Dipolar degrees of freedom and Isospin equilibration processes in Heavy Ion collisions - I

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Abstract - The ⁴⁸Ca⁺²⁷Al, ²⁷Al⁺⁴⁸Ca, ²⁷Al⁺⁴⁶Ca at 40 MeV/nucleon were investigated with the CHIMERA multi-detector. We have determined the time derivative of the total dipole associated to the emitted charged particle using the measured charge and velocity of the multi-detector. This observable is linked in a peculiar way with Isospin equilibration processes.

INTRODUCTION

Global dynamical effects related to Isospin equilibration process can be determined by investigating on the average time derivative of the total dipole associated to the fragment production in a nucleus-nucleus collision.

It was also shown in that this quantity is independent on statistical decay processes which are expected to play a role in the final stage of the equilibration process [1,3]. The investigation on this observable therefore allows highlighting the role played by the density dependence of the symmetry energy in the early stage of the interaction. In this stage pre-equilibrium particles emission, IMF production, transfer of mass/charge between the main partners happens just when the largest changes of the density are expected with respect the saturation value.

EXPERIMENTAL PROCEDURE

To investigate on this observable the system ⁴⁸Ca⁺²⁷Al at 40 MeV/nucleon was studied with the multi-detector CHIMERA [4] at INFN-LNS Catania. Measurement on the auxiliary system ²⁷Al⁺⁴⁸Ca and the reference one ²⁷A⁺⁴⁶Ca were also performed in the same experiment :EQUILIBRATION.

The main goal of the measurement was to evaluate the following quantity: <DZ,c> = ∑ Z_i (V_{Z,c} - V_{Z}^{cm,d}) > , it represents (in unit of the elementary charge) the beam axis component of the partial dipole signal related to all the detected charged particles. In the above expression V_{Z}^{cm,d} is the effective the center of mass (c.m.) velocity associated to the motion of the detected charged particles. It substitutes the c.m. theoretical value appearing in the definition of the total signal <DZ> which includes the effect related to the emitted neutron. Even if <DZ,c> represents a partial dipolar signal it is practically insensitive to eventual systematic errors on the velocity determination. The average <,> is taken over ensemble of well reconstructed events ordered according to the charge of the biggest detected fragment Z_b, and to the estimated Total Kinetic Energy Loss TKEL . Only events with a total detected charge equal to 33 (equal to the total charge of the system) were considered.

The total detected mass was chosen in the interval 62< A_{tot} < 78. The total measured momentum along the beam axis was selected within 70% of the theoretical value.

By means of the measurements on the auxiliary system ²⁷Al⁺⁴⁶Ca and trough a dedicate analysis we have evaluated the effects on possible systematic errors on the indirect charge assignment related to the produced slow fragments in the main investigated system (light partner).

In particular, for TKEL<350 MeV, we have compared the charge distribution of TLF fragments as obtained in the main system with the one associated to the PLF in the auxiliary one (direct charge assignment trough ∆E-E technique). The two charge distributions are shown in the inset of Figure 1. The small difference between the two distribution could generate an average systematic errors ∆Z at most equal to 0.5 unit for charge fragments Z<10 . This produces a rather small error on the investigated quantity ∆<DZ,c> < 0.2 cm/nsec.

In Figure 1 we show for different Z_b values, the measured <DZ,c> values for the system ⁴⁸Ca⁺²⁷Al at 40 MeV/nucleon. The ridge in the plot highlights an increasing trend the signal from negative values to almost zero, for decreasing values of Z_b with respect to Z_{PLF}.
We note that in the initial configuration the system should exhibit a limiting value of $D_m$ (grazing collisions). Figure 1: Panel (a): For the system $^{48}\text{Ca}+^{27}\text{Al}$ at 40 MeV/nucleon, the measured values of $D_{Z,c}$ are plotted for different $Z_b$ associated with the selected events (charged multiplicity $m\geq 2$). The dot-dashed vertical lines indicate the reference limiting values $D_{m}$. Panels (b),(c),(d): $D_{Z,c}$ distributions obtained as projections of the above 2-D plot, for different $Z_b$ intervals. In the panel (b) the $D_{Z,c}$ distribution for $Z_b=20$ and for quasi-elastic events (TKEL < 70 MeV) are plotted with star symbols.

Figure 2 shows analogous plots for the reference isospin quasi-symmetric system $^{27}\text{Al}+^{40}\text{Ca}$ at 40 MeV/nucleon. In this case the limiting value of $D_m$ for “grazing” collisions, is about -2.6 cm/nsec and the data indeed shows values close to zero along with an enhancement near the $D_m$ value (Figure 2b).

The decreasing average values of $<D_{Z,c}>$ for $Z_b$ different from the projectile atomic number (i.e. less peripheral collisions), represent a clear signature of the evolution towards charge/mass equilibration. This behaviour is in fact related to the production, on average, of more charge/mass symmetric fragments.

The limiting values corresponding to the most peripheral selected collisions $D_m$ are shown in Figure 1 by dot-dashed vertical lines. Panels (b), (c) and (d) show the projections of the 2-D plot for different intervals of $Z_b$, where we can clearly see the trend. In particular, in panel (b) the spectrum with star symbols is obtained by imposing a cut of TKEL<70 MeV. The large fluctuations of $<D_{Z,c}>$ around the average value are mainly due to physical reasons (the particular “history” of each event) .

CONCLUSION

The time derivative of the total dipole associated to all the charged particles produced in the collision $^{48}\text{Ca}+^{27}\text{Al}$ at 40 MeV/nucleon (TKEL<350 MeV) has been determined at LNS by means of the multi-detector CHIMERA. The presented results confirm that this observable is able to highlight in a peculiar way the dynamics of the Isospin equilibration[1] processes during the first stage of the nucleus-nucleus collision. The connection between the obtained results and the density dependence of the effective Iso-vectorial interaction are presented in a following (part II) of this report.

REFERENCES