Bolometers with Al film coating: Towards the surface background rejection

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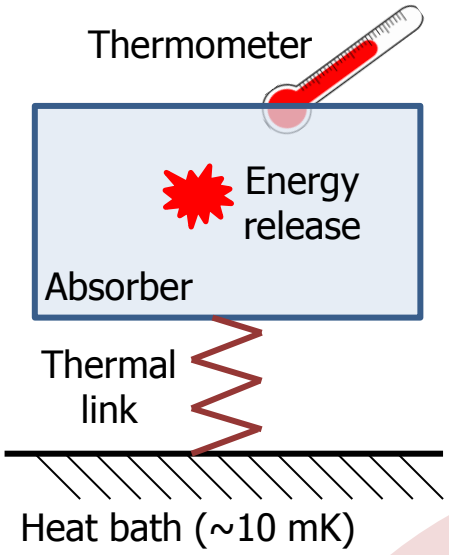
Bolometers in present rare event searches



Phonons

Cryogenic detectors

- Variety of suitable radiopure materials / targets of interest
- Source=Detector and/or Multi-target approaches
- Fully active detectors
- High resolution, low threshold
- Particle ID / PSD capabilities
- Scalability to a tonne-scale
- Long-term duty cycle
- Reasonable cost, multi-usage of a cryogenic set-up

CUORE

AMoRE, CUPID-0, CUPID-Mo

CRESST, COSINUS

EDELWEISS, CDMS

Electrons Holes

GERDA, Majorana, COBRA

CDEX, PandaX

EXO, NEXT, SuperNEMO

XENON, LZ, DarkSide,..

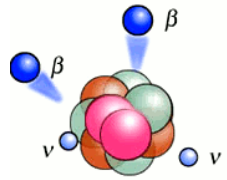
KamLAND-Zen, SNO+, CANDLES,..

DAMA/LIBRA, KIMS, ANAIS, COSINE, SABRE,..

Photons

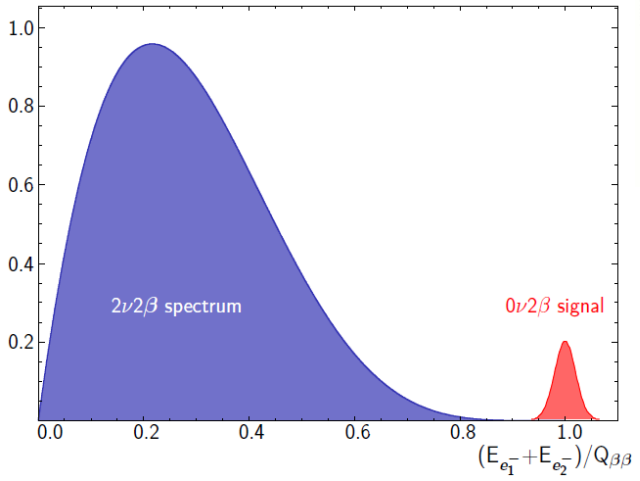
Present and future of 0ν2β decay search

Two neutrino 2β decay

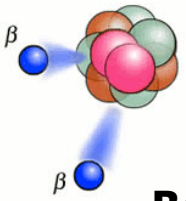


Allowed in the SM

- Rarest observed nuclear decay
  $T_{1/2} \sim 10^{18}$–10^{24} yr
- Information about NME's ⇒ test of theoretical description

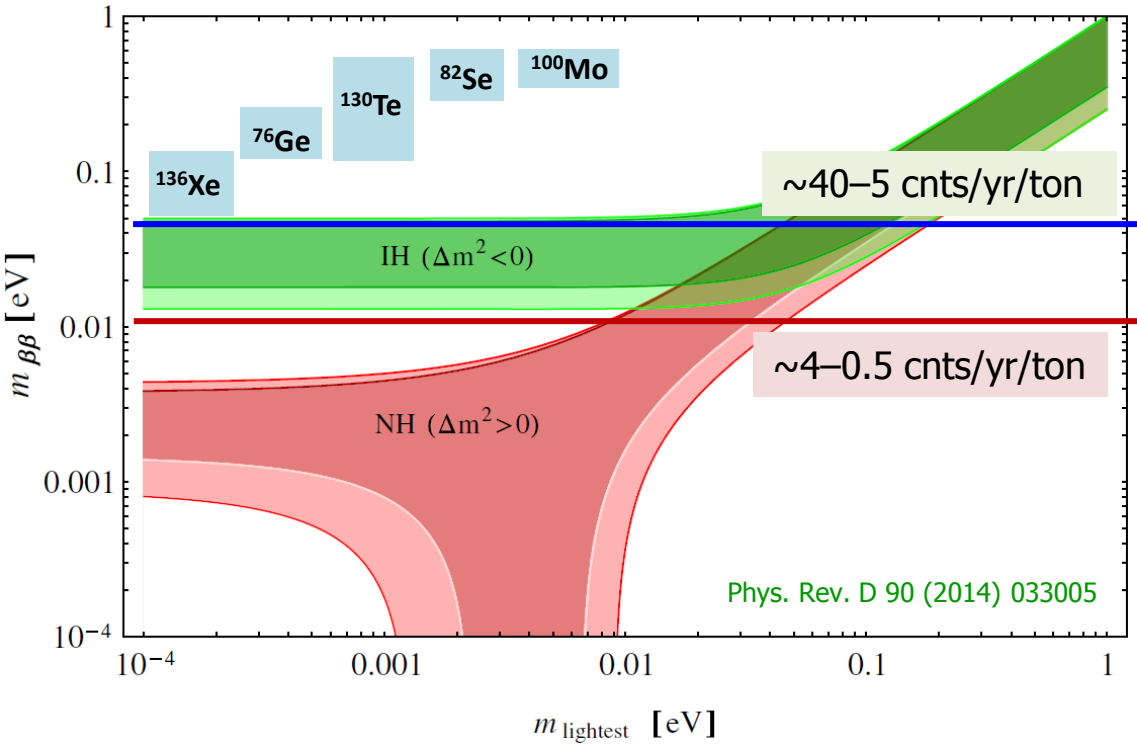


Neutrinoless 2β decay



Beyond the SM

- Total lepton number violation
- Majorana nature of neutrino
- Scale of neutrino masses
  $T_{1/2} \propto 1 / \langle m_{\beta\beta} \rangle^2$



Near future: $T_{1/2}$~10^{26}–10^{27} yr

Most ambitious experiments currently running / in preparation to investigate ~0.1–0.3 ton of isotope of interest

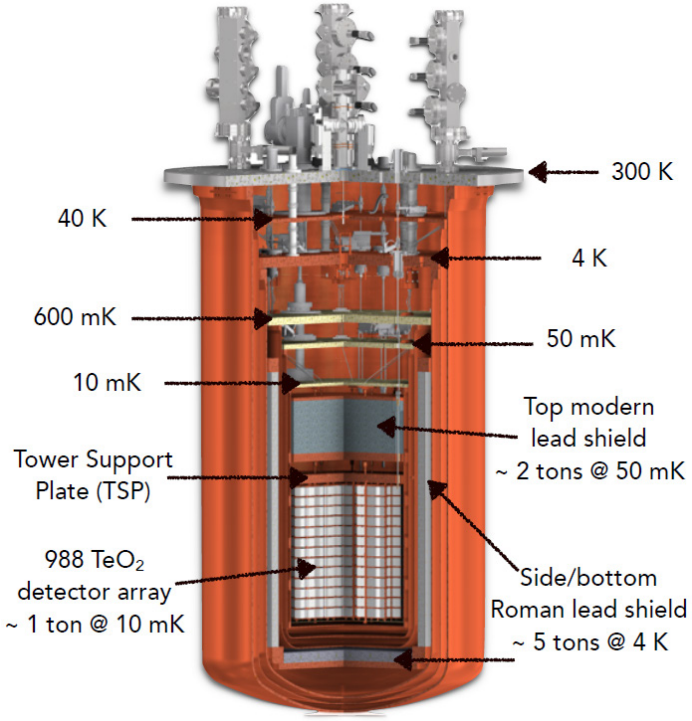
Best Bkg ~ (1–10) cnts/(yr ton keV)

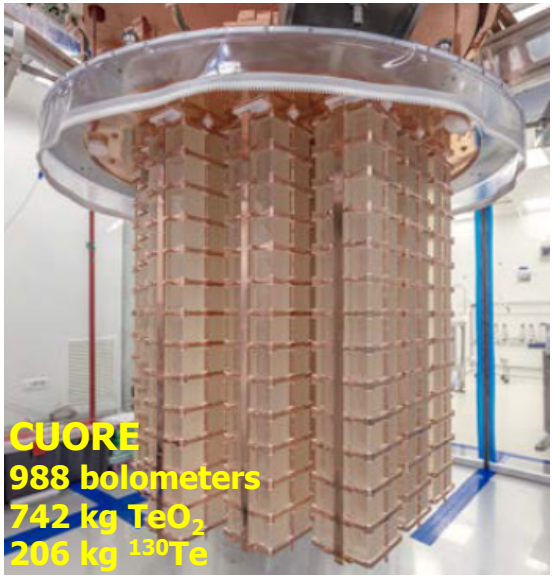
Far future: $T_{1/2}$~10^{27}–10^{28} yr

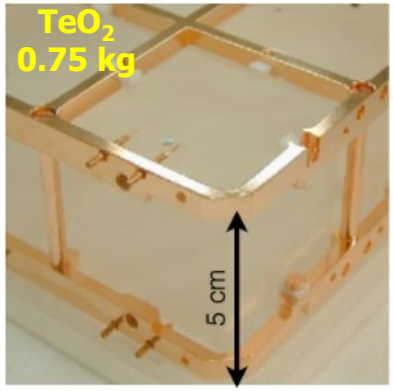
Experiments based on advanced/new low background technologies with ~0.1–1 ton of isotope of interest

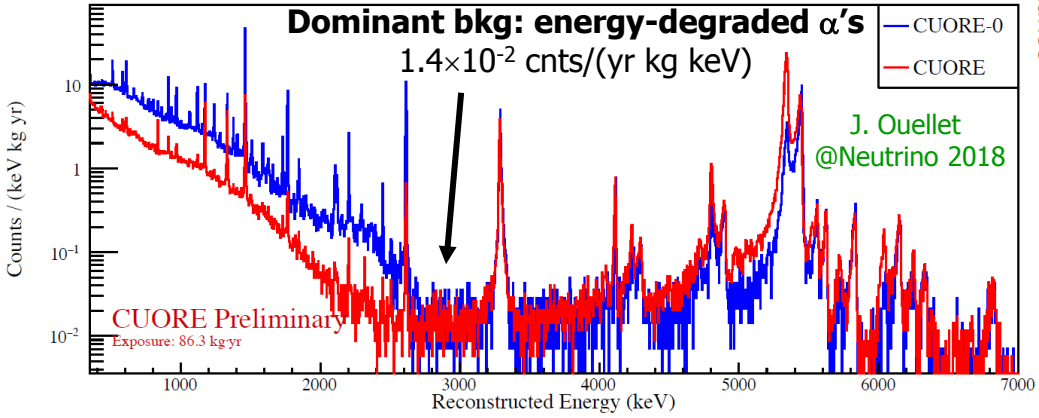
Required Bkg < 0.1 cnts/(yr ton keV)

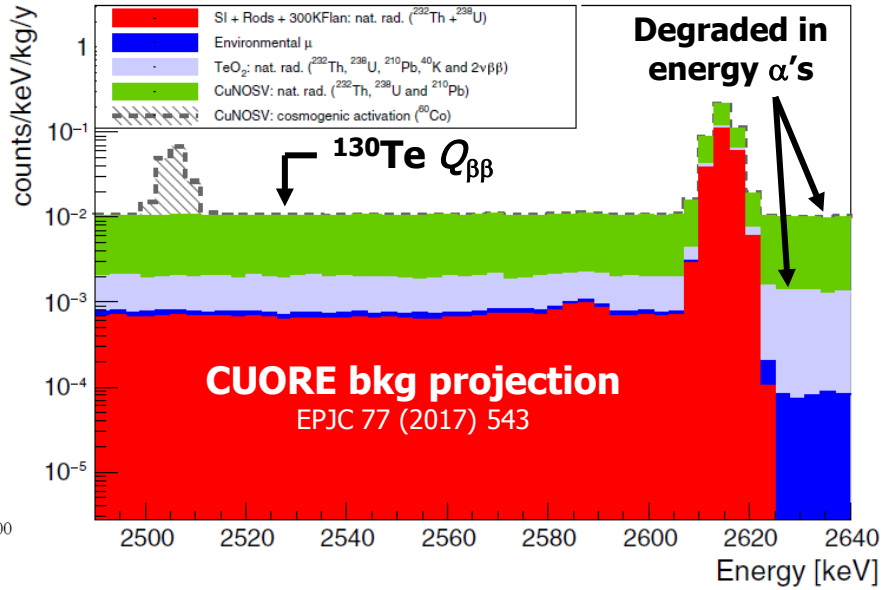
CUORE: 1st tonne-scale cryogenic 0ν2β experiment









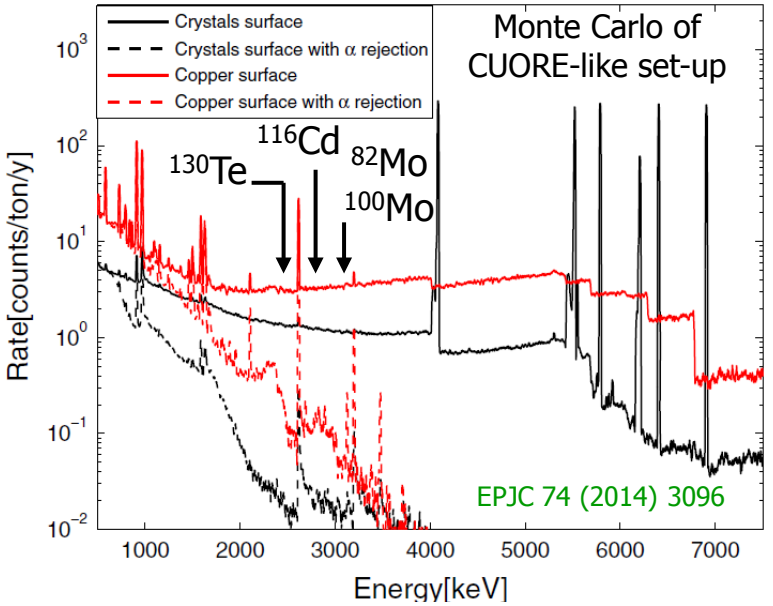


CUORE sensitivity is ~3x **limited by** a dominant alpha background originated to the detector **surface residual contamination**

Beyond CUORE: R&Ds towards CUPID project

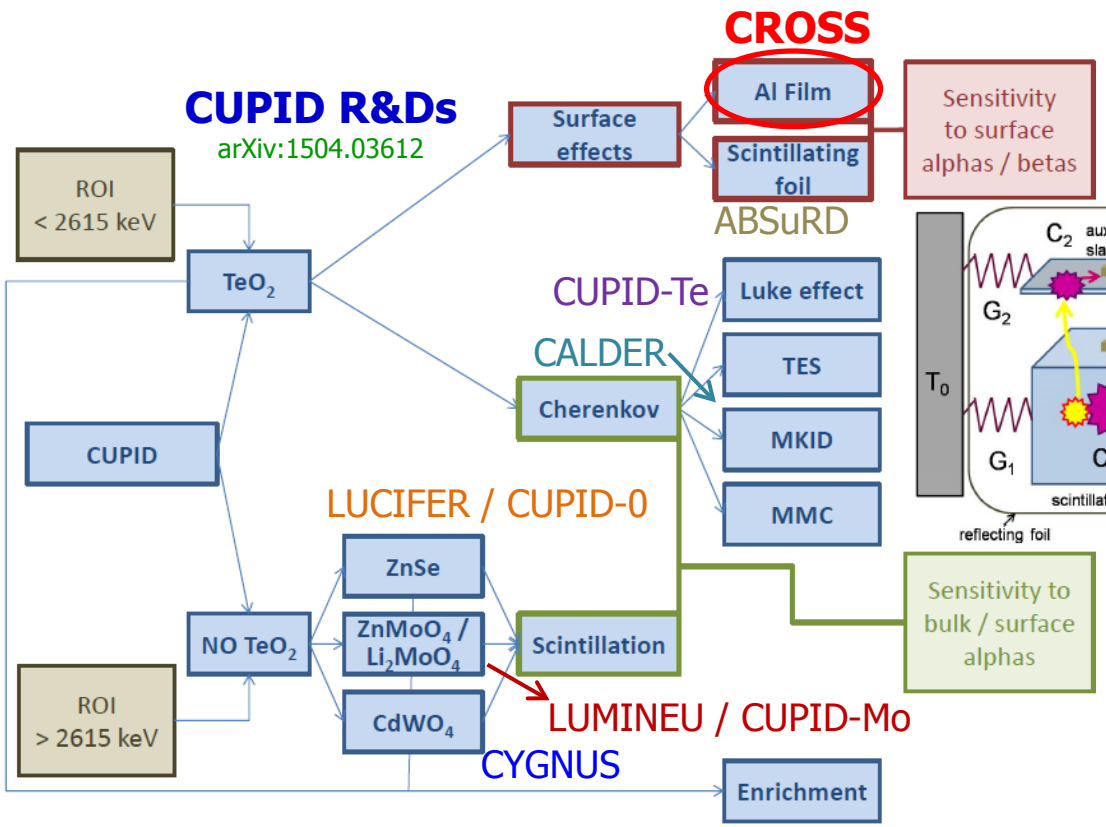
CUORE Upgrade with Particle IDentification

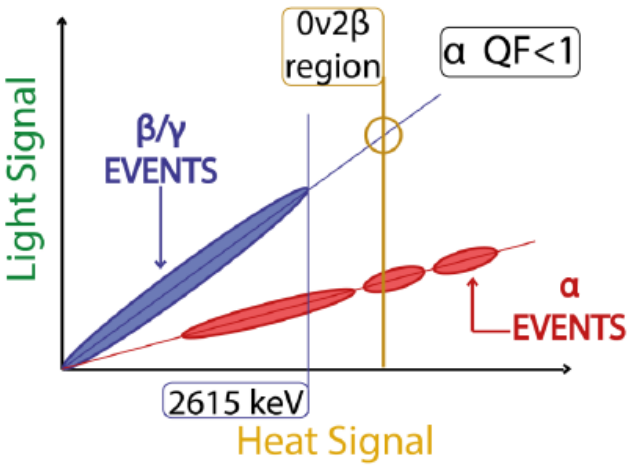
- **A tonne-scale 0νββ search project** arXiv:1504.03599
- **CUORE infrastructure**
  currently hosting a ton-scale TeO_2 bolometers array
- **Enriched cryogenic detectors**
  similar to CUORE TeO_2 radiopurity (≤ 10 μBq/kg U/Th)
  and bolometric performance (≤ 10 keV FWHM in ROI)
- **Active background rejection**
  1/100x CUORE (i.e. 99.9% α rejection)



CUPID R&Ds

arXiv:1504.03612





Parallel R&D of ^{100}Mo-containing scintillating bolometers ($CaMoO_4$,..) is ongoing within AMoRE project

See also a review Int. J. Mod. Phys. A 32 (2017) 1743012

CROSS: a new advancement opportunity

erc

2018-2022

Cryogenic **R**are-event **O**bservatory with **S**urface **S**ensitivity

CROSS develops an innovative bolometric technology for $0\nu2\beta$ search

Core of the project (high risk / high gain):

- Surface background rejection through **pulse shape discrimination**
  - **Surface sensitivity** through **superconductive Al film coating**
  - **Fast NbSi high-impedance TES** to replace / complement NTDs if necessary

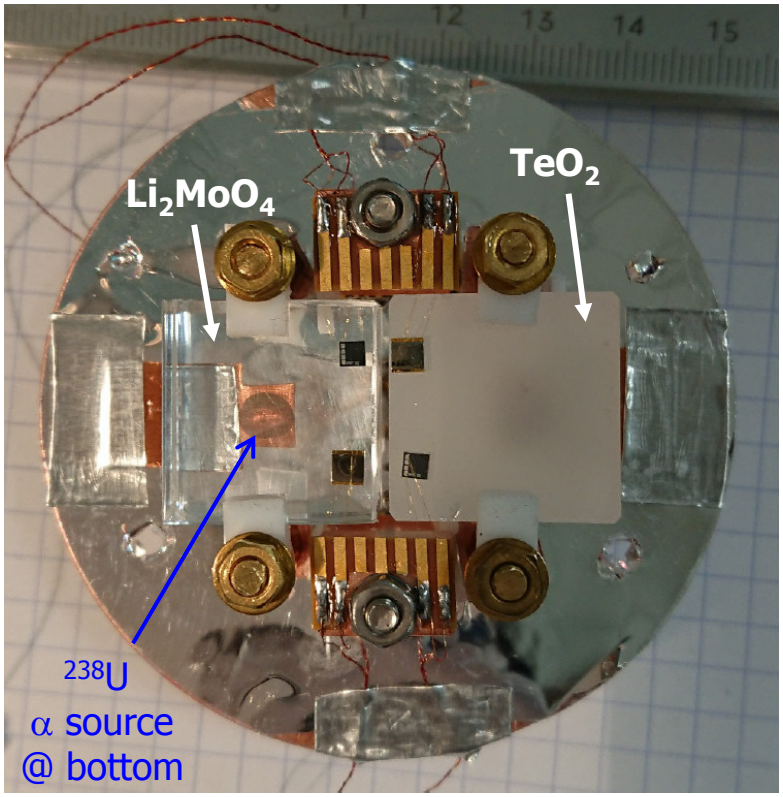
  → **Get rid of bolometric photodetectors**

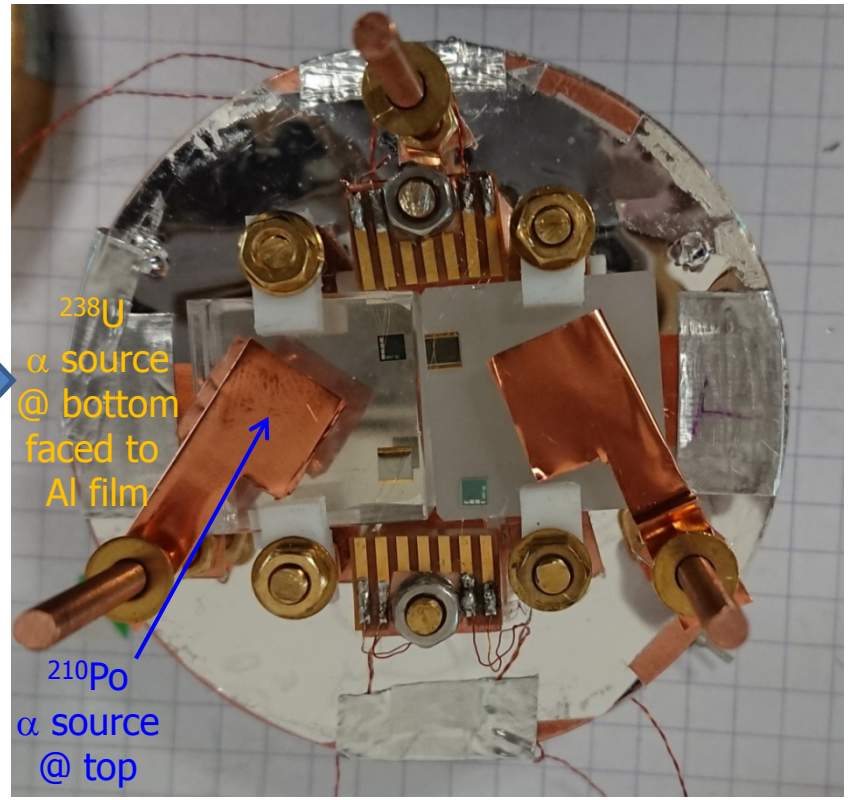
- Complete crystallization of available **^{100}Mo (10 kg)** in Li_2MoO_4 elements
- Purchase / crystallize **^{130}Te (up to 10 kg)** in TeO_2 elements
- Run **demonstrator** in a dedicated cryostat **@ LSC** (Spain)

First CROSS prototypes

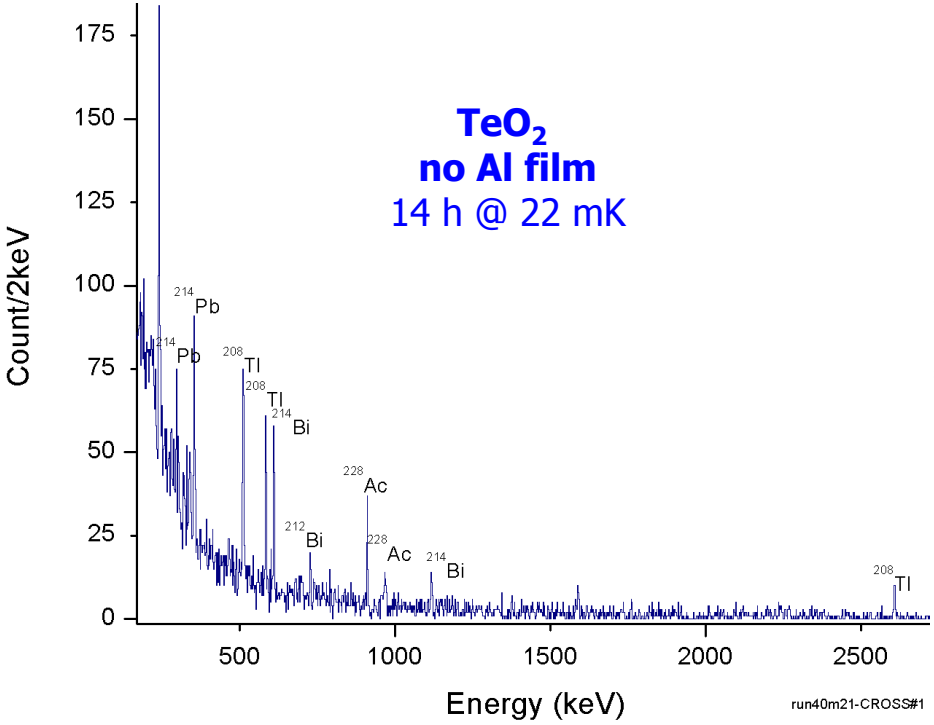
Development and bolometric tests @CSNSM

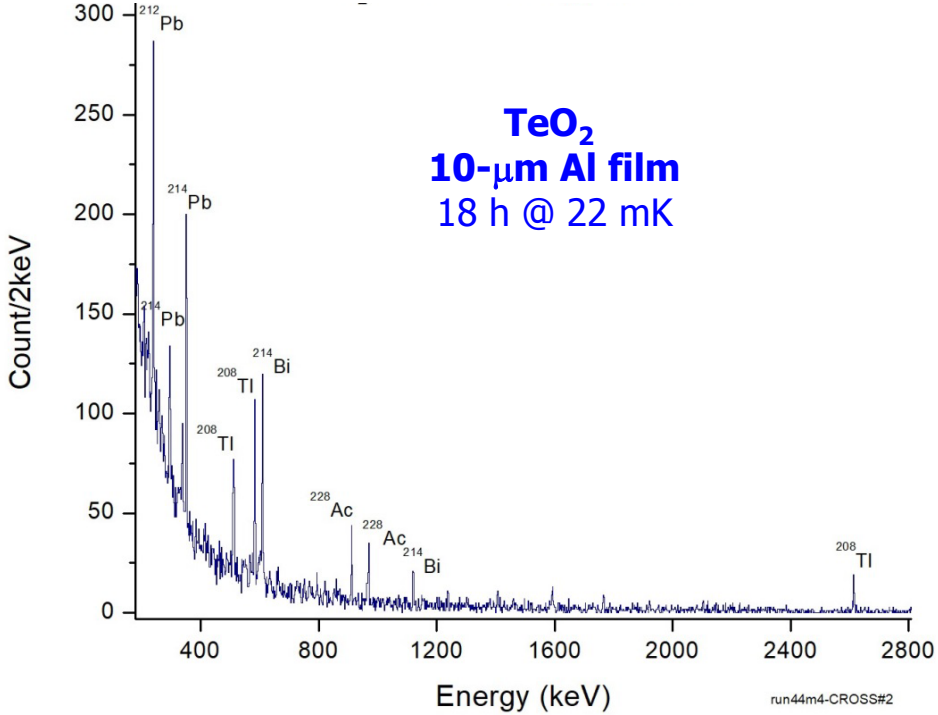
CROSS R&D run	Li_2MoO_4 2×2×1 cm, 12 g	TeO_2 2×2×1 cm, 25 g
#1	no Al	no Al
#2	10 μm Al	10 μm Al
#3	10 μm Al	1 μm Al





Performance of CROSS prototypes





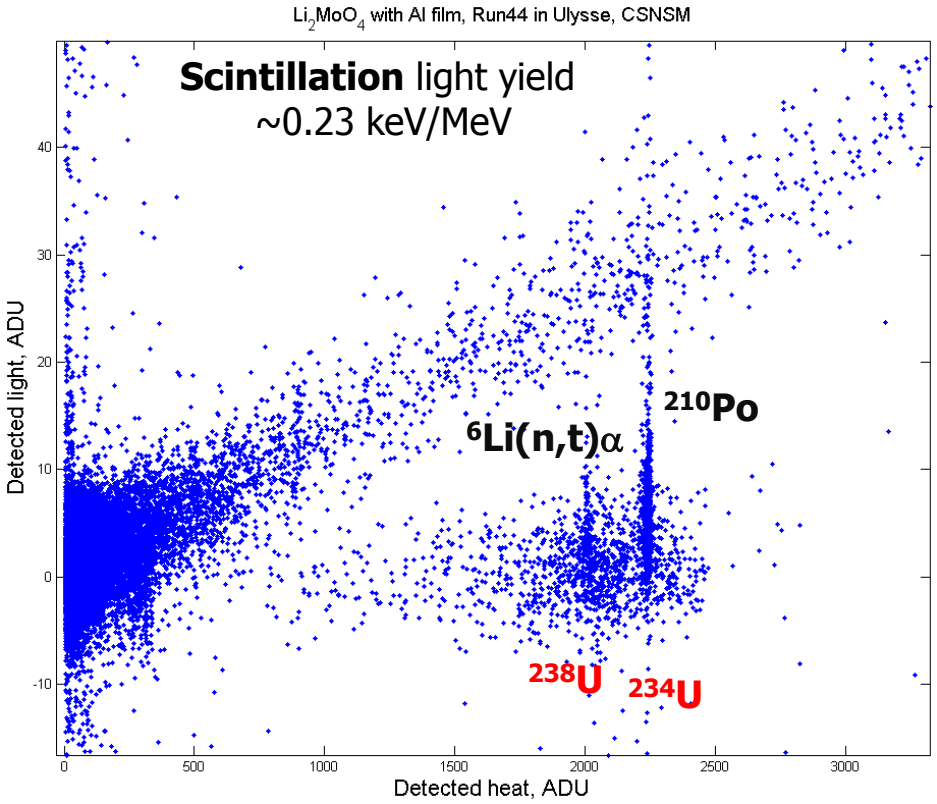
The **aluminum film (10- or 1-μm-thick)**, which covers 1/4 of the crystals surface, **affects neither sensitivity nor energy resolution** of the Li_2MoO_4 & TeO_2 bolometers

Light-assisted particle ID with CROSS prototypes

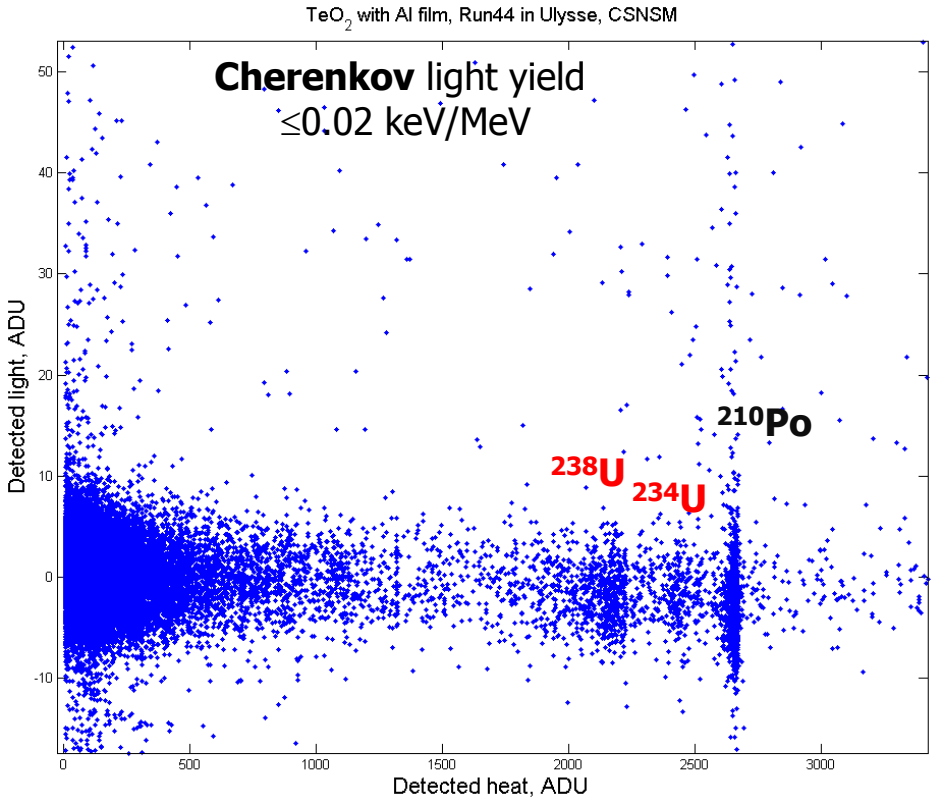
- **"Standard" performance ∅44-mm Ge bolometric photodetector** (0.42 μV/keV & 0.32 keV FWHM baseline noise @ 22 mK)

- **Poor light collection** (crystals were shadowed by the ^{210}Po sources)

Li_2MoO_4
10-μm Al film

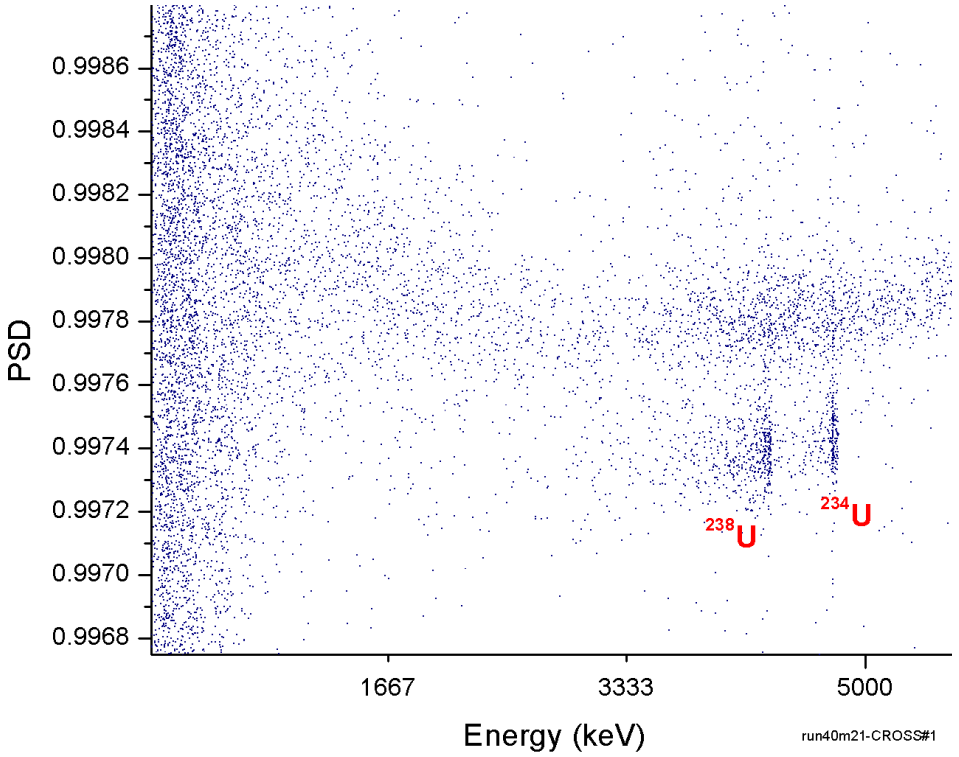


TeO_2
10-μm Al film

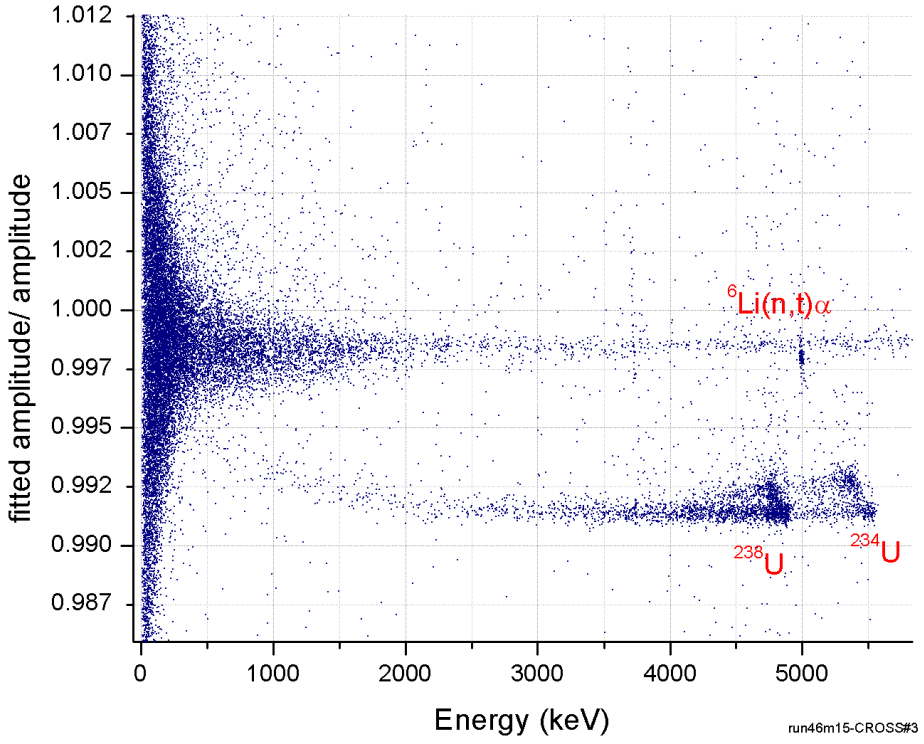


Pulse-shape discrimination with Li_2MoO_4 bolometer

Li_2MoO_4 no Al film



Li_2MoO_4 10-μm Al film



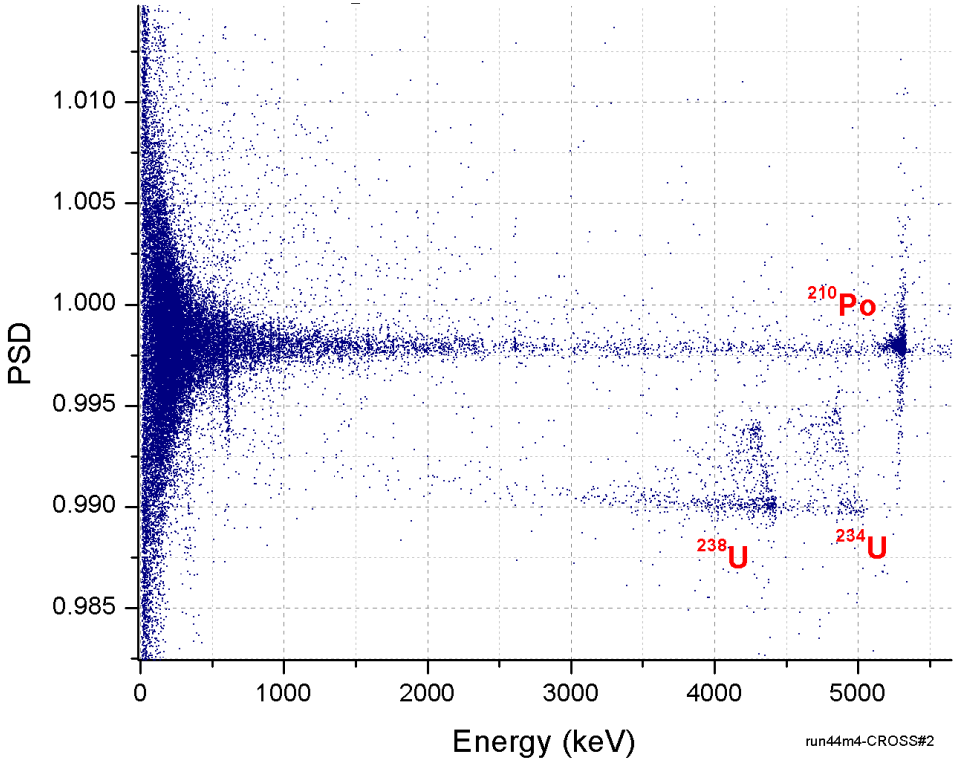
Separation of surface α's: ~3σ

Separation of surface α's: >10σ

The **10-μm-thick aluminum film** significantly **improves** the **pulse-shape discrimination** capability for the Li_2MoO_4 **scintillating bolometer**

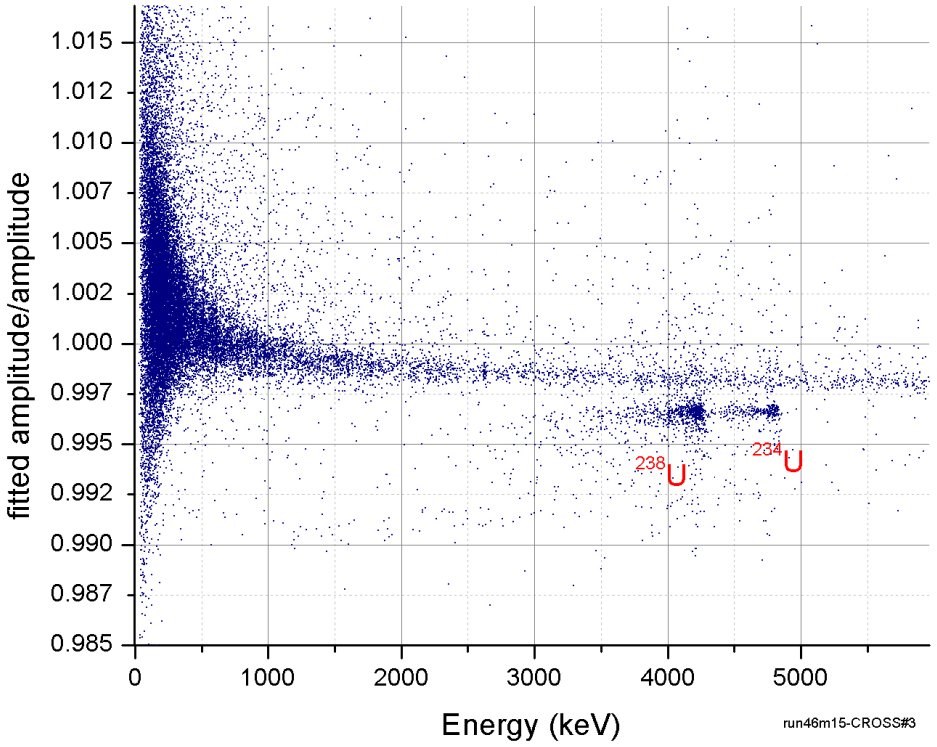
Pulse-shape discrimination with TeO_2 bolometer

TeO_2
10-μm Al film



Separation of surface α's:
>9σ

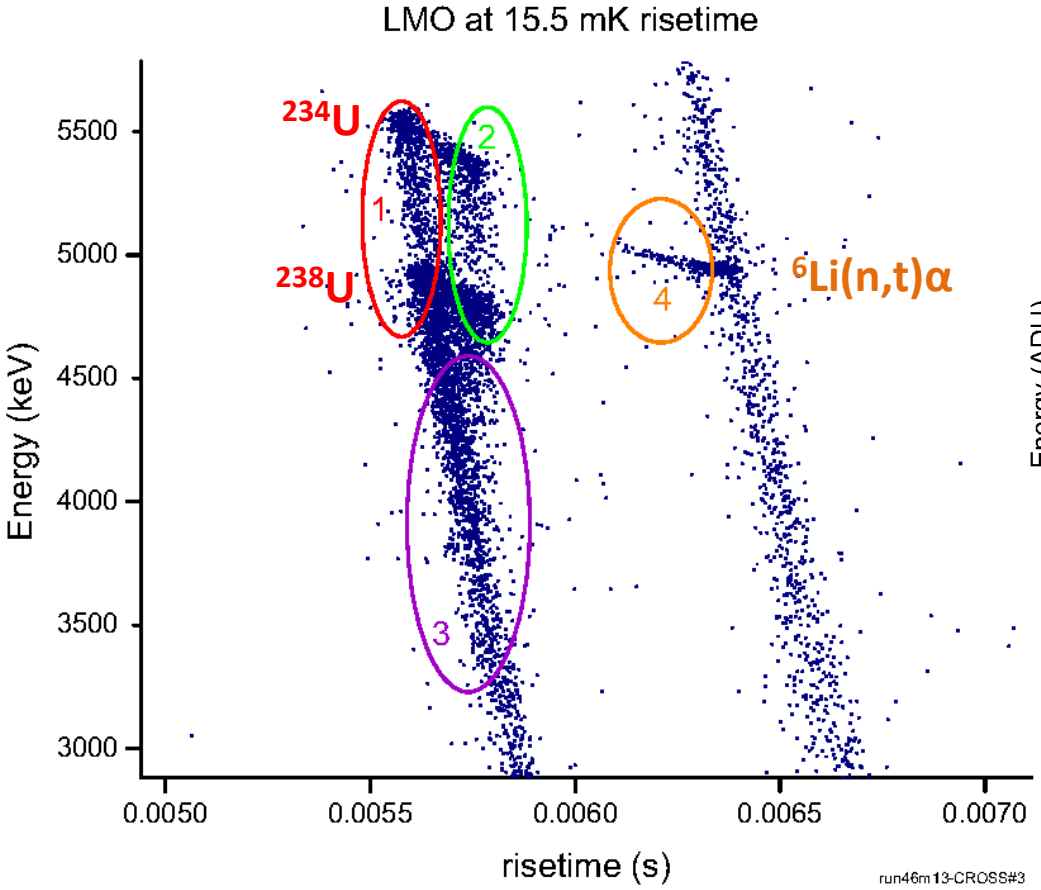
TeO_2
1-μm Al film

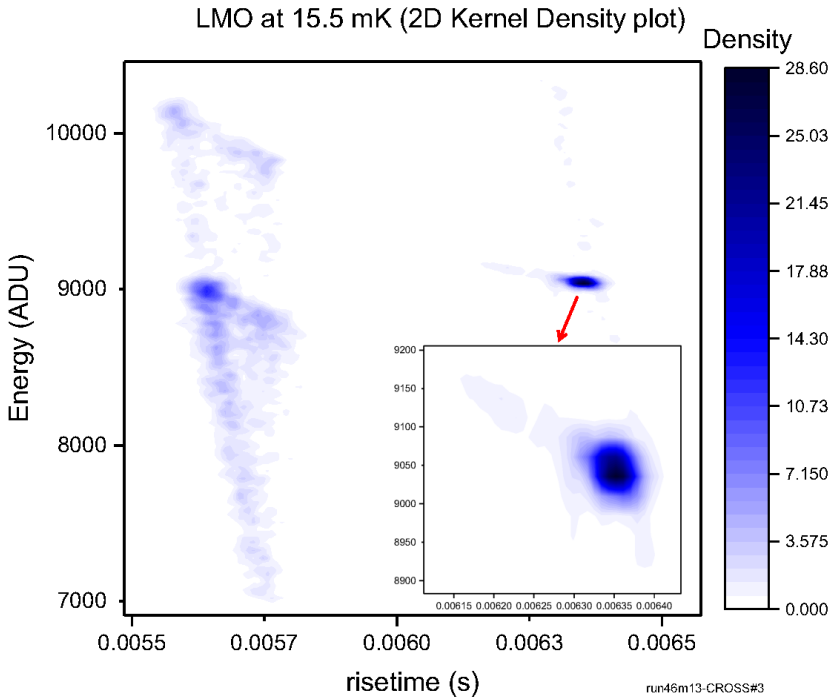


Separation of surface α's:
~ 5σ

Even the **1-μm-thick aluminum film** allows to achieve
the **highly efficient PSD** capability for the TeO_2 **poorly-scintillating bolometer**

Closer view on a pulse-shape difference (Li_2MoO_4)





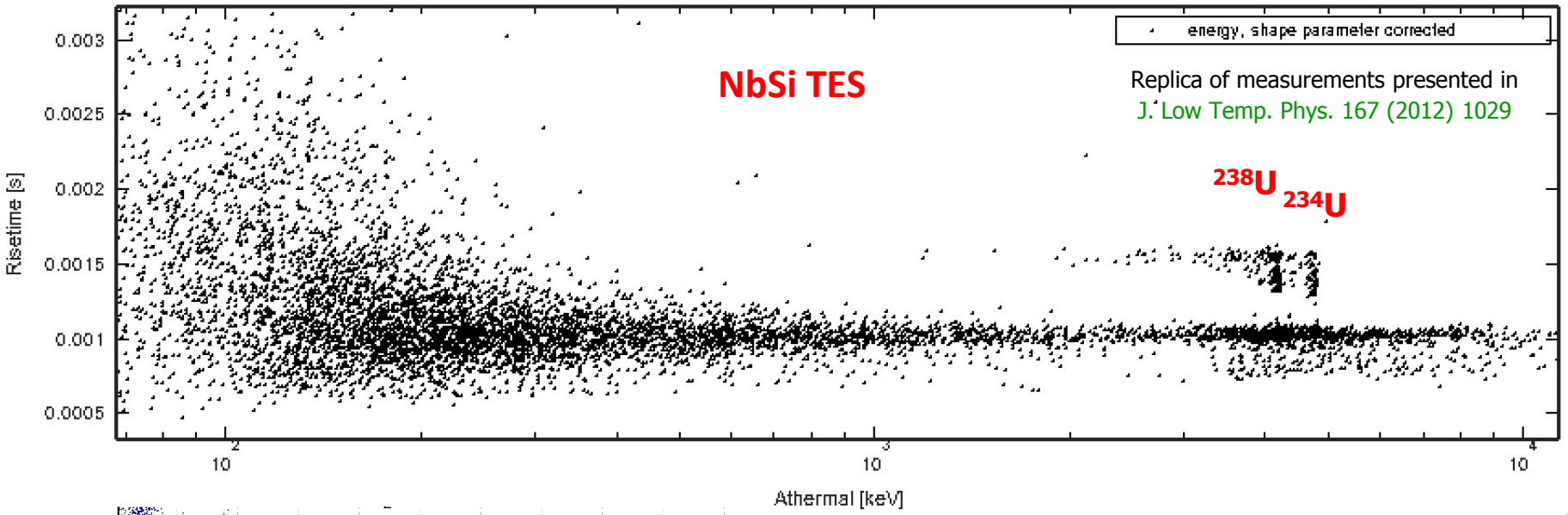
A **pulse-shape difference** for a **full / partial / no energy deposition in the Al film**

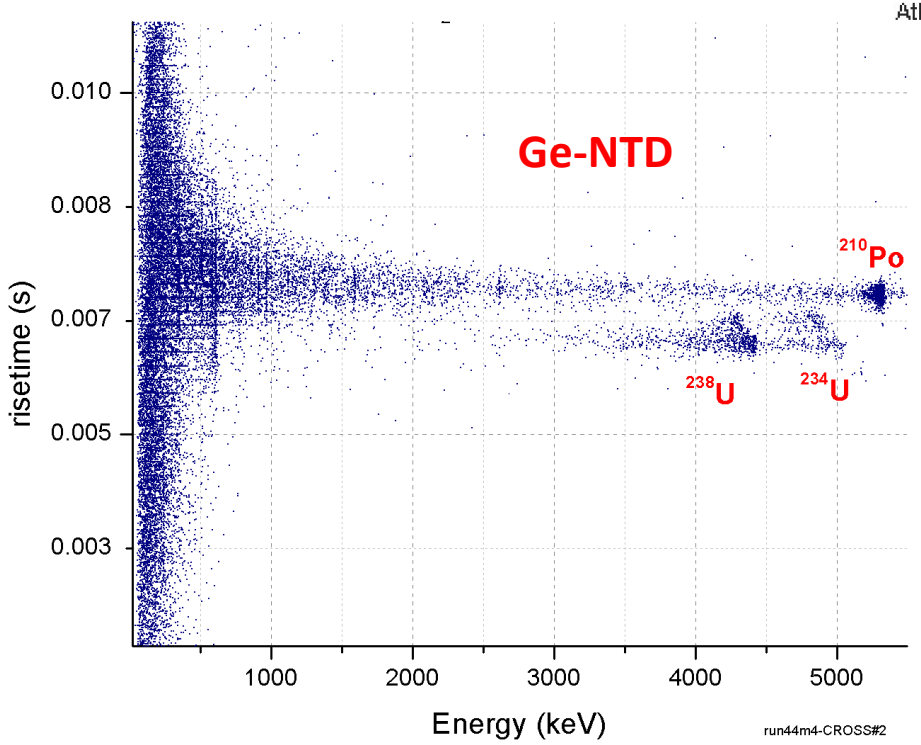
⇓

According to experimental and Monte Carlo data of neutron-induced events,

Al film coated detector shows a PSD sensitivity up to ~1-mm-depth interaction

Solid-state-physics phenomena in superconducting Al





PSD of near surface events in bolometers exploiting solid-state-physics phenomena in superconductors

Sensor	TES	NTD
Sensitivity to	Athermal phonons	Thermal phonons
Nuclear event close to Al film	Cooper pairs break ⇓ "long-lived" quasi-particles	Faster thermalization of athermal phonons
PSD signature	Delayed signal	Faster signal

Summary and perspectives

- Next generation $0\nu2\beta$ searches with cryogenic detectors require an active rejection of surface contamination induced background (at least α' s)

- Most of the present active R&Ds are devoted to the developments of heat-light dual read-out hybrid bolometers for $0\nu2\beta$ searches

- CROSS, recently ERC funded project, aims at development of bolometers capable to reject near surface interaction exploiting superconducting properties of an Al film surface covering

- First CROSS prototypes ($2\times2\times1$-cm Li_2MoO_4 and TeO_2 with ¼ of crystals surface covering by 10- or 1-μm-thick Al film) show no impact of the superconducting layer on the detectors signal amplitude & energy resolution, while they demonstrate a highly efficient PSD of alpha interaction near the Al-covered surface

- Fully covered CROSS prototypes will be investigated at the beginning of 2019