TECHNISCHE UNIVERSITÄT DRESDEN

Fakultät Mathematik und Naturwissenschaften, Institut für Kern- und Teilchenphysik

Various aspects and results on beta decay, DBD, COBRA and LFV

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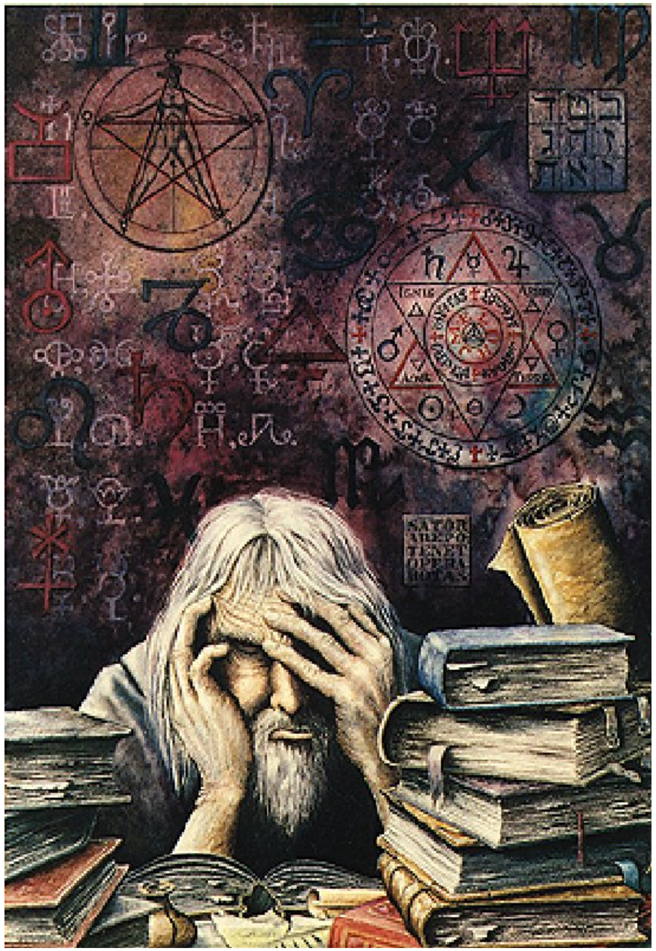
DRESDEN concept

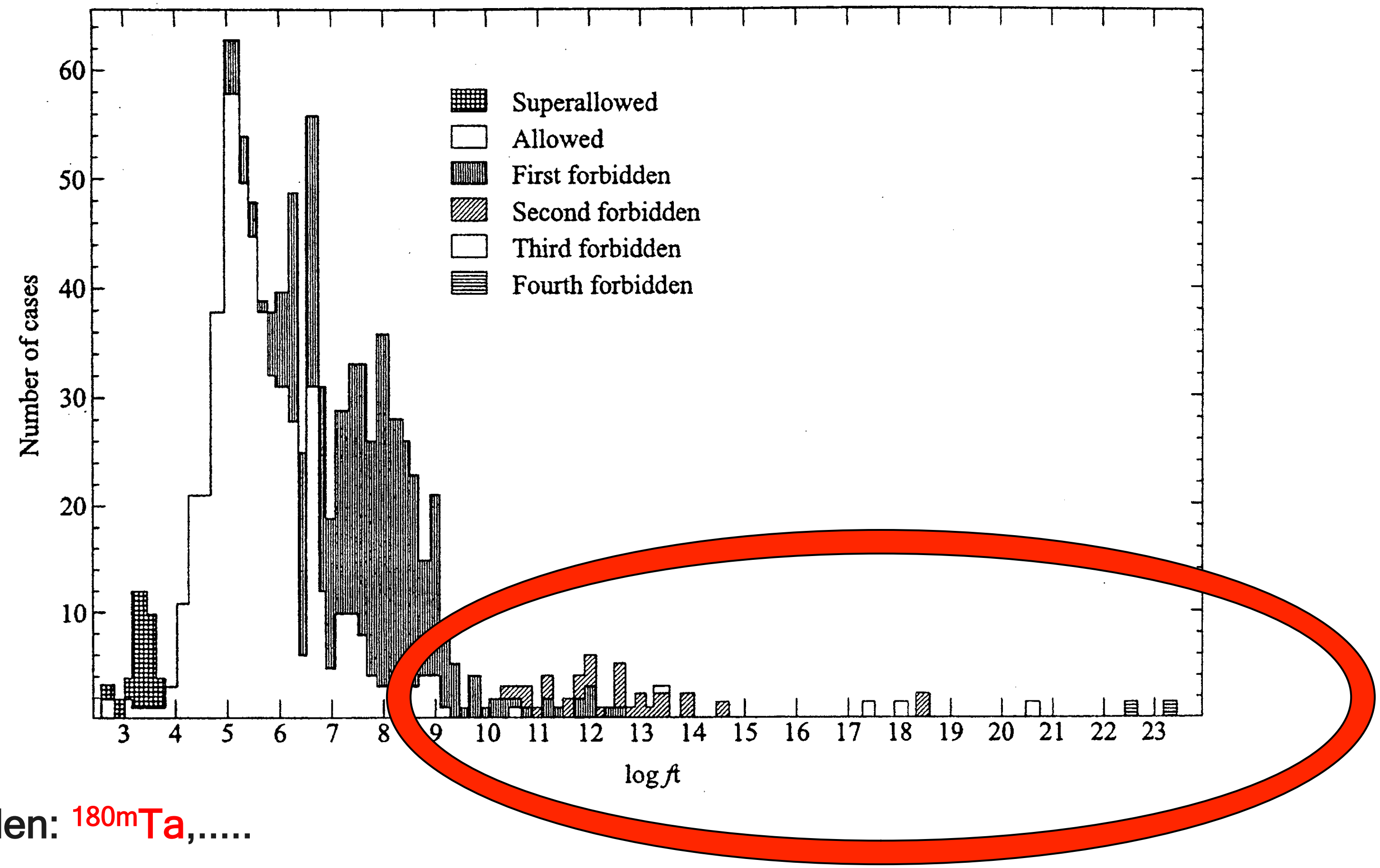
Contents



- ❖ Highly forbidden beta decays
- ❖ Double EC captures
- ❖ Various double beta decays
- ❖ Status of the COBRA experiment
- ❖ Charged lepton number violation
- ❖ Summary

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

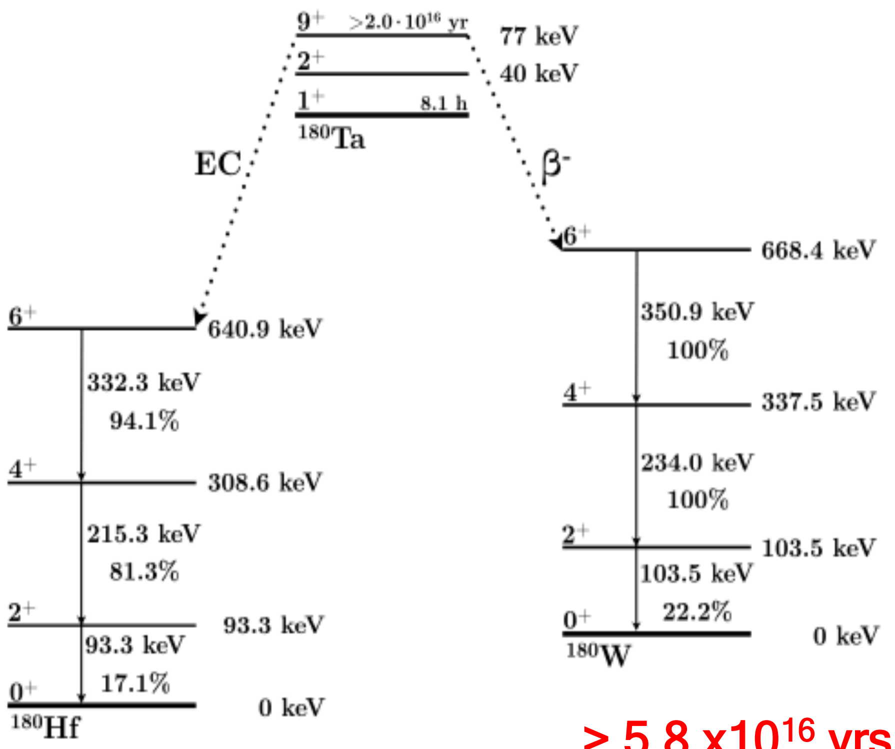
5-fold forbidden: ^{96}Zr, ^{48}Ca (in the range of double beta decay)

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)

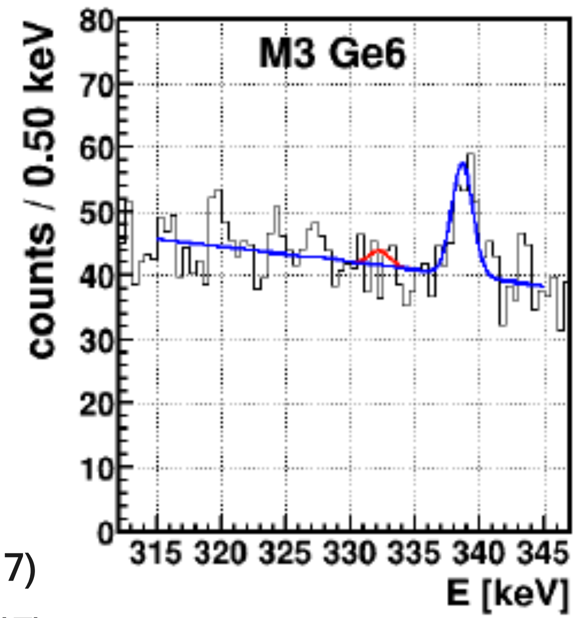


> 2 x10^{17} yrs

> 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:

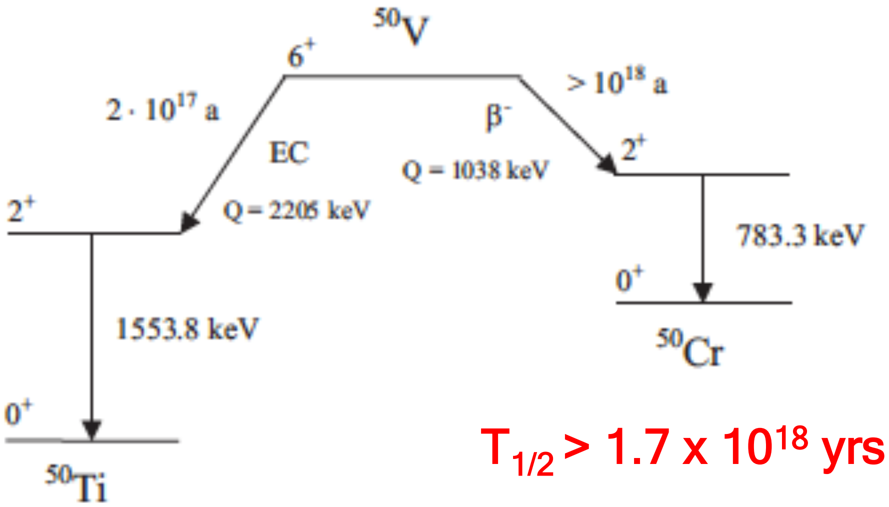


B. Lehnert, M. Hult, G. Lutter, K. Zuber, Phys. Rev. C 95, 044306 (2017)

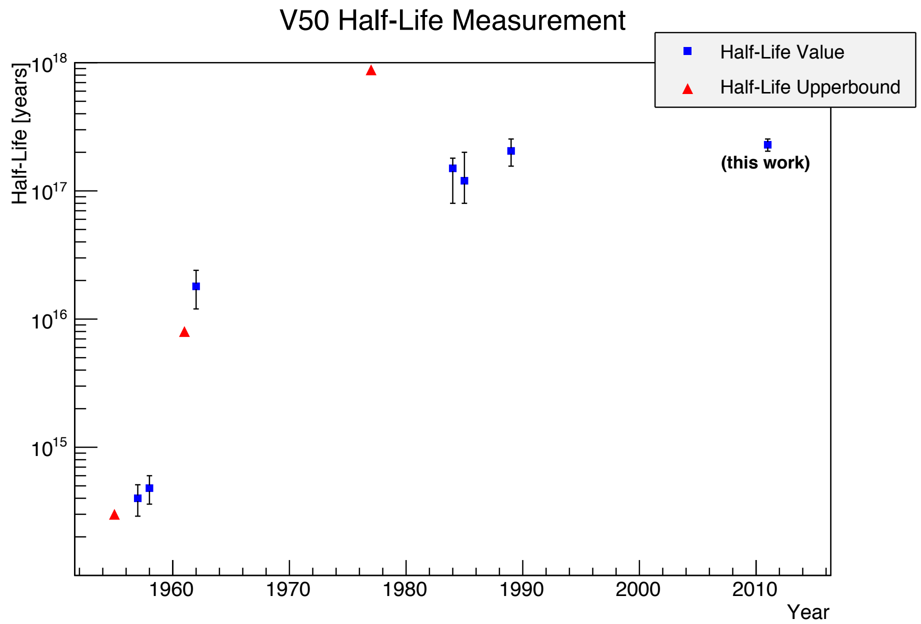
Calculation see H. Ejiri, T. Shima, J. Phys. G 44, 065101 (2017)

The case of V-50

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



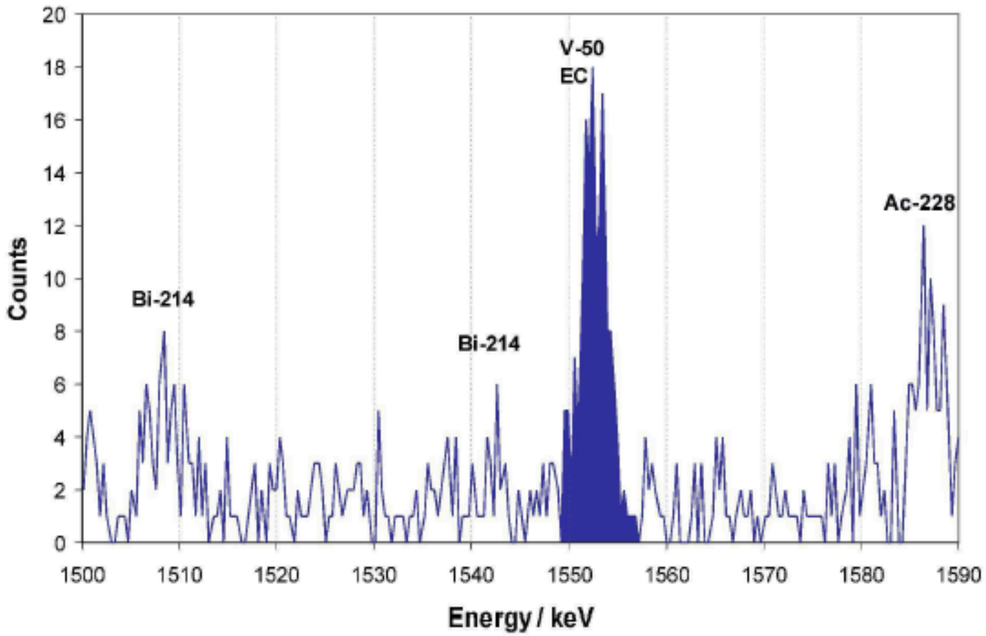
$T_{1/2} > 1.7 \times 10^{18}$ yrs



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

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

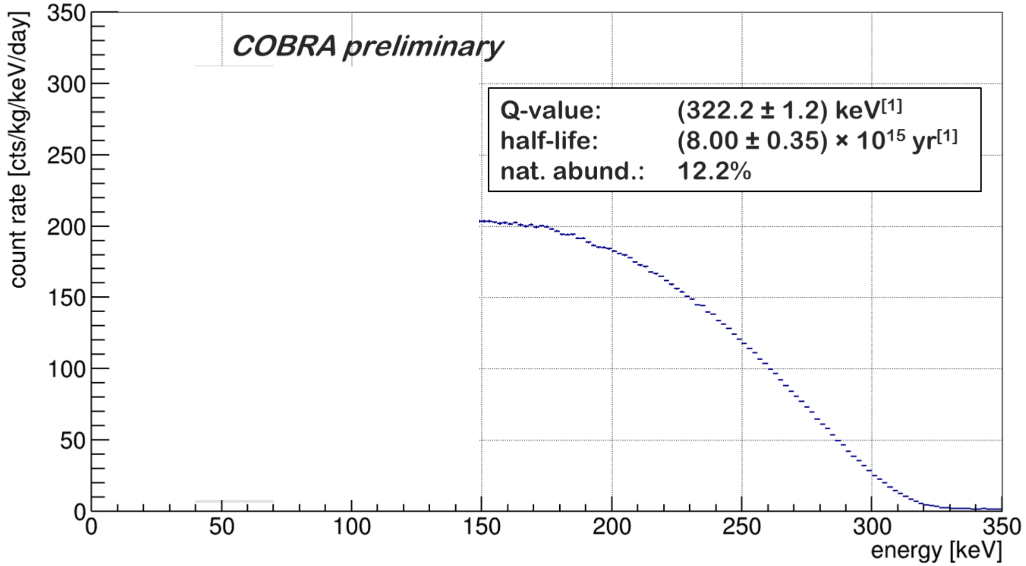
The case of ^{113}Cd

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

COBRA experiment (CdZnTe detectors)

113Cd

Preliminary



Q-value:

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

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)

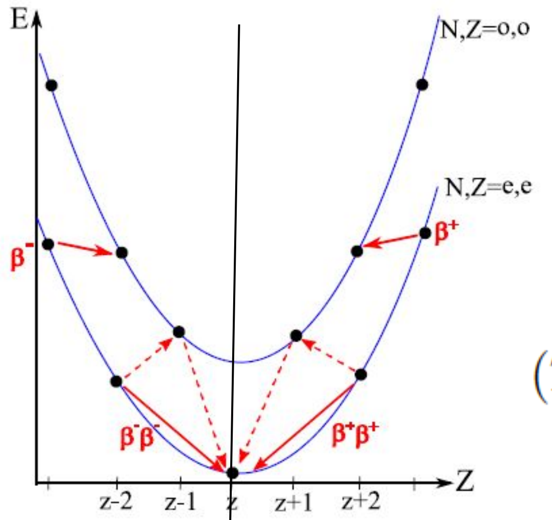
Shape depends on g_A

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

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

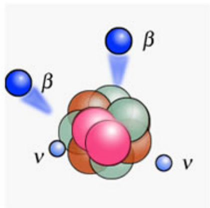
Double EC and DBD

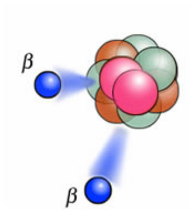
Mass parabola (isobar)

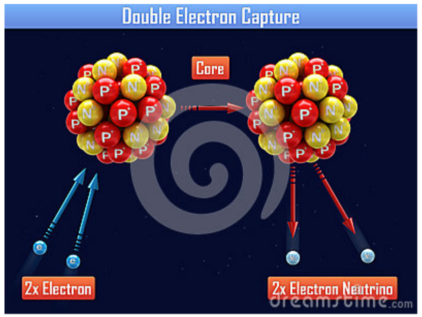


There are 35 double beta (and ECEC) emitters out of which are 6 double positron emitters

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







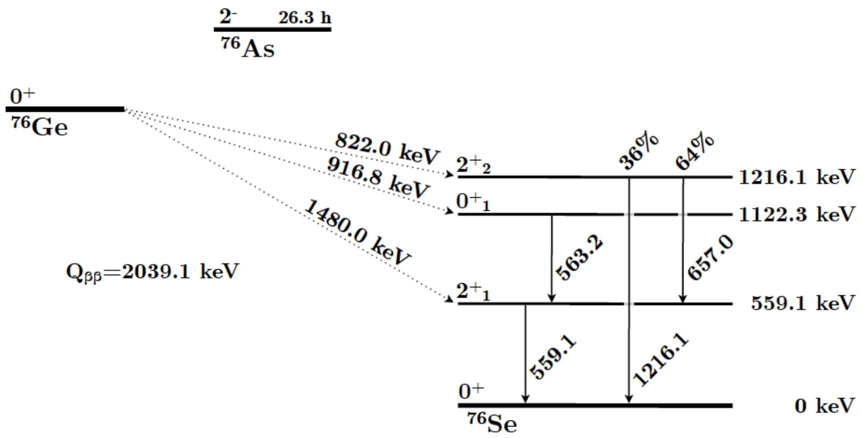
Depending on Q-value competing with double positron and EC/positron decay

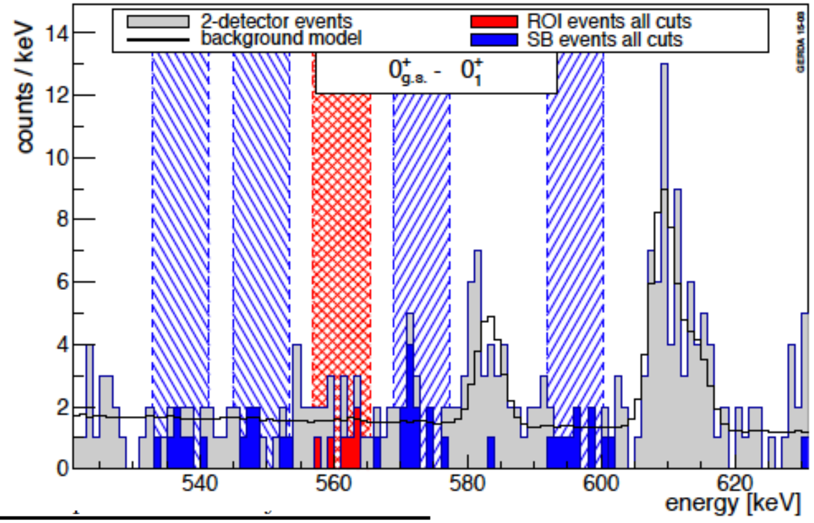
Both modes can occur with/without neutrinos
Also transitions into excited states possible

Excited state transitions

First excited 0^+ states have only 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

iktp

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)

J. Phys. G 43,115201 (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			Eur. Phys. J C 76, 652 (2016)
^{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

Double EC

Suggestion: Use LXe dark matter detectors for search ($^{124,126}Xe$)

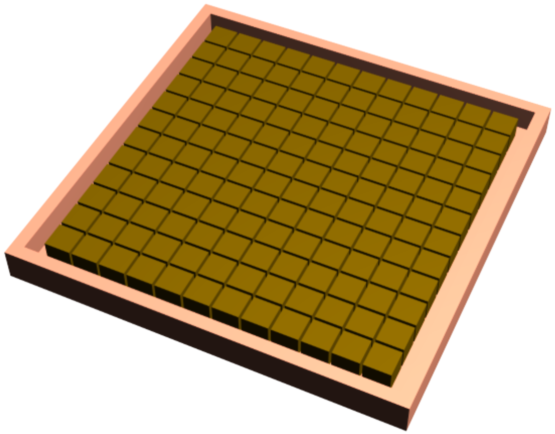
N. Barros, J. Thurn, K. Zuber, J. Phys. G 41, 115105 (2014)

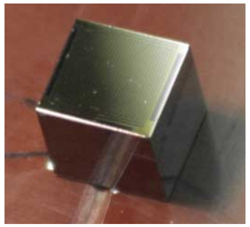
Xenon-collab: T > 6.5 10^{20} years, (124Xe) Phys. Rev. C 95, 024605 (2017)
XMASS-collab.: T > 4.7 10^{21} years (124Xe)
T > 4.3 10^{21} years (126Xe) , Phys. Lett. B 759,64 (2016)
Russian collab.: T > 2.1 10^{21} years (124Xe), Phys. Part. Nucl. 48, 38 (2017)

More to come - more data, larger detectors like DARWIN and others

COBRA

Use large amount of CdZnTe Semiconductor Detectors





Large array of CdZnTe detectors

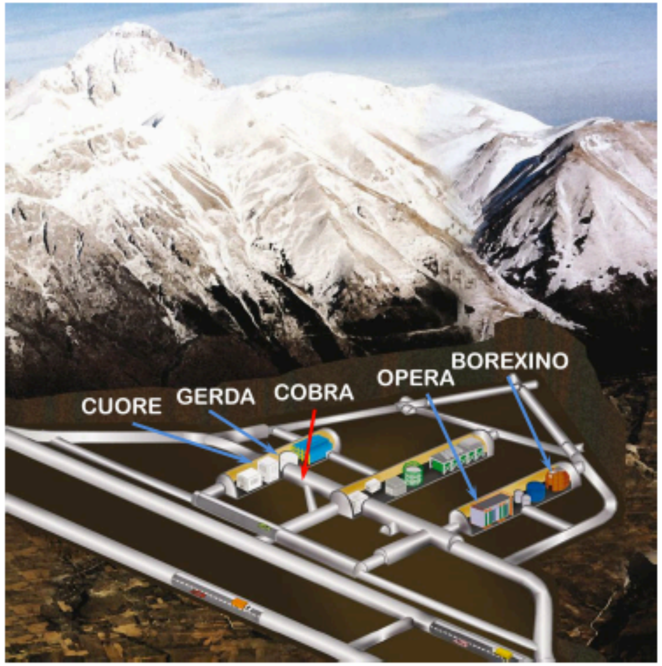
- Allows for searches of Te-130, Te-128, Zn-70, Cd-114, Cd-116 (two electrons)
- Allows for searches of Zn-64, Cd-106, Cd-108, Te-120 (positron/EC)

K. Zuber, Phys. Lett. B 519,1 (2001)

COBRA

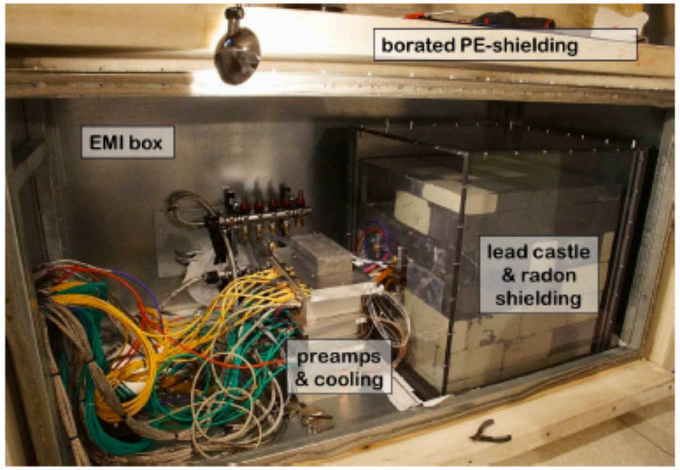
Courtesy of Stefan Zatschler

Operation at LNGS – deep underground



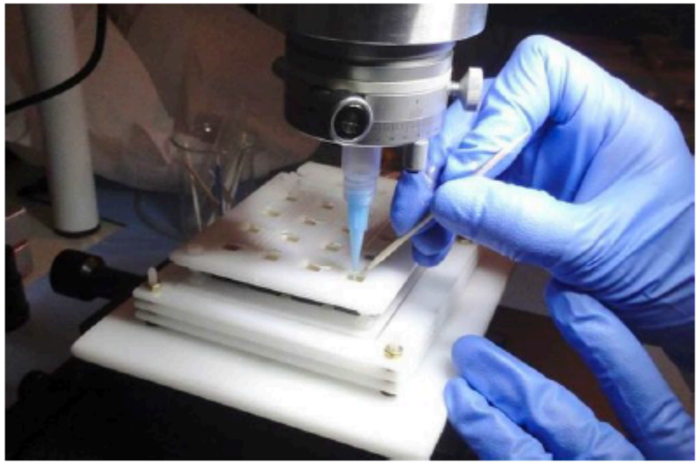
Outer shielding

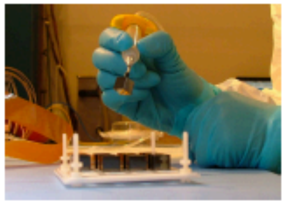
- 1400 m rock coverage (3700 m.w.e.)
- 7 cm boron-loaded polyethylene
- EMI box against electromagnetic interference
- Radon shield and dry N_2-flushing

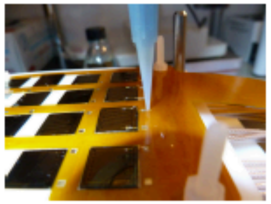


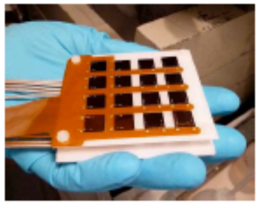
COBRA

On-site detector layer assembly at LNGS



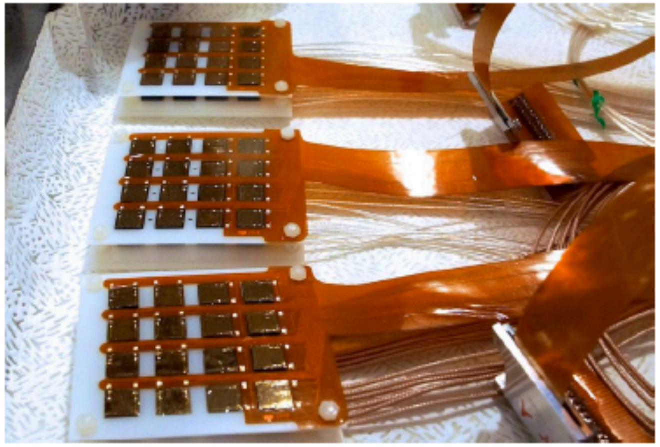


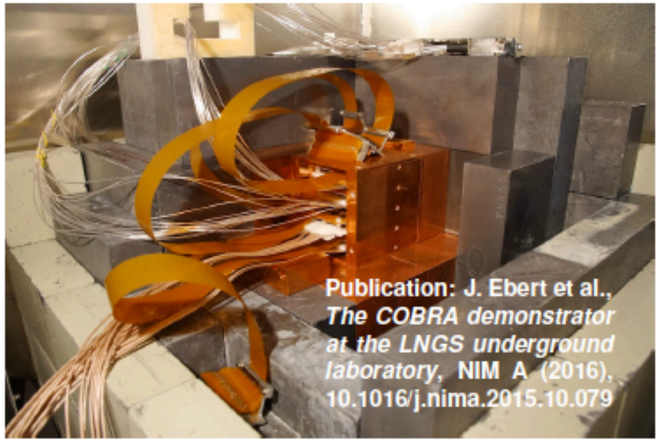




Inner shielding

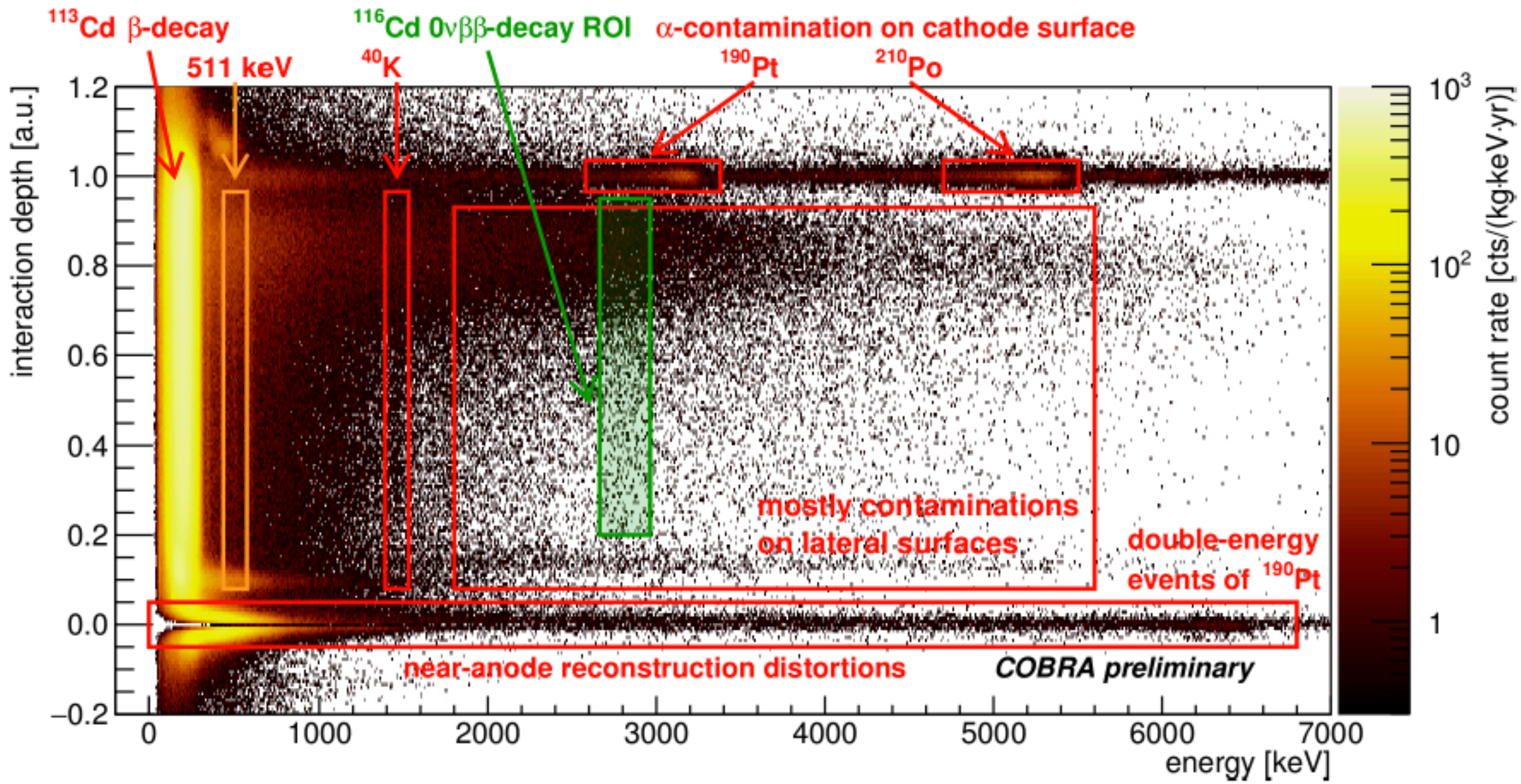
- 5 cm of low level alpha lead (A<3 Bq/kg) and 15 cm standard lead (total 2.3 t)
- nest: 5 cm thick electro-formed copper
  - → setup completed in Nov. '13



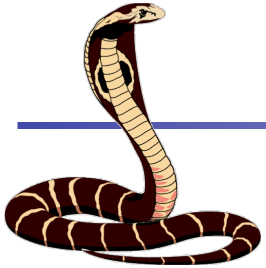


COBRA

Identified background features



Results: PRC



COBRA

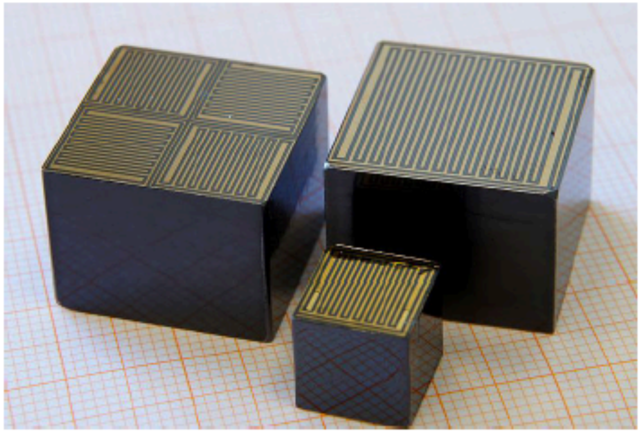
Obtained limits

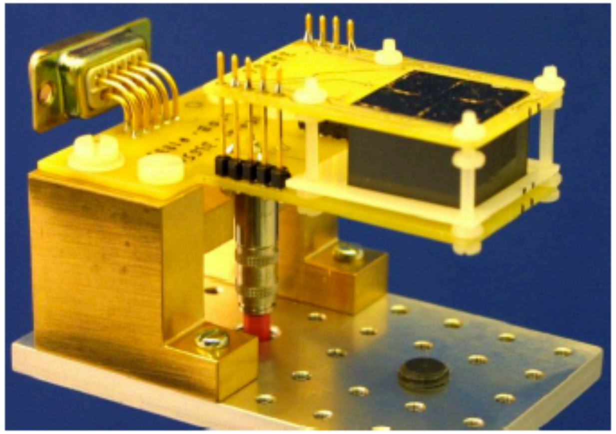
isotope	COBRA‘09	COBRA‘13	COBRA‘15
^{114}Cd	2.0×10^{20}	1.06×10^{21}	**2.27×10^{21}**
^{128}Te	1.7×10^{20}	1.44×10^{21}	**2.39×10^{21}**
^{70}Zn	2.2×10^{17}	2.57×10^{18}	**6.12×10^{18}**
^{130}Te	5.9×10^{20}	3.88×10^{21}	**8.85×10^{21}**
^{116}Cd	9.4×10^{19}	9.19×10^{20}	**1.52×10^{21}**

J. Ebert et al., Phys. Rev. C 94, 024603 (2016)

COBRA

The next stage – COBRA XDEM





- switch to larger crystals $(2.0\times2.0\times1.5)\,cm^3$ (36 g per detector)
  - → higher detection efficiency
  - → reduces surface contribution due to smaller surface-to-volume ratio
- concentrate on quad-CPG approach – hybrid of CPG and pixel detector
  - → improve detector yield, reduce costs
  - → possibility of sub-grid vetoing
  - → detection of in-plane MSEs
- design and build detector module consisting of $9\times6\,cm^3$ CZTs

Publication: J. Ebert et al., *Characterization of a large CdZnTe coplanar quad-grid semiconductor detector*, NIM A (2016), 10.1016/j.nima.2015.09.116

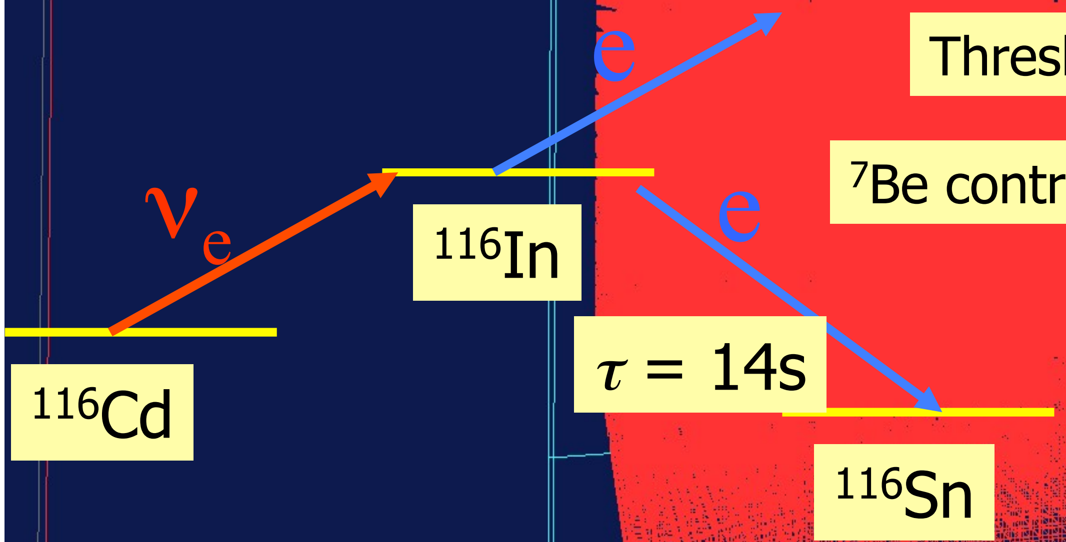
Status: 9 detectors ordered (doubles mass), 4 have arrived, installation autumn 2017

A REAL large scale experiment

A real time low-energy solar neutrino and Supernova experiment?

Threshold energy: 464 keV

^{7}Be contribution g.s. alone: 227 SNU



K. Zuber, Phys. Lett. B 571,148 (2003)
(^{3}He,t) Beamtime at RCNP last year

Charged lepton flavour violation (CLFV)

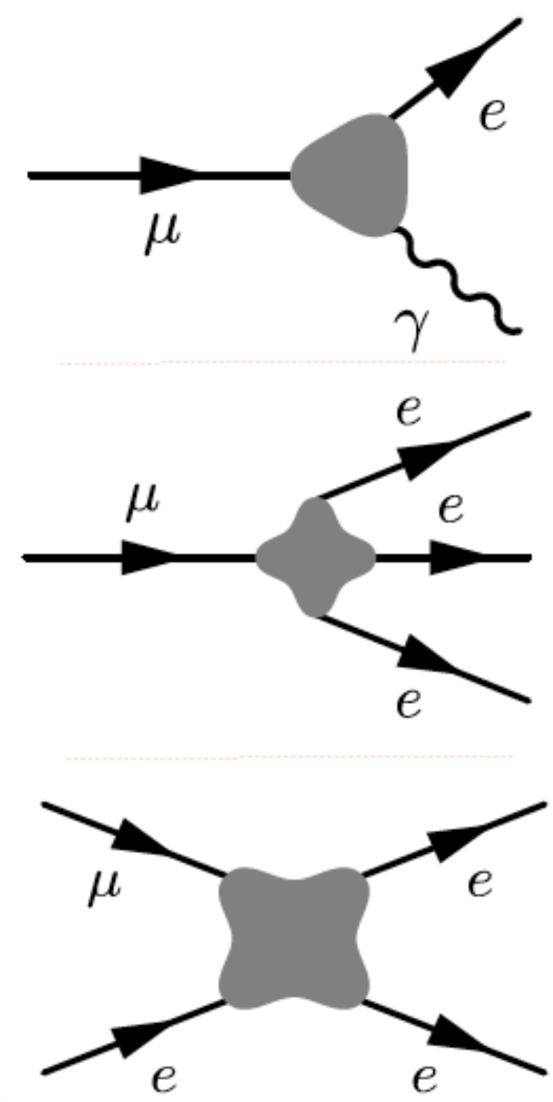
DBD limits have improve by about a factor 10 in 15 years (optimistic)

If you want to have fun: Factor 10000 in 7 years

Mu2e

Focus: Coherent muon - electron conversion on nuclei (coherent = via ground state)

CLFV



$$\mathcal{R} = \frac{\Gamma(\mu\text{-}e \text{ conversion})}{\Gamma(\mu \text{ capture})}$$

Aim : R about 10^{-17}

(My) Questions

- What fraction int muon-electron conversion is mediated via excited states (GDR)?
- This would be most interesting for Aluminum (COMET, Mu2e)
- How does this depend on the element, i.e. target?
- Could there be spin dependent and spin independent reactions like in dark matter?
  See Phys. Lett. B 771, 242 (2017)
- Could/Should there be something like 2 neutrino mu- e^+ decay?

Total lepton number violation

- Neutrino-less double beta decay

$$T_{1/2} \approx 10^{25-26}\, yrs$$

$$\propto U_{ei}^2$$

- μ- - e+ conversion on nuclei (^{32}S)

T. Geib, A. Merle, K. Zuber, PLB 764,157 (2017)
B. Yeo, Y. Kuno, M. Lee, K. Zuber, arXiv:1705:07464

$$\propto U_{ei} U_{\mu i}$$

- Neutrino-less double muon decay of the pion

$$K^+ \rightarrow \pi^- \mu^+ \mu^+$$ (< 8.6 x 10^{-11})

$$\propto U_{\mu i}^2$$

K. Zuber, Phys. Lett. B 479,33 (2000)
J. Barley et al., Phys. Lett. B 769, 67 (2017)

In general: BSM physics

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
- 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
- Big progess expected in the next years in charged lepton number violation processes