Peripherality in inclusive nuclear breakup of halo nuclei

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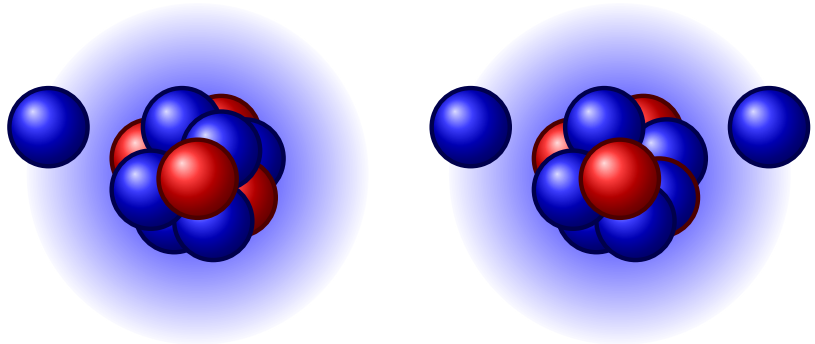
Motivation

- **Halo nuclei** exhibit a very large matter radius
  Compact core + one or two loosely-bound neutrons

Ex : $^{15}\mathrm{C} \equiv {}^{14}\mathrm{C} + n$
$^{11}\mathrm{Li} \equiv {}^{9}\mathrm{Li} + n + n$



Short-lived : cannot be studied through spectroscopic methods
→ studied through **reactions**
(elastic scattering, **breakup**,...)

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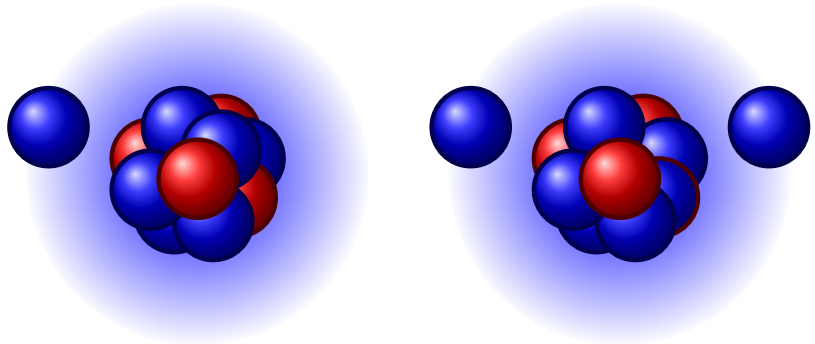

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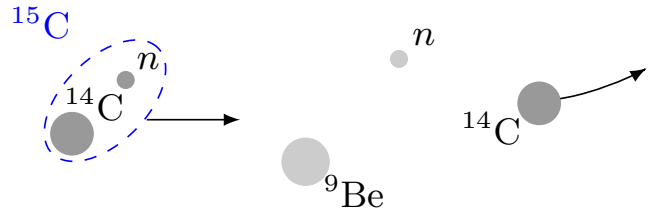
- **Inclusive breakup :**

Ex : $^{15}\mathrm{C} + {}^{9}\mathrm{Be} \rightarrow {}^{14}\mathrm{C} + X$ at $54A$ MeV

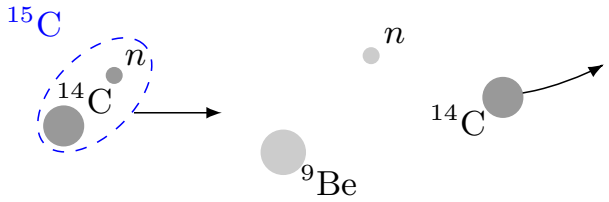


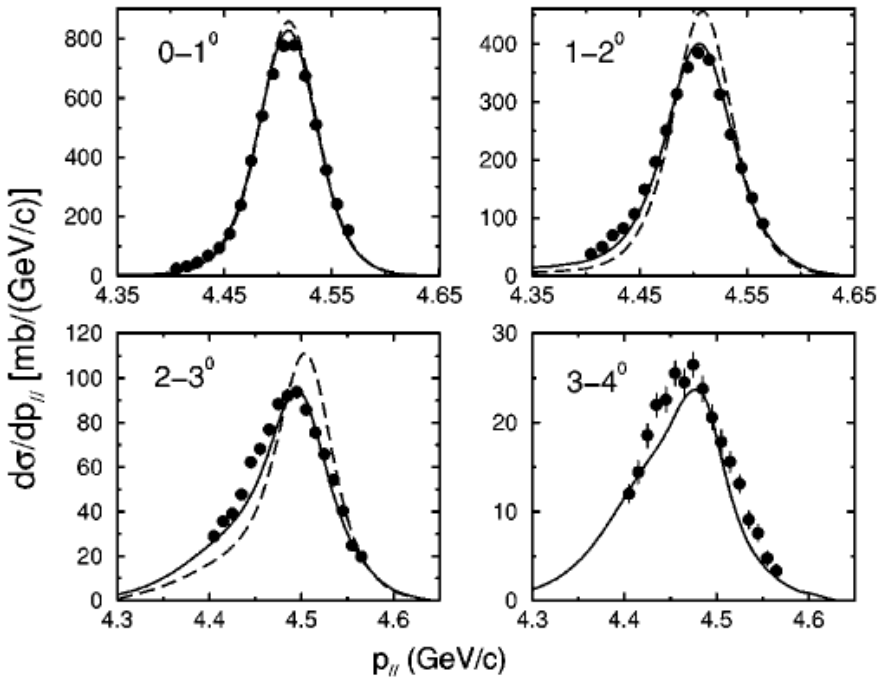
[J. A. Tostevin *et al.*, Phys. Rev. C **66**, 024607 (2002)]

Inclusive nuclear breakup $^{15}\mathrm{C} + {}^{9}\mathrm{Be} \rightarrow {}^{14}\mathrm{C} + X$ at $54A$ MeV

Two contributions : $\sigma = \sigma_{\mathrm{diff}} + \sigma_{\mathrm{strip}}$

- Diffractive (σ_{diff}) : survival of both $^{14}\mathrm{C}$ and n
- Stripping (σ_{strip}) : absorption of n by $^{9}\mathrm{Be}$





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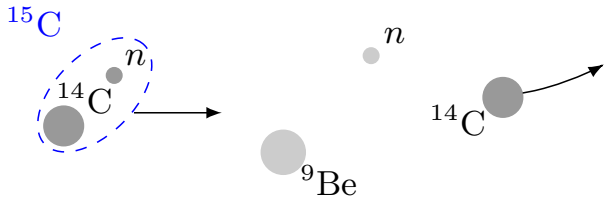

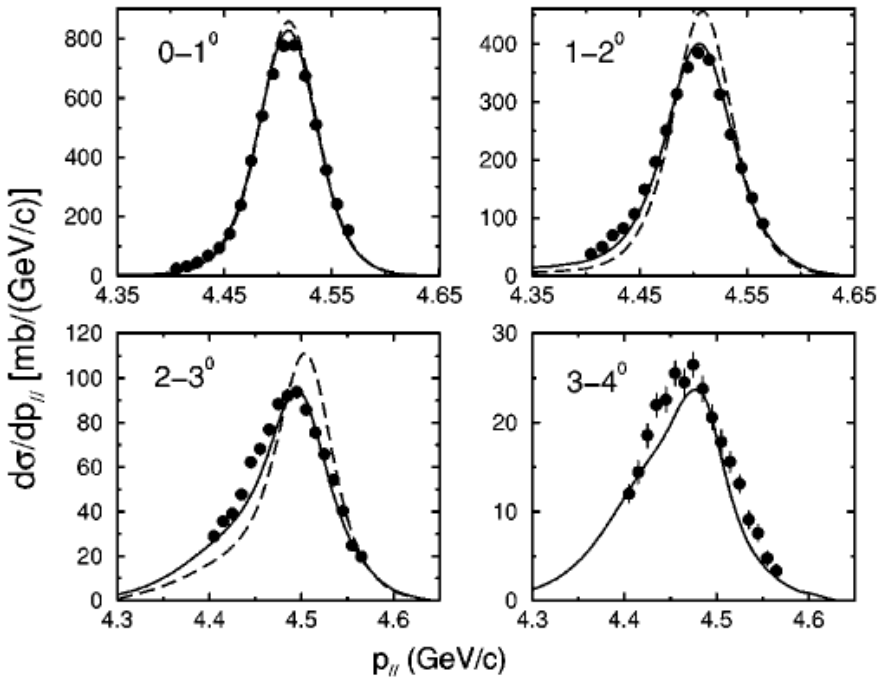

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What physics do we probe with inclusive nuclear breakup ?

See my poster to find out !

Peripherality in inclusive nuclear breakup of halo nuclei

Chloë Hebborn[1,*] and Pierre Capel[1,2]

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[*] FRIA scholarship

Motivation

Halo nuclei: nuclei near the dripline, presenting an exotic structure with large matter radius
→ Due to one or two loosely-bound neutrons
Seen as a compact core + one or two valence neutrons

Ex: $^{15}\mathrm{C} \equiv {}^{14}\mathrm{C} + n$
$^{11}\mathrm{Be} \equiv {}^{10}\mathrm{Be} + n$
$^{11}\mathrm{Li} \equiv {}^{9}\mathrm{Li} + n + n$

Short-lived:
→ Cannot be studied through spectroscopic methods
→ Studied through **reactions:**
elastic scattering, **breakup**,...

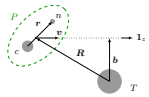
Inclusive breakup:
$^{15}\mathrm{C} + {}^{9}\mathrm{Be} \rightarrow {}^{14}\mathrm{C} + X$ at 54A MeV [1]

Two contributions [2]: $\sigma_{\mathrm{diff}} > \sigma_{\mathrm{strip}}$
- **Diffractive breakup** (σ_{diff}): survival of n and ^{14}C
- Stripping (σ_{strip}): absorption of n by ^{9}Be

What do we probe with diffractive breakup?

Reaction model and description of the halo nucleus

- Two-body projectile (P): $P \equiv$ core (c) + neutron (n)
Internal Hamiltonian: $h_{cn} = T_r + V_{cn}(r)$
with V_{cn} an effective potential for c-n interaction
- Structureless target (T)
- P-T interactions: central optical potentials V_{cT} and V_{nT}



Three-body Schrödinger equation:

$$[T_R + h_{cn} + V_{cT}(\boldsymbol{R},\boldsymbol{r}) + V_{nT}(\boldsymbol{R},\boldsymbol{r})]\,\Psi(\boldsymbol{R},\boldsymbol{r}) = E\,\Psi(\boldsymbol{R},\boldsymbol{r})$$

with the initial condition $\Psi(\boldsymbol{R},\boldsymbol{r}) \underset{Z\to-\infty}{\rightarrow} e^{ikZ+\dots}\Phi_0(\boldsymbol{r})$, i.e., incoming P in its ground state Φ_0 with a velocity $v = \frac{\hbar k}{\mu_{cn}}$

1. Eikonal approximation: at high energy, the wavefunction ≈ plane wave [3]

$$\Psi(\boldsymbol{R},\boldsymbol{r}) = e^{ikZ}\,\tilde{\Psi}(\boldsymbol{R},\boldsymbol{r})\Phi_0(\boldsymbol{r}) \quad \text{with } |\Delta_{\boldsymbol{R}}\tilde{\Psi}| \ll k\left|\tfrac{\partial}{\partial Z}\tilde{\Psi}\right|$$

2. Sudden approximation: $h_{cf} \approx \epsilon_0$ the energy of the ground state

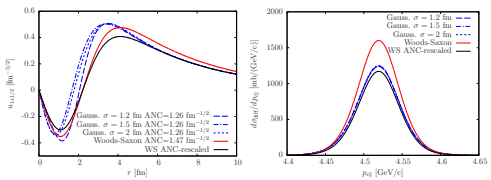
Solutions: $\Psi^{\mathrm{sols}}(\boldsymbol{b},Z,\boldsymbol{r}) \underset{Z\to+\infty}{\rightarrow} e^{ikZ}e^{i\chi(\boldsymbol{b},\boldsymbol{r})}\Phi_0(\boldsymbol{r})$, with $\chi(\boldsymbol{b},\boldsymbol{r}) = -\frac{1}{\hbar v}\int_{-\infty}^{+\infty}[V_{cT}(\boldsymbol{R}',\boldsymbol{r}) + V_{nT}(\boldsymbol{R}',\boldsymbol{r})]dZ'$

How sensitive are the observables to
① **projectile description?** Test with different V_{cn}
- Woods-Saxon potentials fitted to ϵ_0
- Gaussian potentials fitted to both ϵ_0 and ANC (normalisation of the tail of Φ_0) [4,5]

② **optical potentials?** Test with different V_{cT} and V_{nT}

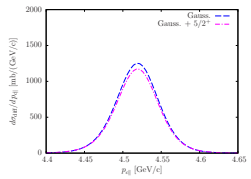
① Sensitivity of diffractive breakup to ^{15}C description

Wavefunction of the ground state $u_{1s1/2}$



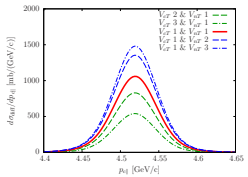
⇒ **Peripheral:** mostly sensitive to the asymptotic behaviour of the ground-state wavefunction

Including the excited bound state $5/2^+$



Interaction in the d-wave → non-zero d phase shifts in the continuum
⇒ **Non-negligible effect of the first excited state**

② Effect of the optical potentials



⇒ **Strongly dependent on the optical potentials**

Conclusions and prospects

Main contribution to inclusive breakup is **diffractive breakup** which
① is **peripheral:** insensitive to the inner part of the wavefunctions
⇒ we can only probe the asymptotic part of the wavefunctions
should **include the excited bound states** (and known resonances?)
② is **very sensitive to the choice of the optical potentials**
→ more realistic description within the Optical Limit Approximation of Glauber?
⇒ **Next step: extension of this analysis to stripping**

References

[1] J. A. Tostevin *et al.*, Phys. Rev. C **66**, 024607 (2002).
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[3] R. J. Glauber, *High energy collision theory*, Lecture in theoretical physics, (1959).
[4] H.-W. Hammer, C. Ji and D. R. Phillips, J. Phys. G. **44**, 103002 (2017).
[5] L. Moschini, Poster to the 57th International Winter Meeting on Nuclear Physics (2019).