Scintillating bolometers of LMO in LNGS

Second general meeting of the ISOTTA project

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Outline

- Bolometers & low background physics

- Scintillating bolometers of LMO
  - tests with α, β/γ, n

- Solar axions search

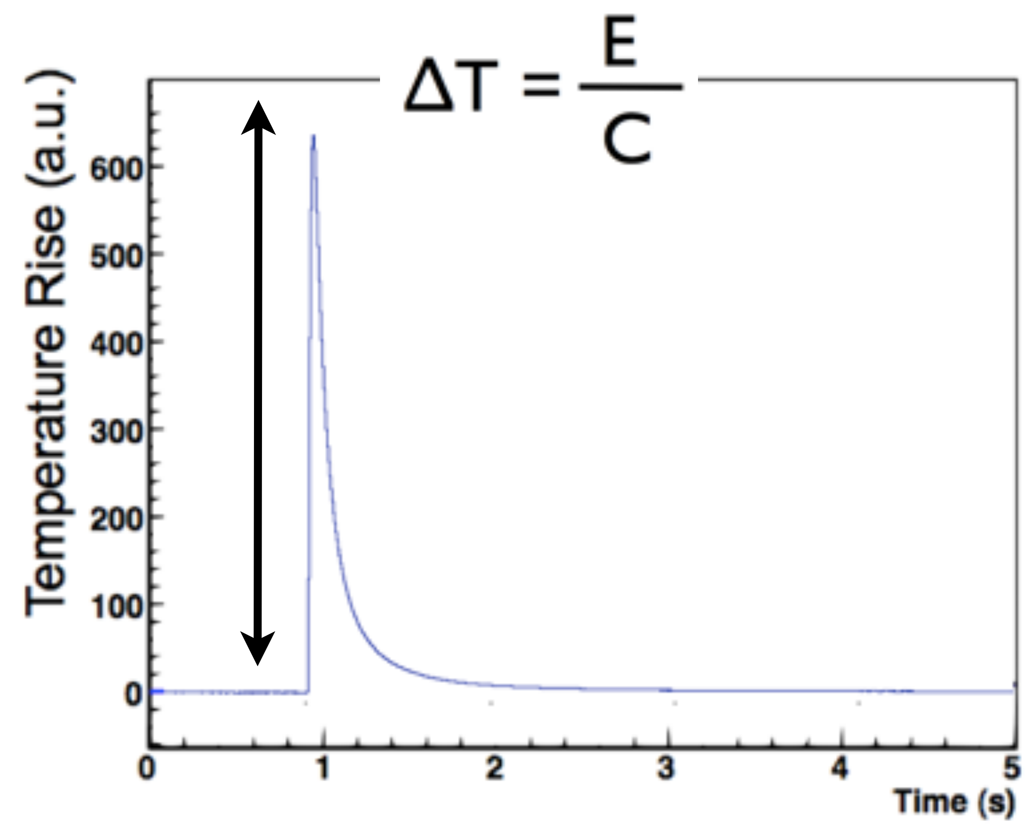
- Conclusions

The bolometric technique

Almost all the deposited energy is converted into phonons which induce a measurable temperature rise

The heat capacity of the crystal must be very small
(-> **low Temperature ~10 mK**)

fully-active detector

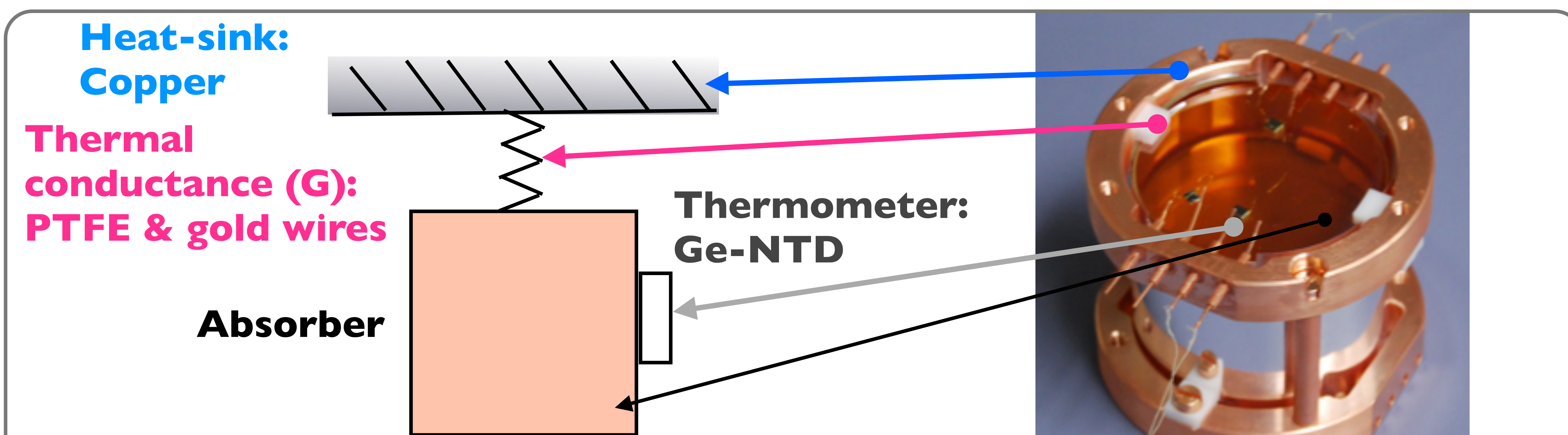


Absorber

- M ~ 0.45 kg
- C ~ 10^{-10} J/K
- $\Delta T/\Delta E$ ~ 500μK/MeV

Sensor

- $R = R_0 \exp[(T_0/T)^{1/2}]$
- R ~ 100 MΩ
- $\Delta R/\Delta E$ ~ 3 MΩ/MeV



The underground facility

Laboratori Nazionali del Gran Sasso
INFN, Italy

Neutrino physics
Dark Matter physics
Rare decays search

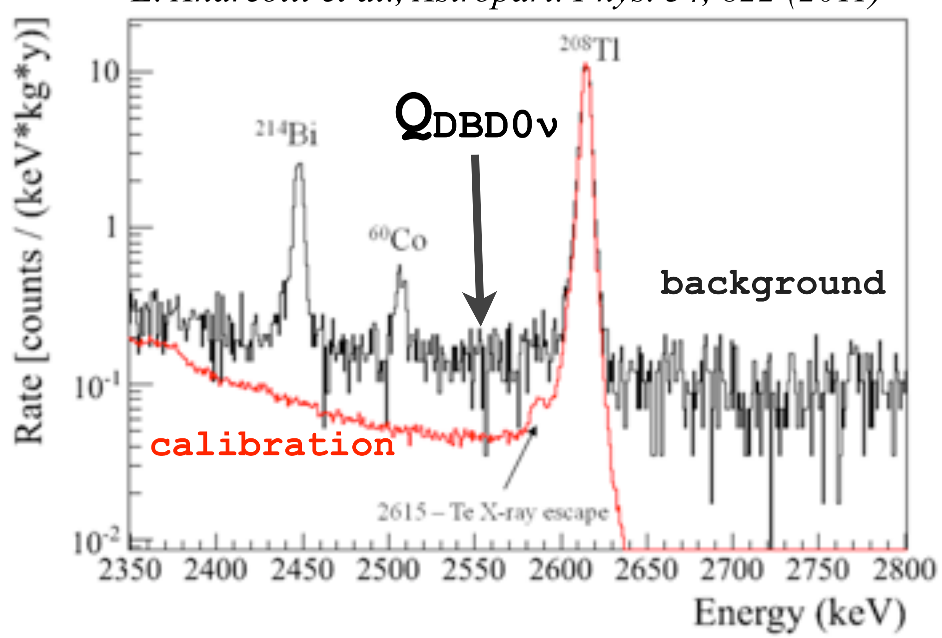
Experimental location:

- Average depth ~ 3650 m w.e.
- Muon flux ~ 2.6×10^{-8} $\mu/s/cm^2$
- Neutrons < 10 MeV: $4*10^{-6}$ $n/s/cm^2$
- Gamma < 3 MeV: 0.73 $\gamma/s/cm^2$

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)

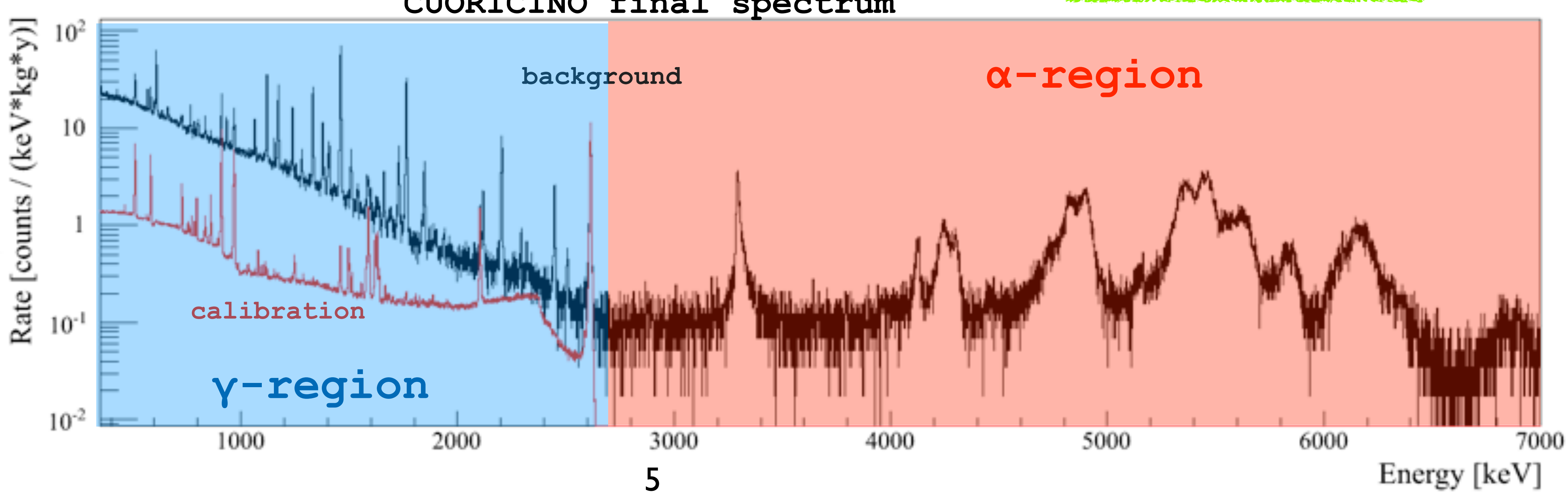


background @ DBD0ν:
0.17 c/keV/kg/y

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

External high energy γ (^{232}Th) **35%**

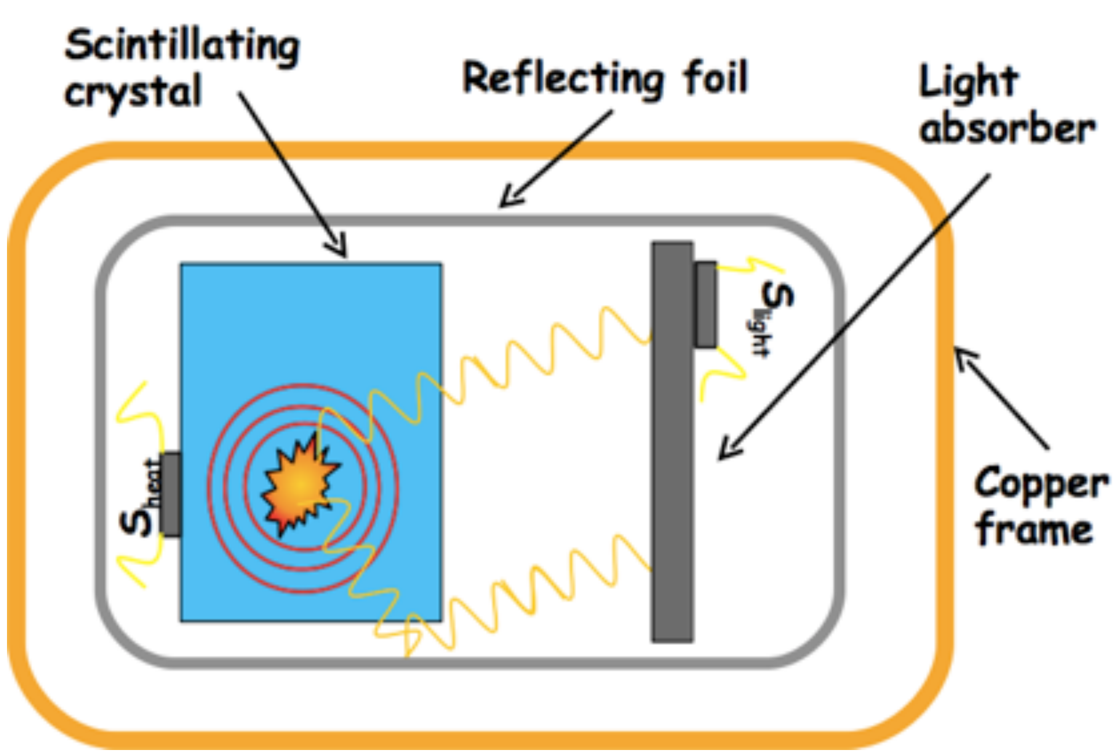
CUORICINO final spectrum

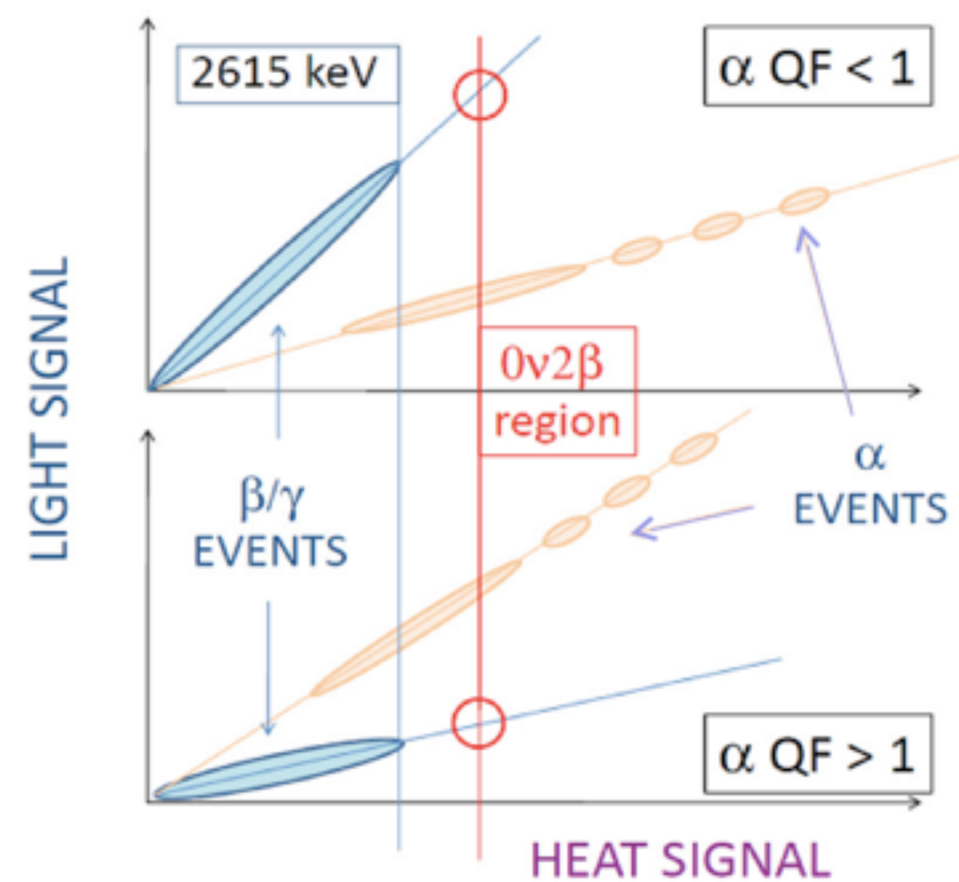


Scintillating bolometers

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

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

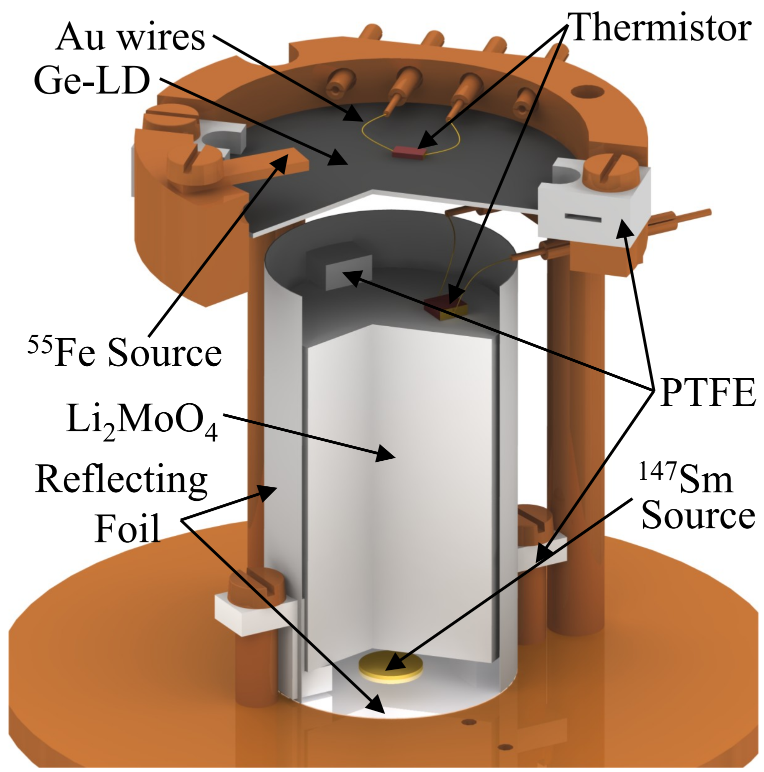




QF: is defined as the ratio of the signal amplitudes induced by an α and an β/γ of the same energy.

Li_2MoO_4

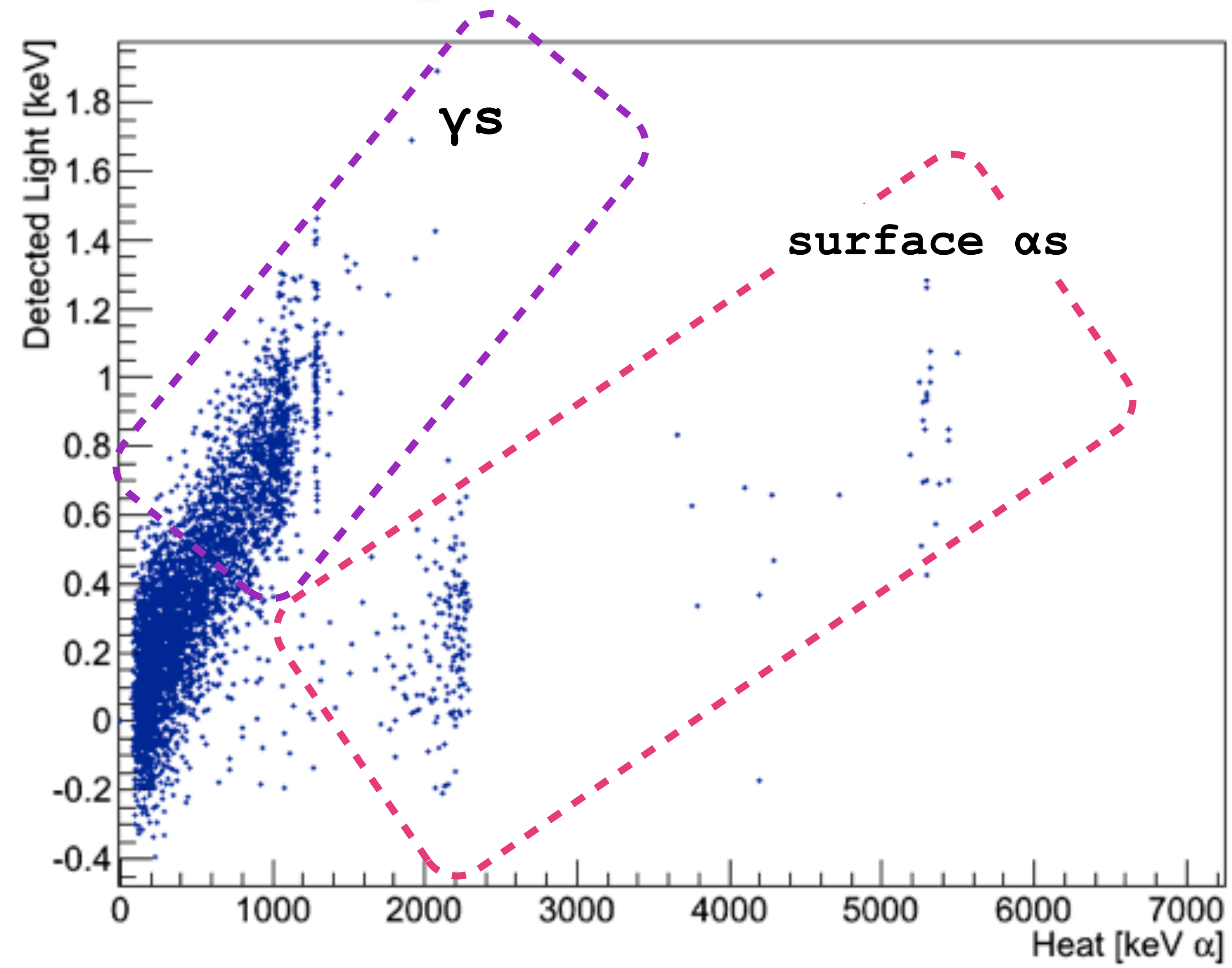
Candidate: ^{100}Mo



	Q-value [keV]	Useful material	$LY_{\beta/\gamma}$ [keV/MeV]	QF_α
Li_2MoO_4	3034	55%	~0.5	~0.4

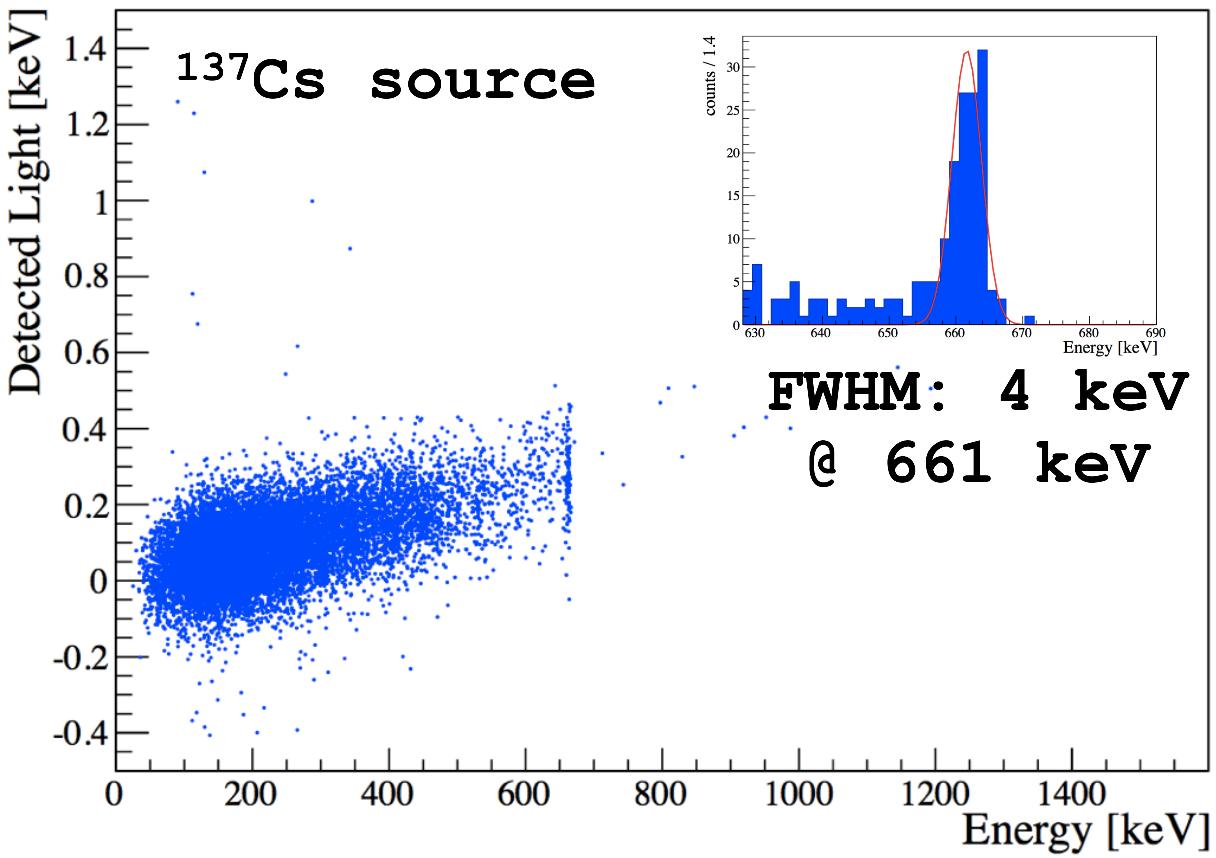
m=33 g
Calibrations α & n & γ
Background 344 h

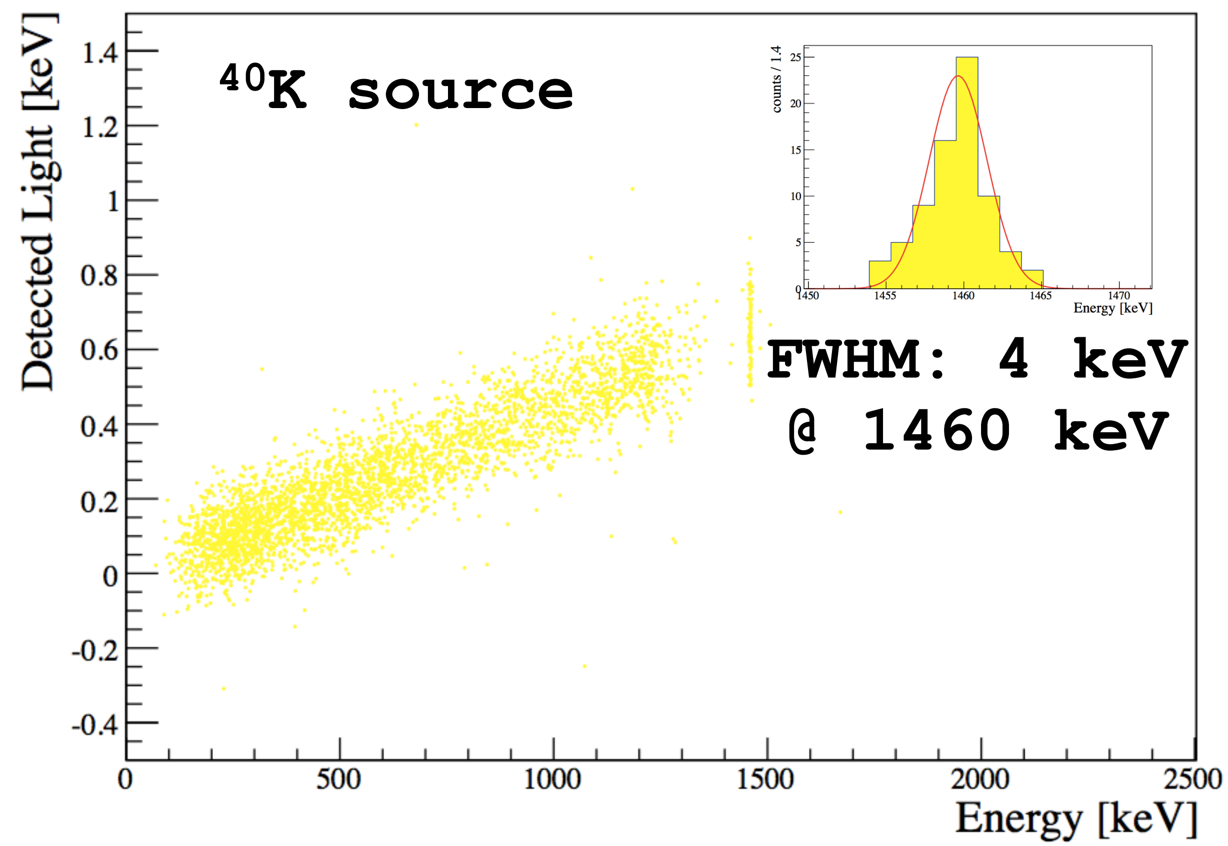
the compound is hygroscopic



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

Li_2MoO_4 with γ-source





$LY_{\beta/\gamma}$ = 0.43 keV/MeV

~30% of $ZnMoO_4$

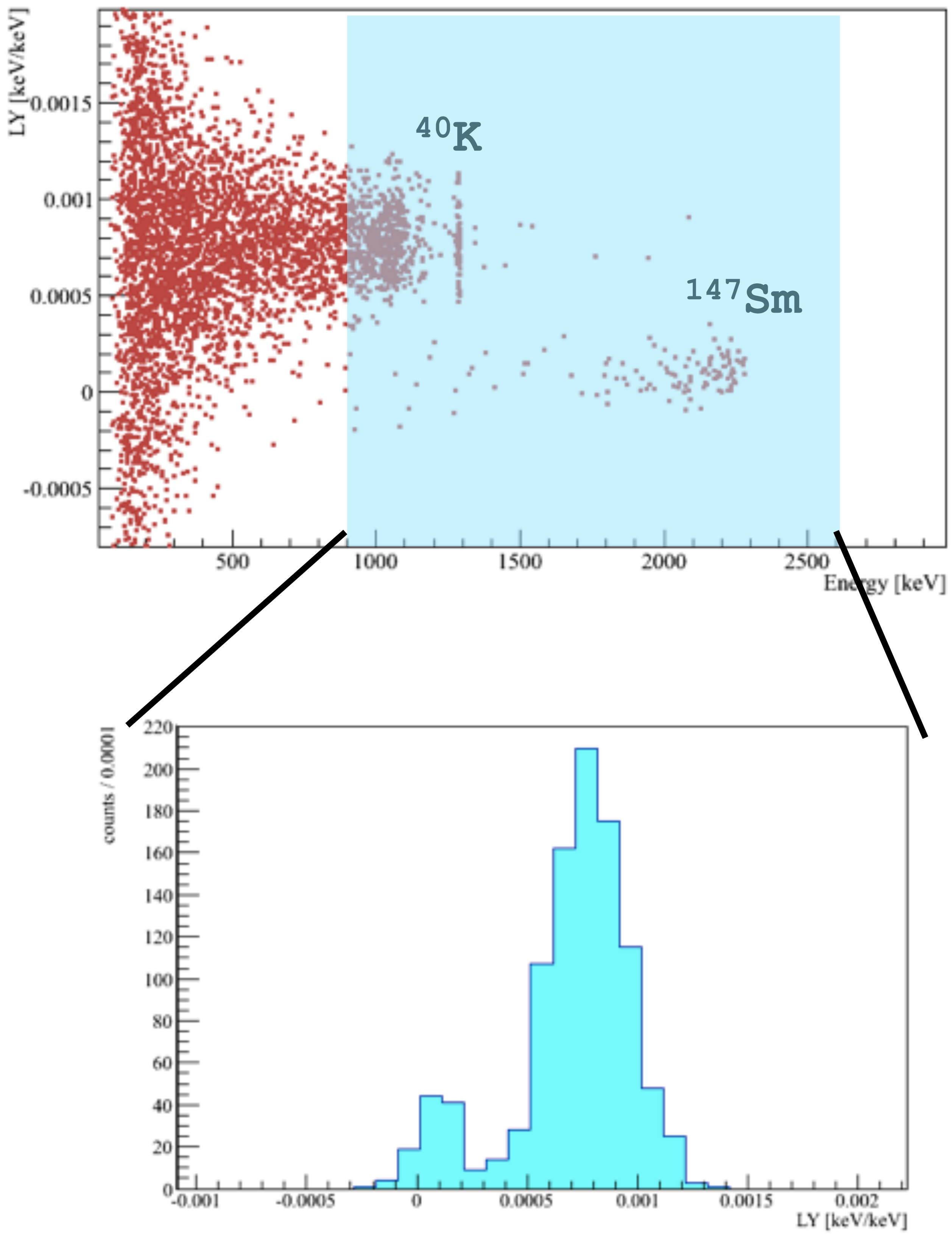
~7% of ZnSe

~2% of $CdWO_4$

Small crystal 22 x 33 mm => difficult calibration at 2615 keV

Li_2MoO_4 with α-source

18 h calibration



$\boxed{QF_\alpha(^{147}Sm) = 0.29}$

$QF_\alpha(^{210}Po) = 0.42$

- ~250% $ZnMoO_4$
- -% ZnSe
- ~5% $CdWO_4$

$$DP(E) = \frac{|\mu_\alpha(E) - \mu_{\beta\gamma}(E)|}{\sqrt{\sigma_\alpha^2(E) + \sigma_{\beta\gamma}^2(E)}}$$

DP(1 MeV-2.3 MeV) ~ 3

small crystal:
difficult comparison for α
and β/γ at higher energy

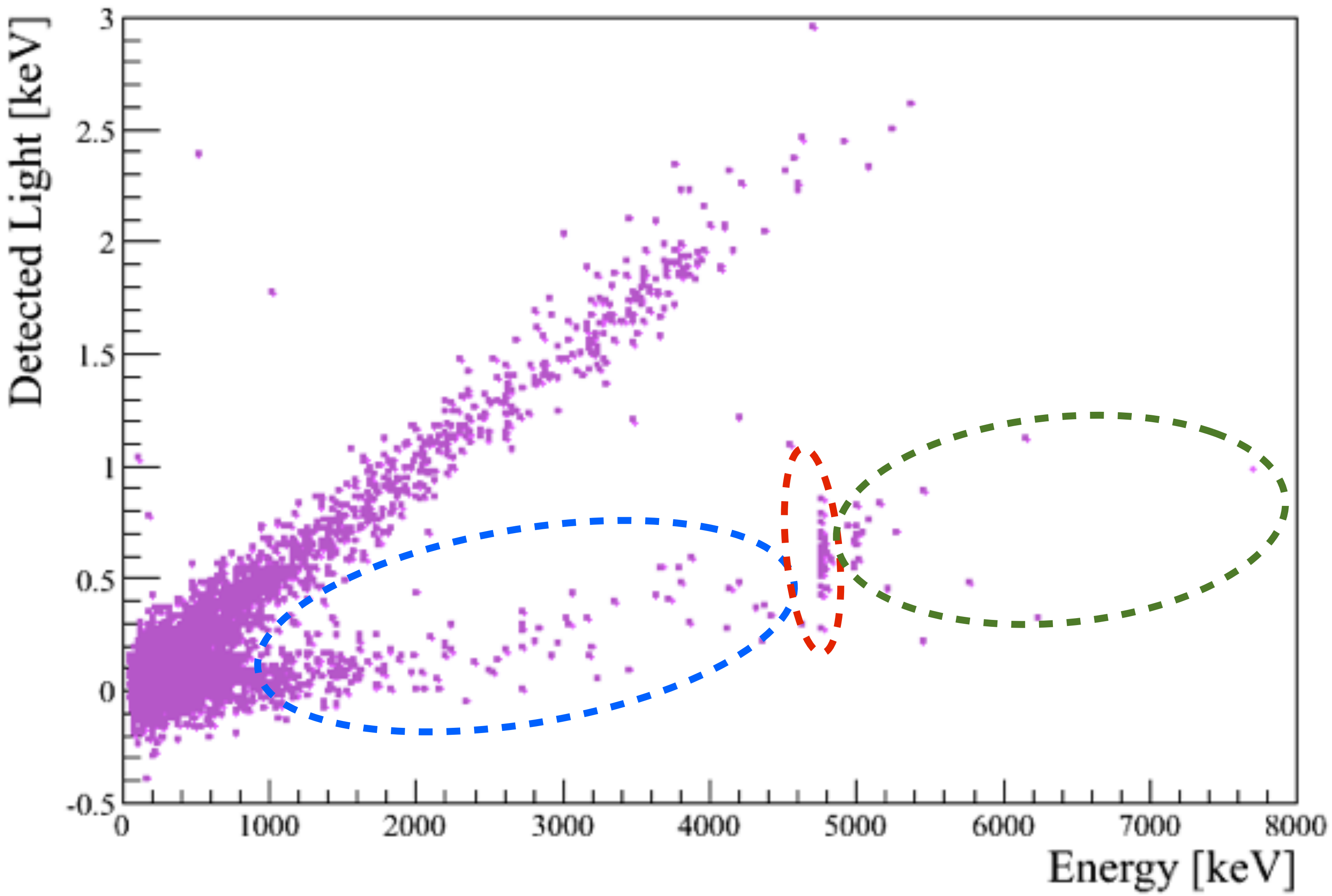
No evidence of particle
discrimination with PSA
=> larger crystals are needed!

Li_2MoO_4 with AmBe-source

$^6Li + {}^1n \rightarrow {}^3H + {}^4He + 4.78$ MeV

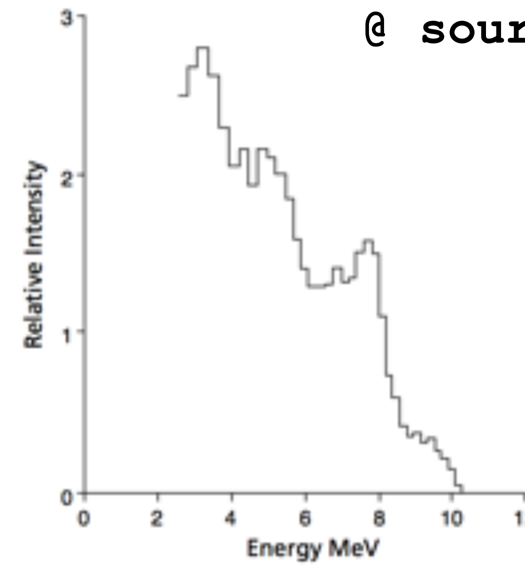
high absorption n cross section

natural i.a.: 7.6%

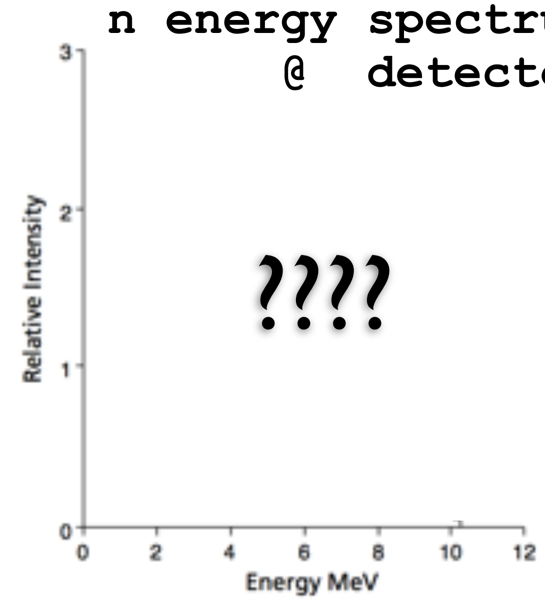


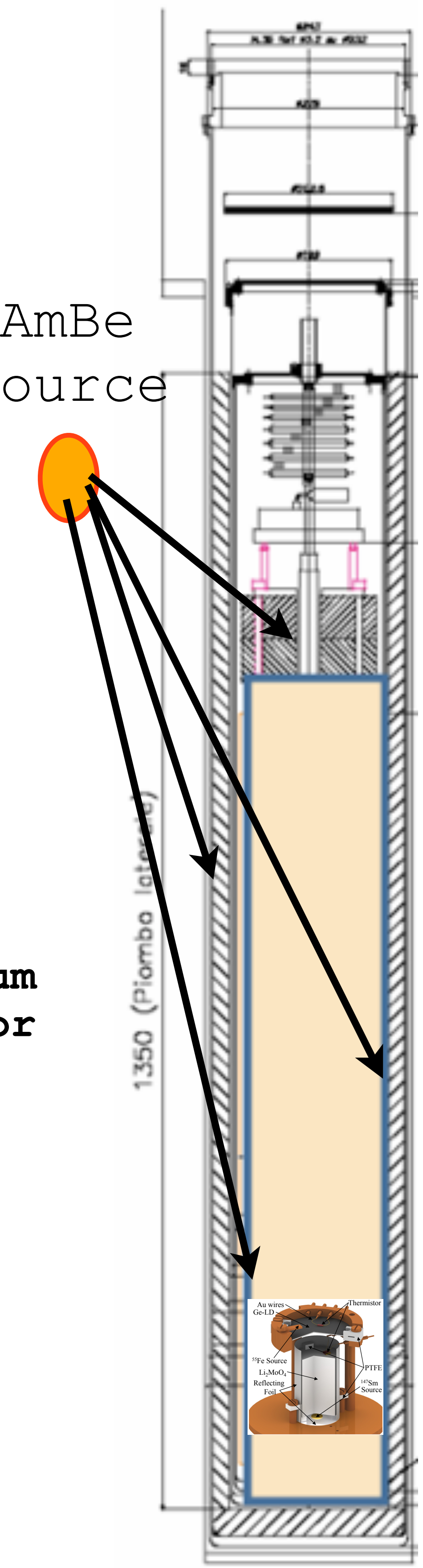
* elastic neutrons scattering
* thermal neutrons absorption
* fast neutrons absorption

n energy spectrum @ source

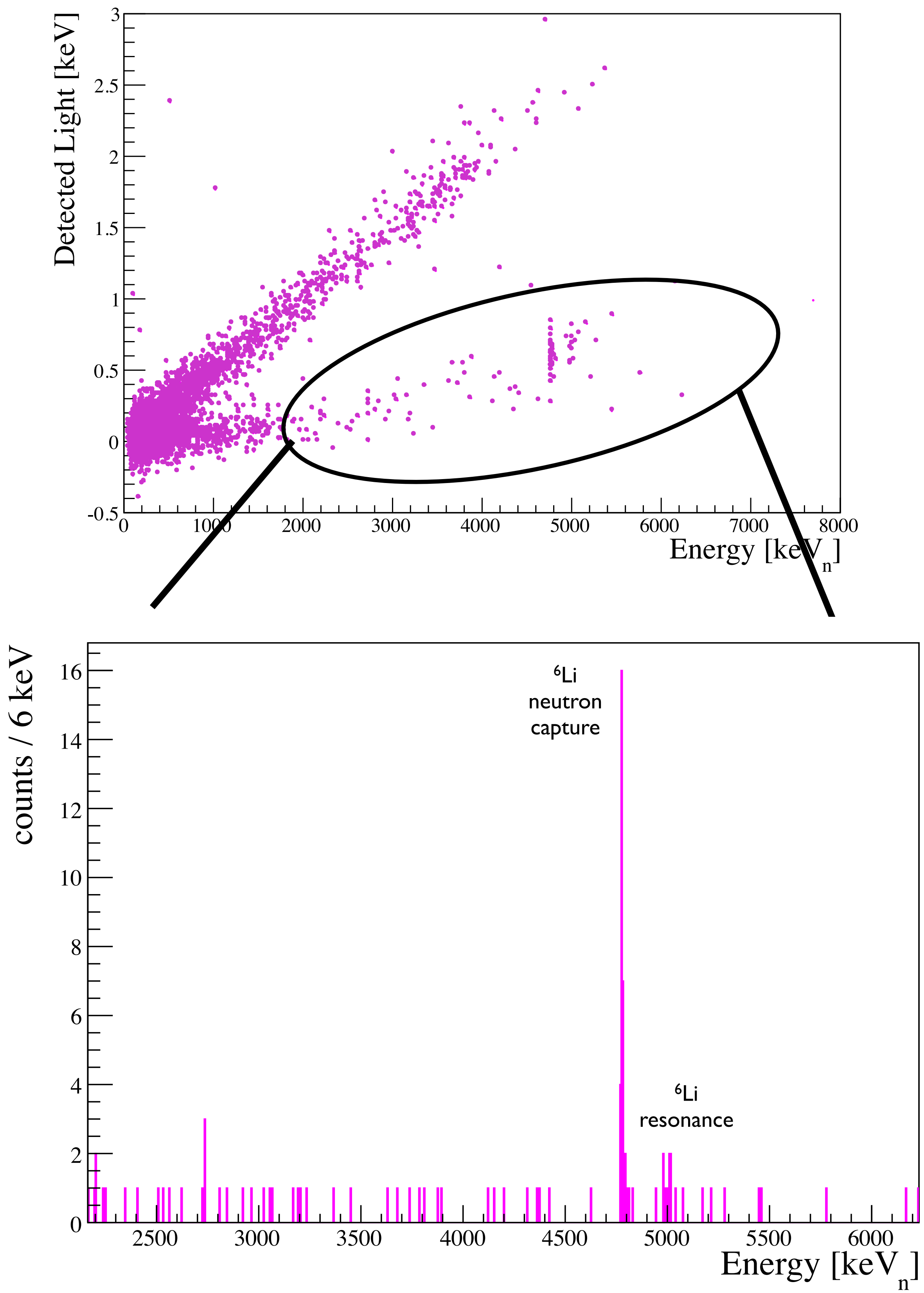


n energy spectrum @ detector

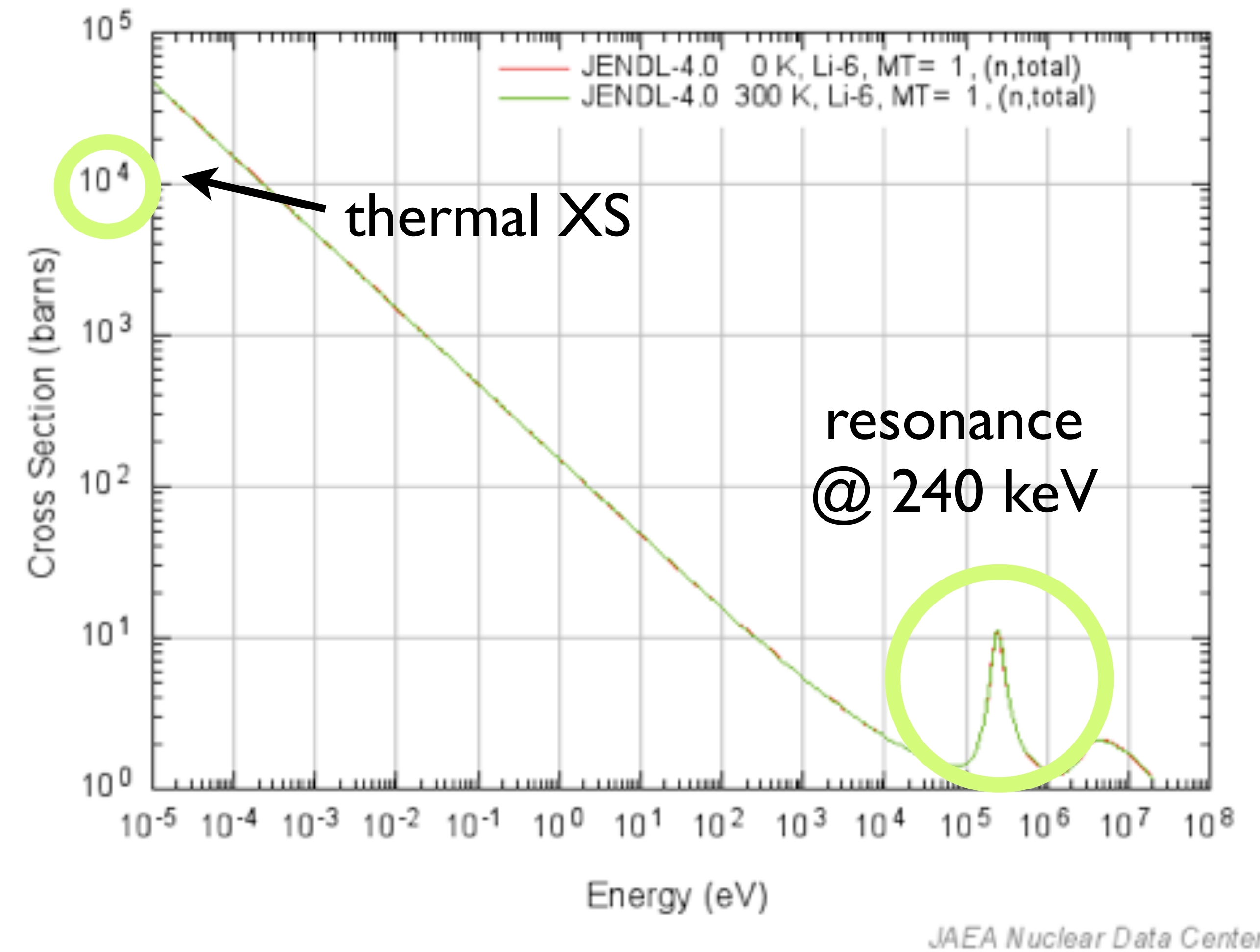




Li_2MoO_4 with AmBe-source



^{6}Li neutron absorption cross section



LY(^{3}H+^{4}He)= 0.12 keV/MeV

FWHM @ 4.78 MeV: 13.5 keV

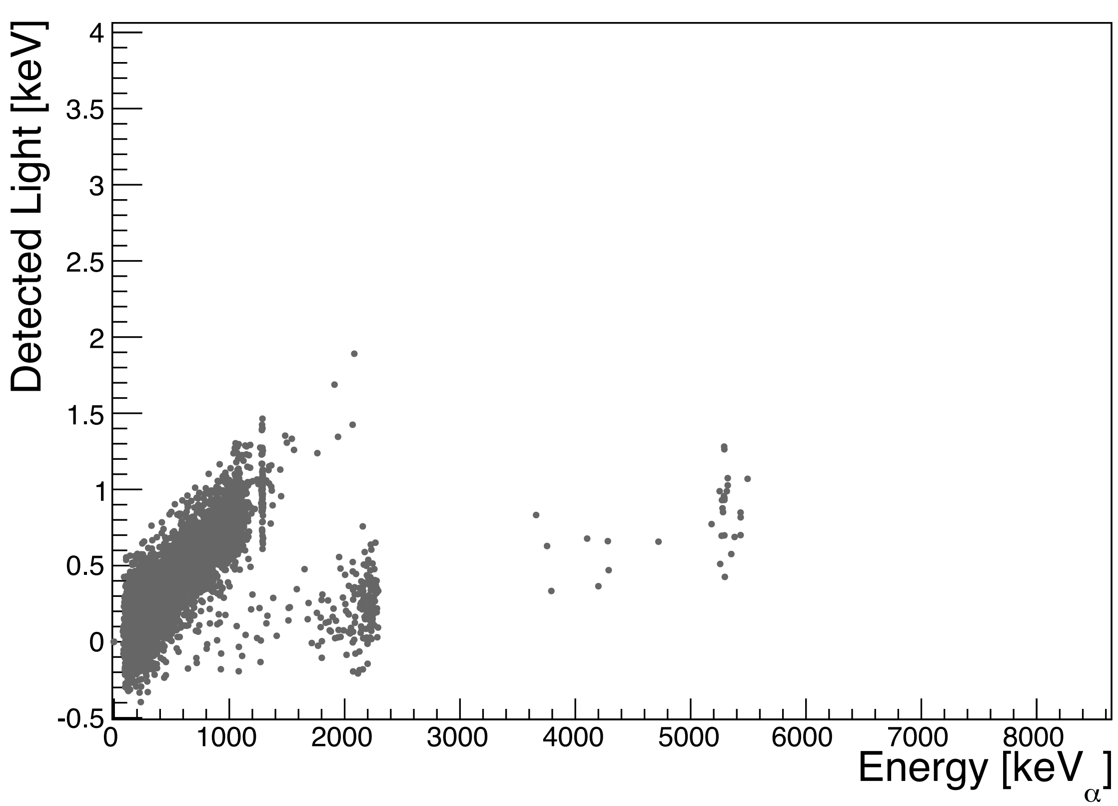
Li_2MoO_4 with AmBe-source

First measurement:
HP-Ge (1240 h)

Chain	Nuclide	Activity (mBq/kg)
^{232}Th	^{228}Ac	≤ 32
	^{212}Pb	≤ 24
	^{208}Tl	≤ 12
^{238}U	^{214}Pb	≤ 20
	^{214}Bi	≤ 21
	^{40}K	$= 170(80)$
	^{60}Co	≤ 8
	^{137}Cs	≤ 4

O.P. Barinova et al., *NIM* A **607** (2009) 573

Scintillating bolometer:
344 h bkg



the crystal is hygroscopic: contaminated in ^{210}Pb (^{210}Po)

New limits:

Chain	Nuclide	Activity [μBq/kg]
^{232}Th	^{232}Th	< 94
^{238}U	^{238}U	< 107
	^{210}Pb	729 ± 160

Solar axions search

Detection of ^{7}Li solar axions by means of resonant absorption on analogue targets in the labs.

In the Sun : *pp* → ... → ^{7}Be + e$^-$ → ^{7}Li* → ^{7}Li + axion

in the lab : ^{7}Li + axion → ^{7}Li* → ^{7}Li + γ

We look for a γ emission at about 478 keV

Doppler effects ~0.5 keV
nuclear recoil ~10^{-2} keV
...

Total number of absorptions:

$$\underbrace{N_{abs}}_{} = \underbrace{N_{^7Li}}_{^7\text{Li nuclei}} \times \underbrace{T}_{\text{Time}} \times \underbrace{C^{te}}_{\text{Constant}} \times \left(\underbrace{\frac{m_a}{1\,eV}}_{\text{Axion mass}}\right)^4$$

M. Krcmar et al., *Phys. Rev.* D **64** (2001) 115016

A.V. Derbin et al., *JETP* Lett. **81** (2005) 365

If we reverse the equation (considering BR and detection ε(~5%)):

small crystal

$$m_a < 39\ keV \quad @ \quad 90\ C.L.$$

on a 33 g crystal & 344 h bkg measurement

Current best limit:

$$m_a < 8.6\ keV \quad @ \quad 90\ C.L.$$

P. Belli et al., *Phys. Lett.* B **711** (2012) 41-45

Conclusions

- Excellent candidate for DBD search of ^{100}Mo:
  => large QF_{α} at high energy

- Good neutron detection in the frame of DM search (WIMPs)

- Good candidate for ^{7}Li solar axions

- ... no large crystal (~100 g) has ever been produced ...

- Good intrinsic radio-purity level

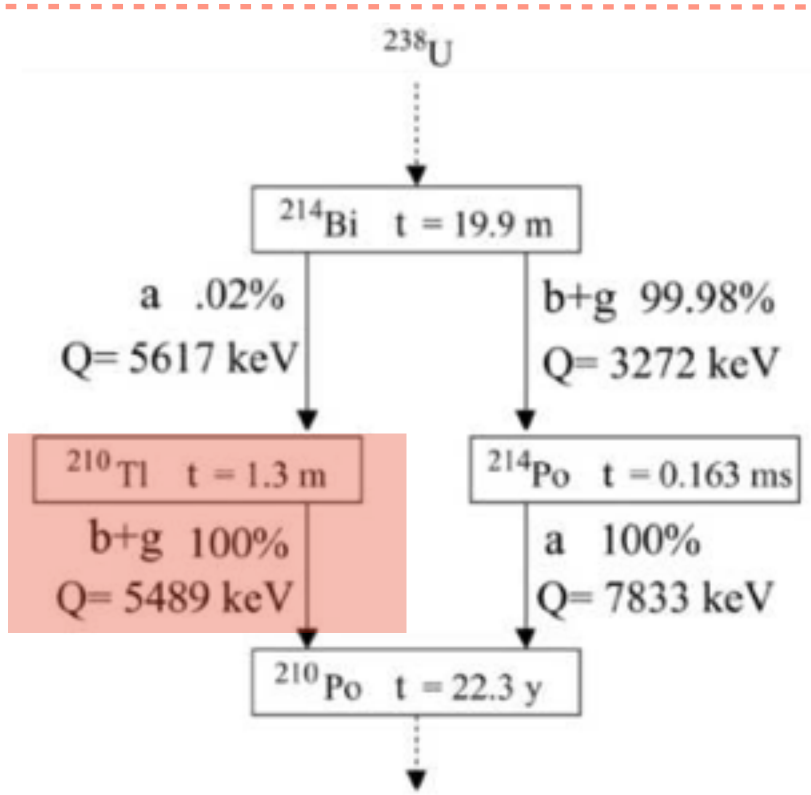
High energy β/γs background

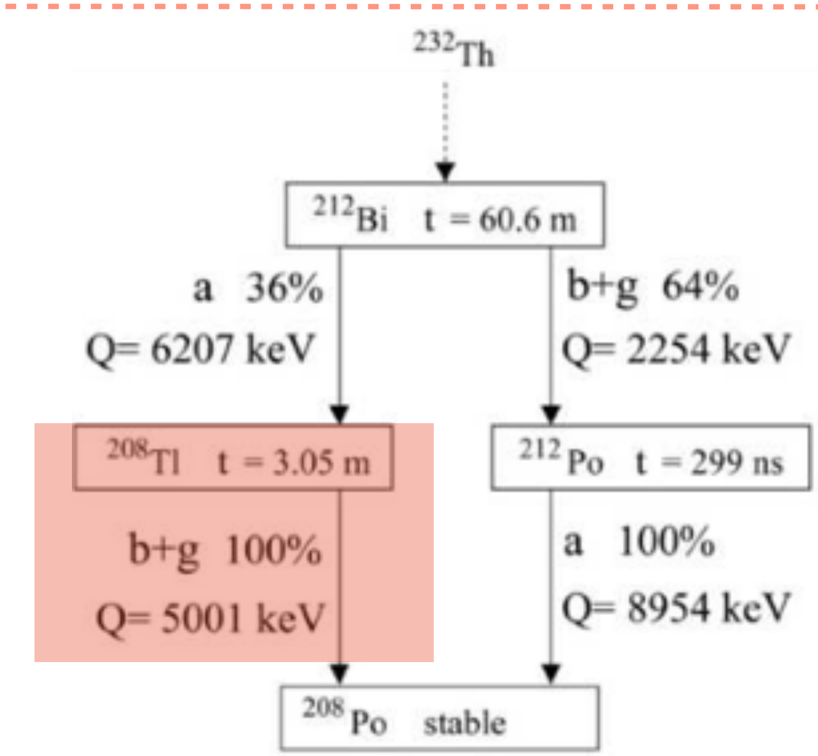
Background can be induced by contaminations
of ^{238}U & ^{232}Th decay products.
Elements with Q_{value} ~ Q_{DBD}:

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





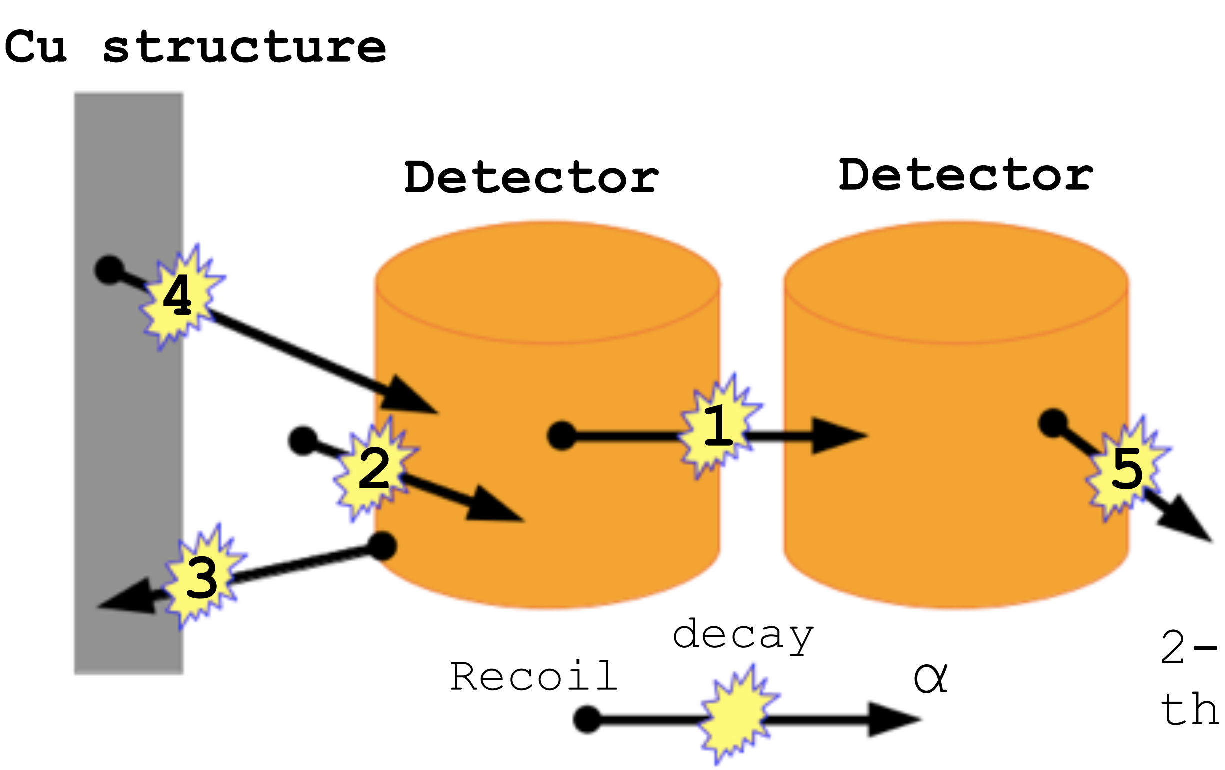
α surface contaminations

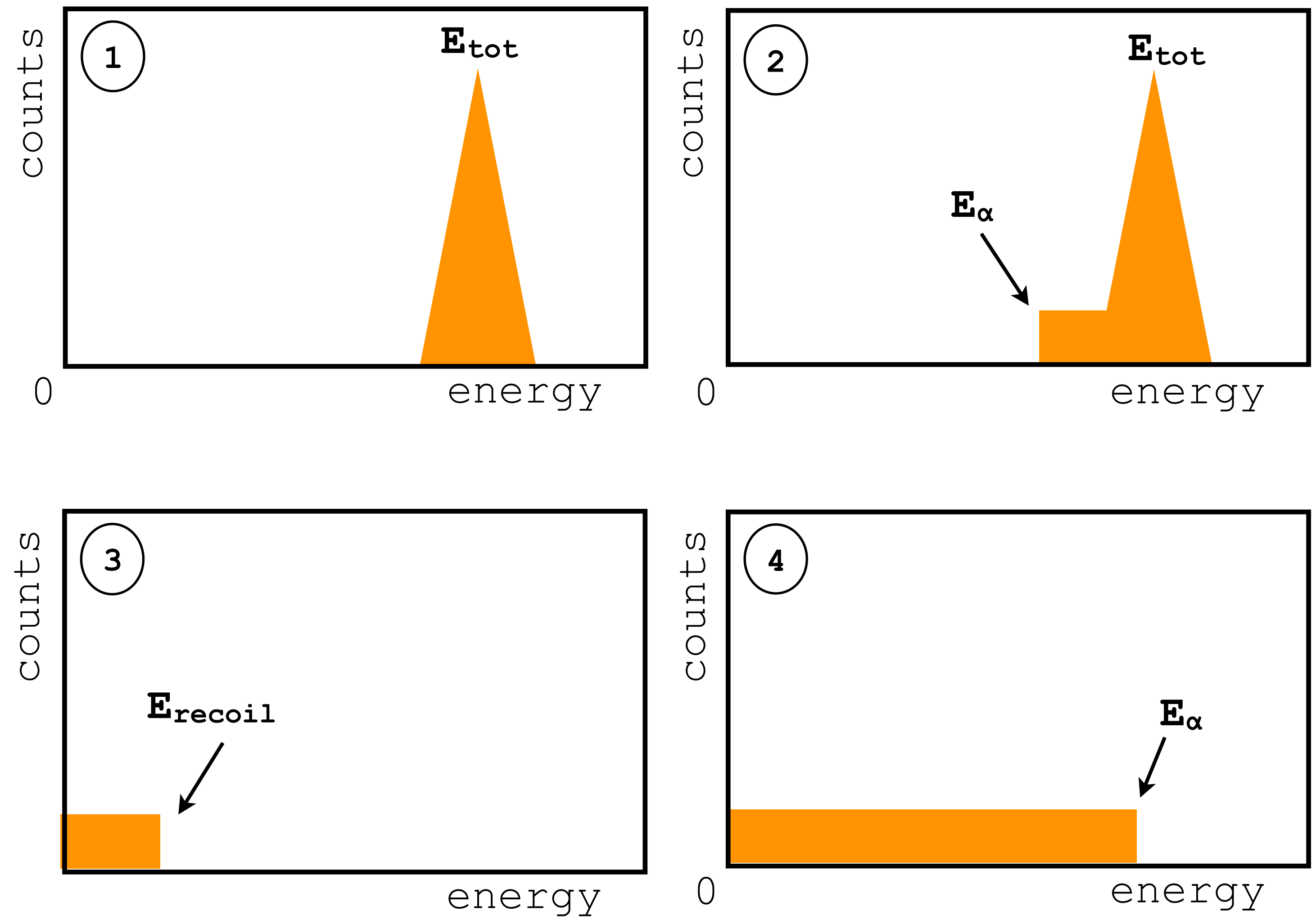
α decays may occur on surfaces of Cu structure or on the detectors due to possible re-contaminations of radio-pure materials.

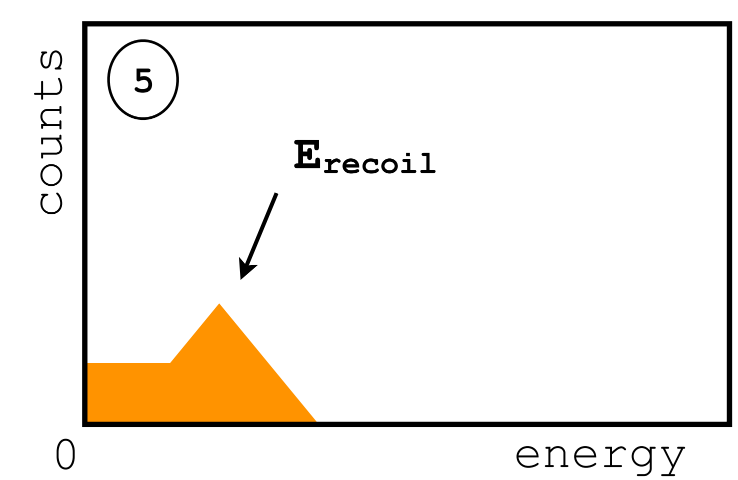
N.B. bolometers are fully-active detectors

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

$$\sim\text{MeV} = \sim\text{MeV} + \sim10\text{-}100\ \text{keV}$$







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

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

. . .

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 $T_{1/2}$: 1.6x10^{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

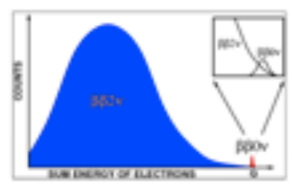
Large mass array

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

ΔE: energy resolution

Bolometric approach

CUORICINO experiment

Cuoricino:
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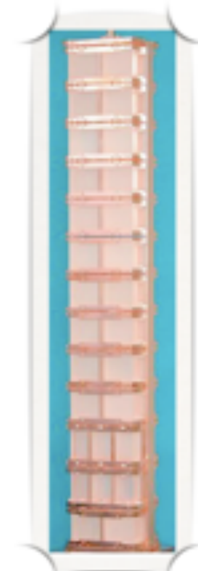

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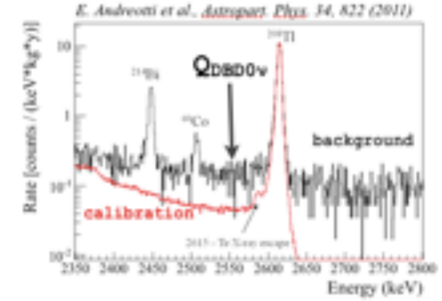

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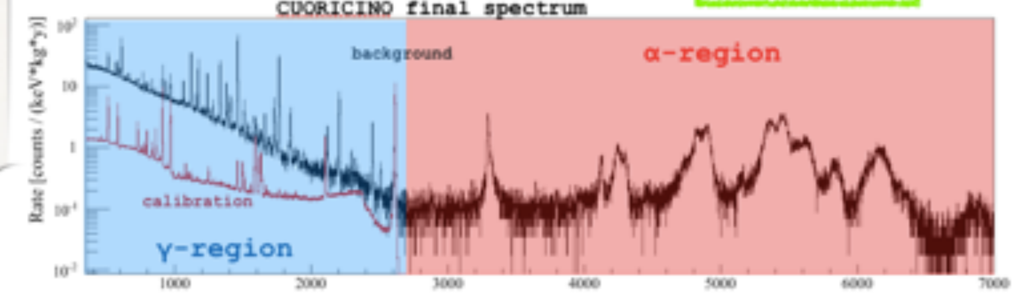
35% External high energy γ (^{232}Th)

CUORICINO final spectrum



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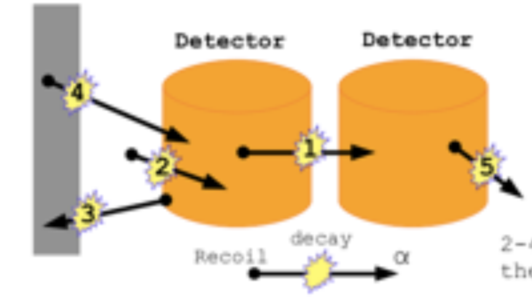
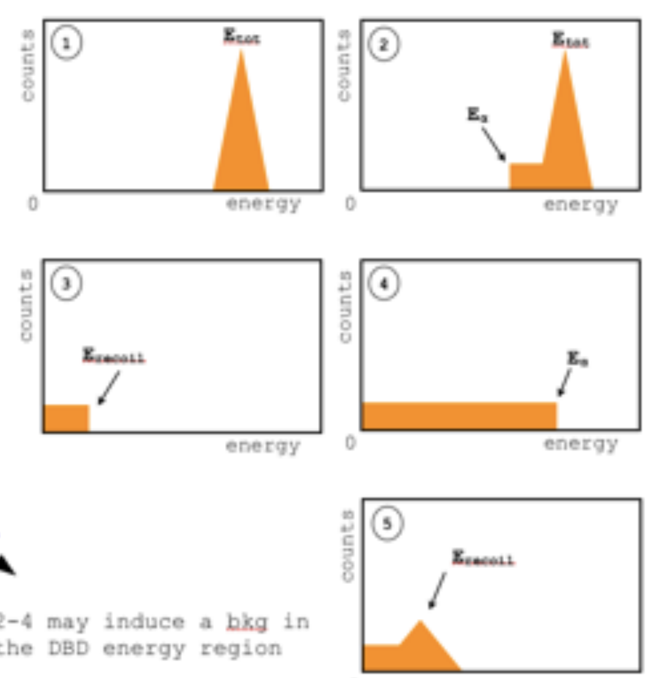
~MeV = ~MeV + ~10-100 keV

Cu structure





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