The KATRIN sensitivity to the neutrino mass and to right-handed currents in beta decay

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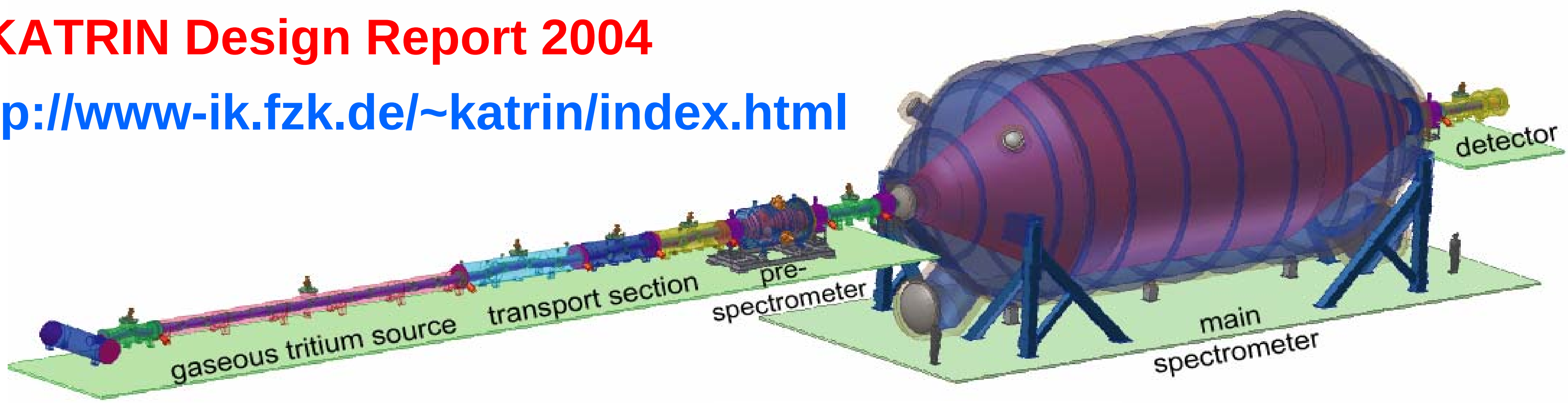
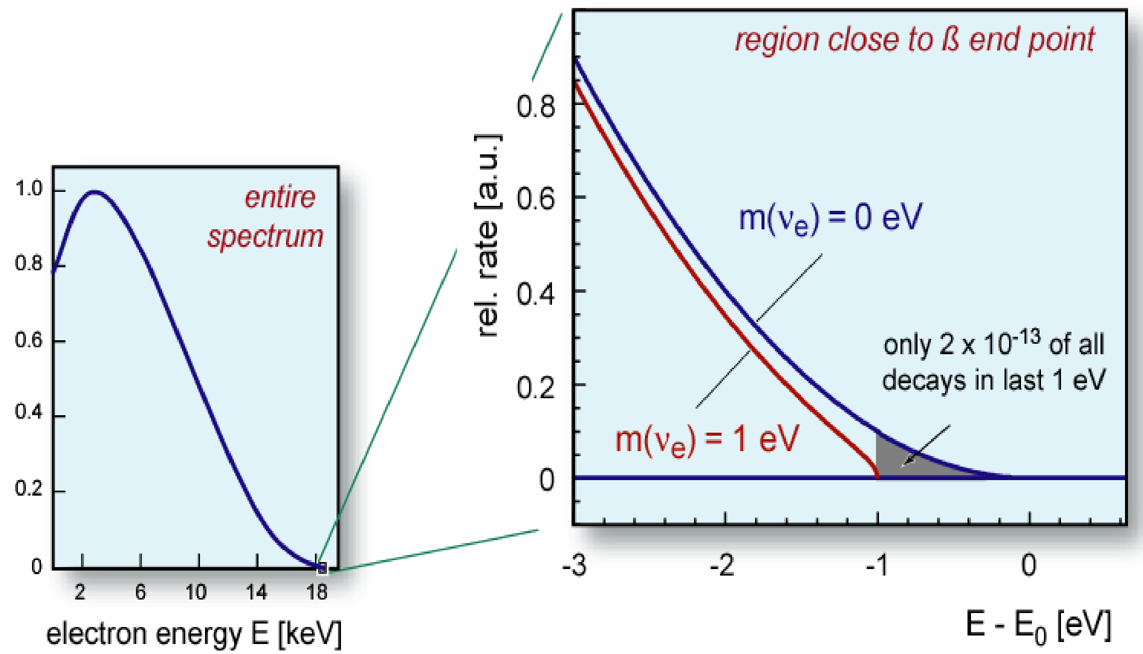
The KArlsruhe TRItium Neutrino Experiment

KATRIN Design Report 2004

http://www-ik.fzk.de/~katrin/index.html



Absolute neutrino mass scale determination down to 0.2 eV, with small model dependence.



Integral electron energy spectrum measurement close to endpoint of molecular tritium (T_2) beta decay.

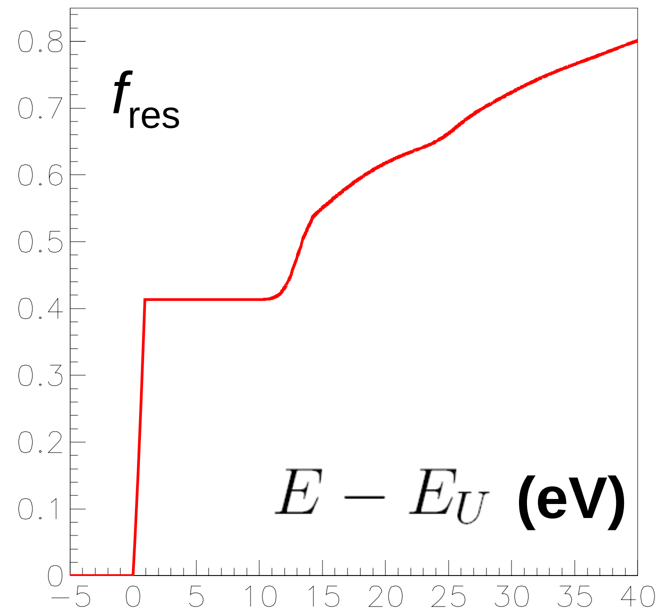
Response function and final state distribution

Integral spectrum:

$$w_{int}(E_U) = \int_{E_U}^{E_0} dE \cdot f_{res}(E - E_U) \cdot w_{diff}(E)$$

$$E_U = e|U_A - U_S|$$ **(minimal electron energy)**

$U_A,\ U_S$ **: potential in analyzing plane of main spectrometer and in source**



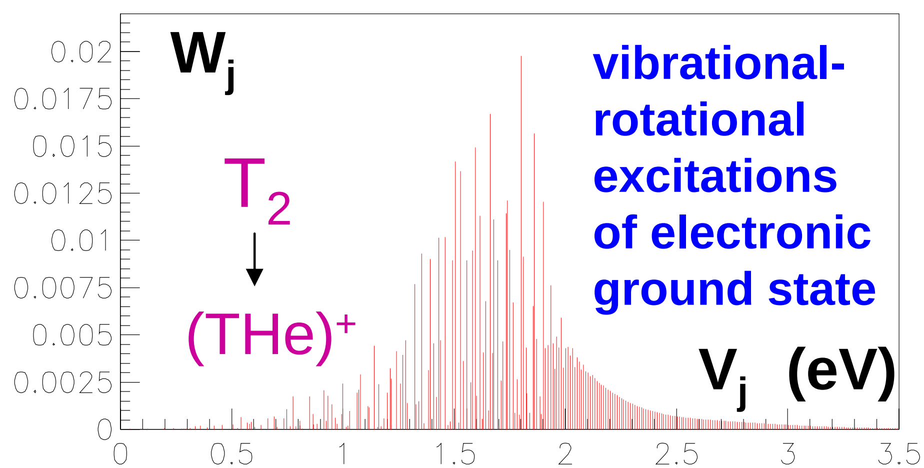
Final state distribution calculation is needed for differential spectrum:

(N. Doss et al., PR C 73, 025502 (2006))

$$w_{diff}(E) = \sum_j W_j \cdot E_{\nu j}\sqrt{E_{\nu j}^2 - m_\nu^2}$$

$$E_{\nu j} = E_0 - V_j - E$$

(assuming degenerate neutrino masses)

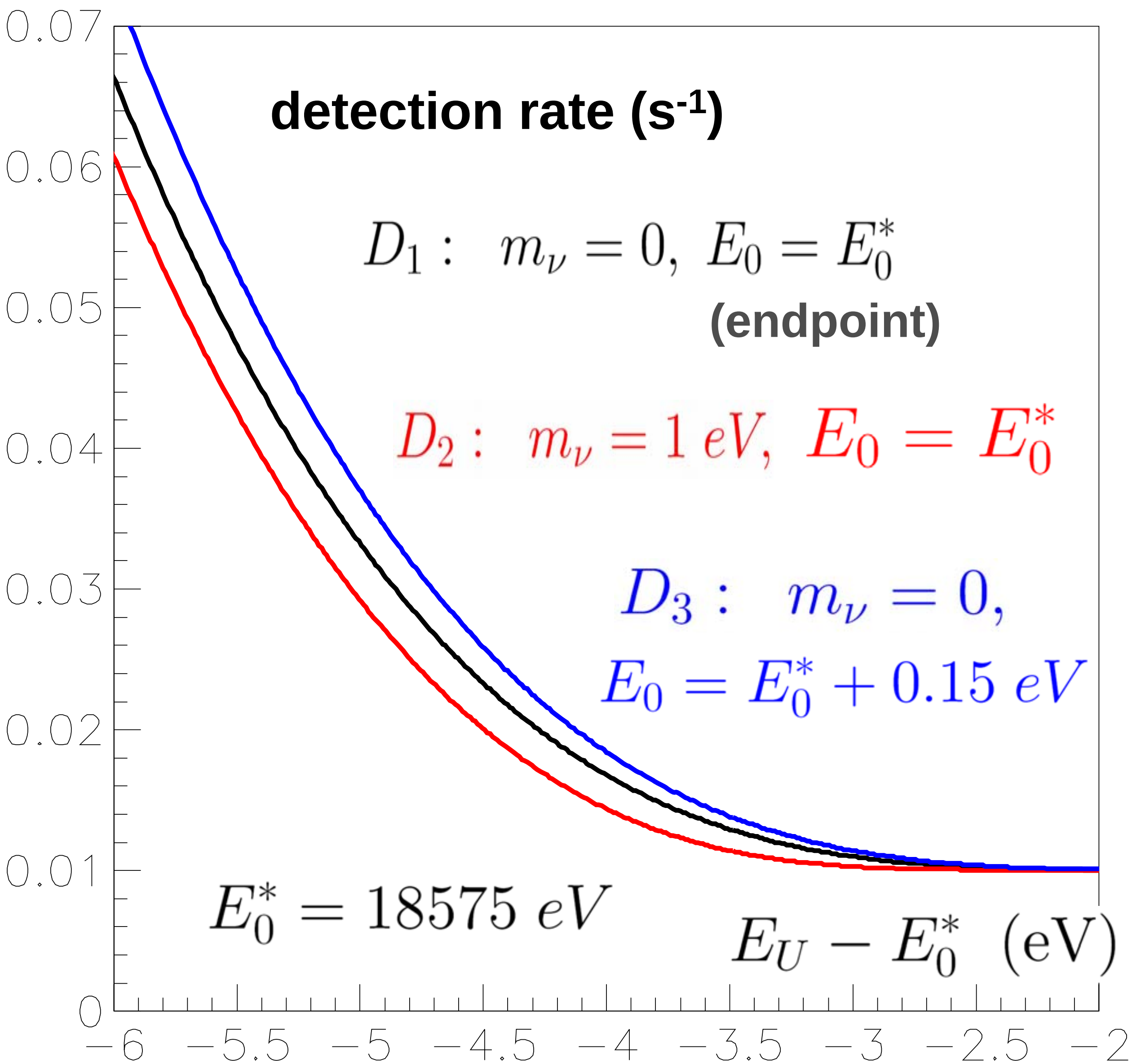


Ground state probability: 0.57

mean: 1.7 eV

$\sigma = 0.4$ eV

Neutrino mass and endpoint dependence of KATRIN detection rate spectrum



With new KATRIN design parameters and assuming 0.01 s^{-1} background

Positive correlation between neutrino mass and endpoint

$$\Delta m_\nu^2 \ (\mathrm{eV}^2) = 7 \Delta E_0 \ (\mathrm{eV})$$

(shift of mass squared due to endpoint shift)

Aim of KATRIN: Neutrino mass squared determination
by $\sigma(m_\nu^2) = 0.025 \ \mathrm{eV}^2$ precision

(fitting the endpoint - as a free parameter - from the KATRIN data)

Fixed endpoint, as external parameter: better than 3.5 meV would be necessary !

(see: E. W. Otten et al., Int. J. Mass Spectr. 251, 173 (2006))

From nuclear mass difference: 1.7 eV endpoint error at present;
absolute electric potential accuracy better than 100 mV also difficult:

→ **endpoint should be determined from KATRIN data as free parameter; analyses assuming fixed endpoint are not relevant for the KATRIN experiment !**

Right-handed couplings and the electron spectrum

The right-handed couplings change the electron spectrum:

$$w_{diff}(E) = \sum_j W_j \cdot E_{\nu j} \sqrt{E_{\nu j}^2 - m_\nu^2} \left(1 + b' \frac{m_\nu}{E_{\nu j}}\right)$$

(valid close to endpoint)

Similar term in beta spectrum from Fierz parameter *b.*

Parameter *b´* is linear combination of right-handed vector, scalar, axialvector and tensor couplings:

$$b' \approx -2 \frac{\Re e(L_V R_V^* + L_V R_S^*)|M_F|^2 + \Re e(L_A R_A^* + L_A R_T^*)|M_{GT}|^2}{|L_V|^2 |M_F|^2 + |L_A|^2 |M_{GT}|^2}$$

Connection with widely used C_j and C_j' couplings (Lee, Yang, 1956):

$$C_j = \frac{G_W}{\sqrt{2}}(L_j + R_j) \quad , \quad C_j' = \frac{G_W}{\sqrt{2}}(L_j - R_j)$$

V-A (SM) model: only L_V and L_A are non-zero

It is expedient to use the left-handed L_j and right-handed R_j parameters

(see: F. Glück et al., Nucl. Phys. A 593, 125 (1995))

Constraints for the parameter b`

95 % confidence limits for the right-handed couplings: **(with L_V=1)**

$$|R_V| < 0.08, \quad |R_A| < 0.10, \quad |R_S| < 0.07, \quad |R_T| < 0.10.$$

(N. Severijns et al., to appear in Rev. Mod. Phys)

Usual beta decay observables are quadratic in R_j

→ no information about their sign

Worst case scenario (to get conservative limit):

signs of R_V, R_A, R_S, R_T are equal, no cancellation in b`

$$|b'| < 0.26 \quad (95\ \%\ \mathrm{CL}), \quad |b'| < 0.31 \quad (99.7\ \%\ \mathrm{CL})$$

More general models:

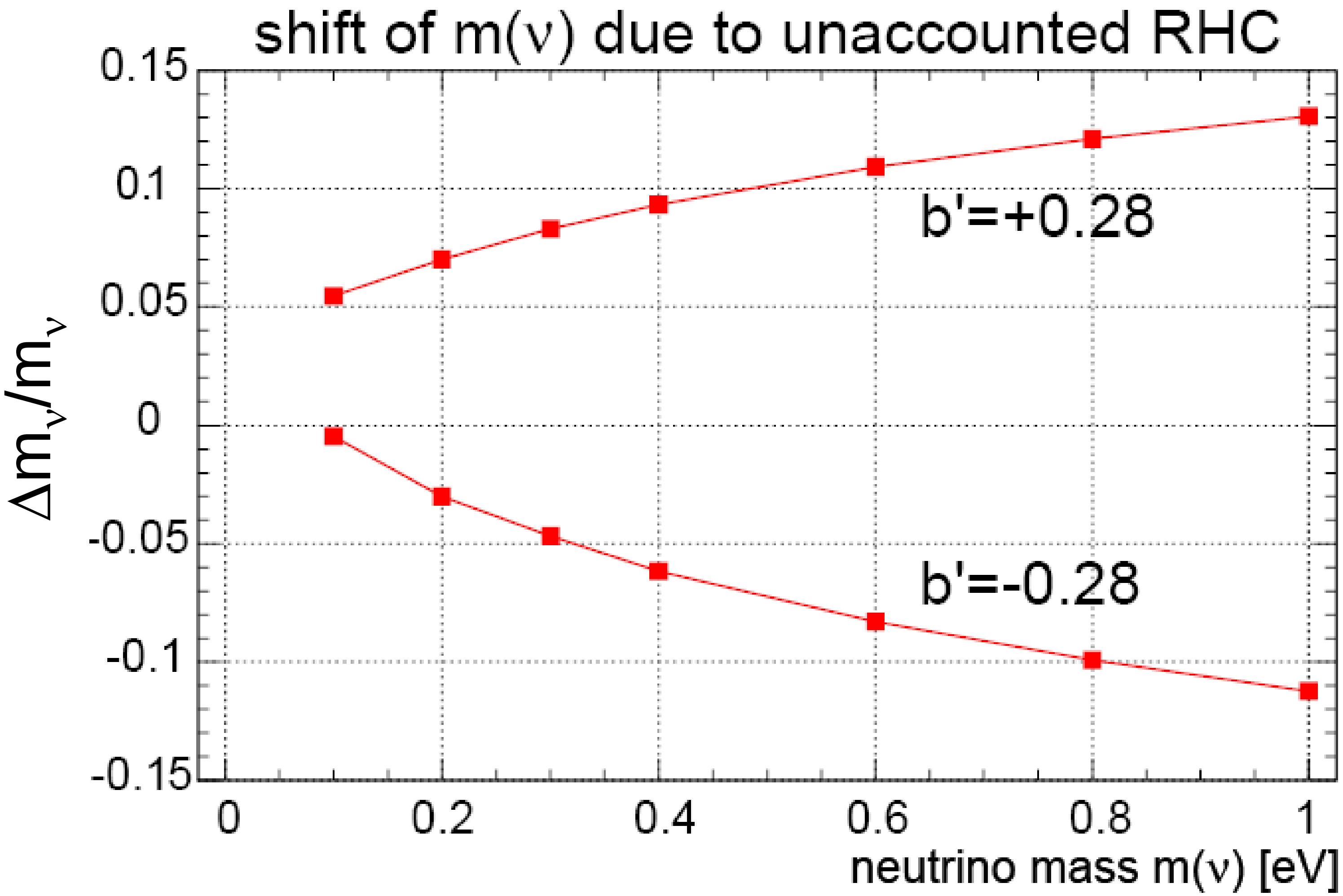
- larger right-handed (Majorana) neutrino masses
- lepton mixing matrices of right-handed couplings different from SM mixing matrix

The above (conservative) limit is still valid !

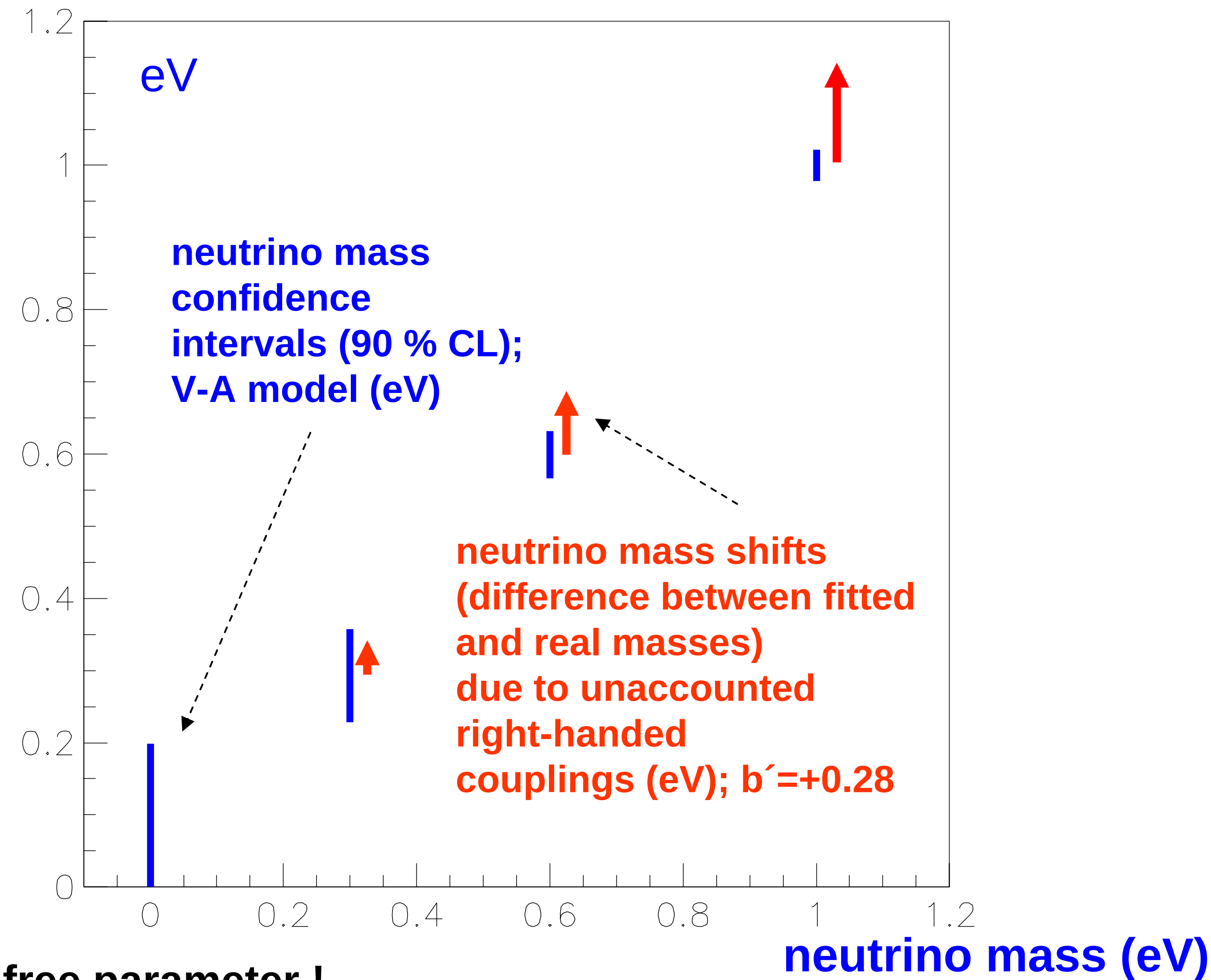
Neutrino mass shift due to unaccounted right-handed couplings

Assuming non-zero b´ parameter in reality, and analyzing with b´=0 formulae ⟶ Δm_ν difference between fitted and real neutrino mass values

Free parameters of the fit: mass squared, endpoint, amplitude, background



Neutrino mass confidence intervals and neutrino mass shifts due to unaccounted right-handed couplings



Endpoint is free parameter !

Effect of right-handed couplings to fitted neutrino mass: big difference between fixed and free endpoint analyses !

Let us assume the following real values:

$$m_\nu^{real} = 0.35 \text{ eV}, \qquad |b'_{real}| = 0.28$$

But we fit with V-A model (without right-handed couplings: b´=0)

Difference between fitted and real neutrino masses ?

b'_{real}	E_0 fixed	E_0 free
-0.28	$m_\nu(fit)$ =0.6 eV	$m_\nu(fit)$ =0.33 eV
+0.28	$m_\nu^2(fit)$ = -0.1 eV^2	$m_\nu(fit)$ =0.38 eV

Analyses assuming fixed endpoint are not relevant for KATRIN !

Effect of right-handed couplings to the fitted neutrino mass:

E_0 fixed: large (100 %) shift for neutrino mass
(negative fitted mass squared possible for large real mass)

E_0 free: small (5-10 %) shift for neutrino mass
(negative fitted mass squared NOT possible for large real mass)

First studies to explain the negative neutrino mass squared problem:

G. J. Stephenson, T. Goldman, PL B 440, 89 (1998);
G. J. Stephenson et al., PR D 62, 093013 (2000).

Recent paper:

A. Yu. Ignatiev, B. H. J. McKellar, PL B 633, 89 (2006).

These papers present substantial right-handed coupling effects for the neutrino mass. But they use fixed endpoint analyses, so their results are not relevant for the KATRIN experiment !

Summary

1. **The right-handed coupling effect to the neutrino mass with fixed endpoint is much larger than with free endpoint. The endpoint in the KATRIN experiment is a free parameter; analyses assuming fixed endpoint are not appropriate for KATRIN.**

2. **Fitting the KATRIN data with V-A model (endpoint is free parameter), in presence of right-handed couplings constrained by many beta decay experiments**:

→ $\Delta m_\nu / m_\nu \sim \; 5 - 10 \; \%$ **error.**

3. **Preliminary result from more general statistical calculations (where b´ is also a free parameter: 5-parameter fit): for small neutrino mass (below 1 eV) KATRIN cannot improve the present constraint for the parameter b´.**