Experimental search for double beta decay of Zr-96 to excited states of Mo-96

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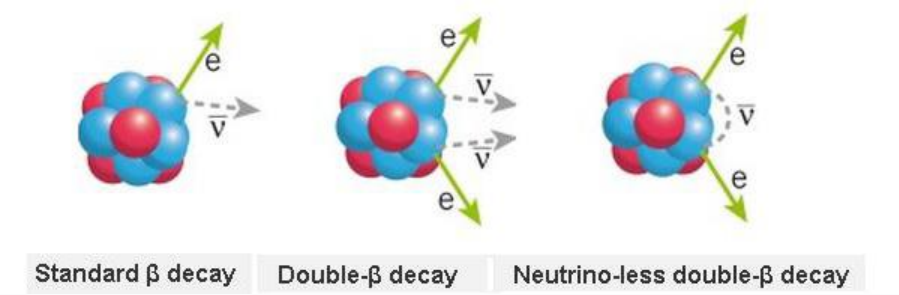
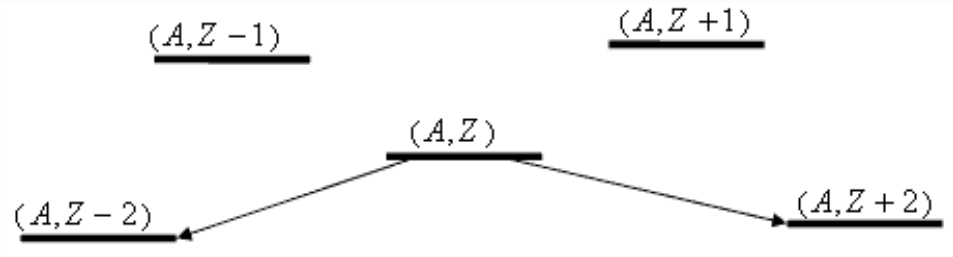
Double beta decay



Different beta decay schemes



Energy conditions for double beta decay

Probability of double beta decay

- Probability can be expressed as the product of the kinematic and nuclear parts:

$$\Gamma^{2\nu} = \frac{1}{T_{\frac{1}{2}}^{2\nu}} = G^{2\nu}\left(Q_{\beta\beta}, Z\right)\left|M^{2\nu}\right|^2$$

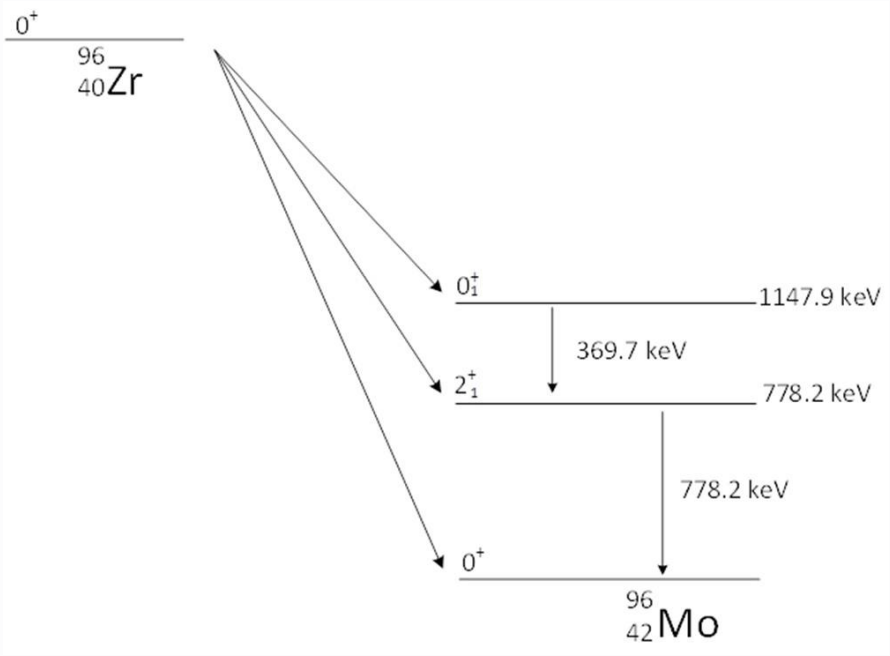
- The probability of a neutrinoless mode, which is forbidden in the SM, can be expressed in a similar form:

$$\Gamma^{0\nu} = \frac{1}{T_{\frac{1}{2}}^{0\nu}} = G^{0\nu}\left(Q_{\beta\beta}, Z\right)\left|M^{0\nu}\right|^2 \langle\eta\rangle^2$$

there: $G^{2\nu}$ and $G^{0\nu}$– phase spaces for standard and neutrinoless modes, proportional to the decay energy and charge number of the decaying isotope

$M^{2\nu}$ and $M^{0\nu}$ – matrix elements

$\langle\eta\rangle$ – parameter characterizing the effective mass of neutrinos



^{96}Zr decay scheme

Previously defined half-lives:

^{100}Mo [1]

$$T_{\frac{1}{2}}(g.s.) = 7.16 \pm 0.01 \cdot 10^{18}\ \text{yr}$$

$$T_{\frac{1}{2}}(0_1^+) = 7.5 \pm 0.6 \cdot 10^{20}\ \text{yr}$$

^{150}Nd [1]

$$T_{\frac{1}{2}}(g.s.) = 9.1 \pm 0.7 \cdot 10^{18}\ \text{yr}$$

$$T_{\frac{1}{2}}(0_1^+) = 7.2 \pm 0.14 \cdot 10^{19}\ \text{yr}$$

^{96}Zr [1,2]

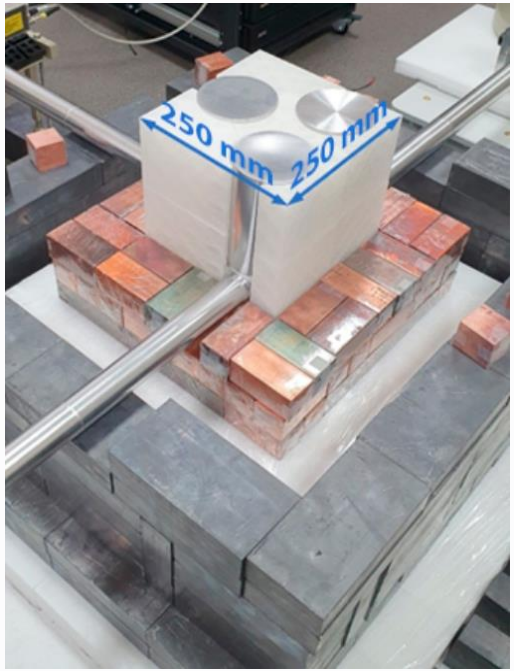
$$T_{\frac{1}{2}}(g.s.) = 2.35 \pm 0.21 \cdot 10^{19}\ \text{yr}$$

$$T_{\frac{1}{2}}(0_1^+) > 3.1 \cdot 10^{20}\ \text{yr}$$

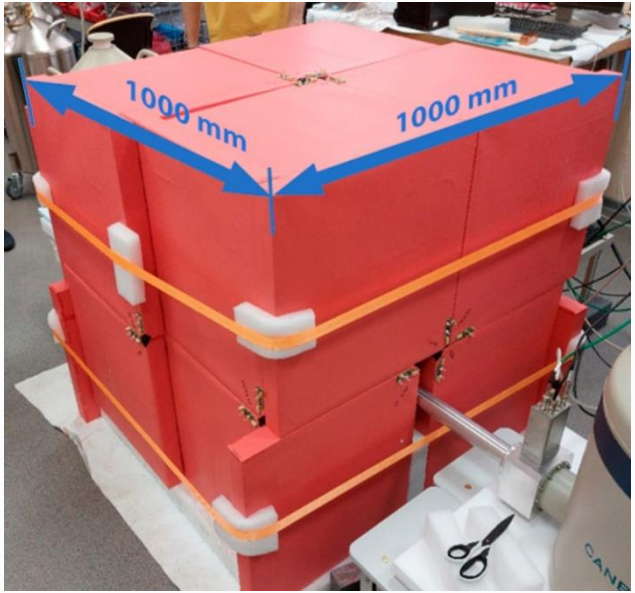
1. Thibaud Le Noblet – Latest results from NEMO-3 and commissioning status of the SuperNEMO demonstrator – TAUP 2017.
2. S. W. Finch and W. Tornow – Search for two-neutrino double-β decay of 96Zr to excited states of 96Mo – PHYSICAL REVIEW C 92, 045501 (2015)

Requirements for the experiment

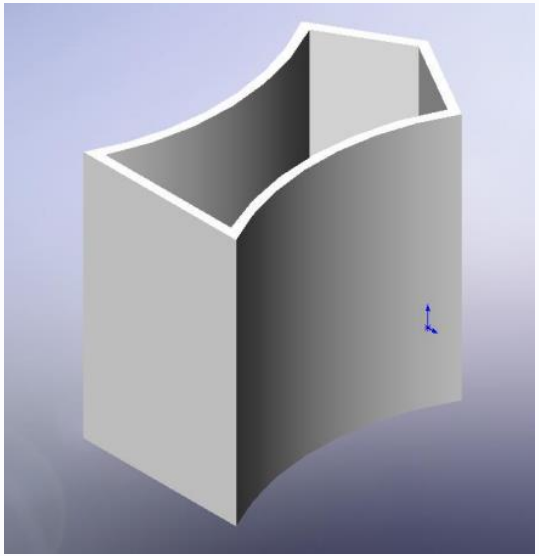
- Zirconium sample that has enough mass (activity) for decay registration
- Absence of radioactive contamination of the test sample
- Low background experimental setup
- A detector with high efficiency and good energy resolution



Detectors and passive shielding



Active shielding



Sample container's scheme

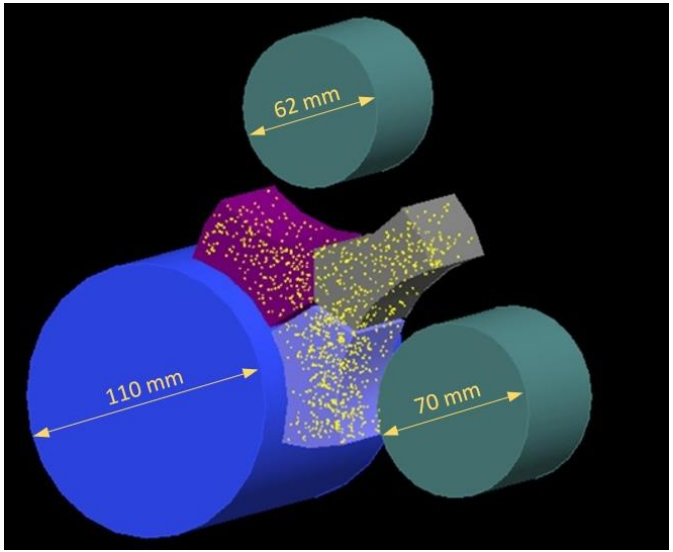
Experimental conditions

- A zirconium sample with a mass of 203.182 g and ^{96}Zr isotope enrichment 88.18% (natural enrichment - 2.81%), supplied by JSC Electrochemical Plant
- High resolution HPGe detectors are used (FWHM=2.9 keV in ROI)
- Members of the collaboration:

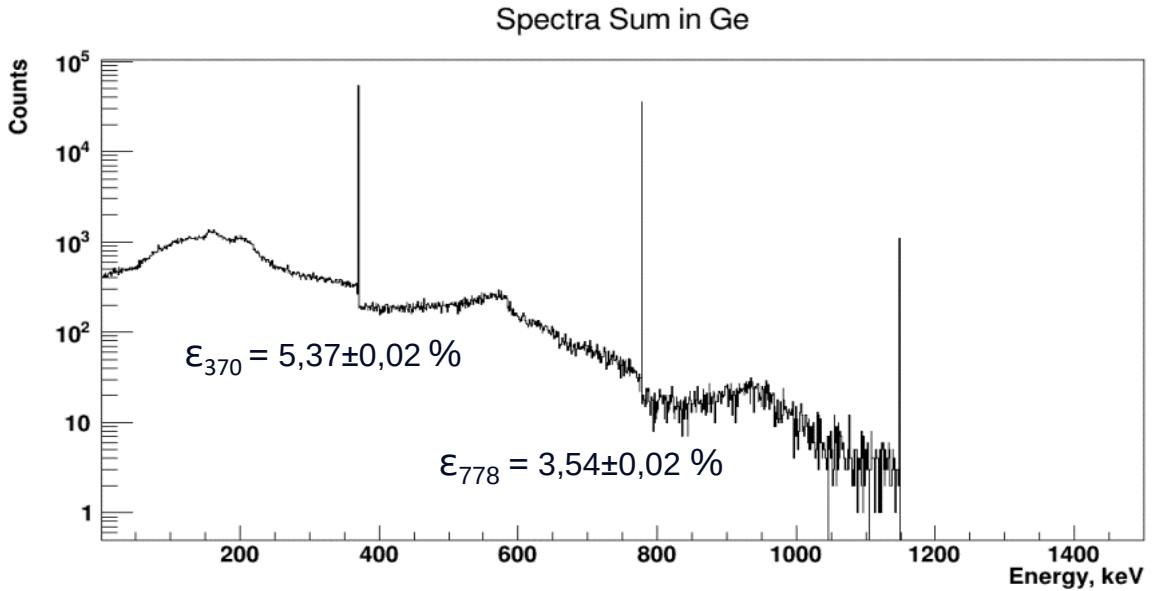
  JINR DLNP

  INR BNO

  Kurchatov Institute ITEP



Setup scheme in Geant4



Setup simulation histogram for 10^6 events

Expected results

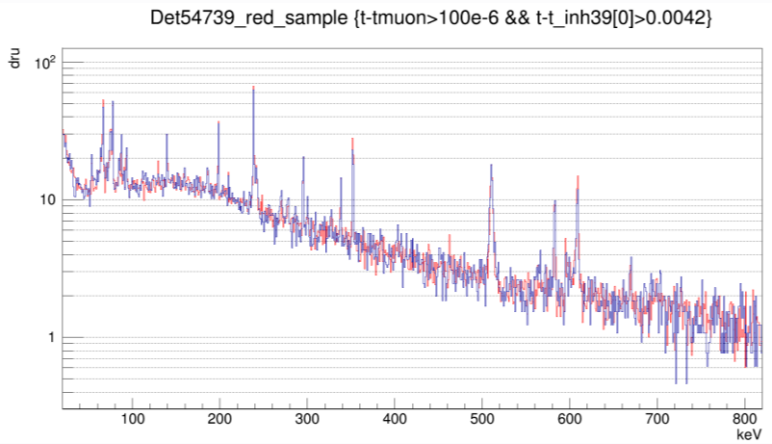
With the following input data:

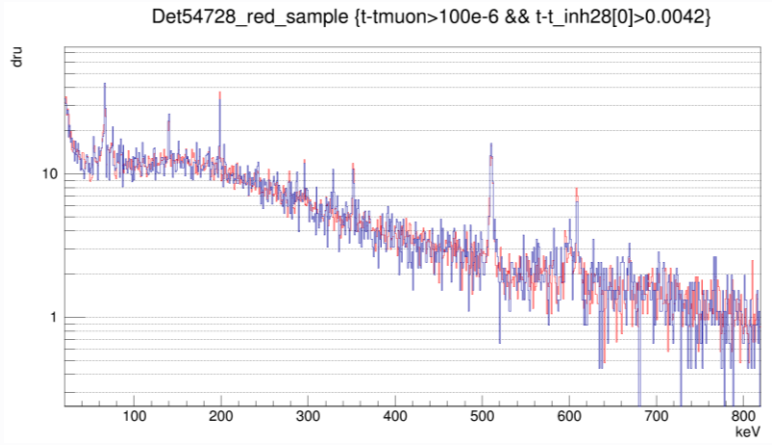
- Pessimistic estimate of expected half-life of 10^{21} years
- Zirconium with a mass 203.182 g
- ^{96}Zr enrichment 88.18 % (isotope mass 179.166 g)

Expectations:

- 2.14 decays per day
- Counts in 370 keV peak – 0.102 per day
- Counts in 778 keV peak – 0.068 per day

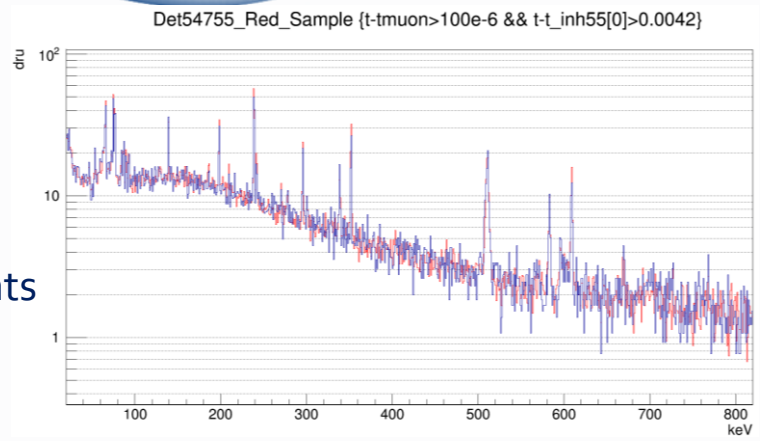
Current results





Background

Sample measurements



Half-life limit set after 10 days measurements in DLNP:

$$T_{\frac{1}{2}}(0_1^+) > 1.19 \cdot 10^{18}\ \text{yr}$$

- Measurements of ^{238}U distributed calibration source for comparison with Monte Carlo
- Setting limits on the thorium content in the sample
- Measurements of zirconium sample in underground laboratory of BNO

Background level in DLNP: 4.94 counts per day in 370 keV peak

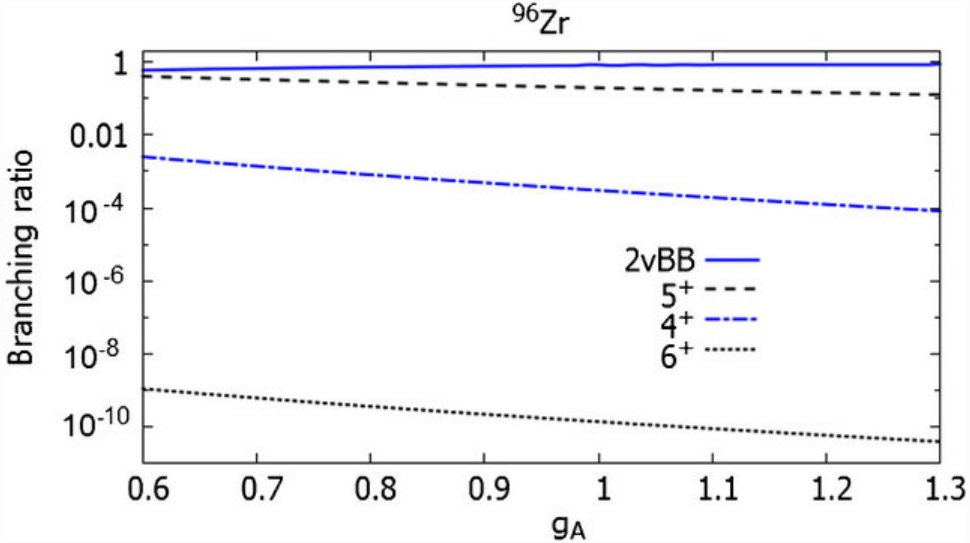
2.21 counts per day in 778 keV peak

Background level in BNO: ~1 count per 50 days

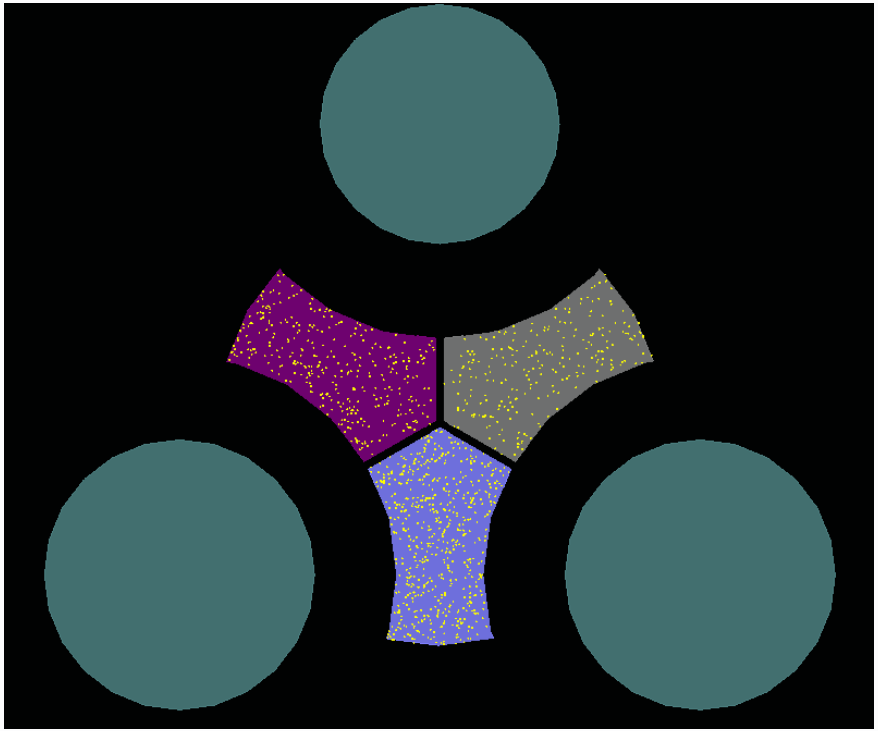
Conclusions

- Experiment is dedicated for the first detection of ^{96}Zr double beta decay to excited states of ^{96}Mo
- It will provide an opportunity to improve the determination of matrix elements of 2β decay
- The obtained results will contribute to expanding of our understanding of the nature of neutrinos

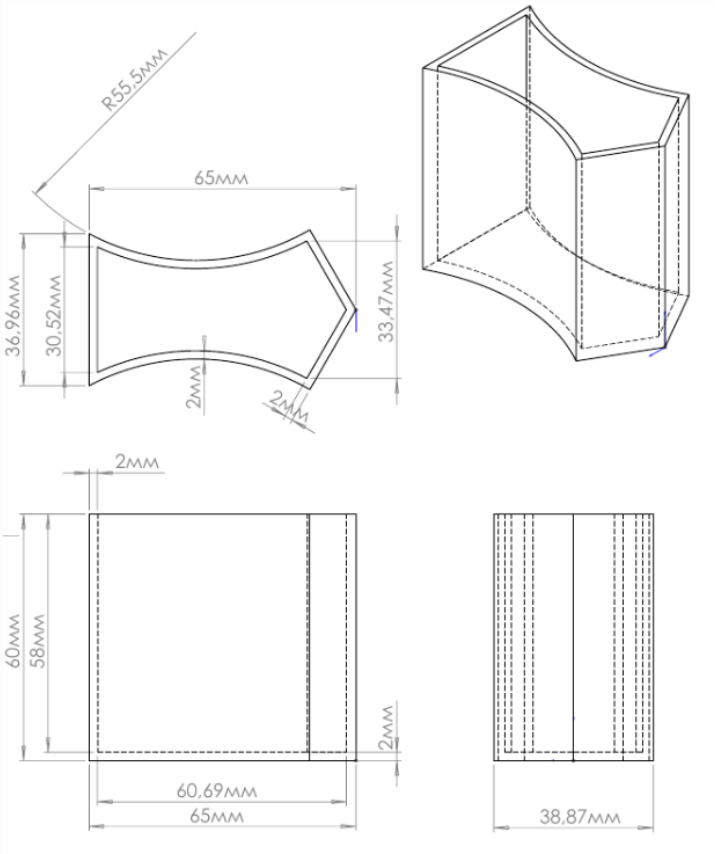
Thank you for attention!



Probabilities of different ^{96}Zr decay modes



Top view of setup
geometry in Geant4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