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Lights and (some) shadows in the comparison among experimental data of heavy ion collisions at Fermi energies and the dynamical model AMD

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Abstract. The simulation of heavy ion collisions in the Fermi energy region is a challenge for the theoretical models; in particular it is difficult to obtain a coherent description in all the impact parameter range and to reproduce all the experimental observables. In this contribution we will show the very good job done by the dynamical model AMD [1] followed by the statistical code GEMINI [2, 3] as an afterburner. The model is able to reproduce the main characteristics of peripheral and semiperipheral collisions, although some discrepancies still persist.

1 Introduction

Heavy ion collisions in the Fermi energy domain present a very rich phenomenology, ranging from binary collisions and midvelocity emission in peripheral collisions up to multifragmentation in central reactions. As a consequence they are a challenge for the theoretical description.

Satisfactory results have been obtained by means of transport models, which can be grouped in two main classes: BUU-like models and Quantum Molecular Dynamics (QMD) models.

AMD (Antisymmetrized Molecular Dynamics [1]) is a QMD model which proved its reliability in the description of central reactions [4, 5]. It is therefore interesting to compare its predictions with experimental results concerning peripheral collisions, as done in [6] for the systems ^{93}Nb+^{93,116}Sn at 38 MeV/nucleon on data collected with the FIASCO setup [7].

FIASCO was equipped with 24 position sensitive Parallel Plate Avalanche Counters, able to measure the velocity vector of heavy ($Z \geq 10$) fragments with very low identification thresholds (0.1 MeV/nucleon), covering the 70% of the forward hemisphere; as a consequence, the setup was particularly well suited for the investigation of peripheral and semiperipheral collisions. 96 ΔE-E silicon telescopes allowed to measure also the charge of the QuasiProjectile QP below 6° and 186 three layer phoswich telescopes, identifying and measuring the time of flight of Light Charged Particles LCP and Intermediate Mass Fragments IMF (up to Z=26), with a coverage corresponding to 30% of the forward hemisphere, completed the setup.

Details on the used version of the AMD model can be found in [6]. Here we only recall that the main free parameter of the model is the in-medium nucleon-nucleon cross section $\sigma = y\rho^{\frac{2}{3}} tanh\left(\frac{\sigma_{free}}{y\rho^{-2/3}}\right)$, ruled by the y parameter, whose standard value is $y = 0.85$. In our analysis also $y = 0.42$ was tested.

Primary AMD data have been de-excited with GEMINI as an afterburner, in both the C++ version [2] and the Fortran90 one [3]. The switching time between the dynamical and the statistical phase has been tested between 200 fm/c and 10000 fm/c.

Experimental QuasiProjectile properties and emitted particle multiplicities for binary events have been compared with the simulation results as a function of the centrality. Before comparison, simulated data have been filtered with a software replica of the setup.

The collision centrality has been estimated as $C_b = \frac{1}{2}Mv_{QP}^{cm}v_{QT}^{cm}$, where $v_{QP(QT)}$ is the center of mass secondary velocity of the QP (QuasiTarget QT); in the experimental case such velocity corresponds to the measured one, for the simulation it is the velocity after the application of the afterburner and of the geometrical filter (except for the 4π simulation). M is the total mass of the system. C_b is well correlated to the impact parameter, as shown in Fig. 2 of [6], at least in the range 5 fm - grazing impact parameter. Below 5 fm C_b loses its reliability as impact parameter estimator because of the increasing weight of ternary events, coming from QP/QT fissions.

2 Results

As shown in Fig. 5 of [6], the simulation is able to well reproduce the behaviour of the center of mass polar angle of the QP as a function of the centrality (Wilczynski

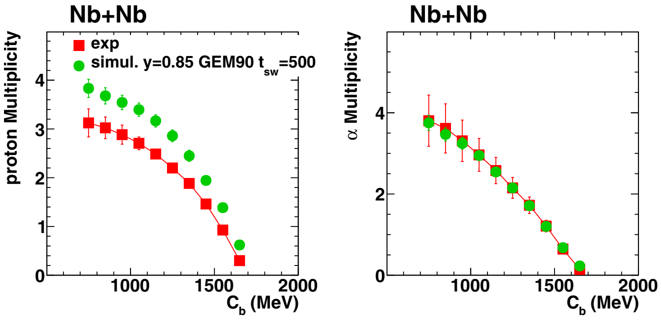

Figure 1. Experimental and simulated (best result: switching time 500 fm/c, GEMINI Fortran90 as afterburner, screening parameter y = 0.85) multiplicity for protons (left) and α particles (right) as a function of the centrality (estimated starting from the velocities of QP and QT, as explained in the text) in binary reactions.

plot) both in terms of average values and of standard deviation of the distribution. All the tested configurations (afterburner, switching time, y parameter) are summarized in table II of [6] with a quality factor indicating the degree of agreement between experimental data and simulation (0 means perfect reproduction of the experimental data). All the tested configurations of the parameters give a satisfactory reproduction of the experimental data.

Also the charge of the QP is well reproduced by the simulation, as shown in Fig. 6 of [6], at least in terms of average value; for the standard deviation, on the contrary, there are some systematic differences. The use of GEMINI Fortran90 clearly improves the quality of the agreement; concerning the switching time, no significant improvement is obtained for times longer than 500 fm/c, while it seems important to prolong the calculation beyond 200 fm/c, as summarized in table III of [6].

The total emitted charge, shown in Fig. 9 of [6], is well reproduced, almost independently of the in-medium cross section, of the afterburner and of the AMD switching time, with the possible exception of 200 fm/c, thus meaning that for such time dynamical effects are still important (and they cannot be mimicked by an afterburner). On the contrary, the chemistry of the emitted particles is strongly dependent on the switching time and the afterburner and -to a minor extent- on the in-medium cross section. For all the particles (Fig 7 of [6], panels b) c) d) e)) except for the protons (Fig 7 of [6] panel a)) the multiplicities are quite well reproduced for a switching time of 500 fm/c and GEMINI f90 as afterburner, while worse results are obtained when GEMINI++ is used. In case of protons simulated data always overestimate the experimental values, although the use of GEMINI f90 strongly reduces the discrepancy. In Fig. 1 the results concerning proton and α particle multiplicities for the best simulation (i.e. switching time 500fm/c, y=0.85, GEMINI f90 as afterburner) are shown. While α multiplicities are very well reproduced, in case of protons, mainly for the most dissipative reactions, the discrepancy between the simulation and experimental data is of the order of 25%. The switching time seems to be the most critical parameter for the particle multiplicities mainly for protons. In fact, as shown in Fig. 8 of [6], while for the other particles the multiplicities directly produced by AMD (i.e. the primary ones) tend to saturate for times longer than 2500 fm/c, in case of protons the primary multiplicity goes on increasing and at 10000 fm/c it reaches the experimental value. Since the excitation energy of QP and QT is still different from 0 at such extreme switching time, it is obvious that the application of whatever afterburner produces a significant overestimation of the final proton multiplicity. Moreover, the behaviour of the two versions of the afterburner is different: while for GEMINI++ the final particle multiplicies seem little depending on the switching time, this is not true for GEMINI Fortran90 concerning protons and deuterons. This different behaviour can be interpreted in the hypothesis that the emission of simple particles from AMD is somehow compatible with that from GEMINI++, while it is different from that of GEMINI f90.

3 Conclusions

The AMD model coupled to GEMINI as an afterburner proved to be able to reproduce the main properties of the QP and of the emitted particles in binary peripheral and semiperipheral events. In particular, the average center of mass polar angle of the QP and its charge as a function of the reaction centrality are well reproduced by the simulation, almost independently of the switching time, of the in-medium cross section and of the version of the afterburner. On the contrary, for light particles better results are obtained if the dynamical code is stopped at 500 fm/c and GEMINI f90 is used as an afterburner. The obtained results are very promising, since they suggest that AMD followed by GEMINI can be used as a predictive tool in the study of heavy ion collisions in the Fermi energy regime.

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