Research Article

Dihadron Azimuthal Correlations in p - p Collisions at $\sqrt{s_{NN}} = 7$ TeV and p -Pb Collisions at $\sqrt{s_{NN}} = 5.02$ TeV

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The dihadron azimuthal correlations in p - p collisions at $\sqrt{s_{NN}} = 7$ TeV and p -Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV are investigated in the framework of a multisource thermal model. The model can approximately describe the experimental results measured in the Large Hadron Collider. We find the p_x amplitude of the source is magnified and the source translates along the direction.

1. Introduction

The theory of Quantum Chromodynamics (QCD) predicts that a nearly perfect quark-gluon plasma (QGP) is formed in the initial stage of high-energy nuclear collisions. The color-deconfined and thermalized state of strongly coupled quarks and gluons exists for only a short time [1, 2]. Effort to investigate the properties of the QGP is an essential subject of high energy physics. We cannot observe the matter directly in the existing laboratory conditions because it is only created for the briefest of instants. However, we can extract potential information about the QGP by measuring and analyzing the properties of final-state particles produced after thermal freeze-out in high energy collisions.

For these years, dihadron correlations in $\Delta\eta$ and $\Delta\phi$ have been observed in nucleus-nucleus collisions at the Relativistic Heavy Ion Collider (RHIC) and the Large Hadron Collider (LHC) [3–10]. Surprisingly, a ridge structure of hadron correlations was also observed in proton-proton and proton-nucleus collisions. It greatly motivated physicists to further study those small collision systems, which are used as baseline measurements for nucleus-nucleus collisions [11]. A variety of physical models have been proposed to explain the peak structure and discuss the dynamics origin of jet characteristics. These mechanisms include gluon

saturation [12], multiparton interactions [13], and collective expansion of the final state [14]. The fact that the dihadron correlation distribution is different from the one expected in normal nucleon-nucleon collisions may be considered as a consequence of QGP formation [15]. Therefore, the measurement of dihadron correlations opens a new window into the study of the QGP. In this paper, we would like to use a multisource thermal model to investigate the dihadron azimuthal correlations in p - p collisions at $\sqrt{s_{NN}} = 7$ TeV and p -Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, measured recently by the ALICE Collaboration and the CMS Collaboration at the LHC [16–20]. Significance of the work is to verify whether the model can describe the azimuthal correlations of the dihadron for different colliding systems and different particle correlations.

The paper is organized as follows: in Section 2, the multisource thermal model is introduced; in Section 3, we compare the modeling results with the experimental data; at the end, we provide a summary in Section 4.

2. Dihadron Azimuthal Correlation in the Model

According to the multisource thermal model [21–25], identified particles are emitted isotropically from different emission

FIGURE 1: Schematic sketch of momentum space in collisions.

sources formed in the reaction process. Many emission points compose a space of emission sources, which are at local equilibrium states.

The oz axis is defined as the beam direction and the yo plane is defined as the reaction plane. The schematic sketch is given in Figure 1. Many thermal sources of final-state particles are assumed to be formed in high energy collisions. In the rest frame of the source, the particles are emitted isotropically. Due to the interactions between the emissions, the sources will expand and translate. For a dihadron observed in final state, the two particles may be considered to be from two emission coordinates in one source or two sources. In the laboratory reference frame, in momentum space p'_x , p'_y , and p'_z , the particle distributions are given by

$$\begin{aligned} p_x &= \alpha_x p'_x + \beta_x, \\ p_y &= \alpha_y p'_y + \beta_y, \end{aligned} \quad (1)$$

where α_x and α_y indicate the amplitude change of the momenta p'_x and p'_y , respectively; β_x and β_y indicate the translational amplitude along p'_x and p'_y , respectively. In the Monte Carlo calculation, the particle momenta are

$$\begin{aligned} p_x &= \alpha_x \sigma \sqrt{-2 \ln x_1} \cos(2\pi x_2) + \beta_x, \\ p_y &= \alpha_y \sigma \sqrt{-2 \ln y_1} \cos(2\pi y_2) + \beta_y, \end{aligned} \quad (2)$$

where x_1, x_2, y_1 , and y_2 are random numbers in $(0, 1)$ and σ is the standard deviation. The formulation of the azimuthal angle can be written as

$$\varphi = \arctan \left[\sigma \frac{\alpha_y \sqrt{-2 \ln y_1} \cos(2\pi y_2) + \beta_y / \sigma}{\alpha_x \sqrt{-2 \ln x_1} \cos(2\pi x_2) + \beta_x / \sigma} \right]. \quad (3)$$

In the calculation, α_x and β_x are regarded as free parameters; the other parameters are taken to be the defaults.

3. Comparison and Discussion

Figure 2(a) presents dihadron azimuthal correlations in rapidity interval $|\Delta\eta| < 0.9$ for $N_{\text{charged}} = 10$ in p - p collisions at $\sqrt{s_{\text{NN}}} = 7$ TeV [16]. $p_{T,\text{trig}}$ and $p_{T,\text{assoc}}$ ranges are $p_{T,\text{trig}} > 0.7$ GeV/ c and $p_{T,\text{assoc}} > 0.4$ GeV/ c , respectively. The symbols in Figure 2(a-A) denote the experimental data

of the ALICE Collaboration at the LHC [16], and the symbols in Figures 2(a-B), 2(a-C), 2(a-D), and 2(a-E) correspond to results calculated by the Monte Carlo generators PHOJET [26], PYTHIA6 Perugia-2011 [27], PYTHIA8 4C [28], and PYTHIA6 Perugia-0 [27], respectively. The lines in the figure are our results calculated by the multisource thermal model. The values of parameters α_x and β_x with the χ^2 per degree of freedom (χ^2/dof) are shown in Table 1. The p_x amplitude of the source is magnified, and the source translates along the positive p_x direction. The peak at $\Delta\varphi \approx 0$ is visible in the figure.

Figure 3 shows $\Delta\varphi$ dependence of the associated yield per trigger particle for h - p correlations for $1.5 < p_T < 2.0$ GeV/ c for the centrality $(0-20\%)$ – $(60-100\%)$ in p -Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV. The $|\Delta\eta|$ range is averaged over $0.8 < |\Delta\eta| < 1.6$ on the near side and $|\Delta\eta| < 1.6$ on the away side. The symbols denote the data of the ALICE Collaboration at the LHC [17], and the solid line is the modeling result. It is seen that the model can approximately describe the experimental data. The values of parameters α_x and β_x extracted from the fits with the χ^2/dof are shown in Table 1. The p_x amplitude of the source is magnified, and the source translates along a negative direction of p_x . In the figure, there is a double-ridge structure.

Figure 4 presents the baseline-subtracted D meson-charged hadron correlations as a function of $\Delta\varphi$ for $|\Delta\eta| < 1.0$ in p - p collisions at $\sqrt{s_{\text{NN}}} = 7$ TeV (a, b) and p -Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV (c, d), for D mesons with $5 < p_T^D < 8$ GeV/ c and associated hadrons with $p_T^{\text{assoc}} > 0.5$ GeV/ c (a, c), and for $8 < p_T^D < 16$ GeV/ c and $p_T^{\text{assoc}} > 1.0$ GeV/ c (b, d). The symbols denote the data of the ALICE Collaboration [18], and the lines are the modeling results. The modeling results are in approximate agreement with the experimental data. The values of α_x , β_x , and χ^2/dof are listed in Table 1. The p_x amplitude of the source is magnified, and the source translates along the positive p_x direction. In both p - p and p -Pb collisions, the values of α_x and β_x for $5 < p_T^D < 8$ GeV/ c and $p_T^{\text{assoc}} > 0.5$ GeV/ c are smaller than those for $8 < p_T^D < 16$ GeV/ c and $p_T^{\text{assoc}} > 1.0$ GeV/ c . For both collision systems, a double-peak shape can be observed in the figure.

Figure 5 shows dihadron azimuthal correlations for the short-range region ($|\Delta\eta| < 1$) minus long-range region ($|\Delta\eta| > 2$) in p -Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV in the multiplicity ranges $220 \leq N < 260$ (a, c, e) and $0 < N < 35$ (b, d, f). Both p_T^{trig} and p_T^{assoc} intervals are 1–3 GeV. (a, b), (c, d), and (e, f) of Figure 5 correspond to $h^\pm - h^\pm$, $K_S^0 - h^\pm$, and

FIGURE 2: Continued.

FIGURE 2: (a) Dihadron azimuthal correlations in p - p collisions at $\sqrt{s_{\text{NN}}} = 7$ TeV. (b) The ratio of fit to data. The symbols in (a-A) denote the experimental data of the ALICE Collaboration at the LHC [13], and the symbols in (a-B), (a-C), (a-D), and (a-E) correspond to results calculated by the Monte Carlo generators PHOJET, PYTHIA6 Perugia-2011, PYTHIA8 4C, and PYTHIA6 Perugia-0, respectively. The lines are our results calculated by the multisource thermal model.

TABLE 1: Values of α_x and β_x of the calculations in Figures 1–5.

Figure	α_x	β_x	χ^2/dof
Figure 2(A)	1.086	0.093	0.745
Figure 2(B)	1.090	0.120	0.316
Figure 2(C)	1.178	0.150	0.523
Figure 2(D)	1.141	0.130	0.427
Figure 2(E)	1.135	0.150	0.481
Figure 3	1.026	−0.008	0.426
Figure 4(a)	2.305	0.055	0.805
Figure 4(b)	3.025	0.635	0.820
Figure 4(c)	2.865	0.525	0.795
Figure 4(d)	3.205	0.535	0.772
Figure 5(a)	2.025	3.155	0.715
Figure 5(b)	1.380	3.000	0.428
Figure 5(c)	1.790	2.820	0.792
Figure 5(d)	1.080	3.080	0.389
Figure 5(e)	2.380	1.720	0.344
Figure 5(f)	2.280	1.780	0.370
Figure 6(a)	3.785	2.375	0.690
Figure 6(b)	3.355	2.295	0.473

$\Lambda/\bar{\Lambda} - h^\pm$ correlations, respectively. The symbols denote the data of the CMS Collaboration at the LHC [19], and the lines denote the modeling results. The values of α_x , β_x , and χ^2/dof are given in Table 1. The results are in good agreement with the experimental data. The p_x amplitude of the source is magnified, and the source translates along the positive p_x direction. For the three species of particle correlations, the values of α_x in the multiplicity range $220 \leq N < 260$ are greater than those in $0 < N < 35$. From the figure, it is

found that the magnitude of the peak is larger for $K_S^0 - h^\pm$ correlations than for $\Lambda/\bar{\Lambda} - h^\pm$ correlations.

Figure 7 presents the baseline-subtracted two-particle correlations as a function of $\Delta\phi$ for $h^\pm - K_S^0$ and $h^\pm - (\Lambda + \bar{\Lambda})$ correlations in p - p collisions at $\sqrt{s_{\text{NN}}} = 7$ TeV. The trigger particle is $h^\pm$ with p_T in 6–12 GeV/c. (a) and (b) of the figure correspond to associated particles K_S^0 and $\Lambda + \bar{\Lambda}$ with p_T in 1–6 GeV/c, respectively. The symbols denote the experimental

FIGURE 3: $\Delta\phi$ dependence of the associated yield per trigger particle for $h - p$ correlations for $1.5 < p_T < 2.0$ GeV/ c for the event class (0–20%)–(60–100%) in p -Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. The $|\Delta\eta|$ range is averaged over $0.8 < |\Delta\eta| < 1.6$ on the near side and $|\Delta\eta| < 1.6$ on the away side. Systematic uncertainty is less than 5%. The symbols denote the data of the ALICE Collaboration at the LHC [14], and the solid line is the modeling result.

FIGURE 4: The baseline-subtracted D meson-charged hadron correlations as a function of $\Delta\phi$ for $|\Delta\eta| < 1.0$ in p - p collisions at $\sqrt{s_{NN}} = 7$ TeV (a, b) and p -Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV (c, d), for D mesons with $5 < p_T^D < 8$ GeV/ c and associated hadrons with $p_T^{\text{assoc}} > 0.5$ GeV/ c (a, c), and for $8 < p_T^D < 16$ GeV/ c and $p_T^{\text{assoc}} > 1.0$ GeV/ c (b, d). The symbols denote the data of the ALICE Collaboration [15], and the lines are the modeling results.

FIGURE 5: Dihadron azimuthal correlations for the short-range region ($|\Delta\eta| < 1$) minus long-range region ($|\Delta\eta| > 2$) in p -Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV in the multiplicity ranges $220 \leq N < 260$ (a, c, e) and $0 \leq N < 35$ (b, d, f). Both p_T^{trig} and p_T^{assoc} intervals are 1–3 GeV. (a, b), (c, d), and (e, f) of the figure correspond to $h^\pm - h^\pm$, $K_S^0 - h^\pm$, and $\Lambda/\bar{\Lambda} - h^\pm$ correlations, respectively. The symbols denote the data of the CMS Collaboration at the LHC [16], and the lines denote the modeling results.

data of the ALICE Collaboration at the LHC [20], and the lines are the modeling results. The values of α_x , β_x , and χ^2/dof are also given in Table 1. The p_x amplitude of the source is also magnified, and the source translates along the positive p_x direction. The values of α_x and β_x for $\Lambda + \bar{\Lambda}$ are greater than those for K_S^0 . The peak at $\Delta\phi \approx 0$ is visible in the figure.

4. Discussions and Summary

The dihadron azimuthal correlations of different particles for different $|\Delta\eta|$ and p_T intervals in p - p collisions at $\sqrt{s_{NN}} = 7$ TeV and p -Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV have been investigated in the framework of the multisource thermal model. From the above discussions, it is seen that the model can approximately describe the experimental data of LHC. In the model, the parameters α_x and β_x indicate the deformation and displacement of the source along the p_x direction, respectively. In the calculation, different α_x and β_x are taken to fit the experimental data. The results show that the p_x amplitude of the source is magnified and the source translates along the positive p_x direction. In addition, there is a peak structure in all the figures. In momentum space, the thermal-source changes in the x and y directions can be described by α_x and β_y or α_y and β_x , respectively. The parameters $\alpha_x > 1$, $\alpha_x = 1$, and $\alpha_x < 1$ present the source expansion, the source isotropy, and the source

compression in the x direction, respectively. The parameters $\beta_x > 1$ and $\beta_x < 1$ present the source translation along the positive x direction and the negative x direction, respectively.

In the multisource thermal model, a particle pair at final state is assumed to be emitted from the two points in a single source or two sources formed in the reaction process. One point projects the “trigger” particle and the other point projects the “associated” particle. There are interactions between the two emission points, which lead to the two-particle azimuthal correlation. The model can be used to describe the dihadron azimuthal correlation. The modeling results reveal a multisource production phenomenon in the colliding process. In fact, the model has also been employed to describe the (pseudo)rapidity, elliptic flow, and multiplicity distributions of the final-state particles [29, 30]. The analysis of dihadron azimuthal correlations in the high energy collisions is expected to provide important input for the underlying mechanism of the particle production. It is of great significance to discuss the dihadron azimuthal correlations of different types of colliding systems and different types of particle pair.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

FIGURE 6: The ratio of fit to data in Figure 5.

FIGURE 7: The baseline-subtracted two-particle correlations as a function of $\Delta\phi$ for $h^\pm - K_S^0$ and $h^\pm - (\Lambda + \bar{\Lambda})$ correlations in $p\text{-}p$ collisions at $\sqrt{s_{\text{NN}}} = 7$ TeV. The symbols denote the experimental data of the ALICE Collaboration at the LHC [17], and the lines are the modeling results.

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