Isospin influence on the decay modes of systems produced in the $^{78,86}$Kr + $^{40,48}$Ca reactions at 10AMeV

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Outline

- The Physics Case

- The Experimental Method

- Experimental Results
  - IMF behavior
  - Global features

- Conclusions and Outlook
Heavy-ion induced reactions with stable and radioactive beams are ideal to explore the response of nuclei under different stress conditions.

Energy domain $E < 15 \text{ MeV/A}$ is dominated by fusion processes in competition with binary reactions.

Both these processes are influenced by many parameters:

- nuclear structure and $N/Z$ of the system
- angular momentum, dynamical effect $\rightarrow$ quasi-fission

Decay modes populate the whole mass/charge domain from evaporated light particles up to the symmetric fission fragments, with the IMF in between.

The decay mechanism are influenced by different parameters:
$E^*, J, N/Z, \text{nuclear structure}$
Formation of two composite systems that are different for 16 neutrons

<table>
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<th></th>
<th>$^{118}\text{Ba}$</th>
<th>$^{134}\text{Ba}$</th>
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</thead>
<tbody>
<tr>
<td>$E^*(\text{MeV})$</td>
<td>215</td>
<td>270</td>
</tr>
<tr>
<td>$V_B(\text{MeV})$</td>
<td>90</td>
<td>87</td>
</tr>
<tr>
<td>$(N/Z)_{\text{tot}}$</td>
<td>1.11</td>
<td>1.39</td>
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-> possibility to explore the dependence of the formation and decay mechanisms of the composite system on the isospin (N/Z)

S. Pirrone et al., EPJ 17 (2011) 16010; G. Politi et al., EPJ 21 (2012) 02003;
S. Pirrone et al., AIP Conf. Proc. 1524 (2013) 7;
G. Politi et al., JPS Conf. Proc. to be published 2015;

**ISODEC Experiment complements the experiment E457S (GANIL)**

-> study of the reactions $^{78,82}\text{Kr} + ^{40}\text{Ca}$ at 5.5 AMeV with the INDRA device same neutron-poor system -> influence of the energy of the entrance channel

G. Ademard et al., PRC 83 (2011) 054619
CHIMERA device at INFN-LNS in Catania – ITALY

4π device
1192 Telescopes
Si (300μm) - CsI(Tl)
Forward part 1°<θ<30°
688 modules
9 Rings 100cm<d<350 cm
Backward part 30°<θ<176°
504 modules
Sphere R=40 cm

Precise measurement of E, TOF, Velocity, θ, φ
Different identification methods: PSD Si, E-ToF, DE/E, PSD CsI

A. Pagano et al., NPA681 (2001) 331
Experimental method

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Different isotopic composition and relative richness of the Carbon for the two systems.

E. De Filippo, A. Pagano, EPJA681 (2014) 32
Experimental results

**IMF behavior**

Mass distributions of different $Z$ for the n-poor system $^{78}\text{Kr} + ^{40}\text{Ca}$ and for the n-rich system $^{86}\text{Kr} + ^{48}\text{Ca}$ at $\theta_{\text{lab}} = 21^\circ$
Charge Yields for IMF of the reactions $^{78,86}$Kr + $^{40,48}$Ca in the range $\theta_{\text{Lab}} = 10^\circ - 16^\circ$

The IMF yields exhibit an odd-even staggering, that is more pronounced for the n-poor system.

In agreement with: I. Lombardo et al., PRC 84 (2011) 024613
G. Casini et al., PRC 86 (2012) 011602
Preliminary comparison with DiNuclear System (DNS) code

S.A. Kalandarov et al., PRC 82 (2010) 044603

Simulation performed for the TOTAL cross section and normalized at \(Z=5\)

DNS seems to reproduce slightly better the n-poor system
Preliminary comparison with Gemini ++ code

Simulation performed for the TOTAL cross section and normalized at Z=14
Gemini++ seems to reproduce slightly better the n-poor system
Experimental results

IMF behavior

Average velocity for $Z = 3-17$ in the center of mass frame for different $Z$ and at different $\theta_{\text{lab}}$

Velocity seems to be independent of the emission angle for all the fragments

$->$ high degree of relaxation of kinetic energy

Signature of a binary process dominated by the Coulomb interaction between the considered fragment and its complementary partner
Average values of the experimental velocity (from $\Theta_{lab}=10.75^0$ to $\Theta_{lab}=15.25^0$) in the center of mass frame compared to the values obtained with the systematic of Viola, with the correction for the asymmetric fission  

D.J. Hinde, NPA472 (1987) 318
Experimental results

**FF behavior**

Angular distributions in the center of mass frame for fission fragments

1/$\sin \theta$ fit -> high degree of relaxation
Production via a long lived system
Similar results for the n-rich system
Angular distributions in the laboratory frame for groups of $Z$ (from $Z=41-42$ up to $Z=45-46$)

These angular distributions are very strongly forward peaked as it is expected for the evaporation residues.
Experimental results

*ER behavior*

Extracted centroids $V_{ER}$ for the evaporation residues vs laboratory angle compared to $V_{CN} \cdot \cos \theta_{lab}$

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**Graphs:**

- **Z=41-42**
- **Z=43-44**
- **Z=45-46**
Global features

$M_{\text{tot}} - P_{\text{tot}}$ plot for complete events selection:
- Multiplicity $\geq 2$
- $0.8 M_{\text{CN}} \leq M_{\text{tot}} \leq 1.1 M_{\text{CN}}$
- $0.6 \leq P_{\text{tot}} / P_{\text{beam}} \leq 1$

$^{78}\text{Kr} + ^{40}\text{Ca}$
Experimental results

*Global features*

Plot mass-\(v_{\parallel}\) of the reaction products with complete events selection

- Important information on the competition between the reaction mechanism
- Very preliminary analysis seems to show that there is a higher ER/FF ratio for n-poor system compared to the n-rich one

![Graphs showing mass-\(v_{\parallel}\) plots for different reactions.](image)
Experimental results

Global features

Preliminary comparison with the INDRA results of the reaction $^{78}\text{Kr} + ^{40}\text{Ca}$ at 5.5 AMeV

G. Ademard et al., PRC 83 (2011) 054619
Experimental results

Very Preliminary comparison with the production cross section of the IMF in the reaction $^{78}\text{Kr} + ^{40}\text{Ca}$ at two different energies

Global features

$^{78}\text{Kr} + ^{40}\text{Ca}$ 5.5 AMeV
G. Ademard et al., PRC 83 (2011) 054619

$^{78}\text{Kr} + ^{40}\text{Ca}$ 10 AMeV
Present work
The results of the analysis of the reactions $^{78,86}\text{Kr} + ^{40,48}\text{Ca}$ at 10 AMeV are presented:

The kinematical characteristics and the angular distributions of the fragments detected seem to indicate for both reactions a high degree of relaxation of the composed system.

The IMF cross section is more flat for the neutron–poor system at the higher energy.

The results put in evidence the influence of the neutron enrichment of the entrance channel on:

- Different isotopic composition and relative richness of the reaction products for the two systems.

- Odd–even effect, Staggering, in the IMF charge distributions

  -> stronger for the n-poor system.

- Sizeable differences for the different reaction channels:

  FF, QF and ER -> there is a higher ER/FF ratio for n-poor system compared to the n-rich one.
Data analysis are in progress:

Cross sections calculations for different mechanisms to confirm this first qualitative observation

Study of the Coincidence between LCP-FF, LCP-ER, LCP-IMF

More precise comparisons with theoretical predictions to provide indications on the isospin influence on the reaction mechanism and fragments production
For a comparison with the results obtained with the stable beams, a LOI was presented at the “Second SPES International Workshop at INFN-LNL” in May 2014 by using radioactive beams for studying the reactions:

\[ ^{92}\text{Kr} + ^{40,48}\text{Ca} \quad 10 \text{ AMev} \quad ^{132,140}\text{Ba}^* \quad \text{E}^* \sim 320 \text{ MeV} \]

These reactions lead to the formation of CN with N/Z = 1.5 greater than the ratio obtained with stable beams.

- study of the evolution, with isospin asymmetry, of the reaction dynamics and competition between different decay modes
- interplay between nuclear structure and reaction mechanism in the emission process
EXOCHIM – ISODEC collaboration

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