CROSS

Cryogenic Rare-event Observatory with Surface Sensitivity

Towards the surface background rejection

Preliminary results and prospects

GDR Neutrino meeting 2019 (Bordeaux, France)

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Outline

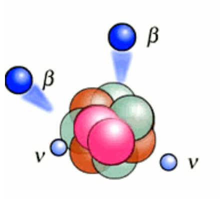
- Neutrinoless double beta decay
- Bolometric technology of CROSS
- CROSS above ground R&D runs at CSNSM (Orsay)
- Status of Canfranc cryostat
- Summary and prospects

Neutrinoless double beta decay

Double-decay in a nutshell

Double beta decay

- 2ν2β: (A,Z) → (A,Z+2) + 2e⁻ + $2\bar{\nu}_e$

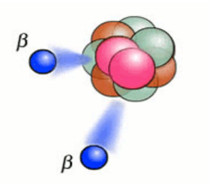


  - Allowed in the standard model for 35 nuclei

    (observed for 11 nuclei: ^{76}Ge, ^{82}Se, ^{100}Mo, ^{116}Cd, ^{130}Te…)
  - Rarest observed nuclear decay: $T_{1/2}$ ~ 10^{18} -10^{24} yr

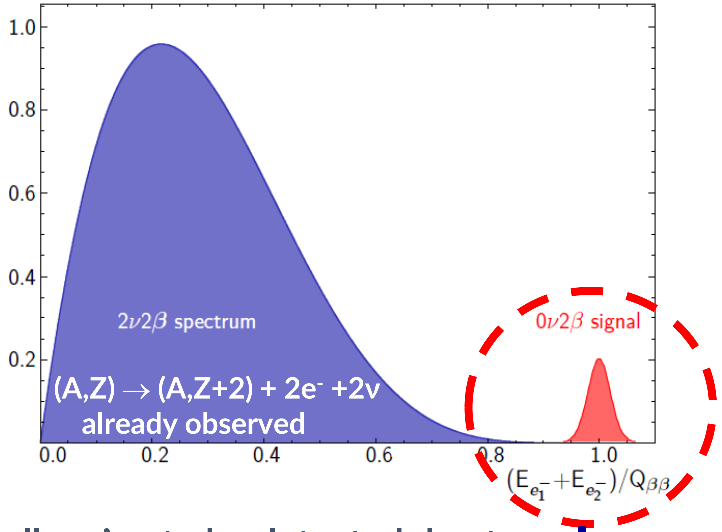
Neutrinoless double beta decay

- 0ν2β: (A,Z) → (A,Z+2) + 2e⁻



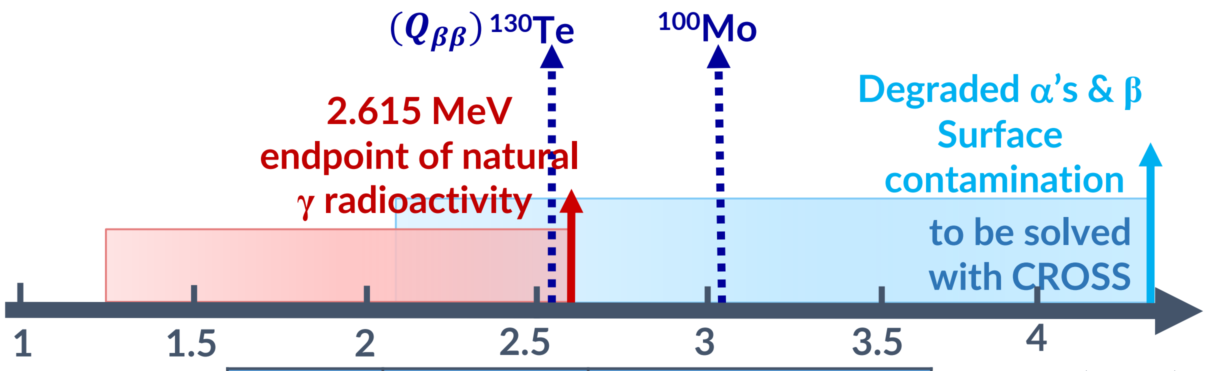
  - Forbidden in the standard model:

    - lepton number violation
  - ν = $\overline{\nu}$ (Majorana particle)
  - $T_{1/2} > 10^{26}$ yr (….very long, e.g. ^{238}U $T_{1/2} = 4.5 \times 10^9$ yr)



very challenging to be detected due to very low rate of the process

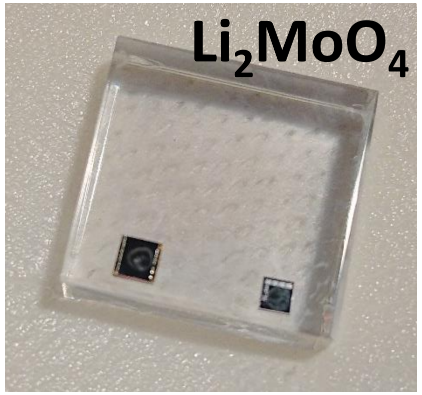
controlling the background is crucial:



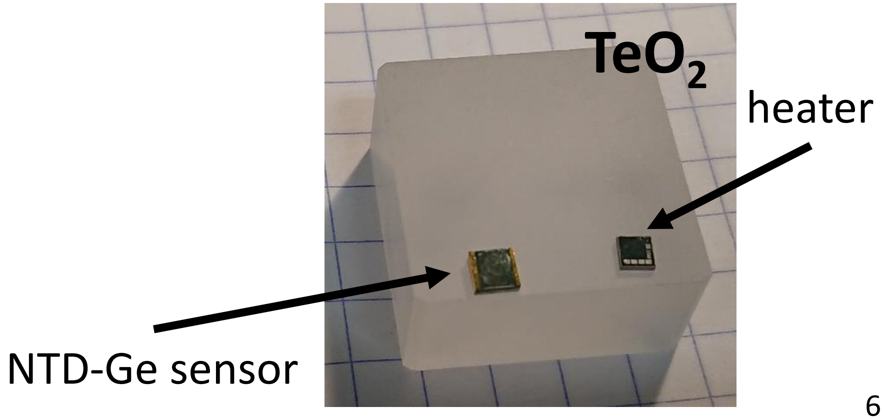
isotope	Q -value	Isotopic abundance
^{100}Mo	3034 keV	9.6 %
^{130}Te	2527 keV	34 %

CROSS Bolometric technology

CROSS Overview



- CROSS is a bolometric experiment to search for $0\nu\beta\beta$
- Two promising Bolometers are used: $Li_2{}^{100}MoO_4$ and $^{130}TeO_2$
- Main Objective: Rejection of surface events due to surface contamination
  - Effective pulse shape discrimination (PSD) capability
  - The surface sensitivity is achieved by Superconducting Al coating
- Assembly simplification: light detector elimination (surface alphas have different light yield from β/γ)



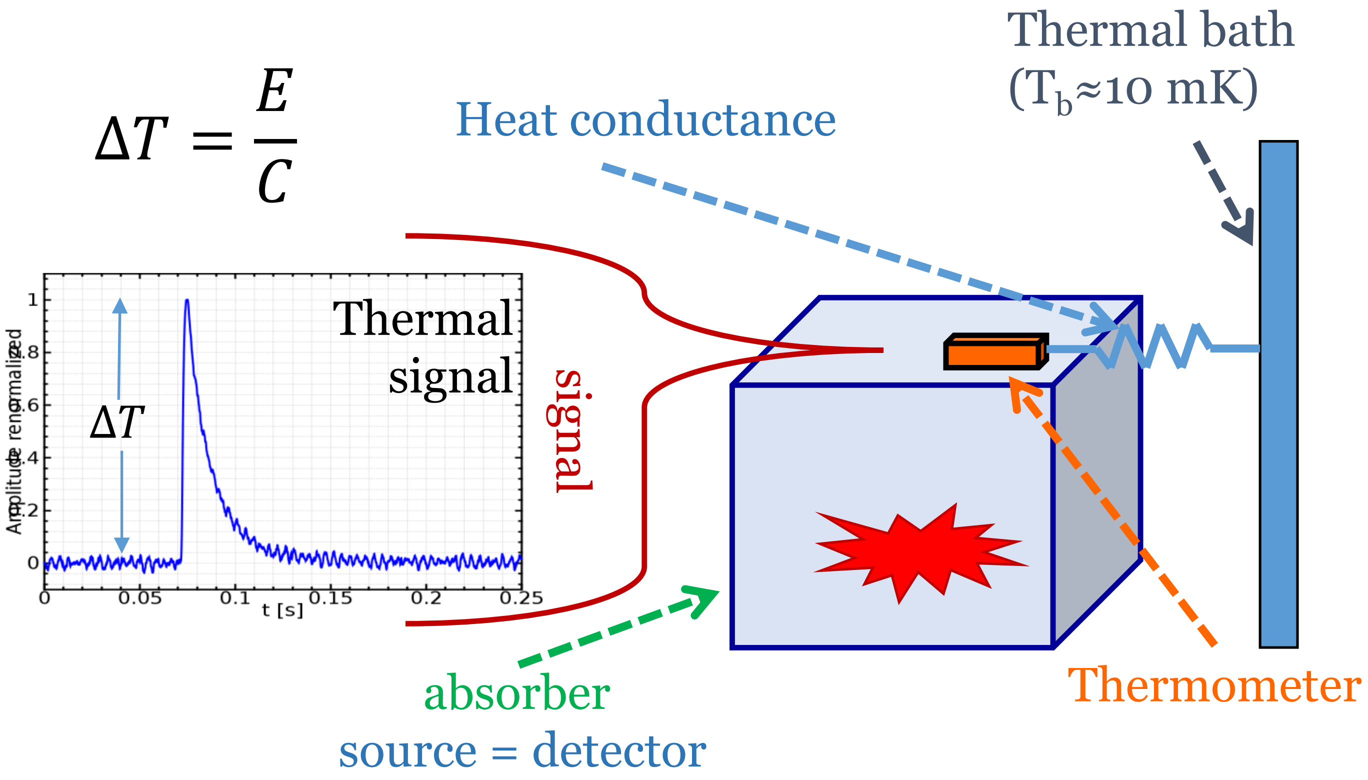
Bolometric detectors

Bolometer
is a low temperature calorimeter which detects particle interaction via a small temperature rise induced by phonons production in the lattice of the absorber

Features

- High energy resolution
- Detector = source
- Full active volume (no dead layer)
- Background rejection methods (hybrid or surface sensitive detectors)
- Flexible material choice (Li_2MoO_4, $ZnMoO_4$, $CaMoO_4$, ZnSe, TeO_2 …)

$$\Delta T = \frac{E}{C}$$



As in **CUORE**: **C**ryogenic **U**nderground **O**bservatory for **R**are **E**vents

Bolometric detectors

Bolometer

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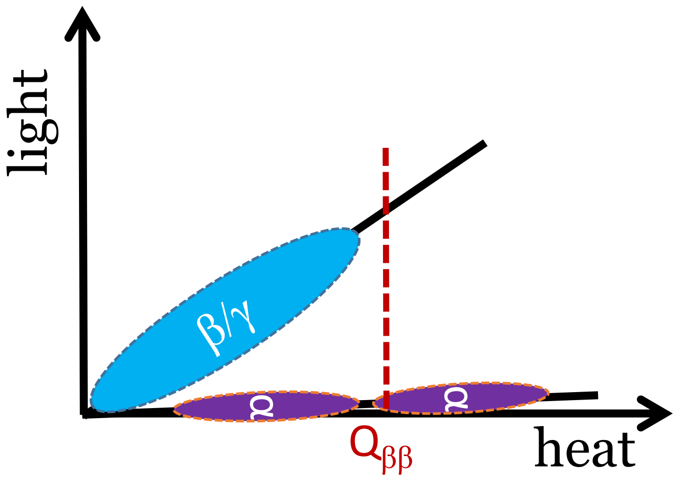
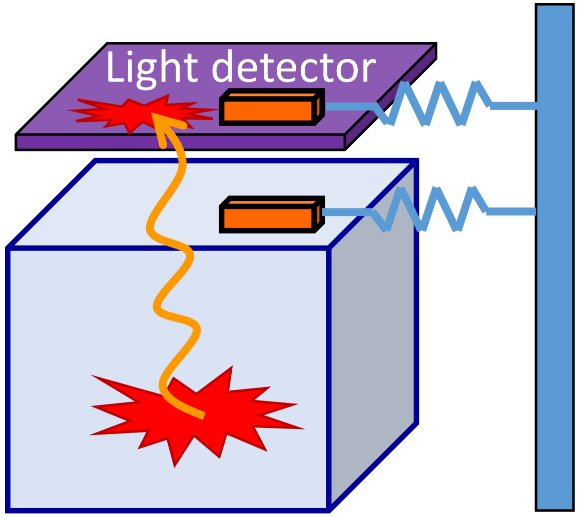
CUPID (CUORE Upgrade with Particle IDentification) adopts a method to reject surface α events in bolometers exploiting the scintillation (**$Li_2{}^{100}MoO_4$**) or Cherenkov radiation (**$^{130}TeO_2$**) emitted by the absorber, since α & β/γ have different light yield.





CROSS proposes a technique to mitigate surface contamination (α's & β's) via providing bolometers with surface sensitivity

➡ no light detector is needed

Dominated by α surface radioactivity

Reject all α's

Dominated by β surface radioactivity

Reject surface α's and β's

b = 10^{-2} counts/(keV kg y)

Pure bolometers

⇒ **CUORE**

b = 10^{-4} counts/(keV kg y)

Scintillating bolometers, alpha/beta separation

⇒ **CUPID**

b = 10^{-5} counts/(keV kg y)

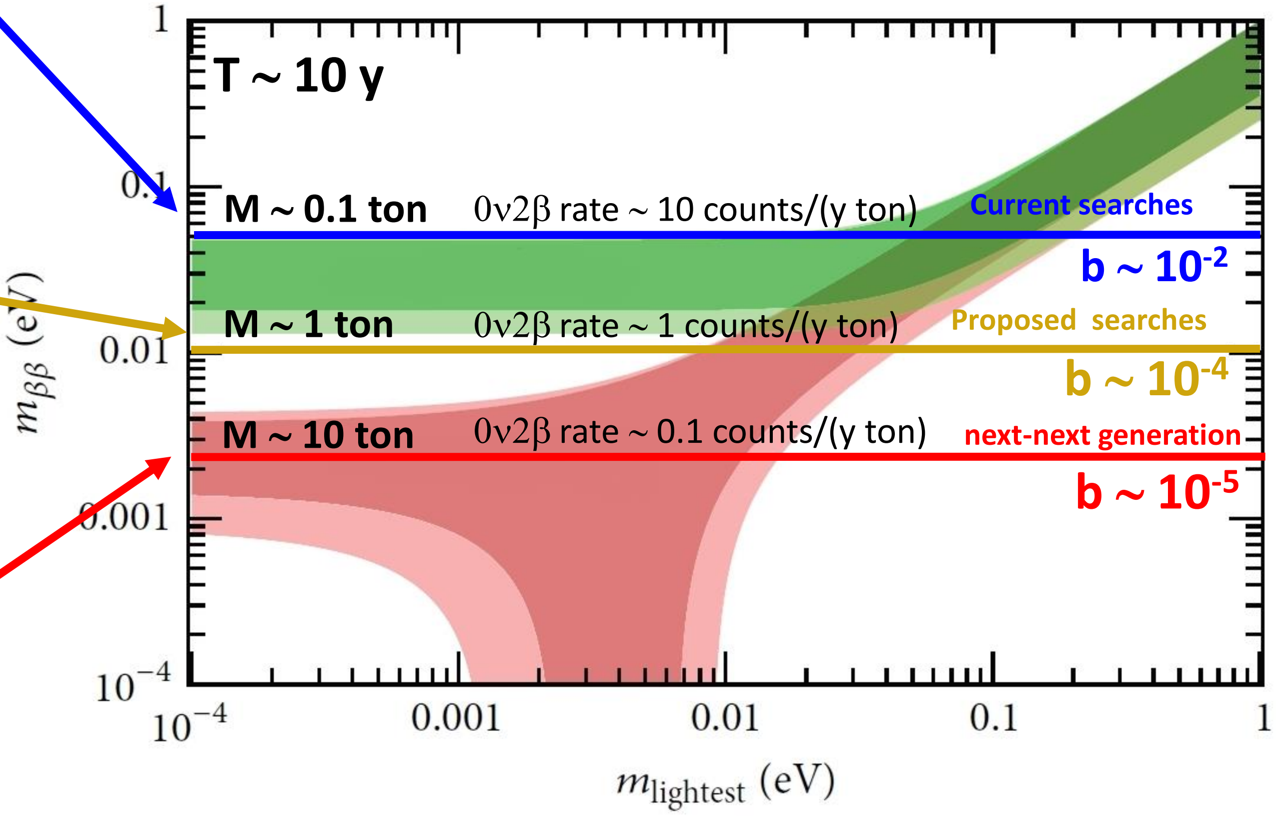
Surface-sensitive bolometers

Surface/bulk separation

⇒ **CROSS**

ΔE_{FWHM} ~ 5 keV for bolometers

Bkg rate in ROI ~ b × M × ΔE_{FWHM}

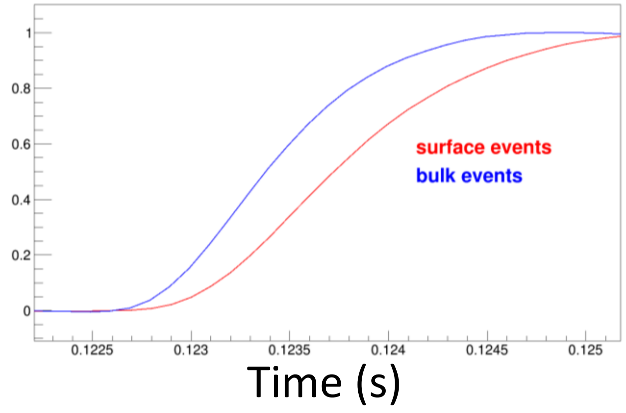


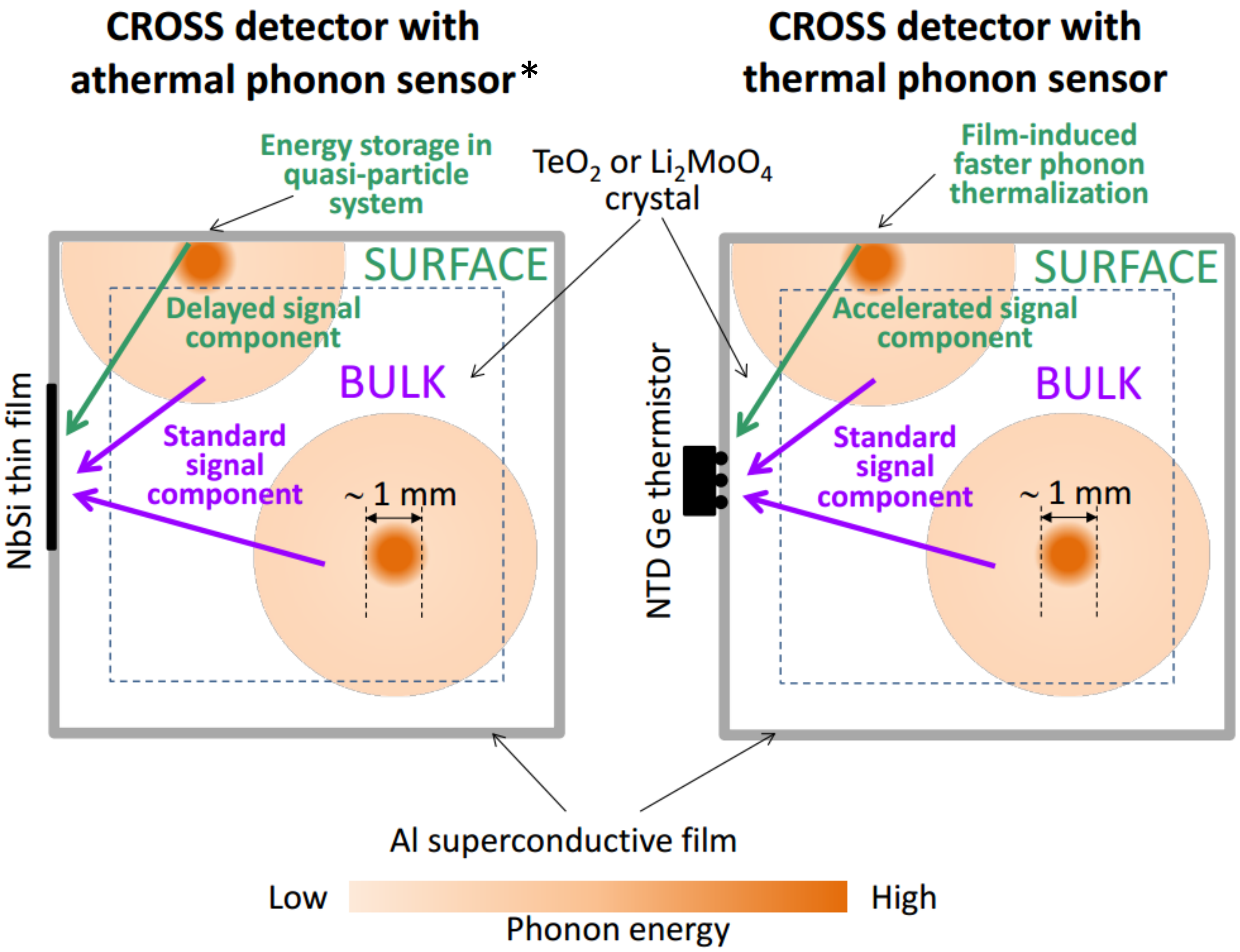
CROSS detector

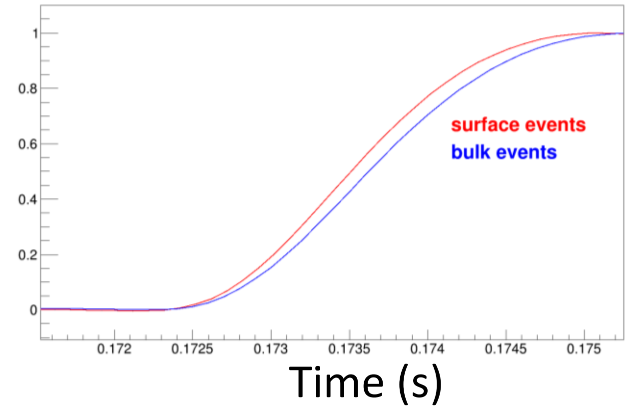
NbSi film (insulator):
Deposited directly on the crystal over a large surface, making them sensitive to the prompt **athermal** component of the phonon population produced by the impinging particle

Athermal phonons are immediately produced after particle interaction in the crystal, and then they evolve toward thermal phonons

NTD (neutron-transmutation-doped):
NTDs are sensitive rather to the **thermal** component due to their intrinsic slowness and the glue interface.



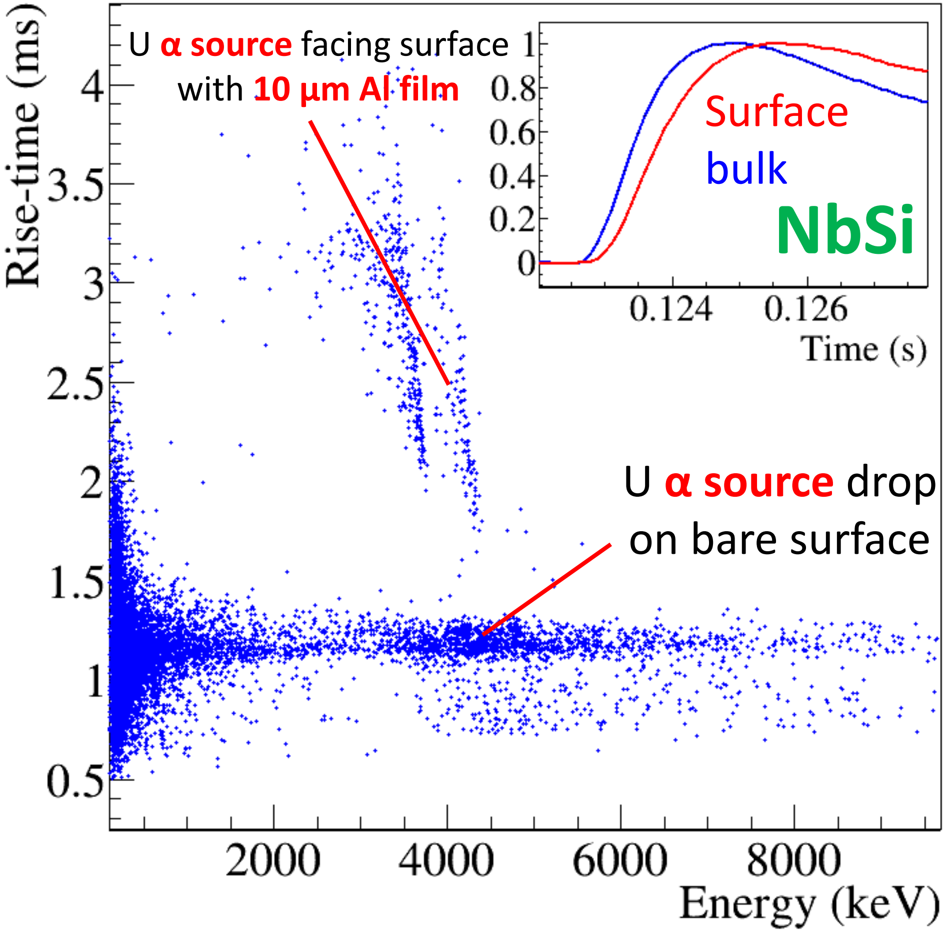




*J Low Temp Phys (**2012**) 167:1029–1034

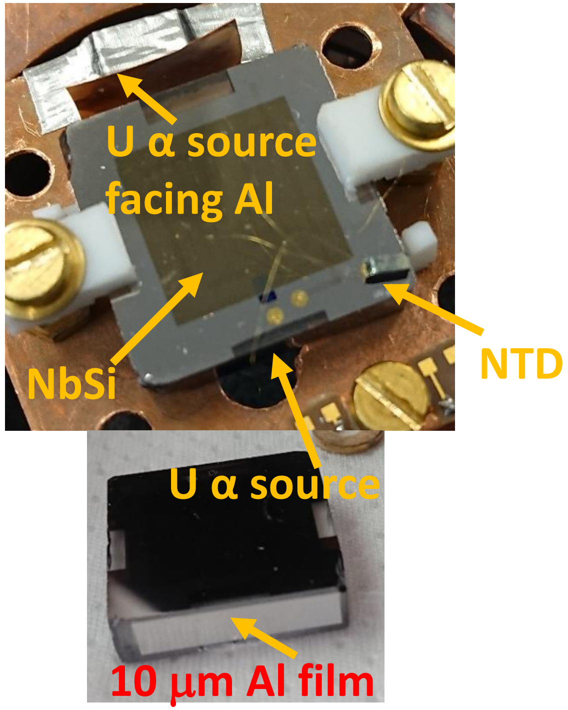
NbSi & NTD on TeO_2

30 mK	Sensitivity (nV/keV)	$FWHM_{baseline}$ (keV)
NTD	70	5.5
NbSi	54	8



Surface events are slower than bulk events

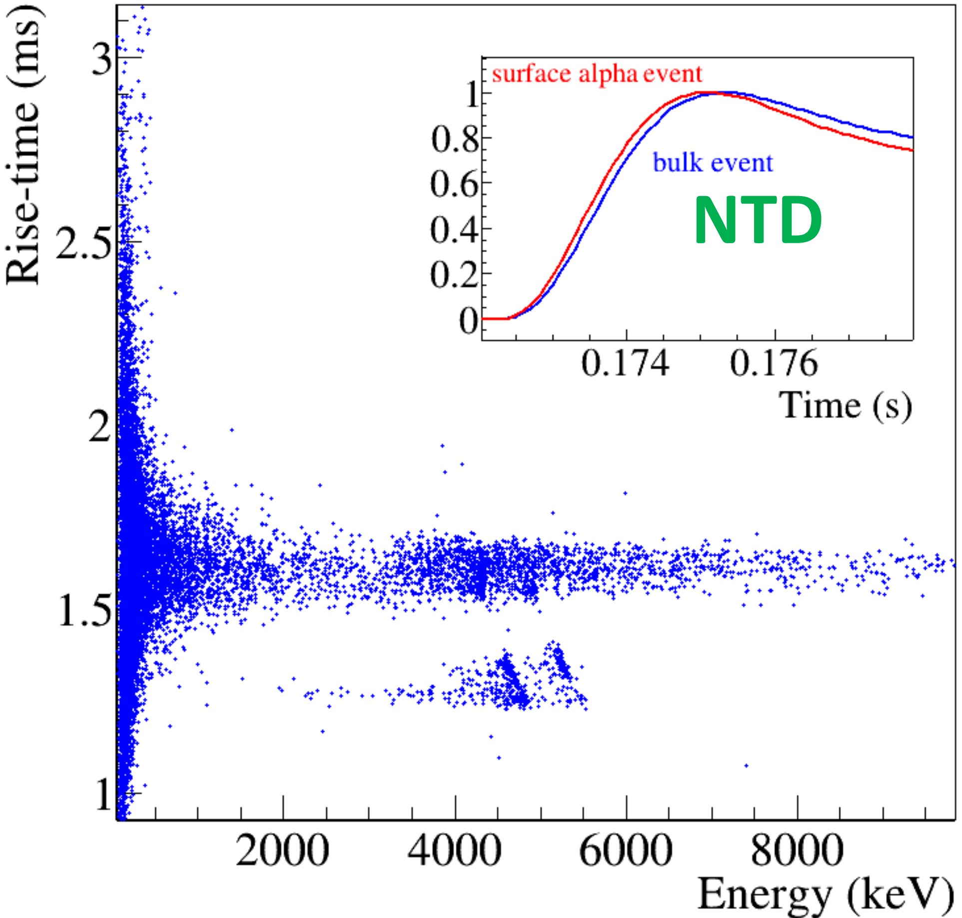
J Low Temp Phys (2012) 167:1029–1034



U α source

^{238}U = 4.2 MeV

^{234}U = 4.78 MeV

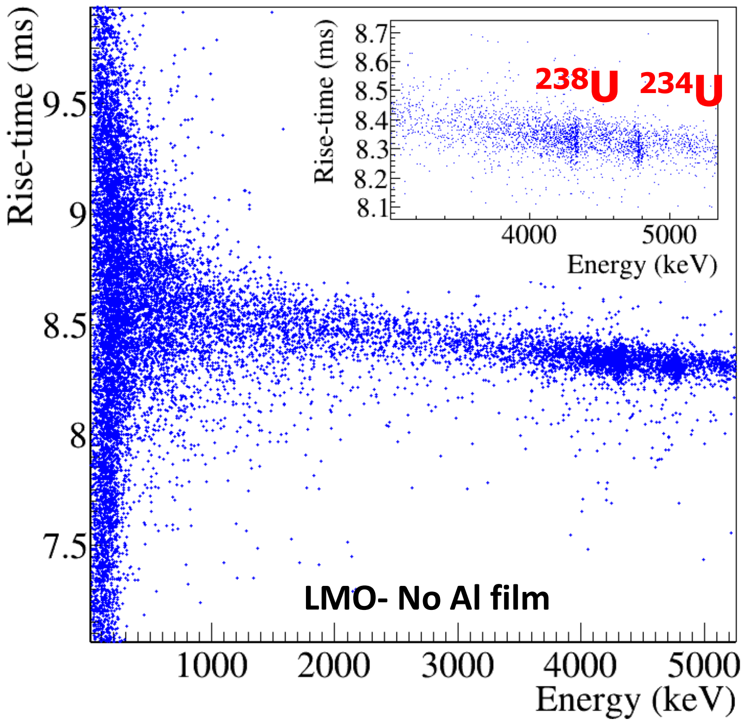


Surface events are faster than bulk events

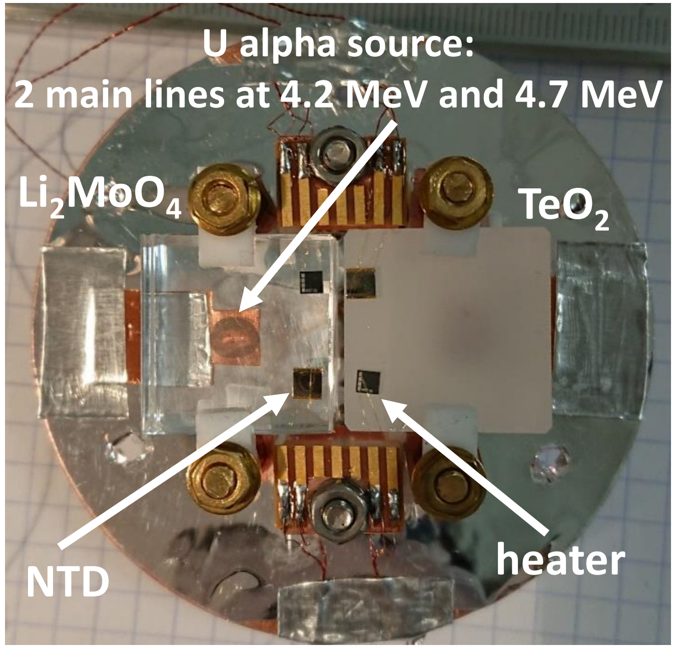
Opposite behavior of NbSi and NTD on the same crystal!

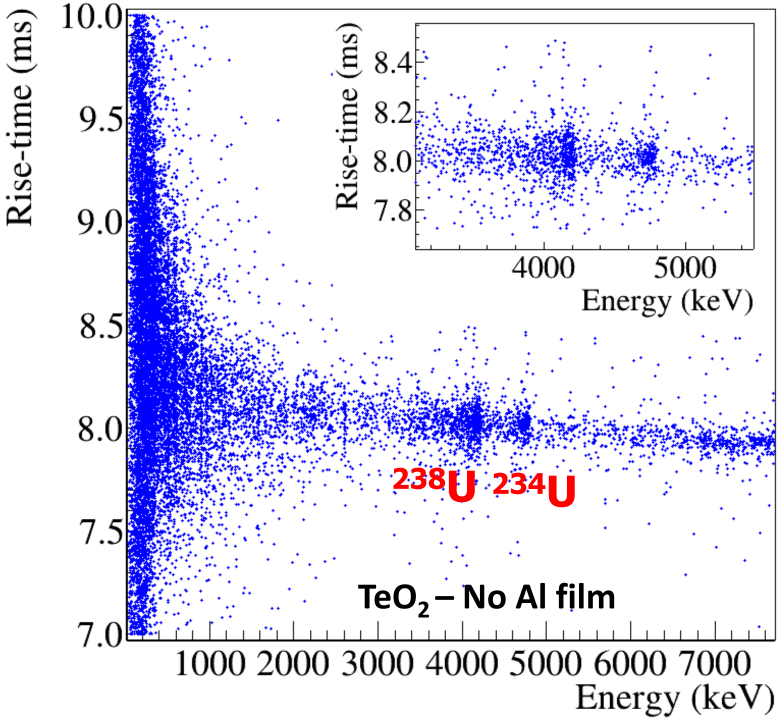
CROSS R&D runs

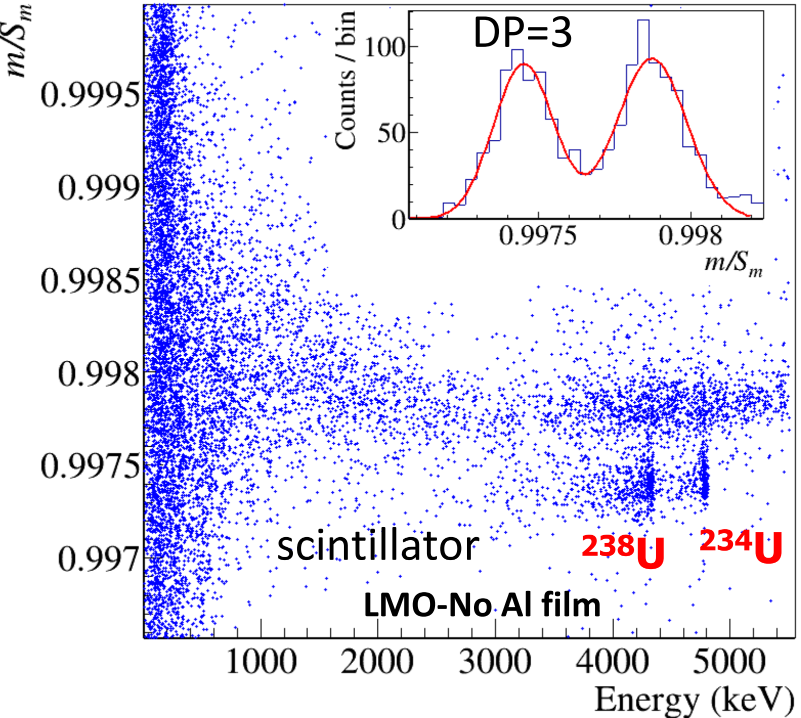
No Al film



CROSS R&D run	Li_2MoO_4 2×2×1 cm³, 12 g	TeO_2 2×2×1 cm³, 25 g
#1	no Al film	no Al film

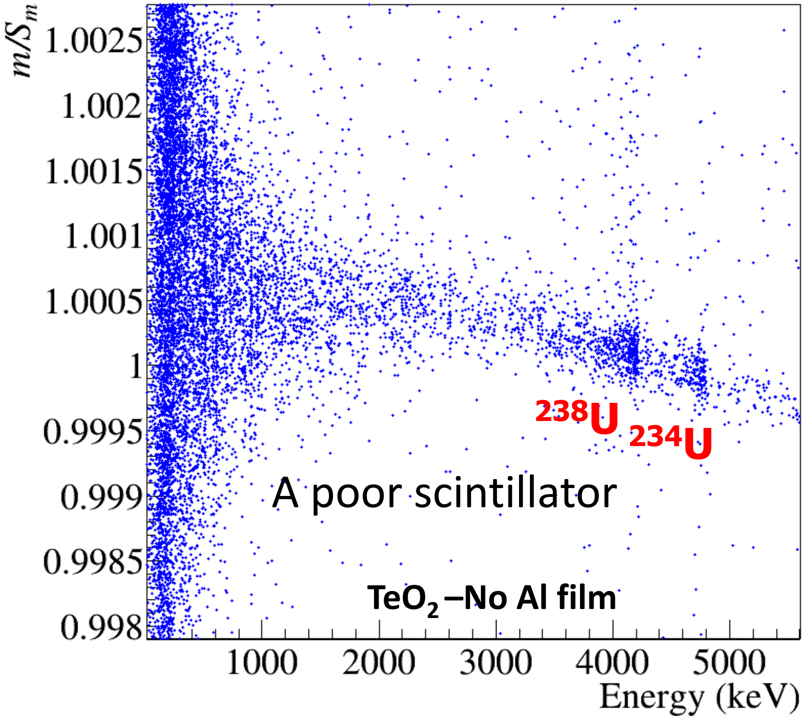




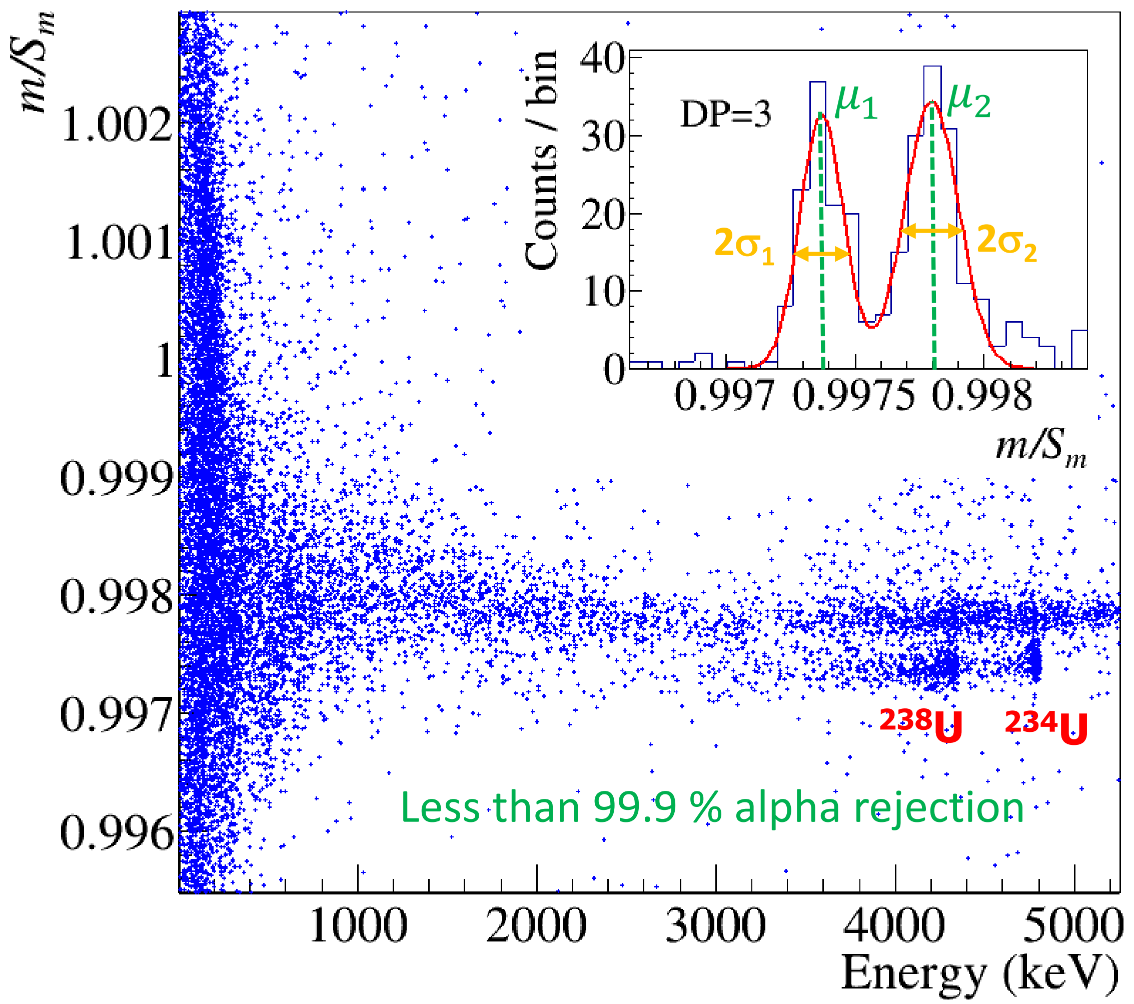


This test was performed to check the intrinsic properties of the crystal:

- Sensitivity
- Energy resolution
- Pulse shape discrimination



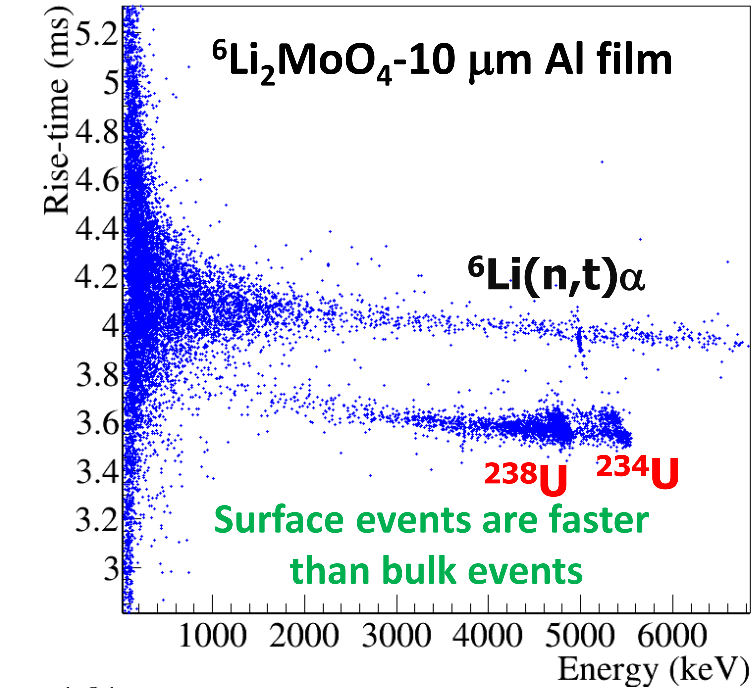
Discrimination power



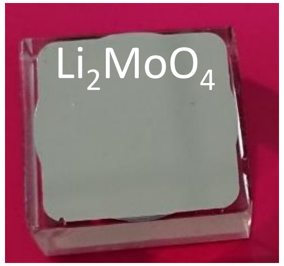
Discrimination power quantifies our ability to separate two populations

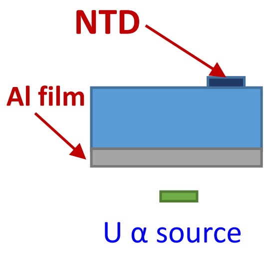
$$DP=\frac{|\mu_2-\mu_1|}{\sqrt{\sigma_2^2+\sigma_1^2}}$$

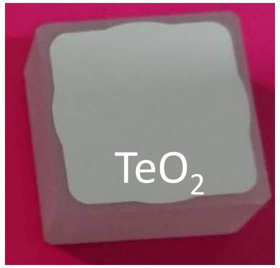
Few µm Al film

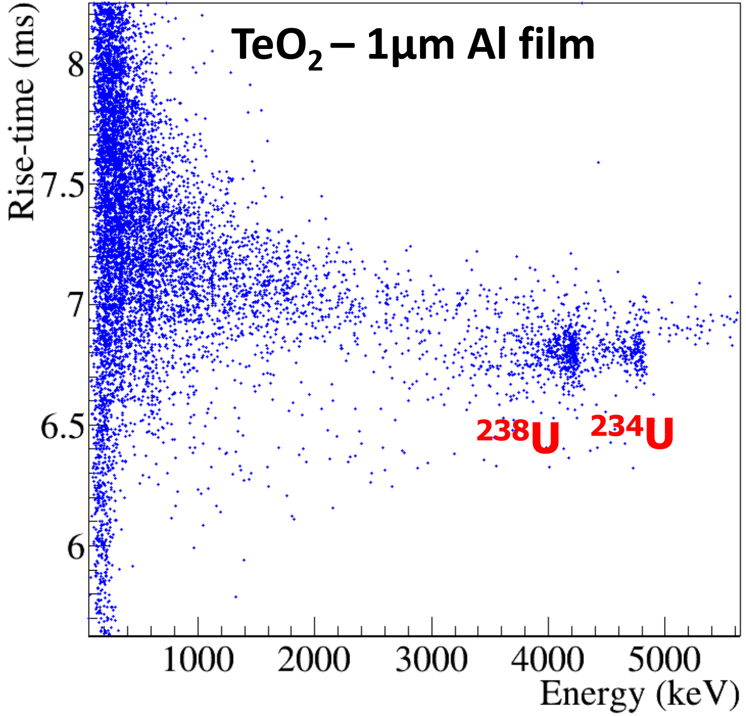


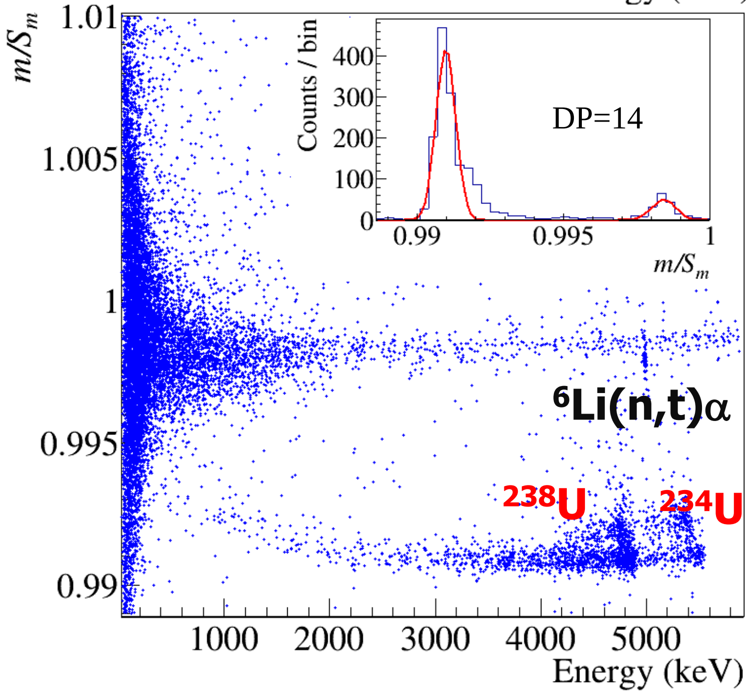
CROSS R&D run	Li_2MoO_4 2×2×1 cm³, 12 g	TeO_2 2×2×1 cm³, 25 g
#2	10µm	1µm



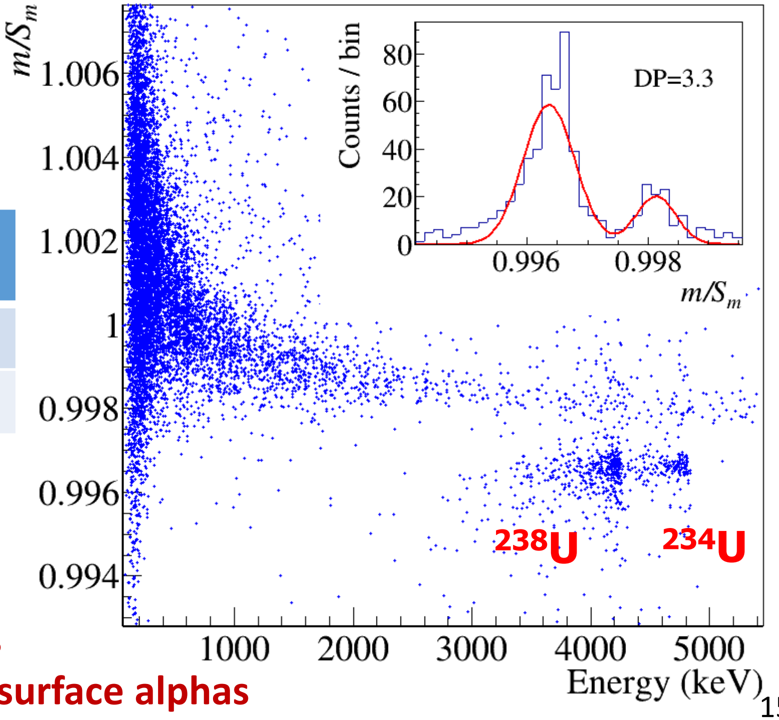






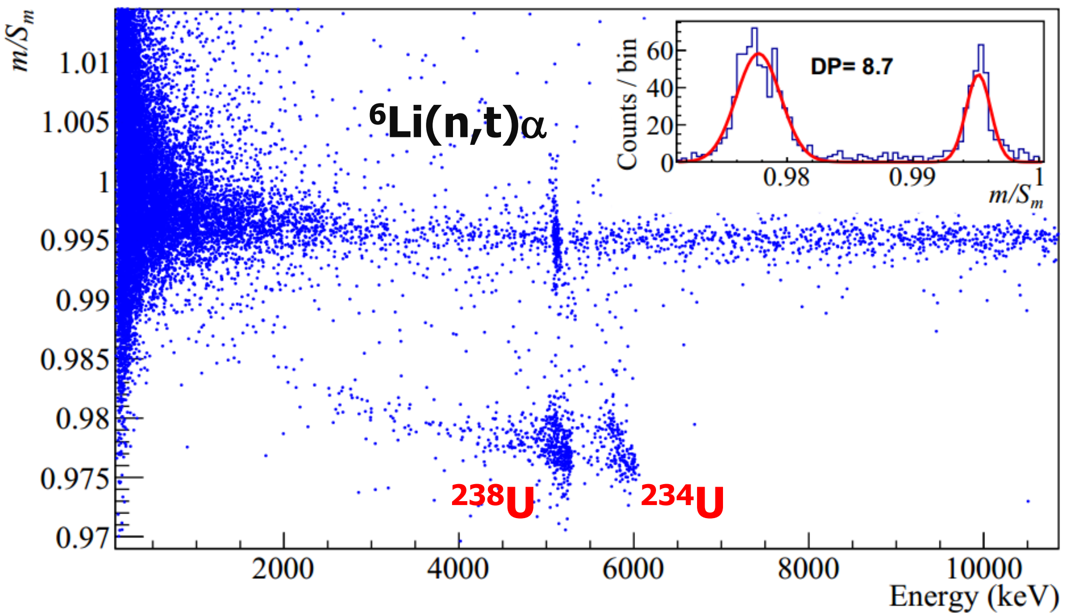


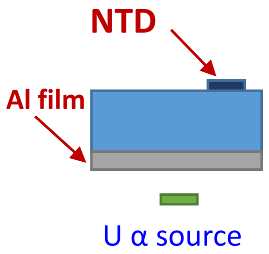
Bolometer (22 mK)	$FWHM_{bsl}$ (keV)	$FWHM_{bsl}$ (keV) no Al	Sensitivity (nV/keV)	Sensitivity (nV/keV) no Al
LMO	**1.86**	1.31	**53**	58
TeO_2	**1.94**	1.53	**43**	48

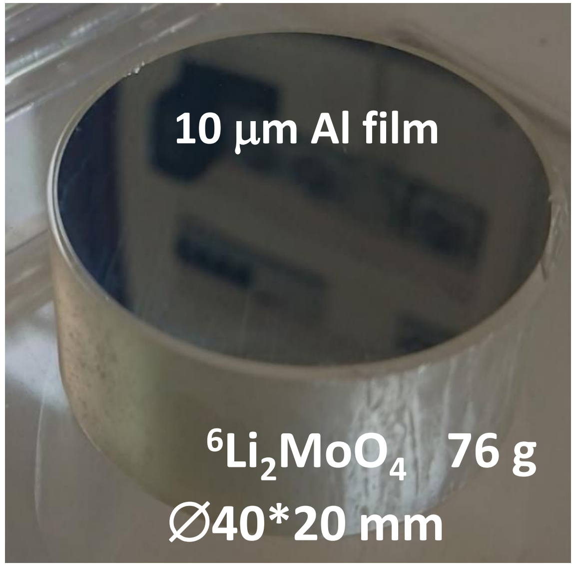


Few-µm-thick aluminum film significantly **improves** the **pulse-shape discrimination** capability for both **bolometers for surface alphas**

Test on a large crystal







Al film works well on a large crystal

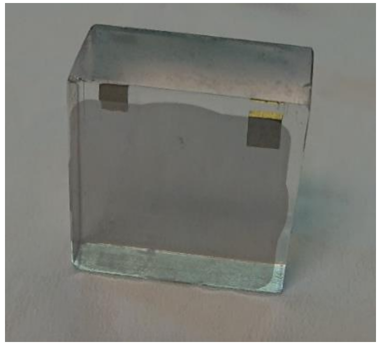
Bolometer	$FWHM_{bsl}$ (keV)	$FWHM_{bsl}$ (nV)	Sensitivity (nV/keV)
LMO-22 mK (m14)	5.7	199	37

Li_2MoO_4 with Palladium film

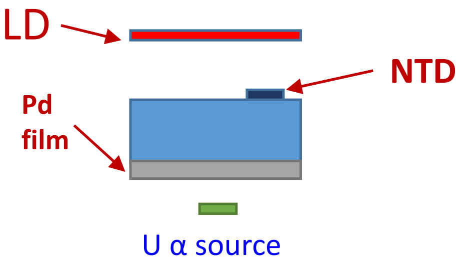
To have a better discrimination (when using NTDs), we rely to have a film that thermalizes faster the athermal phonons

In principle, a normal metal should be a better thermalizer for athermal phonons than a superconductor

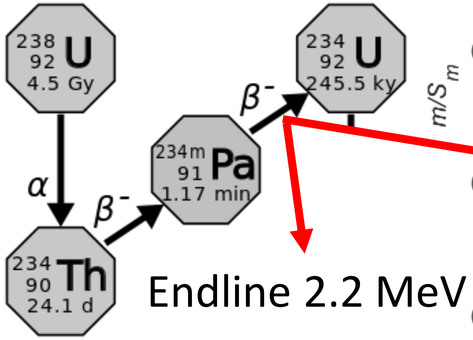
A test was performed on Li_2MoO_4 with 10 nm Pd film coating on one side facing a Uranium alpha source

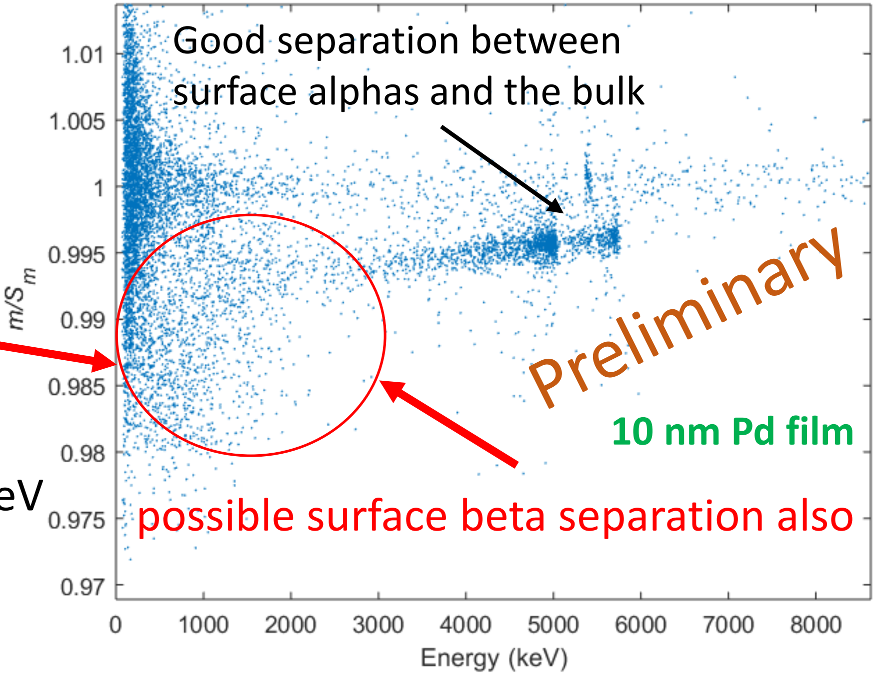


20×20×10 mm³ Li_2MoO_4 + light detector
10 nm thin Pd film
(nm thickness to reduce specific heat capacity of Pd)

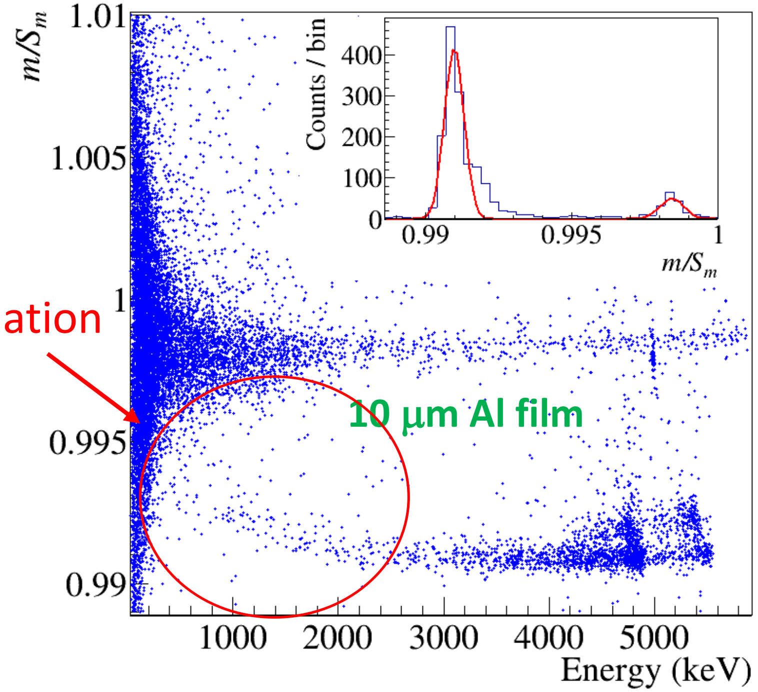


our U α source

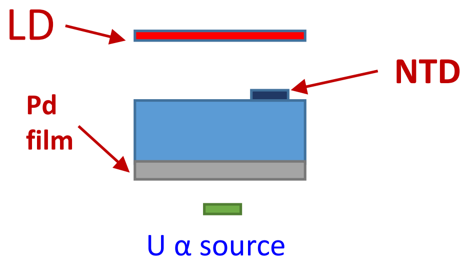




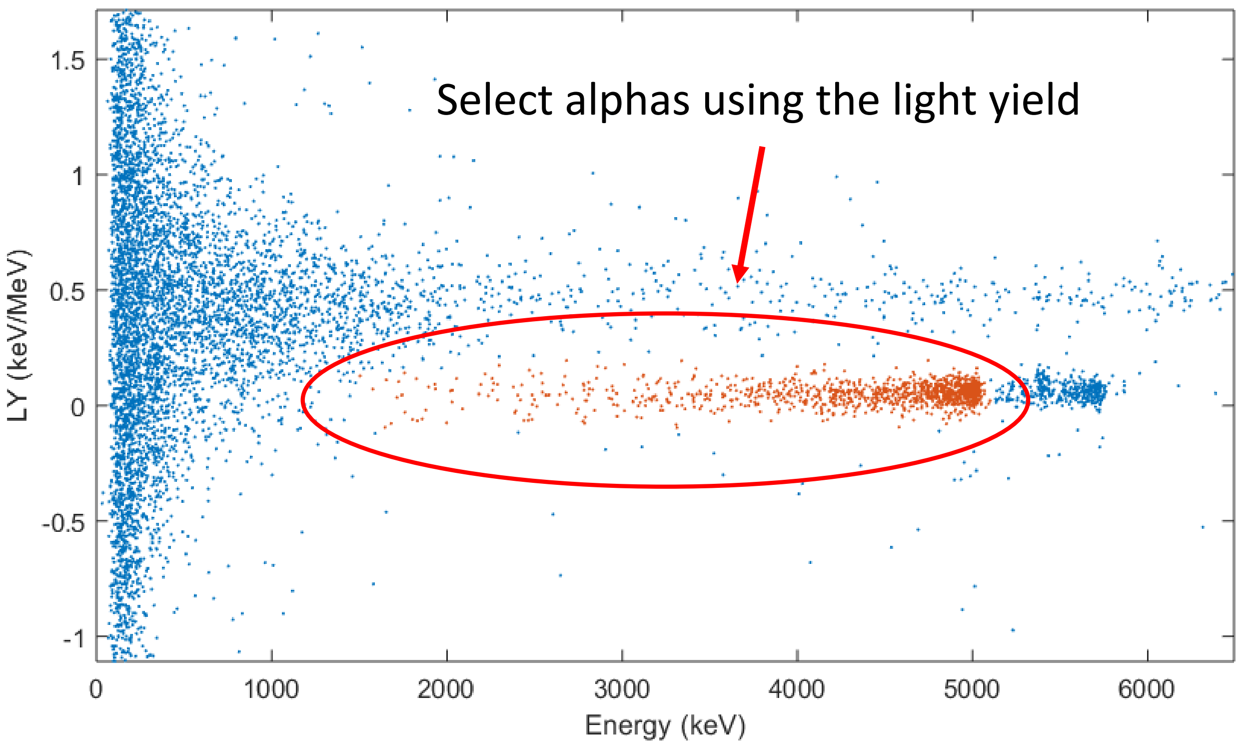
No population



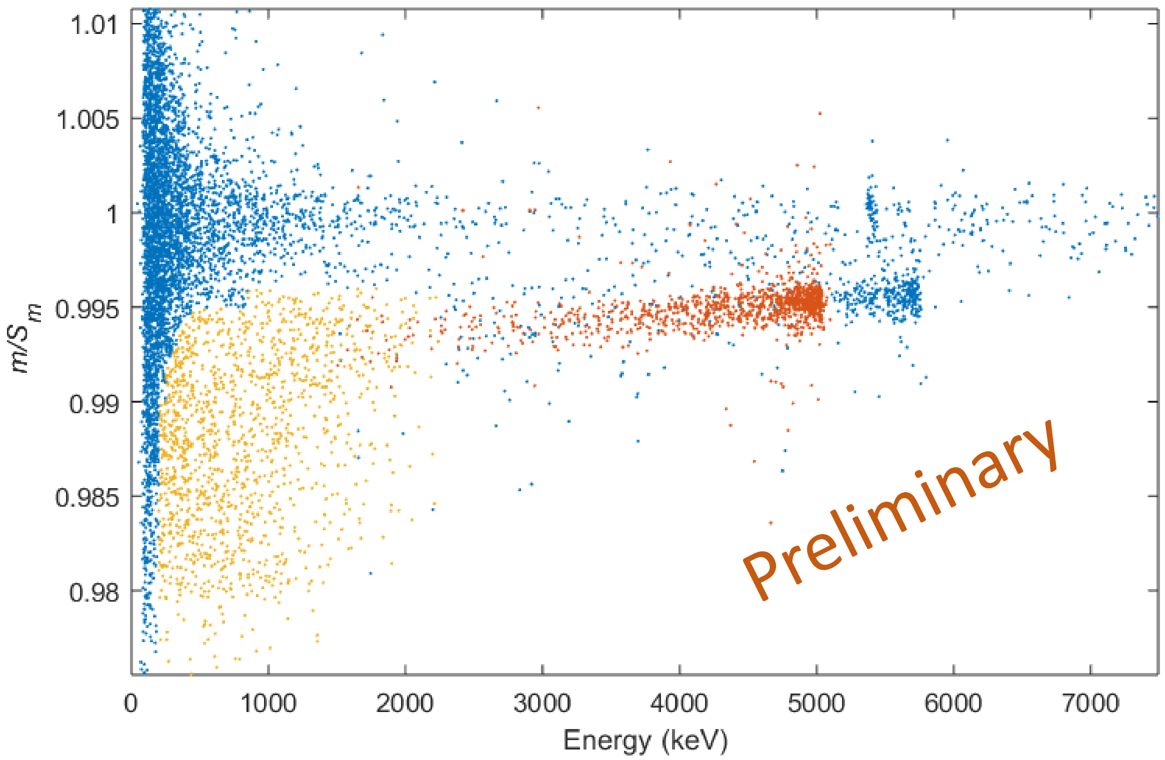
Li_2MoO_4 with Palladium film



Scintillating bolometer (CUPID mode)



Al film bolometer (CROSS mode)

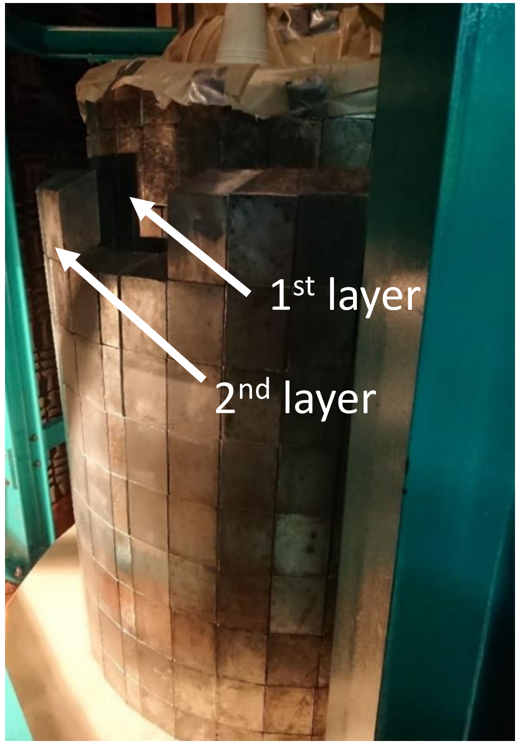


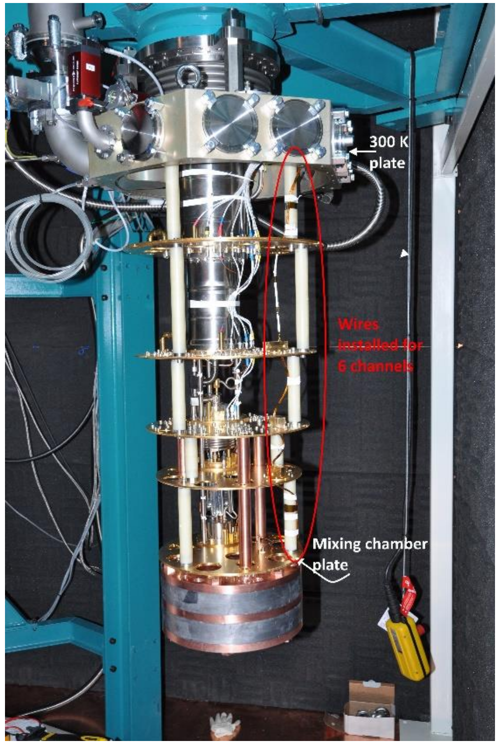
further tests will be performed soon on Li_2MoO_4 fully coated with Pd to confirm our observation

Status of Canfranc cryostat

Commissioning of the CROSS cryostat

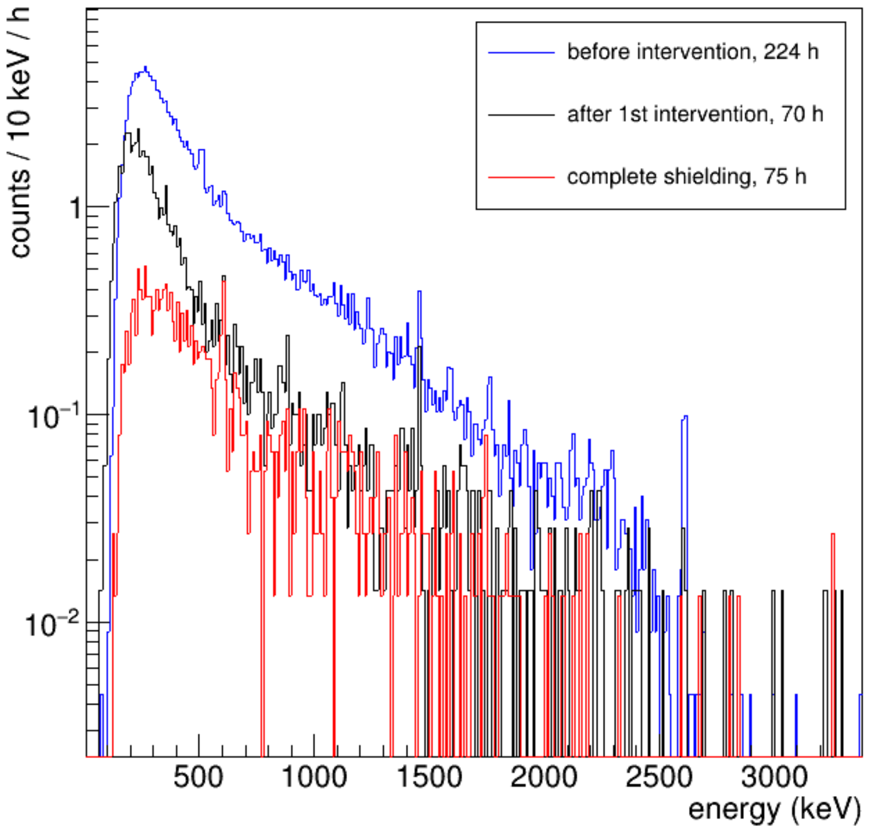
- The CROSS pulse tube cryostat (located in Laboratorio Subtarráneo de Canfranc [LSC]) was installed in April 2019
- Can host up to 90 dual readout bolometers (after upgrade)
- Fabricated with low background materials
- Remote-controlled interface
- Typical powers: 320 uW@100 mK, 6 uW@20 mK, 250 nW@10 mK
- Lead shielding was installed around the outer vacuum chamber (OVC), isolating the detectors from a high fraction of the external γ field

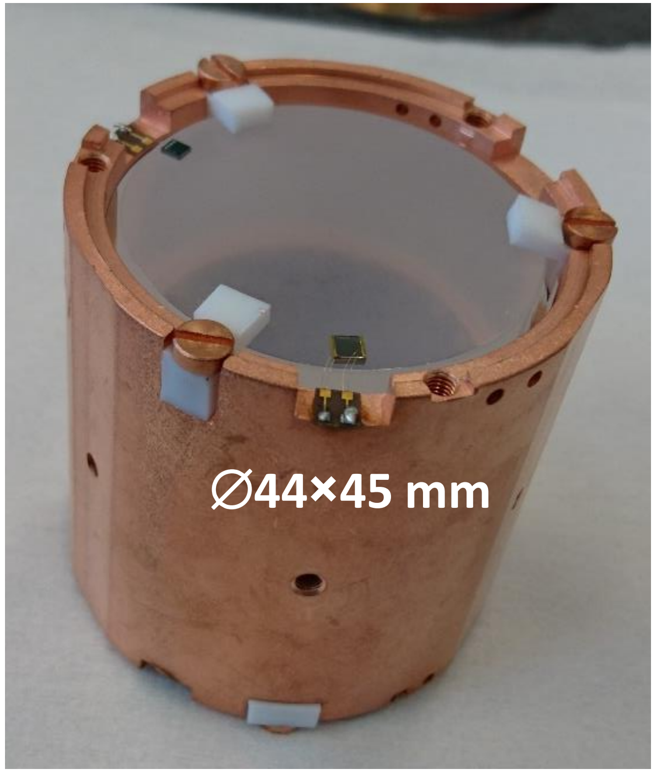




Preliminary detector test

- Natural Li_2MoO_4 scintillating bolometer (mass of 210 g) was running from April tell August 2019 at 10mK (no mechanical suspension of the 10mk plate)





	Sensitivity (nV/keV)	$FWHM_{bsl}$ (keV)
Before inter	**54**	**7.2**
After 1st inter	**50**	**6.8**
After 2nd inter	**78**	**7**

FWHM @ ^{208}Tl 2615 keV = 7.1 keV

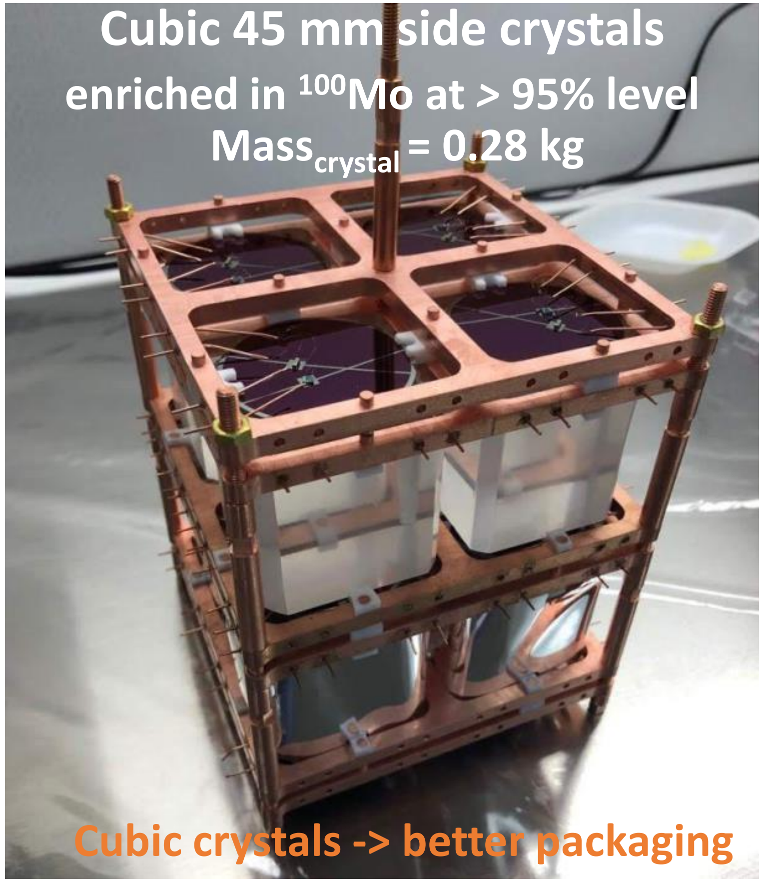
Background level has not been estimated since the experimental volume is not yet fully shielded from the external gamma's

Before intervention: 1 layer of external lead shield around OVC
1st intervention: adding lead shield on the top of the existing lead shield
2nd intervention: adding the 2nd layer of lead around the OVC

In November, a test on this crystal + Al film coating on the lateral surface will be performed (to test discrimination and light collection)

First demonstrator of CROSS

- The planned date of the run: February-March 2020
- 8 $Li_2{}^{100}MoO_4$ crystals, decisions yet to be taken on the detector composition
  - crystals coating and thickness
  - LD coupling
  - NTDs glue
- Crystals coating, copper elements production: November-January 2020
- Detector assembly: January-February 2020
- First results: March 2020

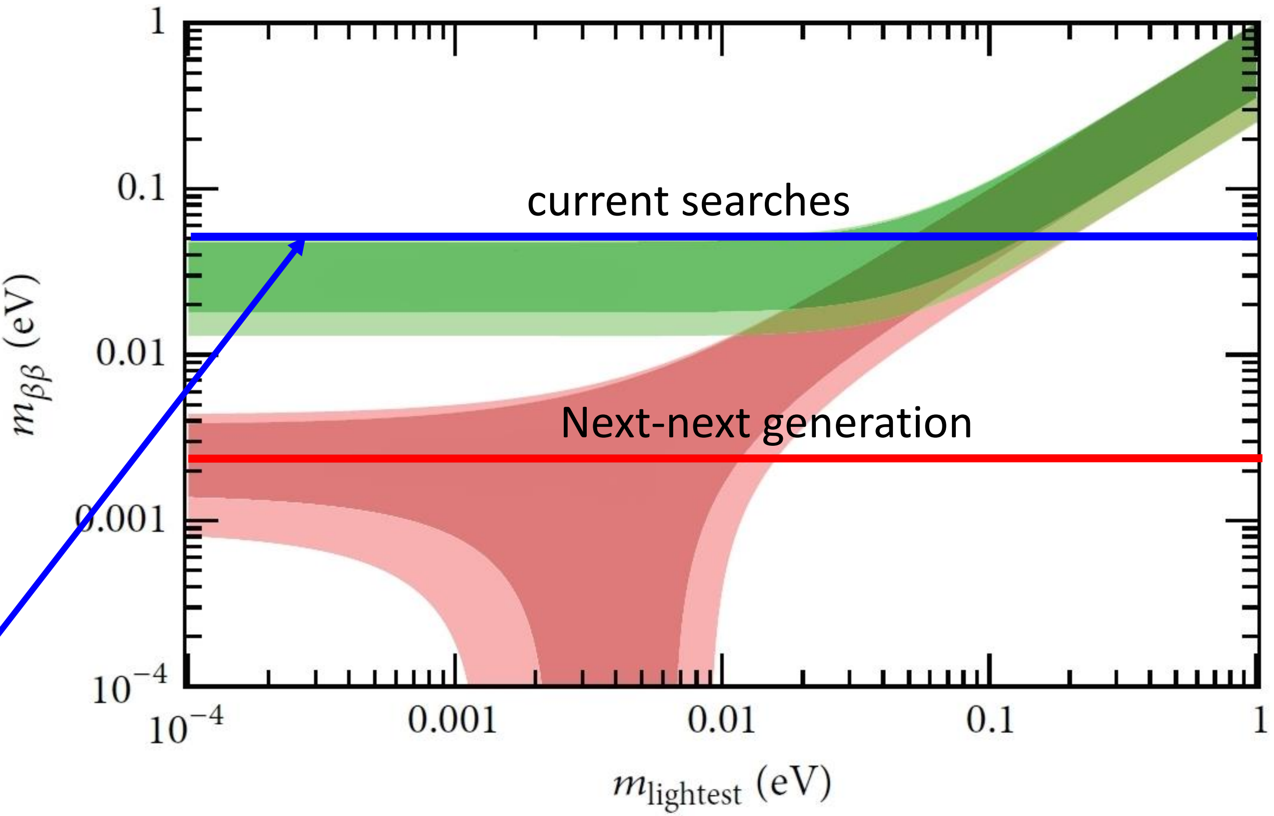


Future medium scale demonstrator of CROSS

- The planned date of the run: 2021
- 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 in the range of 10^{-2}-10^{-3} counts/(keV kg y)

This will test CROSS technique with high statistics and prove the stability and the reproducibility of the CROSS methods

Background level [counts / (keV kg y)]	Live time [y]	Half-life limit [y] (90% c.l.)	$M_{\beta\beta}$ limit [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



Summary and perspective

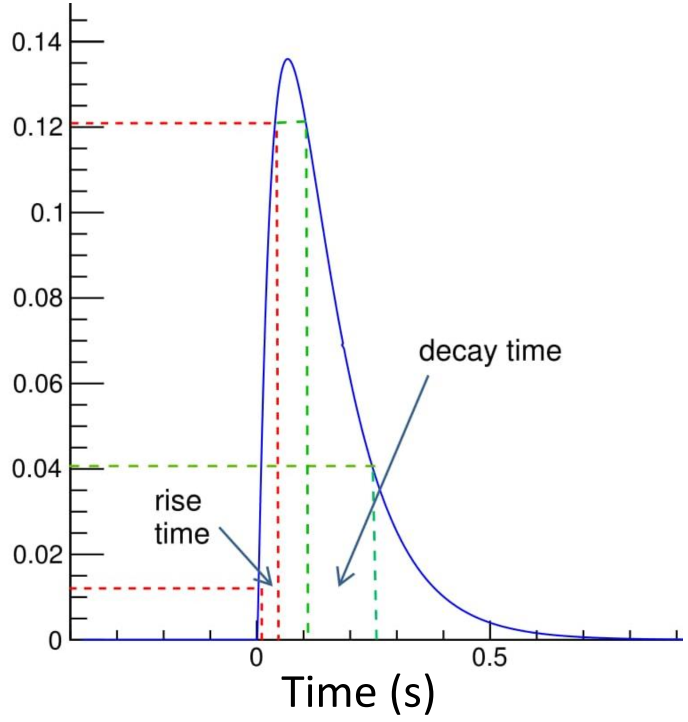
- Next generation $0\nu2\beta$ searches with cryogenic detectors require an active rejection of surface contamination induced background
- Most of the present active R&Ds are devoted to the developments of heat-light dual read-out bolometers for $0\nu2\beta$ searches
- CROSS aims at the development of bolometers capable to reject near surface interaction exploiting surface coating of superconducting Al or Pd films
- This method will allow us to get rid of the light detector, simplifying a lot the bolometric structure
- Prototype tests on fully coated crystals is foreseen (Nov-Dec 2019)
- A mid-scale experiment to be installed underground in the Canfranc laboratory

Thanks for your attention

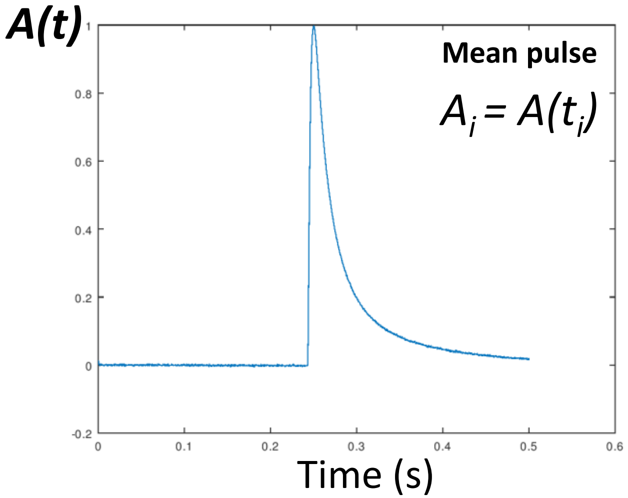
Particle identification parameters

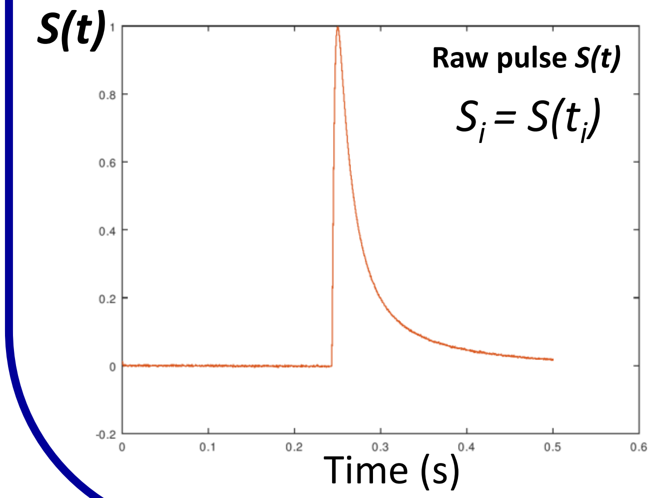
Rise-time

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

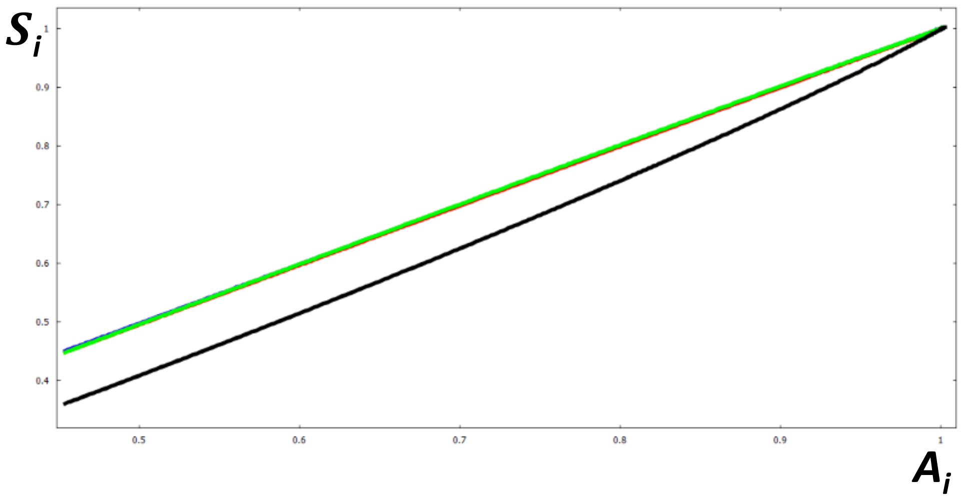


PSD parameter= m/S_m



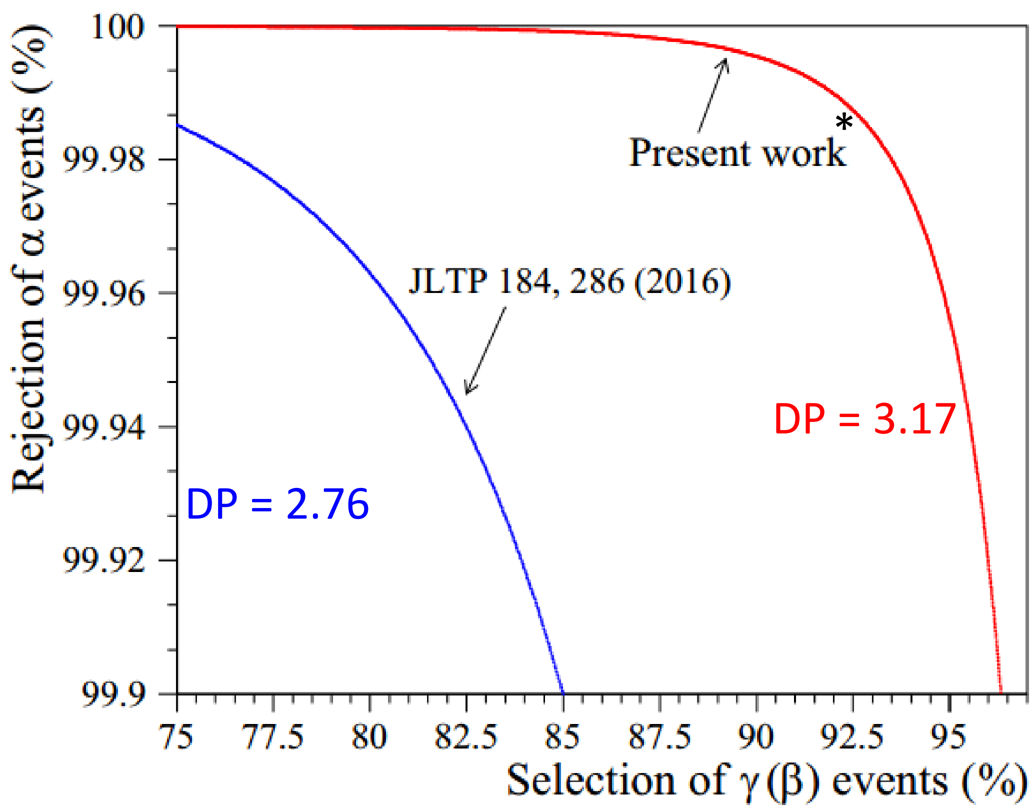


The pulses are synchronized according to their maximum position



Linear fit : $S_i = mA_i + q$

The slope is the PSD parameter



* PHYSICAL REVIEW C **97**, 032501(R) (2018)