Benchmarking reaction theories for nucleon knockout reactions

Phys Rev. C. **97,** 024608 (2018)

Kazuki Yoshida[1]

in collaboration with

M. Gómez-Ramos[2], K. Ogata[3,4], and A. M. Moro[2]

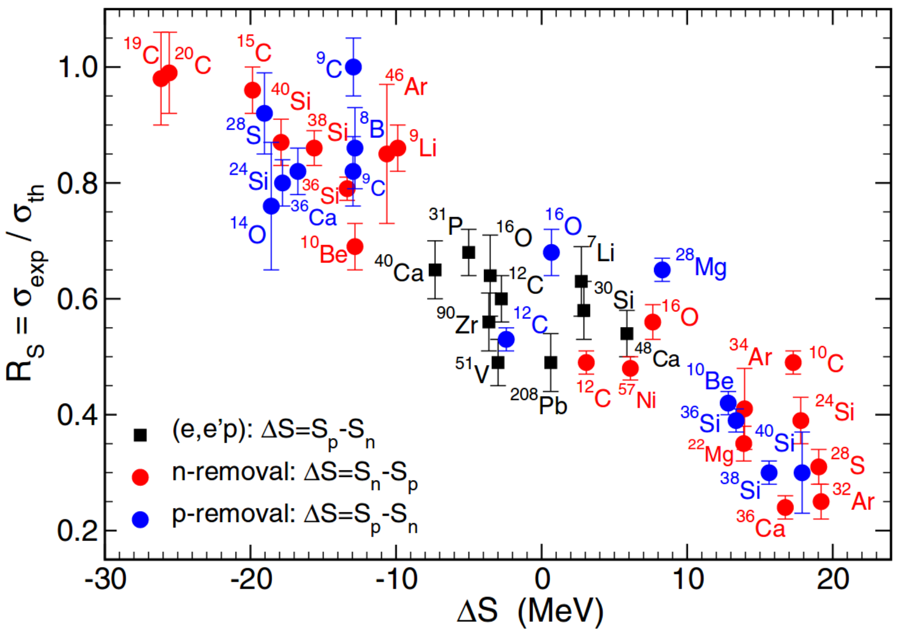
Phys Rev. C. **97,** 024608 (2018)

[1]Advanced Science Research Center, Japan Atomic Energy Agency
[2]Departamento de FAMN, Universidad de Sevilla
[3]Research Center for Nuclear Physics, Osaka University
[4]Osaka City University

Introduction

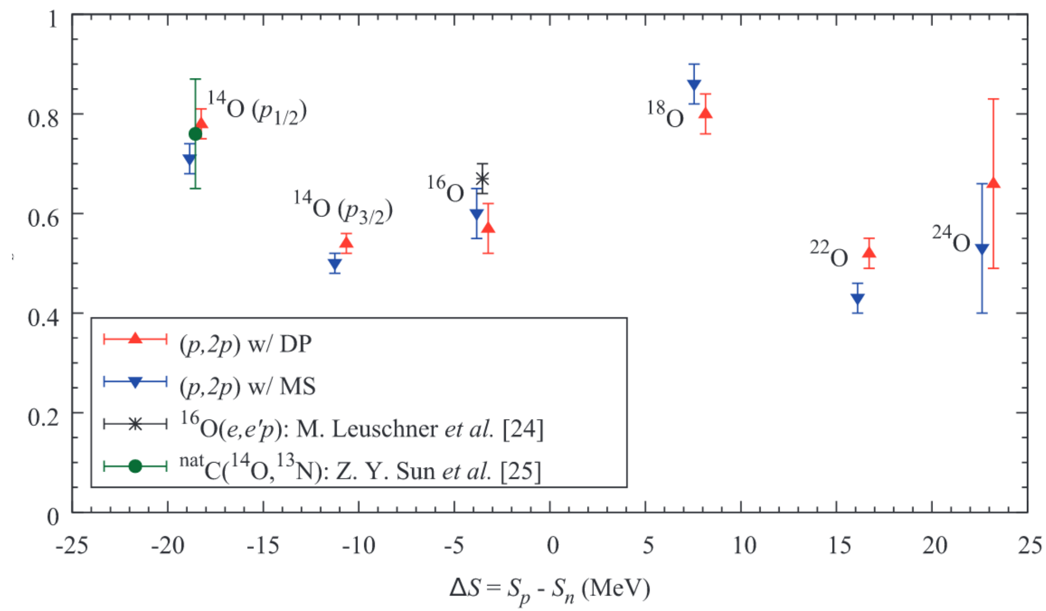
Quenching of spectroscopic factors (SF)

Removal + Glauber model
A(^{9}Be, ^{9}Be+N)B @100 A MeV



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

Knockout + DWIA
^{A}O(p,2p)$^{A\text{-}1}$N @ 200–250 A MeV



S. Kawase *et al*., Prog. Theor. Exp. Phys. **2018**, 021D01 (2018).

Two origins of discrepancy: reaction theory and shell model SF

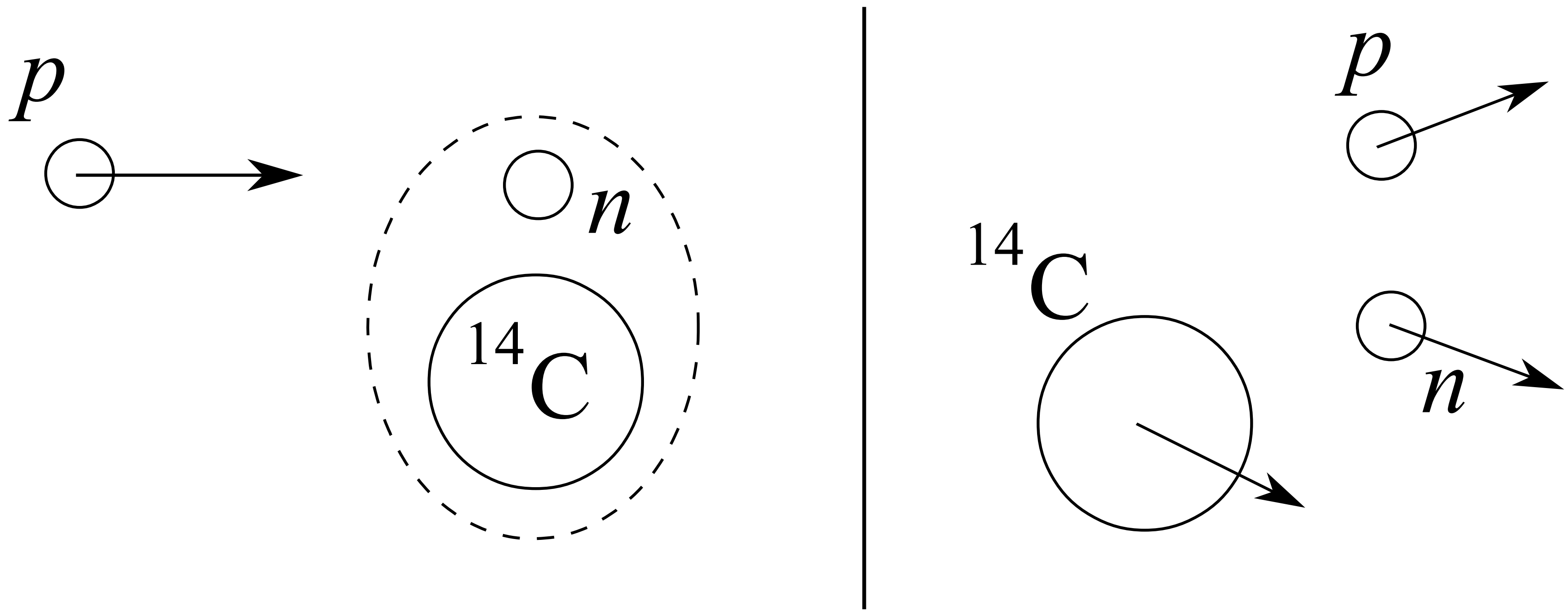
Purpose of this study

- Benchmark comparison between knockout reaction theories
  - to clarify the applicability of reaction theories for spectroscopy
  - to understand uncertainties in reaction theories
  - to settle what is the problem in the quenching of SFs

- Knockout reaction theories investigated in the present study
  1. Distorted Wave Impulse Approximation (DWIA)
  2. Transfer-to-the-Continuum model (TC)
  3. (Faddeev/AGS)

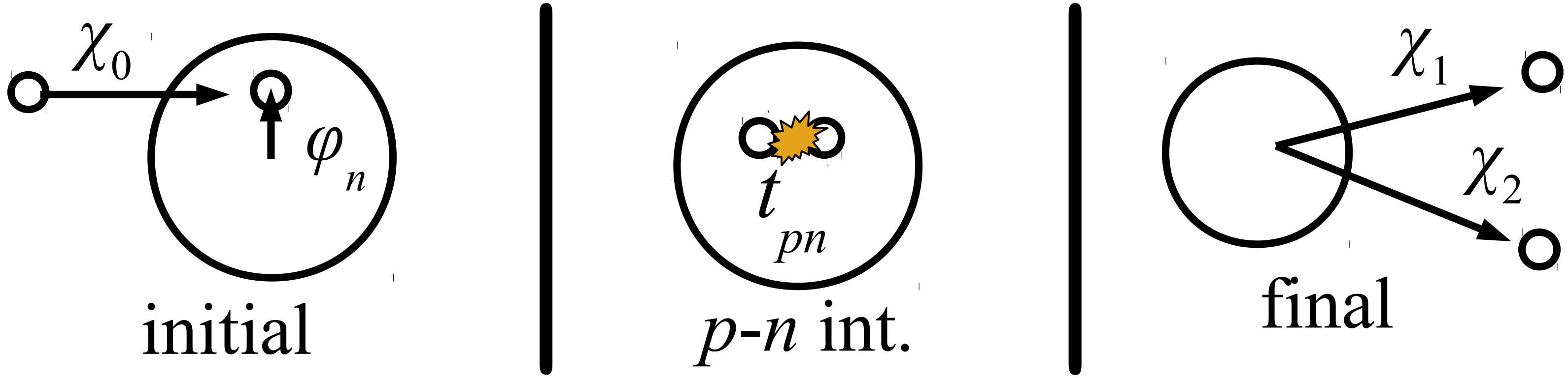
E. Cravo, R. Crespo, and A. Deltuva, Phys. Rev. C **93** , 054612 (2016).

Reaction system: $^{15}\mathrm{C}(p,pn)^{14}\mathrm{C}$ @ 420 MeV



- Momentum distribution of the reaction residue ^{14}C: $\dfrac{d\sigma}{d\boldsymbol{p}_{\mathrm{B}}}$

Framework (1): Distorted Wave Impulse Approximation



- Factorization approx. + on-shell (cross section) approx.

$$T = \langle \chi_1 \chi_2 \,|\, t_{pn} \,|\, \chi_0 \varphi_n \rangle$$

$$\rightarrow \langle \boldsymbol{\kappa}' \,|\, t_{pn} \,|\, \boldsymbol{\kappa} \rangle \int d\boldsymbol{R} \chi_1^*(\boldsymbol{R}) \chi_2^*(\boldsymbol{R}) \chi_0(\boldsymbol{R}) \varphi_n(\boldsymbol{R})$$

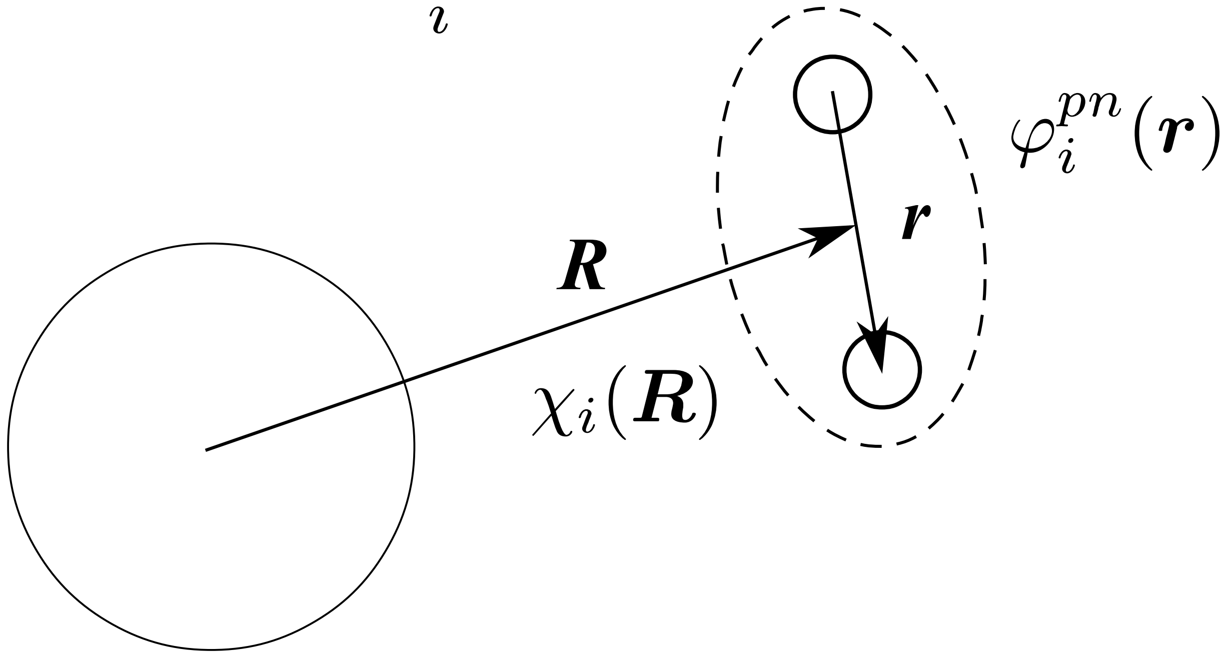
$$\frac{d\sigma}{d\boldsymbol{p}_\mathrm{B}} \propto \frac{d\sigma_{pn}}{d\Omega_{pn}} \left| \int d\boldsymbol{R}\, \chi_1^*(\boldsymbol{R}) \chi_2^*(\boldsymbol{R}) \chi_0(\boldsymbol{R}) \varphi_n(\boldsymbol{R}) \right|^2$$

Framework (2): Transfer-to-the-Continuum

- Prior form of the transition matrix

$$T = \langle \Psi_f \,|\, V_{pn} \,|\, \chi_0 \varphi_n \rangle$$

$$\Psi_f(\boldsymbol{R}, \boldsymbol{r}) \approx \sum\!\!\!\!\!\!\int_i \varphi_i^{pn}(\boldsymbol{r}) \chi_i(\boldsymbol{R})$$



A. M. Moro, Phys. Rev. C 92 044605 (2015).
M. Gómez-Ramos, J. Casal, and A. M. Moro, Phys. Lett. B 772 115 (2017).

Input

Single-particle wave funciton

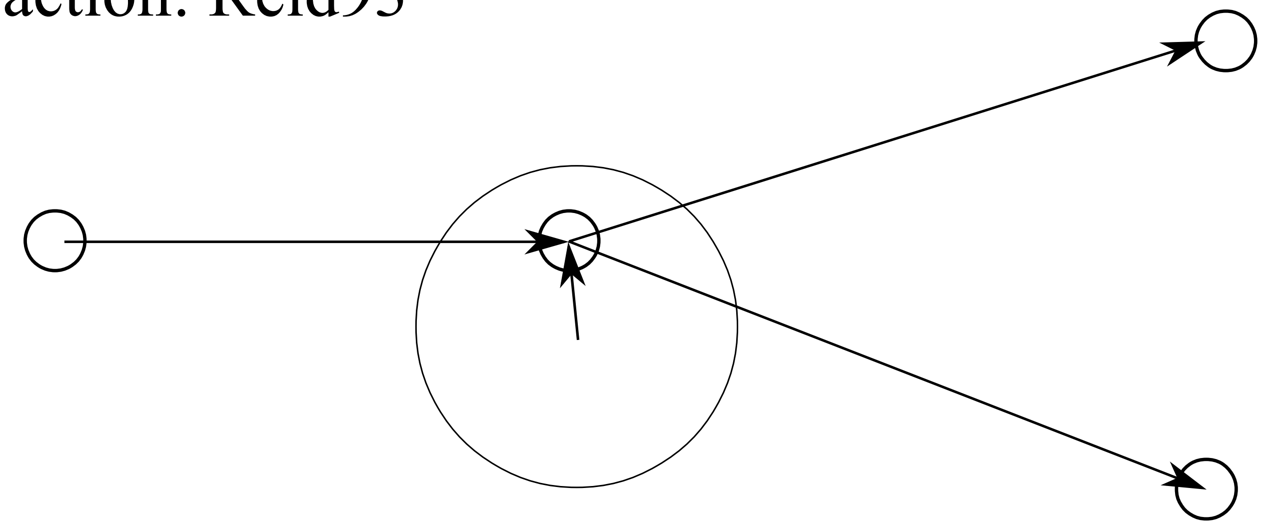
- 1*s* orbital, S_n=1.22 MeV, 5 MeV and 18 MeV
- bound in Woods-Saxon shaped potential with

the range $R = 1.25\ A^{1/3}$ fm and the diffusenes $a = 0.65$ fm

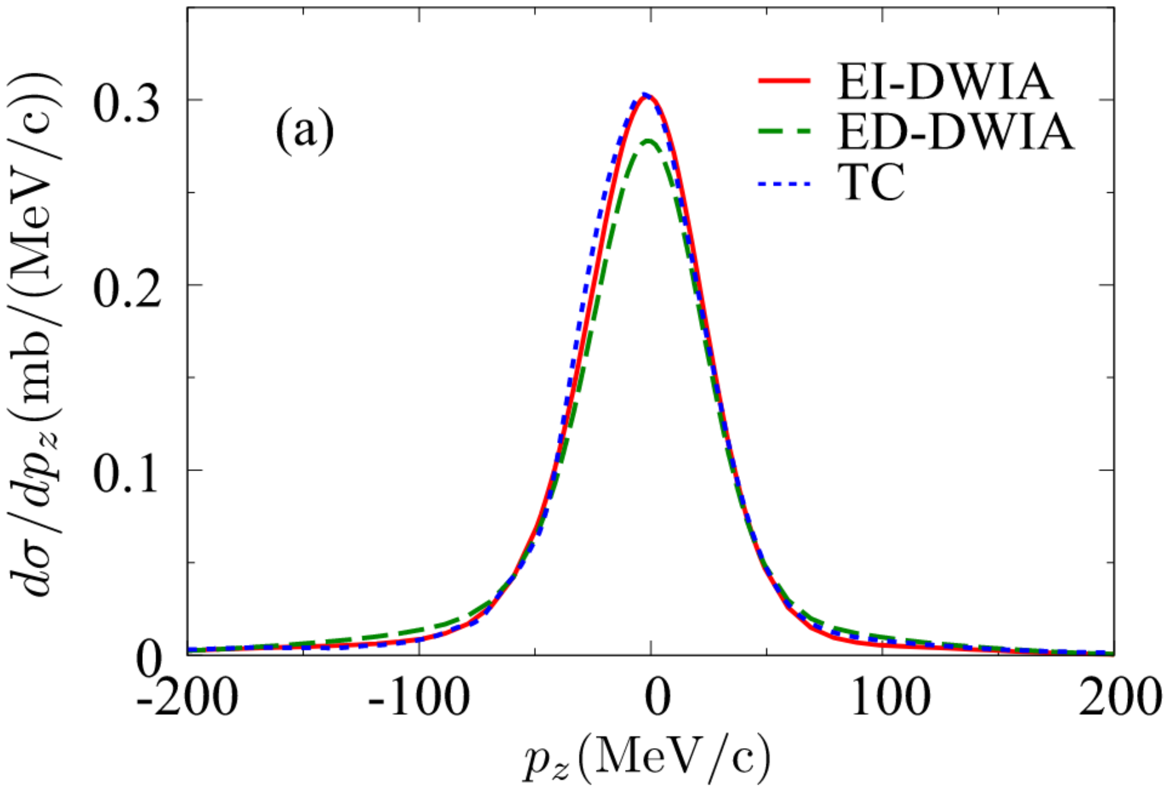
Optical potential for p-^{15}C, p-^{14}C and n-^{14}C:

- EDAD2 parameter set of the Dirac phenomenology
- Energy dependent(ED) / independent (EI, fixed to 210 MeV)

NN interaction: Reid93



results (1): $^{15}C(p,pn)^{14}C$ @420 A MeV

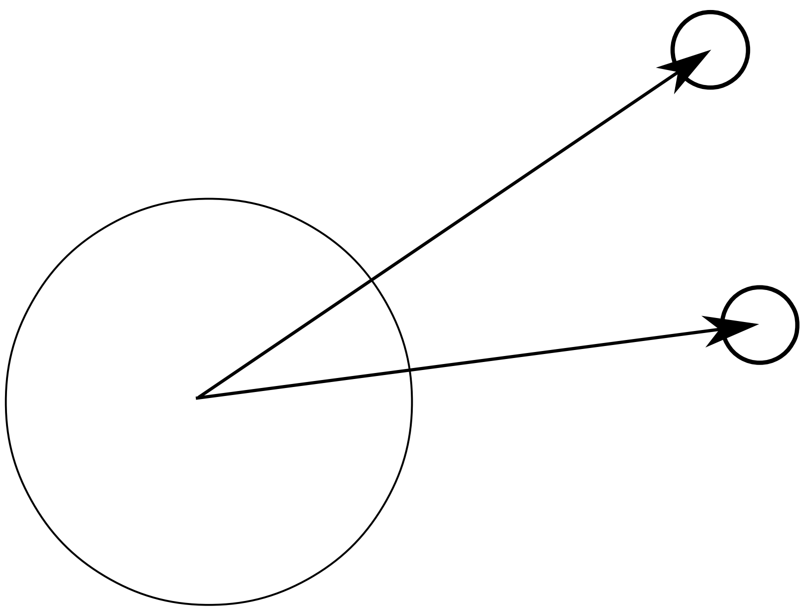


- Excellent agreement between DWIA and TC
- Energy dependence of the optical potentials of the emitted *p* and *n* gives ~8% difference at peak height

Energy dependence of optical potentials

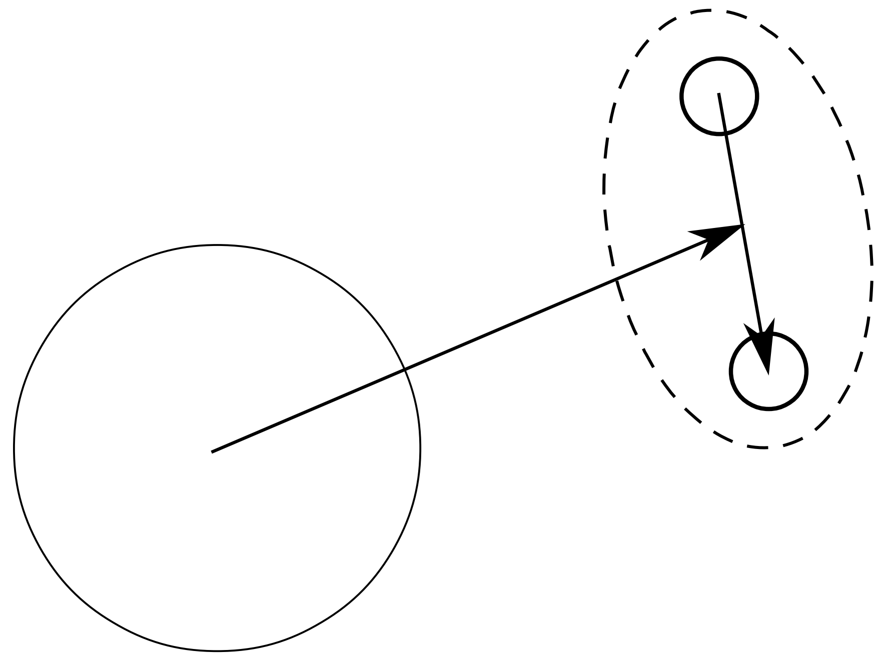
DWIA

Easy to take into account because
p and *n* are assumed to be independent

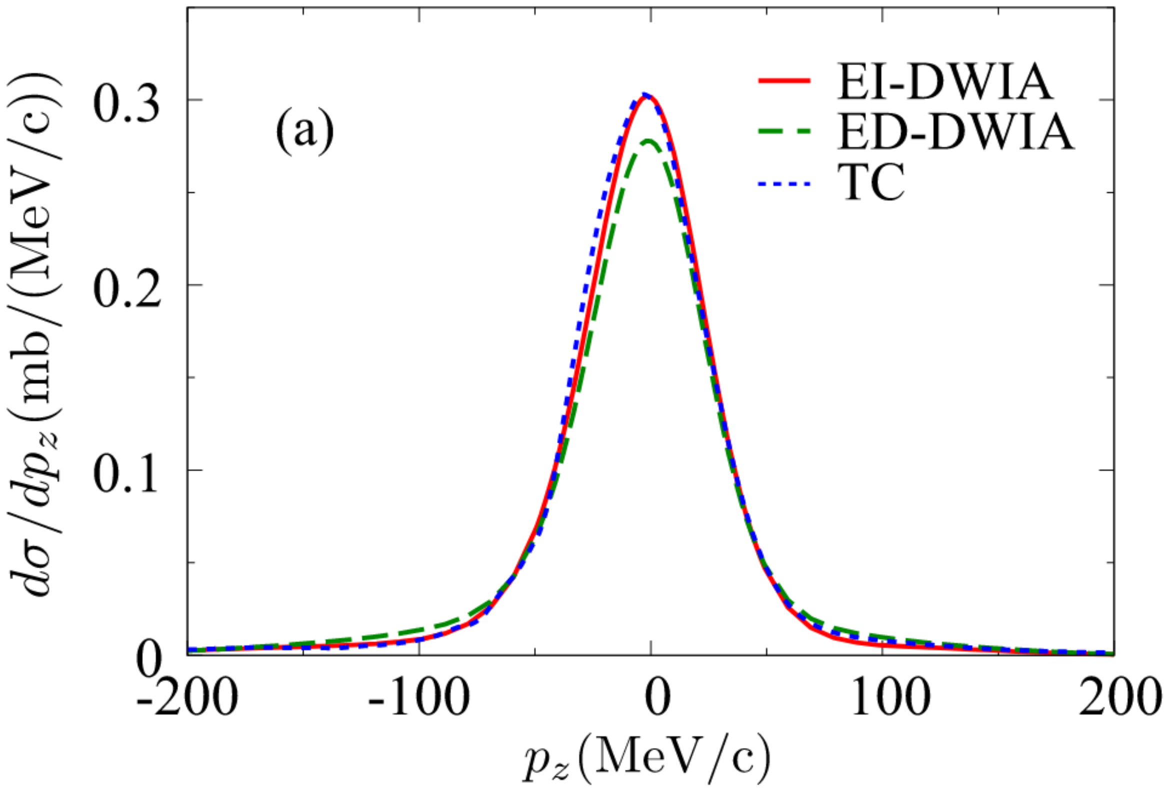


Transfer-to-the-continuum (TC)

Hard to handle because
many configuration of the *p*-*n*
pair are respected including the
continuum

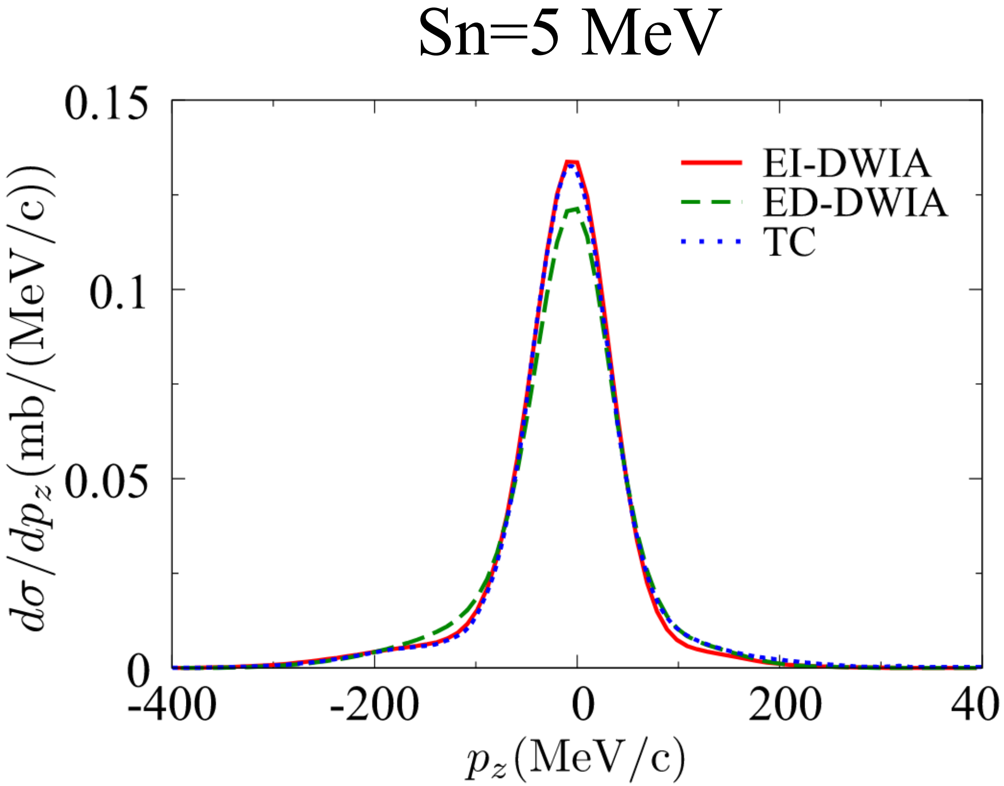


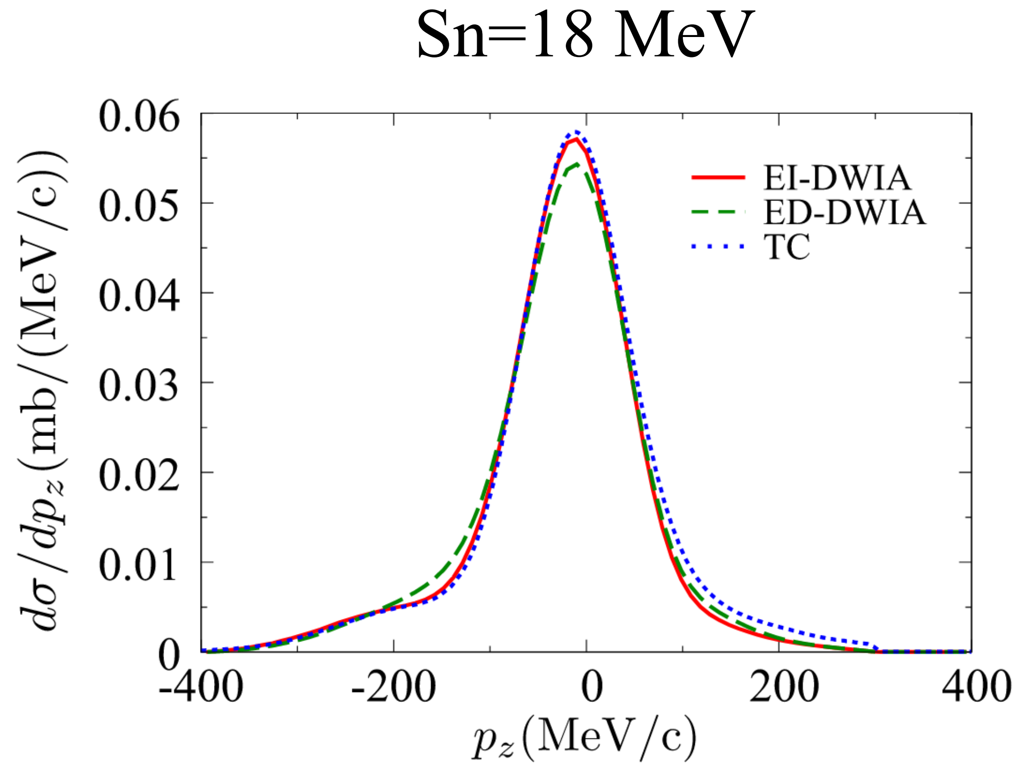
results (1): ^{15}C(p,pn)^{14}C @420 A MeV



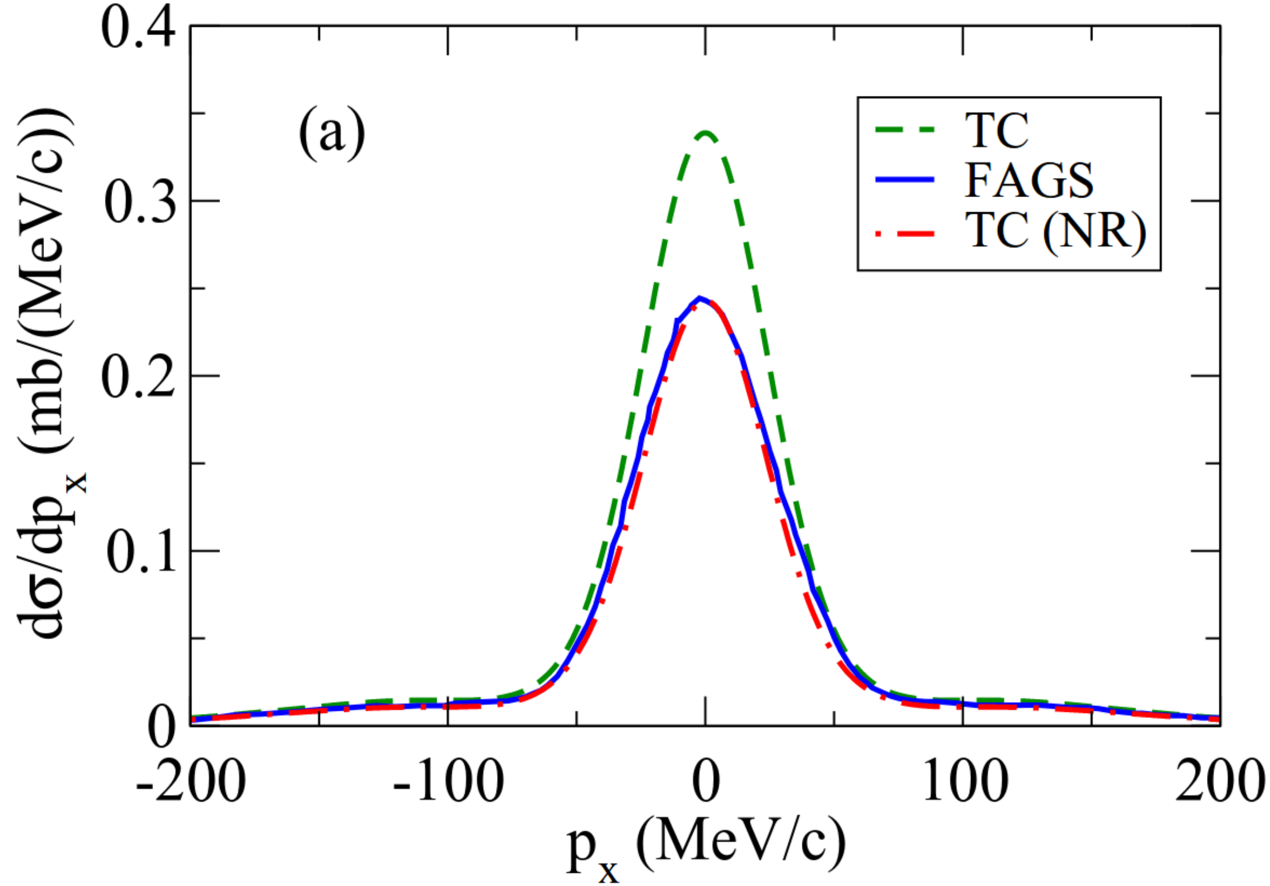
- Excellent agreement between DWIA and TC
- Energy dependence of the optical potentials of the emitted *p* and *n* gives ~8% difference at peak height

results (2): $S_n = 5$ and 18 MeV





results (3): Comparison between TC and FAGS



- NN interaction: CD-Bonn (FAGS), Reid93(TC)
- Optical potential: Koning-Delaroche N-A potential
- relativistic kinematics correction on NN is essential, increase in magnitude by ~ 30%

Summary

- DWIA, TC and FAGS give consistent knockout cross section for $^{15}C(p,pn)^{14}C$ @ 420 MeV, once the same input are given
- In quantitative discussion, the energy dependence of optical potentials (~8%) and the relativistic correction for NN collision (~30%) should be considered

To be investigated

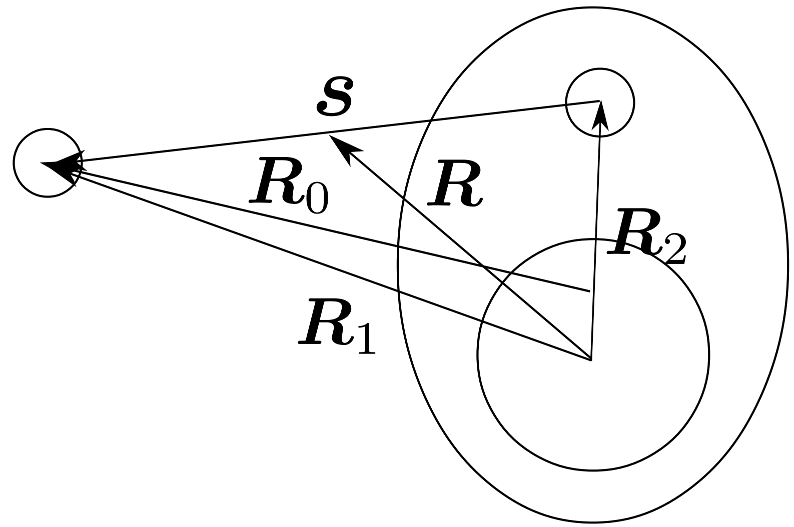
- Comparison in other reaction systems
  - low incident energy
  - finite angular momentum

- Ingredients for knockout reaction
  - Distorted wave, bound state w.f. and their consistency
  - NN interaction (off-shell, density dependence, 3N force, etc.)

Factorization approximation

$$\boldsymbol{R}_0 = \left(1 - \frac{1}{A}\right)\boldsymbol{R} + \frac{A+1}{2A}\boldsymbol{s}$$

$$\boldsymbol{R}_1 = \boldsymbol{R} + \frac{1}{2}\boldsymbol{s} \qquad \boldsymbol{R}_2 = \boldsymbol{R} - \frac{1}{2}\boldsymbol{s}$$



Asymptotic momentum approximation for short distance propagation

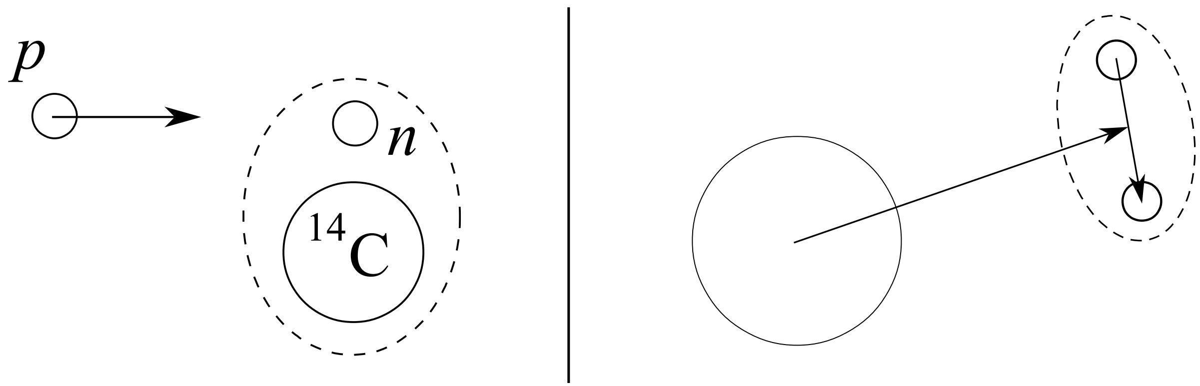
$$\chi_{\boldsymbol{K}}(\boldsymbol{R} + \Delta\boldsymbol{R}) \approx \chi_{\boldsymbol{K}}(\boldsymbol{R}) e^{\boldsymbol{K}\cdot\Delta\boldsymbol{R}}$$

$$T = \langle \chi_1 \chi_2 \,|\, t_{pn} \,|\, \chi_0 \varphi_n \rangle$$

$$\to \langle \boldsymbol{\kappa}' \,|\, t_{pn} \,|\, \boldsymbol{\kappa} \rangle \int d\boldsymbol{R}\, \chi_1^*(\boldsymbol{R}) \chi_2^*(\boldsymbol{R}) \chi_0(\boldsymbol{R}) \varphi_n(\boldsymbol{R})$$

Transfer-to-the-continuum model

$$T_{if}^{nljm} = \left\langle \Psi_f^{3b(-)} \middle| V_{pn} + V_{p\mathrm{B}} - U_{p\mathrm{A}} \middle| \chi_{0,\boldsymbol{K}_0}^{(+)} \varphi^{nljm} \right\rangle$$



$$\Psi_f^{3b(-)}(\mathbf{r},\mathbf{R}) \approx \sum_{Nj'\pi} \phi_N^{j'\pi}(k_N,\mathbf{r})\chi_N^{j'\pi}(\mathbf{K}_N,\mathbf{R})$$

$$T_{if} \approx \sum_{Nj'\pi} \left\langle \phi_N^{j'\pi}\chi_N^{j'\pi} \middle| V_{pn} \middle| \chi_{0,\boldsymbol{K}_0}^{(+)} \varphi^{nljm} \right\rangle$$

A. M. Moro, Phys. Rev. C 92 044605 (2015).

M. Gómez-Ramos, J. Casal, and A. M. Moro, Phys. Lett. B 772 115 (2017).