Particle correlations and the ridge in p-Pb collisions in the LHCb experiment

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Outline

- Motivation
- The LHCb experiment
- Pb-p and p-Pb data taking
- Analysis method
- Data selection
- Results
- Summary

Goal and motivation of the LHCb analysis

- Look for a long-range angular correlations on the near-side („ridge" at $\Delta\varphi=0$)
  - observed in Pb-Pb collisions by the RHIC experiment
  - observed in Pb-Pb, p-Pb and p-p collisions by CMS, ATLAS and ALICE at central rapidities ($|\eta|<2.5$)
- Measure two particle angular correlations of prompt charged particles in the forward region
- Compare long-range correlations in both hemispheres (p-Pb and Pb-p) in relative and absolute activity classes
- The theoretical interpretation of the mechanism responsible for the ridge is still under discussion
- p-Pb collisions are important as a reference sample for Pb-Pb and interesting by themselves

Confirmation of the ridge correlations at large η and comparison of its magnitude for the two beam configuration provide new input to the theoretical understanding of the underlying mechanism

The LHCb experiment

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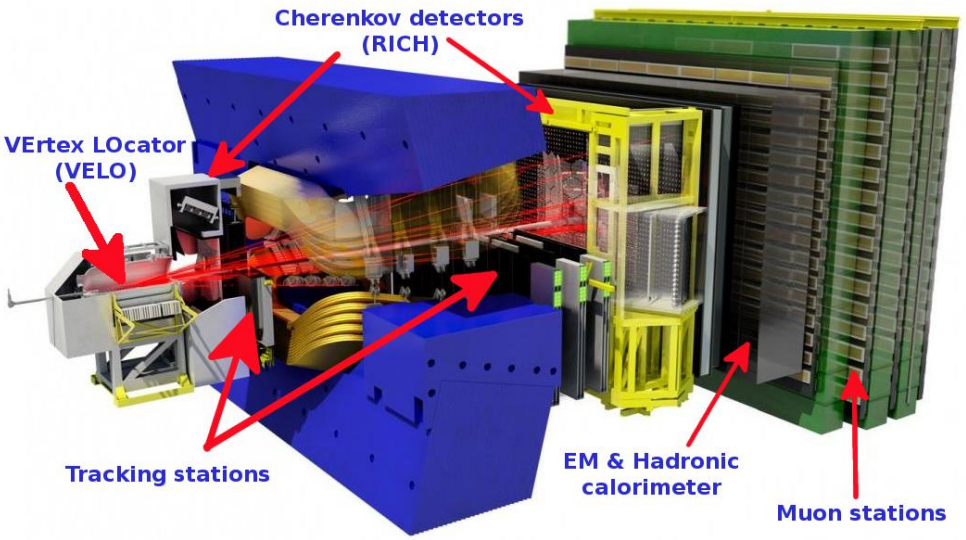
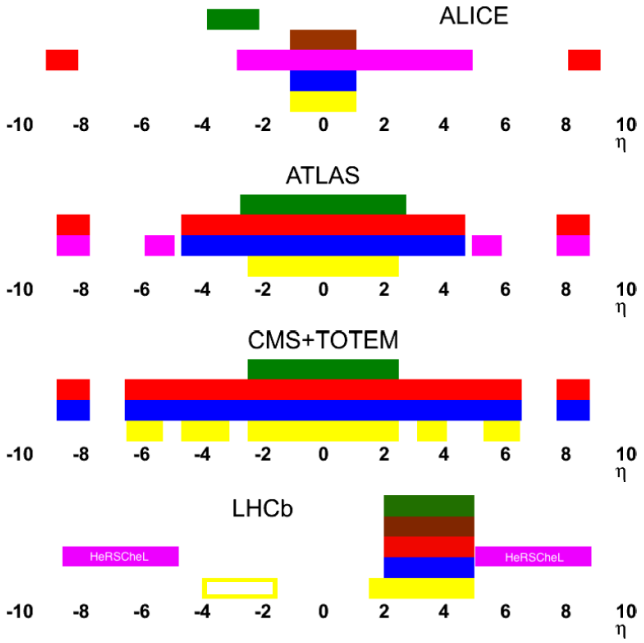




Acceptance $2 < \eta < 5$

Impact parameter resolution 20 μm.

Momentum resolution $\Delta p/p$ = 0.5 - 1.0% (5-200 GeV/c)

Rich K-π separation $\varepsilon(K \rightarrow K) \approx 95\%$ miss ID $(\pi \rightarrow K) \approx 5\%$

Fully instrumented in the forward region.

LHCb experiment is dedicated to heavy flavour physics and searches for physics beyond SM, but it may provide:

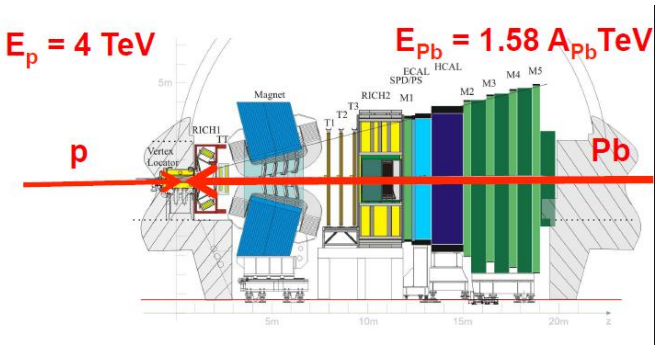
- results on heavy ion physics in unique kinematic region
- complementary results to other LHC experiment

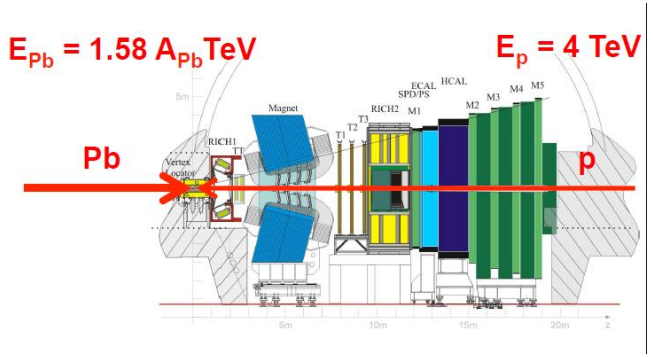
hadron PID
muon system
lumi counters
HCAL
ECAL
tracking

p-Pb and Pb-p in LHCb

- p - Pb
- E_p = 4 TeV, E_{Pb}=1.58 TeV
- Rapidity range: 1.5 < y < 4.4
- Sample used for the analysis 0.46 nb $^{-1}$
  - Total collected 1.1 nb $^{-1}$

- Pb - p
- E_{Pb}=1.58 TeV, E_p = 4 TeV
- Rapidity range: -5.4 < y < -2.5
- Sample used for the analysis 0.30 nb $^{-1}$
  - Total collected 0.5 nb $^{-1}$





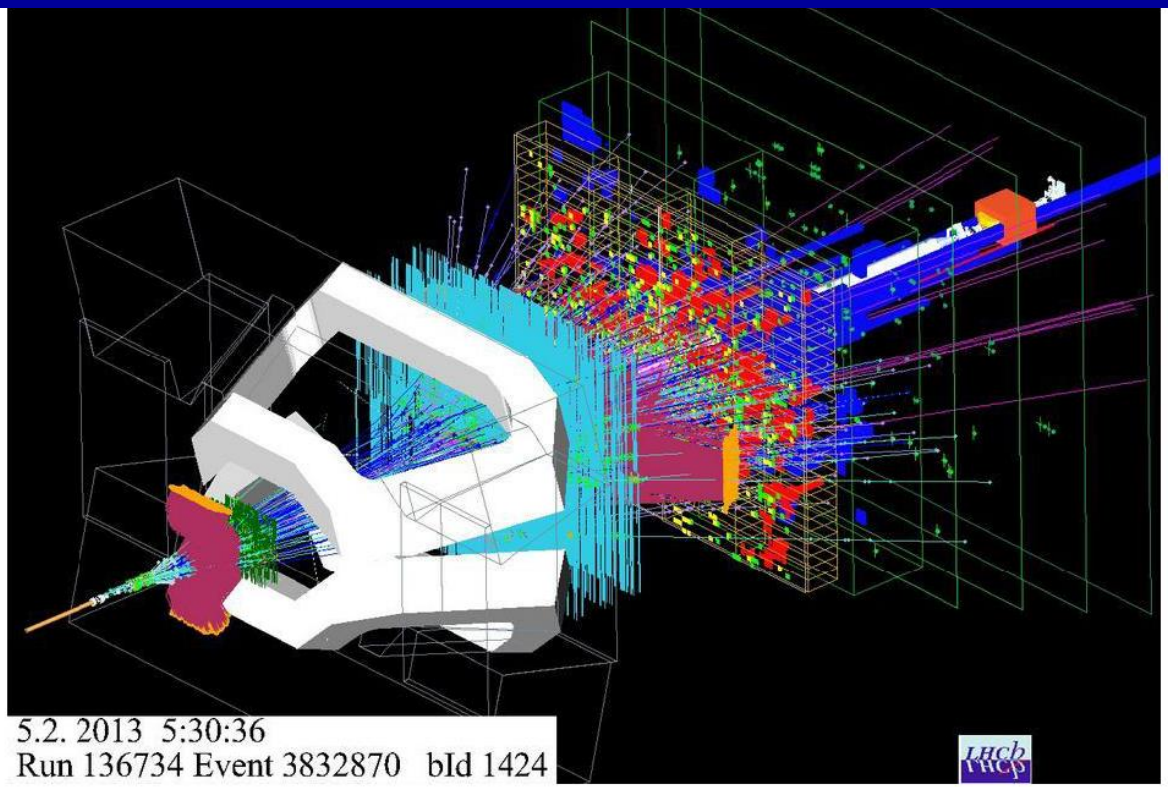
Data collected in 2013

Asymmetric beams: nucleon-nucleon: $\sqrt{s_{NN}}$ = 5 TeV

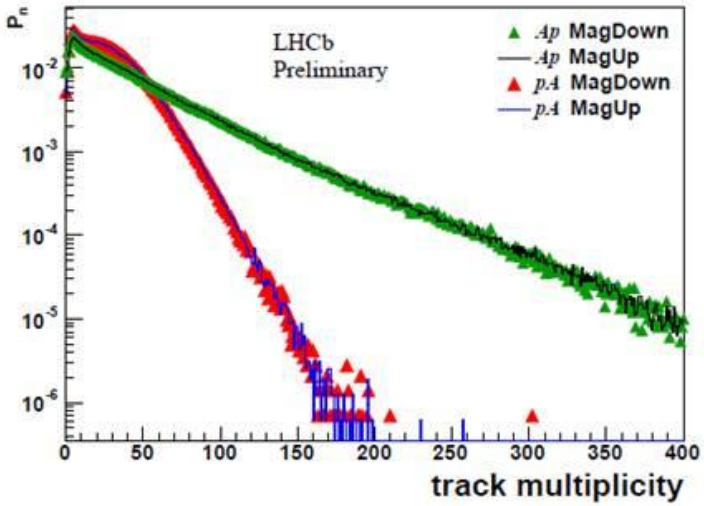
Center of mass system shifted by Δy=0.47 into proton beam direction

Common rapidity range 2.5 < |y| < 4.4

The p-Pb event



Typical pA collision in LHCb

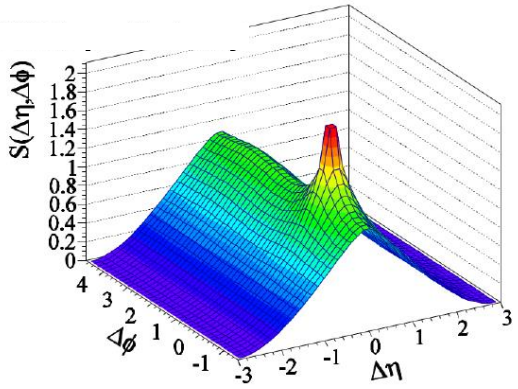


- Multiplicity distributions p-p and p-Pb are comparable in LHCb acceptance
- Pb-p multiplicity is higher

Analysis method

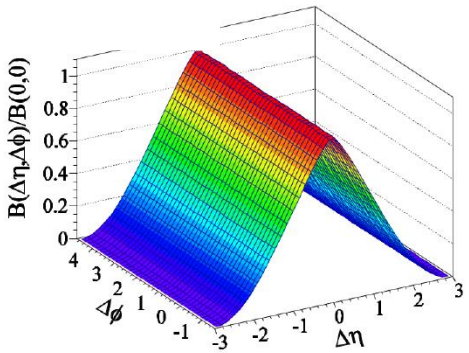
- Two particle correlations are measured for each activity class (defined later)
- 3 p_T intervals [GeV/c]:
  - **[0.15 - 1.0], [1.0 - 2.0], [2.0 - 3.0]**
- Two particle correlation function – binned ratio of signal and background.

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



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

Normalized yield of particle pairs.
Combinations from the same event.



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

Normalized yield of particle pairs.
Combinations from different events (mix).

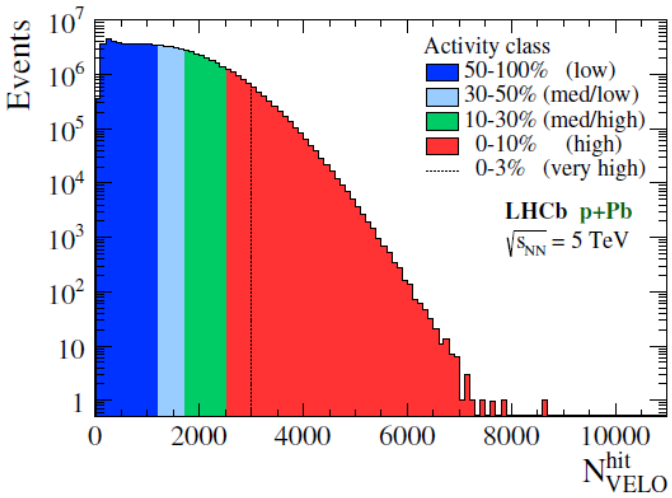
Data selection

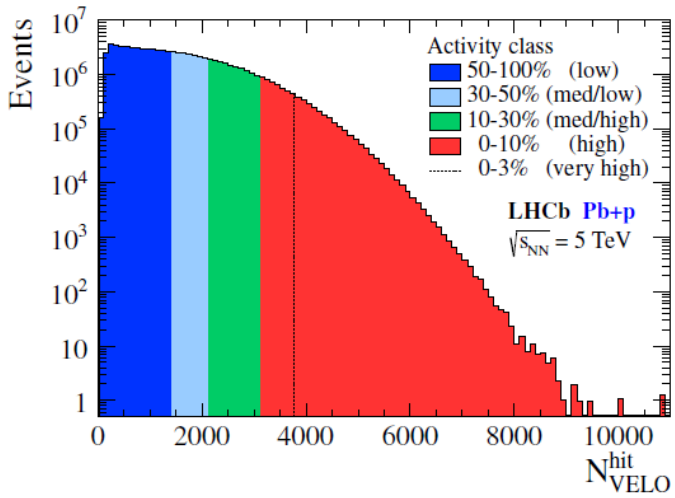
- Event selection
  - One primary vertex (PV) with a position in luminous region ±3σ around mean interaction point (only 2% of interactions with more than one PV)
  - Events with too small ratio between the number of clusters in EM calorimeter and in the VELO are rejected (reduction of beam-gas and secondary interactions with detector material)
- Track selection
  - Select prompt particles (small IP with respect to PV)
  - Charged particles reconstructed in full tracking system (before and after the magnet)
  - Kinematic cuts: $p > 2$ GeV/c, $p_T > 150$ MeV/c $2.0 < \eta < 4.9$
- Corrections
  - Apart from acceptance efficiencies the main effects are due to decreased quality of track reconstruction for high multiplicity events (high density in forward region)
  - Fake tracks suppressed by multivariate classifier while secondary tracks by IP cuts
  - Remaining effects are taken into account by per track weights depending on track purity and track efficiency

$$\omega(\eta, \phi, p_{\mathrm{T}}, \mathcal{N}^{\mathrm{hit}}_{\mathrm{VELO}}) = (1 - \mathcal{P}_{\mathrm{fake}} - \mathcal{P}_{\mathrm{sec}})/(\epsilon_{\mathrm{acc}} \cdot \epsilon_{\mathrm{tr}})$$

Data samples and event activity classes

- Data samples
  - Minimum bias. Randomly selected minimum bias events
  - High-occupancy. Events with > 2200 VELO hits
- Event activity classes. Hit multiplicity in VELO is a good probe of the global event multiplicity.
  - 5 relative event activity classes defined as fractions of hit multiplicity distributions of the minimum-bias samples. Separately for p-Pb and Pb-
  - 5 common absolute activity ranges. Bins for VELO hits in [2200, 3500]



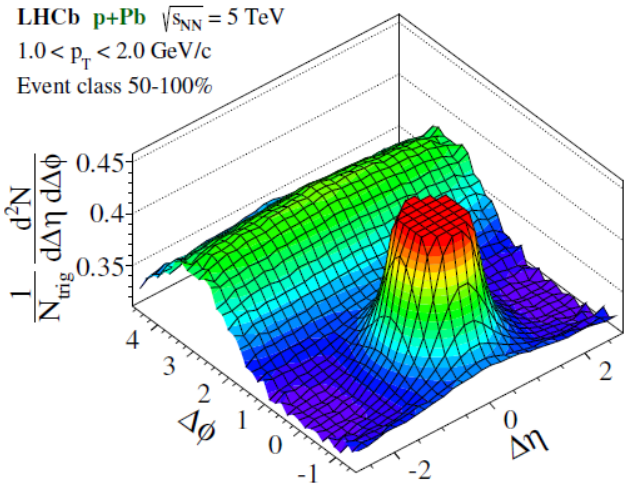


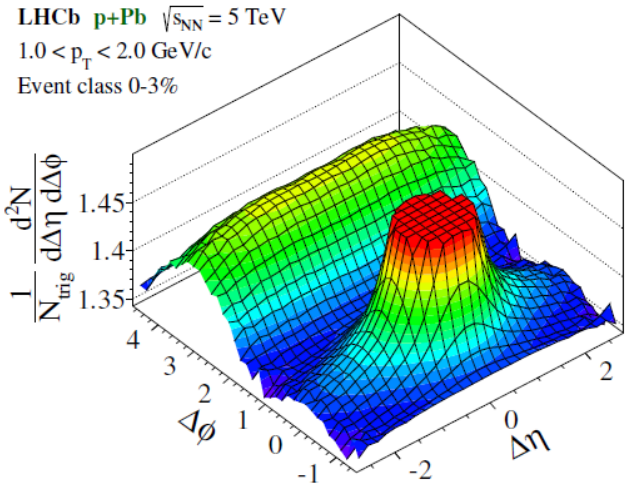
The ridge

$1.0 < p_T < 2.0$ GeV/c

arXiv:1512.00439 [nucl-ex]

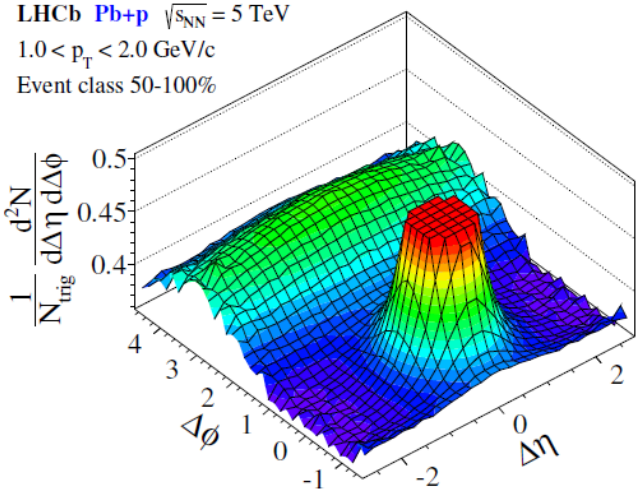
p-Pb 50-100%

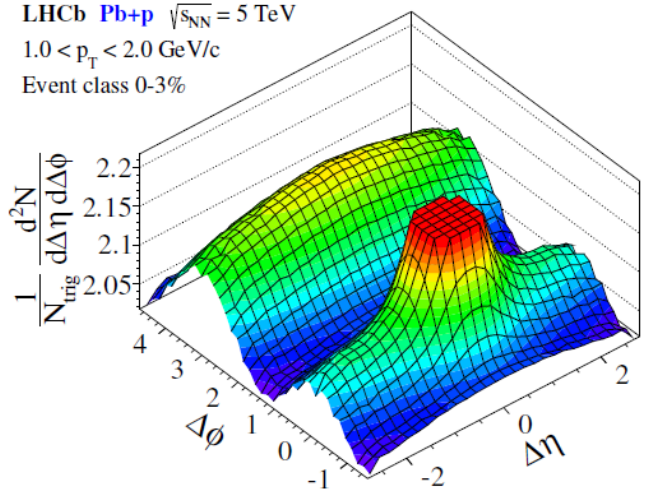




p-Pb 0-3%

Pb-p 50-100%



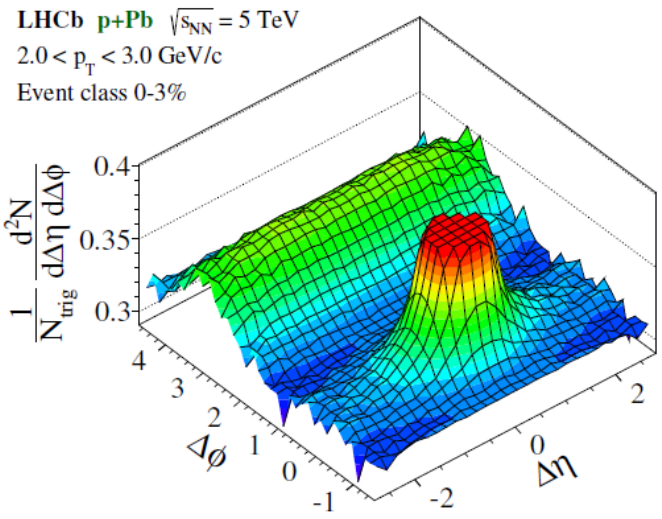


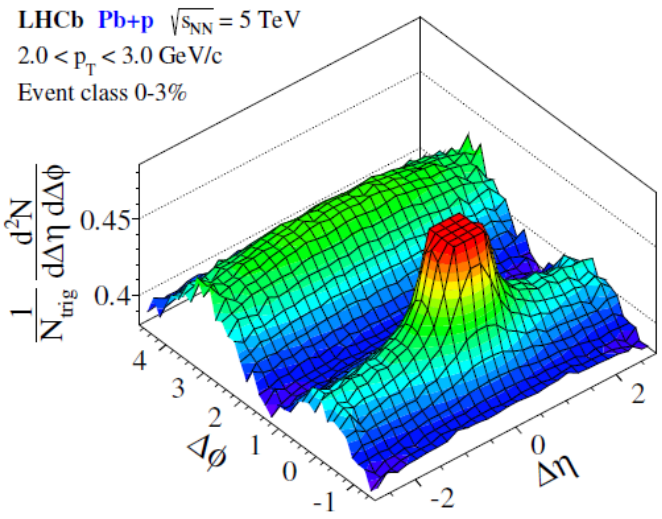
Pb-p 0-3%

The ridge

$2.0 < p_T < 3.0$ GeV/c

p-Pb 0-3%





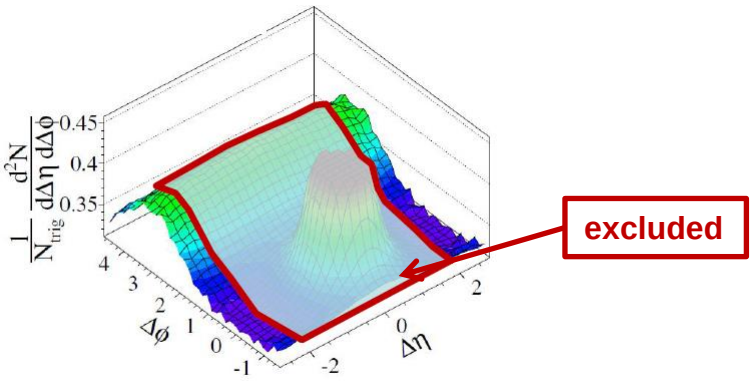
Pb-p 0-3%

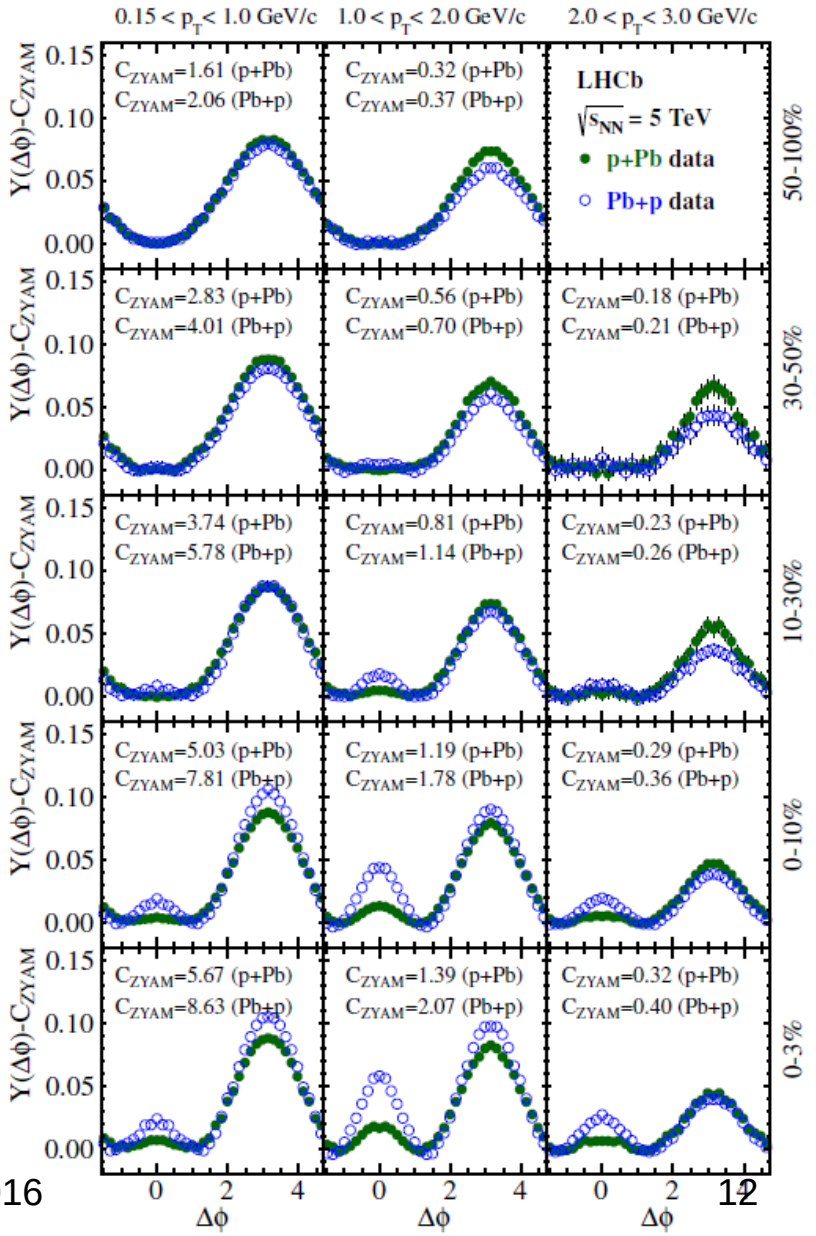
- Near-side ridge present in both configurations.
- Ridge in Pb-p more prononced.

Ridge evolution

$$Y(\Delta\phi) \equiv \frac{1}{N_{\mathrm{trig}}}\frac{\mathrm{d}N_{\mathrm{pair}}}{\mathrm{d}\Delta\phi} = \frac{1}{\Delta\eta_b - \Delta\eta_a}\int_{\Delta\eta_a}^{\Delta\eta_b}\frac{1}{N_{\mathrm{trig}}}\frac{\mathrm{d}^2N_{\mathrm{pair}}}{\mathrm{d}\Delta\eta\mathrm{d}\Delta\phi}\mathrm{d}\Delta\eta.$$

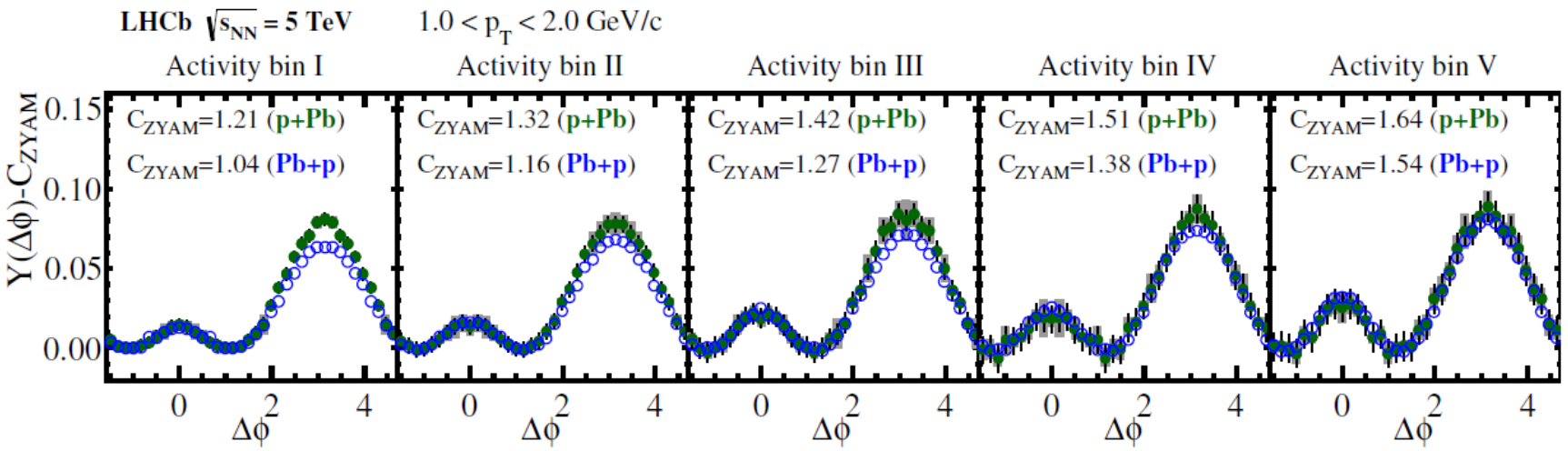
- To study the ridge evolution look at one-dimensional projection on Δφ integrated over $\Delta\eta$ range $2.0 < \Delta\eta < 2.9$ (i.e. excluding the jet peak)
  - Maximum in near-side is observed for $1 < p_T < 2$ GeV/c
  - The away-side ridge increases with event activity and decreases towards higher p_T
  - The correlation is stronger for Pb-p in the p-Pb ina given activity class (asymmetry effect)





The ridge in common activity ranges

- 5 identical activity ranges for p-Pb and Pb-p configurations (VELO hits 2200-3500)
- $2.0 < \Delta\eta < 2.9$



- The away-side and near-side ridge appear to be only dependent on the activity in the direction of the measurement
- The strength of the near-side ridge in both hemispheres are compatible
- Increase of correlation strength with increasing event activity is seen

Summary

- Two-particle angular correlations produced in pPb collisions at $\sqrt{s_{NN}}$ = 5 TeV have been measured for the first time in the forward region in the LHCb experiment
- The near-side ridge effect is observed for both p-Pb and Pb-p configurations and is most pronounced for $1.0 < p_T < 2.0$ GeV/c range
- The correlation structures on the near side and on the away side grow with increasing event activity
- For a given total event activity the ridge is stronger in the Pb direction
- For identical absolute activity the observed long-range correlations are compatible in both hemispheres
- Analysis for p-p is ongoing

Backup slides

Event activity classes

Relative activity class	p+Pb range $\mathcal{N}^{\text{hit}}_{\text{VELO}}$	p+Pb $\langle N_{ch}\rangle_{\text{MC}}$	Pb+p range $\mathcal{N}^{\text{hit}}_{\text{VELO}}$	Pb+p $\langle N_{ch}\rangle_{\text{MC}}$
$50-100\%$ very low	$0-1200$	18.9	$0-1350$	29.2
$30-50\%$ low	$1200-1700$	30.0	$1350-2000$	47.4
$10-30\%$ medium	$1700-2400$	42.8	$2000-3000$	70.9
$0-10\%$ high	$2400-\text{max}$	63.6	$3000-\text{max}$	106.7
$0-3\%$ very high	$3000-\text{max}$	73.7	$3800-\text{max}$	126.4

Common absolute activity bin	$\mathcal{N}^{\text{hit}}_{\text{VELO}}$-range in Pb+$p$ scale	p+Pb $\langle N_{ch}\rangle_{\text{MC}}$	Pb+p $\langle N_{ch}\rangle_{\text{MC}}$
Bin I	$2200-2400$	62.8 ± 6.6	64.4
Bin II	$2400-2600$	68.4 ± 7.1	67.0
Bin III	$2600-2800$	73.7 ± 7.6	76.4
Bin IV	$2800-3000$	79.2 ± 7.9	82.4
Bin V	$3000-3500$	86.7 ± 8.2	92.9