TECHNISCHE UNIVERSITÄT DRESDEN

Fakultät Mathematik und Naturwissenschaften, Institut für Kern- und Teilchenphysik

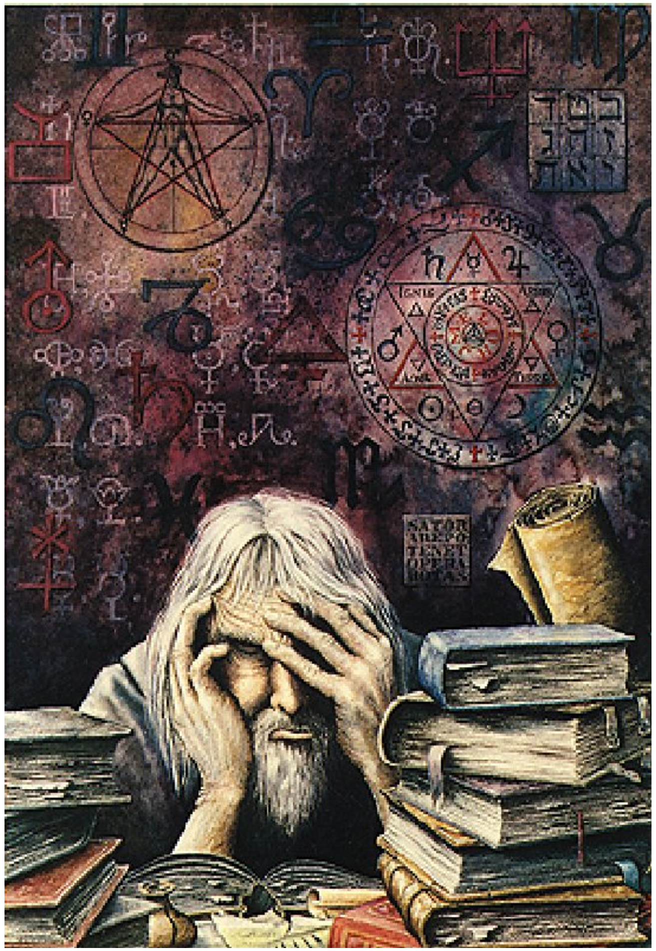
New half-live results on very long-living nuclei

29.9. 2016, NNR 2016 Osaka

Kai Zuber
Institut für Kern- und Teilchenphysik

DRESDEN concept

Contents

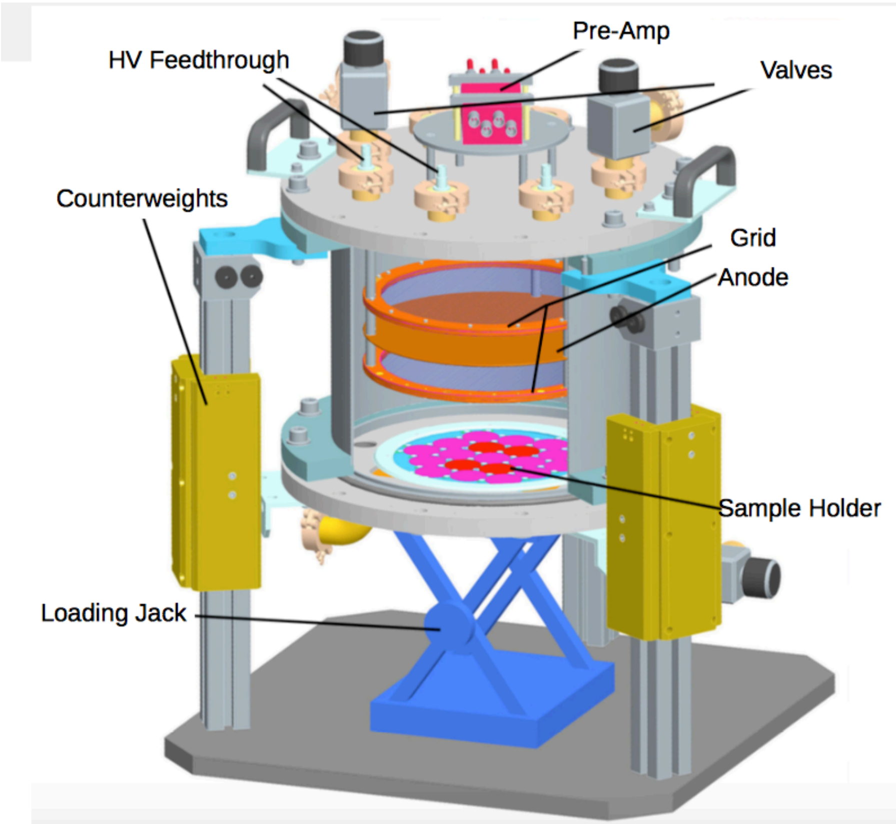


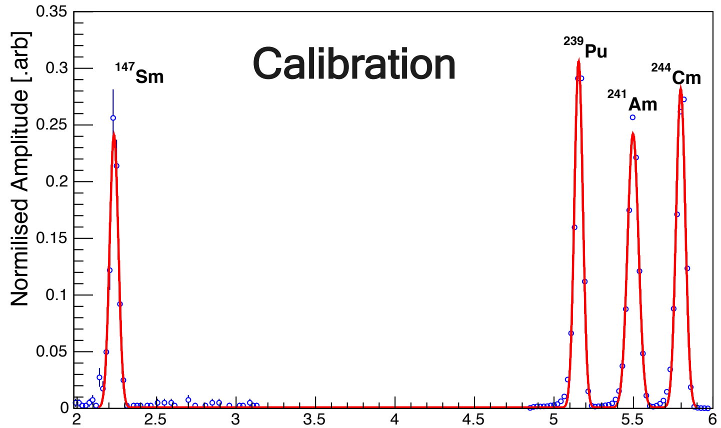
- A look on alpha decays
- Highly forbidden beta decays
- Double EC captures
- Double beta decays
- Nuclear astrophysics
- Summary

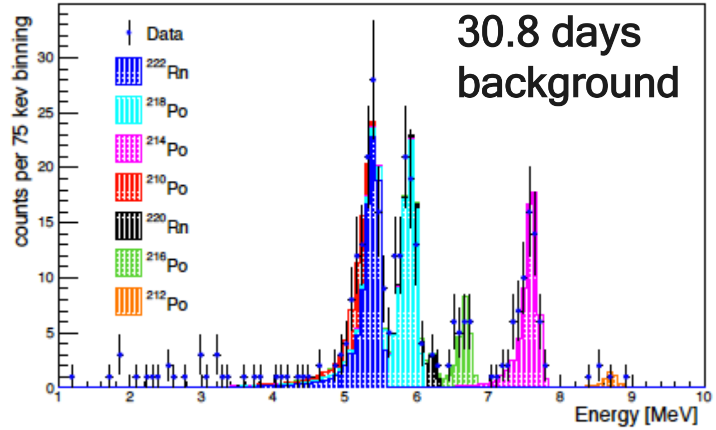
Alpha-decays

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 1 event per 2 days)





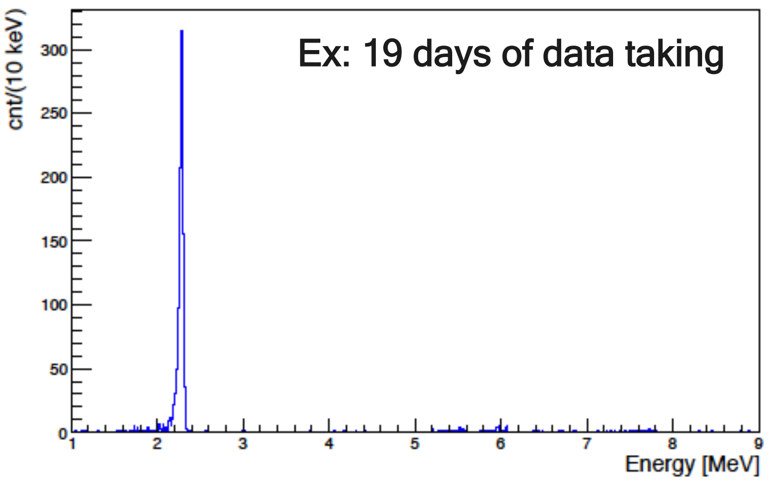


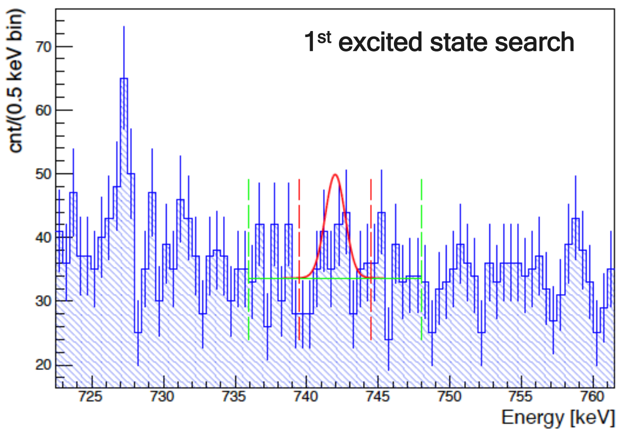
A. Hartmann, J. Hutsch, F. Krüger, M. Sobiella,H. Wilsenach, K. Zuber, NIM A 814, 12 (2016)

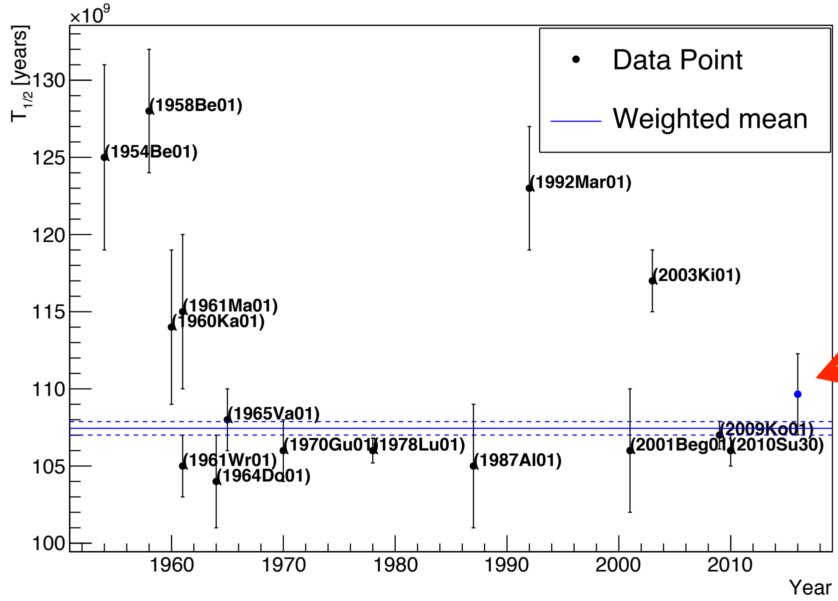
Alpha-decays – Sm147

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) x 10^{11} years

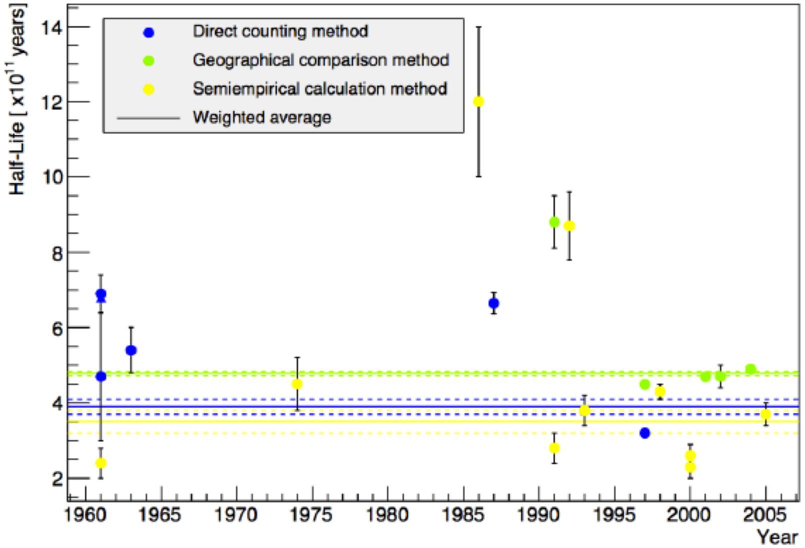
1st excit. state: $T_{1/2}$ > 3.1 10^18 years (90% CL)

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

Alpha-decays – Pt-190

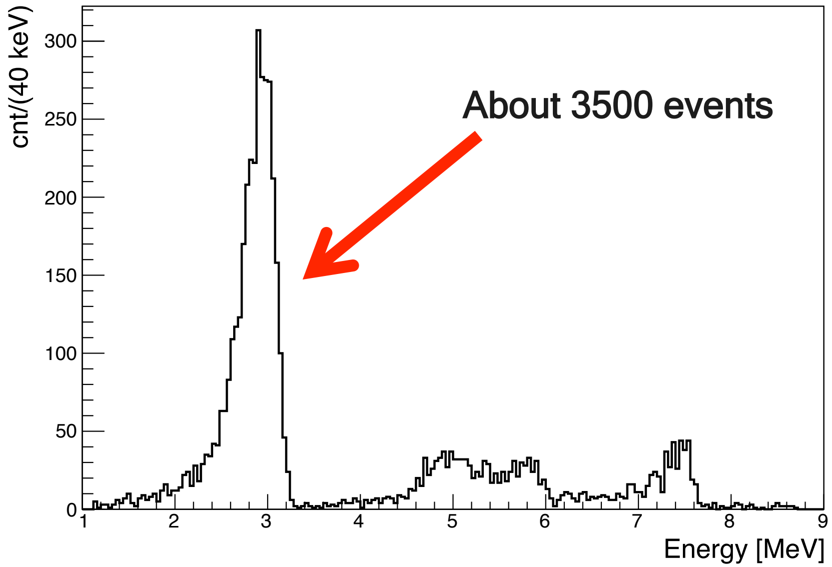
Abundance : 0.014%

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)

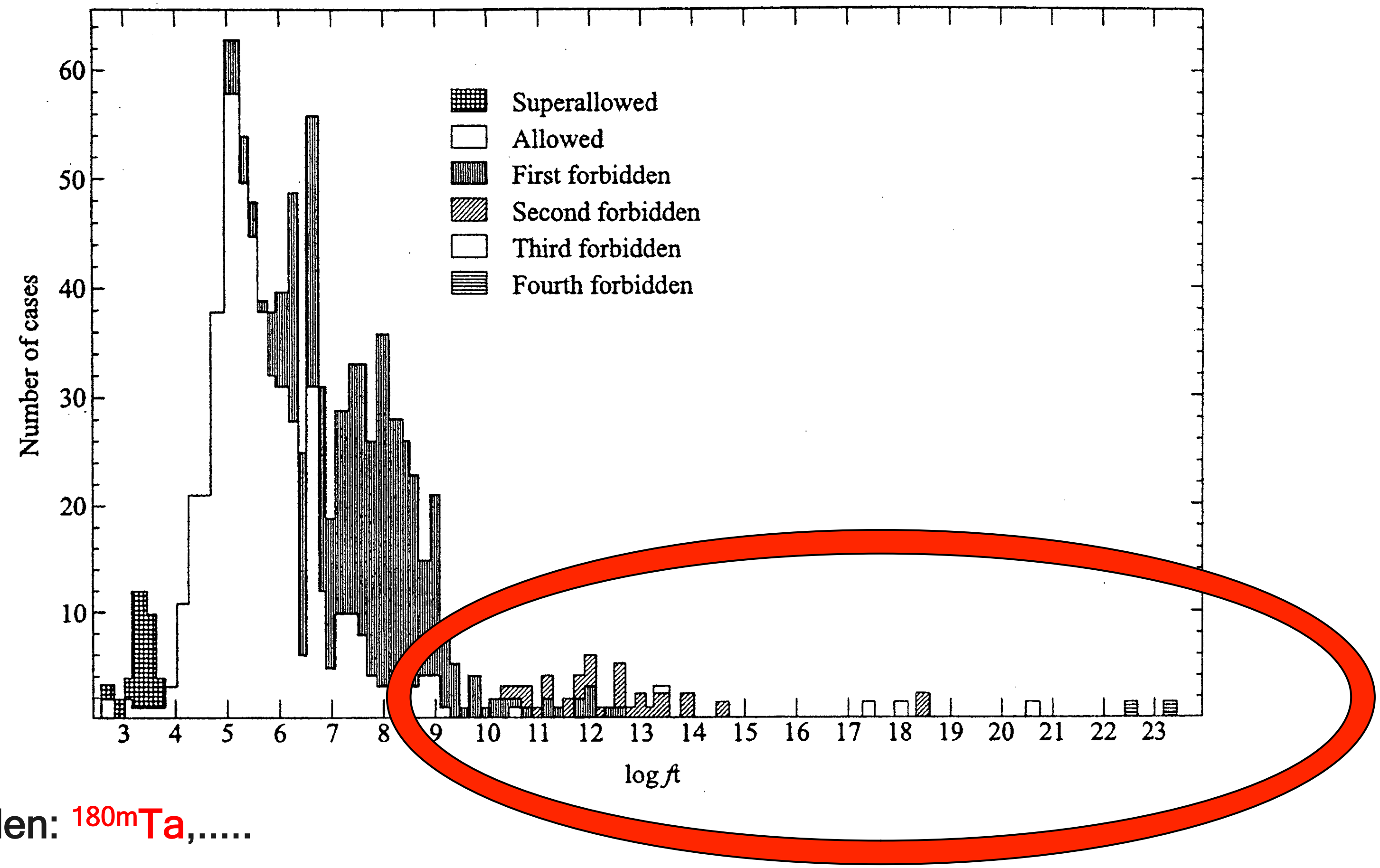


Latest theory: 2.78
Y. Qian, Z. Ren, PLB 738, 87 (2014)

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

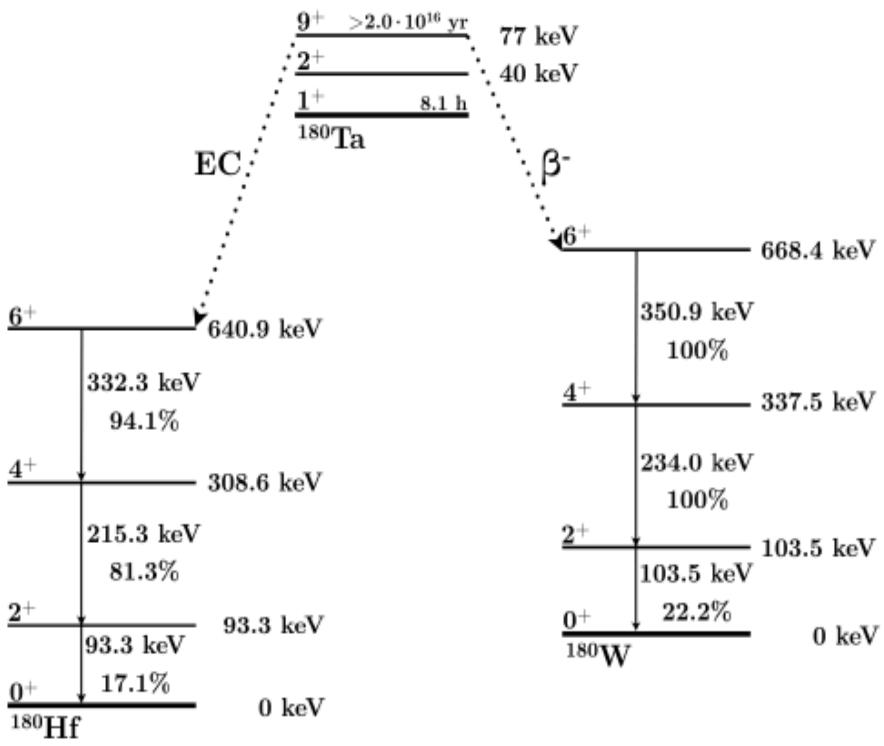
5-fold forbidden: ^{96}Zr, ^{48}Ca (in the range of double beta decay)

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)



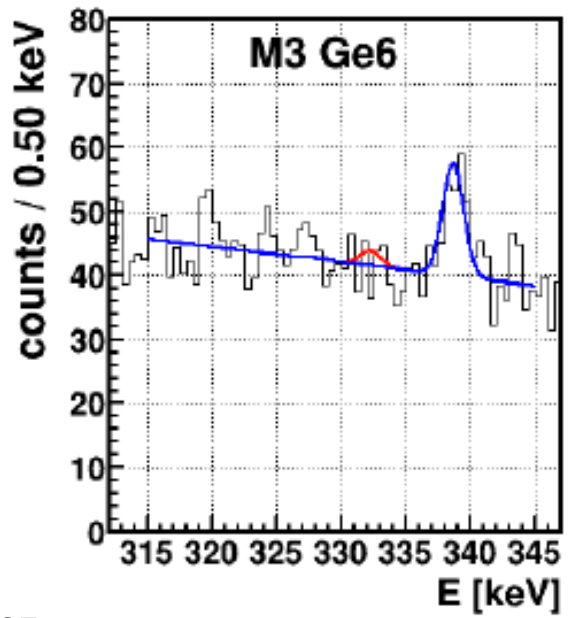
> 2 x10^{17} yrs

> 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

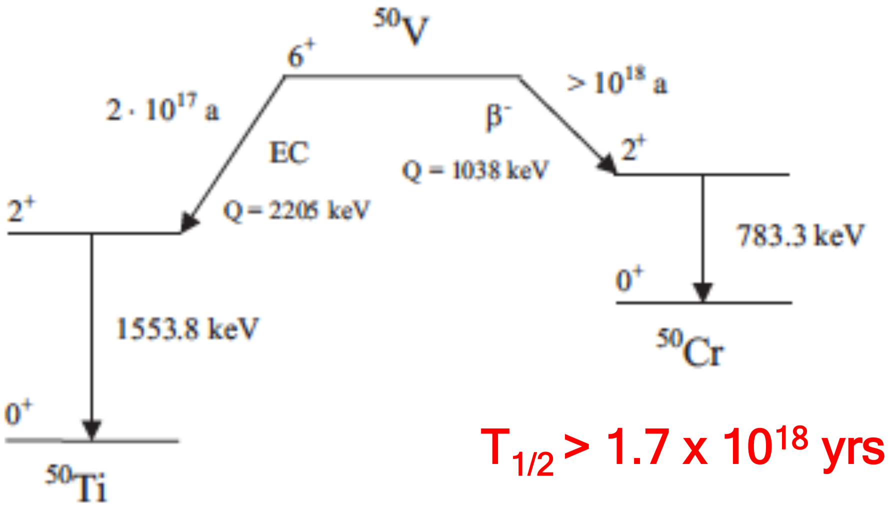
Example:



B. Lehnert, M. Hult, G. Lutter, K. Zuber, arXiv:1609.03725

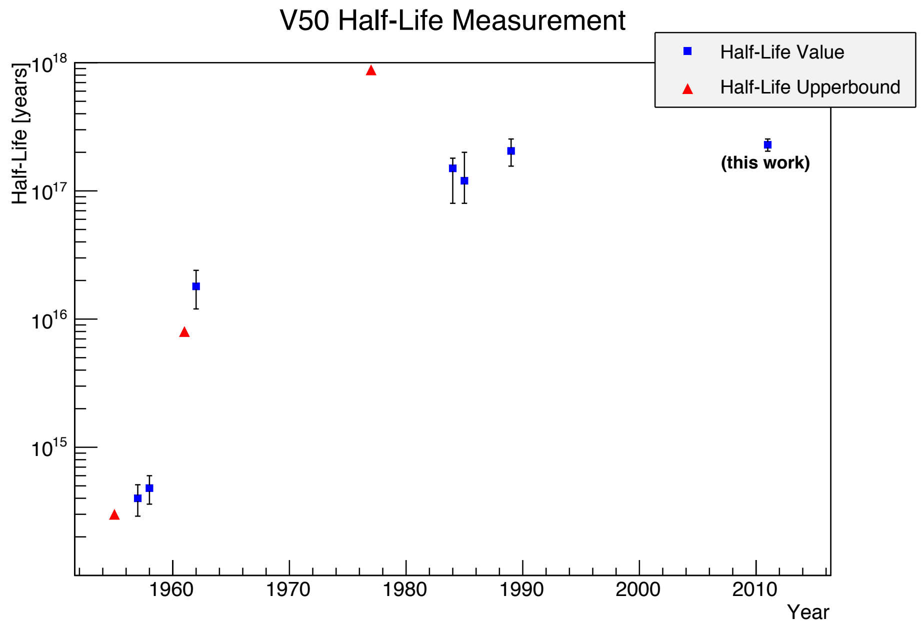
The case of V-50

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



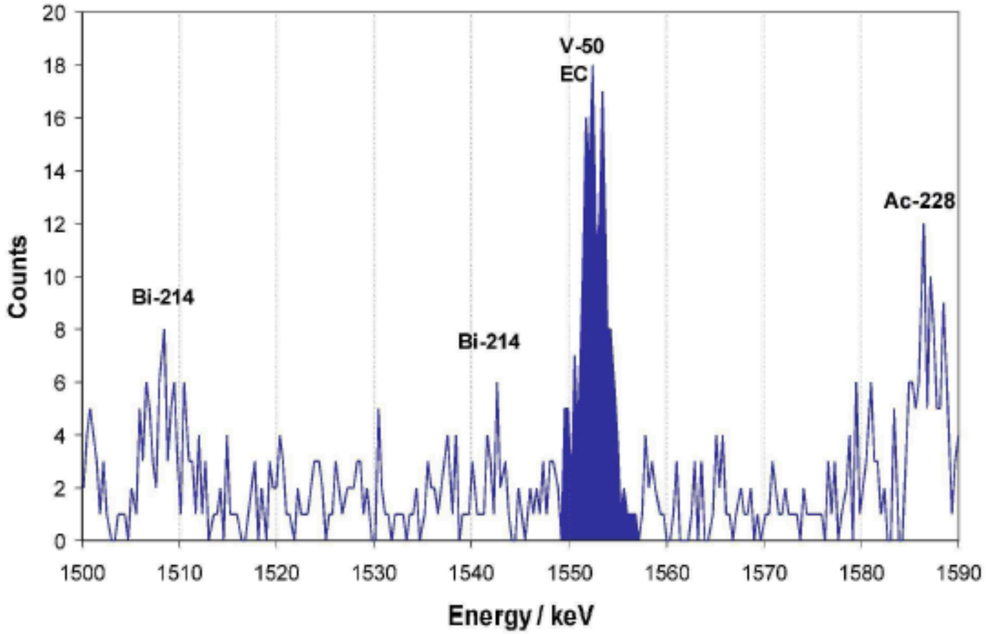
$T_{1/2} > 1.7 \times 10^{18}$ yrs

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



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)

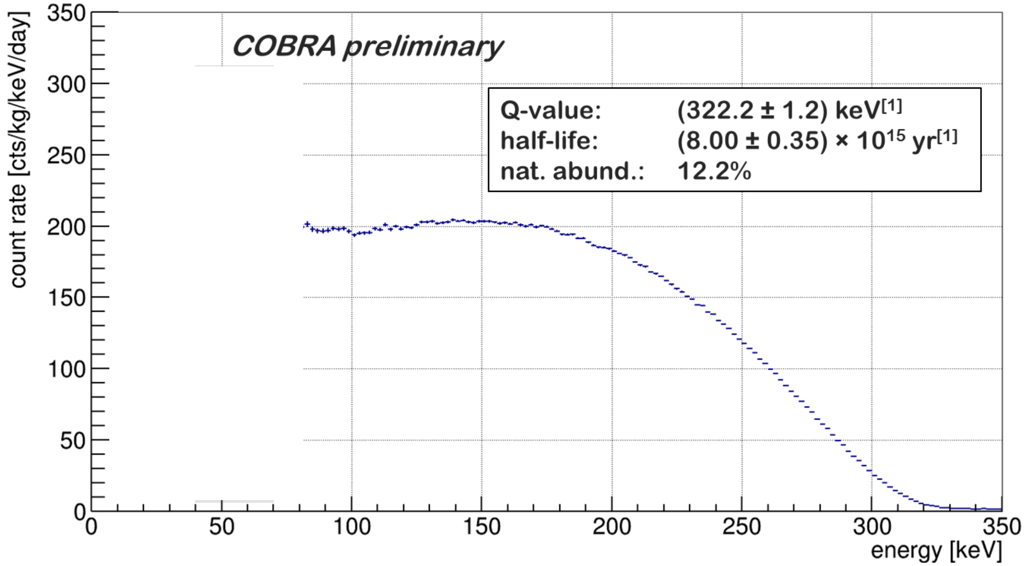
New measurement ongoing at LNGS: M. Laubenstein, S. Nagorny, K. Zuber in preparation

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)

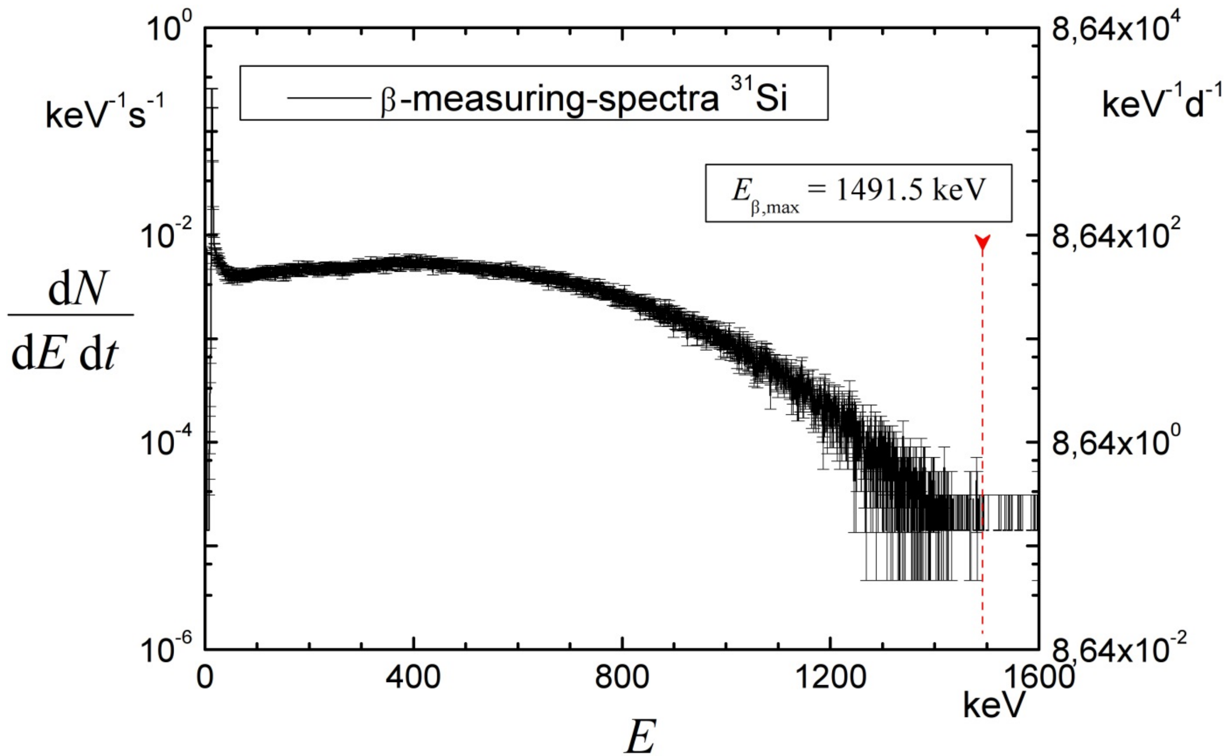
Half-life: $T_{1/2} = 8.00 \pm 0.11(stat.) \pm 0.24(sys.) \times 10^{15}$ years

64 independent measurements of the half-life!

Beta decay spectra

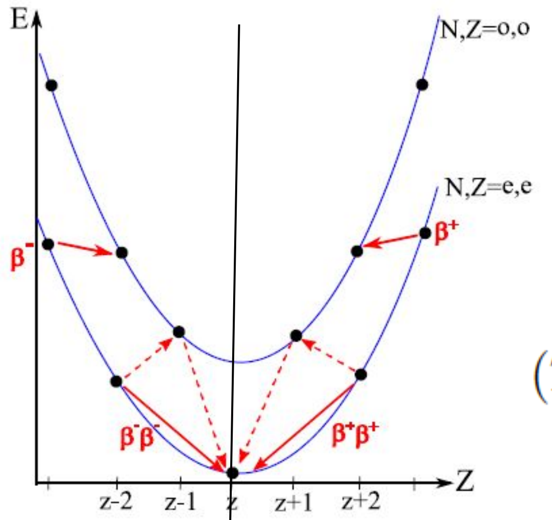
There is a general demand to measure beta spectrafor various reasons

High resolution, low background beta spectroscopy



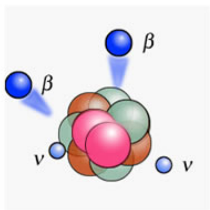
Double EC and DBD

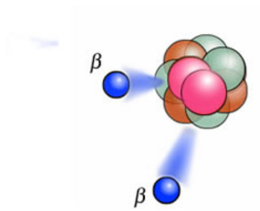
Mass parabola (isobar)

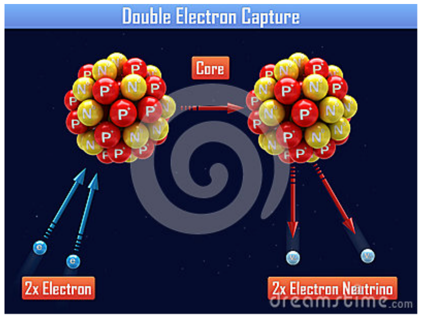


There are 35 double beta (and ECEC) emitters out of which are 6 double positron emitters

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







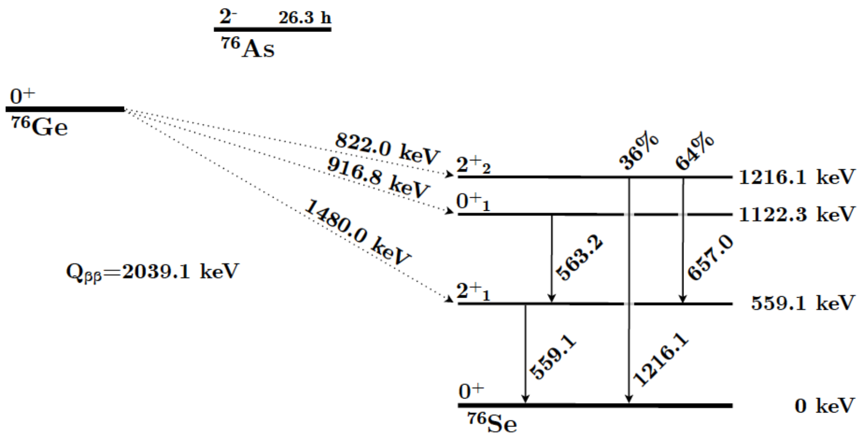
Depending on Q-value competing with double positron and EC/positron decay

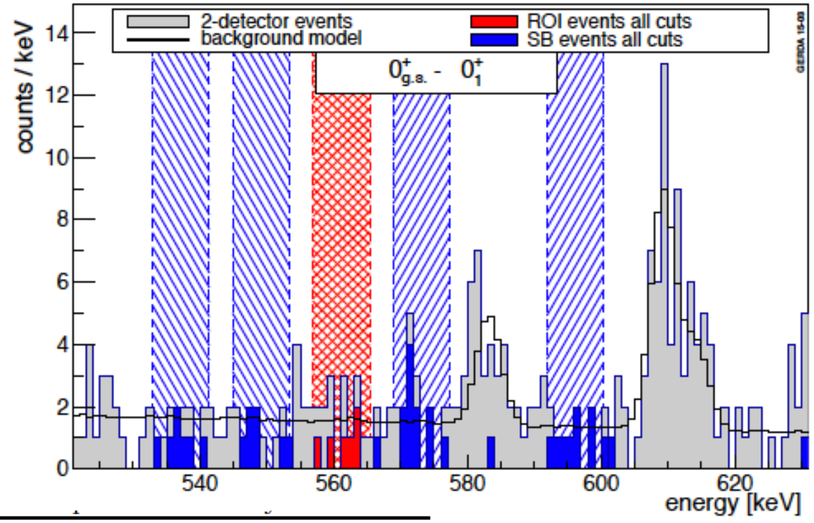
Both modes can occur with/without neutrinos
Also transitions into excited states possible

Excited state transitions

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

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
^{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)

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)

Again more measurements exist

Resonances ?

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

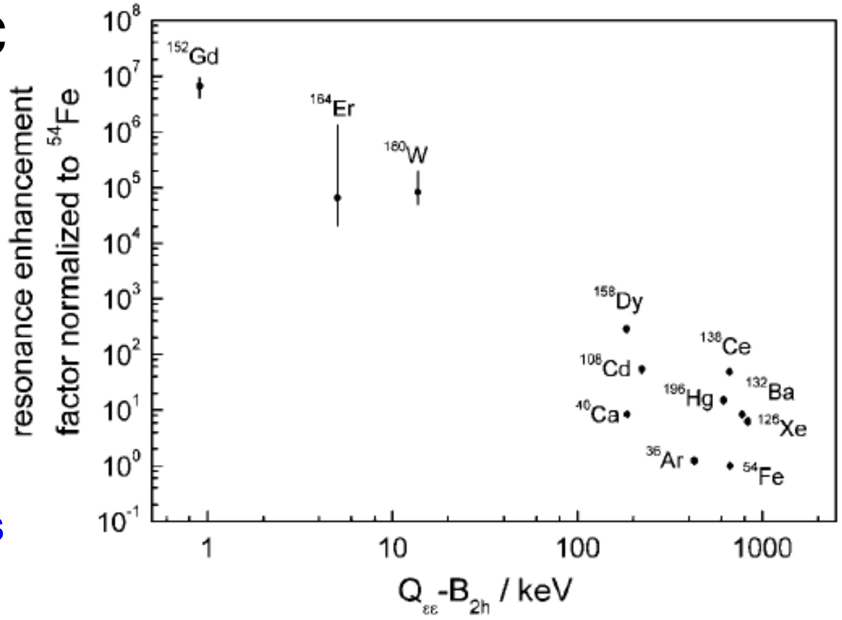
Enhanced if V+A is at work

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. Zujkoswki, S. Wycech, PRC 70, 052501 (2004)



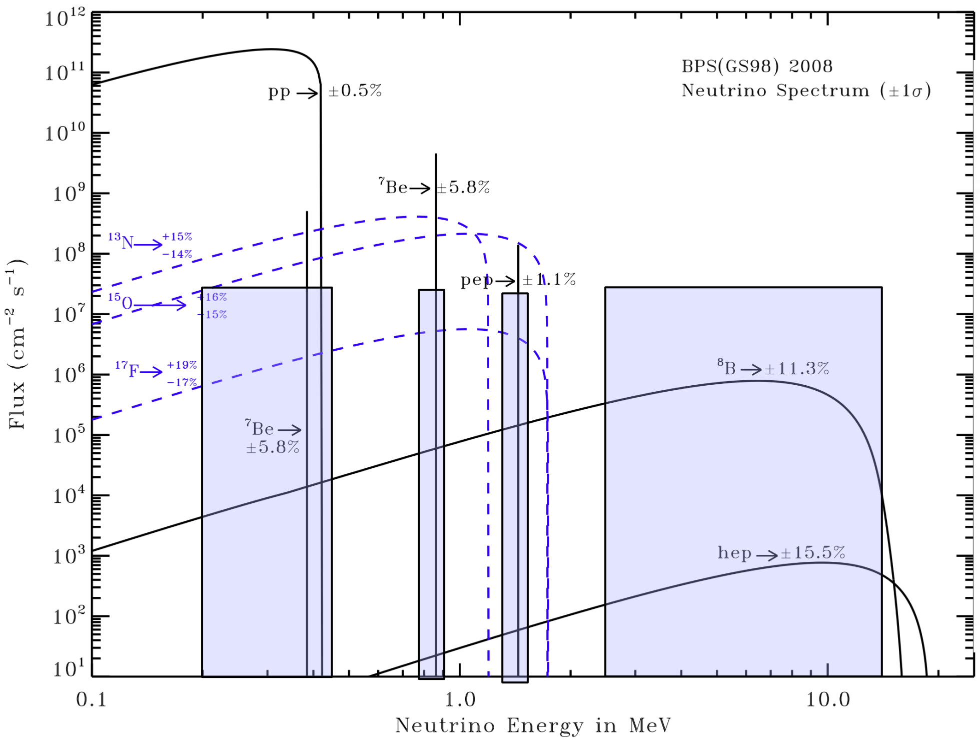
S. Eliseev et al., Phys. Rev. Lett. 106,052504 (2011)

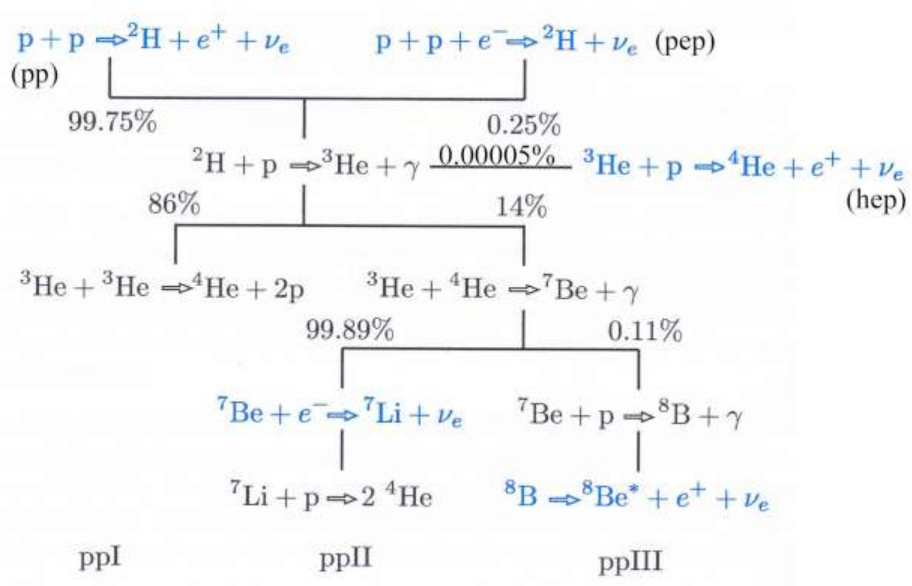
Still not good enough to compete with neutrino mass bounds from double beta decay

Solar neutrinos

Assumption: The Sun is producing energy via nuclear fusion

$$2e^- + 4p \rightarrow {}^4\mathrm{He} + 2\nu_e + 26.73\ \mathrm{MeV}$$





60 billion solar neutrinos penetrate us per cm^2 every second

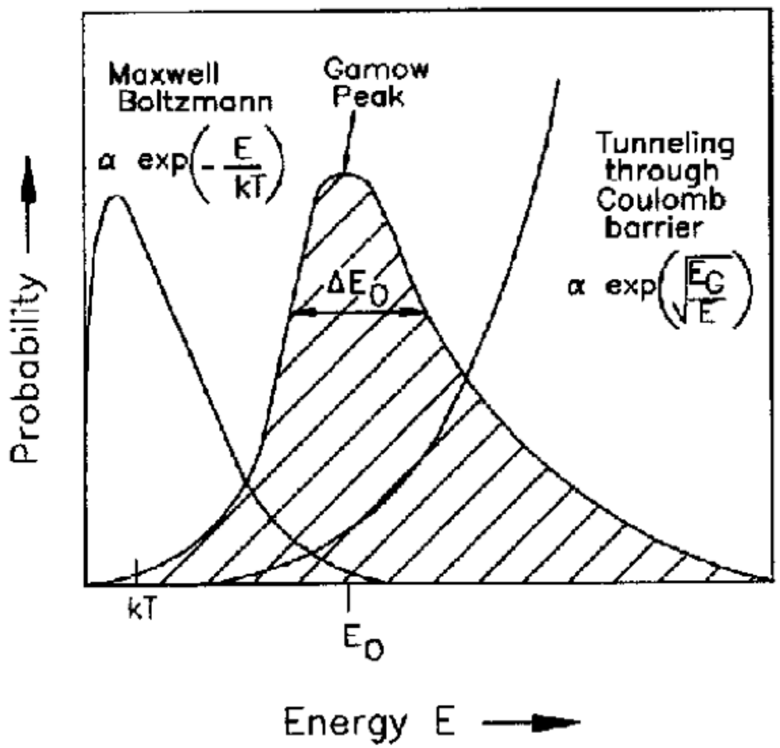
Not measured yet: CNO-neutrinos , hep-neutrinos

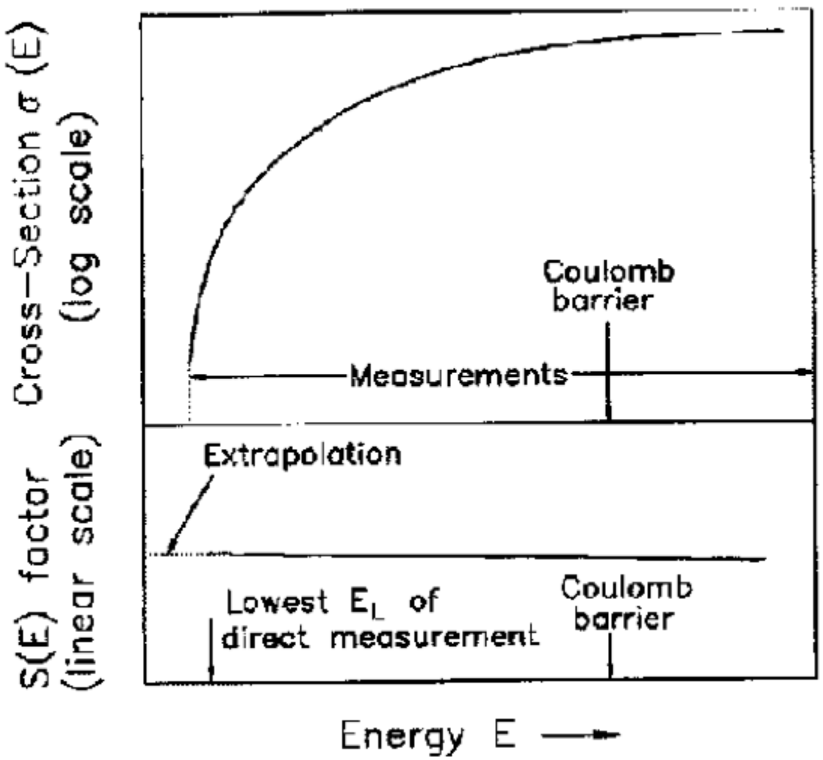
Fusion reactions

Charged particle reactions -> Coulomb barrier

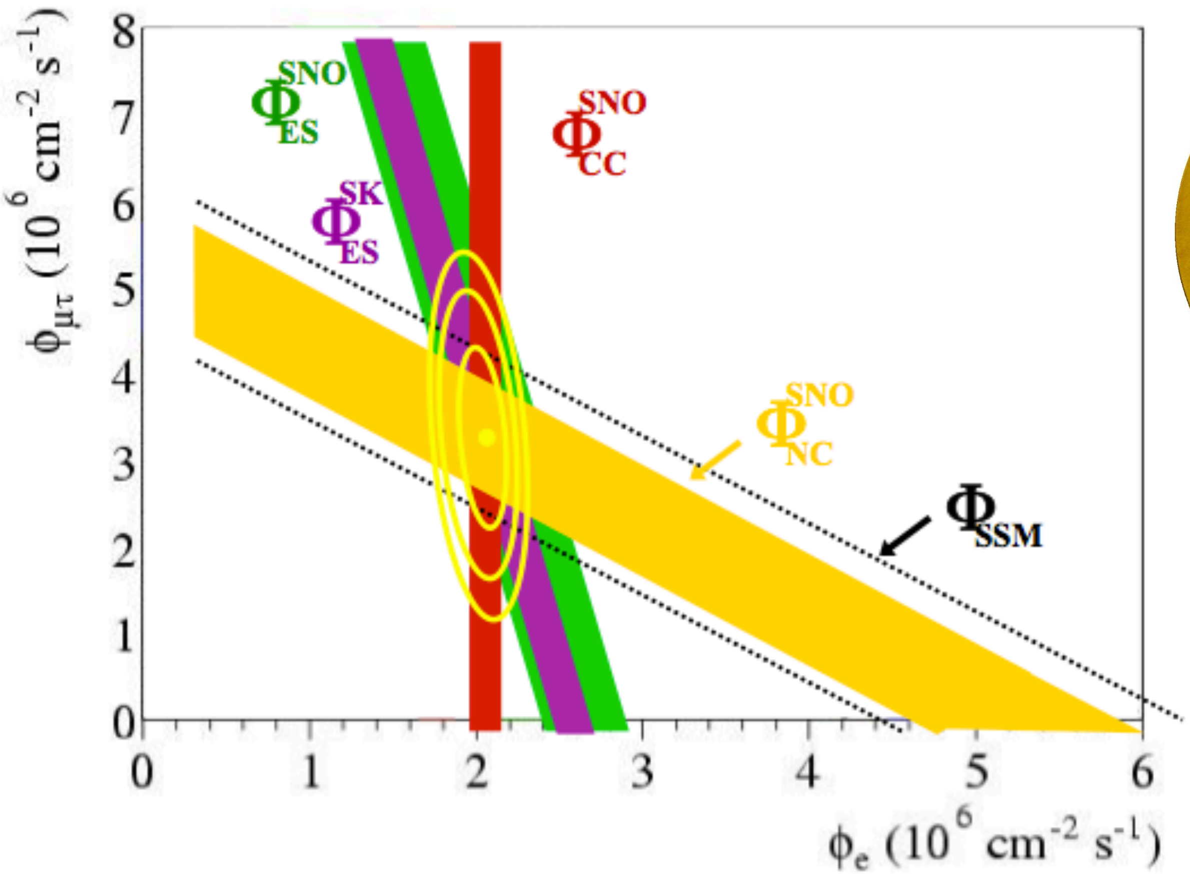
Compromise between Maxwell –Boltzmann distribution and tunneling probability

$$S(E) \equiv \frac{E}{\exp(-2\pi\eta)}\sigma(E)$$





Solar neutrinos - Felsenkeller



SNO for the first time neutrino flux measurements more precise than solar model predictions

Uncertainties

Nuclear reaction rates

	S_{11}	S_{33}	S_{34}	S_{17}	$S_{1,14}$	Opac	Diff
pp	0.1	0.1	0.3	0.0	0.0	0.2	0.2
pep	0.2	0.2	0.5	0.0	0.0	0.7	0.2
hep	0.1	2.3	0.4	0.0	0.0	1.0	0.5
^{7}Be	1.1	2.2	4.7	0.0	0.0	3.2	1.9
^{8}B	2.7	2.1	4.5	7.7	0.0	6.9	4.0
^{13}N	2.1	0.1	0.3	0.0	5.1	3.6	4.9
^{15}O	2.9	0.1	0.2	0.0	7.2	5.2	5.7
^{17}F	3.1	0.1	0.2	0.0	0.0	5.8	6.0

$^3He(\alpha,\gamma)^7Be$

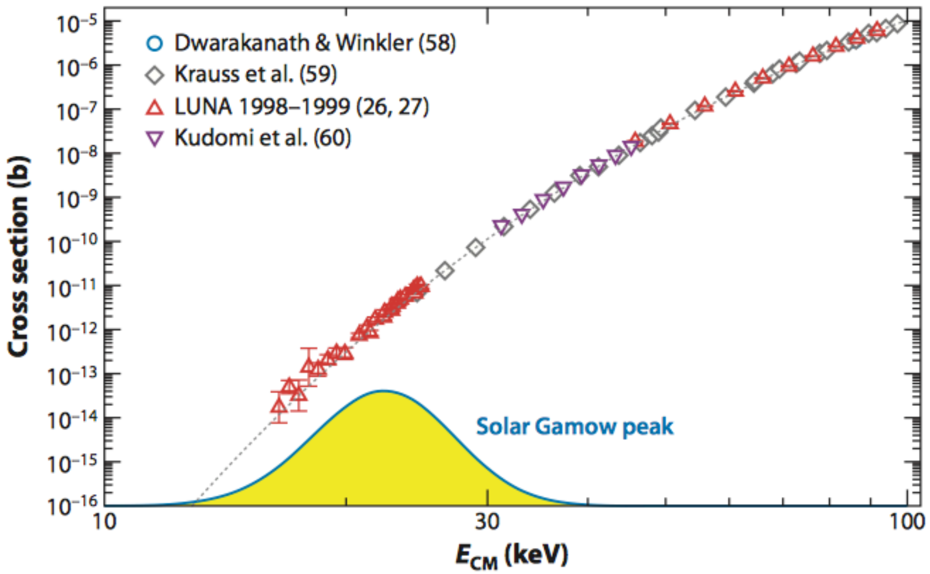
$^7Be(p,\gamma)^8B$

$^{14}N(p,\gamma)^{15}O$

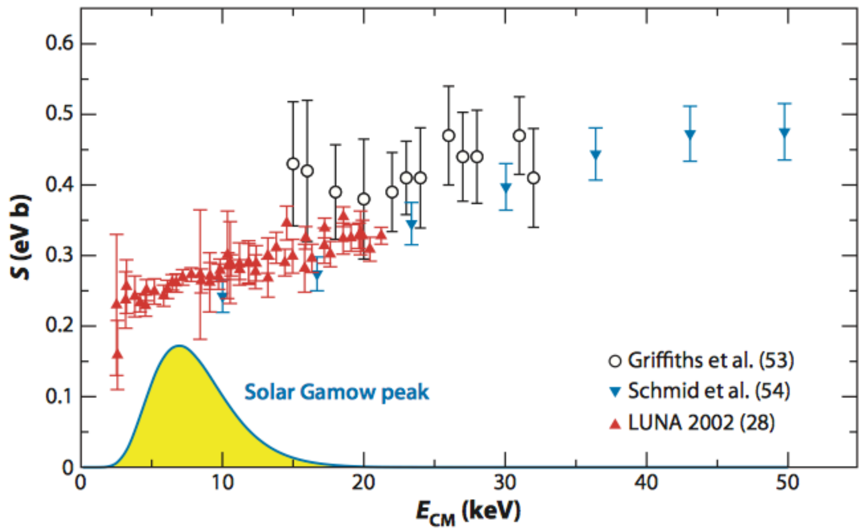
Unsicherheit im vorhergesagten Neutrinofluss, in Prozent

Antonelli et al., 1208.1356

$^3He(^3He,2p)^4He$

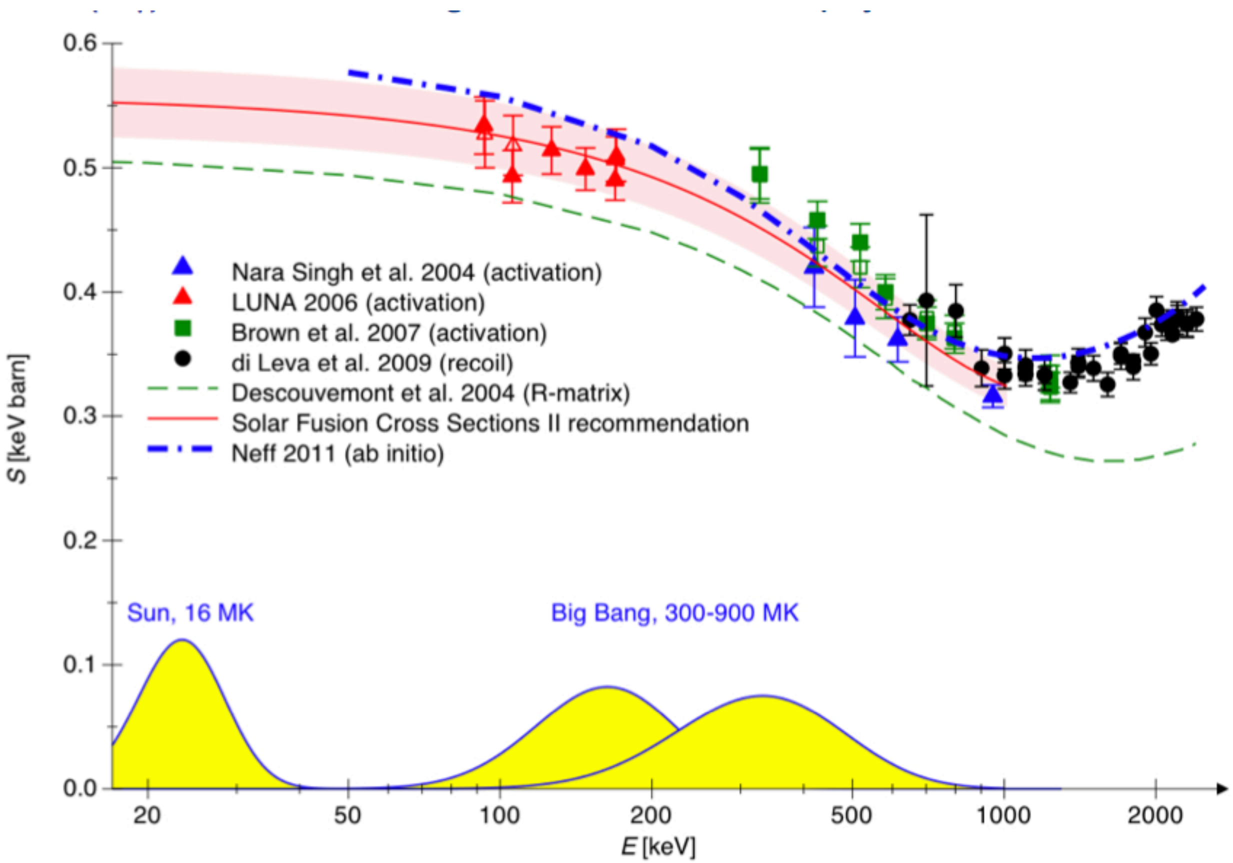


2H(p,γ)3He



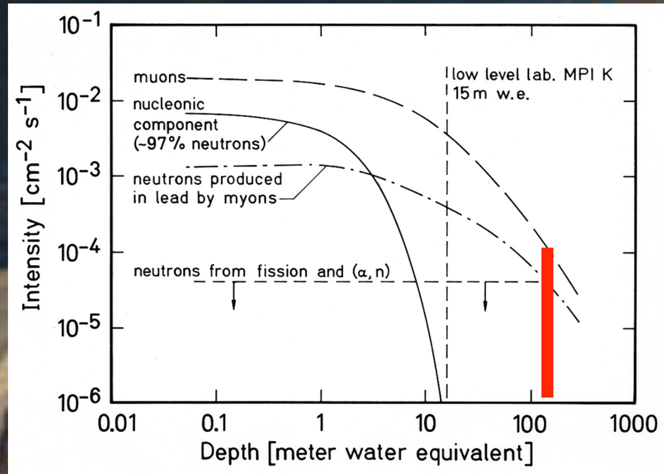
C. Broggini et al., Ann. Rev. Nucl. Part. Sci. 60,53 (2010)

$^{3}He(^{4}He,\gamma)^{7}Be$

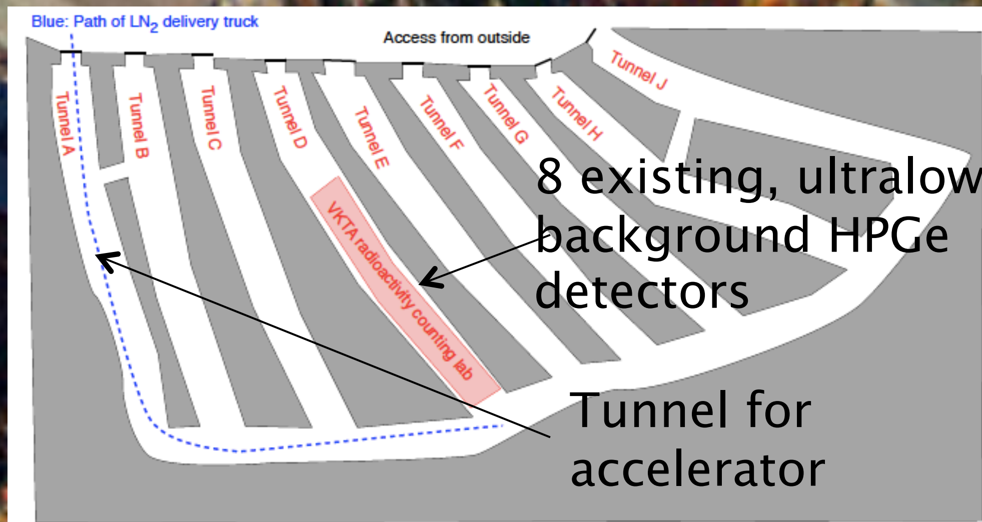


Felsenkeller Laboratory Dresden

T. Szücs et al., Eur. Phys. J. A 48,8 (2012)



We have the accelerator
We have the underground lab



Kai Zuber

Kai Zuber

Felsenkeller -accelerator

Felsenkeller - Status

- Accelerator will provide p, alpha and C beams

- Construction work on site has started one month ago

- Accelerator planned to go underground spring 2017

- „First light“ autumn 2017

Remember: it will be a user facility, i.e. there will be a Scientific Advisory Committee and everybody can send proposals

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

New facilities built to study long-living alpha decays, spectral shapes of beta decays and (soon) cross sections measurements using p, alpha, C - beams