Selfconsistent studies of the dipole response in spherical heavy nuclei using realistic potentials

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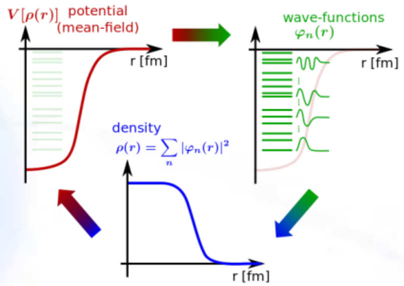
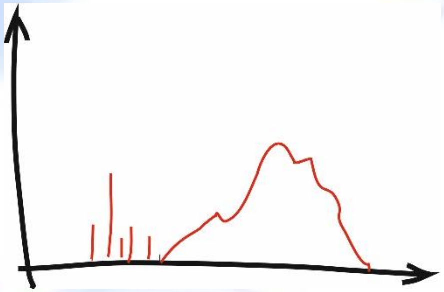
Microscopic description of dipole response





- Microscopic description of collective states (PDR, GDR):

RPA suitable for gross features NOT fine structure

Methods beyond:
Second RPA, Qusiparticle Phonon Model, Extended Theory of finite Fermi systems,
Relativistic Quasiparticle Time Blocking Approximation, Particle Vibration Coupling, Shell Model…

Our framework : **Equation of motion phonon method**

- Mean-field calculation: HF(B), expansion to HO basis
- Excited states and responses: matrix formulation of (Q)TDA,Q(RPA)
- Beyond 1-phonon: EMPM (Equation of Motion Phonon method)
  (subset of) 'complex' (2-phonon) configuration

Role of 'complex' configurations in dipole response in ^{132}Sn, ^{208}Pb.
Knapp et al. Phys. Rev. C **90**, 014310 (2014)
Knapp et al. submitted to Phys. Rev. C

Mean-field

Ingredients: Hamiltonian with 'realistic' 2-body NN interaction + phenomenological density dependent term

$$H = T_{int} + V. \qquad T_{int} = \frac{1}{2m}\sum_i p_i^2 - T_{CM} \qquad V = V_\chi + V_\rho$$

$$V_\rho = \sum_{i<j} v_\rho(ij) \qquad v_\rho = \frac{C_\rho}{6}(1+P_\sigma)\rho(\frac{\vec{r}_1+\vec{r}_2}{2})\delta(\vec{r}_1-\vec{r}_2)$$

Why DD interaction? Simulates 3 body forces

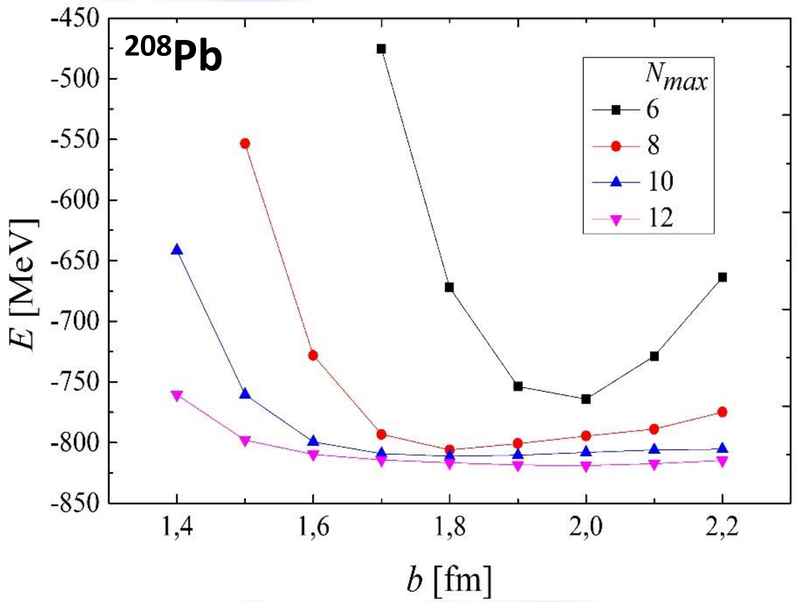
bare chiral NNLO$_{opt}$ (PRL 110, 192502 (2013)) gives large gaps between shells-> GDR peaks are too high in energy. Similar with UCOM and SRG evolved NN interactions , see H. Hergert et al.,PRC 83,064317(2011).

Free parameter C_ρ can be tuned to reproduce centroids of GR at RPA(TDA) level

Mean-field calculation: Hartree-Fock (Bogoljubov)+residual interaction

Future: replace phenomenological density dependent term with consistently derived one

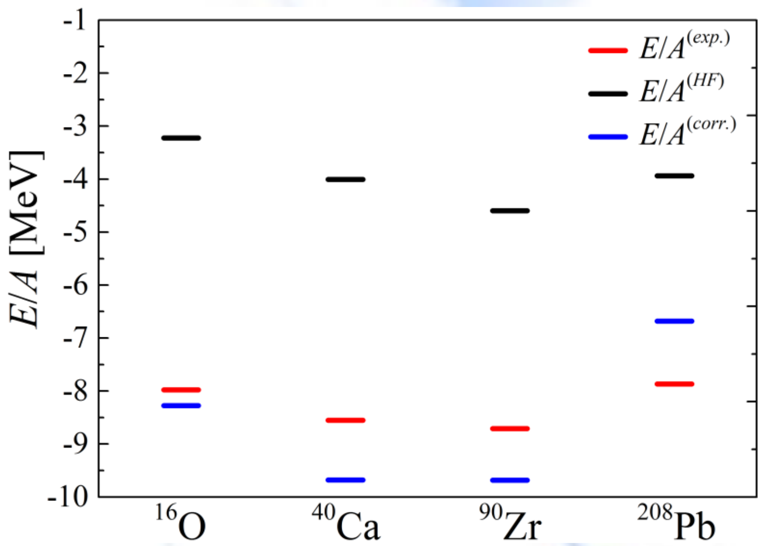
Mean-field

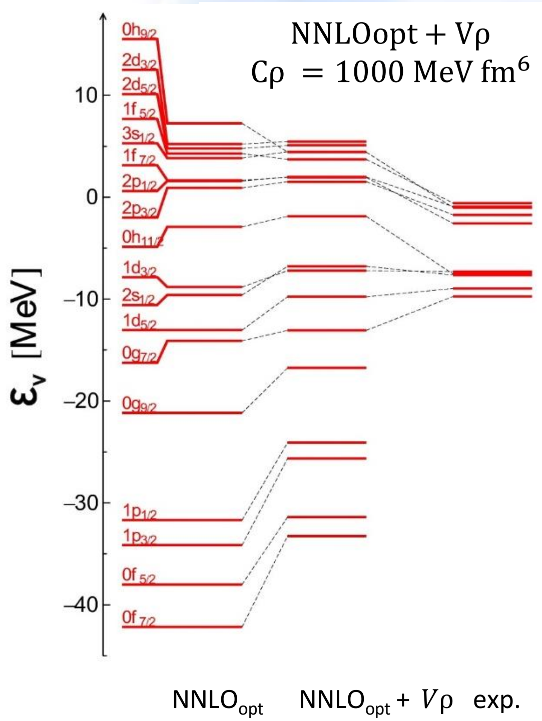


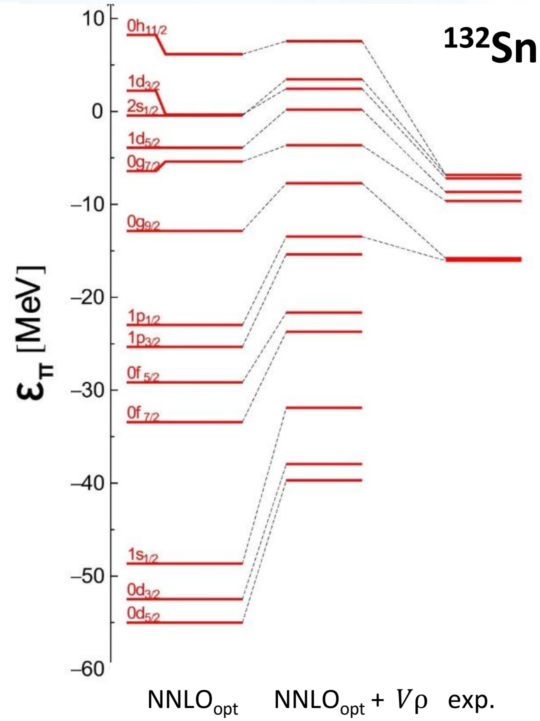
- HF calculation in HO basis
- weak dependence of HF energy on oscillator length *b* for 13 major shells

- 2nd order perturbation theory approaches to experimental binding energy

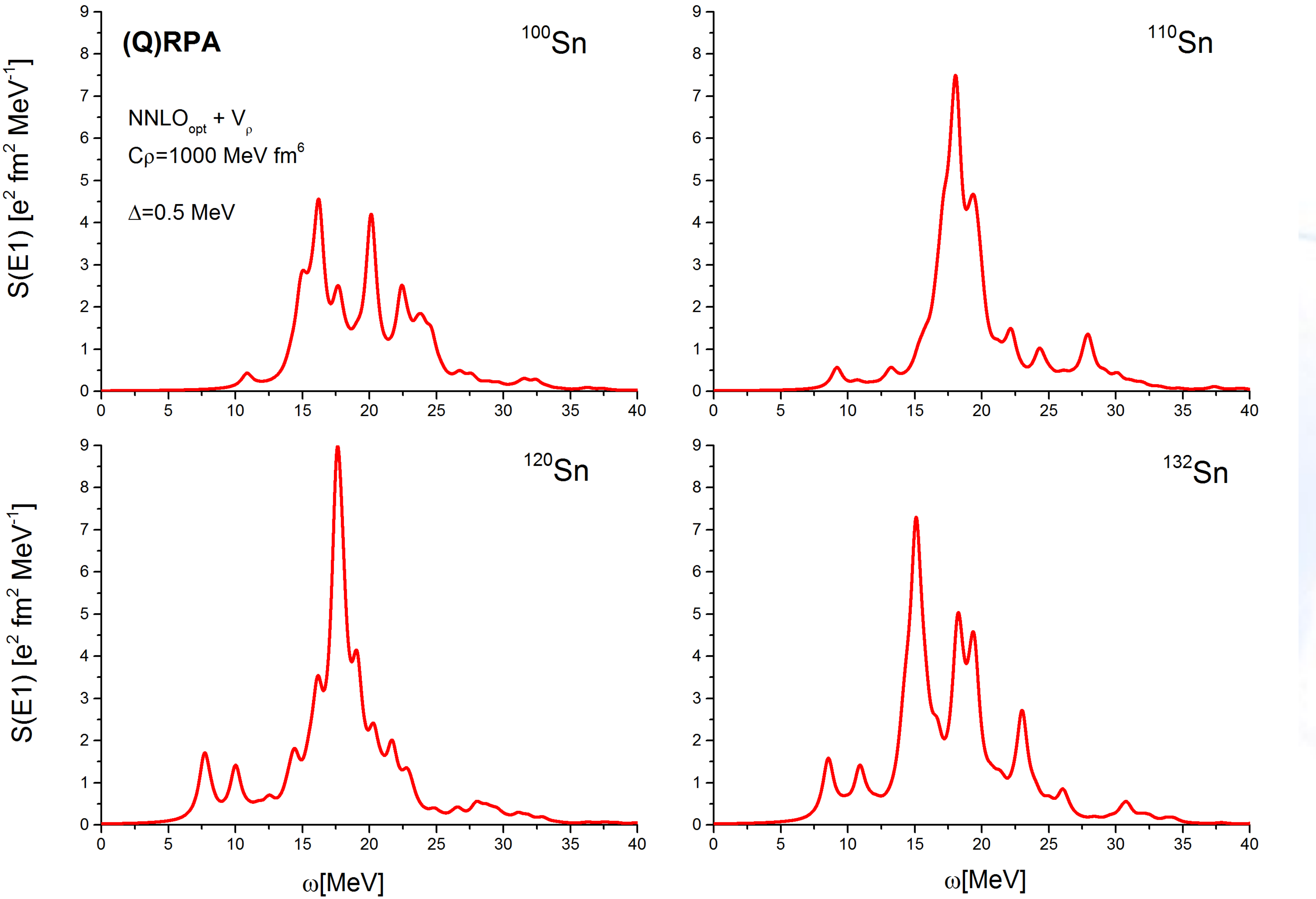
- effect of DD interaction: compression of s.p. spectra



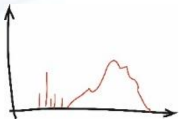




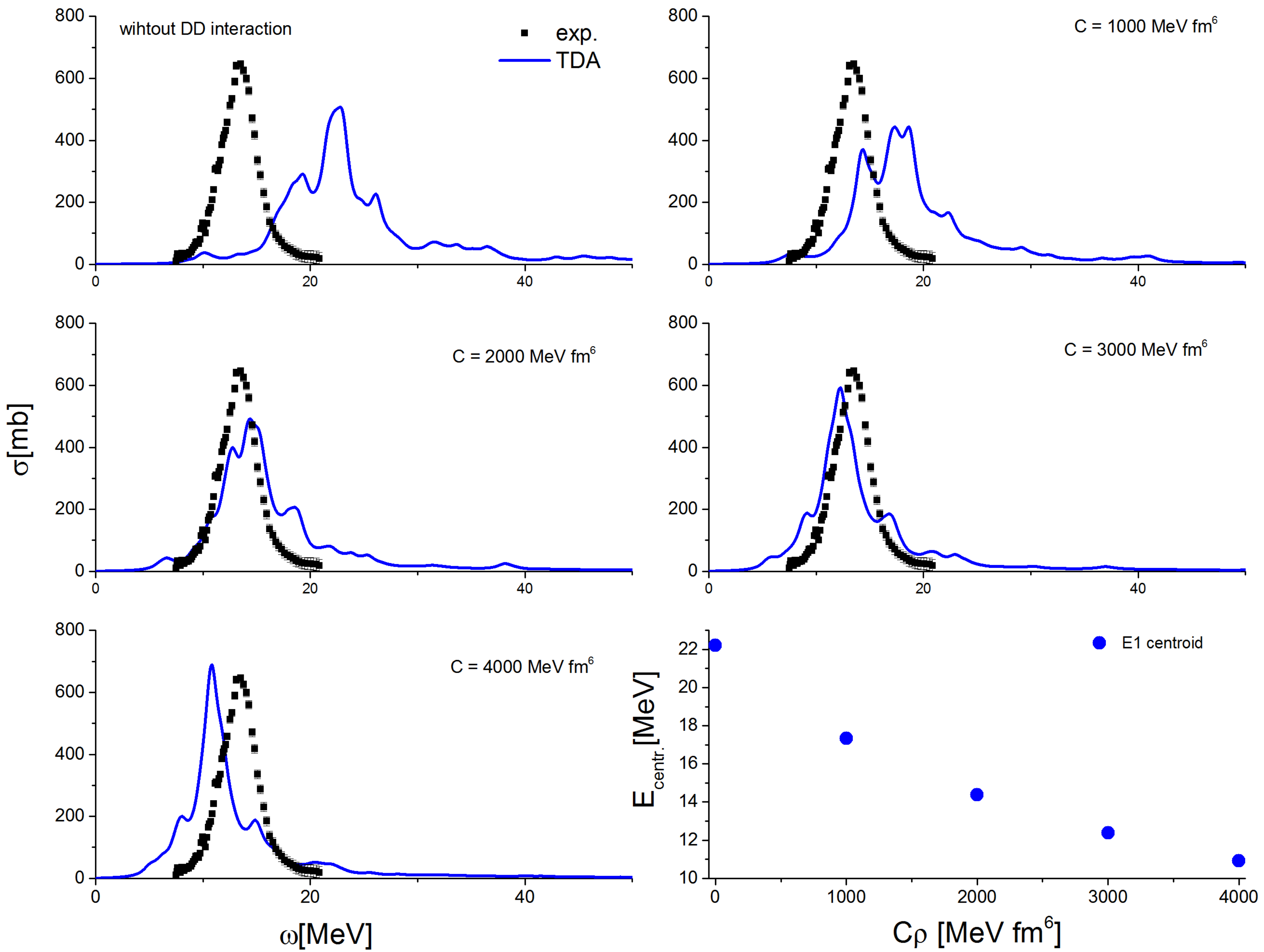
Dipole strength in Sn



Dipole strength in ^{208}Pb



Dependence of GDR centroids on the strength of DD interaction



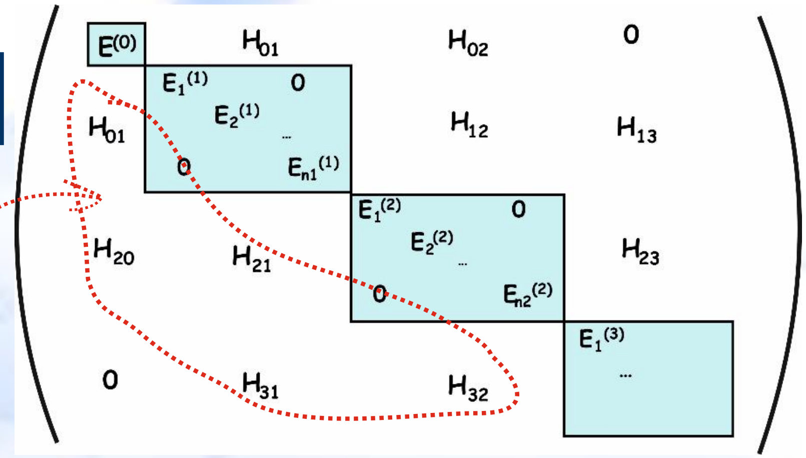
Equation of Motion Phonon Method

Goal: to diagonalize **general two-body** Hamiltonian in basis of TDA 1-phonon, 2-phonon states
all parts of two-body interaction and Pauli principle are taken into account

D. Bianco, F. Knapp, N. Lo Iudice, F. Andreozzi, and A. Porrino,
Phys. Rev. C **85**, 014313 (2012).

$$< n,\beta \parallel [H, O_\lambda^\dagger] \parallel n-1,\alpha > = \left(E_\beta^{(n)} - E_\alpha^{(n-1)}\right) < n,\beta \parallel O_\lambda^\dagger \parallel n-1,\alpha >$$

block-diagonal structure of Hamiltonian



couplings between phonon subspaces

Basis:
|0>
Q^+_λ |0> = |1,λ>
Q^+_λ |1,i>, i=1,2...n_1
Q^+_λ |2,j>, j=1,2...n_2

n-phonon subspace: generalized eigenvalue problem in nonorthogonal redundant basis

$$\mathcal{H}C = (\mathcal{A}\mathcal{D})C = EC$$

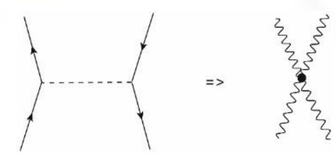
Phonon interaction matrix

$$\mathcal{A}^\beta(\lambda\alpha, \lambda'\gamma) = (E_\lambda + E_\alpha)\delta_{\lambda\lambda'}\delta_{\alpha\gamma} + \sum_\sigma W(\beta\lambda'\alpha\sigma;\gamma\lambda)\mathcal{V}^\sigma_{\lambda\alpha,\lambda'\gamma}$$

Overlap matrix

$$\mathcal{D}^\beta(\alpha\lambda;\alpha'\lambda') = \left[< n-1,\alpha' \mid \times O_{\lambda'}\right]_\beta \left[O_\lambda^\dagger \times \mid n-1'\alpha >\right]$$

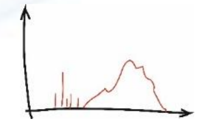
redefined phonon interaction



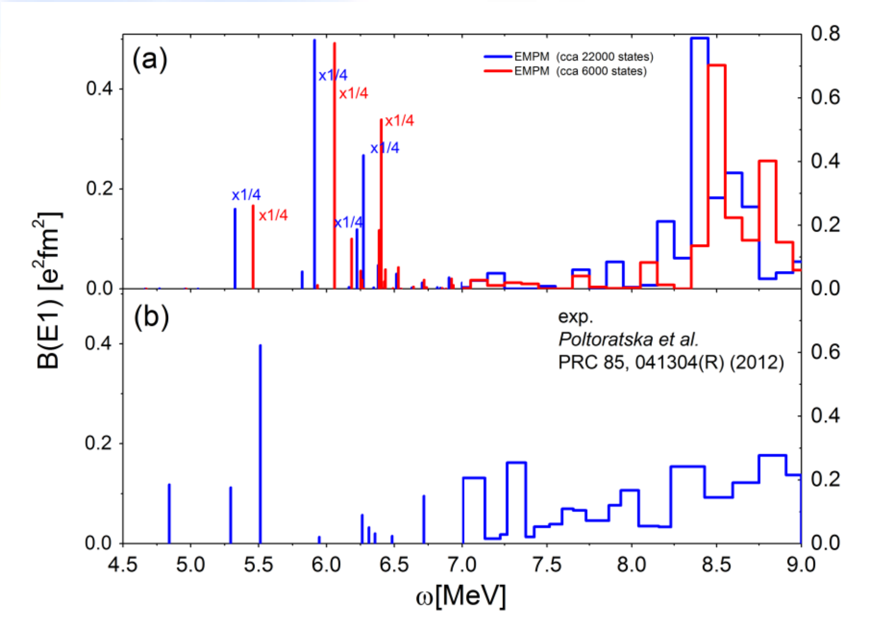
Final wave function

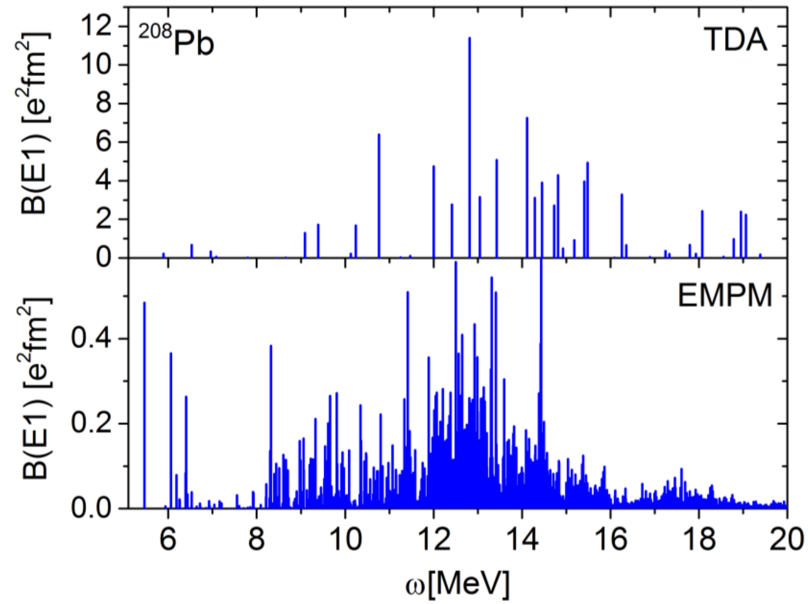
$$\mid \Psi_\nu\rangle = \sum_{n\alpha} C_\alpha^{(\nu)} \mid n;\alpha\rangle$$

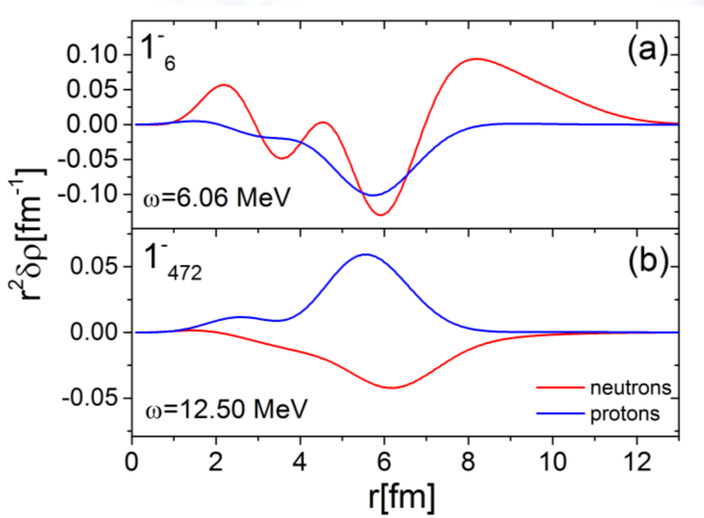
Dipole strength in ^{208}Pb

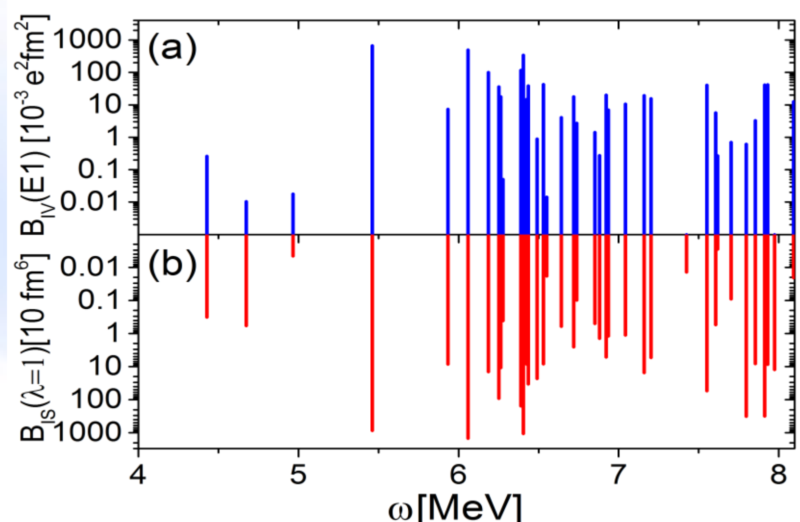


- truncation in phonon basis typically according to energy, collectivity ..
- description of spreading width due to the $\mathbf{Q^+}$ and $\mathbf{[Q_1^+ \times Q_2^+]^{1-}}$ coupling
- spectrum becomes extremely rich in comparison with RPA (TDA)

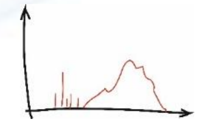


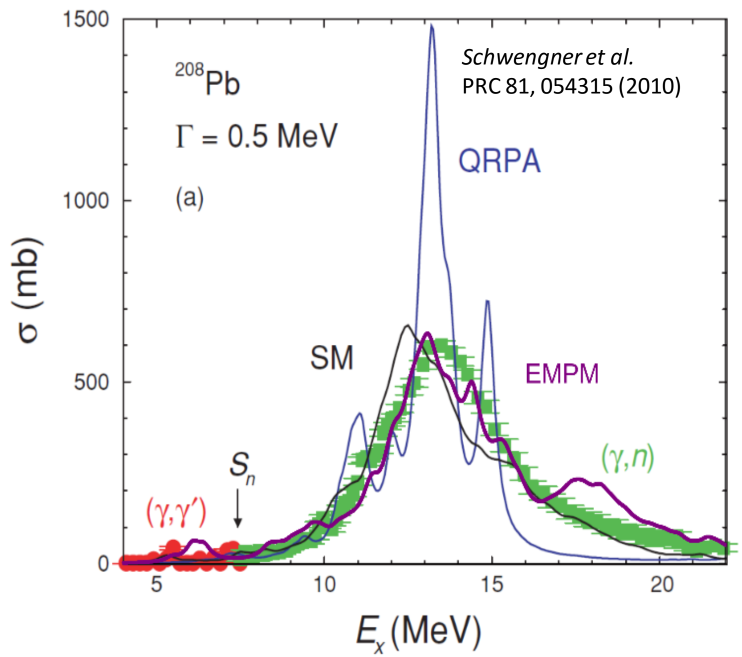


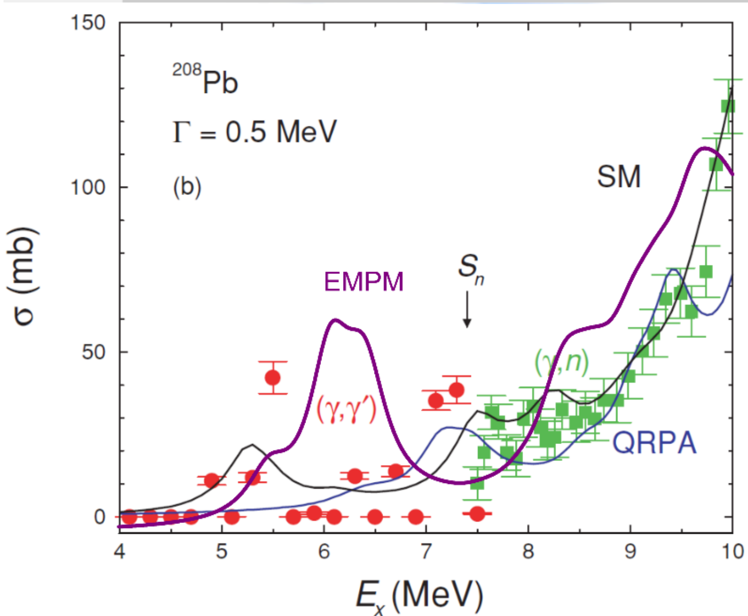




Dipole strength in ^{208}Pb

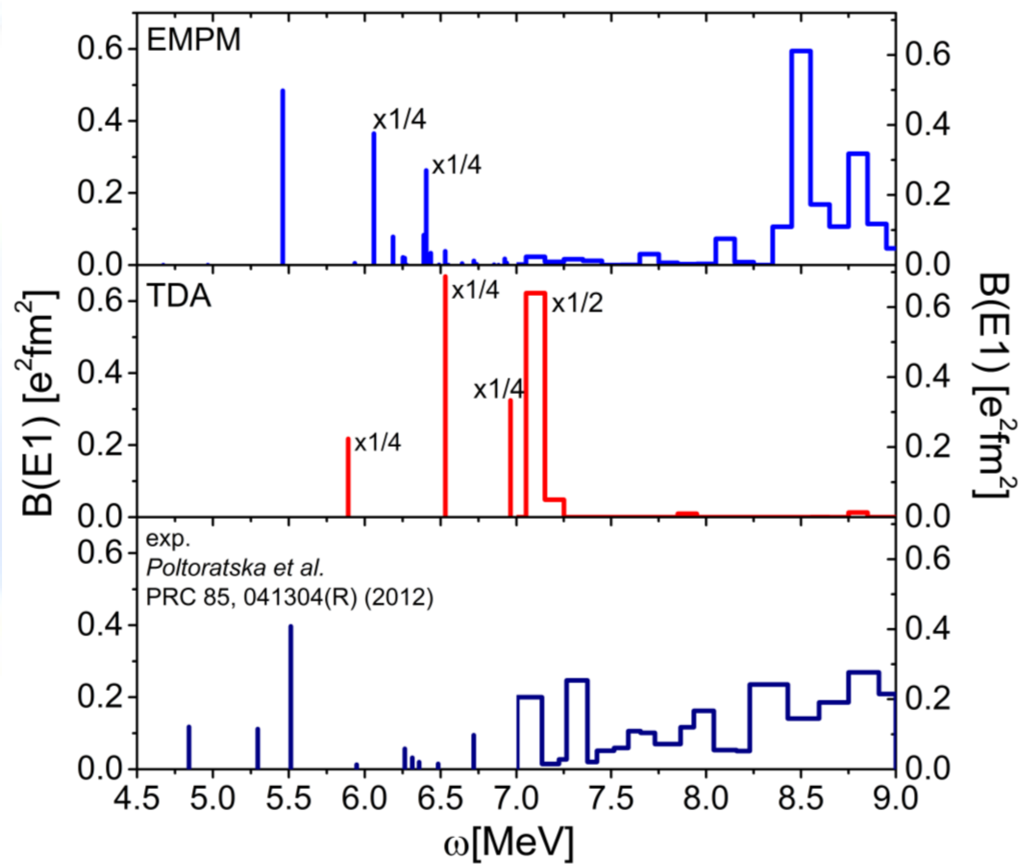






- EMPM predicts strength in the region 7-9 MeV whereas TDA and RPA not.
- density of states reasonable but few states are too strong

Could 3p-3h cure this? Suppression of 1p-1h component due to the 1- 3 phonon coupling



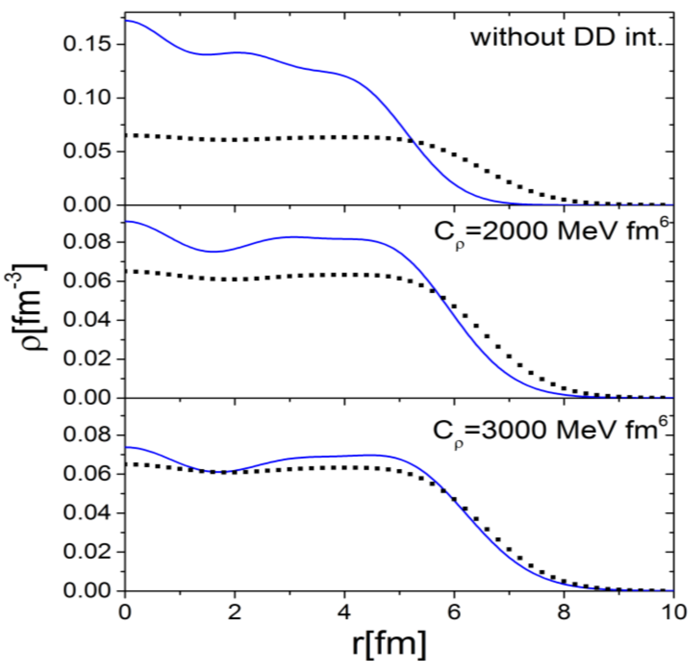
Skin thickness and polarizability in ^{208}Pb

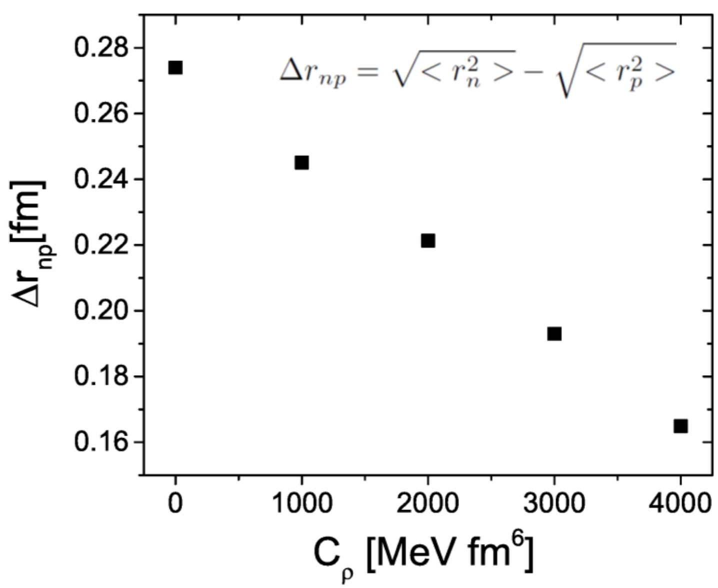
- Skin thickness sensitive to strength of DD interaction.

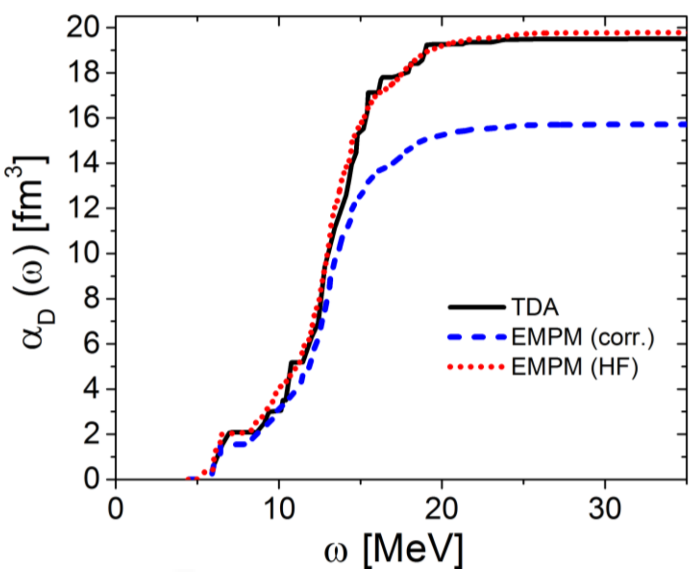
- For C_ρ=2000 MeVfm^6 increase of skin thickness due to the g.s. correlations from 0.22fm at HF to 0.31 fm in EMPM

- Polarizability
$$\alpha_D = \frac{\hbar c}{2\pi^2 e^2} \int_0^\infty \omega^{-2} \sigma(\omega) d\omega.$$

α_D(HF)=19.8 fm^3 with HF w.f.
if correlations are taken into account we get
α_D(corr.)=15.7 fm^3



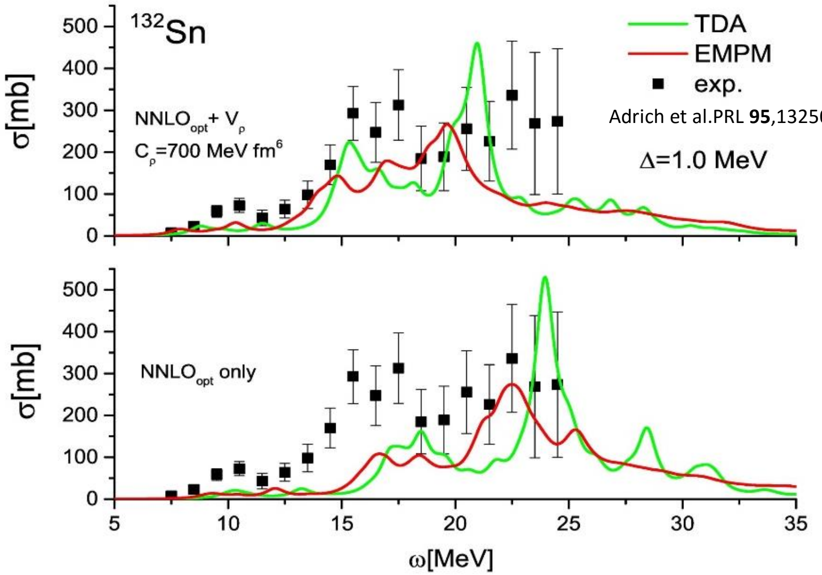


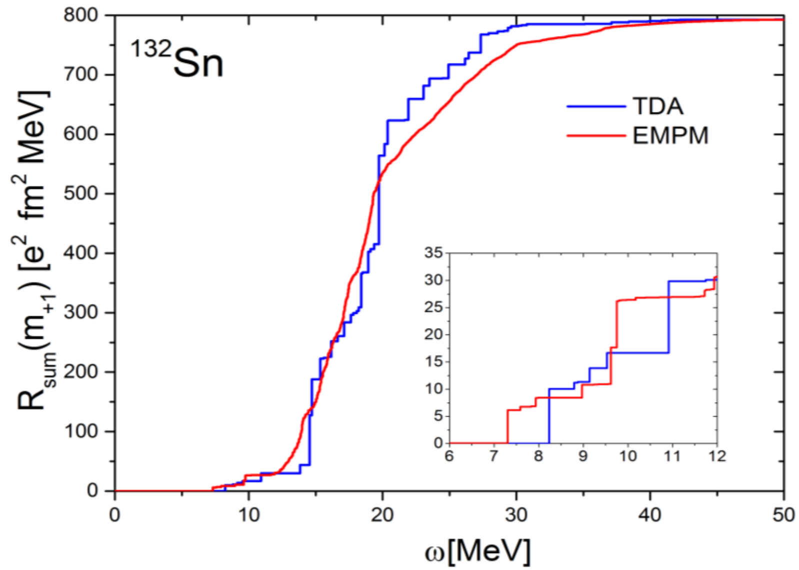


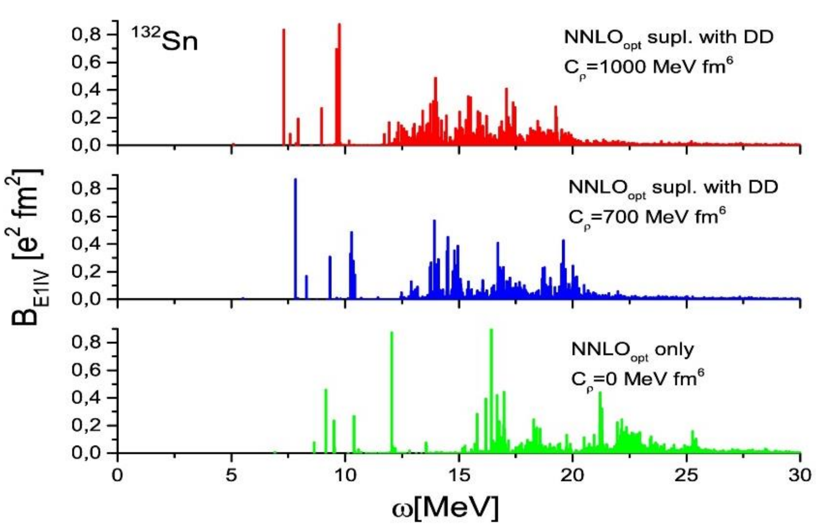
Dipole strength in ^{132}Sn

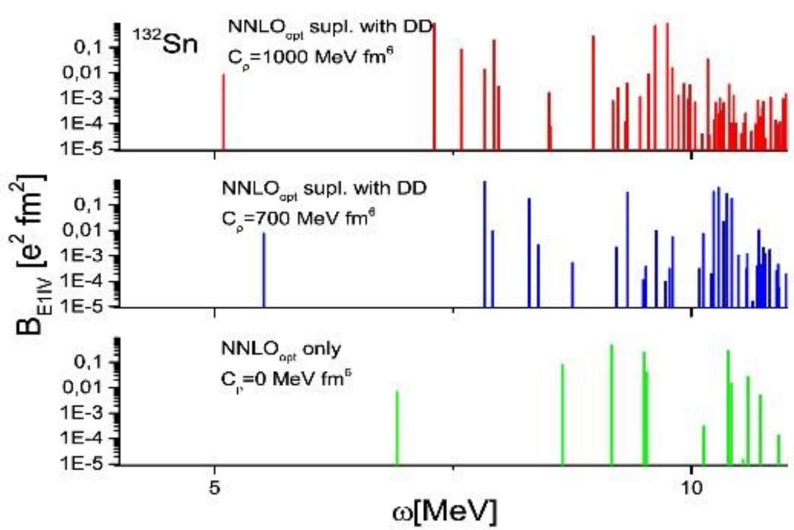
Similar picture as in lead.

details can be found in Knapp et al. Phys. Rev. C 90, 014310 (2014)



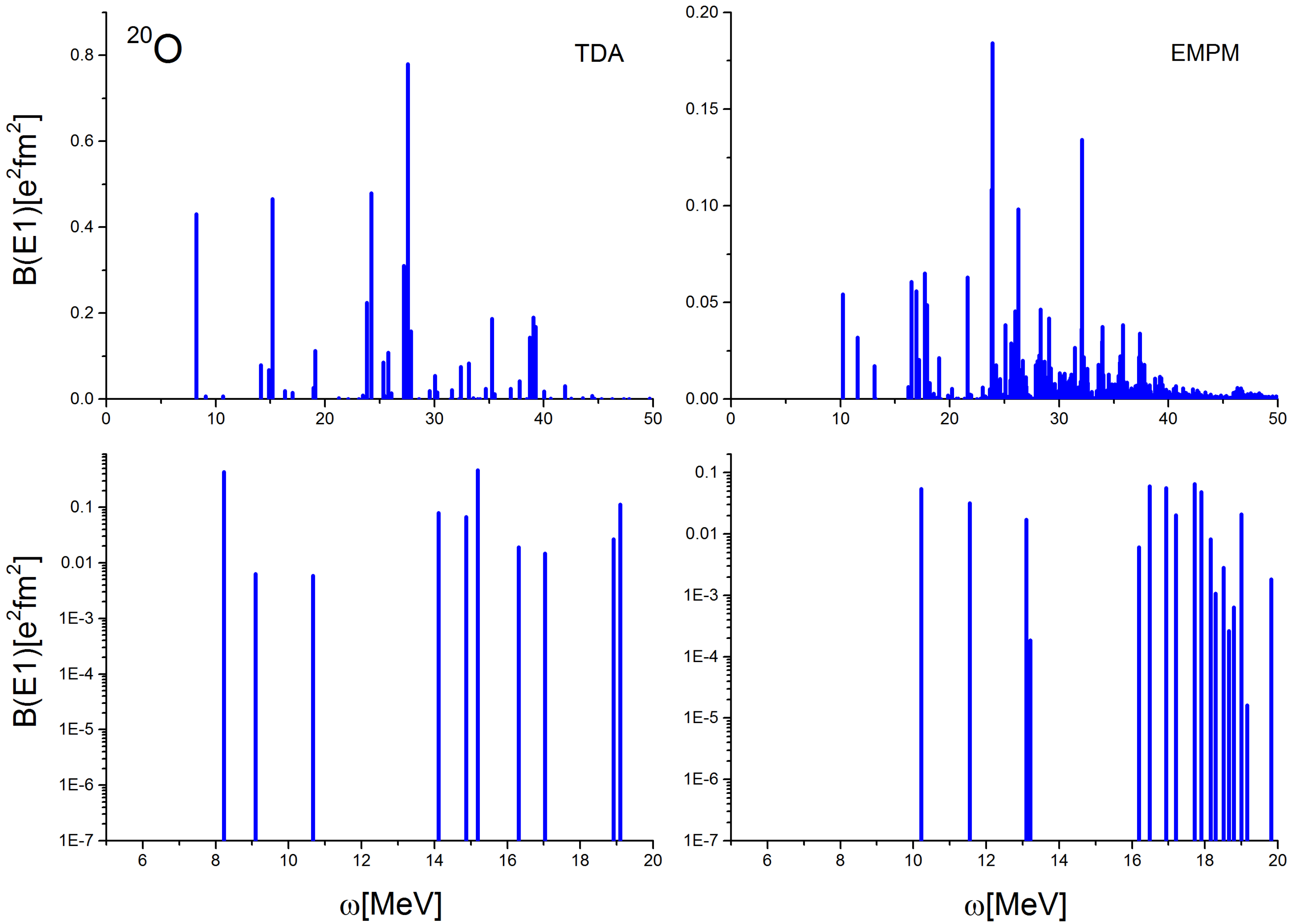






Towards open-shell nuclei

First results: calculation up to 2 phonons (4qp exitations):
strong coupling of valence neutrons with 1p-1h excitations



Summary

- selfconsistent description of E1 strength with realistic NN potential (chiral $NNLO_{opt}$)
- lowest states 1-phonon and 2-phonon character

- shape of GR: sum of many complicated states

- 2 –phonon states complicated combinations of $[Q_1^+ \times Q_2^+]^{1-}$

$[2^+ \times 1^-]^{1-}$, $[4^+ \times 3^-]^{1-}$
- ground state correlations: g.s. w.f typically 80% HF and 20 % 2-phon.

- 2pon.-1-phon. coupling responsible for rich low-lying 1^- spectrum

-> detailed description of pygmy dipole mode, however, sensitive to s.p. details

Future plans:
- first application of quasiparticle formalism for ^{20}O -> in future systematics of PDR strength for open-shell nuclei (P. Veselý)
- odd particle systems: particle phonon coupling (G. De Gregorio)
- 3-body force