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UNDERLYING EVENT BACKGROUND IN TWO-PION CORRELATIONS IN $p+p$ COLLISIONS AT $\sqrt{s}=0.9$ AND 7 TeV

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When analyzing two-particle correlations for identical pions in $p+p$ collisions at $\sqrt{s}=0.9$ and 7 TeV, significant background correlation structures are observed. The structures are also observed for pairs of nonidentical pions and are reproduced by Monte-Carlo simulations. We analyze these structures quantitatively and propose methods to account for their impact on the system sizes extracted from the fits to the identical pion correlation functions.

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INTRODUCTION

The Large Hadron Collider (LHC) has begun its physics programme by colliding protons at the injection energy of $\sqrt{s}=0.9$ TeV and later moved to collisions at 7 TeV. This data has been analyzed by the LHC experiments, in particular, the size of the particle emitting region has been measured with the two-pion Bose–Einstein femtoscopic[1] correlations technique by the CMS Collaboration [1] and the ALICE Collaboration [2]. One of the main sources of the systematic error in this measurement was the proper treatment of the correlated background. In particular, the ALICE Collaboration has shown that a significant long-range correlation, separate from the femtoscopic one, is observed in the collisions at $\sqrt{s}=0.9$ TeV. In this work we analyze this correlation with much higher statistics data at this energy as well as at $\sqrt{s}=7$ TeV. We perform this analysis in three-dimensional relative momentum q space and check whether such correlation is reproduced by the Monte-Carlo. We also analyze it for pairs of opposite charge pions.

1. DATA ANALYSIS

We show the result on identical and nonidentical pion correlations from the ALICE experiment [3]. The sample of 4.4 million minimum-bias events recorded at $\sqrt{s}=0.9$ TeV and approximately 60 million minimum-bias events recorded at $\sqrt{s}=7$ TeV was analyzed. Events were required to have a reconstructed interaction point (primary vertex) within 10 cm

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[1] The femtoscopic correlations are the ones which come from the pair interaction and can be used to extract the system source size.

of the centre of the ALICE Time Projection Chamber (TPC) in the beam direction. Tracks were measured in the TPC and Inner Tracker System (ITS) for $|\eta| < 1.0$. Pions were identified based on the specific energy loss (dE/dx) of each particle in the TPC. Primary particles were selected based on the distance between the track and the primary vertex. In addition, analysis procedures were applied to suppress the undesired two-track effects, such as splitting (one track mistakenly reconstructed as two) and merging (inability of the detector to distinguish two close tracks, due to finite resolution), but these were small effects overall. For the details of the event selection and the description of particle and event selection, please, see, [2].

The analysis was performed in bins of measured multiplicity $N_{\rm ch}$ and pair transverse momentum $k_{\rm T} = |\mathbf{p}_{\rm T,1} + \mathbf{p}_{\rm T,2}|/2$, as both the femtoscopic correlation as well as the underlying event structures appear to scale with these variables. We present plots for one of the multiplicity bins: where the measured raw multiplicity for $|\eta| < 1.0$ was in the range $(17, 23)$.

In the Monte-Carlo simulations we have used two models. The first was PYTHIA ver. 6 [4], in particular its «Perugia-0» tune [5]. This tune was specifically selected because it reasonably reproduces the correlation structures seen in the data. The second model was PHOJET [6, 7].

2. IDENTICAL PION CORRELATIONS

In Fig. 1 we show the correlation function measured in a selected multiplicity/$k_{\rm T}$ bin, for both energies. The three-dimensional correlations are decomposed into Spherical Harmonics, which allow one to show the three-dimensional object as a collection of one-dimensional histograms. The technique is well suited to identical pion correlations, because thanks to the symmetries of the underlying pair distributions most of the l, m components of the decomposition vanish [8, 9]. The first three nonvanishing components: C_0^0, C_2^0, and C_2^2, which capture most of the important correlation features, are shown in the plot.

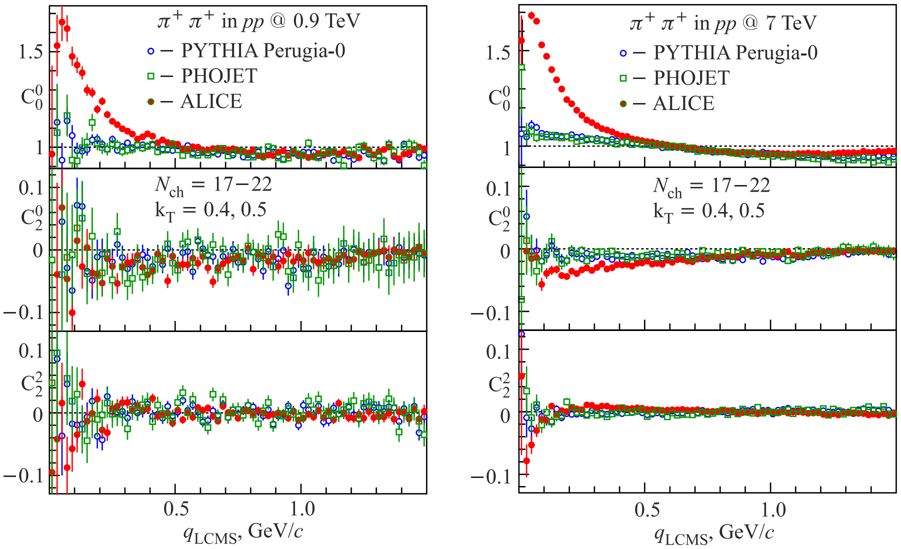

Fig. 1. Spherical harmonics decomposition of the $\pi^+\pi^+$-correlation function for ALICE data, compared to the corresponding Monte-Carlo simulation. Left panel shows data for $\sqrt{s} = 0.9$ TeV; right panel, for 7 TeV

First let us analyze the angle-averaged component C_0^0. The experimental data shows a rapid increase of the correlation below q of 0.5 GeV/c, which comes from the identical pion wave-function symmetrization. The fall in the two lowest bins is the effect of the mutual Coulomb repulsion — it has little influence on the Bose–Einstein peak in general or the extracted system size (radius). This correlation is not seen in the Monte-Carlo, as the two-particle symmetrization effects are not included in the modeling. The structure which is the focus of this study is the broad peak, extending in q from 0 up to at least 1.0 GeV/c. It is clearly seen in the Monte-Carlo at 7 TeV as well, so it apparently is not of femtoscopic origin (i.e., it does not come from the identical boson wave-function symmetrization and cannot be used to extract the source size). It also means that we can try to parameterize it using the Monte-Carlo simulations and then use this parameterization in the fit of the real data. We have tried various functional forms and found that the behavior of the Monte-Carlo correlation, in this and other multiplicity and k_T bins, is acceptably well described by a Gaussian form:

$$B_0^0(q) = N\left[1 + A_h \exp\left(-A_w^2 q^2\right)\right], \tag{1}$$

where A_h and A_w are parameters of the fit. The fit works equally well for both collision energies and yields a comparable correlation width A_w and a correlation strength A_h higher by up to 50% at large pair transverse momentum for the collisions at higher $\sqrt{s}$. The correlation changes significantly with pair momentum: it is practically zero at low pair momentum of about 0.2 GeV/c and has the height of 0.3 at $k_{\rm T}$ of 0.65 GeV/c. It also depends on multiplicity: it is significant at the lowest multiplicity, $N_{\rm ch} < 10$, reaches a maximum at $N_{\rm ch}$ around 15, and then decreases, although slower than $1/N_{\rm ch}$. Even at the highest multiplicity bin in pp collisions at $\sqrt{s} = 7$ TeV, for $N_{\rm ch} > 58$, it is still $1/2$ of the strength at the maximum. The width of the correlation slightly decreases with multiplicity.

The second spherical harmonics component, which is affected by the background, is the C_2^0. For the lower collision energy, the statistics is not sufficient to determine it with certainty, however for the higher energy, the deviation from 0 is clearly visible in Fig. 1 on the right panel. The magnitude of the effect is small, but statistically significant. Similarly to C_0^0, it extends up to q of at least 1.0 GeV/c, but at small q it comes back to 0. We have found that it is well described by a Gaussian depression:

$$B_2^0(q) = B_h \exp\left(-\frac{(q - B_m)^2}{2B_w^2}\right), \tag{2}$$

where B_h, B_m, and B_w are parameters of the fit. The Gaussian has a peak position B_m around 0.5 GeV/c and a magnitude B_h of at most -0.03. The dependence of B_h on multiplicity and pair momentum is qualitatively similar to A_h which strongly suggest that both correlations have the same origin.

In C_2^2, we have not seen significant structures different from 0 in the Monte-Carlo, so it is taken as flat.

3. NONIDENTICAL CORRELATIONS

In the previous section we have shown that the Monte-Carlo simulation describes the long-range nonfemtoscopic correlations seen for identical pions. However, the femtoscopic correlation peak is at least as wide as the region where the data and Monte-Carlo correlations agree, so it is not possible to test this agreement below q of 0.5 GeV/c. The hypothesis for the origin of the long-range correlations is that they are the «minijet» phenomena. If it is correct, similar correlations should also be visible for nonidentical pion pairs. Their advantage is that their femtoscopic effect comes only from their mutual Coulomb interaction and is therefore limited to $q < 0.1$ GeV/c. In Fig. 2, we show the ALICE $\pi^+\pi^-$ correlation function, measured in the same multiplicity and pair momentum range as the identical pion correlations discussed in the previous section. It is compared to the corresponding Monte-Carlo calculation. At low q we observe the expected Coulomb correlation, absent in the Monte-Carlo. We also see some modulations of the smooth Gaussian shape around q of 0.7 GeV/c. These are also present in the Monte-Carlo but at slightly different q and with different magnitude. These correlations have been identified as correlated $\pi^+\pi^-$ pairs coming from the ρ resonance. Peaks from other resonances, like ω, f_0, f_2, etc., can also be seen at other multiplicities. The fact that the Monte-Carlo does not perfectly describe these peaks is also understood as a consequence of the overly simplified treatment of resonance mass modification and rescattering in PYTHIA.

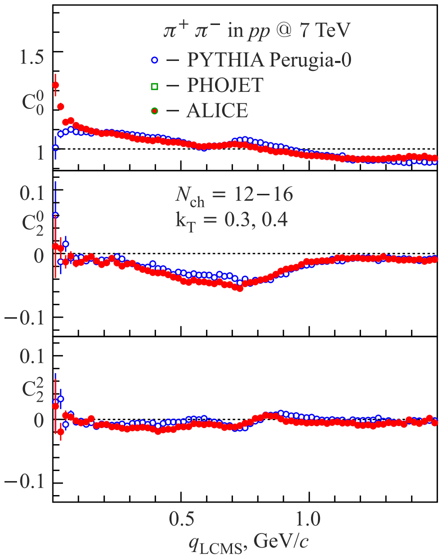

Fig. 2. Spherical harmonics decomposition of the $\pi^+\pi^-$ correlation function for ALICE data, compared to the corresponding Monte-Carlo simulation

Even with all these caveats, we observe long-range correlation structures, similar to the ones for identical pions. They seem to be well described by the Monte-Carlo. They don't have strongly nonmonotonic features at low q, which means that the proposed Gaussian form of the background in Eq. (1) is reasonable. Also the behavior of the C_2^0 component, which is much more prominent in the nonidentical correlations, is well described. The C_2^2 component does have small deviations from zero, but they are located near the resonance peaks, not in the femtoscopic region. This gives us additional confidence that both formulas in Eqs. (1) and (2) will be enough to parameterize the nonfemtoscopic correlations seen in the Monte-Carlo.

4. FINAL FITTING FORM

Having parameterized the long-range nonfemtoscopic correlation structures we can come up with the procedure to fit the femtoscopic component of the identical pion correlation function. We propose to fit the Monte-Carlo simulation, analyzed in the same multiplicity and pair momentum ranges, with Eq. (1) for the C_0^0 component and Eq. (2) for the C_2^0 component. Then one should fix the parameters A_h, A_w, B_h, B_m, and B_w to the values obtained in this fit, and proceed to fit the experimental correlation function with

$$F(\mathbf{q}) = N[1 + C_f(\mathbf{q})][1 + B_0^0(q) + Y_2^0(\mathbf{q})B_2^0(q)], \qquad (3)$$

where N is the overall normalization; C_f is the functional form describing the femtoscopic peak, and Y_2^0 is the $l = 2$, $m = 0$ spherical harmonics coefficient. The systematic error of the fit can be obtained by varying the fixed parameter values in a reasonable range, e.g., in the range that is given by the fits to two independent Monte-Carlo simulations: PYTHIA and PHOJET.

REFERENCES

1. *Khachatryan V. et al. (CMS Collab.)* // Phys. Rev. Lett. 2010. V. 105. P. 032001; arXiv:1005.3294 [hep-ex].
2. *Aamodt K. et al. (ALICE Collab.)* // Phys. Rev. D. 2010. V. 82. P. 052001; arXiv:1007.0516 [hep-ex].
3. *Aamodt K. et al. (ALICE Collab.)* // JINST. 2008. V. 3. P. 08002.
4. *Sjostrand T., Mrenna S., Skands P. Z.* // JHEP. 2006. V. 605 P. 026; arXiv:hep-ph/0603175.
5. *Skands P. Z.* arXiv:0905.3418 [hep-ph]. 2009.
6. *Engel R.* // Z. Phys. C. 1995. V. 66. P. 203.
7. *Engel R., Ranft J.* // Phys. Rev. D. 1996. V. 54. P. 4244; arXiv:hep-ph/9509373.
8. *Chajecki Z., Lisa M.* // Phys. Rev. C. 2009. V. 79. P. 034908; arXiv:0807.3569 [nucl-th].
9. *Kisiel A., Brown D. A.* // Phys. Rev. C. 2009. V. 80. P. 064911; arXiv:0901.3527 [nucl-th].