Elementary reference for the analysis of high energy nuclear collisions

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In this contribution we shall discuss some aspects of the role of elementary reference data for the interpretation of the results from nuclear collisions and show in particular that neutron-proton interactions play a significant role. Furthermore we point out that a complete set of elementary data is desirable, because most theoretical concepts for the interpretation of nuclear collisions rely on such data as input for their calculations.

1. INTRODUCTION

Experiments with relativistic heavy ions are interesting and important, if new aspects of the physics of strong interactions are discovered which are different from those observed in elementary nucleon-nucleon, lepton-nucleon, or lepton-lepton interactions. There are several levels of such differences. Trivial are those which are due to the occurrence of other elementary interactions like those of mesons with nucleons or those which involve hadronic resonances, as well as multi-body interactions. More appealing are phenomena which can be characterized by or attributed to new degrees of freedom and bulk properties of the reaction zone. In fact new phenomena and in particular bulk properties in high energy nuclear collisions have been identified in the past, which are the basis of nowadays physics of high energy nuclear collisions. There are different approaches to establish new phenomena and bulk properties. The first relies on a model independent comparison of nuclear data with a standard which is believed to be given by elementary interactions. It requires well defined observables with weak dependences on the initial conditions of the reaction system like the number of interacting nucleons and their centre-of-mass (c.m.) energy. The reason for such conditions is that the variation of c.m. energy and of the number of participant nucleons is

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significant in nuclear collisions, whereas it is normally absent in elementary interactions. The commonly used standard is *pp* interaction data. This choice assumes that isospin effects are negligible or calculable. An alternative method to identify new phenomena and bulk properties in nuclear collisions, models the cascade-like sequence of collisions with and without invoking collective effects (e.g. mean potentials). Input to such models is differential cross sections of all relevant elementary processes in a broad range of c.m. energies for a given (heavy ion) beam energy. Both approaches need elementary cross sections as reference or input data. In case such data are not available interpolations and extrapolations as well as conservation laws are used to calculate the missing quantities. The direct method to identify bulk properties, by proving the validity of hydrodynamical concepts, is not considered here.

In this contribution we comment on the invariant mass distribution of electron-positron pairs in $p(n)p$ interactions at 1.25 GeV and compare new experimental results on inclusive proton and neutron distributions from *pp* interactions at 158 GeV/c with calculations from microscopic transport models. Finally we take a look at experiments with neutron beams and comment on the prospects of such experiments at the new NICA facility.

2. EXAMPLES FOR THE USE OF REFERENCE DATA

Isospin effects may affect lepton pair production in nucleon-nucleon interactions as is demonstrated Fig. 1. Preliminary HADES data from *pp* and *np* interactions at beam energy of 1.25 GeV reveal different shapes of the invariant mass distributions of electron-positron pairs [1]. This finding allowed to solve the so called "DLS puzzle" [2]. One possible interpretation of the difference, which is most pronounced at large masses, is an enhanced Bremsstrahlung from the *np* encounters.

There are two major classes of models which describe the result of a relativistic nucleus-nucleus collision. Statistical models consider only the final state and describe it with thermodynamical quantities like temperature and chemical potentials. They refer to data from elementary interactions only in case two contributions to the particle abundances in the final state are considered: from the core and from the corona [3]. The former stands for the hot and dense central part of the reaction system, whereas the latter represents reaction products stemming from elementary collisions. The corona contribution is minimal in central collisions and increases with increasing impact parameter.

Elementary interactions are an important ingredient for microscopic transport models of nuclear collisions. These models start from an initial state as given by the energy, the geometrical configuration, and the nucleon content of the incident nuclei. The first generation of nucleon-nucleon interactions constitutes the beginning of the nuclear collision process. A multitude of different schemes are employed to describe the further evolution of the collision, among them are second generation elementary interactions, reinteractions and multibody interactions. Cross section data are needed for all these processes. It is obvious that such data should be based on experimental data as much as possible. It is unavoidable, however, to establish strategies for the determination of unmeasured cross sections and their variation with energy. The advent of new data can then be used to verify the precision of the such calculations, interpolations, and extrapolations. Fig. 2 exemplifies such a comparison. It compares the experimentally determined Feynman x (x_F) distributions of net protons and neutrons with the distributions produced with four different transport model calculations (EPOS [5], HSD [6], UrQMD [7], AMPT [8]). Several comments and observations are noteworthy. Only the authors of EPOS had access to the new data prior to the time this comparison was done. All model calculations agree with the experimental data for protons and neutrons around $\mid x_F \mid = 0.5$. Below and above they over- and underpredict the data except for EPOS, which reproduces both spectra rather well. The differences between protons and deuterons comes out quite well in all models. Stopping is overpredicted by HSD and AMPT.

3. EXPERIMENTS WITH NEUTRONS IN THE INITIAL STATE

Experiments with neutrons in the initial state can be realized in *pn* and *np* configurations. Both types of reactions have been studied in the past by means of deuteron beams or targets, although mostly with small statistics. Experiments at ISR and RHIC have studied *dd* reactions, the latter for direct comparison with AA collision data. So far little effort has been spent to gather a complete set of experimental *np* or *pn* data which is needed to quantify the isospin zero part of the matrix element in nucleon-nucleon collisions.

The main problem of the extraction of e.g. *np* data from *dp* interactions is the identification of the proton spectator and the evaluation and correction of possible final state interactions. Once high intensity deuteron beams are available at heavy ion accelerators new schemes are possible. In both collider and fixed target configurations the spectator proton could be detected in special spectrometer arms which suitably select the proton angle and momentum. Once the momentum vector of the spectator proton is fixed the kinematical configuration of the *np* reactions is well defined. The problem of final state interacttions can be solved by studying *pp* interactions under the same conditions (i.e. in *dp* reactions with suitable spectator neutron selection) and comparison to the correpsonding "free" *pp* interactions. In this case a neutron detector is needed. Its realization depends strongly on the neutron energy and requires a calorimeter for the measurement of hadronic and electromagnetic energy (the latter is needed to identify photons). Once photons and charged particles (detected by a scintillator hodoscope for example) are vetoed the only remaining background comes from neutral kaons. It may be possible to identify a significant fraction of K^0s in a highly sophisticated calorimeter by first fully stopping them and then by detecting four photons from their eventual decay into two π^0s.

4. SUMMARY

There is the need for *np* or *pn* data at all energies. The goal is to measure isospin-equal-zero nucleon-nucleon cross section and thus provide reference data for relativistic nuclear collisions. Such data can be obtained from high statistics *dp* experiments. New heavy ion accelerator facilities like FAIR and NICA can easily provide intensive deuteron beams. Such experiments need sophisticated proton and neutron detectors to identify both types of spectator nucleons.

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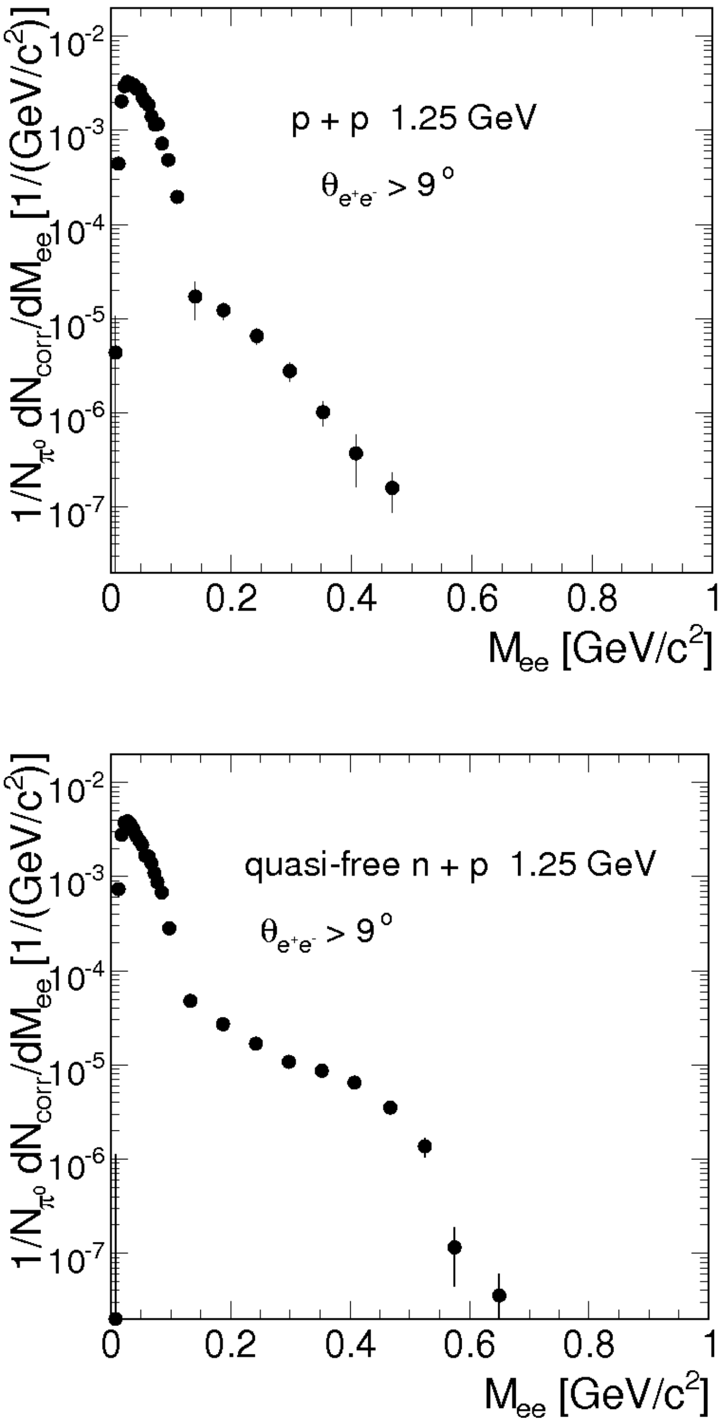

Figure 1. Invariant mass distributions of electron-positron pairs in *pp* (up) and quasi free *np* (down) interactions at 1.25 GeV [1].

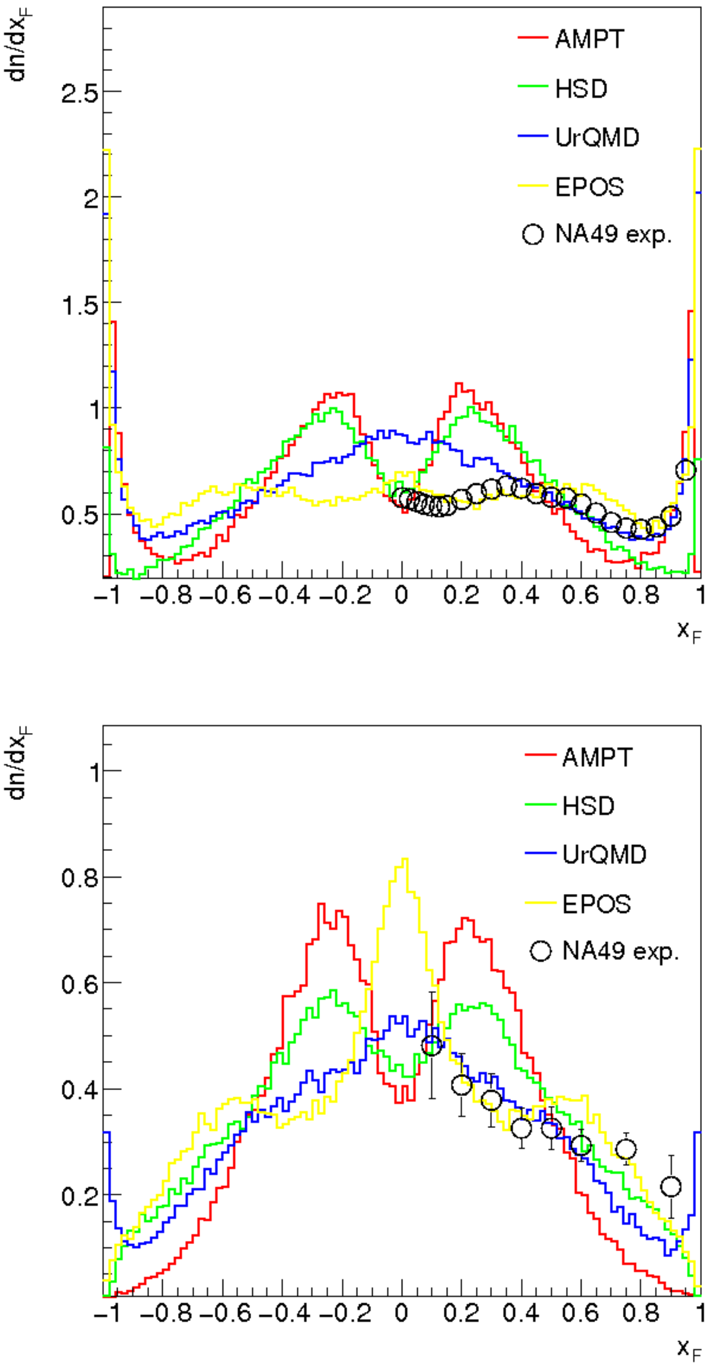

Figure 2. Feynman x distributions of protons (up) and neutrons (down) from pp interactions at 158 GeV/c [4] compared to predictions from four microscopic transport models (see text). (For Black and white prints: The different models can be identified by their amplitudes at $x_F = 0.2$ from highest to lowest: AMPT, HSD, UrQMD, EPOS, and similarily at $x_F = 0.7$: EPOS, UrQMD, HSD, AMPT for protons and EPOS, HSD, UrQMD, AMPT for neutrons.)

FIGURE CAPTIONS

Fig.1: Invariant mass distributions of electron-positron pairs in pp (up) and quasi free np (down) interactions at 1.25 GeV [1].

Fig.2: Feynman x distributions of protons(up) and neutrons(down) from pp interactions at 158 GeV/c [4] compared to predictions from four microscopic transport models (see text). (For Black and white prints: The different models can be identified by their amplitudes at $x_F = 0.2$ from highest to lowest: AMPT, HSD, UrQMD, EPOS, and similarily at $x_F = 0.7$: EPOS, UrQMD, HSD, AMPT for protons and EPOS, HSD, UrQMD, AMPT for neutrons.)