Measurements of two-particle correlations in pp collisions at $\sqrt{s} = 900$ GeV with the ALICE experiment

Jorge Mercado for the ALICE Collaboration

Ruprecht-Karls-Universität Heidelberg, Philosophenweg 12, 69120 Heidelberg, Germany

DOI: http://dx.doi.org/10.5689/UA-PROC-2010-09/23

ALICE is the experiment at the CERN Large Hadron Collider dedicated to study high-energy nuclear collisions which is also exploiting the proton–proton physics program with wide phase-space coverage and good momentum and spatial resolution.

We present first results on two-pion Bose-Einstein correlations in pp collisions at $\sqrt{s} =$ 900 GeV measured with ALICE. An increase of the HBT radius with increasing event multiplicity is observed, in agreement with previous measurements. However, a strong decrease of the radius with increasing transverse momentum, as observed at RHIC and at Tevatron, is not evident in our analysis.

1 Introduction

ALICE (A Large Ion Collider Experiment) has been designed to investigate the physics of strongly interacting matter at extreme values of energy, density, and temperature in PbPb collisions [1]. These studies are to be complemented by measurements of light nuclei and pp collision systems. A distinguishing feature of the system created in heavy-ion collisions is the collective expansion. This view was recently challenged by the observation that at the Relativistic Heavy Ion Collider (RHIC) energies the transverse expansion is already manifest in the transverse momentum spectra of particles emitted in pp collisions, provided the energy and momentum conservation has been properly accounted for in the data analysis [2]. Moreover, dropping of the particle-source size with increasing transverse momentum — another signature of transverse expansion — was reported to be similar in pp and AuAu systems [3].

In this work we look for signatures of collective behavior in pp collisions at LHC energies by studying the size of the pion source as a function of event multiplicity and particle transverse momentum. The source size is deduced from the width of the peak representing the Bose-Einstein (BE) enhancement of identical-pion pairs at low relative momentum. This technique, also known as Hanbury Brown–Twiss (HBT) interferometry [4, 5], is unique among all analysis techniques utilized in subatomic collision experiments as it directly addresses the space-time structure of the evolving system at the femtometer scale and it has been previously successfully applied in elementary particle [6, 7] and heavy-ion [8] collisions.

2 Correlation function measurement

2.1 Data analysis

The results discussed here were obtained from the analysis of 250×10^3 pp collision events recorded in December 2009, during the first stable-beam period of the LHC commissioning. The correlations analysis was performed using charged particle tracks registered in the ALICE Time Projection Chamber (TPC) [9]. The fiducial kinematical region was $|\eta| < 0.8$ and $0 < \phi < 2\pi$. Pion tracks were identified via the specific ionization in the TPC gas. The running conditions and the event and track selections are described in detail in Ref. [10].

2.2 Two-pion correlation functions

Experimentally, the two-particle correlation function is defined as the ratio $C(\mathbf{q}) = A(\mathbf{q})/B(\mathbf{q})$, where $A(\mathbf{q})$ is the measured two-pion distribution of pair momentum difference $\mathbf{q} = \mathbf{p}_2 - \mathbf{p}_1$, and $B(\mathbf{q})$ is a similar distribution formed by using pairs of particles from different events.

The limited statistics available allowed us to perform a detailed analysis only for the one-dimensional two-pion correlation functions $C(q_{\text{inv}})$. The q_{inv} is, for identical mass particles, equal to the modulus of the momentum difference $|\mathbf{q}|$ in the pair rest frame.

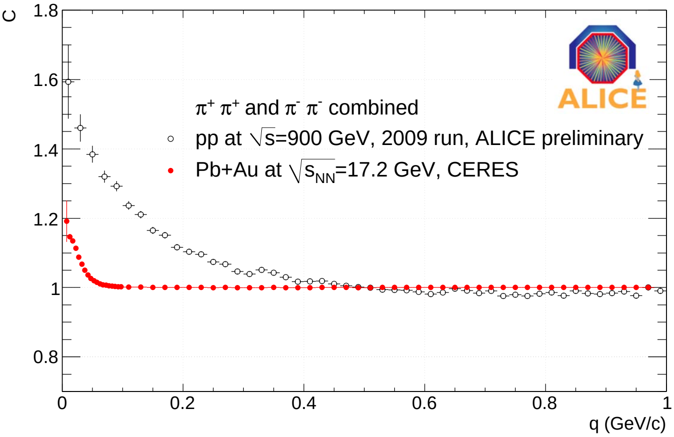

Figure 1: Comparison between the two-pion correlation functions in pp (black open circles) and heavy-ion collisions (red filled dots). Two-track effects, momentum resolution, and Coulomb interaction have to be corrected for in case of nuclear collisions. For hadron collisions, the non-Gaussian shape of the peak and the lack of a well defined flat baseline are the main difficulties.

Figure 1 shows the $\pi^+\pi^+$ and $\pi^-\pi^-$ correlation functions from pp collisions at $\sqrt{s} = 900$ GeV compared to heavy-ion collisions at $\sqrt{s} = 17.2$ GeV. The Bose-Einstein enhancement at low q_{inv} is clearly visible.

In pp collisions, the high q_{inv} part of the correlation function is not flat and it is difficult to separate the Bose-Einstein enhancement from other sources of correlations like those arising from jets or energy and momentum conservation. The situation is different in nuclear collisions where the baseline, i.e. the underlying two-particle correlation without any Bose-Einstein enhancement, is flat and the BE peak can be clearly identified.

Fig. 2 shows the two-pion correlation functions measured by ALICE in pp collisions at $\sqrt{s} = 900$ GeV, as a function of event multiplicity and transverse momentum k_{T} [10]. The denominator of the correlation function was normalized such that the numbers of true and mixed pairs with 0.4 GeV/$c < q_{\text{inv}} <$ 0.6 GeV/c were equal. The q_{inv} range used for normalization was chosen to be outside of the Bose-Einstein peak but as close as possible to it. The normalized distributions of positive and negative pion pairs were added together before building the ratio of true and mixed pairs.

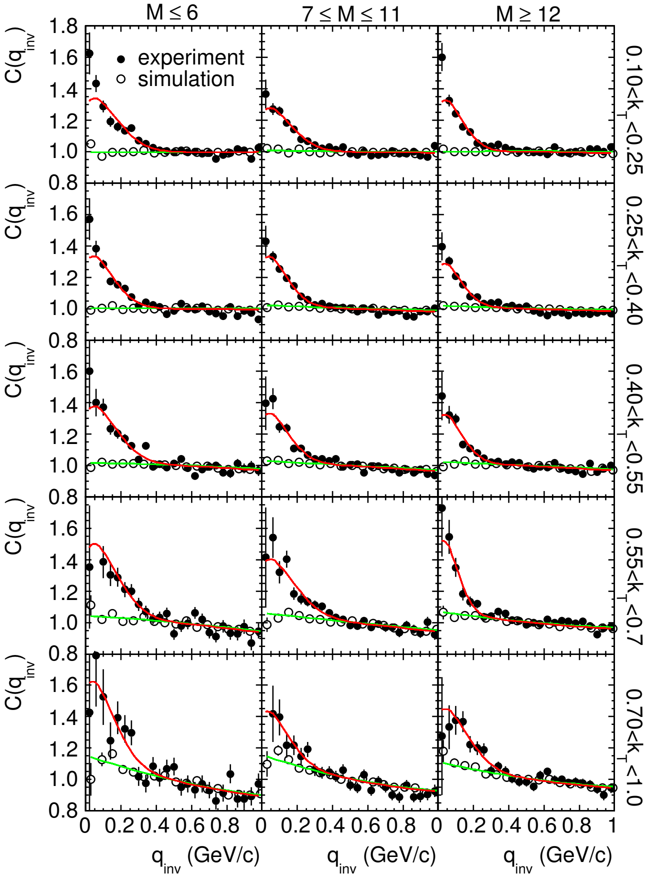

Figure 2: Correlation functions for identical pions from pp collisions at $\sqrt{s} = 900$ GeV (full dots) and those obtained from a simulation using PHOJET (open circles). Positive and negative pion pairs were combined. The three columns represent collisions with different charged-particle multiplicities M; the transverse momentum of pion pairs k_{T} (GeV/c) increases from top to bottom. The lines going through the points represent Gaussian fits as described in the text.

In order to isolate the Bose-Einstein effect from other correlation sources, it is helpful to study the unlike-sign pion correlations for which the Bose-Einstein effect is absent. As displayed in Figure 3, these correlation functions exhibit, in addition to the Coulomb interaction peak at low q_{inv} and the peaks coming from meson decays, broad structures that can be reproduced with Monte Carlo simulations using PHOJET [11] and PYTHIA [12] event generators, combined with a full simulation of the apparatus. The same calculations can thus be used to describe the baseline under the Bose-Einstein peak in the identical-pion correlation function. The fact that the structures are different for the like-sign and unlike-sign pions prevents us from using a ratio of the two correlation functions directly.

The dynamics of the system created in the collision shows up as the dependence of the width of the Bose-Einstein peak on the multiplicity and the transverse momentum. In order to study this dependence quantitatively, and to be able to compare to the existing systematics, the Bose-Einstein peak in the correlation functions was fitted by a Gaussian $G(q_{\rm inv}) = \lambda \exp(-R^2_{\rm inv} q^2_{\rm inv})$ (see lines in Fig. 2), with the correlation strength λ and the HBT radius $R_{\rm inv}$, sitting on a fixed baseline with the shape taken from Monte Carlo as explained above.

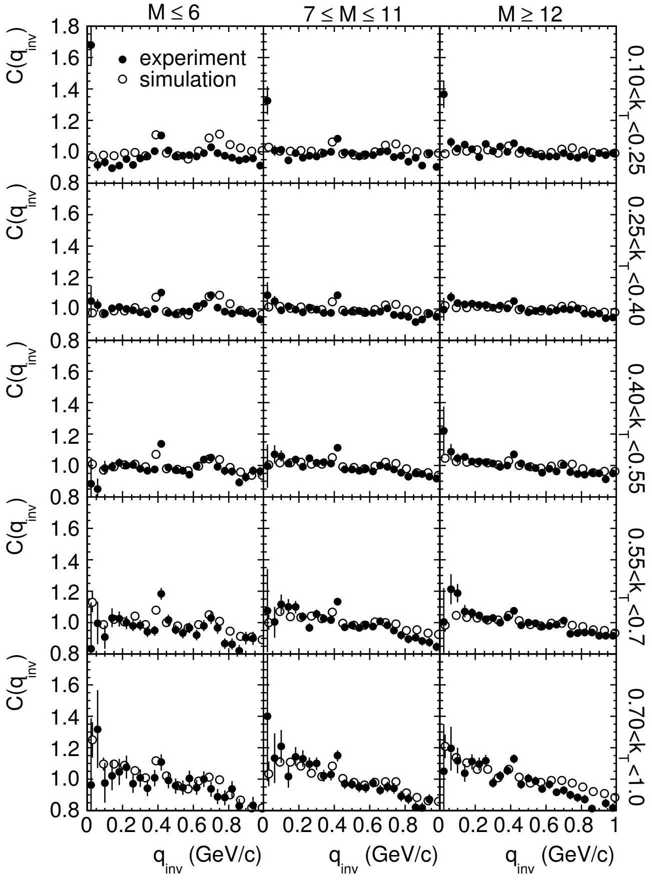

Figure 3: One-dimensional correlation functions for non-identical ($\pi^+\pi^-$) pairs from pp collisions at $\sqrt{s} = 900$ GeV. The columns and rows are defined as in Fig. 2.

3 Multiplicity and transverse momentum dependence

The dependence of the HBT radius on the event multiplicity is shown in the left hand panel of Fig. 4. The tracks used in determining the multiplicity were the same as those used for correlation analysis except that pion identification cuts were not applied. The raw multiplicity was corrected for the reconstruction efficiency and contamination, determined from a Monte

Carlo simulation with the PHOJET event generator and with the full description of the ALICE apparatus.

Like at RHIC and at Tevatron, the ALICE measured HBT radius increases with particle multiplicity. Such an increase is well known in nuclear collisions. Its presence in hadron collisions indicates that the HBT radius is coupled directly to the final multiplicity rather than to the initial collision geometry.

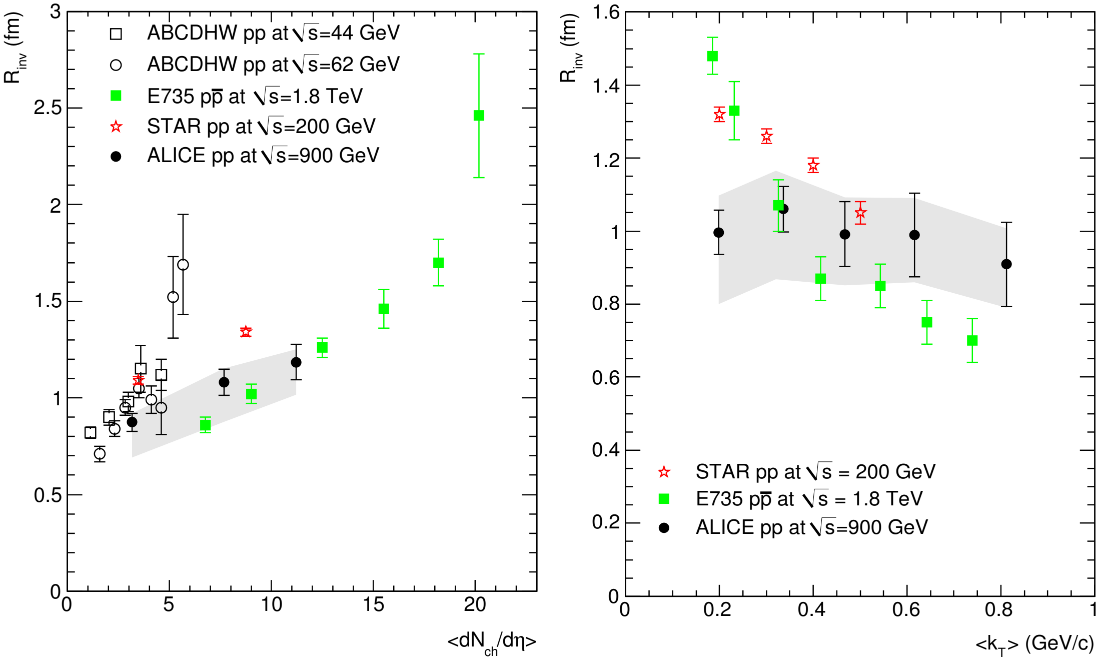

Figure 4: Dependence of HBT radius on multiplicity (left) and transverse momentum $k_T = |\mathbf{p}_{T,1} + \mathbf{p}_{T,2}|/2$ (right). The error bars are statistical and the shaded area represents the systematic errors (for details see Ref. [10]).

The transverse momentum dependence is shown in the right hand panel of Fig. 4. The ALICE measured HBT radius is practically independent of k_T within the studied range. It should be noted that this result crucially depends on the baseline shape assumption, i.e. if the baseline is not taken from event generators but assumed to be flat, then the high k_T points drop by about 30% and an apparent k_T dependence emerges. This is because the broad enhancement caused by other correlations is attributed to Bose-Einstein correlations, giving rise to wider correlation functions which are misinterpreted as smaller radii.

4 Summary

ALICE has measured two-pion correlation functions in pp collisions at $\sqrt{s} = 900$ GeV at the LHC. Consistent with previous measurements of high-energy hadron-hadron and nuclear collisions, the extracted HBT radius R_{inv} increases with event multiplicity. Less consistent is the relation between R_{inv} and the pion transverse momentum where the ALICE measured

HBT radius in minimum-bias events is practically constant within our errors and within the transverse momentum range studied.

References

[1] K. Aamodt *et al.* [ALICE Collaboration], JINST **3**, S08002 (2008).

[2] Z. Chajecki and M. Lisa, Phys. Rev. C **79**, 034908 (2009).

[3] M. M. Aggarwal *et al.* [STAR Collaboration], arXiv:1004.0925 [nucl-ex].

[4] R. Hanbury Brown and R. Q. Twiss, Nature (London) **178**, 1046 (1956).

[5] R. Hanbury Brown and R. Q. Twiss, Philos. Mag. **45**, 663 (1954).

[6] W. Kittel, Acta Phys. Polon. B **32**, 3927 (2001).

[7] G. Alexander, Rep. Prog. Phys. **66**, 481 (2003).

[8] M. A. Lisa, S. Pratt, R. Soltz, and U. Wiedemann, Annu. Rev. Nucl. Part. Sci. **55**, 357 (2005).

[9] J. Alme *et al.*, arXiv:1001.1950 [physics.ins-det].

[10] K. Aamodt *et al.* [ALICE Collaboration], Phys. Rev. D **82**, 052001 (2010).

[11] R. Engel, Z. Phys. C **66**, 203 (1995); R. Engel and J. Ranft, Phys. Rev. D **54**, 4244 (1996).

[12] T. Sjöstrand, S. Mrenna, and P. Z. Skands, JHEP **05**, 026 (2006); P. Z. Skands, arXiv:0905.3418 [hep-ph].