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PLANS FOR CORRELATION STUDIES FOR BES PROGRAM AT RHIC

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We present an overview of the main concepts concerning correlation studies for the Beam Energy Scan Program at STAR. QGP signatures at higher RHIC energies are the most obvious example of the creation of a new state of matter. In order to learn more about the transition to this state and to find a possible location of a critical point between a first-order transition and cross-over area, a new program dedicated to such analyses is formulated. Correlation studies are one of the most important obervables of the scanning of unknown region of the phase diagram. Measurements of elliptic flow, local parity violation in strong interactions, azimuthally sensitive correlations as well as two-proton femtoscopy and nonidentical particle correlations are discussed in this paper.

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INTRODUCTION

The main goals of the Beam Energy Scan (BES) program [1] at the Relativistic Heavy Ion Collider (RHIC) for the Solenoidal Tracker at RHIC (STAR) are:

I) A search for a turn-off of Quark–Gluon Plasma (QGP) signatures. A turn-off of these observables could be observed as different area of the QCD phase diagram than QGP region. The following measurements will be verified:

a) constituent quark number scaling of v_2 that indicates partonic degrees of freedom;

b) nuclear modification factor $R_{\rm CP}$ for hadrons in central collisions;

c) correlations in the space of pair separation in the azimuthal angle and pseudorapidity;

d) local parity violation in strong interactions.

II) A search for signatures of a first-order phase transition and a Critical Point (CP). The following analyses will be performed:

a) elliptic and directed flow (v_1 and v_2) for charged particles;

b) azimuthally sensitive correaltions (asHBT);

c) fluctuation observables.

The QCD phase diagram, schematically shown in Fig. 1, indicates two states of matter: Hadronic Gas and QGP. It also implies an existence of a first-order phase transition, cross-over areas, and a CP between them. So far, it was possible to scan the very narrow region of phase diagram at RHIC, limited to its edge at small value of chemical potential and large temperature indicating smooth cross-over transition. Exploration of the rest of the QCD phase diagram is the intention of the BES program. Different energies of Au + Au collision, from $\sqrt{s_{NN}} = 5$ GeV to 39 GeV, enable us to probe different chemical potentials at various temperatures. The yellow curves in Fig. 1 represent trajectories at given energies for the BES program (from right to left: $\sqrt{s_{NN}} = 5, 7.7, 11.5, 17.3, 27$ and 39 GeV).

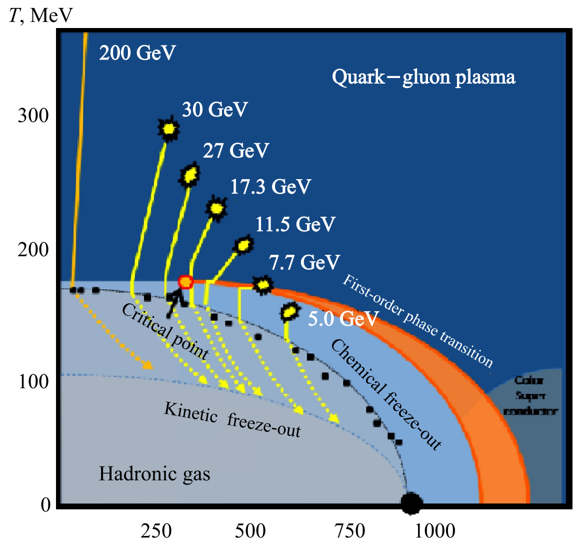

Fig. 1. A scheme of the QCD phase diagram. The critical point is located within the RHIC BES range, as well as first-order phase transition and cross-over areas [1]

1. PARTONIC DEGREES OF FREEDOM

Elliptic flow v_2 plotted as a function of transverse kinetic energy [2] $E_k = (m_T - m_0)/n_q$, for all particles below $E_k = 0.9$ GeV/c^2 follows universal curve. Above that, v_2 of mesons and baryons deviates from each other. After the division of each axis by the number of constituent quarks ($n_q = 2$ for mesons and 3 for baryons), the meson and baryon curves

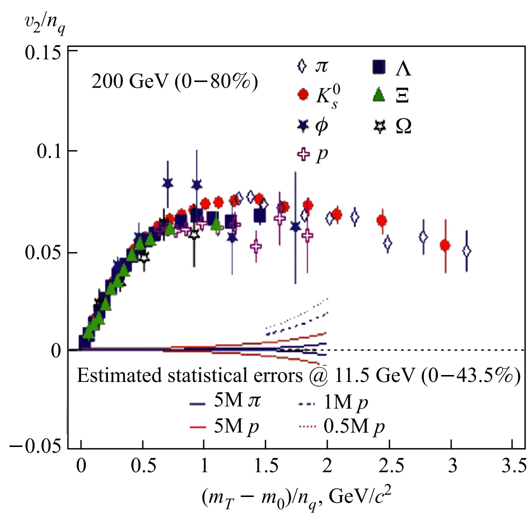

Fig. 2. Elliptic flow scaled by n_q as a function of E_k for Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The solid and dashed curves near $v_2 = 0$ show estimate of statistical error bars from simulation of v_2/n_q for Au + Au collisions at 11.5 GeV [2]

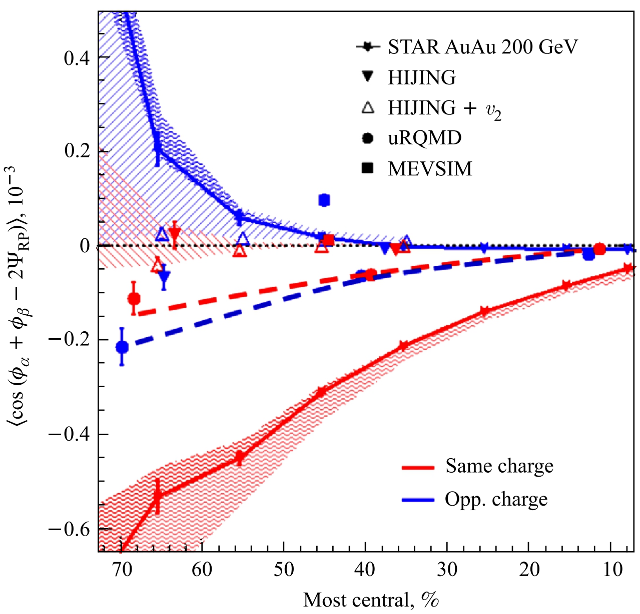

Fig. 3. Centrality dependence of the signal of parity violation in strong interactions from Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV with several model simulations [3]

follow the same tendency over a wide range of E_k (see Fig. 2). This scaling behavior is one of the most exciting evidence for the existence of partonic degrees of freedom. A turn-off of n_q scaling below some threshold beam energy would be an excellent confirmation of our current understanding of the deconfined matter. Effects of parity violation may become visible in noncentral heavy-ion collisions, where a large magnetic field (B) is generated perpendicular to the reaction plane. In the case of a deconfined system with local parity violation, regions with different numbers of left- and right-handed quarks could occur, leading to the separation of charges along the B direction. The results [3] shown in Fig. 3 are partially in agreement with that scenario. The shaded regions in the figure illustrate systematic uncertainties.

2. TWO-PARTICLE CORRELATIONS

2.1. Azimuthally Sensitive Correlations. As is known, the analysis of two-particle correlations provides a powerful tool to study the properties of hot and dense matter created in heavy-ion collisions at ultrarelativistic energies. They provide information of the collision dynamics at early stage. HBT radii measured relative to the event plane provide additional information addressed to a first-order phase transition. STAR has measured the azimuthally sensitive HBT (asHBT) radii for Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV. For more detail of the asHBT program for BES, refer to [4].

2.2. Proton Femtoscopy. Two-particle femtoscopy applied to identical and nonidentical hadron pairs makes the study of space-time evolution possible. Proton femtoscopy allows extraction of the radii of produced sources. They can be compared to those deduced from identical pion studies, providing complete information about source characteristics. More details concerning two-proton correlations can be found in [5].

2.3. Nonidentical Particle Correlations. Nonidentical particle correlation analysis method allows us to study space-time asymmetries in the emission of two types of particles (e.g., proton–antiproton, pion–kaon, pion–proton systems). The distribution of space-time emission points is assumed to be the same for both particles. In the case of pion–kaon analysis, the pion is always taken as a first in the pair. The correlation strength due to Coulomb interactions depends on whether the two particles move towards each other or away from each other in the pair rest frame. To distinguish two scenarios, we calculate the $k^*_{\rm out}$ (the outward component of k^*, parallel to the transverse momentum of the pair) for the pion. The case in which $k^*_{\rm out} < 0$ means the pion is slower. If it is emitted farther to the center of collision, it means that the kaon catches it up and the correlation is stronger for $k^*_{\rm out} < 0$. However, if it is emitted closer to the center, the effect is reversed and the correlation is weaker for $k^*_{\rm out} < 0$. Studying the ratio of the function for positive and negative values of $k^*_{\rm out}$, the information about space-time asymmetry is deduced as a deviation from unity. One can study asymmetries in different directions by investigating the correlations dependence on negative and positive components of k^* projections in three directions. We use the decomposition of k^* into *out*, *side* and *long* components. In STAR due to azimuthal symmetry and symmetry in midrapidity the mean differences:

$$\langle \Delta r^*_{\rm side} \rangle = \langle \Delta r^*_{\rm long} \rangle = 0.$$

The asymmetry can be seen for the *out* projection, and it is a mixture of two components:

$$\langle \Delta r^*_{\rm out} \rangle = \gamma \langle [\langle \Delta r_{\rm out} \rangle - T \langle \Delta t \rangle] \rangle.$$

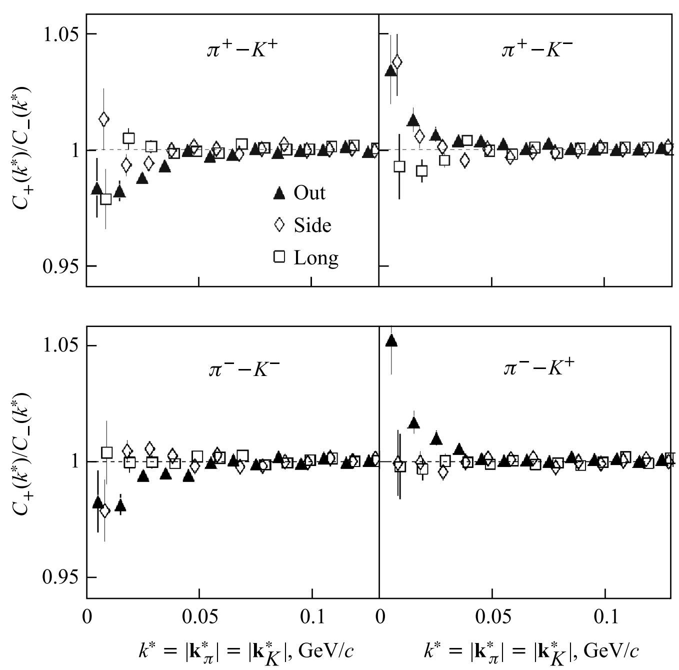

Fig. 4. Double ratios for identical and nonidentical pion–kaon combinations for *out*, *side* and *long* components of k^* for Au + Au collisions at $\sqrt{s_{NN}} = 130$ GeV [6]

Ratios of the two functions from Au + Au collisions at $\sqrt{s_{NN}} = 130$ GeV, presented in Fig. 4, deviate from unity for all charge combinations of the pions and the kaons. Deviation from unity implies an asymmetry in the emission process between pions and kaons. Such results indicate that in general, kaons are emitted later and/or closer to the system edge. For more detail, refer to [6].

3. SUMMARY

We have discussed some of the plans for correlation studies for BES at STAR. We have concentrated on v_2 measurements and its scaling according to the number of constituent quarks, analysis of local parity violation in strong interaction and two-particle femtoscopy: asHBT, two-proton and nonidentcal particle correlations. The BES program contains plans for many other important observables such as: fluctuation measurements ($\langle p_T \rangle$, K/π, p/π, K/p, net proton Kurtosis [7], photon multiplicity), forward-background correlations, identified particles p_T spectra, jet correlations, untriggered and triggered correlations and many others not discussed in this paper. All these observables play an important role in detection of a location of a first-order phase transition and a critical point.

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