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PREDICTIONS OF HBT PARAMETERS IN Pb + Pb COLLISIONS AT $\sqrt{s_{NN}} = 2.76$ TeV FROM A HADRONIC RESCATTERING MODEL

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A kinematic model based on the superposition of $p+p$ collisions, relativistic geometry, and final-state hadronic rescattering is used to predict two-boson HBT parameters in $\sqrt{s_{NN}} = 2.76$ TeV Pb + Pb collisions. A short proper time for hadronization is assumed. Previous calculations using this model which were performed for $\sqrt{s_{NN}} = 200$ GeV Au + Au collisions were shown to describe reasonably well the trends of two-pion HBT in experiments carried out at that energy, giving the present predictions for Pb + Pb at higher energy some degree of credibility.

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INTRODUCTION

The CERN Large Hadron Collider (LHC) has recently begun delivering Pb + Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV to the LHC experiments. These are the highest energy heavy-ion collisions ever produced in the laboratory, and it is hoped that exotic phenomena will be observed which will expand our knowledge of the properties of highly excited matter [1].

In this context, it is the goal of the present paper to make predictions for common two-boson HBT parameters which will be initially measured by LHC experiments in these high-energy Pb + Pb collisions. A hadronic rescattering model in which the initial state is determined by the superposition of proton–proton collisions has been chosen to make these predictions. The advantages of this model for this purpose are: 1) the model has been shown to describe the overall trends of hadronic observables in lower energy Au + Au collisions at $\sqrt{s_{NN}} = 0.20$ TeV from the Relativistic Heavy Ion Collider (RHIC) [2], and 2) the model is easily scalable to LHC energies. These will be «limiting case scenario» predictions in the sense that only hadrons are used as the degrees of freedom in this model even at the early stages of the collision where parton degrees of freedom are thought to be more appropriate, i.e., a short proper time for hadronization of $\tau = 0.1$ fm/c is assumed.

1. DESCRIPTION OF THE MODEL CALCULATIONS AND RESULTS

The model calculations are carried out in five main steps: A) generate hadrons in $p+p$ collisions from PYTHIA, B) superpose $p+p$ collisions in the geometry of the colliding nuclei, C) employ a simple space-time geometry picture for the hadronization of the PYTHIA-generated hadrons, D) calculate the effects of final-state rescattering among the hadrons, and

E) calculate the hadronic observables. A detailed description of these steps may be found elsewhere [3].

Model runs are made to be «minimum bias» by having the impact parameters of collisions follow the distribution $d\sigma/db \propto b$, where $0 < b < 2R$. Observables are then calculated from the model in the appropriate centrality bin by making multiplicity cuts as normally done in experiments, as well as kinematic cuts on rapidity and p_T. For the present study, a full-calculation 3200 event minimum bias run was made from the model for $\sqrt{s_{NN}} = 2.76$ TeV Pb + Pb collisions which was then used to calculate all of the HBT observables shown.

Figures 1 and 2 show predictions from the model for two-pion and two-kaon HBT for $\sqrt{s_{NN}} = 2.76$ TeV Pb + Pb collisions. For the HBT calculations from the model, the three-dimensional two-boson correlation function is formed, and a Gaussian function in momentum difference variables is fitted to it to extract the boson source parameters. Boson statistics are introduced after the rescattering has finished (i.e., when all particles have «frozen out») using the standard method of pair-wise symmetrization of bosons in a plane-wave approximation [4]. The three-dimensional correlation function, $C(Q_{\rm side}, Q_{\rm out}, Q_{\rm long})$, is then calculated in terms of the momentum-difference variables $Q_{\rm side}$, which points in the direction of the sum of the two-boson momenta in the transverse plane, $Q_{\rm out}$, which points perpendicular to $Q_{\rm side}$ in the transverse plane, and the longitudinal variable along the beam direction $Q_{\rm long}$.

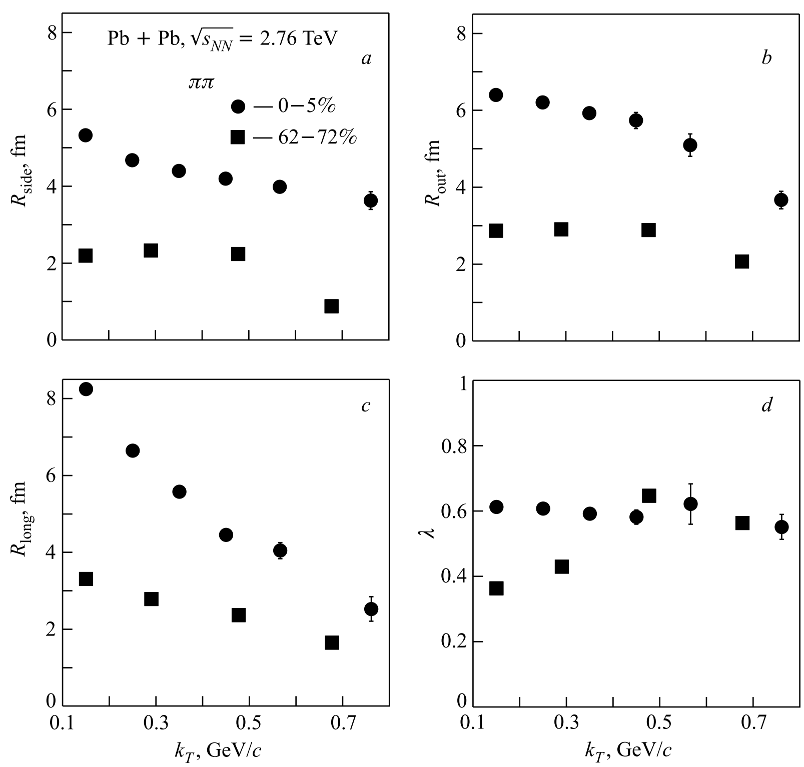

Fig. 1. Model pion source parameters vs. k_T for Pb + Pb collisions, $-1 < \eta < 1$, 0–5% and 62–72% centralities

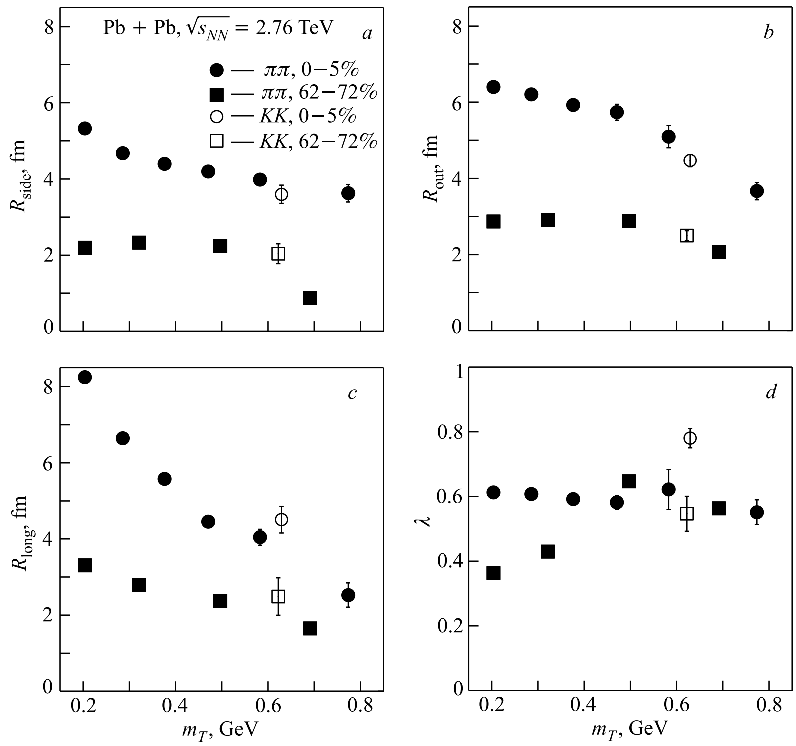

Fig. 2. Comparison of model pion and kaon source parameters vs. m_T for Pb + Pb collisions, $-1 < \eta < 1$, 0–5% and 62–72% centralities

The final step in the calculation is extracting fit parameters by fitting a Gaussian parameterization to the model-generated two-boson correlation function given by, [5]

$$C(Q_{\text{side}}, Q_{\text{out}}, Q_{\text{long}}) = G[1 + \lambda \exp(-Q_{\text{side}}^2 R_{\text{side}}^2 - Q_{\text{out}}^2 R_{\text{out}}^2 - Q_{\text{long}}^2 R_{\text{long}}^2)], \quad (1)$$

where the R parameters, called the radius parameters, are associated with each momentum-difference variable direction; G is a normalization constant, and λ is the usual empirical parameter added to help in the fitting of Eq. (1) to the actual correlation function ($\lambda = 1$ in the ideal case). The fit is carried out in the conventional LCMS frame (longitudinally comoving system) in which the longitudinal boson pair momentum vanishes [5].

Figure 1 compares the model pion source parameters vs. k_T for Pb + Pb collisions, where $-1 < \eta < 1$, for the two centralities 0–5% and 62–72%. For both the centralities the radius parameters are predicted to decrease with increasing k_T showing the effects of «flow» as has been observed in RHIC Au + Au collisions and elsewhere [5, 6]. The overall scales of R_{side} and R_{out} predicted for Pb + Pb are comparable to those seen in RHIC Au + Au collisions, whereas R_{long} is predicted to be about 25% larger than at RHIC [6]. The λ parameter is seen to be mostly independent of k_T with a value of about 0.6, which is significantly less than the «ideal HBT case» of $\lambda = 1$. The main effect causing $\lambda < 1$ in the model is the presence of long-lived resonances such as η and η' which decay into pions late in the collision thus suppressing the correlation function. For the more peripheral centrality case, i.e., 62–72%, the radius parameters are seen to have weaker dependences on k_T than for the more central case, i.e., 0–5%, and are significantly smaller in magnitude. The λ-parameter k_T dependence for the peripheral case is seen to slightly increase with increasing k_T as opposed to being mostly independent of k_T as for the central case. This behavior is due to the smaller particle multiplicity for the peripheral collisions and thus less rescattering present than for the central case, determined by the smaller initial geometric overlap of the projectile-target system in the peripheral case.

Model predictions have also been made for two-kaon HBT as shown in Fig. 2. Figure 2 presents a comparison of model pion and kaon source parameters vs. m_T for Pb + Pb collisions, $-1 < \eta < 1$, centralities 0–5% and 62–72%. A large k_T bin of $0.10 < k_T < 1.00$ GeV/c with an average k_T of $< k_T >= 0.39$ GeV/c was used for the two-kaon calculations in order to obtain reasonable statistical errors from the 3200 event minimum bias Pb + Pb run used in the present study. Also, while a pseudorapidity range of $-1 < \eta < 1$ was used for the 0–5% centrality two-kaon calculation, a range of $-4 < \eta < 4$ was used for the 62–72% centrality two-kaon calculation in order to obtain reasonable statistical errors. As is seen in Fig. 2, the two-kaon calculations obey «m_T-scaling» reasonably well with the two-pion calculations considering the large k_T bin that was necessary to use for the kaons.

2. SUMMARY AND CONCLUSIONS

A kinematic model based on the superposition of PYTHIA-generated $p + p$ collisions, relativistic geometry, and final-state hadronic rescattering has been used in the present work to predict two-boson HBT parameters in $\sqrt{s_{NN}} = 2.76$ TeV Pb + Pb collisions. A short proper time for hadronization of $\tau = 0.1$ fm/c has been assumed as in previous studies with this model which have shown qualitative agreement with experiments. The most noticeable features of the predictions from the present model study are: 1) two-pion HBT radius parameters from LHC Pb + Pb are predicted to be comparable in scale to those from RHIC Au + Au collisions for $R_{\rm side}$ and $R_{\rm out}$, and 25% larger for $R_{\rm long}$ and are predicted to show decreasing magnitude with increasing k_T, i.e., «flow» effects, and 2) two-kaon HBT radius parameters are predicted to show «m_T-scaling».

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