Identical Particle Correlations in STAR

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Preliminary results of identical-particle correlations probing the geometric substructure of the particle-emitting source at RHIC are presented. An m_T-independent scaling of pion HBT radii from large (central Au+Au) to small (p+p) collision systems naively suggests comparable flow strength in all of them. Multidimensional correlation functions are studied in detail using a spherical decomposition method. In the light systems, the presence of significant long-range non-femtoscopic correlations complicates the extraction of HBT radii.

1. Introduction

Particle interferometry is a useful technique that provides information on the space-time properties of nuclear matter created in high energy collisions (for the latest review article see [1]). In this paper results of particle correlations in p+p, d+Au and Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ GeV and Au+Au at $\sqrt{s_{NN}} = 200$ and 62 GeV registered by the STAR experiment are presented. Rich data statistics and the wide acceptance of the detectors gives an opportunity to do a multidimensional femtoscopic analysis. The main focus of this article is on the transverse mass ($m_T = \sqrt{k_T^2 + m_\pi^2}$) dependence of the HBT radii for different system sizes. This allows the study of the dynamics of the source and the conditions of the collision. Importantly, direct comparison between the m_T dependence of radii from p+p and A+A collisions is possible for the first time.

2. Multiplicity Scaling and Expansion

Figure 1 presents the HBT radii dependence on $(dN_{ch}/d\eta)^{1/3}$ (dN_{ch} - number of charged particles) for different colliding systems at different energies of the collisions. The motivation for studying such a relation is its connection to the final state geometry through the particle density at freeze-out. All STAR results, from p+p, d+Au, Cu+Cu and Au+Au collisions, are combined on the left panel of this figure and, as seen, all radii exhibit a scaling with $(dN_{ch}/d\eta)^{1/3}$. On the right panel STAR radii, this time for different range of k_T, are plotted together with AGS/SPS/RHIC systematics [1]. It is impressive that the geometric radii (R_{side} and R_{long}) follow the same curve for different collisions over a wide range of energies and, as it was checked, this observation is valid for all k_T bins studied by STAR. It is a clear signature that the multiplicity is a scaling variable that drives the geometric HBT radii. R_{out} mixes space and time information. Therefore it is

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[*] For the full list of STAR authors and acknowledgments, see appendix 'Collaborations' of this volume.

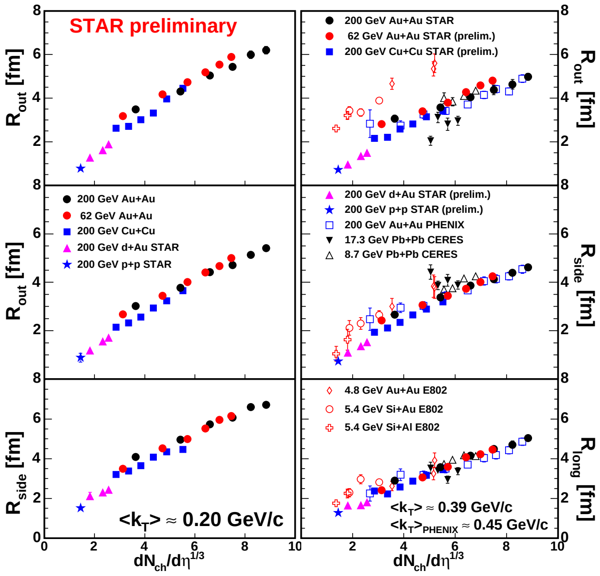

Figure 1. Femtoscopic radii dependence on the number of charged particle.

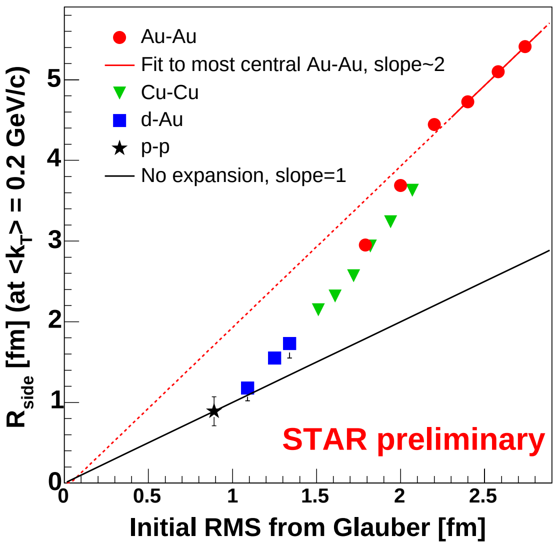

Figure 2. Final size of the source vs. initial radii calculated from Glauber model. STAR Au+Au data from [3].

unclear whether to expect a simple scaling with the final state geometry. Therefore, one can venture to predict the size of the source without knowing anything about the collision (like energy, N_{part}, impact parameter, etc.) except for the multiplicity. This scaling is expected to persist for all systems that are meson dominated but is violated for low energy collisions that are dominated by baryons [1].

Figure 2 suggests that the relationship between initial and final geometry is not trivial, however. There, the final RMS of the source, estimated by R_{side} at low k_T [2], is plotted versus the initial RMS of the overlap region, estimated with a Glauber calculation. The system generated in central Au+Au collisions undergoes a two-fold expansion, while those from the most peripheral d+Au and p+p collisions expand little. Does this imply that small systems are less explosive than large ones? This is explored in the next Section.

3. Transverse Mass Dependence of HBT Radii : p+p vs Au+Au

The m_T dependence of the femtoscopic radii in heavy ion collisions is usually attributed to collective flow of a bulk system, and recent STAR results for central Au+Au collisions support this picture [3]. In a flow scenario, an approximately “universal” m_T dependence should apply to all particle types. This is in fact observed in Figure 3, in which one-dimensional radii from pion [4], charged kaon [4], neutral kaon [5], proton and anti-proton [6], and proton-Λ [7] correlations are plotted. Correlations between particles with very different masses also show characteristic signals of collective flow [8].

Decreasing m_T dependences of the radii have previously been reported for hadron [9] and $e^+ + e^-$ [10] collisions. Until the STAR analysis, a direct comparison of the m_T

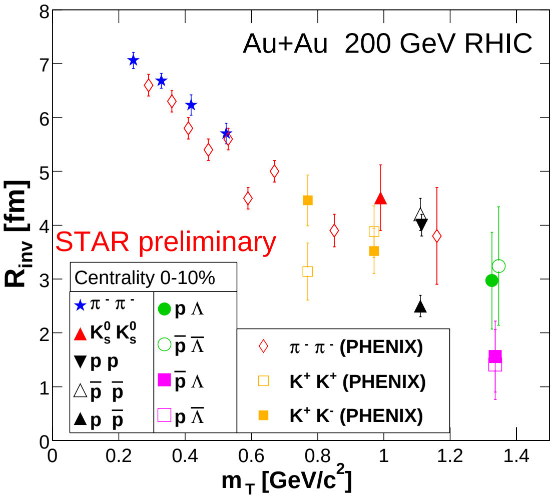

Figure 3. m_T dependence of R_{inv} for different particles. PHENIX data from [4].

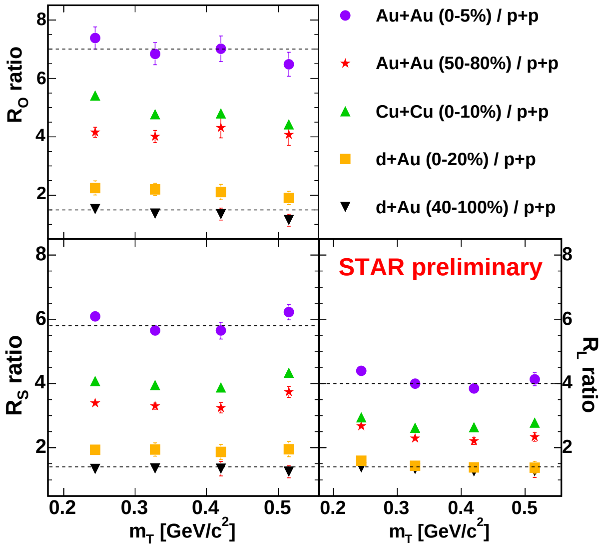

Figure 4. Ratio of HBT radii from Au+Au, Cu+Cu and d+Au by p+p collisions at $\sqrt{s_{NN}} = 200$ GeV.

systematic from hadron collisions with those from A+A collisions had been hampered by the use of quite different parameterizations in the different experiments. As shown in Figure 4, the *ratio* of HBT radii from Au+Au collisions with those from p+p collisions are approximately independent of m_T. It might be that proposed explanations for the m_T dependence in small systems, including Heisenberg-type relations [10] and inside-outside cascade scenarios [11], replicate the m_T dependence from bulk collective flow. This would be a surprising and unfortunate coincidence, suggesting that dynamical signals in the space-time sector cannot distinguish very different underlying physics. Alternatively, as proposed by Csőrgö *et al.* [12], it could be that p+p collisions generate a thermalized *bulk system*, similar to that created in heavy ion collisions. Further theoretical work on this important question would be most welcome. However, as it is mentioned in the next Section, further work is also required on the experimental side.

4. The effect of non-femtoscopic correlations in low-multiplicity events.

HBT radii arise from Gaussian fits to the three-dimensional correlation function [1]. But for low-multiplicity systems, unaccounted-for structures in the correlation function itself are observed. In particular, the value of the correlation function $C(\vec{q})$ for large $|\vec{q}|$ (larger than the scale of quantum statistics or Coulomb interactions) does not approach a common $\vec{q}$-independent value. Thus, non-femtoscopic correlations (e.g. due to momentum conservation) are becoming significant here.

The spherical decomposition of the correlation function in $\vec{q}$-space has been proposed [13] as a sensitive measure of long-range non-femtoscopic correlations. The lowest-l components $A_{l,m}$ of this procedure are shown in Figure 5. For all correlations of femtoscopic origin (Gaussian or not), $A_{l\neq 0,m}$ must vanish [13] for large $\vec{q}$; clearly other correlations are present in STAR data.

While various possible sources of these correlations are still being explored, it is interesting to simply account for the long-range correlations by adding ad-hoc terms to the Gaussian fits, which produce constant values of $A_{2,0}$ and $A_{2,2}$. It was found that the ratios shown in Figure 4 remain m_T-independent, though their values shift somewhat.

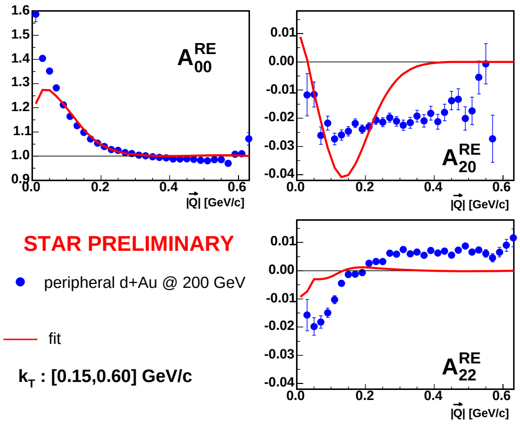

Figure 5: First three non-vanished components of the spherical harmonic decomposition of the correlation function for peripheral d+Au collisions.

5. Conclusions

The results of pion interferometry for all energies and colliding systems at RHIC have been presented. In agreement with data at SPS and AGS, STAR indicates that the multiplicity is the scaling variable that determines the size of the source at freeze-out. Perhaps surprisingly, the m_T dependence of HBT radii appears independent of collision species or multiplicity. Finally, a problem with the baseline of the correlation function for low multiplicity collisions has been reported, and a promising tool based on the spherical harmonic decomposition of the correlation function has been used in order to address it. The physics of this structure remains under investigation.

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