experiment

Anastasiia Zolotarova on behalf of the CROSS collaboration

Background goals: CUPID and beyond

Pure bolometer: CUORE
Background dominated by surface α's

Reject α's

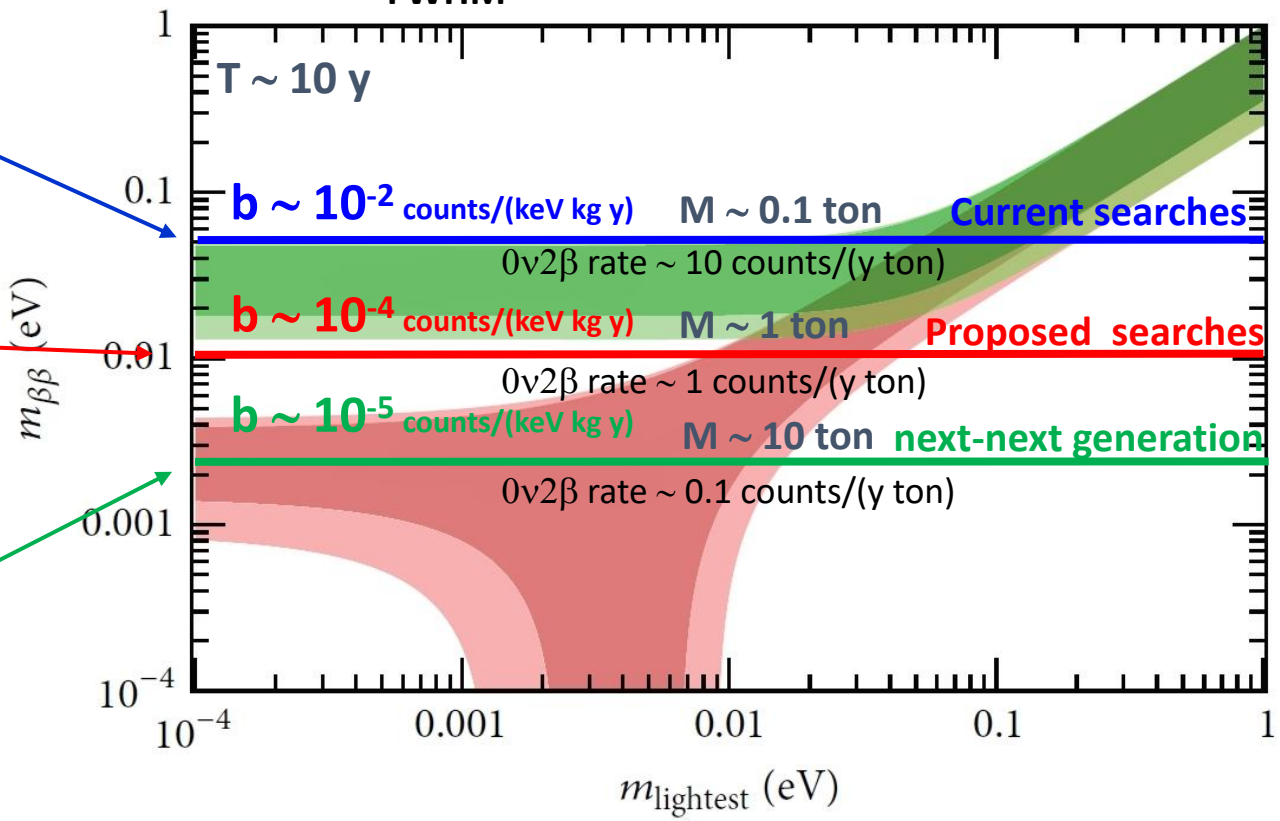
Scintillating bolometer: CUPID
Important contribution from surface β's

Reject surface α's & β's

Surface sensitive bolometer: CUPID-like experiment with CROSS technology

Bkg rate in ROI ~ b × M × ΔE_{FWHM}

ΔE_{FWHM} ~ 5 keV for bolometers



β surface radioactivity

^{238}U chain $\rightarrow$ ^{214}Bi β Q value: 3.3 MeV
(^{210}Tl Q value: 5.5 MeV- 0.02% ^{214}Bi)

$^{214}Bi \xrightarrow{\beta} {}^{214}Po \xrightarrow{\alpha} {}^{210}Pb$
164 μs

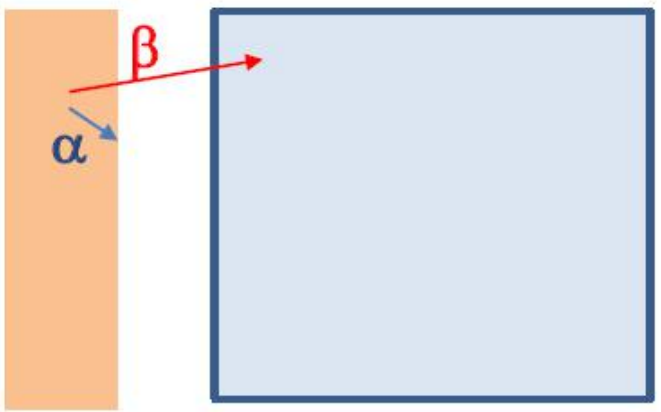
Harmless in the crystal bulk
Mixed α/β event

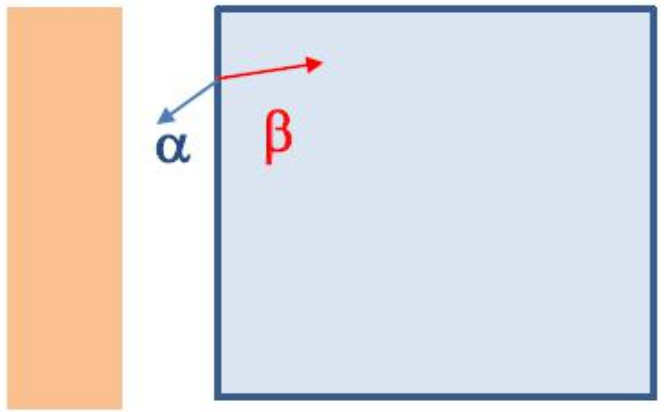
^{232}Th chain $\rightarrow$ ^{208}Tl β Q value: 5.0 MeV

$^{212}Bi \xrightarrow{\alpha} {}^{208}Tl \xrightarrow{\beta} {}^{208}Pb$
3.053 min

Under control in the crystal bulk
Delayed coincidence

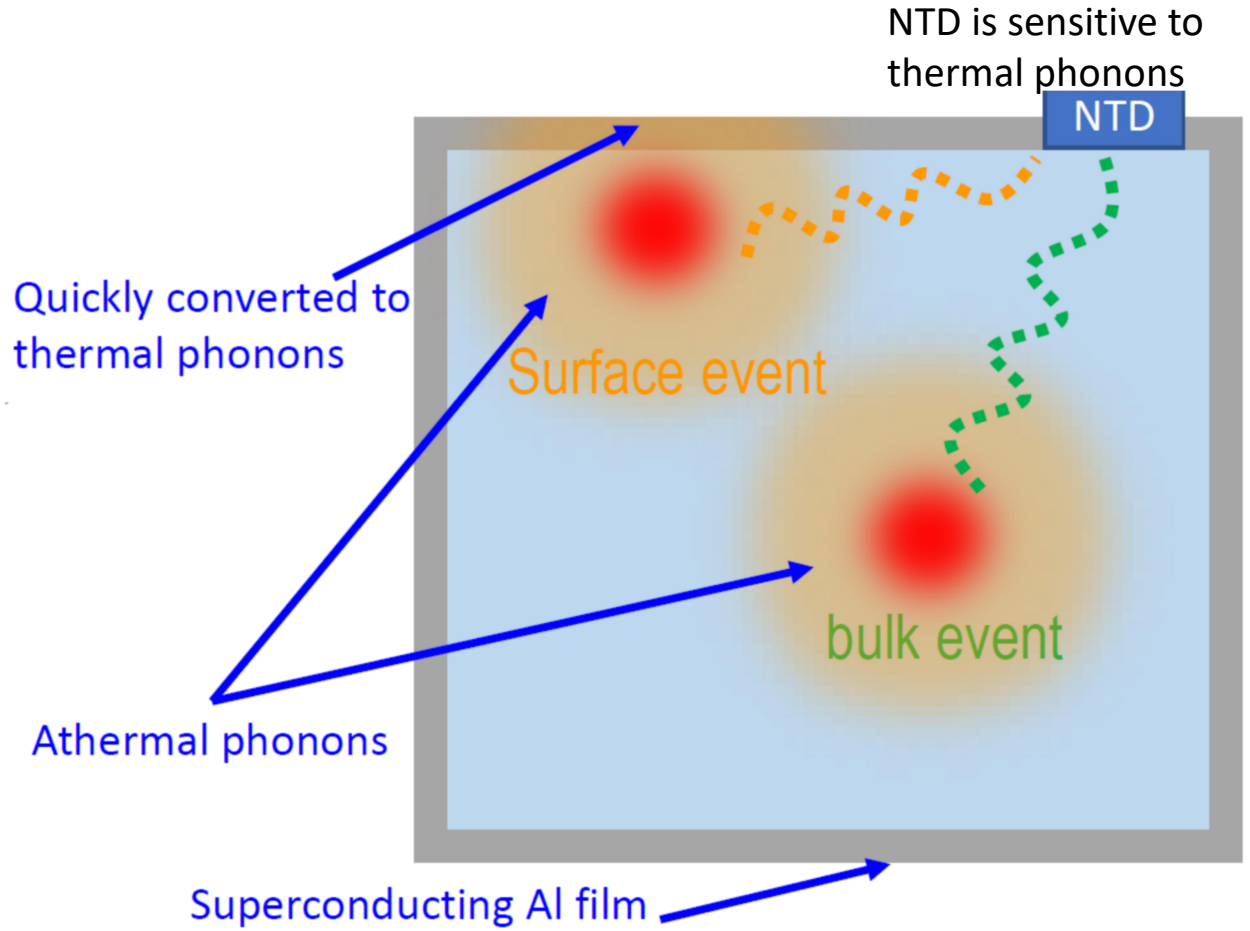
These processes become challenging at the surface $\rightarrow$ it may happen that α escape detection and β is (partially) absorbed

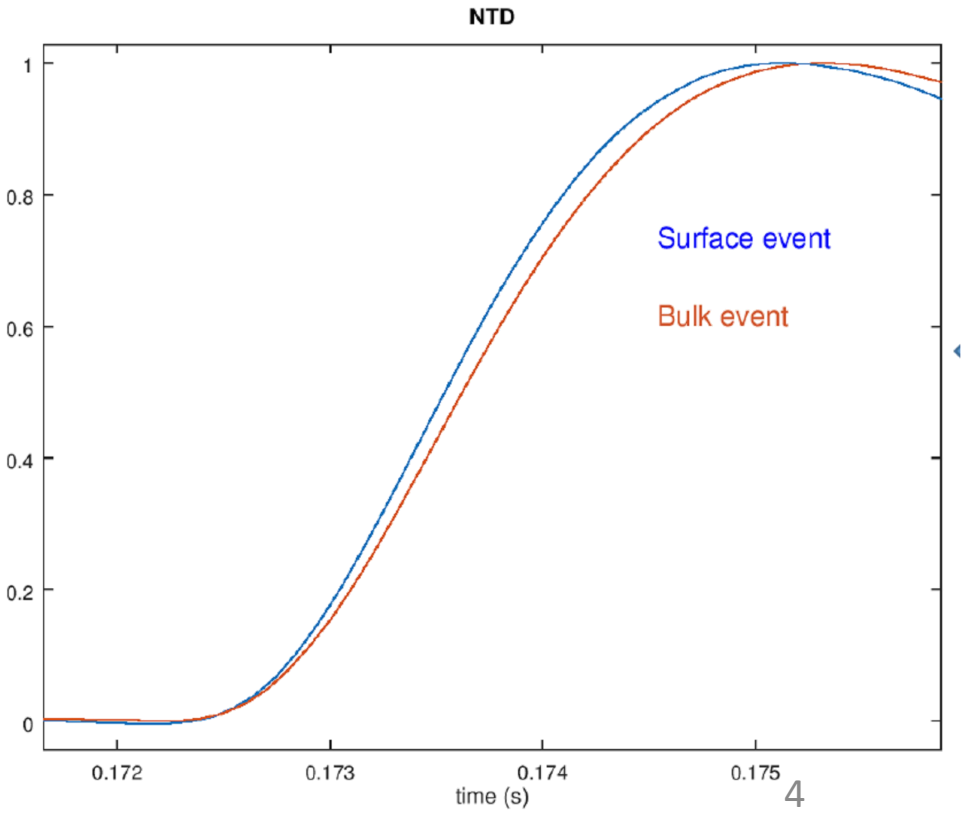




CROSS technology: surface sensitivity

Bolometers with superconducting films to identify near-surface events
(No light detector is needed and advanced particle ID)





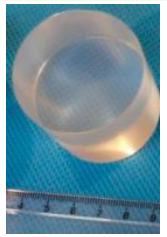
CROSS isotopes and bolometers

^{100}Mo - first choise: **Q = 3034 keV > 2615 keV** **A.I.: 9.7%**

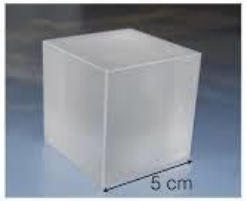
^{130}Te - kept as an option: **Q = 2527 keV < 2615 keV** **A.I.: 34%**

Crystals:

Li_2MoO_4 - basic choise for CUPID



TeO_2 - CUORE compound



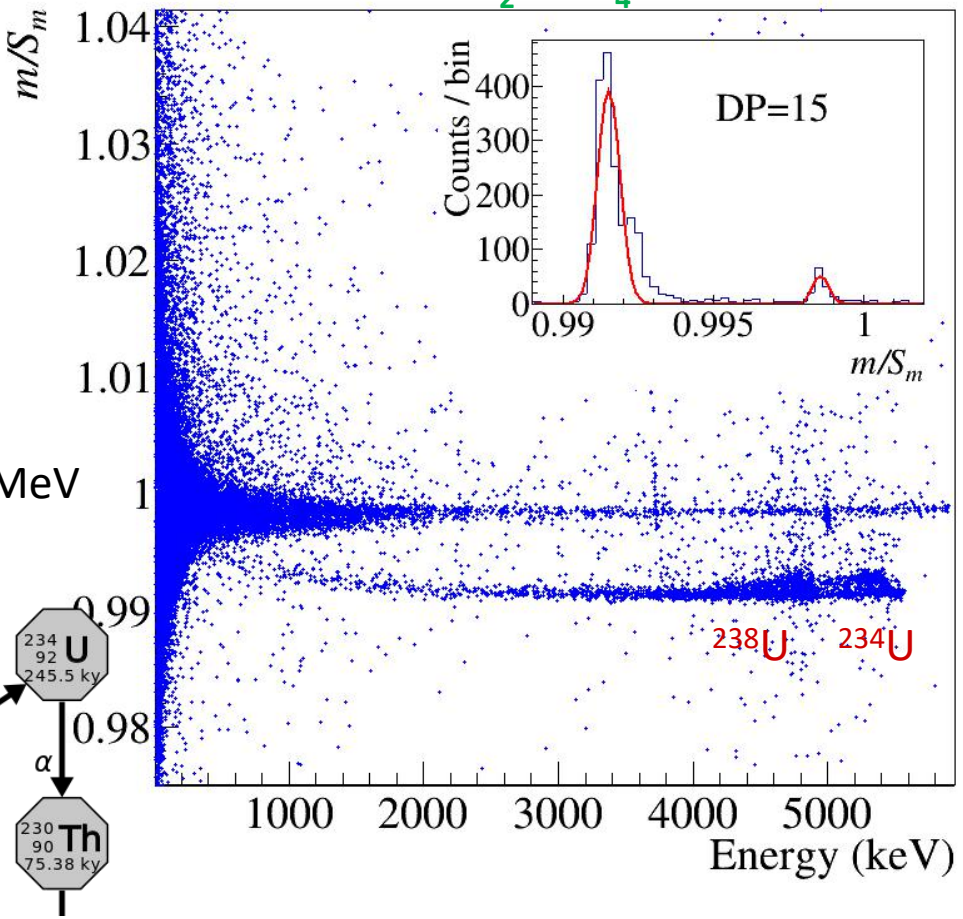
Excellent bolometric properties
High radiopurity
Extensively tested

10.1007/JHEP01(2020)018

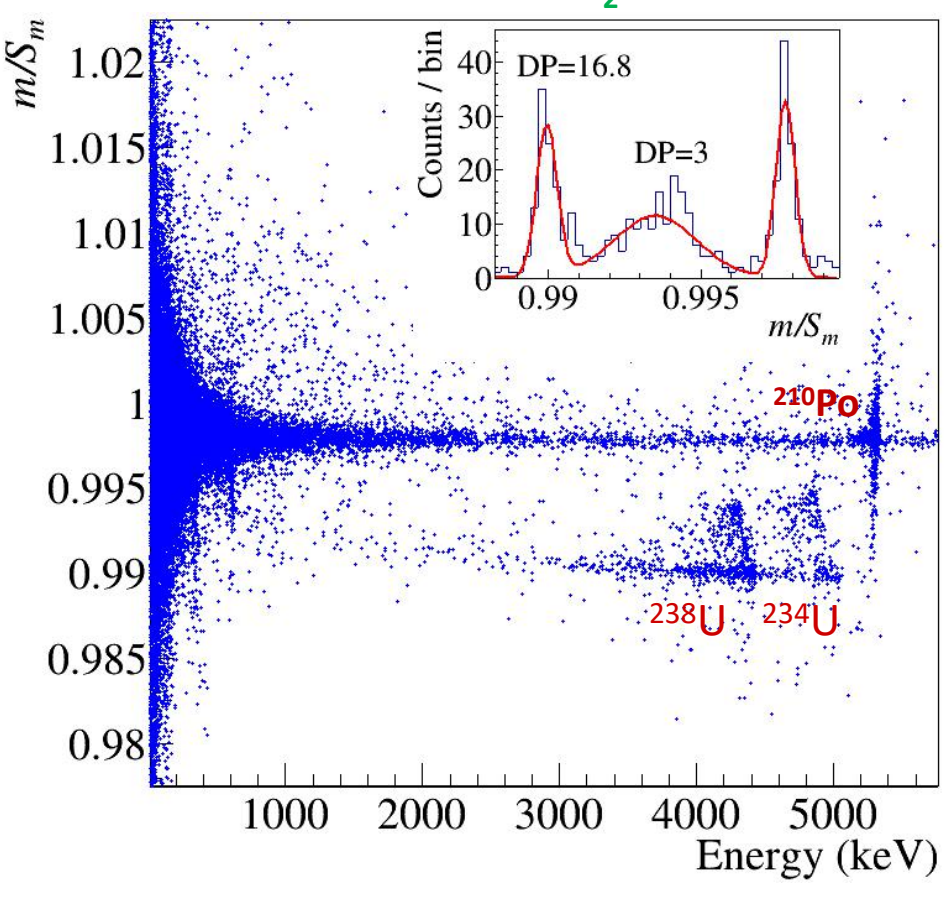
CROSS prototypes: 10 um Al coating

- Prototypes are tested in aboveground tests (IJCLab) with coating on one face, directed to U source

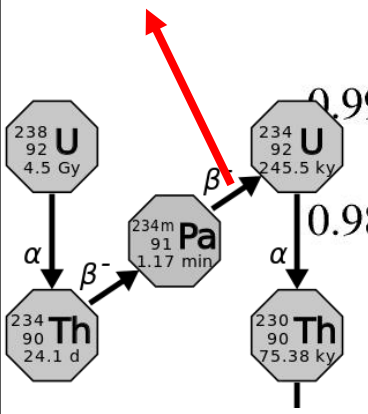
Li_2MoO_4



TeO_2



Endline 2.2 MeV



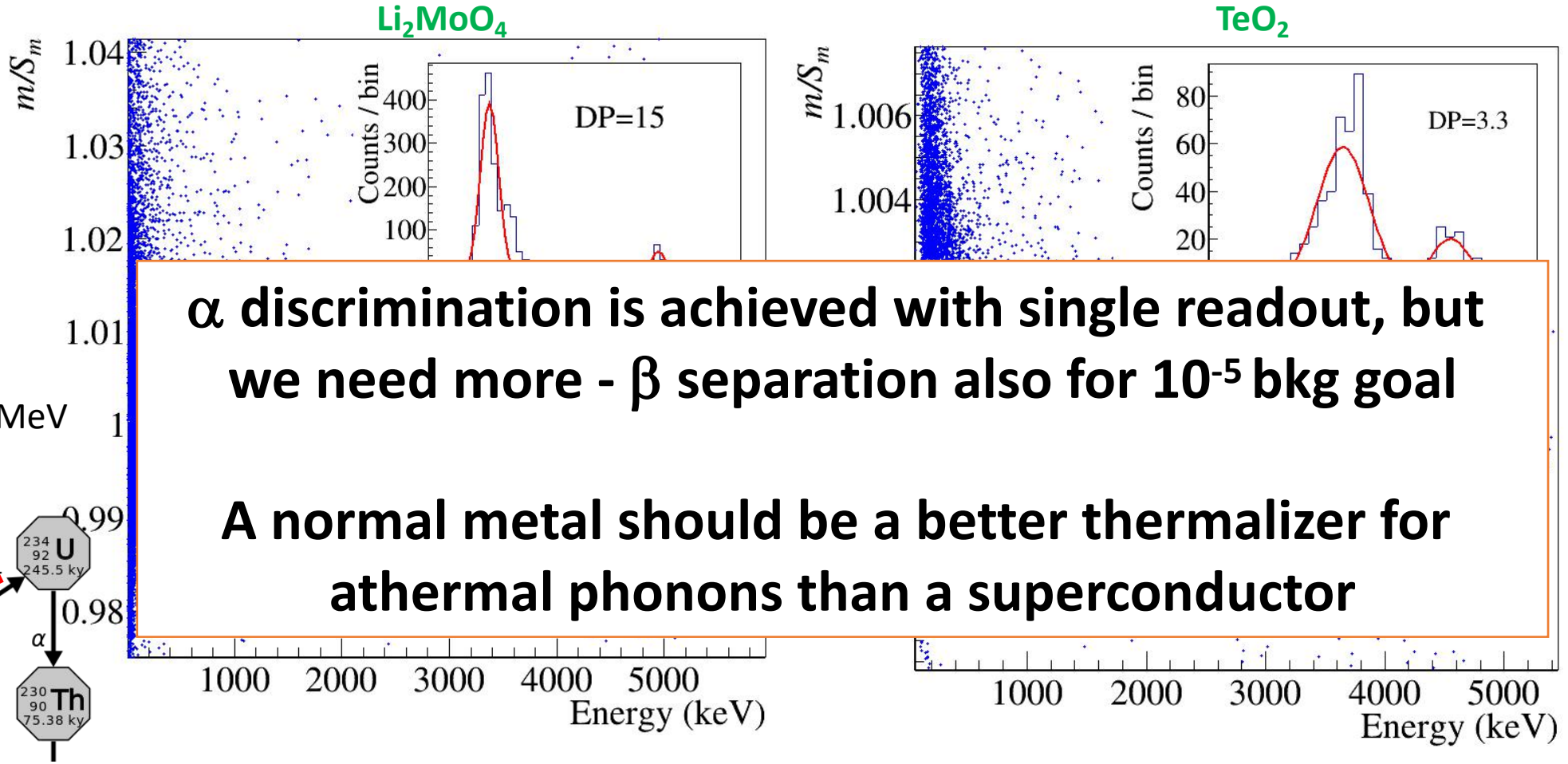
Discrimination power:

$$DP=\frac{|\mu_{\beta/\alpha}-\mu_{\alpha}|}{\sqrt{\sigma^2_{\beta/\gamma}+\sigma^2_{\alpha}}}$$

10.1007/JHEP01(2020)018

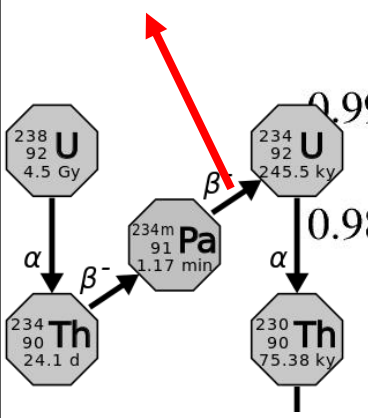
CROSS prototypes: 10 um Al coating

- Prototypes are tested in aboveground tests (IJCLab) with coating on one face, directed to U source



α discrimination is achieved with single readout, but we need more - β separation also for 10^{-5} bkg goal

A normal metal should be a better thermalizer for athermal phonons than a superconductor

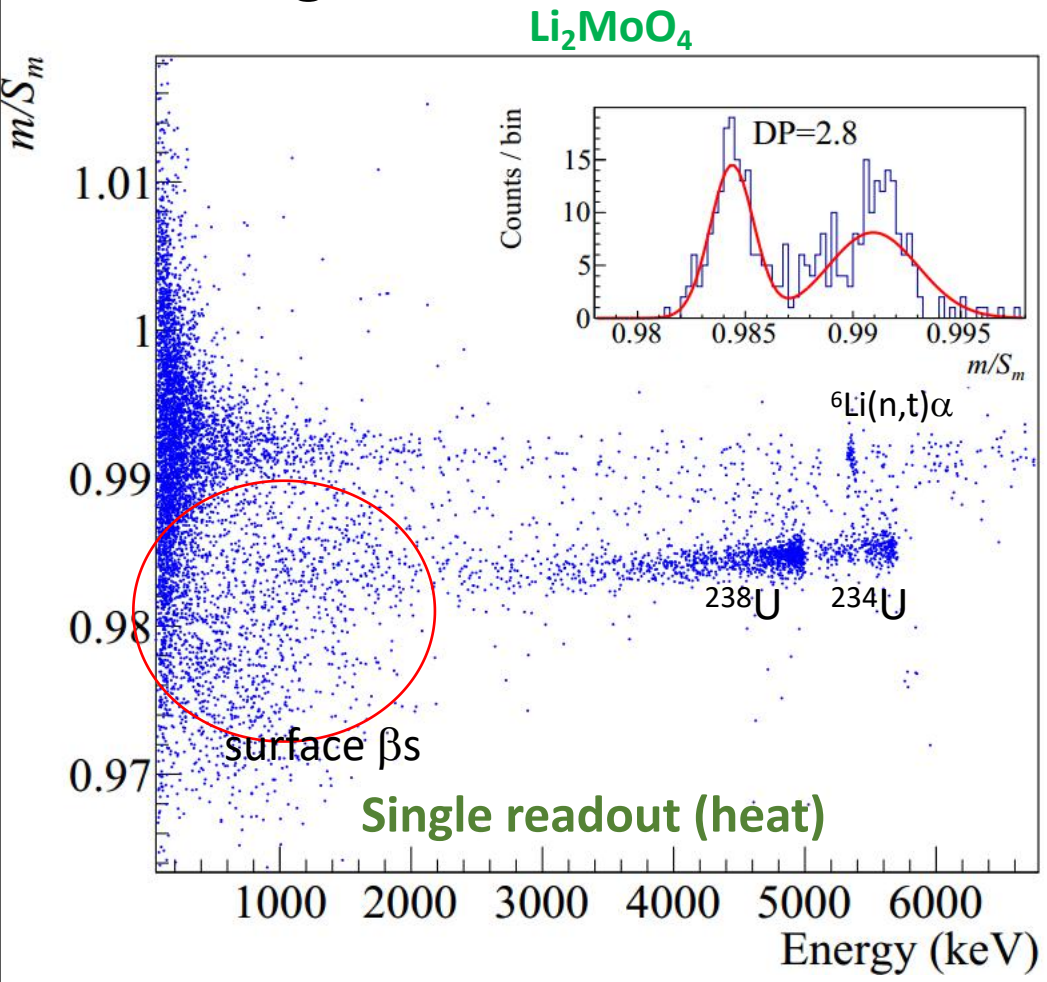


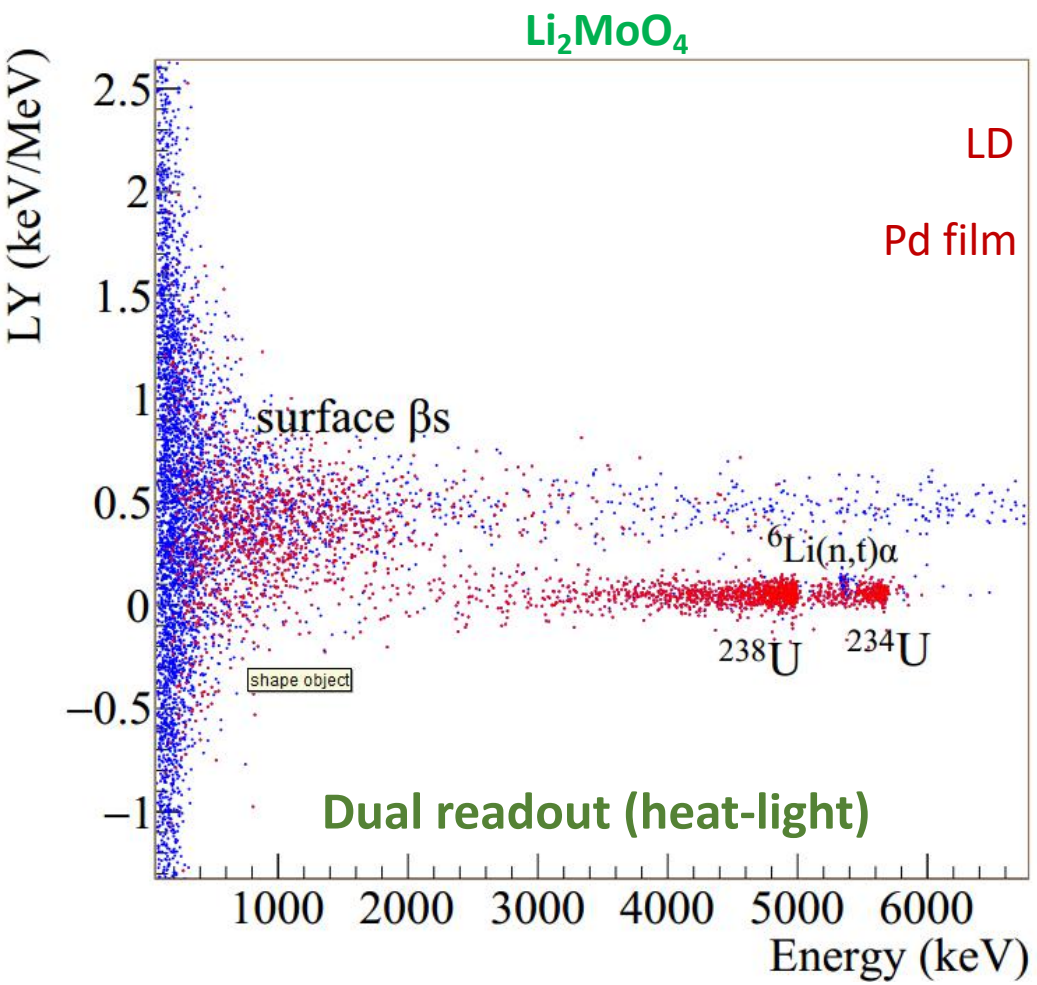
Discrimination power:

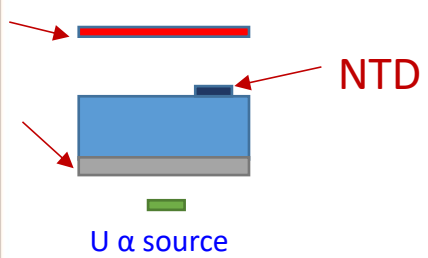
$$DP=\frac{|\mu_{\beta/\alpha}-\mu_{\alpha}|}{\sqrt{\sigma^2_{\beta/\gamma}+\sigma^2_{\alpha}}}$$

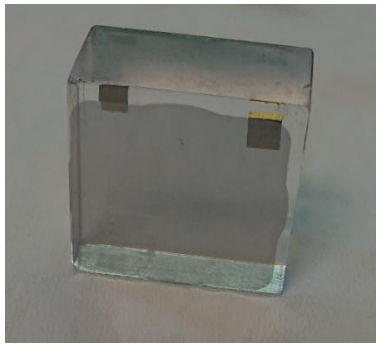
CROSS prototypes: 10 nm Pd coating

- Light detector is used in R&D measurements as additional PID tool



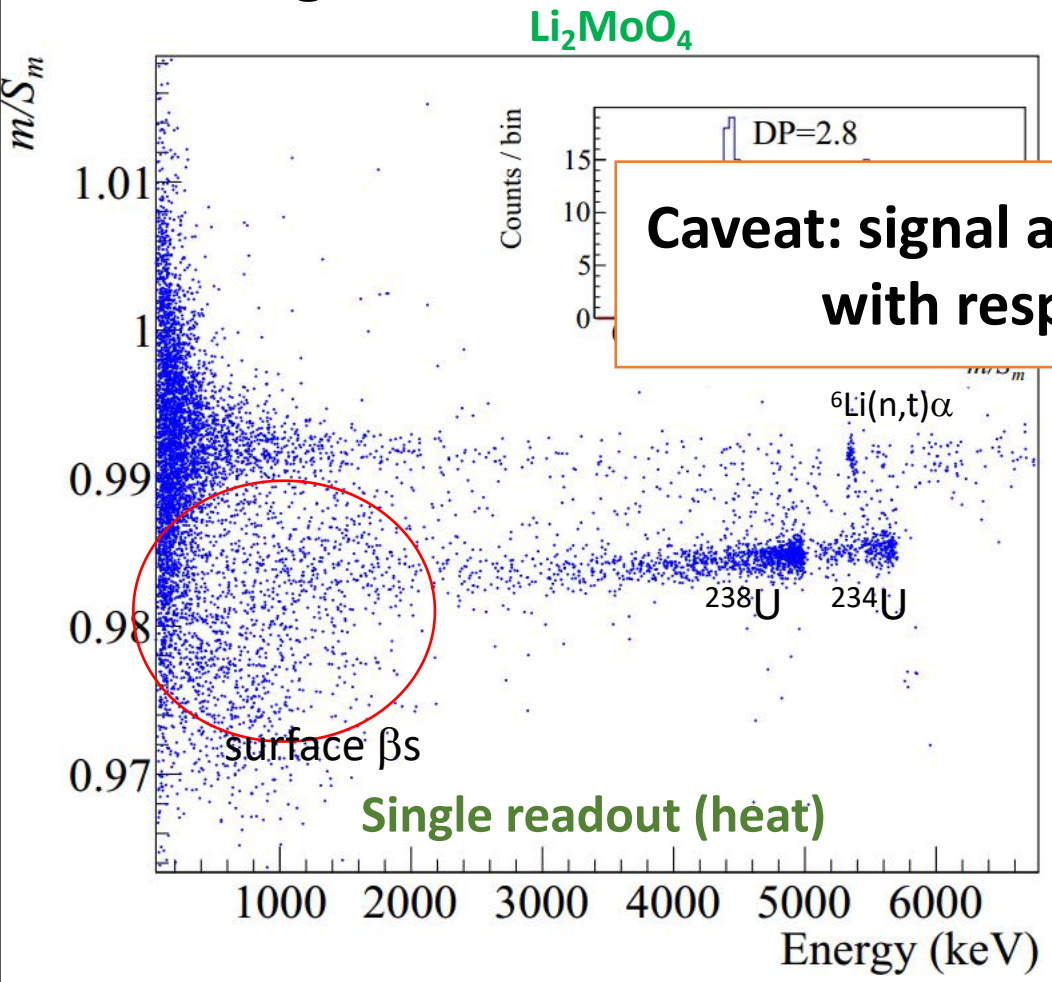




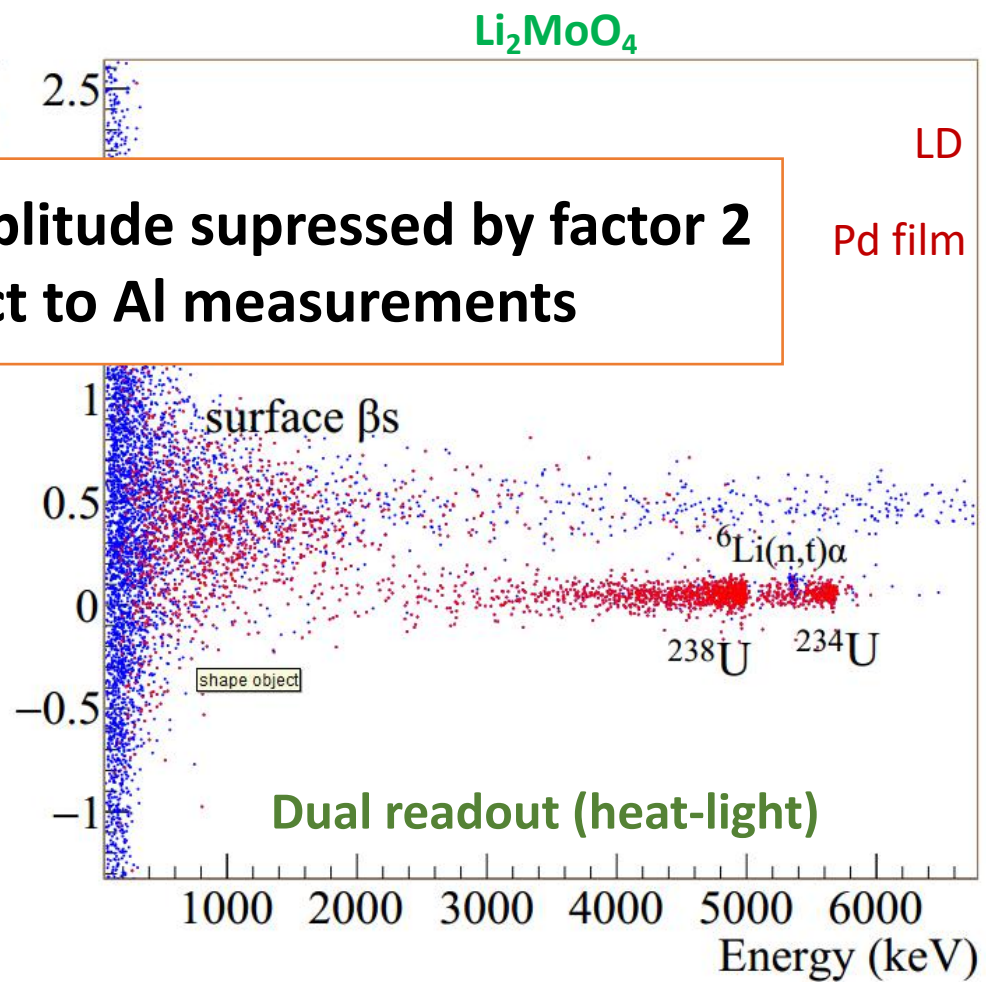


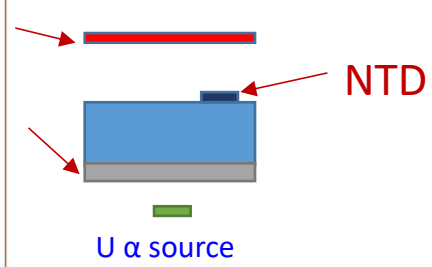
CROSS prototypes: 10 nm Pd coating

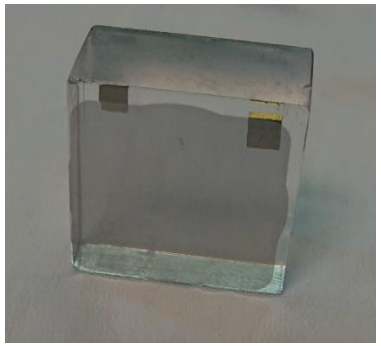
- Light detector is used in R&D measurements as additional PID tool



Caveat: signal amplitude supressed by factor 2 with respect to Al measurements



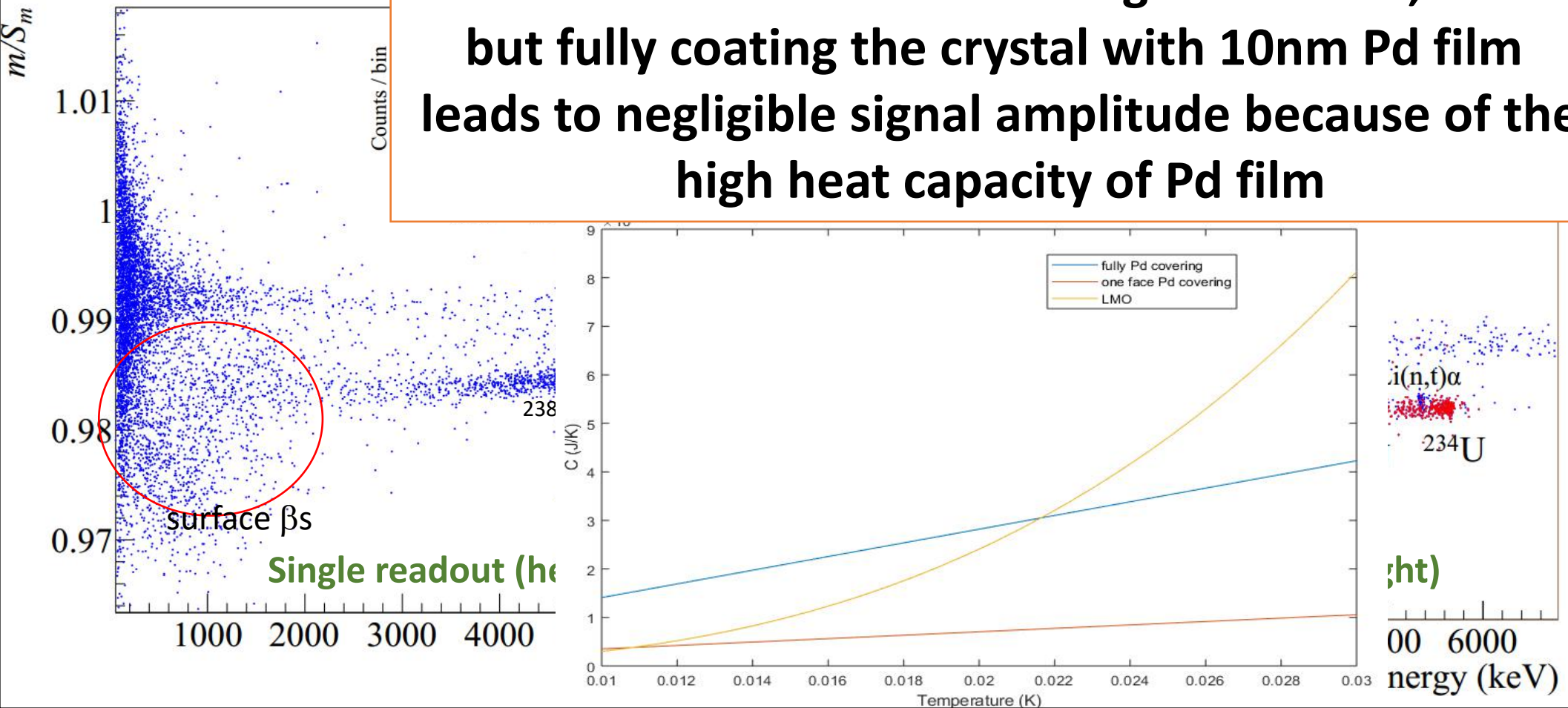


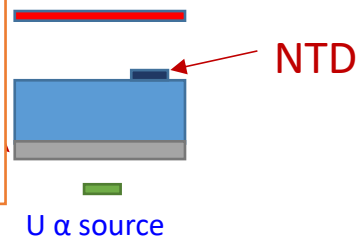


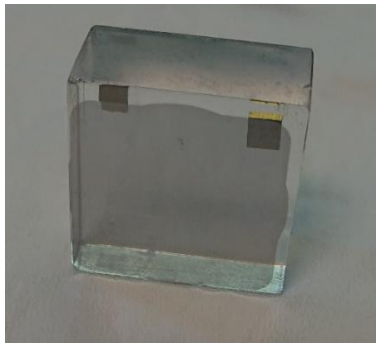
CROSS prototypes: 10 nm Pd coating

- Light dete[illegible] used in R&D measurements as additional PID tool

One face with Pd coating works well,
but fully coating the crystal with 10nm Pd film
leads to negligible signal amplitude because of the
high heat capacity of Pd film







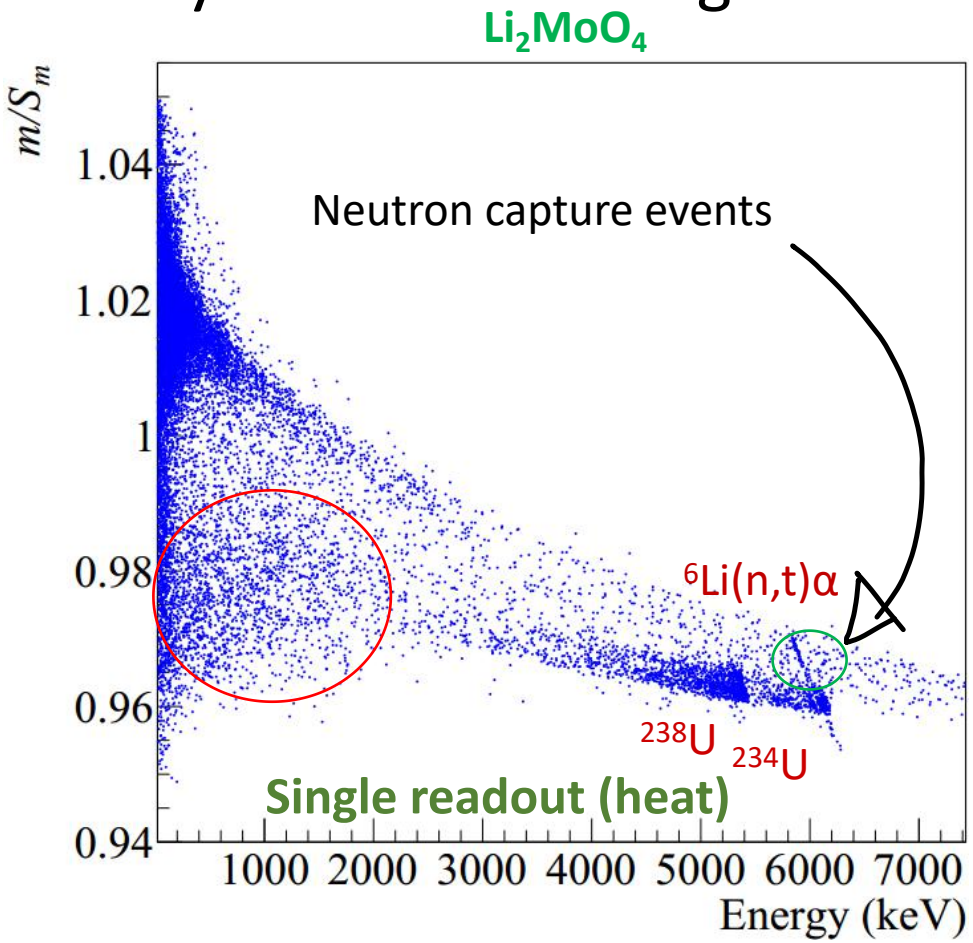
CROSS prototypes: Al-Pd coating

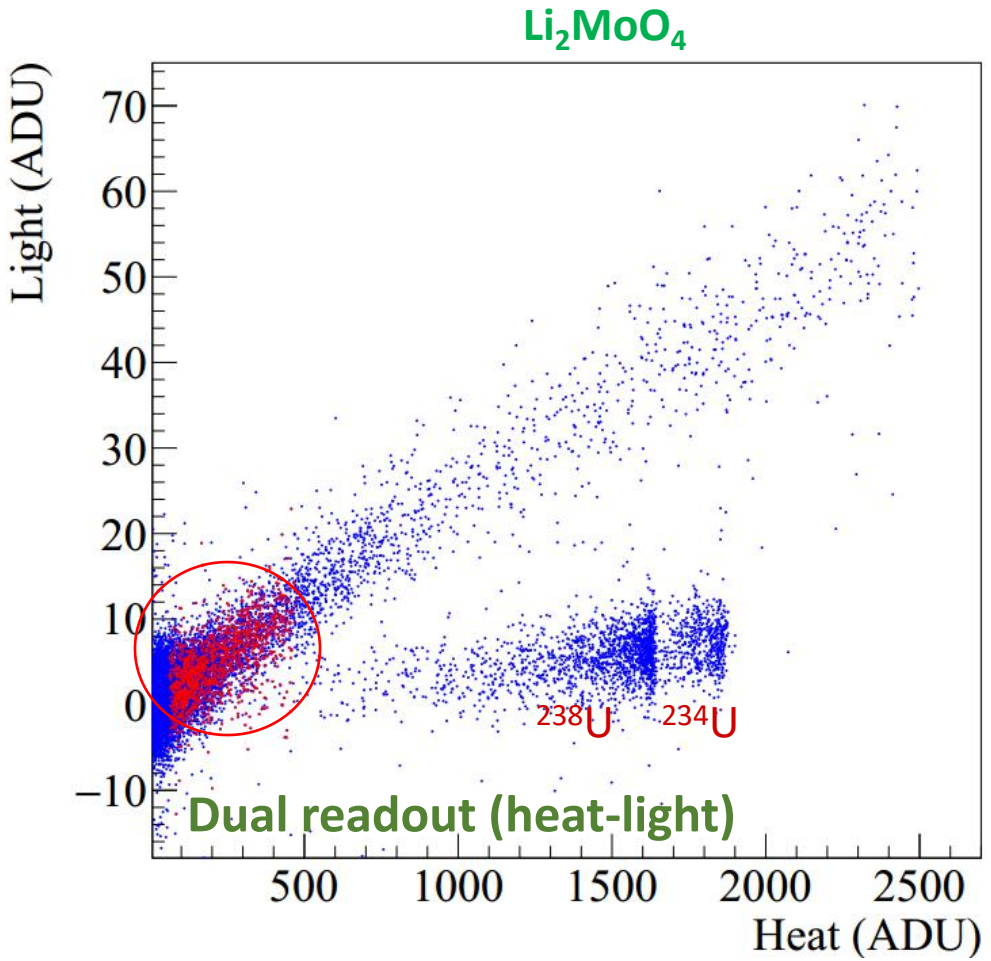
- We want to keep Pd because it showed surface beta separation, **but the heat capacity of Pd should be reduced…how?** **With proximity effect:**

- **Evaporate superconducting Al layer on the Pd film**
  - With the appropriate thickness of Al, at low temperature below the critical temperature, **Al film will introduce superconductivity in Pd film reducing the heat capacity**

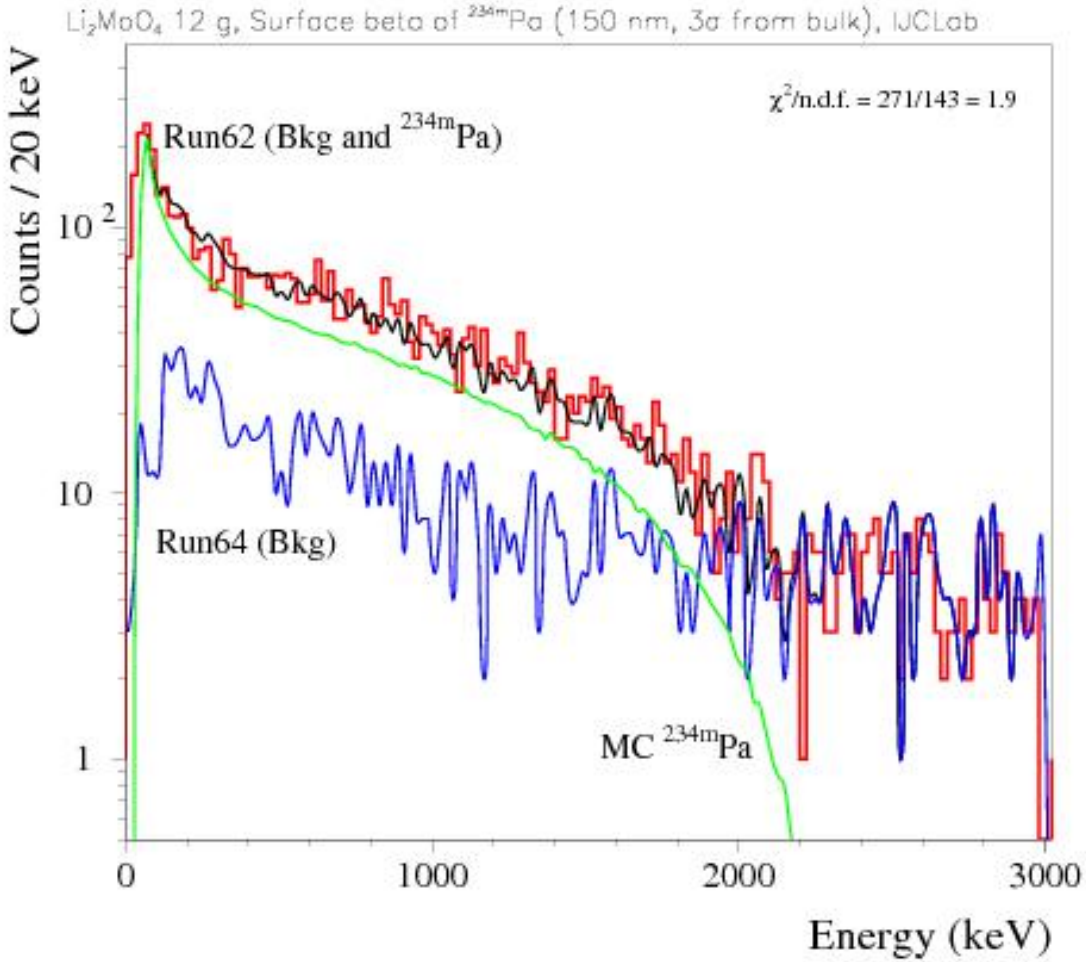
CROSS prototypes: Al-Pd coating

- Signal amplitude is practically at the same level as with Al coating: proximity effect is working!





Fitting the beta spectrum with MC model

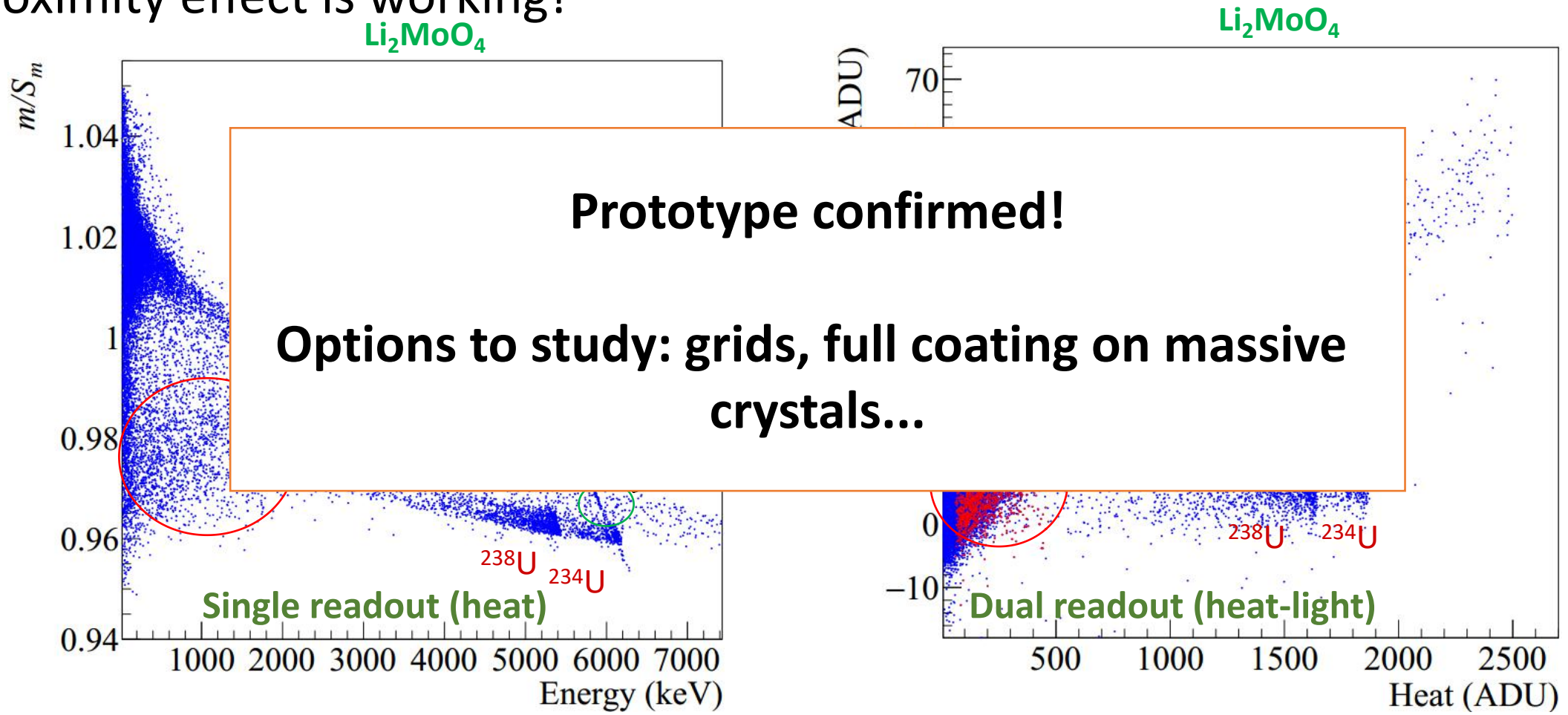


- Data
- Background
- Model
- ^{234m}Pa beta source

- Beta events were selected from the runs with a source. These events contains also background.
- The background was selected from the run without a source.
- MC simulation was performed to get the beta spectrum of ^{234m}Pa.
- Our beta spectrum is well **fitted with a model** (MC+bkg)

CROSS prototypes: Al-Pd coating

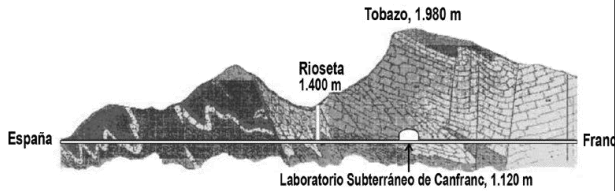
- Signal amplitude is practically at the same level as with Al coating: proximity effect is working!



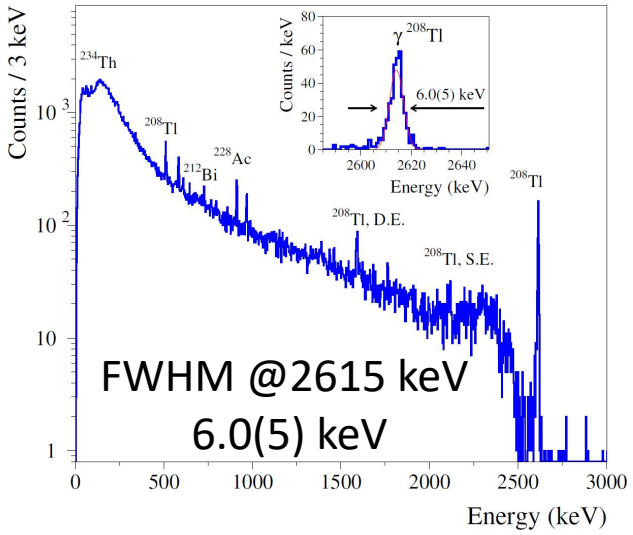
Prototype confirmed!

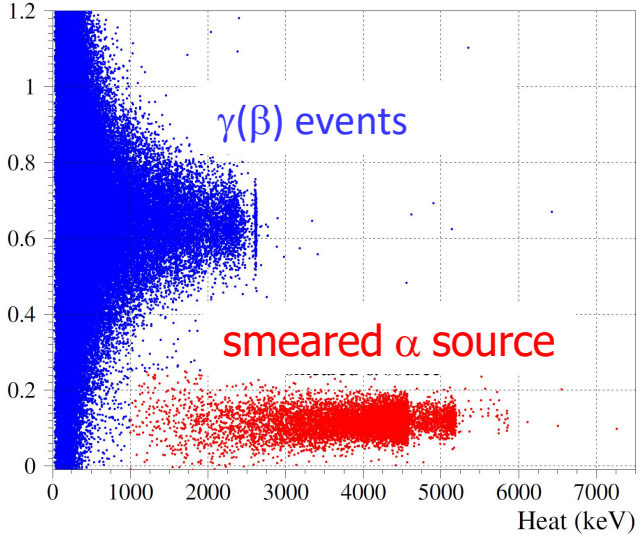
Options to study: grids, full coating on massive crystals...

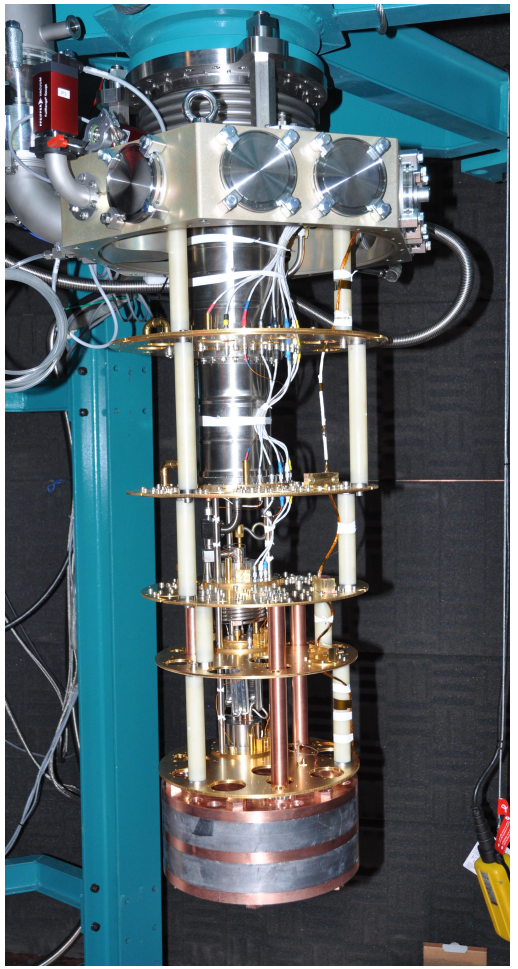
CROSS underground facility



- Cryostat installed and commissionned in April 2019
- This facility will be used also for the final definition of the CUPID structure
- 99% duty cycle, high stability, excellent performance of bolometers
- Optimization of facility is ongoing: muon veto, antiradon shield, etc.





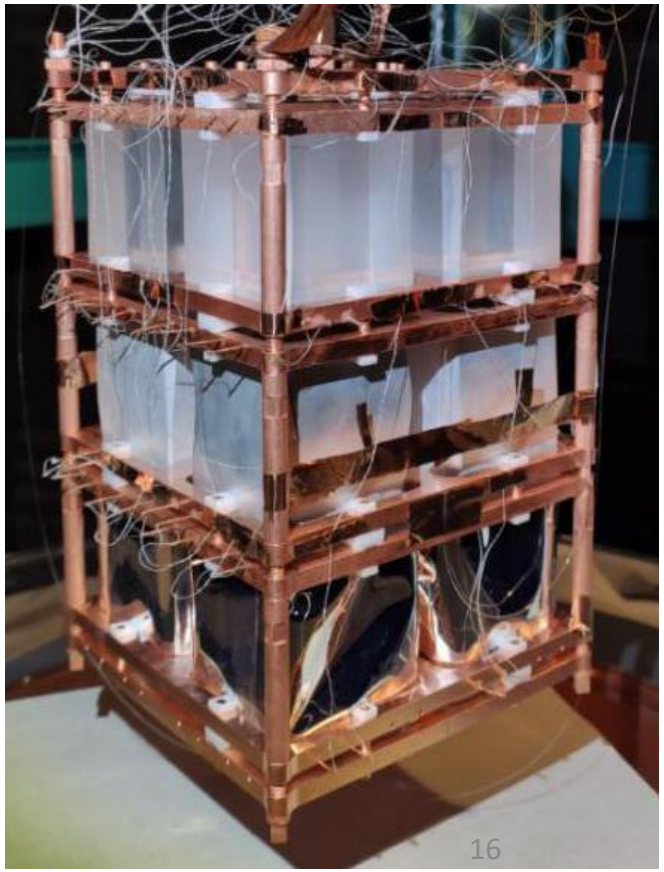


CROSS / CUPID ENTANGLEMENT

The Canfranc CROSS facility is / will be used for a series of tests aiming at defining the final structure of the CUPID detector.

Done - Ongoing - Future

- **Validation of the cubic shape of the Li_2MoO_4 crystals**

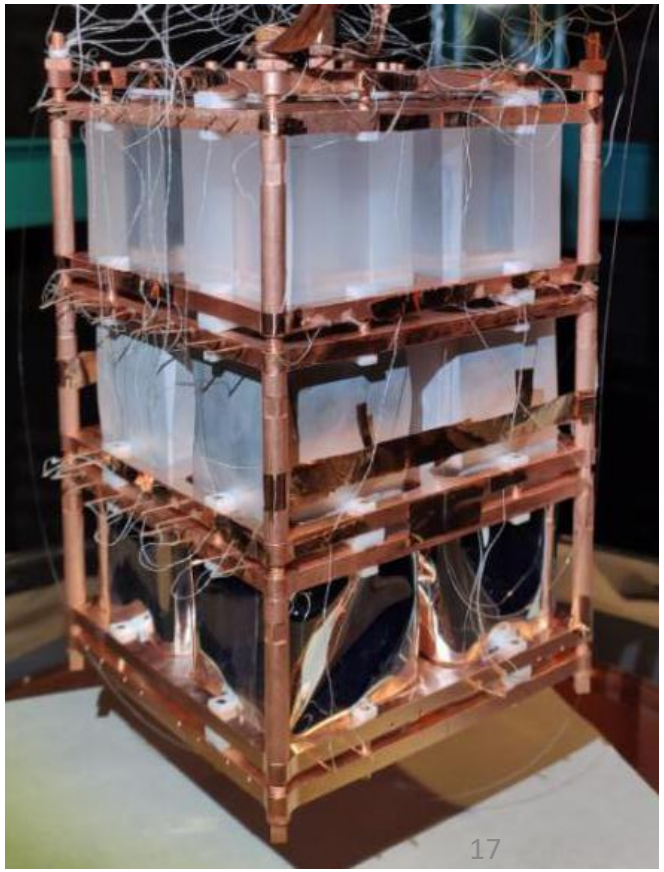


CROSS / CUPID ENTANGLEMENT

The Canfranc CROSS facility is / will be used for a series of tests aiming at defining the final structure of the CUPID detector.

Done - **Ongoing** - **Future**

- **Validation of the cubic shape of the Li_2MoO_4 crystals**
- **Optimization of the NTD sensors**
- **Validation of innovant calibration methods for light**
- **Study of Neganov-Trofimov-Luke light detectors**
- **Light collection studies**
- **Validation of the electronics and custom DAQ boards for CUPID**

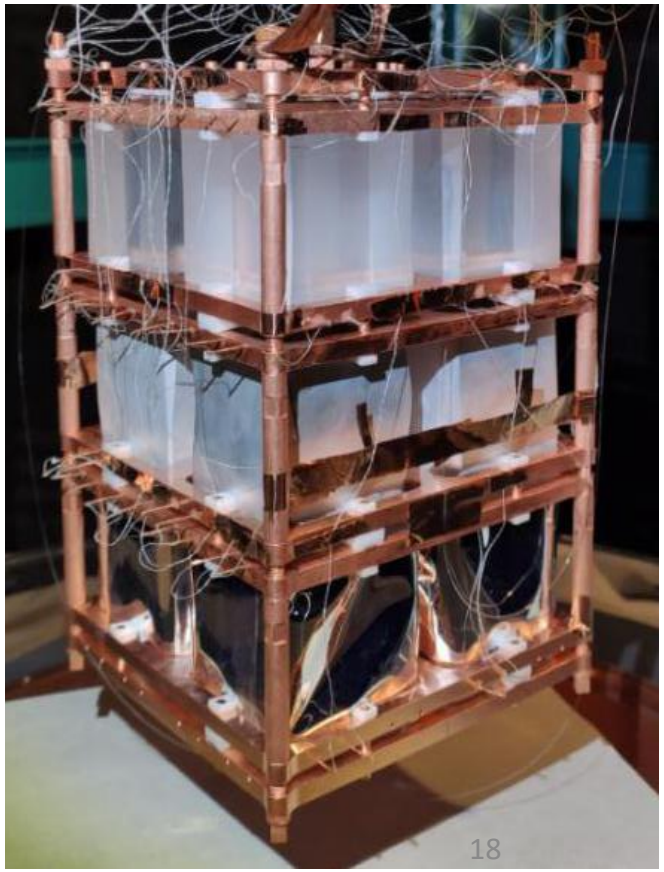


CROSS / CUPID ENTANGLEMENT

The Canfranc CROSS facility is / will be used for a series of tests aiming at defining the final structure of the CUPID detector.

Done - **Ongoing** - **Future**

- **Validation of the cubic shape of the Li_2MoO_4 crystals**
- **Optimization of the NTD sensors**
- **Validation of innovant calibration methods for light**
- **Study of Neganov-Trofimov-Luke light detectors**
- **Light collection studies**
- **Validation of the electronics and custom DAQ boards for CUPID**
- **Set up of a new protocol for enrichment / purification / crystallization**
- **Decision on the light detectors configuration**
- **Design and development of detectors mechanical structure**
- **Validation of the selected options with a multi-detector tower**



COMPOSITION OF THE CROSS DEMONSTRATOR

Currently available $Li_2{}^{100}MoO_4$ crystals:

- **32** cubic crystals [45x45x45 mm – 280 g] grown from NEMO-3 enriched ^{100}Mo
- **20** cylindrical crystals [∅44x45 mm – 210 g] from CUPID-Mo grown from NEMO-3 enriched ^{100}Mo

Under procurement Li_2MoO_4 crystals:

- **16** cubic crystals [45x45x45 mm – 280 g] grown from freshly-enriched Mo [test new enrichment/purification chain]

Under procurement TeO_2 crystals:

- **4 through 8** crystals [50x50x50 mm – 750 g] grown from existing enriched Te [test new purification/crystallization chain]

The final configuration of the demonstrator is still under discussion, depending on the mechanical structure to hold crystals

Minimum configuration: **32 Li_2MoO_4 crystals – 4 TeO_2 crystals**

Maximum configuration: **68 Li_2MoO_4 crystals – 8 TeO_2 crystals**

Summary

- Next-next generation $0\nu2\beta$ searches with cryogenic detectors require an **active rejection of surface contamination** induced background

- CROSS aims at the development of bolometers capable to reject near surface interaction exploiting **metallic film surface covering with single readout**

- **Al-Pd films** offer rejection of both surface α and β events: to be confirmed on bigger scale

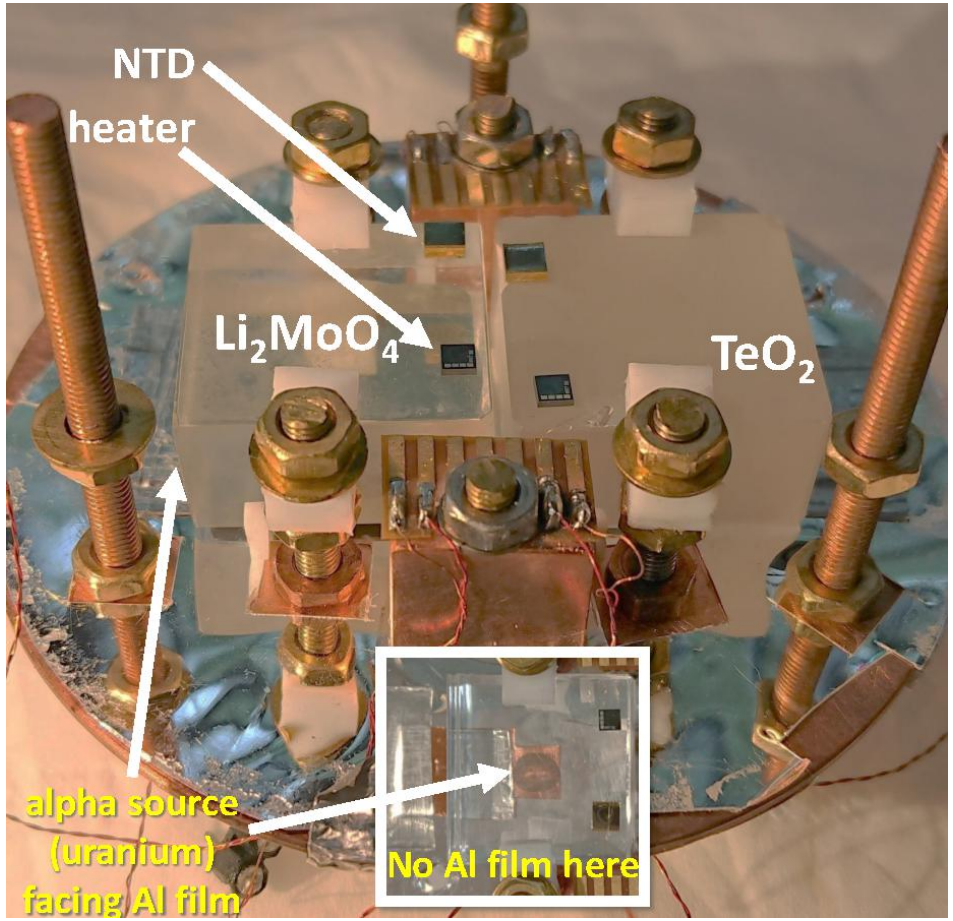
- **CROSS demonstrator** will confirm the robustness of technology for next-next generation experiments

Backups

CROSS demonstrator

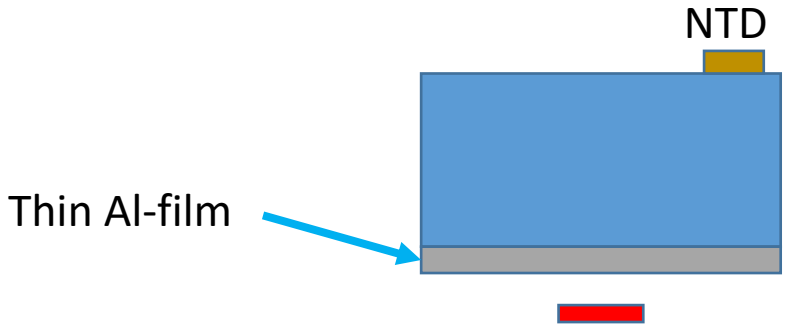
- 32 $Li_2{}^{100}MoO_4$ crystals (4.7 kg of enriched ^{100}Mo (>95%) corresponding to 2.9×10^{25} ^{100}Mo)

Background level [counts / (keV kg y)]	Live time [y]	Lim $T_{1/2}$ [y] (90% c.l.)	Lim $m_{\beta\beta}$ [meV] (90% c.l.)
10^{-2}	2	8.5×10^{24}	124-222
10^{-3}	2	1.2×10^{25}	103-185
10^{-2}	5	1.7×10^{25}	88-159
10^{-3}	5	2.8×10^{25}	68-122



Heater: injects power periodically to be able to stabilize the bolometric performance offline.

$2\times2\times1$ cm^3	$\varnothing4\times2$ cm^3	$2\times2\times1$ cm^3
12 g	67 g	25 g
10 μm Al	10 μm Al	1 μm Al
53 nV/keV	37 nV/keV	44 nV/keV

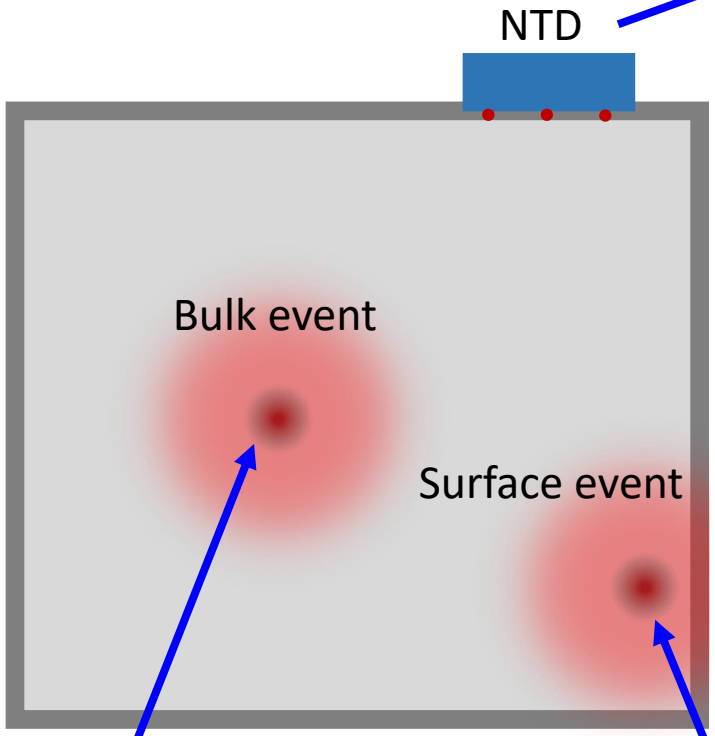


Performing at 22 mK

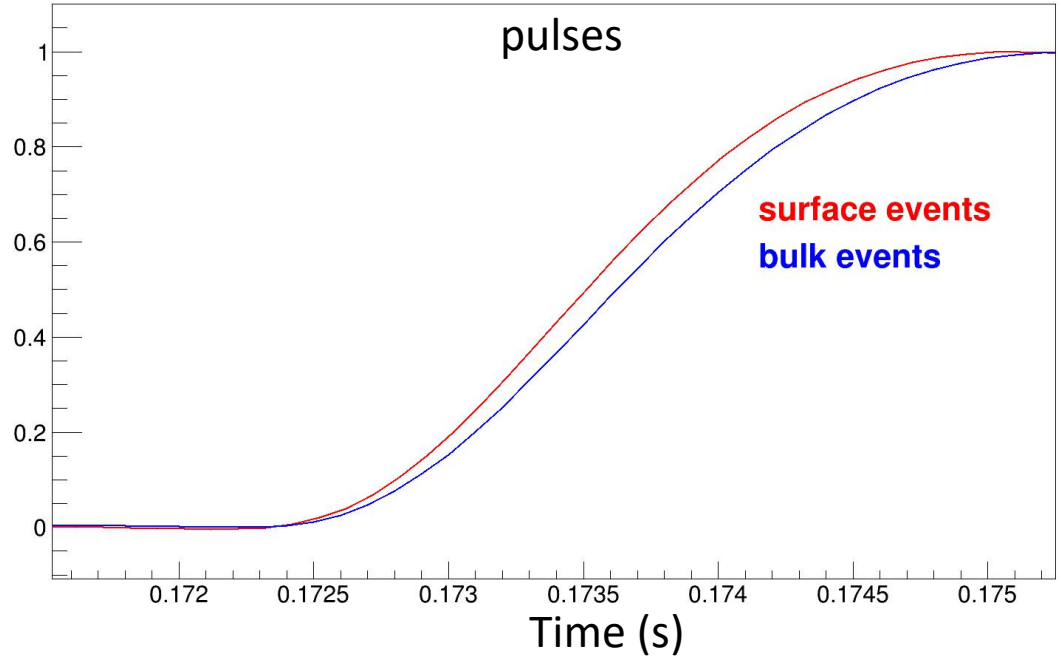
Uranium alpha source to mimic surface events

2 main alpha lines at **4.2 MeV and 4.7 MeV**

It has an intrinsic slowness in addition to having a glue interface with the surface → sensitive to thermal phonons



Athermal phonons are immediately produced after particle interaction in the crystal.



Athermal phonons will eventually evolve into thermal phonons that are registered in the NTD

Athermal phonons will break Cooper pairs in superconducting Al-film, and will be trapped for a few ms in the form of quasi-particles that will eventually recombine to give much lower energy phonons.

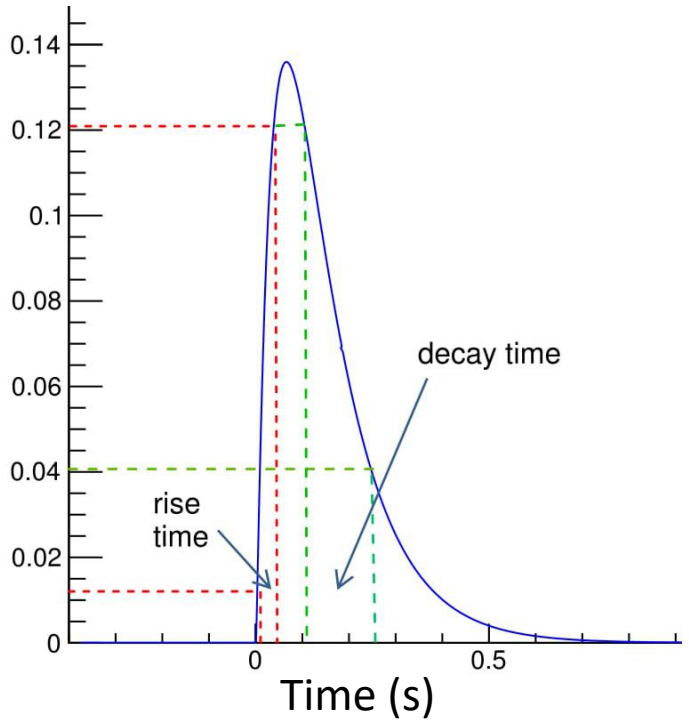
→ **Faster thermalization**

Surface events are faster than bulk events, so it is possible to discriminate pulses by pulse shape comparison (the rise-time for example)

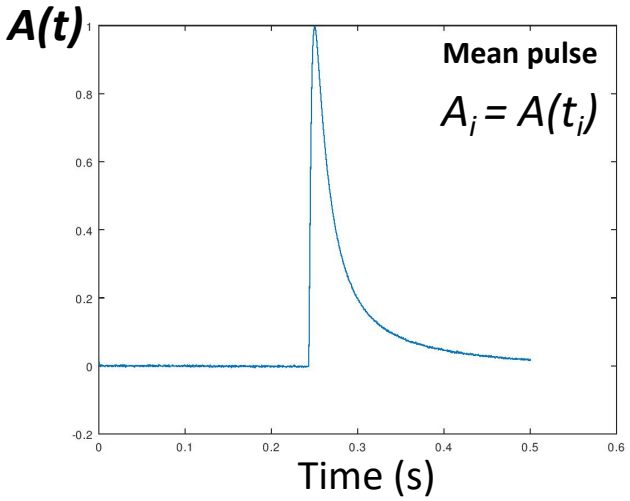
Particle identification parameters

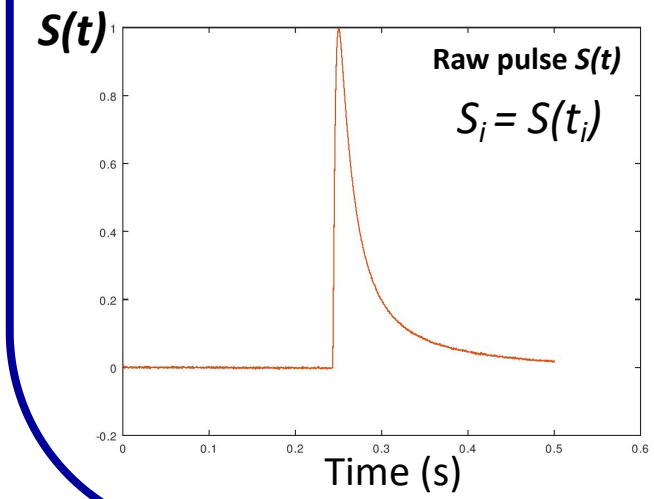
Rise-time

The Rise-time is measured from 10% to 90% of the pulse amplitude

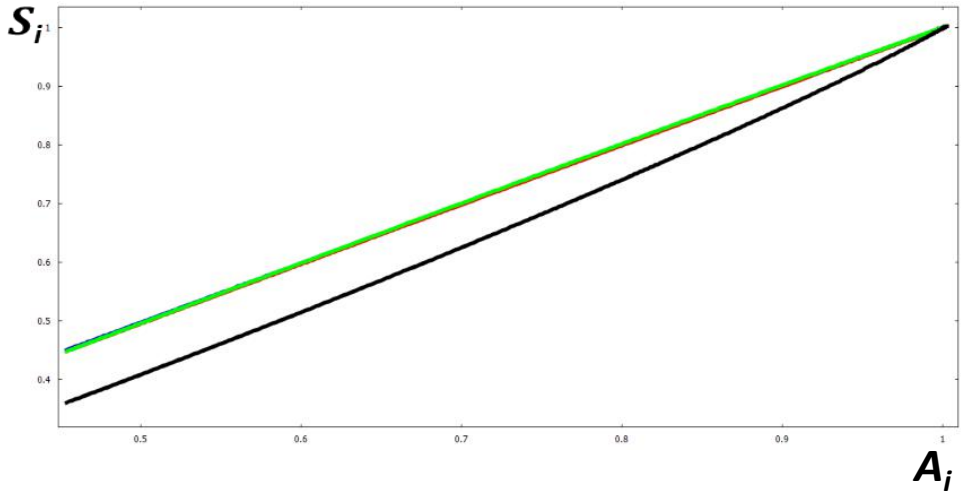


PSD parameter= m/S_m





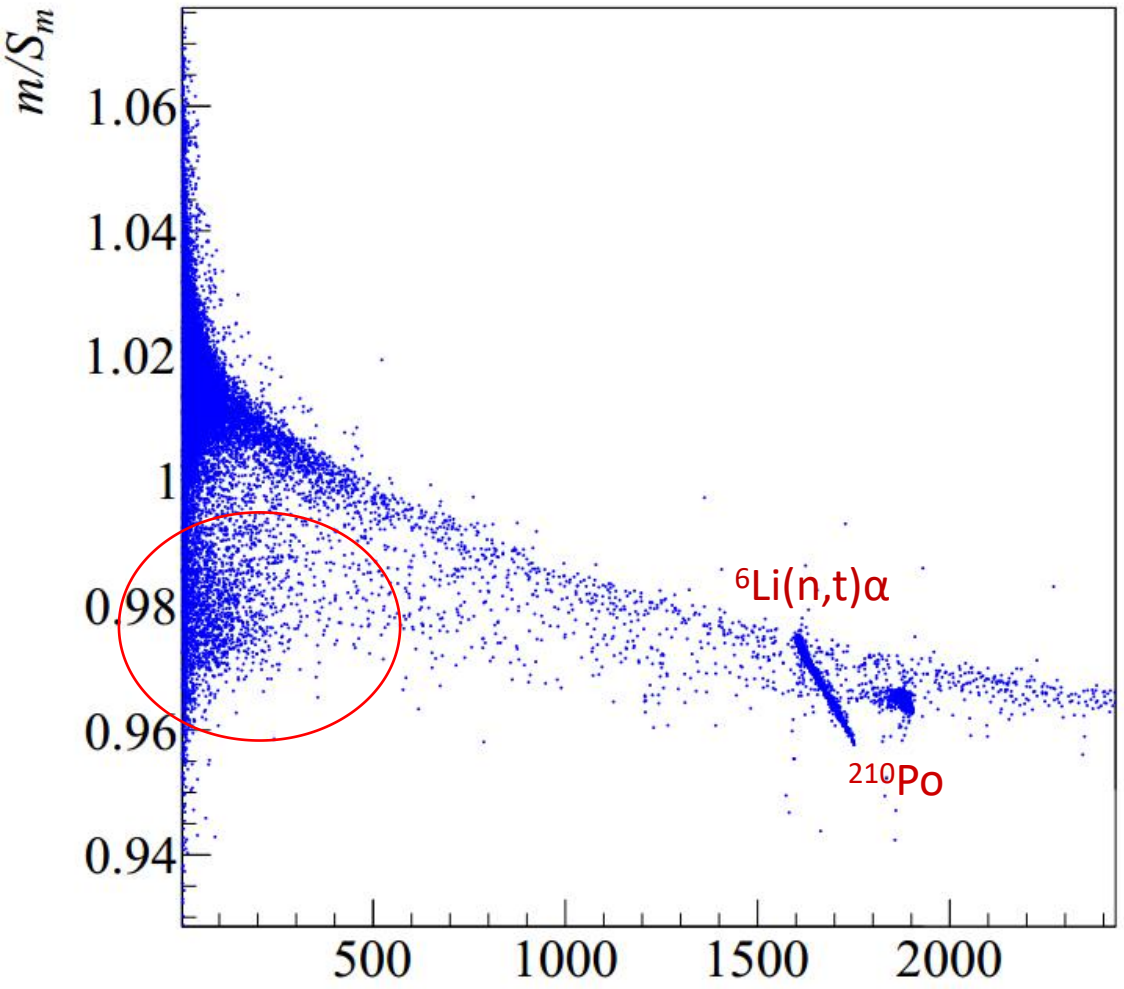
The pulses are synchronized according to their maximum position

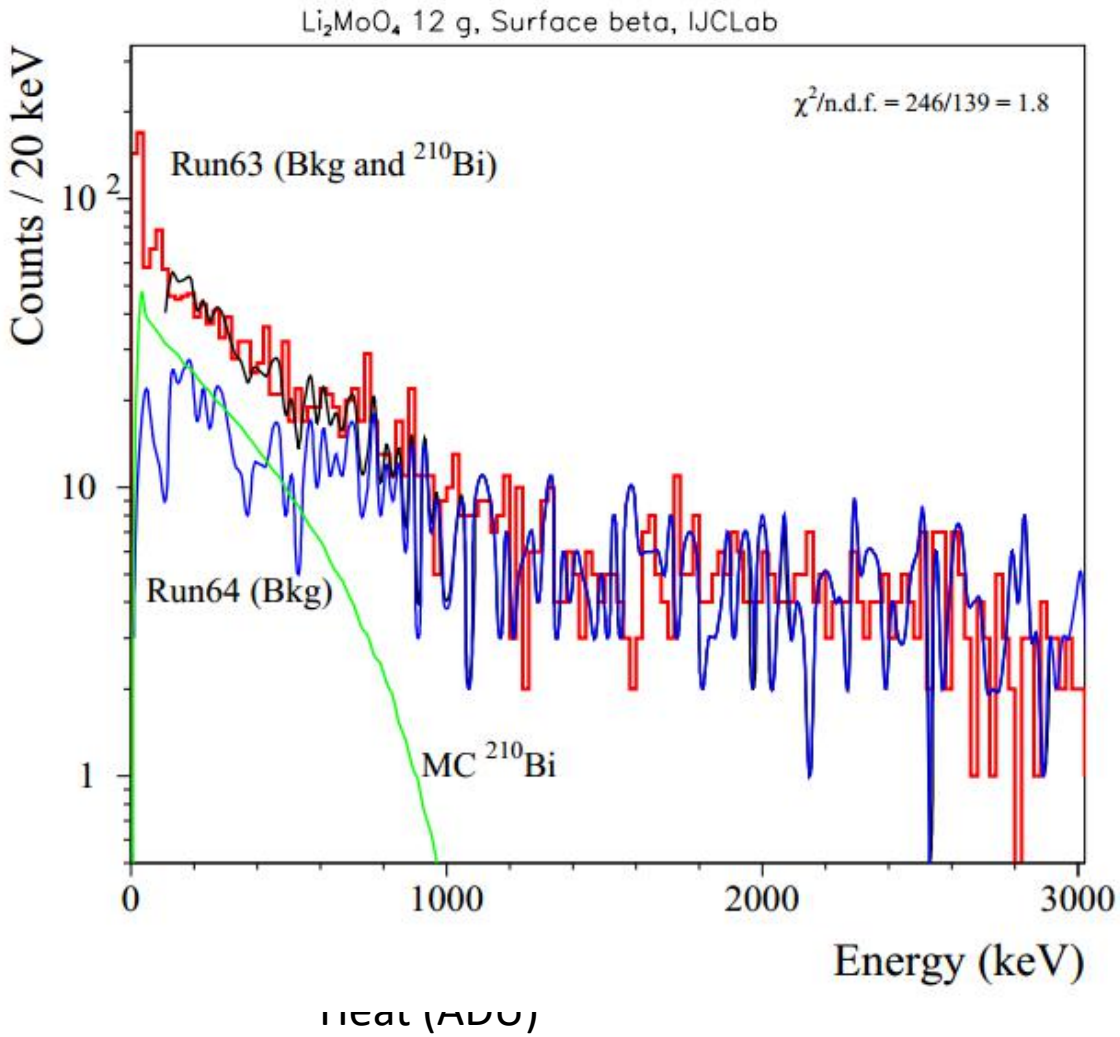


Linear fit : $S_i = mA_i+q$

The slope is the PSD parameter

Al-Pd with Po-210 source





10nm Pd + 100nm Al bilayer film coating of TeO2