The CROSS Experiment: Unveiling Neutrino's Mysteries with Superconductivity Methods

Hawraa Khalife on behalf of the CROSS Collaboration
Centre de Sciences Nucléaires et de Sciences de la Matière (CSNSM), CNRS/IN2P3
Hawraa.Khalife@csnsm.in2p3.fr

Abstract

Neutrinoless double beta (0νββ) decay is a hypothetical rare nuclear transition ($T_{1/2}$ >10²⁶ y), its observation would provide an important information about the nature of neutrinos (Dirac or Majorana particle) demonstrating that the lepton number is not conserved. This decay can be investigated with bolometers embedding the double beta decay isotope (^{76}Ge, ^{82}Se, ^{100}Mo, ^{116}Cd, ^{130}Te...), which perform as low temperature calorimeters (~10 mK) detecting particle interactions via a small temperature rise read out by a dedicated thermometer. CROSS (Cryogenic Rare-event Observatory with Surface Sensitivity) aims at the development of bolometric detectors (Li_2MoO_4 and TeO_2) capable of discriminating surface α and β interactions by exploiting superconducting properties of Al film deposited on the crystal surface. We report in this paper the results of tests on prototypes performed at CSNSM (Orsay, France) that showed the capability of a-few-μm-thick superconducting Al film deposited on crystal surface to discriminate surface α from bulk events, thus providing the detector with the required surface sensitivity capability. The CROSS technology would further improve the background suppression and simplify the detector construction with a view to future competitive double beta decay searches.

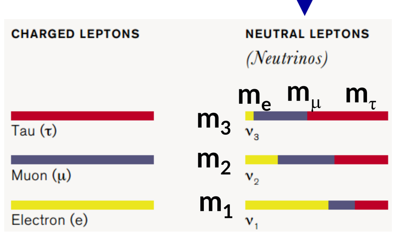
What is a neutrino?

neutral elementary particles

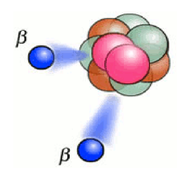
tiny unknown mass

oscillate

Dirac or Majorana



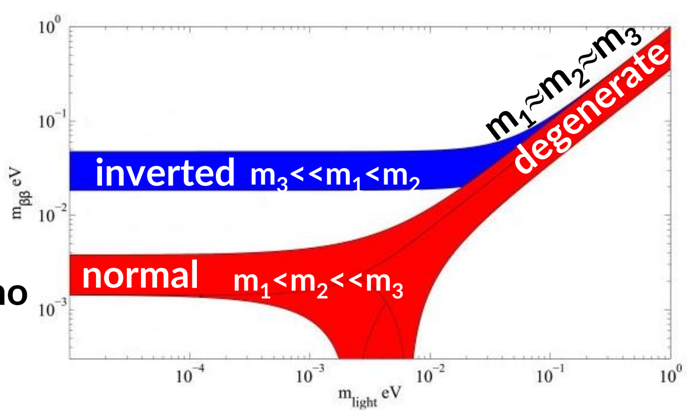
Neutrinoless double beta decay (0νββ): *(A, Z)→ (A, Z+2) + 2e⁻*
evidence will determine some of the unknown properties of ν



$$\left[T^{0\nu}_{1/2}\right]^{-1} = \left|m_{\beta\beta}\right|^2 \left|M^{0\nu}\right|^2 G^{0\nu}$$

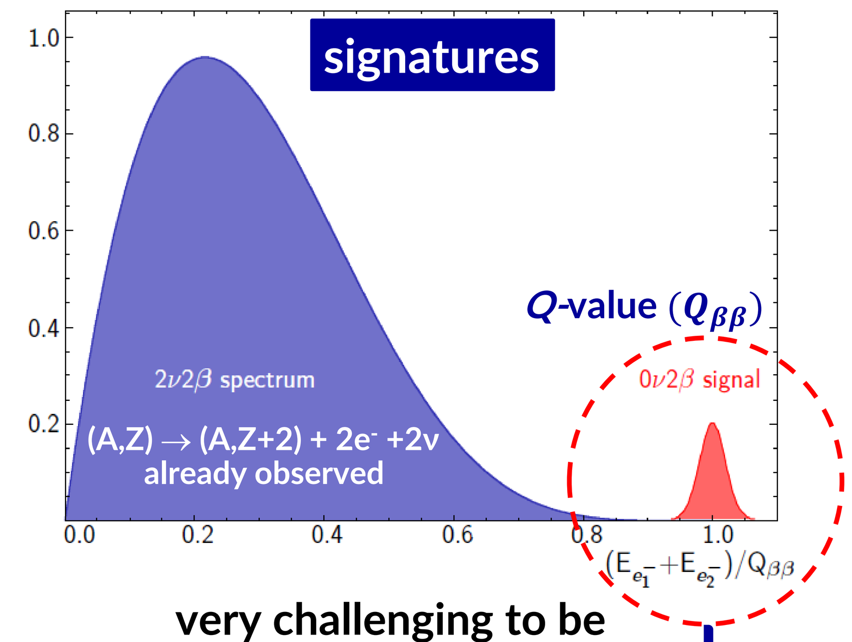
- $m_{\beta\beta}$: effective Majorana mass
- $M^{0\nu}$: nuclear matrix element
- $G^{0\nu}$: phase space factor

- confirm the Majorana nature ($\nu = \bar{\nu}$)
- measure $T^{0\nu}_{1/2}$ ➡ $m_{\beta\beta}$ measurement
- provide insight on the mass pattern problem
- obtain constraint on the absolute scale of neutrino masses



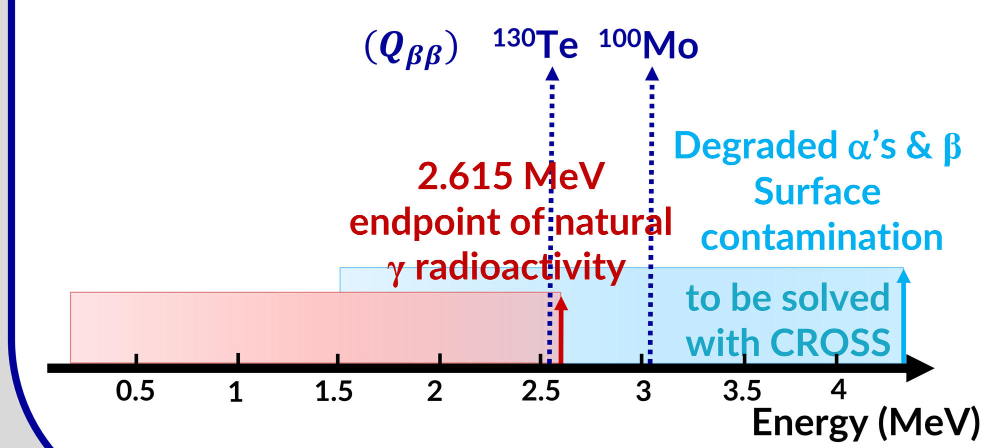
$T_{1/2}$ > 10²⁶ y very long half-life ➡ experiments will face many difficulties

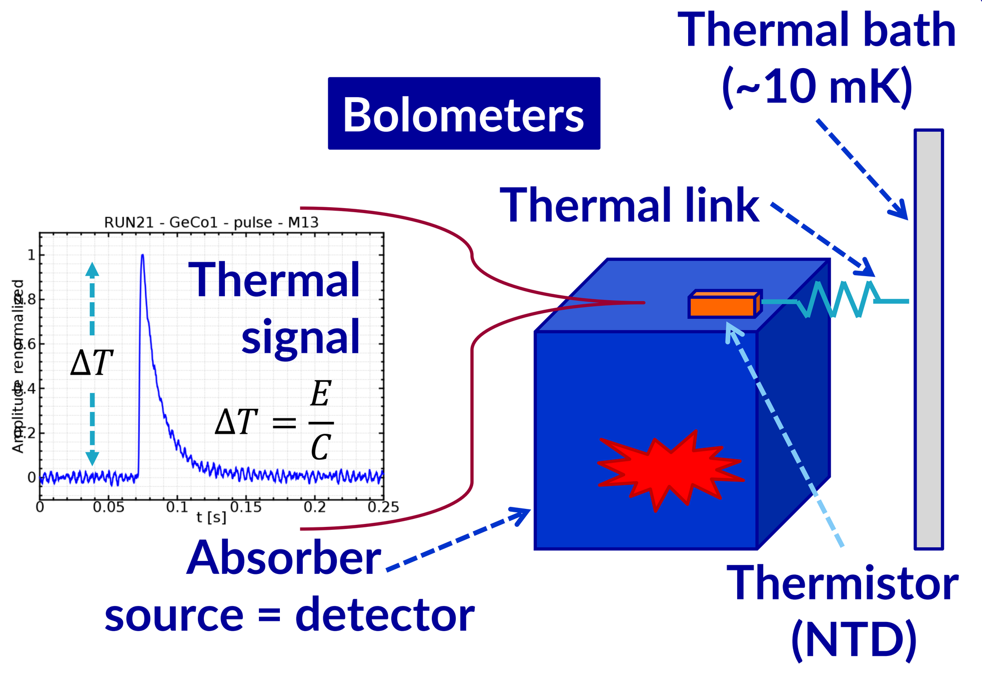
The background problem



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

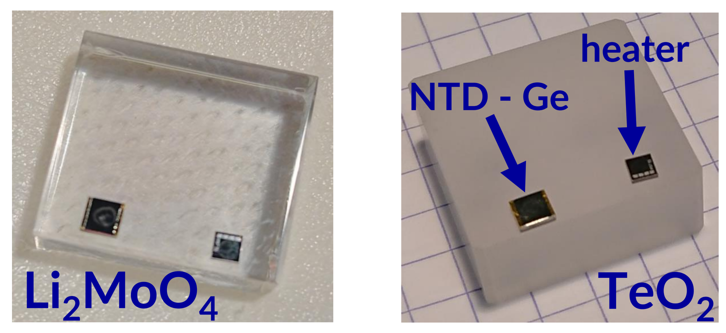
controlling the background is crucial:





- high energy resolution
- full active volume (no dead layer)
- flexible material choice (Li_2MoO_4, $ZnMoO_4$, $CaMoO_4$, ZnSe, TeO_2 ...)

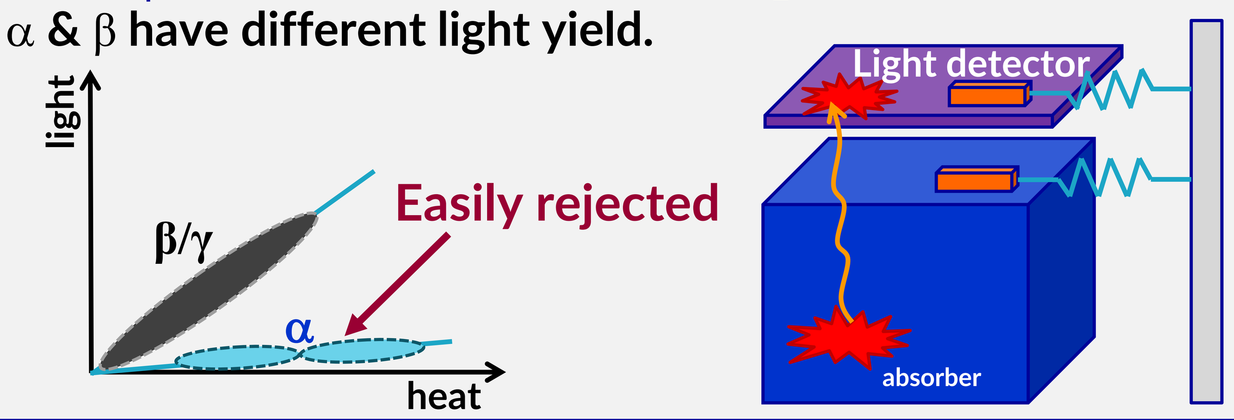
isotope	Q-value	Isotopic abundance
¹⁰⁰Mo	3034 keV	9.6 %
¹³⁰Te	2537 keV	34 %



CROSS technology

Cryogenic Rare-event Observatory with Surface Sensitivity

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 (TeO_2) emitted by the absorber, since α & β have different light yield.



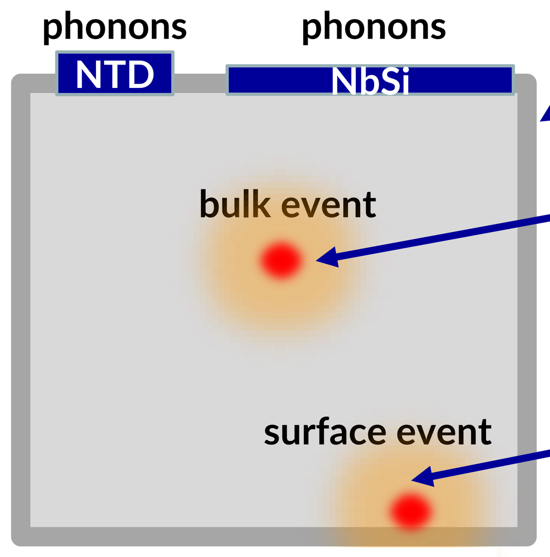
CROSS proposes a technique to mitigate surface contamination via providing bolometers with surface sensitivity ➡ no light detector is needed

The superconductive Al film acts as a pulse shape modifier for surface events

Proof of concept was achieved in a test on TeO_2 with a fast sensor (NbSi) and 10 μm Al film in 2010 (CSNSM, Orsay). [J. Low Temp. Phys. 167 (2012) 1029]

slow sensor sensitive to thermal phonons

fast sensor sensitive to athermal phonons



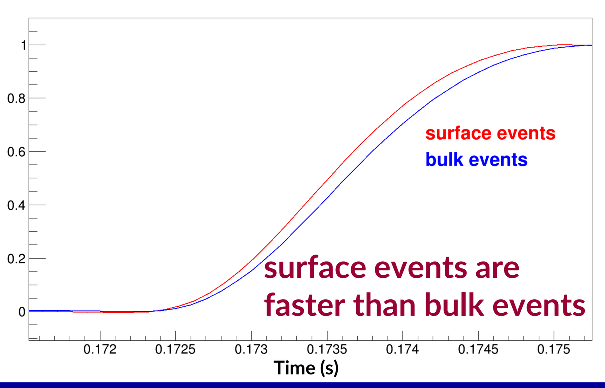
few 10 μm superconducting Al film

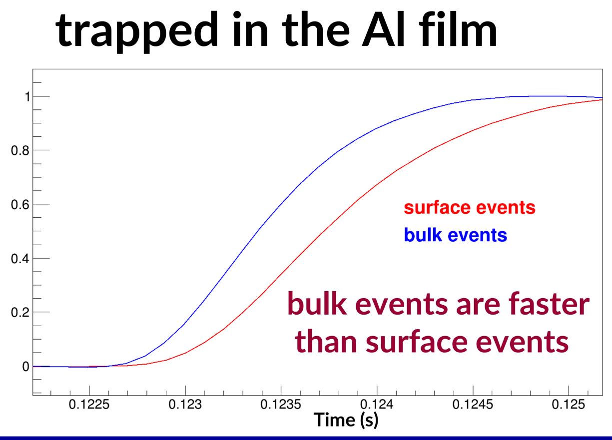
athermal phonons slowly converted to thermal phonons by energy down conversion

athermal phonons quickly converted to thermal phonons thanks to superconducting Al film

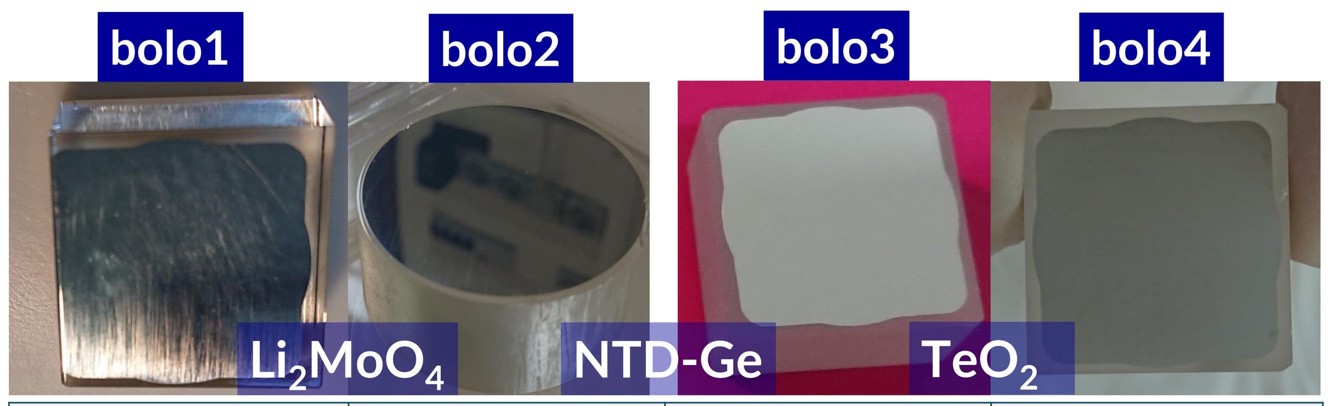
NTD: events close to Al film are thermalized faster than bulk events

NbSi: delayed component for surface events due to being trapped in the Al film

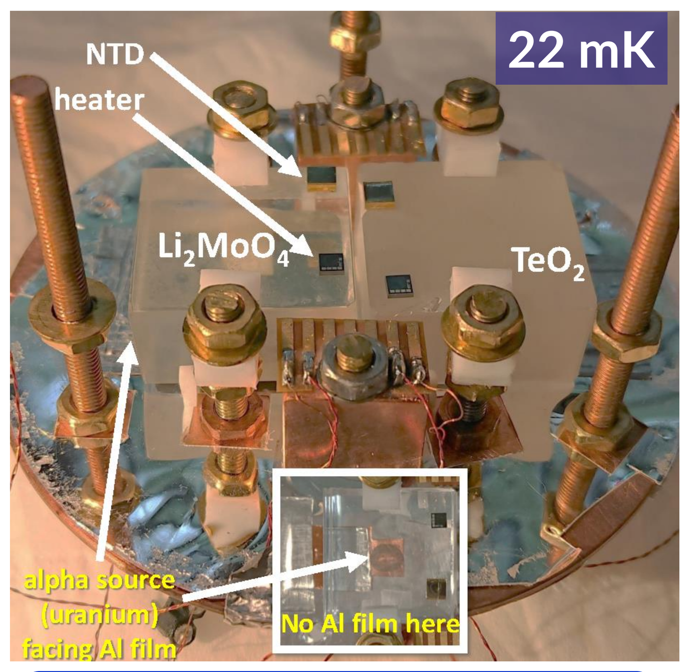




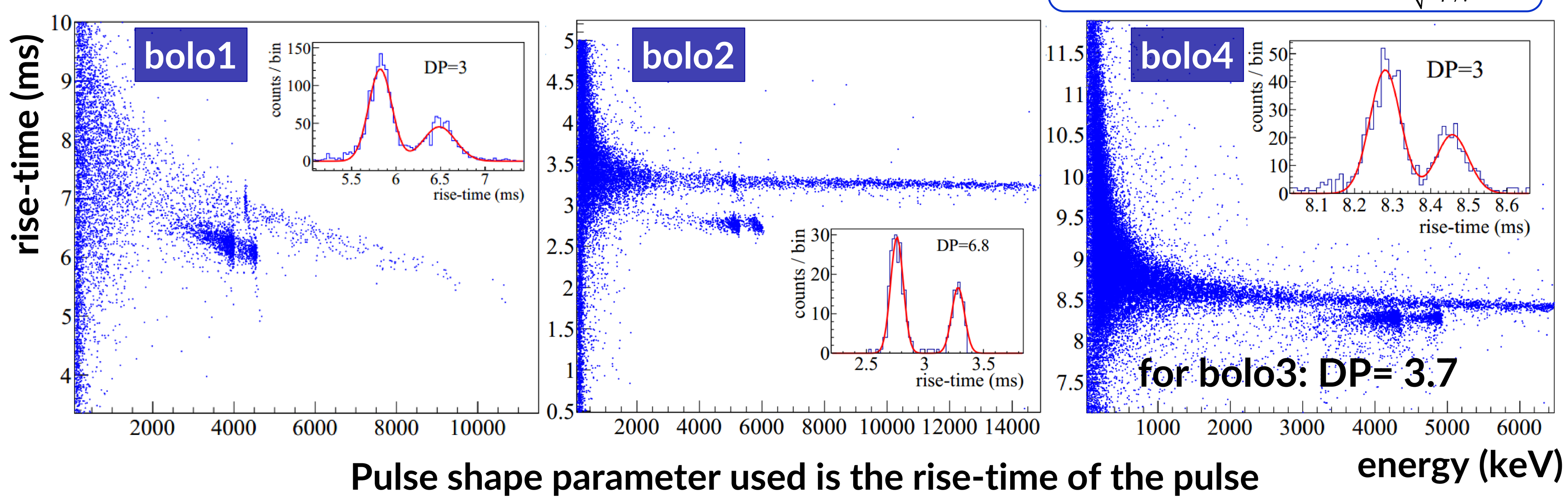
CROSS assembly & results



bolo1	bolo2	bolo3	bolo4
2×2×1 cm³	∅4×2 cm³	2×2×1 cm³	2×2×1 cm³
12 g	67 g	25 g	25 g
10 μm Al	10 μm Al	10 μm Al	1 μm Al
53 nV/keV	37 nV/keV	43 nV/keV	44 nV/keV



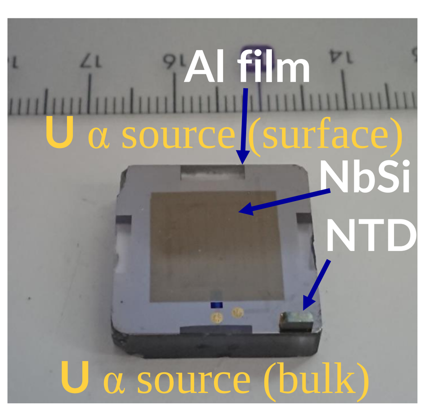
Discrimination power: $DP = \frac{|\mu_{\beta/\gamma} - \mu_\alpha|}{\sqrt{\sigma^2_{\beta/\gamma} + \sigma^2_\alpha}}$



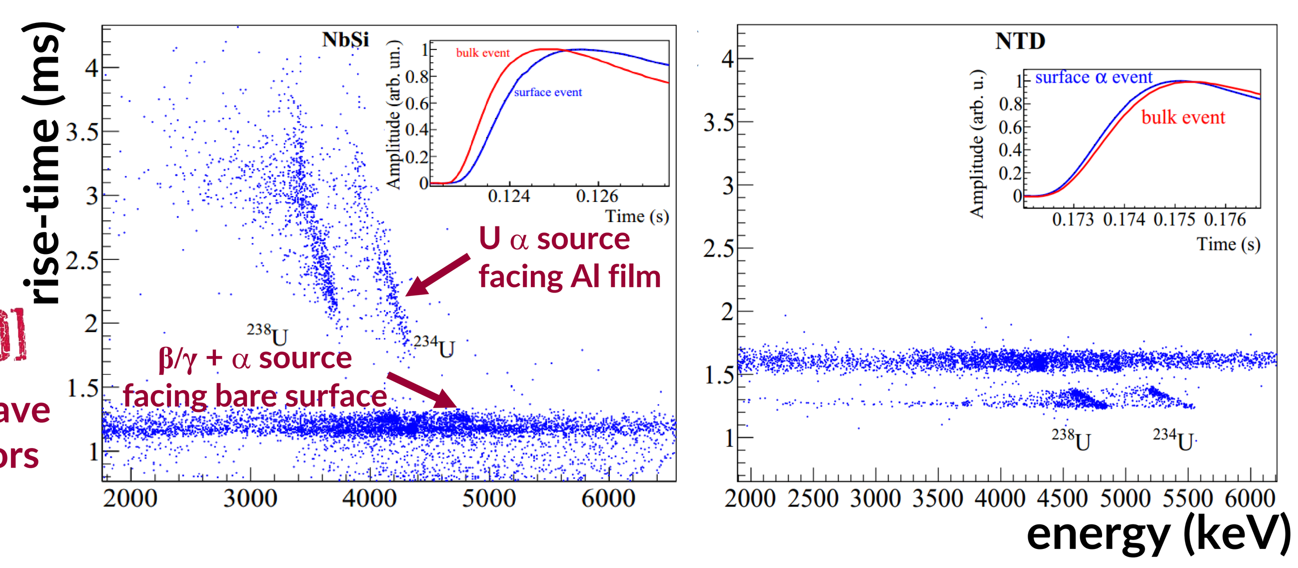
Pulse shape parameter used is the rise-time of the pulse (time from 10% to 90% of the pulse maximum amplitude)

[a more efficient parameter can be found here: arXiv:1906.10233]

NO impact of Al film on bolometeric performance (energy resolution, sensitivity)



[CONFIRMED] NTD and NbSi have opposite behaviors



Near future goals:

- fully coat the crystals with Al film
- test of another coating material
- underground tests (LSC, Spain)

Far future goals:

CUPID demo with 90-crystal array Of enriched $Li_2{}^{100}MoO_4$ & $^{130}TeO_2$ bolometers