Two neutrons transfer and Pairing Vibrations

- Pairing vibrations
- How to describe ?
- How to measure ?

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Pairing vibrations

^{214}Pb	0^+
^{212}Pb	0^+
^{210}Pb	0^+
^{208}Pb	0^+
^{206}Pb	0^+
^{204}Pb	0^+

•Two particles 0+ state ~ independent from the remaining part of the nuclei

→ Harmonic vibrations

•Pairing vibrations : sensitive to the pairing interaction

• Study with 2n transfer reaction : coupling between continuum and pairing in the case of weakly bound probe

QRPA

Unified description of collective excitations :

Study nuclear transitions on the whole chart !

(isotopic chains, open shells, drip-line nuclei, …)

N,Z → **E*, Giant resonances, inelastic cross sections**

N+2,Z → **Pairing vibrations, 2n transfer cross sections**

N+1,Z-1 → **β half-lives, GT strengths, charge exchange cross sections**

Time-Dependent HFB

Generalised density

TDHFB :

$$i\hbar\frac{\partial \mathcal{R}}{\partial t} = [\mathcal{H}(t) + \mathcal{F}(t), \mathcal{R}(t)]$$

External field : $\mathcal{F} = Fe^{-i\omega t} + h.c.$

Small amplitudes :

$$\mathcal{R}(t) = \mathcal{R}^0 + \mathcal{R}'e^{-i\omega t} + h.c.$$

$$\mathcal{H}(t) = \mathcal{H}^0 + \mathcal{H}'e^{-i\omega t} + h.c.$$

$$R^0 = \begin{pmatrix} \rho & \kappa \\ -\kappa^* & 1-\rho^* \end{pmatrix}$$

$$\hbar\omega\mathcal{R}' = [\mathcal{H}', \mathcal{R}^0] + [\mathcal{H}^0, \mathcal{R}'] + [F, \mathcal{R}^0]$$

Quasiparticle representation : H^0 and R^0 are diagonal

Coordinate representation

•Suited to the exact treatment of the continuum : asymptotic conditions

•Variation of 3 quantities instead of 1 (RPA)

$$\rho'(\mathbf{r}\sigma) = \langle 0|\psi^\dagger(\mathbf{r}\sigma)\psi(\mathbf{r}\sigma)|'\rangle \quad \text{: ph}$$

$$\kappa'(\mathbf{r}\sigma) = \langle 0|\psi(\mathbf{r}\bar{\sigma})\psi(\mathbf{r}\sigma)|'\rangle \quad \text{: pp}$$

$$\bar{\kappa}'(\mathbf{r}\sigma) = \langle 0|\psi^\dagger(\mathbf{r}\sigma)\psi^\dagger(\mathbf{r}\bar{\sigma})|'\rangle \quad \text{: hh}$$

$$\boldsymbol{\mathcal{H}}' = \begin{pmatrix} \mathcal{H}'^{11} \\ \mathcal{H}'^{12} \\ \mathcal{H}'^{21} \end{pmatrix} = \mathbf{V}\boldsymbol{\rho}'$$

with

$$\mathbf{V}^{\alpha\beta}(\mathbf{r}\sigma, \mathbf{r}'\sigma') = \frac{\partial^2 \mathcal{E}}{\partial\rho_\beta(\mathbf{r}'\sigma')\partial\rho_{\bar{\alpha}}(\mathbf{r}\sigma)}$$

3x3 residual interaction

E. Khan, N. Sandulescu, Nguyen Van Giai, M. Grasso PRC66(2002)024309

The generalised **Bethe-Salpeter** equation

$$\rho' = \mathbf{G}_0 \mathbf{V} \rho' + \mathbf{G}_0 \mathbf{F}$$

with

$$\mathbf{G}_0{}^{\alpha\beta}(\mathbf{r}\sigma, \mathbf{r}'\sigma'; \omega) = \sum_{ij} \frac{\mathcal{U}_{ij}^{\alpha 1}(\mathbf{r}\sigma)\bar{\mathcal{U}}_{ij}^{T\beta 1}(\mathbf{r}'\sigma')}{\hbar\omega - (E_i + E_j) + i\eta} - \frac{\mathcal{U}_{ij}^{\alpha 2}(\mathbf{r}\sigma)\bar{\mathcal{U}}_{ij}^{T\beta 2}(\mathbf{r}'\sigma')}{\hbar\omega + (E_i + E_j) + i\eta}$$

Unperturbed Green function

Green function : $\rho' = \mathbf{G}\mathbf{F}$

9 coupled equations :

$$\mathbf{G} = (1 - \mathbf{G}_0 \mathbf{V})^{-1} \mathbf{G}_0 = \mathbf{G}_0 + \mathbf{G}_0 \mathbf{V} \mathbf{G}$$

Response function and strength distribution

solution of the BS eq. (response function) :

$$G = \begin{pmatrix} G^{ph,ph} & G^{ph,pp} & G^{ph,hh} \\ G^{pp,ph} & G^{pp,pp} & G^{pp,hh} \\ G^{hh,ph} & G^{hh,pp} & G^{hh,hh} \end{pmatrix}$$

Strength distribution :

$$S(\omega) = \sum_{\upsilon} \left| \langle \upsilon | F^{12} | QRPA \rangle \right|^2 \delta(\hbar\omega - E_{\upsilon})$$

$$= -\frac{1}{\pi} \mathrm{Im} \int F^{12*}(r) G^{22}(r, r', \omega) F^{12}(r') dr dr'$$

The nucleon-nucleon effective interaction

- Spherical symmetry
- Skyrme interaction : SLy4

- Residual interaction : $$\mathbf{V}^{\alpha\beta}(\mathbf{r}\sigma,\mathbf{r}'\sigma') = \frac{\partial^2 \mathcal{E}}{\partial\rho_\beta(\mathbf{r}'\sigma')\partial\rho_{\bar{\alpha}}(\mathbf{r}\sigma)}$$

- Landau-Migdal approximation in the **ph channel** : no terms in gradient

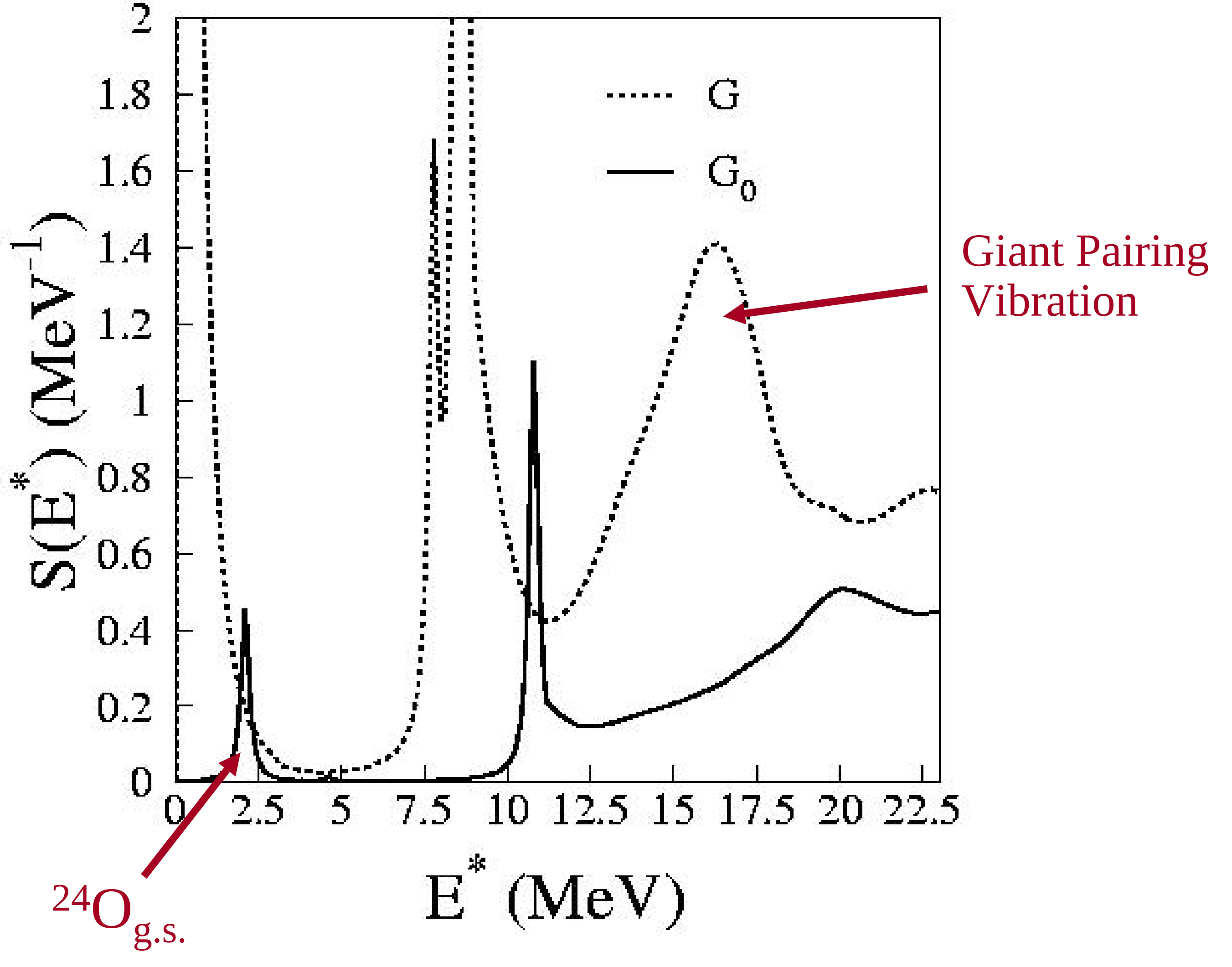
⟹ Renormalisation by a factor 0.8 (IS dipolar mode at 0 MeV)

- **Pairing interaction** : $$V_{pair} = V_0\left[1-\left(\frac{\rho(r)}{\rho_0}\right)^\alpha\right]\delta\left(\mathbf{r}_1-\mathbf{r}_2\right)$$

- Zero range → UV divergence in the pp channel
- Prescription (V_0 , E_{cutoff}) : Δ stable

Collectivity of the response

$^{22}O + 2n \longrightarrow {}^{24}O^*$



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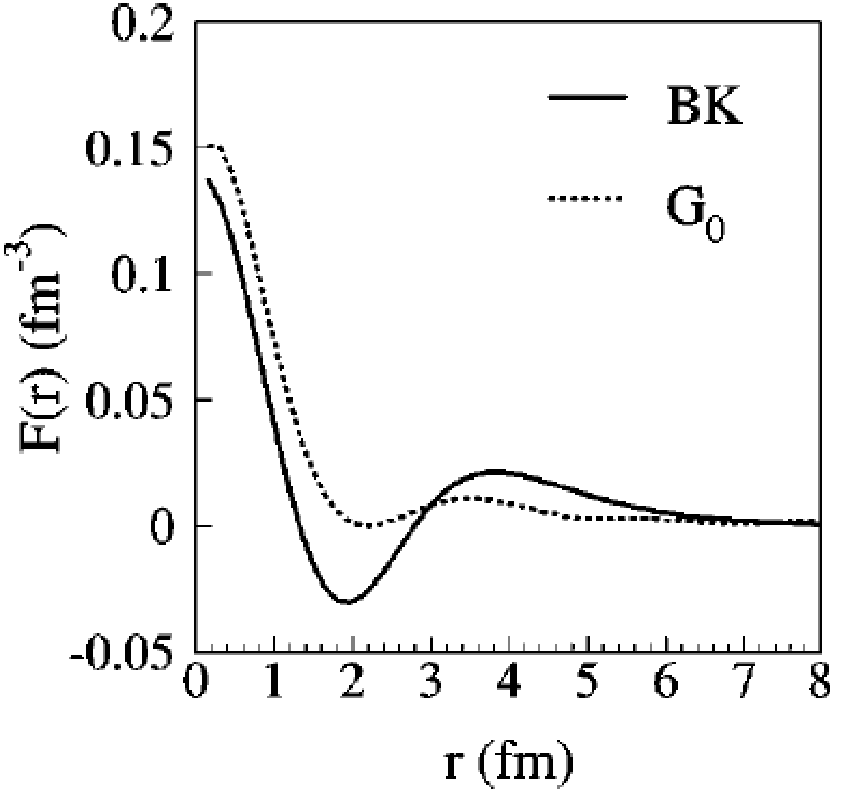
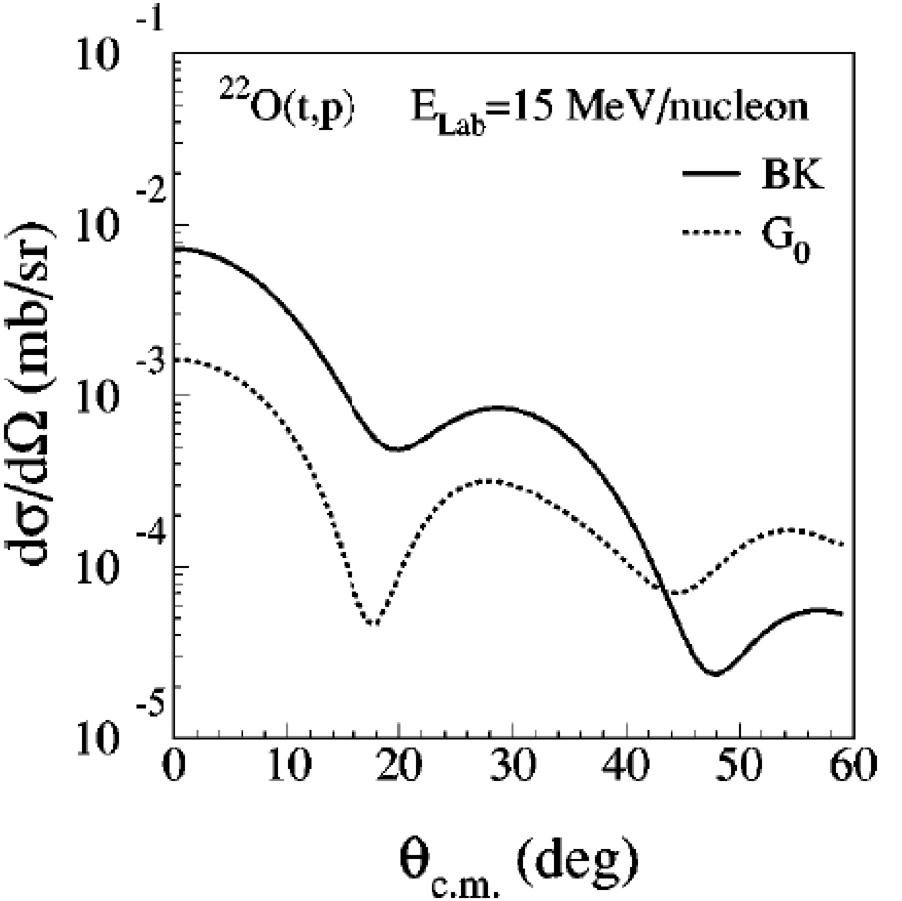
Unperturbed form factors

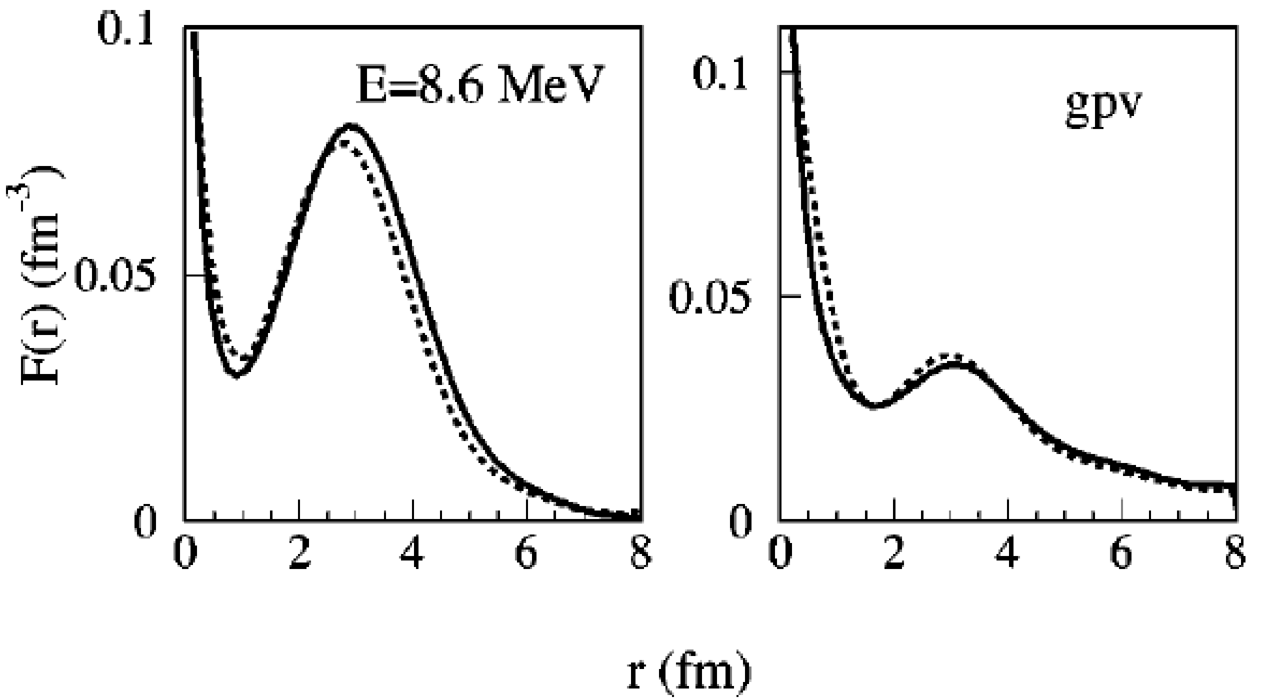


Pair transition density

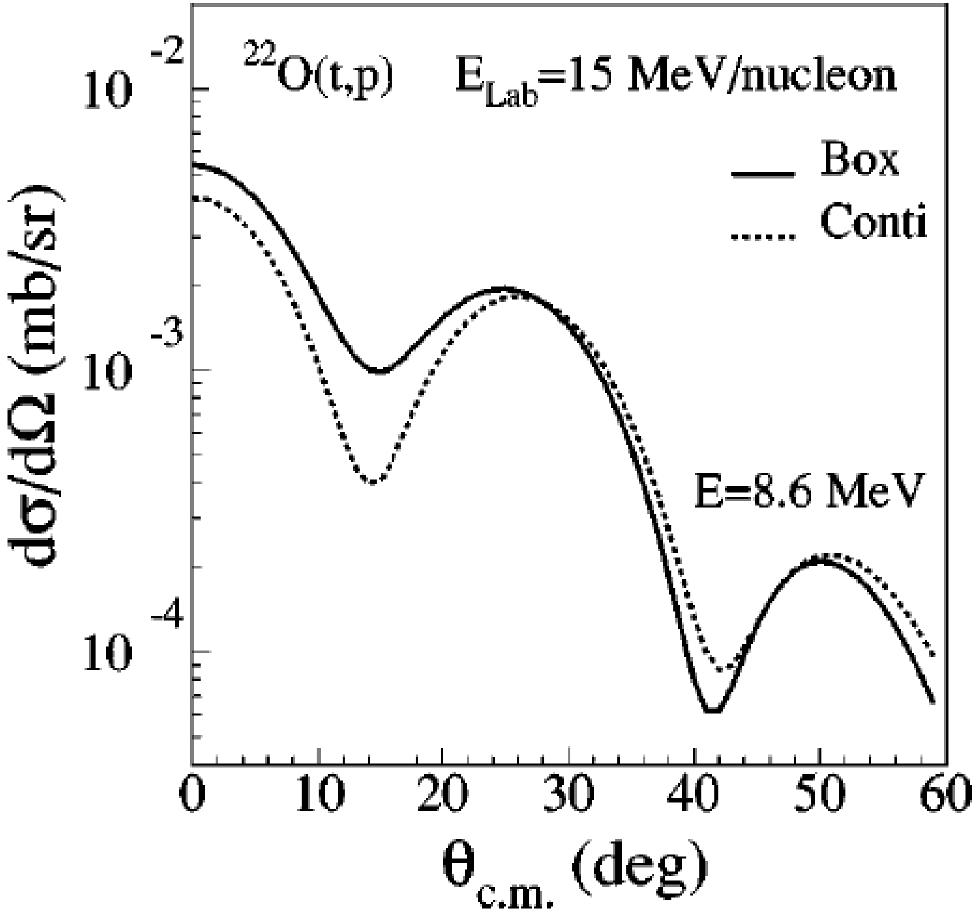


Zero range DWBA

Collective form factors



The impact of the continuum on angular distributions



How to measure Giant Pairing vibrations ?

- **(p,t) or (t,p) with high intensity : 1 μA**

- **Done : (t,p) on ^{208}Pb at E=30 MeV : too low σ and Coulomb barrier**
  (p,t) at E=150 MeV : not good matching for L=0

- **Ep ~ 50 MeV ok**

- **Weakly bound projectile like ^{6}He : high Q-value for a high energy mode**

Theoretical framework

- **QRPA model with exact treatment of the continuum**

  → **microscopic 2n form factor**

- **Absolute σ prediction : finite range DWBA, sequential/direct, …**