MEASUREMENTS OF COLLECTIVITY IN THE FORWARD REGION AT LHCb*

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Particle flow measurements, which provide evidence of the QGP medium, are a powerful tool to study the QGP evolution in heavy-ion collisions. Using the two-particle correlation technique, the LHCb has observed the ridge structure due to particle flow, in the forward pseudorapidity range of $2 < \eta < 5$ alongside the leading jet peak in long-range correlations ($|\Delta\eta| > 2$). This paper will detail the analysis of the ridge structure in pPb/Pbp collisions at 5 TeV and the results, which show that the ridge structure is more pronounced in the low transverse momentum region and the high-multiplicity events where the collective flow property of QGP may be significant. This presentation will also include the details of new LHCb analyses to extract the flow harmonics in the forward region.

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1. Introduction

The asymmetric collisions at the LHCb can reach both low- and high-x as shown in figure 1. The forward region, in which the LHCb is specialized, is sensitive to gluon saturation which is suspected to be the cause of particle correlations seen in peripheral collisions. However, the highest particle densities and multiplicities reached in pPb may share the signatures, such as particle flow, as in heavy-ion collisions. Therefore, the pPb/Pbp results are valuable for different physics interests and help distinguish different nuclear matter effects. This presentation shows the angular correlations results of charged hadrons in both pPb and Pbp collisions at 5 TeV to explore potential flow phenomena in low- and high-x regions.

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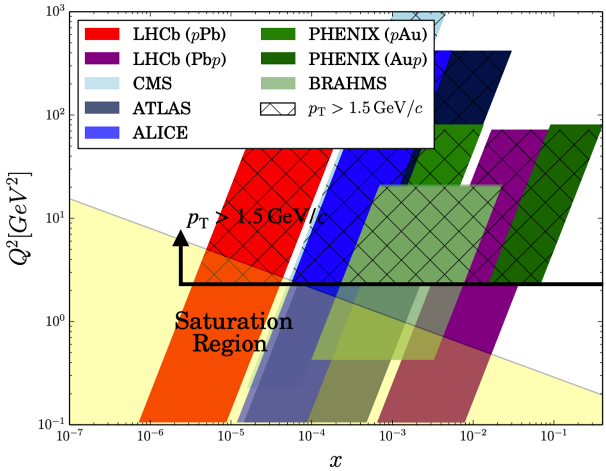

Fig. 1. Q^2–x ranges in different experiments.

2. Azimuthal correlations

The pPb (Pbp) data, which were collected in 2013, had an integrated luminosity of 0.46 nb^{-1} (0.3 nb^{-1}). The LHCb detector covers rapidity between 1.5 and 4.4 (-5.4 and -2.5). Ten activity classes are determined by dividing the distribution of hits at the vertex locator (VELO) [1] in each event evenly, as shown in figure 2. Note that the activity class determinations are done separately for pPb and Pbp data. Therefore, the same activity classes in pPb and Pbp may have different multiplicity distributions.

The angular correlations are obtained using two-particle correlations. Charged tracks with a pseudorapidity between 2 and 4.9, a transverse momentum greater than 0.15 GeV$/c$, and a reconstructed vertex within 1.2 mm away from the reconstructed primary vertex are selected. The correction is applied on each track to account for the detector tracking efficiency, fake track rate, and the rate of secondary particles [2].

Figure 3 shows the $\Delta\phi$–$\Delta\eta$ correlations of charged tracks with a transverse momentum between 1 and 2 GeV$/c$ in two different activity classes. This figure shows clear long-range structures, known as the ridge, in the away-side ($\Delta\phi \approx \pi$). In the near-side ($\Delta\phi \approx 0$), there are pronounced jet-like peaks in both activity classes, but the ridge only emerges in the high-multiplicity events. In the same p_T range and activity classes, the similar ridge and jet-like structures are observed in both near- and away-side using Pbp data as shown in figure 4. Like the pPb data, no ridge structure is shown on the near-side in low-multiplicity events, but it is observed in the high-multiplicity events.

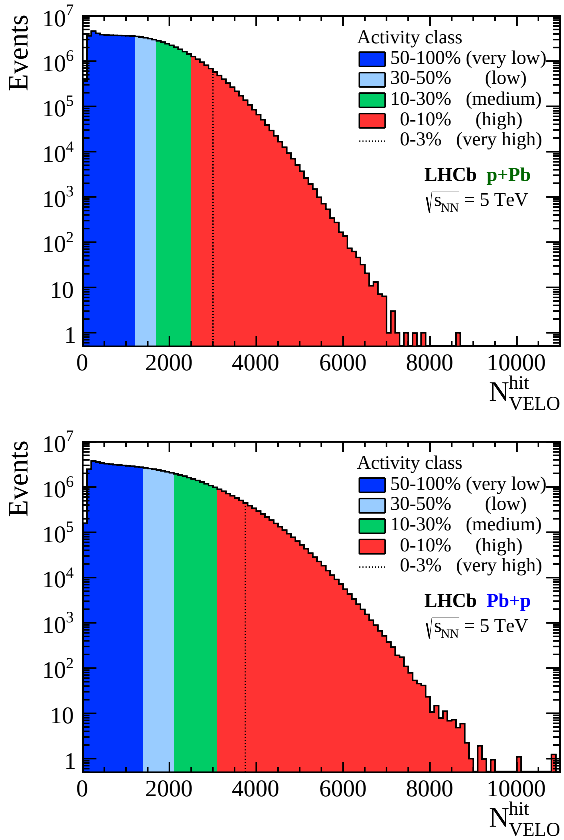

Fig. 2. (Color online) Number of VELO hits distributions of pPb (top) and Pbp (bottom) events. Activity classes are shown in different colors [2].

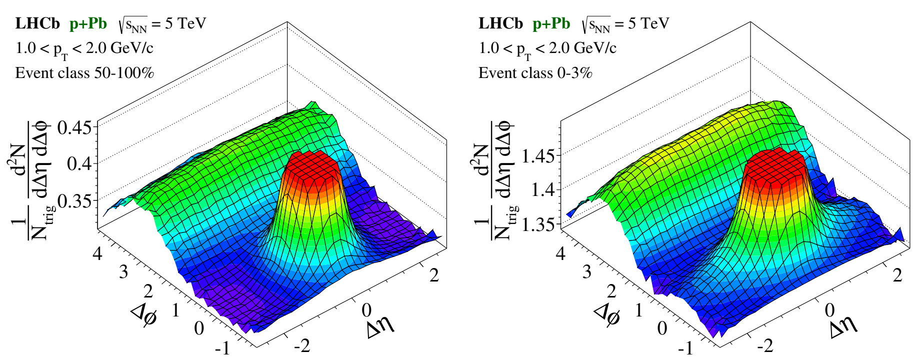

Fig. 3. $\Delta\phi$–$\Delta\eta$ correlations in pPb collisions in 50–100% (left) and 0–3% (right) activity classes [2].

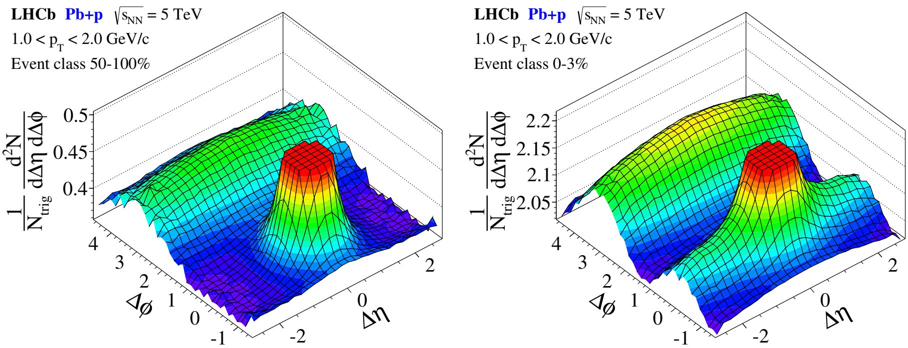

Fig. 4. $\Delta\phi$–$\Delta\eta$ correlations in Pbp collisions in 50–100% (left) and 0–3% (right) activity classes [2].

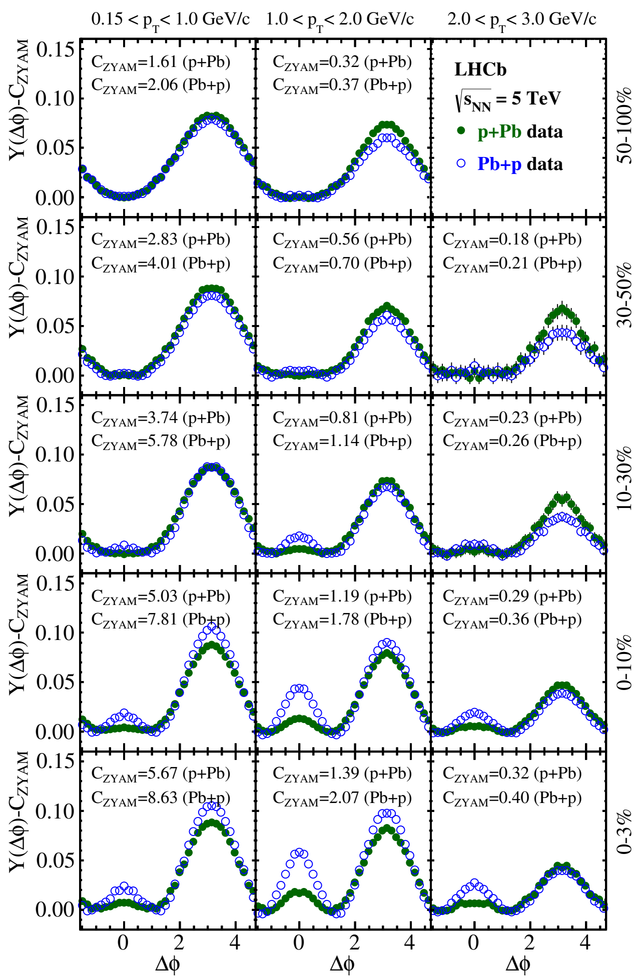

Fig. 5. Azimuthal correlations in pPb and Pbp collisions [2].

The $\Delta\phi$ correlations, which are shown in figure 5, are the projection of the $\Delta\phi$–$\Delta\eta$ correlations shown in figures 3 and 4 with an integration range of $2 \leq \Delta\eta \leq 2.9$. The backgrounds are subtracted using zero yield at the minimum (ZYAM) method [3, 4] with a flat background model. Figure 5 shows that the away-side peaks appear in both pPb and Pbp data, but decrease as track p_{T} increases. Comparing the pPb and Pbp results, the away-side peaks are higher in pPb than in Pbp data at high p_{T} in low-multiplicity events, but the away-side peaks become higher in Pbp than in pPb at low p_{T} in high-multiplicity events. While the away-side peaks are pronounced in different activity classes, the near-side peaks emerge as multiplicity increases. The near-side peaks are higher in the Pbp data than pPb and the amplitude changes with track transverse momentum. These plots show that there are differences in the angular correlations between high-multiplicity pPb and Pbp events, which correspond to low- and high-x regions.

3. Outlook of flow studies at the LHCb

The coming flow studies at the LHCb focus on extracting the flow harmonics coefficients. These studies include charged hadron flow in PbPb data at 5 TeV and pPb/Pbp at 8 TeV, as well as J/ψ flow in pPb/Pbp at 8 TeV. The PbPb data collected in 2018 have an integrated luminosity of 228 μb^{-1}. The pPb/Pbp data collected in 2016 have a combined integrated luminosity of 34.4 nb^{-1}. Finer activity classes can be used as the statistics are higher in the 2016 data compared to the studies in Section 2. One of the highlights of these studies will be the first-order harmonics, v_1, in the forward region as forward v_1 is expected to be stronger than in the mid-rapidity.

The J/ψ flow study will help understand the initial-state effect at low-x. The ALICE results show that the J/ψ v_2 in pPb agree with the PbPb results within the sizable uncertainties [5]. The LHCb, which is designed for heavy-flavor measurements, can provide J/ψ flow results with higher precision to separate potential differences between pPb and PbPb collisions.

The fixed target experiments, known as SMOG, at the LHCb can help bridge the gap between small and large collision systems. The ready-to-analyse SMOG data include three different gases (neon, helium, and argon), three center-of-mass energies (68.6, 86.6, and 110 GeV) and x close to 0.1. The SMOG data have the potential to disentangle cold and hot nuclear matter effects.

4. Summary

To summarize, this paper presented the forward ($2 < \eta < 4.9$) charged particle angular correlations in pPb and Pbp collisions at 5 TeV at the LHCb. The results show that the pronounced away-side peaks of the azimuthal correlations appear in both pPb and Pbp collisions. However, the near-side peaks emerge in higher-multiplicity events with a higher amplitude in Pbp collisions. These differences between the pPb and Pbp events will help understand the particle flow phenomena in low- and high-x regions.

Particle-flow measurements are expanding at the LHCb. The ongoing studies focus on extracting the flow harmonic coefficients. The LHCb, which benefits from the forward detector design, is expected to observe a strong first-order flow harmonic. The LHCb could provide high statistics in J/ψ flow measurements to separate potential initial- and final-state effects. The SMOG data from the LHCb will give additional constraints on the models of cold and hot nuclear matter effects.

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