Rare nuclear processes in Hf isotopes

10th International Conference on New Frontiers in Physics
23 August 2021 to 2 September 2021
Crete, Greece

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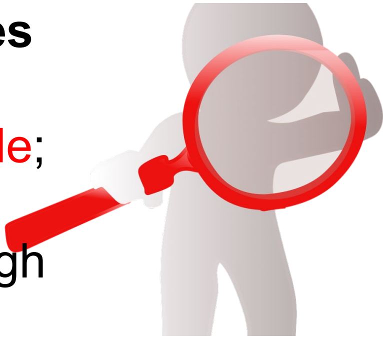
on behalf of the collaboration.
University of Roma “Tor Vergata” and INFN

INTERESTING IN STUDYING THE 34 DBD+ EMITTERS

- DBD modes without the presence of neutrinos, if observed, can open windows on new physics
- to **test calculations** of **different nucleus shapes** and **decay modes** that involve the vector and **axial-vector weak effective coupling constants**; possible study of the "**resonant effect**" on the $0\nu2\varepsilon$ mode;
- **mutual information** from the simultaneous study of **positive** and **negative** DBD can constrain the theoretical parameters with very high confidence
- the nuclear matrix elements for **the two-neutrino mode** and for the **neutrinoless** mode can be **related** to each other through relevant parameters: in the **free nucleon interaction, the g_A value is 1.2701**, but, when considering a nuclear decay, there are indications that the phenomenological axial-vector coupling value is reduced at $g_A < 1$, more precisely: $g_A \approx 1.269\ A^{-0.18}$ **or** $g_A \approx 1.269\ A^{-0.12}$, depending on the nuclear model adopted to infer the g_A value. DBD investigation with various nuclei would shed new light in constraining these and other important model-dependent parameters.
- **As byproduct**: developments of new detectors, e.g., **new crystal scintillators** containing DBD emitters



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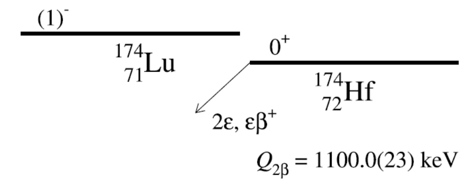
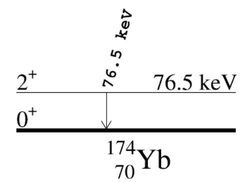
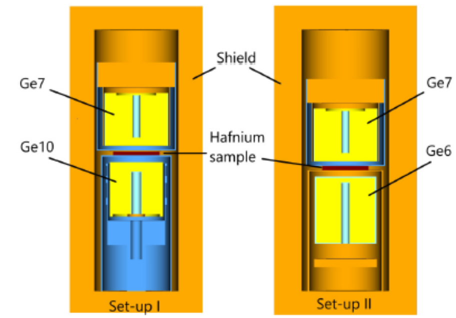
A search for double beta decays in hafnium using HP-Ge gamma spectrometer



The isotope ^{174}Hf is one of the potentially 2ε, εβ$^+$ radioactive nuclides with the energy of decay $Q_{2\beta}$=1100.0(23)keV and the isotopic abundance δ=0.156(6)% (they used the old value 0.16(12)%).





The half-life limits on 2ε and $\varepsilon\beta^+$ processes in ^{174}Hf. The energies of the γ quanta (E_γ), which were used to set the $T_{1/2}$ limits, are listed with their corresponding detection efficiencies (η) and values of lim S.

Channel of decay	Decay mode	Level of daughter nucleus (keV)	E_γ (keV)	η (%)	lim S (counts) at 90% C.L.	Experimental limit $T_{1/2}$ (a) at 90% C.L.
2K	2ν	g.s.	51.4–61.0	1.24	36	$\geq 7.1\times10^{16}$
KL	2ν	g.s.	51.4–61.0	0.73	36	$\geq 4.2\times10^{16}$
2K	2ν	2^+ 76.5	51.4–61.0	1.03	36	$\geq 5.9\times10^{16}$
KL	2ν	2^+ 76.5	51.4–61.0	0.61	36	$\geq 3.5\times10^{16}$
2L	2ν	2^+ 76.5	76.5	0.39	20.4	$\geq 3.9\times10^{16}$
2K	0ν	g.s.	977.4	4.53	10.0	$\geq 5.8\times10^{17}$
KL	0ν	g.s.	1028.9	4.46	3.0	$\geq 1.9\times10^{18}$
2L	0ν	g.s.	1080.4	4.39	7.2	$\geq 7.8\times10^{17}$
2K	0ν	2^+ 76.5	900.9	4.67	8.4	$\geq 7.1\times10^{17}$
KL	0ν	2^+ 76.5	952.4	4.59	9.5	$\geq 6.2\times10^{17}$
2L	0ν	0^+ 76.5	1003.9	4.51	8.0	$\geq 7.2\times10^{17}$
$K\beta^+$	$(2\nu+0\nu)$	g.s.	511	10.6	202	$\geq 1.4\times10^{17}$
$L\beta^+$	$(2\nu+0\nu)$	g.s.	511	10.7	202	$\geq 1.4\times10^{17}$

Nuclear Physics A 996 (2020) 121703

m_{Hf} = 179.8 g, ∅=59.0 mm, h=5.0mm 225 m underground: Joint Research Centre of European Commission (Geel, Belgium). 75 days.

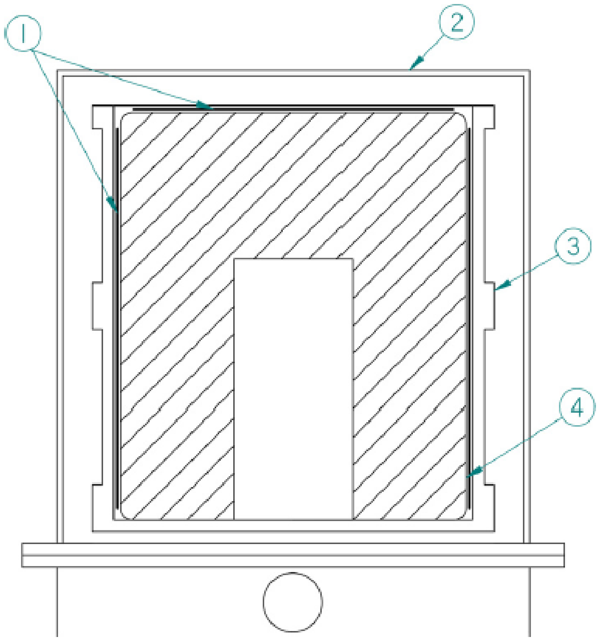
Chain	Nuclide	Activity in the sample (mBq)
	^{40}K	≤ 1.4
	^{60}Co	≤ 0.11
	^{137}Cs	≤ 0.20
	^{172}Hf	≤ 3
	^{175}Hf	0.44 ± 0.05 (0.18 ± 0.04)
	^{178m2}Hf	≤ 0.06
	^{181}Hf	1.45 ± 0.07 (0.12 ± 0.04)
	^{182}Hf	≤ 0.5
^{232}Th	^{228}Ra	3.6 ± 0.7
	^{228}Th	2.38 ± 0.25
^{235}U	^{235}U	3.8 ± 0.5
	^{231}Pa	11 ± 3
	^{227}Ac	2.0 ± 0.5
^{238}U	^{234m}Pa	11 ± 5
	^{226}Ra	≤ 0.7
	^{210}Pb	≤ 50

In case of the 2K and KL capture in ^{174}Hf, a cascade of X-rays (and Auger electrons) of Yb atom with individual energies, in particular, in the energy interval (50.8–61.3)keV is expected, while energies of the 2L capture X-ray quanta are ≈(7 −10)keV, that are below the detectors' energy thresholds. We took into account only the most intense X-rays of ytterbium: 51.4 keV (the intensity of the X-ray quanta is 27.2%), 52.4 keV (47.4%), 59.2 keV (5.2%), 59.4 keV (10.0%), and 61.0 keV (3.4%).

A search for double beta decays in hafnium using HP-Ge gamma spectrometer

Decay Mode	$E_{\gamma,X}$ [keV]	η [%]	Experimental $T_{1/2}$ [a] This work
$2\nu 2K$ (g.s.)	52.4	0.50	$\geq 1.4 \times 10^{16}$
$2\nu KL$ (g.s.)	52.4	0.50	$\geq 1.4 \times 10^{16}$
$2\nu 2K$ (1st exc.)	76.5	3.15	$\geq 7.9 \times 10^{16}$
$2\nu 2K$ (1st exc.)	52.4	0.50	$\geq 1.4 \times 10^{16}$
$2\nu KL$ (1st exc.)	76.5	3.15	$\geq 7.9 \times 10^{16}$
$2\nu KL$ (1st exc.)	52.4	0.50	$\geq 1.4 \times 10^{16}$
$2\nu 2L$ (1st exc.)	76.5	3.15	$\geq 7.9 \times 10^{16}$
$0\nu 2K$ (g.s.)	977.4	7.59	$\geq 2.7 \times 10^{18}$
$0\nu 2K$ (1st exc.)	900.9	8.01	$\geq 2.4 \times 10^{18}$
$0\nu KL$ (g.s.)	1028.9	7.32	$\geq 4.2 \times 10^{17}$
$0\nu KL$ (1st exc.)	952.4	7.72	$\geq 3.1 \times 10^{17}$
$0\nu LL$ (g.s.)	1080.4	7.09	$\geq 3.6 \times 10^{17}$
$0\nu LL$ (1st exc.)	1003.9	7.45	$\geq 9.4 \times 10^{17}$
$K\beta^+$ $(0\nu + \nu\bar{\nu})$	511	11.8	$\geq 5.6 \times 10^{16}$
$L\beta^+$ $(0\nu + \nu\bar{\nu})$	511	11.8	$\geq 5.6 \times 10^{16}$

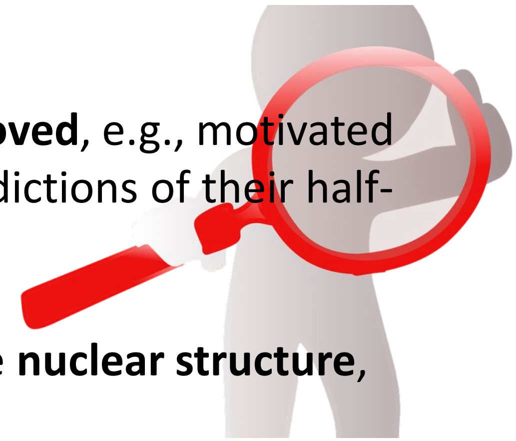
Nuclear Physics A 1012 (2021) 122212



Section view of the detector and sample (not to scale) with 1) hafnium foils on the top and wrapping the Ge crystal acting as the target and high-voltage contact, 2) copper end cap of 1mm thickness, 3) copper HP-Ge crystal holder, and 4) HP-Ge semi-coaxial p-type crystal.

Hf foil: 0.25(1) mm thick, m=55,379(1) g, 310 days.

INTERESTING IN STUDYING RARE α DECAY



- Various **theoretical models are continuously developed or improved**, e.g., motivated by searches for stable or long-lived superheavy isotopes and predictions of their half-lives.
- The study on the **nuclear instability offers information** about the **nuclear structure**, the nuclear levels and the properties of nuclei.
- The phenomenon of α decay can offer information about the **fusion-fission reactions** since the α decay process involves sub-barrier penetration of α particles through the barrier, caused by the interaction between the α and the nucleus
- Among the naturally occurring α-emitting nuclides only those with either A > 208 or A ≈ 145 have α half-lives short enough to be detected
- **As byproduct**: developments of new detectors, e.g., new crystal scintillators containing α emitters

Potentially α decay of naturally occurring Hf-nuclides

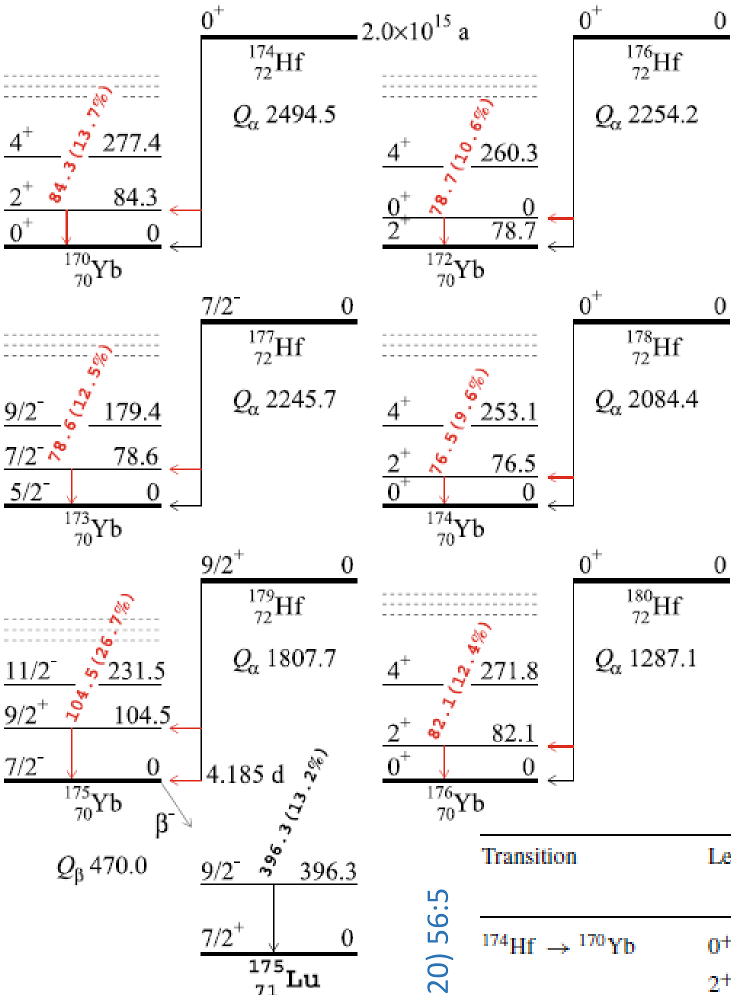
Some potential transitions of Hf isotopes and related information. Only naturally occurring isotopes (with natural abundance δ) and with Q > 0 between g.s. transitions or between g.s. and lowest bound level transitions (with spin/parity J^π) are listed. E is the kinetic energy of the alpha particle. N is the number of nuclei in the CHC crystal used in this work. Experimental measurements (when available) and theoretical prediction of the half-live are reported in the last four columns.

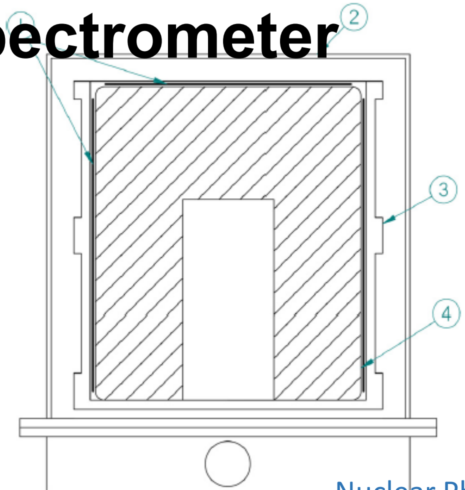
Nuclide Transition	J^π of Parent → Daughter Nuclei and its level (keV) [10, 11]	δ (%) [2]	Q_α (keV) [12]	E_α (keV)	N	$T_{1/2}$ (y)			
						Experimental	Theoretical [15]	[16]	[9]
^{174}Hf → ^{170}Yb	$0^+ \to 0^+$, g.s. $0^+ \to 2^+$, 84.2	0.16(12)	2494.5(2.3)	2437.6(2.2)	1.0×10^{19}	$2.0(4) \times 10^{15}$ [6, 13] $\geqslant 3.3 \cdot 10^{18}$ [14]	$3.5 \cdot 10^{16}$ $1.3 \cdot 10^{18}$	7.4×10^{16} 3.0×10^{18}	3.5×10^{16} 6.6×10^{17}
^{176}Hf → ^{172}Yb	$0^+ \to 0^+$, g.s. $0^+ \to 2^+$, 78.7	5.26(70)	2254.2(1.5)	2203.3(1.5)	3.3×10^{20}	– $\geqslant 3.0 \times 10^{17}$ [14]	2.5×10^{20} 1.3×10^{22}	6.6×10^{20} 3.5×10^{22}	2.0×10^{20} 4.9×10^{21}
^{177}Hf → ^{173}Yb	$7/2^- \to 5/2^-$, g.s. $7/2^- \to 7/2^-$, 78.6	18.60(16)	2245.7(1.4)	2195.3(1.4)	1.2×10^{21}	– $\geqslant 1.3 \times 10^{18}$ [14]	4.5×10^{20} 9.1×10^{21}	5.2×10^{22} 1.2×10^{24}	4.4×10^{22} 3.6×10^{23}
^{178}Hf → ^{174}Yb	$0^+ \to 0^+$, g.s. $0^+ \to 2^+$, 76.5	27.28(28)	2084.4(1.4)	2037.9(1.4)	1.7×10^{21}	– $\geqslant 2.0 \times 10^{17}$ [14]	3.4×10^{23} 2.4×10^{25}	1.1×10^{24} 8.1×10^{25}	2.2×10^{23} 7.1×10^{24}
^{179}Hf → ^{175}Yb	$9/2^+ \to 7/2^+$, g.s. $9/2^+ \to 9/2^+$, 104.5	13.62(11)	1807.7(1.4)	1767.6(1.4)	8.6×10^{20}	$\geqslant 2.2 \times 10^{18}$ [14] $\geqslant 2.2 \times 10^{18}$ [14]	4.5×10^{29} 2.0×10^{32}	4.0×10^{32} 2.5×10^{35}	4.7×10^{31} 2.2×10^{34}
^{180}Hf → ^{176}Yb	$0^+ \to 0^+$, g.s. $0^+ \to 2^+$, 82.1	35.08(33)	1287.1(1.4)	1258.7(1.4)	2.2×10^{21}	– $\geqslant 1.0 \times 10^{18}$ [14]	6.4×10^{45} 4.0×10^{49}	5.7×10^{46} 4.1×10^{50}	9.2×10^{44} 2.1×10^{48}

T.P. Kohman, Phys. Rev. 121, 1758 (1961);

NPA 1002 (2020) 121941

A search for alpha decays in excited states of hafnium isotope using HP-Ge gamma spectrometer



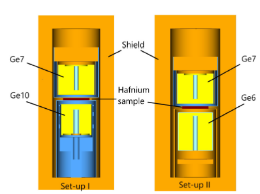


Section view of the detector and sample (not to scale) with 1) hafnium foils on the top and wrapping the Ge crystal acting as the target and high-voltage contact, 2) copper end cap of 1mm thickness, 3) copper HPGe crystal holder, and 4) HPGe semi-coaxial p-type crystal.

Nuclear Physics A 1012 (2021) 122212

Decay Isotope	E_γ [keV] (γ [%])	Experimental $T_{1/2}$ [a] This work
^{174}Hf	84.3 (13.7)	$\geq 2.8 \times 10^{16}$
^{176}Hf	78.7 (10.6)	$\geq 2.7 \times 10^{17}$
^{177}Hf	78.6 (12.5)	$\geq 1.1 \times 10^{18}$
^{178}Hf	76.5 (9.6)	$\geq 1.3 \times 10^{18}$
^{179}Hf	104.5 (26.7)	$\geq 2.7 \times 10^{18}$
^{180}Hf	82.1 (12.4)	$\geq 4.6 \times 10^{17}$

T.P. Kohman, Phys. Rev. 121, 1758 (1961);



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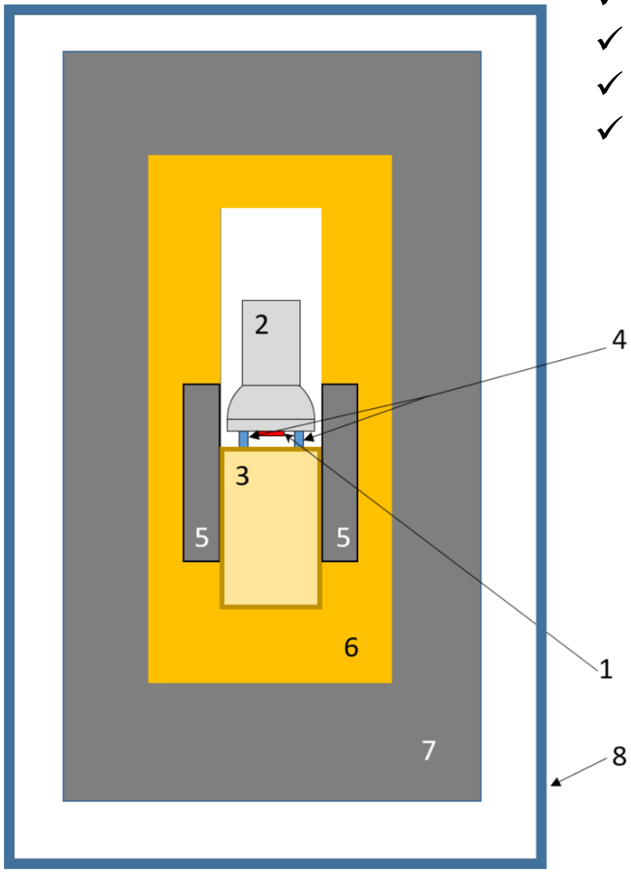
Transition	Level of the daughter nucleus (keV)	Experimental $T_{1/2}$ (a)	Theoretical $T_{1/2}$ (a)		
			[8]	[9, 10]	[11]
^{174}Hf → ^{170}Yb	0^+, g.s.	$= 2.0(4) \times 10^{15}$ [5]	7.4×10^{16}	3.5×10^{16}	3.5×10^{16}
	2^+, 84.3	$\geq 3.3 \times 10^{15}$	3.0×10^{18}	1.3×10^{18}	6.6×10^{17}
^{176}Hf → ^{172}Yb	2^+, 78.7	$\geq 3.0 \times 10^{17}$	3.5×10^{22}	1.3×10^{22}	4.9×10^{21}
^{177}Hf → ^{173}Yb	$7/2^-$, 78.6	$\geq 1.3 \times 10^{18}$	1.2×10^{24}	9.1×10^{21}	3.6×10^{23}
^{178}Hf → ^{174}Yb	2^+, 76.5	$\geq 2.0 \times 10^{17}$	8.1×10^{25}	2.4×0^{25}	7.1×10^{24}
^{179}Hf → ^{175}Yb	$(7/2^-)$, g.s.	$\geq 2.2 \times 10^{18}$	4.0×10^{32}	4.4×10^{29}	4.7×10^{31}
	$(9/2)^+$, 104.5	$\geq 2.2 \times 10^{18}$	2.5×10^{35}	2.0×10^{32}	2.2×10^{34}
^{180}Hf → ^{176}Yb	2^+, 82.1	$\geq 1.0 \times 10^{18}$	4.1×10^{50}	4.0×10^{49}	2.1×10^{48}

Study of rare alpha decay in Hf isotopes using a crystal scintillators (source=detector): the experiment

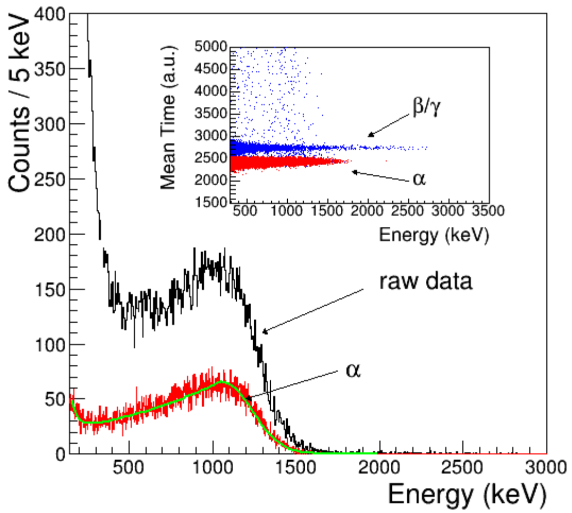
NPA 1002 (2020) 121941

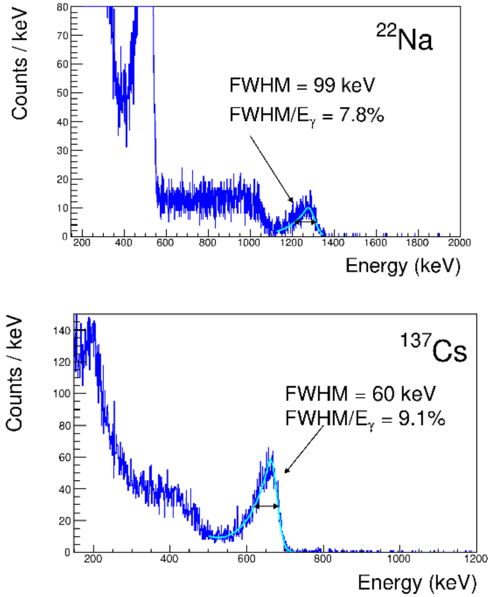
- ✓ Cs_2HfCl_6 crystal (CHC) 6.90(1) g
- ✓ CHC crystal coupled low-radioactivity PMT (Hamamatsu R6233MOD)
- ✓ placed above the end-cap of the ultra-low background HP-Ge
- ✓ CAEN DT5720B digitizer 250 MSamples/s;
- ✓ 2848 h data taking



Energy Calibration

Preliminary quenching factor (QF) estimation





Schematic cross-sectional view of the experimental set-up (not in scale). There are shown the CHC crystal scintillator (1) coupled with a 3 inches PMT (2), the HP-Ge detector (3), which is separated by a cylindrical Teflon ring (4). They are completely surrounded by a passive shield made by archaeological Roman lead (5), high purity copper (6), low radioactive lead (7). The whole set-up (with the exception of the cold finger for the HP-Ge detector) is enclosed in a Plexiglas box (8) continuously flushed with HP-N_2 gas.

Low background measurements of the CHC crystal

NPA 1002 (2020) 121941

Concentrations of trace contaminants in the CHC crystal as measured by ICP-MS analysis. The limits are at 68% C.L.

Nuclide	Concentration (ppb)
^{144}Nd	<2.4
^{147}Sm	0.6(1)
^{148}Sm	0.4(1)
^{151}Eu	19(7)
^{152}Gd	<0.02
^{180}W	<0.4
^{184}Os	<0.003
^{186}Os	<0.25
^{190}Pt	<0.02
^{209}Bi	<2

Isotopic composition of ^{nat}Hf measured in a sample of the CHC crystal by ICP-MS

Isotope	Abundance (%)
^{174}Hf	0.156(6)
^{176}Hf	5.18(5)
^{177}Hf	18.5(1)
^{178}Hf	27.2(1)
^{179}Hf	13.9(1)
^{180}Hf	35.2(2)

Nuclide	Q_α (keV) [10]	$T_{1/2}$ (y) [10]	Isotopic Abundance (%) [2]	E_α (keV)	Expected Counts
^{144}Nd	1906.4(17)	$2.29(16)\times10^{15}$	23.798(19)	1854.8(17)	<0.007
^{147}Sm	2311.2(10)	$1.060(11)\times10^{11}$	15.00(14)	2249.9(10)	36(6)
^{148}Sm	1986.9(10)	$7(3)\times10^{15}$	11.25(9)	1934.6(10)	$3.6(1)\times10^{-4}$
^{152}Gd	2204.4(10) [11]	$1.08(8)\times10^{14}$	0.20(3)	2147.8(10)	$<1\times10^{-3}$
^{186}Os	2820.4(13)	$2.0(11)\times10^{15}$	1.59(64)	2761.0(13)	$<6\times10^{-4}$
^{190}Pt	3252.6(6)	$6.5(3)\times10^{11}$	0.012(2)	3185.5(6)	<0.1
^{209}Bi	3137.3(8)	$2.01(8)\times10^{19}$	100	3078.4(8)	$<4\times10^{-7}$

Low background measurements of the CHC crystal

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Isotope	Abunda…
^{174}Hf	
^{176}Hf	
^{177}Hf	
^{178}Hf	
^{179}Hf	
^{180}Hf	

…n (ppb)
<2.4
0.6(1)
0.4(1)
19(7)
<0.02
<0.4
<0.003
<0.25
<0.02

Nuclide					…ected …unts
^{144}Nd					…007
^{147}Sm					…(6)
^{148}Sm					$\times 10^{-4}$
^{152}Gd					$\times 10^{-3}$
^{186}Os					$\times 10^{-4}$
^{190}Pt					…0.1
^{209}Bi	3137.3(8)	$2.01(8)\times 10^{19}$	100	3078.4(8)	$< 4 \times 10^{-7}$

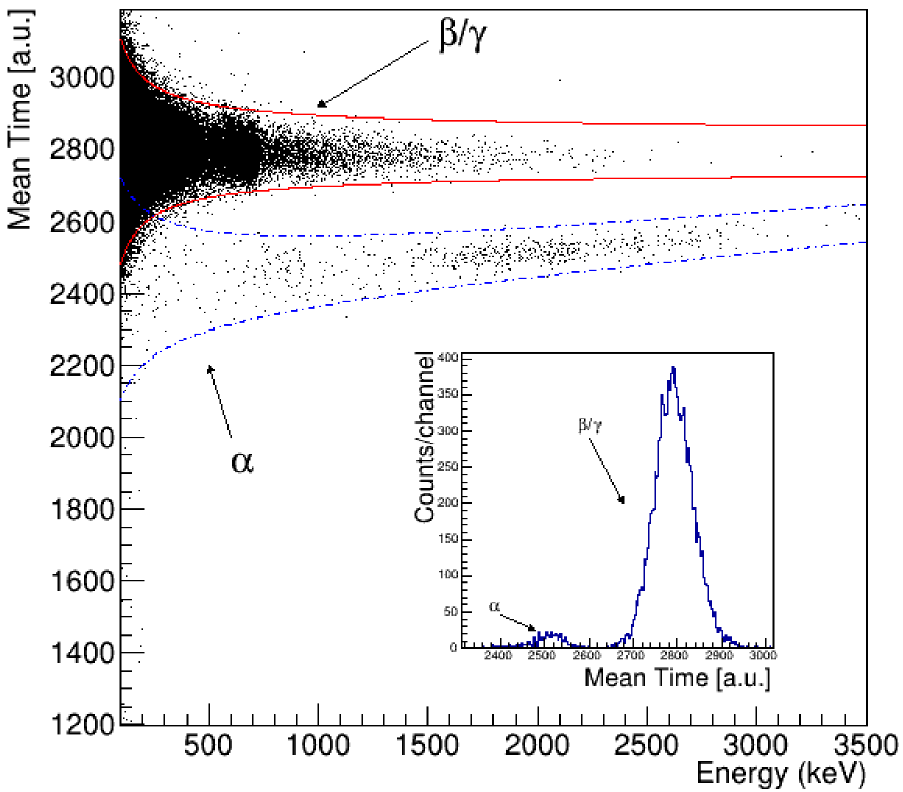
Radioactive contaminations of the CHC crystal measured with the ultra-low background **HP-Ge** spectrometer GeCris of the STELLA facility at LNGS.

Chain	Nuclide	Activity (mBq/kg)
	^{40}K	$0.4(1)\times 10^{3}$
	^{44}Ti	10(4)
	^{60}Co	<25
	^{137}Cs	$0.74(8)\times 10^{3}$
	^{132}Cs	<15
	^{134}Cs	79(8)
	^{181}Hf	<11
	^{190}Pt	<20
	^{202}Pb	<9.1
^{232}Th	^{228}Ra	<12
	^{228}Th	<3.6
^{238}U	^{226}Ra	<23
	^{234}Th	<0.80
	^{234m}Pa	<0.48
^{235}U	^{235}U	<14

Data analysis

Time-amplitude analysis of ^{228}Th sub-chain and the derived Q.F.

Pulse Shape Discrimination (PSD) based on the pulse mean-time



The time-amplitude analysis was used to select the events of the following decay sub-chain of the **^{232}Th family**:
^{224}Ra (Q = 5789 keV; $T_{1/2}$ = 3.66 d) → **^{220}Rn** (Q = 6405 keV; $T_{1/2}$ = 55.6 s) → **^{216}Po** (Q = 6906 keV; $T_{1/2}$ = 0.145 s) → **^{212}Pb**.

An average activity of ^{228}Th in the CHC crystal scintillator has been estimated:
100(50) μBq/kg

NPA 1002 (2020) 121941

Data analysis

Q.F.

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6 d) → ^{220}**Rn** (Q =
Po (Q = 6906 keV;

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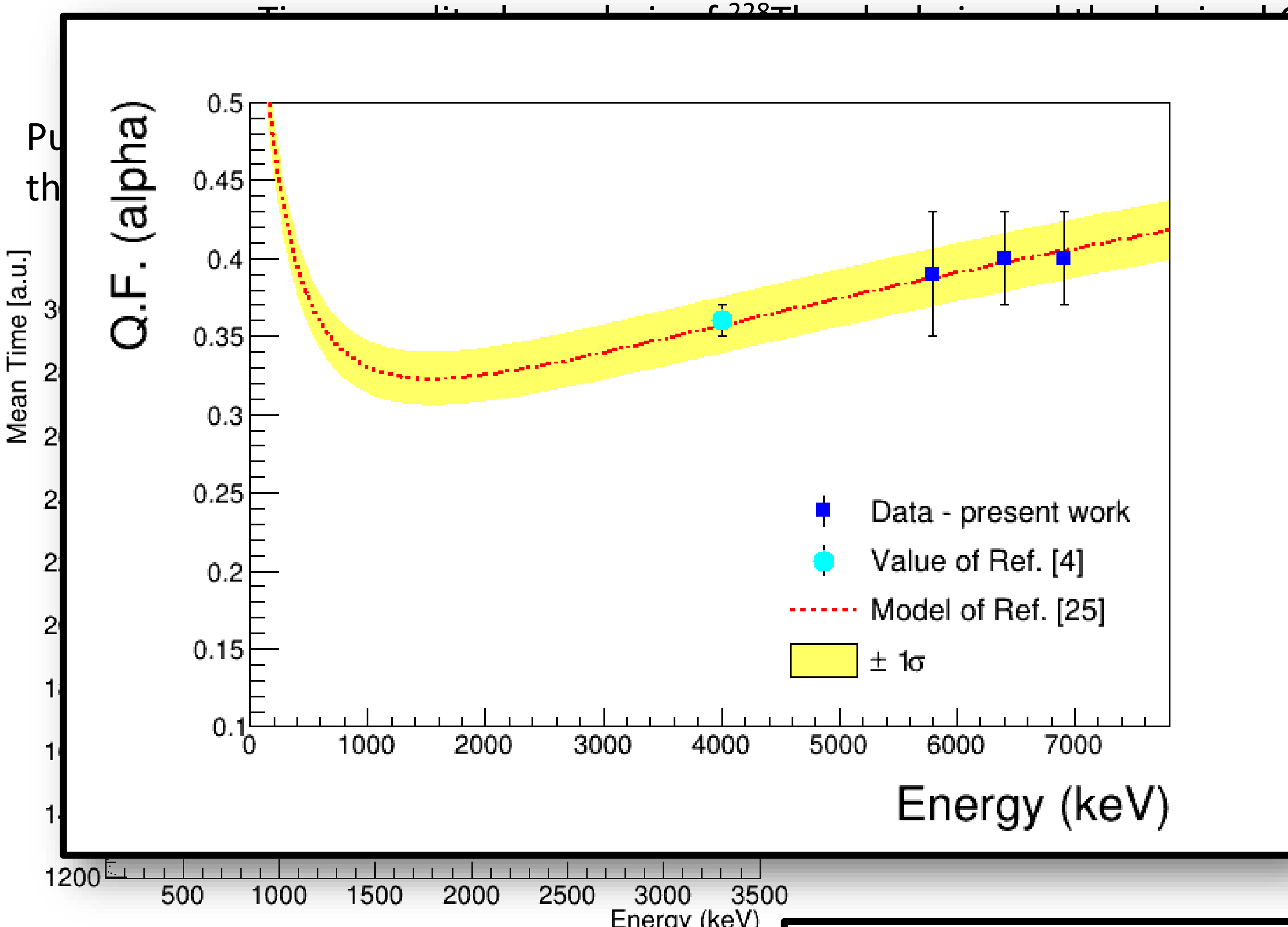
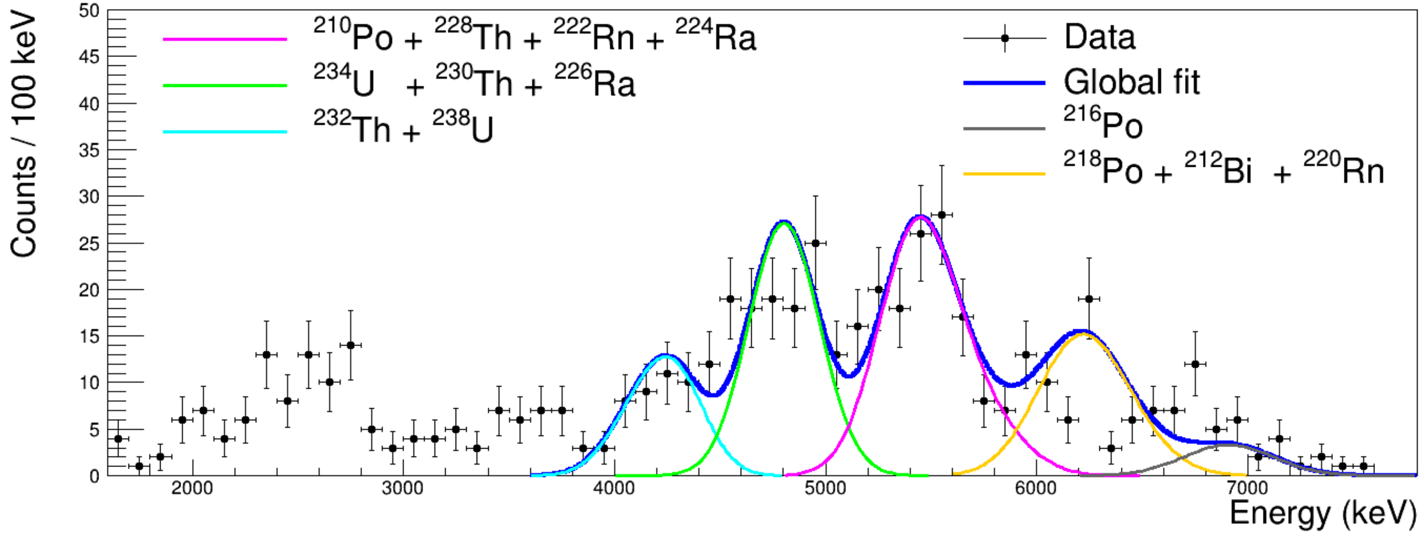


NPA 1002 (2020) 121941

The energies of the peaks of ^{224}**Ra**, ^{220}**Rn** and ^{216}**Po**, selected by the described time-amplitude analysis, are **2260(200) keV**, **2540(200) keV**, **2780(240) keV** (γ scale), respectively.

Results on the decay of naturally occurring Hf isotopes

NPA 1002 (2020) 121941



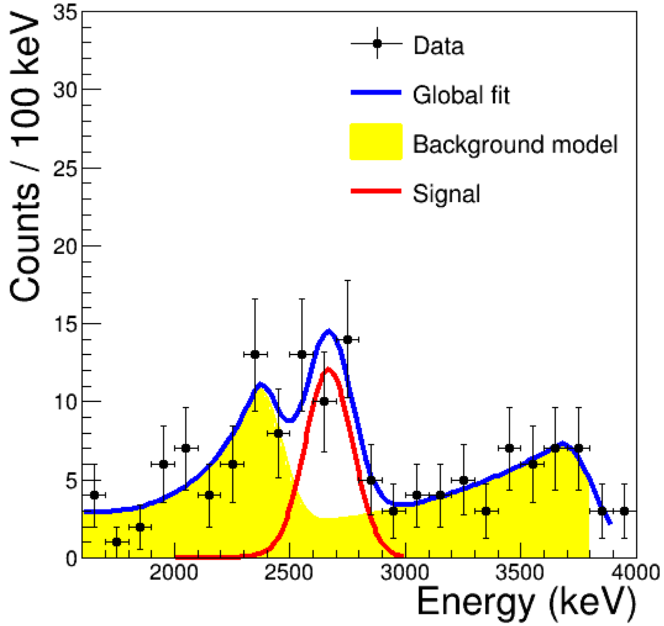
Chain	Sub-Chain	Activity (mBq/kg)
^{232}Th	^{232}Th	0.2(1)
	^{228}Th	0.2(1)
^{238}U	^{238}U	0.6(1)
	^{234}U + ^{230}Th	1.4(2)
	^{226}Ra	0.2(1)
	^{210}Po	1.4(2)

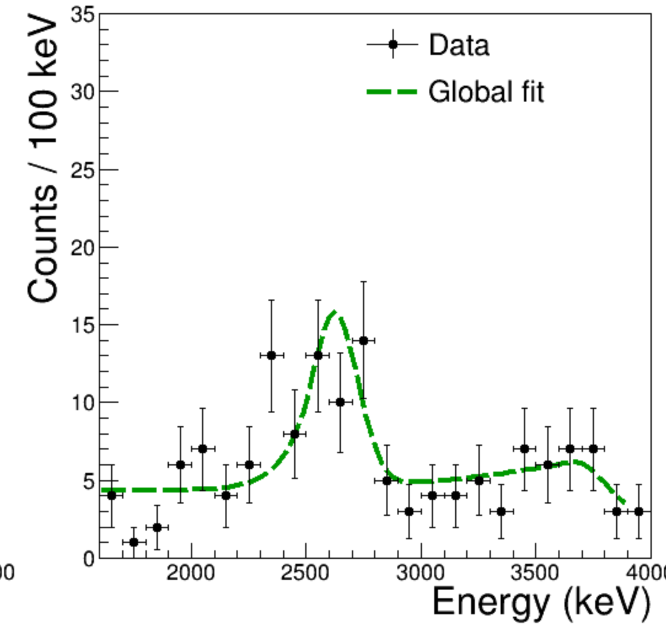
When **adopting** the claimed **half-life 2.0(4) 10^{15}y** for the ^{174}Hf decay, the expected number of events - within **2848** h of data taking with the used CHC crystal - is about **1100** counts. Thus, considering that the measured events are **553(23)** in total, even ascribing all of them to ^{174}Hf decay (despite the analysis reported above), one **can safely rule out the result of 2.0(4) 10^{15}y**; in fact, even in such an unlike hypothesis, the $T_{1/2}$ value derived from the present experimental data would be 4.01(17) 10^{15} y, i.e. is about **4.5 σ far from the value 2.0(4)10^{15}y**. Thus, the **$T_{1/2}$ value 2.0(4) 10^{15}y is safely rejected**. Let us now perform a more refined determination of the $T_{1/2}$ value of the ^{174}Hf decay supported by our data.

Results on the decay of naturally occurring Hf isotopes

χ^2/n.d.f.=0.87
P-value = 38.7%

Running-test,
tail probabilities:
Upper 94%
Lower 12%





χ^2 probability:
1.7%

Nuclide Transition	Parent, Daughter Nuclei and its Energy Level (keV)	$T_{1/2}$ (y) Experimental: present work	Experimental: previous works [14]	Theoretical: [15]	Theoretical: [16]	Theoretical: [9]
^{174}Hf → ^{170}Yb	$0^+ \to 0^+$, g.s.	$7.0 \pm 1.2 \times 10^{16}$	$2.0 \pm 0.4 \times 10^{15}$ [6, 13]	$3.5 \cdot 10^{16}$	7.4×10^{16}	3.5×10^{16}
	$0^+ \to 2^+$, 84.3	$\geqslant 1.1 \times 10^{18}$	$\geqslant 3.3 \times 10^{18}$	$1.3 \cdot 10^{18}$	3.0×10^{18}	6.6×10^{17}
^{176}Hf → ^{172}Yb	$0^+ \to 0^+$, g.s.	$\geqslant 9.3 \times 10^{19}$	–	2.5×10^{20}	6.6×10^{20}	2.0×10^{20}
	$0^+ \to 2^+$, 78.7	$\geqslant 1.8 \times 10^{16}$	$\geqslant 3.0 \times 10^{17}$	1.3×10^{22}	3.5×10^{22}	4.9×10^{21}
^{177}Hf → ^{173}Yb	$7/2^- \to 5/2^-$, g.s.	$\geqslant 3.2 \times 10^{20}$	–	4.5×10^{20}	5.2×10^{22}	4.4×10^{22}
	$7/2^- \to 7/2^-$, 78.6	$\geqslant 7.5 \times 10^{16}$	$\geqslant 1.3 \times 10^{18}$	9.1×10^{21}	1.2×10^{24}	3.6×10^{23}
^{178}Hf → ^{174}Yb	$0^+ \to 0^+$, g.s.	$\geqslant 5.8 \times 10^{19}$	–	3.4×10^{23}	1.1×10^{24}	2.2×10^{23}
	$0^+ \to 2^+$, 76.5	$\geqslant 6.9 \times 10^{16}$	$\geqslant 2.0 \times 10^{17}$	2.4×10^{25}	8.1×10^{25}	7.1×10^{24}
^{179}Hf → ^{175}Yb	$9/2^+ \to 7/2^+$, g.s.	$\geqslant 2.5 \times 10^{20}$	$\geqslant 2.2 \times 10^{18}$	4.5×10^{29}	4.0×10^{32}	4.7×10^{31}
	$9/2^+ \to 9/2^+$, 104.5	$\geqslant 5.5 \times 10^{17}$	$\geqslant 2.2 \times 10^{18}$	2.0×10^{32}	2.5×10^{35}	2.2×10^{34}
^{180}Hf → ^{176}Yb	$9/2^+ \to 7/2^+$, g.s.	–	–	6.4×10^{45}	5.7×10^{46}	9.2×10^{44}
	$9/2^+ \to 9/2^+$, 82.1	–	$\geqslant 1.0 \times 10^{18}$	4.0×10^{49}	4.1×10^{50}	2.1×10^{48}

NPA 1002 (2020) 121941

Conclusion

- To study the decay of naturally occurring hafnium to the ground state and to the first excited states , a CHC crystal scintillator was used in coincidence with a HP-Ge detector in 2848 h of live time.

- The results rules out the $T_{1/2}$ value of the alpha decay of ^{174}Hf given in literature. In particular, we found that the decay of ^{174}Hf to the ground state has been definitely observed with a **$T_{1/2}$ = 7.0(1.2) x 10^{16} y**. This value is in good agreement with the theoretical predictions.

- New lower limits of the half-life for alpha decay of ^{174}Hf to the first excited state and for alpha decays of ^{176}Hf, ^{177}Hf, ^{178}Hf, ^{179}Hf either to the ground states or to the first excited levels of daughter nuclides (10^{16}-10^{20} y) have been set.

- New lower limits of the half-life for 2ε and $\varepsilon\beta^+$ decay of ^{174}Hf (10^{16}-10^{18} y) have been set.