Insights of many body degrees of freedom in (p,pN) reactions

Raquel Crespo

Collaboration: E. Cravo, A. Deltuva, R.B. Wiringa, D. Jurčiukonis, M. Piarulli, A. Arriaga

Synopsis

- Motivation
- Revisit $^{A}X(p,pN)$ at 400 MeV/u (inverse kinematics) for light nuclei

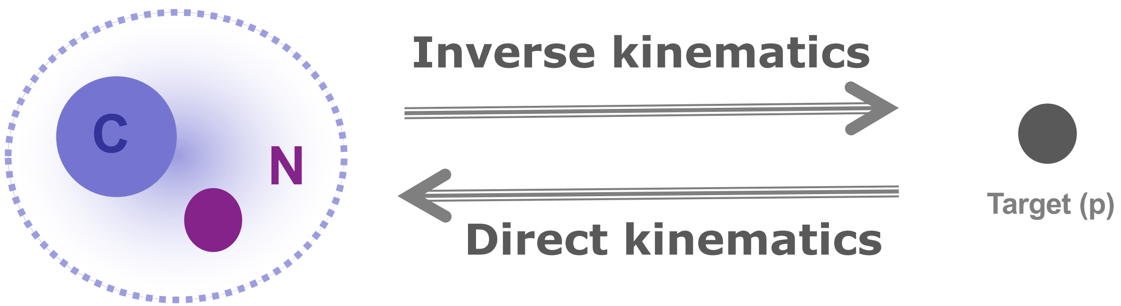
  E. Cravo, R.B. Wiringa, R. Crespo, A.Arriaga, A. Deltuva and M. Piarulli
- Revisit $^{12}C(p,2p)$ at 100 Mev/u (direct kinematics) measured at IUCF

  A. Deltuva, E. Cravo, R. Crespo, D. Jurciukonis, submitted for publication
- Dynamical core excitation signatures in kinematical fully exclusive observables

  E. Cravo, R. Crespo, A. Deltuva
- Perspectives

Motivation

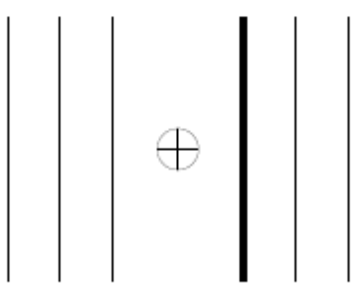
- Truncated Hilbert space



- Spectator core during the scattering process

One-nucleon **spectroscopic overlaps** (its strenght being the **SF**) become the structure input to the reaction formalism.

$$\mathcal{H} = \mathcal{H}_g \oplus \mathcal{H}_x$$

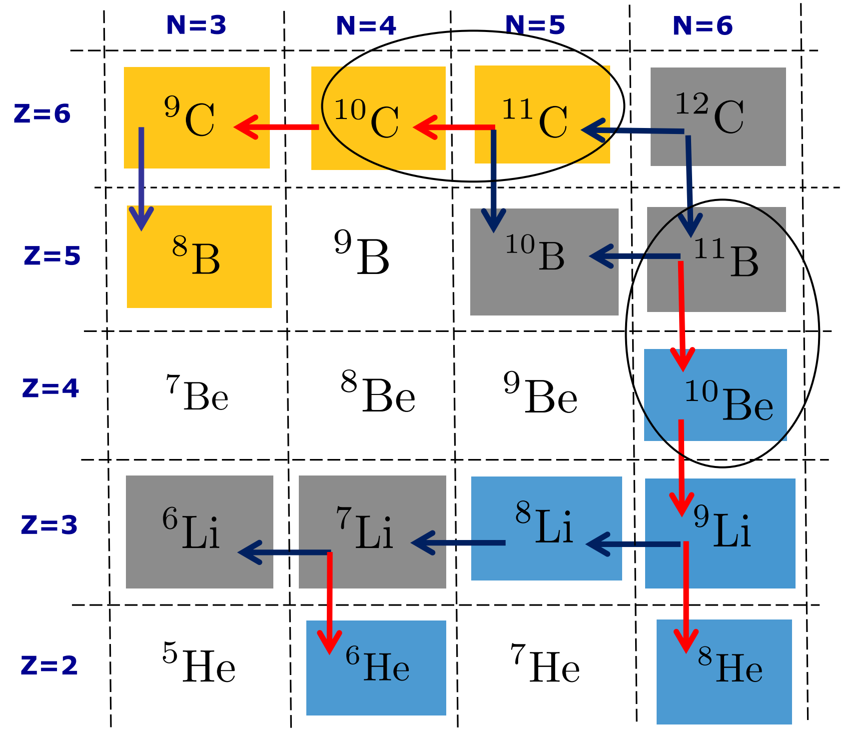


- 2-body DWIA = $\mathcal{R}$ x PWIA
- 3-body Faddeev-AGS (F/AGS)
- 3-Body CDCC, TC,
- ...

Motivation

- Can the *p*-shell spectroscopic quenching obtained from structure and reactions be conciliated **?**
- Can observables for (p,pN) reactions provide unequivocal information about nuclear spectroscopy, testing structure models and their underlying interactions **?**
- What is the role of many-body degrees of freedom **?**

Revisit ^{A}X(p,pN) at 400 MeV/u (inverse kinematics)



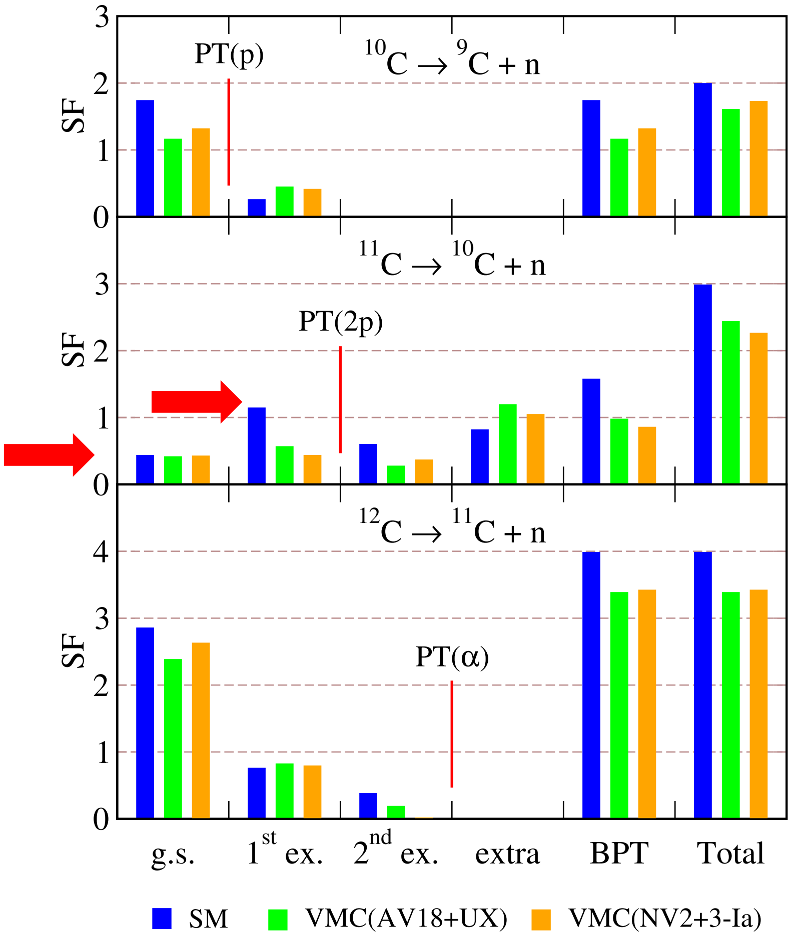
Knockout of a **deficient species nucleon N** (n/p)

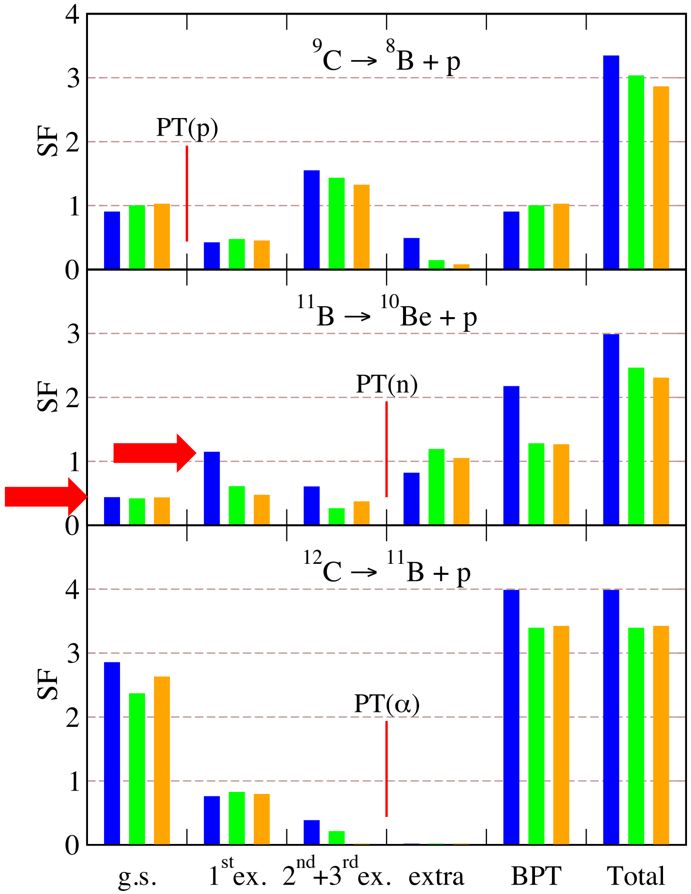
Approach: Merging into the **Fadd/AGS** reaction mechanism the SO overlaps deduced from **Quantum Monte Carlo Techniques (QMC)** using two interactions:

- Argonne V18 two-nucleon and Urbana X three-nucleon potentials (AV18+UX)
- Norfolk NV2+3 Δ-full local chiral field theory

Revisit $^{A}X(p,pN)$ at 400 MeV/u (inverse kinematics)

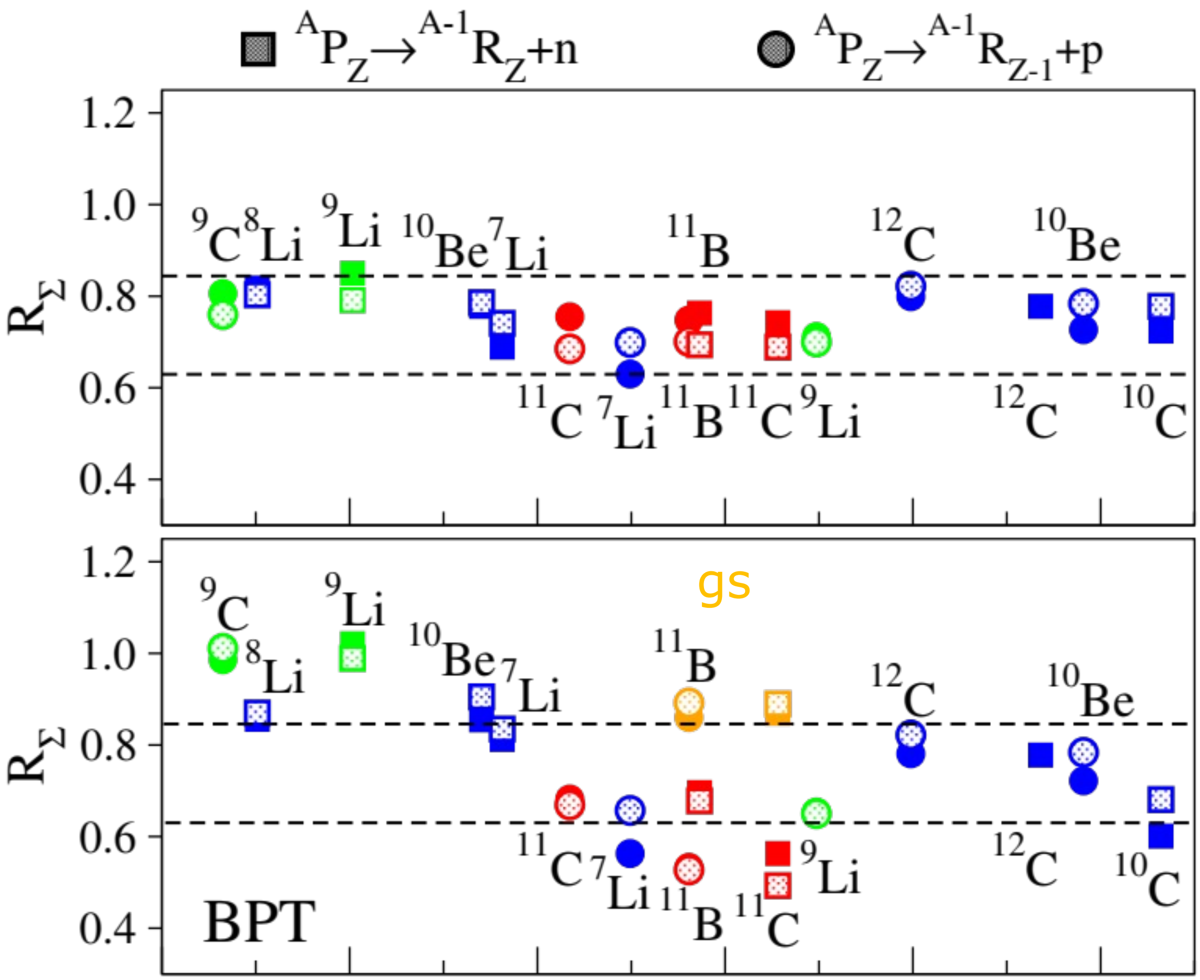
Selected examples and **special cases in mirror transitions**





E.C., R.B.W., R.C., A.A., A.D. and M.P.

Revisit $^{A}X(p,pN)$ at 400 MeV/u (inverse kinematics)



$$\Sigma(\mathcal{M}) = \sum_i Z^i(\mathcal{M})$$

$$R_\Sigma = \frac{\Sigma(\mathrm{QMC})}{\Sigma(\mathrm{SM})}$$

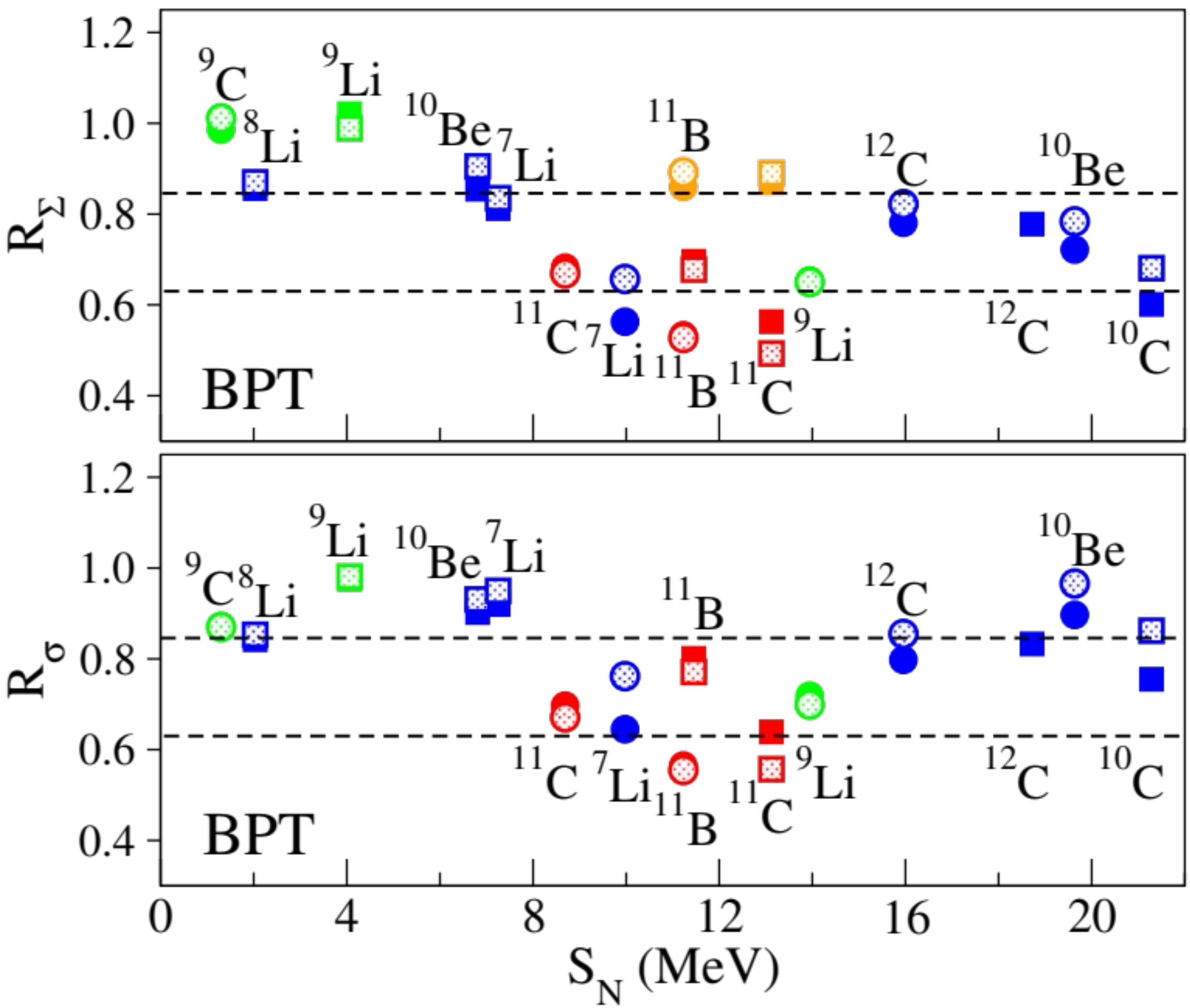
Total sums of SFs

$$R_\Sigma \sim 2/3$$

Sums of SFs that contains the states BPT

E.C., R.B.W., R.C., A.A., A.D. and M.P.

Revisit $^{A}X(p,pN)$ at 400 MeV/u (inverse kinematics)



Sums of cross sections BPT, using the standard Fadeev/AGS reaction formalism

$$\sigma_{\rm th}(\mathcal{M}) = \sum_i Z^i(\mathcal{M})\sigma^i_{\rm sp}(\mathcal{M})$$

$$R_\sigma = \frac{\sigma_{\rm th}(\rm QMC)}{\sigma_{\rm th}(\rm SM)}$$

E.C., R.B.W., R.C., A.A., A.D. and M.P.

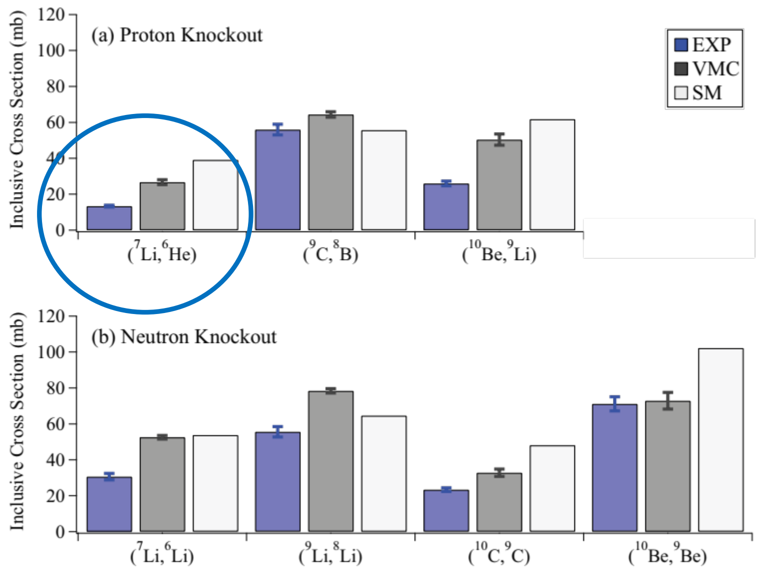
Revisit $^{A}X(p,pN)$ at 400 MeV/u (inverse kinematics)

Reaction	QMC			SM	
	AV18-UX	NV2+3-Ia	NV2+3-Ia*/IIb*	CK	OXBASH [5, 10]
$^{12}C(p,2p)^{11}B$	0.90	0.79	0.99/0.84	0.72	0.60(6)(4)
$^{12}C(p,pn)^{11}C$	1.08	−−	−−	0.90	0.80(9)(7)
$^{11}C(p,2p)^{10}B$	1.34	1.52	−−	0.92	0.86(4)(5)
$^{11}C(p,pn)^{10}C$	1.81	2.08	−−	0.96	1.06(9)(12)
$^{10}C(p,pn)^{9}C$	1.43	1.23	−−	1.08	0.99(13)(9)

$$R_S(\mathcal{M}) = \frac{\sigma_{\text{exp}}}{\sigma_{\text{th}}(\mathcal{M})}$$

The theoretical QMC cross sections **underestimates** the data for ~ factor **2** for **^{11}C(p,pn)**

E.C., R.B.W., R.C., A.A., A.D. and M.P.



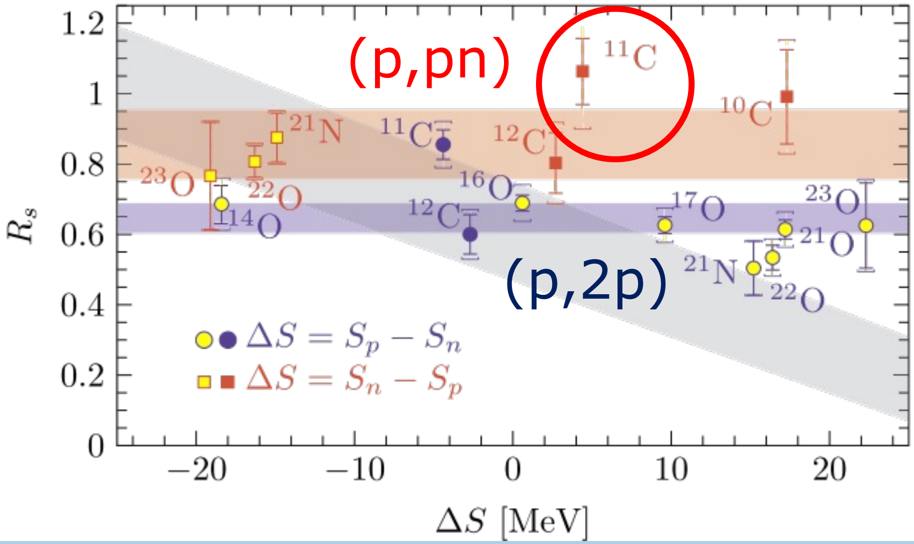
The theoretical QMC cross sections **overestimates** the data for ~ factor **2** for **p removal from ^{7}Li**

G.F. Grinyer, D. Bazin, A. Gade, J.A. Tostevin et al, Pys Rev C 86, 024315 (2012)

Revisit $^{A}X(p,pN)$ at 400 MeV/u (inverse kinematics)

$$R_S(\mathcal{M}) = \frac{\sigma_{\rm exp}}{\sigma_{\rm th}(\mathcal{M})}$$

Reaction	QMC			SM	
	AV18-UX	NV2+3-Ia	NV2+3-Ia*/IIb*	CK	OXBASH [5, 10]
$^{12}C(p,2p)^{11}B$	0.90	0.79	0.99/0.84	0.72	0.60(6)(4)
$^{12}C(p,pn)^{11}C$	1.08	−−	−−	0.90	0.80(9)(7)
$^{11}C(p,2p)^{10}B$	1.34	1.52	−−	0.92	0.86(4)(5)
$^{11}C(p,pn)^{10}C$	1.81	2.08	−−	0.96	1.06(9)(12)
$^{10}C(p,pn)^{9}C$	1.43	1.23	−−	1.08	0.99(13)(9)

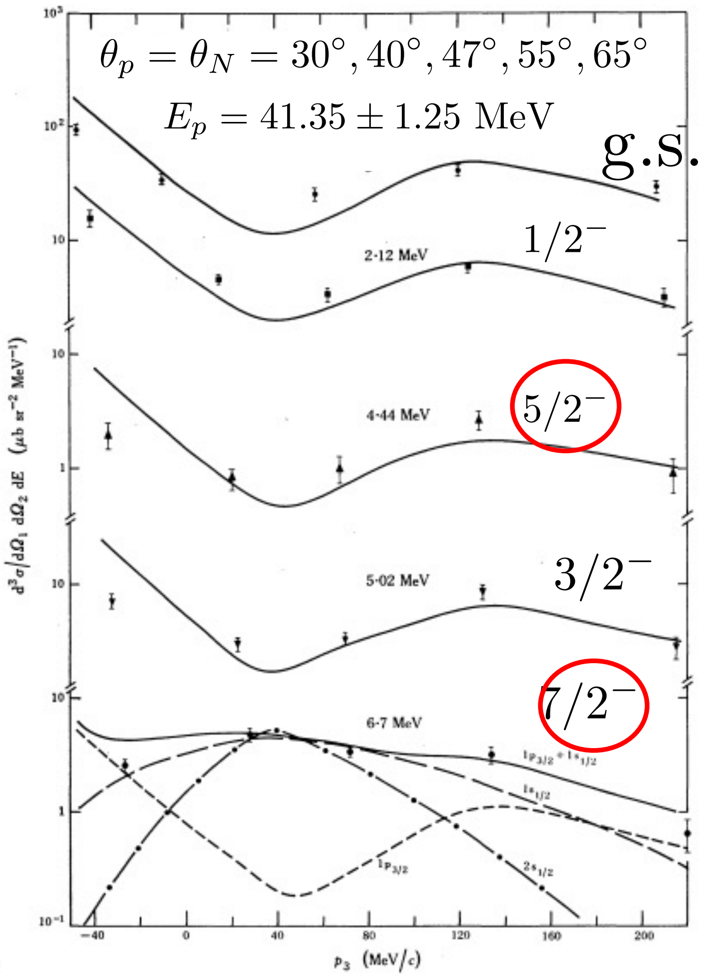


DWIA + SM-OXBAH ~1

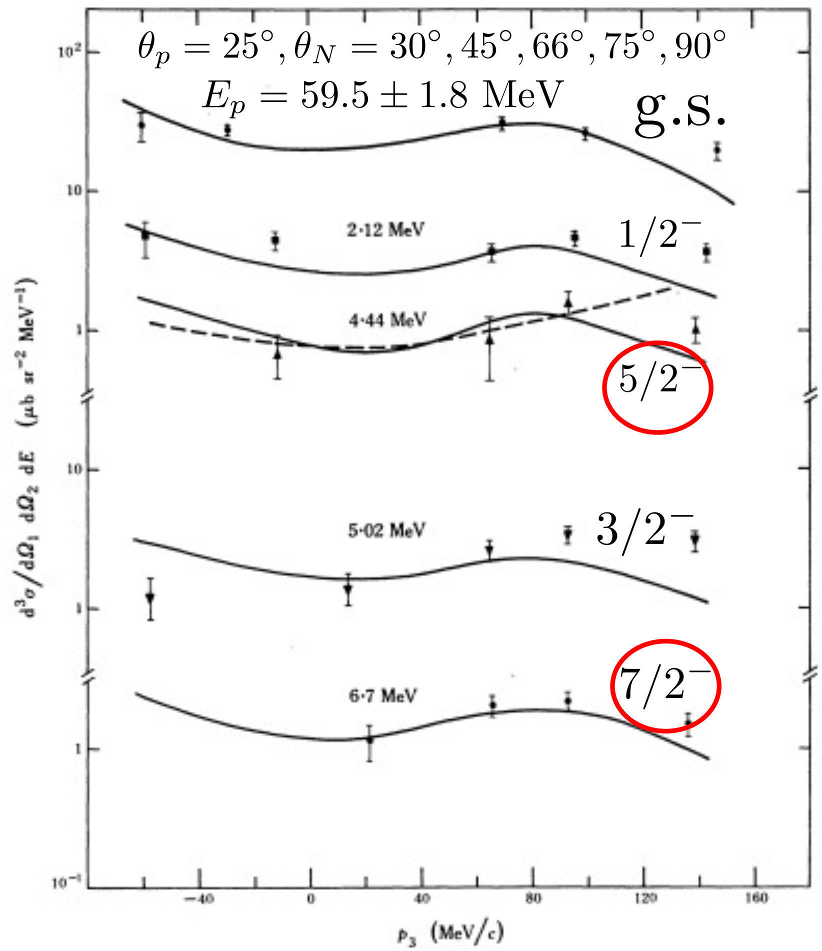
M.Holl, V. Panin, H. Alvarez-Pol, L. Atar, T. Aumann et al, Phys Lett B 795 (2019), 682

Revisit ^{12}C(p,2p) at 100 MeV/u (direct kinematics)

Geometry: coplanar, Symmetric



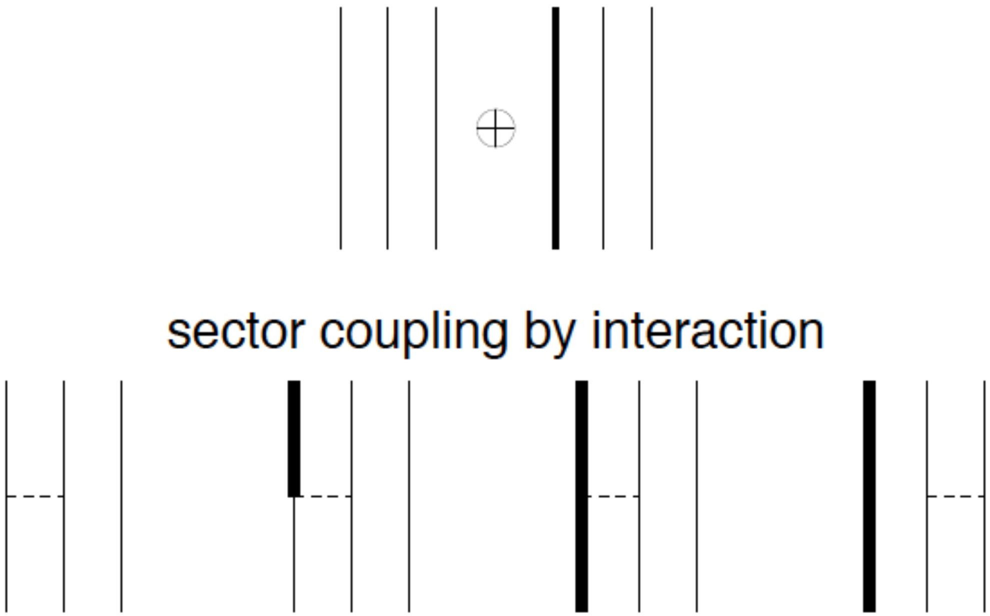
Geometry: coplanar, Asymmetric



Devins et al, Aust. J. Phys 32, 323 (1979)

Revisit $^{12}C(p,2p)$ at 100 MeV/u (direct kinematics)

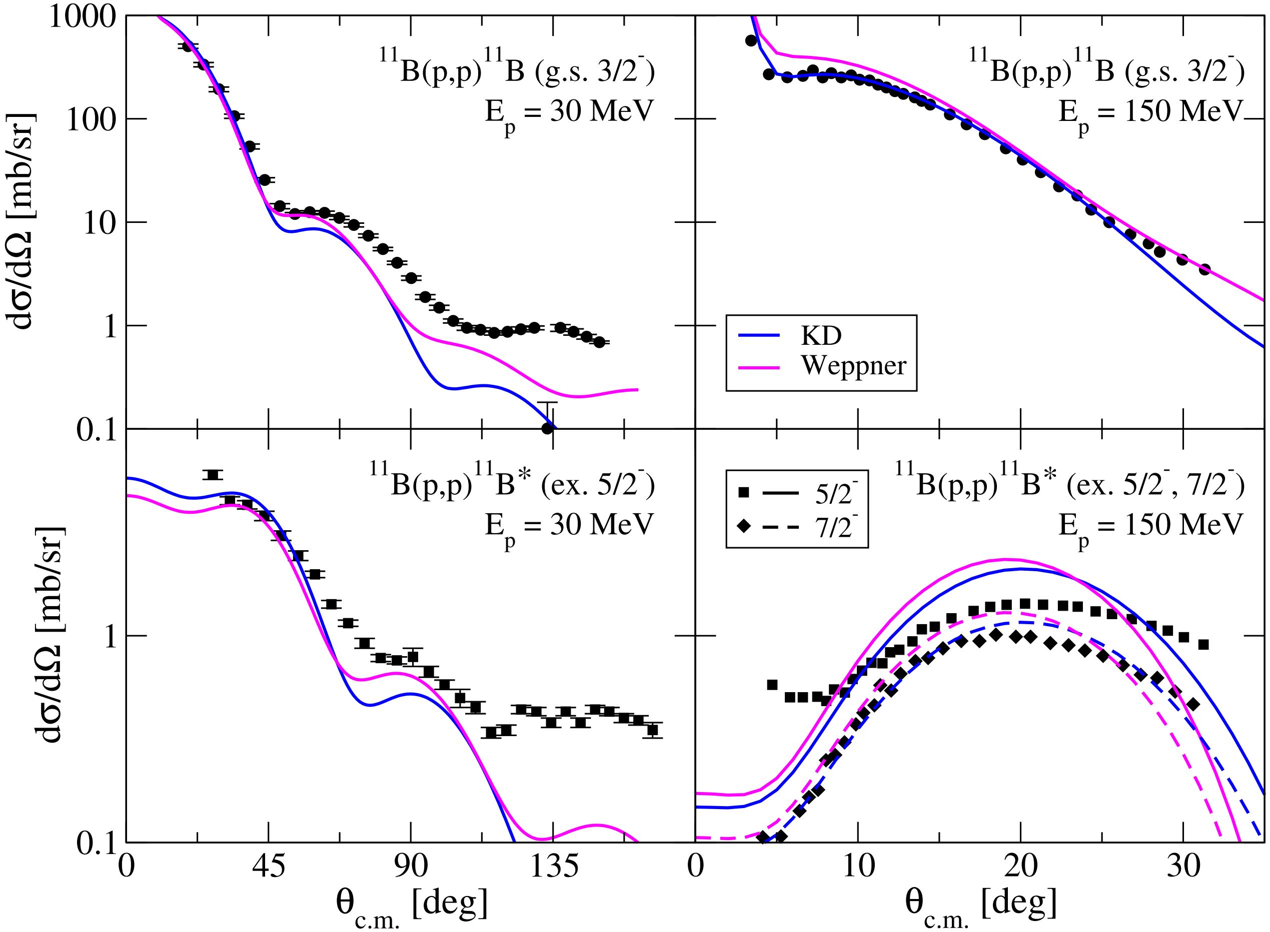
$$\mathcal{H} = \mathcal{H}_g \oplus \mathcal{H}_x$$



The two sectors <u>are coupled</u> by the core – valence nucleon interaction

A. Deltuva, PRC 88, 011601 (R) & A. Deltuva talk

Revisit $^{12}C(p,2p)$ at 100 MeV/u (direct kinematics)



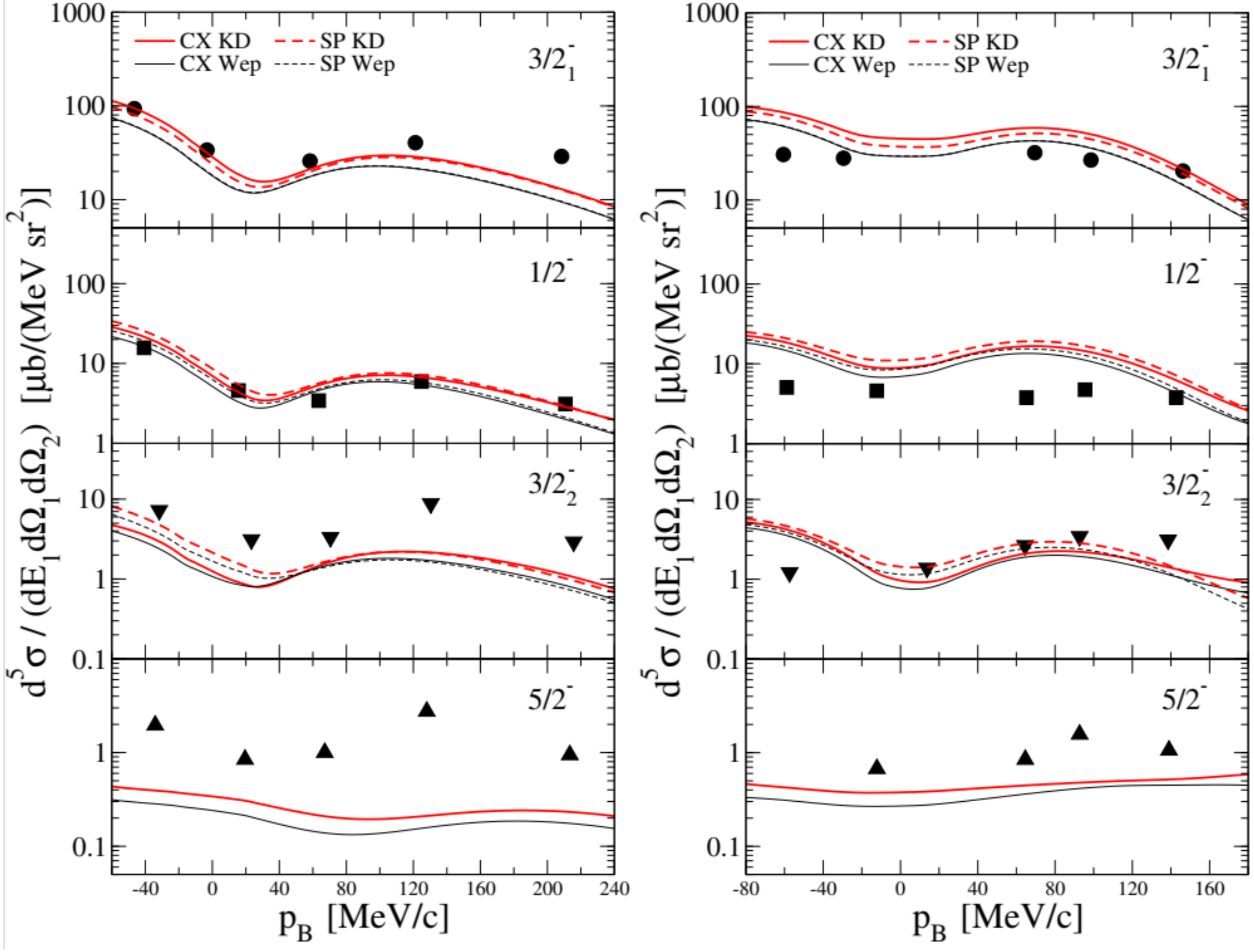
- Data: V.M. Hannen *et al*, Phys ReV C67, 054320 (2003)

A.D., E.C., R.C., D.J.

Revisit $^{12}C(p,2p)$ at 100 MeV/u (direct kinematics)

$\theta_p = \theta_N = 30°, 40°, 47°, 55°, 65°$ $\quad E_p = 41.35 \pm 1.25$ MeV

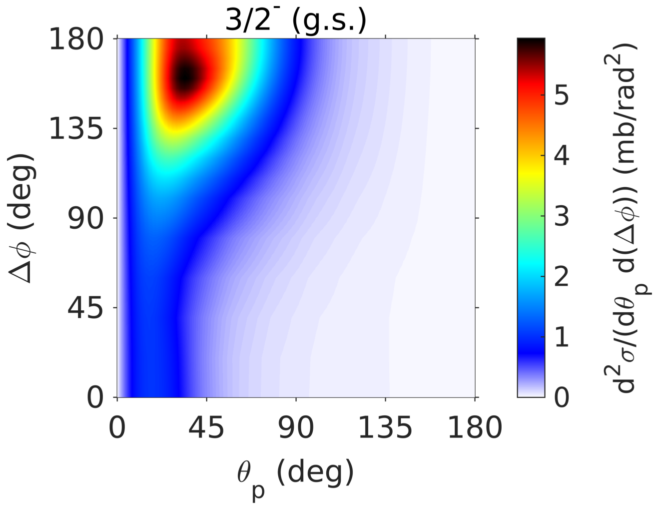
$\theta_p = 25°, \theta_N = 30°, 45°, 66°, 75°, 90°$ $\quad E_p = 59.5 \pm 1.8$ MeV

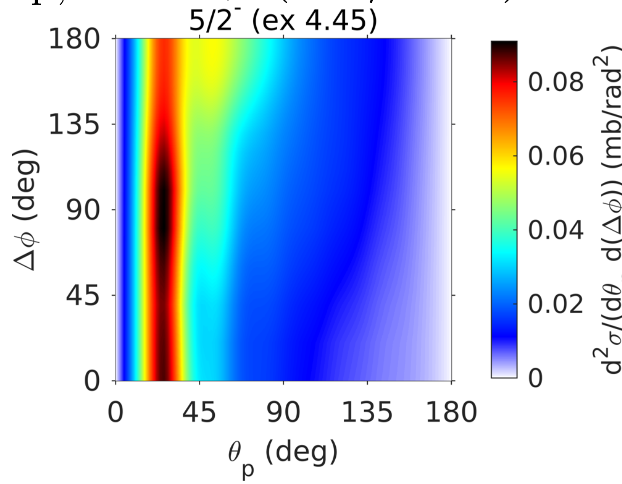


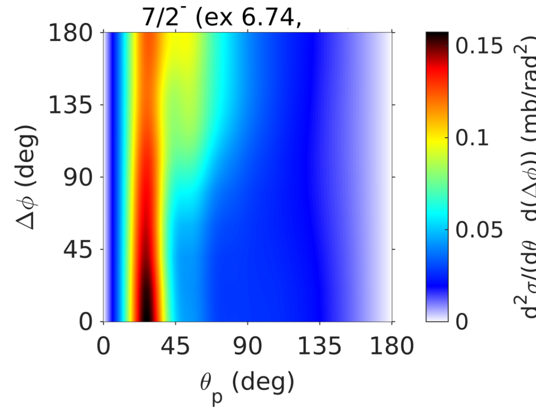
A.D., E.C., R.C., D.J.

Dynamical core excitation signatures

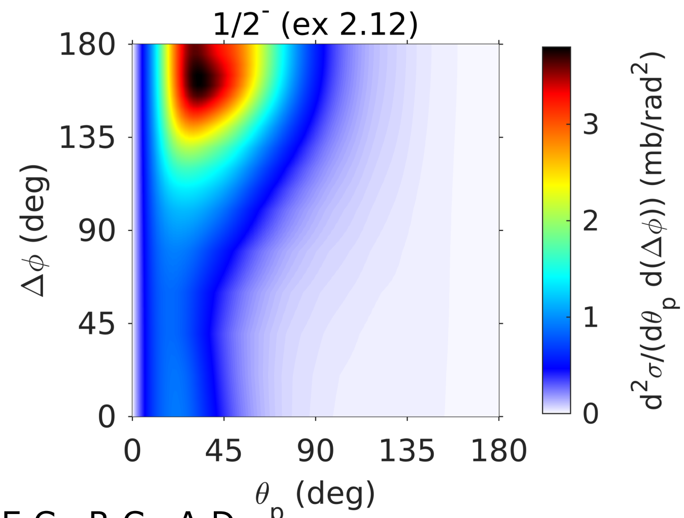
$$d^2\sigma/d\theta_{\mathrm{p,lab}}\, d\Delta\phi \ (\mathrm{mb/rad^2})$$

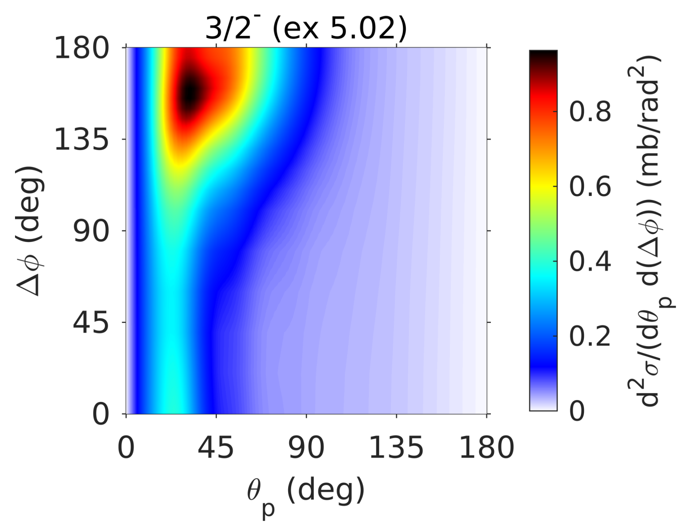






Randon distribution of the measured proton

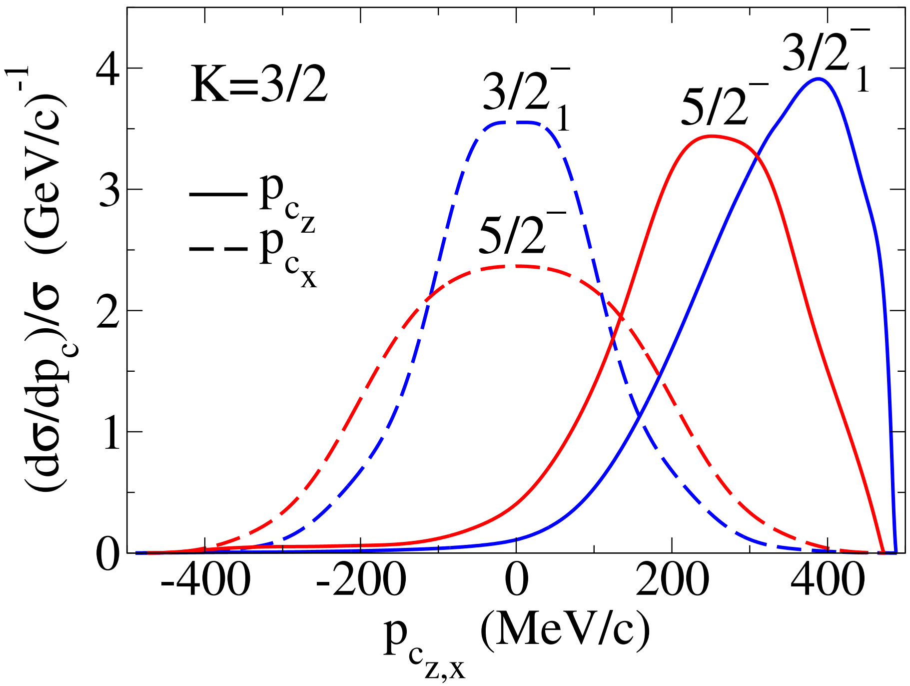




E.C., R.C., A.D.

Dynamical core excitation signatures

Renormalized core momentum distributions for comparison

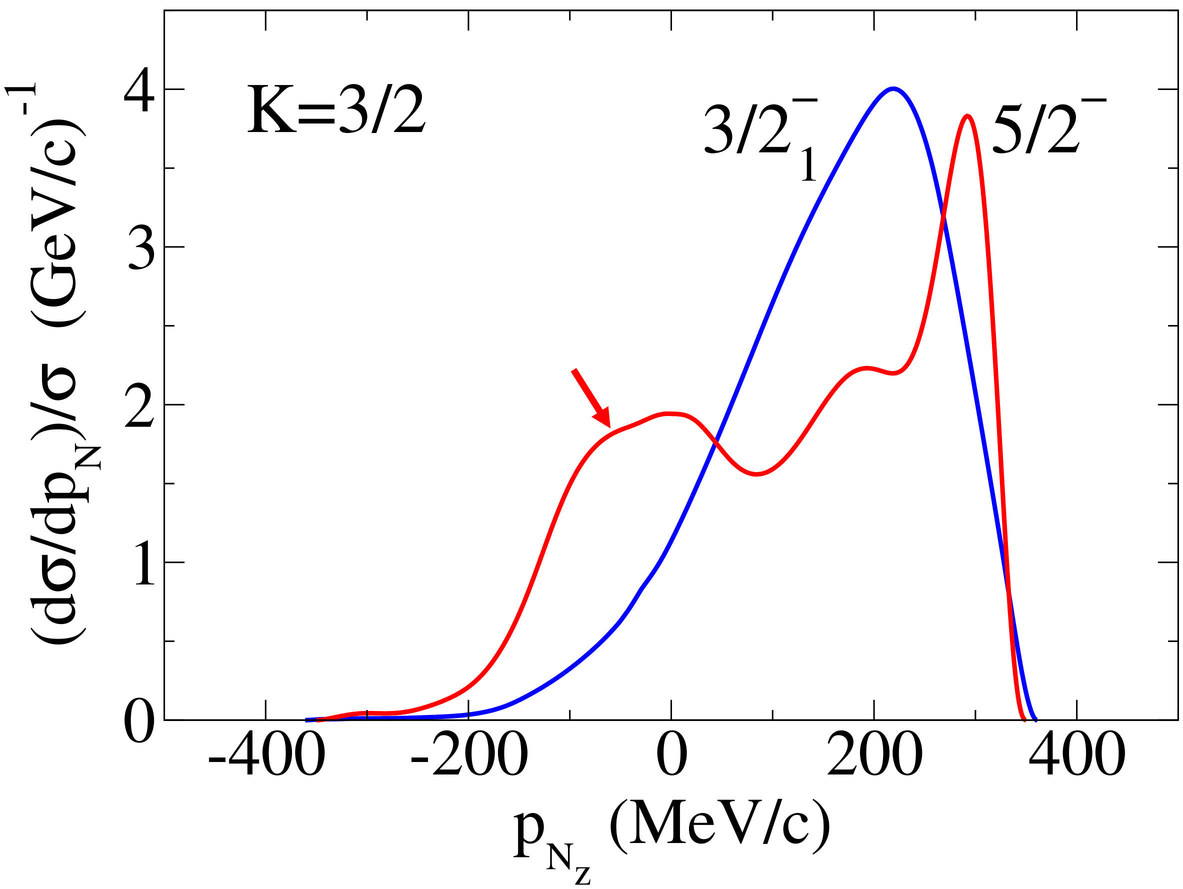


Signature of core excitation:

- The **longitudinal core** momentum distribution peaks at lower momentum
- The **transverse core** momentum distribution is broader

E.C., R.C., A.D.

Dynamical core excitation signatures

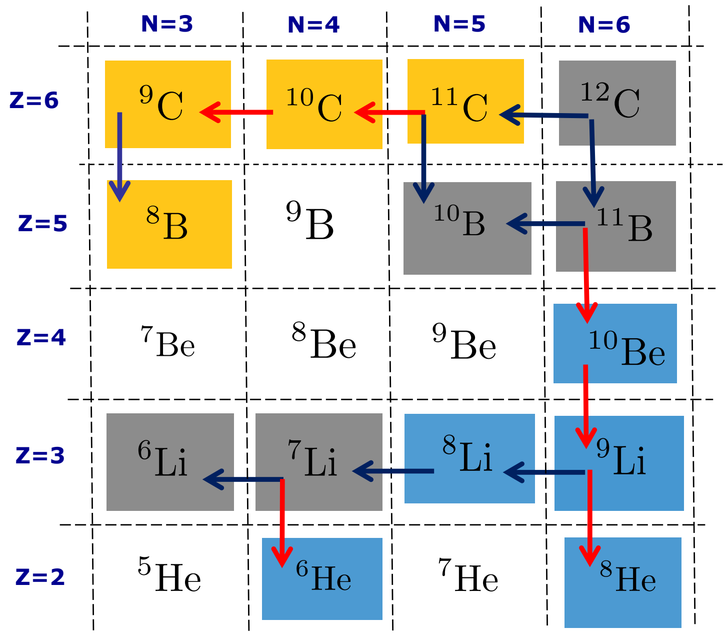


Clear signature of core excitation:

The longitudinal longitudinal nucleon momentum distribution has a **double peak structure**

E.C., R.C., A.D.

Perspectives



Comprehensive theoretical & experimental program of N- knockout with light nuclei (A <= 12)

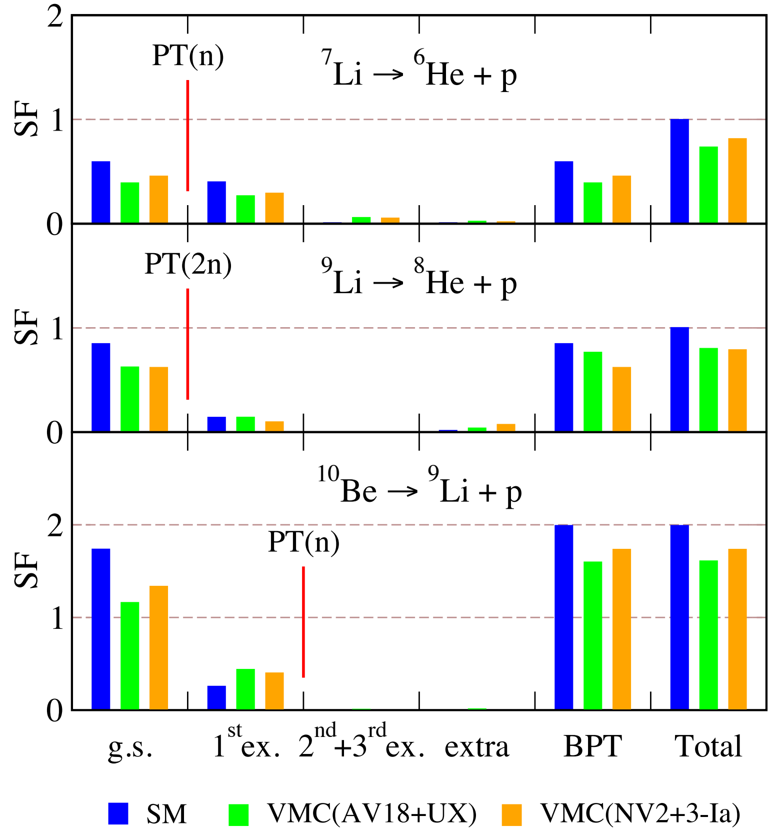
Thank you !

Extra

Extra slides

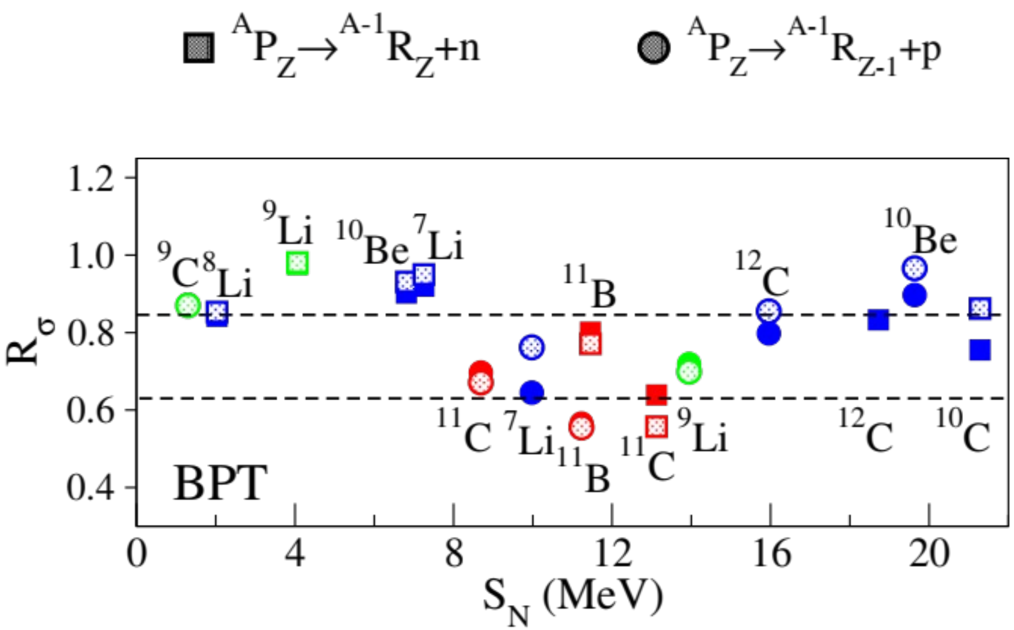
Revisit $^{A}X(p,pN)$ at 400 MeV/u (inverse kinematics)

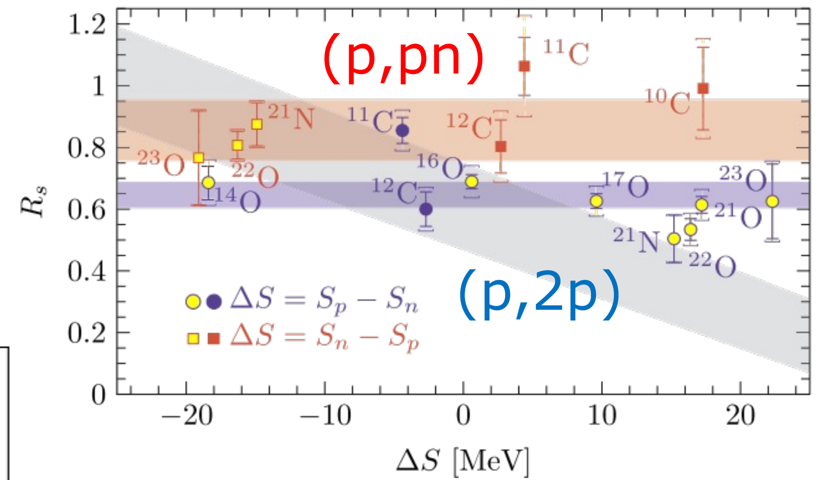
Selected examples and **special cases in mirror transitions**



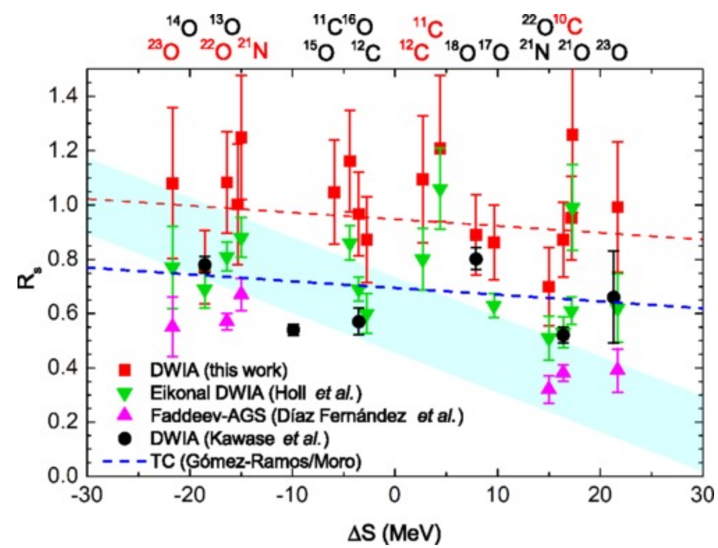
E.C., R.B.W., R.C., A.A., A.D. and M.P.

Revisit $^{A}X(p,pN)$ at 400 MeV/u (inverse kinematics)





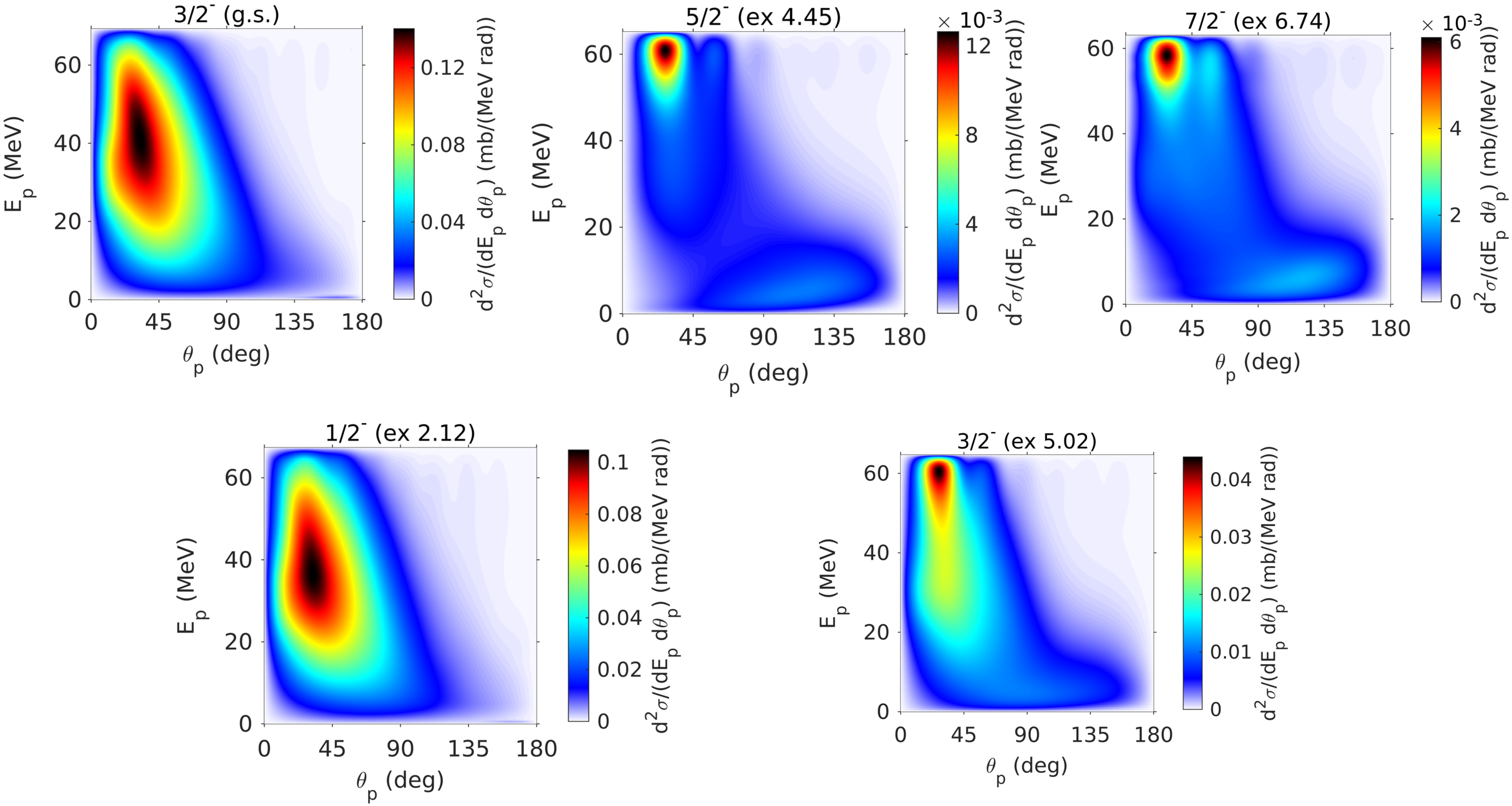
M.Holl, V. Panin, H. Alvarez-Pol, L. Atar, T. Aumann et al, Phys Lett B 795 (2019), 682



Nguyen Tr Toan Phuc, K. Yoshida, K. Ogata, Phys Rev C100, 064604

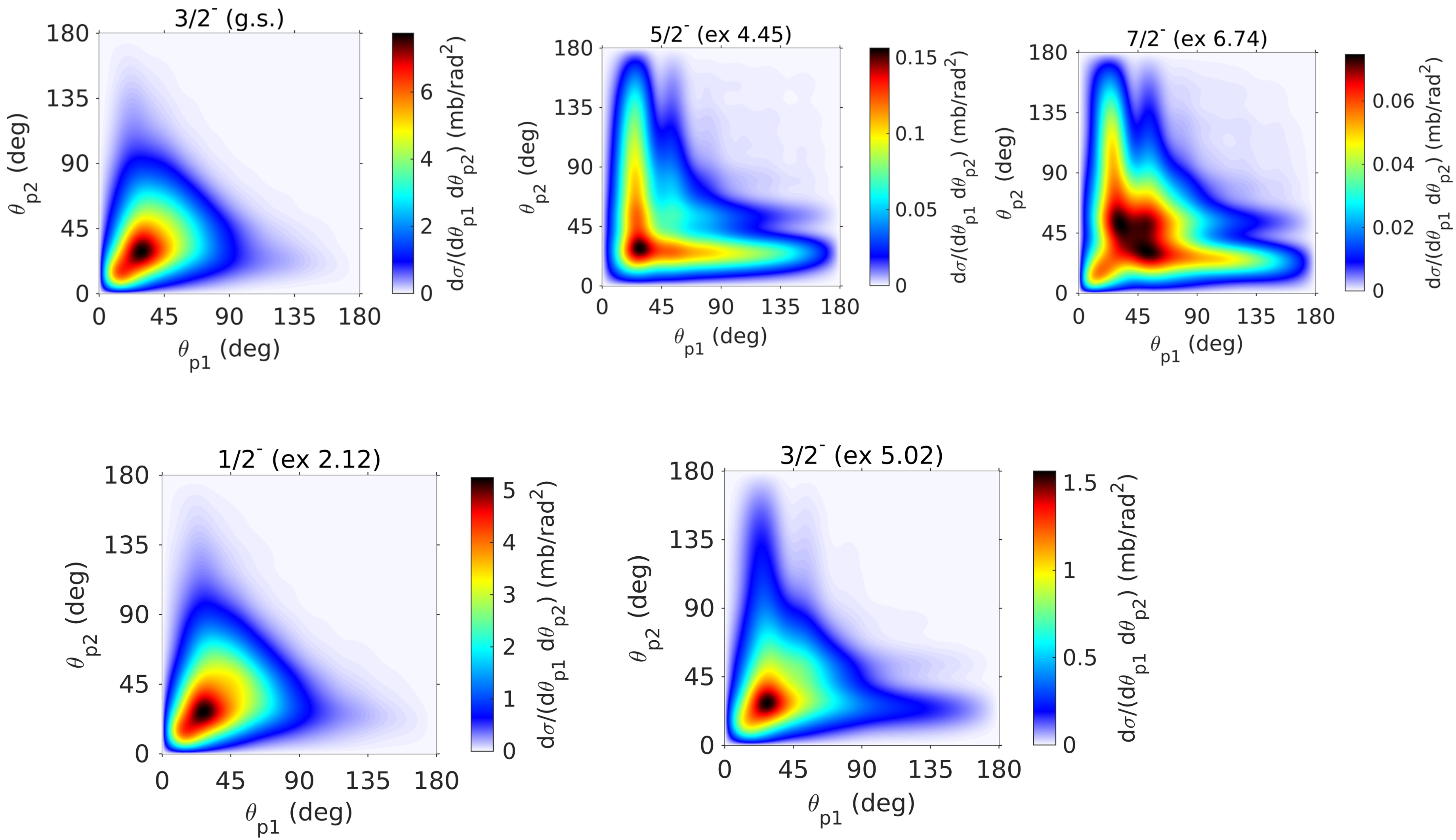
Dynamical core excitation signatures

$$d^2\sigma/dE_{\mathrm{p,cm}}d\theta_{\mathrm{p,cm}}\ (\mathrm{mb/MeV\,rad})$$



E.C., R.C., A.D.

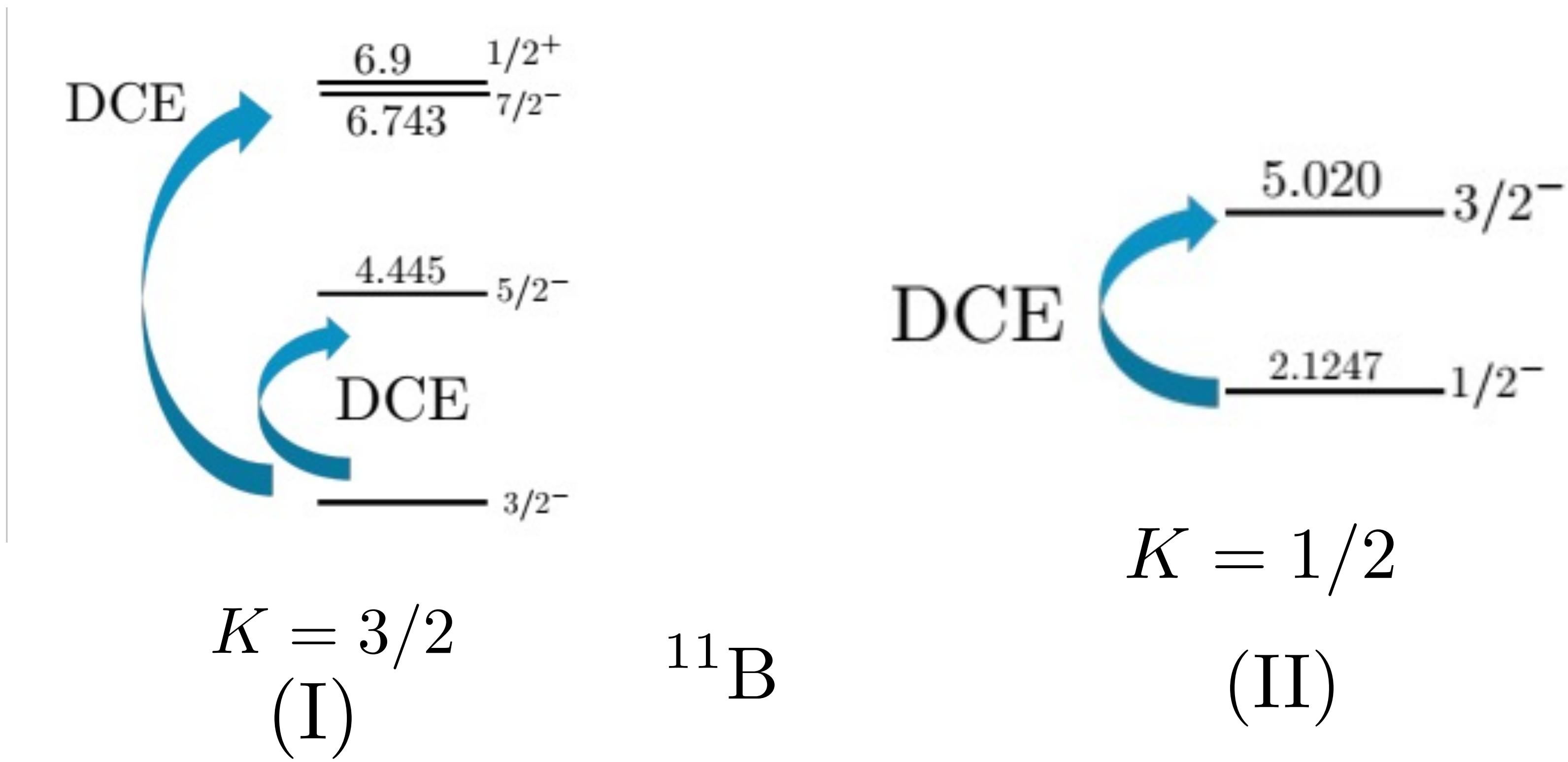
Dynamical core excitation signatures



E.C., R.C., A.D.

Revisit $^{12}C(p,2p)$ at 100 MeV/u (direct kinematics)

Two independent dynamical coupling problems for the scattering process



$$\text{(I)} \qquad |\Phi^{JM}(^{12}\text{C}) > \simeq \; \alpha|3/2^-_1 \otimes p_{3/2}(\pi) >$$

$$\text{(II)} \qquad |\Phi^{JM}(^{12}\text{C}) > = \; \beta|1/2^- \otimes p_{3/2}(\pi) > + \gamma|3/2^-_2 \otimes p_{3/2}(\pi) >$$

Motivation

Geometry: coplanar, Symmetric

$$\theta_p = \theta_N = 30^\circ, 40^\circ, 47^\circ, 55^\circ, 65^\circ$$
$$E_p = 41.35 \pm 1.25 \text{ MeV}$$

Geometry: coplanar, Asymmetric

$$\theta_p = 25^\circ, \theta_N = 30^\circ, 45^\circ, 66^\circ, 75^\circ, 90^\circ$$
$$E_p = 59.5 \pm 1.8 \text{ MeV}$$

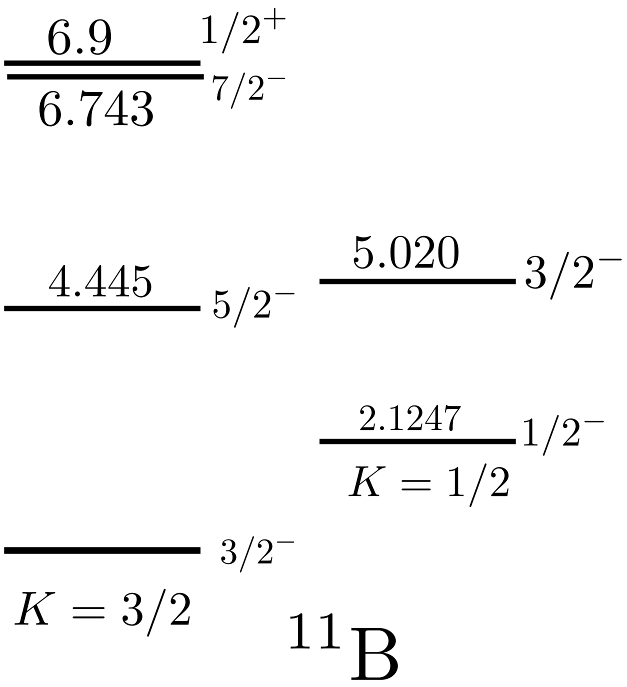
Table 2. Spectroscopic factors obtained from DWIA calculations for ^{11}B states populated in ^{12}C(p, 2p)^{11}B

State of ^{11}B		Spectroscopic factors C^2S				
		Experimental geometry		Theoretical results[A]		
E_x (MeV)	J^π	Symmetric	Asymmetric	CK	S	K
g.s.	$3/2^-$	2·0 ±0·2	1·0 ±0·2	2·85	3·27	2·79
2·12	$1/2^-$	0·33±0·06	0·20±0·05	0·38	0·60	0·79
4·44	$5/2^-$	0·10±0·05	0·11±0·04	—	—	0·0005[B]
5·02	$3/2^-$	0·33±0·1	0·13±0·03	0·75	0·12	0·345
6·74[C]	$7/2^-$	0·06±0·03	0·12±0·04	—	—	0·035[B]
6·79[C]	$1/2^+$	0·05±0·02				

[A] Results from: CK, intermediate coupling calculation of Cohen and Kurath (1967); S, Singh *et al.* (1973); K, Kurath (1968).
[B] These calculations assumed f-wave knockout.
[C] These states were not resolved; see the text for the method of estimating their separate contributions.

Devins et al, Aust. J. Phys 32, 323 (1979)

Motivation



^{11}B is strongly deformed and the low lying states are of rotational nature:

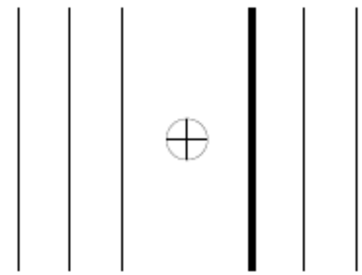
The excitation spectra exhibit na approximate J(J+1) dependence

Revisit ^{12}C(p,2p) at 100 MeV/u (direct kinematics)

$$U_{\beta\alpha} = \bar{\delta}_{\beta\alpha} G_0^{-1} + \sum_{\sigma} \bar{\delta}_{\beta\sigma} T_\sigma G_0 U_{\sigma\alpha}$$

$$U_{0\alpha} = G_0^{-1} + \sum_{\sigma} T_\sigma G_0 U_{\sigma\alpha}$$

$$\mathcal{H} = \mathcal{H}_g \oplus \mathcal{H}_x$$



$$T_\sigma = v_\sigma + v_\sigma G_0 T_\sigma$$ 2-particle Transition operator

$$G_0 = (E + i0 - H_0)^{-1}$$ Free resolvent

channel states $(E - H_0 - v_\alpha)|\phi_\alpha\rangle = 0$

$$H_0|\mathbf{p}_\alpha \mathbf{q}_\alpha\rangle_a = [p_\alpha^2/2\mu_\alpha + q_\alpha^2/2M_\alpha + (m_{A^*} - m_A)\delta_{ax}]|\mathbf{p}_\alpha \mathbf{q}_\alpha\rangle_a$$

Where the extended free Hamiltonian H_0 is the sum of the kinetic energy operator and the intrinsic operator of the core whose contribution is the mass difference relative to the A+p+n treshold

Revisit $^{12}C(p,2p)$ at 100 MeV/u (direct kinematics)

2-particle transition operator, requires the potencials v_σ for each interaction pair

$$T_\sigma = v_\sigma + v_\sigma G_0 T_\sigma$$

- Realistic CD BONN for the np interaction

- **N–Core** and **p-Core** interactions are obtained from a **rotation model for the core with a permanant quadrupole deformation**. In the body-fixed frame, the surface radius is parametrized as

$$R(\hat{\xi}) = R_0[1 + \beta_2 Y_{20}(\hat{\xi})]$$

Input parameter: deformation lenght

Revisit ^{12}C(p,2p) at 100 MeV/u (direct kinematics)

Deformed surface radius $R(\hat{\xi}) = R_0[1 + \beta_2 Y_{20}(\hat{\xi})]$

The N–Core and p-Core interactions are obtained assuming that the interaction follows the deformation of the Core.

That is: starting from a central potential, $V_{xc}^{(0)}(r)$

the X-core (x=N,p) interaction is obtained by **deforming this central interaction**

$$V_{xc}(r,\hat{\xi})) = V_{xc}^{(0)}(r)\left[r - \delta_2 Y_{20}(\hat{\xi})\right] \;;\; \delta_2 = \beta_2 R_0$$

The deformed central interaction is supplemented by a central/deformed spin-orbit term

Input parameter: deformation lenght $\delta_2 = 1.5 \text{ fm}$