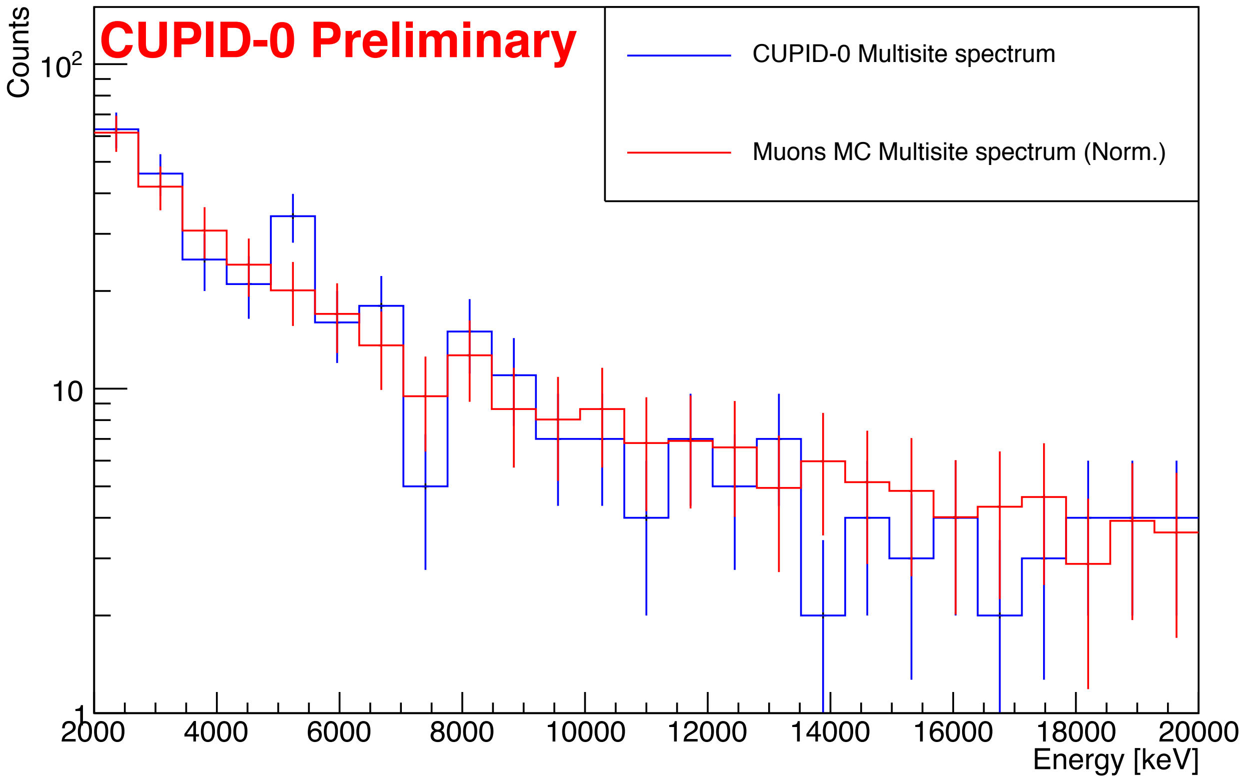
- Exposure: 2.90 kg x y of ^{82}Se (5.46 kg x y ZnSe)
- Energy Resolution in ROI: 23.0 ± 0.6 keV
- Efficiency (trigger + data selection + ββ containment): 75 ± 2%

- Perform a UELM fit in the signal region:



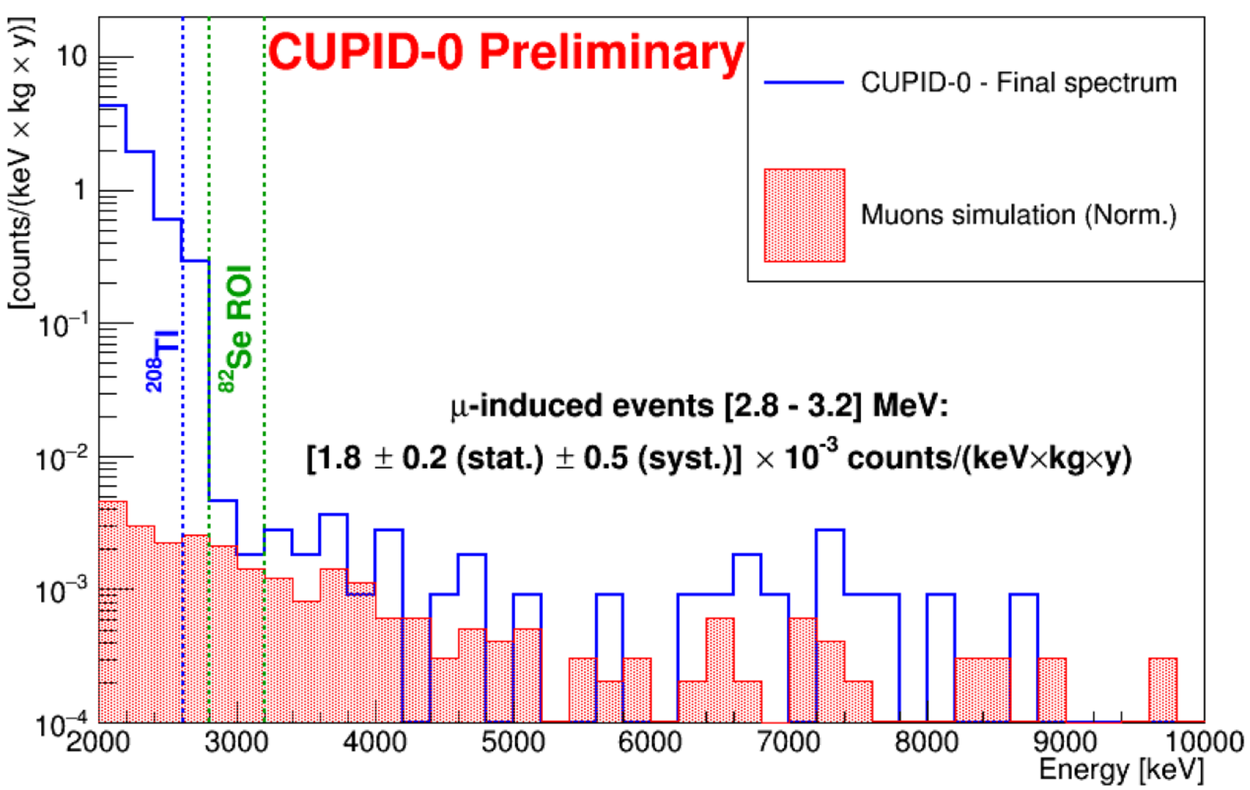
- Background Level: 3.2x10^{-3} counts/(keV kg y)
- $T_{1/2}$(^{82}Se—>^{82}Kr) > 4.0x10^{24} y (90%C.I.)

Background Interpretation



- 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

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



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

Conclusions

Proved the potential of ParticleID for background suppression

Despite the small exposure, best limit on the $0\nu\beta\beta$ decay of ^{82}Se

Now increasing the statistics to study background contributions in CUPID

Conclusions

Thanks for the attention!

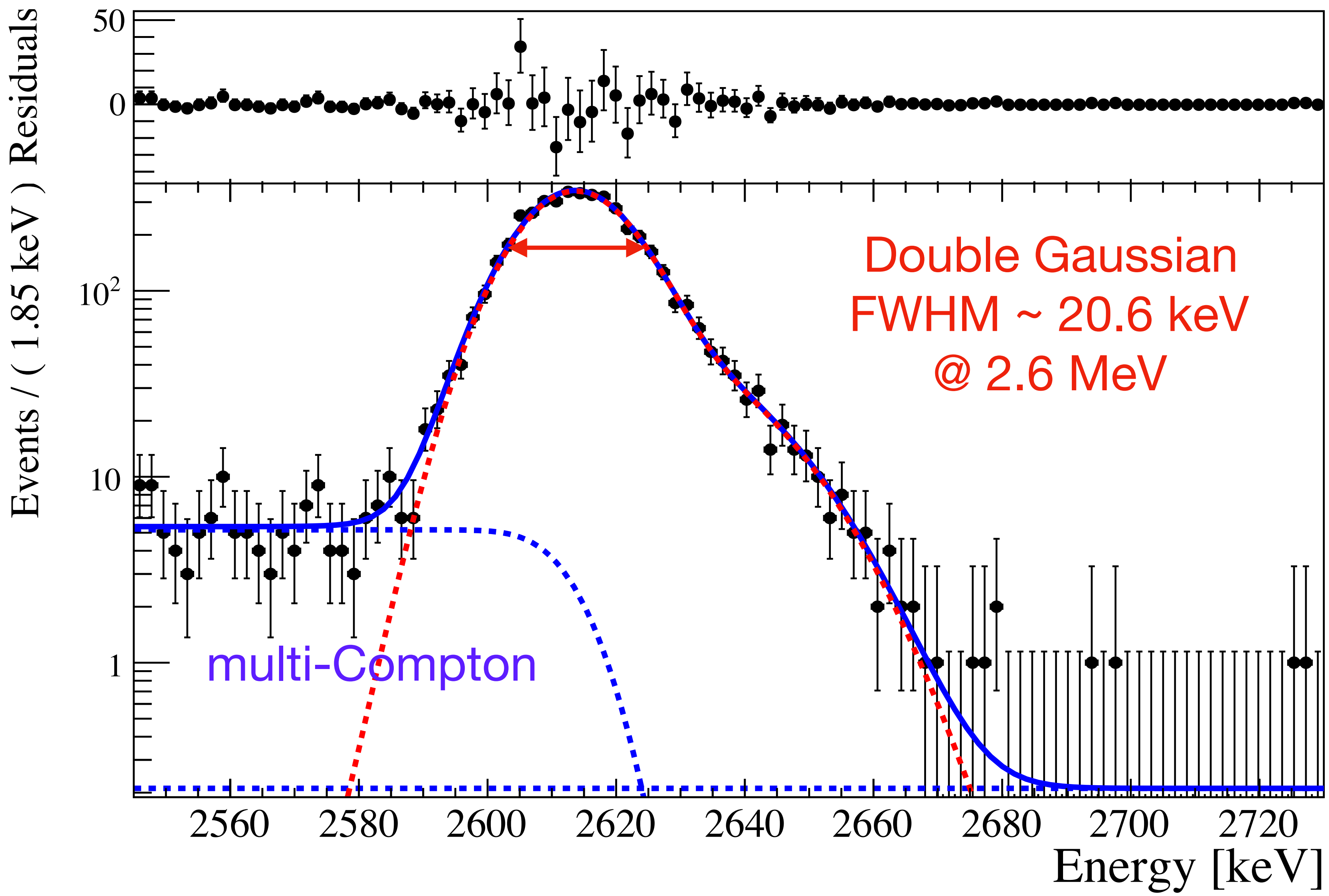
Proved the potential of ParticleID for background suppression

Despite the small exposure, best limit on the $0\nu\beta\beta$ decay of ^{82}Se

Now increasing the statistics to study background contributions in CUPID

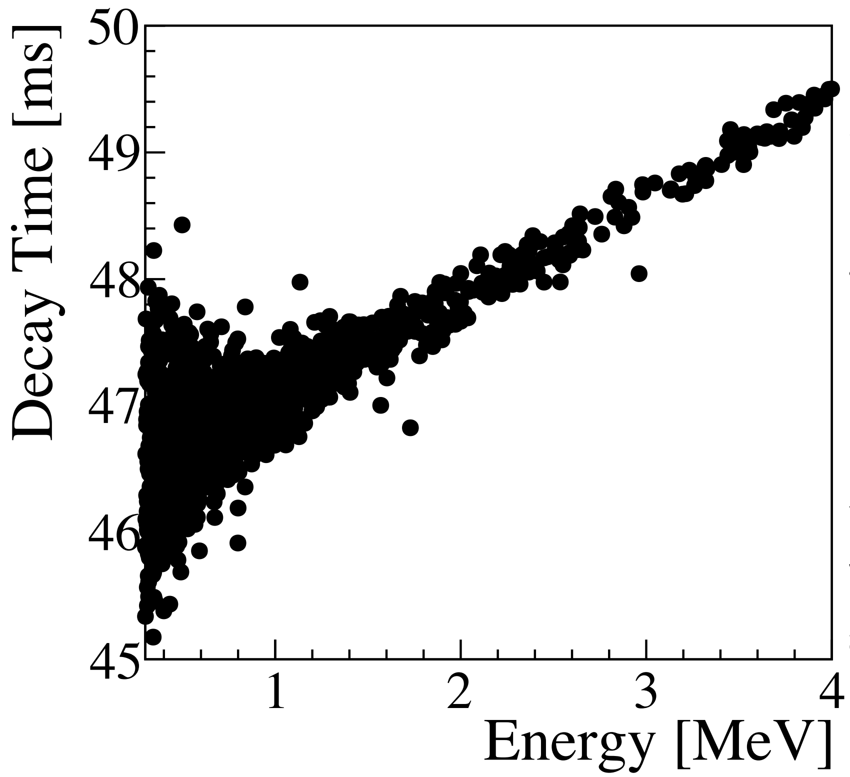
Detector Response

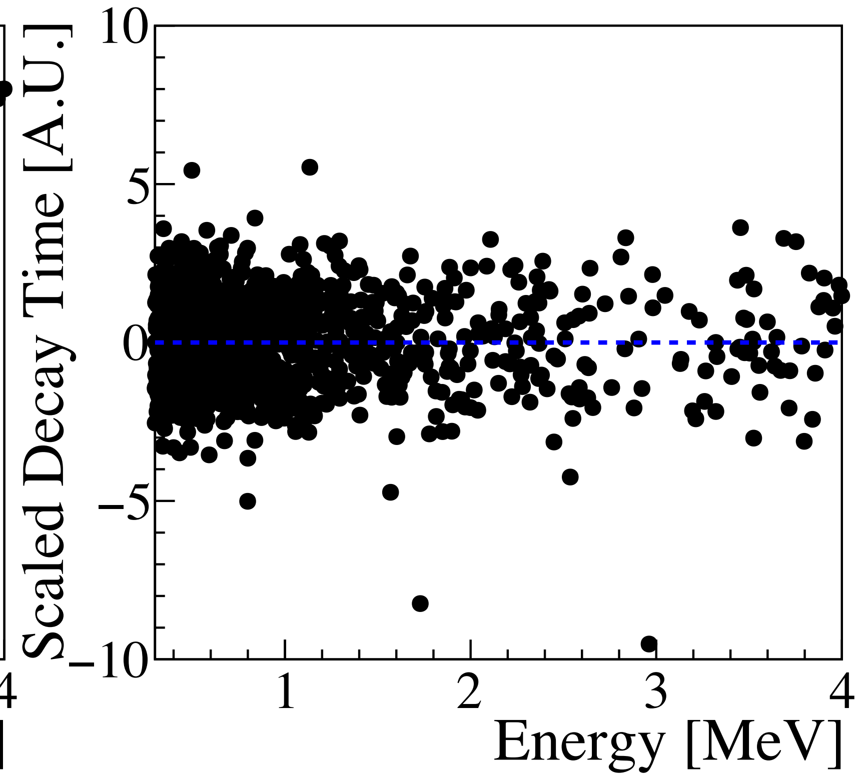
Study response to the 2615 keV peak to determine detector response to a signal



Results in the next slides always extracted with this signal shape

Cut Optimization

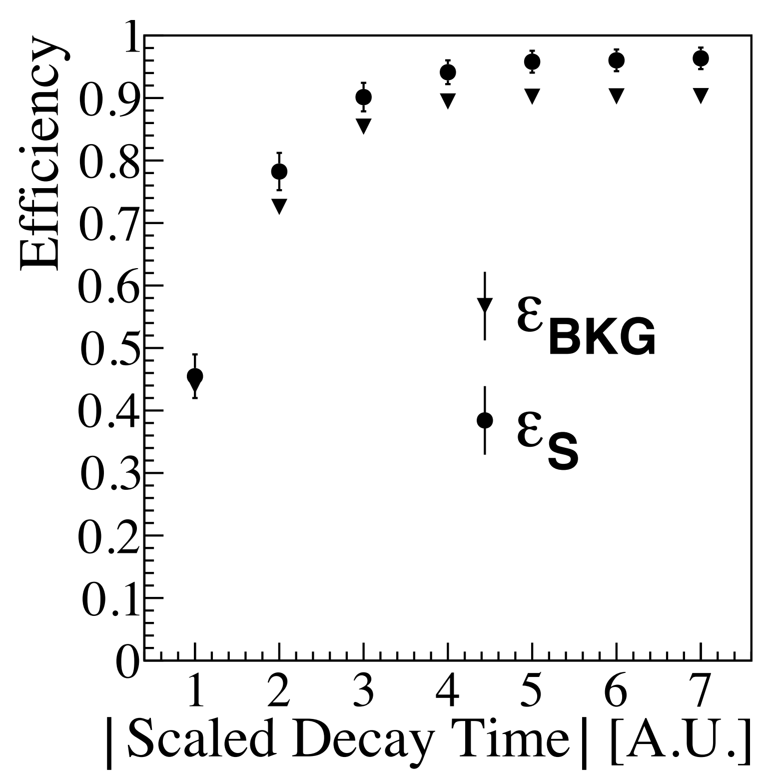


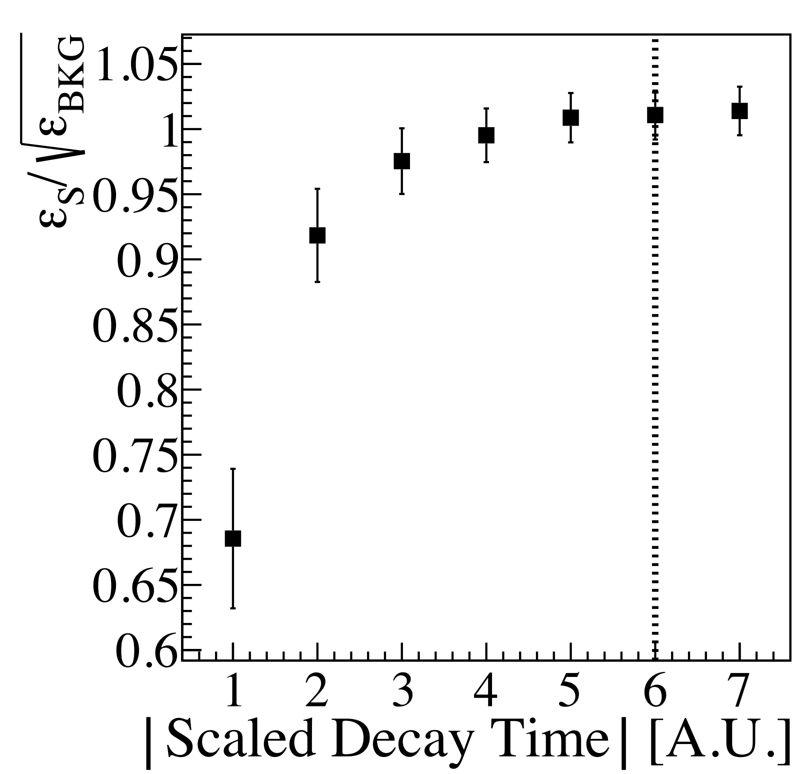


Remove energy-dependency of the shape parameters for energy-independent cuts

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

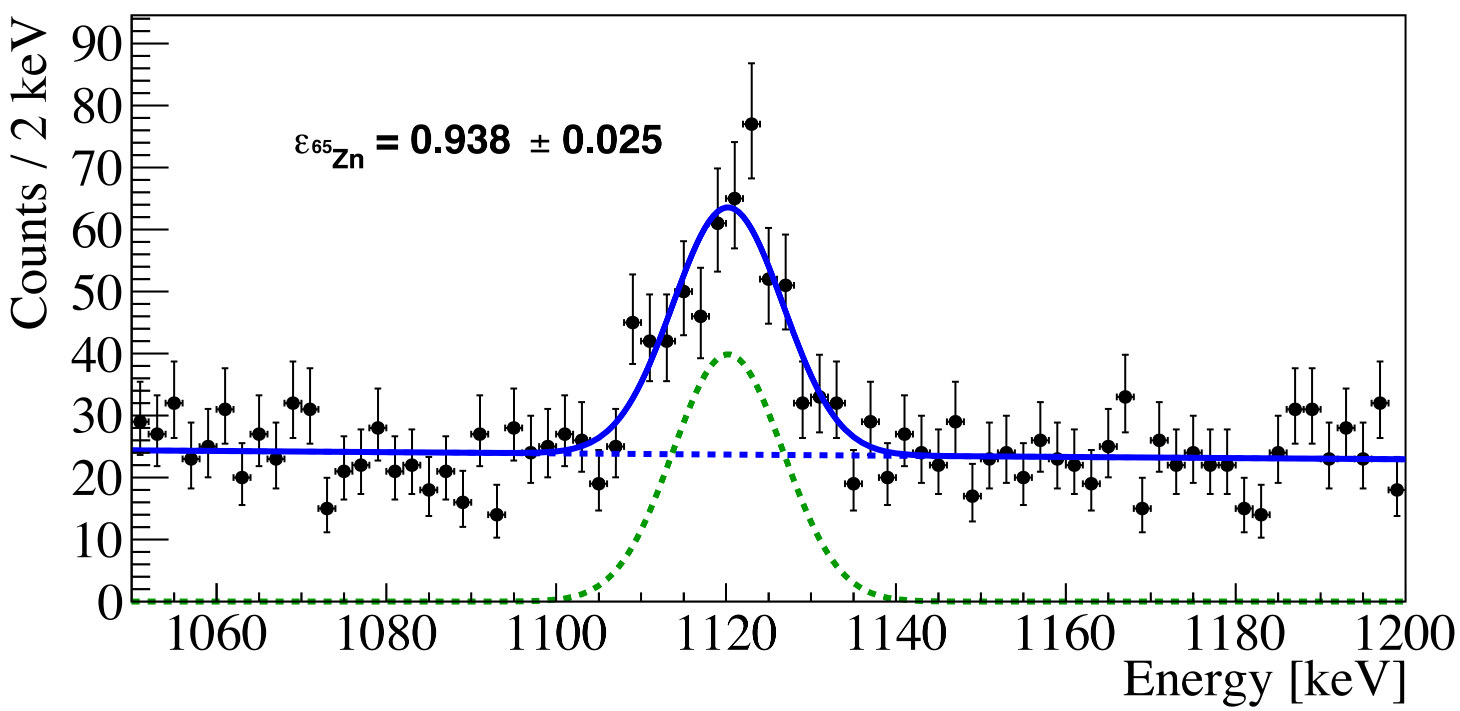
Chose the cut value that optimizes the signal-to-backgrdound ratio

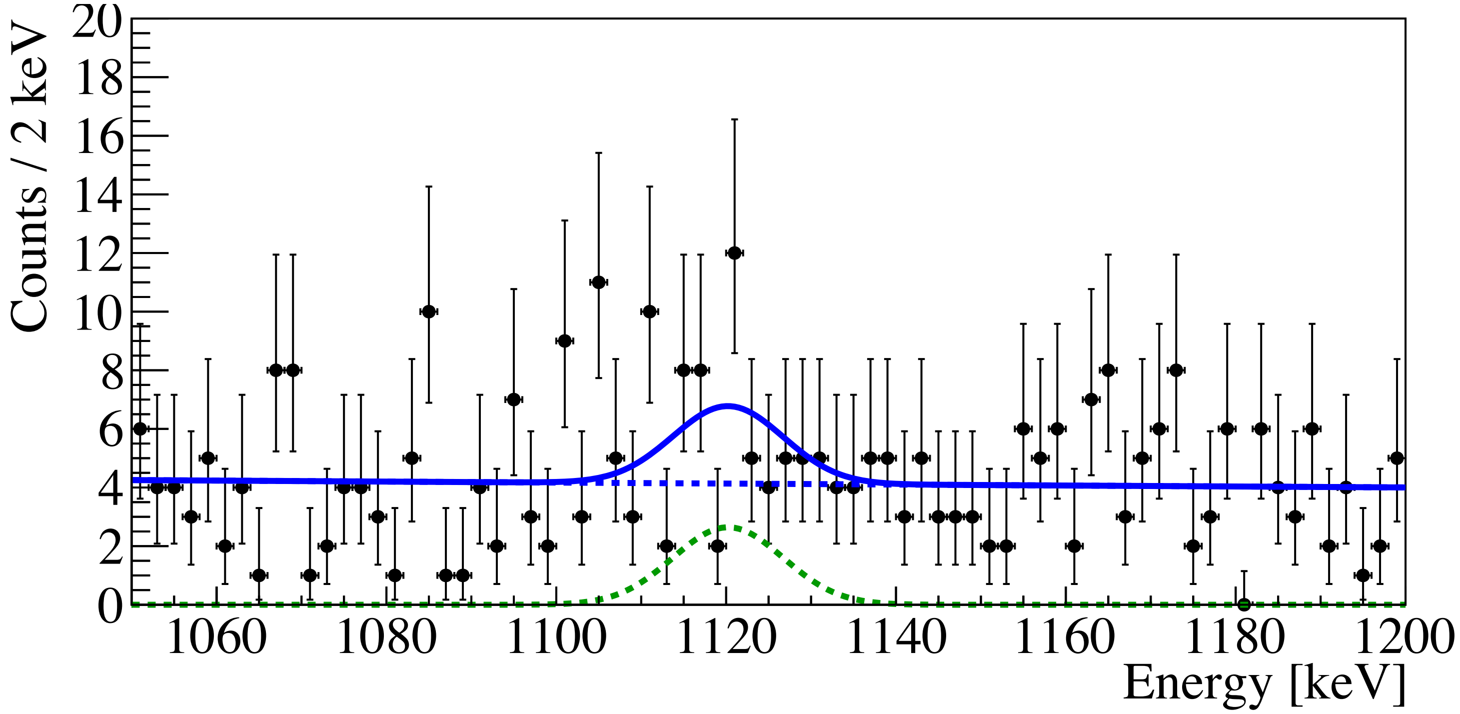




Efficiency Heat

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



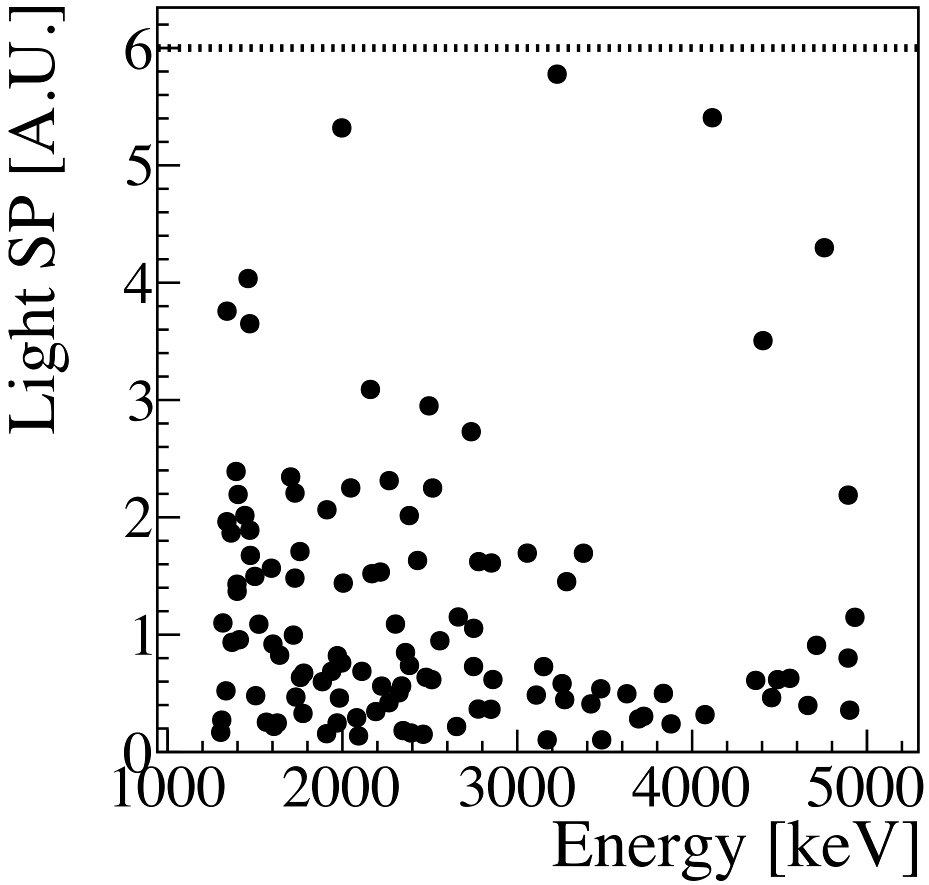


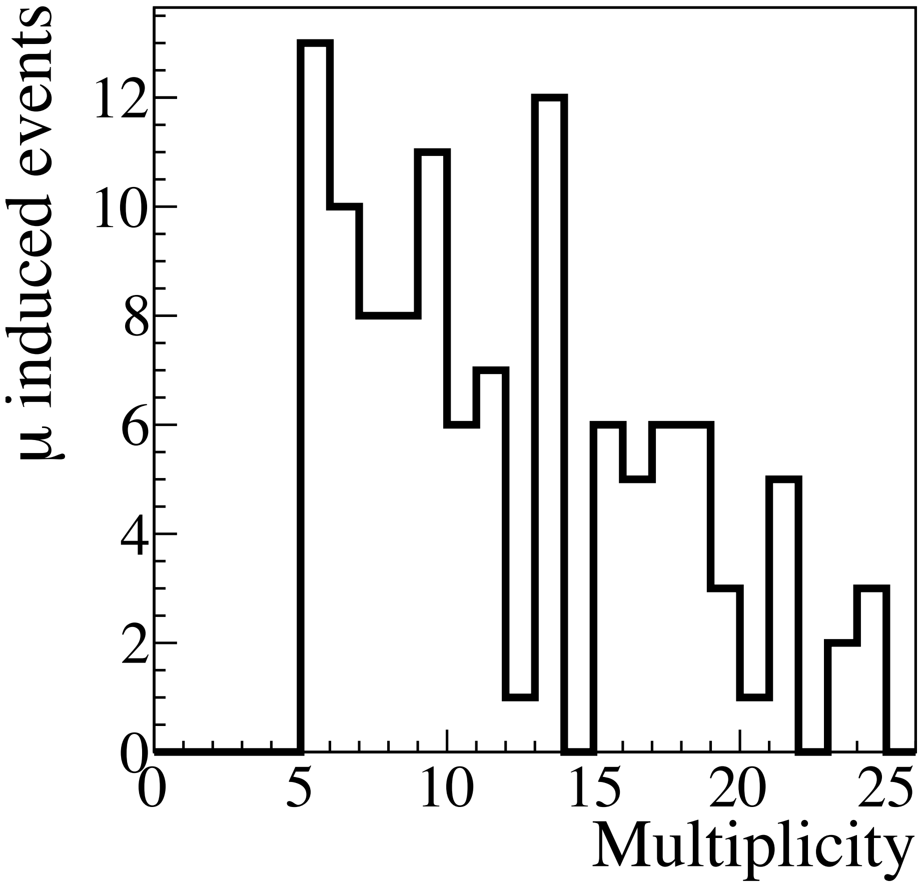
Efficiency Light

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

Study the distribution of the light shape parameter

Set the cut to have 100% efficiency on these events





2νββ

- $2x10^5$ events of 2νββ collected
- Now analysis of half-life