First measurements of long-range near-side angular correlations in $\sqrt{s_{NN}} = 5$ TeV proton-lead collisions in the forward region

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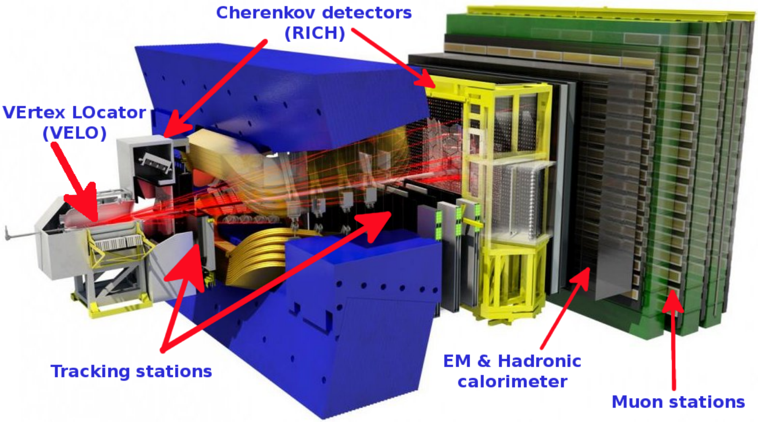
Outline

The LHCb experiment

LHCb is a forward spectrometer designed to study flavour physics but actually it is a general purpose detector, capable to do also heavy ion and fixed target physics



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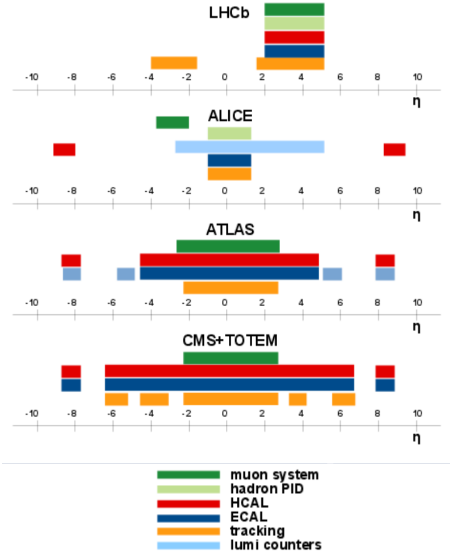
The LHCb experiment



Characteristics

- Impact parameter: $\sigma_{\text{IP}} = 20\mu\text{m}$
- Momentum resolution: $\Delta p/p = 0.5 \sim 0.8\%$ $(5 - 100\ \text{GeV/c})$
- RICH $K - \pi$ separation: $\varepsilon(\text{K} \to \text{K}) \sim 95\%$ mis-ID$\epsilon(\pi \to K) \sim 5\%$
- Acceptance $2 < \eta < 5$
- Fully instrumented in the forward region
  - $\rightarrow$ Heavy Ion physics studies in a unique kinematic area
  - $\rightarrow$ Complementary measurements to other LHC experiments
- Forward and backward coverage using p-Pb and Pb-p beams

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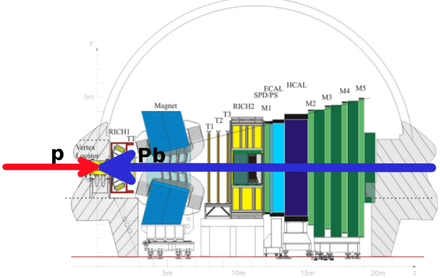
Proton-Lead data taking

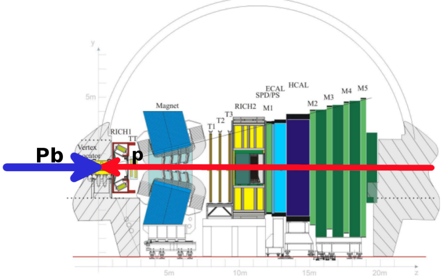
p-Pb configuration (Forward)

- Beam 1 energy: $E_p = 4$ TeV
- Beam 2 energy: $E_{Pb} = 1.58$ TeV
- $\eta_{lab} - \eta = +0.47$ in lab system
- rapidity coverage: $1.5 < y < 4.4$
- collected data $\mathcal{L} = 1.1\ nb^{-1}$



Pb-p configuration (Backward)

- Beam 1 energy: $E_{Pb} = 1.58$ TeV
- Beam 2 energy: $E_p = 4$ TeV
- $\eta_{lab} - \eta = -0.47$ in lab system
- rapidity coverage: $-5.4 < y < -2.5$
- collected data $\mathcal{L} = 0.6\ nb^{-1}$



- Common range for measurements: $2.5 < |y| < 4.4$
- Center-of-mass energy : $\sqrt{S_{NN}} = 5$ TeV
- Data collected in the proton-ion runs in 2013

Theoretical frame of the Two-particle correlations

Initial state effects:

- Local anisotropy of target fields
- Spatial variation of partonic density
- Glasma graph contributions to particle production within the CGC approach to high-energy hadronic scattering
  - → Numerical calculations reproduce the systematics of ridge correlations
  - → The physics underlying is not clear

Final state effects:

- Hydrodynamic-based models:
  - → Describe qualitatively features of the high multiplicity pp and pPb data
  - → Challenging to explain the physics process of the pp final state

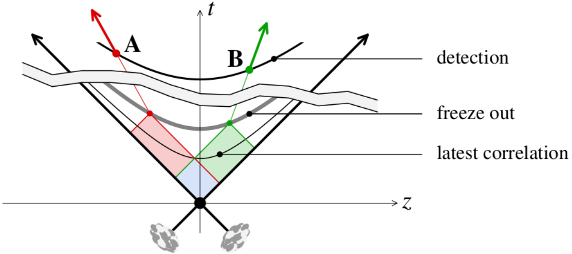


Figure from: Physics Letters B 697 (2011) 21-25

Expectations for all the models do not depend on the pseudorapidy

Two-particle correlations in p-Pb and Pb-p

- Measurement of two-particle angular $(\Delta\eta, \Delta\phi)$-correlations of prompt charged particles
- Motivation:
  - → Look for a long-range correlation on the near side ("the ridge"), which has been observed in PbPb collisions by the RHIC experiments and then in PbPb, pp and pPb collisions by CMS, ATLAS and ALICE, at central rapidities ($\eta < 2.5$)
  - → LHCb can confirm the ridge at large rapidities ($2 < \eta < 5$)
- Compare long-range correlations in both hemispheres (p and Pb direction) in relative and in common absolute activity ranges
- Both beam configurations are analysed separately

$$\text{p-Pb} \quad \Rightarrow \quad \mathcal{L} = 0.46\ \text{nb}^{-1}$$
$$\text{Pb-p} \quad \Rightarrow \quad \mathcal{L} = 0.30\ \text{nb}^{-1}$$

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Selection and data correction

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

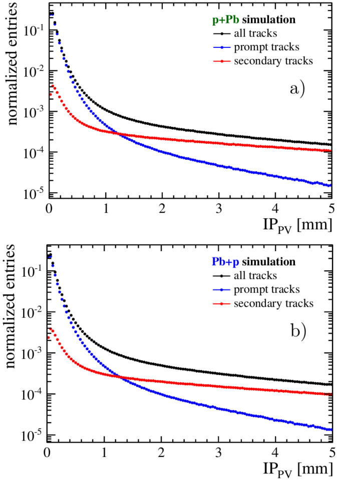
Track selection

- Select prompt particles by using impact parameter
- Select charged particles that traverse the full LHCb tracking system
- Kinematic range: $p > 2$ GeV/c, $p_T > 150$ MeV/c and $2.0 < \eta < 4.9$

Corrections

- Assign per-track weights, ω, to statistically correct contaminations and limited efficiencies
  - → Purity: $\omega_p(\eta, \phi, p_T, \mathcal{N}^{hits}_{VELO}) = 1 - \mathcal{P}_{fake} - \mathcal{P}_{sec}$ (fake tracks and secondary particles)
  - → Efficiency: $\omega_\varepsilon(\eta, \phi, p_T, \mathcal{N}^{hits}_{VELO}) = 1/(\varepsilon_{acc} \times \varepsilon_{tr})$ (detector acceptance and track reconstruction)

$$\omega(\eta, \phi, p_T, \mathcal{N}^{hits}_{VELO}) = \frac{1-\mathcal{P}_{fake}-\mathcal{P}_{sec}}{\varepsilon_{acc}\times\varepsilon_{tr}}$$



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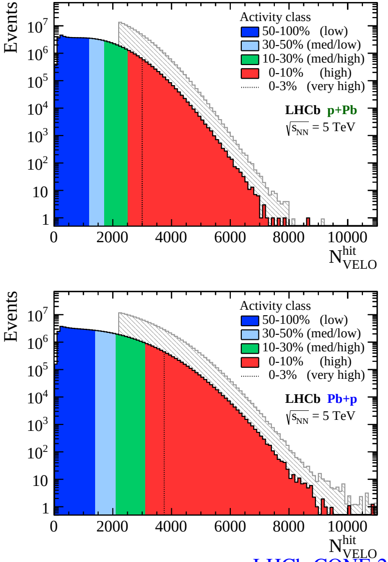
Activity classes and data samples

Data samples

- **Minimum bias:** Randomly selected events. $\mathcal{L} \approx 95\ \mu b^{-1}$
- **High-occupancy:** Events with > 2200 VELO hits. $\mathcal{L} \approx 764\ \mu b^{-1}$

Event activity

- Use VELO-hit multiplicity to measure the event activity
  - → VELO surrounds the interaction point
  - → most comprehensive measure of event activity
  - → proportional to number of charged particles
- 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 Pb-p and p-Pb
  - → 5 bins from 2200-3500 VELO hits



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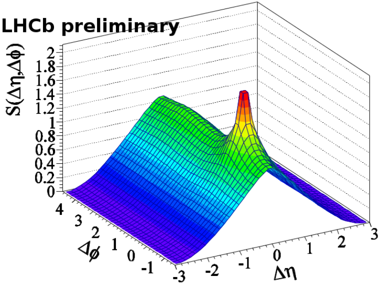
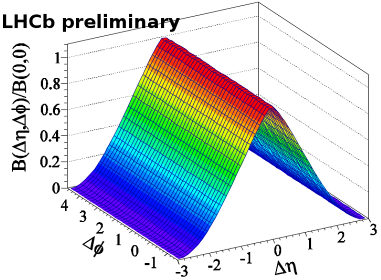
Analysis method

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



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

Per-trigger particle associated yield for particle pairs, N_{same}, formed from the same event



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

Yield of uncorrelated particles. Particle pairs, N_{mix}, from combinations from different events

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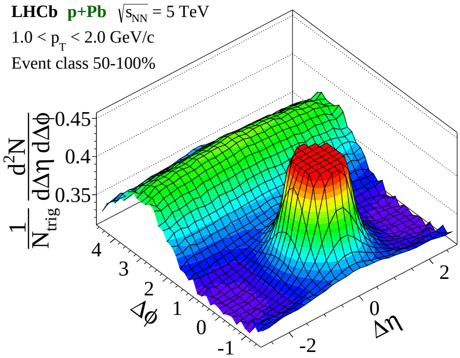
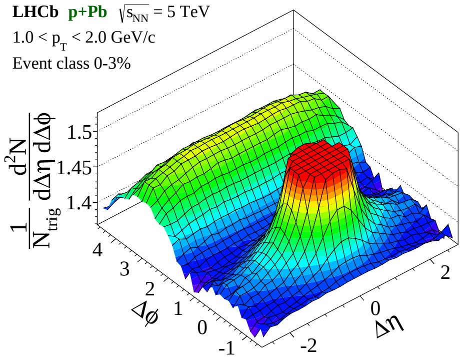
Ridge emergence

p-Pb configuration and $p_T \in [1.0, 2.0~\mathrm{GeV}/c]$



Low event-activity (50-100 %):

- $\Delta\phi = \pi \rightarrow$ Away-side ridge
- $\Delta\phi = 0 \rightarrow$ Jet peak



High event-activity (0-3 %):

- $\Delta\phi = \pi \rightarrow$ Away-side ridge
- $\Delta\phi = 0 \rightarrow$ Jet peak + near-side ridge

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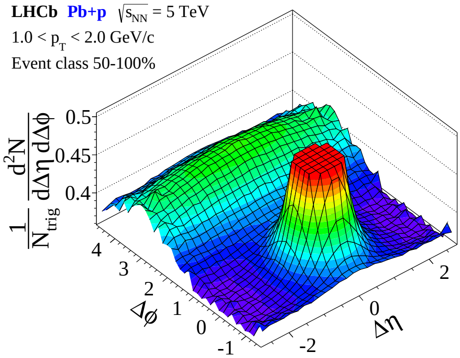
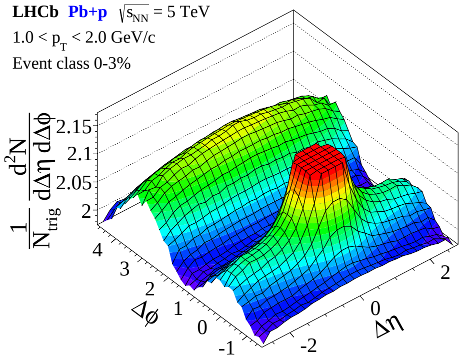
Ridge emergence

Pb-p configuration and $p_T \in [1.0, 2.0\ \mathrm{GeV}/c]$





Low event-activity (50-100 %):

- $\Delta\phi = \pi \rightarrow$ Away-side ridge
- $\Delta\phi = 0 \rightarrow$ Jet peak

High event-activity (0-3 %):

- $\Delta\phi = \pi \rightarrow$ Away-side ridge
- $\Delta\phi = 0 \rightarrow$ Jet peak + near-side ridge (very pronounced)

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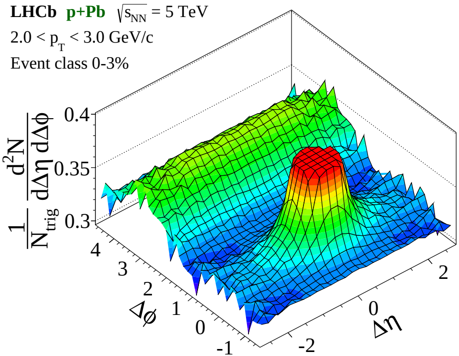
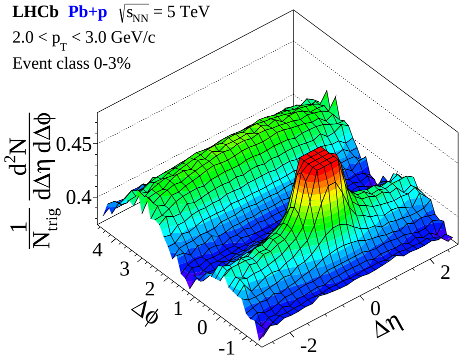
Ridge emergence

High event activity class and $p_T \in [2.0, 3.0\ \mathrm{GeV}/c]$





p-Pb configuration:

- $\Delta\phi = \pi \rightarrow$ Away-side ridge
- $\Delta\phi = 0 \rightarrow$ Jet peak + near side ridge

Pb-p configuration:

- $\Delta\phi = \pi \rightarrow$ Away-side ridge
- $\Delta\phi = 0 \rightarrow$ Jet peak + near-side ridge (again much more pronounced than in p-Pb configuration)

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Ridge evolution

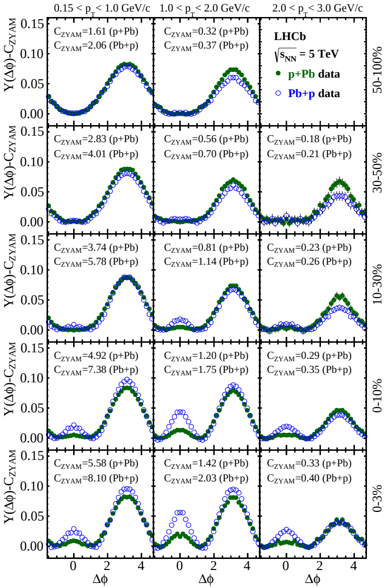
Projection of the correlation function on $\Delta\phi$:

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

- $2 < \Delta\eta < 2.9$
- Subtract the zero-yield-at-minimum (ZYAM)

Comments

- 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 ridge is more pronounced in Pb-p than in p-Pb



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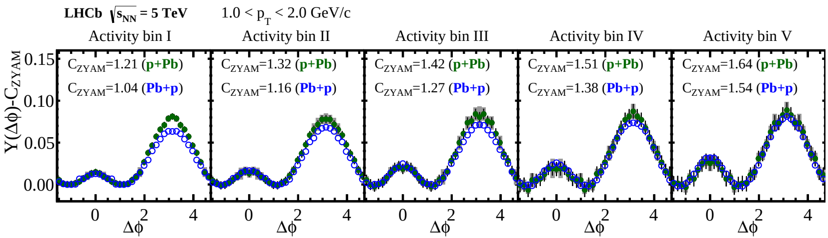
Ridge evolution

Common absolute activity ranges



- Five identical activity ranges for the p-Pb and Pb-p configurations ($2200 < \mathcal{N}_{VELO}^{hits} < 3500$)
- $2.0 < \Delta\eta < 2.9$

- 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 ridges in both hemispheres are compatible with each other
- Different rapidity ranges in both beam configurations show no sizable effect

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Summary and prospects

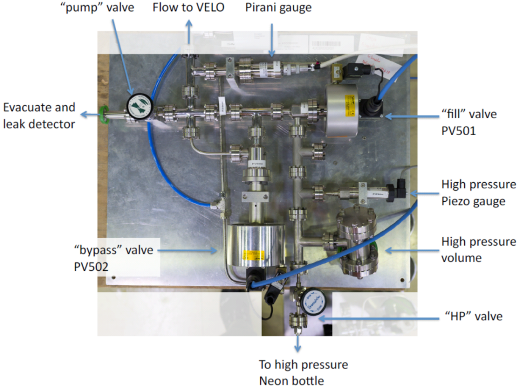
- LHCb is a general purpose experiment
- Two-particle angular correlations produced in pPb collisions at $\sqrt{S_{NN}} = 5$ TeV have been measured for the first time in the forward region
- A long-range correlation on the near-side (the ridge) is observed in both configurations p-Pb and Pb-p
- The correlation 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 direction compared to in the p direction
- For identical absolute activities, the ridges in both hemispheres are compatible

- We expect to collect $50 - 80\ \mu b^{-1}$ of PbPb luminosity this year
- We expect $\mathcal{O}(10\ nb^{-1})$ of pNe and PbNe luminosity by the end of this year
- In 2016 we plan to take pPb, pAr and PbAr data
- In 2017 there will be no heavy ions run. We foresee to take one week of pAr

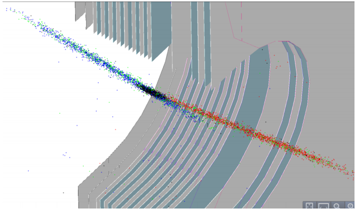
Backup

Fixed Target Physics with LHCb

SMOG: System for Measuring the Overlap with Gas



- Injection of (Ne) gas into the interaction region
- very simple robust system
- used for a precise luminosity determination



SMOG can be used for fixed target physics:

- Precise vertexing allows to separate beam-beam and beam-gas contributions
- Strong acceptance effects as a function of the z possition