Available online at www.sciencedirect.com
ScienceDirect
Nuclear Physics A 00 (2019) 1–4
Nuclear Physics A

Azimuthally differential pion femtoscopy in Pb-Pb collisions at 2.76 TeV with ALICE at the LHC

Vera Loggins (for the ALICE Collaboration)[1]

Wayne State University, 42 W. Warren Ave, Detroit, MI 48202

Abstract

Femtoscopy of non-central heavy ion collisions provides access to information on the geometry of the effective pion-emitting source. In particular, the source shape can be studied by measuring femtoscopic radii as a function of the pion emission angle relative to the collision symmetry planes. We present the results of azimuthally differential femtoscopy of Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV at the LHC relative to the second harmonic event plane. We observe a clear oscillation of the extracted radii as a function of the emission angle. We find that R_{side} and R_{out} oscillate out of phase for all centralities and pion transverse momenta. The relative amplitude of R_{side} oscillation decreases in more central collisions, but remains positive, which indicates that the source remains out-of-plane extended qualitatively similar to what was observed at RHIC energies. We compare our results to existing hydrodynamical and transport model calculations.

Keywords: LHC, ALICE, femtoscopy, radii oscillation, final eccentricity, freeze-out

1. Introduction

Two particle correlations at small relative momenta (commonly known as *femtoscopy*) is an effective tool to probe the space and time characteristics of the particle emitting source in relativistic heavy ion collisions [1, 2]. The results presented here are obtained in the so-called Longitudinal CoMoving System (LCMS) in which the total pair momentum along the z direction is zero, ($p_{1,z} = -p_{2,z}$). In this system, the extracted freeze-out radii provide information on the system evolution in the following manner: R_{side} is mostly determined by the system geometrical size, R_{out} is mostly determined by the system geometrical size and the emission duration, and R_{long} is mostly determined by the total emission time. Dependence of the radii on the transverse momentum provides information on the system's collective radial expansion (flow) [3]. Flow is due to pressure gradients which are higher in the plane of reaction (in-plane) than perpendicular to it (out-of-plane). Due to flow, the freeze-out source shape may be less out-of-plane extended, and more in-plane extended [3]. In this analysis, we focus on the azimuthal dependence of the radii with respect to the reaction plane to get information on the shape of the source at freeze-out.

2. Data Analysis

The data sample used for this analysis is recorded by ALICE during the 2011 heavy-ion run, Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. There are roughly 30 million min-bias and triggered (central and semi-

[1] A list of members of the ALICE Collaboration and acknowledgements can be found at the end of this issue.

central) events used in this analysis. The tracks are reconstructed using the Time Projection Chamber (TPC) [4]. Both the TPC and the Time of Flight (TOF) [4] were used for pion identification in the pseudorapidity range $|\eta| < 0.8$. The correlation function is defined as the ratio of signal and background relative momentum distribution of two identical pions. The signal distribution was formed using particles from the same event, whereas the background distribution was formed using particles from different events. The pair cuts have been applied to reduce "track splitting" (false pairs created at low relative momentum) and "track merging" (when two tracks are reconstructed as one).

3. Azimuthally Differential Pion Femtoscopy Results

Azimuthally differential femtoscopic analysis of pion production relative to the second harmonic event plane has been performed for Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. Femtoscopic radii have been extracted from the fit to the correlation function using Bowler-Sinyukov fitting procedure [5]:

$$C(\vec{q}, \Delta\phi) = N[(1-\lambda) + \lambda K(\vec{q})(1 + G(\vec{q}, \Delta\phi)], \tag{1}$$

where $G(\vec{q}, \Delta\phi) = e^{-q_{out}^2 R_{out}^2(\Delta\phi) - q_{side}^2 R_{side}^2(\Delta\phi) - q_{long}^2 R_{long}^2(\Delta\phi) - q_{out} q_{side} R_{os}^2(\Delta\phi)}$, N is the normalization parameter, $K(\vec{q})$ is the Coulomb component, λ is the fraction of pairs participating in the Bose-Einstein correlation, and $\Delta\phi = \varphi_{pair} - \Psi_{EP,2}$ is the relative pair angle with respect to the second harmonic event plane defined by the TPC tracks. The extracted radii as a function of $\Delta\phi$ are fitted by the following Fourier expansion:

$$\begin{aligned} R_\mu^2 &= R_{\mu,0}^2 + 2R_{\mu,2}^2 \cos[2(\Delta\phi)] \quad (\mu = out, side, long), \\ R_\mu^2 &= 2R_{\mu,2}^2 \sin[2(\Delta\phi)] \quad (\mu = out\text{-}side). \end{aligned} \tag{2}$$

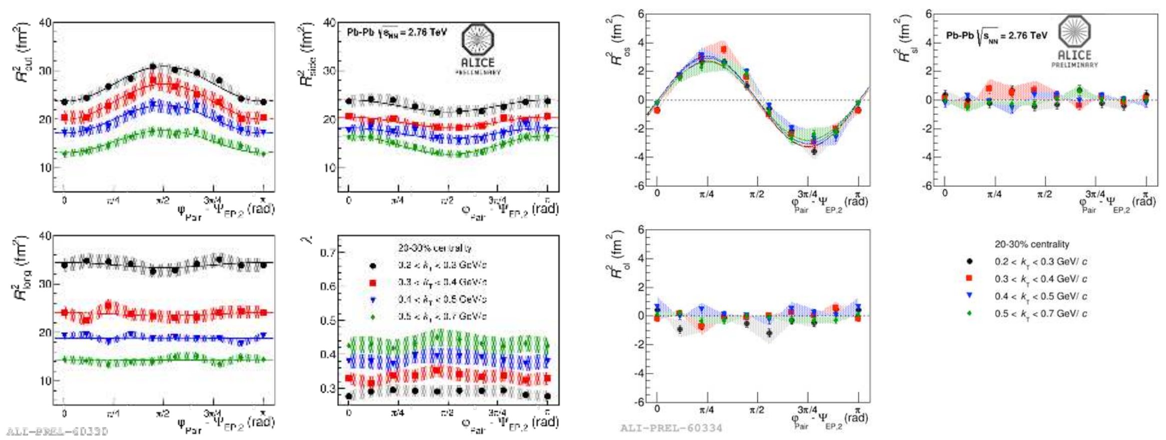

Figure 1: R_{out}^2, R_{side}^2, R_{long}^2, and λ (left) and R_{os}^2, R_{sl}^2, and R_{ol}^2 (right) at 20-30% centrality as a function of emission angle $\Delta\phi$ for different $k_{\rm T}$ intervals: 0.2-0.3, 0.3-0.4, 0.4-0.5, and 0.5-0.7 GeV/c. Lines represent the fits to the radii using Eq. 2. The statistical errors are shown by the error bars and systematic errors are indicated by shaded regions.

Figure 1 (left) presents the R_{out}^2, R_{side}^2, R_{long}^2 radii and λ dependence on transverse momentum $k_{\rm T}$, ($k_{\rm T} = p_1 + p_2/2$) at 20-30% centrality. Figure 1 (right) shows similar dependence of *out-side*, R_{os}, *side-long*, R_{sl}, and *out-long*, R_{ol}, the cross-radii. The values of the radii R_{out}^2, R_{side}^2, and R_{long}^2 at $0.2 < k_{\rm T} < 0.3$ GeV/c are higher than the values of the radii obtained at a high $k_{\rm T}$, $0.5 < k_{\rm T} < 0.7$ GeV/c, as expected due to radial flow. The oscillations for R_{out}^2 and R_{side}^2 are out-of-phase at all measured $k_{\rm T}$ ranges. We compare results obtained at $\sqrt{s_{\rm NN}} = 2.76$ TeV in Pb-Pb collisions to results obtained at RHIC [6] in Au-Au collisions at $\sqrt{s_{NN}} = 200$ GeV in Figure 2. The radii oscillations are similar between RHIC and LHC. The results

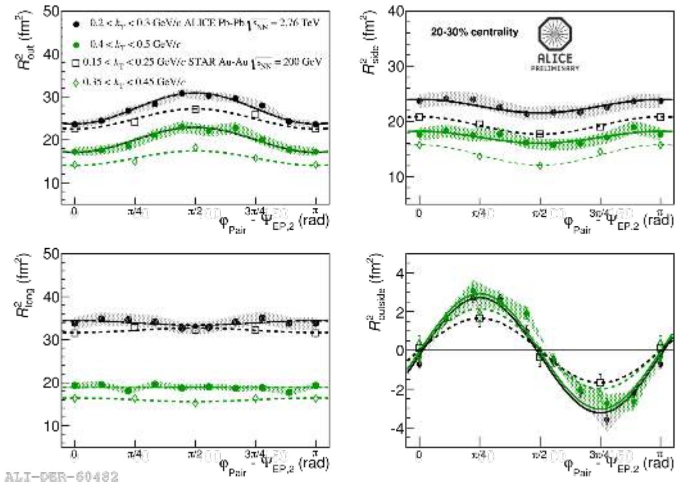

Figure 2: Centrality comparison of radii vs. pair emission angle at ALICE k_{T} of 0.2-0.3 GeV/c, 0.4-0.5 GeV/c, and STAR k_T ranges 0.15-0.25 GeV/c, and 0.35-0.45 GeV/c [6] for 20-30% centrality. The statistical errors are shown by the error bars and the systematic errors are indicated by shaded regions.

contradict to AZHYDRO calculations [7] that predicted a sign inversion in the oscillation amplitude for R_{side} at low k_{T}.

Figure 3 shows comparisons of $R^2_{side,0}$, (left), and $R^2_{side,2}/R^2_{side,0}$, (right), with the most recent (3+1D) hydrodynamical calculations [8]. As was shown in [3], $2R^2_{side,2}/R^2_{side,0}$ at small k_{T} can be used as an estimate for the final freeze-out eccentricity. We compare the final source eccentricity with experiments at lower energies in Figure 4. Final source eccentricity is lower at higher energies as expected due to longer evolution time [9]. HYDRO calculations [10] predict much stronger energy dependence than observed experimentally. UrQMD model [11] describes the energy dependence of the final source eccentricity rather well, but it fails to describe $R_{side,0}$ and $R_{side,2}$ separately (not shown).

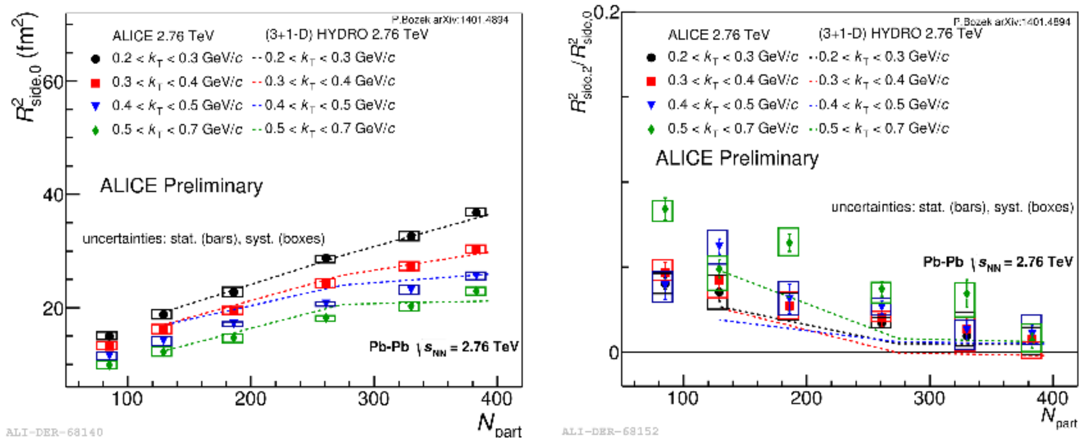

Figure 3: (3+1D) HYDRO model by P. Bozek [8] compared to $R^2_{side,0}$ (fm^2) (left) and $R^2_{side,2}/R^2_{side,0}$ (right). The statistical errors are shown by the error bars and the systematics are indicated by boxes.

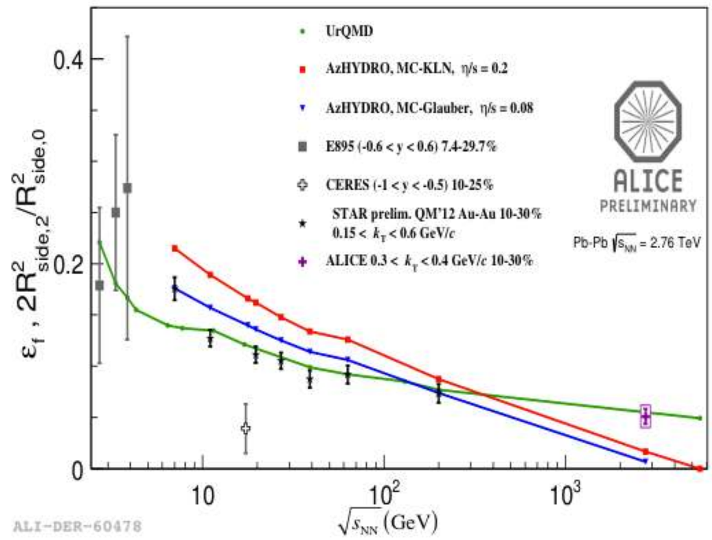

Figure 4: $\sqrt{s_{\rm NN}}$ dependence of the final spatial eccentricity. The statistical (systematic) errors are shown by the error bars (boxes).

4. Summary

We have performed an analysis of azimuthally differential pion femtoscopy relative to the second-order event plane for Pb-Pb collisions at $\sqrt{s_{\rm NN}}$=2.76 TeV. The radii oscillations as a function of two particle emission angle relative to the second order harmonic plane are found very similar at LHC to those at RHIC. The relative amplitude of oscillation, $R^2_{side,2}/R^2_{side,0}$ is found to decrease with collision energy reflecting lower source eccentricity in the freeze-out stage. We obtain a positive value for ϵ_f indicating no change in the source geometry at freeze-out. In the future, these observations will be studied further with additional measurements at higher energies.

References

[1] G. I. Kopylov, M. I. Podgoretsky, Sov. J. Nucl. Phys. 15, 219-223 (1972).
[2] G. I. Kopylov, V. L. Lyuboshits, M. I. Podgoretsky, JINR-P2-8069.
[3] M. A. Lisa, S. Pratt, R. Soltz and U. Wiedemann, Ann. Rev. Nucl. Part. Sci. 55, 357 (2005).
[4] K. Aamodt et al., JINST 3 (2008) S08002.
[5] K. Aamodt et al. (ALICE Collaboration), Phys.Rev. D84 (2011) 112004, arXiv:1101.3665 [hep-ex].
[6] J. Adams et al. [STAR Collaboration], Phys. Rev. Lett. 93, 012301 (2004), arXiv:nucl-ex/0312009].
[7] E. Frodermann, Rupa Chatterjee, and Ulrich Heinz, J. Phys. G: Nucl Part. Phys. 34 (2007) 2249-2254.
[8] P. Bozek, Phys. Rev. C 89, 044904 (2014), arXiv:1401.4894 [nucl-th].
[9] Adam Kisiel et al., Phys. Rev. C 79, 014902 (2009).
[10] C. Shen and U. Heinz, Nucl. Phys. 2 A904-905 2013, 361c (2013), arXiv:1210.2074 [nucl-th].
[11] M. A. Lisa, E. Frodermann, G. Graef, M. Mitrovski, E. Mount, H. Petersen and M. Bleicher, New J. Phys. 13, 065006 (2011) 12, arXiv:1104.5267 [nucl-th].