On microscopic nature of the photon strength function

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Two definitions.

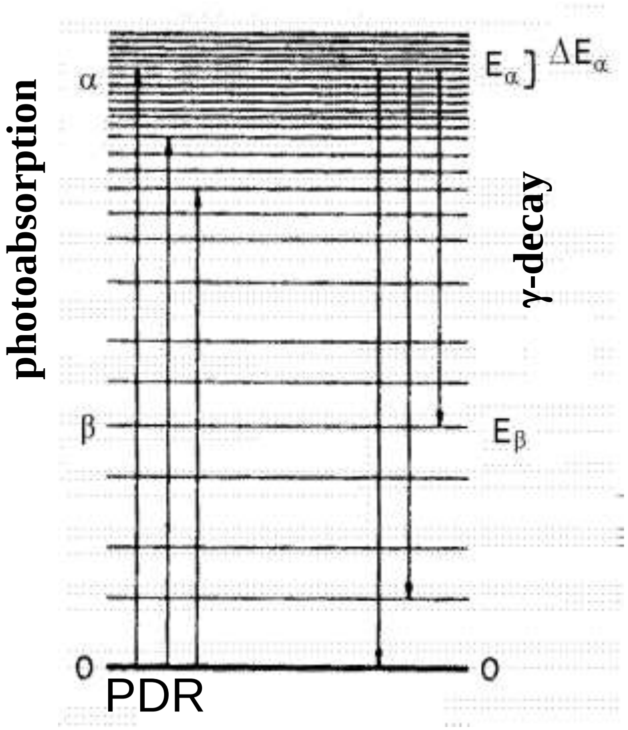
EMPIRE: 6 phenomenological models of PSF

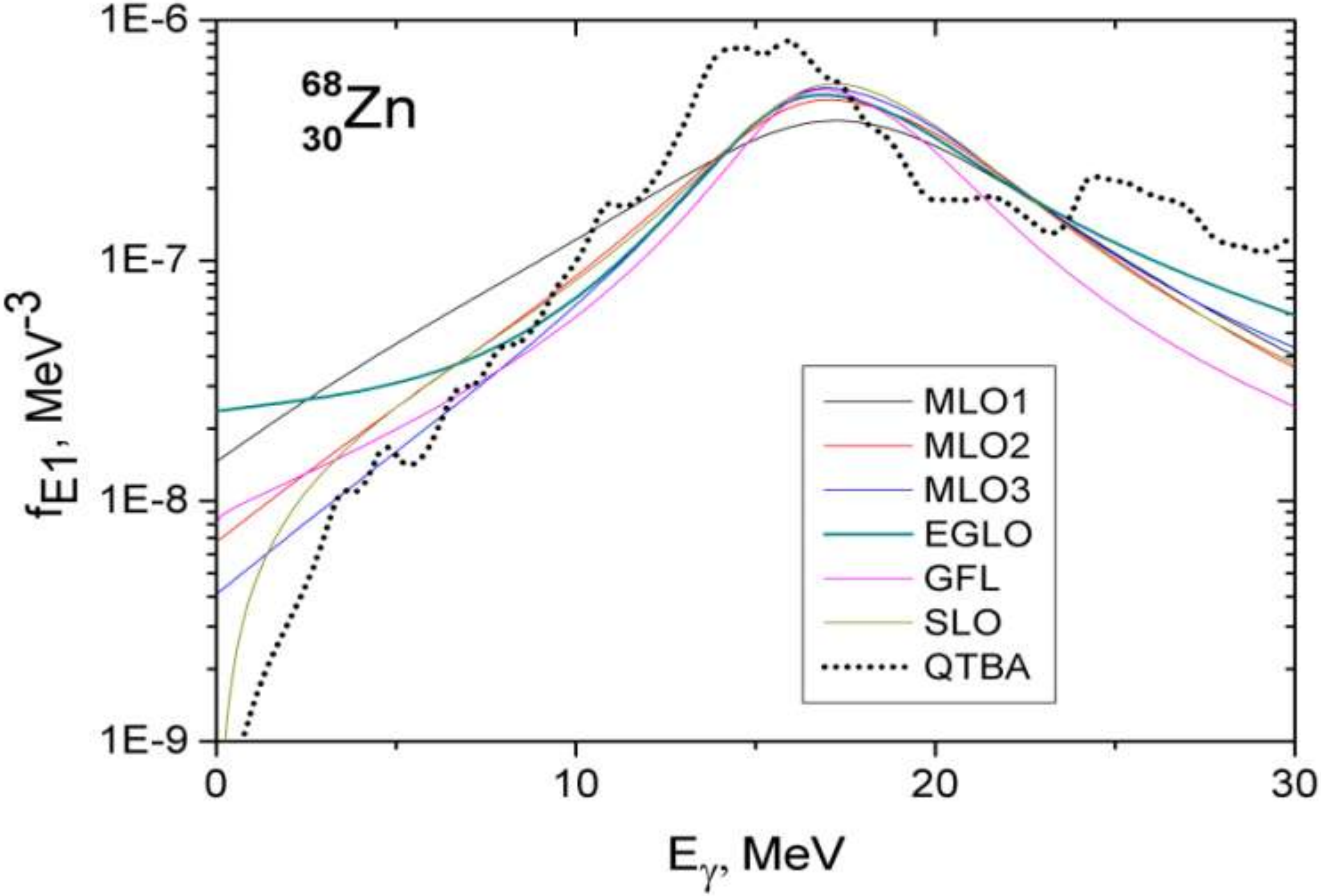
Photon strength function (radiative strength function):

The most popular definition of PSF: describes the energy distribution of photon emission between **excited** states

{The PSF and appropriate nuclear data businesses are based on the Axel-Brink hypothesis which was not justified microscopically so far ...}

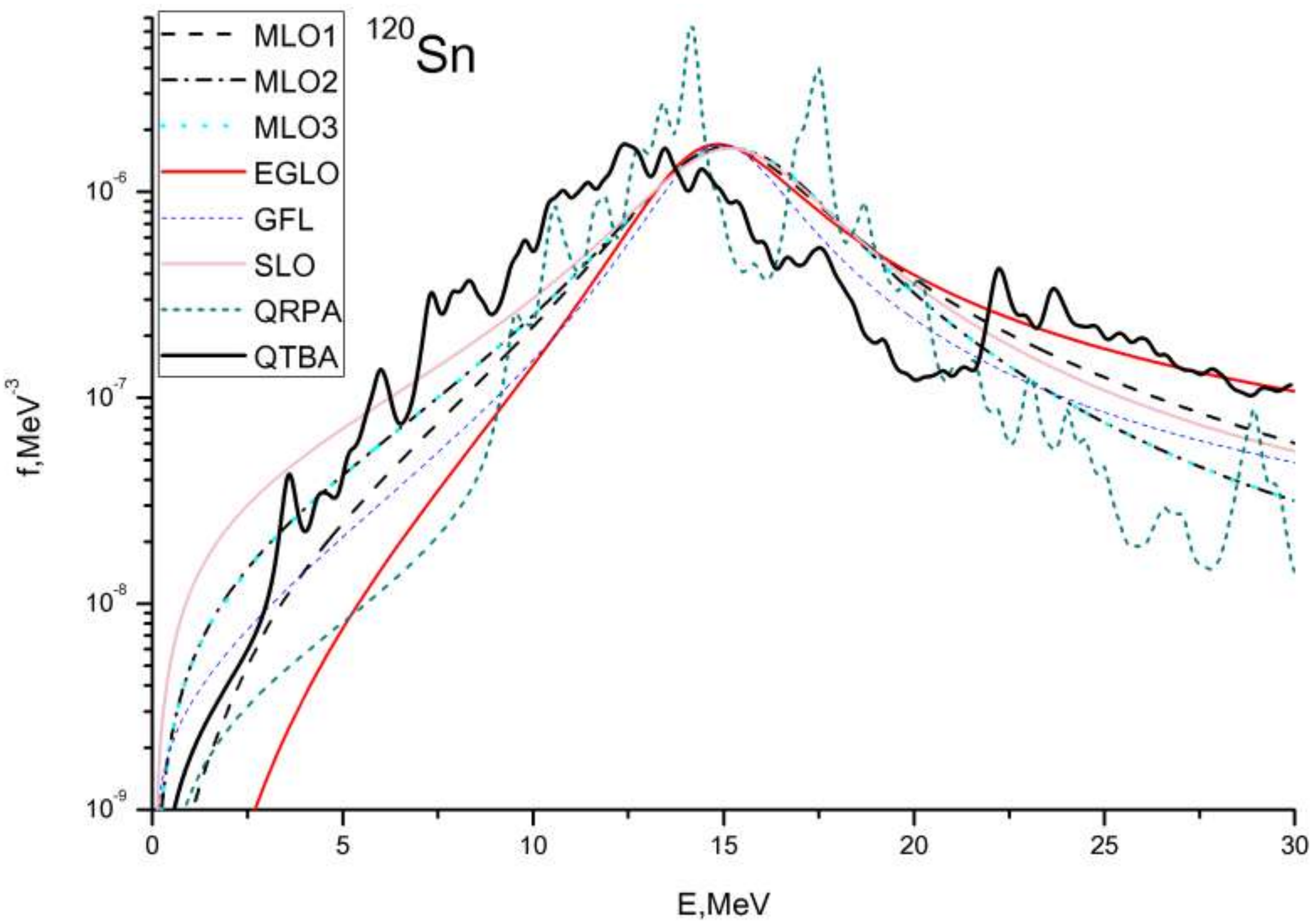
The microscopic description is necessary for neutron-rich nuclei, where phenomenological approaches are non-applicable





1E-6
1E-7
1E-8
1E-9
0
10
20
30
$^{68}_{30}Zn$
f_{E1}, MeV^{-3}
E_γ, MeV
MLO1
MLO2
MLO3
EGLO
GFL
SLO
QTBA

Photon strength functions



RIPL: The Lorentzian and previously described closed-form expressions for the γ-ray strength suffer from various shortcomings:

(1) they **are unable to predict the resonance-like enhancement of the E1 strength at energies below the neutron separation energy** as demonstrated, for example, by nuclear resonance fluorescence experiments

(2) they are **unable to describe isospin structure of the RSF**, specifically observed isospin splitting of the GDR in light- and middle-weight atomic nuclei [336]–[339];

(3) even if a Lorentzian function provides a suitable representation of the E1 strength, the location of the maximum and width still need to be predicted from some underlying model for each nucleus, as described in the previous sections. **This approach lacks reliability when dealing with exotic nuclei.**

For these reasons, in [RIPL2, 2004], RIPL3 appeared “Microscopic approach based on the HFB+QRPA method of S. Goriely. However it is not enough !

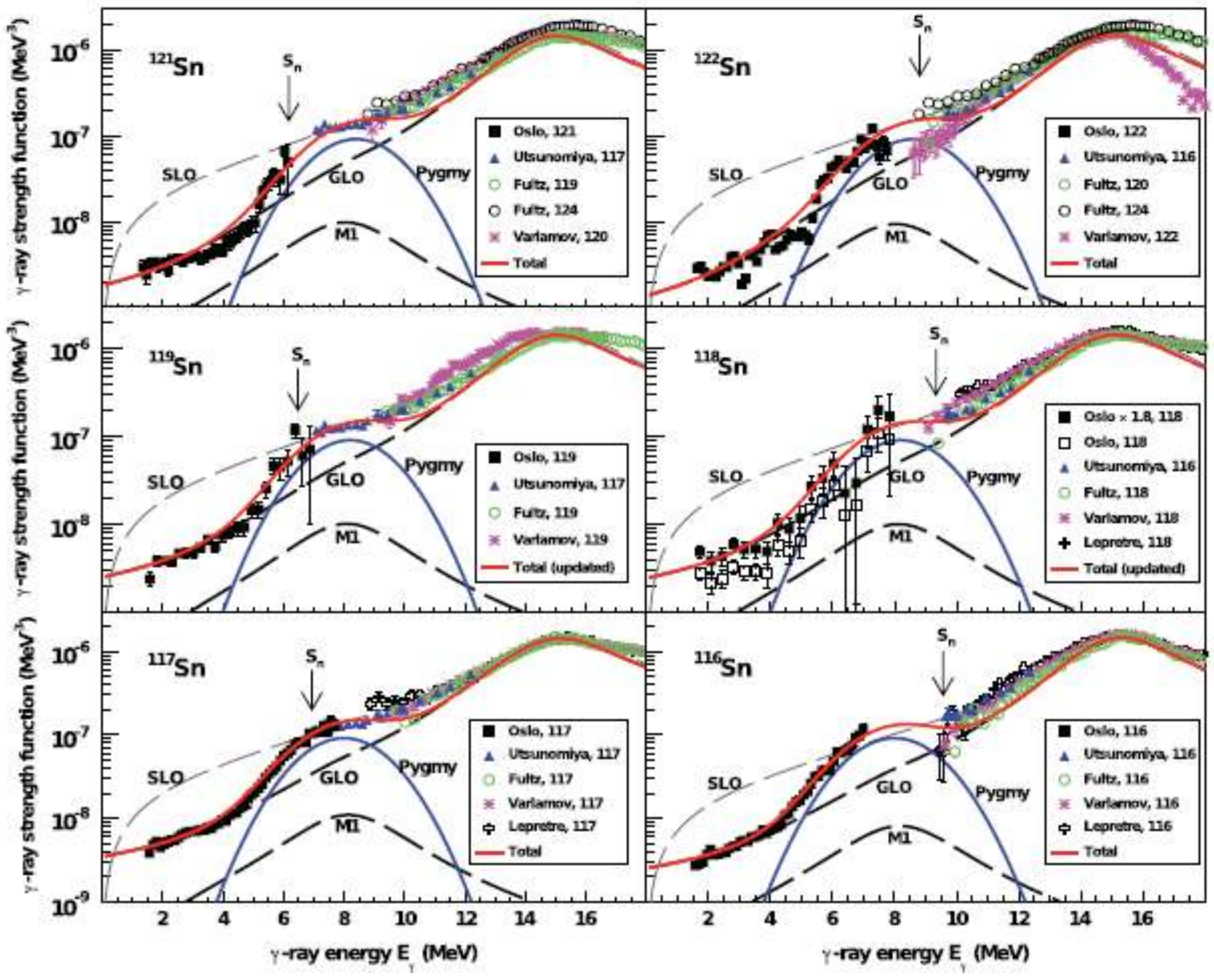


Fig. 25. Comparison of experimental data from the Oslo group (low-energy part) and other experiments with predictions for the γ-ray strength function. The inclusion of a E1 PDR around 8–8.6 MeV is necessary to explain the measured data.
Source: Reprinted figure with permission from [174].

H.K. Toft et al., PRC 83 (2011) 044320

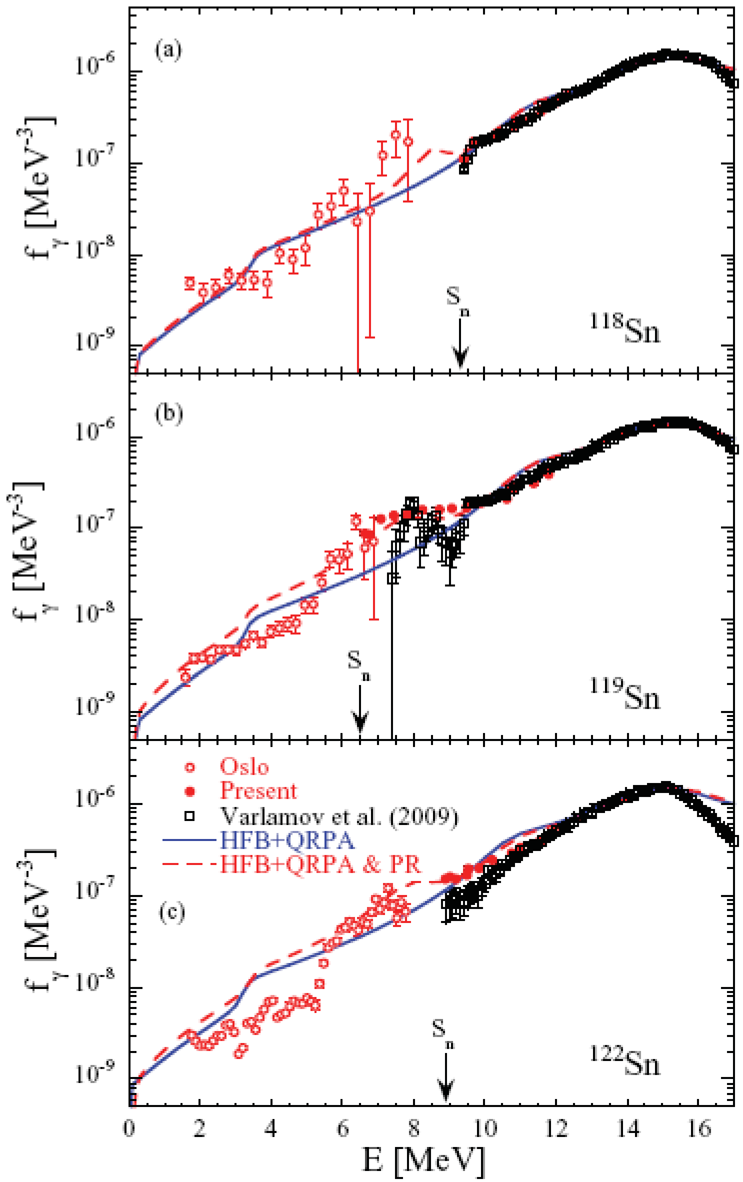


FIG. 10. (Color online) Comparison between the HFB + QRPA strength (with and without the inclusion of the PR) and the experimental data of the Oslo group [9,10], from photodata [18] as well as the present photoemission data, for ^{118}Sn (a), ^{119}Sn (b), and ^{122}Sn (c).

This is a direct evidence of necessity of taking the phonon coupling (and M1 ?) into account

Utsunomiya,Goriely et al., PRC 84, 055805(2011)

Связь с фононами учитывалась [N.Paar et al.,2007]:

1.NFT (Bohr, Mottelson Vol.2)

2. QPM model by Soloviev

3.Ka-ev, Speth, Tertychny, ETFFS[Phys.Rep.2004]

{Isaak,…,Ka-ev !,…, Phys.Rev.C83,034304 (2011) –PDR in 44Ca}

!+4. Релятивистский подход (Ring, Tselyaev, Litvinova)

Fotoabsorption cross section and strength function S are connected as follows (QPM, ETFFS):

$$\sigma(\omega) = 4.022\omega S(\omega)$$

$$S(\omega) = \frac{dB(E1)}{dE}$$

If the Brink-Axel hypothesis is correct:

$$f(E1) = \frac{1}{3(\pi hc)^2}\frac{\sigma(\omega)}{\omega} = 3.487 \cdot 10^{-7} S(\omega),$$

где S берётся в $\text{Фм}^2\text{МэВ}^{-1}$, $f(E1)$ в МэВ^{-3}

Проблемы РСФ=проблемам (ПДР + ГБА) !

Self-consistency:

1. Mean field (ground state) is determined by the first derivative of the **functional**

2. Effective pp- and ph-interactions are the second derivative of the same functional :

$$\mathcal{F}^{\xi}(\rho) = \frac{\delta^2 \mathcal{E}}{\delta \nu^2}$$

$$\mathcal{F} = \frac{\delta^2 \mathcal{E}}{\delta \rho^2},$$

- 1. Two self-consistent approaches with small number universal phenomenological parameters
- ---self-consistent mean field theories
- (beginning: parameterizing of the interaction by (usually) Skyrme forces parameters to solve HFB equations)
- ---energy density functional (EDF) theory
- (beginning: parameterizing of the functional itself)

Self-consistent extended theory of finite fermi systems (ETFFS)

contains:

1.(Q)RPA

2.Phonon coupling

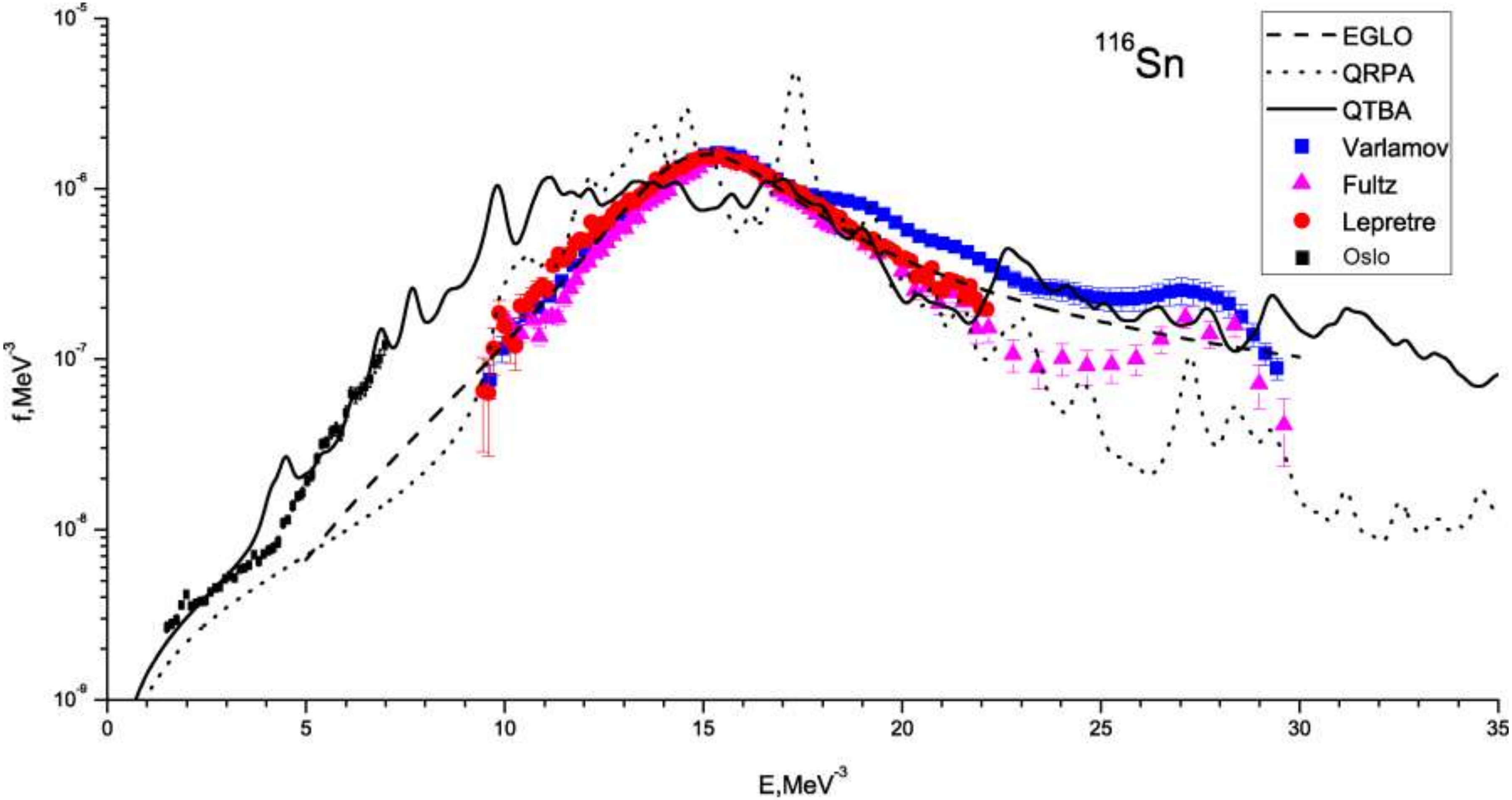
3.Single-particle continuum

and used the Skyrme forces

Features of the ETFFS microscopic approach

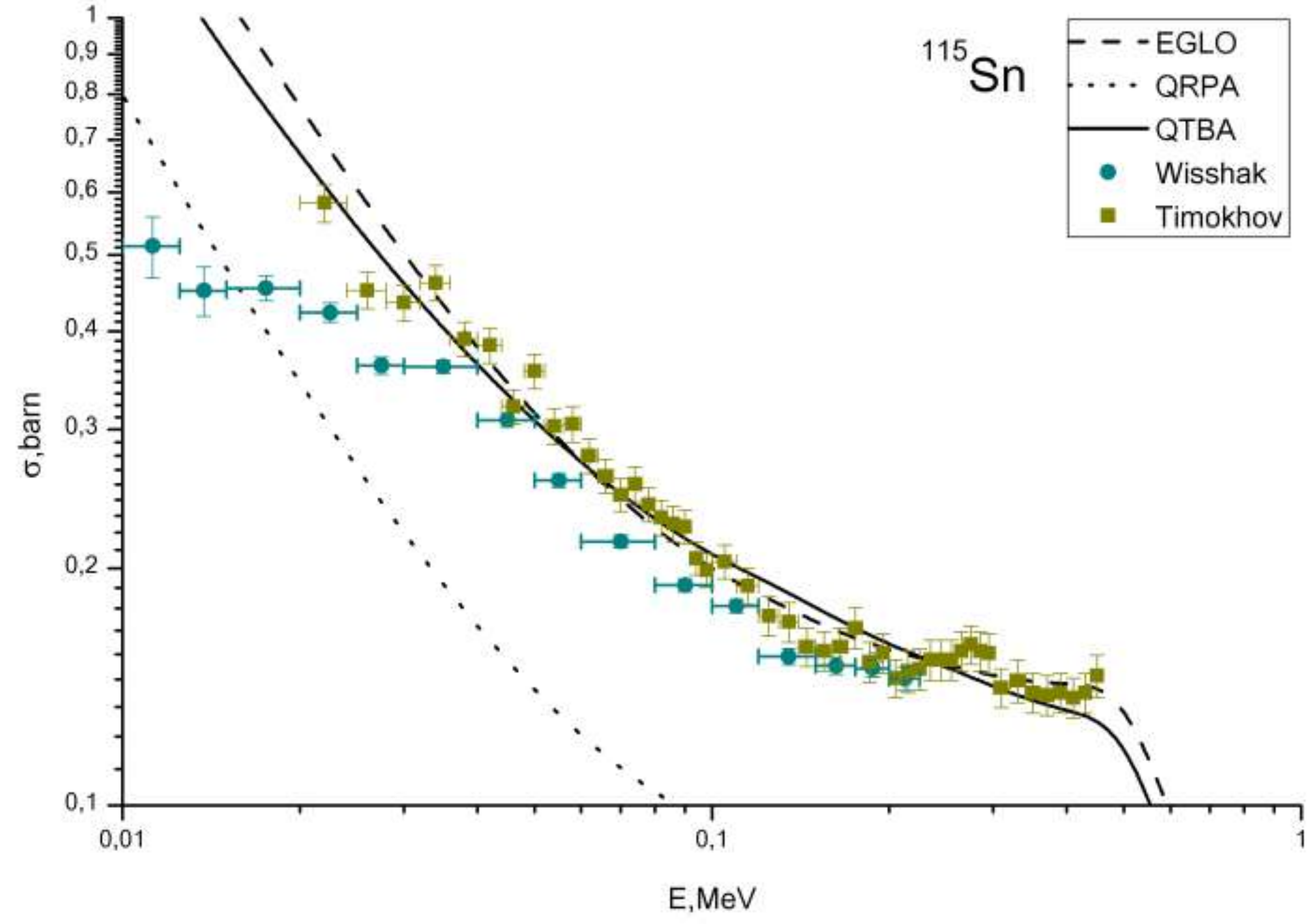
- Individual approach to each nucleus (due to single-particle scheme and , therefore, PSF structures)
- “First principle” approach (parameters of the Skyrme forces or functional are universal for all nuclei except for light ones)
- Great predictive power
- However!: much computer time and less predictive power, if all parameters are taken from experiment !

^{116}Sn PSF

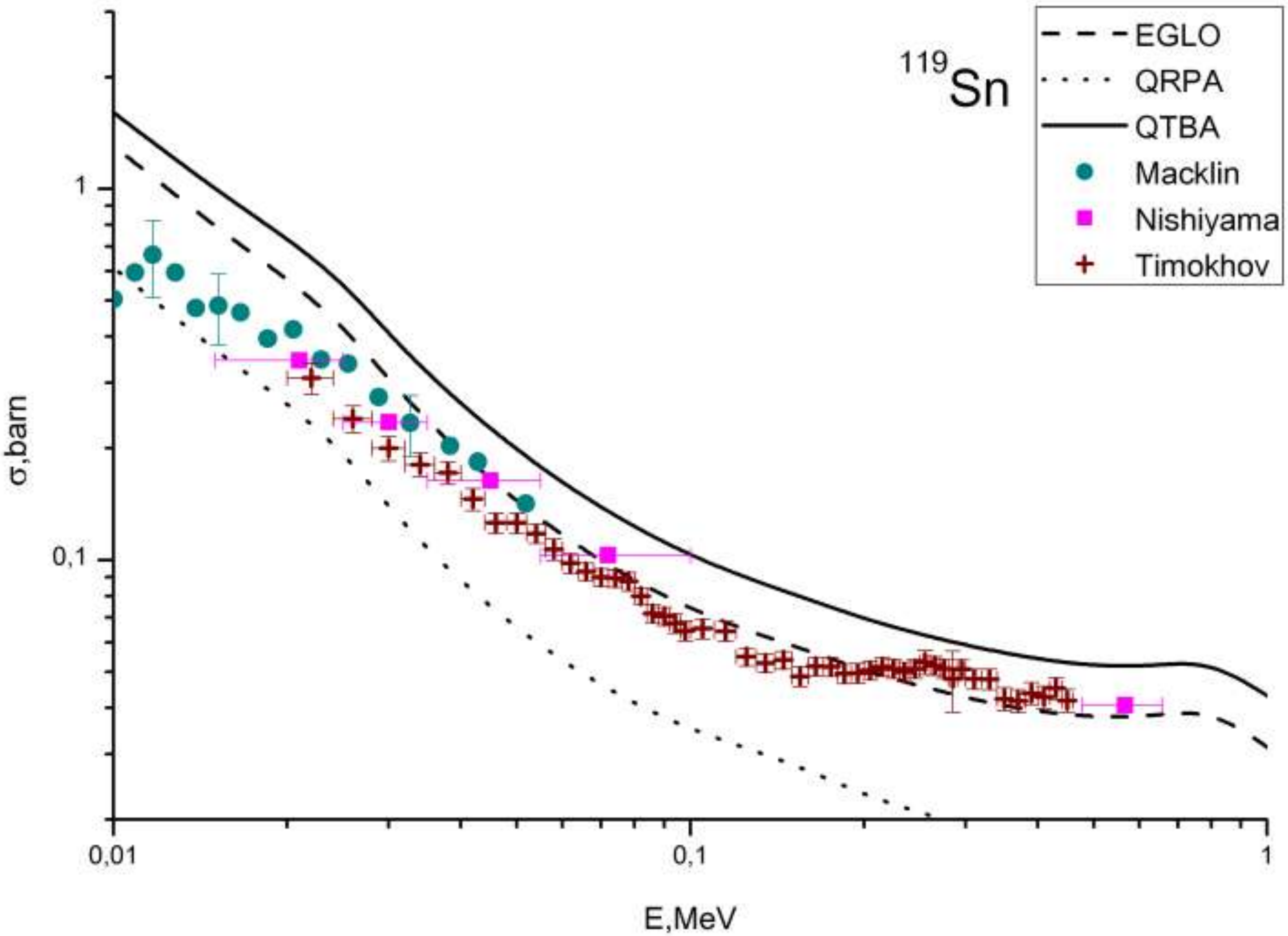


116Sn
EGLO
QRPA
QTBA
Varlamov
Fultz
Lepretre
Oslo
f,MeV-3
E,MeV-3
10-5
10-6
10-7
10-8
10-9
0
5
10
15
20
25
30
35

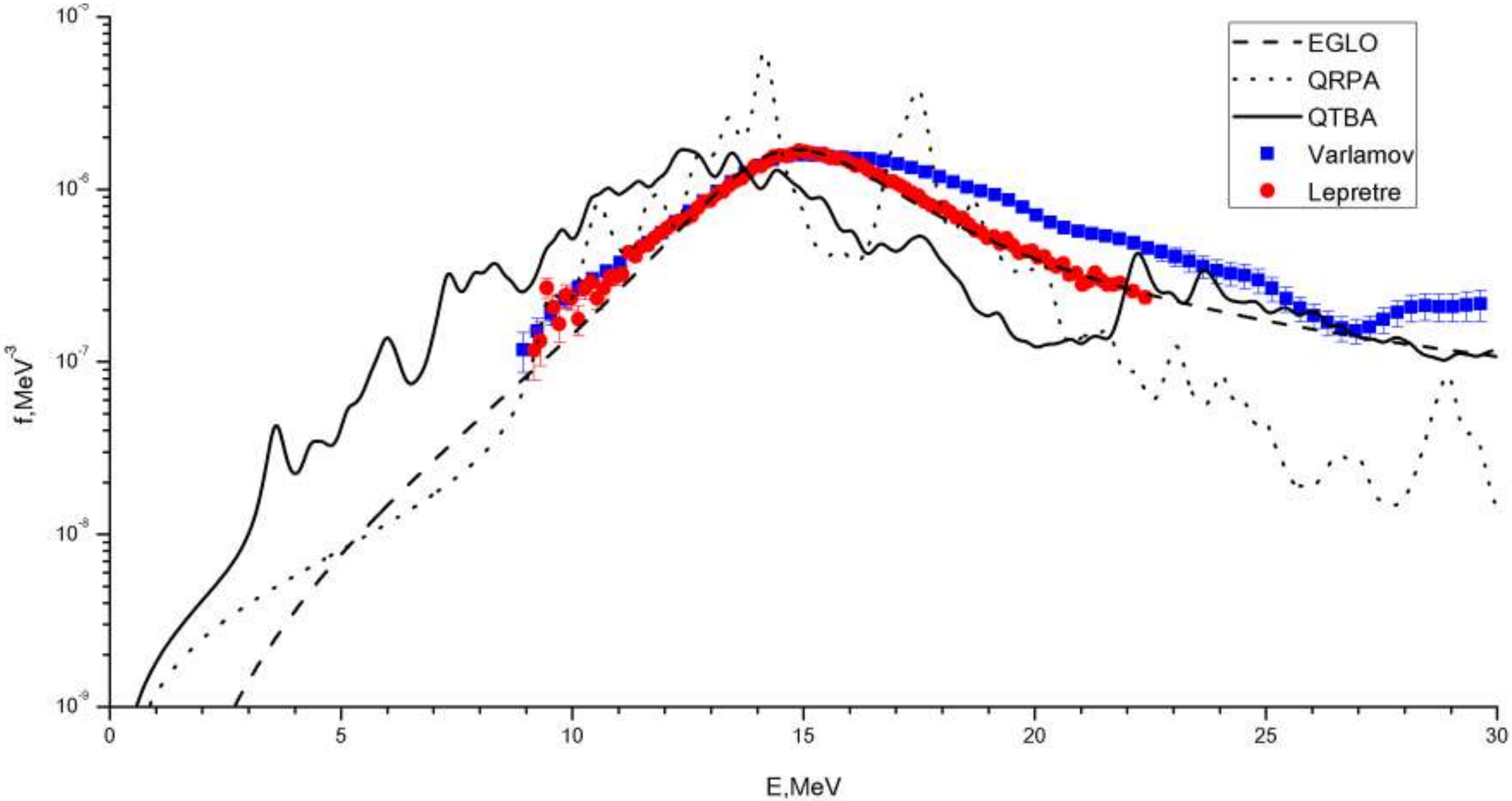
^{115}Sn(n,gamma) cross section [EMPIRE3.1]



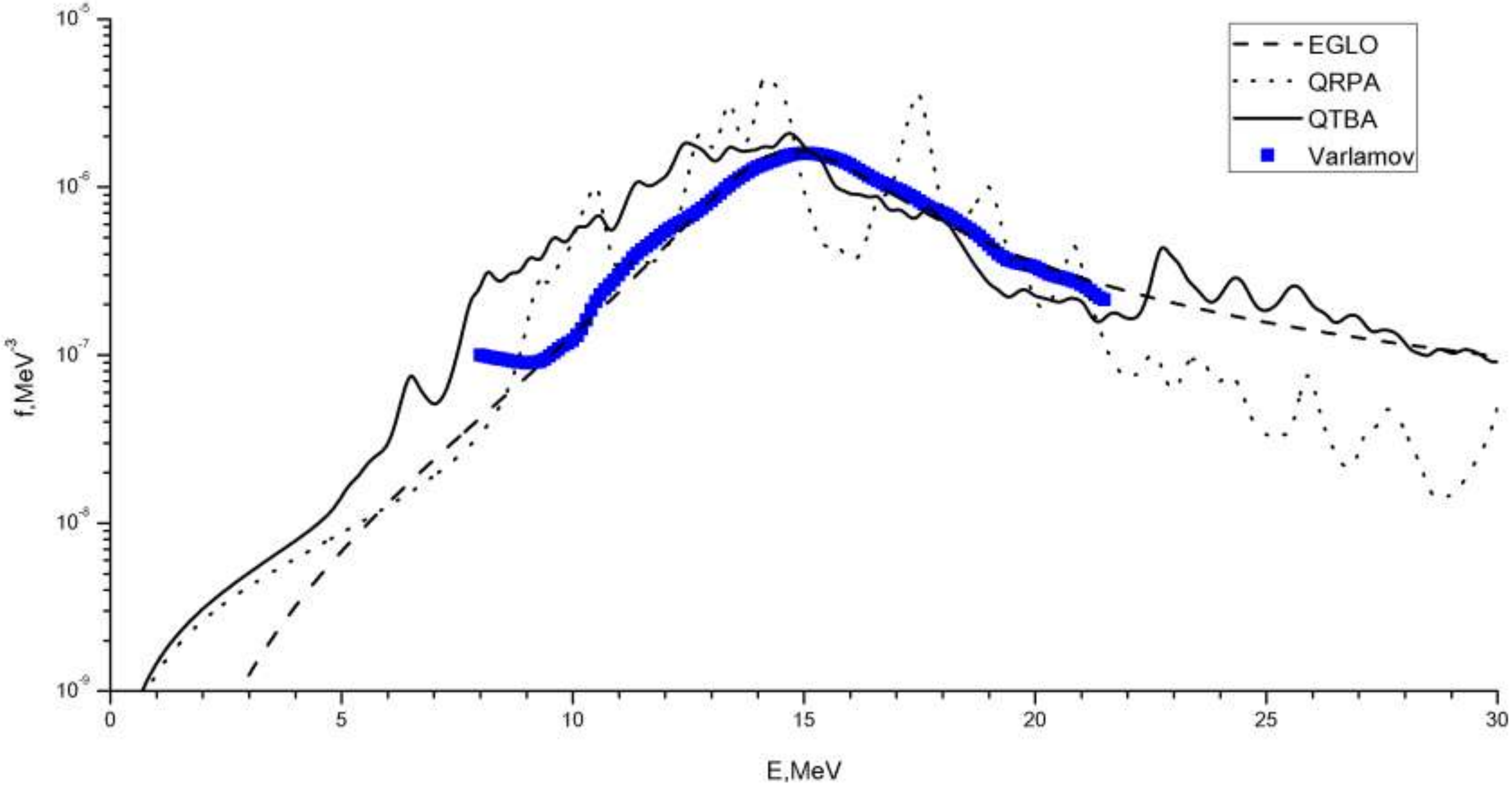
^{119}Sn(n,gamma) cross section[EMPIRE3.1]



^{120}Sn PSF



^{124}Sn PSF



EGLO
QRPA
QTBA
Varlamov
f,MeV^{-3}
E,MeV
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
0
5
10
15
20
25
30

^{68}Ni PSF

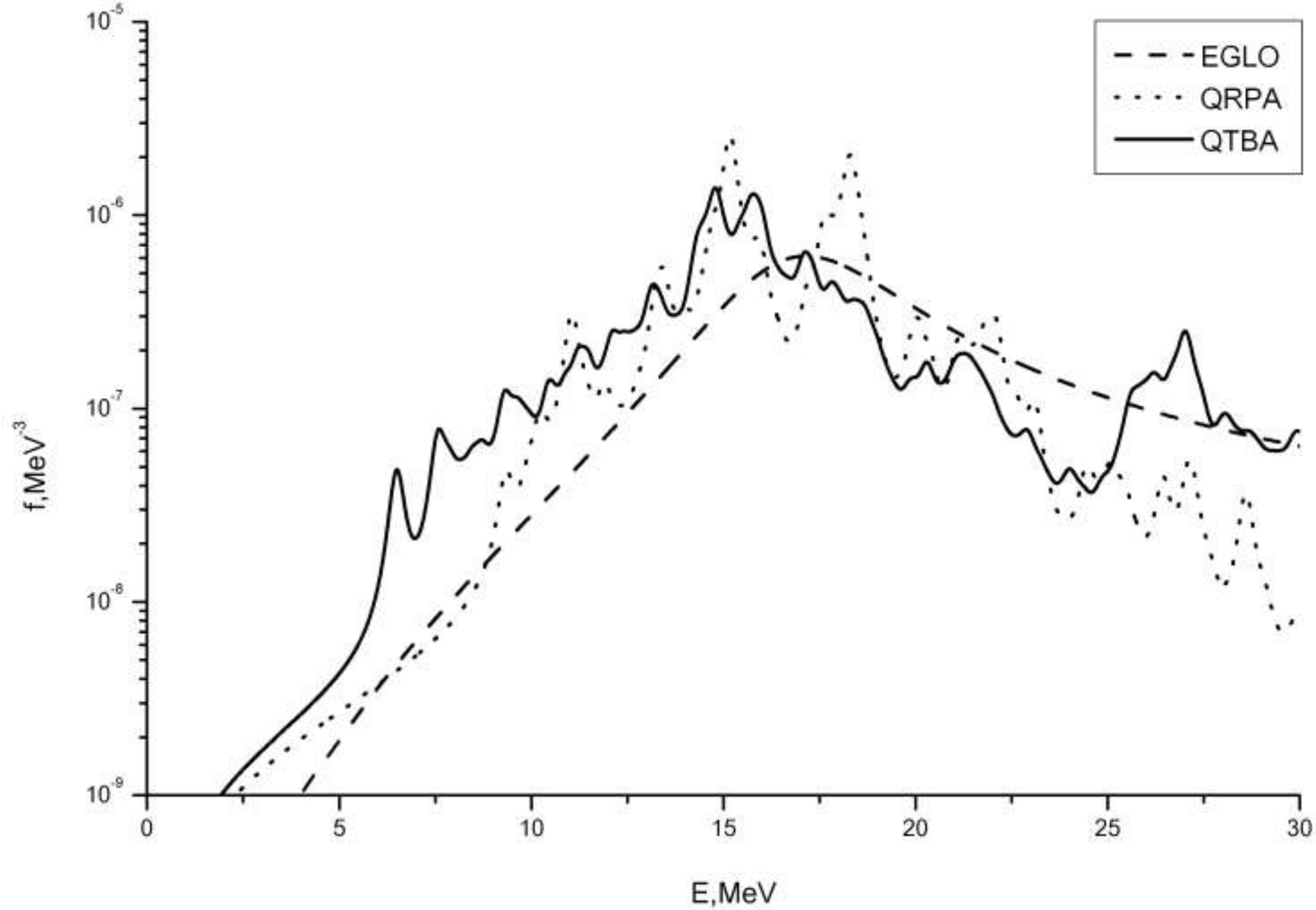
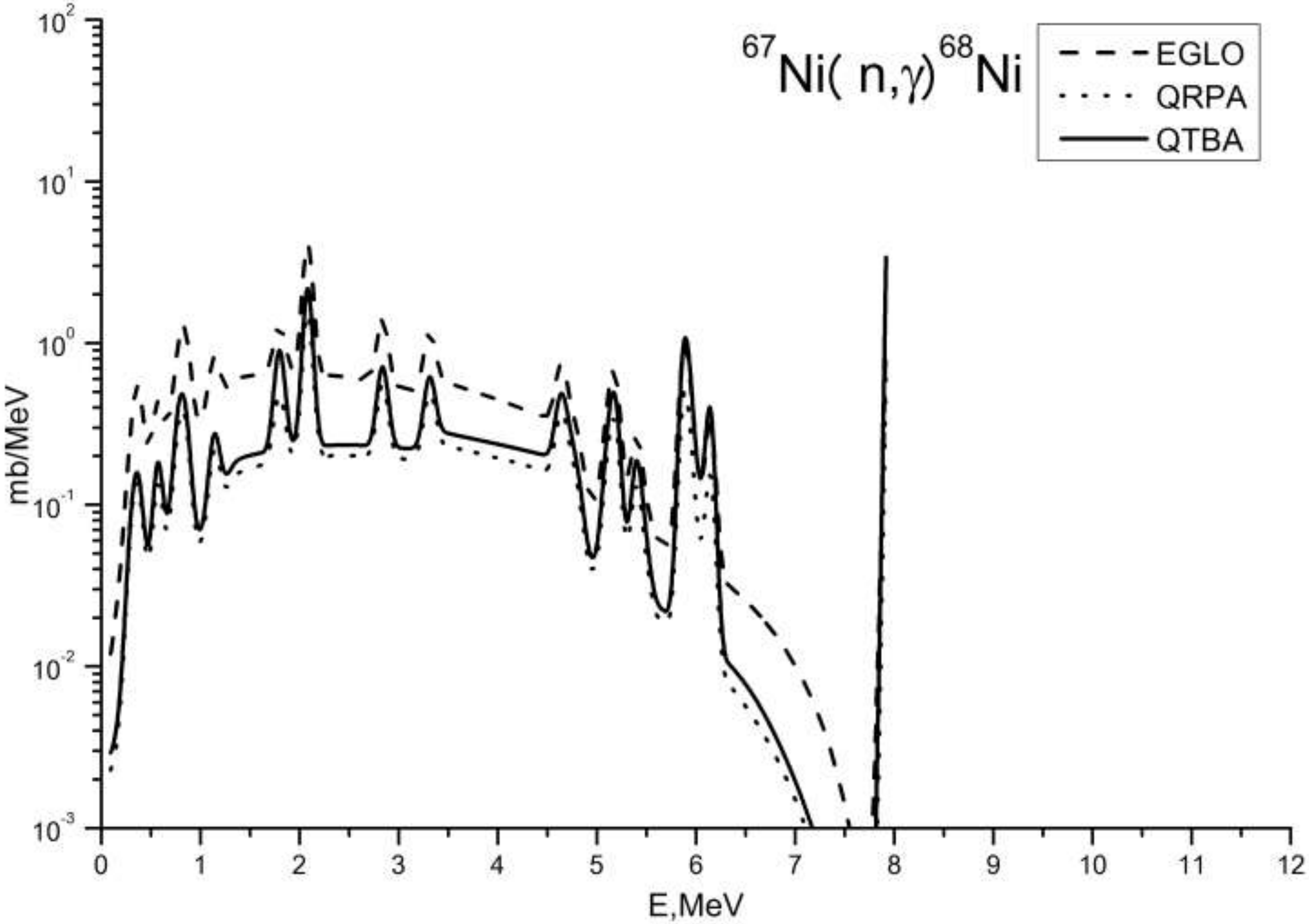


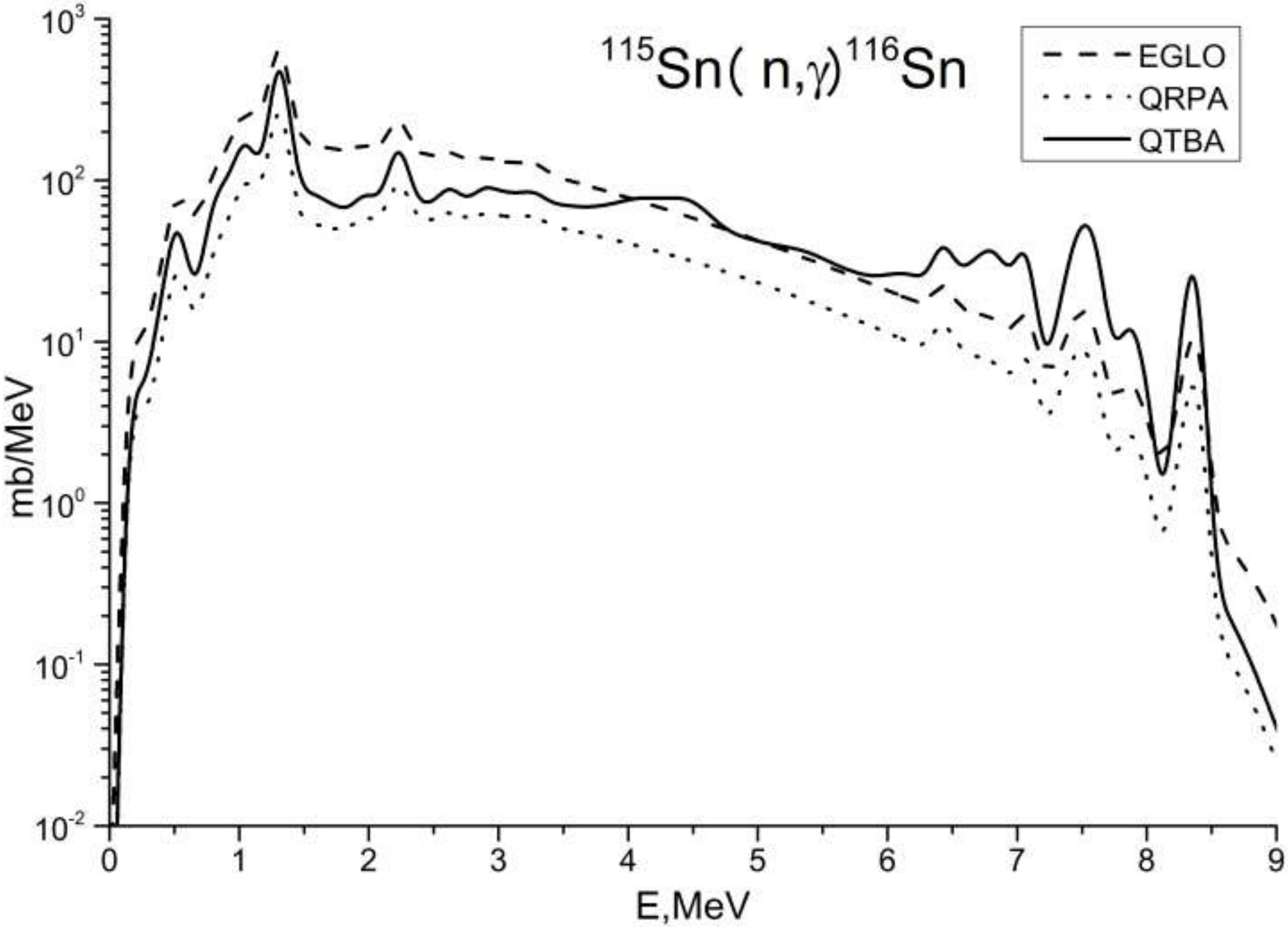
Таблица 1. Интегральные характеристики гигантского $E1$ и пигми-дипольного резонансов в рассчитанные без учёта (QRPA) и с учётом связи с фононом (ОТКФС (КПВБ)) по формулам (1)-(2) для двух вариантов сил Скирма

Силы	Интервал (0-30) МэВ				Интервал (7-13) МэВ			
	QRPA		ОТКФС (КПВБ)		QRPA		ОТКФС (КПВБ)	
	$\langle E \rangle$, МэВ	D, МэВ	$\langle E \rangle$, МэВ	D, МэВ	$\langle E \rangle$, МэВ	%	$\langle E \rangle$, МэВ	%
$SLy4$	17.48	1.66	18.54	3.97	11.0	4.85	10.75	8.73
$BSk17$	17.82	1.92	19.03	4.38	10.24	5.32	10.28	6.85
Эксперимент	[36]		18.1 (5)	6.1 (5)	[36]		10.4 (4)	4.1 (1.9)
					[35]		≈11	≈5

Capture gamma-ray spectra



See Poster of Achakovskiy et al.



$^{115}Sn(n,\gamma)^{116}Sn$
EGLO
QRPA
QTBA
mb/MeV
E,MeV
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
0
1
2
3
4
5
6
7
8
9

Average radiative widths for ^{116}Sn:

Preliminary [A.Suchovoy]

$\Gamma\gamma$=45.1meV(QRPA)

=120.4meV(QTBA)

(<D>=25eV,level density model-back shift fermi gas)

Conclusion

1. Microscopic approach gives structures caused by both the QRPA and PC effects.

2. It is able to predict PSF in unstable nuclei

3. Phonon coupling in E1 PSF is necessary ! (M1 ?)

4. As a rule, the QTBA results are in a better agreement with EGLO than with the QRPA values. This fact confirms the necessity of phonon coupling too.