New results on collectivity with LHCb

Renata Kopečná
on behalf of the LHCb collaboration

Physikalisches Institut
University of Heidelberg

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The LHCb Detector

Cherenkov detectors
$\varepsilon(K \rightarrow K) \sim 95\%$
at 5% $\pi \rightarrow K$ mis-identification

Muon system
$\varepsilon(\mu \rightarrow \mu) \sim 97\%$
at 1-3% $\pi \rightarrow \mu$ mis-identification

VELO
$\sigma_{ip} \sim 20 \mu m$
for high $p_T$ tracks

Tracking system
$\Delta p/p = 0.4\%$ at 5 GeV
to 0.6% at 100 GeV

Calorimeters
ECAL: $\sigma/E \sim 1\% \oplus 10%/\sqrt{E}$ [GeV]
The LHCb Detector

- Full measurement capacity in the forward rapidity $2 < \eta < 5$
  - Complimentary measurement to other LHC experiments
- Low $p_T$
- Low pile-up environment
- Occupancy limitation in Pb–Pb collisions:
  - Current tracking algorithms 50%-100% in centrality
  - Limited by tracking detectors granularity
    Number of Velo Clusters < 15 000

PbPb performance figures:
https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbPlots2015

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Data taking

- $p + p$
  June 2015 at $\sqrt{s_{pp}} = 13$ TeV (Dedicated)

- $p + Pb$ and $Pb + p$
  December 2013 at $\sqrt{s_{NN}} = 5.02$ TeV
  December 2016 at $\sqrt{s_{NN}} = 8.16$ TeV

- $Pb + Pb$
  December 2015 at $\sqrt{s_{NN}} = 5.02$ TeV

- Fixed target (SMOG)
  pHe, pNe, pAr, PbAr
  at $54$ GeV $< \sqrt{s_{NN}} < 110$ GeV

$y^*$: rapidity in NN CMS system, with forward direction ($y^* > 0$) in direction of the proton/beam
Two-particle correlations
Two-particle correlations in the forward region

- Measurement of angular ($\Delta \eta$, $\Delta \phi$) correlations of prompt charged particles
- Look for a long-range correlation on the near side (the ridge) which has been observed in $p + p$, $p + Pb$ and $Pb + Pb$ collisions at central rapidities $\eta < 2.5$
- LHCb can study the ridge at large rapidities
  - Low Bjorken-$x$ studies
  - Advantage but also a challenge
  ⇒ Forward $\eta$ coverage
Two-particle correlation function

\[
\frac{1}{N_{\text{trig}}} \frac{d^2 N_{\text{pair}}}{d\Delta \eta d\Delta \phi} = \frac{S(\Delta \eta, \Delta \phi)}{B(\Delta \eta, \Delta \phi)} \times B(0, 0)
\]

\[
S(\Delta \eta, \Delta \phi) = \frac{1}{N_{\text{trig}}} \frac{d^2 N_{\text{same}}}{d\Delta \eta d\Delta \phi}
\]

Correlation of all particle pairs in the same event
Correlations are dominated by acceptance effects

\[
B(\Delta \eta, \Delta \phi) = \frac{d^2 N_{\text{mix}}}{d\Delta \eta d\Delta \phi}
\]

Correlation of all particle pairs in similar events
Activity and z_{pv} requirement
No physical correlations
Can be understood as a pair-acceptance efficiency

CERN-LHCb-CONF-2015-004
Two-particle correlations in $p + Pb$ and $Pb + p$

- Minimum bias data at $\sqrt{s_{NN}} = 5.02$ TeV (2013)
- Separate analysis for both configurations
- 5 activity classes using VELO hits:
  - 0 - 3%
  - 3 - 10%
  - 10 - 30%
  - 30 - 50%
  - 50 - 100%
- 3 $p_T$ classes:
  - 0.15 - 1 GeV
  - 1 - 2 GeV
  - 2 - 3 GeV
- 1 primary vertex per event with $z_{PV}$ in luminous region
- Track selection:
  - Charged particles traversing the full LHCb tracking system
  - Kinematic range: $p > 2$ GeV, $p_T > 150$ MeV, $2.0 < \eta < 4.9$
  - Select prompt particles by using distance to the primary vertex
  - Suppress reconstruction artifacts by quality requirements
  - Statistically corrected per-track for contaminations and limited efficiencies in $(\eta, \phi, p_T) \times N_{VELO}^{\text{hits}}$
Two-particle correlations in $p + Pb$

- Minimum bias data at $\sqrt{s_{NN}} = 5.02$ TeV (2013)
- $p + Pb$ configuration
  - $\mathcal{L} = 0.46$ nb$^{-1}$
  - At low event-activity (50 %-100 %) no sign of a near-side ridge
  - At high event-activity (0 %-3 %) not-very pronounced near-side ridge
Two-particle correlations in $Pb + p$

- Minimum bias data at $\sqrt{s_{NN}} = 5.02$ TeV (2013)
- $Pb + p$ configuration
  - $\mathcal{L} = 0.30$ nb$^{-1}$
  - At low event-activity (50 %-100 %) no sign of a near-side ridge
  - At high event-activity (0 %-3 %) very pronounced near-side ridge

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Long range correlation yield

\[ Y(\Delta \phi) := \frac{1}{\Delta \eta_b - \Delta \eta_a} \int_{\Delta \eta_a}^{\Delta \eta_b} \frac{1}{N_{\text{trig}}} \frac{d^2N_{\text{pair}}}{d\Delta \eta d\Delta \phi} d\Delta \eta \]

- Average of the 2D yield in \(2.0 < \Delta \eta < 2.9\)
- Subtract the zero yield at minimum (ZYAM)
- Ridge present even at large rapidity gap ⇒ collective behavior

⇒ The correlation yield increases with event activity
⇒ The away-side ridge decreases towards higher \(p_T\)
⇒ On the near side, the second ridge emerges with a maximum in the range \(1 < p_T < 2\) GeV
⇒ Near side is more pronounced in \(Pb + p\) than in \(p + Pb\)
Long range correlation yield

\[ Y(\Delta \phi) := \frac{1}{\Delta \eta_b - \Delta \eta_a} \int_{\Delta \eta_a}^{\Delta \eta_b} \frac{1}{N_{\text{trig}}} \frac{d^2N_{\text{pair}}}{d\Delta \eta d\Delta \phi} d\Delta \eta \]

\[ \Rightarrow \text{The correlation yield increases with event activity} \]
\[ \Rightarrow \text{The away-side ridge emerges with a maximum in the range } 1 < p_T < 2 \text{ GeV} \]
\[ \Rightarrow \text{Compare long-range correlations in both hemispheres in common absolute activity ranges} \]


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Outlook: Two particle correlations in $p + p$

- Two dedicated trigger settings in June 2015:
  - Minimum bias sample $\sim 180$M events
  - High multiplicity sample $\sim 47$M events
  $\Rightarrow$ 26 times increased trigger efficiency in high multiplicity

- Track selection:
  - Same as in $p + Pb$ and $Pb + p$ except:
    + $1.9 < \eta < 4.9$
    + 4D correction ($\eta, \phi, p_T, N_{VELO}^{\text{hits}}$)
    + 4 $p_T$ classes
    + 4 multiplicity classes
Outlook: Two particle correlations in $p + p$

- Two dedicated trigger settings in June 2015:
  - Minimum bias sample $\sim 180M$ events
  - High multiplicity sample $\sim 47M$ events

- Full analysis soon to be finished
  - Including the harmonics fit
Outlook

- 2016 data from $p + Pb$ run being analyzed
  - Dedicated high-multiplicity trigger
  - Novelty: Tracks reconstructed and persisted already in the trigger (Turbo stream)
    See Roel’s talk on Friday!
    (Real-time physics: performance and novel developments at LHCb experiment)

- Ongoing Bose-Einstein correlations analysis

- Many more possible measurements
  - Studies per species
  - Comparison with pp results ($R_{AA}$)
  - Forward-backward rapidity comparison ($R_{FB}$)
Conclusion

- LHCb is more than a $p + p$ heavy-flavor experiment!

- LHCb can bridge the gap between the SPS and RHIC up to the LHC (SMOG)!

- Observable near-side ridge in the highest activity class in $p + Pb$, $Pb + p$ and $p + p$ collisions even in the forward region!

- Stay tuned!
BACKUP
LHCb scheme

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SMOG: System for Measuring Overlap with Gas

- Fixed target mode!
- Injecting noble gas in the VELO
- Primarily for luminosity measurements
- SMOG can be used for fixed target physics:
  - Precise vertexing allows separating beam-beam and beam-gas contributions
  - Possibility to inject (noble) gases: Ne or He, Ar
  - Very simple robust system
- Energy ranges:
  - 2.5 - 7 TeV proton beam: $69 \text{ GeV} < \sqrt{s_{NN}} < 115 \text{ GeV}$
  - 2.5 TeV lead beam: $\sqrt{s_{NN}} = 69 \text{ GeV}$
- LHCb is a central detector for fixed target collisions
Event Activity for $p + Pb$ and $p + Pb$

VELO $\eta$ coverage: $-4.0 < \eta < -1.5; 1.5 < \eta < 5.0$

Hit-multiplicities in $Pb + p$ greater than in $p + Pb$

Relative activity classes
→ from low (50-100%) to very high (0-3%) event activity.

Common absolute activity classes for $p + Pb$ and $p + Pb$
→ 5 bins from 2200-3500 VELO hits