Probe p_{T}-dependent flow vector fluctuations with ALICE

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One of the main goals of ultra-relativistic nuclear collisions is to create a new state of matter called quark-gluon plasma (QGP) and study its properties. One of the experimental observables is anisotropic flow v_n, defined as correlation of azimuthal angle of each particle with respect to a common symmetry plane Ψ_n. The v_n and Ψ_n represent the magnitude and angle of a complex flow vector $\boldsymbol{V}_n$. Event-by-event fluctuations in initial conditions and dynamics during expansion of the medium lead to fluctuations of the flow vector, as shown by hydrodynamic calculations. We present measurements of the p_{T}-dependent flow vector fluctuations using multi-particle correlations in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV recorded with the ALICE experiment in Run 2 at the LHC.

I. Motivation

- Hydrodynamic simulations show p_{T}-dependent flow vector fluctuations in Pb–Pb collisions
  - Traditionally measured with 2-particle correlations.
  - Novel 4-particle correlations allow us to separate effects of flow magnitude and flow angle fluctuations.
- The magnitude of flow vector fluctuations is sensitive to both initial conditions and the properties of the created QGP $\Rightarrow$ These measurements will help us better study the dynamic evolution of the created QGP.

II. Method

- Data is collected from the ALICE experiment.
- Data collected during Pb–Pb data taking in 2015.
- The 2- and 4-particle correlations are all calculated using the Generic Framework [1].

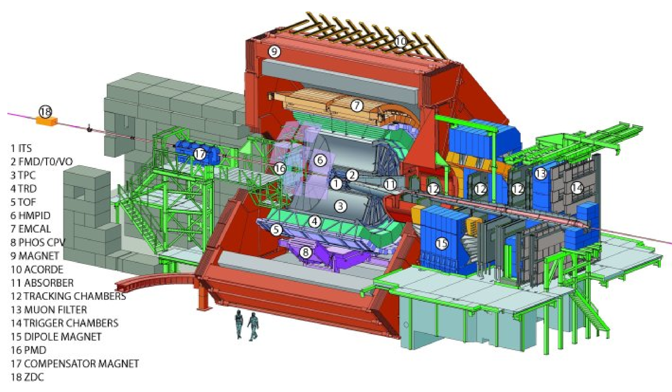

Fig. 1: The ALICE detector at the LHC.

- The particles are selected from different pseudorapidity and p_{T}-ranges

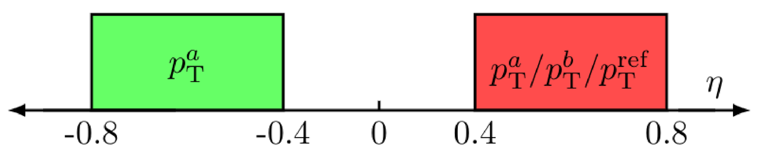

Fig. 2: Illustration of particle p_{T}-selection and $|\Delta\eta|$ gap method for multi-particle correlations

III. Flow vector fluctuations

- Ratio of $v_n\{2\}$ and $v_2[2]$ [2]:

$$v_n\{2\}/v_n[2] = \frac{\langle v_n(p_{\mathrm{T}}^{a}) v_n^{\mathrm{ref}} \cos[n(\Psi_n(p_{\mathrm{T}}^{a}) - \Psi_n)]\rangle}{\sqrt{\langle v_n(p_{\mathrm{T}}^{a})\rangle}\sqrt{\langle {v_n^{\mathrm{ref}}}^2\rangle}} \tag{1}$$

- Factorization ratio r_n [3]:

$$r_n = \frac{V_{n\Delta}(p_T^a, p_T^b)}{\sqrt{V_{n\Delta}(p_T^a, p_T^a) V_{n\Delta}(p_T^b, p_T^b)}} \tag{2}$$

- If flow vector fluctuations are present $v_n\{2\}/v_n[2] < 1$, $r_n < 1$
- p_{T}-dependent flow vector fluctuations observed in central collisions. This effect is also indicated by hydrodynamic models although extension to higher p_{T} is desirable.

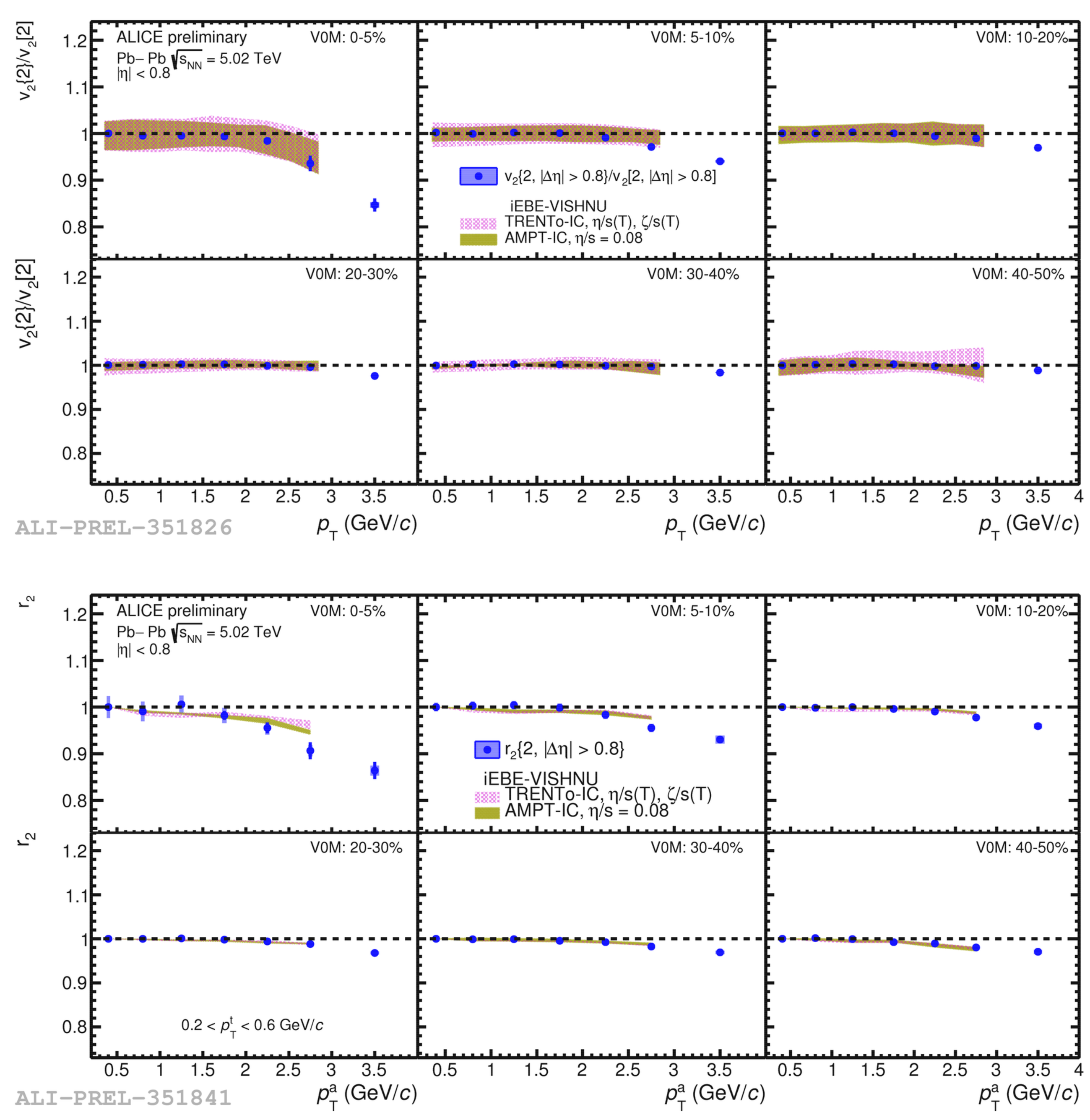

Fig. 4: $v_2\{2\}/v_2[2]$ with $|\Delta\eta| > 0.8$ (Top) and r_2 with $|\Delta\eta| > 0.8$ and $0.2 < p_{\mathrm{T}}^{b} < 0.6$ GeV/c (Bottom) in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$= 5.02 TeV. iEBE-VISHNU hydrodynamic calculations with TRENTo and AMPT initial conditions are shown with colored bands.

IV. Flow Angle Fluctuations

- Probe of the flow angle fluctuation:

$$\frac{\langle \cos[n(\phi_1^a + \phi_2^a - \phi_3^b - \phi_4^b)]\rangle}{\langle \cos[n(\phi_1^a + \phi_2^b - \phi_3^a - \phi_4^b)]\rangle} = \frac{\langle v_n^{a2} v_n^{b2} \cos[2n(\Psi_n^{p_T^a} - \Psi_n^{p_T^b})]\rangle}{\langle v_n^{a2} v_n^{b2}\rangle} \approx \langle \cos[2n(\Psi_n^{p_T^a} - \Psi_n^{p_T^b})]\rangle \tag{3}$$

- Second equality holds if non-flow is the same.

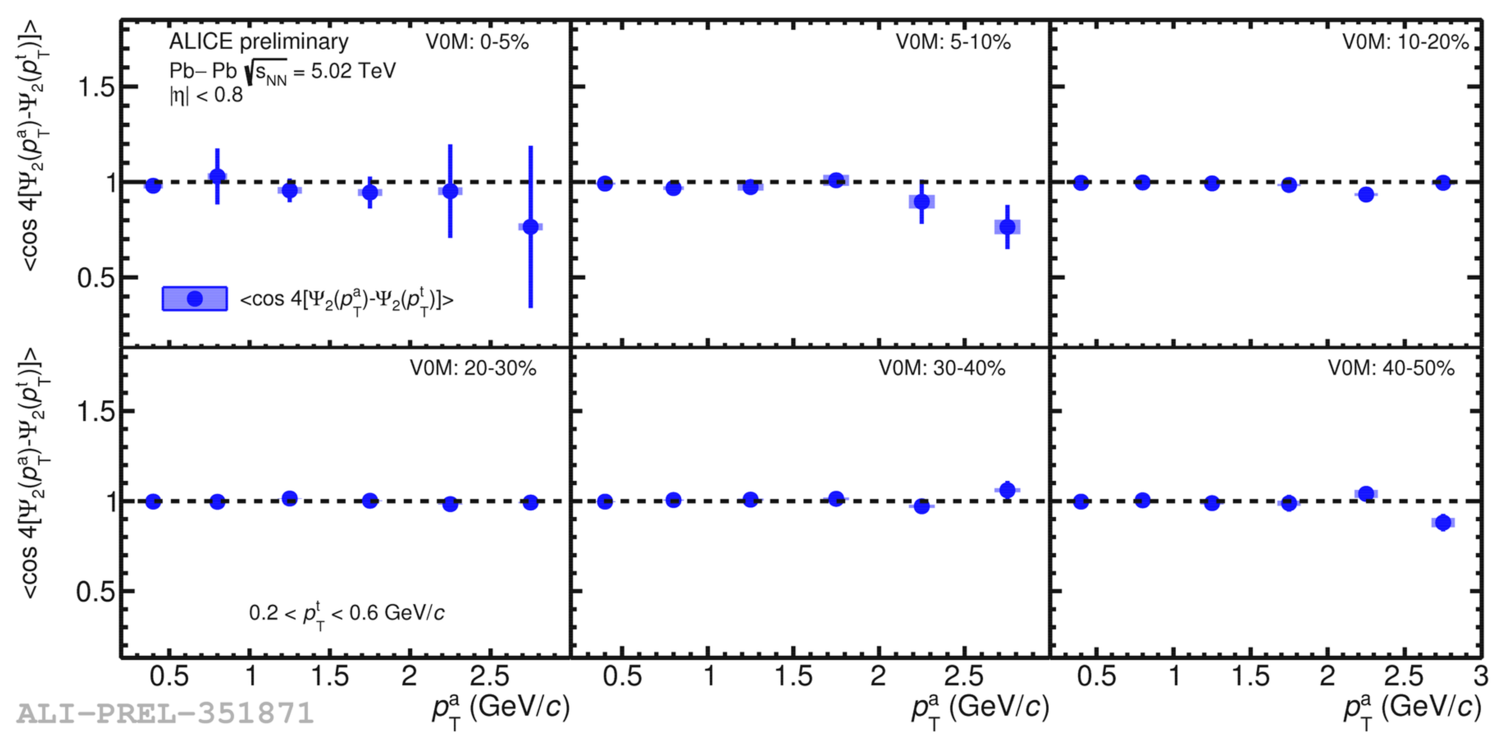

Fig. 5: $\langle\cos[4(\Psi_2^{p_T^a} - \Psi_2^{p_T^b})]\rangle$ in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with $0.2 < p_{\mathrm{T}}^{b} < 0.6$ GeV/c.

- Flow angle decorrelation consistent with unity.
  $\Rightarrow$ p_{T}-dependent fluctuations of V_2 mainly carried by flow magnitude fluctuations.

V. Flow Magnitude Fluctuations

- Normalized single-differential symmetric cumulant:

$$NSC(n, m_{p_T}) = \frac{\langle v_n^2 v_m(p_T)^2\rangle - \langle v_n^2\rangle\langle v_m(p_T)^2\rangle}{\langle v_n^2\rangle\langle v_m(p_T)^2\rangle} \tag{4}$$

- p_{T}-dependent NSC$(3, 2_{p_{\mathrm{T}}})$ and NSC$(4, 2_{p_{\mathrm{T}}})$ observed in central collisions.

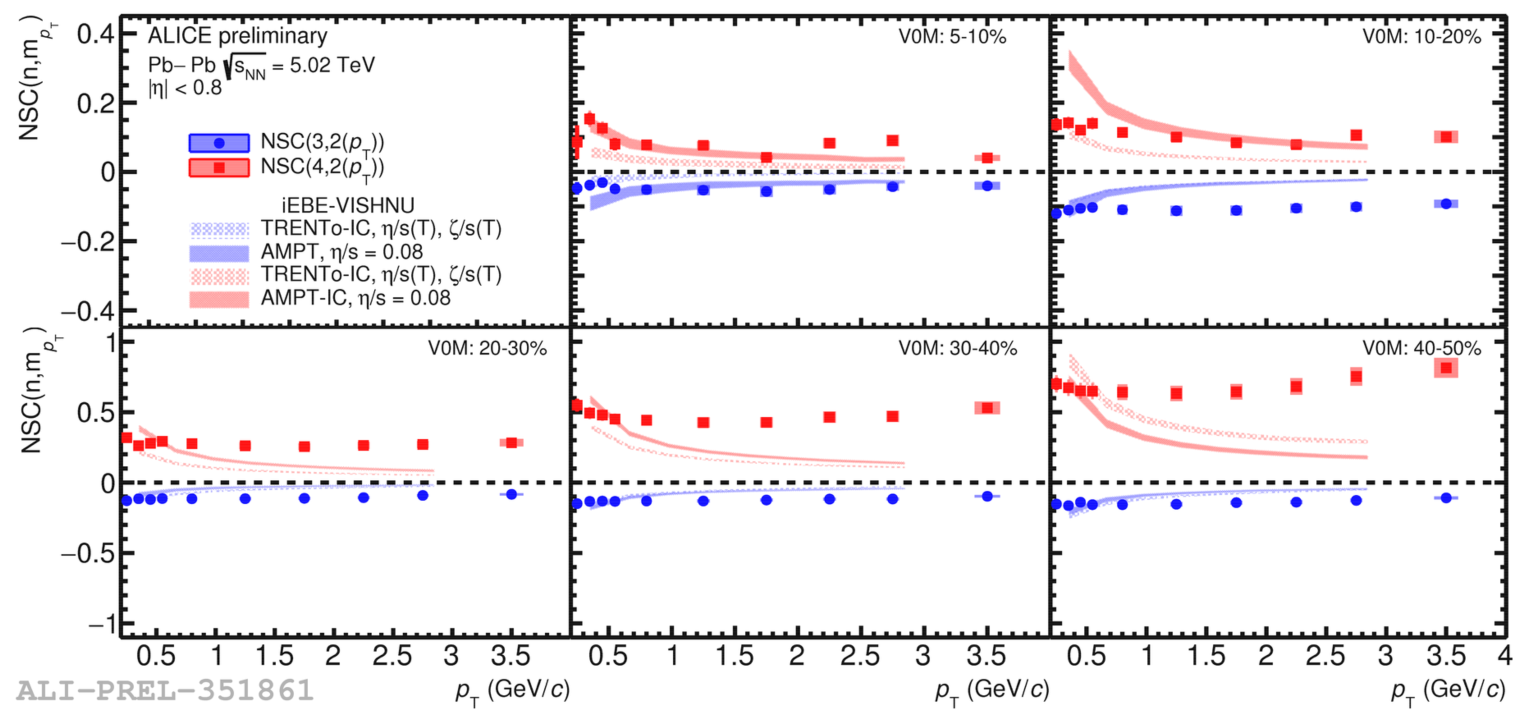

Fig. 6: NSC(n, m_{p_T}) in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$= 5.02 TeV. iEBE-VISHNU hydrodynamic calculations with TRENTo and AMPT initial conditions are shown in colored bands.

VI. Summary and Conclusions

- The two-particle correlation observables $v_2\{2\}/v_2[2]$ and r_2 are measured in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$= 5.02 TeV.
  $\Rightarrow$ p_{T}-dependent flow vector fluctuations are observed in central collisions.
- Four-particle correlation observables NSC$(3, 2_{p_{\mathrm{T}}})$, NSC$(4, 2_{p_{\mathrm{T}}})$ and $\langle\cos[4(\Psi_2^{p_T^a} - \Psi_2^{p_T^b})]\rangle$ are measured in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$= 5.02 TeV.
  $\Rightarrow$ The measurements indicate that p_{T}-dependent flow vector fluctuation are mainly driven by fluctuations in the flow magnitude.
- These new measurements help us understand the dynamic evolution of the created QGP in high-energy heavy-ion collisions.

References

[1] A. Bilandzic *et al.* In: *Phys. Rev. C89, no.6, 064904* (2014).
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[3] F. Gardim *et al.* In: *Phys. Rev. C 87, 031901(R)* (2013).

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