The Triple Nuclear Collisions Method opens a new frontier to investigate the QCD matter properties at ultrahigh baryonic charge densities

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Introduction

We suggest to explore an entirely new method to experimentally and theoretically study the phase diagram of strongly interacting matter based on the triple nuclear collisions (TNC). We simulated the TNC using the UrQMD 3.4 model at the beam center-of-mass collision energies $\sqrt{s_{NN}} = 200$ GeV and $\sqrt{s_{NN}} = 2.76$ TeV. It is found that in the most central and simultaneous TNC the initial baryonic charge density is about 3 times higher than the one achieved in the usual binary nuclear collisions at the same energies. As a consequence, the production of protons and Λ-hyperons is increased by a factor of 2 and 1.5, respectively. Using the MIT Bag model equation we study the evolution of the central cell in TNC and demonstrate that for the top RHIC energy of collision the baryonic chemical potential is 2-2.5 times larger than the one achieved in the binary nuclear collision at the same type of reaction. Based on these estimates, we argue that TNC offers an entirely new possibility to study the QCD phase diagram at very high baryonic charge densities.

Triple Nuclear Collisions

After about three decades of investigating the phase diagram of strongly interacting matter in binary nuclear collisions (BNC) it became clear that the most interesting phenomena such as the expected chiral symmetry restoration and the deconfinement phase transitions may occur at rather low center-of-mass collision energies with the thresholds $\sqrt{s_{NN}} \simeq 4-5$ GeV [1, 2] for the chiral symmetry restoration phase transition and $\sqrt{s_{NN}} \simeq 9-10$ GeV [1, 2] for the deconfinement one. Recently the community of heavy-ion collisions came to a conclusion that in addition to the A+A collisions we inescapably need an independent and reliable source of information about the equation of state (EoS) of strongly interacting matter [3, 4]. In line with this idea, we suggest to consider the TNC [5]. The TNC can be done either by inserting a super-thin target into the interaction zone of two colliding beams, or by making the jet target consisting of small metallic droplets of about 1-2 μm size, or by installing the third (storage) ring in a perpendicular direction to two colliding beams. Since the TNC idea is a fresh one, here we just outline a few principal advantages of TNC over the BNC, whereas the estimates of TNC rates and details of the experimental setup we will discuss in the separate publications.

Results

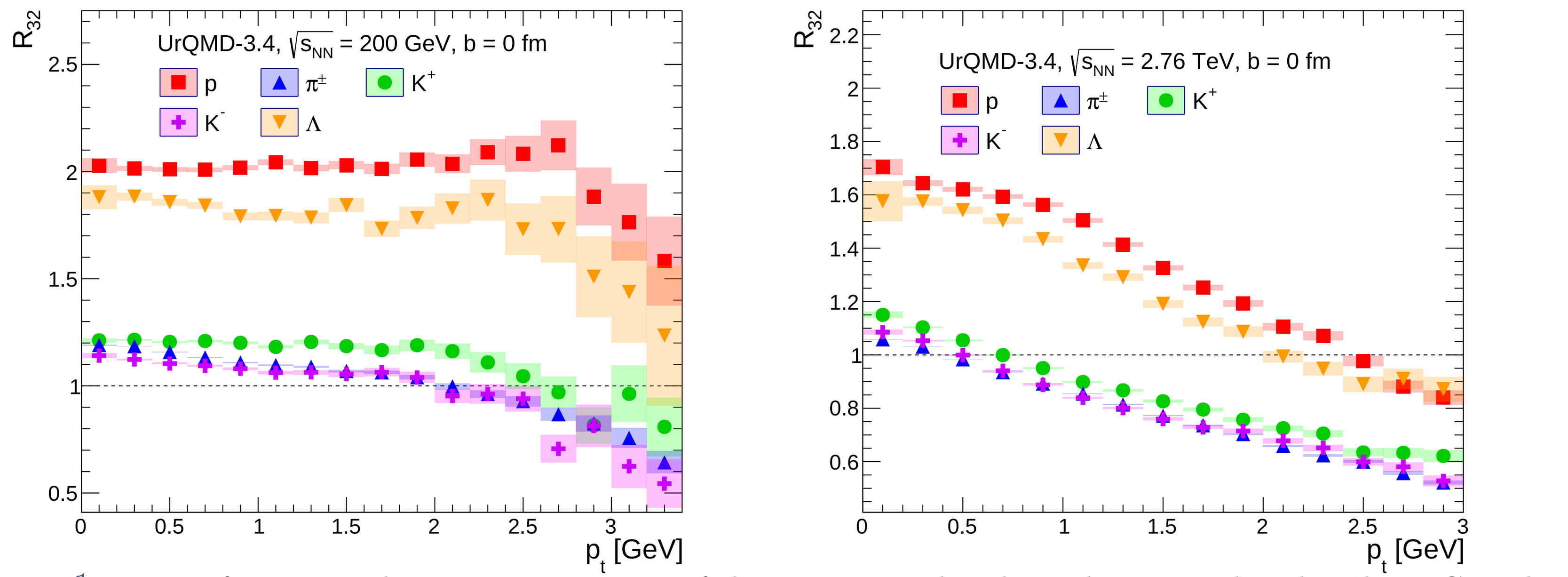

Figure 1: Ratio of transversal momentum spectra of the most central and simultaneous Pb+Pb+Pb TNC to the one found for the most central Pb+Pb collisions (3-to-2 nuclei enhancement factor for p_T spectra) of hadrons obtained for the same collision energy $\sqrt{s_{NN}} = 200$ GeV (left) and for $\sqrt{s_{NN}} = 2760$ GeV (right) as a function of particle transverse momentum found for vanishing impact parameter $b = 0$.

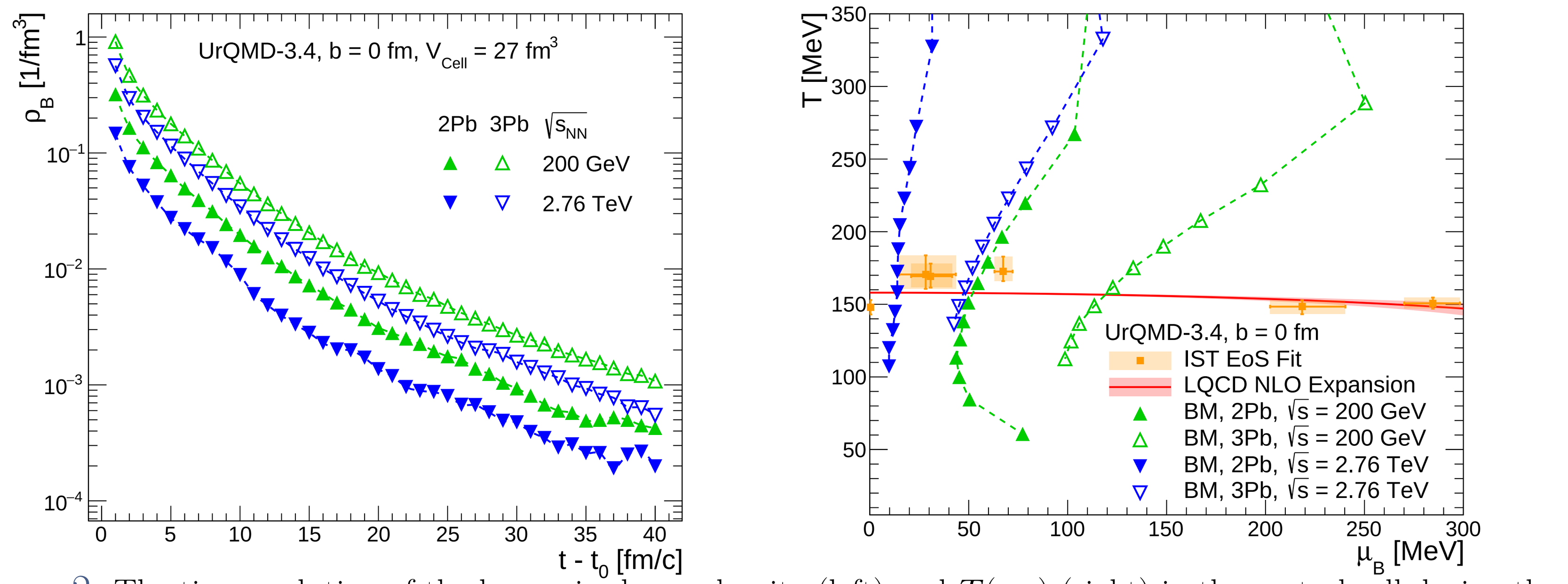

Figure 2: The time evolution of the baryonic charge density (left) and $T(\mu_B)$ (right) in the central cell during the process of ordinary BNC (filled symbols) and for the TNC (empty symbols) found for the same energies as in Fig. 1 (left). The baryonic chemical potential μ_B and temperature T in the central cell were obtained with the MIT Bag Model equation of state [6]. The topmost points correspond to the time $t - t_0 > 1$ fm (t_0 is beginning of expansion). The orange curve of pseudo-critical temperature corresponds to a lattice QCD NLO parameterization [7], while the crosses correspond to the chemical freeze-out parameters in Pb+Pb collisions found in Ref. [1].

Our simulations with UrQMD 3.4 model show us that using the TNC one can probe the **new extreme conditions**, namely very high baryonic, even at highest RHIC energies of collisions. In Fig. 1 we demonstrate the 3-to-2 enhancement factor as a ratio of the quantity obtained by UrQMD 3.4 model for the most central Pb+Pb+Pb to the same quantity found for the most central Pb+Pb collisions at the same energy of colliding beams $\sqrt{s_{NN}} = 200$ GeV (left) and $\sqrt{s_{NN}} = 2760$ GeV (right). As one can see from Fig. 1, the yield of protons and Λ-hyperons in the TNC is enhanced almost by a factor of 2 at low transverse momenta. This feature can be used to detect the TNC in the event-by-event analysis. Also we studied the evolution of the central cell with the size $3 \times 3 \times 3$ fm^3. The results for the most central Pb+Pb+Pb TNC for $\sqrt{s_{NN}} = 200$ GeV (RHIC) and $\sqrt{s_{NN}} = 2.76$ TeV (LHC) are shown in Fig. 2. To estimate the values of baryonic chemical potential μ_B and temperature T inside the central cell, we used the MIT Bag Model equation of state [5] for 3 colors and 3 massless quark flavors, i.e. for the system pressure $p^{BM} = \frac{95}{180}\pi^2 T^4 + \frac{T^2\mu_B^2}{6} + \frac{\mu_B^4}{108\pi^2} - B_{vac}$, with a typical value $B_{vac}^{\frac{1}{4}} = 206$ MeV. Equating the baryonic charge density ρ_{cell} and the energy density ϵ_{cell} found for the central cell to the corresponding quantities of the MIT Bag Model $\rho_{BM} \equiv \frac{\partial p^{BM}}{\partial \mu_B}$ and $\epsilon_{BM} = T\frac{\partial p^{BM}}{\partial T} + \mu_B \rho_{BM} - p^{BM}$, we found the values of μ_B and T in central cell (see Fig. 2). As one can see from the right panel of Fig. 2, for the same temperature the values of μ_B are essentially larger in the TNC than in the BNC.

Conclusions

The new and exciting physics of TNC awaits for us. We hope that many new phenomena will be discovered with TNC.

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