ACCESSING DYNAMICAL EMISSIONS WITH TWO-PARTICLE CORRELATIONS IN HEAVY-ION COLLISIONS*

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In this work, we present a study of two-proton correlation functions measured in Xe+Au collisions at $E/A = 50$ MeV. The main goal of the analysis consists of understanding the space-time properties of the two-proton emitting source. In order to answer this question, we study transverse momentum gated correlations, guided by indications provided by BUU transport model simulations. The source profiles extracted by imaging techniques are studied to understand to what extent information on the space-time properties of pre-equilibrium stages can be explored. These studies are key to address open problems such as the density dependence of the symmetry energy that affects significantly the dynamical pre-equilibrium neutron/proton emission in heavy-ion collisions.

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1. Introduction

Two-particle correlation functions have been extensively used to study the space-time properties of nuclear reactions [1–6]. During an energetic collision between two heavy-ions, nuclear matter under extreme conditions of temperature and density is produced. Therefore, heavy-ion collisions represent the only terrestrial means to access the equation of state of nuclear matter. The complexity of these systems stems from the fact that particles are emitted by multiple sources. The observed single particle spectra contain contributions from fast pre-equilibrium emissions, dominating the early stages of the reaction, and slowly evolving evaporative and secondary decay sources. Secondary decays are known to represent a significant limitation to the extraction of information related to the equation of state from measured experimental spectra. More recently, this sensitivity has been considered crucial for accessing information on the density dependence of the symmetry energy. Indeed, simulations have revealed that two-proton, two-neutron and proton–neutron correlation functions are sensitive to the symmetry energy in asymmetric nuclear matter [7]. In order to access this important physics information, it is necessary to shed light on two-proton source imaging trying to isolate as much as possible dynamical emissions from the emitted proton–proton correlations. If successful, the profile of the source thus obtained from more selective sets of data can be compared to transport model simulations to probe the equation of state, the symmetry energy and details about nucleon–nucleon collisions in the nuclear medium [7].

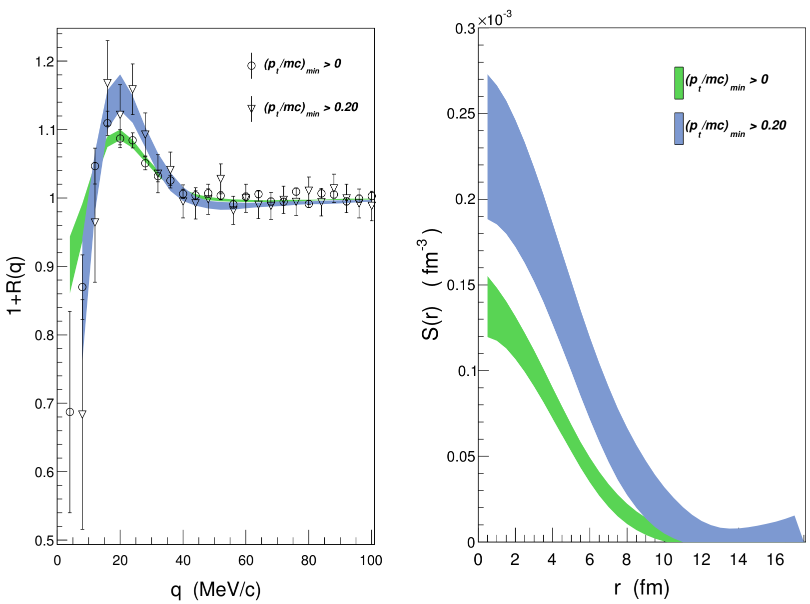
In this proceeding, we present a preliminary study devoted to characterizing the space-time properties of emission processes at the dynamical stage via two-proton source imaging measured in Xe+Au collisions at $E/A = 50$ MeV. The data were collected using the LASSA array, consisting of nine telescopes, each one having two layers of Double Sided Silicon Strip Detector (DSSSD) and four CsI crystals [8]. This high angular resolution array was coupled to the Miniball/Miniwall array [9] used to better isolate central collision events. This is accomplished by selecting a high multiplicity of charged particles detected by the combined array Miniball/Miniwall+LASSA.

2. Access to dynamical sources with transport models and HBT

It is well known that the pre-equilibrium stage of a heavy-ion collision at intermediate energies is dominated by nucleon–nucleon collision phenomena that dominate reaction dynamics during the first 100 fm/c's, depending on the incident energy, impact parameter and projectile and target masses. These nucleon–nucleon collisions can scatter neutrons and protons out of the reaction plane. Transport model simulations, such as those provided by the BUU (Boltzmann–Uehling–Uhlenbeck) model, are often used to simulate the early dynamical stage of the reaction. They are less reliable in handling secondary decays by excited primary fragments. Therefore, a large amount of long-lived emissions is poorly described and needs to be taken into account when studying observables that are sensitive to long-lived decays. Due to these difficulties, two-proton correlation functions have been hardly described by BUU simulations [10, 11]. In order to overcome this difficulty, *ad hoc* approaches have been proposed. In particular, the integral of the source, commonly indicated with the λ parameter representing the fraction of proton pairs emitted at the dynamical stage of the reaction, can be re-scaled and comparisons between source shapes extracted from data and simulated in models are performed [12].

According to recent results from BUU simulations [13], protons that are detected at large transverse momenta are most likely to be emitted within the early 100 fm/c's of the reaction. Therefore, high $p_{\rm t}c/mc^2 = p_{\rm t}/mc$ protons may predominatly originate from the dynamical early stage. The quantity $p_{\rm t}/mc$ can be easily measured in experimental data and might be used as a possible filter for dynamical emission processes in heavy-ion collisions.

Driven by these ideas, we try to study the possibility of imaging the early dynamical proton emissions in our experimental data using gates on transverse momenta. Figure 1 (a) shows correlation functions measured in central Xe+Au collisions at $E/A = 50$ MeV with two different gates in



(a) (b)

Fig. 1. Measured correlation (a) and source (b) functions extract from imaging method for $b_{\rm red} < 0.3$, $p_{\rm t}/mc > 0$ and $p_{\rm t}/mc > 0.20$ respectively.

transverse momentum $p_t/mc > 0$ (circles) and $p_t/mc > 0.20$ (triangles), respectively. The colored shaded bands refer to the correlation functions reconstructed from the imaging analysis (for more details, see [14]). It is possible to note how the amplitude of the peak is larger in the case of higher transverse momentum protons. Figure 1 (b) shows the corresponding imaged source functions. From the extracted source profiles, one can deduce the fraction of proton pairs contained in the integral, λ, of $S(r)$. We obtain about $\lambda = 0.12$ and 0.32, respectively in the case of protons without and with transverse momentum gate. The corresponding fractions of single particle (proton) emission is given by $f = \sqrt{\lambda}$ and corresponds to about 35% and 57% of the dynamically emitting sources. The remaining percentage of protons are most likely to be emitted by evaporation processes and secondary decays.

The fraction, f, dynamically emitted protons is shown in Fig. 2 as a function of transverse momentum cuts. The increasing trend of f as p_t/mc increases seems to be consistent with increasing contributions of protons emitted in the dynamical stage of the reaction. These observations seem to be consistent with BUU predictions [15] suggesting that high p_t/mc protons may predominantly originate from the dynamical early stage, $t < 100$ fm$/c$. The quantity p_t/mc can be easily evaluated in experimental data and might be used as a possible filter for dynamical emission processes in heavy-ion collisions. Furthermore, we also study the variation of the source size, estimated as the FWHM $r_{1/2}$ of the source profile $S(r)$ (Fig. 3). We observe

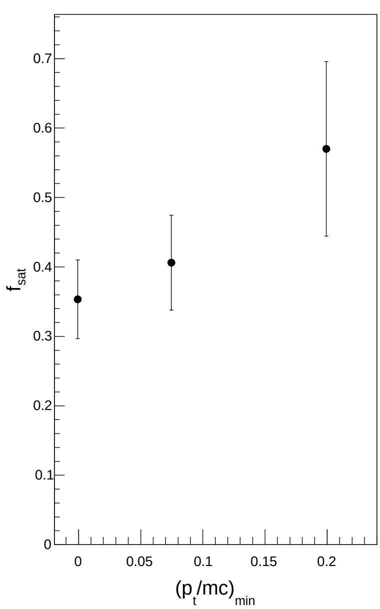


Fig. 2. Fraction of protons f as a function to transverse momentum cuts.

a small sensitivity of the source size on the transverse momentum, even if the error bars are large and require higher statistics experiments. Analyses aimed at a better understanding of this sensitivity are still in progress and may reveal further insights into the space-time nature of proton emitting sources at intermediate energies.

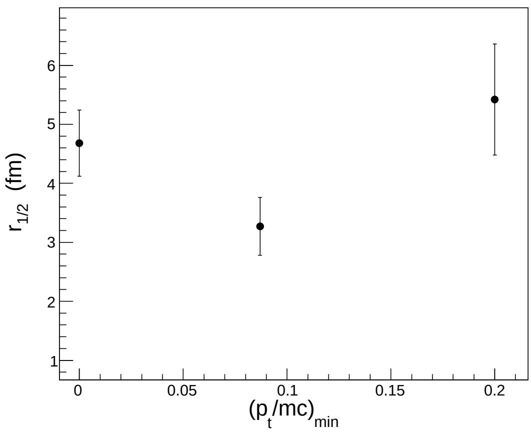


Fig. 3. Source size as a function to transverse momentum cuts.

3. Conclusions

In this preliminary work, two-proton correlation functions are studied as a function of transverse momentum. This analysis is motivated by the fact that the two-proton source extracted from the measured range of q-values in the experimental data should be dominated by the dynamical emitting processes characterizing early stages in the reaction. This idea is reinforced by transport model simulations performed with BUU suggesting that protons with high transverse momentum are most likely to be emitted earlier in the collision, before 100 fm/c. The trend of transverse momentum gated correlations measured in central Xe+Au collisions at $E/A = 50$ MeV and studied with imaging techniques seems to be consistent with typical spatial extent and lifetimes characterizing the early stage of the reaction where nucleon–nucleon collision processes are important.

These studies are relevant in the perspective of using transport models to probe the density dependence of the symmetry energy. This important property of the equation of state of nuclear matter affects the early pre-equilibrium stage of the reaction and imaging two-nucleon correlation functions seems to be a good technique to probe important information about the properties of this early dynamical stage.

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