In-medium dynamics in nuclear structure

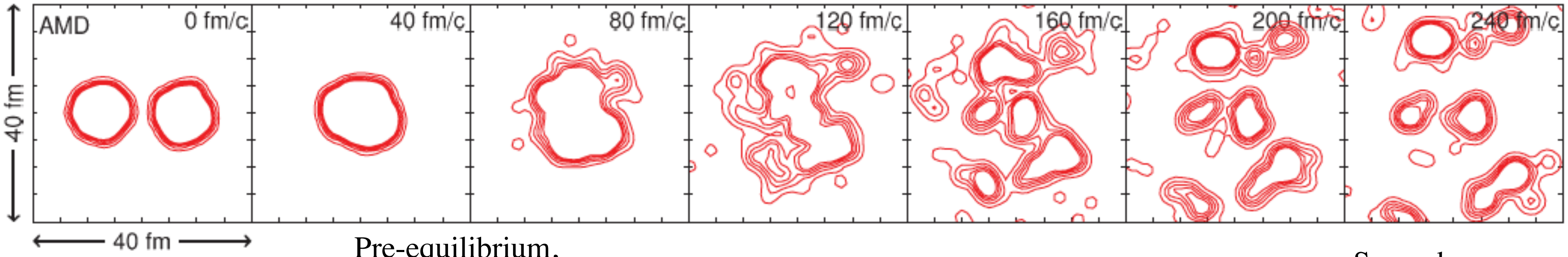
laboratoire commun CEA/DSM CNRS/IN2P3

A. Chbihi (GANIL) & G. Verde (IPNO / INFN-CT)

- Reaction dynamics
- Medium effects on nuclear binding energies (based on generalized RMF approach)
- Isotopic distribution analysis in term of RMF
- Experimental signals of BEC
- Investigation of Hoyle state of 12C
- Experimental perspectives: FAZIA-MUST2@LISE
- Conclusions

Time evolution of HIC at intermediate energies

M. Colonna, A. Ono and J. Rizzo PRC82, 054613 (2010)   Typical event of Xe+Sn @ E/A =50 MeV



Pre-equilibrium, stopping, compression   Flow, expansion   Fragmentation   Secondary decays

- HIC produce very exotic nuclei during different stages of the reaction
  - ✧ Light clusters dynamically produced at early stage of the reaction
  - ✧ Light clusters at late secondary decay stages as evaporation from excited frag at unbound states.

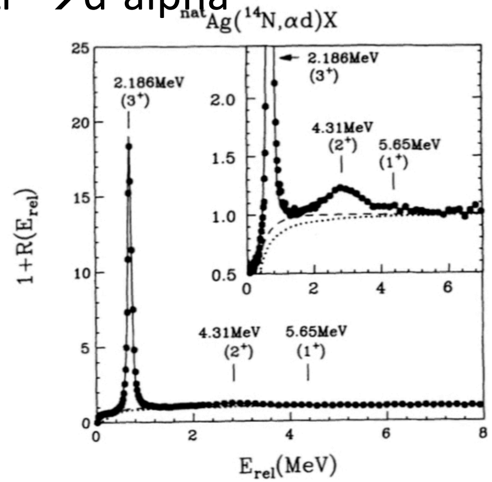
- HIC scan densities and temperatures comparable to those expected on the neutrinosphere in core collapse supernovea

- What is the effect on in-medium dynamics on the structure properties of nuclei?

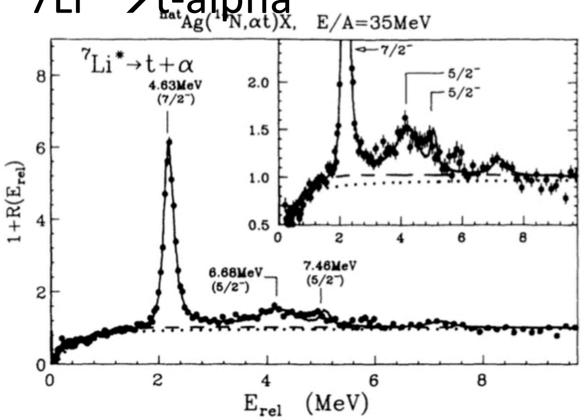
Special role of alpha particle and their clustering

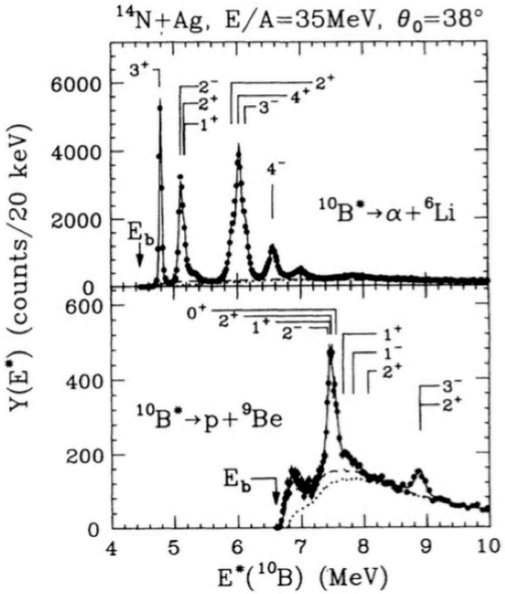
Reconstruction of invariant mass spectra:
Peaks → decay of unstable states

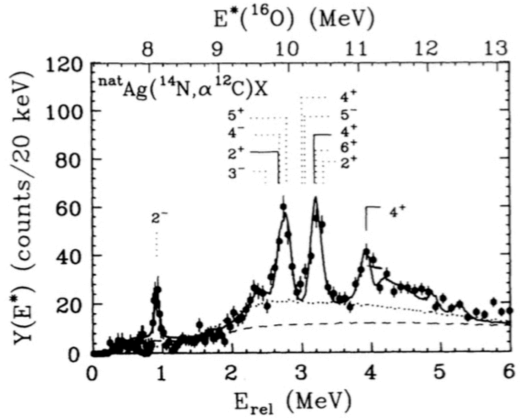
6Li*→d-alpha



7Li*→t-alpha







14N+Ag @ E/A=35 MeV

10B*→alpha-Li

10B*→p+9Be

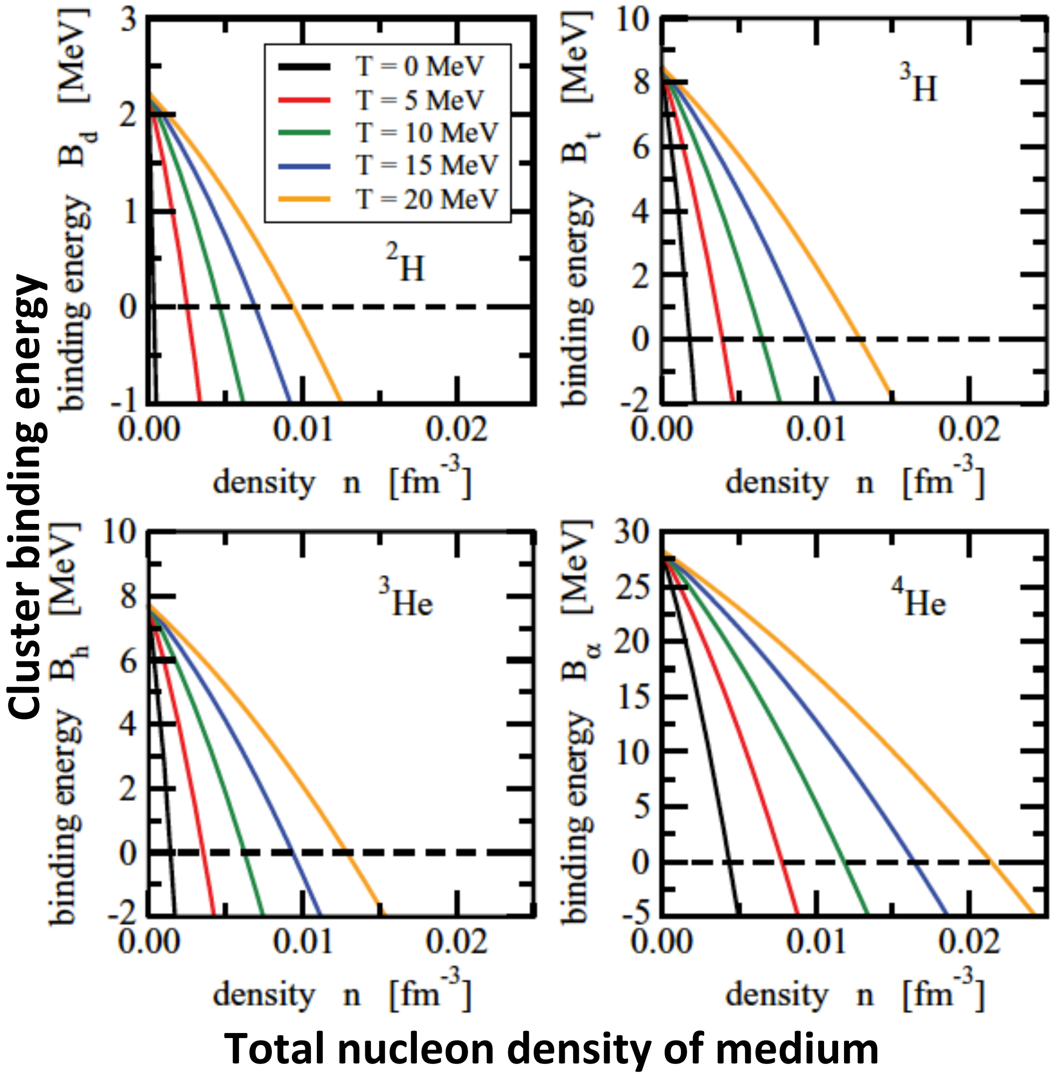
The temperatures of the emitting sources are extracted from relative population of particle-unstable states.

Is structure of these nuclei modified by the medium ?

T.K. Nayak et al., PRC45, 132, 1992

Predictions of in-medium effect on cluster BE

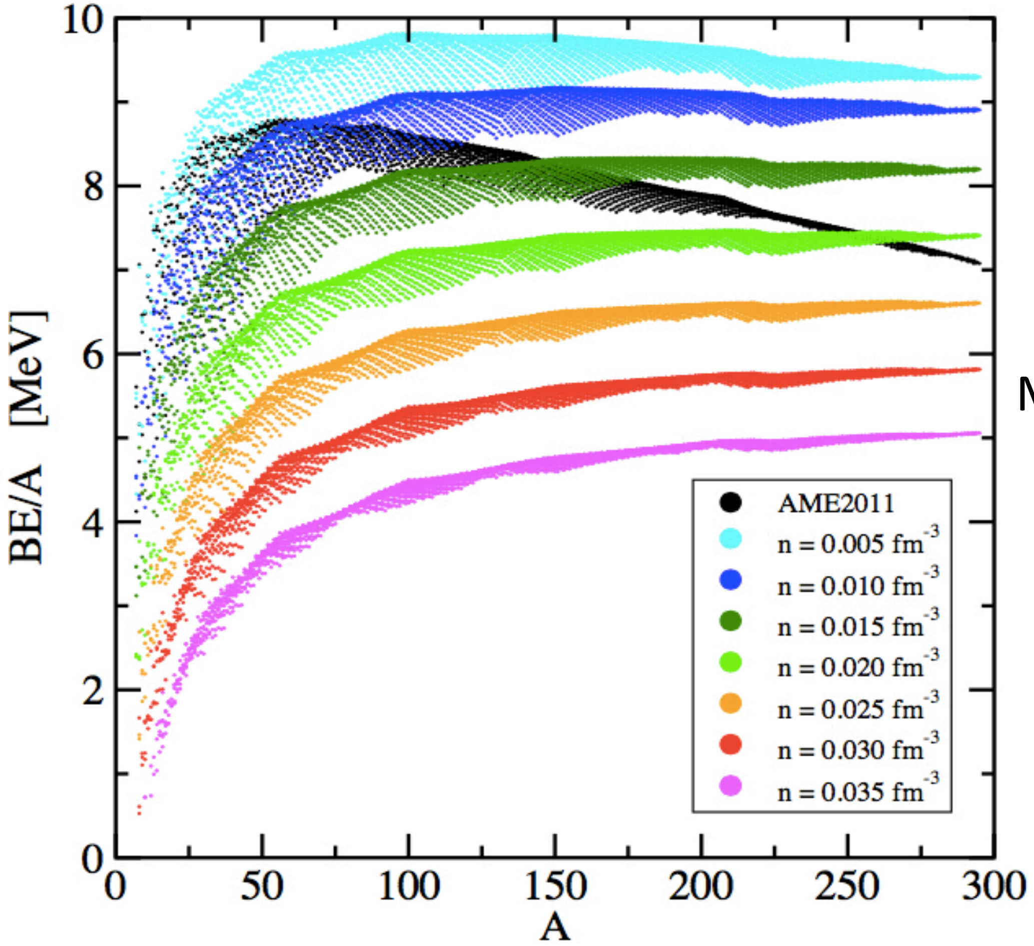
Based on Quantum Satistical and Generalized RMF approaches



- n → 0, Bi = experimental B
- For the density where cluster becomes unbound, n(Bi<=0), density increases with increasing T.
- modification of cluster properties with change of nuclear medium

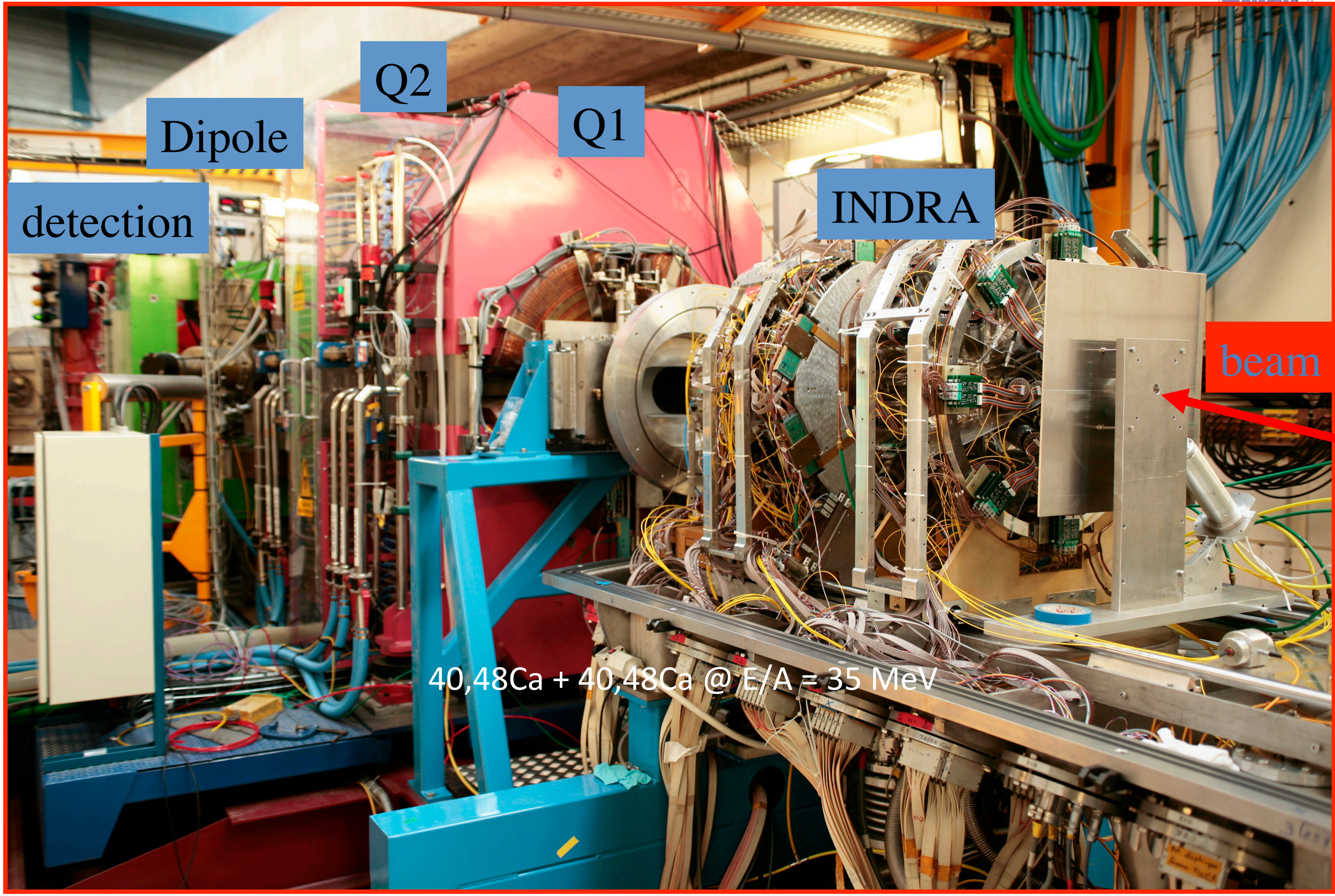
S. Typel et al., PRC81, 015803 (2010)

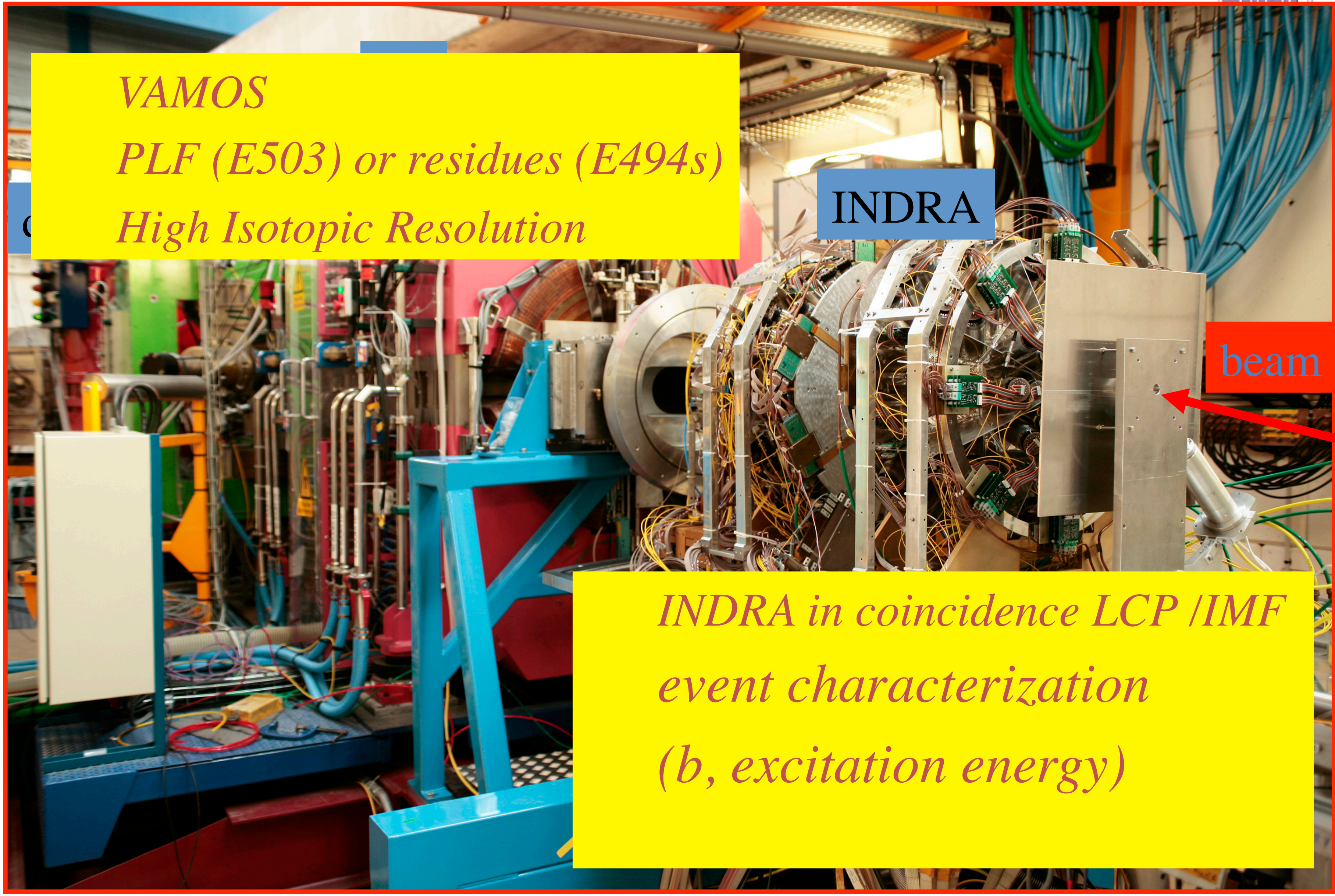
Predictions of in-medium effect on heavier fragment BE



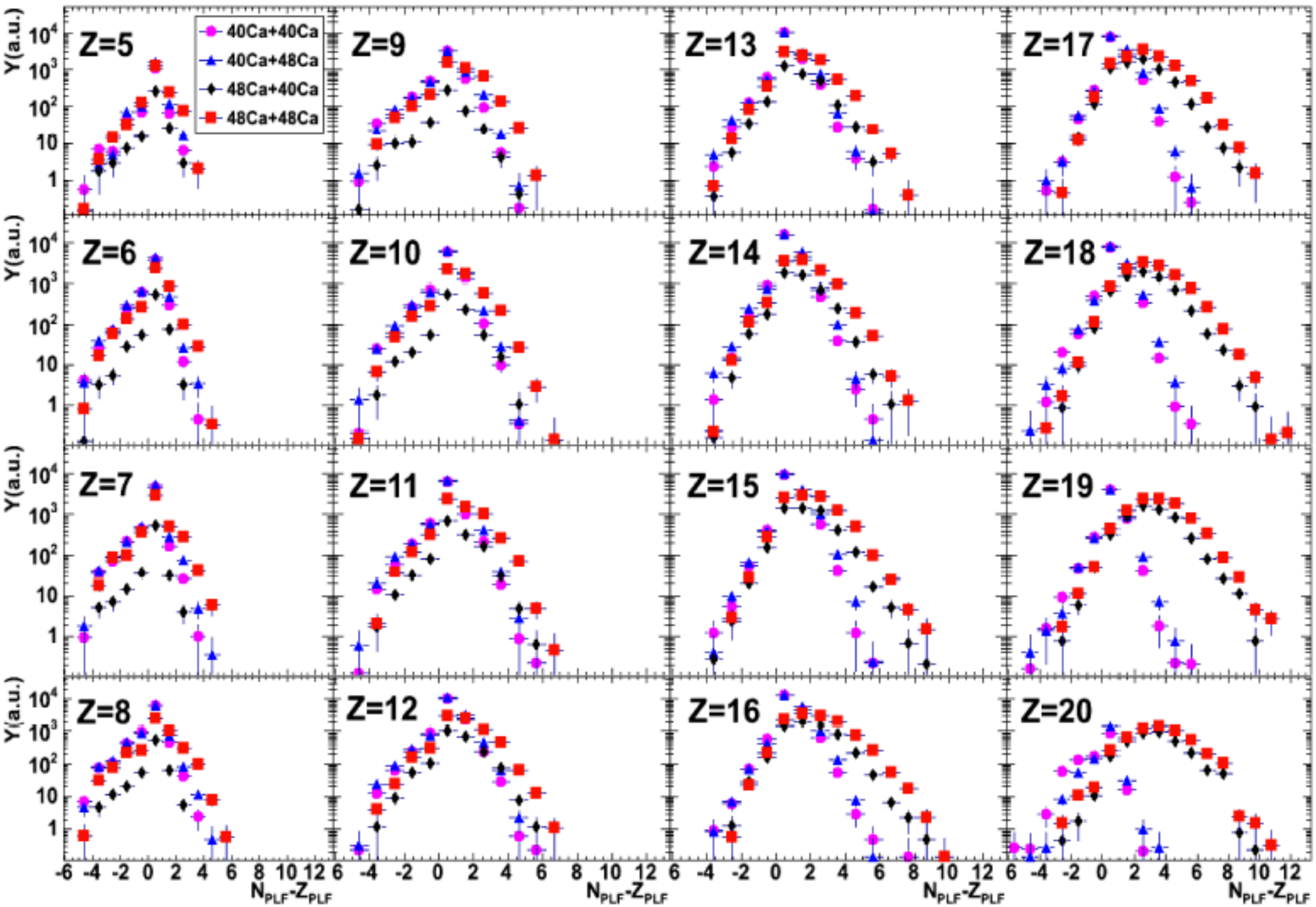
Modification of BE with densities

S. Typel et al., J of Phys., Conf. Series 420, 012078


Q2
Dipole
Q1
detection
INDRA
beam
40,48Ca + 40,48Ca @ E/A = 35 MeV


VAMOS
PLF (E503) or residues (E494s)
High Isotopic Resolution
INDRA
beam
INDRA in coincidence LCP /IMF
event characterization
(b, excitation energy)

Isotopic distributions of the PLF
For $^{40,48}Ca + ^{40,48}Ca$ @ E/A = 35 MeV



WORK in progress

Constraints on the Generalized RMF

Collaboration with Stefan Typel

Step 1:

- Input density and temperature
- Fit the experimental isotopic distributions
- Result : Density vs temperature distributions for
  different asymmetric nuclei
  not only, the density dependence of Esym can extrcated

Step 2:

- Experimental characterization of nuclear medium
  will be shown by G. Verde on Friday (femtoscopy)

Work in collaboration with S. Typel (GSI) laboratoire commun CEA/DSM CNRS/IN2P3

Physics Letters B 756 (2016) 194–199

Contents lists available at ScienceDirect

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Signals of Bose Einstein condensation and Fermi quenching in the decay of hot nuclear systems

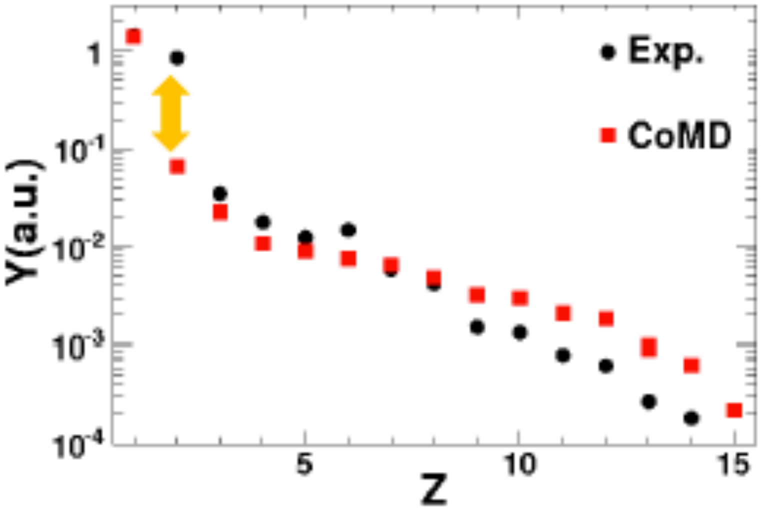
CrossMark

P. Marini [a,*,1], H. Zheng [b,c], M. Boisjoli [a,d], G. Verde [e,f], A. Chbihi [a], P. Napolitani [e], G. Ademard [e], L. Augey [g], C. Bhattacharya [h], B. Borderie [e], R. Bougault [g], J.D. Frankland [a], Q. Fable [a], E. Galichet [e,i], D. Gruyer [a], S. Kundu [h], M. La Commara [j,k], I. Lombardo [j,k], O. Lopez [g], G. Mukherjee [h], M. Parlog [g,l], M.F. Rivet [e,2], E. Rosato [j,k,2], R. Roy [d], G. Spadaccini [j,k], M. Vigilante [j,k], P.C. Wigg [m], A. Bonasera [b,c]
(INDRA Collaboration)

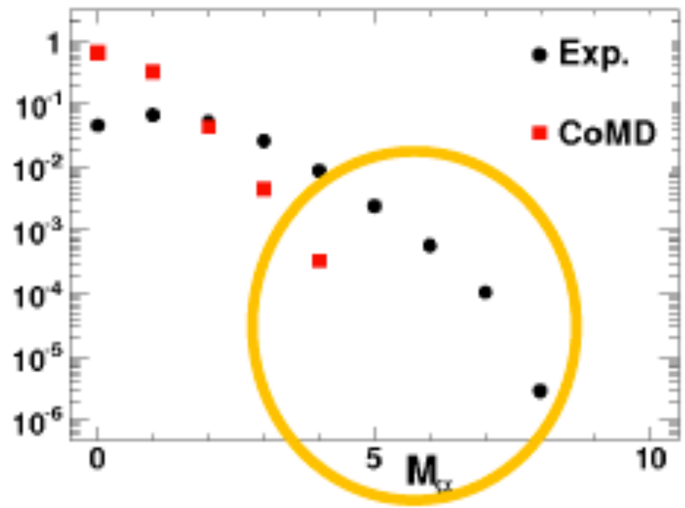
Comparison to CoMD

40Ca + 40Ca @ E/A = 35 MeV

Charge distribution



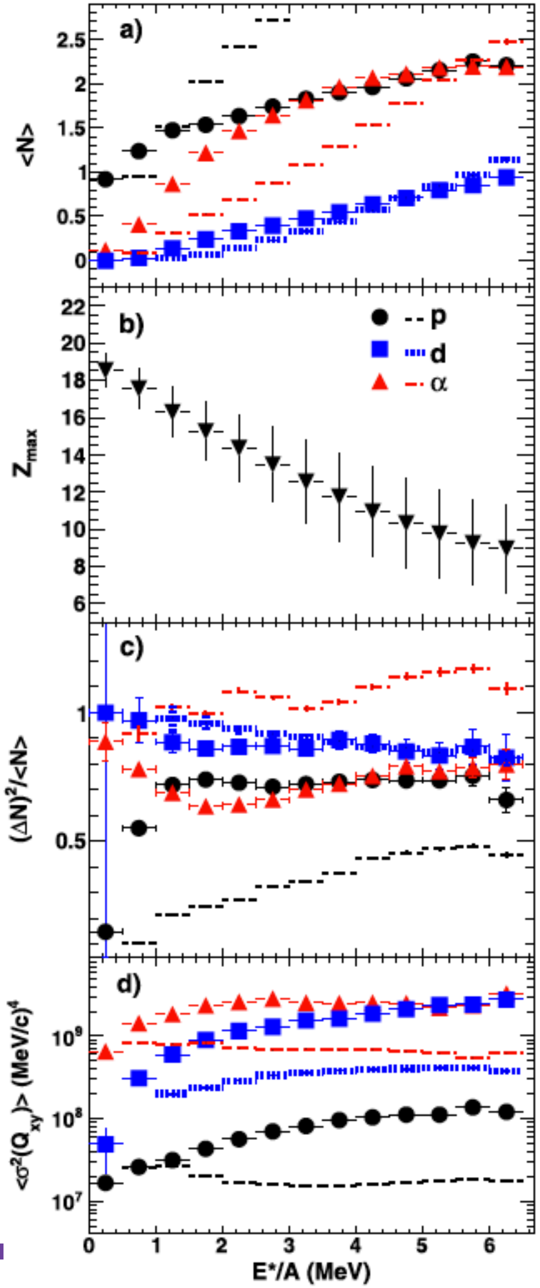
Alpha multiplicity distribution



Cluster formation : Alpha production is underestimated

Do and when bosonic properties dominate over the fermionic properties ?

Observables



multiplicity

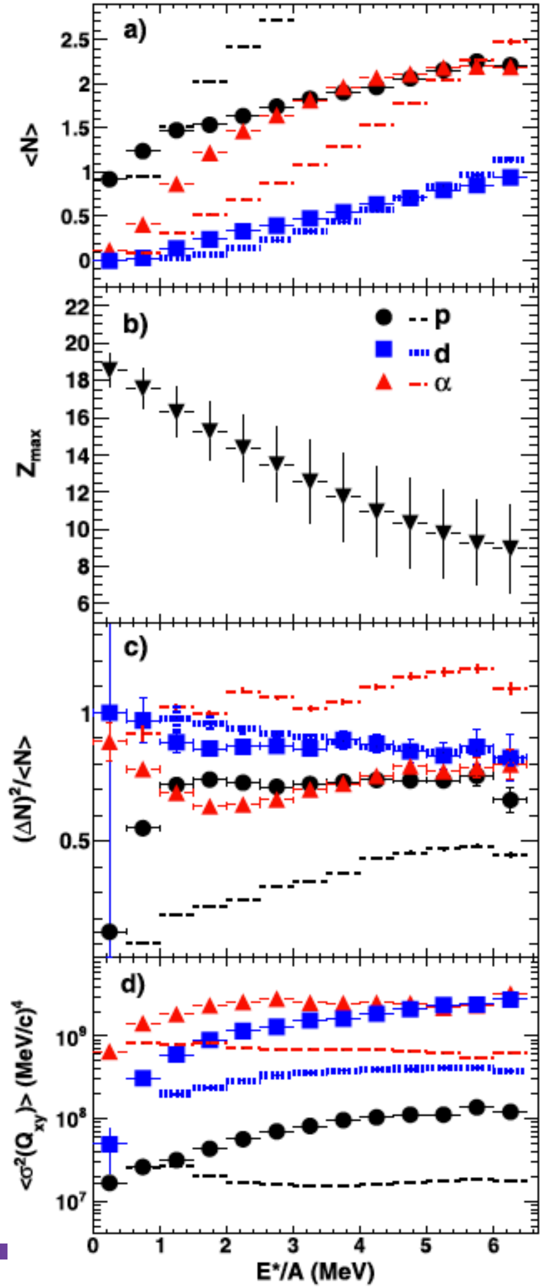
● p
■ d
▲ α

Zbig

Multiplicity fluctuation

Quadripole moment fluctuation

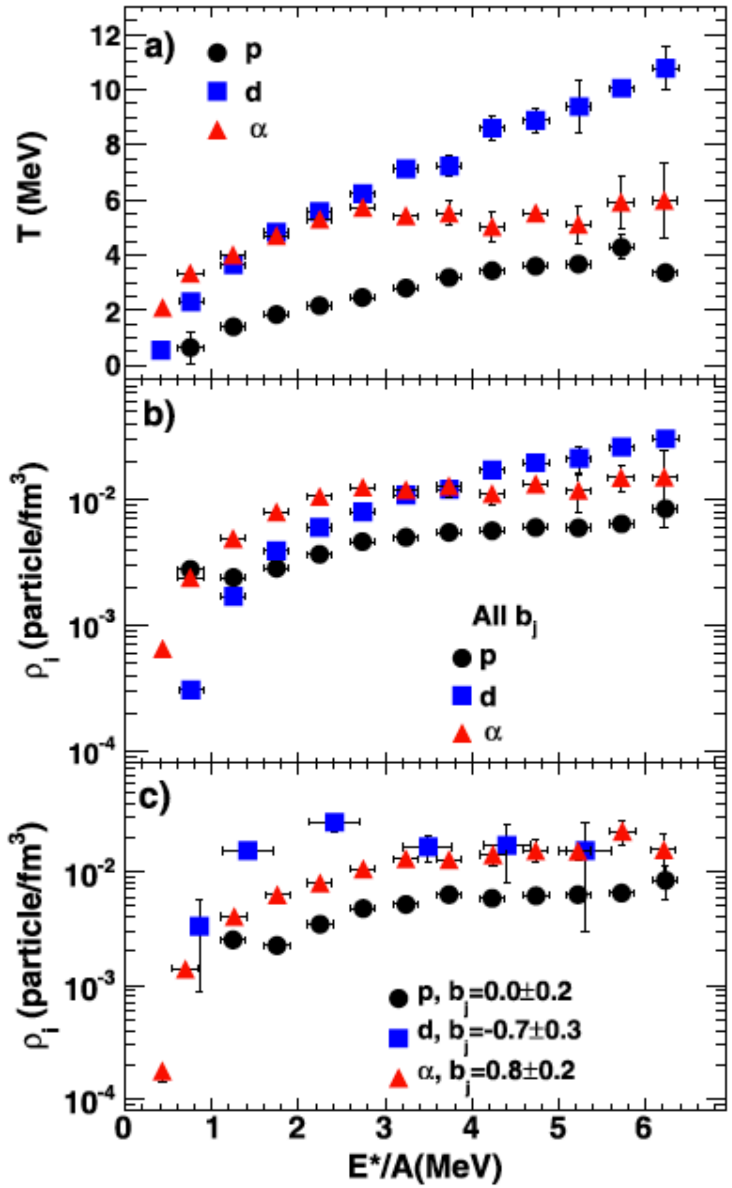
Observables



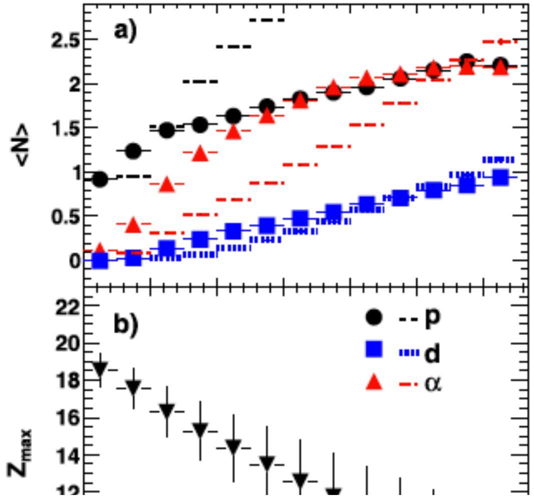
● p
■ d
▲ α

From Quantum-fluctuation analysis technique
Local densities of bosons and fermions
were extracted

$$\begin{cases} <N>_i = f_1\,(T_i, \rho_i, \mu_i) \\ (\Delta N_i\,)^2/<N>_i = f_2\,(T_i, \rho_i, \mu_i) \\ \sigma^2(Q_{xy})_i = f_3\,(T_i, \rho_i, \mu_i) \end{cases}$$

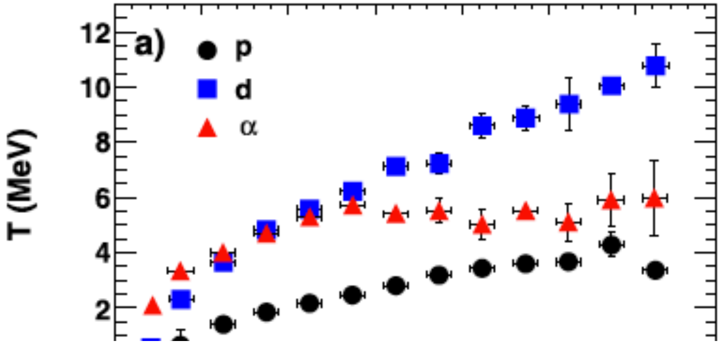


Observables



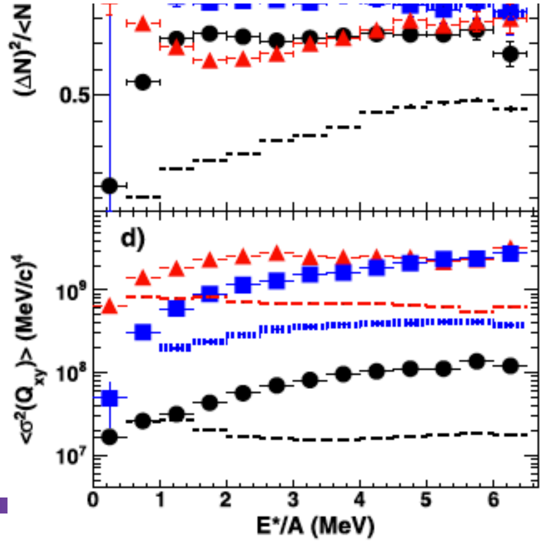
● p
■ d
▲ α

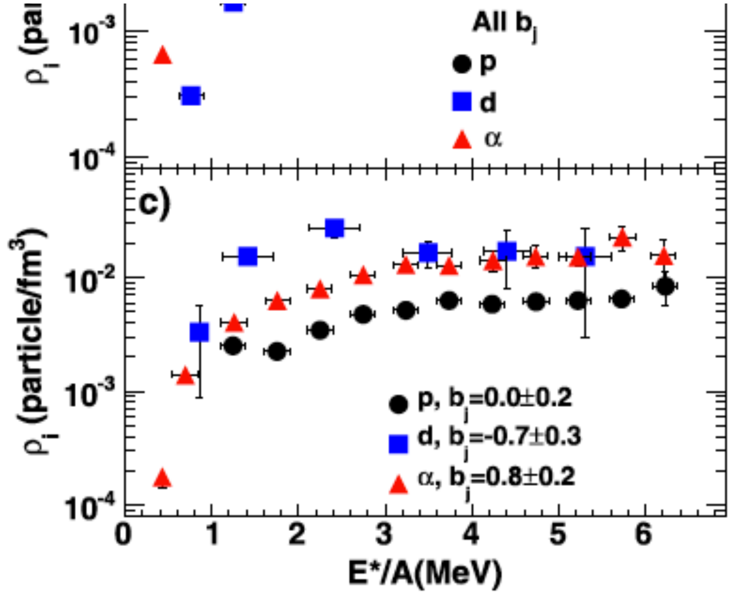
Quantum-fluctuation analysis technique
Local densities of bosons and



$\rho_{fermions} < \rho_{bosons}$ independently of the presence of fermions in the event

Possible BEC **persisting** in presence of fermions





Other signal of BEC

Energy per particle

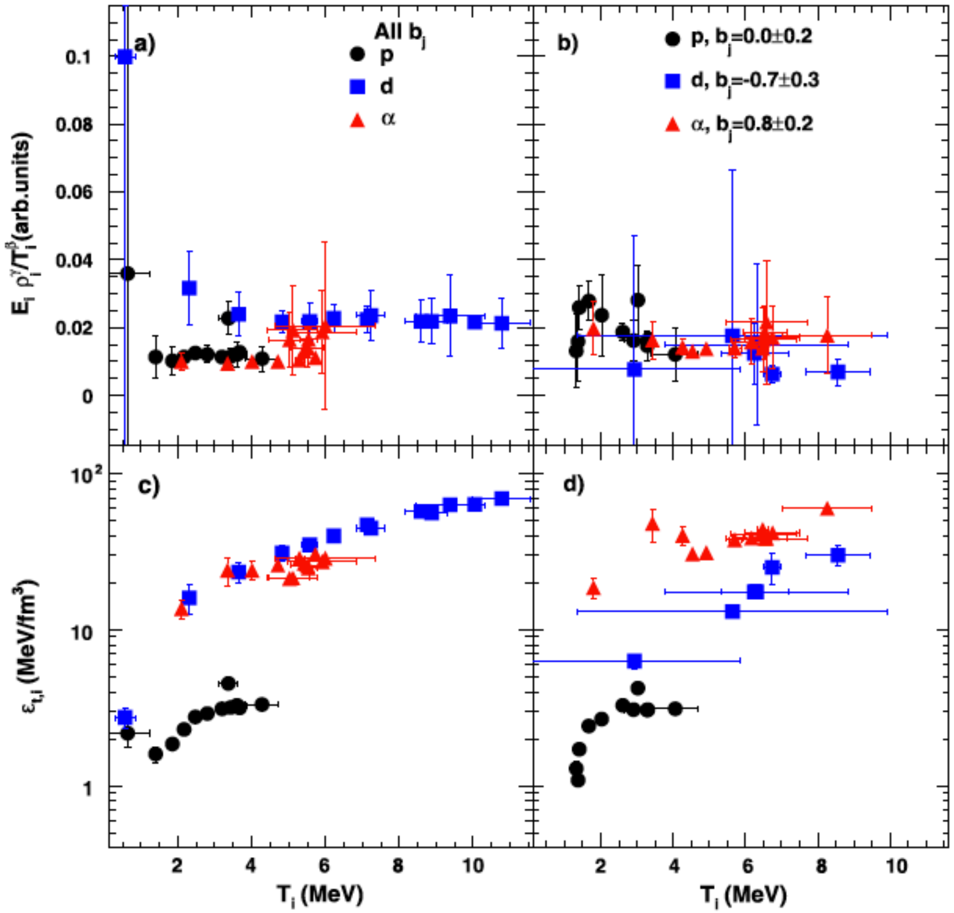
$E_i = A_i\, E^*/A_{QP}$

Ideal Fermi gas : $E_i \quad T_i^2/\rho_i^{2/3}$

Ideal Bose gas : $E_i \quad T_i^{5/2}/\rho_i$

Energy density

$\varepsilon_{t,i} = (E^*+m_i)/V$



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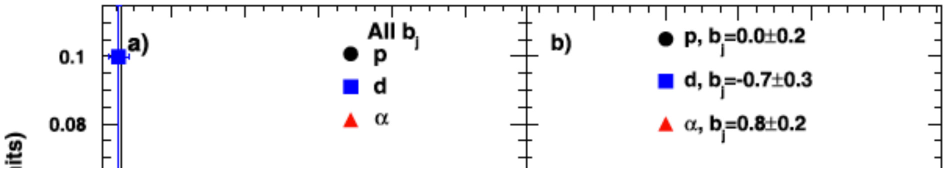
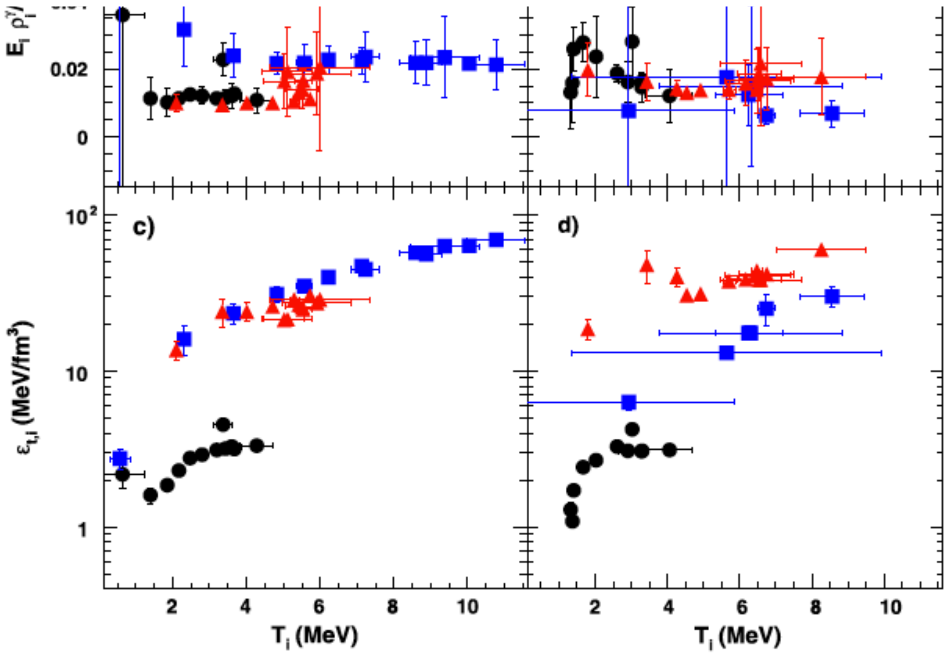


Different quantum behavior to the density profile



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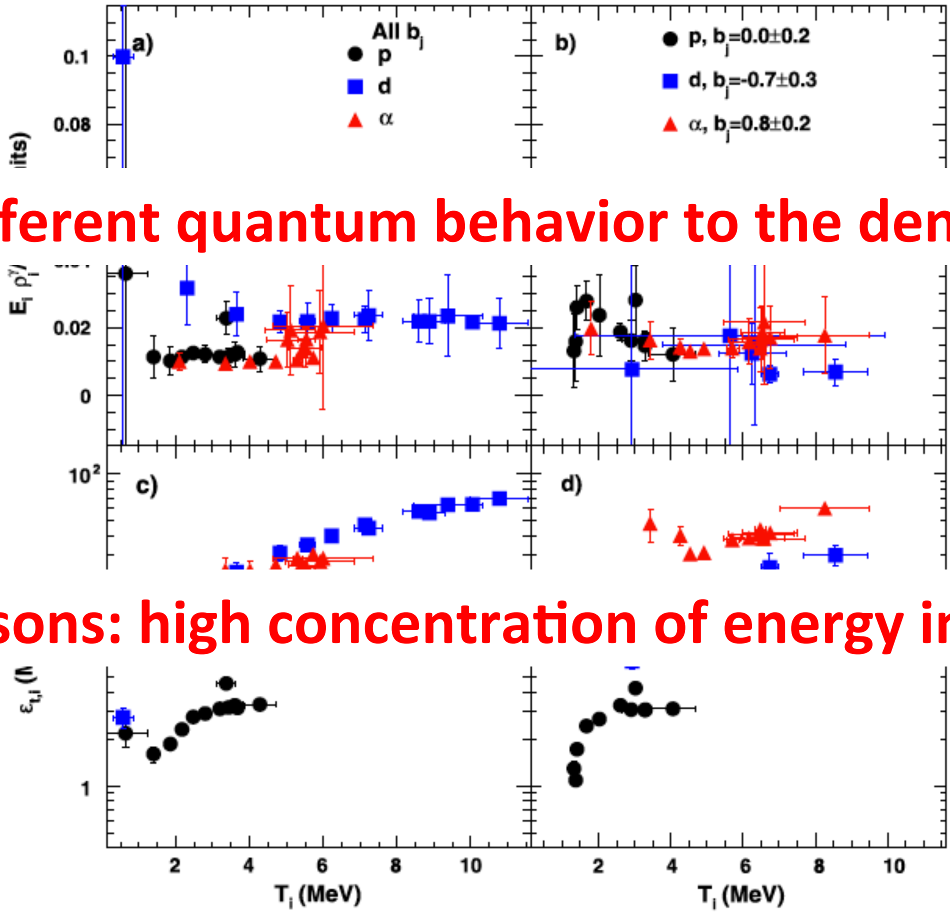


Different quantum behavior to the density profile

Energy **For bosons: high concentration of energy in small volume**

$\varepsilon_{t,i} = (E^*+m_i)/V$

Direct vs Sequential decay mechanisms of Hoyle state

PhD Thesis: Lucia Quattrocchi

Direct vs Sequential decay mechanisms of Hoyle state

PhD Thesis: Lucia Quattrocchi

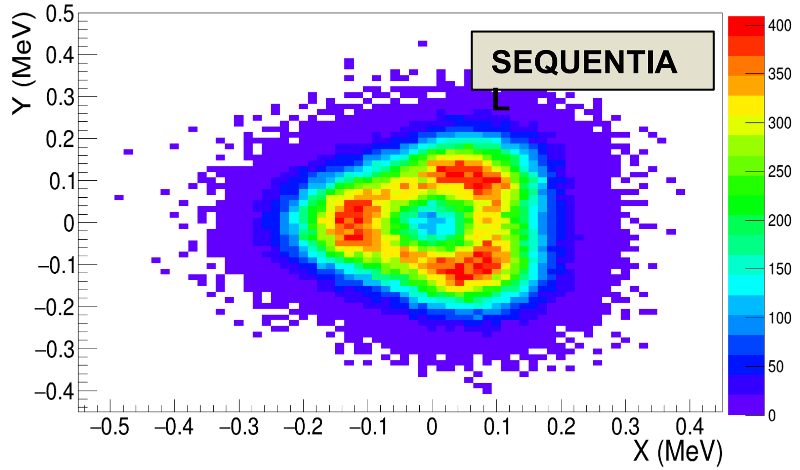
Dalitz parameter

$$x = \sqrt{3}(E_{1CM} - E_{2CM})/3$$

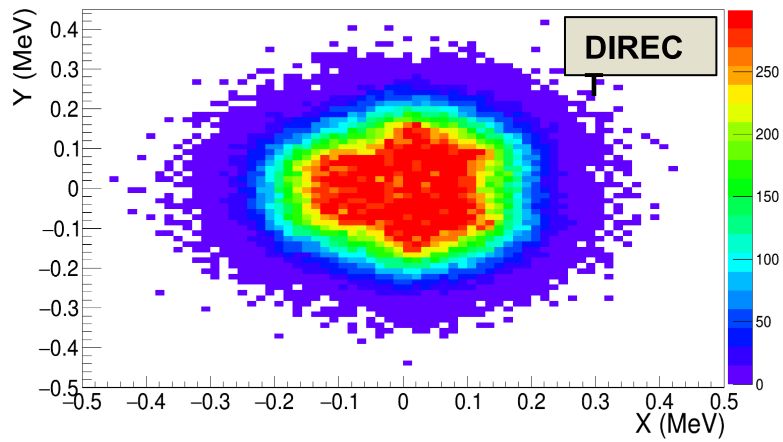
$$y = (2E_{3CM} - E_{1CM} - E_{2CM})/3$$

MONTECARLO SIMULATIONS

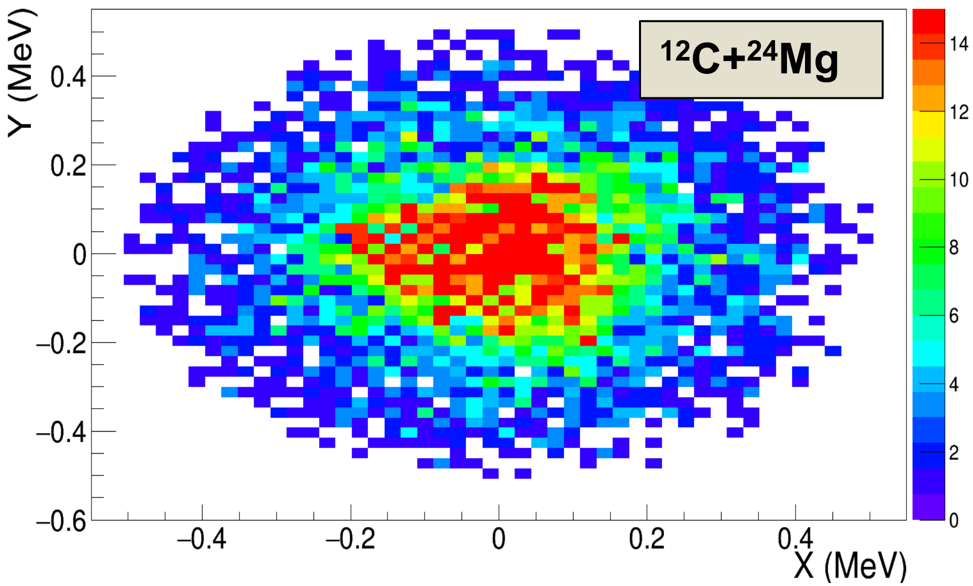
$^{12}C^*\rightarrow\alpha+{}^{8}Be\rightarrow3\alpha$



$^{12}C^*\rightarrow3\alpha$



EXPERIMENTAL DATA



The comparison between experimental and simulated data evidences the contribution of a direct mechanism component in decay of the Hoyle state!!

Direct vs Sequential decay mechanisms of ^{12}C resonances

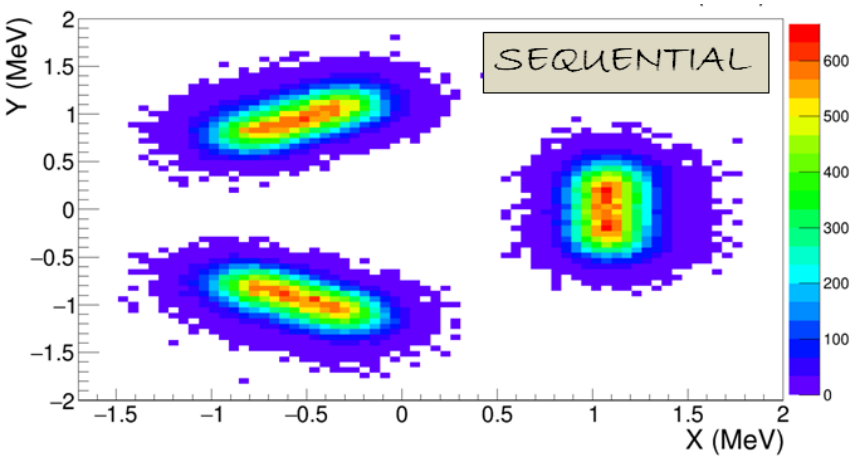
MONTECARLO SIMULATIONS

Dalitz parameter

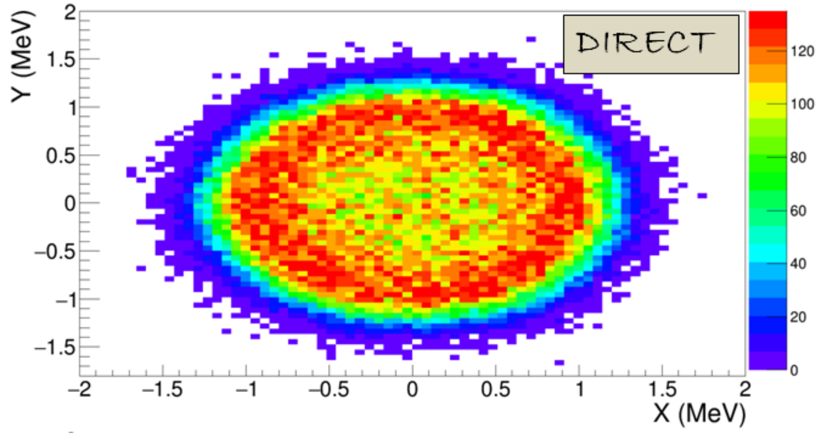
$$x = \sqrt{3}(E_{1CM} - E_{2CM})/3$$

$$y = (2E_{3CM} - E_{1CM} - E_{2CM})/3$$

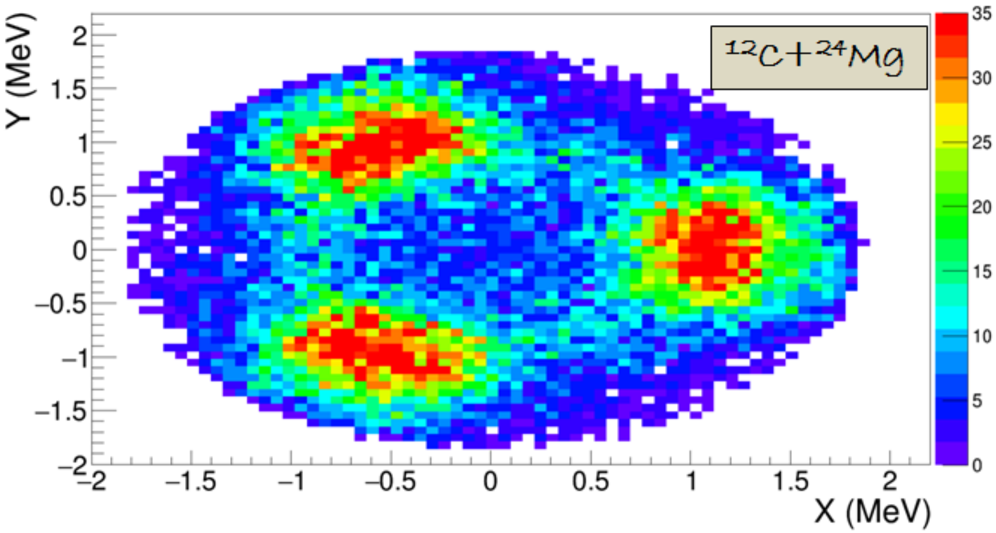
$^{12}C^*$(9.64 MeV)->α+^{8}Be->3α



$^{12}C^*$(9.64 MeV)->3α



EXPERIMENTAL DATA

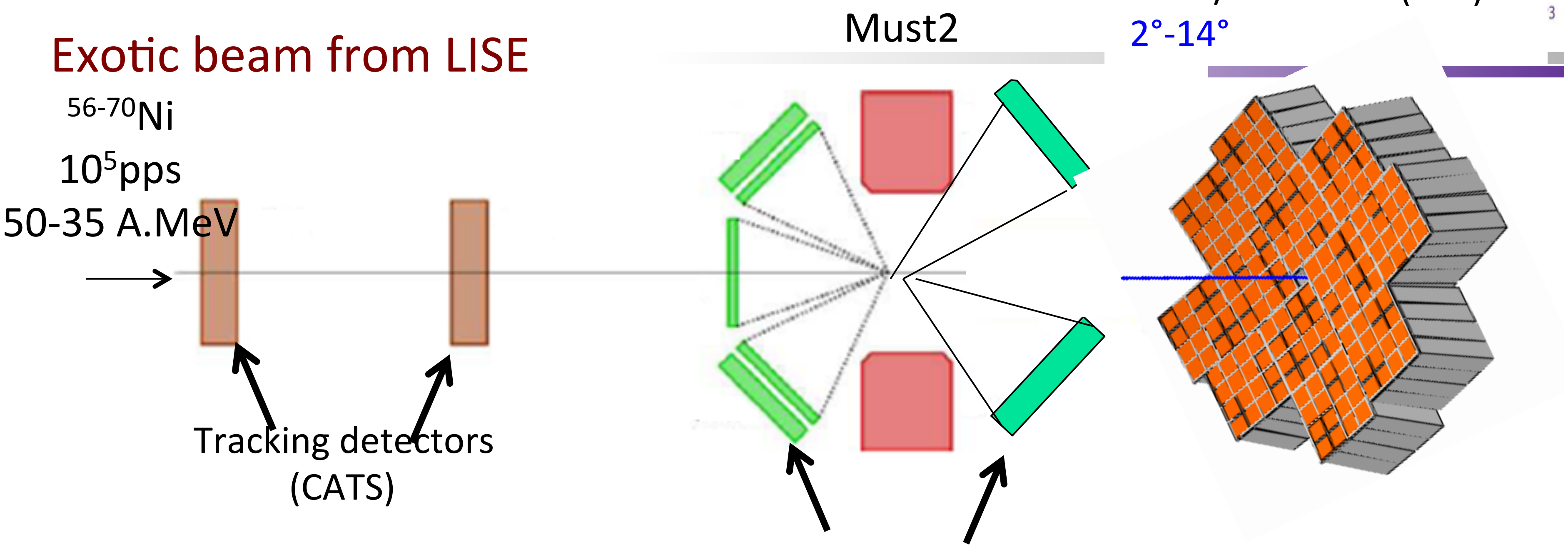


Dominence of sequential mechanism but direct one is not excluded

Dynamics and particle-particle correlation studies @ LISE

FAZIA/ 12 blocks (192)
2°-14°

Exotic beam from LISE



δ = (N-Z)/A = 0.2, for ^{70}Ni
δ = 0.0 for ^{56}Ni

Must2
14°- 58°
122°-166°

- Fazia 2°-14° : isotopic distributions of the PLF in coinc with LCP in Fazia and Must2 provide the primary isotopic distribution → E_{sym}.
- Must2 14°- 58° and 122°-166° (it covers the MR region (90° CM)) :
  - ✓ correlation function for space-time characterization of sources
  - ✓ estimation of the density around the projectile and MR
  - ✓ In-medium short-lived nuclei as well as out-of-medium

Perspectives

- Experimental program at LNS4 FAZIA blocks
  Two experiments accepted will be scheduled in 2016
- FAZIA-INDRA at GANIL : 2017, for experiments in 2018
- FAZIA-LISE 2018-2019

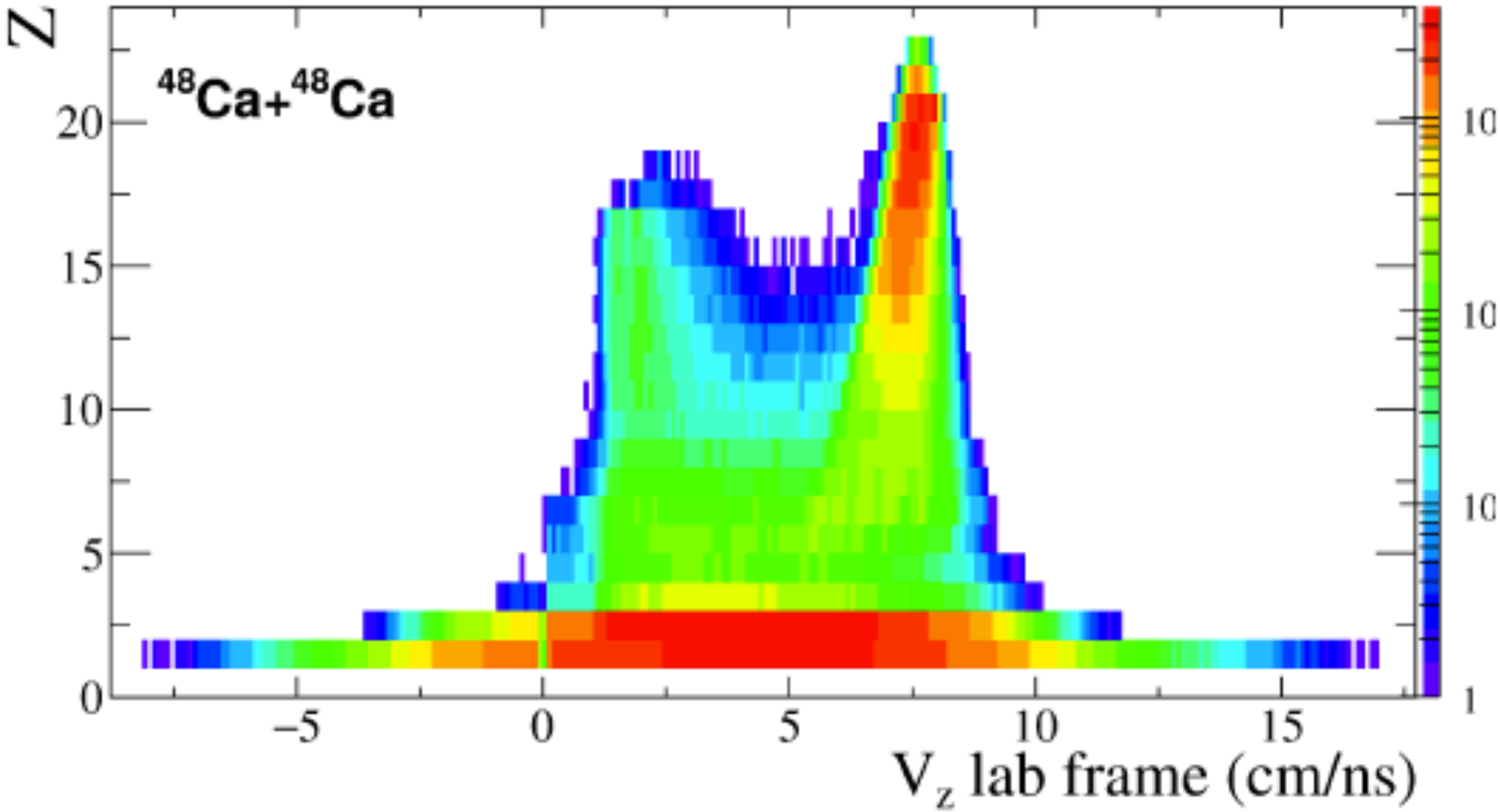
Collaboration France – Italy - Poland

CHIMERA-INDRA
INDRA-VAMOS
FAZIA
LNL GARFIELD

Organization of IWM-EC2016

Organized by CHIMERA-INDRA Collaborations

Every two years



Z
^{48}Ca+^{48}Ca
20
15
10
5
0
−5
0
5
10
15
V$_z$ lab frame (cm/ns)
1

Temperatures and mean partial densities

Method: quantum fluctuation analysis technique

H. Zheng et al., Nucl. Phys. A 892 (2012) 43; PLB 696 (2011) 178; PRC 86 (2012) 027602

Ingredients :

- Fermions follow the Fermi statistics and bosons the Bose statistics
- Coulomb repulsion is accounted for

$$\longrightarrow \begin{cases} \langle N \rangle_i = f_1\,(T_i, \rho_i, \mu_i) \\ (\Delta N_i)^2/\langle N \rangle_i = f_2\,(T_i, \rho_i, \mu_i) \\ \sigma^2(Q_{xy})_i = f_3\,(T_i, \rho_i, \mu_i) \end{cases} \Rightarrow$$

(T_i, ρ_i) for each particle species i from experimental data

T : temperature
ρ : mean partial density
μ : chemical potential