Halo structure by the ratio method

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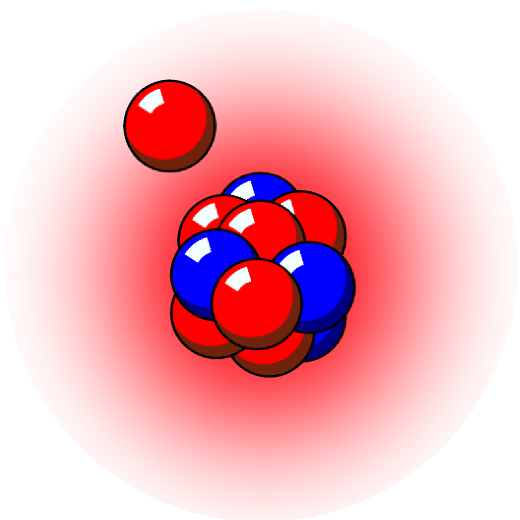
Halo nuclei



- Very neutron-rich nuclei that exhibit a large matter radius and a low separation energy of one or two neutrons.
- Seen as a *core* surrounded by one or two loosely-bound neutrons which form a sort of *halo*.

  Examples: ^{11}Be, ^{15}C (one-neutron halo), ^{6}He, ^{11}Li (two-neutron halo)
- Studied through *reactions* (e. g. elastic scattering, breakup,...)

  ⇒ need an accurate theoretical description of those reactions and/or observable insensitive to reaction process.

Angular distributions

Angular distributions for elastic scattering and breakup are very similar [1].
⇒ projectile scattered similarly whether bound or broken up
This can be explained within the Recoil Excitation and Breakup model [2], which

- assumes an adiabatic treatment of the projectile excitation
- neglects the interaction V_{nT} between the halo neutron and the target

⇒ excitation and breakup of the projectile due to the recoil of the core.
REB predicts for elastic scattering

$$\frac{d\sigma_{el}}{d\Omega} = |F_{00}|^2 \left(\frac{d\sigma}{d\Omega}\right)_{pt} \quad (1)$$

with $F_{00} = \int |\Phi_0|^2 e^{i\boldsymbol{Q}\cdot\boldsymbol{r}} d\boldsymbol{r}$ where $\boldsymbol{Q} \propto (\boldsymbol{K} - \boldsymbol{K}')$
⇒ scattering of a composite nucleus ≡ form factor × scattering of a pointlike nucleus
Similarly for breakup:

$$\frac{d\sigma_{bu}}{dEd\Omega} = |F_{E,0}|^2 \left(\frac{d\sigma}{d\Omega}\right)_{pt} \quad (2)$$

with $|F_{E,0}|^2 = \sum_{ljm} \left| \int \Phi_{ljm}(E) \Phi_0 e^{i\boldsymbol{Q}\cdot\boldsymbol{r}} d\boldsymbol{r} \right|^2$

This explains the similarities in angular distributions and provides the ratio idea.

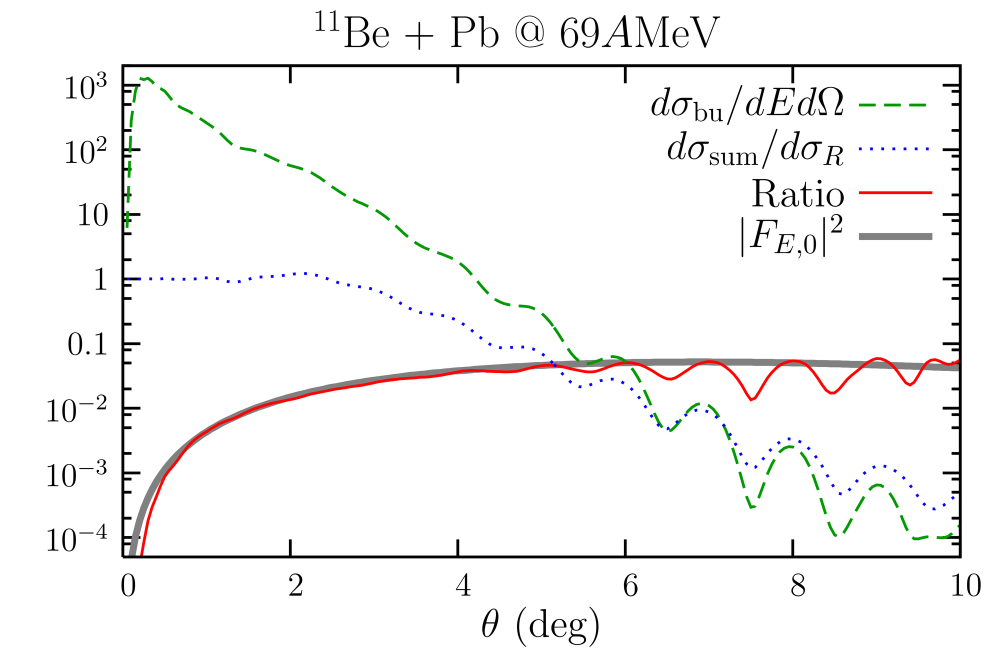
Ratio Idea

Following (1) and (2),

$$\frac{d\sigma_{bu}/dEd\Omega}{d\sigma_{el}/d\Omega} = \frac{|F_{E,0}(\boldsymbol{Q})|^2}{|F_{00}(\boldsymbol{Q})|^2} \quad (3)$$

- independent of reaction process
- probes only nuclear structure
- no need of normalising experimental cross sections

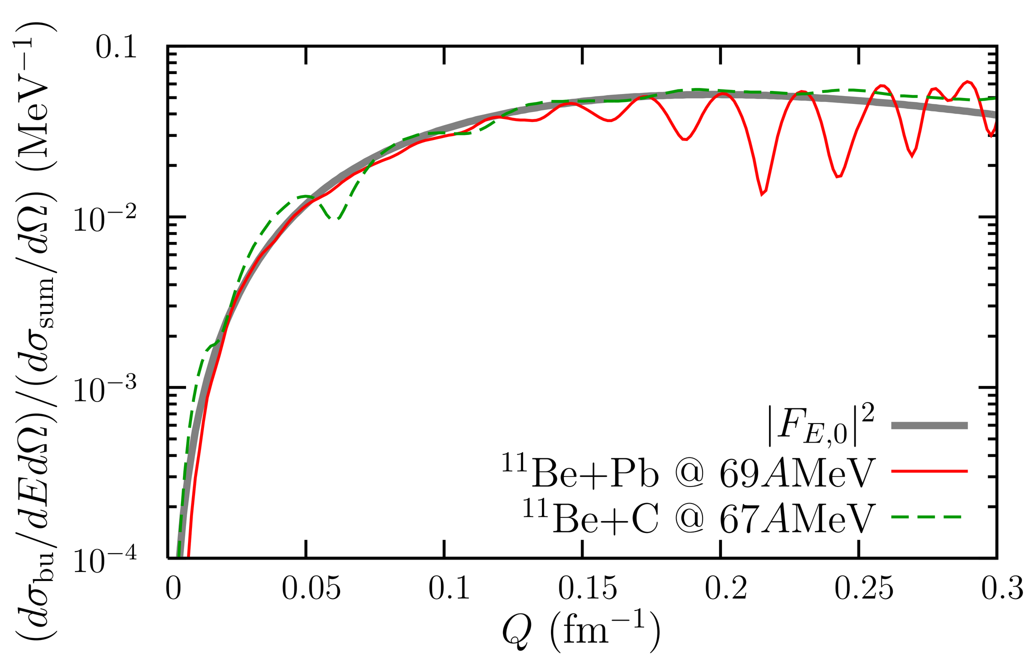
Test within the Dynamical Eikonal Approximation [3], which includes the projectile dynamics and V_{nT}.
We use $d\sigma_{bu}/d\sigma_{sum} = |F_{E,0}|^2$ with $\frac{d\sigma_{sum}}{d\Omega} = \frac{d\sigma_{el}}{d\Omega} + \frac{d\sigma_{inel}}{d\Omega} + \int \frac{d\sigma_{bu}}{dEd\Omega} dE$.



Angular distributions for breakup and all processes are compared to their ratio and its prediction $|F_{E,0}|^2$ [4].

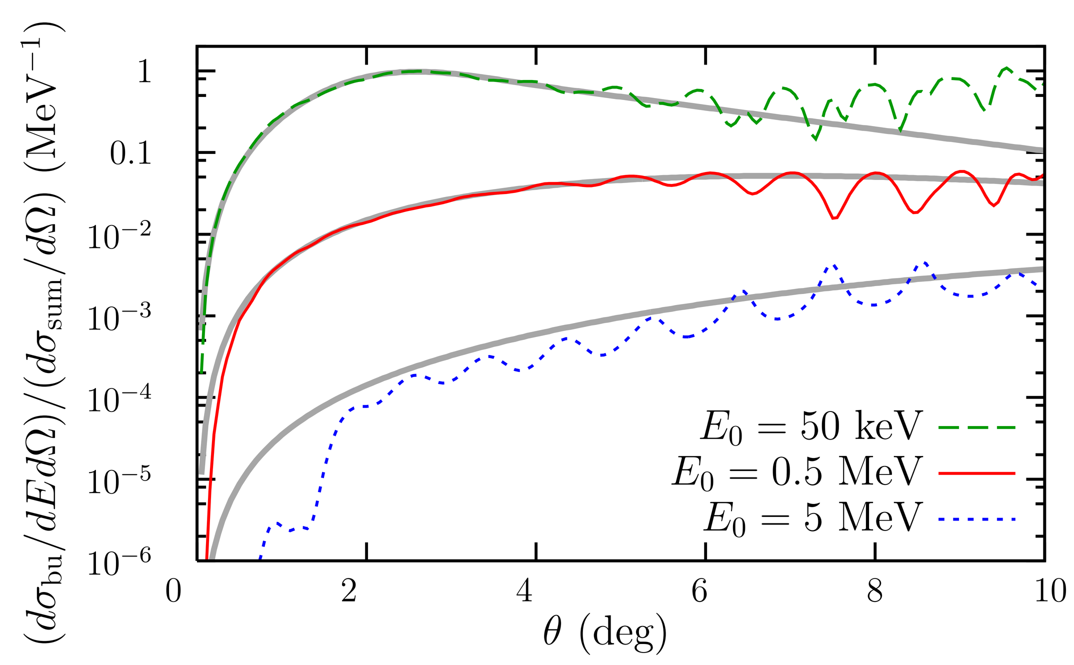
- Ratio removes most angular dependence
- DEA ratio in excellent agreement with REB $|F_{E,0}|^2$

No dependence on target

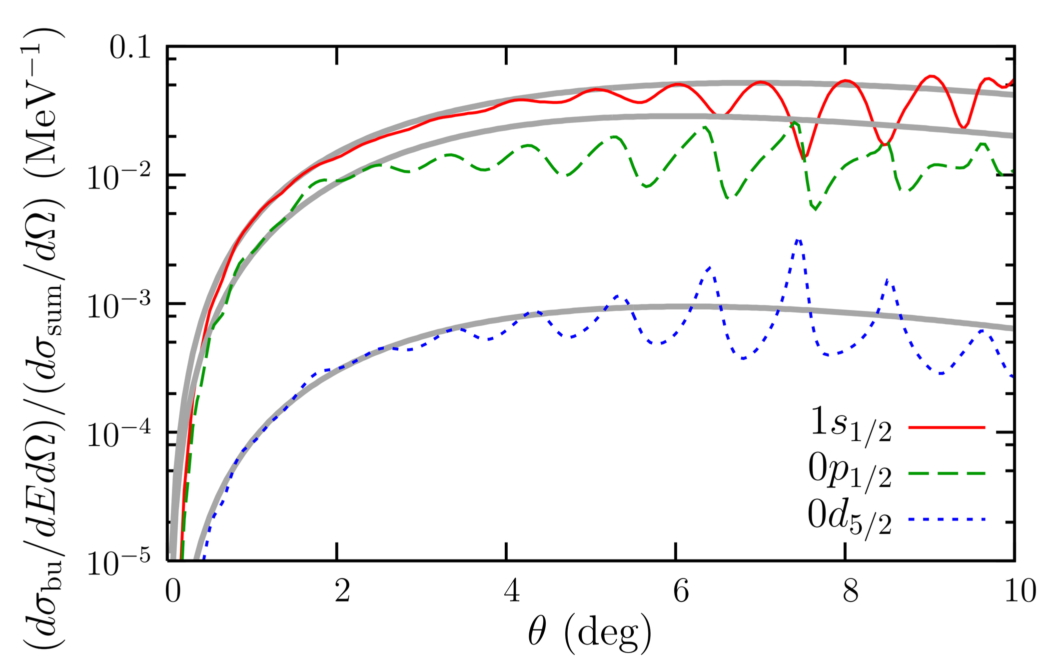


Similar ratios for Coulomb and nuclear dominated collisions
⇒ independent of the reaction process

Sensitivity to projectile structure



Ratio sensitive to projectile binding energy in both shape and magnitude



Ratio sensitive to partial-wave configuration in both shape and magnitude

Ratio is also sensitive to details of the radial wave function [4].

Conclusion & Outlook

- Ratio of angular distributions provides a reaction-independent observable to study halo nuclei.
- Sensitive to binding energy, partial-wave configuration and radial wave function.
- Can it be extended to two-neutron halœs and/or proton halœs ?
- Can we obtain information about spectroscopic factor ?

References

[1] P. Capel, M.S. Hussein, and D. Baye, Phys. Lett. **B693**, 448 (2010)
[2] R.C. Johnson, J.S. Al-Khalili, and J.A. Tostevin, Phys. Rev. Lett. **79**, 2771 (1997)
[3] D. Baye, P. Capel, and G. Goldstein Phys. Rev. Lett. **95**, 082502 (2005)
[4] P. Capel, R.C. Johnson, and F.M. Nunes, Phys. Lett. **B705**, 112 (2011)

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