High-lying Gamow-Teller resonances and neutrino capture cross-section for 76Ge

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Plan

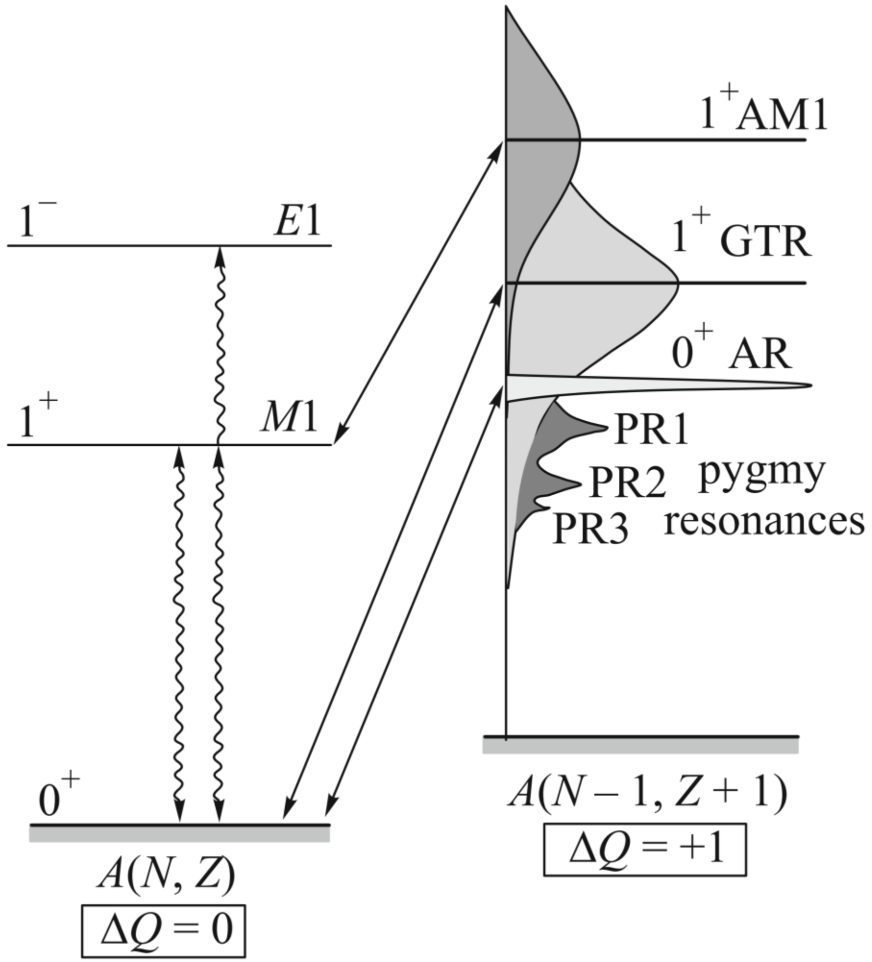
- The excitation states structure for 76As
- The cross-section estimation for (ν,e) reaction
- The framework of the self-consistent theory of finite Fermi systems
- Results

Motivation

- Direct research of the neutrino-nuclear interaction is very hard experimental problem
- Beta-decay matrix elements could be researched in charge-exchange reactions like (p,n), (3He,t), (d,2He)
- Giant GT-resonance and pygmy-resonances (PR1,PR2…) determine a significant part of the Strength function

- So, resonant component could make substantial contribution into neutrino capture cross-section…

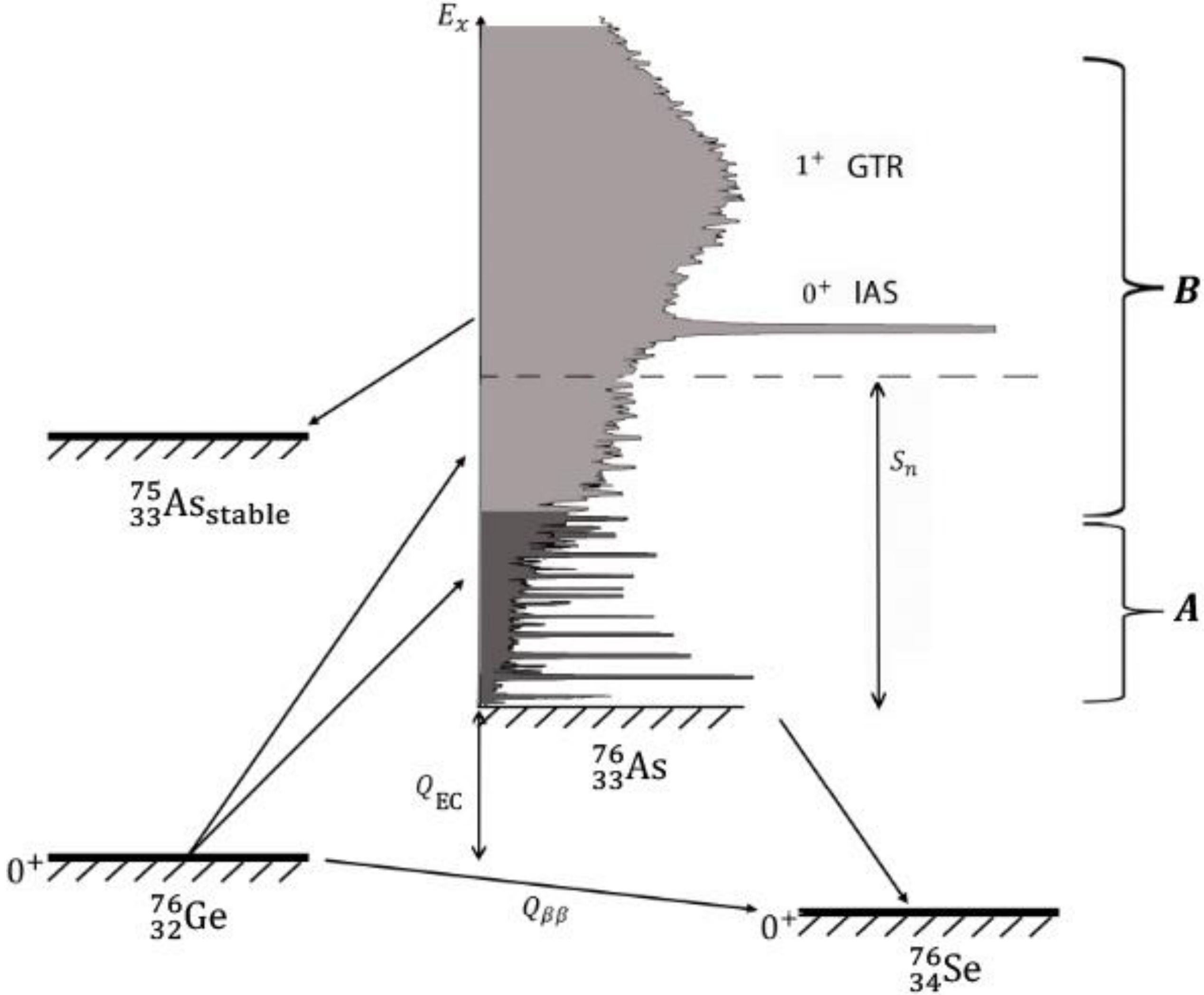
Nuclear Resonances (general view)



GTR predictions
Yu. V. Gaponov,
Yu. S. Lyutostanskii,
***JETP Lett.* 15, 120 (1972).**

PR calculations
Yu. S. Lutostansky
***JETP Lett.* 106, 7 (2017)**

Nuclear Resonances for 76As



B – resonances domination region

A – discrete levels domination region

(ν,e) cross-section

$$\sigma_{total}(E_\nu) = \sigma_{discr}(E_\nu) + \sigma_{res}(E_\nu)$$

$$\sigma_{discr}(E_\nu) = \frac{1}{\pi}\sum_k G_F^2 \cos^2\theta_C \, p_e E_e F(Z,E_e)[B(F)_k + (\frac{g_A}{g_V})^2 B(GT)_k]$$

$$E_e - m_e c^2 = E_\nu - Q_{EC} - E > 0$$

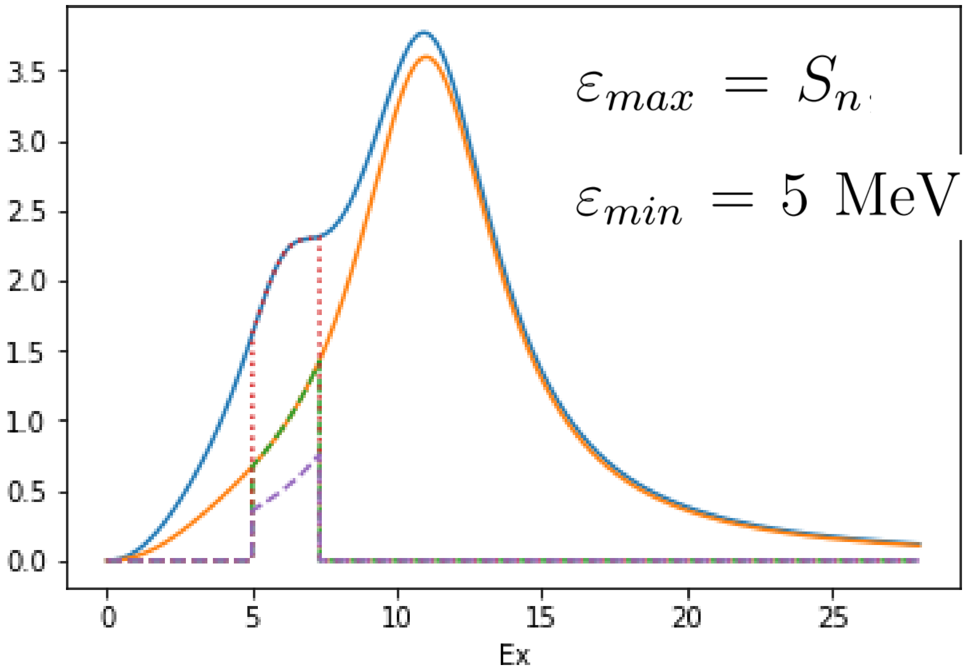
$$\sigma_{res}(E_\nu) = \frac{1}{\pi}\int_{\varepsilon_{min}}^{\varepsilon_{max}} G_F^2 \cos^2\theta_C \, p_e E_e F(Z,E_e) S(E) dE$$

Normalization and Quenching effect

$$\sum_i M_i^2 = \sum_k B(GT)_k + \int_{\Delta_{min}}^{\Delta_{max}} S(E)dE = 3 \cdot (N - Z) \cdot q_{exp} = 36 \cdot q_{exp}$$

$$\Delta_{min} = 0 \ \text{MeV}$$

$$\Delta_{max} = 28 \ \text{MeV}$$



$$\varepsilon_{max} = S_n$$

$$\varepsilon_{min} = 5 \ \text{MeV}$$

$$q_{exp}^{min} = 0.55$$

$$q_{exp}^{max} = 1$$

R. Madey et al. Phys. Rev. C ***40****, 540 (1989)*

Fitting parameters

$$S_i(E) = M_i^2 \cdot \frac{\Gamma_i(1-\exp(-(E/\Gamma_i)^2))}{(E-w_i)^2+\Gamma_i^2}$$

- shape form for all the resonances. 3 free parameters: the centroid energies, the widths, and the amplitudes.

$$\frac{d^2\sigma}{dEd\Omega} = N_0 \frac{1-\exp[(E_t-E_0)/T]}{1+[(E_t-E_{QF})/W^2]}$$

- QFC background shape *J. Jänecke et al. Phys. Rev. C* ***48****, 2828 (1993)*

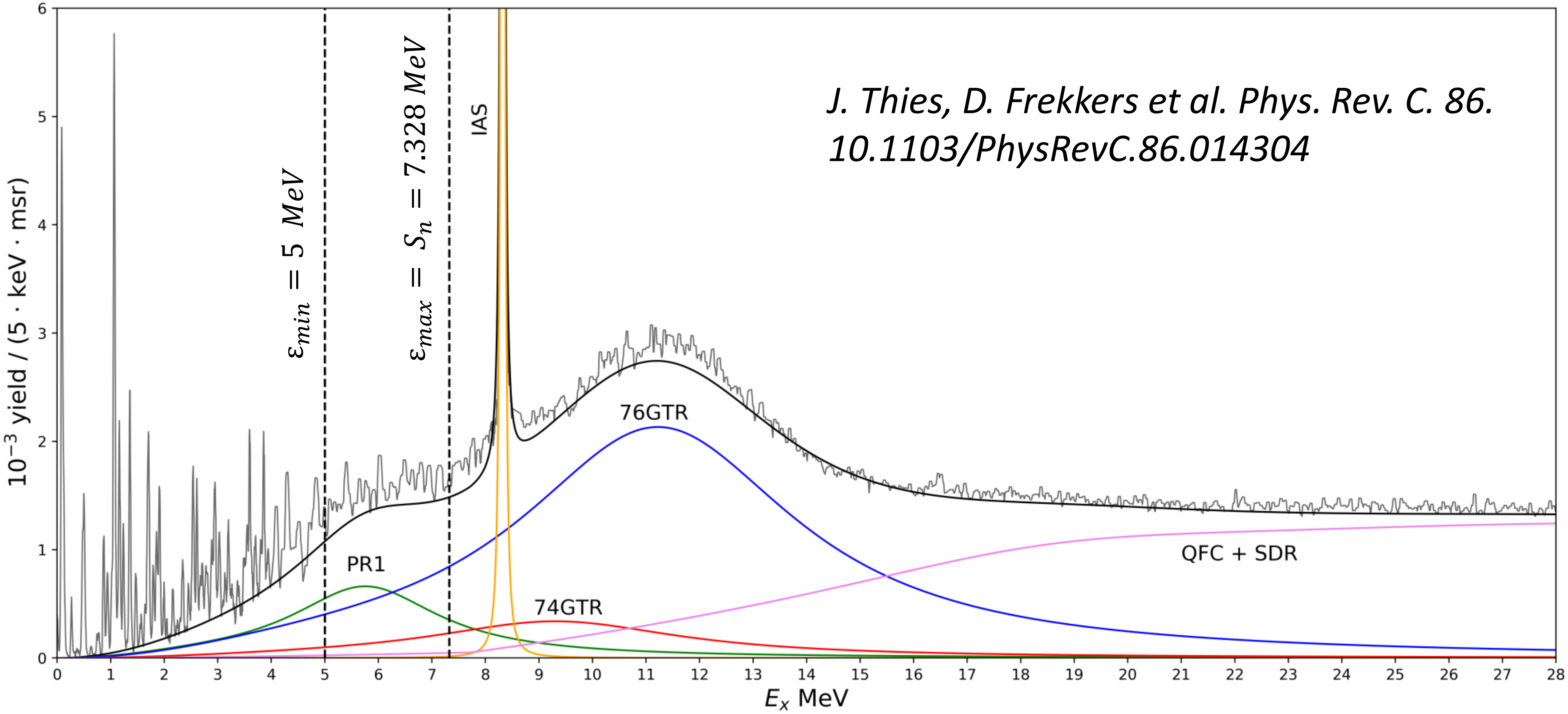
Only N_0 and E_{QF} are used as free parameters.

Data for the fit is taken from *J. Thies, D. Frekkers et al. Phys. Rev. C. 86. 10.1103/PhysRevC.86.014304.*

Simultaneous fit for 3 angles: $(0.0° - 0.5°)$, $(0.5° - 1.0°)$ and $(1.0° - 1.5°)$.
Same shape parameters, only amplitudes are independent

Experimental data and Fitting (76Ge+74Ge)

$(0.0° - 0.5°)$



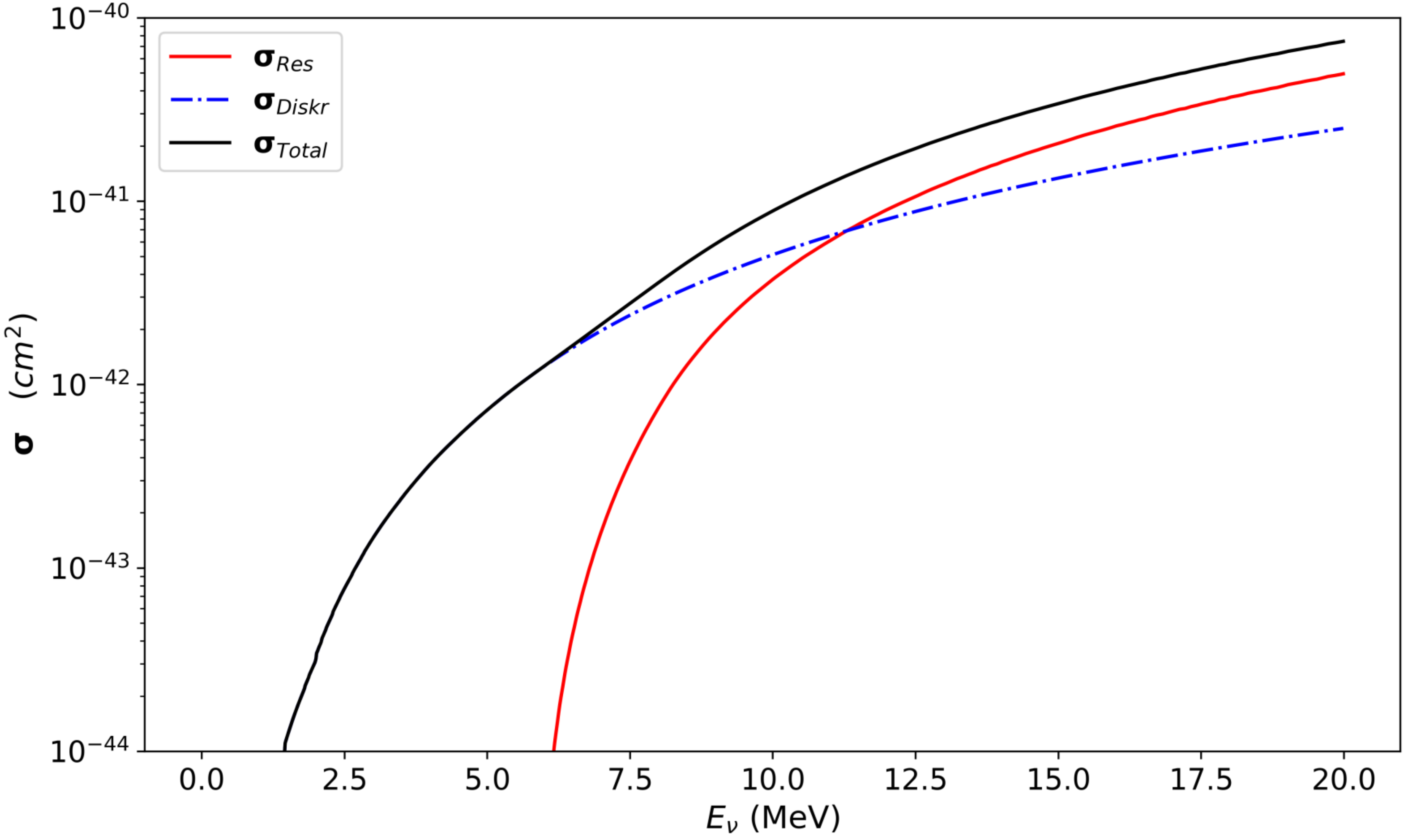
Solar neutrino capture rate

$$R = \int_0^{E_{max}} \rho_{solar}(E_\nu)\sigma_{solar}(E_\nu)dE_\nu \qquad E_{max} = 18.79$$

$$R_{total} = R_{discr} + R_{res}$$

Capture rate [SNU]	pep	hep	^{13}N	^{17}F	^{15}O	^{8}B	Total capture rate
R_{discr}	1.369	0.045	0.102	0.021	0.828	13.542	15.9
R_{res}, $q_{exp} = 1$	0.0	0.051	0.0	0.0	0.0	7.595	7.645
R_{GTR}, $q_{exp} = 1$	0.0	0.023	0.0	0.0	0.0	3.438	3.461
R_{res}, $q_{exp} = 0.55$	0.0	0.027	0.0	0.0	0.0	4.044	4.071
R_{GTR}, $q_{exp} = 0.55$	0.0	0.012	0.0	0.0	0.0	1.831	1.843
R_{total}, $q_{exp} = 1$	1.369	0.096	0.102	0.021	0.828	21.137	23.552
R_{total}, $q_{exp} = 0.55$	1.369	0.072	0.102	0.021	0.828	17.586	19.977

Neutrino capture cross-section for 76Ge



Microscopic description - 1

The Gamow–Teller resonance and other charge-exchange excitations of nuclei are described in Migdal TFFS-theory by the system of equations for the effective field:

$$V_{pn} = e_q V^{\omega}_{pn} + \sum_{p'n'} \Gamma^{\omega}_{np,\,n'p'} \rho_{p'n'} \qquad V^{h}_{pn} = \sum_{p'n'} \Gamma^{\omega}_{np,\,n'p'} \rho^{h}_{p'n'}$$

$$d^{1}_{pn} = \sum_{p'n'} \Gamma^{\xi}_{np,\,n'p'} \varphi^{1}_{p'n'} \qquad d^{2}_{pn} = \sum_{p'n'} \Gamma^{\xi}_{np,\,n'p'} \varphi^{2}_{p'n'}$$

where V_{pn} and V_{pn}^{h} are the effective fields of quasi-particles and holes, respectively;
V_{pn}^{ω} is an external charge-exchange field; d_{pn}^{1} and d_{pn}^{2} are effective vertex functions that describe change of the pairing gap Δ in an external field;
Γ^{ω} and Γ^{ξ} are the amplitudes of the effective nucleon–nucleon interaction in, the particle–hole and the particle–particle channel;
ρ, ρ^{h}, φ^{1} and φ^{2} are the corresponding transition densities.

Effects associated with change of the pairing gap in external field are negligible small, so we set $d_{pn}^{1} = d_{pn}^{2} = 0$, what is valid in our case for external fields having zero diagonal elements

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Width: $\Gamma = -2\,\mathrm{Im}\,[\sum(\varepsilon + iI)] = \Gamma = \alpha\,.\varepsilon\,|\,\varepsilon\,| + \beta\varepsilon^3 + \gamma\,\varepsilon^2\,|\,\varepsilon\,| + O(\varepsilon^4)\ldots,$ **where** $\alpha \approx \varepsilon_F^{-1}$

$\Gamma_i(\omega_i) = 0{,}018\ \omega_i^2$ **MeV**

Microscopic description - 2

For the GT effective nuclear field, system of equations in the energetic λ-representation has the form [FFST Migdal A. B.]:

$$\left.\begin{aligned} V_{\lambda\lambda'} &= V^{\omega}_{\lambda\lambda'} + \sum_{\lambda_1\lambda_2} \Gamma^{\omega}_{\lambda\lambda'\lambda_1\lambda_2} A_{\lambda_1\lambda_2} V_{\lambda_2\lambda_1} + \sum_{\nu_1\nu_2} \Gamma^{\omega}_{\lambda\lambda'\nu_1\nu_2} A_{\nu_1\nu_2} V_{\nu_2\nu_1}; \\ V_{\nu\nu'} &= \sum_{\lambda_1\lambda_2} \Gamma^{\omega}_{\nu\nu'\lambda_1\lambda_2} A_{\lambda_1\lambda_2} V_{\lambda_2\lambda_1} + \sum_{\nu_1\nu_2} \Gamma^{\omega}_{\nu\nu'\nu_1\nu_2} A_{\nu_1\nu_2} V_{\nu_2\nu_1}; \\ V^{\omega} &= e_q \sigma \tau^+; \quad A^{(p\bar{n})}_{\lambda\lambda'} = \frac{n^n_\lambda (1 - n^p_{\lambda'})}{\varepsilon^n_\lambda - \varepsilon^p_{\lambda'} + \omega}; \quad A^{(n\bar{p})}_{\lambda\lambda'} = \frac{n^p_\lambda (1 - n^n_{\lambda'})}{\varepsilon^p_\lambda - \varepsilon^n_{\lambda'} - \omega}. \end{aligned}\right\}$$

G -T selection rules:

- **Δ*j* =0;±1**
- **Δ*j* =+1:** *j=l+1/2 → j =l–1/2*
- **Δ*j* =0:** *j=l±1/2 → j=l±1/2*
- **Δ*j* = –1:** *j=l–1/2 → j=l+1/2*
- *j =l–1/2→ j =l–1/2*

where n_λ and ε_λ are, respectively, the occupation numbers and energies of states λ.

Local nucleon–nucleon δ-interaction Γ^{ω} in the Landau-Migdal form used:

$$\Gamma^{\omega} = C_0 (f_0' + g_0' \sigma_1\sigma_2)\, \tau_1\tau_2\, \delta(r_1 - r_2)$$

where coupling constants of: f_0'=1.35 – isospin-isospin and g_0'=1.22 – spin-isospin quasi-particle interaction with L = 0.

Matrix elements M_{GT} : $M^2_{GT} = \sum_{\lambda_1\lambda_2} \chi_{\lambda_1\lambda_2} A_{\lambda_1\lambda_2} V^{\varpi}_{\lambda_1\lambda_2}$ where $\chi_{\lambda\nu}$ – mathematical deductions

GT - values are normalized in FFST: $\sum_i M_i^2 = e_q^2\, 3(N - Z)$

Yu. S. Lutostansky and V.N.Tikhonov, Physics of Atomic Nuclei, 2016, Vol. 79, No. 6

First calculation of NME for 76Ge and 74Ge

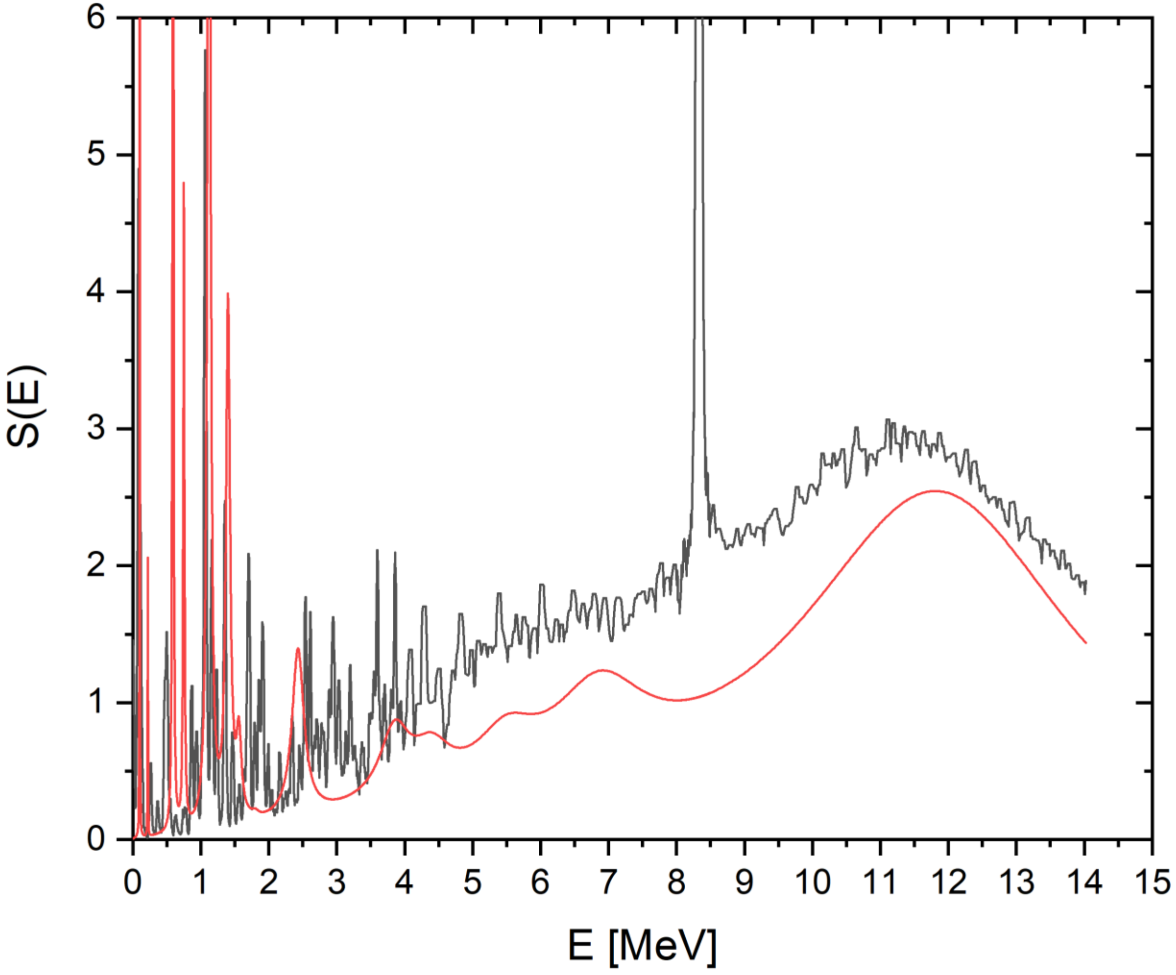
74Ge		76Ge	
E_{GT}	M^2	E_{GT}	M^2
10.49	8.13	11.82	9.74
6.77	0.23	6.86	0.861
6.05	0.06	5.49	0.29
5.50	0.14	4.39	0.16
5.04	0.17	3.85	0.20
4.85	0.15	2.43	0.02
4.18	0.07	1.80	0.031
3.57	0.21	1.56	0.04
2.99	0.15	1.40	0.204
2.52	0.33	1.12	0.401
2.24	0.22	0.88	0.001
1.78	0.14	0.75	0.073
		0.59	0.173
		0.22	0.018
		0.10	0.348

For simplification of comparison between theoretical and experimental results only nucleon degrees of freedom with energies below 25 MeV are taken into account.

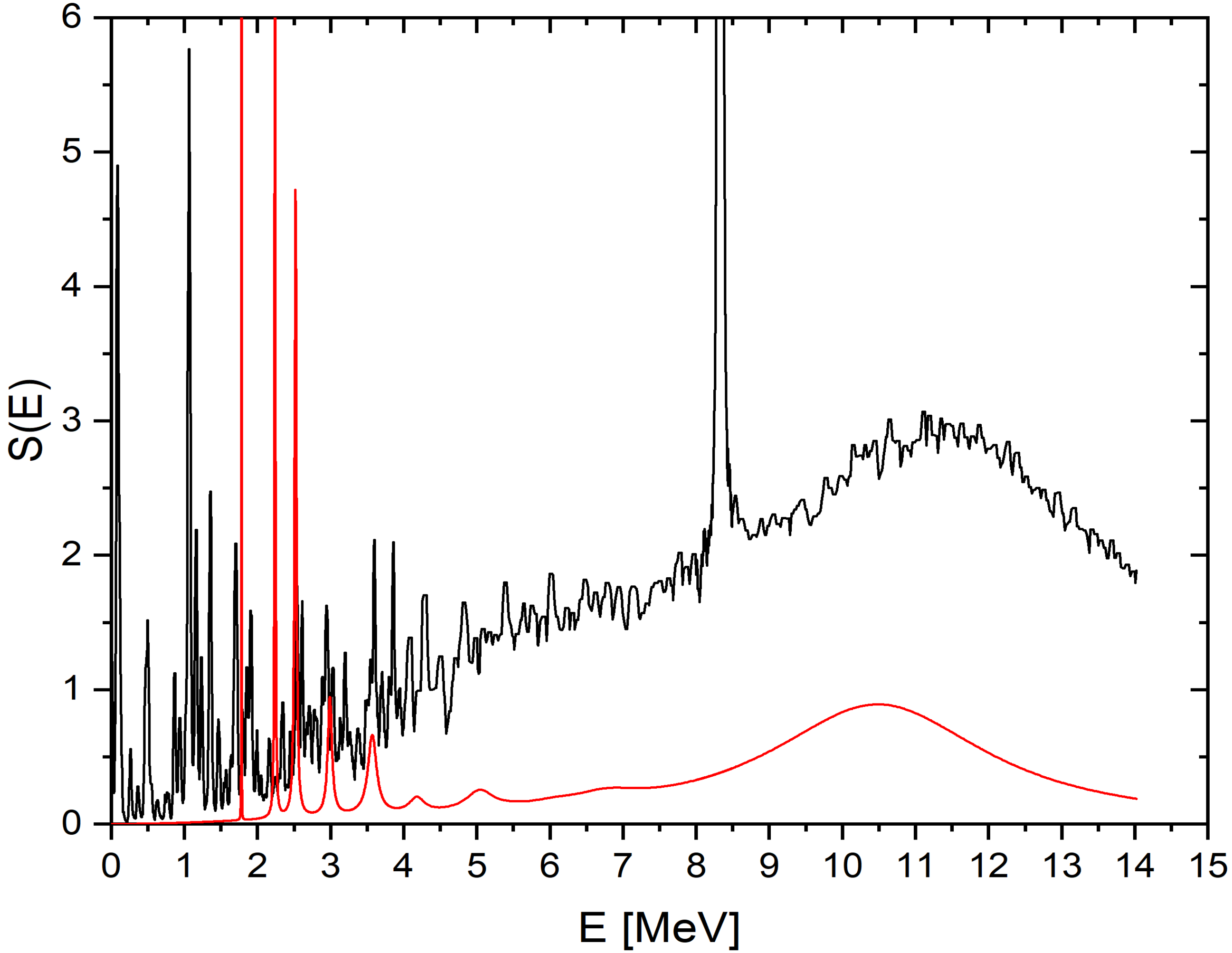
TFFS predicts existence of a few pygmy resonances within the discrete levels dominant region.

Article is in progress…

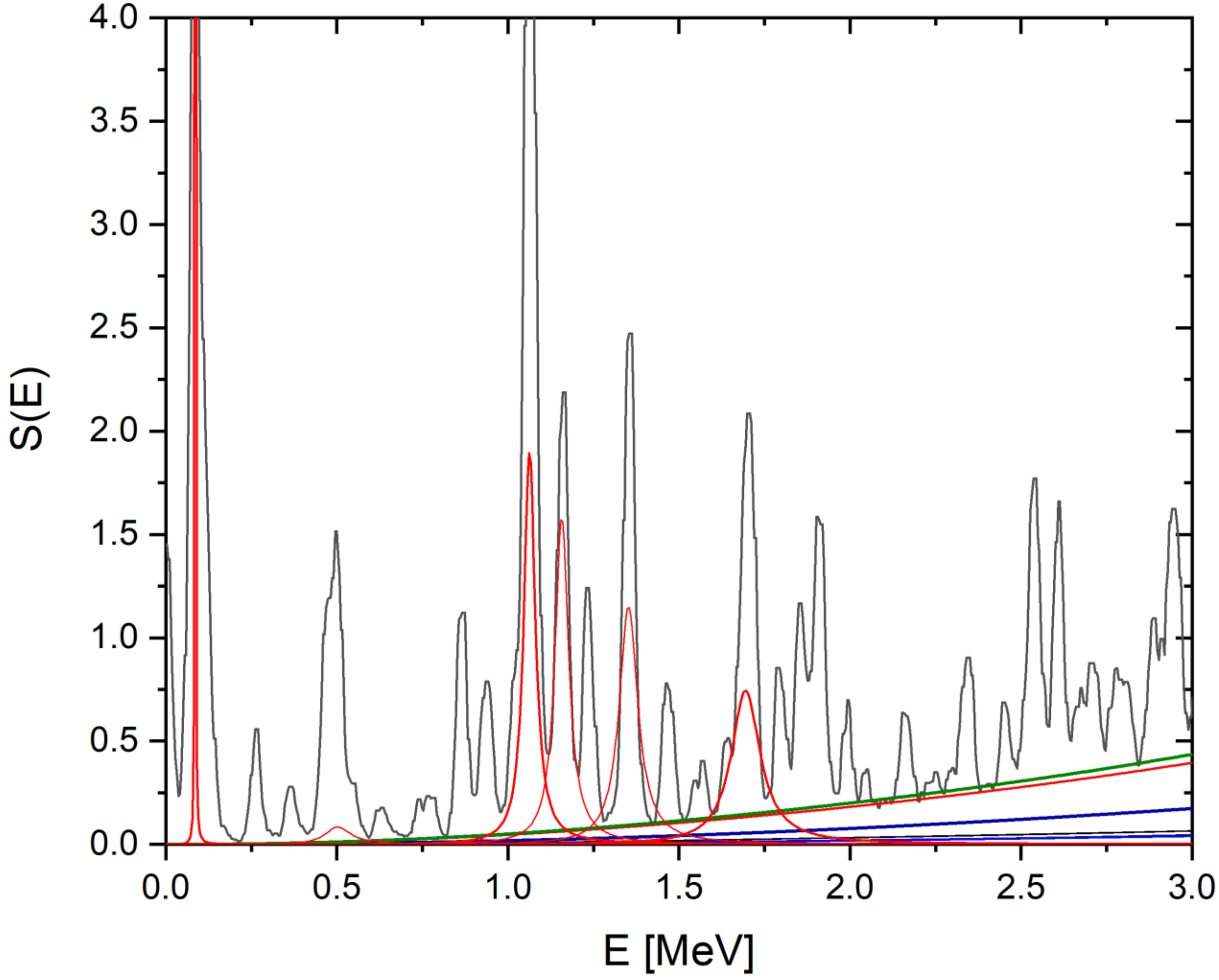
Theoretical Strength function only for 76Ge



Theoretical Strength function only for 74Ge



Theoretical Strength function for 76Ge + 74Ge (low part)



CONCLUSION

High-lying resonant GT states make a significant contribution into neutrino capture cross-section comparable to the contribution from discrete levels.

Different quantities of the experimental quenching effect increase the total capture rate value by a factor from 1.25 to 1.5.

These contributions should be taken into account for calculating background index for GERDA-type experiments.

Thank you for your attention!