NUKLEONIKA 2004;49(Supplement 2):S77–S80

PROCEEDINGS

Non-identical particle correlations in STAR

Michał Janik,
Adam Kisiel,
Piotr Szarwas

for the STAR Collaboration

Abstract Non-identical particle correlations offer new methods of probing the dynamics of heavy-ion collision. In STAR we have performed a correlation analysis of pion-kaon and pion-proton systems for $\sqrt{s_{NN}}$ = 130 AGeV Au+Au collisions. The results show that average emission space-time points of pions, kaons and protons are not the same. These results are studied with the help of heavy-ion collision models. The asymmetries appear as a consequence of space-momentum correlations produced by transverse radial expansion of the system. The effects of emission time differences, coming from the decay of resonances are also investigated, and found to explain only part of the asymmetry.

Key words correlations • non-identical dynamics • emission asymmetries

Introduction

In the collisions of Au nucleons occurring in the Relativistic Heavy-Ion Collider operating in the Brookhaven National Laboratory, a hot and dense system of strong interacting nuclear matter is produced. It has been extensively studied by RHIC experiments, one of which is STAR. One of the important experimental observables is the collective behavior of matter, specifically hydrodynamics-like flow. Non-identical particle correlations [9–12, 16] have been proposed [8] as a measure of the transverse radial flow as well as asymmetries in particle emission from the expanding system produced in the heavy-ion collision.

Non-identical particle correlations technique

Identical particle correlations (HBT) have been used to study the space-time characteristics of the system produced in heavy-ion collisions [4]. Non-identical particle correlations, which were also measured by STAR [1], have been proposed as a method giving supplementary information as well as providing new insights into the dynamics of the collision [8].

Correlation functions

The correlation of non-identical particles at low relative velocity arises from their Coulomb (for charged particles) and strong (for hadrons) interactions, which occur after their chemical and kinetic freeze-out. We construct the correlation functions for pairs of particles with small relative momentum, which corresponds to close velocities

M. Janik✉, A. Kisiel, P. Szarwas
Faculty of Physics,
Warsaw University of Technology,
75 Koszykowa Str., 00-662 Warsaw, Poland,
Tel.: +48 22/ 660 73 75, Fax: +48 22/ 628 21 71,
e-mail: Janik@if.pw.edu.pl

Received: 10 March 2004

in the source rest frame. The height and width of the correlation effect carry the information about the size of the emission region.

"Double ratios"

The correlation functions of non-identical particles also carry a qualitatively new piece of information – the emission asymmetries [12]. The technique makes use of the fact that both particles are identifiable. We divide particle pairs in two groups – with $k_x^* > 0$ and $k_x^* < 0$, where k_x^* is the component of the relative momentum of the first particle in one of the following directions: *out* – the direction of pair momentum, *long* – the direction of beam axis or *side* – perpendicular to both previous ones. We can then construct two correlation functions: $C^+_{(k^*)}$ for pairs with $k_x^* > 0$, and $C^-_{(k^*)}$ for pairs with $k_x^* < 0$. It can be shown that these two functions should be identical if the average emission points of the two particle species are the same. However, if there is a non-zero difference $\langle \Delta r_x \rangle$ between average emission points $\langle r_x \rangle$ of both particle species in the given direction x, the functions will be different, and their difference, visible in the "double ratio" will deviate from one.

By symmetry considerations it can be shown that $\langle \Delta r_{side} \rangle = 0$. For a symmetric system with a symmetric rapidity coverage (as is the case in Au+Au collisions at STAR), we also have $\langle \Delta r_{long} \rangle = 0$. The only direction where we expect the asymmetry is *out*. In can be written:

$$\left\langle \Delta r_{out} \right\rangle = \left\langle \gamma \left(\left\langle \Delta r^*_{out} \right\rangle - \beta \left\langle \Delta t \right\rangle \right) \right\rangle \tag{1}$$

where values with asterisk (*) are in the pair rest frame and therefore can be measured, while values without the asterisk are in the source rest frame. From Eq. (1) one can see that the observable asymmetry can come from space and/or time component.

Results from the STAR experiment

The non-identical particle correlations have been studied by the STAR experiment [1]. In this analysis, we have used pions, kaons and protons identified in the STAR Time Projection Chamber (TPC) detector [5]. Only central (13% of the total hadronic cross-section) Au+Au collisions at 130 AGeV were studied. Based on the dE/dx and momentum information, a probability for each particle to be a pion,

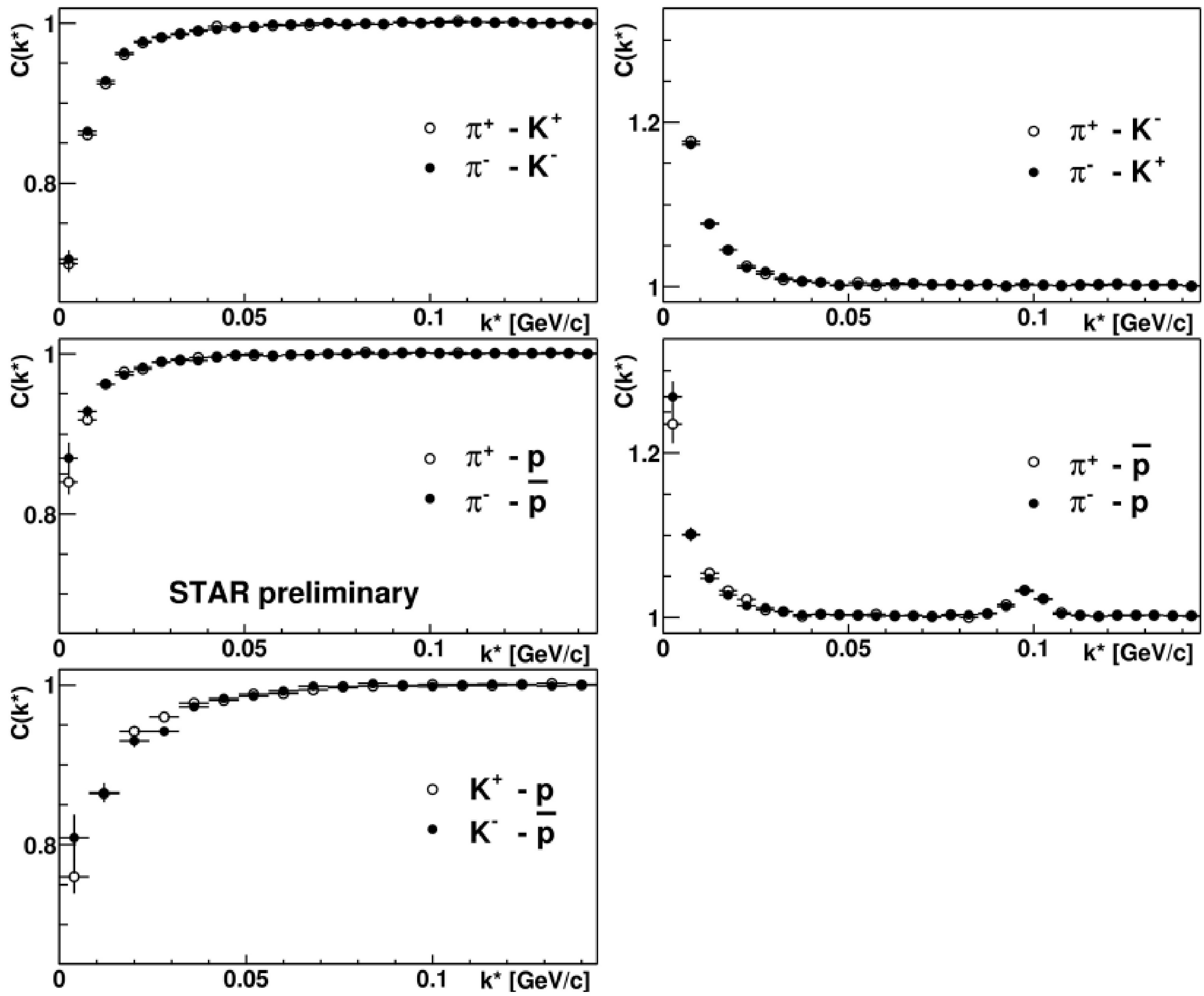

Fig. 1. The correlation functions for (from top to bottom) pion-kaon and pion-proton pairs.

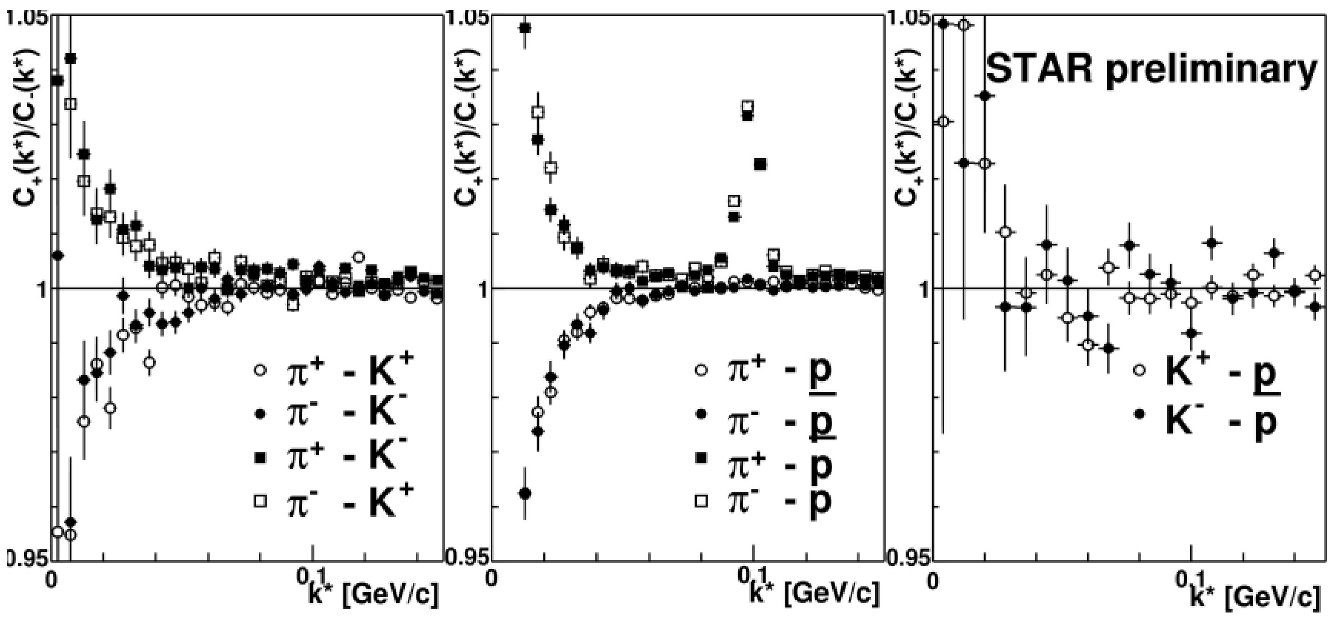

Fig. 2. The "double" ratios in the *out* direction for (from left to right) pion-kaon and pion-proton pairs.

kaon, proton and electron has been calculated. Only particles within the central rapidity region ($-0.5 < y < 0.5$) were used, because of best TPC acceptance. The momentum ranges (in GeV) were: (0.08, 0.5) for pions, (0.3, 1.0) for kaons and (0.3, 1.2) for protons. The reconstruction purity of the pair was calculated with the help of the dE/dx information. Only the pairs with at least 60% chance of being a right pair were accepted for the analysis. Also special care has been taken to eliminate e^+e^- pairs, as the pairs coming from γ decays were found to significantly distort the correlation functions for opposite-charge pairs. Two-track effects were also taken into account: a cut was applied to eliminate pairs of tracks which shared more than 10% of their hits in the TPC. Momentum resolution and purity corrections were also applied.

On the left identical charge combinations are plotted, on the right – opposite-charge.

In Fig. 1 we present the correlation functions for all combinations of pion-kaon and pion-proton pairs. Please note that results for pion-proton are preliminary. It can be seen that the correlation functions for all like-sign and opposite-sign combinations agree, which suggests that the emission mechanisms for opposite charge pions, kaons and protons are the same.

In Fig. 2 we present the "double" ratios in the *out* direction for pion-kaon and pion-proton. They clearly deviate from unity for all the combinations, showing that pions, kaons and protons are not emitted from the same average space-time point.

To quantify that shift in space-time emission point a fitting procedure is applied to the data. A source is assumed to be a Gaussian in r^*_{out}, and a width σ and shift $<r^*_{out}>$ of this distribution are taken as parameters of the fit. For each value of these parameters, with the use of the experimental momentum distribution, a theoretical correlation function is constructed. Then a χ^2 value is calculated for each of these generated correlation functions. The one with the lowest value is taken as the "best fit". The results of this fitting procedure are shown in Fig. 3.

Understanding space-time asymmetries from models

Heavy-ion reaction models, which study the dynamics of the collision, provide a description of the emitting source. They also give the predictions for the emission asymmetries, which can be directly compared to our experimental results and used to gain a better understanding of the reaction.

Blast-wave parameterization

The blast-wave parameterization [13, 15] inspired by hydrodynamic calculations provides a simple way of describing a system with strong transverse radial flow. The asymmetry comes from the interplay between a flow velocity and thermal smearing of the emission point. This model shows that radial flow does produce the emission asymmetry that we expect. Moreover, the blast-wave calculation done with the parameters fixed by other measurements (elliptic flow – [2], $\pi\pi$ HBT [4], single particle spectra [3]) predict an asymmetry which is consistent with the data.

Rescattering models

We also studied the predictions of the RQMD model [14], UrQMD model [6], and Rescattering model [7], which produce radial flow through hadronic rescatterings. In addition, they allow for a complete treatment of resonances. Their decay can be a source of delayed (relative to the direct production) emission of pions, kaons and protons. Since the average delays are different for different particle species, we see a resulting average time shift between pions, kaons and protons, which produces emission asymmetries which sum with the spatial asymmetry coming from flow (see Eq. (1)). It is impossible to disentangle experimentally space and time contributions to the observed asymmetry, however in the study of rescattering model we are able to observe asymmetries from both time and apace shift separately.

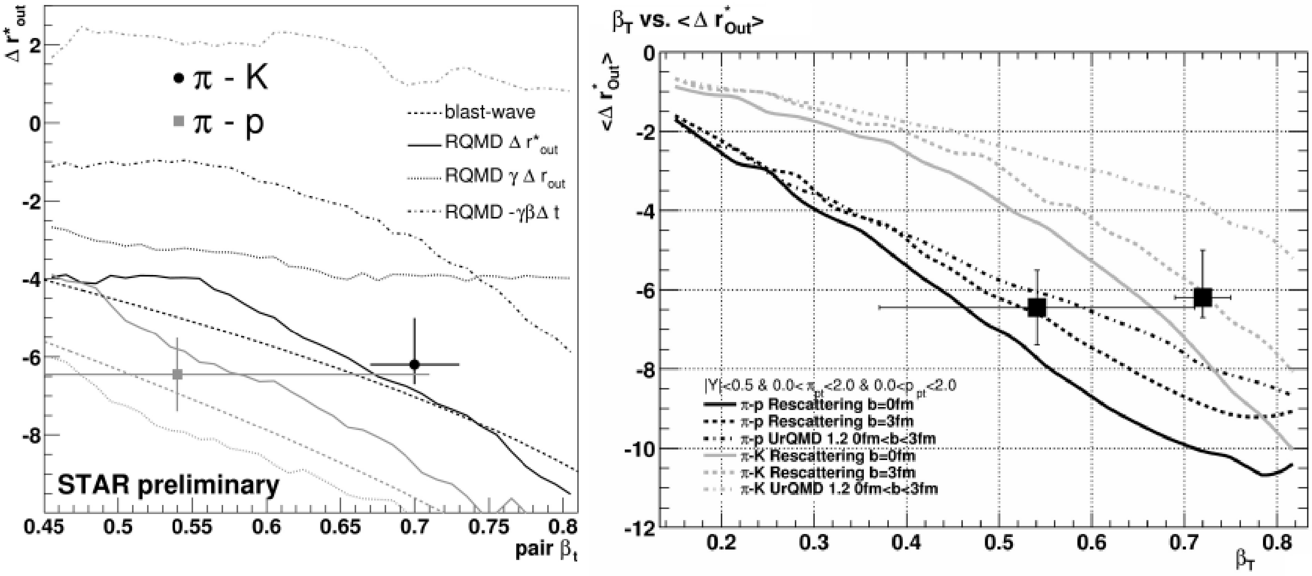

Fig. 3. Comparing pion-kaon and pion-proton correlation function fit results with the predictions of models: blast-wave parameterization (dashed line) and RQMD (solid line) on the left plot. We also show a space (dotted line) and time (dashed-dotted line) component of the asymmetry from RQMD separately. On the right plot comparison to Rescattering model for impact parameters 0 fm (solid line) and 3 fm (dashed line) and UrQMD model (dashed-dotted line).

Conclusions

We have presented preliminary results of pion-kaon and pion-proton correlations measurements from the STAR experiment. The technique of measuring emission asymmetries has been described and applied to the STAR data. The emission asymmetry between pions and kaons as well as pions and protons have been measured. They are shown to be consistent with the hypothesis of transverse radial flows produced in heavy-ion collisions, as seen e.g. in the blast-wave parameterization. Rescattering models were used to study the effect of emission time differences, as well as the developement of radial flow through rescatterings. Both effects are present in the observed asymmetry.

References

1. Adams J, Adler C, Aggarwal MM *et al*. (for the STAR Collaboration) (2003) Pion kaon correlations in Au+Au collisions at s(NN)**(1/2) = 130 GeV. Phys Rev Lett 91:262302, (nucl-ex/0307025)
2. Adler C, Ahammed Z, Allgower C *et al*. (for the STAR Collaboration) (2001) Identified particle elliptic flow in Au+Au collisions at s(NN)**(1/2) = 130 GeV. Phys Rev Lett 87:182301, (nucl-ex/0107003)
3. Adler C, Ahammed Z, Allgower C *et al.* (for the STAR Collaboration) (2001) Multiplicity distribution and spectra of negatively charged hadrons in Au+Au collisions at s(NN)** (1/2) = 130 GeV. Phys Rev Lett 87:112303, (nucl-ex/0106004)
4. Adler C, Ahammed Z, Allgower C *et al*. (for the STAR Collaboration) (2001) Pion interferometry of s(NN)**(1/2) = 130 GeV Au+Au collisions at RHIC. Phys Rev Lett 87:082301, (nucl-ex/0107008)
5. Anderson M, Berkovitz J, Betts W *et al*. (2003) The STAR time projection chamber: a unique tool for studying high multiplicity events at RHIC. Nucl Instrum Meth Phys Res A 499:659–678
6. Bass SA, Belkacem M, Bleicher M *et al.* (1998) Microscopic models for ultrarelativistic heavy ion collisions. Prog Part Nucl Phys 41:225–370
7. Humanic T (1998) Constraining a simple hadronization model of relativistic heavy ion collisions using hadronic observables. Phys Rev C 57:866–876
8. Lednický R (2004) Correlation femtoscopy of multiparticle processes. Phys Atom Nucl 67:72–82, (nucl-th/0305027)
9. Lednický R, Lyuboshitz VL (1982) Final state interaction effect on pairing correlations between particles with small relative momenta. Sov J Nucl Phys 35:770–778
10. Lednický R, Lyuboshitz VL (1990) Final state interaction effect on correlations in narrow particles pairs. In: Ardouin D (ed) CORINNE'90: Proc of the Int Workshop on Particle Correlations and Interferometry in Nuclear Collisions, 28–30 June 1990, Nantes, France. World Scientific, Singapore, pp 42–54
11. Lednický R, Lyuboshitz (1996) The influence of final state interaction on two-particle correlations in multiple production of particles and resonances. Heavy Ion Phys 3;1/2:93–113
12. Lednický R, Lyuboshitz VL, Erazmus B, Nouais D (1996) How to measure which sort of particles was emitted earlier and which later. Phys Lett B 373:30–34
13. Retière F, Lisa M (2003) Observable implications of geometrical and dynamical aspects of freeze-out in heavy ion collisions. (nucl-th/0312024)
14. Sorge H (1995) Flavor production in Pb(160 AGeV) on Pb collisions: effect of color ropes and hadronic rescattering. Phys Rev C 52:3291–3314
15. Tomásik B, Wiedemann UA, Heinz U (2003) Reconstructing the freeze-out state in Pb+Pb collisions at 158 AGeV/c. Heavy Ion Phys 17:105–14
16. Voloshin S, Lednický R, Panitkin S, Xu N (1997) Relative space-time asymmetries in pion and nucleon production in noncentral nucleus-nucleus collisions at high energies. Phys Rev Lett 79:4766–4769