Influence of the description of the projectile continuum on breakup calculations

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Outlook

- Introduction
- Theoretical reaction models
- Analysis of the influence of the projectile description:
  - Breakup of ^{8}B on nickel at 25 MeV
  - Breakup of ^{11}Be on lead at $70A$MeV
  - Breakup of ^{11}Be on carbon at $70A$MeV
- Conclusion

Introduction

- RIB facilities give us access to exotic nuclei
- Breakup is used to study loosely bound nuclei
  In this reaction, the projectile dissociates
  through its interaction with a target
- Also indirect method to study radiative capture

$\Rightarrow$ Need of an accurate description of the reaction
Several models exist: CDCC, time-dependent,...

Projectile usually seen as a 2-body system
Sensitivity of the calculations to the potential?
Small binding energy $\Rightarrow$peripheral? $\Rightarrow \sigma_{\rm bu} \propto$ANC^2?
Role of the continuum? couplings in the continuum?

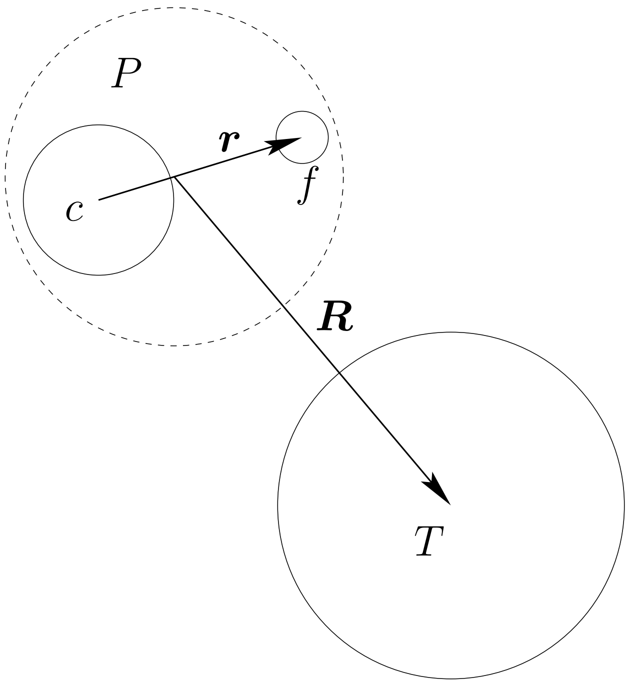
We address this issue for ^{8}B and ^{11}Be breakups

Theoretical framework

Projectile (P) $\equiv$ core (c) + fragment (f)

$\Rightarrow$ Hamiltonian: $H_0(\boldsymbol{r}) = -\frac{\hbar^2}{2\mu}\Delta_r + V_{cf}(r)$

V_{cf} is a local potential adjusted to reproduce bound states of P and some resonances



Interactions with target T simulated with optical potentials

Breakup $\equiv$ three-body scattering problem:

$H(\boldsymbol{r},\boldsymbol{R})\Psi(\boldsymbol{r},\boldsymbol{R}) = E_T\Psi(\boldsymbol{r},\boldsymbol{R})$, with

$$H(\boldsymbol{r},\boldsymbol{R}) = T_R + H_0(\boldsymbol{r}) + V_{cT}(R_{cT}) + V_{fT}(R_{fT})$$

CDCC

In Continuum Discretised Coupled Channels method
wave function is expanded over H_0 eigenstates:

$$\Psi^{\mathrm{CDCC}}(\boldsymbol{r},\boldsymbol{R}) = \sum_\alpha \phi_\alpha(\boldsymbol{r})\chi_\alpha(\boldsymbol{R})$$

where $$H_0\phi_\alpha(\boldsymbol{r}) = \epsilon_\alpha\phi_\alpha(\boldsymbol{r})$$

Continuum states ($\epsilon_\alpha > 0$) discretised in energy bins

$\Rightarrow$ resolution of coupled equations

$$[T_R + V_{\alpha\alpha}(\boldsymbol{R}) + E_T - \epsilon_\alpha]\,\chi_\alpha(\boldsymbol{R}) = -\sum_{\beta\neq\alpha} V_{\beta\alpha}(\boldsymbol{R})\chi_\beta(\boldsymbol{R})$$

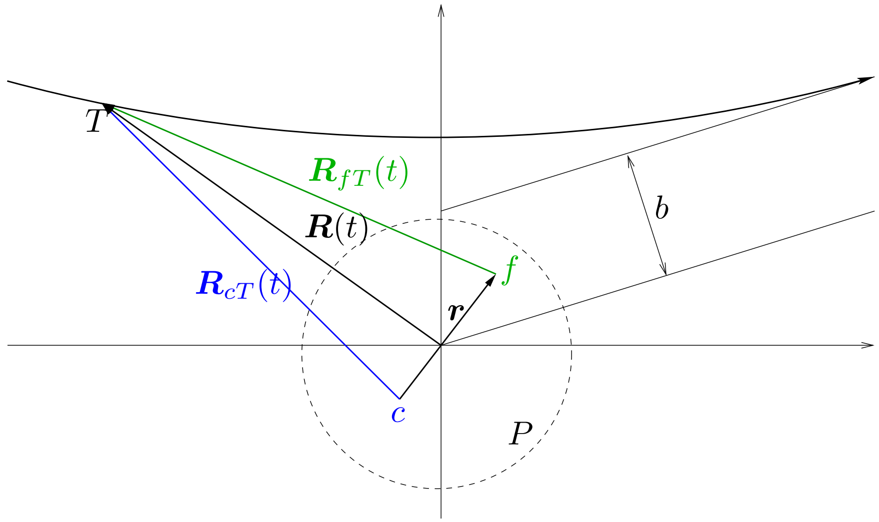
the coupling interactions are

$$V_{\alpha\beta}(\boldsymbol{R}) = \langle\phi_\alpha|V_{cT}(R_{cT}) + V_{fT}(R_{fT})|\phi_\beta\rangle$$

Time-dependent

The Time-dependent method: semiclassical approx.

Target follows
classical trajectory $\boldsymbol{R}(t)$
(straight lines)



P-T interaction modelled by
time-dependent potential

$\Rightarrow$ Resolution of TDSE:

$$i\frac{\partial}{\partial t}\Psi^{\mathrm{TDSE}}(\boldsymbol{r},t) = \left[H_0 + V_{cT}(t) + V_{fT}(t)\right]\Psi^{\mathrm{TDSE}}(\boldsymbol{r},t)$$

TDSE has been improved to the dynamical eikonal approximation Baye, PC, Goldstein PRL 95, 082502 (2005)
(see Daniel Baye's seminar)

^{8}B

^{8}B: Candidate one-p halo nucleus

modelled as ^{7}Be$(3/2^-)$+p

2^+	-0.137	$0p3/2$

Its Coulomb breakup used to infer S_{17}

Its breakup on ^{58}Ni at 26 MeV measured at ND

Guimarães *et al.* PRL 84, 1862 (2000)

CDCC calculation in good agreement with experiment

Tostevin, Nunes, Thompson PRC 63, 024617 (2001)

Sensitvity of the calculation to ^{7}Be-p potential?

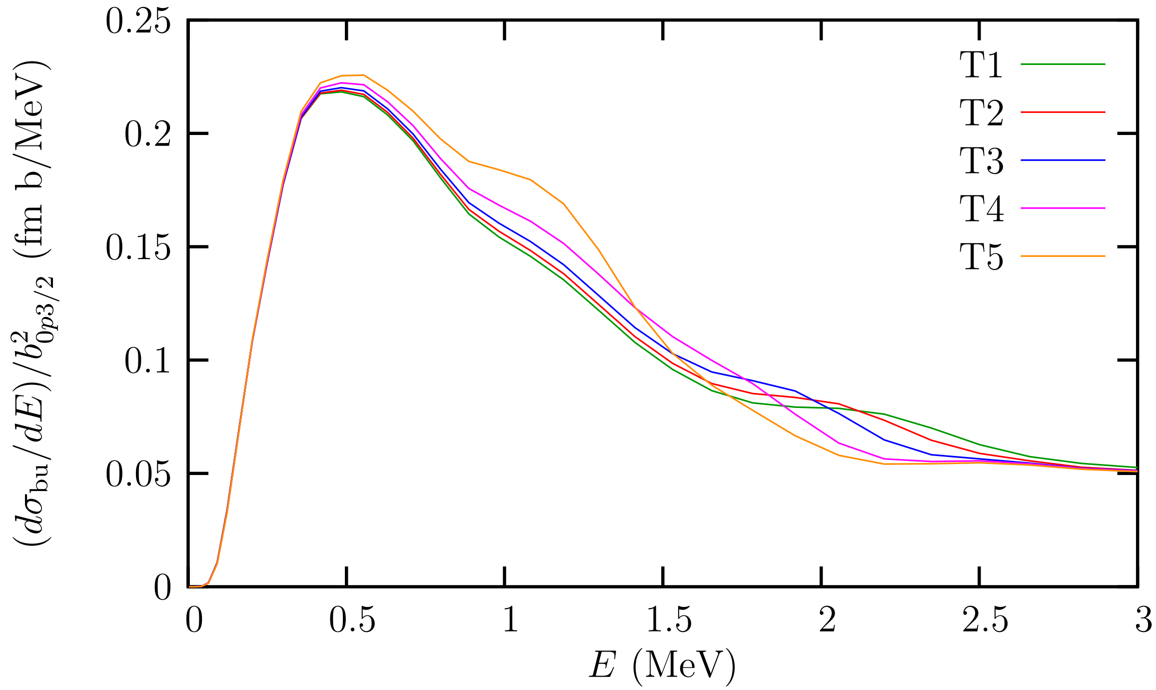
Calculations within CDCC approach

5 potentials based on Esbensen, Bertsch NPA 600, 37 (1996)

WS with different a (T1–T5) reproducing only the gs

they also exhibit an unfitted $p1/2$ resonance

^{8}B breakup on ^{58}Ni @ 26MeV



$\sigma_{\rm bu}$ approximately $\propto$ ANC^2 $\Rightarrow$ peripheral reaction

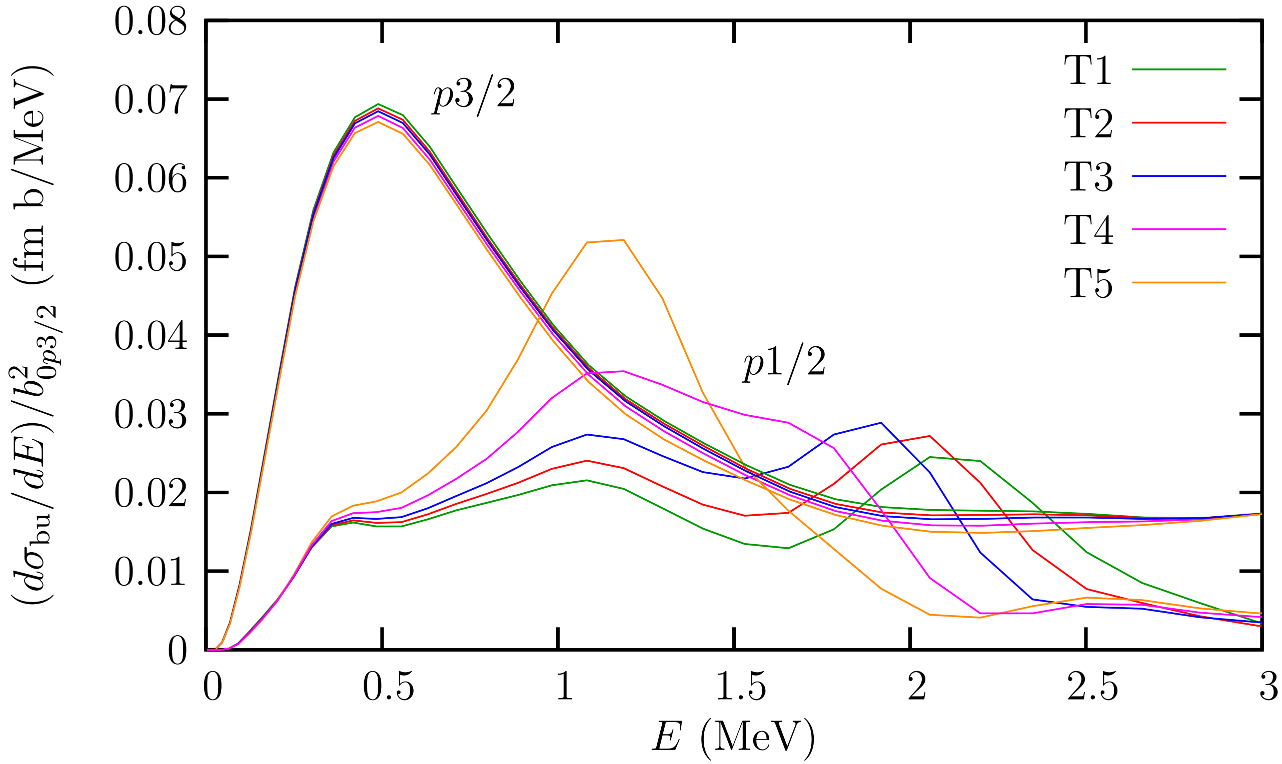
But bumps above 0.5 MeV

If Coulomb waves describe the continuum,

- No bumps
- $\sigma_{\rm bu}$ exactly $\propto$ ANC^2

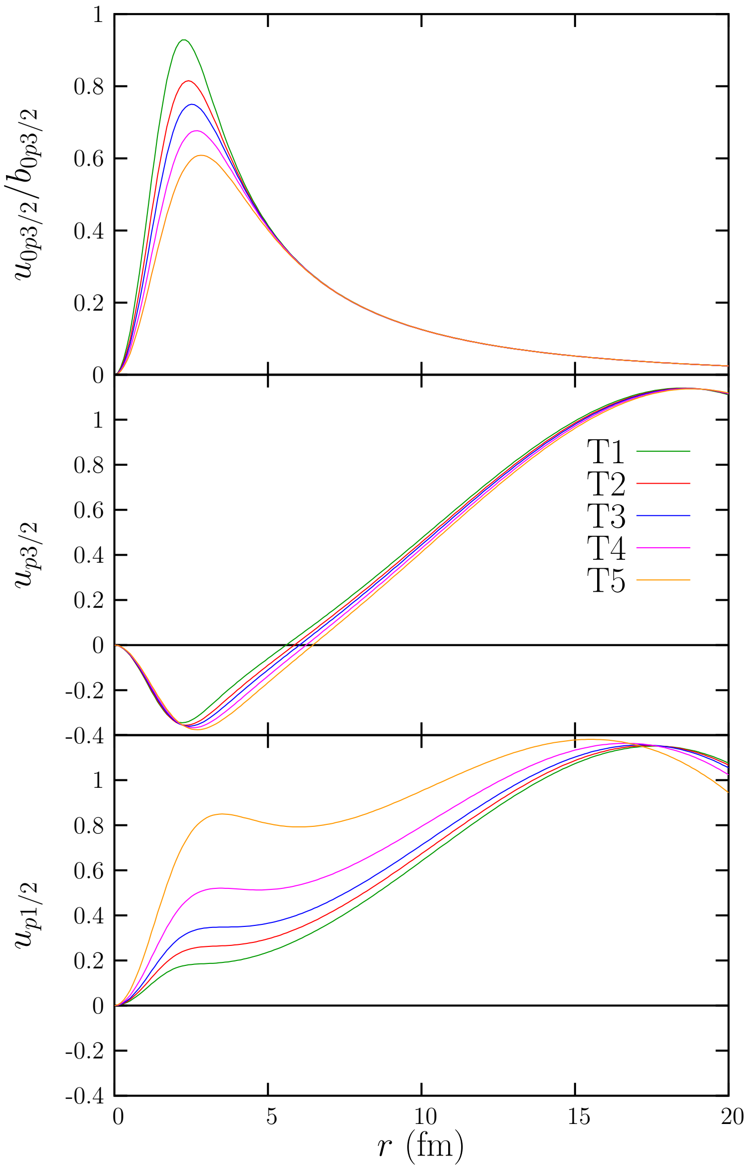
$\Rightarrow$ continuum plays a role

^{8}B: partial-wave contributions



- Dominant $p3/2 \propto \mathrm{ANC}^2$
- Bumps only in $p1/2$ due to unfitted resonance
- Same in DWBA $\Rightarrow$explained by 1-step transitions $\Rightarrow$little influence of couplings in the continuum

^{8}B: first-order analysis



- gs $\propto$ ANC above 5 fm
  $\sigma_{\rm bu} \propto$ ANC^2 when
  Coulomb waves
  $\Rightarrow$ peripheral
- $p3/2$:
  not much differences
  $\Rightarrow$explains the $\propto$ ANC^2
- $p1/2$:
  large differences
  due to $p1/2$ resonance

Differences in $\sigma_{\rm bu}$ explained by gs and continuum

^{11}Be

^{11}Be: best known one-n halo nucleus
modelled as ^{10}Be(0^+)+n

$5/2^+$	1.274	$d5/2$
$1/2^-$	-0.184	$0p1/2$
$1/2^+$	-0.504	$1s1/2$

Breakup on Pb and C at $70A$MeV measured at RIKEN

Fukuda *et al*. PRC 70, 054606 (2004)

They find $C^2S(^{10}\mathrm{Be}(0^+) \otimes s1/2)$=0.7

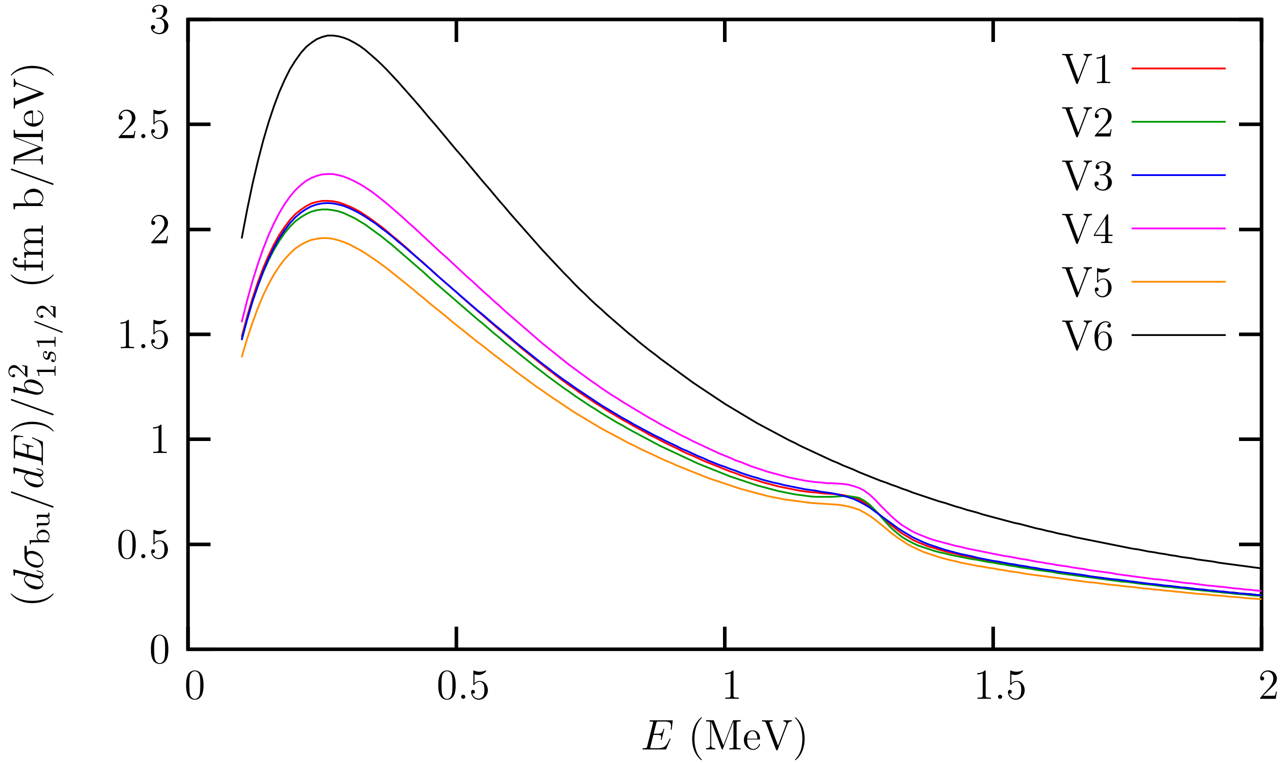
Sensitivity of this figure to ^{10}Be-n potential?

Calculations with time-dependent model

5 potentials [WS with different r_0 and a (V1–V5)]
they reproduce the first 3 states
+ potential of Fukuda *et al*. (V6)

it reproduces only the ground state

^{11}Be breakup on Pb @ $69A$MeV



Large differences $\Rightarrow C^2S$ questionable

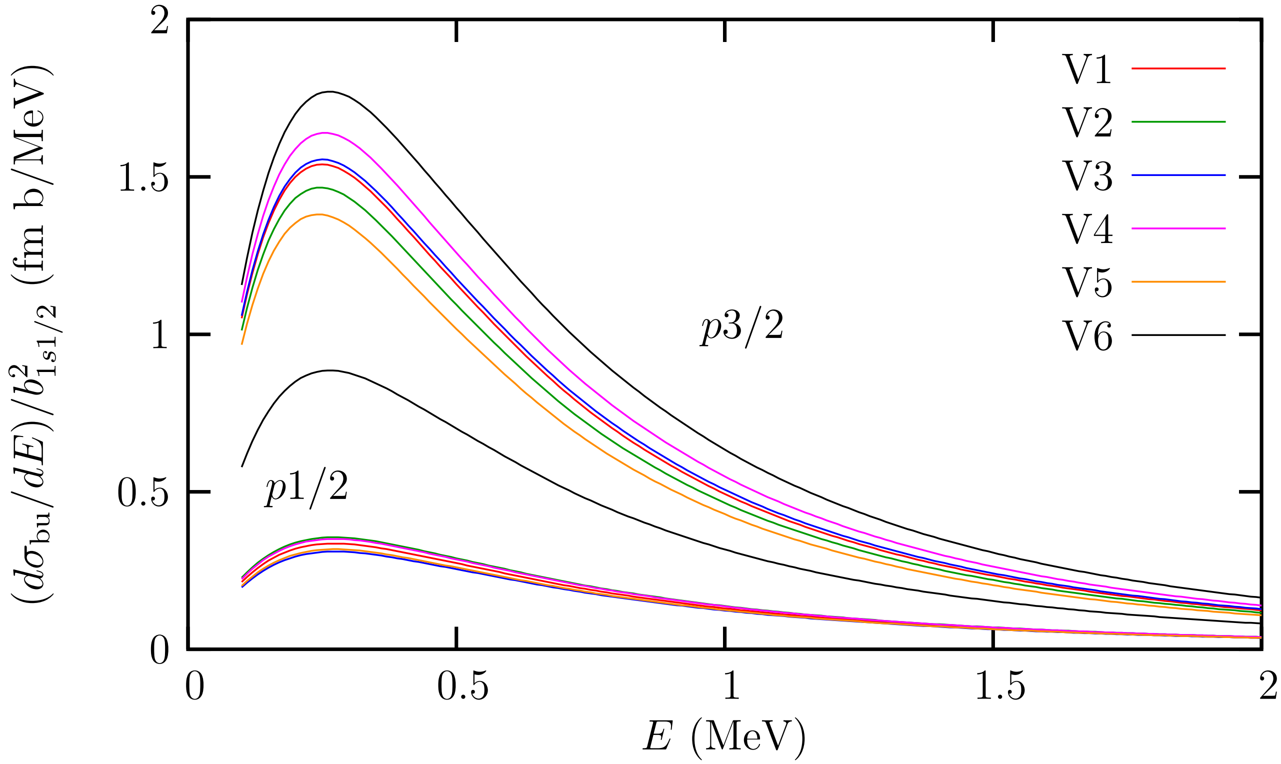
$\sigma_{\rm bu}$ NOT $\propto$ to ANC^2

Bump at 1.3 MeV due to $d5/2$ resonance

Using plane waves $\Rightarrow \sigma_{\rm bu} \propto$ ANC^2

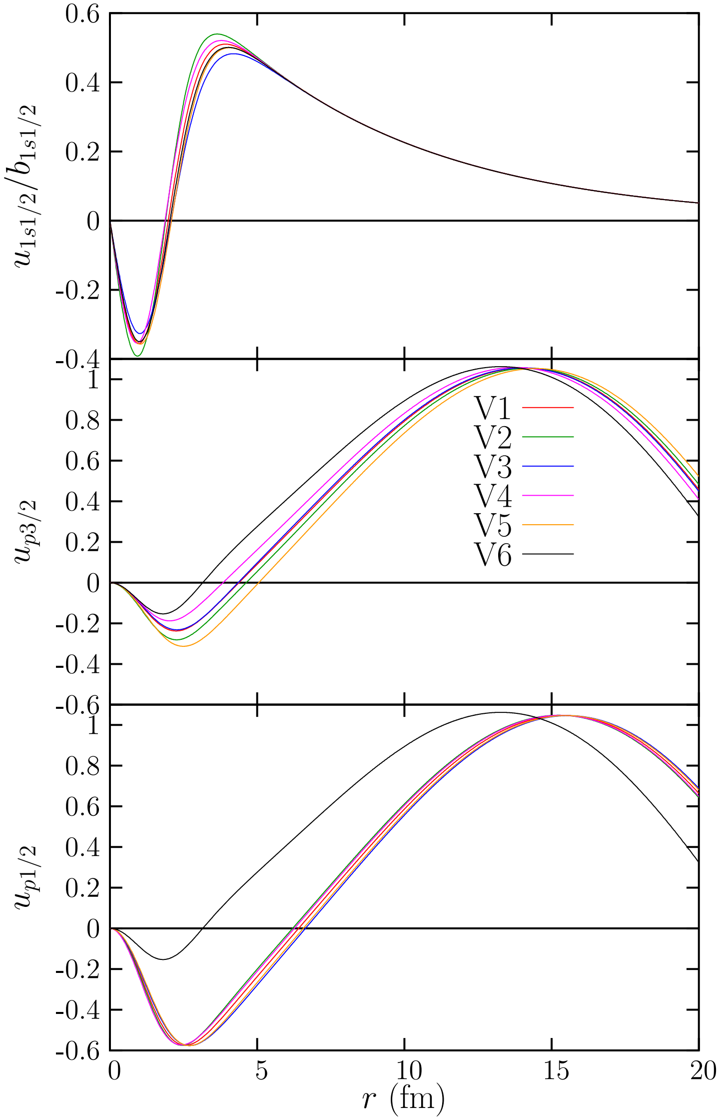
$\Rightarrow$ influence of continuum

^{11}Be: partial-wave contributions



- Dominant $p3/2$ contains the difference in V1–V5
- $p1/2$ approximatively $\propto$ ANC^2 but for V6
- Same result at first-order
  $\Rightarrow$ explained by 1-step transition

^{11}Be: first-order analysis



- gs $\propto$ ANC above 5 fm
  $\sigma_{\text{bu}} \propto \text{ANC}^2$ when
  plane waves $\Rightarrow$peripheral
  $\Rightarrow C^2S$ questionable
- $p3/2$:
  large differences
  in phase shift
- $p1/2$:
  V1–V5 small differences
  but V6 very different
  due to $p1/2$ bound state

Differences in σ_{bu} explained by differences in δ_{lj}
$\Rightarrow$ breakup probes ground state and the continuum

Constraining the continuum

Breakup of loosely bound nuclei is peripheral
$\Rightarrow \sigma_{\mathrm{bu}}$ sensitive to ANC of gs AND to phase-shifts

Adjusting the potential to gs is not sufficient
Need to constrain the continuum description

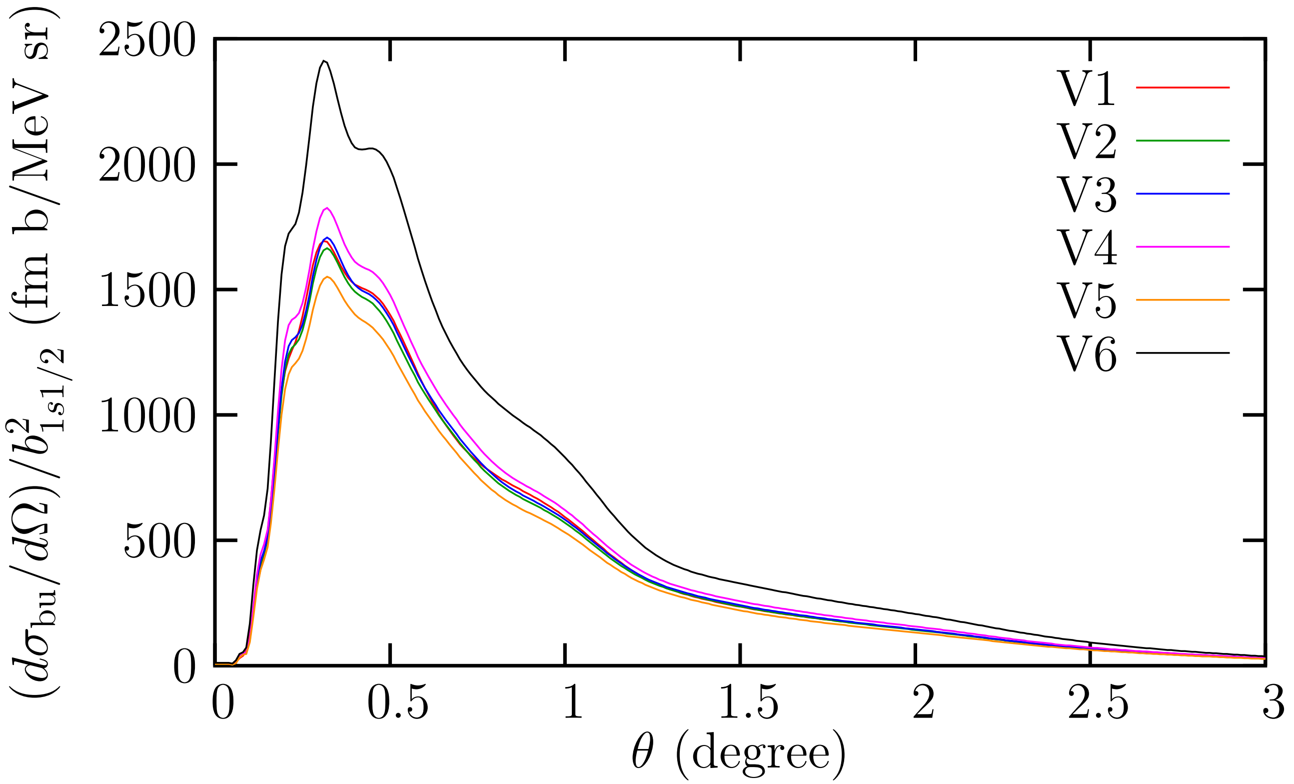
Adjusting excited states constrains phase-shifts
Is this accurate?

Unfortunately scattering data are scarce

$\Rightarrow$other observables (angular distributions,...)?

$\Rightarrow$other reactions (nuclear breakup,...) ?

^{11}Be: angular distribution



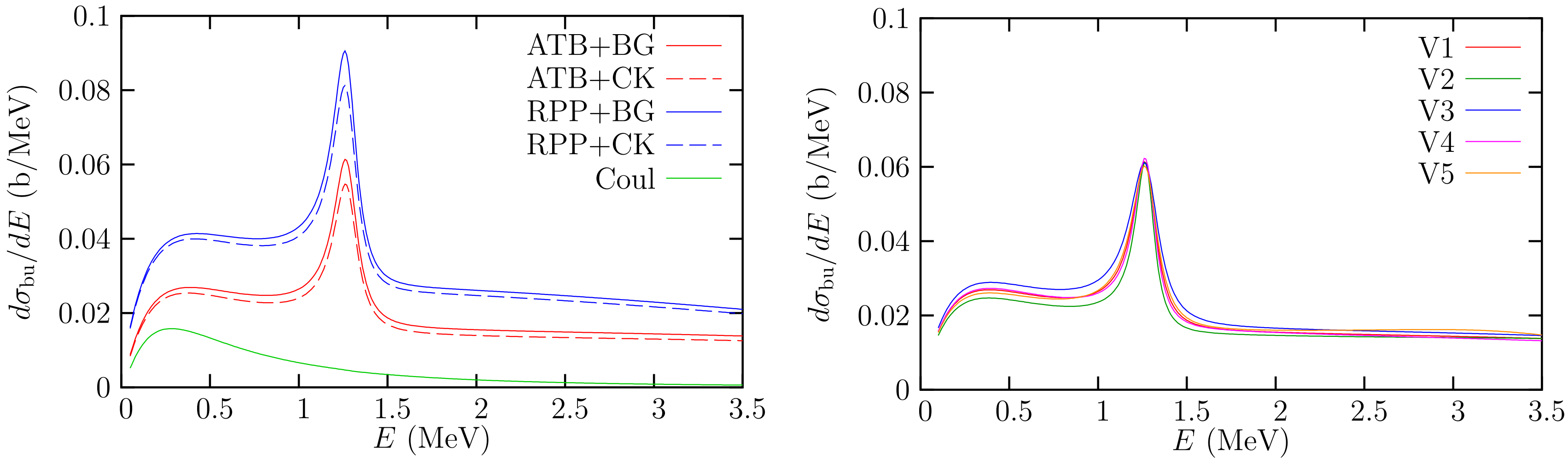
- Same shape for all potentials
- Change in amplitude similar to $\sigma_{\rm bu}$

$\Rightarrow$Angular distribution does not constrain continuum

^{11}Be breakup on C @ $68A$MeV

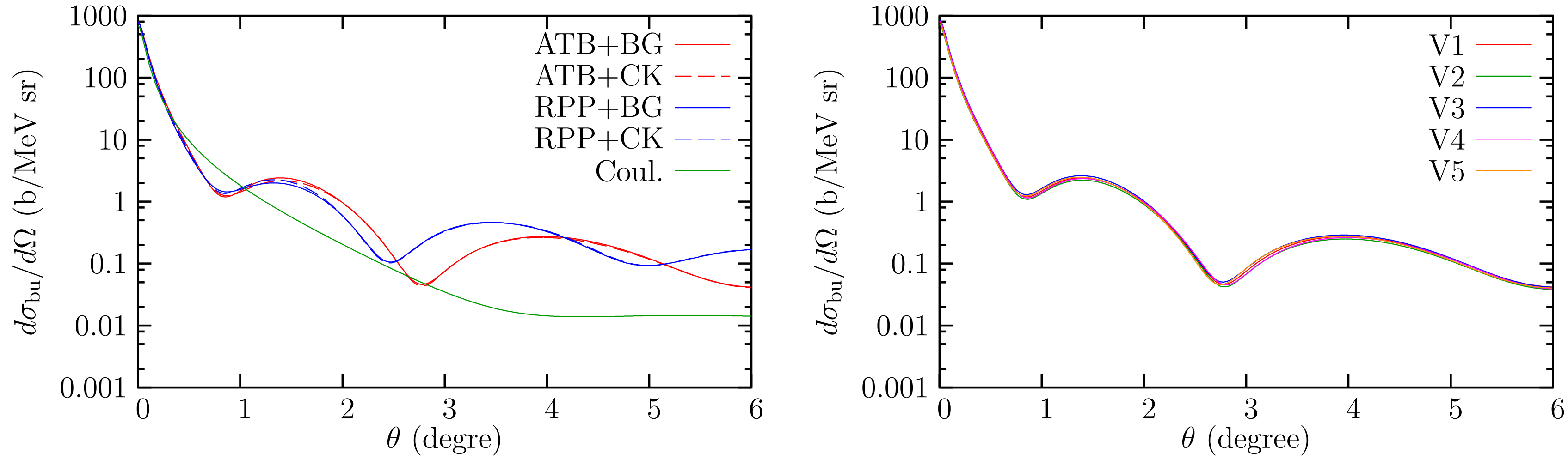
Measured at RIKEN Fukuda *et al.* PRC 70, 054606 (2004)

Calculated in PC, Goldstein, Baye PRC 70, 064605 (2004)



- Breakup is nuclear dominated ⇒sensitive to V_{PT}
- Breakup on light target is also sensitive to V_{cf} but same difference ⇒no additional information
- Sensitivity to V_{cf} smaller than to V_{PT}

^{11}Be + C: angular distribution



- Large sensitivity to optical potentials
- All V_{cf} potentials lead to similar angular distribution: small difference in amplitude

$\Rightarrow$Angular distribution on light target
does not constrain the continuum

But can constrain V_{PT}

Conclusion

- Analysis of the sensitivity of breakup calculations on V_{cf} for ^{11}Be and ^{8}B
- $\sigma_{\rm bu}$ depends significantly on the potential choice even if fitted on same levels
- Influence of both bound and scattering states
- Coulomb reaction mostly peripheral
  $\Rightarrow$ depends on asymptotic part of wave functions
  $\Rightarrow C^2S$ questionable

$\Rightarrow$ Continuum must be constrained
to extract information from breakup measurements
Since direct measurement is difficult
perhaps other observables/reactions can be used?