Experiments on Neutrinoless Double Beta Decay: Current Status and Prospects

Vladimir Kazalov

Baksan Neutrino Observatory of INR RAS

vvk1982@mail.ru
kazalov@inr.ru

Baksan Neutrino Observatory
Institute for Nuclear Research RAS

XXIII INTERNATIONAL SEMINAR ON HIGH-ENERGY PHYSICS
QUARKS-2026
Petrozavodsk, Russia
18-23 May 2026
https://petrozavodsk.cosmosgroup.ru/

Why are we searching for neutrinoless double beta decay?

Key question: Is the neutrino its own antiparticle? (Majorana or Dirac particle?)

•**Search for New Physics.** Neutrinoless double beta decay (0νββ) is a hypothetical process forbidden within the Standard Model (SM) of particle physics. Its observation would be the first direct and indisputable proof of physics beyond the SM.

•**Testing lepton number conservation.** Unlike the allowed two-neutrino decay (2νββ), which produces two antineutrinos, 0νββ decay emits no neutrinos at all. This directly violates the fundamental law of lepton number conservation – a key requirement for explaining why matter dominates over antimatter in the Universe.

•**A direct path to the nature of neutrinos.** Observing 0νββ decay is the only known practical way to prove that the neutrino is a **Majorana particle**, i.e., identical to its own antiparticle.

Current status: Experiments (CUORE, LEGEND, AMoRE) are pushing the limits of sensitivity, trying to detect a single event with a half-life exceeding 10^{26} years.

What would the discovery of neutrinoless double beta decay give us?

Fundamental consequences for physics and cosmology:

- **Proof that the neutrino is a Majorana particle.** This would mean that neutrinos and antineutrinos are the same particle. The discovery would confirm Ettore Majorana's hypothesis, put forward back in 1937.

- **Observation of lepton number violation.** This would be the first observed process to violate this fundamental law. Such violation is one of the key conditions (the Sakharov conditions) for generating the matter–antimatter asymmetry in the early Universe.

- **Key to the matter–antimatter asymmetry.** It would explain why matter survived after the Big Bang while antimatter almost completely vanished. Lepton-number-violating processes like $0\nu\beta\beta$ could have created the excess of matter in the young Universe.

- **Measurement of the absolute neutrino mass scale.** The rate of $0\nu\beta\beta$ decay depends directly on the neutrino mass. The discovery would allow precise measurement of this fundamental quantity (at the ~10 meV level) and determination of the neutrino mass hierarchy (normal or inverted).

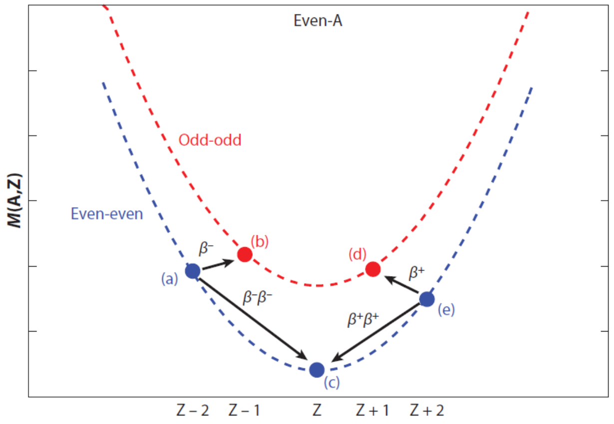
- **A window to "new physics".** Even establishing stricter limits on $0\nu\beta\beta$ (a null result) rules out many theoretical models beyond the SM and guides future searches.

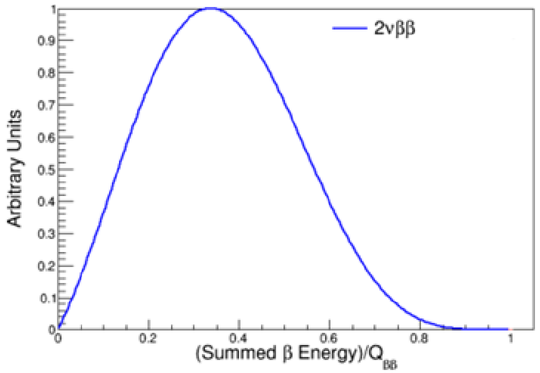
Two-neutrino double beta decay (2νββ)

Two-neutrino double beta decay is a rare weak nuclear process that has been observed.

$$\beta^-\beta^- : (A, Z) \rightarrow (A, Z+2) + 2e^- + 2\bar{\nu}_e\,,$$
$$\beta^+\beta^+ : (A, Z) \rightarrow (A, Z-2) + 2e^+ + 2\nu_e\,,$$
$$\mathrm{ECEC} : 2e^- + (A, Z) \rightarrow (A, Z-2) + 2\nu_e\,,$$
$$\mathrm{EC}\beta^+ : e^- + (A, Z) \rightarrow (A, Z-2) + e^+ + 2\nu_e$$

$$Q_{\beta\beta} = M(A, Z) - M(A, Z+2)$$

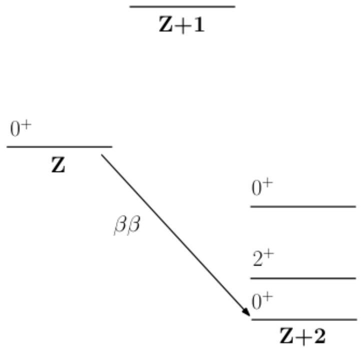




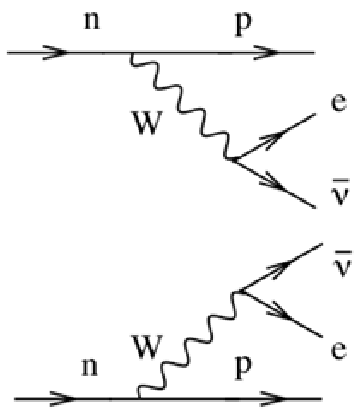
Dirac neutrino

$\nu \neq \bar{\nu}$

In nature we only observe ν_L and $\bar{\nu}_R$

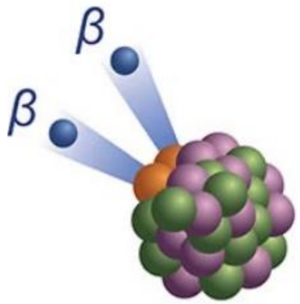


F. Avignone *et al.* Rev. Mod. Phys. 2008



- "**Extremely rare:** Half-lives of $\mathbf{10^{19}}$–$\mathbf{10^{24}}$ **years** (longest ever measured)
- "**Nuclear structure probe:** Tests wavefunction overlap predictions (QRPA, IBM-2 models)
- "**Measured in 10+ isotopes:** ^{48}Ca, ^{82}Se, ^{100}Mo, ^{130}Te, ^{136}Xe (most studied)

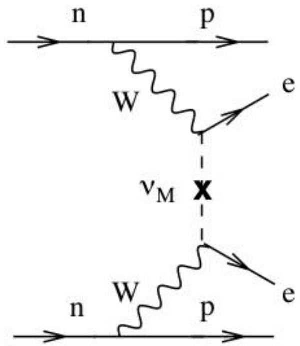
Neutrinoless double beta decay(0νββ)



In search of a theoretical process:

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

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

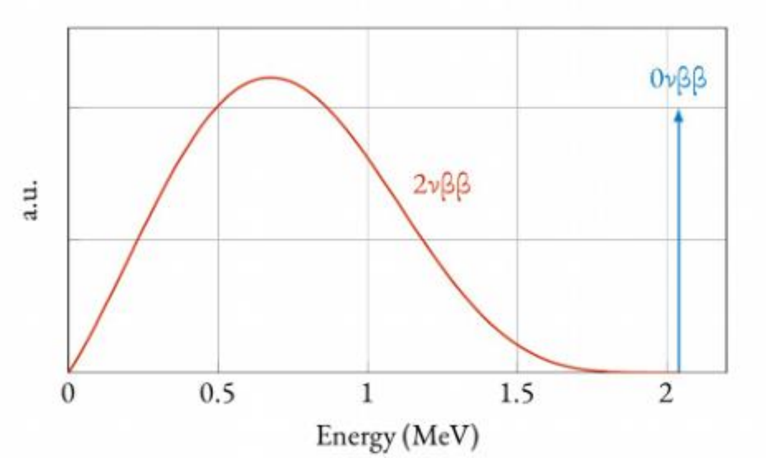


Majorana neutrino

$\nu = \bar{\nu}$

1937 year

That's because they are simply just ν_L and ν_R



Why Study Neutrinoless Double Beta Decay?

Key Fundamental Questions:

1. Lepton number violation (ΔL=2)

Would prove neutrinos are Majorana particles

2. Neutrino mass nature (Dirac or Majorana?)

Majorana neutrinos imply new physics beyond Standard Model

3. Absolute mass scale

Measure or constrain the lightest neutrino mass (m_1)

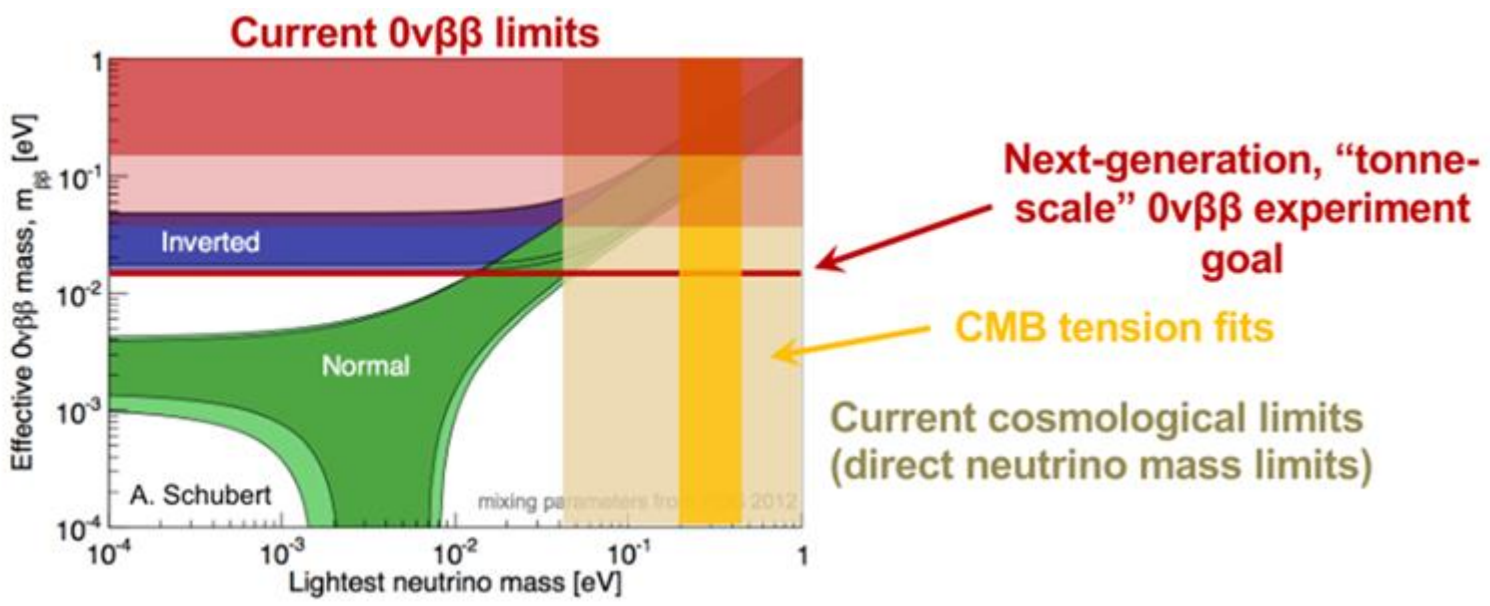
4. Mass hierarchy type

Normal / Inverted / Quasi-degenerate ordering

5. CP violation in leptonic sector

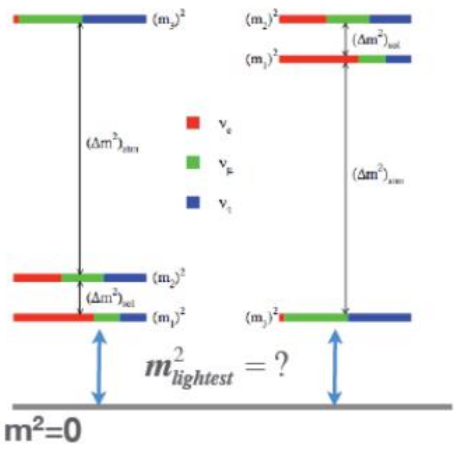
Links to matter-antimatter asymmetry in the universe

Sensitivity to Neutrino Mass

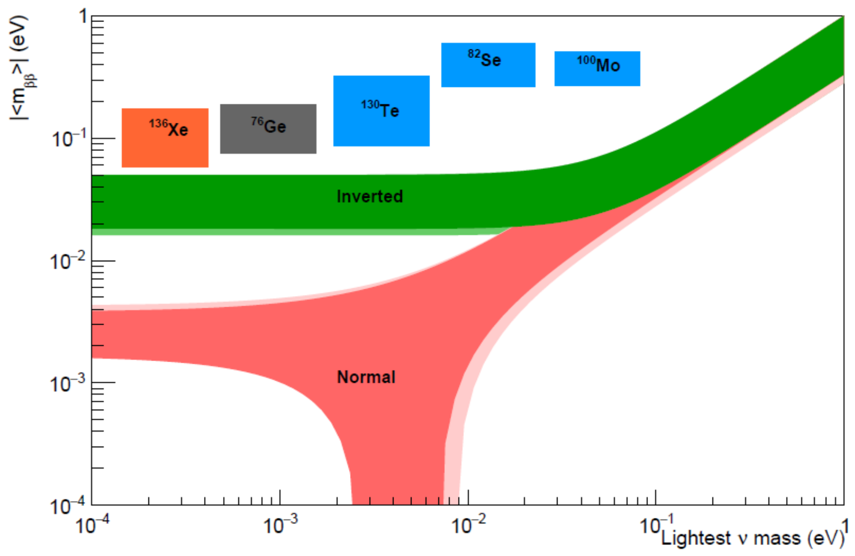


Half-life of 0νββ related to neutrino mass scale

- $\left(T^{0\nu}_{1/2}\right)^{-1} = G^{0\nu}|M_{0\nu}|^2\left(\frac{\langle m_{\beta\beta}\rangle}{m_e}\right)^2$
- $\langle m_{\beta\beta}\rangle = \left|\sum U^2_{ei} m_i\right|$



- **Axes:**
  - X: Lightest neutrino mass (m_lightest) — sets the absolute scale
  - Y: Effective Majorana mass (m_ββ) — direct observable in 0νββ decay
- **Theoretical bands (from oscillation data):**
  - Upper band: Inverted Ordering (IO) — robust lower bound ~15–18 meV
  - Lower band: Normal Ordering (NO) — can vanish due to Majorana phase cancellation
  - Width comes from unknown CP phases & nuclear matrix element uncertainties
- **Experimental overlays:**
  - Red-crimson exclusion: 0νββ limits (KamLAND-Zen, CUORE) cut into parameter space
  - Cosmology cap: Planck + BAO limit on Σm_ν squeezes the right-hand side of the plot
- **Strategic roadmap:**
  - Next-generation experiments aim to cover the entire IO band (sensitivity ~15 meV)
  - No signal → IO strongly disfavoured; neutrino likely a Dirac particle
  - Signal found → $m_{\beta\beta}$ value reveals mass ordering: high (>20 meV) → IO; low → NO



The most interesting isotopes from an experimental point of view and their key featuresc

There are 35 isotopes in nature that are capable of double beta decay.

^{48}Ca, ^{70}Zn, ^{76}Ge, **^{82}Se**, ^{86}Kr, ^{94}Zr, **^{96}Zr**, ^{98}Mo, **^{100}Mo**, ^{104}Ru, ^{110}Pd, ^{114}Cd, **^{116}Cd**, ^{122}Sn, ^{124}Sn, ^{128}Te, ^{130}Te, ^{134}Xe, ^{136}Xe, ^{142}Ce, ^{146}Nd, ^{148}Nd, **^{150}Nd**, ^{154}Sm, ^{160}Gd, ^{170}Er, ^{176}Yb ^{186}W, ^{192}Os, ^{198}Pt, ^{204}Hg

Isotope	Abund. (%)	$Q_{\beta\beta}$ (MeV)	$T_{1/2}^{2\nu/2\nu ECEC}$ (yr)	Best $T_{1/2}^{0\nu}$ Limit (yr)	$\langle m_{\beta\beta}\rangle$ (meV)	Experiment (Year)
^{48}Ca	0.187	4.268	4.4×10^{19}	$> 6.2 \times 10^{22}$	250–700	NEMO-3 (2018)
^{76}Ge	7.73	2.039	1.93×10^{21}	$> 5.8 \times 10^{26}$	79–180	LEGEND-200 / GERDA (2024)
^{78}Kr	0.355	2.848	1.9×10^{22}	$> 1.1 \times 10^{22}$	—	Baksan (2022)
^{82}Se	8.73	2.995	9.2×10^{19}	$> 3.6 \times 10^{24}$	300–900	NEMO-3 (2023)
^{96}Zr	2.80	3.350	2.35×10^{19}	$> 1.0 \times 10^{23}$	200–600	NEMO-3 (2019)
^{100}Mo	9.82	3.034	6.93×10^{18}	$> 2.9 \times 10^{24}$	210–610	AMoRE-1 (2025)
^{116}Cd	7.49	2.813	2.8×10^{19}	$> 2.4 \times 10^{23}$	200–500	CUPID-0 / NEMO-3 (2023)
^{124}Xe	0.095	2.857	1.1×10^{22}	$> 2.1 \times 10^{23}$	—	XENONnT (2022)
^{128}Te	31.7	0.867	7.2×10^{24}	$> 1.0 \times 10^{24}$	200–700	Geochemical
^{130}Te	34.1	2.527	8.2×10^{20}	$> 2.2 \times 10^{25}$	75–260	CUORE (2024)
^{130}Ba	0.106	2.619	6.0×10^{20}	$> 4.0 \times 10^{21}$	—	Geochemical
^{136}Xe	8.9	2.458	2.165×10^{21}	$> 2.3 \times 10^{26}$	36–156	KamLAND-Zen (2023)
^{150}Nd	5.6	3.367	9.11×10^{18}	$> 2.0 \times 10^{22}$	1200–4000	NEMO-3 (2019)

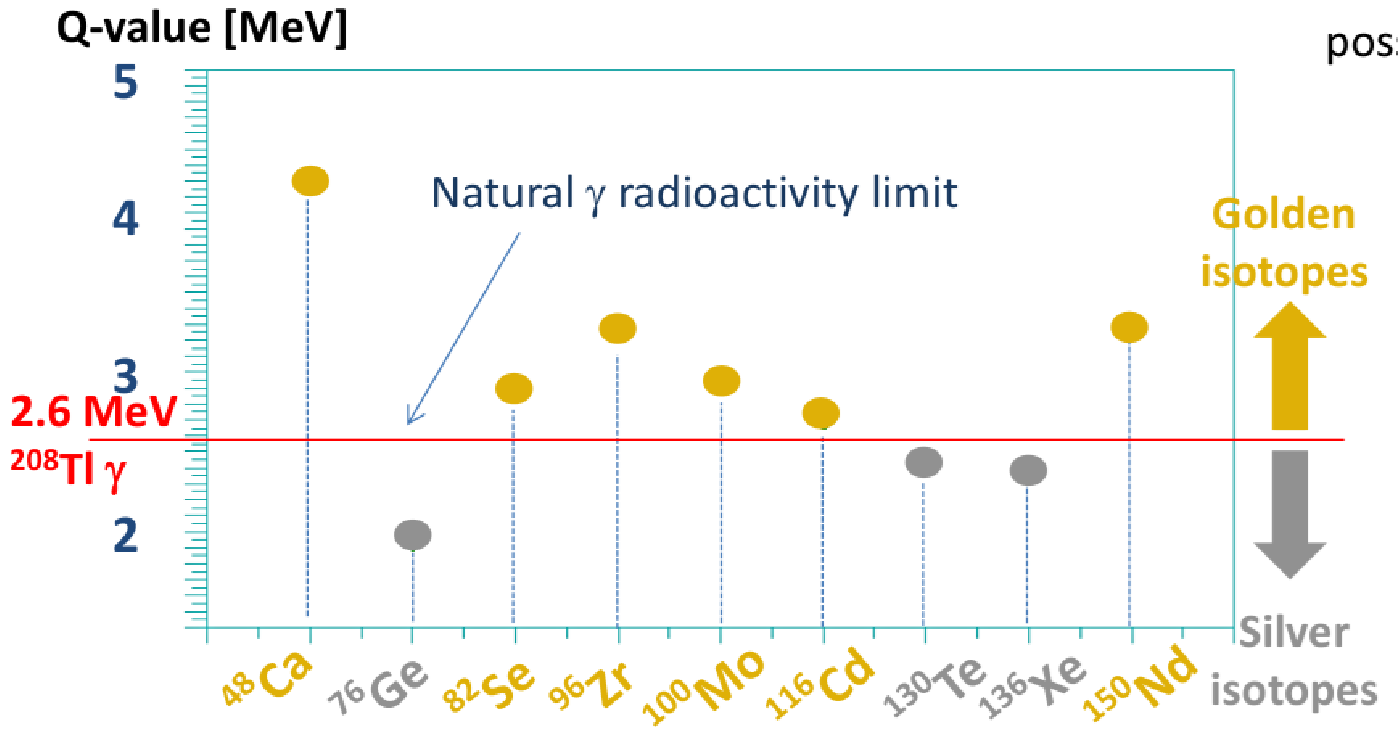
Golden and Silver Isotopes (large $Q_{\beta\beta}$ value)

Q is the crucial factor → Phase space: $G(Q,Z) \propto Q^5$ / Background ⇒ **Magnificent Nine candidates**

Golden isotopes: ^{48}**Ca** – ^{150}**Nd** – ^{96}**Zr** – ^{100}**Mo** – ^{82}**Se** – ^{116}**Cd**

Silver isotopes: ^{76}**Ge** – ^{130}**Te** – ^{136}**Xe**

Large-scale enrichment is possible



^{130}Te is almost golden: Q-value (**2530 keV**) in a clean window between **2615 keV** γ and its Compton edge (**2382 keV**)

from Andrea Giuliani, GDR Neutrino meeting, May 29-30 2017

The goal of the experiment

Andrea Giuliani, 10.53941/pac.2026.100006

- **The case of a non-zero background:**

$$T_{1/2}^{0\nu}(exp) = (ln2)N_A\frac{a}{A}\varepsilon\sqrt{\frac{Mt}{b\Delta E}}$$

Isotope mass

Isotopic abundance

Exposure time

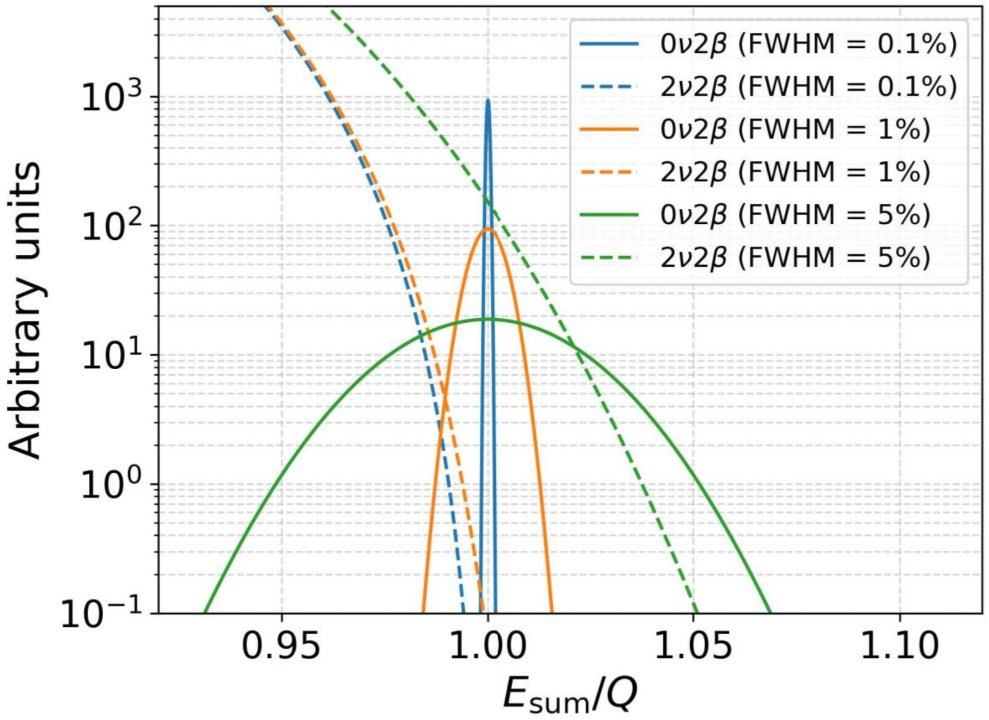
Energy resolution

Atomic mass

Background index

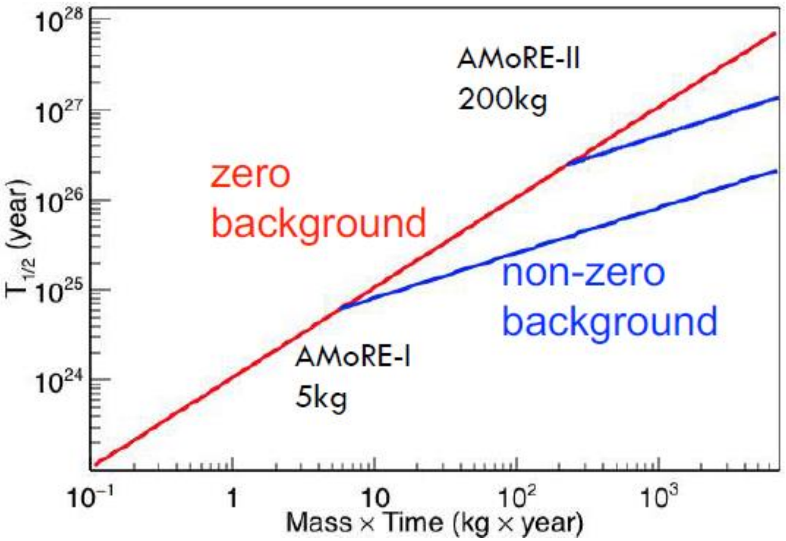
Sensitivity to $T_{1/2}^{0\nu}$

Registration efficiency



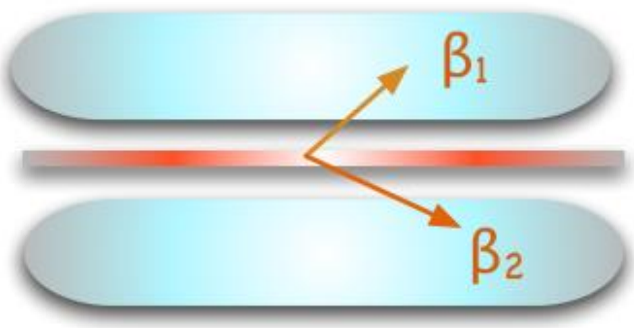
- **The case of a "zero" background:**

$$T_{1/2}^{0\nu}(exp) = (ln2)N_A\frac{a}{A}\varepsilon Mt$$



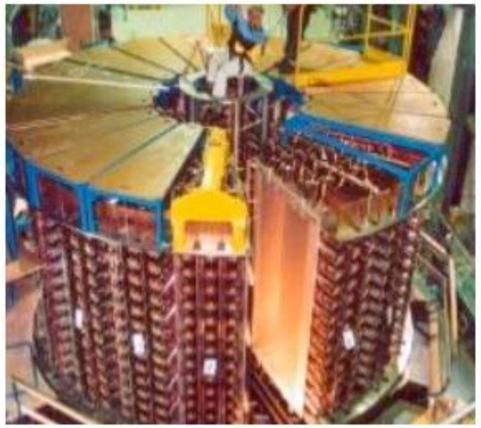
Experimental methodology: two main approaches

Souce ≠ Detector



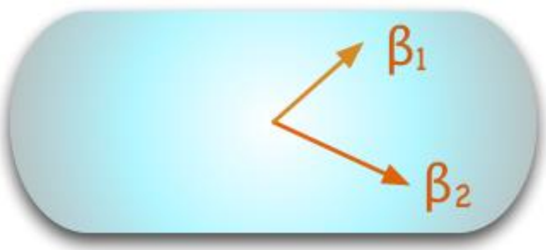
Thin-Foil Sources

The electrons are detected using a variety of techniques, including scintillators, TPCs (time projection chambers), drift chambers, and semiconductor detectors.



NEMO (Modane/Frejus)

Source = Detector (calorimeters)



The **sum of the energies** of two electrons is measured
Signature: **peak at the $Q_{\beta\beta}$ decay value**
Detectors: Scintillators, HPGe, bolometers

Experiments:

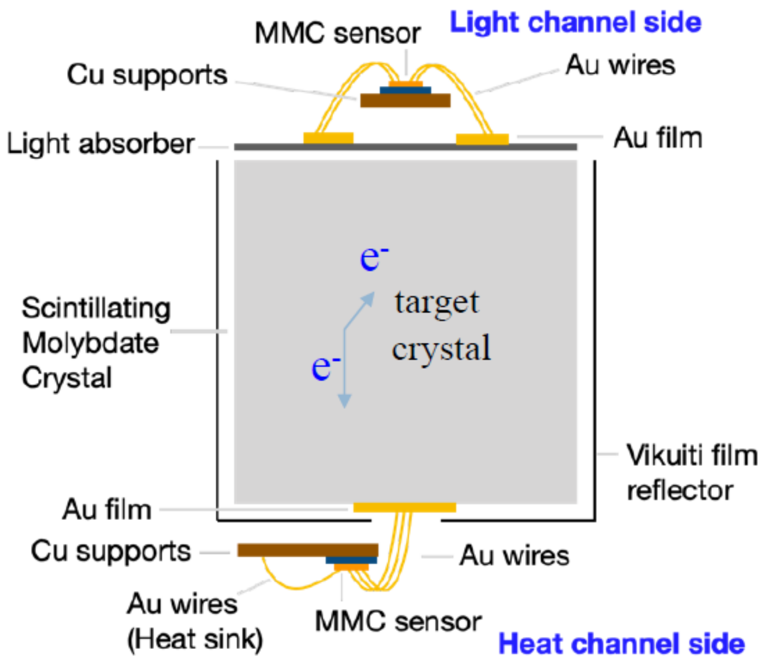
^{76}Ge - GERDA, MAJORANA DEMONSTRATOR, LEGeND, CDEX
^{136}Xe - EXO200, nEXO, KamLAND-Zen
^{100}Mo - AMoRE, LUMINEO (CUPID-Mo)
^{130}Te – CUORE, SNO+
^{82}Se – CUPID-0

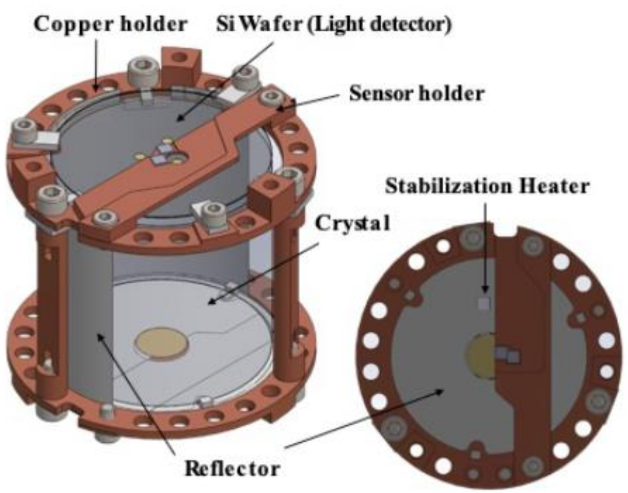
Classification of “Source = Detector” Technologies for 0νββ Search

Technology	Detection Principle	Key Isotopes	Leading Experiments
Semiconductor detectors	High-purity enriched Ge diodes; ionisation measured	^{76}Ge	GERDA, MAJORANA DEMONSTRATOR → **LEGEND**
Bolometers (cryogenic calorimeters)	Crystals operated at mK; heat (phonon) readout, often with light for particle ID	^{130}Te (TeO_2), ^{82}Se (ZnSe), ^{100}Mo (Li_2MoO_4)	CUORE, CUPID, AMoRE
Liquid scintillators	Isotope-loaded organic liquid scintillator; scintillation light detected	^{136}Xe, ^{130}Te	KamLAND-Zen, SNO+
Time Projection Chambers (TPCs)	Liquid or gaseous isotope serves as sensitive volume; ionisation + scintillation (or electroluminescence) allow 3D track reconstruction	^{136}Xe, ^{82}Se, ^{136}Ba (daughter) tagging possible	EXO-200 → nEXO (liquid Xe), NEXT (high-pressure gas Xe)

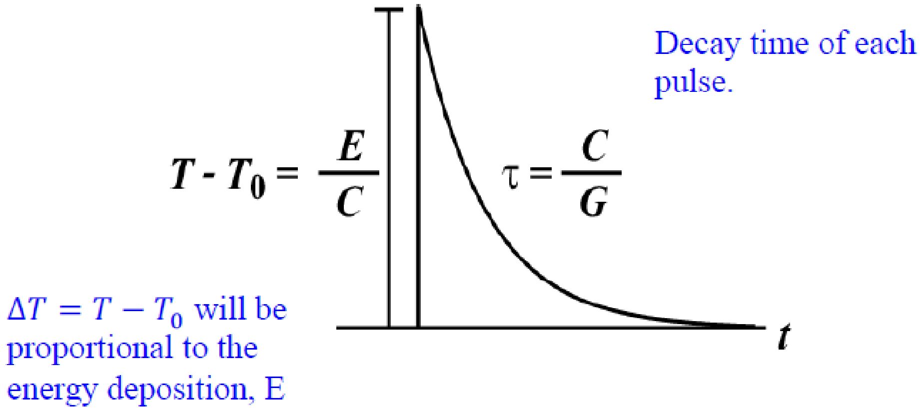
Bolometers in nutshell

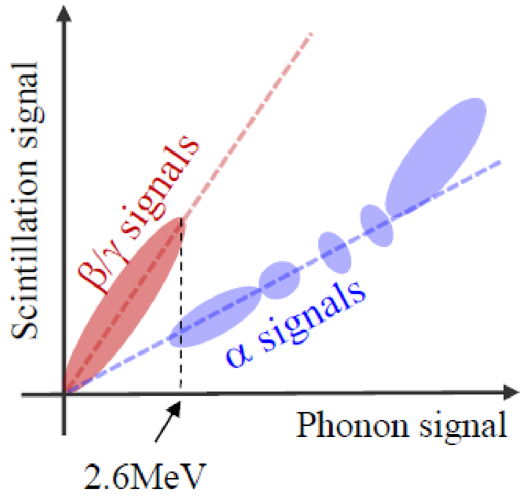
AMoRE Detector



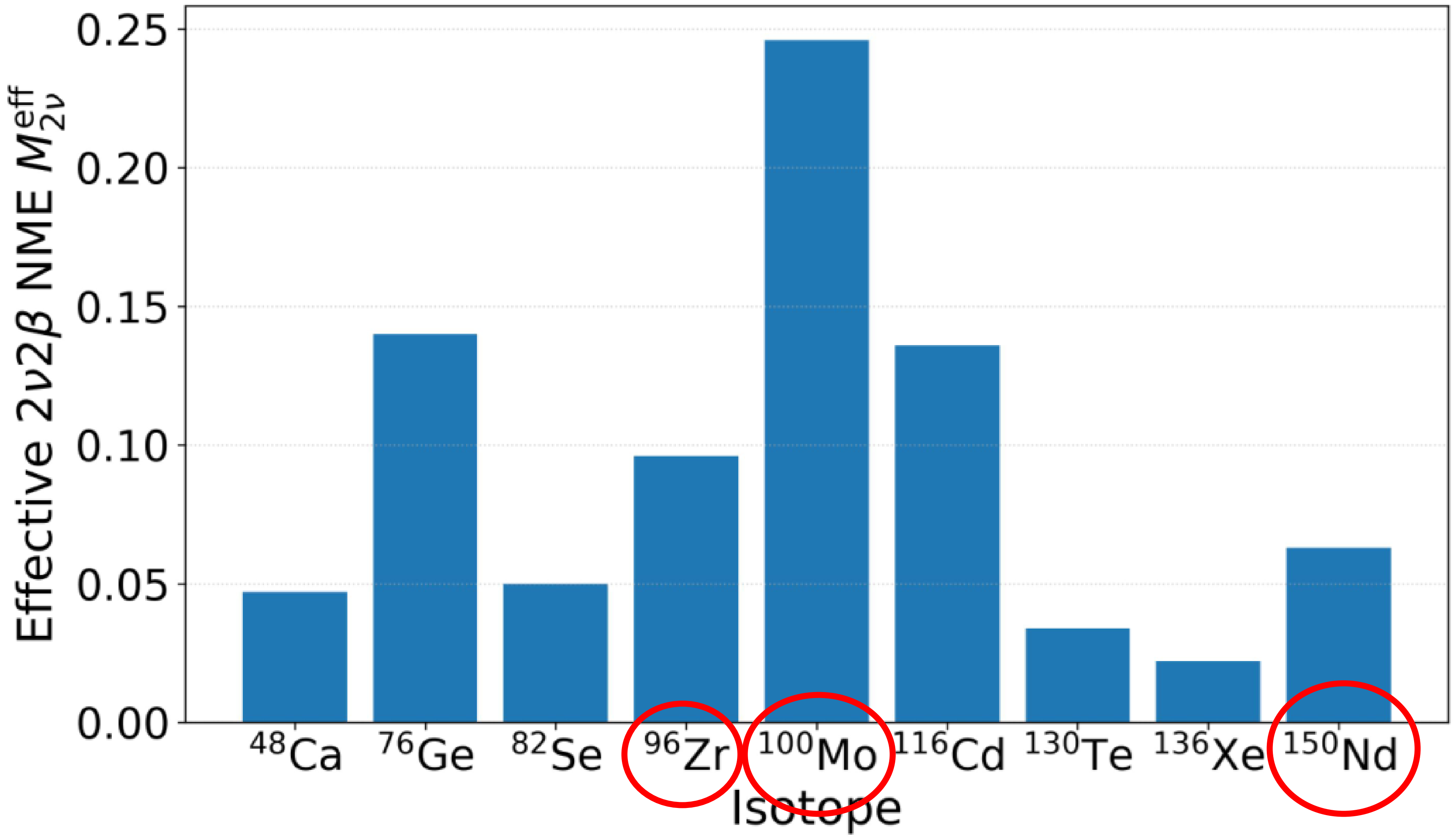


Surface alphas are continuous in energy and can be rejected by scintillation measurement with MMC+SQUID sensors.





Effective 2ν2β nuclear matrix elements for the “magnificent nine” isotopes.



Andrea Giuliani, [10.53941/pac.2026.100006](https://doi.org/10.53941/pac.2026.100006)

Search for neutrinoless double beta decay ^{96}Zr

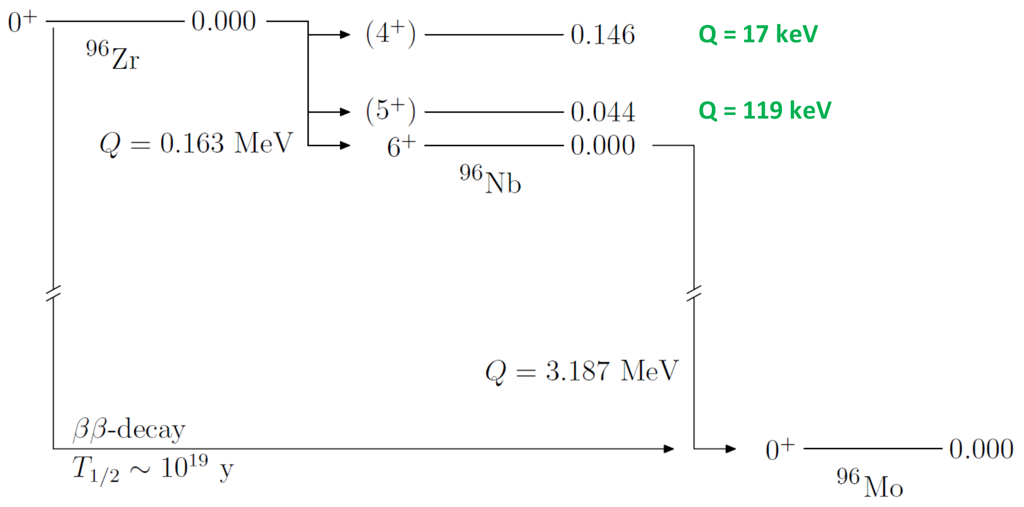
A. Leoncini MEDEX 2023

Experiment	Transition	$T_{1/2}$ @ 90% C.L. (yr)	Ref.	Technique
ZICOS (Kamioka Observatory, Japan)	$^{96}Zr \rightarrow {}^{96}Mo$ (g.s.)	under construction	[1]	Liquid scintillator
NEMO-3 (Frejus, France)	$^{96}Zr \rightarrow {}^{96}Mo$ (g.s.)	$> 9.2\times10^{21}$ $> 1.29\times10^{22}$	[2] [3]	Tracking detector
Kimballton Underground Research Facility, (USA)	$^{96}Zr \rightarrow {}^{96}Mo$ (2^+_1)	$> 3.1\times10^{20}$	[4]	HPGe
Collaboration at Frejus, (France)	$^{96}Zr \rightarrow {}^{96}Mo$ (2^+_1, 0^+_1, 2^+_2, 2^+_3)	$> (2.6 - 7.9)\times10^{19}$	[5]	HPGe
Collaboration at LNGS	$^{96}Zr \rightarrow {}^{96}Mo$ (2^+_1)	$> 3.8\times10^{19}$	[6]	HPGe
Collaboration at LNGS	$^{94}Zr \rightarrow {}^{94}Mo$ (2^+_1)	$> 2.1\times10^{20}$	[7]	HPGe
TILES (TIFR, Mumbai)	$^{94}Zr \rightarrow {}^{94}Mo$ (2^+_1)	$> 5.2\times10^{19}$	[8]	HPGe
Kimballton Underground Research Facility (USA)	$^{96}Zr \rightarrow {}^{96}Mo$ (6^+)	$> 2.4\times10^{19}$	[9]	HPGe

[1] EPS-HEP (2019) 437
[2] NPA 847 (2010) 168
[3] PhD U. Coll. London (2015)
[4] S.W. Finch et W. Tornow, Phys, Rev. C 92 (2015) 045501
[5] J. Phys. G: Nucl. Part. Phys. 22 (1996) 487
[6] C. Arpesella et al. Lett. 27 (l) (1994) 29
[7] E.Celi et al., Eur. Phys. J. C 83 (2023) 396
[8] N. Dokania et al. J. Phys. G: Nucl. Part. Phys. 45 (2018) 075104
[9] S.W. Finch, W. Tornow, Nucl. Inst. Meth. A 806 (2016) 70
[10] J. Heeck and W. Rodejohann, EPL 103 (2013) 32001

β- and ββ-decays of ^{96}Zr Presented: Decay energy (Q-value) and selected excited states of ^{96}Nb

H Heiskanen, M T Mustonen and J Suhonen,
doi:10.1088/0954-3899/34/5/005



- $Q_{\beta\beta}$ = **3,35 МэВ**
- Interesting from a theoretical point of view – $T_{1/2} \sim (Q_{\beta\beta})^5$
- Isotopic abundance - **2,8 %**

Search for neutrinoless double beta decay ^{96}Zr

Search for neutrinoless double beta decay in $^{94,96}Zr$ isotopes using Cs_2ZrCl_6 crystal scintillators

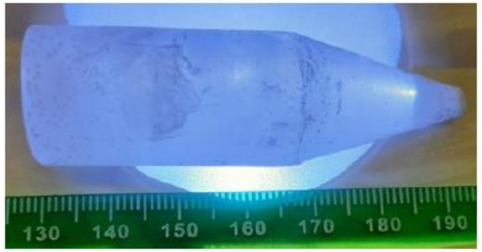
A. Leoncini [1,2], P. Belli [1,2], R. Bernabei [1,2], F. Cappella [3,4], V. Caracciolo [1,2], R. Cerulli [1,2], A. Incicchitti [3,4], M. Laubestein [5], V. Merlo [1,2], V. Nahorna [8], S. Nagorny [6,7], S. Nisi [5], P. Wang [8]

Some general properties	Cs_2ZrCl_6
Effective atomic number	46.6
Density (g/cm³)	3.4
Melting point (°C)	850
Crystal structure	Cubic
Emission maximum (nm)	450 - 470
Scintillation time constants (μs)	0.4; 2.7; 12.5*
Light Yield	up to 41000 photons/MeV**
Linearity of the energy response	Excellent, down to 100 keV
Energy resolution (FWHM, %) @ 662 keV	3.5 - 7.0***
Pulse-shape discrimination ability	Excellent
Mass fraction of Zr (%)	16

* *for alpha events at room temperature* (*Dalton Trans. 2022, 51, 6944-6954*)
** *for gamma quanta at room temperature (article in press)*
*** *depends on the crystal quality, surface treatment and readout system*

Produced at Queen's University

CsCl (99.9%) +
$ZrCl_4$ (99.9%) double sublimed
Bridgman growth technique

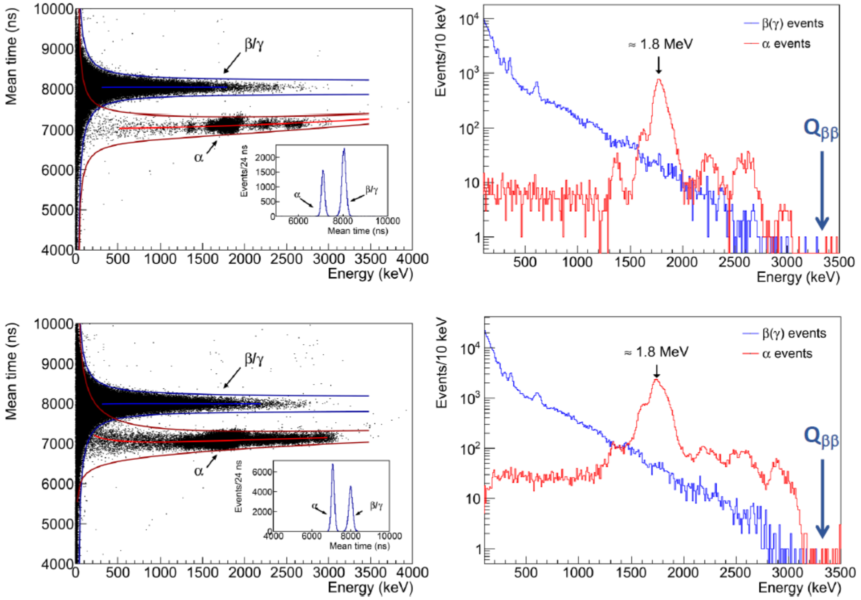


∅21.5×60 mm, about 60 g

Pulse-shape discrimination and background α event selection

Cone
FoM = 7.8

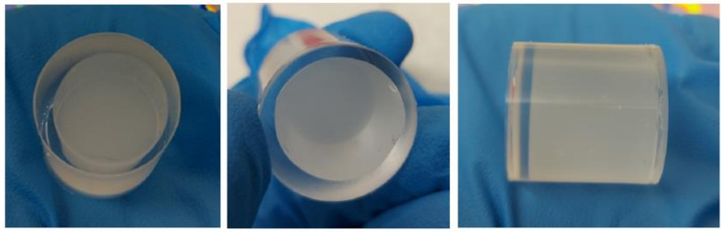
Cylinder
FoM = 7.2



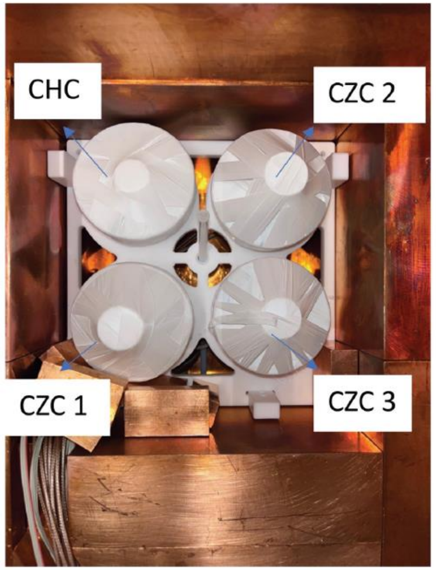
Selection efficiency is 99.7% in [0.1–3.5] MeV

Counting rate at ROI is 0.09 counts/(kg·keV·yr)

New low-background measurements in DAMA/CRYS setup (LNGS)

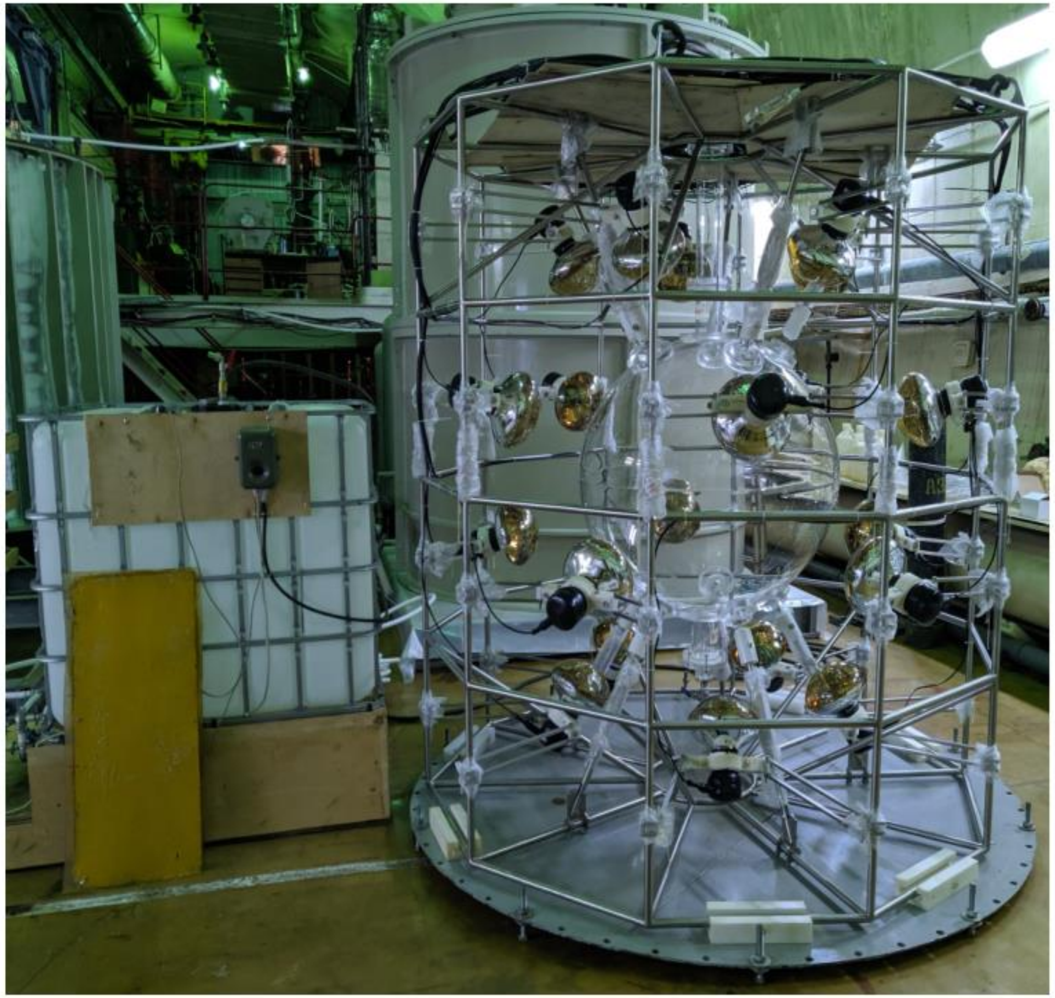


- Three new Cs_2ZrCl_6 crystals (more crystals are under production)
- Total mass = 59.5 g
- FWHM = 6-8% @ 662keV
- Produced from high purity and purified raw materials (> 99.99%)
- Crystals are encapsulated in a silicon-base resin + quartz window
- Modified experimental setup
- Measurements started in June 30th, 2023



Isotope-loaded organic liquid scintillator

N. A. Ushakov, New large-volume detector at the Baksan Neutrino Observatory: Detector prototype, doi:10.1088/1742-6596/1787/1/012037



Which isotopes can be loaded in a liquid scintillator:

1) Nd (Nd-150) - scintillator is being developed at INR RAS and KBSU
2) Zr (Zr-96, Zr-94) - scintillator is being developed at INR RAS and KBSU
3) Te (Te-130, Te-128) - scintillator is being developed at JINR

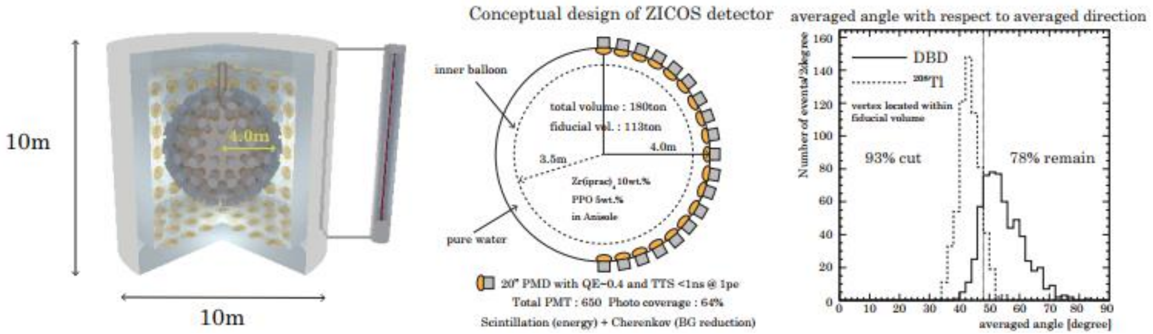
ZICOS - Neutrinoless Double Beta Decay experiment using Zr-96 with an organic liquid scintillator -

Yoshiyuki FUKUDA[1], **Shigetaka MORIYAMA**[2][6], **Katsuki HIRAIDE**[2][6], **Izumi OGAWA**[3], **Takahiro GUNJI**[4], **Ryohei HAYAMI**[4], **Satoru TSUKADA**[4] and **Shunsuke KUROSAWA**[5]

[1] Department of Physics, Faculty of Education, Miyagi University of Education, 149 Aza-Aoba, Aramaki, Aoba-ku,Sendai, Miyagi, 980-0845 Japan [2] Kamioka Observatory, Institute for Cosmic Ray Research, the University of Tokyo, 456 Higashi-Mozumi, Kamioka, Hida, Gifu, 506-1205, Japan [3] Department of Applied Physics, Faculty of Engineering, University of Fukui, 3-9-1 Bunkyo, Fukui, Fukui, 910-8507, Japan [4] Department of Pure and Applied Chemistry, Faculty of Science and Technology, Tokyo University of Science, 2641 Yamazaki, Noda, Chiba, 278-8510, Japan [5] New Industry Creation Hatchery Center (NICHe), Tohoku University, 6-6-10 Aza-Aoba, Aramaki, Aoba-ku, Sendai, Miyagi, 980-8579, Japan [6] Kavli Institute for the Physics and Mathematics of the Universe (WPI), the University of Tokyo, Kashiwa, Chiba, 277-8582, Japan

E-mail: `fukuda@staff.miyakyo-u.ac.jp`

Abstract. A liquid scintillator containing a tetrakis(isopropyl acetoacetato)zirconium has been developed for ZICOS experiment. In order to reach the sensitivity $T^{0\nu}_{1/2} \geq 10^{27}$ years, we have to use tone scale of ^{96}Zr and have to reduce 95 % of backgrounds from ^{208}Tl decay, which should be major backgrounds observed around Q-value (3.35 MeV) of ^{96}Zr neutrinoless double beta decay. According to the Monte Carlo simulation, we demonstrated that new method using the topological information of Cherenkov light could reduce 93 % of ^{208}Tl background with 78 % efficiency for $0\nu\beta\beta$ signal. For an identification of Cherenkov light, the precise spectral pulse shape from both Cherenkov and scintillation was directly measured by using sub-MeV electrons from ^{90}Sr/^{90}Y beta source. The observed pulse rise and fall (decay) time for Cherenkov light were 0.8 ns and 2.5 ns, respectively. They were actually shorter than those times of scintillation light which were also measured by 1.6 ns and 6.5 ns, respectively. This clear difference of rise time will be used for the pulse shape discrimination in order to select photomultiplier tube which receives Cherenkov lights, and the topological information of Cherenkov light will be used for the reduction of backgrounds from ^{208}Tl decay.



Fabrication of Liquid Scintillators Loaded with 6-Phenylhexanoic Acid-Modified ZrO_2 Nanoparticles for Observation of Neutrinoless Double Beta Decay

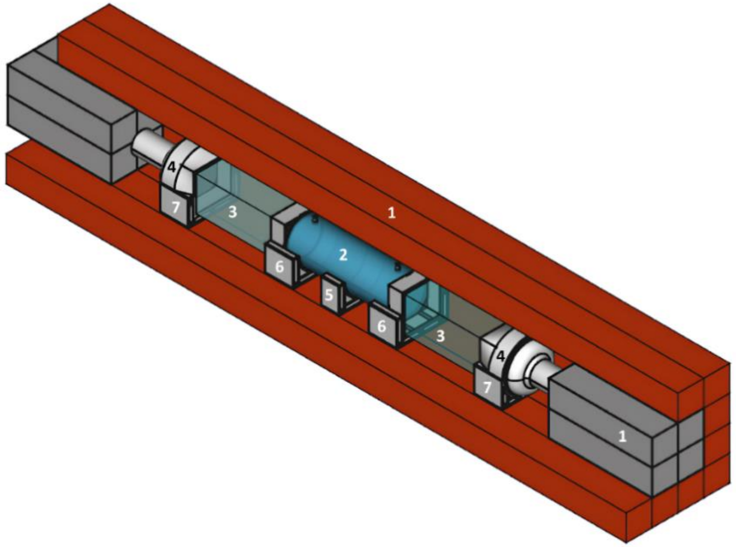
Akito Watanabe [1,*], Arisa Magi [1], Akira Yoko [2], Gimyeong Seong [3], Takaaki Tomai [4], Tadafumi Adschiri [2,3,4], Yamato Hayashi [1], Masanori Koshimizu [1], Yutaka Fujimoto [1] and Keisuke Asai [1]

1 Department of Applied Chemistry, Graduate School of Engineering, Tohoku University, 6-6-07 Aoba, Aramaki, Aoba-ku, Sendai 980-8579, Japan; arsm723.tmsj@gmail.com (A.M.); hayashi@aim.che.tohoku.ac.jp (Y.H.); koshi@qpc.che.tohoku.ac.jp (M.K.); fuji-you@qpc.che.tohoku.ac.jp (Y.F.); asai@qpc.che.tohoku.ac.jp (K.A.)
2 WPI-AIMR, Tohoku University, 2-1-1 Katahira, Aoba-ku, Sendai 980-8577, Japan; akira.yoko.c7@tohoku.ac.jp (A.Y.); tadafumi.ajiri.b1@tohoku.ac.jp (T.A.)
3 New Industry Creation Hatchery Center, Tohoku University, 6-6-10 Aoba, Aramaki, Aoba-ku, Sendai 980-8579, Japan; kimei.sei.c6@tohoku.ac.jp
4 Institute of Multidisciplinary Research for Advanced Materials, Tohoku University, 2-1-1 Katahira, Aoba-ku, Sendai 980-8577, Japan; takaaki.tomai.e6@tohoku.ac.jp
* Correspondence: akito.watanabe.p7@dc.tohoku.ac.jp; Tel.: +81-22-795-7219

Abstract: The observation of neutrinoless double beta decay is an important issue in nuclear and particle physics. The development of organic liquid scintillators with high transparency and a high concentration of the target isotope would be very useful for neutrinoless double beta decay experiments. Therefore, we propose a liquid scintillator loaded with metal oxide nanoparticles containing the target isotope. In this work, 6-phenylhexanoic acid-modified ZrO_2 nanoparticles, which contain ^{96}Zr as the target isotope, were synthesized under sub/supercritical hydrothermal conditions. The effects of the synthesis temperature on the formation and surface modification of the nanoparticles were investigated. Performing the synthesis at 250 and 300 °C resulted in the formation of nanoparticles with smaller particle sizes and higher surface modification densities than those prepared at 350 and 400 °C. The highest modification density (3.1 ± 0.2 molecules/nm^2) and Zr concentration of (0.33 ± 0.04 wt.%) were obtained at 300 °C. The surface-modified ZrO_2 nanoparticles were dispersed in a toluene-based liquid scintillator. The liquid scintillator was transparent to the scintillation wavelength, and a clear scintillation peak was confirmed by X-ray-induced radioluminescence spectroscopy. In conclusion, 6-phenylhexanoic acid-modified ZrO_2 nanoparticles synthesized at 300 °C are suitable for loading in liquid scintillators.

Development of a Liquid Scintillator Prototype Detector for 0νββ Decay Search in ^{150}Nd

As a prototype for a large-scale detector, we are developing a detector within the framework of the "New methods for investigating double beta decay without the use of neutrinos" project (FZZR-2022-0004). The goal of this project is to construct a novel scintillation detector for the search for neutrinoless double-beta decay in ^{150}Nd, ^{96}Zr

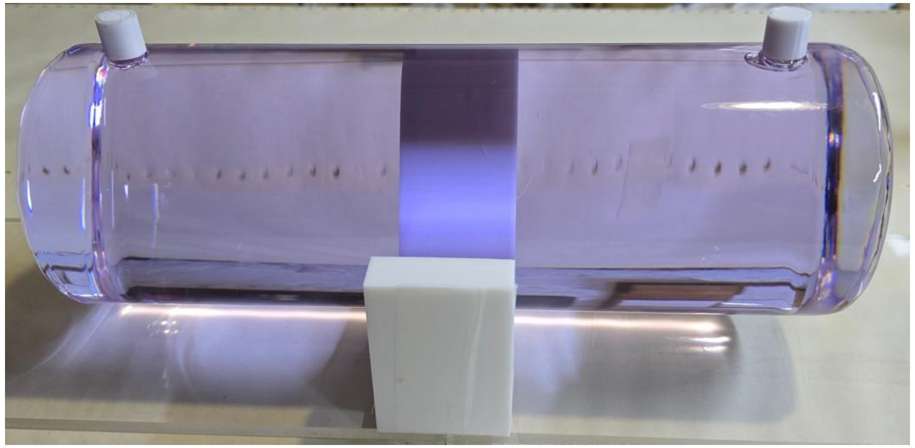


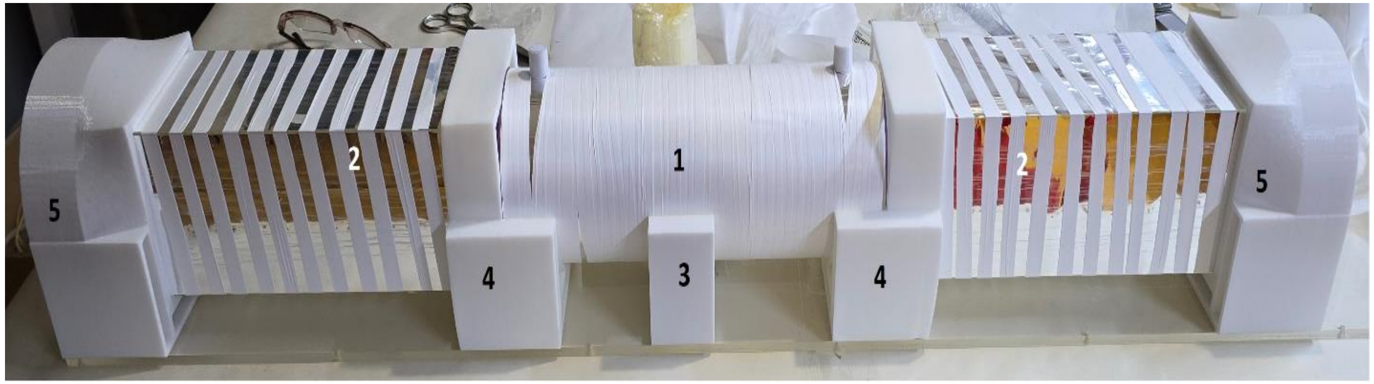
Schematic representation of the detector prototype

1 – Copper;
2 – Quartz cell filled with liquid scintillator;
3 – Plexiglass light guides;
4 – PMT in a light-protective casing made of PETG plastic;
5 – PETG cell stand;
6 – adapters for optical connection of quartz cell and light guides, material PETG plastic;
7 – adapters for optical connection of light guides and photomultiplier tubes, material PETG plastic;

Elements of a low-background liquid scintillation detector

Quartz cell filled with neodymium-containing liquid scintillator





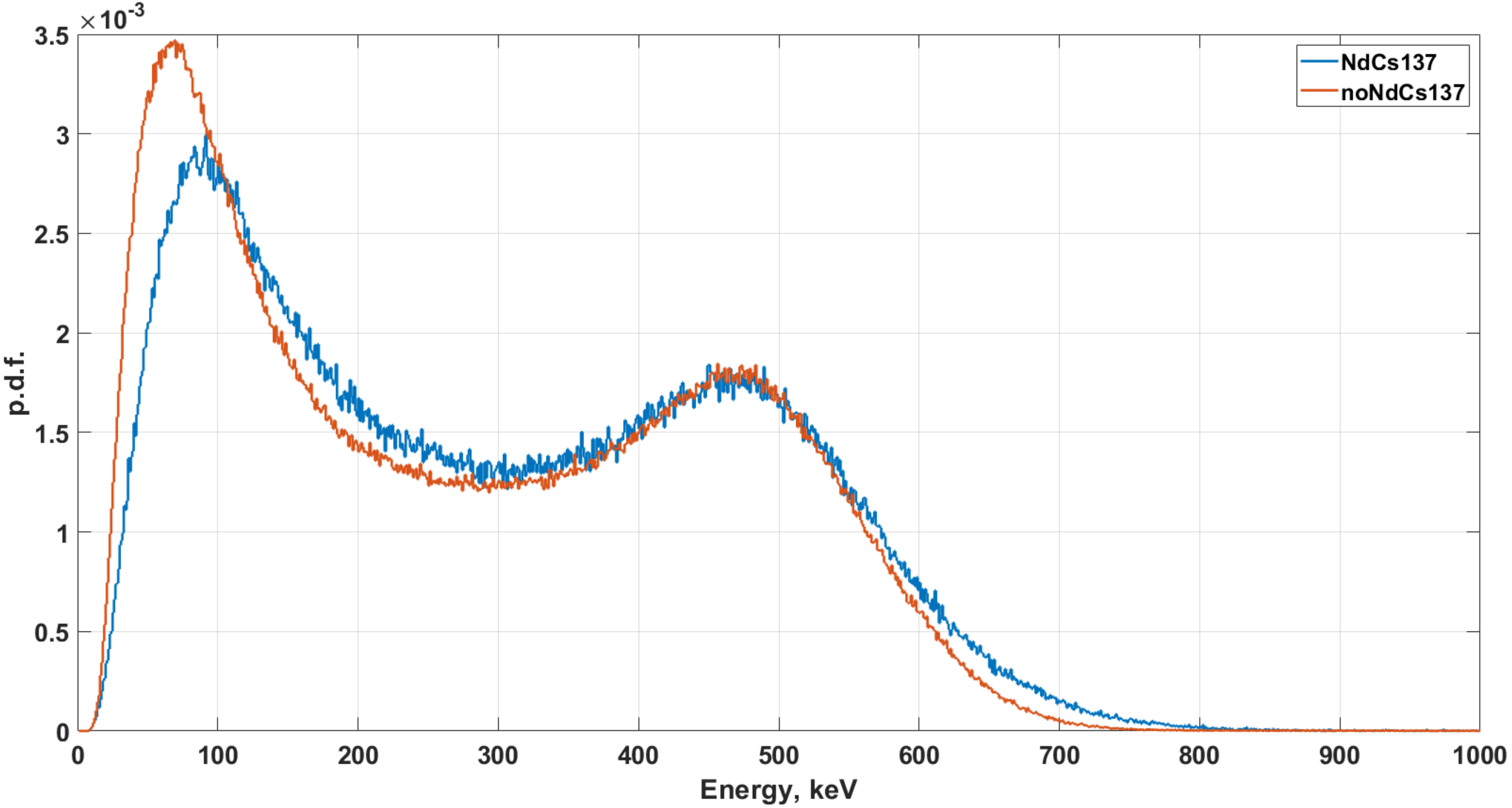
1. - quartz cell wrapped with VM2000 reflector + fluoroplastic tape,
2. - light guides wrapped with VM2000 reflector + fluoroplastic tape,
3. - stand for quartz cell, PETG material,
4. - adapters for optical connection of quartz cell and light guides, PETG material,
5. - adapters for optical connection of light guides and PMT (not shown in the photo), PETG material.

Detector Arrangement Inside Low-Background Shielding

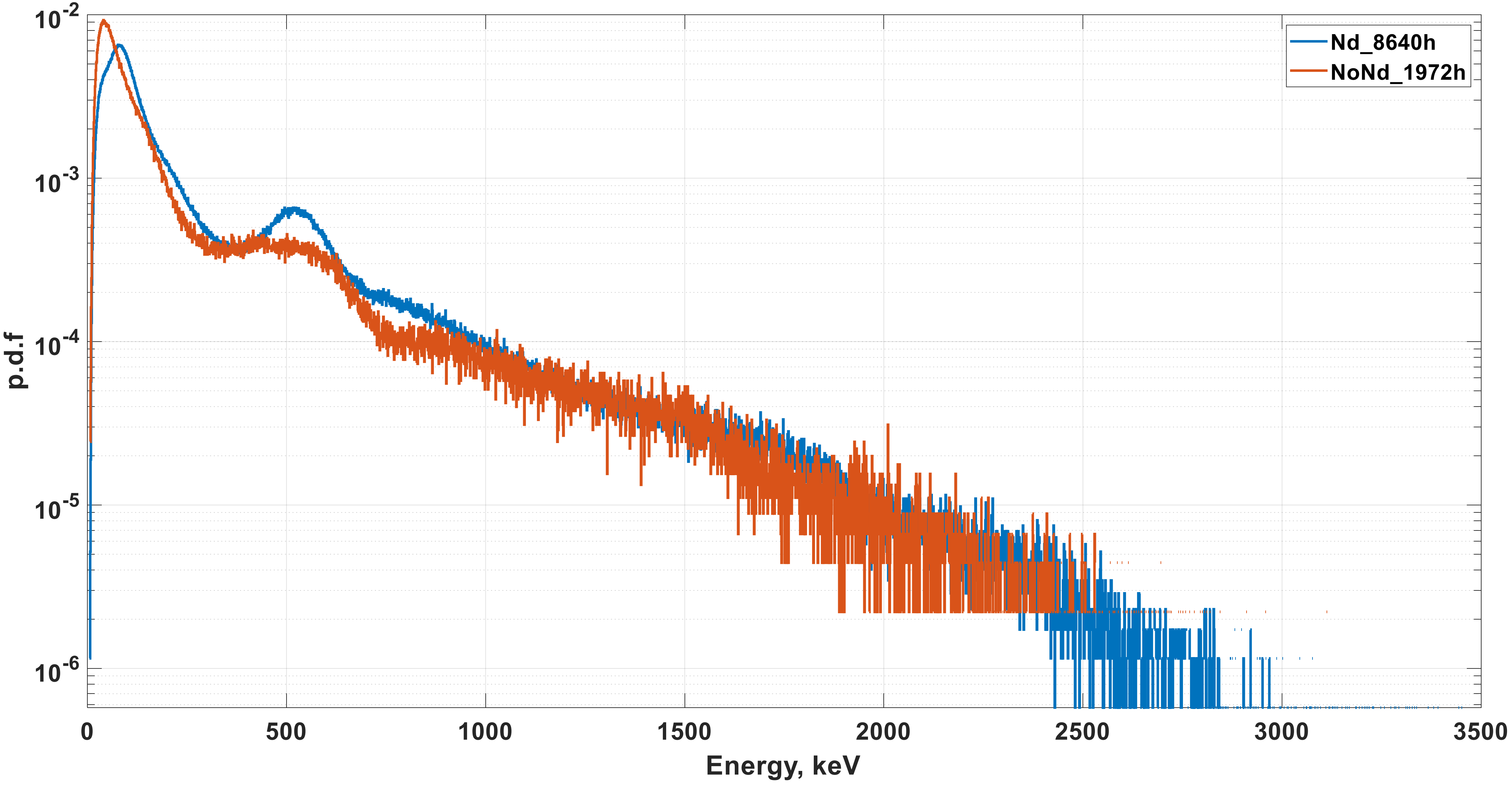
1. - copper,
2. - quartz cell,
3. - light guides,
4. - adapters for optical connection of quartz cell and light guides, PETG material,
5. - adapters for optical connection of light guides and photomultiplier tube, PETG material,
6. - photomultiplier tube in a light-protective casing made of PETG plastic

Experimental Setup (Full Assembly)

Thank you very much for your attention!

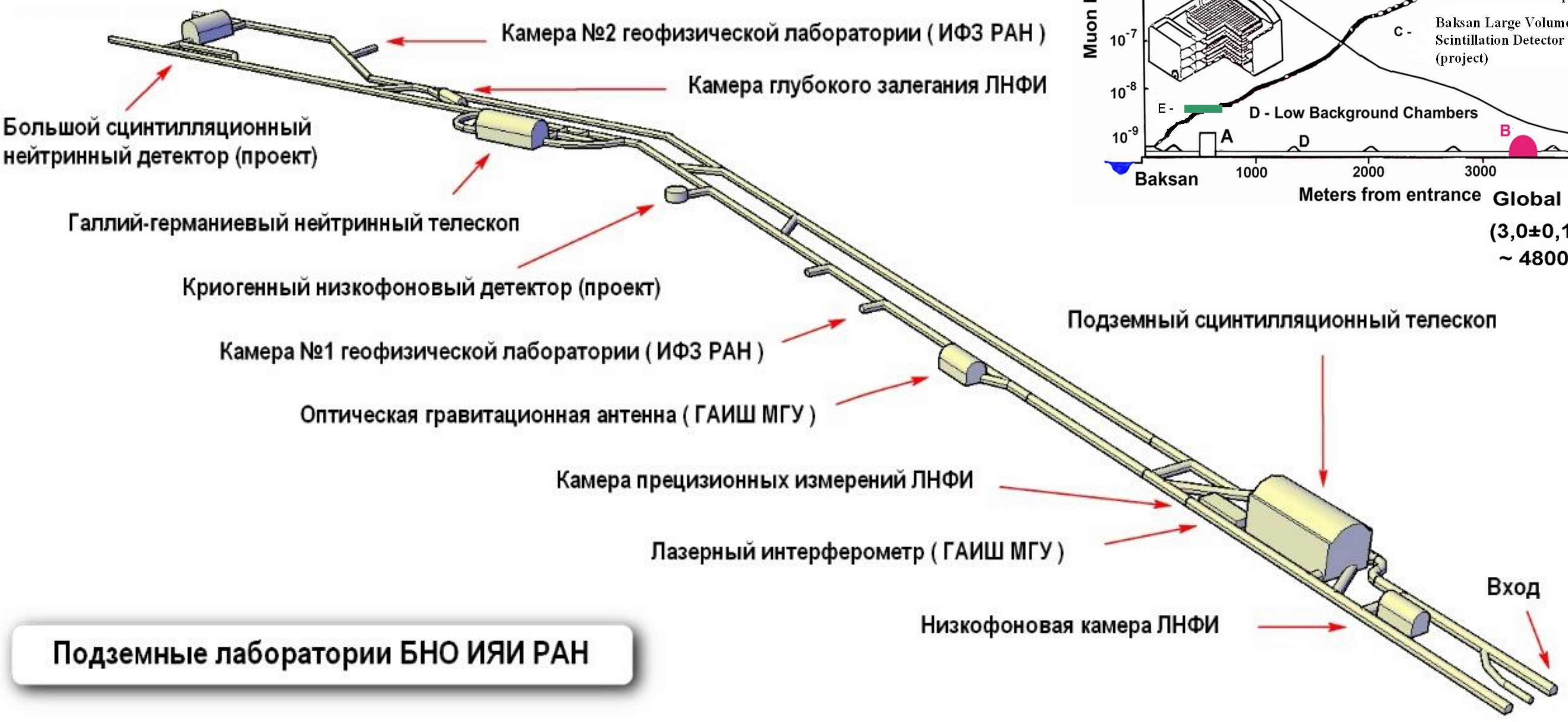


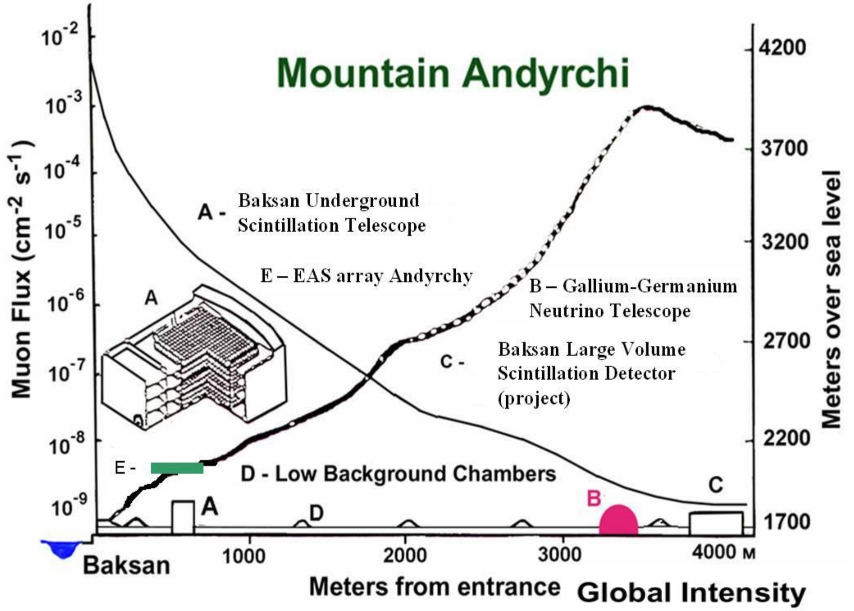
×10^-3
3.5
3
2.5
2
1.5
1
0.5
0
p.d.f.
0
100
200
300
400
500
600
700
800
900
1000
Energy, keV
NdCs137
noNdCs137



Nd_8640h
NoNd_1972h
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
p.d.f
0
500
1000
1500
2000
2500
3000
3500
Energy, keV

Подземные лаборатории БНО ИЯИ РАН





Global Intensity

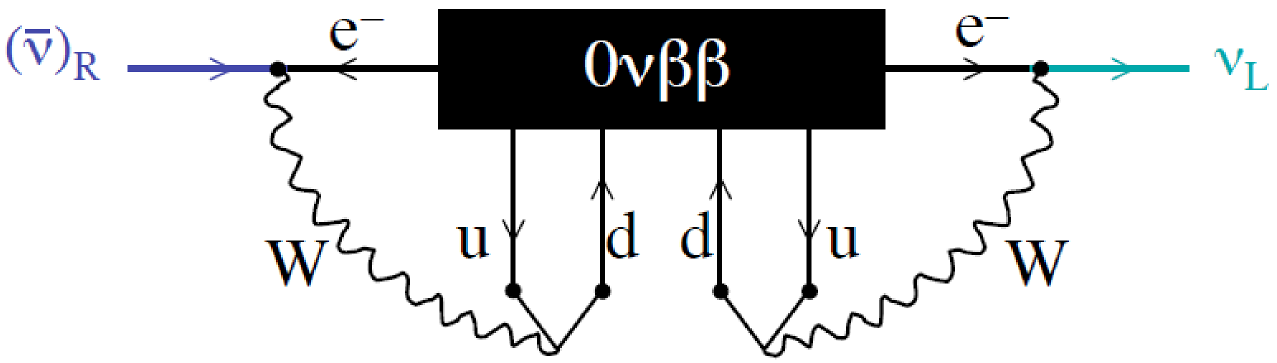
$(3,0\pm0,15)\cdot10^{-9}$ μ $cm^{-2}\cdot s^{-1}$

~ 4800 m.w.e.

0νββ as a "Black Box"

Whatever processes cause 0νββ, i.e. independently of the content of the dd->uuee black box below, its observation would imply the existence of a Majorana mass term:

Schechter and Valle 82

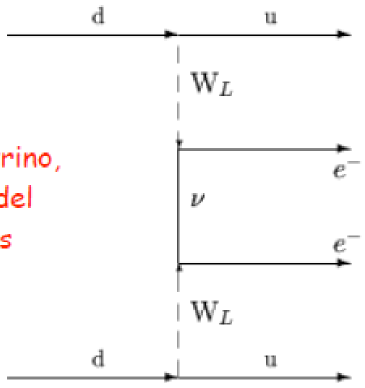


$(\bar{\nu})_R \rightarrow \nu_L$: A Majorana mass term

What is in the black box?

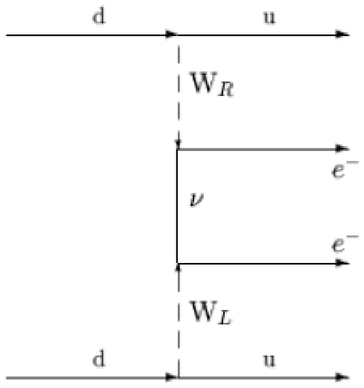
All these diagrams can contribute to the $0\nu\ \beta\beta$ decay

Exchange of a **light** neutrino, only left-handed currents



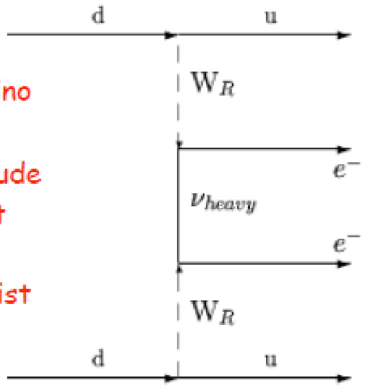
Light Majorana neutrino, only Standard Model weak interactions

Exchange of a light or heavy neutrino and one **right-handed** $\mathbf{W}_R$



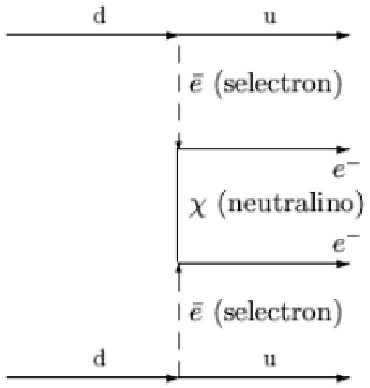
Light or heavy Majorana neutrino. Model extended to include right-handed W_R. Mixing extended between the left and right-handed neutrinos. Light Majorana neutrinos exist also.

Exchange of a **heavy** neutrino, short range hadron physics at play



Heavy Majorana neutrino interacting with W_R. Model extended to include right-handed current interactions. Light Majorana neutrinos exist also.

Exchange of **supersymmetric** particles, R-symmetry violated

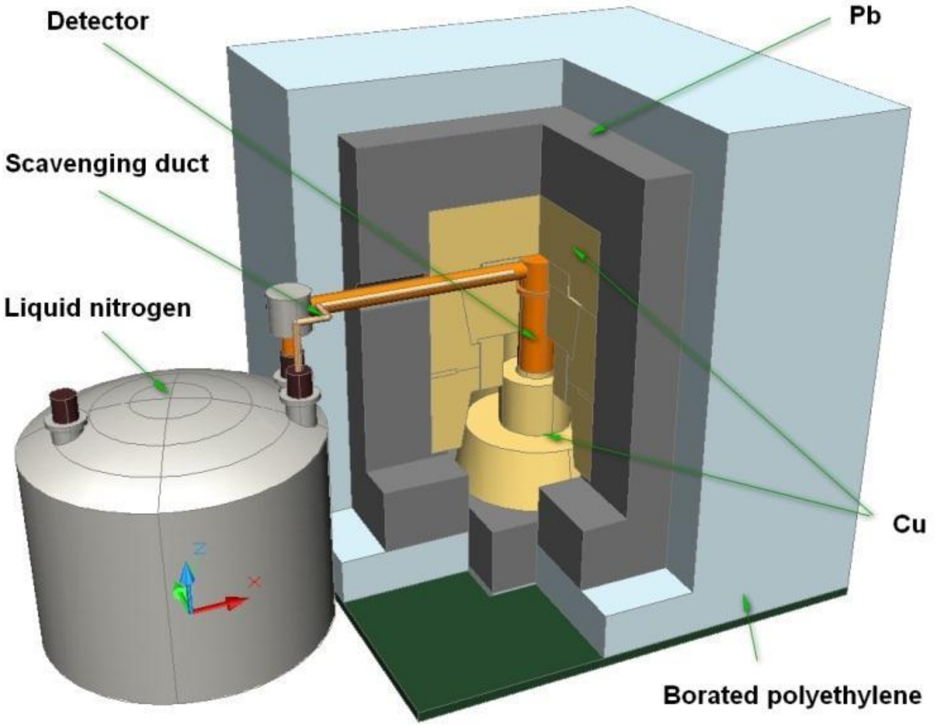


Supersymmetry with R-parity violation. Many new particles invoked. Light Majorana neutrinos exist also.

Ultra-low background gamma-spetrometer «СНЕГ»

Characteristics of HPGe detector

Detector	Ge-76
Type of crystal	Coaxial
Type of semiconductor	P-type
Mass, g	896
External diameter, mm	65
Height, mm	54
The thickness of the dead layer, mm	≈2
The effective mass, g	680
The wall thickness of the cryostat, mm	1
The ratio Peak / Compton (1332 keV)	45.4
The energy resolution, keV (1332 keV)	3.5



Low-background shield is consists of: 80 mm of polyethylene, 1 mm of cadmium (Cd), 150 mm of lead (Pb) and 180 mm of copper (Cu)