TECHNISCHE UNIVERSITÄT DRESDEN

Fakultät Mathematik und Naturwissenschaften, Institut für Kern- und Teilchenphysik

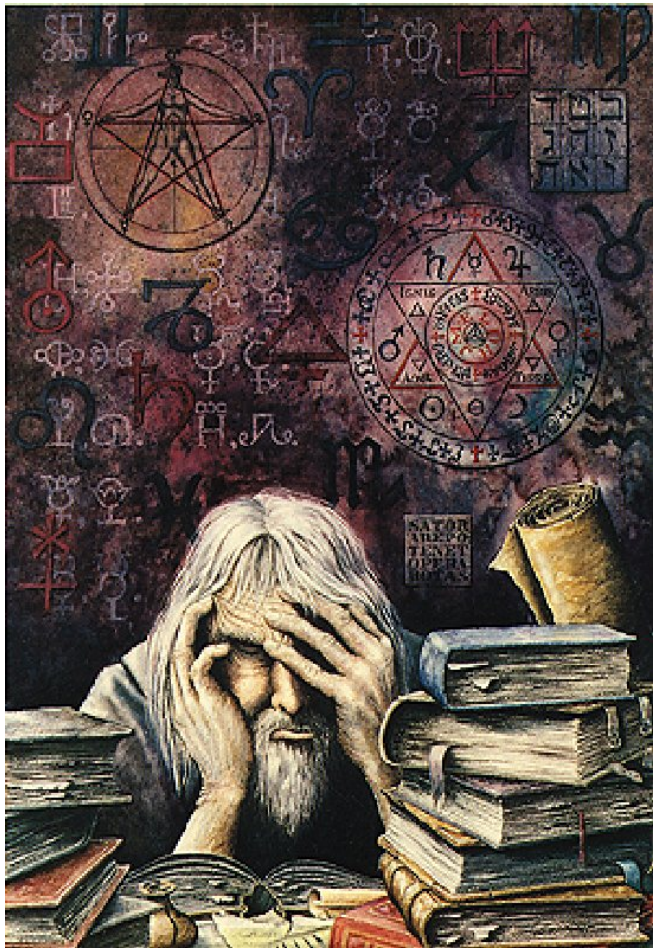
New half-live results on very long-living nuclei

13.9. 2016, INPC 2016 Adelaide

Kai Zuber
Institut für Kern- und Teilchenphysik

DRESDEN concept

Contents

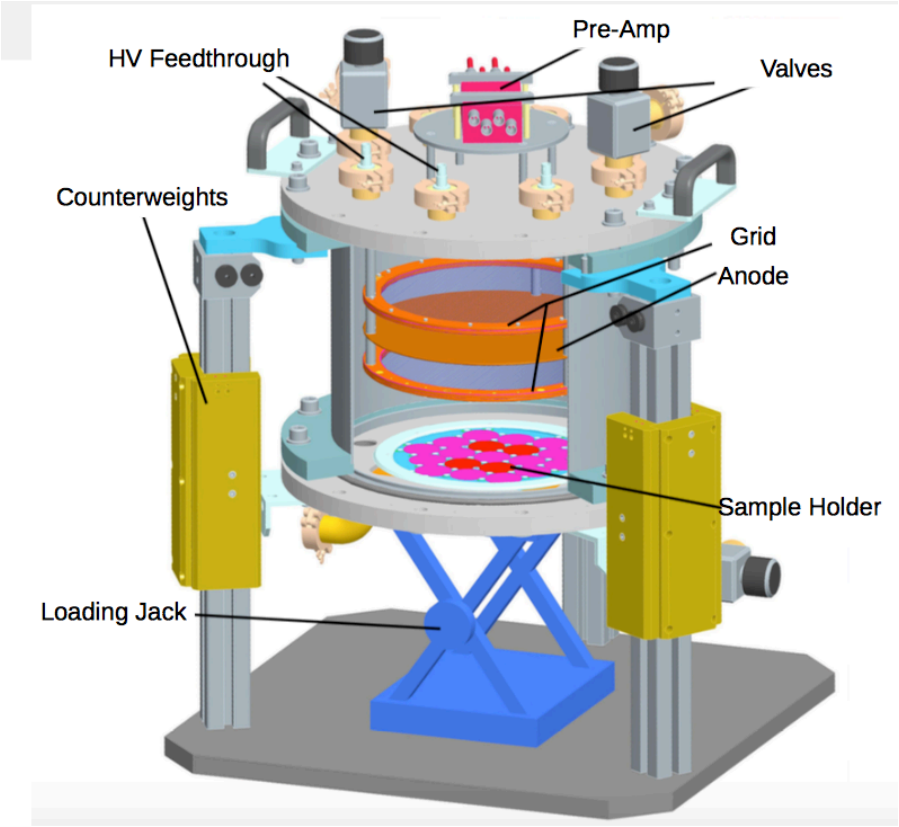


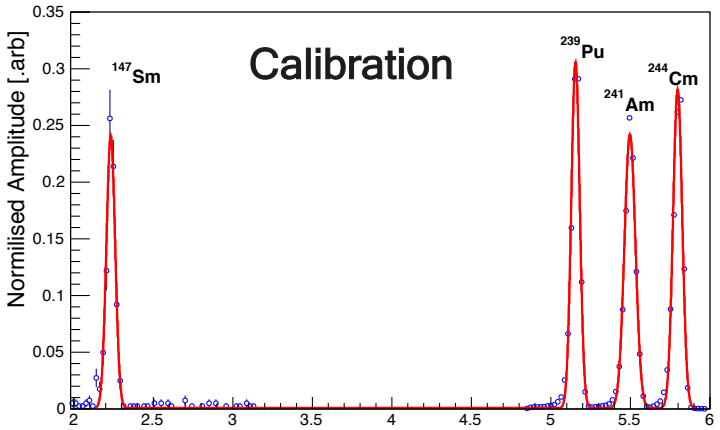
- A look on alpha decays
- Highly forbidden beta decays
- Double EC captures
- Double beta decays
- Summary

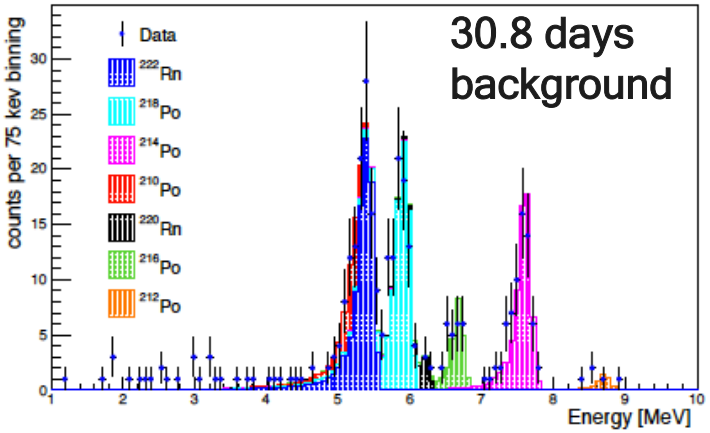
Alpha-decays

Long living = Half-life longer than the age of the Universe

Low background Frisch grid ionisation chamber
(< 10 per day between 1-9 MeV, in region 1-3 MeV only 16 events)





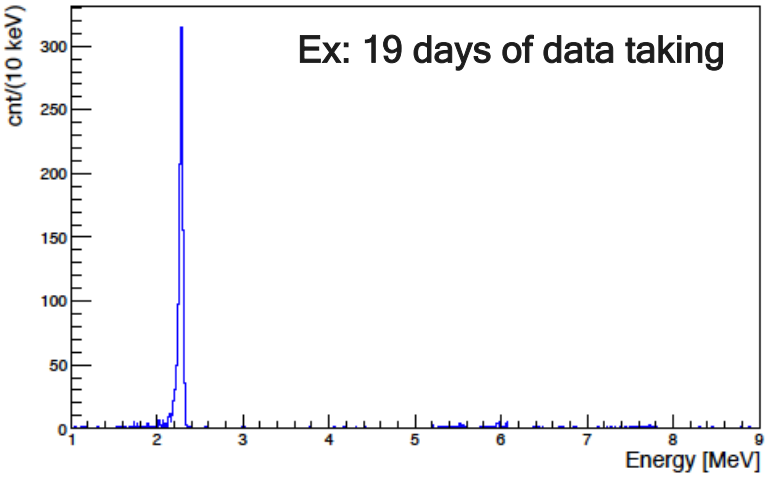


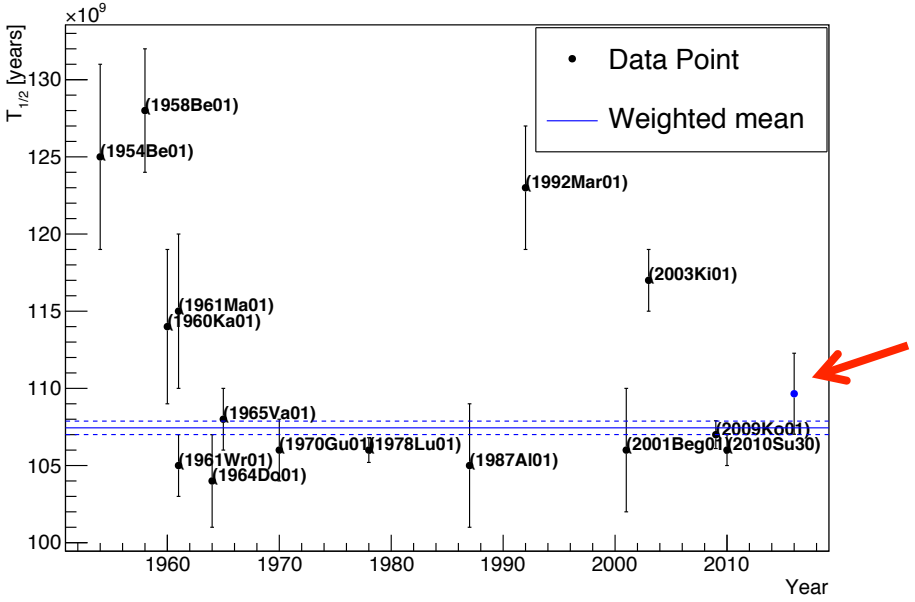
A. Hartmann, J. Hutsch, F. Krüger, M. Sobiella,H. Wilsenach, K. Zuber, NIM A 814, 12 (2016)

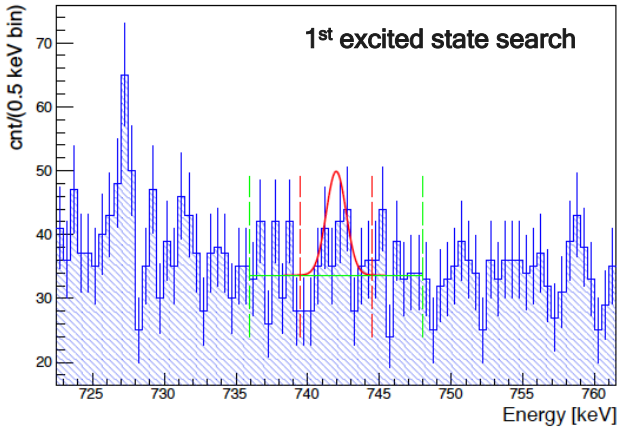
Alpha-decays – Sm147

Abundance : 14.99%
Our ICP-MS: 14.77%

First test: Calibration source







In total about 60000 Sm-147 events

Results: Ground state: $T_{1/2} = 1.097(35) \times 10^{11}$ years

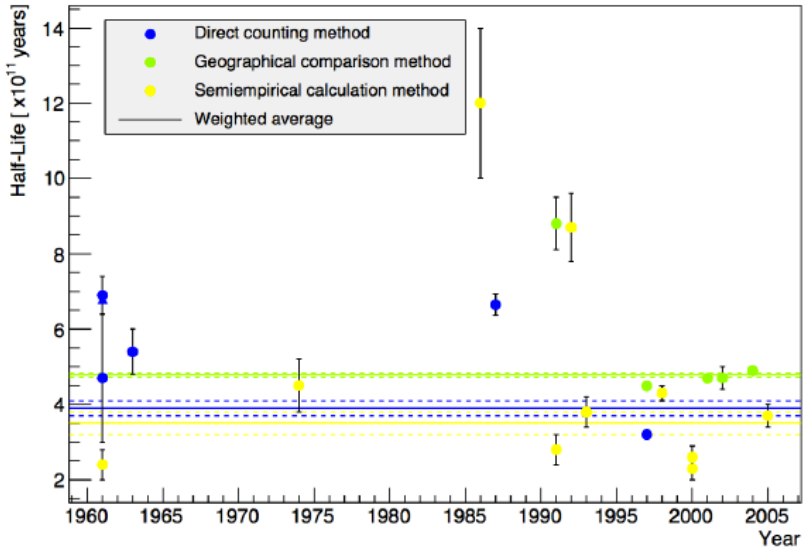
1st excit. state: $T_{1/2} > 3.1\ 10^{\wedge 18}$ years (90% CL)

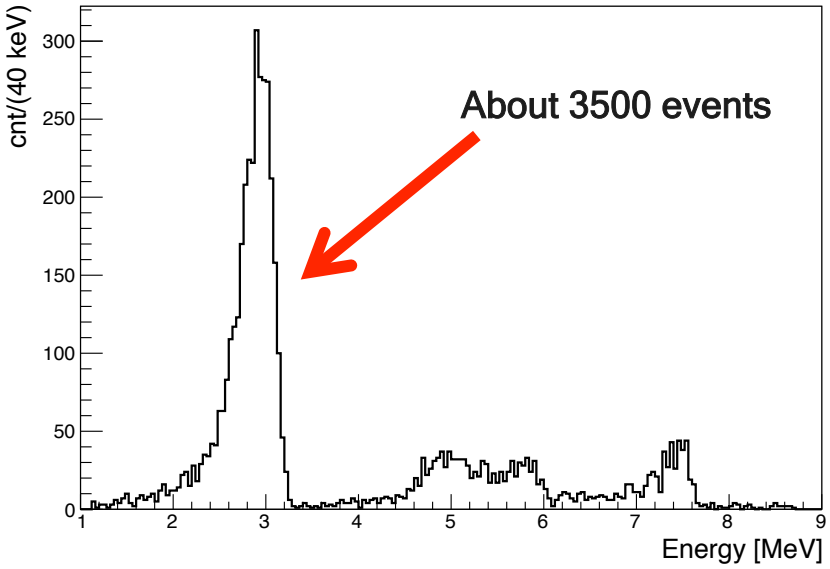
R. Heller, V. Neu, H. Wilsenach, K. Zuber, in preparation

Alpha-decays – Pt-190

Abundance : 0.014%

Can we use Pt-190 as cosmochronometer?





Laboratory: 3.9 +- 0.2 [10^11 years]
Geochemical : 4.78 +- 0.05
Semi-empirical calculations : 3.5+- 0.3

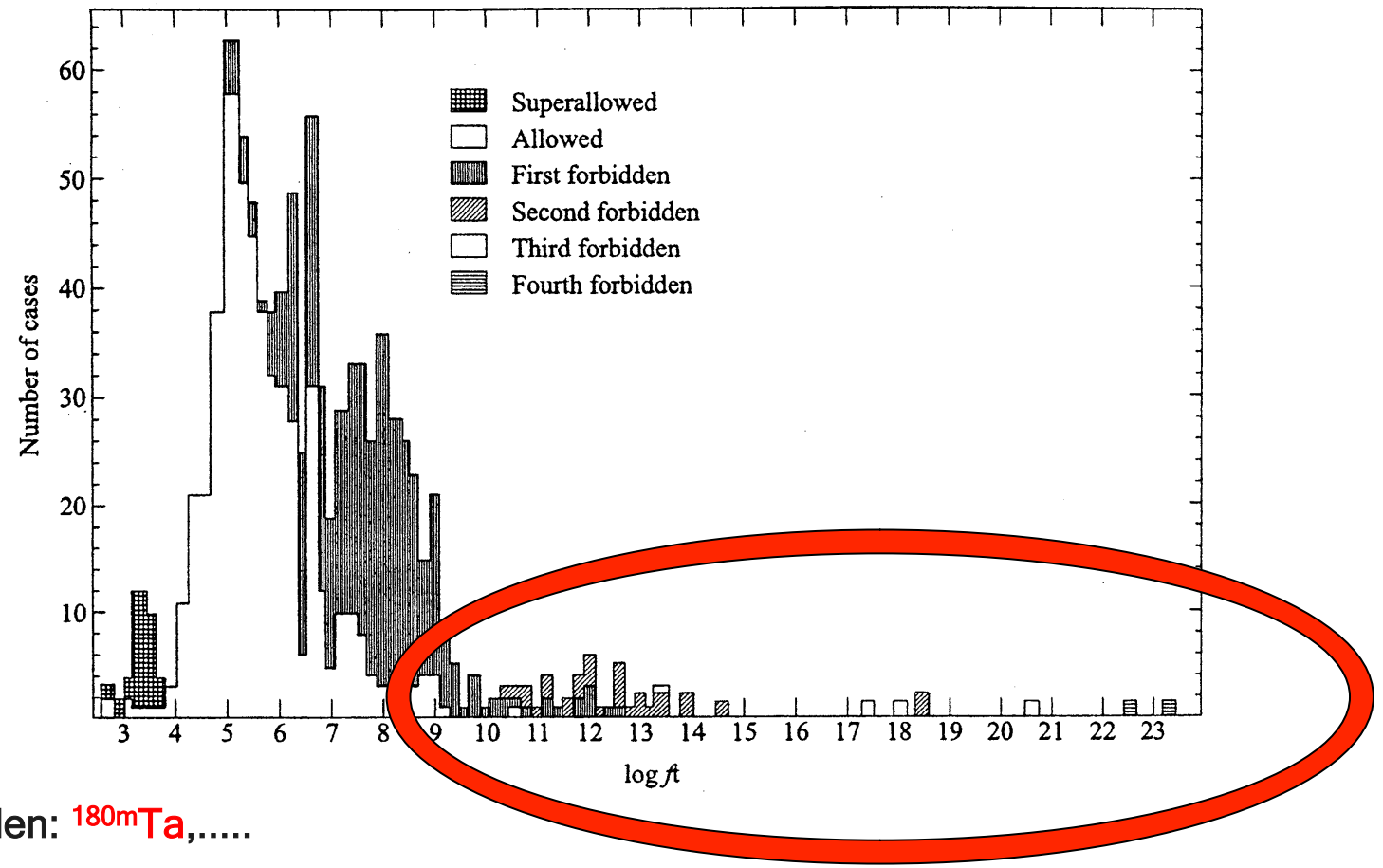
O,Tavares et al., NIM B 243, 256 (2006)

Latest theory: 2.78
Y. Qian, Z. Ren, PLB 738, 87 (2014)

Y. Georgiev, H. Wilsenach, K. Zuber, in preparation

Highly forbidden beta decays

Highly forbidden decays have different energy spectra, a lot of operators



3-fold forbidden: ^{180m}Ta,.....

4-fold forbidden non-unique: ^{50}V,^{113}Cd,^{115}In

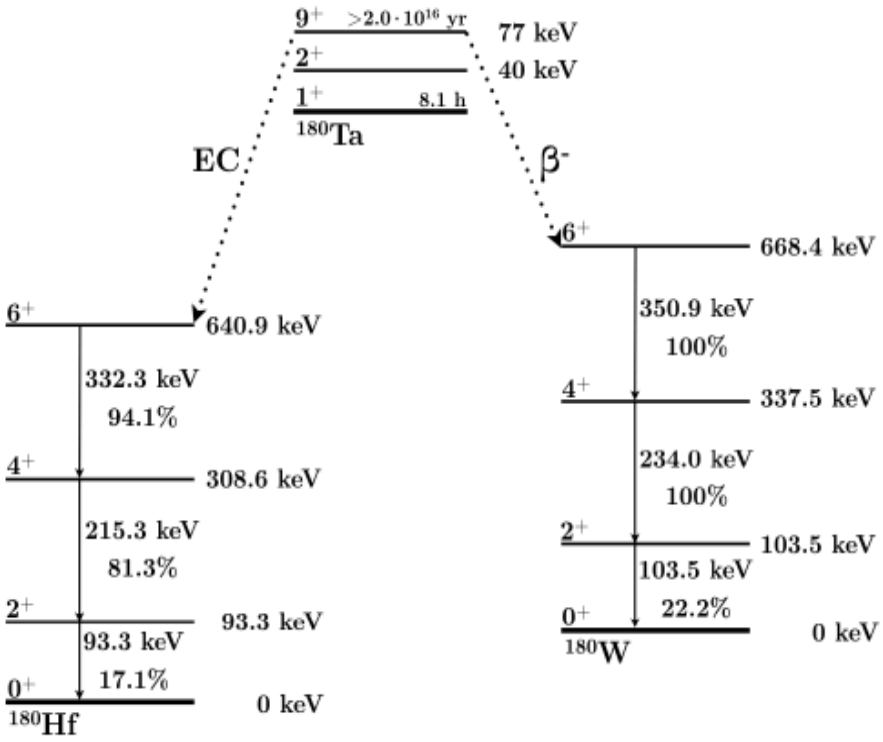
5-fold forbidden: ^{96}Zr, ^{48}Ca (in the range of double beta decay)

Cd-113

Ta-180m

Natures rarest “stable“ isotope, only nucleus present in nature in an isomeric state

M. Hult et al., Appl. Rad. Isot. 67, 918921 (2009)



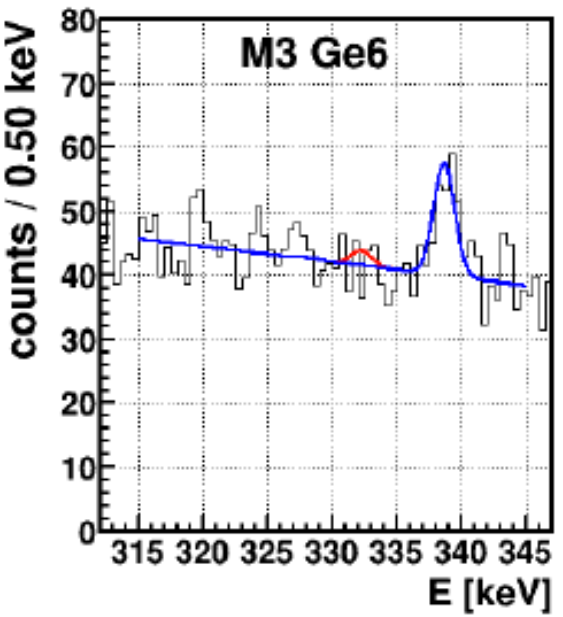
> 2 x10^{17} yrs

> 5.8 x10^{16} yrs

New measurement :

- Sandwich Ge-detector at HADES
- Almost twice as much statistics
- Lower intrinsic background
- Improved statistical analysis
- Combining all data sets

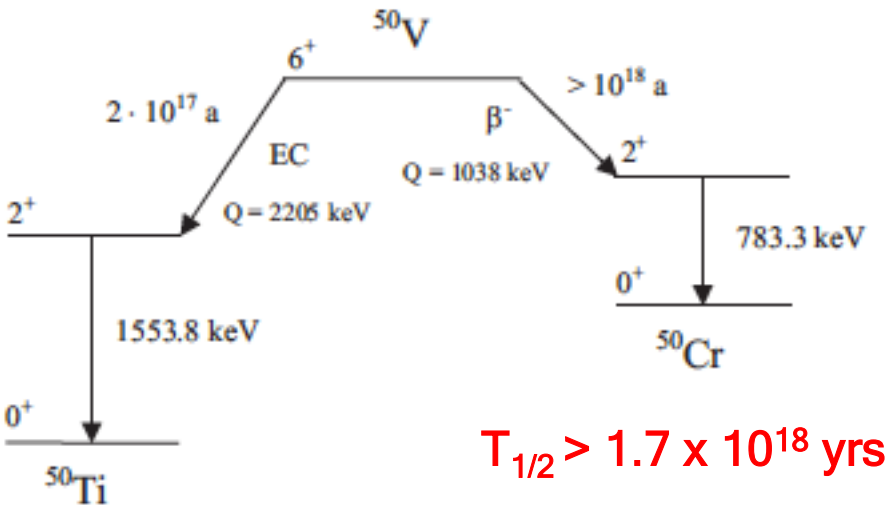
Example:



B. Lehnert, M. Hult, G. Lutter, K. Zuber, submitted

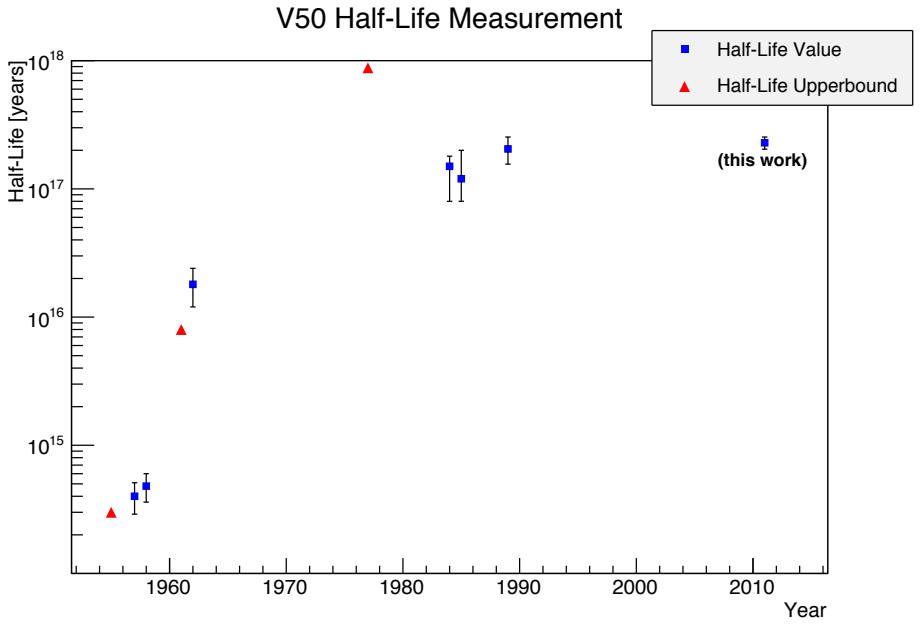
The case of V-50

The search for V-50 has a long history...started 1955



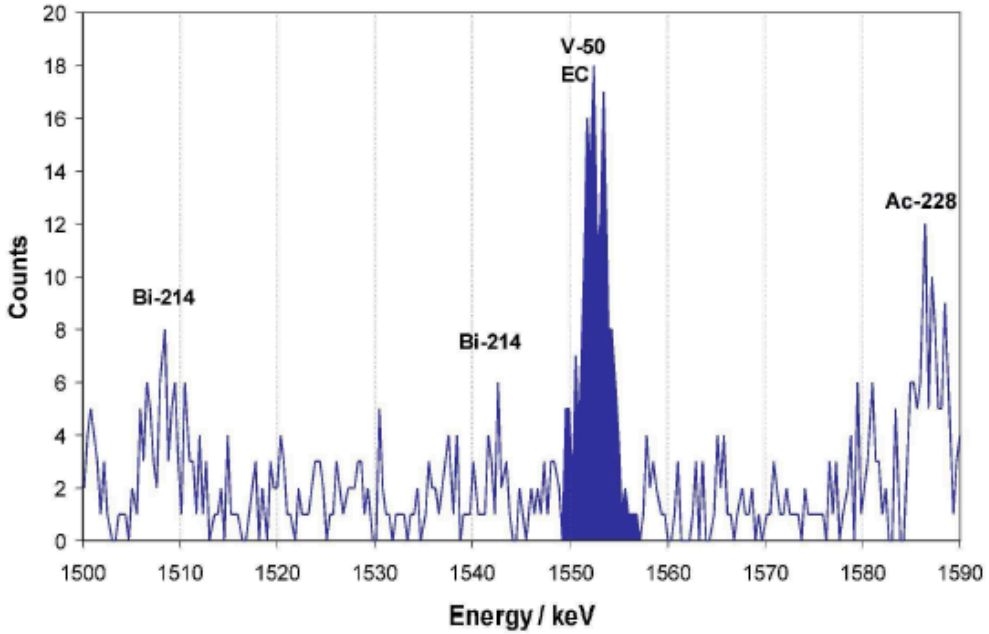
$T_{1/2} > 1.7 \times 10^{18}$ yrs

$$T_{1/2} = 2.29 \pm 0.25 \times 10^{17}\ years$$



Measurement at PTB Braunschweig (ASSE)

The case of V-50



H. Dombrowski, S. Neumaier, K. Zuber, PRC 83, 054322 (2011)

What about beta- branch?

Theoretical prediction (shell model) for beta- branch: $T_{1/2} \approx 2 \times 10^{19}\, yrs$

M. Haaranen, P. Srivastava, J. Suhonen, K. Zuber, PRC 90, 044314 (2014)

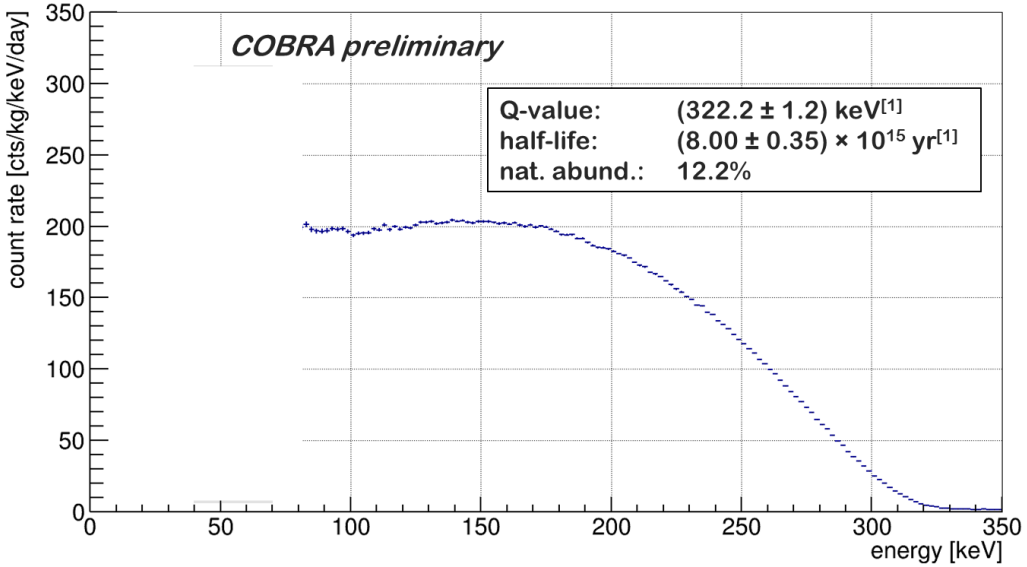
New measurement ongoing at LNGS: M. Laubenstein, S. Nagorny, K. Zuber in preparation

The case of ^{113}Cd

4-fold forbidden non-unique beta decay ($1/2^+ \rightarrow 9/2^+$)

COBRA experiment (CdZnTe detectors)

113Cd Preliminary



Q-value:

$$322 \pm 0.3(stat.) \pm 0.9(sys.)\ \text{keV}$$

J. V. Dawson et al., Nucl. Phys. A 818,264 (2009)

AME 2012 value: 322.6 0.8 keV

Penning trap value: 323.89 (27) keV

N. D. Gamage et al., Phys. Rev. C 94,025505 (2016)

Shape depends on g_A

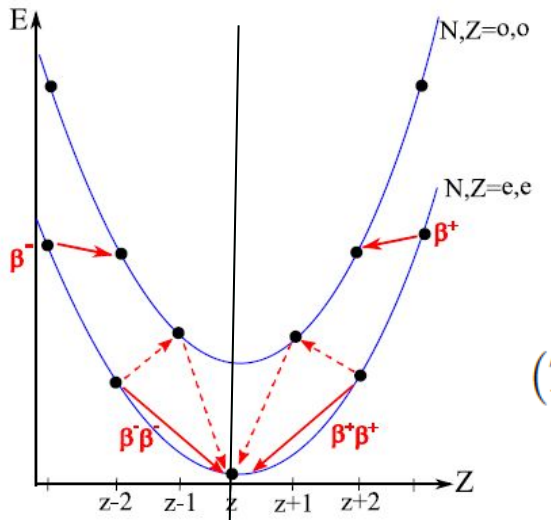
M. T. Mustonen, M. Aunola, J. Suhonen , PRC 73,054301 (2006)
M. T. Mustonen, J. Suhonen,, PLB 657,38 (2007)

Half-life: $T_{1/2} = 8.00 \pm 0.11(stat.) \pm 0.24(sys.) \times 10^{15}$ years

64 independent measurements of the half-life!

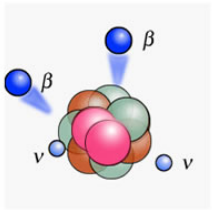
Double EC and DBD

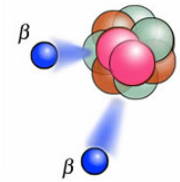
Mass parabola (isobar)

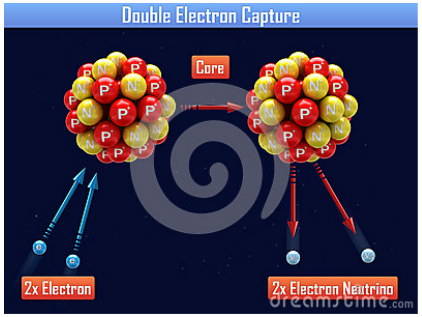


There are 35 double beta (and ECEC) emitters out of which are 6 double positron emitters

$$(T^{0\nu}_{1/2})^{-1} = G^{0\nu} g_A^4 \mid M^{0\nu} \mid^2 \left(\frac{\langle m_{ee} \rangle}{m_e} \right)^2$$







Depending on Q-value competing with double positron and EC/positron decay

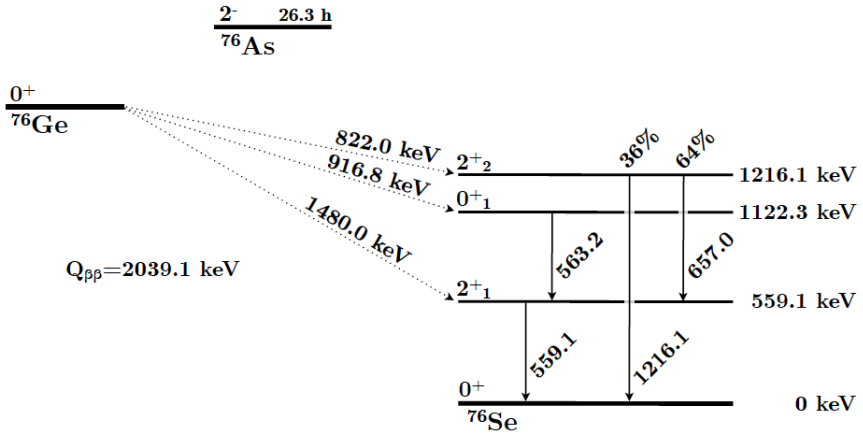
Both modes can occur with/without neutrinos
Also transitions into excited states possible

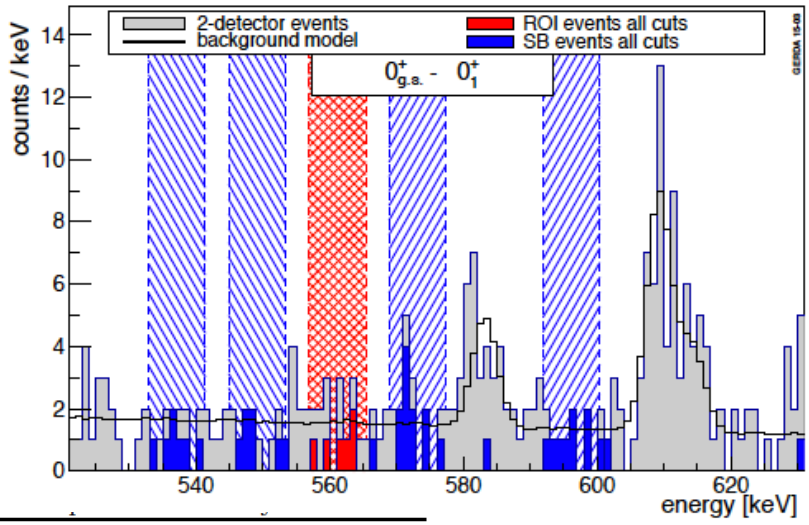
Excited state transitions

Only first excited 0^+ state has been seen in Mo-100 and Nd-150

See GERDA talk by K. Gusev

GERDA phase I : First (and only) multi-detector analysis in GERDA





Decay mode	n_k	m_k	ϵ_k [%]	Frequentist 90 % C.L. $T_{1/2}$ [10^{23} yr]	Frequentist 90 % C.L. $\widehat{T_{1/2}}$ [10^{23} yr]	Bayesian 90 % C.I. $T_{1/2}$ [10^{23} yr]	Bayesian 90 % C.I. $\widehat{T_{1/2}}$ [10^{23} yr]
$0^+_{g.s.} - 2^+_1$	2	10	0.389	> 1.6	> 1.3	> 1.3	> 1.2
$0^+_{g.s.} - 0^+_1$	5	34	0.919	> 3.7	> 1.9	> 2.7	> 1.8
$0^+_{g.s.} - 2^+_2$ branch 1	6	29	0.594	> 1.7	> 1.2	> 1.4	> 1.1
$0^+_{g.s.} - 2^+_2$ branch 2	0	2	0.092	> 0.74	> 0.64	> 0.49	> 0.46
$0^+_{g.s.} - 2^+_2$ combined	-	-	-	> 2.3	> 1.4	> 1.8	> 1.3

M. Agostini et al.,
J. Phys. G 42. 115201 (2015)

Excited state transitions

More measurements :

Nuclide	γ-energies	HL limit	Reference
$0/2\nu\beta\beta$ decays into excited states		Our measurements	
^{76}Ge	563.2 / 559.1 keV	$3.7 \cdot 10^{23}$ yrs (90% CL)	J. Phys. G: Nucl. Part. Phys. 42 115201 (2015)
^{110}Pd	815.3 / 657.8 keV	$4.0 \cdot 10^{21}$ yrs (90% CI)	arXiv:1606.06616[nucl-ex] , accepted
^{102}Pd	468.6 / 475.1 keV	$8.8 \cdot 10^{18}$ yrs (90% CI)	arXiv:1606.06616[nucl-ex] , accepted
^{74}Se	595.9 keV	$9.2 \cdot 10^{18}$ yrs (90% CI)	J. Phys. G: Nucl. Part. Phys. 43 085201 (2016)
^{136}Xe	760.5 / 818.5 keV	$6.9 \cdot 10^{23}$ yrs (90% CL)	Phys. Rev. C 93 035501 (2016)
^{130}Te	1257.5 / 536.1 keV	$1.3 \cdot 10^{23}$ yrs (90% CL)	Phys. Rev. C 85 045503 (2012)
^{74}Se	1196.7 keV	$9.6 \cdot 10^{18}$ yrs (90% CI)	J. Phys. G: Nucl. Part. Phys. 43 085201 (2016)

More half-life limits exist but almost always below 10^{20} years

Double EC and DPD

Theory prediction lacking for neutrinoless double EC:
- Internal bremsstrahlungs gamma (monoenergetic)
-Pair production in nuclear field
- Internal conversion

M. Doi, T. Kotani, Prog. Theo. Phys. 89,130 (1993)

(GERDA and our measurements)

Nuclide	γ-energies	HL limit	Reference
radiative 0νECEC decays			
^{36}Ar	429.9 keV	$3.6 \cdot 10^{21}$ yrs (90% CL)	arXiv:1605.01756[nucl-ex]
^{58}Ni	1918.3 keV	$2.1 \cdot 10^{21}$ yrs (90% CL)	J. Phys. G: Nucl. Part. Phys. 43 065201 (2016)
^{74}Se	1196.7 keV	$9.6 \cdot 10^{18}$ yrs (90% CI)	J. Phys. G: Nucl. Part. Phys. 43 085201 (2016)

Again more measurements exist

Resonances?

- $(A,Z) \rightarrow (A,Z-2) + 2\,e^+ (+2\nu_e)$ β+β+ $Q-4m_ec^2$
- $e^- + (A,Z) \rightarrow (A,Z-2) + e^+ (+2\nu_e)$ β+/EC $Q-2m_ec^2$
- $2\,e^- + (A,Z) \rightarrow (A,Z-2) (+2\nu_e)$ EC/EC Q

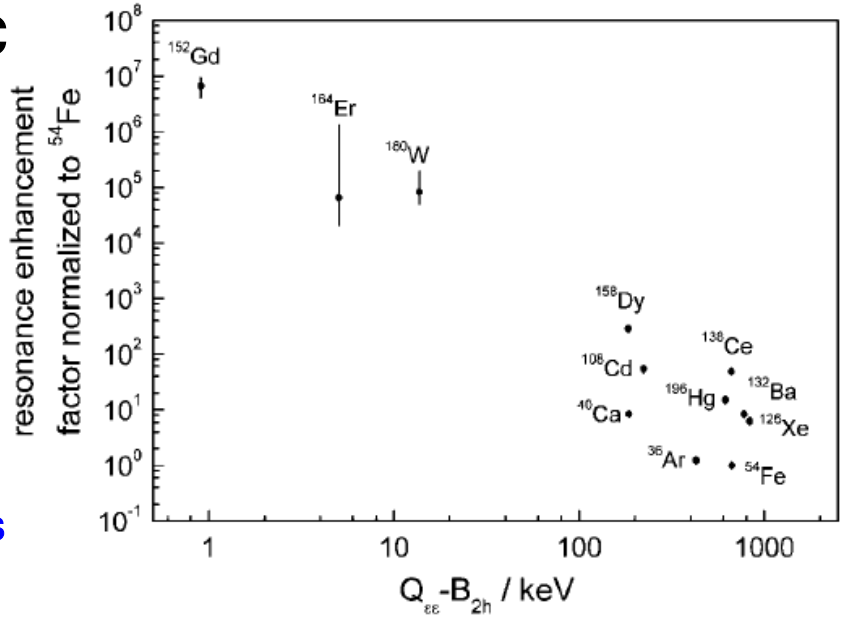
Enhanced if V+A is at work

M. Hirsch et al, Z. Phys. A 347,151 (1994)

Best candidate : 152Gd
measured with SHIPTRAP at GSI

Resonant enhancement (*10^6) of 0nu ECEC if excited state in daughter is degenerate (within 200 eV) with initial ground state (-> Q-values)

J. Bernabeu, A. deRujula, C. Jarlskog, Nucl. Phys. B 221,15 (1983)
S. Zujkoswski, S. Wycech, PRC 70, 052501 (2004)



Still not good enough to compete with neutrino mass bounds from double beta decay

S. Eliseev et al., Phys. Rev. Lett. 106,052504 (2011)

Summary

- Measurement of half-lives of long living nuclides is still interesting as some values are not as good as they look at first glance
- A new half-live measurement of Pt-190 has been obtained
- The EC-branch half-life of V-50 has been measured
- A new value for Ta-180m half-live is given
- Spectral shape searches in highly forbidden beta decay sounds interesting for learning about quenching of g_A
- Various new limits on excited states searches in double beta decay and in radiative double EC have been obtained
- Resonance enhancement for double EC into excited state seems to be realised in Gd-152, but still worse than neutrino mass searches in double beta decay