GT Nuclear resonances for 71Ga(ν,e)71Ge reaction investigation

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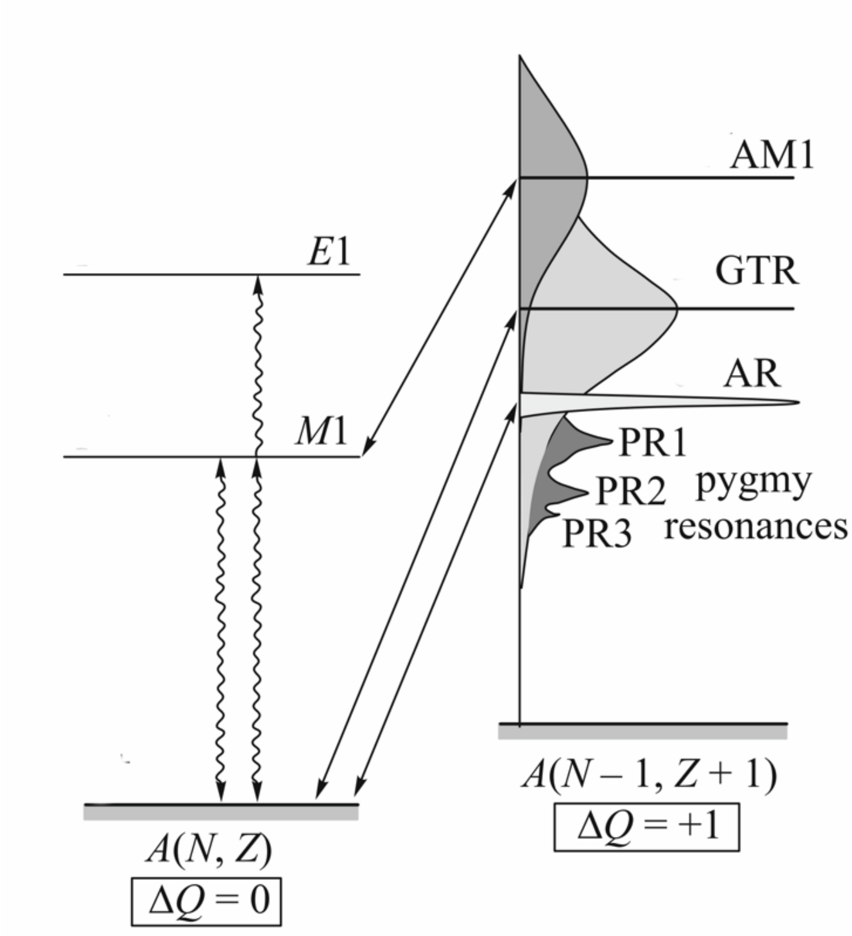
Motivation

- Neutrino capture strength function could be investigated using charge-exchange reactions.
- (p,n), (3He,t), (d,2He) reactions provide essential information about strength functions and their resonant structure.
- Giant GT-resonance and pygmy-resonances (PR1,PR2…) determine a significant part of the Strength function.
- Nuclear phenomenology could partially explain the increase in cross-sectional assessment.

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)**

This resonances are exited in neutrino capture process or into charge-exchange reactions

Neutrino Capture Cross-Section

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

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

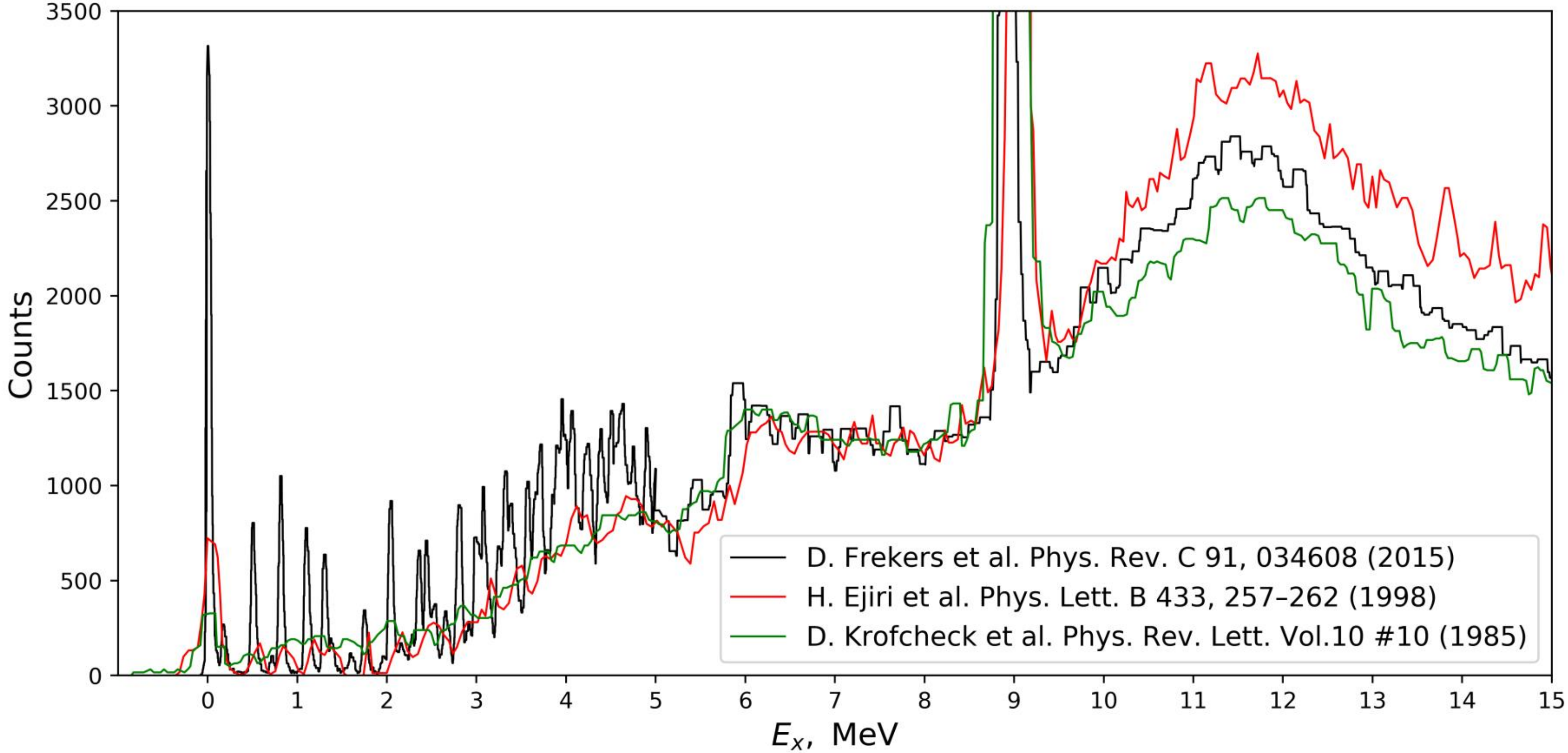
$$E_e - m_e c^2 = E_\nu - Q_{EC} - E > 0$$

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

***Phys.Atom.Nucl.* 82 (2019) 5, 477-482**
***AIP Conf.Proc.* 2165 (2019) 1, 020015**

Fermi-function taken from M. Behrens and J. Janecke, ¨ Elementary Particles, Nuclei and Atoms¨, Landolt-Bornstein Group I: Nuclear Physics and Technology, Vol. 4 (Springer, Berlin, 1969)

Charge-Exchange Reactions Comparison (^{3}He,t) and (p,n)



Fitting Parameters

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

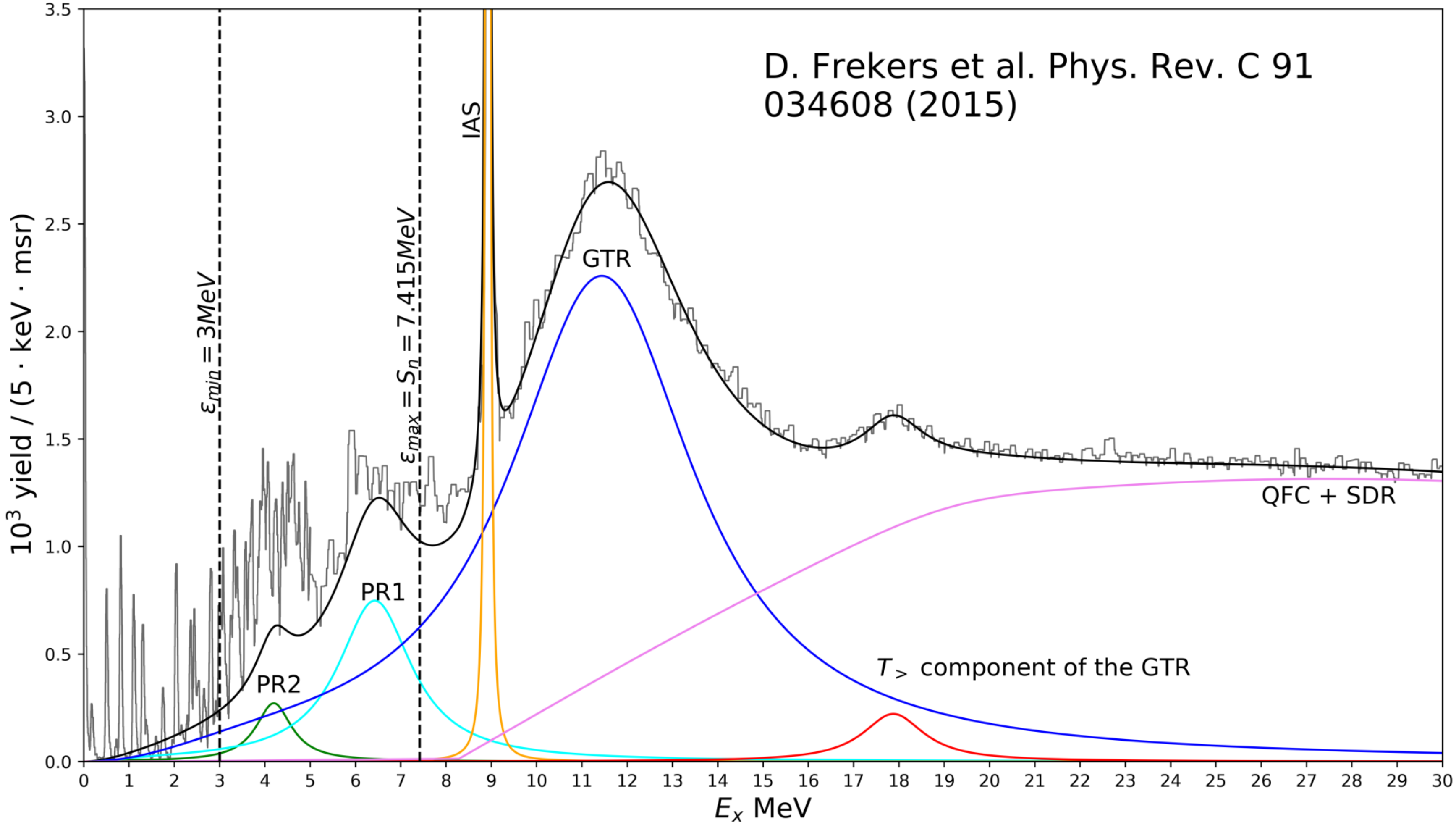
- shape form for all the resonances. 3 free parameters: the centroid energies, the widths, and the amplitudes.

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

- QFC background shape *J. Jänecke et al. Phys. Rev. C* ***48****, 2828 (1993)*
Only N_0 and E_{QF} are used as free parameters.

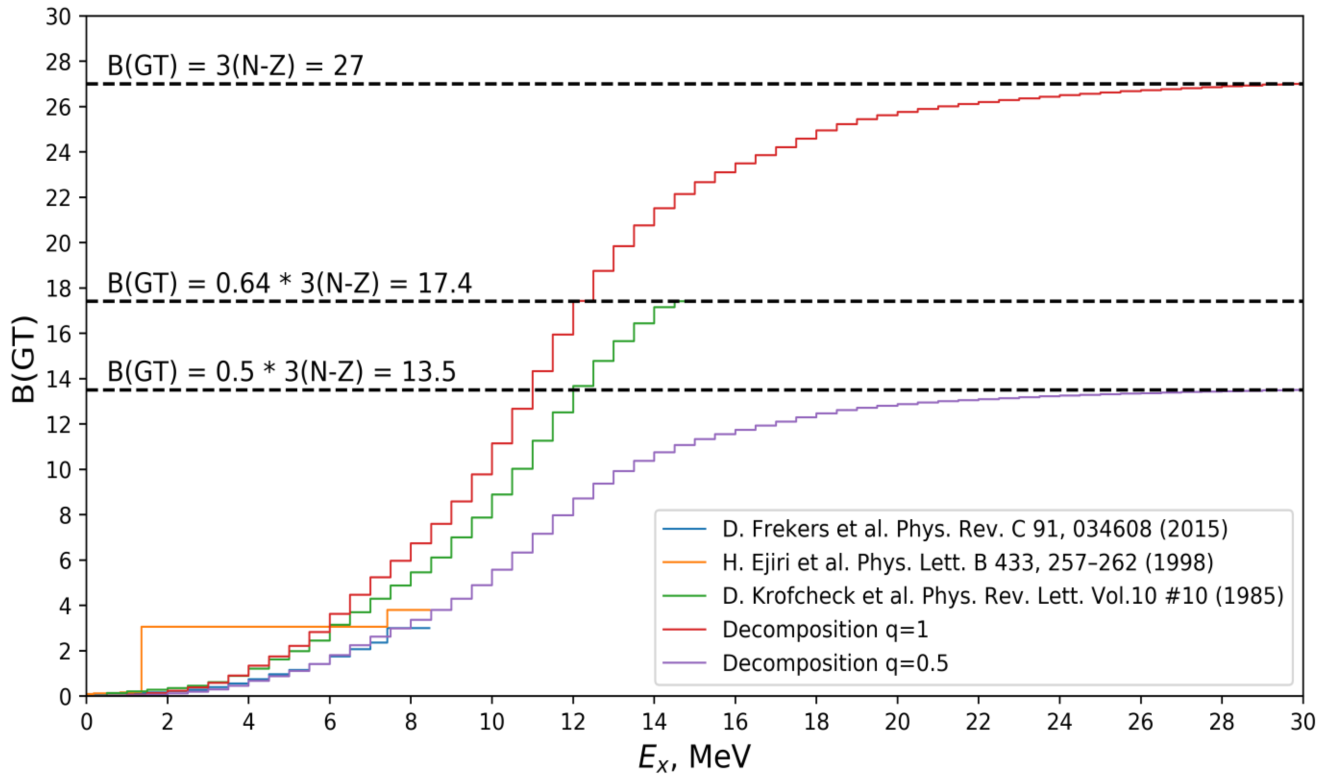
Data for the fit is taken from **D. Frekers et al. Phys. Rev. C 91, 034608 (2015)**

Experimental data and Fit



Normalization and Quenching effect

$$\sum_i M_i^2 = \sum_k B(GT)_k + \int_{\Delta_{min}=0}^{\Delta_{max}=30\ MeV} S(E)dE = 3 \cdot (N-Z) \cdot q_{exp} = 27 \cdot q_{exp}$$



NORMALISATION
"*Quenching*" effect
(Losing of sum rule in beta-strength) is the main ~ 50 - 70%

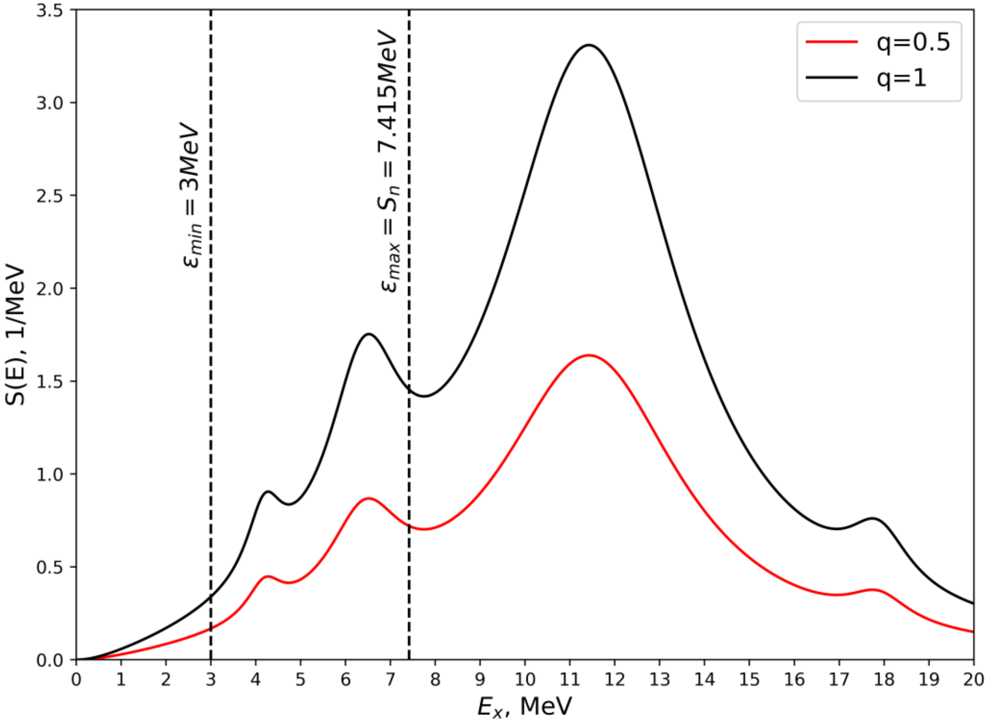
$$q_{exp}^{max} = 1$$

$$q_{exp} \approx 0.5$$

Solar neutrino capture rate

$$R = \int_0^{E_{max}=18.79\,MeV} \rho_{solar}(E_\nu)\sigma_{solar}(E_\nu)dE_\nu \qquad R_{total} = R_{discr} + R_{res}$$

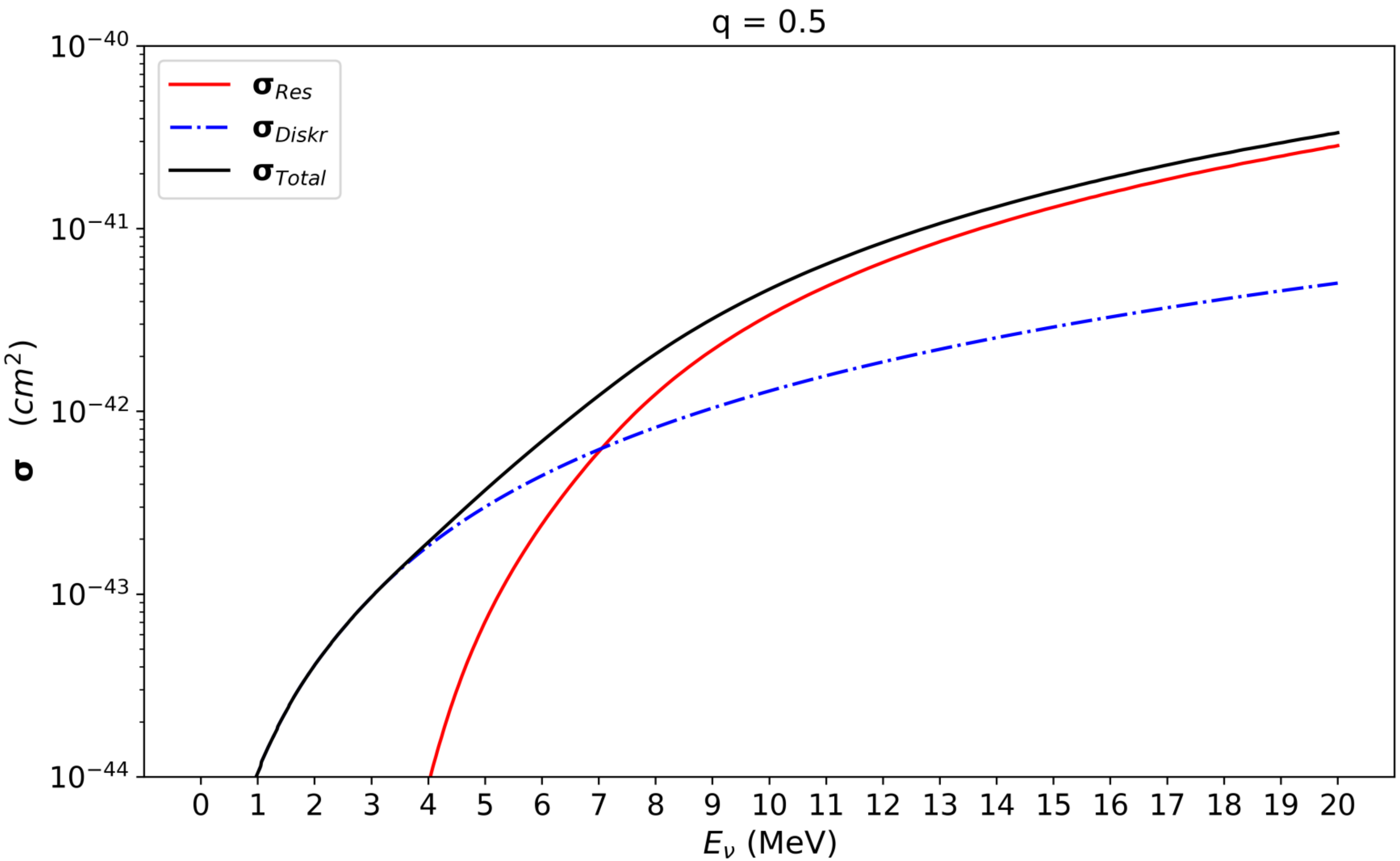
$$\sigma_{res}(E_\nu) = \frac{1}{\pi}\int_{\varepsilon_{min}}^{\varepsilon_{max}} G_F^2 \cos^2\theta_C\, p_e E_e F(Z, E_e) S(E) dE$$



Neutron emission (S_n) role was discused by

A. Fazliakhmetov
https://indico.tlabs.ac.za/event/85/contributions/1552/

Neutrino capture cross-section for 71Ga



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:

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

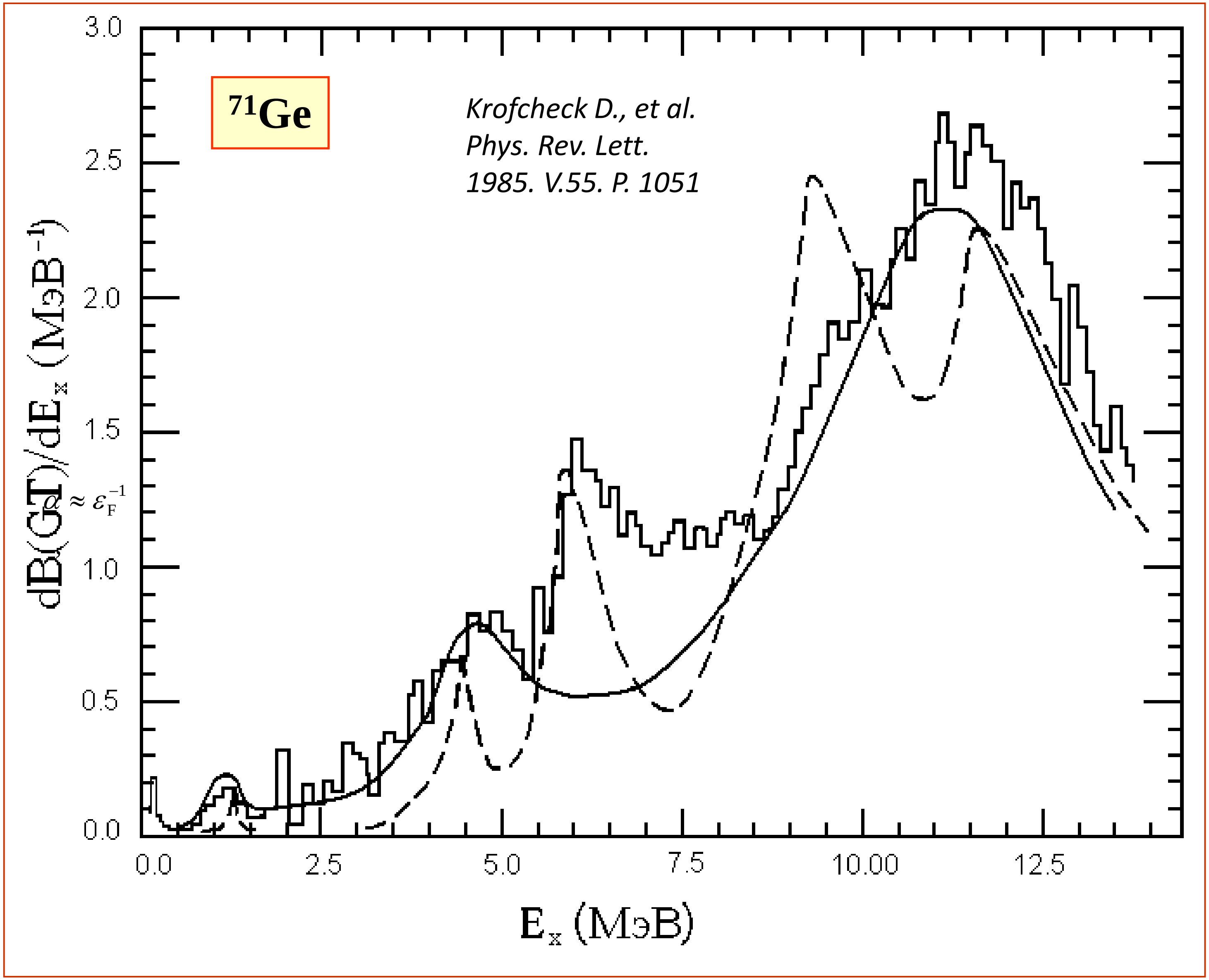
where coupling constants of: f_0'=1.35 – isospin-isospin and g_0'=1.22 – spin-isospin quasi-particle interaction with L = 0.

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

Theoretical strength function for 71Ga (early FTTS calculations)

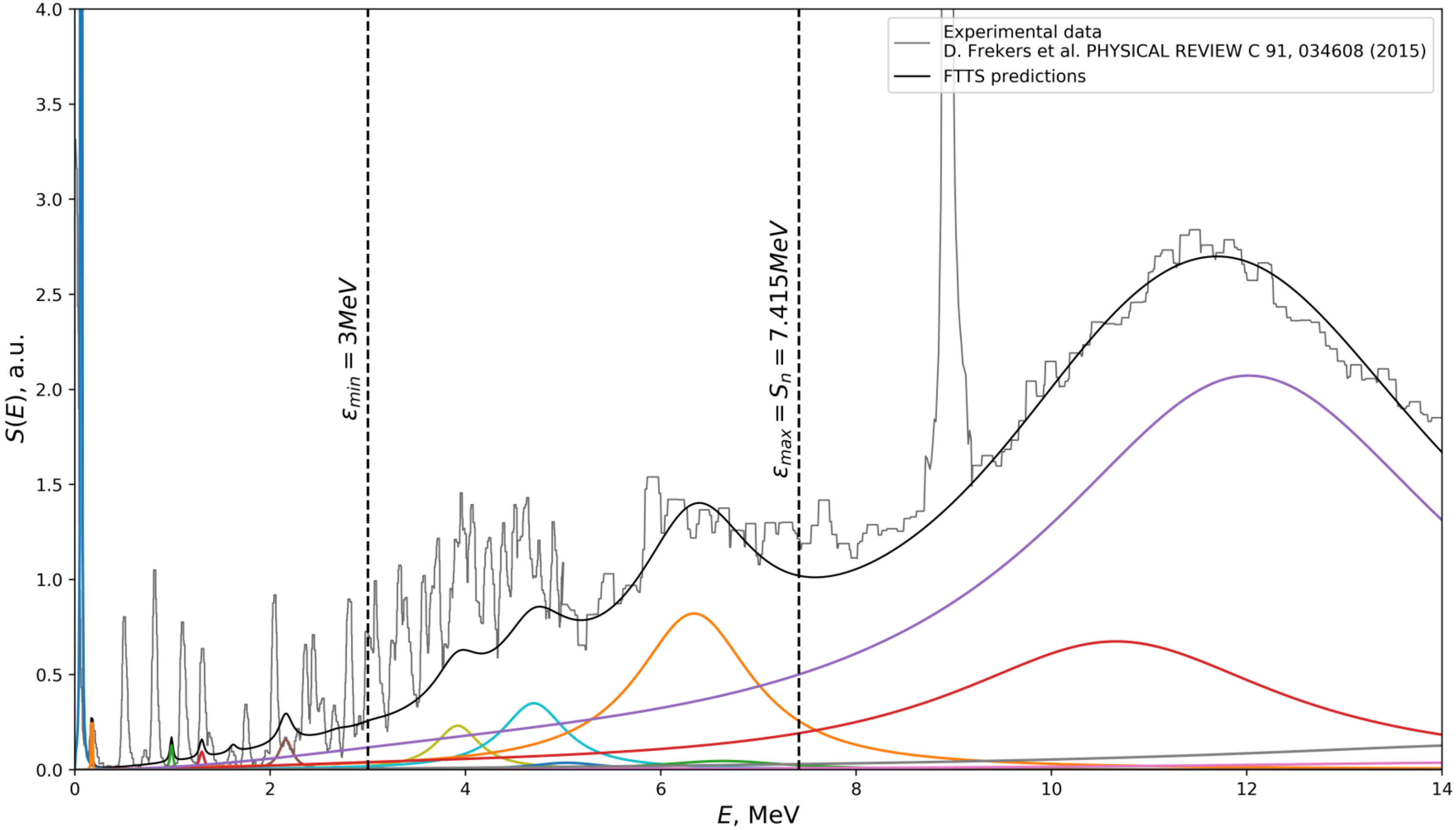


Yu.S. Lutostansky, N.B. Shulgina. Phys. Rev. Lett. 1991. V. 67. P. 430;

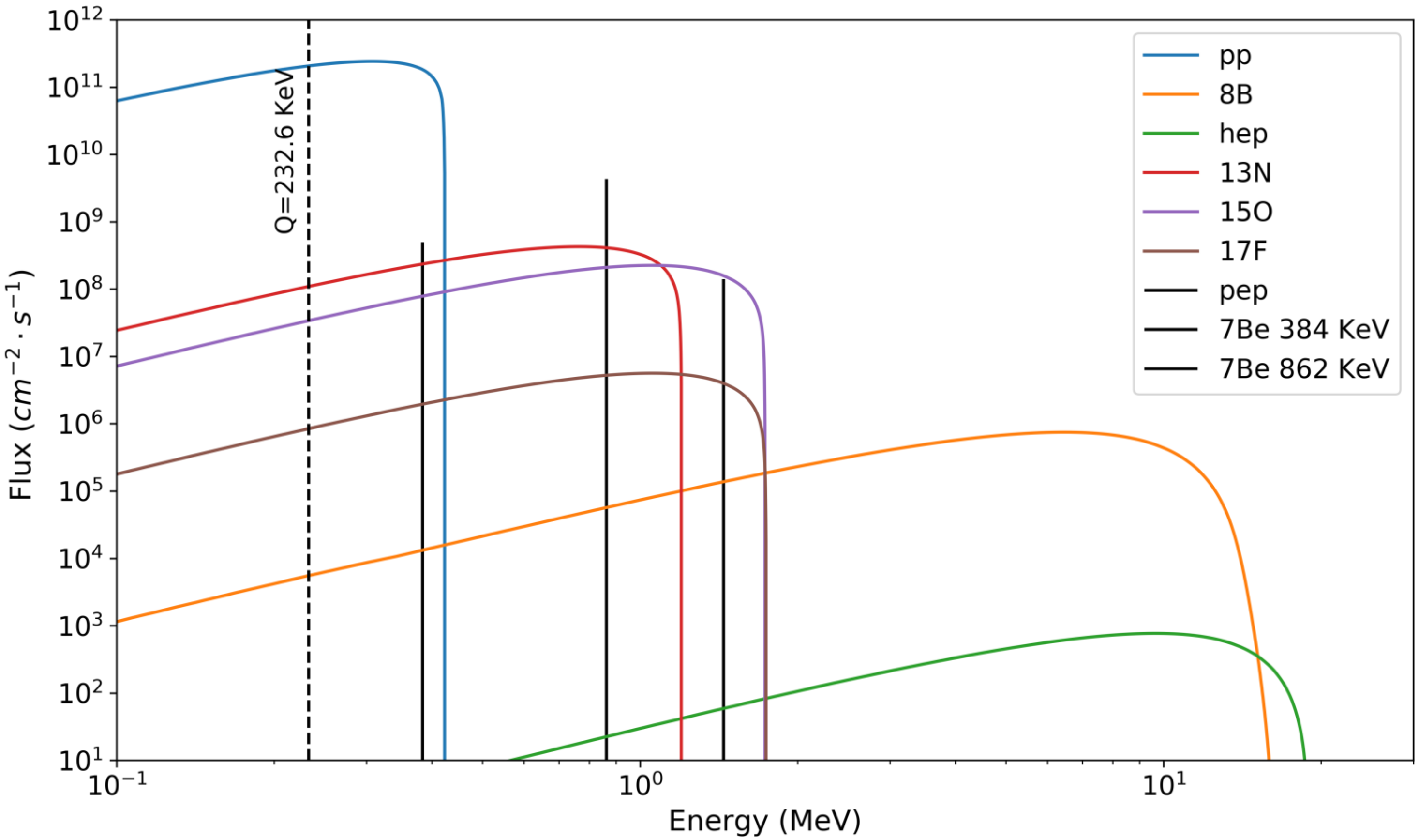
Borzov I.N., Fayans S.A., Trykov E.L. Nucl. Phys. A. 1995. V. 584. P. 335

$$\Gamma = -2\,\mathrm{Im}\,[\sum(\varepsilon + iI)] = \alpha\cdot\varepsilon\,|\,\varepsilon\,| + \beta\varepsilon^3 + \gamma\,\varepsilon^2\,|\,\varepsilon\,| + O(\varepsilon^4)\ \ldots$$

TFFS prediction for GT-resonances spectrum vs. experimental strength function



Solar neutrino spectrum



According to D. Frekers et al. Phys. Rev. C 91, 034608 (2015) the fluxes were taken from (*) except hep, it was taken from (**)

***** A. Ianni, Phys. Dark Universe **4**, 44 (2014)

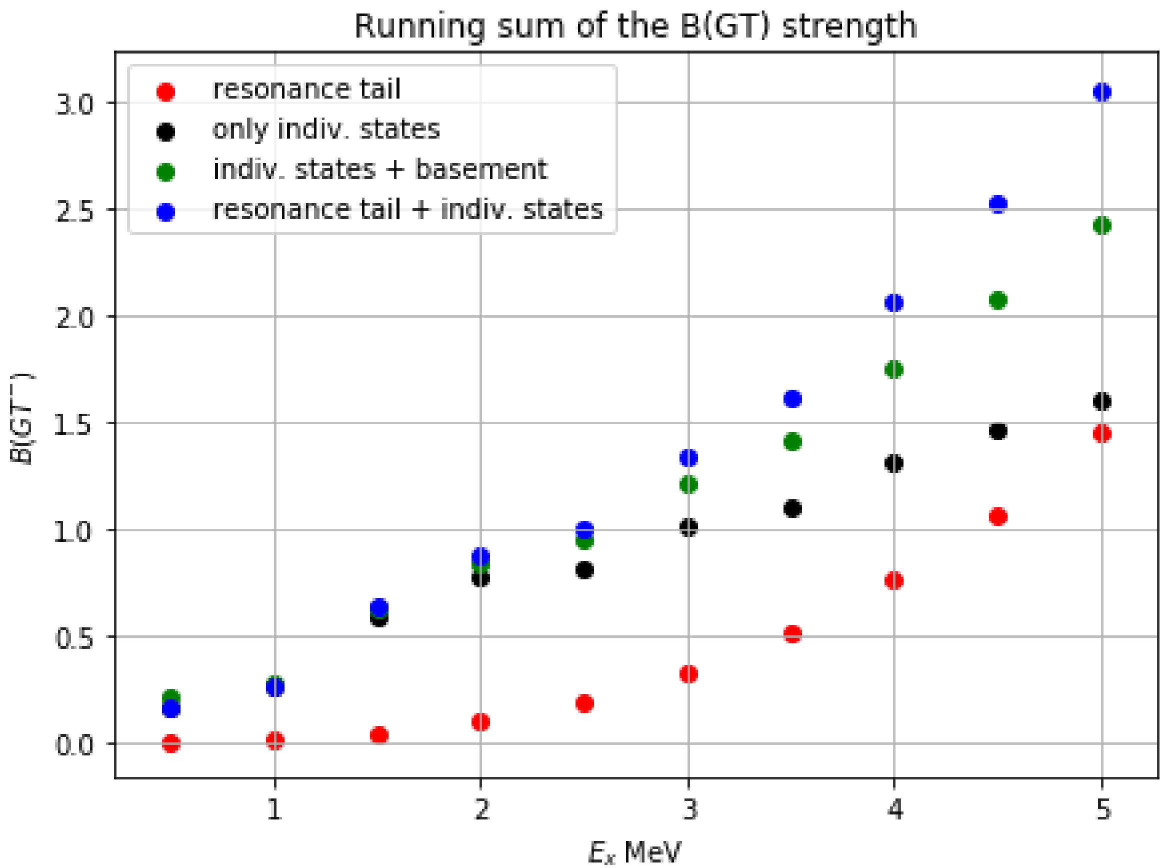
****** B. Aharmim, S. N. Ahmed, A. E. Anthony, E. W. Beier, A. Bellerive, M. Bergevin, S. D. Biller, M. G. Boulay, Y. D. Chan, M. Chen *et al.*, Astrophys. J. **653**, 1545 (2006)

Solar neutrino capture rate

Capture rate [SNU]	D. Frekers et al. Phys. Rev. C 91, 034608 (2015)	Calculation q=1	Calculation q=0.5
R_{diskr}	115.9	119.5	119.5
R_{3-S_n}	6.5	14.2	7.0
R_{total}	122.4	133.7	126.5

Solar component	Total capture rate [SNU]		
	D. Frekers et al. Phys. Rev. C 91, 034608 (2015)	Calculation q=1	Calculation q=0.5
pp	69.9	72.0	72.0
pep	3.4	3.5	3.5
^{7}Be	36.7	38.1	38.1
^{8}B	10.1	17.7	10.6
$\left\{\begin{array}{l} ^{13}N \\ ^{15}O \\ ^{17}F \end{array}\right.$	2.2	2.3	2.3
R_{total}	122.4	133.7	126.5

Alternative version of the basement for



- **Black** and **Green** points as in **the D. Frekers et al. Phys. Rev. C 91, 034608 (2015)**
- **Red** and **Blue** points corresponds to the our B(GT) extraction from resonant part of the experimental strength function and their sum with individual states.

- Here we use just the most "conservative" estimation, only from GTR and PR1, PR2 resonances.

CONCLUSION

Charge-exchange strength functions are useful for neutrino capture analysis.

High-lying resonant GT states make a perceptible contribution into neutrino capture cross-section.

Quenching effect needs detailed analysis.

Current experimental data corresponds to factor $q \approx 0.5$.

Inclusion of resonance effects leads to an increase of the cross section estimation.

Thank you for your attention!