Elastic scattering and reaction mechanisms induced by light halo nuclei

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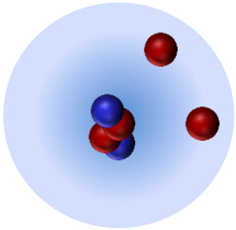
ASY-EOS 2012 **International Workshop on Nuclear Symmetry Energy and Reaction Mechanisms, 4-7 September 2012 - Siracusa, Sicily, Italy**

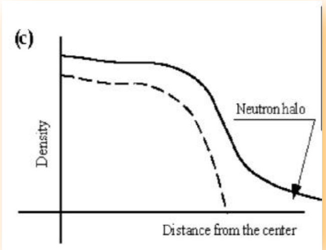
Outline of the talk

- **Motivations**
- **Elastic scattering and direct reactions induced by halo nuclei and our $^{6}He+^{64}Zn$ and $^{11}Be+^{64}Zn$ data**
- **A brief summary on the results**
- **Fusion reactions and our $^{6}He+^{64}Zn$ data**
- **Conclusions**

Collisions around the barrier induced by neutron halo nuclei

n-halo nucleus





Some examples:

$^{6}He \equiv {}^{4}He + n + n$
$^{11}Li \equiv {}^{9}Li + n + n$
$^{11}Be \equiv {}^{10}Be + n$

Characteristics of the projectiles:
Low break-up energy threshold + long tail in density distribution

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What do we expect for direct reactions?

Are direct mechanisms (e.g. break-up, transfer) favourite ?

What do we expect for fusion reactions ?

Extended tails
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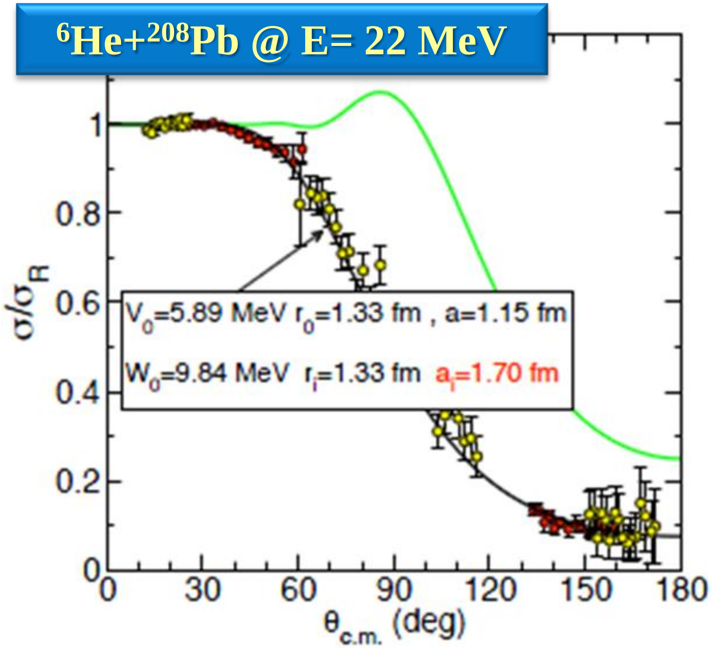
enhancement of sub-barrier fusion

Key question: which is the effect of coupling to continuum on the other channels ?

Elastic scattering: a fundamental tool to investigate

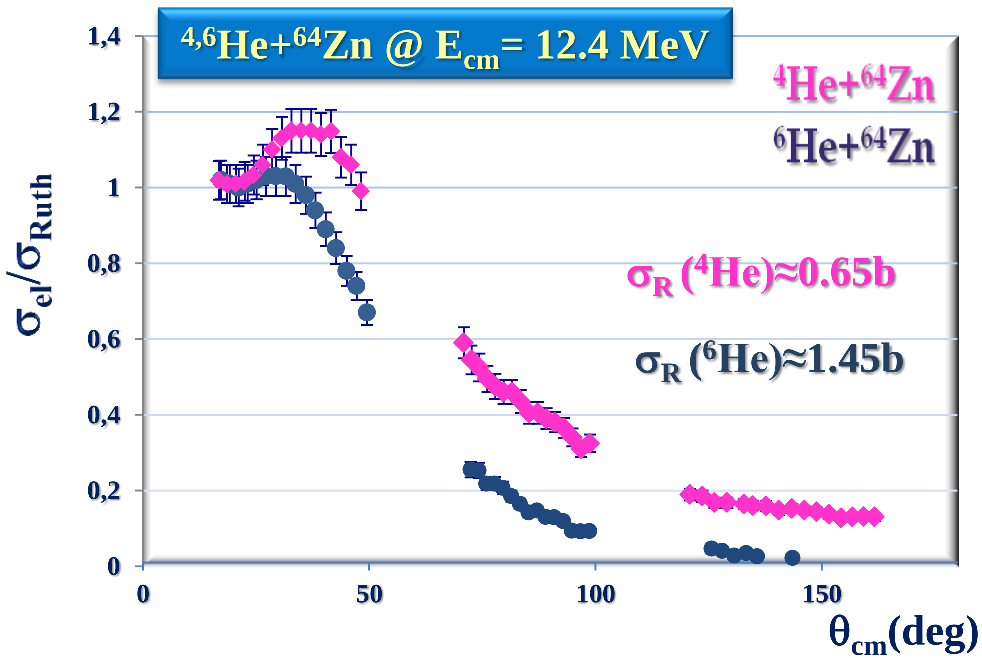
- halo structure
- influence of break-up channel
- nuclear potential between the colliding nuclei

Most of the experiments performed with ^{6}He beams



Shows a reduction in the elastic cross-section
Requires a large imaginary diffuseness !
long-range absorption

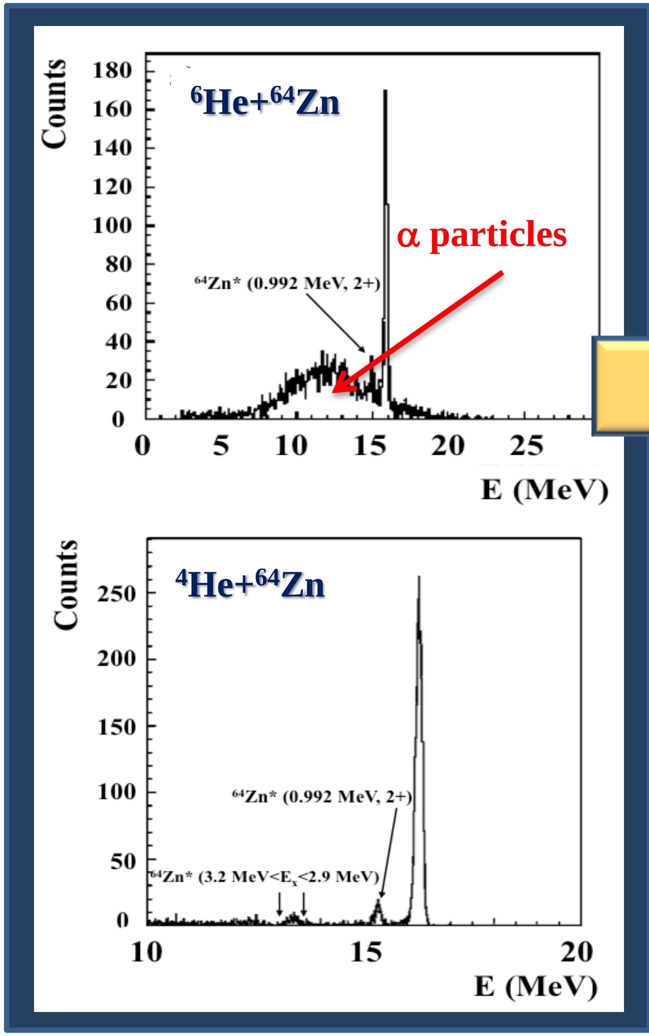
L. Acosta et al Phys Rev, C 84, 044604 (2011)

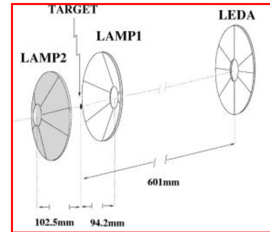


Larger total reaction cross-section for ^{6}He induced collision with respect to ^{4}He at the same Ecm.

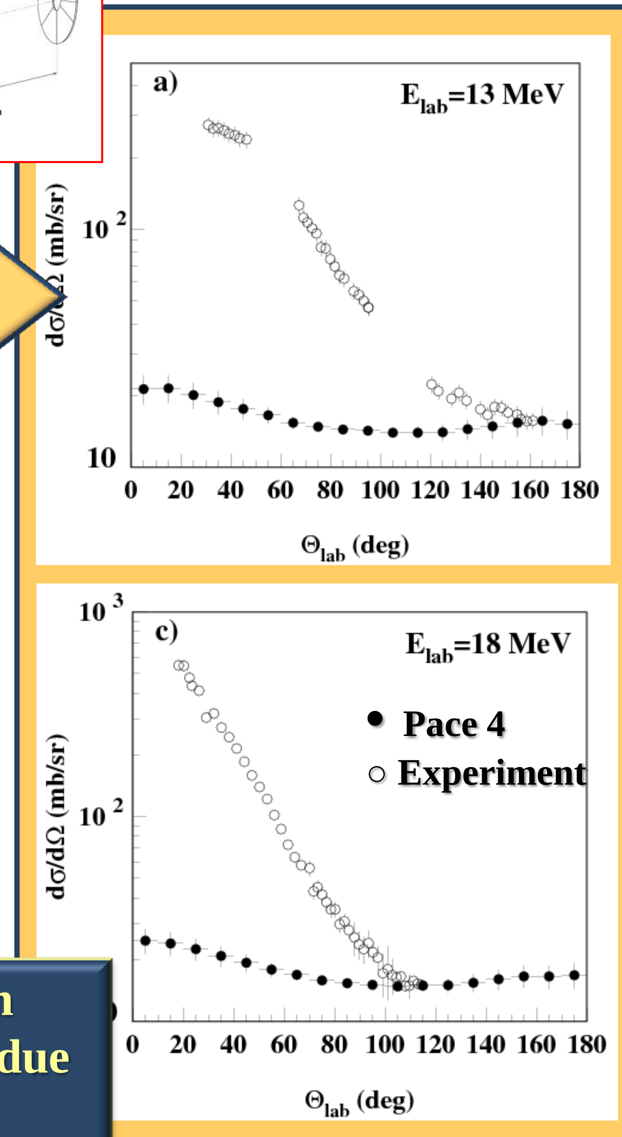
A. Di Pietro et al. Phys. Rev. C 69(2004)044613

^{4,6}He+^{64}Zn @ LLN: transfer and break-up processes





^{6}He+^{64}Zn



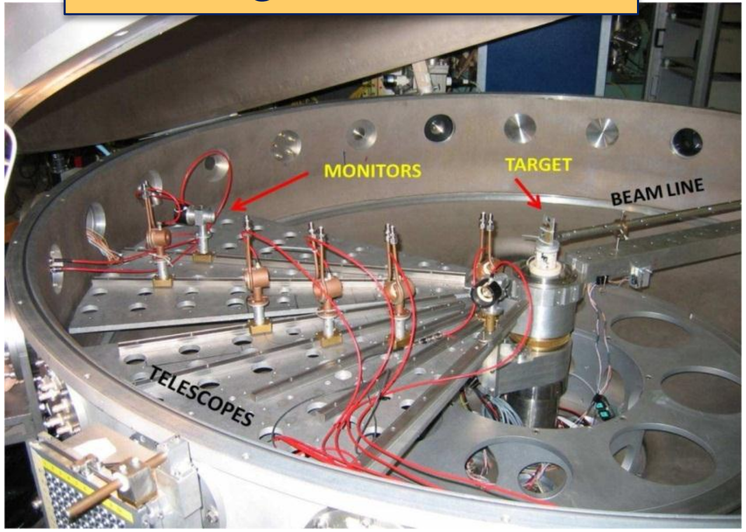
Most of the α-particle cross-section (≈ 80% of the reaction cross-section) due to transfer and break-up

V. Scuderi et al. Phys.Rev. C 84, 064604 (2011)

Experiment with post - accelerated 1n-halo ^{11}Be beam

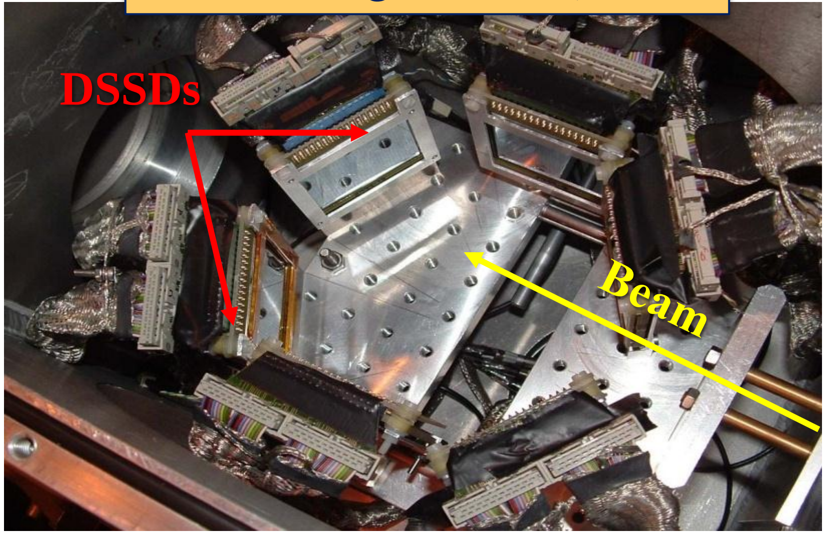
- ^{9,10,11}Be + ^{64}Zn elastic scattering angular distributions @ 29 MeV.
- Why comparison with the reactions induced by ^{9,10}Be on ^{64}Zn ?
  - ➢ ^{10}Be core of ^{11}Be
  - ➢ ^{9}Be weakly bound but non-halo.
- ^{11}Be transfer/break-up angular distribution.

^{9}Be+^{64}Zn @ INFN-LNS Catania



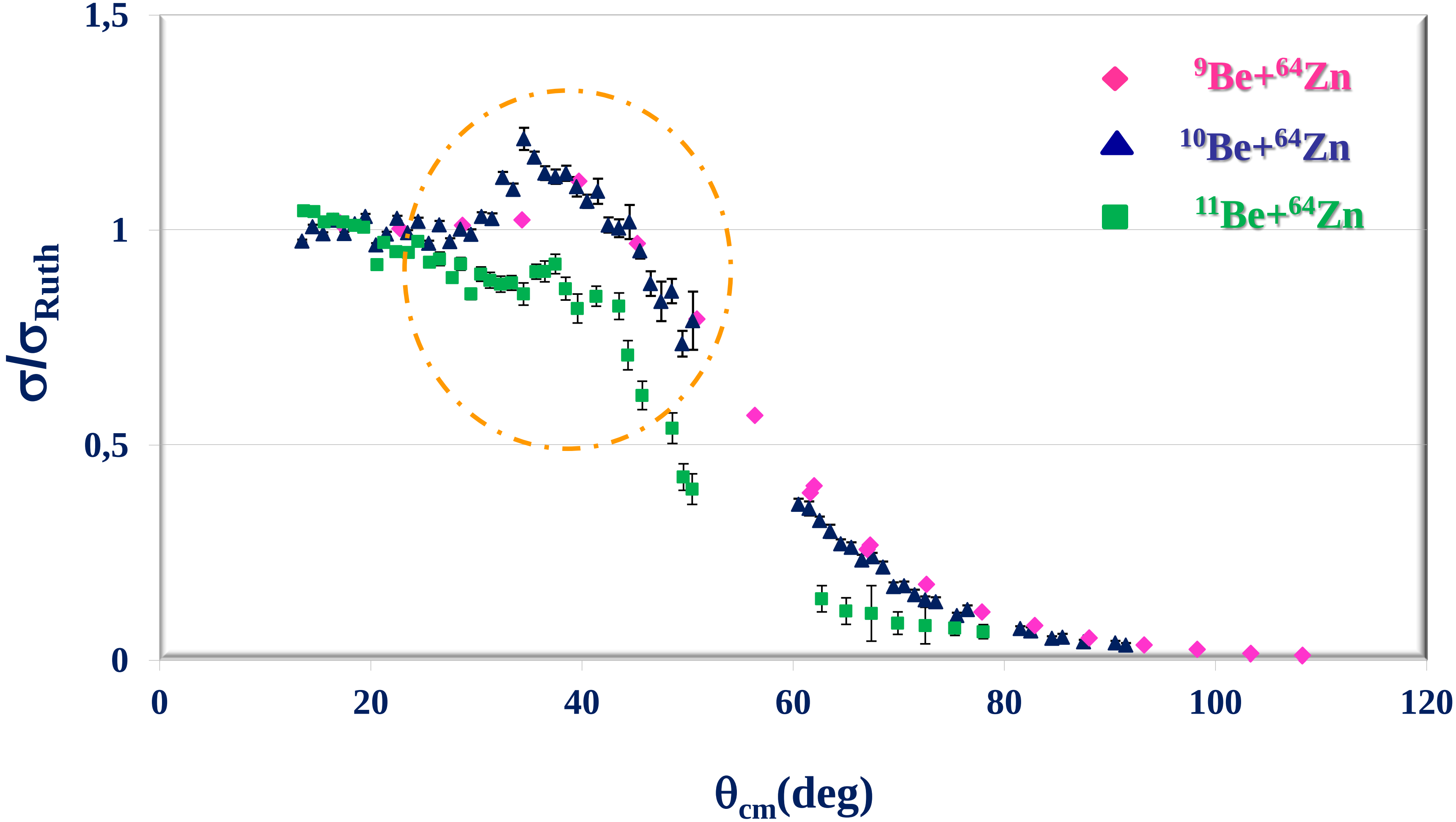
- ➢ 5 ΔE (6-15 μm) - E (90-130 μm) Si Surface Barrier detector telescopes
- ➢ Angular distribution: 15°≤ θ_{lab} ≤110°

^{10,11}Be+^{64}Zn @ Rex-Isolde, CERN



- ➢ 6 ΔE (50 μm DSSDs) -E (1500 μm Single Pad) Si detector telescopes
- ➢ Total covered angular range 10°≤ θ_{lab}≤150°

$^{9,10,11}Be + ^{64}Zn$ elastic scattering angular distributions



A. Di Pietro, G. Randisi, V. Scuderi et a. Phys. Rev. Lett. 105,022701(2010)

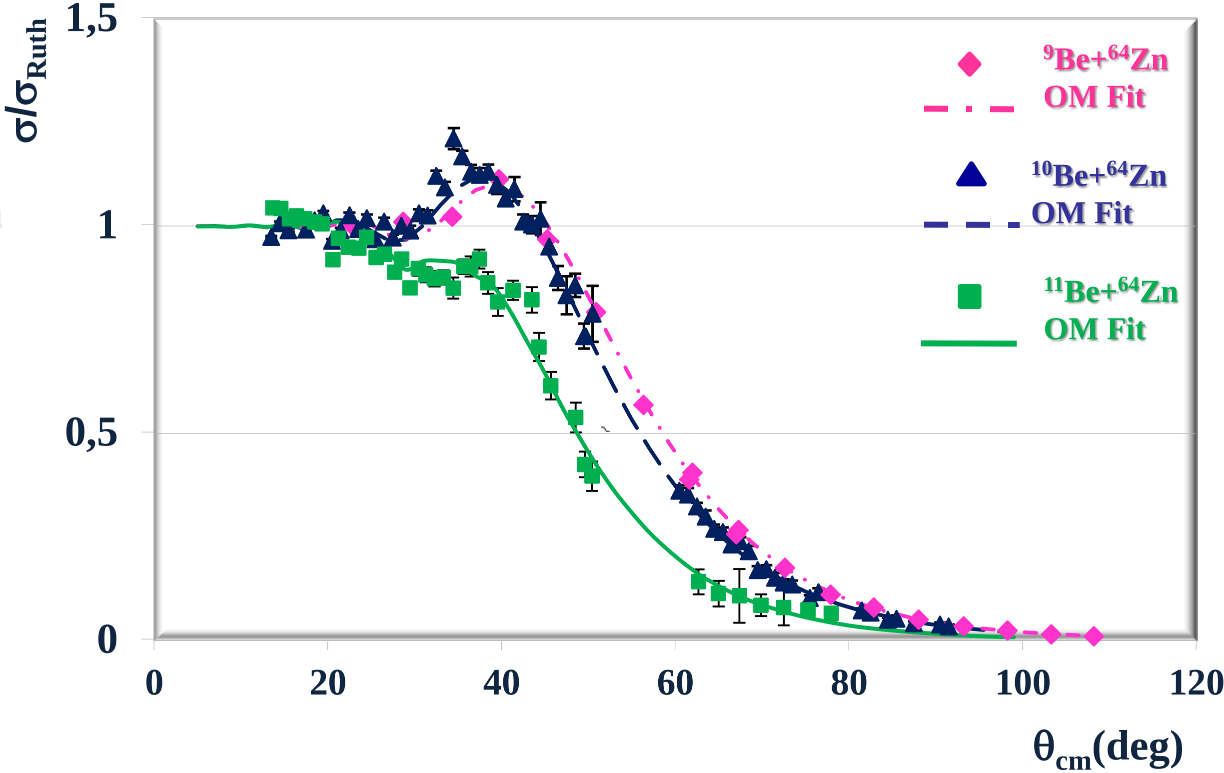
Optical Model analysis

Adopted procedure:

volume potential responsible for the core-target interaction obtained from the $^{10}Be+^{64}Zn$ elastic scattering fit.

+

DPP: surface imaginary term having the shape of a W-S derivative (similar procedure used in A.Bonaccorso and F.Carstoiu NPA 706(2002)322)



A very large diffuseness of DPP ($a_{si} \approx 3.5$fm) is needed

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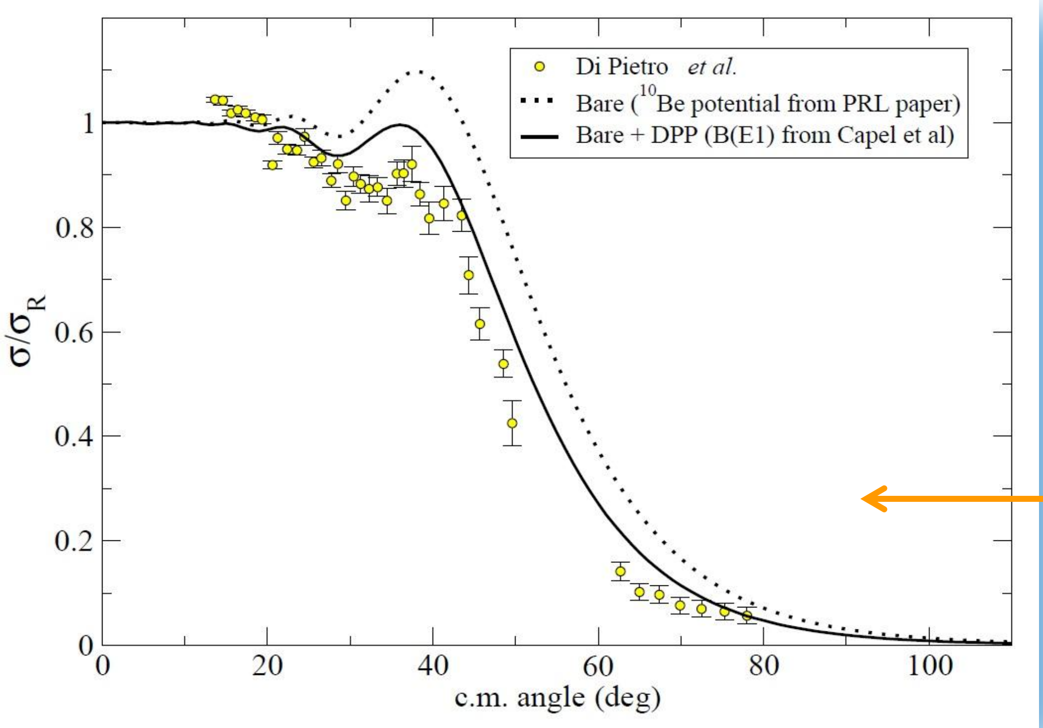
long range absorption mechanisms

A. Di Pietro, G. Randisi, V. Scuderi et a. Phys. Rev. Lett. 105,022701(2010)

Optical Model analysis



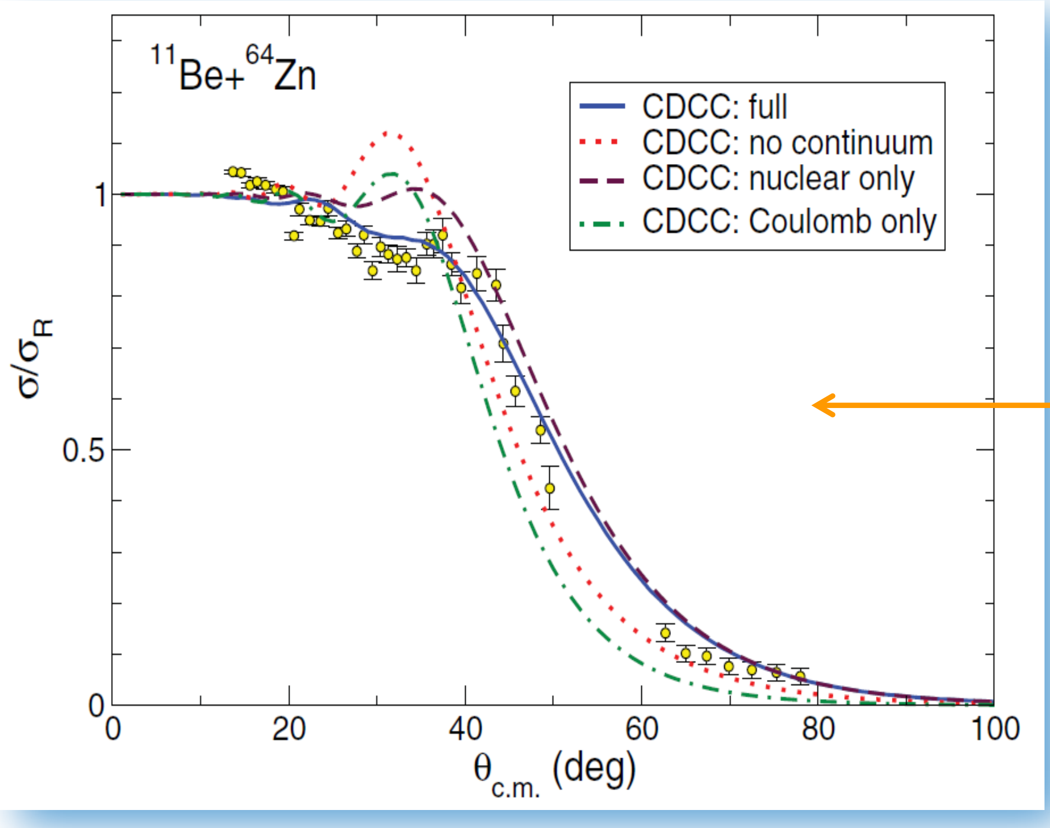
Effect of coupling to Coulomb Dipole break-up

OM with DPP
W-S volume potential of the core + DPP due to Coulomb dipole coupling

A. Di Pietro, V. Scuderi, A.M. Moro et al., Phys. Rev. C 85, 054607 (2012)

Elastic suppression non well reproduced

Continuum Discretised Coupled Channel Calculations



Experimental elastic a.d. reproduced only taking into account coupling to continuum via the Coulomb and nuclear interactions

A. Di Pietro, V. Scuderi, A.M. Moro et al., Phys. Rev. C 85, 054607 (2012)

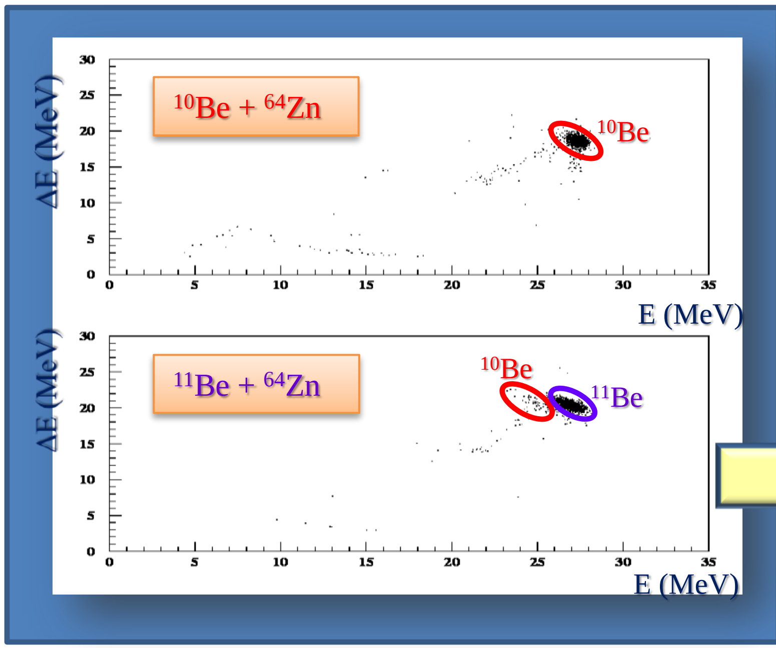
Suppression of the elastic: coupling to Coulomb or nuclear break-up?

Both nuclear and Coulomb couplings are responsible for the suppression of the quasi-elastic cross-section

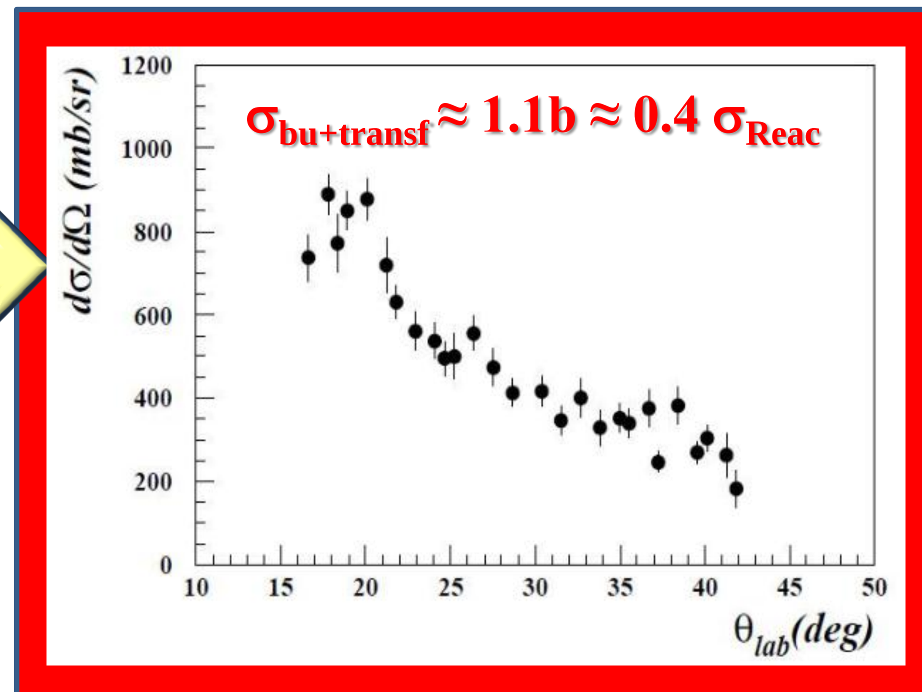
Reaction cross-section

$\sigma_{Reac}(^{9}Be) \approx 1.1b$ $\sigma_{Reac}(^{10}Be) \approx 1.2b$
$\sigma_{Reac}(^{11}Be) \approx 2.7b$

Which is the origin of the ^{11}Be total reaction enhancement?



$^{11}Be+^{64}Zn$ break-up/transf. contribution



A. Di Pietro, G. Randisi, V. Scuderi et al.
Phys. Rev. Lett. 105,022701(2010)

Collisions around the barrier induced by halo nuclei

- Damping of elastic cross-section for the halo nucleus at large impact parameters due to the coupling to the continuum.
- Both Coulomb and nuclear coupling contribute to the effect.
- Total reaction cross-sections for the halo nucleus larger than for the well bound isotopes
  e.g. $\sigma_{Reac}(^{6}He) \approx 2\ \sigma_{Reac}(^{4}He)$, $\sigma_{Reac}(^{11}Be) > 2\ \sigma_{Reac}(^{9,10}Be)$.
- Very large cross-section for transfer and breakup events saturating most of the $\sigma_{Reac.}$

New data with halo beams different than ^{6}He needed

Fusion reactions around the barrier with halo nuclei

Again most of the experiments performed with ^{6}He beams
(e.g. ^{6}He+^{64}Zn, ^{6}He+^{209}Bi, ^{6}He+^{238}U, ^{6}He+^{65}Cu, ^{6}He+^{197}Au, ^{6}He +^{206}Pb, ^{11}Be+^{209}Bi)

Different conclusions reached concerning the presence of enhancement effects on low energy fusion cross sections due to the projectile halo structure

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Most of data do not explore the sub barrier region with reasonable errors

Static effects

Halo affects the shape of the projectile-target potential reducing the barrier diffuse tail ⇒ reduction of Coulomb barrier and increase of σ_{FUS} ?

Dynamic effects

Coupling not only to bound states but also to continuum

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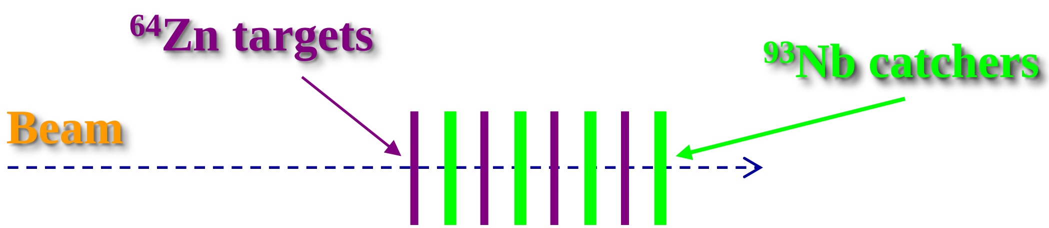
Role played by static and dynamic effects on conclusions not always clear

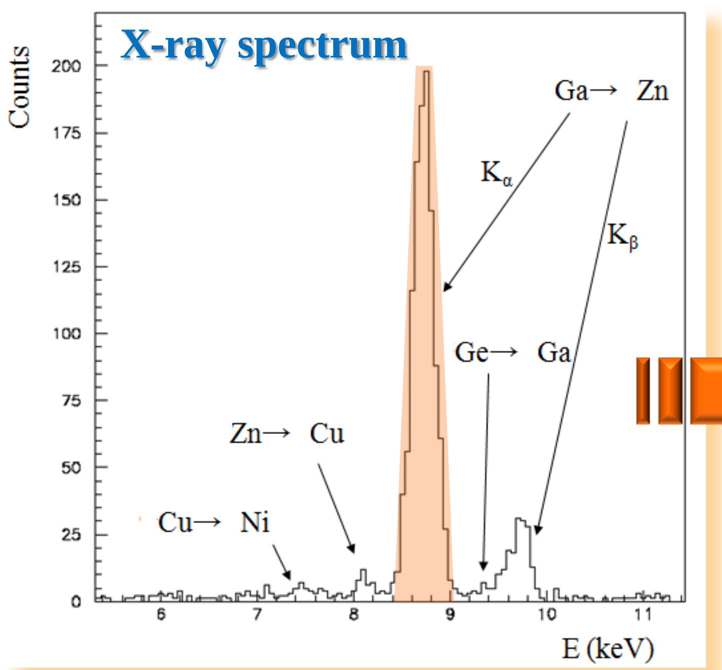
The activation technique we are using to measure $\sigma_{FUS}(E)$

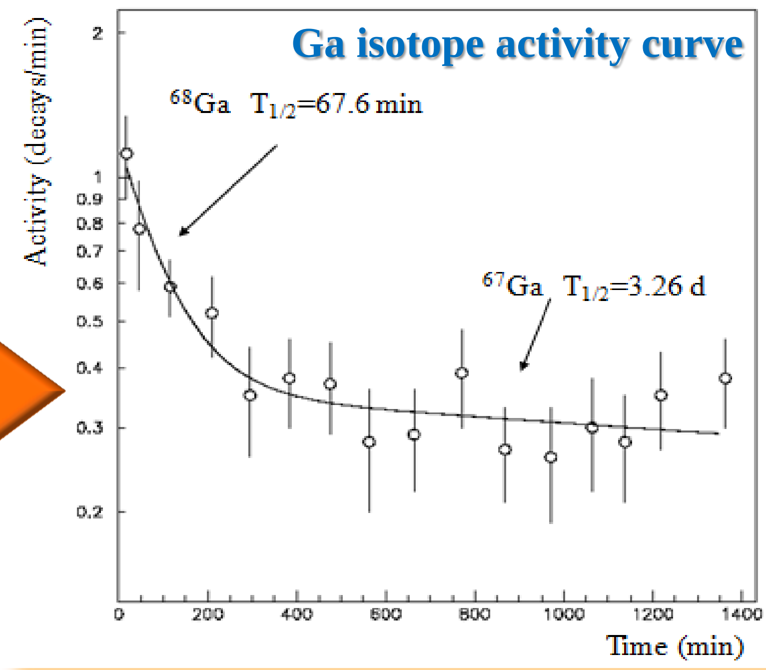
Off line detection of atomic X rays following EC decay of the ER.

- **100% intrinsic detection efficiency for X rays + very low background**
  ⇒ suitable for experiments with RIBs
- **Z and A ER identification**

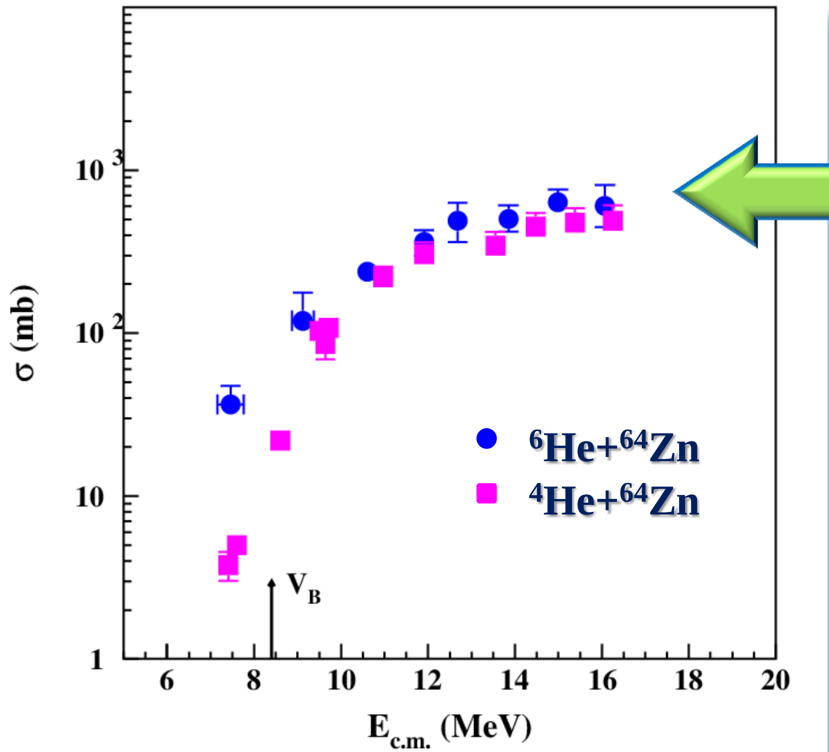
Example: The $^{6}He+^{64}Zn$ collision @ LLN





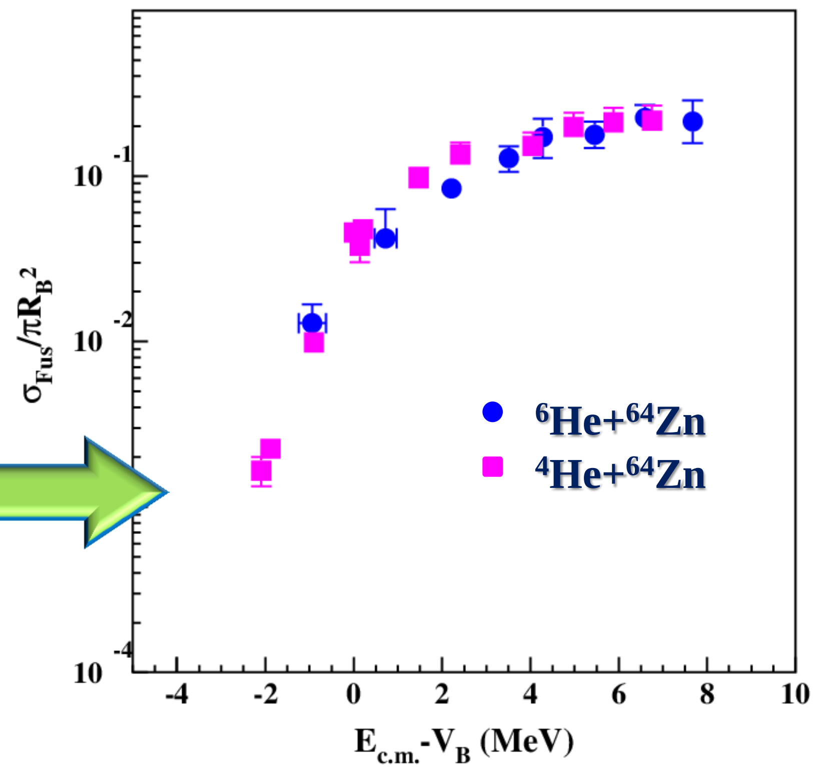


$^{4,6}He + ^{64}Zn$ @ LLN and RBI Zagreb : fusion excitation functions



Enhancement of σ_{Fus} for ^{6}He with respect to σ_{Fus} for ^{4}He

Reduced excitation functions to eliminate static effects as suggested in *L.F.Canto et al* NPA 821, 51, (2009)



V_B and R_B from double folding potential

The observed enhancement can be explained as due to static effects

V. Scuderi et al. PRC 84, 064604, (2011)

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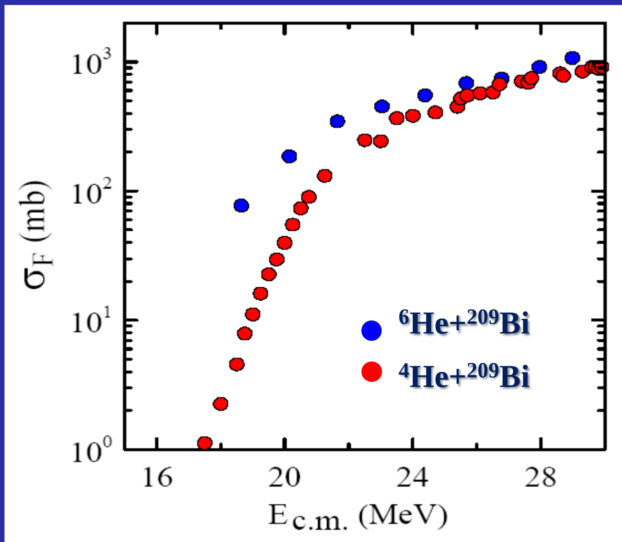
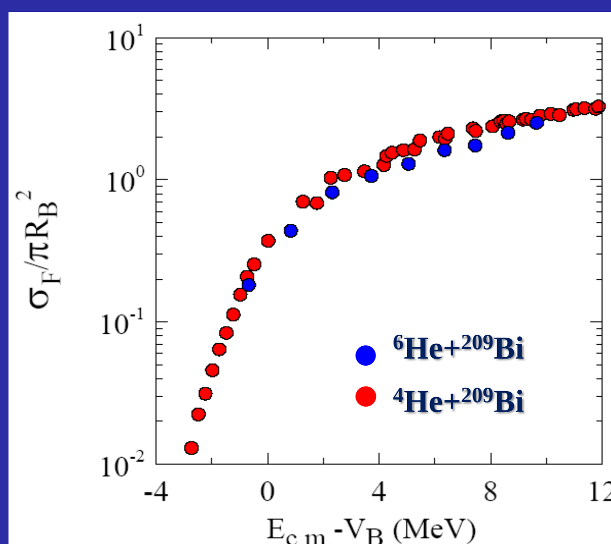
Fusion with halo nuclei : additional examples from literature

$^{4,6}He+^{209}Bi$



Data:
J.J. Kolata et al
PRL 81,4580,(1998)
Figures:
L.F.Canto et al
NPA 821, 51, (2009)

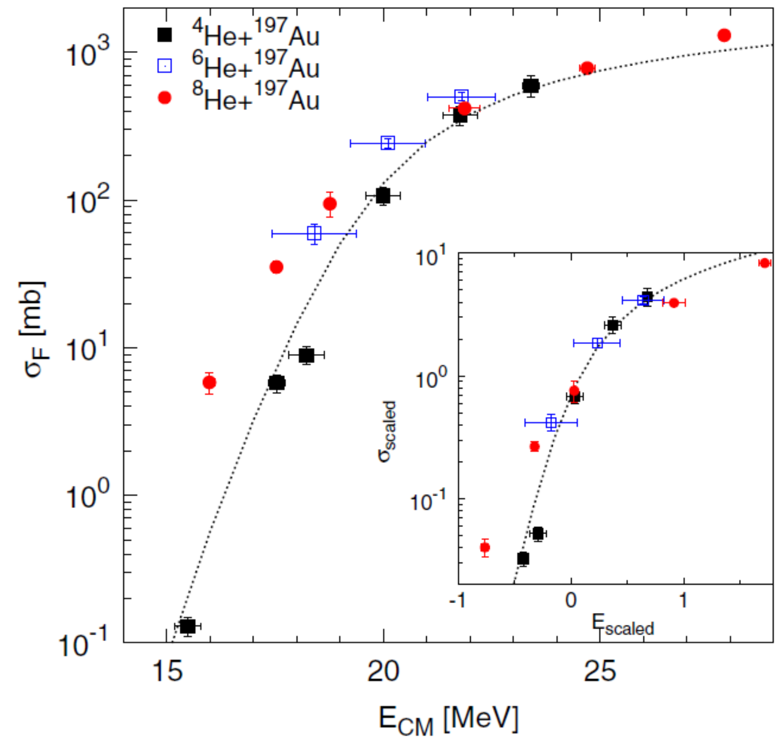


Same result as for $^{4,6}He+^{64}Zn$

$^{4,6}He+^{197}Au$ @ DUBNA and $^8He+^{197}Au$ @ GANIL

Activation techniques used.
Off-line γ and γ-X coincidences measured

Enhancement of σ_{FUS} for $^{6,8}He$ with respect to σ_{FUS} for ^4He



A.Lemasson et al, PRL 103,232701,(2009)
Yu.E.Penionzhkevich et al, EPJ A31,185,(2007)

Fusion of halo nuclei: can we reach some conclusions?

- There is an effect of the halo structure on fusion below the barrier

- Static effects appears to be important but probably not the only ones

- Most of the experiments performed with ^{6}He beams and few data below the barrier

Need for new precise data and systematic analysis

Collaboration

L. Acosta, F. Amorini, M.J.G. Borge, A. Di Pietro, P. Figuera, M. Fisichella, L.M. Fraile, J. Gòmez-Camacho, H. Jeppesen, M. Lattuada, I. Martel, M. Milin, A. Musumarra, A. M. Moro, M. Papa, M.G. Pellegriti, R.Raabe, G.Randisi, F. Rizzo, D. Santonocito, E.M.R. Sanchez, G. Scalia, V. Scuderi, O. Tengblad, D. Torresi, A.M. Vidal, M. Zadro

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- Departamento de Física Atómica, Moleculary Nuclear, Universidad de Sevilla, Spain
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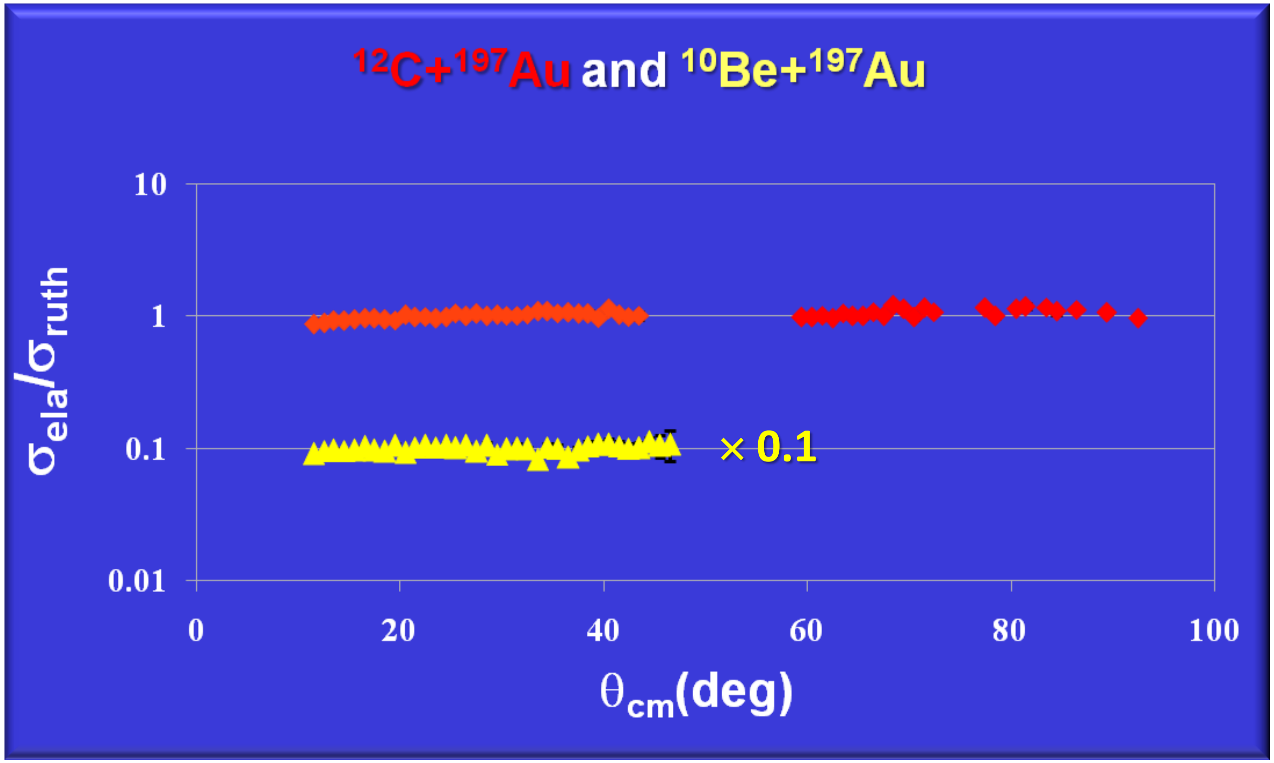
- DAPNIA/SPhN, CE Saclay, Gif-sur-Yvette
- LPC Caen, ENSICAEN, Université de Caen, CNRS/IN2P3, Caen, France

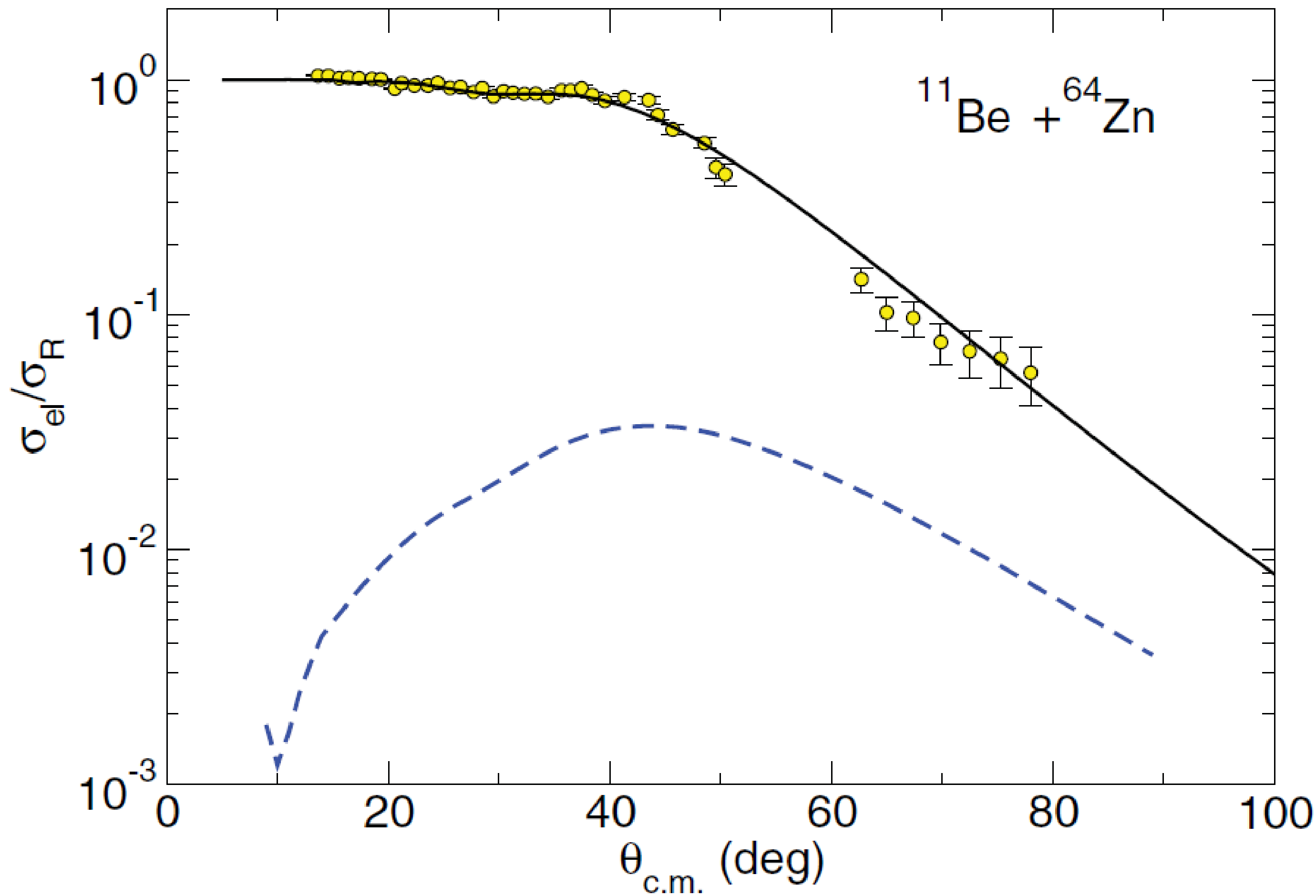
Thank you

Detector geometry determination

Rutherford scattering for ^{12}C + ^{197}Au @ 28 MeV and ^{10}Be + ^{197}Au @ 29.4 MeV to cross check the geometry determination.



^{11}Be+^{64}Zn quasi-elastic angular distribution



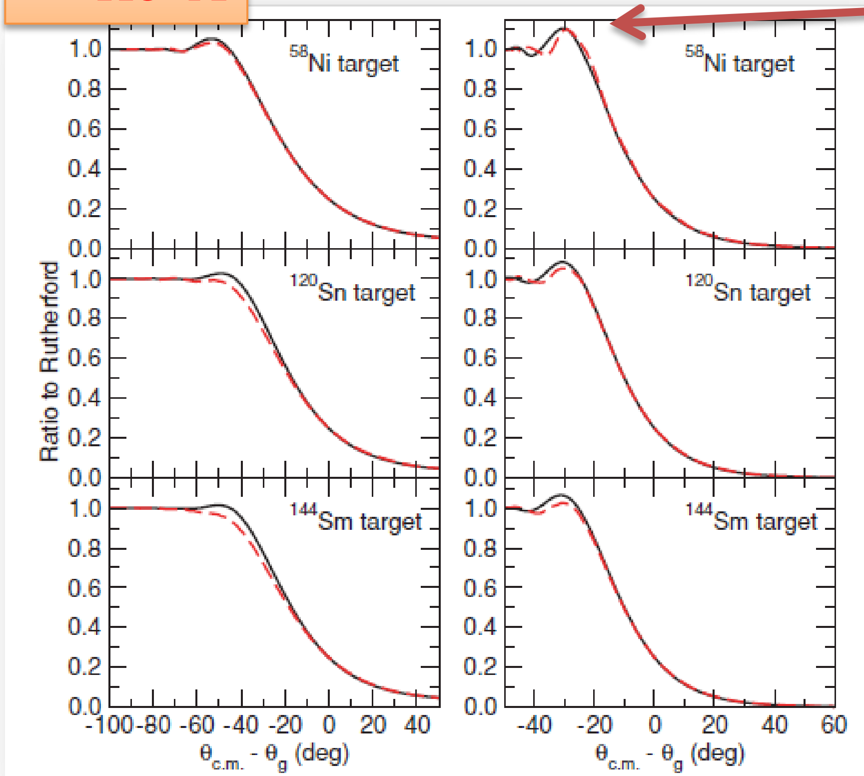
$$\sigma_{inelastic} \approx 400$$

Effect of coupling to Coulomb dipole break-up as a function of the target charge for ^{6}He induced collision at energy around the barrier

Coupling to Coulomb Dipole break-up as a function of target Z for ^{6}He collision around the barrier.

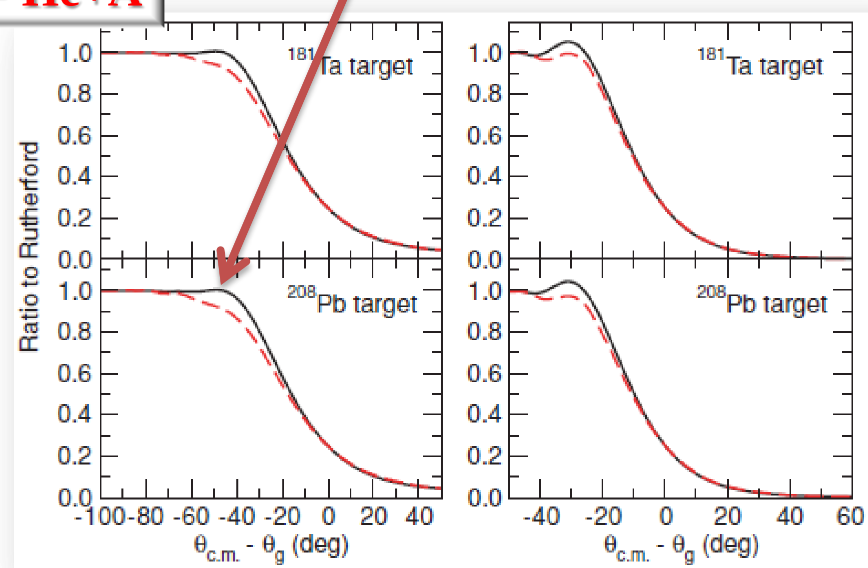
—^{6}Li+A
---^{6}He+A

No suppression on medium mass targets



—^{6}Li+A
---^{6}He+A

Suppression on heavy targets



$^{9,10,11}Be+^{64}Zn$ optical potentials

Reaction	V(MeV)	a(fm)	R_0(fm)	V_i(MeV)	a_i(fm)	R_{i0}(fm)	V_{Si}(MeV)	a_{Si}(fm)	R_{Si}(fm)
$^{9}Be+^{64}Zn$	126	0.6	1.1	17.3	0.75	1.2			
$^{10}Be+^{64}Zn$	86.2	0.7	1.1	43.4	0.6	1.2			
$^{11}Be+^{64}Zn$	86.2	0.7	1.1	43.4	0.6	1.2	0.151	3.5	1.3