Investigation of 2β decay of ^{150}Nd to the first 0^+ excited level of ^{150}Sm with the help of HPGe γ-spectrometry

D.V. Kasperovych[1], A.S. Barabash[2], P. Belli[3,4], R. Bernabei[3,4], R.S. Boiko[1,5], F. Cappella[6], V. Caracciolo[7], R. Cerulli[3,4], F.A. Danevich[1], A. Di Marco[3,4], A. Incicchitti[6,8], R.V. Kobychev[1], V.V. Kobychev[1], S.I. Konovalov[2], M. Laubenstein[7], D.V. Poda[1,9], O.G. Polischuk[1], V.I. Tretyak[1], V.I. Umatov[2]

[1] Institute for Nuclear Research, 03028 Kyiv, Ukraine

[2] National Research Centre Kurchatov Institute, Institute of Theoretical and Experimental Physics, 117218, Moscow, Russia

[3] INFN, sezione di Roma "Tor Vergata", I-00133, Rome, Italy

[4] Dipartimento di Fisica, Università di Roma "Tor Vergata", I-00133, Rome, Italy

[5] National University of Life and Environmental Sciences of Ukraine, 03041 Kyiv, Ukraine

[6] INFN, sezione di Roma, I-00185 Rome, Italy

[7] INFN, Laboratori Nazionali del Gran Sasso, I-67100 Assergi (AQ), Italy

[8] Dipartimento di Fisica, Universita di Roma "La Sapienza", I-00185 Rome, Italy

[9] CSNSM, Université Paris-Sud, CNRS/IN2P3, Université Paris-Saclay, 91405 Orsay, France

2β processes

β decay: $(A,Z) \rightarrow (A,Z+1) + e^- + \tilde{\nu}_e$

Two neutrino (2ν) double β decay: $(A,Z) \rightarrow (A,Z+2) + 2e^- + 2\tilde{\nu}_e$

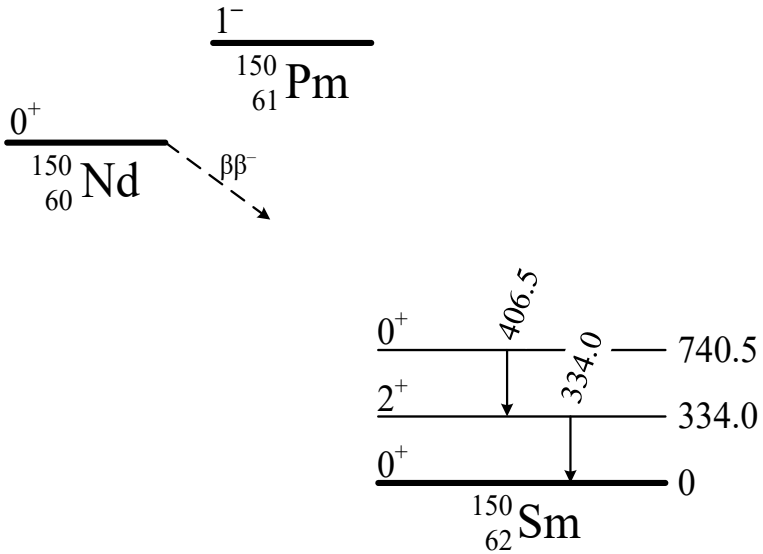
Neutrinoless (0ν) double β decay: $(A,Z) \rightarrow (A,Z+2) + 2e^-$

2ν2β – allowed in SM (observed for 11 isotopes with $T_{1/2} \simeq 10^{18} – 10^{24}$ y)

0ν2β – forbidden in SM (due to lepton number violation $\Delta L=2$; $T_{1/2} \geq 10^{23} – 10^{26}$ y; predicted by many SM extensions).

Observation of 0ν2β decay allows to test the nature of neutrino, the lepton number violation, an absolute scale of neutrino mass and neutrino mass hierarchy.

2β decay of ^{150}Nd



Decay scheme of ^{150}Nd

^{150}Nd is one of the most prospective isotopes for 2β experiments:

- High energy release

  $Q_{2\beta}$ = 3371.38(20) keV [1];

- Reasonably high natural isotopic abundance

  δ = 5.638(28)% [2];

- 2β decay to the excited states of ^{150}Sm can be investigated with high energy resolution (HP Ge γ-spectrometry).

[1] V.S. Kolhinen et al., Phys. Rev. C 82 (2010) 022501.

[2] J. Meija et al., Pure Appl. Chem. 88 (2016) 293.

Experimental results for $^{150}Nd \rightarrow {}^{150}Sm$ (0^+, 740.5 keV)

Short description	$T_{1/2}$, × 10^{19} yr	Year
Modane underground laboratory (4800 m w.e.), HP Ge 400 cm^3, 3046 g of Nd_2O_3 (δ = 5.638%), 11321 h, 1-d spectrum	14^{+5}_{-4}	2004 [1]
Re-estimation of the result [1]	$13.3^{+4.5}_{-2.6}$	2009 [2]
Modane underground laboratory (4800 m w.e.), NEMO-3 detector, foil with 57.2 g of $^{150}Nd_2O_3$ (δ = 91.0%), 40774 h, energies of e^- and γ, tracks for e^- (preliminary result)	7.1 ± 1.6	2013 [3]
Kimballton Underground Research Facility, 2 HP Ge (~304 cm^3 each), 50 g $^{150}Nd_2O_3$ (δ = 93.6%), 15427 h, coincidence spectrum	$10.7^{+4.6}_{-2.6}$	2014 [4]

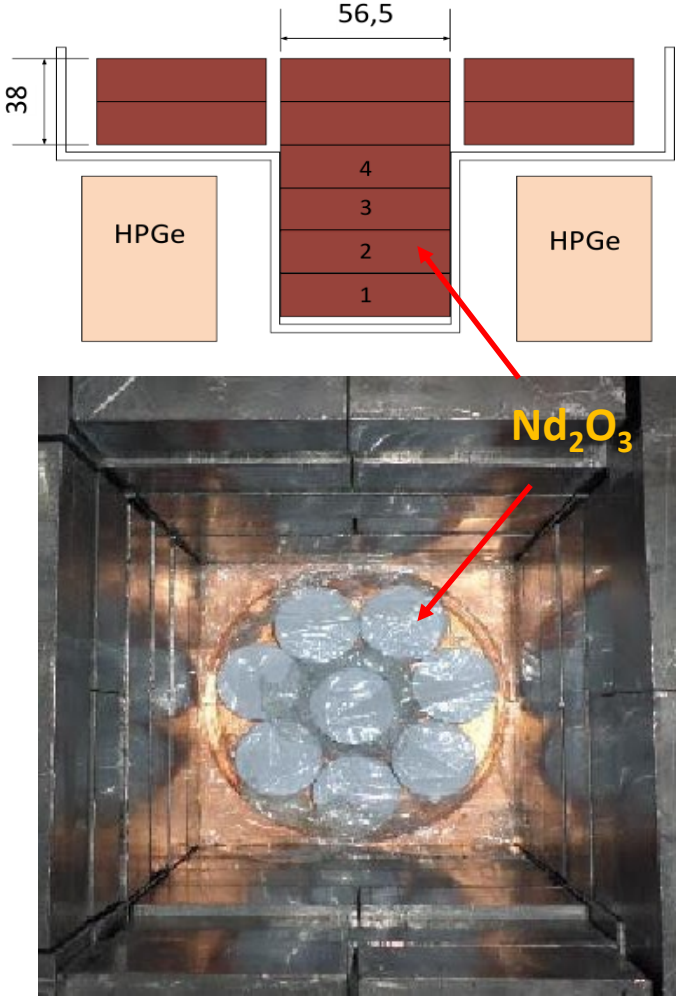
[1] A.S. Barabash et al., Phys. Atom. Nucl. 67 (2004) 1216.

[2] A.S. Barabash et al., Phys. Rev. C 79 (2009) 045501.

[3] S. Blondel, PhD thesis, LAL, Orsay, France, LAL 13-154 (2013).

[4] M.F. Kidd et al., Phys. Rev. C 90 (2014) 055501.

Experiment in Gran Sasso Underground Laboratory (~3600 m w.e.)

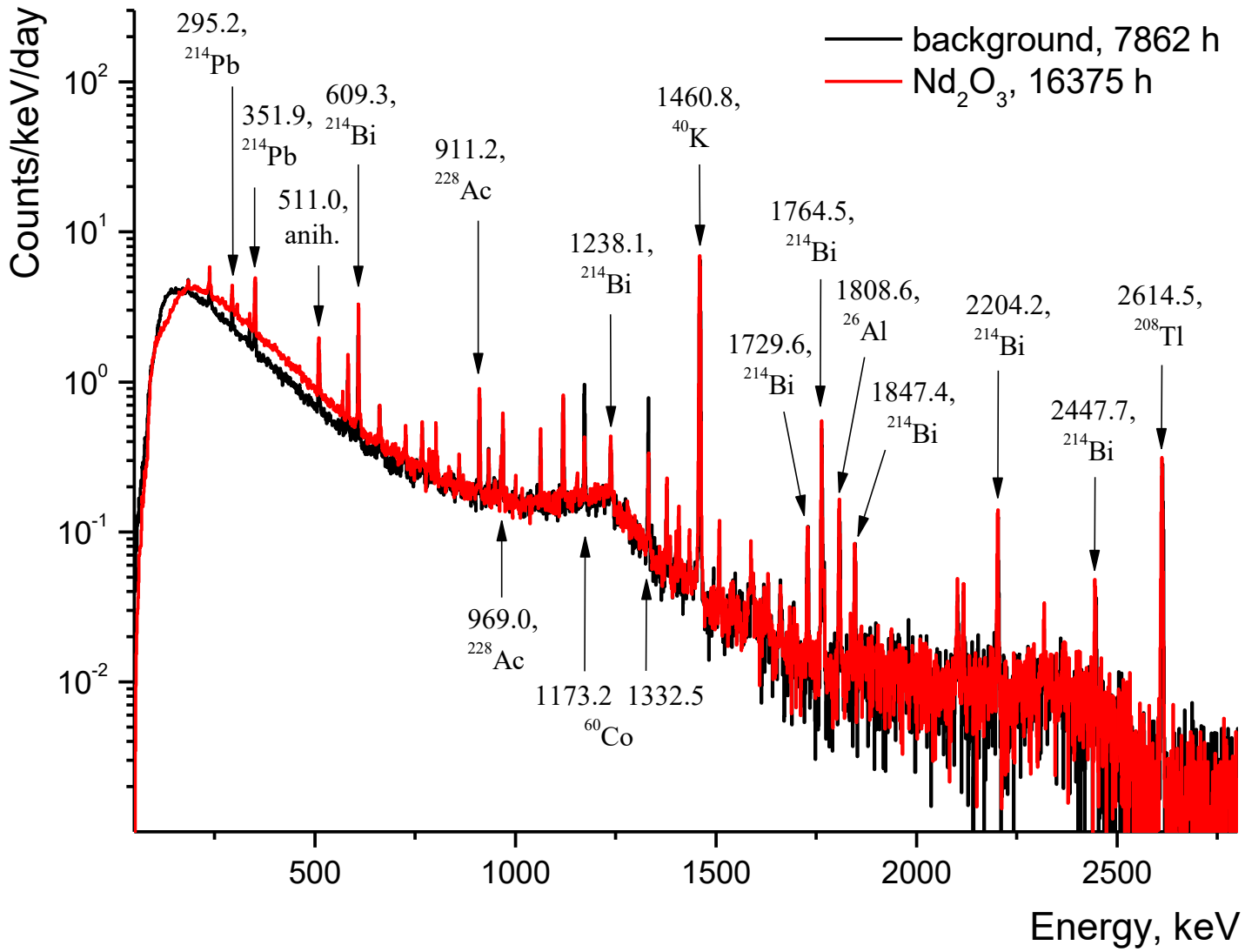


- 4 HP Ge detectors (≃225 cm^3 each) in a cryostat with cylindric well in the center
- Shielded by copper (10 cm), lead (20 cm)
- Plexiglas container flushed with high-purity nitrogen gas (to remove radon)
- 2.381-kg highly purified Nd_2O_3 sample
- 16375 h of measurement

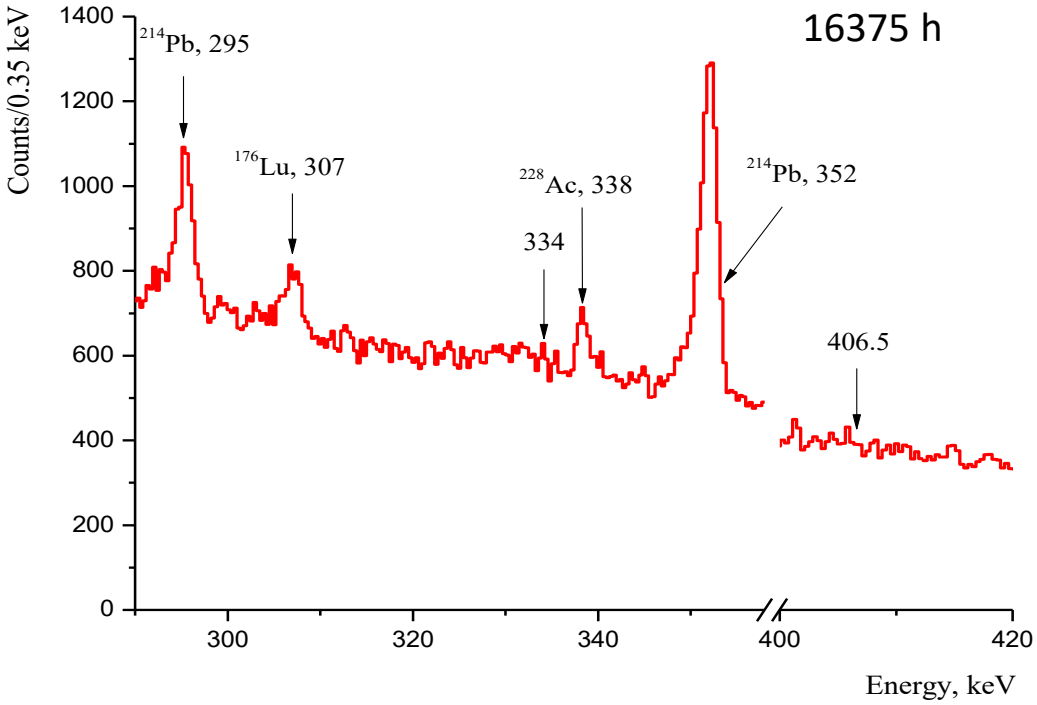
Energy resolution of the HP Ge detectors

No. of detector	FWHM, keV (1333 keV, ^{60}Co)
1	2.36(2)
2	2.01(2)
3	2.06(2)
4	4.01(4)

Energy spectra



Spectrum of single events



$$T_{1/2} = \frac{\ln 2 * N * \varepsilon * t}{S},$$

S is a peak area;

ε = is a full absorption γ peak detection efficiency (2.24% and 2.42% for 334 and 406.5 keV, respectively);

t = 16375 h – time of measurement;

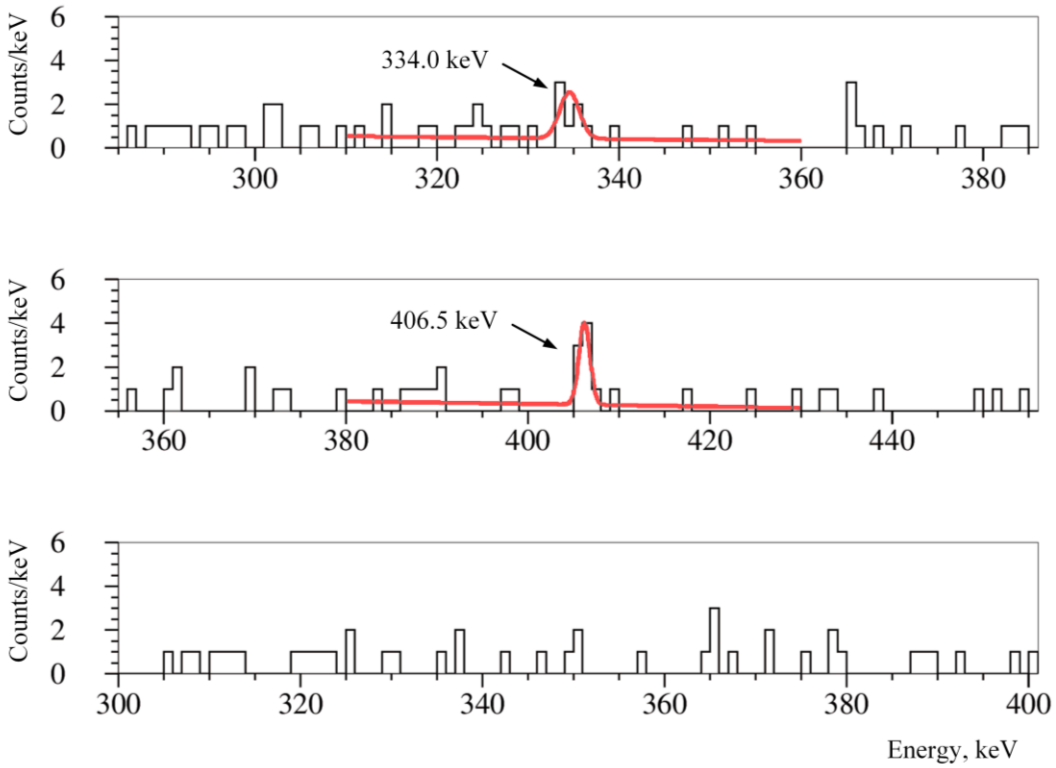
N = 4.8 × 10^{23} – number of ^{150}Nd nuclei in the sample.

334 keV and 406.5 keV γ peaks are not observed. It provides only lower limits on $T_{1/2}$ (90% C.L.):

5.6×10^{19} y (334 keV)

7.9×10^{19} y (406.5 keV)

Analysis of coincidence spectra

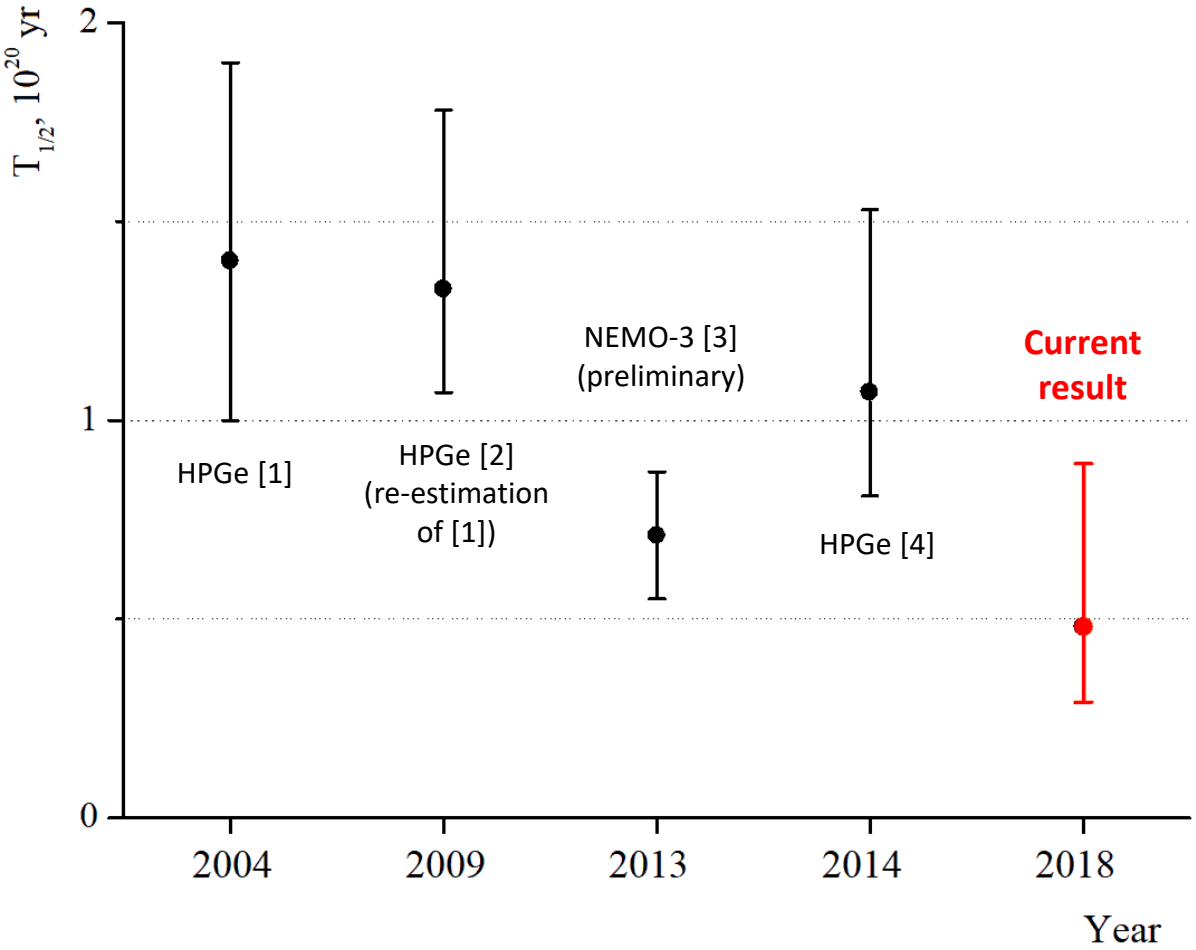


334 keV and 406.5 keV gammas in cascade, expected in the decay ^{150}Nd → ^{150}Sm (0_1^+), are observed in the spectra of coincidences.

$$S = 5.7^{+3.8}_{-2.6}$$

$$T_{1/2} = (4.7^{+4.1}_{-1.9}(stat.) \pm 0.5(syst.)) \times 10^{19}\ \text{y}$$

Comparison with previous results



[1] A.S. Barabash et al., Phys. Atom. Nucl. 67 (2004) 1216.
[2] A.S. Barabash et al., Phys. Rev. C 79 (2009) 045501.
[3] S. Blondel, PhD thesis, LAL, Orsay, France, LAL 13-154 (2013).
[4] M.F. Kidd et al., Phys. Rev. C 90 (2014) 055501.

Conclusions

- The 2β decay of ^{150}Nd to the first 0^+ excited state of ^{150}Sm was measured by using 4-detector low-background HPGe γ-spectrometer GeMulti at the Gran Sasso underground laboratory.
- The ^{150}Nd→^{150}Sm (0_1^+, 740.5 keV) process have not been observed in the 1-dimensional background spectrum over 16375 h with the 2.381-kg Nd_2O_3 sample due to a rather high background counting rate.
- The spectrum of coincidences of different pairs of the detectors have been investigated. The area of the effect has been obtained as $5.7^{+3.8}_{-2.6}$ counts. The half-life of ^{150}Nd relatively to the 2β decay to the 0_1^+ state of the daughter nucleus is

$$T_{1/2} = (4.7^{+4.1}_{-1.9}(\text{stat.}) \pm 0.5(\text{syst.})) \times 10^{19} \text{ y}$$

The $T_{1/2}$ is in agreement with the previous experimental results. Experiment is in progress to improve the half-life value accuracy.