Results of femtoscopic correlations at CMS

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Abstract. The two particle correlations as a function of relative momenta of identified hadrons involving K^0_S and $\Lambda/\overline{\Lambda}$ are measured in PbPb collisions at $\sqrt{s_\mathrm{NN}} = 5.02$ TeV with the data samples collected by the CMS experiment at the LHC. Such correlations are sensitive to the quantum statistics and possible final state interactions between the particles. The source radii are extracted from $\mathrm{K}^0_\mathrm{S}\mathrm{K}^0_\mathrm{S}$ correlations in different centrality regions and found to decrease from central to peripheral collisions. The strong interaction scattering parameters are extracted from $\Lambda\mathrm{K}^0_\mathrm{S} \oplus \overline{\Lambda}\mathrm{K}^0_\mathrm{S}$ and $\Lambda\Lambda \oplus \overline{\Lambda\Lambda}$ correlations using the Lednicky-Lyuboshits model, and compared with other experimental and theoretical results. In addition, we present results for the source radii of charged hadrons considering the Lévy type source distributions in PbPb collisions at $\sqrt{s_\mathrm{NN}} = 5.02$ TeV.

1 Introduction

Identical and nonidentical particle short-range correlations in relative momentum, known as "femtoscopic" correlations, can be used to study the space-time extent of the particle emitting source created in relativistic heavy ion collisions [1]. The identical particle correlations are sensitive to quantum statistics (QS) and to possible final-state interactions (FSI), while nonidentical particle correlations are only sensitive to final state interactions. The correlations among the neutral K^0_S, Λ, and $\overline{\Lambda}$ particles, collectively referred to as V^0 particles, are of specific interest. They can be used to extract the size of the particle-emitting source, and, in a way complementary to dedicated scattering experiments, the strong-interaction parameters, i.e., the scattering length and the effective range. Because of their heavy mass and absence of Coulomb interactions, femtoscopy based on K^0_S particles complements the more commonly studied charged hadrons femtoscopy. By studying $\Lambda\mathrm{K}^0_\mathrm{S}(\overline{\Lambda}\mathrm{K}^0_\mathrm{S})$ and $\Lambda\Lambda(\overline{\Lambda\Lambda})$ correlations, it is possible to extract the strong interaction scattering parameters for baryon-meson and baryon-baryon systems, which can shed light on the nature of the strong interaction.

Generally, in femtoscopic measurements, Gaussian source distributions are assumed. However, recent high precision correlation measurements at the BNL RHIC facility for gold-gold (AuAu) collisions at $\sqrt{s_\mathrm{NN}} = 200$ GeV have shown that the Gaussian approximation is not adequately reproduce the measured results [2]. Therefore, Lévy alpha-stable distribution, characterized by the Lévy-exponent α is introduced.

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This note presents the $\mathrm{K^0_SK^0_S}$, $\Lambda\mathrm{K^0_S} \oplus \overline{\Lambda}\mathrm{K^0_S}$, $\Lambda\Lambda \oplus \overline{\Lambda\Lambda}$ and charged hadron femtoscopic correlations in lead-lead (PbPb) collisions at center-of-mass energy per nucleon pair of $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV using the data recorded by the CMS [3] experiment at the LHC. The $\mathrm{K^0_SK^0_S}$ and charged hadron correlations were measured in the extended range of centrality bin (0–60%), where centrality is defined as the fraction of the total nucleus-nucleus cross section, with 0% denoting the maximum overlap of the colliding nuclei. The charged hadron correlations were measured with considering the Lévy type source distributions. The $\Lambda\mathrm{K^0_S}\oplus\overline{\Lambda}\mathrm{K^0_S}$ and $\Lambda\Lambda\oplus\overline{\Lambda\Lambda}$ correlations were measured in centrality range 0–80%.

2 $\mathrm{K^0_SK^0_S}$, $\Lambda\mathrm{K^0_S} \oplus \overline{\Lambda}\mathrm{K^0_S}$, and $\Lambda\Lambda \oplus \overline{\Lambda\Lambda}$ femtoscopic correlations

The left panel of figure 1 shows the $\mathrm{K^0_SK^0_S}$ correlation measurement as a function of relative momenta of the particle pair q_{inv} [1, 4] in 20–30% centrality with $0 < k_T < 2.5$ GeV, where $k_T \equiv |\vec{p}_{\mathrm{T},1} + \vec{p}_{\mathrm{T},2}|/2$ is the average transverse momentum of the pair [4]. The size of the particle-emitting source R_{inv} extracted from $\mathrm{K^0_SK^0_S}$ correlation using the Lednicky-Lyuboshits fit [5] together with nonfemtoscopic background [4] for different centrality ranges and plotted in the right panel of figure 1 [4]. It can be seen that R_{inv} decreases from central (0–10%) to peripheral (50–60%) events, as expected from a simple geometric picture of the collisions. The values of R_{inv} as extracted by considering only the QS effect are larger than those found from considering both QS and FSI effects, which suggests that the FSI effect needs to be consider for the accurate measurement of R_{inv}.

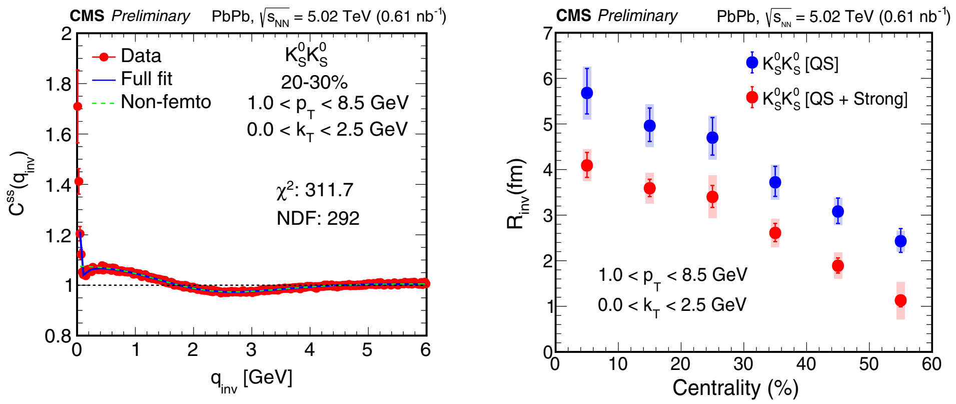

Figure 1. Left: An example of correlation measurement and their fit for $\mathrm{K^0_SK^0_S}$ in 20–30% centrality. In this panel, red circles are the experimental results, the blue solid line is the full fit [4], and the green dotted line is the nonfemtoscopic background [4]. Right: R_{inv} as a function of centrality by considering only the QS (blue circles) and both the QS and strong FSI effects (red circles). For each data point, the line and shaded area indicate the statistical and systematic uncertainties, respectively.

Figure 2 shows the $\Lambda\mathrm{K^0_S} \oplus \overline{\Lambda}\mathrm{K^0_S}$ (left) and $\Lambda\Lambda \oplus \overline{\Lambda\Lambda}$ (right) correlation measurements in $0-80\%$ centrality with no restriction on k_T [4]. The strong-interaction scattering parameters: real scattering length ($\Re f_0$), imaginary scattering length ($\Im f_0$), and effective range (d_0), were extracted from the $\Lambda\mathrm{K^0_S} \oplus \overline{\Lambda}\mathrm{K^0_S}$ and $\Lambda\Lambda \oplus \overline{\Lambda\Lambda}$ correlations using Lednicky-Lyuboshits fit [5]. Figure 3 shows d_0 versus $\Re f_0$ (left) and $\Im f_0$ versus $\Re f_0$ (right). Comparisons to theoretical calculations and results from other experiments are shown [6–10]. The negative value of $\Re f_0$ in $\Lambda\mathrm{K^0_S} \oplus \overline{\Lambda}\mathrm{K^0_S}$ correlations suggests that the $\Lambda\mathrm{K^0_S}$ ($\overline{\Lambda}\mathrm{K^0_S}$) interaction is repulsive while $\Im f_0$

is consistent with zero within uncertainty, preventing us from drawing any conclusion about inelastic processes [4]. A positive $\Re f_0$ value for the $\Lambda\Lambda \oplus \overline{\Lambda\Lambda}$ correlations indicates that the $\Lambda\Lambda(\overline{\Lambda\Lambda})$ interaction is attractive.

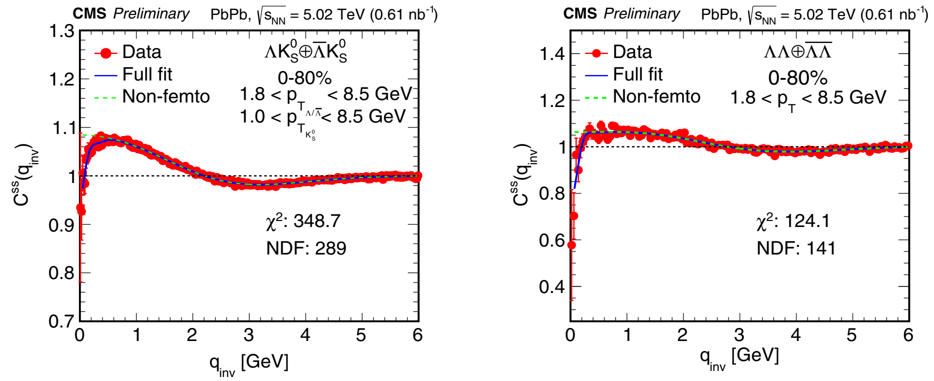

Figure 2. The correlation measurements and their fits for $\Lambda K^0_S \oplus \overline{\Lambda} K^0_S$ (left) and $\Lambda\Lambda \oplus \overline{\Lambda\Lambda}$ (right)in 0–80% centrality. In these plots, red circles are the experimental results, the blue solid line is the full fit, and the green dotted line is the nonfemtoscopic background fit [4]. For each data point, the line indicate the statistical uncertainties.

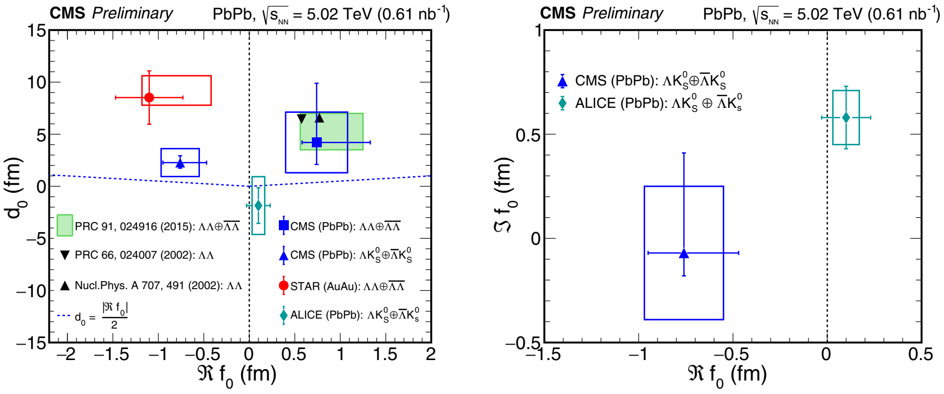

Figure 3. The values of d_0 and $\Re f_0$ (left) and the values of $\Im f_0$ and $\Re f_0$ (right). In the left plot, the blue triangle and square marker are for $\Lambda K^0_S \oplus \overline{\Lambda} K^0_S$ and $\Lambda\Lambda \oplus \overline{\Lambda\Lambda}$ correlations, respectively. The results are compared with the $\Lambda\Lambda \oplus \overline{\Lambda\Lambda}$ results from STAR experiment [7] and $\Lambda K^0_S \oplus \overline{\Lambda} K^0_S$ result from ALICE experiment [6]. A reanalysis of STAR data for $\Lambda\Lambda \oplus \overline{\Lambda\Lambda}$ correlations is shown in the shaded area [8]. Theory calculations of the $\Lambda\Lambda$ interaction parameters are shown as black triangles [9, 10]. In the right plot, the triangle is for $\Lambda K^0_S \oplus \overline{\Lambda} K^0_S$ correlation, and is compared with ALICE $\Lambda K^0_S \oplus \overline{\Lambda} K^0_S$ results [6]. For each data point, the two lines and the box indicate the (one-dimensional) statistical and systematic uncertainties, respectively.

3 Charged hadron femtoscopic correlations

Figure 4 shows the source size $R \equiv R_{\mathrm{inv}}$ versus the transverse mass m_T in different centrality classes for positive (left) and negative (right) hadron pairs considering the Lévy type source distributions. [2]. It can be seen that R decreases with m_T for both positive and negative pairs, which is expected from hydrodynamics [2]. A clear centrality dependence is also visible similar to $\mathrm{K_S^0K_S^0}$ pairs in Fig. 1.

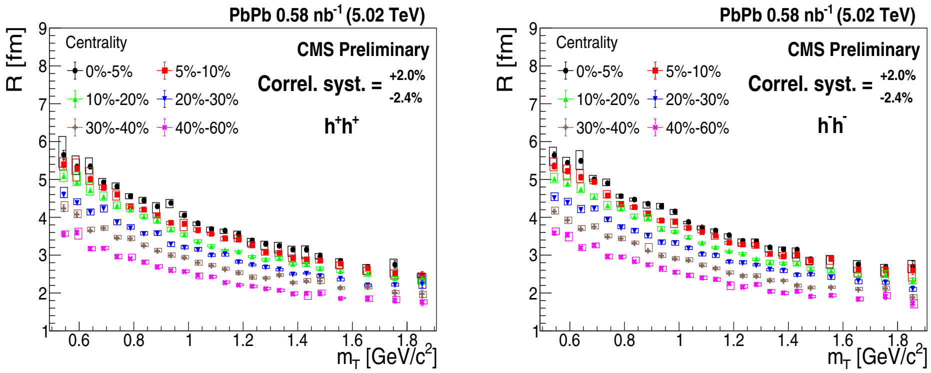

Figure 4. Source size R versus the transverse mass m_T in different centrality classes for positive (left) and negative (right) hadron pairs. The error bars are the statistical uncertainties, while the boxes indicate the systematic uncertainties. The correlated systematic uncertainty is also indicated.

4 Summary

The identified hadrons femtoscopic correlation ($\mathrm{K_S^0K_S^0}$, $\Lambda\mathrm{K_S^0} \oplus \overline{\Lambda}\mathrm{K_S^0}$, and $\Lambda\Lambda \oplus \overline{\Lambda\Lambda}$) and charged hadron femtoscopic correlations are presented in PbPb collisions at a center-of-mass energy per nucleon pair of $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV, as measured by the CMS experiment at the LHC. This is the first report of $\Lambda\Lambda \oplus \overline{\Lambda\Lambda}$ correlations in PbPb collisions. The source size as a function of centrality as extracted for $\mathrm{K_S^0K_S^0}$ and charged hadron correlations show similar behavior. The Lednicky-Lyuboshits model fit to the data suggests that the $\Lambda\Lambda \oplus \overline{\Lambda\Lambda}$ interaction is attractive, whereas the $\Lambda\mathrm{K_S^0} \oplus \overline{\Lambda}\mathrm{K_S^0}$ interaction is repulsive.

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