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The role of deformation in the ^{17}C structure and its influence in transfer and breakup reactions

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GOBIERNO DE ESPAÑA

MINISTERIO DE CIENCIA E INNOVACIÓN

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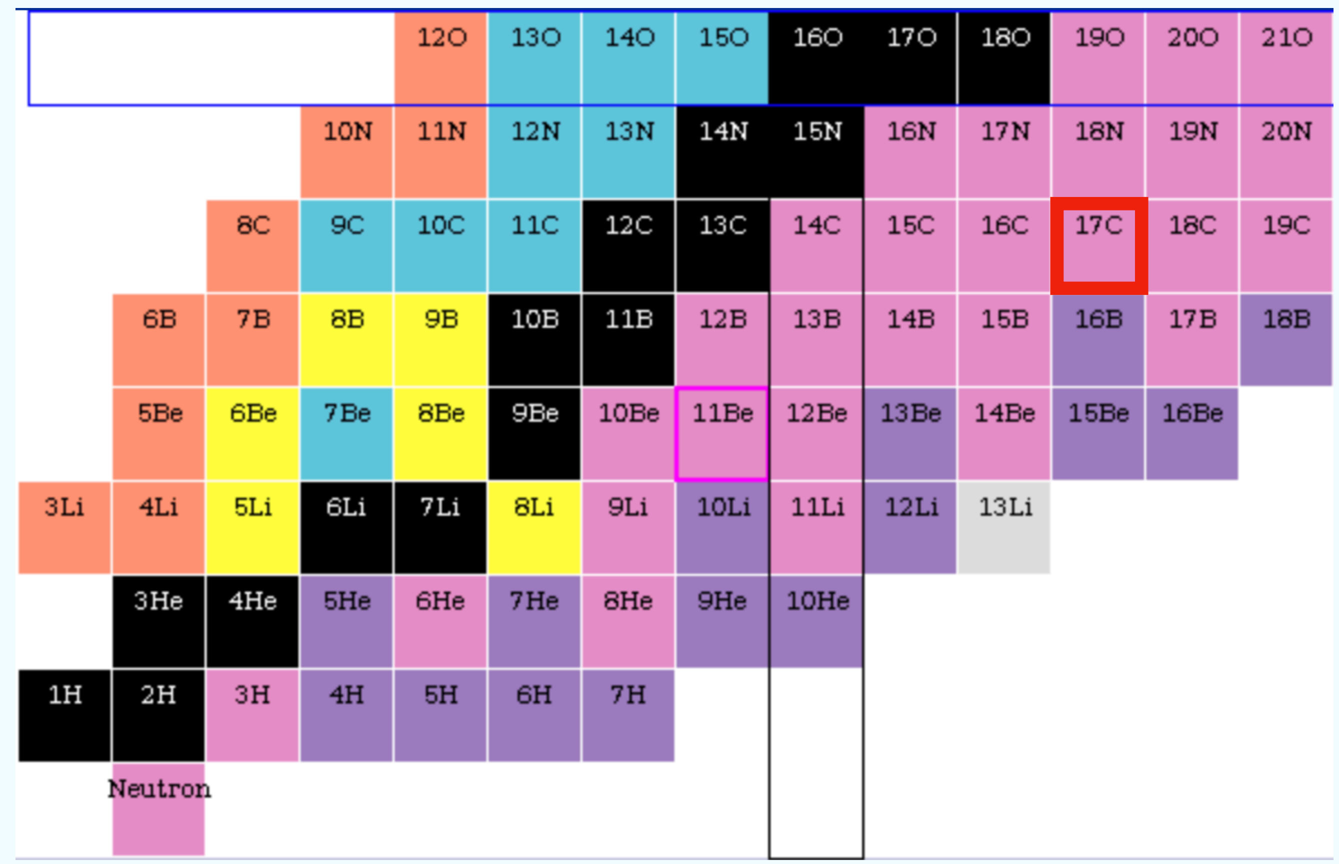
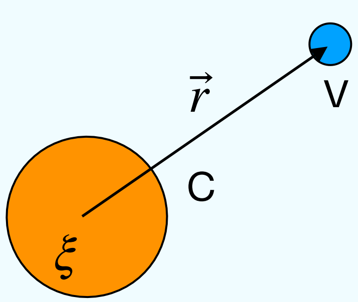
Introduction

^{17}C

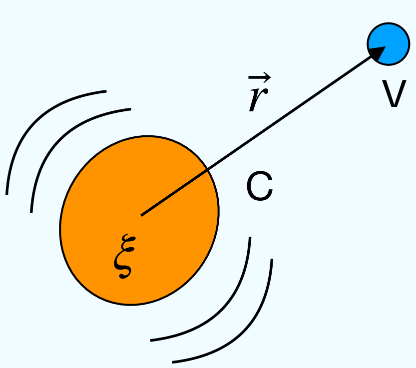
- Weakly bound exotic nucleus
- Halo nature of its first excited state
- Two-body structure models applied to reactions





Iner Core

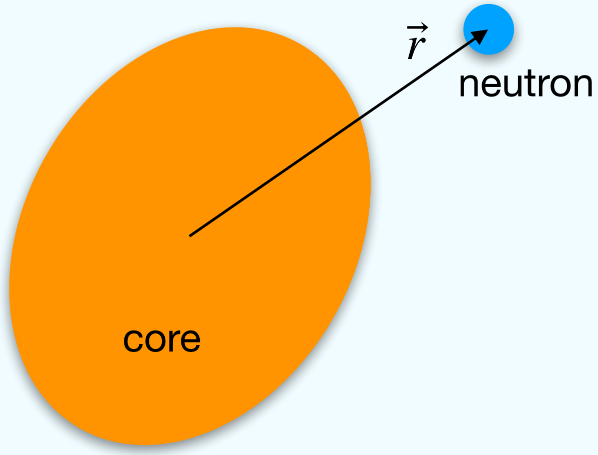
Significant effect of core deformation



Core Excitations

Structure

- 2-body model (neutron+core)
- Deformation via:
  - Nilsson model
  - PAMD [PRC**89** (2014) 014333]



- Eigenstates from diagonalization in THO basis

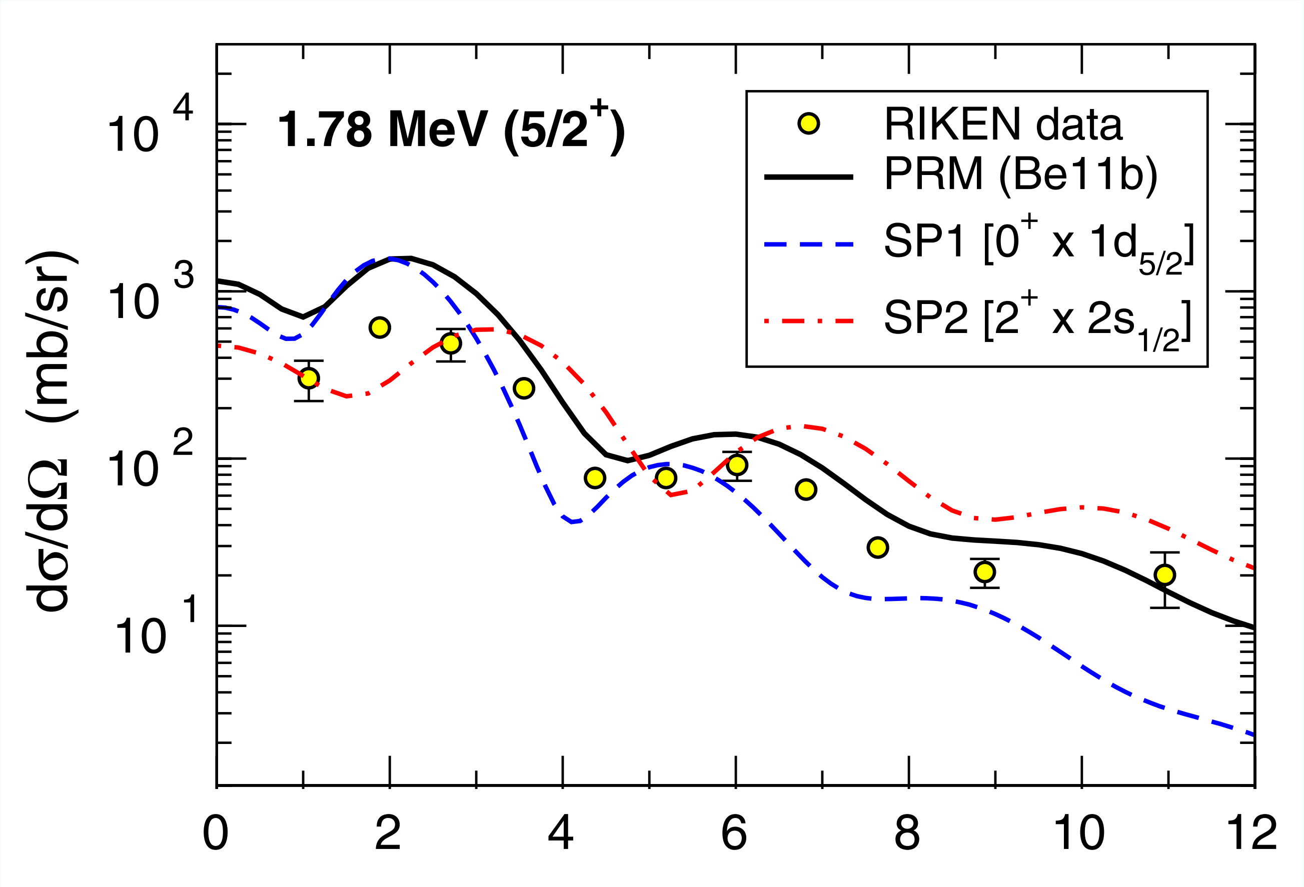
$$\phi_{nl}^{THO}(r) = \sqrt{\frac{ds}{dr}}\phi_{nl}^{HO}[s(r)]$$

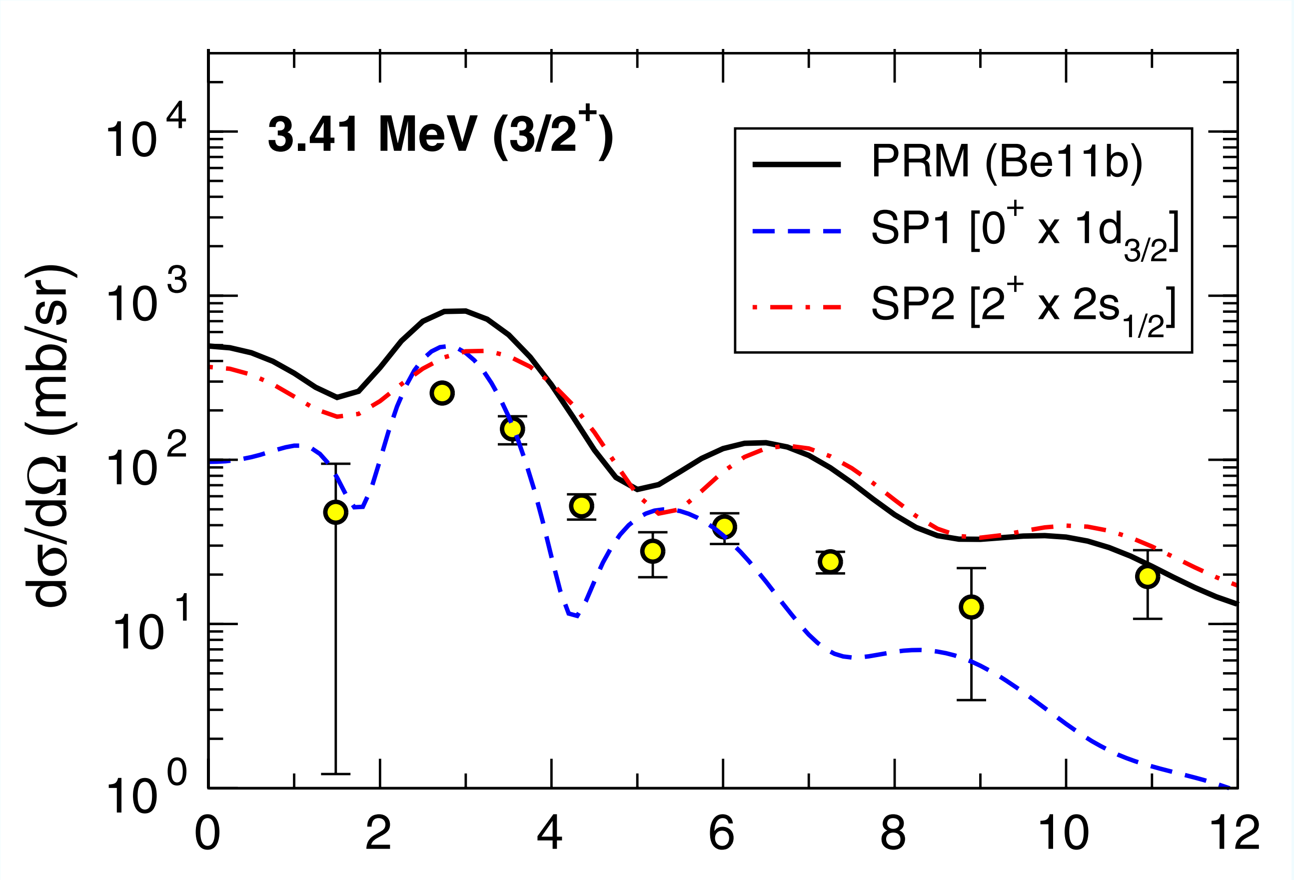
$$s(r) = \left[r^{-m} + \left(\gamma\sqrt{r}\right)^{-m}\right]^{-\frac{1}{m}}$$

[PRC**71** (2005) 064601]

THO Application Example

Resonant breakup of ^{11}Be on a ^{12}C target at 70 MeV/nucleon





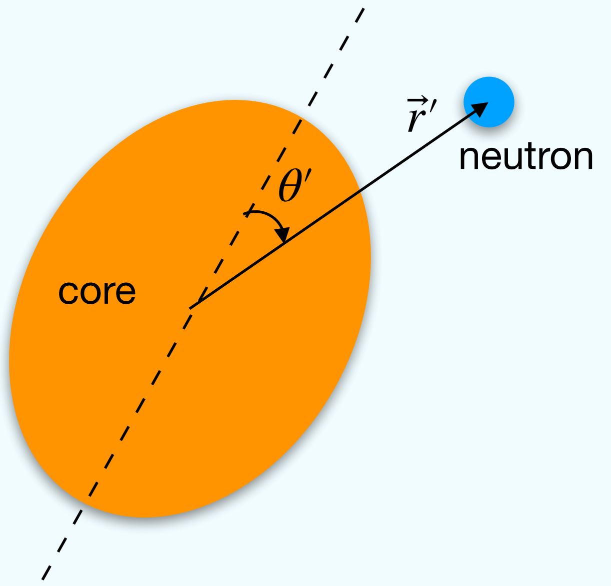
A. M. Moro and J. A. Lay, Phys. Rev. Lett. 109 (2012) 232502

Experimental data: Fukuda et al, Phys. Rev. C 70, 054606 (2004)

Nilsson Hamiltonian

$$H = -\frac{\hbar^2}{2\mu}\nabla^2 + V_c(r) + V_{ls}(r)(\vec{l}\cdot\vec{s}) - r\beta\frac{dV_c(r)}{dr}Y_{20}(\theta') + \frac{\hbar^2}{2\mathcal{J}}\vec{I}^2$$

- Axially symmetric quadrupole deformation
- Collective rotational degree of freedom
- Deformed Woods-Saxon potential



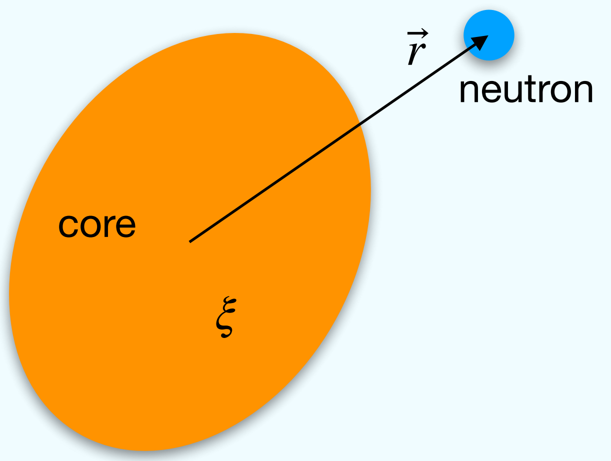
$$V(\vec{r}') \approx V_c(r) - r\beta\frac{dV_c(r)}{dr}Y_{20}(\theta')$$

I. Hamamoto, PRC76 (2007) 054319

PAMD Hamiltonian

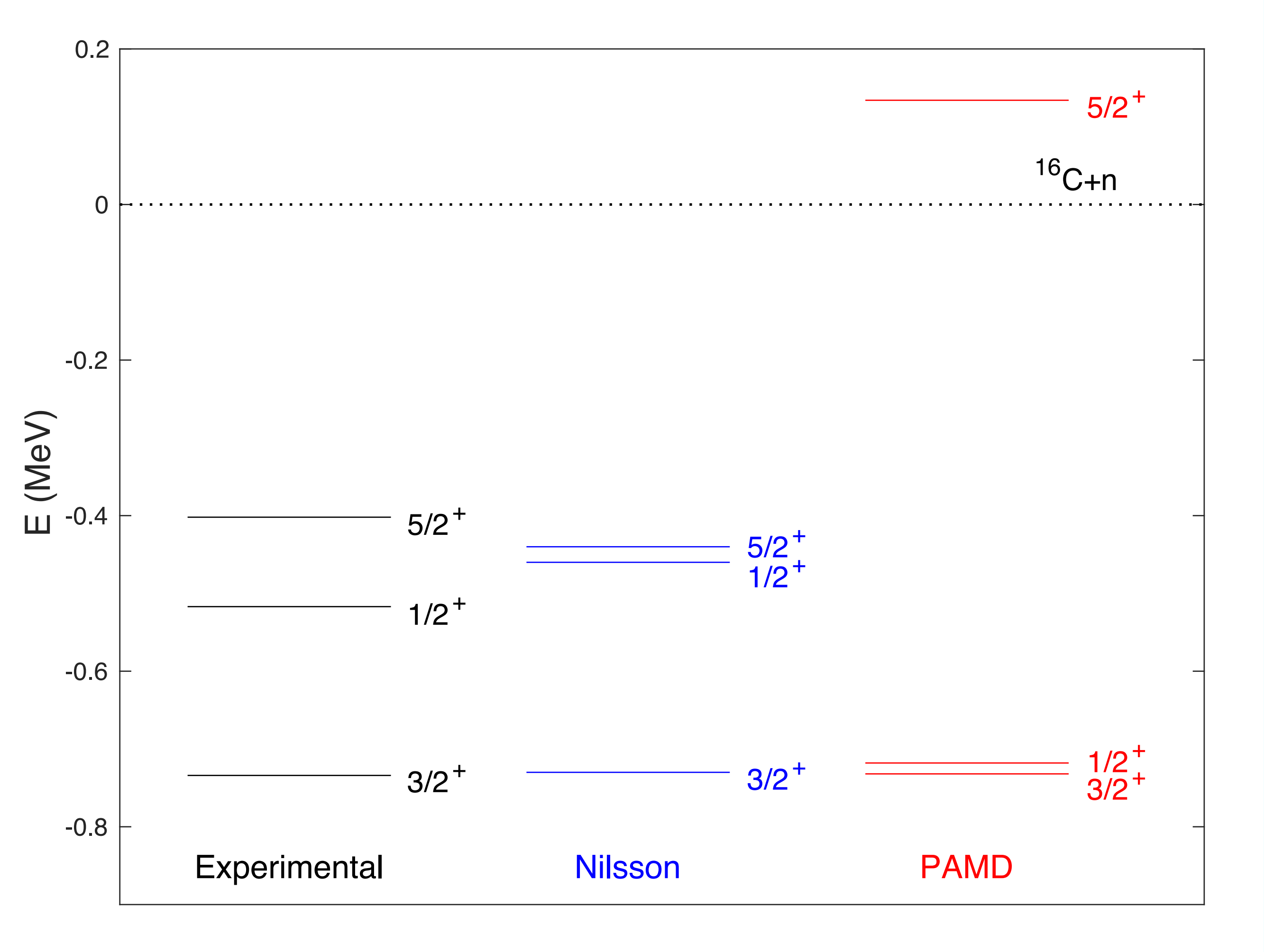
$$H = -\frac{\hbar^2}{2\mu}\nabla^2 + V_{ls}(r)(\vec{l}\cdot\vec{s}) + V_{vc}(\vec{r},\xi) + h_{core}(\xi)$$

- Extension of particle-rotor model
- Semi-microscopic coupling potential (Antysymmetrized Molecular Dynamics)
- Core excitations



Low-lying Spectrum of ^{17}C

Level Scheme



Mean Square Radii

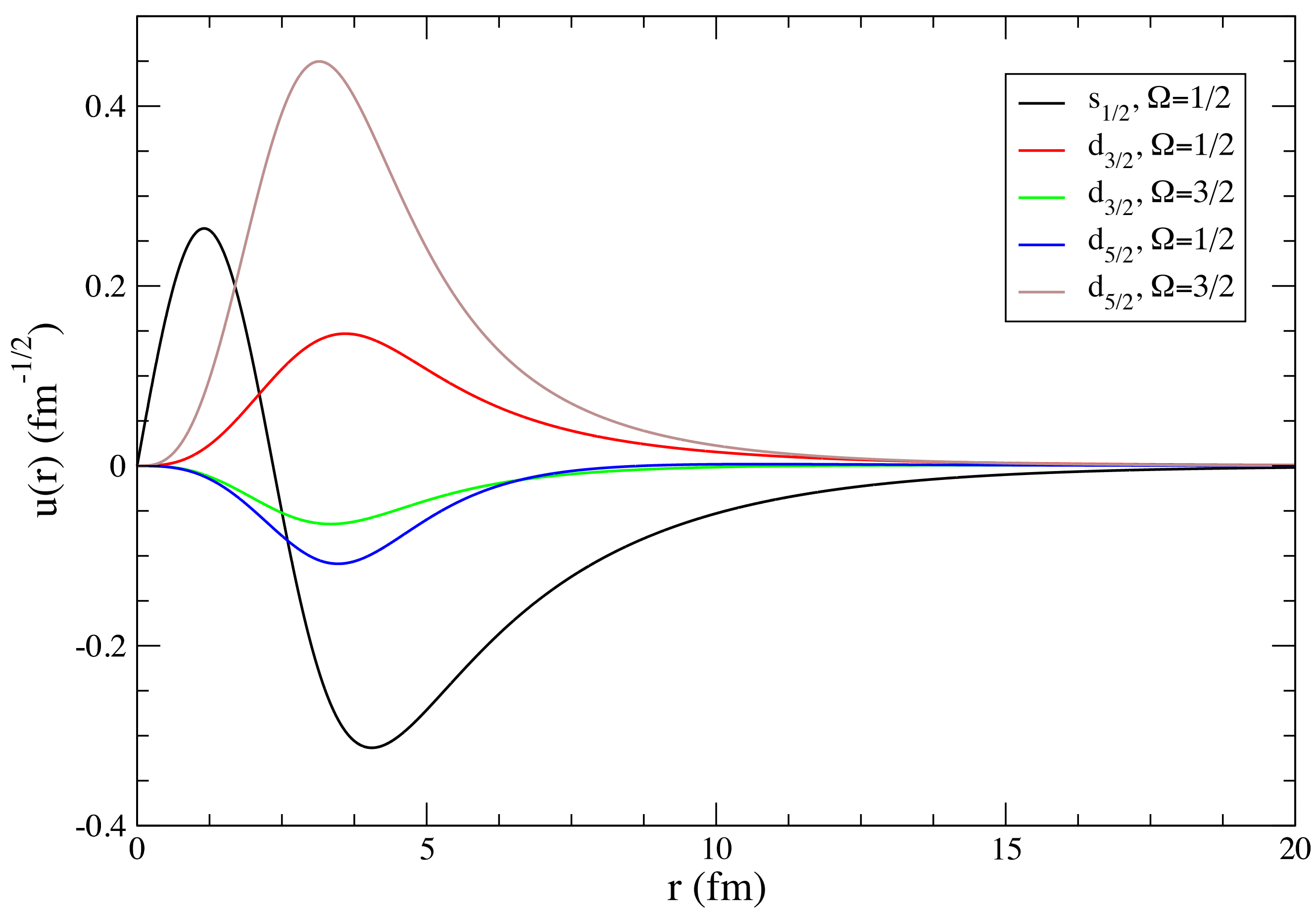
r_{ms} (fm)	Nilsson	PAMD
gs-$3/2^+$	4.18	4.03
1ex-$1/2^+$	6.44	5.24
2ex-$5/2^+$	4.25	-

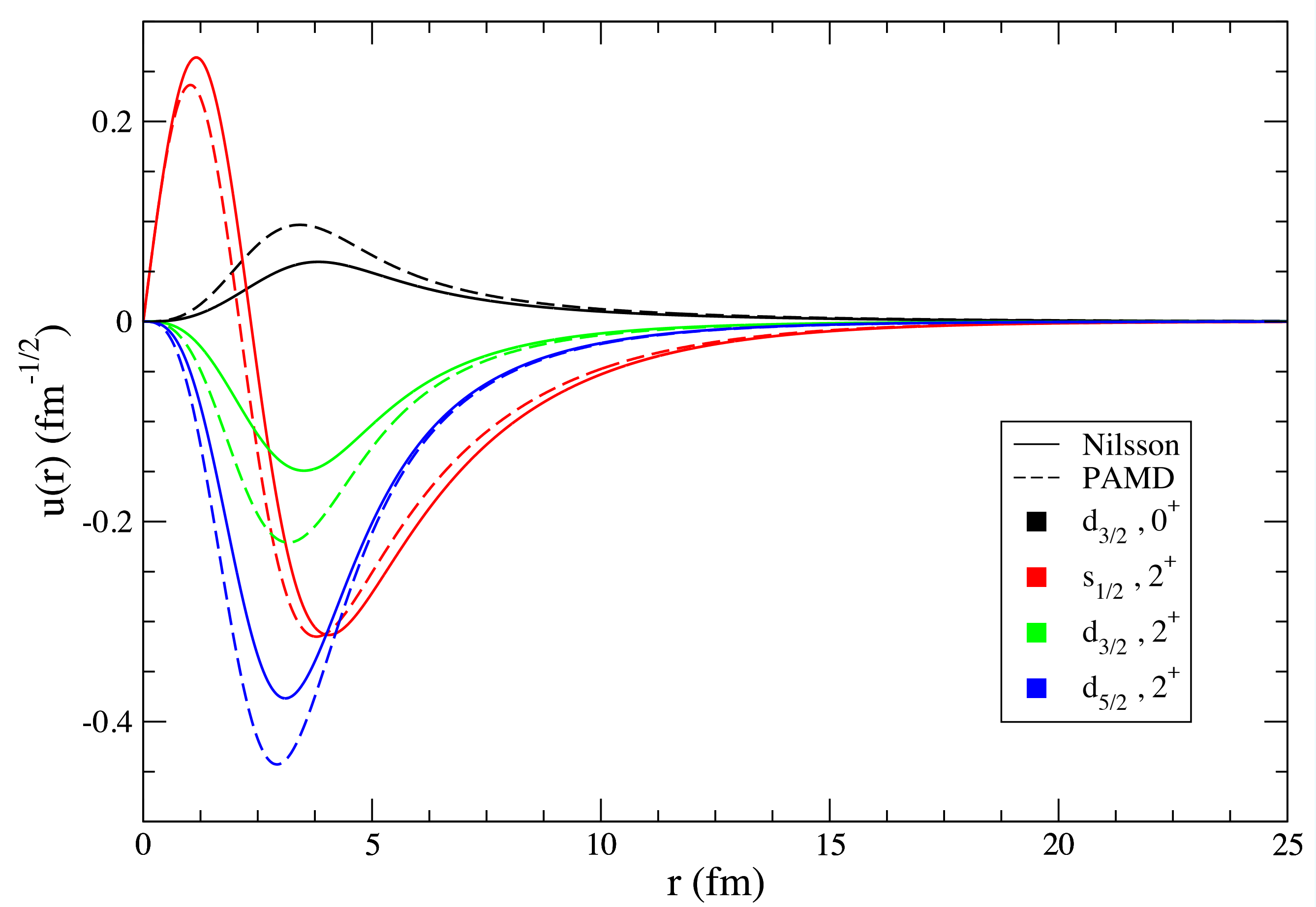
Spectroscopy Factors

SF	Conf	Nilsson	PAMD
gs-$3/2^+$	$d_{3/2}$, 0^+	0.01	0.03
1ex-$1/2^+$	$s_{1/2}$, 0^+	0.67	0.51
2ex-$5/2^+$	$d_{5/2}$, 0^+	0.33	0.32

Wave Functions

^{17}C ground state $3/2^+$



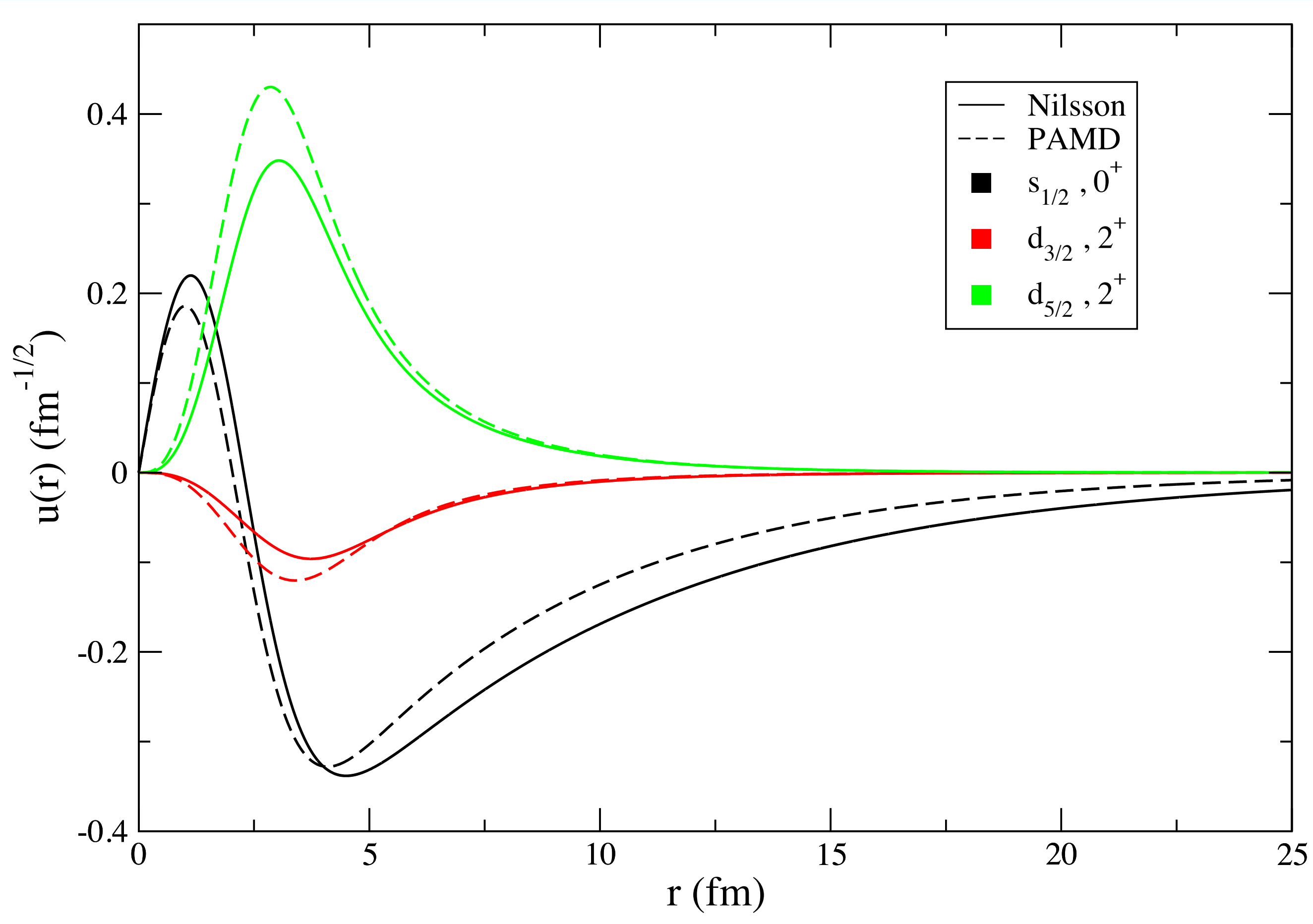


Ω - axial projections ⟶ I - core states

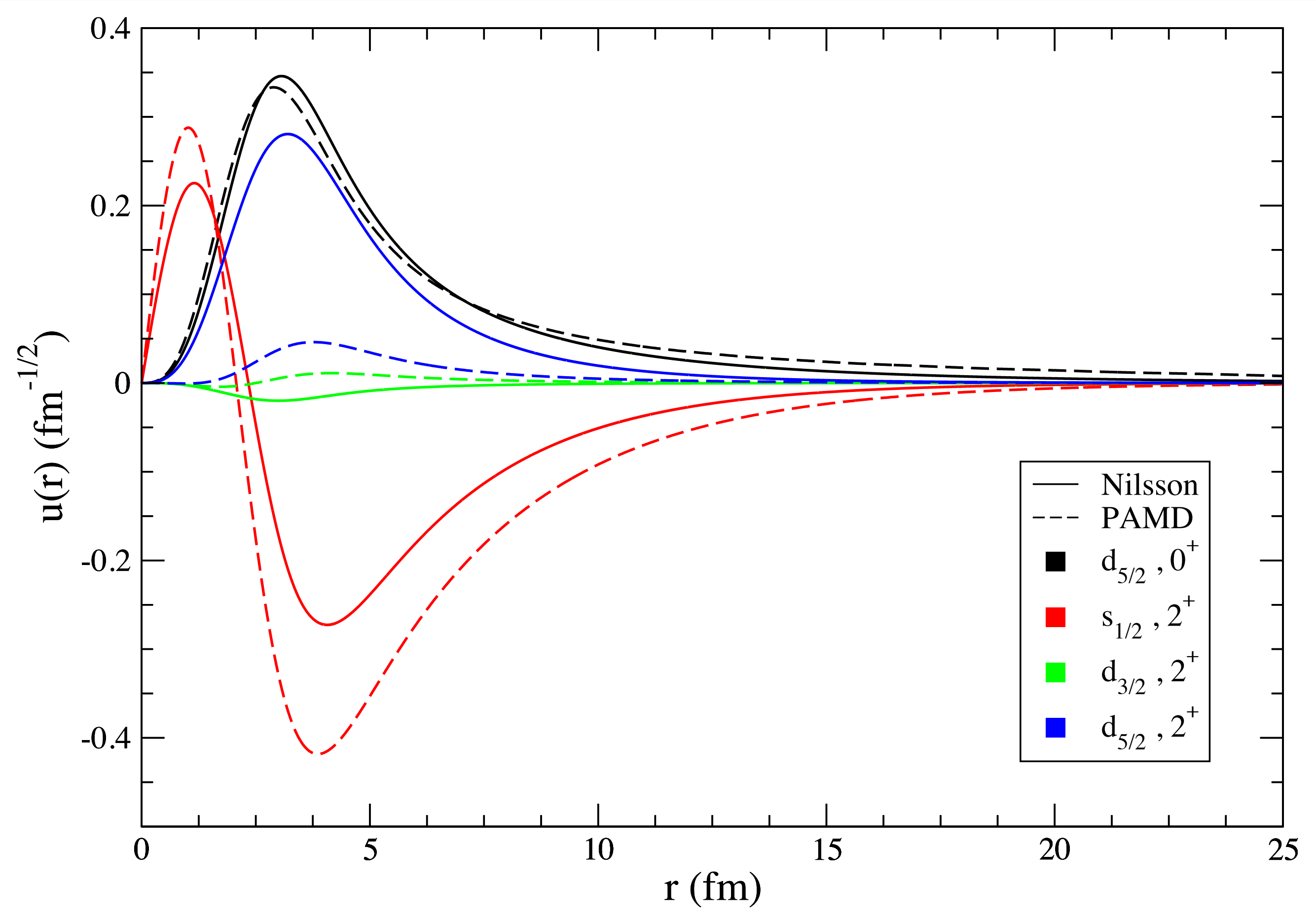
$$u_{jI}^{\lambda J^\pi}(r) = \sqrt{2} \sum_{\Omega} (-1)^{J+\Omega} \langle I0 \,|\, j - \Omega J \Omega \rangle u_{j\Omega}^{\lambda J^\pi}(r)$$

Wave Functions

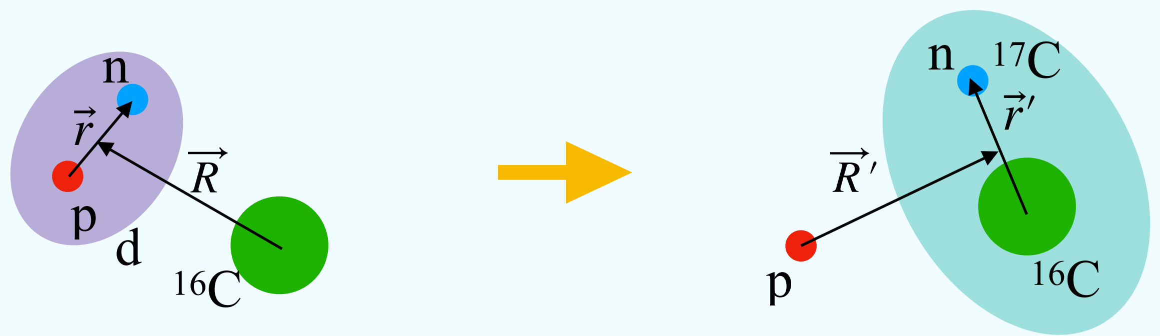
^{17}C first excited state $1/2^+$



^{17}C second excited state $5/2^+$



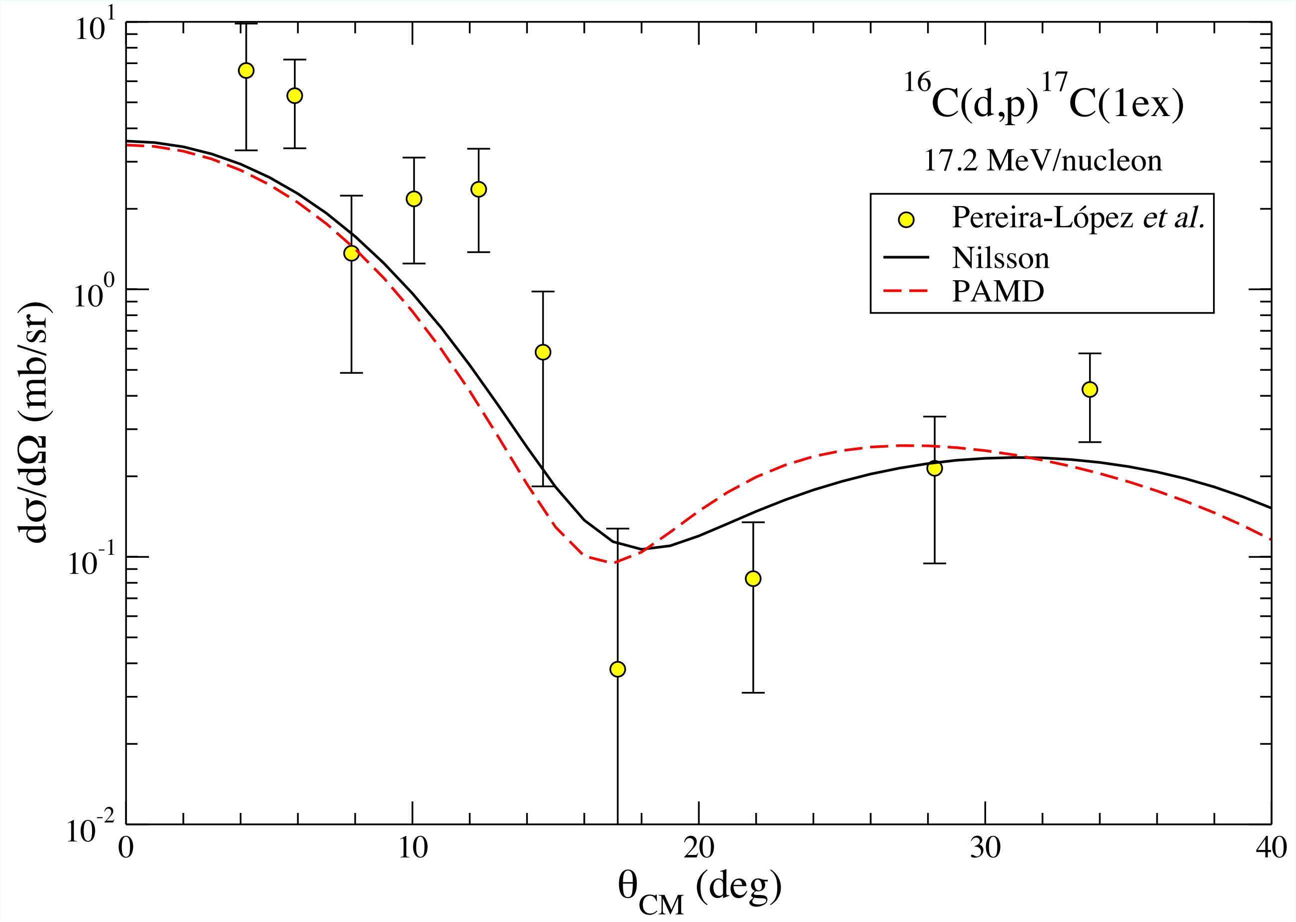
Application to ^{16}C(d,p)^{17}C



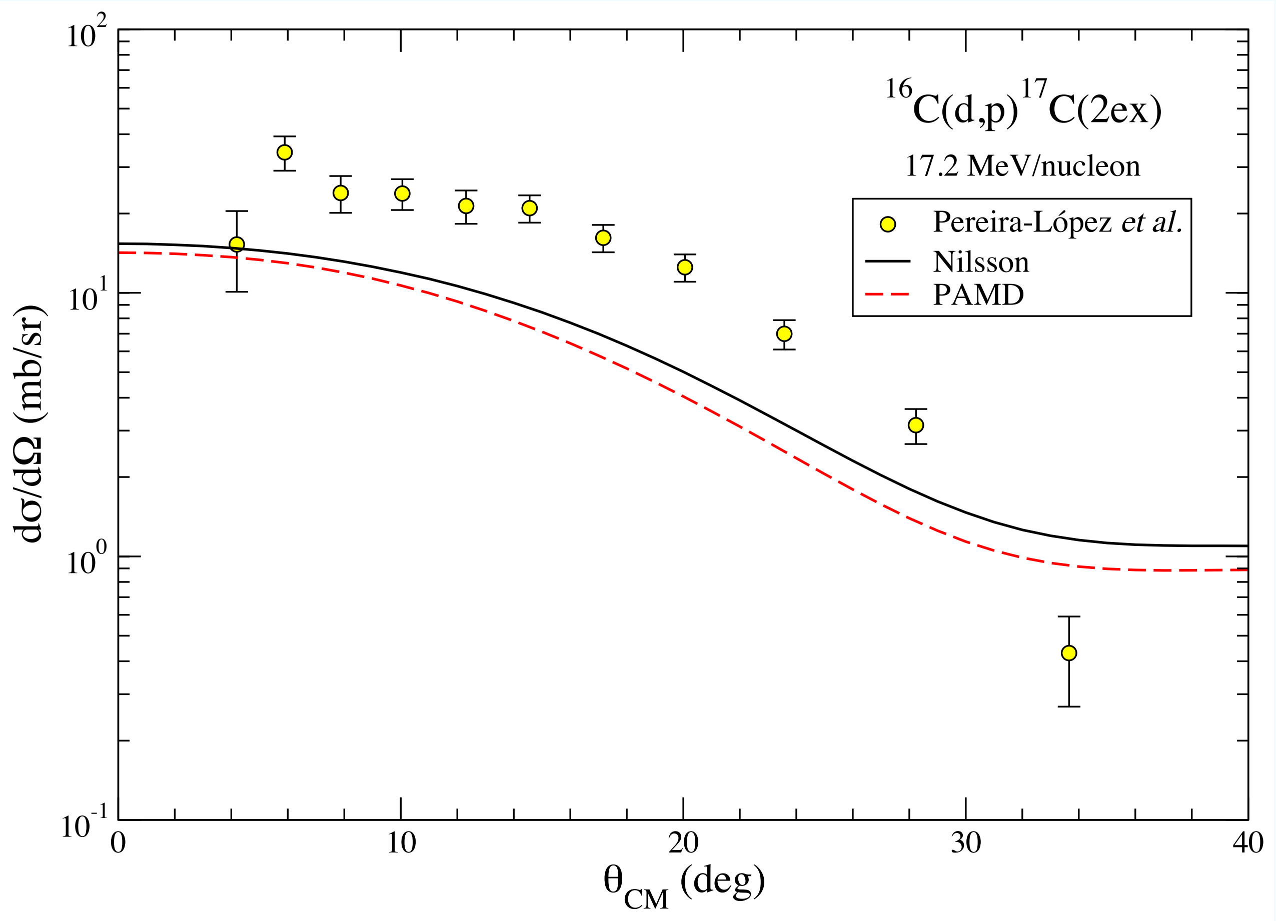
- A neutron transfer reaction has been studied applying the Adiabatic Distorted Wave Approximation (ADWA).
- Wave functions obtained with our two models are used as input overlaps.
- Calculations are compared with recent experimental data:
    - GANIL, 17.2 MeV/nucleon beam [PLB**811** (2020) 135939]

Transfer to bound states

^{17}C first excited State $1/2^+$

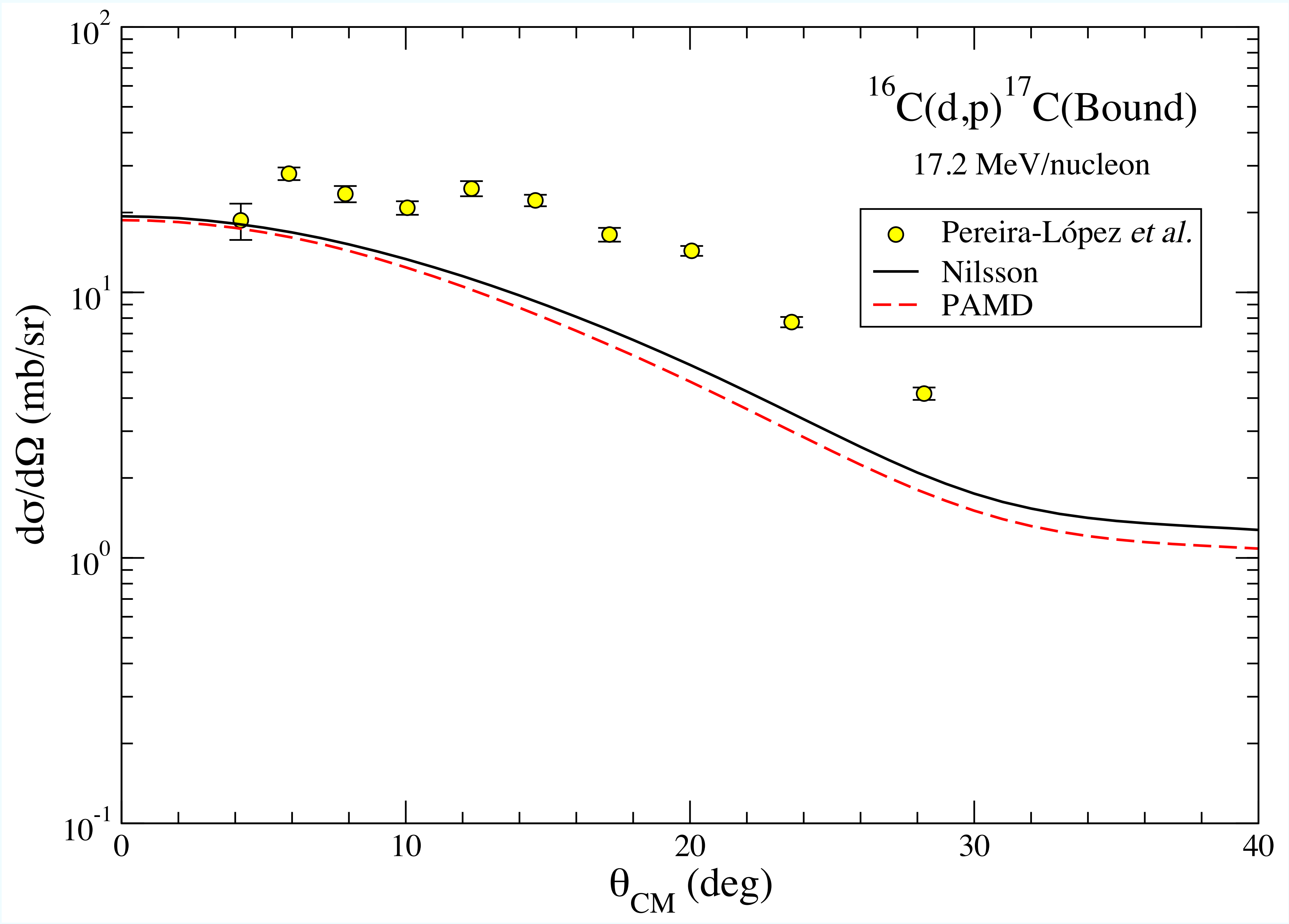


^{17}C second excited State $5/2^+$



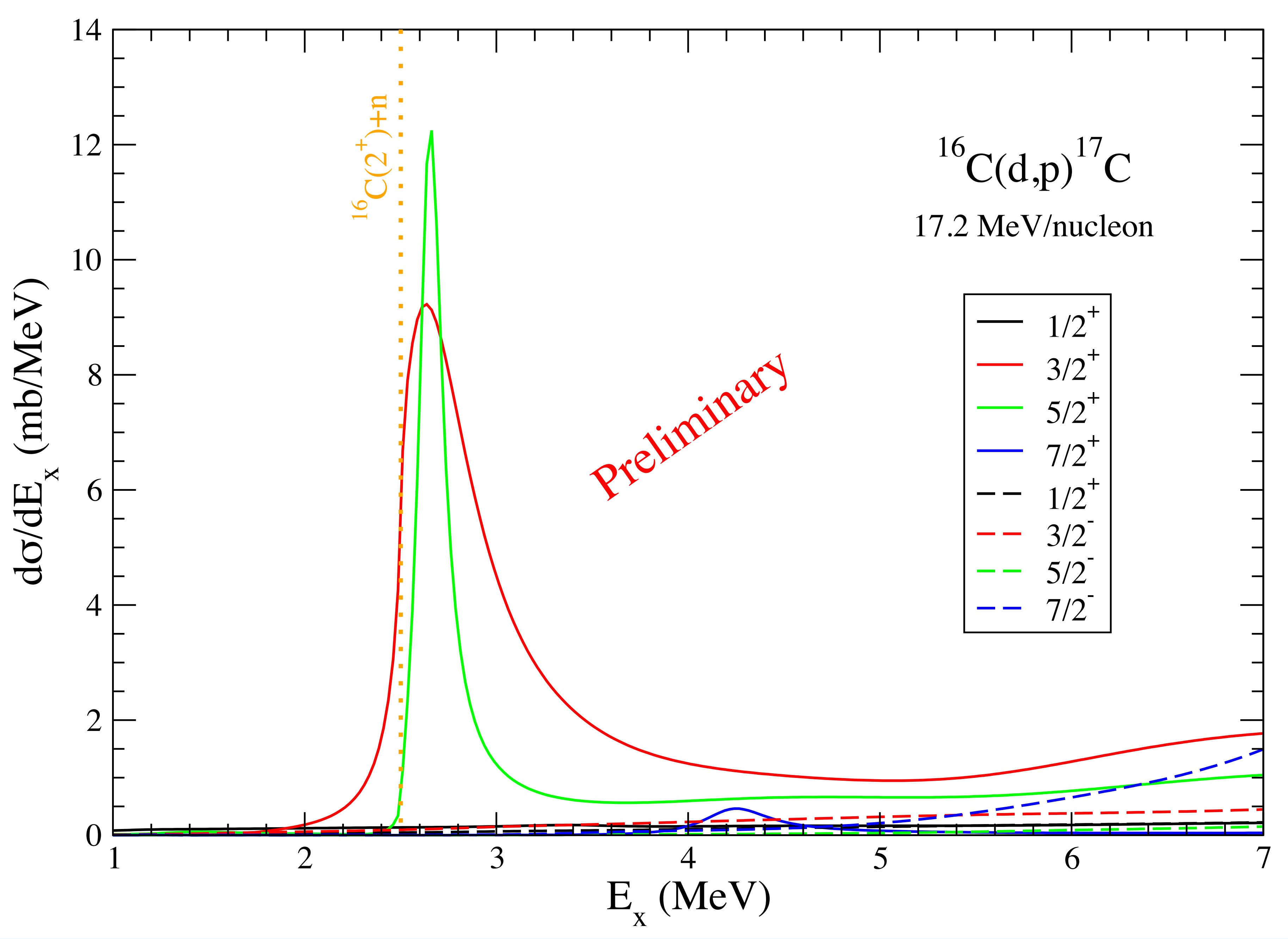
Transfer to bound states

Sum for the three bound states



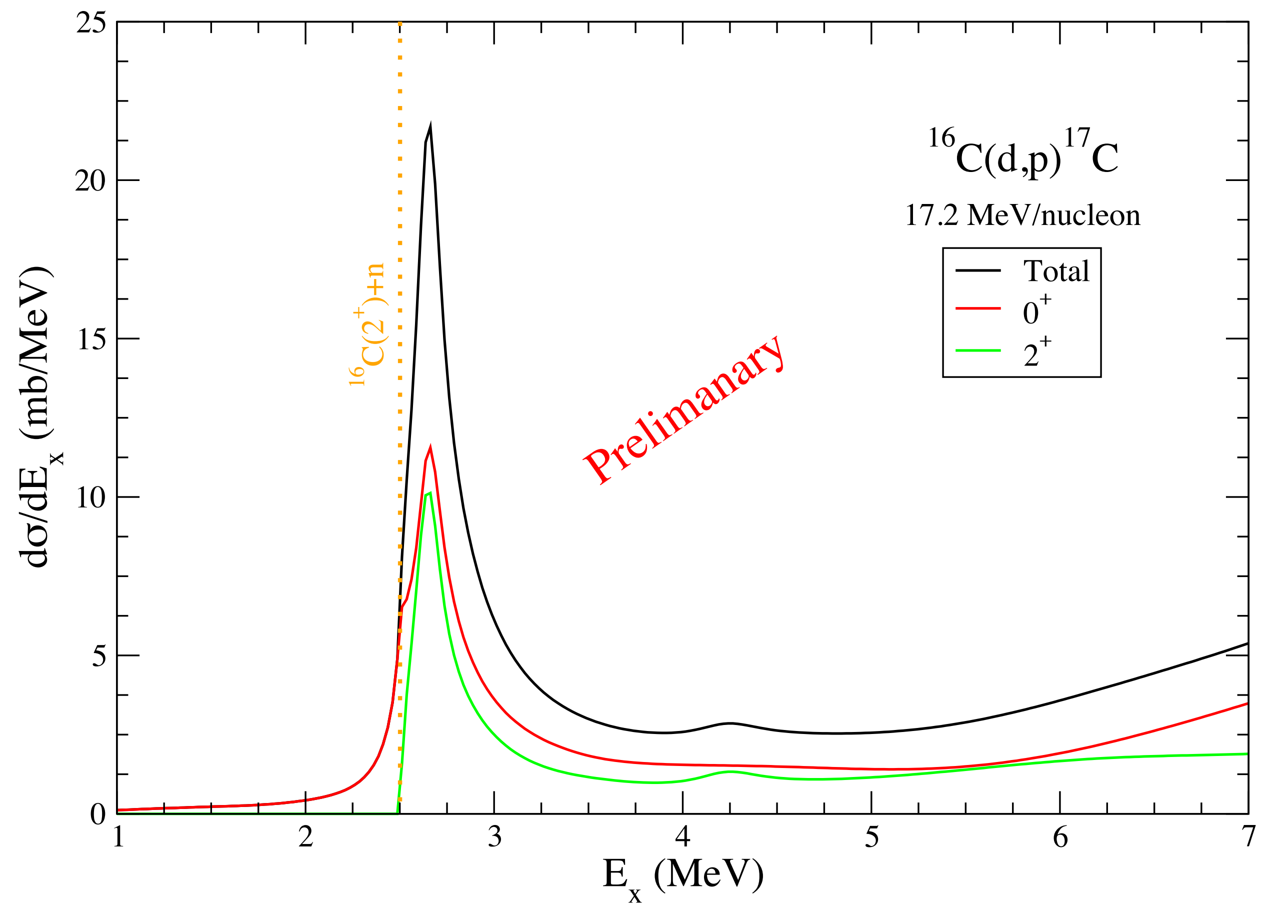
Transfer to the Continuum

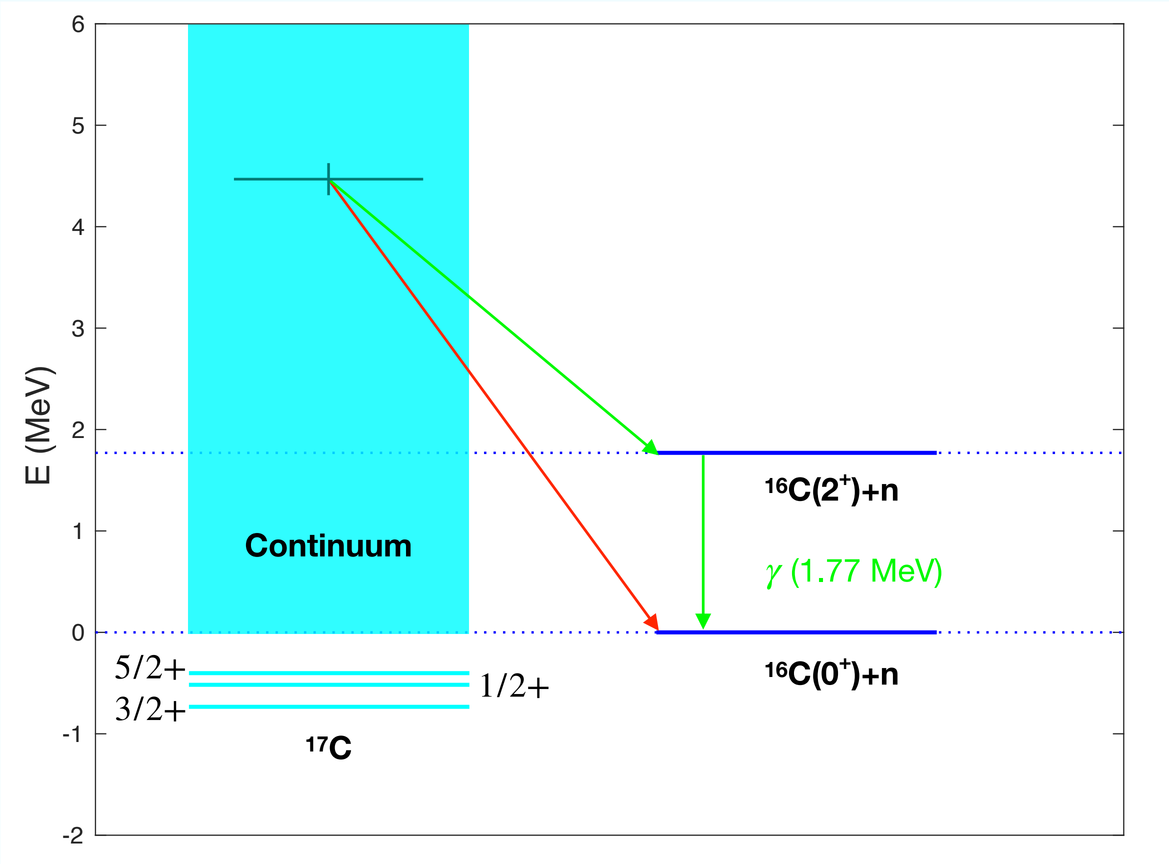
Preliminary calculation for the continuum with PAMD model



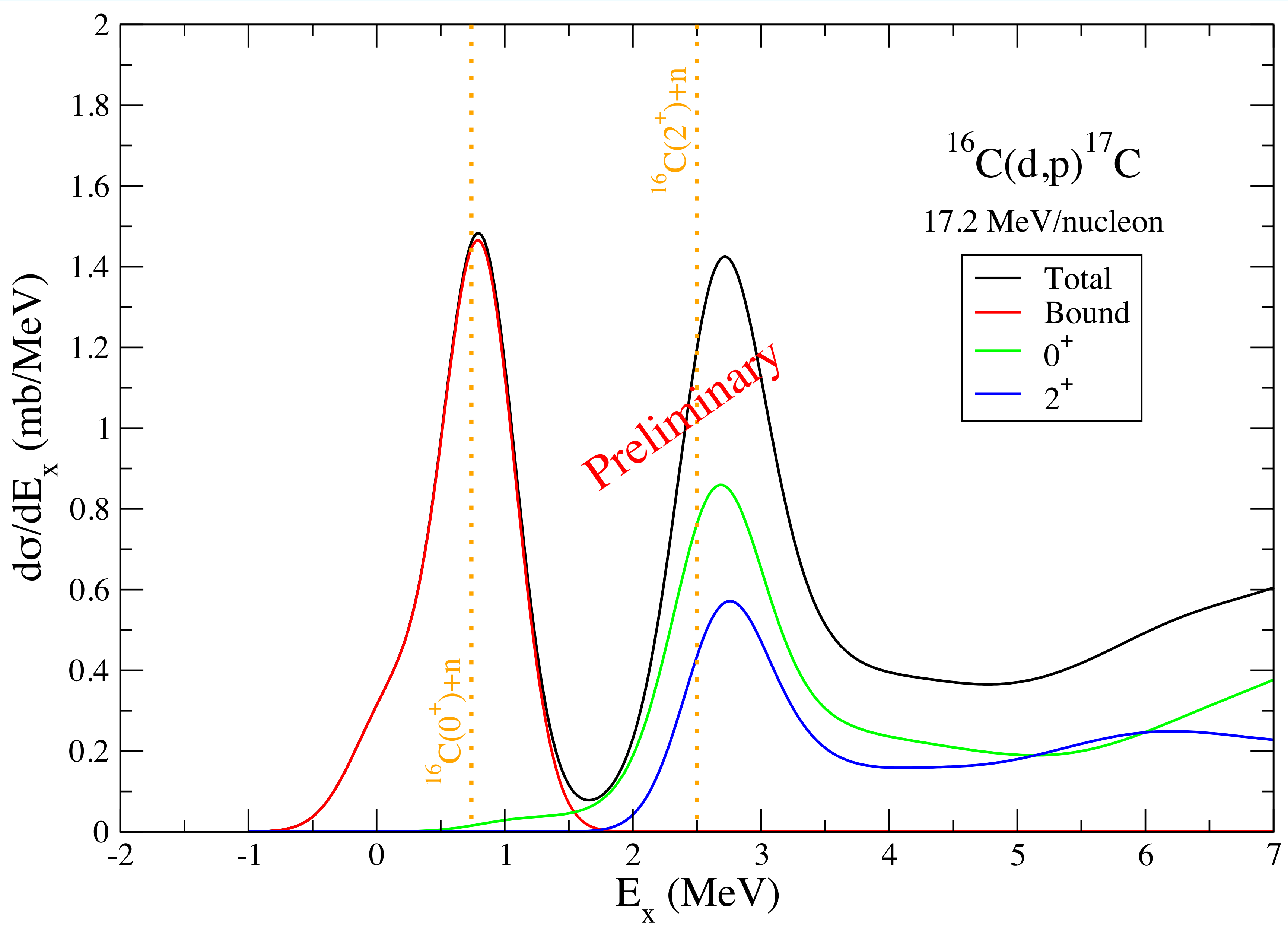
Transfer to the Continuum

Preliminary calculation for the continuum with PAMD model



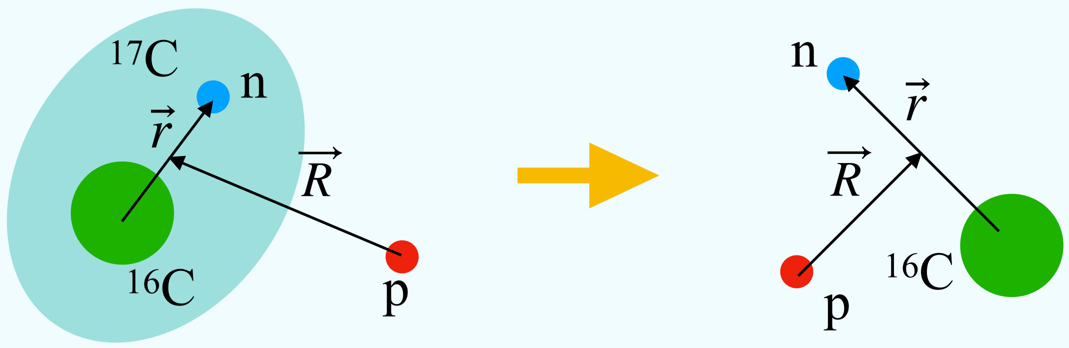


$^{16}C(d,p)^{17}C$



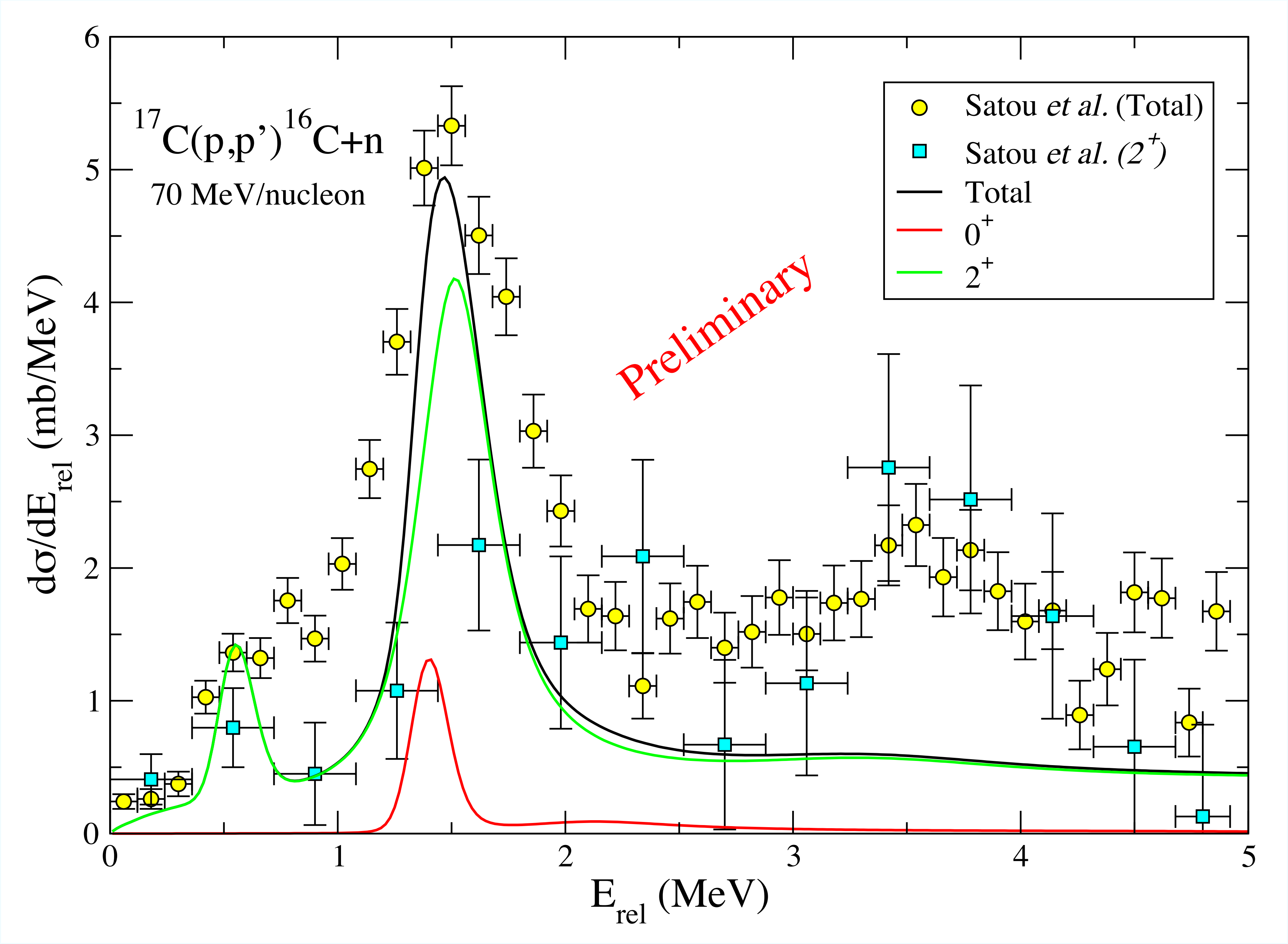
Comparison with experimental data in progress

Application to ^{17}C+p Breakup



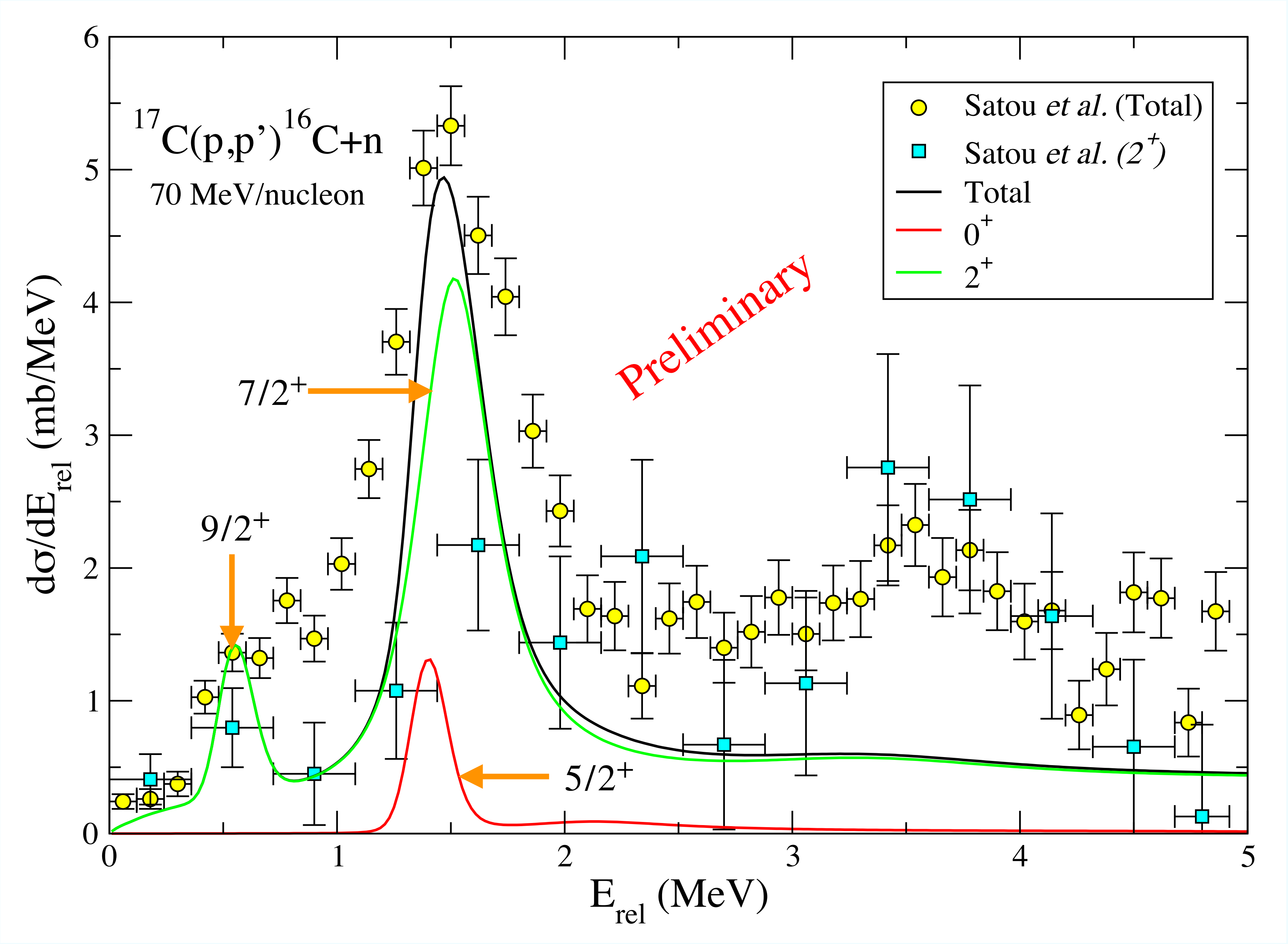
- Extended Continuum-Discretized Coupled-Chanels calculations including core excitation (XCDCC) have been performed for study the break up reaction
    - XCDCC - [PRC**74** (2006) 014606, PRC**89** (2014) 064609].
- The PAMD model is used to describe the ^{17}C system.
- Results are compared with the experimental data:
    - RIKEN, 70 MeV/nucleon beam [PLB**660** (2008) 320]

$^{17}C(p,p')^{16}C+n$



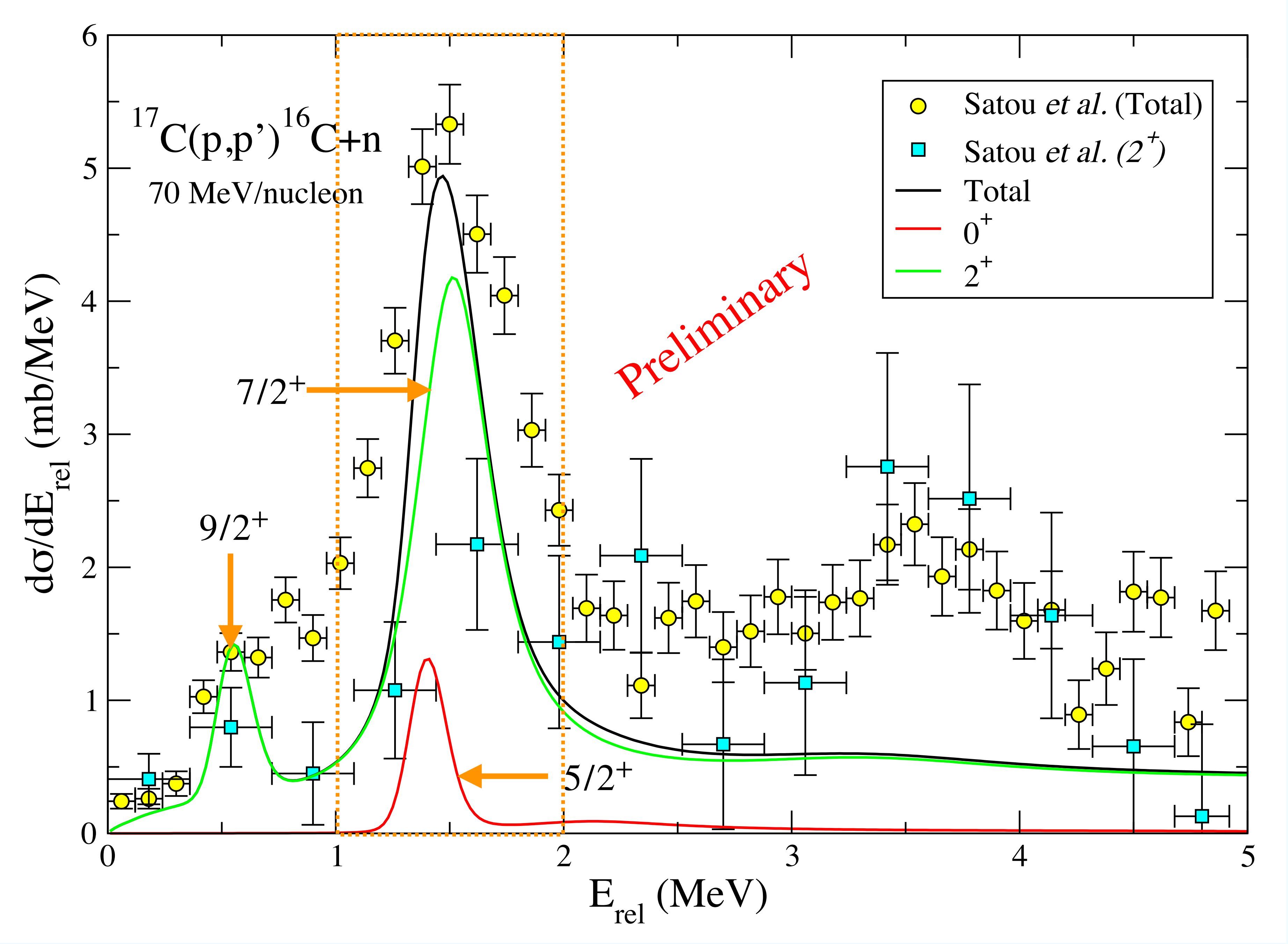
$^{17}C(p,p')^{16}C+n$
70 MeV/nucleon
Satou et al. (Total)
Satou et al. (2^+)
Total
0^+
2^+
Preliminary
$d\sigma/dE_{rel}$ (mb/MeV)
E_{rel} (MeV)
0
1
2
3
4
5
6

$^{17}C(p,p')^{16}C+n$



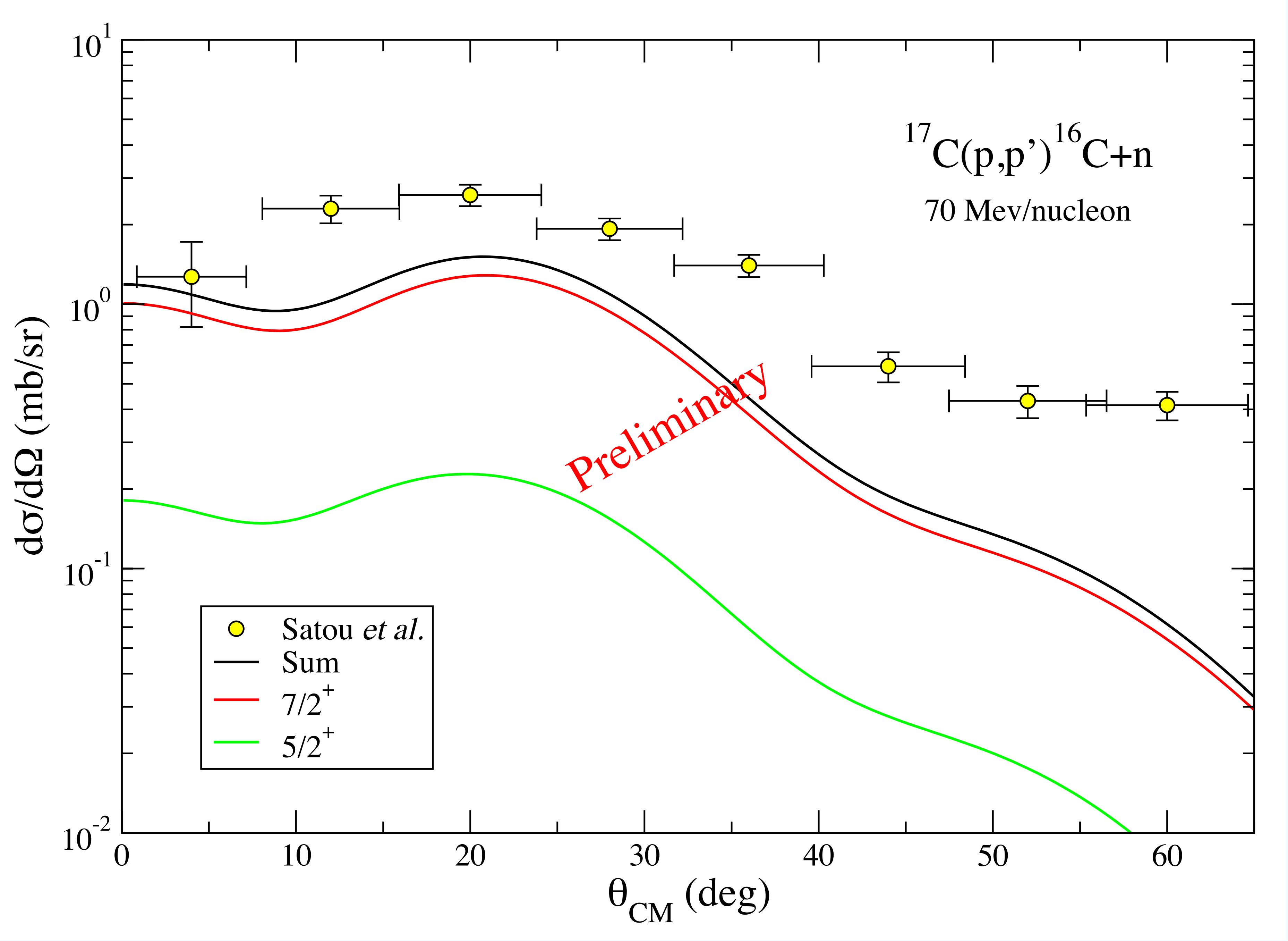
$^{17}C(p,p')^{16}C+n$
70 MeV/nucleon
Satou et al. (Total)
Satou et al. (2^+)
Total
0^+
2^+
Preliminary
$7/2^+$
$9/2^+$
$5/2^+$
$d\sigma/dE_{rel}$ (mb/MeV)
E_{rel} (MeV)
0
1
2
3
4
5
6

$^{17}C(p,p')^{16}C+n$



$^{17}C(p,p')^{16}C+n$
70 MeV/nucleon
Satou et al. (Total)
Satou et al. (2^+)
Total
0^+
2^+
Preliminary
$7/2^+$
$9/2^+$
$5/2^+$
$d\sigma/dE_{rel}$ (mb/MeV)
E_{rel} (MeV)

Angular distribution for E_{rel}~1.5 MeV



Conclusions

- Two models are considered for ^{17}C, Nilsson and PAMD, which account for the effect of deformation in the weak- and strong-coupling limits.
- A theoretical study of the transfer reaction $^{16}C(d,p)^{17}C$ and the breakup reaction $^{17}C(p,p')^{16}C+n$ has been performed.
- Transfer calculations to bound states shows encouraging agreement with the existing data.
- The study of the transfer reaction populating unbound states is in progress.
- The analysis of the breakup data supports the presence of some resonances predicted by the PAMD model.
- Other weakly bound nuclei (e.g. ^{11}Be, ^{19}C) and other reactions (e.g. $^{11}Be(p,d)^{10}Be$) are studied with these models.

- PhD Grant
- PAIDI - Proyectos I+D+i **P20_01247**

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Thanks for your attention

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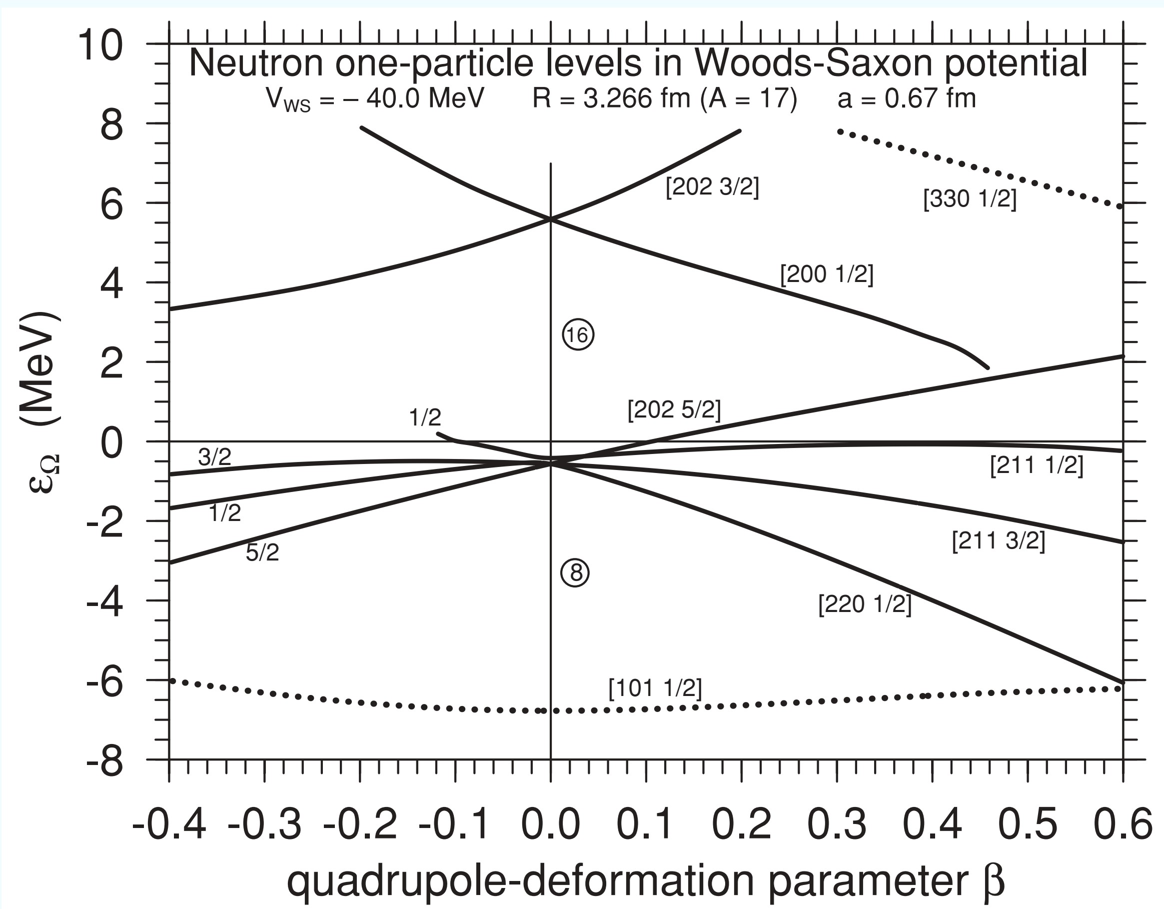
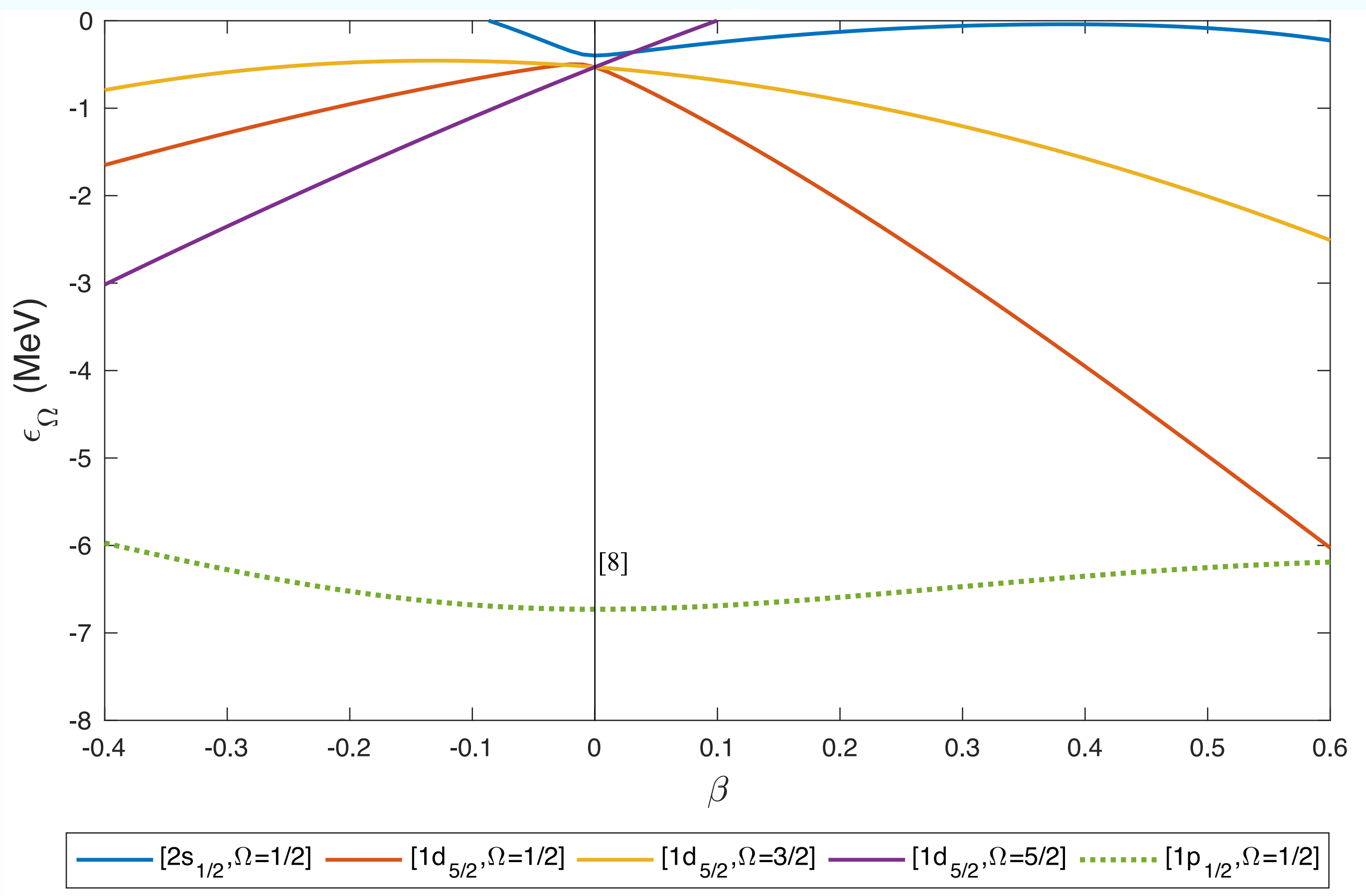
- Plan Estatal 2017-2020 - Proyectos I+D+i **PID2020-114687GB-I00**

Backup

Nilsson Diagram for ^{17}C

$$H_{sp} = -\frac{\hbar^2}{2\mu}\nabla^2 + V_c(r) + V_{ls}(r)(\vec{l}\cdot\vec{s}) - r\beta\frac{dV_c(r)}{dr}Y_{20}(\theta')$$





I. Hamamoto, PRC76 (2007) 054319

Potentials

$^{16}C(d,p)^{17}C$

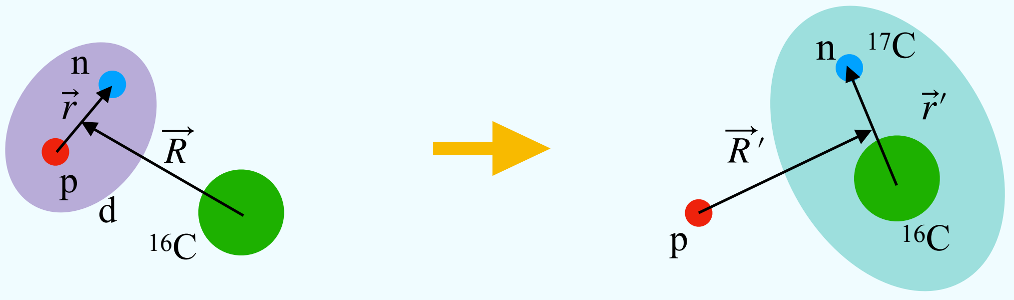
- p-n: Reid soft-core
- ^{16}C-n: PAMD/Nilsson
- ^{16}C-d: finite-range adiabatic potential (Johnson-Tandy)
- ^{17}C-p: Chapel-Hill (CH89)

$^{17}C(p,p')^{16}C+n$

- p-n: fitted Gaussian potential
- ^{16}C-n: PAMD
- ^{17}C-p: Koning-Delaroche (KD02)

Neutron Transfer Reactions

$^{16}C(d,p)^{17}C$



p-^{17}C Optical potential

d-^{16}C Adiabatic Potential

$$\frac{d\sigma}{d\Omega} = \frac{\mu_\alpha \mu_\beta}{(2\pi\hbar^2)^2} \left| \int \chi_p^{(-)*}(\vec{k}_p, \vec{R}\,')\psi^*_{^{17}C}(\vec{r}\,')\Delta V \chi_d^{(+)}(\vec{k}_d, \vec{R})\psi_d(\vec{r})d\vec{r}d\vec{R} \right|^2$$

Our Model

p-n potential