Forward particle flow measurements in PbPb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV with the LHCb detector

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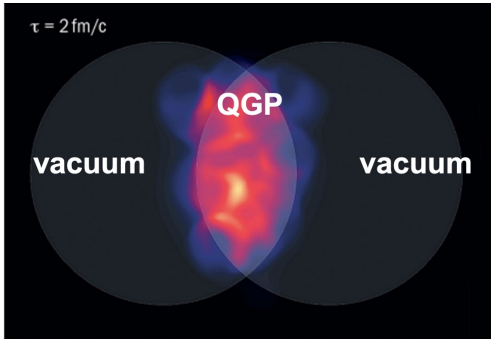
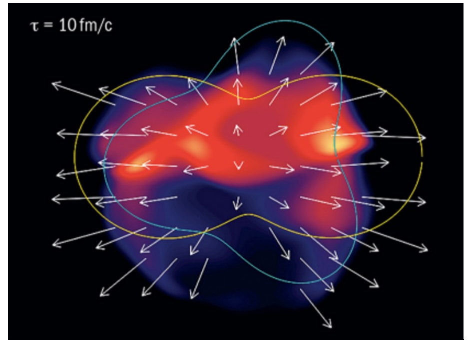
Outline

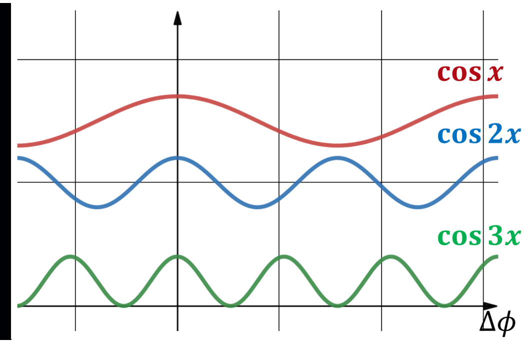
- Introduction
- The LHCb detector
- Analysis strategy
- Forward 2D correlation functions
- Forward charged-hadron correlations in PbPb at 5 TeV
- Summary and outlook

Introduction

- Flow Harmonics (spatial anisotropy of final particles)







$$\frac{dN_{flow}}{d\Delta\phi} = \frac{N}{2\pi}\left[1 + 2\sum_{n=1} v_n cos(n \cdot \Delta\phi)\right]$$

Flow harmonics

v_1: Directed flow. Deflection of the nuclear matter

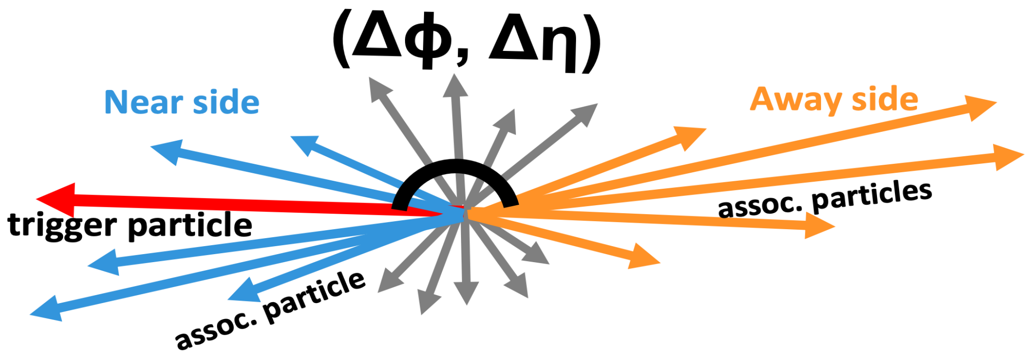
v_{2k}: Spatial anisotropy

v_{2k+1}: Fluctuation of the Initial Geometry

- Evolution and the properties of the QGP
  - Thermalization process
  - Initial- and final-state effects
  - Transport properties (η/s)

Introduction

- Two-particle correlations in the forward region



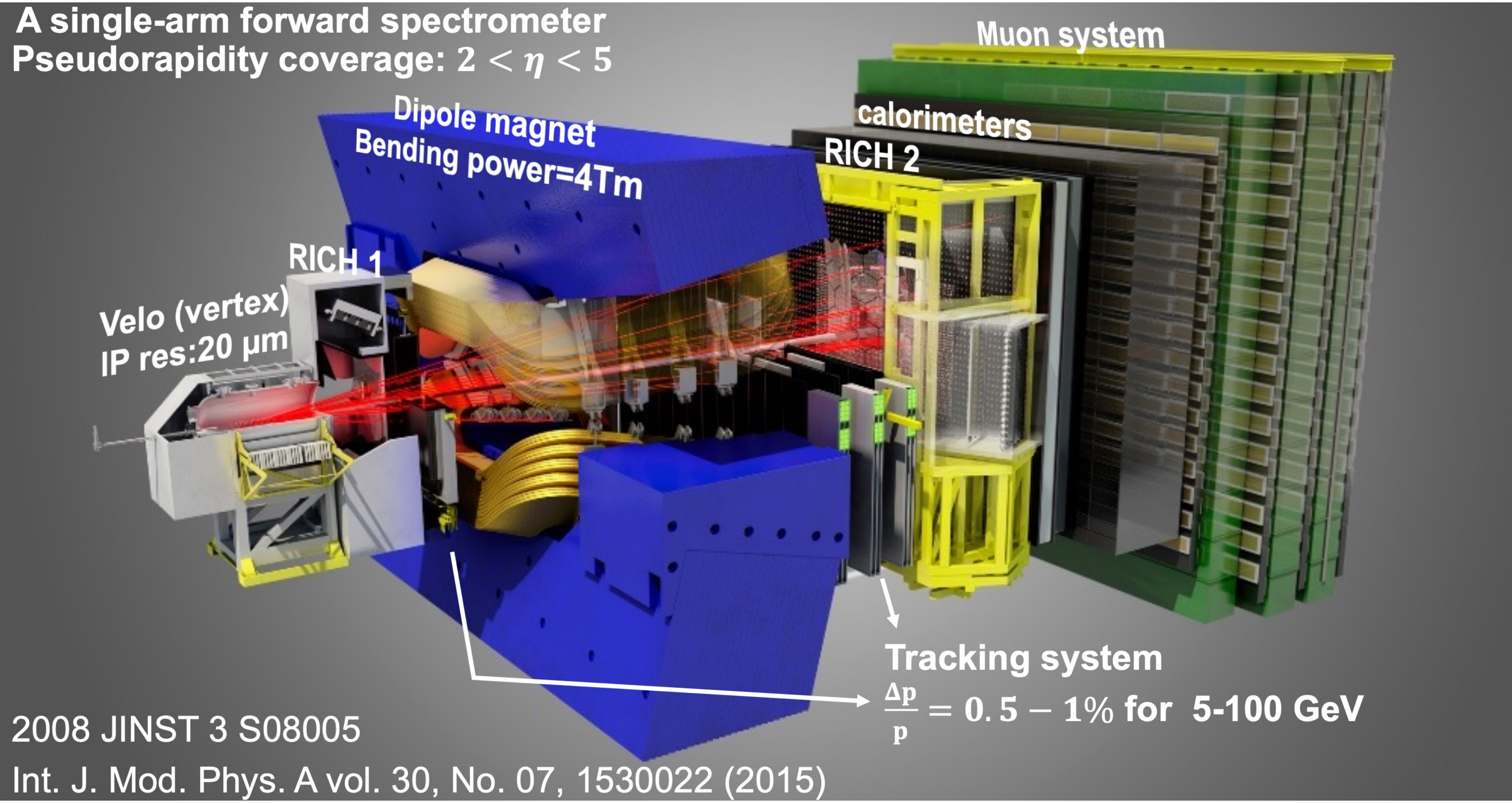
- Observed quantity: (Δϕ,Δη) of different particle pairs event by event
- Flow in the forward direction is heavily affected by "cooler" hadronic freeze-out

Phys. Rev. C90 (2014) 044904, arXiv:1407.8152.

- Test hydrodynamic and transport models with the non-equilibrium hadronic phase
- Complementary to other LHC results at central-pseudorapidity

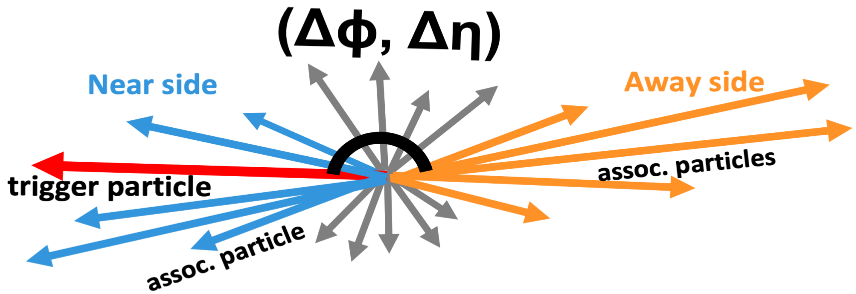
The LHCb detector

- High-precision momentum measurement and vertex reconstruction



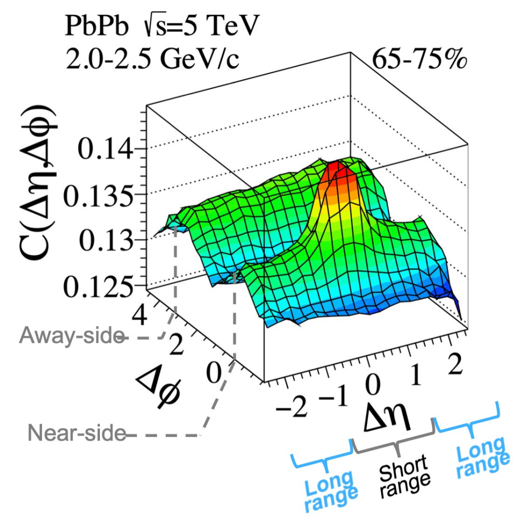
Analysis strategy

- 2D angular correlations with mixed-event corrections



$$C(\Delta\eta,\Delta\phi)=\frac{S(\Delta\eta,\Delta\phi)}{B(\Delta\eta,\Delta\phi)}$$

- C : correlation function
- S : distribution of particle pairs from same-event
  Signal biased by detector effects
- B : distribution of particle pairs from mixed-event
  No flow in B because of the random reaction plane

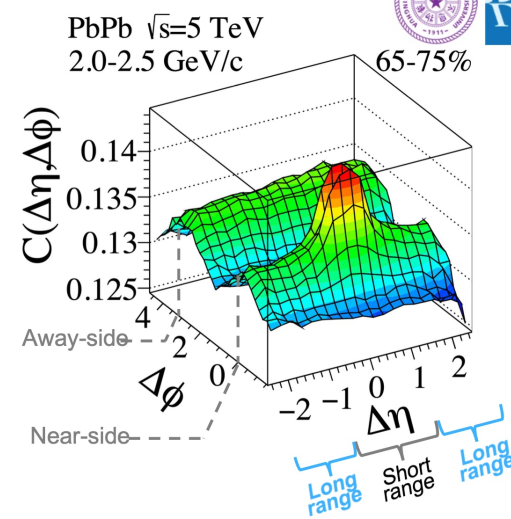


In the ratio C, the acceptance effects largely cancel out and only the physical correlations remain

Analysis strategy

- 1D two-particle azimuthal (Δϕ) correlation
  - Remove |Δη| ≤ 1 region to reduce short-range nonflow contributions

$$C(\Delta\phi) = \frac{\int_1^{2.9} S(|\Delta\eta|,\Delta\phi)\, d(|\Delta\eta|)}{\int_1^{2.9} B(|\Delta\eta|,\Delta\phi)\, d(|\Delta\eta|)}$$



  - Perform a Fourier series fit to this function including the the first three harmonic terms

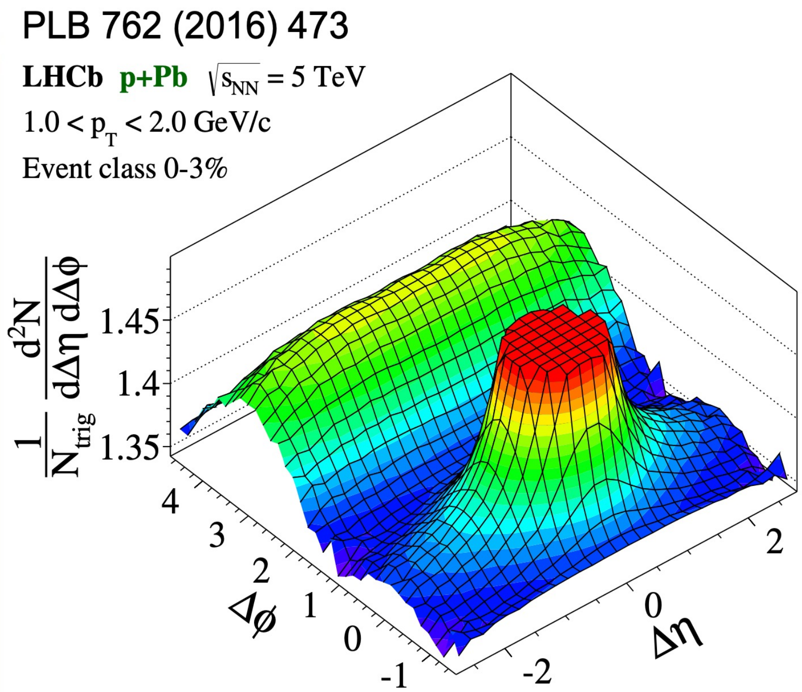
$$C(\Delta\phi) = A\left[1 + 2\sum_{n=1}^{3} V_n(p_{T_a}, p_{T_b})\cos(n\cdot\Delta\phi)\right]$$

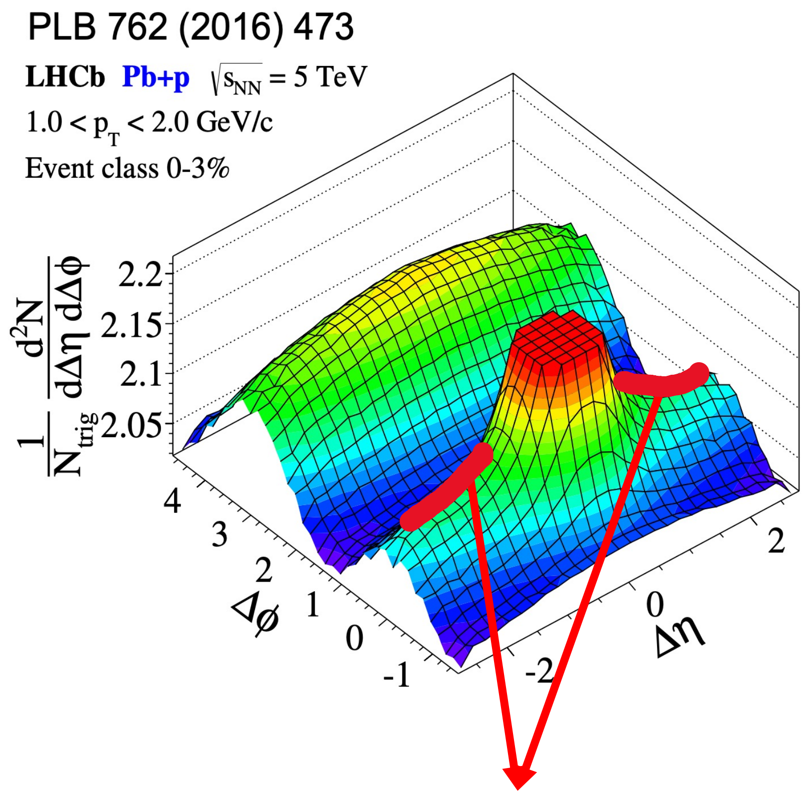
  - Extract the n^{th} flow harmonic coefficient of particle as a function of transverse momentum $v_n(p_T)$

$$V_n\left(p_{T_a}, p_{T_b}\right) = v_n^a(p_{T_a})\cdot v_n^b(p_{T_b})$$

Forward 2D correlation functions

- Small system(pPb & Pbp)



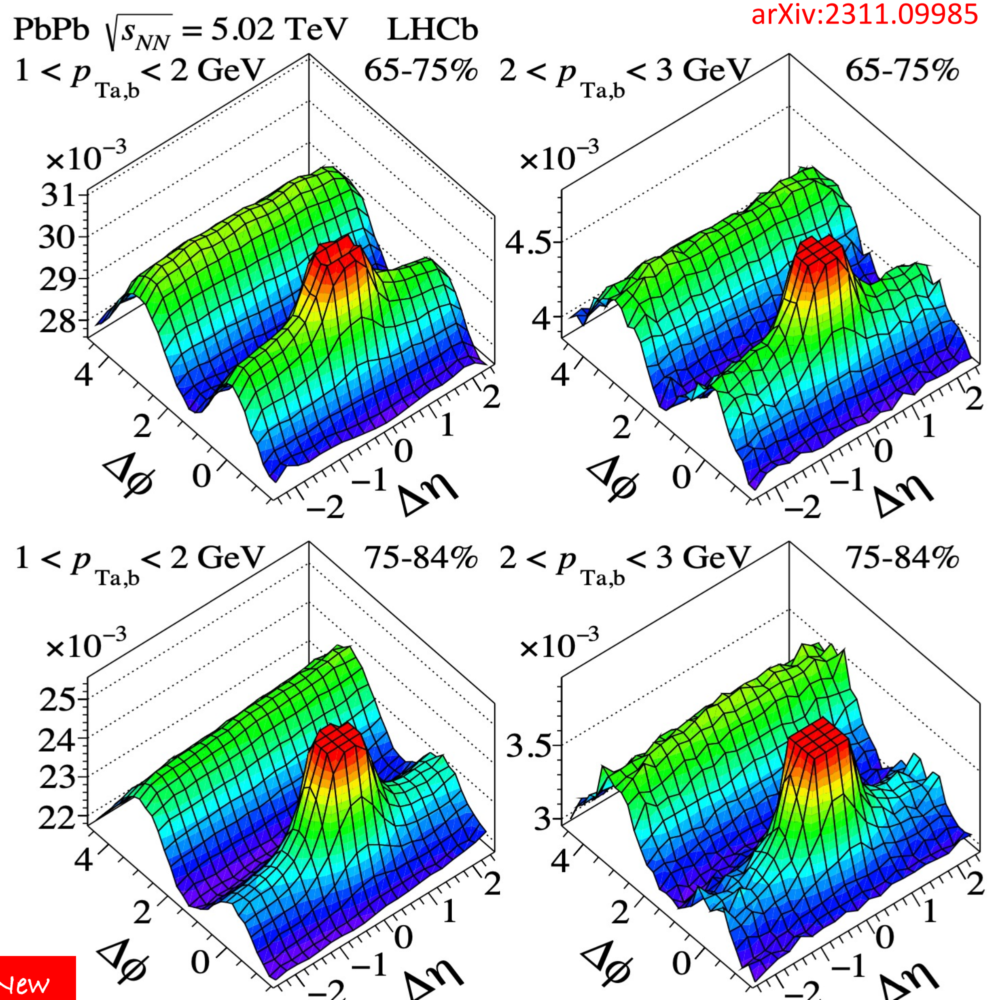


Noticeable lang range near-side ridge in Pbp compared to pPb

Forward 2D correlation functions

- Large system(PbPb)
  - New peripheral PbPb results show stronger near-side range

arXiv:2311.09985

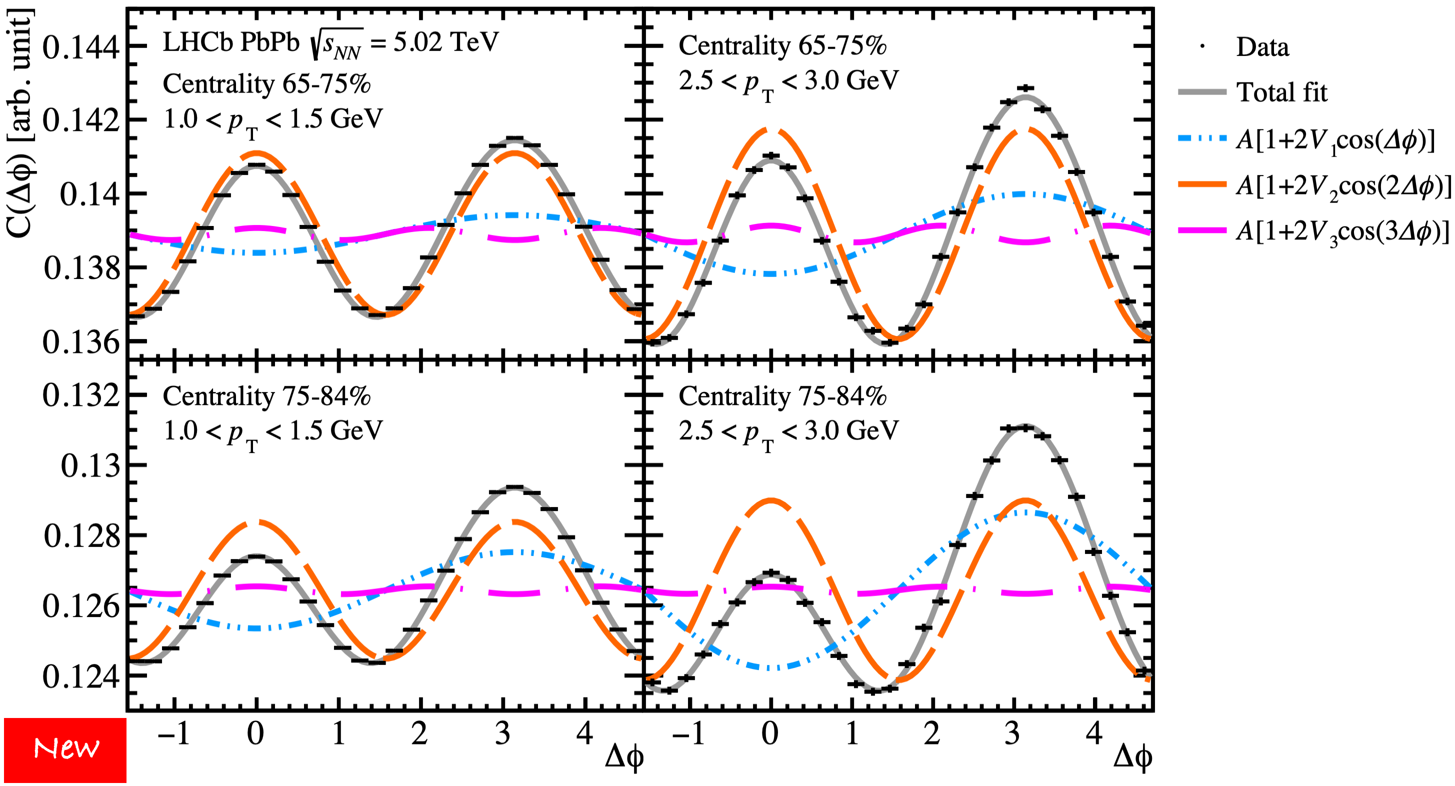


New

Forward charged-hadron correlations in PbPb at 5 TeV

- 1D correlation functions

arXiv:2311.09985

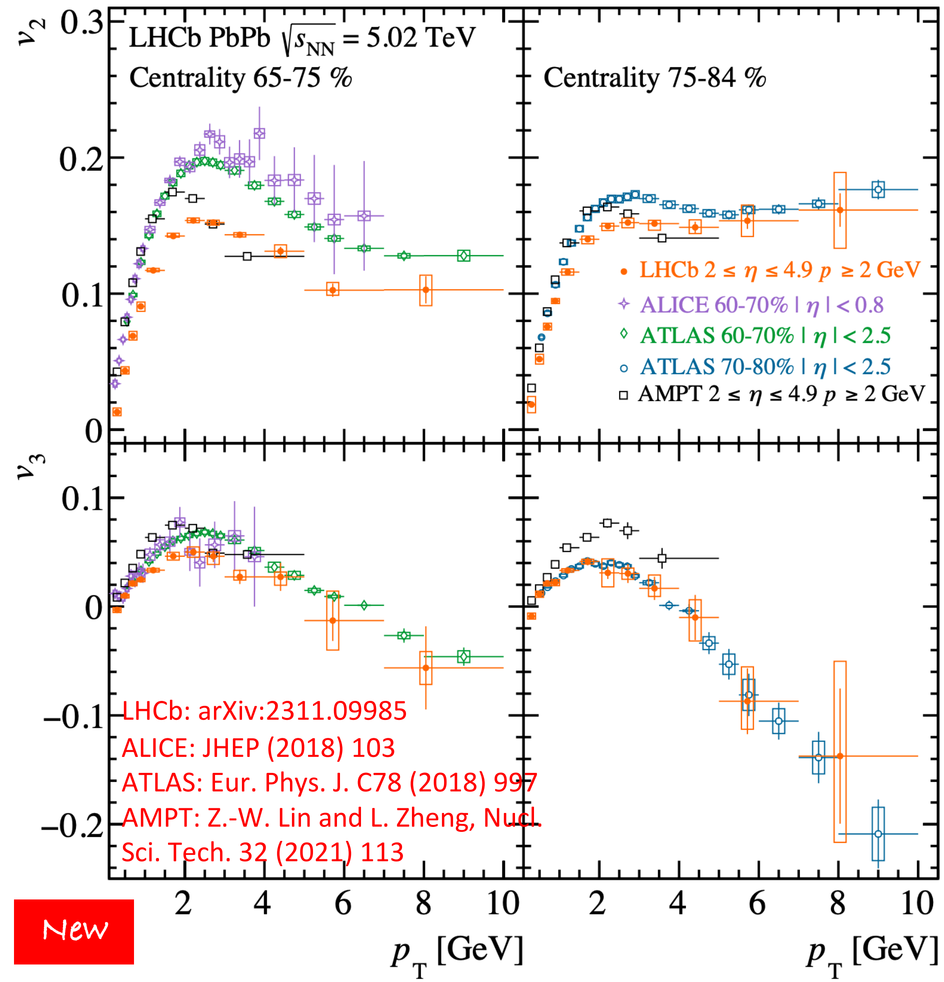


- Relative amplitude difference between the near- and away-side peaks at high p_T and in peripheral events
- Flow harmonic coefficients, $v_2(p_T)$ and $v_3(p_T)$ extracted from the Fourier series fits in different p_T ranges and centrality classes

Forward charged-hadron correlations in PbPb at 5 TeV

- First measurement of charged hadron $v_n(p_T)$ at LHCb

	Centrality class		Pseudorapidity
LHCb	65-75%	75-84%	$2 \leq \eta \leq 4.9$
ALICE	60-70%		$\|\eta\| < 0.8$
ATLAS	60-70%	70-80%	$\|\eta\| < 2.5$
AMPT	65-75%	75-84%	$2 \leq \eta \leq 4.9$



- LHCb results in the forward region show weaker v_n compared to ALICE and ATLAS results
- Constrain the theoretical model

Summary and outlook

- Two-particle angular correlation analysis
  - First measurement of charged hadron $v_n(p_T)$ at LHCb
  - Pronounced near-side ridges in PbPb than pPb $\rightarrow$ stronger forward particle flow
  - Generally smaller v2 and v3 values $\leftarrow$ different η range
  - Constrain the theory models
  - Evolution of QGP

- More measurements in small systems with high statistics are in process

Thank you for attention!

Backup

- Extract $v_n(p_T)$ from parameters $V_n(p_{T_a}, p_{T_b})$
  - First measure tracks from the reference tracks only

$$V_n(p_{T_b}, p_{T_b}) = v_n^b(p_{T_b}) \cdot v_n^b(p_{T_b})$$

  - Not apply to the first-order flow harmonic coefficient due to the long-range nonflow contributions

Backup

- Data selection
  - 2018 PbPb at $\sqrt{s_{\rm NN}} = 5.02$ TeV , 3.33 billion events, $\mathcal{L} = 213.7\ \mu\text{b}^{-1}$

Event	centrality	65–100%
	num. of reconstructed PV	nPV$\geq$1
	vertex	$0.758 < \text{PV}_\text{x} < 0.95$ mm
		For runNum< 218773, $0.08 < \text{PV}_\text{y} < 0.25$ mm
		For runNum≥ 218773, $-0.01 < \text{PV}_\text{y} < 0.168$ mm
		$-134.7 < \text{PV}_\text{z} < 140.1$ mm
	bunch-bunch crossing	bunch crossing type=3
	num. of back tracks	num. of back tracks≥ 15
	SMOG contamination cut	$\text{E}_\text{cal} > 2.7\times10^2\cdot\text{nVeloCluster} - 8\times10^5$
Single track	remove ghost track	ghost track probability≤ 0.2
	prompt particles	IP $\chi^2 \leq 9$
	track type	track type=3 (long track) [default cut]
	pseudorapidity	$2 \leq \eta \leq 4.9$ [implicit cut]
	associate p_T	$0.2 \leq p_{T,a} \leq 5$ GeV
	full momentum	$p > 2$ GeV [implicit cut]
	Clone track	KL distance≥ 5000 [default cut]

Backup

- Systematic uncertainties
  - a. Primary vertex requirement
  - b. Track fit quality requirement (ghost probability cut)
  - c. PbNe event contamination
  - d. Fourier fit fluctuation
  - e. Fluctuation of the mixed-event correlations
  - f. Unidentified charged Hadron efficiency and fake track rate

v_2 for centrality 65–75%						
p_T (GeV)	σ_a	σ_b	σ_c	σ_d	σ_e	σ_f
0.2–0.4	4%	< 1%	19–22%	< 1%	< 1%	6%
0.4–3.0	< 1%	< 1%	< 5%	< 1%	< 1%	< 5%
3.0–10.0	< 4%	< 1%	< 5%	< 1%	< 1%	< 10%
v_2 for centrality 75–84%						
p_T (GeV)	σ_a	σ_b	σ_c	σ_d	σ_e	σ_f
0.2–0.4	< 1%	< 1%	17–18%	< 1%	< 1%	27%
0.4–3.0	< 1%	< 1%	< 3%	< 1%	< 1%	< 6%
3.0–10.0	< 1%	< 1%	< 4%	< 1%	< 1%	1–17%
v_3 for centrality 65–75%						
p_T (GeV)	σ_a	σ_b	σ_c	σ_d	σ_e	σ_f
0.2–0.4	14%	2%	23–34%	< 1%	5%	64%
0.4–3.0	< 5%	< 2%	< 19%	< 1%	< 2%	3–9%
3.0–10.0	2–54%	< 9%	< 152%	< 2%	4–22%	7–133%
v_3 for centrality 75–84%						
p_T (GeV)	σ_a	σ_b	σ_c	σ_d	σ_e	σ_f
0.2–0.4	13%	1%	21–28%	< 1%	2%	14%
0.4–3.0	< 9%	< 2%	< 20%	< 1%	1–4%	2–35%
3.0–10.0	< 56%	1–20%	21–142%	< 8%	5–31%	18–146%