Study of "quenching factors" for (p, pn) and $(p, 2p)$ reactions through the Transfer to the Continuum formalism

M. Gómez-Ramos, A. M. Moro

University of Seville

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Quenching factors

- SF from IPM or shell-model
- Can be related to experiment through:

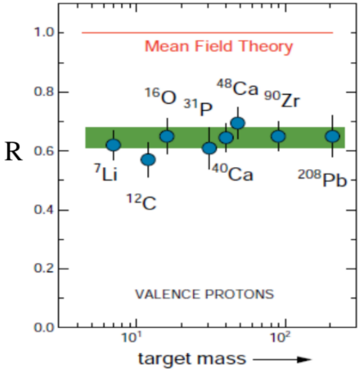
$$\sigma_{\rm th} = C^2 S \times \sigma_{s.p.}$$

- Quenching of spectroscopic factors:

$$R_s = \frac{\sigma_{\rm exp}}{\sigma_{\rm th}}$$

- Related to beyond-shell-model effects (Short-range correlations)

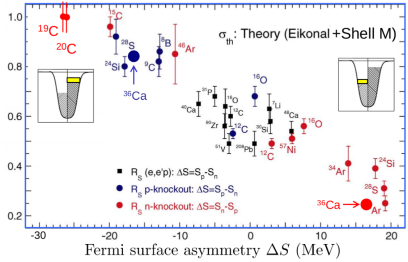
(e,e'p) reactions



H. Dickhoff, C. Barbieri, Prog. Part. Nucl. Phys. 52, 377 (2004)
NIKHEF data: L. Lapikas Nucl. Phys. A 553, 297c (1993)

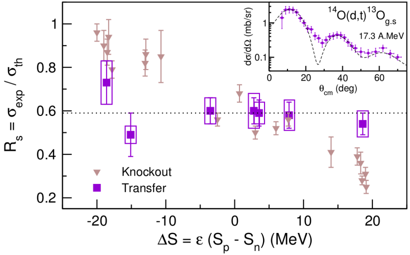
Quenching factors

- Knockout reactions



J. Tostevin & A. Gade, Phys.Rev. C 90, 057602 (2014)

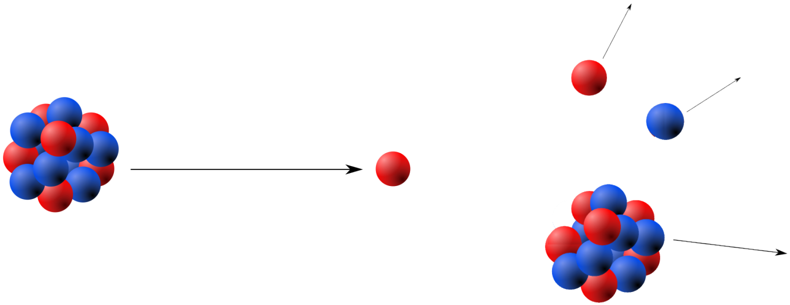
- Transfer reactions



F. Flavigny *et al*, Phys. Rev. Lett. 110, 122503 (2013)

Different tendencies: reaction description in question?

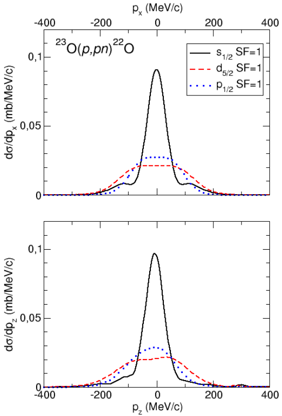
(p, pN) reactions



- A proton and a nucleus collide in such a way that a proton or neutron is removed and the residual nucleus remains.
- High energies ($\sim$ 200-400 MeV) to increase mean free path of nucleon in nucleus.
- Used to obtain single-particle information of nuclei.
- It is sometimes referred to as "quasifree" because the main interaction can be modelled as if it were a free collision between the incoming proton and the removed nucleon.

Momentum distributions

- Momentum distributions of residual nucleus (core)
- Inclusive measurements: Only core is measured. Integration over all angles of ejected proton and nucleon
- Shape gives information about quantum numbers of extracted nucleon
- Magnitude gives information about s.p. occupation numbers



A.M.M. PRC **92**, 044605(2015)

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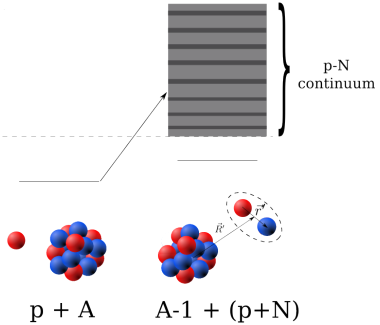
Reaction formalism: Transfer to Continuum

- We consider a calculation without explicit IA, including interaction with residual nucleus in matrix element and without factorization approximation.

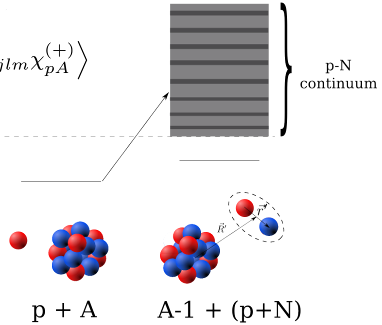


Reaction formalism: Transfer to Continuum

- We consider a calculation without explicit IA, including interaction with residual nucleus in matrix element and without factorization approximation.

- Prior representation of the T-matrix for the process $p + A \rightarrow p + N + C$, approximating the exact wf $\Psi_f^{(-)}$ by a 3-body CDCC wf $\psi_f^{3b-CDCC(-)}$

$$\mathcal{T}_{if}^{3b} = \left\langle \psi_f^{3b-CDCC(-)} | V_{pN} + U_{pC} - U_{pA} | \psi_{jlm} \chi_{pA}^{(+)} \right\rangle$$



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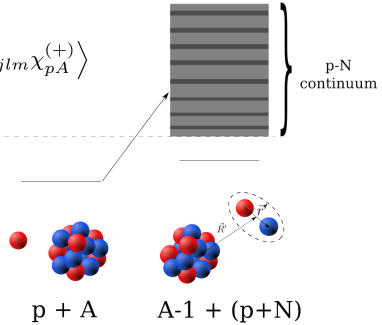
- p-N continuum states discretized in energy bins
  Deuteron included for (p, pn)

$$\phi_n^{j,\pi}(k_n, \vec{r}') = \sqrt{\frac{2}{\pi N}} \int_{k_{n-1}}^{k_n} \phi_n^{j,\pi}(k, \vec{r}')\mathrm{d}k$$



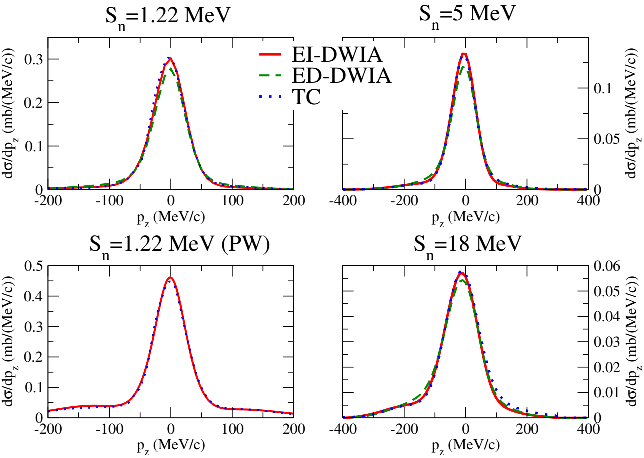
- 3-body final state wavefunction expanded in proton-nucleon states

$$\psi_f^{3b-CDCC(-)} \approx \sum_{n,j,\pi} \phi_n^{j,\pi}(k_n, \vec{r}') \chi_{n,j,\pi}^{(-)}(\vec{K_{pn}}', \vec{R}')$$

Contents

Benchmark with DWIA: ^{15}C$(p,pn)^{14}$C @ 420 MeV/A

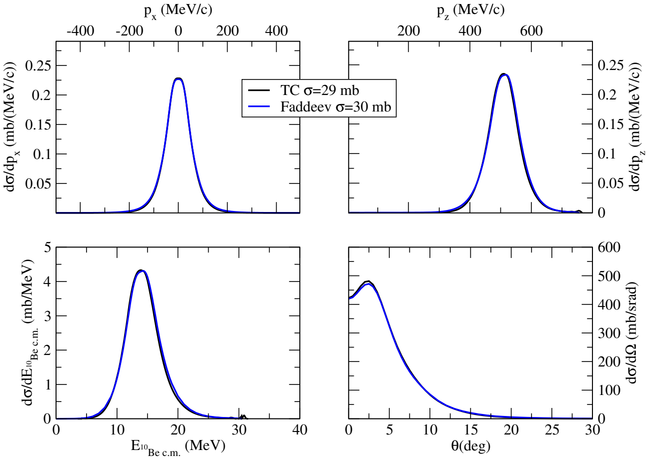
- In collaboration with K. Yoshida and K. Ogata (PRC **97** 024608 (2018))



See talk by K. Yoshida

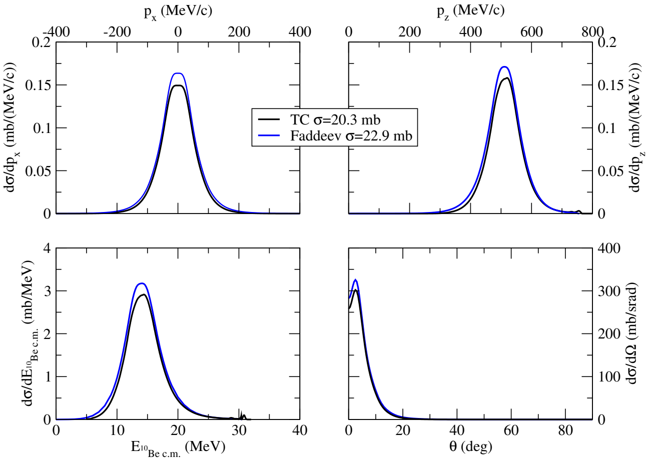
Benchmark with Faddeev: ^{11}Be$(p, pn)^{11}$Be @ 200 MeV/A (p wave)

- In collaboration with A. Deltuva



Benchmark with Faddeev: ^{11}Be$(p, pn)^{11}$Be @ 200 MeV/A (p wave) Reid93

- In collaboration with A. Deltuva



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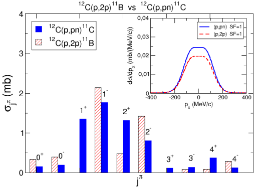
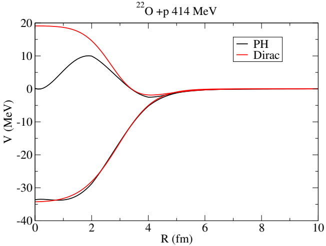
Inputs of the calculation

- Nucleon-nucleon interaction: Reid93



- Bound states from Woods-Saxon
  - $a = 0.7$ fm
  - r_0 chosen to reproduce HF rms (SkX)

- Distorting potentials
  - Folding from Paris-Hamburg g-matrix effective interaction and HF density (SkX)
  - Phenomenological Dirac parametrization (EDAD2)



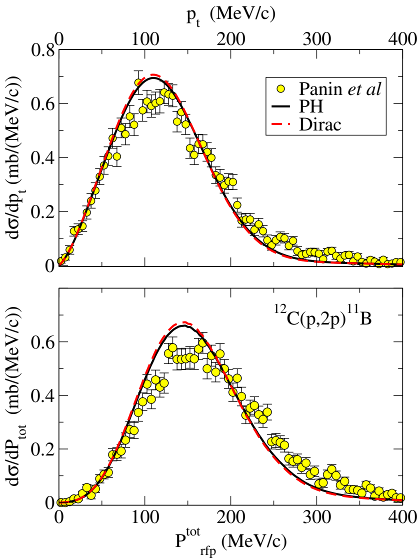
- SF obtained using WBT interaction

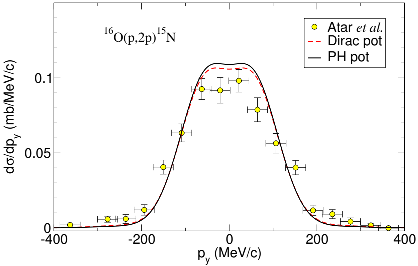
Experimental data

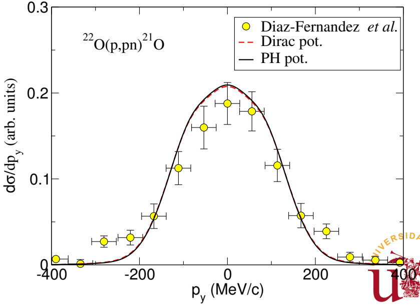
Reaction	E/A	Ref	Reaction	E/A	Ref
^{13}O$(p, 2p)$	401	1	^{21}O$(p, 2p)$	449	1
^{14}O$(p, 2p)$	351	1	^{21}N(p, pn)	417	2
^{15}O$(p, 2p)$	310	1	^{21}N$(p, 2p)$	417	2
^{16}O$(p, 2p)$	451	1	^{22}O(p, pn)	414	2
^{17}O$(p, 2p)$	406	1	^{22}O$(p, 2p)$	414	2
^{18}O$(p, 2p)$	368	1	^{23}O(p, pn)	445	2
^{12}C$(p, 2p)$	398	3	^{23}O$(p, 2p)$	445	2

1: L. Atar *et al* Phys. Rev. Lett. **120**, 052501 (2018)
2: P. Díaz-Fernández *et al* Phys. Rev. C **97**, 024311 (2018)
3: V. Panin *et al* Phys. Lett. B **753**, 204 (2016)

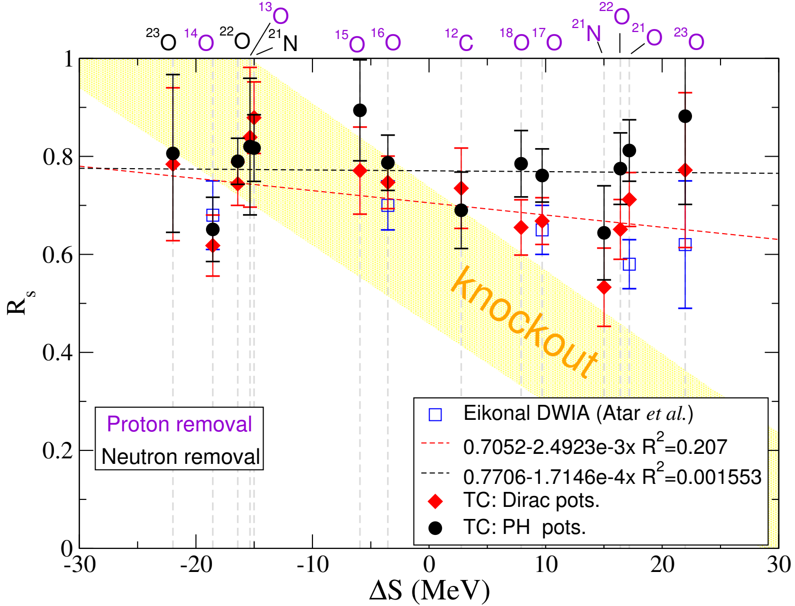
Momentum distributions



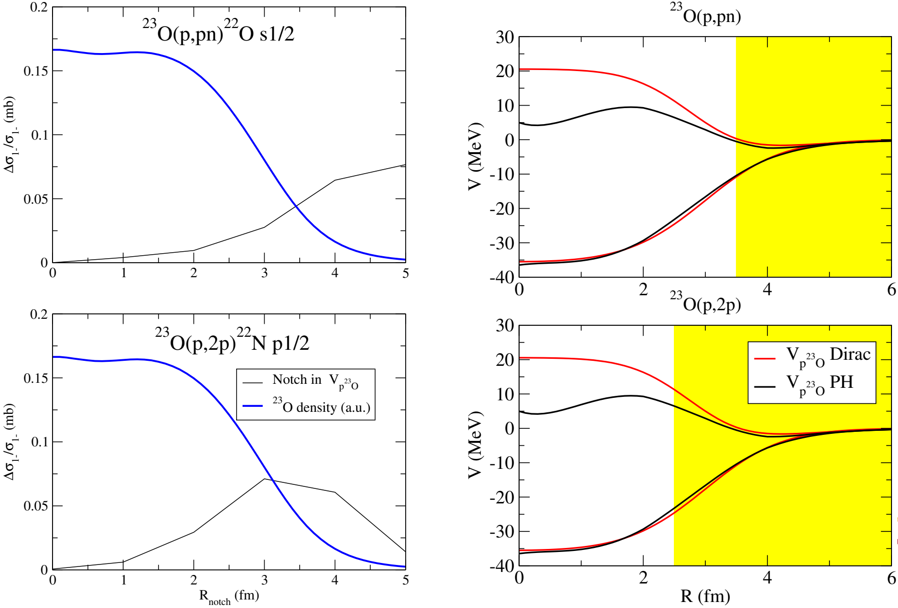




Quenching factors

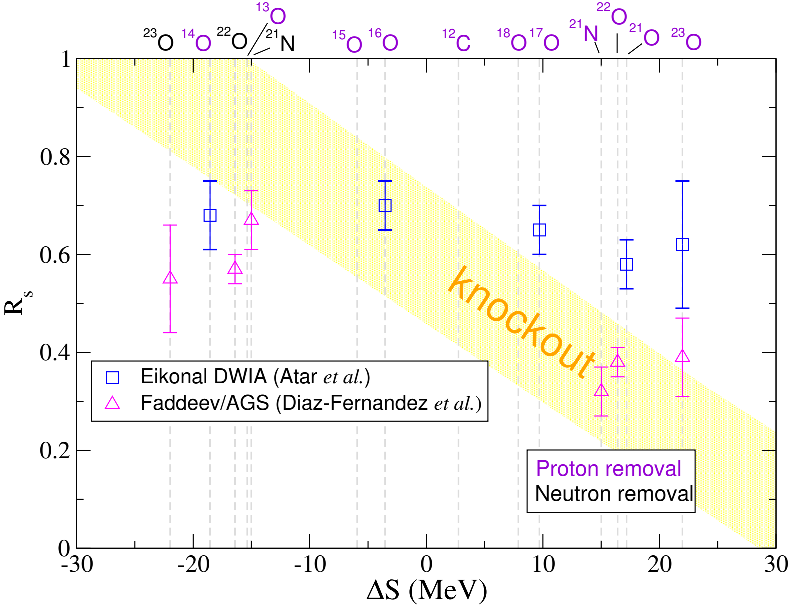


Notch test

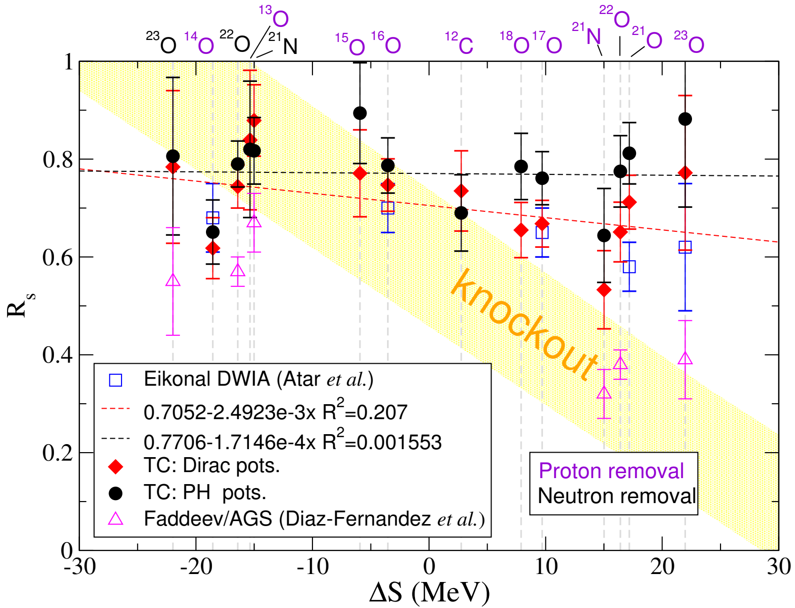


^{23}O(p,pn)^{22}O s1/2
^{23}O(p,2p)^{22}N p1/2
$\Delta\sigma_{1-}/\sigma_{1-}$ (mb)
R_{notch} (fm)
Notch in $V_{p^{23}O}$
^{23}O density (a.u.)
^{23}O(p,pn)
^{23}O(p,2p)
V (MeV)
R (fm)
$V_{p^{23}O}$ Dirac
$V_{p^{23}O}$ PH

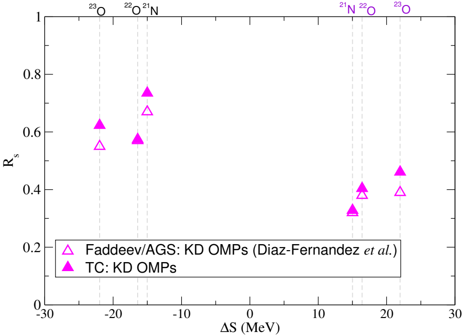
Quenching factors



Quenching factors



Quenching factors. KD potentials



- Köning-Delaroche potentials at 200 MeV
- No relativistic modifications
- WS geometry: $r_0 = 1.25$ fm $a = 0.65$ fm

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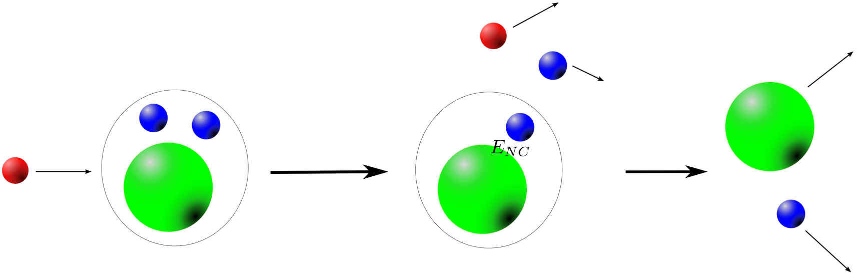
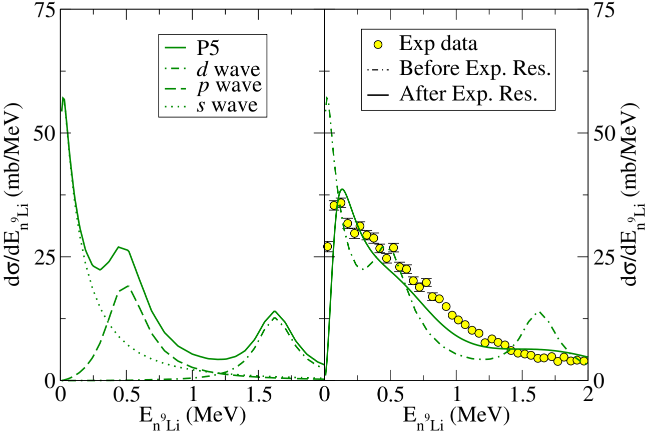
(p, pN) reactions with Borromean nuclei (in collaboration with J. Casal)



- A high-energy proton impinges on a Borromean system with two loosely bound nucleons
- The proton knocks out one nucleon, leaving the core and the other nucleon in a state with positive energy E_{N-C} (since the original nucleus was Borromean)
- The $N - C$ system decays emitting a low-energy nucleon

$^{11}Li(p,pn)^{10}Li^*$: $I_{^9Li} = 0 + d$ wave

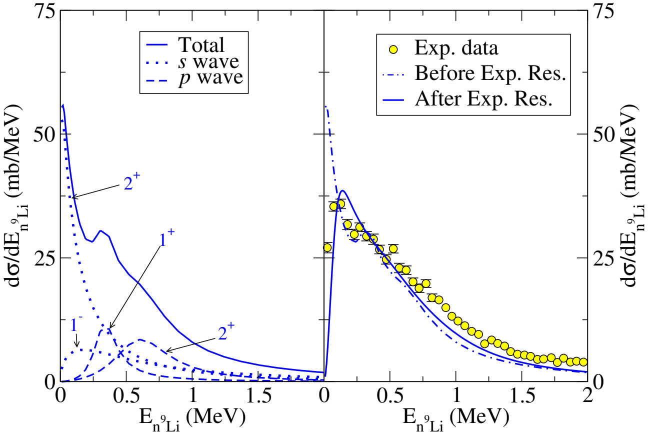
	E_p MeV	a (fm)	E_d (MeV)	$\%p_{1/2}$	$\%s_{1/2}$	$\%d_{5/2}$	r_{mat} (fm)	r_{ch} (fm)
P5	0.50	-29.8	1.5	39	35	23	3.2	2.42



M.G.-R., J. Casal, A.M.M. PLB **772**, 115 (2017)

^{11}Li$(p, pn)^{10}$Li*: $I_{^9\mathrm{Li}} = 3/2^-$

	E_r (MeV)		a (fm)		$\%p_{1/2}$	$\%s_{1/2}$	r_{mat} (fm)	r_{ch} (fm)
	1^+	2^+	1^-	2^-				
P1I	0.37	0.61	–	-37.9	31	67	3.2	2.41



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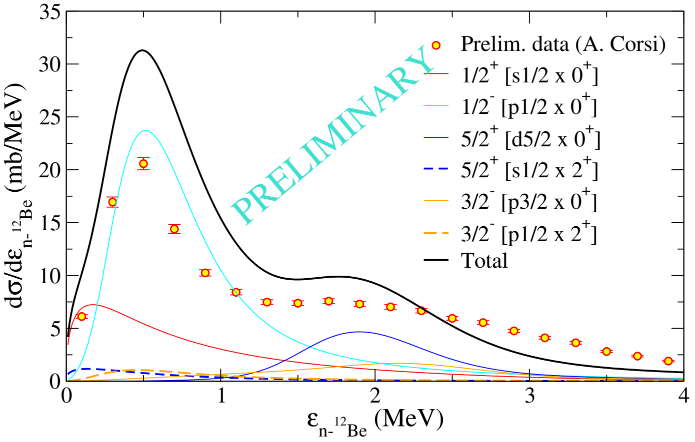
$^{14}Be(p, pn)^{13}Be^*$



Contents

Summary

- Transfer to Continuum (TC) developed for the study of (p, pN) reactions at high and intermediate energies.
- Benchmark with Faddeev and DWIA shows encouraging agreement
  - × Difference with Faddeev when using Reid93 (still unclear)
- "Quenching factors" obtained show small dependence on ΔS
  - ☐ Agreement with transfer experiments
  - ☐ Disagreement with mid-energy knockout reactions
- Good agreement with published eikonal DWIA R_s for small binding energies, but increased disagreement for larger binding energies
- Overall R_s 0.7∼0.8 larger than overall value for R_s for $(e, e'p)$ with IPM 0.6∼0.7
- Formalism has been extended to study Borromean nuclei: ^{11}Li$(p, pn)^{10}$Li has been published and analysis of ^{14}Be(p, pn) is underway

Collaborators

- K. Yoshida
- K. Ogata
- A. Deltuva
- J. Casal
- A. Corsi

Focus on peak