Neutrinoless double beta decay : bolometric experiments at IJClab

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FIRST FLAVOR DAY AT IJCLAB

27/10/2021

université PARIS-SACLAY

cnrs

IJCLab Irène Joliot-Curie
Laboratoire de Physique des 2 Infinis

Double Beta Decay

- $(A,Z) \rightarrow (A,Z+2) + 2e^- + 2\bar{\nu}_e$ $\boldsymbol{2\nu 2\beta}$
- Standard Model process
- Possible for 35 nuclides
  - Even-Even nucleus
  - Occurs when single beta is not energetically possible

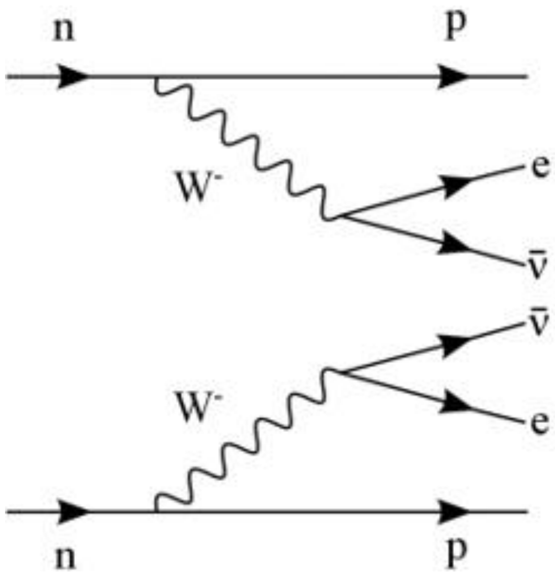
SEPTEMBER 15, 1935 PHYSICAL REVIEW VOLUME 48

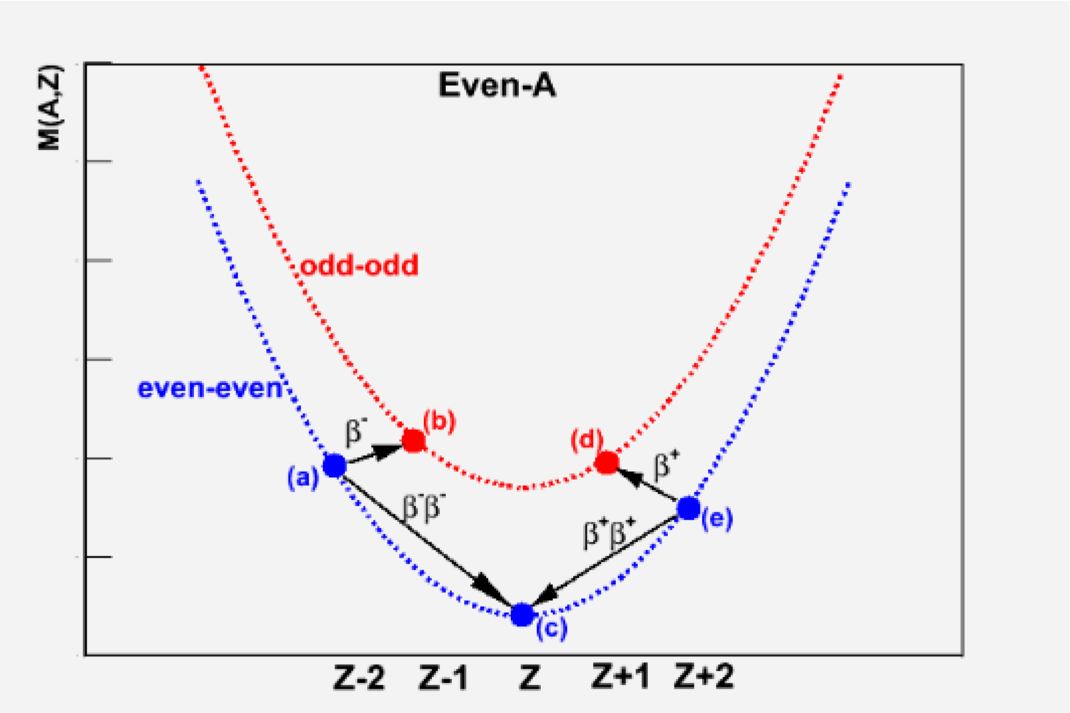
Double Beta-Disintegration

M. GOEPPERT-MAYER, *The Johns Hopkins University*
(Received May 20, 1935)

From the Fermi theory of β-disintegration the probability of simultaneous emission of two electrons (and two neutrinos) has been calculated. The result is that this process occurs sufficiently rarely to allow a half-life of over 10^{17} years for a nucleus, even if its isobar of atomic number different by 2 were more stable by 20 times the electron mass.

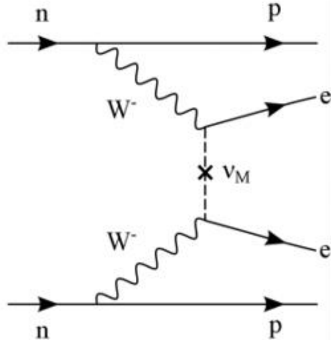
- Observed for 9 isotopes
- $T_{1/2} \sim 10^{18}$- 10^{24} yr





Neutrinoless Double Beta Decay

- Hypothetical decay
- $(A, Z) \rightarrow (A, Z+2) + 2e^-$ **$0\nu2\beta$**
- **Lepton number violation ΔL = 2**
- Majorana neutrino $\nu = \bar{\nu}$



Majorana neutrino is needed in leptogenesis to explain the matter/antimatter asymmetry

TEORIA SIMMETRICA DELL'ELETTRONE E DEL POSITRONE

Nota di ETTORE MAJORANA

[Nuovo Cimento 14(1937)171-184]

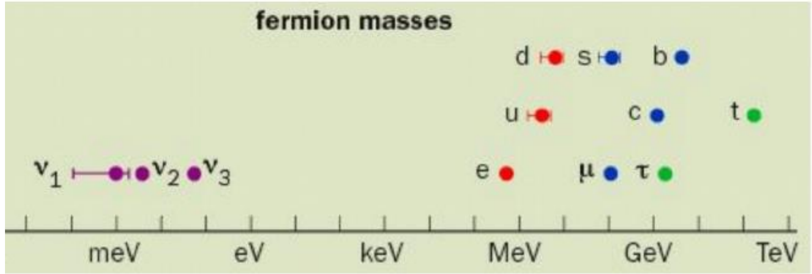
Sunto. - *Si dimostra la possibilità di pervenire a una piena simmetrizzazione formale della teoria quantistica dell'elettrone e del positrone facendo uso di un nuovo processo di quantizzazione. Il significato delle equazioni di* DIRAC *ne risulta alquanto modificato e non vi è più luogo a parlare di stati di energia negativa; nè a presumere per ogni altro tipo di particelle, particolarmente neutre, l'esistenza di « antiparticelle » corrispondenti ai « vuoti » di energia negativa.*

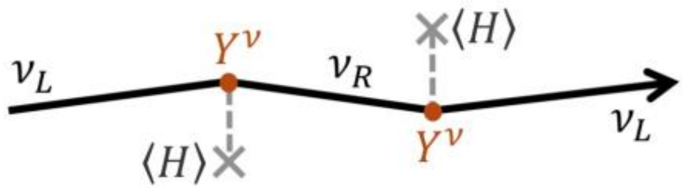
Dirac mass

$$\mathcal{L} \supset Y_\nu^{ij} L_i N_j \phi = M_D^{ij} \nu_i N_j$$

Small Yukawa coupling :

$$m_\nu / \Lambda_{EW} \leq 10^{-12}$$



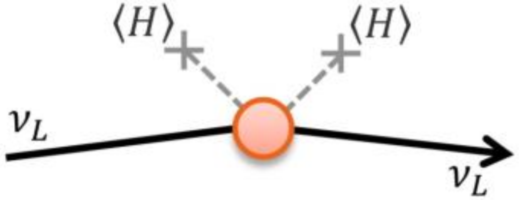


Majorana mass

$$\mathcal{L} \supset Y_\nu^{ij} L_i N_j \phi + M^{ij} N_i N_j$$
$$= M_D^{ij} \nu_i N_j + M_M^{ij} N_i N_j$$

$$\mathrm{M}_\nu = \begin{pmatrix} \delta m_\nu^{1loop} & M_D \\ M_D^T & M_M \end{pmatrix}$$

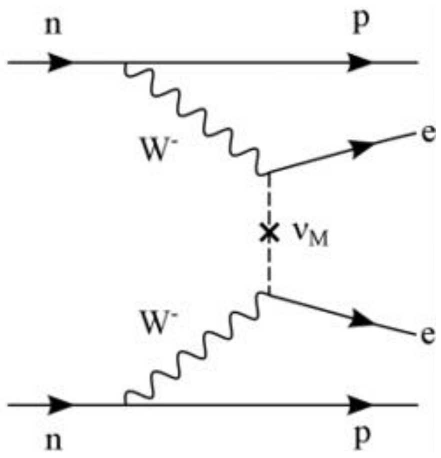
Diagonalisation with M_M >> M_D: **See-saw type 1**



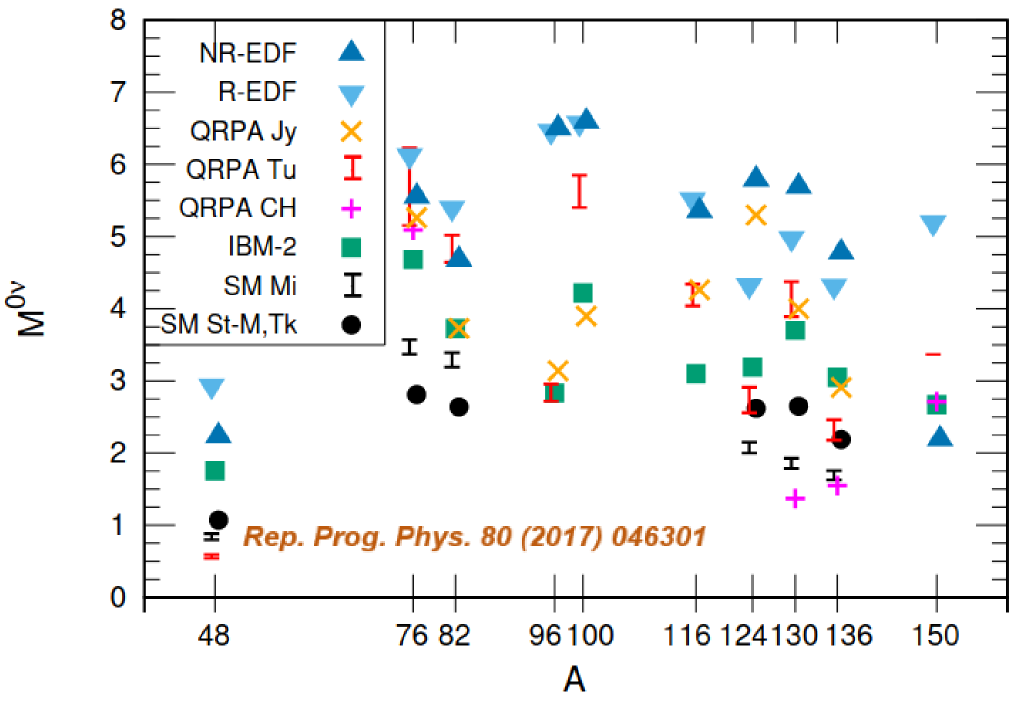
$\nu \simeq \nu_L + \theta v_R^c$ $\quad m_\nu \simeq \frac{M_D^2}{M_M}$ mainly **active** $SU(2)_L$ doublet states with **light** masses

$N \simeq \nu_R + \theta^T v_L^c$ $\quad m_N \simeq M_M$ mainly **sterile** singlet states with **heavy** masses

Light Majorana neutrino exchange

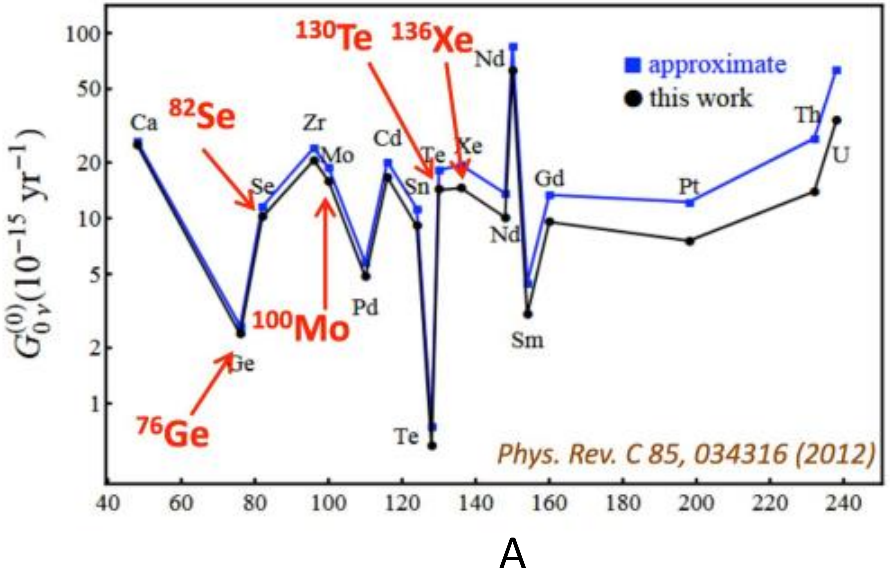


$$\left(T_{1/2}^{0\nu}\right)^{-1} = G_{0\nu}\, g_A^4\, M^2 \left|\frac{m_{\beta\beta}}{m_e}\right|^2$$



Space phase factor :

Known and calculated to good accuracy



Nuclear Matrix Element :

- Differences between different nuclear models

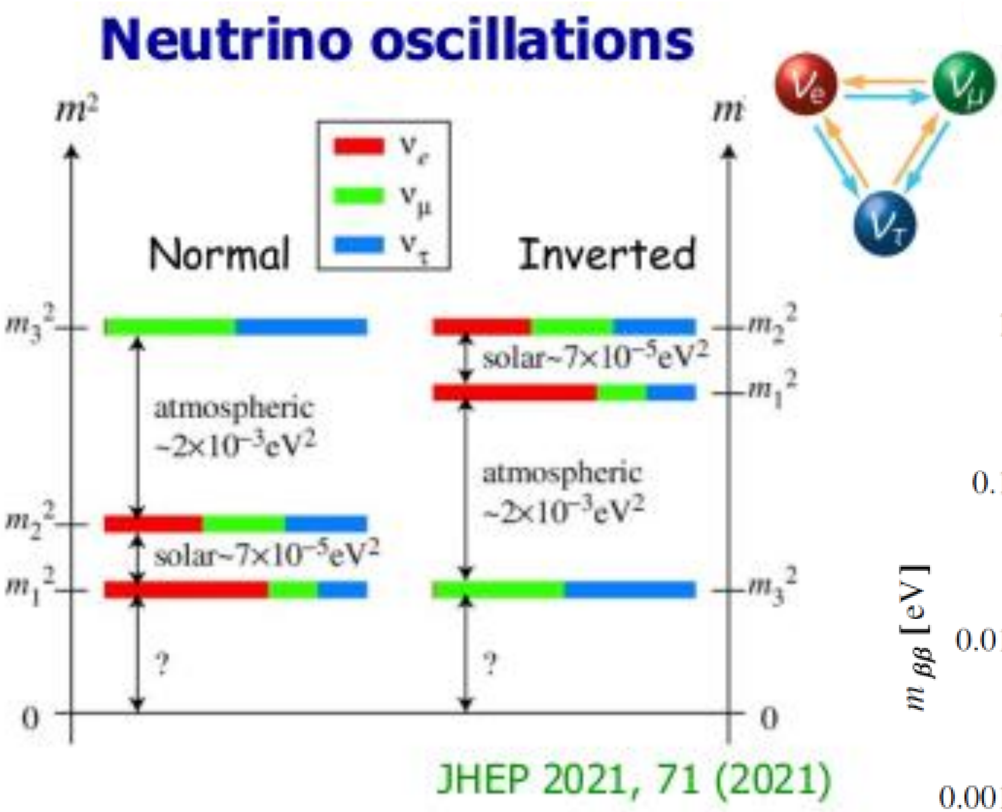
Weak axial-vector coupling strenght :

- Question of g_A quenching under study

Effective Majorana mass :

$$m_{\beta\beta} = \left|\, |U_{e1}|^2 m_1 + e^{i\alpha_1} |U_{e2}|^2 m_2 + e^{i\alpha_2} |U_{e3}|^2 m_3 \right|$$

Where we are



Best current limits :

KamLAND-Zen on ^{136}Xe :

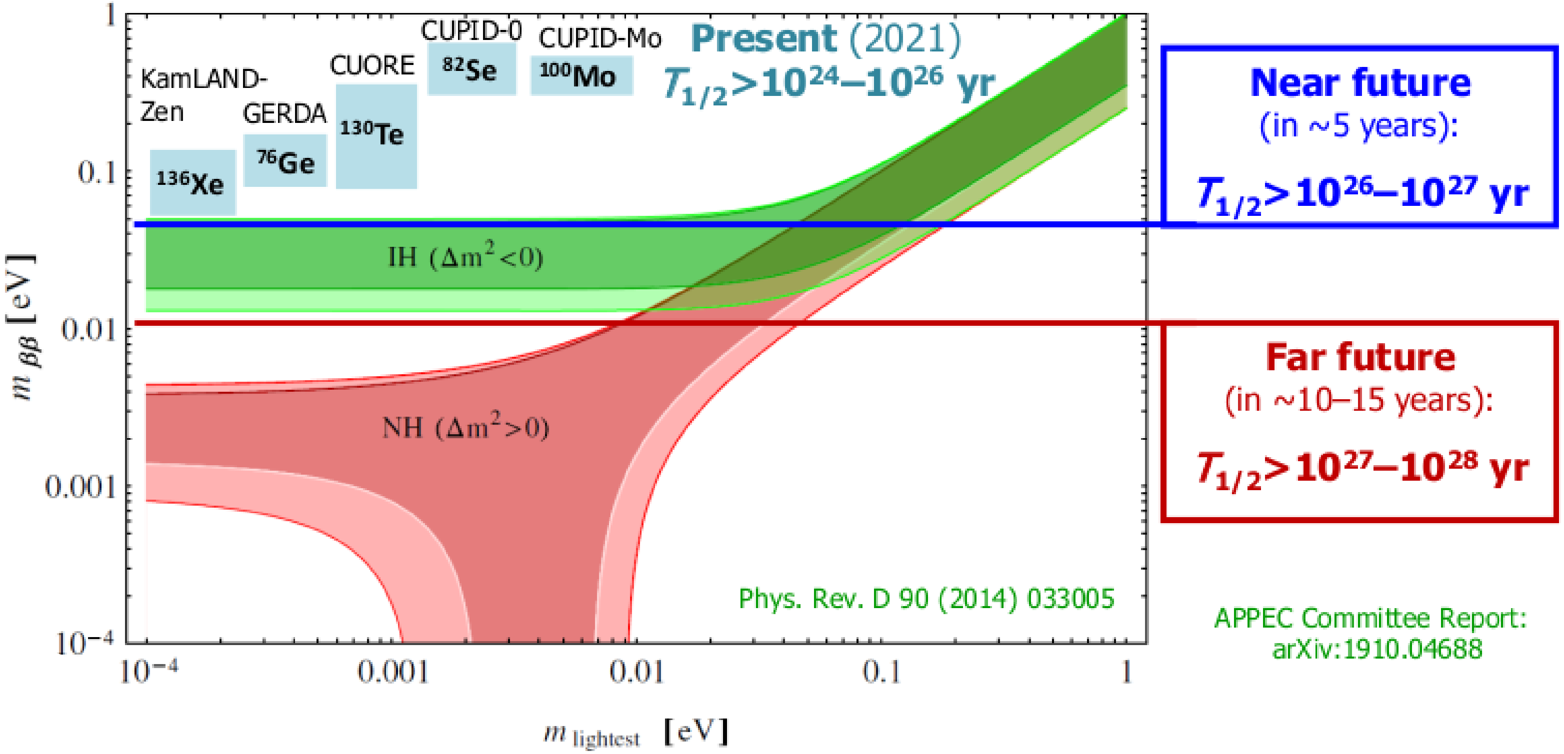
- $T_{1/2} > 1.07 \times 10^{26}\ yr$
- $m_{\beta\beta} < 61\ - 165\ meV$

arXiv:1605.02889
PRL 117, 082503 (2016)

GERDA on ^{76}Ge :

- $T_{1/2} > 1.8 \times 10^{26}\ yr$
- $m_{\beta\beta} < 79\ - 180\ meV$

arXiv:2009.06079
PRL 125, 252502 (2020)



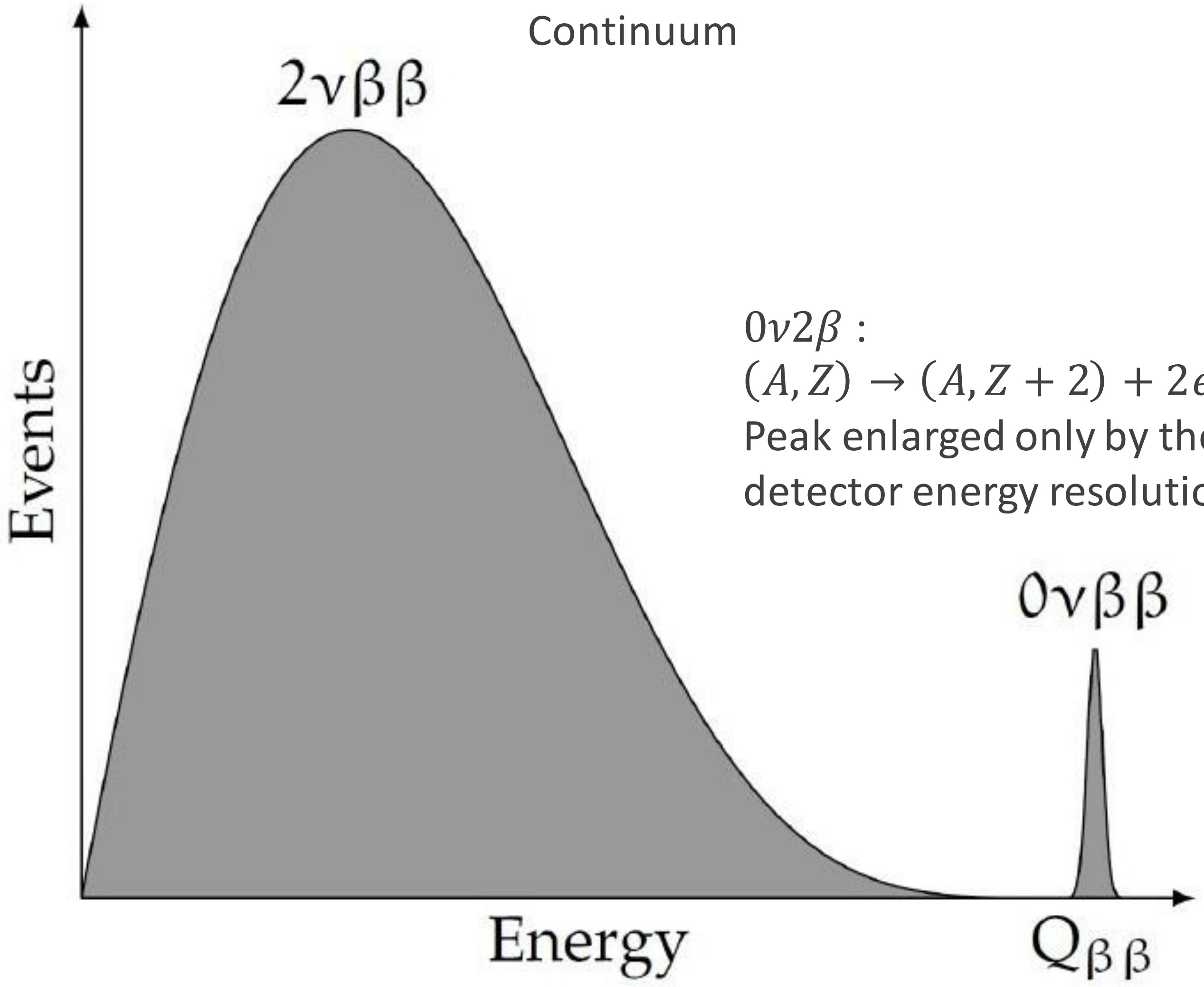
APPEC Committee Report: arXiv:1910.04688

Searching for $0\nu2\beta$

The shape of the two-electron sum-energy spectrum enables to distinguish between the 0ν (new physics) and the 2ν decay modes

- Requires :
  - Low background in the ROI (around the $Q_{\beta\beta}$)
  - Good energy resolution

$2\nu2\beta$:
$(A,Z) \rightarrow (A,Z+2) + 2e^- + 2\bar{\nu}_e$
Continuum

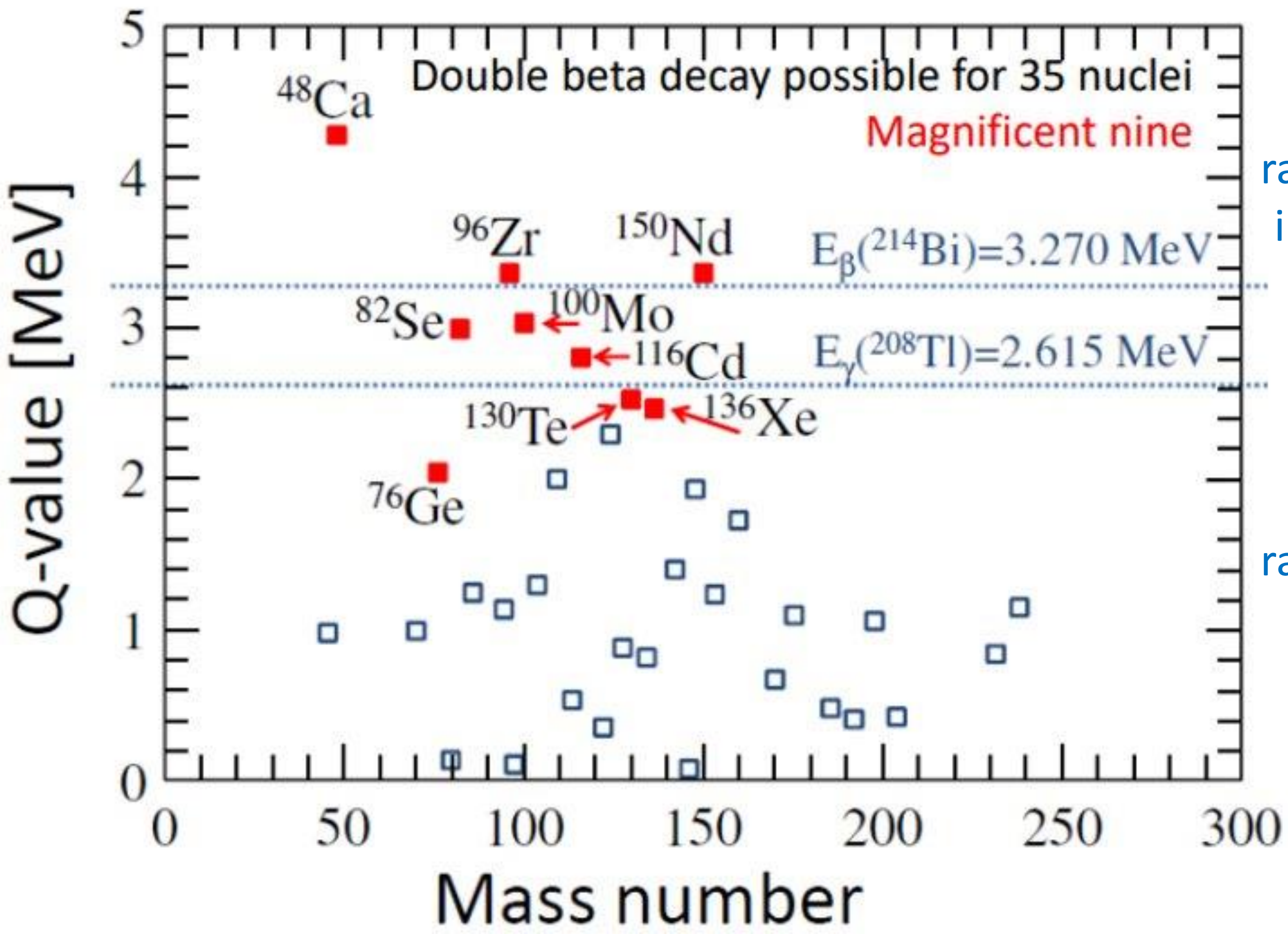


$0\nu2\beta$:
$(A,Z) \rightarrow (A,Z+2) + 2e^-$
Peak enlarged only by the detector energy resolution

Experimental challenge

- $Q_{\beta\beta}$ is a crucial factor – the higher the better
  - Phase space $G_{0\nu} \propto Q^5$
  - Background

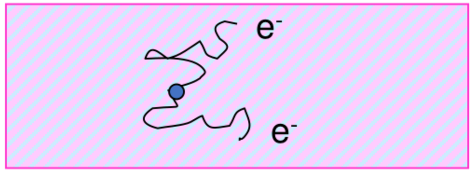
- Main background is coming from **natural radioactivity**
  - α, β, γ



End of natural radioactivity induced by ^{214}Bi

End of γ natural radioactivity

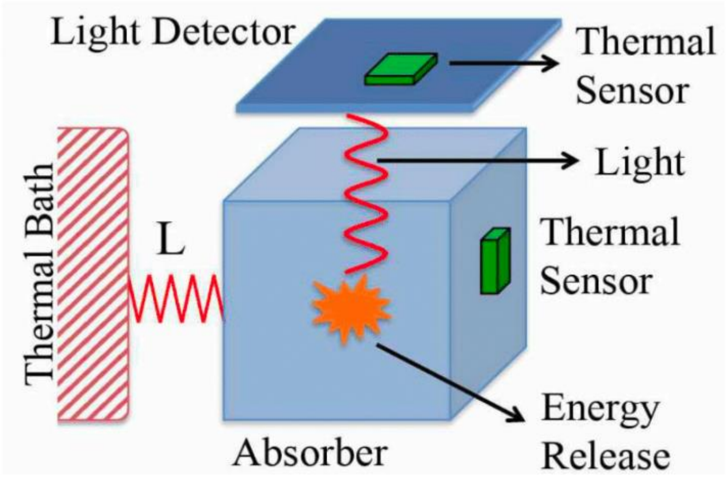
Bolometric technique



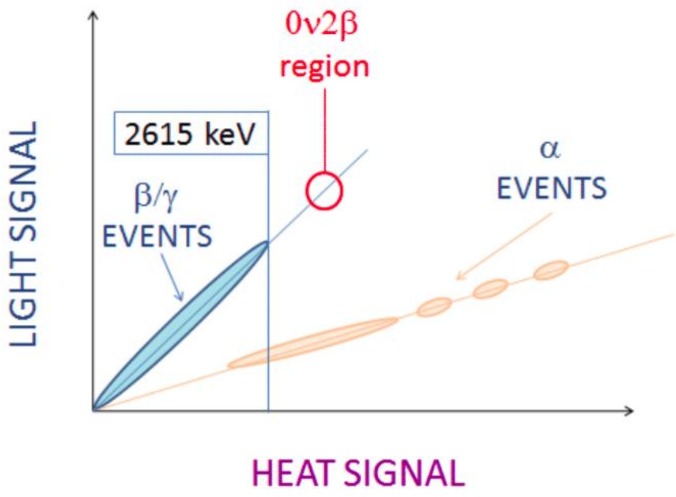
Source ≡ Detector

- Crystals cool down to ~ 10-20 mK
- $\Delta T = E/C$
- Detector = source
  - High detection efficiency
- Good energy resolution

Scintillating Bolometer



Particle Identification



- Scintillating bolometers
  - Discriminations between β/γ and α particles
  - Heat and Light signals

CUPID-Mo

Demonstrator for the next generation ton scale experiment CUPID

Installed at Laboratoire Souterrain de Modane (LSM)

Installed in EDELWEISS cryostat

^{100}Mo, $Q_{\beta\beta}$ = 3034 keV

20 $Li_2{}^{100}MoO_4$ scintillating bolometers

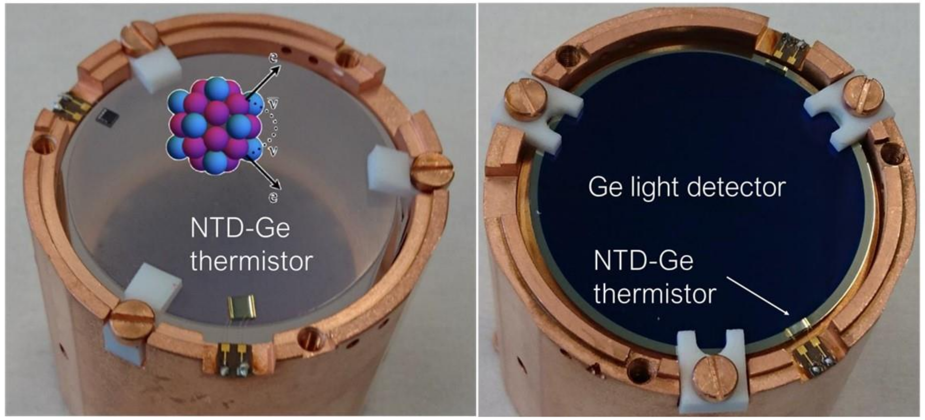
- 0.2 kg $Li_2{}^{100}MoO_4$ cylindrical crystals
- ^{100}Mo enrichment ~ 97 %
- Ge wafers as Light Detectors
- NTD Ge thermistors
- Cu holders, PTFE supports, reflecting foils

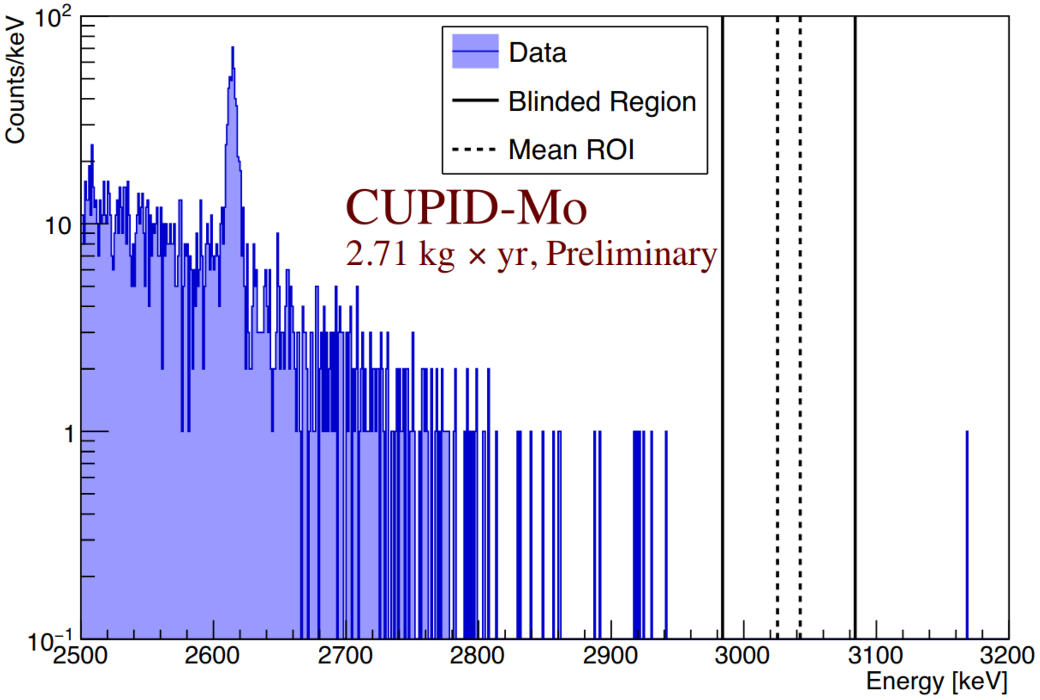
CUPID-Mo data taking (2019–2020)

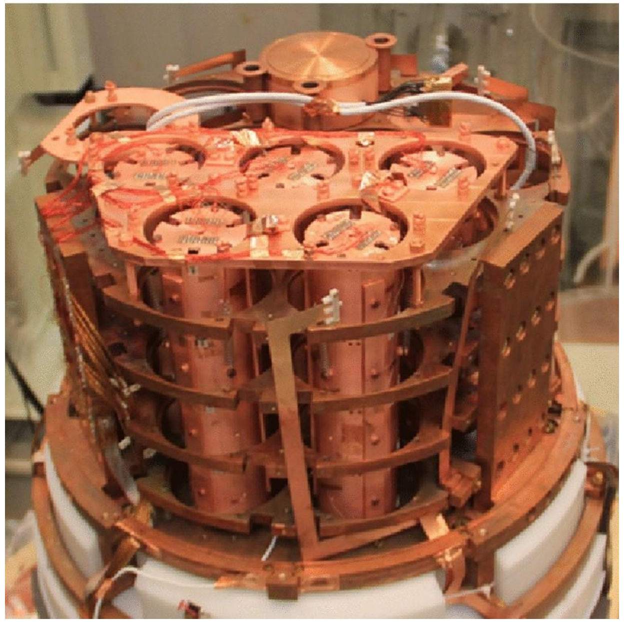
New world best limit on ^{100}Mo

- **$T_{1/2}$ > 1.8 × 10^{24} years**

["New Results from the CUPID-Mo demonstrator on the 100Mo 0vbb decay half-life", TAUP2021]







CROSS

Demonstrator for the next generation ton scale experiment CUPID

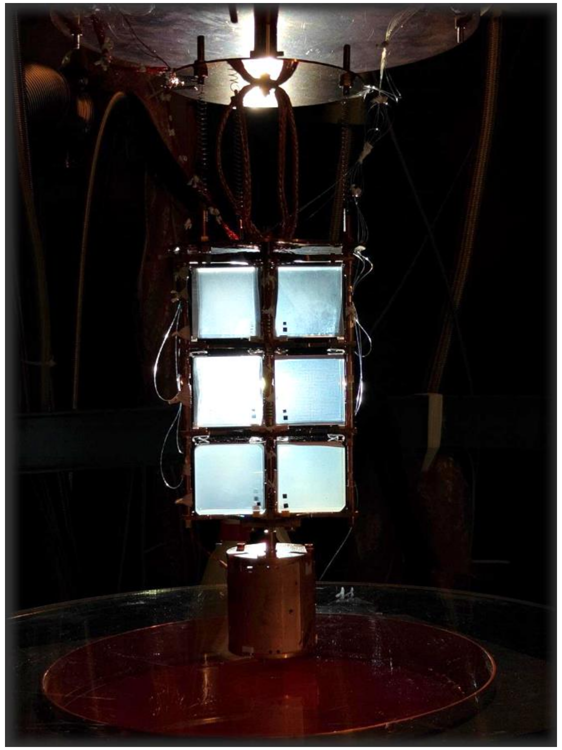
Installed at Laboratorio Subterraneo de Canfranc

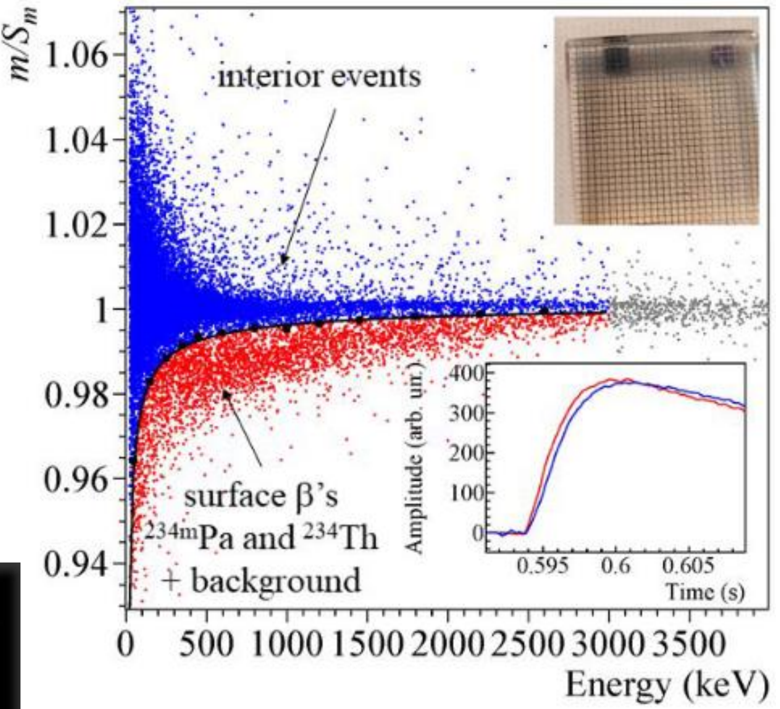
Study of different configurations to compare light collection and performances

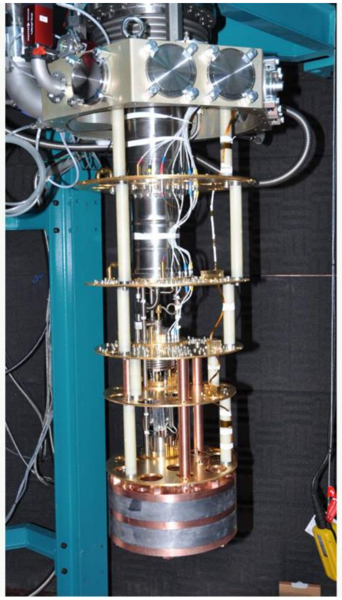
R&D on metal-coated bolometers to identify near surface α and β particle interactions

CROSS demonstrator with 32 cubic $Li_2{}^{100}MoO_4$ crystals

CROSS demonstrator data taking (2023–2028)







CUPID

Next bolometric ton scale experiment for the search of the neutrinoless double beta decay

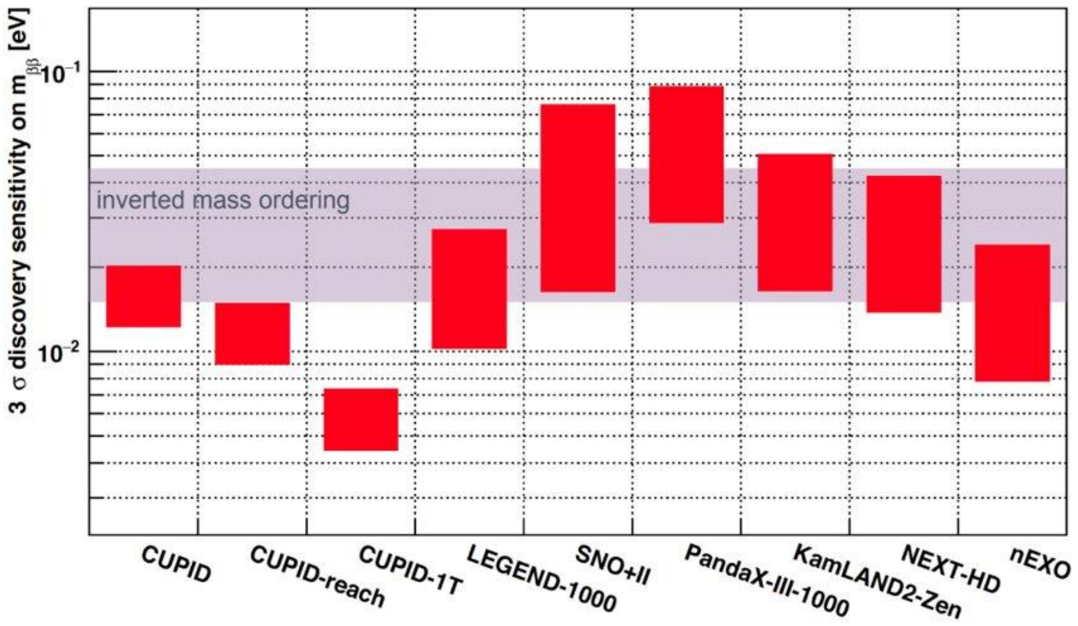
To be installed at **Laboratori Nazionali del Gran Sasso** (LNGS) in the **CUORE cryostat**

^{100}Mo, $Q_{\beta\beta}$ = 3034 keV

$Li_2{}^{100}MoO_4$ scintillating crystals

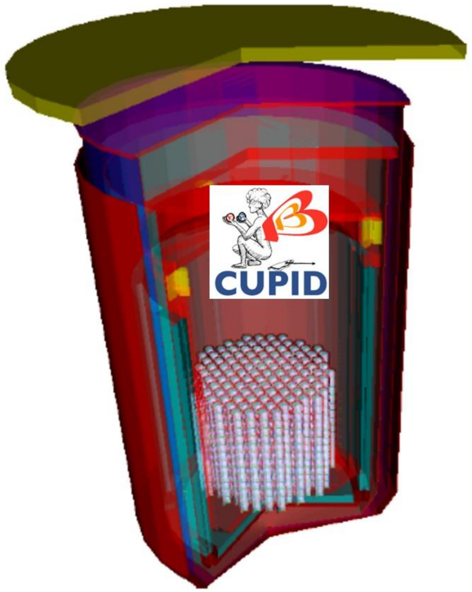
- Enrichment > 95 %
- Cubic crystals : 45×45×45 mm³ -> 0.28 kg
- ~ 1596 crystals ~ 240 kg of ^{100}Mo
- ΔE FWHM ~ 5 keV @ Q-value 3034 keV
- α rejection using light signal
- Background Index goal : 10^{-4} counts/keV/kg/yr

CUPID data taking and physics results (2025–2035)



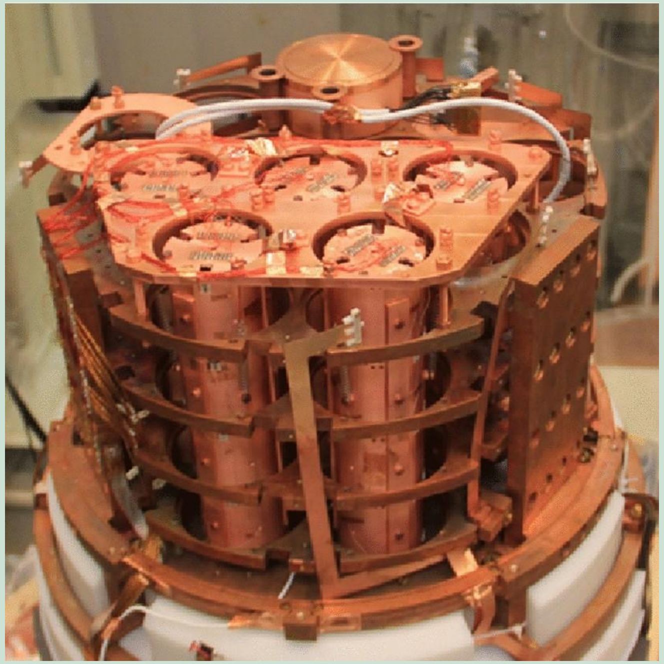
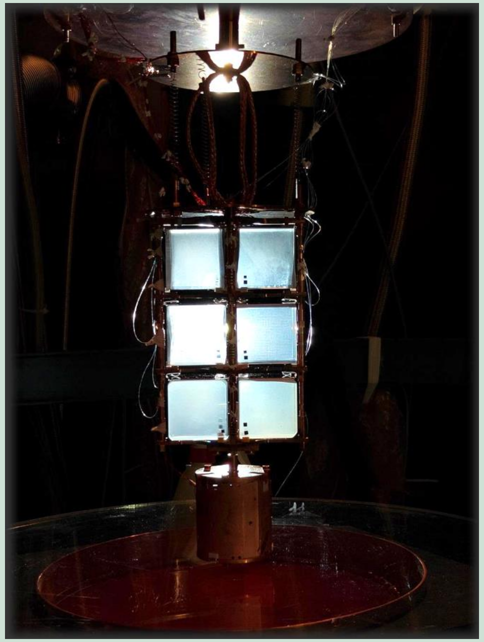
0νββ sensitivity goal

- $T_{1/2}$ ~ 10^{27} years
- $m_{\beta\beta}$ ~ 12 - 20 meV



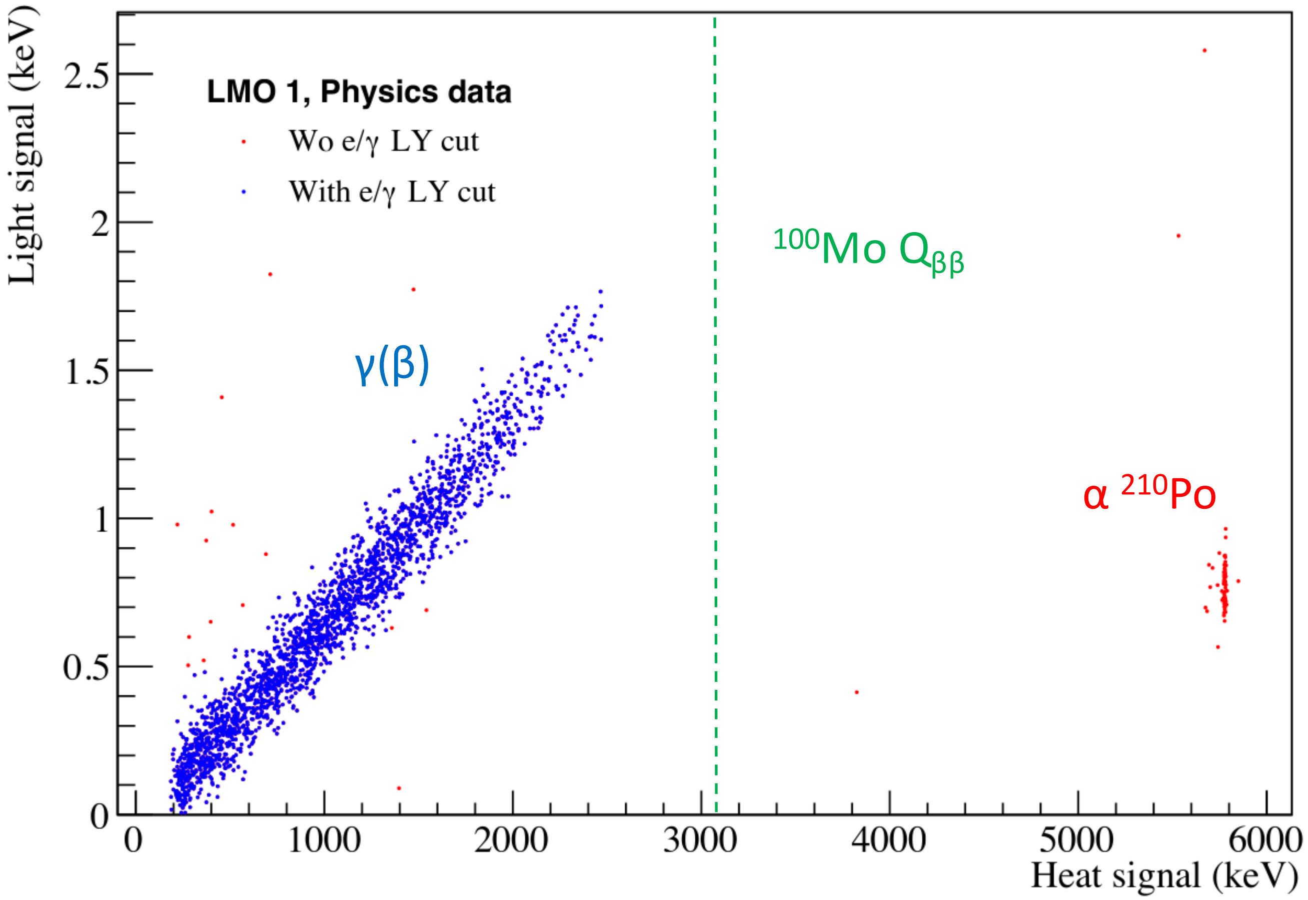
Summary

IJClab is involved in 3 bolometric neutrinoless double beta decay projects :

CUPID-Mo	CROSS	CUPID
• End of data analysis • Simulation / Background Model • World best limit on $T^{0\nu}_{1/2}$ of ^{100}Mo 	• Ongoing tests and R&D @ IJClab and Canfranc • Detector construction • Data analysis / Background Model 	• Development of alternative structure • Light Detector / Detector structure design • Background control 

Back-up

Light Yield



LMO 1, Physics data
Wo e/γ LY cut
With e/γ LY cut
γ(β)
100Mo Qββ
α 210Po
Light signal (keV)
Heat signal (keV)
0
0.5
1
1.5
2
2.5
0
1000
2000
3000
4000
5000
6000