# Flow measurements at LHCb experiment

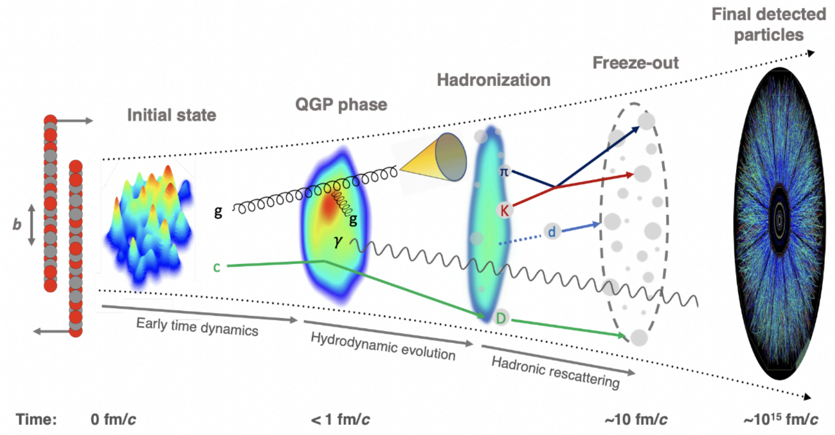
Jianqiao Wang
on behalf of the LHCb collaboration

October 26, 2025

The 11th China LHC Physics Conference

# *Standard Model* for heavy-ion collisions

- Time evolution of heavy-ion collisions



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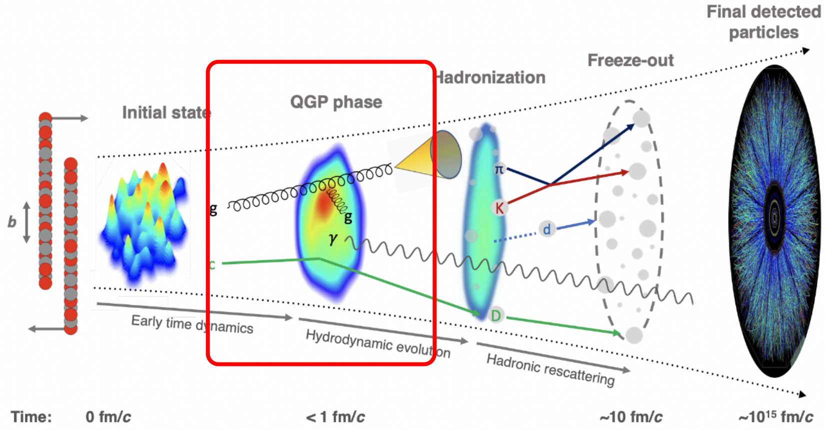
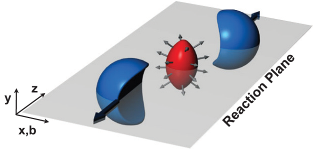
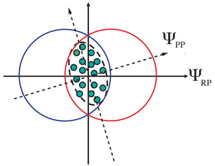


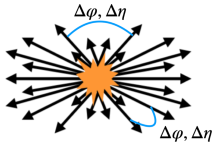

- Fluid-like QGP created in PbPb collisions

# Flow

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



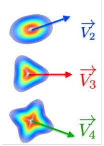




- Characterized by Fourier coefficients $v_n$ :

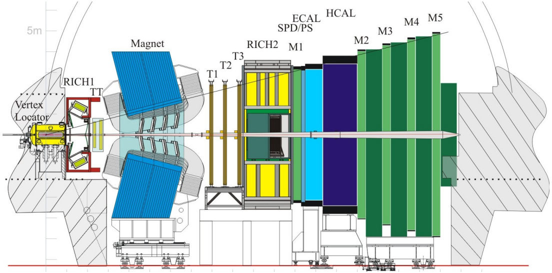
$$E\frac{\mathrm{d}^3N}{\mathrm{d}p^3} = \frac{1}{2\pi}\frac{\mathrm{d}^2N}{p_\mathrm{T}\mathrm{d}p_\mathrm{T}\mathrm{d}y}\left(1 + 2\sum_1^\infty v_n \cos[n(\phi - \Psi_\mathrm{R})]\right)$$

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

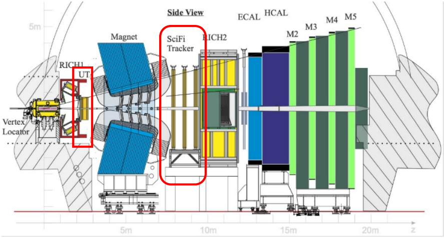


# LHCb detector in Run2

- 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

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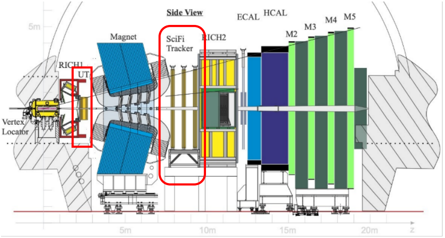
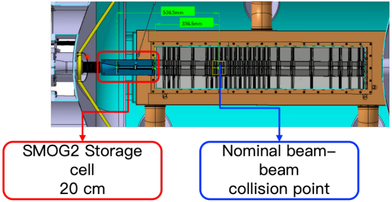


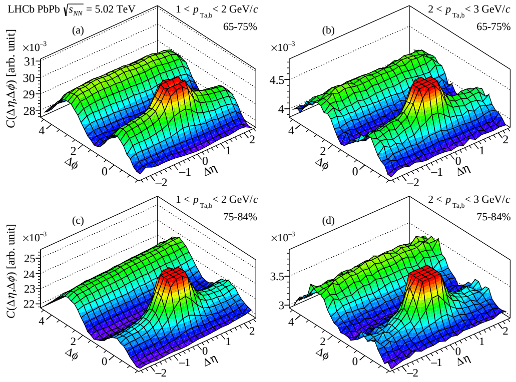




- Upgraded tracking and trigger system to operate at higher luminosities
- More central data accessible for heavy-ion collisions
  - Up to 30% for PbPb, full-centrality for light-ion
- New SMOG2 system for fixed-target program
  - Running simultaneously with collider mode
  - Unique energy range $\sqrt{s_{\mathrm{NN}}}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

# Flow at forward rapidity

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

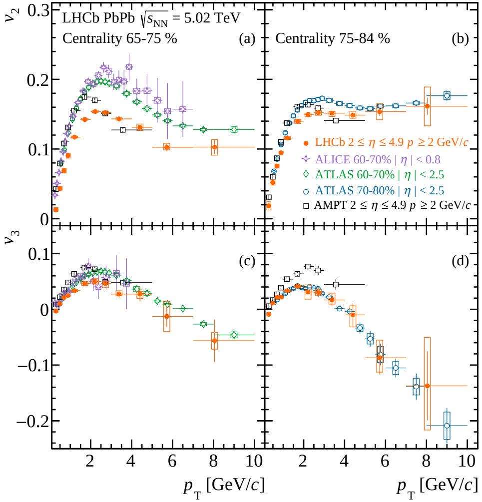
Phys.Rev.C109(2024)054908




- 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

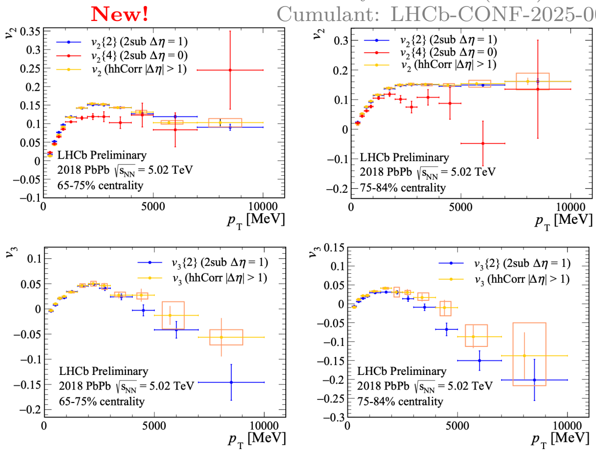
Phys.Rev.C109(2024)054908




- 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

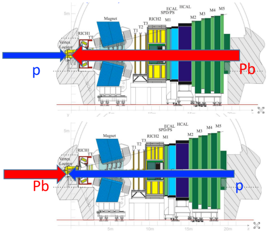
2PC: Phys.Rev.C109(2024)054908
Cumulant: LHCb-CONF-2025-001



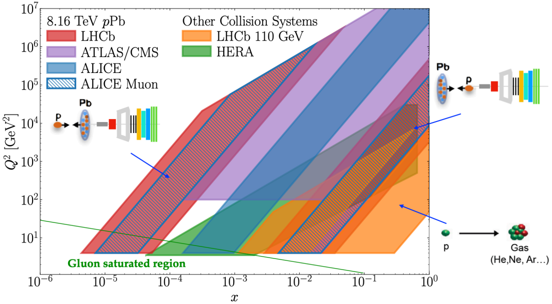

- Smaller $v_2(p_T)$ and $v_3(p_T)$ compared to ALICE and ATLAS results at midrapidity, possibly due to the dominant freeze-out phase at forward rapidity
- AMPT overestimates $v_n$ at forward rapidity
- Validation with cumulant method
  - Good agreement between two methods
  - Better non-flow subtraction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

# Flow in $p$Pb

- Explanation for the QGP signature in high-multiplicity small systems
  - QGP droplet formation? Transport?
  - Glasma?




- Unique coverage to investigate possible gluon saturation



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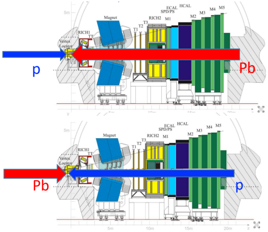
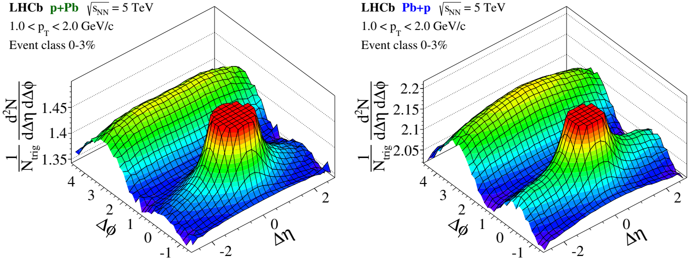



- Long-range correlations observed in 5 TeV $p$Pb

Phys.Lett.B762(2016)473-483

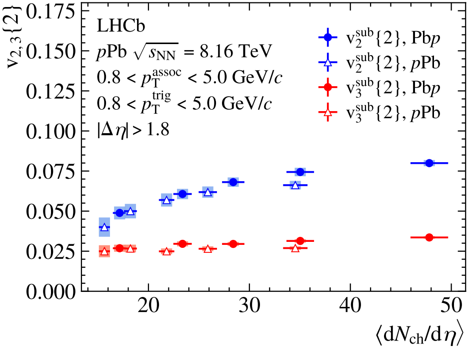



- No flow extraction unfortunately

# Flow in 8.16 TeV $p$Pb

- More detailed analysis and higher statistics with Run2 $p$Pb
- Improved non-flow suppression compared to PbPb: large $\eta$ 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?

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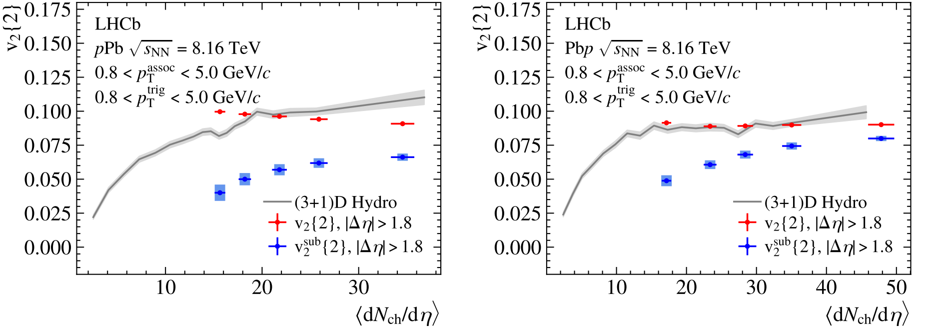
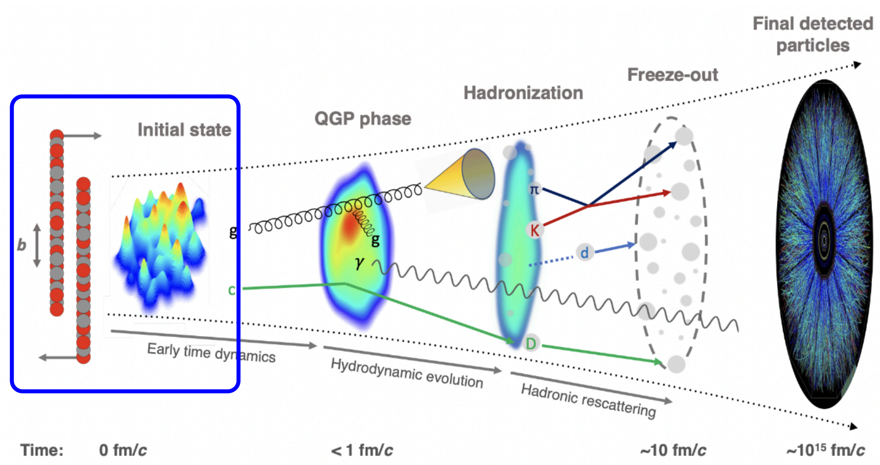



- Compared with (3+1)D hydrodynamic model, which calibrated with $pp$ results at different energies
- Clearly overestimates $v_2$
  - Issue of fluid parametrization or hydrodynamics itself in small systems?

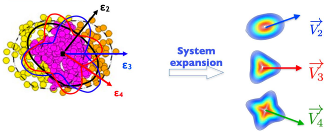
# Initial geometry

- Other knowledge from flow measurements



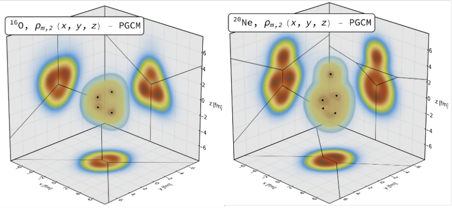
# Nuclear shape

- Anisotropy initial shape can be converted to collevtive 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

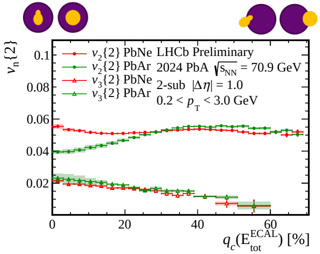
Phys. Rev. Lett. 135, 012302



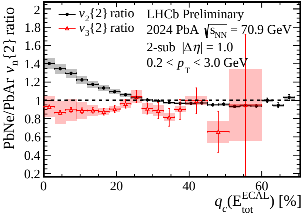

- Even more pronounced differences in fixed-target systems!

# 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




**New!** LHCb-CONF-2025-001



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- 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

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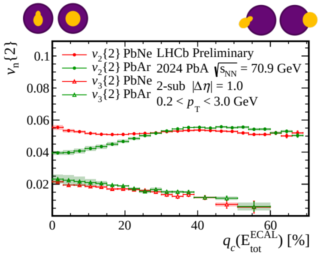


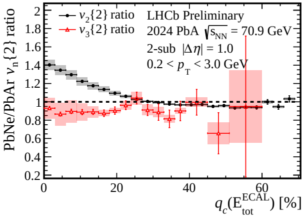


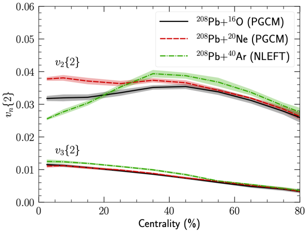


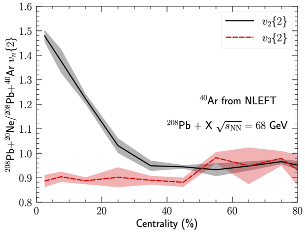

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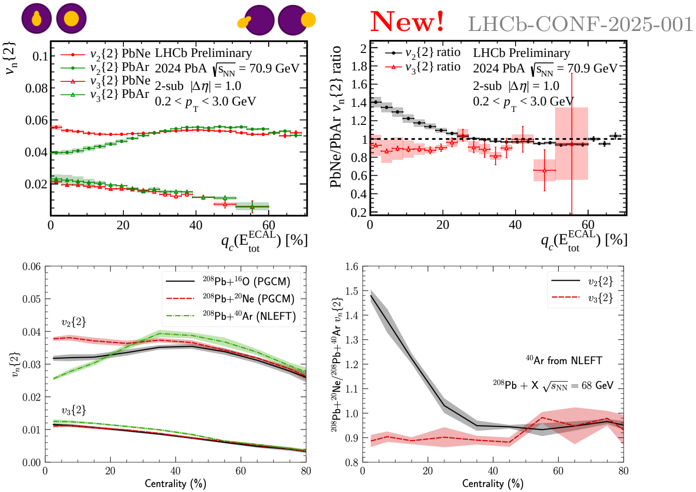
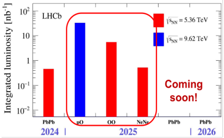
- Trend well described by 3+1D hydro prediction with ab-initio nuclear-structure (PGCM and NLEFT), suggesting the **elongated Neon shape** and the validity of **hydrodynamic description** in these systems
- Improved centrality calibration and updated models will be implemented for final results

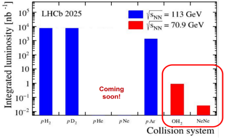
New! LHCb-CONF-2025-001



# Light-ion data taking

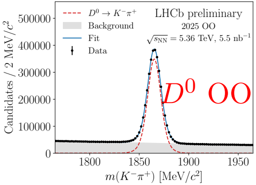
- Both collider and fixed-target data from light-ion runs

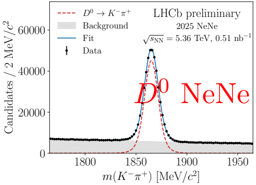


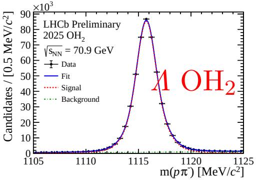



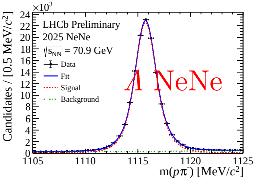

- Excellent data collected in OO and NeNe run
- Search QGP signature in small systems and study the *transition* from large system
- Fixed-target $OH_2$ and NeNe data simultaneously with collider mode
- Unique opportunity for cosmic ray and nuclear imaging

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



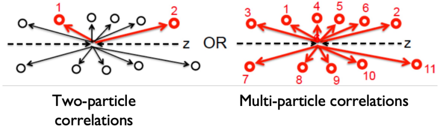
# Summary and Prospects

- 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 descrepancy
  - **First** preliminary result with upgraded SMOG2 system, suggesting the $^{20}$Ne **nucleus deformation**
- Outlook
  - Further measurements ($e.g.$ $v_n - p_{\mathrm{T}}$ correlation) for studying cluster structures of light nuclei
  - Excellent data from light-ion run both for colliding and fixed-target modes

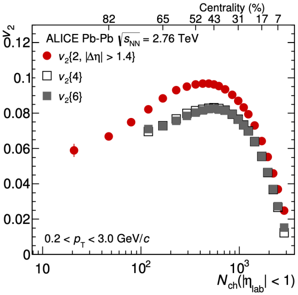
**Thanks for your attention!**

# Cumulant method

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

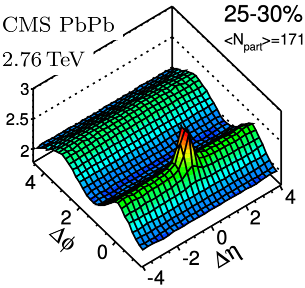


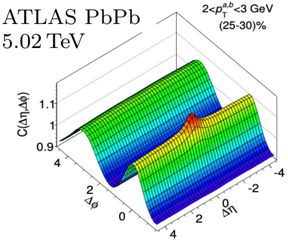

$$v_2\{2\} = (c_2\{2\})^{1/2}, \quad v_2\{4\} = (-c_2\{4\})^{1/4}$$




- 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

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

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