INFN LNS
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Sud

Investigations of proton-halo effects with ^{8}B beam

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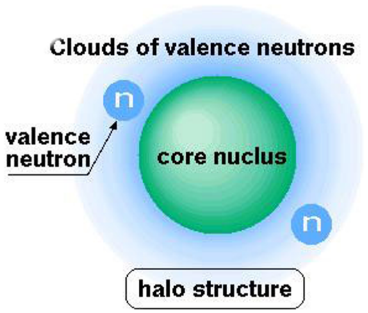
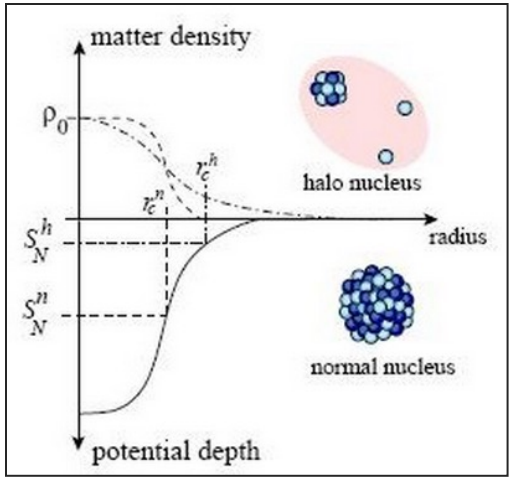
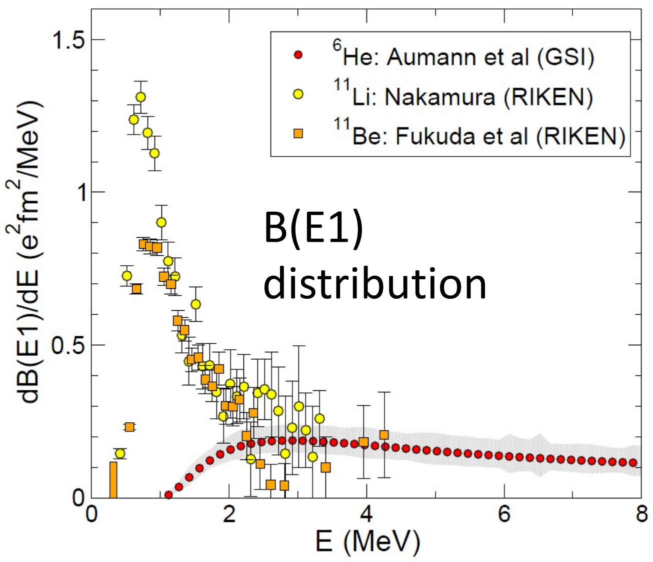
INFN-Laboratori Nazionali del Sud

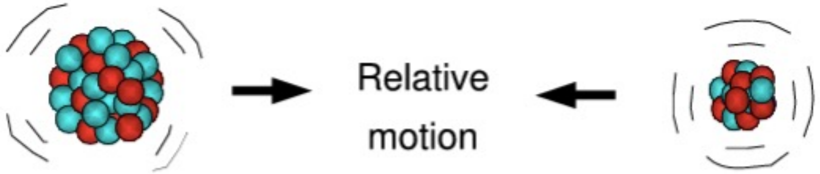
Halo nuclei: how nuclear halo influences reactions?





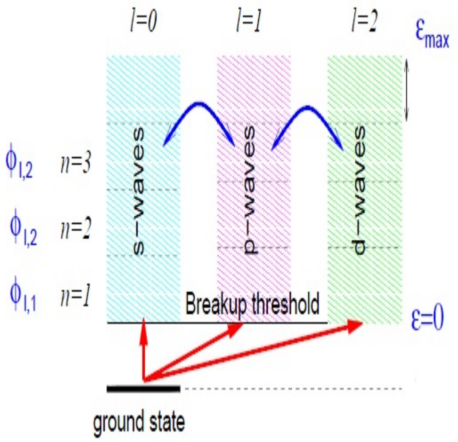


- Weakly bound (easy to break-up)
- Easy to polarise (large B(E1) low energy strenght)
- Suffer lower Coulomb barrier
- Higher transfer cross-section?



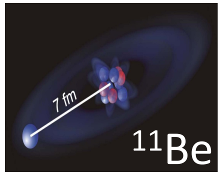
Coupling between relative motion and intrinsic excitation relevant at low energy.

g.s. close to the continuum → important to include coupling to the continuum in reaction dynamics –> CDCC

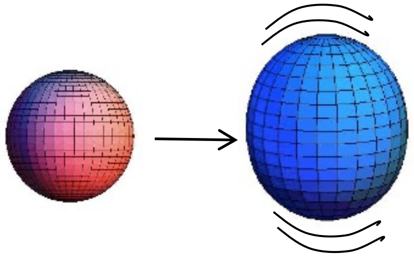


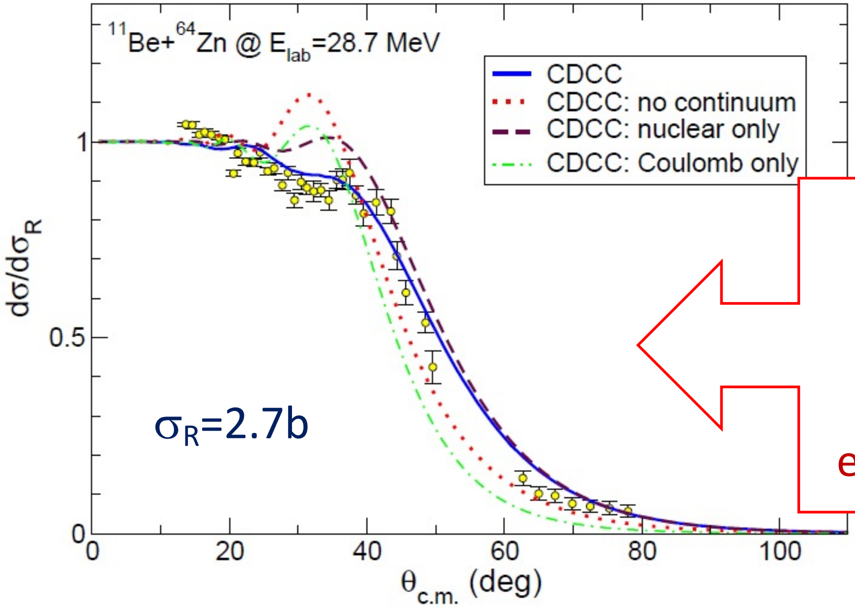
Elastic Scattering

The neutron halo case



$^{11}Be+^{64}Zn$ elastic angular distribution



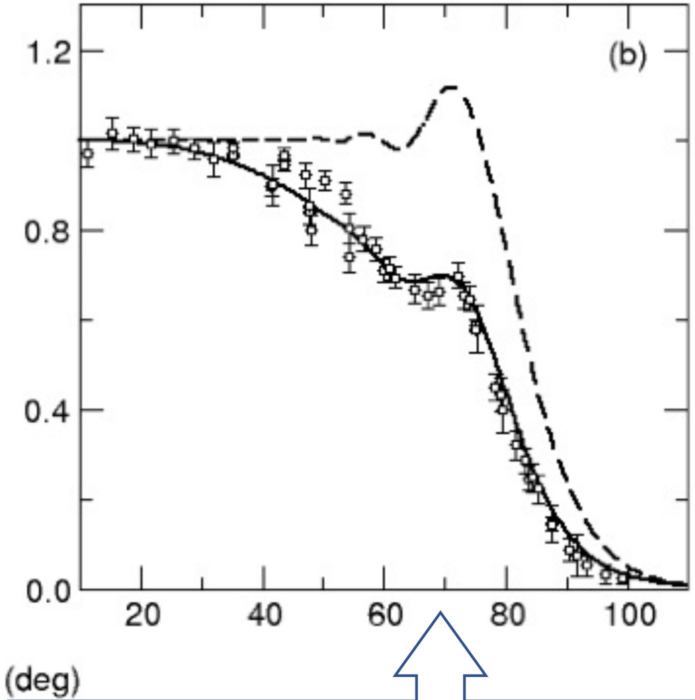


Both Coulomb and nuclear break-up important. Long range absorption due to extended nuclear matter

A. Di Pietro et al. Phys. Rev. Lett. 105, 022701(2010)
A. Di Pietro et al. Phys. Rev. C 85, 054607 (2012)

$^{18}O + ^{184}W$

W.G. LOVE, T. TERASAWA, G.R SATCHLER NPA291 (1977) 183



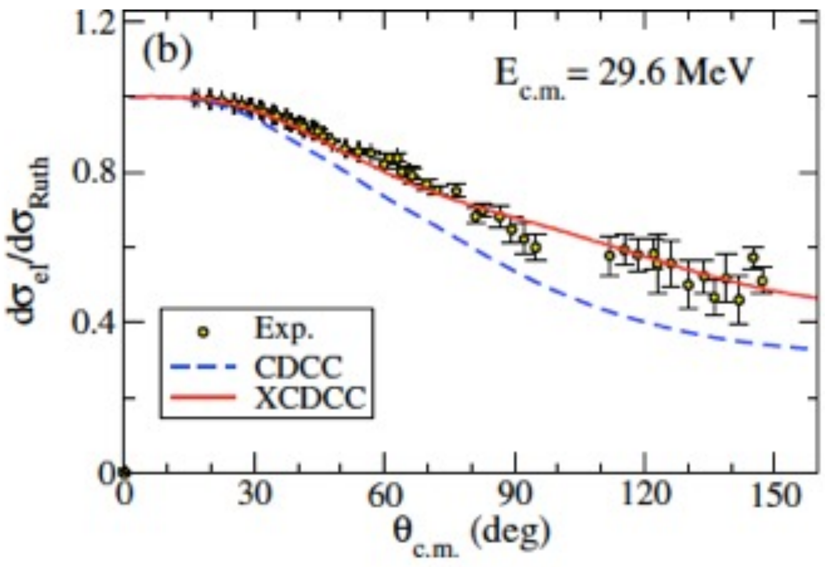
Long-range absorption due to coupling with quadrupole states of deformed target → long range Coulomb interaction

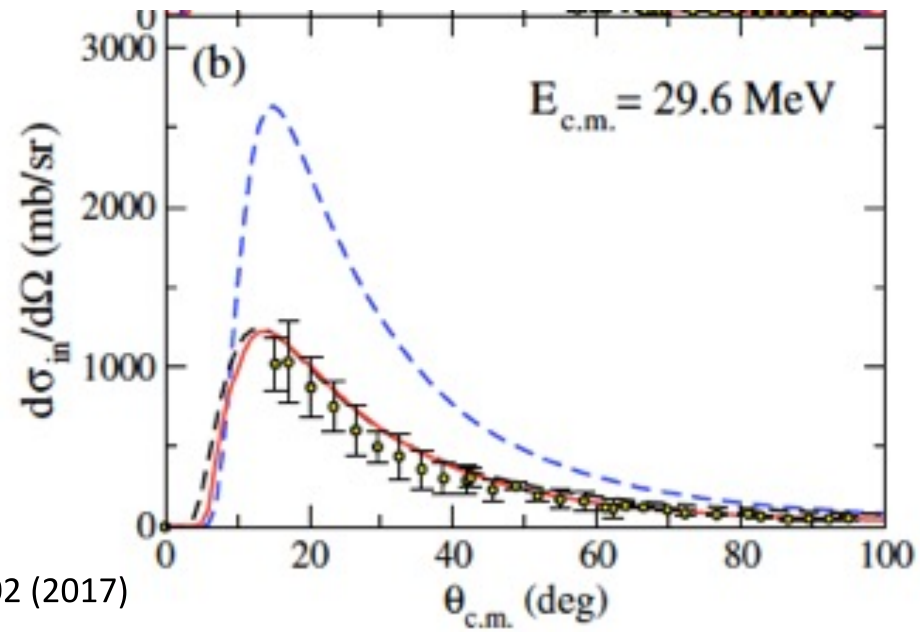
The importance of core-excitation

Elastic scattering

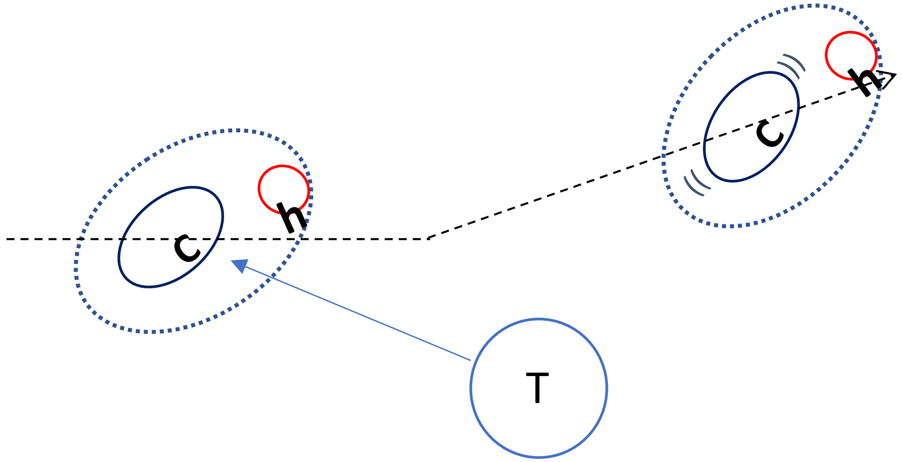
$^{11}Be+^{197}Au$ @ TRIUMF

$^{11}Be^{*}_{1/2-}+^{197}Au$



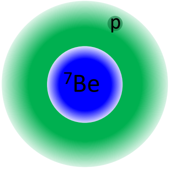


V. Pesudo et al. Phys. Rev. Lett. 118, 152502 (2017)



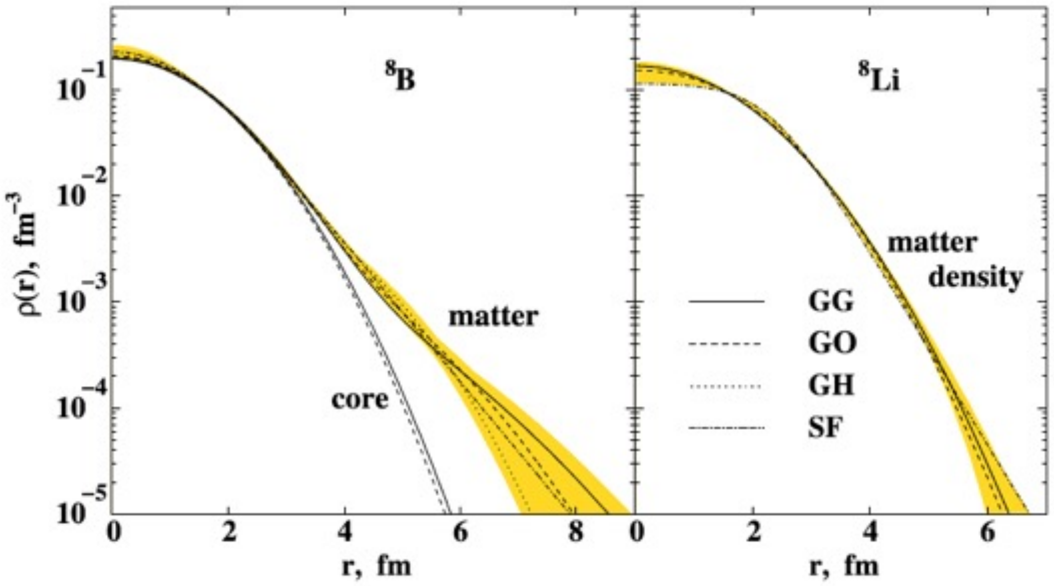
CDCC accounts of halo degrees of freedom. Coupling to continuum effects insufficient to reproduce the experimental data.

XCDCC accounts for both the halo and core degrees of freedom. The structure model accounts for the appropriate admixture of 0+ and 2+ components in the ^{10}Be core.



^{8}B extremely low binding energy
Sp=0.14 MeV
p-wave valence proton

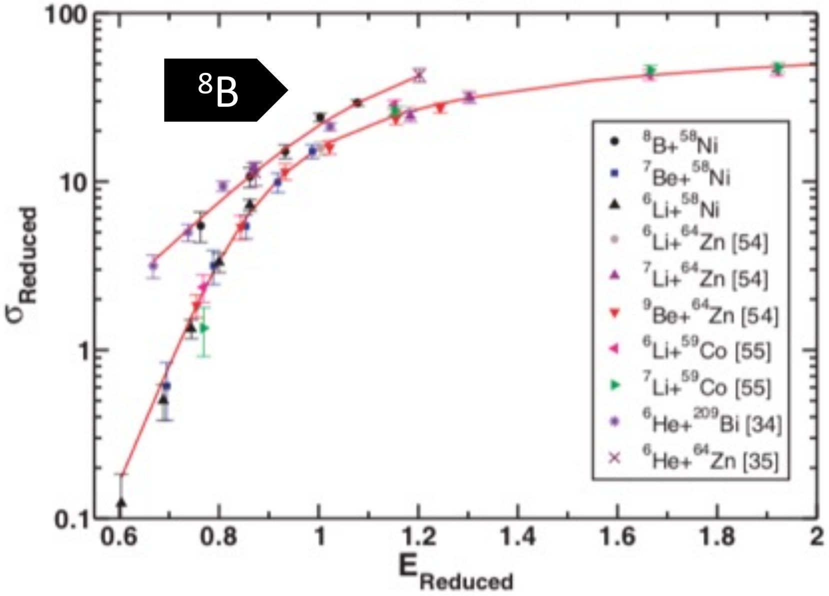
^{8}B *vs* ^{8}Li density distribution



G.A. Korolev et al. Phys.Lett. B 780 (2018) 200

In-flight ^{8}B beam @ Notre Dame

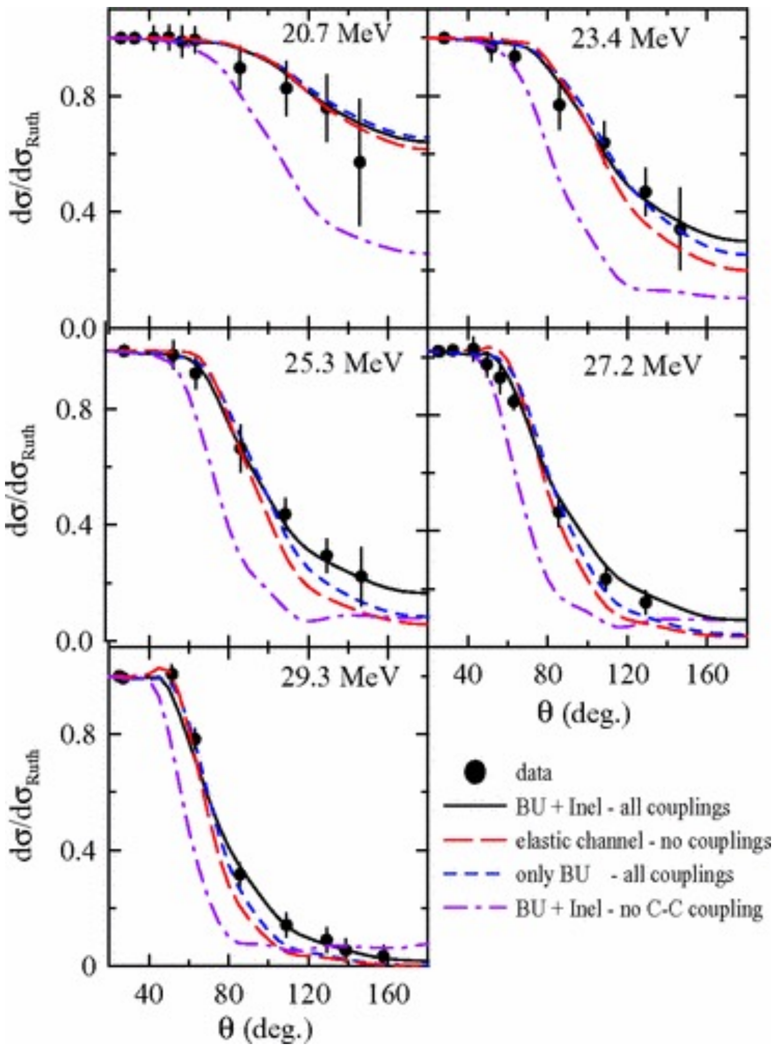
$^{8}B+^{58}Ni$ @ 20 - 30 MeV



Small effects on elastic scattering however large total-reaction cross-section extracted from elastic data.

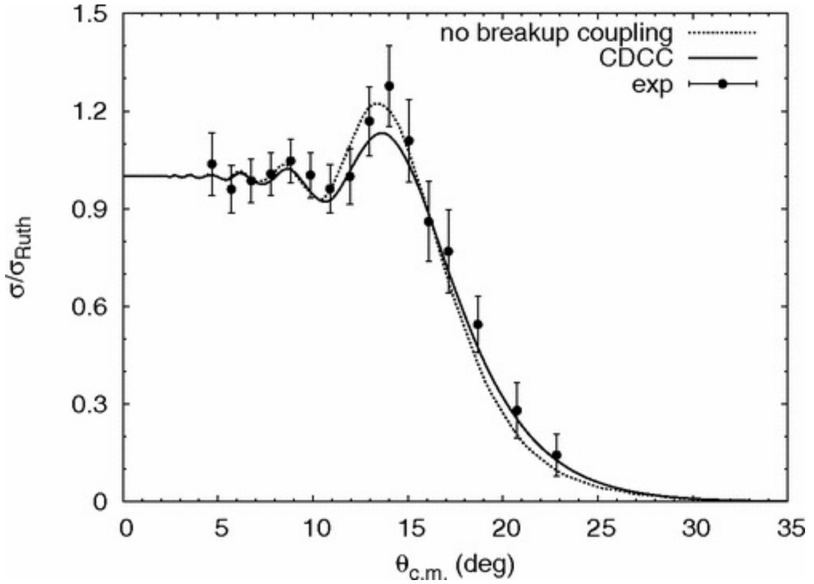
Found similar trend as for n-halo nuclei

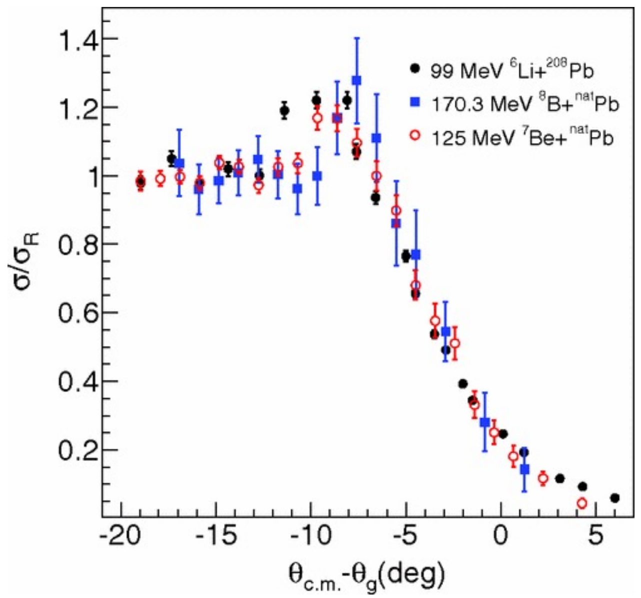
E. Aguilera et al. Phys. Rev. C 79 (2009) 021601



J. Lubian et al Phys. Rev. C 79, 064605 (2009)
data from E.F. Aguilera et al. PR C 79, 021601(R) 2009

^{8}B+^{208}Pb@ RIBLL

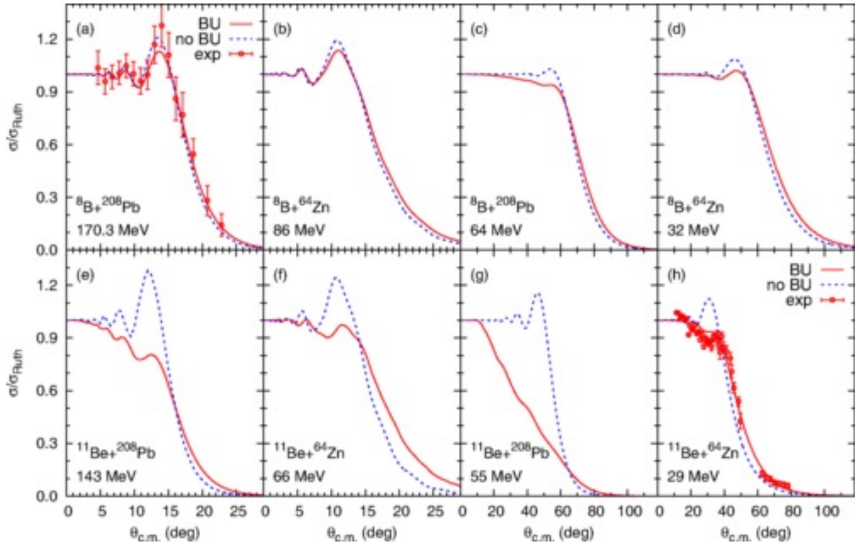




Y. Y. Yang *et al.* Phys. Rev. C **87**, 044613, 2013

^{8}B

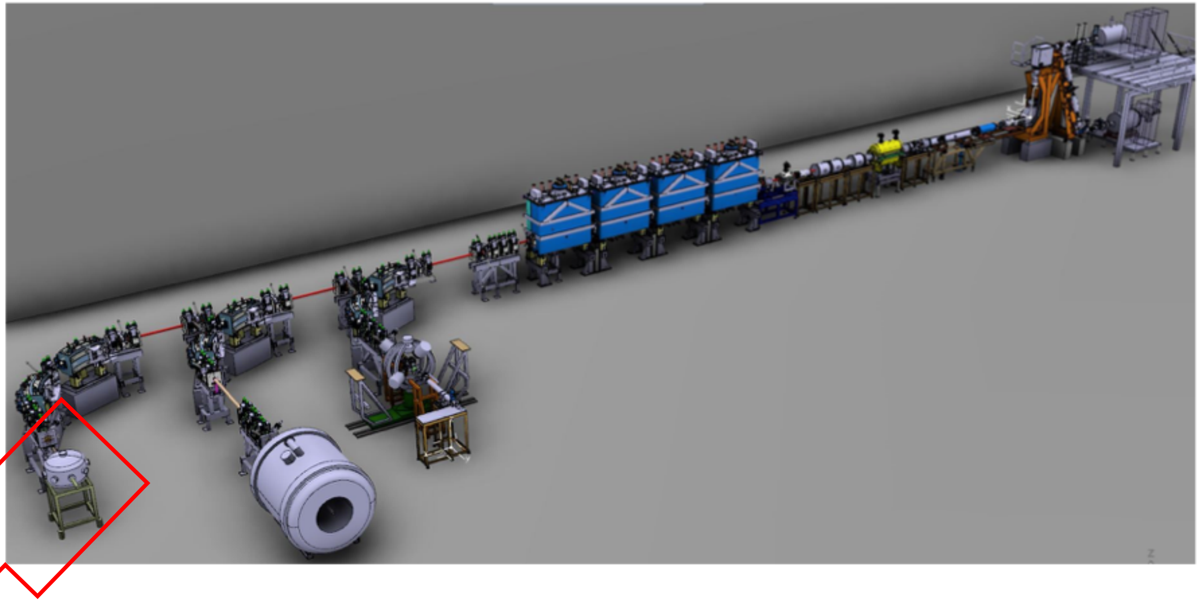
^{11}Be



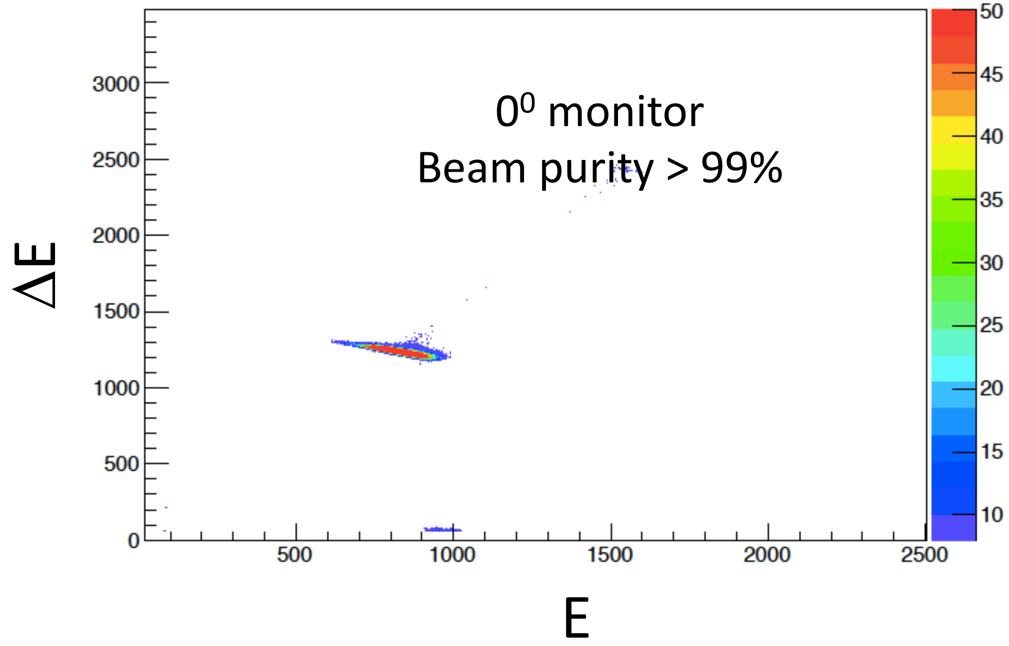
Calculations show independence on beam energy and target charge

Y. Y. Yang, X. Liu, and D. Y. Pang
Phys. Rev. C **94**, 034614, 2016

First ISOL ^{8}B beam @ HIE-ISOLDE (i ~ 400 pps)



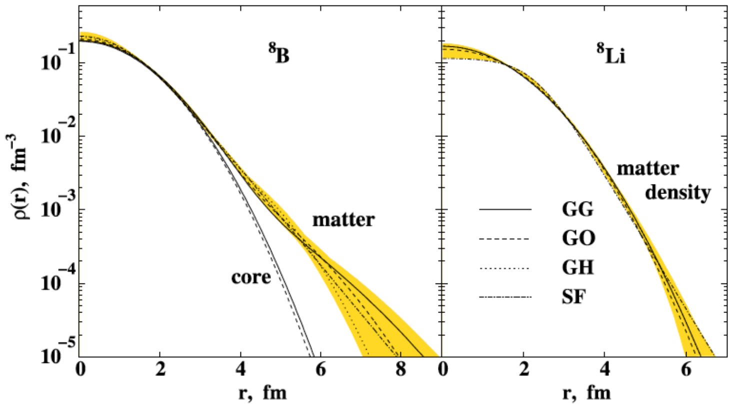
Large angular range - high granularity GLORIA detector array mounted in the SEC scattering chamber



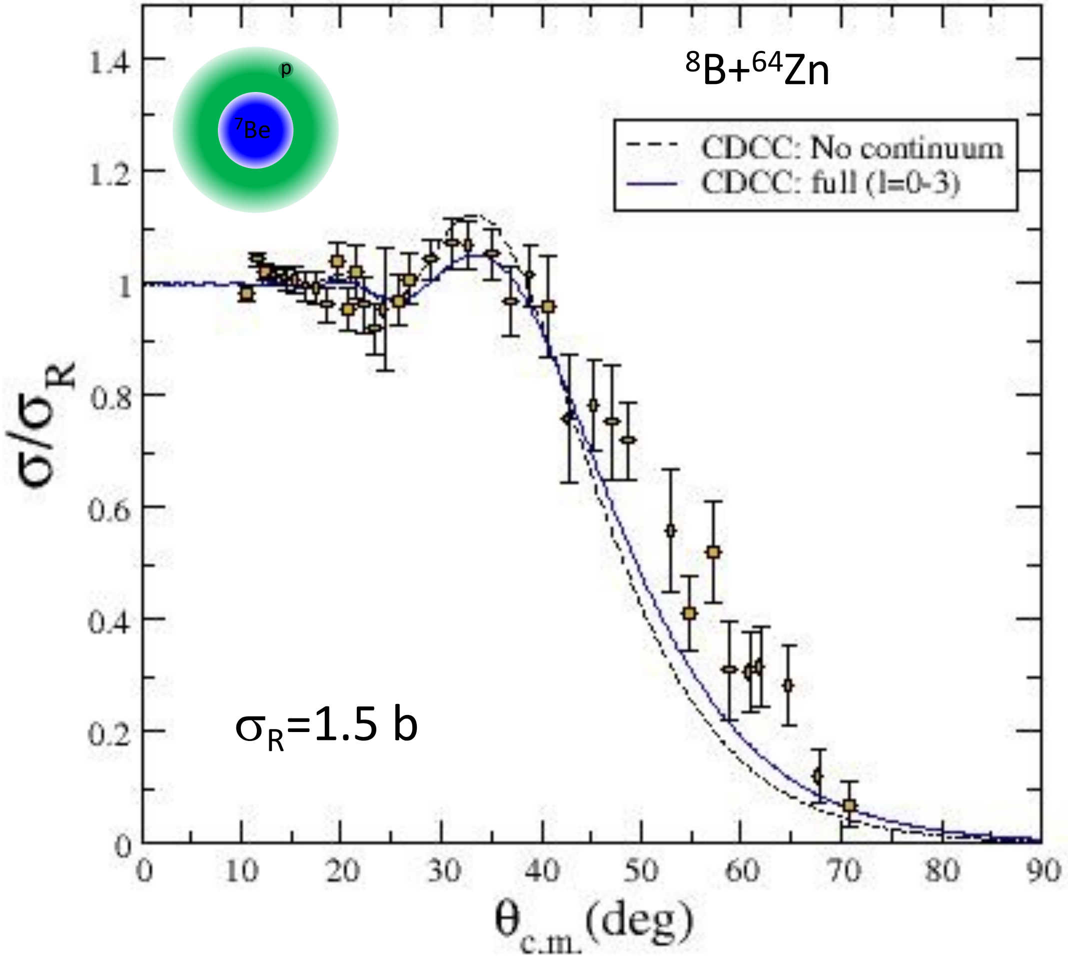
^{8}B+^{64}Zn elastic scattering

^{8}B extremely low binding energy
Sp=0.14 MeV

^{8}B *vs* ^{8}Li density distribution



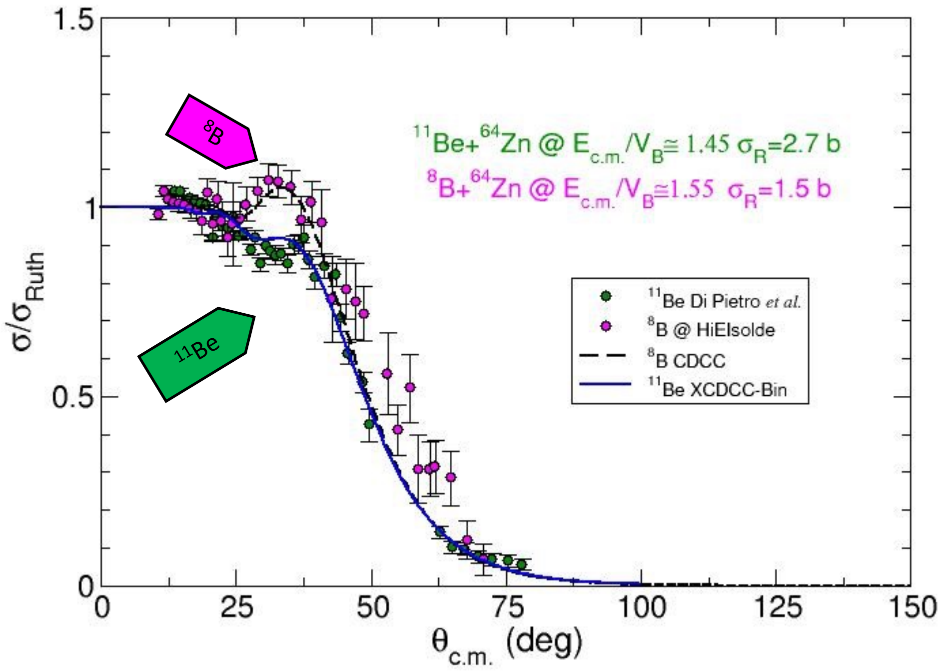
G.A. Korolev et al. Phys.Lett. B 780 (2018) 200

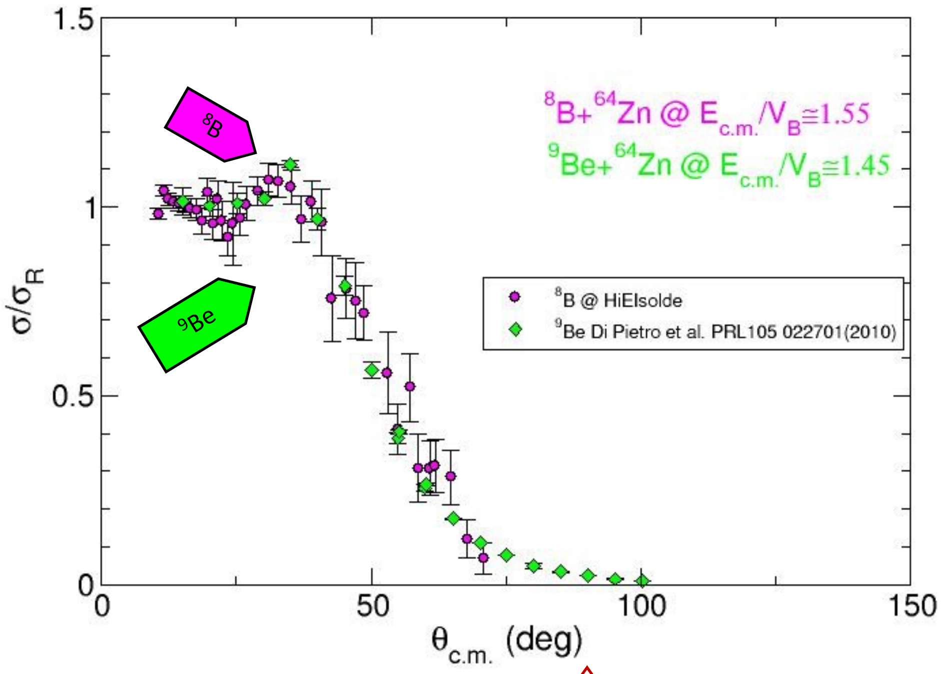


R. Spartà et al. Phys. Lett. B 820(2021)136477

^{8}B,^{11}Be+^{64}Zn: p-halo *vs* n-halo

^{8}B,^{9}Be+^{64}Zn: p-halo *vs* weakly bound



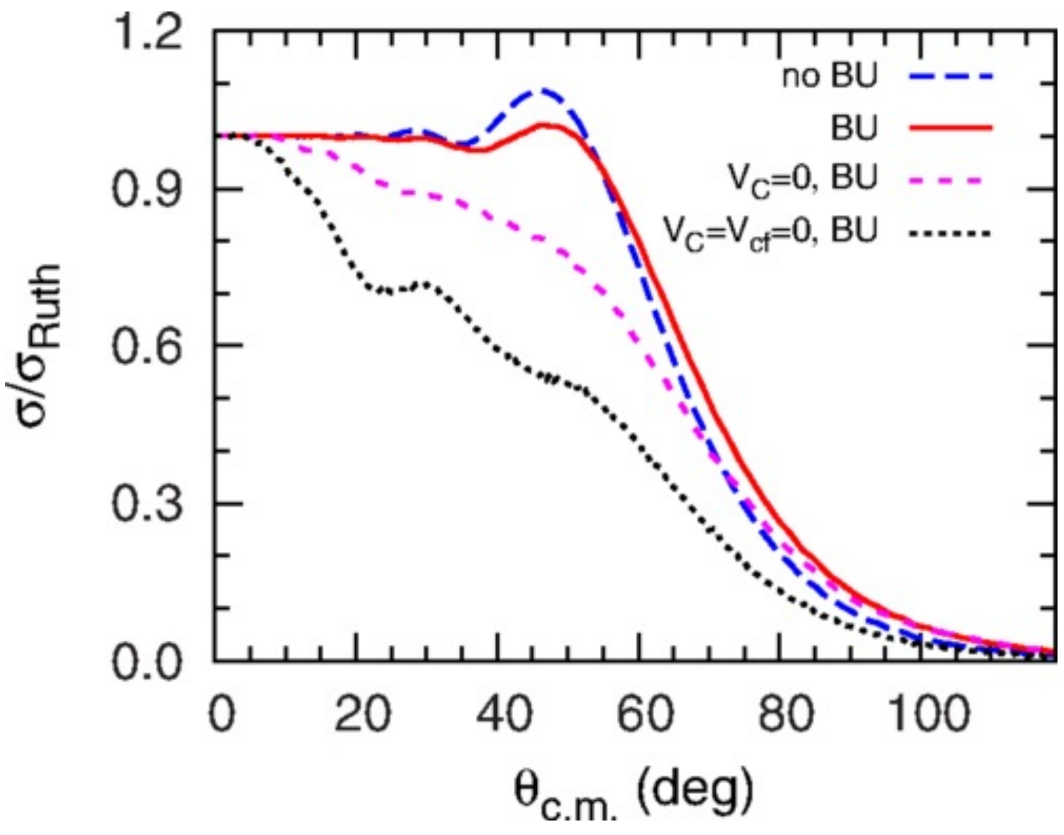


No suppression of elastic cross-section in the 'rainbow' for the p-halo.
For ^{8}B total σ_R a factor ~ 2 lower than in n-halo

Total reaction cross-section for ^{8}B+^{64}Zn σ_R ≅1.5 b similar to ^{9}Be+^{64}Zn at similar $E_{c.m.}$ / V_c
Proton halo behaves as a neutron state bound with a "normal" energy of several MeV as predicted by A. Bonaccorso et al. PRC 69, 024615 (2004)

$^{8}B+^{64}Zn$ why no elastic suppression?

$^{8}B+^{64}Zn$ @ 32 MeV

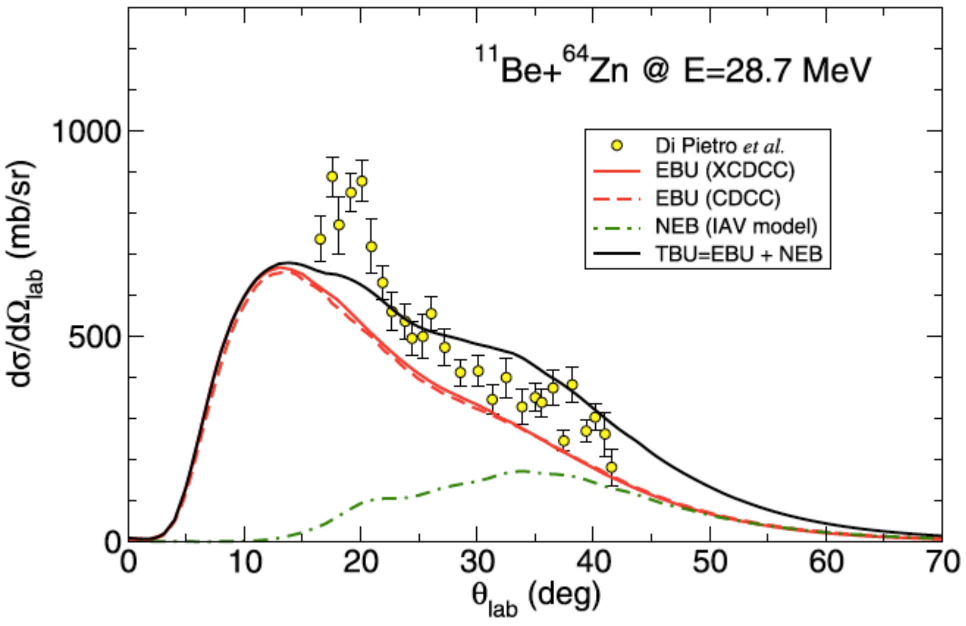


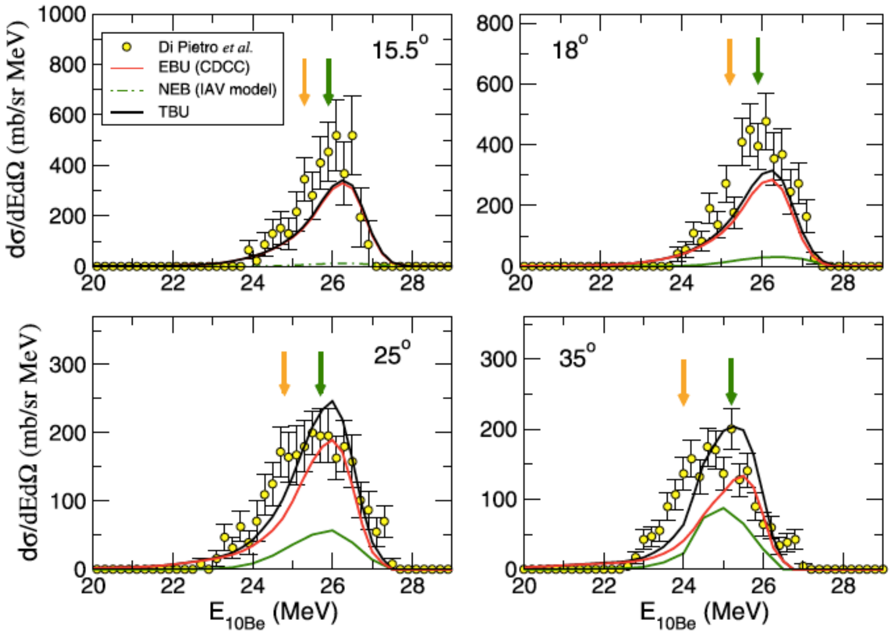
The Coulomb and centrifugal barriers experienced by the valence proton in the ground state of ^{8}B, which do not exist for the valence neutron in the ground state of ^{11}Be, are found to be the reason for the differences in the angular distributions

Y. Y. Yang, X. Liu, and D. Y. Pang Phys. Rev. C **94**, 034614, 2016

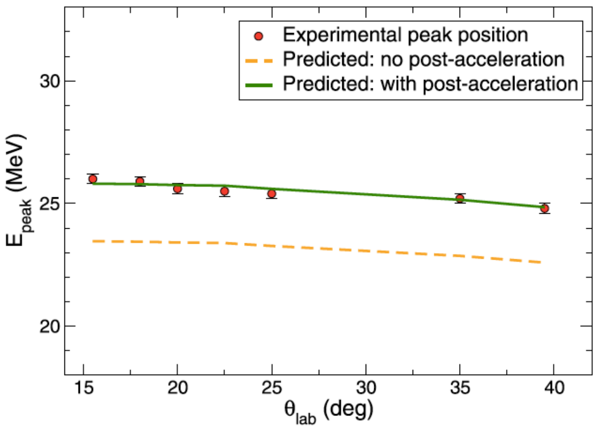
Breakup

The neutron-halo case: ^{11}Be beakup





Direct breakup dominates the breakup cross-section except at larger angles where non-elastic breackup gives a somilar contribution



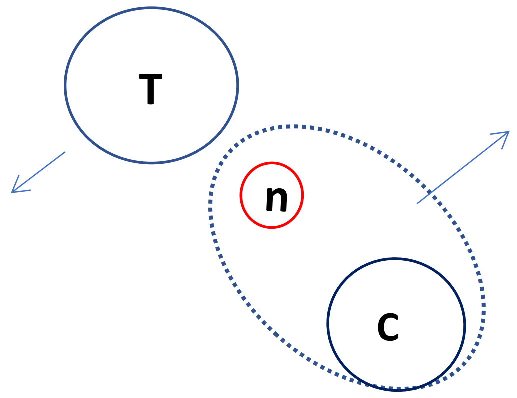
Post-acceleration effect observed in the energy distribution of the ^{10}Be fragments.

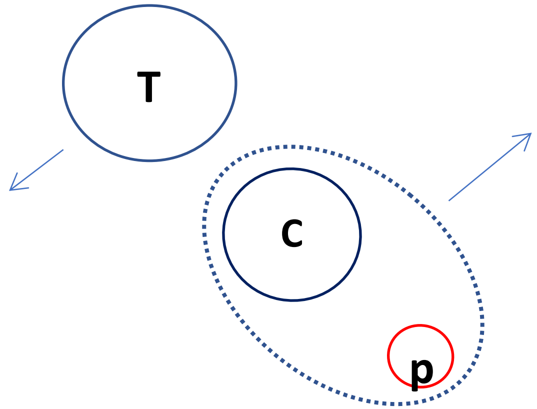
A. Di Pietro et al. / Physics Letters B 798 (2019) 134954

p-halo *vs* n-halo induced collisions

- p in the halo feels Coulomb interaction, expected dynamics different from n-halo
  (e.g. Kucuc&Moro PRC86,034601,(2012) or A.Bonaccorso et al.: PRC69,024615,(2004)).

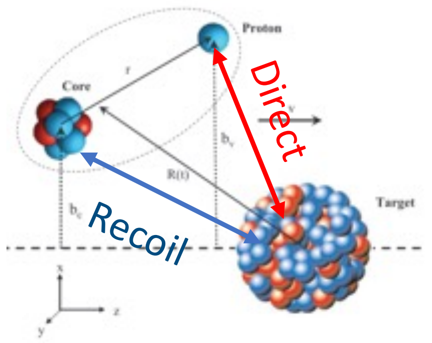
Possible semiclassical picture



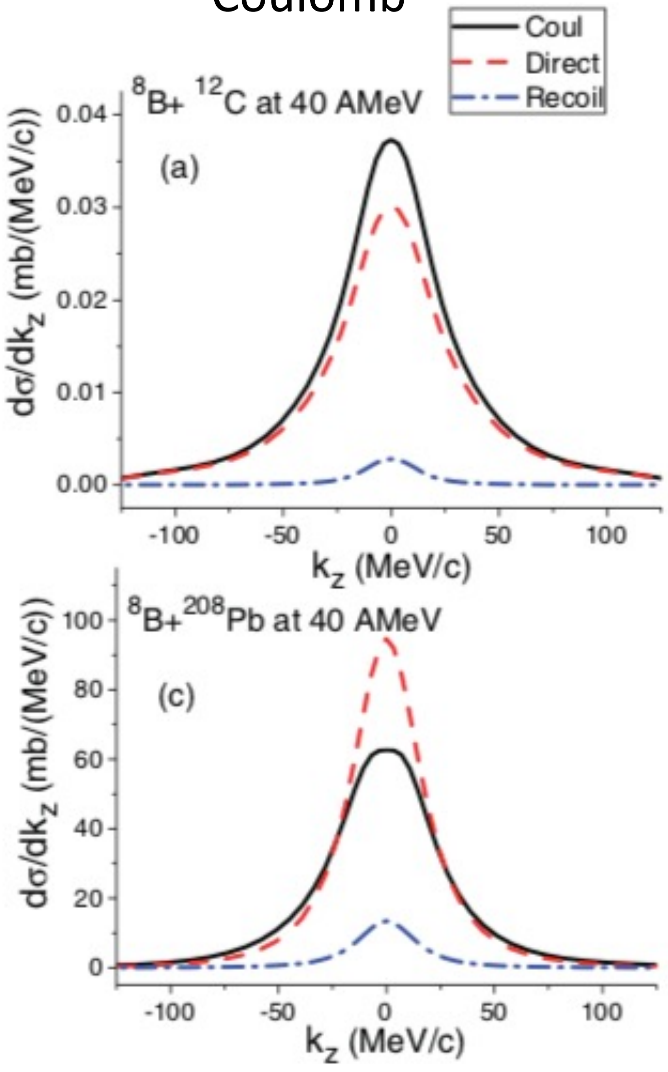


Due to a dynamic polarization effect, the valence proton is expected to be displaced behind the nuclear core and shielded from the target; this effect causes a reduction of break-up probability compared to first-order perturbation theory predictions

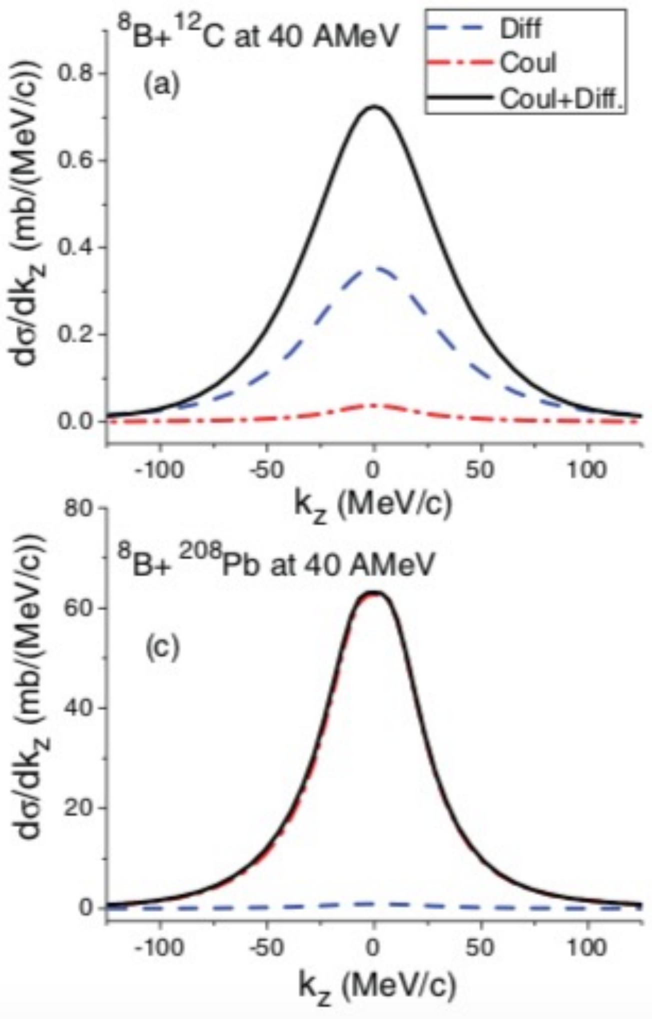
The proton-halo case



Coulomb

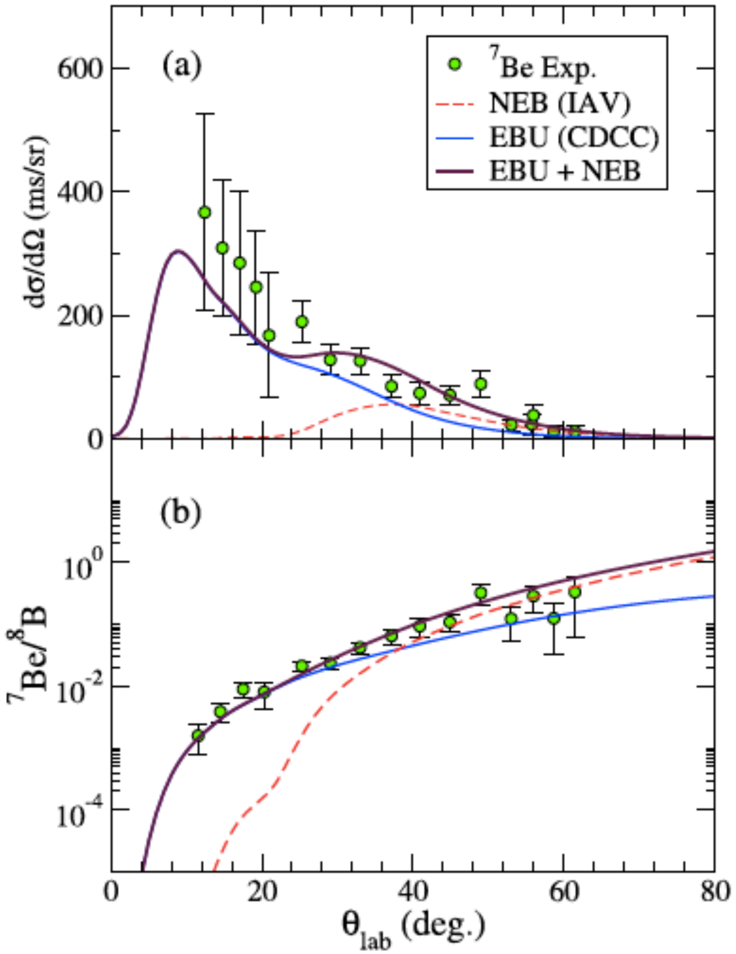


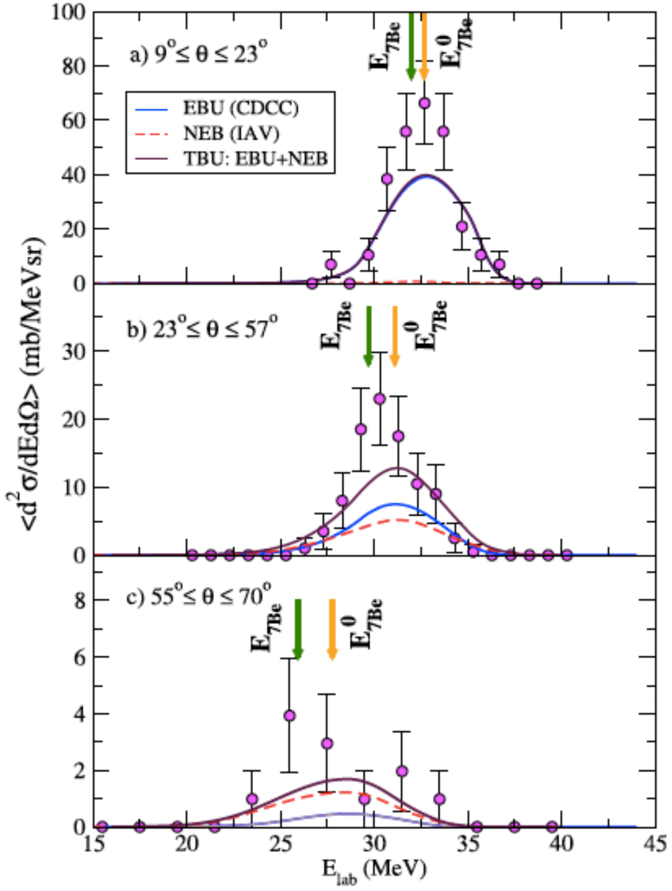
Coulomb+nuclear

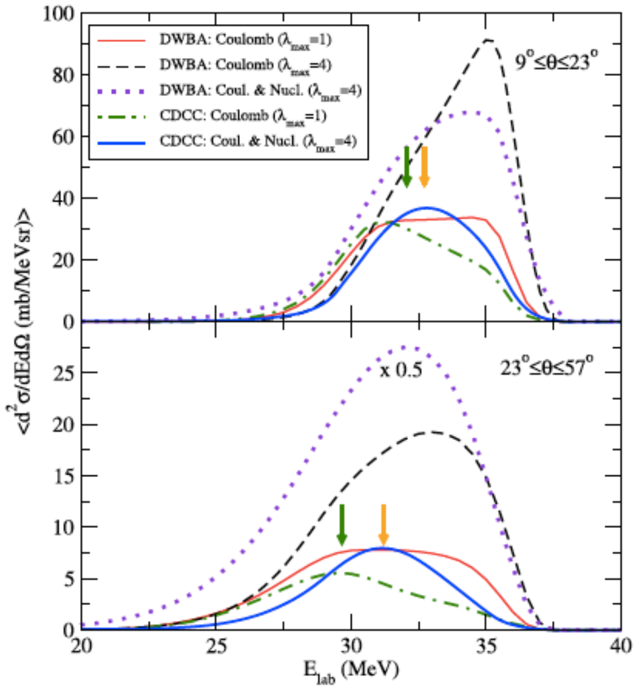


R. Kumar and A. Bonaccorso Phys. Rev. C.86.061601.2012

$^{8}B+^{64}Zn$ beakup







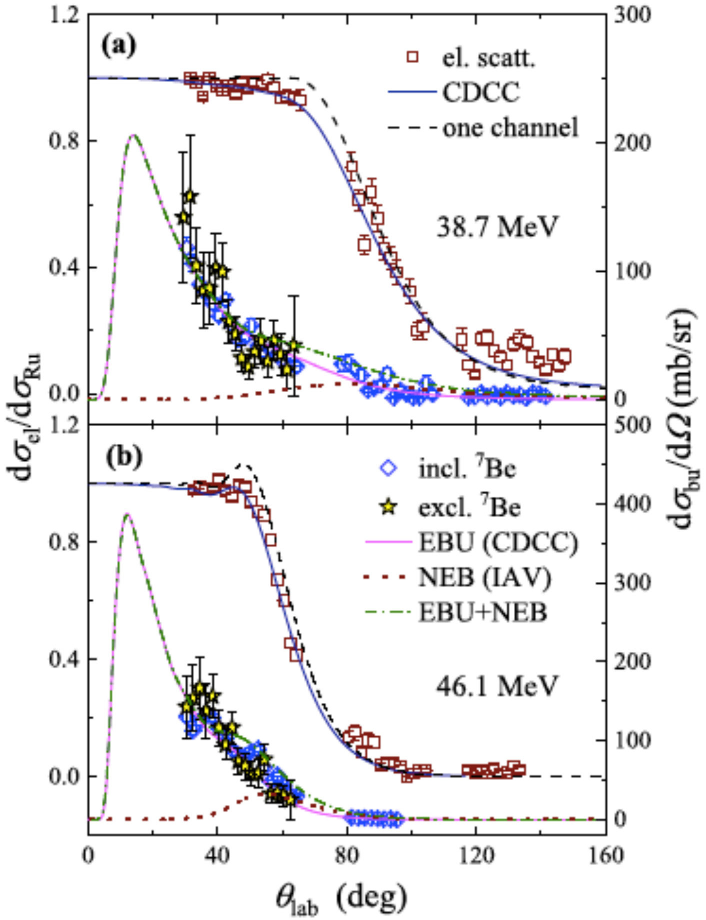
Direct breakup dominates the breakup cross-section except at larger angles where non-elastic breackup gives a somilar contribution

R. Spartà et al. Phys. Lett. B 820(2021)136477

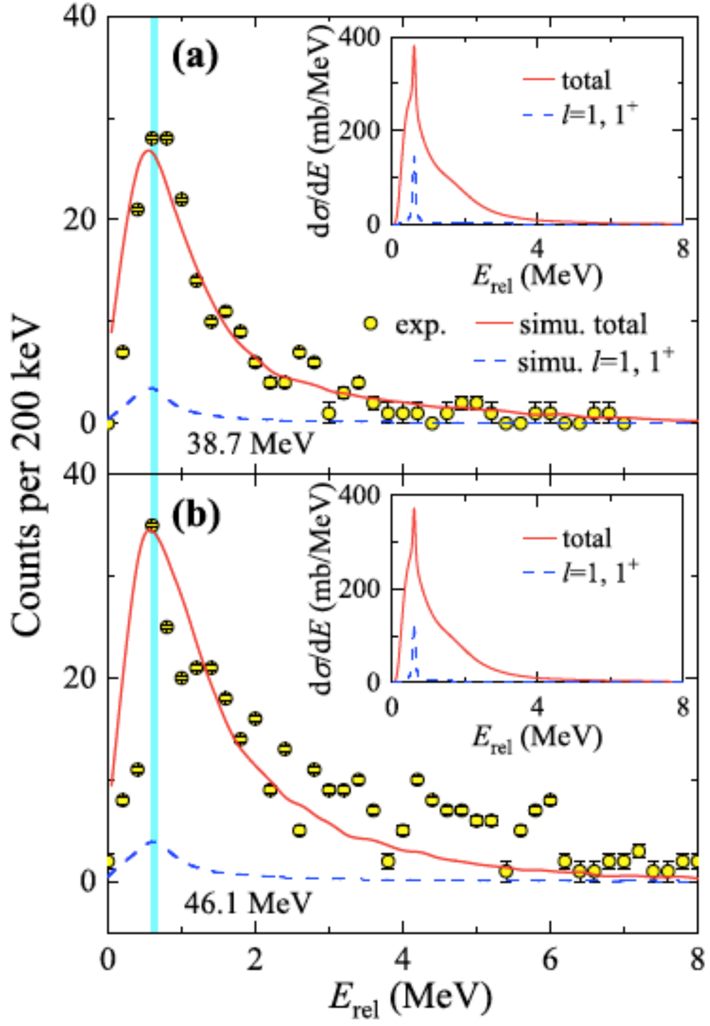
Comparison of first order with all-orders calculations including only E1 Coulomb couplings confirms the deceleration effect predicted by the classical model but if higher couplings are considered, no apparent acceleration or deceleration of the ^{7}Be fragment with respect to the ^{8}B c.m. motion is expected.

$^{8}B+^{120}Sn$ @ RIKEN

Elastic and breakup angular distributions



^{7}Be-p relative energy distribution



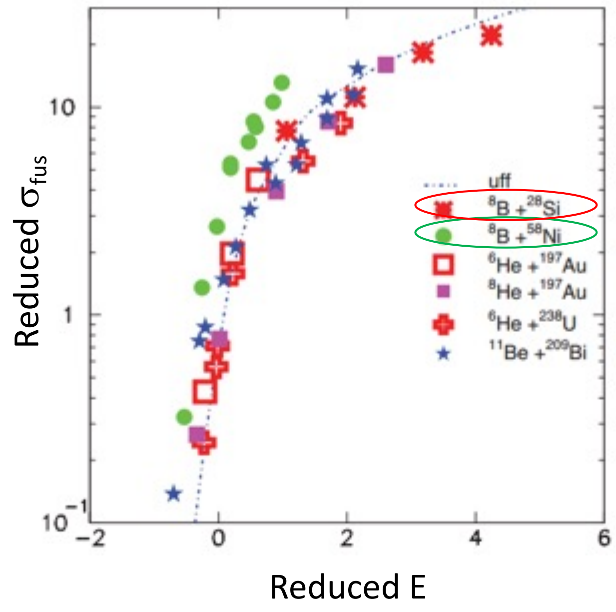
Elastic scattering shows small suppression of the cross-section due to coupling to the continuum. The prompt breakup mechanism dominates, occurring predominantly on the outgoing trajectory. The asymptotic breakup contribution is negligible

L. Yang et al. Nature Communications I (2022) 13:7193

Fusion

The p-halo case: ^{8}B fusion

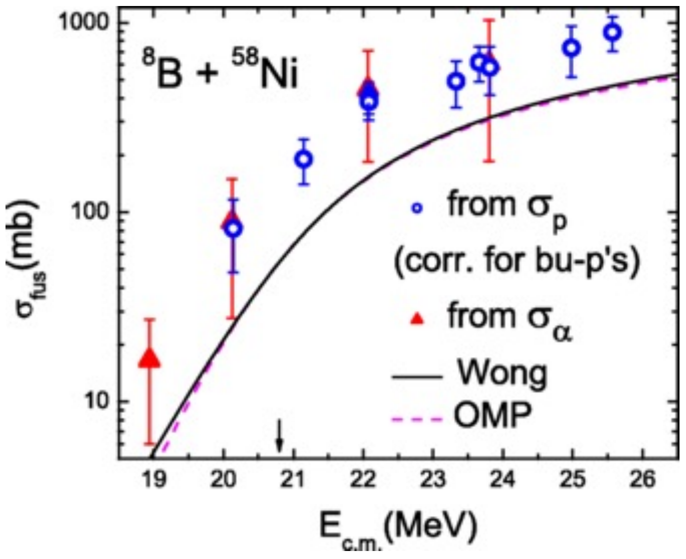
Fusion cross-section in the ^{8}B case was deduced from α and p measurements in the case of $^{8}B+^{28}Si$ and $^{8}B+^{58}Ni$.

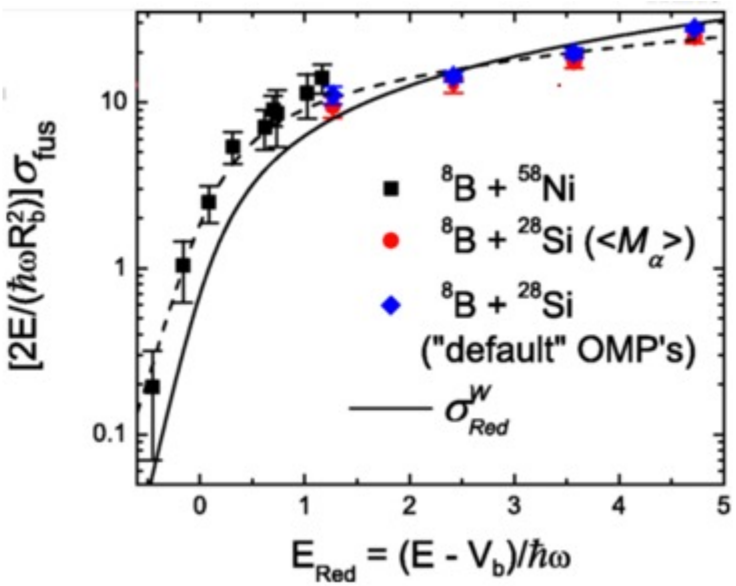


Systematics of fusion of n- and p- halo.
A.Pakou et al., PR C 87, 014619 (2013)

E.F. Aguilera et al, PRL107, 092701 (2011)

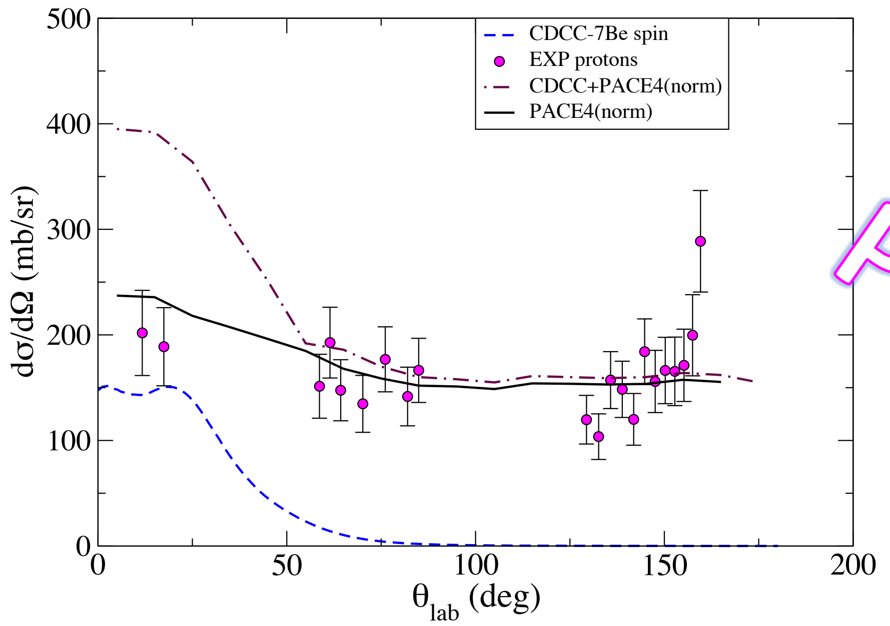
E.F. Aguilera et al, Phys. Rev. C **93**, 034613, 2016





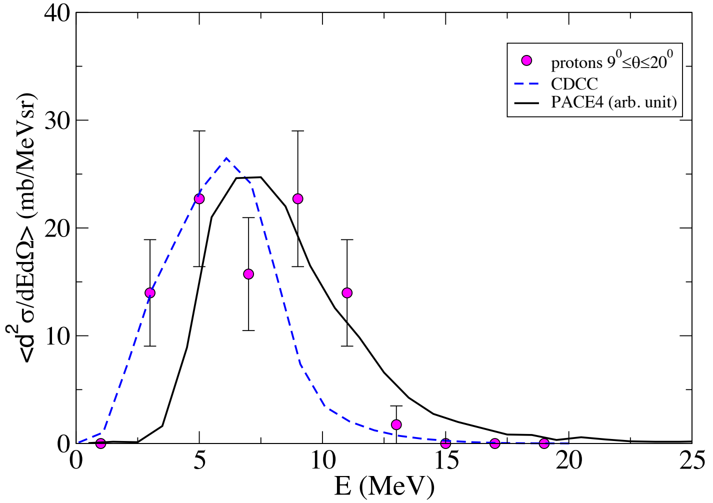
$^{8}B+^{64}Zn$ @ ISOLDE

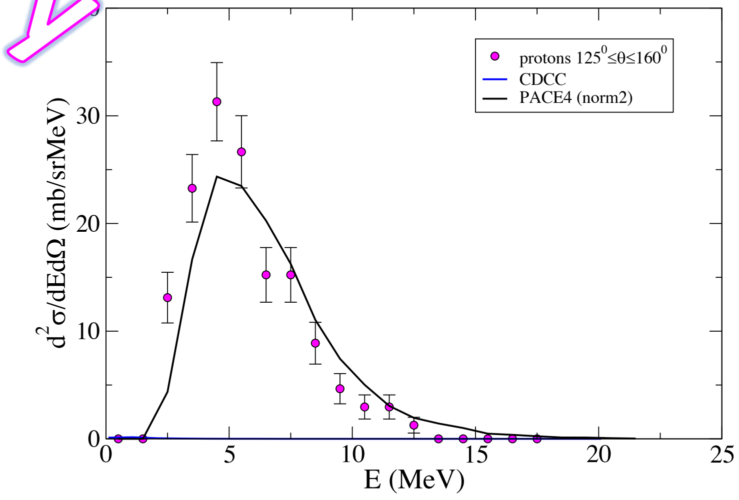
p - angular distribution



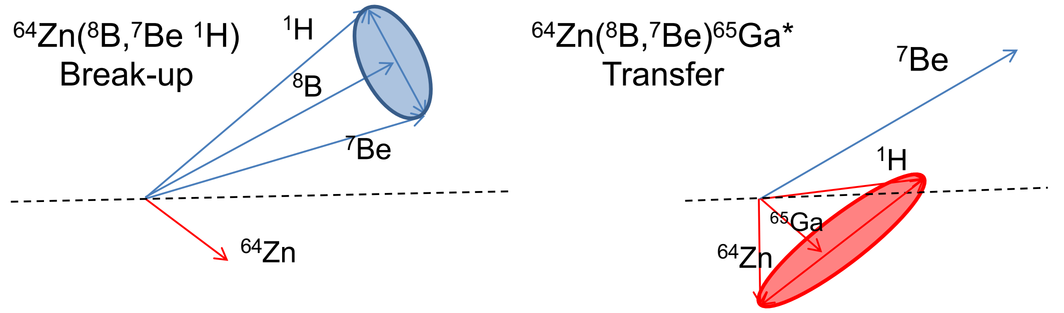
Preliminary

p - energy distribution
Calculations are normalised to the data



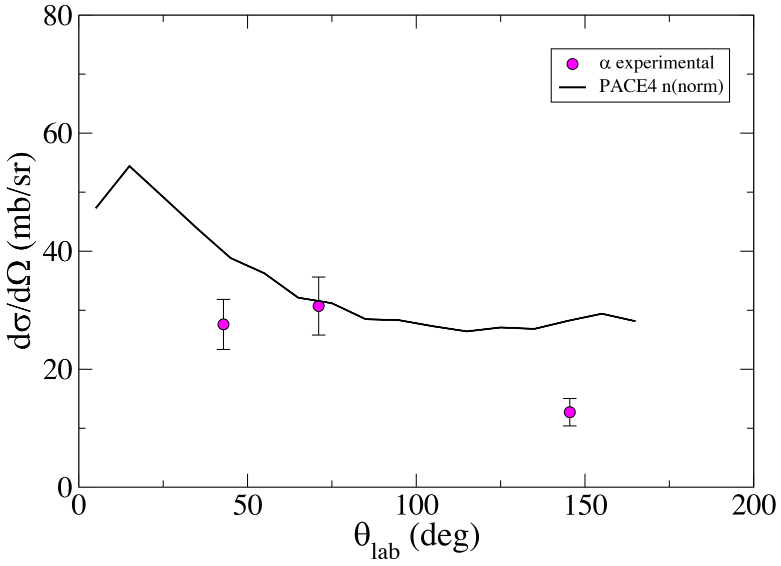


Sources of p besides fusion



$^{8}B+^{64}Zn$ @ ISOLDE

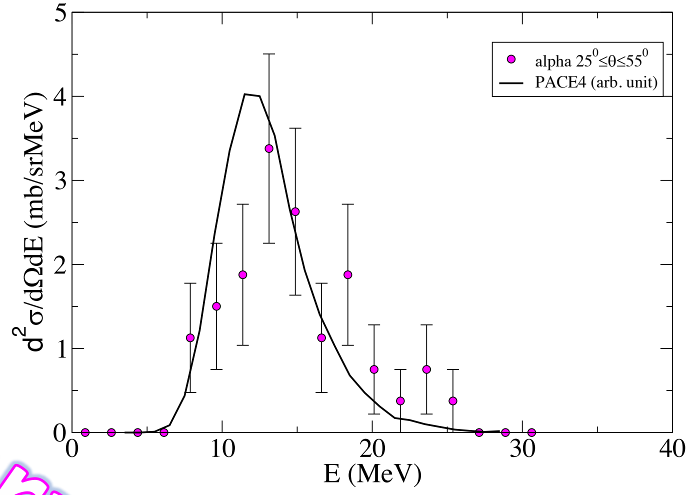
α - angular distribution

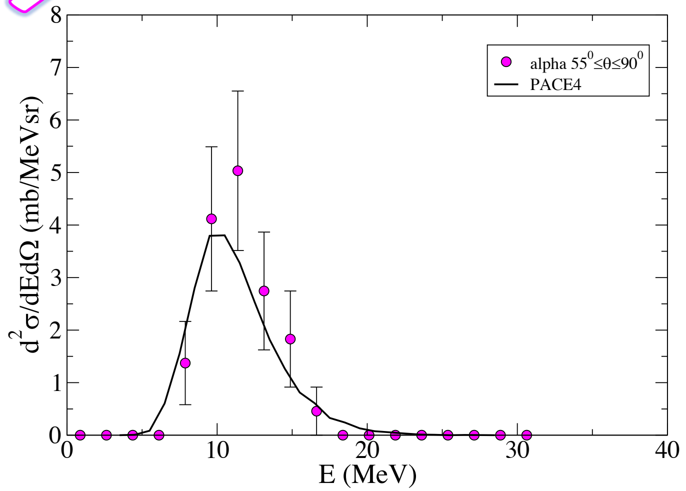


Preliminary

α - energy distribution

Calculations are normalised to the data





Other sources of α-particles

- ^{8}B three-body breakup above the $^{3}He+^{4}He+p$ threshold (Ex=1.72 MeV)
- IF of ^{3}He, leaving the $^{5}Li^{*}$ which decays to $^{4}He+p$

Conclusions

Structural effects influence the reaction dynamic. This is particularly true in the case of halo nuclei. The experimental study of the dynamics of reaction induced by exotic nuclei has shown how it strongly depends on their structure:

n-halo nuclei

- ➢ suppression of elastic cross-section
- ➢ high inclusive breakup cross-section

→

- ✓ Dynamic core excitation
- ✓ Transfer
- ✓ Incomplete fusion

p-halo nuclei

- ➢ Similar behaviour as weakly bound stable nuclei in the case of elastic scattering
- ➢ Breakup cross-section dominated by direct breakup. However much smaller than in neutron-halo case
- ➢ Fusion enhanced?

What need to be done in the ^{8}B study:

•Availability of higher intensity beam would allow more precise data and exclusive measurements.
•Investigations in broad energy range and with a variety of target masses to study breakup.
•Core excitation effects?

IS616 collaboration

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- L Fraile - Facultad de Ciencias Físicas, Madrid, Spain
- D Galaviz – LIP, Lisbon, Portugal
- J Halkjaer Jensen - University of Aarhus, Aarhus, Denmark
- B Jonson - Chalmers University of Technology, Sweden
- N Soic - Ruđer Bošković Institute, Zagreb, Croatia