SHAKE AS THE MAIN MECHANISM OF THE NEUTRINOLESS DOUBLE ELECTRONIC CAPTURE

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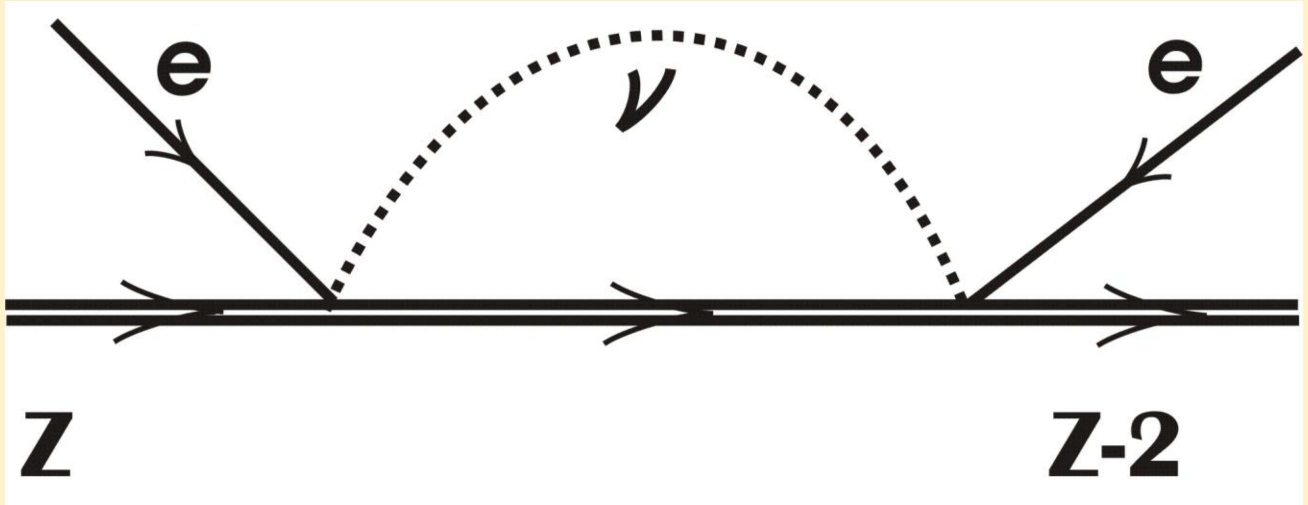
It is generally accepted that double neutrinoless electron capture is a resonance process. The calculations of the probability of shaking with the ionization of the electron shell occurring during the transformation of 164Er nucleus – one of main candidates for discovering the neutrinoless mode – are performed below. The result shows predominant contribution of the new mechanism. Its probability is three times as high as that of the traditional mechanism. Thus, in principle, double neutrinoless electron capture appears not to be a resonance process at all.

Школа внутренней конверсии ПИЯФ

2e0ν capture – test of the Majorana neutrino



$$Q = M(A,Z) - M(A,Z-2) > 0$$

$$Q_{\text{eff}}(n_1 l_1; n_2 l_2) = Q - E_A^* \quad - \text{ м.б.} < 0$$

«Раздутые» состояния и дефект резонанса

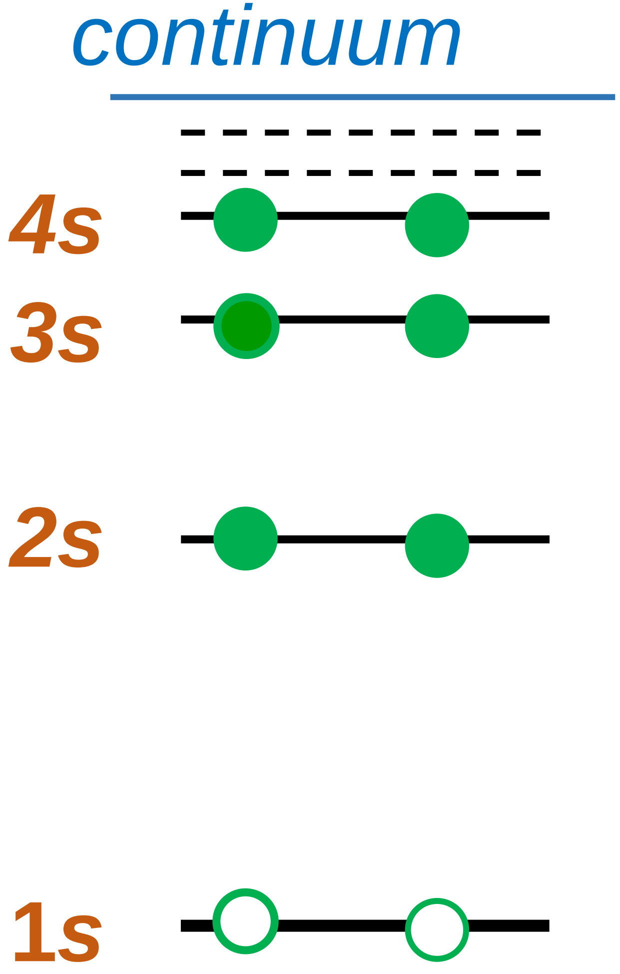
$$Q_{\text{eff}}(n_1 l_1; n_2 l_2) = Q - E_A^* < Q$$

$$E_A^* = I_{1s} + I_{3s}$$

$$\Delta = \left| Q_{\text{eff}} \right|$$

Resonance mechanism:

$$P_{2e0\nu} = W_{2e} \frac{\Gamma / 2\pi}{\Delta^2 + (\Gamma / 2)^2}$$



Способ наблюдения: *сателлиты*

САТЕЛЛИТЫ: $^{78}Kr \rightarrow {}^{78}Se$, 2*K*-захват

Ф. Ф. Карпешин, М. Б. Тржасковская, В. В. Кузьминов, Изв. РАН, сер. Физ., **76**, 986 (2012).

S.S.Ratkevich, A.M.Gangapshev, Yu.M.Gavrilyuk, F.F.Karpeshin, V.V.Kazalov, V.V. Kuzminov, S.I.Panasenko, M.B.Trzhaskovskaya, S.P.Yakimenko, Phys. Rev. C 96, 065502 (2017).

Энергии квантов флуоресценции при двойном двухнейтринном *K*-захвате в сравнении с обычными квантами флуоресценции

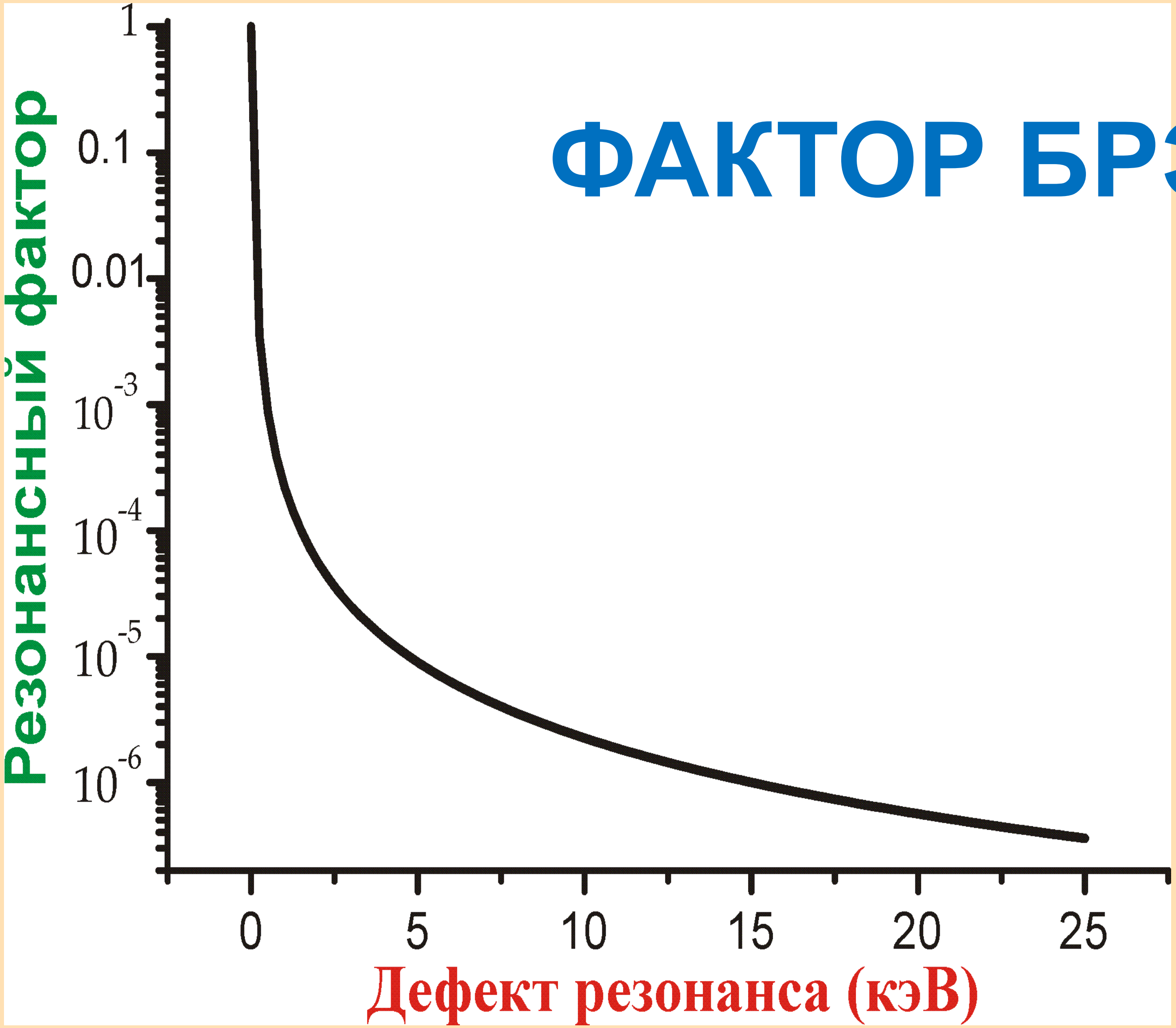
Переход	ω_X^1, эВ	ω_X^2, эВ	ω_X^0, эВ
$2p_{1/2} \rightarrow 1s$	11560	11262	11205
$2p_{3/2} \rightarrow 1s$	11606	11308	11248
$3p_{1/2} \rightarrow 1s$	12950		12490
$3p_{3/2} \rightarrow 1s$	12967		12496

Резонансно-флюоресцентный механизм *2e0v*-захвата

$$P_{2e0\nu} = W_{2e} \frac{\Gamma / 2\pi}{\Delta^2 + (\Gamma / 2)^2}$$

Типичные значения: Г= 30 эВ, Δ ≈ 10 кэВ:

ФАКТОР БРЭЙТА – ВИГНЕРА

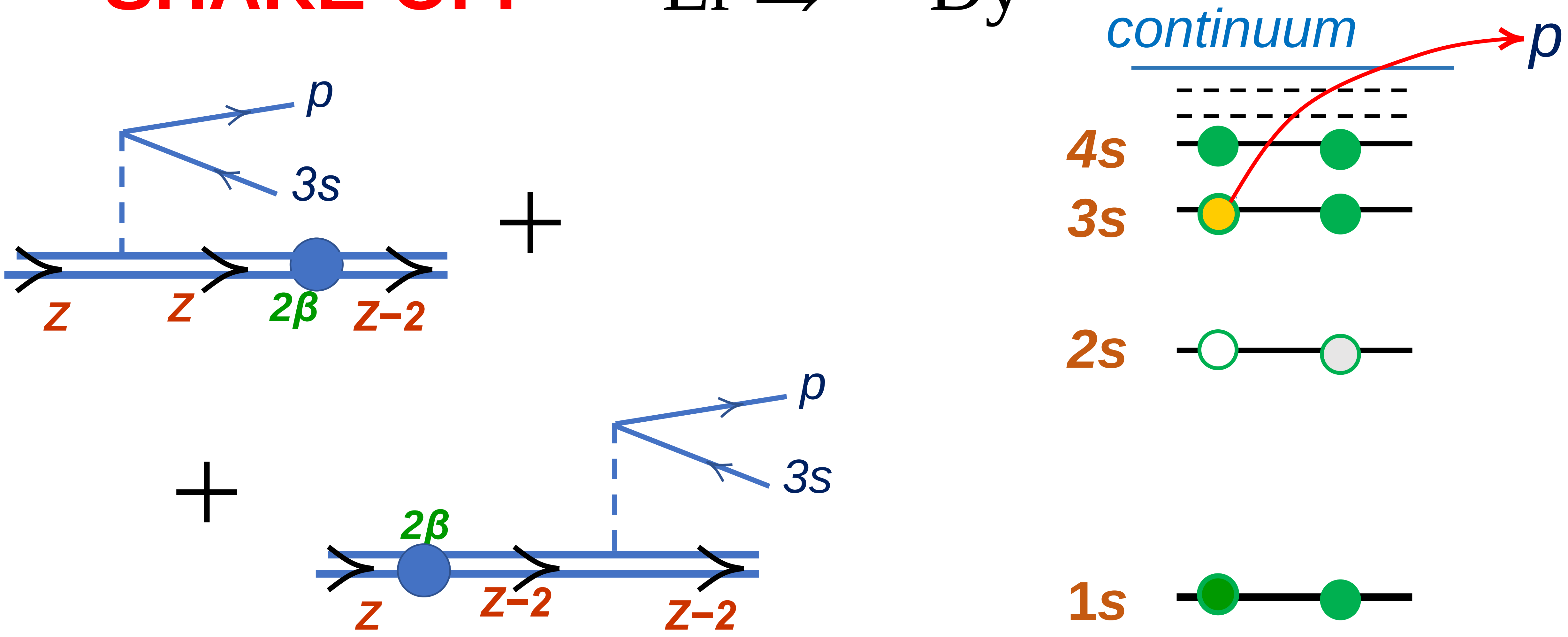


Three most promising double-electron-capture transitions between nuclear ground states

S A Eliseev, Yu N Novikov et al., J. Phys. G: Nucl. Part. Phys. 39 (2012) 124003

$\varepsilon\varepsilon$-transition	$^{152}Gd \rightarrow {}^{152}Sm$	$^{164}Er \rightarrow {}^{164}Dy$	$^{180}W \rightarrow {}^{180}Hf$
Reference	[63]	[57]	[64]
Electron orbitals	KL_1	L_1L_1	KK
$Q_{\varepsilon\varepsilon}$ (old)/keV	54.6 (35)	23.3 (39)	144.4 (45)
Δ (old)/keV	−0.27(350)	5.05(390)	12.4(45)
$Q_{\varepsilon\varepsilon}$ (new)/keV	55.70(18)	25.07(12)	143.20(27)
Δ (new)/keV	0.83(18)	6.82(12)	11.24(27)
Nuclear matrix element M	2.7–3.2	2.3–2.6	1.8–2
Min. half-life/y	1×10^{26}	2×10^{30}	3×10^{28}
Max. half-life/y	1×10^{27}	2×10^{30}	4×10^{28}

SHAKE-OFF $^{164}\text{Er} \Rightarrow {}^{164}\text{Dy}$



$$\langle p\,|V_Z(r)|\,3s\rangle \frac{A_{2\beta}}{-Q_{\text{eff}}} + \frac{A_{2\beta}}{Q_{\text{eff}}}\langle p\,|V_{Z-2}(r)|\,3s\rangle = -\frac{A_{2\beta}}{Q_{\text{eff}}}\langle p\,|V_Z(r) - V_{Z-2}(r)|\,3s\rangle$$

SHAKE-OFF: possible, if still $Q_{\mathrm{eff}} > 0.$

$$W_{sh} = |F_{\mathrm{sh}}|^2 \equiv |\langle \phi_E | \phi_i \rangle|^2 \approx \left| \frac{\langle \phi_E | \Delta V(r) | \phi_i \rangle}{\Delta} \right|^2$$

with the energy of the emitted electron $E = \Delta - I_i$

As a result of shake-off, *energy conservation is restored*, but:

$$P^{(sh)}_{2e0\nu} = W_{2e} W_{sh}$$

The gain:

$$G = \frac{P^{(sh)}_{2e0\nu}}{P_{2e0\nu}} = \frac{W_{sh}}{\dfrac{\Gamma / 2\pi}{\Delta^2 + (\Gamma / 2)^2}}$$

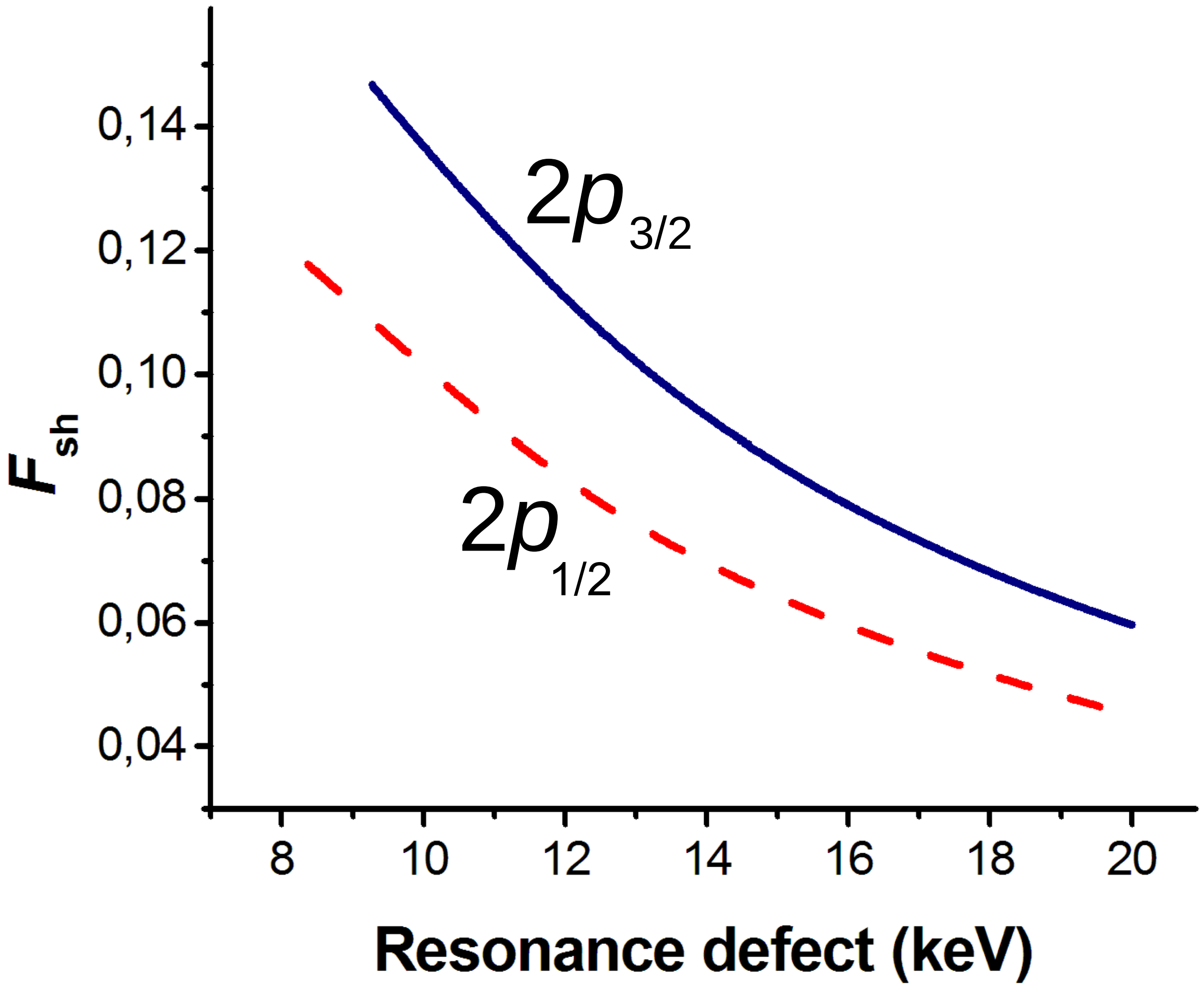
$^{164}Er \rightarrow {}^{164}Dy$ *L_1L_1* ***2e0ν capture***

$\boldsymbol{Q}$ = 25.07(12) keV

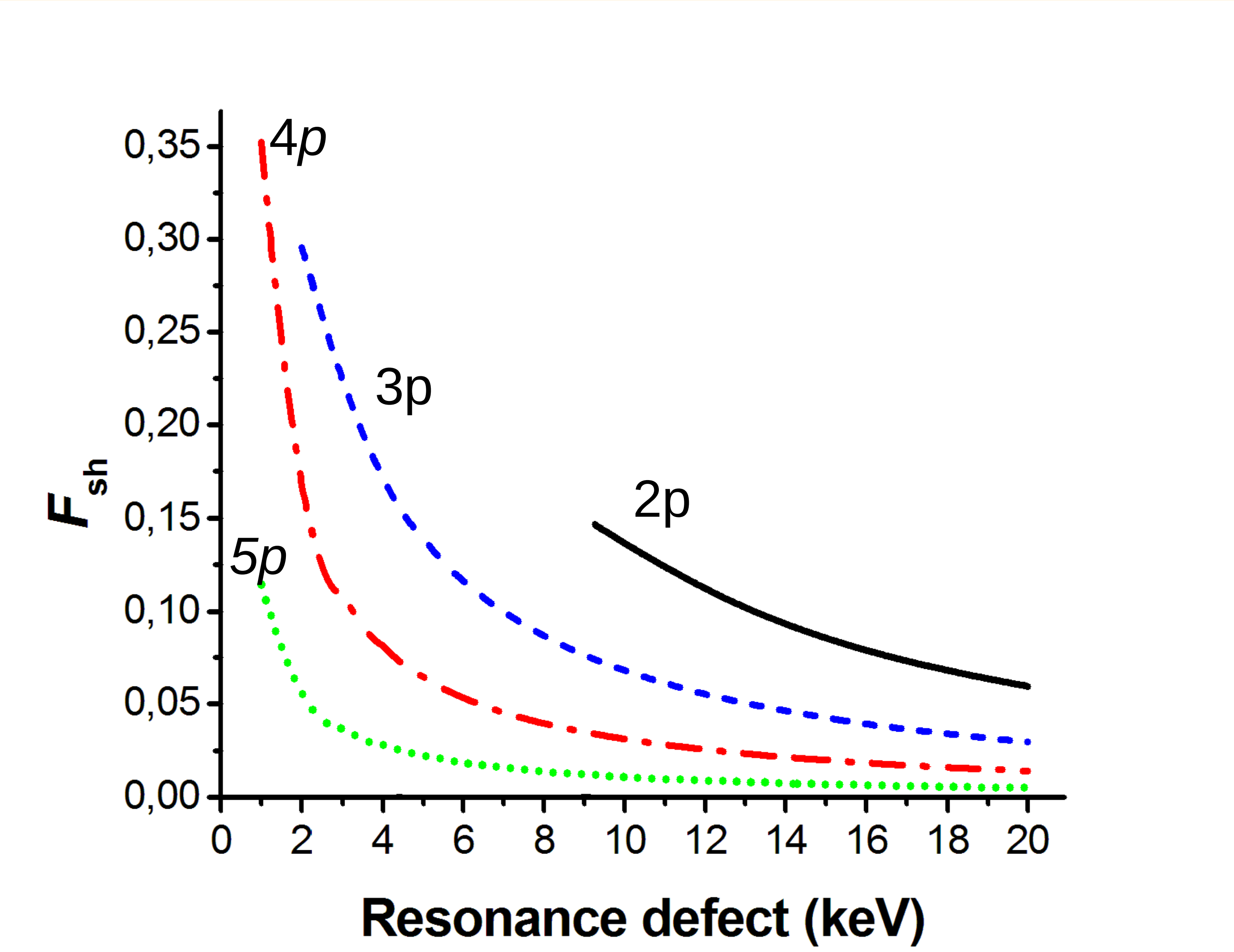
Δ = 6.82(12) keV

Half-life: 2 x 10^{30} years *(old)*

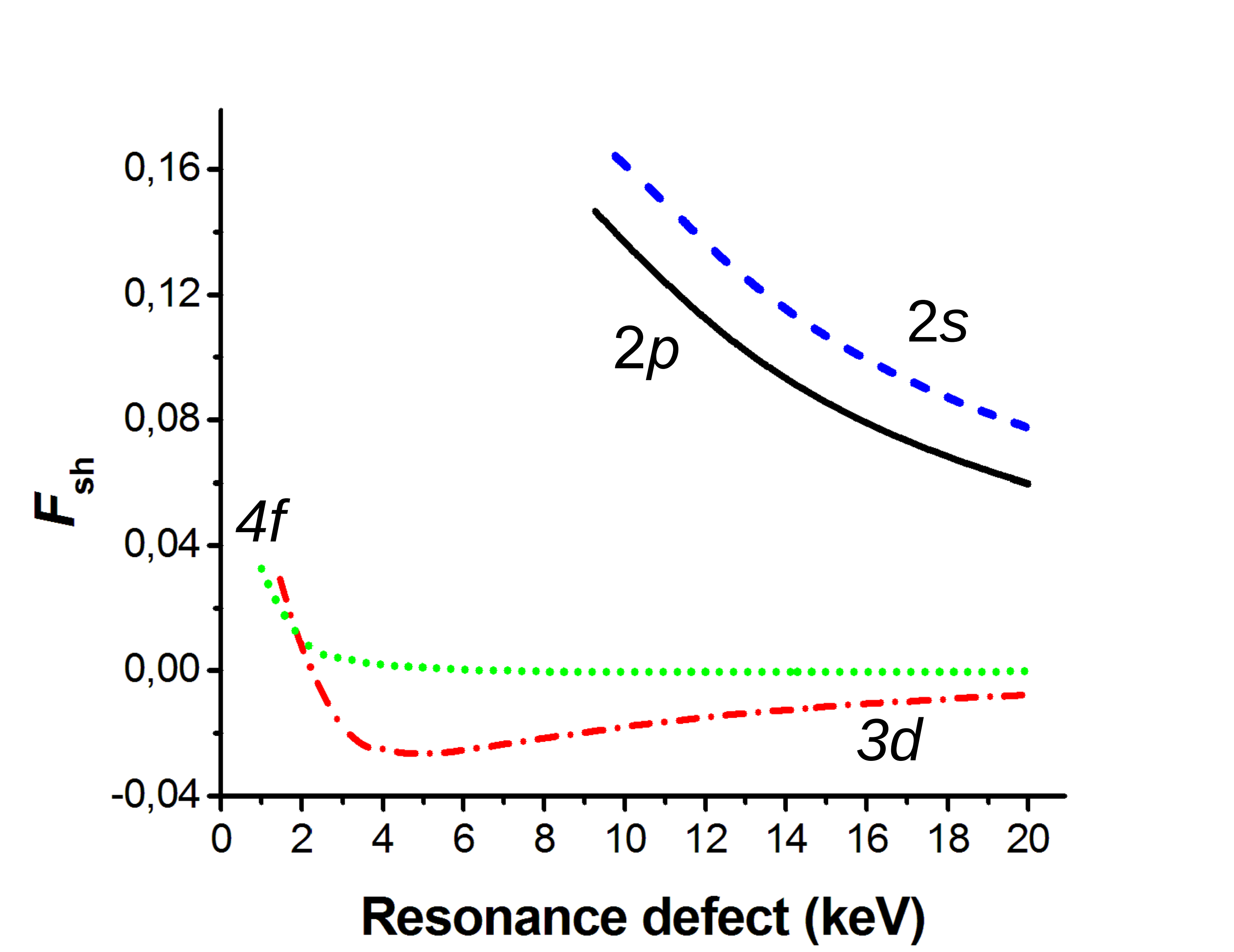
Матричные элементны встряски



Матричные элементы встряски



Матричные элементы встряски



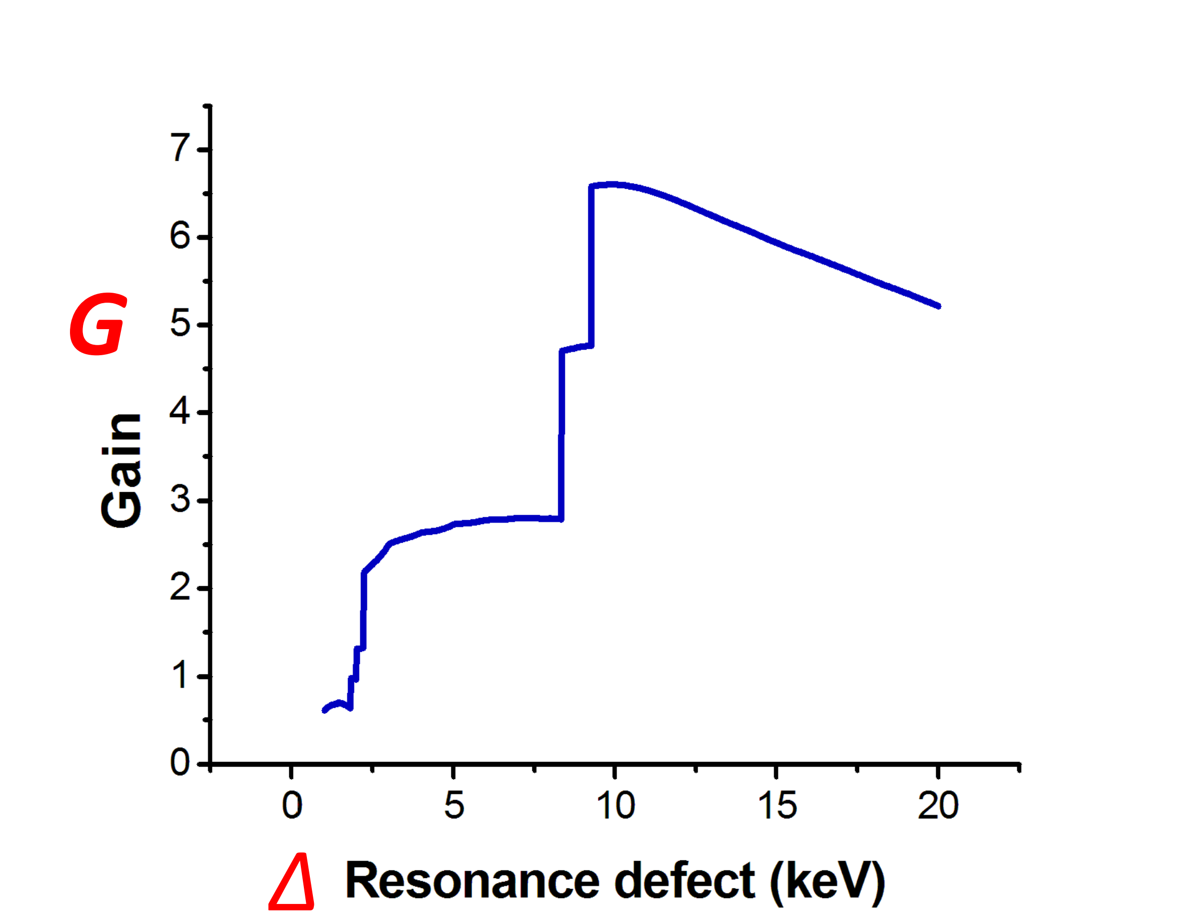
$^{164}Er \rightarrow {}^{164}Dy$ *L_1L_1* *2e0ν capture*

Q = 25.07(12) keV

Δ = 6.82(12) keV

Half-life: 2 x 10^{30} years *(old)*

G = 3



Вклад других каналов

$$G_{ik} = \frac{\rho_i(0)\rho_k(0)}{\rho_{L_1}^2(0)} \sum_j N_j |F_{\rm sh}^{(j)}(|Q_{\rm eff}^{(ik)}|)|^2 / B_W$$

Вклад других каналов

Оболочка	Δ (кэВ)	$\rho(0)$ [1)]	G
LL	6.82	1	2.81
LM	14	0.218	1.22
MM	21	0.048	0.20
LN	15.6	0.051	0.29
MN	22.6	0.011	0.05
NN	24.3	0.003	0.01
Итого:	–	–	4.58

1) *I.M.Band et al.* ATOMIC DATA AND NUCLEAR DATA TABLES **23**, 295-314 (1979)

Half-life *new*: 4.2 x 10^{29} years

Order of magnitude faster!

Ядра	$^{152}Gd \rightarrow {}^{152}Sm$ a)	$^{164}Er \rightarrow {}^{164}Dy$	$^{180}W \rightarrow {}^{180}Hf$
Канал распада	KL	LL	KK
Δ (кэВ)	0.910	6.82	12.5
Резонансный период (лет)	10^{27}	2×10^{30}	3×10^{28}
Нерезонанс-ный период	8×10^{26}	4.2×10^{29}	3×10^{27}

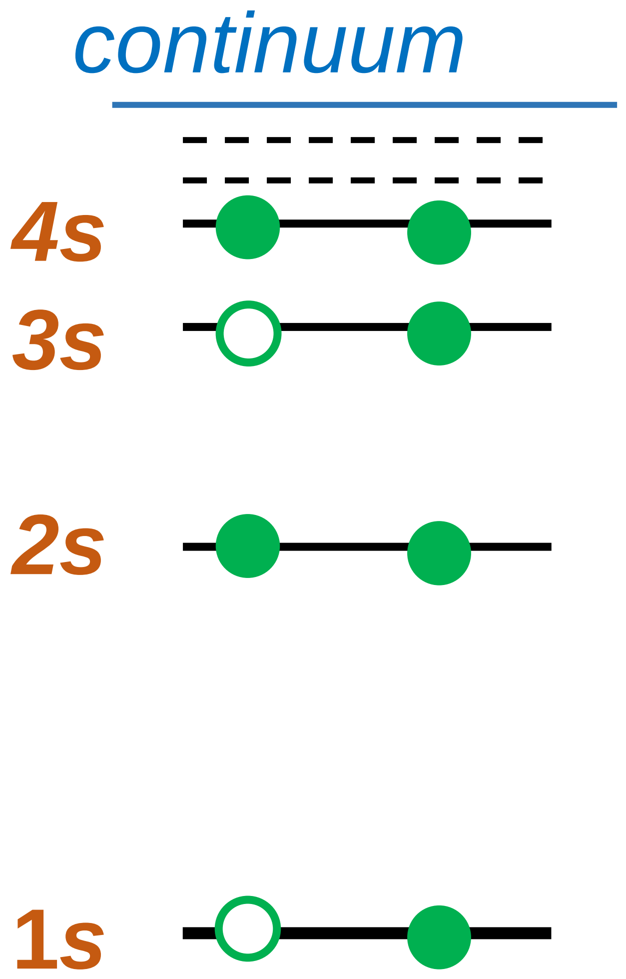
a) Ф. Ф. Карпешин, М. Б. Тржасковская, Л. Ф. Витушкин, ЯФ, **83,** 344 (2020)

CONCLUSION

- We have proposed a new mechanism of neutrinoless nuclear double electron capture. This is a *nonresonance mechanism* of *shake-off* in the electron shell of the final atom. Therefore, it is expected that, it will turn out to be more probable. In the case 164Er, the nonresonance mechanism shortens its lifetime by *4.6 times*, thus making it more attractive candidate in searches for neutrinoless double electron capture as an indication of the Majorana nature of the neutrino.
- List of candate nuclei should be modified.

Thank you!

Спасибо!


continuum
4s
3s
2s
1s