Transfer to the continuum calculations of (p, pN) reactions

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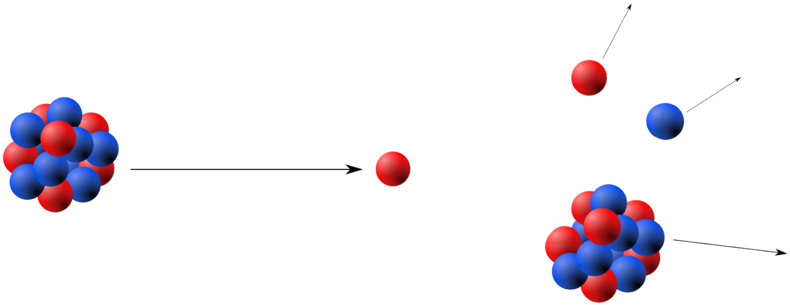
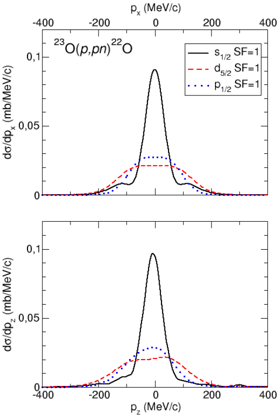
(p, pN) reactions



- 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 happens between the incoming proton and the extracted nucleon as if it was a free collision.

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 occupation number



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

"Quenching factors"

- Spectroscopic factors

$$\sigma_{p,pN} = S_F \sigma_{sp}$$

  - $\sigma_{s.p.}$: Single-particle cross section, obtained from reaction calculation
  - S_F: Spectroscopic factor: obtained from shell model calculation
  - $\sigma_{p,pN}$: Measured cross section

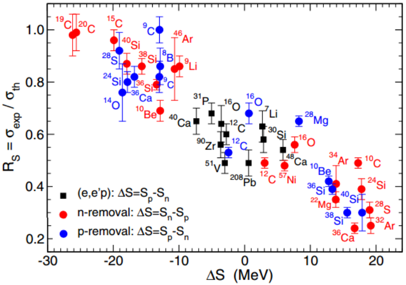
- "Measured" spectroscopic factors

$$S_F^{exp} = \frac{\sigma_{exp}}{\sigma_{s.p.}}$$

- "Quenching factors"

$$R_s = \frac{S_F^{exp}}{S_F \begin{pmatrix}\text{shell} \\ \text{model}\end{pmatrix}}$$

- Correlation between "*quenching factors*" and $S_n - S_p$



J.A.Tostevin and A.Gade *PRC*, **90**,*057602* (2014)

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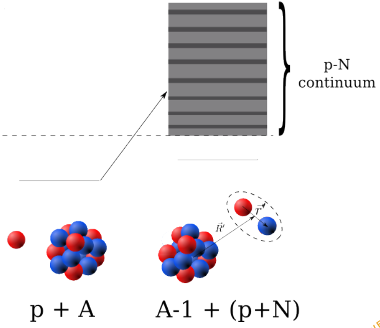
Reaction formalism: Transfer to Continuum

- We consider a calculation beyond IA, including interaction with core in matrix element and without factorization approximation, expected to be suitable at lower energies and less restrictive geometries.



Reaction formalism: Transfer to Continuum

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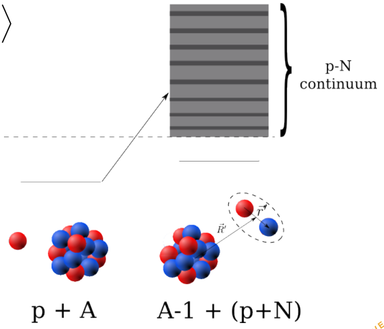
- Post representation of the T-matrix for the process $p + A \to p + N + C$

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



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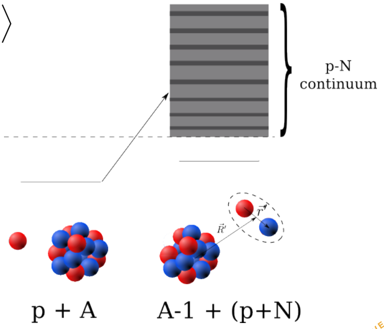
- p-N continuum states discretized in energy bins
  Deuteron included for (p, pn)

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

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

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



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Calculations: Details of the calculation

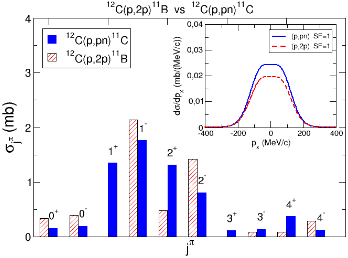
Potentials

- V_{pN}: Reid 93
- V_{pA} : $E/A \geq 100$MeV: Paris-Hamburg g matrix effective NN interaction folded with Hartree-Fock density
- V_{pA} : $E/A \leq 100$MeV: JLM interaction folded with Hartree-Fock density

Continuum discretization

- $E/A \geq 100$MeV :
  - Main J^π: $\Delta E = 15$MeV
  - Other J^π: $\Delta E = 25$MeV
- $E/A \leq 100$MeV :
  - Main J^π: $\Delta E = 5$MeV
  - Other J^π: $\Delta E = 10$MeV

- Different J^π of $p - N$ subsystem uncoupled: Effect of 10%

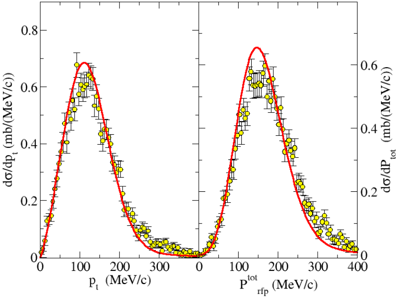


A.M.M PRC **92**, 044605(2015)

- Convergence with J^π of proton-nucleon states

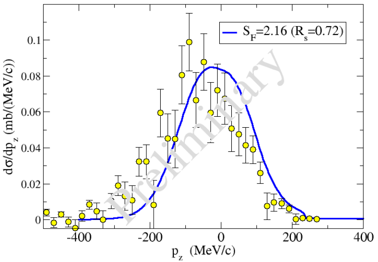
Preliminary calculations: $^{12}\mathrm{C}(p,2p)^{11}\mathrm{B}$ @ 400 MeV/A and $^{11}\mathrm{C}(p,pn)^{10}\mathrm{C}$ at 325 MeV/A

$^{12}\mathrm{C}(p,2p)^{11}\mathrm{B}$ @ 400 MeV/A



	$\frac{\sigma_{exp}}{\sigma_{th}}$
Eikonal DWIA V.Panin et al PLB **753**, 204 (2016)	2.58
Transfer to continuum	3.73

$^{11}\mathrm{C}(p,pn)^{10}\mathrm{C}$ at 325 MeV/A



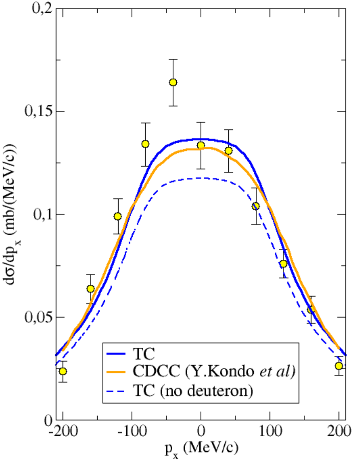
	$\frac{\sigma_{exp}}{\sigma_{th}}$	R_s
Eikonal DWIA *M.Holl PhD Thesis* (Preliminary)	2.47	0.82
Transfer to continuum	2.16	0.72

Preliminary calculations: ^{18}C$(p,pn)^{17}$C* at 81 MeV/A

- Formalism applicable to intermediate energies
- $^{18}C(g.s.) \to ^{17}C^*$
  E_x=0.33 MeV, $5/2^+$ $d_{5/2}$
- Exp. data and CDCC calculation: Y.Kondo *et al* (PRC **79**, 014602(2009))

	$\frac{\sigma_{exp}}{\sigma_{th}}$	R_s
TC	2.69	0.82
CDCC (Y.Kondo)	2.39	0.75

- Deuteron contribution of 14% (No deuteron TC $R_s = 0.95$)



EPJ Web of Conferences **117**, 062024 (2016)

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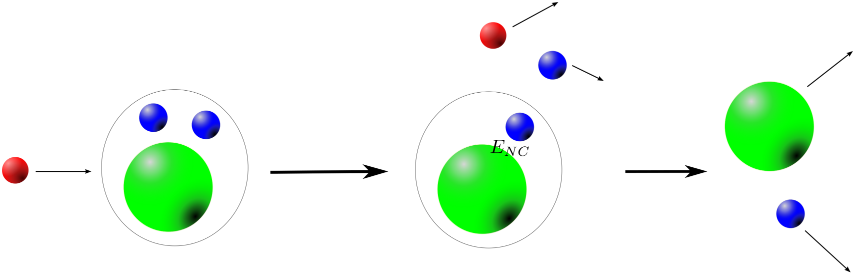
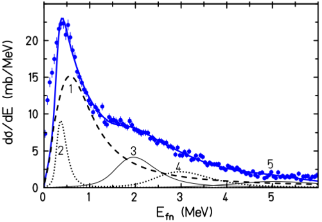
(p, pN) reactions with Borromean nuclei *(in collaboration with J.Casal)*





Y. Aksyutina *et al*, PLB **718**,1309 (2013)

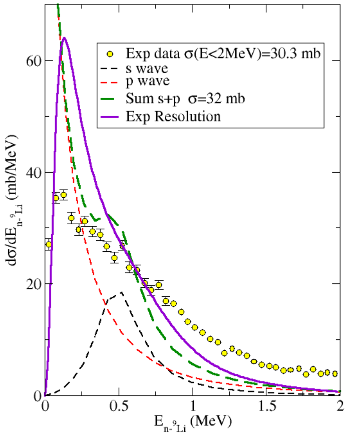
- Spectroscopic information obtained through fitting
- Reaction formalism???

(p, pN) reactions with Borromean nuclei: ^{11}Li *(in collaboration with J.Casal)*

$^{11}\mathrm{Li}(p, pn)^{10}\mathrm{Li}^*$

- Spin of ^{9}Li ignored
- Only p and s waves considered
- Process is expected to be sudden, so no coupling between states with different $E_{n^9\mathrm{Li}}$ is considered
- $\frac{d\sigma}{dE_{n^9\mathrm{Li}}} \propto K(E_{n^9\mathrm{Li}}) \sum_{l,j} \sigma_{l,j}(E_{n^9\mathrm{Li}})$
  - $K(E_{n^9\mathrm{Li}})$ Kinematic factor
  - $\sigma_{l,j}(E_{n^9\mathrm{Li}})$ Cross section to ^{10}Li with energy $E_{n^9\mathrm{Li}}$ and l, j angular momenta of the nucleon
- Overlap obtained from 3-body calculation

$$\varphi_{lj}(\vec{r}_n, E_{n^9\mathrm{Li}}) = \langle ^{10}\mathrm{Li}(E_{n^9\mathrm{Li}}) | ^{11}\mathrm{Li}(g.s.) \rangle$$



Exp data from
Y. Aksyutina *et al* PLB **666**,430(2008)

(p,pN) reactions with Borromean nuclei: Factorization of cross section *(in collaboration with J.Casal)*

- $\dfrac{\mathrm{d}\sigma}{\mathrm{d}E_{n^9\mathrm{Li}}} \propto \int \mathrm{d}\vec{r}|\varphi_{lj}|^2(E_{n^9\mathrm{Li}})$ **?**

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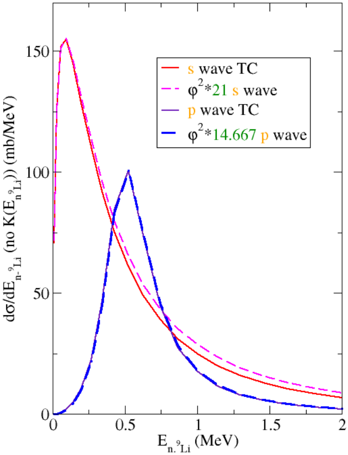
  - p wave follows shape
  - s wave shows different shape



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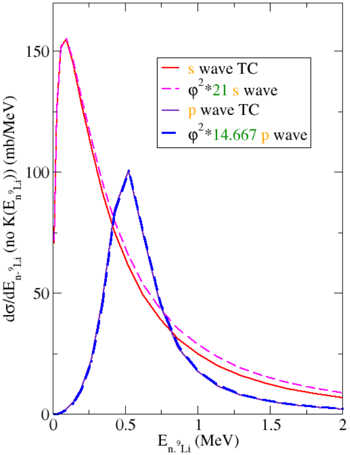
$$\frac{d\sigma}{dE_{n^9\mathrm{Li}}} = \sum_{lj} K(E_{n^9\mathrm{Li}}) S_F^{lj}(E_{n^9\mathrm{Li}}) \sigma_{lj}$$



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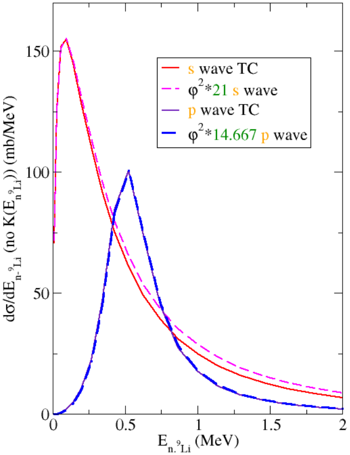

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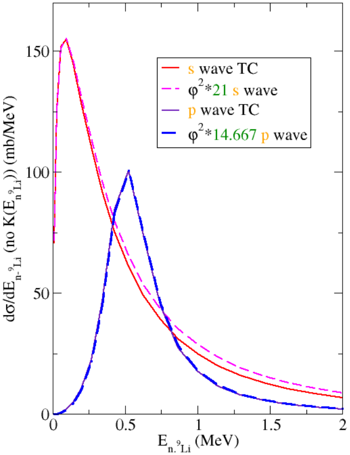
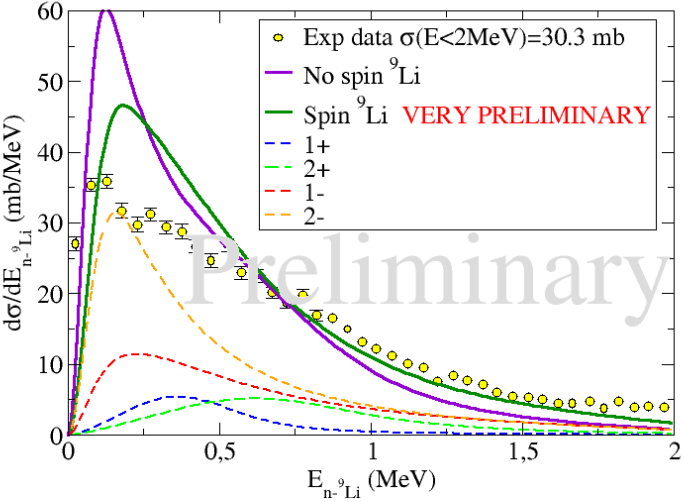
BUT!!!

- Ratio depends on l, j: Reaction model is necessary to obtain relative weights of components



Effect of ^{9}Li spin



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Summary

- Transfer to Continuum (TC) is being developed for the study of (p, pN) reactions at high and intermediate energies. Its main virtues are:
  - Realistic $p - N$ interaction: Reid93
  - Does not employ IA approximation, so it can be used at lower energies than DWIA
  - Final state $p - N$ interactions described accurately (including p-n bound state)
- Preliminary results show encouraging agreement with experimental data
- Reactions with Borromean nuclei are currently under study. Factorization of reaction and structure is to be studied.

Influence of optical potentials