Bulk flow and correlation measurements at LHCb

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Abstract. Particle correlations are a powerful tool to study the properties of the bulk nuclear matter produced in relativistic heavy ion collisions. The momentum correlations between identical particles originating from the same particle-emitting source, referred to as the Bose-Einstein correlations, measure scales that are related to the geometrical size of the source. The two-particle azimuthal angular correlations measure the spatial anisotropy of produced particles, providing information on collective phenomena arising in the dense nuclear medium. This contribution will discuss new LHCb measurements of Bose-Einstein correlations and, for the first time, the collective flow coefficients in the far forward rapidity region.

1 Introduction

This presentation shows the latest results of two-particle correlations in momentum and spatial spaces. The four-momentum correlations of identical particles, known as the Bose-Einstein correlations (BEC), are used to study the space-time properties of the particle emitting source. The latest BEC results from the LHCb experiments analyzed data of pPb and Pbp collisions at the center-of-mass energy of 5.02 TeV collected in 2013 [1]. The integrated luminosities of the pPb and Pbp datasets are 1.06 nb^{-1} and 0.52 nb^{-1}, respectively. The BEC in small systems, such as pPb and Pbp with a shorter lifetime compared to AA collisions, give information on the early system dynamics and the initial geometry. The forward region at $\eta > 2$ also contains information on particle production processes.

The measurement of spatial anisotropy of the final particles, known as flow, is used to study the initial- and final-state effects, evolution, and transport properties of the quark gluon plasma. Peripheral PbPb data at the center-of-mass energy of 5.02 TeV corresponding to an integrated luminosity of 214 μb collected in 2018 is used to measure forward flow using the two-particle angular correlation (2PC) technique [2]. The flow measurement in the forward direction that is heavily affected by the non-equilibrium hadronic phase [3] can test the limits of hydrodynamics and transport models.

These BEC and 2PC results in the forward pseudorapidity from the LHCb experiment also complement central pseudorapidity results from other LHC experiments.

2 Bose-Einstein Correlations

The four-momentum correlations of same-sign charged pions are the ratio of the charged pion pair from the same events to the correlations of the charged pion pair from different

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events. This technique is known as event-mixing. The four-momentum correlations ($C_2(Q)$) are modeled using Bowler-Sinyukov formalism [4, 5], which includes the Coulomb interaction term ($K(Q)$) for point-like source, and the non-femtoscopic background contributions ($\Omega(Q)$) that are estimated using opposite-sign charged pion pair correlations. The corrected four-momentum correlations are written as

$$C_2(Q) = N\,[1 - \lambda + \lambda K(Q) \times C_{2,BEC}(Q)] \times \Omega(Q)\,, \tag{1}$$

where N is the normalization parameter, and λ is the intercept parameter that describes the correlation strength. The function, $C_{2,BEC}(Q)$, in Eq. (1) describes the BEC in the form of a Lévy-type correlation with the Lévy index of stability set to 1 [6], that is

$$C_{2,BEC}(Q) = 1 + e^{-|RQ|}\,, \tag{2}$$

where R is the correlation radius that is treated as the effective size of the particle emitting source.

Figure 1 shows the correlation radius and the intercept parameter as a function of track multiplicity, N_{VELO}, measured by the vertex locator (VELO) [7]. The correlation radius increases with track multiplicity indicating a larger particle-emitting source of the high multiplicity events. This relation can be described by a hydrodynamics-like function, $R \propto \sqrt{N_{\mathrm{VELO}}}$, as drawn as solid lines on the left of Fig. 1. The correlation radius is systematically larger in Pbp collisions than pp or pPb collisions, hinting at a larger particle-emitting source of Pbp events than pp or pPb events. However, the uncertainty prevents a precise conclusion. The intercept parameter decreases with track multiplicity indicating that the correlation strength decreases in high multiplicity events.

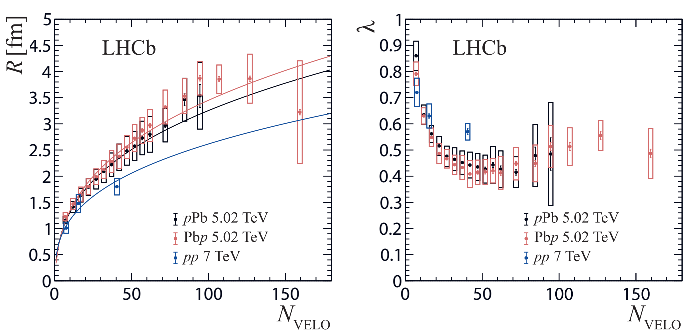

Figure 1. Left: correlation radius as a function of charged track multiplicity. Right: intercept parameter as a function of charged track multiplicity [1].

3 Two-particle correlations

The two-dimensional and one-dimensional angular correlations of two charged particles are obtained using the event-mixing technique. The two-dimensional angular correlations are plotted as a function of $\Delta\eta$ and $\Delta\phi$, which are the relative pseudorapidity and relative azimuth, respectively, between two charged particles. The one-dimensional angular correlations are plotted as a function of $\Delta\phi$. Fig. 2 shows an example of the $\Delta\eta$–$\Delta\phi$ correlation in PbPb collisions in the centrality range between 65% and 75%, and $1 < p_T < 2$ GeV. A prominent peak is observed at $(\Delta\eta, \Delta\phi) = (0, 0)$ due to short-range nonflow contributions, such as collimated jets. Ridges are observed in near- ($\Delta\phi = 0$) and away-side ($\Delta\phi = \pi$). The near-side ridge that is the sign of particle flow is more pronounced compared to the high-multiplicity pPb and Pbp events [8], indicating stronger particle flow in peripheral PbPb events.

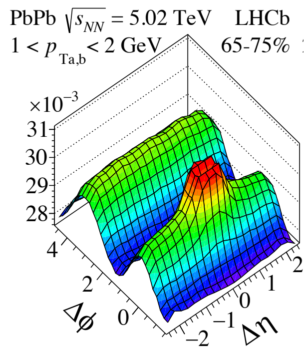

Figure 2. Two dimensional $\Delta\eta - \Delta\phi$ correlation of forward charged particles in peripheral PbPb collisions [9].

The azimuth correlations, $C(\Delta\phi)$, require $|\Delta\eta| > 1$ to avoid short-range nonflow contributions. The azimuth correlations are fitted with a Fourier series included the first three term of harmonics. The Fourier series is written as

$$C(\Delta\phi) = A\left[1 + 2\sum_{n=1}^{3} V_n(p_{Ta}, p_{Tb})\cos(n \cdot \Delta\phi)\right], \tag{3}$$

where A and $V_n(p_{Ta}, p_{Tb})$ are extracted from the fit. The coefficient $V_n(p_{Ta}, p_{Tb})$ of the n^{th} ($n = 1, 2, 3$) term for a pair of particles a and b with transverse momenta of p_{Ta} and p_{Tb}, respectively, can be factorized to

$$V_n(p_{Ta}, p_{Tb}) = v_n^a(p_{Ta}) \cdot v_n^b(p_{Tb}), \tag{4}$$

where $v_n^a(p_{Ta})$ ($v_n^b(p_{Tb})$) is the n^{th} flow harmonic coefficient of particle a (b). The second- and third-order flow harmonics coefficients are extracted following the procedure in Ref. [10], and plotted as a function of p_T in Fig. 3. However, the first-order flow harmonic coefficient is not reported due to concern of factorization breaking in Eq. (4) [11, 12].

Figure 3 shows forward v_n as a function of p_T in the peripheral PbPb events. The forward v_n rises at p_T below 2.5 GeV, then falls at high p_T. These rising and falling features are also observed in the central pseudorapidity v_n measured by ALICE and ATLAS in similar centrality ranges. However, the forward v_n is smaller than the central pseudorapdity v_n. This difference in v_n could be caused by the stronger influence of the hadronic phase in the forward region that suppresses particle flow. This difference due to pseudorapidity reduces in more peripheral events. The multi-phase transport model (AMPT) [13, 14] overestimates v_n at p_T below 2.5 GeV, indicating that refinement on parton density and flow model in AMPT may be needed.

4 Summary

This presentation showed the new results of two-particle correlations in the momentum- and azimuth-space from the LHCb. The BEC results show the size of the particle emitting source

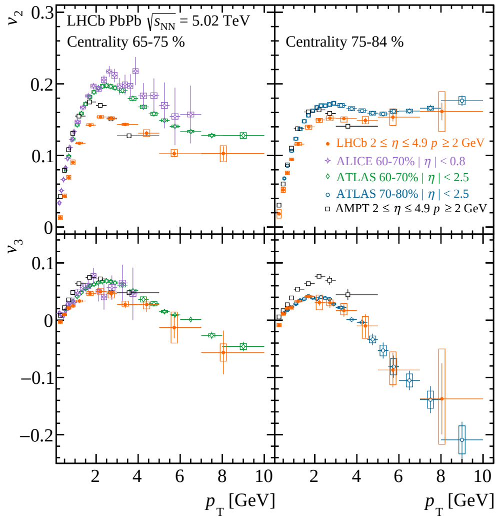

Figure 3. Second- and third-order flow harmonic coefficients of charged particles as a function of transverse momentum in peripheral PbPb collisions [9].

increases with charged track multiplicity. Moreover, these new BEC results hint at larger system size in Pb*p* collisions compared to *p*Pb and *pp* collisions. The flow harmonic coefficients of forward charged hadrons are presented by the LHCb for the first time. The smaller flow harmonic coefficients in the forward region than the central pseudorapidity hints at weaker flow in the forward region due to stronger influences of the hadronic phase. These forward flow results will help constraint theory models in the hadronic phase dominated region.

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