Self-Consistent Calculations of Radiative Nuclear Reaction Characteristics for ^{56}Ni, ^{132}Sn, ^{208}Pb

O. Achakovskiy[1], S. Kamerdzhiev[2]

1. Institute for Physics and Power Engineering, Obninsk, Russia

2. National Research Centre "Kurchatov Institute", Moscow, Russia

Plan

- Aims
- Microscopic self-consistent calculations of photon strength functions (PSFs) in ^{56}Ni (for the first time), ^{132}Sn, ^{208}Pb to account for the QRPA and PC effects
- Using our microscopic PSFs , to calculate with EMPIRE3.1: neutron capture cross sections and average radiative widths
- Conclusion

Aims of calculations:

We want to investigate the specifities of double-magic nuclei in the radiative nuclear reaction characteristics :

- To take self –consistency into account.
  (such an approach has a higher predictive power as compared with phenomenological approaches (SLO, MLO, EGLO etc.))
- To describe structures of photon strength functions (PSFs) microscopically with both QRPA and PC effects using universal parameters (same as for semi-magic as for double magic)
- To calculate neutron capture cross sections and average radiative widths for the compound nuclei ^{56}Ni, ^{132}Sn, ^{208}Pb
- To compare the (γ, γ’) results and (^{3}He, ^{3}He’ γ) Oslo exp. data for ^{208}Pb

Photon strength function

- Photon strength functions describe average electromagnetic transitions strengths - in particular in the quasi-continuum of nuclear states at high excitation energy and incudes the transition between excited states

$$f_{E1}^{\downarrow}(E_\gamma)=\langle\Gamma_{i\to g.s.}\rangle\rho(E_i)/E_\gamma^3$$

- Photoabsorption

$$f_{E1}^{\uparrow}(E_\gamma)=\sigma_{abs}(E_i)/3(\pi\hbar c)^2 E_\gamma$$

- Brink-Axel hypothesis:
  the strength function does not depend on the excitation energy.

- The principle of detailed balance:
  the strength function for excitation is identical with the one for deexcitation.

$$f_{E1}^{\uparrow}(E_\gamma)=f_{E1}^{\downarrow}(E_\gamma)=\sigma_{abs}(E_\gamma)/3(\pi\hbar c)^2 E_\gamma=16\pi^2 e^2/27(\hbar$$

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

ETFFS(QTBA) contains:

1.(Q)RPA

2. Phonon coupling

3.Single-particle continuum

and uses the known Skyrme forces to calculate self-consistently at the same time the mean field, effective interaction and phonon characteristics

No new parameters !

Method:

Kamerdzhiev *et al.*, Phys. Rep. **393**, 1, (2004)
Tselyaev, Rhys. Rev. C **75**, 024306 (2007)

Some our articles:

Avdeenkov *et al.,* Phys. Rev. C **83**, 064316 (2011)
Achakovskiy *et al.,* Phys. Rev. C **91**, 034620 (2015)
Kamerdzhiev *et al.*, JETP Lett., **101**, No. 11, 725 (2015)
Kamerdzhiev *et al.*, Phys. Atom. Nucl., **79**, 567 (2016)
Achakovskiy *et al.,* JETP Lett., **104,** No.6 (2016)

Features of the self-consistent approaches

- Self-consistency:
  Mean field (ground state) is determined by the first derivative of the **density functional**
  Effective pp- and ph-interactions for phonons are the second derivative of the same functional
- Individual approach to each nucleus due to single-particle and phonon spectra
  Therefore, the PSF structures can be described
- “First principle” approach (parameters of the Skyrme forces or functional are universal for all nuclei except for light ones)
- Great predictive power

In general, phonon coupling has been taken into account in:

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]

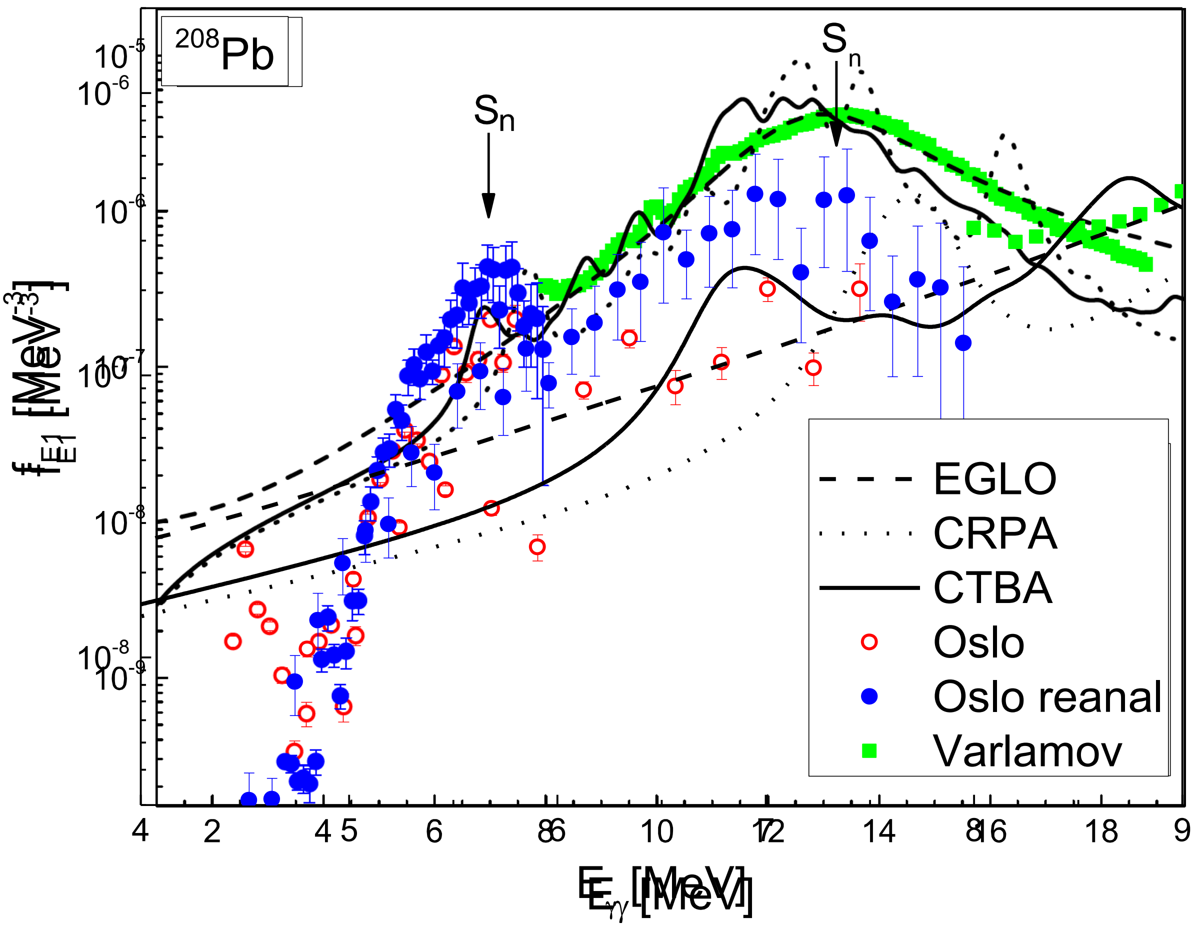
Self-consistent approaches:

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

5. Relativistic QTBA (Ring, Tselyaev, Litvinova)

N.Paar *et al.*, Rep. Prog. Phys. **70**, 691

PSF for ^{208}Pb (CTBA)



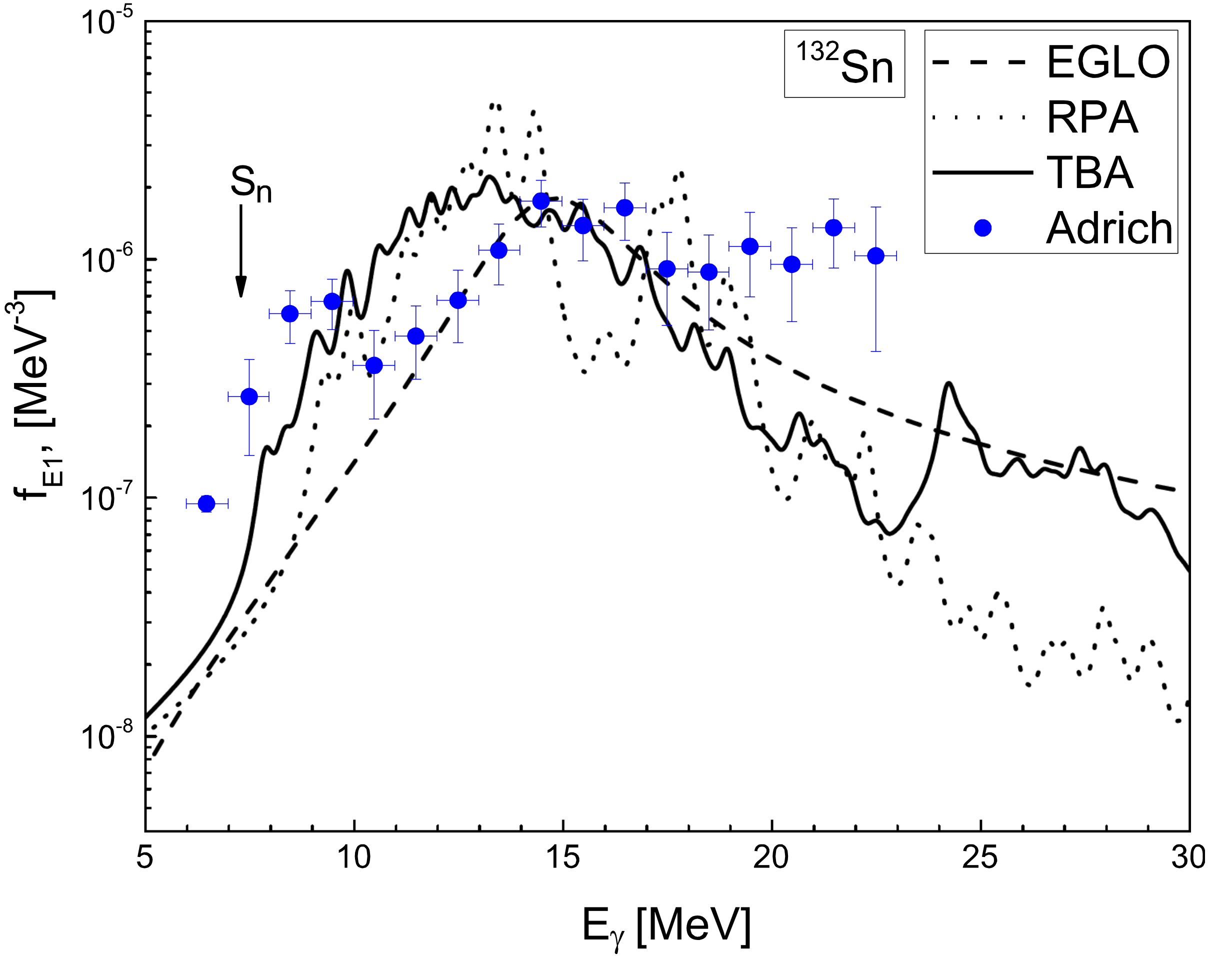
A new (as compared with QTBA) microscopic method for magic nuclei (CTBA):
N. Lyutorovich *et al.*, Phys. Lett B 749, 292 (2015)

$S{\downarrow}n = 7.37\ MeV \qquad \Delta = 400\ keV$

The improved CTBA approach describes the reanalyzed data better at E>5 MeV

Exp. data:
Oslo group - N.U.H.Syed *et al.,* PRC **79**, 024316 (2009), private communication (reanalyzed data)
V. V. Varlamov, *et al.,* Vop. At. Nauki i Tekhn., Ser. Yadernye Konstanty 1-2 (2003)

PSF for ^{132}Sn (QTBA)

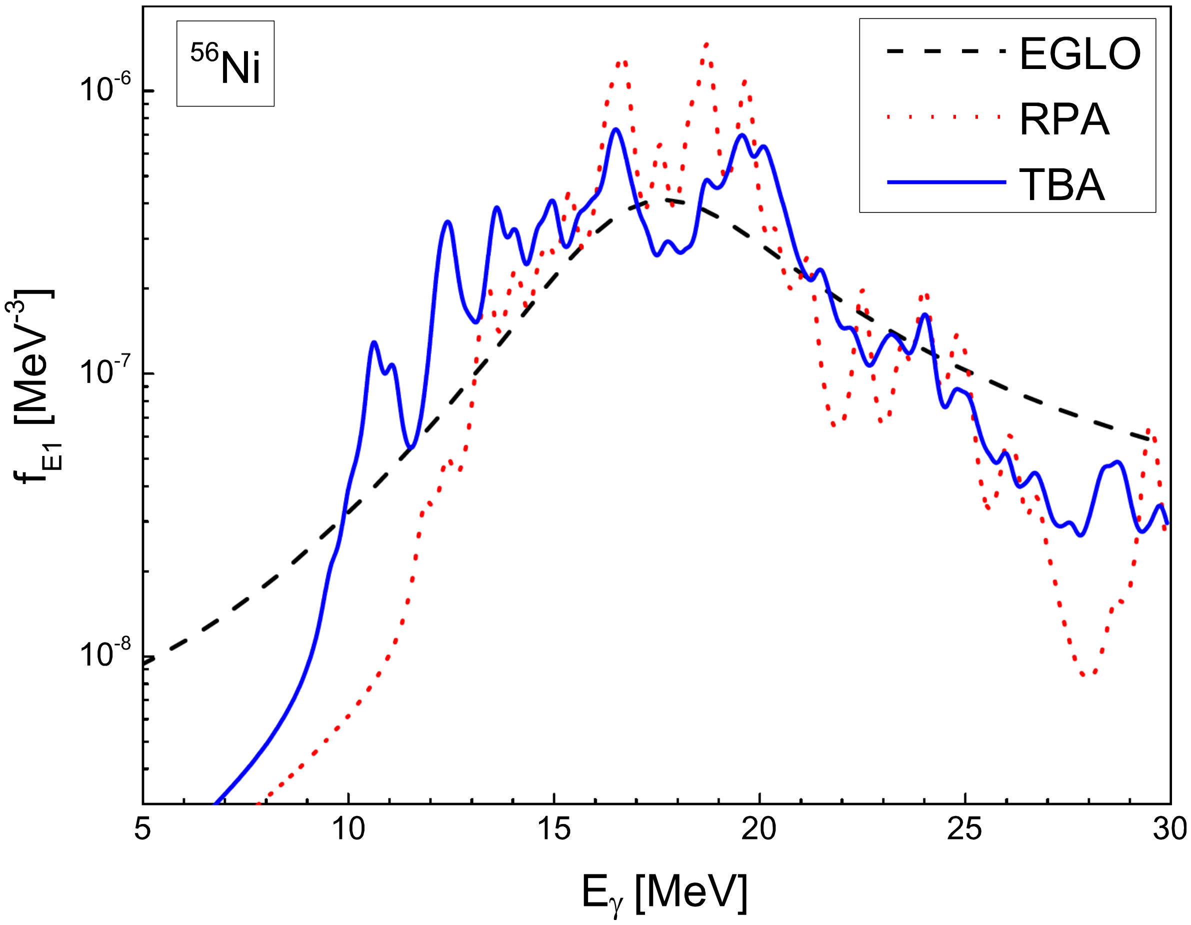


$S_n = 7.34$ MeV

$\Delta = 200\ keV$

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

PSF for ^{56}Ni (QTBA)

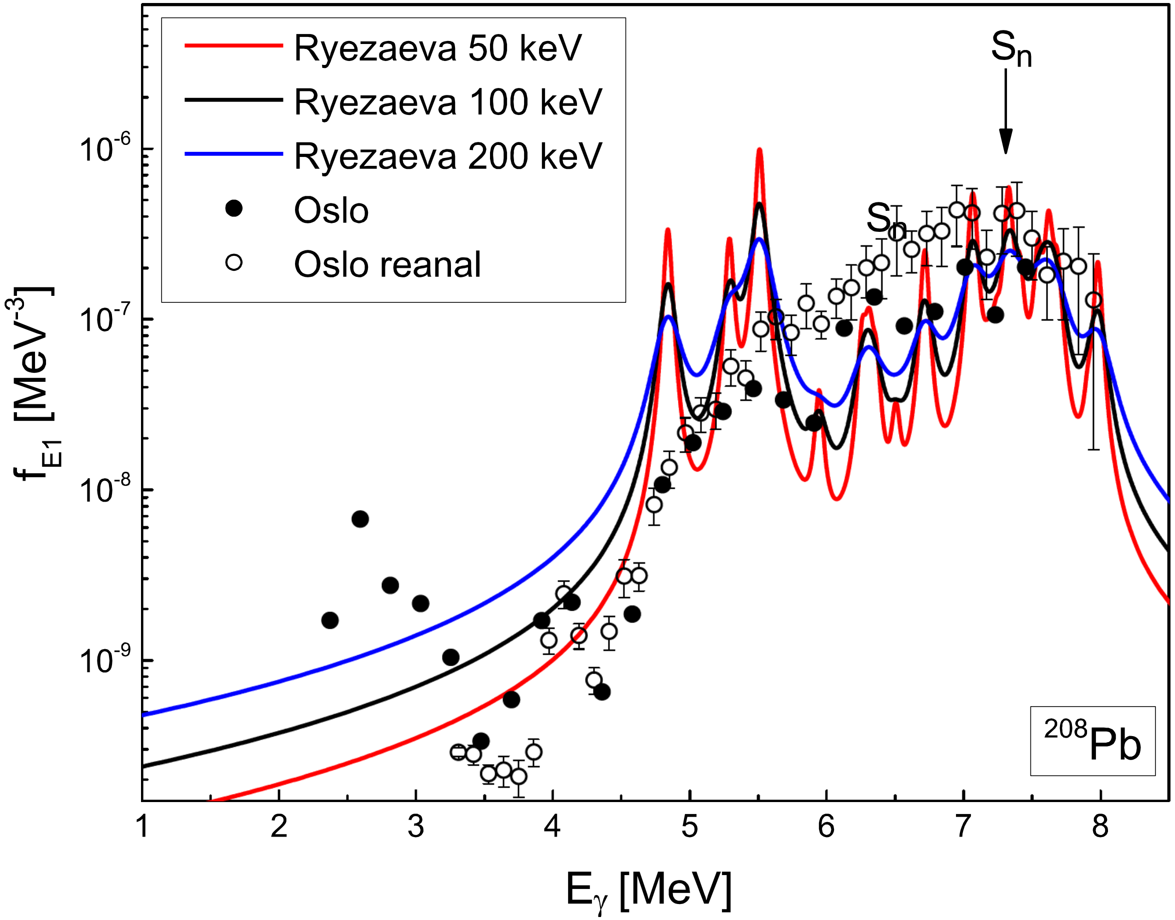


$S_n = 16.64$ MeV

Δ=200 keV

PC give additional (as compared with QRPA) PSF structures and allow us to describe structures in PDR energy region

PSF for ^{208}Pb : comparison of experimental data sets



$$f_{E1}(E_\gamma) = \frac{8\pi}{27(\hbar c)^3} \sum_s B(E1)_s \frac{\Delta}{2\pi\left[(E_\gamma - E_s)^2 +\right.}$$

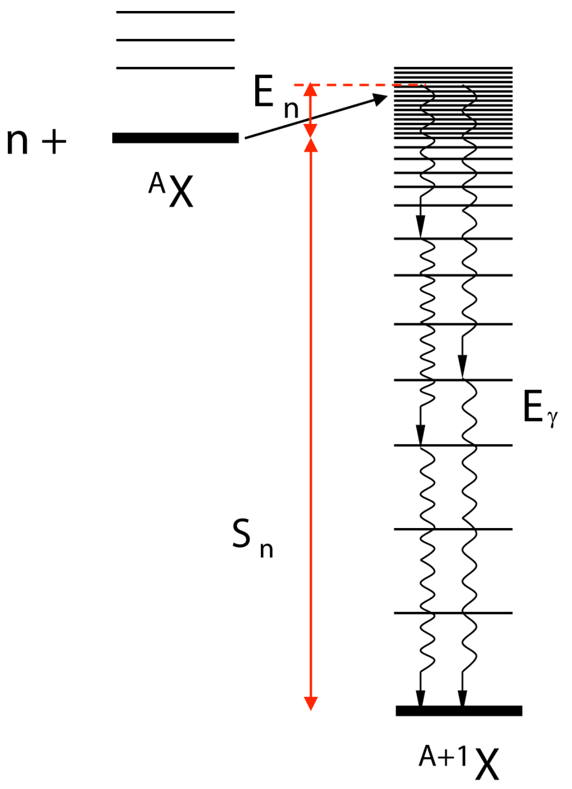
Some additional transitions between excited states at E>5 Mev?
The PSF structures at E<4.84 MeV may be or caused by the (M1?) transitions between excited states.

(^{3}He, ^{3}He’ γ) - N.U.H. Syed *et al.,* PRC **79**, 024316 (2009), private communication (reanalyzed data)
(γ, γ’) - N. Ryezayeva, *et al.*, Phys. Rev. Lett. 89, 272502 (2002)

Calculating Radiative Nuclear Reaction Characteristics

Neutron capture reaction

n+target → population of compound nucleus (CN)



Theoretical description – nuclear code EMPIRE

Hauser-Feshbach theory:

$$\sigma_{n\gamma}=\pi/k_n^2 \sum_{J,\pi} g_J\, T_\gamma(E_n,J,\pi)T_n(E_n,J,\pi)$$

T_γ is gamma transition coefficient

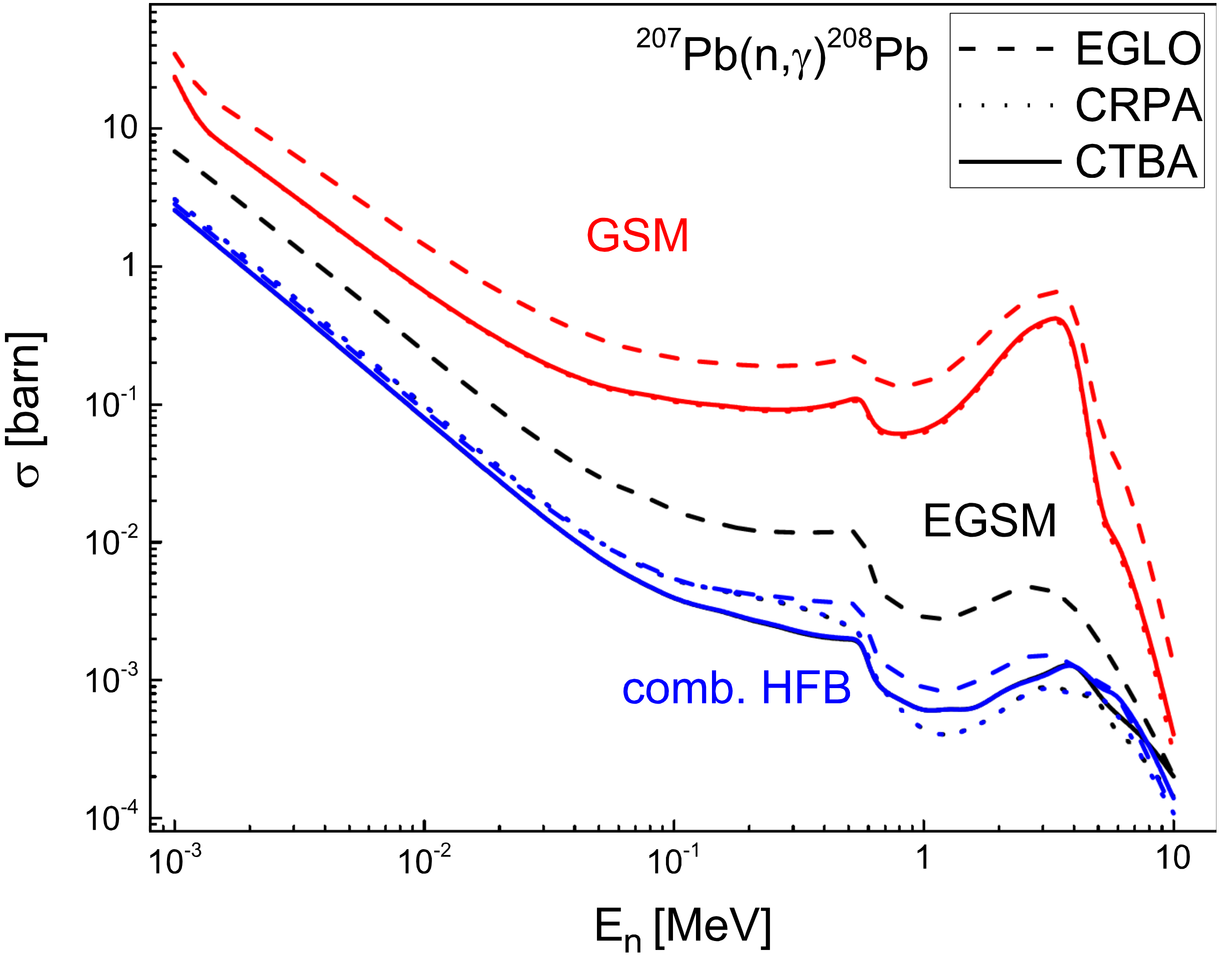
$$T_\gamma(E_n,J,\pi)=2\pi\sum_{X,\lambda}\int E_\gamma^{2L+1} f_{X\lambda}(E_\gamma)\rho($$

T_n is neutron transition coefficient

$$T_{tot}=T_n+T_p+T_d+T_t+T_\alpha+T_\gamma$$

$$\Gamma_{\gamma,E1}=D_0\int_0^{S_n} E_\gamma^3 f_{E1}(E_\gamma)\rho(S_n-E_\gamma)$$

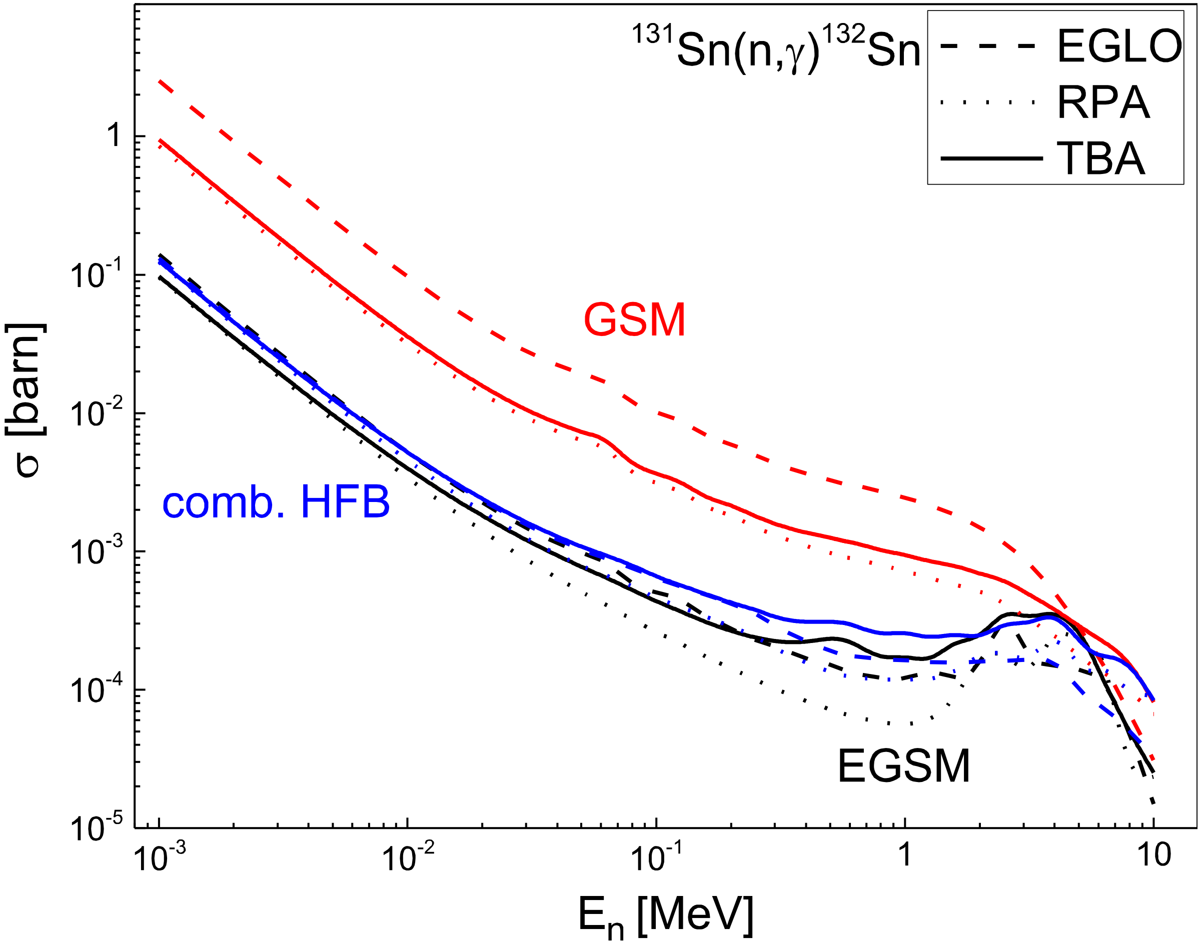
Neutron capture for ^{208}Pb



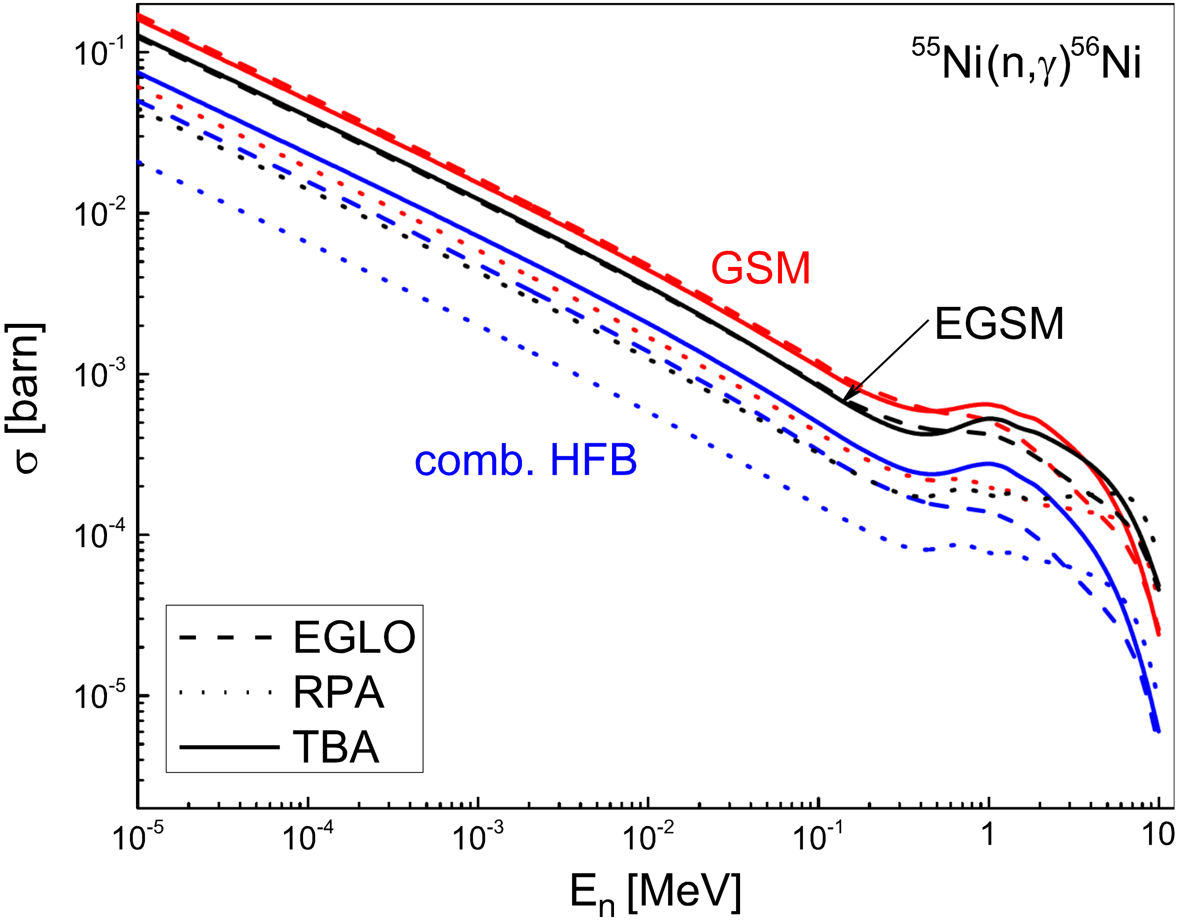
Very large difference between the results obtained with the traditional GSM and other NLD models (Enhanced GSM and combinatorial HFB)

Difference between the results obtained with CRPA and CTBA for one NLD model is much smaller than for different NLD models

Neutron capture for ^{132}Sn



Neutron capture for ^{56}Ni



Noticeable difference between results for RPA and TBA can be caused by the fact that PDR is lower than S_n

Similar results are observed for semi-magic nuclei

Average radiative widths E1+M1

Nuclei	NLD model	EGLO	RPA	TBA	System.	M1 contrib.
^{208}Pb	GSM	10,56	4,44	4,61	5070 3770	0,79
	EGSM	6292	2562	2109		6,56
	Comb. HFB	2734	2973	2448		5,25
^{132}Sn	GSM	398	133	148		40,9
	EGSM	7340	4675	5186		515,3
	Comb. HFB	4444	4279	4259		340,7
^{56}Ni	GSM	2279	270	656	2800	24,8
	EGSM	8073	1790	4160		214,3
	Comb. HFB	3132	647	1794		85,8

For ^{208}Pb:
D_0(GSM) = 0.00441 keV
D_0(EGSM) = 32.0 keV
D_0(HFB) = 37.6 keV
D_0(exp) = 30 (8) keV

Contribution of M1 resonance (Bohr model) is rather small

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

Conclusions

- Our results confirm the necessity of inclusion both the QRPA and PC effects in the theory of radiative nuclear data for double-magic nuclei, especially for PSFs
- We have more pronounced PSF structure for double magic nuclei than for semi-magic nuclei
- For ^{208}Pb and ^{132}Sn the contribution of PC to radiative cross sections and average radiative widths is not so noticeable as compared with the semi-magic nuclei
- For ^{208}Pb structures in PSF at E<4.8 MeV may be only caused by the transitions between excited states
- There is great disagreement between the results obtained with the phenomenological GSM and other two used NLD models in EMPIRE

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