Towards neutrino mass determination in traps

Yuri Novikov

PNPI (St.Petersburg) and *GSI (Darmstadt)*

HITRAP meeting
GSI, November 20-21, 2006

Masses of oscillating neutrinos

The β-decay/capture neutrino effective mass:

$$m_\nu(\beta) = \{a \cdot m_1^2 + b \cdot m_2^2 + c \cdot m_3^2\}^{1/2}$$

States of oscillating neutrinos:

$|\nu_\alpha\rangle = \Sigma\, U_{\alpha i}|\nu_i\rangle$, where I = 1,2,3; α = e, μ, τ - flavor

A probability of flavor change :

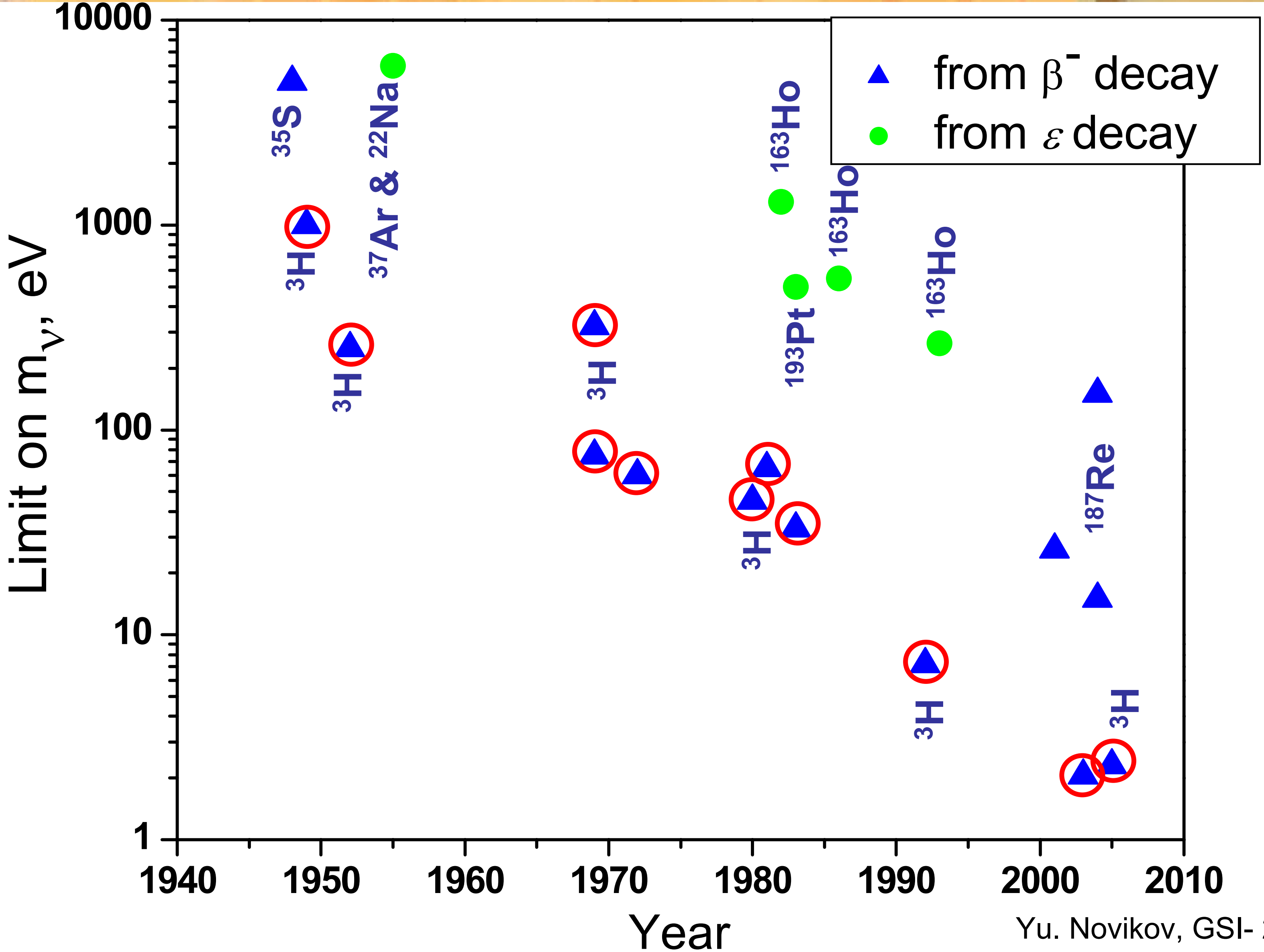
$$\Lambda = \sin^2(2\theta) \cdot \sin^2\{1.27 \Delta m^2 \cdot L/E\} \quad [eV^2 \cdot m/MeV]$$

Experimentally are determined:

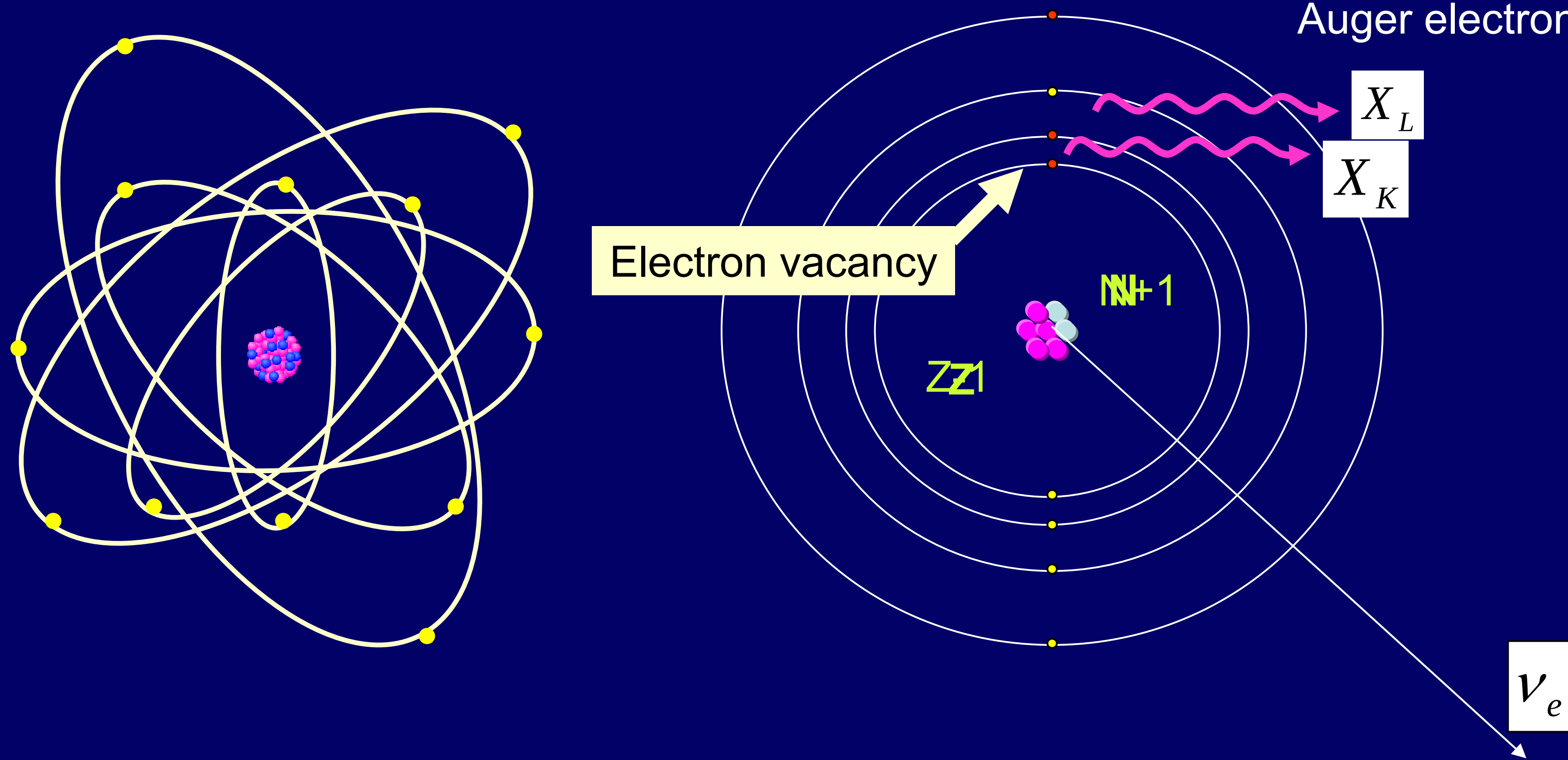
<u>for the mixing angle</u> - $\tan^2\theta = 0.4$;

<u>for mass difference squared</u> $\Delta m^2 = m_2^2 - m_1^2 = 8.2 \cdot 10^{-5}$ eV^2.

History of m_ν measurements



Atomic process



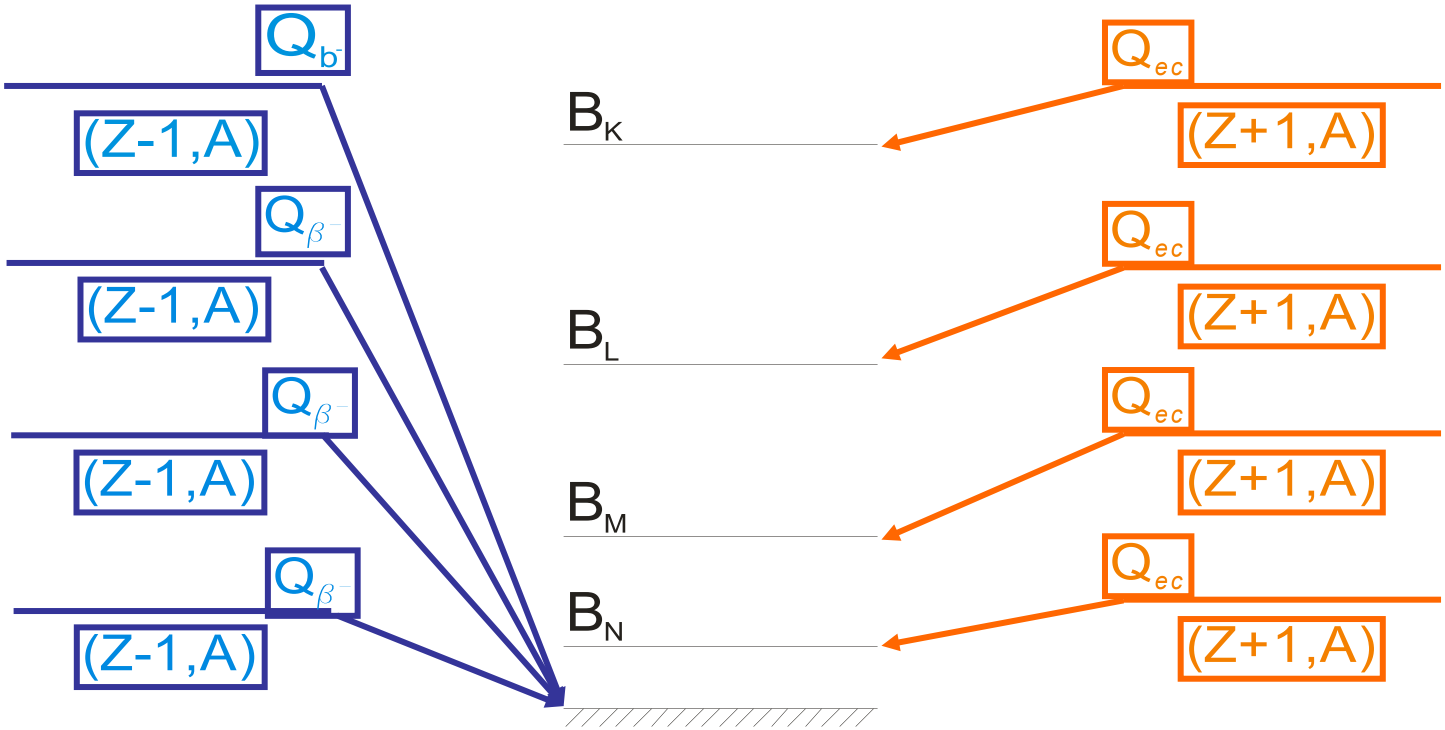
start

Time range

0 10^{-18}s 10^{-10}s

courtesy of J. Khuyagbaatar (GSI)

Differences in the neutrino mass determination in β⁻ and ec - processes

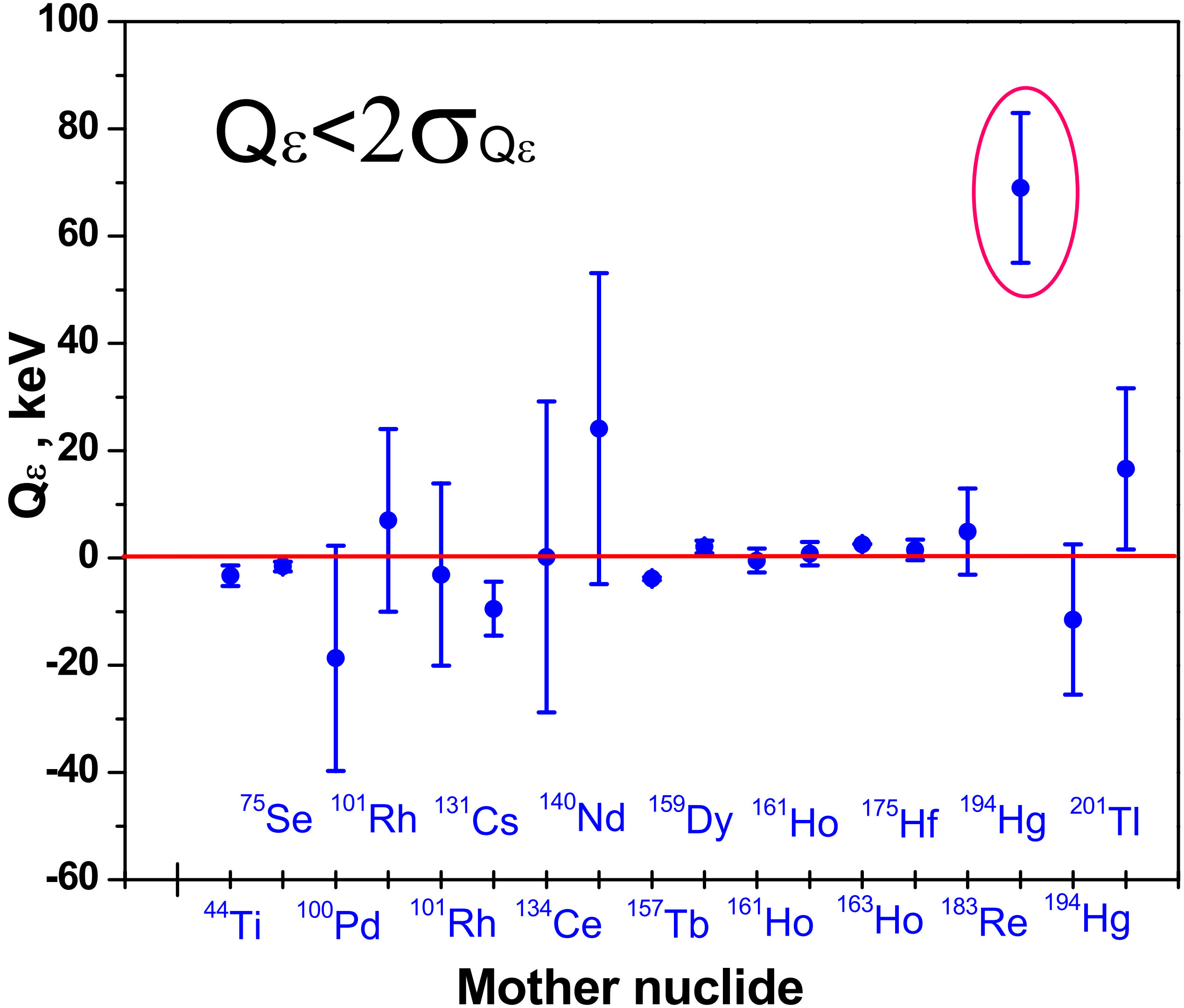


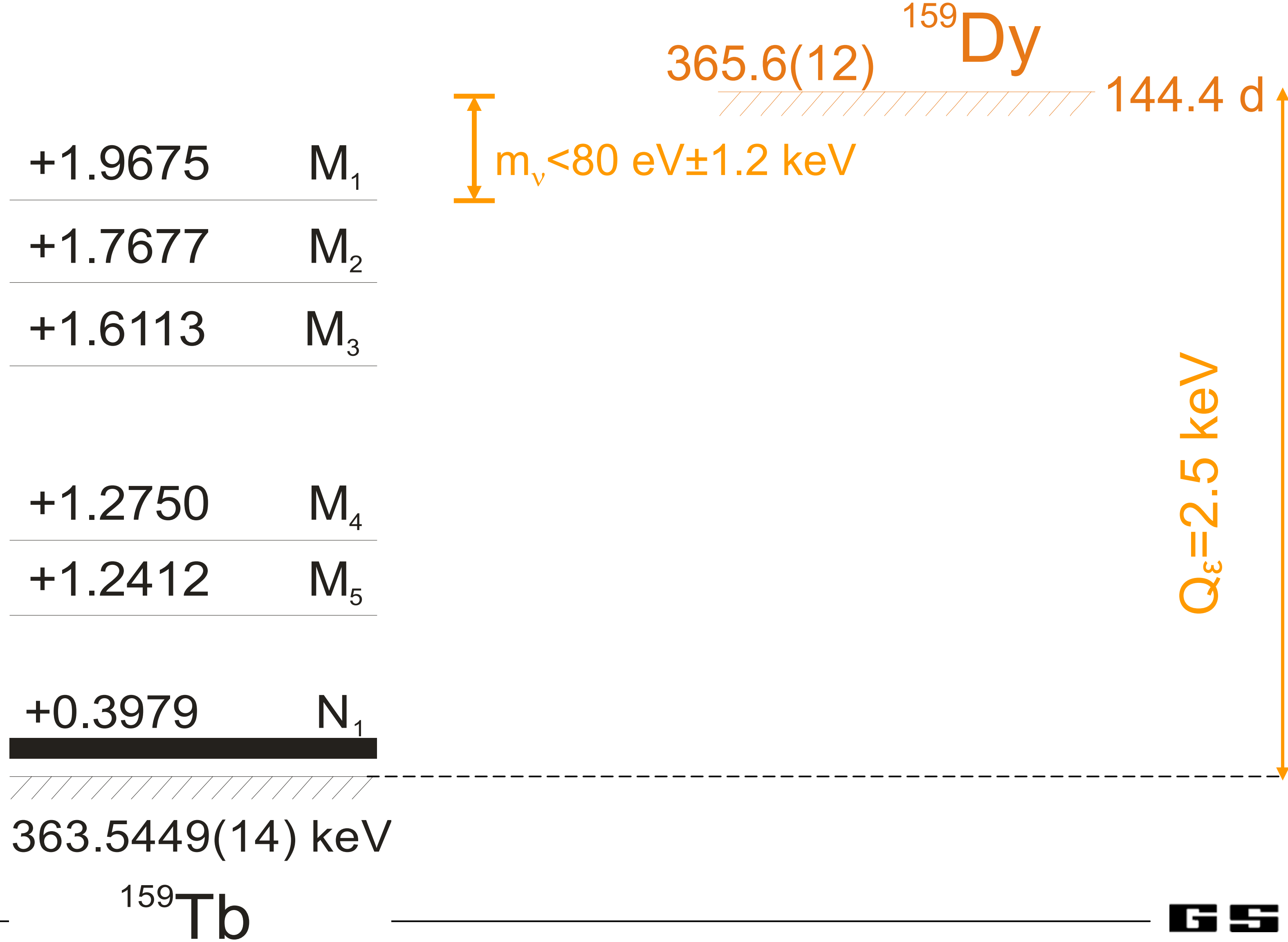
$m_\nu < Q_\beta$

$m_\nu < Q_{ec} - B_i$

First possibility

Nuclides with the smallest ε-energies

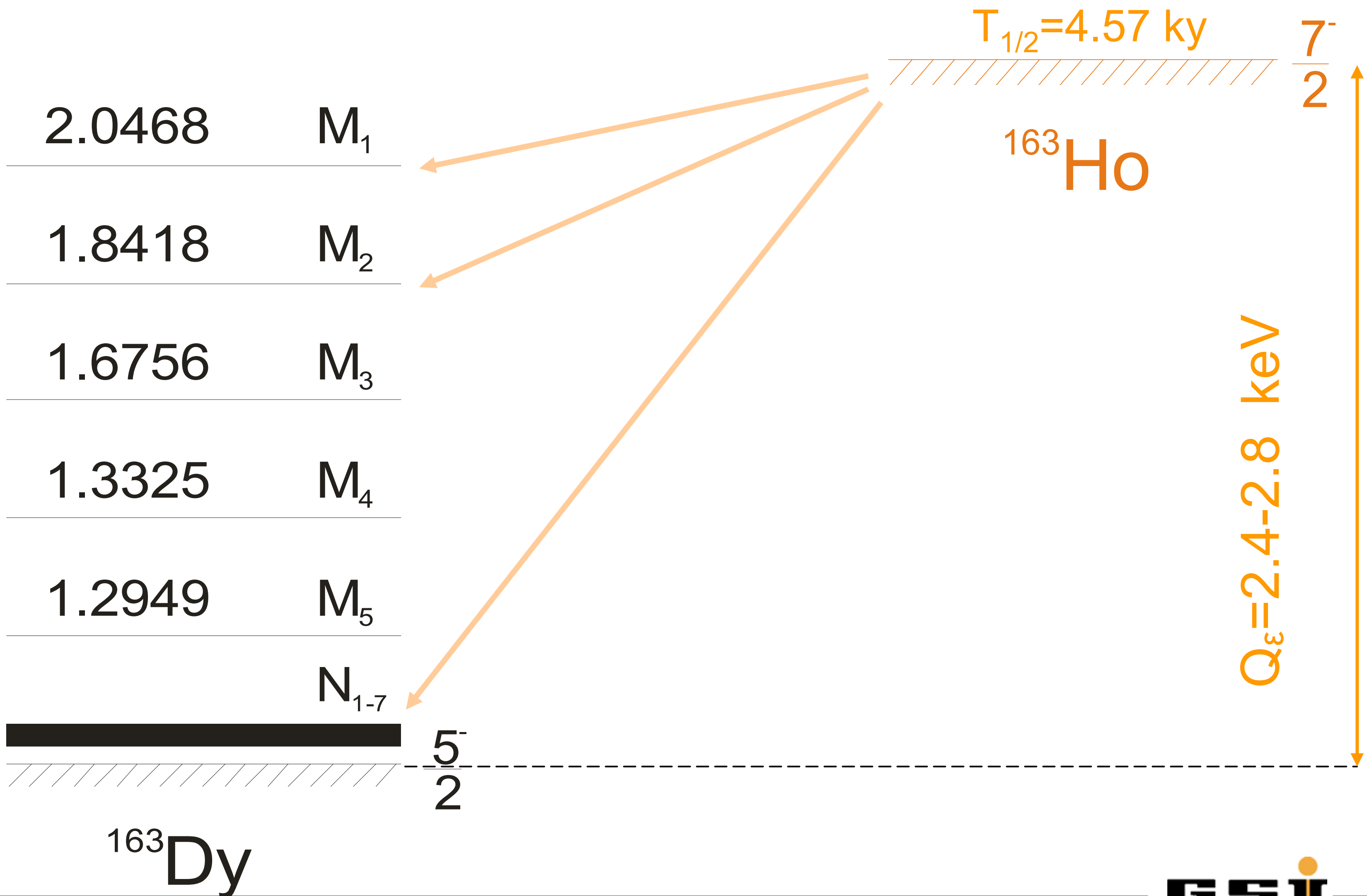




^{159}Dy
365.6(12)
144.4 d
m_ν<80 eV±1.2 keV
+1.9675 M_1
+1.7677 M_2
+1.6113 M_3
+1.2750 M_4
+1.2412 M_5
+0.3979 N_1
Q_ε=2.5 keV
363.5449(14) keV
^{159}Tb

Second possibility

Example for an electron-capture nuclide



How can we derive the neutrino mass from electron-capture ?

Total capture probability for allowed transition:

$$\Lambda = \frac{1}{4} g^2 \pi^2 \{M_0(1,1)^2 + M_1(1,1)^2\} \sum_i n_i W_i \beta_i^2 B_i$$

Capture ratios for "2" and "1" atomic levels:

$$\frac{\lambda_2}{\lambda_1} = \eta \frac{W_2}{W_1} \frac{q_2}{q_1}$$, where

$W_i = Q_\varepsilon - B_i$

$$q_i = \sqrt{(W_i^2 - m_\nu^2)}$$ (i = 1,2)

η can be determined from λ_i / Λ – ratio, where $\Lambda = \frac{\ln 2}{T_{1/2}}$

Block of tasks N1 (smallest Q_ε-B_i)

SHIPTRAP (TOF & FT)

^{100}Pd-^{100}Rh, ^{101}Rh-^{101}Ru, ^{131}Cs-^{131}Xe, ^{134}Ce-^{134}La, ^{140}Nd-^{140}Pr, ^{161}Ho-^{161}Dy, ^{175}Hf-^{175}Lu, ^{183}Re-^{183}W, ^{194}Hg-^{194}Au

ISOLTRAP +JYFLTRAP

^{77}As-^{77}Se, ^{155}Eu-^{155}Gd, ^{171}Tm-^{171}Yb, ^{201}Tl-^{201}Hg,

----

^{75}Se-^{75}As, ^{130}Cs-^{130}Ba, ^{157}Tb-^{157}Gd, ^{159}Dy-^{159}Tb

LEBIT

^{44}Ti-^{44}Sc, ^{75}Se-^{75}As

HITRAP

^{159}Dy-^{159}Tb and other selected pairs

Atomic physics calculations a_i, B_i, ΣB_i

Gran Sasso

Levels population, accurate level energy

Block of tasks N2 (neutrino mass determination)

HITRAP

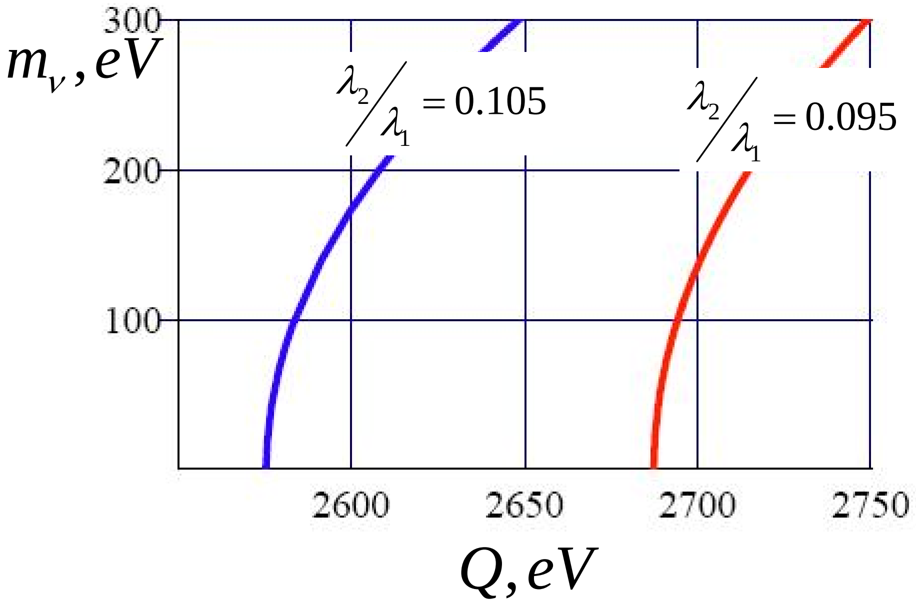
^{163}Ho-^{163}Dy, ^{161}Ho-^{161}Dy, ^{159}Dy-^{159}Tb

Calorim. Lab

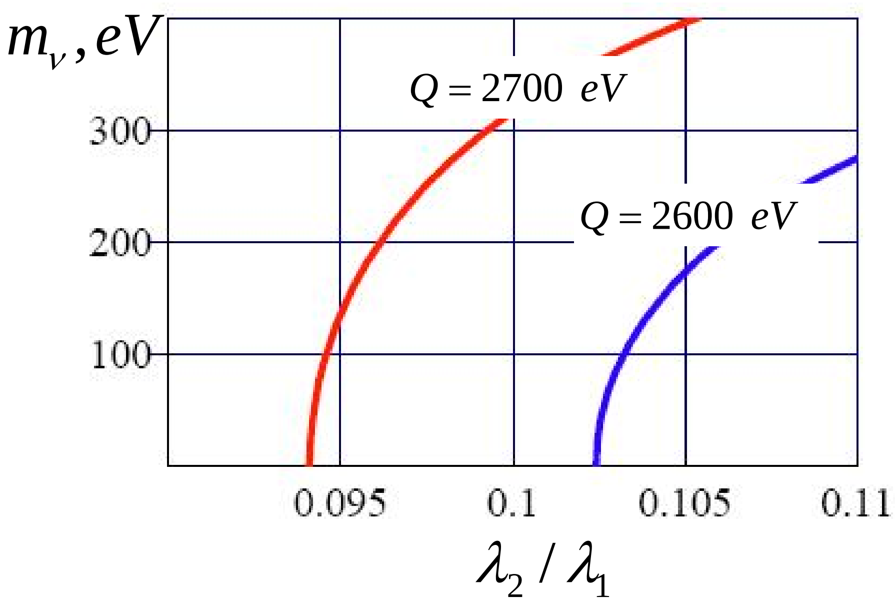
λ_i/λ_j	^{163}Ho-^{163}Dy
$\lambda_i/\Sigma\lambda_i$	^{161}Ho-^{161}Dy

Dependence of neutrino mass value on Q_ε and $\lambda_{M2}/\lambda_{M1}$

Neutrino mass dependence on Q-value



Neutrino mass dependence on λ_2 / λ_1



Conclusions

- masses for twenty pairs of nuclides must be measured at the conventional traps with precision better than 10^{-8} (~1 keV),
- masses for chosen nuclides should be ultraprecisely measured at the HITRAP with precision better than 10^{-10},
- atomic electron capture ratios should be measured as precisely as possible (e.g., for ^{163}Ho it should be $<10^{-3}$) .

Thanks to collaborators

"Initiative team" in traps

H.-J. Kluge (*GSI*),
K. Blaum (*Mainz Uni*),
S. Eliseev *(GSI)*,
F. Herfurth *(GSI)*,
Yu. Novikov (*PNPI*),
W. Quint *(GSI)*,
A. Sokolov *(Heidelberg Uni)*