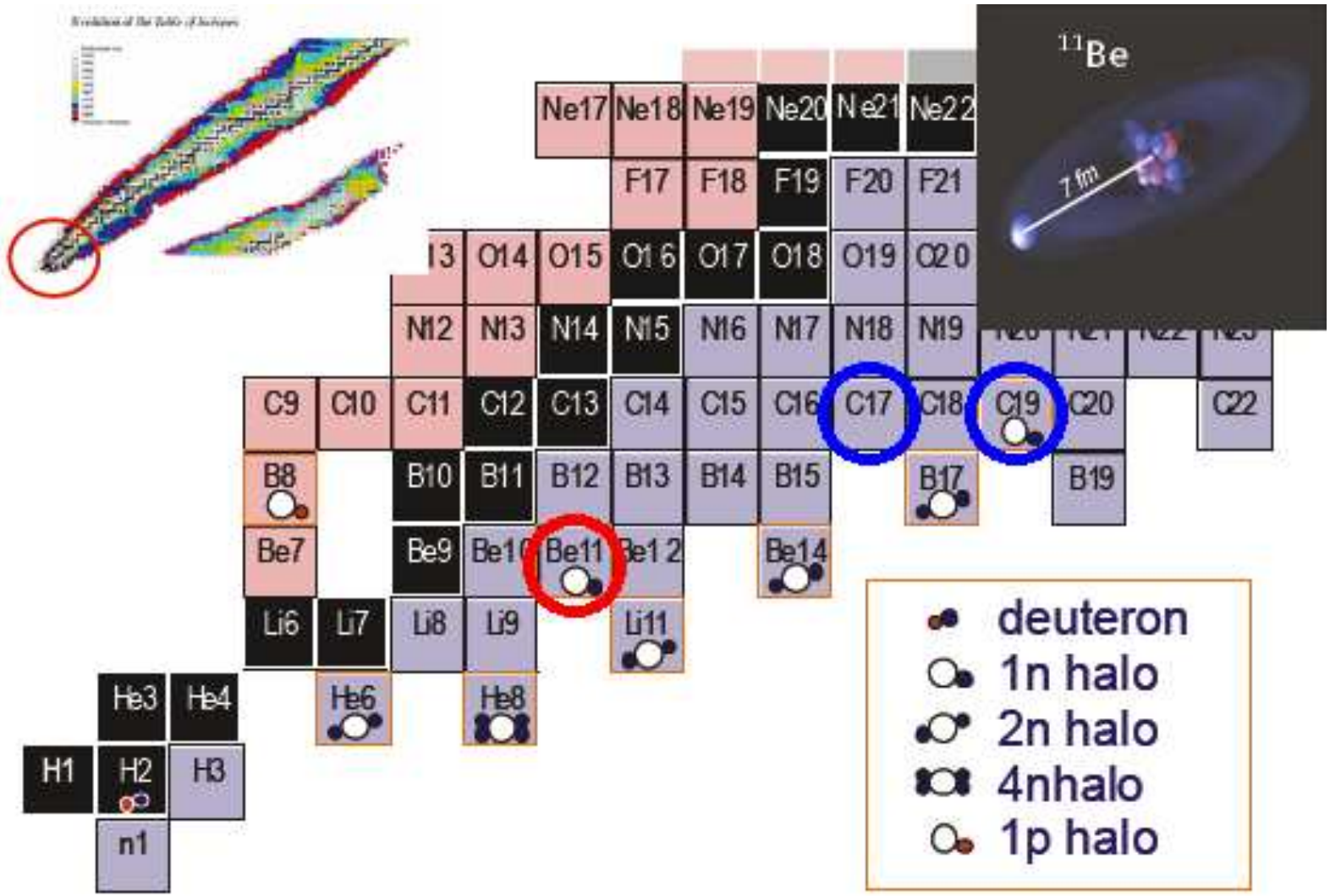
Semi-microscopic description of core excitations in halo nuclei within breakup reactions

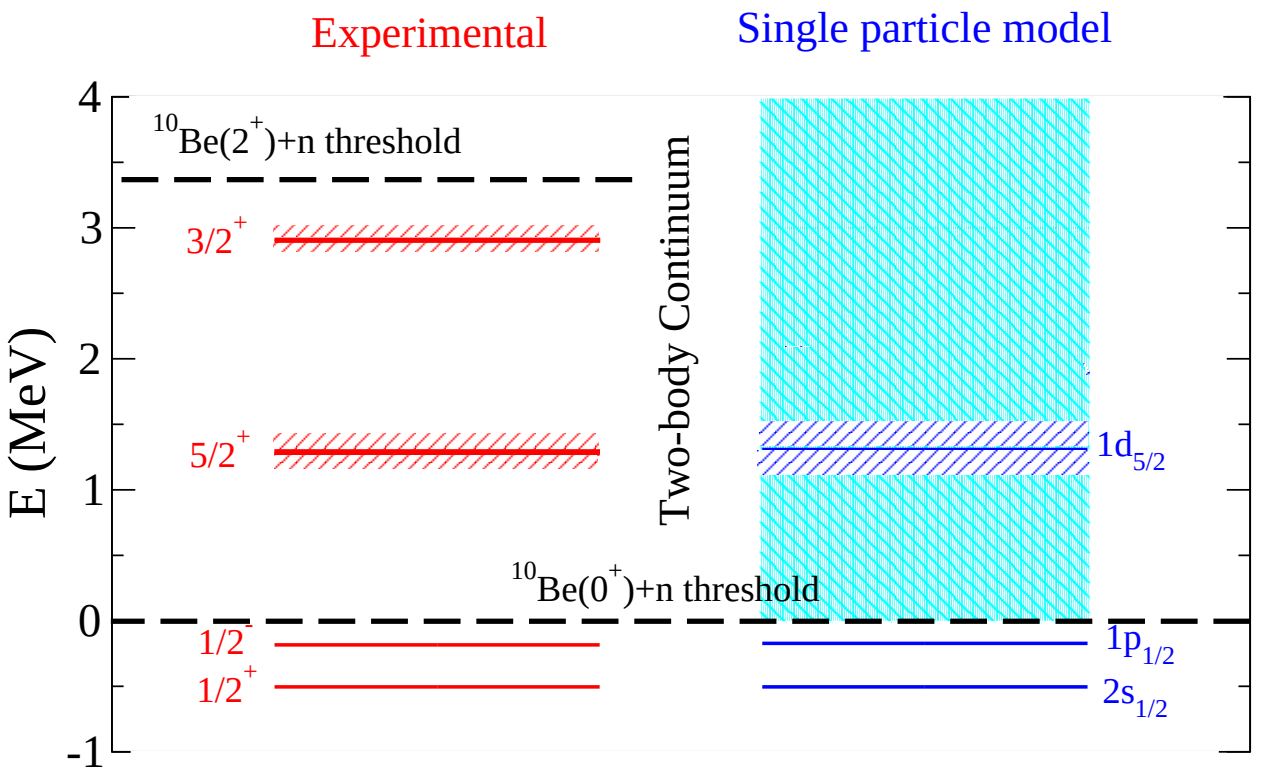
J. A. Lay[1], J. M. Arias[2], A. M. Moro[2], R. de Diego[3]

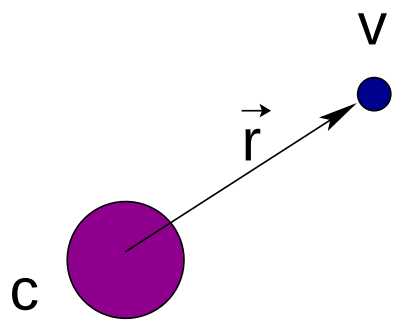
[1]Dipartimento di Fisica Galileo Galilei and INFN, Via Marzolo 8, I-35131 Padova, Italy;
[2]Dpto. de FAMN, Universidad de Sevilla, Apdo. 1065, E-41080 Sevilla, Spain;
[3]Centro de Física Nuclear, Universidade de Lisboa, Av. Prof. Gama Pinto 2, P-1649-003 Lisboa, Portugal

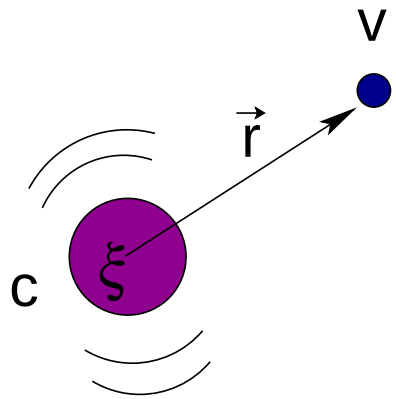
Trento, 20^{th} October 2014



Ne17 Ne18 Ne19 Ne20 Ne21 Ne22
F17 F18 F19 F20 F21
O14 O15 O16 O17 O18 O19 O20
N12 N13 N14 N15 N16 N17 N18 N19
C9 C10 C11 C12 C13 C14 C15 C16 C17 C18 C19 C20 C22
B8 B10 B11 B12 B13 B14 B15 B17 B19
Be7 Be9 Be11 Be14
Li6 Li7 Li8 Li9 Li11
He3 He4 He6 He8
H1 H2 H3
n1
11Be
7 fm
deuteron
1n halo
2n halo
4nhalo
1p halo

^{11}Be in a single particle model







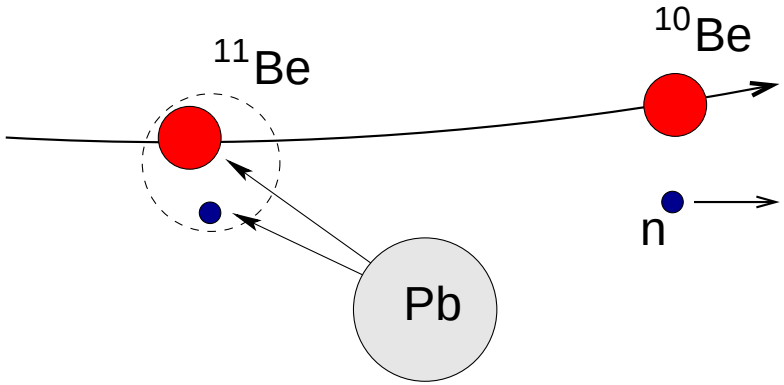
x No core excitations

$$|^{11}\mathrm{Be}(1/2^+)\rangle = 1|^{10}\mathrm{Be}(0^+ \text{ g.s.}) \otimes \nu\, s_{1/2}\rangle$$

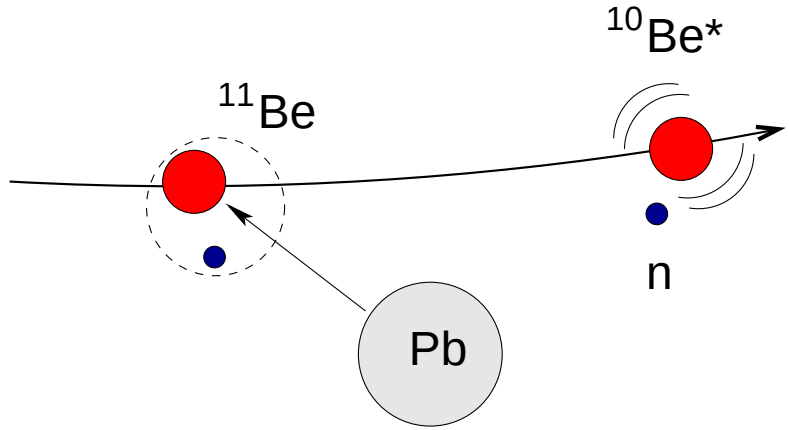
✓ Core excitations

$$|^{11}\mathrm{Be}(1/2^+)\rangle = \alpha|^{10}\mathrm{Be}(0^+ \text{ g.s.}) \otimes \nu s_{1/2}\rangle + \beta|^{10}\mathrm{Be}(2^+) \otimes \nu d_{5/2}\rangle + \ldots$$

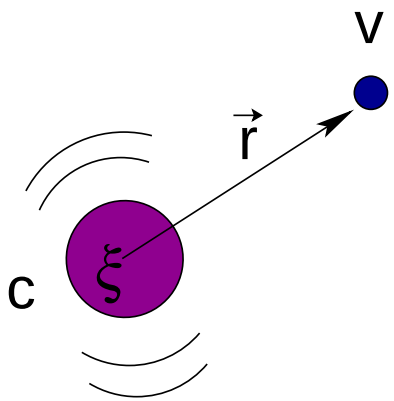
$|\alpha|^2, |\beta|^2$ = spectroscopic factors



x Pure valence excitation



✓ Core-excitation mechanism



Hamiltonian with core excitation

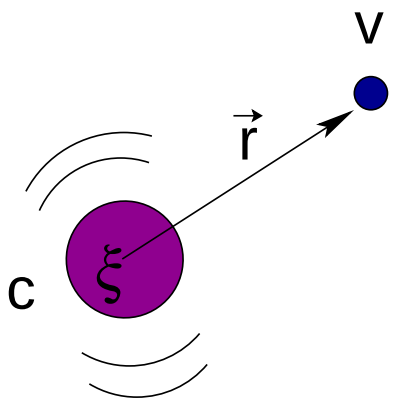
$$\mathcal{H}_p = T(\vec{r}) + h_{core}(\xi) + V_{NC}(\vec{r}, \vec{\xi})$$

Model for the core $h_{core}(\xi)$

- Selecting the model space $\Rightarrow$ which states are included
- The model for core excitations will determine $V_{NC}(\vec{r}, \vec{\xi})$

Same formalism for different interaction models:

- Particle-Rotor model (deformed core)
- Particle-Vibration
- From microscopic transition densities
- ...



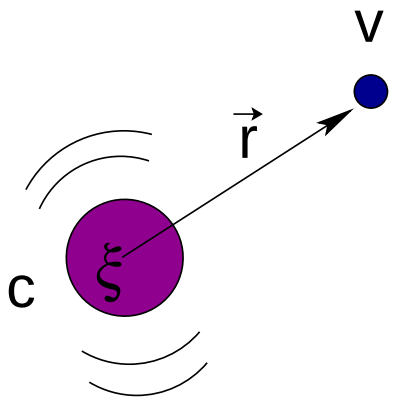
Hamiltonian with core excitation

$$\mathcal{H}_p = T(\vec{r}) + h_{core}(\xi) + V_{NC}(\vec{r}, \vec{\xi})$$

We look for a basis including core degrees of freedom

Coupling core $\varphi_I(\vec{\xi})$ and single particle $\mathcal{Y}_{\ell sj}(\hat{r})$ to the total J_p

$\Rightarrow$ n_α different possible combinations or channels $\alpha = \{I, s, j, I\}$



Hamiltonian with core excitation

$$\mathcal{H}_p = T(\vec{r}) + h_{core}(\xi) + V_{NC}(\vec{r}, \vec{\xi})$$

Set of $\mathcal{L}^2$ functions in this scheme:

$$|\phi_{i,J_p}(\vec{r}, \vec{\xi})\rangle = \sum_\alpha R^{THO}_{i,\alpha}(r) \left[\mathcal{Y}_{\ell s j}(\hat{r}) \otimes \varphi_I(\vec{\xi})\right]_{J_p} \qquad i = 1, .., N$$

$\Rightarrow$ Total number of functions: N times the number of channels

$$N \cdot n_\alpha$$

Pseudo-states (PS) discretization method

- Discrete set of $\mathcal{L}^2$ functions: $|\phi_n\rangle$

Completeness condition:

$$\sum^{N} |\phi_i\rangle\langle\phi_i| \approx \mathrm{I}$$

- To diagonalize the internal Hamiltonian of a projectile $\mathcal{H}_p$

Matrix elements:

$$\mathcal{H}_p \longmapsto \sum_{n,n'} |\phi_n\rangle\langle\phi_n|\mathcal{H}_p|\phi_{n'}\rangle\langle\phi_{n'}|$$

Pseudo-states (PS) discretization method

Eigenstates of the matrix NxN:

$$|\varphi_n^{(N)}\rangle = \sum^{N} C_i^n |\phi_i\rangle$$

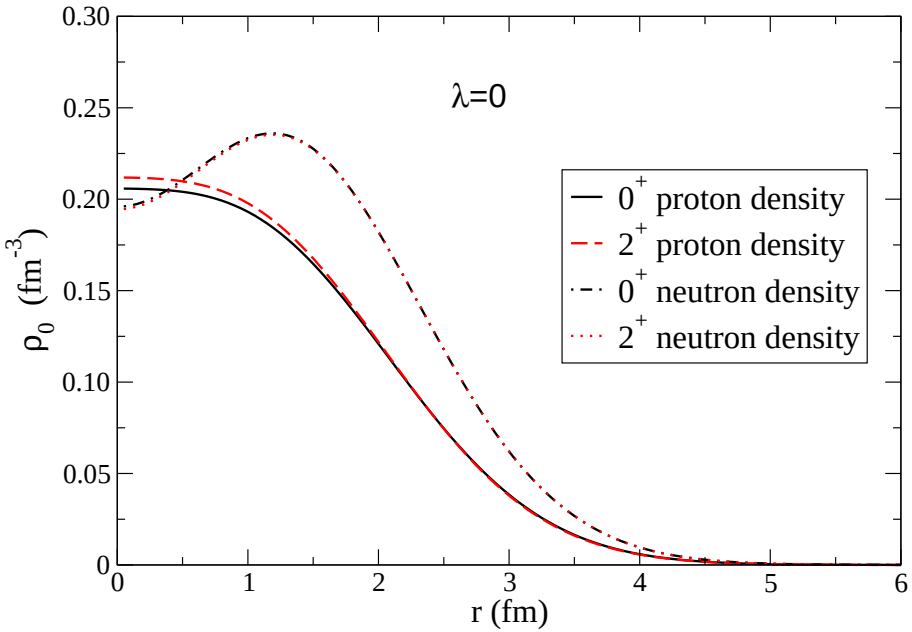
- $\begin{cases} n_b \text{ states with } \varepsilon_n < 0 \text{ representing the bound states.} \\ \text{N-}n_b, \varepsilon_n > 0 \Rightarrow \text{discrete representation of the Continuum} \end{cases}$
- Orthogonal and normalizable.

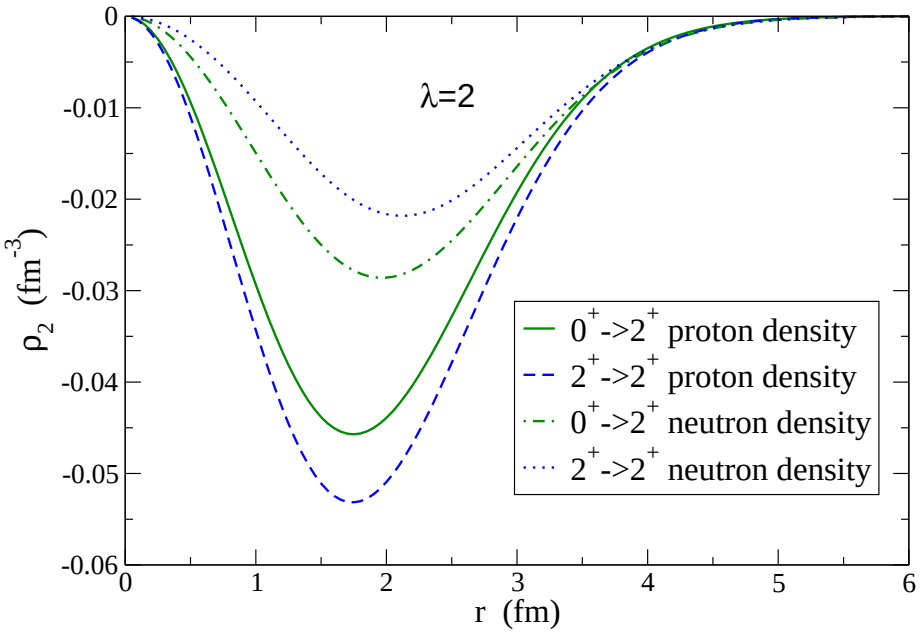
What is the most suitable basis? Lagrange, Sturmian, Harmonic Oscillator?

HO vs THO:

$$\phi(s) \longmapsto e^{-\left(\frac{s}{b}\right)^2} \quad \Longrightarrow \quad \phi[s(r)] \longmapsto e^{-\frac{\gamma^2}{2b^2} r}$$

P-AMD

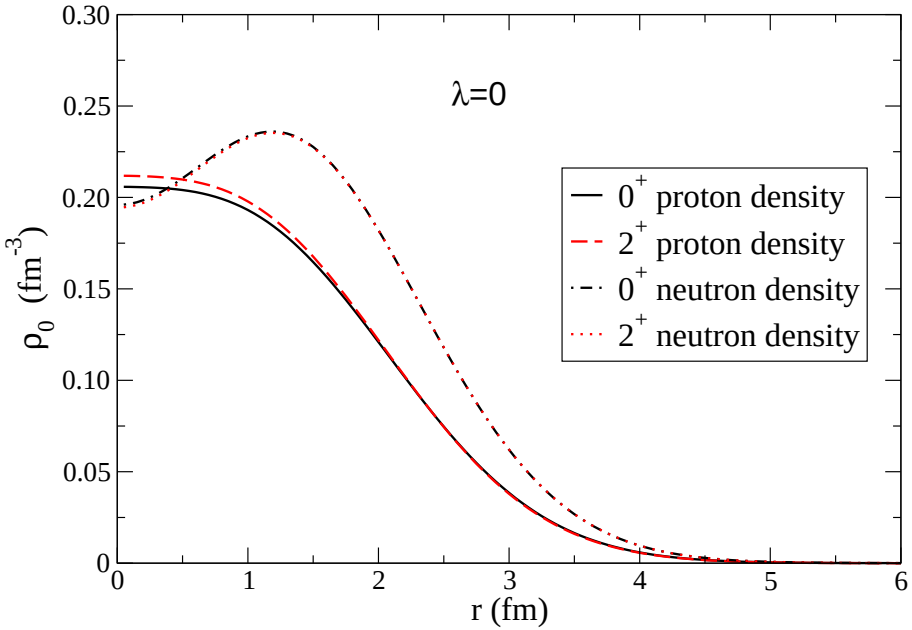


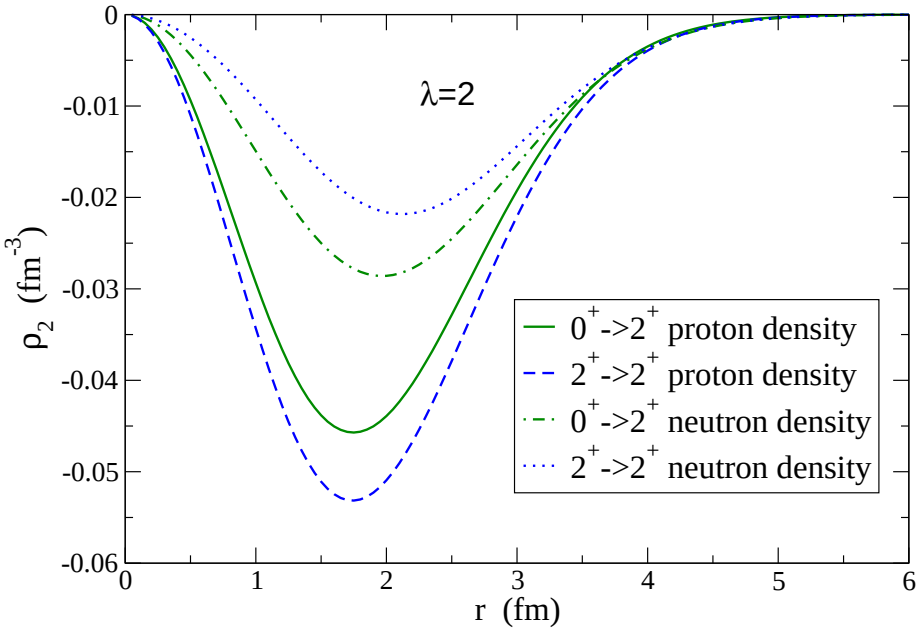


Densities from Antisymmetrized Molecular Dynamics (AMD)

Y. Kanada-En'yo *et al.* Phys. Rev. C 60, 064304 (1999)

P-AMD

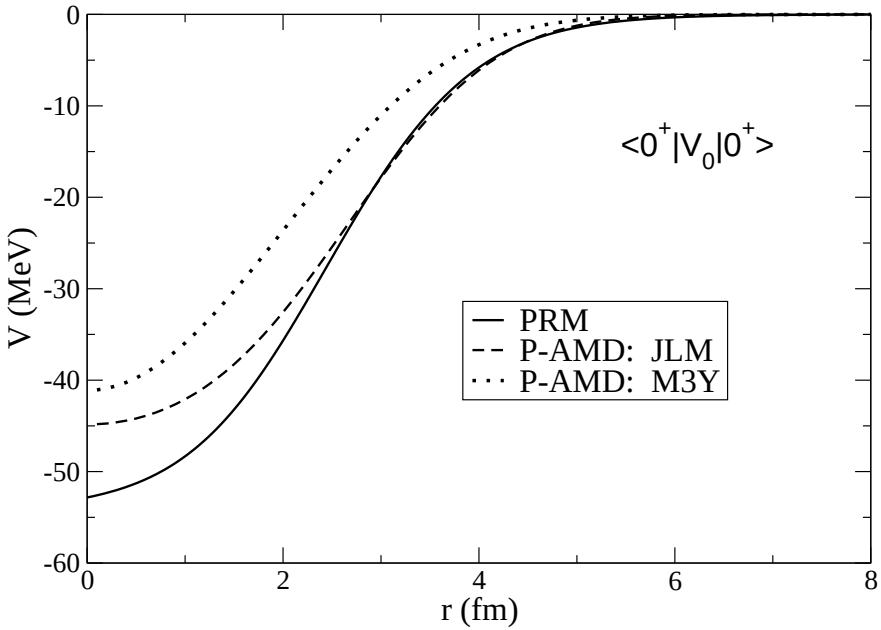


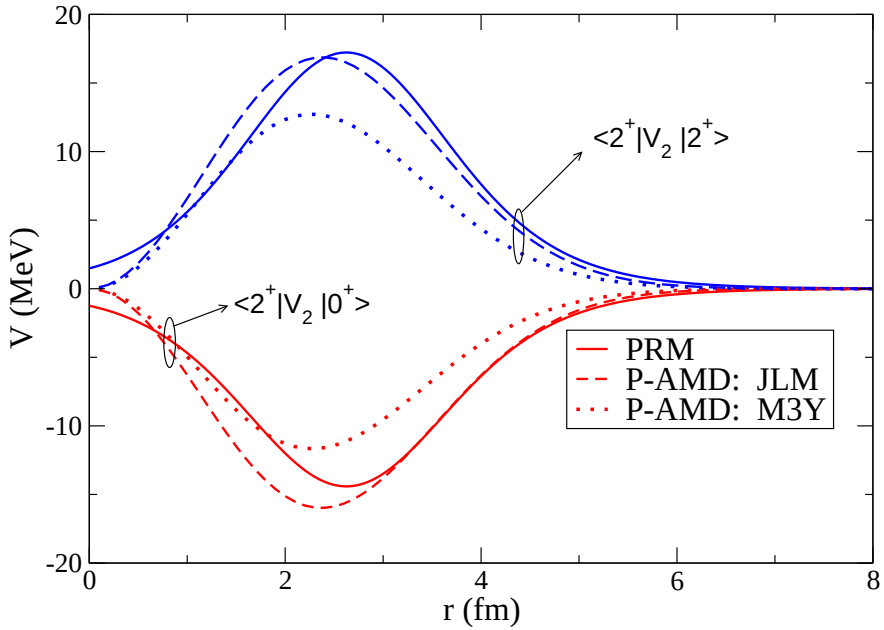


$$\langle I||V^{\lambda}_{NC}(r,\vec{\xi})||I'\rangle = \int dr' \left[\langle I||\rho_{\lambda}(r',\xi)||I'\rangle v_{nn}(|\vec{r}-\vec{r'}|)\right]$$

JLM interaction Phys. Rev. C 16, 80 (1977).

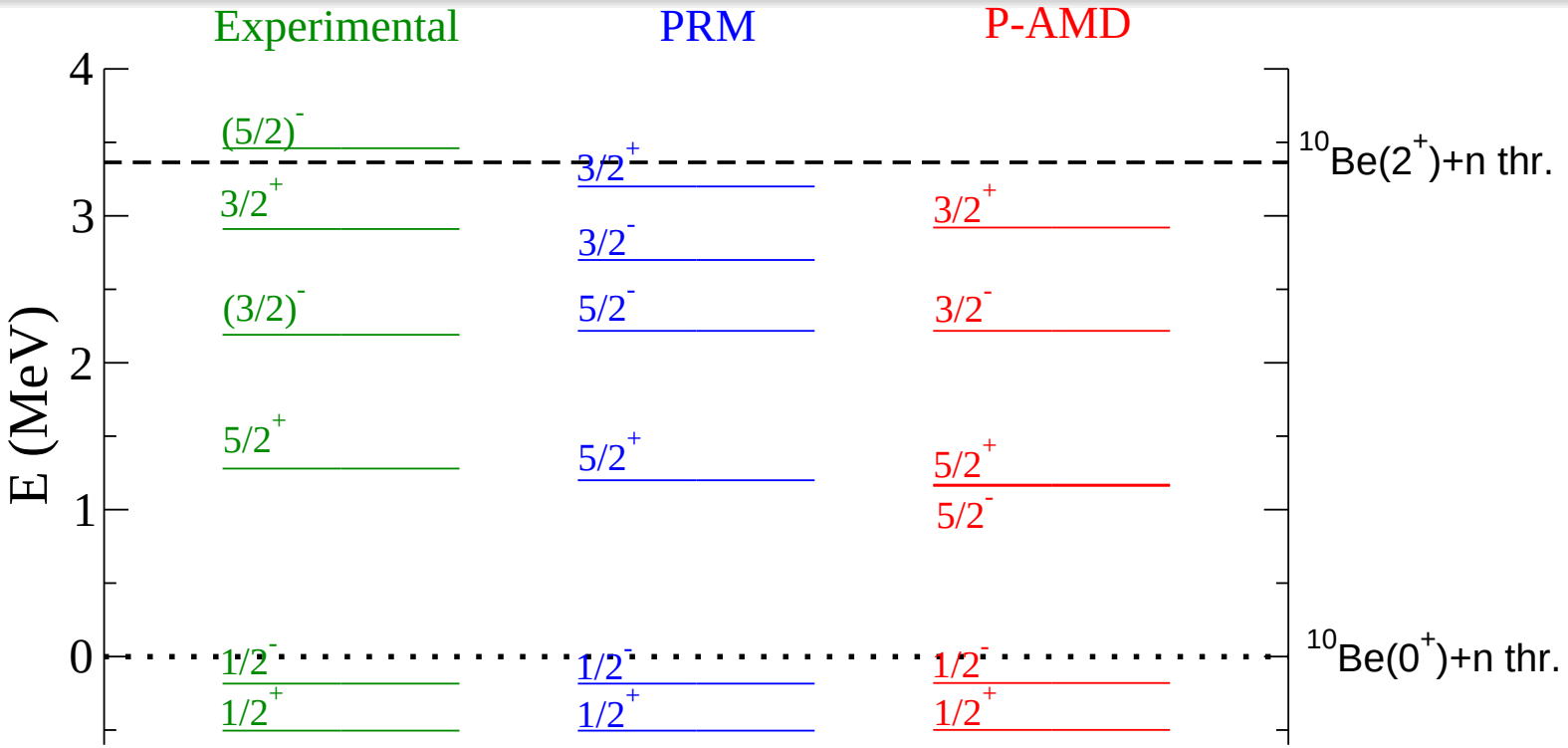
P-AMD





PRC89, 014333 (2014)

^{11}Be Spectrum

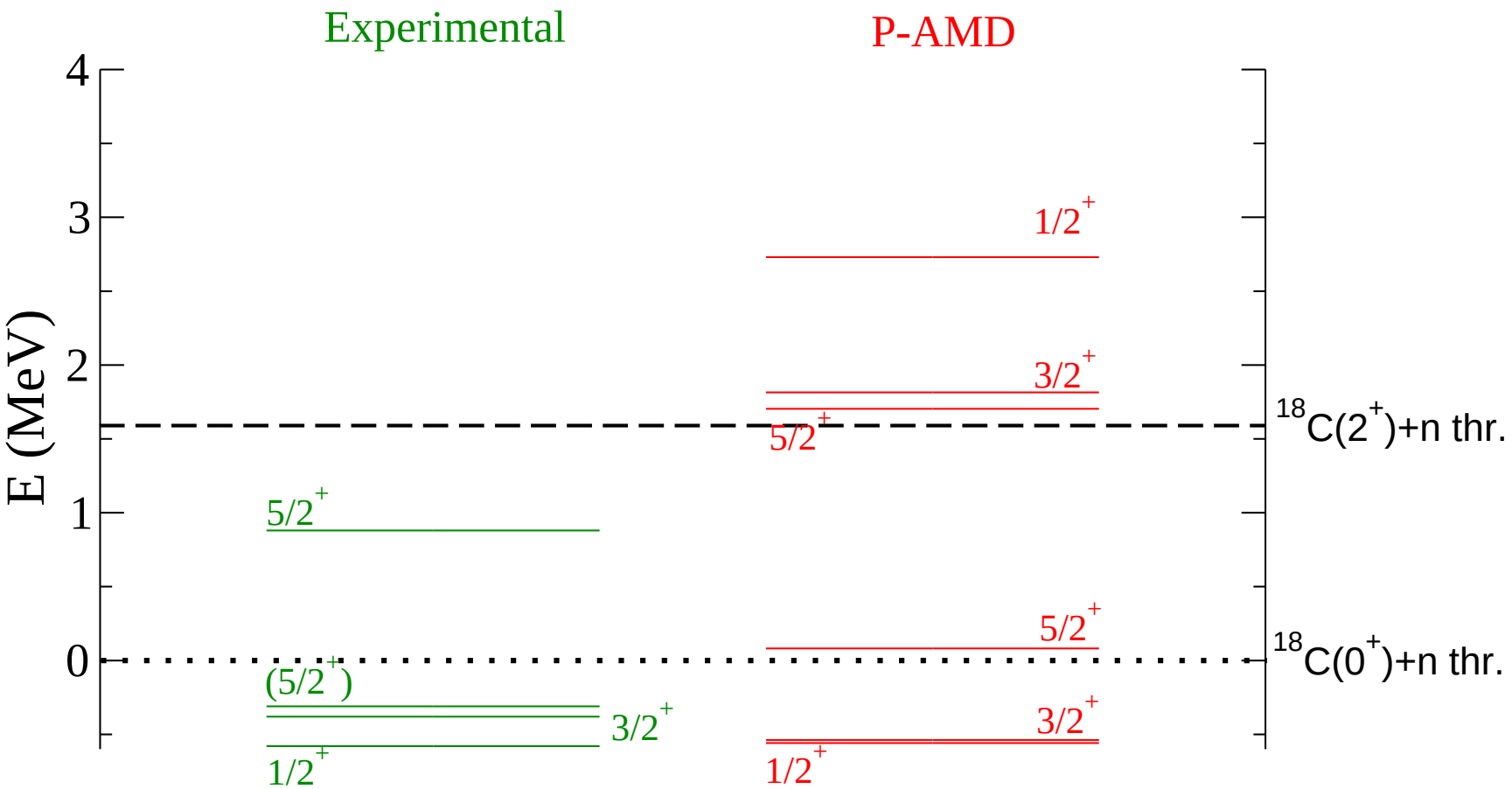


Renormalization factors

$$\lambda_+ = 1.058 \text{ and } \lambda_- = 0.995$$

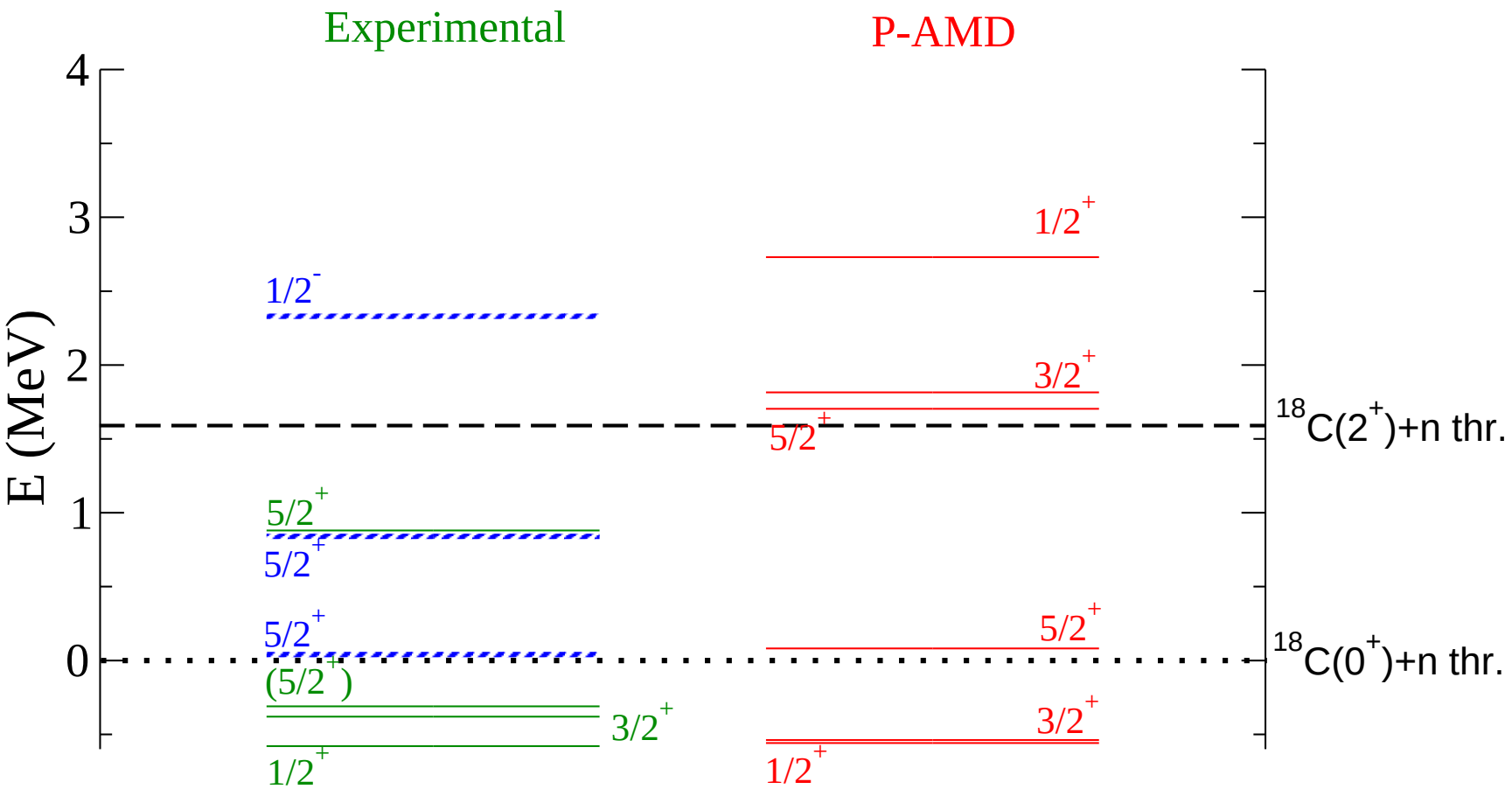
PRC 70, 054606 (2004); PRC 81, 034321 (2010); PL B 611, 239 (2005).

^{19}C Spectrum



PL B 660, 320 (2008); PL B 614, 174 (2005) SAMURAI

^{19}C Spectrum



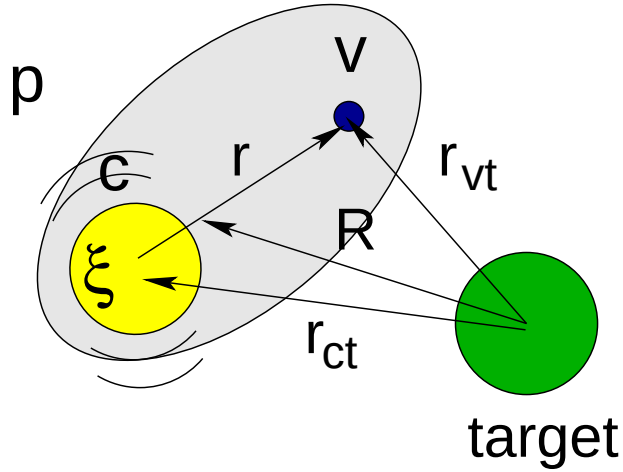
PL B 660, 320 (2008); PL B 614, 174 (2005) SAMURAI

Reactions

DWBAx

^{19}C+p @ 67 MeV/u

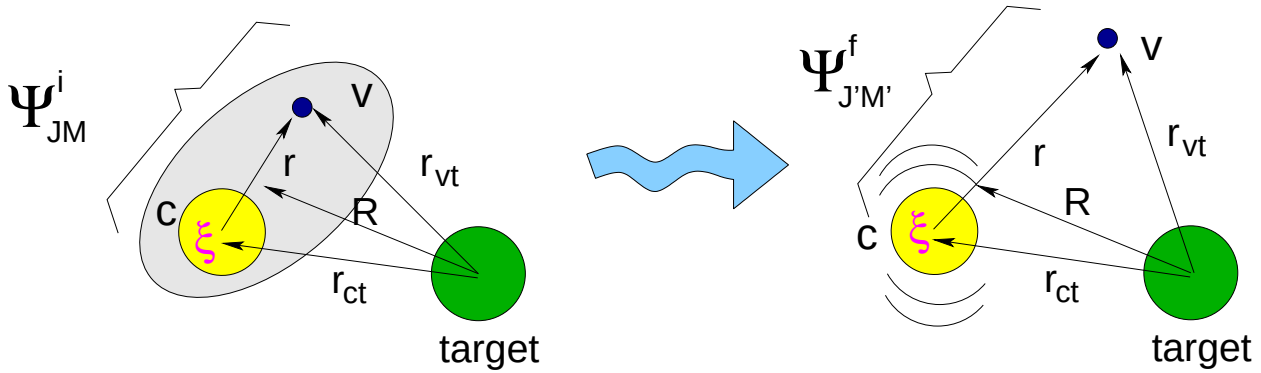
DWBAx calculations



No-recoil approach

⇒ Only first order excitation.

⇒ Same results for these energies than XCDCC.
A. M. Moro *et al.* AIP Conf. Proc. 1491, 335 (2012)



$$T_{if}^{JM,J'M'} \approx T_{val}^{JM,J'M'} + T_{core}^{JM,J'M'}$$

Only first order plus no-recoil:

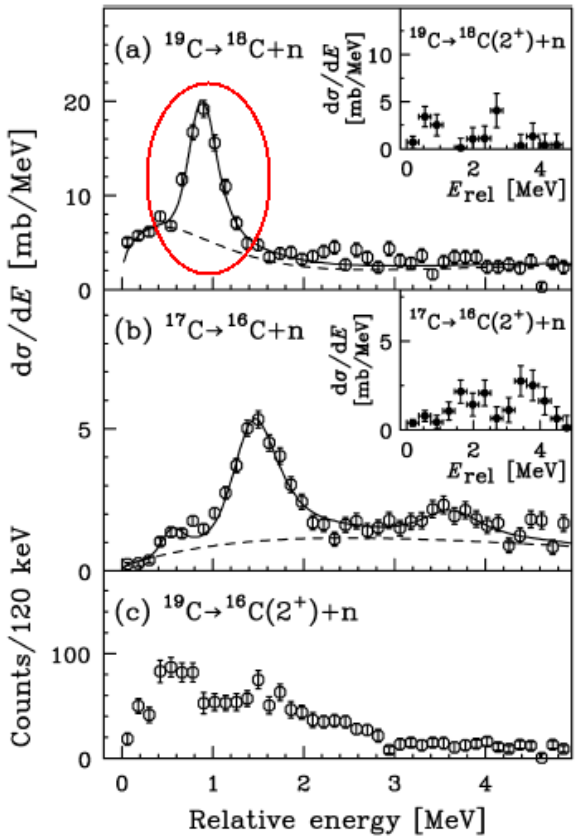
1. $T_{val}^{JM,J'M'} \Rightarrow$ Valence excitations
2. $T_{core}^{JM,J'M'} \Rightarrow$ Core excitations

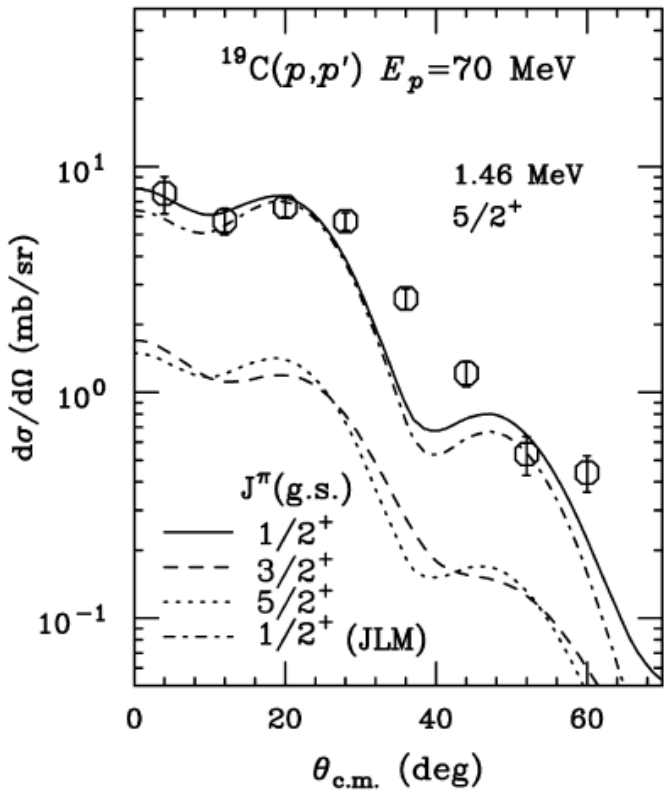
$\Rightarrow$ They explicitly separates in the calculation
A. M. Moro & R. Crespo, Phys. Rev. C 85, 054613 (2012)

$\Rightarrow$ We can extract spectroscopic factors from their interference
A. M. Moro & J. A. Lay, Phys. Rev. Lett. 109, 232502 (2012)

^{19}C+p @ 67 MeV/u

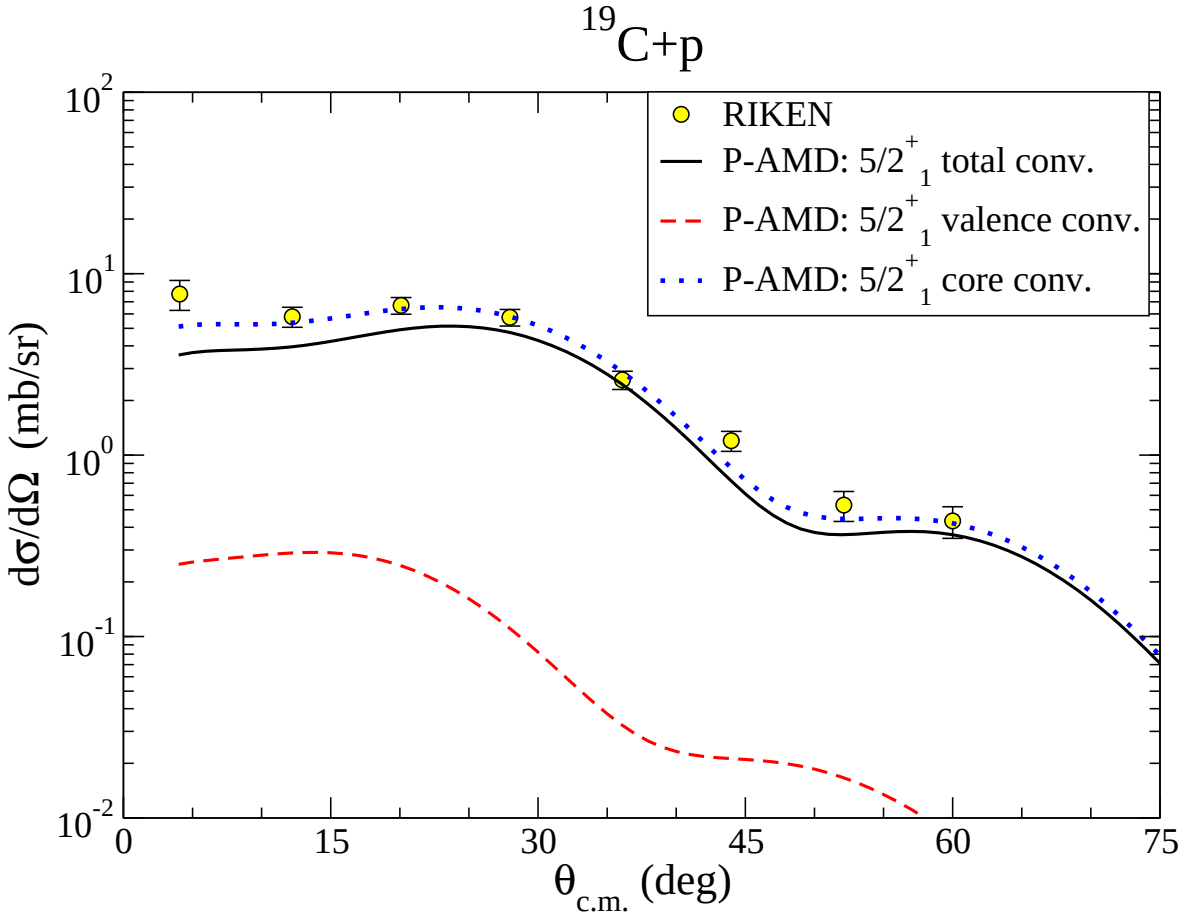
Y. Satou *et al.*, Phys. Lett. B 660, 320 (2008).



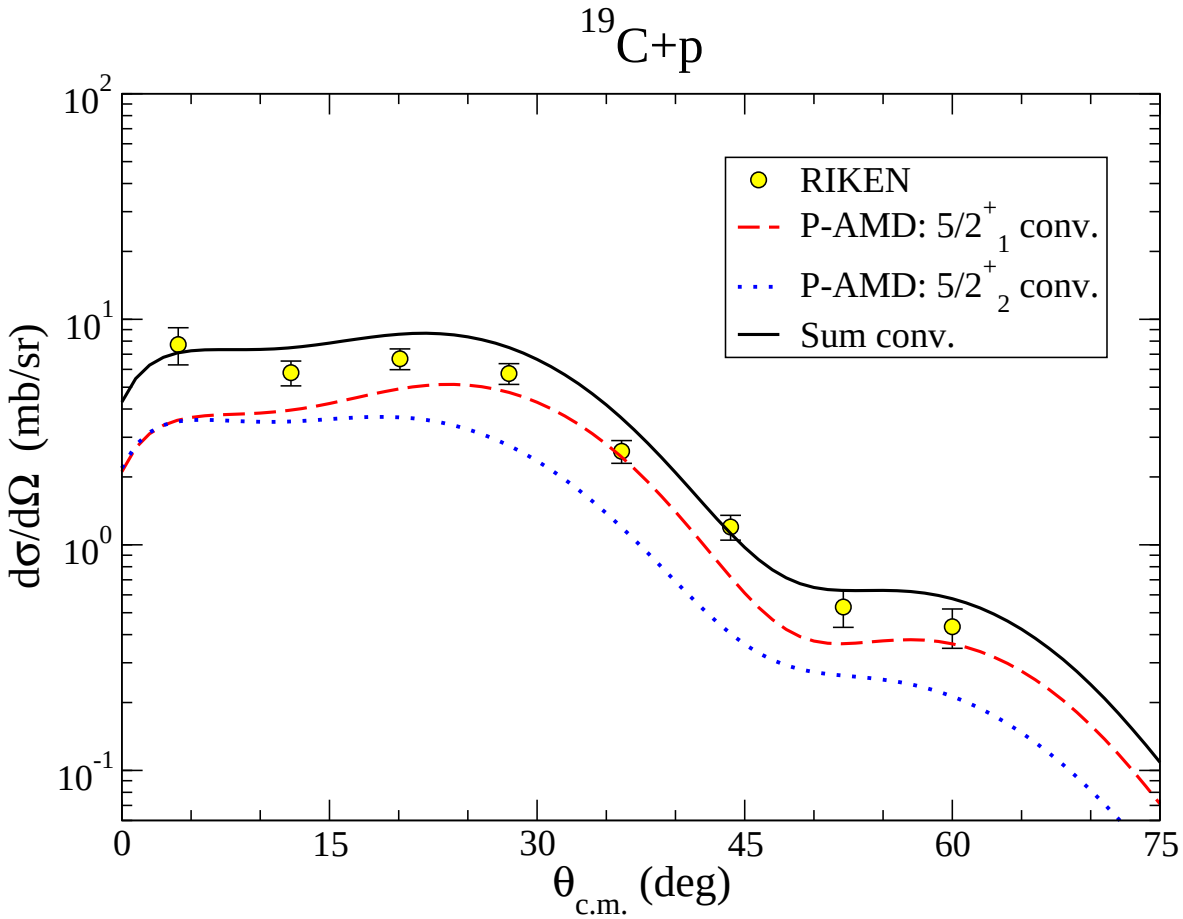


Microscopic DWBA calculations suggest a $1/2^+ \Rightarrow 5/2^+$ transition

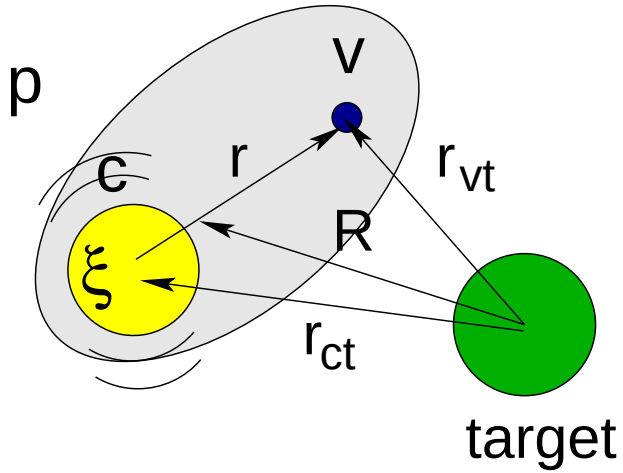
^{19}C+p @ 67 MeV/u


19C+p
RIKEN
P-AMD: 5/2+1 total conv.
P-AMD: 5/2+1 valence conv.
P-AMD: 5/2+1 core conv.
dσ/dΩ (mb/sr)
θc.m. (deg)
10^2
10^1
10^0
10^-1
10^-2
0
15
30
45
60
75

^{19}C+p @ 67 MeV/u


19C+p
RIKEN
P-AMD: 5/2+ 1 conv.
P-AMD: 5/2+ 2 conv.
Sum conv.
dσ/dΩ (mb/sr)
θc.m. (deg)
10^2
10^1
10^0
10^-1
0
15
30
45
60
75

XCDCC calculations



Including core excitations in CDCC

- ⇒ We already showed how to discretize the continuum with core excitations
- ⇒ DWBA only valid for intermediate and high energies
- ⇒ CDCC also includes the effect of break up in the elastic cross section

☞ *V. Pesudo's Talk*

P-AMD

- Accurate semi-microscopic description of even-odd halo nuclei
- Predictive power for unknown halo nuclei like ^{19,21}C
- Could be able to include core excitations from different sources

Break up

- The interplay between core and valence contributions is crucial to understand resonant break up of halo nuclei
- Break up reactions are sensitive to spectroscopic factors of resonant states difficult to populate in traditional transfer reactions

Next steps

- Apply the P-AMD model with other densities and other halo nuclei
- Perform full PS-XCDCC calculations with the P-AMD model
- Continue for inclusive observables

Thank you!!

And also to:

Theory

- University of Seville : J. Gómez-Camacho
- University of Lisbon : R. Crespo
- University of Surrey : R. C Johnson
- Yukawa Institute, Kyoto University : Y. Kanada-En'yo

Experiment

- IEM-CSIC, Madrid : V. Pesudo, M. J. G. Borge, O. Tengblad
- S1202 Collaboration (formerly E1104)