Resonance structure of the charge-exchange strength function of Tellurium isotopes 128 and 130

A. N. Fazliakhmetov[1,2,3], Yu. S. Lutostansky[1], B. K. Lubsandorzhiev[2], G. A. Koroteev[1,2,3], A. Yu. Lutostansky[1], V. N. Tikhonov[1]

[1]National Research Centre “Kurchatov Institute”, Moscow, Russia

[2]Institute for Nuclear Research of the Russian Academy of Sciences

[3]Moscow Institute of Physics and Technology

The experiments to measuring $T_{1/2}^{2\nu\beta\beta}$ and searching for $0\nu\beta\beta$ in $^{130}\mathrm{Te}$

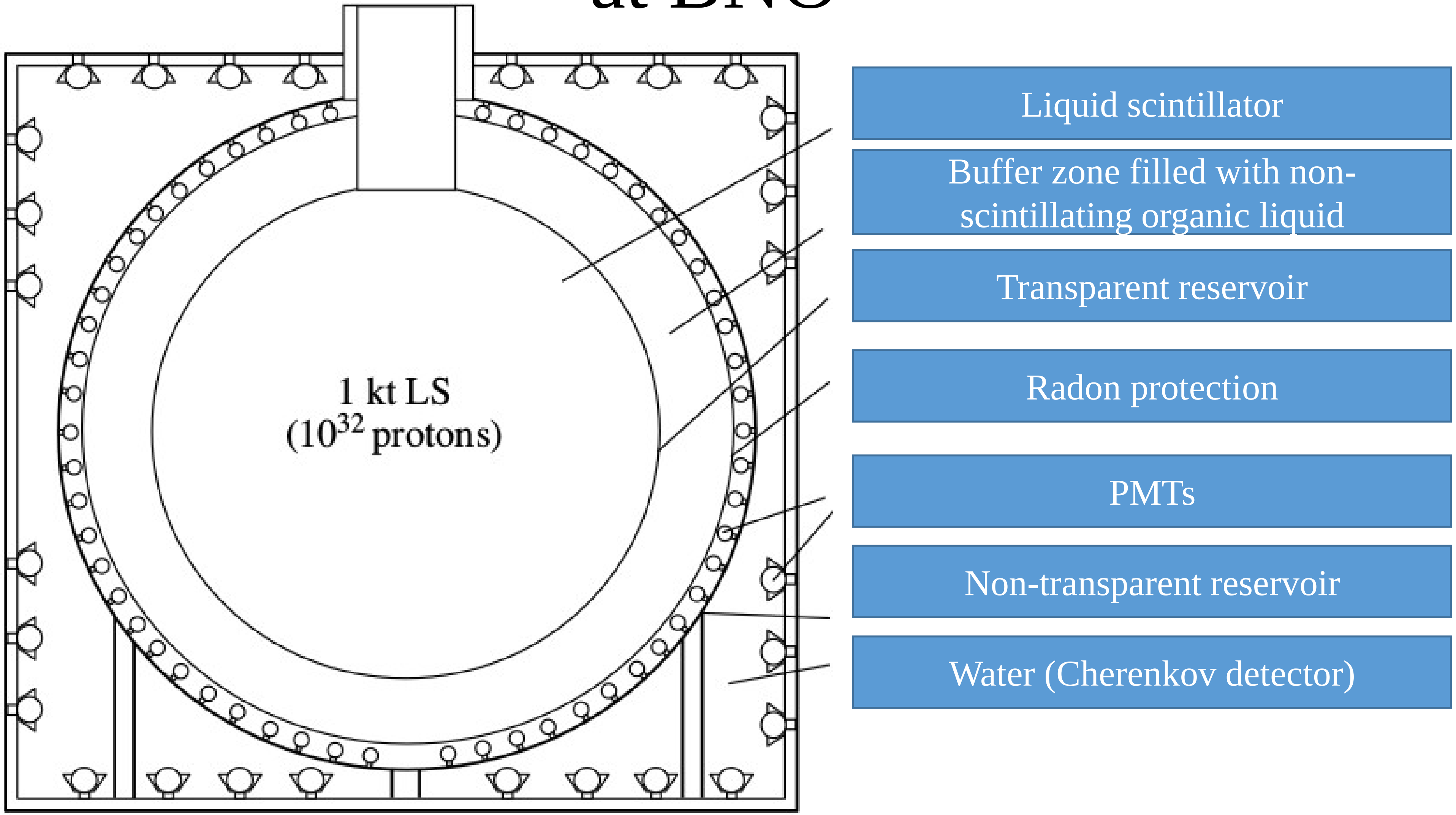
Name	Location	Description	Status
SNO+	Sudbury Neutrino Observatory, Canada	Liquid scintillator inside an acrylic sphere with a mass of 780 tons with natural Tellurium dissolved in it with a concentration of 0.5% by mass (1.3 tons ^{130}Te) of the first phase of the experiment to search the process $0\nu\beta\beta$ in ^{130}Te. An array of ~9400 photomultiplier tubes observes the sphere.	From May 2017 to June 2019 was the water phase of the experiment. In 2019 the sphere was filled with scintillator. By the end of 2022, the scintillator is expected to be loaded with Tellurium [2]. Expected sensitivity: $T_{1/2}^{0\nu\beta\beta} > 7 \times 10^{26}$ years for ^{130}Te at 90% confidence level after 5 years of data set if Tellurium concentration will be increased to 5% ($T_{1/2}^{0\nu\beta\beta} > 9 \times 10^{25}$ years at concentration 0.3%) [1].

1. SNO+ Collaboration, Advances in High Energy Physics, 6194250 (2016)
2. Ana Sofia Inácio for the SNO+ collaboration., PoS PANIC2021 (2022), 274

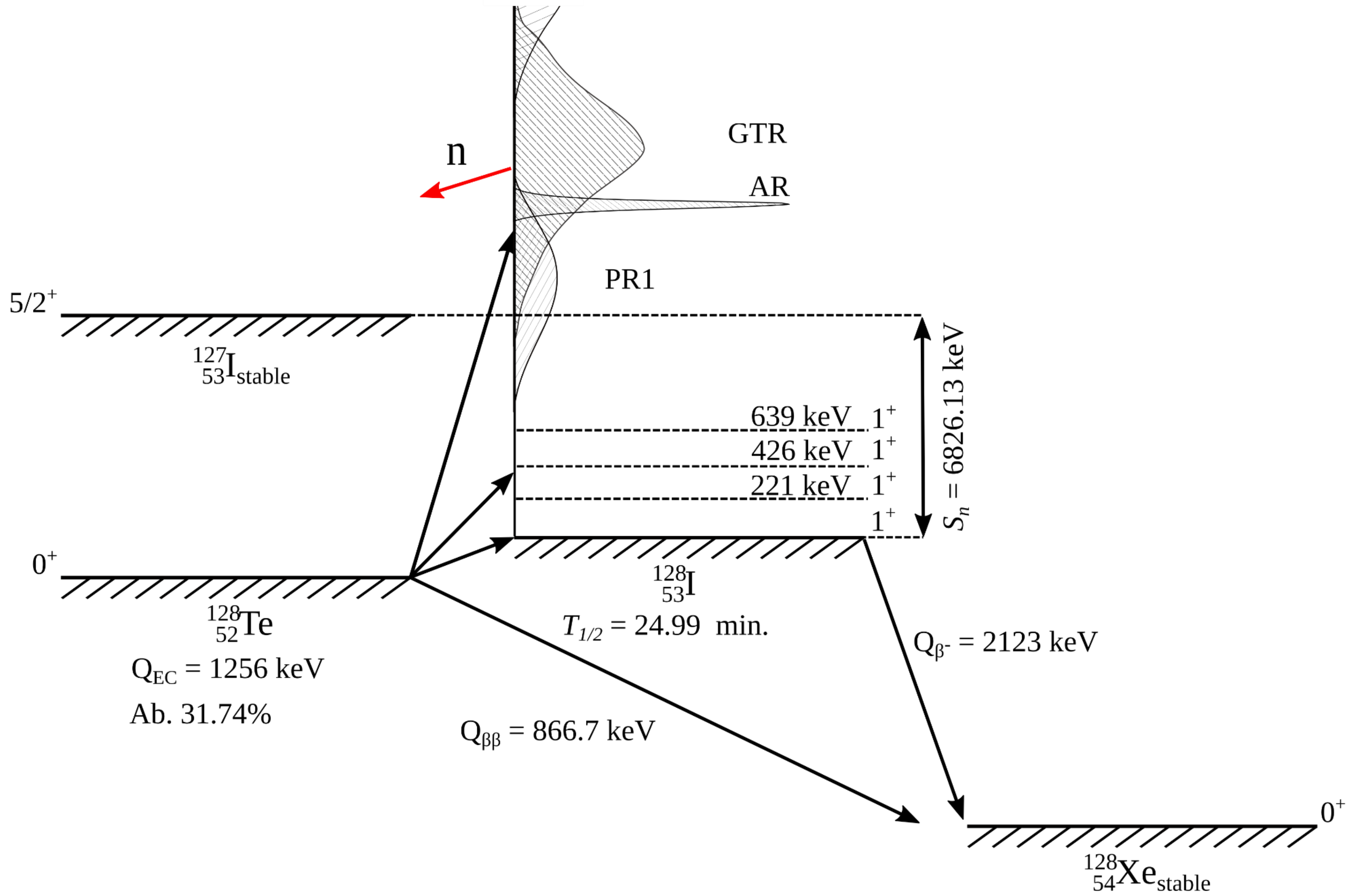
CUORE	Laboratori Nazionali del Gran Sasso (LNGS), Italy	An array of 988 TeO_2 crystals (206 kg ^{130}Te), which operate both as a source of decaying isotopes and as a cryogenic bolometric detector	Analysis of data collected from May 2017 to July 2019 with a total exposure of 103.6 kg*years for ^{130}Te gives a limit for the half-life $T_{1/2} = 3.2 \times 10^{25}$ years in the $0\nu\beta\beta$ channel with 90% confidence level [3]. For the double beta decay period $T_{1/2}^{2\nu} = 7.71^{+0.08}_{-0.06}(stat.)^{+0.12}_{-0.15}(syst.) \times 10^{20}$ years [4].
COBRA	Laboratori Nazionali del Gran Sasso (LNGS), Italy	An array of CdZnTe semiconductor crystals that operate both as a source of decaying isotopes and as a semiconductor detector	Analysis of the data collected from September 2011 to February 2015 gives a limit for ^{130}Te $T_{1/2} = 6.1 \times 10^{21}$ years on the $0\nu\beta\beta$ channel with a 90% confidence level [5].
NEMO-3	Modane Underground Laboratory (LSM), France	Direct detection of two electrons from β-decay in a tracking chamber and in a calorimeter	An analysis of data collected during an exposure time of 1275 days for 661 g of isotope ^{130}Te gives a value $T_{1/2}^{2\nu} = 7.0 \pm 0.9(\text{стат.}) \pm 1.1(\text{сист.}) \times 10^{20}$ years [6].

3. D. Q. Adams et al., Phys. Rev. Lett. 124, 122501 (2020)
4. D. Q. Adams et al., Phys. Rev. Lett. 126, 171801 (2021)
5. Joachim Ebert et al., Phys. Rev. C **94**, 024603 (2016)
6. R. Arnold *et al.*, Phys. Rev. Lett. **107**, 062504 (2011)

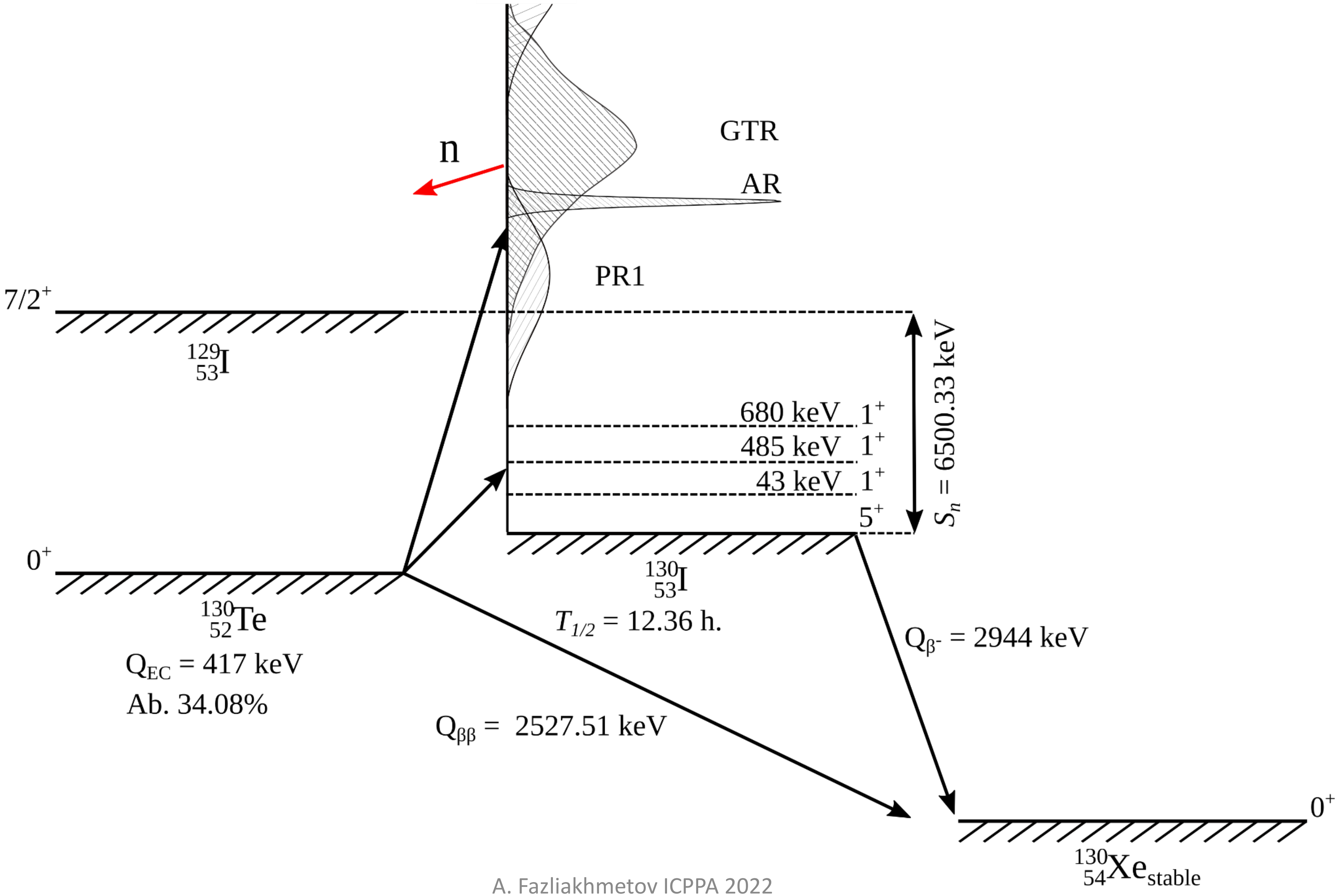
Supposed construction of Large volume detector at BNO



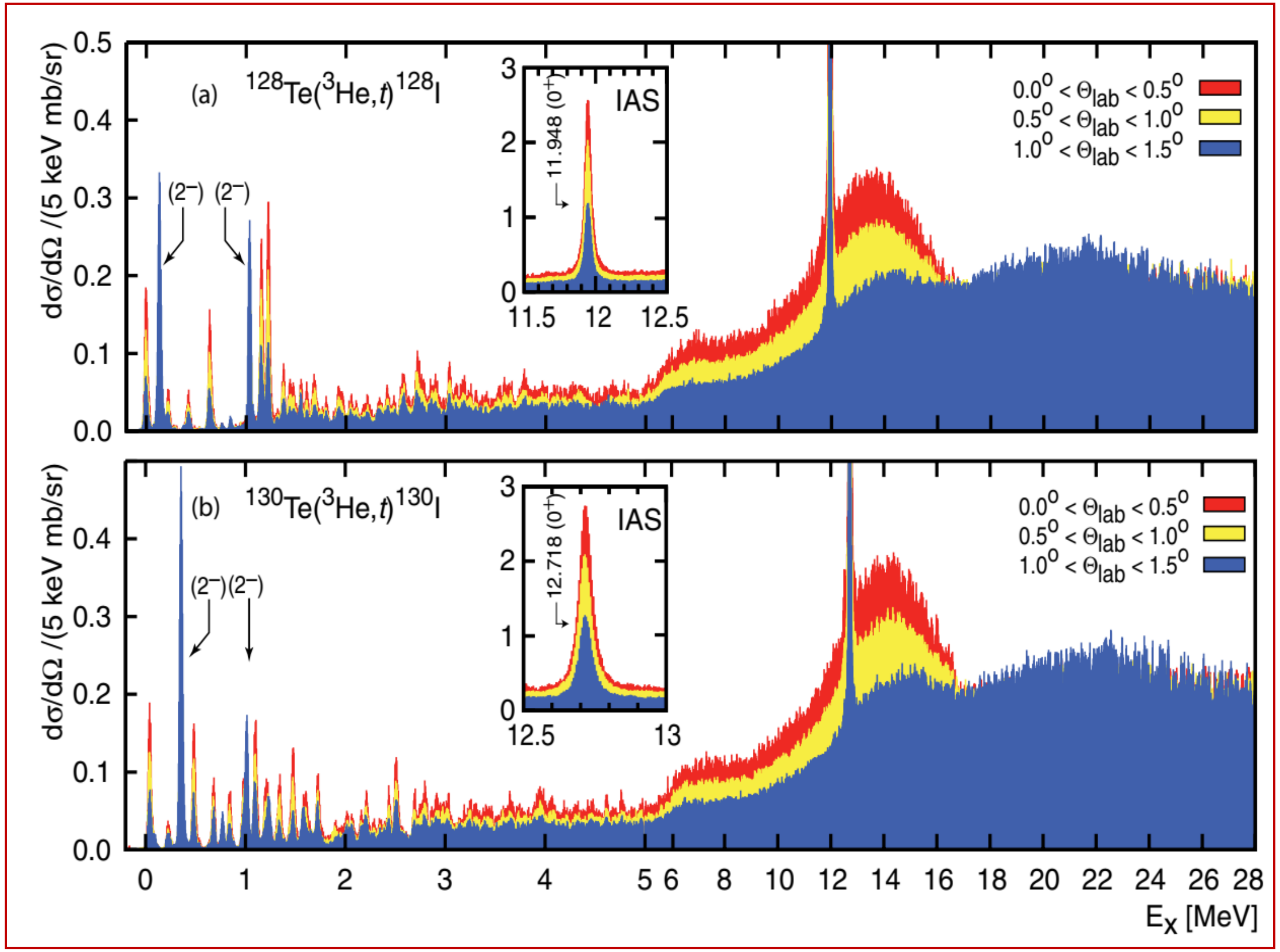
Charge-exchange excitations scheme for ^{128}Te



Charge-exchange excitations scheme for ^{130}Te

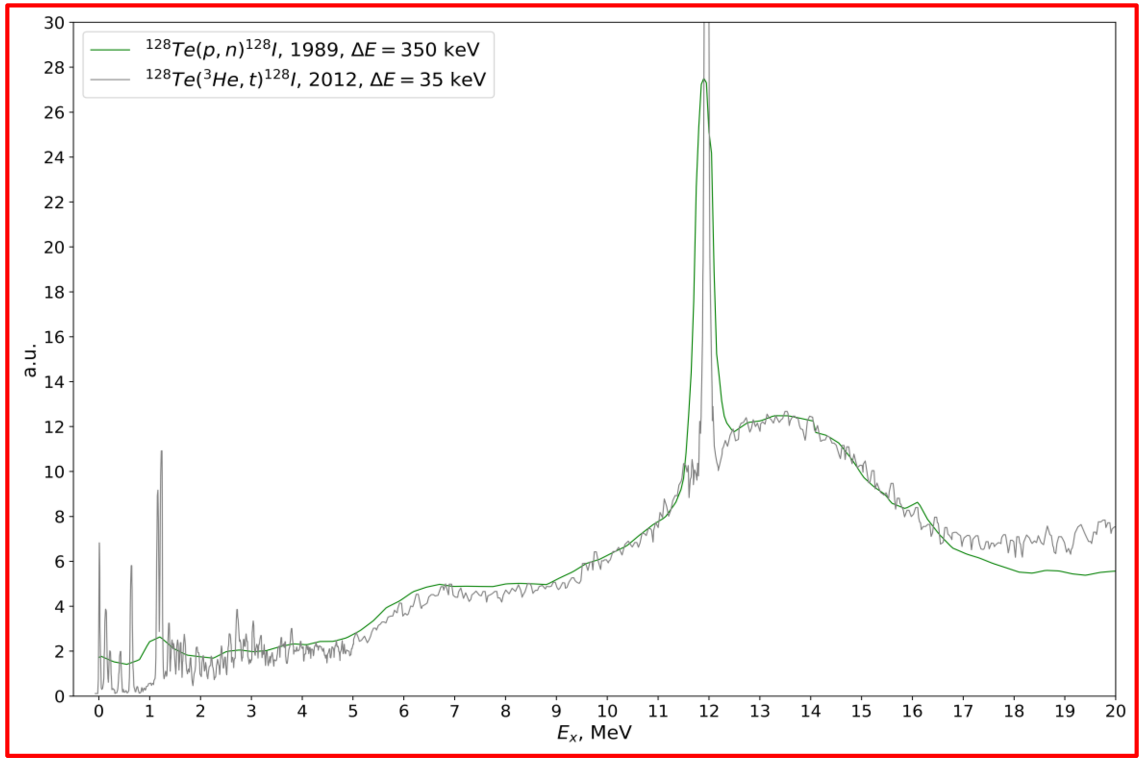


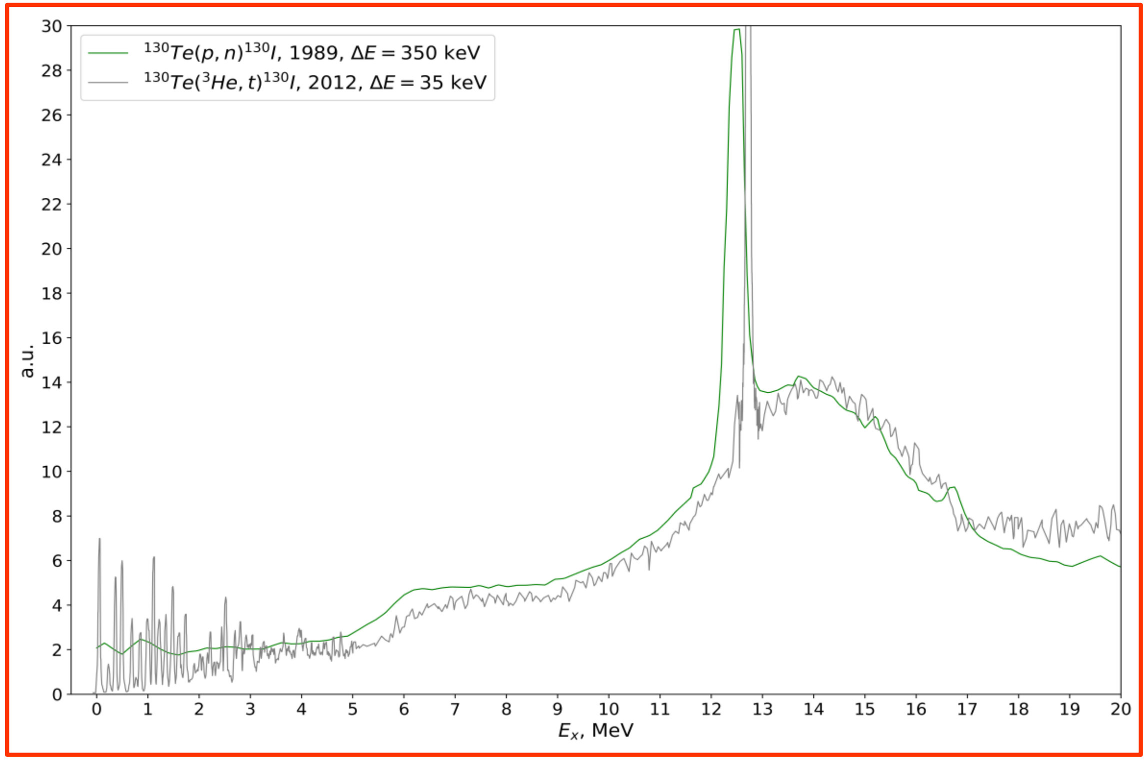
Experimental data: charge-exchange reactions $^{128,130}Te(^{3}He, t)^{128,130}I$



P. Puppe, A. Lennarz, T. Adachi, H. Akimune, H. Ejiri, D. Frekers, H. Fujita, Y. Fujita, M. Fujiwara, *et. al*. Phys. Rev. C **86**, 044603 (2012).

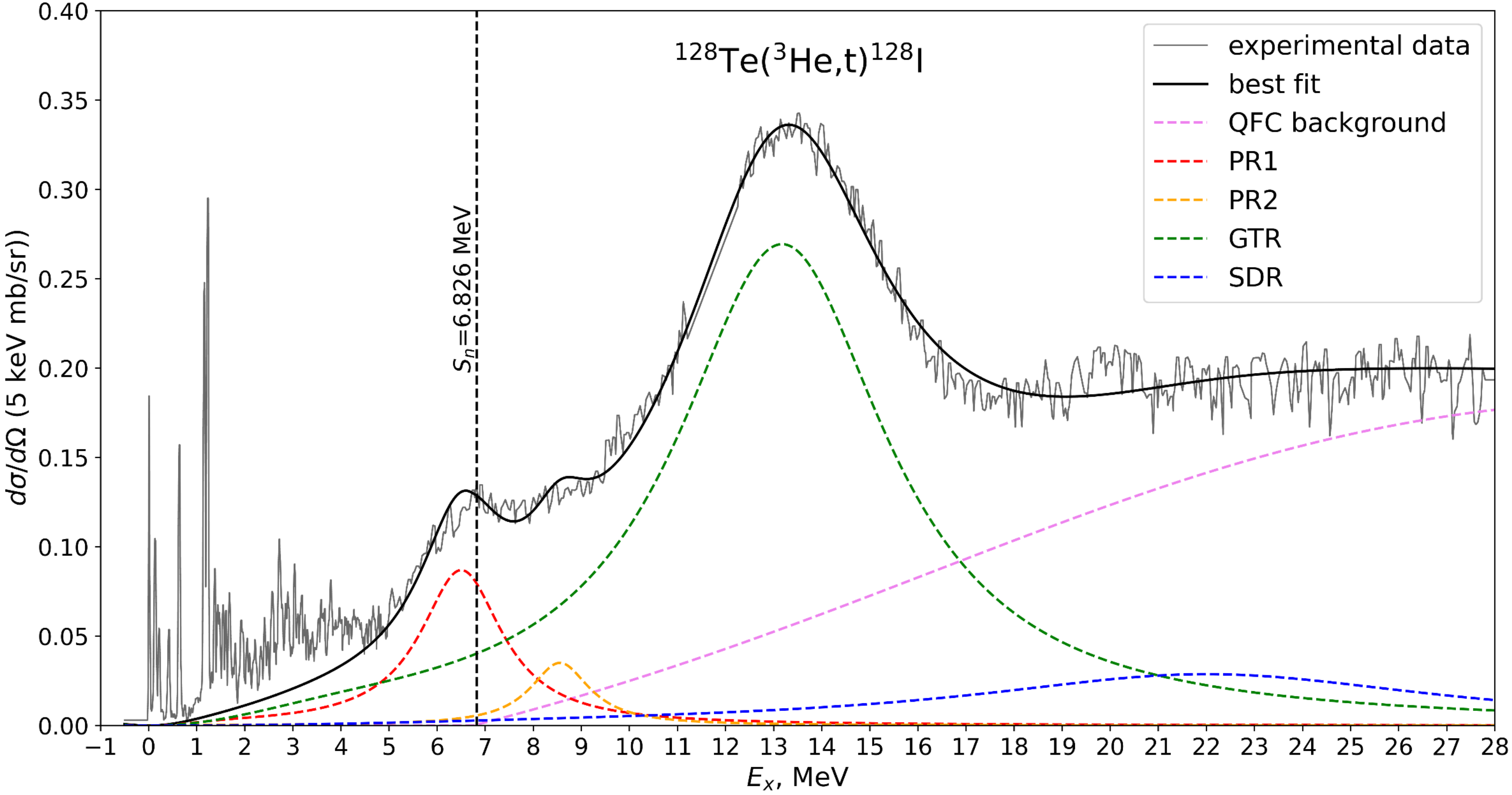
Charge-exchange reactions comparison: (^{3}He,t) and (p,n)



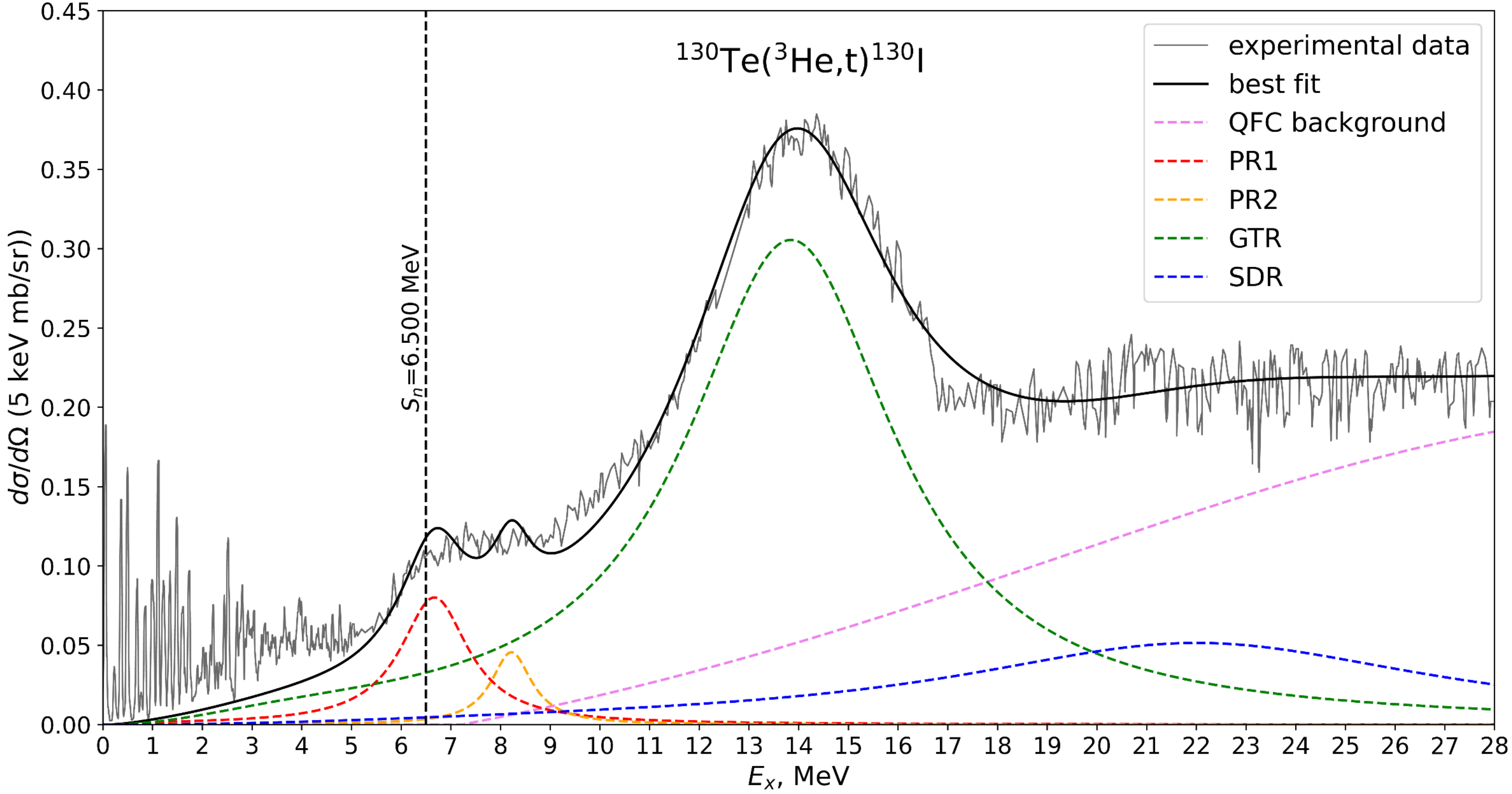


R. Madey, B.S. Flanders, B.D. Anderson, A.R. Baldwin, and J.W. Watson, Phys. Rev. C 40, 540 (1989).
P. Puppe, A. Lennarz, T. Adachi, H. Akimune, H. Ejiri, D. Frekers, *et. al*. Phys. Rev. C 86, 044603 (2012).

Experimental data fit: ^{128}Te(^{3}He, t)^{128}I



Experimental data fit: $^{130}Te(^{3}He, t)^{130}I$



ISOBARIC STATES 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 <u>effective fields</u> of quasi-particles and holes, respectively;
V_{pn}^{ω} is an <u>external</u> charge-exchange <u>field</u>; d_{pn}^{1} and d_{pn}^{2} are effective vertex functions that describe change of the <u>pairing gap Δ</u> in an external field;
Γ^{ω} and Γ^{ξ} are the amplitudes of the <u>effective nucleon–nucleon interaction</u> 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 <u>$d_{pn}^{1} = d_{pn}^{2} = 0$</u>, what is valid in our case for external fields having zero diagonal elements

---

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

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

ISOBARIC STATES 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:

$\Delta j = 0; \pm 1$

$\Delta j = +1$: $j = l+1/2 \rightarrow j = l-1/2$

$\Delta j = 0$: $j = l \pm 1/2 \rightarrow j = l \pm 1/2$

$\Delta j = -1$: $j = l-1/2 \rightarrow j = l+1/2$

$j = l-1/2 \rightarrow j = l-1/2$

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:

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

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

Constants f' and g' are the phenomenological parameters.

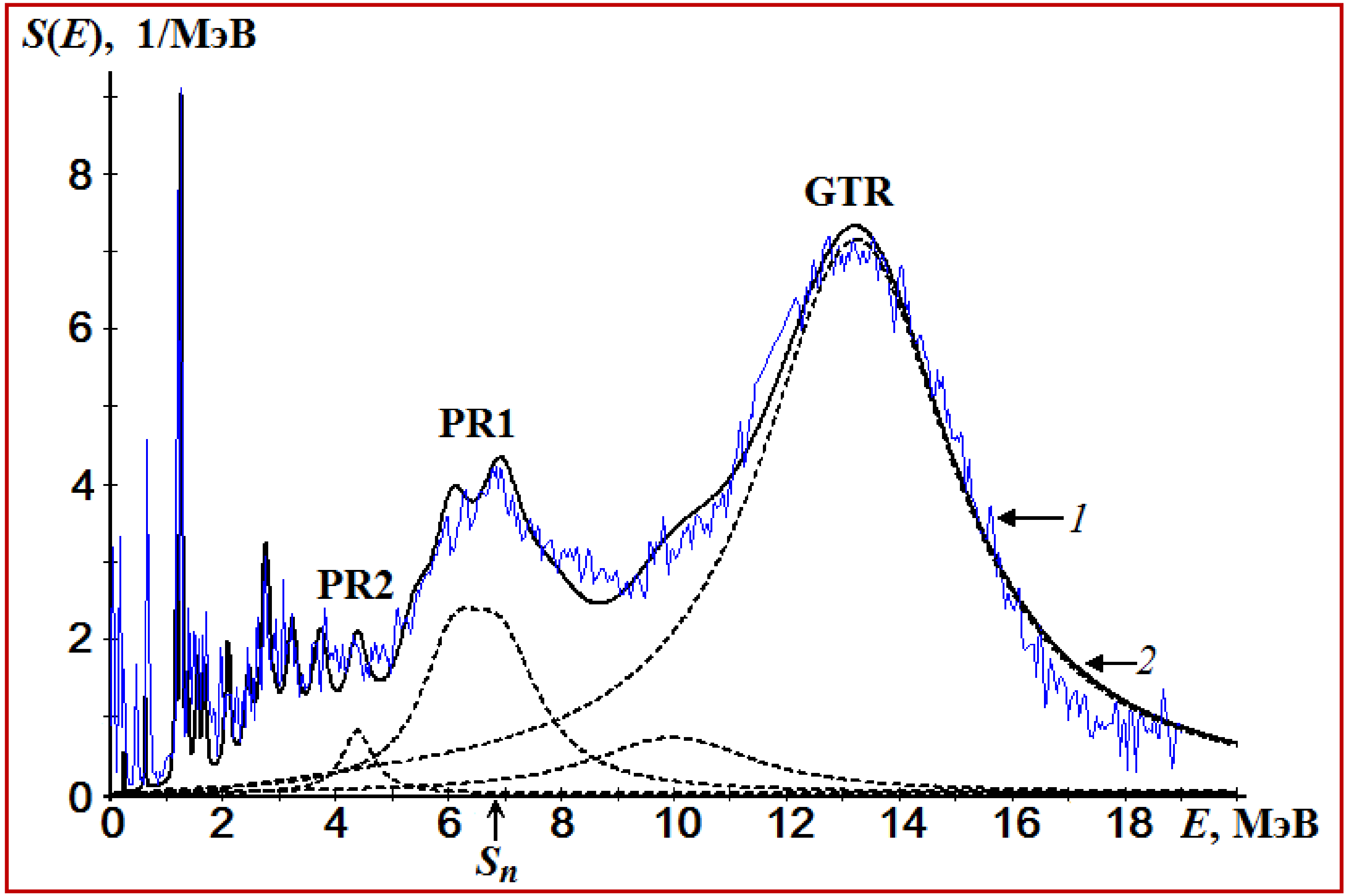
Matrix elements M_{GT} : $M^2_{GT} = \sum_{\lambda_1\lambda_2} \chi_{\lambda_1\lambda_2} A_{\lambda_1\lambda_2} V^{\varpi}_{\lambda_1\lambda_2}$ where $\chi_{\lambda\nu}$ – mathematical deductions

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

Effective quasiparticle charge $e_q^2 = 0.8 - 1.0$ ***is the "quenching" parameter of the theory.***

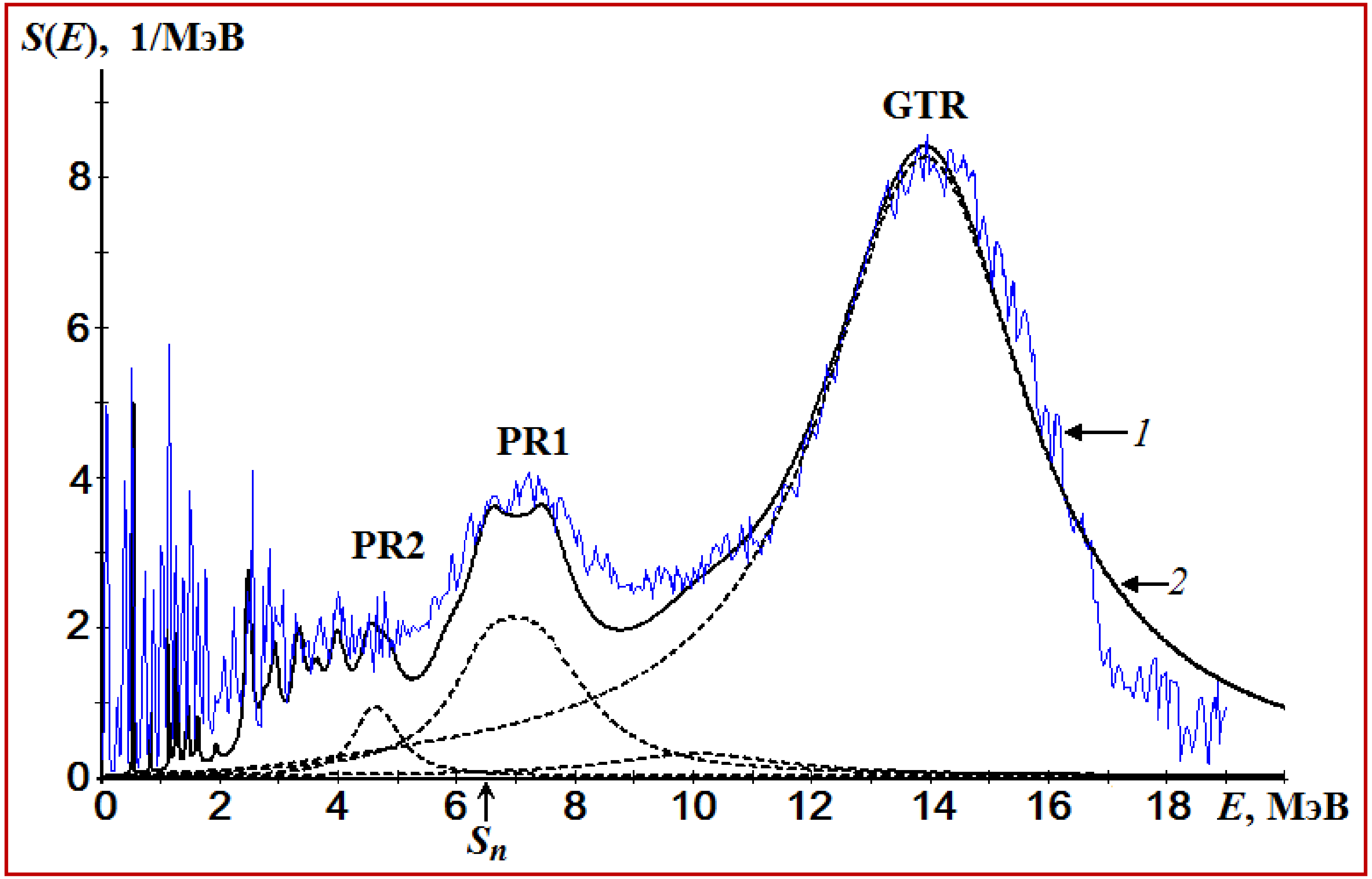
***"Quenching"* effect (Losing of sum rule in beta-strength) is the main in heavy nuclei ~ 50%**

Charge-exchange strength function for $^{128}Te(^{3}He, t)^{128}I$



1 – P. Puppe *et. al*. Phys. Rev. C 86, 044603 (2012).
2 - TFFS with e_q=0.9

Charge-exchange strength function for $^{130}Te(^{3}He, t)^{130}I$



1 – P. Puppe *et. al*. Phys. Rev. C 86, 044603 (2012).
2 - TFFS with e_q=0.9

Conclusion

- The charge-exchange strength functions S(E) of the isotopes ^{128}Te, ^{130}Te are presented

- Both experimental data on the charge-exchange strength functions *S(E)* obtained in (^{3}He, t) reactions and the *S(E)* strength functions calculated in the microscopic theory of finite fermi-systems (TFFS) are analyzed.

- The resonance structure of the strength function *S(E)* is investigated, and the Gamow-Teller and Pygmy resonances are distinguished. The energies and matrix elements of these resonances are calculated.

- Next step: to calculate solar neutrino capture rate (in development). Capturing solar neutrinos is an unavoidable background in experiments searching for neutrinoless double beta decay.