On microscopic theory of radiative nuclear reaction characteristics

S. Kamerdzhiev[1], O. Achakovskiy[2], A. Avdeenkov[2], S. Goriely[3]

1. *Institute for Nuclear Power Engineering, Obninsk, Russia*
2. *Institute for Physics and Power Engineering, Obninsk, Russia*
3. *Institut d`Astronomie et d`Astrophysique, ULB, Brussels, Belgium*

Microscopic approach uses nuclear effective forces to calculate self-consistently:

1. Ground state characteristics (HFB mean field)
2. Nuclear excitations (HFB mean field, QRPA and QRPA+phonon coupling)
3. Nuclear reaction characteristics with HFB **NLD models and microscopic PSFs** using the same parameters for effective forces (Skyrme, Gogny) or for the energy functional (Fayans).

Microscopy means a high predictive power which is necessary for astrophysics and new facilities !

Plan

1.Microscopic photon strength functions (PSF)

1.1 Phenomenological approaches

1.2.Recent experiments (Oslo method, Utsunomia; **Ni, Mo**)

1.3.Self-consistent calculations of PSF

1.4. EMPIRE and TALYS calculations of:

- neutron capture cross sections,
- neutron capture gamma-ray spectra
- average radiative widths and

<u>using the microscopic PSF's and NLD with the known Skyrme forces with parameters universal for all nuclei</u>

2.Microscopic nuclear level density (NLD) models

Self-consistency:

1. Mean field (ground state) is determined by the first derivative of the **energy density functional**
2. Effective pp- and ph-interactions are the second derivative of the same functional :

$$\mathcal{F} = \frac{\delta^2 \mathcal{E}}{\delta \rho^2} \qquad \mathcal{F}^{\xi} = \frac{\delta^2 \varepsilon}{\delta \nu^2}$$

3. This effective interactions are used for calculations of nuclear excitations

(No new or fitted parameters in calculations! Therefore, a high predictive power)

Features of the self-consistent approach

- Individual approach to each nucleus due to its single-particle and phonon spectra

  Therefore, the PSF structures must exists !
- “First principle” approach (parameters of the Skyrme forces or functional are universal for all nuclei except for light ones)
- High predictive power

- However!: much computer time and, in general, **less accurate** as compared with the case when all parameters are taken from experiment (mainly for stable nuclei <u>while astrophysics needs info for all (8500?) nuclei !)</u>

The PSF f(E1) and appropriate nuclear data businesses are based on the Brink-Axel hypothesis.

If the Brink-Axel hypothesis (BAH) is correct:

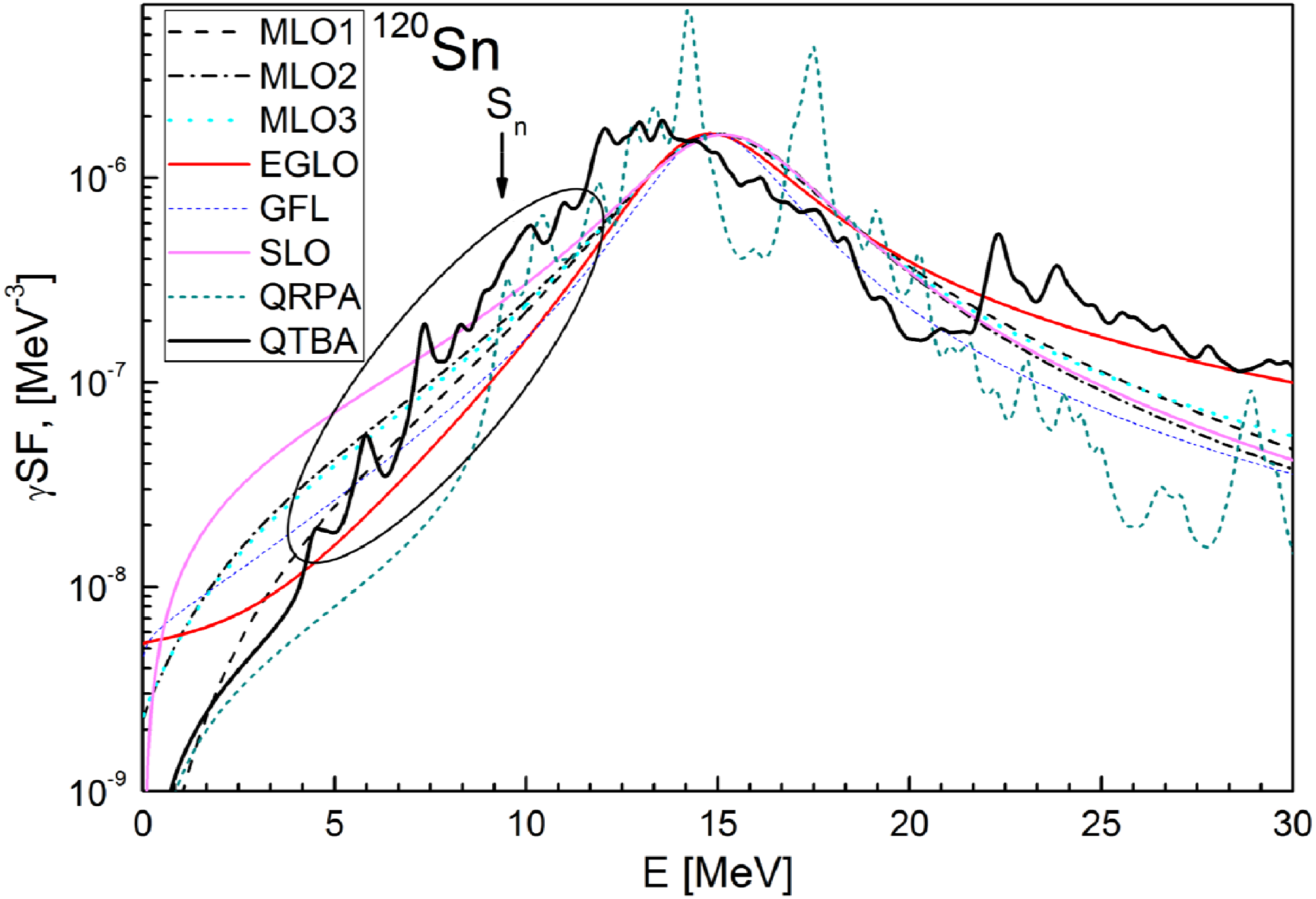
$$f(E1) = \frac{1}{3(\pi hc)^2}\frac{\sigma(\omega)}{\omega} = 3.487 \cdot 10^{-7} S(\omega),$$

where the E1 photoabsorption cross section is in mb and S is taken in $fm^2 MeV^{-1}$, $f(E1)$ in MeV^{-3}

$$\sigma(\omega) = 4.022\omega S(\omega) \quad S(\omega) = \frac{dB(E1)}{dE}$$

Thus, problems of PSF are problems of Pygmy- and Giant-Dipole Resonances + BAH (PDR , GDR+ BAH) !

Photon strength functions:
phenomenology vs. microscopy (QRPA and QTBA = QRPA+Phonon Coupling give structures !)



Reference Input Parameters Library (RIPL2, 2006):

„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. **„This approach lacks reliability when dealing with exotic nuclei.“** 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.

For these reasons, in RIPL2, RIPL3 appeared Microscopic approach based on the HFB+QRPA method of S. Goriely.

However it is not enough! Necessary to add phonon coupling effects

Proof of phonon coupling necessity

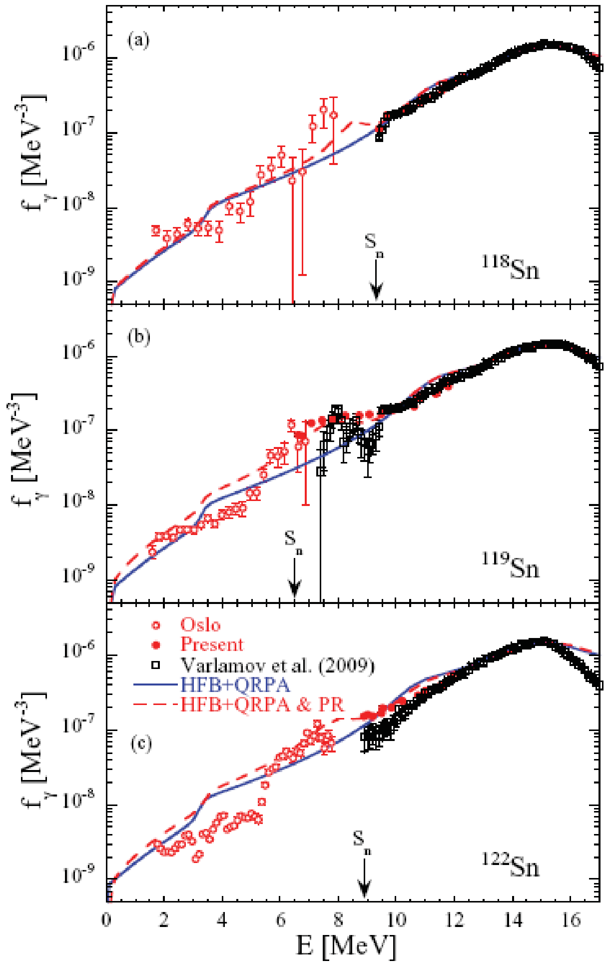


FIG. 10. (Color online) Comparison between the HFB + QRPA strength (with and without the inclusion of the PR) and the experimental data of the Oslo group [9,10], from photodata [18] as well as the present photoemission data, for ^{118}Sn (a), ^{119}Sn (b), and ^{122}Sn (c).

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

This is a direct evidence of necessity of accounting for the phonon coupling, in addition to QRPA, for description of PDR

Phonon coupling has been taken into account in, see review [N.Paar et al.,2007]:

Non self-consistent approaches:

1.NFT (Bohr, Mottelson Vol.2)

2. QPM model by Soloviev et al.

3.Kamerdzhiev, Speth, Tertychny, ETFFS[Phys.Rep.2004]

Self-consistent approaches:

4.Self-consistent ETFFS(QTBA) (Avdeenkov, Kamerdzhiev, Tselyaev)

5. Relativistic QTBA (Ring, Tselyaev, Litvinova)

Self-consistent Extended Theory of Finite Fermi Systems in the QTBA approximation

ETFFS(QTBA), or simply QTBA, contains:

1. (Q)RPA
2. Phonon coupling
3. Single-particle continuum

and uses the known Skyrme forces SLy4

No new parameters !

Our major works (microscopic photon strength functions within the self-consistent QRPA +PC):

- S. Kamerdzhiev, J. Speth, and G. Tertychny, Phys. Rep. **393**, 1 (2004).
- V. Tselyaev Phys. Rev. C **75**, 024396 (2007)

- A. Avdeenkov, S. Goriely, S. Kamerdzhiev and S. Krewald, Phys. Rev. C **83**, 064316 (2011).
- S. P. Kamerdzhiev, A. V. Avdeenkov, and O. I. Achakovskiy, Phys. At. Nucl. **77**, 1303 (2014).

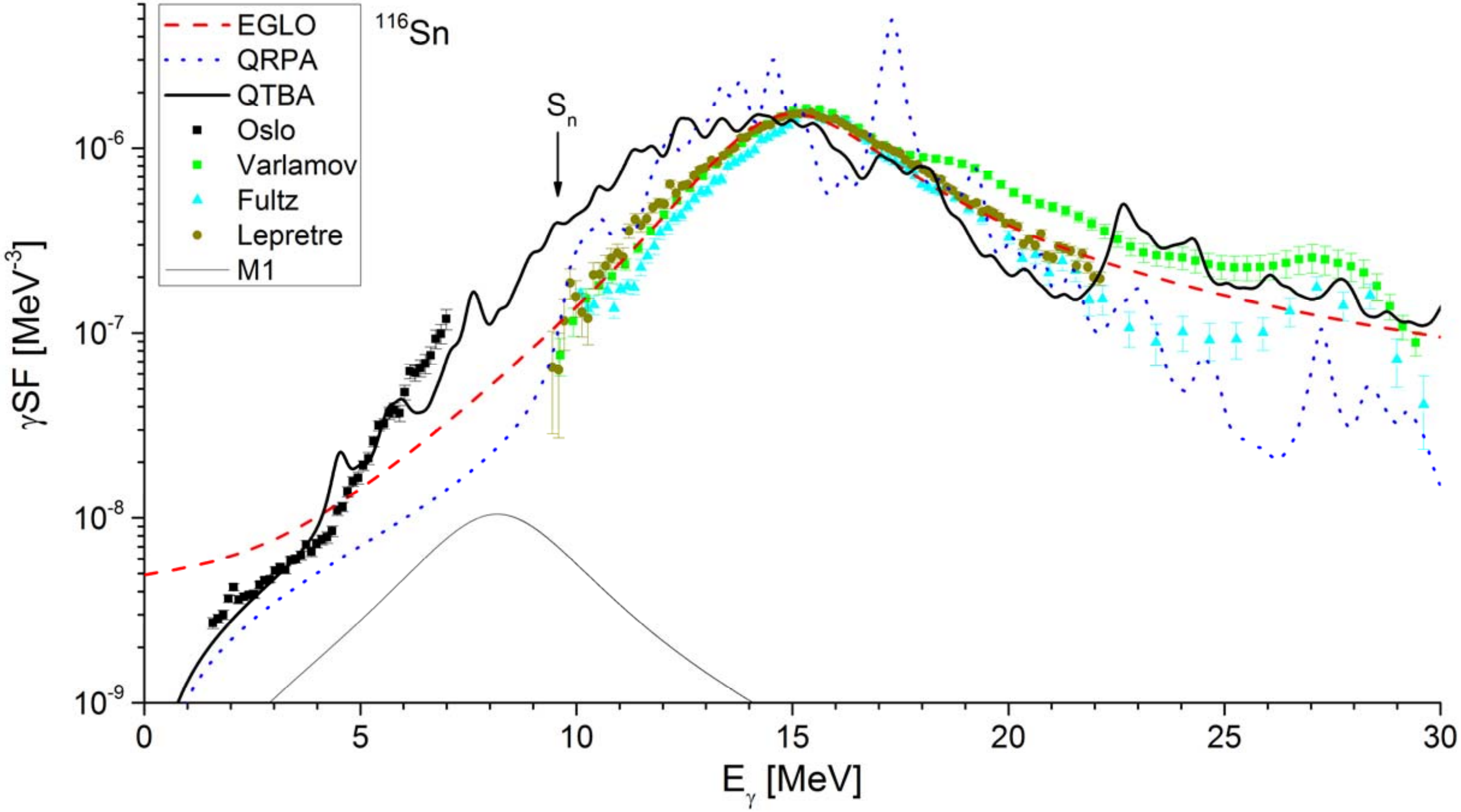
- **O.Achakovskiy, A. Avdeenkov, S. Kamerdzhiev, D. Voitenkov Proc. Intern. Seminar on Interaction of Nuclei with Nucleons, ISINN22, Dubna, 27-30.05.2014. P.207-212 and P.213-219**

- **O.Achakovskiy, A. Avdeenkov, S. Goriely *et al.*, Phys. Rev. C 91, 034620 (2015)**

- **Kamerdzhiev *et al.*, JETP Lett., 101, 819 (2015)**

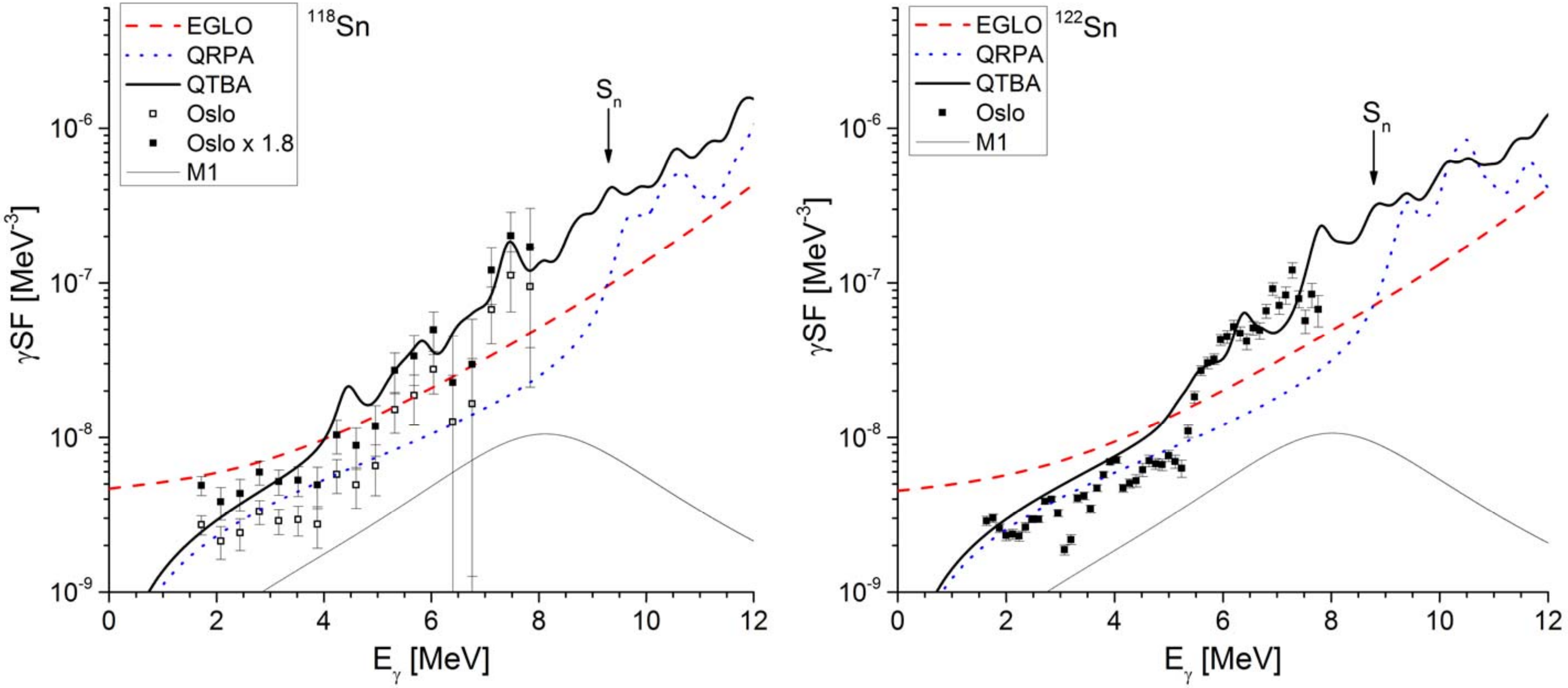
3.Self-consistent calculations :

^{116}Sn PSF (the smoothing parameter is 200 keV)



Exp. data: H. K. Toft *et al.,* PRC **81**, 064311 (2010); Varlamov *et al.,* Vop. At. Nauki i Tekhn., Ser. Yad. Kons. 1-2 (2003); Fultz *et al.,* Phys. Rev. **186**, 1255 (1969); Lepretre *et al.,* Nucl. Phys. A**219**, 39 (1974);

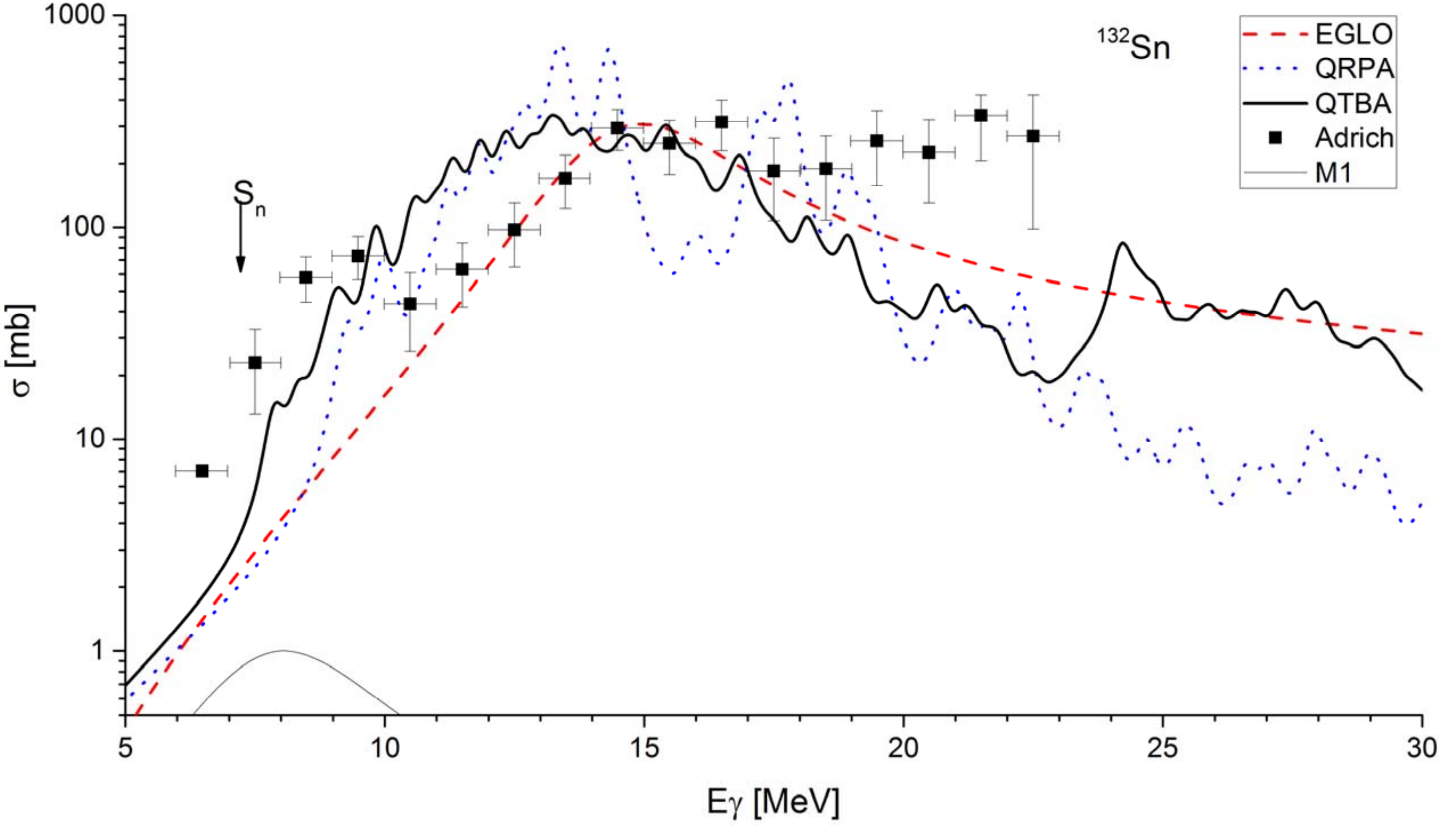
^{118}Sn and ^{122}Sn PSF



An agreement with experimental data at E>5 MeV is only due to PC

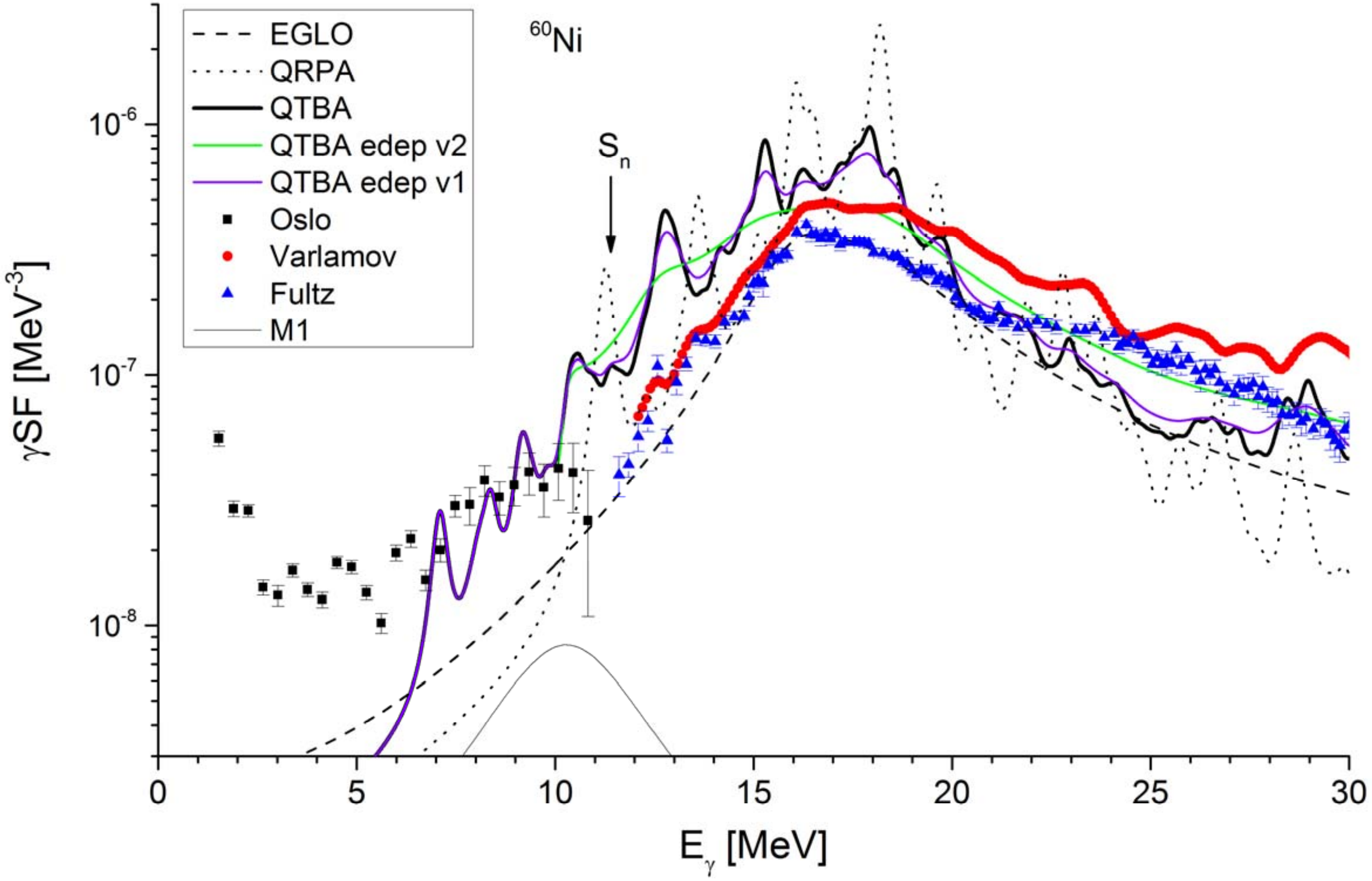
Exp. data: H. K. Toft *et al.,* PRC**81**, 064311 (2010); H. K. Toft *et al.,* PRC**83**, 044320 (2011)

Photoabsorption for double-magic ^{132}Sn



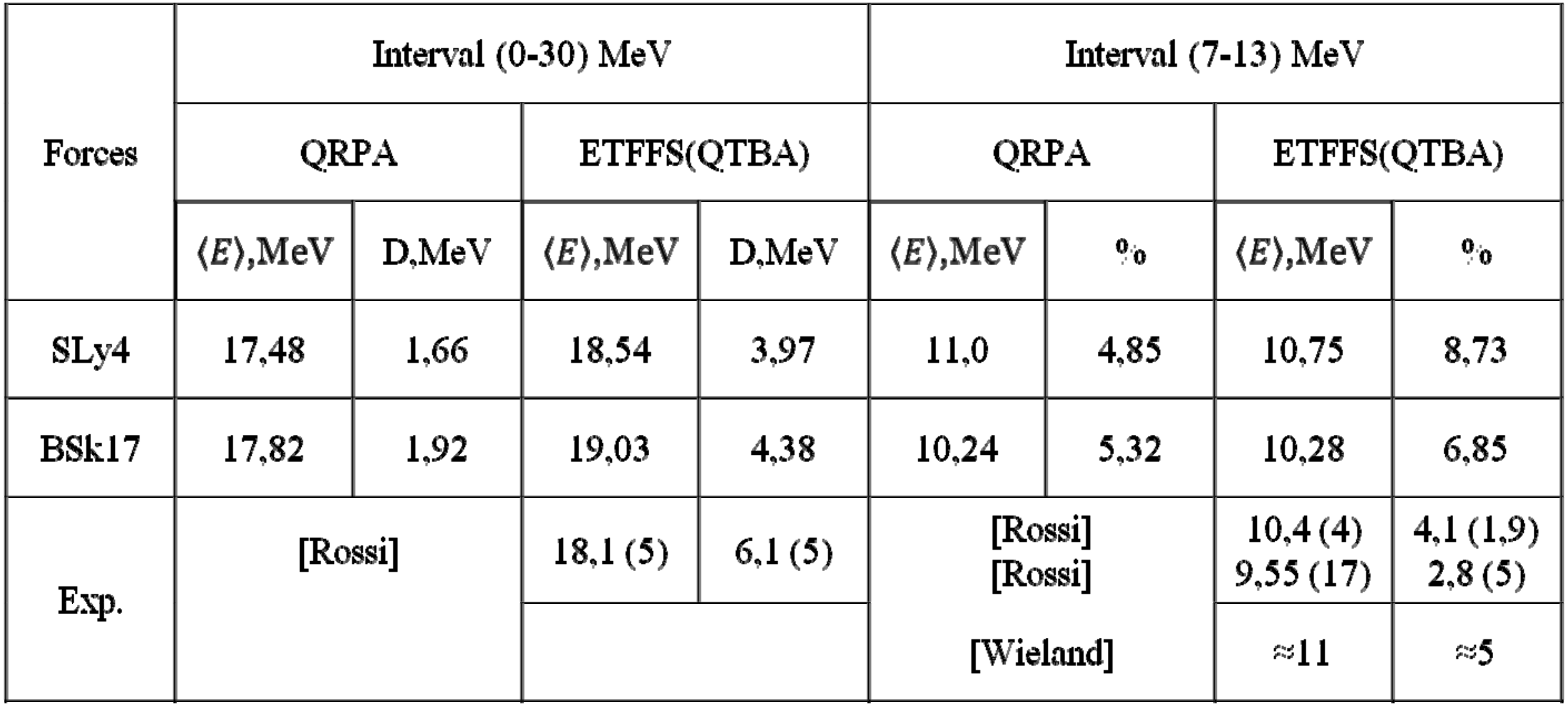
Exp. data: P. Adrich *et al.,* PRL **95**, 132501 (2005)

^{60}Ni PSF (Skyrme SLy5)



Exp. data: ; V. Varlamov et al., J. Izv., 67, 656, 2003; Fultz et al. PRC 10 608 7408

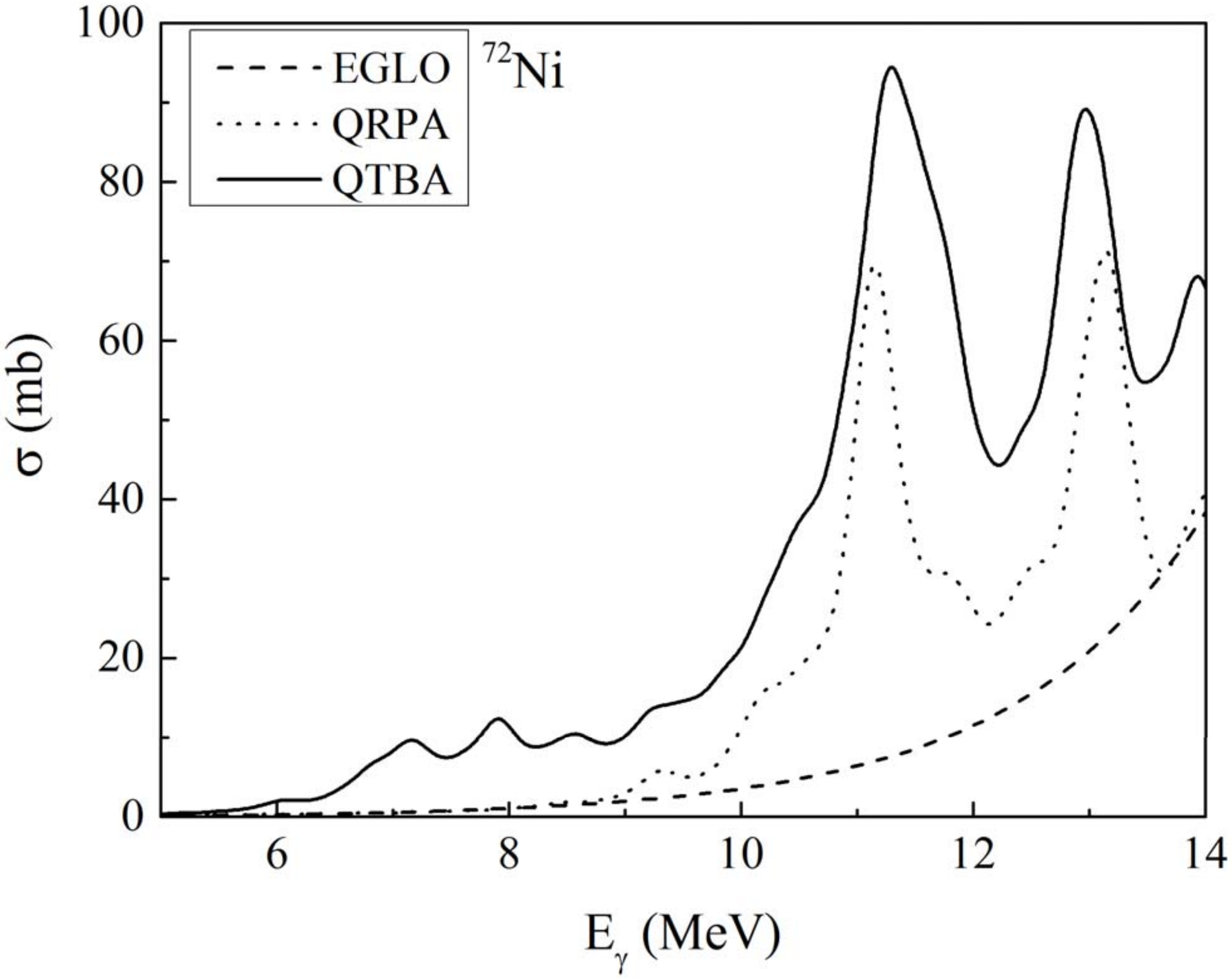
Integral characteristics of GDR and PDR in ^{68}Ni



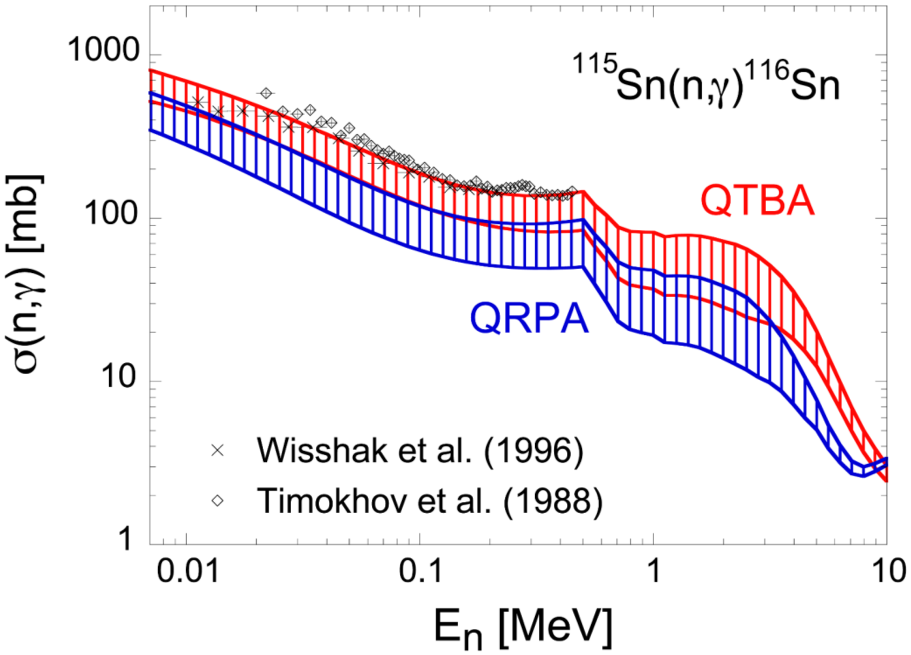
Forces	Interval (0-30) MeV				Interval (7-13) MeV			
	QRPA		ETFFS(QTBA)		QRPA		ETFFS(QTBA)	
	$\langle E \rangle$,MeV	D,MeV	$\langle E \rangle$,MeV	D,MeV	$\langle E \rangle$,MeV	%	$\langle E \rangle$,MeV	%
SLy4	17,48	1,66	18,54	3,97	11,0	4,85	10,75	8,73
BSk17	17,82	1,92	19,03	4,38	10,24	5,32	10,28	6,85
Exp.	[Rossi]		18,1 (5)	6,1 (5)	[Rossi] [Rossi]		10,4 (4) 9,55 (17)	4,1 (1,9) 2,8 (5)
					[Wieland]		≈11	≈5

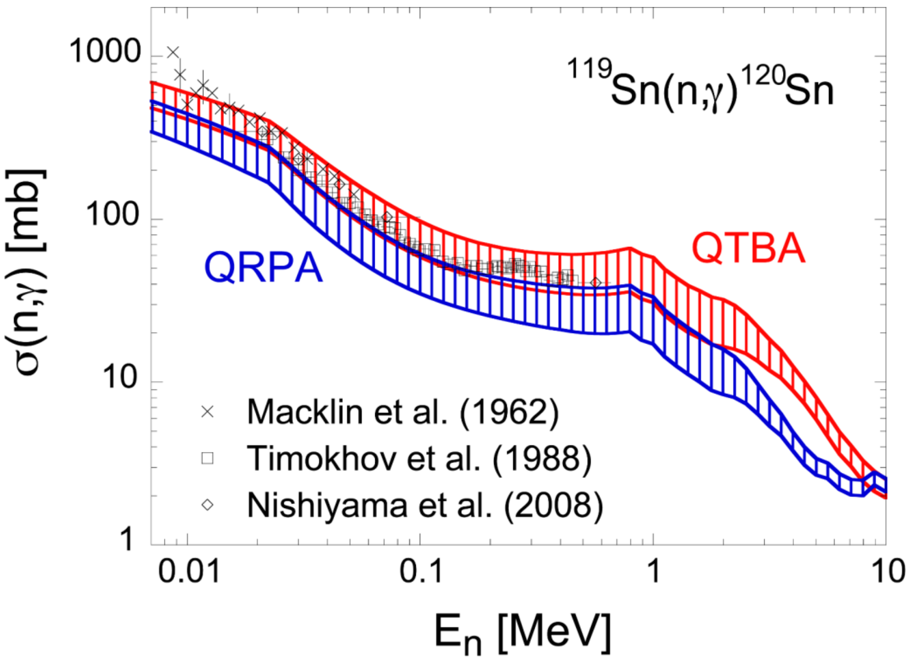
Exp. data: O. Wieland *et al.,* PRL **102**, 092502 (2009); D. M. Rossi *et. al.,* J. Phys. Conf. Ser. **420**, 012072 (2013); D. M. Rossi *et. al.,* J. Phys. Conf. Ser. **420**, 012072 (2013); D. M. Rossi *et. al* PRL**111**, 242503 (2013)

Predictions of PDR in ^{72}Ni: 14.7 MeV; 25.7% EWSR (!) (in the interval (8-14)MeV)



4.TALYS calculations of neutron capture cross sections (S.Goriely)





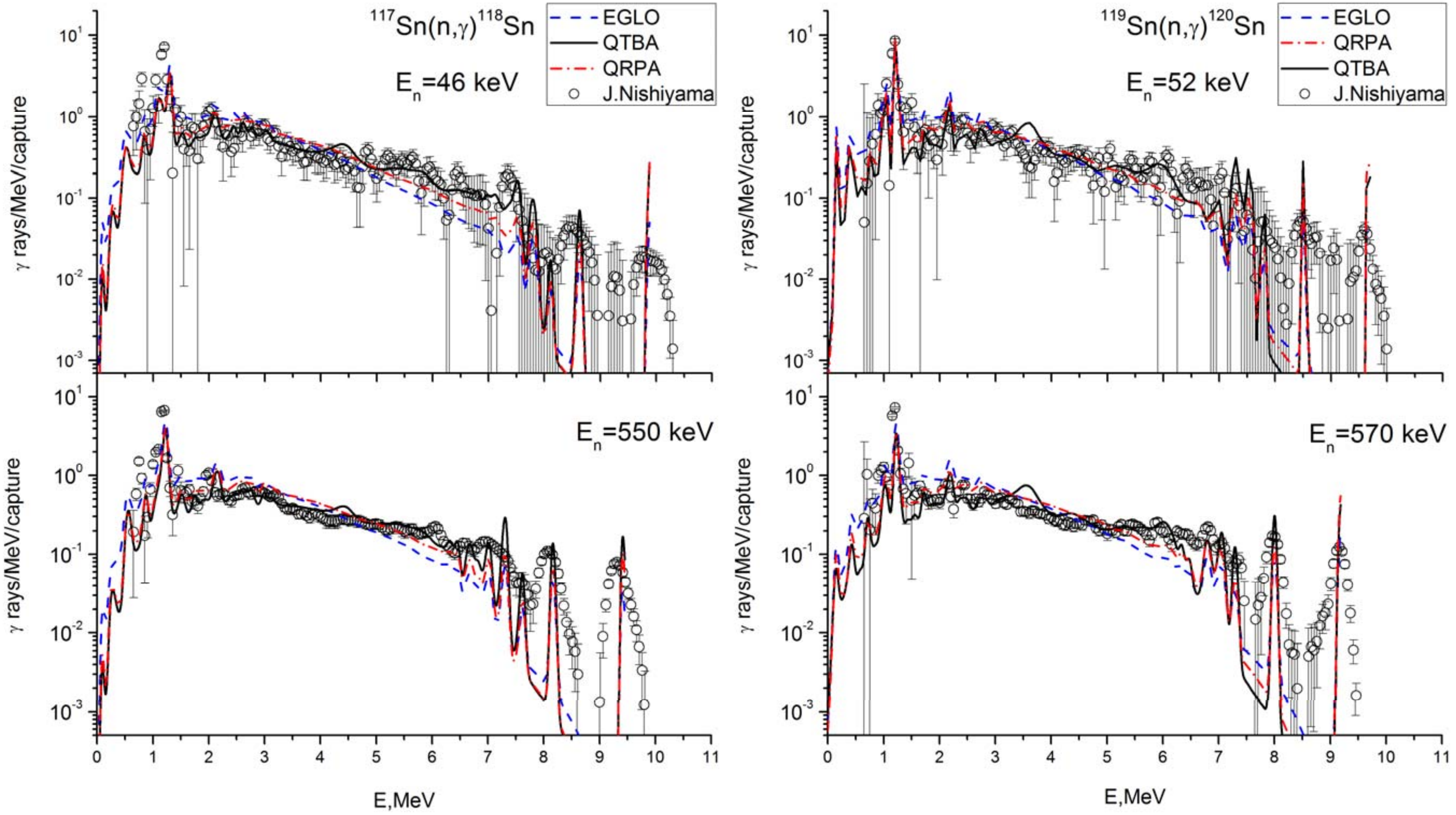
Uncertainty band is due to different NLD’s:

- BSFG (A. J. Koning, S. Hilaire, and S. Goriely, Nucl. Phys. A **810**, 13 (2008)
- GSM (RIPL2)
- HFB+Combinat.NLD(S. Goriely, *et al.,* PRC **78**,064307 (2008))
- HFB+Combinat.NLD (S. Hilaire, M. Girod, S. Goriely, and A. J. Koning, Phys. Rev. C**86**, 064317 (2012))

The agreement with experiment is possible only due to the PC effect

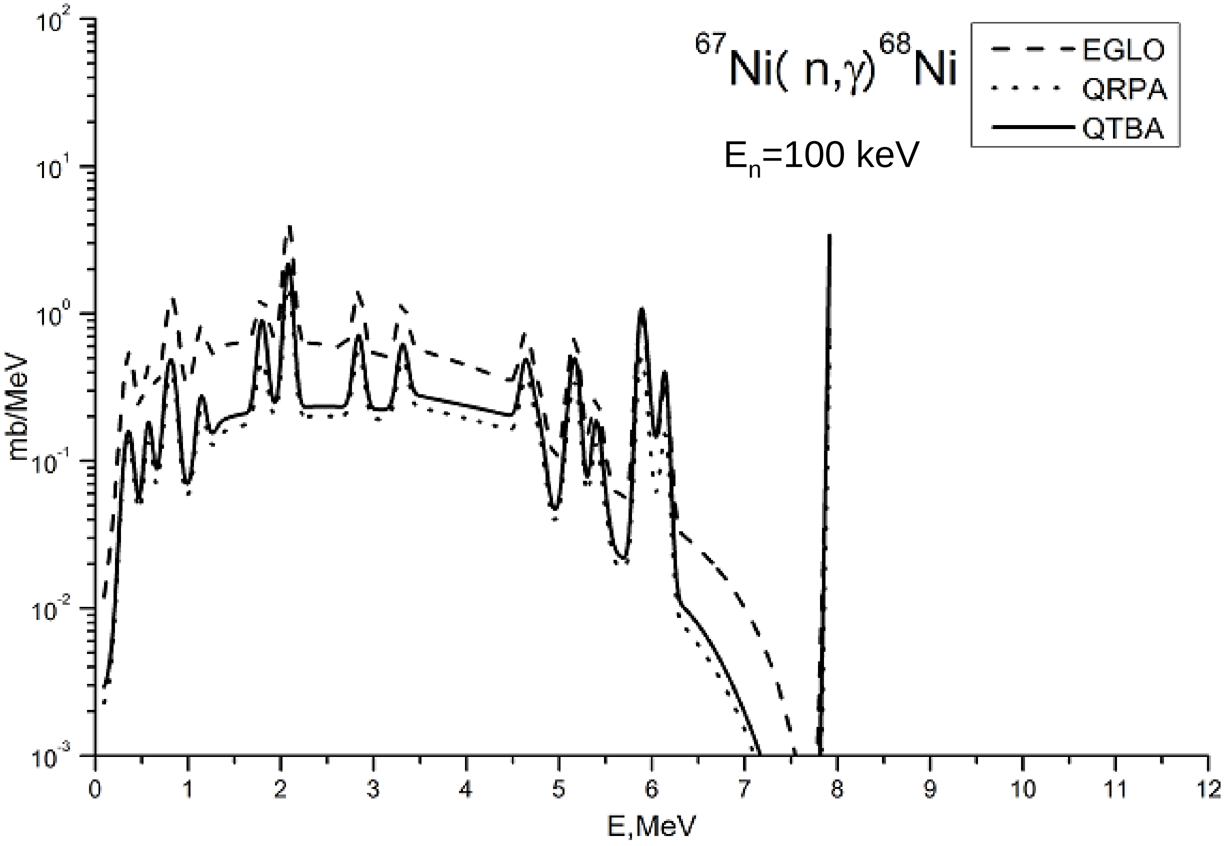
Capture gamma-ray spectra

NLD model is HFB+combinatorial model (S. Goriely, *et al.,* PRC **78**, 064307 (2008))



Exp. data: J.Nishiyama *et al.*, J. Nucl. Sci. Technol. (Tokyo) **45**, 352 (2008)

Capture gamma-ray spectra for ^{68}Ni



NLD model for this case is also HFB+combimatorial model

There is big difference between phenomenological (EGLO) and microscopical (QRPA and QTBA) models since ^{68}Ni is neutron rich nucleus

Average radiative widths

$$\Gamma_\gamma\left(I_t \pm \tfrac{1}{2}, \Pi_t\right) = \frac{1}{2\rho\left(B_n, I_t \pm \frac{1}{2}, \Pi_t\right)} \int_0^{B_n} d\varepsilon_\gamma \varepsilon_\gamma{}^3 \left(f_{E1}(\varepsilon_\gamma) + f_{M1}(\varepsilon_\gamma)\right)$$

$$\times \sum_{J=-1}^{1} \rho\left(B_n - \varepsilon_\gamma, I_t \pm \tfrac{1}{2} + J\right)$$

$$D_{0s}{}^{-1} = \begin{cases} \left(\rho\left(B_n, I_t + {}^1\!/_2\right) + \rho\left(B_n, I_t - {}^1\!/_2\right)\right)/2 & for\ \ I_0 \neq 0 \\ \rho\left(B_n, {}^1\!/_2\right)/2 & for\ \ I_0 = 0 \end{cases}$$

$$\sigma_{n\gamma} \cong \frac{C\pi^2 \lambda_n{}^2}{2I_0 + 1} \frac{\Gamma_\gamma}{D_{0s}}$$

Average radiative widths for s-neutron (meV)

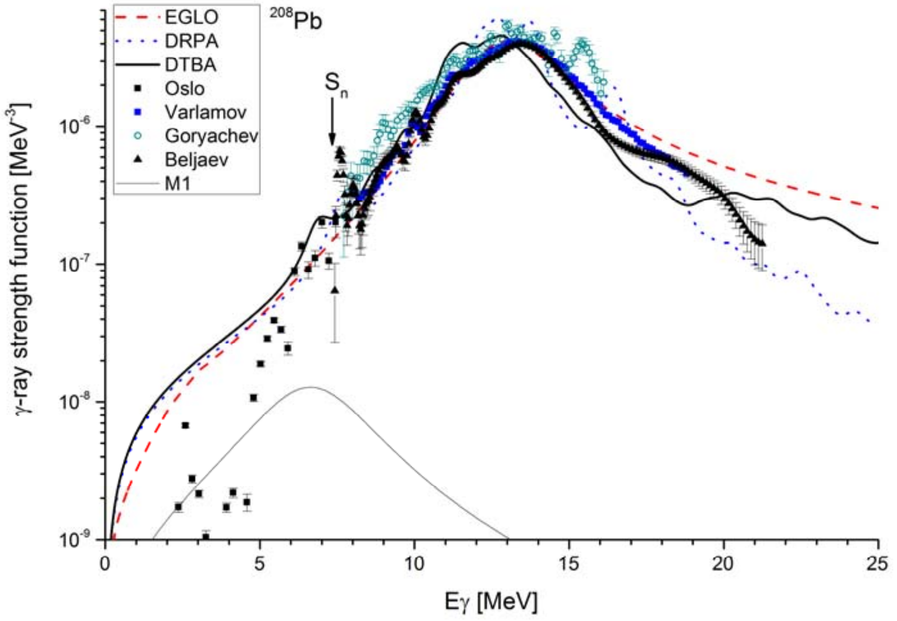
(EMPIRE3.1 calculations with microscopic PSF's, GSM model (first line) and HFB +combinatorial NLD model (second line))

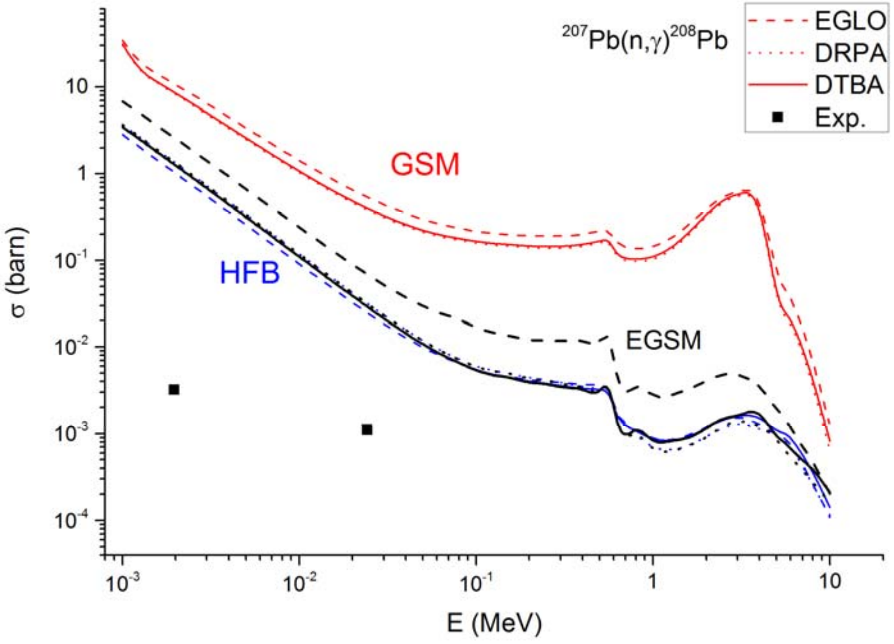
	^{110}Sn	^{112}Sn	^{116}Sn	^{118}Sn	^{120}Sn	^{122}Sn	^{124}Sn	^{136}Sn	^{58} Ni	^{60}Ni	^{62}Ni	^{68}Ni	^{72} Ni
EGLO (E1+M1)	147.4	105.5	72.9	46.6	55.0	56.6	49.9	11.1	1096	474	794	166	134
	207.9	160.3	108.9	106.7	124.3	110.2	128.7	295	2017	1882	1841	982.2	86.4
QRPA (E1+M1)	45.6	34.4	30.4	22.1	23.8	27.9	22.3	11.2	358	594	623	75.4	83.8
	71.0	49.7	44.3	40.3	43.0	50.1	68.9	448	451	1646	491	406	46.7
QTBA (E1+M1)	93.5	65.7	46.8	33.1	34.1	35.8	27.9	12.3	1141	971	1370	392	154
	119.9	87.0	58.4	58.1	61.5	64.0	84.8	509	1264	2800	2117	2330	53.8
Exp.				117 (20) 80 (20)	100 (16)					2200 (700)	2000 (300) 2200 (700)		
M1	13.0	9.6	8.9	6.1	6.6	7.3	4.9	1.3	46.1	32	23.2	36.0	49.6
	29.1	18.1	18.5	13.2	13.4	13.1	15.5	87.2	17.0	52	31.8	81.6	27.5
System.	112	109	107	106	105	104	103	73	2650	1900	1300	420	320

Exp. data: RIPL2 and S. F. Mughabghab, *Atlas of Neutron Resonances, Resonance Parameters and Thermal Cross Sections Z = 1–100* (Elsevier, Amsterdam, 2006)

The double-magic ^{208}Pb

Tselyaev's PSF, smoothing parameter is 400 keV and Skyrme SLy4





N.U.H.Syed *et al.,* PRC **79**, 024316 (2009)

R.C Greenwood et al., PRC,4,2249,1971
O.A.Wasson et al., Rept. USNDC-7 P36

Average radiative widths for double-magic ^{132}Sn and ^{208}Pb (meV)

		EGLO	QRPA DRPA	QTBA DTBA	System.	M1 contribution
^{132}Sn	GSM	398	133	148		40.9
	empire-specific	7340	4675	5186		515.3
	HFB com.	4444	4279	4259		340.7
^{208}Pb	GSM	10.56	7.80	8.24	5070 3770	0.79
	empire-specific	6292.4	3141.3	2942.0		6.56
	HFB com.	2733.7	3647.8	3417.1		5.25

^{208}Pb: D_0^{GSM} =0.00441 keV; D_0^{EGSM} =32 keV; D_0^{HFB} =37.6 keV; $D_0^{exp.}$ =30 (8) keV

GSM NLD model isn’t suitable for double-magic nuclei in contrast HFB NLD model!

Exp. data and system. : S. F. Mughabghab, *Atlas of Neutron Resonances, Resonance Parameters and Thermal Cross Sections Z = 1–100* (Elsevier, Amsterdam, 2006)

Conclusion 1

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

2. Phonon coupling in E1 PSF is necessary!

4. Integral characteristics of the pygmy-dipole resonance in ^{68}Ni have been explained within ETFFS and predicted in ^{72}Ni (with a very large %!)

5. For the first time the Γ_γ values have been calculated (15 isotopes) and a good agreement with the available experiment for (^{118,120}Sn and ^{60,62}Ni) has been obtained

6. The QTBA approach can predict PSF's more reliably than QRPA and should be used in neutron-rich nuclei

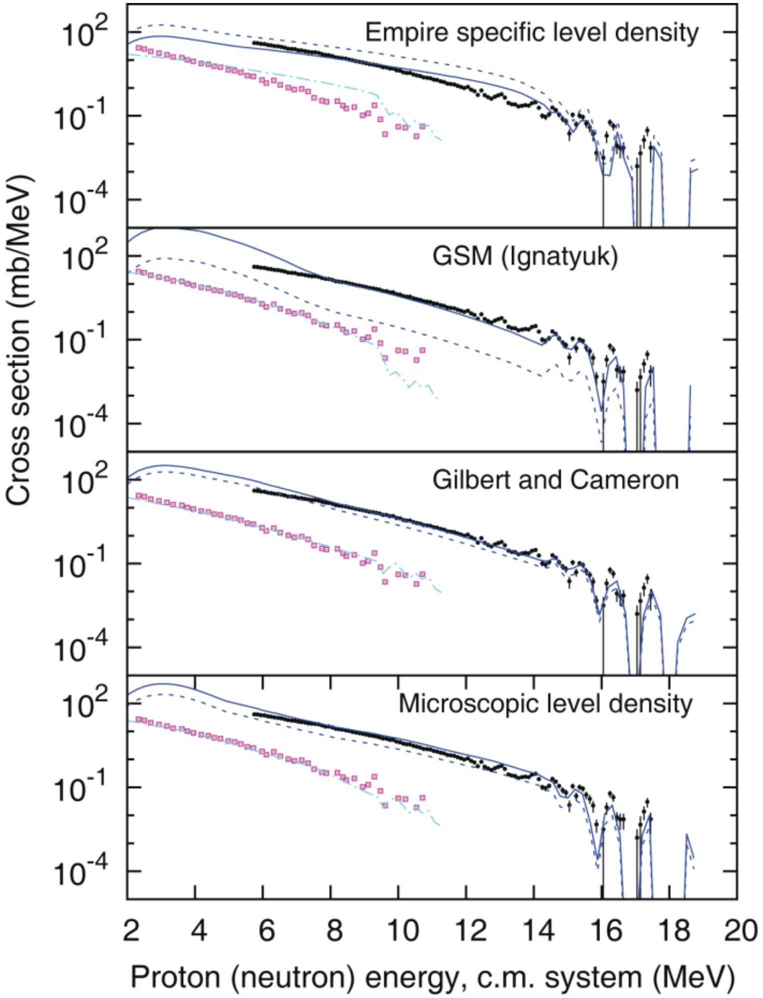
7.The **GSM NLD model** is not suitable for double-magic nuclei

QUESTIONS:

M1- ? –phenomenology ?, new results at E<4 MeV ?

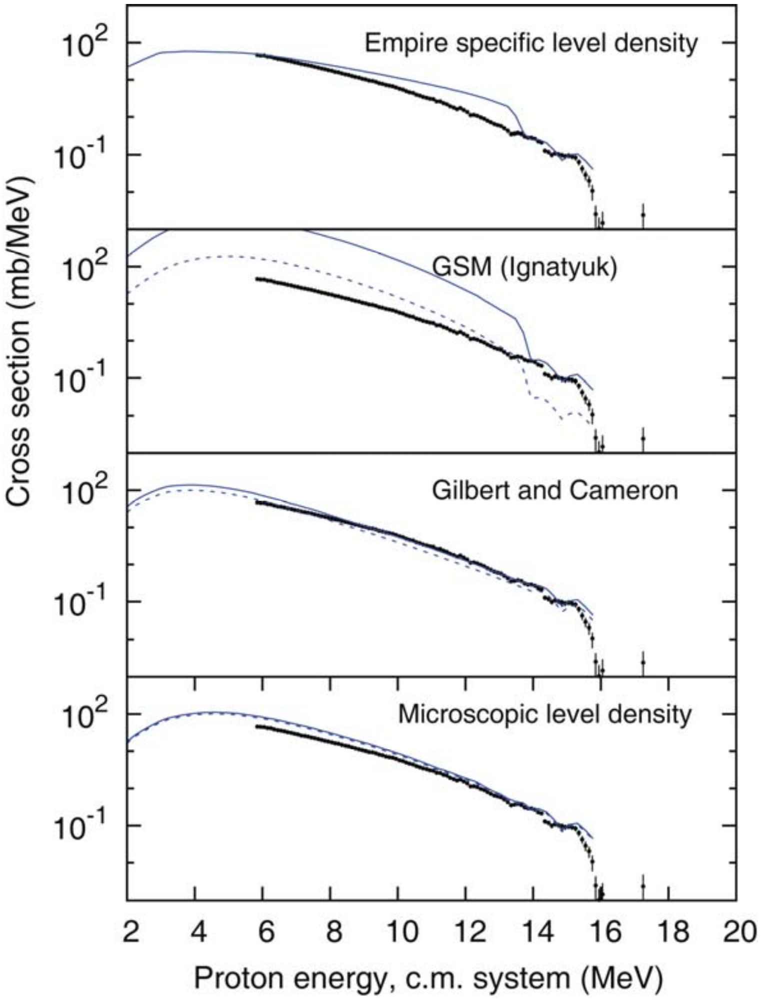
Justification of the Brink-Axel hypothesis ?

Voinov et al.,PRC 88 054607 (2013)



Experimental proton and neutron differential cross sections versus EMPIRE calculations with different input level density models. **^{59}Co(α, p)** (points) with E_α = 21 MeV and **^{59}Co(α, n)** (squares) with E_α = 17.6 MeV. Dashed lines are original calculations. Solid lines are original calculations scaled to match experimental points in the discrete level region.

Voinov et al.,PRC 88 054607 (2013)



Experimental proton and neutron differential cross sections versus EMPIRE calculations with different input level density models. ^{57}Fe(α, p) with $E_\alpha = 21$ MeV

Global combinatorial NLD formula (Goriely et al., PRC 78, 064307 (2008)

- Ground-state properties obtained within HFB with the BSk14 Skyrme force (force fitted to 2353 exp. nuclear masses with rms=0.739MeV).

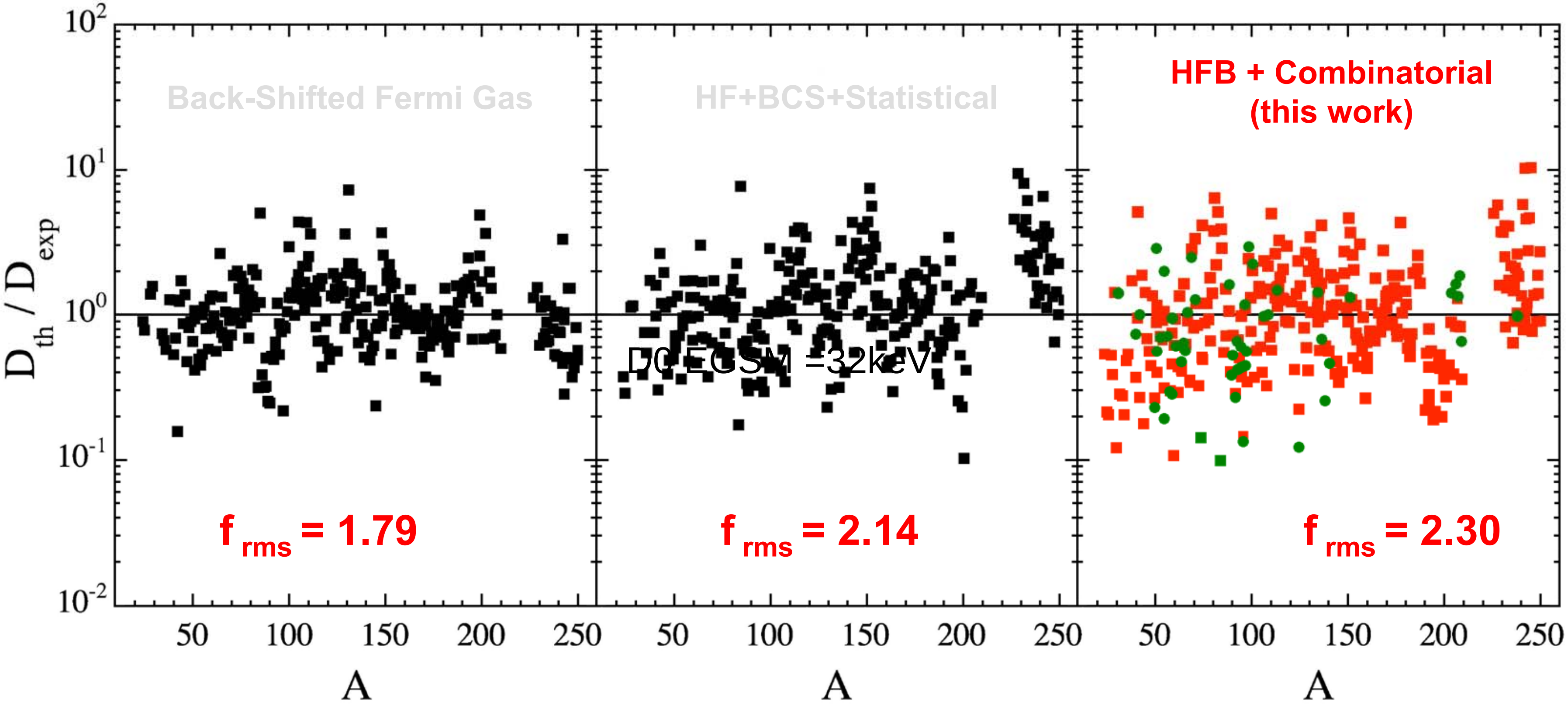
  NLD are made available for **8500 nuclei** in a table format for practical applications
  - Single particle level scheme
  - Pairing strength *(consistency between BSk14 and experimental pairing gaps)*
- NLD formula within the combinatorial method (Hilaire 2008)
  - *Parity*, angular momentum, pairing correlations, shell effect and rotational and vibrational enhancement treated explicitely and coherently
  - Consistent treatment of the disappearance of deformation effects at increasing excitation energies

Global combinatorial calculations of practical use in applications

- Particle-hole as well as total parity-, spin- and E-dependent NLD
- Deviation from the statistical limit at low energies (discrete counting)

Results at B_n

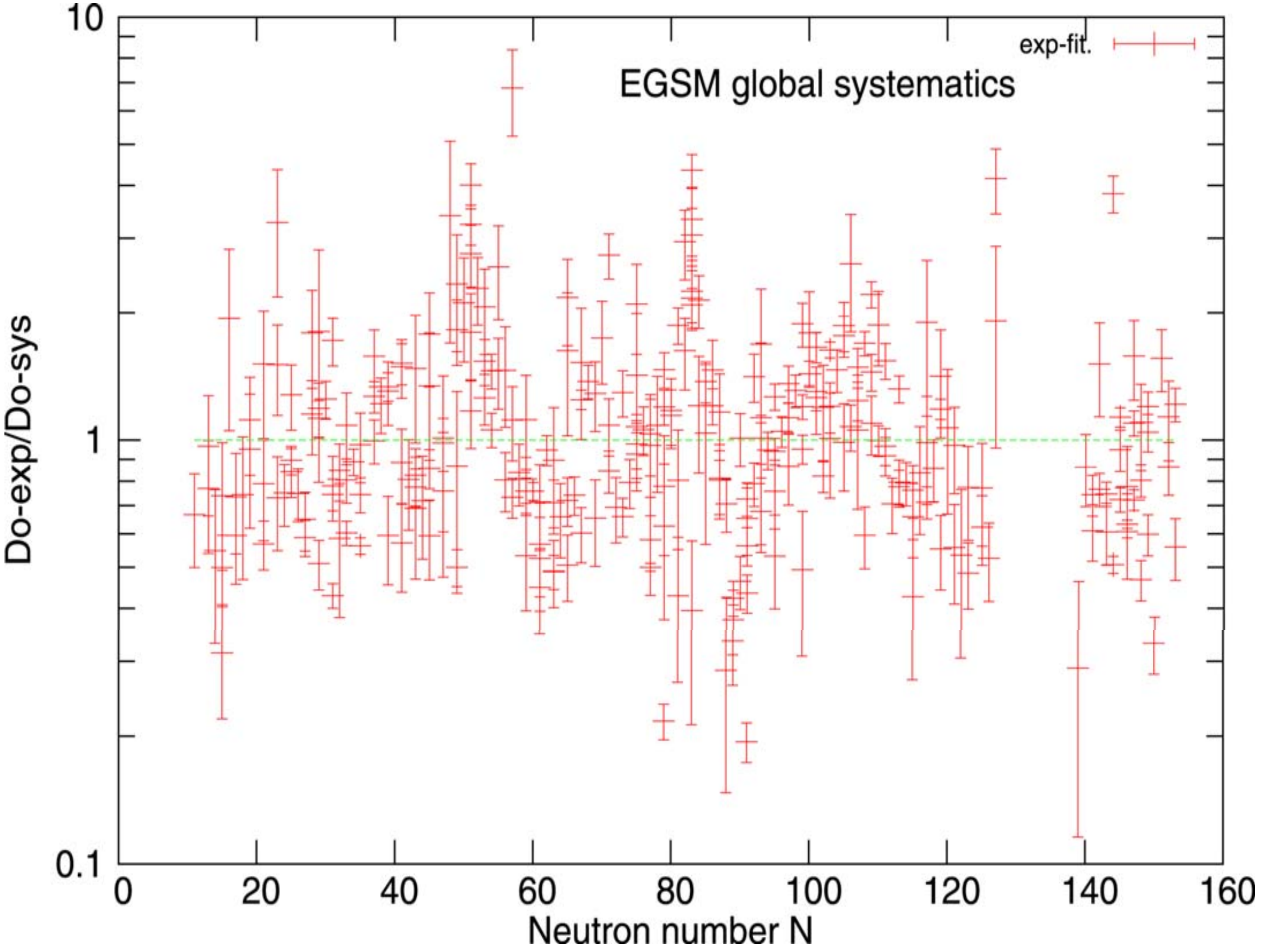
D values (s-waves & p-waves)



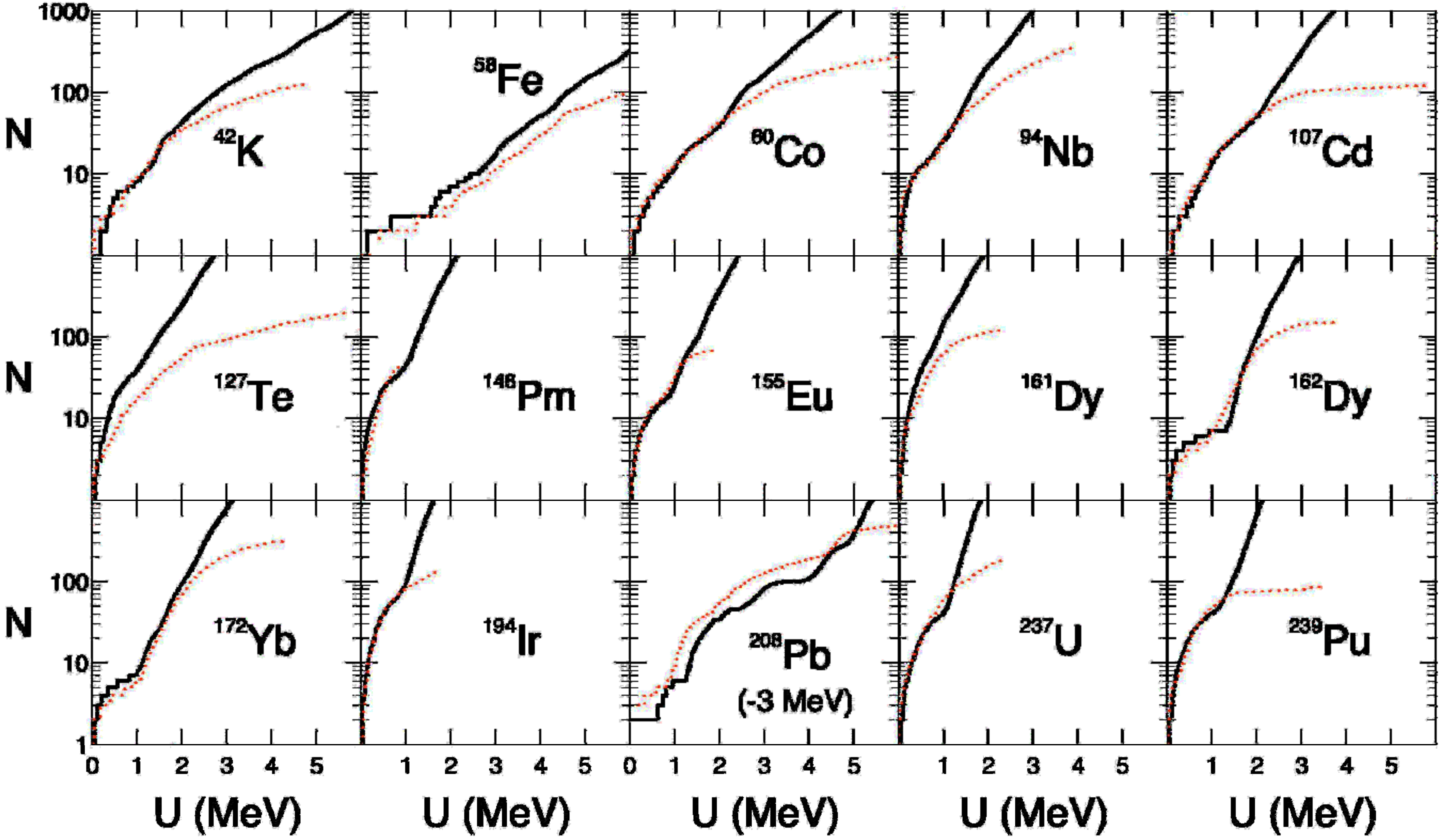
➡ **Description similar to that obtained with other global approaches**

Ratio of the experimental s-wave resonance spacings D_0 to the predictions of the global EGSM systematics as a function of the neutron number N.

[RIPL3: Capote et al., Nucl.Data Shits **110**,3107 (2009)]



Results for cumulated histograms



➡ **Structures typical of non-statistical feature,**

(red lines-experiment)

Improved collective effect description
S.Hilaire et al. PRC 86, 064317 (2012)

- **Gogny force** **instead of Skyrme force**

  ⇒ introduction of quadrupole energies based on microscopic predictions

- **Introduction of temperature in the HFB calculations**

  ⇒ microscopic vanishing of pairing and shell effects

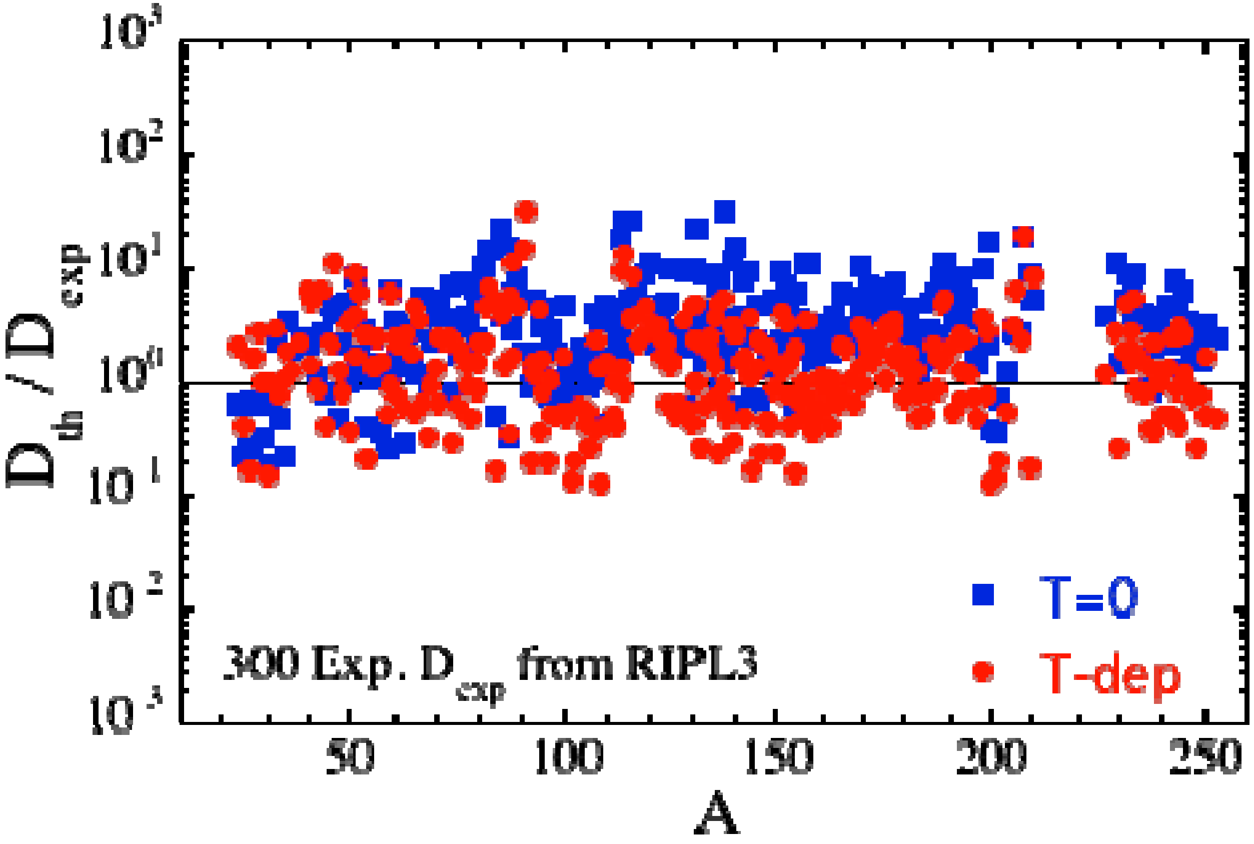
  ⇒ microscopic reduction of deformation

  ⇒ microscopic superfluidity to rigid moment of inertia

$$\Rightarrow \overline{O} = \frac{\int O(q) \exp[-F(q)/T]\, dq}{\int \exp[-F(q)/T]\, dq} \quad \text{with } F=E(T)-TS(T)$$

Method applied using the D1M Gogny force single particle levels, moments of inertia, quadrupole vibrational levels.

- D1M (rms ≈ 798 keV) = update of D1S (rms ≈ 3 MeV) . 8500 nuclei !



frms = 4.0

frms = 2.7

Conclusion 2

"Similar to other phenomenological approaches, EGSM ("Empire Global Specific Model") application to nuclei far from the stability valley is questionable."
[RIPL3: R.Capote, A.Ignatyuk et al., Nucl. Data Sheets 110, 3107 (2009)]

The **GSM NLD model** is too old, in our opinion

The developed microscopic combinatorial NLD models can clearly compete with the statistical ones in the global reproducing of exp. data, not to mention their higher predictive power.
It provides energy, spin and parity dependence of NLD and at low energies describes the nonstatistical limit.

Microscopic theory of nuclear data works very reasonably.
It is absolutely necessary for astrophysics and new facilities.

Thank you for your attention!

Conclusion

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

2. Phonon coupling in E1 PSF is necessary!

3. On the whole, the QTBA results are in a better agreement with EGLO than with the QRPA values (for stable nuclei !). This fact confirms the necessity of phonon coupling too.

4. Integral characteristics of the pygmy-dipole resonance in ^{68}Ni have been explained within ETFFS and predicted in ^{72}Ni (with a very large % !)

5. For the first time the Γ_γ values have been calculated (15 isotopes) and a good agreement with the available experiment for (^{118,120}Sn and ^{60,62}Ni) has been obtained

6. The QTBA approach can predict PSF's more reliably than QRPA and can be used in <u>neutron-rich</u> nuclei

7. The **GSM NLD model** is not suitable for double-magic nuclei

8. **M1- ? –**phenomenology ?, new results at E<4 MeV ?

Proof of phonon coupling necessity

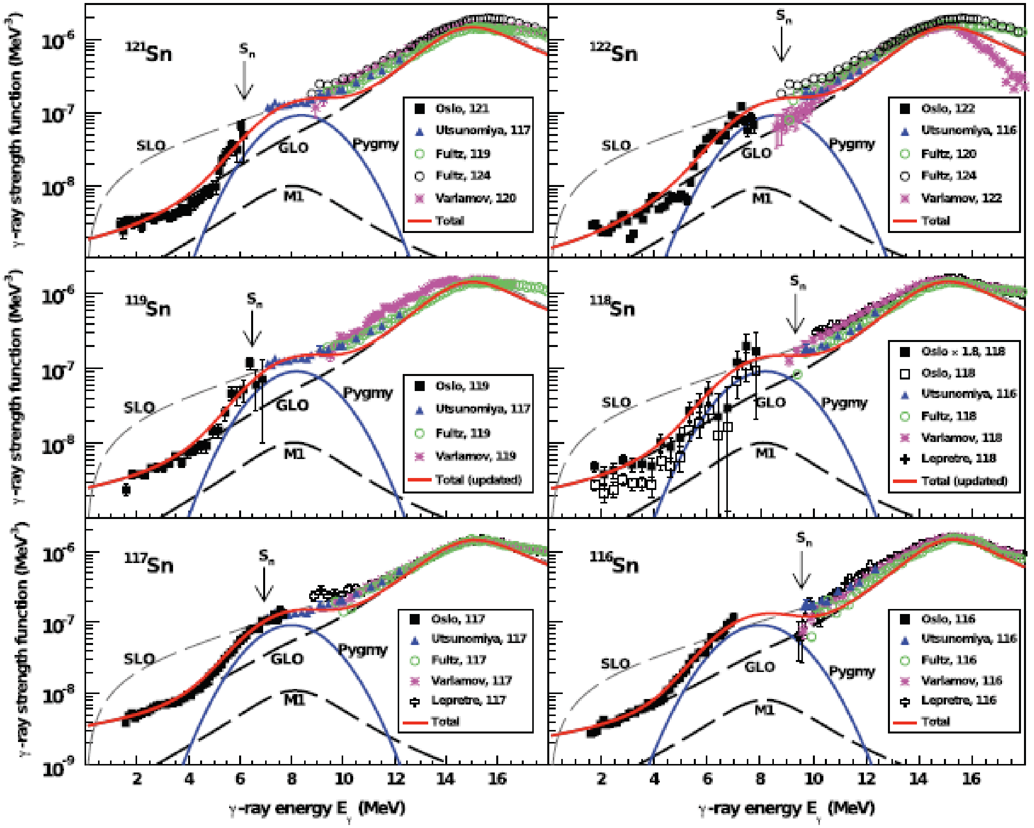


Fig. 25. Comparison of experimental data from the Oslo group (low-energy part) and other experiments with predictions for the γ-ray strength function. The inclusion of a E1 PDR around 8–8.6 MeV is necessary to explain the measured data.

Source: Reprinted figure with permission from [174].

© 2011, by the American Physical Society.

These Oslo results have shown some additional strength in addition to the standard phenomenological models

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

Low-energy enhancement of magnetic dipole radiation

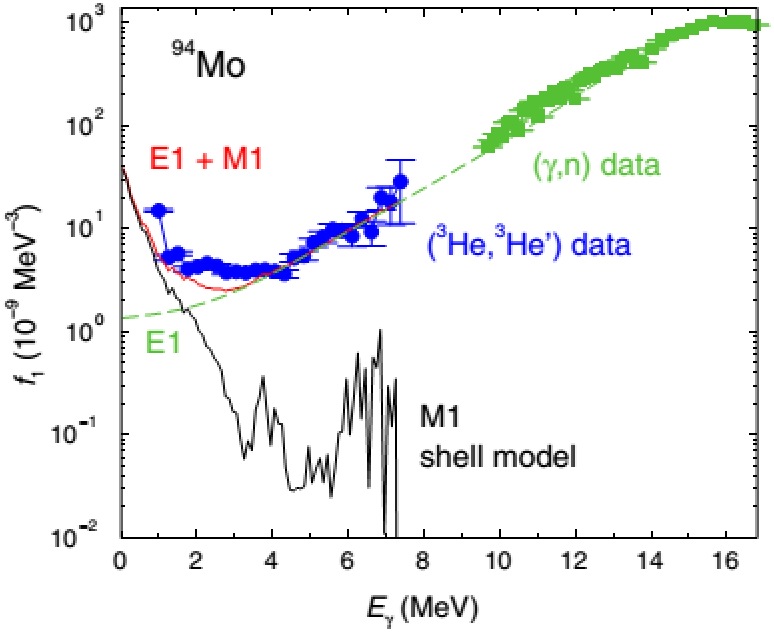


FIG. 1 (color online). Strength functions for ^{94}Mo deduced from (^{3}He, ^{3}He′) (blue circles) and (γ, n) (green squares) experiments, the $M1$ strength function from the present shell model calculations (black solid line), $E1$ strength according to the GLO expression with parameters $E_0 = 16.36$ MeV, $\sigma_0 =$ 185 mb, $\Gamma = 5.5$ MeV, $T = 0.35$ MeV (green dashed line), and the total ($E1 + M1$) dipole strength function (red solid line).

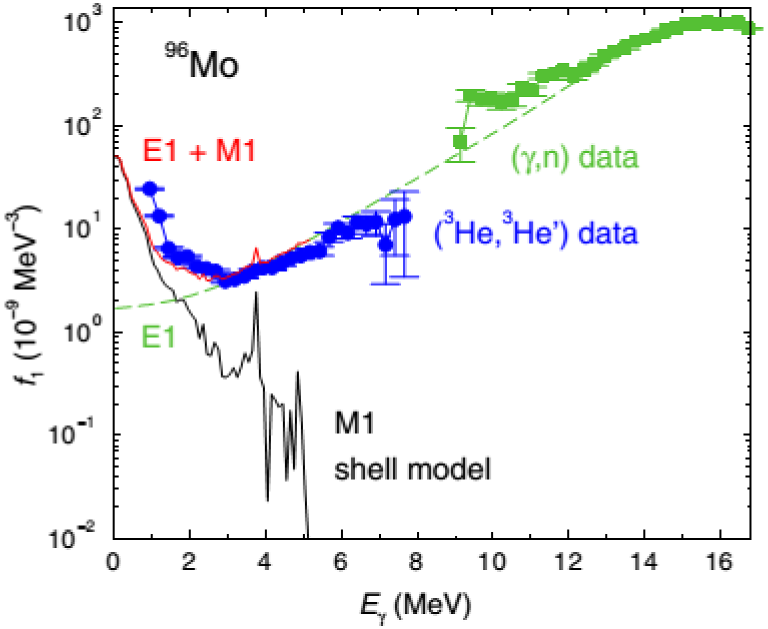


FIG. 3 (color online). As Fig. 1, but for ^{96}Mo.

R. Schwengner, S. Frauendorf, A. C. Larsen;
Phys. Rev. Lett. **111**, 232504 (2013)

Multiplicity

for GSM NLD model (first line) and HFB+Comb. NLD model (second line)

	EGLO	QRPA	QTBA	Exp.
117Sn 550 keV	4,03	3,66	3,39	3.45 (9)
	3,48	4,24	3,73	
119Sn 570 keV	3,96	3,55	3,26	3.80 (20)
	4,11	3,59	3,33	
117Sn 46 kev	3,64	3,32	2,99	3.31 (16)
	3,86	3,4	3,12	
119Sn 52 keV	3,57	3,23	2,96	3.66 (19)
	3,74	3,28	3,03	

Exp. data: J.Nishiyama *et al.*, J. Nucl. Sci. Technol. (Tokyo) **45**, 352 (2008)

Definition of smearing parameter (Phys.Rep. 2004)

$$S(\omega, \Delta) = -\frac{1}{\pi}\,\mathrm{Im}\sum_{12} e_q V_{21}^{0*}\,\rho_{12}(\omega + \mathrm{i}\Delta)$$

The PSF f(E1) and appropriate nuclear data businesses are based on the Brink-Axel hypothesis.

If the Brink-Axel hypothesis (BAH) is correct:

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

where S is taken in $fm^2 MeV^{-1}$, $f(E1)$ in MeV^{-3}

$$\sigma(\omega) = 4.022\omega S(\omega) \quad S(\omega) = \frac{dB(E1)}{dE}$$

Thus, problems of PSF are problems of Pygmy, Giant-Dipole Resonances + BAH (PDR , GDR+ BAH) !

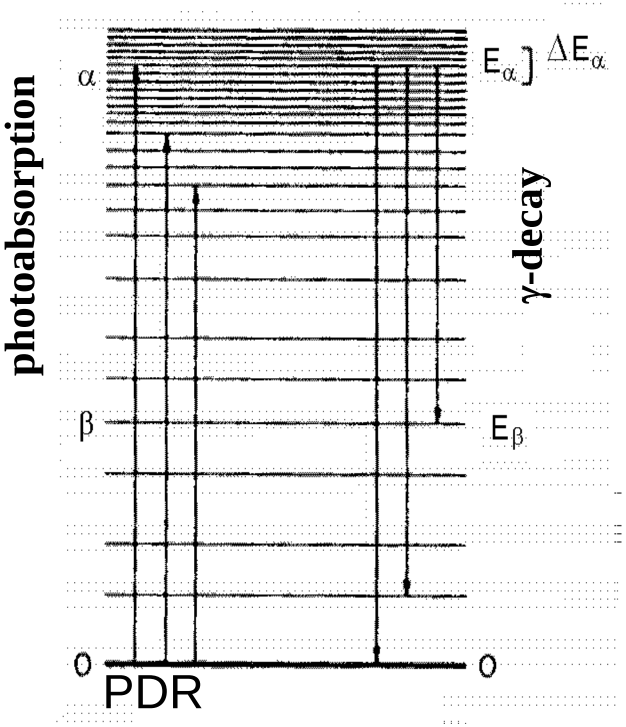
Formula for integrated features (mean energy and width)

$$\langle E\rangle = E_{1,0} = \frac{m_1}{m_0}, \quad D = \sqrt{\frac{m_2}{m_0} - \left(\frac{m_1}{m_0}\right)^2}$$

Photon strength function (PSF) (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 wave function must contain simple (1p1h) and complex 1p1h⊗phonon configurations :

$$\Psi_i = \underbrace{\sum_{1,2} c^{i}_{12}\varphi_1^{*}\varphi_2}_{\text{(Q)RPA}} + \underbrace{\sum_{1,2,s} c^{i}_{12s}\varphi_1^{*}\varphi_2\Phi_s}_{\text{Phonon coupling}}$$

where φ – s.p. wave function, Φ_s - phonon wave function

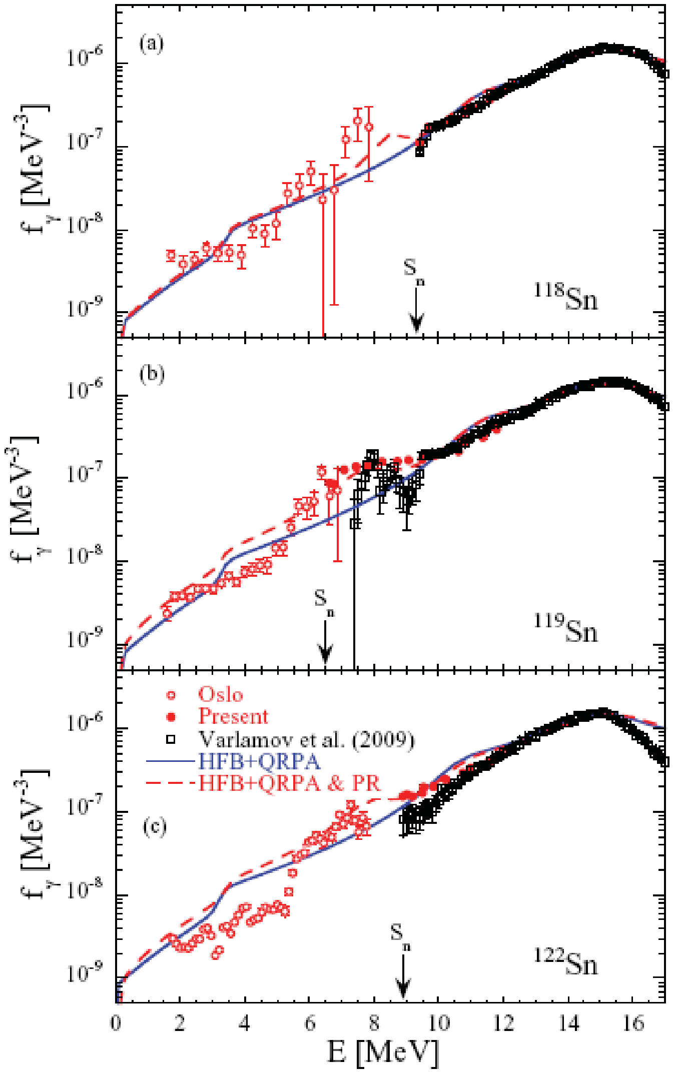
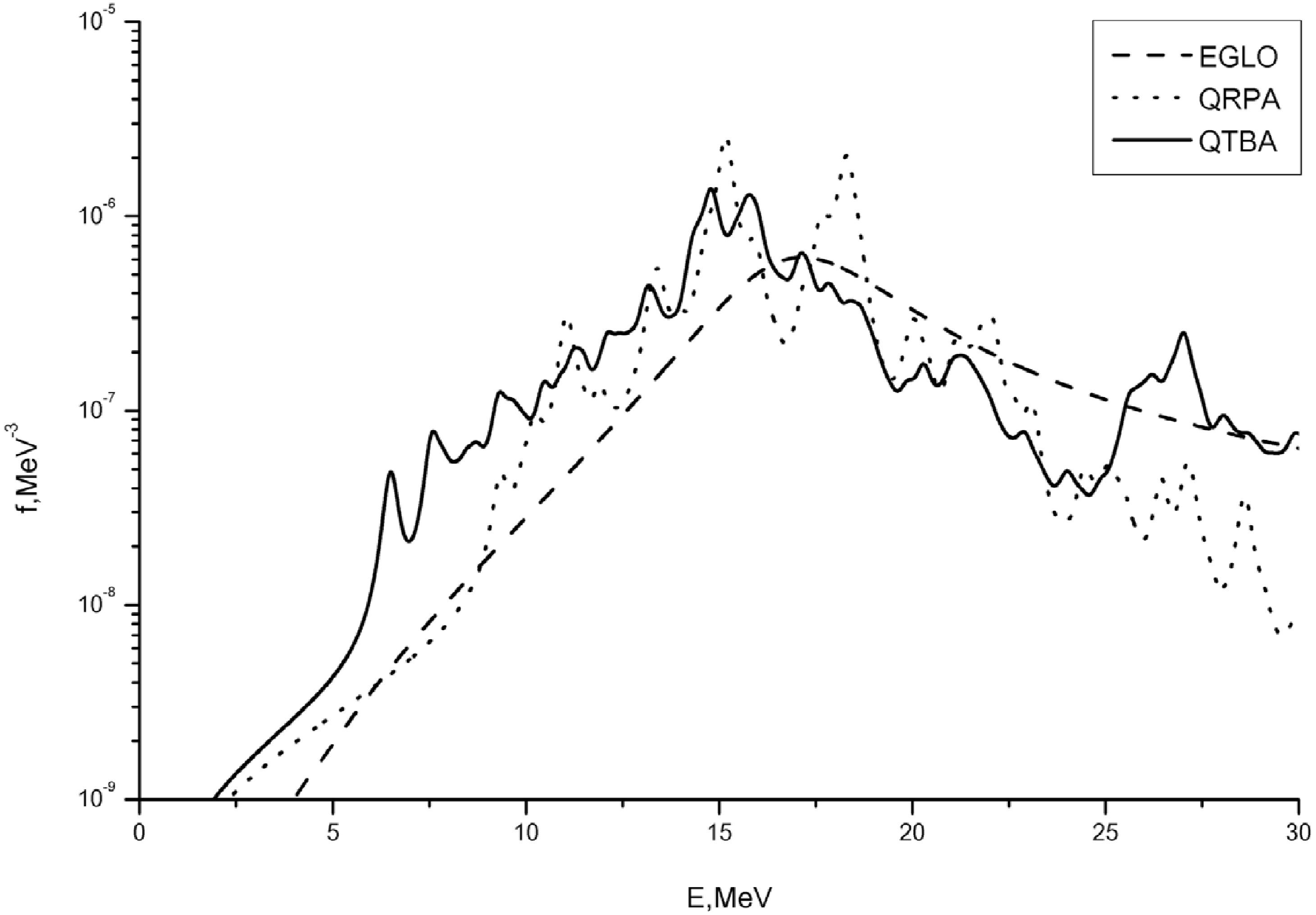


FIG. 10. (Color online) Comparison between the HFB + QRPA strength (with and without the inclusion of the PR) and the experimental data of the Oslo group [9,10], from photodata [18] as well as the present photoemission data, for ^{118}Sn (a), ^{119}Sn (b), and ^{122}Sn (c).

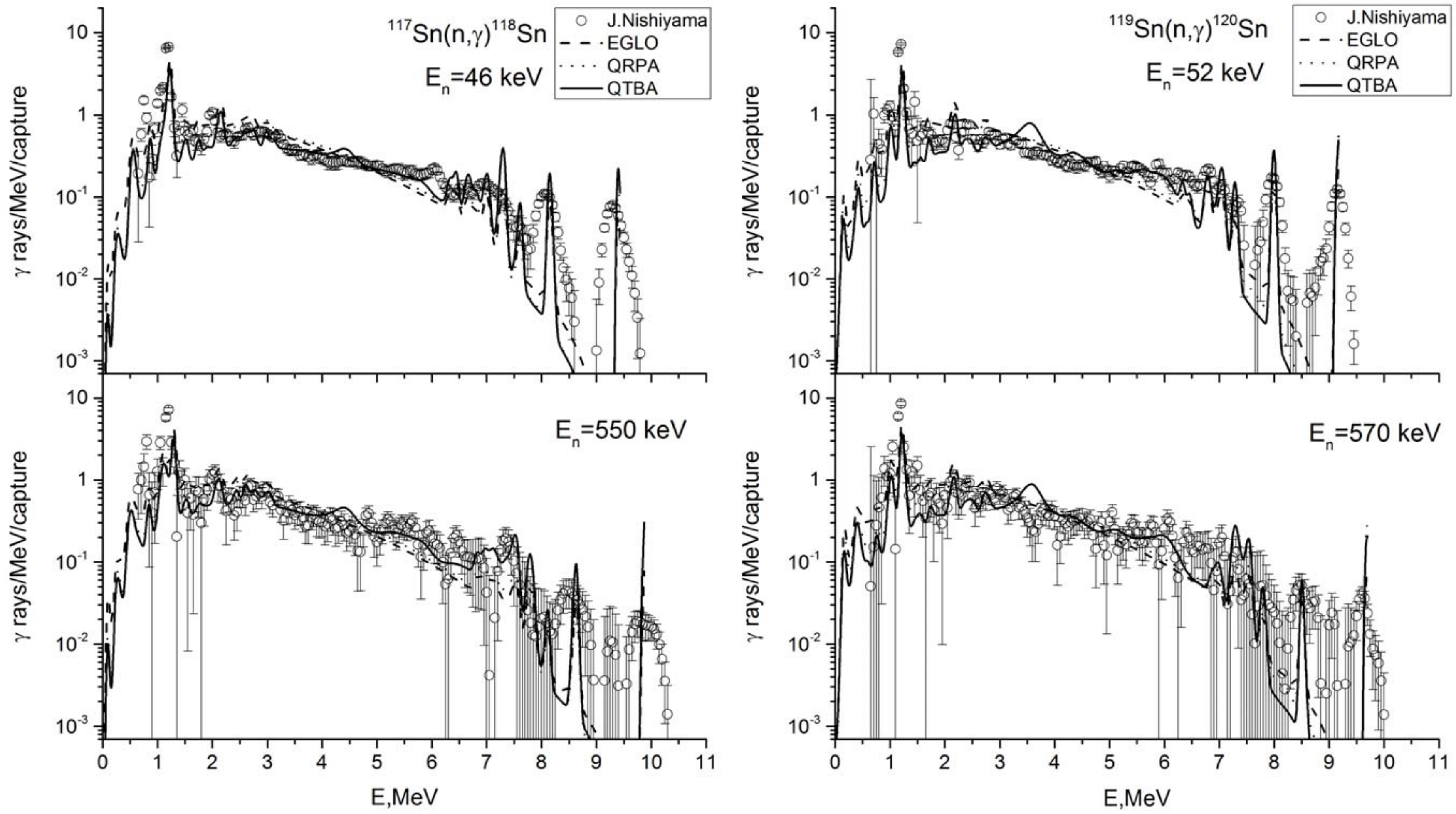
Utsunomiya, Goriely et al.,
PRC 84, 055805(2011)

^{68}Ni PSF



Capture gamma-ray spectra

NLD is GSM (RIPL2)



Average radiative widths

$$\Gamma_\gamma\left(I_t \pm \tfrac{1}{2}, \Pi_t\right) = \frac{1}{2\rho\left(B_n, I_t \pm \frac{1}{2}, \Pi_t\right)} \int_0^{B_n} d\varepsilon_\gamma \varepsilon_\gamma{}^3 \left(f_{E1}(\varepsilon_\gamma) + f_{M1}(\varepsilon_\gamma)\right) \times \sum_{J=-1}^{1} \rho\left(B_n - \varepsilon_\gamma, I_t \pm \tfrac{1}{2} + J\right)$$

$$D_{0s}{}^{-1} = \begin{cases} \left(\rho\left(B_n, I_t + {}^1\!/_2\right) + \rho\left(B_n, I_t - {}^1\!/_2\right)\right)/2 & for\ \ I_0 \neq 0 \\ \rho\left(B_n, {}^1\!/_2\right)/2 & for\ \ I_0 = 0 \end{cases}$$

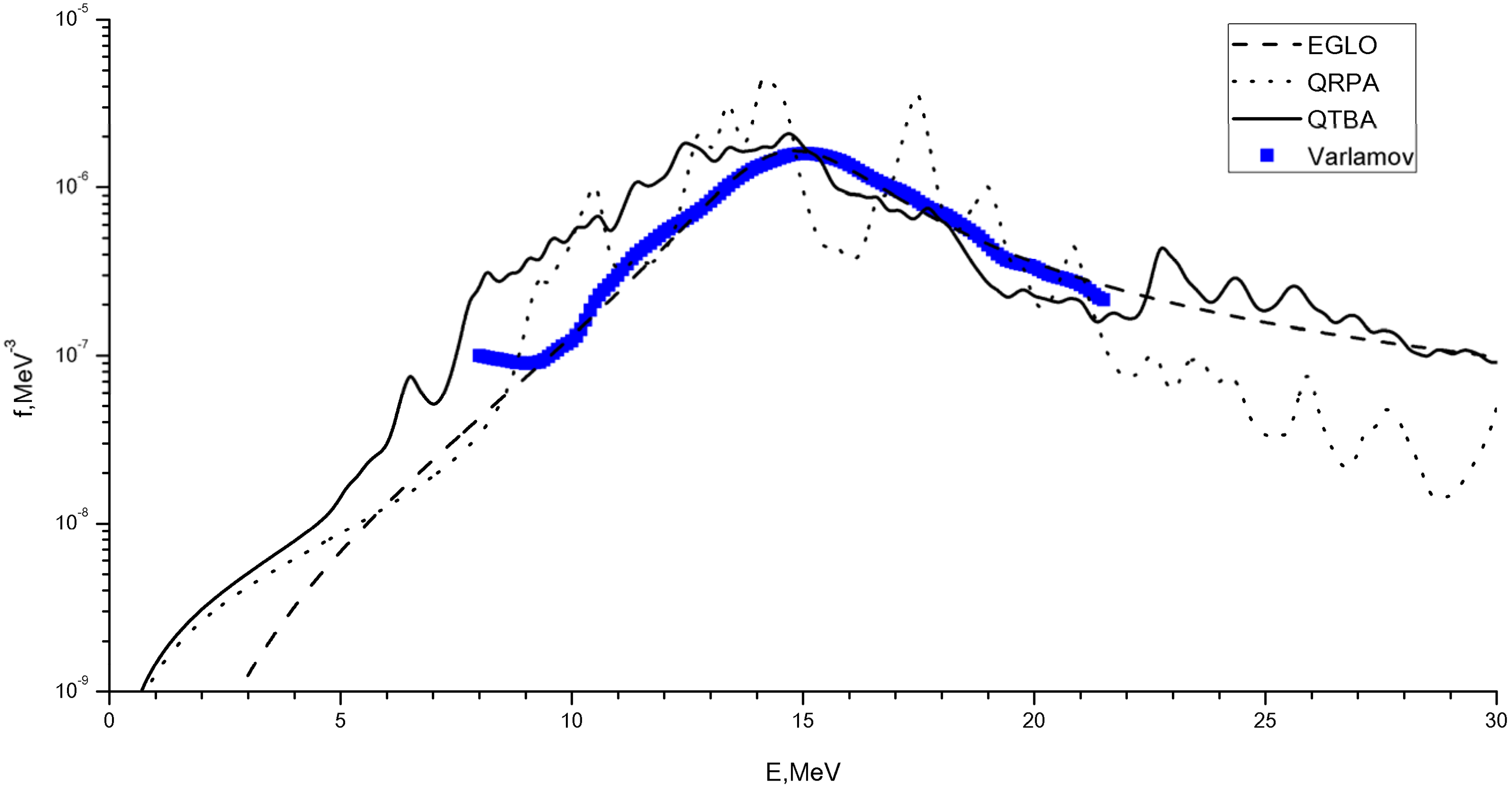
$$\sigma_{n\gamma} \cong \frac{C\pi^2 \lambda_n{}^2}{2I_0 + 1} \frac{\Gamma_\gamma}{D_{0s}}$$

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

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

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

^{124}Sn PSF



In all Sn isotopes considered there is some additional strength due to PC around 8 MeV in according to [Toft]

Two self-consistent approaches

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)

Phonon coupling has been taken into account in [N.Paar et al.,2007]:

1.NFT (Bohr, Mottelson Vol.2)

2. QPM model by Soloviev et al.

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

Self-consistent approaches:

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

!+4. Relativistic QTBA (Ring, Tselyaev, Litvinova)

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

MICROSCOPIC NATURE OF THE PHOTON STRENGTH FUNCTION: STABLE AND UNSTABLE Ni AND Sn ISOTOPES

O. Achakovskiy4, A. Avdeenkov[4], S. Goriely3, S. Kamerdzhiev1,
S. Krewald3, D. Voitenkov4

1Institute for nuclear Power Engineering, Obninsk, Russia
2Institut d’Astronomie et d’Astrophysique, ULB, CP 226, B-1050, Brussels, Belgium
3 Institut für Kernfizik, Forshungszentrum Jülich, D-52425 Jülich, Germany
4.IPPE

CGS15
Dresden (25-29.08.14)

ON MICROSCOPIC THEORY OF RADIATIVE NUCLEAR REACTION CHARACTERISTICS

Kamerdzhiev S.P.[1], Achakovskiy O.I.[2], Avdeenkov A.V.[2], Goriely S.[3]
[1] *Institute for Nuclear Power Engineering NRNU MEPHI, Obninsk, Russia;*
[2] *Institute for Physics and Power Engineering, Obninsk, Russia;*
[3] *Institut d'Astronomie et d'Astrophysique, ULB, Brussels, Belgium*
E-mail: kaev@obninsk.com

A survey of some results in the modern microscopic theory of properties of nuclear reactions with gamma-rays is given. First of all, we discuss the impact of phonon coupling (PC) on the photon strength function (PSF) because the most natural physical source of additional strength, that was found for Sn isotopes in the recent Oslo group experiments [1] and could not be explained within the microscopic HFB+QRPA approach [2], is the microscopic PC effect. In order to check this statement, the self-consistent version of the Extended Theory of Finite Fermi Systems [3] in the Quasiparticle Time Blocking Approximation, or simply QTBA, was applied (see Ref. [4]). It uses the HFB mean field and includes both the QRPA and PC effects. Only the known parameters of the Sly4 force were used in the calculations. With our microscopic *E*1 PSFs in the EMPIRE3.1 code, the following properties have been calculated for many stable and unstable even-even Sn and Ni isotopes [4–7]: 1) neutron capture cross sections, 2) corresponding neutron capture gamma-spectra, 3) average radiative widths of neutron resonances. In all the considered properties, the PC contribution turned out to be significant, as compared with the QRPA one, and necessary to explain the available experimental data. The very topical question about the M1 resonance contribution to PSFs is also discussed.

Secondly, as in order to calculate the above-mentioned properties it is necessary to use the nuclear level density models, we also discuss the modern microscopic models based on the self-consistent HFB method, for example, see [8], and show their better applicability to explain experimental data as compared with the old phenomenological models.

The use of these self-consistent microscopic approaches is of particular relevance for nuclear astrophysics and also for double-magic nuclei.

1. H.K.Toft *et al.* // Phys. Rev. C. 2011. V.83. 044320.
2. H.Utsunomiya *et al.* // Phys. Rev. C. 2011. V.84. 055805.
3. S.Kamerdzhiev, J.Speth, G.Tertychny // Phys. Rep. 2004. V.393. P.1.
4. A.Avdeenkov *et al.* // Phys. Rev. C. 2011. V.83. 064316.
5. O.Achakovskiy *et al.* // accepted in Phys. Rev. C. 2015.
6. S.P.Kamerdzhiev *et al.* // submitted to JETP Letters.
7. O.Achakovskiy *et al.* // Proc. of ISINN22. Dubna, 2014.
8. S.Hilaire, M.Girod, S.Goriely, A.J.Koning // Phys. Rev. C. 2012. V.86. 064317.