Mid-velocity LCP and IMF emissions

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Abstract: An experiment is proposed to study the mid-velocity emissions in semiperipheral collisions, by varying the size and the mass asymmetry of the colliding system.

The physics case. – In peripheral to mid-central collisions of heavy ions at *Fermi energies* (30–50 AMeV) an intense emission of light charged particles (LCP) and especially of intermediate mass fragments (IMF) at velocities intermediate between that of projectile- and target-like fragments (PLF and TLF) is observed [1, 2]. These emissions (socalled "neck-emissions") may be seen as a step in the evolution from the fast 3-body processes found at lower energies [3, 4] to the fragmentation of the "participant zone" at much higher energies; indeed, interpretations varying between these two extremes have been suggested in the recent literature. Presently, also the isospin composition of the mid-velocity emissions is highly debated, as it can be related to the composition of the emitting source (see [5] and references therein; [6, 7, 8]).

Concerning more specifically the mid-velocity IMFs, the question about the mechanism responsible for their emission (whether they arise from the surface instability of nonspherical transient shapes produced during the interaction or from proximity effects in the rapid statistical decay of PLF or TLF) remains still open. Since emission of mid-velocity IMFs is a characteristic feature of transport codes [9], their occurrence has been usually attributed to dynamical effects [2, 8], but recently also a statistical origin has been proposed [10].

The INDRA collaboration [2] had already shown that, for a given bombarding energy, the largest ratio (up to ≈3) of *mid-velocity* to *evaporative* IMFs is found in non-central collisions ($b/b_{max} \approx 0.6$). However, it was the Fiasco setup [11] which, thanks to its very low threshold for TLF detection, extended the study of such emissions to very peripheral collisions (up to $b/b_{max} \approx 0.85$), where the *mid-velocity* component becomes dominant (a factor 20-80 more intense than the *evaporative* component) and hence it can be more cleanly discriminated against the evaporation of statistical IMFs from the excited reaction partners [12, 13].

First results from the second campaign (2001) of Fiasco on the systems ^{93}Nb+^{93}Nb and ^{116}Sn+^{116}Sn at 17, 23, 30 and 38 AMeV show [13] that the IMF emission at mid-velocity:

- occurs preferentially in the reaction plane (defined by the beam- and separation-axis);
- produces sizable recoil effects in the final residues (secondary PLF and TLF);
- accounts for about one half of the kinetic energy dissipated from the initial relative motion;
- differs in "chemical" composition from the evaporation of the residues;
- has a yield correlated with that of the statistical evaporation from the residues.

These features speak against the existence of a relevant hot intermediate source, decoupled from the PLF and TLF, whose decay produces the "mid-velocity" emissions (picture *à la* "participant-spectator"); they rather suggest that the IMF emission occurs in a phase of still rather strong interaction with the PLF and TLF residues.

The proposal. – We intend to continue our investigation of the mid-velocity emission of LCPs and IMFs (a subject which has gained a renewed, strong interest in the recent literature) with the aim of shedding more light on their origin and production mechanism. In doing this, we would take advantage of the now completed Chimera multidetector, presently installed in Ciclope. We envisage two aspects which we would like to study.

First we would like to vary the size of the system, to possibly discriminate between bulk effects and surface (or shape) effects. If the mid-velocity emission is alike the low-energy "fast oriented fission", it should be sensitive to the deformability of the nuclei: in heavier nuclei the difference between ground-state and saddle-point shapes is smaller and hence the probability of readsorbing the deformation caused by the neck rupture is lower.

Symmetric systems allow to perform useful checks of consistency between the distributions measured in the projectile and target phase-space regions (in these two regions the response of any detector is likely to be different due to different granularity, thresholds and resolutions); therefore we propose to measure two symmetric systems at Fermi energies, with total masses appreciably lighter and heavier than those (A_{tot}= 186, 232) measured with Fiasco.

At LNS, the only developed beam heavier than Sn is Au, at the rather low (for our purposes) bombarding energy of 23 AMeV. From discussions with the cyclotron staff, we found that they are very interested in a ^{165}Ho beam, which seems easy to produce in the source and to accelerate in the CS (it is mono-isotopic). Thus we ask to develop such a beam: our heavier system would then be Ho+Ho at the maximum energy (which is expected to be around 30 AMeV). For the lighter system, the best choice seems to be Ni+Ni, at the same energy. Moreover, to match the event selection criteria and the analysis methods of the Fiasco experiment with those of Chimera, we need to measure also one of the systems already measured with Fiasco: for example the Nb+Nb (or Sn+Sn) collision at 30 or 38 AMeV.

The second question we would like to investigate is which is the reference system appropriate to "mid-velocity" LCPs and IMFs: whether it is the nucleon-nucleon or the projectile-target center-of-mass system. For this purpose symmetric systems are useless, one needs (very) asymmetric entrance channels, which could be realized with the same beams, by exchanging the targets: Ho+Ni and Ni+Ho. Direct and the reverse kinematics are needed because the IMFs emitted backwards with respect to the CM system are very hard to identify both in mass and charge. For example, IMFs with Z=6 (10) cross the 300 μm thick Silicon detector and reach the CsI crystal only if they have a lab-energy larger than $\approx$11 (15) AMeV (to be compared to the energy of $\approx$15 AMeV of an IMF emitted at rest in the CM-system in the Ni+Ho reaction at 30 AMeV).

We ask for the Ni beam also at the highest available energy of 45 AMeV (relative velocity of the collision 93 mm/ns). In fact the mid-velocity emission usually has an appreciable overlap with the evaporation from PLF and TLF. For example, at 30 AMeV the relative velocity of the PLF and TLF sources is $\approx$76 mm/ns for quasi-elastic collisions and decreases with decreasing impact parameter. The evaporation of Z$\geq$2 particles from these sources occurs with velocities of $\approx$20 mm/ns, and with decreasing impact parameter their exponential tails may extend with appreciable yield up to values as high as 40 mm/ns. The subtraction of the evaporative background is an essential ingredient (and it represents a major sources of uncertainty too): the higher bombarding energy would allow to push further apart the velocity regions of PLF- and TLF- evaporation, thus opening a wider gap of nearly background-free space for the mid-velocity emission.

For all these systems, an interesting comparison will be possible not only with the data of Fiasco, but also with the systems in inverse kinematics studied by the Reverse experiment [14].

We wish also to investigate if the theoretical approach recently proposed to explain the spectra of IMF in light ion induced reactions [15] may be extended to the case of peripheral interactions of heavier projectiles. This approach assumes that the coalescence of nucleons excited in the primary two-nucleon collisions significantly contributes to the emission of IMF.

The setup. – With respect to Fiasco, Chimera has big advantages (and some disadvantage).

The advantages are those connected with the $\approx 4\pi$ coverage, which gives an almost complete reconstruction of the event topology, allows a (charged) multiplicity selection of the events and makes it possible to perform different kinds of global analyses on a single event.

Moreover, the isotopic identification of LCPs and IMFs will give precious information on the controversial isospin composition of the mid-velocity emissions and hence of their source.

The disadvantages are mainly concentrated in the quasi-elastic region typical of the most peripheral collisions (corresponding to about the first 200–300 MeV of kinetic energy dissipation), where the de-excitation of the primary reaction partners proceeds mainly via neutron evaporation (with little emission of charged particles) and the somewhat coarse position resolution (just the detector granularity) hinders a clean kinematic reconstruction and classification of the events.

As we are interested in the outer range of impact parameters (from semi-central to peripheral), it is for us of primary importance to have a good detection not only of the projectile-, but also of the target-remnants, at least for what concerns energy and time measurements. This in fact allows a better classification of the events in the low (charged) multiplicity region and allows a meaningful comparison with the wealth of data previously obtained with Fiasco.

Thus in the test run performed in March 2003 with Sn+Sn at 35 AMeV, we checked different trigger conditions, detector thresholds and target orientations. The test run has shown the feasibility of an experiment with a minimum-bias trigger of M $\geq$ 2, low thresholds for the detectors located near $\theta_{\rm lab}$=90° and target tilted by about 45°; these conditions seem to give access, at least partly, to the quasi-elastic region, although a quantitative estimate is difficult without the final calibrations of the campaign, which are in progress.

Beam requests. – As usual for the Chimera multidetector, we need beams with good time structure (around 1 ns or better). This limits the current intensities which can be delivered by the cyclotron to $\leq$0.1 pnA, similar to the values used with Fiasco. So the time needed to obtain reasonable statistics necessary to build threefold or fourfold differential distributions are expected to be roughly the same. The 4π coverage of Chimera (compared to the 70% coverage of the forward hemisphere for PLFs and TLFs in Fiasco) will thus give not appreciably higher statistics of events, but rather more complete information on the single event. Thus basing on our previous experience with Fiasco, we estimate that about 1.5–2 days are necessary per beam-target combination at a given energy. Our requests are therefore:

Ho	+Ni, Ho	at ≈30* AMeV:	12 BTU	(*) or maximum obtainable energy
Ni	+Ni, Ho	at ≈30** AMeV:	12 BTU	(**) same as above
Ni	+Ni, Ho	at 45 AMeV:	12 BTU	
Nb+Nb	or Sn+Sn	at 30 or 38 AMeV:	6 BTU	(for comparison with Fiasco)

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