Double-β Decay

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Half-life Measurements and Limits for Double-β Decay

In most cases the transitions (Z,A) $\rightarrow$ (Z+2,A) + $2e^-$ + (0 or 2) $\overline{\nu}_e$ to the 0^+ ground state of the final nucleus are listed. However, we also list transitions that increase the nuclear charge ($2e^+$, e^+/EC and ECEC) and transitions to excited states of the final nuclei (0^+_i, 2^+, and 2^+_i). In the following Listings, only best or comparable limits or lifetimes for each isotope are reported and only those with $T_{1/2} > 10^{20}$ years that are relevant for particle physics. For 2ν decay, which is well established, only measured half-lives with the smallest (or comparable) error for each nucleus are reported.

$t_{1/2}(10^{21}$ yr)	CL%	ISOTOPE		TRANSITION	METHOD	DOCUMENT ID	
• • • We do not use the following data for averages, fits, limits, etc. • • •							
$0.82 \pm 0.02 \pm 0.06$		^{130}Te	2ν		CUORE-0	[1] ALDUINO	17
$(2.74 \pm 0.04 \pm 0.18)$E-2		^{116}Cd	2ν		NEMO-3	[2] ARNOLD	17
> 100.0	90	^{116}Cd	0ν		NEMO-3	[2] ARNOLD	17
> 3.6	90	^{36}Ar	0ν	ECEC	GERDA	[3] AGOSTINI	16
> 4000	90	^{130}Te	0ν	g.s.$\rightarrow$ g.s.	CUORE(CINO)	[4] ALDUINO	16
> 14	90	^{40}Ca	0ν	ECEC, g.s.	CRESST-II	[5] ANGLOHER	16B
$(6.4^{+0.7}_{-0.6}{}^{+1.2}_{-0.9})$E-2		^{48}Ca	2ν		NEMO-3	[6] ARNOLD	16
$(9.34 \pm 0.22^{+0.62}_{-0.60})$E-3		^{150}Nd	2ν		NEMO-3	[7] ARNOLD	16A
> 20.0	90	^{150}Nd	0ν		NEMO-3	[7] ARNOLD	16A
> 26000	90	^{136}Xe	0ν	g.s.$\rightarrow 2^+_1$	KamLAND-Zen	[8] ASAKURA	16
> 26000	90	^{136}Xe	0ν	g.s.$\rightarrow 2^+_2$	KamLAND-Zen	[9] ASAKURA	16
> 24000	90	^{136}Xe	0ν	g.s.$\rightarrow 0^+_1$	KamLAND-Zen	[10] ASAKURA	16
> 1.1	90	^{106}Cd	0ν	ECEC	^{106}CdWO$_4$	[11,12] BELLI	16
> 0.85	90	^{106}Cd	0ν	ECEC, 4^+	^{106}CdWO$_4$	[11,13] BELLI	16
> 1.4	90	^{106}Cd	0ν	ECEC, 2,3$^-$	^{106}CdWO$_4$	[11,14] BELLI	16
> 1.6	90	^{114}Cd	0ν		COBRA	[15] EBERT	16
> 107000	90	^{136}Xe	0ν	g.s.$\rightarrow$ g.s.	KamLAND-Zen	[16] GANDO	16
1.926 ± 0.094		^{76}Ge	2ν	g.s.$\rightarrow$ g.s.	GERDA	[17] AGOSTINI	15A
$(6.93 \pm 0.04) \times 10^{-3}$		^{100}Mo	2ν		NEMO-3	[18] ARNOLD	15
> 1100	90	^{100}Mo	0ν		NEMO-3	[19] ARNOLD	15
$2.165 \pm 0.016 \pm 0.059$		^{136}Xe	2ν	g.s.$\rightarrow$ g.s.	EXO-200	[20] ALBERT	14
> 11000	90	^{136}Xe	0ν	g.s.$\rightarrow$ g.s.	EXO-200	[21] ALBERT	14B
> 1100	90	^{100}Mo	0ν	$\langle m \rangle$-driven	NEMO-3	[22] ARNOLD	14
> 600	90	^{100}Mo	0ν	$\langle \lambda \rangle$-driven	NEMO-3	[23] ARNOLD	14
> 1000	90	^{100}Mo	0ν	$\langle \eta \rangle$-driven	NEMO-3	[24] ARNOLD	14
$0.107^{+0.046}_{-0.026}$		^{150}Nd	0ν+2ν	$0^+ \rightarrow 0^+_1$	γ in Ge det.	[25] KIDD	14
> 21000	90	^{76}Ge	0ν	g.s.$\rightarrow$ g.s.	GERDA	[26] AGOSTINI	13A
> 0.13	90	^{96}Ru	0ν+2ν	$2\beta^+$, g.s	Ge counting	[27] BELLI	13A
$9.2^{+5.5}_{-2.6} \pm 1.3$		^{78}Kr	2ν2K	g.s.$\rightarrow$ g.s.	BAKSAN	[28] GAVRILYAK	13
> 5.4	90	^{78}Kr	0ν2K	g.s.$\rightarrow 2^+$	BAKSAN	[29] GAVRILYAK	13

>940	90	^{130}Te	0ν	$0^+ \rightarrow 0^+_1$	CUORICINO	[30] ANDREOTTI	12
>1.0	90	^{106}Cd	0ν	ECEC, g.s.	$^{106}CdWO_4$ scint.	[31] BELLI	12A
>2.2	90	^{106}Cd	0ν	β^+EC, g.s.	$^{106}CdWO_4$ scint.	[32] BELLI	12A
>1.2	90	^{106}Cd	0ν	$2\beta^+$, g.s.	$^{106}CdWO_4$ scint.	[33] BELLI	12A
$2.38 \pm 0.02 \pm 0.14$		^{136}Xe	2ν	g.s.$\rightarrow$ g.s.	KamLAND-Zen	[34] GANDO	12A
$0.7 \pm 0.09 \pm 0.11$		^{130}Te	2ν		NEMO-3	[35] ARNOLD	11
>130	90	^{130}Te	0ν		NEMO-3	[36] ARNOLD	11
>1.3	90	^{112}Sn	0ν	$0^+ \rightarrow 0^+_3$	γ Ge det.	[37] BARABASH	11
>0.69	90	^{112}Sn	0ν	$0^+ \rightarrow 0^+_2$	γ Ge det.	[38] BARABASH	11
>1.3	90	^{112}Sn	0ν	$0^+ \rightarrow 0^+_1$	γ Ge det.	[39] BARABASH	11
>1.06	90	^{112}Sn	0ν		γ Ge det.	[40] BARABASH	11
$(69 \pm 9 \pm 10)$E-2		^{130}Te	2ν		NEMO-3	[41,42] BARABASH	11A
>360	90	^{82}Se	0ν		NEMO-3	[42,43] BARABASH	11A
>100	90	^{130}Te	0ν		NEMO-3	[42,44] BARABASH	11A
>0.32	90	^{64}Zn	0ν	ECEC, g.s.	$ZnWO_4$ scint.	[45] BELLI	11D
>0.85	90	^{64}Zn	0ν	β^+EC, g.s.	$ZnWO_4$ scint.	[45] BELLI	11D
>0.11	90	^{106}Cd	0ν	$0^+ \rightarrow 4^+$	TGV2 det.	[46] RUKHADZE	11
$(2.35 \pm 0.14 \pm 0.16)$E-2		^{96}Zr	2ν		NEMO-3	[47] ARGYRIADES	10
>9.2	90	^{96}Zr	0ν		NEMO-3	[48] ARGYRIADES	10
>0.22	90	^{96}Zr	0ν	$0^+ \rightarrow 0^+_1$	NEMO-3	[49] ARGYRIADES	10
$0.69^{+0.10}_{-0.08} \pm 0.07$		^{100}Mo	2ν	$0^+ \rightarrow 0^+_1$	Ge coinc.	[50] BELLI	10
>0.43	90	^{64}Zn	0ν	β^+EC	$ZnW0_4$ scint.	[51] BELLI	09A
>0.11	90	^{64}Zn	0ν	ECEC	$ZnW0_4$ scint.	[52] BELLI	09A
$0.55^{+0.12}_{-0.09}$		^{100}Mo	2ν+0ν	$0^+ \rightarrow 0^+_1$	Ge coincidence	[53] KIDD	09
>0.22	90	^{64}Zn	0ν		$ZnWO_4$ scint.	[54] BELLI	08
>1.1	90	^{114}Cd	0ν	2β	$CdWO_4$ scint.	[55] BELLI	08B
>58	90	^{48}Ca	0ν		CaF_2 scint.	[56] UMEHARA	08
$0.57^{+0.13}_{-0.09} \pm 0.08$		^{100}Mo	2ν	$0^+ \rightarrow 0^+_1$	NEMO-3	[57] ARNOLD	07
>89	90	^{100}Mo	0ν	$0^+ \rightarrow 0^+_1$	NEMO-3	[58] ARNOLD	07
>160	90	^{100}Mo	0ν	$0^+ \rightarrow 2^+$	NEMO-3	[59] ARNOLD	07
22300^{+4400}_{-3100}		^{76}Ge	0ν		Enriched HPGe	[60] KLAPDOR-K...	06A
>1800	90	^{130}Te	0ν		Cryog. det.	[61] ARNABOLDI	05
>100	90	^{82}Se	0ν		NEMO-3	[62] ARNOLD	05A
$(9.6 \pm 0.3 \pm 1.0)$E-2		^{82}Se	2ν		NEMO-3	[63] ARNOLD	05A
>140	90	^{82}Se	0ν		NEMO-3	[64] ARNOLD	04
$0.14^{+0.04}_{-0.02} \pm 0.03$		^{150}Nd	0ν+2ν	$0^+ \rightarrow 0^+_1$	γ in Ge det.	[65] BARABASH	04
>31	90	^{130}Te	0ν	$0^+ \rightarrow 2^+$	Cryog. det.	[66] ARNABOLDI	03
>110	90	^{128}Te	0ν		Cryog. det.	[67] ARNABOLDI	03
$(0.029^{+0.004}_{-0.003})$		^{116}Cd	2ν		$^{116}CdWO_4$ scint.	[68] DANEVICH	03
>170	90	^{116}Cd	0ν		$^{116}CdWO_4$ scint.	[69] DANEVICH	03
>29	90	^{116}Cd	0ν	$0^+ \rightarrow 2^+$	$^{116}CdWO_4$ scint.	[70] DANEVICH	03
>14	90	^{116}Cd	0ν	$0^+ \rightarrow 0^+_1$	$^{116}CdWO_4$ scint.	[71] DANEVICH	03
>6	90	^{116}Cd	0ν	$0^+ \rightarrow 0^+_2$	$^{116}CdWO_4$ scint.	[72] DANEVICH	03
>1.1	90	^{186}W	0ν		$CdWO_4$ scint.	[73] DANEVICH	03
>1.1	90	^{186}W	0ν	$0^+ \rightarrow 2^+$	$CdWO_4$ scint.	[74] DANEVICH	03

>15700	90	^{76}Ge	0ν		Enriched HPGe	[75] AALSETH	02B
$>$ 58	90	^{134}Xe	0ν		Liquid Xe Scint.	[76] BERNABEI	02D
$>$ 1.3	90	^{160}Gd	0ν		Gd_2SiO_5:Ce	[77] DANEVICH	01
$>$ 1.3	90	^{160}Gd	0ν	$0^+ \rightarrow 2^+$	Gd_2SiO_5:Ce	[78] DANEVICH	01
$>$ 19000	90	^{76}Ge	0ν		Enriched HPGe	[79] KLAPDOR-K...	01
(9.4 ± 3.2)E-3		^{96}Zr	$0\nu+2\nu$		Geochem	[80] WIESER	01
$0.042^{+0.033}_{-0.013}$		^{48}Ca	2ν		Ge spectrometer	[81] BRUDANIN	00
$0.021^{+0.008}_{-0.004} \pm 0.002$		^{96}Zr	2ν		NEMO-2	[82] ARNOLD	99
$>$ 2.8	90	^{82}Se	0ν	$0^+ \rightarrow 2^+$	NEMO-2	[83] ARNOLD	98
$(6.75^{+0.37}_{-0.42} \pm 0.68)$E-3		^{150}Nd	2ν		TPC	[84] DESILVA	97
$0.043^{+0.024}_{-0.011} \pm 0.014$		^{48}Ca	2ν		TPC	[85] BALYSH	96
$0.026^{+0.009}_{-0.005}$		^{116}Cd	2ν	$0^+ \rightarrow 0^+$	ELEGANT IV	EJIRI	95
7200 ± 400		^{128}Te	$0\nu+2\nu$		Geochem	[86] BERNATOW...	92
2.0 ± 0.6		^{238}U	$0\nu+2\nu$		Radiochem	[87] TURKEVICH	91
1800 ± 700		^{128}Te	$0\nu+2\nu$		Geochem.	[88] LIN	88B

[1] ALDUINO 17 use the CUORE-0 detector containing 10.8 kg of ^{130}Te in 52 crystals of TeO_2. The exposure was 9.3 kg yr of ^{130}Te. This is a more accurate rate determination than in ARNOLD 11 and BARABASH 11A.

[2] ARNOLD 17 use the NEMO-3 tracking calorimeter, containing 410 g of enriched ^{116}Cd exposed for 5.26 yr, to determine the half-life value and limit. Supersedes BARABASH 11A.

[3] AGOSTINI 16 search for a sharp energy photon of 429.88 ± 0.19 keV providing the signature of the radiative 0νECEC decay of ^{36}Ar. The bare Ge detectors are immersed in 89.2t of LAr, corresponding to 298 kg of ^{36}Ar. The GERDA phase I ran from 11/2011 to 5/2013. The obtained limit is still many orders of magnitude from the theoretical predication.

[4] ALDUINO 16 report result obtained with 9.8 kg y of data collected with the CUORE-0 bolometer, combined with data from the CUORICINO. Supersedes ALFONSO 15.

[5] ANGLOHER 16B use the CRESST-II detector and $CaWO_4$ crystals to search for the 0ν 2EC decay of ^{40}Ca. Limits for ^{180}W, which is one of the best candidates to observe resonant transition enhancement, are also reported.

[6] ARNOLD 16 use the NEMO-3 detector and a source of 6.99 g of ^{48}Ca. The half-life is based on 36.7 g year exposure. It is consistent, although somewhat longer, than the previous determinations of the half-life. Supersedes BARABASH 11A.

[7] ARNOLD 16A use the NEMO-3 tracking calorimeter, containing 36.6 g of ^{150}Nd exposed for 1918.5 days, to determine the half-life. Supersedes ARGYRIADES 09.

[8] ASAKURA 16 use the KamLAND-Zen liquid scintillator calorimeter (^{136}Xe 89.5 kg yr) to place a limit on the $0\nu\beta\beta$-decay into the first excited state of the daughter nuclide.

[9] ASAKURA 16 use the KamLAND-Zen liquid scintillator calorimeter (^{136}Xe 89.5 kg yr) to place a limit on the $0\nu\beta\beta$-decay into the second excited state of the daughter nuclide.

[10] ASAKURA 16 use the KamLAND-Zen liquid scintillator calorimeter (^{136}Xe 89.5 kg yr) to place a limit on the $0\nu\beta\beta$-decay into the third excited state of the daughter nuclide.

[11] BELLI 16 report on searches for various $\beta\beta$ decay modes in ^{106}Cd isotope into ground state and into excited levels of the daughter nucleus. In particular, a search for the resonant 0ν2EC decay into excited states is considered. They use 545.2 days of data from an isotopically enriched $^{106}CdWO_4$ (216 g) scintillator, in coincidence with 4 Ge detectors.

[12] Assume resonant 0ν2EC (2K) decay into the $E^* = 2718$ keV excited state.

[13] Assume resonant 0ν2EC (KL_1) decay into the $E^* = 2741$ keV excited state.

[14] Assume resonant 0ν2EC (KL_3) decay into the $E^* = 2748$ keV excited state.

[15] EBERT 16 use the COBRA demonstrator with CdZnTe semiconductor detectors to obtain 0ν half-life limits for a number of isotopes. The limit for ^{114}Cd fulfills the listing criteria; it is based on a total detector mass exposure of 212.8 kg day.

[16] GANDO 16 use the the KamLAND detector to search for the 0ν decay of ^{136}Xe. With a significant background reduction, the combination of results of the first (270.7 days) and the second phase (263.8 days) of the experiment leads to about six fold improvement over the previous limit. Supersedes GANDO 13A.

[17] AGOSTINI 15A use 17.9 kg yr exposure of the GERDA calorimeter to derive an improved measurement of the $2\nu\beta\beta$ decay half life of ^{76}Ge.

[18] ARNOLD 15 use the NEMO-3 tracking calorimeter with 34.3 kg yr exposure to determine the $2\nu\beta\beta$-half life of ^{100}Mo. Supersedes ARNOLD 05A and ARNOLD 04.

[19] ARNOLD 15 use the NEMO-3 tracking calorimeter with 34.3 kg yr exposure to determine the limit of $0\nu\beta\beta$-half life of ^{100}Mo. Supersedes ARNOLD 2005A and BARABASH 11A.

[20] ALBERT 14 use the EXO-200 tracking detector for a re-measurement of the $2\nu\beta\beta$-half life of ^{136}Xe. A nuclear matrix element of 0.0218 ± 0.0003 MeV^{-1} is derived from this data. Supersedes ACKERMAN 11.

[21] ALBERT 14B use 100 kg yr of exposure of the EXO-200 tracking calorimeter to place a lower limit on the $0\nu\beta\beta$-half life of ^{136}Xe. Supersedes AUGER 12.

[22] ARNOLD 14 use 34.7 kg yr of exposure of the NEMO-3 tracking calorimeter to derive a limit on the $\langle m \rangle$-driven (light neutrino mass) $0\nu\beta\beta$-half life of ^{100}Mo. Supersedes BARABASH 11A.

[23] ARNOLD 14 use 34.7 kg yr of exposure of the NEMO-3 tracking calorimeter to derive a limit on the $\langle \lambda \rangle$-driven (right handed quark and lepton currents) $0\nu\beta\beta$-half life of ^{100}Mo.

[24] ARNOLD 14 use 34.7 kg yr of exposure of the NEMO-3 tracking calorimeter to derive a limit on the $\langle \eta \rangle$-driven (right handed quark current) $0\nu\beta\beta$-half life of ^{100}Mo.

[25] KIDD 14 utilize two undergraound Ge detectors to determine the inclusive double beta decay rate to the first excited 0^+_1 state using γ-γ coincidences.

[26] AGOSTINI 13A use 21.6 kg yr of data, collected with GERDA detector array, to place a lower limit on the $0\nu\beta\beta$-half life of ^{76}Ge. This result is in tension with the evidence for $0\nu\beta\beta$-decay reported in KLAPDOR-KLEINGROTHAUS 06A. This half-life limit exceeds the limit reported in KLAPDOR-KLEINGROTHAUS 01.

[27] BELLI 13A use an underground Ge detector to search for the $2\beta^+$-decay of ^{96}Ru via the intensity of the annihilation peak. This method cannot distinguish two from zero neutrino decay.

[28] GAVRILYAK 13 use a proportional counter filled with Kr gas to search for the $2\nu 2$K decay of ^{78}Kr. Data with the enriched and depleted Kr were used to determine signal and background. A 2.5σ excess of events obtained with the enriched sample is interpreted as an indication for the presence of this decay.

[29] GAVRILYAK 13 use a proportional counter filled with Kr gas to search for the $0\nu 2$K decay of ^{78}Kr into 2828 keV excited state of ^{78}Se. This transition could be subject to resonant rate enhancement. Data obtained with the enriched and depleted Kr were used to determine signal and background.

[30] ANDREOTTI 12 use high resolution TeO_2 bolometric calorimeter to search for the $0\nu\beta\beta$ decay of ^{130}Te leading to the excited 0^1_+ state at 1793.5 keV.

[31] BELLI 12A use $^{106}CdWO_4$ 215 g crystal scintillator to search for various $\beta\beta$ decay modes. The limit for the ECEC mode is derived from the fit to the background spectrum in the 1.8–3.2 MeV energy interval in the run of 6590 hours. The same analysis provides several limits ($\sim$ 2–5 $\times 10^{20}$ years) for the ECEC mode leading to the excited 0^+ and 2^+ states. Also a similar size limits for the possible resonance process populating states at 2718 keV, 2741 keV, and 2748 keV were obtained.

[32] BELLI 12A use $^{106}CdWO_4$ 215 g crystal scintillator to search for various $\beta\beta$ decay modes. The limit for the ECβ^+ mode is derived from the fit to the background spectrum in the

2.0–3.0 MeV energy interval in the run of 6590 hours. The same analysis provides several limits ($\sim$ 0.5–1.3 $\times$ 10^{21} years) for the ECβ^+ mode leading to the excited 0^+ and 2^+ states.

[33] BELLI 12A use ^{106}CdWO$_4$ 215 g crystal scintillator to search for various $\beta\beta$ decay modes. The limit for the $\beta^+\beta^+$ mode is derived from the fit to the background spectrum in the 0.76–2.8 MeV energy interval in the run of 6590 hours. The same analysis provides the limit (1.2 $\times$ 10^{21} years) for the $\beta^+\beta^+$ mode leading to the first excited 2^+ state.

[34] GANDO 12A use a modification of the existing KamLAND detector. The $\beta\beta$ decay source/detector is 13 tons of enriched ^{136}Xe-loaded scintillator contained in an inner balloon. The $2\nu\beta\beta$ decay rate is derived from the fit to the spectrum between 0.5 and 4.8 MeV. This result is in agreement with ACKERMAN 11.

[35] ARNOLD 11 use enriched ^{130}Te in the NEMO-3 detector to measure the 2ν $\beta\beta$ decay rate. This result is in agreement with, but more accurate than ARNABOLDI 03.

[36] ARNOLD 11 use the NEMO-3 detector to obtain a limit for the 0ν $\beta\beta$ decay.This result is less significant than ARNABOLDI 05.

[37] BARABASH 11 use 100 g of enriched ^{112}Sn to determine a limit for the ECEC $0\nu\beta\beta$ decay to the 0^+_3 state of ^{112}Cd by searching for the de-excitation γ with a Ge detector. This decay mode is a candidate for resonant rate enhancement.

[38] BARABASH 11 use 100 g of enriched ^{112}Sn to determine a limit for the ECEC $0\nu\beta\beta$ decay to the 0^+_2 state of ^{112}Cd by searching for the de-excitation γ with a Ge detector.

[39] BARABASH 11 use 100 g of enriched ^{112}Sn to determine a limit for the ECEC $0\nu\beta\beta$ decay to the 0^+_1 state of ^{112}Cd by searching for the de-excitation γ with a Ge detector.

[40] BARABASH 11 use 100 g of enriched ^{112}Sn to determine a limit for the ECEC $0\nu\beta\beta$ decay to the ground state of ^{112}Cd by searching for the de-excitation γ with a Ge detector.

[41] Supersedes ARNABOLDI 03.

[42] BARABASH 11A use the NEMO-3 detector to measure $2\nu\beta\beta$ rates and place limits on $0\nu\beta\beta$ half lives for various nuclides.

[43] Supersedes ARNOLD 05A, ARNOLD 04, ARNOLD 98, and ELLIOTT 92.

[44] Less restrictive than ARNABOLDI 08.

[45] BELLI 11D use ZnWO$_4$ scintillator calorimeters to search for various $\beta\beta$ decay modes of ^{64}Zn, ^{70}Zn, ^{180}W, and ^{186}W.

[46] RUKHADZE 11 uses 13.6 g of enriched ^{106}Cd to search for the neutrinoless ECEC decay into an excited state of ^{106}Pd and its characteristic γ-radiation using the TGV2 detector. This decay mode is a candidate for resonant rate enhancement, however, hindered by the large spin difference.

[47] ARGYRIADES 10 use 9.4 $\pm$ 0.2 g of ^{96}Zr in NEMO-3 detector and identify its $2\nu\beta\beta$ decay. The result is in agreement and supersedes ARNOLD 99.

[48] ARGYRIADES 10 use 9.4 $\pm$ 0.2 g of ^{96}Zr in NEMO-3 detector and obtain a limit of the $0\nu\beta\beta$ decay. The result is in agreement and supersedes ARNOLD 99.

[49] ARGYRIADES 10 use 9.4 $\pm$ 0.2 g of ^{96}Zr in NEMO-3 detector and obtain a limit of the $0\nu\beta\beta$ decay into the first excited 0^+_1 state in ^{96}Mo.

[50] BELLI 10 use enriched ^{100}Mo with 4 HP Ge detectors to record the 590.8 and 539.5 keV γ rays from the decay of the 0^+_1 state in ^{100}Ru both in singles and coincidences. This result confirms the measurement of KIDD 09 and ARNOLD 07 and supersedes them.

[51] BELLI 09A use ZnWO$_4$ scintillating crystals to search for various modes of $\beta\beta$ decay. This work improves the limits for different modes of ^{64}Zn decay into the ground state of ^{64}Ni, in this case for the $0\nu\beta^+$EC mode. Supersedes BELLI 08.

[52] BELLI 09A use ZnWO$_4$ scintillating crystals to search for various modes of $\beta\beta$ decay. This work improves the limits for different modes of ^{64}Zn decay into the ground state of ^{64}Ni, in this case for the $0\nu\beta\beta$ ECEC mode. Supersedes BELLI 08.

[53] KIDD 09 combine past and new data with an improved coincidence detection efficiency determination. The result agrees with ARNOLD 95. Supersedes DEBRAECKELEER 01 and BARABASH 95.

[54] BELLI 08 use $ZnWO_4$ scintillation calorimeter to search for neutrinoless β^+ plus electron capture decay of ^{64}Zn. The halflife limit for the $2\nu\beta\beta$ mode is 2.1×10^{20} years.

[55] BELLI 08B use $CdWO_4$ scintillation calorimeter to search for $0\nu\beta\beta$ decay of ^{114}Cd.

[56] UMEHARA 08 use CaF_2 scintillation calorimeter to search for double beta decay of ^{48}Ca. Limit is significantly more stringent than quoted sensitivity: 18×10^{21} years.

[57] First exclusive measurement of 2ν-decay to the first excited 0^+_1-state of daughter nucleus. ARNOLD 07 use the NEMO-3 tracking calorimeter to detect all particles emitted in decay. Result agrees with the inclusive ($0\nu +\ 2\nu$) measurement of DEBRAECKELEER 01.

[58] Limit on 0ν-decay to the first excited 0^+_1-state of daughter nucleus using NEMO-3 tracking calorimeter. Supersedes DASSIE 95.

[59] Limit on 0ν-decay to the first excited 2^+-state of daughter nucleus using NEMO-3 tracking calorimeter.

[60] KLAPDOR-KLEINGROTHAUS 06A present re-analysis of data originally published in KLAPDOR-KLEINGROTHAUS 04A. Modified pulse shape analysis leads the authors to claim improved 6σ statistical evidence for observation of 0ν-decay, compared to 4.2σ in KLAPDOR-KLEINGROTHAUS 04A. Analysis of the systematic uncertainty is not presented. This re-analysis is disputed in AGOSTINI 13A and SCHWINGENHEUER 13.

[61] Supersedes ARNABOLDI 04. Bolometric TeO_2 detector array CUORICINO is used for high resolution search for $0\nu\beta\beta$ decay. The half-life limit is derived from 3.09 kg yr ^{130}Te exposure.

[62] NEMO-3 tracking calorimeter is used in ARNOLD 05A to place limit on $0\nu\beta\beta$ half-life of ^{82}Se. Detector contains 0.93 kg of enriched ^{82}Se. Supersedes ARNOLD 04.

[63] ARNOLD 05A use the NEMO-3 tracking detector to determine the $2\nu\beta\beta$ half-life of ^{82}Se with high statistics and low background (389 days of data taking). Supersedes ARNOLD 04.

[64] ARNOLD 04 use the NEMO-3 tracking detector to determine the limit for $0\nu\beta\beta$ halflife of ^{82}Se. This represents an improvement, by a factor of ~ 10, when compared with ELLIOTT 92. It supersedes the limit of ARNOLD 98 for this decay using NEMO-2.

[65] BARABASH 04 perform an inclusive measurement of the $\beta\beta$ decay of ^{150}Nd into the first excited (0^+_1) state of ^{150}Sm. Gamma radiation emitted in decay of the excited state is detected.

[66] Decay into first excited state of daughter nucleus.

[67] Supersedes ALESSANDRELLO 00. Array of TeO_2 crystals in high resolution cryogenic calorimeter. Some enriched in ^{128}Te. Ground state to ground state decay.

[68] Calorimetric measurement of $2\nu\beta\beta$ ground state decay of ^{116}Cd using enriched $CdWO_4$ scintillators. Agrees with EJIRI 95 and ARNOLD 96. Supersedes DANEVICH 00.

[69] Limit on $0\nu\beta\beta$ decay of ^{116}Cd using enriched $CdWO_4$ scintillators. Supersedes DANEVICH 00.

[70] Limit on $0\nu\beta\beta$ decay of ^{116}Cd into first excited 2^+ state of daughter nucleus using enriched $CdWO_4$ scintillators. Supersedes DANEVICH 00.

[71] Limit on $0\nu\beta\beta$ decay of ^{116}Cd into first excited 0^+ state of daughter nucleus using enriched $CdWO_4$ scintillators. Supersedes DANEVICH 00.

[72] Limit on $0\nu\beta\beta$ decay of ^{116}Cd into second excited 0^+ state of daughter nucleus using enriched $CdWO_4$ scintillators. Supersedes DANEVICH 00.

[73] Limit on the $0\nu\beta\beta$ ground state decay of ^{186}W using enriched $CdWO_4$ scintillators.

[74] Limit on the $0\nu\beta\beta$ decay of ^{186}W to the first excited 2^+ state of the daughter nucleus using enriched $CdWO_4$ scintillators.

[75] AALSETH 02B limit is based on 117 mol·yr of data using enriched Ge detectors. Background reduction by means of pulse shape analysis is applied to part

of the data set. Reported limit is slightly less restrictive than that in KLAPDOR-KLEINGROTHAUS 01 However, it excludes part of the allowed half-life range reported in KLAPDOR-KLEINGROTHAUS 01B for the same nuclide. The analysis has been criticized in KLAPDOR-KLEINGROTHAUS 04B. The criticism was addressed and disputed in AALSETH 04.

[76] BERNABEI 02D report a limit for the 0ν, $0^+ \rightarrow 0^+$ decay of ^{134}Xe, present in the source at 17%, by considering the maximum number of events for this mode compatible with the fitted smooth background.

[77] DANEVICH 01 place limit on $0\nu\beta\beta$ decay of ^{160}Gd using Gd_2SiO_5:Ce crystal scintillators. The limit is more stringent than KOBAYASHI 95.

[78] DANEVICH 01 place limits on $0\nu\beta\beta$ decay of ^{160}Gd into excited 2^+ state of daughter nucleus using Gd_2SiO_5:Ce crystal scintillators.

[79] KLAPDOR-KLEINGROTHAUS 01 is a continuation of the work published in BAUDIS 99. Isotopically enriched Ge detectors are used in calorimetric measurement. The most stringent bound is derived from the data set in which pulse-shape analysis has been used to reduce background. Exposure time is 35.5 kg y. Supersedes BAUDIS 99 as most stringent result.

[80] WIESER 01 reports an inclusive geochemical measurement of ^{96}Zr $\beta\beta$ half life. Their result agrees within 2σ with ARNOLD 99 but only marginally, within 3σ, with KAWASHIMA 93.

[81] BRUDANIN 00 determine the $2\nu\beta\beta$ halflife of ^{48}Ca. Their value is less accurate than BALYSH 96.

[82] ARNOLD 99 measure directly the $2\nu\beta\beta$ decay of Zr for the first time, using the NEMO-2 tracking detector and an isotopically enriched source. The lifetime is more accurate than the geochemical result of KAWASHIMA 93.

[83] ARNOLD 98 determine the limit for $0\nu\beta\beta$ decay to the excited 2^+ state of ^{82}Se using the NEMO-2 tracking detector.

[84] DESILVA 97 result for $2\nu\beta\beta$ decay of ^{150}Nd is in marginal agreement with ARTEMEV 93. It has smaller errors.

[85] BALYSH 96 measure the $2\nu\beta\beta$ decay of ^{48}Ca, using a passive source of enriched ^{48}Ca in a TPC.

[86] BERNATOWICZ 92 finds ^{128}Te/^{130}Te activity ratio from slope of ^{128}Xe/^{132}Xe vs ^{130}Xe/^{132}Xe ratios during extraction, and normalizes to lead-dated ages for the ^{130}Te lifetime. The authors state that their results imply that "(a) the double beta decay of ^{128}Te has been firmly established and its half-life has been determined ... without any ambiguity due to trapped Xe interferences... (b) Theoretical calculations ... underestimate the [long half-lives of ^{128}Te ^{130}Te] by 1 or 2 orders of magnitude, pointing to a real suppression in the $2\nu\beta\beta$ decay rate of these isotopes. (c) Despite [this], most $\beta\beta$-models predict a *ratio* of $2\nu\beta\beta$ decay widths ... in fair agreement with observation." Further details of the experiment are given in BERNATOWICZ 93. Our listed half-life has been revised downward from the published value by the authors, on the basis of reevaluated cosmic-ray ^{128}Xe production corrections.

[87] TURKEVICH 91 observes activity in old U sample. The authors compare their results with theoretical calculations. They state "Using the phase-space factors of Boehm and Vogel (BOEHM 87) leads to matrix element values for the ^{238}U transition in the same range as deduced for ^{130}Te and ^{76}Ge. On the other hand, the latest theoretical estimates (STAUDT 90) give an upper limit that is 10 times lower. This large discrepancy implies either a defect in the calculations or the presence of a faster path than the standard two-neutrino mode in this case." See BOEHM 87 and STAUDT 90.

[88] Ratio of inclusive double beta half lives of ^{128}Te and ^{130}Te determined from minerals melonite ($NiTe_2$) and altaite (PbTe) by means of mass spectroscopic measurement of abundance of $\beta\beta$-decay products. As gas-retention-age could not be determined the authors use half life of ^{130}Te (LIN 88) to infer the half life of ^{128}Te. No estimate of the systematic uncertainty of this method is given. The directly determined half life ratio agrees with BERNATOWICZ 92. However, the inferred ^{128}Te half life disagrees with KIRSTEN 83 and BERNATOWICZ 92.

$\langle m_\nu \rangle$, The Effective Weighted Sum of Majorana Neutrino Masses Contributing to Neutrinoless Double-β Decay

$\langle m_\nu \rangle = |\Sigma\ U^2_{1j} m_{\nu_j}|$, where the sum goes from 1 to n and where n = number of neutrino generations, and ν_j is a Majorana neutrino. Note that U^2_{ej}, not $|U_{ej}|^2$, occurs in the sum. The possibility of cancellations has been stressed. In the following Listings, only best or comparable limits or lifetimes for each isotope are reported.

VALUE (eV)	CL%	ISOTOPE	TRANSITION	METHOD	DOCUMENT ID	
• • • We do not use the following data for averages, fits, limits, etc. • • •						
$<$ 1.4–2.5	90	^{116}Cd	0ν	NEMO-3	[1] ARNOLD	17
$<$ 0.27–0.76	90	^{130}Te	0ν,g.s.$\rightarrow$ g.s.	CUORE(CINO)	[2] ALDUINO	16
$<$ 1.6–5.3	90	^{150}Nd	0ν	NEMO-3	[3] ARNOLD	16A
$<$ 0.061–0.165	90	^{136}Xe	0ν,g.s.$\rightarrow$ g.s.	KamLAND-Zen	[4] GANDO	16
$<$ 0.33–0.62	90	^{100}Mo	0ν	NEMO-3	[5] ARNOLD	15
$<$ 0.19–0.45	90	^{136}Xe	0ν,g.s.$\rightarrow$ g.s.	EXO-200	[6] ALBERT	14B
$<$ 0.2–0.4	90	^{76}Ge	0ν	GERDA	[7] AGOSTINI	13A
$<$ 0.3–0.6	90	^{136}Xe	0ν,g.s.$\rightarrow$ g.s.	KamLAND-Zen	[8] GANDO	12A
$<$ 0.89–2.43	90	^{82}Se	0ν	NEMO-3	[9] BARABASH	11A
$<$ 7.2–19.5	90	^{96}Zr	0ν	NEMO-3	[10] ARGYRIADES	10
$<$ 3.5–22	90	^{48}Ca	0ν	CaF_2 scint.	[11] UMEHARA	08
$<$ 9.3–60	90	^{100}Mo	$0^+ \rightarrow 0^+_1$	NEMO-3	[12] ARNOLD	07
$<$ 6500	90	^{100}Mo	$0^+ \rightarrow 2^+$	NEMO-3	[13] ARNOLD	07
0.32$\pm$0.03	68	^{76}Ge	0ν	Enriched HPGe	[14] KLAPDOR-K...	06A
$<$ 0.2–1.1	90	^{130}Te		Cryog. det.	[15] ARNABOLDI	05
$<$ 0.7–2.8	90	^{100}Mo	0ν	NEMO-3	[16] ARNOLD	05A
$<$ 1.7–4.9	90	^{82}Se	0ν	NEMO-3	[17] ARNOLD	05A
$<$ 0.37–1.9	90	^{130}Te		Cryog. det.	[18] ARNABOLDI	04
$<$ 0.8–1.2	90	^{100}Mo	0ν	NEMO-3	[19] ARNOLD	04
$<$ 1.5–3.1	90	^{82}Se	0ν	NEMO-3	[19] ARNOLD	04
0.1–0.9	99.7	^{76}Ge		Enriched HP Ge	[20] KLAPDOR-K...	04A
$<$ 7.2–44.7	90	^{48}Ca		CaF_2 scint.	[21] OGAWA	04
$<$ 1.1–2.6	90	^{130}Te		Cryog. det.	[22] ARNABOLDI	03
$<$ 1.5–1.7	90	^{116}Cd	0ν	$^{116}CdWO_4$ scint.	[23] DANEVICH	03
$<$ 0.33–1.35	90			Enriched HPGe	[24] AALSETH	02B
$<$2.9	90	^{136}Xe	0ν	Liquid Xe Scint.	[25] BERNABEI	02D
$0.39^{+0.17}_{-0.28}$		^{76}Ge	0ν	Enriched HPGe	[26] KLAPDOR-K...	02D
$<$ 2.1–4.8	90	^{100}Mo	0ν	ELEGANT V	[27] EJIRI	01
$<$ 0.35	90	^{76}Ge		Enriched HPGe	[28] KLAPDOR-K...	01
$<$23	90	^{96}Zr		NEMO-2	[29] ARNOLD	99
$<$ 1.1–1.5		^{128}Te		Geochem	[30] BERNATOW...	92
$<$5	68	^{82}Se		TPC	[31] ELLIOTT	92
$<$8.3	76	^{48}Ca	0ν	CaF_2 scint.	YOU	91

[1] ARNOLD 17 utilize NEMO-3 data, taken with enriched ^{116}Cd to limit the effective Majorana neutrino mass. The reported range results from the use of different nuclear matrix elements. Supersedes BARABASH 11A.

[2] ALDUINO 16 place a limit on the effective Majorana neutrino mass using the combined data of the CUORE-0 and CUORICINO experiments. The range reflects the authors' evaluation of the variability of the nuclear matrix elements. Supersededs ALFONSO 15.

[3] ARNOLD 16A limit is derived from data taken with the NEMO-3 detector and ^{150}Nd. A range of nuclear matrix elements that include the effect of nuclear deformation have been used. Supersedes ARGYRIADES 09.

[4] GANDO 16 result is based on the 2016 KamLAND-Zen half-life limit. The stated range reflects different nuclear matrix elements, an unquenched $g_A = 1.27$ is used. Supersedes GANDO 13A.

[5] ARNOLD 15 use the NEMO-3 tracking calorimeter with 34.3 kg yr exposure to determine the neutrino mass limit based on the $0\nu\beta\beta$-half life of ^{100}Mo. The spread range reflects different nuclear matrix elements. Supersedes ARNOLD 14 and BARABASH 11A.

[6] ALBERT 14B is based on 100 kg yr of exposure of the EXO-200 tracking calorimeter. The mass range reflects the nuclear matrix element calculations. Supersedes AUGER 12.

[7] AGOSTINI 13A is based on 21.6 kg yr of data collected by the GERDA detector. The reported range reflects different nuclear matrix elements. This result is in tension with the evidence for $0\nu\beta\beta$-decay reported in KLAPDOR-KLEINGROTHAUS 06A and earlier references to that work.

[8] GANDO 12A limit is based on the KamLAND-Zen data. The reported range reflects different nuclear matrix elements. Superseded by GANDO 13A.

[9] BARABASH 11A limit is based on NEMO-3 data for ^{82}Se. The reported range reflects different nuclear matrix elements. Supersedes ARNOLD 05A and ARNOLD 04.

[10] ARGYRIADES 10 use ^{96}Zr and the NEMO-3 tracking detector to obtain the reported mass limit. The range reflects the fluctuation of the nuclear matrix elements considered.

[11] Limit was obtained using CaF_2 scintillation calorimeter to search for double beta decay of ^{48}Ca. Reported range of limits reflects spread of QRPA and SM matrix element calculations used. Supersedes OGAWA 04.

[12] ARNOLD 07 use NEMO-3 half life limit for 0ν-decay of ^{100}Mo to the first excited 0^+_1-state of daughter nucleus to obtain neutrino mass limit. The spread reflects the choice of two different nuclear matrix elements. This limit is not competitive when compared to the decay to the ground state.

[13] ARNOLD 07 use NEMO-3 half life limit for 0ν-decay of ^{100}Mo to the first excited 2^+-state of daughter nucleus to obtain neutrino mass limit. This limit is not competitive when compared to the decay to the ground state.

[14] Re-analysis of data originally published in KLAPDOR-KLEINGROTHAUS 04A. Modified pulse shape analysis leads the authors to claim 6σ statistical evidence for observation of 0ν-decay. Authors use matrix element of STAUDT 90. Uncertainty of nuclear matrix element is not reflected in stated error. Supersedes KLAPDOR-KLEINGROTHAUS 04A.

[15] Supersedes ARNABOLDI 04. Reported range of limits due to use of different nuclear matrix element calculations.

[16] Mass limits reported in ARNOLD 05A are derived from ^{100}Mo data, obtained by the NEMO-3 collaboration. The range reflects the spread of matrix element calculations considered in this work. Supersedes ARNOLD 04.

[17] Neutrino mass limits based on ^{82}Se data utilizing the NEMO-3 detector. The range reported in ARNOLD 05A reflects the spread of matrix element calculations considered in this work. Supersedes ARNOLD 04.

[18] Supersedes ARNABOLDI 03. Reported range of limits due to use of different nuclear matrix element calculations.

[19] ARNOLD 04 limit is based on the nuclear matrix elements of SIMKOVIC 99, STOICA 01 and CIVITARESE 03.

[20] Supersedes KLAPDOR-KLEINGROTHAUS 02D. Event excess at $\beta\beta$-decay energy is used to derive Majorana neutrino mass using the nuclear matrix elements of STAUDT 90. The mass range shown is based on the authors evaluation of the uncertainties of the STAUDT 90 matrix element calculation. If this uncertainty is neglected, and only statistical errors are considered, the range in $\langle m \rangle$ becomes (0.2–0.6) eV at the 3 σ level.

[21] Calorimetric CaF_2 scintillator. Range of limits reflects authors' estimate of the uncertainty of the nuclear matrix elements. Replaces YOU 91 as the most stringest limit based on ^{48}Ca.

[22] Supersedes ALESSANDRELLO 00. Cryogenic calorimeter search. Reported a range reflecting uncertainty in nuclear matrix element calculations.

[23] Limit for $\langle m_\nu \rangle$ is based on the nuclear matrix elements of STAUDT 90 and ARNOLD 96. Supersedes DANEVICH 00.

[24] AALSETH 02B reported range of limits on $\langle m_\nu \rangle$ reflects the spread of theoretical nuclear matrix elements. Excludes part of allowed mass range reported in KLAPDOR-KLEINGROTHAUS 01B.

[25] BERNABEI 02D limit is based on the matrix elements of SIMKOVIC 02. The range of neutrino masses based on a variety of matrix elements is 1.1–2.9 eV.

[26] KLAPDOR-KLEINGROTHAUS 02D is a detailed description of the analysis of the data collected by the Heidelberg-Moscow experiment, previously presented in KLAPDOR-KLEINGROTHAUS 01B. Matrix elements in STAUDT 90 have been used. See the footnote in the preceding table for further details. See also KLAPDOR-KLEINGROTHAUS 02B.

[27] The range of the reported $\langle m_\nu \rangle$ values reflects the spread of the nuclear matrix elements. On axis value assuming $\langle \lambda \rangle = \langle \eta \rangle = 0$.

[28] KLAPDOR-KLEINGROTHAUS 01 uses the calculation by STAUDT 90. Using several other models in the literature could worsen the limit up to 1.2 eV. This is the most stringent experimental bound on m_ν. It supersedes BAUDIS 99B.

[29] ARNOLD 99 limit based on the nuclear matrix elements of STAUDT 90.

[30] BERNATOWICZ 92 finds these majorana neutrino mass limits assuming that the measured geochemical decay width is a limit on the 0ν decay width. The range is the range found using matrix elements from HAXTON 84, TOMODA 87, and SUHONEN 91. Further details of the experiment are given in BERNATOWICZ 93.

[31] ELLIOTT 92 uses the matrix elements of HAXTON 84.

Limits on Lepton-Number Violating ($V+A$) Current Admixture

For reasons given in the discussion at the beginning of this section, we list only results from 1989 and later. $\langle \lambda \rangle = \lambda \sum U_{ej} V_{ej}$ and $\langle \eta \rangle = \eta \sum U_{ej} V_{ej}$, where the sum is over the number of neutrino generations. This sum vanishes for massless or unmixed neutrinos. In the following Listings, only best or comparable limits or lifetimes for each isotope are reported.

$\langle \lambda \rangle$ (10^{-6})	CL%	$\langle \eta \rangle$ (10^{-8})	CL%	ISOTOPE	METHOD	DOCUMENT ID	
• • • We do not use the following data for averages, fits, limits, etc. • • •							
$<$ 0.9–1.3	90	$<$ 0.5–0.8	90	^{100}Mo	NEMO-3	[1] ARNOLD	14
$<$120	90			^{100}Mo	$0^+ \rightarrow 2^+$	[2] ARNOLD	07
$0.692^{+0.058}_{-0.056}$	68	$0.305^{+0.026}_{-0.025}$	68	^{76}Ge	Enriched HPGe	[3] KLAPDOR-K...	06A
$<$ 2.5	90			^{100}Mo	0ν, NEMO-3	[4] ARNOLD	05A
$<$ 3.8	90			^{82}Se	0ν, NEMO-3	[5] ARNOLD	05A
$<$ 1.5–2.0	90			^{100}Mo	0ν, NEMO-3	[6] ARNOLD	04
$<$ 3.2–3.8	90			^{82}Se	0ν, NEMO-3	[7] ARNOLD	04
$<$ 1.6–2.4	90	$<$ 0.9–5.3	90	^{130}Te	Cryog. det.	[8] ARNABOLDI	03
$<$ 2.2	90	$<$2.5	90	^{116}Cd	^{116}CdWO$_4$ scint.	[9] DANEVICH	03
$<$ 3.2–4.7	90	$<$ 2.4–2.7	90	^{100}Mo	ELEGANT V	[10] EJIRI	01
$<$ 1.1	90	$<$0.64	90	^{76}Ge	Enriched HPGe	[11] GUENTHER	97
$<$ 4.4	90	$<$2.3	90	^{136}Xe	TPC	[12] VUILLEUMIER	93
		$<$5.3		^{128}Te	Geochem	[13] BERNATOW...	92

[1] ARNOLD 14 is based on 34.7 kg yr of exposure of the NEMO-3 tracking calorimeter. The reported range limit on $\langle \lambda \rangle$ and $\langle \eta \rangle$ reflects the nuclear matrix element uncertainty in ^{100}Mo.

[2] ARNOLD 07 use NEMO-3 half life limit for 0ν-decay of ^{100}Mo to the first excited 2^+-state of daughter nucleus to limit the right-right handed admixture of weak currents $\langle\lambda\rangle$. This limit is not competitive when compared to the decay to the ground state.

[3] Re-analysis of data originally published in KLAPDOR-KLEINGROTHAUS 04A. Modified pulse shape analysis leads the authors to claim 6σ statistical evidence for observation of 0ν-decay. Authors use matrix element of MUTO 89 to determine $\langle\lambda\rangle$ and $\langle\eta\rangle$. Uncertainty of nuclear matrix element is not reflected in stated errors.

[4] ARNOLD 05A derive limit for $\langle\lambda\rangle$ based on ^{100}Mo data collected with NEMO-3 detector. No limit for $\langle\eta\rangle$ is given. Supersedes ARNOLD 04.

[5] ARNOLD 05A derive limit for $\langle\lambda\rangle$ based on ^{82}Se data collected with NEMO-3 detector. No limit for $\langle\eta\rangle$ is given. Supersedes ARNOLD 04.

[6] ARNOLD 04 use the matrix elements of SUHONEN 94 to obtain a limit for $\langle\lambda\rangle$, no limit for $\langle\eta\rangle$ is given. This limit is more stringent than the limit in EJIRI 01 for the same nucleus.

[7] ARNOLD 04 use the matrix elements of TOMODA 91 and SUHONEN 91 to obtain a limit for $\langle\lambda\rangle$, no limit for $\langle\eta\rangle$ is given.

[8] Supersedes ALESSANDRELLO 00. Cryogenic calorimeter search. Reported a range reflecting uncertainty in nuclear matrix element calculations.

[9] Limits for $\langle\lambda\rangle$ and $\langle\eta\rangle$ are based on nuclear matrix elements of STAUDT 90. Supersedes DANEVICH 00.

[10] The range of the reported $\langle\lambda\rangle$ and $\langle\eta\rangle$ values reflects the spread of the nuclear matrix elements. On axis value assuming $\langle m_\nu\rangle$=0 and $\langle\lambda\rangle$=$\langle\eta\rangle$=0, respectively.

[11] GUENTHER 97 limits use the matrix elements of STAUDT 90. Supersedes BALYSH 95 and BALYSH 92.

[12] VUILLEUMIER 93 uses the matrix elements of MUTO 89. Based on a half-life limit 2.6×10^{23} y at 90%CL.

[13] BERNATOWICZ 92 takes the measured geochemical decay width as a limit on the 0ν width, and uses the SUHONEN 91 coefficients to obtain the least restrictive limit on η. Further details of the experiment are given in BERNATOWICZ 93.

Double-β Decay REFERENCES

ALDUINO	17	EPJ C77 13	C. Alduino *et al.*	(CUORE Collab.)
ARNOLD	17	PR D95 012007	R. Arnold *et al.*	(NEMO-3 Collab.)
AGOSTINI	16	EPJ C76 652	M. Agostini *et al.*	(GERDA Collab.)
ALDUINO	16	PR C93 045503	C. Alduino *et al.*	(CUORE Collab.)
ANGLOHER	16B	JP G43 095202	G. Angloher *et al.*	(CRESST-II Collab.)
ARNOLD	16	PR D93 112008	R. Arnold *et al.*	(NEMO-3 Collab.)
ARNOLD	16A	PR D94 072003	R. Arnold *et al.*	(NEMO-3 Collab.)
ASAKURA	16	NP A946 171	K. Asakura *et al.*	(KamLAND-Zen Collab.)
BELLI	16	PR C93 045502	P. Belli *et al.*	(DAMA-INR Collab.)
EBERT	16	PR C94 024603	J. Ebert *et al.*	(COBRA Collab.)
GANDO	16	PRL 117 082503	A. Gando *et al.*	(KamLAND-Zen Collab.)
AGOSTINI	15A	EPJ C75 416	M. Agostini *et al.*	(GERDA Collab.)
ALFONSO	15	PRL 115 102502	K. Alfonso *et al.*	(CUORE Collab.)
ARNOLD	15	PR D92 072011	R. Arnold *et al.*	(NEMO-3 Collab.)
ALBERT	14	PR C89 015502	J. Albert *et al.*	(EXO-200 Collab.)
ALBERT	14B	NAT 510 229	J.B. Albert *et al.*	(EXO-200 Collab.)
ARNOLD	14	PR D89 111101	R. Arnold *et al.*	(NEMO-3 Collab.)
KIDD	14	PR C90 055501	M.F. Kidd *et al.*	
AGOSTINI	13A	PRL 111 122503	M. Agostini *et al.*	(GERDA Collab.)
BELLI	13A	PR C87 034607	P. Belli *et al.*	(DAMA-INR Collab.)
GANDO	13A	PRL 110 062502	A. Gando *et al.*	(KamLAND-Zen Collab.)
GAVRILYAK	13	PR C87 035501	Yu.M. Gavrilyuk *et al.*	
SCHWINGEN...	13	ANP 525 269	B. Schwingenheuer	(MPIH)
ANDREOTTI	12	PR C85 045503	E. Andreotti *et al.*	(CUORICINO Collab.)
AUGER	12	PRL 109 032505	M. Auger *et al.*	(EXO-200 Collab.)
BELLI	12A	PR C85 044610	P. Belli *et al.*	
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ACKERMAN	11	PRL 107 212501	N. Ackerman *et al.*	(EXO Collab.)
ARNOLD	11	PRL 107 062504	R. Arnold *et al.*	(NEMO-3 Collab.)

BARABASH	11	PR C83 045503	A.S. Barabash *et al.*	
BARABASH	11A	PAN 74 312	A.S. Barabash *et al.*	(NEMO-3 Collab.)
		Translated from YAF 74 330.		
BELLI	11D	JP G38 115107	P. Belli *et al.*	(DAMA-INR Collab.)
RUKHADZE	11	NP A852 197	N.I. Rukhadze *et al.*	(TGV-2 Collab.)
ARGYRIADES	10	NP A847 168	J. Argyriades *et al.*	(NEMO-3 Collab.)
BELLI	10	NP A846 143	P. Belli *et al.*	(DAMA-INR Collab.)
ARGYRIADES	09	PR C80 032501	J. Argyriades *et al.*	(NEMO-3 Collab.)
BELLI	09A	NP A826 256	P. Belli *et al.*	(DAMA-INR Collab.)
KIDD	09	NP A821 251	M. Kidd *et al.*	
ARNABOLDI	08	PR C78 035502	C. Arnaboldi *et al.*	
BELLI	08	PL B658 193	P. Belli *et al.*	(DAMA-INR Collab.)
BELLI	08B	EPJ A36 167	P. Belli *et al.*	
UMEHARA	08	PR C78 058501	S. Umehara *et al.*	
ARNOLD	07	NP A781 209	R. Arnold *et al.*	(NEMO-3 Collab.)
KLAPDOR-K...	06A	MPL A21 1547	H.V. Klapdor-Kleingrothaus, I.V. Krivosheina	
ARNABOLDI	05	PRL 95 142501	C. Arnaboldi *et al.*	(CUORICINO Collab.)
ARNOLD	05A	PRL 95 182302	R. Arnold *et al.*	(NEMO-3 Collab.)
AALSETH	04	PR D70 078302	C.E. Aalseth *et al.*	
ARNABOLDI	04	PL B584 260	C. Arnaboldi *et al.*	
ARNOLD	04	JETPL 80 377	R. Arnold *et al.*	(NEMO-3 Collab.)
		Translated from ZETFP 80 429.		
BARABASH	04	JETPL 79 10	A.S. Barabash *et al.*	
KLAPDOR-K...	04A	PL B586 198	H.V. Klapdor-Kleingrothaus *et al.*	
KLAPDOR-K...	04B	PR D70 078301	H.V. Klapdor-Kleingrothaus, A. Dietz, I.V. Krivosheina	
OGAWA	04	NP A730 215	I. Ogawa *et al.*	
ARNABOLDI	03	PL B557 167	C. Arnaboldi *et al.*	
CIVITARESE	03	NP A729 867	O. Civitarese, J. Suhonen	
DANEVICH	03	PR C68 035501	F.A. Danevich *et al.*	
AALSETH	02B	PR D65 092007	C.E. Aalseth *et al.*	(IGEX Collab.)
BERNABEI	02D	PL B546 23	R. Bernabei *et al.*	(DAMA Collab.)
KLAPDOR-K...	02B	PPNL 110 57	H.V. Klapdor-Kleingrothaus, A. Dietz, I.V. Krivosheina	
KLAPDOR-K...	02D	FP 32 1181	H.V. Klapdor-Kleingrothaus, A. Dietz, I.V. Krivosheina	
SIMKOVIC	02	hep-ph/0204278	F. Simkovic, P. Domin, A. Faessler	
DANEVICH	01	NP A694 375	F.A. Danevich *et al.*	
DEBRAECKEL...	01	PRL 86 3510	L. De Braeckeleer *et al.*	
EJIRI	01	PR C63 065501	H. Ejiri *et al.*	
KLAPDOR-K...	01	EPJ A12 147	H.V. Klapdor-Kleingrothaus *et al.*	
KLAPDOR-K...	01B	MPL A16 2409	H.V. Klapdor-Kleingrothaus *et al.*	
STOICA	01	NP A694 269	S. Stoica, H.V. Klapdor-Kleingrothous	
WIESER	01	PR C64 024308	M.E. Wieser, J.R. De Laeter	
ALESSAND...	00	PL B486 13	A. Alessandrello *et al.*	
BRUDANIN	00	PL B495 63	V.B. Brudanin *et al.*	(TGV Collab.)
DANEVICH	00	PR C62 045501	F.A. Danevich *et al.*	
ARNOLD	99	NP A658 299	R. Arnold *et al.*	(NEMO Collab.)
BAUDIS	99	PR D59 022001	L. Baudis *et al.*	(Heidelberg-Moscow Collab.)
BAUDIS	99B	PRL 83 41	L. Baudis *et al.*	(Heidelberg-Moscow Collab.)
SIMKOVIC	99	PR C60 055502	F. Simkovic *et al.*	
ARNOLD	98	NP A636 209	R. Arnold *et al.*	(NEMO-2 Collab.)
DESILVA	97	PR C56 2451	A. de Silva *et al.*	(UCI)
GUENTHER	97	PR D55 54	M. Gunther *et al.*	(Heidelberg-Moscow Collab.)
ARNOLD	96	ZPHY C72 239	R. Arnold *et al.*	(BCEN, CAEN, JINR+)
BALYSH	96	PRL 77 5186	A. Balysh *et al.*	(KIAE, UCI, CIT)
ARNOLD	95	JETPL 61 170	R.G. Arnold *et al.*	(NEMO Collab.)
		Translated from ZETFP 61 168.		
BALYSH	95	PL B356 450	A. Balysh *et al.*	(Heidelberg-Moscow Collab.)
BARABASH	95	PL B345 408	A.S. Barabash *et al.*	(ITEP, SCUC, PNL+)
DASSIE	95	PR D51 2090	D. Dassie *et al.*	(NEMO Collab.)
EJIRI	95	JPSJ 64 339	H. Ejiri *et al.*	(OSAK, KIEV)
KOBAYASHI	95	NP A586 457	M. Kobayashi, M. Kobayashi	(KEK, SAGA)
SUHONEN	94	PR C49 3055	J. Suhonen, O. Civitarese	
ARTEMEV	93	JETPL 58 262	V.A. Artemiev *et al.*	(ITEP, INRM)
		Translated from ZETFP 58 256.		
BERNATOW...	93	PR C47 806	T. Bernatowicz *et al.*	(WUSL, TATA)
KAWASHIMA	93	PR C47 R2452	A. Kawashima, K. Takahashi, A. Masuda	(TOKYC+)
VUILLEUMIER	93	PR D48 1009	J.C. Vuilleumier *et al.*	(NEUC, CIT, VILL)
BALYSH	92	PL B283 32	A. Balysh *et al.*	(MPIH, KIAE, SASSO)
BERNATOW...	92	PRL 69 2341	T. Bernatowicz *et al.*	(WUSL, TATA)
ELLIOTT	92	PR C46 1535	S.R. Elliott *et al.*	(UCI)
SUHONEN	91	NP A535 509	J. Suhonen, S.B. Khadkikar, A. Faessler	(JYV+)
TOMODA	91	RPP 54 53	T. Tomoda	

TURKEVICH	91	PRL 67 3211	A. Turkevich, T.E. Economou, G.A. Cowan	(CHIC+)
YOU	91	PL B265 53	K. You *et al.*	(BHEP, CAST+)
STAUDT	90	EPL 13 31	A. Staudt, K. Muto, H.V. Klapdor-Kleingrothaus	
MUTO	89	ZPHY A334 187	K. Muto, E. Bender, H.V. Klapdor	(TINT, MPIH)
LIN	88	NP A481 477	W.J. Lin *et al.*	
LIN	88B	NP A481 484	W.J. Lin *et al.*	
BOEHM	87	Massive Neutrinos	F. Bohm, P. Vogel	(CIT)
Cambridge Univ. Press, Cambridge				
TOMODA	87	PL B199 475	T. Tomoda, A. Faessler	(TUBIN)
HAXTON	84	PPNP 12 409	W.C. Haxton, G.J. Stevenson	
KIRSTEN	83	PRL 50 474	T. Kirsten, H. Richter, E. Jessberger	(MPIH)