Pairing field due to the induced interaction in coordinate space

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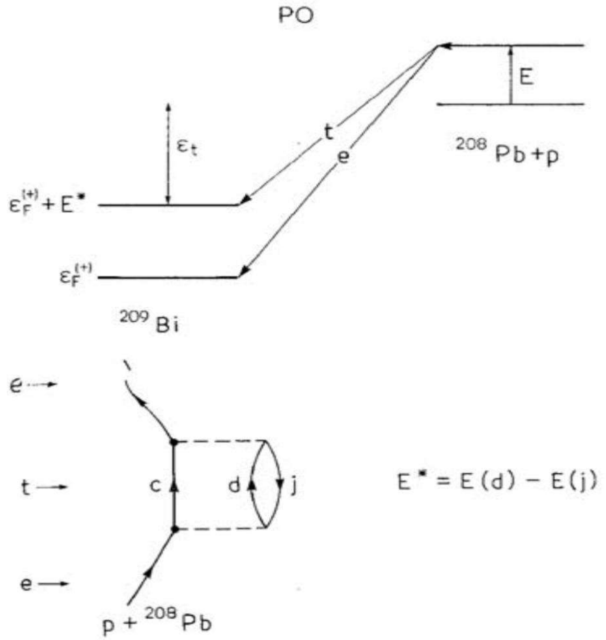
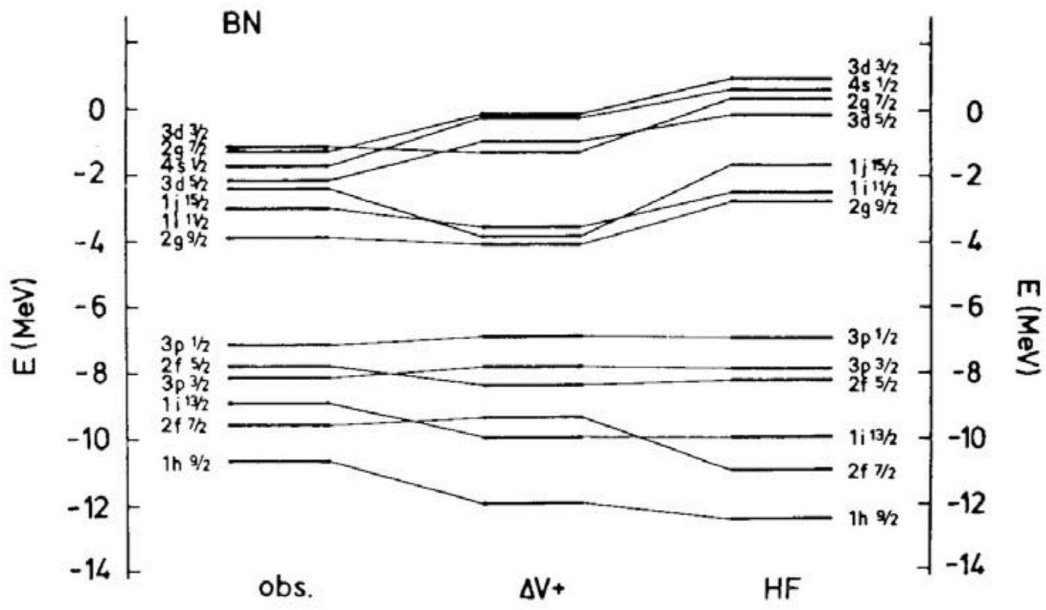
C. Mahaux et al., Dynamics of the shell model



C. Mahaux et al., Dynamics of the shell model



We know the importance of the role of the vibrations to describe correctly the single particle levels

↓

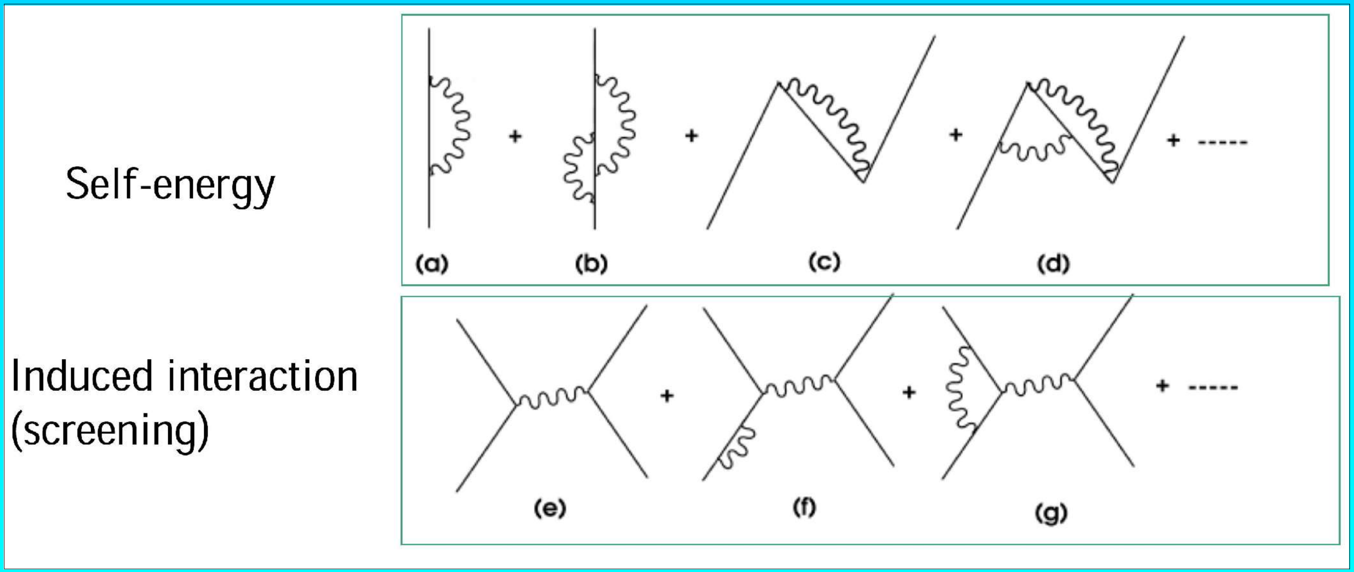
Effective mass m_{ω}

The usual approach to study the pairing correlations is to employ a mean field calculation (HFB) using a Gogny interaction.

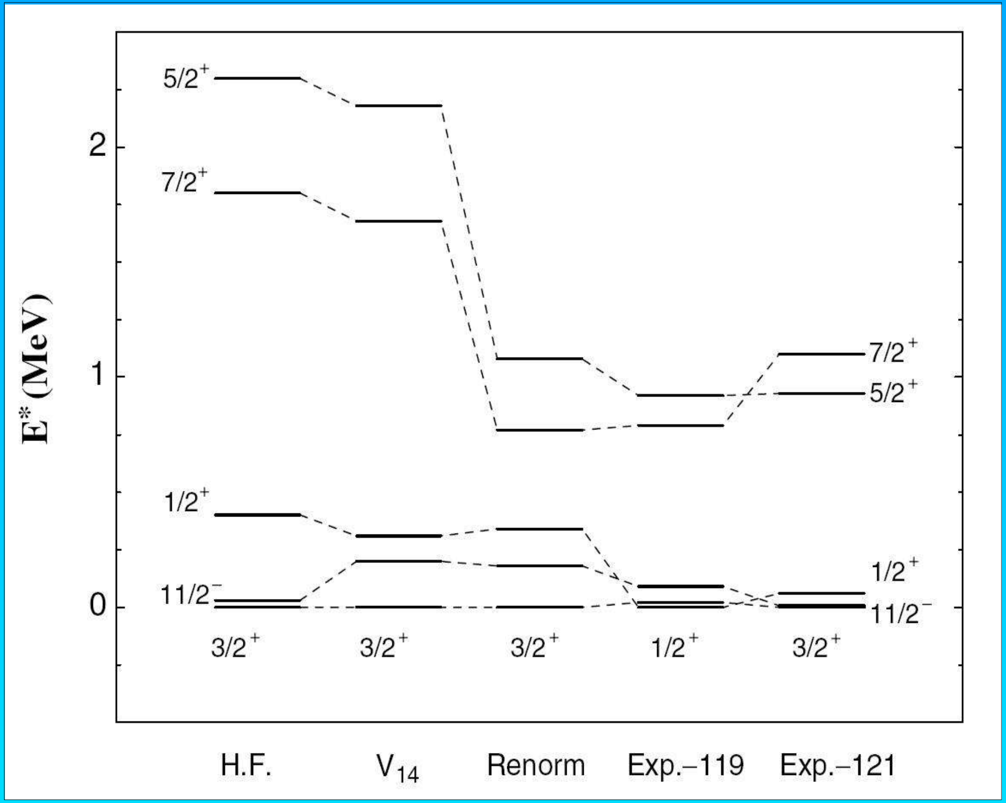
We have overall agreement with 'experimental' pairing gap, but there are open questions:

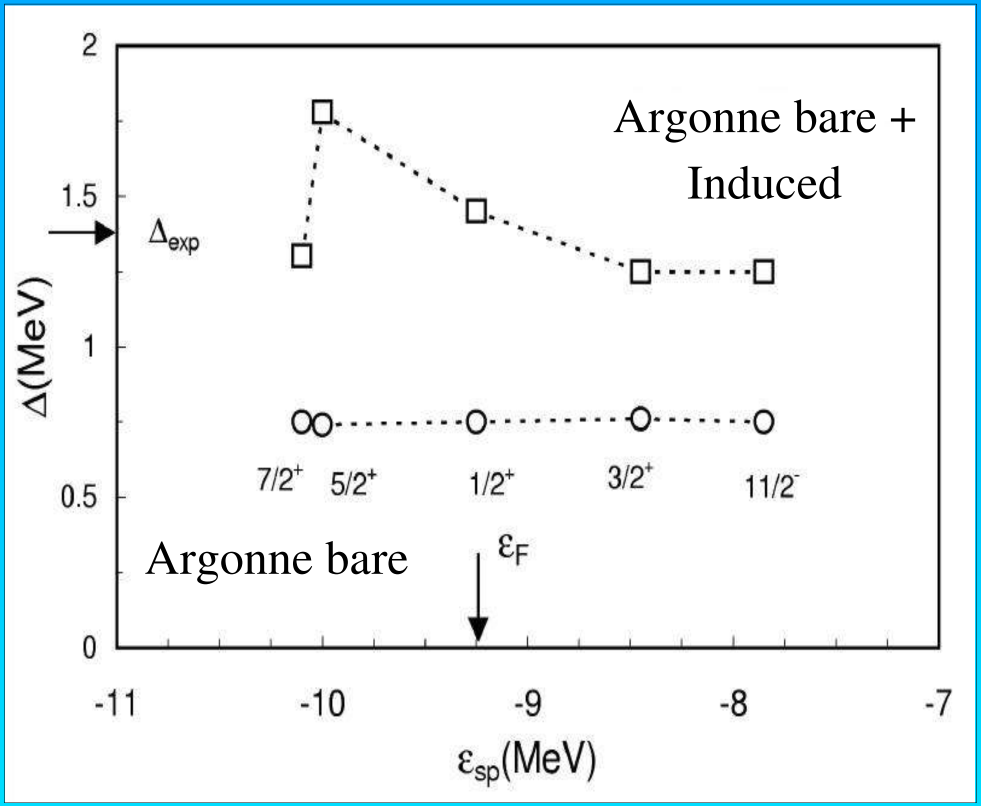
- detailed isotopic dependence
- isospin dependence
- connection with the bare force
- connection with other fields

To go beyond the mean field approach we will consider the effects of the medium polarization.



Nuclei in the stability valley: ^{120}Sn



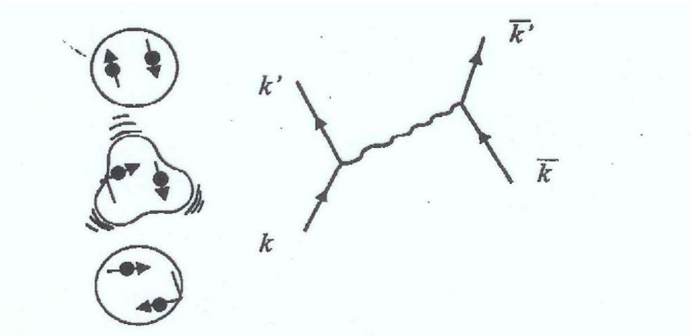


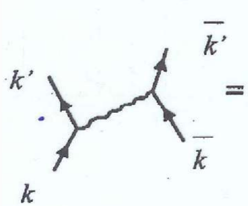
To reproduce the experimental data (***Exp.-119 Exp. -121***), it is not sufficient to use a pure bare NN interaction ($\boldsymbol{V_{14}}$ ***Argonne***), but we get a better result if we consider the coupling of nucleons with phonons (***Renormalization***).

F.Barranco, P.F. Bortignon, R.A. Broglia, G. Colo', G. Gori and E. Vigezzi
Eur. Phys. J. A 21 (2004)

The induced interaction (a simple model)

A more phenomenological approach: particle-vibration matrix elements derived from properties of experimental surface vibrations (2+,3-,4+,5-)

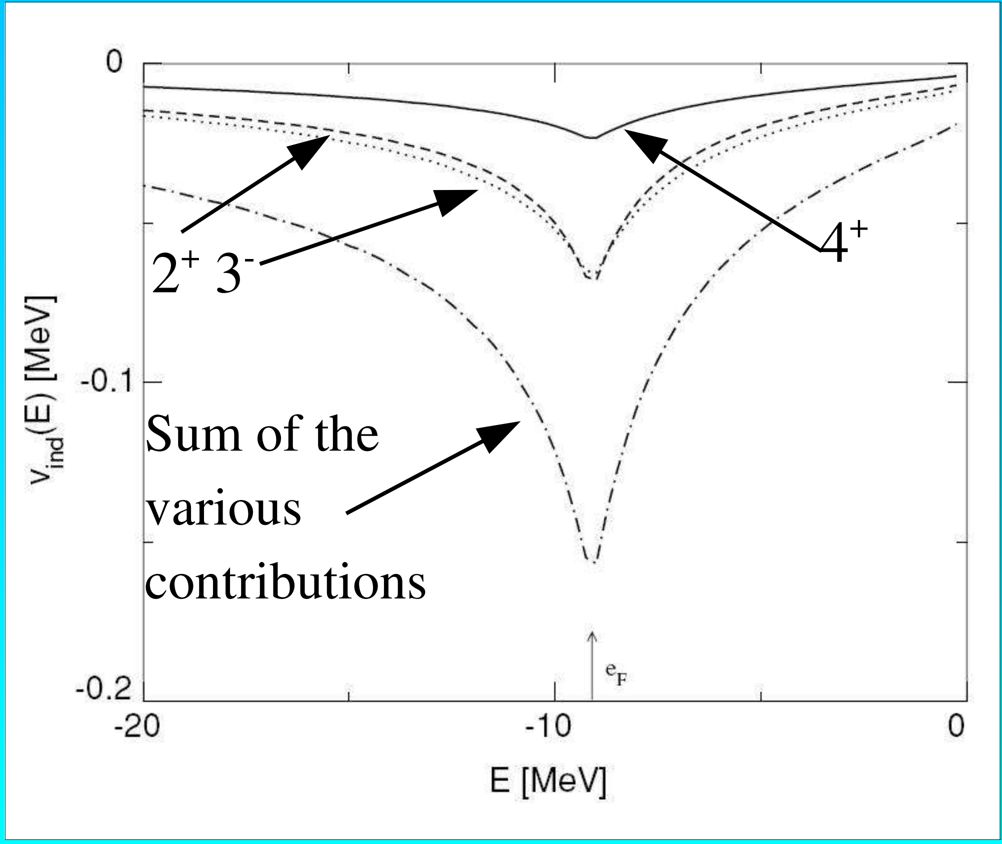




$$= \sum_\lambda \frac{2\beta_\lambda^2}{(2\lambda+1)} \frac{\left|\left\langle k \left\| R_0 \frac{\partial U}{\partial r} Y_\lambda \right\| k' \right\rangle\right|^2}{\sqrt{2j_k+1}\sqrt{2j_{k'}+1}} * \frac{1}{E_0 - \left(|\varepsilon_k - \varepsilon_F| + |\varepsilon_{k'} - \varepsilon_F| + \hbar\omega_\lambda\right)}$$

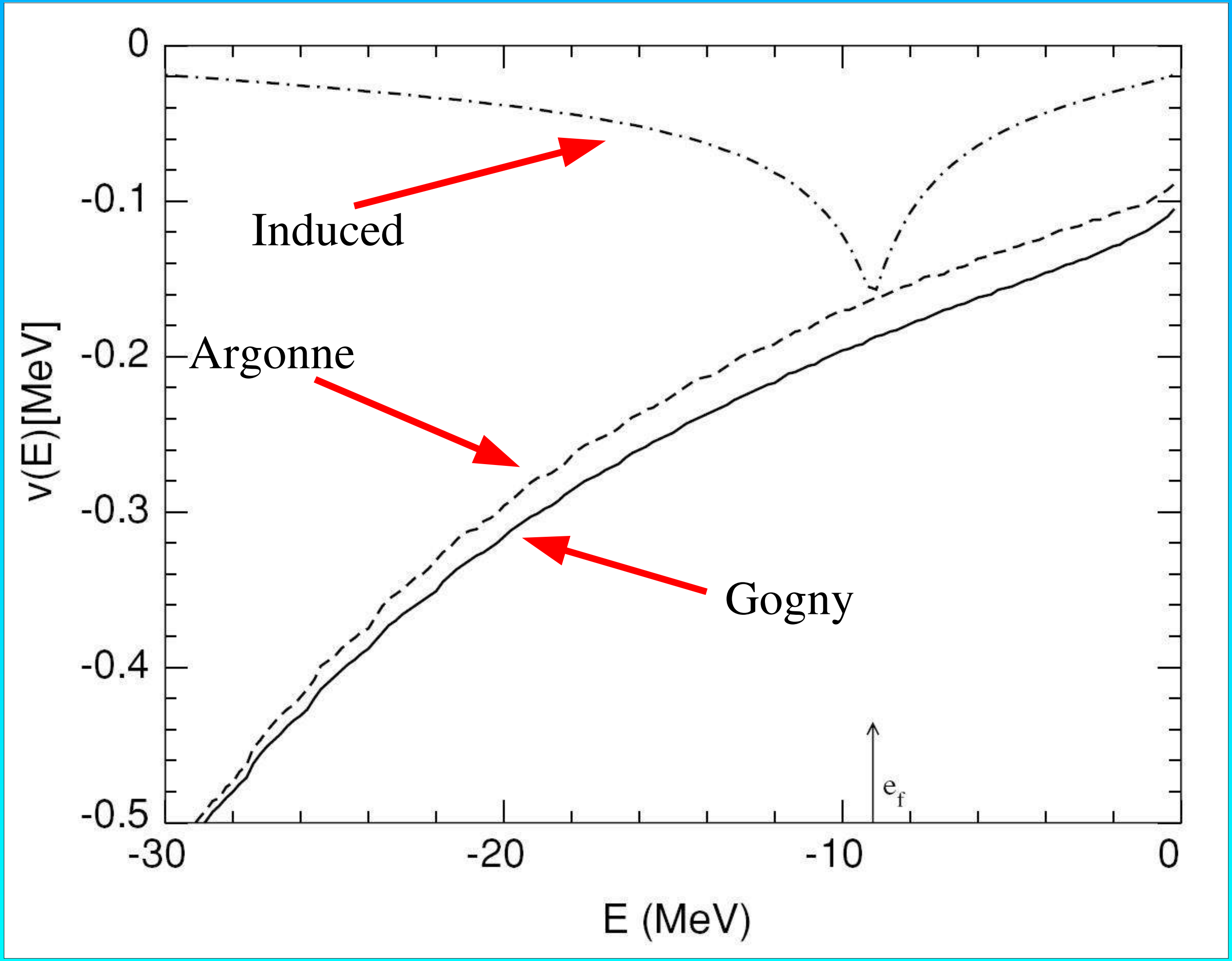
Matrix element calculated on the basis of a Wood - Saxon potential for the form factor f_{Ln}.

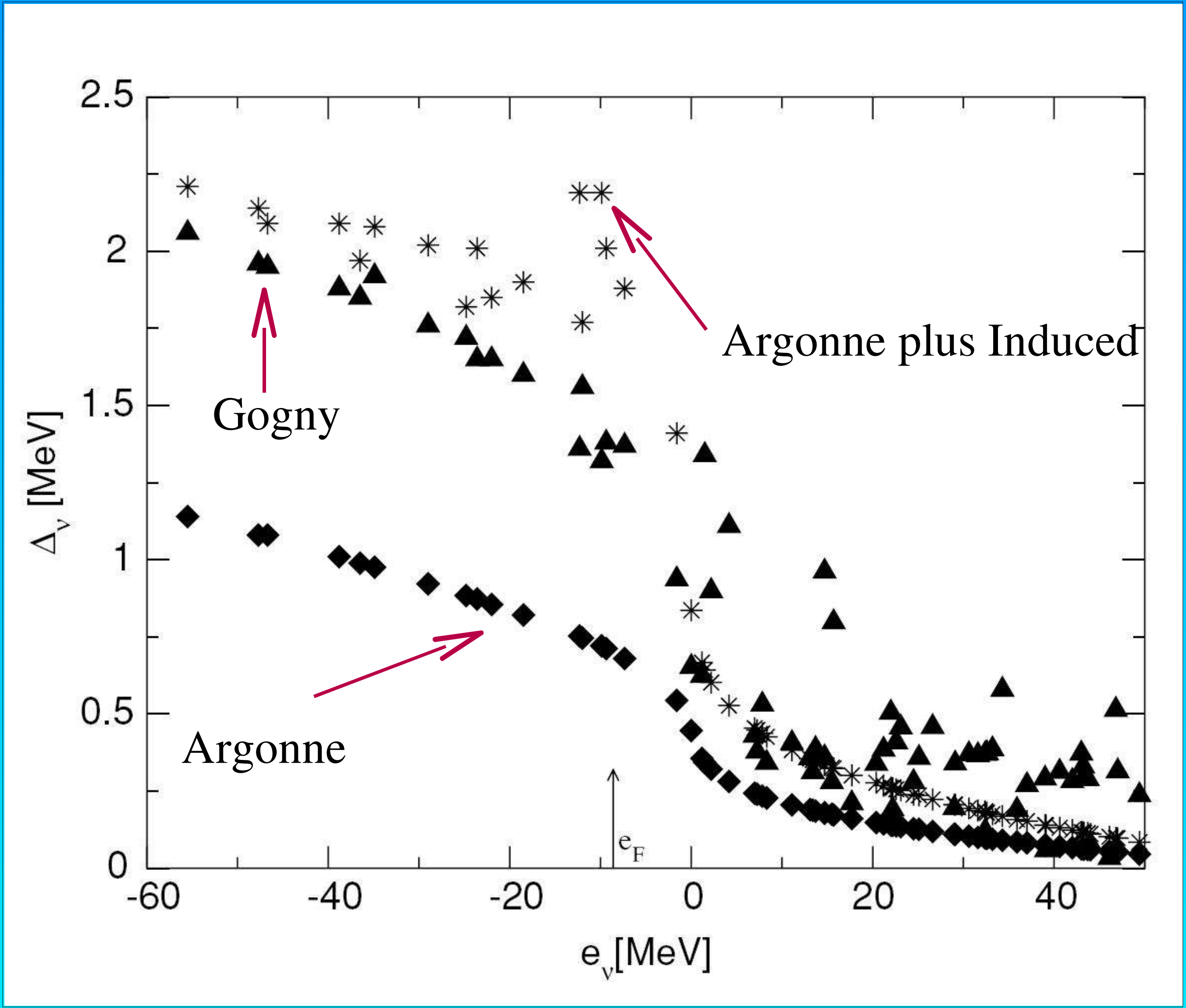
We fix the single-particle levels and we study only the contribution of low-multipolarity phonons (2^+,3^-,4^+,5^-), because they contribute for the major part to the induced interaction.



F.Barranco, P.F. Bortignon, R.A. Broglia, G. Colo', P. Schuck, E. Vigezzi and X. Vinas Phys. Rev. C 72 (2005)

The matrix elements calculated with Gogny and with Argonne interaction show a similar behavior, while the ones that come from the induced interaction are not negligible only around the Fermi energy.





Considering the contribution to the gap of the Induced matrix element and Argonne matrix element we can reproduce well for bound states the experimental value that we get using directly a Gogny interaction.

"Nuclear Superfluidity" D.M. Brink and R.A. Broglia
Cambridge University Press 2005

Description in coordinate space:

- Solution of the HFB equations with a Gogny-type pairing interaction

$$(\epsilon_{nlj} - \epsilon_F)U^q_{nlj} + \sum_{n'} \Delta_{nn'lj} V^q_{n'lj} = E^q_{lj} U^q_{nlj}$$

$$-(\epsilon_{nlj} - \epsilon_F)V^q_{nlj} + \sum_{n'} \Delta_{nn'lj} U^q_{n'lj} = E^q_{lj} V^q_{nlj}$$

- Changing the base to the coordinate space

$$\Delta_{nn'lj} = \langle nn'lj; J = 0 | \Delta(\vec{r_1}, \vec{r_2}) \rangle$$

- Fourier transform of the pairing field

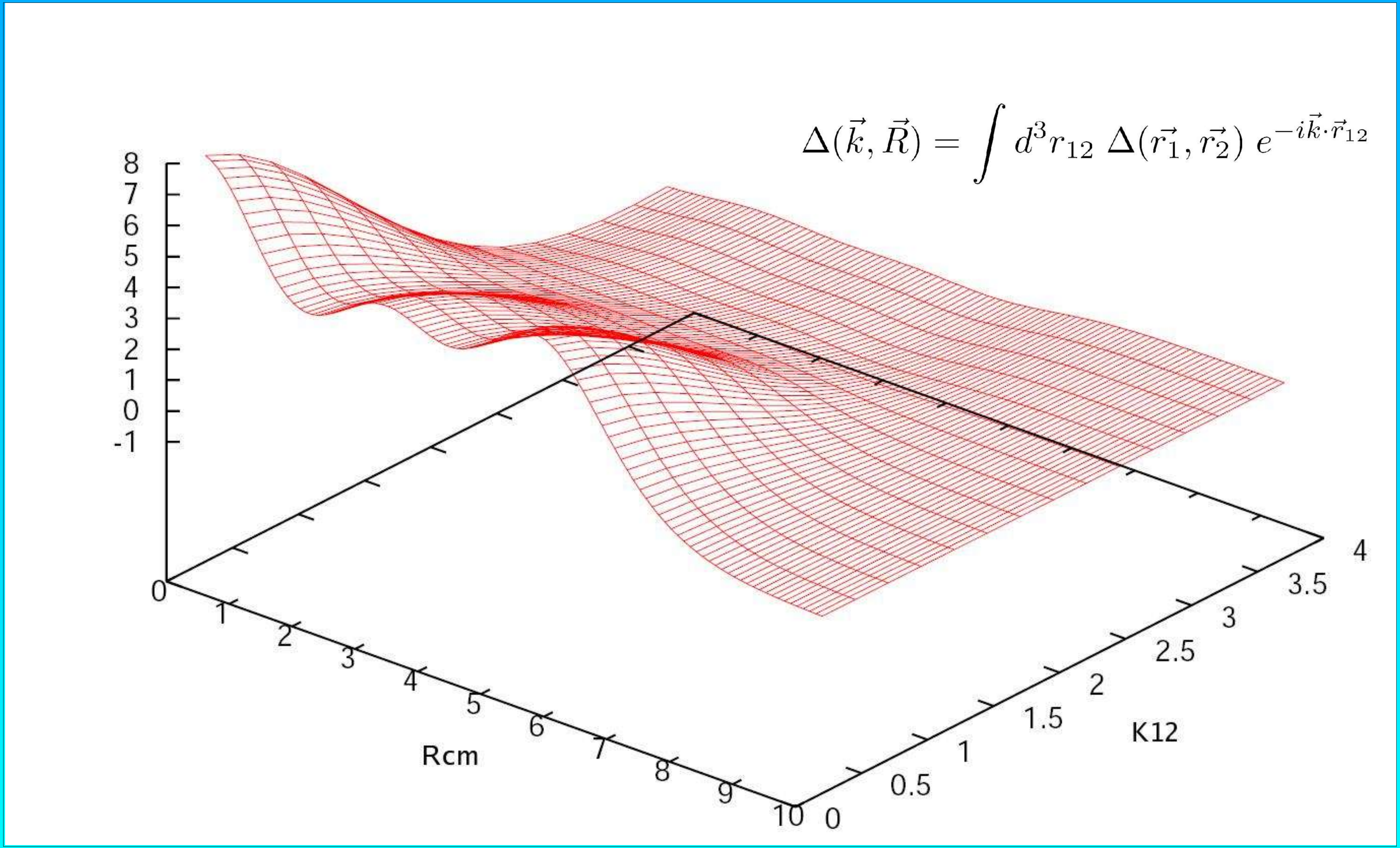
$$\Delta(\vec{k}, \vec{R}) = \int d^3 r_{12}\, \Delta(\vec{r_1}, \vec{r_2})\, e^{-i\vec{k}\cdot\vec{r}_{12}}$$

- Pairing field calculated at local Fermi momentum

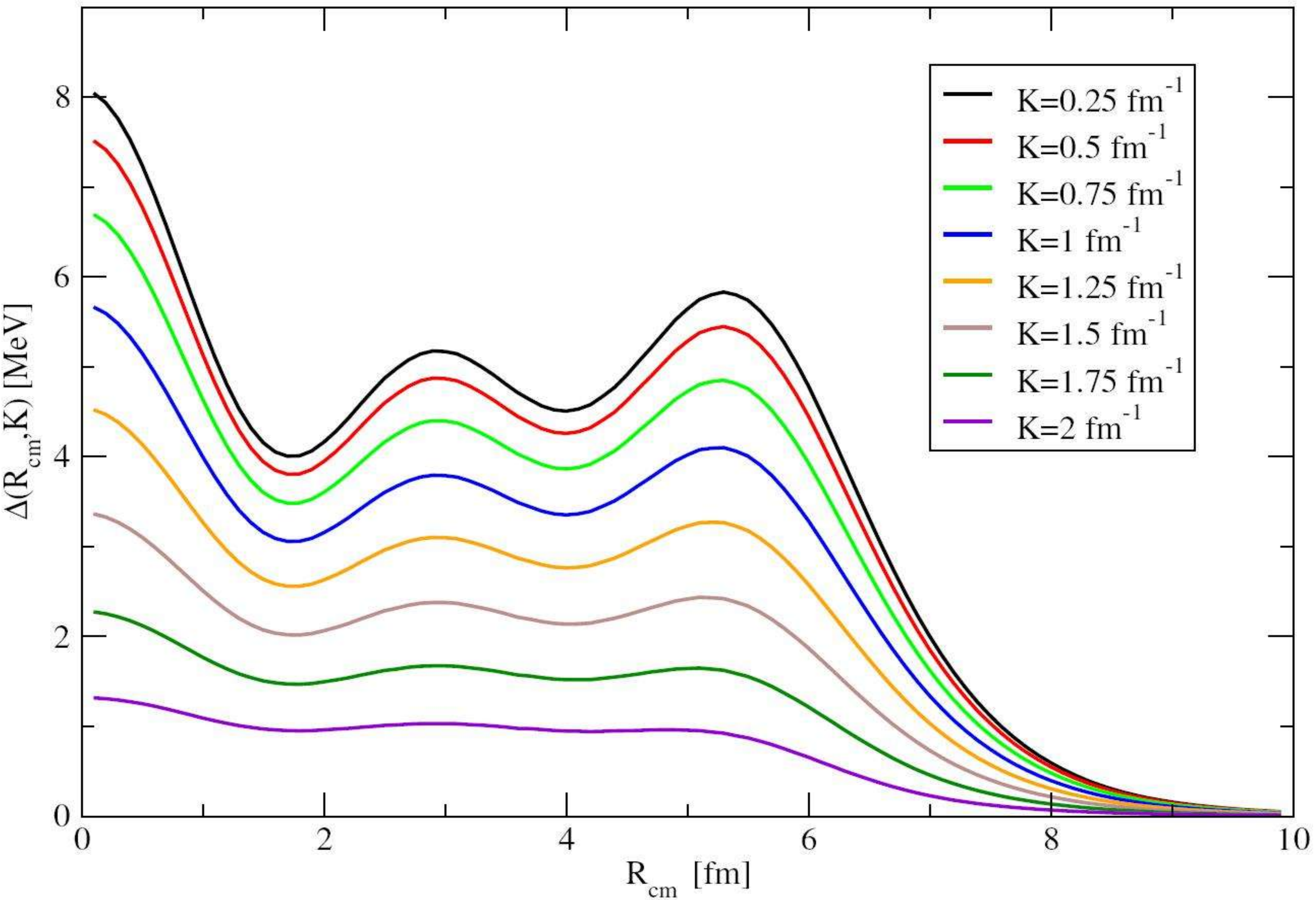
$$\Delta(R) = \Delta(R, k_F(R))$$

F. Barranco, R.A. Broglia, H. Esbensen and E. Vigezzi
Phys. Rev. C 58, 1998

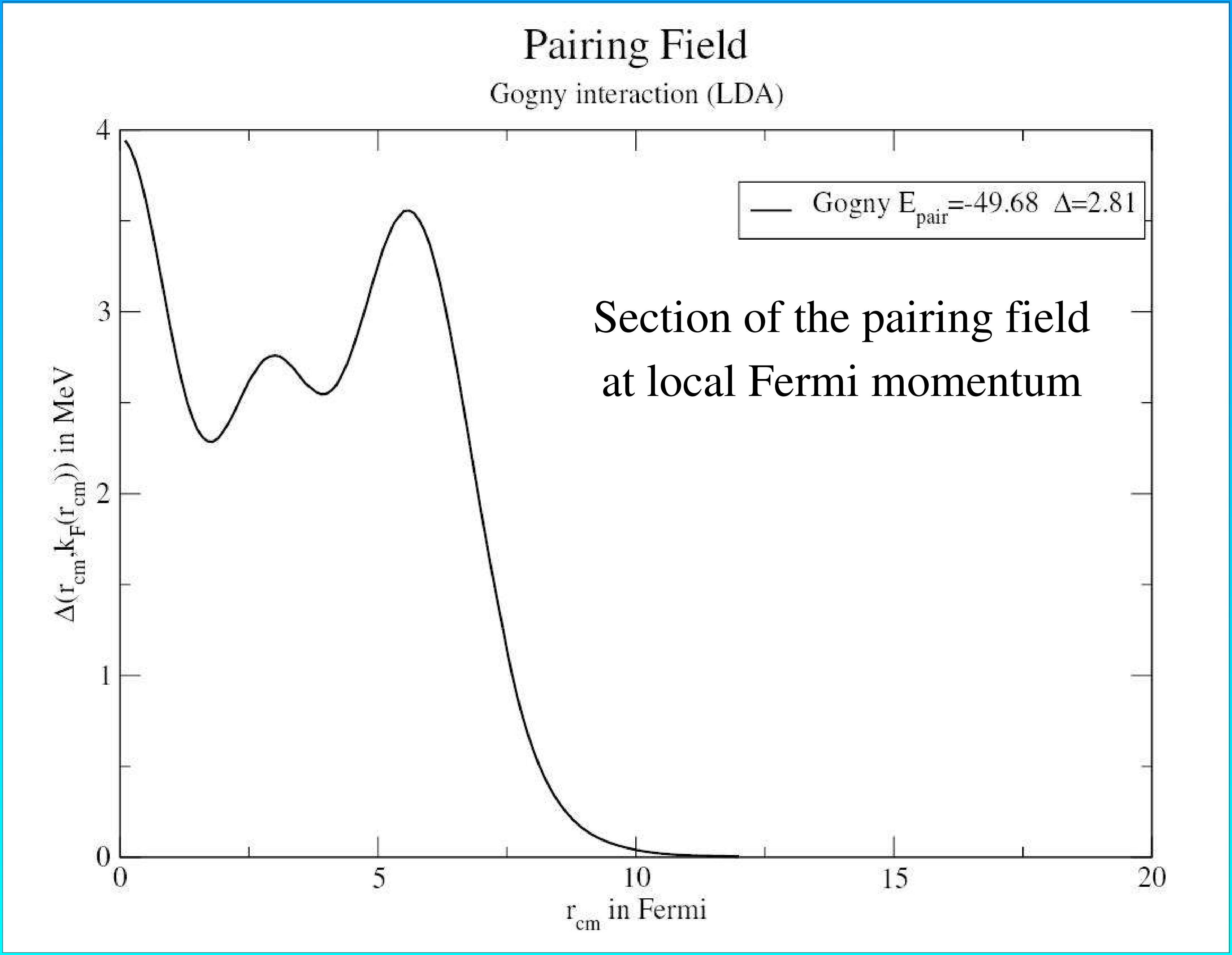
Pairing field using a Gogny interaction for ^{120}Sn

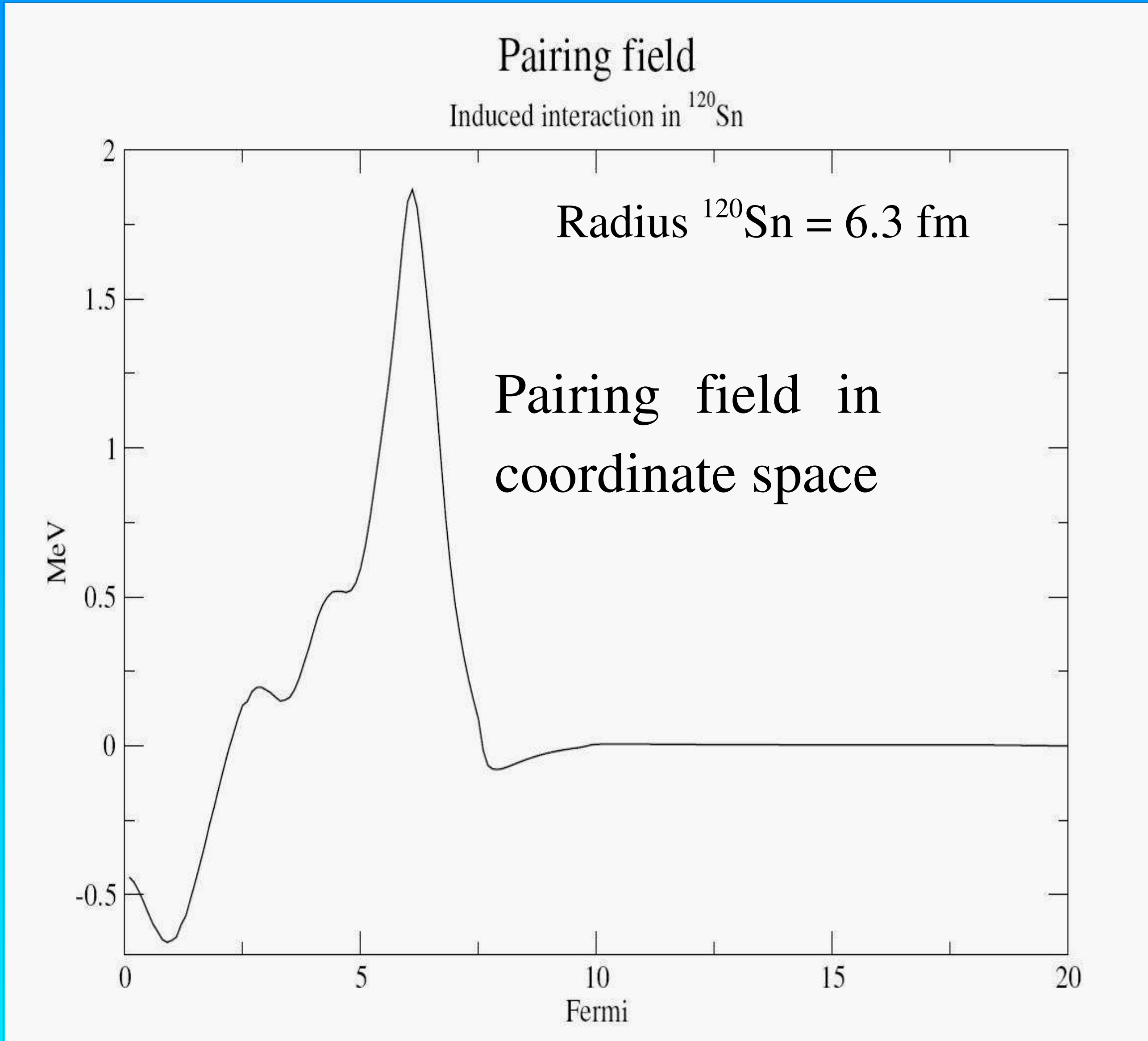


Level curves of the pairing field with different momenta



Result of semi classical approximation

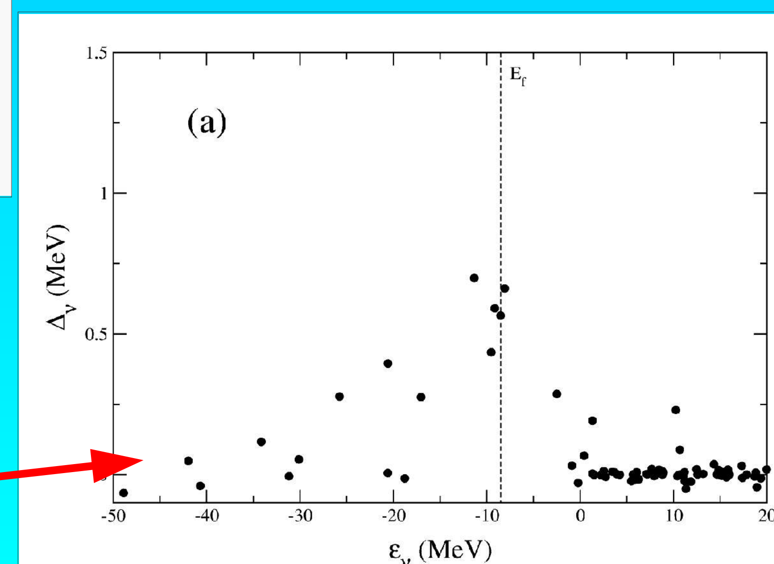


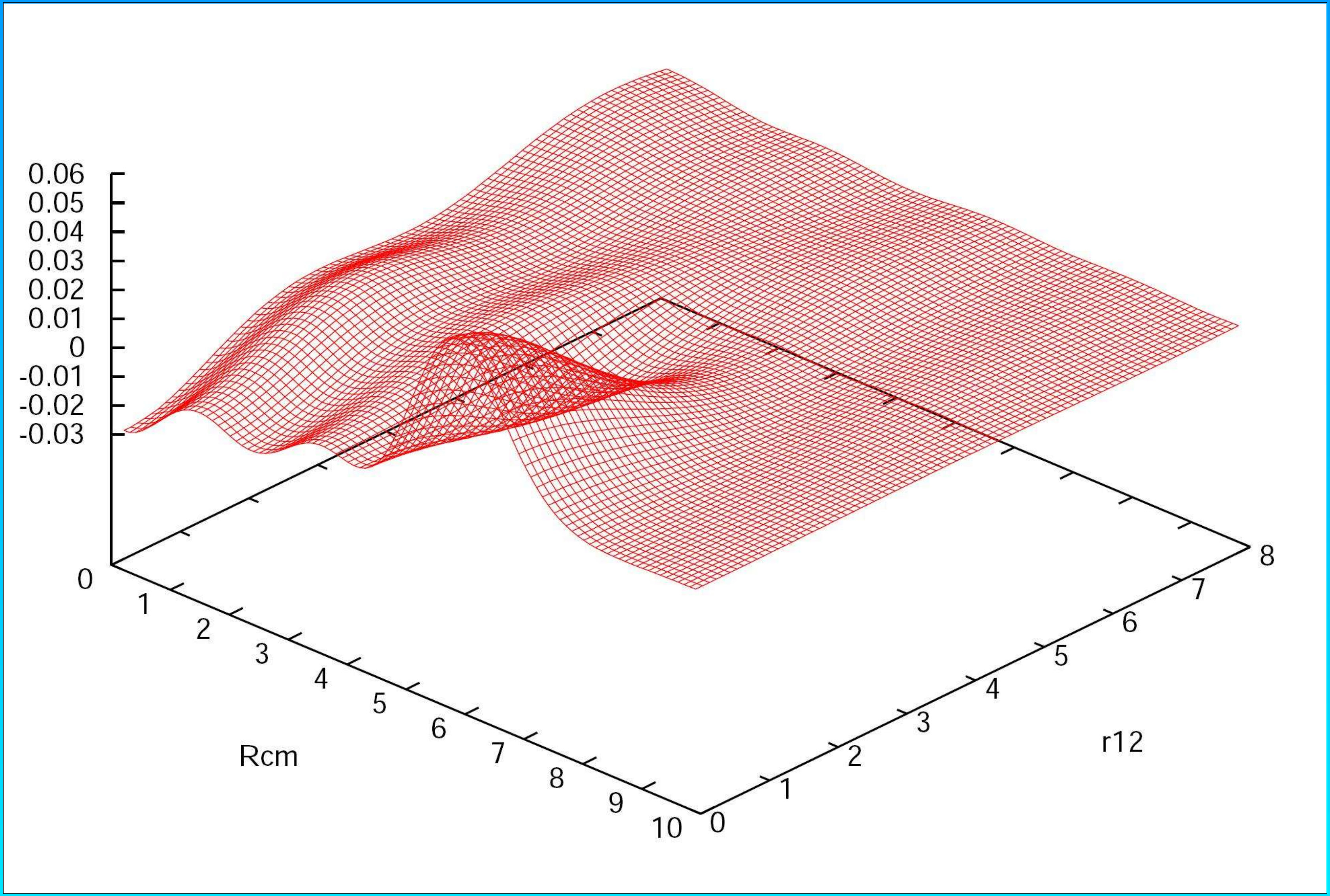


Pairing field obtained only considering the induced interaction (phonons 2^+,3^-,4^+,5^-) for ^{120}Sn.

$$\langle \nu' \bar{\nu}' | v_{\rm ind} | \nu, \bar{\nu} \rangle = 2 \sum_{LMn} \frac{\langle \nu | f_{Ln} Y_{LM} | \nu' \rangle \langle \bar{\nu} | f_{Ln} Y^*_{LM} | \bar{\nu}' \rangle}{E_0 - |e_\nu - e_F| - |e_{\nu'} - e_F| - \hbar\omega_{Ln}}$$

Pairing matrix elements for the induced interaction only.





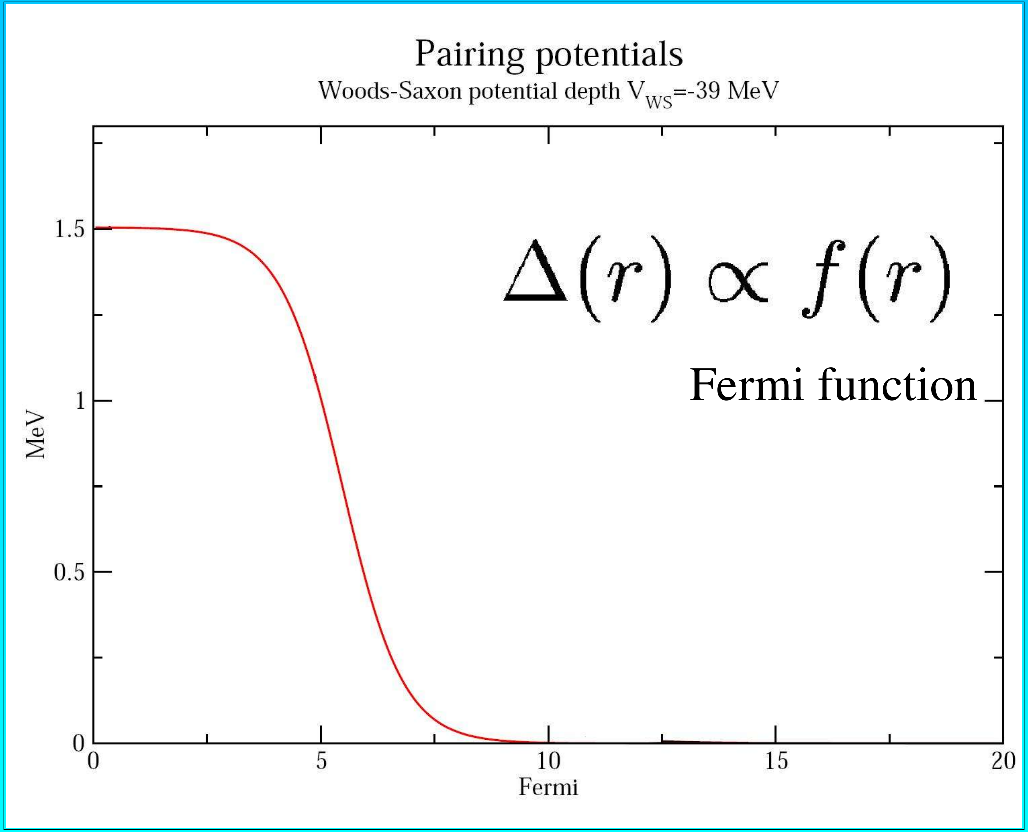
An overall vision of the pairing field obtained using the induced interaction in coordinate space.

A first approach to Halo Nuclei: model and formula

$$\left(\frac{d^2}{dr^2} - \frac{l(l+1)}{r^2} + \frac{2m}{\hbar^2}[\lambda + E_{qp} - V(r) - V_{so}(r)]\right) U_{lj}(r) - \frac{2m}{\hbar^2}\Delta(r) V_{lj}(r) = 0$$

$$\left(\frac{d^2}{dr^2} - \frac{l(l+1)}{r^2} + \frac{2m}{\hbar^2}[\lambda - E_{qp} - V(r) - V_{so}(r)]\right) V_{lj}(r) + \frac{2m}{\hbar^2}\Delta(r) U_{lj}(r) = 0$$

For the pairing field it has been used the *ansatz* of a function proportional to the Fermi function.



I. Hamamoto, and B. Mottelson
Phys. Rev. C 68, 2004

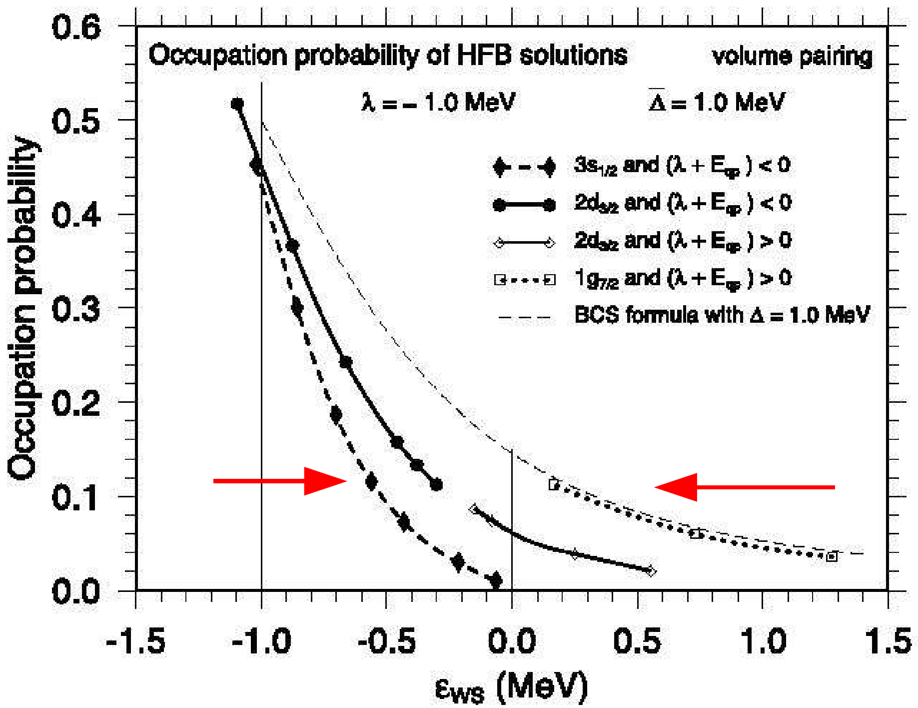


FIG. 7. Occupation probability of $3s_{1/2}$, $2d_{3/2}$, and $1g_{7/2}$ orbits estimated in our HFB approach as a function of one-particle bound or resonant energy of the Woods-Saxon potential. The volume-type pairing (16) is used together with parameters $A=80$, $\lambda=-1$ MeV, and $\bar{\Delta}=1$ MeV, which are the same as those in Figs. 3–5. In order to vary ϵ_{WS}, the depth of the Woods-Saxon potential V_{WS} is varied, keeping all other parameters unchanged. For the $1g_{7/2}$ orbit with the present parameters no HFB discrete solution exists for any value of ϵ_{WS}. Though ϵ_{WS} values in the x axis are varied from negative to positive values, all occupation probabilities are calculated using well-bound wave functions $v_{\ell j}(E_{qp},r)$ obtained in our HFB approach. The thin short-dashed curve shows the occupation probability estimated using the BCS expression in Eq. (20) with $\Delta=1$ MeV.

Experimentally it is known the crucial role of s-states in halo systems, but from the calculations seems that s-states do not couple trough the pairing field because they extend too far beyond the nuclear radius, while the pairing field is all concentrated within the nuclear radius.

I. Hamamoto, and B. Mottelson
Phys. Rev. C 68, 2004

A special case: ^{11}Li

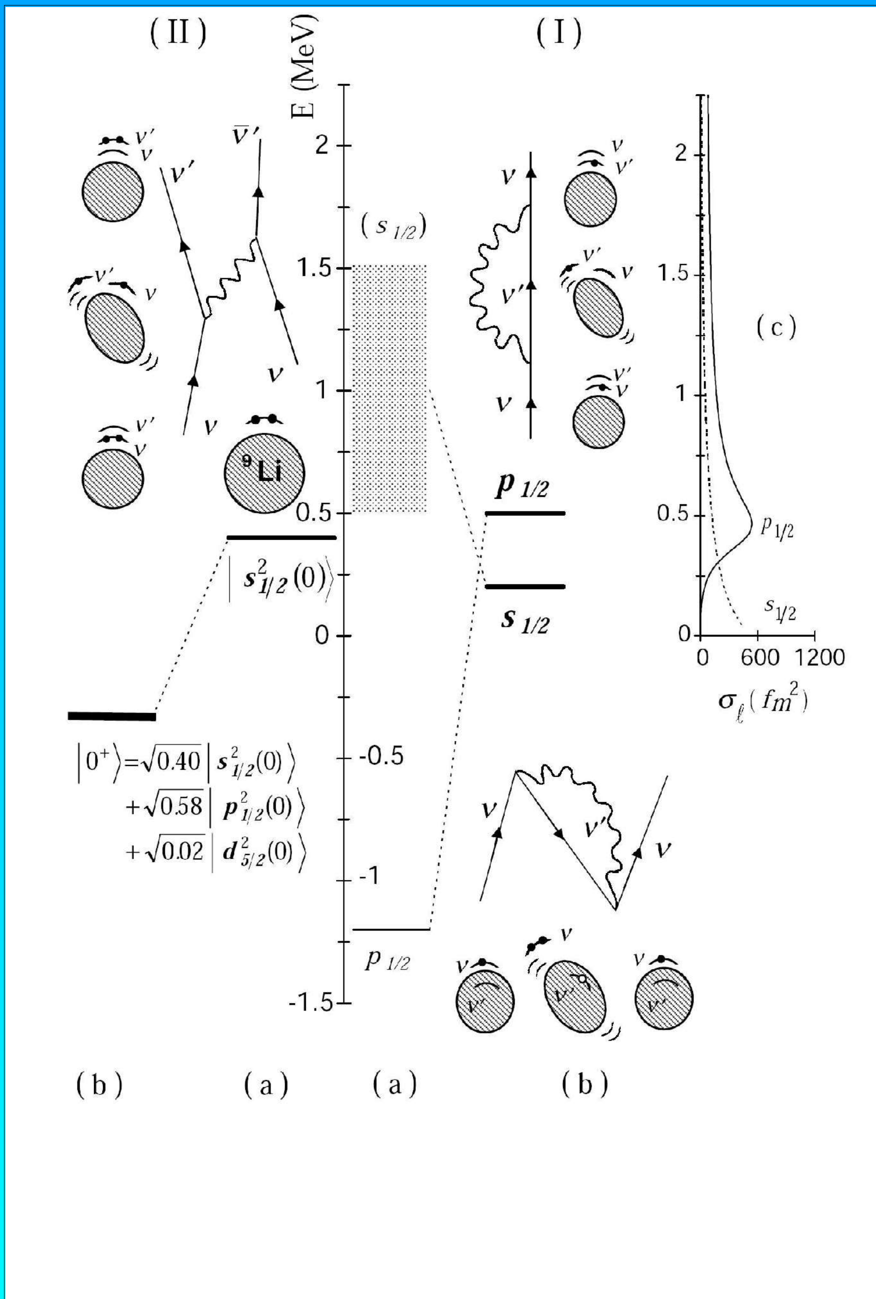


Fig. 1. (I) Single-particle neutron resonances in ^{10}Li. In (a) the position of the levels $s_{1/2}$ and $p_{1/2}$ calculated making use of mean-field theory is shown (hatched area and thin horizontal line, respectively). The coupling of a single-neutron (upward pointing arrowed line) to a vibration (wavy line) calculated making use of the Feynman diagrams displayed in (b) (schematically depicted also in terms of either solid dots (neutron) or open circles (neutron hole) moving in a single-particle level around or in the ^{9}Li core (hatched area)), leads to conspicuous shifts in the energy centroid of the $s_{1/2}$ and $p_{1/2}$ resonances (shown by thick horizontal lines) and eventually to an inversion in their sequence. In (c) we show the calculated partial cross-section σ_l for neutron elastic scattering off ^{9}Li. (II) The two-neutron system ^{11}Li. We show in (a) the mean-field picture of ^{11}Li, where two neutrons (solid dots) move in time-reversal states around the core ^{9}Li (hatched area) in the $s_{1/2}$ resonance leading to an unbound $s^2_{1/2}(0)$ state where the two neutrons are coupled to zero angular momentum. The exchange of vibrations between the two neutrons shown in the upper part of the figure leads to a density-dependent interaction which, added to the nucleon-nucleon interaction, correlates the two-neutron system leading to a bound state $|0^+\rangle$, where the two neutrons move with probability 0.40, 0.58 and 0.02 in the two-particle configurations $s^2_{1/2}(0)$, $p^2_{1/2}(0)$ and $d^2_{5/2}(0)$, respectively.

G. Gori, F. Barranco, E. Vigezzi and R.A. Broglia
Phys. Rev. C 69, 2004