CROSS experiment

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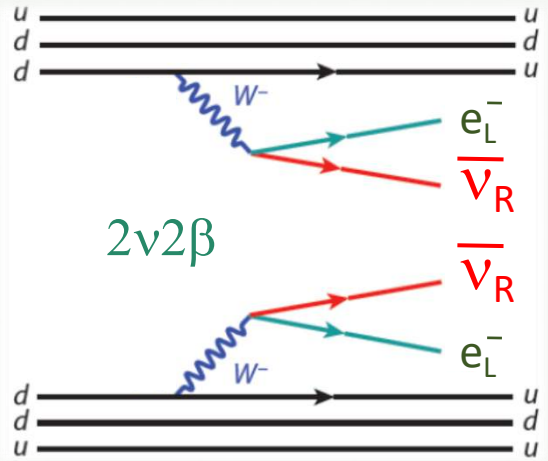
on behalf of the CROSS collaboration

GDR Deep Underground Physics kick-off meeting, 31 May 2021

Double beta decay

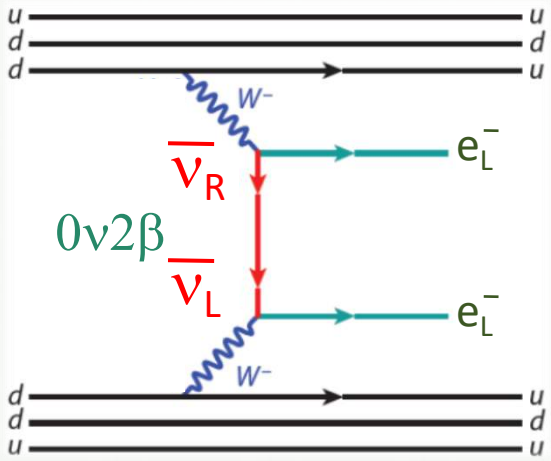


$(A,Z) \rightarrow (A,Z+2) + 2e^- + 2\bar{\nu}_e$

Rarest observed nuclear decay

Observed in 11 isotopes

$T_{1/2}(2\nu2\beta) \sim 10^{18}\text{-}10^{24}$ yr



$(A,Z) \rightarrow (A,Z+2) + 2e^-$

Never observed

Total lepton number violation → **new physics beyond SM**

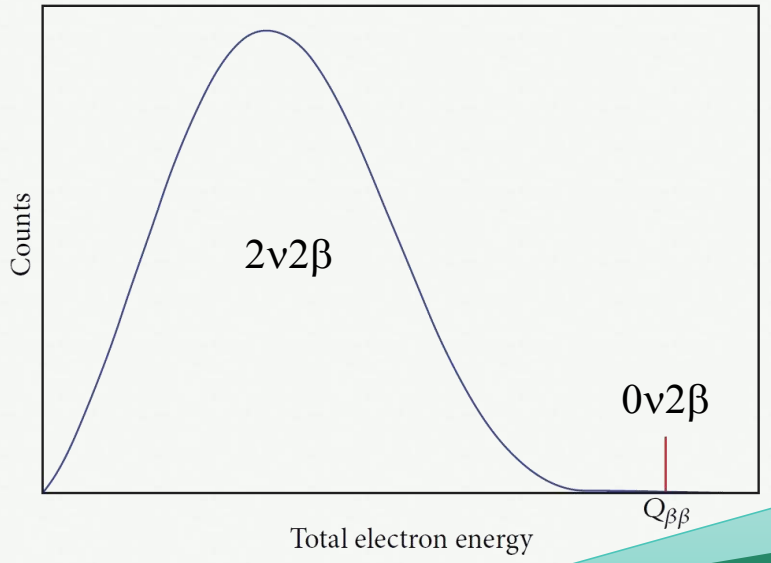
$T_{1/2}\ (0\nu2\beta) > 10^{25}\text{-}10^{26}$ yr

If $0\nu2\beta$ is observed, neutrino is a **Majorana particle**:

$$\nu \equiv \bar{\nu}$$

Lepton number violation → leptogenesis → **matter-antimatter asymmetry**

Information on neutrino masses



Background sources and 2β isotope choice

- Cosmic muons, neutrons
- Environmental γ's, α's and β's
- $2\nu2\beta$ decay

Background sources and isotope choice

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Underground lab, Radiopurity, Shielding

High energy resolution (**bolometers**), 2β isotope with low $2\nu2\beta$ rate

Choose **high Q-value** (> 2.6 MeV) isotopes

Develop **advanced detectors** with particle and impact-point identification

Background sources and isotope choice

- Cosmic muons, neutrons
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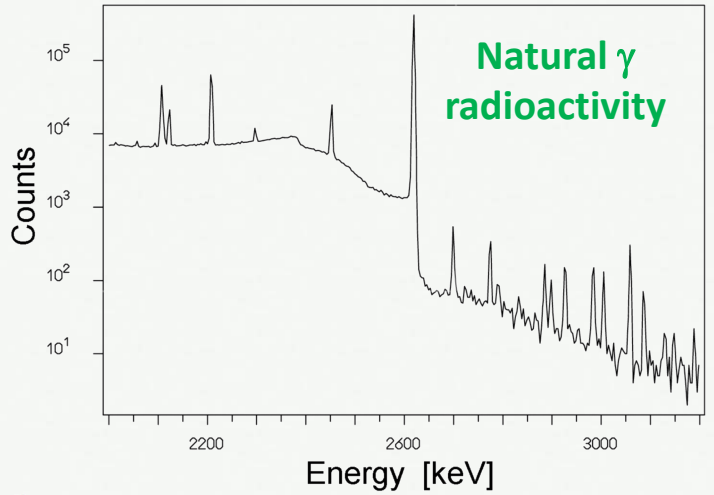
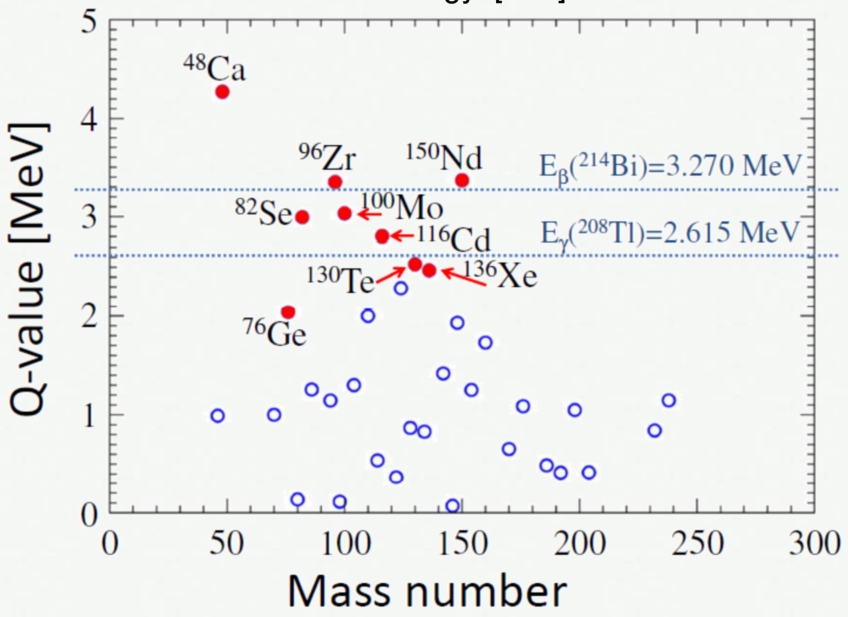
- 2ν2β decay

Develop **advanced detectors** with particle and impact-point identification





β surface radioactivity

^{238}U chain → ^{214}Bi Q_β = 3.3 MeV

(^{210}Tl Q_β value: 5.5 MeV; 0.02% ^{214}Bi)

$^{214}Bi \xrightarrow{\beta} {}^{214}Po \xrightarrow[164\ \mu s]{\alpha} {}^{210}Pb$

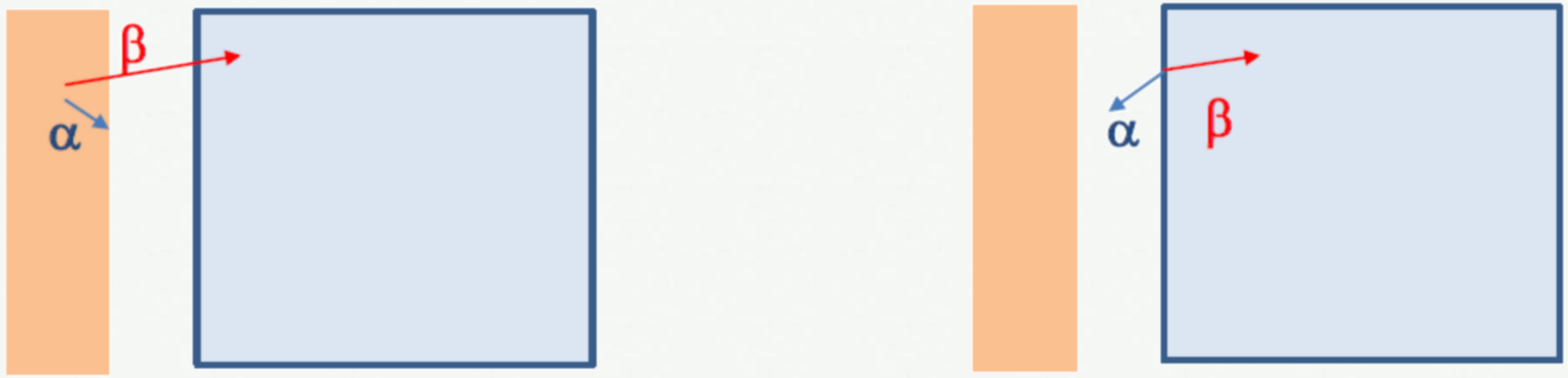
Harmless in the crystal bulk
Mixed α/β event

^{232}Th chain → ^{208}Tl Q_β = 5.0 MeV

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

Under control in the crystal bulk
Delayed coincidence

These processes become challenging at the surface → it may happen that α escapes detection and β is (partially) absorbed



Background goals: CUPID and beyond

$$(T_{1/2}^{0\nu2\beta})^{-1} = G^{0\nu}(Q,Z)\,|M^{0\nu}|^2 \frac{m_{\beta\beta}^2}{m_e^2}$$

Bkg rate in ROI ~ b × M × ΔE_{FWHM}

ΔE_{FWHM} ~ 5-10 keV for bolometers

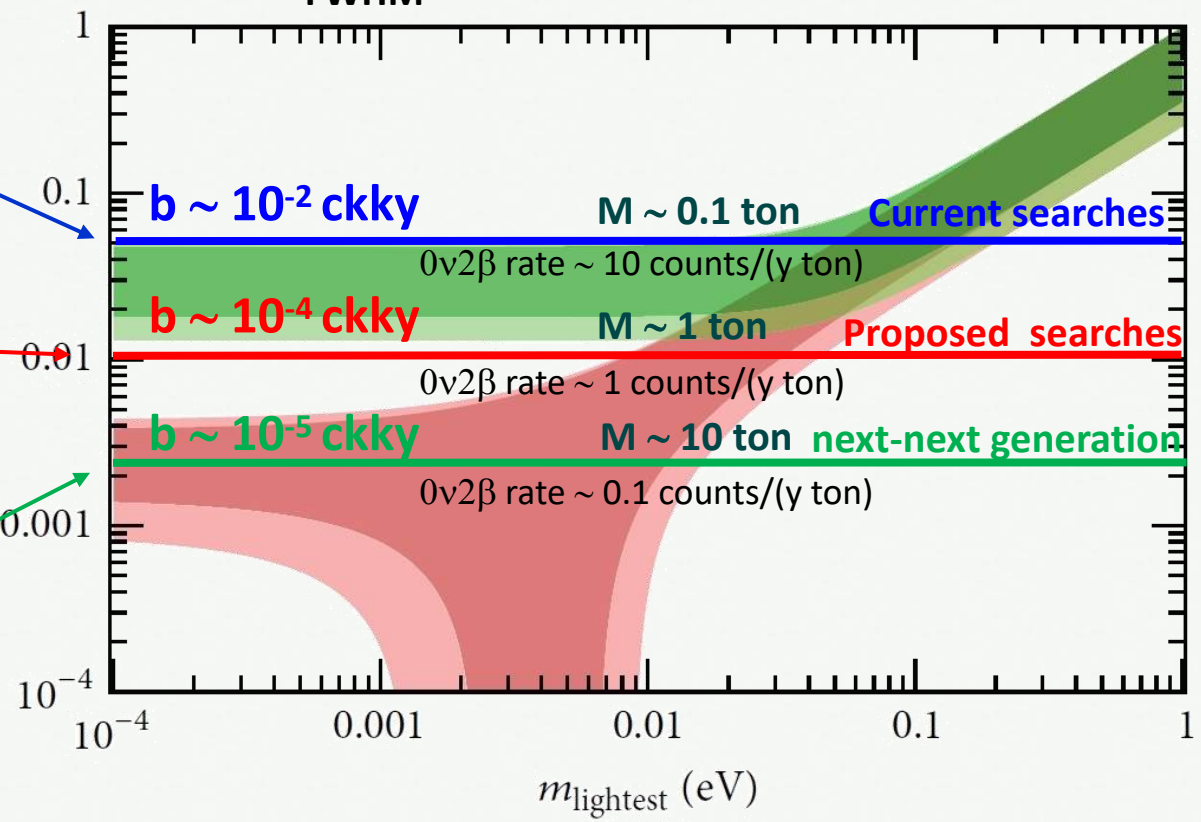
Pure bolometer: CUORE
Background dominated by surface α's

Reject α's + $Q_{2\beta}$>2.6 MeV

Scintillating bolometer: CUPID
Important contribution from surface β's

Reject surface α's & β's + $Q_{2\beta}$>2.6 MeV

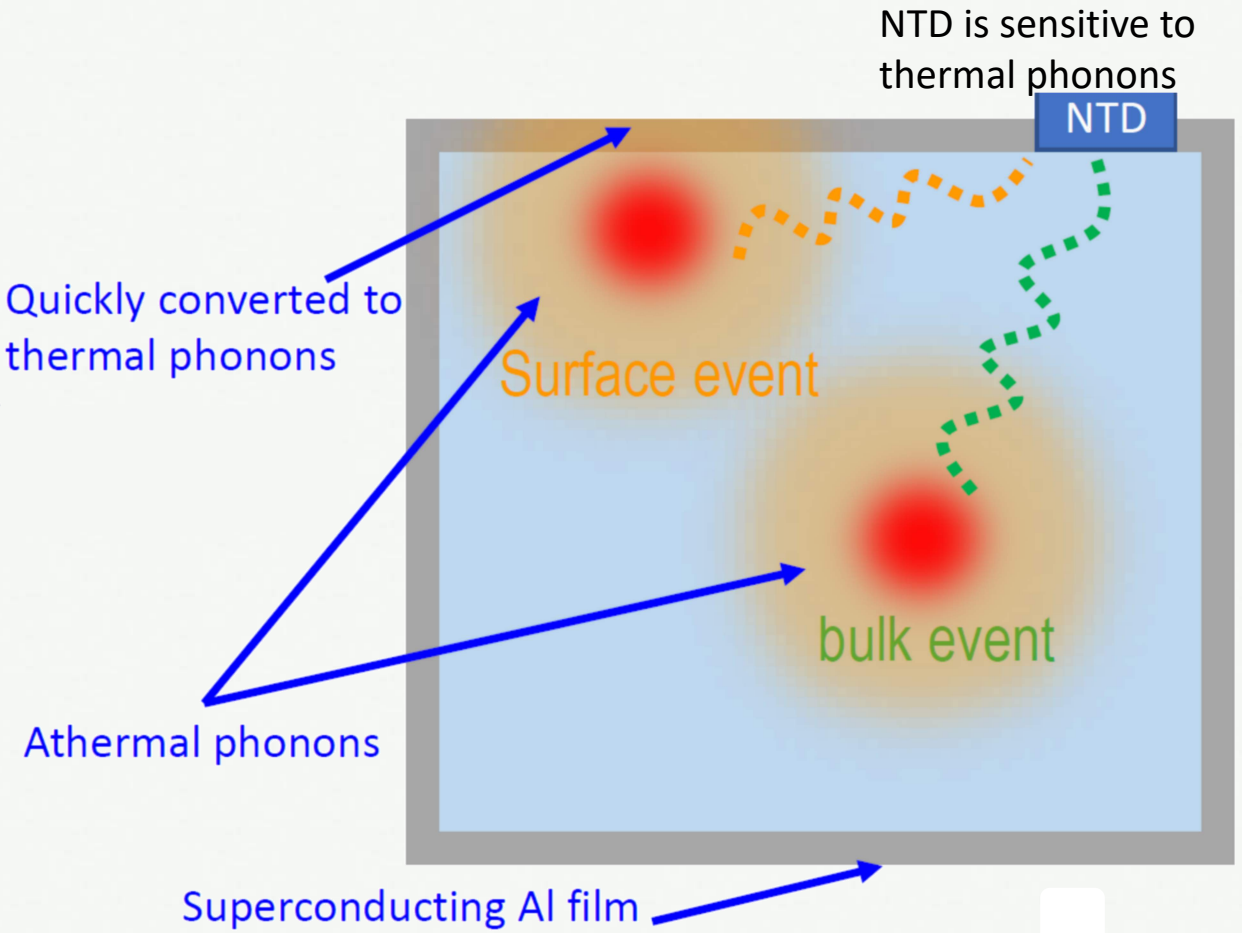
Surface sensitive bolometer: CUPID-like experiment with CROSS technology

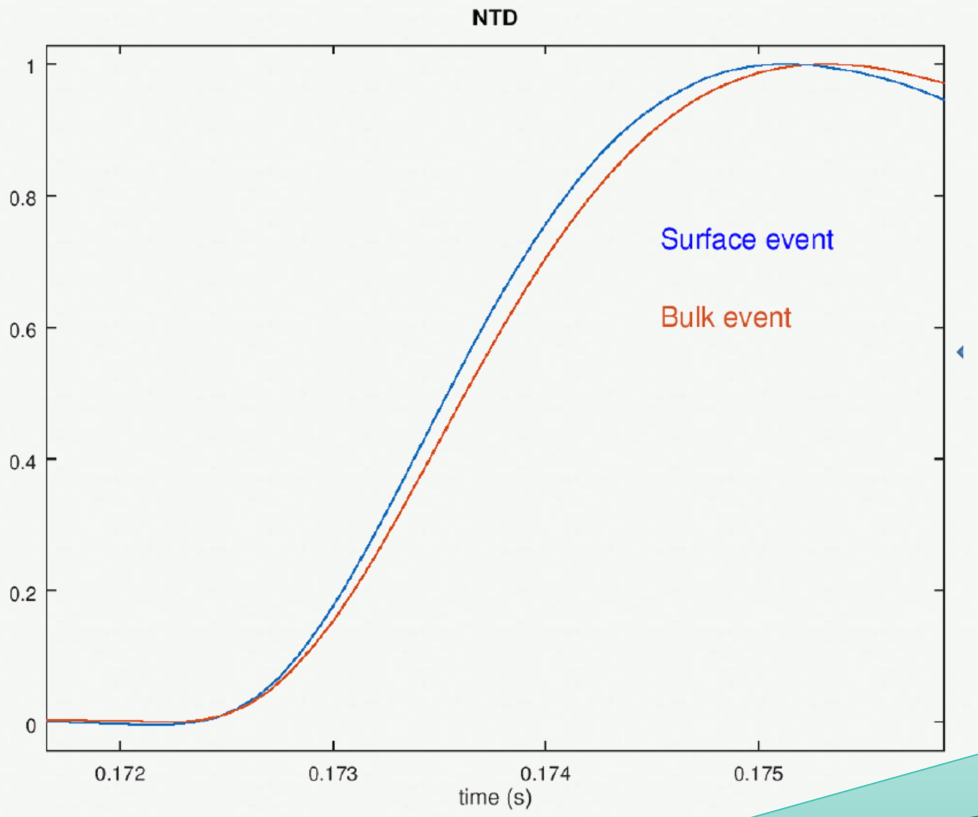


ckky = counts/keV/kg/yr

CROSS technology: surface sensitivity

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





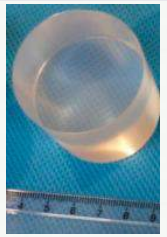
CROSS isotopes and bolometers

^{100}Mo - primary choice: **$Q_{2\beta}$ = 3034 keV** **isotopic abundance = 9.7%**

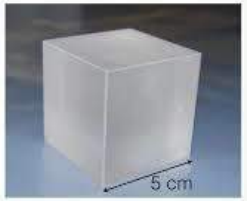
^{130}Te - kept as an option: **$Q_{2\beta}$ = 2527 keV** **isotopic abundance = 34%**

Crystals:

Li_2MoO_4 - basic choise for CUPID



TeO_2 - CUORE compound



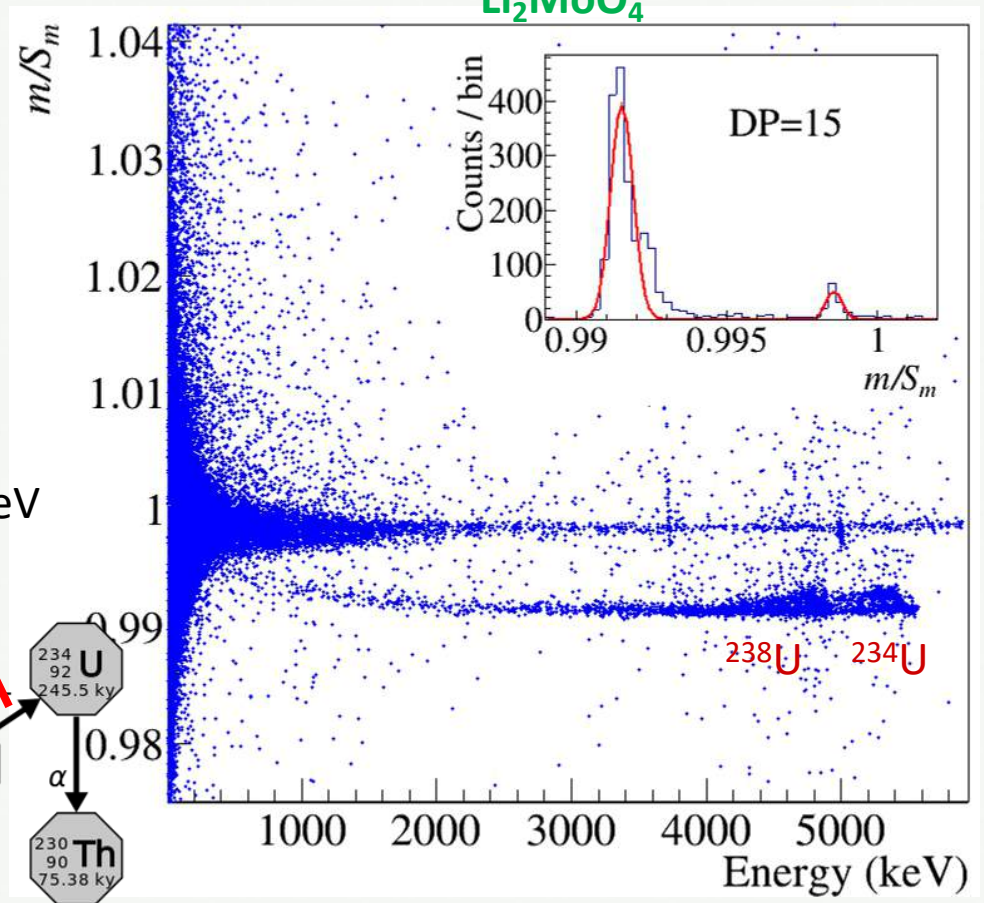
Excellent bolometric properties
High radiopurity
Extensively tested

JHEP 2020, 018 (2020)

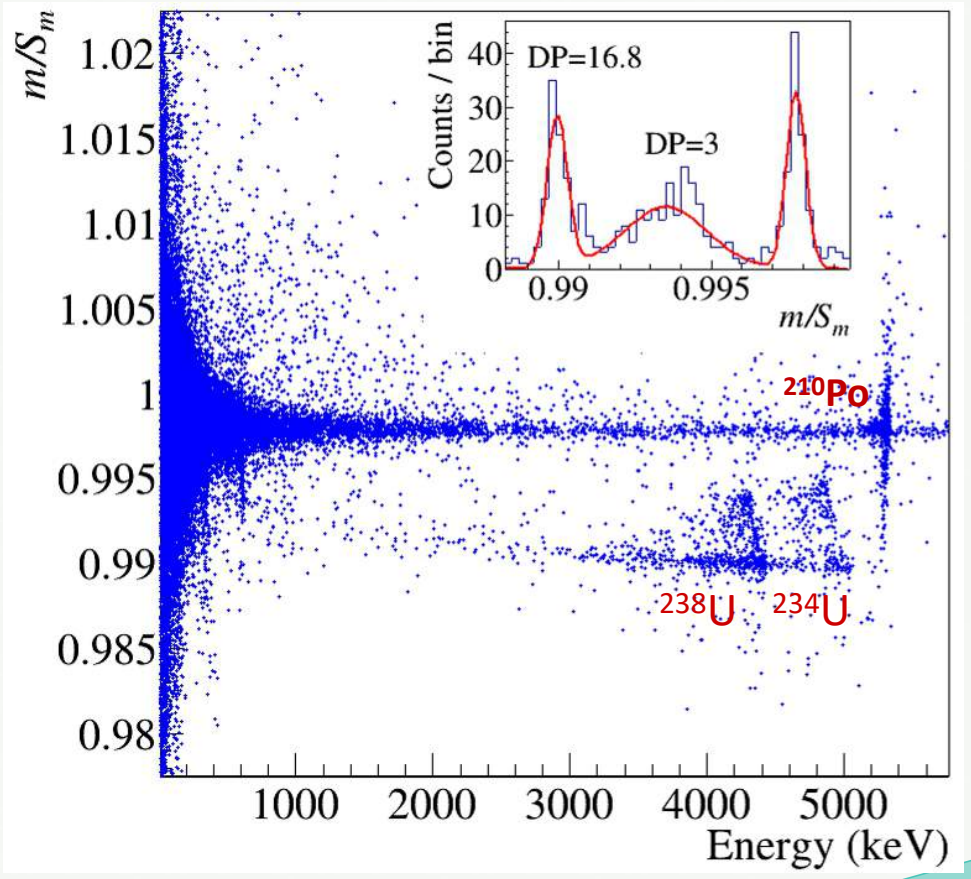
CROSS prototypes: 10 um Al coating

- Prototypes are tested in aboveground tests (IJCLab) with coating on one face, irradiated than by a U source

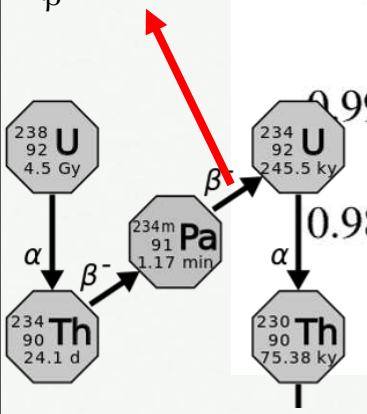
Li_2MoO_4



TeO_2



Q_β= 2.2 MeV



Discrimination power:

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

JHEP 2020, 018 (2020)

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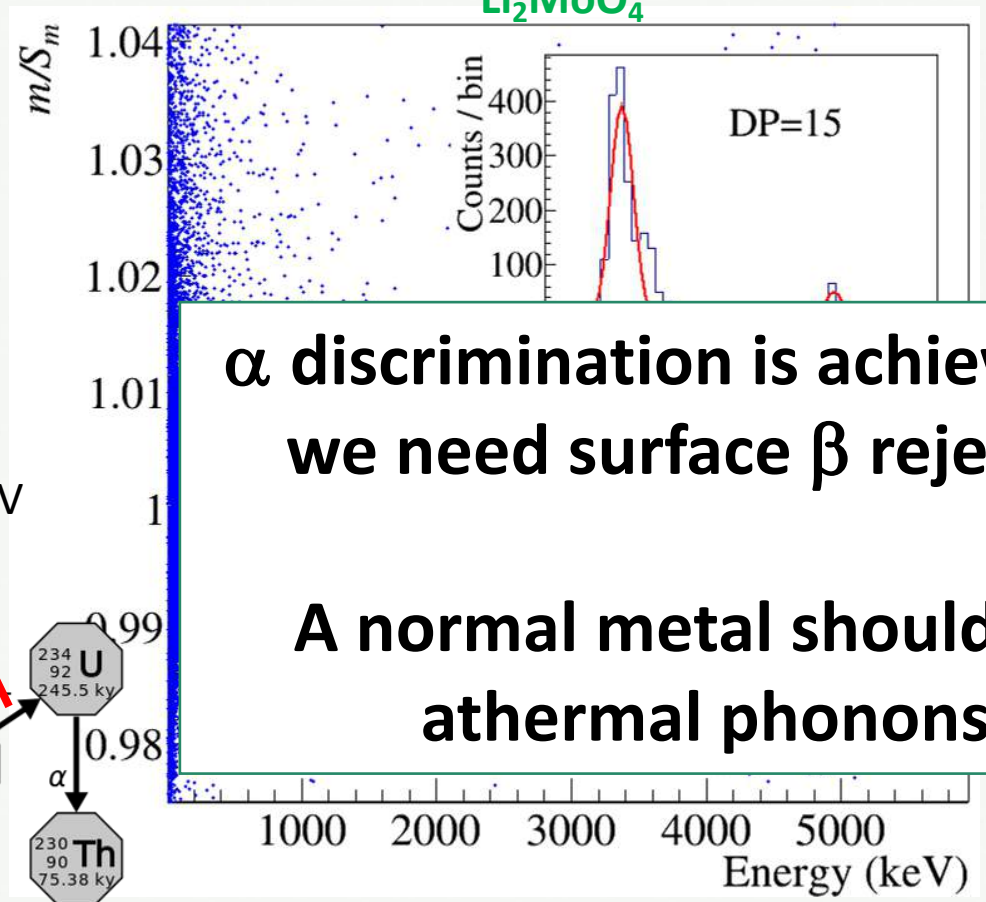
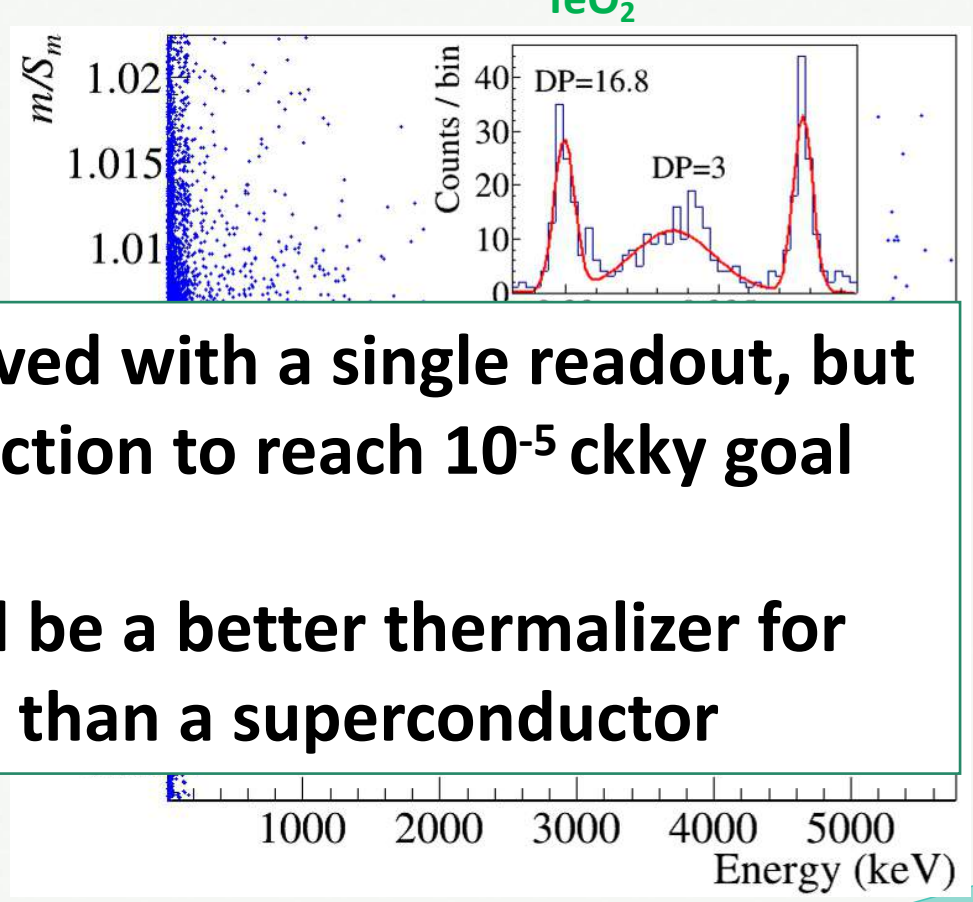
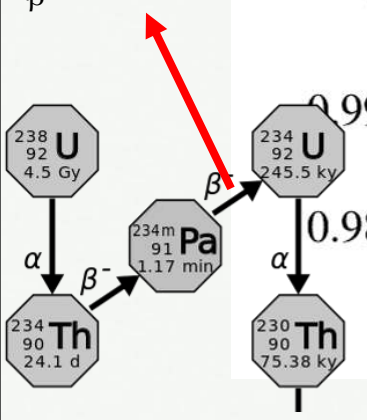




α discrimination is achieved with a single readout, but we need surface β rejection to reach 10^{-5} ckky goal

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

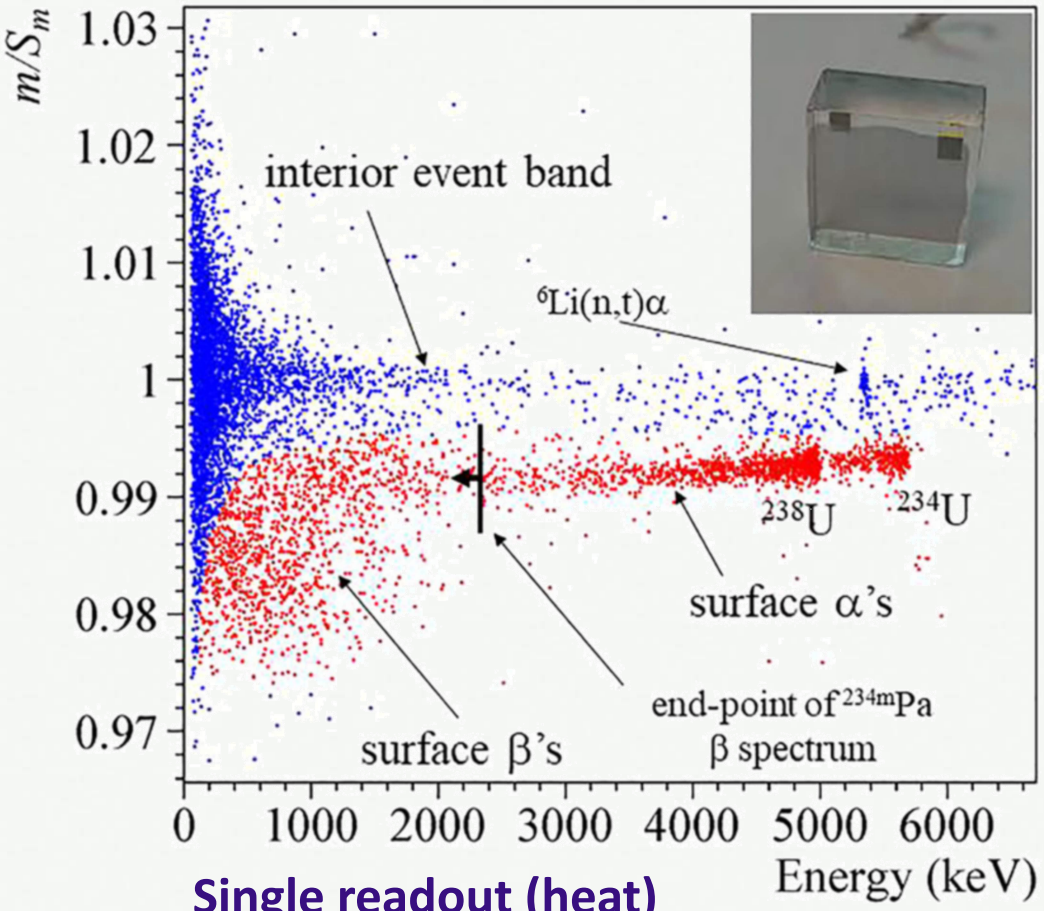


Discrimination power:

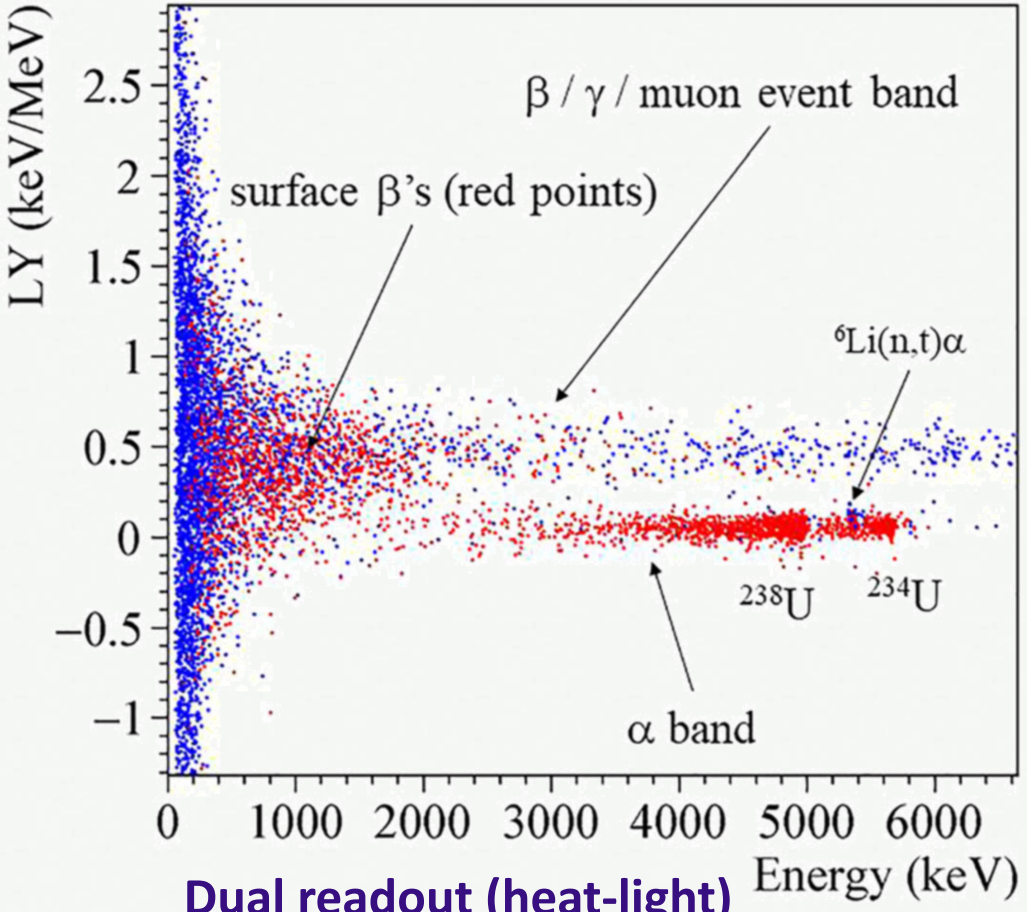
$$DP=\frac{|\mu_{\beta/\alpha}-\mu_{\alpha}|}{\sqrt{\sigma^2_{\beta/\gamma}+\sigma^2_{\alpha}}}$$

CROSS prototypes: 10 nm Pd coating

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



Single readout (heat)



Dual readout (heat-light)

Appl. Phys. Lett 118, 184105 (2021)

CROSS prototypes: Al-Pd coating

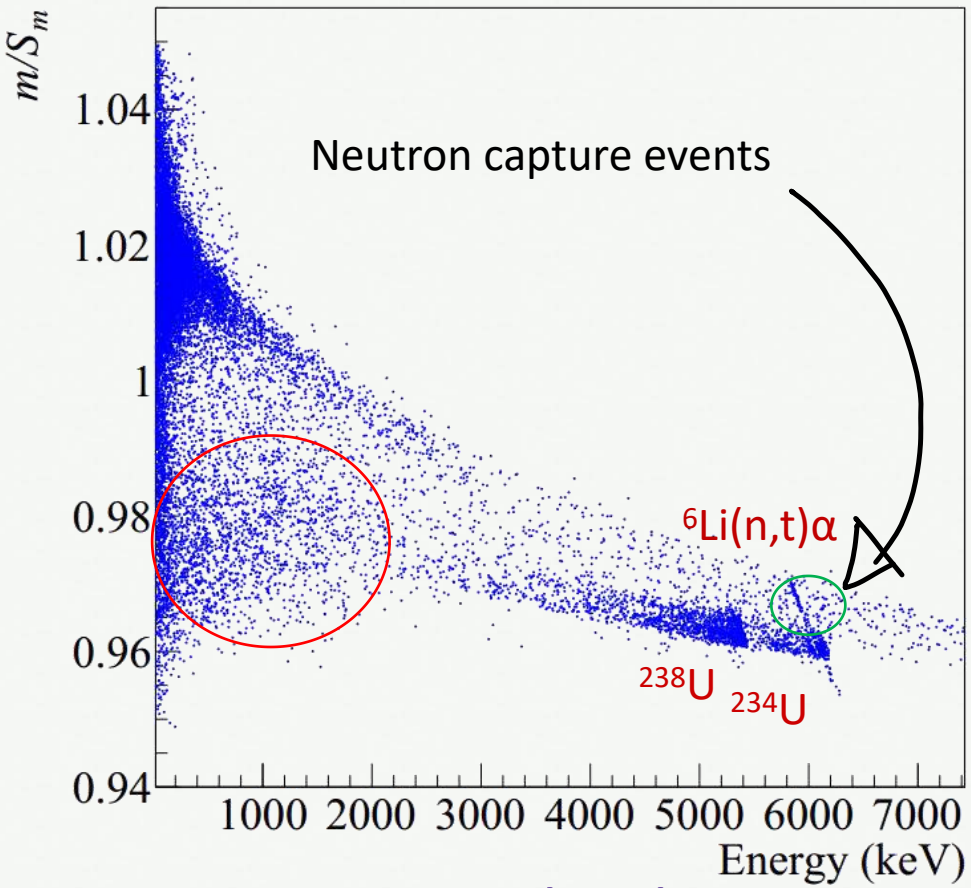
- We want to keep Pd because it showed surface beta separation, **but the heat capacity of Pd should be reduced…how?**
  With proximity effect!

- **Evaporate superconducting Al layer on the Pd film**

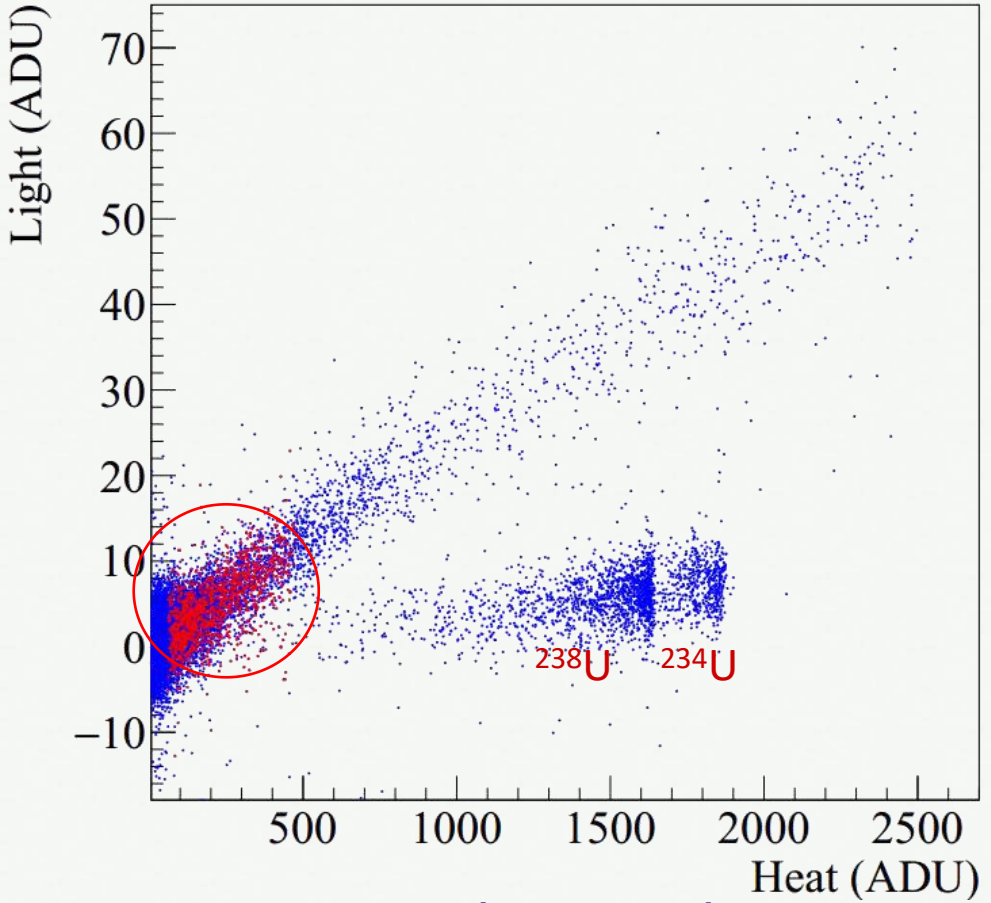
  With the appropriate thickness of Al, at low temperature below the critical temperature, **Al film will introduce superconductivity in Pd film reducing the heat capacity**

CROSS prototypes: Al-Pd coating

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



Single readout (heat)



Dual readout (heat-light)

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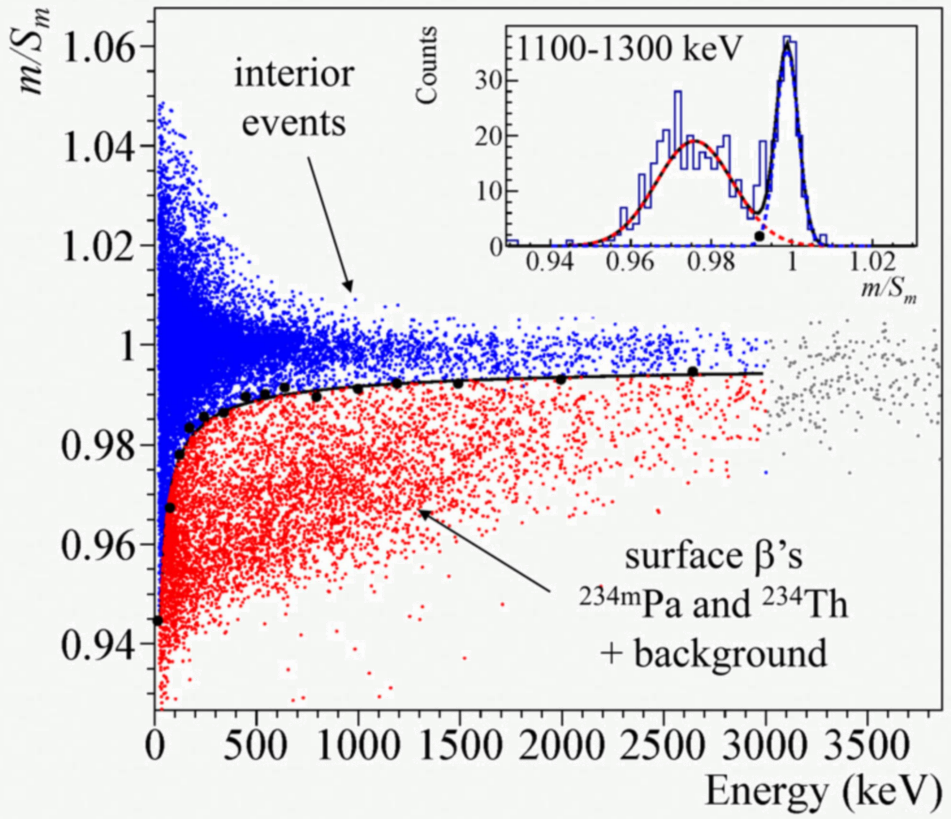
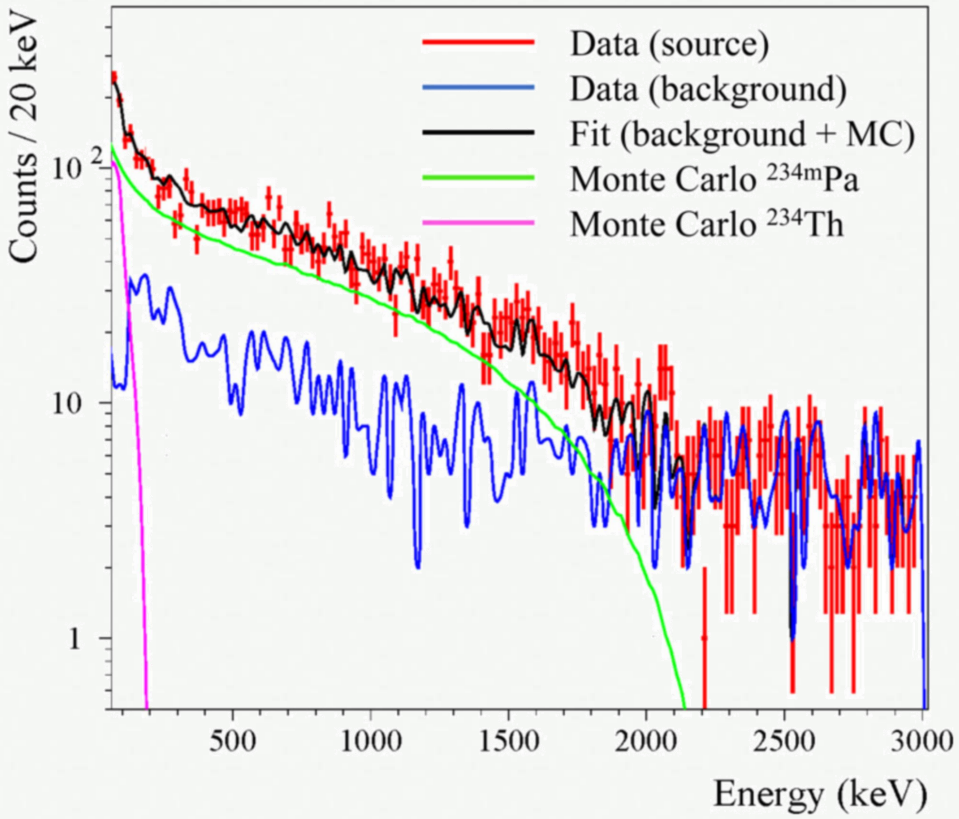
Fitting the β spectrum with MC model



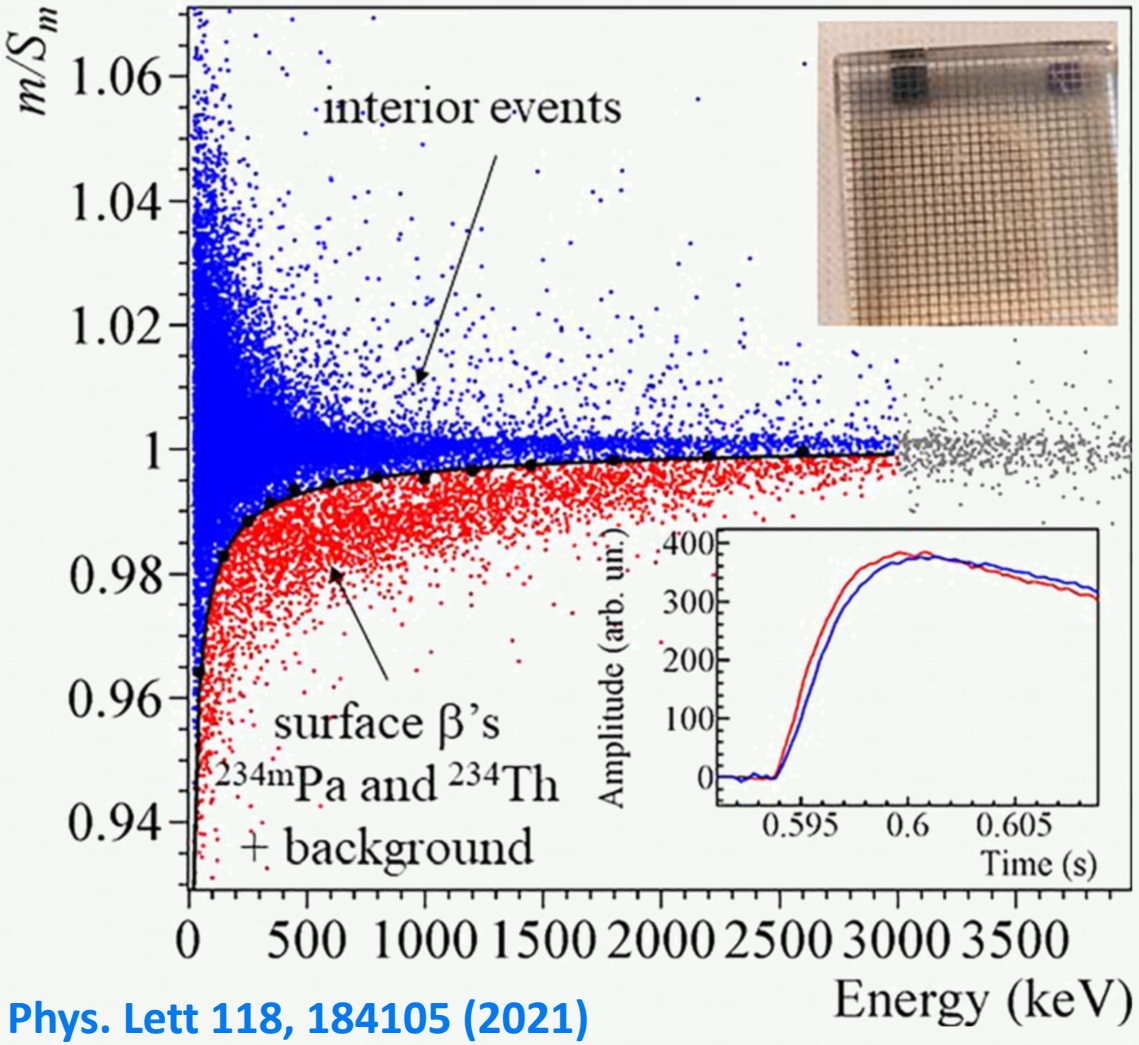


- Beta events were selected from the runs with a source. These events contains also background
- Background was selected from the run without a source
- MC simulation was performed to get the beta spectrum of ^{234m}Pa
- Our beta spectrum is well **fitted with a model** (MC+bkg)

Appl. Phys. Lett 118, 184105 (2021)

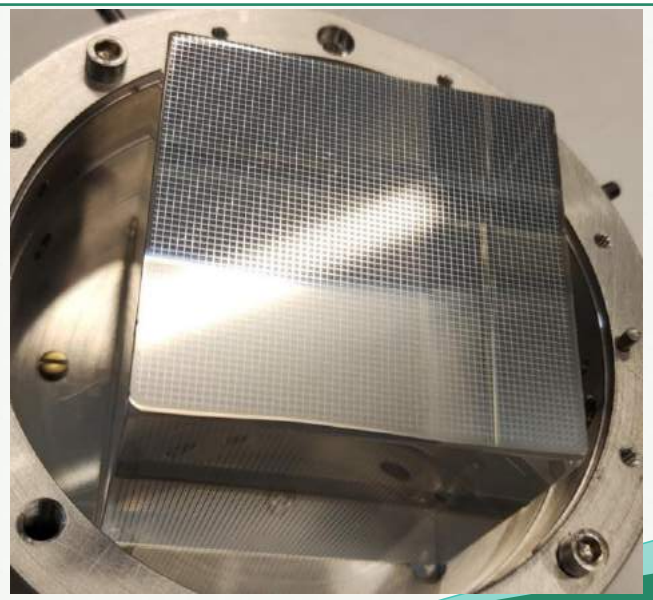
CROSS prototypes: Al-Pd grids

- Grids allow to reduce amount of material for coating, but keep PID



Prototype confirmed!

Further steps: massive crystals, bigger scale confirmation of PID capability.



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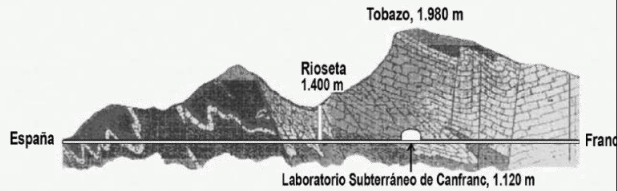
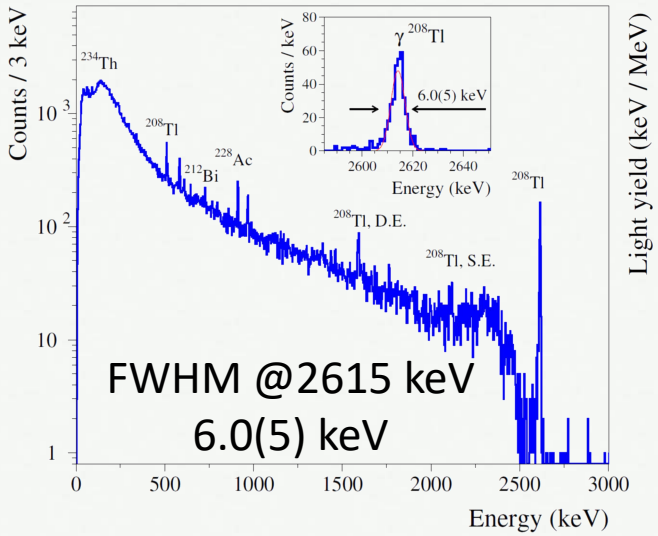
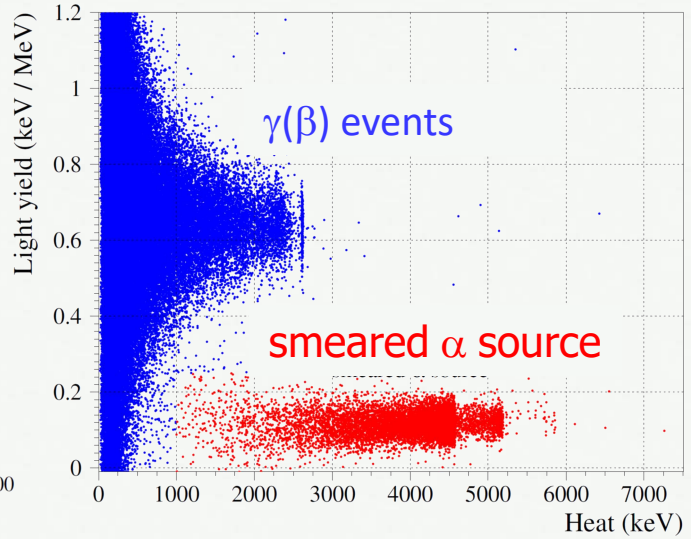
CROSS underground facility



- Cryostat installed and commissioned 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.





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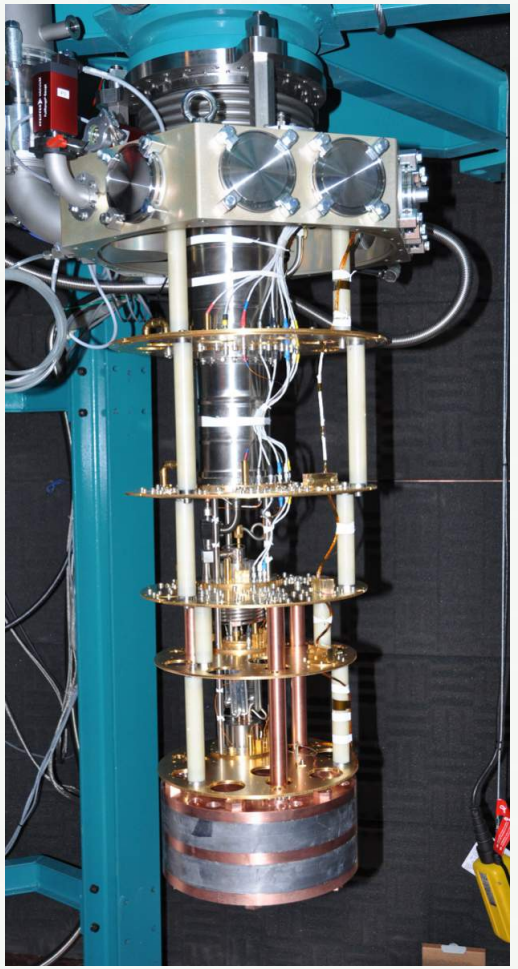
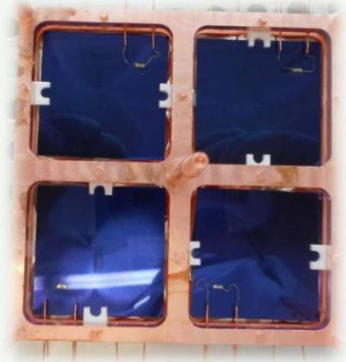
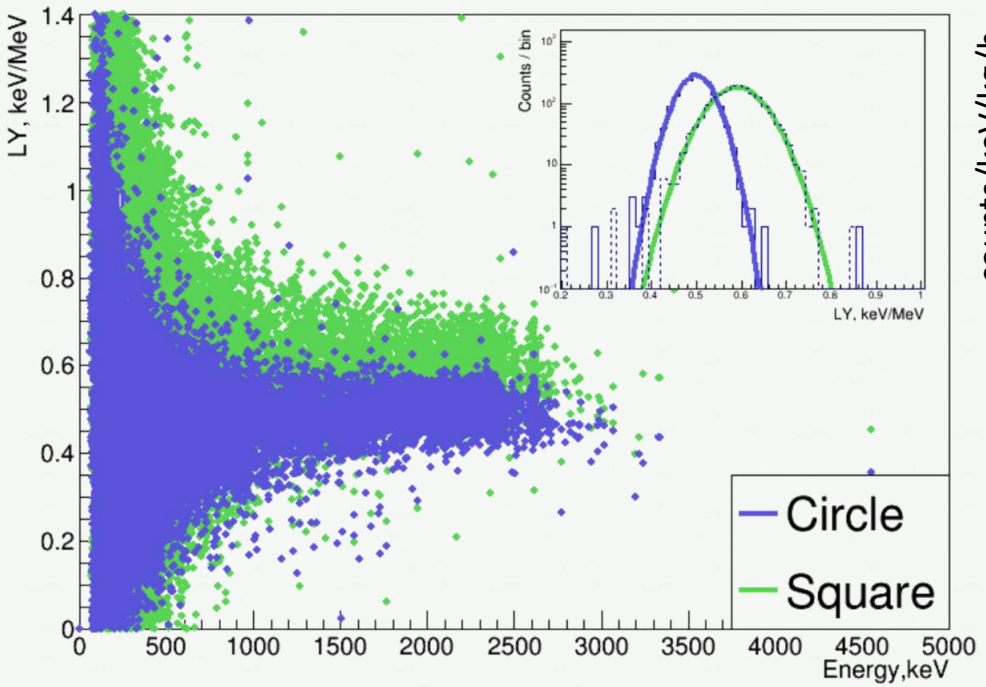
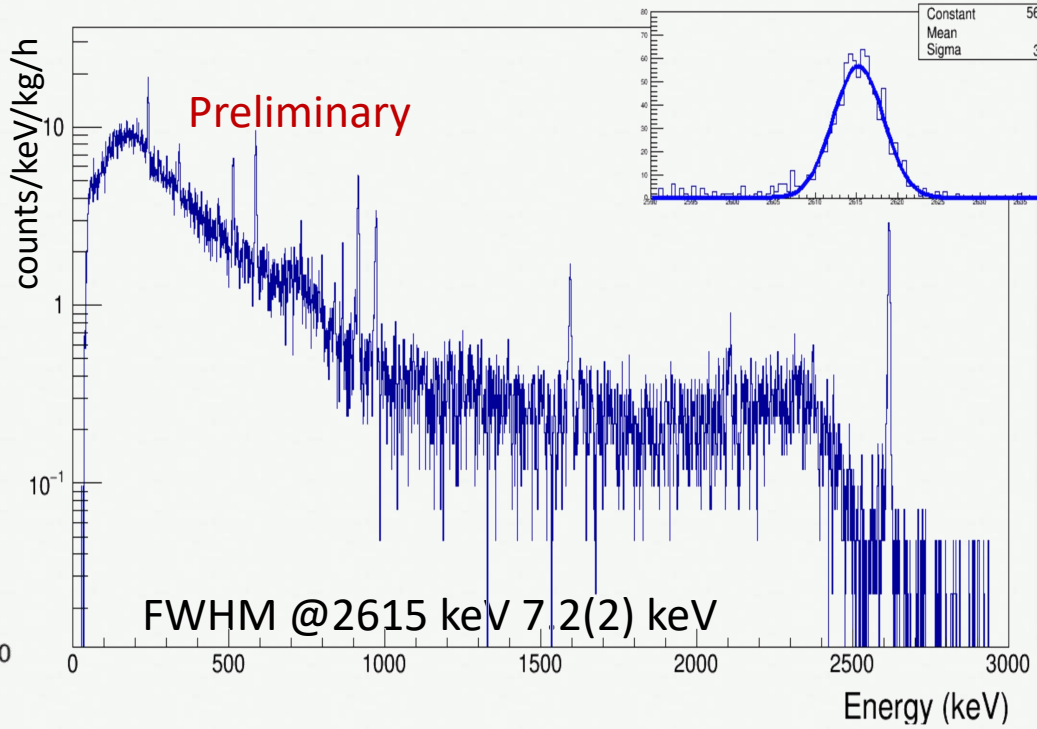


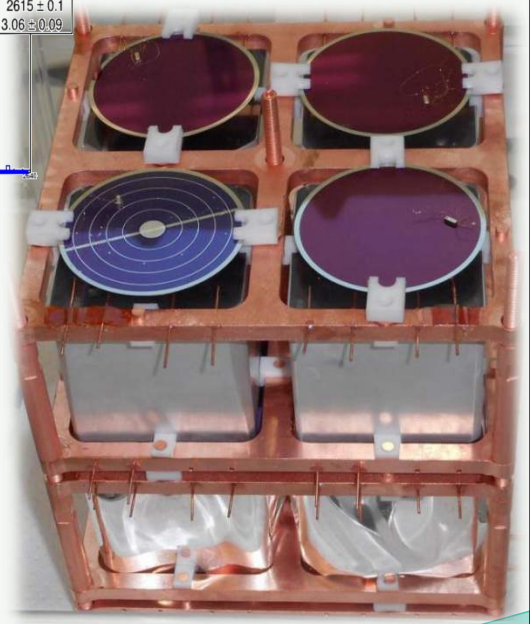
Joint CROSS/CUPID measurements

- Joint CROSS/CUPID run with 12 $Li_2{}^{100}MoO_4$ crystals ~280 g each and 16 Ge light detectors
- Study of different configurations to compare light collection and performances

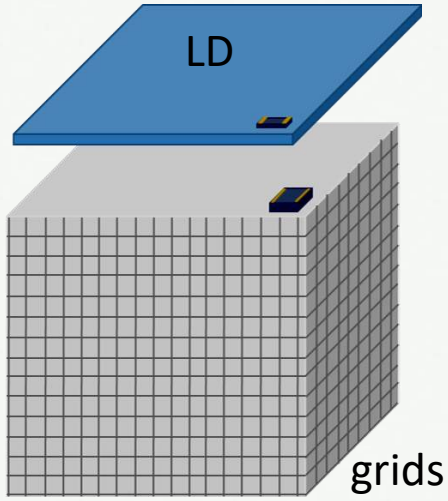








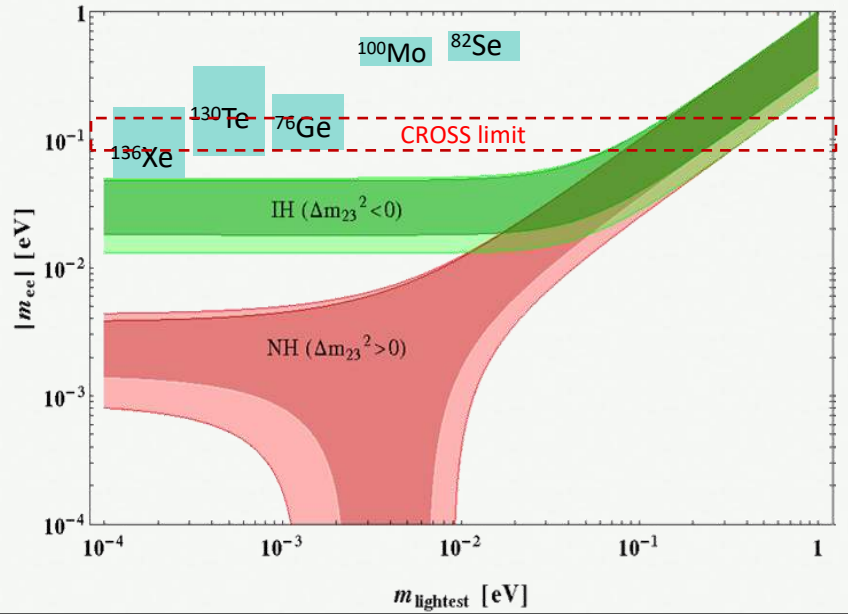
CROSS demonstrator



- Demonstrator with 42 $Li_2{}^{100}MoO_4$ cubic (45^3 mm) crystals with CROSS technology + 20 CUPID-Mo crystals: **6.6 kg of ^{100}Mo**

- With BI=10^{-3} ckky and 2 yr livetime: $T_{1/2}$ limit =1.96×10^{25} yr, **$m_{\beta\beta}$ ~(86-149) meV**

- Technology mature for next-generation $0\nu2\beta$ searches with BI ≈ 10^{-5} ckky



Summary

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

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

- **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

Thanks for the attention!