

Halo nuclei breakup studies on a proton target around QFS conditions

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Nordic Winter Meeting on Physics @ FAIR

Björkliden

March 24th, 2010

Overview

★ **Neutron halo** breakup under **QFS** kinematical conditions:
Spectroscopic factors

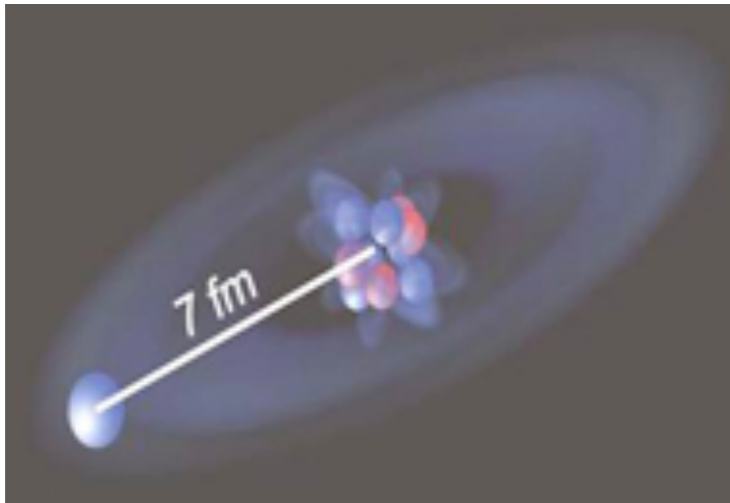
➔ Few-body reaction formalism: **Faddeev/AGS**

★ First case studies at present **R³B**:

➔ ¹⁵C and ¹¹Be

★ Outlook at **FAIR**

Halo nuclei



^{11}Be

Few body systems

$$A = C + n$$

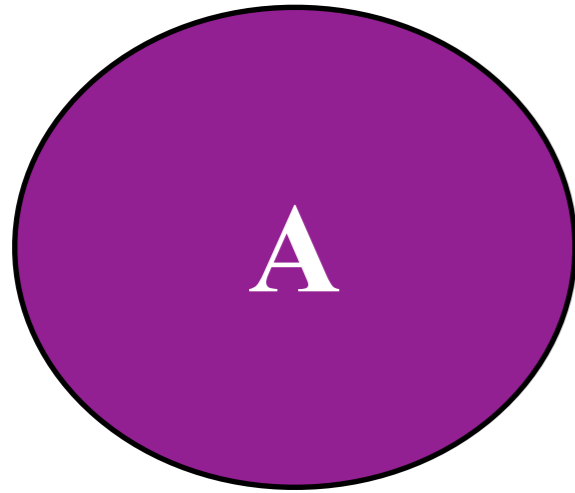
Goal: Extract **Spectroscopic factors** (g.s.)

Tool: Study the breakup process of one neutron halo nuclei
@ QFS using exact three-body reaction theory

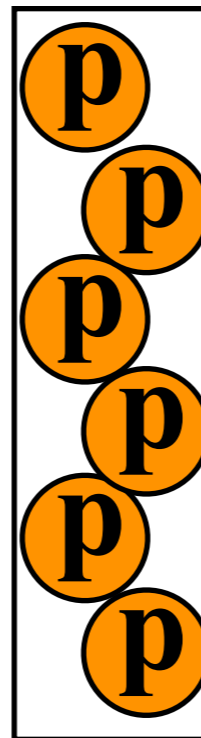
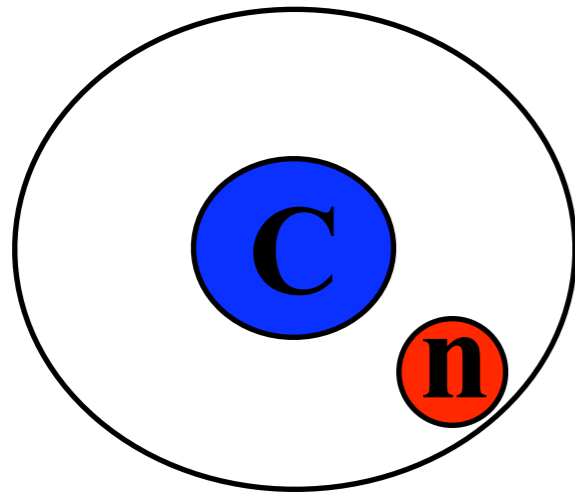
A. Delgado *et al.*, Phys. Rev. C 71 (2005) 054005

R. Crespo *et al.* Phys. Rev. C 79 (2009) 014609

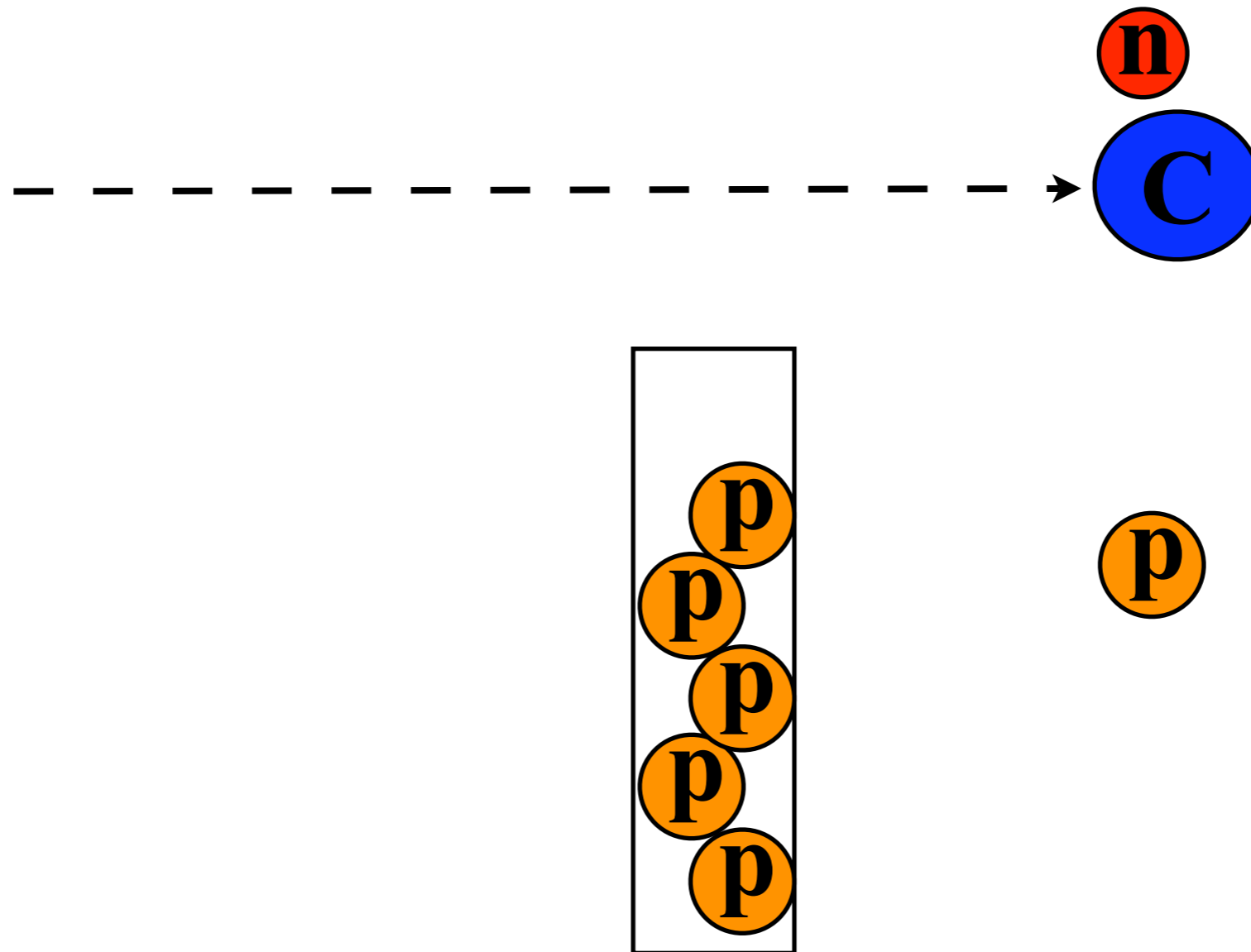
Breakup @ QFS



Breakup @ QFS



Breakup @ QFS



Breakup @ QFS

- 3 particles in the final state:

→ 9 kinematical variables

n

C

- Considering momentum and energy conservation:

→ 5 kinematical variables

p

Fully exclusive cross section:

$$d^5\sigma / d\Omega_C d\Omega_n dS (mb / MeV \cdot sr^2)$$

$$dS = (dE_C^2 + dE_n^2)^{1/2}$$

Semi-inclusive cross section:

$$d^3\sigma / d\Omega_C dE_C (mb / MeV \cdot sr)$$

Inclusive momentum distributions:

$$d\sigma / dp_C^x (mb / MeV / c)$$

Faddeev/AGS formalism

Considering the interaction of **three particles**
by means of **2-body potentials**

Pair transition amplitudes: $t_\gamma = v_\gamma + v_\gamma G_0 t_\gamma$

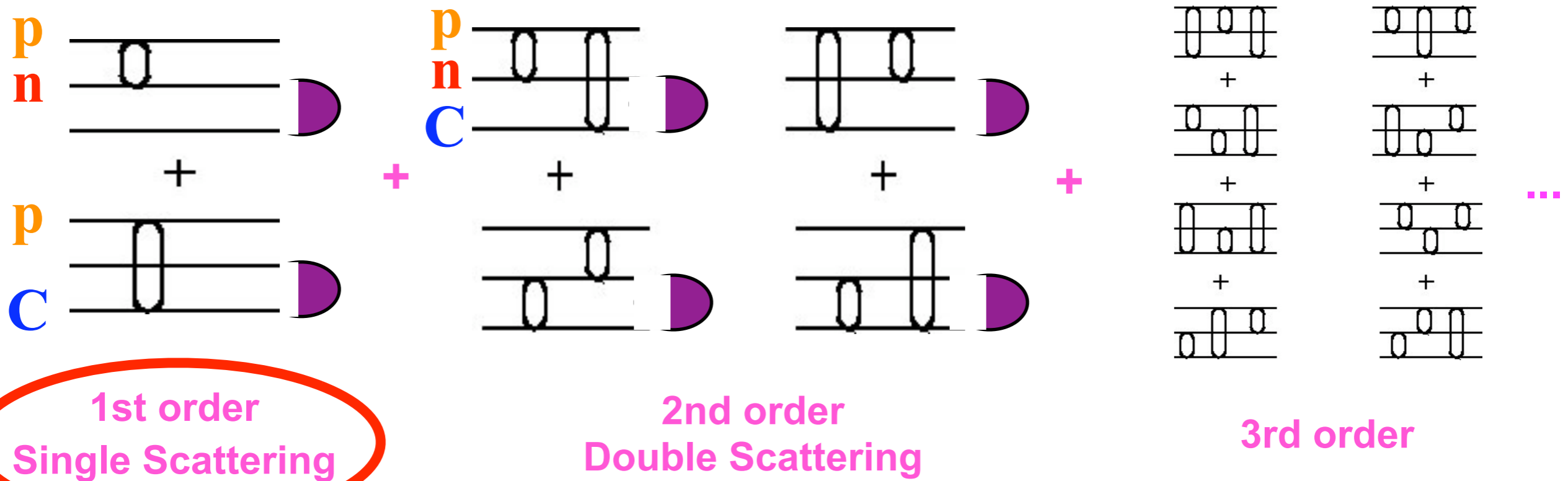
with $G_0 = (E + i0 - H_0)^{-1}$ H_0 Kinetic energy operator
 E Total energy of the system

Faddeev/AGS equations:

Expansion series in terms of pair operators

$$U^{\beta\alpha} = \bar{\delta}_{\beta\alpha} G_0^{-1} + \sum_\gamma \bar{\delta}_{\beta\gamma} t_\gamma G_0 U^{\gamma\alpha} \quad \bar{\delta}_{\beta\alpha} = 1 - \delta_{\beta\alpha}$$

Faddeev/AGS formalism



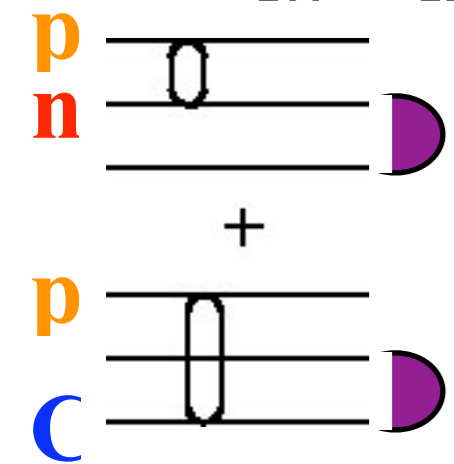
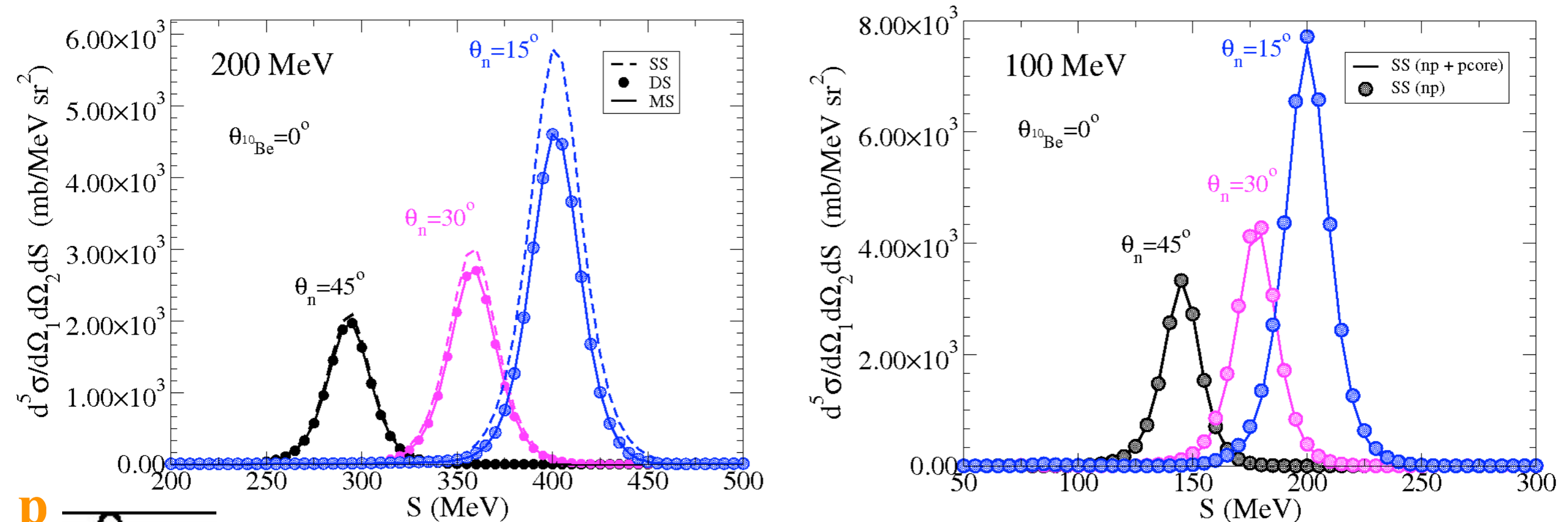
Calculation to the n^{th} order or summing series using Padé

Faddeev/AGS equations

solved in **momentum space** using partial wave decomposition

Moving to QFS conditions

Fully exclusive cross sections
 $^{11}\text{Be}(p,pn)^{10}\text{Be}$

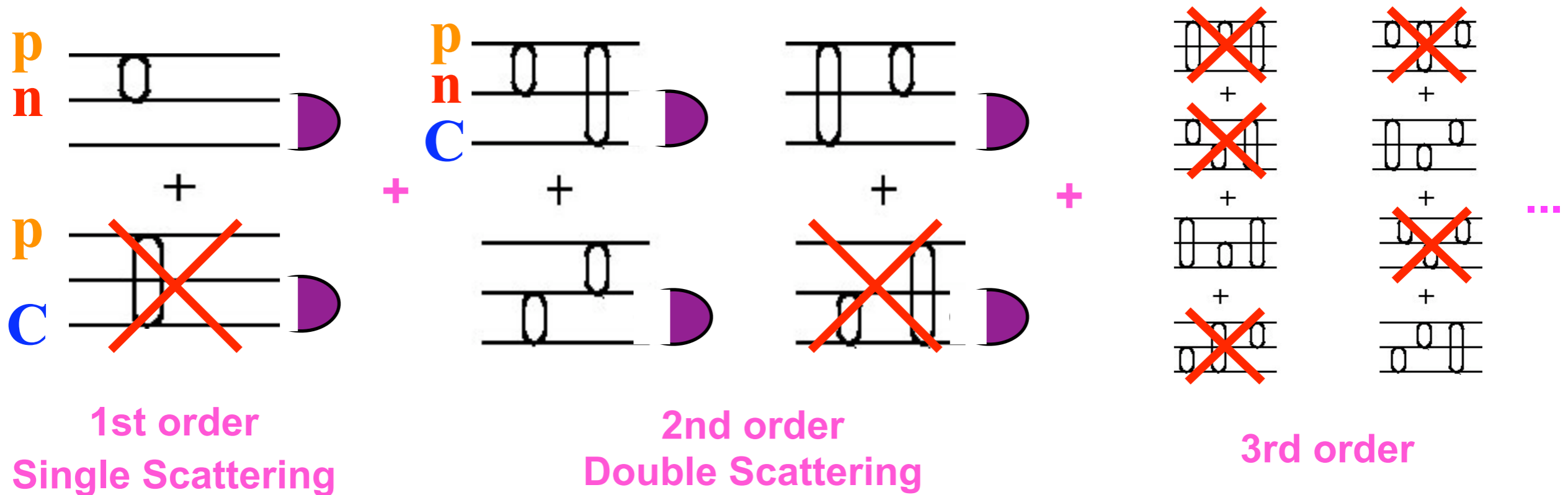


SSA works for fully exclusive!

$$\text{SSA: } t_{pn}(\omega_{pn}) \times \phi_{nC}(q_{nC})$$

unambiguous extraction of Spectroscopic factor

Comparison to DWIA



$A(a, ab)B$

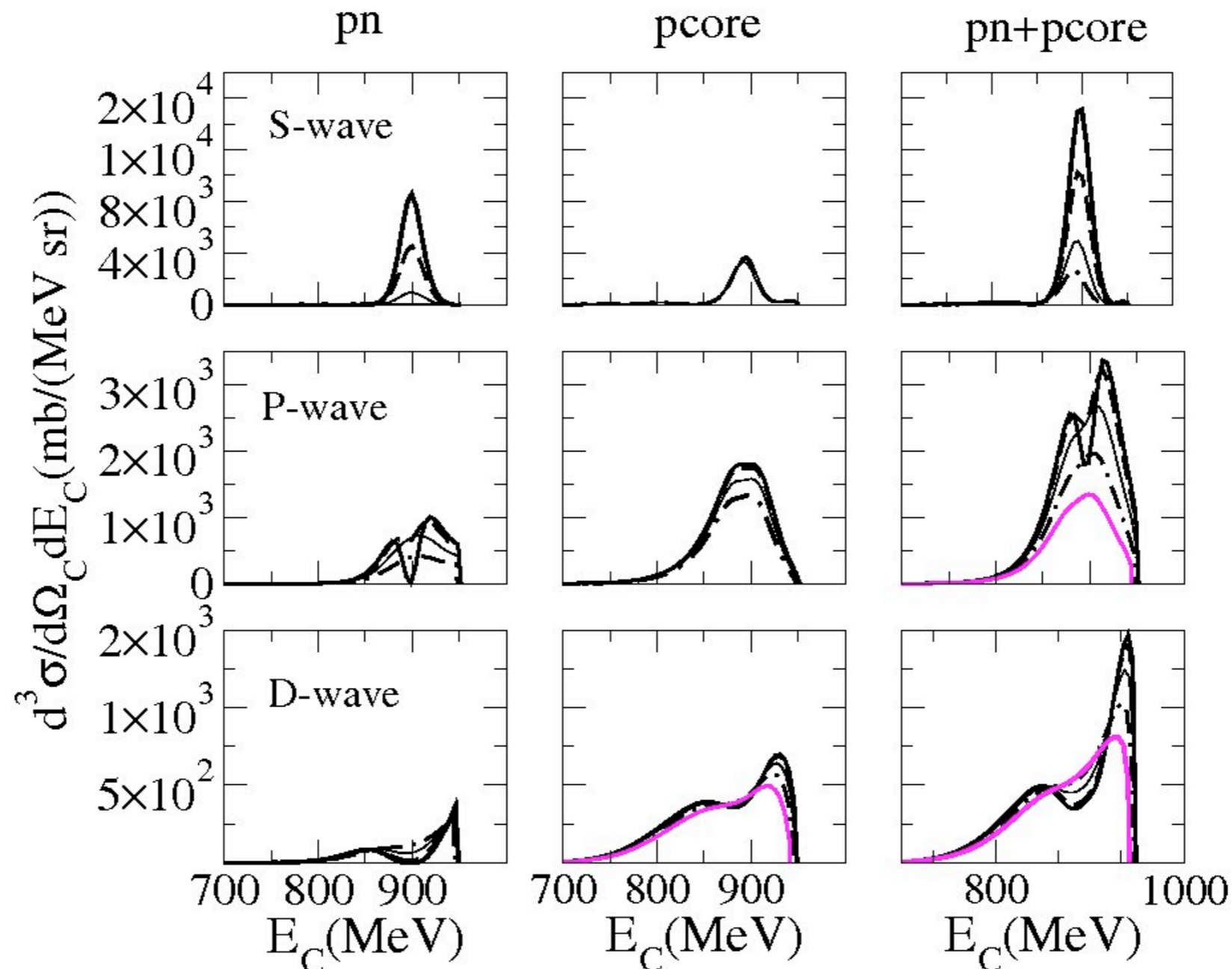
$$\langle \eta_{abB} | t_{ab} | \eta_{Aa} \phi_{bB} \rangle \approx \langle \eta_{aB} \eta_{bB} | t_{ab} | \eta_{Aa} \phi_{bB} \rangle$$

Chant and Ross, Phys. Rev. C 15 (1977) 57

- **Full DWIA:** truncated incomplete series
- **Standard DWIA:** Full DWIA + factorization + on-shell

Comparison to DWIA

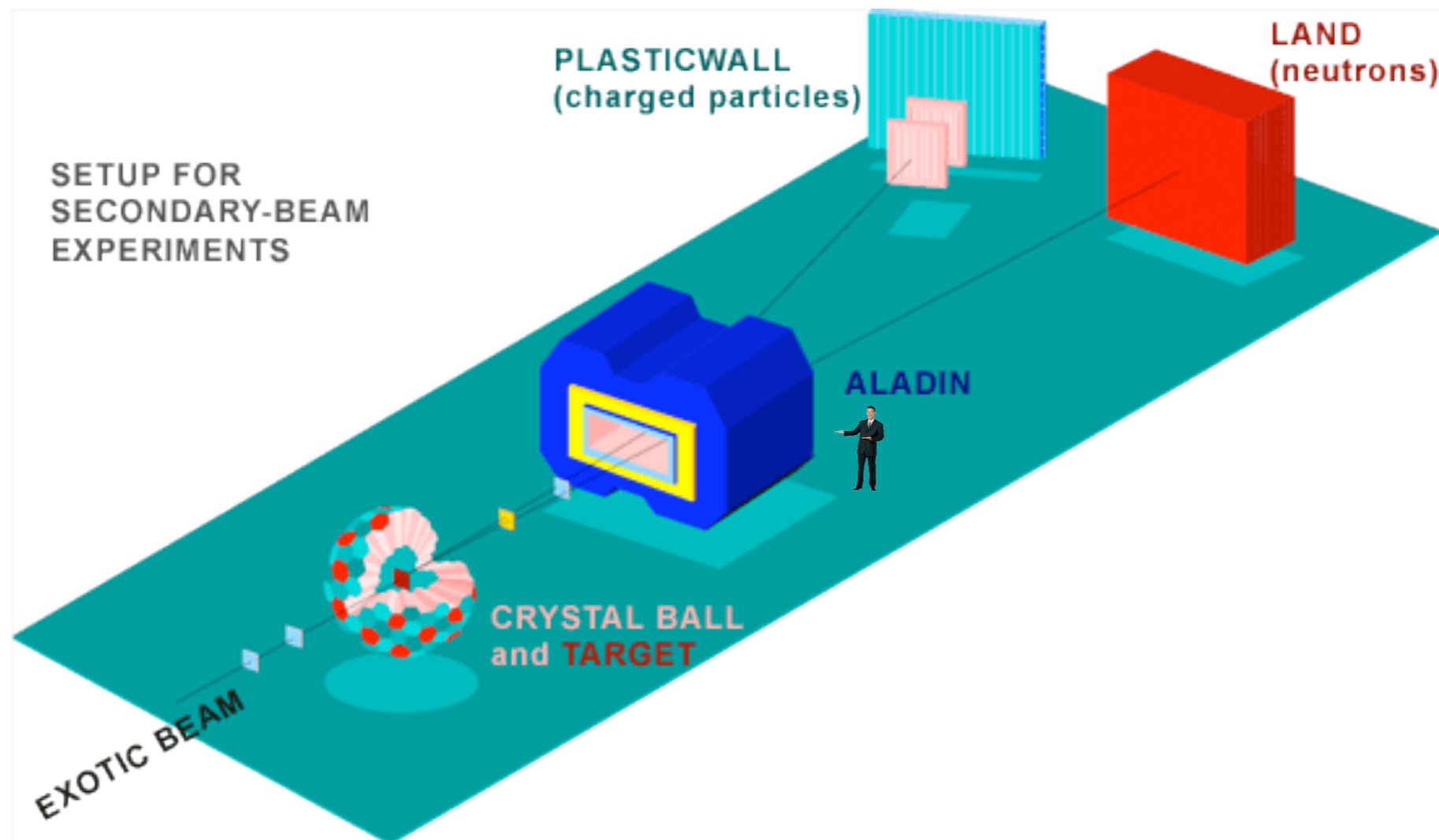
Semi-inclusive $p(^{14}\text{Be}, ^{13}\text{Be})pn$ @ 69 MeV/u



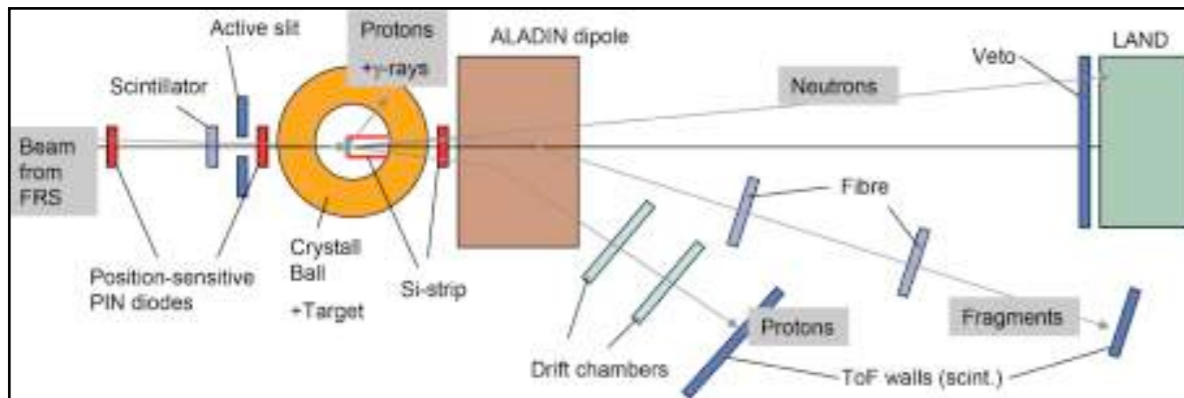
R. Crespo *et al.*, Phys. Rev. C 79 (2009) 014609

QFS @ GSI

Present **R³B** setup (former LAND-ALADIN) @ Cave C



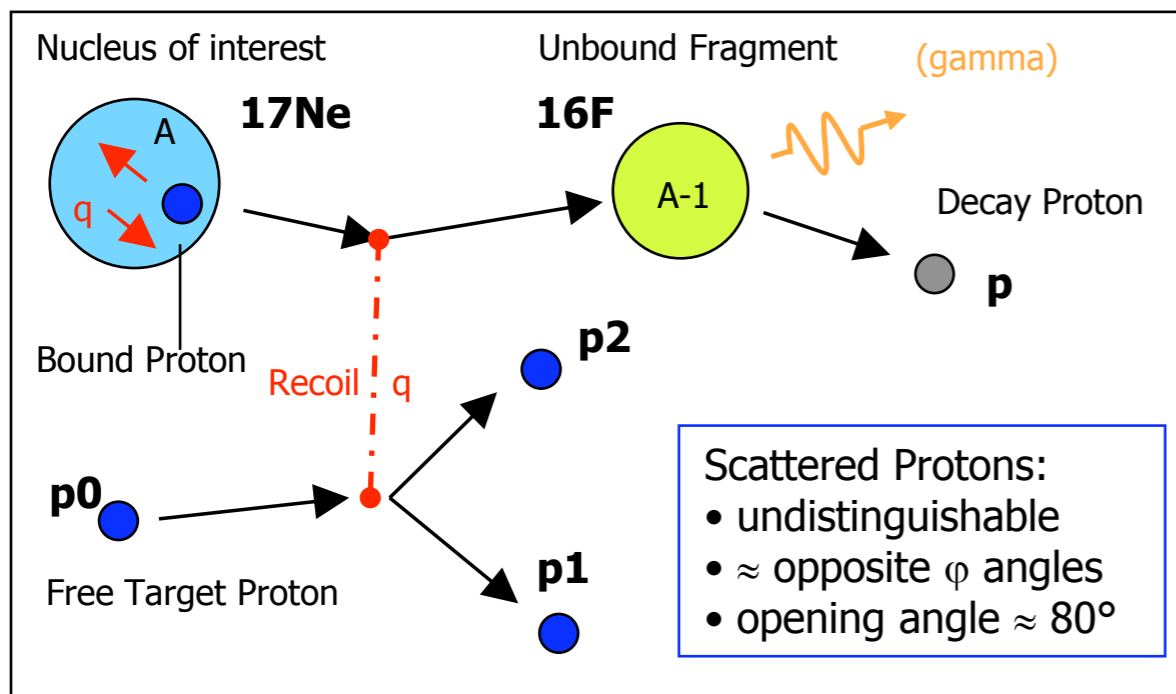
LAND experimental setup



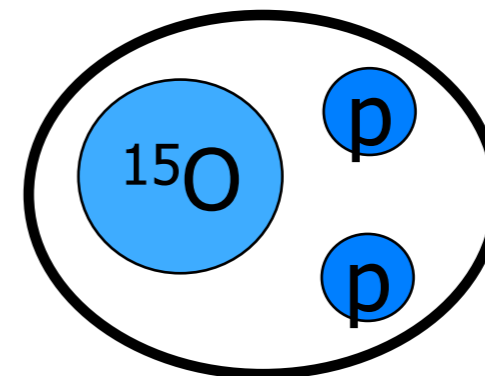
s296: stable ^{12}C beam, C/CH₂ targets

- Benchmark experiment for (p,2p) and (p,pn)
- Confirm nuclear structure knowledge about ^{12}C
- Establish QFS_IK as method for future experiments with radioactive beams

QFS: inv. Kinematics @ 500 A MeV



s318: unstable ^{17}Ne beam, Pb/C/CH₂



- Study of the borromean 2-p-halo (?) nucleus $^{17}\text{Ne} \approx ^{15}\text{O} + 2p$
- Quasi-free 1-proton knockout from 'halo' and core states of ^{17}Ne by a CH₂ target
→ GS wavefunction and spectroscopic factors
- Cross-check QFS results with results by established knockout and Coulomb breakup methods

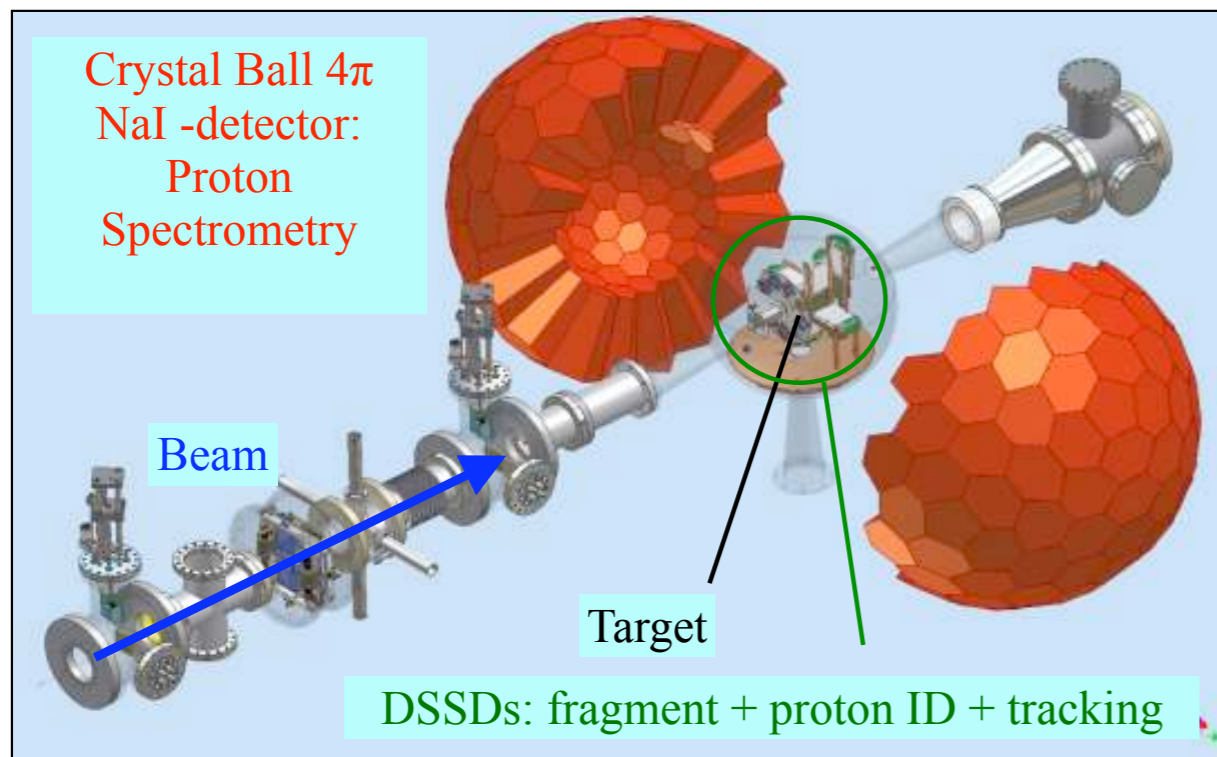
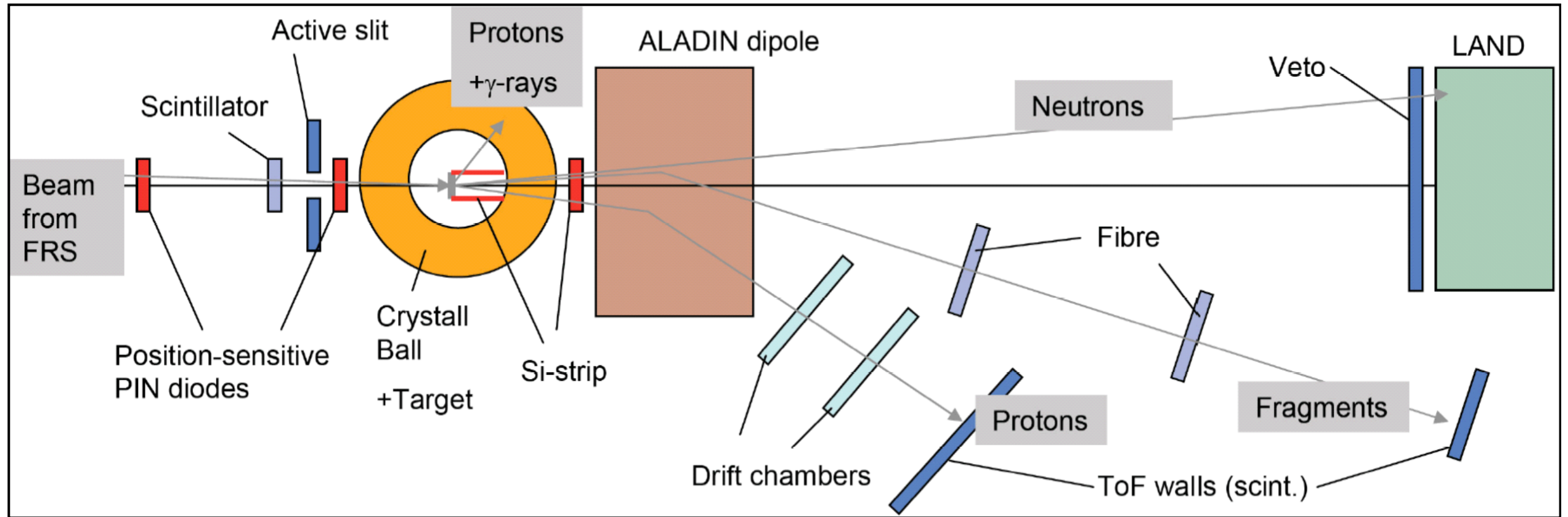
Internal Momentum

$$q = -p_{A-1} = p_1 + p_2 - p_0$$

Separation Energy

$$E_S = T_1 + T_2 + T_{A-1} - T_0$$

Present R³B setup



Capability to measure all reaction products

Measurement of **Fully Exclusive** breakup Cross Section

^{15}C

$$|^{15}\text{C} (1/2^+) \rangle = \mathbf{1} |^{14}\text{C}(0^+) \otimes n2s_{1/2} \rangle$$

Ground State **Spectroscopic factor**

| | | |
|--|-----------------|--|
| $^{14}\text{C}(d,p)^{15}\text{C}$ | 0.99 | J. A. Tostevin <i>et al.</i> , Phys. Rev. C 66 (2002) 024607 |
| | 0.88 | |
| | 1.03 | |
| | 0.76 | |
| $^9\text{Be}(^{15}\text{C}, ^{14}\text{C})X$ | 0.74 ± 0.09 | U. Datta-Pramanik <i>et al.</i> , Phys. Lett. B511 (2003) 63 |
| | 0.84 ± 0.10 | |
| | 0.90 ± 0.10 | |
| ^{15}C Coul. Breakup | 0.73 ± 0.05 | T. Nakamura <i>et al.</i> , Phys. Rev. C 79 (2009) 035805 |
| | 0.97 ± 0.08 | |
| | 0.72 ± 0.05 | |
| | 0.91 ± 0.06 | |

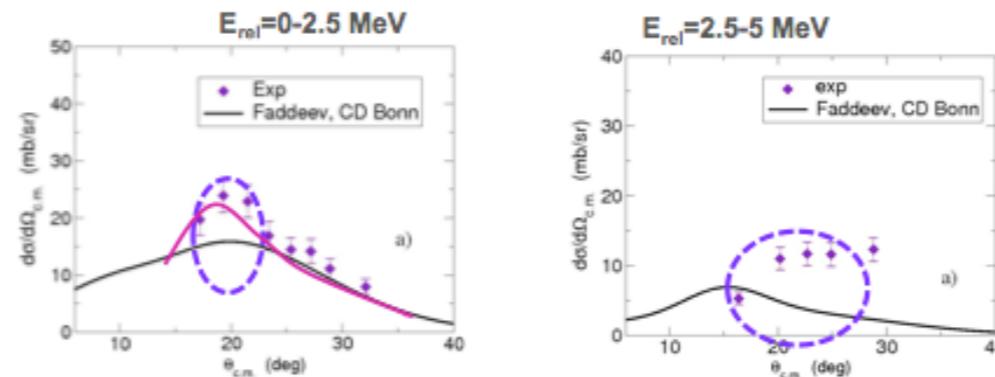
No excitation of the core expected

Very clean case for first

fully exclusive breakup measurement

^{11}Be

Resonant and nonresonant breakup $p(^{11}\text{Be}, ^{10}\text{Be})np$ @ 63.7 MeV/u



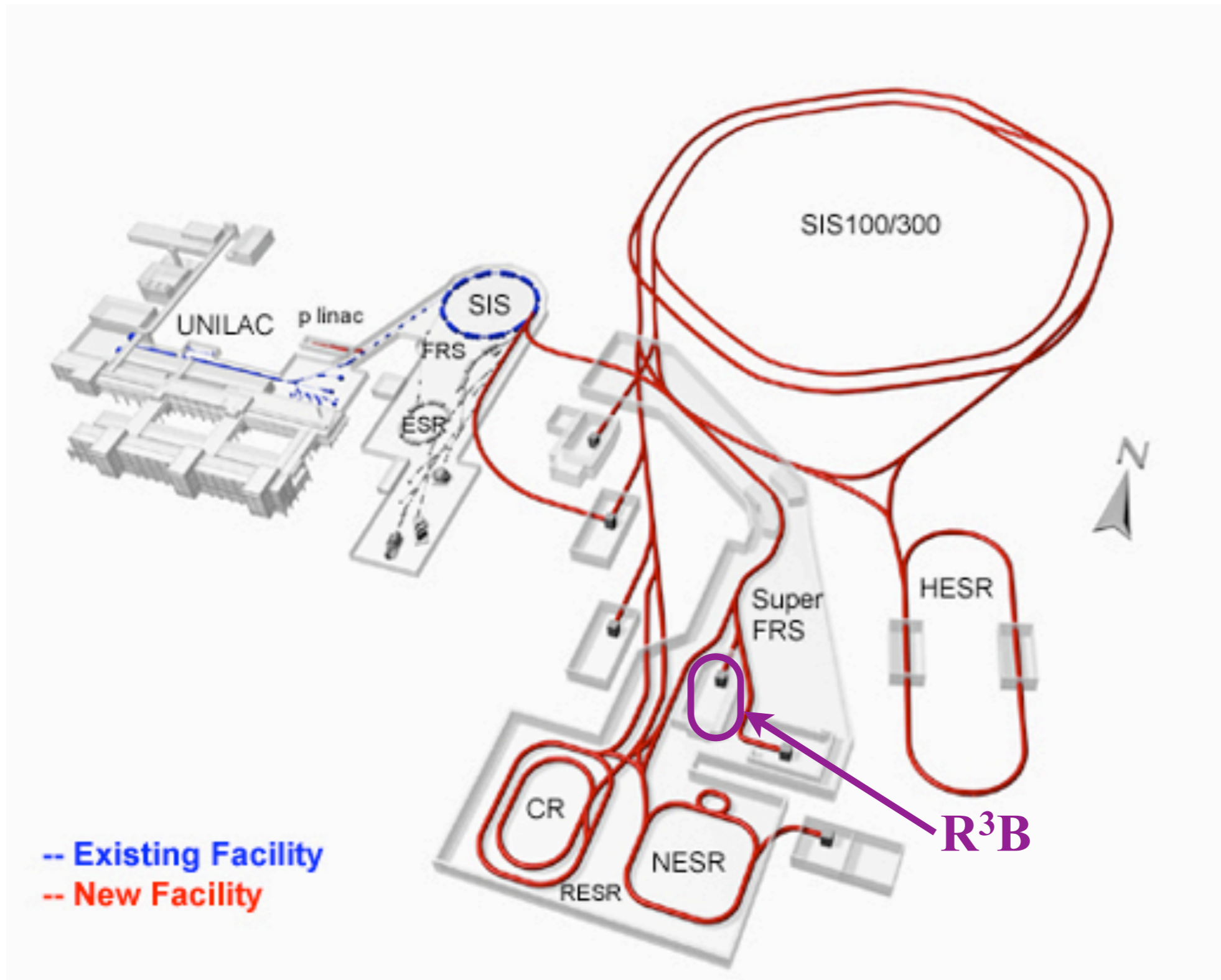
$$|^{11}\text{Be}(1/2^+); \text{gs}\rangle = a |^{11}\text{Be}(0_1^+) \times n2s_{1/2}\rangle + b |^{11}\text{Be}(2_1^+) \times n1d_{5/2}\rangle$$
$$|^{15}\text{C}(1/2^+); \text{gs}\rangle = 1 |^{14}\text{C}(0_1^+) \times n2s_{1/2}\rangle$$

➡ Call for future experiments:
Measurement of breakup $p(^{15}\text{C}, ^{14}\text{C})pn$ @ ~ 70 MeV/u

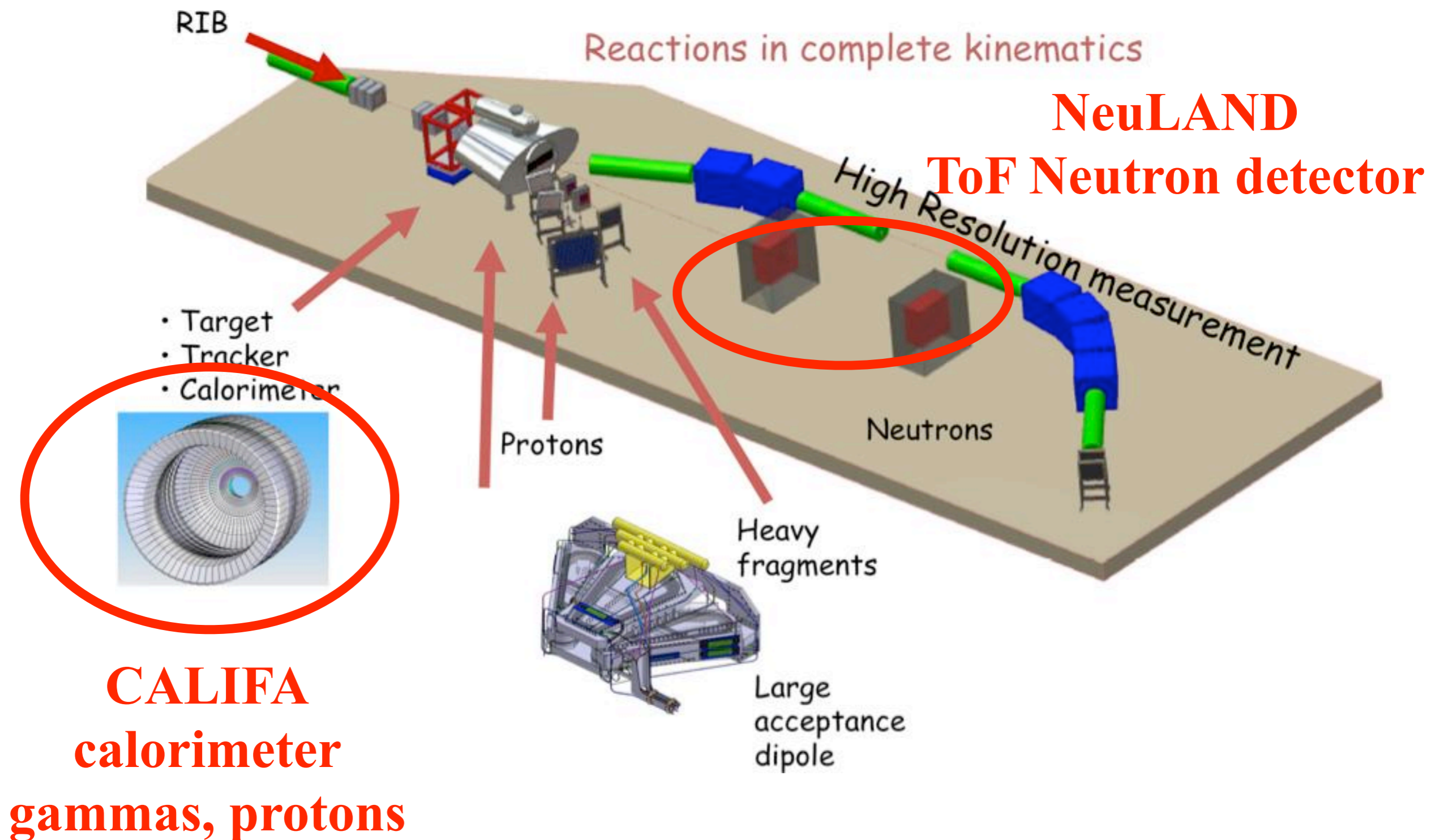
R. Crespo's talk

- Fully exclusive measurement at the R³B setup
- Precise study of possible core excitation contributions

R³B @ FAIR



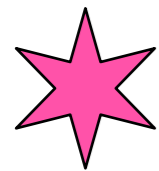
R³B @ FAIR



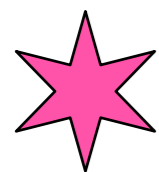
Summary



Tool to extract Spectroscopic factors:
QFS @ R³B setup



Formalism: Faddeev/AGS



First case studies this Summer at GSI: ¹⁵C & ¹¹Be

QFS People @ Lisbon

P. Velho

A. Henriques

D. Galaviz



E. Cravo

R. Crespo

A. Deltuva

A. Fonseca

Thank you!