A self-consistent equation of motion multi-phonon method for even mass nuclei

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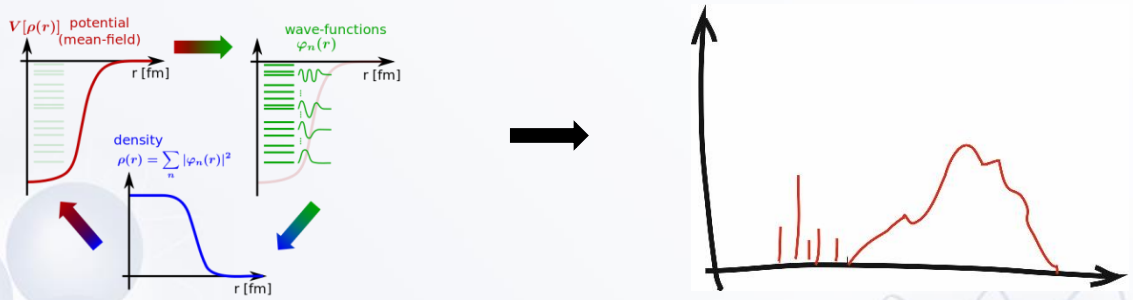
Microscopic description of collective states



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

RPA suitable for gross features **NOT** fine structure

How to get it?

Second RPA, Quasiparticle 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 (EMPM)**

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

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).*

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

Basis:

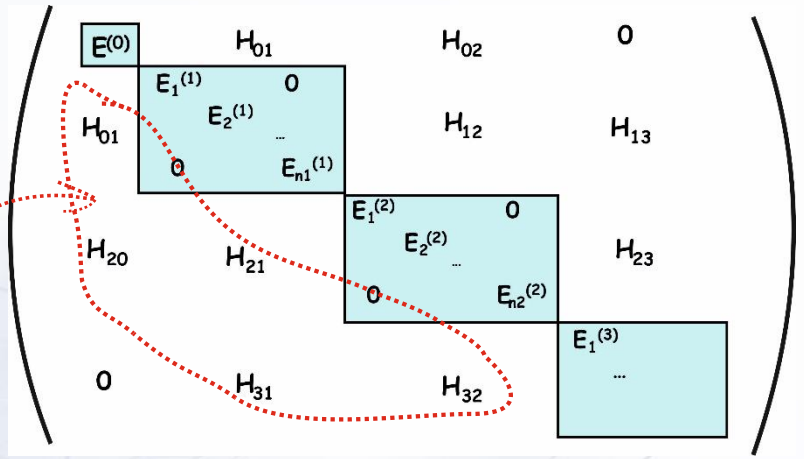
$|HF(B)\rangle$

$Q^{+}_{\lambda}\,|HF(B)\rangle = |1,\lambda\rangle$ Q(TDA)

$Q^{+}_{\lambda}\,|1,i\rangle$, $i=1,2\ldots n_1$

$Q^{+}_{\lambda}\,|2,j\rangle$, $j=1,2\ldots n_2$

couplings between phonon subspaces



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

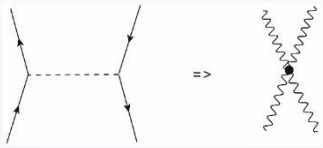
$$\mathcal{H}C = (\mathcal{A}\mathcal{D})C = EC$$

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

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



Wave function $\quad |\Psi_{\nu}\rangle = \sum_{n\alpha} C^{(\nu)}_{\alpha} \mid n;\alpha\rangle$

Hamiltonian

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

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

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

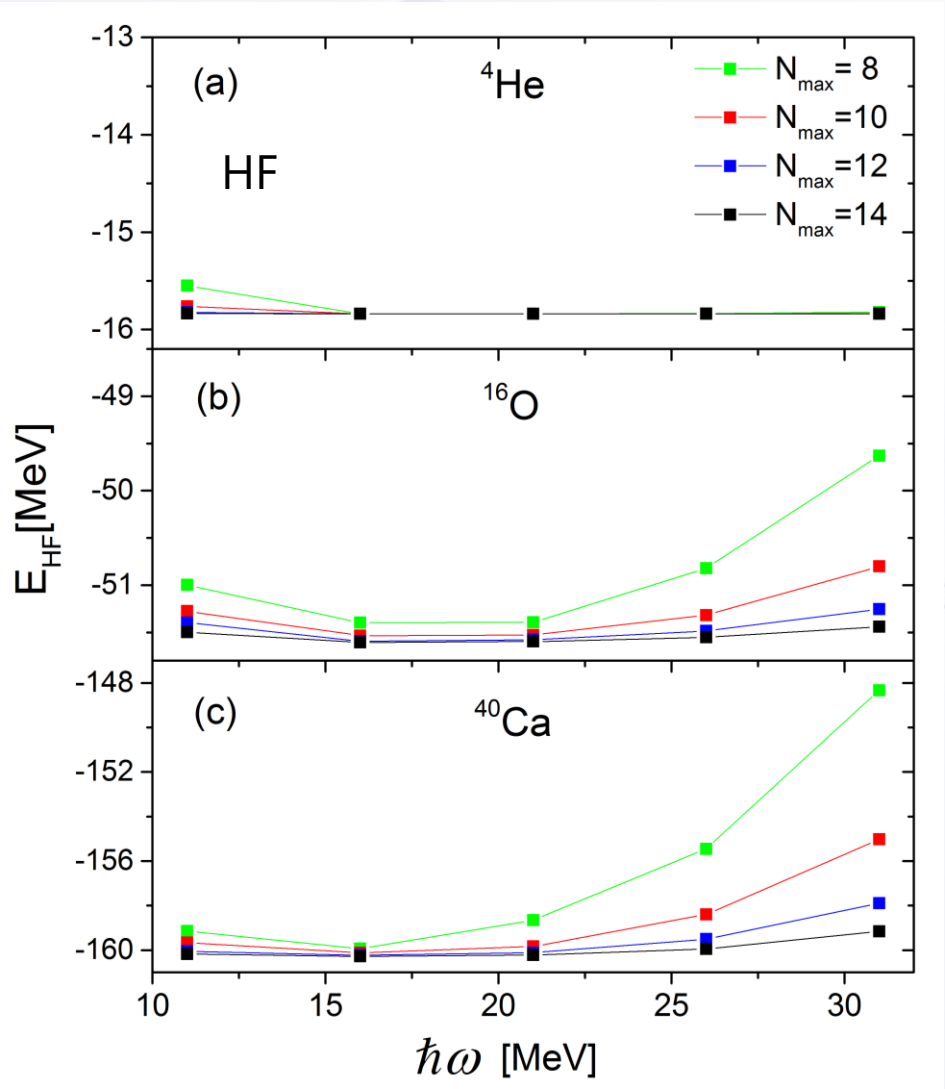
V_χ NNLO$_{opt}$ (*Ekstrom et al., PRL 110, 192502 (2013)*)
produces large gaps between shells → GDR peaks are too high in energy.

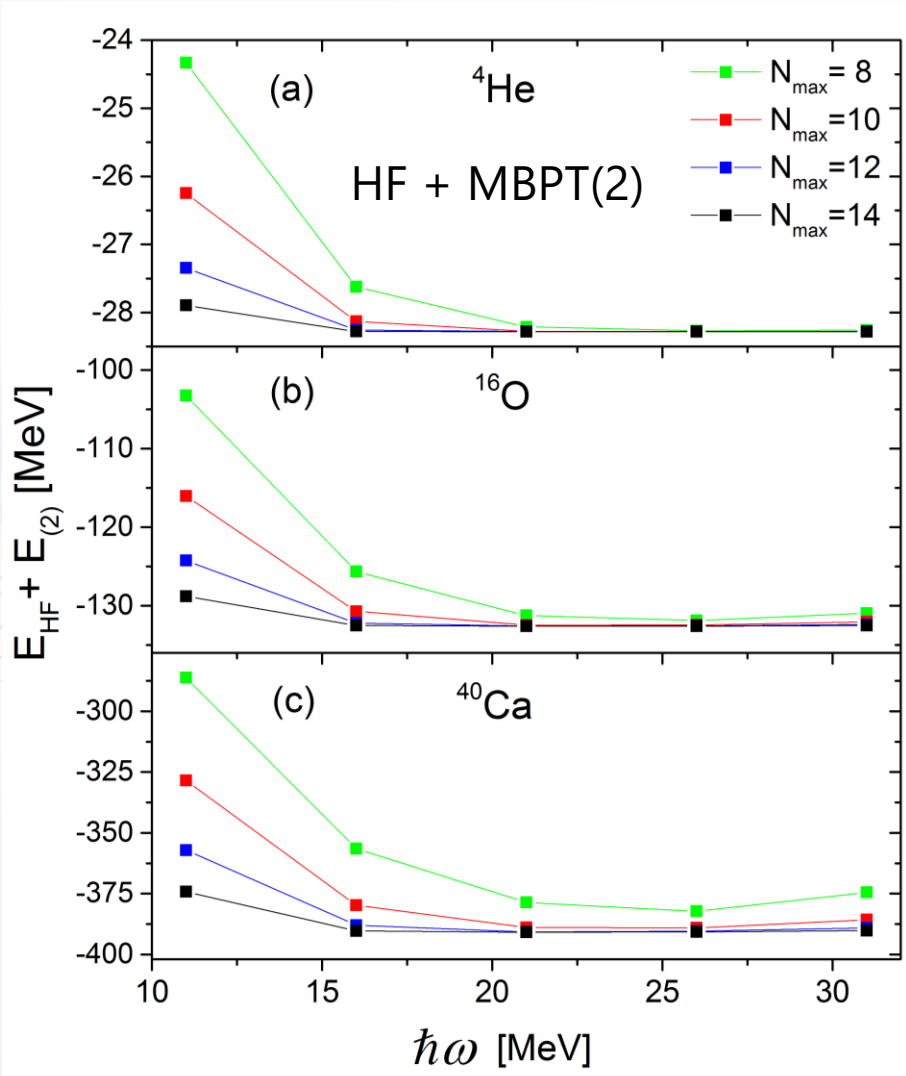
similar to UCOM and SRG evolved NN interactions (*Hergert et al.,PRC 83,064317(2011)*)
→
DD interaction V_ρ : missing (3-body) forces

Mean-field calculation: Hartree-Fock (Bogoljubov)
Ground state and collective excitations (E1): Equation-of-motion Phonon Method

Ground state properties

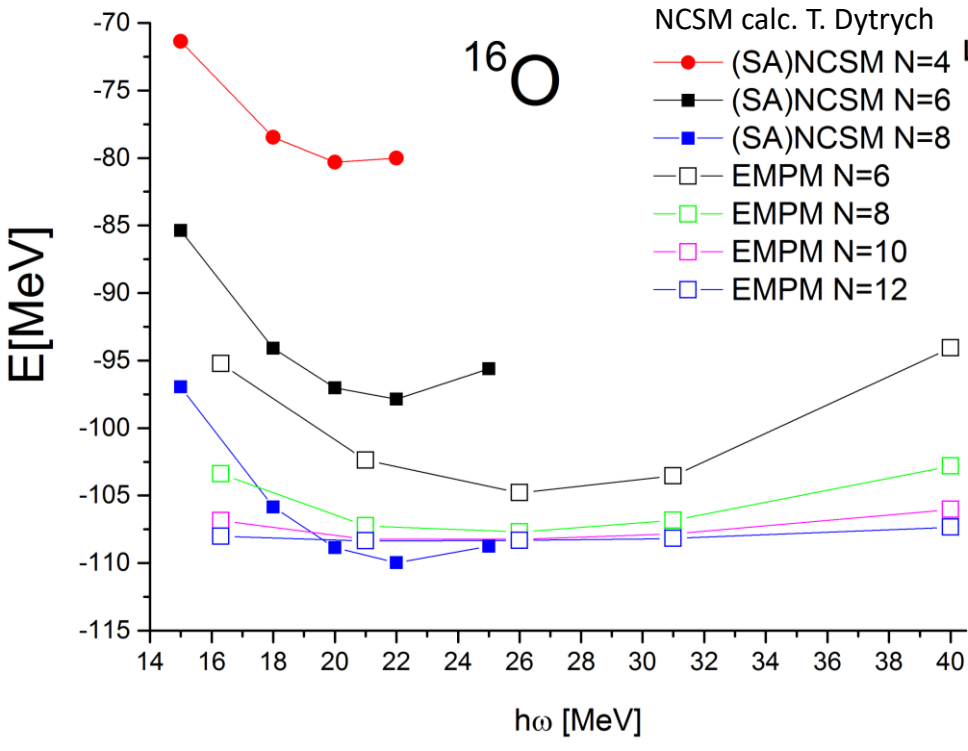
- bare NNLO$_{opt}$ interaction, (DD interaction **not included!)**
- binding energies HF + MBPT(2)

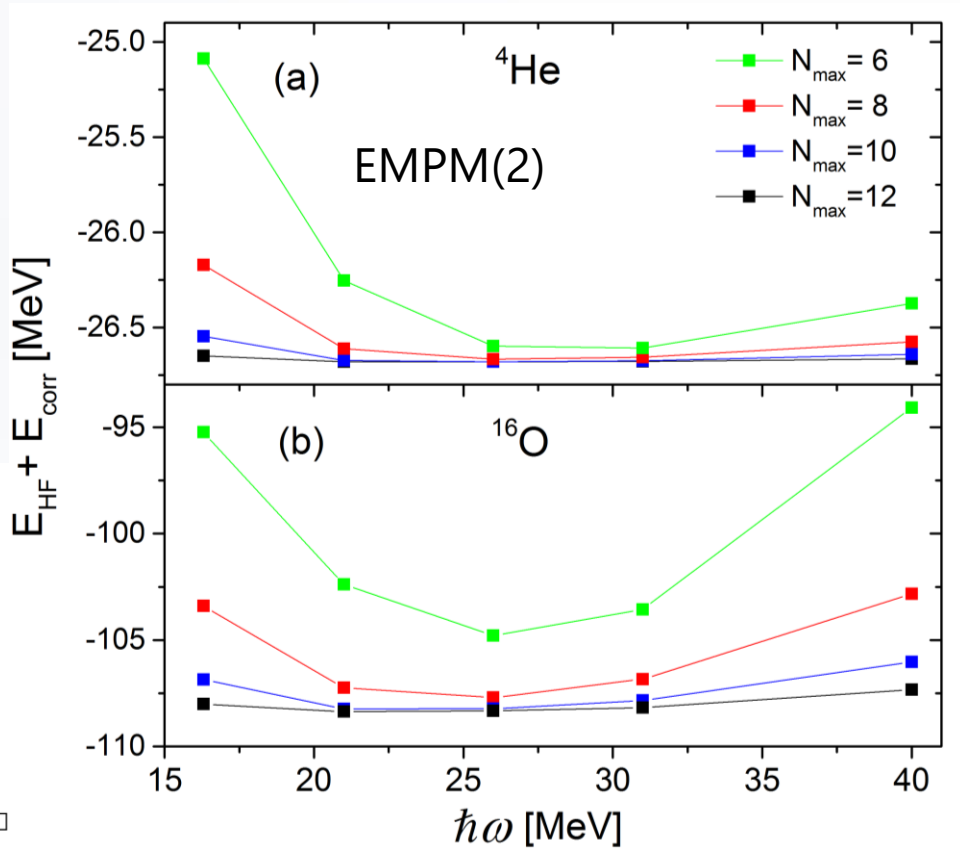




Ground state properties

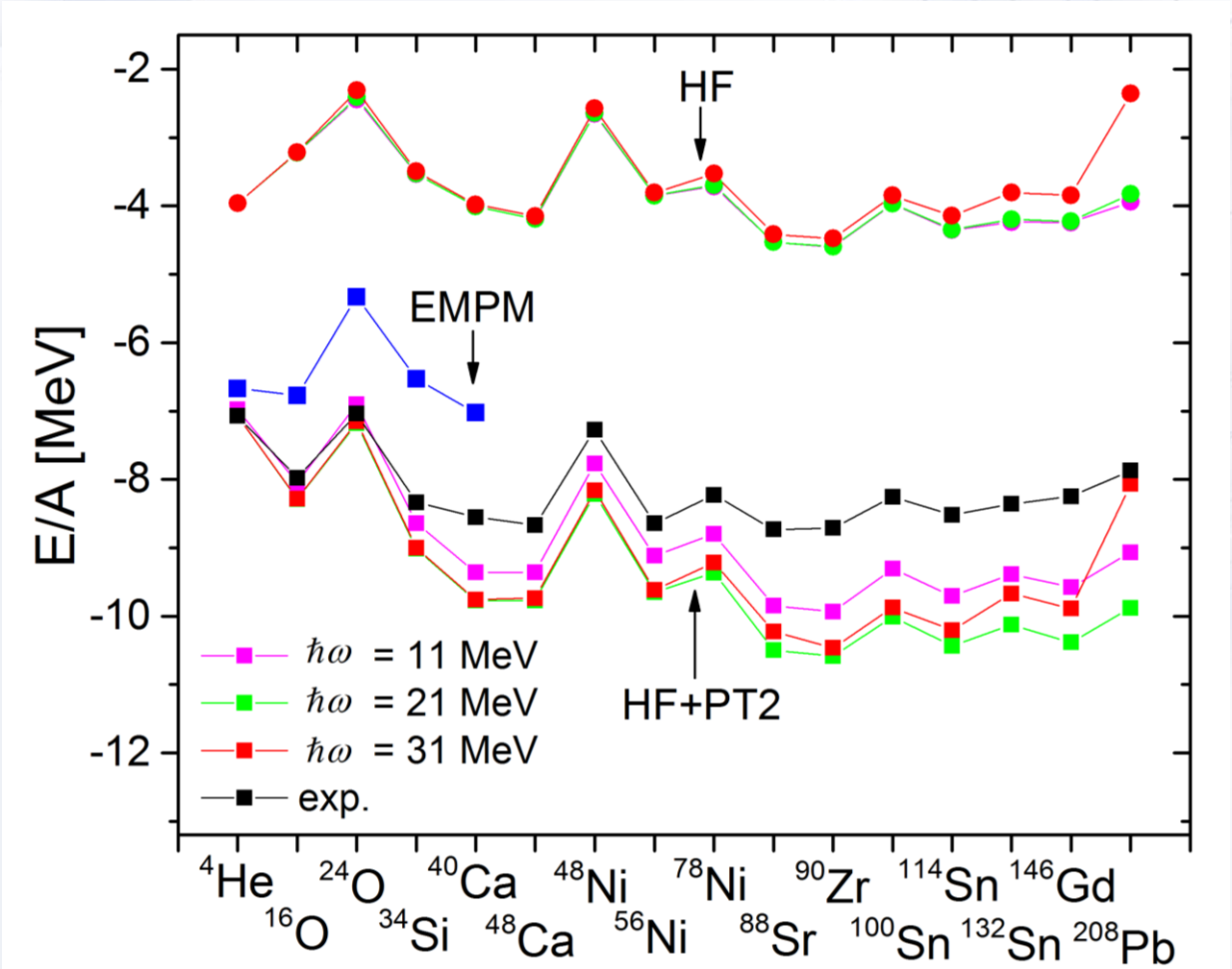
- converged g.s energies for ^{16}O
- net contribution of 2phon. to correlation energy
- need to include 3-phon., 4-phon.



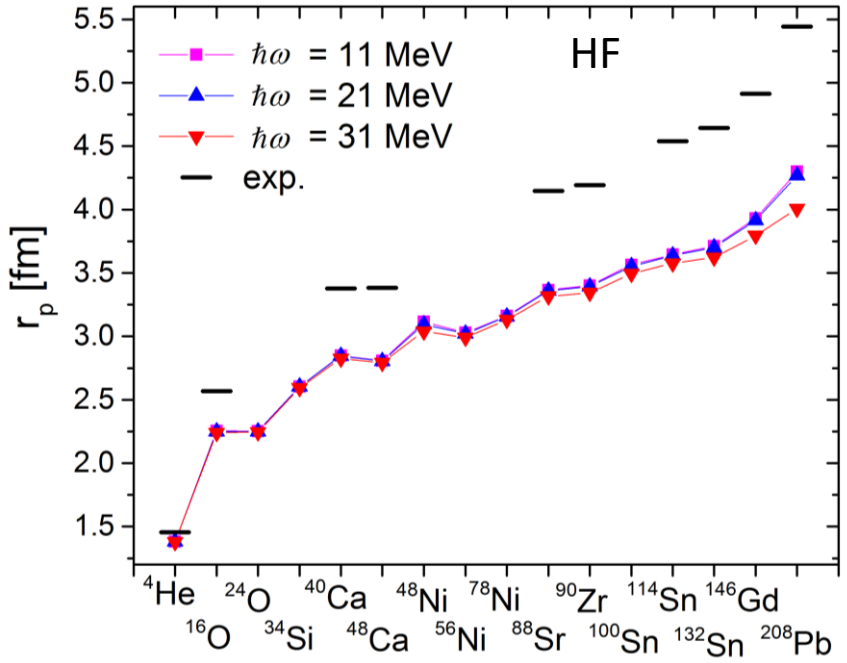


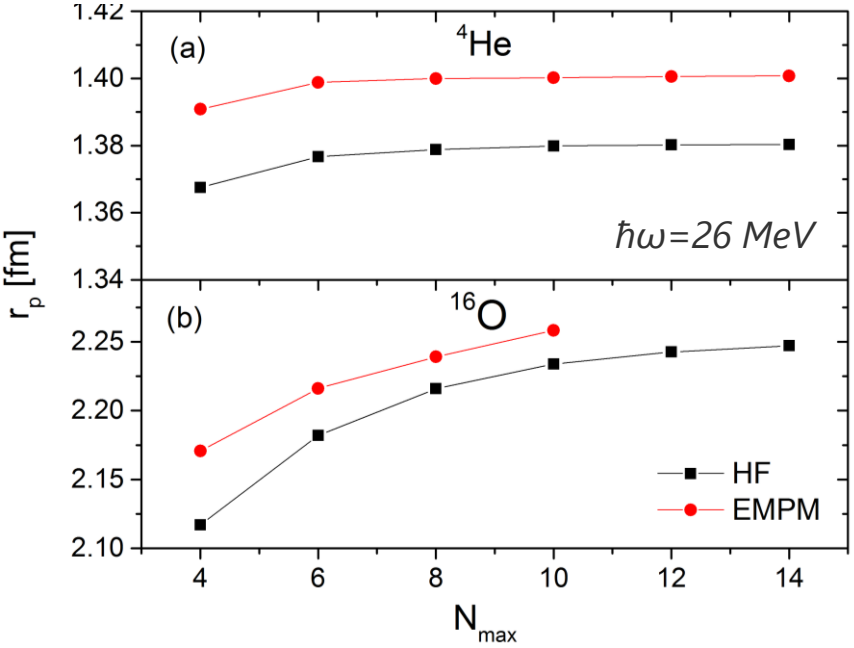
Ground state properties

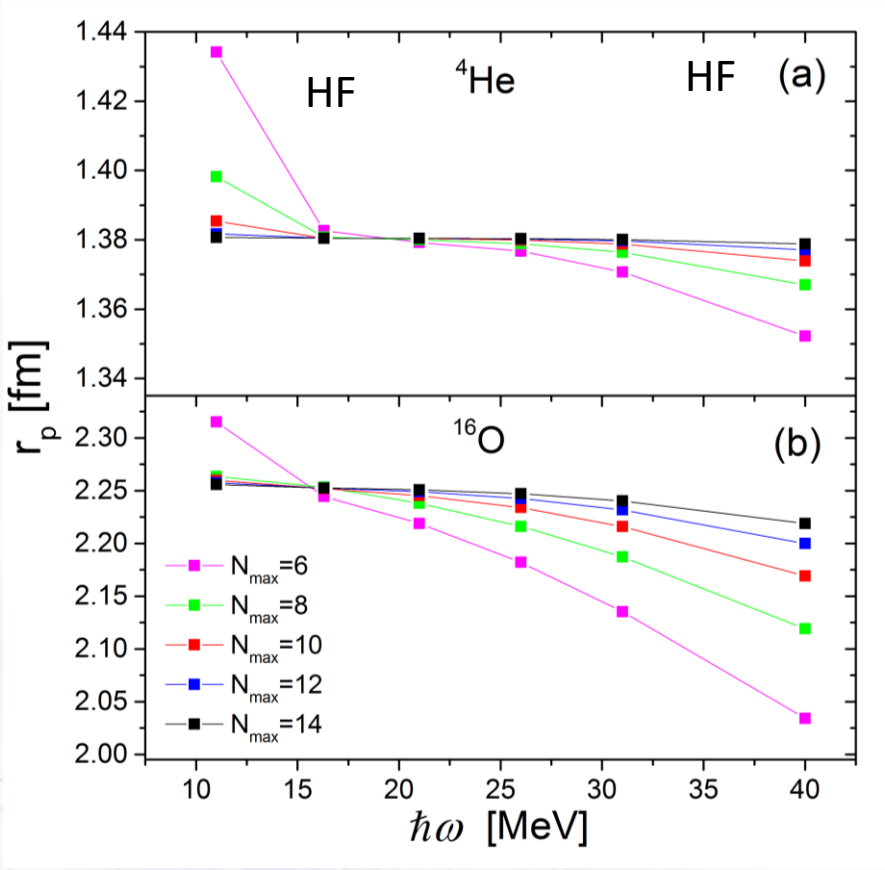
- HF typically 40-50% of total BE, similar to UCOM, MBPT(2) overbinding (*Roth. et al. Phys. Rev. C **73**, 044312(2006)*)
- HF almost independent on $\hbar\omega$ up to *Ni*, dependence for MBPT(2)
- EMPM – converged results for ^{16}O (N_{max}=12), not converged for ^{40}Ca, ^{34}Si, ^{48}Ca,
- g.s. w.f. : typically 80% HF 20% 2-phon.
- EMPM smaller binding compared to MBPT(2)



Ground state properties







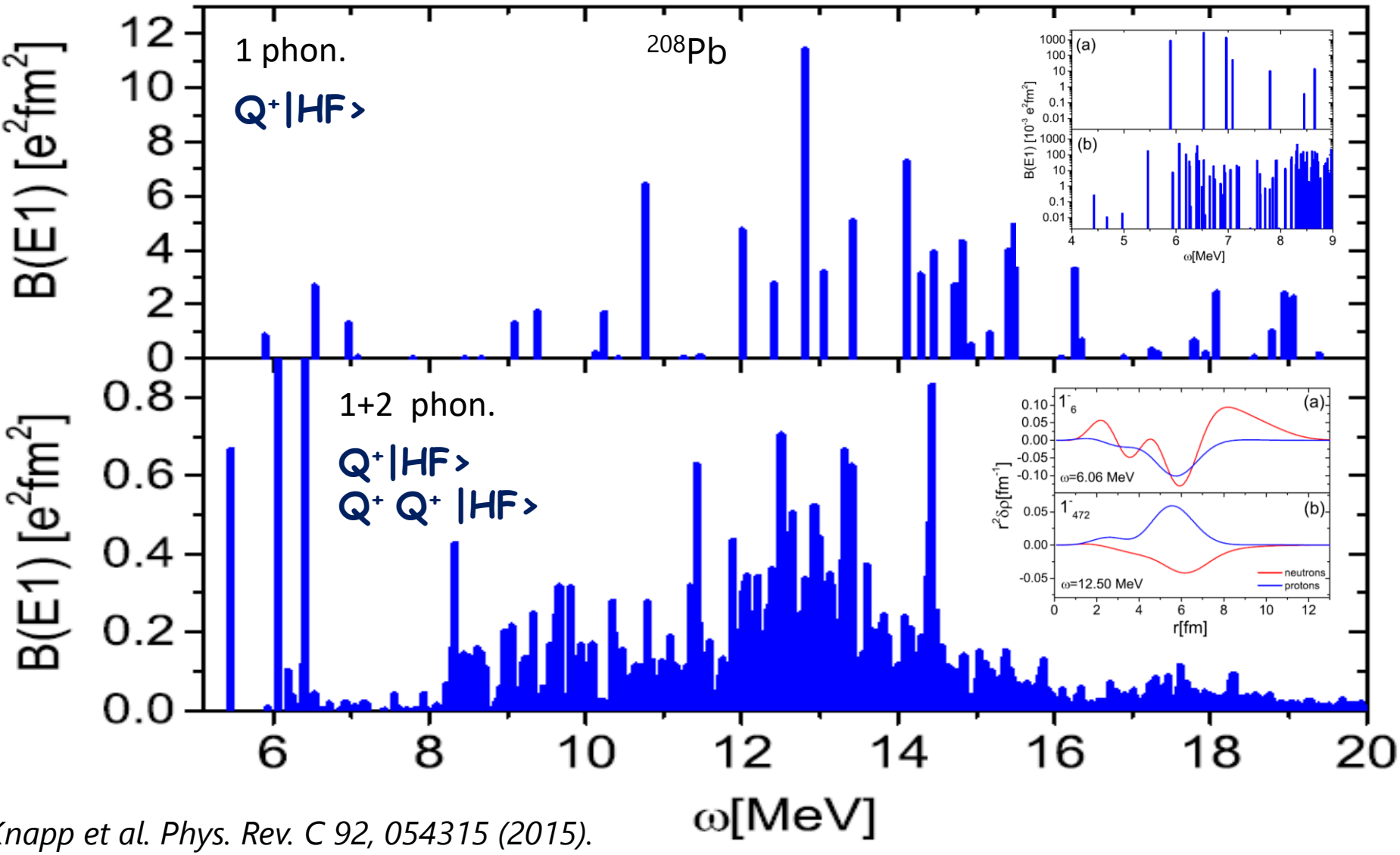
- small radii at HF level
- 2-phonon (2p2h) contribution

improves it (0.02-0.05 fm), but still big discrepancy

De Gregorio et al., submitted to PRC.

Dipole strength in ^{208}Pb

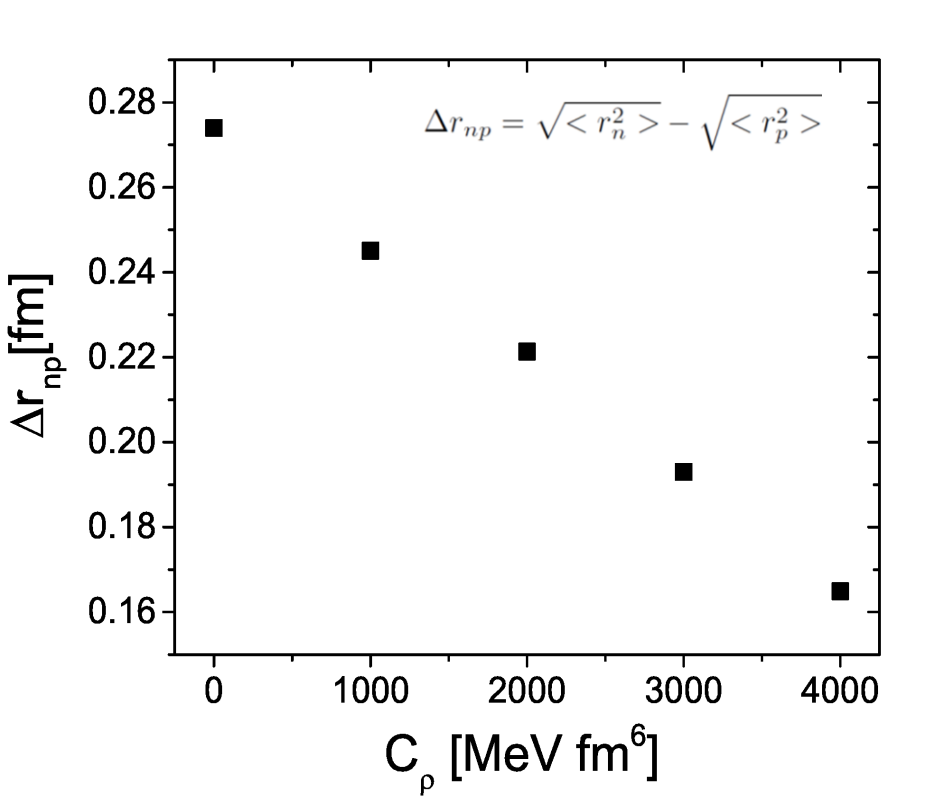
- phenomenological DD term → compression of s.p. spectrum, increase of radius
- EMPM up to 2-phonons: subset of phonons with energy < 30 MeV

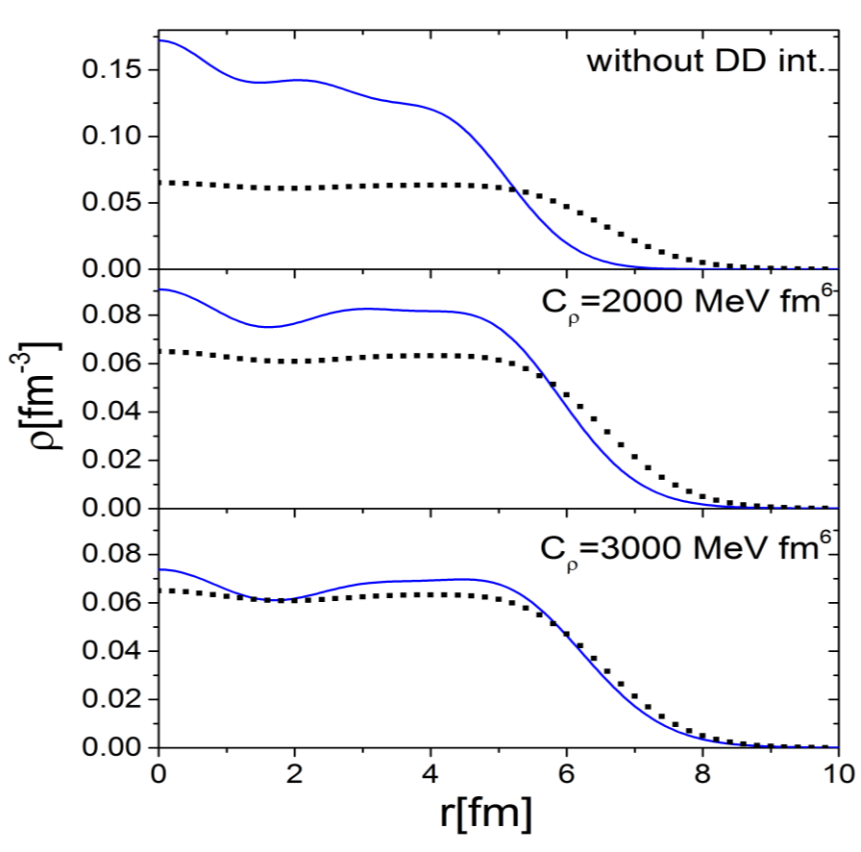


Knapp et al. Phys. Rev. C 92, 054315 (2015).

Skin thickness in ^{208}Pb

- Radii and skin thickness sensitive to the strength of DD interaction.
- For C_ρ=2000 $\mathrm{MeV}fm^6$ increase of skin thickness due to the g.s. correlations from 0.22 fm at HF to 0.31 fm in EMPM





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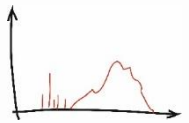
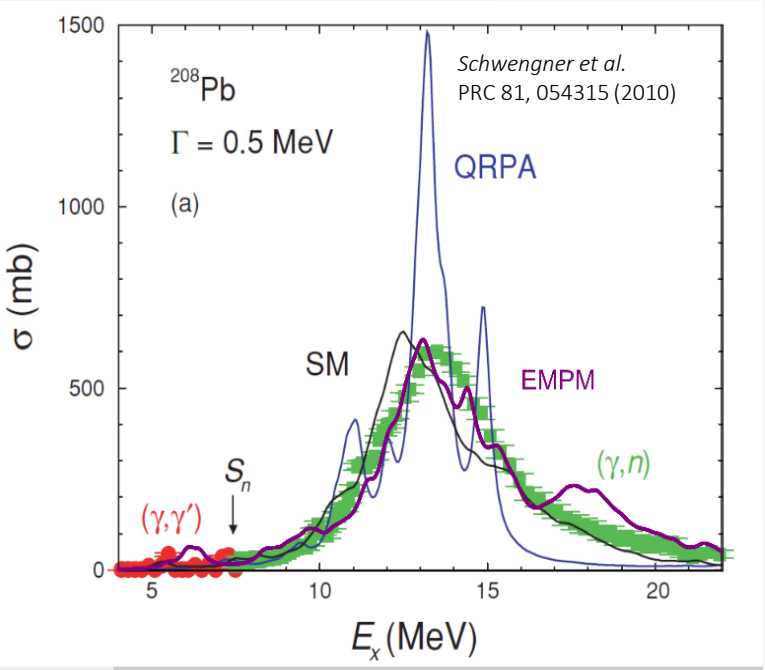
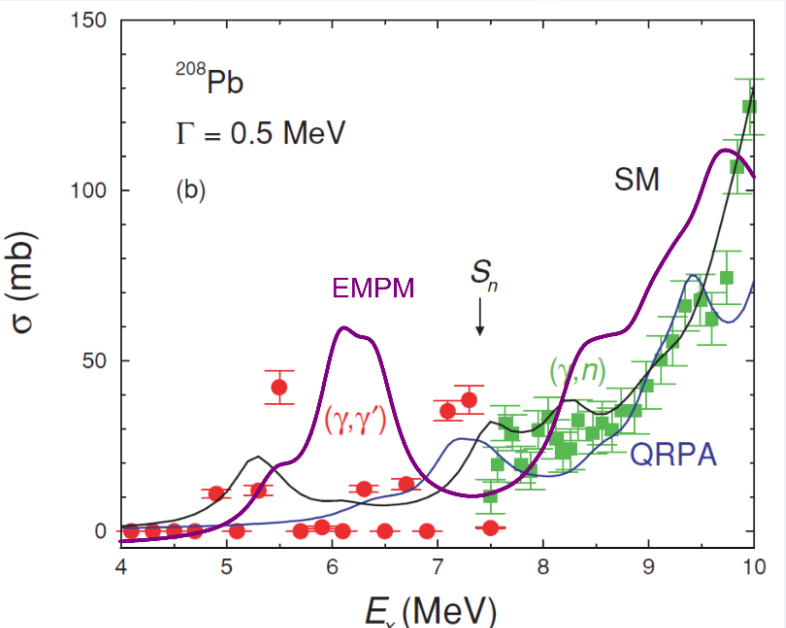
Dipole strength in ^{208}Pb



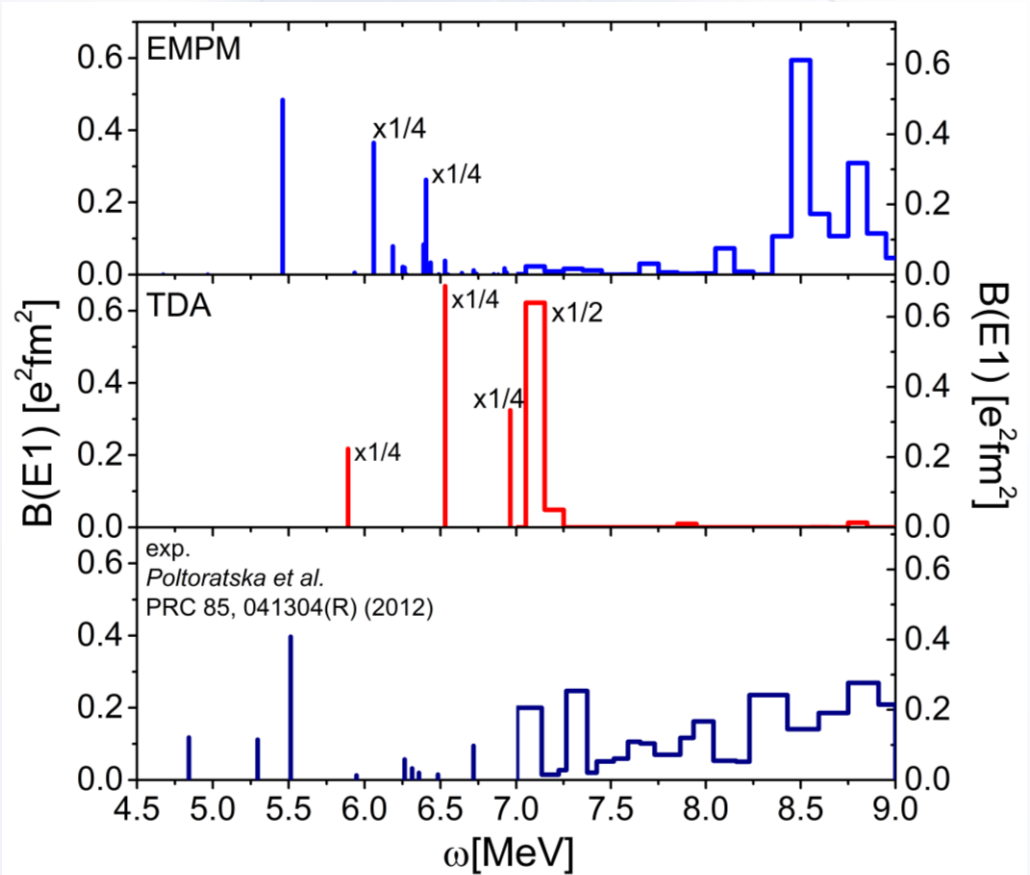




- EMPM predicts fragmented strength in the region 7-9 MeV whereas TDA,RPA not.
- density of states reasonable but few states are too strong

→

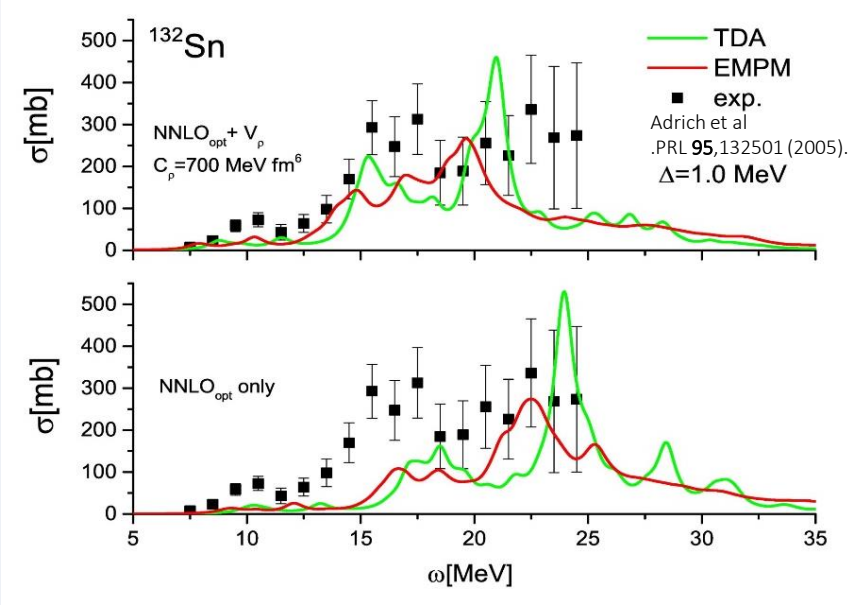
3-phon. could cure this due to the suppression of 1-phon. component via strong 1- 3-phonon coupling

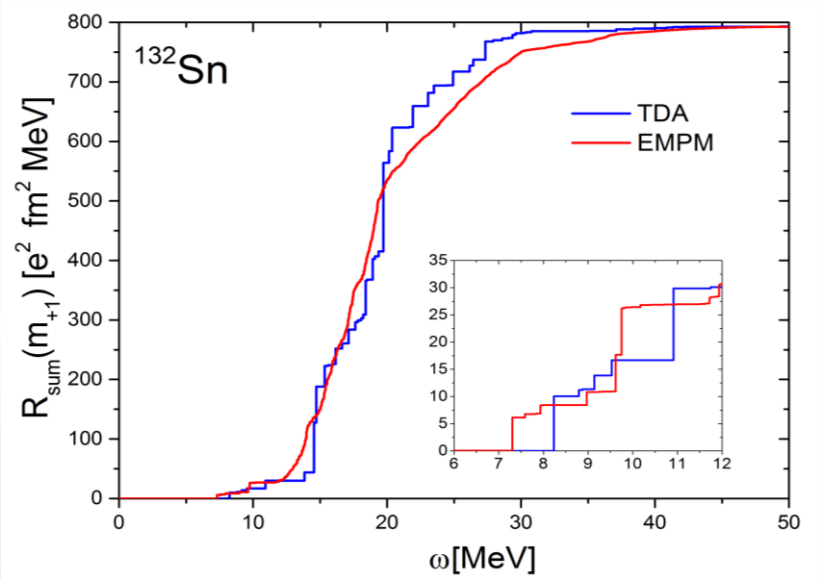


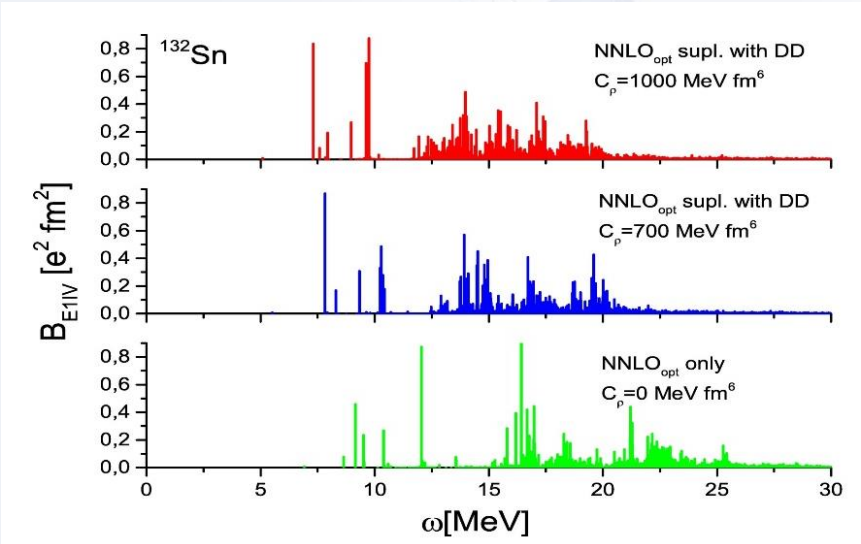
Dipole strength in ^{132}Sn

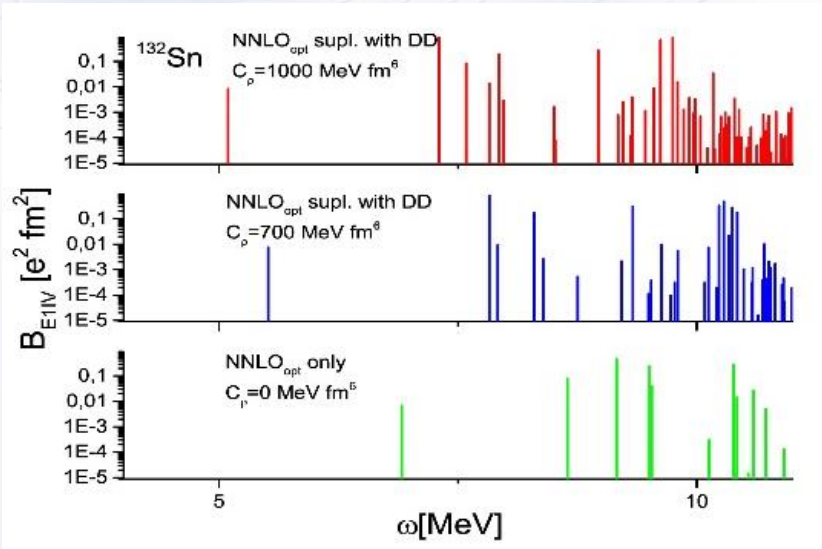
Similar picture to ^{208}Pb.

Knapp et al. Phys. Rev. C 90, 014310 (2014)



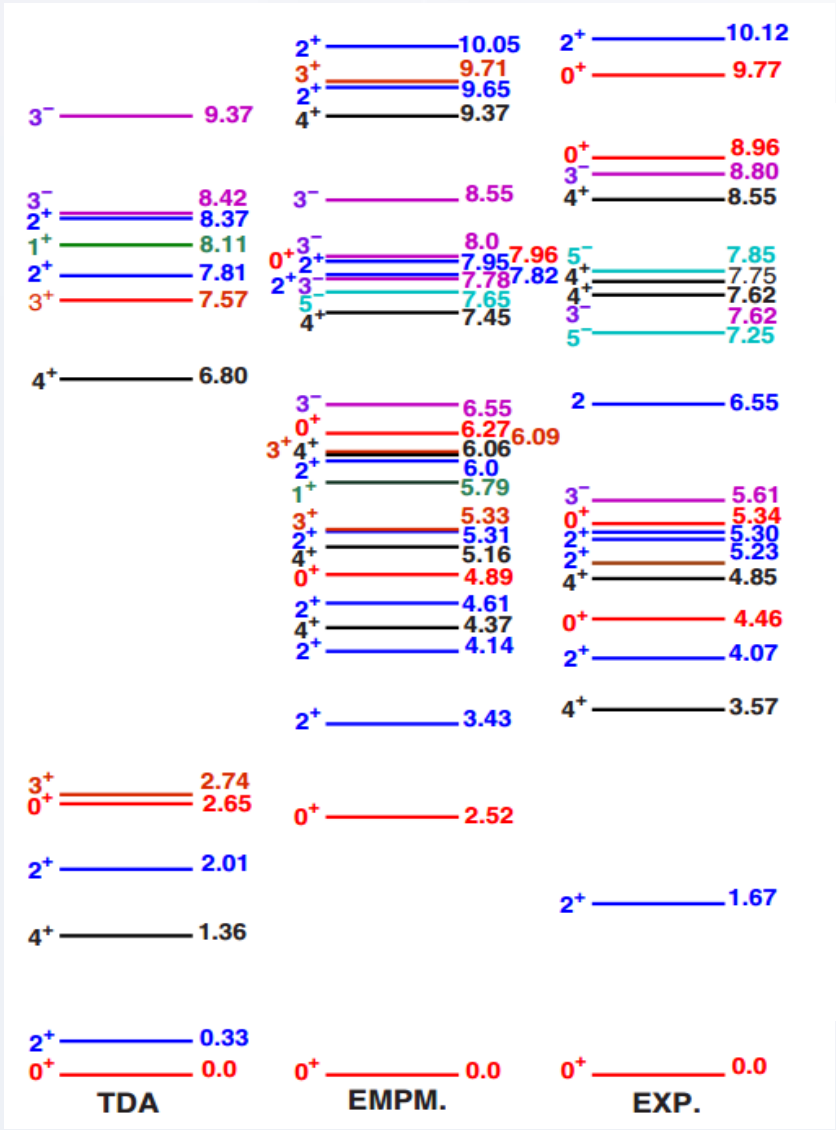


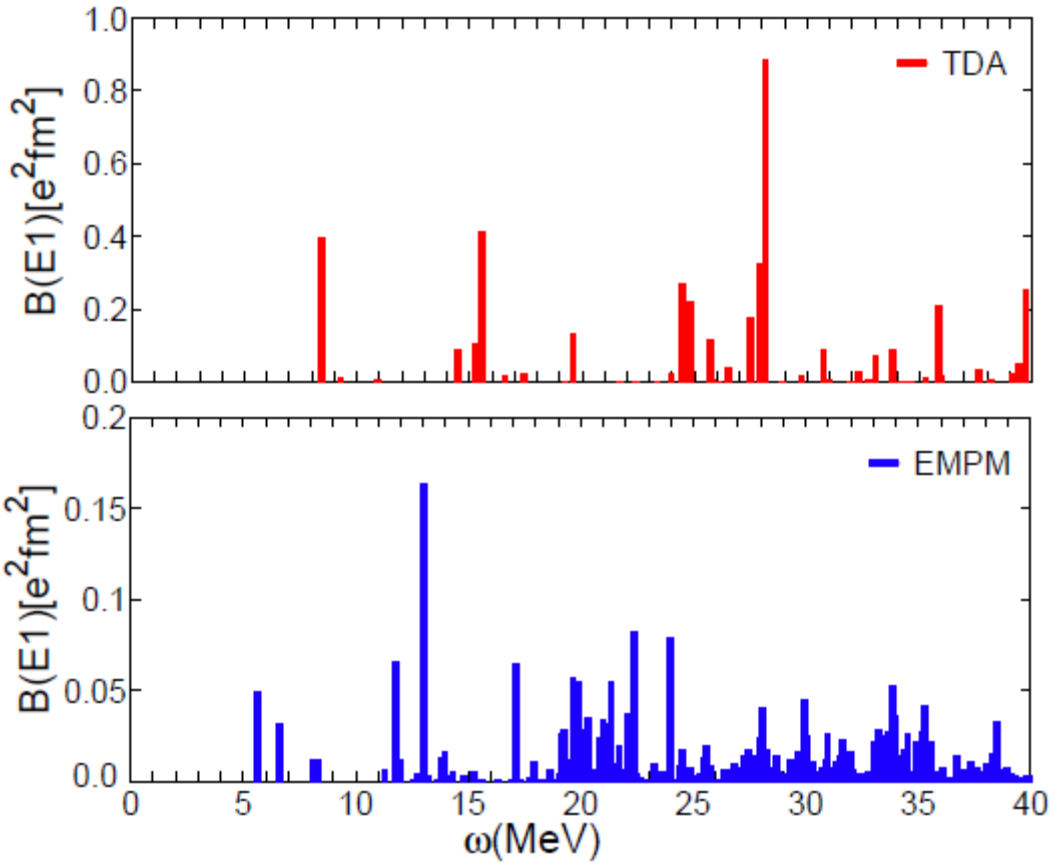




Dipole strength in ^{20}O

- quasiparticle version of EMPM.
- many low lying 1^- states: 2-phonon structure $0\hbar\omega$ coupled with $1\hbar\omega$ excitations





De Gregorio et al. Phys. Rev. C 93, 044314 (2016)

Summary

- ground state correlations in EMPM
  w.f typically 80% HF and 20 % 2-phon.

- radii: contribution from 2-phon. states very small

- selfconsistent description of E1 strength with realistic NN potential ($NNLO_{opt}$ + DD force)
- lowest states $\mathbf{1^-}$: mixture of 1-phon. and 2-phon. components
- shape of GR: sum of many complicated states of type $\mathbf{[Q_1^+ \times Q_2^+]^{1-}}$

$\mathbf{[2^+ \times 1^-]^{1-}}$, $\mathbf{[4^+ \times 3^-]^{1-}}$

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

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

odd particle systems → next talk by **G. De Gregorio**

Future:

- Include 3-phonon sector (at least in non-interacting approximation)
- 3-body force (density dependent 2-body)
- Other ‚realistic' forces ($NNLO_{sat}$)