EFFECT OF TENSOR CORRELATIONS ON THE GAMOW-TELLER STRENGTH DISTRIBUTION IN CLOSED-SHELL PARENT NUCLEI.

V.I. BONDARENKO[1)], M.H.URIN[2)]

[1)]Shubnikov Institute of Crystallography, Federal Research Center "Crystallography and Photonics," Russian Academy of Sciences, Moscow, Russia;

[2)]National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Russia

Outline

I. Introduction.
II. Basic relations.
III. GT strength distribution in ^{208}Bi.
IV. Conclusions.

I. Introduction

- In spherical nuclei, giant resonances (GRs) associated with high-energy (isoscalar and isovector) particle-hole (p-h) excitations, along with the “transferred” total momentum and parity (quantum numbers Jπ), are also characterized by orbital and spin momenta (quantum numbers L and S, respectively). The terms "multipole" and "spin-multipole" are related to the classification of GRs according to L and S.
- However, due to the spin-orbit component of the mean field used in any microscopic (or semi-microscopic) description of GR, the quantities L and S are not exact quantum numbers. Due to this component, some mixing of the GRs with the given values of Jπ and different values of L and (or) S occurs. In other words, tensor correlations (which we will call correlations of the first kind) are realized in the formation of the considered GR ($J \neq 0$).
- In monograph (U., Energoatomizdat, 1991), the equations of the continuum version of the random phase approximation (cRPA) are obtained using the p-h interaction in the form of (central) Landau-Migdal forces and taking into account tensor correlations of the first kind in the description of the GR strength functions. These equations correspond to the so-called asymmetric (or off-diagonal) cRPA version, in which the spin-angular symmetry of the effective (one-particle) field differs from the symmetry of the corresponding external field.

- If, along with the central forces, one assumes the existence of a tensor p-h interaction, then the latter also leads to tensor correlations (which we will call correlations of the second kind). As applied to the description of the Gamow-Teller strength function in a number of spherical nuclei, the corresponding separable tensor forces were used (Severyukhin, Sagawa., PTEP, 2013).
- In this work, we propose an approach to taking tensor correlations into account in the formation of charge exchange spin multipole GRs in medium-heavy magic parent nuclei. The approach includes the tensor part of the p-h interaction, chosen as a direct generalization of the Landau-Migdal forces. The main object of research is the Gamow-Teller Resonance (GTR) characterized by the values $J^{\pi} = 1^{+}$. The proposed approach is a version of the particle-hole dispersive optical model (PHDOM) modified by taking into account tensor correlations. The model basic version used earlier to describe the main characteristics of various GRs in medium-heavy magic nuclei is a generalization of the symmetric version of the cRPA to the case of taking into account (phenomenologically and in average over the energy) the spreading effect (see, e.g., Gorelik at al., PRC, 2021 and references therein).
- In the present work, within the framework of a modified version of the PHDOM, the GT strength distribution in ^{208}Bi is investigated. This strength distribution is well studied experimentally (Akimune, *et al.*, PRC, 1995; Krasznahorkay et al., PRC, 2001).

II. Basic relations.

1. The spin-isospin part of the Landau-Migdal forces with tensor interaction (S = 1):

$$F_{s-is}(x_1, x_2) = \vec{\tau}_1\vec{\tau}_2(r_1, r_2)^{-1}\delta(r_1 - r_2)$$

$$\left[G' \sum_{JLM} T^{+}_{JLSM}(\vec{n}_1)T_{JLSM}(\vec{n}_2) + G'_t \sum_{JLM} T^{+}_{JLSM}(\vec{n}_1)T_{J\bar{L}SM}(\vec{n}_2)\right]$$

In particular, these forces lead to mixing 1^+ states of spin-monopole (J = 1, L = 0) and spin-quadrupole (J = 1, $\bar{L} = 2$) excitations of particle-hole type.

2. Effective field method (follows from formulation of PHDOM in terms of the particle-hole Green function).

Let $V^{(\mp)}_{JLS\mathcal{M}}(x) = \tau^{(\mp)} V_{JLS}(r) T_{JLSM}(\vec{n})$ - be the external field (probe operator), leading to excitation of the corresponding charge-exchange spin-multipole giant resonance.
The effective field contains two terms:

$$\tilde{V}^{(\mp)}_{J(L)S\mathcal{M}}(r,\omega) = \tau^{(\mp)} \sum_{L_1 = L,\bar{L}} \tilde{V}^{(\mp)}_{J(L)L_1 S\mathcal{M}}\ (r,\omega)\ T_{JL_1 S\mathcal{M}}(\vec{n}).$$

In particular for GTR $V_{GT}(r) = 1$, L=0, $\bar{L}$=2, and for 1^{+} $\mathrm{IVGSQR}^{(\mp)}$ resonance L=2, $\bar{L}$=0

The radial components of the effective field obey the system of equations ($L'=L, \bar{L}$):

$$\tilde{V}^{(\mp)}_{J(L)L'S}(r,\omega) = V_{JLS}(r)\delta_{LL'} +$$

$$\frac{2}{r^2}\int \sum_{L''=L,\bar{L}} \left[G' A^{(\mp)}_{J,L'S,L''S}(r,r',\omega) + G'_t A^{(\mp)}_{J,\bar{L'}S,L''S}(r,r',\omega)\right] \tilde{V}^{(\mp)}_{JL''S}(r',\omega)dr'$$

Here, ω is the excitation energy, $A^{(\mp)}_{J,L_1S,L_2S}(r,r',\omega)$ -are the radial components of the "free" p-h propagator. The explicit expression for $A^{(\mp)}_{J,L_1S,L_2S}(r,r',\omega)$ is rather combersome. It can be obtained from the expression for $A^{(\mp)}_{0,00,00}(r,r',\omega)$ (given in details in Kolomiytsev at.al., EPJA. 2018) by substitution of kinematic factors:

$$(t^{000}_{(\pi)(\nu)})^2 = \frac{1}{4\pi}(2j_\nu + 1) \quad \delta_{(\pi)(\nu)} \longrightarrow$$

$$\longrightarrow t^{JL'S}_{(\pi)(\nu)} t^{JL''S}_{(\pi)(\nu)} = \frac{1}{2J+1}\langle(\pi)\|T_{JL'S}\|(\nu)\rangle\langle(\pi)\|T_{JL''S}\|(\nu)\rangle$$

Here, $(\lambda) = j_\lambda, l_\lambda$ - are the quantum numbers of single-particle states for neutrons ($\lambda = \nu$) and protons ($\lambda = \pi$).

3. Strength functions

The strength functions related to the probe operators $V^{(\mp)}_{JLS\mathcal{M}}(x)$ are given by:

$$\mathrm{S}^{(\mp)}_{J(L)L'S}(\omega) = -\frac{1}{\pi}\mathrm{Im}\sum_{\mathrm{L}''=L,\bar{L}}\int \mathrm{V}_{L'}(\mathrm{r})\mathrm{A}^{(\mp)}_{J,L'S,L''S}(\mathrm{r},\mathrm{r}',\omega)\,\tilde{\mathrm{V}}^{(\mp)}_{J(L)L''S}(\mathrm{r}',\omega)\mathrm{d}\mathrm{r}\mathrm{d}\mathrm{r}'$$

The strength functions $\mathrm{S}^{(\mp)}_{J(L)L'S}(\omega)$ obey the non-energy-weighted sum rule:

$$\mathrm{NEWSR}_{\mathrm{J(L)}L'\mathrm{S}} = \int_{Q^{(-)}}^{\infty} \mathrm{s}^{(-)}_{\mathrm{J(L)}L'\mathrm{S}}(\omega)\mathrm{d}\omega - \int_{Q^{(+)}}^{\infty} \mathrm{s}^{(+)}_{\mathrm{J(L)}L'\mathrm{S}}(\omega)\mathrm{d}\omega = \delta_{LL'}\int_{0}^{\infty} \mathrm{V}^{2}_{\mathrm{JLS}}(\mathrm{r})\mathrm{n}^{(-)}(\mathrm{r})\mathrm{r}^{2}\mathrm{dr}$$

where $n^{(-)}(r)$ – neutron-excess density in the parent nucleus, ω is the excitation energy counted off the parent-nucleus ground-state energy.

III. GT strength distribution in ^{208}Bi

1. Input data:
   - A realistic partially self-consistent phenomenological mean field (see e.g., Gorelik at. al. PRC, 2021)
   - Strength parameters (G', G'$_T$) = (g', g'$_t$) 300 MeV Fm^3
   - The experimental values of GTR energy and total width ω_{GT}^{exp} = (19,3 ± 0,2) MeV, Γ_{GT}^{exp} = (3.72 ± 0.25) MeV and total width of IVGSMR$^{(-)}$ Γ_{SM}^{exp} = (14 ± 3) MeV.
   - In each variant of calculations, the parameter g ' is selected from the condition $\omega_{GT}^{calc} = \omega_{GT}^{exp}$, and g'$_t$ is a variable parameter.

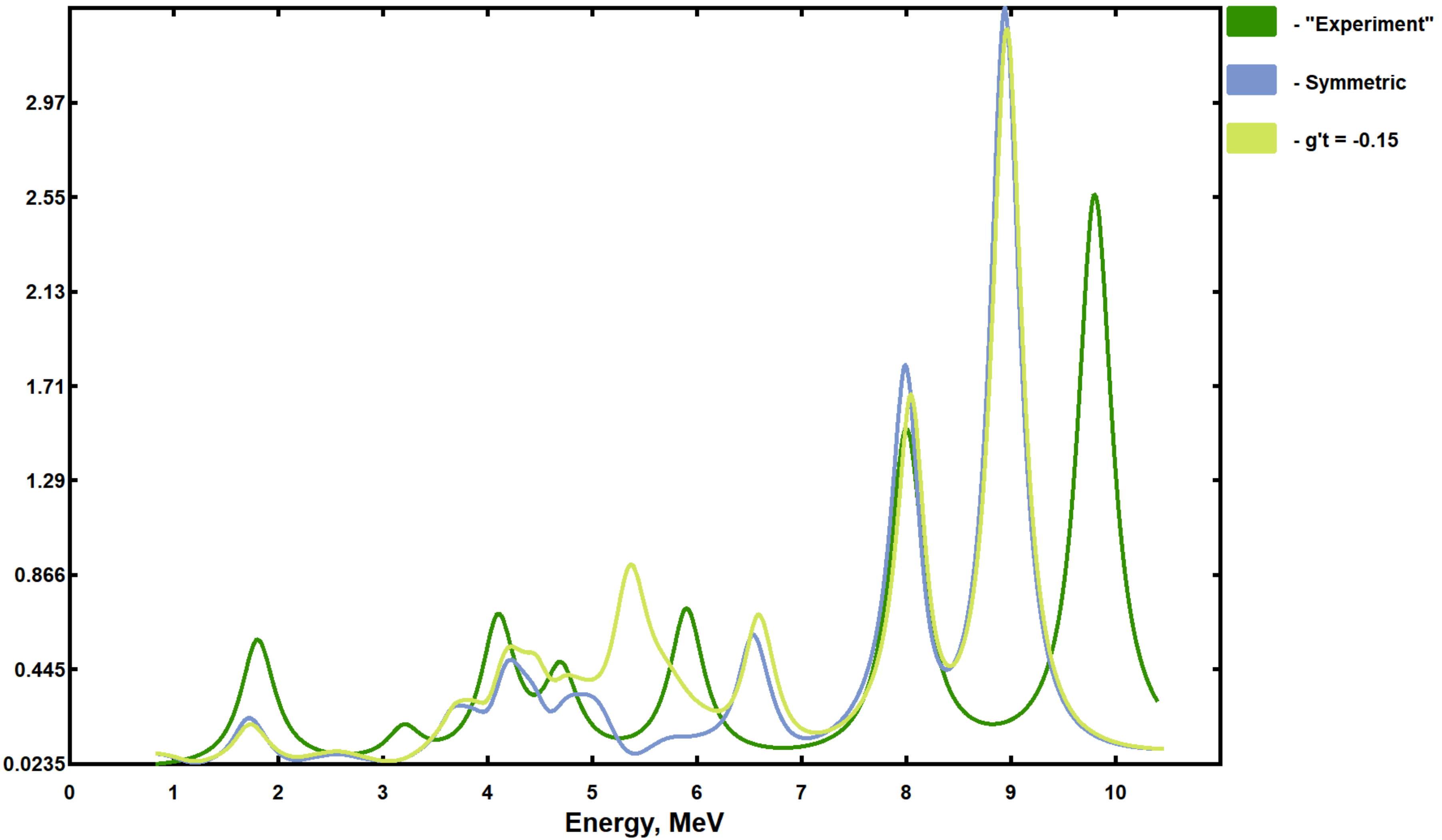
2. Calculation results:

- The GT sum rule fractions are evaluated for following excitation energy intervals $E_{x,1} \div E_{x,2}$:
  - $X_<$ ~ [0, 10.5] MeV
  - X_{peak} ~ [10.5, 19.8] MeV
  - $X_>$ ~ [19.8, 66.3] MeV
  - X_{total} ~ [0, 66.3] MeV

Sum rule fractions (cRPA)

Approximation	$x_<$, %	x_{peak},%	$x_>$,%	x_{total},%
Symmetric, g‘ = 0.783	8,31	74,15	14,79	97,25
Non-symmetric, g‘ = 0.767	9,13	73,59	15,59	98,31
Non-symmetric, g‘ = 0.809, g'_t = 0,15	8,69	74,61	14,64	97,94
Non-symmetric, g'=0.761, g'_t = -0,15	9,54	69,24	17,76	96,54
Experiment	18 ± 5	60 ± 15	--	--

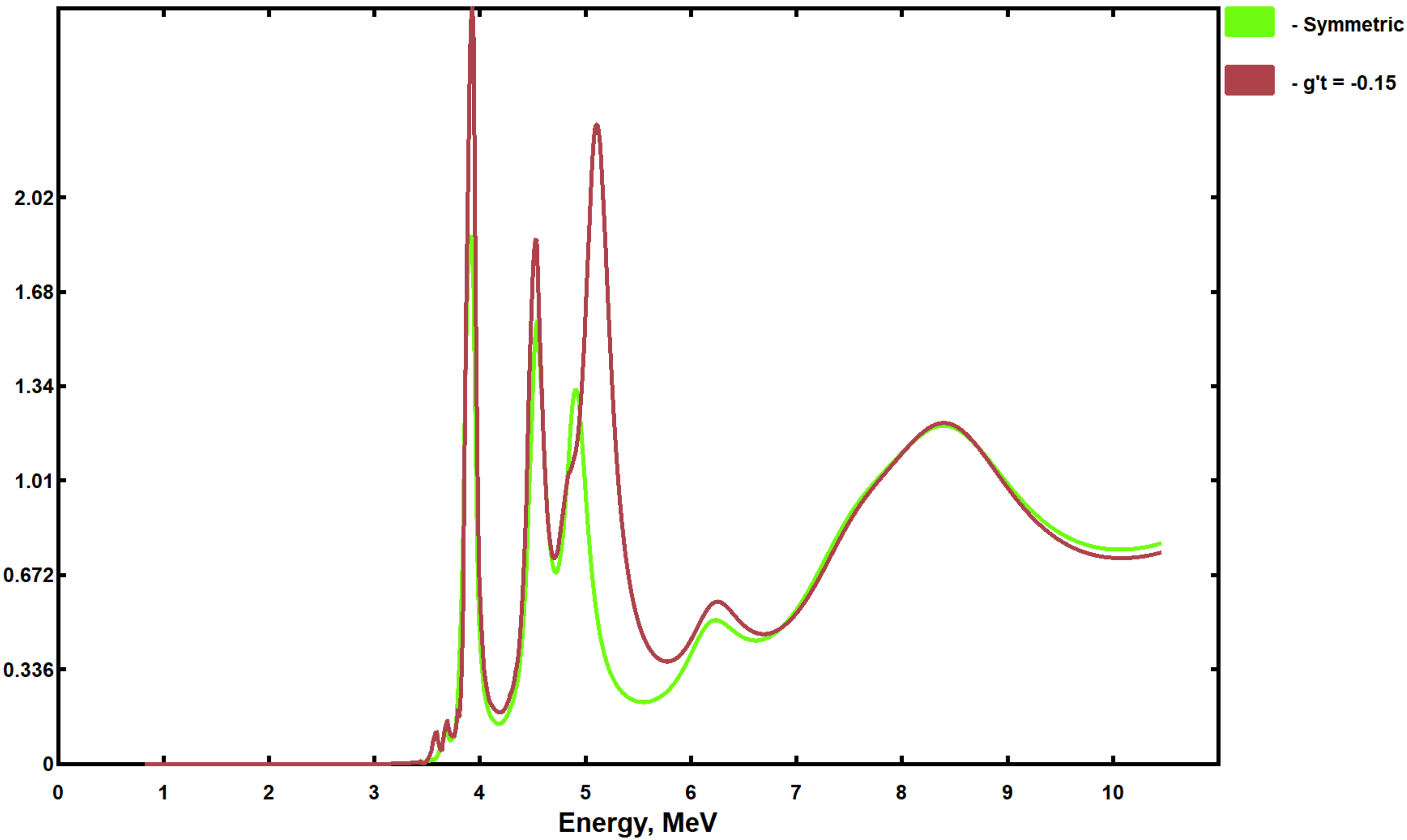
Low-energy part of the GT strength distribution (cRPA)



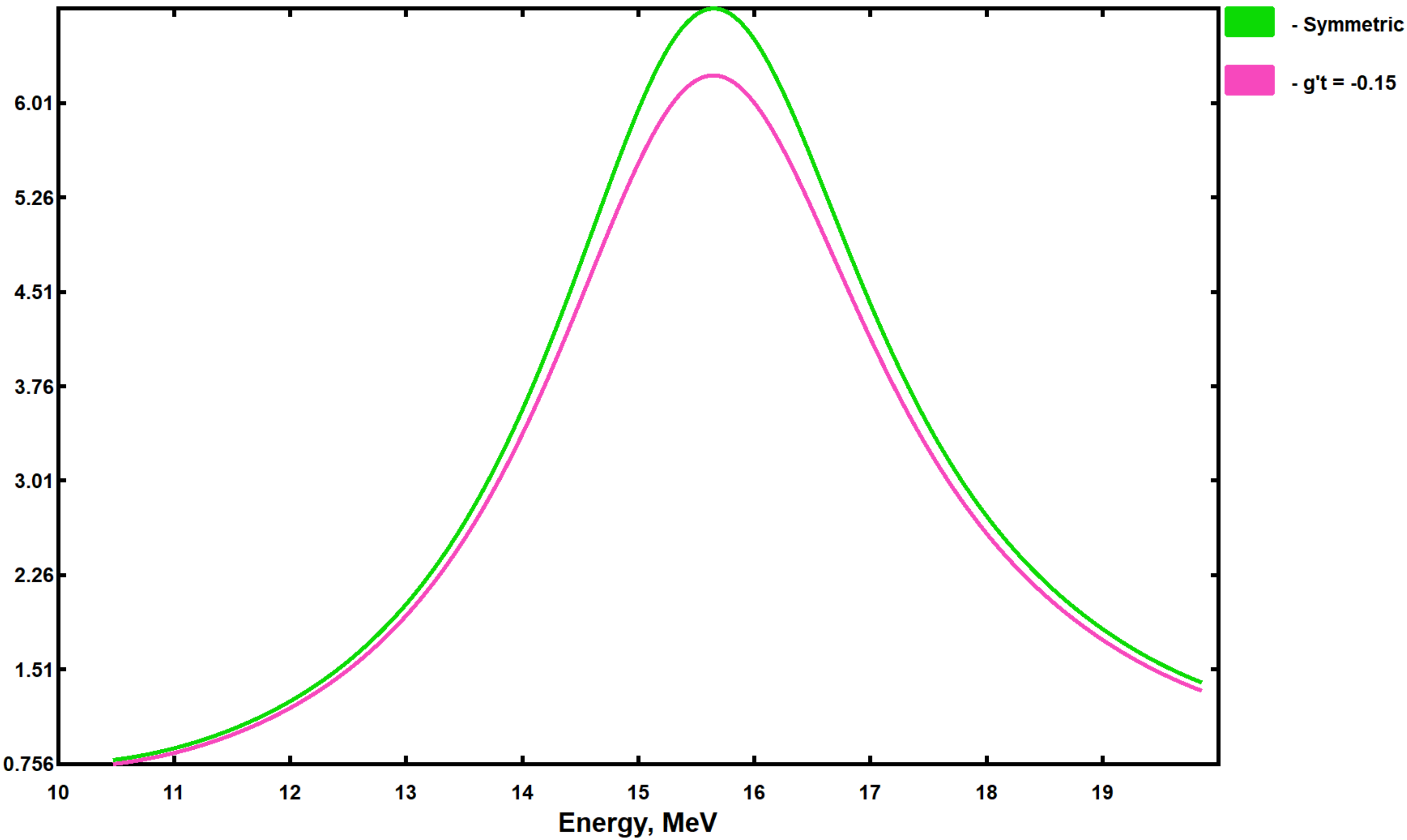
Sum rule fractions (PHDOM)

Approximation	$x_<$, %	x_{peak},%	$x_>$,%	x_{total},%
Symmetric, g'=0.756	11,01	66,07	21,52	98,60
Non-symmetric, g'=0.761	10,94	64,75	21,77	97,46
Non-symmetric, g'=0.788, g'_t=0,15	11,15	66,10	22,00	99,25
Non-symmetric, g'=0.724, g'_t=-0,15	12,80	61,76	24,32	98,88
Experiment	18 ± 5	60 ± 15	--	--

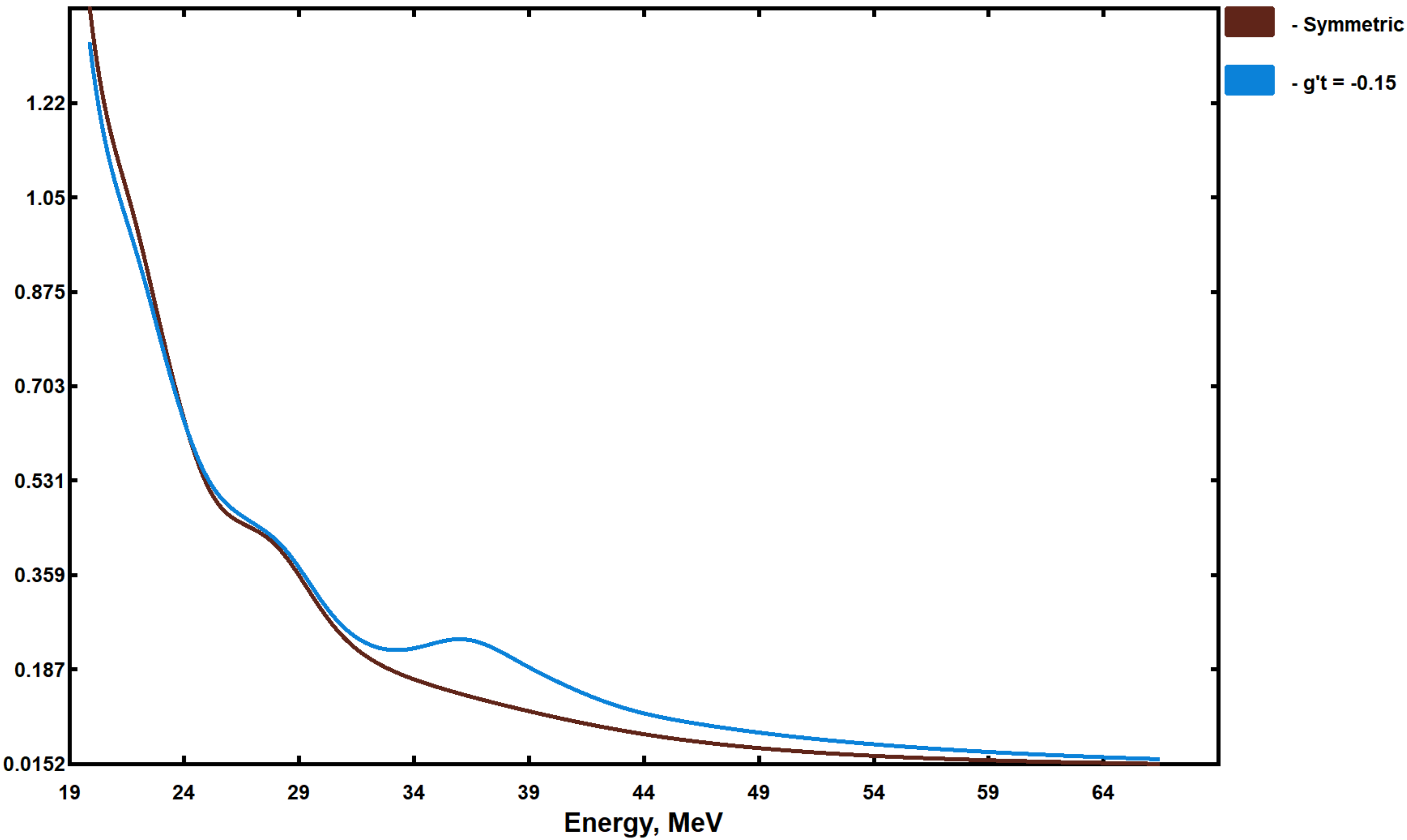
Low-energy part of the GT strength distribution (PHDOM)



Main-peak energy part of the GT strength distribution (PHDOM)



High-energy part of the GT strength function (PHDOM)



IV.Conclusion

- Being based on the continuum-random-phase-approximation, we propose a modified version of the particle-hole dispersive optical model in which tensor correlations in formation of charge-exchange spin-multipole giant resonances in closed-shell parent nuclei are taken into account

- The proposed approach is realized in applying to Gamow-Teller Resonance in ^{208}Bi. The Gamow-Teller strength function is evaluated for wide excitation-energy interval in various approximations and with the use of various values of the adjusted Landau-Migdal parameters g' and g'_t. As expected, the tensor correlations effect on formation of the Gamow-Teller strength function main (monopole) component is not-too-large. Nevertheless, taking this effect into account allows one to somewhat improve the description of respective experimental data.
- Consideration of the quantities, which exist only due to tensor correlations such as the quadrupole component of the Gamow-Teller strength function and transition density is in progress.