

Projectile and Compound Nucleus Decay with light beams provided by SPES

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Outline

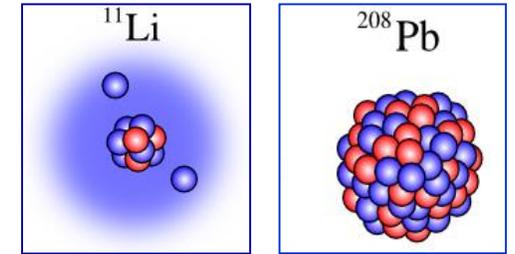
- Physics Framework & Cases
 - Collisions around the barrier
 - Example & experimental technique
 - Fusion-Evaporation Reactions and clustering
 - Experimental set-up & analysis
- Summary

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

Characteristics of the projectiles:
Low break-up thresholds, diffuse tails



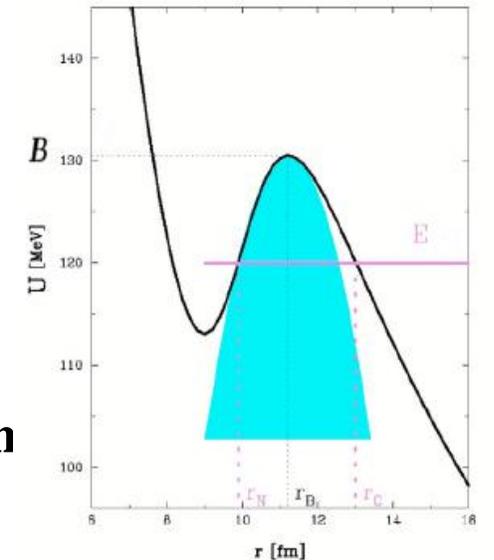
Coupling to continuum effects expected to be important.



Direct mechanisms (e.g. break-up, transfer) expected to be important.

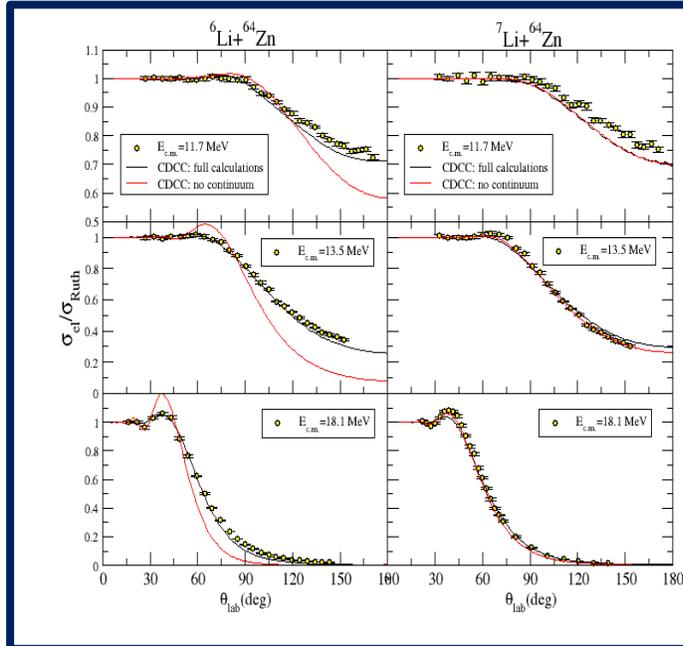
What do we expect for fusion reactions ?

- a) Static effects:
diffuse tail affects the shape of the potential
- b) Dynamic effects:
coupling not only to bound states but also to continuum
- c) Contribution of Incomplete Fusion (ICF) can be important



**Important effects on reaction dynamics observed not only with halo nuclei
but also with stable weakly bound ones**

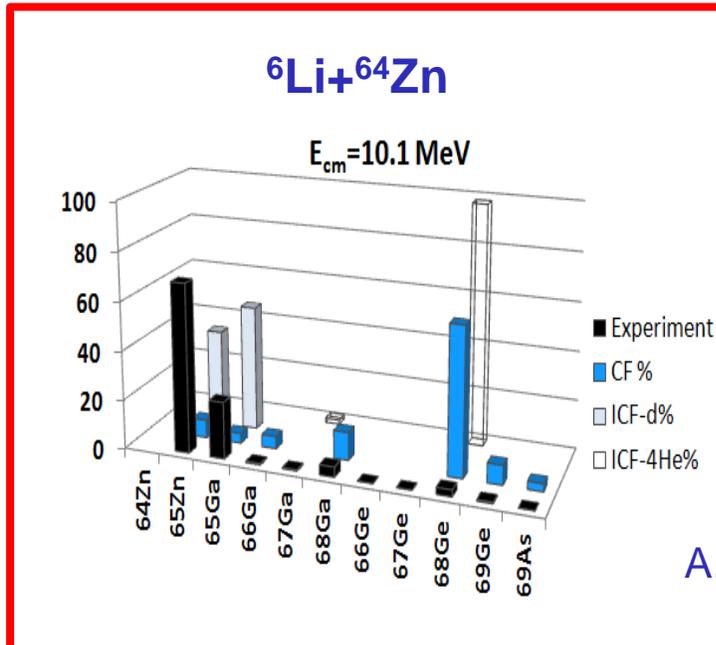
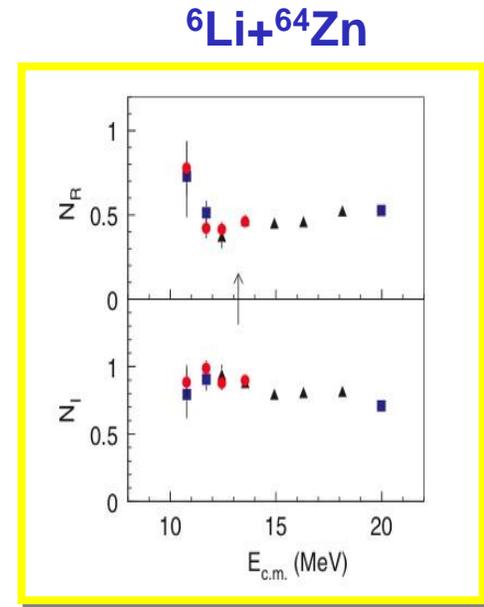
Example of some results with stable weakly bound beams at LNS



Coupling to continuum effects in elastic scattering AD and barrier distributions are evident and are stronger for ${}^6\text{Li}$ than for ${}^7\text{Li}$

Absence of usual threshold anomaly in the optical potential is observed

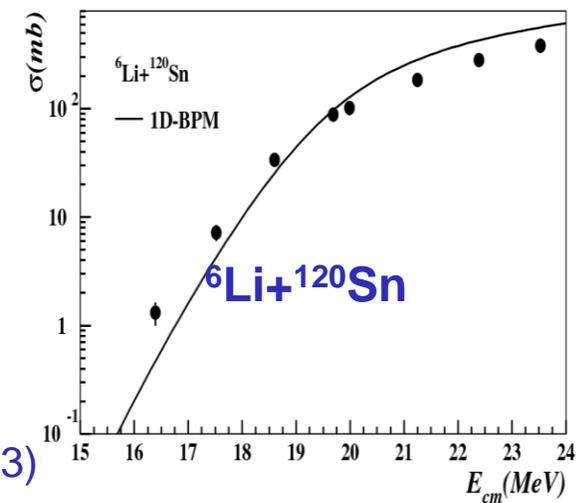
M.Zadro et al.:
 PRC 80,064610, (2009);
 Phys. Rev. C 87,054606, (2013)



On medium mass targets fusion of ${}^6,7\text{Li}$ is dominated by CF above barrier and by deuteron ICF below.

CF suppression above barrier with ${}^6,7\text{Li}$ due to BU followed by ICF is observed on heavier targets

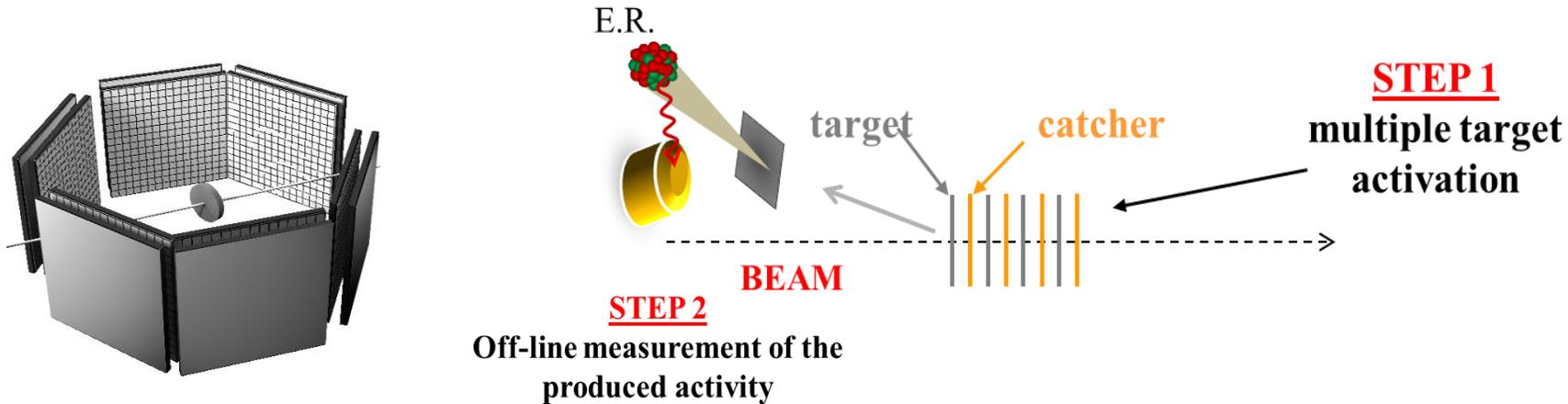
A. Di Pietro et al. : PRC . 87, 064614, (2013) and to be published



Example of possible studies with ^{17}F at SPES

^{17}F proton rich weakly bound (S_p)=0.6 MeV, 1 bound excited state.

Reaction dynamic studies around the Coulomb barrier on medium mass and heavy targets



Charged particles with the **LNS-CLAD** setup: 6 $\Delta E(20\mu\text{m})$ - $E(1000\mu\text{m})$ DSSSD) telescopes
high granularity and solid angle, good energy resolution.

- Coupling to continuum effects on elastic scattering
- Total reaction cross section, do we observe enhancement effects ?
- ^{16}O -p coincidences, breakup and transfer cross sections

Excitation functions for heavy residues identified in mass and charge with a single beam energy can be studied with a stack activation technique.

- Fusion enhancement/ suppression effects
- Competition between complete and incomplete fusion

Charged particle and fusion with the stack activation technique can be measured at the same time as already done by the LNS group with low intensity ^6He beams in:

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

Fusion-Evaporation Reactions

- The statistical theory of compound nucleus decay.
- Above the thresholds for particle decay, level densities are only accessible in evaporation reactions. NLD parameter for a given nucleus $A(N,Z)$ should decrease with increasing $(N-Z)$; *Al-Quraishi Phys. Rev. C67, 015803(2003)*
- mainly inclusive experiments have been used up to now to constrain this fundamental quantity.
- hot light nuclei, in this mass region and excitation energy ~ 3 A.MeV are produced in multifragmentation in a **wide range of N/Z** (excited unstable nuclei)

M.D'Agostino et al., CSYM experiment, LNL, February 2010

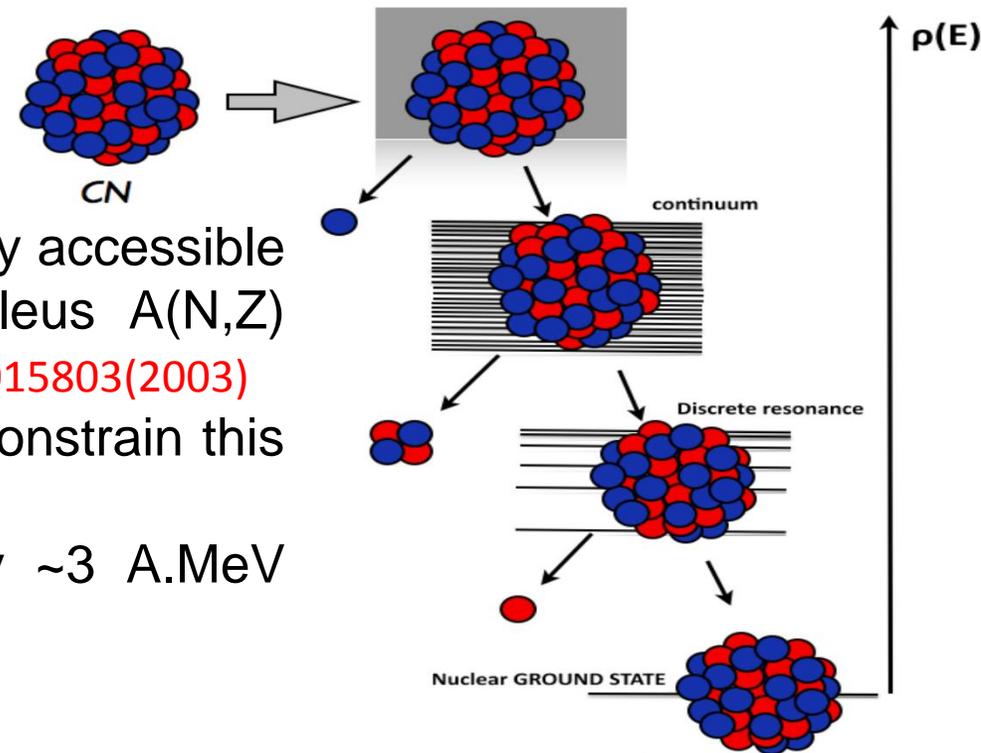
EXP: highly exclusive detection

NUCL-EX collaboration campaign:

STATistical properties of LIGHT nuclei from Fus-Evap.

- ❖ low multiplicity evts. & high detection coverage
- ❖ high energy and angular resolution
- ❖ complete evt. Reconstruction
- ❖ global control on the decay mechanism

GARFIELD+RCO @ LNL



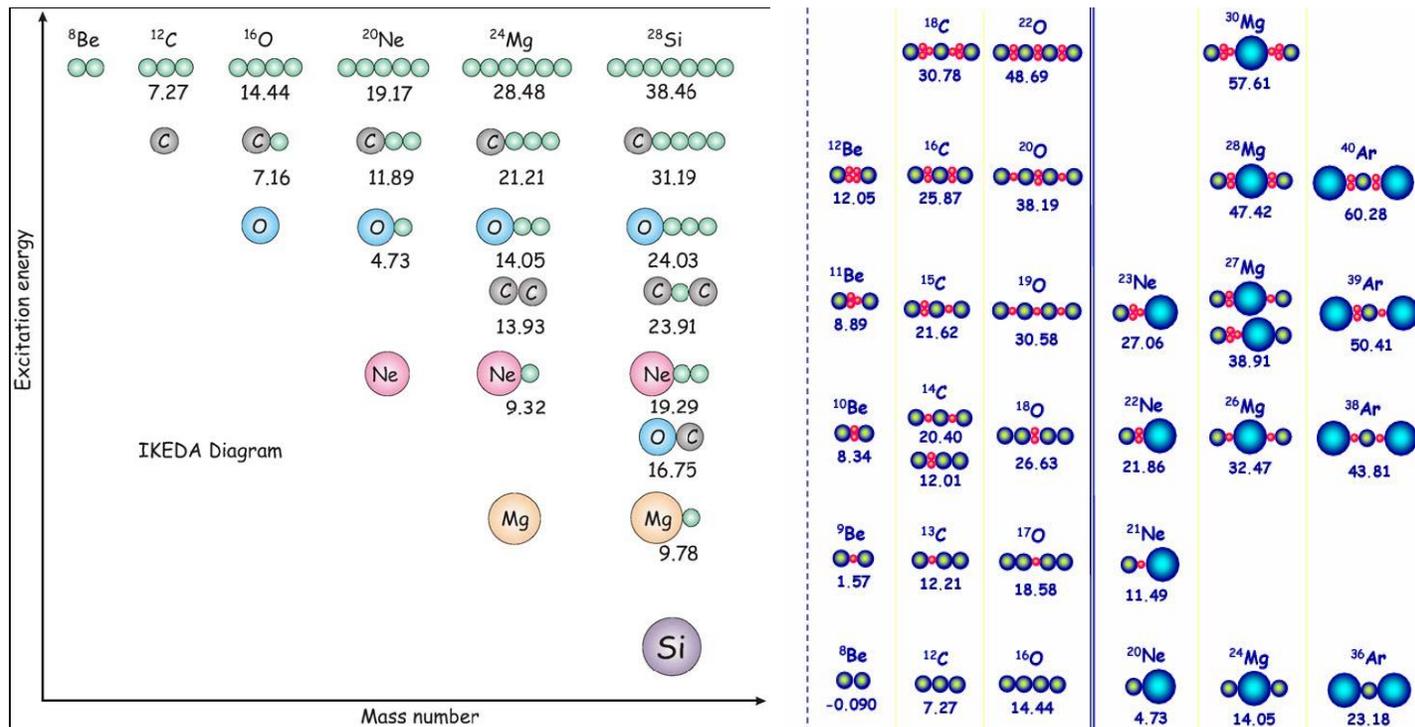
TH: decay codes constrained to available data

- ❖ Compound Nucleus formation and decay
- ❖ Level Density for $A \sim 20$, $e^* \sim 3$ A. MeV

Monte Carlo Hauser-Feshbach

Clustering

- Cluster structures appear mainly at excitation energies close to the thresholds for nucleus decomposition into clusters;
- Evidence for cluster structures comes from decay widths and branching ratios
- Preferential decay to α -structures in daughter nuclei
- Molecular resonances at higher excitation energy.



- which cluster structures and at which E^* can be found varying the N/Z in a given isotopic chain?
- Using stable and unstable beams we can explore the two diagrams!

T. Ichikawa and W. Von Oertzen, Phys. Rev. C **83**,(2011)

T.Neff, H.Feldmeier, Nucl.Phys. A738 (2004) 357

M. Freer, Rep. on Prog. in Phys. 70 (2007) 2149

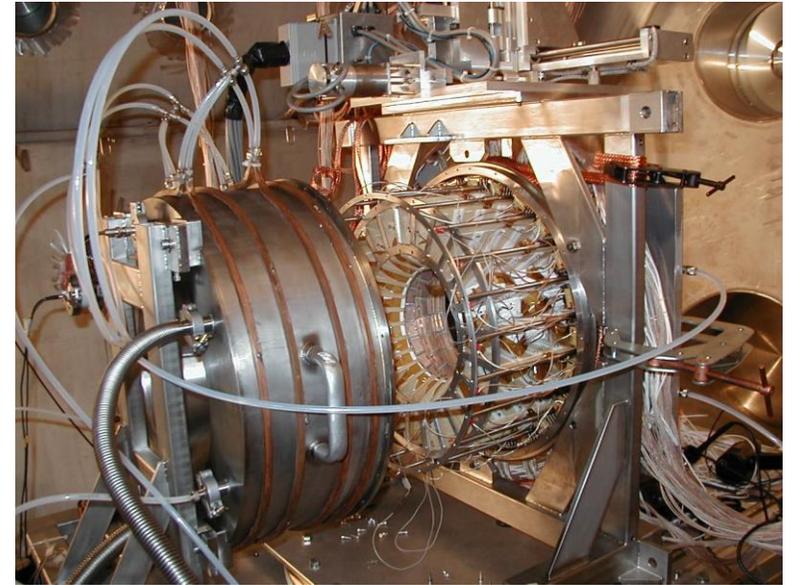
Experimental set-up @ LNL-INFN

European Physical Journal A



GARFIELD + RCo digital upgrade.....
By M. Bruno et al.
Eur. Phys. J. A (2013) 49: 128

- μ SGC + CsI(Tl), 180 CsI
detection of LCP and fragments:
- ✓ low identification thresholds (0.8–1 MeV/u)
 - ✓ angular coverage $30^\circ < \theta_{\text{lab}} < 150^\circ$
24 azimuthal sector
 - ✓ Z identification, A identification for $1 \leq Z \leq 3$



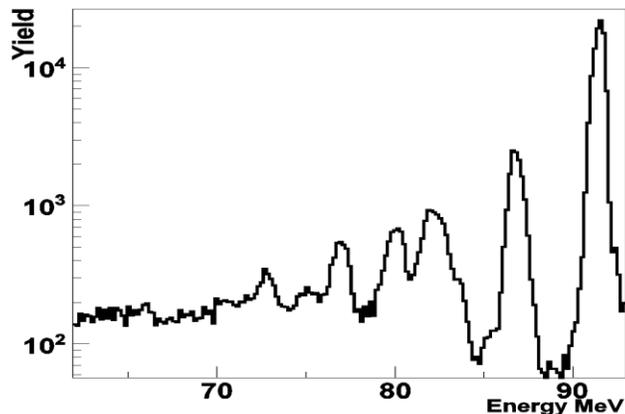
- IC+Si+CsI(Tl), 64 telescopes
- ✓ detection of ER,
low E thresholds

- ✓ high granularity and θ -resolution:
 0.8° for $5^\circ < \theta_{\text{lab}} < 17^\circ$
- ✓ energy resolution of Si strips and CsI(Tl) given by 0.3% and 2-3%



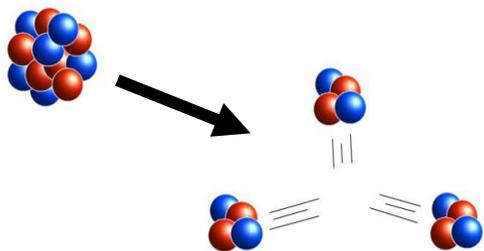
PROJECTILE & FUSION-EVAPORATION

- **12C excited state**

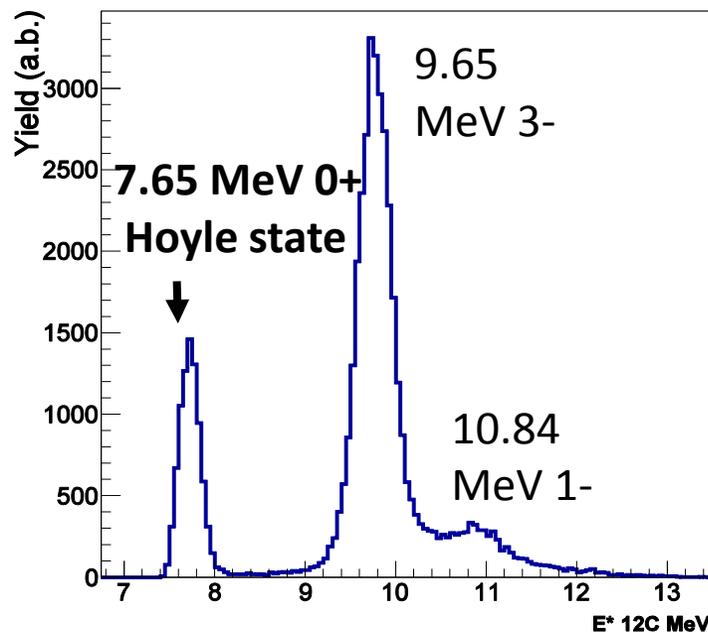


- **completeness** of the detection
Zdet 100% (Zproj+targ)
- Longitudinal **momentum**
 $q_z/q_{beam} > 0.8$
- **coincidence** between
LCP in GARFIELD and
Evaporation Residue in RCo

- **12C* decay in 3- α**



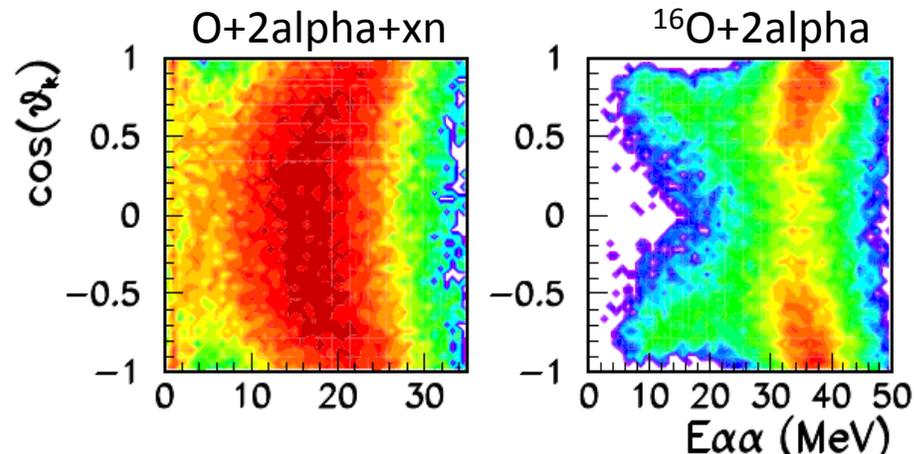
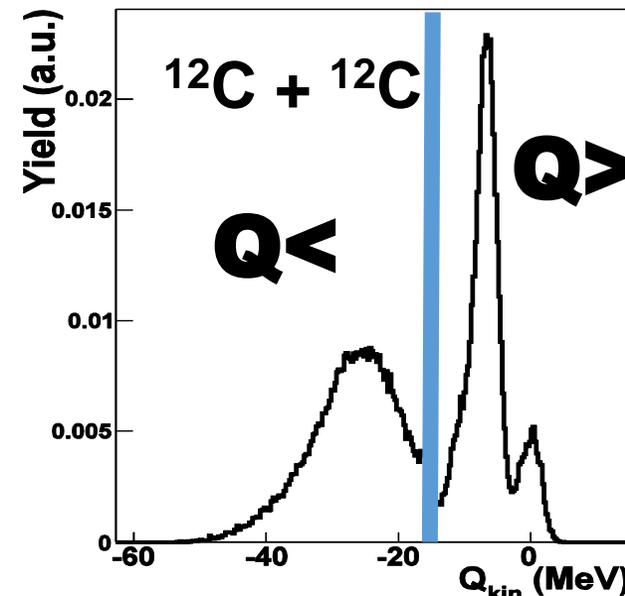
Freer PRC 49 (1994) R1751
Raduta PLB 705, 65 (2011)
O.S.Kirsebom PRL 108 (2012)
J.Manfredi PRC 85 (2012)



Invariant mass method

Oxygen + 2 α + neutron(s) channel

$$Q_{kin} = E_{kin} - E_{beam} = \sum^N E_i - E_{beam}$$



G. Baiocco 2013 *Phys. Rev. C* **87** 054614.
L. Morelli et al. *J. of Phys. G* IN PRESS (two papers)

Summary

We propose to measure:

^{17}F medium
+ mass
 ^{7}Be targets

REACTION	ACN	ZCN	E*CN
$^{17}\text{F} + ^7\text{Li}$	24	12	2-3 A MeV
$^{25}\text{Al} + ^7\text{Li}$	32	16	2-3 A MeV
$^{25}\text{Al} + ^{11}\text{B}$	36	18	2-3 A MeV
$^{10}\text{Be} + ^4\text{He}$	14	6	

+ reference reactions on ^{179}Au

$$E_{\text{beam}} = (6 - 10 \text{ A.MeV})$$

$$i_{\text{beam}} = 10^{6/7} \text{ pps}$$

to study:

- ✓ the competition of different reaction mechanisms, projectile Break-Up and Fusion-Evaporation
- ✓ the statistical behavior of hot light nuclei and/or possible clustering effects

feasible with: GARFIELD+ (RCo or FAZIA) and CLAD

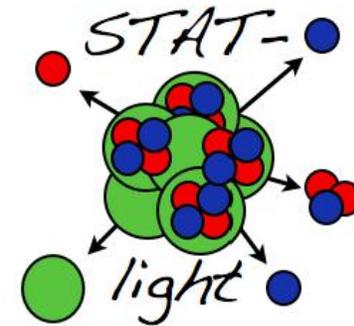
- ✓ possible upgrades of the set-up!
- ✓ preparatory experiments on the decay of light system are needed.



performed with an ACTIVE TARGET?

...thank you for your attention!

- L. Morelli, M. D'Agostino, M. Bruno, F. Gulminelli, A. Di Pietro, P. Figuera, M. Lattuada, S. Barlini, M. Bini, G. Casini, M. Cinausero, M. Degerlier, D. Fabris, N. Gelli, F. Gramegna, T. Marchi, A. Olmi, G. Pasquali, S. Piantelli, S. Valdrè, E. Vardaci.
- (NUCL-EX collaboration)



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