Determination of the Neutrino Mass by Electron Capture

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1)Faessler, Gastaldo, Simkovic, J. Phys. G 42, 015108 (2015)

2)Faessler, Simkovic, Phys. Rev C91, 045505 (2015)

3)Faessler, Enss, Gastaldo, Simkovic, Phys. Rev. C91, 064302 (2015)

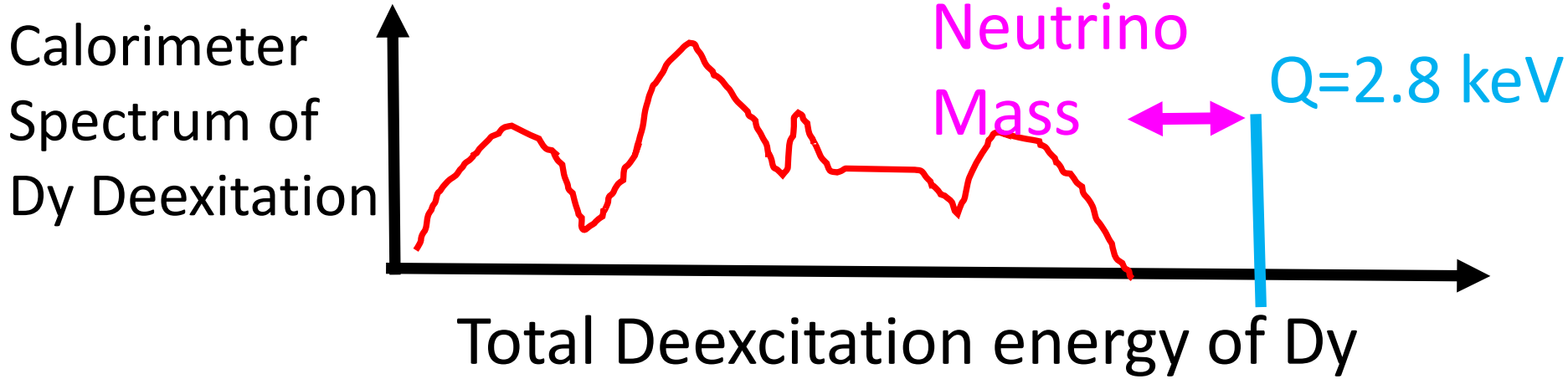
4) Faessler, Gastaldo, Simkovic, Phys. Rev. C95, 045502 (2017)

5) Faessler, Int. J. Mod. Phys., Walter Greiner Memorial Vol. 2018

Determination of the Electron-Neutrino Mass by Capture of a bound electron in Holmium:

$^{163}_{67}$Holmium (Proton) + bound Electron → $^{163}_{66}$Dysprosium*(Neutron) + Electron-Neutrino

ECHo = Electron Capture by Ho; Heidelberg (Loredana Gastaldo), Mainz, Tübingen.



Others: HOLMES, Milano (B. Alpert et al.) ; NuMECS, LosAlamos (G. Kunde et al.);

For Electron Capture (in Holmium 163):

1) Electron at nucleus → s1/2 and p1/2

2) Electron binding energy < Q-value ≈ 2.8 [keV]

$E(1s_{1/2}, K,Ho) = 55.6$ keV
$E(2s_{1/2}, L1,Ho) = 9.4$ keV
$E(2p_{1/2}, L2,Ho) = 8.9$ keV
$E(2p_{3/2}, L3,Ho) = 8.1$ keV

$E(3s_{1/2}, M1,Ho) = 2.0$ keV
$E(3p_{1/2}, M2,Ho) = 1.8$ keV
$E(4s_{1/2}, N1,Ho) = 0.4$ keV
$E(4p_{1/2}, N2,Ho) = 0.3$ keV
$E(5s_{1/2}, O1,Ho) = 0.05$ keV

Selfconsistent Dirac-Hartree-Fock approach:

$$|G>=a_1^\dagger a_2^\dagger a_3^\dagger \ldots a_Z^\dagger |0>$$

Holmium

$$|A'_{p',f':q'>0}>= a_1'^\dagger a_2'^\dagger \ldots a_{f'-1}'^\dagger a_{f'+1}'^\dagger \ldots a_{p'-1}'^\dagger a_{p'+1}'^\dagger \ldots a_Z'^\dagger a_{q'>0}'^\dagger |0>$$

Shake-up and Shake-off

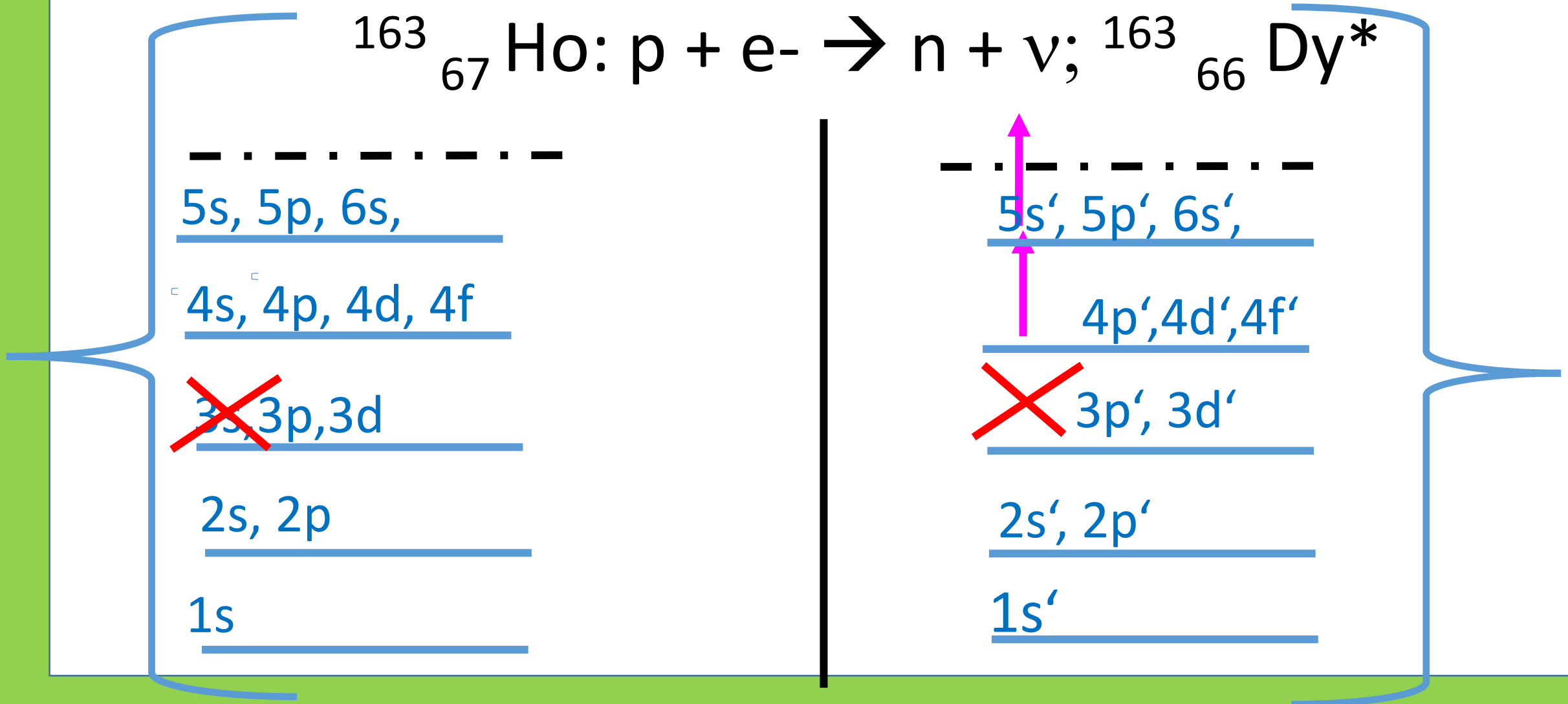
$$|A'_f>= a_1'^\dagger a_2'^\dagger \ldots a_{f-1}'^\dagger a_{f+1}'^\dagger \ldots a_Z'^\dagger |0>$$

Dysprosium

A. Faessler, E. Huster, O. Krafft, F. Krahn, Z. Phys. 238 (1970) 352.

Sudden Desription of Bolometer Spectrum

$^{163}_{67}Ho: p + e^- \rightarrow n + \nu; \; ^{163}_{66}Dy^*$



An upper limit for Shake-off.

– – – – – – – –	DHF	$1- < DHF >^4$
$< 3s, Ho \vert 3s, Dy >$	0.99940	0.00239
$< 4s, Ho \vert 4s, Dy >$	0.99909	0.00363
$< 3s, Ho \vert 4s, Dy >$	-0.01982	
$< 4s, Ho \vert 3s, Dy >$	0.02067	
$< 3s, Ho \vert 4s, Ho >$	0.0	
$< 3s, Dy \vert 4s, Dy >$	0.0	

< 0.36 %

For overlap 0.9 this limit is:

$1.0 - 0.9^4 = 0.34$

→ 34%

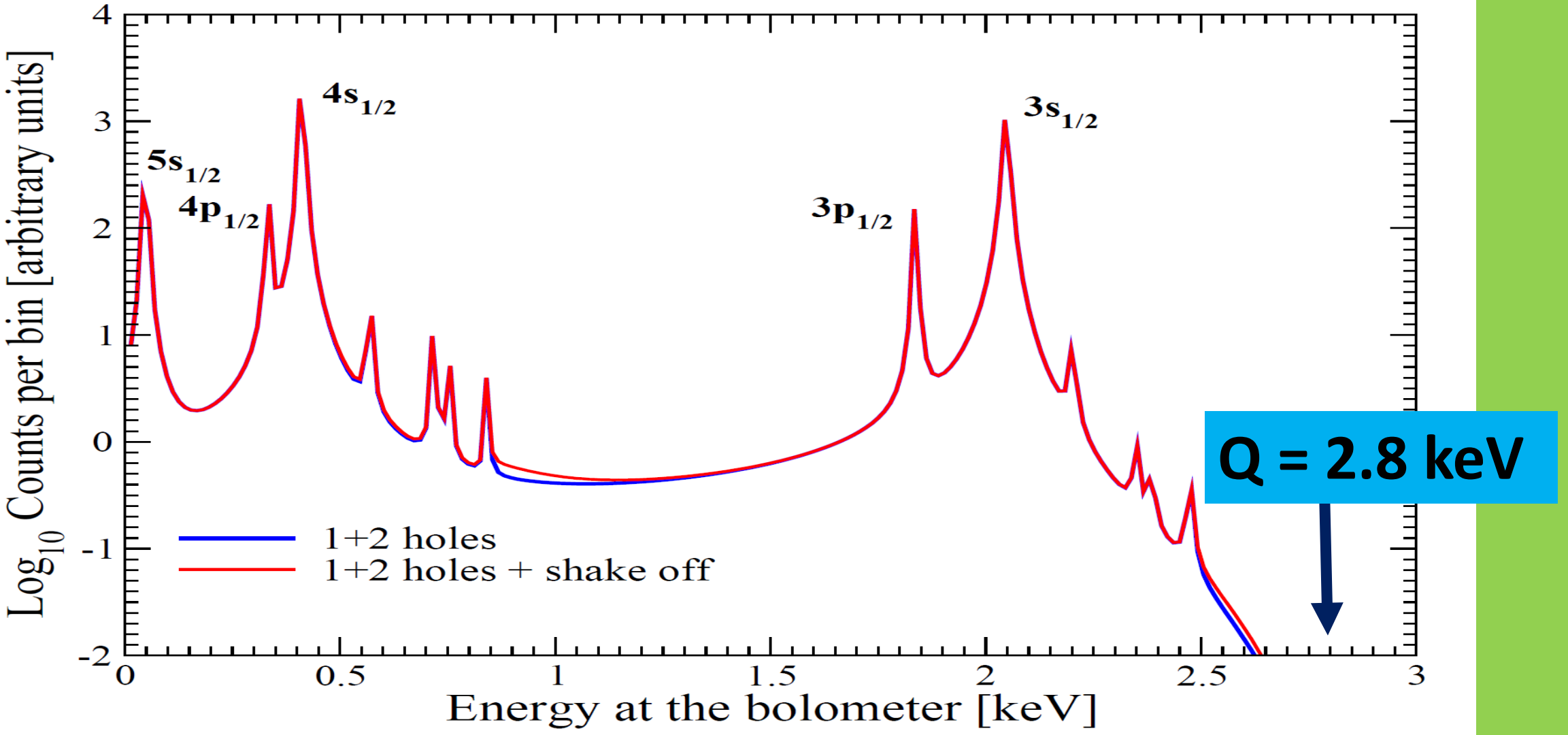
1-Hole,2-hole and shake-off Bolometer Spectrum in ^{66}Dy

$$\frac{d\Gamma}{dE_c} \propto \sum_{i=1,\dots N_\nu} (Q - E_c) \cdot U_{e,i}^2 \cdot \sqrt{(Q - E_c)^2 - m_{\nu,i}^2} * \Big(\sum_{f=f'} \lambda_0 B_f \frac{\Gamma_{f'}}{2\pi} \frac{1}{(E_c - E_{f'})^2 + \Gamma_{f'}^2/4} +$$

$$\sum_{f=f';p'<F;q'_b>F} \lambda_0 B_{f,p'<F;q'_b>F} \frac{\Gamma_{f',p'}}{2\pi} \frac{1}{(E_c - E_{f',p'})^2 + \Gamma_{f',p'}^2/4} +$$

$$\sum_{f=f';p'<F;q'>0} \circ \int dk_{q'} \lambda_0 B_{f,p'<F;q'_c>0} \frac{\Gamma_{f',p',q'}}{2\pi} \frac{1}{(E_c - E_{f',p',q'})^2 + \Gamma_{f',p',q'}^2/4} \Big)$$

Theoretical Bolometer Spectrum



How did we improve Intemann and Pollock (Phys.Rev.157(1967)41 ?

(in the version used by DeRujula and Lusignoli, JHEP1605(2016) 015)

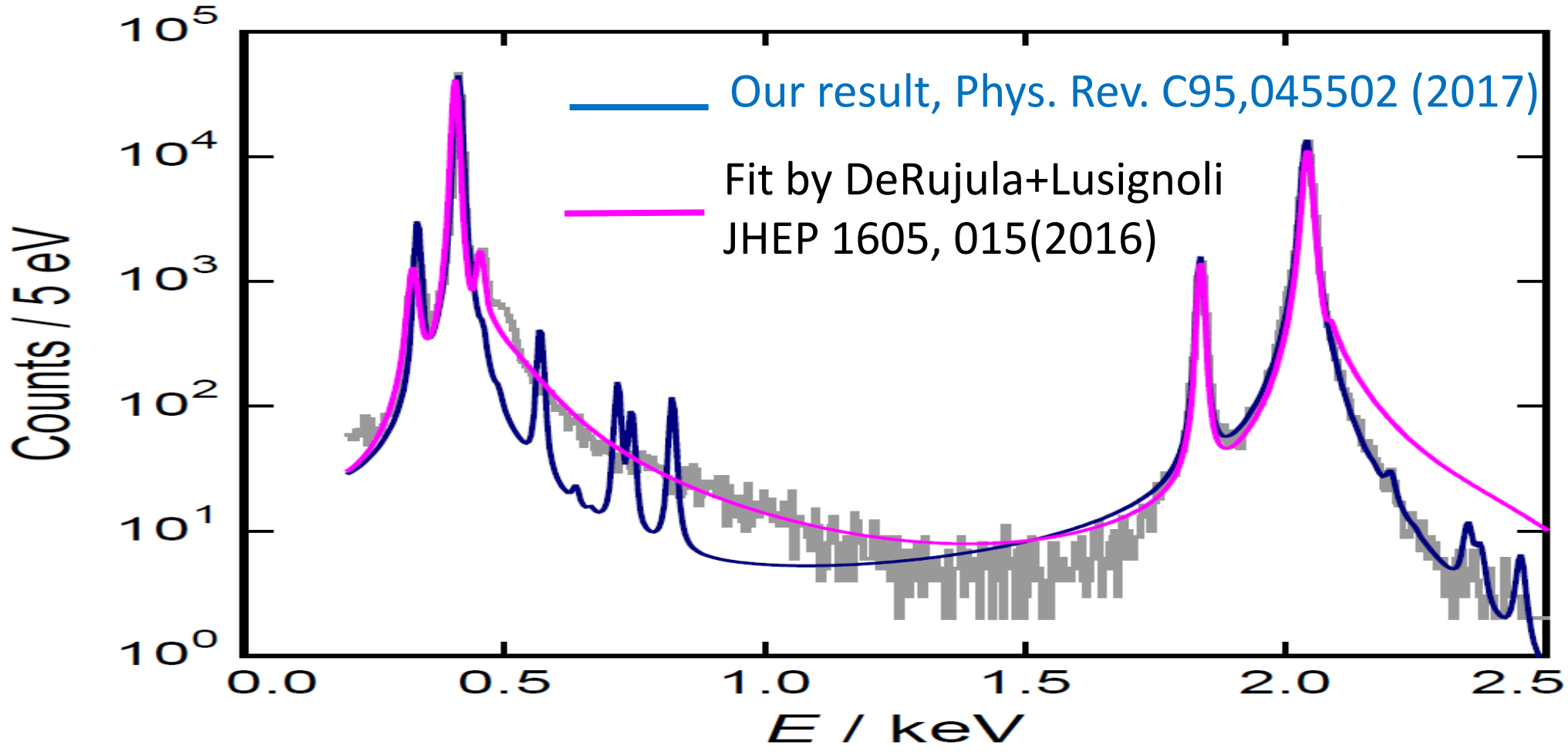
- Bound wave functions Ho +Dy Dirac-Hartree-Fock → non-relativistic screened Coulomb for Ho + first order perturbation Dy.
- Dirac continuum wavefunctions in selfconsistent potential of Dy → first order perturbation.
- Overlap <3s,HO|3s,Dy> limits shake-off to 0.4 %

→bad wave functions factor 100 larger.

- We show the results without modifications!!! The only other shake-off calculation (DeRujula+Lusignoli, JHEP 1605) fits the spectrum. They write:

" Our estimate of the height of the N1(4s)O1(5s) shakeup peak is a factor ≈ 2.5 too low. It is possible to correct in similarly moderate ways the other contributions such as to agree with the data. One possibility, illustrated in figure (3), is to correct the N1(4s)O1(5s) (capture, shakeup) peak by the cited factor and to leave N1(4s)O1(5s) (capture,shake-off) ... as predicted, while reducing the N1(4s)N4/5(4d3/2/4d5/2) features by a factor ≈ 3."

Comparison with Echo-Measurement in the Modane Underground Lab.



Summary

- Determination of the neutrino mass by electron capture in principle possible, but difficult.
- Shake-off proposed by Intemann and Pollock (Phys. Rev. 157 (1967) 41) is an interesting effect .
- But it is small and probably not relevant f mass determination in electron capture i

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