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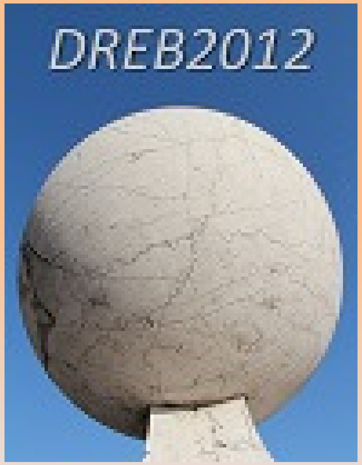
Fusion reactions and neutron transfer in collisions induced by Li isotopes on Sn and Zn targets



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OUTLINE OF THE TALK

1. Introduction on reactions induced by weakly bound nuclei
2. $^{6}Li + {}^{120}Sn$ and $^{7}Li + {}^{119}Sn$ fusion reactions
3. $^{6}Li + {}^{64}Zn$ and $^{7}Li + {}^{64}Zn$ fusion reactions
4. Summary, conclusions and future perspectives

COLLISIONS INDUCED BY WEAKLY BOUND NUCLEI

Weakly bound nuclei are characterized by

- ✓ low breakup threshold
- ✓ cluster structure
- ✓ diffuse matter distribution

⇓

Direct processes are expected to be favored

Which are the effects on fusion channel ?

Static effects: diffuse structure ⇒ lowering of Coulomb barrier

Dynamic effects: coupling not only to bound states but also to continuum

Some authors have predicted that coupling with breakup generates in CF cross section:

1. an **enhancement** at energies **below** the Coulomb barrier
2. a **reduction** at energies **above** the Coulomb barrier

BREAKUP AND FUSION

To study the effects of breakup on fusion

^{9}Be (S_n=1.57 MeV) ^{6}Li (S_α=1.48 MeV) ^{7}Li (S_α=2.45 MeV)

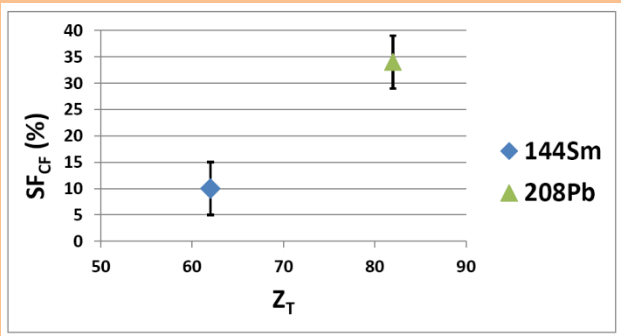
on light, medium and heavy mass targets

Fusion evaporation reaction on:
- ✓ heavy targets ⇨ **easy** CF and ICF separation
- ✓ light and medium targets ⇨ **difficult** CF and ICF discrimination

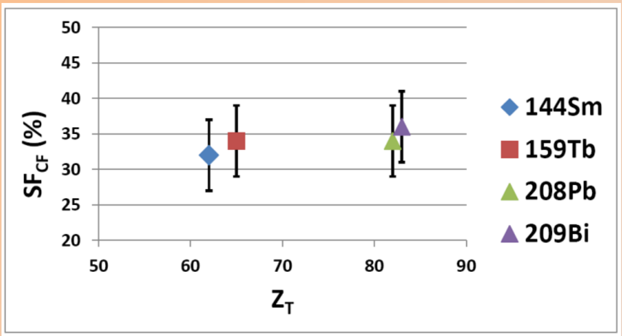
Suppression of CF with respect to 1D BPM or experimental data concerning collisions induced by well bound nuclei on the same targets **at energies above the barrier on heavy targets is a well establish effect**

Complete Fusion Suppression factor (SF_{CF})

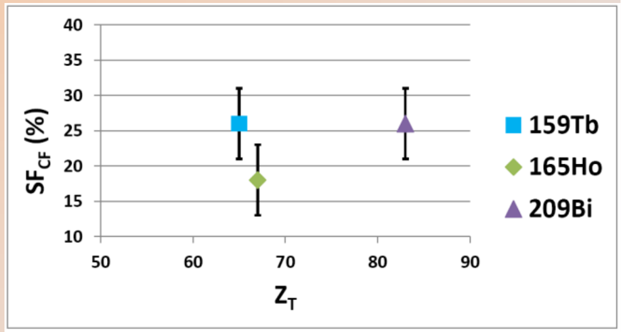
^{9}Be



^{6}Li

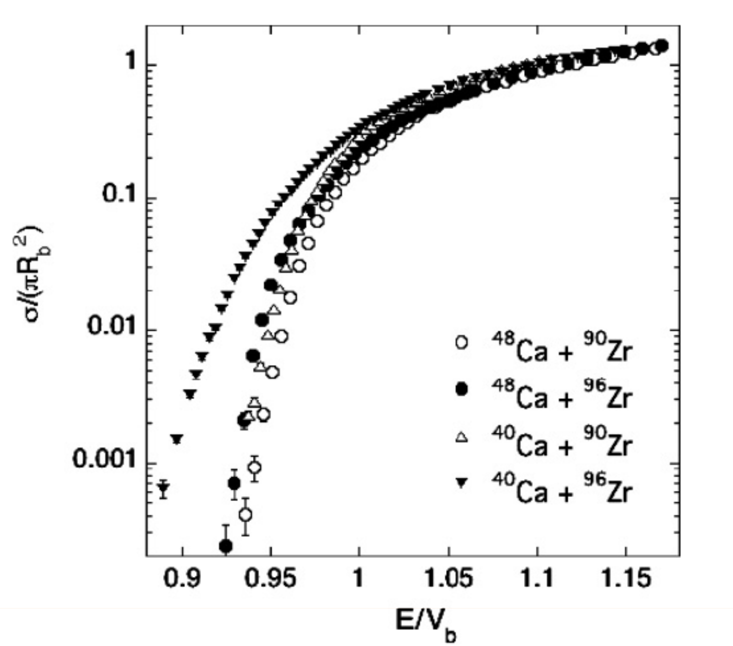


^{7}Li



In ^{6}Li-induced reactions SF is almost independent from Z of the target nucleus. The same cannot be said for ^{7}Li and ^{9}Be induced reactions

NEUTRON TRANSFER AND FUSION

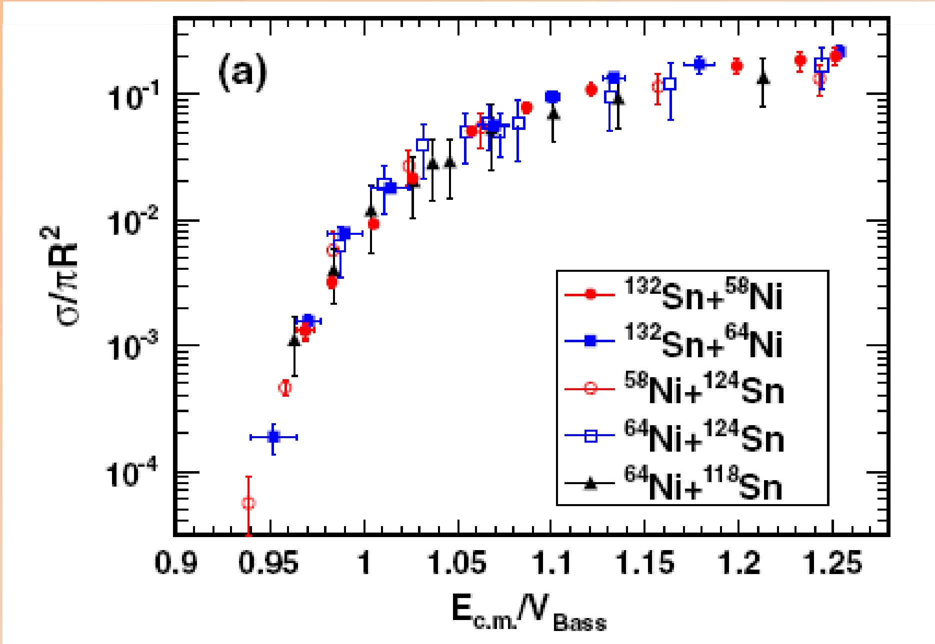


Stefanini Phys.Rev.C 73 034606 (2006)

The sub-barrier enhancement in $^{40}Ca+^{96}Zr$ has been attributed to the presence of neutron transfer channels with large positive Q-values.

... **BUT** ...

In Sn+Ni and Te+Ni fusion reactions **no sub-barrier fusion enhancement** has been observed **even in the presence of large Q-values** for multineutron transfer



Kohley, PRL 107 202701 (2011)

FUSION REACTIONS IN COLLISIONS INDUCED BY Li ON Sn TARGETS

To investigate the role played by the coupling to direct channels at energies above and below the barrier, we proposed to study:

Reactions	Q (1n transfer)	Q (2n transfer)
^{6}Li + ^{120}Sn	0.51 MeV	-12.3 MeV
^{7}Li + ^{119}Sn	1.858 MeV	2.36 MeV
^{8}Li + ^{118}Sn	4.451 MeV	6.3 MeV
^{9}Li+^{117}Sn	5.26 MeV	9.714 MeV

performed @LNS

to be performed @TRIUMF

✓ In these collisions it is possible to discriminate CF from ICF

✓ These reactions lead to the same compound nucleus and are characterized by different Q-values for neutron transfer

We wish to investigate:

- **Above the barrier** **the complete fusion suppression in a target mass range never studied before**
- **Below the barrier** **the role played by the different n-transfer Q-values by comparing the fusion excitation functions for all the systems**

ACTIVATION TECHNIQUE FOR FUSION CROSS SECTION MEASUREMENTS

The evaporation residues (E.R.)

cannot be directly identified

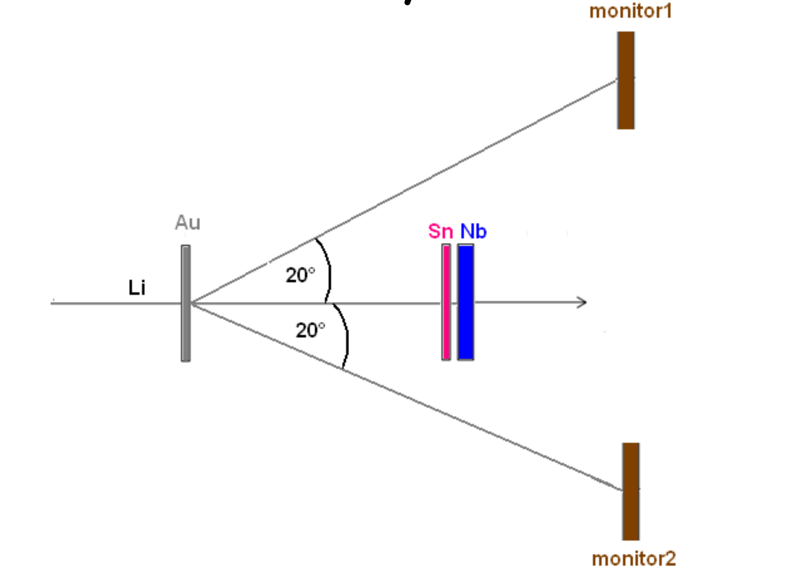
BUT

are unstable and decay by Electron Capture

To measure the fusion cross section we used an activation technique based on the off-line measurement of the atomic X-ray emission following the E.C.

"ON-LINE" TARGET ACTIVATION @ LNS

^{6,7}Li delivered by TANDEM

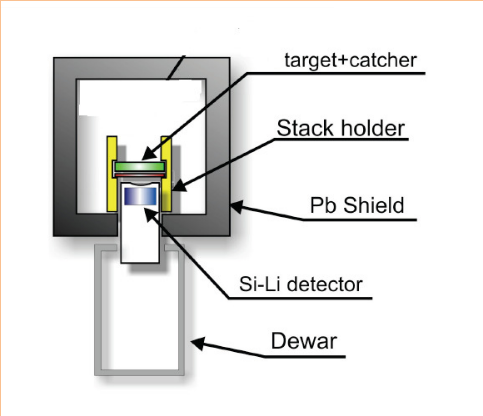


^{93}Nb catchers are used in order to stop the residues emerging from the target

Energy range investigated:
16 MeV $< E_{cm} <$ 24 MeV
(V_b=19.2 MeV)

Beam intensity
from Rutherford scattering

“OFF-LINE” CHARACTERISTIC X-RAY MEASUREMENTS

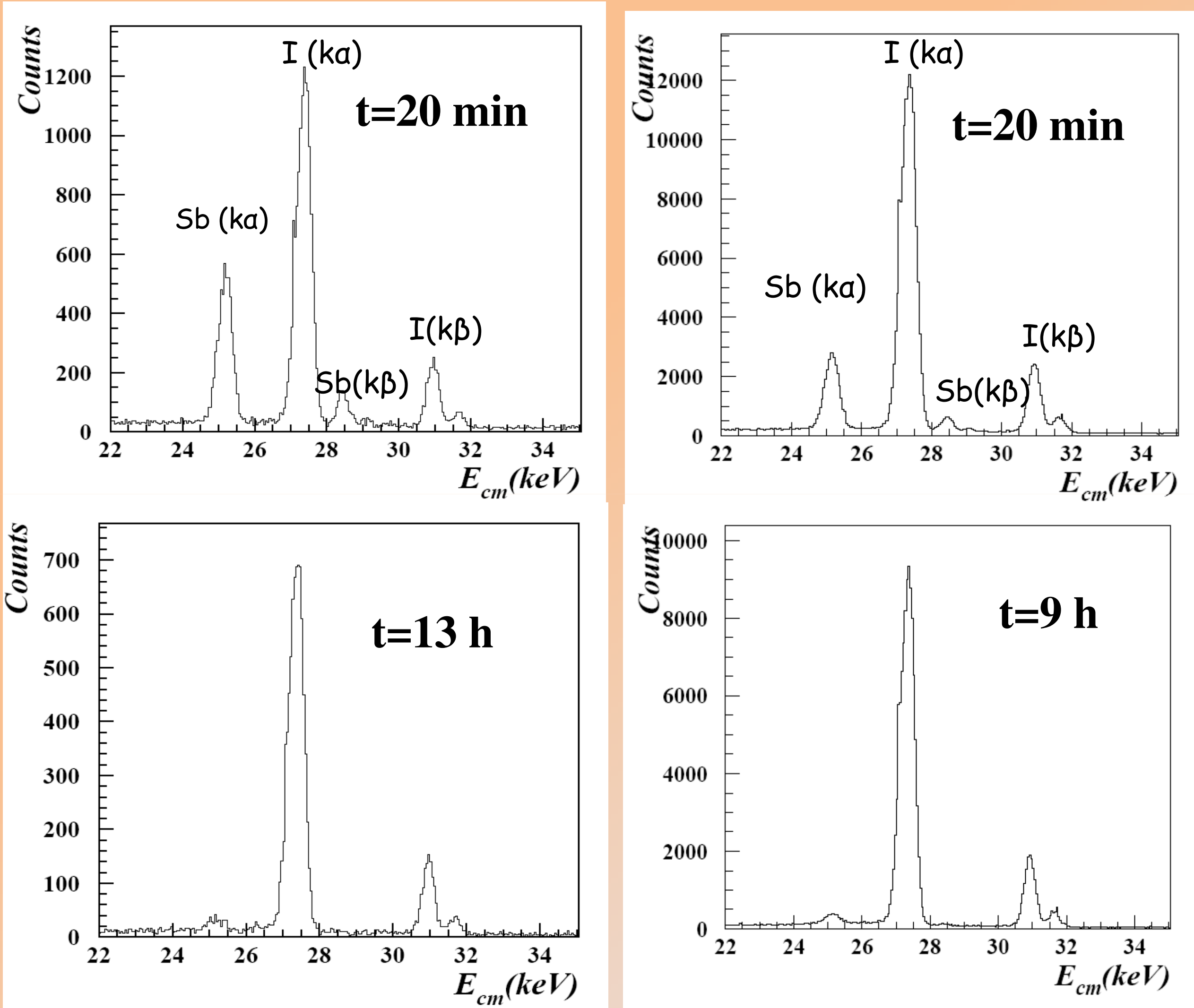


The radioactive E.R. that should be observed in both reaction are:

Complete Fusion: I

Incomplete Fusion: Sb

^{6}Li + ^{120}Sn (E=25MeV) **^{7}Li + ^{119}Sn (E=25 MeV)**

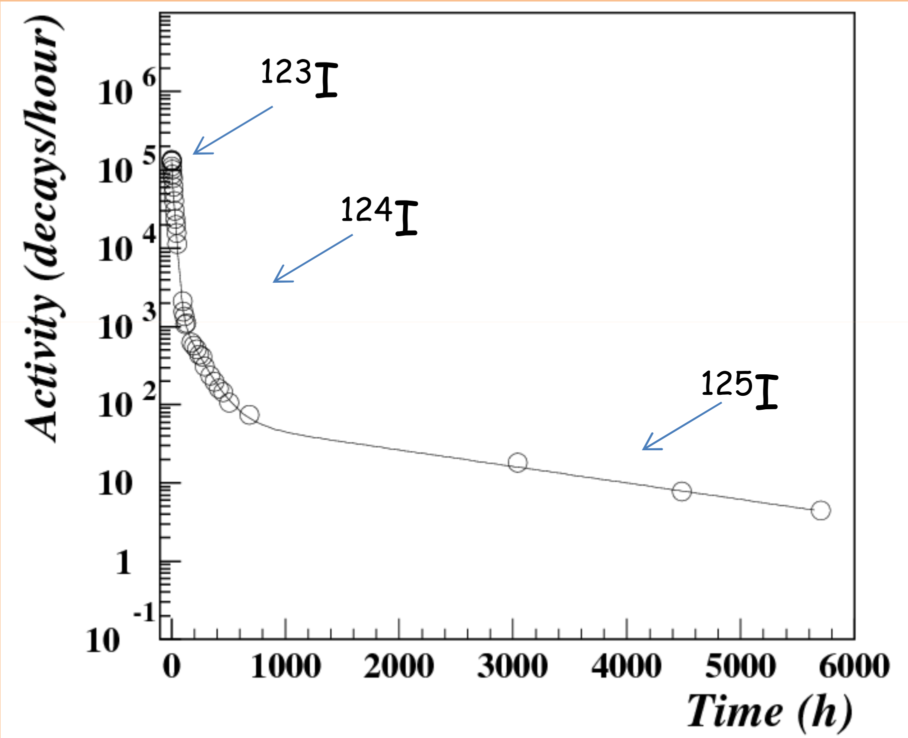


From the X-ray energies we can only identify different elements but not different isotopes

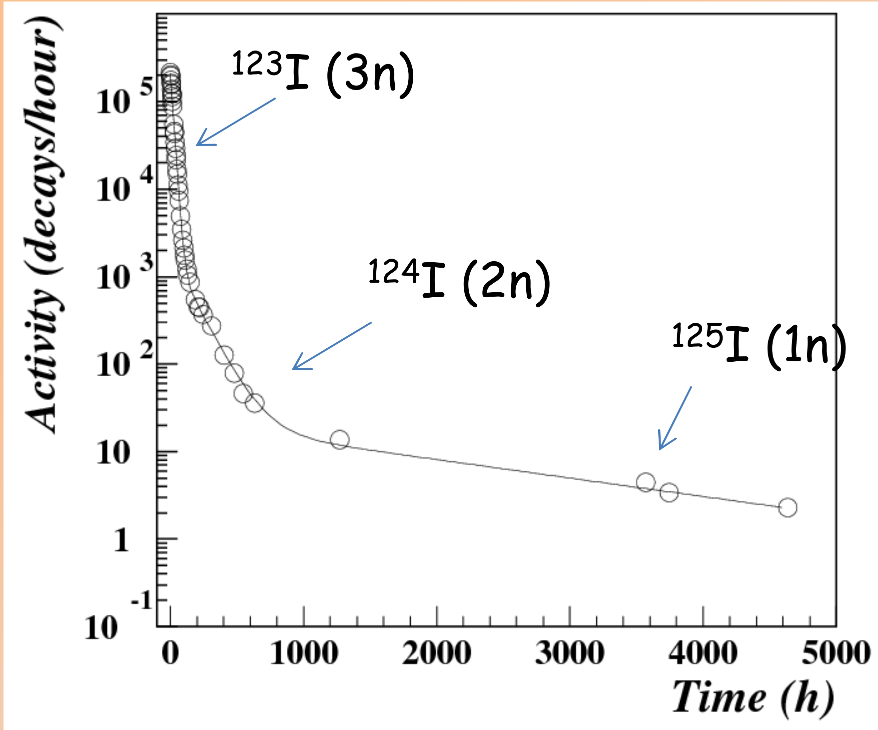
ACTIVITY CURVES

Different isotopes can be discriminated by following the X-ray activity as a function of time

$^{6}Li + ^{120}Sn$ (E=25MeV)



$^{7}Li + ^{119}Sn$ (E=25 MeV)



From the fit of the activity curve, the experimental activity A_{0exp} for each produced residue at the end of the irradiation is obtained

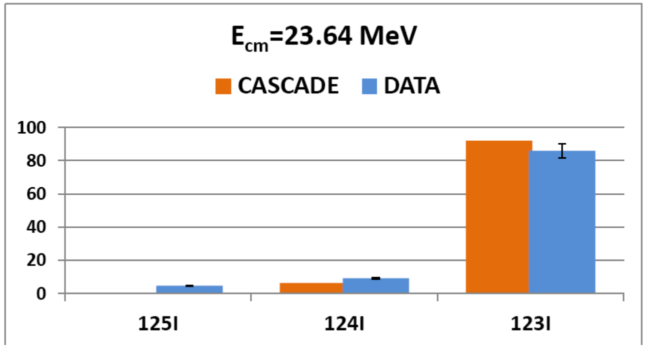
RELATIVE YIELDS OF EVAPORATION RESIDUES

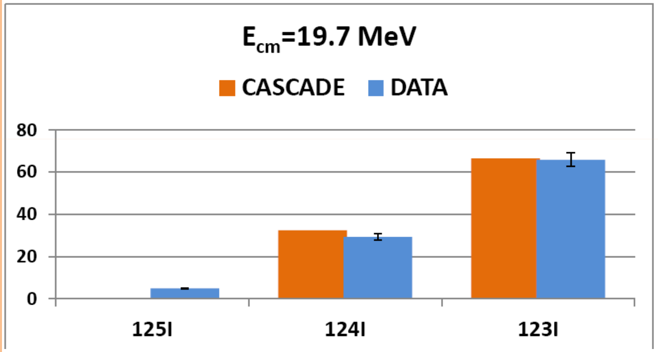
By knowing:

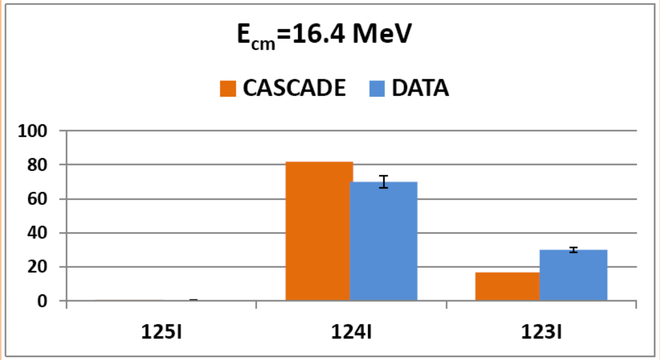
- ✓ A_{0exp}
- ✓ $\varepsilon_{Si(Li)}$
- ✓ k_a
- ✓ beam current
- ✓ target thickness

Production cross section for the E.R.

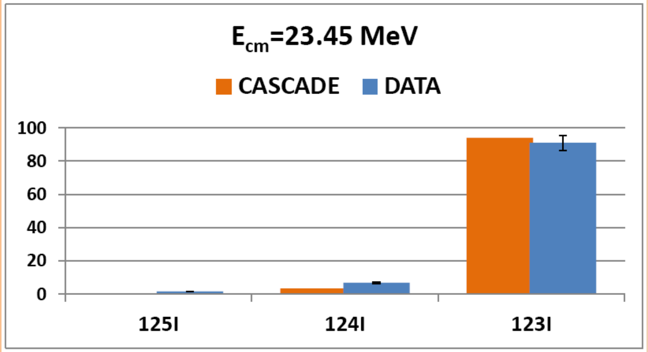
$^{6}Li + ^{120}Sn$

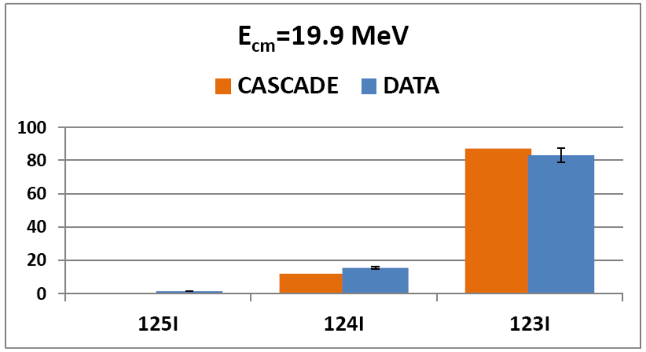


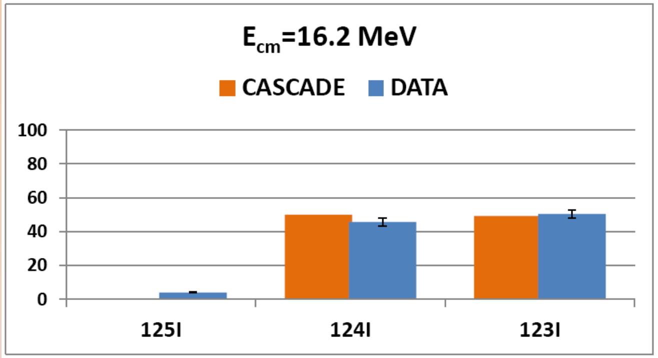




$^{7}Li + ^{119}Sn$

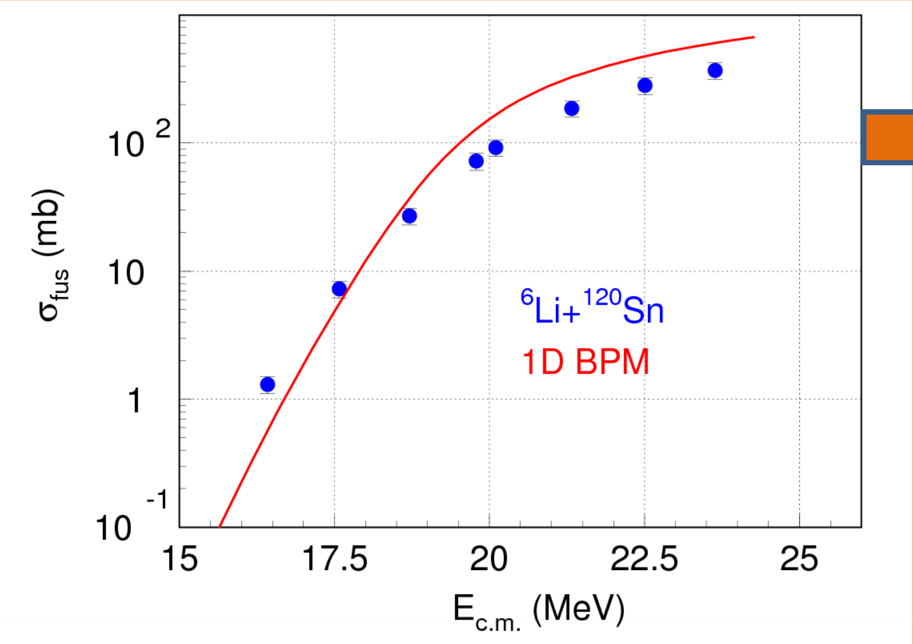


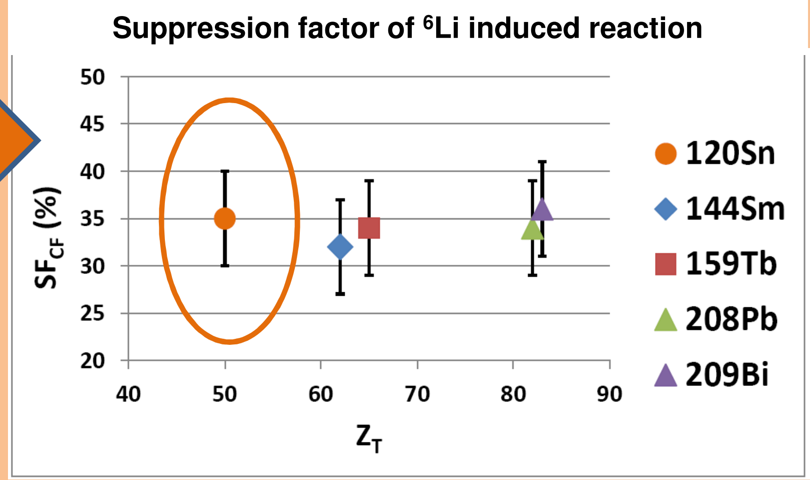




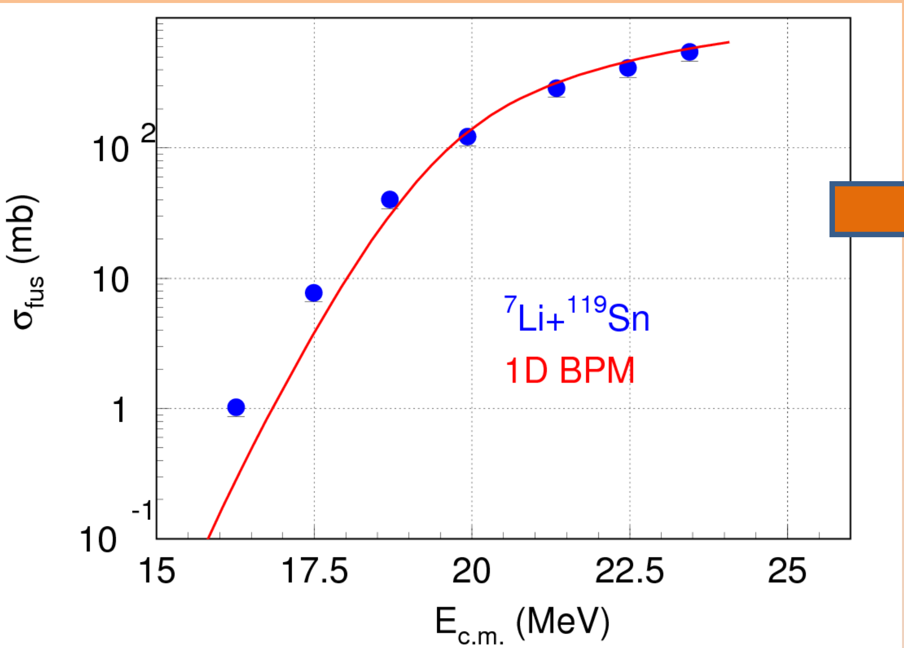
There is a good agreement between experimental data and CASCADE predictions

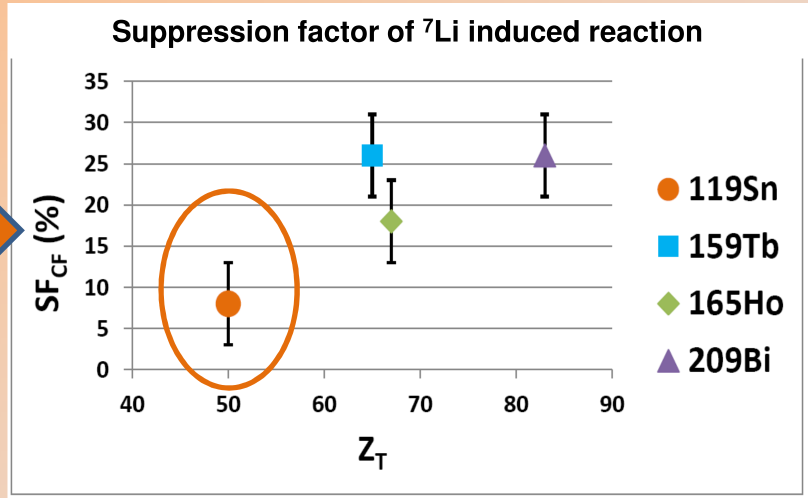
COMPLETE FUSION EXCITATION FUNCTION: PRELIMINARY RESULTS (I)





Good agreement with respect to targets with higher Z

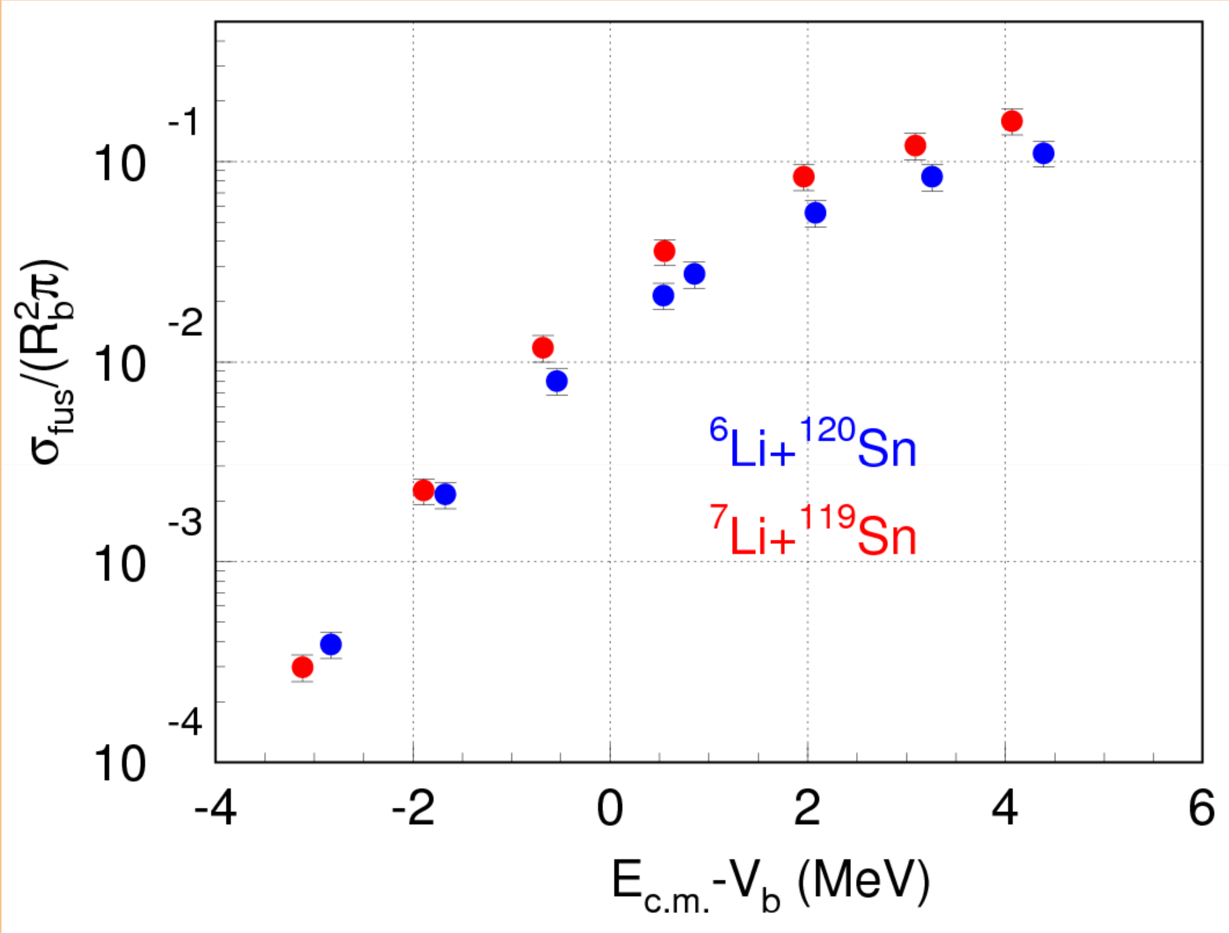




The SF of ^{7}Li +^{119}Sn is lower than the values extracted for reactions induced on targets with higher Z

COMPLETE FUSION EXCITATION FUNCTION: PRELIMINARY RESULTS (II)

To investigate effects of transfer Q-values we should compare
all the Li+Sn systems and perform CDCC calculation



Sub-barrier fusion enhancement in the ^{7}Li induced collisions
due to larger n-transfer Q value cannot be deduced from the present data

^{6,7}Li + ^{64}Zn FUSION REACTIONS @ LNS

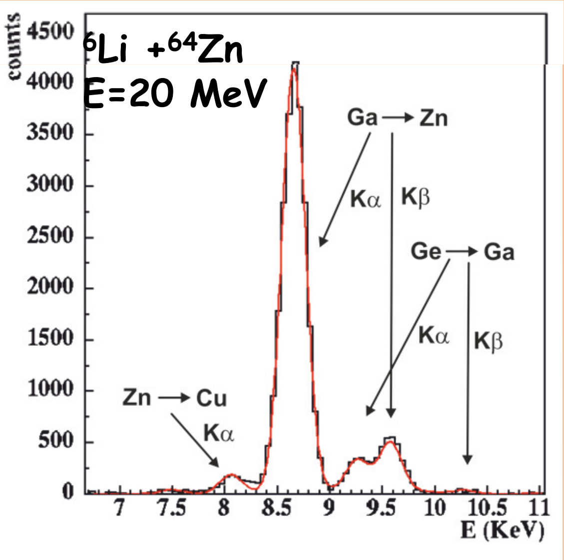
Aim of the study:

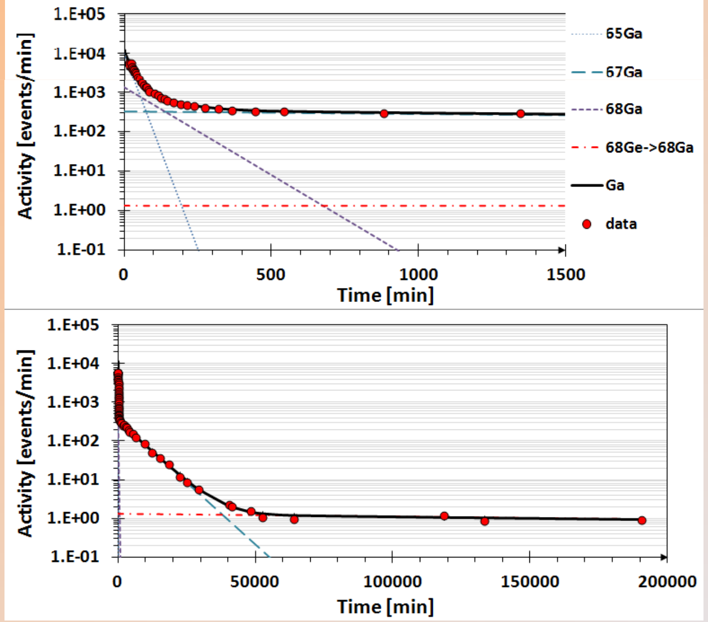
investigate on possible effects on the sub-barrier fusion cross section due to :

✓ different structure ✓ different breakup threshold

^{6}Li (α+d) S_α = 1.4 MeV	no bound excited states
^{7}Li (α+t) S_α = 2.5 MeV	first excited state ~ 0.5MeV

We used the activation technique as in the case of Li+Sn …

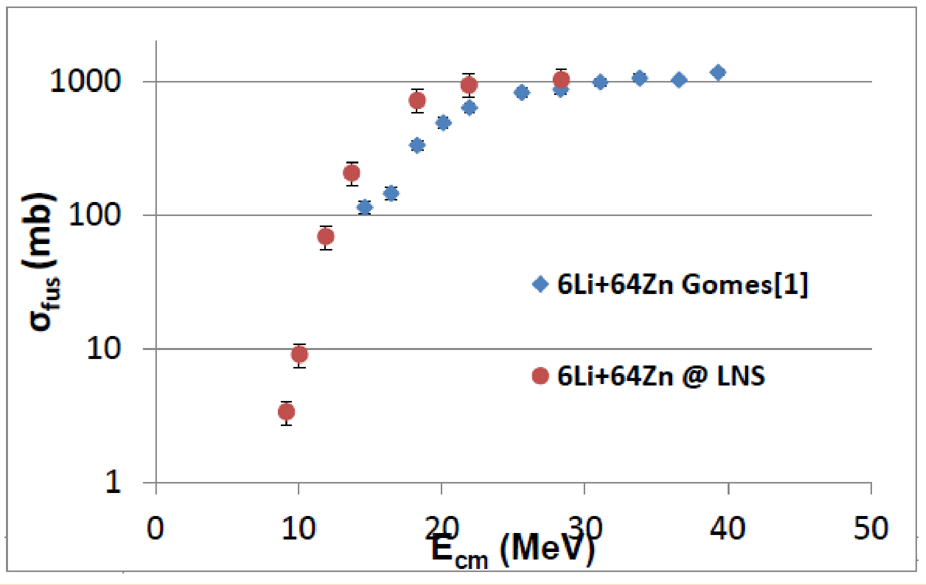


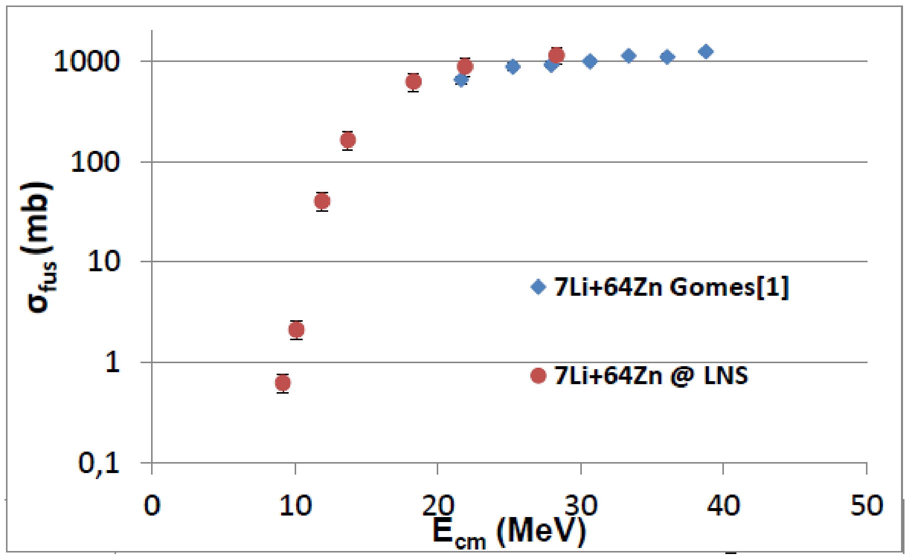


… BUT …

discrimination of the CF and ICF is not possible ➡ **Total fusion cross section**

COMPARISON WITH GOMES et al. [1] $^{6,7}Li+^{64}Zn$



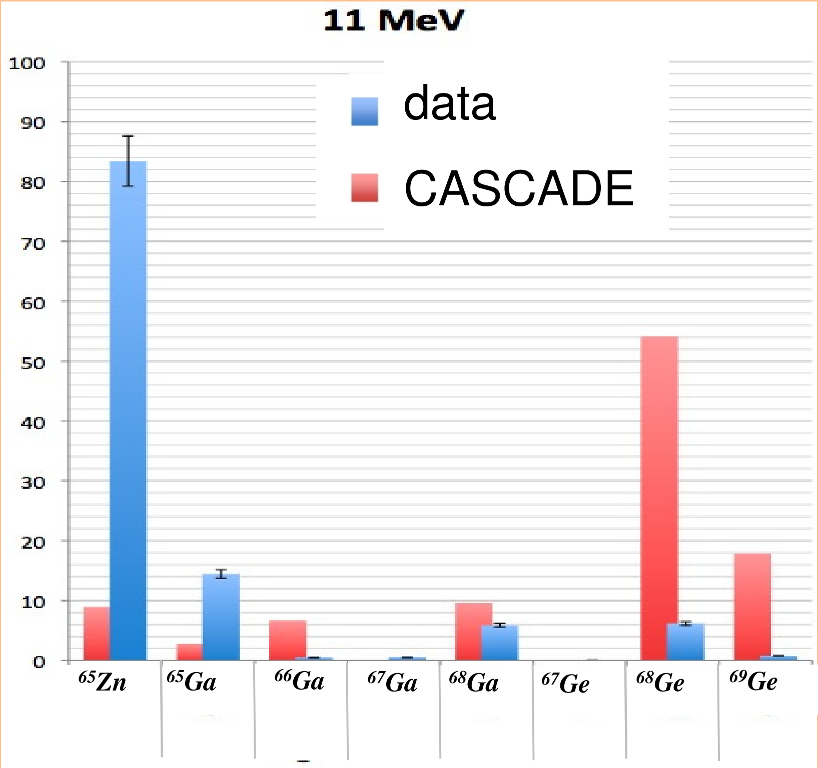


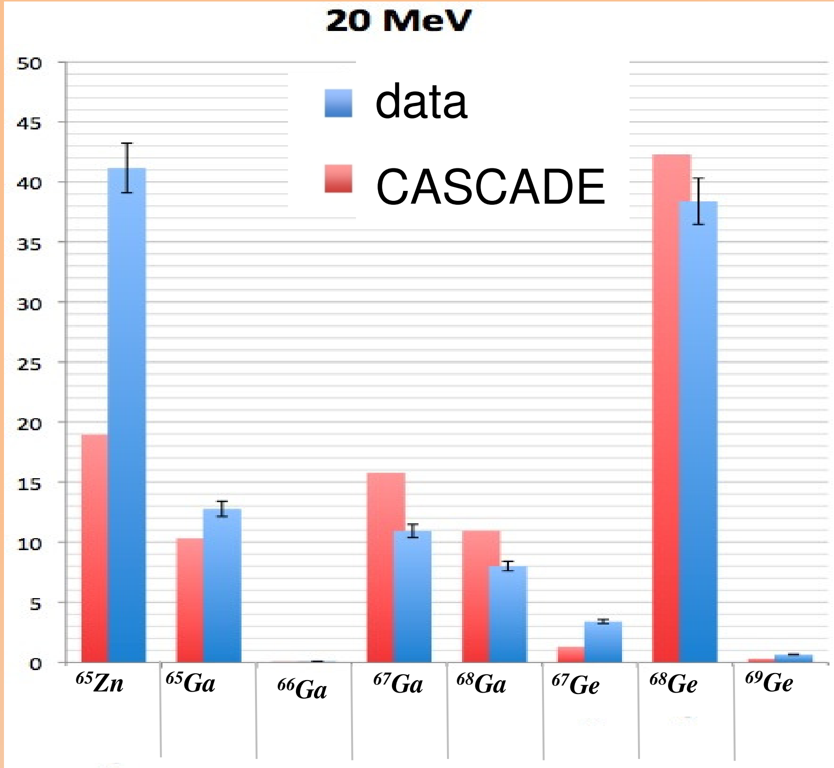
$^{6,7}Li + ^{64}Zn$ cross sections measured @ LNS are larger than the one previous measured

This result appears to confirm the presence of possible experimental problems suggested by Gomes [Phys.Rev.C 79 (2009) 027606]

[1] Phys. Rev. C 71 034608 (2005)

RELATIVE YIELDS OF EVAPORATION RESIDUES:
$^{6}Li+^{64}Zn$ ($V_b \approx 13$MeV)

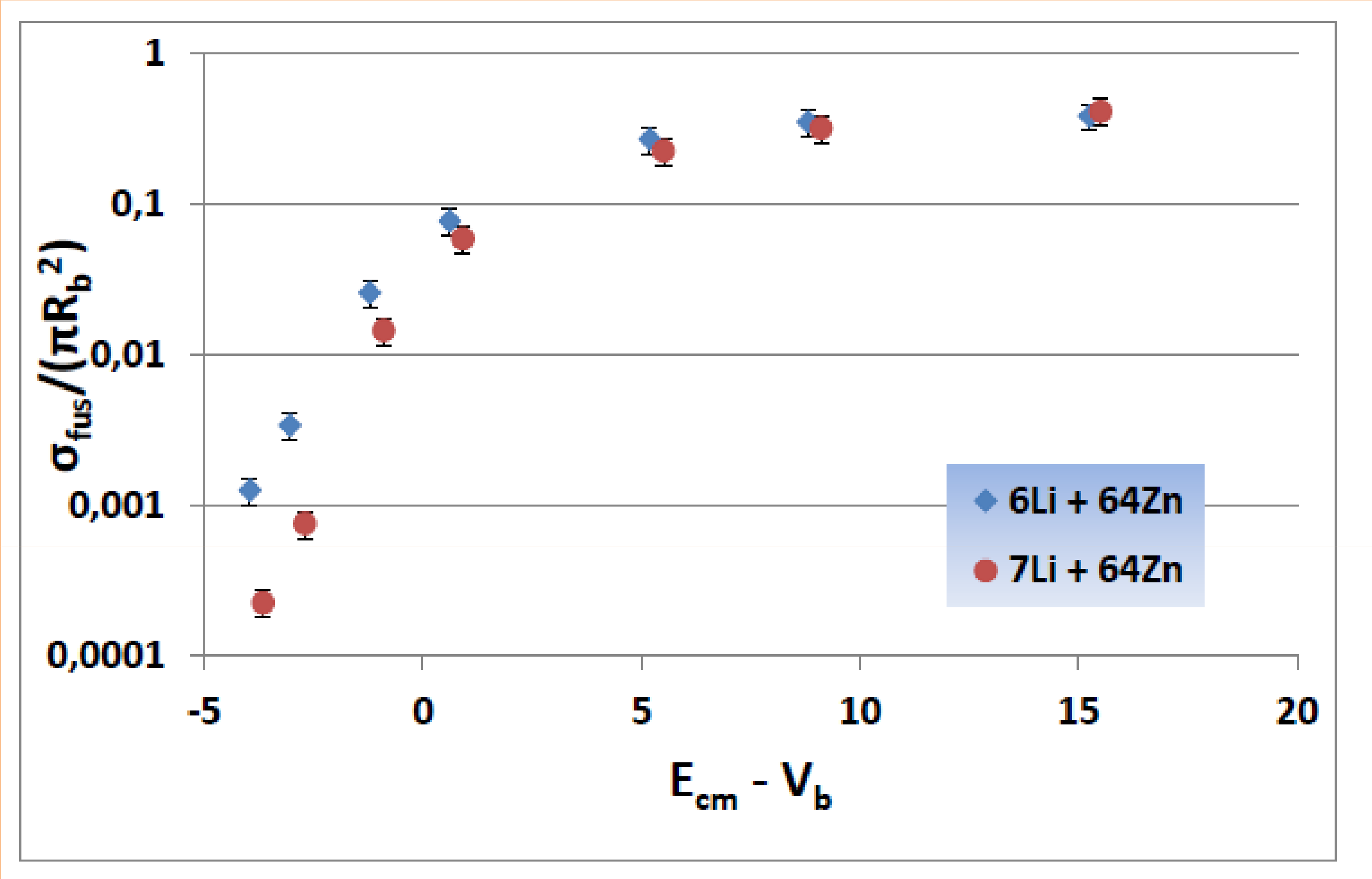




Above the Coulomb barrier complete fusion is the dominant process.

Below the barrier heavy residue production in the region is clearly dominated by d-ICF and n-transfer

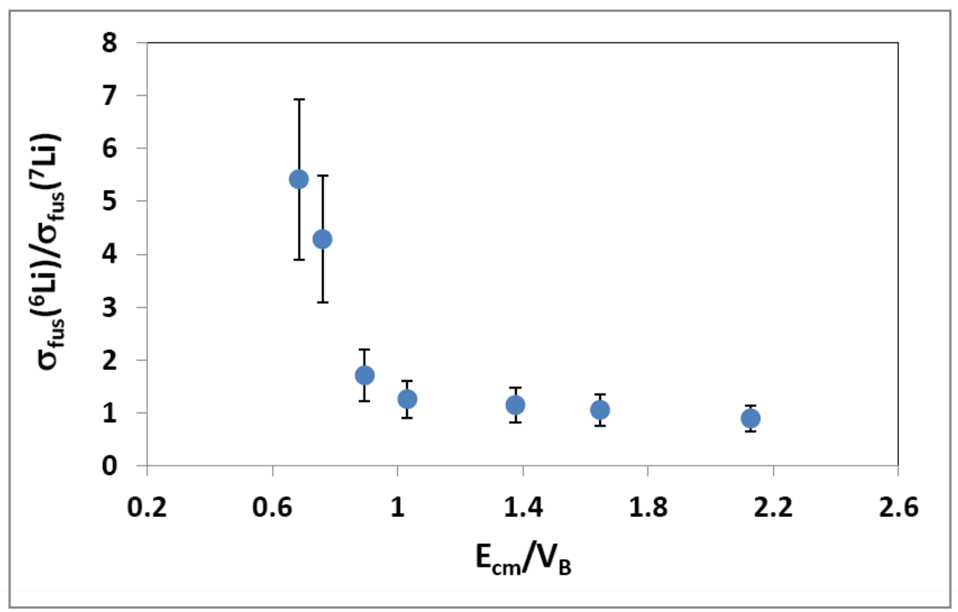
^{6}Li + ^{64}Zn AND ^{7}Li+^{64}Zn FUSION EXCITATION FUNCTION (I)



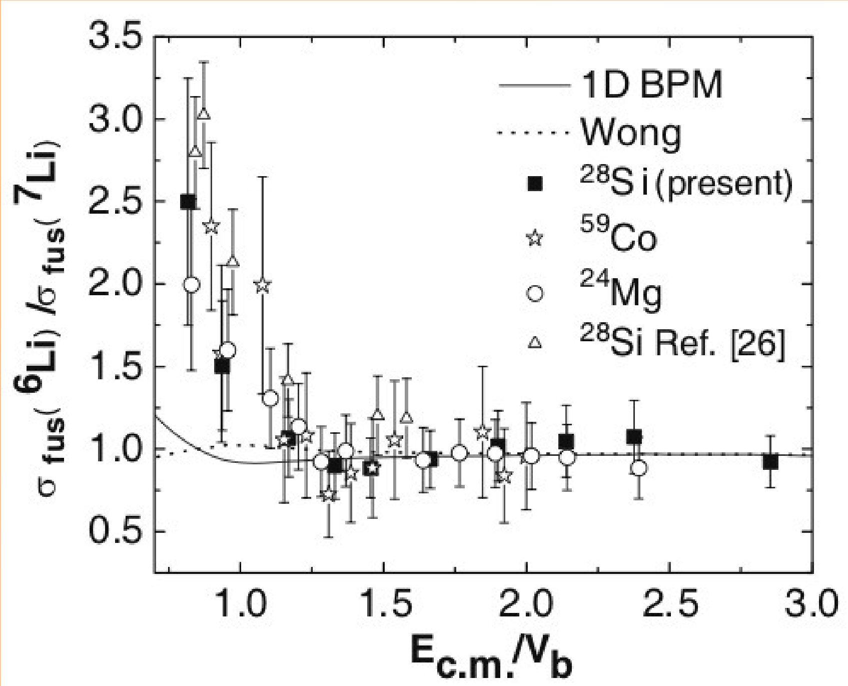
V_b and R_b are taken from *Canto et al., Nucl. Phys. A 821, 51 (2009)*

A clear enhancement of ^{6}Li induced reaction with respect to the ^{7}Li one is observed at energies below the Coulomb barrier

$^{6}Li + ^{64}Zn$ AND $^{7}Li + ^{64}Zn$ FUSION EXCITATION FUNCTION (II)



This behavior has already been observed in fusion reaction induced by $^{6,7}Li$ on other targets



Mandira Sinha et al. Eur.Phys.Jour. A 44,403 (2010)

The origin of this increasing trend has been studied within CDCC calculations for the $^{6,7}Li + ^{59}Co$ [A. D.Torres et al., Phys. Rev. C 68, 044607 (2003)]:

it has been attributed to the different breakup thresholds of $^{6,7}Li$.

SUMMARY AND CONCLUSIONS

We performed fusion reactions induced by ^{6}Li and ^{7}Li to investigate the effects of breakup and neutron transfer on fusion process.

For **Li+Sn reactions**

- at energy **above** the barrier a suppression of CF excitation function with respect to 1D BPM was observed. The SF for the ^{6}Li induced reaction is in agreement with the others reported in literature. The SF for the ^{7}li+^{119}Sn is lower than those extracted from reactions on heavier targets.
- at energies **below** the barrier, only from the comparison of the two system nothing could concluded about the possible influence of n-transfer Q-value.

In the future we would like to
- extend these measurements to lower energies.
- perform the ^{8}Li+^{118}Sn ^{9}Li+^{117}Sn experiments and compare the four fusion excitation functions.
- do CDCC calculations to take into account the coupling with breakup.

For the ^{6,7}**Li+**^{64}**Zn reactions**

- the comparison with CASCADE code has shown that direct reactions play an important role at sub-barrier energies
- a large sub-barrier enhancement of fusion excitation function in the case the 6li+64Zn with respect to 7Li+64Zn.

As next step we will perform CDCC calculations to understand the origin of this enhancement

COLLABORATION

A. Di Pietro[1] P. Figuera[1], M, Fisichella[1,2] M. Lattuada[1,3],

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