



Flow measurements at LHCb experiment

Jianqiao Wang
on behalf of the LHCb collaboration

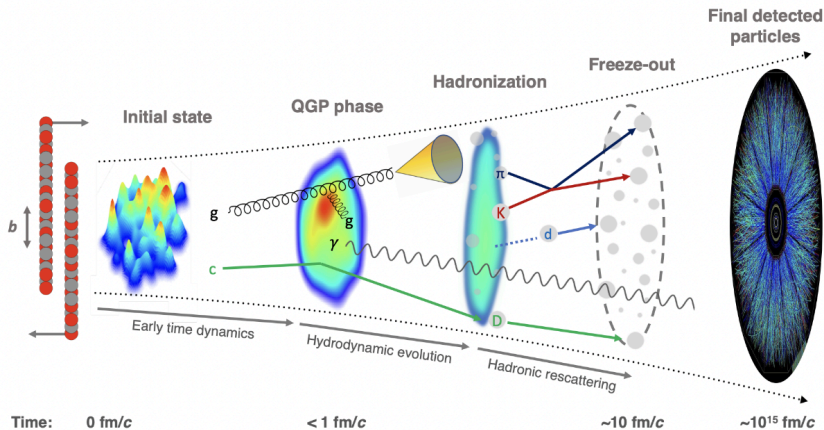
October 26, 2025



- 1 Physics background
- 2 Flow in 5.02 TeV PbPb
- 3 Flow in small systems
- 4 Flow in fixed-target PbNe and PbAr
- 5 Light-ion data taking
- 6 Summary and Prospects

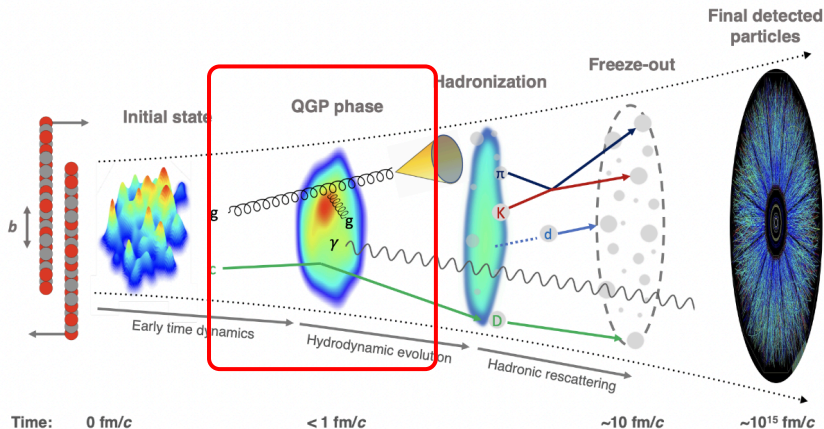
Standard Model for heavy-ion collisions

- Time evolution of heavy-ion collisions



Standard Model for heavy-ion collisions

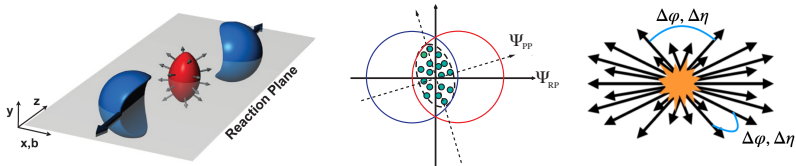
- Time evolution of heavy-ion collisions



- Fluid-like QGP created in PbPb collisions

Flow

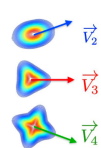
- Hydrodynamic and thermal expansion of medium can lead to particle collectivity
- Flow considered as one of the key signatures of QGP formation



- Characterized by Fourier coefficients v_n :

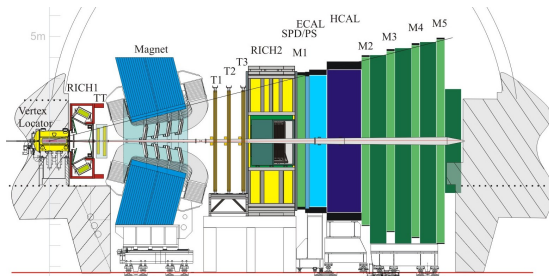
$$E \frac{d^3N}{dp^3} = \frac{1}{2\pi} \frac{d^2N}{p_T dp_T dy} \left(1 + 2 \sum_1^{\infty} v_n \cos[n(\phi - \Psi_R)] \right)$$

- ▶ v_1 : direct flow
- ▶ v_2 : elliptic flow
- ▶ v_3 : triangular flow

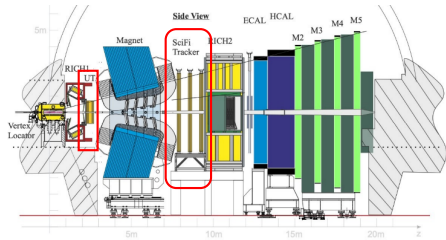


LHCb detector in Run2

- A single-arm general-purpose forward spectrometer, covering the pseudo-rapidity range of $2 < \eta < 5$.
- Excellent tracking and particle identification capabilities
- Complementary to other LHC experiments: forward rapidity, unique fixed-target mode, high-purity heavy flavor signals for flow measurements

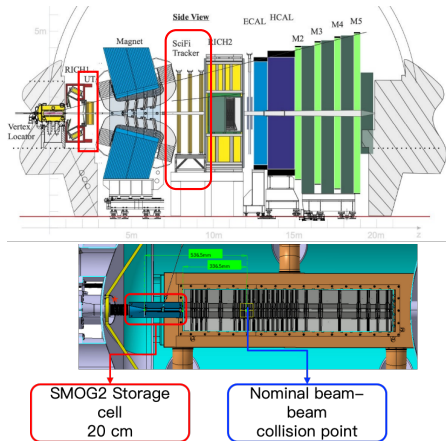


LHCb detector in Run3



- Upgraded tracking and trigger system to operate at higher luminosities
- More central data accessible for heavy-ion collisions
 - ▶ Up to 30% for PbPb, full-centrality for light-ion

LHCb detector in Run3

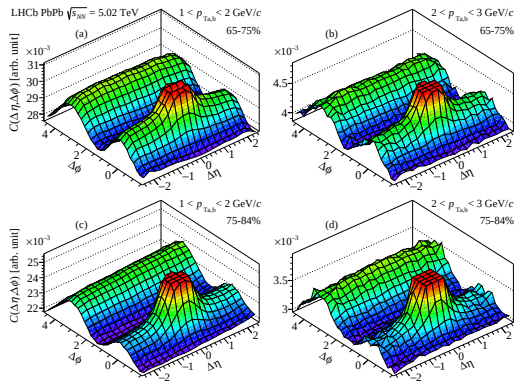


- Upgraded tracking and trigger system to operate at higher luminosities
- More central data accessible for heavy-ion collisions
 - ▶ Up to 30% for PbPb, full-centrality for light-ion
- New SMOG2 system for fixed-target program
 - ▶ Running simultaneously with collider mode
 - ▶ Unique energy range $\sqrt{s_{NN}} \sim 30\text{--}110\text{ GeV}$ and very backward rapidity
 - ▶ Wider choice of gas (H_2 , He, Ne, Ar)

Flow at forward rapidity

- Flow measurement with two-particle correlation with Run2 PbPb data at $\sqrt{s_{NN}} = 5.02$ TeV

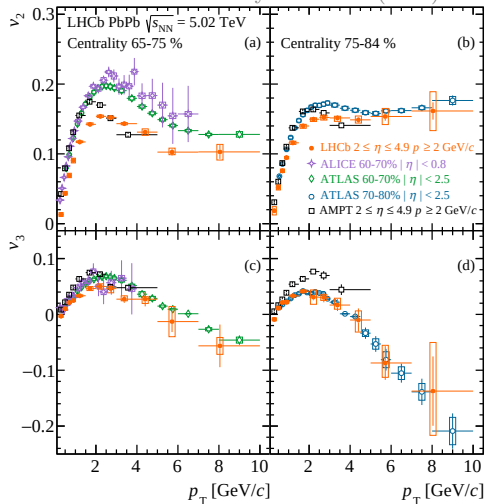
Phys.Rev.C109(2024)054908



- Near-side ridge observed in (peripheral) PbPb at forward rapidity, similar to midrapidity results
- Lower ridge for more peripheral collisions
- Non-flow subtracted by excluding jet region

Flow in 5.02 TeV PbPb

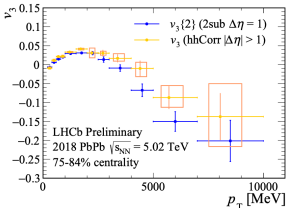
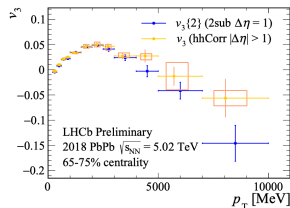
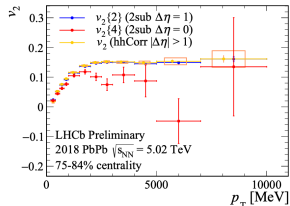
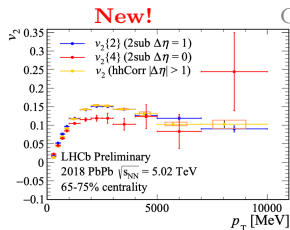
Phys.Rev.C109(2024)054908



- Smaller $v_2(p_T)$ and $v_3(p_T)$ compared to ALICE and ATLAS results at midrapidity, possibly due to the dominant freeze-out phase at forward rapidity
- AMPT overestimates v_n at forward rapidity

Flow in 5.02 TeV PbPb

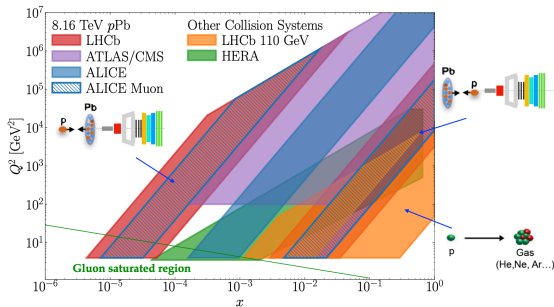
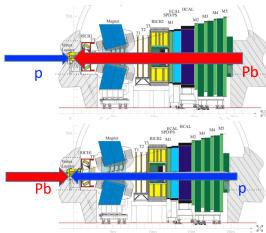
2PC: Phys.Rev.C109(2024)054908
Cumulant: LHCb-CONF-2025-001



- Smaller $v_2(p_T)$ and $v_3(p_T)$ compared to ALICE and ATLAS results at midrapidity, possibly due to the dominant freeze-out phase at forward rapidity
- AMPT overestimates v_n at forward rapidity
- Validation with cumulant method
 - ▶ Good agreement between two methods
 - ▶ Better non-flow subtraction with cumulant method

Flow in $p\text{Pb}$

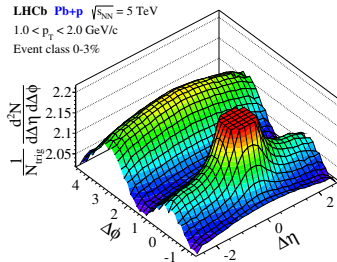
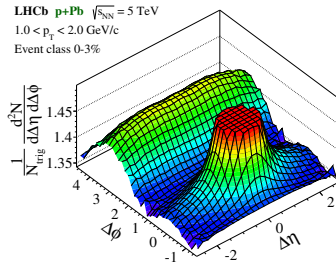
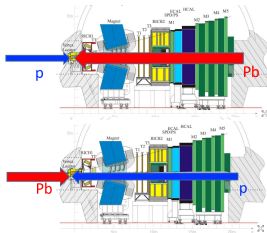
- Explanation for the QGP signature in high-multiplicity small systems
 - QGP droplet formation? Transport?
 - Glasma?
- Unique coverage to investigate possible gluon saturation



Flow in $p\text{Pb}$

- Explanation for the QGP signature in high-multiplicity small systems
 - ▶ QGP droplet formation? Transport?
 - ▶ Glasma?
- Long-range correlations observed in 5 TeV $p\text{Pb}$

Phys.Lett.B762(2016)473-483

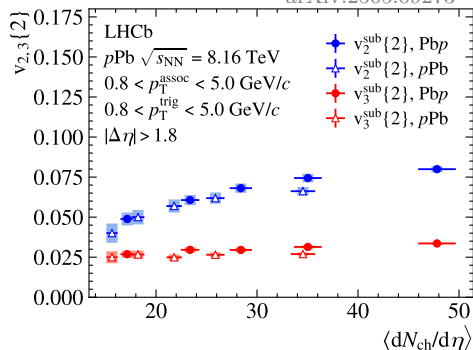


- No flow extraction unfortunately

Flow in 8.16 TeV $p\text{Pb}$

- More detailed analysis and higher statistics with Run2 $p\text{Pb}$
- Improved non-flow suppression compared to PbPb: large η gap, jet-yield subtracted method

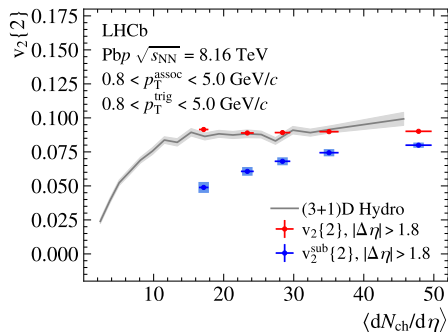
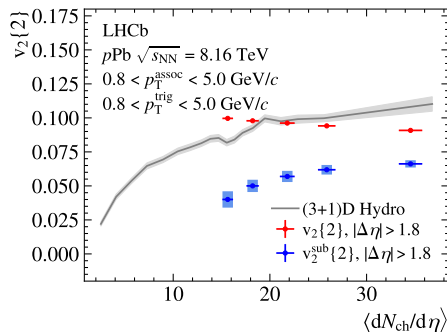
arXiv:2505.09273



- Rising v_2 and flat v_3 trends as a function of charged particle density
- Consistent result for both rapidities. No Bjorken- x dependence observed
- Final state effects dominant?

Flow in 8.16 TeV $p\text{Pb}$

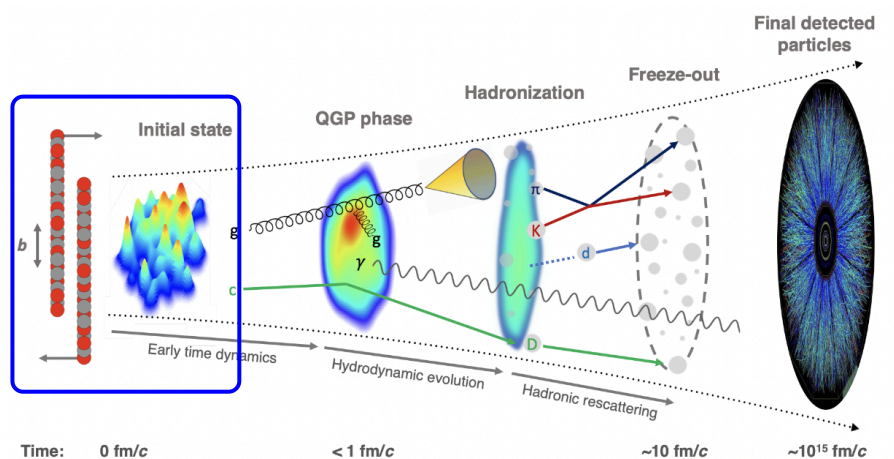
arXiv:2505.09273



- Compared with (3+1)D hydrodynamic model, which calibrated with pp results at different energies
- Clearly overestimates v_2
 - Issue of fluid parametrization or hydrodynamics itself in small systems?

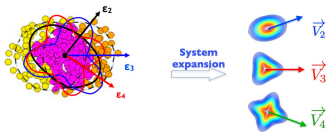
Initial geometry

- Other knowledge from flow measurements

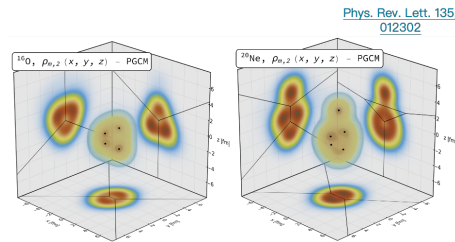


Nuclear shape

- Anisotropy initial shape can be converted to collective motion in momentum space

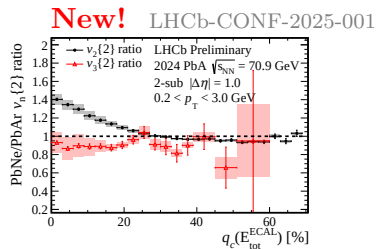
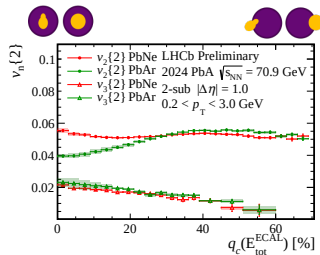


- Different nuclear structure predictions
 - ▶ Ne: strongly deformed **bowling pin shape**
 - ▶ O, Ar: nearly spherical
- Large v_2 difference expected between the most central AA collisions
- Even more pronounced differences in fixed-target systems!



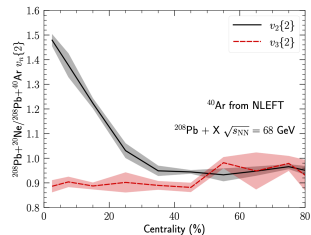
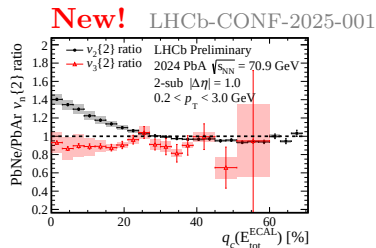
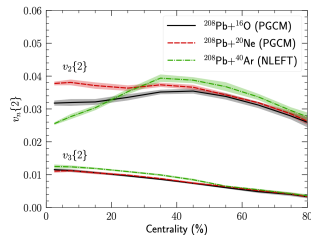
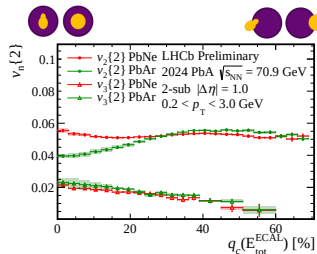
Flow in fixed-target PbNe and PbAr

- Flatter v_2 for PbNe compared with PbAr and similar decreasing v_3
- Significant enhanced ($\sim 40\%$) v_2 ratios between PbNe and PbAr as collision goes central



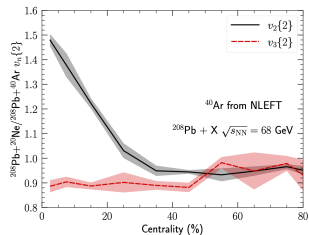
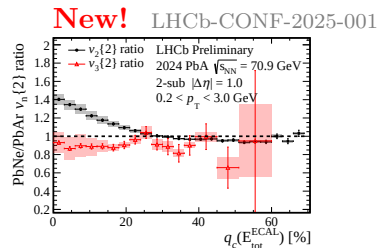
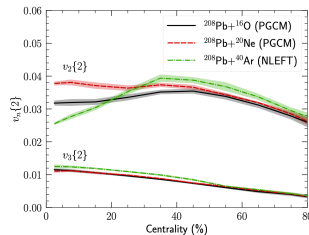
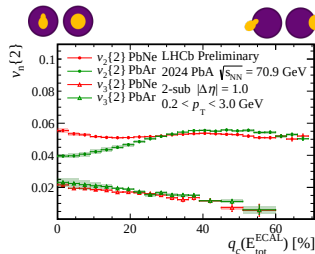
Flow in fixed-target PbNe and PbAr

- Flatter v_2 for PbNe compared with PbAr and similar decreasing v_3
- Significant enhanced ($\sim 40\%$) v_2 ratios between PbNe and PbAr as collision goes central
- Trend well described by 3+1D hydro prediction with ab-initio nuclear-structure (PGCM and NLEFT), suggesting the **elongated Neon shape** and the validity of **hydrodynamic description** in these systems



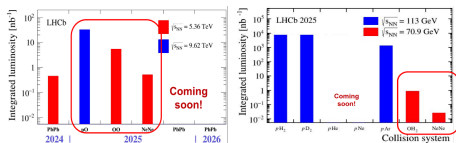
Flow in fixed-target PbNe and PbAr

- Flatter v_2 for PbNe compared with PbAr and similar decreasing v_3
- Significant enhanced ($\sim 40\%$) v_2 ratios between PbNe and PbAr as collision goes central
- Trend well described by 3+1D hydro prediction with ab-initio nuclear-structure (PGCM and NLEFT), suggesting the **elongated Neon shape** and the validity of **hydrodynamic description** in these systems
- Improved centrality calibration and updated models will be implemented for final results



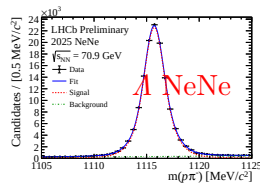
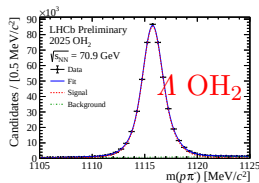
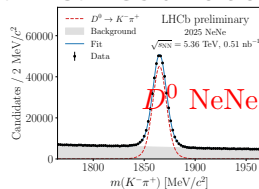
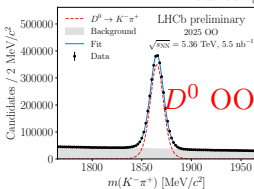
Light-ion data taking

- Both collider and fixed-target data from light-ion runs



- Excellent data collected in OO and NeNe run
- Search QGP signature in small systems and study the *transition* from large system
- Fixed-target OH₂ and NeNe data simultaneously with collider mode
- Unique opportunity for cosmic ray and nuclear imaging

Collider: LHCb-FIGURE-2025-017
Fixed-target: LHCb-FIGURE-2025-019



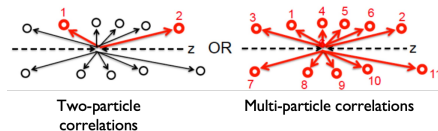
Summary and Prospects

- Growing contributions on flow results from LHCb experiment
 - ▶ Significant charged particle v_2 in p Pb and PbPb collisions at forward rapidity, smaller than that observed at midrapidity
 - ▶ Hydrodynamic model overestimates v_2 in p Pb collisions, more studies needed to understand the discrepancy
 - ▶ **First** preliminary result with upgraded SMOG2 system, suggesting the ^{20}Ne **nucleus deformation**
- Outlook
 - ▶ Further measurements (*e.g.* $v_n - p_T$ correlation) for studying cluster structures of light nuclei
 - ▶ Excellent data from light-ion run both for colliding and fixed-target modes

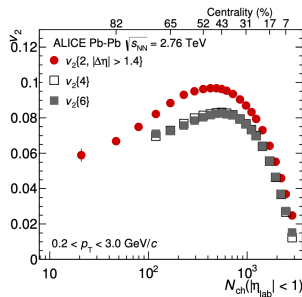
Thanks for your attention!

Cumulant method

- Cumulant method: n th order cumulant $c_n\{m\}$ can be derived from Q_n vectors

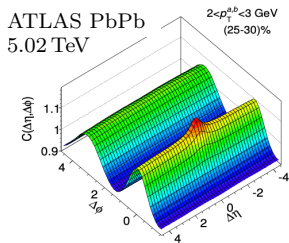
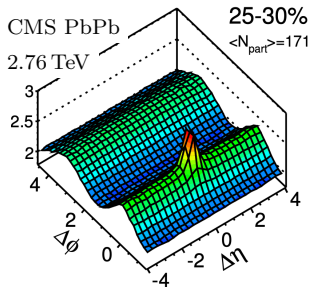


$$v_2\{2\} = (c_2\{2\})^{1/2}, \quad v_2\{4\} = (-c_2\{4\})^{1/4}$$



- Non-flow effects with suppressed with more particles correlated
- Results directly come from the event-by-event measurement

Two-particle correlation



- Two-particle correlation: $(\Delta\eta, \Delta\phi)$ correlation function
- Obtained by comparing distributions same-event and mixed-event pairs

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

- Long-range correlation *ridge* symbolises the positive v_2
- Significant ridge and jet (non-flow) structures
- What about forward rapidity?