# Experimental activity of the LNS-Stream collaboration

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# Outline of the talk

## Collisions around the barrier induced by halo and/or weakly bound nuclei

- Motivations
- Experimental methods
- Collisions induced by halo nuclei
- Collisions induced by stable weakly bound  nuclei
- Summary and perspectives

## MSM: Medea-Sole-Maciste

- Description of the setup
- Past and future studies on GDR emission with MSM

# Collisions around the barrier induced by halo and/or weakly bound nuclei

**Characteristics of the projectiles:**

**Low break-up thresholds, diffuse tails**

$\Downarrow$

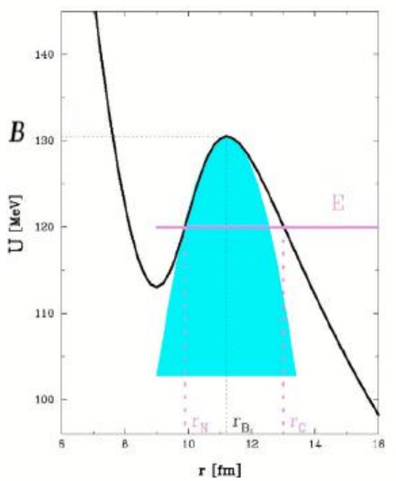
**What do we expect for direct reactions?**

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

**What do we expect for fusion reactions ?**

**a) Static effects:**

**diffuse tail $\Rightarrow$ reduction of Coulomb barrier and increase of $\sigma_{FUS}$ ?**




**b) Dynamic effects:**

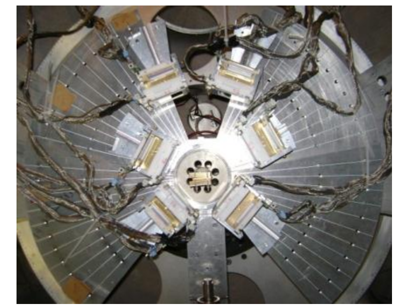
**Coupling to bound and continuum states**

**Key question: which is the effect of coupling to continuum ?**

# Experimental techniques
# for elastic and direct reaction measurements

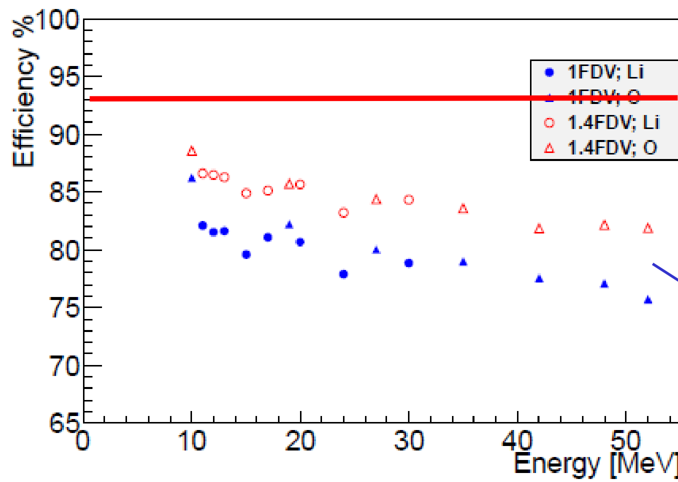
**Aim**: measure charged particles in single and coincidence with low intensity beams
**Need for**: large solid angles + good granularity $\Rightarrow$ wide use of segmented Si detectors

**Example**
**CLAD @ LNS**
**6 ΔE-E Si Telecopes 50-1000 μm**



## Interstrip effects in DSSSD

**Negative and reduced amplitude signals**
$\Downarrow$
**Efficiency for full energy detection different than geometric**




**Geometric**

**Full Energy efficiency for the CLAD 1000 μm DSSSD**

**Experimental**

**In progress: interstrip effect study. Collaboration LNS+RBI-Zagreb**

# Experimental techniques
# for fusion excitation function measurements

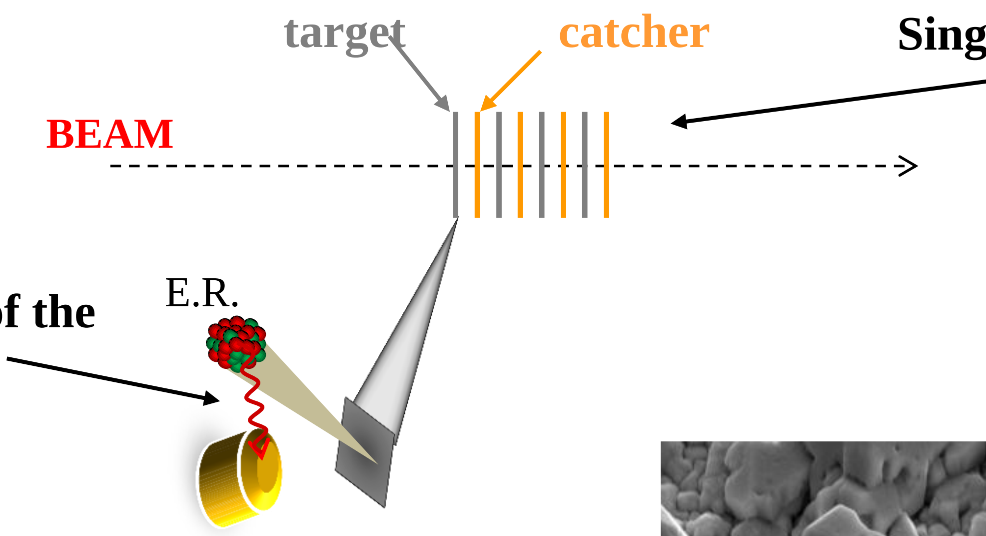
**Aim**: measure σ(E) for fusion evaporation reactions

**Problems**: low $\sigma_{Fus}$ and beam intensities, direct ER detection impossible ⇒

**Activation techniques widely used !**

**STEP 1**

**Single or multiple target Activation**

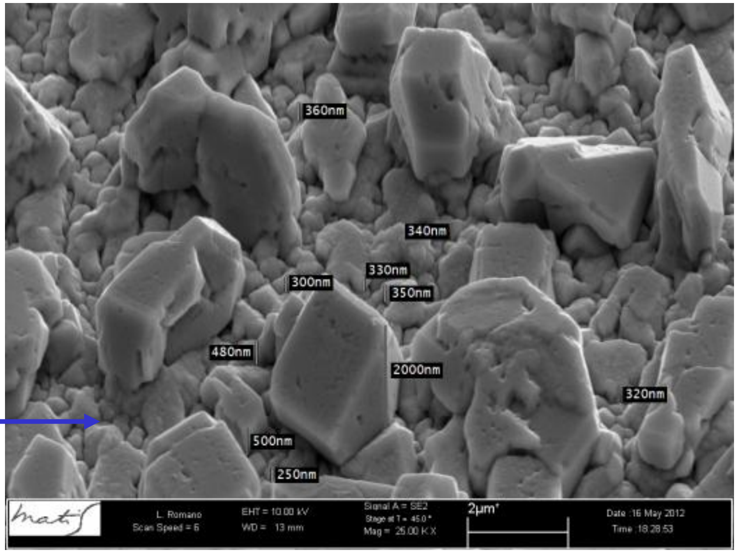



**STEP 2**

**Off-line measurement of the produced activity (X or α or γ)**

**Our evaporated targets are not always what we believe they are !**

**SEM view of a Sn evaporated target on Nb**

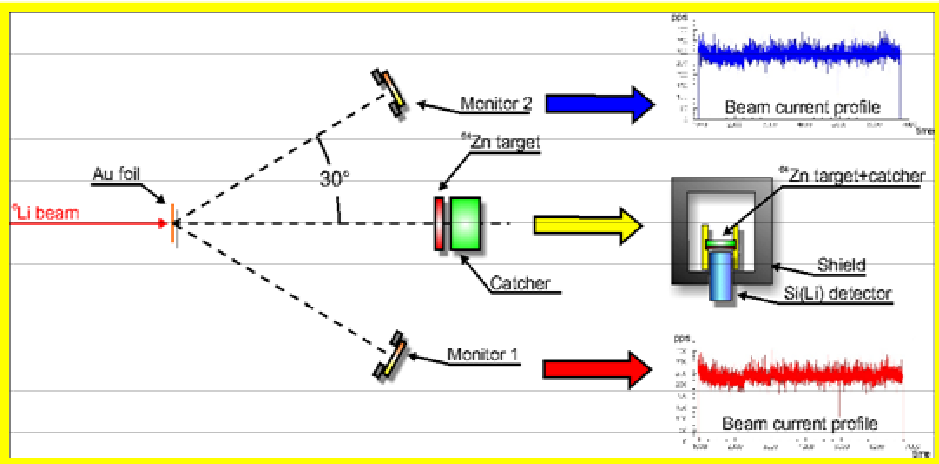


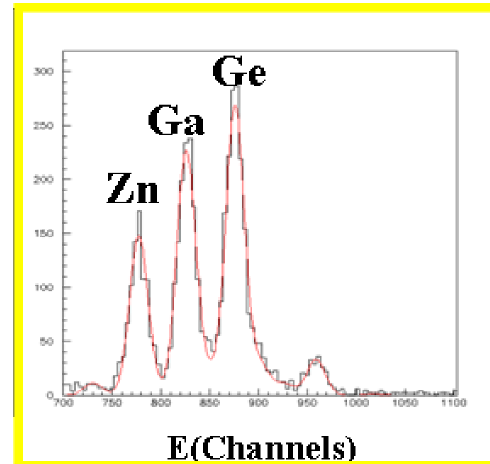

**Target non uniformities have to be considered !**

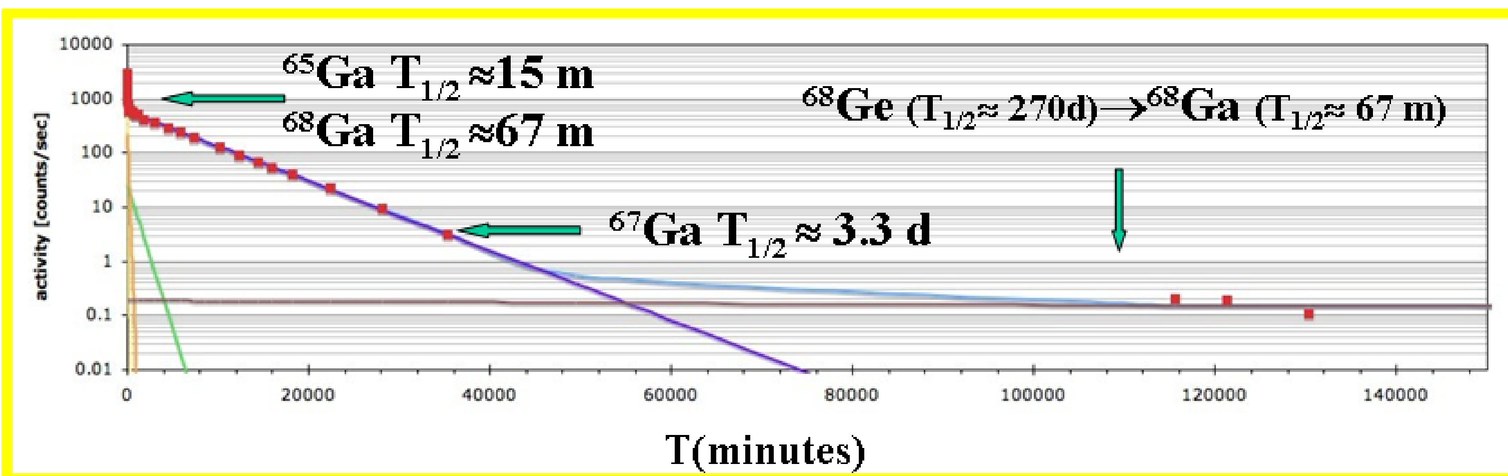
# The activation technique we are using to measure $\sigma_{FUS}(E)$

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

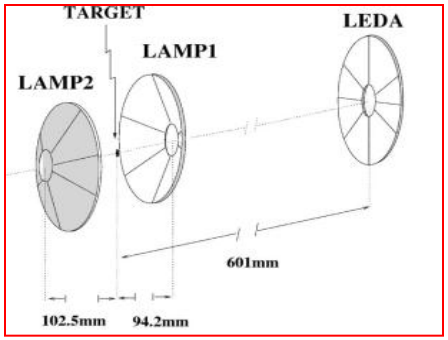
- **100% intrinsic detection efficiency for X rays + very low background**
  **$\Rightarrow$ suitable for experiments with RIBs**
- **Z and A ER identification**

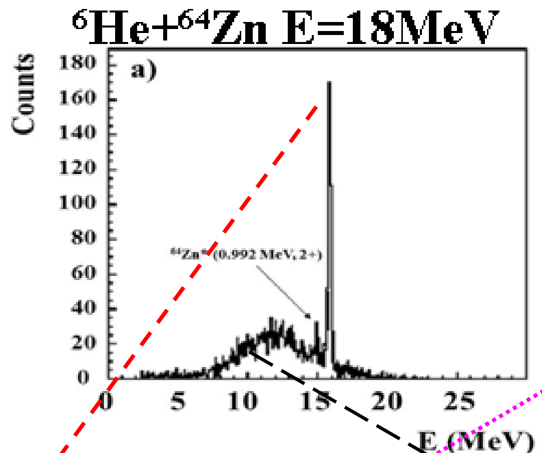


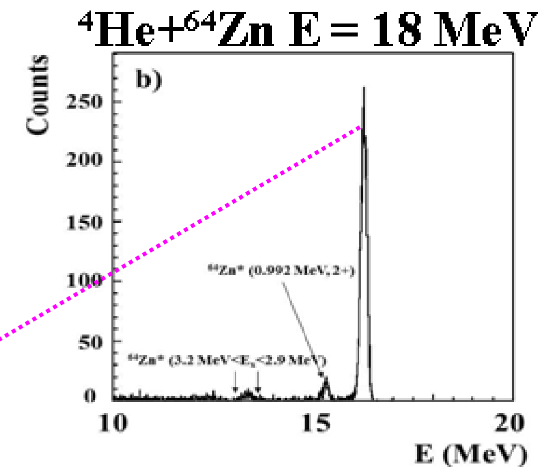



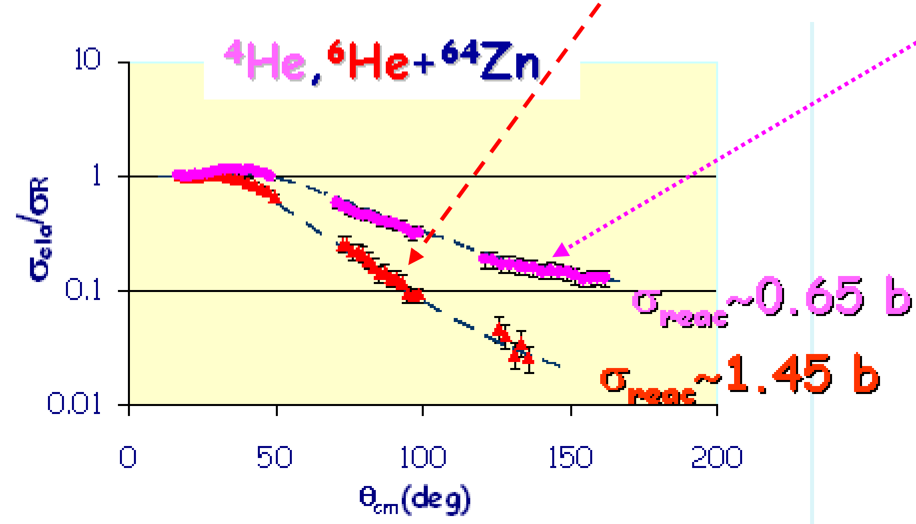



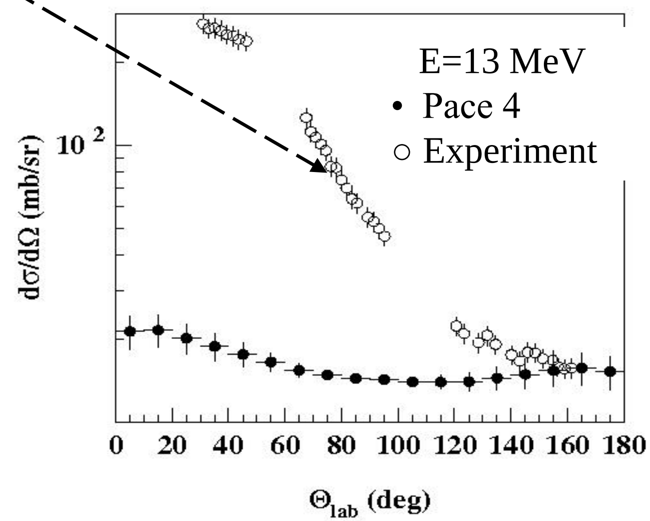
# $^{4,6}He+^{64}Zn$ @ LLN: elastic and transfer + break-up



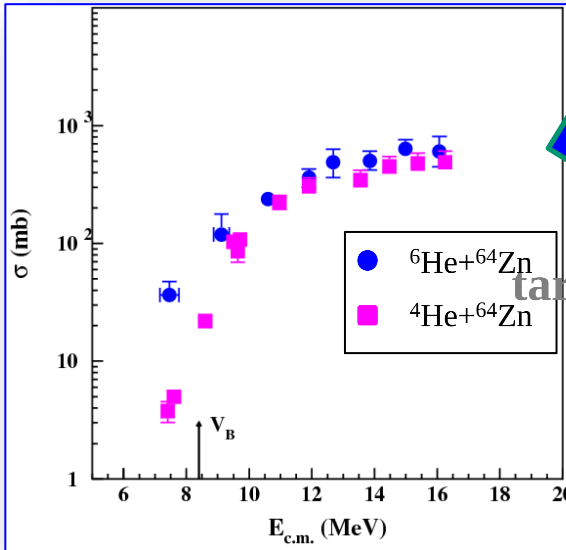




## $^6He+^{64}Zn$: conclusions.

- Presence of large alpha particle yield due to tranfer and B.U. events.
- Transfer+B.U cross section dominates (~80%) total reaction .

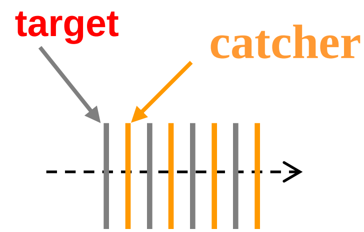
A. Di Pietro et al.: Phys.Rev.C 69(2004)044613, V.Scuderi et al.: Phys.Rev. C 84, 064604 (2011)

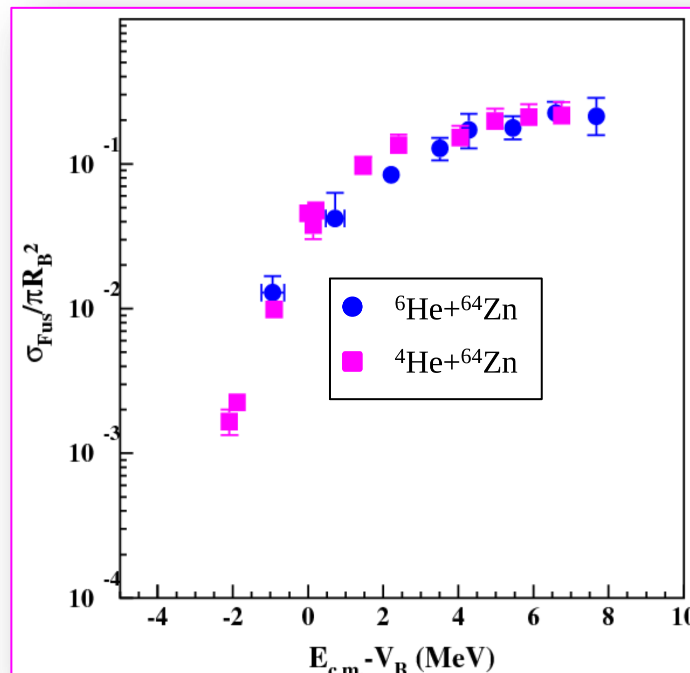
# $^{4,6}$He+$^{64}$Zn @ LLN and RBI Zagreb : fusion excitation functions




Activation technique used.
Off-line measurement of X-rays.

Enhancement of $\sigma_{FUS}$ for $^6$He
with respect to $\sigma_{FUS}$ for $^4$He




Reduced excitation functions
to eliminate static effects.

$V_B$ and $R_B$
from double folding potential.

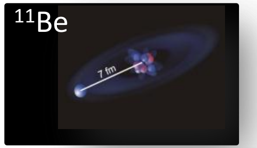
The observed enhancement can be
explained as due to static effects.

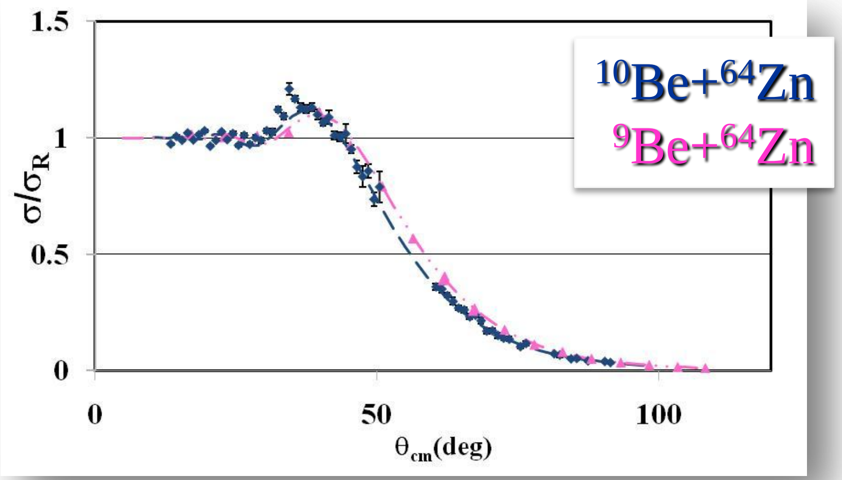
V.Scuderi et al. PRC 84, 064604, (2011)

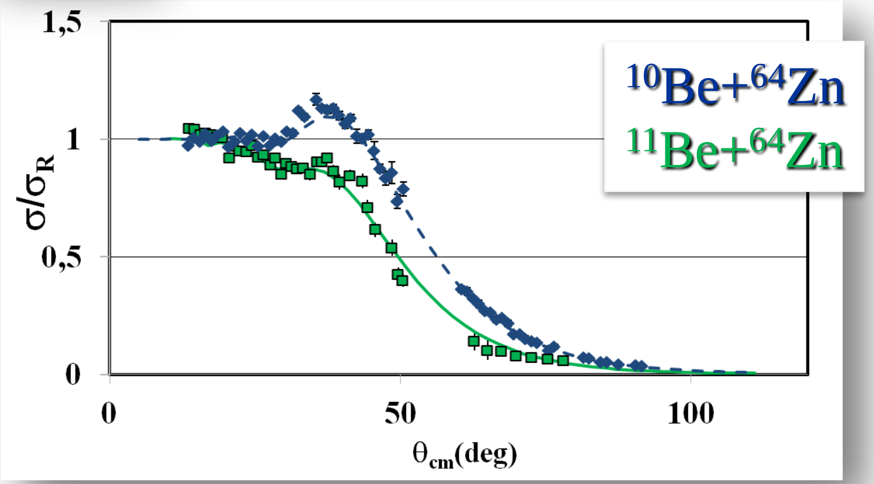
# $^{9,10,11}Be+^{64}Zn$ elastic scattering angular distributions

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

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



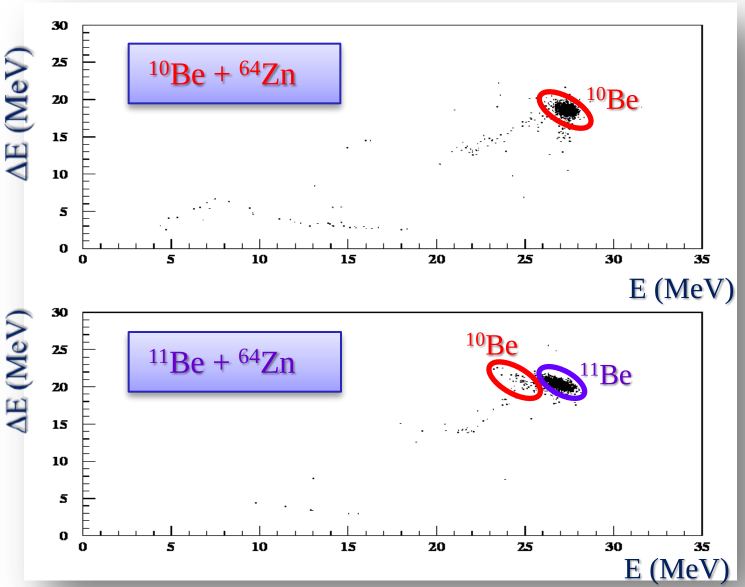




**Reaction cross-sections**

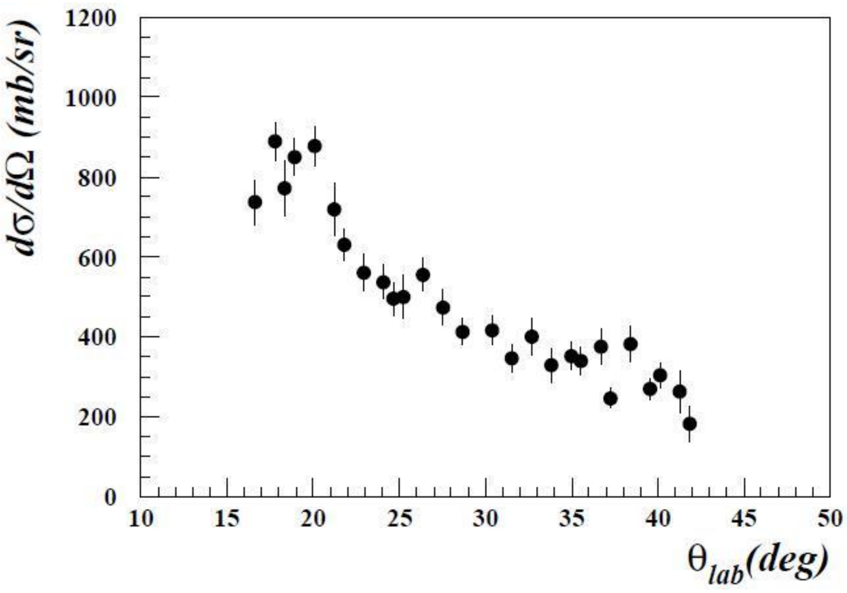
$\sigma_R\,^{9}Be \approx 1.1b$ $\sigma_R\,^{10}Be \approx 1.2b$ $\sigma_R\,^{11}Be \approx 2.7b$

A. Di Pietro et al. Phys. Rev. Lett. 105,022701(2010)

# $^{11}$Be+$^{64}$Zn Transfer+B.U. angular distributions




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




## Conclusions on $^{9,10,11}$Be+$^{64}$Zn

**Similar total reaction cross sections for $^{9,10}$Be**

$$\sigma_{REACT}(^{11}Be) \approx 2\ \sigma_{REACT}(^{9,10}Be)$$

$$\sigma_{TR+BU} \approx 40\%\ \sigma_{REACT}$$

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

# Collisions around the barrier induced by stable weakly bound nuclei.

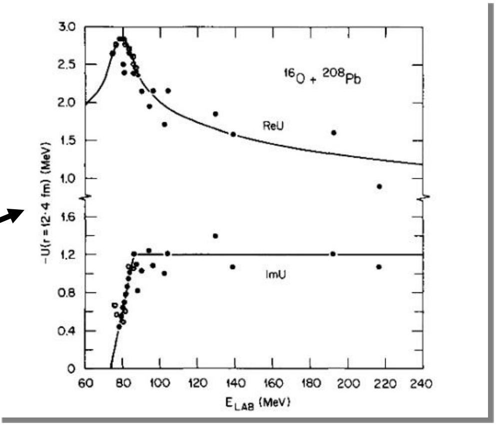
**Key question is still:** coupling to continuum effects?
**But stable beams $\Rightarrow$** better data quality.

**Example: The $^{6,7}$Li+$^{64}$Zn case @ LNS**

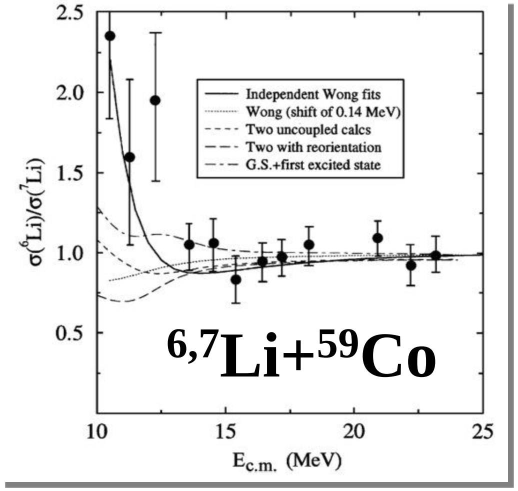
Elastic scattering AD and $\sigma_{FUS}(E)$ measured at several energies around the Coulomb barrier.

**AIMS**

- Is usual Treshold anomaly in O.P. present?




- Problems in previously existing data suggested in the literature $\Rightarrow$ cross check with a different technique.
- Extract information on CF/ICF relative yield.
- Look for possible enhancement in $\sigma_{FUS}(^6Li)/\sigma_{FUS}(^7Li)$ ratio as observed in other systems.




C.Beck et al: Phys.Rev.C67,054602,(2003)

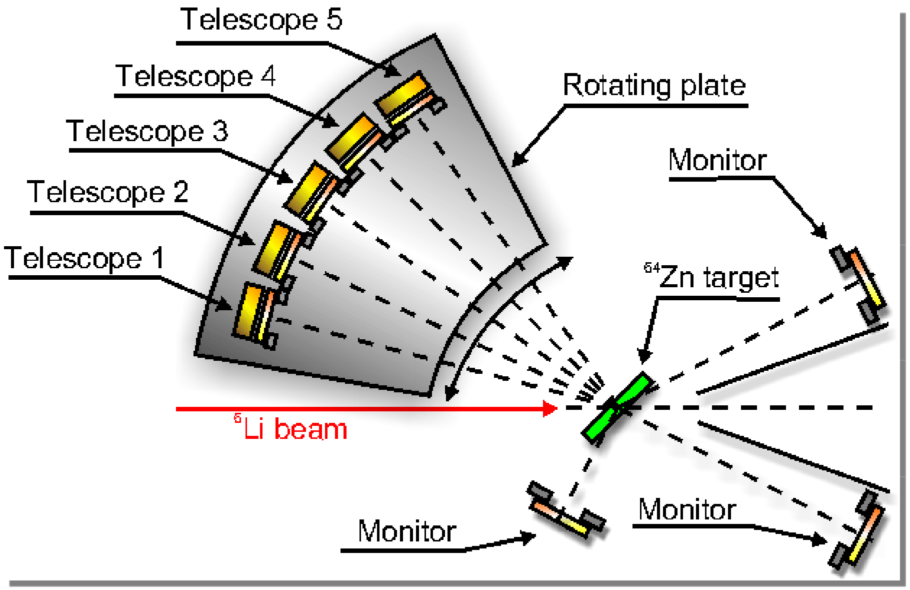
# $^{6,7}Li+^{64}Zn$ Elastic scattering angular distributions

## Experimental setup

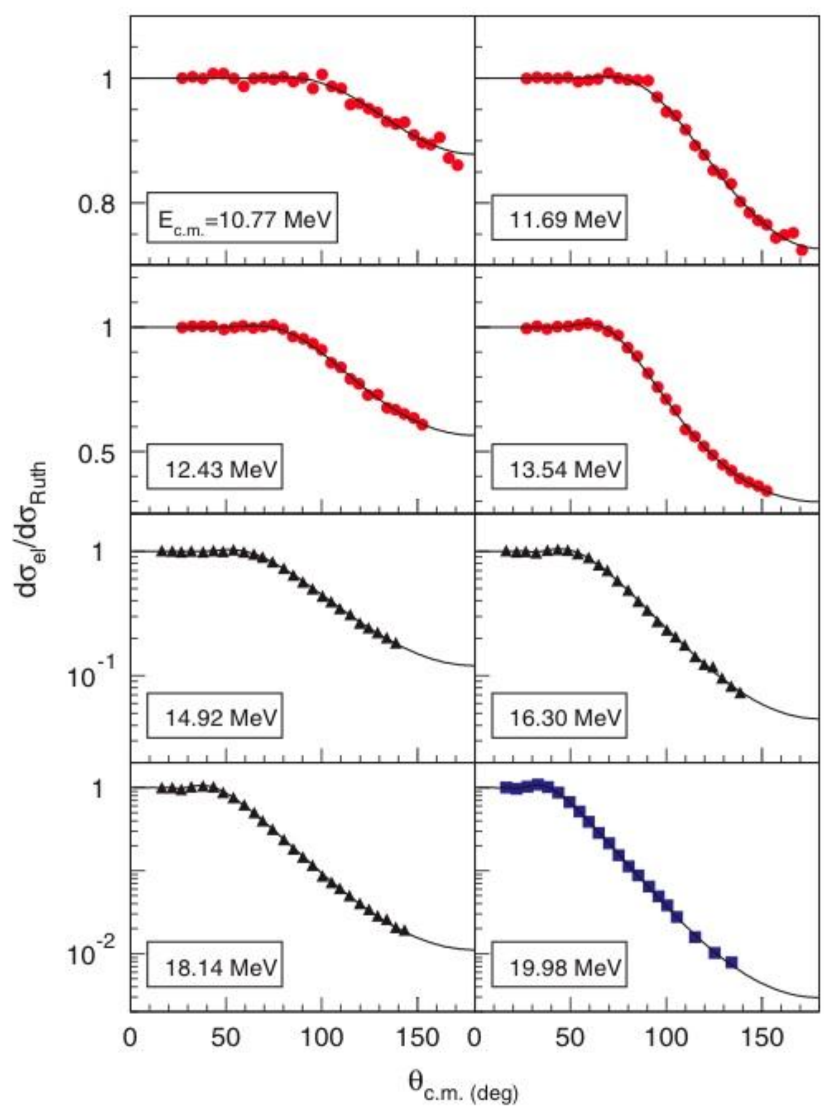
**5 DE(10μm)-E(200μm) telescopes**

**+**

**2 monitor detectors**

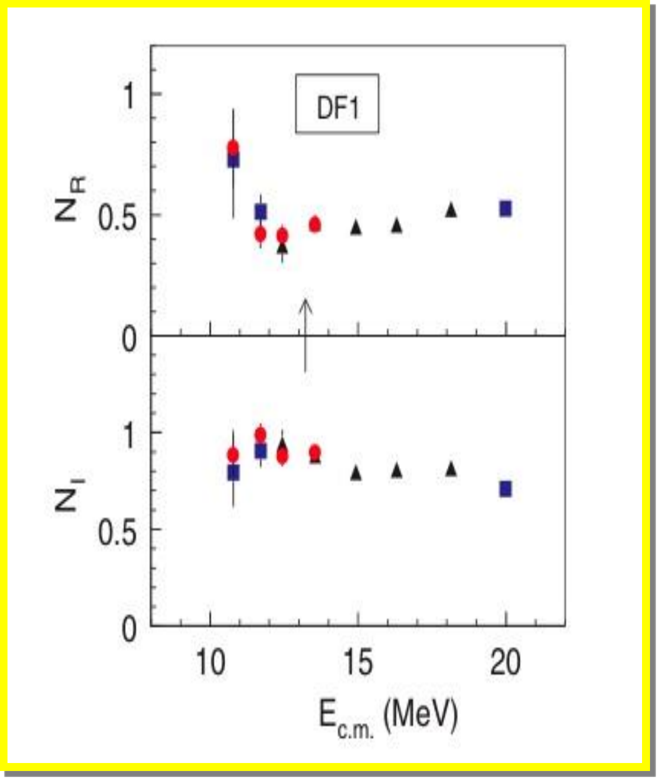



## Example : $^{6}Li+^{64}Zn$

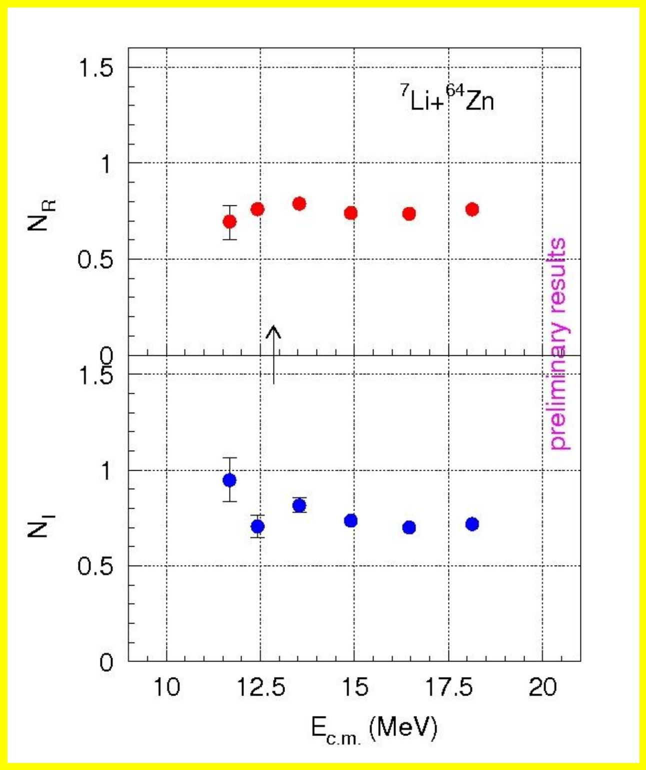


# $^{6,7}Li+^{64}Zn$ O.P. and threshold anomaly

## $^{6}Li+^{64}Zn$



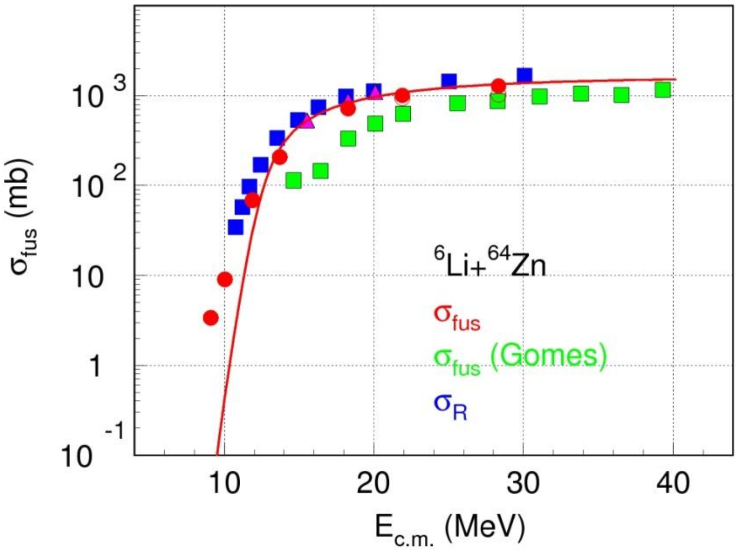

## $^{7}Li+^{64}Zn$

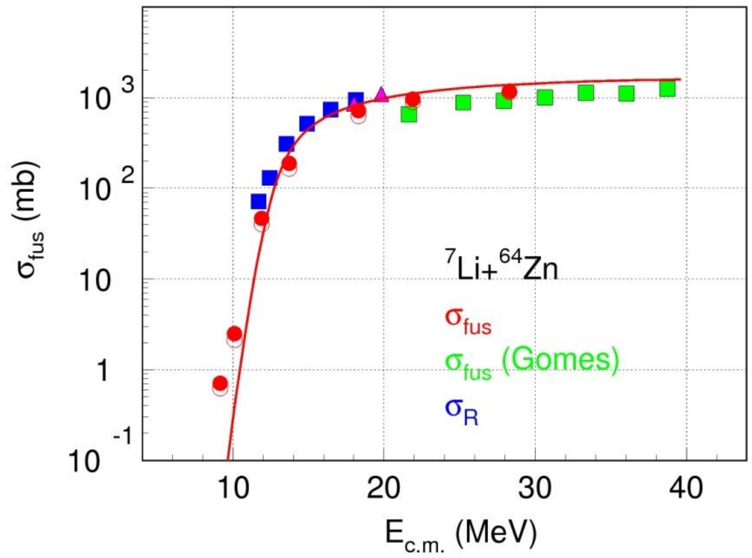


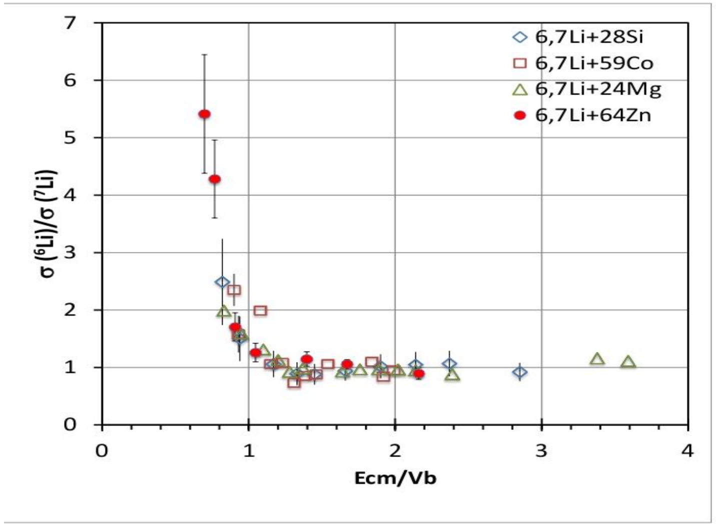

## No usual threshold anomaly is observed

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

# $^{6,7}$Li+$^{64}$Zn fusion and total reaction excitation functions



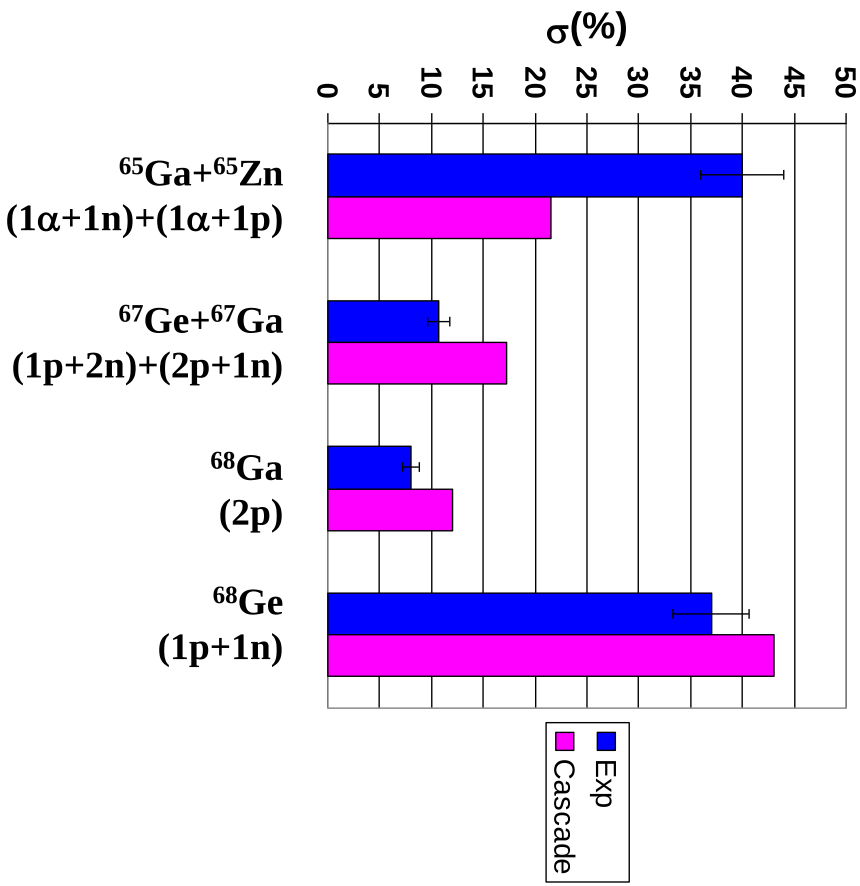




- **Problems in previously published $\sigma_{FUS}(E)$ confirmed.**
- **Good agreement with previously published $\sigma_{REACT}(E)$.**
- **$\sigma(^6Li)/\sigma(^7Li)$ ratio similar to other systems.**

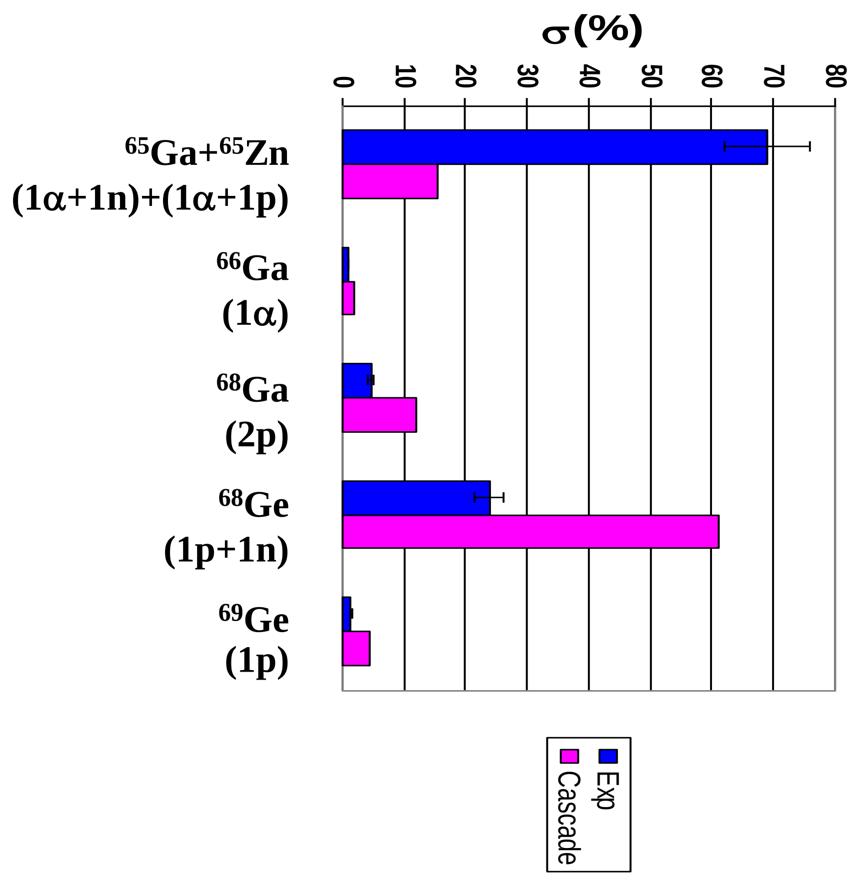
# $^{6}Li+^{64}Zn$ ER relative yield

**Can we get information on the CF/ICF relative yield via comparison with CF cascade calculation ?**

## $E_{Lab}$=20MeV




## $E_{Lab}$=13MeV




**Above barrier (Vc~13 MeV) CF dominates, below barrier d ICF or n transfer dominate**

# Summary and perspectives

## Collisions around the barrier induced by halo nuclei

- 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+$^{208}$Pb, $^{6}$He+$^{120}$Sn)

- Suppression of elastic scattering A.D. in the 'rainbow' region ⇒ total reaction cross sections for $^{6}$He much larger than for $^{4}$He
- Very large α particle yield from direct processes saturating most of the $\sigma_R$
- 2n transfer most important reaction channel with $^{6}$He
- First data with projectiles different than $^{6}$He confirm such findings

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

However

- Most of data do not explore the sub barrier region with reasonable errors
- Role played by static and dynamic effects on conclusions not always clear.

- New data with halo beams different than $^{6}$He needed.
- New sub barrier fusion data with halo nuclei needed.
- Consistent systematic comparison of fusion data to separate different effects needed

(See e.g. L.F. Canto et al. Nucl. Phys. A821,51,(2009))

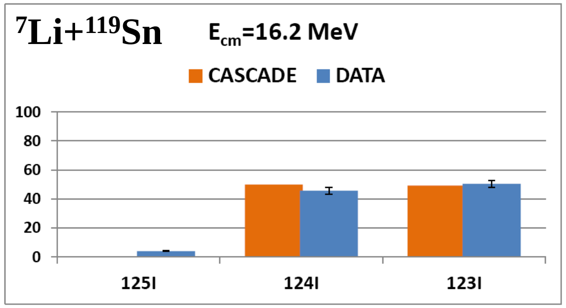
# Summary and perspectives

## Collisions around the barrier induced by stable weakly bound nuclei

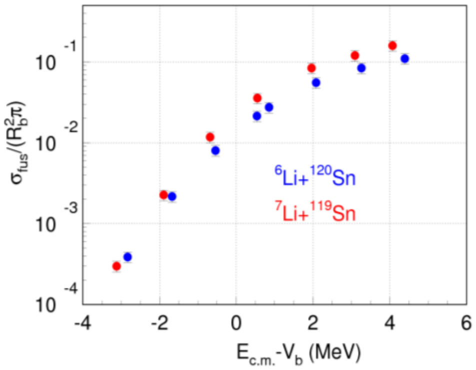
- Absence of usual T.A. observed for many systems
- Suppression of CF above the barrier on heavy targets well estabilished
- New subbarier fusion data needed
- Better understanding of CF/ICF competition on light-medium mass targets needed

# Planned activities for LNS-STREAM

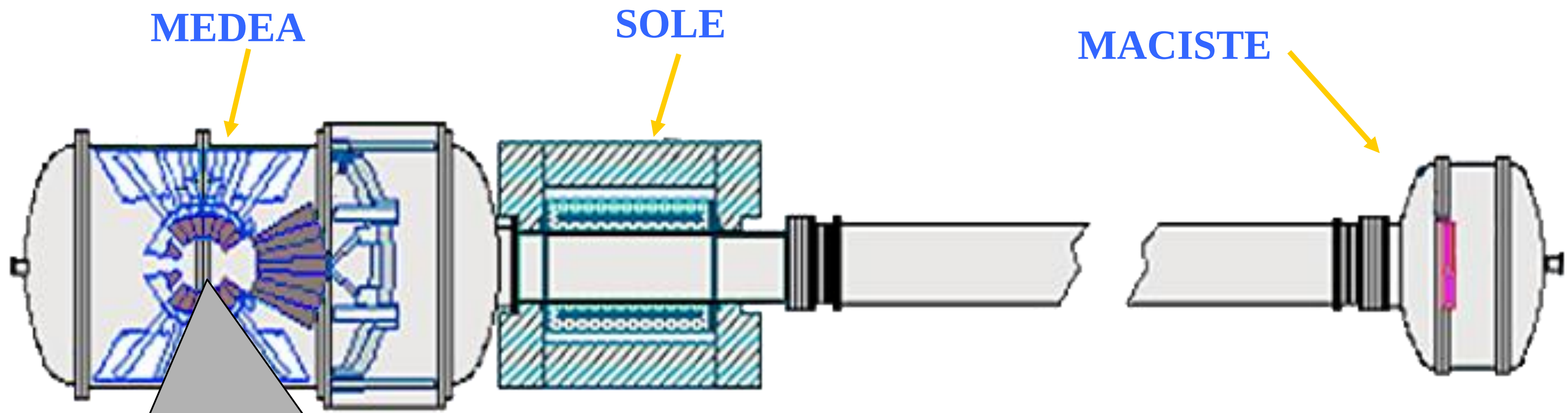
- Still working on old $^{6}$He data
- New experiments with $^{8}$B
- New experiments with $^{10}$Be beams

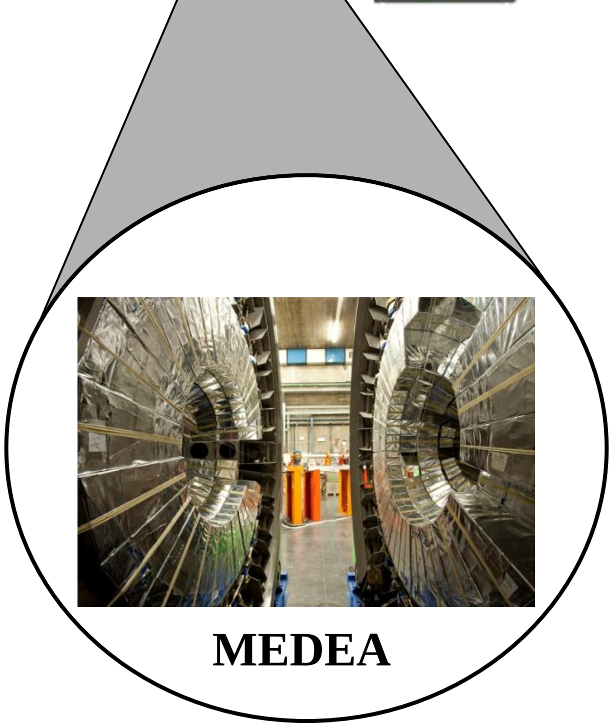



- New fusion data with $^{6,7}$Li

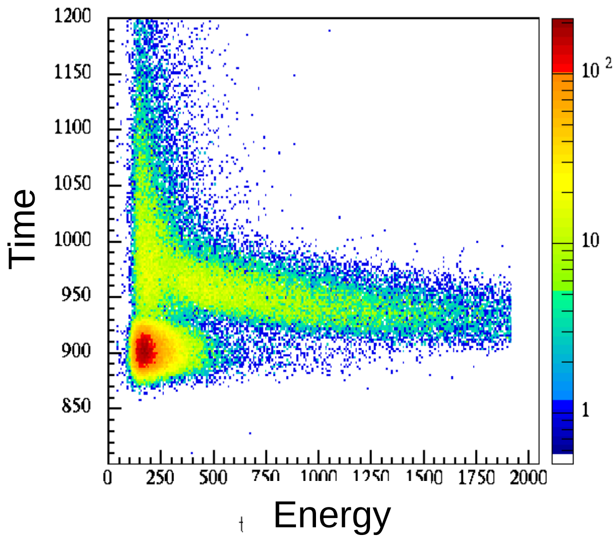


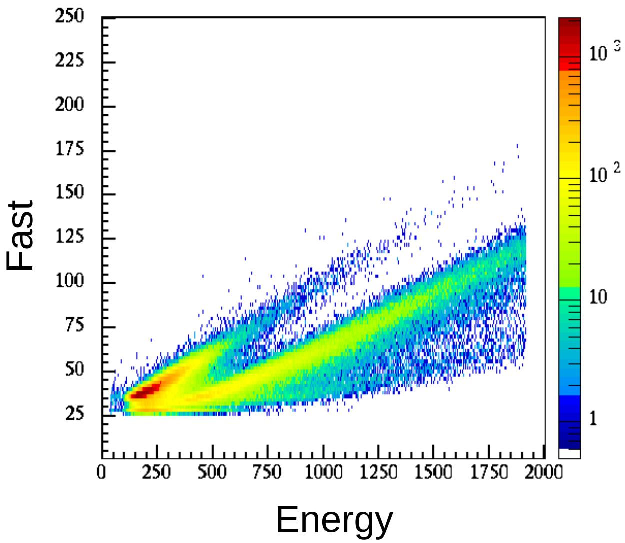
# Experimental set-up: MEDEA + SOLE + Maciste




**MEDEA: 180 $BaF_2$ scintillators.**
**8 rings and in a spherical geometry of 22 cm radius.**
**Detection of: gamma-rays up to 200 MeV and light charged particles (Z=1,2) from 30° to 170°.**



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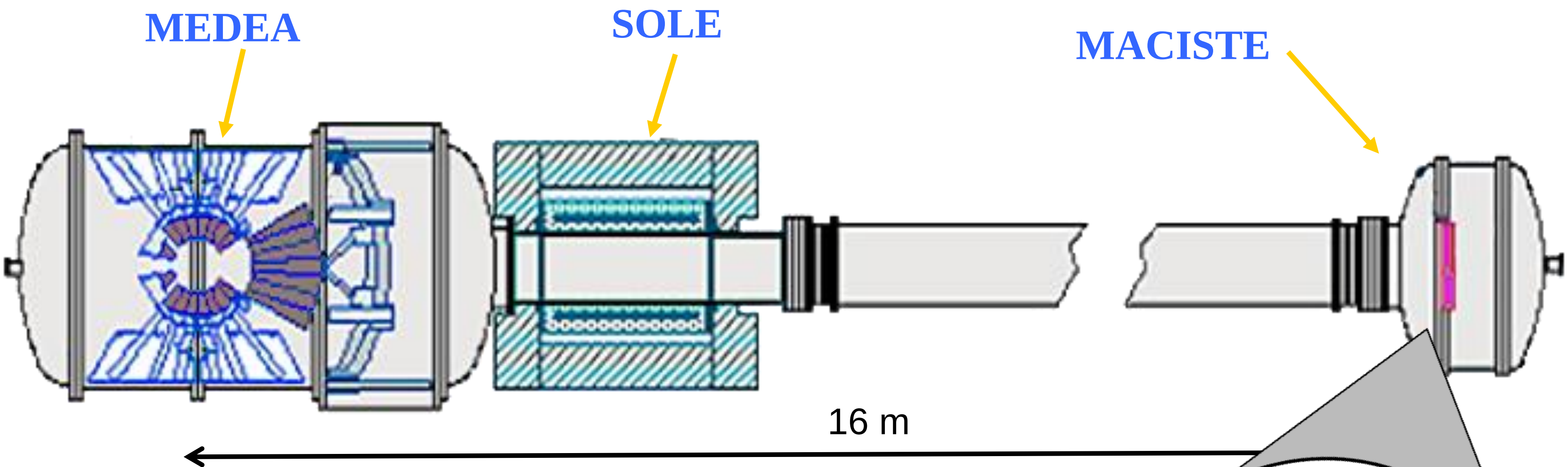
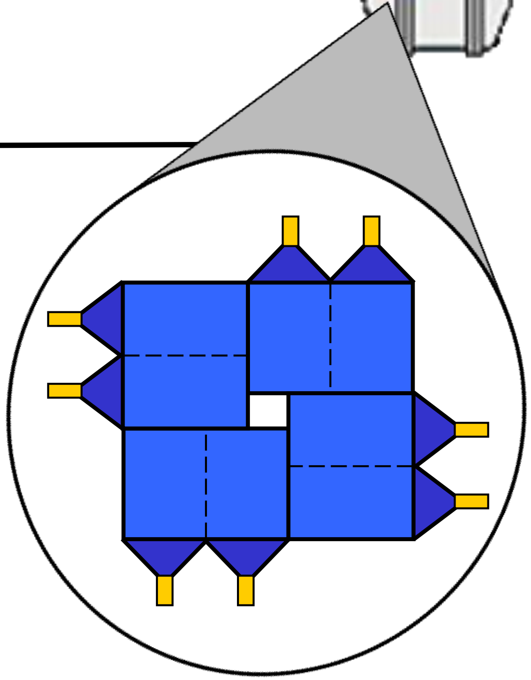


**SOLE Superconducting Solenoid**

**$B_{max}$ = 5 Testa, Maximum Solid angle = 40 msr**

**Acceptance: Angular = ±6.5° , Momentum = ± 10%**

**MACISTE:**

**4 DE-E telescopes consisting of:**

**I.C.** **10 cm thick (working conditions 10-150 mbar)**

**MWPC** **(position resol. = 3 mm, time resol = 500ps)**

**Plastic Scintillators** **( BC-408 - 2 cm thick)**

# Previous activity of MEDEA + SOLE + MACISTE

**Intermediate energies: 10 $<E_{beam}<$ 100 MeV/A**

**Nuclei at very high E* populated.**

**Pre-equilibrium phenomena due to nucleon-nucleon collisions appear.**
**(High energy gammas and energetic nucleons)**

**Study of the origin of high energy protons and high energy gamma-rays**

***Alba et al. PLB 322 (1994) 38, Coniglione et al. PLB 471 (2000) 339, Sapienza et al PRL 73 (1994) 1769***

**Pre-equilibrium GDR emission**

***Martin et al. PLB 664 (2008) 47***

- **Study of the GDR quenching at high E* for nuclei with A ~100÷130**

***Le Faou et al. PRL 72(1994)3321, Santonocito et al. E.P.J.. A30 (2006) 183,***
***Santonocito et al. Nucl. Phys. A788 (2007) 215c***

# Study of the GDR gamma multiplicity saturation

**Reactions**

**$^{36}Ar + ^{90}Zr$ @ 27 MeV/A**

**$^{36}Ar + ^{98}Mo$ @ 37 MeV/A**

- Hot nuclei populated through incomplete fusion
- Evaporation residues measured in coincidence with LCP and gamma-rays

300<E*<500

(through velocity measurement and the study of light charged particle spectra)

**● Experimental data**

**- - - Standard CASCADE**

**——— CASCADE with a cut-off at E* = 240 MeV**

**CASCADE: input GDR**

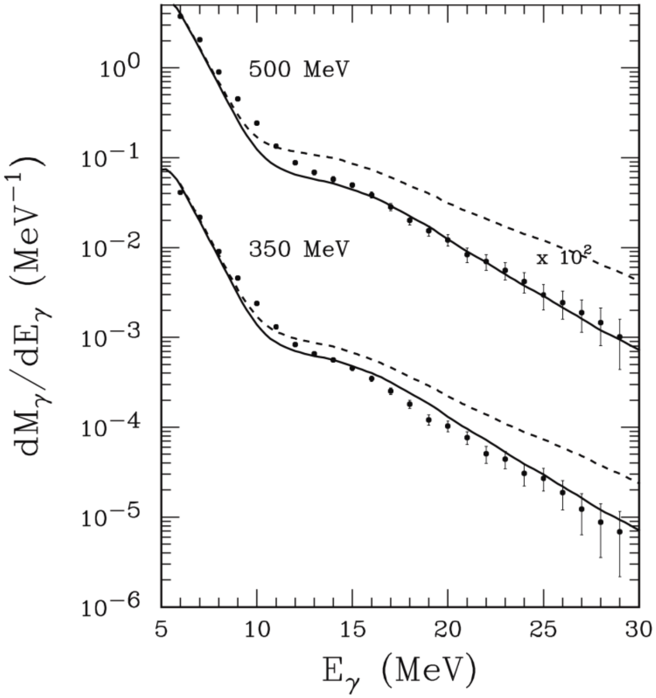
**S = 100% EWSR, Γ = 12 MeV**

**$E_{GDR} = 76 / A^{1/3}$ a = a(T)**

**The saturation of the γ multiplicity is consistent with GDR disappearance above E* > 250 MeV**

**Same cut-off value reproduces the γ spectra at different energies (350<E*<500 MeV)**

*PRC53(1996)2258*




Evidence of a limiting E*/A ~ 2.2 MeV/A for the collective motion

# Study of the GDR saturation onset @ LNS

**Investigate the GDR properties in the excitation energy region 150<E*<330 MeV to map the progressive disappearance of the GDR**

**Reactions studied at LNS - CATANIA:**

**$^{116}Sn + ^{12}C, ^{24}Mg$ @ 17 MeV/A**

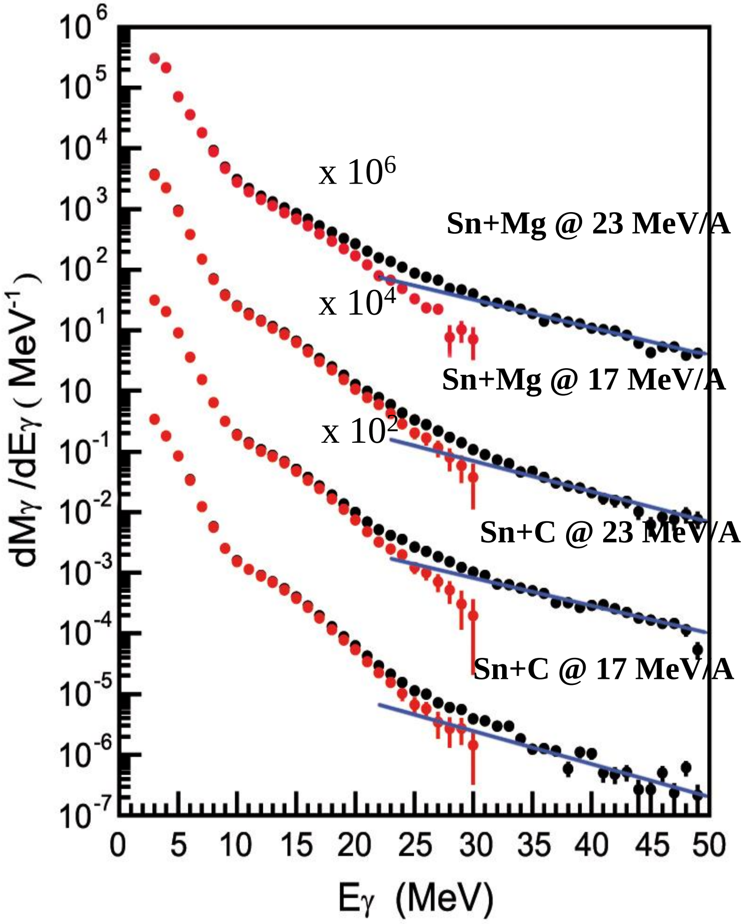
**$^{116}Sn + ^{12}C, ^{24}Mg$ @ 23 MeV/A**

→ **hot nuclei populated through ICF and CF**

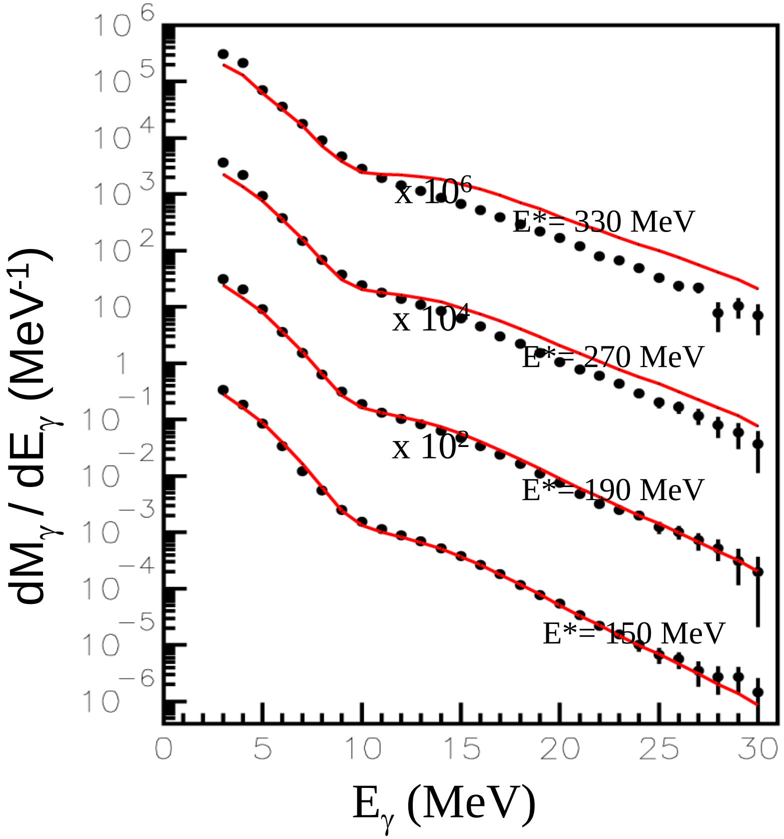
→ **ER in coincidence with LCP and gamma**

→ **<E*> and <A> of decaying systems from LMT and LCP spectra**

- Full $\gamma$ spectrum for all reactions
- — Exponential fits of the *np* Bremsstrahlung component for $E_\gamma$ >35 MeV
- Statistical $\gamma$ spectrum after subtraction of the bremsstrahlung component extrapolated to low energies

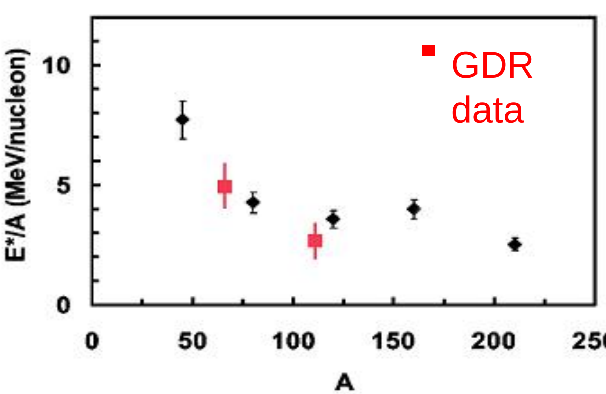


# Saturation onset from comparison with CASCADE calculation



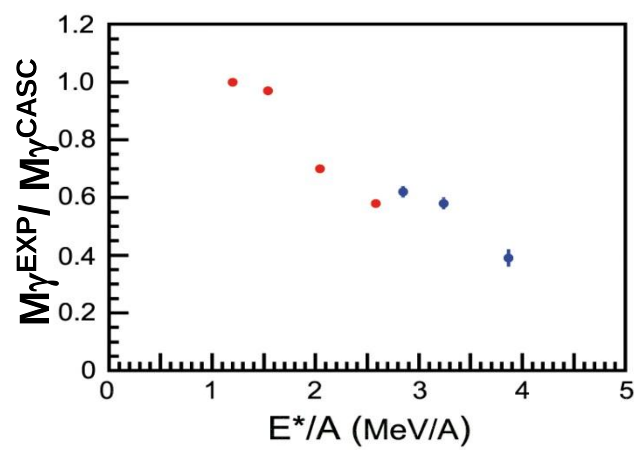

CASCADE at 150 MeV A=124
CASCADE at 190 MeV A=123
CASCADE at 270 MeV A=132
CASCADE at 330 MeV A=128
Other CASCADE inputs:

- 100% EWSR
- $E_{GDR}$ = 15
- $\Gamma_{GDR}$ = 12
- a = a(T) (Ormand et al PRC40(1989)1510)




γ multiplicity integrated in the region 12 – 20 MeV

- New data
- $^{36}$Ar + $^{98}$Mo @ 37 MeV/A




**Measurements for Er + Sc, Al, Mg planned to explore the region A ~190**

# LNS-STREAM

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