Investigation of 2β decays of ^{184,192}Os

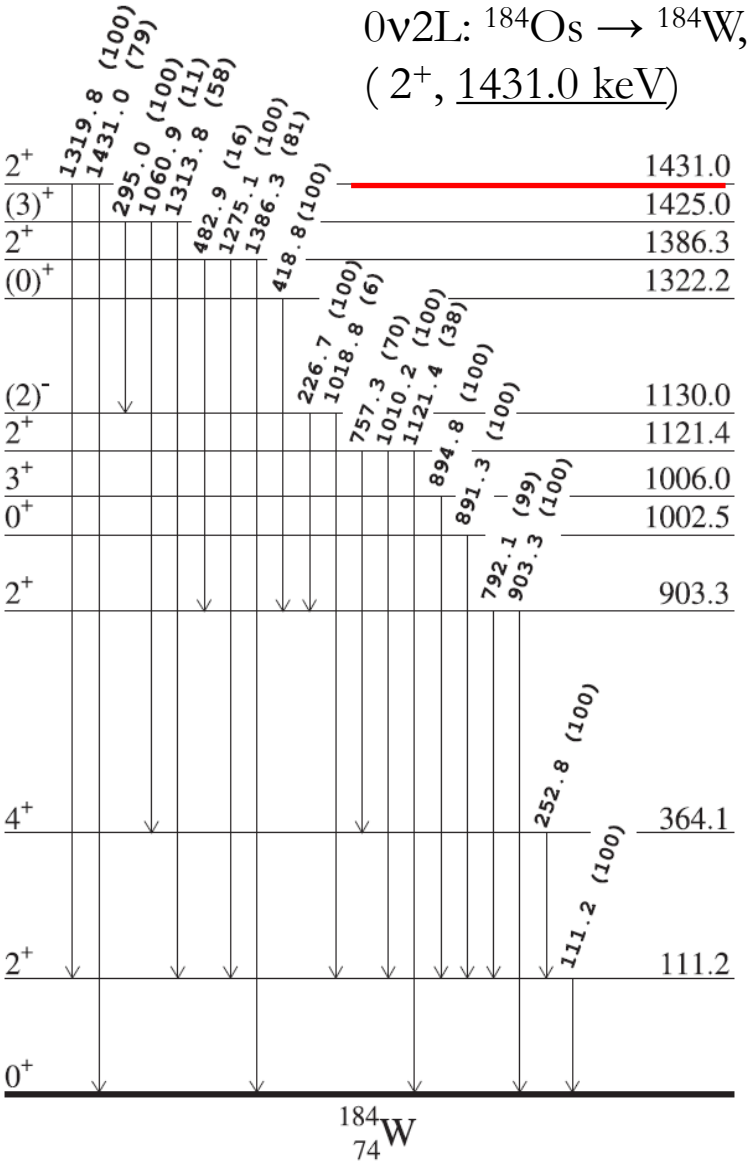
O.G. Polischuk[1,2], P. Belli[3,4], R. Bernabei[3,4], F. Cappella[2,5], R. Cerulli[3,4], F. A. Danevich[1,3], Incicchitti[2,5], D. V. Kasperovych[1], V. V. Kobychev[1], G. P. Kovtun[6,7,†], N. G. Kovtun[6], A. Leoncini[3,4], M. Laubenstein[8], V. Merlo[3,4], D. V. Poda[9], A. P. Shcherban[6], S.Tessalina[10] and V. I. Tretyak[1,8]

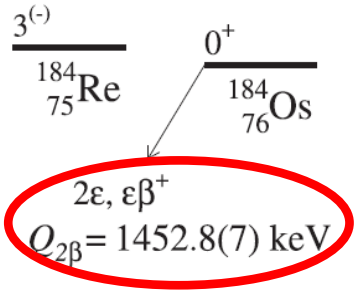
[1]Institute for Nuclear Research of NAS of Ukraine, Kyiv, Ukraine
[2] INFN, sezione di Roma, Rome, Italy
[3] INFN, sezione di Roma "Tor Vergata", Rome, Italy
[4] Dipartimento di Fisica, Università di Roma "Tor Vergata", Rome, Italy
[5] Dipartimento di Fisica, Università di Roma 'La Sapienza', Rome, Italy
[6] National Science Center 'Kharkiv Institute of Physics and Technology', Kharkiv, Ukraine
[7] V.N. Karazin Kharkiv National University, Kharkiv, Ukraine
[8] INFN, Laboratori Nazionali del Gran Sasso, Assergi (AQ), Italy
[9] Université Paris-Saclay, CNRS/IN2P3, IJCLab, Orsay, France
[10] John de Laeter Centre for Isotope Research, Curtin University, Bentley, WA, Australia

† Deceased

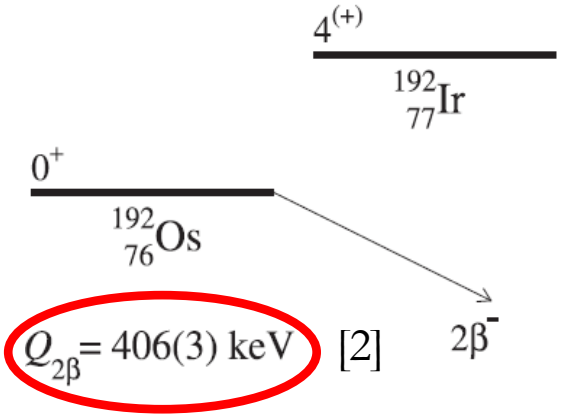
2β decay of osmium

The resonant 0ν2ε:
0ν2L: $^{184}Os \rightarrow {}^{184}W$,
(2^+, 1431.0 keV)





[1]



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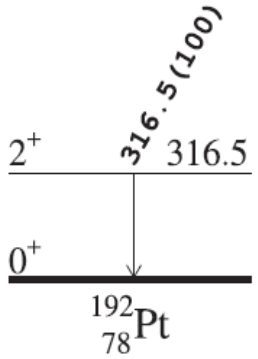


Isotope	*Q*, keV	Isotop. abundance, %	Transition
^{184}Os	1452.9(7)	0.0170(7)*	2ε, εβ+
^{192}Os	406(3)	40.86(5)*	2β-

[1] C.M.Baglin 2010 Nuclear data sheets for *A* = 184 *Nucl. Data Sheets* **111** 275
[2] C.M.Baglin 2012 Nuclear data sheets for *A* = 192 *Nucl. Data Sheets* **113** 1871

*P. Belli et al., PRC **102**, 024605 (2020)

Os isotopes

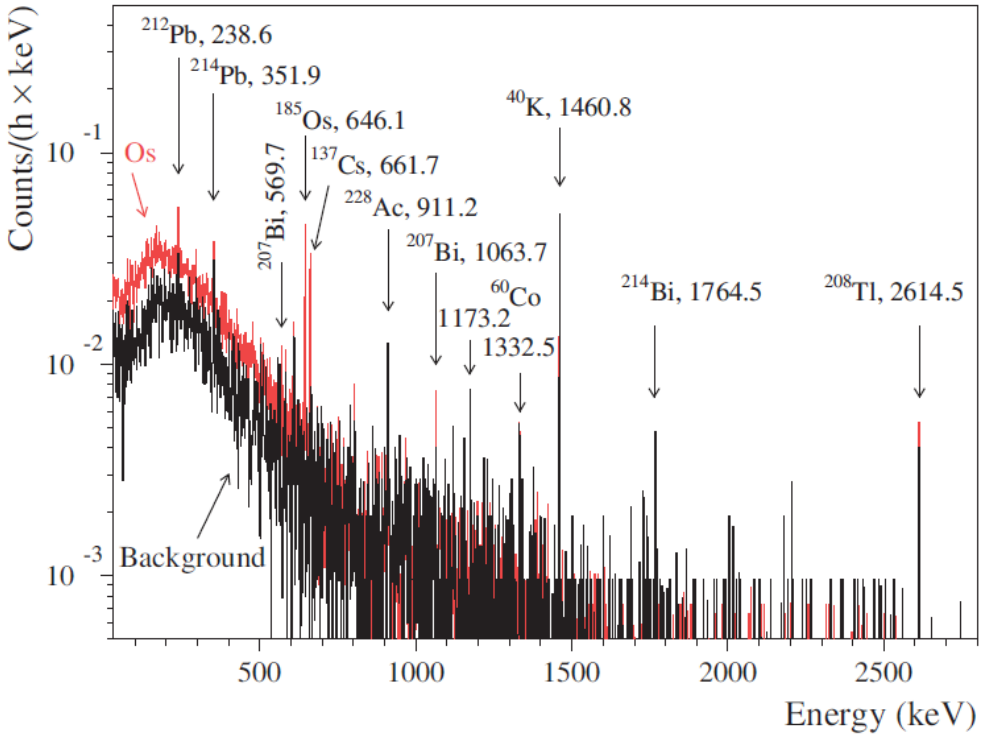
Isotope	δ (%) IUPAC [1]	This work
^{184}Os	0.02(2)	0.0170(7)
^{186}Os	1.59(64)	1.5908(6)
^{187}Os	1.96(17)	1.8794(6)
^{188}Os	13.24(27)	13.253(3)
^{189}Os	16.15(23)	16.152(4)
^{190}Os	26.26(20)	26.250(8)
^{192}Os	40.78(32)	40.86(5)

The Os isotopic composition was analyzed at the John de Laeter Centre at Curtin University (Perth, Western Australia) with high precision using negative thermal ionization mass spectrometry*.

[1] J. Meija *et al.*, Isotopic compositions of the elements 2013 (IUPAC Technical Report), Pure Appl. Chem. **88**, 293 (2016).
*P. Belli et al., PRC **102**, 024605 (2020)

The Os sample and experimental set-up (1st configuration)

The experiment has been realized with the help of an ultra-low background **HPGe** detector (465 cm^3) and an ultrapure osmium sample (**173 g**, 99.999% purity) at the Gran Sasso National Laboratory of the INFN (Italy).
The detector was shielded by copper (≈ 10 cm) and lead (≈ 25 cm).



Energy spectra measured with the ultralow background HPGe γ spectrometer with the osmium sample over 2741 h (Os) and without the sample over 1046 h (Background).

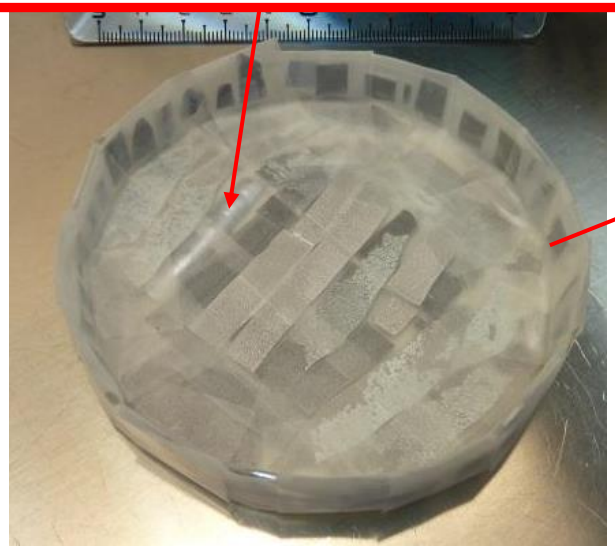
2β processes in ^{184}Os have been limited at the level of lim$T_{1/2}$~ 10^{14} – 10^{17}yr.
Possible resonant double-electron captures in ^{184}Os were searched for with a sensitivity of $T_{1/2}$~10^{16} yr.
A half-life limit $T_{1/2} \geq 5.3\times10^{19}$ yr (90% C.L.) was set for the 2β decay of ^{192}Os to the first excited level of ^{192}Pt.

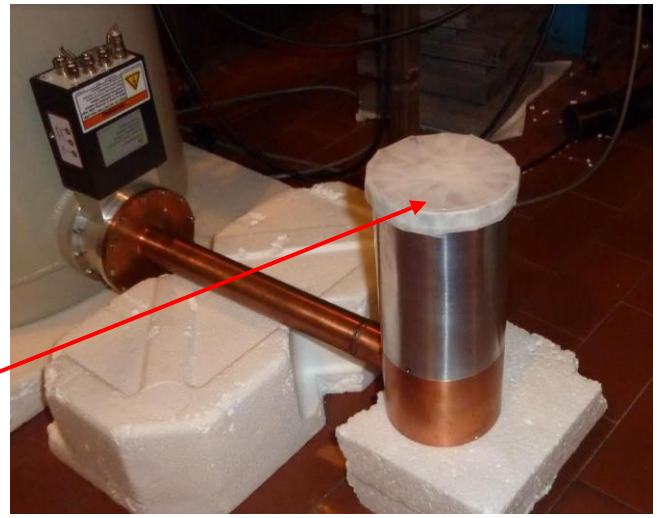
P. Belli et al., Eur. Phys. J. A (2013) 49: 24

The Os sample and experimental set-up (2nd configuration)

The experiment has been realized with the help of an ultra-low background broad-energy germanium detector (**112 cm^3**) and a thin **osmium sample (118 g)** at the **Gran Sasso National Laboratory of the INFN (Italy)**.

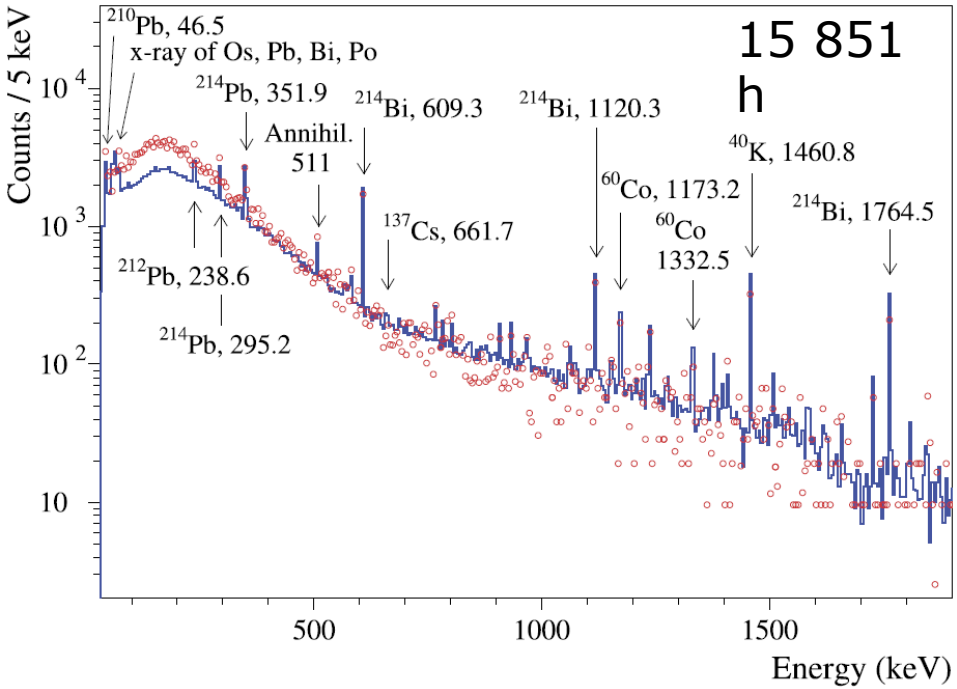
The ingots were cut into thin slices with a thickness of (0.79–1.25) mm by electroerosioncutting with a brass wire in kerosene.





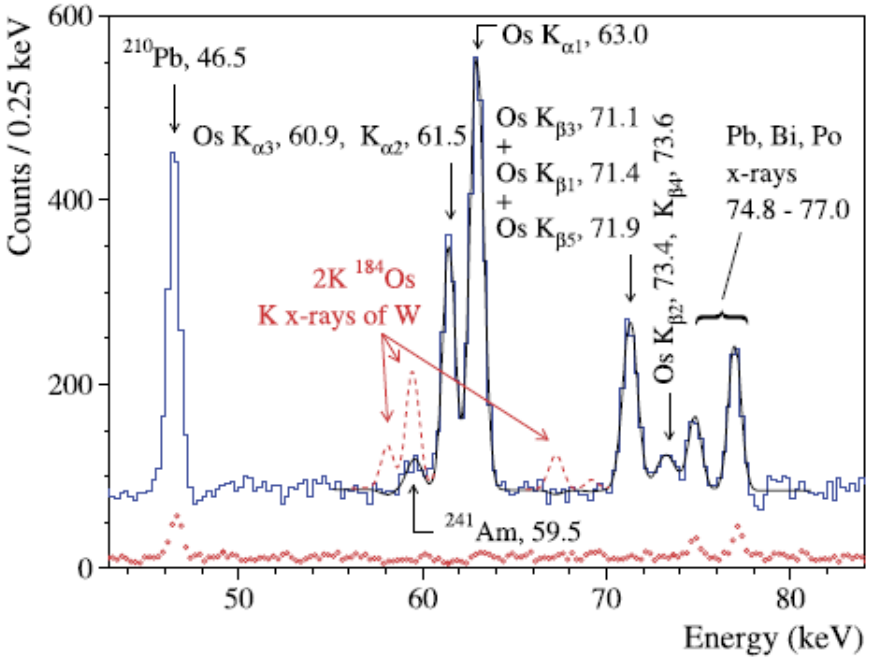
P. Belli et al., PRC **102**, 024605 (2020)
P. Belli et al., J. Phys. G: Nucl. Part. Phys. **48,** 085104(2021)

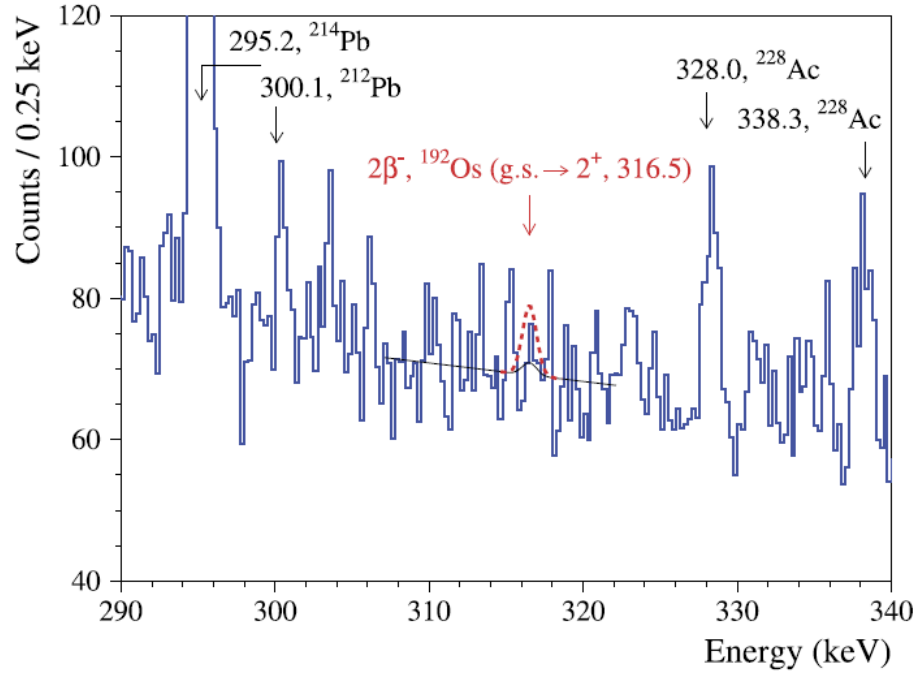
Radioactive trace impurities in the Os sample



Decay chain	Radionuclide	Specific activity (mBq/kg)
	^{40}K	11 ± 4
	^{60}Co	$\leqslant 1.3$
	^{137}Cs	0.5 ± 0.1
	^{241}Am	$\leqslant 5.6$
^{232}Th	^{228}Ra	$\leqslant 6.6$
	^{228}Th	$\leqslant 16$
^{235}U	^{235}U	$\leqslant 8.0$
	^{231}Pa	$\leqslant 3.5$
	^{227}Ac	$\leqslant 1.1$
^{238}U	^{238}U	$\leqslant 35$
	^{226}Ra	$\leqslant 4.4$
	^{210}Pb	$\leqslant 180$

Results of the 2nd stage of the experiment



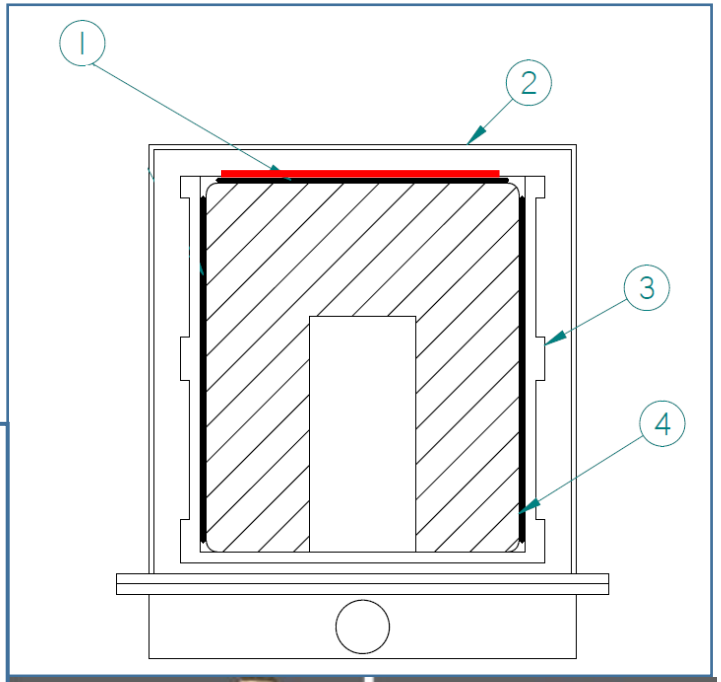


After **15851 h** of data taking new limits on 2EC and electron capture with positron emission in ^{184}Os were set at the level of **lim $T_{1/2} \sim 10^{16}$–10^{17} yr**.
In particular, the 2ν2K and 2νKL decays of ^{184}Os to the ground state of ^{184}W are restricted as **$T_{1/2} > 3.0 \times 10^{16}$ yr** and **$T_{1/2} > 2.0 \times 10^{16}$ yr**, respectively.

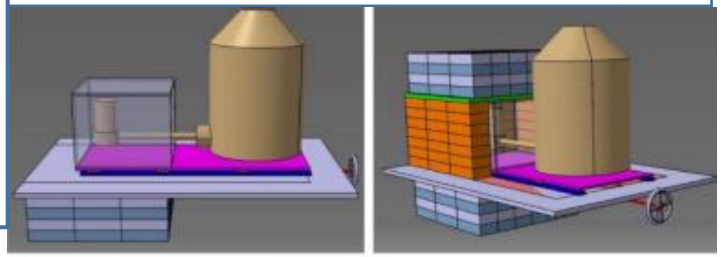
A lower limit on $T_{1/2}$ for the 2β decay of ^{192}Os to the first excited level of ^{192}Pt was set as lim **$T_{1/2} = 2.0 \times 10^{20}$ yr** at 90% C.L.

New configuration of the experiment with Os

The main part of the osmium slices before assembling on a plastic support



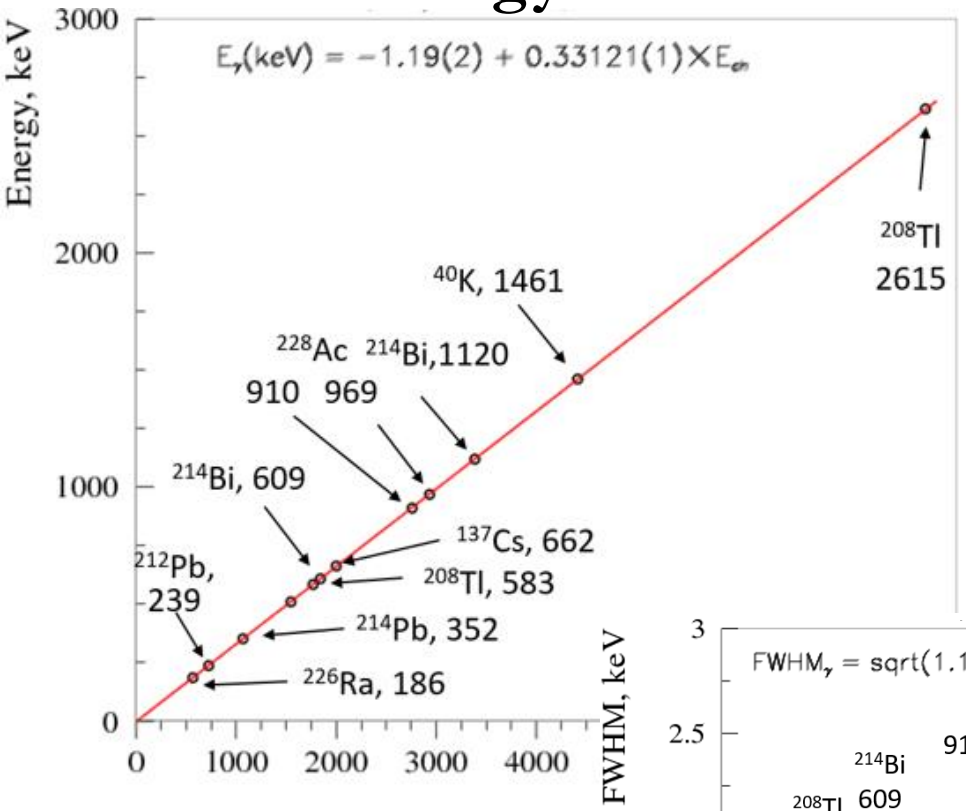
A sample of Os (1) in form of slices is located on the top of the Ge crystal (4); (2) detector end cap; (3) crystal holder.

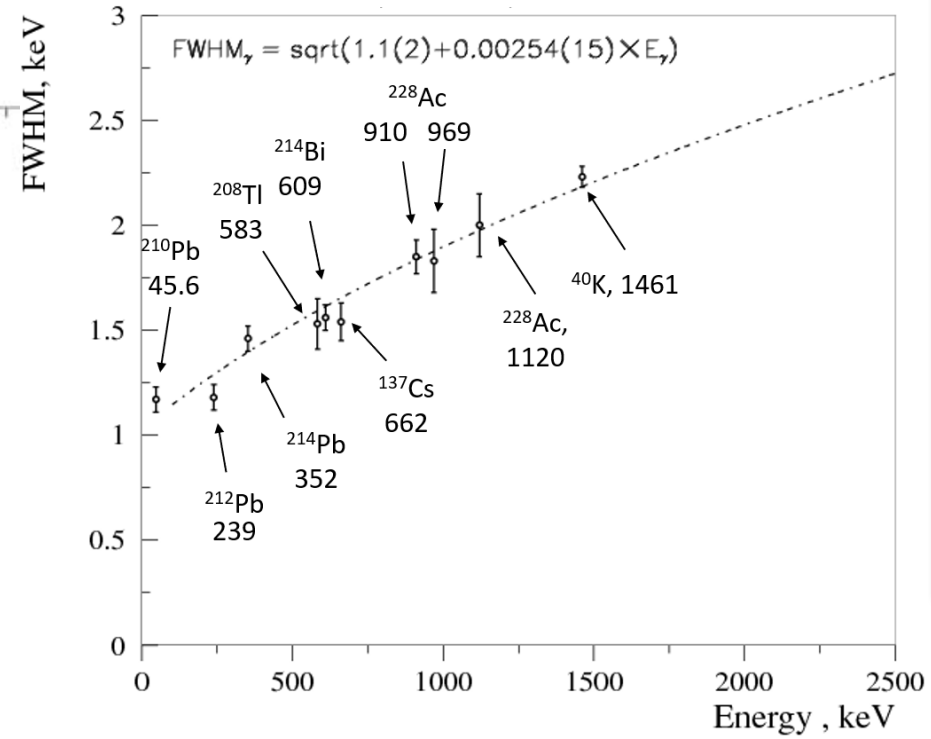


Osmium metal pieces **(58.78 g)** glued to a plate mounted directly on Ge crystal of the detector at LNGS to improve the detection efficiency to low energy gamma-ray quanta.

$t_{measur.}$ = **23840 h**

Energy calibration and energy resolution

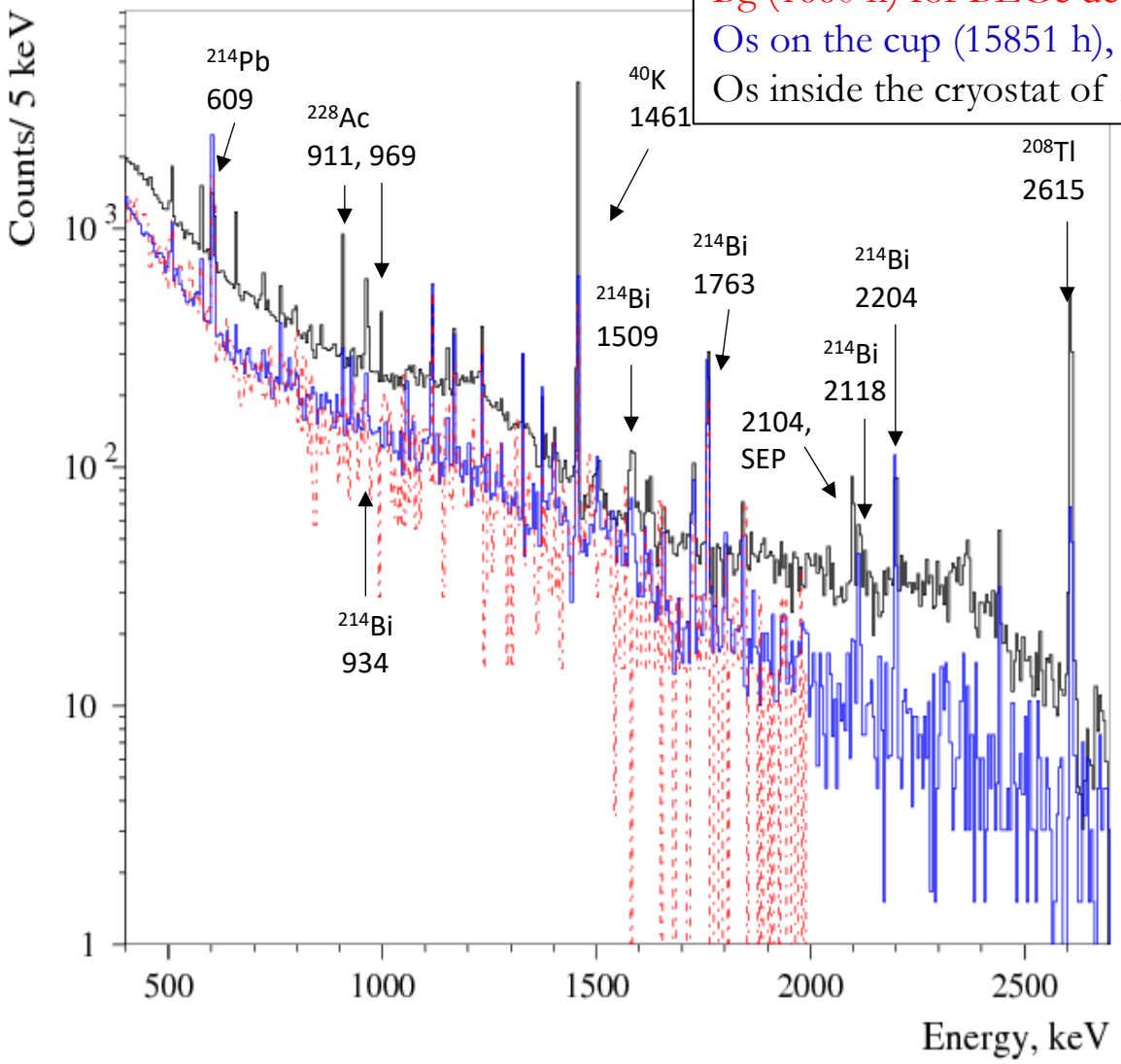


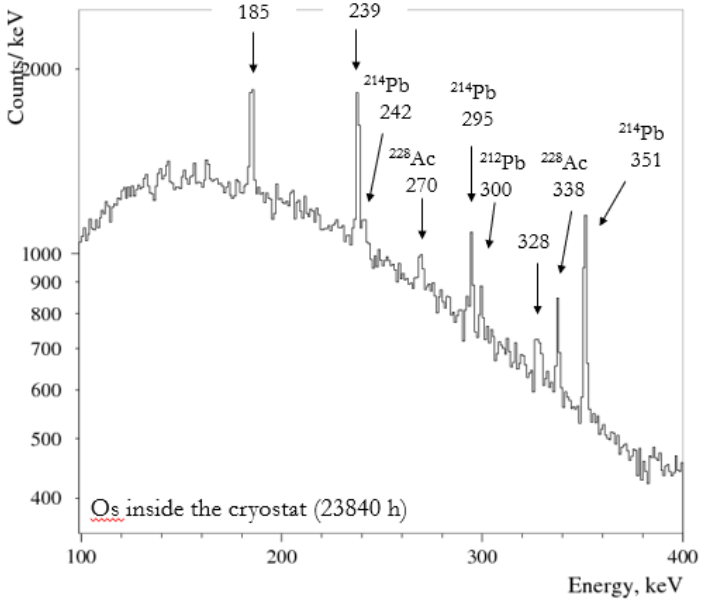


Isotope	E_γ, кеВ
^{226}Ra	186.2
^{212}Pb	238.6
^{214}Pb	351.9
^{208}Tl	583.2
^{214}Bi	609.3
^{137}Cs	661.7
^{228}Ac	910.3
^{228}Ac	969.0
^{214}Bi	1120.3
^{40}K	1460.8
^{208}Tl	2614.5

Energy spectrum with Os on the cup of the BEGe detector and inside the cryostat of HPGe detector

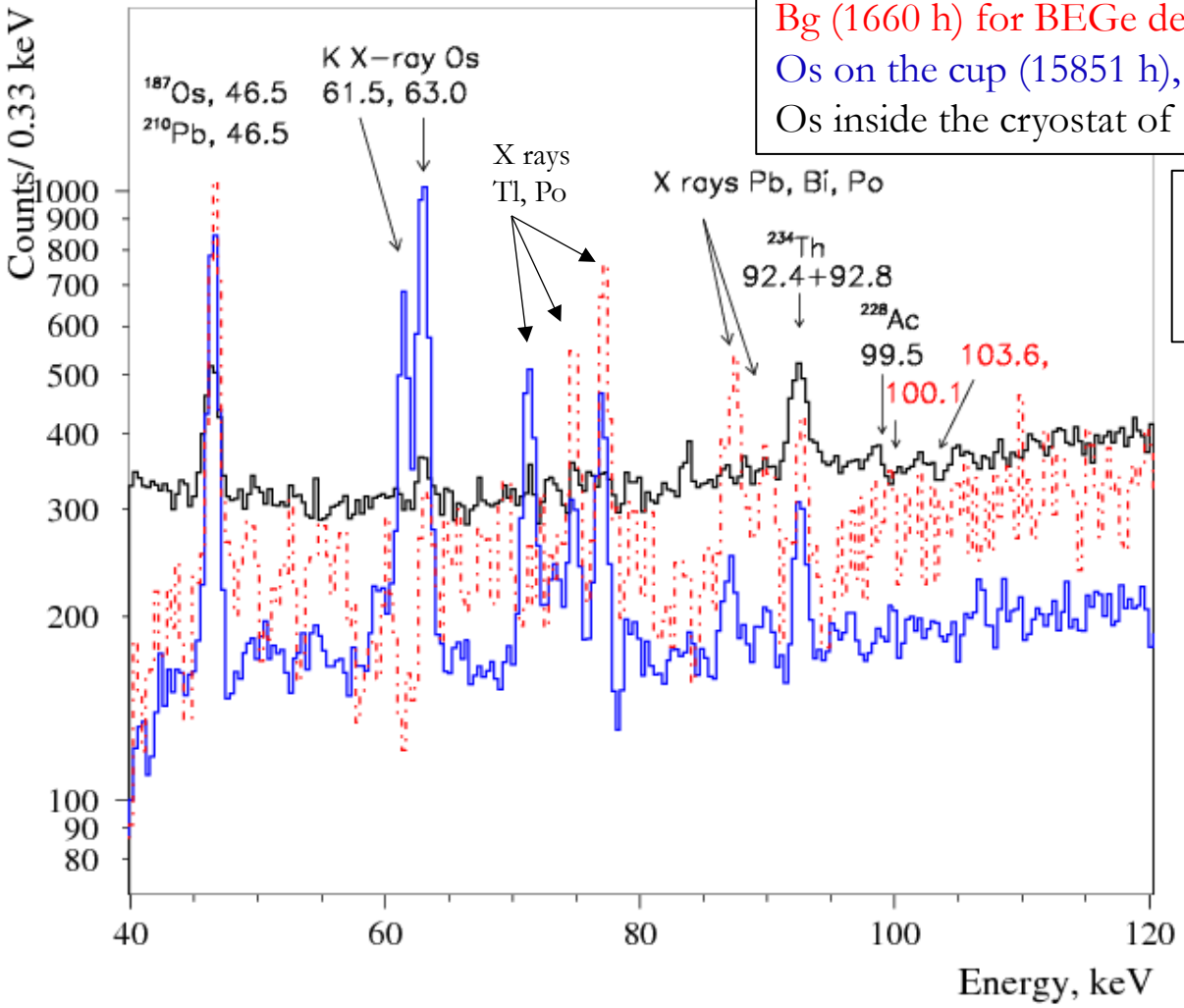
Bg (1660 h) for BEGe detector
Os on the cup (15851 h), Phys. Rev. C 102, 024605 (2020)
Os inside the cryostat of HPGe detector (23840 h), new data





Low-energy part of the spectrum with Os inside the cryostat of the HPGe detector

Low energy part of the spectrum with Os on the cup of the BEGe detector and inside the cryostat of HPGe detector



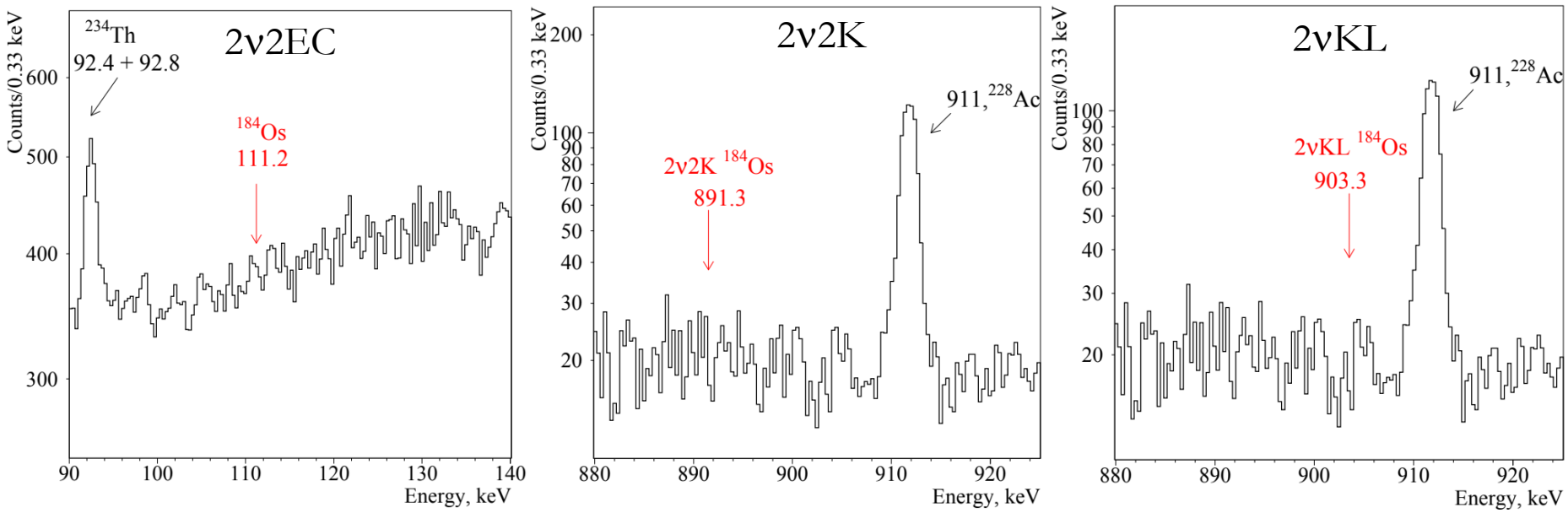
Bg (1660 h) for BEGe detector

Os on the cup (15851 h), Phys. Rev. C 102, 024605 (2020)

Os inside the cryostat of HPGe detector (23840 h), new data

Osmium metal pieces **(58.78 g)** placed on Ge crystal of the HPGe detector

Data analysis



Feldman-Cousins procedure [1] was applied for the peaks area at the position of the signal searched for, obtaining the following sensitivity (also combining the data of the 2nd stage experiment)

^{184}Os, 2ν2EC → ^{184}W, 111.2 keV: peak area: 21.9 ± 29.2 → lim S = 70 → $T_{1/2} > 7.9 \times 10^{15}$ yr

^{184}Os, 2ν2K → ^{184}W, 1002.5 keV: peak area: 4.8 ± 6.3 → lim S = 15.1 → $T_{1/2} > 3.5 \times 10^{17}$ yr

^{184}Os, 2νKL → ^{184}W, 903.3 keV: peak area: -1.5 ± 7.8 → lim S = 11.4 → $T_{1/2} > 2.3 \times 10^{17}$ yr

[1] PRD 57, 3873 (1998)

Results

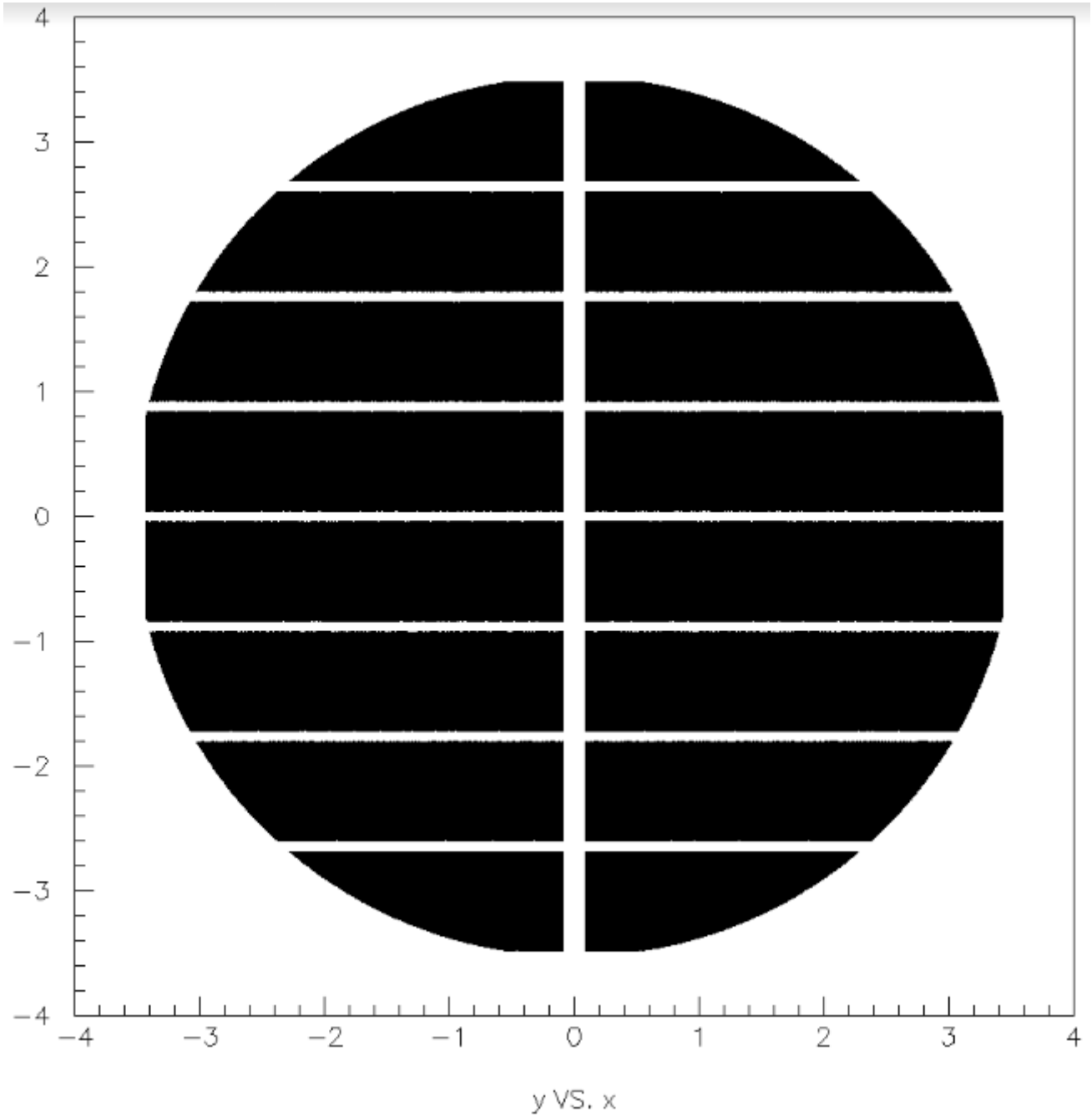
$$T_{1/2}(\text{new data + [1]}) = \ln 2 \times (N_1 \times \varepsilon_1 \times t_1 + N_2 \times \varepsilon_2 \times t_2) \,/\, (\lim\_(S_1+S_2))$$

Transition	Level of daughter	Energy, keV	ε_1	ε_2	S_1+S_2	$\Delta(S_1+S_2)$	$T_{1/2}$_sum	$T_{1/2}$ [1]
2v2EC	2^+ 111.2	111.2	0.0034	0.004773	21,9	29,2	7.9×10^{15}	1.1×10^{16}
2v2EC	2^+ 903.3	903.3	0.0123	0.028272	-1,5	7,8	$\mathbf{2.3 \times 10^{17}}$	7.6×10^{16}
2v2EC	0^+ 1002.5	891.3	0.02397	0.055424	4,8	6,3	$\mathbf{3.5 \times 10^{17}}$	2.8×10^{17}
2v2EC	2^+ 1121.4	757.3	0.00802	0.01743	-1,4	7,8	$\mathbf{1.5 \times 10^{17}}$	8.5×10^{16}
2vKL	(0^+) 1322.2	903.3	0.01056	0.021547	-1,5	7,8	1.9×10^{17}	6.1×10^{16}
2v2L	2^+ 1386.3	1275.1	0.00967	0.022682	20	6,8	$\mathbf{6.8 \times 10^{16}}$	6.3×10^{16}
2v2L	(3) 1425.0	903.3	0.00518	0.010267	-1,5	7,8	$\mathbf{9.0 \times 10^{16}}$	2.9×10^{16}
2v2L	2^+ 1431.0	1319.8	0.01002	0.023531	11,1	5,8	$\mathbf{1.1 \times 10^{17}}$	1.3×10^{17}
0v2K	g.s.	1313.1-1314.5	0.01838	0.04548	2,3	4,1	$\mathbf{1.6 \times 10^{17}}$	1.6×10^{17}
0vKL	g.s.	1370.5-1373.8	0.01827	0.043454	4,9	4,4	$\mathbf{3.4 \times 10^{17}}$	1.3×10^{17}
0v2L	g.s.	1427.9-1433.1	0.01833	0.042436	10,2	5,8	$\mathbf{7.3 \times 10^{16}}$	7.3×10^{16}
0v2K	2^+ 111.2	1201.9-1203.3	0.01911	0.046396	10,1	6,2	$\mathbf{7.6 \times 10^{16}}$	7.6×10^{16}
0vKL	2^+ 111.2	57-69	0.01584	0.045172	-92	84	$\mathbf{6.3 \times 10^{16}}$	1.9×10^{16}
0v2EC	2^+ 903.3	903.3	0.01019	0.021285	-1,5	7,8	$\mathbf{5.9 \times 10^{16}}$	5.9×10^{16}
0v2EC	0^+ 1002.5	310.6-312.0	0.03773	0.062667	1,8	7,3	$\mathbf{4.9 \times 10^{17}}$	4.9×10^{17}
0v2EC	2^+ 1121.4	757.3	0.00736	0.015559	-1,4	7,8	$\mathbf{1.3 \times 10^{17}}$	7.6×10^{16}
0vKL	$(0)^+$ 1322.2	903.3	0.01045	0.021505	-1,5	7,8	$\mathbf{1.9 \times 10^{17}}$	6.0×10^{16}
0v2L	2^+ 1386.3	1275.1	0.00966	0.022706	20	6,8	$\mathbf{6.8 \times 10^{16}}$	6.3×10^{16}
0v2L	$(3)^+$ 1425.0	903.3	0.00517	0.01031	-1,5	7,8	$\mathbf{9.0 \times 10^{16}}$	2.9×10^{16}
$2\beta^-(2\nu+0\nu)^{192}$Os	2^+ 316.5	316.5	0.04820	0.08185	43.1	32.9	$\mathbf{1.2 \times 10^{20}}$	5.3×10^{19}

[1] J. Phys. G: Nucl. Part. Phys. **48** (2021) 085104
The detection efficiency was simulated with the GEANT 4 package and the DECAY0 event generator

Висновки

1. Три етапи експерименту з пошуку 2β-розпаду ^{184,192}Os було виконано за допомогою зразка надчистого осмію та наднизькофонових детекторів у підземній лабораторії Гран-Сассо (Італія).
2. Час набору даних кожного етапу склав 2741, 15851 та 23840 годин, відповідно.
3. Ізотопний склад зразка осмію виміряно з високою точністю за допомогою мас-спектрометрії з негативною термічною іонізацією у Дослідницькому центрі Джона де Лейтера, університет Кертіна (Австралія).
4. Встановлено нові обмеження на періоди напіврозпаду ^{184}Os відносно дво- та безнейтринної мод подвійного електронного поглинання (2ε) та електронного поглинання з випромінюванням позитрона (εβ$^+$) на рівні 10^{16} – 10^{17} років (з довірчою ймовірністю 90%). Також встановлено обмеження на 2β$^-$ розпад ^{192}Os на перший збуджений рівень ядра ^{192}Pt як 1.2×10^{20} років.
5. Існує можливість покращення чутливості експерименту за допомогою збагаченого ізотопу ^{184}Os (вже є) та можливої реєстрації α-розпадів ізотопів ^{184,186}Os.



The thickness has been determined taking into account the sample mass (58.78 g), the Os density (22.57 g/cm3) and the shape of the sample shown in Fig.
with a max diameter of 70.5 mm and thickness of 0.8 mm.

sigma[keV] = sqrt(1.41+1.97*E[MeV]) / 2.35482