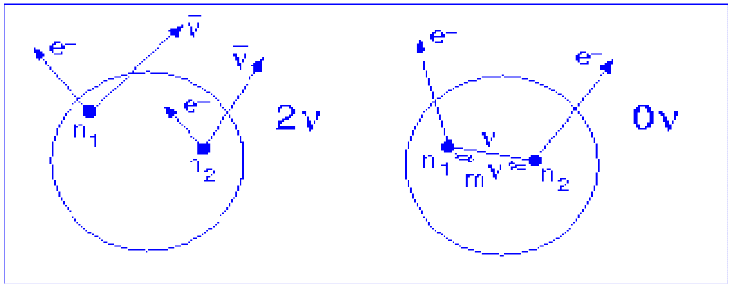
K. Zuber, TU Dresden
24.5.2010

Trap measurements of relevance for double beta decay

Double beta decay

- $(A,Z) \rightarrow (A,Z+2) + 2e^- + 2\bar{\nu}_e$ $2\nu\beta\beta$
- $(A,Z) \rightarrow (A,Z+2) + 2e^-$ $0\nu\beta\beta$



Unique process to measure the mass of the neutrino

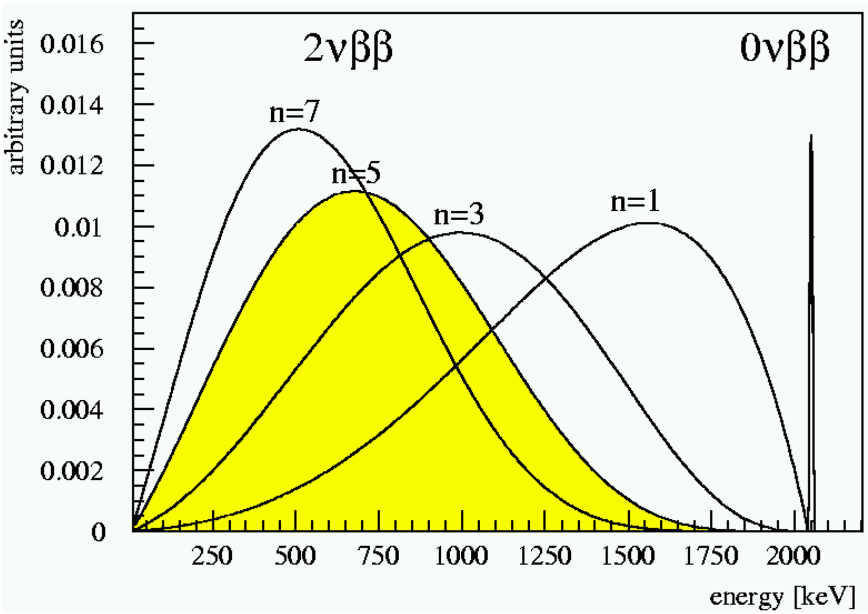
Unque process to measure character of neutrino

Requires half-life measurements well beyond 10^{20} yrs!!!!

The smaller the neutrino mass the longer the half-life

Spectral shapes

0νββ: Peak at Q-value of nuclear transition



Sum energy spectrum of both electrons

Measured quantity: Half-life

Dependencies (BG limited)

$T_{1/2} \propto a \bullet \varepsilon\, (M \bullet t / \Delta E \bullet B)^{1/2}$

link to neutrino mass

$1 / T_{1/2} = PS * ME^2 * (m_\nu / m_e)^2$

Candidates

$0\nu\beta\beta$ decay rate scales with Q^5

$2\nu\beta\beta$ decay rate scales with Q^{11}

Isotope	*Q-Value (keV)*	*Nat. abund. (%)*	*$(G\ 0\nu)^{-1}$ (yrs x eV^2)*	*$(G\ 2\nu)^{-1}$ (yrs)*
Ca 48	**4271**	**0.187**	**4.10E24**	**2.52E16**
Ge 76	**2039**	**7.8**	**4.09E25**	**7.66E18**
Se 82	**2995**	**9.2**	**9.27E24**	**2.30E17**
Zr 96	**3350**	**2.8**	**4.46E24**	**5.19E16**
Mo 100	**3034**	**9.6**	**5.70E24**	**1.06E17**
Pd 110	**2013**	**11.8**	**1.86E25**	**2.51E18**
Cd 116	**2809**	**7.5**	**5.28E24**	**1.25E17**
Sn 124	**2288**	**5.64**	**9.48E24**	**5.93E17**
Te 130	**2529**	**34.5**	**5.89E24**	**2.08E17**
Xe 136	**2479**	**8.9**	**5.52E24**	**2.07E17**
Nd 150	**3367**	**5.6**	**1.25E24**	**8.41E15**

Future projects, ideas

K. Zuber, Acta Polonica B 37, 1905 (2006), updated

Experiment	Isotope	Experimental approach
CANDLES	^{48}Ca	Several tons of CaF_2 crystals in Liquid scintillator
COBRA	^{116}Cd, ^{130}Te	420 kg CdZnTe semiconductors
CUORE	^{130}Te	750 kg TeO_2 cryogenic bolometers
DCBA	^{150}Nd	20 kg Nd layers between tracking chambers
EXO	^{136}Xe	1 ton Xe TPC (gas or liquid)
GERDA	^{76}Ge	$\sim$ 40 kg Ge diodes in LN_2, phase 3 with MAJORANA
MAJORANA	^{76}Ge	$\sim$ 180 kg Ge diodes, expand to larger masses
MOON	^{100}Mo	several tons of Mo sheets between scintillator
SNO+	^{150}Nd	1000 t of Nd-loaded liquid scintillator
'LNGS'	^{150}Nd	10 ton Nd-loaded liquid scintillator
SuperNEMO	^{82}Se(?), ^{150}Nd (?)	100-200 kg of Se or Nd foils between TPCs ← running as NEMO-3
KamLAND	^{136}Xe	300 kg (2013) , 1 ton (2015?) of Xe in liquid scintillator
XMASS	^{136}Xe	10 t of liquid Xe
NEXT	^{136}Xe	High Pressure Xe TPC
LUCIFER	^{82}Se	300 kg ZnSe cryogenic bolometers

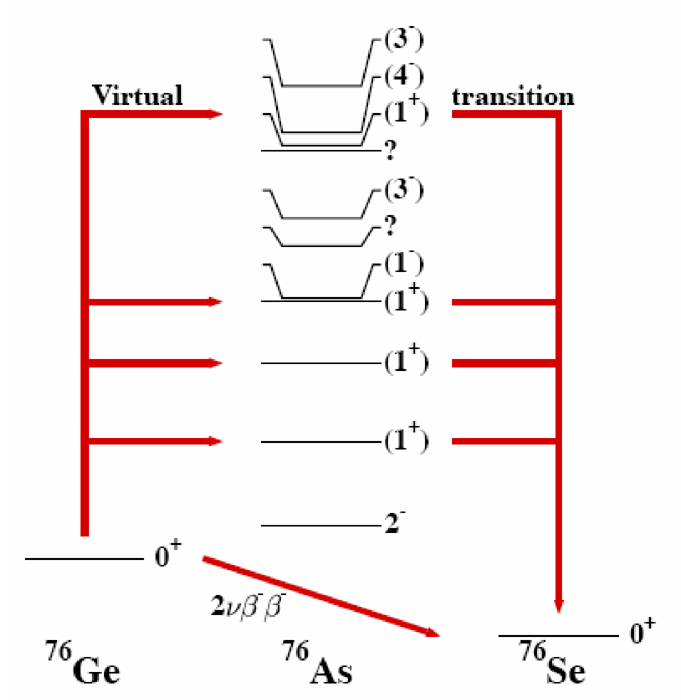
small scale ones will expand, very likely not a complete list...

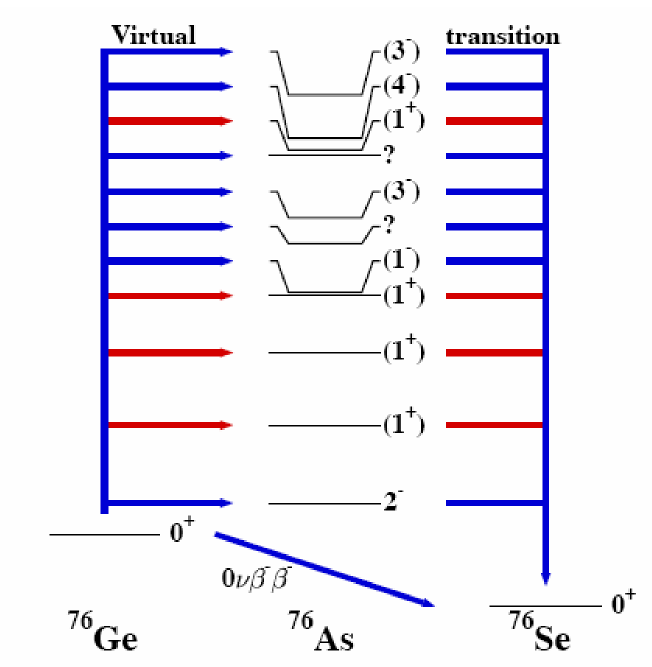
Nuclear matrix elements

The dark side of double beta decay

Nuclear matrix elements

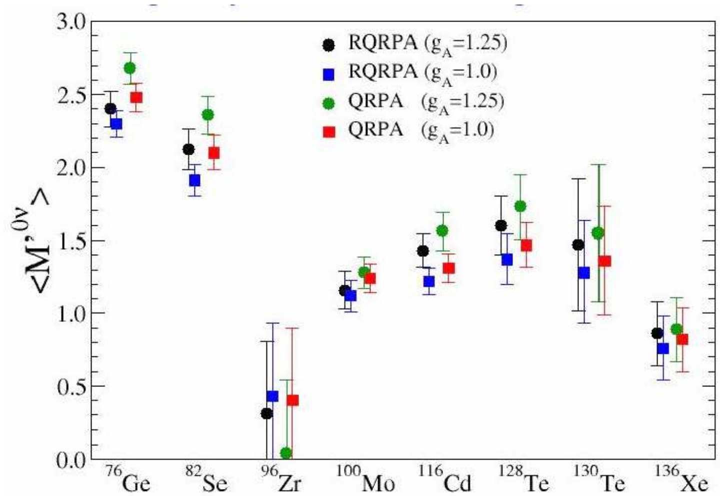
2νββ: Only intermediate 1^+ states contribute



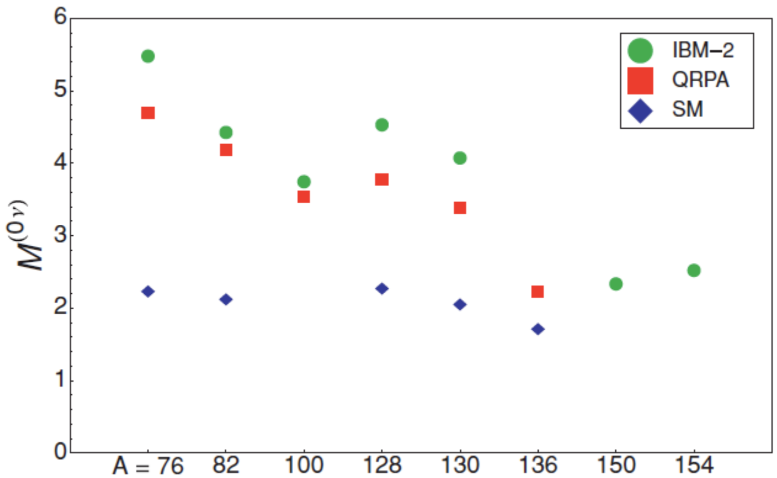


NME – current status

2005



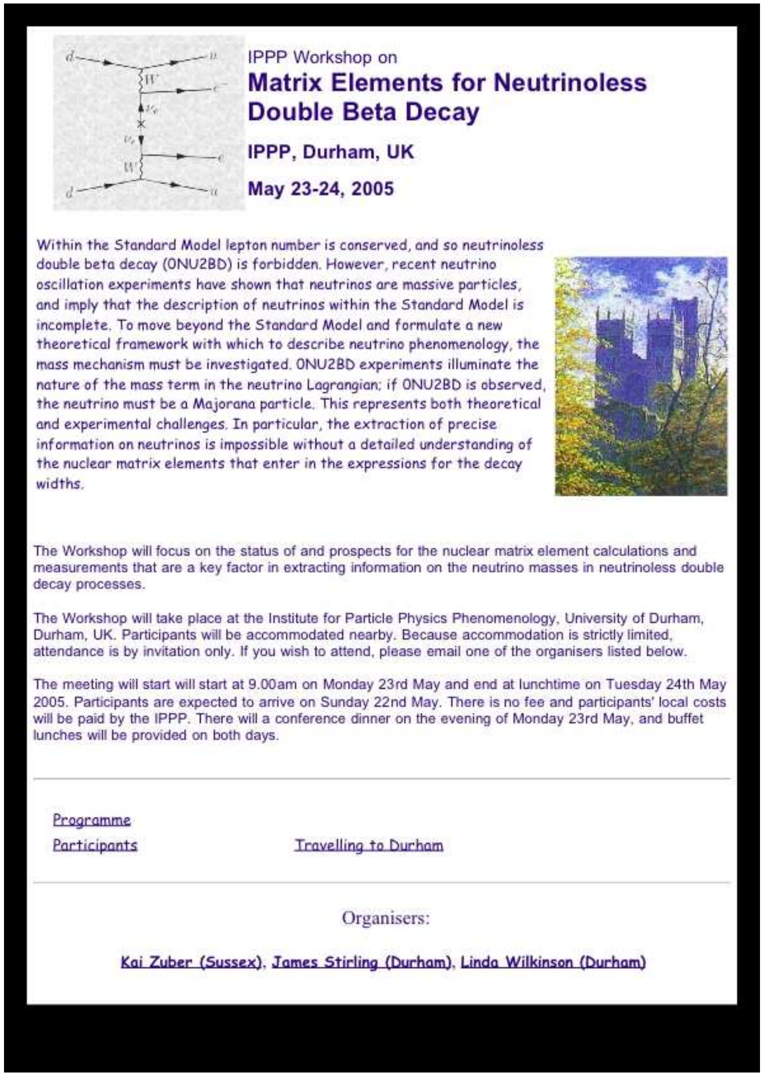
2009



Looks like 1998...

Deformation not taken into account (except for IBM), important for ^{150}Nd

Supportive measurements



IPPP Workshop on

Matrix Elements for Neutrinoless Double Beta Decay

IPPP, Durham, UK

May 23-24, 2005

Within the Standard Model lepton number is conserved, and so neutrinoless double beta decay (0NU2BD) is forbidden. However, recent neutrino oscillation experiments have shown that neutrinos are massive particles, and imply that the description of neutrinos within the Standard Model is incomplete. To move beyond the Standard Model and formulate a new theoretical framework with which to describe neutrino phenomenology, the mass mechanism must be investigated. 0NU2BD experiments illuminate the nature of the mass term in the neutrino Lagrangian; if 0NU2BD is observed, the neutrino must be a Majorana particle. This represents both theoretical and experimental challenges. In particular, the extraction of precise information on neutrinos is impossible without a detailed understanding of the nuclear matrix elements that enter in the expressions for the decay widths.

The Workshop will focus on the status of and prospects for the nuclear matrix element calculations and measurements that are a key factor in extracting information on the neutrino masses in neutrinoless double decay processes.

The Workshop will take place at the Institute for Particle Physics Phenomenology, University of Durham, Durham, UK. Participants will be accommodated nearby. Because accommodation is strictly limited, attendance is by invitation only. If you wish to attend, please email one of the organisers listed below.

The meeting will start will start at 9.00am on Monday 23rd May and end at lunchtime on Tuesday 24th May 2005. Participants are expected to arrive on Sunday 22nd May. There is no fee and participants' local costs will be paid by the IPPP. There will a conference dinner on the evening of Monday 23rd May, and buffet lunches will be provided on both days.

Programme
Participants
Travelling to Durham

Organisers:

Kai Zuber (Sussex), James Stirling (Durham), Linda Wilkinson (Durham)

Working packages

Charge exchange reactions

Precise Q-value measurements

ft-values

Muon capture

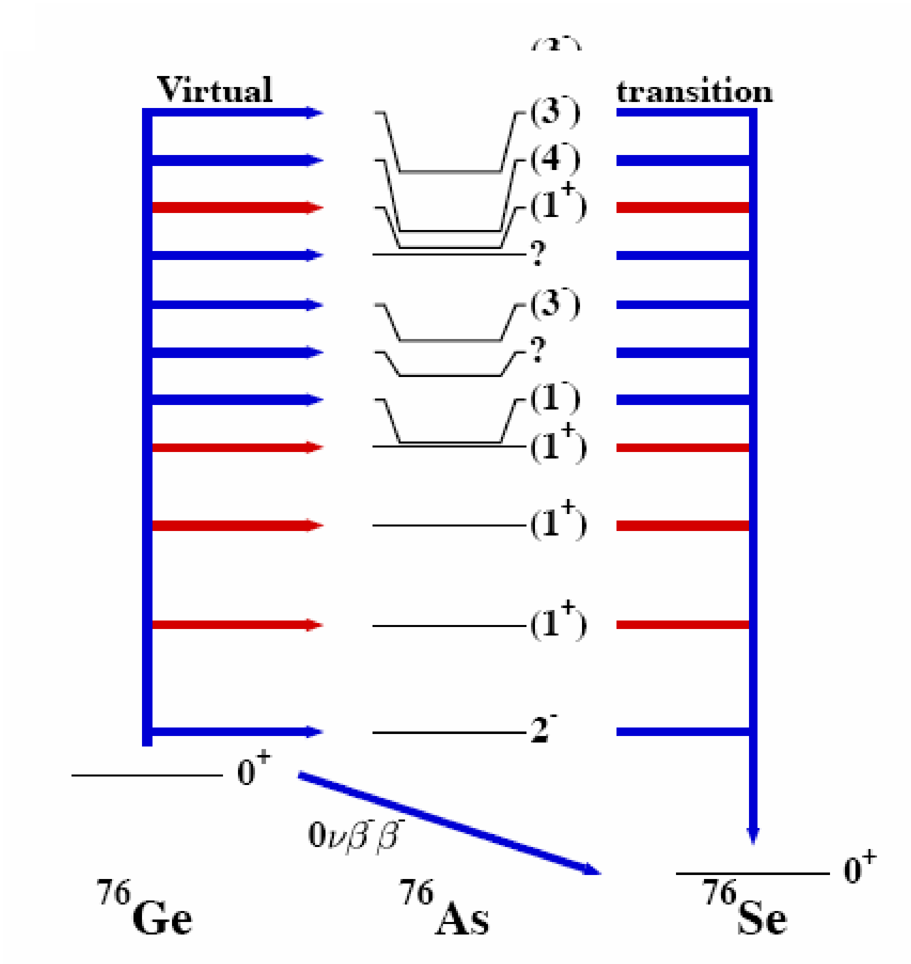
Double electron captures

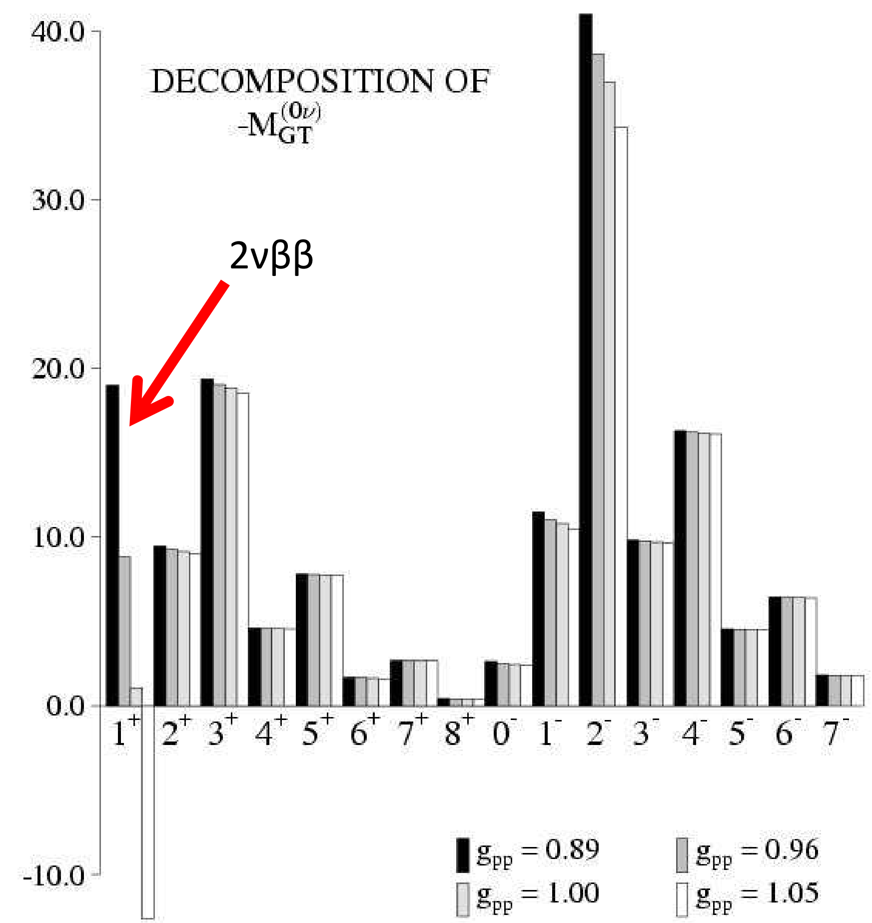
Neutrino-Nucleus scattering

Nucleon transfer reactions

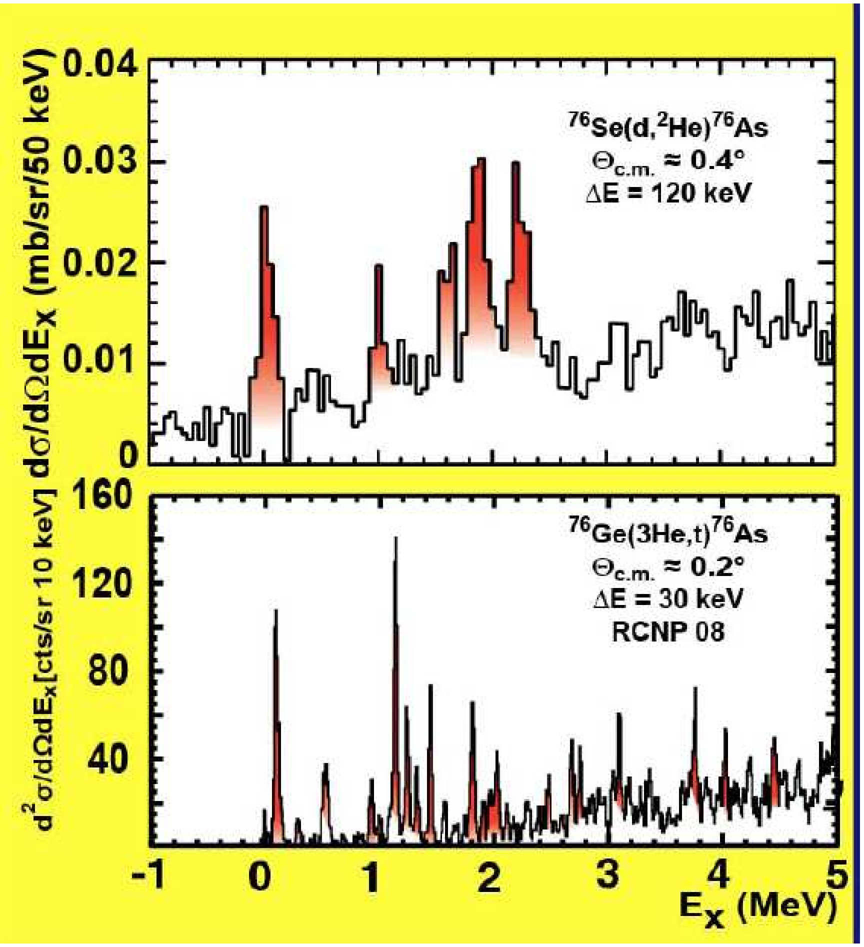
Consensus Report:
K. Zuber, nucl-ex/0511009

NME – Intermediate states





^{76}Ge-^{76}Se



D. Frekers, ECT Trento 2008

Anticorrelation in strengths (seen in most isotope pairs)

Effect of deformation on 2nu matrix element seems to be a state-to-state mismatch not an overall effect.
What does this imply for 0nu ME?

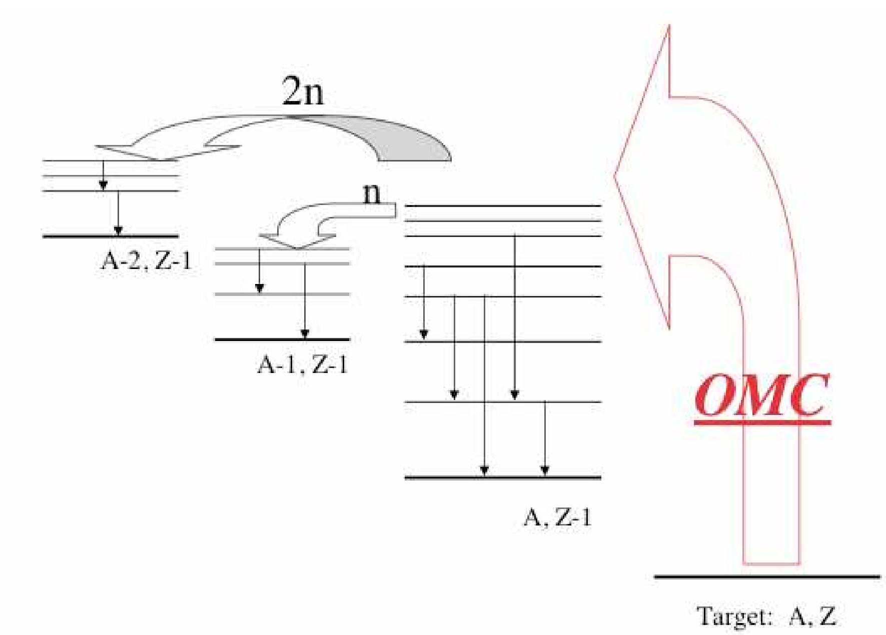
Important is the difference in shapes between mother and daughter not absolute deformation

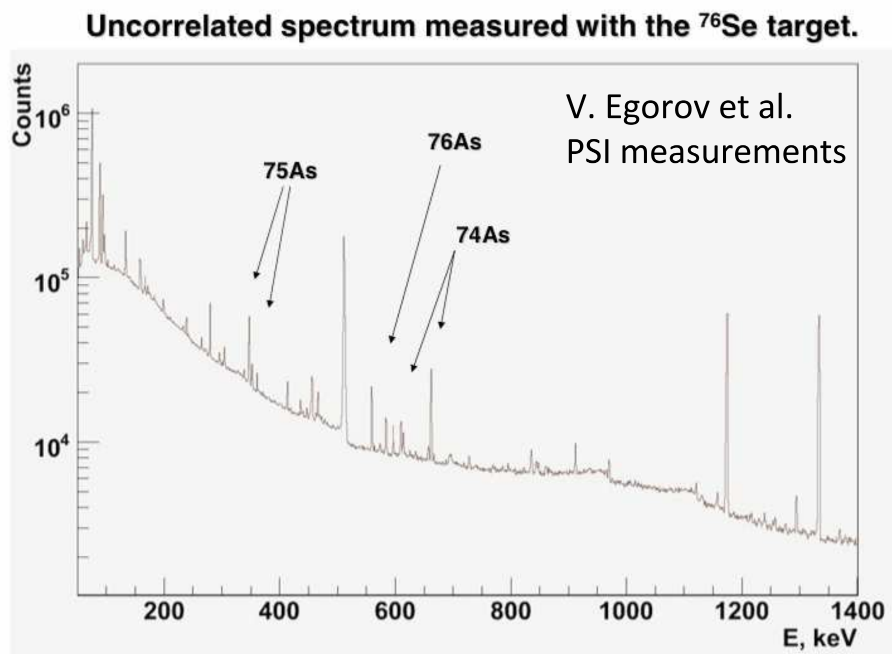
^{96}Zr and ^{100}Mo seem to show single state dominance

There still seems to be some classic nuclear structure physics to be done!

Ordinary muon capture (OMC)

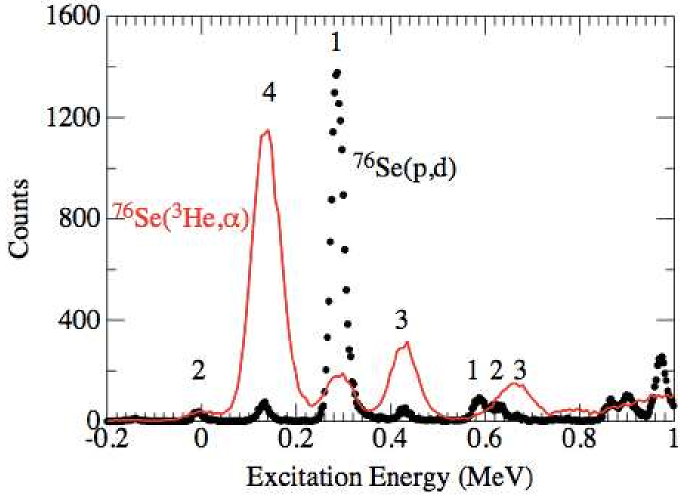
Wants to measure partial capture rates! Non-trivial
Populates all states in intermediate nucleus via „right leg“

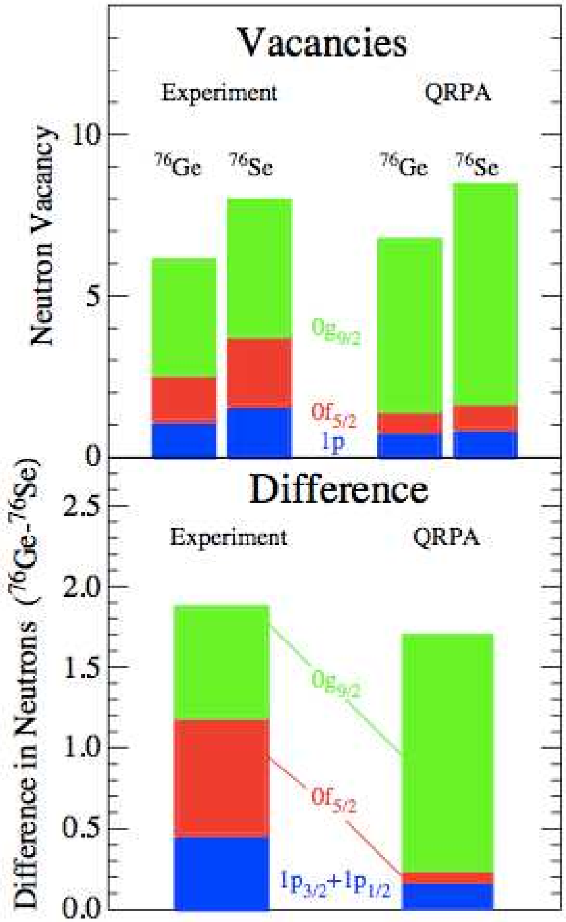




Again effects observed which are not in agreement with theory
(based on total capture rates)

Nucleon transfer reactions

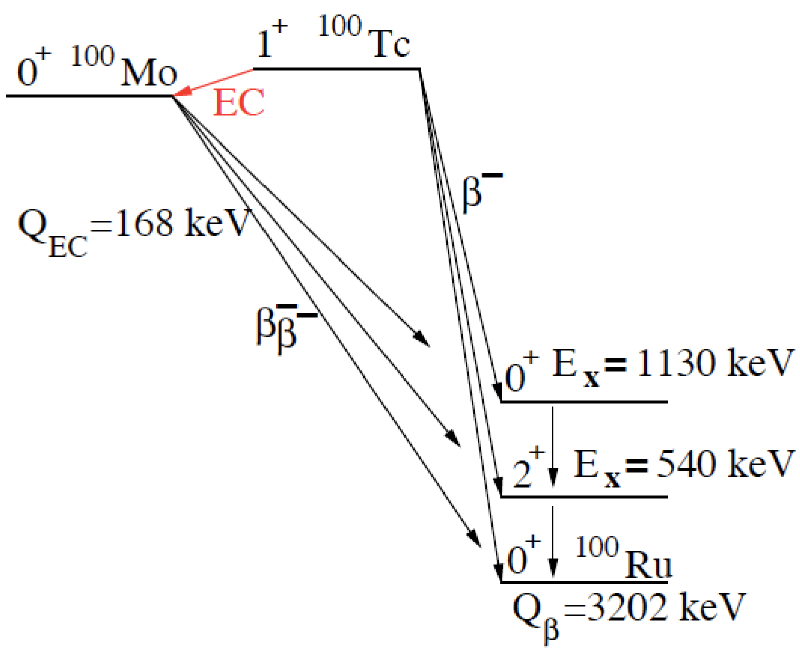




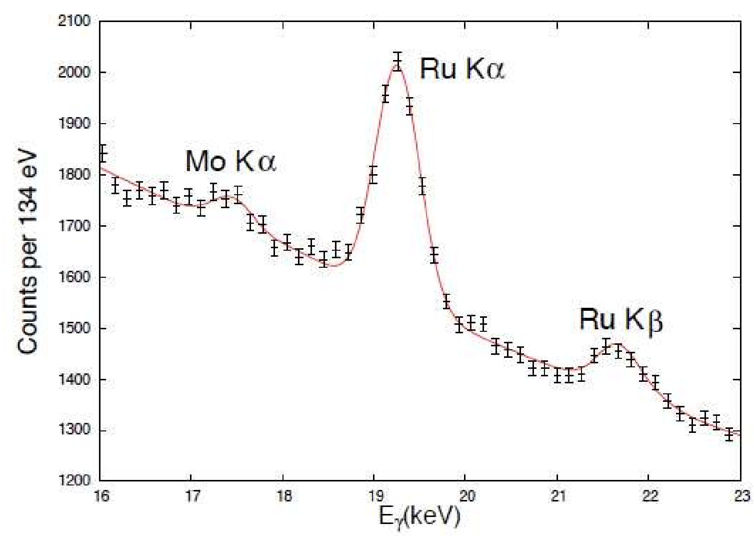
J. Schiffer et al.,
Phys. Rev. Lett. 100,112501 (2008)

Ft-values

Ft-values of EC badly known, if at all! These are ground state transitions!



S.K.L. Sjue et al., Phys.Rev.C 78,064317 (2008)



Extracted B(GT) of EC differs by 80% from charge exchange reaction, Disagreement with QRPA calculation (unless you allow fitting of g_A with values smaller than 1)

Q-values

Initiated during MEDEX07, Prague

International Statement of Interest for measurements using precision mass spectrometry for double beta decay experiments

F. AVIGNONE, A. BARABASH, R. BERNABEI, A. CALDWELL, O. CIVITARESE, O. CREMONESI, J. ENGEL, S. ELLIOTT, V. EGOROV, H. EJIRI, A. FAESSLER, E. FIORINI, D. FREKERS, A.GIULIANI, H. KOSMAS, M. LINDNER, B. MAJOROVITS, E. NORMAN, M. PAVAN, A. PIEPKE, R. SAAKYAN, S. SCHOENERT, S. SEMENOV, F. SIMKOVIC, J. SUHONEN, I. STEKL, J. WILKERSON, K. ZUBER

Neutrinoless double beta is one of the central research fields in neutrino physics. This lepton number violating process is only possible if neutrinos are massive and their own antiparticle (so called Majorana neutrinos). The measurement of neutrino masses in the region of 100 meV and below requires half-life measurements well beyond 10^{25} yrs and hundreds of kilograms of enriched isotopes. Next generation experiments will be able to perform these measurements. As the decay rate scales with 5^{th} power of the Q-value only eleven isotopes can be considered. The expected background and small amount of signal events requires precise knowledge (less than a 1 keV) of the Q-value. The usage of high resolution detectors and the possible vicinity of dangerous background lines requires that. One of the systems (^{76}Ge-^{76}Se) has already been measured to that precision.

In addition, there is a renewed interest to perform neutrinoless double electron capture searches. This transition is resonantly enhanced if there is a degeneracy between the initial state and an excited state in the daughter nucleus. As the resonance is very sharp a precision mass knowledge (of order 200 eV) of the involved nuclei is necessary, assuming that the energies of the excited state levels are known accurate enough.

Hence, the double beta community is suggesting that the measurement of the ten potential double beta candidates and some promising double electron capture candidates should be performed in atomic traps to obtain the necessary information. In a prioritised list this would be:

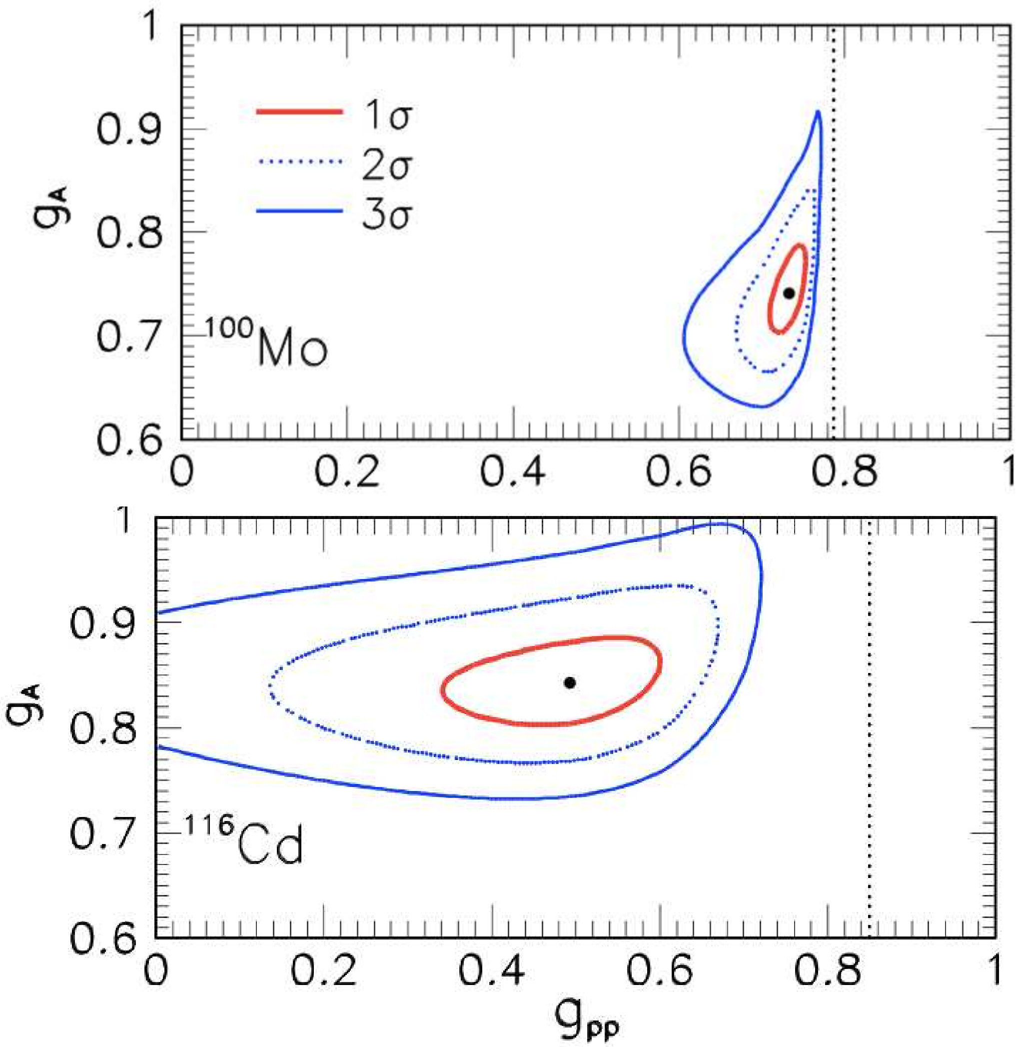
1.) Measurement of the systems ^{74}Se-^{74}Ge, ^{106}Cd-^{106}Pd, ^{112}Sn-^{112}Cd, ^{120}Te-^{120}Sn, ^{124}Xe-^{124}Te ^{130}Ba-^{130}Xe, ^{136}Ce-^{136}Ba and ^{138}Ce-^{138}Ba. These systems look most promising for neutrinoless double electron capture via degenerate levels. It would be very important to have this information soon to start or drop activities in that direction.

2.) Measurement of ^{76}Ge-^{76}Se,^{100}Mo-^{100}Ru, ^{130}Te-^{130}Xe and ^{136}Xe-^{136}Ba. These isotopes are used in current large scale experiments or will be used soon.

3.) Measurement of ^{48}Ca-^{48}Ti, ^{82}Se-^{82}Kr, ^{116}Cd-^{116}Sn and ^{150}Nd-^{150}Sm. These isotopes are used in smaller scale experiments as first steps towards large scale experiments which might be realised in the near future.

4.) Measurement of ^{96}Zr-^{96}Mo, ^{110}Pd-^{110}Cd and ^{124}Sn-^{124}Te. Currently there is no experimental proposal for a large scale experiment of these isotopes.

g_A



A. Faessler et al. ,
J. Phys. G 35, 075104 (2008)

Q-values

Using Penning traps for accurate mass measurements

Isotope	*Q-Value (keV)*	*Nat. abund. (%)*	*Q-Value 2009 (keV)*	
Ca 48	**4271 ± 4**	**0.187**	4274 ± 4	
Ge 76	**2039.6 ± 0.9**	**7.8**	**2039.04± 0.16**	**2039.006± 0.050**
Se 82	**2995 ± 6**	**9.2**	2995.5 ± 1.9	
Zr 96	**3350 ± 3**	**2.8**	3347.7 ± 2.2	
Mo 100	**3034 ± 6**	**9.6**	**3034.40 ± 0.17**	
Pd 110	**2013 ± 19**	**11.8**	2004 ± 11	
Cd 116	**2802 ± 4**	**7.5**	2809 ± 4	
Sn 124	**2288.1 ± 1.6**	**5.64**	2287.8 ± 1.5	
Te 130	**2533 ± 4**	**34.5**	**2527.01± 0.32**	**2527.518±0.013**
Xe 136	**2479 ± 8**	**8.9**	**2457.83 ± 0.37**	
Nd 150	**3367.1± 2.2**	**5.6**	3367.7 ± 2.2	

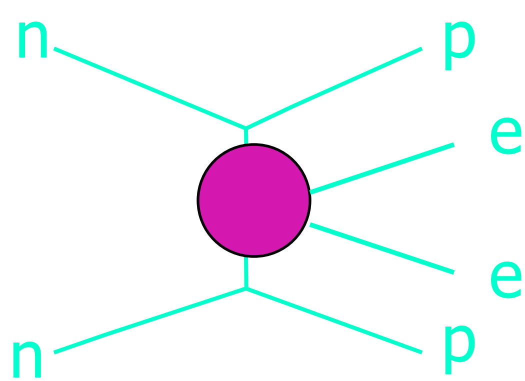
F.Boehm, P. Vogel, Physics of massive neutrinos, 1992

G. Audi et al. AME 2003

$\beta^+\beta^+$ - modes

In general:

Double charged higgs bosons,
R-parity violating SUSY couplings,
leptoquarks...

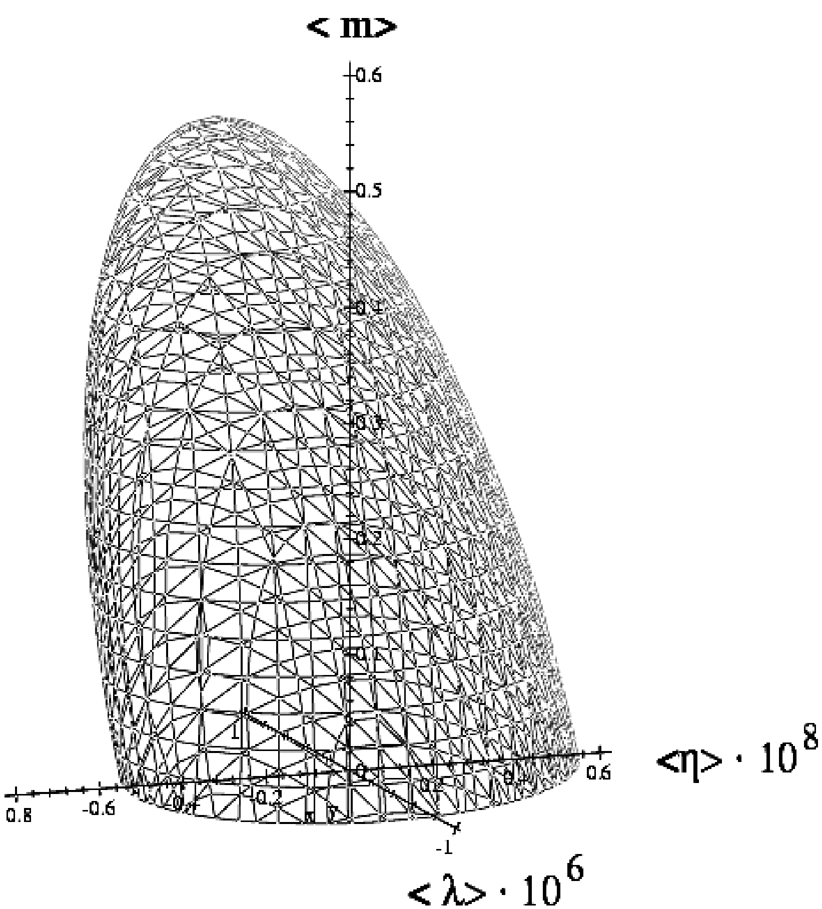


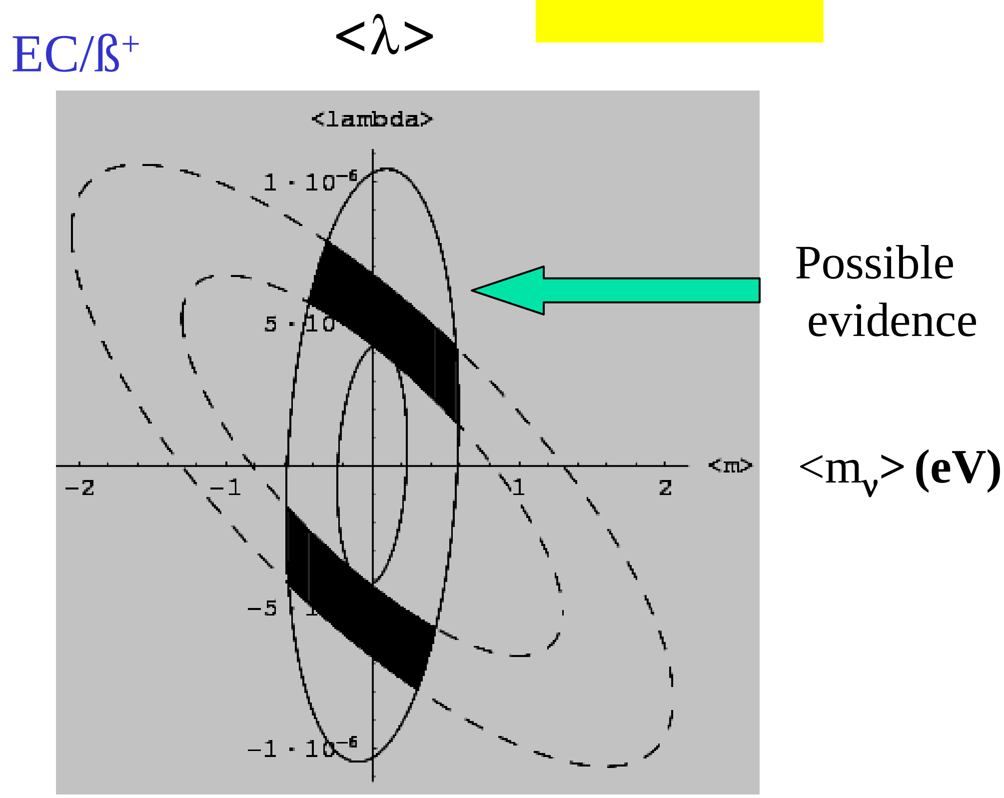
- $(A,Z) \rightarrow (A,Z-2) + 2\,e^+ \,(+2\nu_e)$ — $\beta^+\beta^+$ — $Q-4m_ec^2$
- $e^- + (A,Z) \rightarrow (A,Z-2) + e^+ \,(+2\nu_e)$ — β^+/EC — $Q-2m_ec^2$
- $2\,e^- + (A,Z) \rightarrow (A,Z-2)\,(+2\nu_e)$ — EC/EC — Q

Important to reveal mechanism if $0\nu\beta\beta$ is discovered

β^+/EC Enhanced sensitivity to right handed weak currents (V+A)

Neutrino mass vs. right handed currents





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

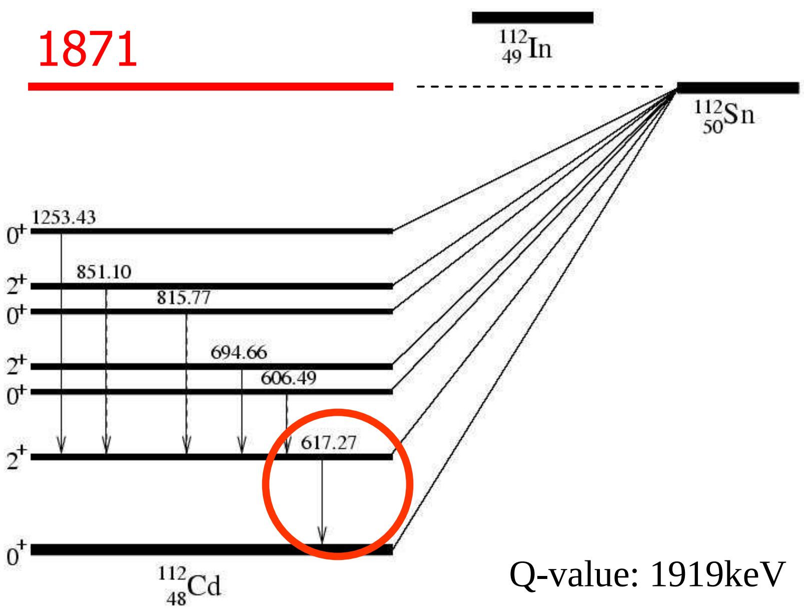
Double beta studies on tin

Notice difference: Here source not equal to detector
→ only X-rays and gamma rays can be observed (excited states)

Resonant enhancement (*10⁶) of 0nu ECEC if excited state in daughter is degenerate (within 200 eV) with initial ground state.

J. Bernabeu et al, Nucl. Phys. B 222,15 (1983)
S. Wycech, Z. Sujkowsi, Phys. Rev. C 70, 052501 (2004)

112Sn: Double EC and β^+/EC



All de-excite with emission of 617.3 keV gamma , more complex patterns

Double EC with tin

J. Dawson et al., arXiv:0709.4342, Nucl. Phys. A 799, 167 (2008)

Ge-Detector on surface

J. Dawson et al., arXiv:0804.1198, Phys. Rev. C 78,035503 (2008)

Ge-Detector underground (Felsenkeller Dredsen 125 mwe)

A. Barabash, et al, arXiv:0804.3849, Nucl. Phys. A 807,269 (2008)

Ge - detector Underground (Modane, 4500 mwe)

M. Kidd et al., Phys. Rev. C 78, 035504 (2008)

Sandwich Ge-detector on surface

A. Barabash et al., Phys. Rev. C 80. 035501 (2009)

Enriched tin (Modane, 4500 mwe)

Half-life limit on excited 1871keV > 4.2 x 10^{20} yrs (90%CL)

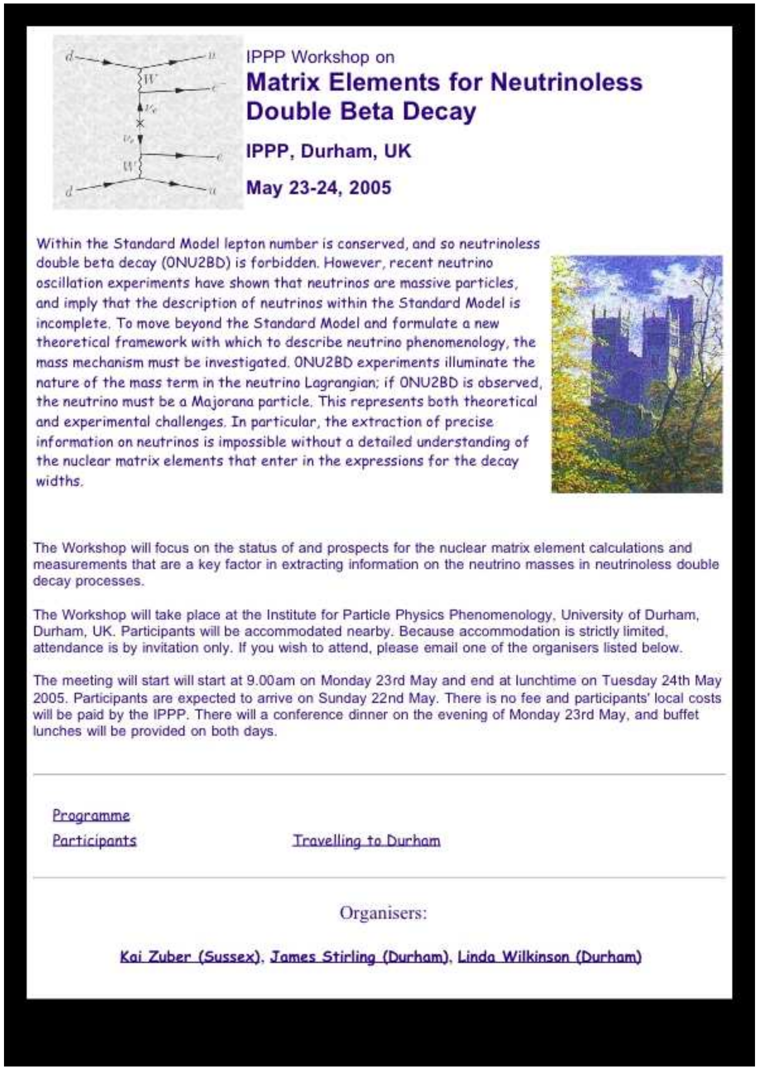
Double Electron capture

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

Nuclei	A,%	ΔM,keV	E*,keV	E_K	E_{L2}
^{74}Se	0.89	1209.7±2.3	1204.2(2^+)	11.1	1.23
^{78}Kr	0.35	2846.4±2.0	2838.9(2^+)	12.6	1.47
^{96}Ru	5.52	2718.5±8.2	2700(?)	20	2.86
^{106}Cd	1.25	2770±7.2	2741.0(1,2^+)	24.3	3.33
^{112}Sn	0.97	1919.5±4.8	1871.0(0^+)	26.7	3.73
^{130}Ba	0.11	2617.1±2.0	2608.4(?)	34.5	5.10
^{136}Ce	0.20	2418.9±13	2399.9(1^+,2^+) 2392.1(1^+,2^+)	37.4	5.62
^{162}Er	0.14	1843.8±5.6	1745.7(1^+)	53.8	8.58

A.Barabash, MEDEX 07

NME + Experiments



IPPP Workshop on

Matrix Elements for Neutrinoless Double Beta Decay

IPPP, Durham, UK

May 23-24, 2005

Within the Standard Model lepton number is conserved, and so neutrinoless double beta decay (0NU2BD) is forbidden. However, recent neutrino oscillation experiments have shown that neutrinos are massive particles, and imply that the description of neutrinos within the Standard Model is incomplete. To move beyond the Standard Model and formulate a new theoretical framework with which to describe neutrino phenomenology, the mass mechanism must be investigated. 0NU2BD experiments illuminate the nature of the mass term in the neutrino Lagrangian; if 0NU2BD is observed, the neutrino must be a Majorana particle. This represents both theoretical and experimental challenges. In particular, the extraction of precise information on neutrinos is impossible without a detailed understanding of the nuclear matrix elements that enter in the expressions for the decay widths.

The Workshop will focus on the status of and prospects for the nuclear matrix element calculations and measurements that are a key factor in extracting information on the neutrino masses in neutrinoless double decay processes.

The Workshop will take place at the Institute for Particle Physics Phenomenology, University of Durham, Durham, UK. Participants will be accommodated nearby. Because accommodation is strictly limited, attendance is by invitation only. If you wish to attend, please email one of the organisers listed below.

The meeting will start will start at 9.00am on Monday 23rd May and end at lunchtime on Tuesday 24th May 2005. Participants are expected to arrive on Sunday 22nd May. There is no fee and participants' local costs will be paid by the IPPP. There will a conference dinner on the evening of Monday 23rd May, and buffet lunches will be provided on both days.

Programme

Participants

Travelling to Durham

Organisers:

Kai Zuber (Sussex), James Stirling (Durham), Linda Wilkinson (Durham)

Summary

Major activity started to provide new data for double beta isotopes of interest to make nuclear matrix elements more reliable

Traps already contribute to mass measurements , of relevance to determine Q-values precise and explore degeneracy in double EC

Titan can/will provide important in form of ft-value measurements

At the end of the day we are talking about a limited number of isotope pairs of interest, but these should be explored as much as possible