Scintillating bolometers of ZnSe in LNGS

Second general meeting of the ISOTTA project

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Outline

- Why ZnSe

- Background source in bolometers

- Scintillating bolometers of ZnSe
  - LY
  - particle discrimination
  - internal contaminations

- Conclusions

Sensitivity for DBD0ν

$S_{0\nu}$: half-life corresponding to the minimum number of detectable signals above background at a given C.L.

ββ candidate: Te-130
Q_value: 2528 keV
Material: TeO_2
Natural a.i.: 34%
Source Mass: 206 kgTe-130
Projected Bkg: 0.01 c/keV/kg/y
Resolution: ~ 5 keV @ROI
Sensitivity $T_{1/2}$: 1.6×10^{26} y in 5 y

F.Alessandria et al., arXiv:1109.0494

high natural i.a. among 0νββ candidates or enrichment

a.i.: isotopic abundance

Large mass array

M: detector mass

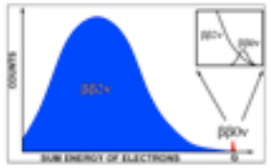
Stable over long time (~y)

t: measuring time

$$S_{0\nu} \propto a.i. \sqrt{\frac{M \cdot t}{B \cdot \Delta E}}$$

B: background

ΔE: energy resolution



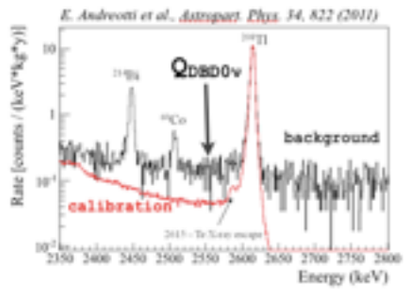
- Deep underground location
- Material selection (radio-pure)
- High granularity

Bolometric approach

CUORICINO experiment

Cuoricino:
- first large array (62 bolometers = ~41 kg) for DBD
- high statistics (exposure: 19.75 kg(Te^{130})×y)
- energy resolution @ DBD0ν: 6.3±2.5 keV

E. Andreotti et al., Astropart. Phys. 34, 822 (2011)

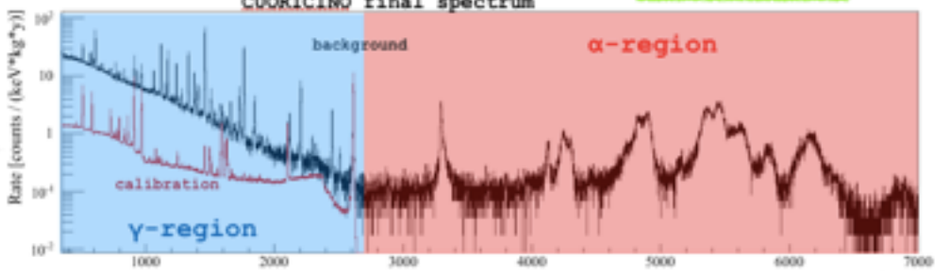


background @ DBD0ν:
0.17 c/keV/kg/y

65% Degraded α struggling from TeO_2 and Cu surface contaminations (^{232}Th & ^{238}U)

External high energy γ (^{232}Th) 35%

CUORICINO final spectrum



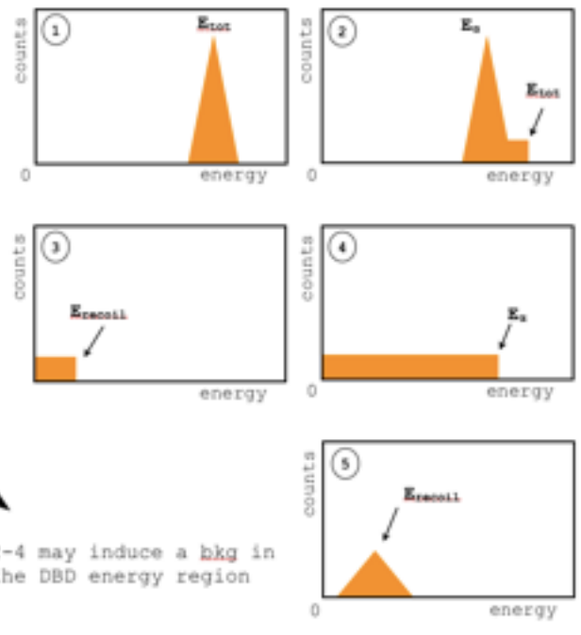
α surface contaminations

α decays may occur on surfaces of Cu structure or on the detectors due to possible re-contaminations of radio-pure materials.

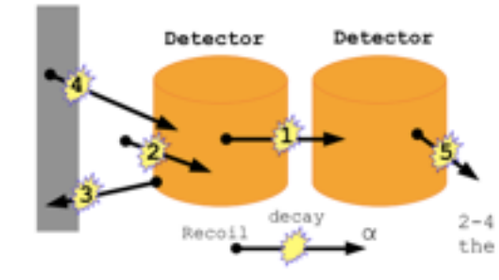
N.B. bolometers are fully-active detectors

$E_{tot} = E_\alpha + E_{recoil}$

~MeV = ~MeV + ~10-100 keV



Cu structure



2-4 may induce a bkg in the DBD energy region

M. Clemenza et al., Eur. Phys. J. C 71, 1805 (2011)

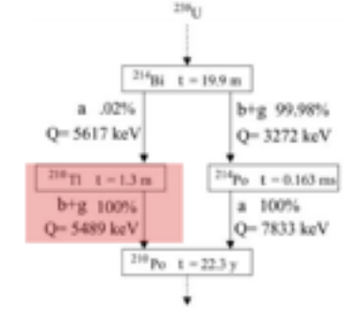
High energy β/γs background

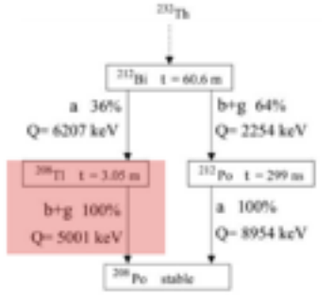
Background can be induced by contaminations of ^{238}U & ^{232}Th decay products.
Elements with Q_{value} ~ Q_{DBD}:

Near contaminations (crystal or Cu structure):

- ^{214}Bi-^{214}Po : Q_{value} 3.27 MeV => rejection because of pile-up with ^{214}Po and slow thermal signal
- ^{210}Tl-^{210}Po : Q_{value} 5.49 MeV => delayed coincidence with ^{214}Bi α
- ^{208}Tl-^{208}Pb : Q_{value} 5.00 MeV => delayed coincidence with ^{212}Bi α

Far contaminations (external) are dangerous => proper shields & material selection

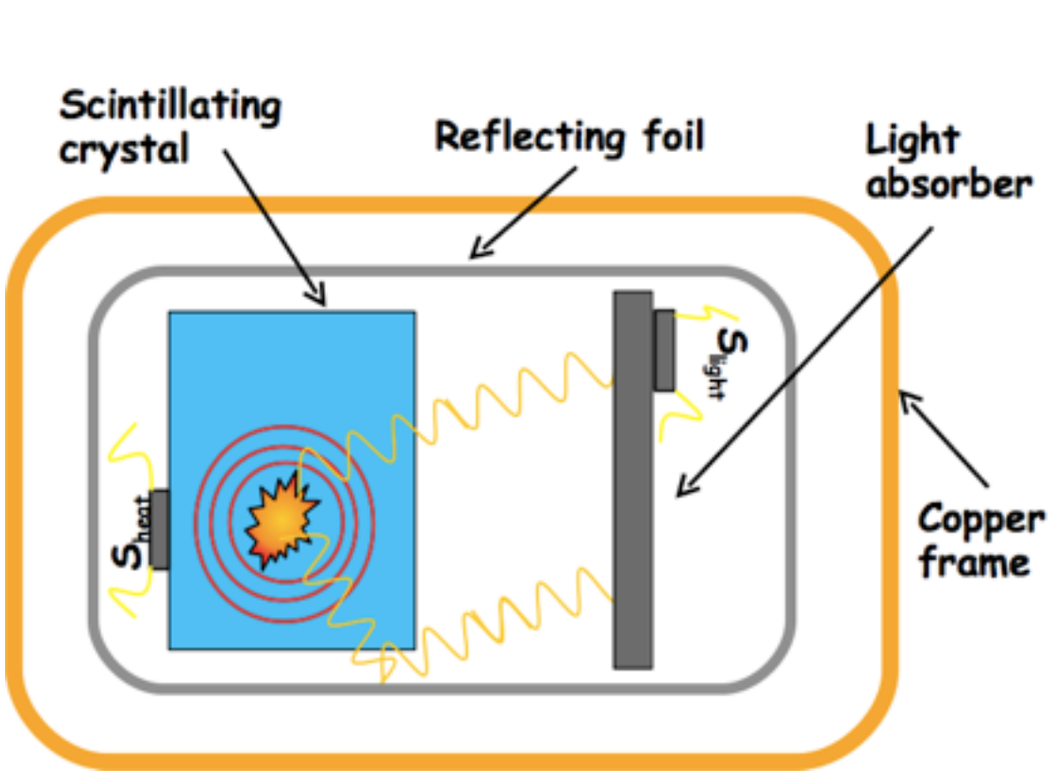


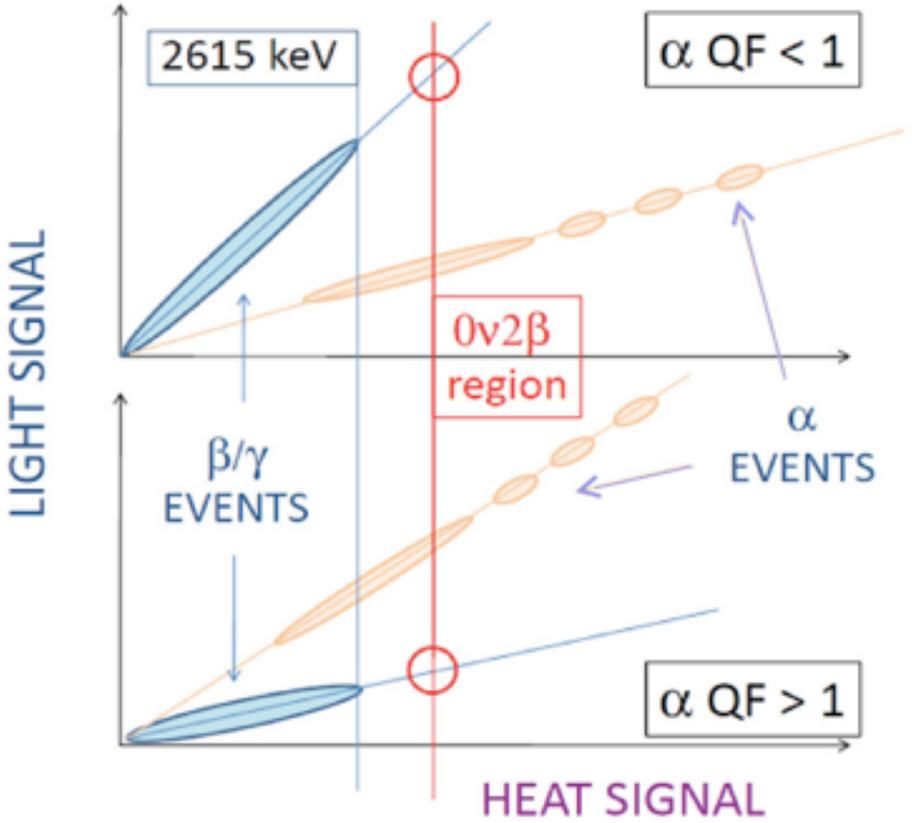


Scintillating bolometers

When a **bolometer is an efficient scintillator** at low temperature, a small but significant fraction of the deposited energy is converted into scintillation photons while the remaining dominant part is detected through the heat channel.

The simultaneous read-out of **light** and **thermal** signals allows to discriminate the α background thanks to the scintillation yield different from β particles.

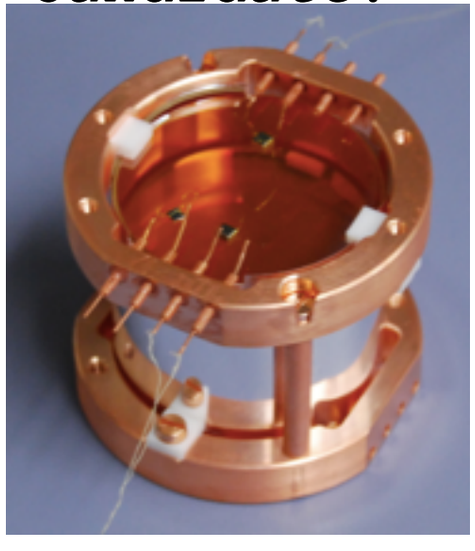




QF: is defined as the ratio of the signal amplitudes induced by an α and an β/γ of the same energy.

ZnSe

Candidate: ^{82}Se



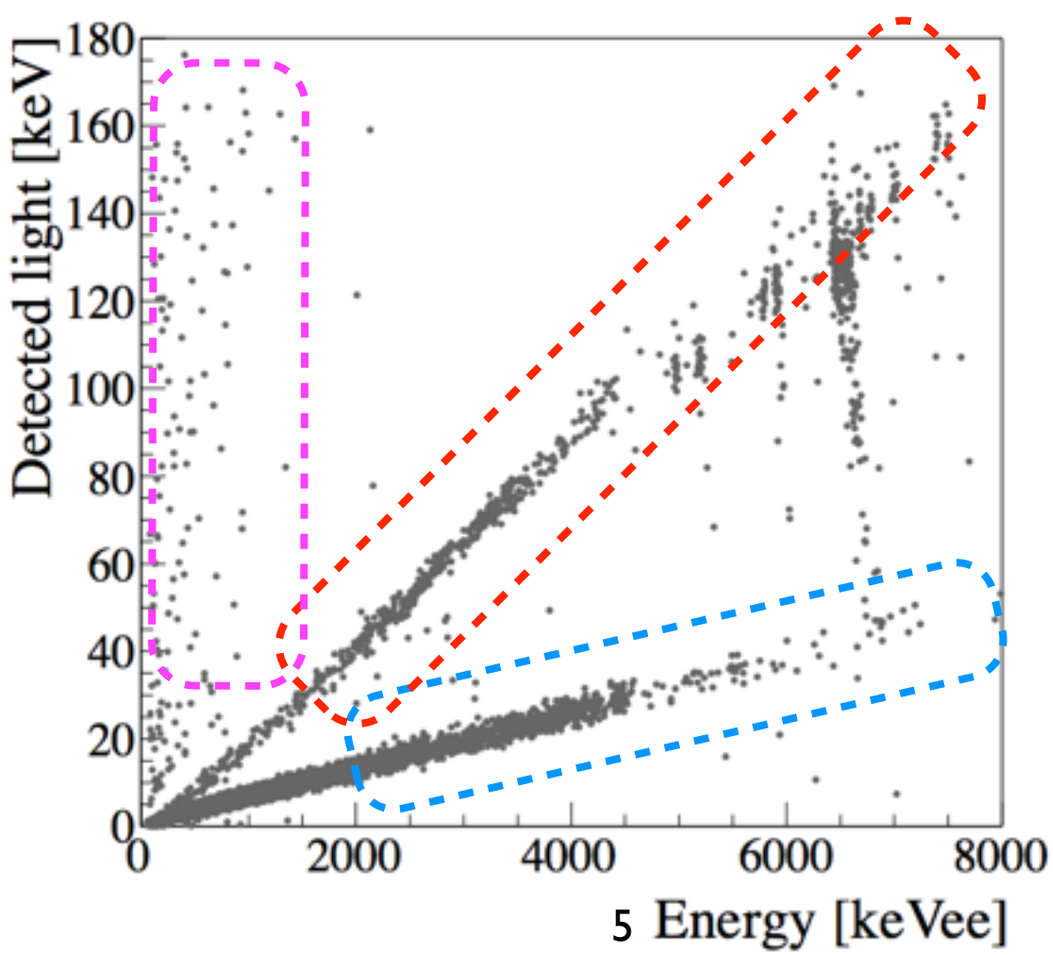
m=430 g
Calibrations α & n & γ
Background 524 h

	Q-value [keV]	Useful material	$LY_{\beta/\gamma}$ [keV/MeV]	QF_{α}
ZnSe	**2995**	**56%**	**~6**	**~4**

Birks' law: αs have higher dE/dx than β/γs, thus saturation effects on the luminescence centers arise.

Odd QF_{α} for ZnSe:
αs produce more light than β/γs

FWHM @ 2615 keV
13.4 keV



Excellent particle discrimination using **Light vs. Heat**

γs from n-source

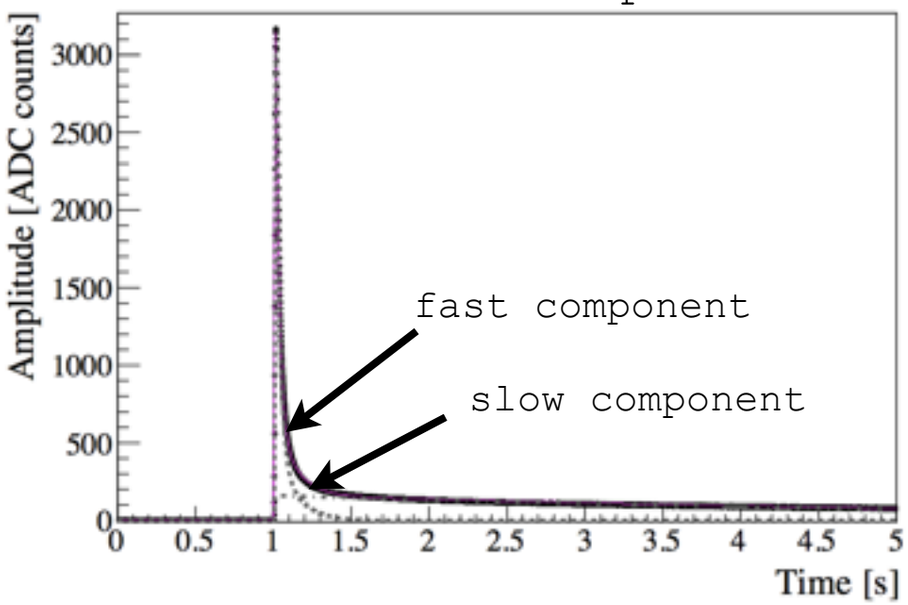
surface and bulk αs

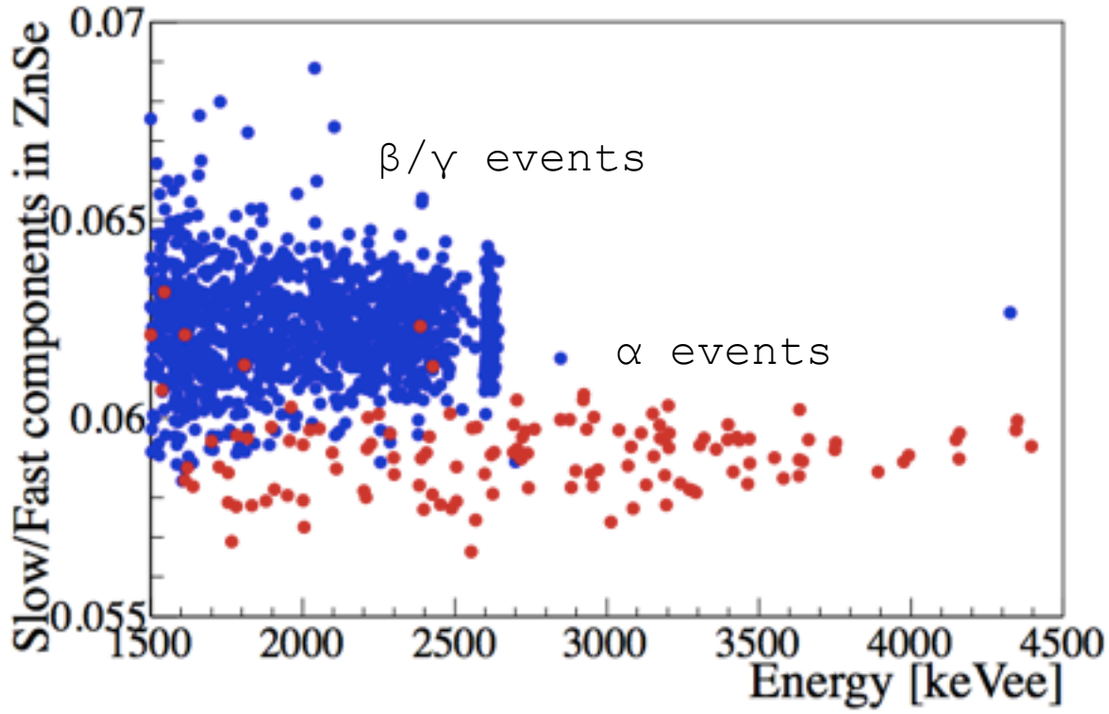
direct ionization in LD

ZnSe PSA

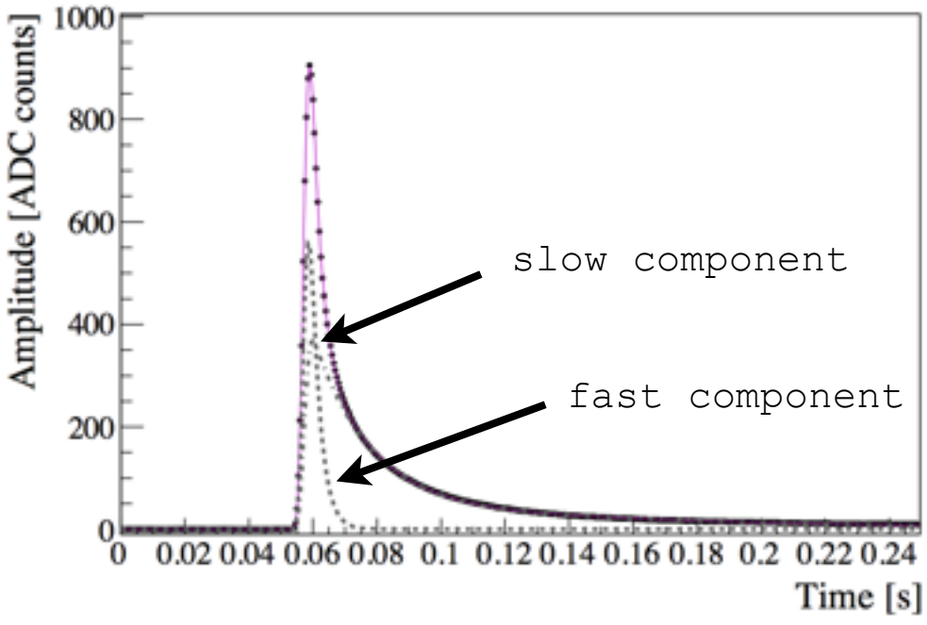
Excellent particle discrimination
(not just Heat vs. Light)

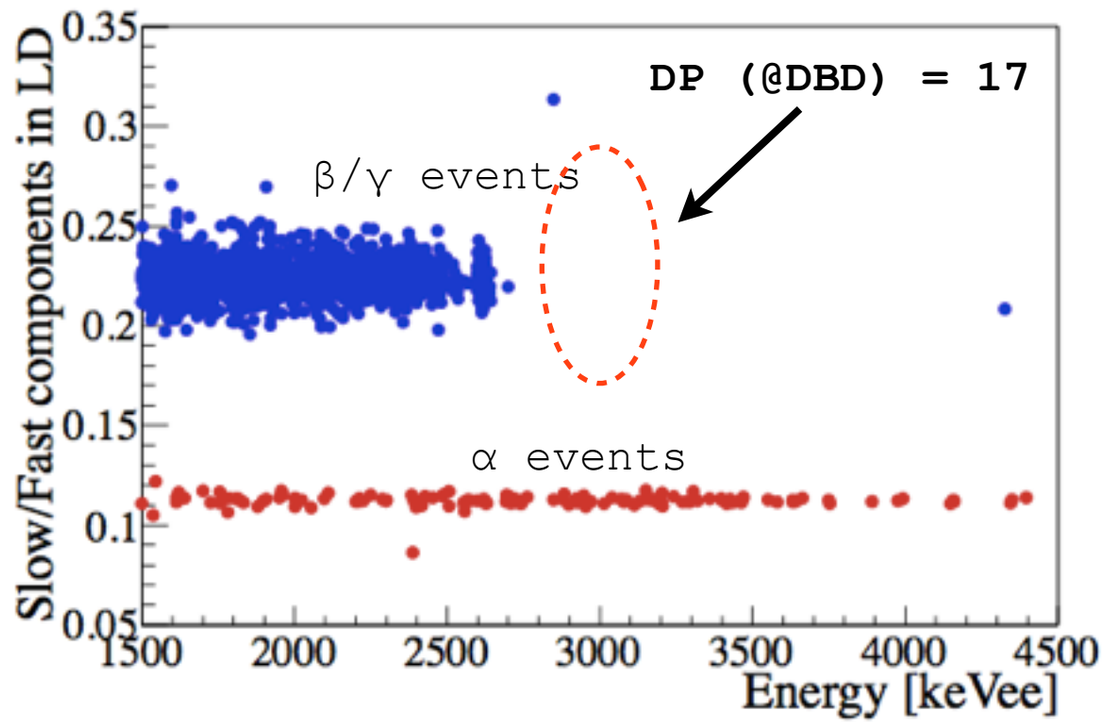
ZnSe thermal pulse





LD thermal pulse

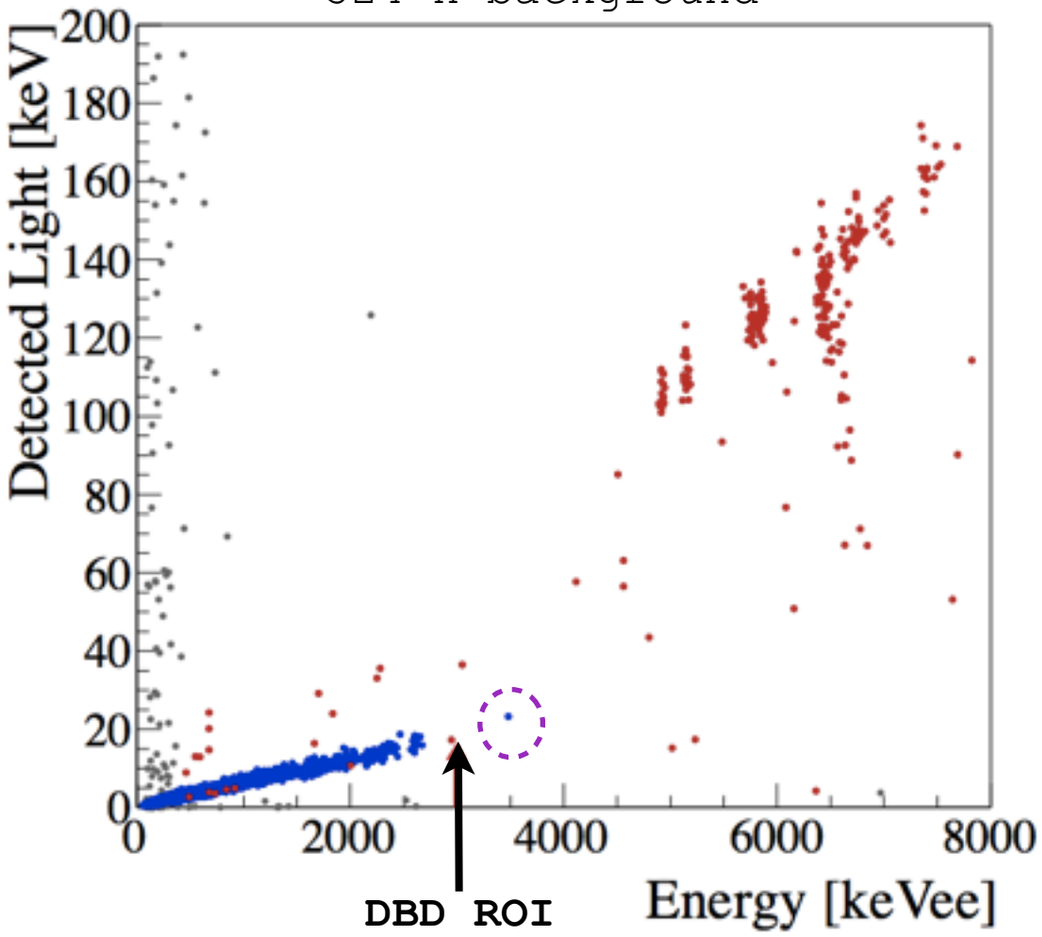




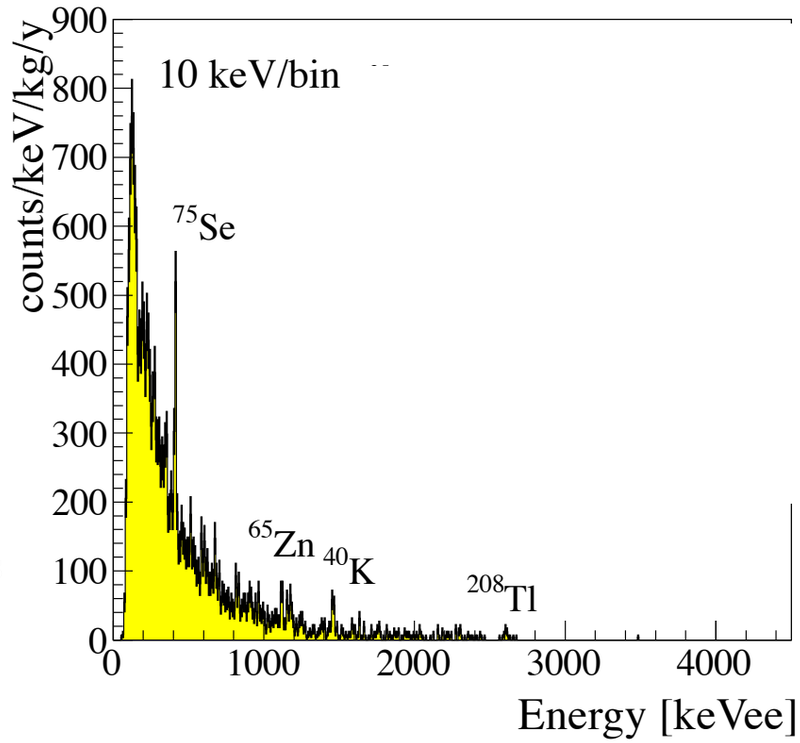
ZnSe background

Background measurement performed with Roman Lead shields inside the cryostat

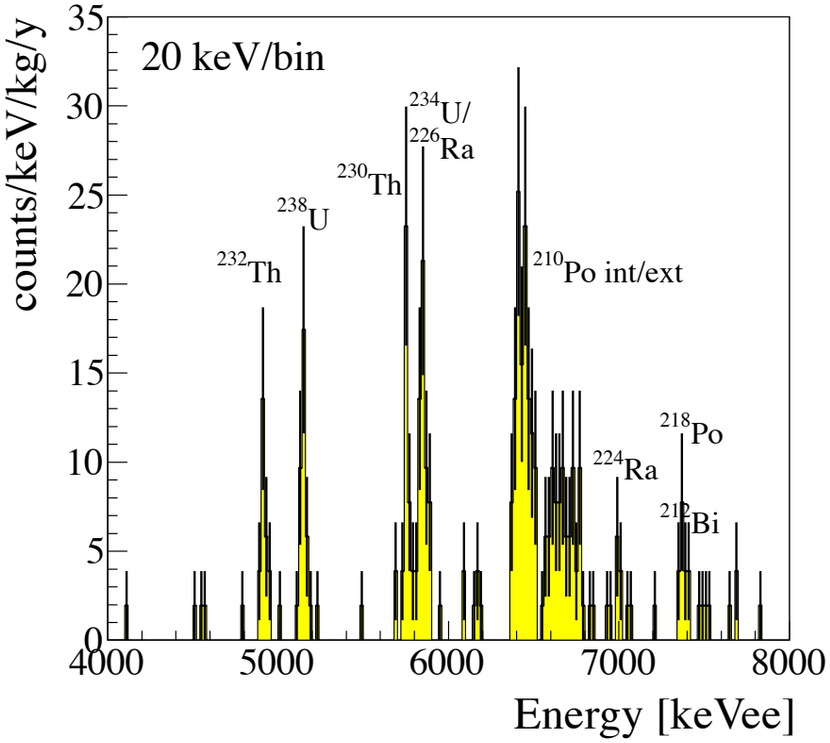
524 h background



β/γ events selection



α events selection



- Cosmogenic activation ^{75}Se and ^{65}Zn
- Natural radioactivity ^{40}K, ^{232}Th & ^{238}U (~20 μBq/kg)
  - 1 β/γ event @ ~3.5 MeV: coincidence with other detectors (**muon**)

ZnSe background

Internal contaminations

Chain	Nuclide	Activity [μBq/kg]
^{232}Th	^{232}Th	17.2 ± 4.6
	^{228}Th	11.1 ± 3.7
^{238}U	^{238}U	24.6 ± 5.5
	^{234}U	17.8 ± 3.3
	^{230}Th	24.6 ± 5.5
	^{226}Ra	17.8 ± 3.3
	^{210}Po	$< 90.9 \pm 10.6$

bkg in the ROI

→ 2.5x10^{-3} c/keV/kg/y (^{212}Bi) ✘

{ if we use delayed coincidences we have:
- x3 less bkg
- 10% dead time

→ 3x10^{-4} c/keV/kg/y (^{210}Tl) ✔

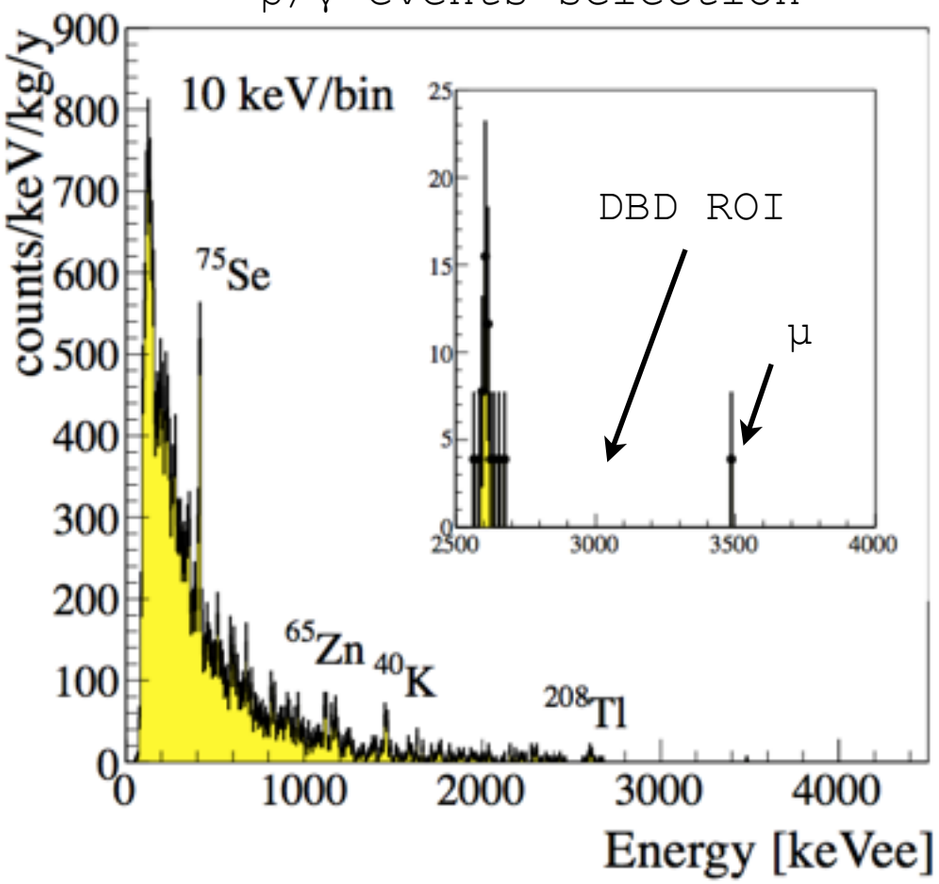
Not a primary issue for a bkg level of ~10^{-3} c/keV/kg/y

Exercise:
- 0 counts in 1.3 MeV region [2.7,4.0] MeV
- mass = 0.43 kg
- t = 0.06 y

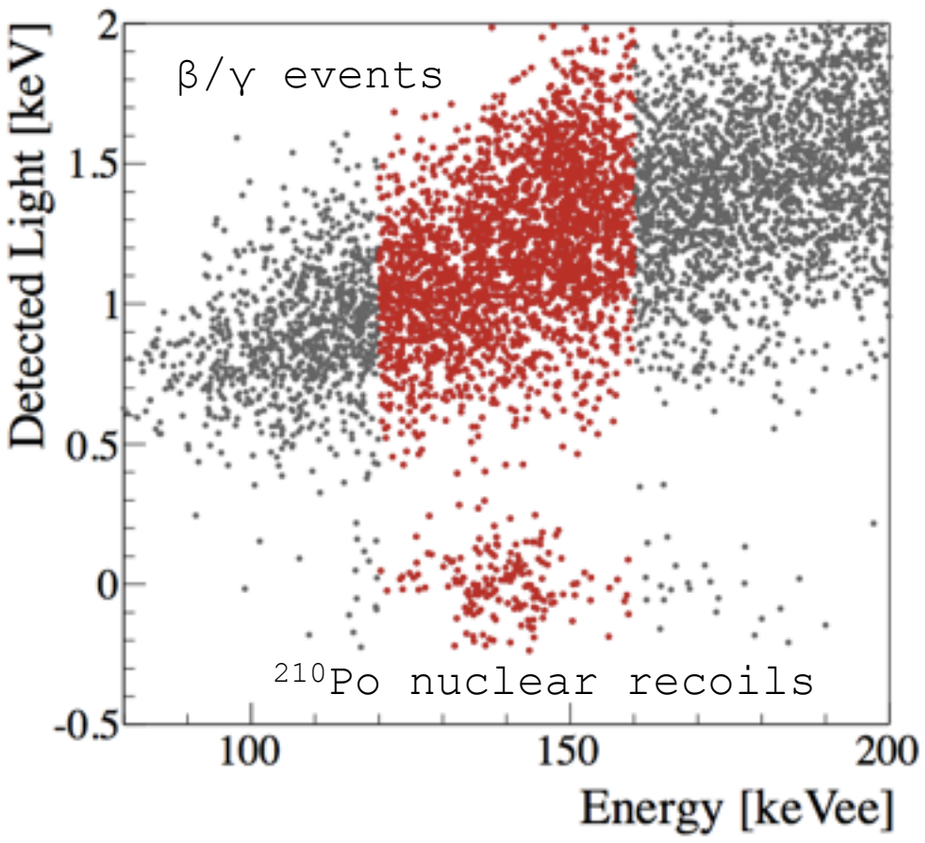
=> < 0.07 c/keV/kg/y

1 crystal, 3 weeks live time

β/γ events selection



ZnSe nuclear recoils discrimination



- ^{210}Po nuclear recoils energy is shifted by ~35% (they are expected @ 103 keV)

- ^{210}Po nuclear recoils produce a light signal < 14 eV

- LY_{nr} < 0.140 keV/MeV

- Energy threshold @ 70 keV_{ee} (~50 keV_{nr})

To be sensitive to WIMP nuclear recoils thresholds < 30 keV_{ee} (10 keV_{nr}) are needed as well as LDs with baseline energy resolution **< 20 eV** for the discrimination β/γ - NR

We are here

Detector	$FWHM_{baseline}$ [eV]	$FWHM_{^{55}Fe}$ [eV]
LD	160	262

a lot of work has still to be done...

J W Beeman *et al* 2013 *JINST* **8** P05021

LUCIFER crystals

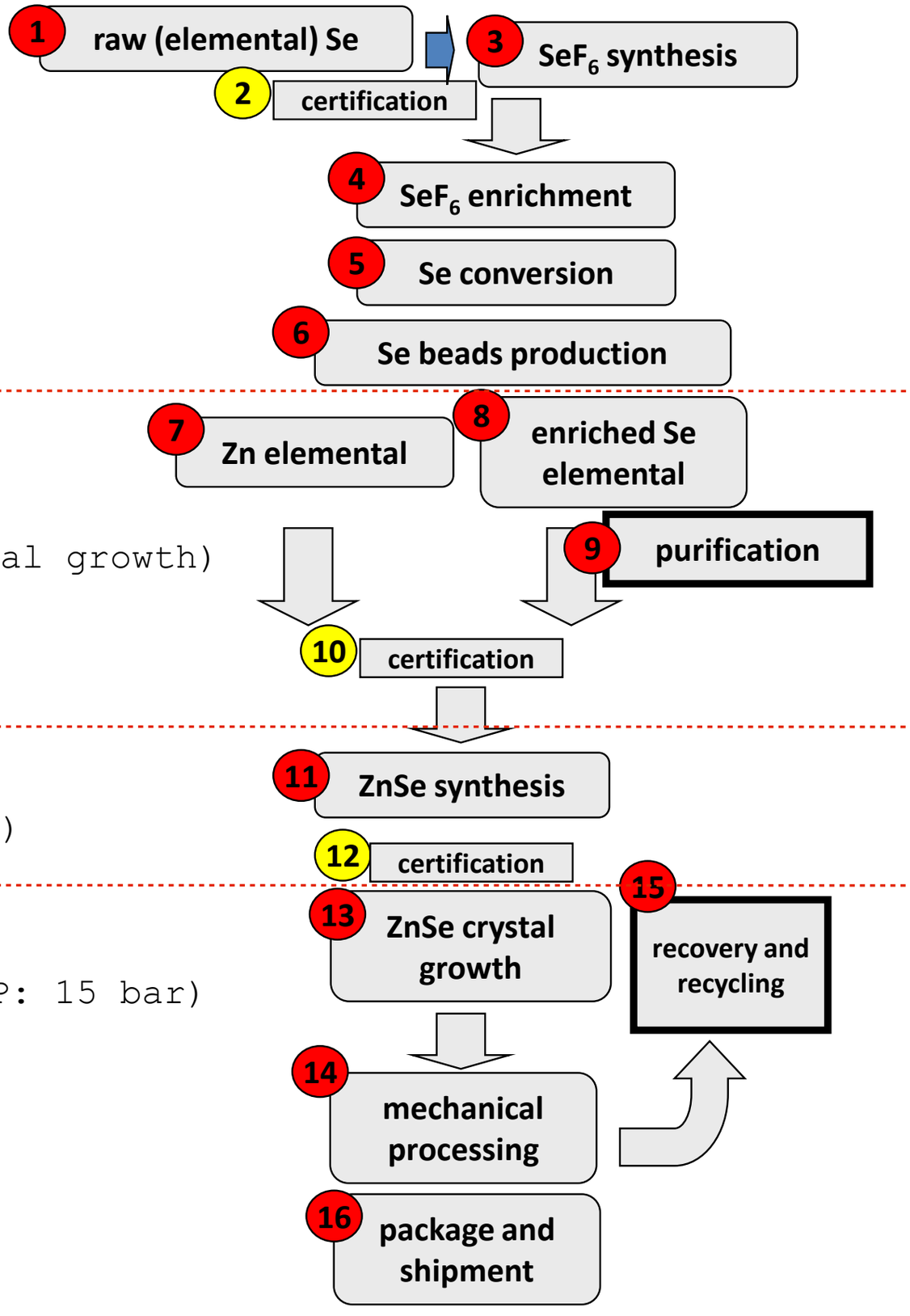
ZnSe is not a standard crystal.
Glass is used for laser application

- **Production of ^{82}Se**
  - production of clean (chemistry) Selenium

- **Raw materials production: metallic Zn and Se**
  - beads dimensions (powder not good for crystal growth)

- **Synthesis of ZnSe** (!!!)
  - production of ZnSe compound
  (different melting&condensation T for Zn & Se)

- **Crystal growth**
  - Bridgman growth (high T: ~1500 C and high P: 15 bar)
  - not mono-crystal
  - reproducibility
  - low yield of production



Conclusions

* ZnSe scintillating bolometers allow an excellent particle discrimination (Heat vs. Light, Heat, Light)

* In ZnSe compound the amount of useful material is 55% (higher than most of “interesting compound”)

* Problems concerning crystal growth are under investigation

* Dark Matter search with ZnSe is not so far...