



French-Ukrainian WORKSHOP

Instrumentation developments
for high energy physics



October 12-14, 2026

IJCLab, Orsay - France

CROSS experiment

Denys Poda

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on behalf of the CROSS Collaboration



CROSS: From idea to first prototypes

Cryogenic Rare-event Observatory with Surface Sensitivity



Start date

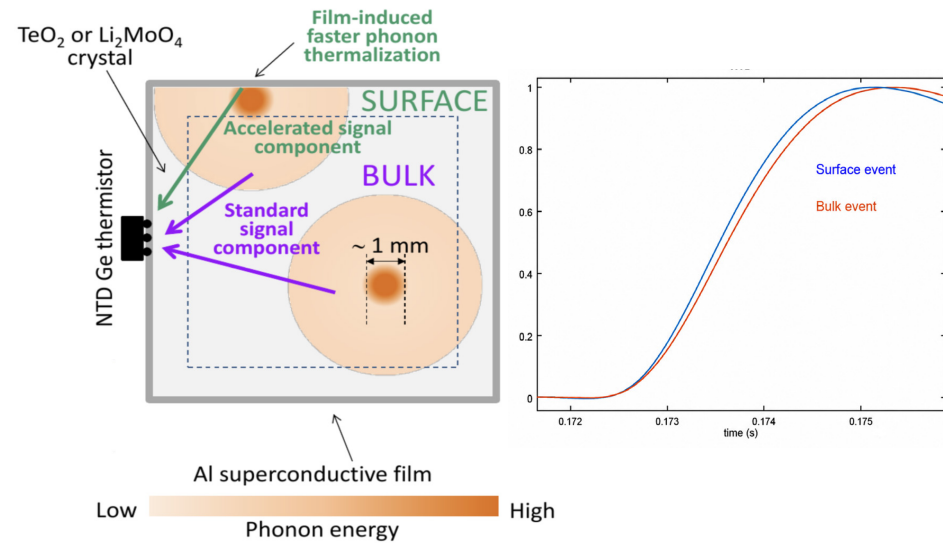
1 January 2018

End date

31 March 2025

❑ Main goals of the CROSS project:

- R&D on **metal-coated cryogenic detectors** for active **discrimination surface-vs-bulk events**
- Development of enriched crystals $\text{Li}_2^{100}\text{MoO}_4$ & $^{130}\text{TeO}_2$ with the size of **45×45×45 mm**
- **High-sensitivity searches for $^{100}\text{Mo } 0\nu 2\beta$ decay** at the **Canfranc underground laboratory** (Spain)



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The $0\nu 2\beta$ -decay CROSS experiment: preliminary results and prospects

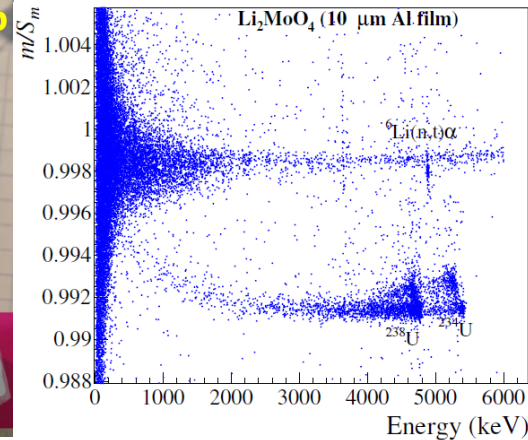
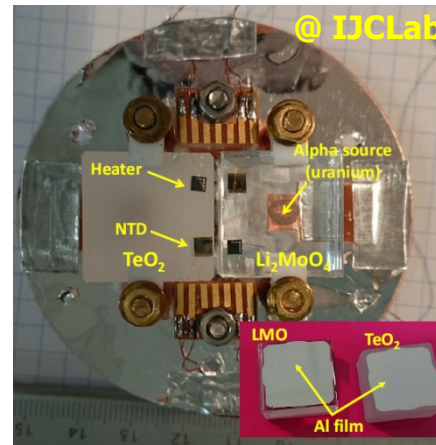


The CROSS collaboration

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France: c, d, f
Ukraine: h
Spain: a
Italy: e, g

JHEP01(2020)018



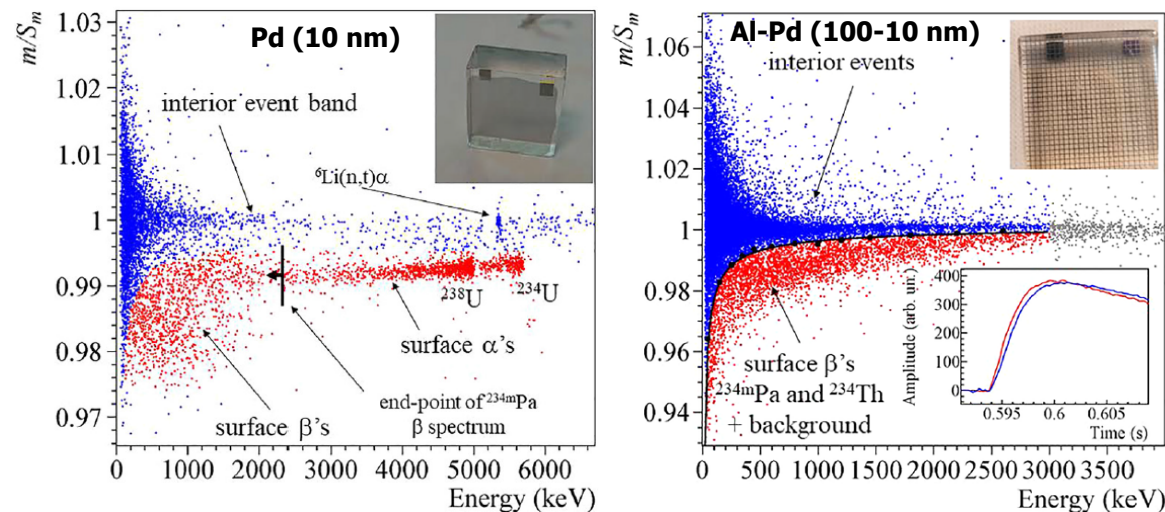
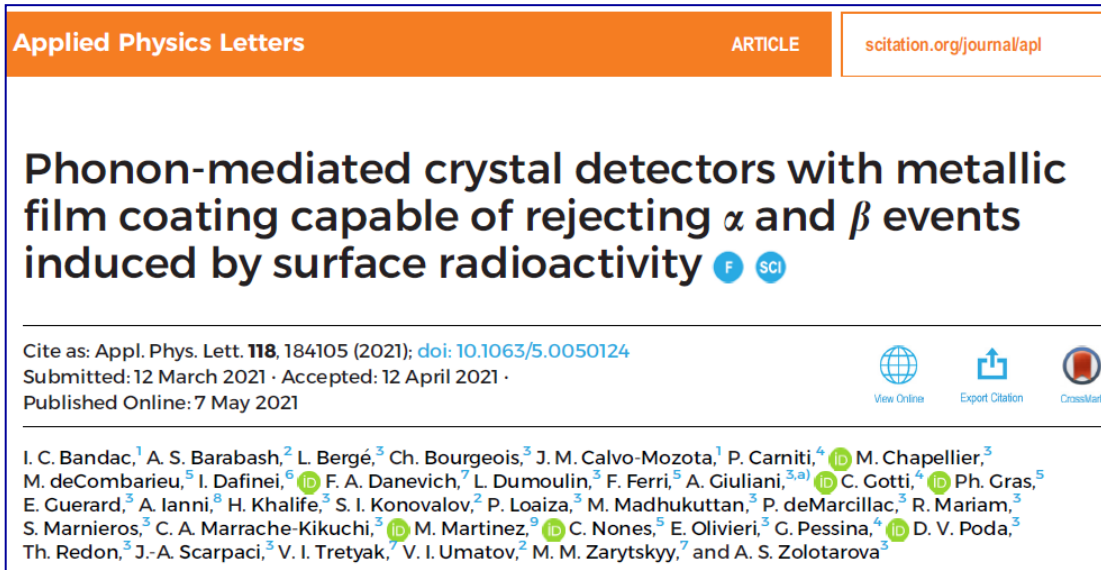
32x $\text{Li}_2^{100}\text{MoO}_4$ & conservative / optimistic background

Background level	Live time	Background counts	Feldman-Cousins count limit	Half-life limit	$m_{\beta\beta}$ limits
[counts/(keV kg y)]	[y]	in ROI	(90% c.l.)	(90% c.l.)	(90% c.l.)
10^{-2}	2	1.4	3.6	8.5×10^{24}	124–222
10^{-3}	2	0.14	2.5	1.2×10^{25}	103–185

CROSS: advancement in Particle IDentification

❑ CROSS technology of metal-coated cryogenic detectors:

- ✓ Successfully demonstrated with small-size prototypes (4 cm³) [Appl. Phys. Lett. 118 (2021) 184105]



❑ Other CROSS innovations relevant to next-generation $0\nu 2\beta$ searches:

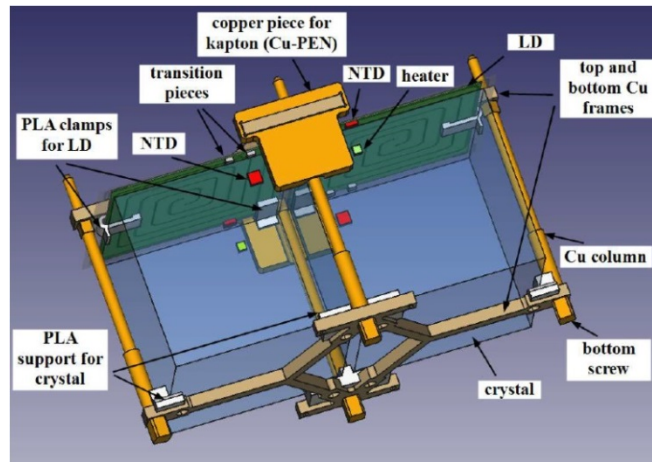
- **Large cubic $\text{Li}_2^{100}\text{MoO}_4$ and $^{130}\text{TeO}_2$ thermal detectors with high energy resolution & low-level radioactivity**
⇒ compact detector array, maximization of isotopes of interest, minimization of backgrounds
- **High-performance cryogenic light detectors (Ge and Si)**
⇒ scintillation-assisted particle identification & pile-up rejection
- **Low-mass mechanical structure of a detector module**
⇒ reduced components of radioactivity close to detectors

⇓
CROSS demonstrator

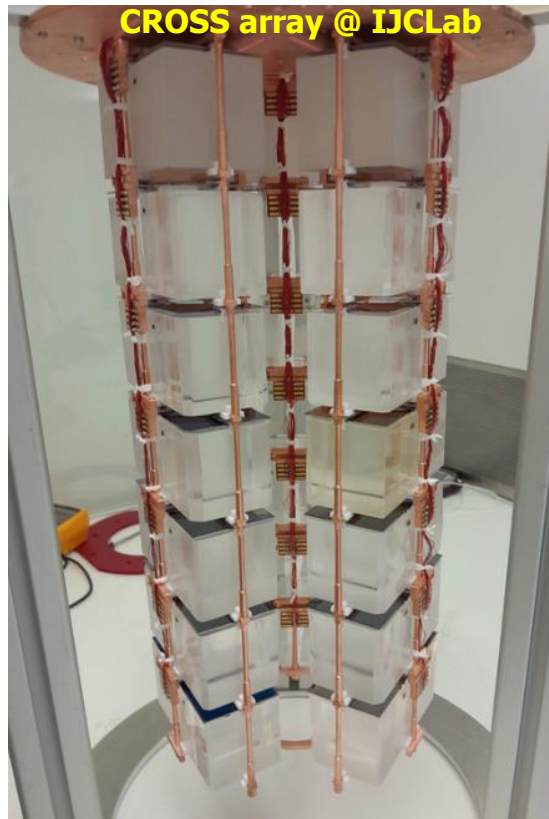
- Not mature enough to be scaled to large-size detectors (90 cm³) [https://theses.hal.science/tel-03168547]

CROSS array construction (2024-2025)

CROSS detector module



CROSS array @ IJCLab

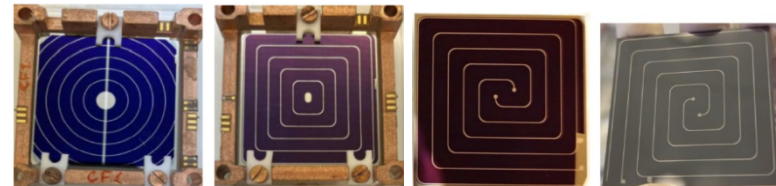


42 crystals (45×45×45 mm each)

- **6x TeO₂ enriched in ¹³⁰Te** (0.56 kg; ¹³⁰Te ~ 91%) [JINST 19 (2024) P09014]
- **36x Li₂MoO₄ crystals** (0.28 kg) grown using **different ¹⁰⁰Mo content**
 - 32x **enriched in ¹⁰⁰Mo** (¹⁰⁰Mo ~ 98%) [JINST 18 (2023) P06018]
 - 2x **depleted in ¹⁰⁰Mo** (¹⁰⁰Mo < 0.01%) [Sensors 23 (2023) 5465]
 - 2x **natural Mo content** (¹⁰⁰Mo ~ 10%) [SIMaP France, SICCAS China]

42 wafers (45×45 mm² shaped)

- **26x Ge** (0.3 mm thick), **SiO-coated on both sides** [@IJCLab]
 - **16x Si** (0.65 mm thick), **no antireflective coating**
 - **Al electrodes** evaporated **on one side** [@IJCLab; NIMA 940 (2019) 320]
- circular** [JINST 21 (2026) P01035]
(12x Ge)
semi-square
(1x Ge)
double spiral
(13x Ge & 16x Si)

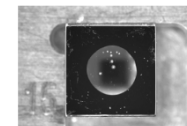
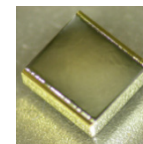


⇒ **Thermal signal amplification** based on **Neganov-Trofimov-Luke effect**

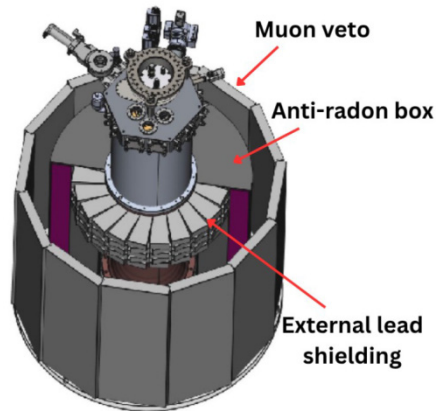
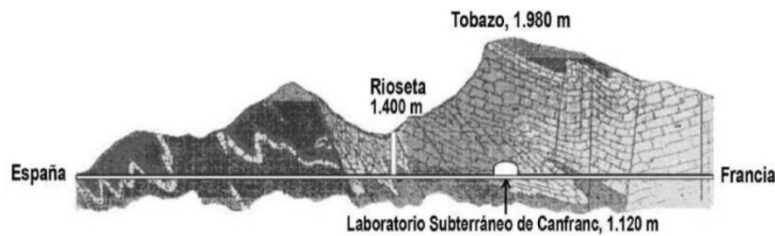
$$E_{\text{NTL}} = E_0 \cdot (1 + e \cdot V_{\text{NTL}} \cdot \eta / \epsilon)$$

Sensors, gluing, wiring

- **Neutron Transmutation Doped Ge thermistors and Si:P heaters**
- **Robotic** [@CEA] / **manual** [@IJCLab] **gluing of NTDs for crystals** (2:1) using **UV-cured glue** [PERMABOND UV620]
- **Manual gluing of LD NTDs** (+3x TeO₂) and **crystals' heaters** with **epoxy** [Araldite Rapid]
- **Au-wire** (Ø25 µm) **bonding, CUPID-Mo-like wiring** of towers

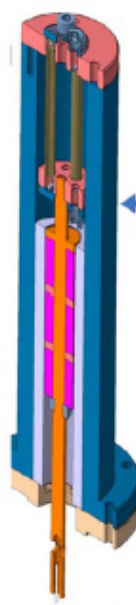
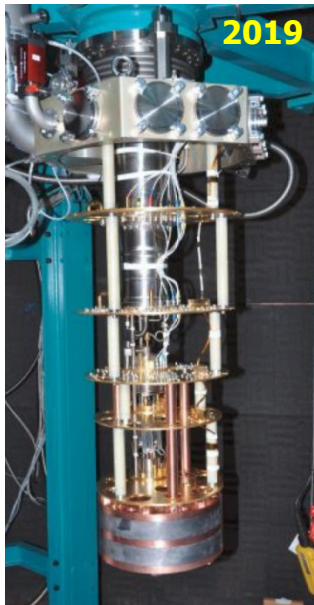


CROSS cryogenic facility @LSC (Spain)



CROSS facility at Canfranc underground laboratory

- Hall A @LSC, rock overburden: 2450 m of water equivalent
- Pulse-tube-based dilution refrigerator by Cryoconcept with Ultra-Quite Technology (UQT) [JINST 16 (2021) P02037]
- Detector plate suspension with magnetic dampers @ 4 K [JINST 18 (2023) P12004]
- External (20 cm of Pb) and internal (Cu/Pb) shielding
- Hermetic container flushed with boiled nitrogen
- Muon veto [JINST 21 (2026) P05007]
- CROSS electronics – demo for CUPID next-gen experiment [JLTP 199 (2019) 833] & [NIMA 1045 (2023) 167658]



CROSS experiment: milestones 2025-2026

- **July 2025:** **CROSS array transportation from Orsay to LSC (Spain) & installation inside the cryogenic facility**
- **October 3rd:** **Start of cooling down** (delay due to failure of the chiller)
- **October 15th:** **Base temperature reached**
- **November-December:** **Commissioning, calibration measurements**
- **January-August, 2026:** **Commissioning, background (no source) measurements**
- **Fall 2026:** **Cryostat maintenance, intervention to the array**

❑ CROSS data acquired

- ~100 channels, 2 kHz sampling rate

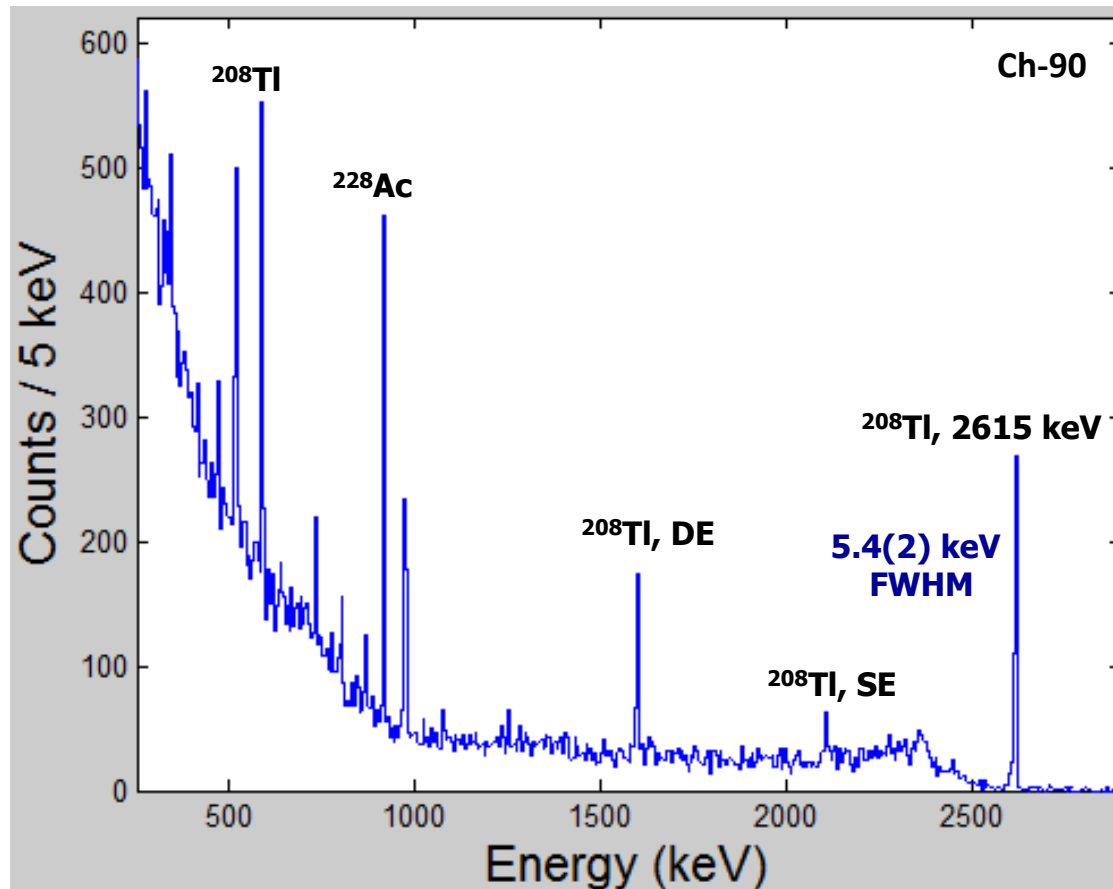
TOTAL (h)	5495
Th-232 calibration (h)	675
Background (h)	4821

❑ Data processing & tools

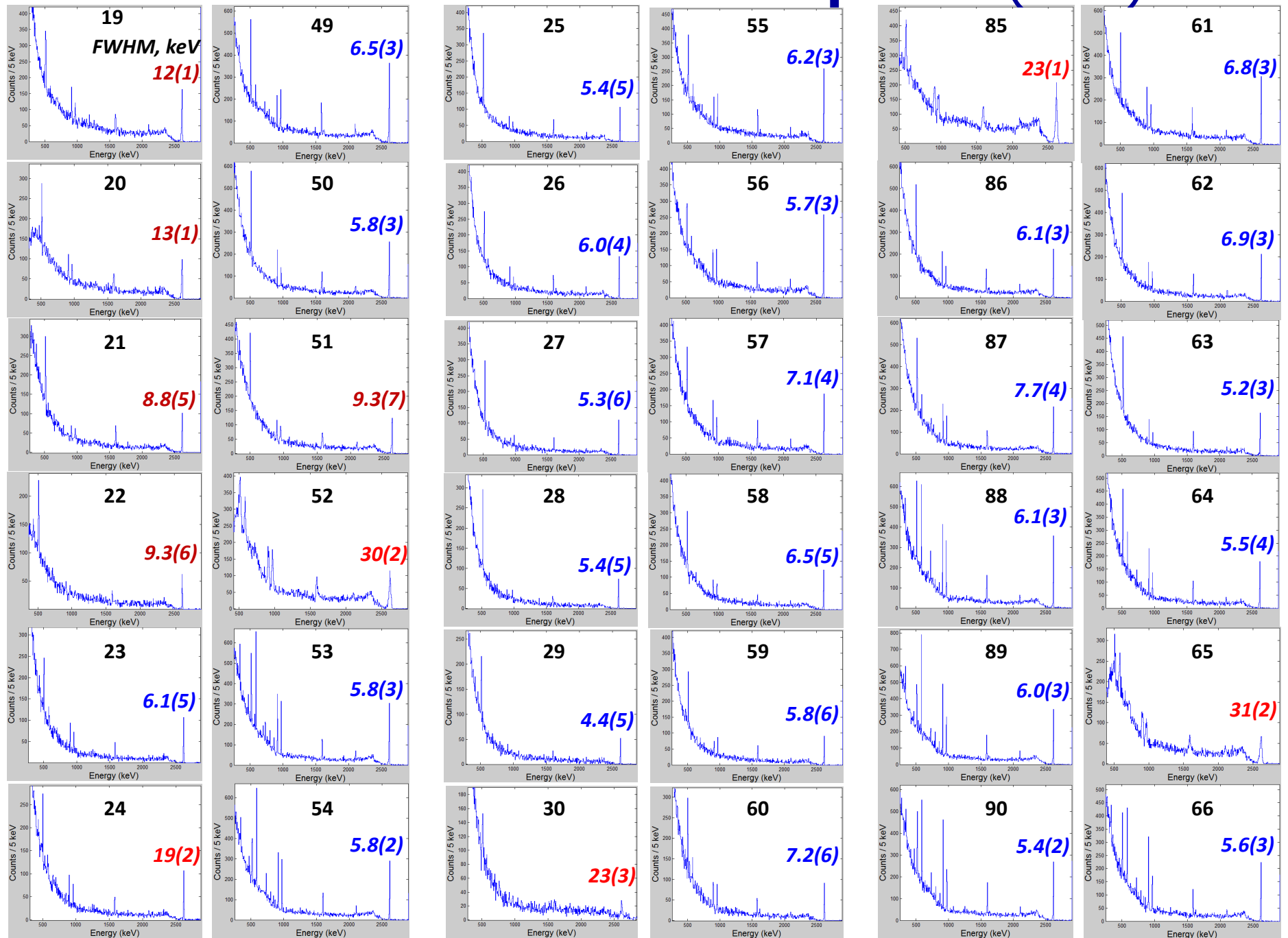
- **Gatti-Manfredi Optimum Filter**
[Nucl. Instr. Meth. A 287 (1990) 513]
- **Argonauts** (v7.4) [developed @IJCLab]
- **Octopus** [co-developed @IJCLab for CUPID]

CROSS: Calibration of LMO detectors

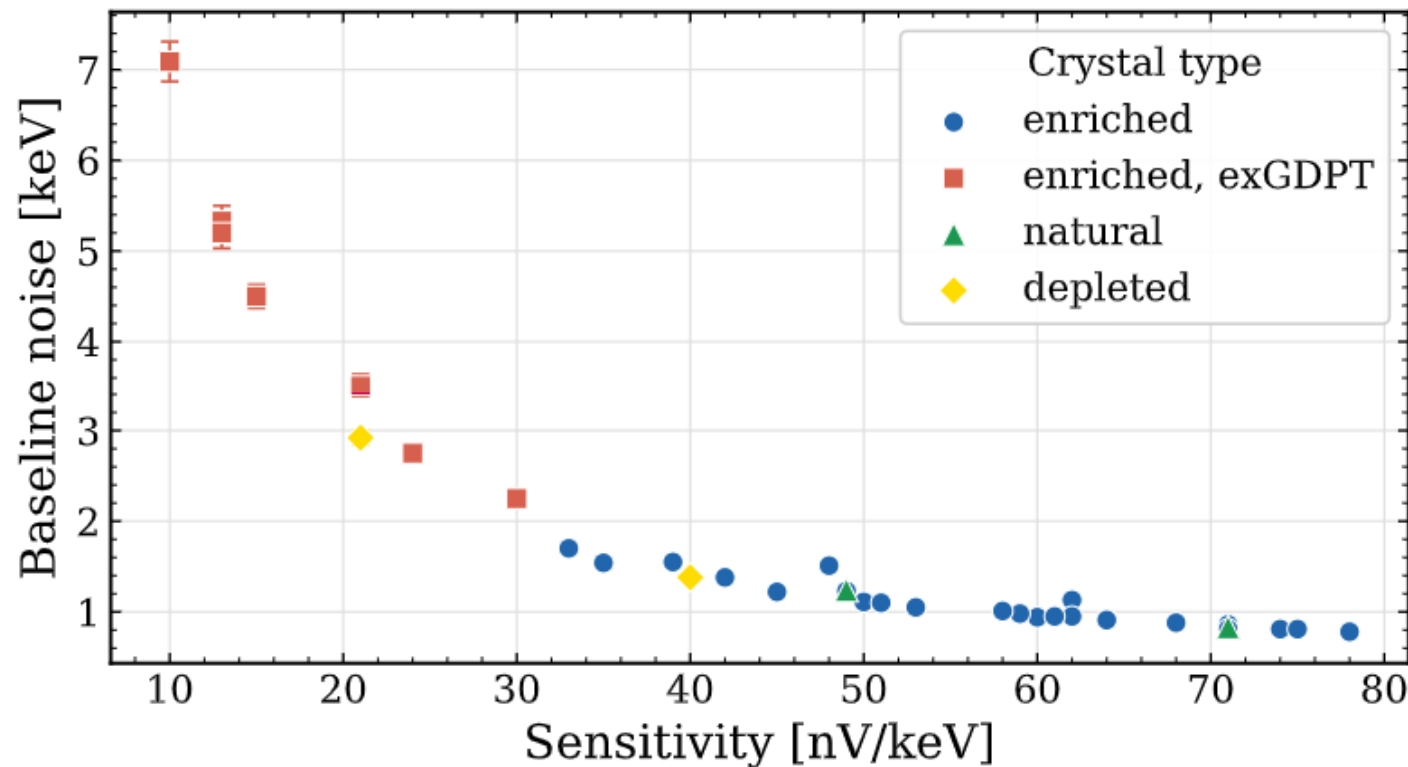
- **A movable ThO_2 source is used in the CROSS setup**
 - ⇒ inserted inside a tube between the lead shield and the outer vacuum chamber
 - ⇒ on-site / remote control of the source position
- **The insertion position is chosen to keep a counting rate on the level of ≤ 1 Hz**
 - ⇒ reduced impact of random coincidences affecting measured spectra
 - ⇒ ~30-h-long run is sufficient for a reliable calibration



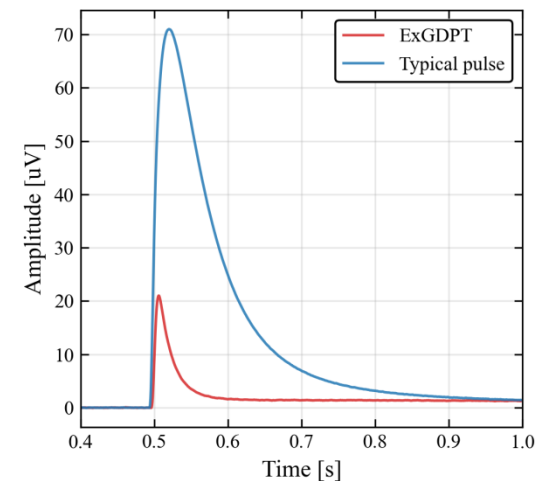
CROSS: LMO calibration spectra (64 h)



CROSS: Performance of LMO detectors

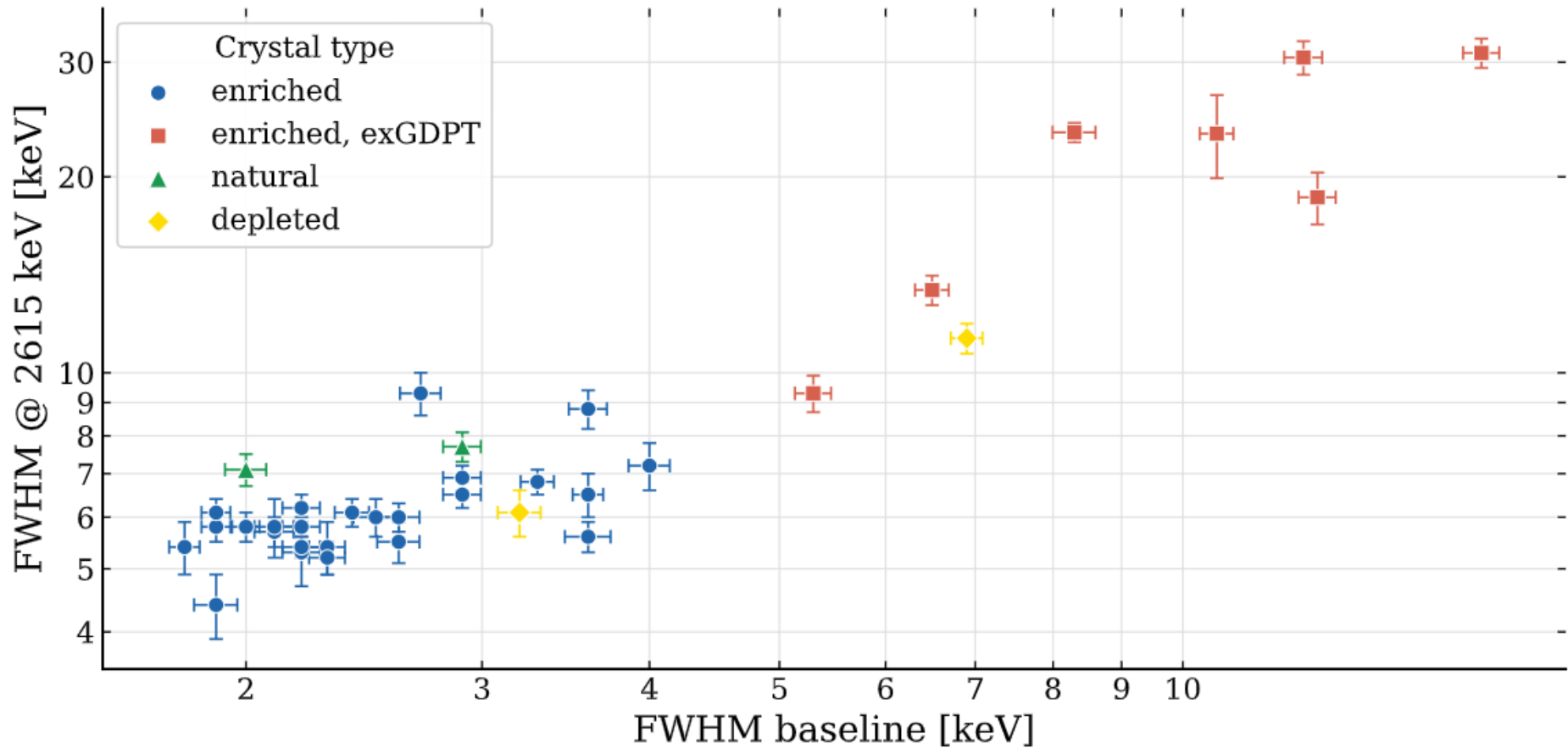


- **Uniform electronic noise** across all LMO detectors
- **All $\text{Li}_2^{100}\text{MoO}_4$ detectors, but exGDPT crystals based devices, have baseline noise resolution < 2 keV RMS**
⇒ **harmonic mean: 2.9 keV FWHM** (2.5 keV excluding exGDPT)
- **Impact of humidity on “exGDPT” crystals (+ ^{100}Mo -depleted sample), after previous low-temperature tests, exhibited by degraded pulse shape / performance**
⇒ **crystal polishing allows to recover detector performance**
(it was found too late to be applied for CROSS)



GDPT test: [EPJC 85 (2025) 935]

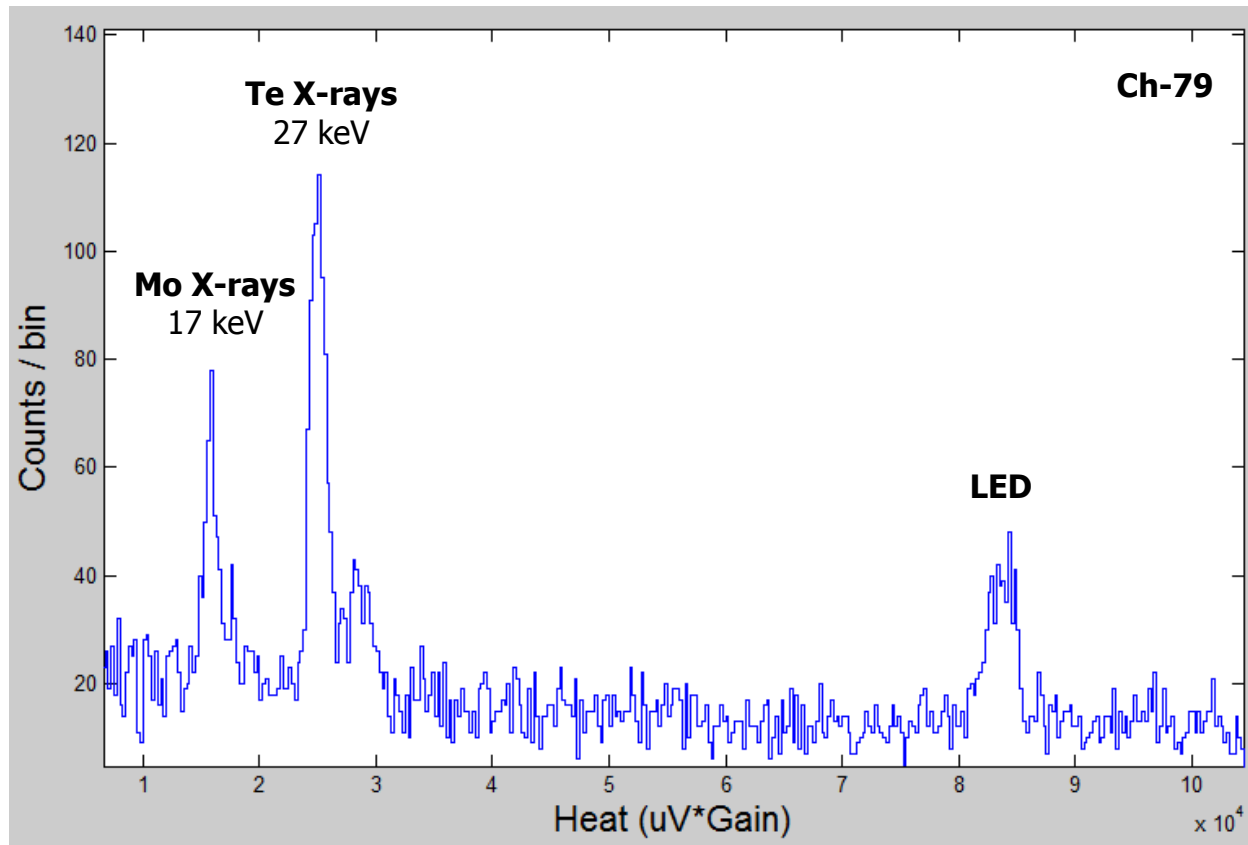
CROSS: Performance of LMO detectors



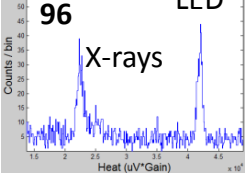
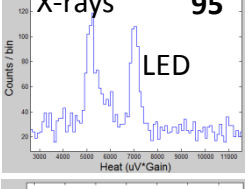
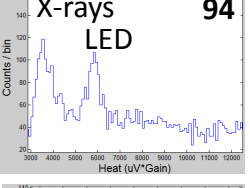
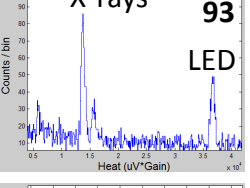
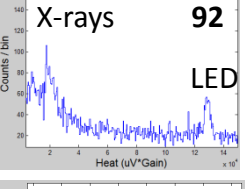
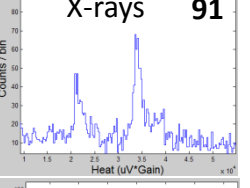
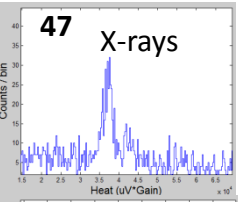
- **High energy resolution** demonstrated by **all Li_2MoO_4 detectors**, **but exGDPT** crystals based devices
⇒ **harmonic mean: 7.1 keV FWHM @ 2615 keV** (6.2 keV excluding exGDPT)
- **Two natural CUPID R&D crystals have similar energy resolution to CROSS enriched detectors**
⇒ important result in view of Li_2MoO_4 crystals mass production for the CUPID experiment

CROSS: Calibration of light detectors

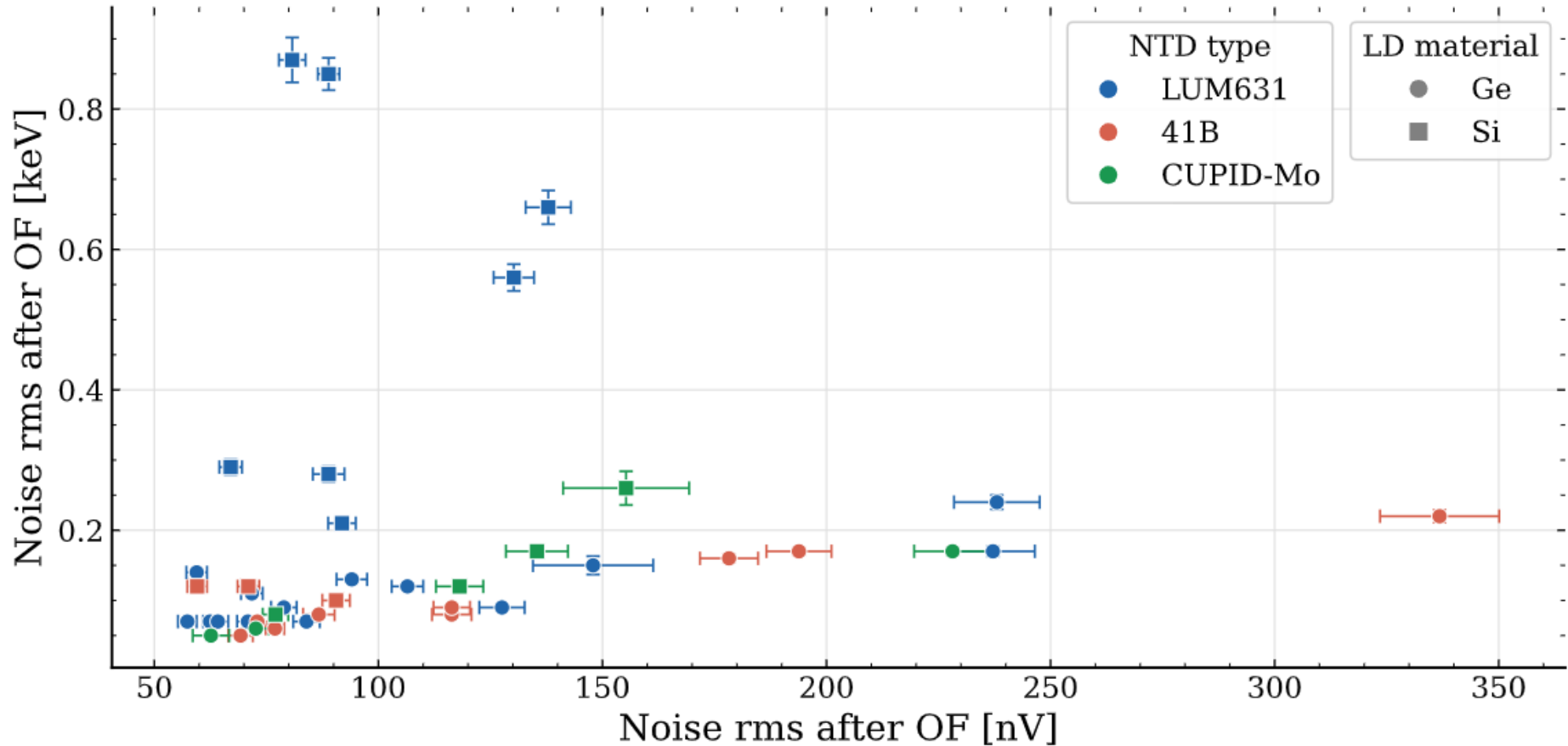
- **The same movable ThO_2 source is used for LDs calibration**
 - ⇒ gamma-source-induced X-ray emission by coupled crystals is exploited
- **The insertion position is chosen to maximize the counting rate of massive detectors**
 - ⇒ data of massive detectors are strongly affected by pile-ups (i.e. not exploitable)
 - ⇒ ~30-h-long dedicated run is sufficient for a reliable calibration
- **LED & LMO scintillation, calibrated by X-rays, could be used for LDs calibration too**



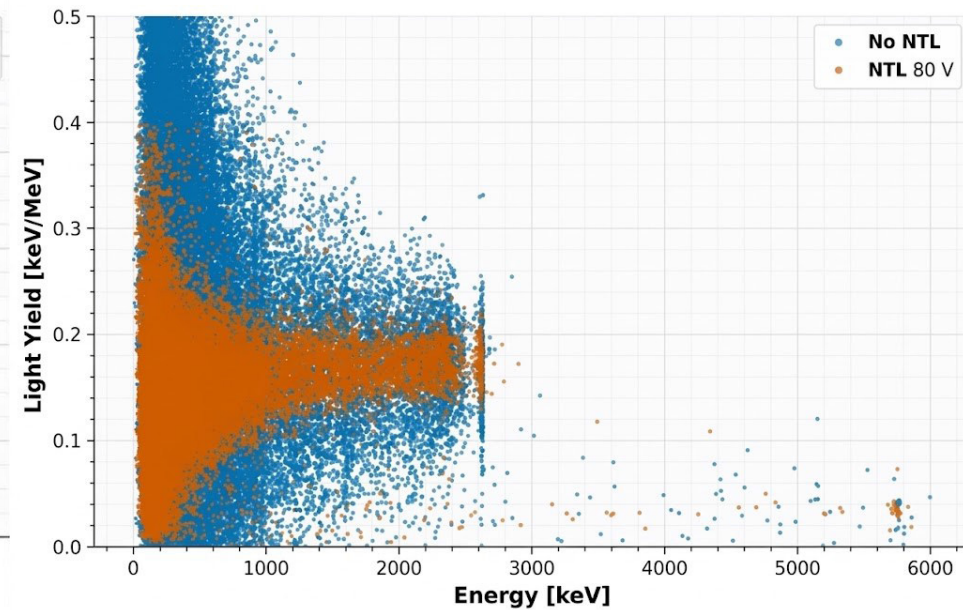
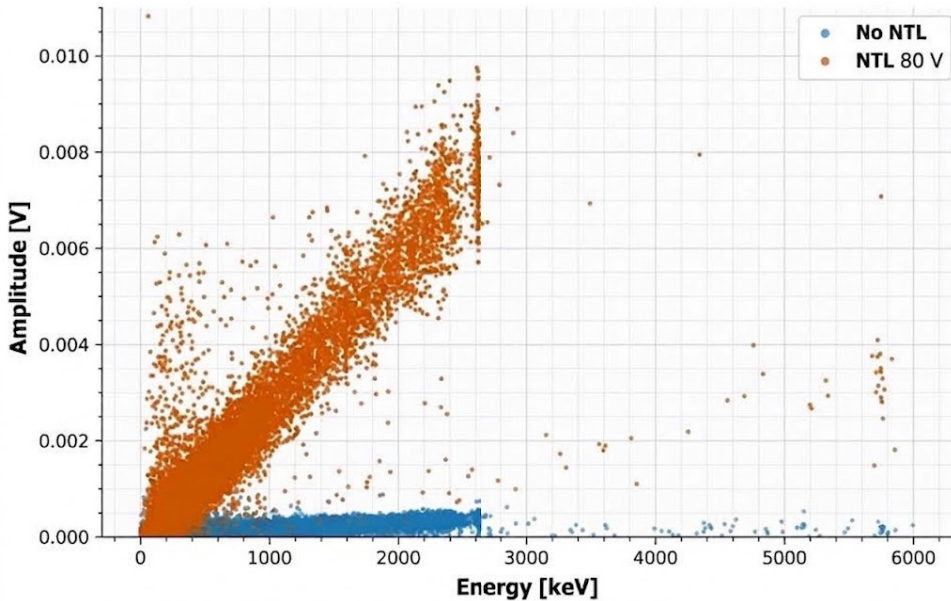
Mo → Mo & Te Te



CROSS: Performance of light detectors

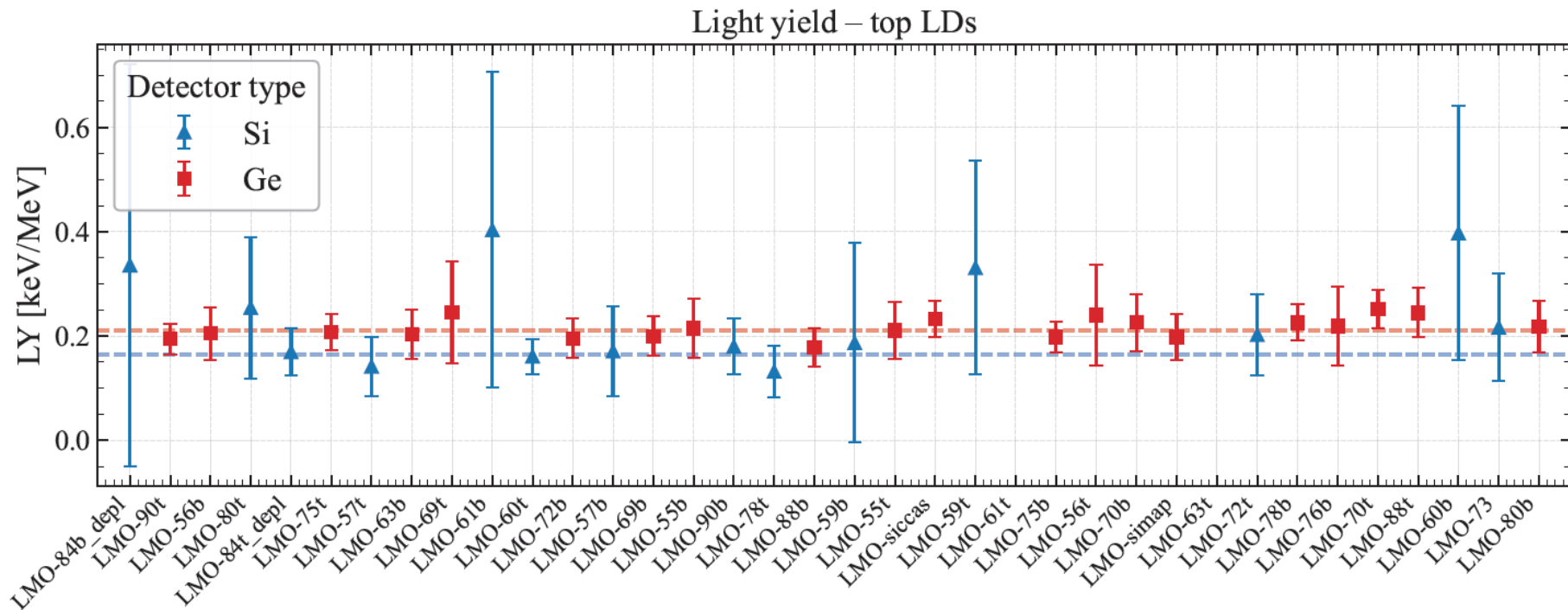


CROSS: Impact of NTL mode on Particle ID



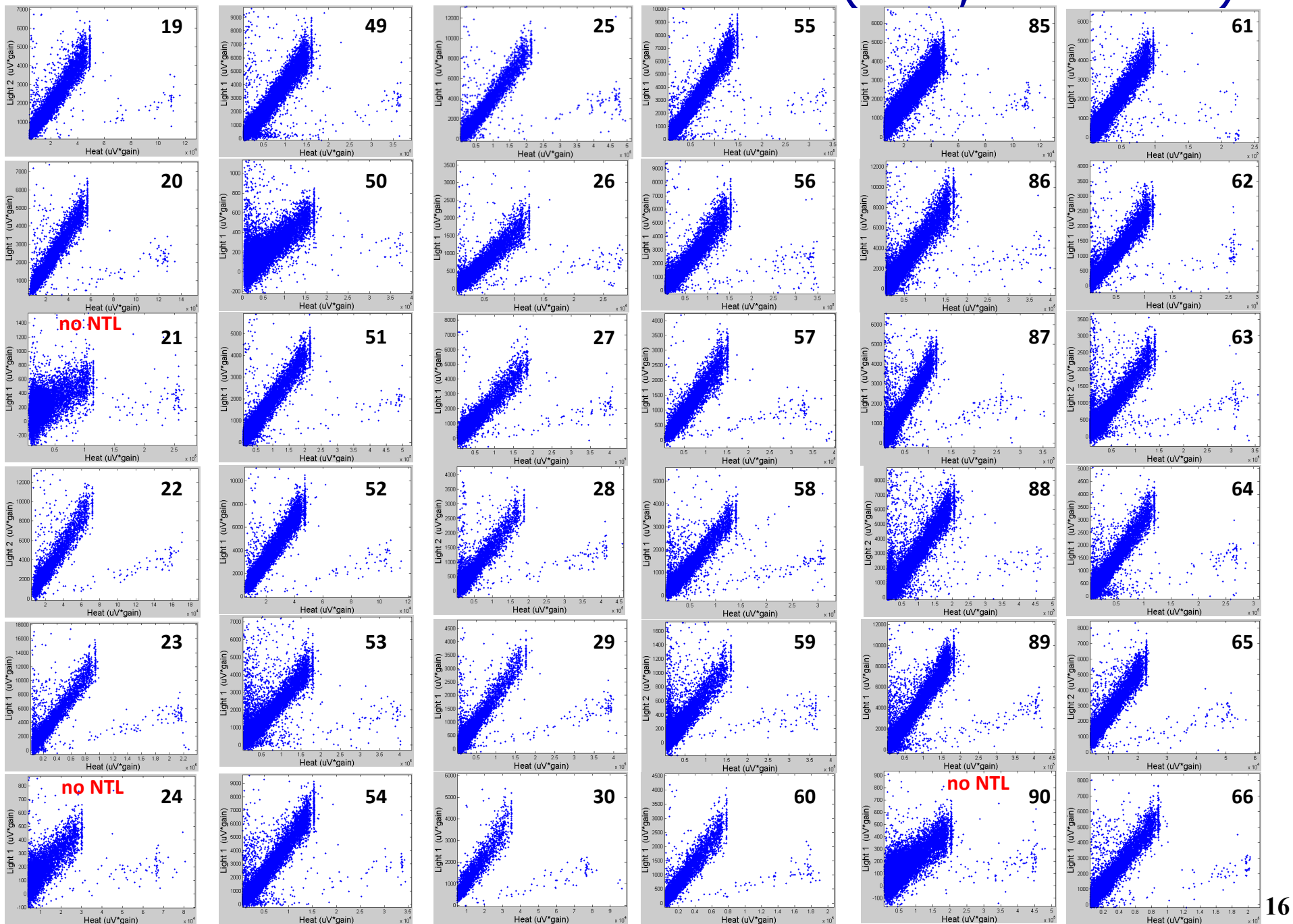
- Despite a **low scintillation efficiency of LMO**, a **low light collection efficiency** in the open detector structure, and **poor performance of some LDs at $V_{\text{NTL}} = 0$ V**, a **full separation between $\gamma(\beta)$ and α events** can be achieved **thanks to the NTL mode**
- Typical **gain for $\gamma(\beta)$ -induced scintillation** achieved by **LDs with dual-spiral electrodes**
Ge: 15x @ 67 V
Si: 30x @ 100 V

CROSS: LMO scintillation

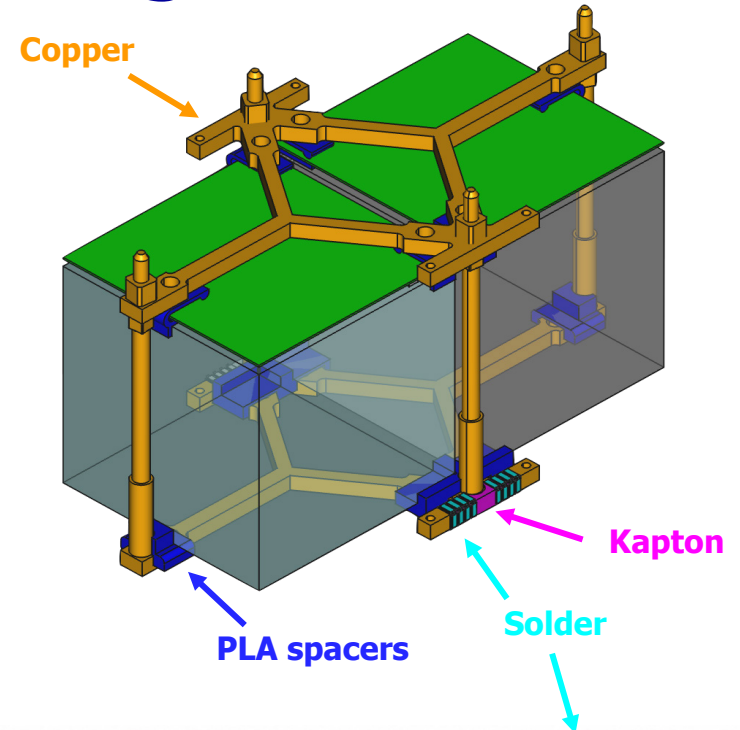
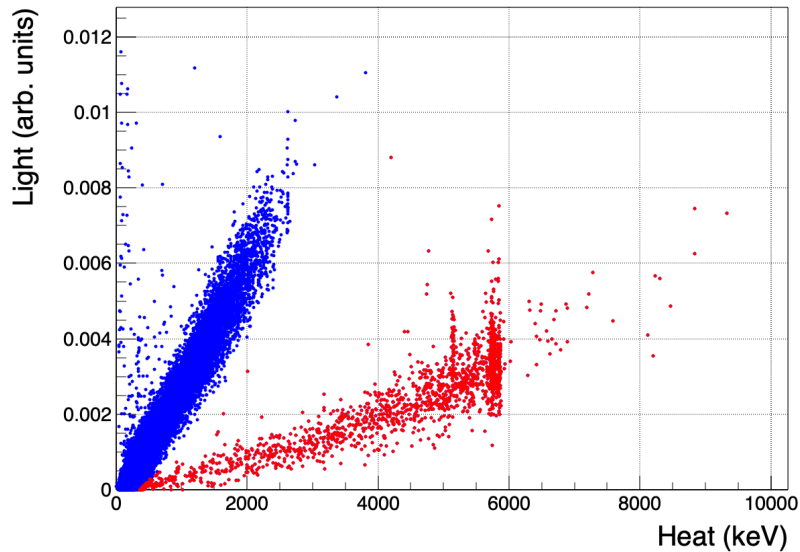


- **Low detected scintillation signal due to geometrical configuration**
- **Weighted average light-to-heat signal ratio ("light yield") for $\gamma(\beta)$ interactions**
Ge: 0.21(1) keV/MeV (with SiO antireflecting coating, enhancing light collection by $\sim 30\%$)
Si: 0.17(2) keV/MeV (without antireflective coating)
- **Scintillation induced by α particles is $\sim 20\%$ of signal induced by $\gamma(\beta)$ events**
 $\Rightarrow$ key difference exploited for particle identification

CROSS: Particle IDentification (24 h, NTL mode)

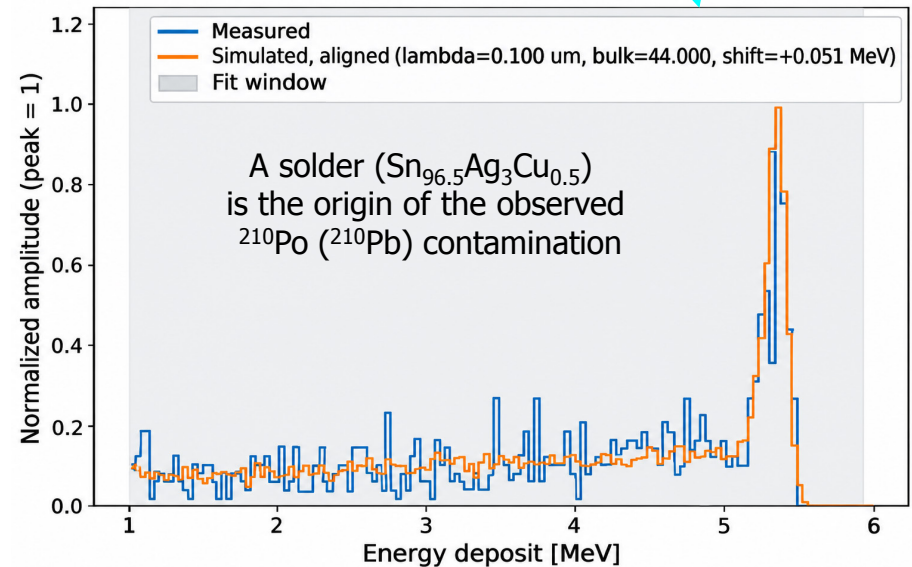
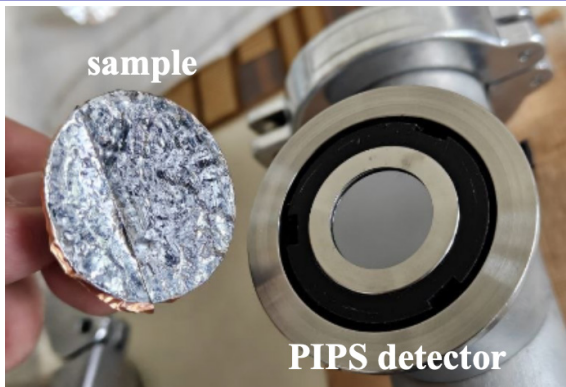


CROSS: α -active background



Study of α -induced background in CROSS

- High α contamination is present close to the detectors
⇒ more complicated analysis and difficulties in understanding the residual background in the ROI
- Screening of close detector components using Passivated Implanted Planar Silicon (PIPS) @IJCLab

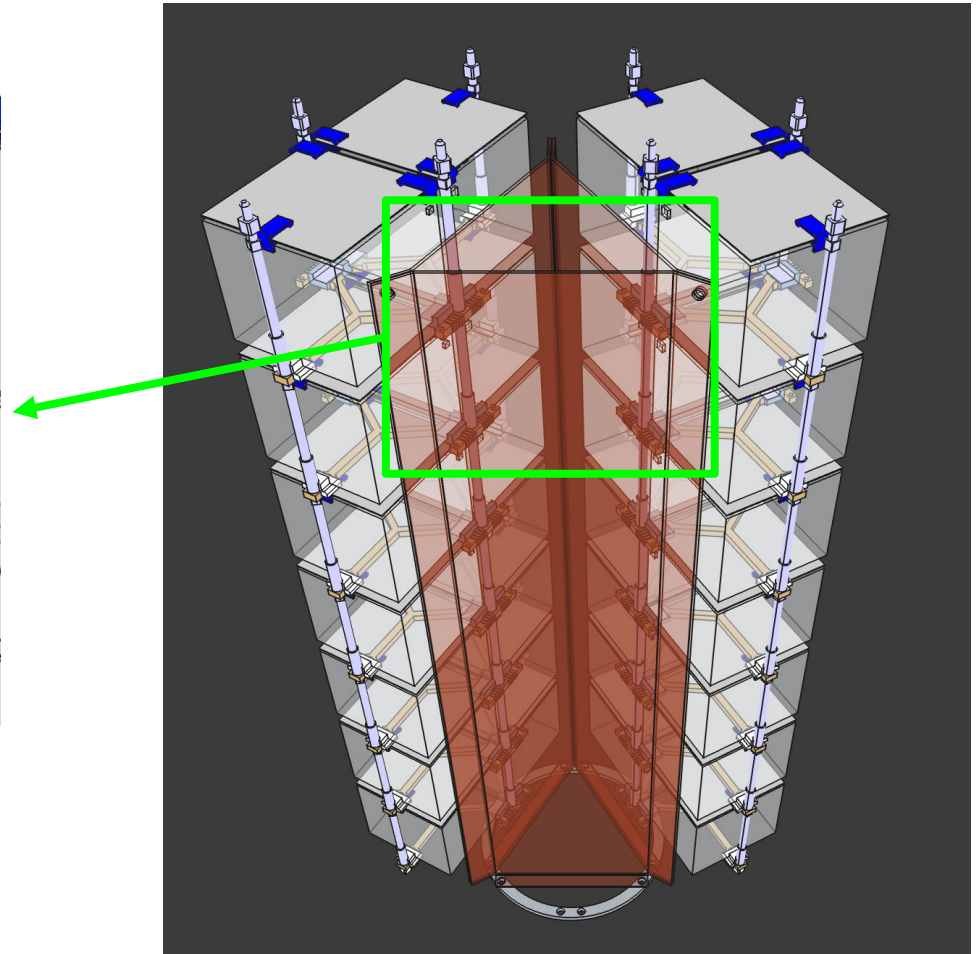
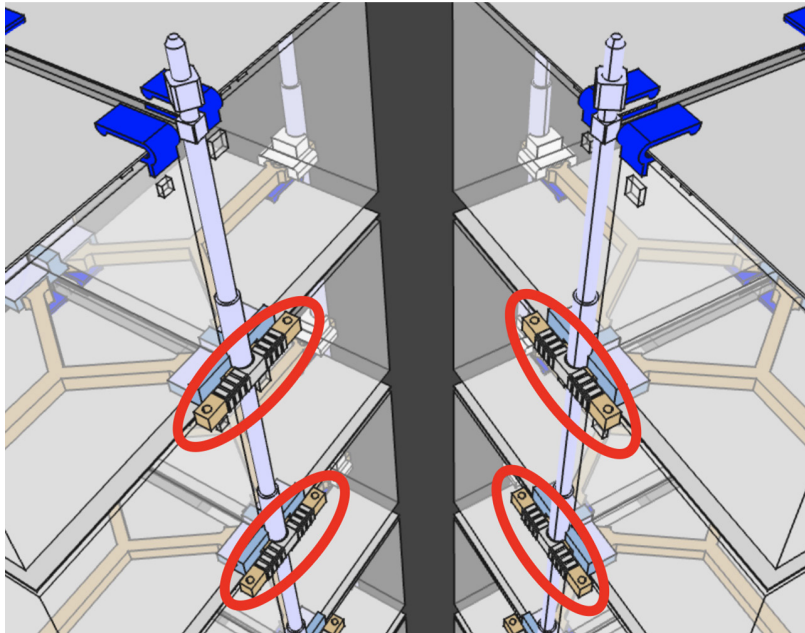


CROSS: suppression of α -active background

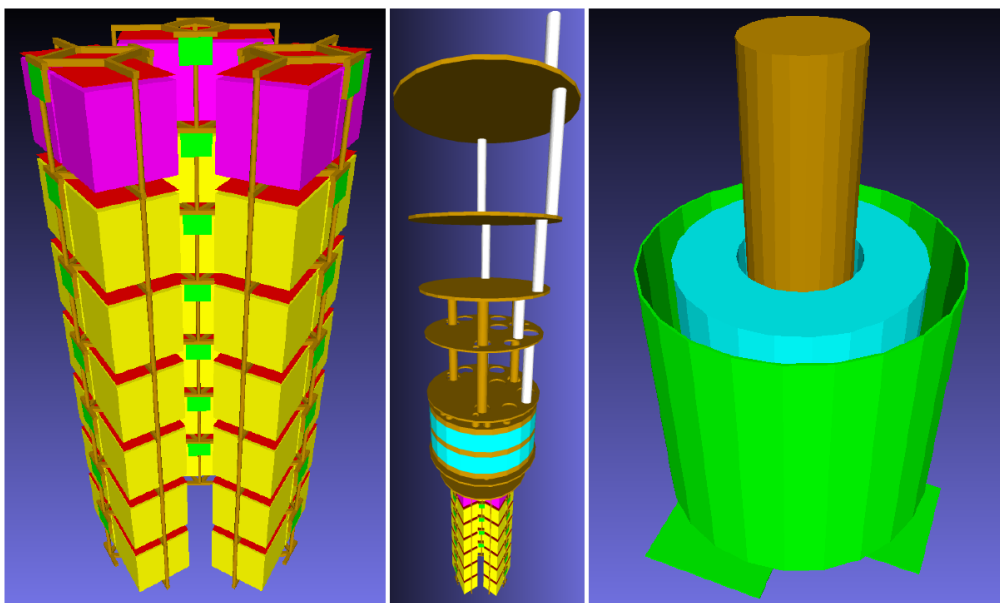
- A major intervention to the **CROSS** setup is ongoing this week to shield detectors against α -active soldering



A triangular thin Cu prism will be inserted in **between the 3 towers**



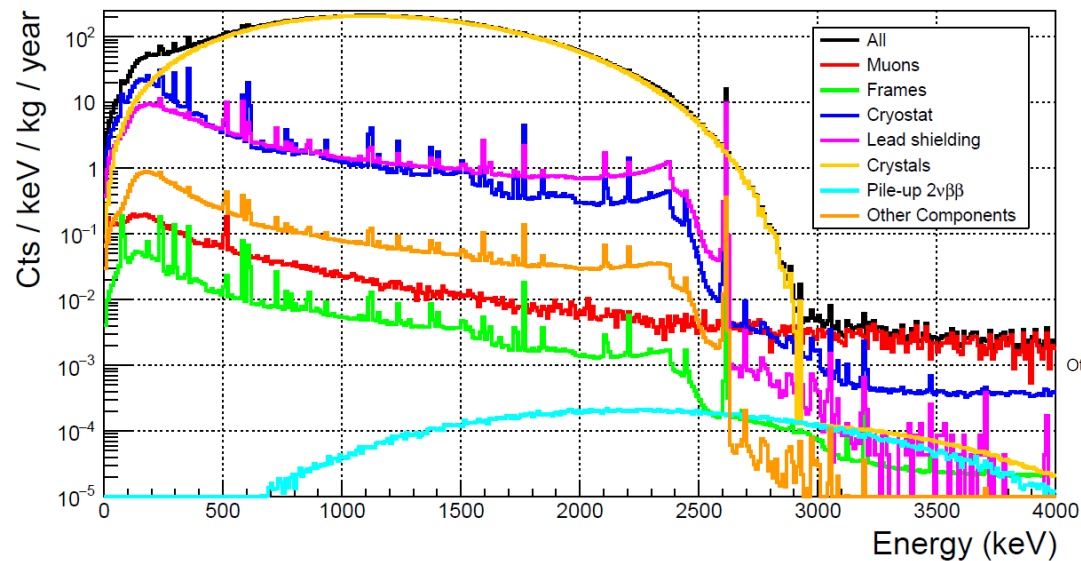
CROSS: background model



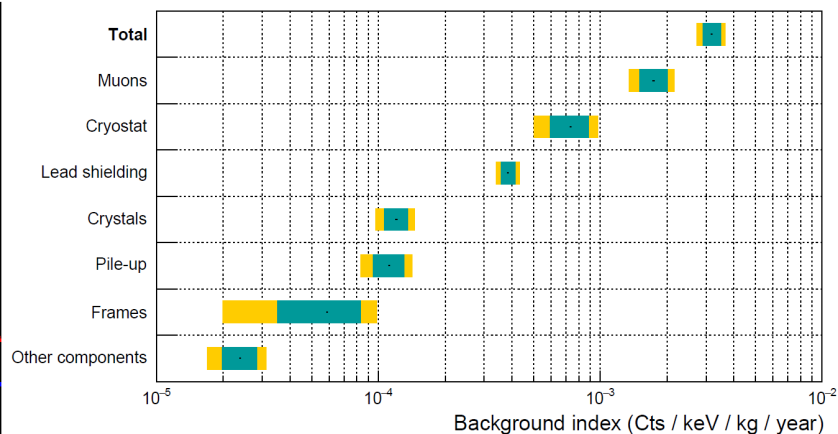
☐ CROSS GEANT4-based MC model

- Pre-tested detector & veto performance
- HPGe screening of cryostat components
- CUPID-Mo experiment based radiopurity of LMO crystals, Cu frames & Kapton pads

Material	^{226}Ra ($\mu\text{Bq/kg}$)	^{228}Th ($\mu\text{Bq/kg}$)
Copper screens	$0.6(1) \times 10^3$	$0.3(1) \times 10^3$
Electronic pins	$1.33(4) \times 10^6$	$2.39(3) \times 10^6$
Crystals (bulk)	0.39(6)	0.57(7)
Copper frames	25(15)	33(16)
Lead shielding	< 120	< 460
Fiberglass bars	$3.4(4) \times 10^3$	$1.41(5) \times 10^3$
Kapton pads	$14(7) \times 10^3$	$67(31) \times 10^3$



[arXiv:2607.26732]



☐ CROSS background index in ROI

- ROI: ^{100}Mo $Q_{\beta\beta}$ (3034 keV) $\pm$ 50 keV
- BI: $3.2(5) \times 10^{-3}$ cts/keV/kg/yr

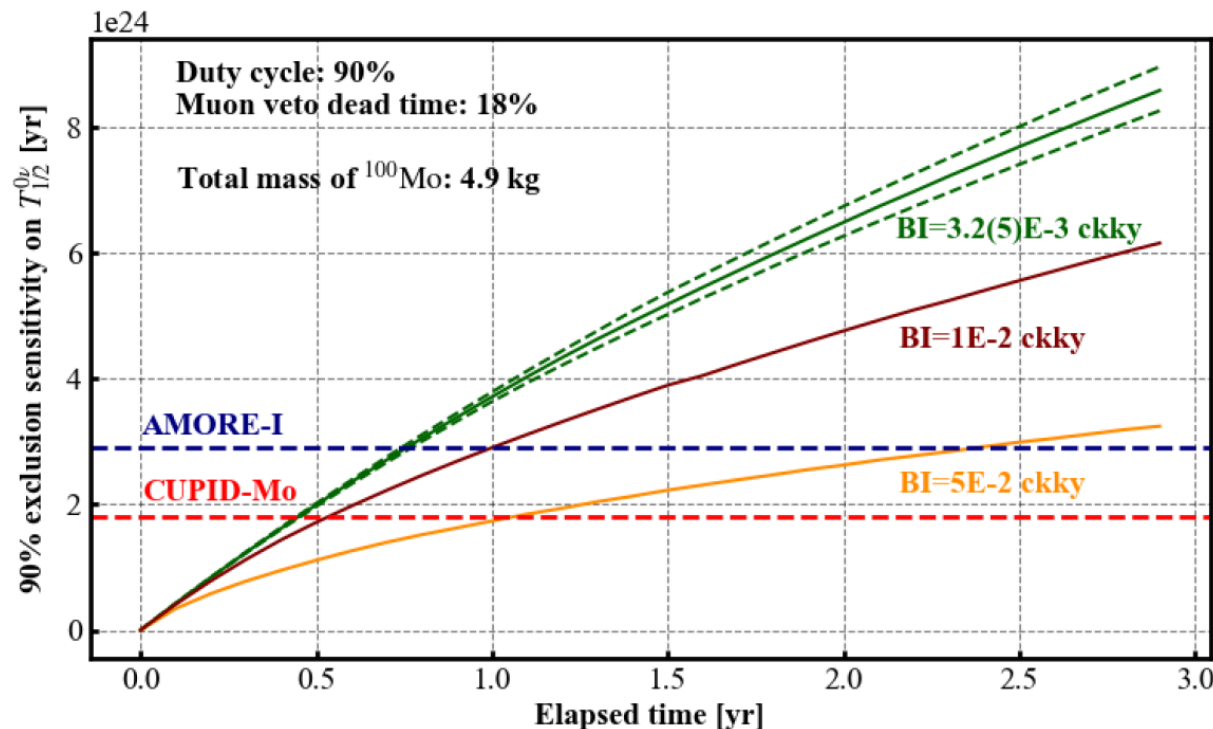
CROSS sensitivity to ^{100}Mo $0\nu 2\beta$ decay

❑ CROSS experiment sensitivity

- ^{100}Mo nuclei: 2.95×10^{25}
- Region Of Interest : **17 keV** (like in CUPID-Mo, $Q_{\beta\beta} \pm 2.7\sigma$)
- Containment efficiency: **78%**
- Selection efficiency: **90%**
- Muon cut dead time: **18%** (due to O(100 Hz) veto rate)
- Duty cycle of the facility: **90%**
- Feldman-Cousins procedure: number of excluded events @90% C.L.



$\lim T_{1/2} \sim 3.8 \times 10^{24} \text{ yr}$ in 1 year of data taking



[arXiv:2607.26732]

Summary

- **Metal-coated cryogenic detectors capable to discriminate surface-vs-bulk interactions are developed by the CROSS Collaboration**
 - ⇒ Technology is not mature enough for applications to next-generation $0\nu 2\beta$ searches
- **CROSS experiment with 42 cryogenic detectors with heat-scintillation readout was successfully commissioned @ LSC (Spain) over Nov. 2025 – Aug. 2026**
 - ⇒ High energy resolution of (most) LMO thermal detectors
 - ⇒ High performance of light detectors in the NTL amplification mode provides a highly-efficient $\alpha/\gamma(\beta)$ separation for (most) LMO detectors
 - ⇒ Unexpected α activity of ^{210}Po in a “Pb-free” solder will be suppressed using a Cu triangular prism, inserted between towers
 - ⇒ Analysis of background data is ongoing
- **Monte Carlo simulations predict that the CROSS experiment can achieve the best sensitivity to ^{100}Mo $0\nu 2\beta$ decay in 1 year of data taking**
 - ⇒ Stay tuned!