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Isospin transport phenomena in semiperipheral heavy ion collisions at Fermi energies

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Summary. — The FAZIA collaboration started its physics program in 2015 with a setup consisting of four complete blocks (ISOFAZIA experiment). Results concerning isospin transport phenomena and QP fission for the systems ^{80}Kr + ^{40,48}Ca at 35 MeV/nucleon are discussed. A comparison with the prediction of the AMD model is also presented.

1. – FAZIA and ISOFAZIA

FAZIA (Forward A and Z Identification Array) ([1] and references therein) is the fruit of an european collaboration, aimed at the construction of a modular detector with high resolution in terms of mass and charge identification and low thresholds. The commissioning of the first detection module (the so-called "block", consisting of 16 three-layer Si-Si (300μm and 500μm thick) - CsI (10 cm thick, read out by a photodiode) telescopes, with an active area of 20x20 mm^2) took place in 2014. In 2015 the first physics experiment (ISOFAZIA), whose results will be the subject of this work, was performed at LNS-INFN with a reduced version of the setup (only 4 blocks). In 2019 12 blocks of FAZIA will be coupled to the INDRA detector [2] at GANIL, Caen (F), to pursue the physics program of the collaboration, focused on items where the isotopic identification of fragments with medium-high Z is mandatory. The extremly good performances of FAZIA in terms of A identification (up to Z=25 with the standard Δ-E technique, e.g. Fig. 3 of [4], and up to Z=20 with the Pulse Shape Analysis (PSA) for ejectiles stopped in the first detection layer, see e.g Fig.5 of [3]) are due to the use of reverse mounted n-TD Silicon detectors with good doping uniformity ($< 3\%$), cut is such a way to avoid the channeling phenomenon, and the fact that each block is fully equipped with digital electronics. Moreover, particular attention was paid to the tuning of the signal processing algorithm employed for the PSA [3].

The four blocks used for the ISOFAZIA experiment [5] were symmetrically located with respect to the beam axis in a belt configuration, 80 cm far from the target and they covered the polar angles between 2.3° and 16.6°. A ^{80}Kr beam (N/Z=1.22) at 35 MeV/nucleon and two different targets, a n-rich ^{48}Ca (N/Z=1.40) and a n-poor ^{40}Ca (N/Z=1.00) were used .

2. – Results

The main goal of the experiment is the investigation of the isospin dynamics during the collision, also looking at the QuasiProjectile (QP) fission, in order to gain information on the symmetry energy term of the nuclear equation of state, thanks to the comparison of the experimental results with the prediction of transport models, such as AMD [6], coupled to GEMINI++ [7] as afterburner. AMD was run with an asystiff (L=108 MeV) and an asysoft (L=46 MeV) parametrization, as suggested in [8], and the dynamical calculation was stopped at 500 fm/c. Before comparing experimental and simulated events, a software replica of the setup was applied to the results of the simulation.

For such purposes peripheral Deep Inelastic (DIC) - type events have been selected by means of a cut on the flow angle ϑ^{cm}_{flow} ($8° \leq \vartheta^{cm}_{flow} \leq 30°$), built including all the

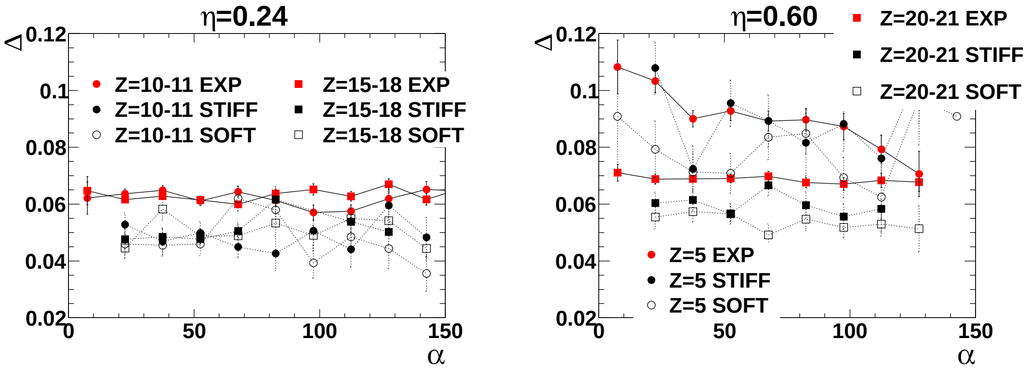

Fig. 1. – $\Delta =< \frac{N-Z}{A} >$ as a function of α for $\eta = 0.24$ (left) and $\eta = 0.60$ (right). Red symbols: experimental data for the reaction ^{80}Kr+^{48}Ca. Full (open) black symbols: simulation with asy-stiff (asy-soft) EOS. From [12]

detected ejectiles. The selection of the QP fission fragments has been obtained requiring that in events with two fragments, with individual charges greater than 5 and adding up to at least Z=18, their relative angle in the centre of mass between is $40° \leq \vartheta_{rel}^{cm} \leq 100°$ and their relative velocity is compatible with the fission systematics [9]. All the adopted selections have been checked by means of the simulation; more details are reported in [5].

An interesting result concerning the isospin equilibration of the QP fission fragments was found looking at the isospin asymmetry $\Delta =< \frac{N-Z}{A} >$ as a function of the α angle, defined as the angle between the QP splitting axis and the QP-QuasiTarget (QT) separation axis, as in [10, 11], for some selected fission pairs corresponding to different asymmetries $\eta = \frac{Z_{big}-Z_{small}}{Z_{big}+Z_{small}}$, as shown in figure 1, for experimental (red symbols) and simulated (black symbols) data.

For small mass asymmetry (left side of Fig. 1), where the α distribution is flat (see Fig.6, right side, of [12]) without a preferential direction for the light fragment emission (as shown also in [13,14]), a complete equilibration of the isospin between the two fission fragments is achieved, without dependence on α, compatible with long splitting times. On the contrary, for large mass asymmetries (right side of Fig. 1), a preferential aligned fission pattern emerges, with the small fragment emitted towards the QT (Fig.6, right side, of [12] and [13,14]), compatible with a faster fission process, not allowing the isospin equilibration between the two fission partners. As a consequence, as found in [10, 11], the small fragment has an higher Δ for small α (faster splitting, emission of the light fragment towards the QT, closer to the midvelocity region) and a smaller one for large α (slower splitting). This behaviour can be interpreted in terms of the isospin drift mechanism [15, 16], which predicts a neutron enrichment in the midvelocity region due to the density gradient between QP/QT and the neck zone. The simulation is able to reproduce in a reasonable way the observed trend, although with a systematic shift in the absolute values.

In Fig. 2 the experimental first and second moments of the isotopic distribution of the IMF detected in DIC events are compared to the simulated oneswith two different parametrizations of the symmetry energy. Full squares (L=108 MeV) better follow the experimental data than open squares (L=46 MeV). Similar weak indications come also

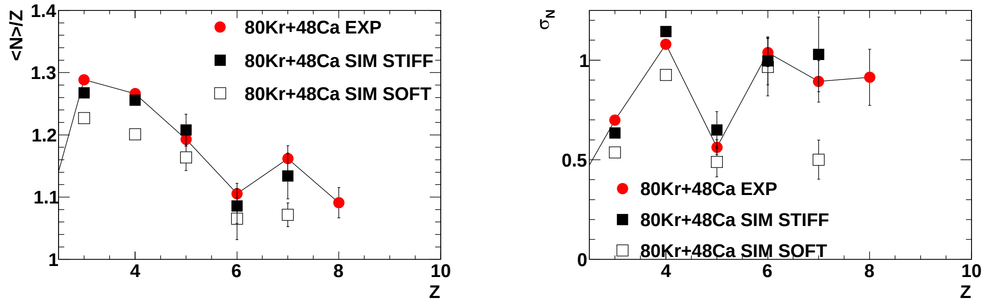

Fig. 2. – First (left) and second (right) moment of the IMF isotopic distribution vs. the IMF charge. Data refer to ^{80}Kr+^{48}Ca. Full circles: experimental data. Squares: simulation with asystiff (full) and asysoft (open) parametrization. From [12]

from the d/p ratio vs. v_z (where v_z is the particle centre of mass velocity component along the QP axis) and from $< N > /Z$ vs. v_z for Z=1,3,4. Concerning the isospin diffusion process [15-17], driven by the isospin gradient between target and projectile, exploiting the excellent isotopic resolution of FAZIA we observed a systematic isospin enrichment for the QP for the reaction on ^{48}Ca (Fig.3 of [12]), confirming other direct and indirect (i.e. based on the QP emitted particles) results [20, 21, 14, 22, 18, 19].

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