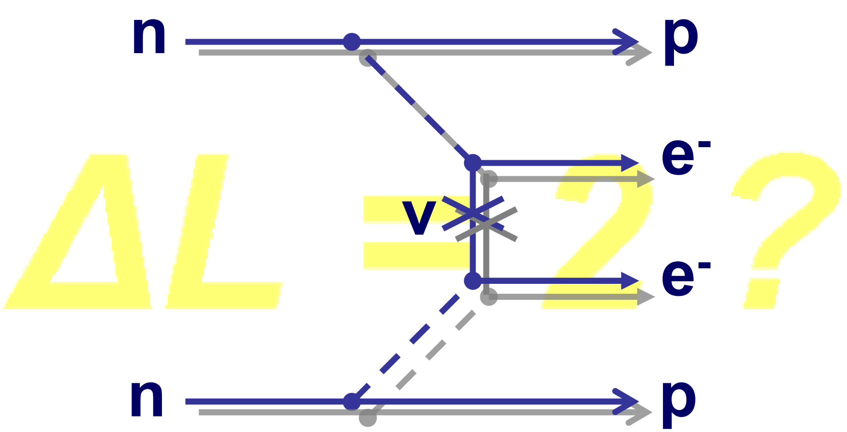
Neutrinoless Double Beta Decay



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Friday Seminar 18.03.2005

Outline

- Motivation
- Theoretical aspects: Oscillations and $0\nu\beta\beta$
- Experiments
- Outlook / Summary

Motivation

- What do we know: Neutrinos have masses (oscillations)
- Open question: What is the absolute mass scale?
- Three types of experiments (with different sensivitities):
  - Beta-decay (e.g. KATRIN) ~ 0.2 eV
  - Cosmology (model dependent) ~ 1 eV
  - Neutrinoless double beta decay < 1 eV
- What is the nature of the neutrino? Dirac? Majorana?

Theory: Oscillations I

- Neutrino oscillations:

Flavor and mass eigenstates are not the same

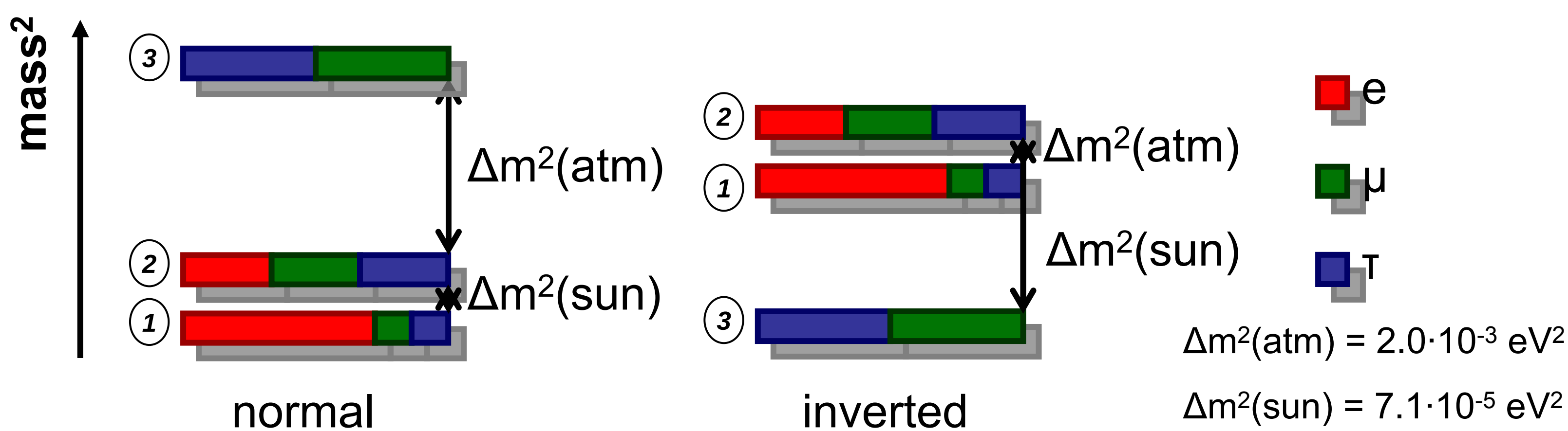
- Use simple QM → Oscillations between eigenstates
  → Frequency proportional to Δm^2
  → Mass difference => neutrino mass

- Leptonic mixing matrix („Maki-Nakagawa-Sakata matrix“) is the analogon to the CKM quark mixing matrix.

(6+3 parameters)

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix} \cdot \mathrm{diag}\left\{e^{i\alpha_1/2}, e^{i\alpha_2/2}, 1\right\} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

- Oscillation parameters measured by experiments, but ambiguities (sign of Δm^2)
- Three possible hierarchies (if 3 neutrinos)



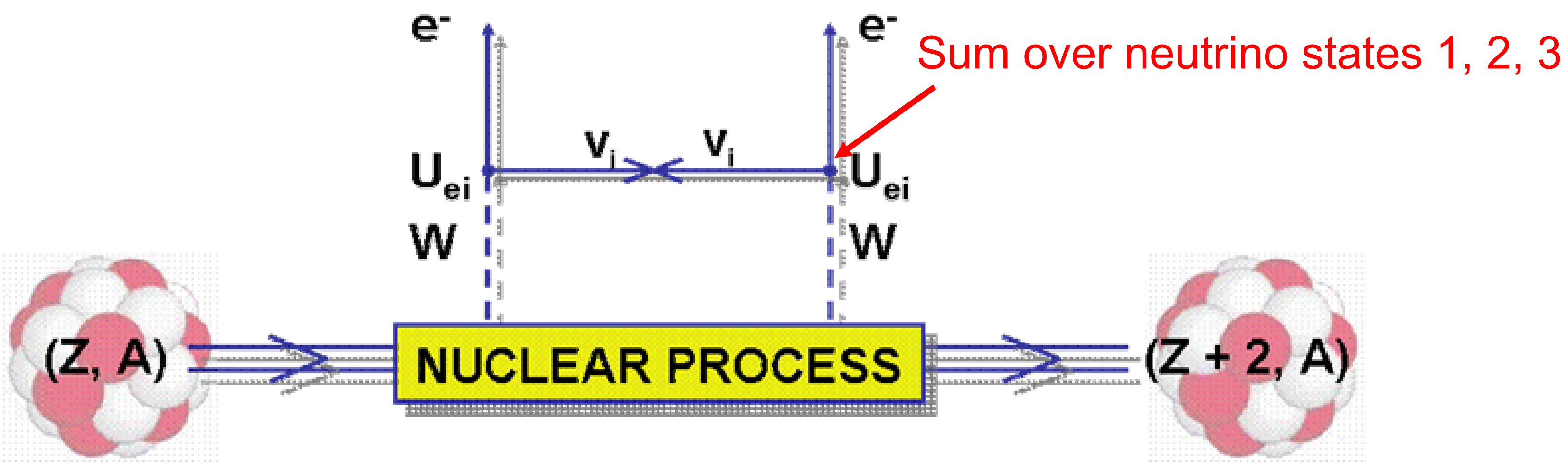
Theory: 0νββ I

- (Neutrinoless) double beta decay:
  - Rare spontaneous nuclear reaction

$(Z, A) \rightarrow (Z+2, A) + e^- + e^- + 2\nu \quad \Delta L = 0$ (measured)

$(Z, A) \rightarrow (Z+2, A) + e^- + e^- \quad \Delta L = 2$

  - Lepton number violation (forbidden in EW theory)



Theory: 0νββ II

- Calculation of decay rate:

$$\left[T_{1/2}\right]^{-1} = \sum_{spins} \int |M|^2 \delta(E_1 + E_2 - Q) \frac{d^3 p_1}{2\pi^3} \frac{d^3 p_2}{2\pi^3}$$

$$\left[T_{1/2}\right]^{-1} = G(Q,Z) \cdot \left| M^{GT} - \frac{g_V^2}{g_A^2} M^F \right| \cdot \left\langle m_{\beta\beta} \right\rangle^2$$

Phase space — Nucl. Matrix elements — Coherent mass

- Mass parameter:

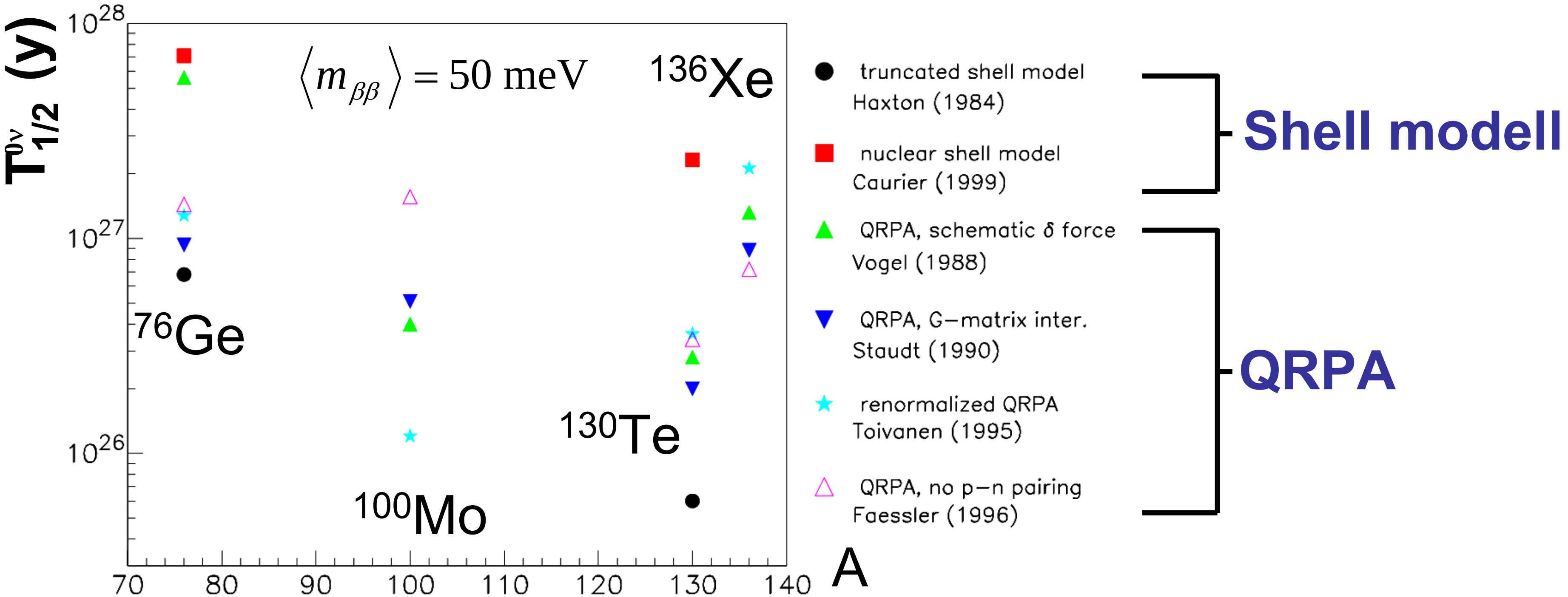
$$\left\langle m_{\beta\beta} \right\rangle = \left| \sum_j m_j U_{ej}^2 \right| = \left| m_1 \cdot |U_{e1}|^2 + m_2 \cdot |U_{e2}|^2 e^{i(\alpha_2 - \alpha_1)} + m_3 \cdot |U_{e3}|^2 e^{i(-\alpha_1 - 2\delta)} \right|$$

Indirectly measured quantity

- Determination of the mass parameter:

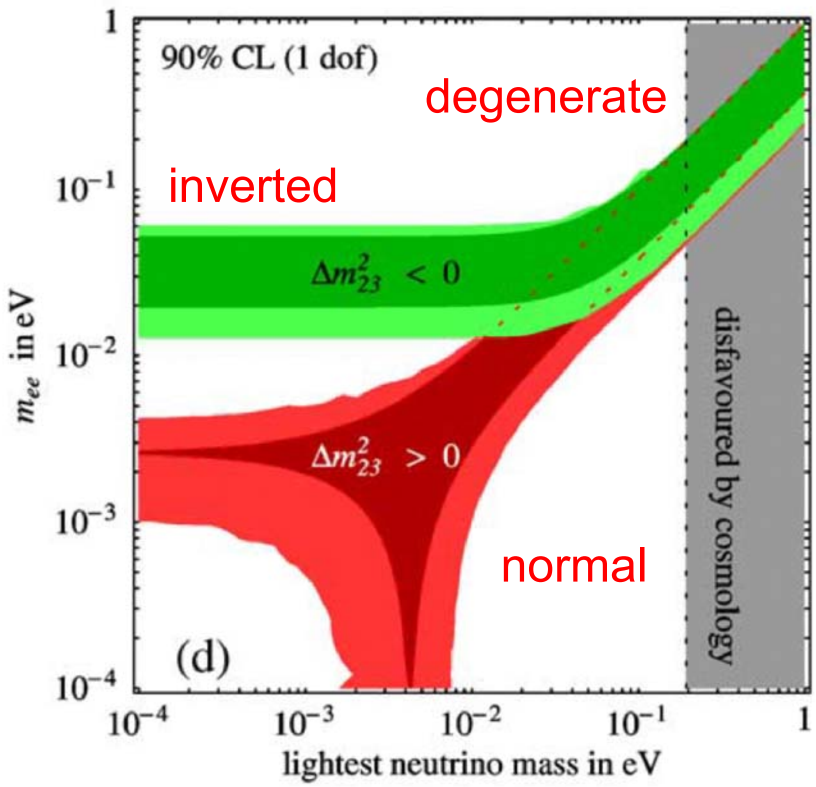
$$\langle m_{\beta\beta} \rangle^2 = \frac{1}{G(Q,Z) \cdot |M_{nucl}| \cdot T_{1/2}}$$

- Problem: Nuclear matrix element calculations



Theory: 0νββ IV

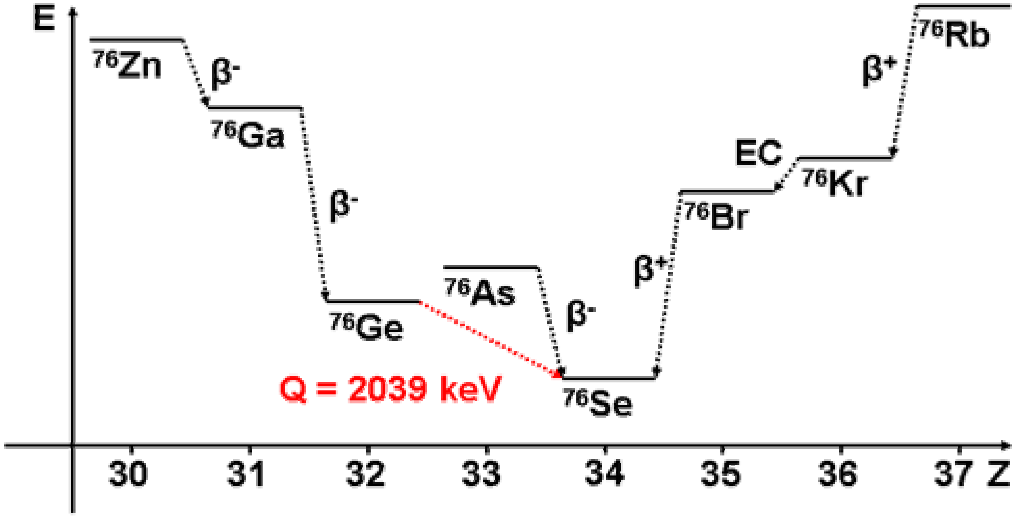
- Possible mass parameters:



Measurement of mass parameter can give hint on hierarchy

Experiments I

- Initial nucleus has to be less bound than final one but more than intermediate.
- Realized for some even-even nuclei in nature (never for any odd number)



Some isotopes with ββ decay:

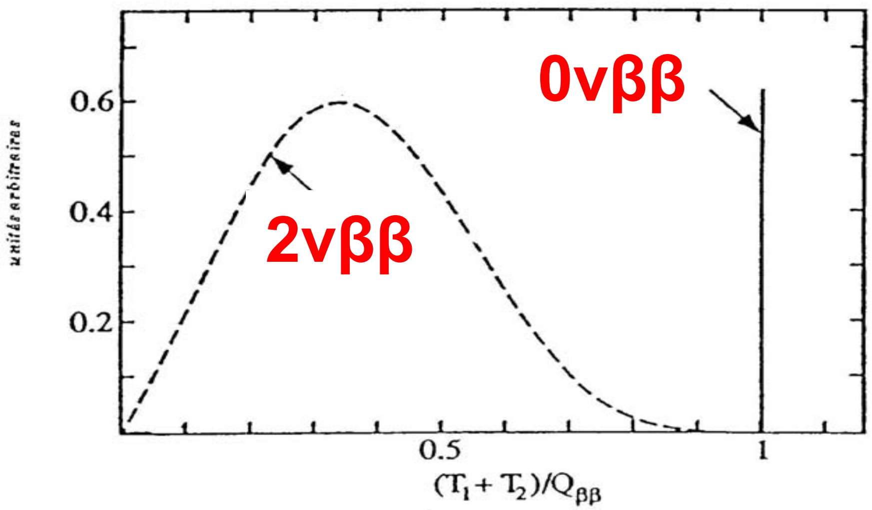
$^{76}Ge \rightarrow {}^{76}Se$	Q = 2.039 MeV
$^{100}Mo \rightarrow {}^{100}Ru$	Q = 3.034 MeV
$^{130}Te \rightarrow {}^{130}Xe$	Q = 2.529 MeV

Experiment II

- Experimentally, 2 electrons are measured with $T_{e1}+T_{e2} = Q$
- Rate is very low ⇔ long half-life: 2νββ: $T_{1/2} = O(10^{21}\ y)$

  0νββ: $T_{1/2} = O(10^{25}\ y)$
- Background suppression important
- Use large detectors /

  large time scales



Experiments III

- Recent experiments and limits:

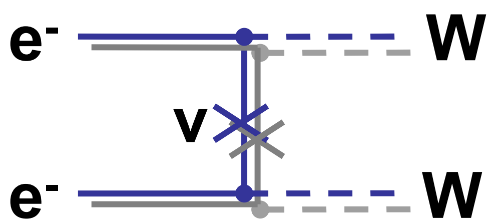
Experiment	Isotope	$\langle m_{\beta\beta} \rangle$ [meV]	$T_{1/2}$ [y]
Heidelberg-Mosow	^{76}Ge	440	$1.2 \cdot 10^{25}$
IGEX	^{76}Ge	< 360 – 1070	$> 1.6 \cdot 10^{25}$
CUORICINO	^{130}Te	< 200 – 1100	$> 1.8 \cdot 10^{24}$
NEMO-3	^{100}Mo	< 700 – 1200	$> 3.5 \cdot 10^{24}$
NEMO-3	^{82}Se	< 1300 – 3200	$> 1.9 \cdot 10^{23}$

Outlook

- More experiments on the way: Majorana/GERDA,
  CUORE,
  Super-NEMO, ...

  with more mass x time

- Where else could Majorana/Dirac nature be clarified? ILC



Advantage: no nucl. Matrix elements

Summary

- If neutrinoless double beta decay is observed:
  - Neutrino is Majorana
  - Lepton number violation
  - Absolute mass scale of neutrinos
  - Hierarchy

- Some helpful literature:

S. Eidelman *et al.*, Physics Letters **B592**, 1 (2004) (PDG WWW pages)

S. Elliott, J. Engel, hep-ph/0405078

D. Caldwell, Current Aspects of Neutrino Phyics