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FUSION REACTIONS OF $^{58,64}Ni + {}^{124}Sn$

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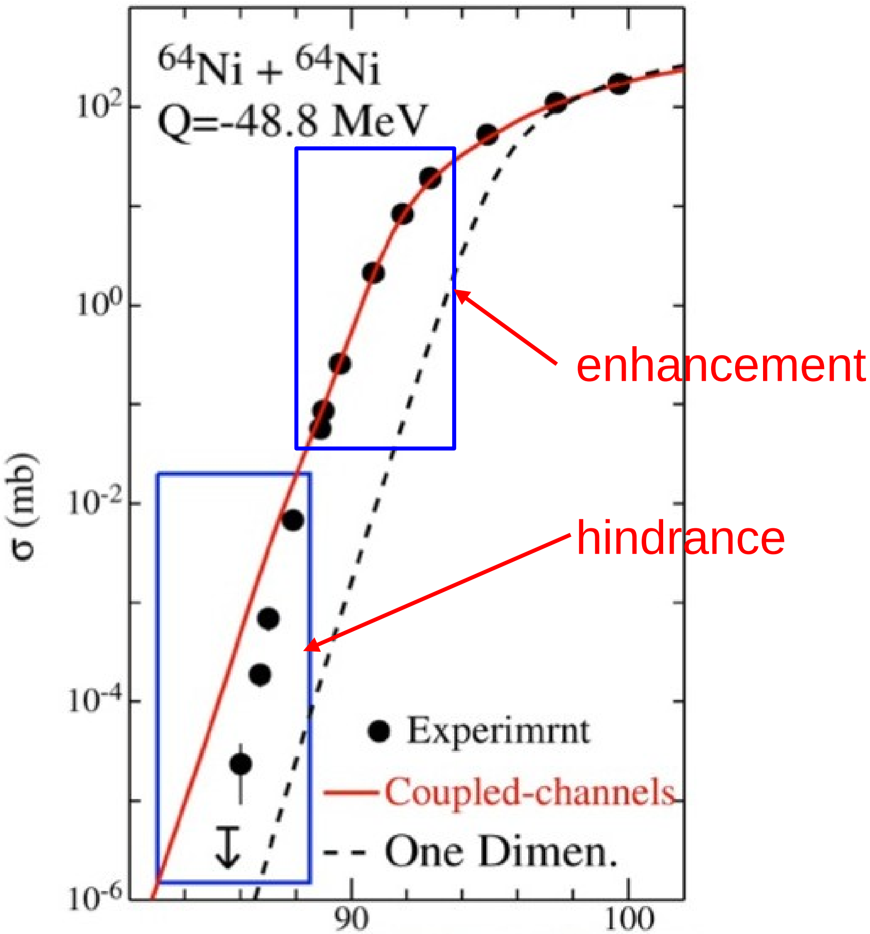
OUTLINE

- Introduction: fusion dynamics near and below the barrier
- Systematics for transfer effect and hindrance in sub-barrier fusion reactions
- The experiment: fusion reactions of $^{58,64}Ni + ^{124}Sn$ at the Laboratori Nazionali of Legnaro
- Experimental results and comparison with CC calculations

FUSION DYNAMICS NEAR AND BELOW THE BARRIER

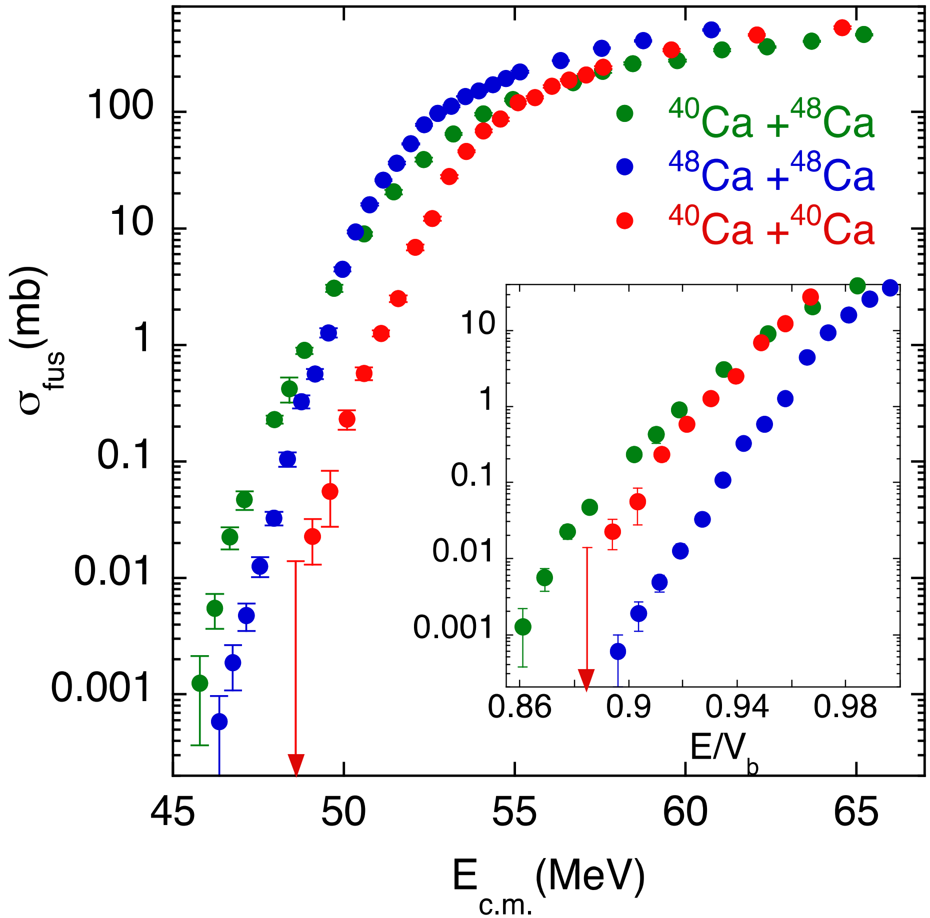


C. L. Jiang et al., PRL 93, 012701 (2004)
PRC 73, 014613 (2006)

The low-lying collective structure of the colliding nuclei strongly influences the dynamics of low-energy fusion reactions, through CC effects.

At very low energies CC calculations overestimate the experimental cross sections. This may be an evidence of "fusion hindrance".

EFFECT OF TRANSFER ON FUSION CROSS SECTIONS

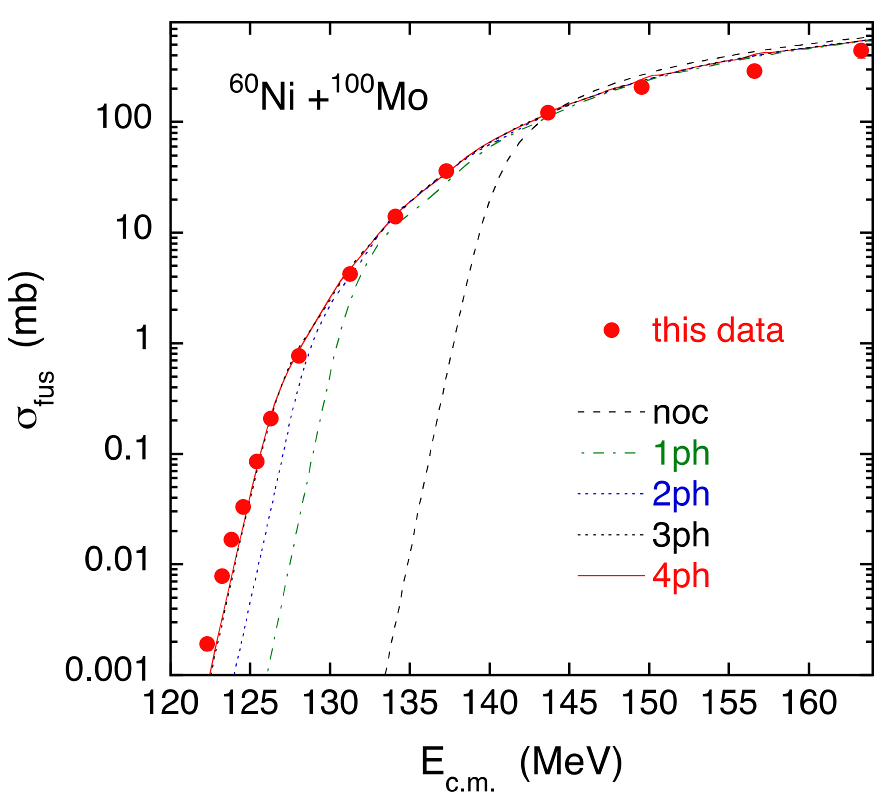


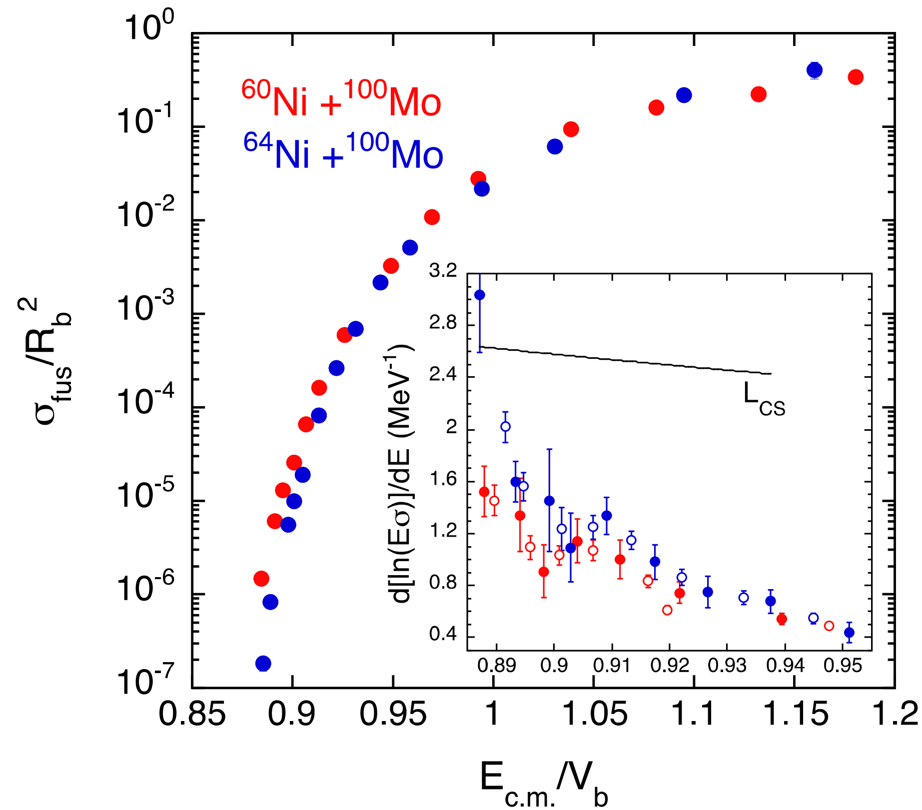
Recent measurements on 40Ca+40Ca, 40Ca+48Ca and 48Ca+48Ca show evidence for the effect of Q>0 transfer couplings at sub-barrier energies

G. Montagnoli et al., PRC 85, 024607 (2012)
C. L. Jiang et al., PRC 82, 041601(R) (2010)
A. M. Stefanini et al., PLB 679, 95 (2009)

Do we observe analogous effects
when moving to heavier systems?

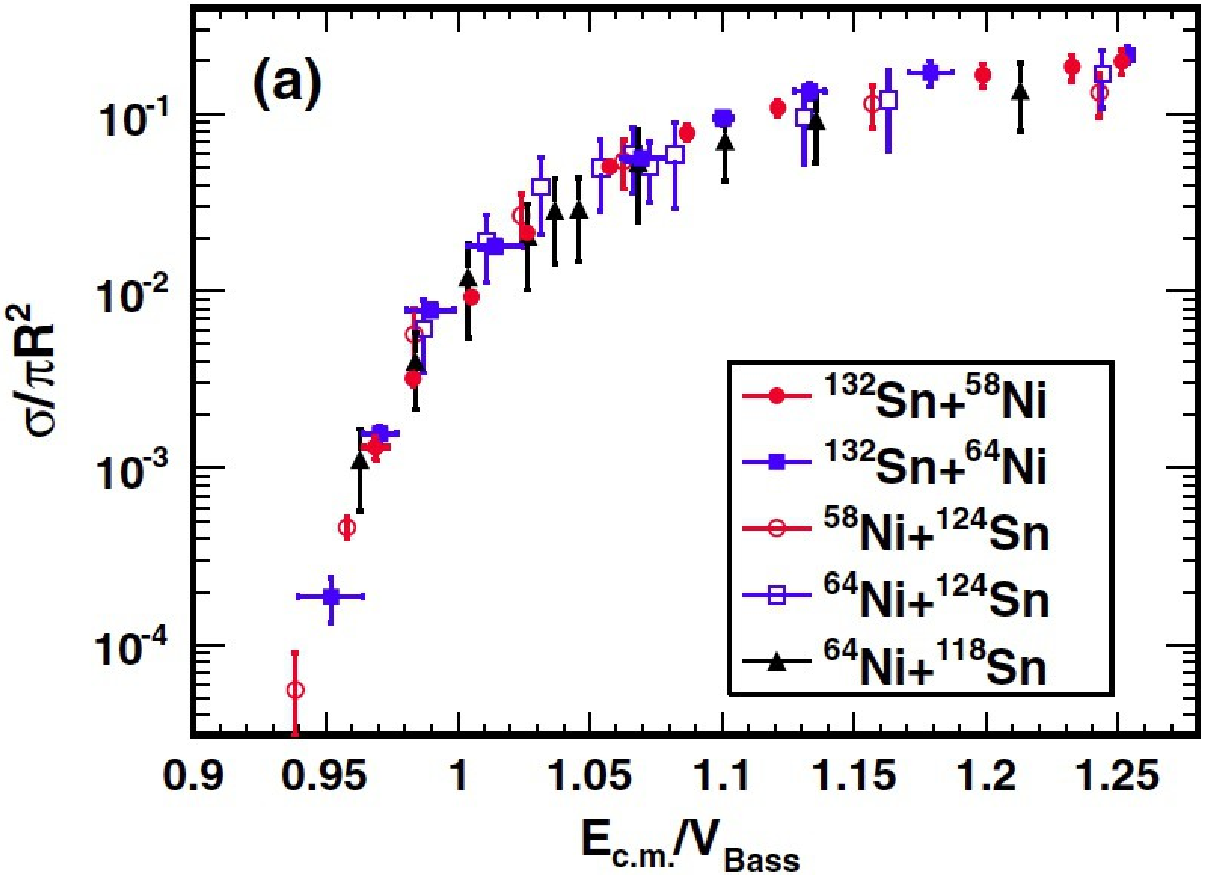
Heavy systems involving soft vibrational nuclei: multi-phonon excitations are dominant





A. M. Stefanini et al., EPJA 49, 63 (2013)

The results of Kohley et al. using the exotic ^{132}Sn beam

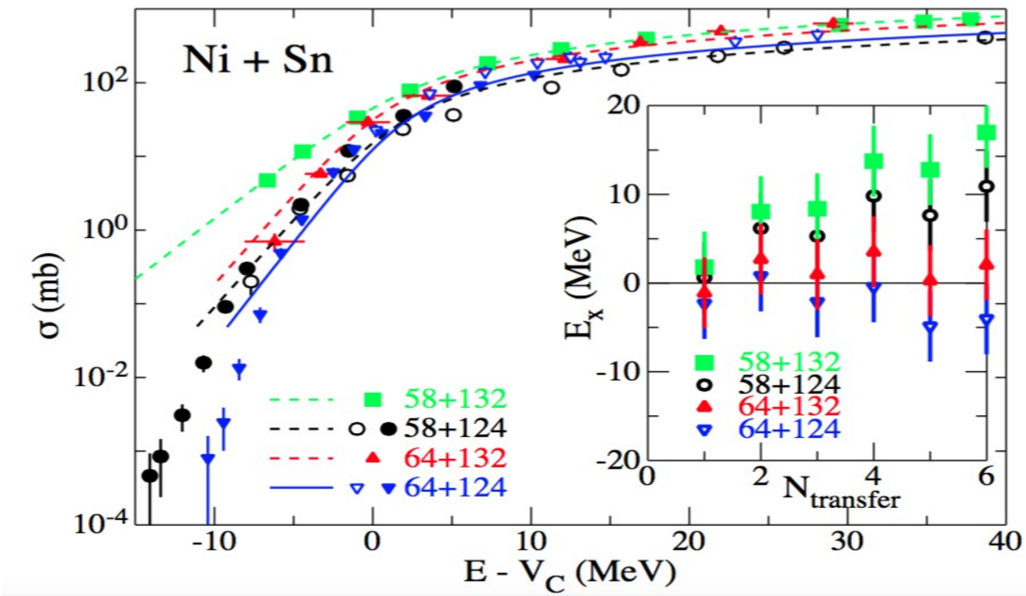


No significant difference between the various cases seems to show up in this picture but… What if we move to lower cross sections?

The low-energy behaviour of ^{58,64}Ni + ^{124}Sn has to be clarified. Transfer coupling effects are expected!

Z. Kohley et al., , Phys. Rev. Lett. 107 , 202701 (2011)

INFLUENCE OF TRANSFER: A PHENOMENOLOGICAL APPROACH



The curves are fits with the Wong formula:

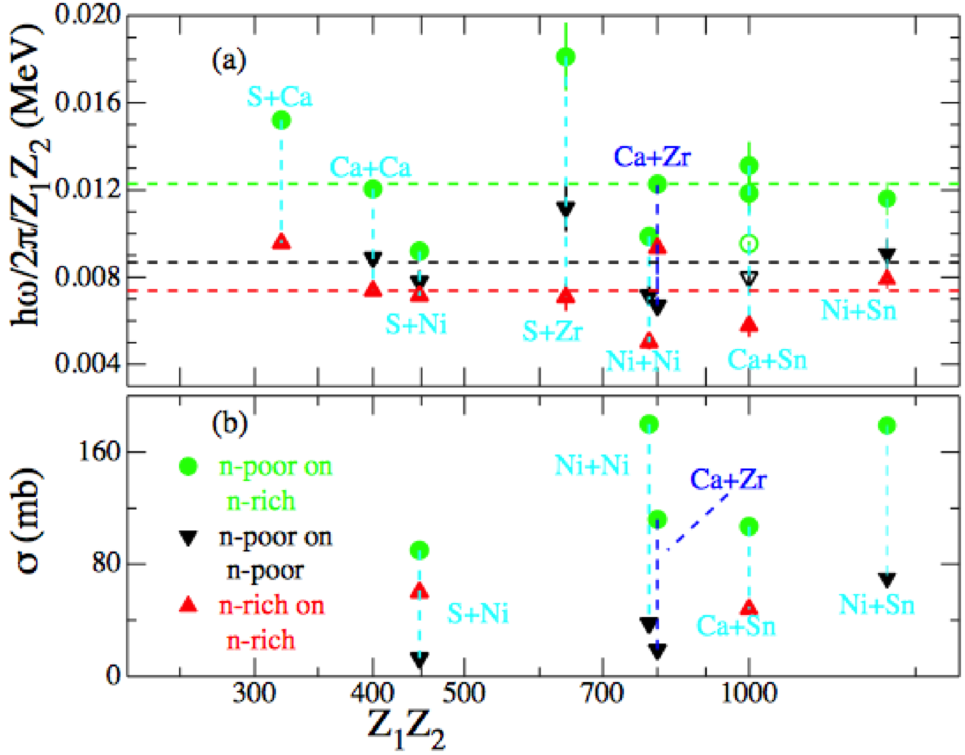
$$\sigma = \frac{R_C^{\,2}}{2E}\hbar\omega \ln\left\{1+\exp\left[\frac{2\pi}{\hbar\omega}(E-V_C)\right]\right\}$$

System	$\hbar\omega$ (MeV)
^{58}Ni + ^{132}Sn	16.3 ± 1.0
^{58}Ni + ^{124}Sn	11.4 ± 0.5
	12.2 ± 0.9
^{64}Ni + ^{132}Sn	11.1 ± 0.6
^{64}Ni + ^{124}Sn	9.8 ± 0.6
	8.7 ± 7.5

	^{58}Ni+^{124}Sn	^{64}Ni+^{124}Sn	^{58}Ni+^{132}Sn	^{64}Ni+^{132}Sn
Q (+1n)	0.510 MeV	-2.391 MeV	1.656 MeV	-1.245 MeV
Q (+2n)	5.952 MeV	0.615 MeV	7.833 MeV	2.497 MeV

C. L. Jiang et al., Phys. Rev. C 89, 051603(R) (2014)

SYSTEMATIC TRENDS



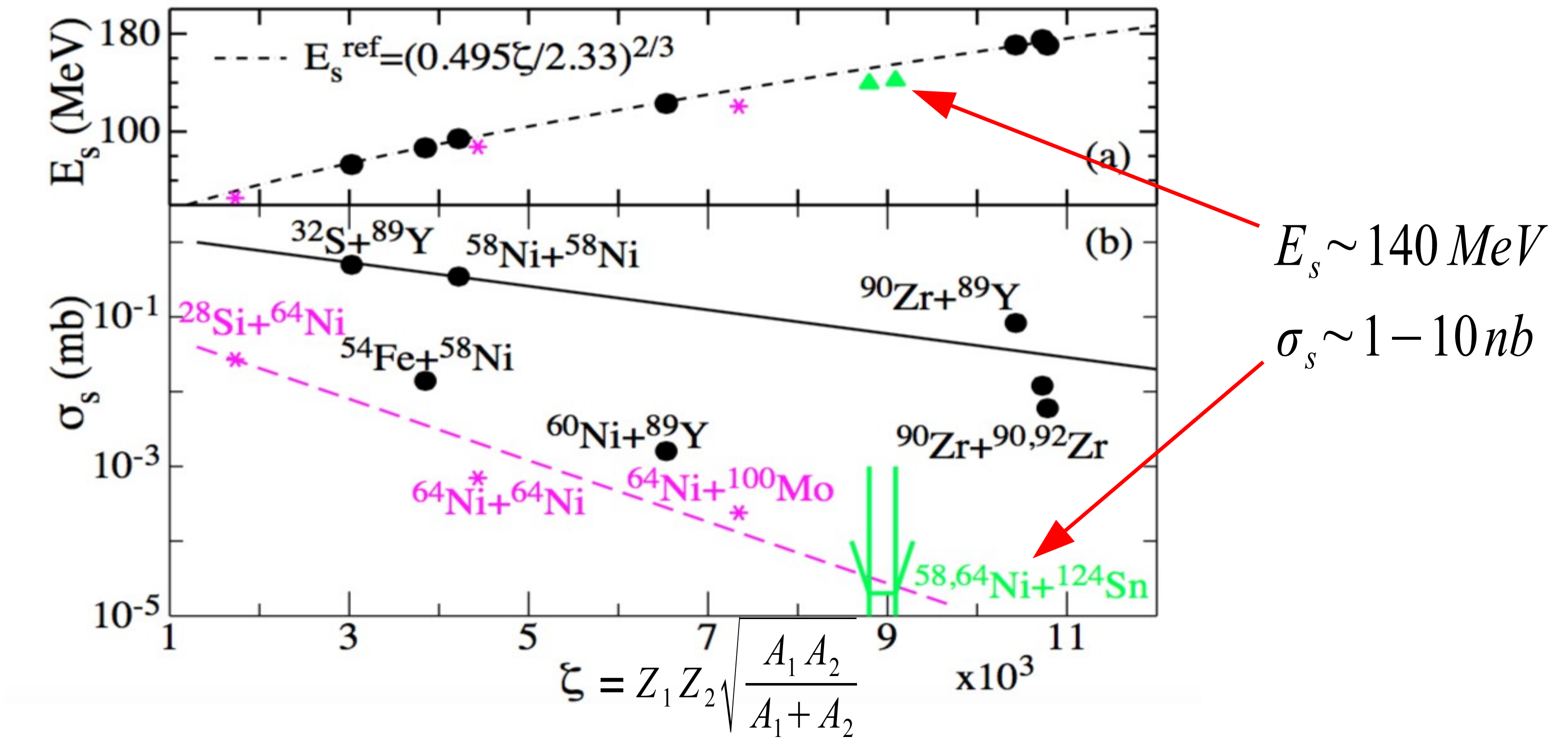
A larger curvature ħω means a thinner barrier and then a fusion enhancement.

Larger “reduced” ħω, and larger transfer yields, are found for all systems with Q>0 transfer channels.

σ = Total neutron transfer cross sections near the barrier

$$\frac{\hbar\omega}{Z_1 Z_2}$$ = Fitted reduced curvatures of the Coulomb barrier

SYSTEMATICS FOR HINDRANCE

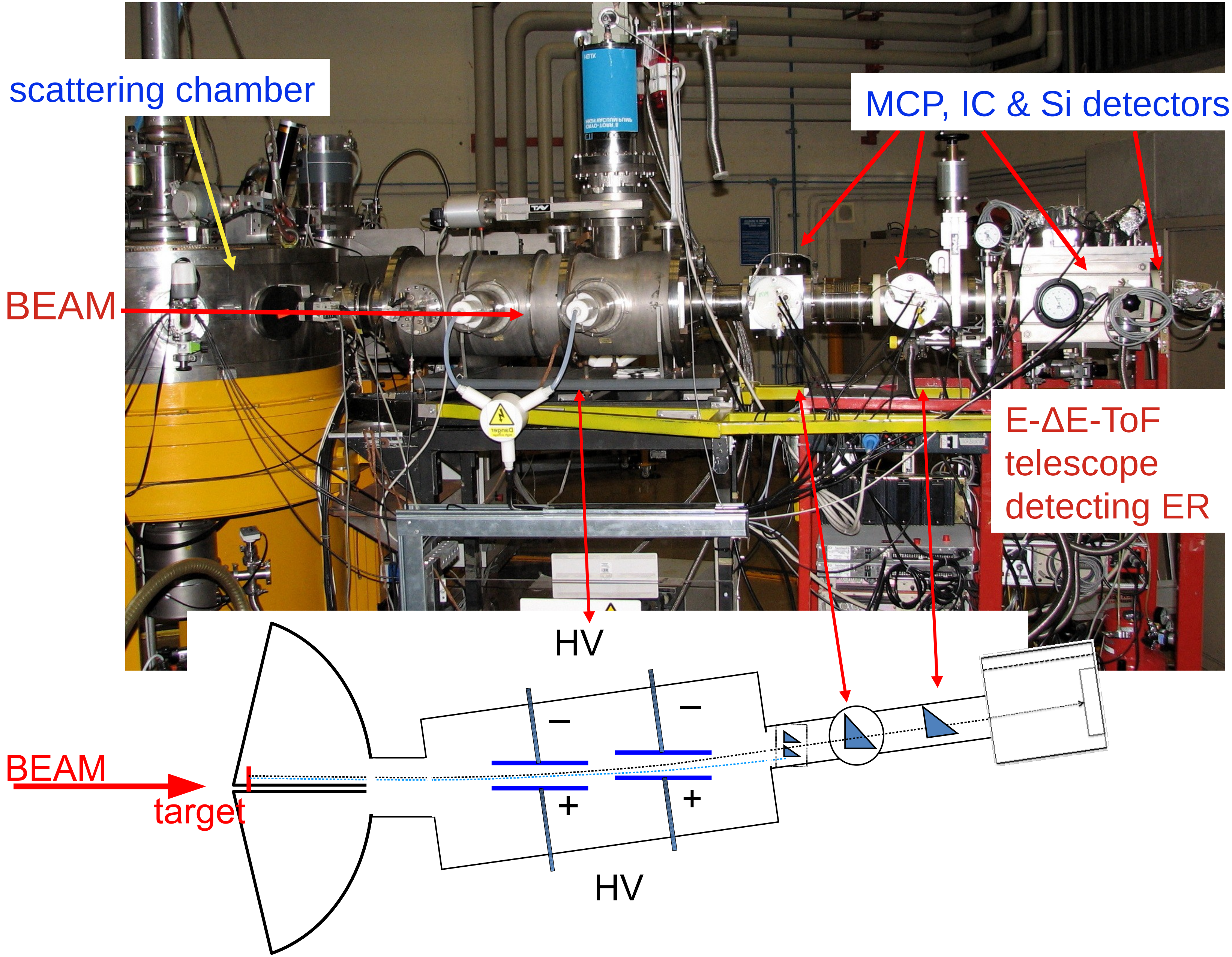


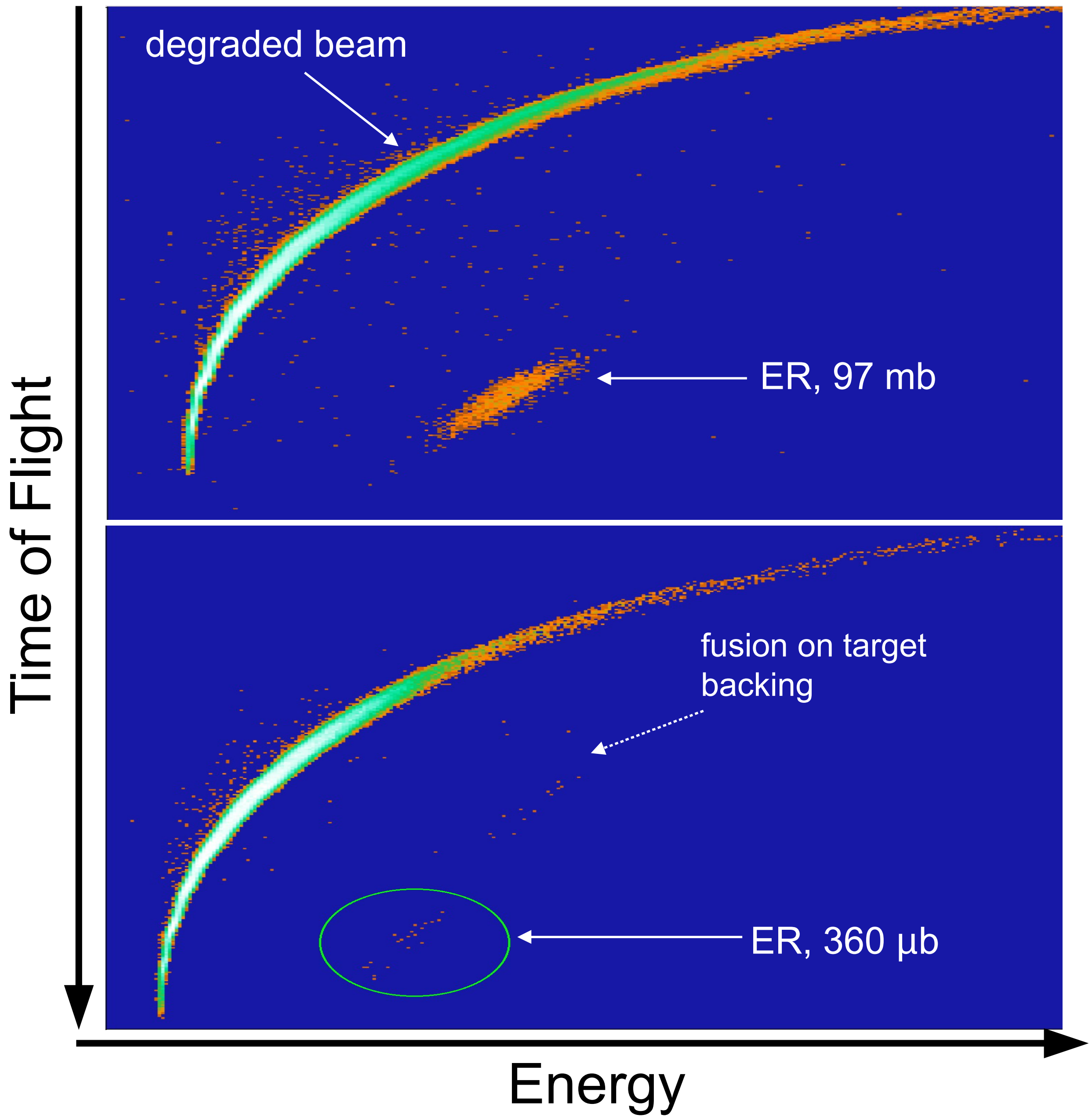
No fusion hindrance is expected at the measured cross sections! → A standard Woods-Saxon potential can be used for the ion-ion interactions

THE EXPERIMENT

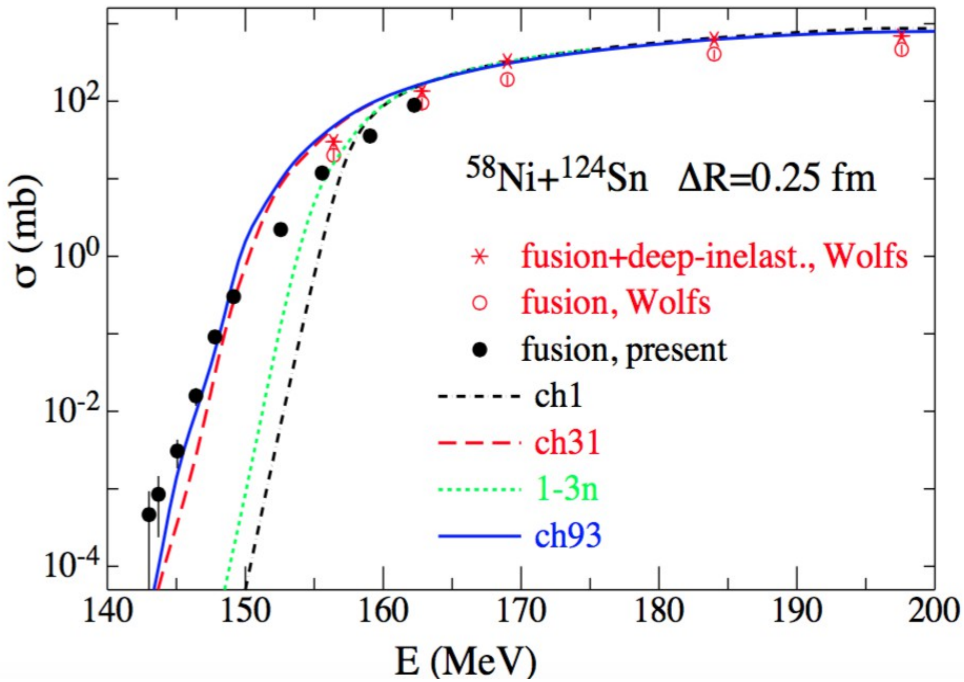
- Doubly-stripped beams of $^{58,64}Ni$ with charge states 11^+ and 18^+ respectively with a current of 1-3 pnA;
- ^{124}Sn target with a thickness of 50 μg/cm² evaporated on a 20 μg/cm² carbon backing. The isotopic abundance of ^{124}Sn was 96.6%.
- Four Si detectors placed around the target at 22.5° served as monitors to get the absolute cross sections;
- Two angular distributions were measured in the range $-4° \leq \theta \leq 4°$ at E_{lab} = 246.1 MeV and 234.0 MeV for the $^{64}Ni+^{124}Sn$ system.
- Evaporation residues were detected at 1° and 2° with the Legnaro electrostatic separator in its upgraded configuration.

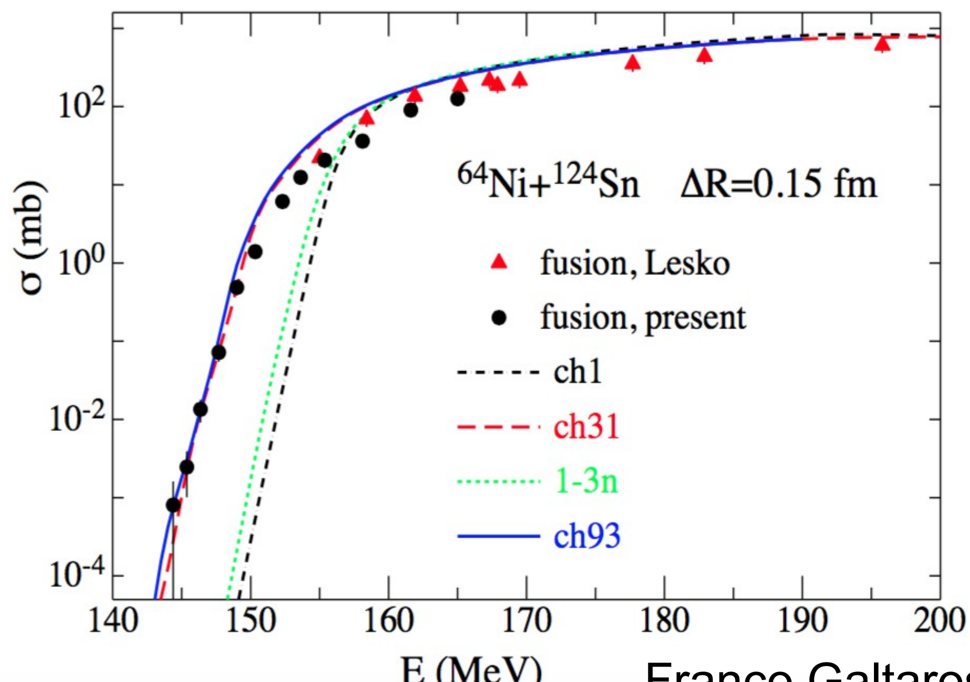
Electrostatic separator and E-ΔE-TOF telescope to detect evaporation residues at ≈ 0 degrees





Very good identification of evaporation residues!



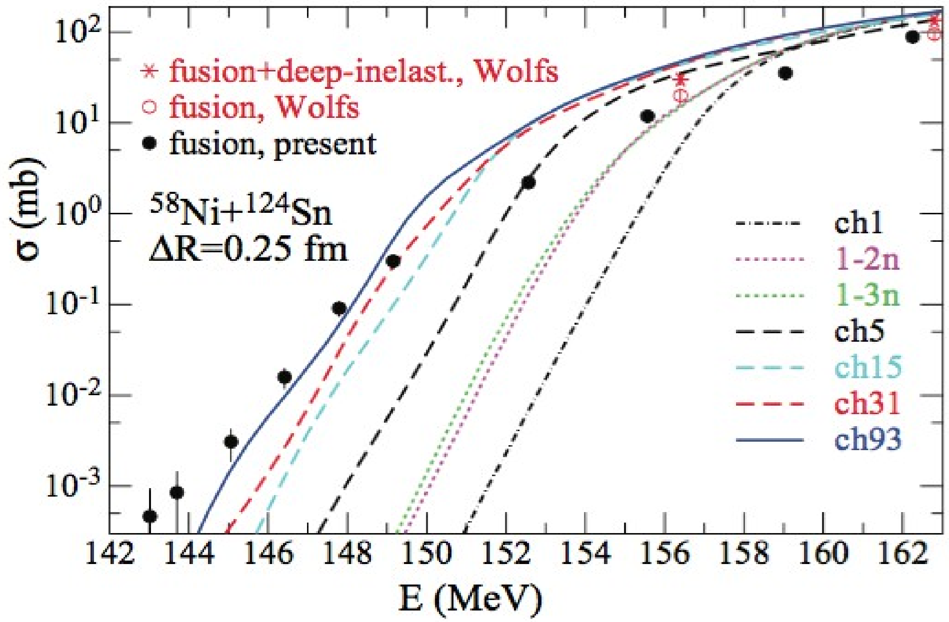


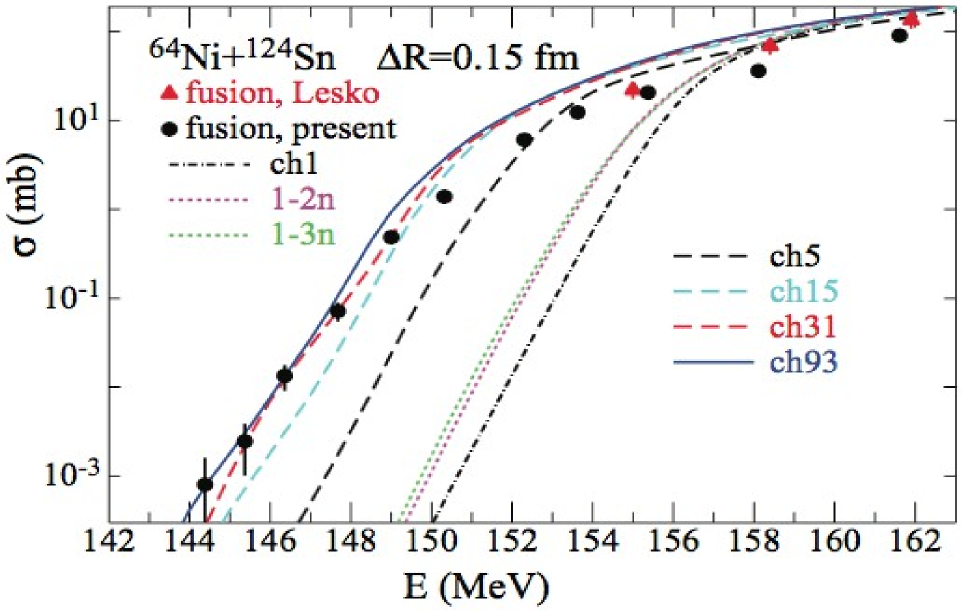
1. The largest enhancement of the fusion cross section comes from inelastic excitations.
2. The system ^{58}Ni+^{124}Sn exhibits a larger influence from transfer reactions with respect to ^{64}Ni+^{124}Sn.

Transfer strenghts and spectroscopic factors for the CC calculations were taken from:

- H. Esbensen, C. L. Jiang and K. E. Rehm, Phys. Rev. C **57**, 2401 (1998).
- C. L. Jiang *et al.*, Phys. Rev. C **57**, 2393 (1998).
- J. Lee *et al.*, Phys. Rev. C **79**, 054611 (2009).

Ch1 = no coupling
1-2n = one- and two-neutron transfer
1-3n = one-, two- and three-neutron transfer
Ch5 = one-phonon excitation
Ch15 = two-phonon excitation (one- and two-phonon states and mutual excitations of the low-lying 2^+ and 3^- states)
Ch31 = three-phonon excitation (three mutual one-phonon excitations and mutual excitations of one- and two-phonon states)
Ch93 = inelastic (one, two and three phonons) + transfer (one and two neutrons)





CONCLUSIONS

- We measured the excitation functions for the fusion reactions of $^{58,64}Ni + {}^{124}Sn$ with the Legnaro electrostatic separator down to 1 – 0.5 μb.
- We compared the experimental results with detailed CC calculations using a standard Woods-Saxon potential.
- As expected, no hindrance behaviour was observed at these cross sections.
- The influence of transfer was observed, in particular in the $^{58}Ni + {}^{124}Sn$ system, in agreement with the Q-value systematics previously described.

PHYSICAL REVIEW C **91**, 044602 (2015)

Fusion reactions of $^{58,64}Ni + ^{124}Sn$

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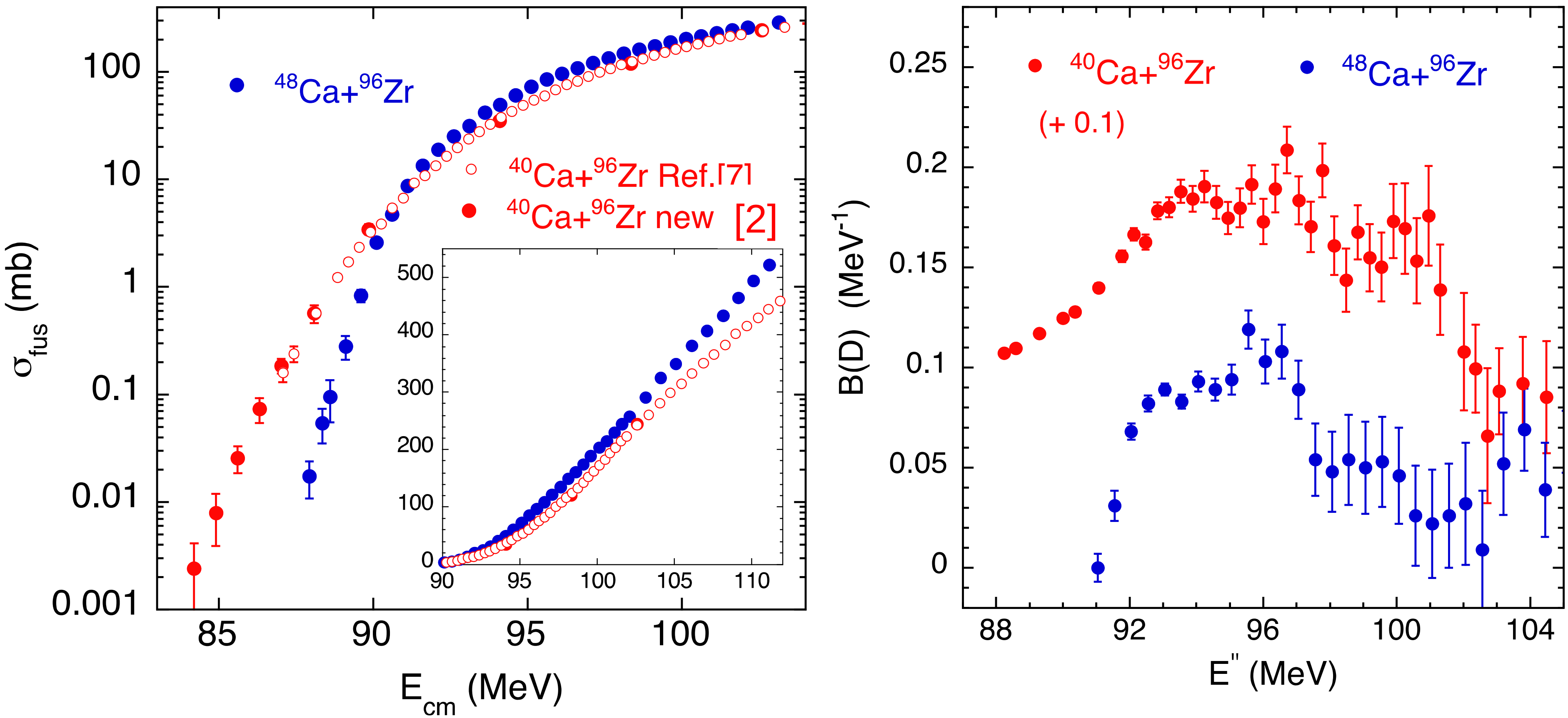
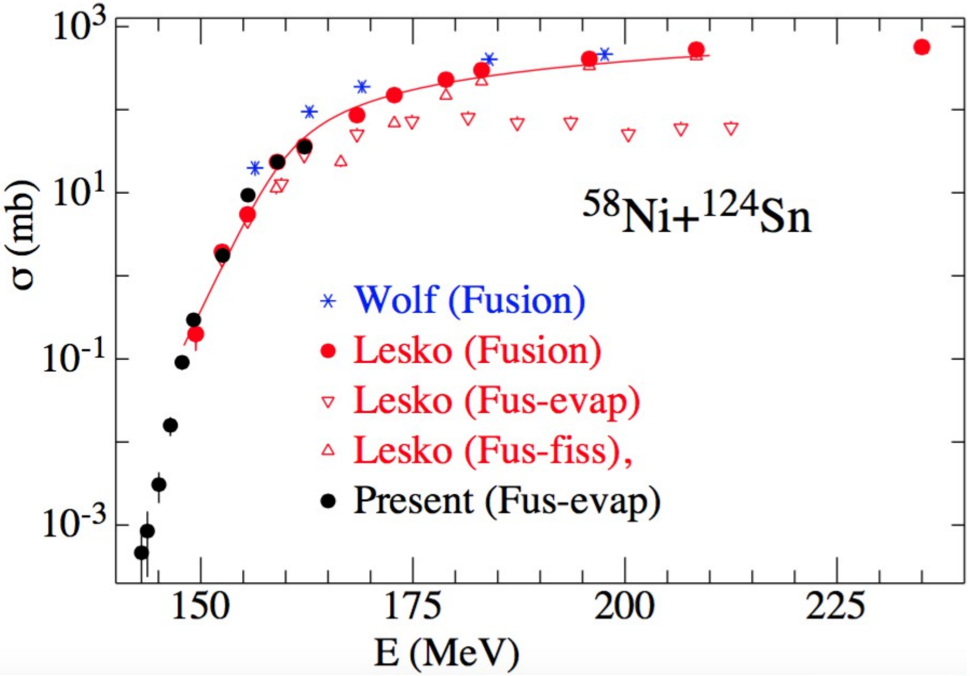
Thank you for the attention

The case of the Ca+Zr systems



Transfer couplings affect the sub-barrier excitation functions of 40Ca + 96Zr (with Q>>0) down to very small cross sections. This is indicated by the comparison with other Ca + Zr systems and with CC calculations.

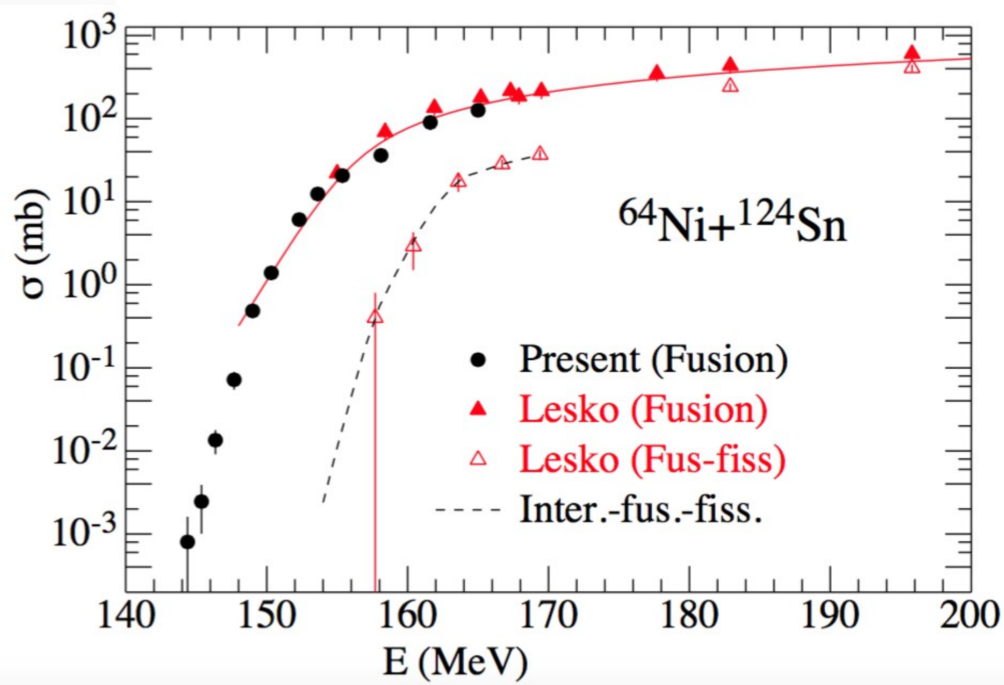
A. M. Stefanini et al., Phys. Lett. B728 (2014) 639



Fusion-evaporation and fusion-fission cross sections are taken from previous measurements and used to correct our experimental data

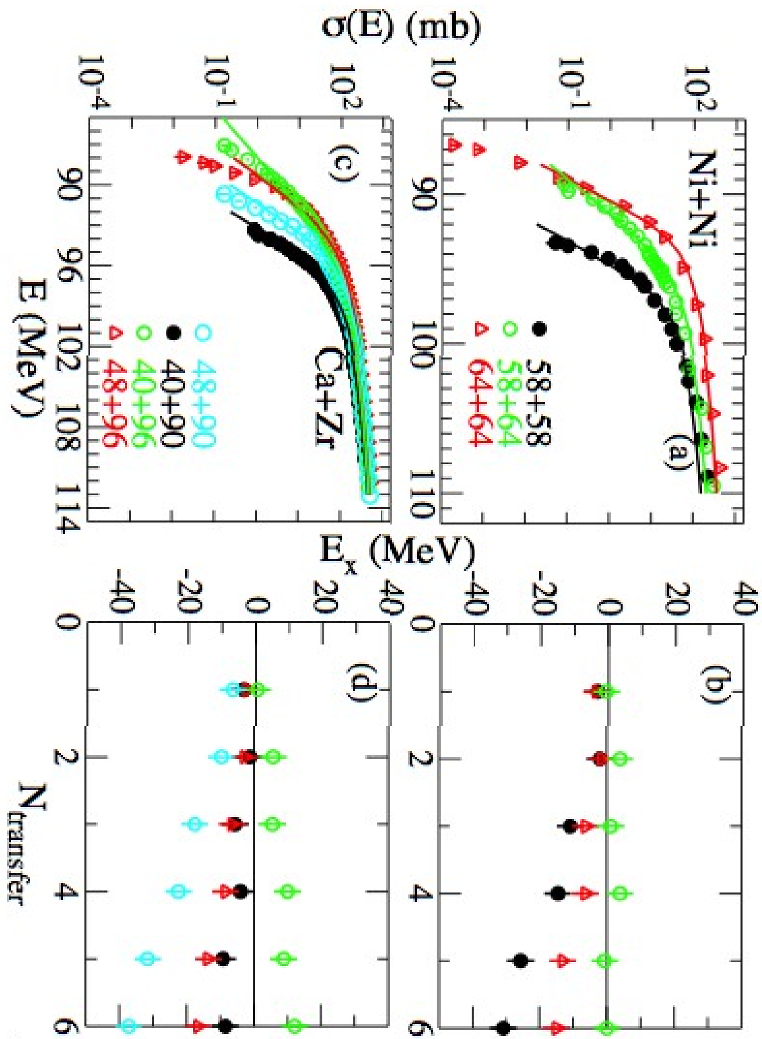
K. T. Lesko *et al.*, Phys. Rev. Lett. **55**, 803 (1985); Phys. Rev. C **34**, 2155 (1986).

F. L. H. Wolfs, W. Henning, K. E. Rehm, and J. P. Schiffer, Phys. Lett. B **196**, 113 (1987); F. L. H. Wolfs, Phys. Rev. C **36**, 1379 (1987).



Franco Galtarossa

Fusion excitation functions and excitation energies Ex for neutron transfer reactions



$$E_x \approx Q_{g.s.} + (Bi - Bf)$$

58Ni+64Ni and 40Ca+96Zr show excitacion functions with shallower slopes.
They have positive Q-values for neutron transfer channels and
Ex≥0 states (near Qgs).

C.L.Jiang et al., PRC 89, 051603(R) 2014