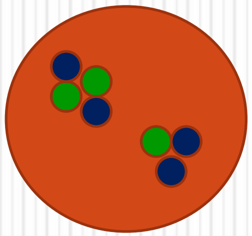
3rd one day workshop of HINP

8th of April 2016

Probing the clustering structure of 7Li via elastic scattering on protons and deuterons in inverse kinematics



Athena Pakou, University of Ioannina

Future perspectives and the life tree

FROM
1st HINP workshop 8th of September 2012

→ To
3rd HINP workshop 8th of April 2016

Nucleus-Nucleus optical potential, and relevant reaction mechanisms

6,7Li+28Si

^{8}B, ^{7}Be, ^{6}He +^{28}Si

Akis

^{20}Ne+^{28}Si-

inverse kinematics probing clustering effects

Proton-Nucleus optical potential

17F+p off resonances

6Li+p inclusion of compound couplings

6Li+p inclusion of excitation to continuum

And resonance states

Vassilis

18Ne+p inclusion of clustering effects

7Li+p, 7Li+d inclusion of clustering effects

Outline of our work - :

last 15 years

- **The optical Potential**
- **Energy dependence of the optical potential**
- **Reaction mechanisms-direct versus compound**
- **Coupling effects-Clustering effects**

2 Αγροτες Που Σκαβουν, Βαν Γκογκ | Καμβάς, αφίσα, κορνίζα, λαδοτυπία, πίνακες ζωγραφικής | Artivity.gr

Completed work on : $^{6,7}Li+^{28}Si$

REACTIONS with WEAKLY BOUND STABLE NUCLEI on LIGHT TARGETS near BARRIER

- **ELASTIC SCATTERING**
- **BREAKUP**
- **TOTAL REACTION CROSS SECTIONS**
- **TRANSFER at BARRIER**
- **FUSION MEASUREMENTS**

A. Pakou et al, **PRC78**,067601; **PRC76**,054601; **PRC73**,051603; **PRC71**,014603; **PRC69**,057602; **PRC69**,054602, **EPJA39**,187; **NPA784**,13; **PRL90**,202701,**PLB556**,21;**PLB633**,691

K. Zerva et al, **EPJA48**,102;**PRC82**,044607;**PRC80**,017601

First observation:

The threshold anomaly is different for the weakly bound systems. It is different for ^{6}Li than ^{7}Li.

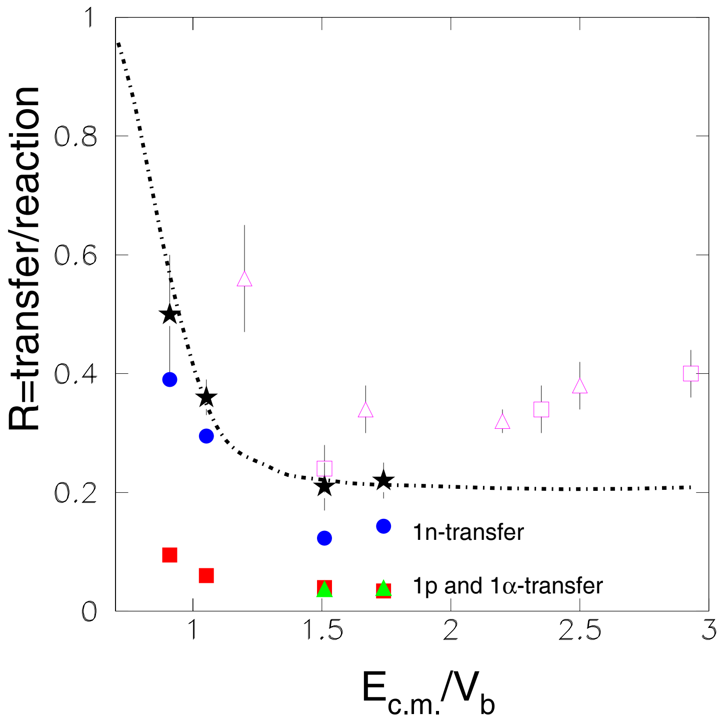
The dispersion relation may not be valid

Second observation : Referring to almost spherical targets, and light projectiles

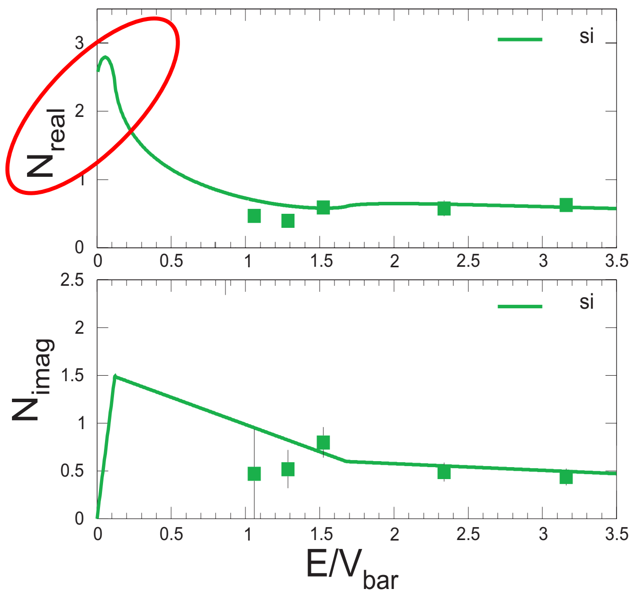
If we carefully disentangle the direct from compound contribution then fusion even for weakly bound nuclei can be described by a Wong one barrier penetration model prediction

Third observation : Direct reaction channels are the strongest below barrier

Direct to total-$^{6}Li+^{28}Si$



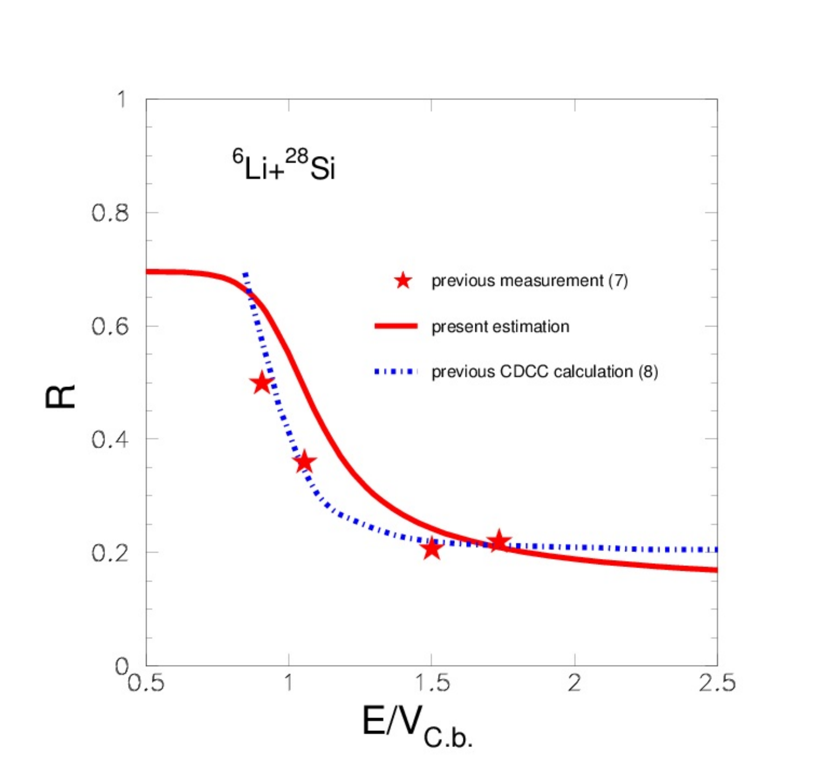
Optical potential

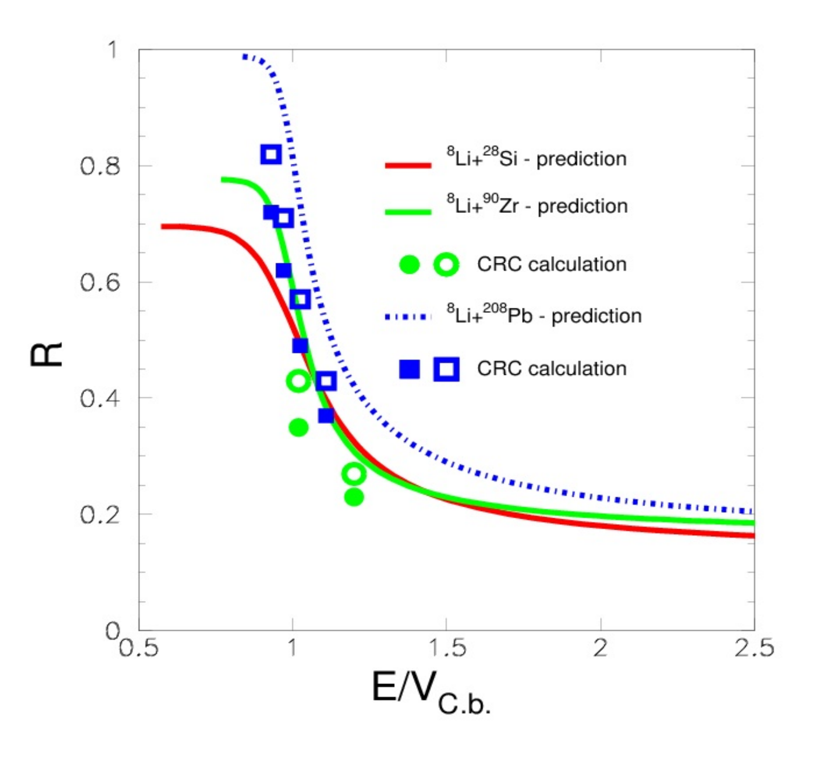


Zerva et al., EPJA48,102(2012)

Need for data at deep sub-barrier energies

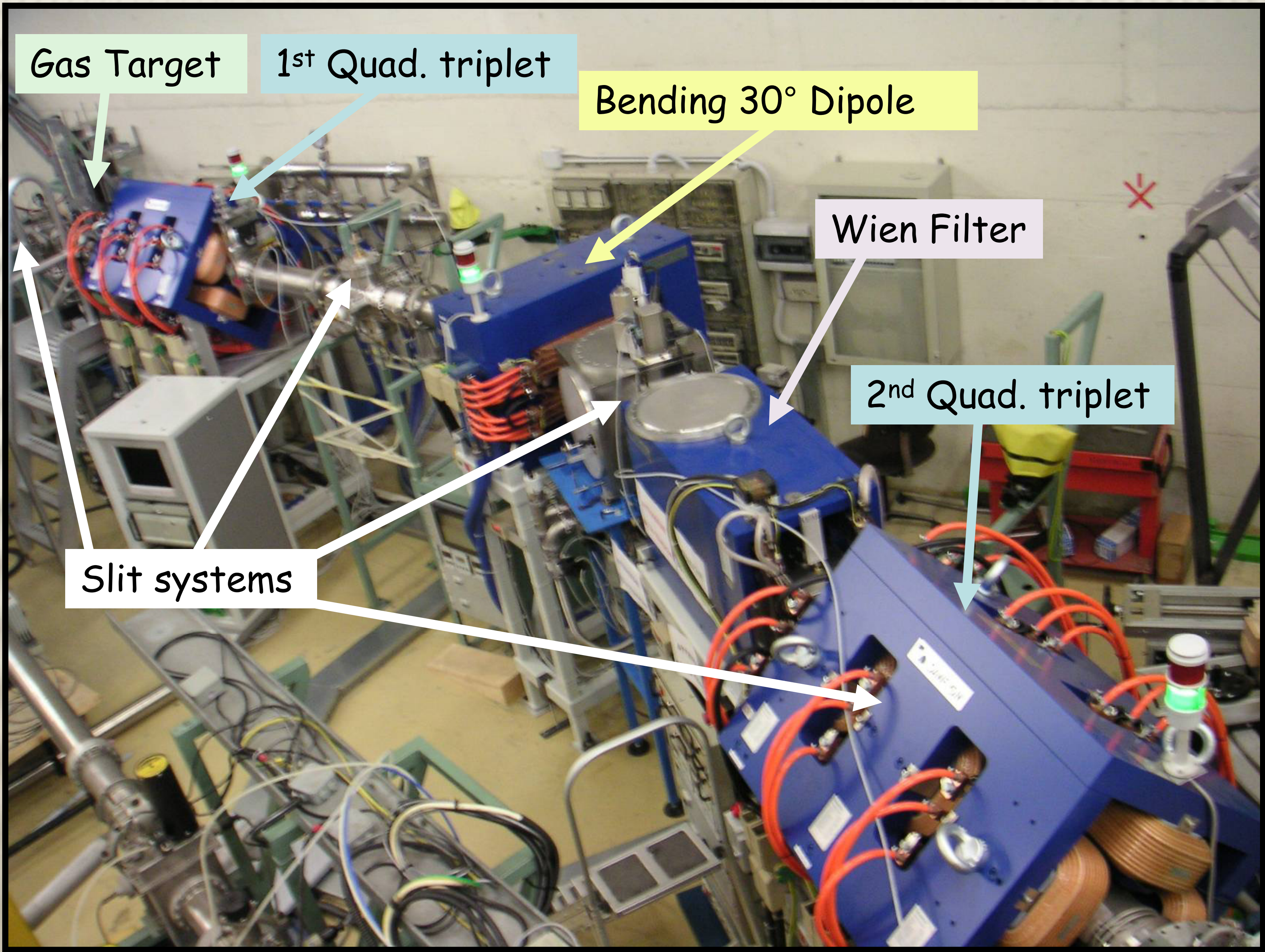
Direct versus total



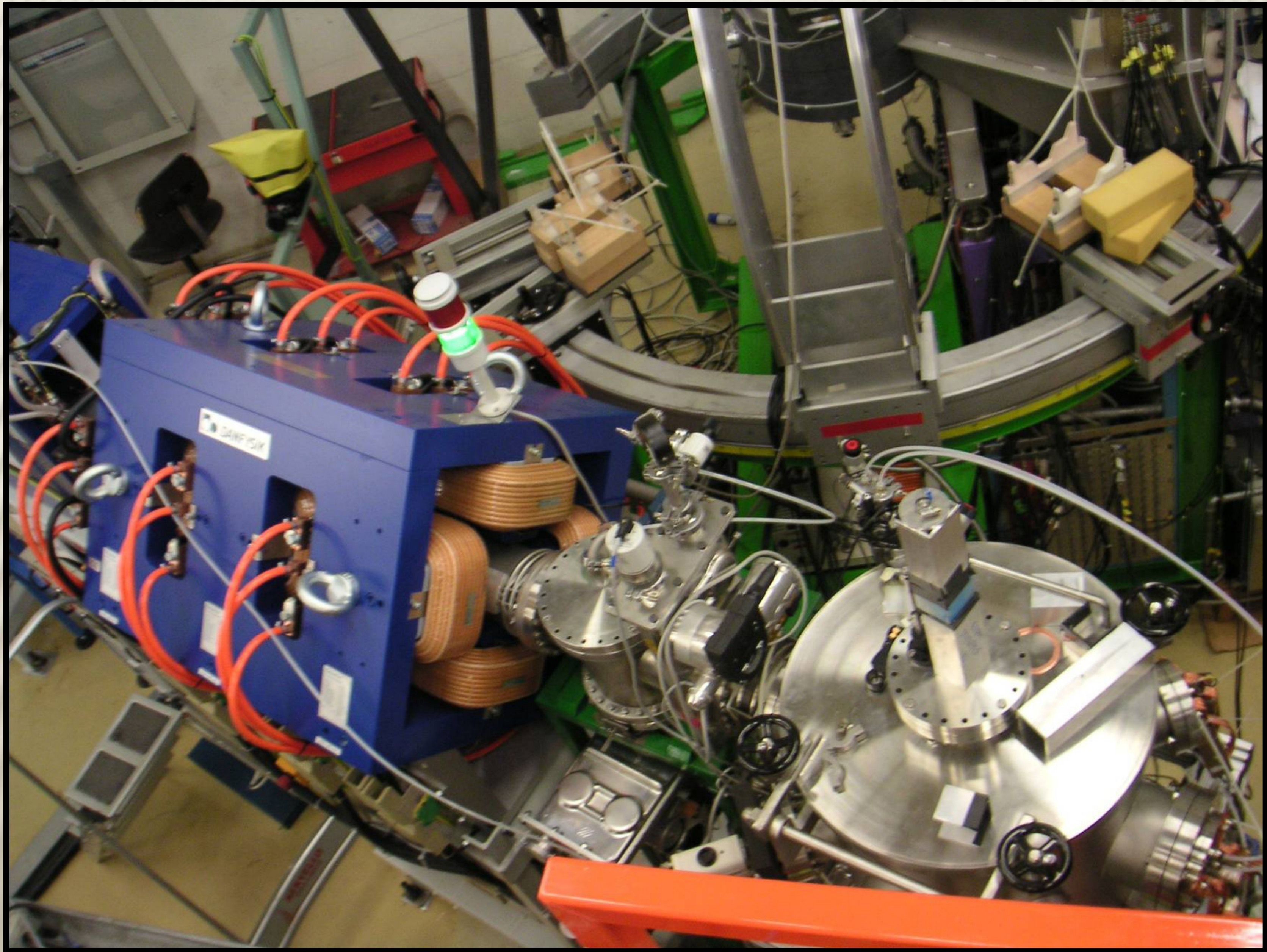


Pakou et al, PRC87,014619(2013); EPJA51,55(2015)

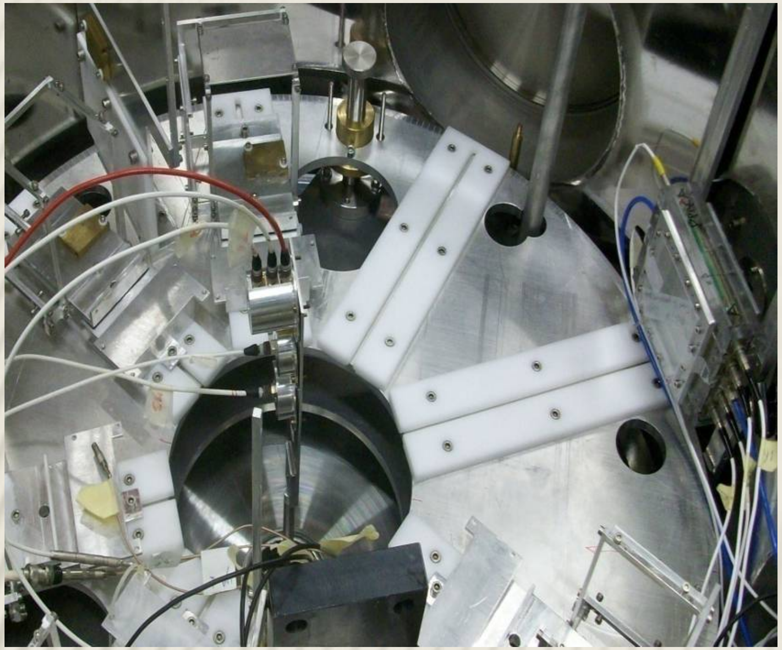
EXOTIC beam line-LNL ITALY

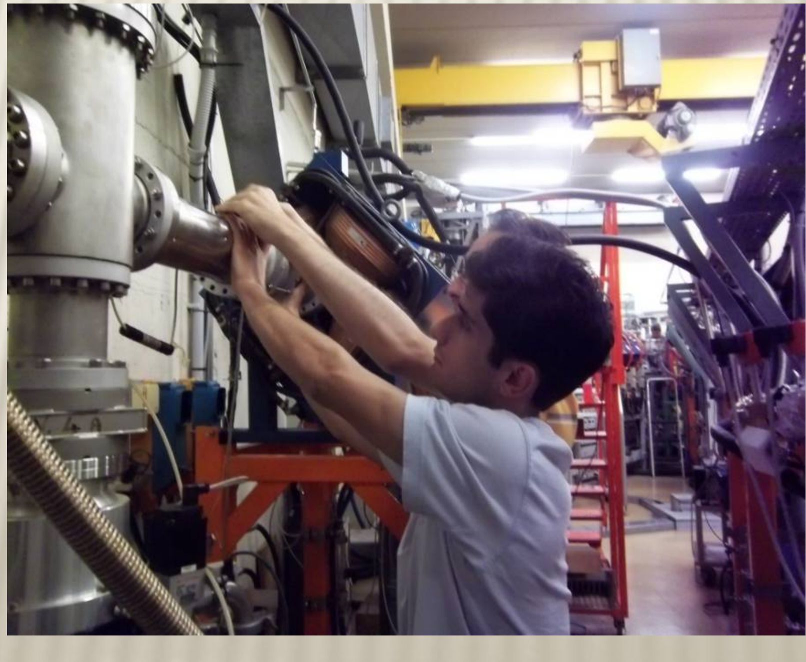


2nd 4-pole triplet and final measuring point



Reaction chamber at the EXOTIC Facility LNL





EXOTIC facility @LNL: in-flight production of light Radioactive Ion Beams

via inverse-kinematics reactions, induced by high intensity heavy-ion beams delivered from the LNL-XTU Tandem accelerator impinging on a gas target, which can be filled with H, D, $^{3,4}He$.

- p (^{17}O, ^{17}F) n
- p (^{7}Li, ^{7}Be) n
- d (^{7}Li, ^{8}Li) p
- ^{3}He (^{6}Li, ^{8}B) n

Our work with radioactive projectiles

Last 5 years

^{17}F ^{8}B ^{7}Be ^{8}Li

- **17F+p**

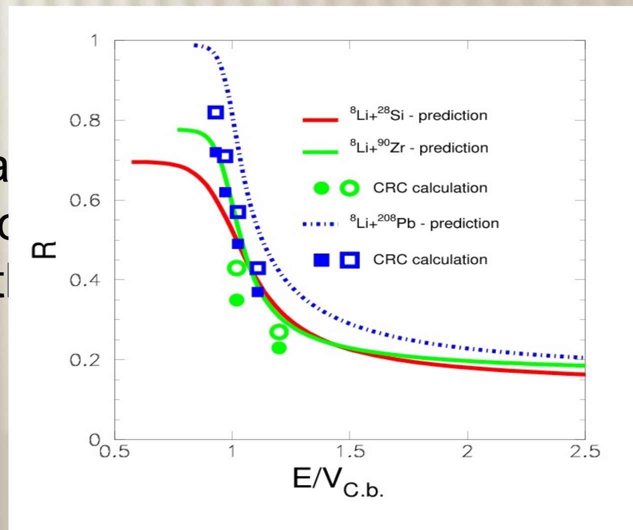
  as a probe to the JLM potential and the neutron skin structure of the projectile- Patronis et al PRC85, 024609(2012)

- **^{8}B + ^{28}Si**

  Fusion cross section measurements- Pakou et al. PRC 87, 049901 (2013)

- **^{7}Be + ^{28}Si**

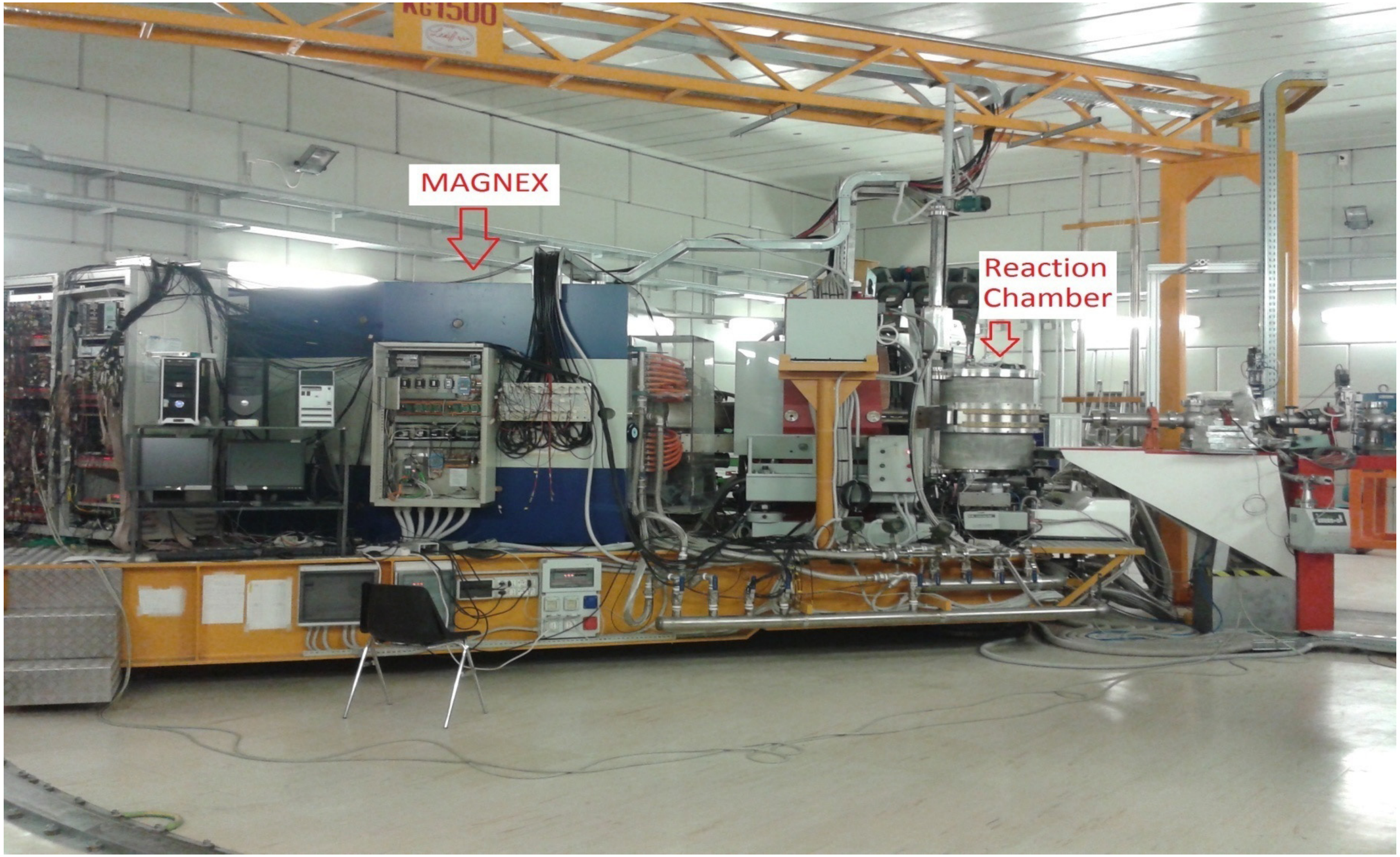
  Energy dependence of the optical potentia
  Reaction mechanisms- Direct versus compo
  sections- Sgouros et al- papers and a PhD t

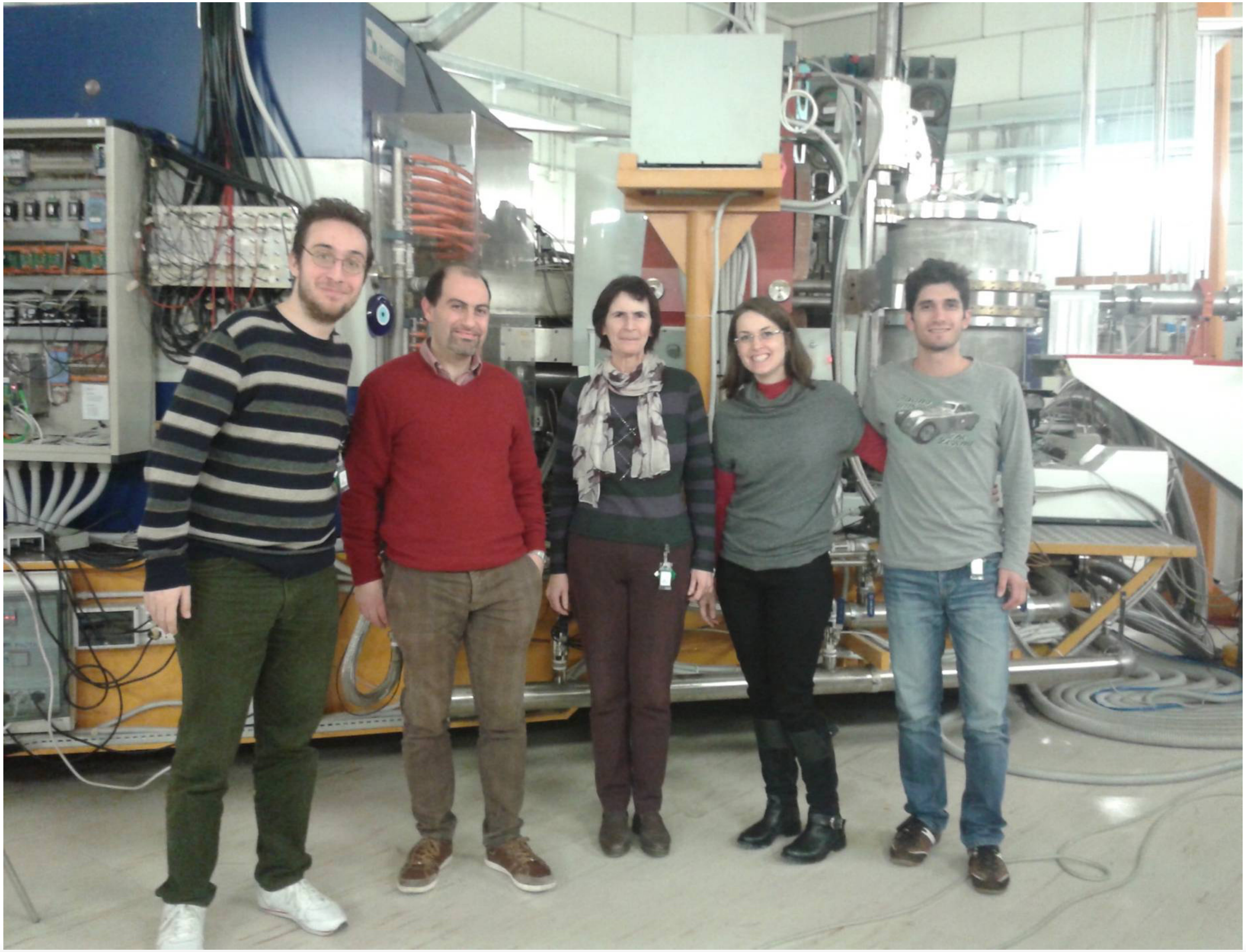


- **^{8}Li + ^{90}Zr**

  Optical potential-direct versus compound-
  A. Pakou et al., EPJA 51, 55(2015); EPJA 51, 90 (2015)

MAGNEX Spectrometer at LNS





Continuation of our work with weakly bound projectiles at the MAGNEX facility

- **$^{6}Li + p$**

  Probing the optical potential via elastic scattering and breakup measurements- PhD Thesis and papers in progress; and Soukeras et al., PRC 91, 057601 (2015)

- **$^{6}Li + p \rightarrow {}^{4}He + {}^{3}He$**

  Probing the reaction mechanisms; Msc Thesis and Betsou et al. EPJA 51, 55 (2015)

- **$^{7}Li + p$ and $^{7}Li + d$**

  Probing the optical potential via elastic scattering and breakup
  Probing the clustering structure of ^{7}Li

Probing the clustering structure of ^{7}Li via elastic scattering in inverse kinematics

- Clustering is the propensity for objects to congregate in all physical scales from the assemblage of stars into galaxies, of planets within the solar system to quarks confined within hadrons with only particular number of constituents

- Clustering in nuclear physics can be observed in nuclear structure properties as well as in reaction dynamics

- ^{7}Li is a light nucleus an interesting case for clustering with the well-known weakly bound $\alpha + t$ *structure (S = 2.47 MeV)* and the more strongly bound clusters ^{6}He + *p* (S=9.98 *MeV)* ^{5}*He +d (S=* 9.52 *MeV) and* ^{6}*Li+n (S=7.249 MeV)*

^{7}Li+p and ^{7}Li+d elastic scattering
MOTIVATION

- This is the follow up experiment to ^{6}Li + p- **Systematic - JLM potential**

- The binding energy for ^{6}Li to **α + d** is 1.47 MeV and 1st resonance at 2.19MeV
  for ^{7}Li to **α + t** is 2.47 MeV and 1st resonance at 4.63MeV

- Choosing the same energies as for ^{6}Li, in the ^{7}Li case we can isolate **clustering effects from couplings to continuum and resonance states**

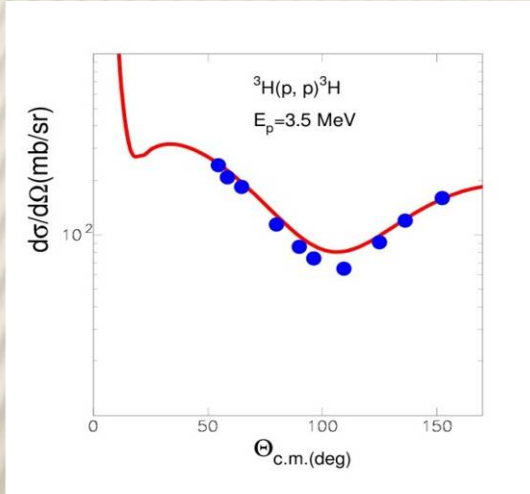
- Choosing the appropriate energies we can take advantage only of one cluster structure, the **α + t** one, avoiding other more bound clusters

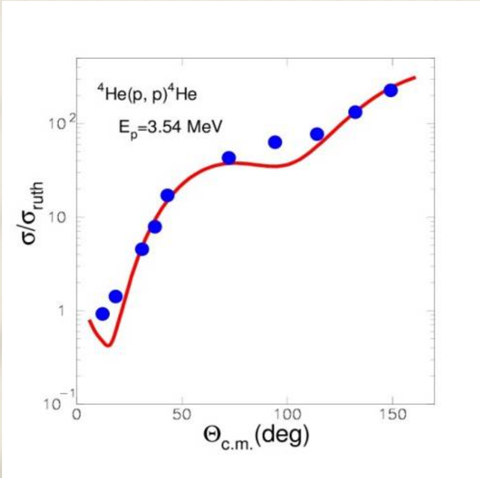
α + t (S=2.47MeV) **^{6}Li + n** (S=7.25MeV) **^{6}He + p** (S=9.97MeV) **^{5}He +d** (S=9.52MeV)

EXPERIMENTAL DETAILS and DETAILS of CDCC calculation will be given by Vassilis SOUKERAS

❖ **For the calculation we adopt the code FRESCO , in the form based in a cluster structure of the projectile or target.**

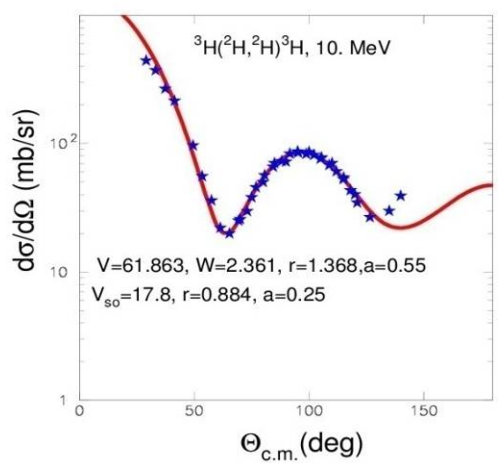
❖ **Then, the Coulomb and nuclear excitations can be interpreted and calculated in terms of the interactions of each cluster and the target.**

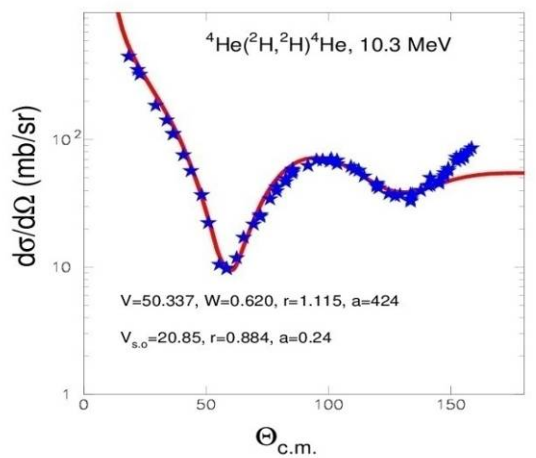




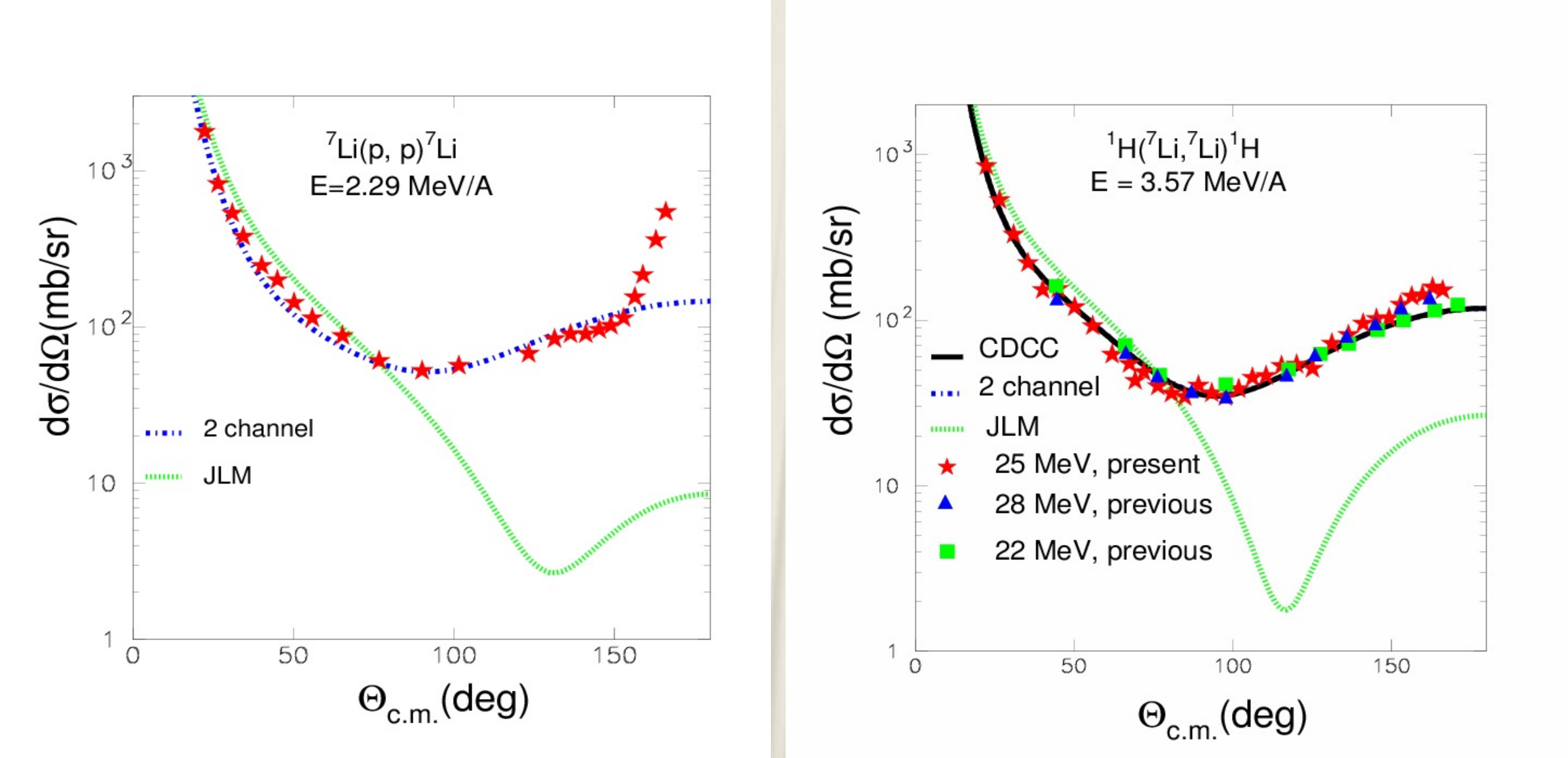
Description of **p+t** and **p+α** data

Description of **d+t** and **d+α** data



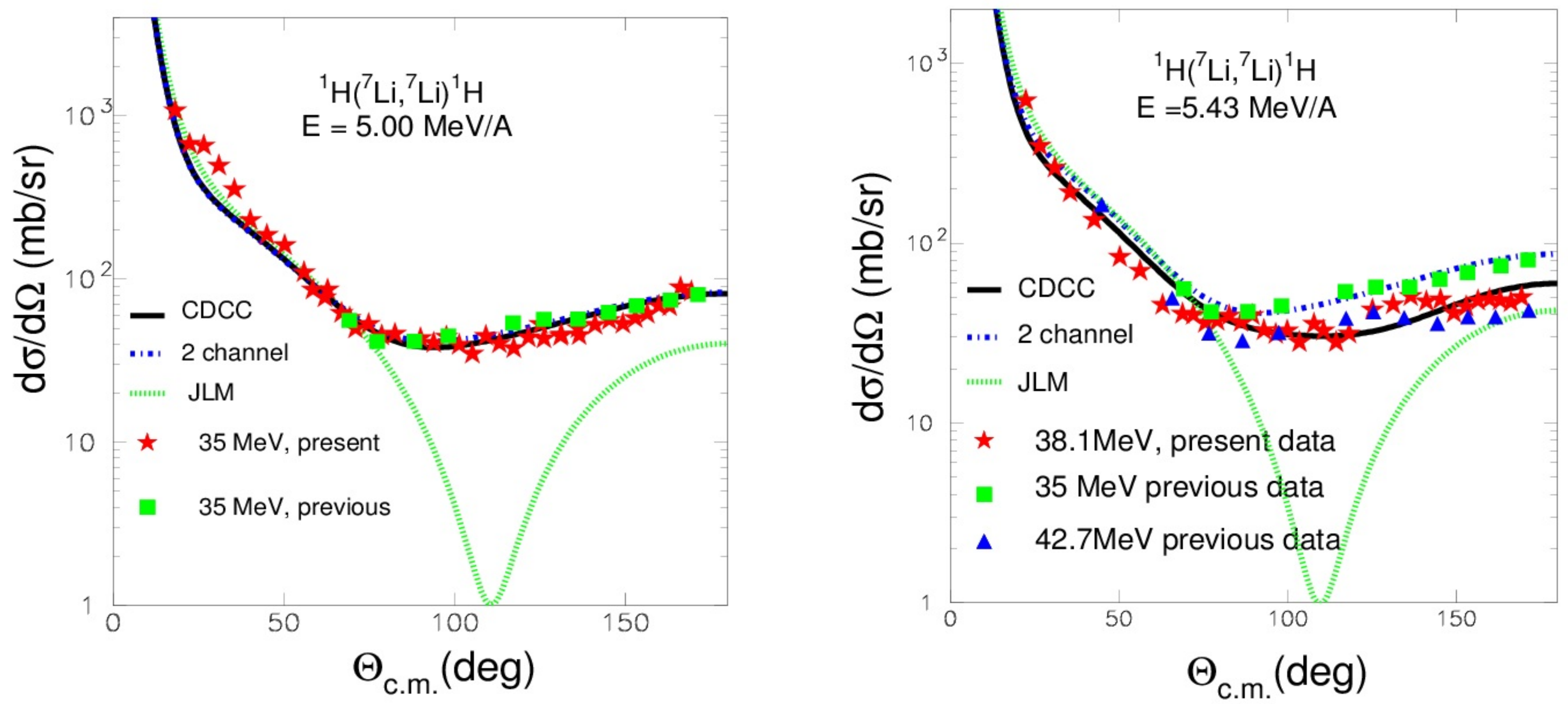


7Li + p



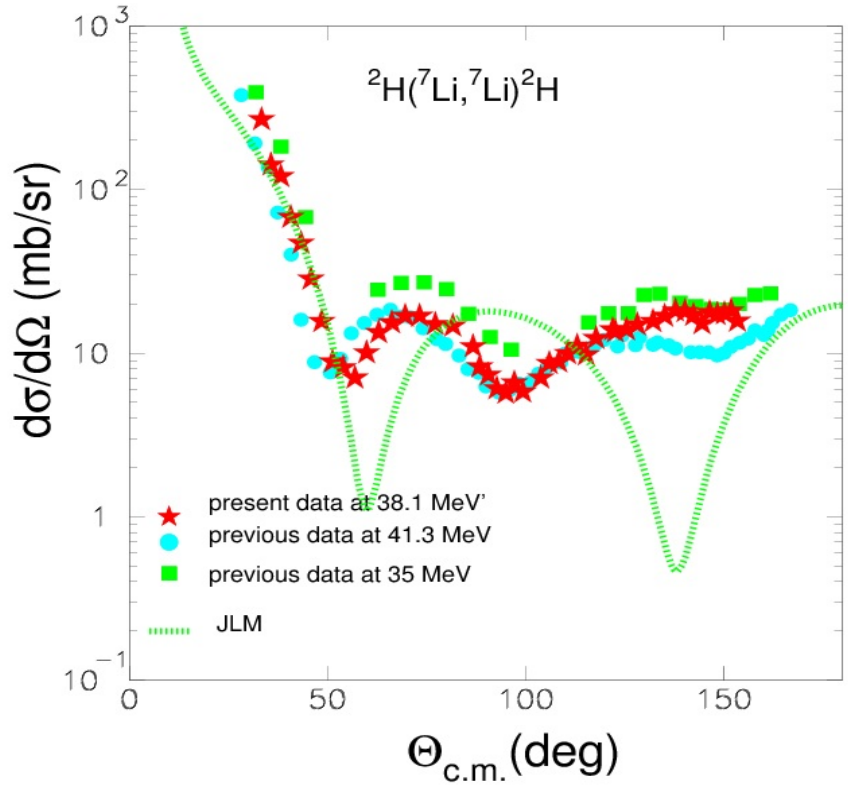
^{7}Li(p, p)^{7}Li
E=2.29 MeV/A
dσ/dΩ(mb/sr)
2 channel
JLM
Θc.m.(deg)
^{1}H(^{7}Li,^{7}Li)^{1}H
E = 3.57 MeV/A
dσ/dΩ (mb/sr)
CDCC
2 channel
JLM
25 MeV, present
28 MeV, previous
22 MeV, previous
Θc.m.(deg)

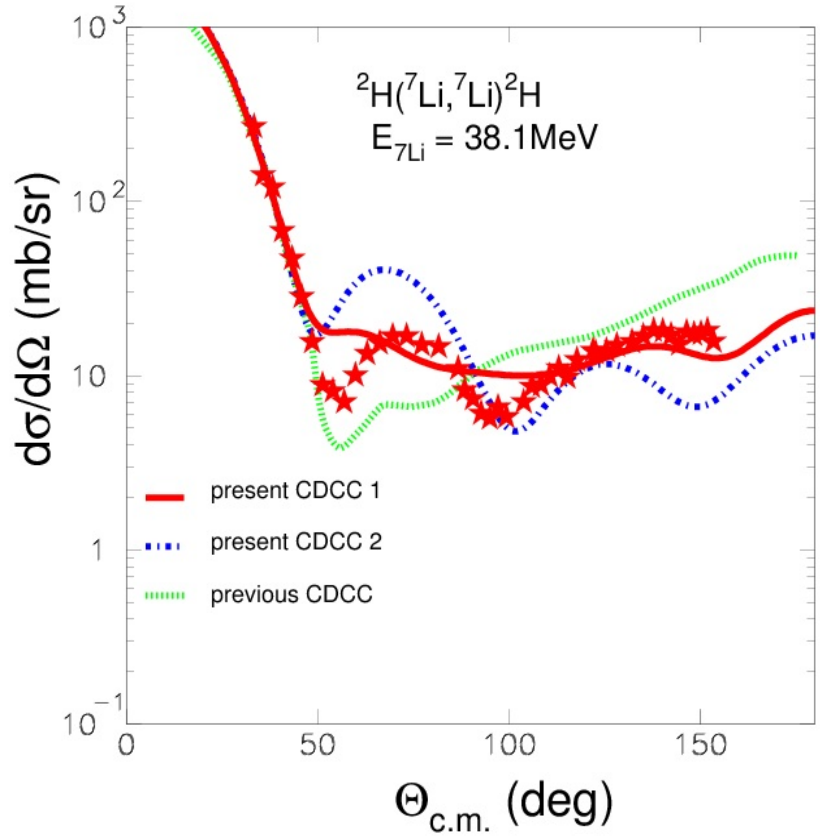
7Li + p



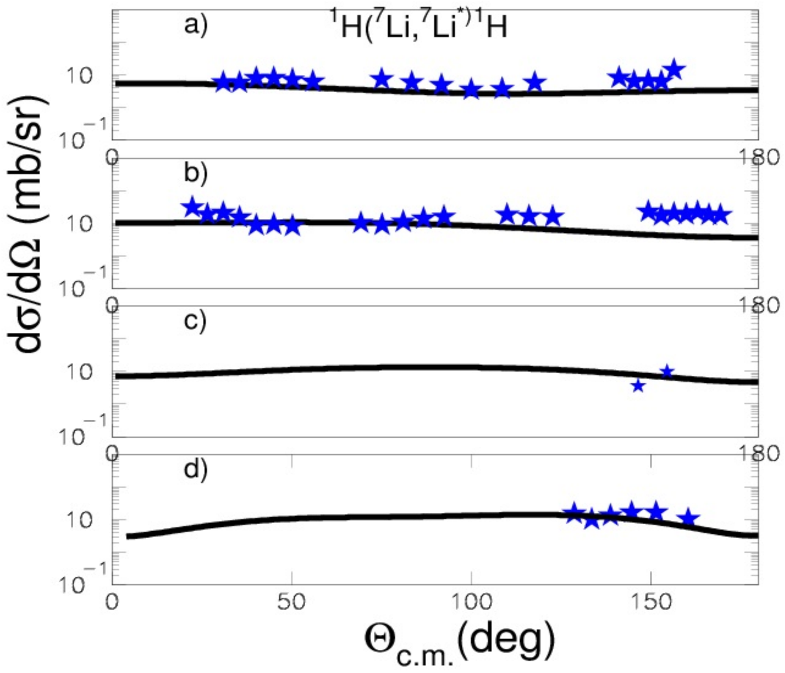
$^1H(^7Li,^7Li)^1H$
E = 5.00 MeV/A
CDCC
2 channel
JLM
35 MeV, present
35 MeV, previous
dσ/dΩ (mb/sr)
Θc.m.(deg)
$^1H(^7Li,^7Li)^1H$
E =5.43 MeV/A
CDCC
2 channel
JLM
38.1MeV, present data
35 MeV previous data
42.7MeV previous data
dσ/dΩ (mb/sr)
Θc.m.(deg)

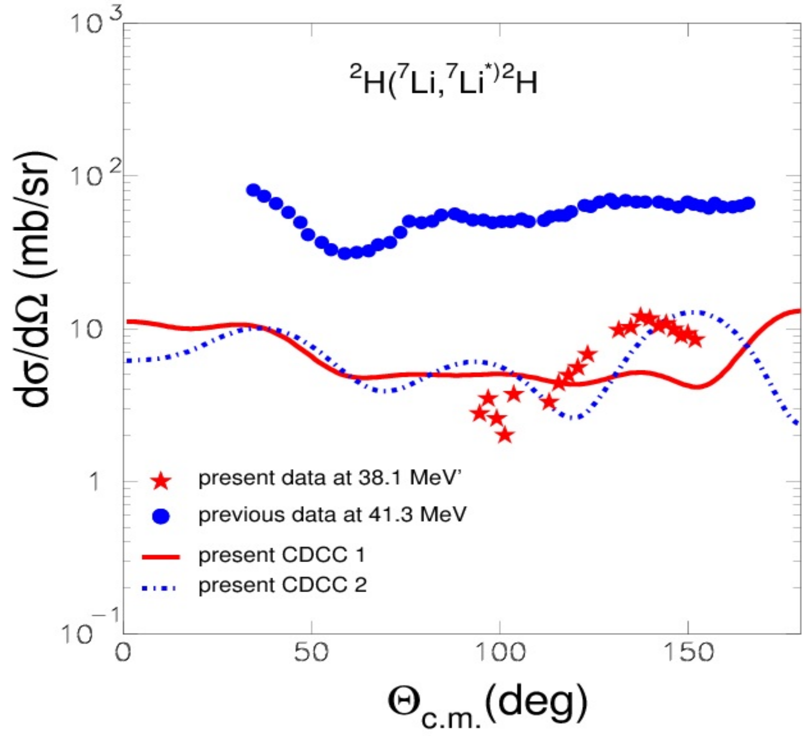
7Li + d


$^2H(^7Li,^7Li)^2H$
present data at 38.1 MeV'
previous data at 41.3 MeV
previous data at 35 MeV
JLM
dσ/dΩ (mb/sr)
$\Theta_{c.m.}$(deg)


$^2H(^7Li,^7Li)^2H$
E_{7Li} = 38.1MeV
present CDCC 1
present CDCC 2
previous CDCC
dσ/dΩ (mb/sr)
$\Theta_{c.m.}$ (deg)

7Li + d - inelastic





Conclusions

The last years we have established our technique on reaction mechanisms and optical potential at near barrier energies with weakly bound nuclei in nucleus-nucleus collisions at near barrier energies. Comprehensive studies were done for ^{6,7}Li + ^{28}Si

The unique tool for accomplishing our nucleon-nucleus research proved to be the MAGNEX spectrometer in CATANIA

Recently our technique was applied for radioactive projectiles as ^{8}B, ^{8}Li and ^{7}Be on fusion measurements total reaction cross section and direct to total reaction ratios. A strong direct channel was reported for below barrier energies, which for heavy targets saturates close to unity.

Our research now is focused on nucleon-nucleus collisions in inverse kinematics with weakly bound projectiles
Clustering effects and couplings to continuum and resonance states are probed.

Elastic scattering results for ^{7}Li+p and ^{7}Li+d were reported at energies 5 to 7 times the Coulomb barrier compatible with simple OMP calculations BUT where the clustering structure of the projectile was taken into account and proved to be the key for interpreting the elastic scattering results