Effects of coupling to breakup channels in reactions induced by weakly bound and halo nuclei.

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Contents

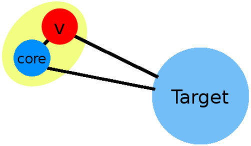
Introduction

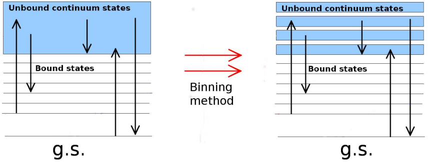
Weakly bound nuclei (^{6,7}Li): Low break-up threshold.
S_α=1.47(2.47) MeV
Cluster structure ($^{6,7}\text{Li}\rightarrow \alpha+d(t)$)
$\Downarrow \Downarrow$
Coupling to breakup channels expected to be important.

Halo nuclei (^{6}He): Low break-up threshold.
S_{2n}=0.98 MeV
Halo structure ($^{6}\text{He}\rightarrow \alpha+n+n$)
$\Downarrow \Downarrow$
Coupling to breakup channels expected to be important.

Continuum-Discretized Coupled-Channels (CDCC) formalism

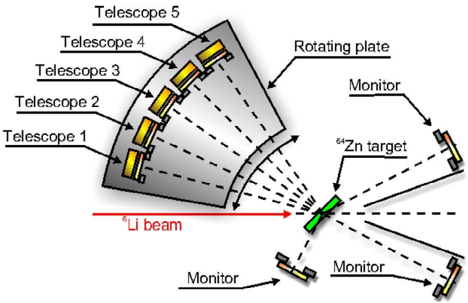
- Uses Coupled-Channel (CC) method to solve the scattering problem.
- For weakly bound/halo nuclei it is important to introduce the continuum (unbound) states of the projectile.
- Unbound states of the projectile included by means of a discretization procedure (binning).
- Describes the reaction using an effective 3-body model.
- The breakup process is treated as an inelastic excitation of the projectile.

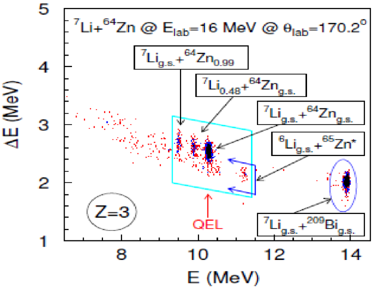




Experiment ^{6,7}Li+^{64}Zn at LNS laboratory, Italy

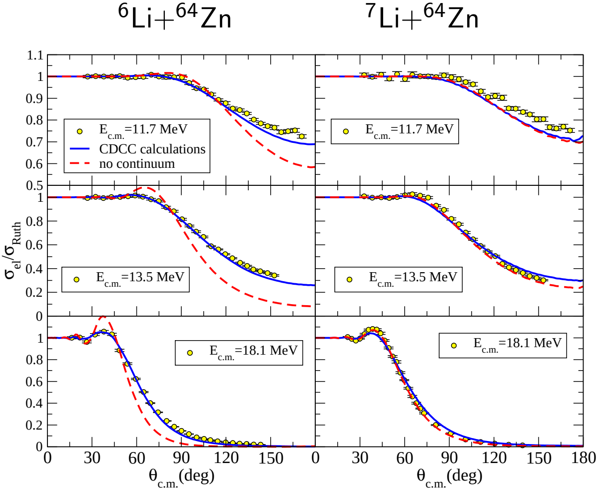
- ^{6,7}Li+^{64}Zn@$E_{c.m.}$ = 11.7, 12.4, 13.5, 15.0, 16.3 and 18.1 MeV.
- 5 Telescopes ΔE (10 μm) + E (200 μm).
- Stable beam. Good data quality.





M. Zadro *et al.* Phys. Rev. C 80, 064610 (2009), M. Zadro *et al.* Phys. Rev. C 87, 054606 (2013) and to be published

CDCC calculations - Coupling to the continuum effect



Coupling to breakup channels are more important for ^{6}Li.
$S_\alpha(^{6}\text{Li})$=1.47 MeV $S_\alpha(^{7}\text{Li})$=2.47 MeV

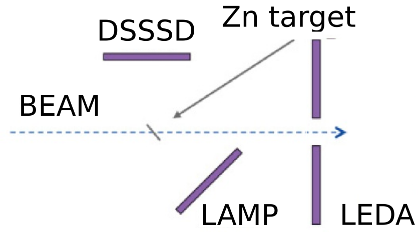
Experiment $^{6}He+^{64}Zn$ at CRC laboratory, Belgium.

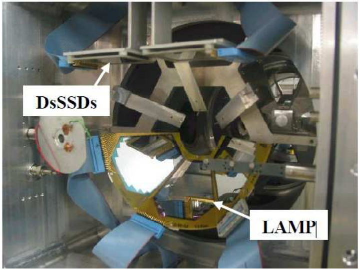
New experimental data above the Coulomb barrier - $E_{c.m.} = 13.5$ and 16.5 MeV.

Angular range between 5 -120 degrees.

DSSSDs	LAMP	LEDA
67°-120°	22°-65°	5°-12°

A ^{64}Zn target of 0.5 mg/cm^2 was used and rotated 45°.

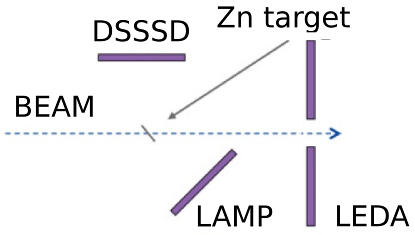


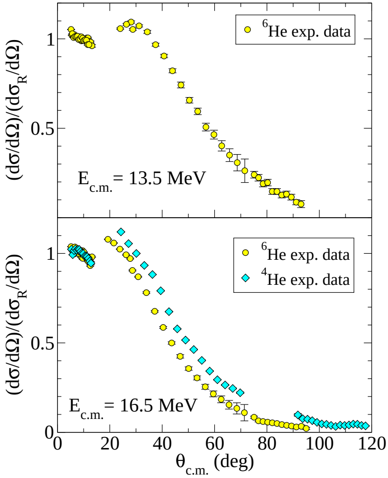


Experiment $^6He+^{64}Zn$ - $E_{c.m.} = 13.5$ and 16.5 MeV.

New experimental data above the Coulomb barrier

Angular range between 5 -120 degrees.

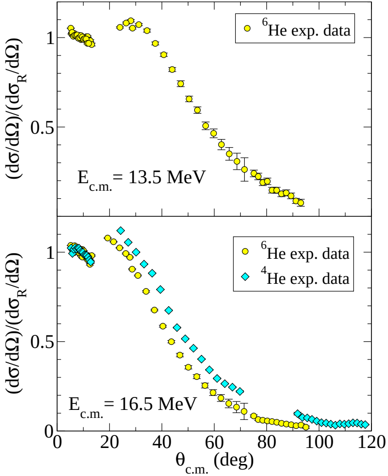




Experiment ^{6}He+^{64}Zn - $E_{c.m.} = 13.5$ and 16.5 MeV.

Angular range between 5 -120 degrees.

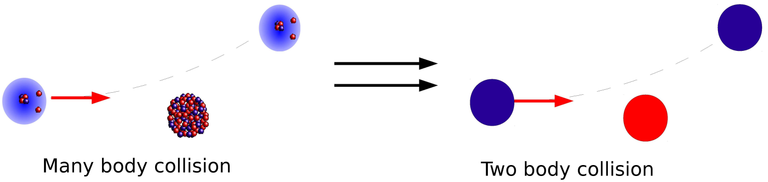
- Deviation from Rutherford.
- Diminution of Fresnel peak.
- Expected important nuclear and/or Coulomb couplings.



Optical model analysis

Describes the interaction projectile-target with a effective average potential $U(R) = V(R) + iW(R)$

The absorption of the elastic channel is represented by an imaginary part in the nuclear potential



- $U(R)$ phenomenological - Woods-Saxon form.

$$U(R) = V_0 f + iW_0 f$$

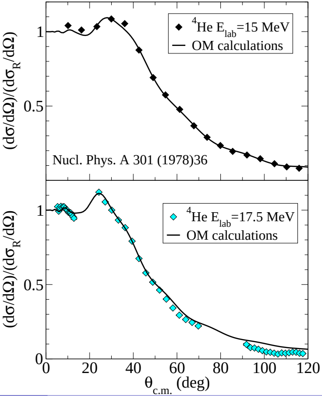
$$f(R,\ R_x,\ a_x) = \frac{1}{e^{\frac{R-R_x}{a_x}} + 1}$$

Optical model analysis - ^{4}He+^{64}Zn

$$U(R)=U_{\alpha}(R)+W_{L}(R)\begin{cases} U_{\alpha}(R)=V(R)+iW(R) - \text{Core potential} \\ W_{L}(R)=df(R)/dR - \text{Long range effect} \end{cases}$$

E_{lab}=15 MeV[a]	**V_0(MeV)**	**r_0(fm)**	**a_0(fm)**
	131.1	1.04	0.594
	W_0(MeV)	**r_i(fm)**	**a_i(fm)**
	11.53	1.27	0.358
E_{lab}=17.5 MeV	**V_0(MeV)**	**r_0(fm)**	**a_0(fm)**
	22.38	1.2	0.43
	W_0(MeV)	**r_i(fm)**	**a_i(fm)**
	23.86	1.05	0.43

[a] T. B. Robinson and V. R. W. Edwards Nucl. Phys. A 301 (1978) 36

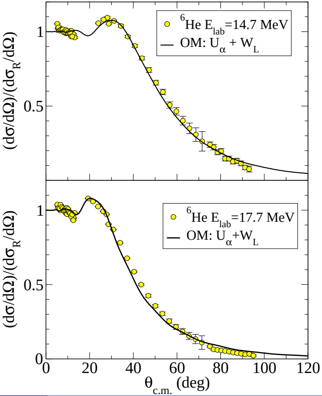


Optical model analysis - ^{6}He+^{64}Zn

$$U(R)=U_\alpha(R)+W_L(R)\begin{cases} U_\alpha(R)=V(R)+iW(R) - \text{Core potential} \\ W_L(R)=df(R)/dR - \text{Long range effect}\end{cases}$$

E_{lab}=15 MeV	W_L(MeV)	r_L(fm)	a_L(fm)
	2.62	1.2	0.71

E_{lab}=18 MeV	W_L(MeV)	r_L(fm)	a_L(fm)
	2.28	1.2	0.94



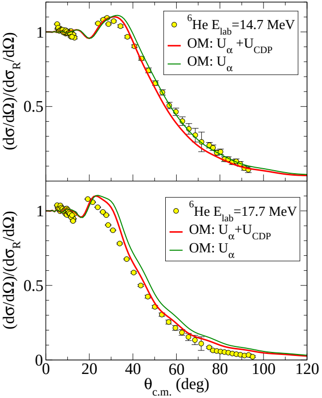
Optical model analysis - $^6He+^{64}Zn$

$$U(R) = U_\alpha(R) + U_{CDP}(R)$$

$$U_{\mathrm{CDP}} = -\frac{4\pi}{9}\frac{Z_t^2 e^2}{\hbar \cdot v}\frac{1}{(r-a_0)^2 r}\int_{\varepsilon_b}^{\infty} \mathrm{d}\varepsilon \frac{\mathrm{d}B(E1,\varepsilon)}{\mathrm{d}\varepsilon} F(r,\varepsilon)$$

$$F(r,\varepsilon) = g\left(\frac{r}{a_0} - 1, \xi\right) + i f\left(\frac{r}{a_0} - 1, \xi\right)$$

M. V. Andrés, J. Gómez-Camacho and M. A. Nagarajan, Nucl. Phys. A 583, 817 (1995)



Optical model analysis - ^{6}He+^{64}Zn

$$U(R)=U_\alpha(R)+W_L(R) + U_{CDP}(R)$$

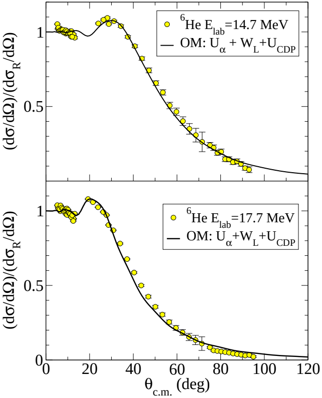
$$U_{\mathrm{CDP}} = -\frac{4\pi}{9}\frac{Z_t^2 e^2}{\hbar\cdot v}\frac{1}{(r-a_0)^2 r}\int_{\varepsilon_b}^{\infty} \mathrm{d}\varepsilon \frac{\mathrm{d}B(E1,\varepsilon)}{\mathrm{d}\varepsilon} F(r,\varepsilon)$$

$$F(r,\varepsilon) = g\left(\frac{r}{a_0}-1,\xi\right) + if\left(\frac{r}{a_0}-1,\xi\right)$$

M. V. Andrés, J. Gómez-Camacho and M. A. Nagarajan, Nucl. Phys. A 583, 817 (1995)

E_{lab}=15 MeV	a_L=0.71 fm → 0.69 fm
E_{lab}=18 MeV	a_L=0.94 fm → 0.90 fm

Small effects of the dipole Coulomb couplings.



Optical model analysis - ^{6}He+^{64}Zn

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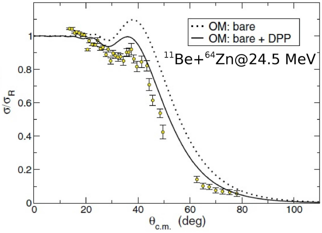
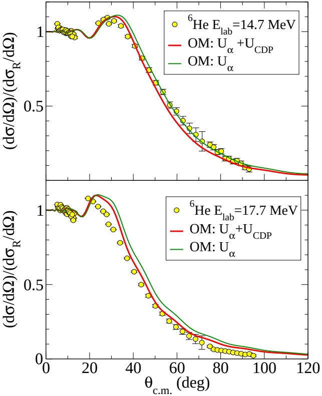
Di Pietro et al. Phys. Rev. C 85, 054607(2012)





Optical model analysis - ^{6}He+^{64}Zn

$$U(R)=U_\alpha(R)+U_{CDP}(R)$$

$$U_{\mathrm{CDP}} = -\frac{4\pi}{9}\frac{Z_t^2 e^2}{\hbar\cdot v}\frac{1}{(r-a_0)^2 r}\int_{\varepsilon_b}^{\infty} \mathrm{d}\varepsilon \frac{\mathrm{d}B(E1,\varepsilon)}{\mathrm{d}\varepsilon} F(r,\varepsilon)$$

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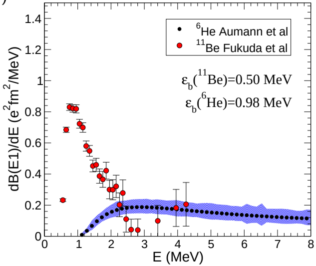
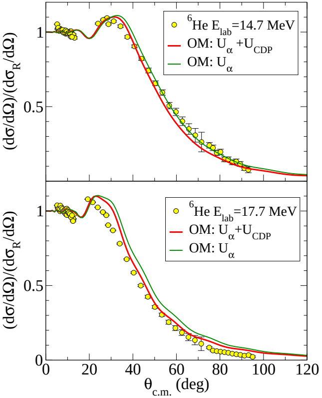
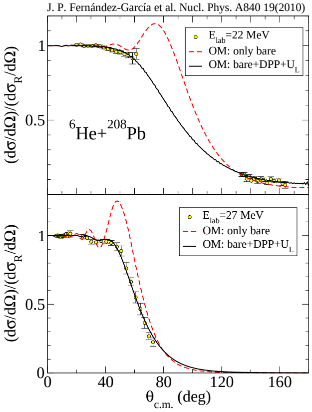
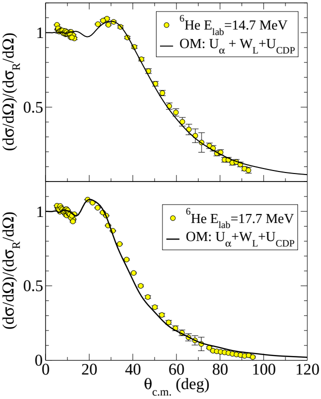




Optical model analysis - ^{6}He+^{64}Zn

$$U(R) = U_\alpha(R) + W_L(R) + U_{CDP}(R)$$



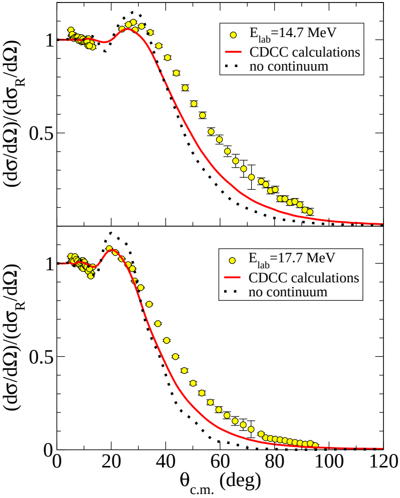


a_L=1.9 fm → 1.0 fm

a_L=0.94 fm → 0.90 fm

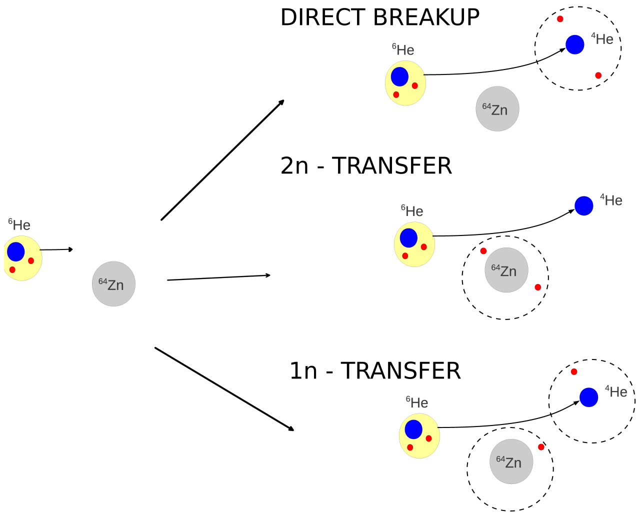
CDCC calculations - Coupling to the continuum effect

- Effective 3-body model ($^{4}He+2n+^{64}Zn$)
- The breakup process is treated as an inelastic excitation of the projectile.
- CDCC calculations underestimate the experimental data.

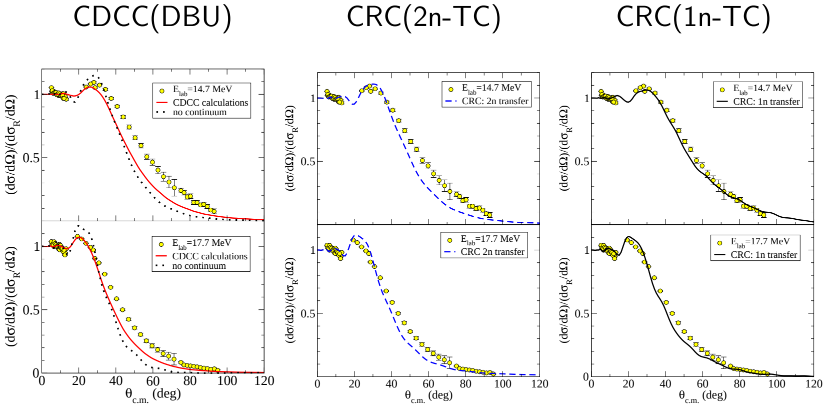


The couplings to breakup channels are important.

Break-up mechanism - ^{6}He+^{64}Zn

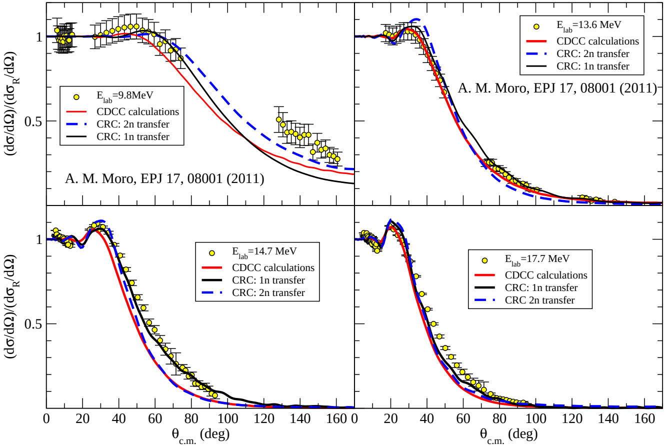


Break-up mechanism - $^{6}He+^{64}Zn$



CRC calculations, based on 1n-transfer mechanism, reproduce the experimental data.

Break-up mechanism - $^6He+^{64}Zn$



CRC calculations, based on 1n-transfer mechanism, are in reasonable agreement with the experimental data.

Conclusions

- The reactions ^{6,7}Li+^{64}Zn were measured at energies around the Coulomb barrier at LNS, Italy.
- CDCC calculations suggest more important effects of the coupling to the continuum states of the projectile in the reactions induced by ^{6}Li compared with the ones induced by ^{7}Li.

Conclusions

- New measurements of $^{6}He+^{64}Zn$ at energies above the Coulomb barrier have been presented.
- Optical Model calculations have been performed, showing long range effects.
- Small effect of the dipole Coulomb potential has been observed.
- Calculations including couplings to the continuum have been performed within different breakup mechanism.
- We have shown that the CRC method, based on one-neutron transfer mechanism, provides a more suitable approach.

Acknowledgment

Acknowledgment

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