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КРІОГЕННІ СЦИНТИЛЯЦІЙНІ БОЛОМЕТРИ З КРИСТАЛАМИ $ZnMoO_4$ ДЛЯ ЧУТЛИВИХ ДОСЛІДЖЕНЬ ВЛАСТИВОСТЕЙ НЕЙТРИНО

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1. Introduction

Double beta decay (2β) is a rare nuclear transition which changes the nuclear charge by two units.

2ν2β decay

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

allowed be the Standard Model, possible for 69 isotopes,

observed for 11 isotopes:

^{48}Ca, ^{76}Ge, ^{82}Se, ^{96}Zr, ^{100}Mo, ^{116}Cd, ^{128}Te, ^{130}Te, ^{136}Xe, ^{150}Nd, ^{238}U

0ν2β decay

$(A,Z) \rightarrow (A,Z+2) + 2e^-$

process without emission of neutrino or antineutrino

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violation of lepton number

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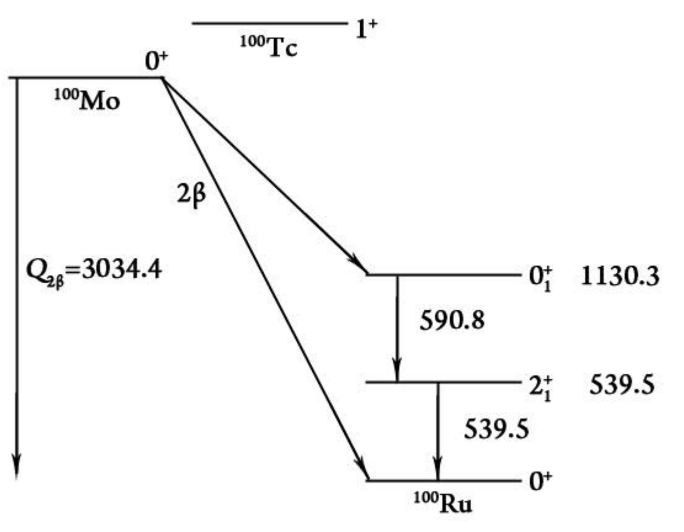
forbidden by the Standard Model

was not observed

Observation of 0ν2β:

- **establish the Majorana nature of the neutrino**
- **determine of the absolute scale of neutrino masses**
- **prove the lepton number violation**



^{100}Mo is one of the most promising 2β isotopes because of its large transition energy **$Q_{2\beta}$ = 3034.4 keV** and a considerable natural isotopic abundance **δ = 9.82%**

Current results for 2β decay of ^{100}Mo

$T_{1/2}^{2\nu}(2\nu2\beta)$ = (7.17 ± 0.54)×10^{18} y [1]

$T_{1/2}^{2\nu}(0^+ \rightarrow 0^+_1)$ = (6.9 ± 0.7)×10^{20} y 90% C.L. [2]

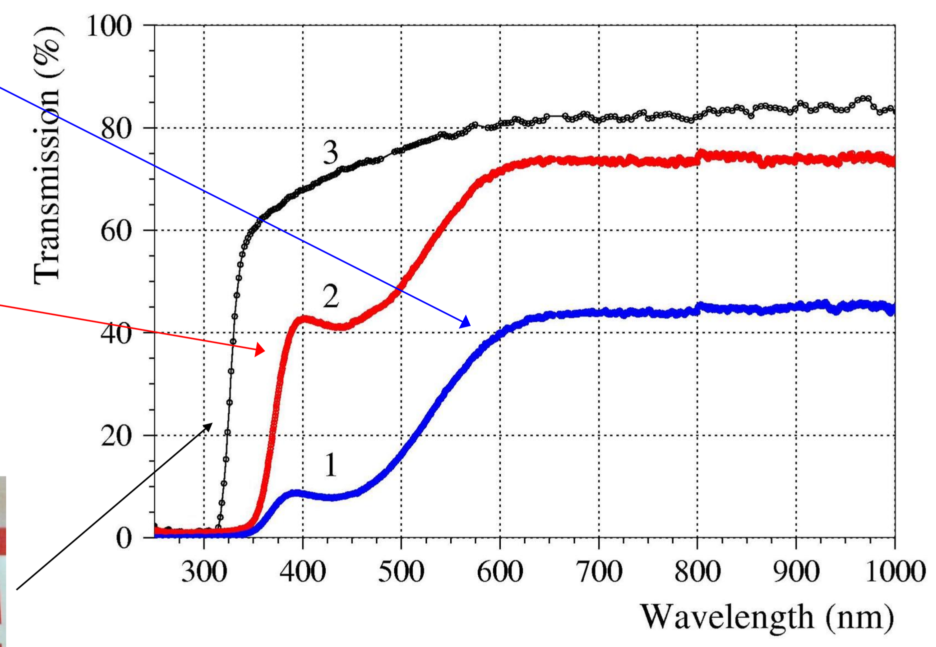
$T_{1/2}^{0\nu}$> 1.0×10^{24} y 90% C.L. [1]

2. Development of $ZnMoO_4$

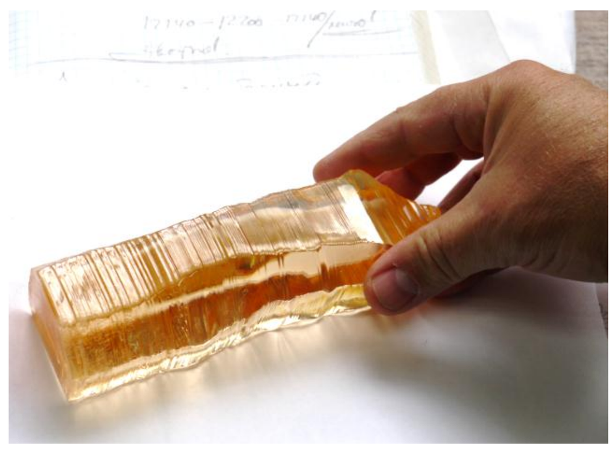
2008 Czochralski and Kyropoulos methods (GPI, Moscow, Russia) [3] — Ø 15 × 40 mm, Ø 30 × 15 mm

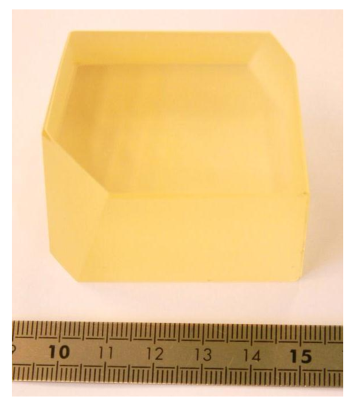
2009 Czochralski method (ISM, Kharkov, Ukraine) [4] — Ø 25 × 11 mm

2010 Low-thermal-gradient Czochralski technique (NIIC, Novosibirsk, Russia) [5] — Ø 25 × 60 mm



2012 Low-thermal-gradient Czochralski technique (NIIC, Novosibirsk, Russia)





≈ 50 × 50 × 40 mm

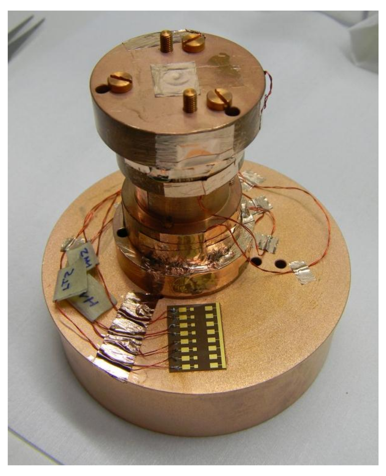
Large **$ZnMoO_4$** crystal scintillator with a mass of **~ 1 kg** was produced for the first time.

Development of $Zn^{100}MoO_4$ crystal scintillators from ~ 1 kg of enriched ^{100}Mo is in progress

3. 24 g $ZnMoO_4$ crystal as scintillating bolometer

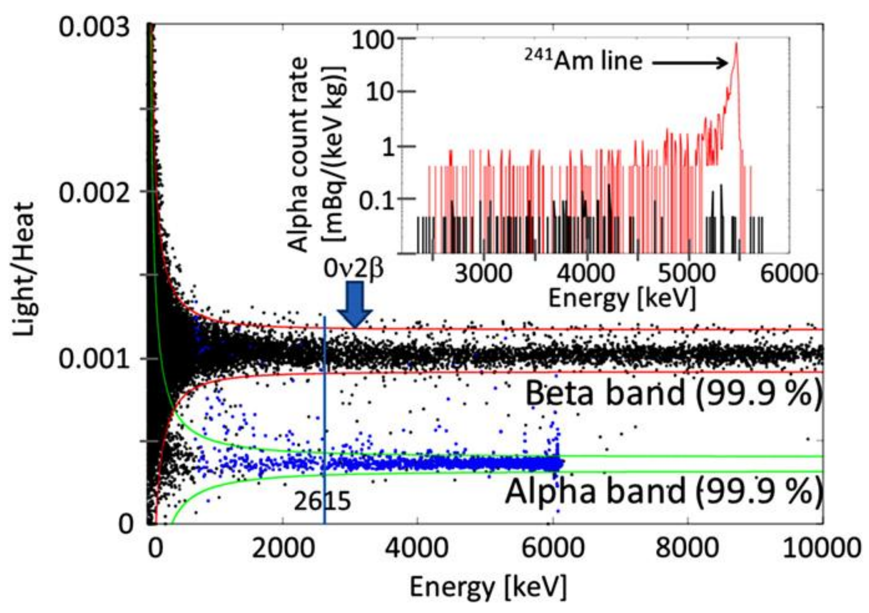
Measurements were carried out at **18 mK** at the aboveground level in the **Centre de Spectrométrie Nucléaire et de Spectrométrie de Masse (CSNSM, Orsay, France).**

- **Intrinsic energy resolution (heat channel) ~ 800 eV**
- **α/β rejection factor better than 99.9% (at ≈ 3 MeV)**



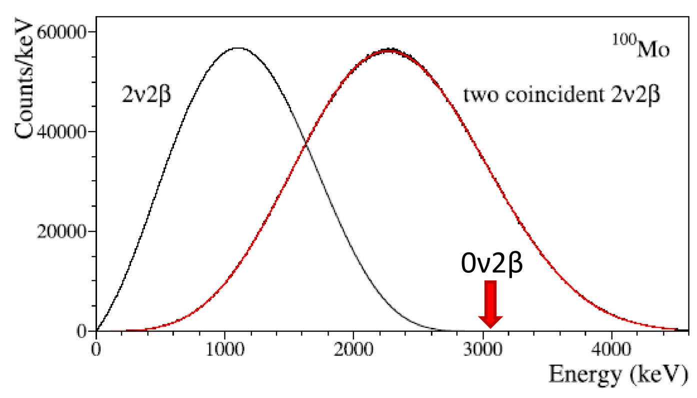
Next stage set-up with **23.8 g $ZnMoO_4$** crystal was mounted at the **Laboratoire Souterrain de Modane (Modane, France).**

Cryostat operated at **18 mK** and the energy resolution of the heat channel was **1.34 keV FWHM @ 356 keV.**



Measurements and data analysis are in progress

4. Pulse-shape discrimination of random coincident events



Poor time resolution of scintillating bolometers

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Background from random coincidence of 2ν2β events

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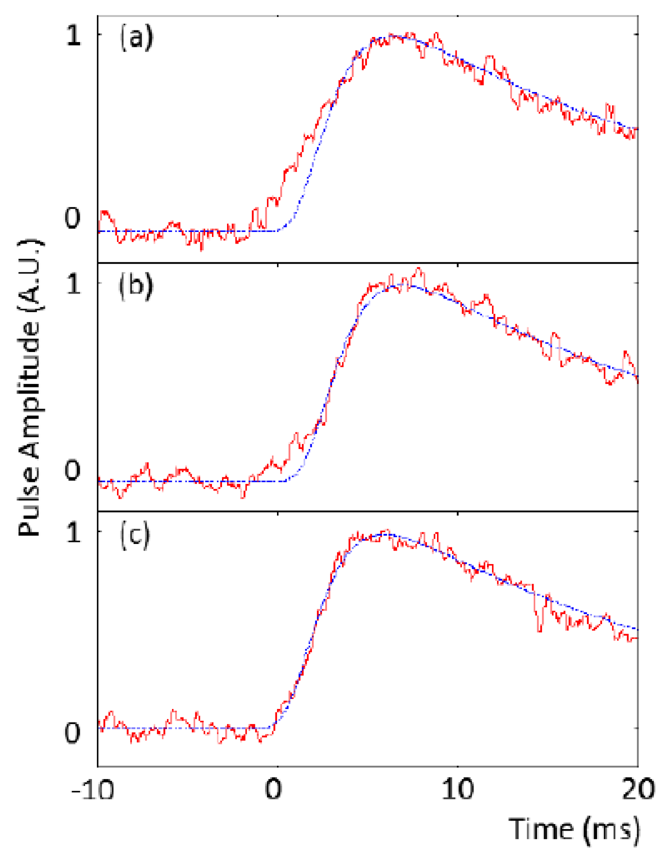
Pulse shape discrimination of the signals

Pulses and noise from a $ZnMoO_4$ scintillating bolometer were used to develop pulse-shape discrimination technique to select random coincident events [6]



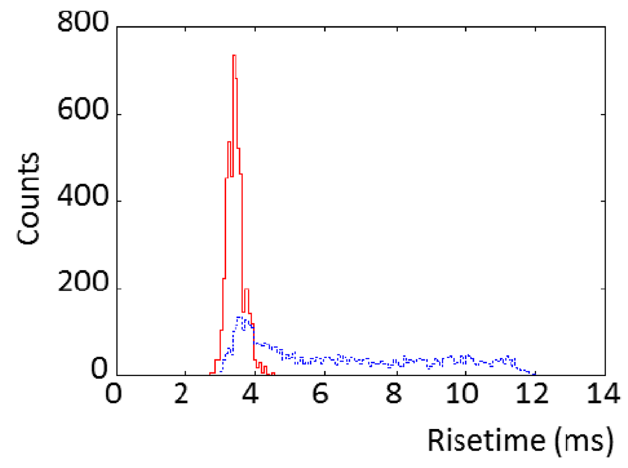
a) pile-up of two pulses shifted by 3 ms with equal amplitude

b) pile-up of two pulses shifted by 3 ms with amplitude ratio = 4 (the smaller pulse occurs first)

c) single pulse

Three different approaches were used:

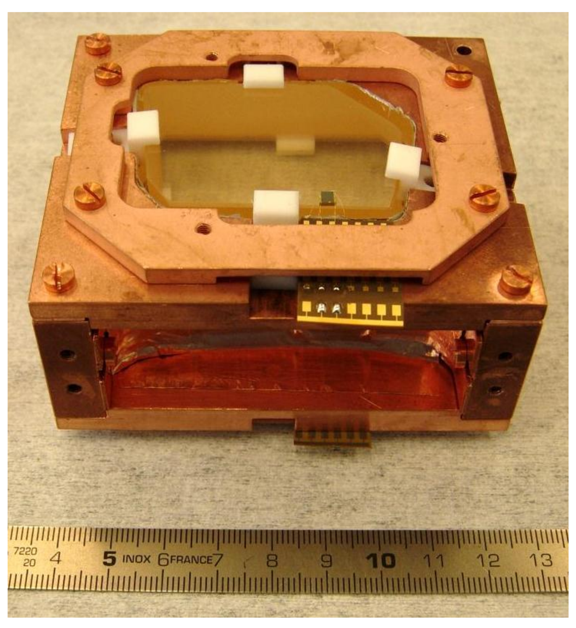
1. Rise time from 15 % to 90 % of the amplitude
2. χ^2 method using an average pulse as a standard shape function
3. Optimal filter method

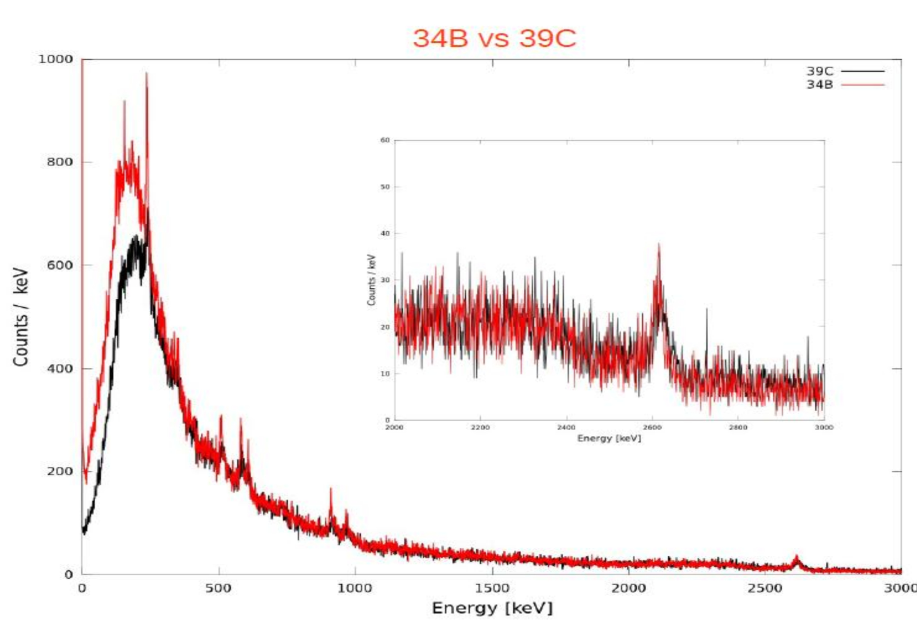


Rejection efficiency of the piled-up pulses is (80–90)%

5. Test of the large $ZnMoO_4$ crystal as scintillating bolometer

Measurements and data analysis with a **313 g $ZnMoO_4$** scintillating bolometer are in progress in the **Centre de Spectrométrie Nucléaire et de Spectrométrie de Masse (Orsay, France)**





Energy resolution FWHM = 1.2% @ 2615 keV due to overloading of the pulses because a very high counting rate

Preliminary results prove the possibility of the large-scale next-generation experiment with $ZnMoO_4$ crystals

Number of ≈ 400 g Crystals	Total isotope mass [kg]	Half-life sensitivity [10^{26} y]	$m_{\beta\beta}$ sensitivity [eV]
2000	92.5	9.25	0.01–0.04

Sensitivity to 0ν2β decay of ^{100}Mo on the level of $T_{1/2}$ ≈ 10^{27} yr (⟨m_ν⟩ ≈ 0.01 – 0.04 eV) can be reached [7], which allow to scrutinize the inverted hierarchy region of the neutrino mass pattern

6. Conclusions

- **Large volume $ZnMoO_4$ crystals of improved quality were grown by the low-thermal gradient Czochralski technique**
- **The present bolometric detector technologies enable to control two-neutrino double 2ν2β decay form of background at the required level**
- **Detector prototypes of the cryogenic scintillating bolometers with a 23.8 g and 313 g $ZnMoO_4$ scintillating crystals were constructed and tested**
- **Development of $Zn^{100}MoO_4$ crystal scintillators from ~ 1 kg of enriched ^{100}Mo is in progress**

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$ZnMoO_4$ scintillating bolometers are promising detectors for a next-generation 0ν2β experiment capable to explore the inverted hierarchy region of the neutrino mass pattern

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