Source Parameters from Identified Hadron Spectra and HBT Radii for Au-Au Collisions at $\sqrt{s_{NN}}=200$ GeV in PHENIX

J. M. Burward-Hoy\textsuperscript{a}, for the PHENIX Collaboration\textsuperscript{*}

\textsuperscript{a}Physics and Applied Technology Directorate, Lawrence Livermore National Laboratory, 7000 East Avenue L-305, Livermore, California 94550

The characteristics of the particle emitting source are deduced from low $p_T$ identified hadron spectra ($m_T - m_0 < 1$ GeV) and HBT radii using a hydrodynamic interpretation. From the most peripheral to the most central data, the single particle spectra are fit simultaneously for all $\pi^\pm$, $K^\pm$, and $p/p$ using the parameterization in [1] and assuming a linear transverse flow profile. Within the systematic uncertainties, the expansion parameters $T_{fo}$ and $\beta_T$, respectively decrease and increase with the number of participants, saturating for both at mid-centrality. The expansion using analytic calculations of the $k_T$ dependence of HBT radii in [2] is fit to the data but no $\chi^2$ minimum is found.

1. INTRODUCTION

Identified charged hadrons in 11 different centrality selections [3] and the transverse momentum ($p_T$) dependence of HBT radii in 9 $k_T$ bins [4] are measured in Au-Au collisions at 200 GeV by the PHENIX Experiment [5]. In both the 200 GeV and previously measured 130 GeV data [6], the $\langle p_T \rangle$ of all particles increases from the most peripheral to the most central events and with heavier particle mass ($m_0$). The dependence of the $\langle p_T \rangle$ on $m_0$ suggests a radial expansion, and its dependence on the number of participant nucleons (N\textsubscript{part}) may be due to an increasing radial expansion from peripheral to central events. The $k_T$ dependence of the HBT radii was also observed and interpreted as a radial expansion.

Both the spectra and the $k_T$ dependence of the HBT radii are fit using parameterizations based on a simple model for the source, where fluid elements are each in local thermal equilibrium and move in space-time with a hydrodynamic expansion [1, 2]. The assumptions are: (1) no temperature gradients, (2) longitudinal boost invariance along the collision axis $z$, (3) infinite extent in space-time rapidity $\eta$, and (4) cylindrical symmetry with radius $r$. The particles are emitted along a hyperbola of constant proper time $\tau_0 = \sqrt{t^2 - z^2}$ and short emission duration, $\Delta t < 1$ fm/c.

The $m_T$ dependence of the yield $\frac{d^2N}{mdmdy}|_{y=0}$ is calculated after integrating the source over space-time (azimuthal and rapidity coordinates) [4]. It is assumed that all particles decouple kinematically on the freeze-out hypersurface at the same freeze-out temperature.

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Figure 1. Simultaneous fits in the range \((m_T - m_0) < 1\) (solid lines) for \(\pi^-\) (top) and \(\bar{p}\) (bottom) in all 11 centralities (scaled for visual clarity) \([4]\). The \(\pi\) resonance region is excluded in the fit.

In order to minimize contributions from hard processes, all \(m_T\) dependent particle yields are fit in the range \((m_T - m_0) < 1\) GeV. As resonance decays are known to produce pions at low \(p_T\) \([9]\), we place a lower \(p_T\) threshold of 500 MeV/c on \(\pi\) in the fit. A similar approach was followed by NA44, E814, and other experiments at lower energies. In Fig. 1, \(\pi^-\) and \(\bar{p}\) yields are shown as a function of \(p_T\) for each event centrality \([4]\). The top 5 centralities are scaled for visual clarity. The solid lines are the simultaneous fits in the limited \(p_T\) range. Similar results are obtained for \(K^{\pm}\), \(\pi^+\), and \(p\) yields.

2. RESULTS

2.1. Fitting the single particle spectra

We use analytic expressions to calculate the HBT radii \([3]\). A linear flow rapidity profile in the transverse plane is assumed and a Gaussian distribution is used for the particle density dependence on \(r\). The parameters are the geometric radius \(R\), the freeze-out temperature \(T\), the flow rapidity at the surface \(\eta_T (\beta_T = \tanh (\eta_T))\) and the freeze-out proper time \(\tau_0\).
The systematic uncertainty in $T_\text{fo}$ is determined by adding in quadrature the change in inverse slope due to the $p_T$ dependent uncertainties in each particle yield at low $p_T$. For $\pi^\pm$, $K^\pm$, and $\bar{p}/p$, the uncertainty is ±10, ±13, and 16 MeV respectively. Added in quadrature, the total systematic uncertainty in the inverse slope is ±23 MeV. The systematic uncertainty in $\beta_T$ is dominated by the uncertainty in the $\bar{p}/p$ spectral shape at low $p_T$ and is determined by measuring the change in $\beta_T$ after fitting for $p_T > 0.85$ GeV/c. The systematic uncertainty in $\beta_T$ is 17.5%.

For the 5% most central events, particles are coupled to an expanding system with a surface velocity of $\beta_T = 0.7 \pm 0.2 \text{(syst.)}$ and decouple at a common temperature of $T_\text{fo} = 110 \pm 23 \text{(syst.)}$ MeV with negligible statistical errors. For the most peripheral events, $T_\text{fo} = 135 \pm 3 \text{(stat.)} \pm 23 \text{(syst.)}$ and $\beta_T = 0.46 \pm 0.02 \text{(stat.)} \pm 0.2 \text{(syst.)}$. The statistical error only is included in the fit, resulting in $\chi^2/\text{dof} = 260.9/52$ for the most central and 321.5/52 for the most peripheral events. At 130 GeV, similar results were obtained, with $\beta_T = 0.70 \pm 0.01$, $T_\text{fo} = 121 \pm 4$, and $\chi^2/\text{dof} = 34.0/40.0$ for the most central events (statistical and systematic errors are added in quadrature before the fit).

The fit results of all particles within each event centrality are shown in Fig. 2. The top panel is $T_\text{fo}$ and the bottom panel is $\beta_T$, both plotted as a function of $N_{\text{part}}$. Within the systematic uncertainties, the expansion parameters respectively decrease and increase with the number of participants, saturating at mid-centrality.

### 2.2. Fitting the $k_T$ dependence of the HBT radii

The HBT radii are measured from identical charged $\pi$ pairs in 9 $k_T$ selections for 10% central events [3]. The systematic uncertainty in the data is 8.2%, 16.1%, and 8.3% for $R_s$, $R_o$, and $R_L$, respectively. A simultaneous fit to the HBT data could not be found over a broad range of parameter space. As an example, if the parameters $\beta_T$ and $T_\text{fo}$ are set to the values from the spectra analysis, then the fit to the HBT results constrains $R$ and $\tau_0$ from the $R_s$ and $R_L$ data respectively, yet the model overpredicts $R_o$ by more than 3$\sigma$ for all but the first $m_T$ data point (Fig. 3). The systematic uncertainties in $\beta_T$ and $T_\text{fo}$ are represented by the shaded region. Within these boundaries, $R$ ranges between 6.9 – 16.8 fm and $\tau_0$ ranges between 11.2 – 16.7 fm/c.

The $\chi^2$ contour levels of the expansion parameters $T_\text{fo}$ (vertical) and $\eta_T$ (horizontal) are shown for simultaneous fits to the spectra and separate fits to each HBT radius in Fig. 4. We note that no $\chi^2$ minima are found, hence the contours are not closed. For the
spectra, the contours are closed and show an anticorrelation, however there is no overlap with the HBT contours. The HBT radius $R_s$ prefers large flow rapidity $\eta_T > 1.0$ and low temperatures $T_{fo} < 50$ MeV. The parameterization has the most difficulty reproducing $R_\circ$.

3. CONCLUSION

The single particle spectra are qualitatively described by a hydrodynamic parameterization that assumes boost invariance and a linear transverse flow profile. The transverse expansion in 11 different centrality classes is extracted from the single particle spectra. Within the systematic uncertainties, the expansion parameters $T_{fo}$ and $\beta_T$, respectively decrease and increase with the number of participants, saturating at mid-centraliy. Expressions for the HBT radii based on similar hydrodynamic assumptions and Gaussian density profiles do not describe the identical $\pi$ pair data. Such fits worked well at CERN SPS energies [11], but fail at RHIC energies.

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