Scintillating bolometers of LMO in LNGS

Fourth and final general meeting of the ISOTTA project

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Outline

- Intro
- LMO bolometric performance
- Particle identification (heat & light)
- LMO background measurement
- Scintillation properties
- applications

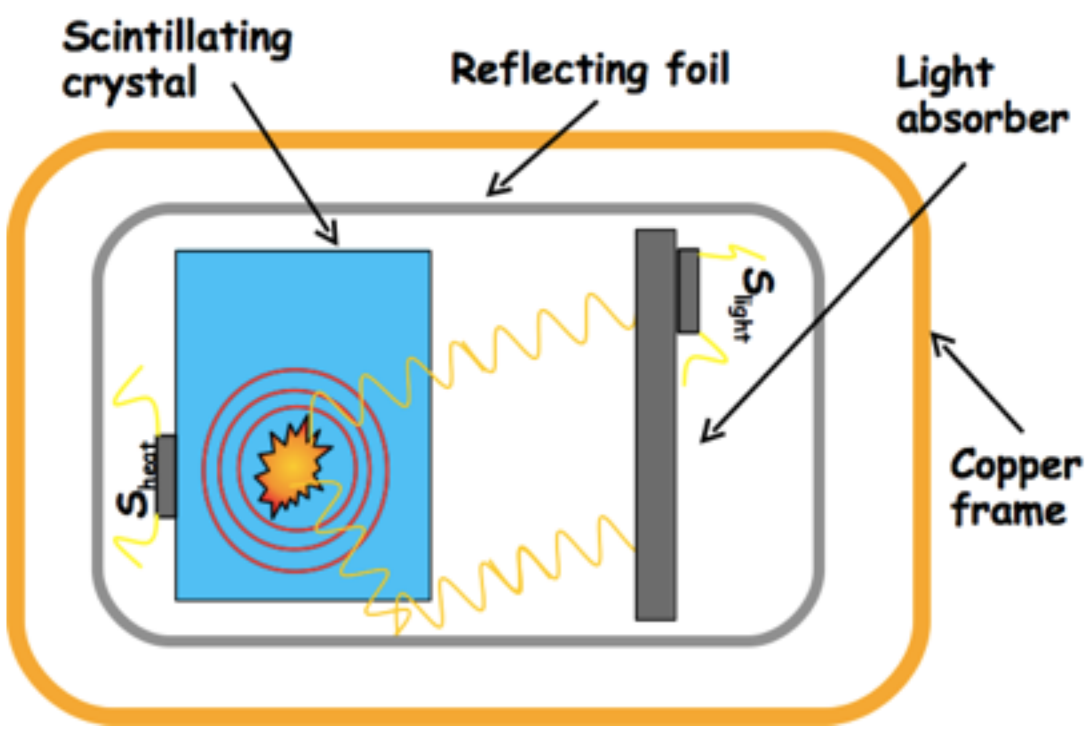
Scintillating bolometers

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.

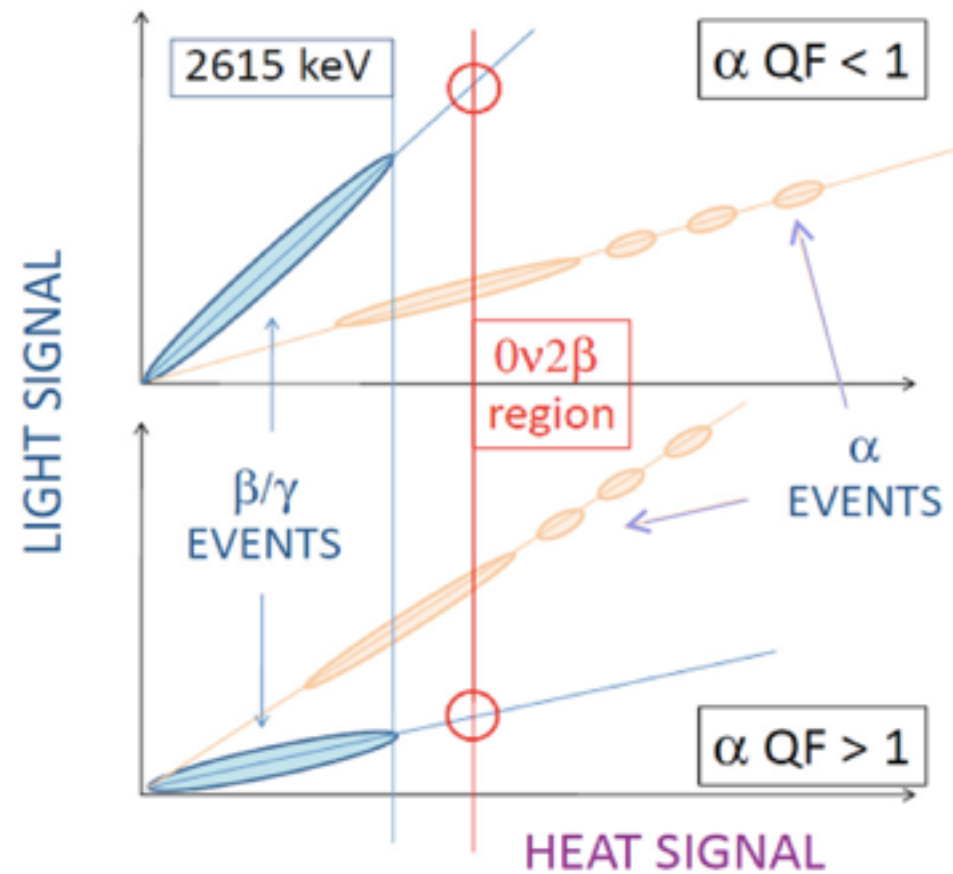
Double signal read-out:

Heat: absorber+thermometer

Light: PM / SiPM / bolometer



A. Alessandrello et al., Nucl. Phys. B 28 (1992) 233-235



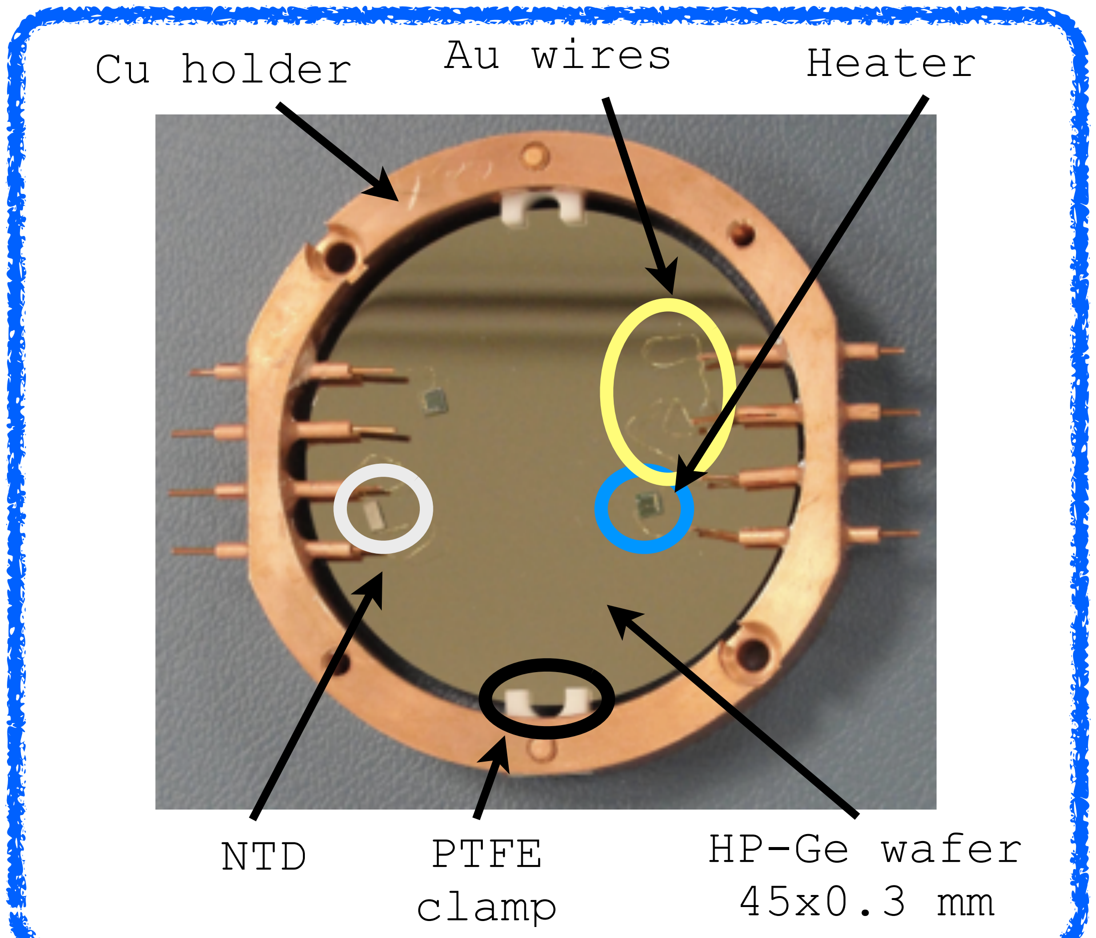
QF: ratio of the light signal amplitudes induced by α and an β/γ particles of the same energy.

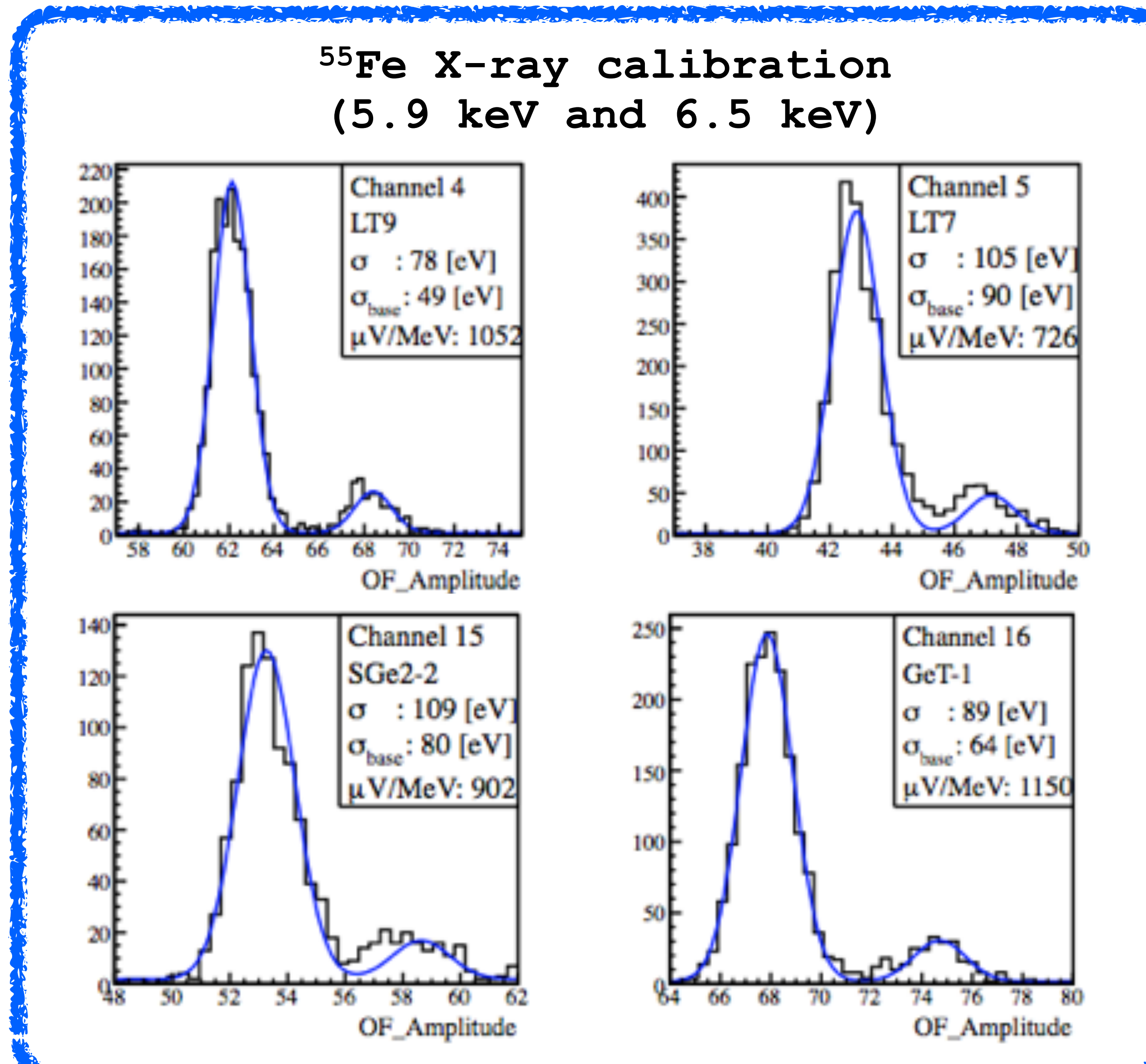
Light detectors (LD)

Light signal:

=> few keV/MeV
=> is isotropic

Light detector:	PMT	Bolometer
=> quantum efficiency	✘	✔
=> energy resolution	✘	✔
=> intrinsic radio-purity	✘	✔
=> must work @ low T	✘	✔
=> energy threshold	✔	✘

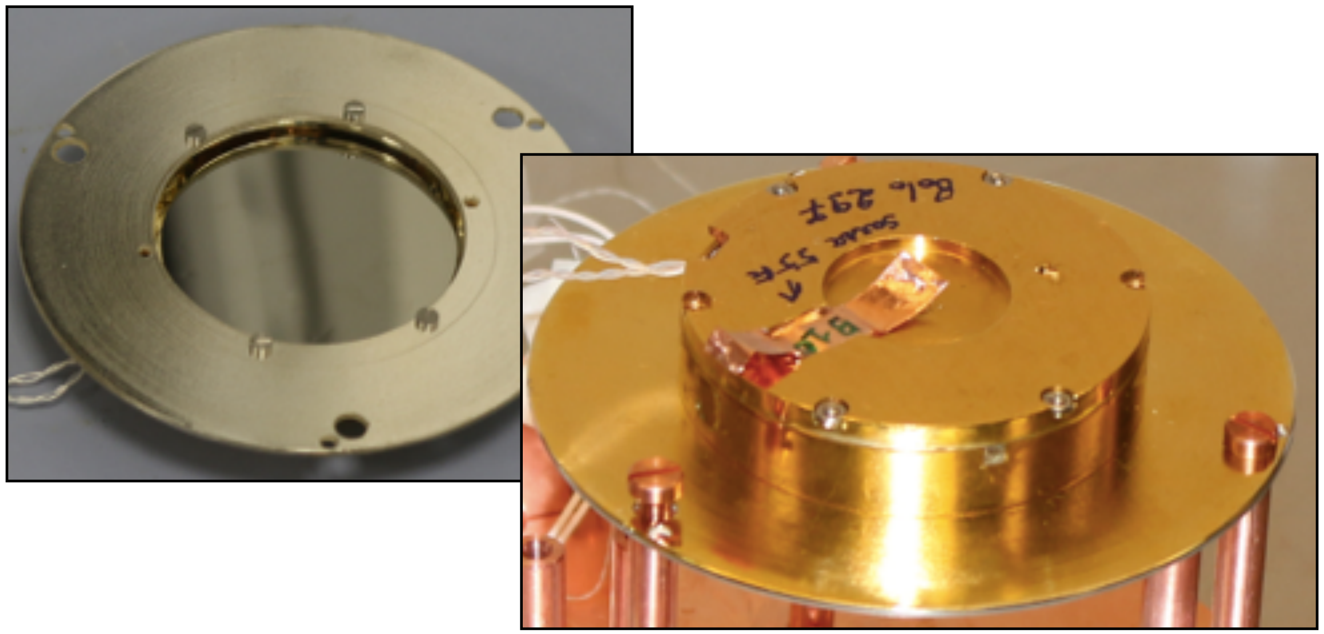


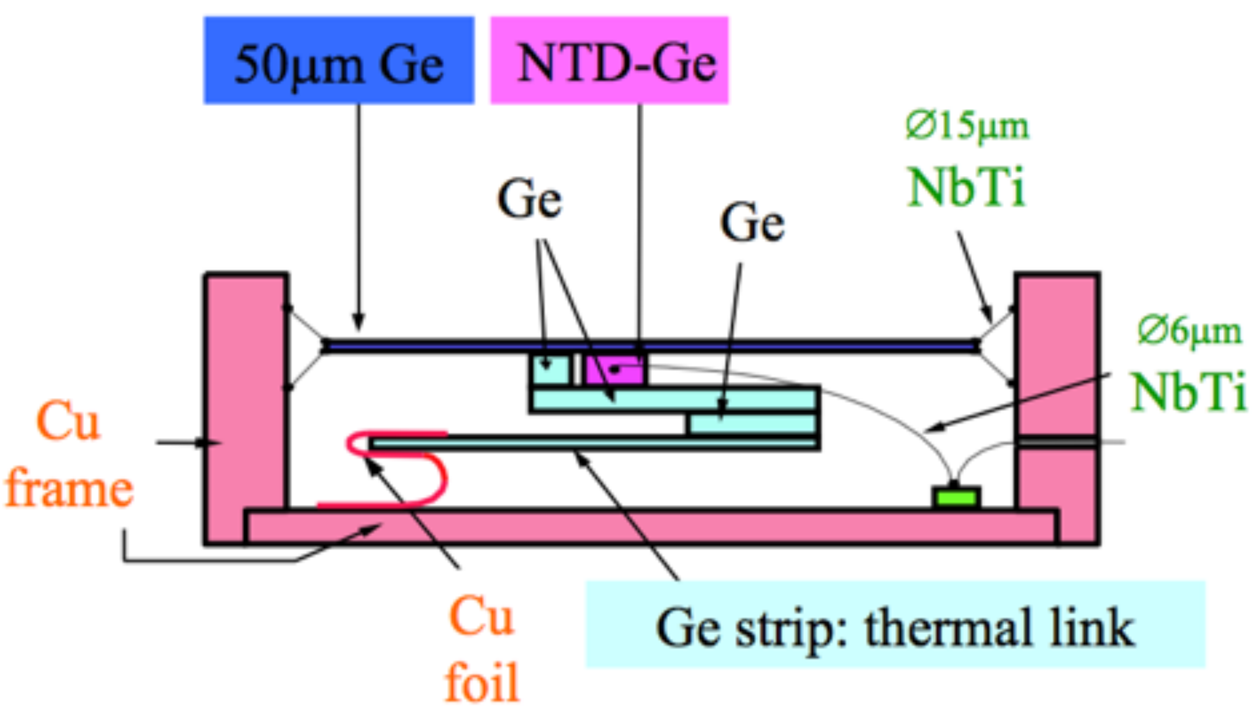


Light detectors (2)

Light detector

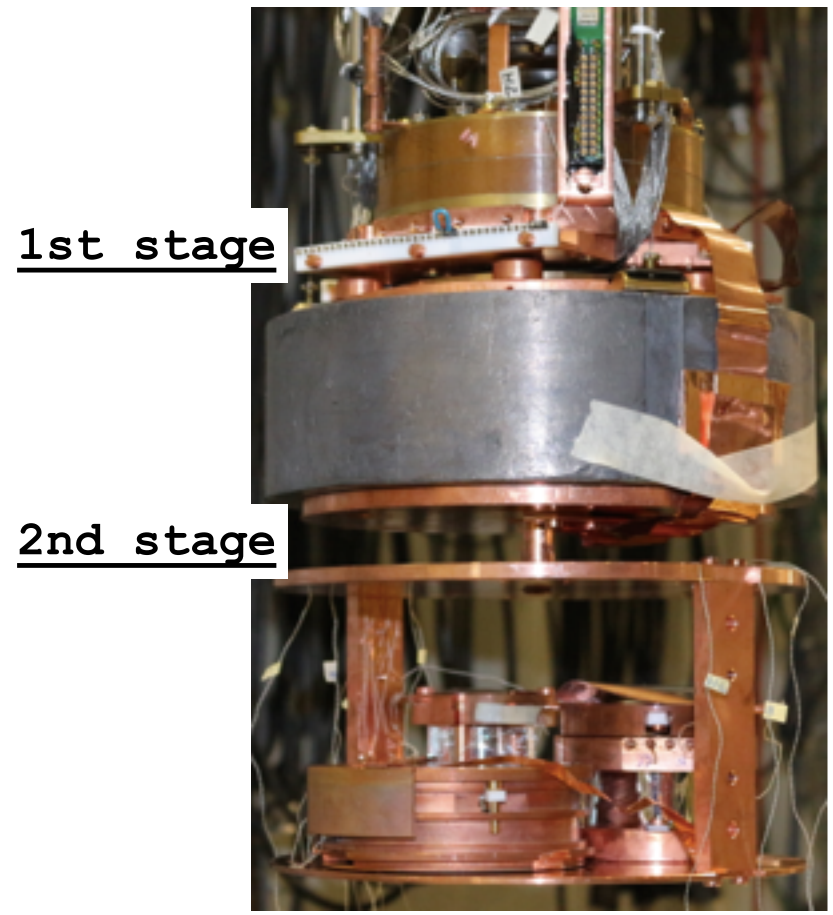
HPGe 40 x 0.05 mm Ge disk





Cryostat

Low-microphonic noise:
two decoupling stages

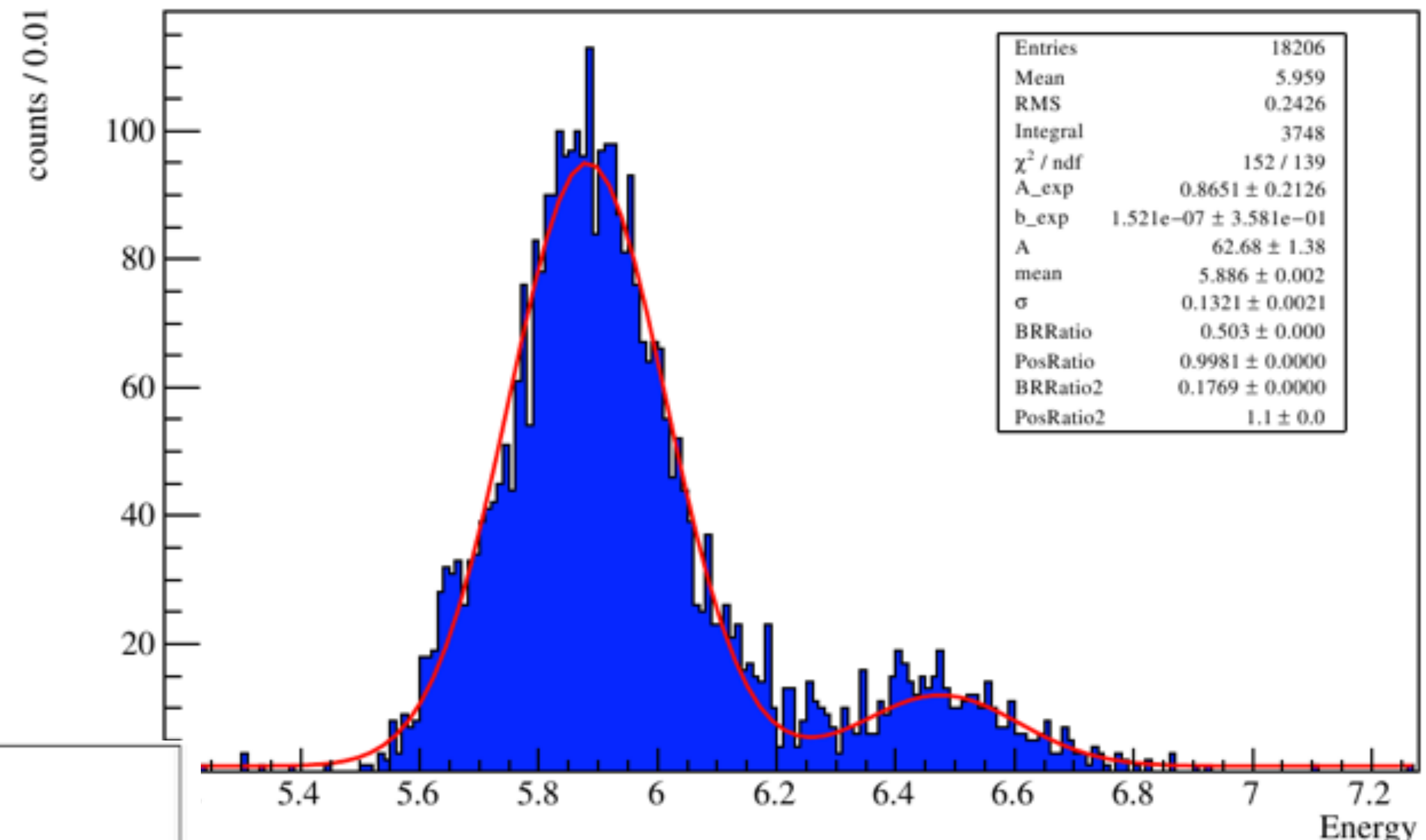


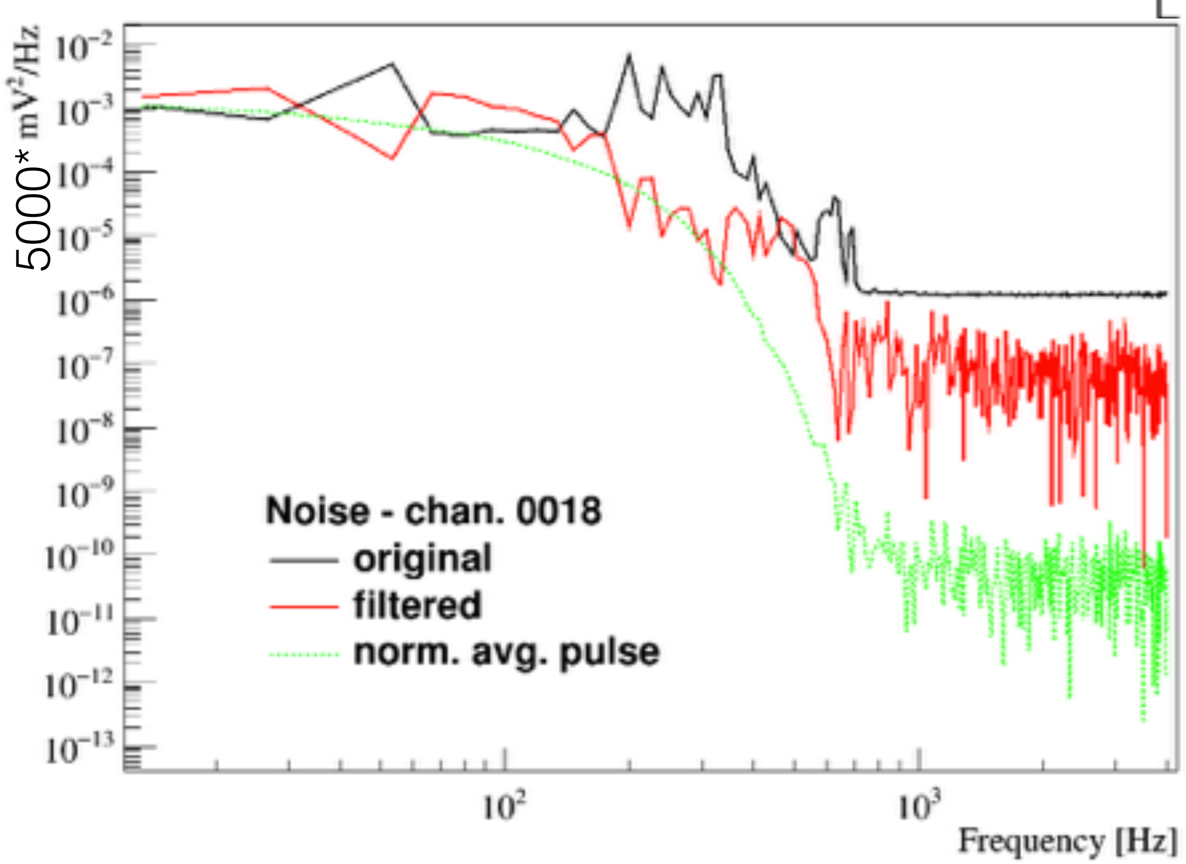
Low-noise electronics:
Cold pre-amplifier @ 110K
Amplifier @ 300K

N. Coron et al.,
Opt. Eng. 43 (7) 1568-1576

Light detectors (3)

Calibration source ^{55}Fe:
^{55}Mn K_α - K_β





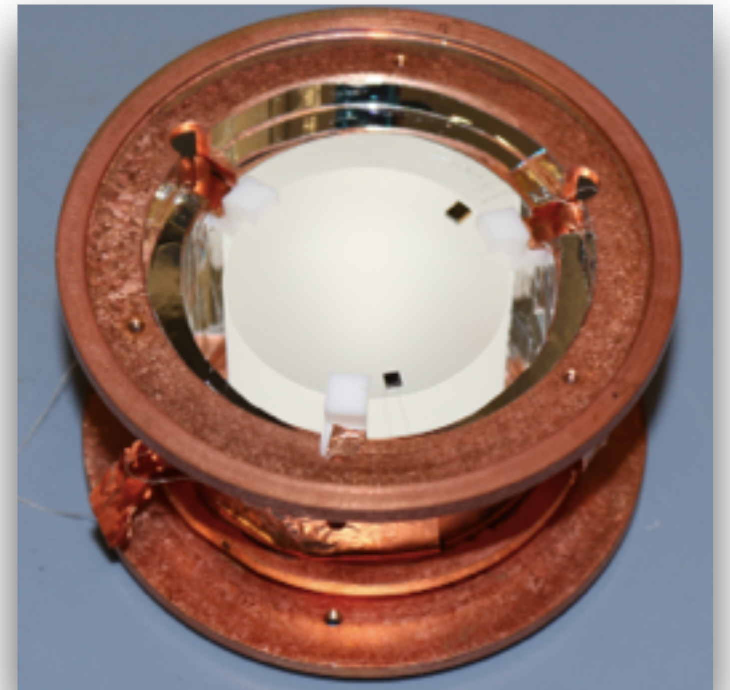
sigma @ 5.9 keV = 132 eV

sigma @ 0 keV = 16 eV

Impressive performance, comparable to TES-based LD

Li_2MoO_4

Candidate: ^{100}Mo



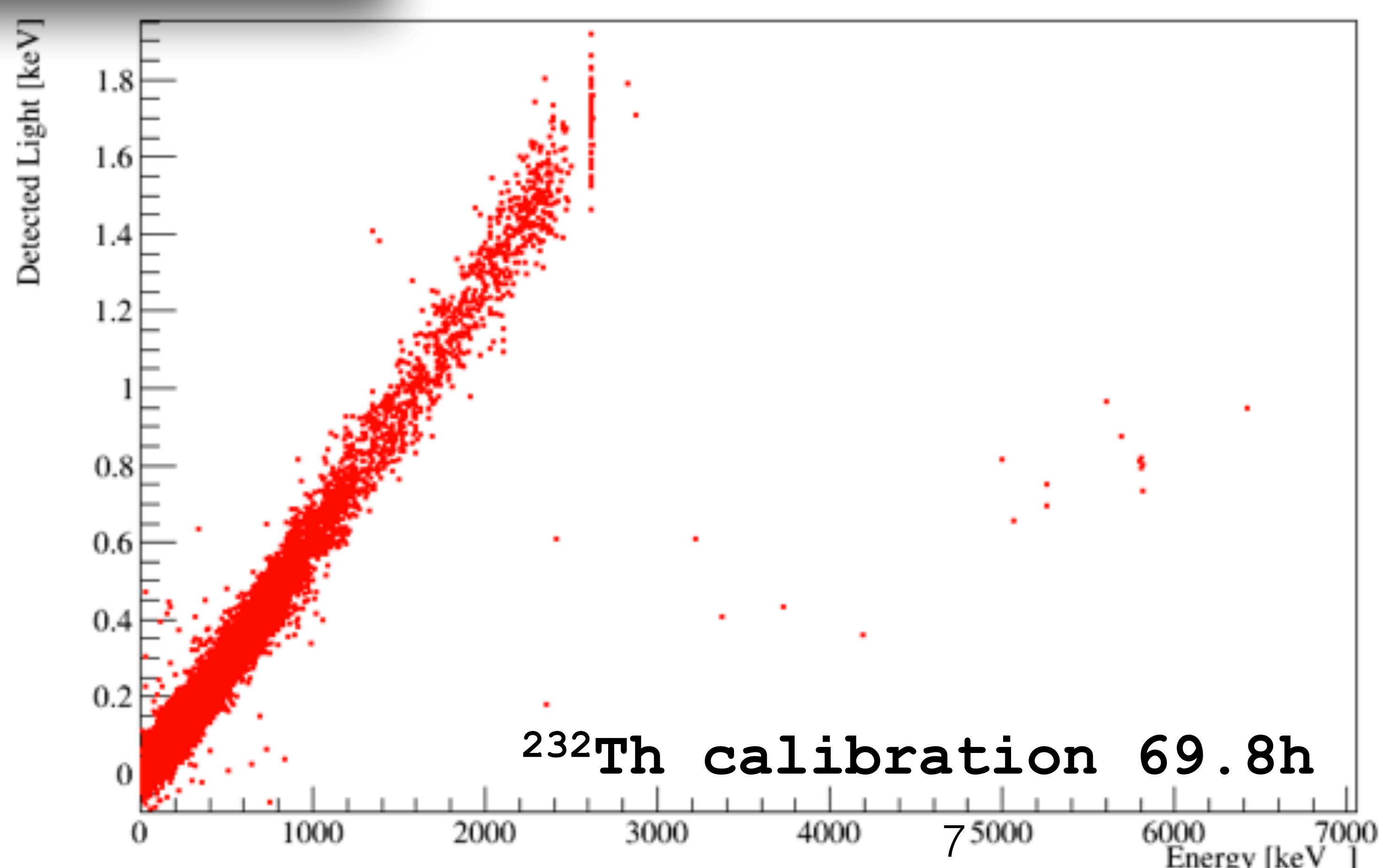
	Q-value [keV]	Useful material	LY [keV/MeV]	QF
Li	3034	55%	~0.5	~0.4

the compound is hygroscopic

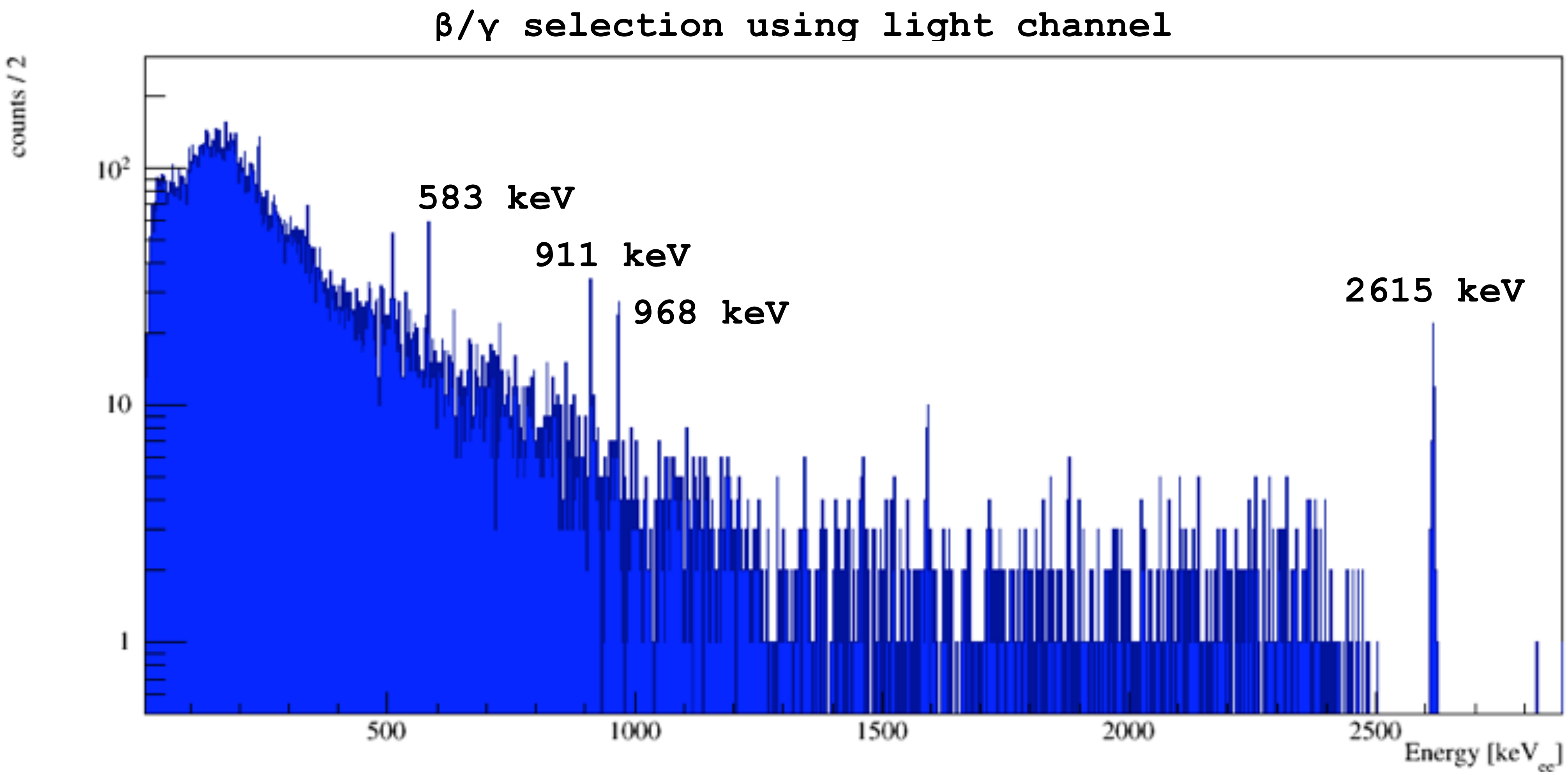
40 x 40 mm
m = 150 g
Background + Calibration

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

hygroscopicity is not a high risk issue



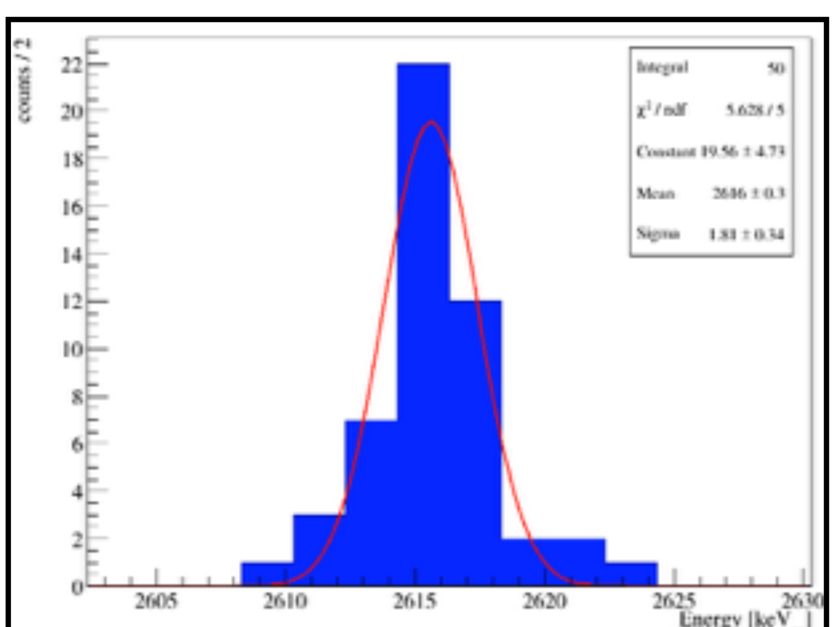
LMO energy resolution

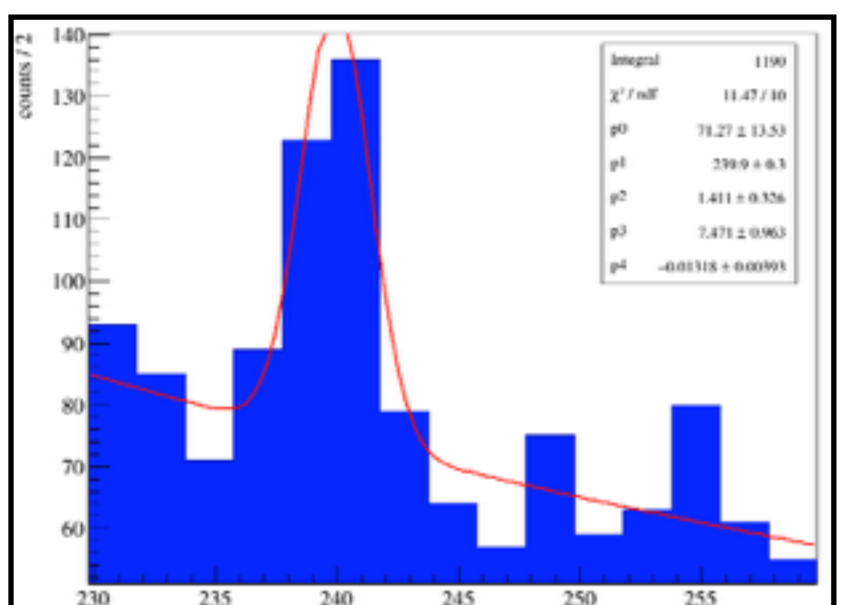


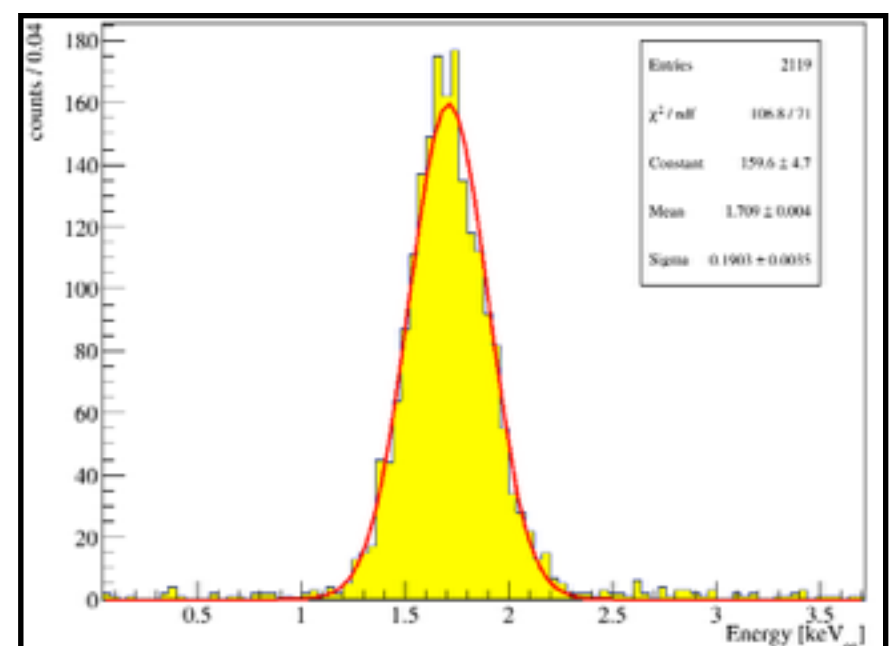
FWHM @ 2.6 MeV = 4.3 keV

FWHM @ 238 keV = 3.3 keV

FWHM @ 0 keV = 447 eV







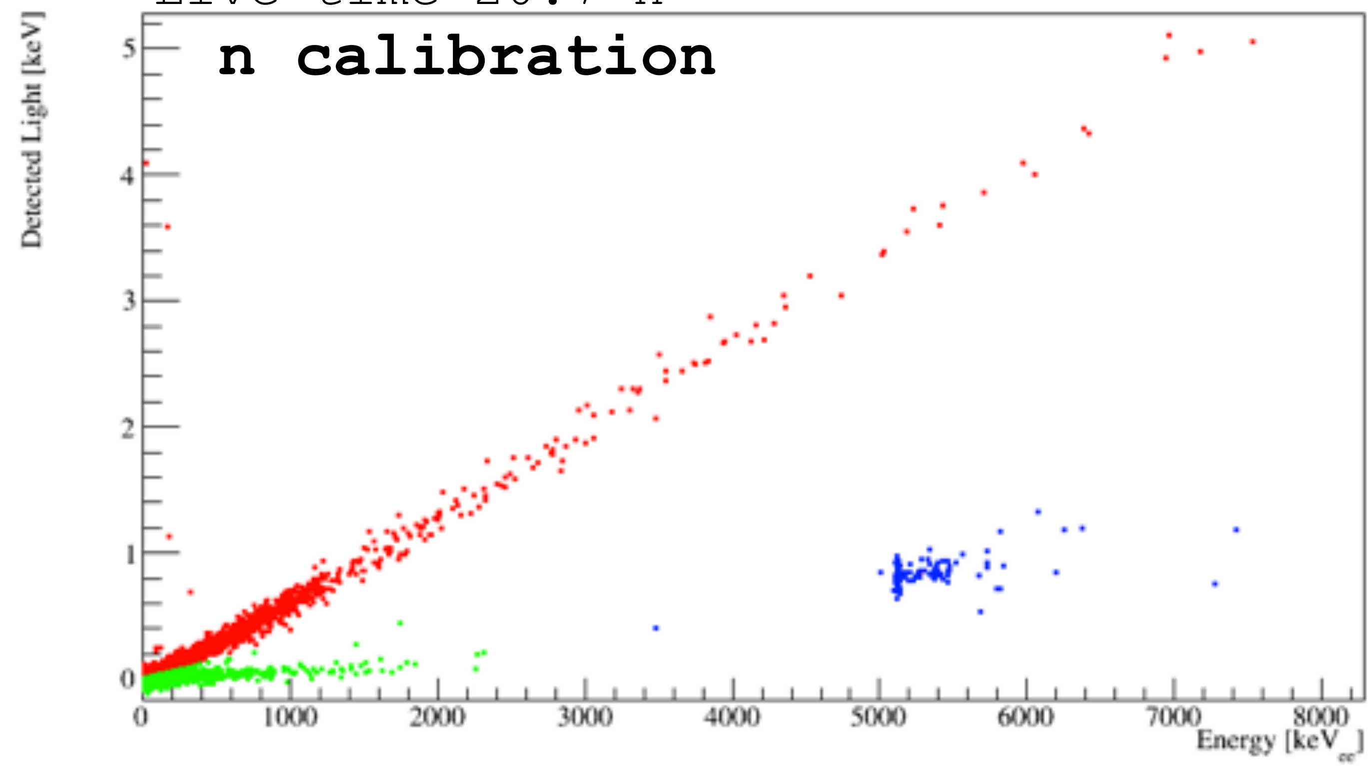
LMO n calibration

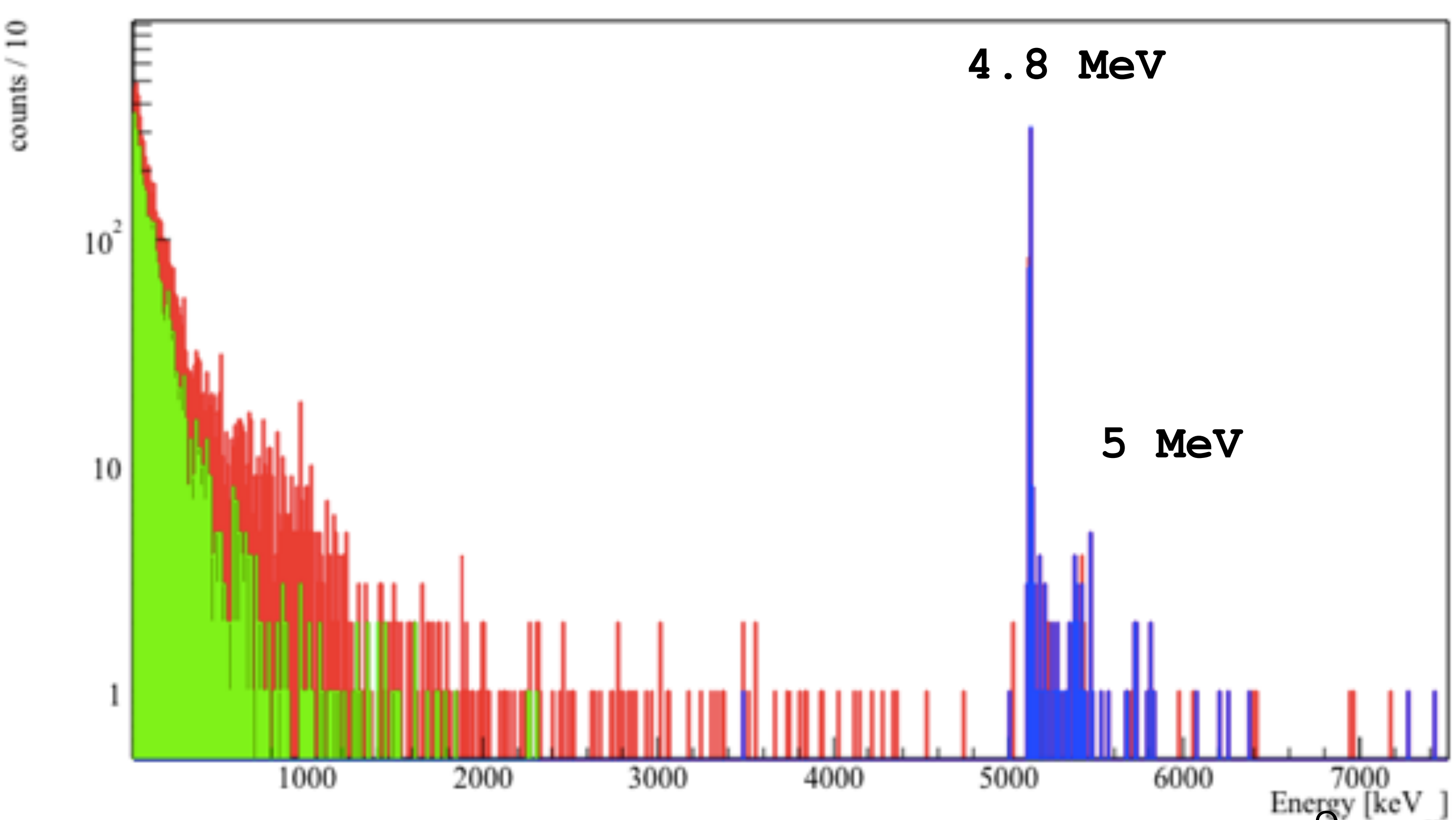
AmBe source faced to the crystal
^{6}Li (7.6% i.a.) allows neutron spectroscopy:

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

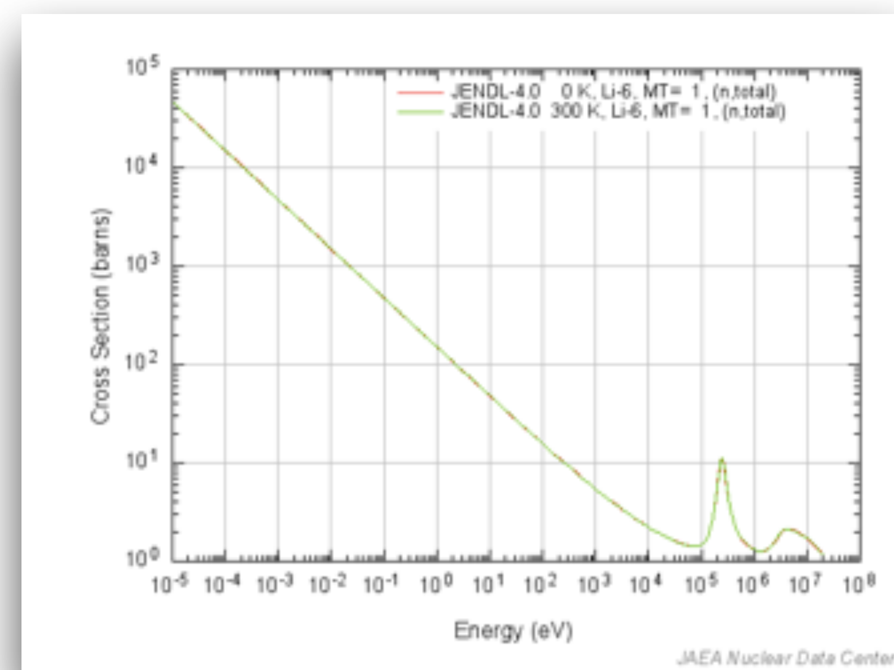
- beta/gamma interactions
- n captures
- n elastic scattering

Live time 20.7 h





^{6}Li absorption XS:
@ 0.025 eV : 1000 b
@ 240 keV : 10 b (resonance)



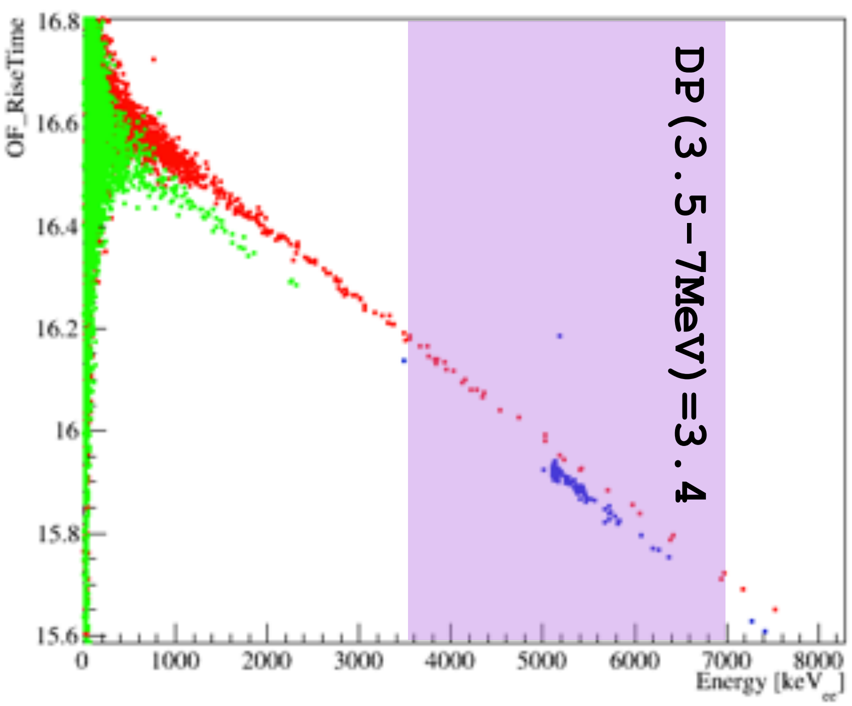
LMO Pulse Shape Analysis

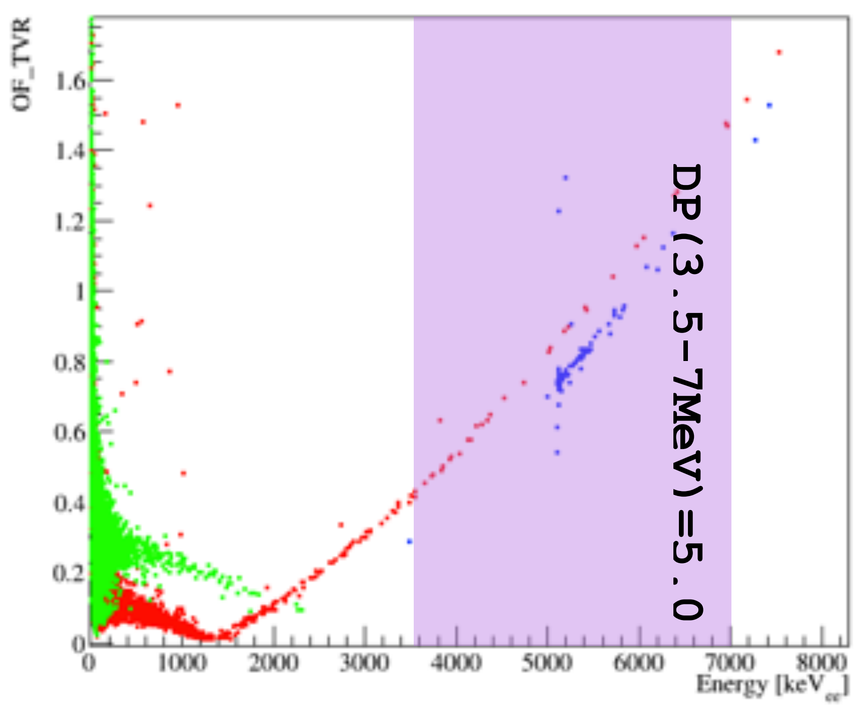
Particle identification is also possible looking at shape of heat pulses (like all the Mo-compounds)

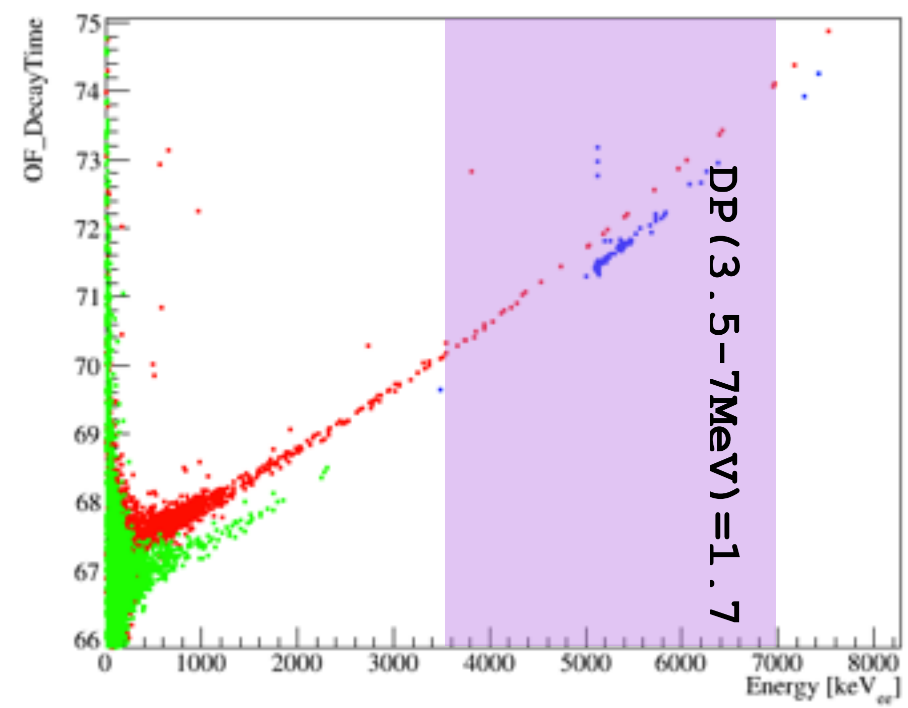
$$DP(E) = \frac{|\mu_\alpha(E) - \mu_{\beta\gamma}(E)|}{\sqrt{\sigma_\alpha^2(E) + \sigma_{\beta\gamma}^2(E)}}$$

Discrimination potential @ 5MeV
(lack of low energy α @ DBD $Q_{\beta\beta}$= 3MeV):

μ: central value of the distribution
σ: width of the distribution



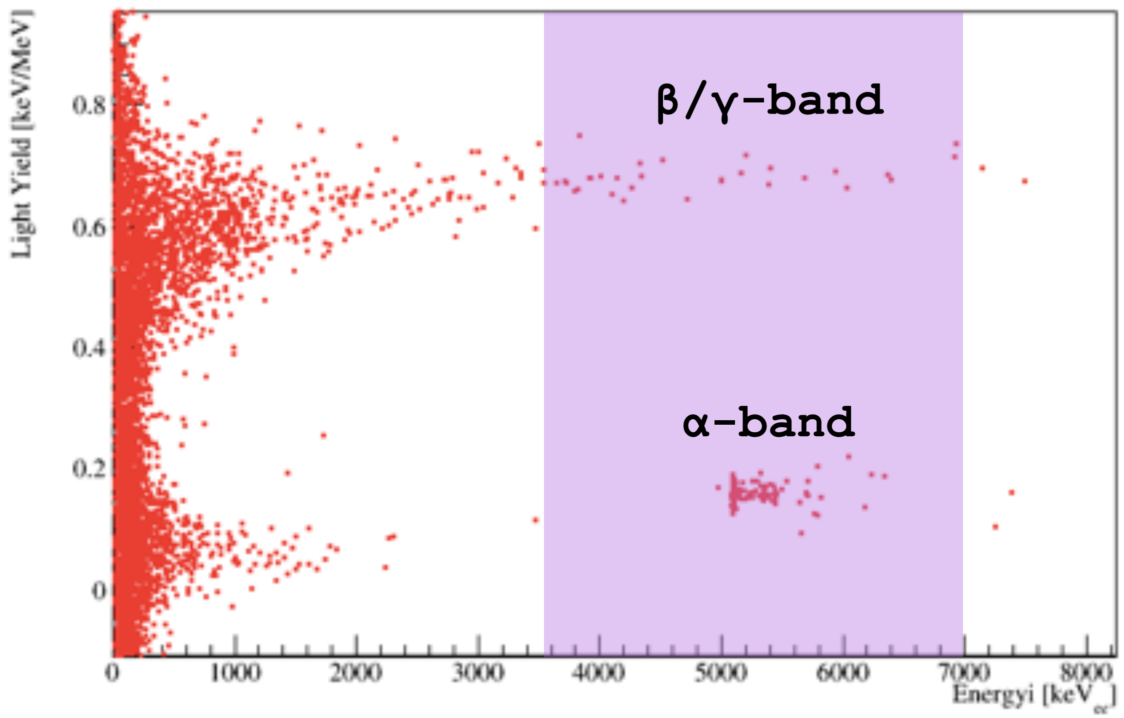


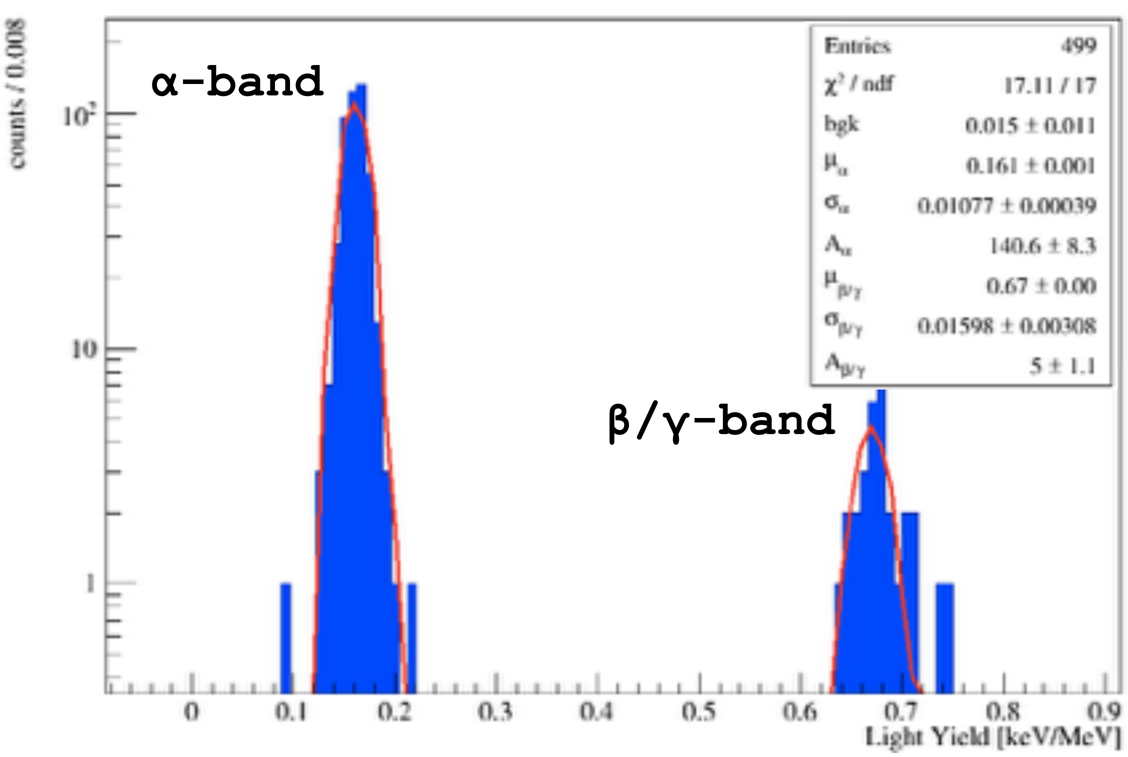


Heat channel is enough to perform a full particle ID!

LMO LY discrimination

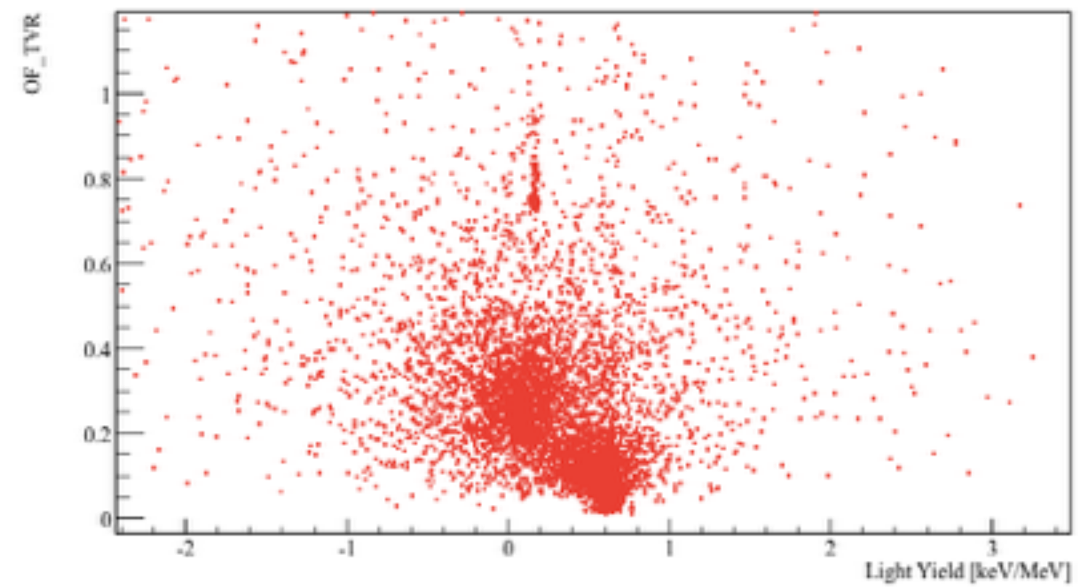
Looking at the light channel:





DP(3.5-7MeV)=30

No strong correlation



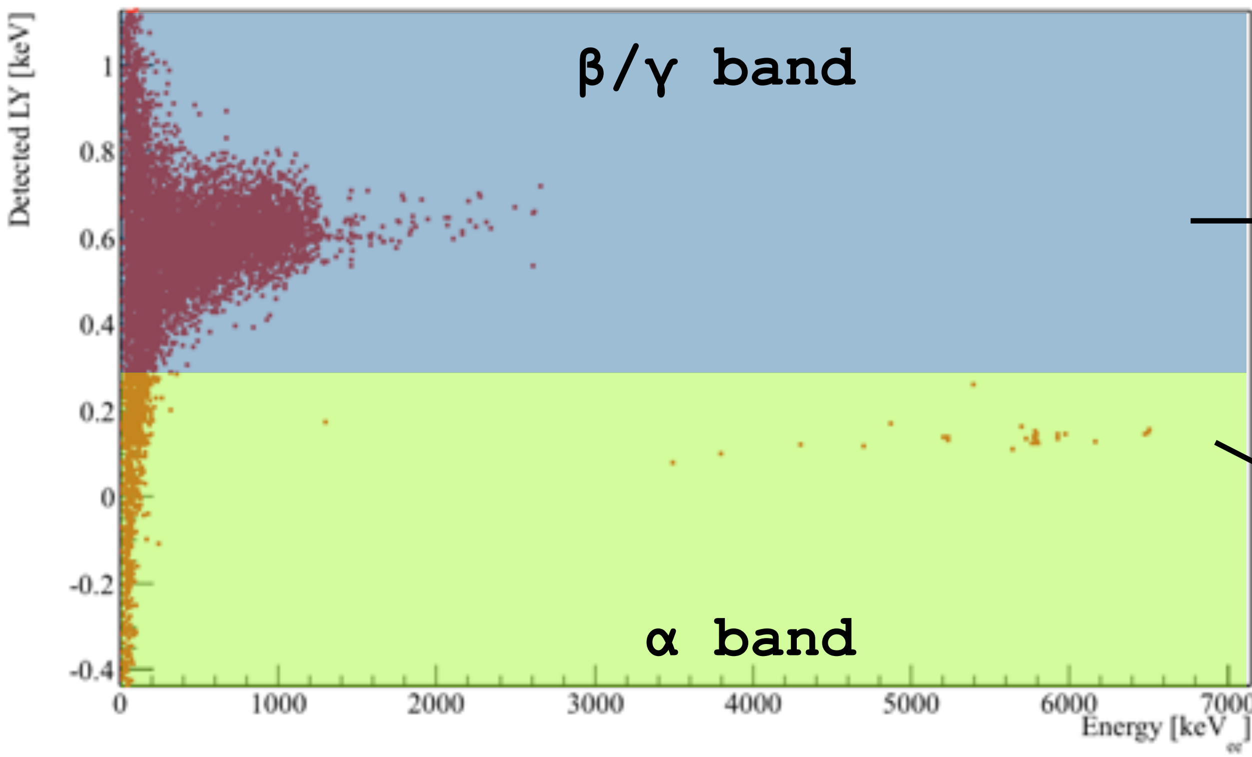
Assuming a 0 correlation between the two variables with the strongest DP, we obtain:

$$DP_{LY} \oplus DP_{OF\_TVR} = 35\ \sigma$$

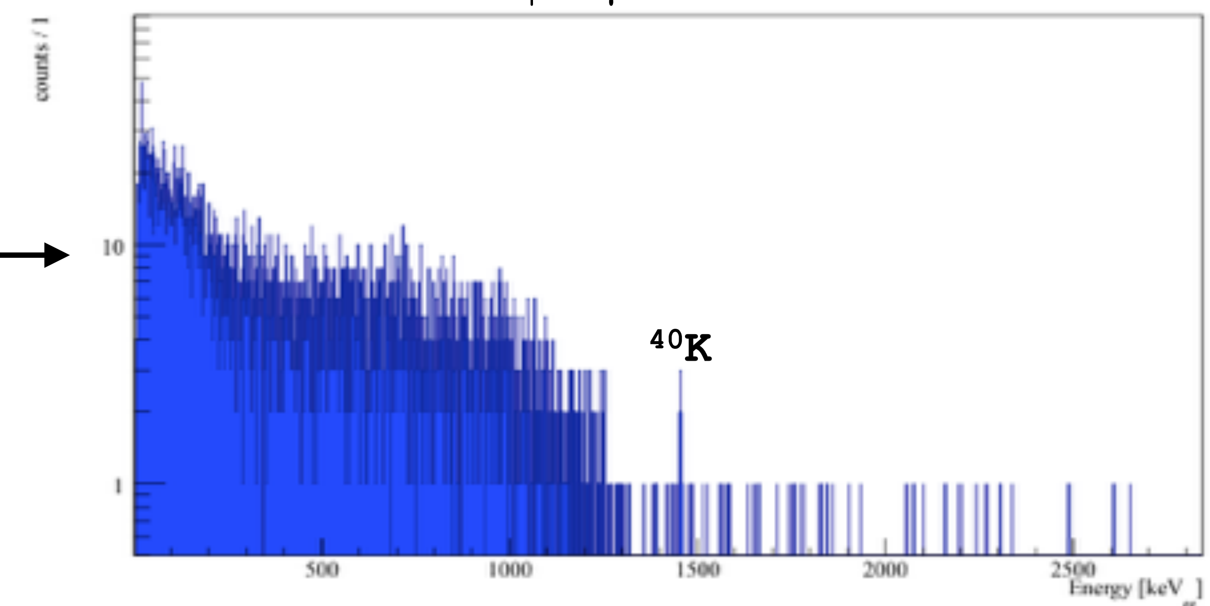
-> <u>Full identification of particle interaction</u>

LMO background

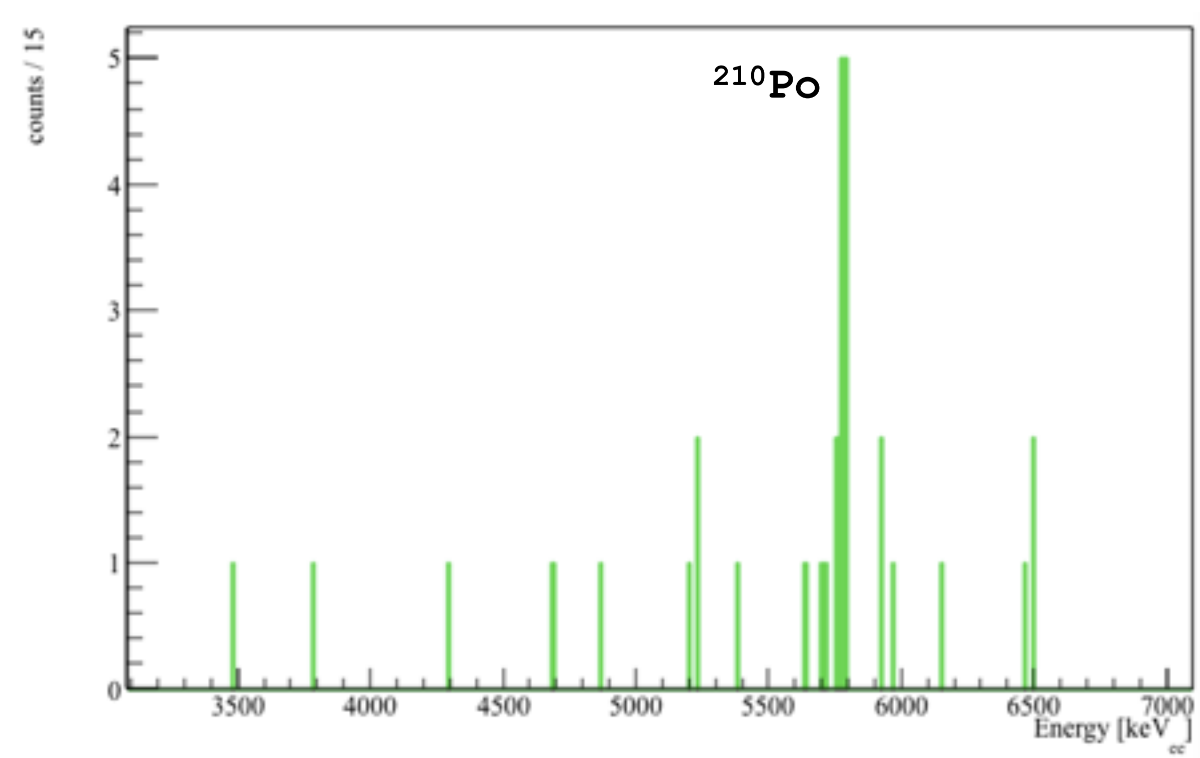
live time 237.5 h



β/γ event selection



α event selection

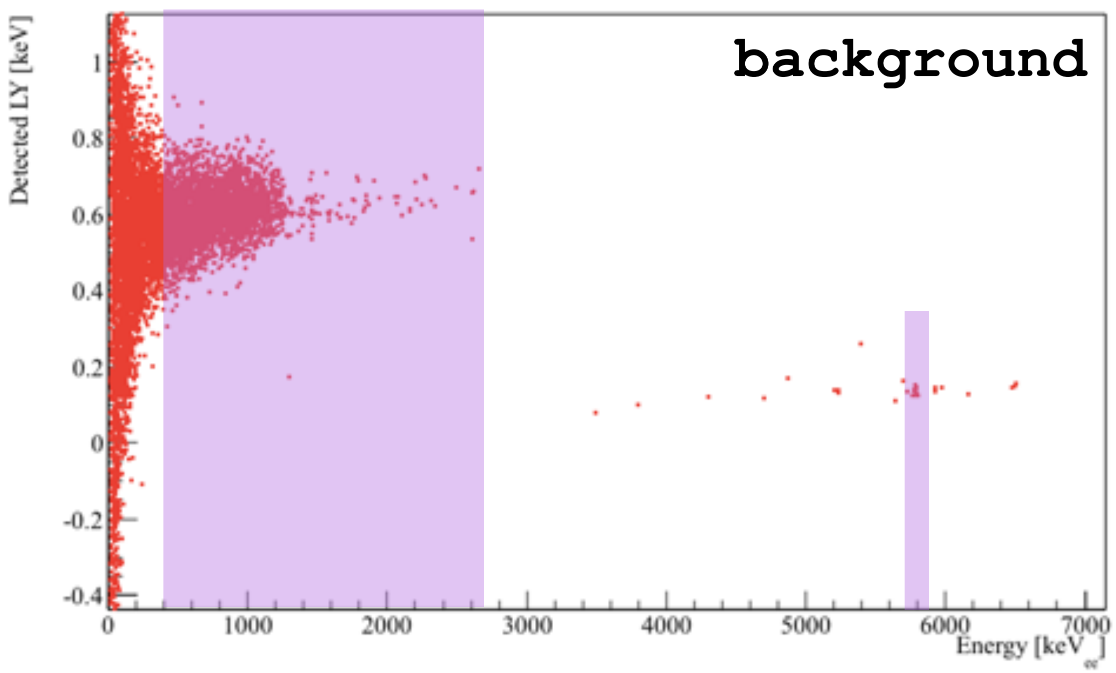


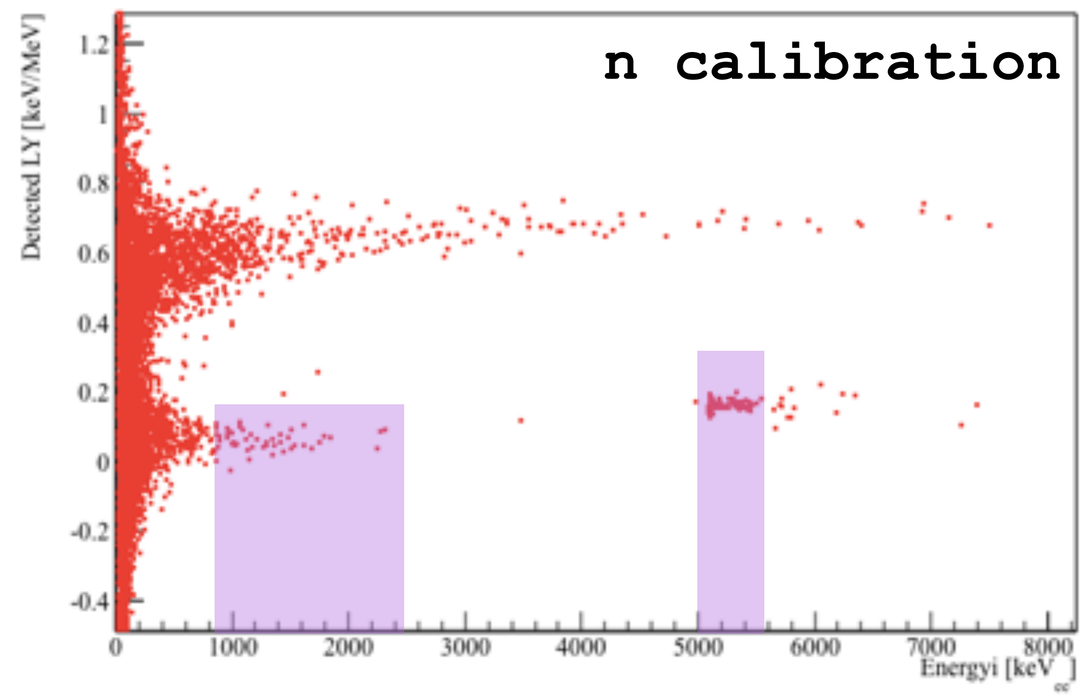
Internal contaminations:

U238		
	U238	<19 uBq/kg
	Ra226	<8.4 uBq/kg
	Po210	93±27 uBq/kg
Th232		
	Th232	<19 uBq/kg
K40		
	K40	~60 mBq/kg

high radiopurity level
even if not optimized

LMO LY & QF$_\alpha$





measured LY(^{210}Po) = 0.13±0.02 keV/MeV$_{ee}$

measured LY(α+^{3}H) = 0.16±0.01 keV/MeV$_{ee}$

measured LY(β/γ) = 0.67±0.01 keV/MeV$_{ee}$

measured LY(n) = 0.06±0.02 keV/MeV$_{ee}$

QF$_\alpha$ @ 5.3 MeV = 0.20±0.03

LMO Comparison

JINST
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Development of a Li_2MoO_4 scintillating bolometer for low background physics

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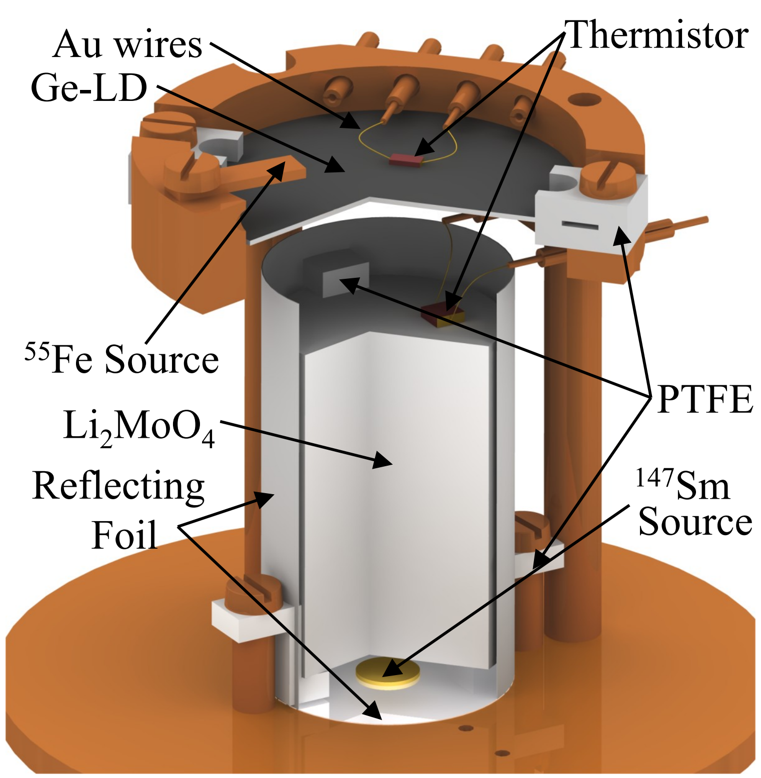


OLD	**NEW**
m = 33 g	m = 150 g
$QF_\alpha(^{210}Po)=0.42$	$QF_\alpha(^{210}Po)=0.20$
$LY_{\beta/\gamma}=0.43$ keV/MeV	$LY_{\beta/\gamma}=0.67$ keV/MeV
^{232}Th: <94 uBq/kg	^{232}Th: <19 uBq/kg
^{238}U: <107 uBq/kg	^{238}U: <19 uBq/kg
^{226}Ra: <107 uBq/kg	^{226}Ra: <8.4 uBq/kg
DP_{LY}(1-2.3 MeV)=3	DP_{LY}(3.5-7 MeV)=30
FWHM @ ^{40}K=4keV	FWHM @ ^{40}K=4keV

Solar axions search

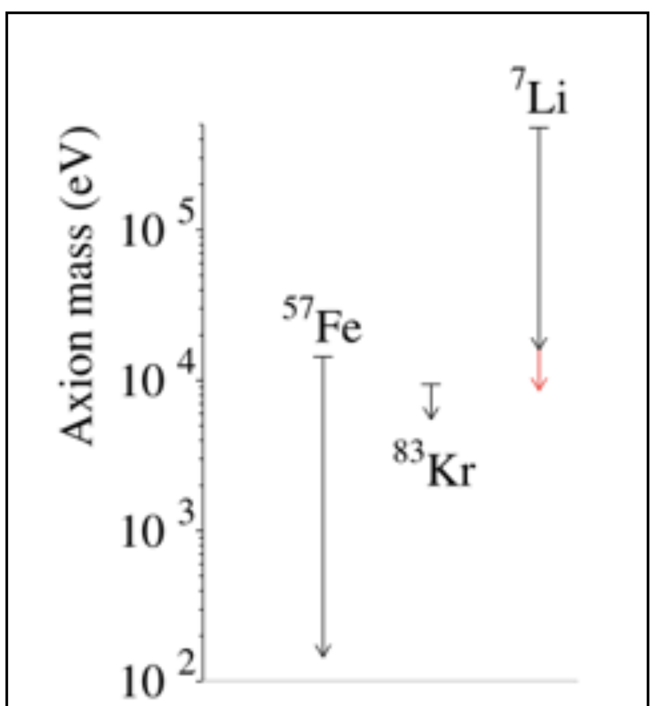
Detection of ^{7}Li solar axions by means of resonant absorption on analogue targets in the labs.

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 v emission at about 478 keV

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



Total number of absorptions:

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

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

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

LMO application axions

If we reverse the equation:

$$N_{abs} = N_{^7Li} \times T \times C^{te} \times \left(\frac{m_a}{1\,eV}\right)^4$$

- N_{abs}: # ^{7}Li axions converted to gamma quanta
- $N_{^7Li}$: # ^{7}Li nuclei in the target
- T: live time of the measurement
- C^{te}: C^{te} (BR, doppler effect, ε, ..)
- m_a: ^{7}Li solar axion mass

Current best limit:

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

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

Specifics

- HP-Ge measurement(ε~2%)
- LiF crystal ~130g$_{^7Li}$
- T ~ 4000h
- bkg in ROI 250 c/keV
- FWHM in ROI 1.6 keV

Our measurement:

$$m_a < 9\,keV \; @ \; 90\,C.L.$$

Specifics

- Bolom. measurement(ε~98%)
- Li_2MoO_4 crystal ~5.5g$_{^7Li}$
- T ~ 240h
- bkg in ROI 5 c/keV
- FWHM in ROI 2.3 keV

CONCLUSIONS

- Promising candidate for DBD search of ^{100}Mo:

  => excellent particle discrimination
  heat & light channels
  => excellent intrinsic radiopurity
  better material selection (K40 & Ra226)

  => good size

- High efficiency in neutron detection

  => applications in WIMP searches

- Good candidate for ^{7}Li solar axions