Two-particle correlations in p-Pb collisions at LHCb

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Outline

- Physics motivation
- p-Pb and Pb-p collisions at LHCb
- Data samples
- Analysis method
- Results
- Summary

Physics motivation

- Two particle-correlations:

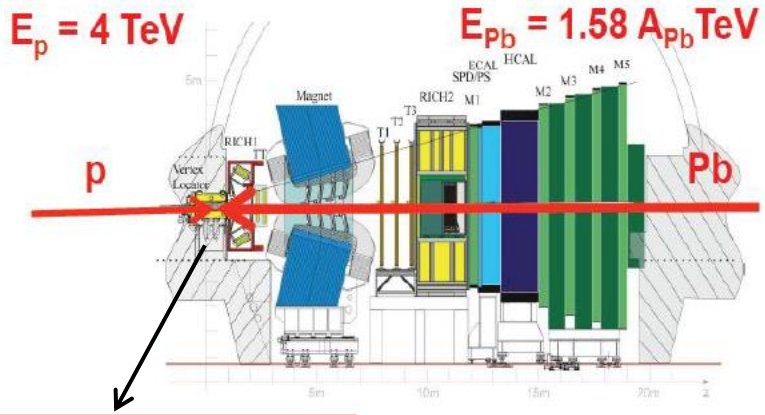
  angular correlations in ($\Delta\eta$,$\Delta\phi$) in pairs of prompt charged particles
- Long-range correlation on near-side (`ridge` at $\Delta\phi = 0$):
  - in Pb-Pb collisions (RHIC)
  - in Pb-Pb, p-Pb and p-p collisions at central rapidities $|\eta| < 2.5$ (ATLAS, CMS, ALICE)
- Theoretical explanation of the ridge still **under discussion** (e.g. gluon saturation, multiparton interactions, jet-medium interactions, collective effects)

- LHCb – results in the **forward direction** ($2.0 < \eta < 4.9$) **complementary** to measurements from other experiments
  - for two different beam configurations (p-Pb, Pb-p)
  - in different bins of event activity
  - in three p_T ranges
- This measurement gives an **additional input** for understanding the underlying physics

LHCb and pPb data taking

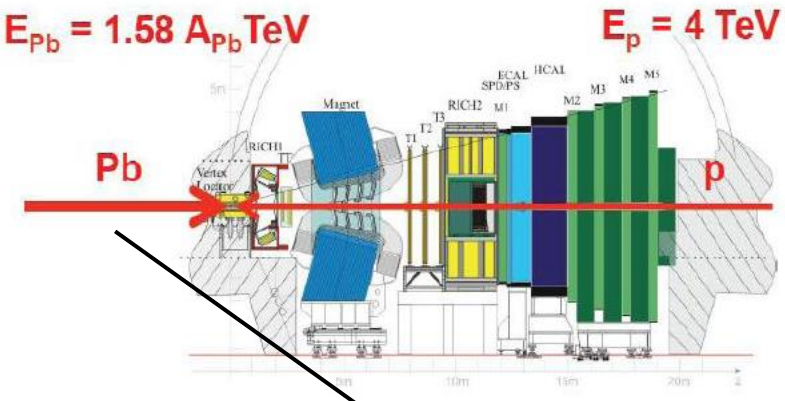
- LHCb designed to study CP violation and rare B decays, but can also do heavy ion and fixed target physics
- p-Pb and Pb-p data collected at $\sqrt{s_{NN}} = 5$ TeV in 2013
- **asymmetric beams**: nucleon-nucleon center-of-mass system shifted by Δy = 0.47 in direction of the proton beam

rapidity range: $1.5 < y_{CMS} < 4.5$
data collected: ~1.1 nb^{-1}



VELO detector used in definition of event activity

rapidity range: $-5.5 < y_{CMS} < -2.5$
data collected: ~0.5 nb^{-1}



higher activity expected when Pb goes `towards` the detector

- common rapidity range: $2.5 < |\, y_{CMS}| < 4.5$

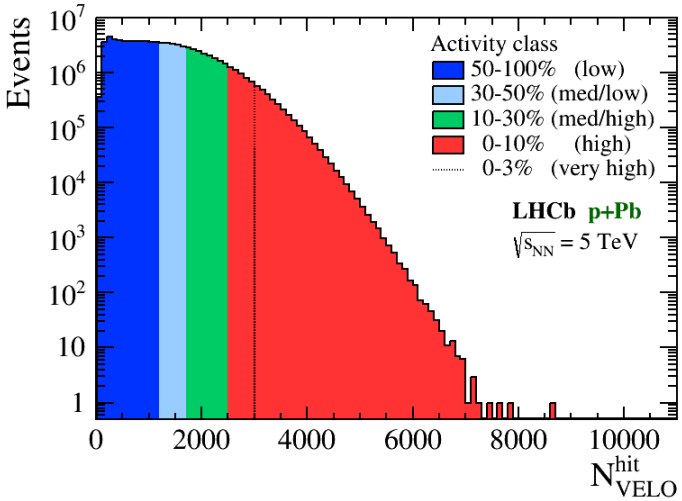
* y_{CMS}: rapidity in nucleon-nucleon center-of-mass system, with forward direction (positive values) in direction of the proton beam

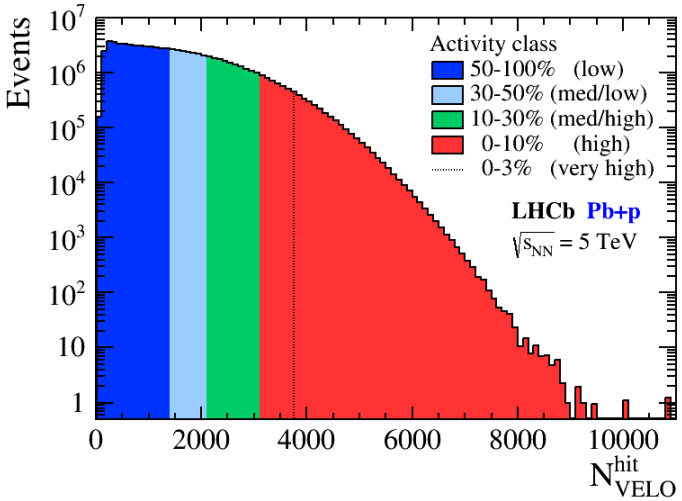
Data samples and activity classes

- Minimum bias samples from p-Pb and Pb-p collisions at $\sqrt{s_{NN}} = 5$ TeV (2013)
- 5 **relative** event activity classes

  defined as **fractions of VELO hit multiplicity distribution** for minimum bias samples (separately for p-Pb and Pb-p)
- 5 **common absolute** activity classes

  in high-multiplicity region $2200 < N^{hit}_{VELO} < 3500$ (comparison of p-Pb and Pb-p possible)





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Analysis method

- Take only events with **1PV**
  and choose **charged, prompt** particles from kinematic region:

  $p > 2$ GeV/c, $p_T > 150$ MeV/c, $2.0 < \eta < 4.9$

- Two-particle correlations are measured:
  - for different classes of **event activity**
  - in 3 **p_T ranges** [GeV/c]:

    [0.15–1.0], [1.0-2.0], [2.0-3.0]

- correlation function

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

pairs from the same event

normalization factor for background

# of candidate particles for pairs in all events

pairs from mixing

- mixing with particles from 5 random events of the same activity and p_T

Ridge effect (p_T: 1.0-2.0 GeV/c)

(1) jet peak ($\Delta\phi = 0$, $\Delta\eta = 0$):

- truncated to make other effects visible

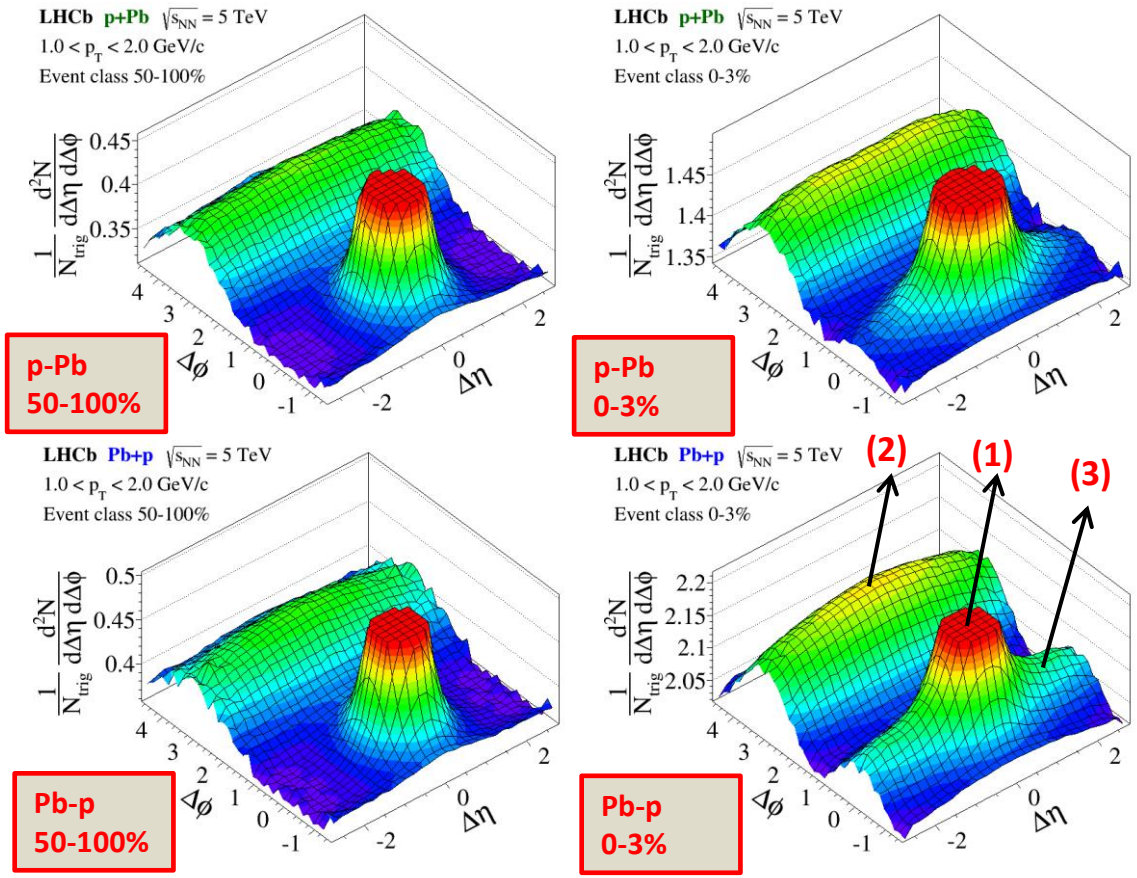
(2) away-side ridge ($\Delta\phi = \pi$):

- energy-momentum conservation balancing the jet peak

(3) near-side ridge ($\Delta\phi = 0$):

- appears in both p-Pb and Pb-p for high activity classes
- more prominent in Pb-p

p_T: 1.0 – 2.0 GeV/c



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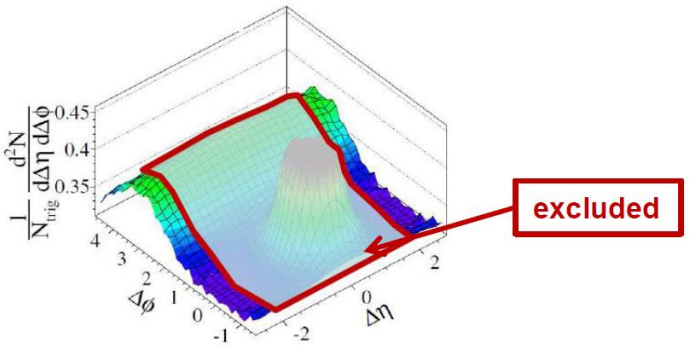
Ridge evolution (relative activity)

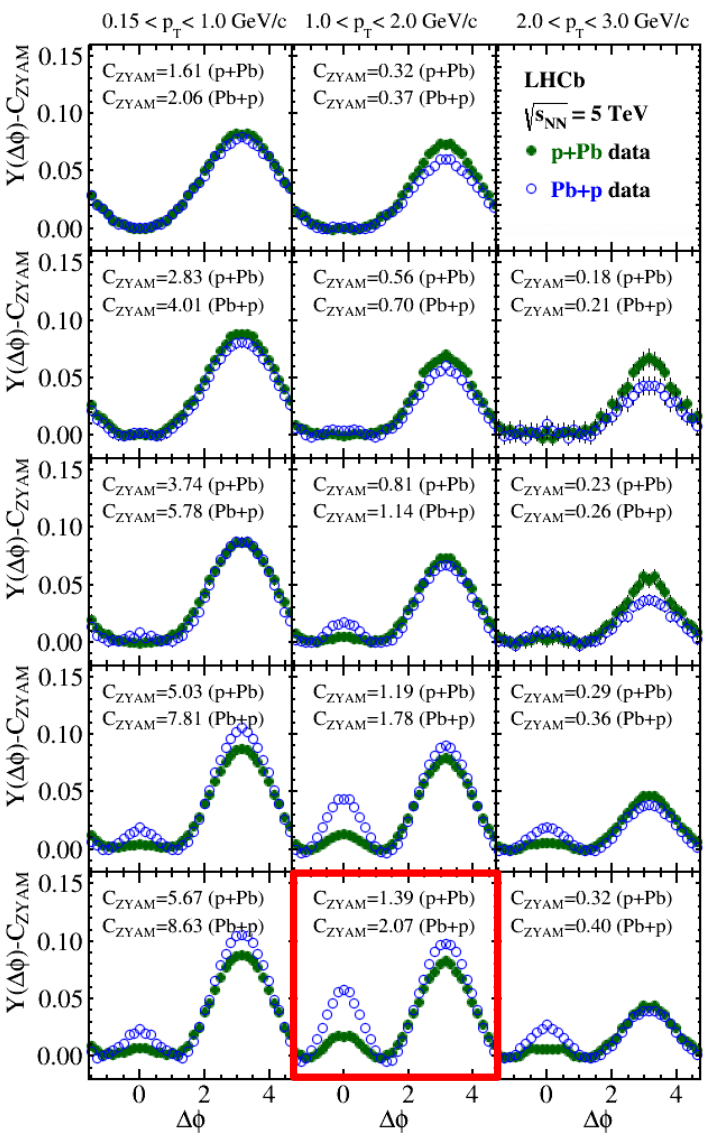
- to study the ridge -> make a **1D projection** of the correlation function:

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

- **exclude the jet** peak! (integrate in range of $\Delta\eta$: 2.0 – 2.9)



- comments:
  - correlation stronger with increasing event activity
  - away-side ridge getting smaller with rising p_T
  - near-side ridge strongest in p_T range: 1.0 – 2.0 GeV/c
  - the near-side ridge more prominent for Pb-p than p-Pb (larger event activity for Pb-p)



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Ridge evolution (common absolute activity)

- ridge evolution in **common absolute** activity classes
  (5 bins in $2200 < N_{VELO} < 3500$)
- in the p_T region with strongest near-side effect (1.0 – 2.0 GeV/c)

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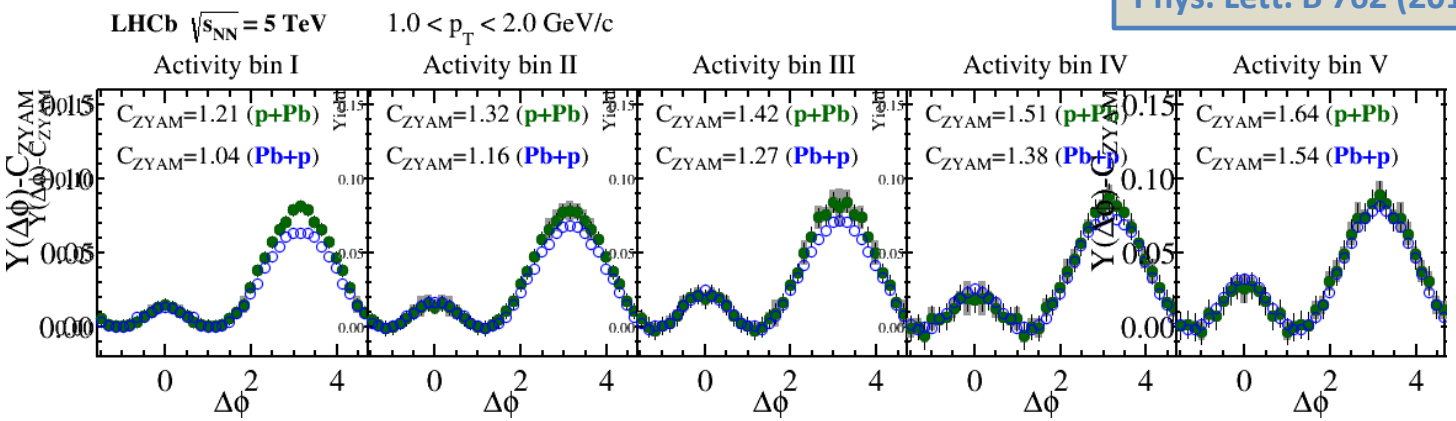

- correlation effect stronger with increasing event activity
- near-side ridge **compatible** for p-Pb and Pb-p collisions
- away-side effect also compatible for p-Pb and Pb-p collisions (apart from bin I)

Summary

- Two-particle angular correlations for p-Pb collisions at $\sqrt{s_{NN}} = 5$ TeV have been measured for the first time in the **forward region** ($2.0 < \eta < 4.9$)
- The near-side ridge effect has been observed in both p-Pb and Pb-p beam configurations (strongest in p_T range: 1.0 – 2.0 GeV/c)
- Both near-side and away-side ridge effects are getting stronger with increasing event activity
- In relative activity bins, the near-side ridge effect is stronger for Pb-p configuration
- The **ridge effects are compatible** for p-Pb and Pb-p collisions in **common absolute** activity classes
- **Theoretical explanation** of this phenomena still **under discussion**

- Planned analysis for other collision types (e.g. p-p, p-Ne) and other collision energies

BACKUP SLIDES

Data selection

- **Event selection**
  - events with exactly 1 PV (only 2% events with more than 1 PV)
  - PV must be in a luminous region (±3σ from the mean interaction point)
  - events with too small ratio between the number of clusters in the EM calorimeter and in the VELO are rejected

reduction of beam-gas and secondary interactions with detector material

- **Track selection**
  - prompt particles (small IP with respect to PV -> for IP < 1.2mm less than 3.5% secondaries left)
  - charged particles with hits in full LHCb tracking system (before and after the magnet)
  - kinematic region: $p > 2$ GeV/c, $p_T > 150$ MeV/c, $2.0 < \eta < 4.9$
- **Corrections**
  - fake tracks suppressed by using a multivariate classifier
  - other effects: acceptance and track reconstruction efficiency (the latter decreasing for high multiplicity events)
  - per-track weights assigned for correction:

$$\omega(\eta,\varphi,p_T,N_{VELO}) = (1 - P_{fake} - P_{sec}) / (\varepsilon_{acc} * \varepsilon_{tr})$$

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 – max	63.6	3000 – max	106.7
0 – 3% very high	3000 – max	73.7	3800 – 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