Measurements of collectivity in the forward region at LHCb

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on behalf of the LHCb collaboration

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Particle Flow in Asymmetric Collisions

QGP droplets in small systems?

The highest particle densities and multiplicities reached in pPb at the LHC are of a similar size to those in peripheral AA collisions. Looking for signatures which were so far mainly studied in AA collisions.
Particle Flow in Asymmetric Collisions

LHCb can reach $x \approx 10^{-6}$ for pPb and $x \approx 10^{-2}$ for Pbp

Forward region is sensitive to gluon saturation

Particle correlations induced by gluon saturation

Using charged hadron correlations in pPb and Pbp at 5 TeV
Charged Hadron Correlations

- Construct \((\Delta \phi, \Delta \eta)\) of charged hadron pair with the same \(p_T\) range in the same events
- Using mixed-event technique to correct for detector acceptance

\[
\frac{\text{Same events}}{\text{Mixed events}} = \text{Correlation functions}
\]

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A single armed forward spectrometer
Pseudorapidity coverage: $2 < \eta < 5$

Tracking system
\[ \frac{\Delta p}{p} = 0.5 - 1\% \text{ for } 5-100 \text{ GeV} \]
Beam Configurations

Event display of a pPb event

\[ \sqrt{s_{NN}} = 5 \text{ TeV} \]
\[ \int L dt = 0.46 \text{ nb}^{-1} \]
\[ 1.5 < y < 4.4 \]
Beam Configurations

Event display of a pPb event

$\sqrt{s_{NN}} = 5$ TeV
$\int Ldt = 0.30$ nb$^{-1}$
$-5.4 < y < -2.5$
Activity Class Determination

- Five activity classes determined using hit multiplicity in the Velo (vertex detector)
- Activity classes of Pb+p have higher multiplicity than pPb
Efficiency Corrected Two-Particle Correlations in p+Pb

- Clear long-range away-side ($\Delta \phi \approx \pi$) structures in both activity classes
- Pronounced jet-like peaks in low and high multiplicity events
- Less pronounced long-range near-side ($\Delta \phi \approx 0$) structure appears in high multiplicity events
Efficiency Corrected Two-Particle Correlations in Pb+p

LHCb Pb+p √s_{NN} = 5 TeV
1.0 < p_T < 2.0 GeV/c
Event class 50-100%

LHCb Pb+p √s_{NN} = 5 TeV
1.0 < p_T < 2.0 GeV/c
Event class 0-3%

Similar long-range structures shown in Pb+p collisions in high multiplicity events
Quantitative Comparison

- Integrate over \(2 < \Delta \eta < 2.9\) to avoid jet-like contributions
- Using zero-yield-at-minimum (ZYAM) to remove combinatorial background

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Correlations in Different Kinematic Range

PLB 762 (2016) 473

Correlations in Different Kinematic Range

Low multiplicity

High multiplicity

LHCb

\( \sqrt{s_{NN}} = 5 \text{ TeV} \)

\( p+p \) data

\( Pb+p \) data

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Correlations in Different Kinematic Range

Lower activity events (>30%)
- Pronounced away-side peaks in both pPb and Pbp data
- Away-side peaks reduce at higher $p_T$
- Away-side peaks are higher in pPb than in Pbp
- No significant near-side peak
Correlations in Different Kinematic Range

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Higher activity events (<30%)
- Near-side peaks emerge in more central events
- Near-side peaks are higher in Pbp than in pPb
- Indication of p_T dependence for both near and away-side peaks
Current Flow Analyses at LHCb

- Charged hadron $v_n$ in PbPb at 5 TeV
  - $\int L dt = 228 \, \mu$b$^{-1}$
  - Centrality determination using calorimeter energy and Glauber model
  - Study $v_1$ in forward region

 integral graphs and distributions
Current Flow Analyses at LHCb

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  - Centrality determination using calorimeter energy and Glauber model
  - Study $v_1$ in forward region

- Charged hadron & $J/\psi$ $v_n$ pPb and Pbp at 8 TeV
  - Total $\int L dt = 34.4 \text{ nb}^{-1}$
  - Finer activity classes
  - Study initial state effects at low $x$

- ALICE results show agreement of $J/\psi$ $v_2$ in PbPb (black and green) and pPb (blue and red) with the sizable uncertainties

- LHCb has good statistics of $J/\psi$ which will help improve the measurements
Potential Flow Analysis: Flow in UPC Events

- Study particle flow induced by gluon saturation
- CGC calculation show agreements with photo-production events at low $p_T$
- More experimental results needed to constraint CGC models and provide reference for future EIC experiments
Potential Flow Analysis: Chiral Magnetic Effects

• Quarks in the QGP form an electric dipole due to the strong magnetic field from the spectator protons ➔ charged hadrons emitted in different direction based on their signs

• In case of charge asymmetry, the charge imbalance transfer to $\Delta \nu_1$ between positive and negative tracks

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PRL 125, 022301 (2020)
ALICE PbPb 5.02 TeV
Potential Flow Analysis: Chiral Magnetic Effects

- Quarks in QGP form an electric dipole due to the strong magnetic field from the spectator protons \( \rightarrow \) charged hadrons emitted in different direction based on their signs

- In case of charge asymmetry, the charge imbalance transfer to \( \Delta v_1 \) between positive and negative tracks

- Forward and backward results will help reduce the uncertainty of the fit

- Good statistics of D meson in LHCb \[ \text{[ JHEP 10 (2017) 090 ]} \]
LHCb SMOG Programs

- Rising interest in small systems
- But intermediate size systems are missing

Look forward for the collider mode with the argon or oxygen beams in the future.

Collisions systems at RHIC
LHCb SMOG Programs

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Look forward for the collider mode with the argon or oxygen beams in the future

Or dive right in with LHCb SMOG datasets

Collisions systems at RHIC

More SMOG talks
S. Mariani, T15, April 6th
J.Y. Sun, T11, April 7

Beam Energy

protons (Pb) on target \(10^{22}\)

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Summary

• Collectivity in the forward region at LHCb
  - Asymmetric collision at LHCb can benefit to both low and high-x physics
  - Two-particle correlation shows difference near-side structure between pPb and Pbp in high multiplicity events

• Coming flow analyses at LHCb
  - With pPb/Pbp and PbPb datasets
  - Flow harmonic coefficients of charged hadrons and J/ψ
  - Forward $v_1$

• Potential flow study in the future:
  - UPC events $\rightarrow$ CGC
  - Charged dependence $v_1$ $\rightarrow$ chiral magnetic effect
  - SMOG dataset $\rightarrow$ QGP in intermediate system size
Back Up
Clear near-side ridge in Pb+pb collisions
Potential Flow Analysis: Chiral Magnetic Effects

- A brief but strong magnetic field created by the spectator protons (red)
- Quarks inside the QGP form a dipole due to the strong magnetic field
- The angular correlations of the same-sign (opposite-sign) hadron pair at the final state are emitted in the same (opposite) side

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Potential Flow Analysis: Chiral Magnetic Effects

In case of symmetry breaking, for example: more positive tracks

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Potential Flow Analysis: Chiral Magnetic Effects

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Differences in $v_1$ between positive and negative trigger

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