NON-IDENTICAL PARTICLE CORRELATIONS AT STAR*

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Correlations of particles produced in heavy ion collisions are sensitive to the space-time structure of the emitting system because of strong and Coulomb Final State Interactions. Moreover, non-identical particle correlations are a unique tool to probe the system collective expansion. The STAR experiment at RHIC allows to measure correlations of non-identical particles with close velocities. We have performed such an analysis from data obtained by the STAR detector for Au+Au collisions at 130 GeV and 200 GeV. The first results indicate that the average space-time emission points of pions, kaons and protons are different. The origin of such differences can be related to the time shift in the emission of different particle species or/and to the strong transverse radial flow. This result provides a new independent evidence that the system created at RHIC undergoes a strong collective transverse expansion.

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1. Introduction

The Solenoidal Tracker at RHIC (STAR) is one of four-detector systems constructed at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory. Key features of the collisions produced at RHIC are: a large number of produced particles (approximately 1.5 thousand per pseudorapidity unit) [1], suppression of jet attributed to parton energy loss in a high density medium [2,3] and collective flow phenomena [4]. STAR experiment is

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designed to measure many observables simultaneously and thus may allow to obtain fundamental understanding of the bulk properties of nuclear systems at high energy densities.

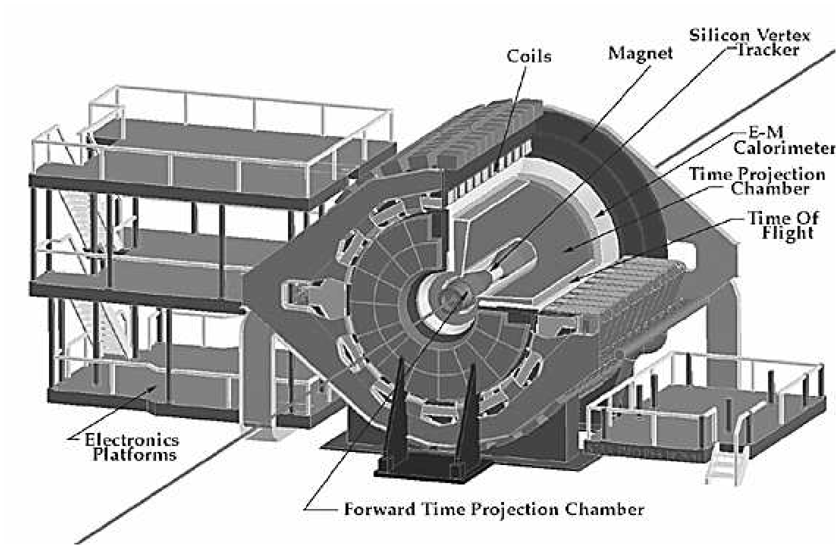

Fig. 1. Perspective view of the STAR detector, with a cutaway for viewing inner detector systems.

The base of the STAR detector is a time projection chamber (TPC) placed in a solenoidal magnetic field of maximum value 0.5 T, covering ± 1.8 units of the central rapidity. The cylindrical TPC is four meters in diameter (at the radial distance from 50 to 200 cm from the beam axis) and four meters long [5]. It is the main subdetector and a tracking device. Ionization charge produced along particle trajectories is drifted to the two end plates, where induced signals and arrival times are read out on 150,000 cathode pads. Particle identification is possible via dE/dx.

During the past three years it has collected sets of data from Au–Au, p–p, and d–Au collisions. In this paper we present results of the analysis of two non-identical particle correlations in Au–Au collisions at $\sqrt{s_{nn}} =$ 130 GeV and 200 GeV.

2. Non-identical particle correlation analysis

The technique of non-identical particle correlations was first proposed at [6]. The method allowing to measure the asymmetry in space-time distributions of non-identical particles was proposed in [7] and further refined in [8, 10].

We study the correlation of non-identical particles using relative four momentum $\tilde{q} = q - P(qP)/P^2$ where $q = p_1 - p_2$ and $qP = m_1^2 - m_2^2$. In the pair rest frame $\vec{P} = 0$ and $\tilde{q} = \{0, 2\vec{k^*}\}$ the $\vec{k^*}$ is momentum of one particle in the pair rest frame. The correlation between non-identical particles arises from Final State Interactions (FSI), Coulomb for charged particles and strong for all types of hadrons. It depends on $\vec{k}^*$, the relative momentum and $\vec{\Delta r}^*$, the relative separation in the pair rest frame. The correlation is strong, when $|\vec{\Delta r}^*|$ and $k^* = |\vec{k}^*|$ are small (which implies that particles have close velocity not momenta, because of different masses). From the classical point of view the correlation strength for a pair of particles depends, due to FSI, on whether both particles move initially toward each other (stronger correlation) or away from each other (weaker correlation). We assume that both particles are emitted from the same space point but lighter particle is emitted first. To distinguish two cases we calculate k^*_{out} for lighter particle. The case in which $k^*_{\mathrm{out}} > 0$ means that the particles catch up with each other because lighter particle is faster, what can be seen as stronger correlation effect.

The value of k^*_{out} is a projection of $\vec{k^*}$ on one of the interferometric directions, defined as follows: *out* along the pair transverse velocity, *long* along the beam axis, and *side* — perpendicular to both previous ones.

To measure correlation effect we define correlation function $C(k^*) = \frac{A(k^*)}{B(k^*)}$, where $A(k^*)$ is the distribution of pairs coming from the same event, and $B(k^*)$ the distribution of pairs coming from different events. To measure asymmetry for non-identical particles we build a more sophisticated observable, a double ratio, defined as the ratio C_-/C_+. In this quotient C_+ (C_- respectively) is the correlation function calculated for positive (negative) k^*_{out} value. If our new observable deviates from unity, it means, that on average there is a space-time separation between sources of both particle species.

Because of azimuthal symmetry and symmetry over mid-rapidity we expect $\langle \Delta r^*_{\mathrm{side}} \rangle = \langle \Delta r^*_{\mathrm{long}} \rangle = 0$. The value of $\langle \Delta r^*_{\mathrm{out}} \rangle$ contains information about space-time separation of different particle sources and thus it should differ from 0. Of course, from the relation $\langle \Delta r^*_{\mathrm{out}} \rangle = \langle \gamma_{\mathrm{pair}} (\langle \Delta r \rangle - \beta_{\mathrm{pair}} \langle \Delta t \rangle) \rangle$ it is evident that we cannot distinguish between space shift and time shift. According to our expectations and theoretical models, time shift may come from average freeze-out ordering of different particle species, whereas space shift may appear from transverse collective motion (flow).

3. Events and particles selection

The object of our analysis where pions, kaons and protons reconstructed and identified by STAR TPC in Au–Au collisions at $\sqrt{s_{NN}} = 130$ GeV and $\sqrt{s_{NN}} = 200$ GeV. Central events accounting for 12% of the total hadronic cross section are selected. All particles are taken from the rapidity window $|Y| < 0.5$. Particle species are selected using dE/dx information and Particle Identification (PID) tables. These tables are constructed using Bethe–Bloch formula, accounting for the relative yield of different particle species in the momentum region where their dE/dx is similar (*e.g.* pion and electron with 0.12 GeV/c). Tracks were extrapolated to the primary vertex. If the shortest distance between extrapolated track and the vertex exceeded 3 cm the particle was discarded, which removes significant fraction of secondary tracks. In order to exclude two track effects all particle pairs sharing more than 10–20% (depending on analysis) points in TPC were also removed.

Special care must be taken when one deals with systematic errors, primary particle purity, momentum resolution and momentum shift due to energy loss, as they directly affect the shape of the correlation function and in consequence the double ratio. Primary particle purity is the percentage of primary πK (πp,Kp) pairs in all πK (πp,Kp) pairs satisfying all cuts. This number is the product of two contributions: the probability of identifying π, K, p particles using dE/dx information and the probability of excluding π, K, p that do not originate from primary vertex. Systematic errors were precisely estimated, using STAR detector simulations. To simulate collision and subsequent treating of created particles trough the detector, HIJING, GEANT and TPC Response Simulator (TRS) were used. Main sources of systematic errors come from identification of particles, weak decays, momentum resolution and systematic shift for low transverse momentum. According to this information systematic errors were calculated. Moreover the real (true) correlation function have to be purity corrected according to equation $C_{\text{true}} = (C_{\text{measured}} - 1)/(\text{purity} + 1)$. For more detailed information concerning event and particle selection and error estimation see [9].

4. Analysis of results

We study πK, πp and Kp systems for 130 GeV and 200 GeV data. Figure 2 shows the correlation function of all charge configurations for πp. On the plot one can clearly see the difference between correlation functions for $k^*_{\text{out}} > 0$ and $k^*_{\text{out}} < 0$. We can conclude that pion–proton pairs are not emitted on average from the same space-time position. We do not see any signal (deviation from unity) in double ratios in k^*_{side} and k^*_{long} directions, therefore correlation functions for those directions were not presented here. The form of the correlation function is not suitable for regular function fitting. Thus theoretically predicted correlation function have to be constructed, and χ^2 test must be used to find the best one. The obtained results are presented in Table I. The free parameters are the Gaussian mean, $\langle \Delta r^*_{\rm out}\rangle = \langle r^*_{\rm out}(\pi) - r^*_{\rm out}(K)\rangle$ ($\langle \Delta r^*_{\rm side}\rangle = \langle \Delta r^*_{\rm long}\rangle = 0$) and the Gaussian width, $\sigma = \sigma_{r^*_{\rm out}} = \sigma_{r^*_{\rm side}} = \sigma_{r^*_{\rm long}}$.

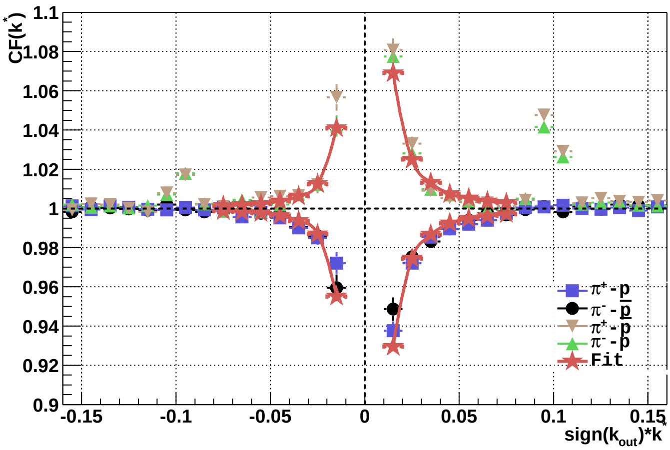

Fig. 2. Correlation functions for identical and opposite charge pairs configuration. Solid lines indicate fit to the data.

TABLE I

Preliminary results of fitting [16].

Pair	σ (fm)	$\langle \Delta r^*_{\rm out}\rangle$ (fm)	χ^2/dof	$\langle \beta_t \rangle$
πK ($\sqrt{s_{NN}} = 130$ GeV)	$12.5 \pm 0.4^{+2.2}_{-3}$	$-5.6 \pm 0.6^{+1.9}_{-1.3}$	134/110	0.65
πp ($\sqrt{s_{NN}} = 130$ GeV)	$11.3 \pm 0.6^{+2}_{-5}$	$-7.3 \pm 0.6^{+3}_{-1}$	103/56	0.55
Kp ($\sqrt{s_{NN}} = 200$ GeV)	$8.5 \pm 0.4^{+2}_{-5}$	$0.9 \pm 0.7^{+3}_{-3}$	107/64	0.62

5. Comparing data to models

In order to be able to describe the properties of the source, a comparison to the models is necessary. We investigate one simple parametrization of the final state and three more realistic physical models incorporating particles propagation through the very dense medium to freeze-out. The obtained from the models asymmetries in space-time distributions of non-identical particle pairs are listed in Table II.

TABLE II

Asymmetry in space-time distributions of non-identical particle pairs from models ($\langle \Delta r^{\star}_{\text{out}} \rangle$). All results are preliminary.

Pair	UrQMD	RQMD	RM	BW
πK	$-2,6$	$-8,0 \pm 0,6$	$-9,7$	$-6,9 \pm 0,3$
πp	$-10,6$		$-5,3$	$-6,2 \pm 0,5$

5.1. Hydrodynamical Blast–Wave parametrization

Blast–Wave parametrize the final state of the expanding fire-ball [12]. The parameters of the parametrization were constrained using other measurements from the STAR experiment — the single particle spectra and identical pion correlations. The following parameters were used: transverse radius of the emission region $R = 13$ fm, temperature $T = 110$ MeV and transverse flow rapidity $\rho(r) = \rho_0 * r/R$ with $\rho_0 = 0.9$. These parameters are obtained by fitting pion, kaon, proton and lambda transverse mass spectra and the pion source radii. Therefore no free parameters were introduced in the comparison with data. The difference between emission points of different particle species emerges from strong transverse collective flow. The flow produces correlation between emission point and momentum direction, which is weaker for particles with lower masses. Therefore flow introduces average emission transverse radius ordering. The sequence is following (starting from the surface of the source): protons then kaons and at the end pions. This shows that transverse flow does produce the asymmetry.

5.2. Transport/Rescattering Models

Our data were compared to the three transport models RQMD [13], UrQMD [14] and Rescattering Model [15]. In all of them time shift and space-momentum correlation contribute to the asymmetry in k_{out} direction. Figure 3 shows a comparison of the data with prediction from hadronic cascade model UrQMD and Rescattering Model.

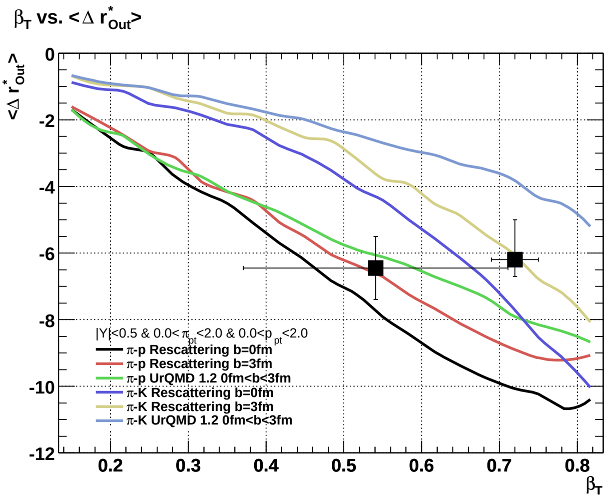

Fig. 3. Average shift between pion, kaon and proton sources in the pair rest frame. All results are preliminary.

6. Conclusions

We have shown πK, πp and Kp correlations measured by the STAR Collaboration in Au–Au collisions at RHIC. The measurements indicate that pions, kaons and protons are not emitted at the same average space-time position. Time shift and momentum-space correlation cannot be separated in this analysis. In order to do that, the data were compared to models including both time and space shifts, that appear to be consistent with our measurements, but with our big errors we cannot really prove which models agree and which disagree with our measurement. It is worth mentioning that Blast–Wave parametrization gives good qualitative agreement with a wide set of STAR data including non-identical correlations. Furthermore, the application of this non-identical two-particle correlation analysis technique at RHIC offers unique new opportunities to improve our understanding of transverse flow.

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