CROSS: A new technology in bolometric searches for neutrinoless double-beta decay

Madhujith MADHUKUTTAN, IJCLab, Orsay

CAT DOCTORAL SEMINAR

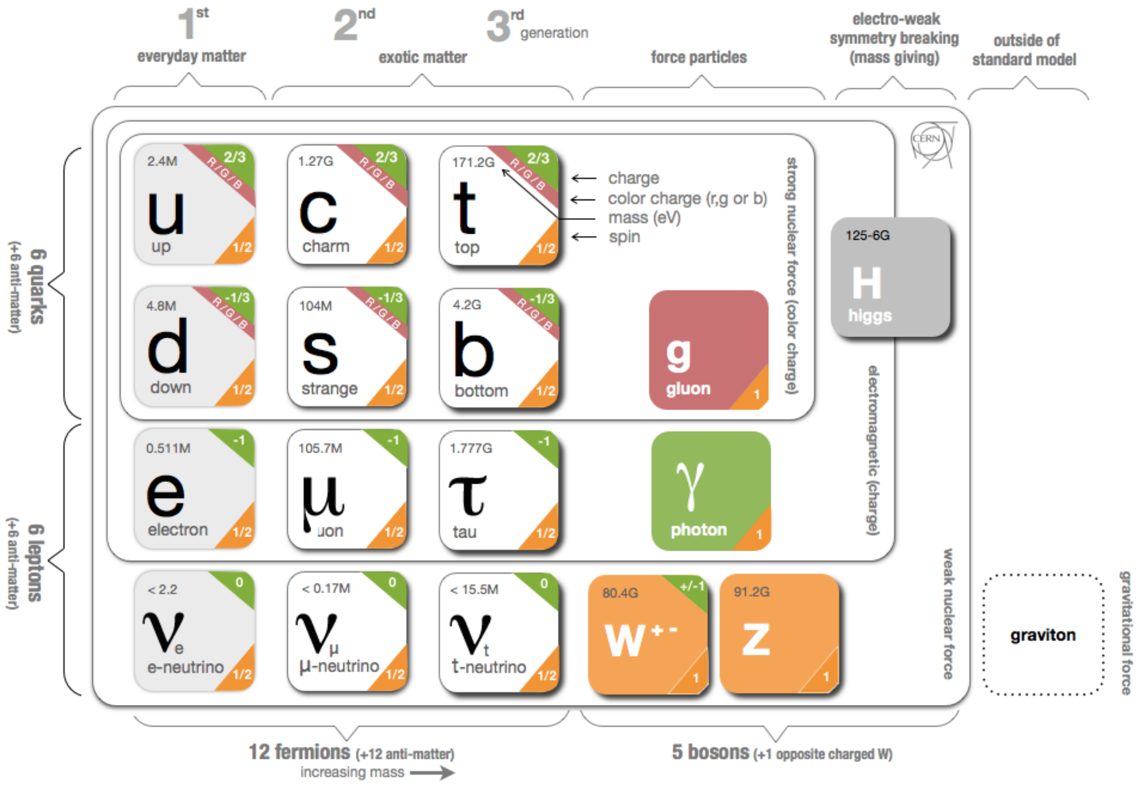
25/05/2021

Neutrino

- The Standard Model (SM) describes and predicts the behaviors of the basic building blocks of the universe

- It consists of 6 quarks, 6 leptons, force-carrier particles (gluons, photons, W and Z bosons) and the Higgs boson

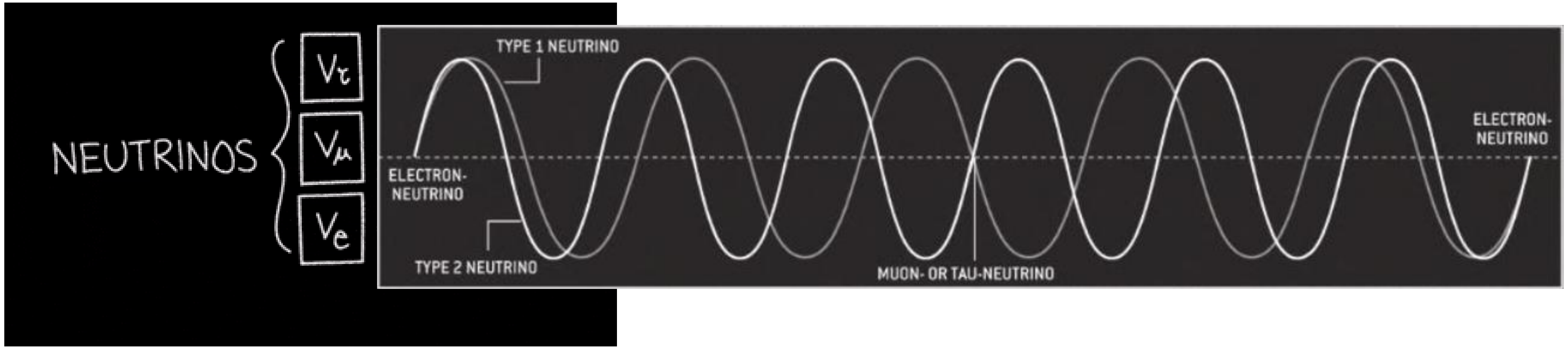
- The three neutral lepton particles neutrinos, are tricky and mysterious.



Standard Model says about neutrinos is that

- 3 Flavors : Electron, Muon and Tau neutrino

- Massless



Current Experiment aims at

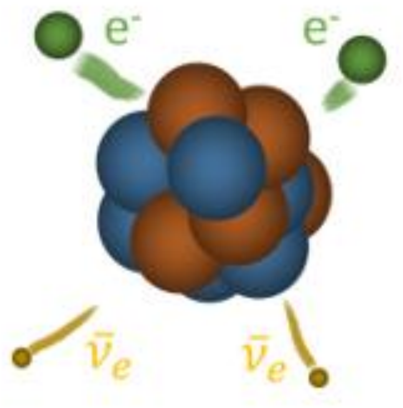
- The fundamental nature: Dirac or Majorana

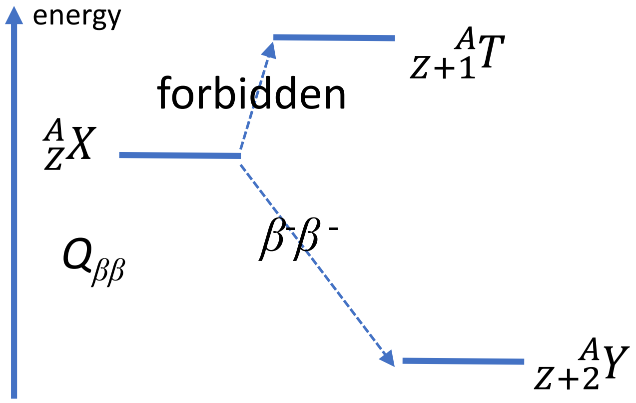
Two neutrino DoubleBeta Decay (2νββ)

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

- This process is allowed in the SM of physics and is allowed for 35 nuclides but observed only ~1/3 of them

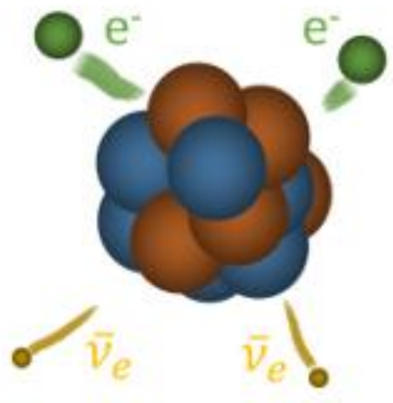
- $T_{1/2} \sim 10^{18} - 10^{24}$ years



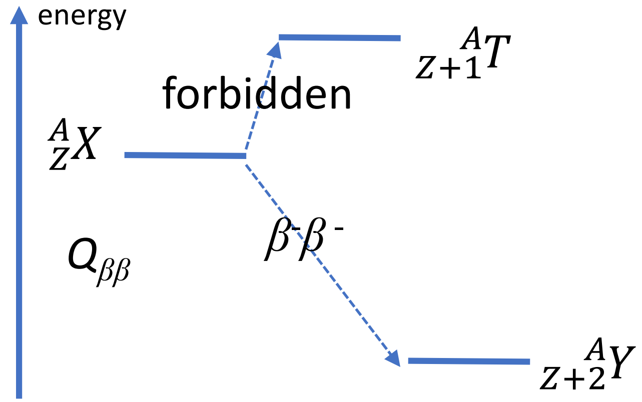


Two neutrino DoubleBeta Decay (2νββ)

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

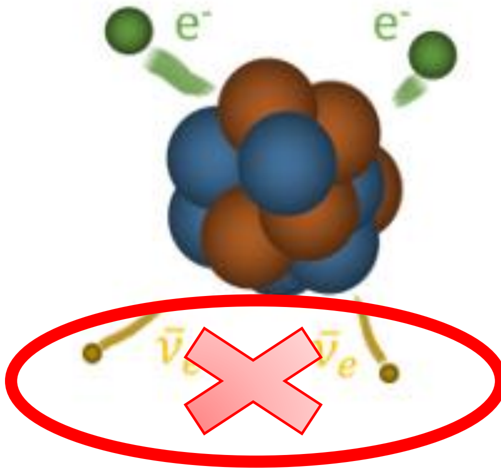


- This process is allowed in the SM of physics and is allowed for 35 nuclides but observed only ~1/3 of them
- $T_{1/2} \sim 10^{18} – 10^{24}$ years



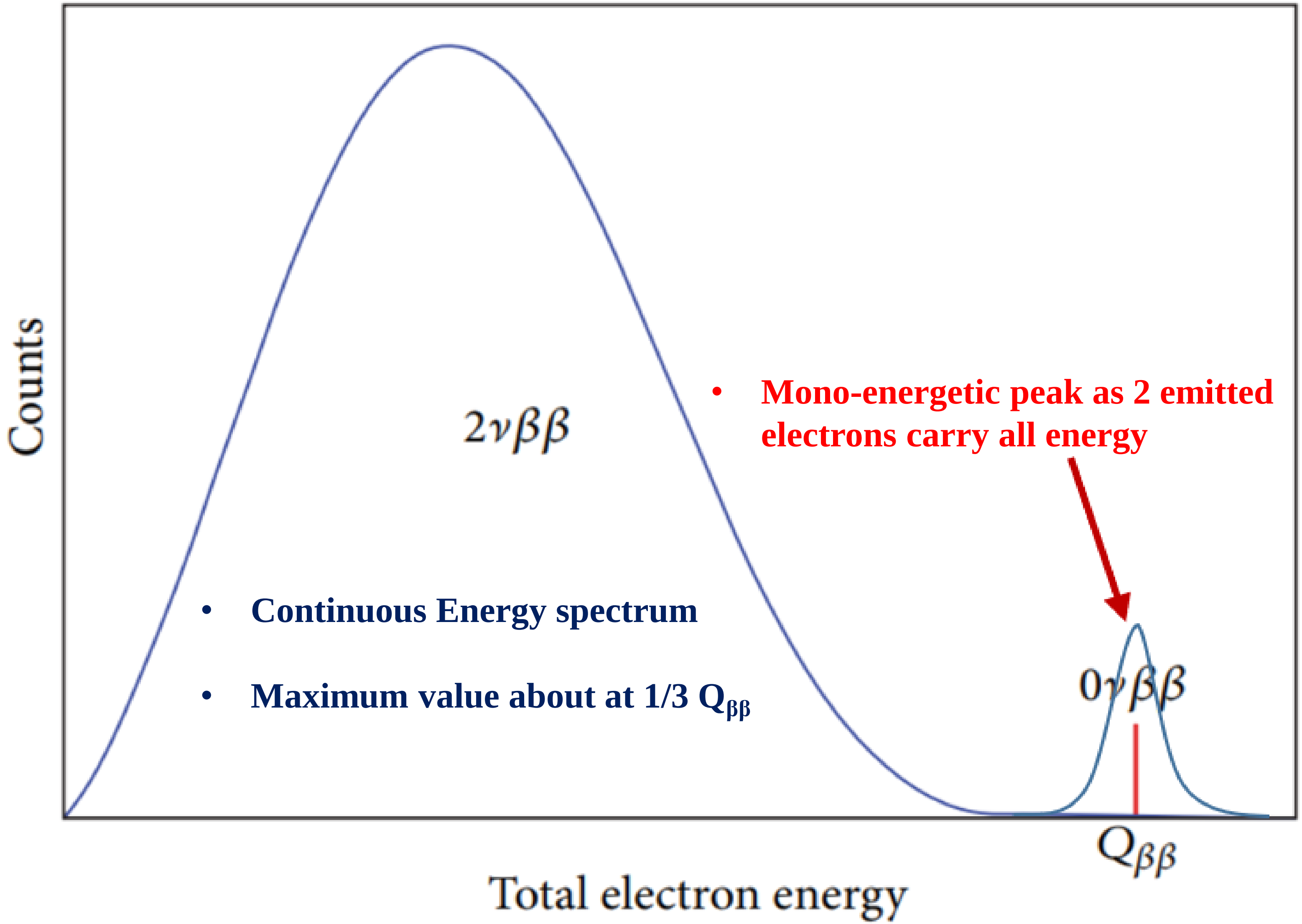
Neutrinoless Double Beta Decay (0νββ)

(A, Z) → (A, Z + 2) + 2e⁻



- This process is not allowed in the SM of physics and this happens only if
  - The total Lepton Number violates
  - Neutrinos coincide with their antiparticle, i.e. Majorana Particles
- $T_{1/2} > 10^{24} – 10^{26}$ years

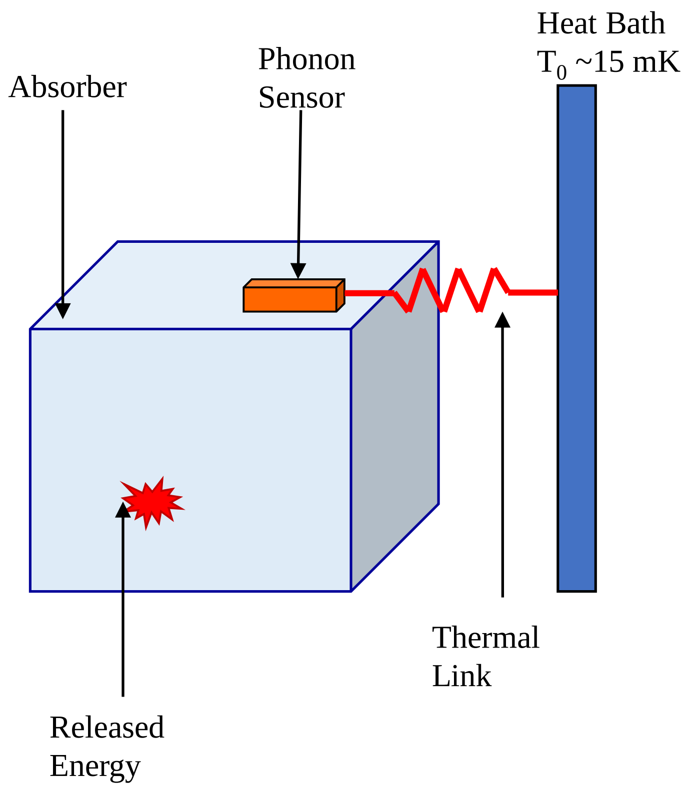
Energy spectrum of sum of energies of the emitted electrons for $2\nu\beta\beta$ and $0\nu\beta\beta$



- Continuous Energy spectrum
- Maximum value about at 1/3 $Q_{\beta\beta}$

- Mono-energetic peak as 2 emitted electrons carry all energy

Bolometers



Particle releases energy

↓

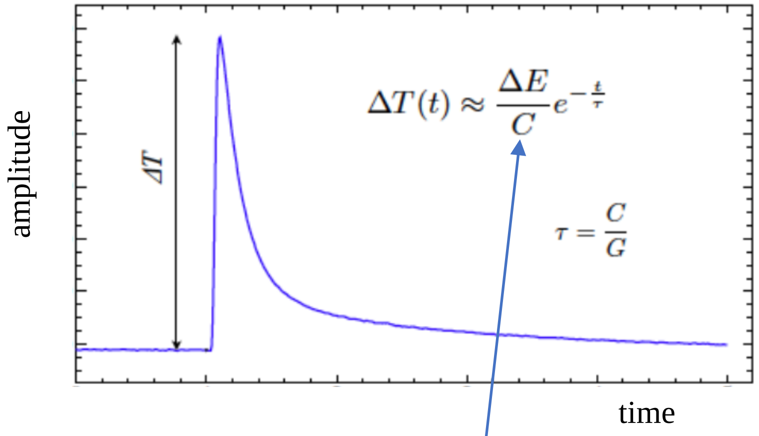
Energy is converted into lattice vibrations

↓

Generate temperature rise inside absorber

↓

Measured by the sensor



Heat capacity → $C(T) \propto \left(\frac{T}{\theta_D}\right)^3$

The absorber is a diamagnetic and dielectric crystal

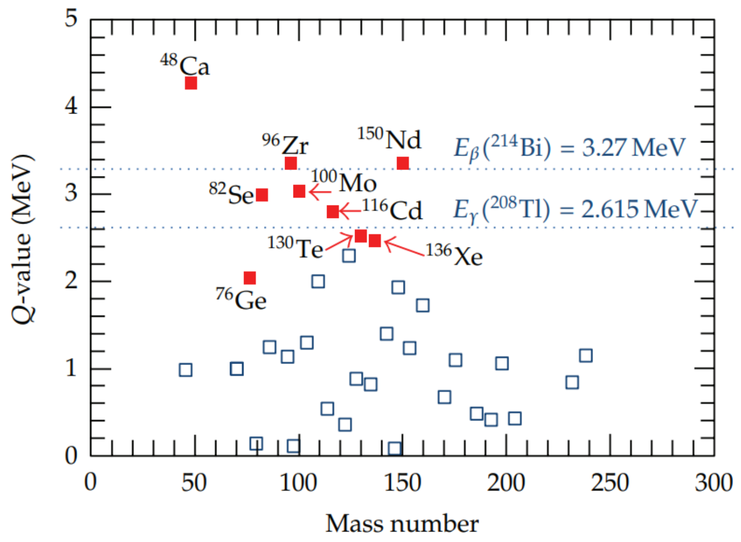
Why Bolometers?

- Most of the favorable $0\nu\beta\beta$ candidates can be studied with this technique.
- High intrinsic energy resolution (0.2% at $Q_{\beta\beta}$).
- High detection efficiency.
- Possibility to construct detectors using radiopure materials and it can be isotopically enriched
- Scalability to a ton scale experiment through arrays

Bolometric Compound

Two bolometers are considered for this search

Li_2MoO_4 (Lithium Molybdate) and TeO_2 (Tellurium Oxide)



- Both have excellent energy resolution.
- High Internal radiopurity
- Easy crystal growth with high-quality and high purity crystals.
- $Q_{\beta\beta}$ of $^{130}TeO_2$ is 2527 keV which is slightly below end-line of the most intensive natural γ-radioactivity.
- $Q_{\beta\beta}$ of $Li_2{}^{100}MoO_4$ is 3034 keV which is above end line of natural γ-radioactivity.

Background Sources

- Cosmic Rays
  - Underground experiment and muon veto.
- Cosmogenic Activation
  - Store the detector and material underground for a long period before measurement.
- Radioactive contamination from far sources
  - Lead and polythene can be used to reduce contamination from far sources like neutrons and gammas.
- Radioactive contamination from near sources
  - Detector bulk contamination.
  - Surface contamination (Background from the surface alphas and betas).

Cryogenic Rare-event Observatory with Surface Sensitivity
CROSS Technology

Main objective is to reject α and β surface events due surface contamination.

Surface vs bulk events

High energy phonons are generated

↓

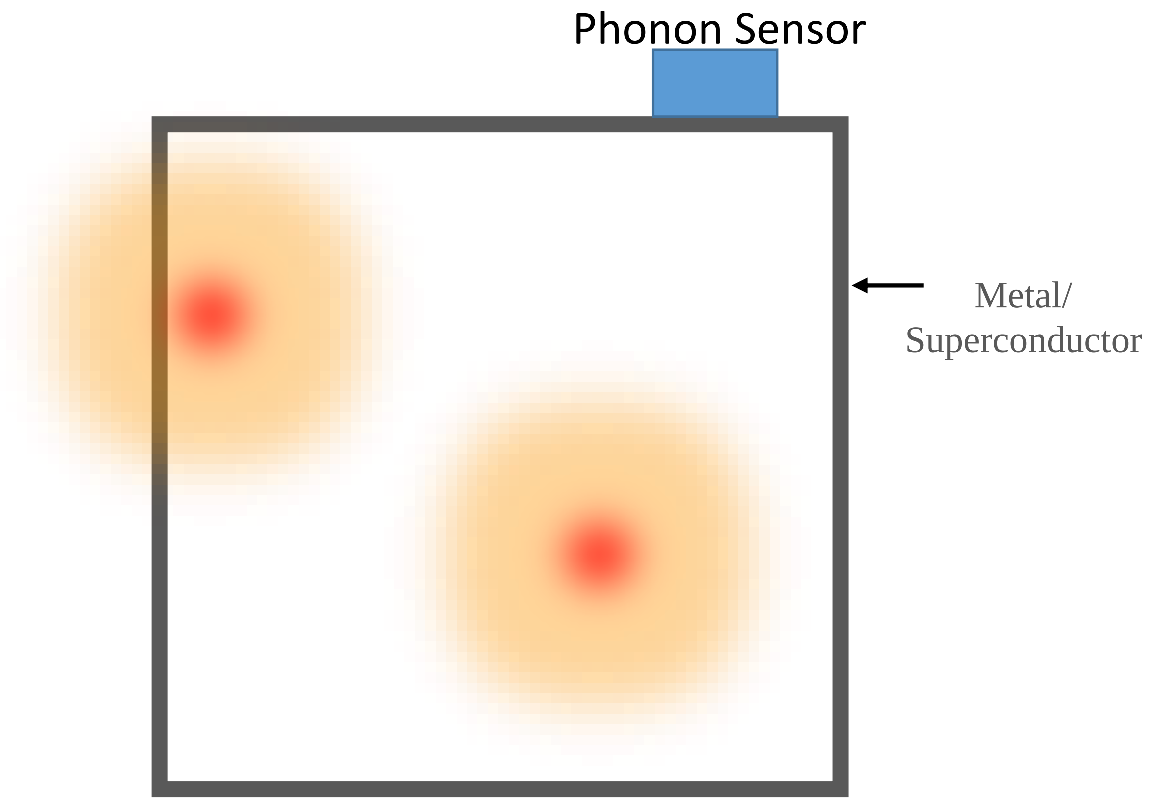
More efficient trapping of out-of-equilibrium phonons for surface events by metal (normal or superconductor)

↓

Fast energy degradation of out-of-equilibrium phonons in a metal

↓

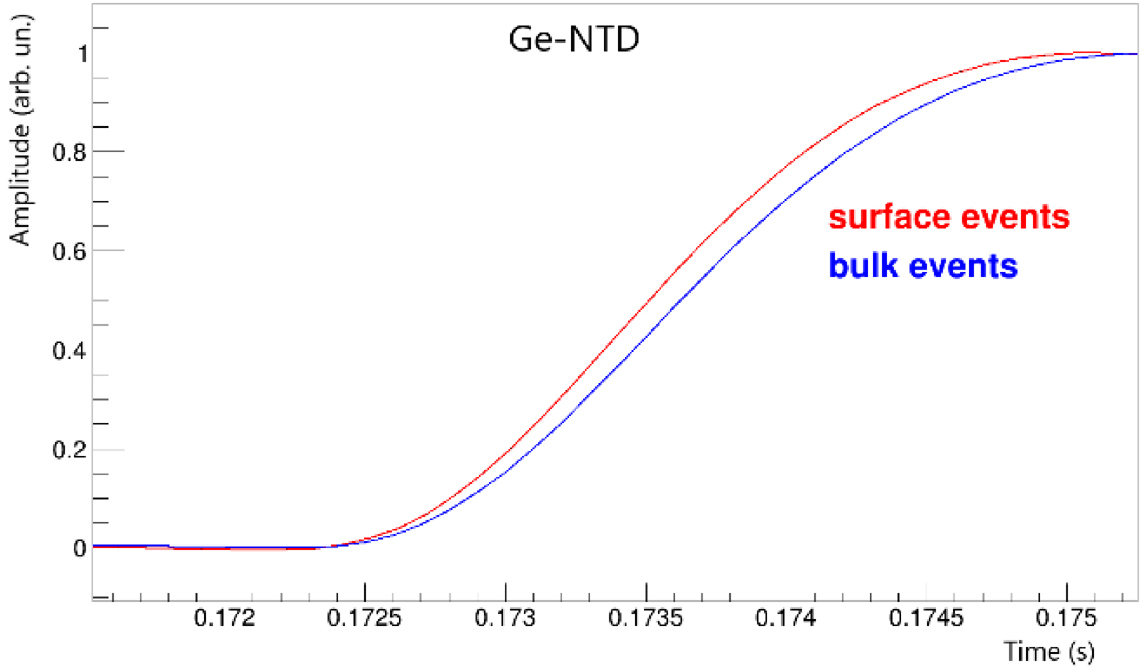
Acceleration of thermalization of phonons induced by surface events

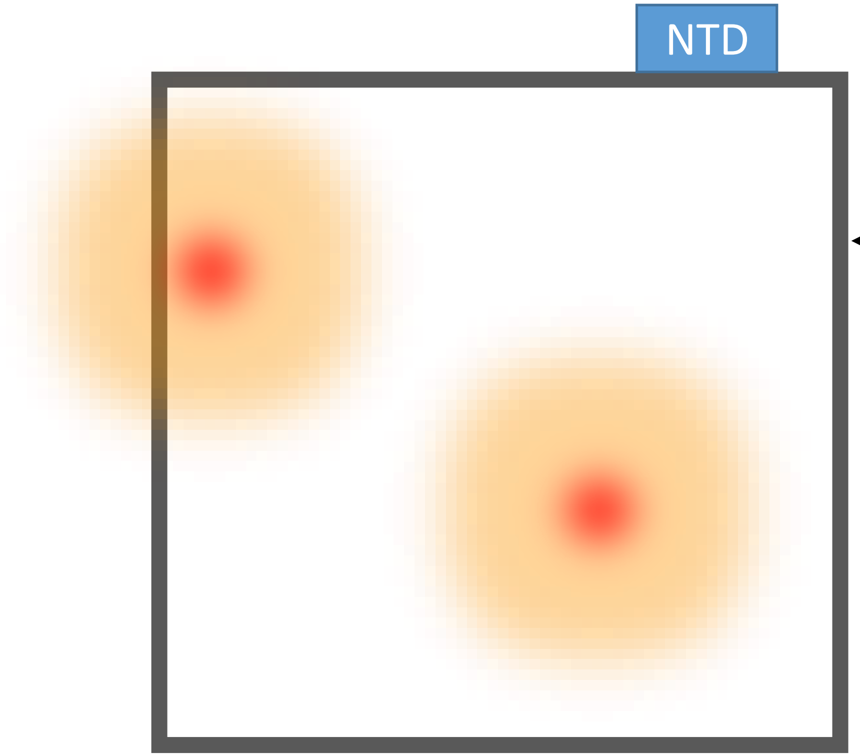


Journal of High Energy Physics **volume 2020**, Article number: 18 (2020)

The sensor that will be used in this work is neutron-transmutation-doped germanium thermistor (Ge-NTD).

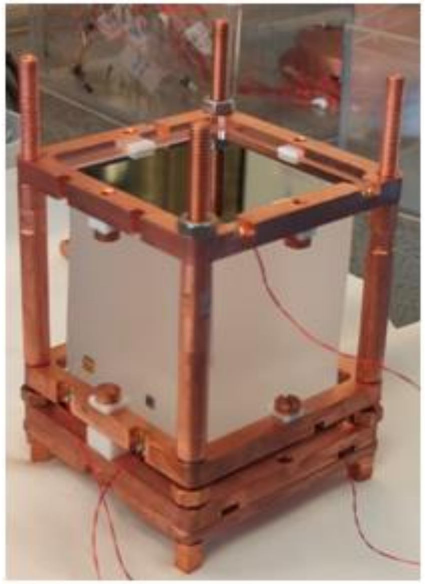
Cryogenic Rare-event Observatory with Surface Sensitivity
CROSS Technology

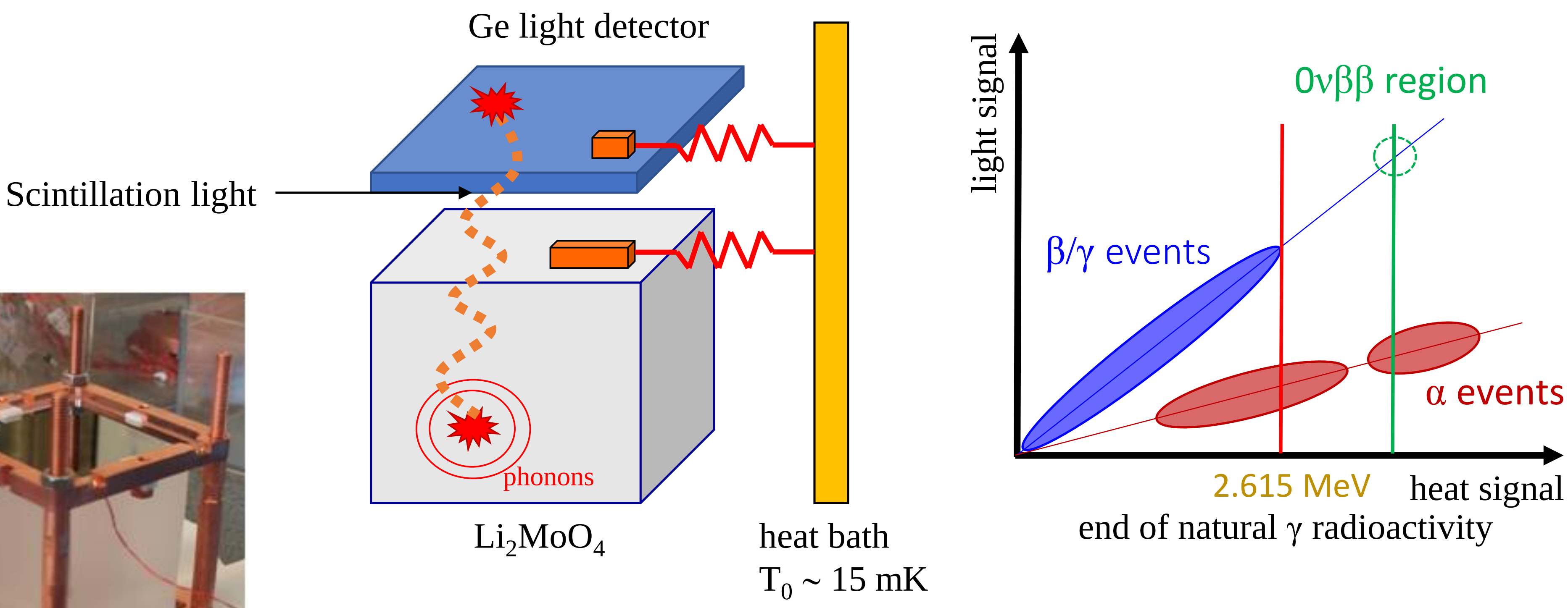




Use superconductor film (Al, T_c =1.2 K)
to reduce the heat capacity ($T \ll T_c$)

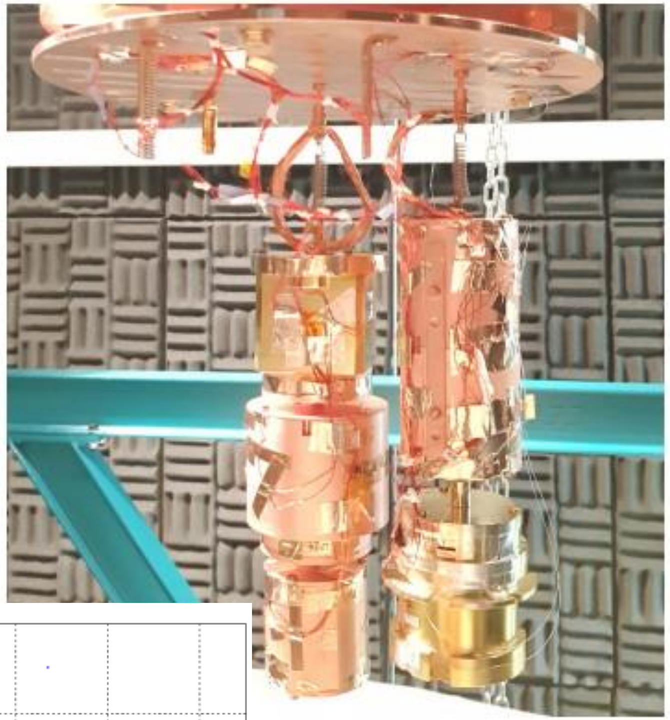
Dual Heat-Light readout



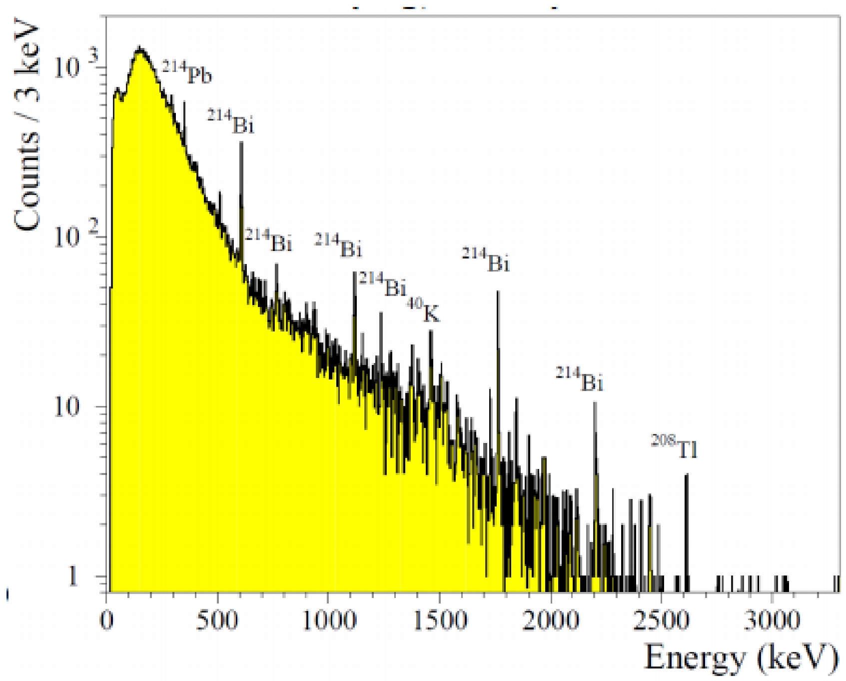


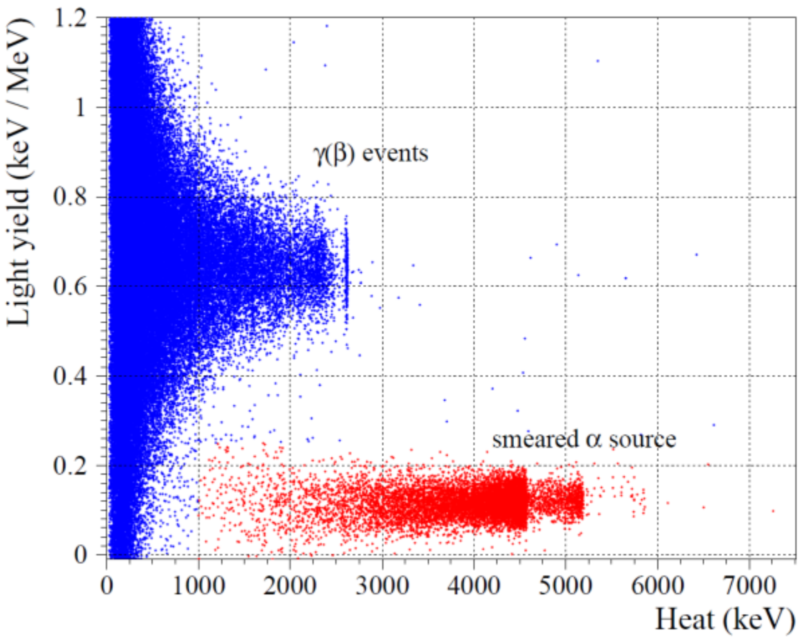
Full Discrimination of alpha events

CROSS Run @ LSC
(Canfranc underground Laboratory)



- This run had a data collection for 2369 hours with 90% duty cycle.
- 4 Li_2MoO_4 and 2 $CdWO_4$ were studied in this run.

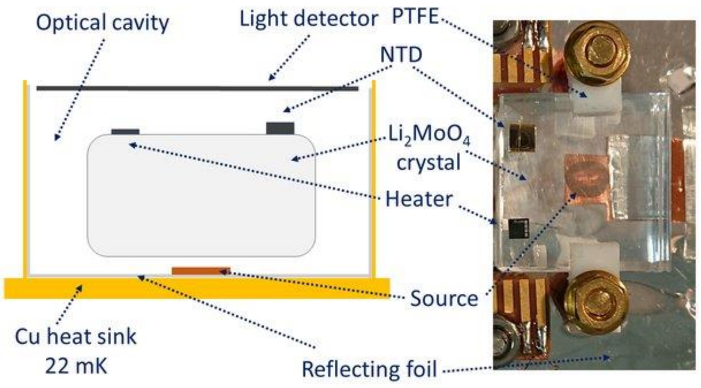


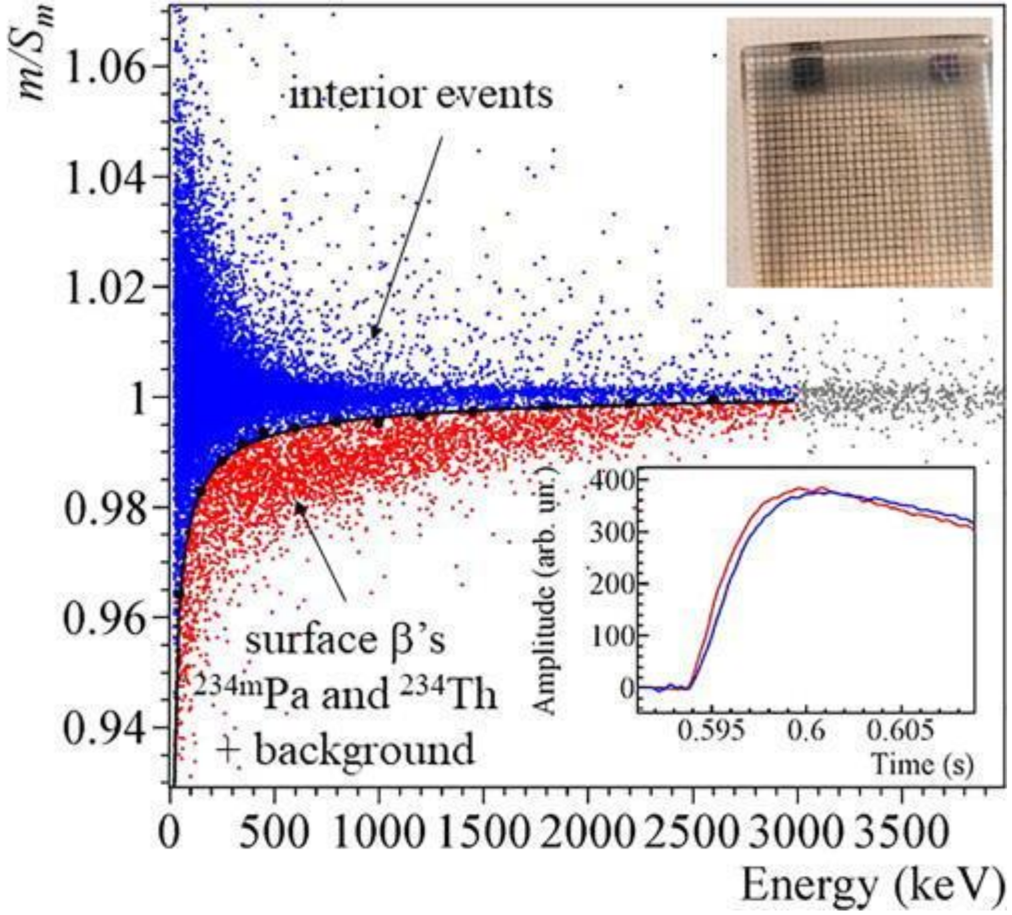


Journal of Instrumentation, Volume 16, February 2021

Cubic LMOs (^{100}Mo) show excellent performance of the dual read-out (heat and light detectors), light-assisted PID, hint on high crystal radiopurity.

CROSS R&D @ IJCLab





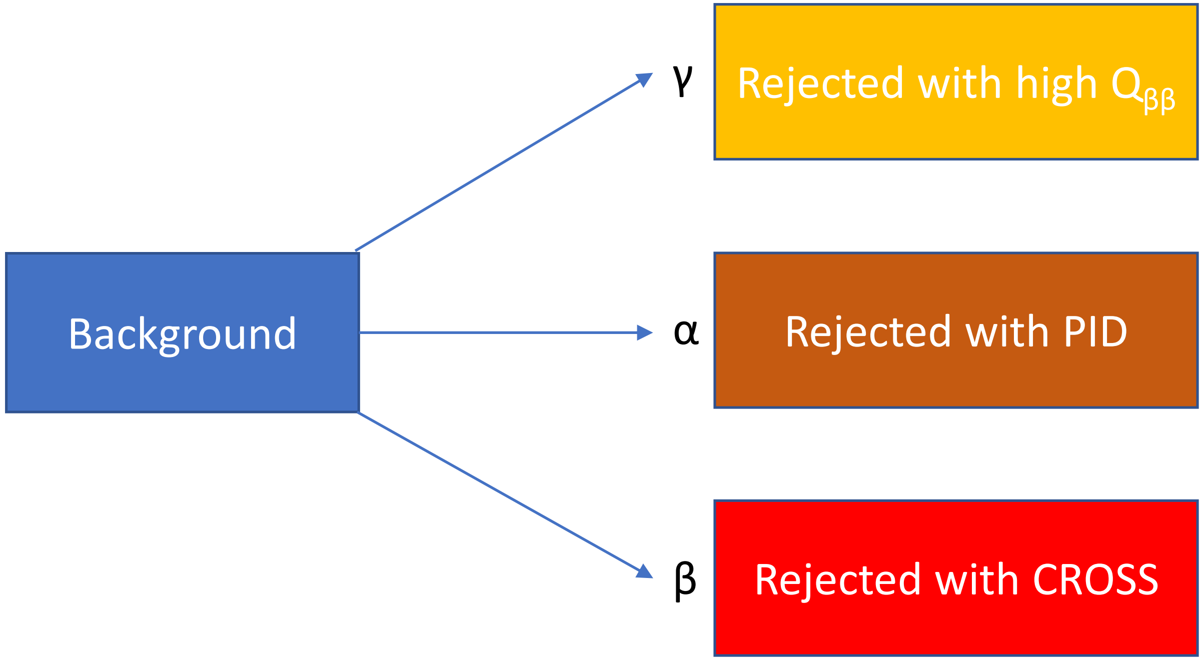
- Achieved excellent alpha particle rejection efficiency

- Both α and β particles absorbed close to a metal-coated surface of a Li_2MoO_4 bolometer can be rejected with high efficiency (>90%) by pulse-shape discrimination.

- The grid method is currently our protocol for surface event discrimination.

Appl. Phys. Lett. **118**, 184105 (2021)

Conclusion and Future Plans



- To unfold the mysteries of neutrinos, neutrinoless double decay is an important process to look for.
- Bolometric detectors are the most promising detector technologies to study about this process with high sensitivity.
- CROSS technology could allow us to achieve a very low background level 0.01 counts/(tonne y keV) as it separates surface alphas and betas.

❖ CROSS Perspectives

- CROSS demonstrator is planned at the CROSS facility @ LSC with 42 Li_2MoO_4 crystals which holds 6.2kg of ^{100}Mo.