First advanced isospin studies with the FAZIA detector

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Scientific GOAL

Investigation of the isospin dynamics, focusing on the isospin diffusion:

1. In a binary channel
2. In the QP break up channel

Aiming at:

1. experimentally compare the reaction channels
2. extract information on the parameters of the nuclear Equation of State

**Binary Channel**

QP decays through the emission of IMF and/or LCP

**Break up channel**

QP splits in two fragments
FAZIA-SYM experiment

At the Laboratori Nazionali del Sud:

- $^{40}\text{Ca} + ^{40}\text{Ca}$
- $^{48}\text{Ca} + ^{40}\text{Ca}$
- $^{48}\text{Ca} + ^{48}\text{Ca}$

@ 35 MeV/u

Geometry:

- 4 blocks located around the beam axis and 80cm far from the target
- Covered polar angle in the laboratory frame:
  - $\Theta_{\text{min}} = 2^\circ$
  - $\Theta_{\text{max}} = 8^\circ$

GOAL:

Investigation of isospin diffusion in the $^{48}\text{Ca} + ^{40}\text{Ca}$, as a function of the reaction centrality, both in the binary and in the break up channel
We identify both in Z and A fragments up to projectile charge (Z=20), and even more..

... allowing to **isotopically resolve** the QP remnant in the binary channel

and **isotopically reconstruct** the QP in the break up channel
AMD: Antisymmetrized Molecular Dynamics

Montecarlo code: transport model.


Nuclear interaction: **Skyrme potential** with stiff \((L=108\text{MeV})\) and soft \((L=46\text{MeV})\) parametrization

Dynamic calculation stopped at 500 fm/c and the GEMINI++ as afterburner: statistical fission and evaporation of the fragments produced by AMD

AMD := AMD + GEMINI

48Ca+48Ca @ 35 MeV/u

AMD+GEMINI events are filtered via software:
- Geometrical acceptance
- Identification thresholds
- Detector energy resolution

AMD := AMD + GEMINI
Event Selection

Only Big Fragments isotopically identified are considered:

Vocabulary:
- LCP → $Z=1$ & $Z=2$
- IMF → $Z=3$ & $Z=4$
- Big Fragment → $Z \geq 5$

BF multiplicity = 1

BF multiplicity = 2

We define QP remnant a BF with:
- $12 \leq Z^{QP} \leq 22$
- $v_{par} > v_{cm}$

We define a reconstructed QP:
- $12 \leq Z^{rec} = Z^{H} + Z^{L} \leq 22$
- $v_{par}^{H} > v_{cm}^{H} \& v_{par}^{L} > v_{cm}^{L}$

QP Remnant channel ($QP_R$)

QP break up channel ($QP_B$)
The gross properties of the $QP_R$ channel are globally well described by AMD.
QP\textsubscript{B} characterization

..as well as the QP\textsubscript{B} characteristics, even if with less accuracy
Impact parameter estimation

By means of the AMD simulation we can extract information on the reduced impact parameter $b_{\text{red}}$:

A linear correlation between $v_{\text{red}}$ and $b_{\text{red}}$ is observed in the reduced velocity range of $0.4 - 1$.

\[ v_{\text{norm}} = \frac{v_{\text{QP}}}{v_{\text{cm}}} \]
We can look at the average neutron to proton ration $<N/Z>$ as a function of $v_{\text{red}}$ combining the information of the three systems:

- In the 4840 system, the QP$_R$ are neutron poorer than those in the 4848 system.

**ISOSPIN DIFFUSION**


- $<N/Z>$ decreases as the reaction centrality increases

- In the 4840 system, the more damped the collision, the more n-poor the QP remnants with respect to the n-rich system.
Equilibration in the $QP_R$ channel

By mean of the Imbalance ratio we can enhance the equilibration due to the isospin diffusion:

$$R(x) = \frac{2x^{4840} - x^{4848} - x^{4040}}{x^{4848} - x^{4040}} \quad x = \langle \frac{N}{Z} \rangle$$


The more damped the collision, the more equilibrated the isospin.
We can compare the QP break up channel with the QP remnant channel:

- Flatter distribution in the QP\textsubscript{B} channel as function of the centrality
- The hierarchy of the three systems is still preserved, pointing out the isospin diffusion in the QP\textsubscript{B} channel
Equilibration in the $QP_B$ channel

By mean of the Imbalance ratio we can enhance the equilibration due to the isospin diffusion:

The equilibration degree seems similar in both channels, compatible with a $QP$ break up after the separation between projectile and target.
The imbalance ratio is an observable sensitive to the stiffness of the EoS.

With the FAZIASYM setup, at 35 MeV/u, according to the AMD model, we cannot discriminate between the STIFF and the SOFT parametrization.
AMD STIFF predictions

By mean of the Imbalance ratio we can enhance the equilibration due to the isospin diffusion:

Both in $QP_R$ and $QP_B$ channel, the predicted isospin equilibration is too strong with respect to the experimental data.
We investigated the isospin diffusion in Ca reactions by means of 4 FAZIA blocks. In particular we compared the QP remnant with the reconstructed QP in the break up channel, both isotopically resolved.

We experimentally observed that:

- The QP remnant in the $^{48}$Ca+$^{40}$Ca reaction manifests the typical characteristic due to the presence of isospin diffusion.
- The more damped the collision the more equilibrated the isospin.
- In the break up channel, once we reconstruct the QP, the same degree of equilibration is observed.

Concerning the AMD model:

- It globally well reproduces the gross properties of the reactions but..
- It does not reproduce the experimentally observed <$N/Z$>, neither the absolute values, nor the equilibration as a function of the centrality.
- No discrimination between STIFF and SOFT parametrization at 35MeV/u of bombarding energy.
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Thank you for the attention

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Impact parameter estimation

Considering the LCP forward (i.e. statistically) emitted with respect the QP:

\[ f = N_1 \frac{E - B_1}{T_1} e^{\frac{E - B_1}{\tau_1}} + N_2 \frac{E - B_2}{T_2} e^{\frac{E - B_2}{\tau_2}} \]

The more damped the collision, the more excited the QP, thus confirming the scaling of \( v_{\text{red}} \) as a function of \( b_{\text{red}} \).