Analysis of ^{8}B breakup experiments with a Dynamical Eikonal Approximation

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What makes ^{8}B so interesting?

- One-p halo candidate ($S_\mathrm{p} = 137$ keV);
  seen as $^8\mathrm{B} \equiv\ ^7\mathrm{Be} + \mathrm{p}$
  Breakup used to study halo structure
- Coulomb breakup of astrophysical interest:
  Inverse reaction of $^7\mathrm{Be}(\mathrm{p},\gamma)^8\mathrm{B}$,
  important for solar-neutrino studies
  Idea: extract σ_capture from σ_bu

We (re)analyse several ^{8}B-breakup experiments

within one model: Dynamical Eikonal Approximation

Outline

- Dynamical Eikonal Approximation
- ^{8}B breakup experiments:
  - 44 & 81 AMeV $p_{||}$ distributions (MSU)
  - 83 AMeV energy distribution (MSU)
  - 52 AMeV angular distribution (RIKEN)

  Analysis of dynamics: role of nuclear interaction, multipole contributions, higher-order effects...
- Conclusion and prospects

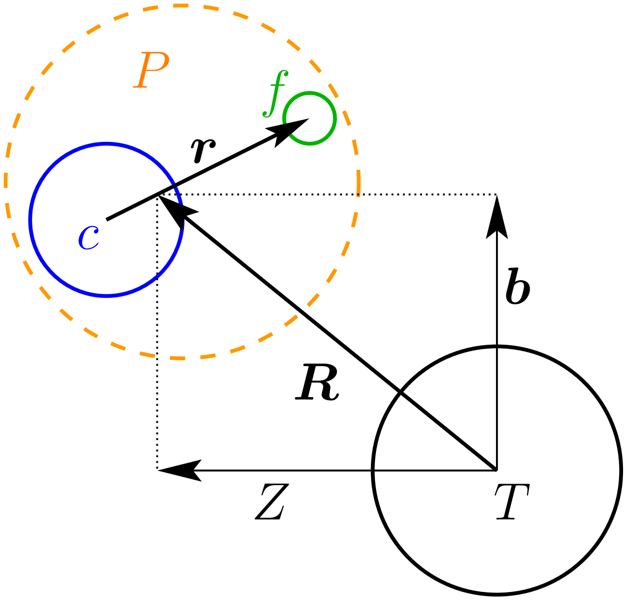
Theoretical framework

Projectile (P) modelled as a two-body system:
core (c)+loosely bound nucleon (f) described by

$$H_0 = T_r + V_{cf}(\boldsymbol{r})$$

V_{cf} adjusted to reproduce bound state

Target T seen as structureless particle



P-T interaction simulated by optical potentials

$\Rightarrow$ breakup reduces to three-body scattering problem:

$$[T_R + H_0 + V_{cT} + V_{fT}]\,\Psi(\boldsymbol{R},\boldsymbol{r}) = E_T\Psi(\boldsymbol{R},\boldsymbol{r})$$

Dynamical eikonal approximation (1)

Three-body scattering problem

$$[T_R + H_0 + V_{cT} + V_{fT}]\,\Psi(\boldsymbol{r},\boldsymbol{R}) = E_T\Psi(\boldsymbol{r},\boldsymbol{R})$$

with condition $\Psi(\boldsymbol{r},\boldsymbol{R}) \underset{Z\to-\infty}{\longrightarrow} e^{iK_0Z}\Phi_0(\boldsymbol{r})$

To remove the rapid variation in $\boldsymbol{R}$ we factorise $\Psi(\boldsymbol{r},\boldsymbol{R}) = e^{iK_0Z}\widehat{\Psi}(\boldsymbol{r},\boldsymbol{R})$:

$$\begin{aligned} H\Psi &= e^{iK_0Z}[T_R + vP_Z + \frac{1}{2}\mu_{PT}v^2 \\ &\quad + (H_0 + V_{cT} + V_{fT})]\widehat{\Psi} \end{aligned}$$

Neglecting T_R vs vP_Z and using $E_T = \frac{1}{2}\mu_{PT}v^2 + E_0$

$$i\hbar v\frac{\partial}{\partial Z}\widehat{\Psi}(\boldsymbol{r},\boldsymbol{b},Z) = [H_0 - E_0 + V_{cT} + V_{fT}]\widehat{\Psi}(\boldsymbol{r},\boldsymbol{b},Z)$$

Dynamical eikonal approximation (2)

$$i\hbar v\frac{\partial}{\partial Z}\widehat{\Psi}(\boldsymbol{r},\boldsymbol{b},Z)=[H_0-E_0+V_{cT}+V_{fT}]\widehat{\Psi}(\boldsymbol{r},\boldsymbol{b},Z)$$

is equivalent to a TDSE with straight line trajectories
BUT here $\boldsymbol{b}$ and Z are quantal ⇒ no trajectory

The usual eikonal uses adiabatic approx. $H_0-E_0\sim 0$
⇒ neglects internal dynamical effects of projectile

$$\widehat{\Psi}^{\rm eik}(\boldsymbol{r},\boldsymbol{b},Z)=e^{-\frac{i}{\hbar v}\int_{-\infty}^{Z}dZ'\left[V_{cT}(\boldsymbol{r},\boldsymbol{b},Z')+V_{fT}(\boldsymbol{r},\boldsymbol{b},Z')\right]}\Phi_0(\boldsymbol{r})$$

⇒ dynamical eikonal generalises TDSE and eikonal

- improves TDSE by including interferences
- improves eikonal by including dynamical effects
- we know how to solve accurately TDSE

Breakup cross section

Breakup transition matrix element:

$$T_{fi}^{\rm bu} \; = \; \langle e^{i\boldsymbol{K}\cdot\boldsymbol{R}}\chi_{\boldsymbol{k}}^{(-)}|V_{cT}+V_{fT}|e^{iK_0Z}\widehat{\Psi}\rangle,$$

where $H_0\chi_{\boldsymbol{k}}^{(-)} = E\chi_{\boldsymbol{k}}^{(-)}$ (ingoing scattering wave)

At forward angle, assuming $\boldsymbol{q} = \boldsymbol{K} - K_0\widehat{\boldsymbol{Z}}$ transverse

$$T_{fi}^{\rm bu} \; \approx \; i\hbar v \int d\boldsymbol{b} e^{i\boldsymbol{q}\cdot\boldsymbol{b}}\langle\chi_{\boldsymbol{k}}^{(-)}|\widehat{\Psi}(Z\to\infty)\rangle$$

$$\propto \; \sum_{lm} Y_l^m(\Omega_k)e^{-im\varphi}\int_0^\infty J_{|m|}(qb)\langle\Phi_{klm}|\widehat{\Psi}(Z\to\infty)\rangle b db,$$

Cross sections:

$$\frac{d\sigma_{\rm bu}}{d\boldsymbol{k}d\Omega} \propto |T_{fi}^{\rm bu}|^2 \xrightarrow{\int d\Omega_k, \int d\Omega} \frac{d\sigma_{\rm bu}}{dEd\Omega} \text{ and } \frac{d\sigma_{\rm bu}}{dE}$$

⇒ DEA includes interferences between *trajectories*

^{8}B

^{8}B has only one 2^{+} loosely-bound state $S_{\mathrm{p}} = 137$ keV

seen as $|{}^{8}\mathrm{B}(2^{+})\rangle = |\,{}^{7}\mathrm{Be}(\frac{3}{2}^{-})\otimes\mathrm{p}(p3/2)\rangle$

Description of Esbensen & Bertsch [NPA 600, 37 (96)]

^{7}Be assumed spherical, its spin is neglected

^{7}Be-p potential is WS+S0

Coulomb breakup can be used to infer $^{7}\mathrm{Be}(\mathrm{p},\gamma)^{8}\mathrm{B}$ radiative capture cross section if

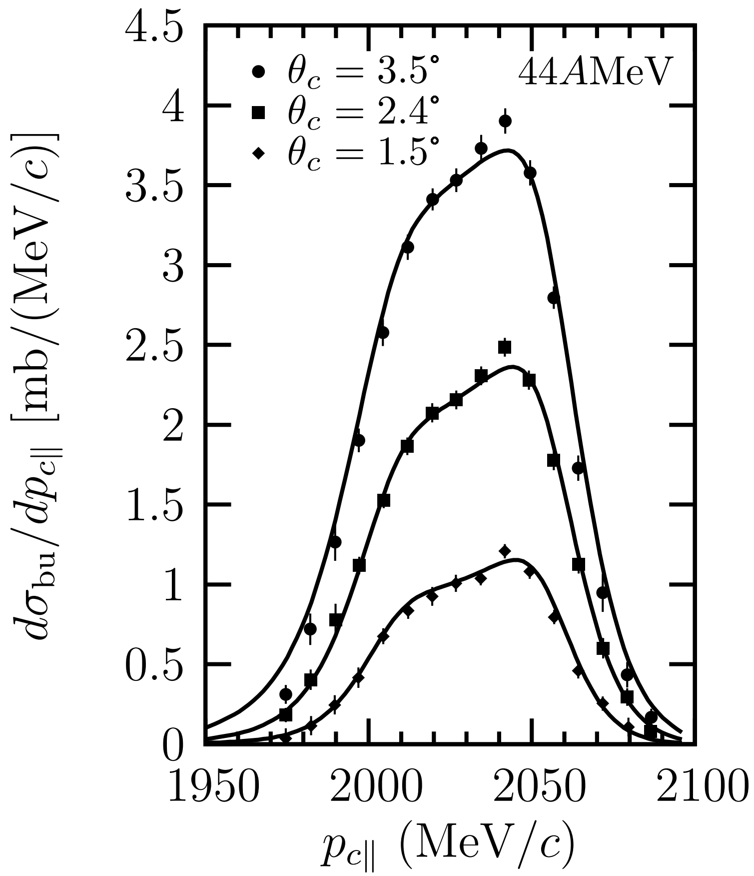
- purely Coulomb (ie nuclear interaction negligible)
- purely E1 (ie no E2 contribution)
- occurs at first-order (ie no higher-order effects)

⇒ We study ^{8}B breakup addressing these issues

[G. Goldstein, P.C., D. Baye PRC 76, 024608 (2007)]

Parallel-momentum distributions

^{8}B + Pb @ 44*A*MeV (MSU) [Davids PRL 81, 2209 (98)]



Excellent agreement with exp.
(no fitting parameter)
in particular:

- magnitude (no scaling factor)
- width
- asymmetry due to E1-E2 interferences

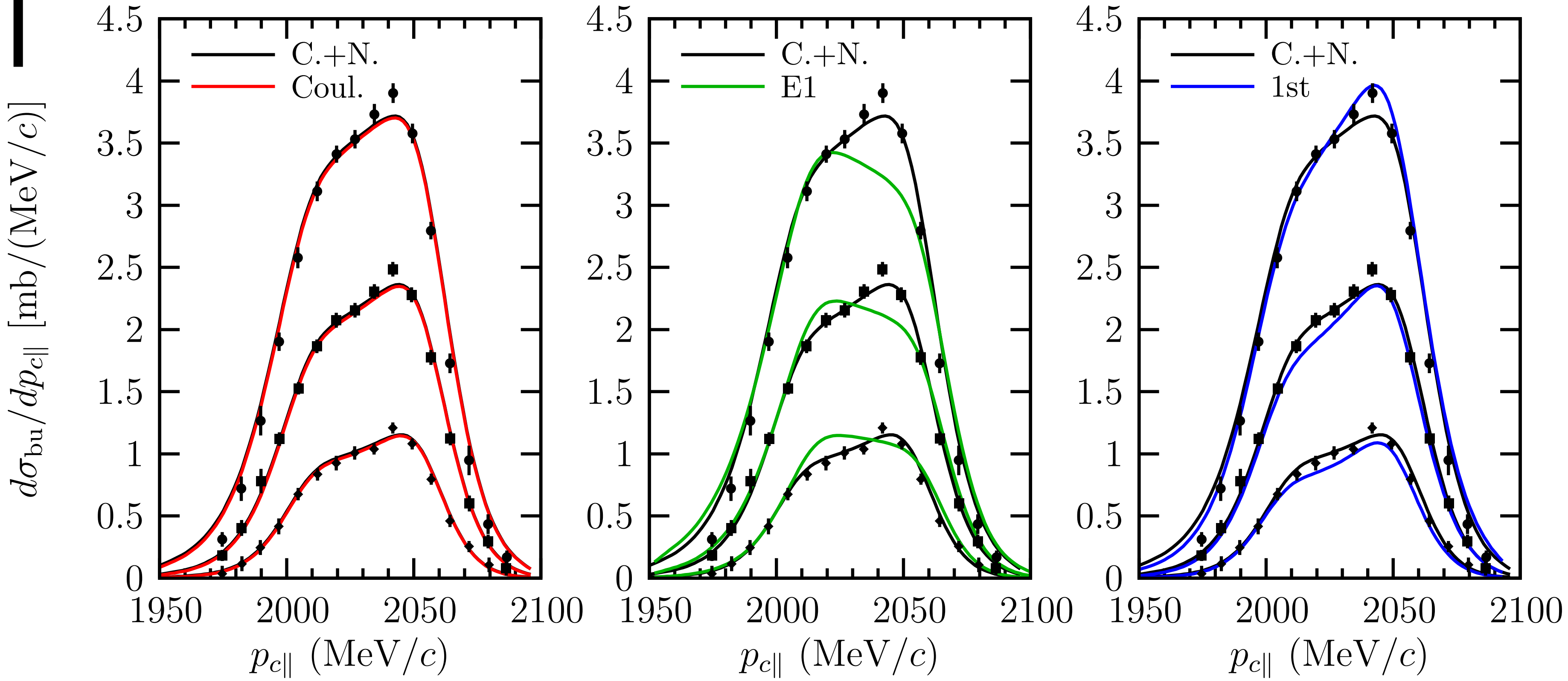
  (no need to renormalise E2)

Validates the DEA for breakup calculations

Indicates that a simple description of ^{8}B is sufficient

Analysis of the dynamics

^{8}B + Pb @ 44 AMeV (MSU) [Davids PRL 81, 2209 (98)]



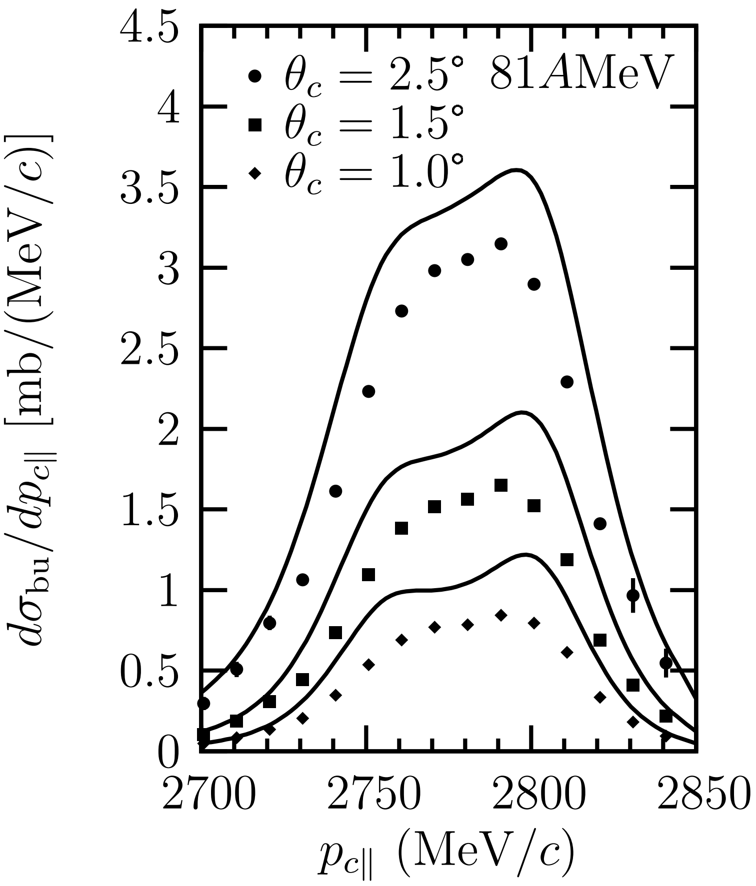
Nuclear interaction negligible at forward angles

Significant E1-E2 interference (asymmetry)

First-order: more asymmetric
⇒ higher-order

Parallel-momentum @ 81*A*MeV

^{8}B + Pb @ 81*A*MeV (MSU) [Davids PRL 81, 2209 (98)]



Less good agreement with exp.
(no fitting parameter)
in particular:

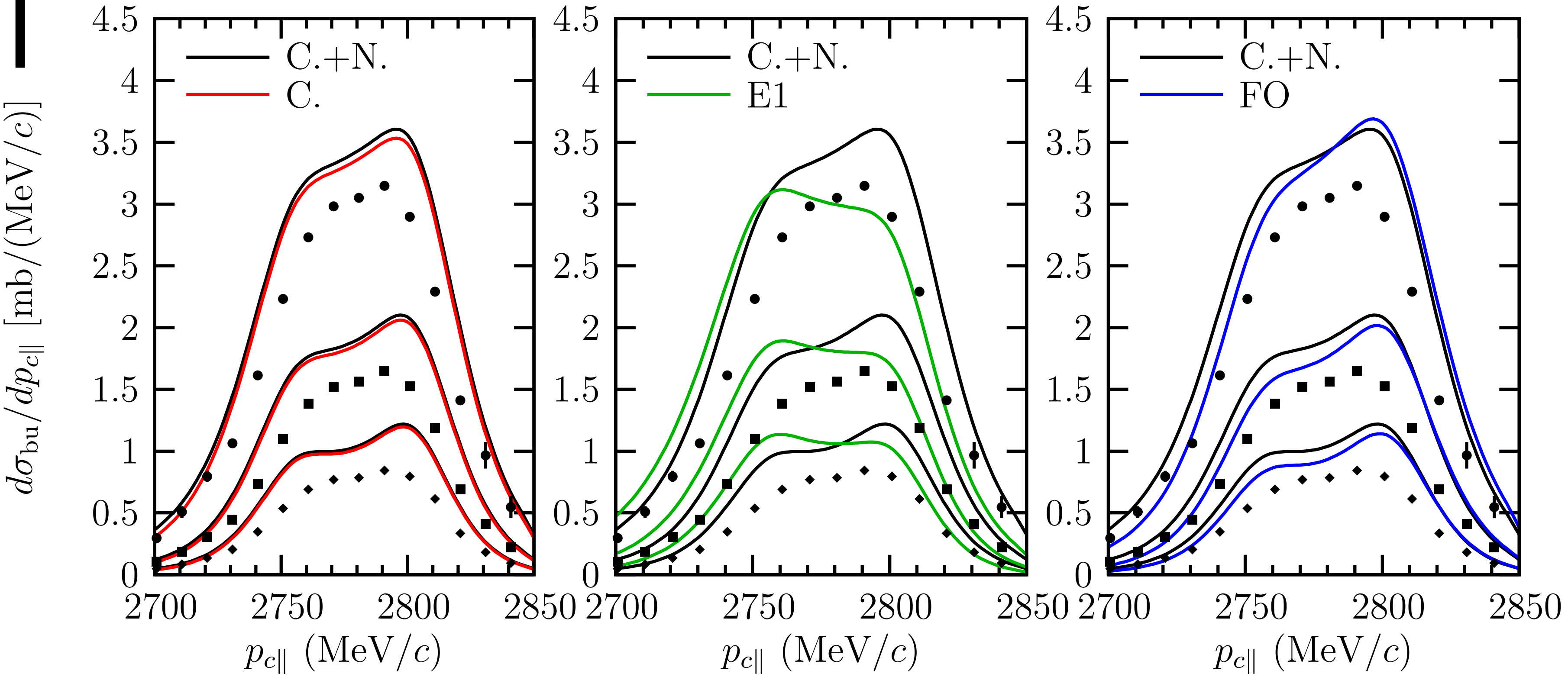
- too high 10–25%
- a bit too wide
- but correct slope

Representative of the actual exp./th. uncertainty ?

Larger energy ⇒ larger relativistic effects ?

Analysis of the dynamics

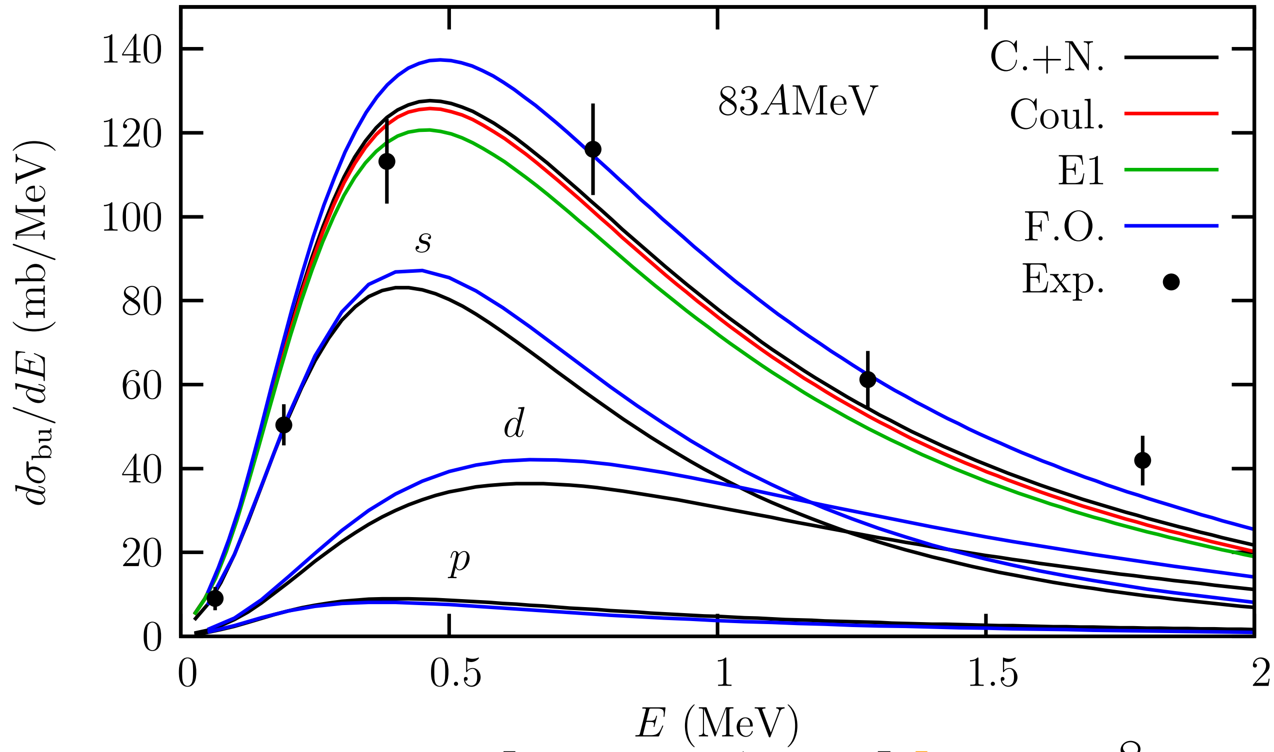
^{8}B + Pb @ 81 AMeV (MSU) [Davids PRL 81, 2209 (98)]



Same conclusions about the dynamics as @ 44AMeV

Energy distribution

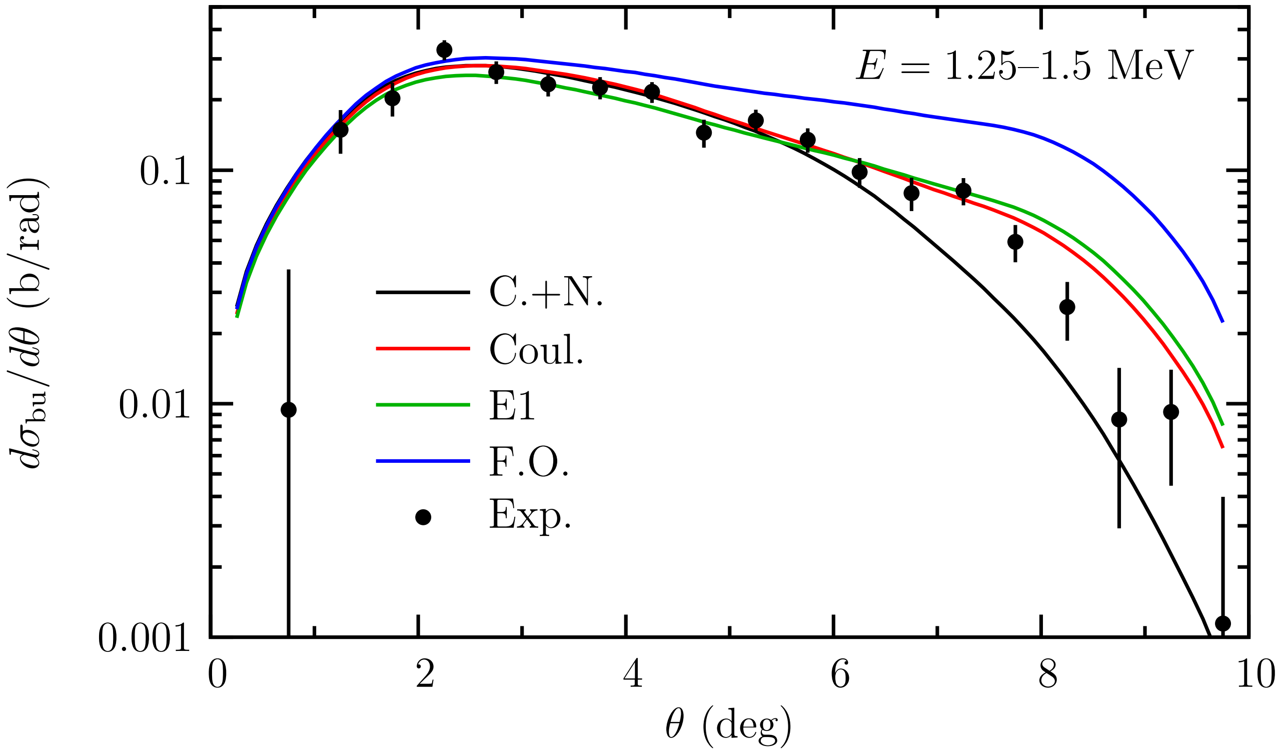
^{8}B + Pb @ 83AMeV (MSU) [Davids PRL 83, 2750 (01)]



- Fair agreement with exp. (need better ^{8}B model?)
- No influence of nuclear interaction
- Small influence of E2 $\Rightarrow$ no study of E2
- Higher-order effects (s and d $\searrow$, while p $\nearrow$)

Angular distribution

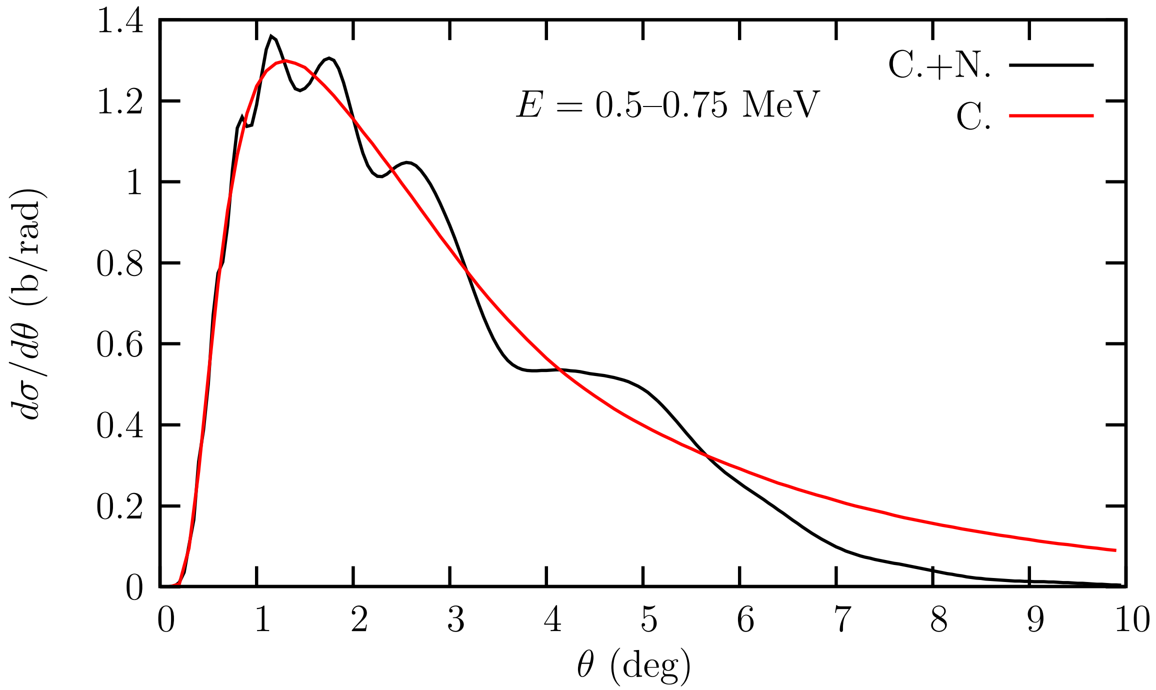
^{8}B + Pb @ 52AMeV (RIKEN) [Kikushi PLB 391, 261 (97)]



- Good agreement with experiment
- Nuclear interaction influent only at large angle
- Small influence of E2 ⇒ no study of E2
- First-order too large ⇒ higher-order effects

No effect of nuclear interaction?

Actually there is an effect of nuclear interaction, even at low scattering angle:



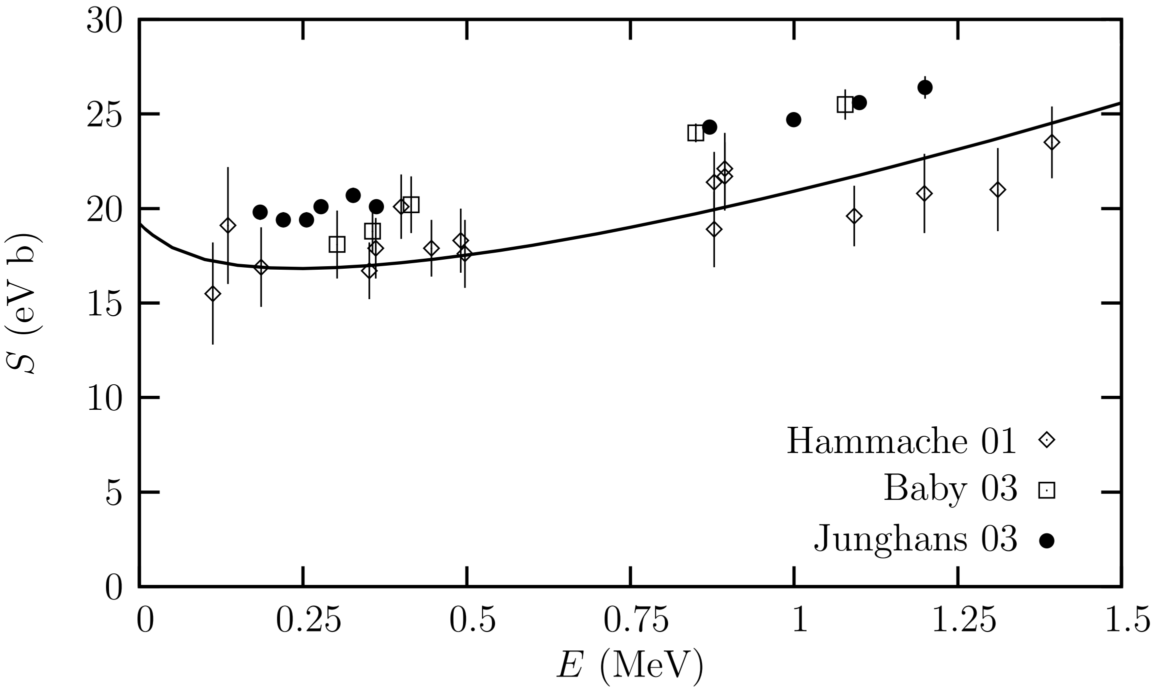
C.+N. oscillates around C. [Ogata PRC 73, 024605 (2006)]

⇒ unseen for too low angular resolution

What affects these oscillations?

S_{17}

Using this ^{8}B description, the $^{7}\mathrm{Be}(\mathrm{p},\gamma)^{8}\mathrm{B}$ S_{17} is



We obtain $S_{17} = 19.2$ b eV at $E = 0$

Good agreement with Hammache [PRL 86, 3985 (01)]

Too low but good shape compared to Junghans

[PRC 68, 065803 (03)]

Conclusion

- Study of several ^{8}B Coulomb breakup experiments
- New reaction model: Dynamical Eikonal Approx.
- Good agreement for various observables with only one reaction model, and one ^{8}B description
  $\Rightarrow$ physics of Coulomb breakup well understood
- Nuclear interaction negligible at forward angle
- Large E1-E2 interference in breakup
- Significant higher-order effects

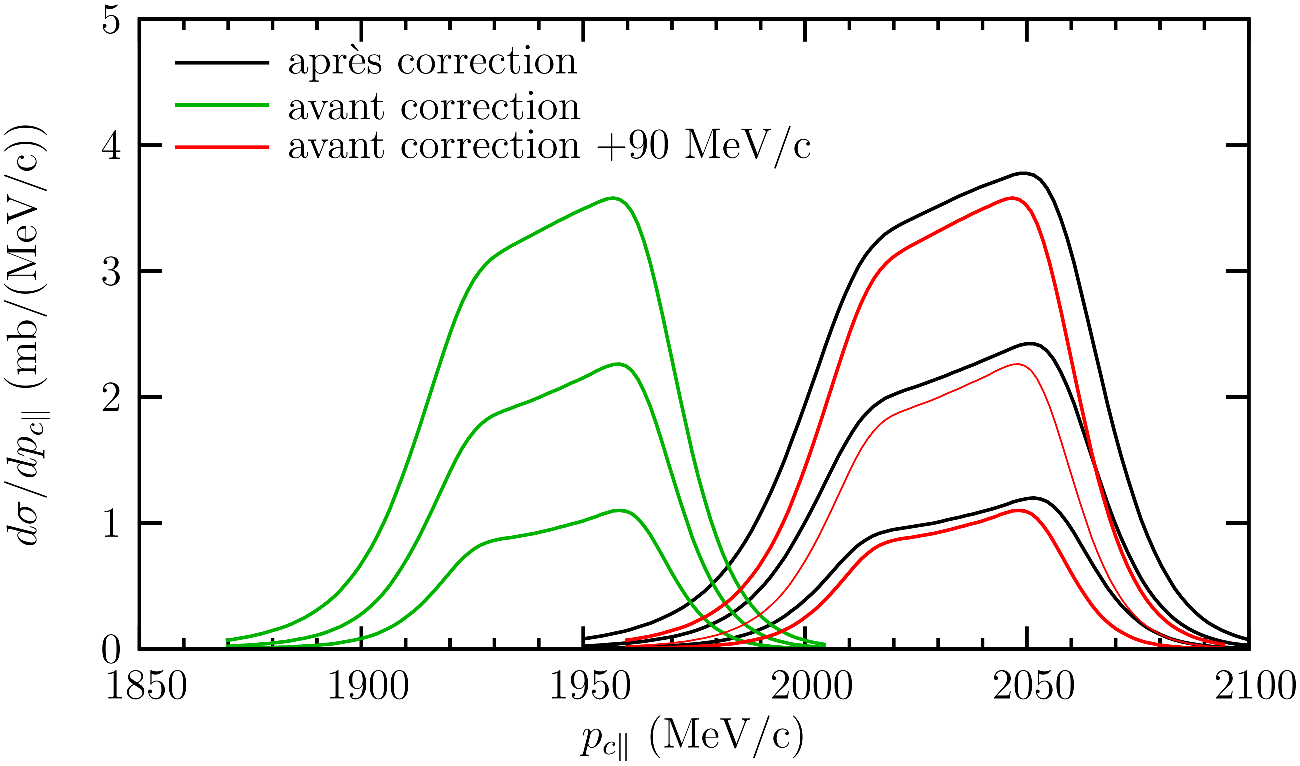
$\Rightarrow$ Uncertainties in extracting $\sigma_{\rm capture}$ from $\sigma_{\rm bu}$

S_{17} from ^{8}B description in agreement with direct data

Future:
- influence of ^{8}B description
- reasons of the oscillations in angular distr.

Relativistic correction

$$P_i \xrightarrow{\text{R}} m_P v_i = \hbar K_0 \xrightarrow{\text{NR}} \text{DEA calcul.} \xrightarrow{\text{NR}} m_c v_c \xrightarrow{\text{R}} p_c$$

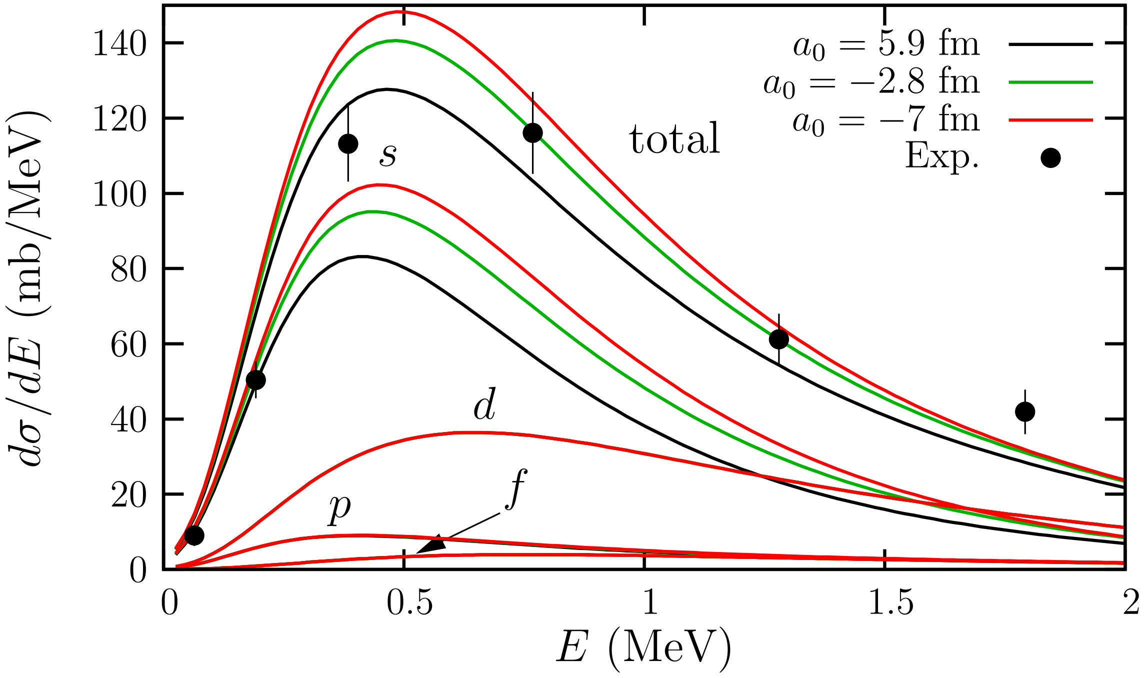


Distribution shifted to the right momentum,

and increased in magnitude and width

Influence of the projectile descriptio

First test: different scattering lengths (still $I_c = 0$)



Difference ● only in s wave

● in magnitude (no distortion)

$\Rightarrow$ small influence of projectile description ?

A proper test should include I_c