Flow measurements at LHCb experiment

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on behalf of the LHCb collaboration

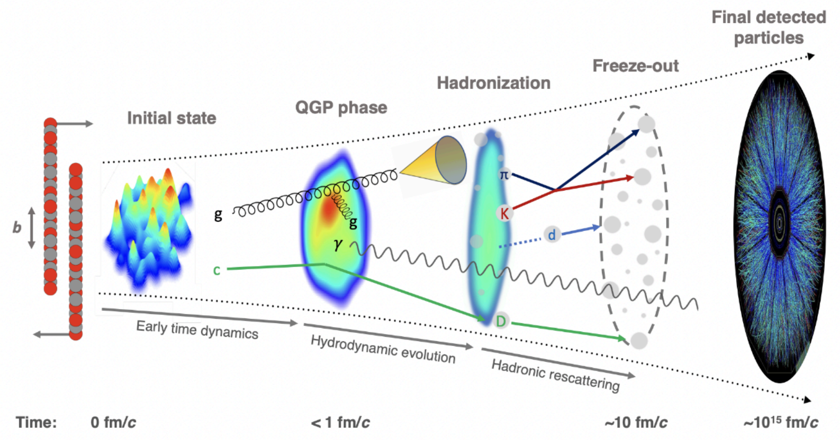
October 31, 2025

The 11th China LHC Physics Conference

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



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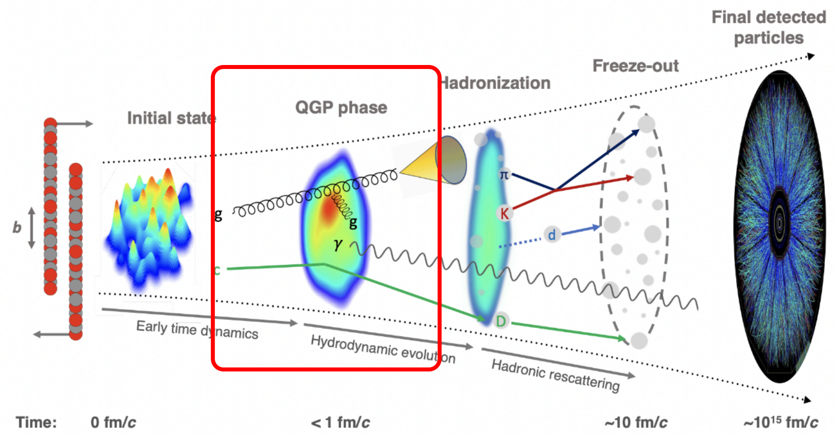
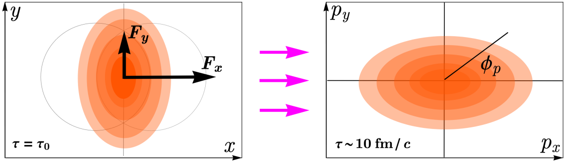


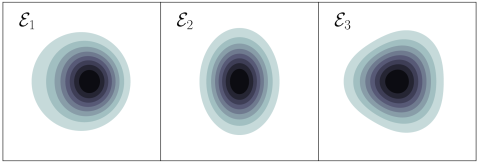
- Strongly coupled QGP created in PbPb collisions
- Hot, dense and nearly *perfect* fluid

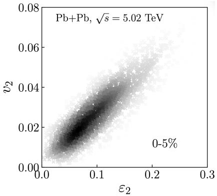
Collective flow

- Hydrodynamic expansion of QGP medium originates from the pressure gradients
- Controlled by the QCD equation of state (EoS)



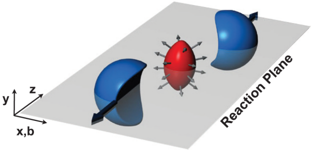
- Collectivity of final-state particles reflects both initial geometry and medium's hydro response

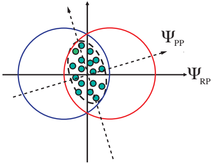


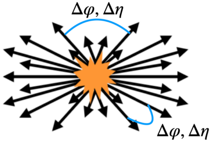


Flow coefficients

- Anisotropic flow quantified by Fourier coefficients v_n of azimuthal distribution in transverse plane:

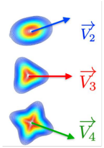






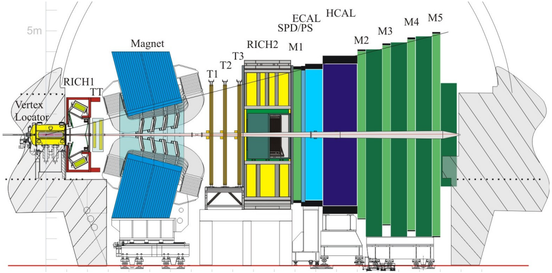
$$E\frac{\mathrm{d}^3N}{\mathrm{d}p^3} = \frac{1}{2\pi}\frac{\mathrm{d}^2N}{p_\mathrm{T}\mathrm{d}p_\mathrm{T}\mathrm{d}y}\left(1 + 2\sum_1^\infty v_n\cos[n(\phi - \Psi_\mathrm{R})]\right)$$

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

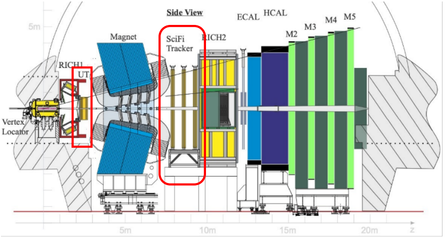


LHCb detector in Run2

- 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 and fixed-target collision

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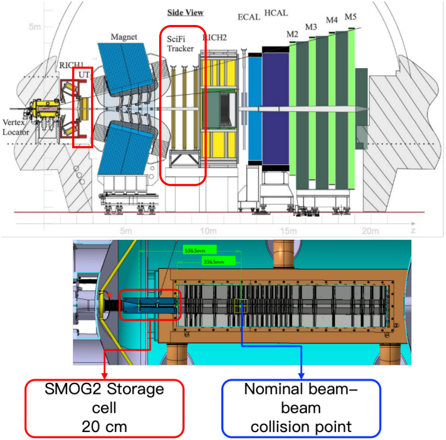

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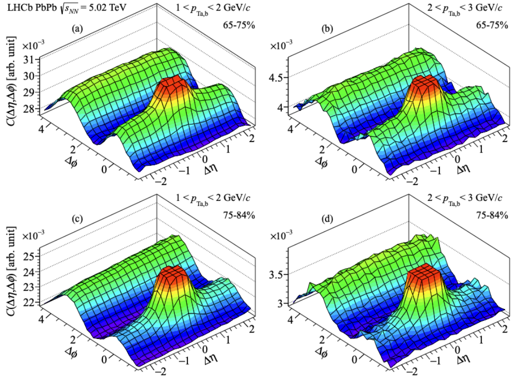
- More central data accessible for heavy-ion collisions
  - Up to 30% for PbPb, full centrality for light-ion and fixed-target collision
- New SMOG2 system for fixed-target program
  - Running simultaneously with collider mode
  - Unique energy range $\sqrt{s_{\mathrm{NN}}} \sim 30\text{–}110\,\mathrm{GeV}$ 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 (peripheral) PbPb data at $\sqrt{s_{\mathrm{NN}}} = 5.02\,\mathrm{TeV}$

Phys.Rev.C109(2024)054908



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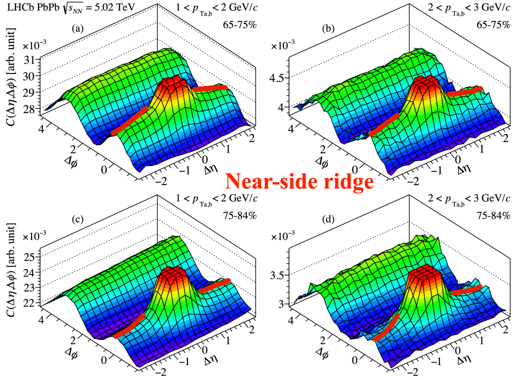

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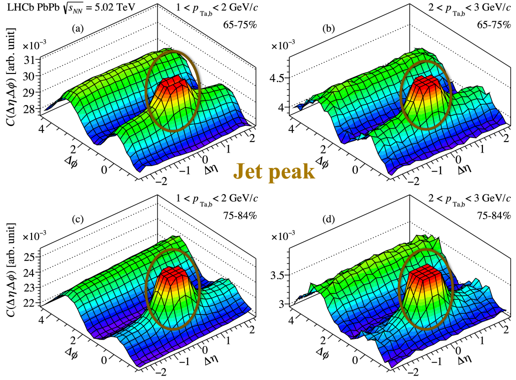

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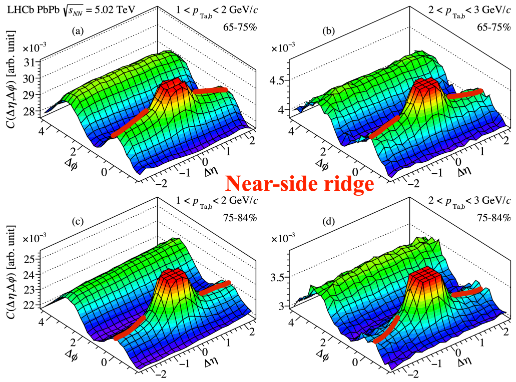

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- Dominant non-flow contribution from jet peak at $(\Delta\eta, \Delta\phi \sim 0, 0)$, subtracted by excluding short range region
- Lower ridge for more peripheral collisions

Flow in 5.02 TeV PbPb

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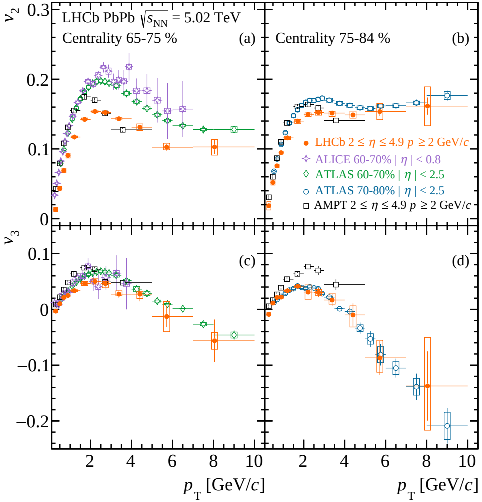
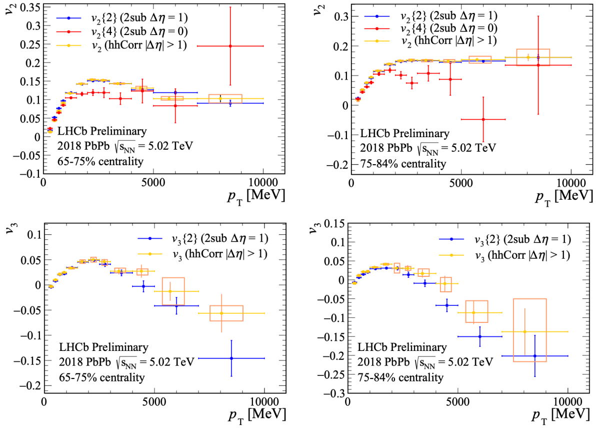


- Smaller $v_2(p_T)$ and $v_3(p_T)$ compared to ALICE and ATLAS results at midrapidity, possibly due to the dominant hadronic viscosity at forward rapidity [PRC.90.044904]
- AMPT overestimates v_n at forward rapidity. LHCb results can be helpful for tuning

Flow in 5.02 TeV PbPb

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

New!



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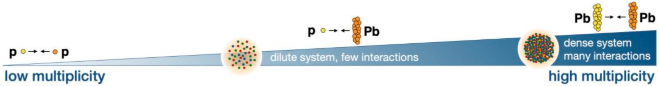
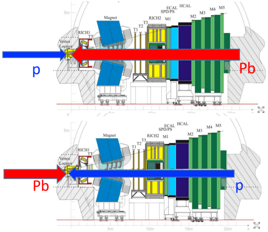
- AMPT overestimates v_n at forward rapidity. LHCb results can be helpful for tuning
- Validation with cumulant method
  - Good agreement between two methods
  - Different $v_2\{2\}$ and $v_2\{4\}$ due to fluctuation

Flow in pPb

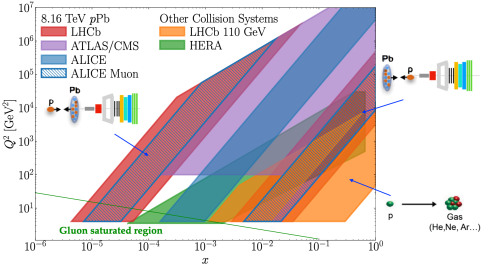
- QGP formation was not expected in small systems



- Explanation for collectivity in high-multiplicity small systems
  - QGP droplet? Transport? Glasma?



- Unique coverage to investigate possible gluon saturation



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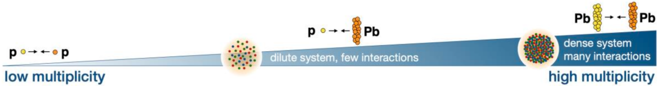

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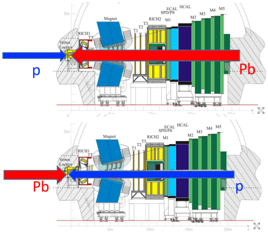
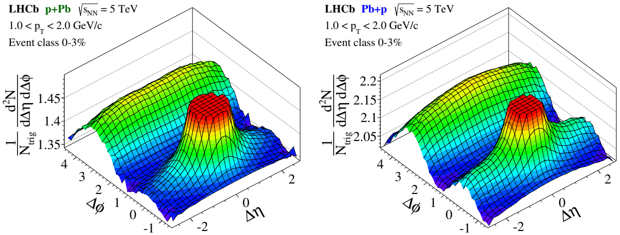


- Long-range correlations observed in 5 TeV pPb

Phys.Lett.B762(2016)473-483

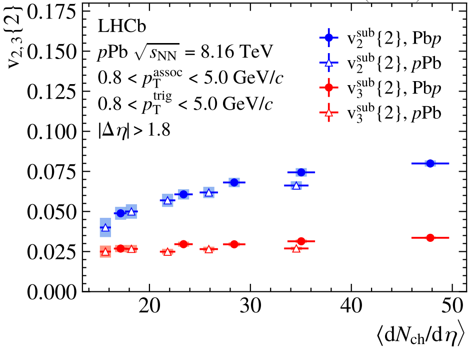


- No v_n extraction unfortunately

Flow in 8.16 TeV pPb

- More detailed analysis and higher statistics with Run2 pPb
- Improved non-flow suppression compared to PbPb: large η gap, jet-yield subtraction method

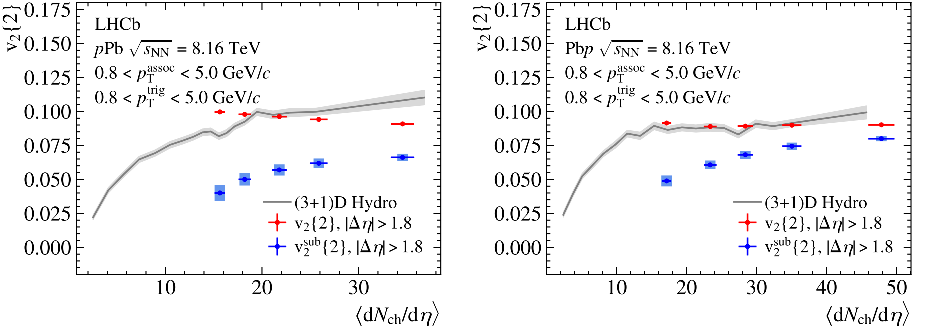
JHEP10(2025)124



- 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 pPb

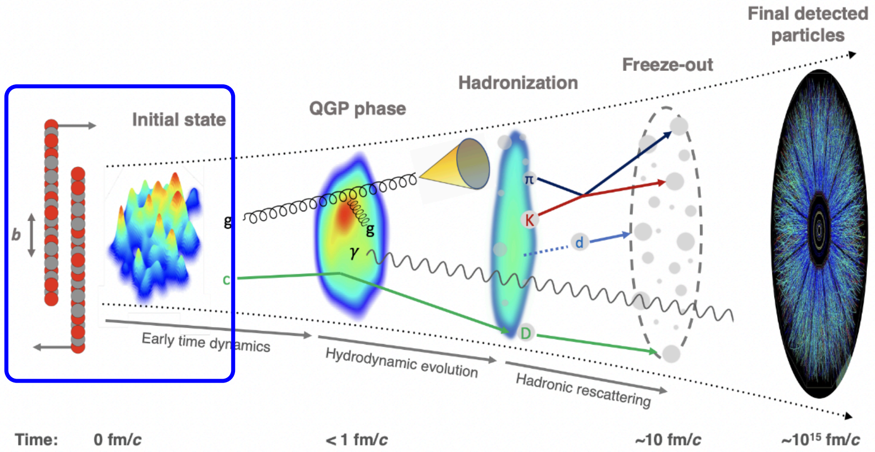
JHEP10(2025)124



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

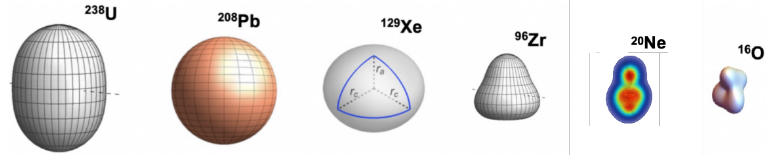
Initial geometry

- Other knowledge from flow measurements

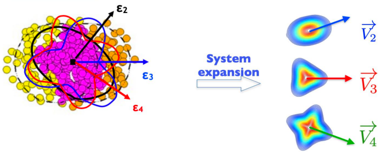


Nuclear shape

- Nuclear shape not necessarily spherical, indicated by low-energy nuclear experiments

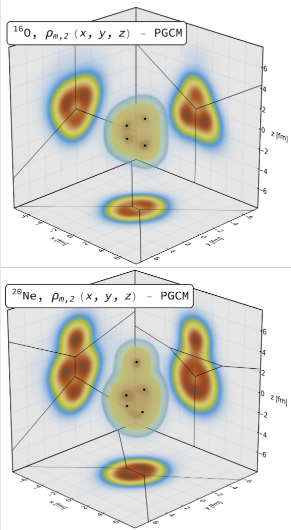


- Various descriptions: Woods-Saxon parametrization, ab initio calculation
- High-energy heavy-ion collisions provide a unique *imaging-by-smashing* technique
  - Anisotropic initial shape can be converted to collective motion in momentum space



Nuclear shape

- Newest ab initio prediction
  - ^{16}O: nearly spherical shape consisting of 4 α-clusters
  - ^{20}Ne: strongly deformed *bowling pin* shape with an extra α-cluster



Phys. Rev. Lett. 135, 012302

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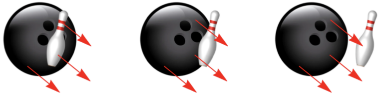
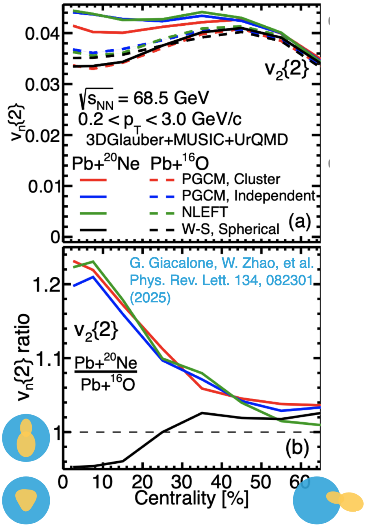
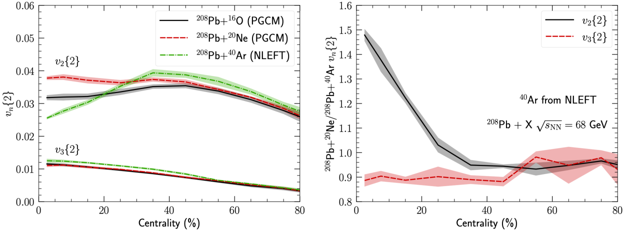
- Different v_2 expected
  - Medium effects largely canceled in v_2 ratio
  - Sensitive to ^{20}Ne deformation in the most central collisions
  - Even more pronounced differences in fixed-target systems!





Flow in fixed-target PbNe and PbAr

- Unfortunately no ^{16}O injection but ^{40}Ar (nearly spherical) available as reference
- Negligible contribution from more symmetric ^{22}Ne



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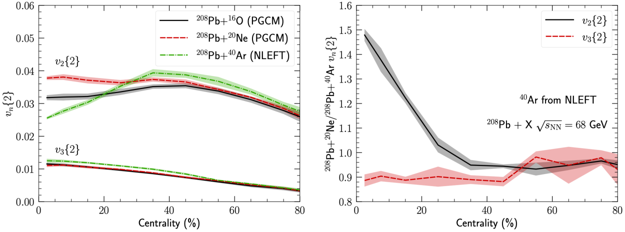
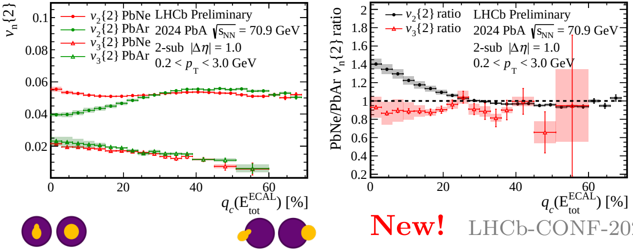
- Flatter v_2 for light ions and decreasing v_3 from central to peripheral: validity of **hydrodynamic description**
- Significant enhanced v_2 ($\sim 40\%$) for PbNe at the most central collisions and trend well described by (3+1)D hydro predictions with ab-initio nuclear-structure: **elongated ^{20}Ne shape**





New! LHCb-CONF-2025-001

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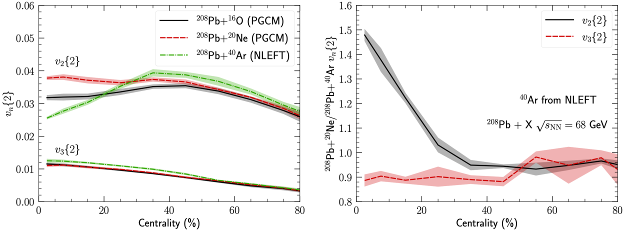

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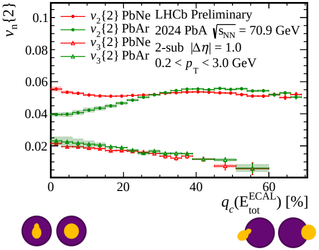
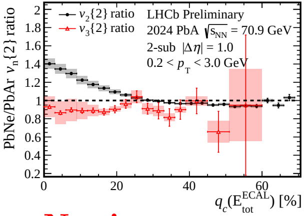
- Significant enhanced v_2 ($\sim 40\%$) for PbNe at the most central collisions and trend well described by (3+1)D hydro predictions with ab-initio nuclear-structure: **elongated** ^{20}Ne **shape**
- Improved centrality calibration and updated models on the way for final results

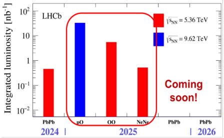


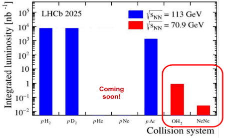


New! LHCb-CONF-2025-001

Light-ion data taking

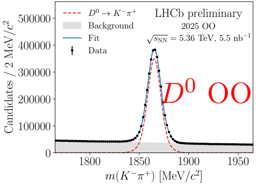
- Both collider and fixed-target data from light-ion runs

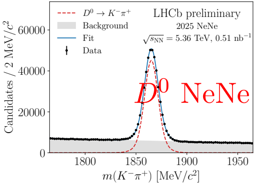


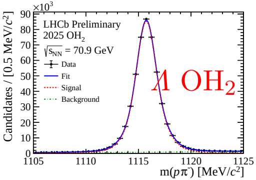


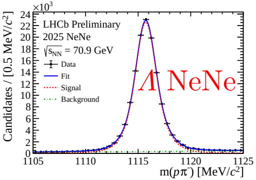
- Excellent data collected in OO and NeNe run
- Search QGP signature in small systems and study the *transition* from large system
- Fixed-target OH_2 and NeNe data simultaneously with collider mode
- Unique opportunity for cosmic ray and nuclear imaging

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









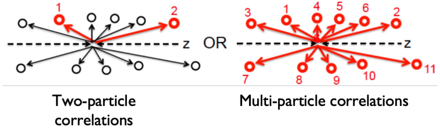
Summary and Prospects

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

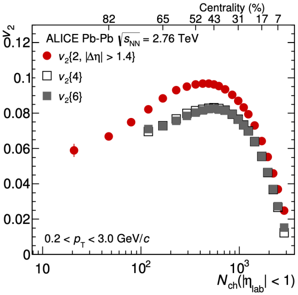
Thanks for your attention!

Cumulant method

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

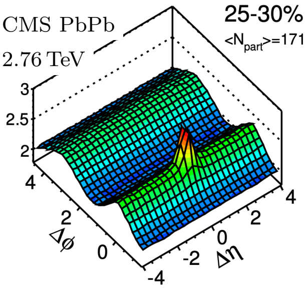


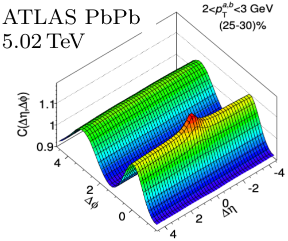
$$v_2\{2\} = (c_2\{2\})^{1/2}, \quad v_2\{4\} = (-c_2\{4\})^{1/4}$$



- 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?