Long-range near-side angular correlations in the forward region in p+Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5 TeV with LHCb

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on behalf of the LHCb collaboration

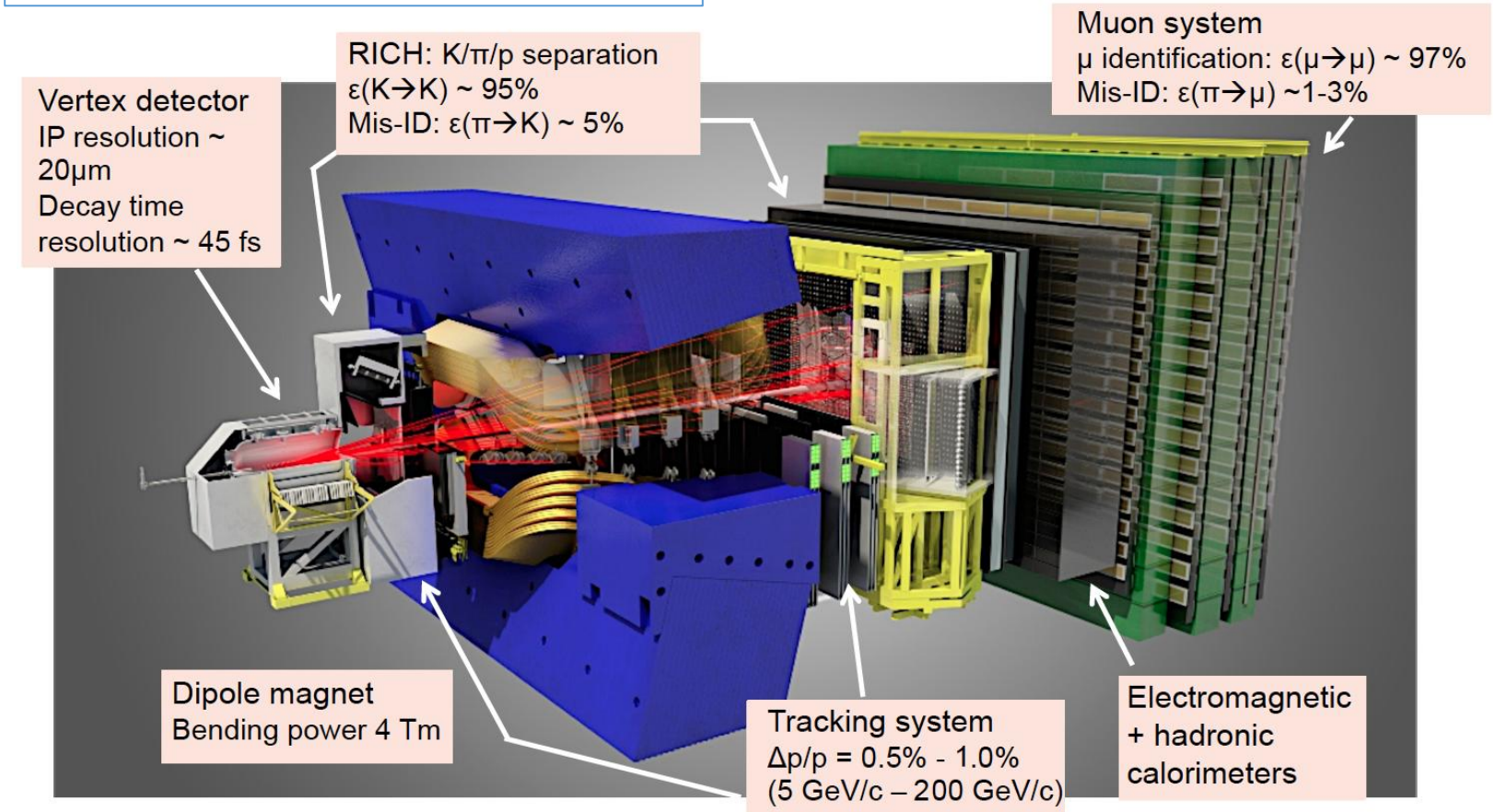
Outline

- The LHCb detector
- p+Pb data taking and physics motivation
- Two particle correlations in p+Pb
- Prospects
- Summary

The LHCb detector

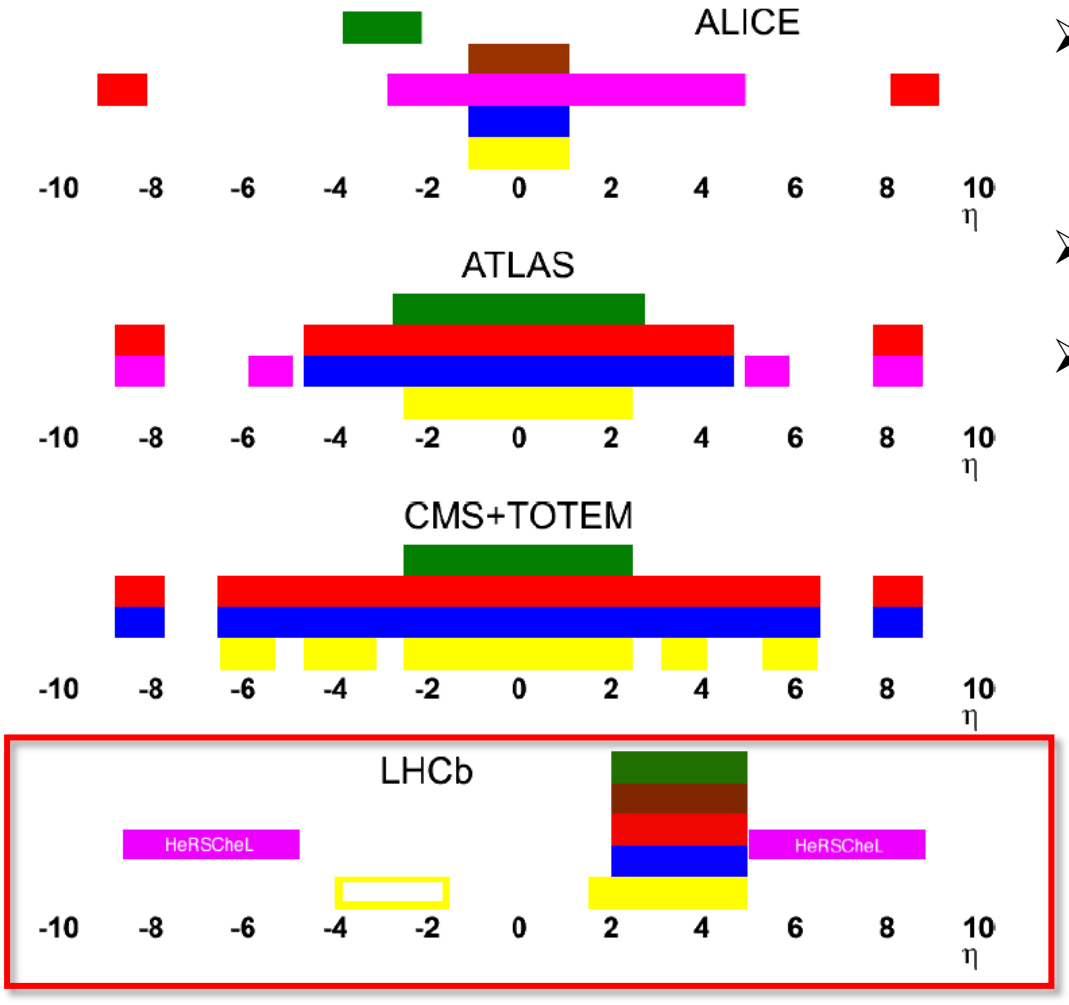
A single arm **general purpose detector** at **forward** rapidity !

pseudorapidity coverage $2 < \eta < 5$



JINST 3 (2008) S08005
IJMPA 30 (2015) 1530022

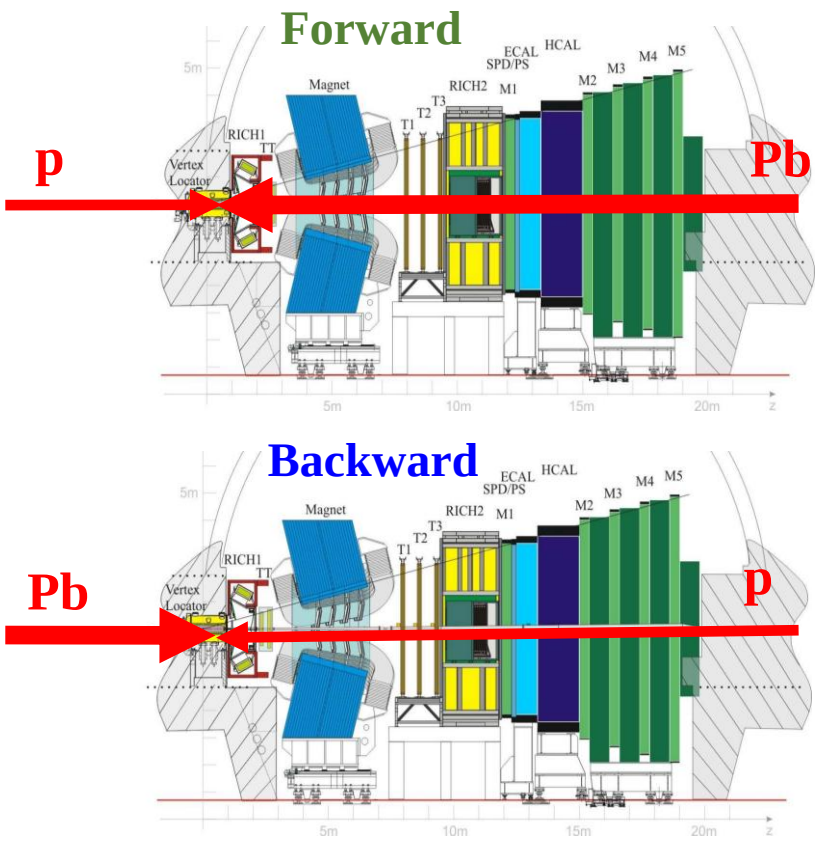
The LHCb detector



- ALICE
  - central
  - forward coverage for muon only
- ATLAS & CMS
  - central detectors
- LHCb
  - forward detector
  - tracking, particle-ID and calorimetry in full acceptance !

hadron PID
muon system
lumi counters
HCAL
ECAL
tracking

p+Pb data taking in 2013



- Asymmetric collision energy
  - $E_p = 4$ TeV
  - $E_{\mathrm{Pb}} = 1.58$ TeV per nucleon
  - $\sqrt{S_{\mathrm{NN}}} = 5$ TeV
  - $y_{\mathrm{cms}} = \pm 0.465$, nucleon-nucleon cms
- Rapidity coverage
  - Rapidity in nucleon-nucleon cms, y
  - **Forward (p+Pb)**: $1.5 < y < 4.4$
  - **Backward (Pb+p)**: $-5.4 < y < -2.5$
- Integrated luminosity
  - **Forward (p+Pb)**: $\mathcal{L} =$ 1.1 nb^{-1}
  - **Backward (Pb+p):** $\mathcal{L} =$ 0.5 nb^{-1}

Why two particle correlation in p+Pb ?

- The $(\Delta\eta, \Delta\phi)$ correlations of two prompt charged particles are important probes for multiple partonic interactions.
- A long-range correlation on the near-side ("**the ridge**"), has been observed in heavy ion collisions by RHIC and LHC experiments, at mid-rapidity ($|\eta| < 2.5$).
- Then, the ridge was also found in high multiplicity p+p and p+Pb collisions at LHC, at mid-rapidity ($|\eta| < 2.5$).
- LHCb can confirm the ridge at large rapidities ($2 < \eta < 5$).
- LHCb can compare long-range correlations in both hemispheres (p and Pb direction) in relative and in common absolute event activity ranges!

Event selection

- **Trigger:**
  - hardware: non-empty beam bunch crossings
  - HLT: at least one reconstructed track in the VELO
- **Event selection:**
  - Only events with 1 primary vertex (PV)
  - PV must be in a luminous region, defined as 3σ-range around the mean interaction point
  - Events with too small ratio between the number of clusters in the EM calorimeter and in the VELO are rejected
- **Data sample used in analysis:**
  - Minimum-bias events:
    randomly selected events, 1.1×10^8 for ***p*+Pb** and **Pb+*p*** each.
  - High-multiplicity events:
    all recorded events with VELO hits larger than 2200, 1.1×10^8 for ***p*+Pb** and 1.3×10^8 for **Pb+*p***.

Definition of event activity

- Use VELO-hit multiplicity to measure the event activity
  - VELO surrounds the interaction point
  - most comprehensive variable of event activity
  - proportional to number of charged particles
- Hit-multiplicity in **Pb+*p*** greater than ***p*+Pb**
- **Relative activity classes**
  - from low (50-100%) to very high (0-3%) event activity
- **Common absolute activity classes** for **Pb+*p*** and ***p*+Pb**
  - 5 bins in $2200 < \mathcal{N}_{VELO}^{hits} < 3500$

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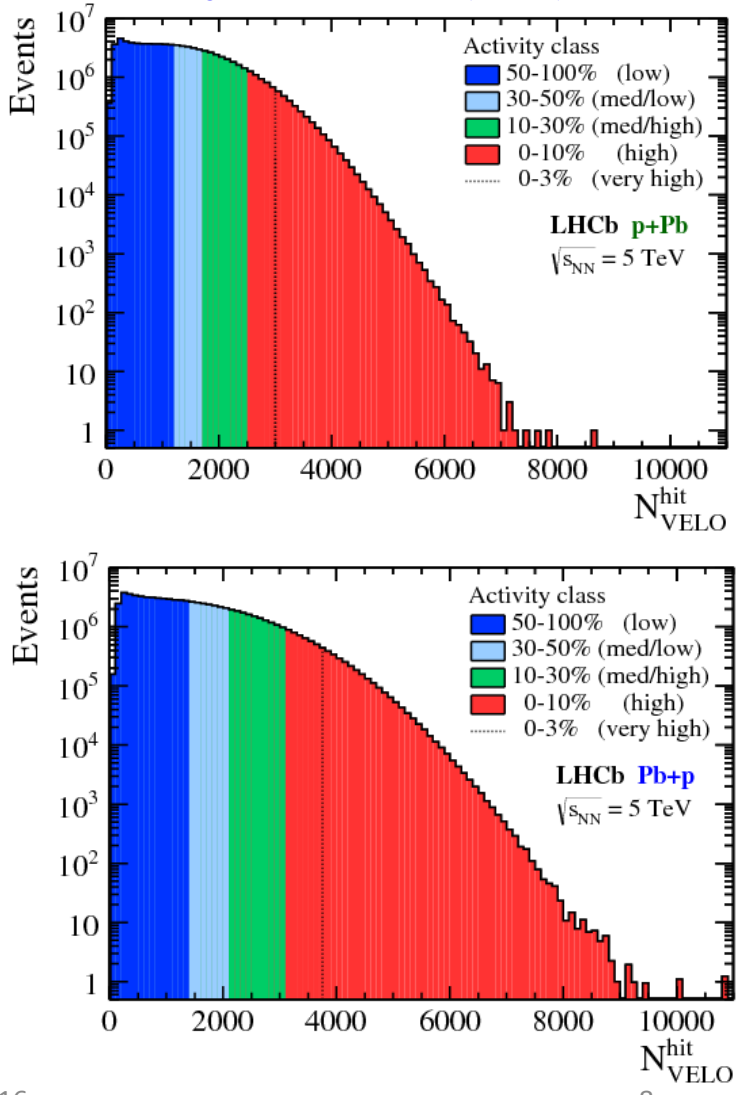


Track selection and correction

- Select prompt charged particles by using impact parameter
- Select charged particles that traverse the full LHCb tracking system
- Kinematic range: $p > 2$ GeV/c, $p_{\mathrm{T}} > 0.15$ GeV/c and $2.0 < \eta < 4.9$
- **Corrections:**
  Assign per-track weights, ω, to statistically correct for contaminations and limited efficiencies
  - Purity: fake tracks and secondary particles

$$\boldsymbol{\omega_p\left(\eta, \phi, p_T, \mathcal{N}^{hit}_{VELO}\right) = 1 - \mathcal{P}_{fake} - \mathcal{P}_{sec}}$$

  - Efficiency: detector acceptance and track reconstruction

$$\boldsymbol{\omega_\epsilon\left(\eta, \phi, p_T, \mathcal{N}^{hit}_{VELO}\right) = 1/(\epsilon_{acc} \times \epsilon_{tr})}$$

$$\boldsymbol{\omega\left(\eta, \phi, p_T, \mathcal{N}^{hit}_{VELO}\right) = \frac{1 - \mathcal{P}_{fake} - \mathcal{P}_{sec}}{\epsilon_{acc} \times \epsilon_{tr}}}$$

Two particle correlations

- The correlation function is defined as ***per-trigger associated particle yield***

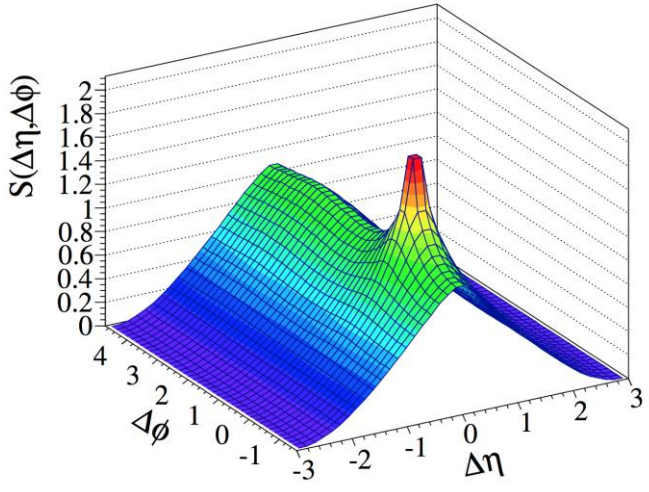
$$\frac{1}{N_{trig}}\frac{d^2N_{pair}}{d\Delta\eta d\Delta\phi} = \frac{S(\Delta\eta,\Delta\phi)}{B(\Delta\eta,\Delta\phi)} \times B(0,0)$$

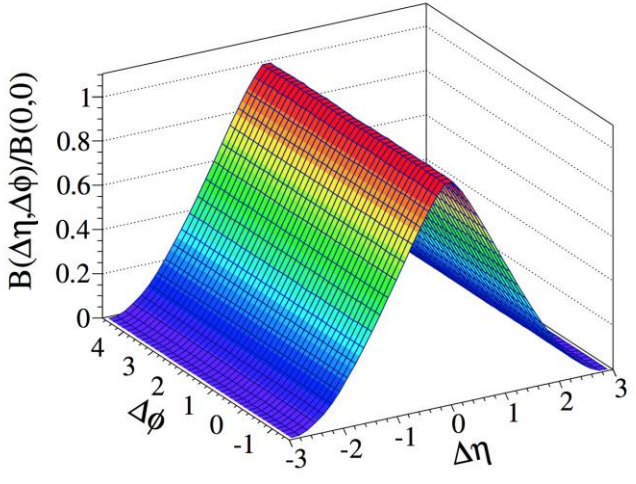
Signal: $S(\Delta\eta,\Delta\phi) = \frac{1}{N_{trig}}\frac{d^2N_{same}}{d\Delta\eta d\Delta\phi}$

Particle pairs for all combinations N_{same} of two particles within the **same event**. Calculate $\Delta\eta$ and $\Delta\phi$ for each pair.

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

Mix particles of one event with particles of **another five similar events**, → N_{mix} particle pairs.





The ridge in p+Pb collisions

p_T range : 1.0 - 2.0 GeV/c

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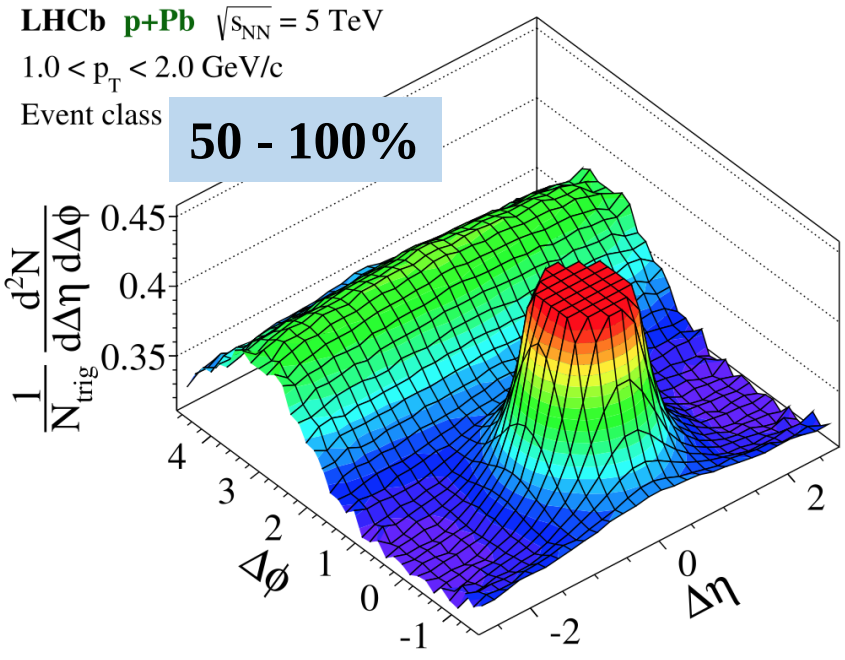

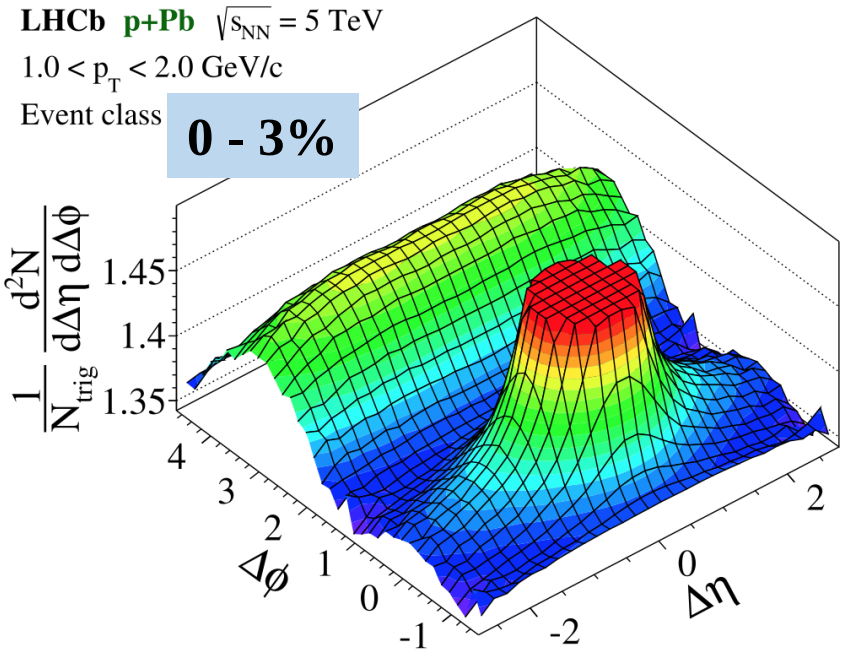

At low event activity (50-100%)

- $\Delta\phi = \pi$: away side ridge present
- $\Delta\phi = 0$: No sign of near-side ridge

At high event activity (0-3%)

- $\Delta\phi = \pi$: away side ridge present
- **$\Delta\phi = 0$: near-side ridge is evolving and clearly visible!**

The ridge in Pb+p collisions

p_T range : 1.0 - 2.0 GeV/c

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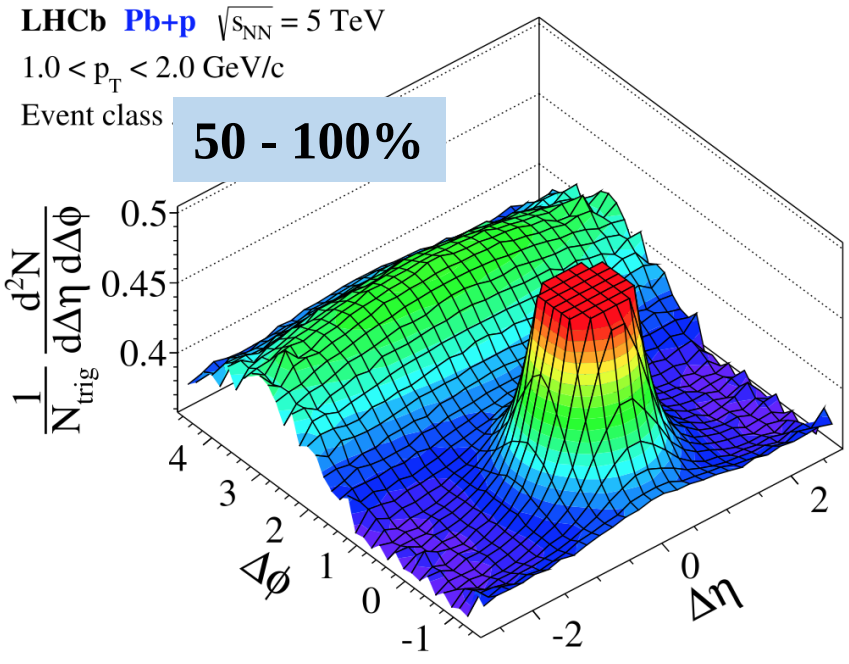

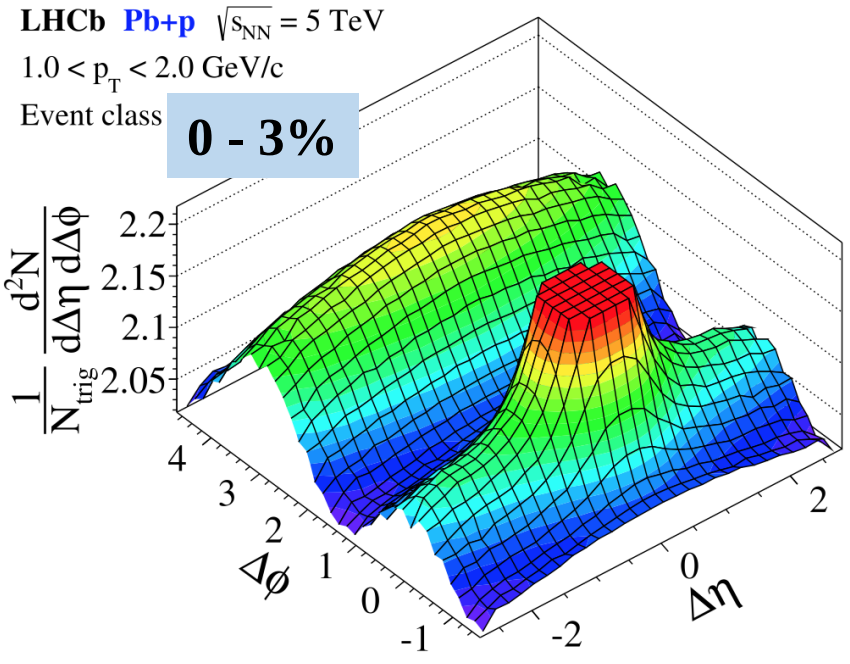

At low event activity (50-100%)

- $\Delta\phi = \pi$: away side ridge present
- $\Delta\phi = 0$: No sign of near-side ridge

At high event activity (0-3%)

- $\Delta\phi = \pi$: away side ridge present
- **$\Delta\phi = 0$: near-side ridge elongated over large $\Delta\eta$!**

The ridge evolution

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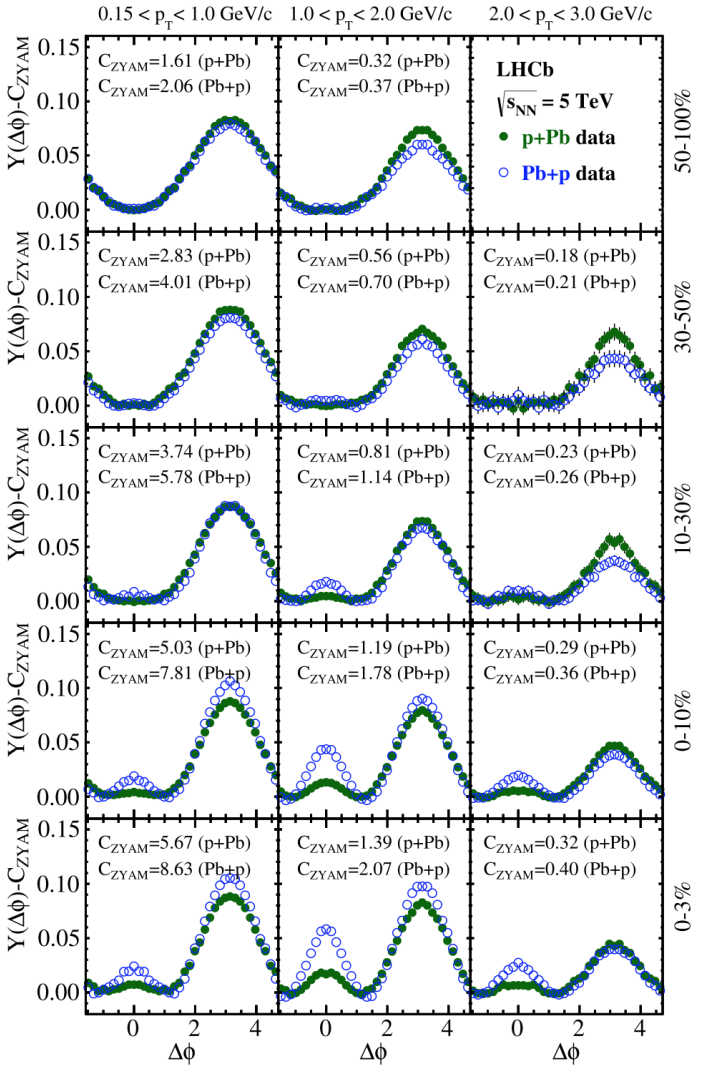
- Average the 2D-yield in the range of $2.0 < \Delta\eta < 2.9$, to exclude short-range correlations (jet peak)

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

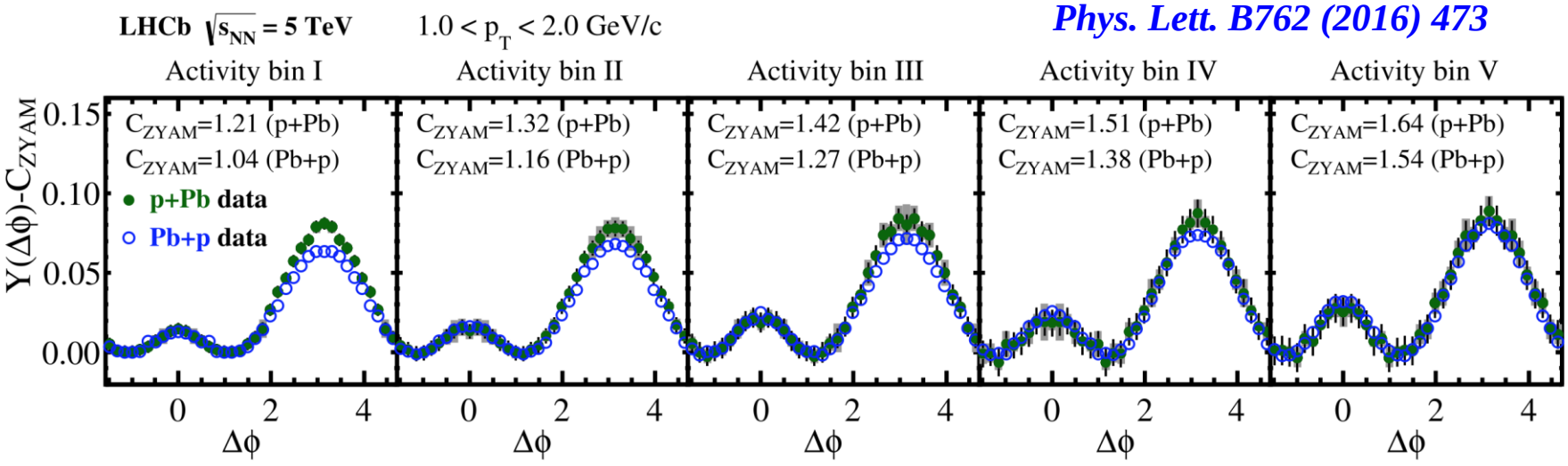
- Subtract the zero-yield-at-minimum (ZYAM)



- 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/c.
- Near side is more pronounced in **Pb+*p*** than in ***p*+Pb**.

The ridge evolution

- Compare both hemispheres (Pb or p direction) in **common absolute activity ranges**.
- Five identical activity ranges for the ***p*+Pb** and **Pb+*p*** configurations ($2200 < \mathcal{N}_{VELO}^{hits} < 3500$), the same particle production in $2.0 < \eta < 4.9$.

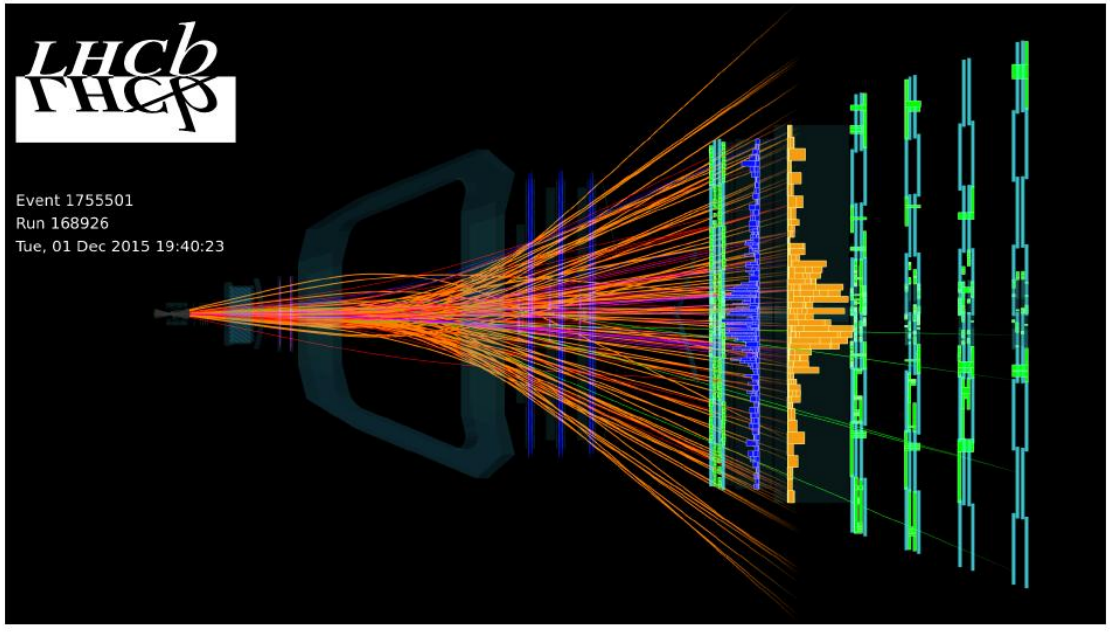


- Strength of **near-side ridges in both hemispheres are compatible with each other!**
- Different probed rapidity ranges in both beam configurations show no sizable effect. ***p*+Pb: $1.5 < y < 4.4$;** **Pb+*p*: $-5.4 < y < -2.5$**

Pb+Pb data taking in 2015

- LHCb first participated in Pb+Pb run in December 2015
- 24 colliding bunches, integrated luminosity $\mathcal{L}$ = 3 - 5 μb^{-1}
- Minimum bias trigger
- Tracking may be possible up to ~15k VELO hits (**100% - 50% centrality**)

https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbPlots2015



A Pb+Pb event with 1130 reconstructed tracks and a J/ψ candidate

Summary

- Two particle correlations in the forward rapidity have been measured in p+Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5 TeV
- A long-range correlation on the near-side (the ridge) is observed in both p+Pb and Pb+p configurations.
- The correlation structures on the near-side and on the away-side grow stronger with increasing event activity.
- In a given total event activity, the ridge is stronger in the Pb-going direction compared to in the p-going direction
- For the same absolute activities, the ridges in both hemispheres are compatible
- **Outlook**
  - Two particle correlations in $\sqrt{s}$ = 13 TeV p+p collisions at forward rapidity.
  - Two particle correlations in $\sqrt{s_{\mathrm{NN}}}$ = 5 TeV Pb+Pb collisions at forward rapidity.
  - Two particle correlations at mid-rapidity in fixed-target data
  - New p+Pb data taking at $\sqrt{s_{\mathrm{NN}}}$ = 8 TeV (high statistics) in 2016

Thanks!

The ridge in higher p_T bin

p_T range : 2.0 - 3.0 GeV/c

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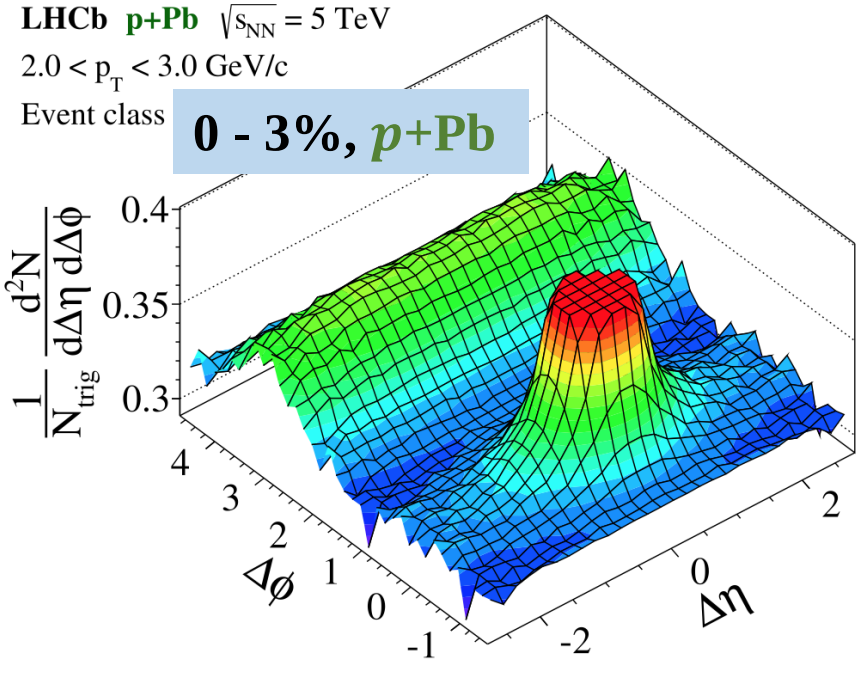
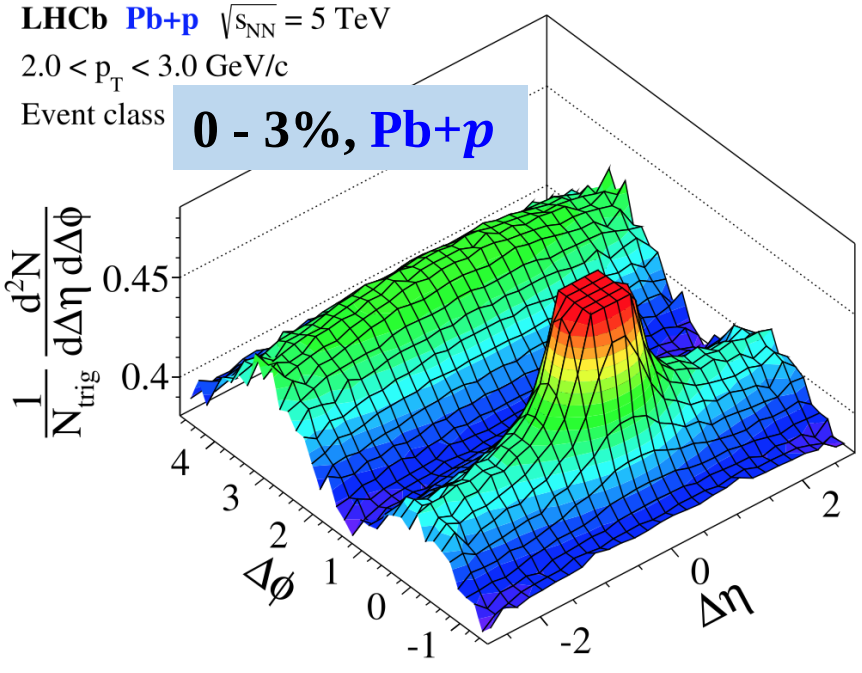




***p*+Pb** collisions (0-3%)

- $\Delta\phi = \pi$: away side ridge
- $\Delta\phi = 0$: near-side ridge visible

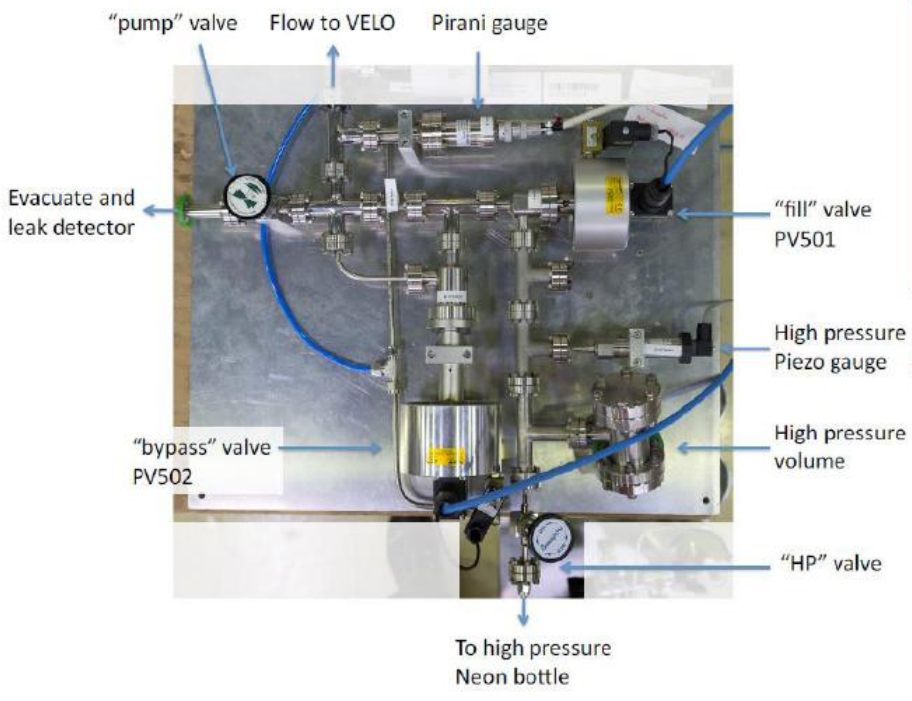
Pb+*p* collisions (0-3%)

- $\Delta\phi = \pi$: away side ridge
- $\Delta\phi = 0$: **near-side ridge much more pronounced!**

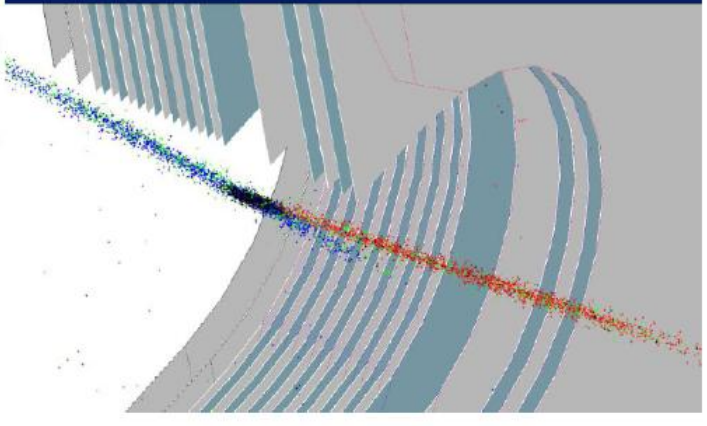
Fixed-target experiment with LHCb

SMOG: System for Measuring Overlap with Gas

JINST 9 (2014) P12005



- injection of gas into interaction region
- very simple robust system
- used for a precise luminosity determination



- Inject noble gases (He, Ne, Ar) into the LHCb vertex detector
- fixed-target physics in pA and PbA configuration, **covering mid-rapidity!**

Bridge the gap from SPS to LHC in a single experiment!