Population of the Giant Pairing Vibration in the $^{12}C(^{18}O,^{16}O)^{14}C$ reaction

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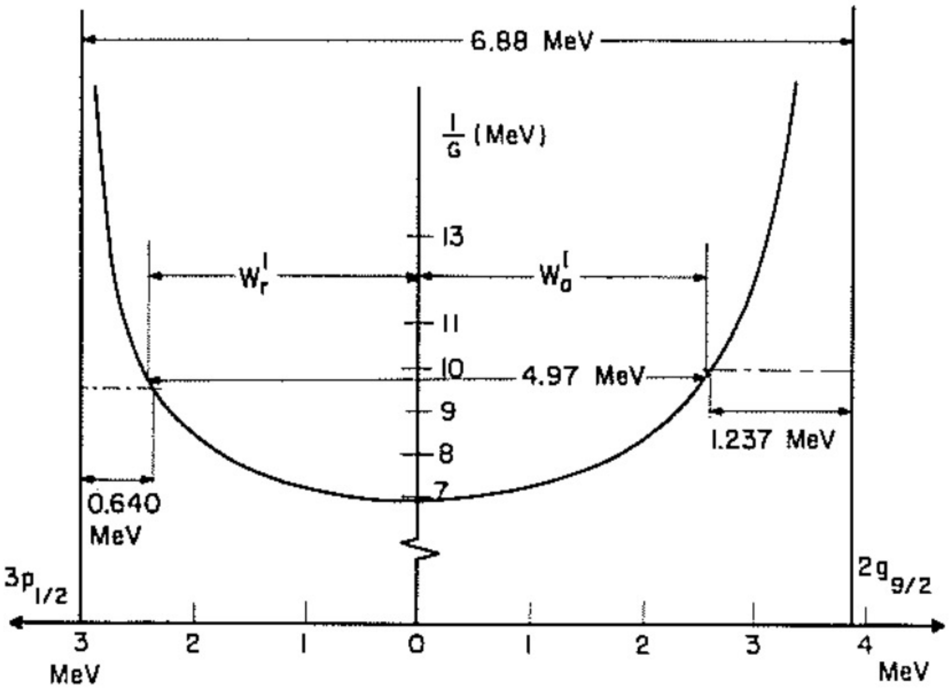
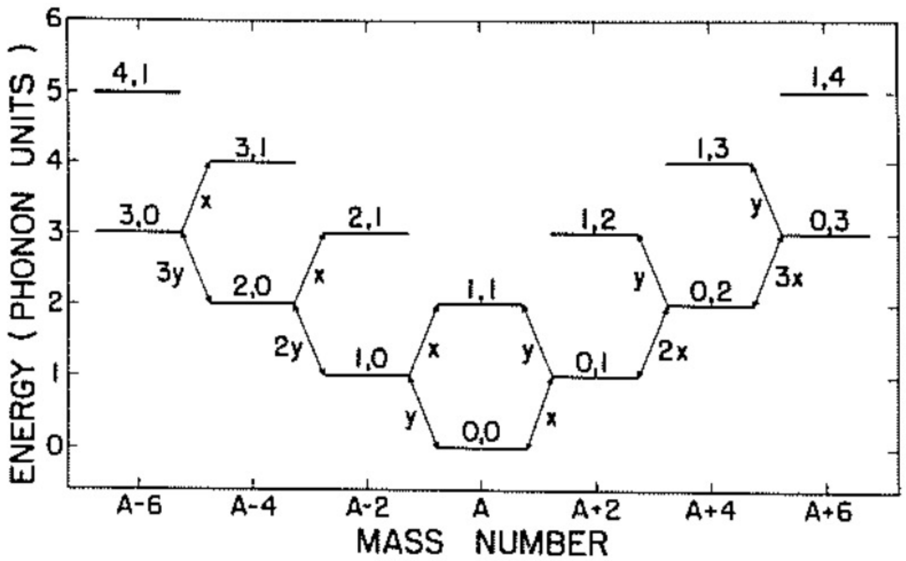
A collective nuclear mode: monopole pairing vibrations

^{208}Pb





R.A. Broglia, O. Hansen, C.Riedel, Adv. Nucl. Phys. 6 (1973) 287

The Giant Pairing Vibration

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HIGH-LYING PAIRING RESONANCES*

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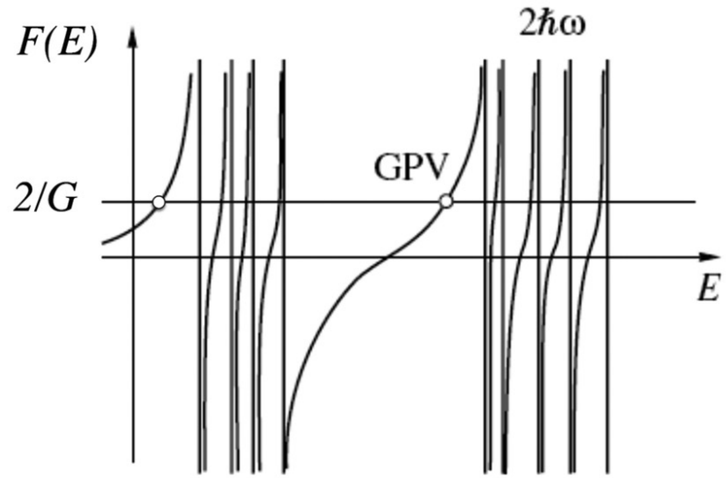
Pairing vibrations based on the excitation of pairs of particles and holes across major shells are predicted at an excitation energy of about $70/A^{1/3}$ MeV and carrying a cross section which is 20%–100% the ground state cross section.



$$\hbar\omega_{GPV} \sim 2\hbar\omega_0 - \Omega G \sim \frac{65 MeV}{A^{1/3}}$$

$$F(E) = \sum_j \frac{(2j+1)}{E - 2e_j} = \frac{2}{G} .$$

M. Assié et al., EPJ A 55 (2019) 245

The pp-RPA equations

$$|A+2,\tau\rangle = \left(\sum_{m<n} X^{\tau}_{mn} a^+_m a^+_n - \sum_{i<j} Y^{\tau}_{ij} a^+_j a^+_i \right) |A,0\rangle$$

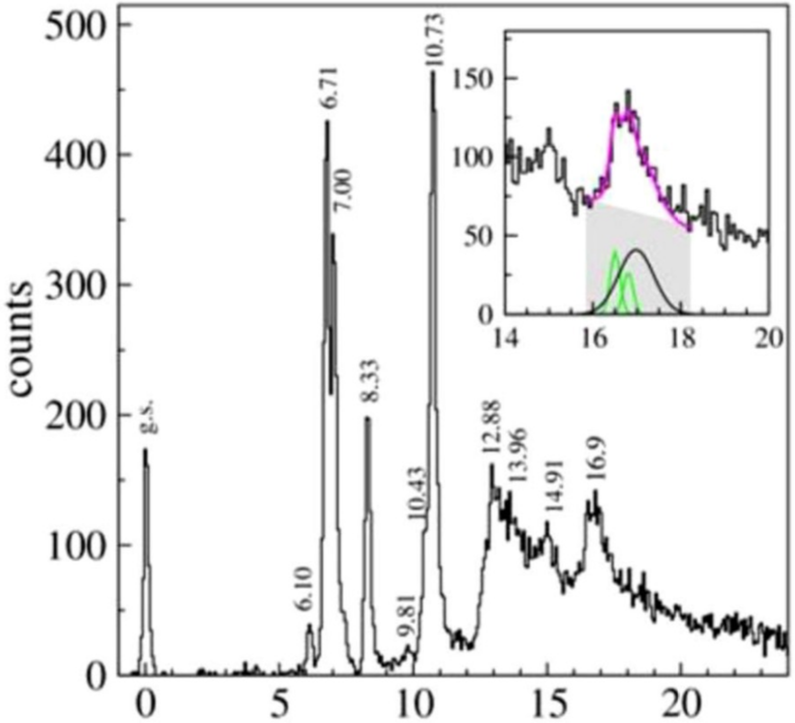
$$\begin{pmatrix} A & B \\ B^+ & C \end{pmatrix} \begin{bmatrix} R_p^{\tau,\lambda} \\ R_h^{\tau,\lambda} \end{bmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \begin{bmatrix} R_p^{\tau,\lambda} \\ R_h^{\tau,\lambda} \end{bmatrix} \cdot \hbar\Omega_{\tau,\lambda},$$

$$A_{mnm'n'} = \delta_{mm'}\delta_{nn'}(\epsilon_m + \epsilon_n) + \bar{v}_{mnm'n'},$$
$$C_{iji'j'} = -\delta_{ii'}\delta_{jj'}(\epsilon_i + \epsilon_j) + \bar{v}_{iji'j'},$$
$$B_{mnij} = -\bar{v}_{mnij},$$

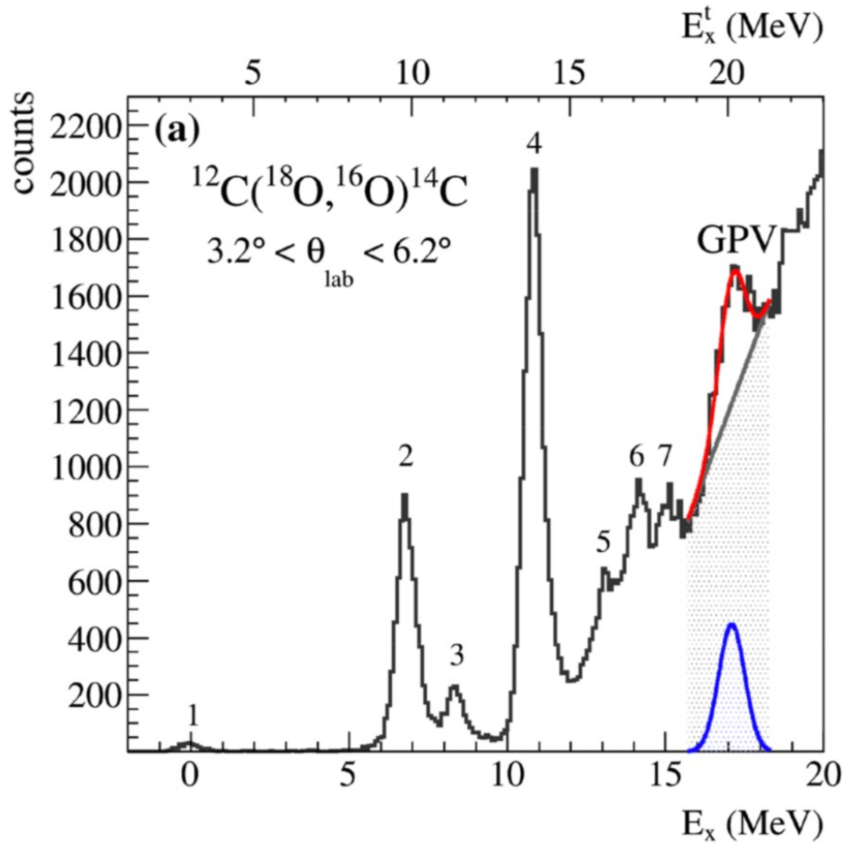
$$(R_p^{\tau})_{mn} = X^{\tau}_{mn}, \qquad (R_p^{\lambda})_{mn} = Y^{\lambda}_{mn},$$
$$(R_h^{\tau})_{ij} = Y^{\tau}_{ij}, \qquad (R_h^{\lambda})_{ij} = X^{\lambda}_{ij}.$$

Ring and Schuck

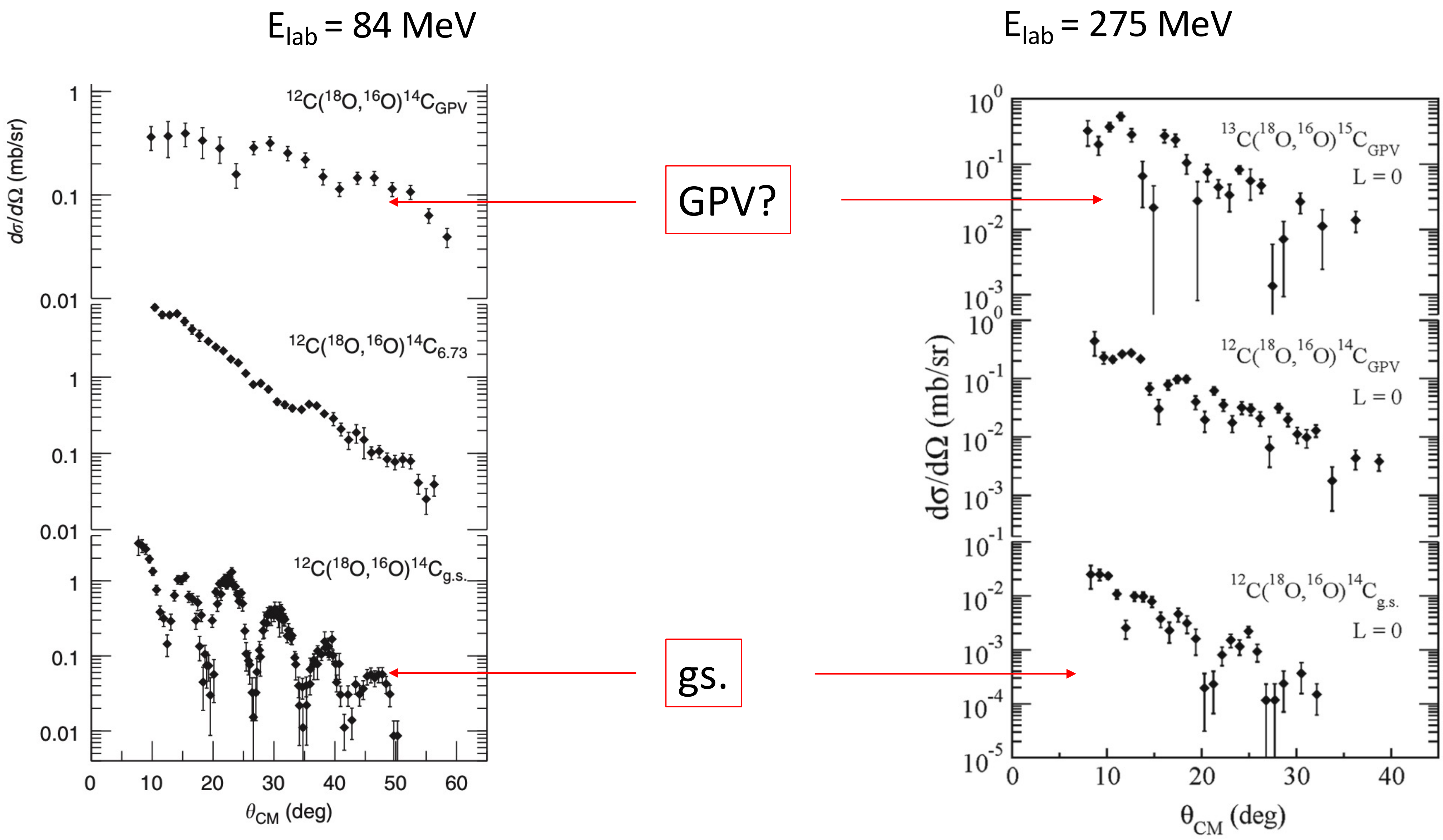
Several unsuccessful experimental searches have been carried out over the years , but recently a bump has been detected at E* ≈ 16 MeV in the reaction $^{12}C(^{18}O,^{16}O)^{14}C$ at E_{lab} = 84 and 275 MeV and intepreted as a signature of GPV



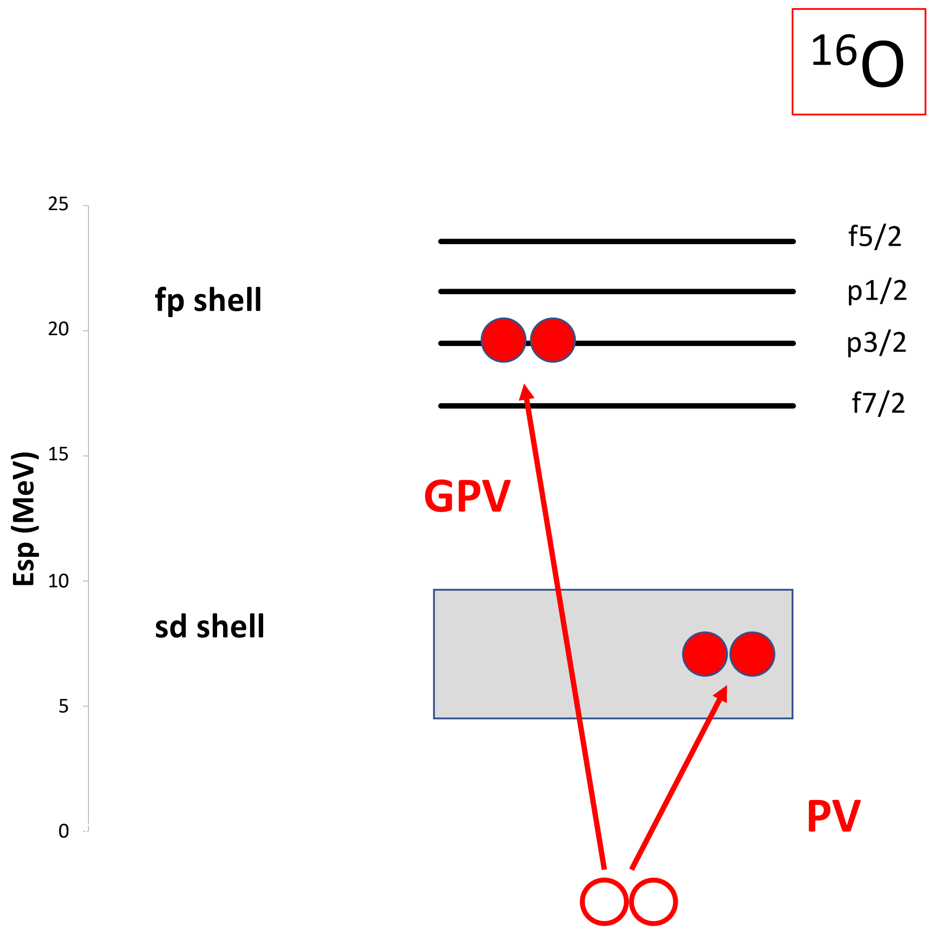
F. Cappuzzello et al., Nat. Comm. 6 (2015) 6743



F. Cappuzzello et al., Eur. Phys. J. A 57 (2021) 34



E_lab = 84 MeV
E_lab = 275 MeV
12C(18O,16O)14C_GPV
12C(18O,16O)14C_6.73
12C(18O,16O)14C_g.s.
dσ/dΩ (mb/sr)
θ_CM (deg)
GPV?
gs.
13C(18O,16O)15C_GPV
L = 0
12C(18O,16O)14C_GPV
L = 0
12C(18O,16O)14C_g.s.
L = 0
dσ/dΩ (mb/sr)
θ_CM (deg)

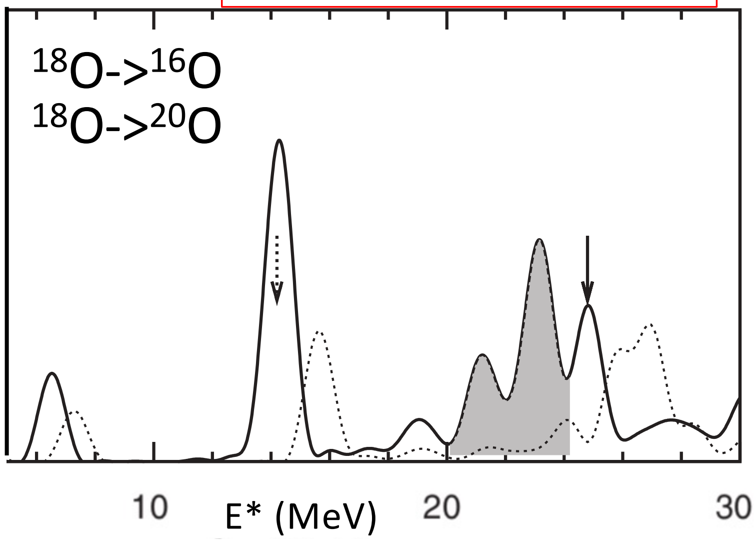


16O
25
20
15
10
5
0
Esp (MeV)
fp shell
sd shell
f5/2
p1/2
p3/2
f7/2
GPV
PV

pp-RPA with the Gogny force

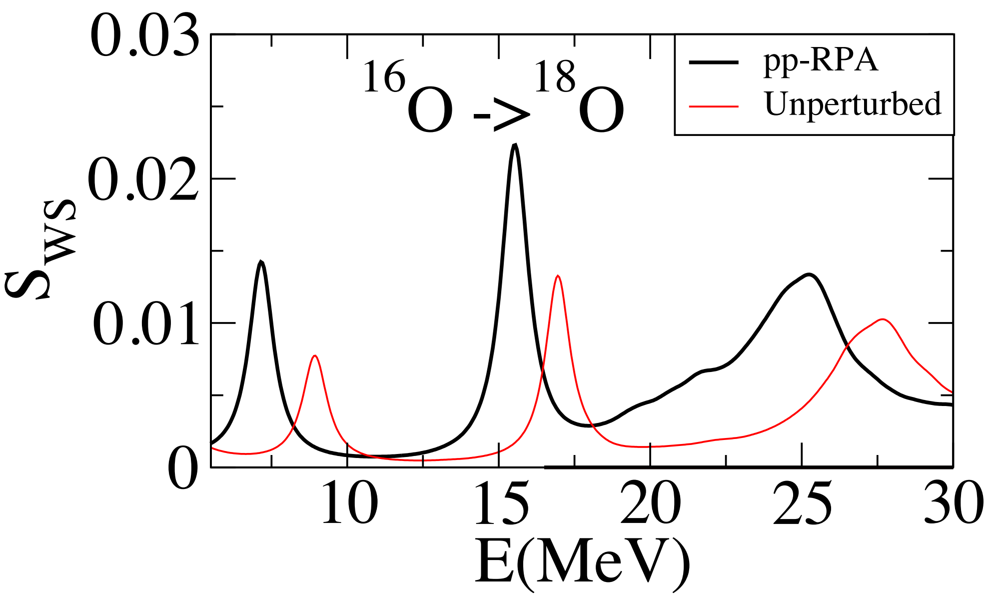
(Blanchon et al. PRC 82 (2010) 034313

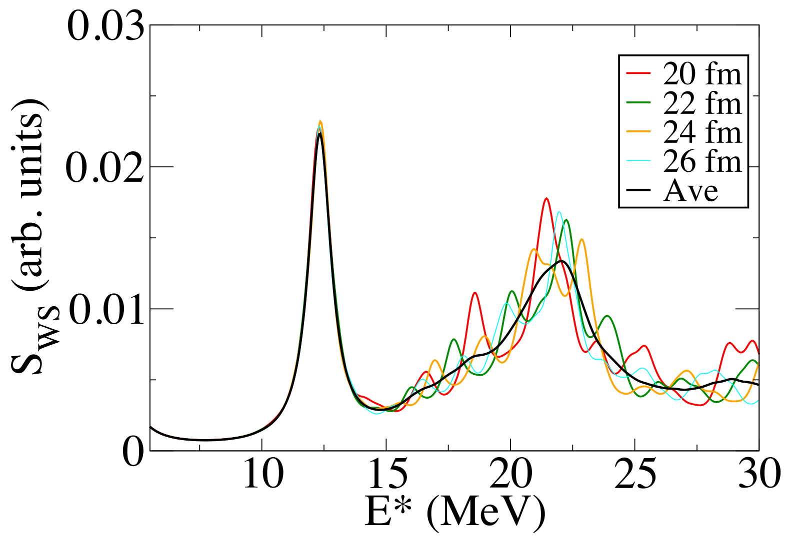
TDHF Avez PRC 78 (2008) 044318

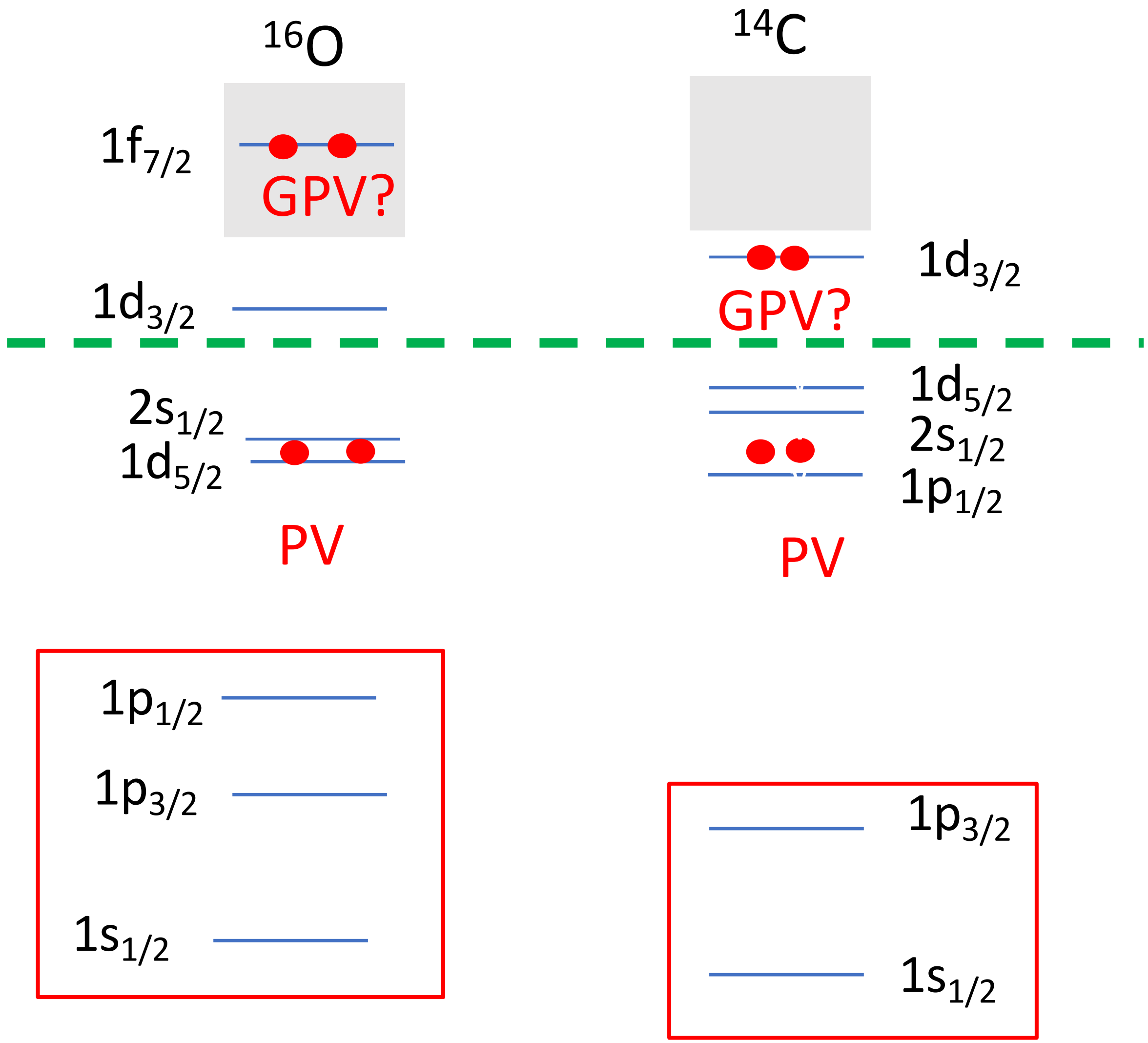


$$S^i_{WS} = \sum_{nn'lj} [X^i_{nn'lj} + Y^i_{nn'lj}] \int drG(r)\psi_{nlj}(r)\psi_{n'lj}(r).$$

$$G(r) \equiv (1 + exp[(r - R_S)/a_S]$$





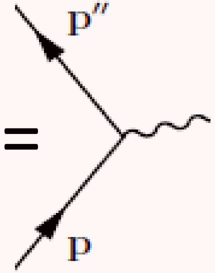


^{16}O
$1f_{7/2}$
GPV?
$1d_{3/2}$
$2s_{1/2}$
$1d_{5/2}$
PV
$1p_{1/2}$
$1p_{3/2}$
$1s_{1/2}$
^{14}C
$1d_{3/2}$
GPV?
$1d_{5/2}$
$2s_{1/2}$
$1p_{1/2}$
PV
$1p_{3/2}$
$1s_{1/2}$

EXTENDED pp-RPA

$$\begin{pmatrix} A_{pp'p''p'''} & B_{pp'h''h'''} \\ B_{p''p'''hh'} & A_{hh'h''h'''} \end{pmatrix} \begin{pmatrix} X_{p''p'''} \\ Y_{h''h'''} \end{pmatrix} = E \begin{pmatrix} X_{pp'} \\ Y_{hh'} \end{pmatrix}$$

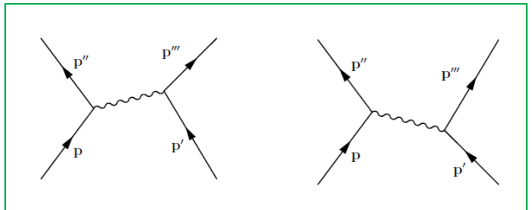
PVC

$h_{pp''\lambda\nu} =$ 

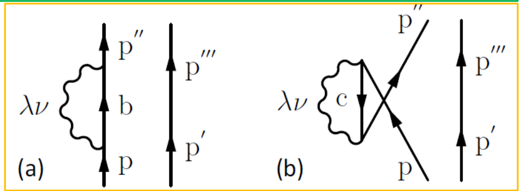
Includes Self-energy and Induced Interaction <-> PVC

$$A_{pp'p''p'''} = [(\epsilon_p + \epsilon_{p'}) + \Sigma_{pp''(p')}(E)\delta_{p'p'''} + \Sigma_{p'p'''(p)}(E)\delta_{pp''} + V^{bare}_{pp'p''p'''} + V^{ind}_{pp'p''p'''}(E) + Exch(p,p')]N_{pp'p''p'''}$$

$$B_{pp'hh'} = [V^{bare}_{pp'hh'} + V^{ind}_{pp'hh'}(E) + Exch(p,p')]\, N_{pp'p''p'''}$$



$$V^{ind}_{pp'p''p'''} = \sum_{\lambda\nu} \left[\frac{h_{pp''\lambda\nu} h_{p'''p'\lambda\nu}}{E - (\epsilon^{emp}_{p''} + \epsilon^{emp}_{p'} + \hbar\omega_{\lambda\nu})} + \frac{h_{p''p\lambda\nu} h_{p'p'''\lambda\nu}}{E - (\epsilon^{emp}_{p} + \epsilon^{emp}_{p'''} + \hbar\omega_{\lambda\nu})} \right]$$

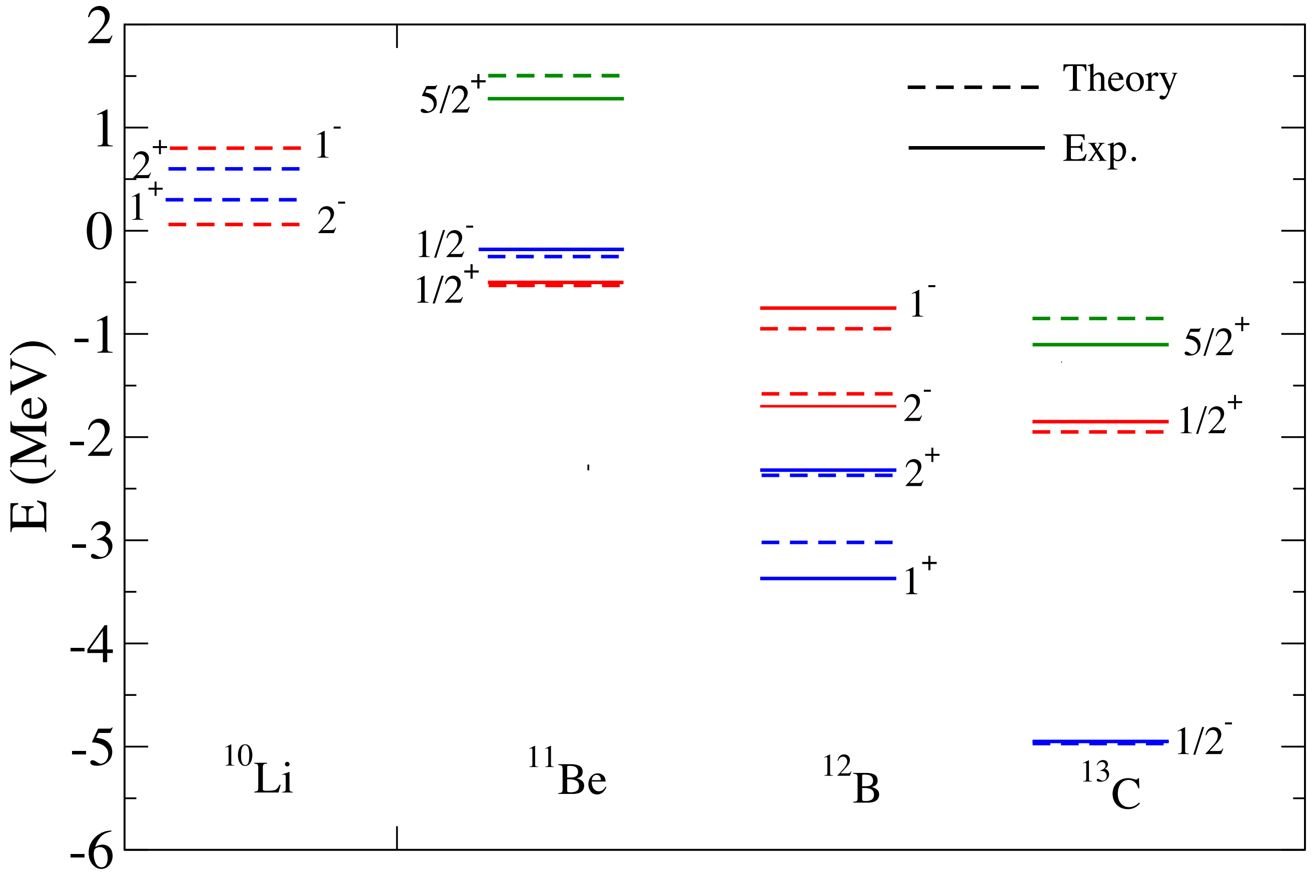


$$\Sigma_{pp''(p')}(E) = \sum_{b,\epsilon_b > \epsilon_F \lambda\nu} \frac{h_{pb\lambda\nu} h_{p''b\lambda\nu}}{E - (\epsilon^{emp}_b + \epsilon^{emp}_{p'} + \hbar\omega_{\lambda\nu})} + \sum_{c,\epsilon_c < \epsilon_F \lambda\nu} \frac{h_{pc\lambda\nu} h_{p''c\lambda\nu}}{E - \epsilon^{emp}_c - \epsilon^{emp}_{p'} + \hbar\omega_{\lambda\nu}} \quad (6)$$

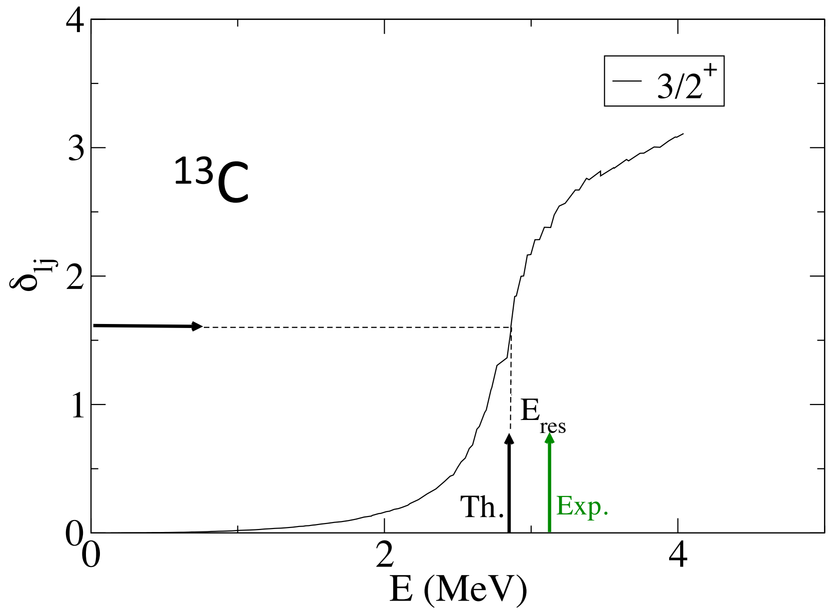
The self-energy and the induced interaction are energy-dependent, but it is possible to reconstruct the amplitudes of the resulting 0+ states on the intermediate 2p-1phonon states, so that they can be written:

$$|0^+_n> \;=\; \sum_{pp'} \left(X_{pp'}(n)\,|pp'(0^+)> + \; Y_{hh'}(n)\,|h\,h'(0^+)> \right) \;+$$
$$\sum_{pp'\nu} A_{pp'\nu}(n)\,|pp'(2^+)\nu(2^+)>$$

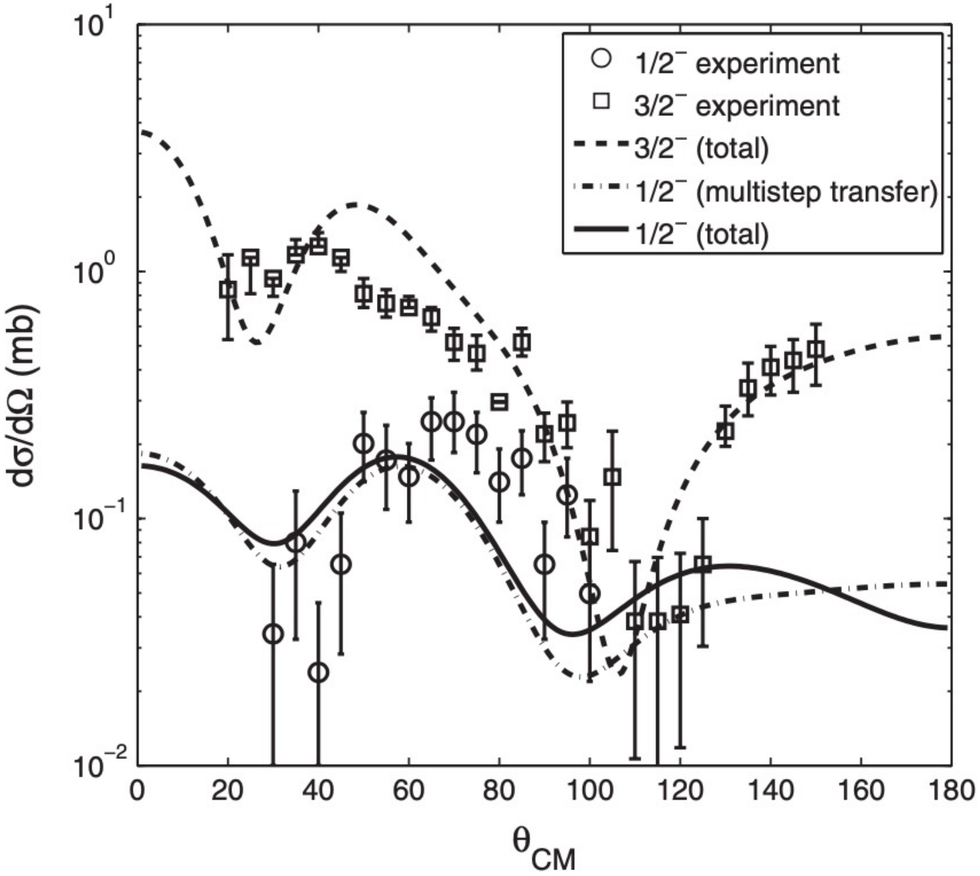
Many-body states in N=7 isotones arising from quadrupole coupling with single-particle states calculated in a common mean-field potential



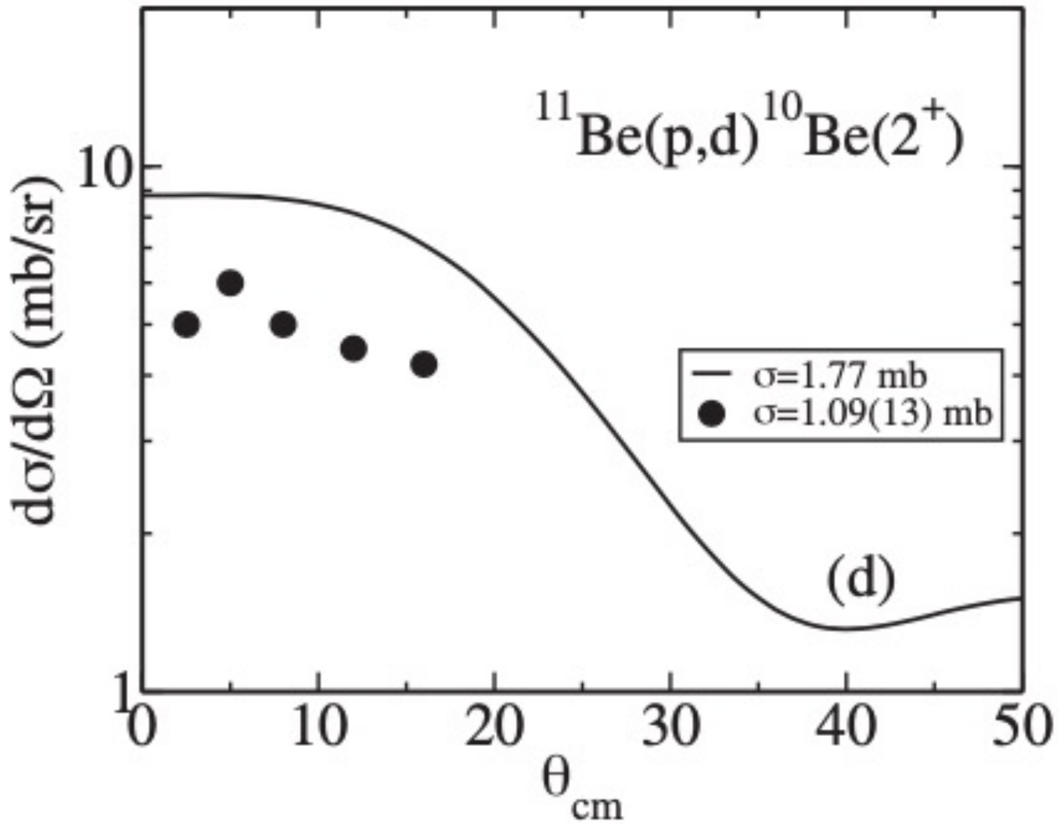
3/2+ many-body phase shift



p(^{11}Li,^{9}Li)t

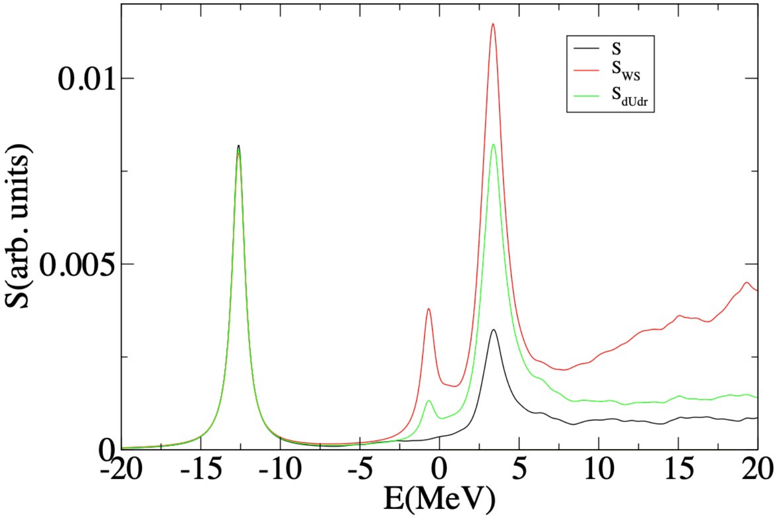


G. Potel et al, PRL 105 (2010) 172502

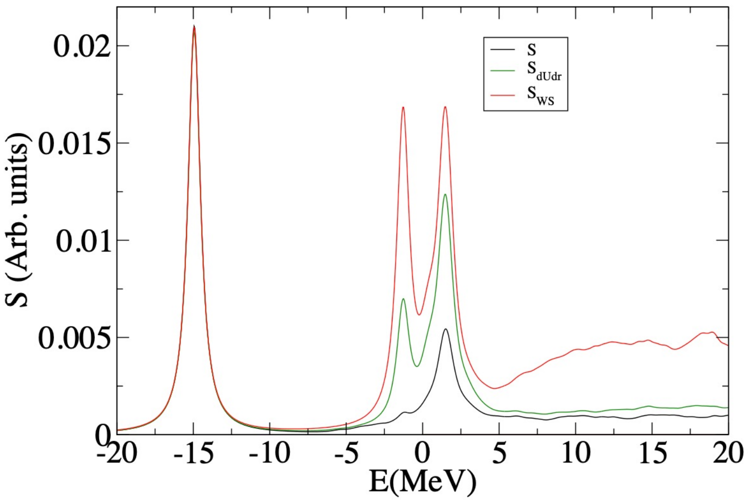


F. Barranco et al, PRL 119 (2017) 082501

Unperturbed



Gogny p-p



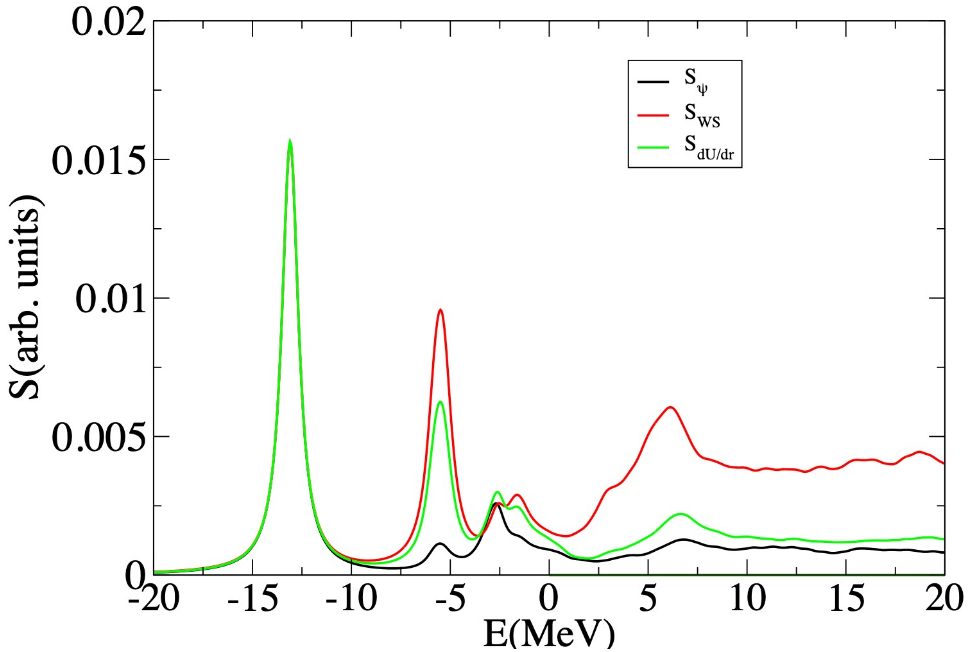
Form factors:

volume

density

surface

Gogny p-p + phonon coupling



$^{18}O + ^{12}C$ optical potential

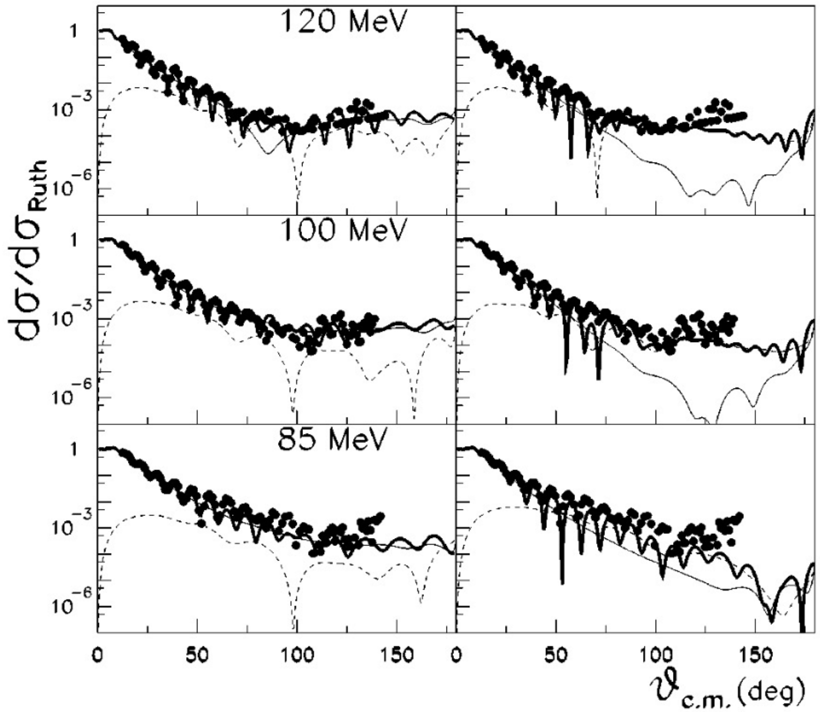


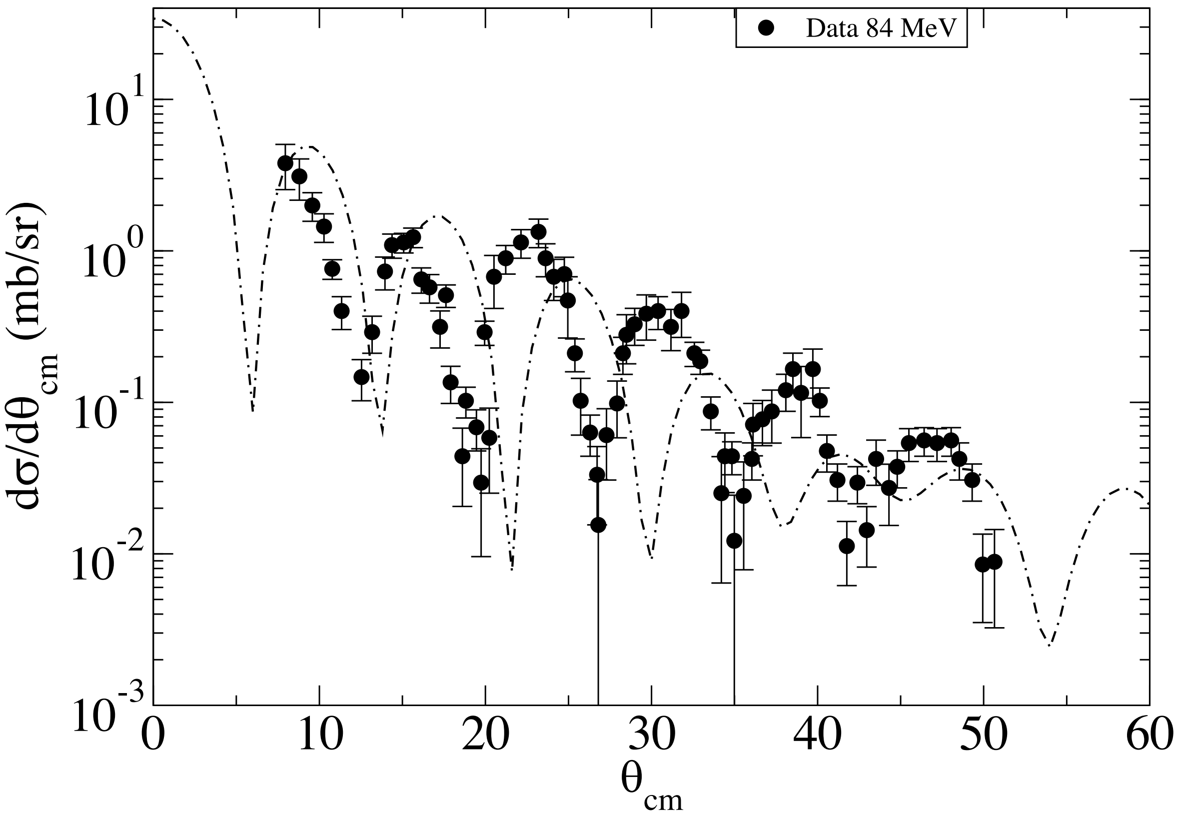
FIG. 2. Same caption as for Fig. 1 but for the $^{18}O + ^{12}C$ elastic scattering at 120, 100, and 85 MeV.

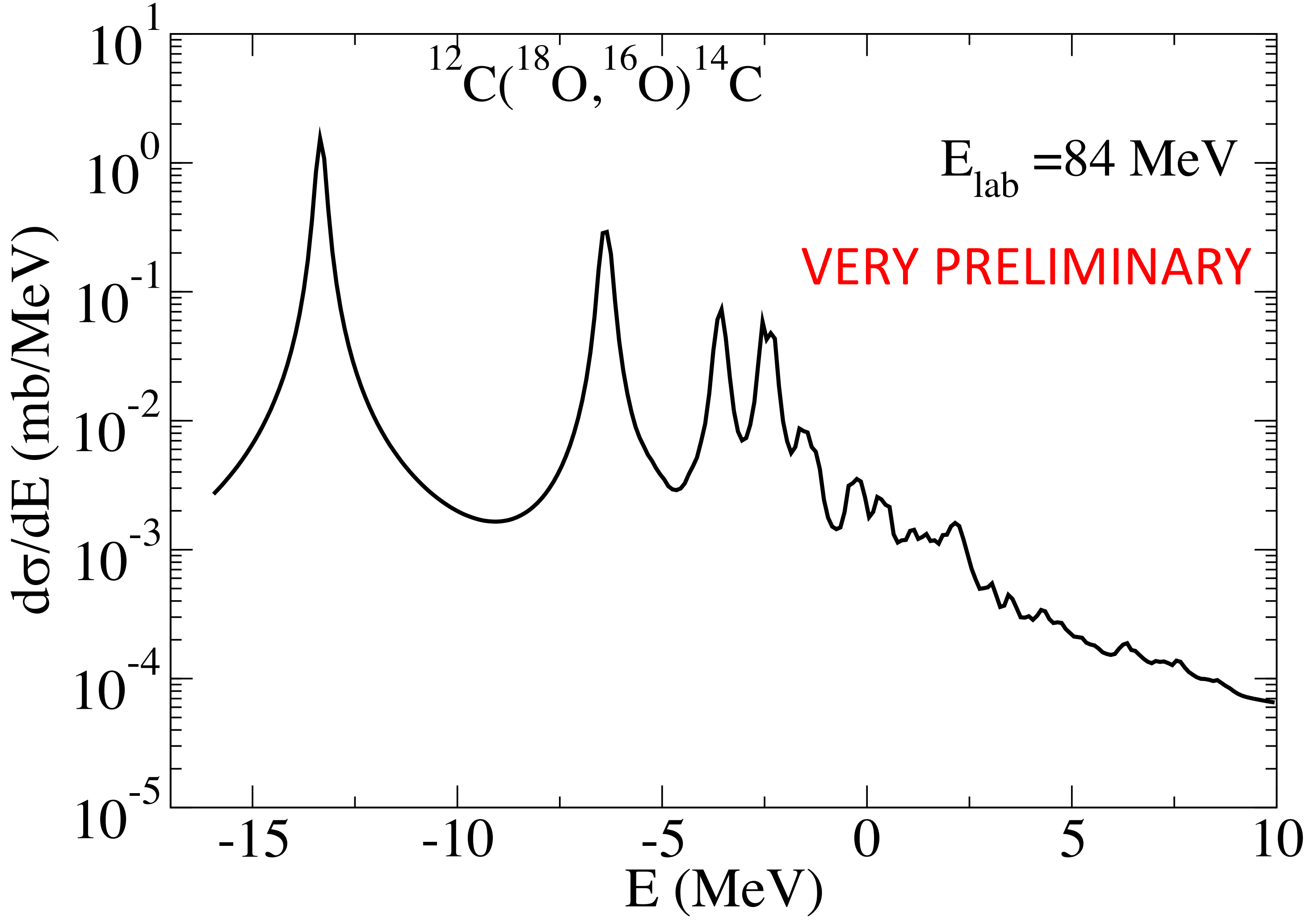
TABLE II. Phenomenological potentials; the real part is a WS2 term and the imaginary part is a WS1 term (pure volume).

E_{lab} (MeV)	$E_{c.m.}$ (MeV)	V (MeV)	W (MeV)	R_W (fm)	a_W (fm)
$^{16}O + ^{12}C$ $R_V = 4$ fm, $a_V = 1.4$ fm					
132	56.6	293	13.4	5.900	0.603
124	53.2	290	14.1	5.712	0.636
115.9	49.7	290	13.0	5.878	0.522
100	42.9	297	10.4	6.079	0.523
94.8	40.6	297	8.8	6.672	0.317
80.0	34.3	297	9.0	6.557	0.322
$^{18}O + ^{12}C$ $R_V = 4.08$ fm, $a_V = 1.38$ fm					
120	48	293	13.4	6.443	0.523
100	40	305	13.9	6.270	0.615
85	34	324	18.3	5.930	0.562

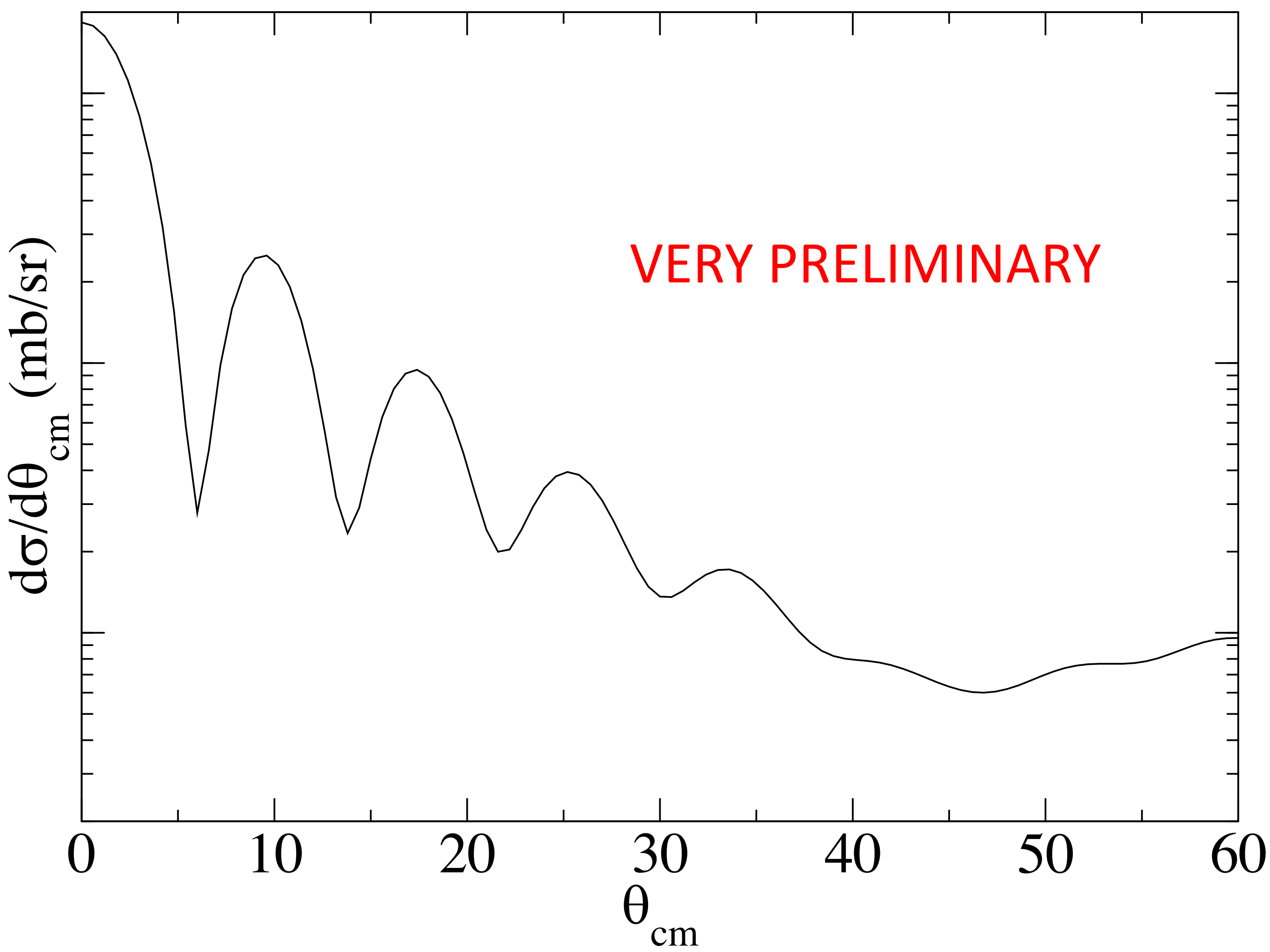
$^{12}C(^{18}O,^{16}O)^{14}C(gs)$ at E_{lab} = 84 MeV

2nd order DWBA calculation (G. Potel, Rep. Prog. Phys. 76(2013) 106301)





$^{12}C(^{18}O,^{16}O)^{14}C$
E_{lab} =84 MeV
VERY PRELIMINARY
$d\sigma/dE$ (mb/MeV)
E (MeV)
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
-15
-10
-5
0
5
10


VERY PRELIMINARY
dσ/dθcm (mb/sr)
0
10
20
30
40
50
60
θcm

CONCLUSIONS

We have computed the 2n-transfer strength to populate 0+ states in the continuum of 14C and made the first steps to compute the absolute cross section of the reaction $^{12}C(^{18}O,^{16}O)^{14}C$. The theoretical model is based on particle-particle RPA extended to include the effects of coupling to collective quadrupole vibrations, in keeping with previous calculations of weakly-bound systems.

The aim is to compare our results with the bump and the associated angular distribution revealed in the excitation spectrum and attributed to the Giant Pairing Vibration.