Breakup of halo nuclei within a Coulomb-Corrected Eikonal model

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Outline

- Introduction on halo nuclei
- **Eikonal** description of reactions
- Why a **Coulomb** correction?
- Analysis of $^6$He **Coulomb** breakup
- Conclusions
Introduction: Halo Nuclei

Exotic nuclei with peculiar quantal structure:

- Light, n-rich nuclei
- Large matter radius
- Exhibit a low separation energy of 1 or 2 neutrons

⇒ strongly clusterised system: neutrons tunnel far from the core and form a halo

Two-neutron halo nuclei are Borromean:
three bodies bound but not two-body subsystems
Examples: $^6\text{He} \equiv ^4\text{He} + n + n$; $^{11}\text{Li} \equiv ^9\text{Li} + n + n$
Breakup reaction

Halo nuclei are short-lived ⇒ studied in indirect ways

Coulomb breakup ≡ dissociation of halo from core by interaction with a heavy target (e.g. Pb)

⇒ Need accurate theoretical description of breakup coupled to realistic model of projectile

Various breakup models exist:

- Elaborate models (CDCC, TDSE) are expensive ⇒ limited in projectile description (two body)
- Simpler models (eikonal, FO) limited application

⇒ We seek (and succeed) to improve eikonal to study Coulomb breakup of two-neutron halo nuclei
Framework

**Projectile** ($P$) modelled as a three-body system: core ($c$) + 2 neutrons (1, 2) described by

\[ H_0 = T_y + T_x + V_{c1} + V_{c2} + V_{12} \]

$V_{ij}$: effective potentials adjusted on binding energy

Target $T$ seen as structureless particle

$P$-$T$ interaction simulated by **optical potentials** $U_{iT}$

\[ \Rightarrow \] breakup reduces to **four-body** scattering problem:

\[ [T_R + H_0 + U_{cT} + U_{1T} + U_{2T}] \Psi = E_T \Psi \]
Eikonal model

\[
[T_R + H_0 + U_{PT}] \Psi(R, x, y) = E_T \Psi(R, x, y)
\]

with condition \( \Psi(R, \ldots) \xrightarrow{Z \to -\infty} e^{iKZ} \Phi_0 \)

Eikonal approximate solution:

\[
\Psi^{eik}(b, Z) = e^{iKZ} e^{i\chi(b, Z)} \Phi_0,
\]

\[
\chi(b, Z) = -\frac{1}{\hbar \nu} \int_{-\infty}^{Z} U_{PT}(b, Z') dZ'
\]

- Easy to interpret and implement
- Fast calculations

⇒ Possible to extend to two-neutron halos
Coulomb Corrected Eikonal

BUT incompatible with Coulomb interaction:

$$\chi_C(b) = -\frac{1}{\hbar v} \int_{-\infty}^{\infty} \frac{Z_c Z_T e^2}{R_{cT}} dZ \propto \frac{1}{b}$$

$$\Rightarrow e^{i\chi_C} = 1 + i\chi_C - \frac{1}{2}\chi_C^2 + \ldots \text{ diverges when } \int db$$

Idea: replace $\chi_C$ by $\chi_{FO}$ from perturbation theory

[Margueron, Bonaccorso, and Brink, NPA 720, 337 (2003)]

$$\chi_{FO}(b) = -\frac{1}{\hbar v} \int_{-\infty}^{\infty} e^{i\omega Z} \frac{Z_c Z_T e^2}{R_{cT}} dZ \propto e^{-\omega b},$$

with correct asymptotics. The correction then reads

$$e^{i\chi} = e^{i\chi_N} \left(e^{i\chi_C} - i\chi_C + i\chi_{FO}\right)$$

OK for one-neutron halo [P. C. et al. PRC 78, 054602 (’08)]
$^6\text{He}$

$^6\text{He} \equiv ^4\text{He} + n + n$

\[
\begin{array}{c}
2^+ & 0.824 \text{ MeV} (\Gamma = 113 \text{ keV}) \\

^4\text{He} + n + n
\end{array}
\]

\[
\begin{array}{c}
0^+ & -0.973 \text{ MeV} \\

^6\text{He}
\end{array}
\]

Structure calculation in a three-body model within hyperspherical harmonics framework

$V_{\alpha n}:$ Kanada et al. [Prog. Theor. Phys. 61, 1327 (1979)]

$V_{nn}:$ Minnesota interaction [NPA 286, 53 (1977)]
Coulomb breakup of $^6$He

$^6$He + Pb $\rightarrow$ $^4$He + n + n + Pb @ 240 AMeV

[T. Aumann et al. PRC 59, 1252 (1999)]

- Agreement at large $E$ (no parameter)
- Theory predicts a broad peak at low $E$
  $\equiv 1^-$ resonance; unseen experimentally

$\Rightarrow$ Error in $^6$He calculation or in experiment?
Different interactions

$B(E1)$ computed with different interactions adjusted to reproduce $^6$He binding energy

- All effective interactions display the low-$E$ peak
- Plane waves are not realistic (no interaction)
- In agreement with other calculations
Conclusions and Perspectives

Coulomb Corrected Eikonal is a reaction model based on eikonal approximation with a First-Order correction for Coulomb interaction [P. C. et al. PRC 78, 054602 (2008)]

First calculation of \(^6\)He Coulomb breakup [D. Baye et al. accepted in PRC (2009)]

- Good agreement with data at large energy
- Theory predicts a peak at low \(E \) (1\(^-\) resonance) unseen experimentally

Breakup is efficient tool for halo-nuclei spectroscopy Requires new measurements to test theory