Recent results on flow and flow fluctuations with the ALICE detector

Ya Zhu (for the ALICE Collaboration)

Central China Normal University
&
University of Copenhagen

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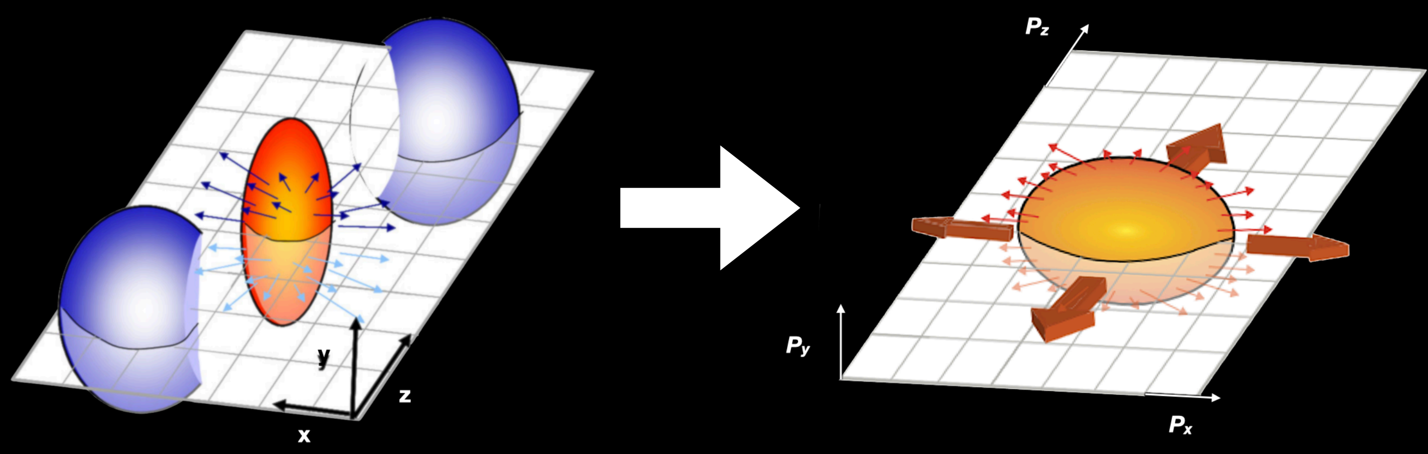
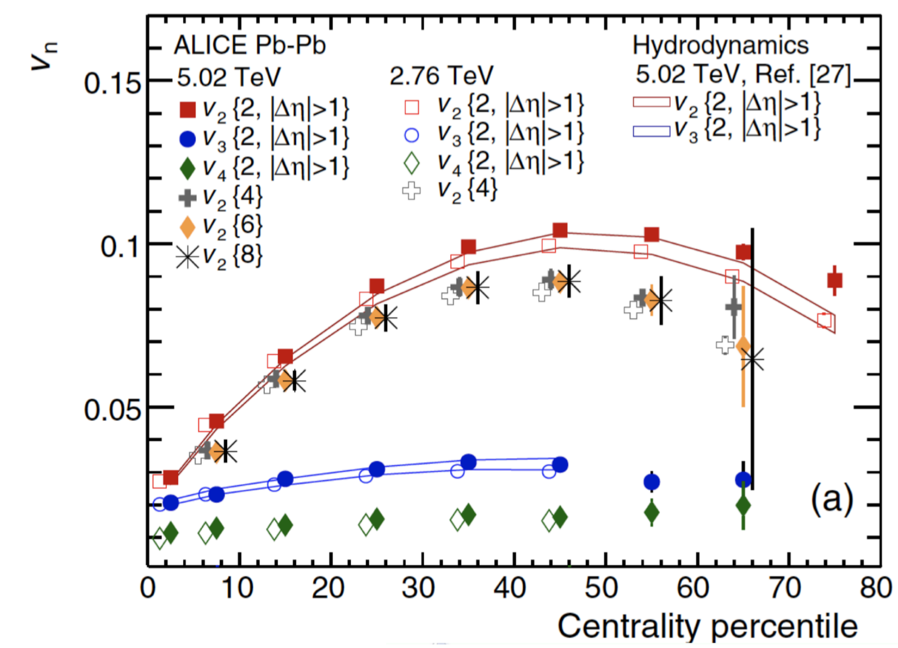
Anisotropic flow and flow fluctuations in heavy-ion collisions



[ALICE, PRL 116 (2016) 132302)]



- Initial spatial anisotropy $\Rightarrow$ momentum anisotropy
- Azimuthal asymmetries are quantified by the anisotropic flow coefficients:

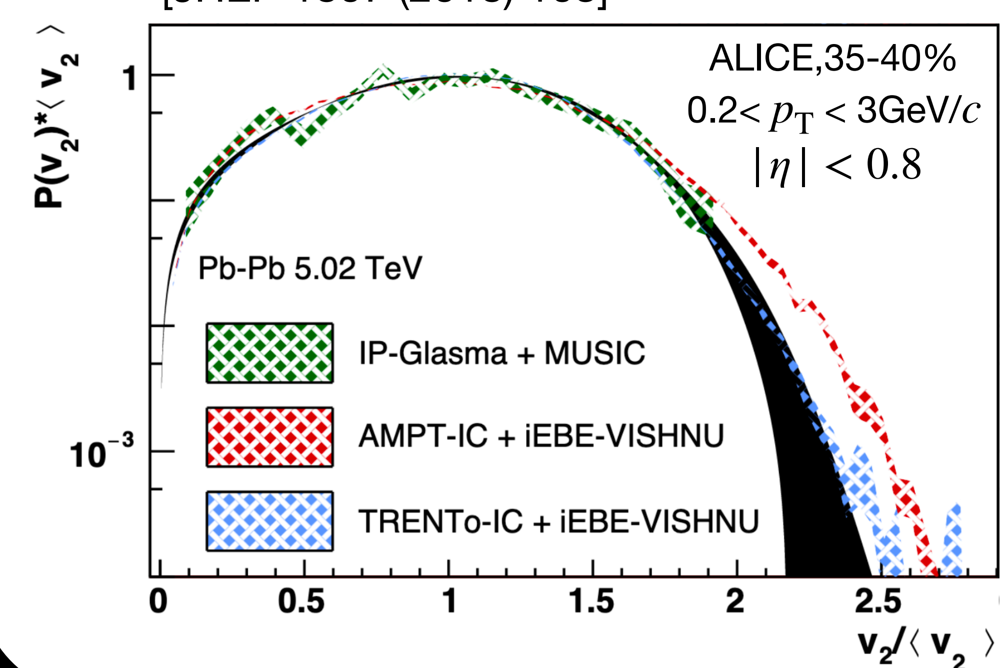
  $v_n = < \cos(\mathrm{n}[\phi - \Psi_\mathrm{n}]) >$
- v_n are sensitive to the evolution of the collision system. (Initial condition, transport properties)
- Initial geometry fluctuations lead to flow fluctuations in the final state:

  $< v_n^k > \neq < v_n >^k$
- Develop more observables to describe the flow fluctuations:

  $v_2\{6\}/v_2\{4\}$, $v_2\{8\}/v_2\{4\}$, γ_N, flow vector fluctuations, PDFs with ESE, $F\{v_n\}$
- Further constraints to the initial conditions
- 2- & multi-particle cumulants are obtained using Generic Framework

[A. Bilandzic et al, Phys. Rev. C 89 (2014) 064904]

[JHEP 1807 (2018) 103]



The ALICE detector

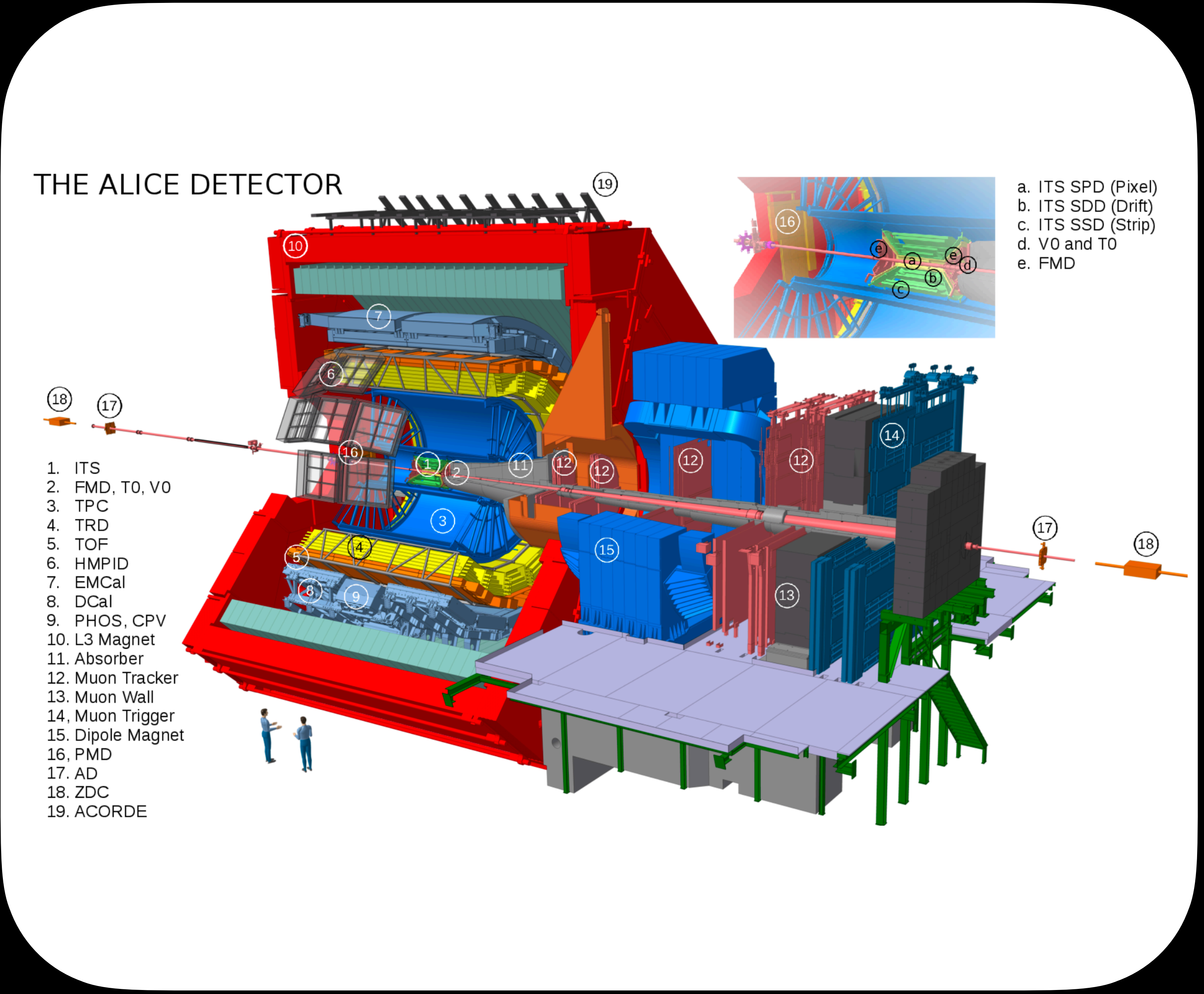
ALICE Pb–Pb at 5.02 TeV

- ITS: Tracking, vertexing, triggering
- TPC: Tracking, PID
- TOF: PID
- V0 :

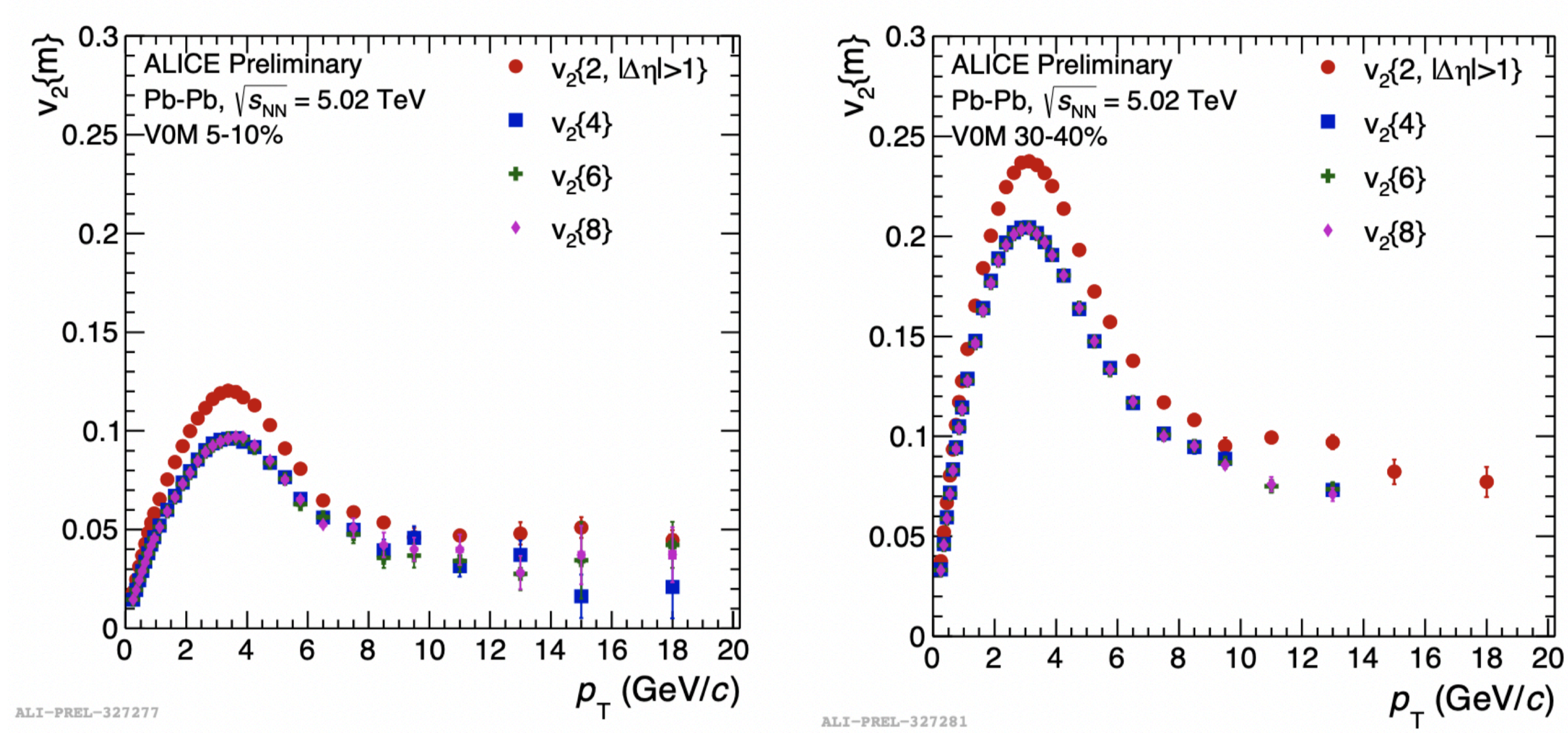
  V0A $(2.8 < \eta < 5.1)$

  V0C $(-3.7 < \eta < -1.7)$

  Triggering, multiplicity estimation



p_T-differential $v_2\{m\}$



- Plethora of charged particles $v_2\{2\}$, $v_2\{4\}$, $v_2\{6\}$ and $v_2\{8\}$ measurements in the ALICE
- $v_2\{2\}$ larger than $v_2\{4\}$, $v_2\{6\}$ and $v_2\{8\}$: fluctuations and non-flow

p_T-differential v_2 PDFs

Different moments (Skewness γ_1 and Kurtosis γ_2) of the distribution from $v_2\{m\}$were calculated:

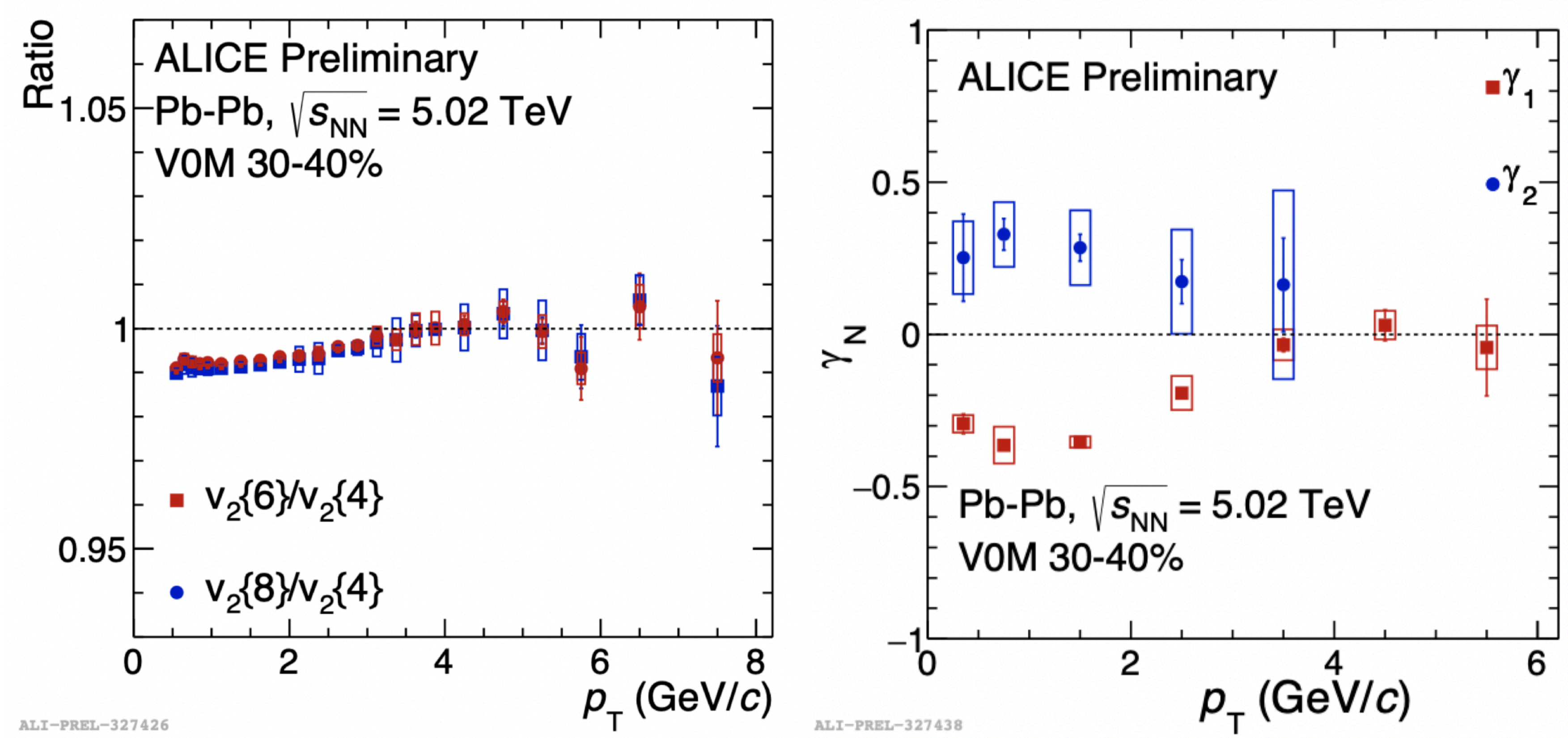
[G. Giacalone et al, Phys. Rev. C 95 (2017) 014913]

$$\gamma_1 \simeq -2^{3/2}\frac{v_2\{4\}^3 - v_2\{6\}^3}{(v_2\{2\}^2 - v_2\{4\}^2)^{3/2}}, \qquad \gamma_2 \simeq -\frac{3}{2}\frac{v_2\{4\}^4 - 12v_2\{6\}^4 + 16v_2\{8\}^4}{(v_2\{2\}^2 - v_2\{4\}^2)^2}$$

- Deviation of $v_2\{6\}/v_2\{4\}$ and $v_2\{8\}/v_2\{4\}$ from unity at low p_T
  $\Rightarrow$ Bessel-Gaussian parametrisation of v_n PDFs is not valid
- Higher p_T (> 3 GeV/c):

  γ_1 and γ_2 are consistent

  with 0
- Non-trivial evolution with p_T



Flow vector fluctuations

Two-particle azimuthal correlations can be expanded in a Fourier series:

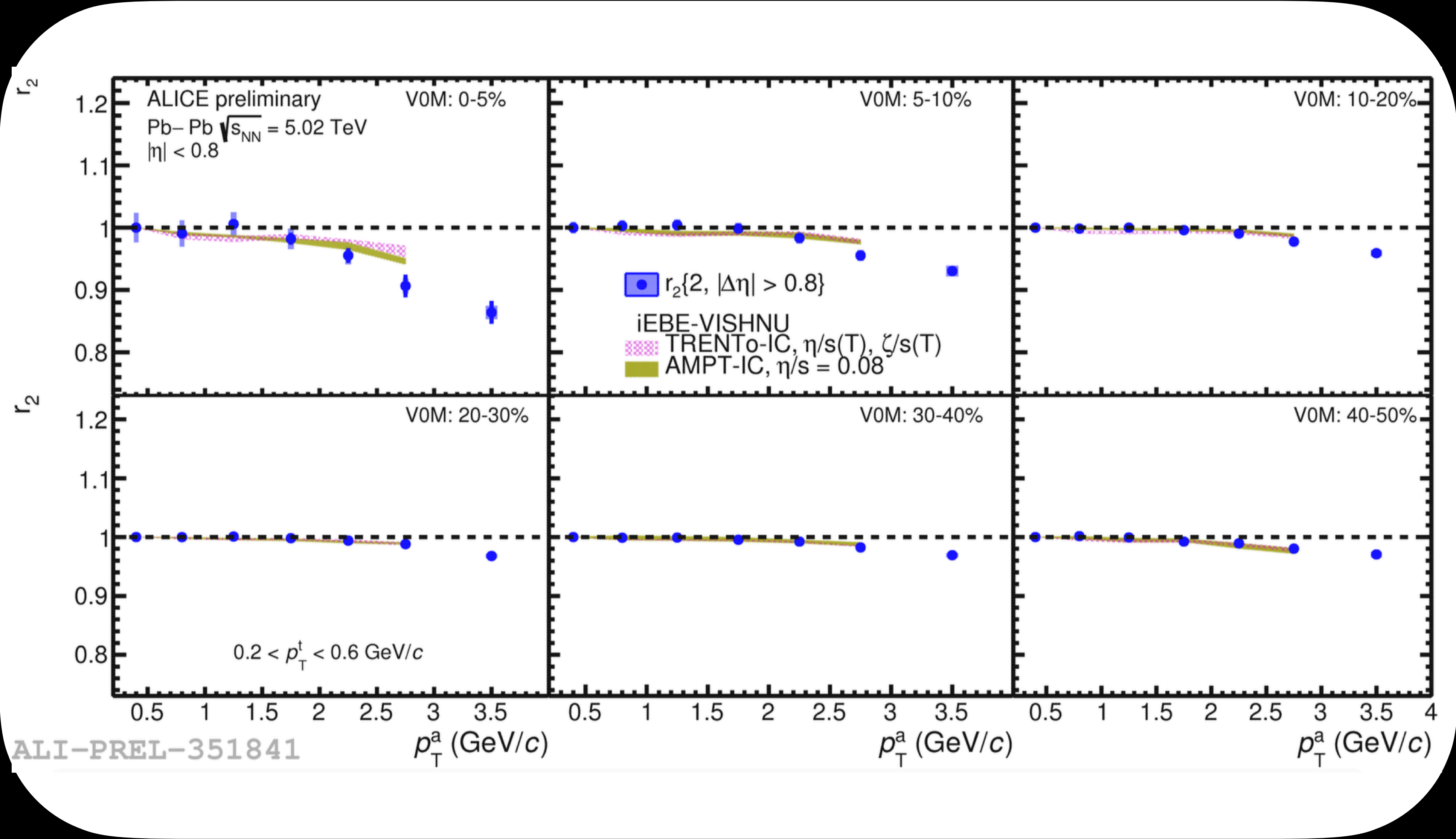
$$\frac{d^3N^{pair}}{dp_T^a dp_T^b d\Delta\phi} \propto 1 + \sum_{n=1}^{\infty} 2V_{n\Delta}(p_T^a p_T^b)\cos(n\Delta\phi)$$

One new observable “Factorisation ratio” named r_n:

Phys.Rev.C 87 (2013) 3, 031901

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

- $r_n < 1$, especially in central collisions
- May caused by flow magnitude fluctuations or(and) flow angle fluctuations with p_T dependence
- Confirm the hydrodynamic prediction

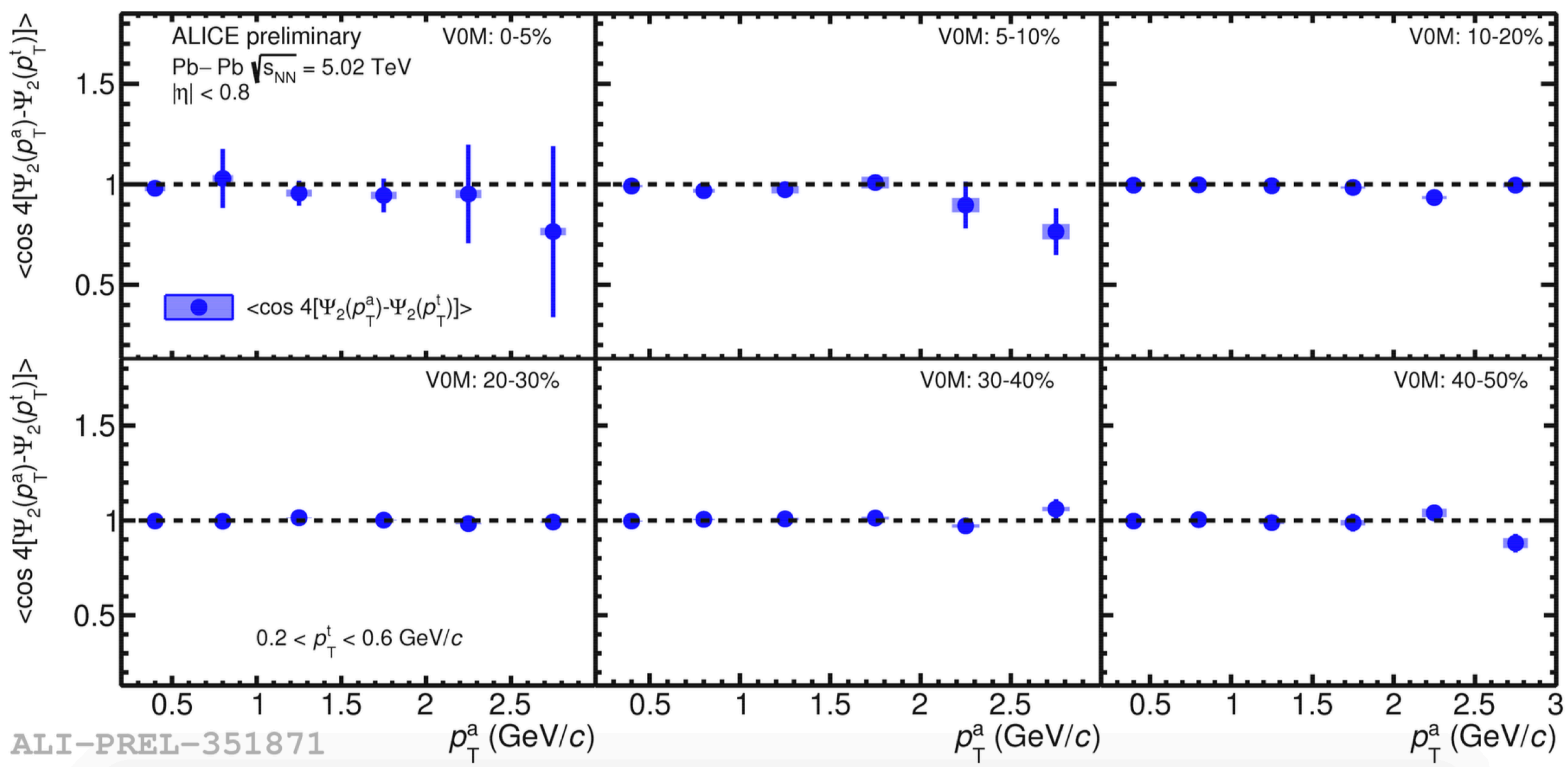


Flow angle fluctuations

The $p_{\rm T}$-dependent flow angle fluctuations can be probed by:

$$\frac{< \cos n(\phi_1^a + \phi_2^a - \phi_3^b - \phi_4^b) >}{< \cos n(\phi_1^a + \phi_2^b - \phi_3^a - \phi_4^b) >} = < \cos[2n(\Psi_n^a - \Psi_n^b)] >$$

- Consistent with unity in 10-40%
- Flow vector fluctuations driven by $p_{\rm T}$-dependent flow magnitude fluctuations

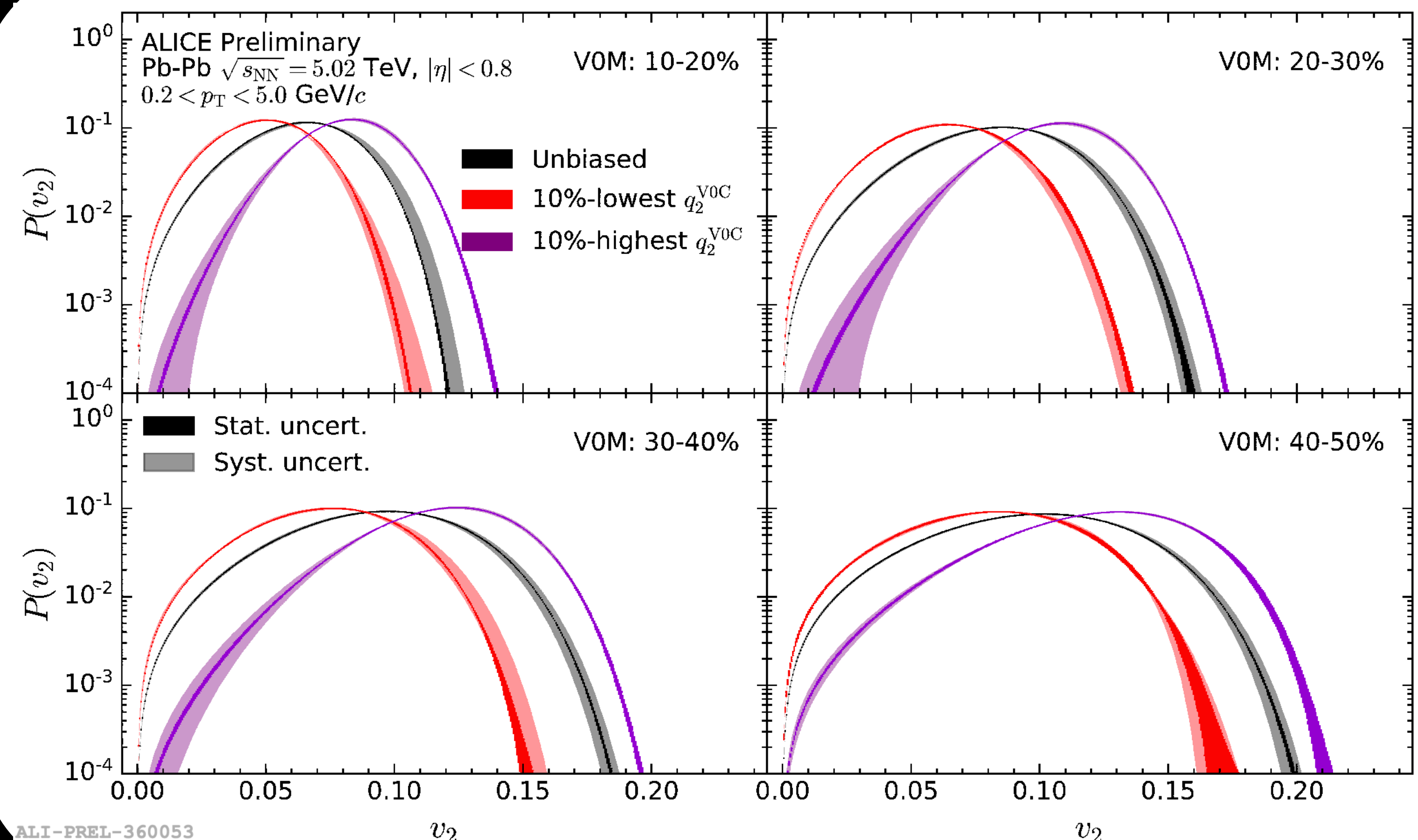


The probability density function with ESE

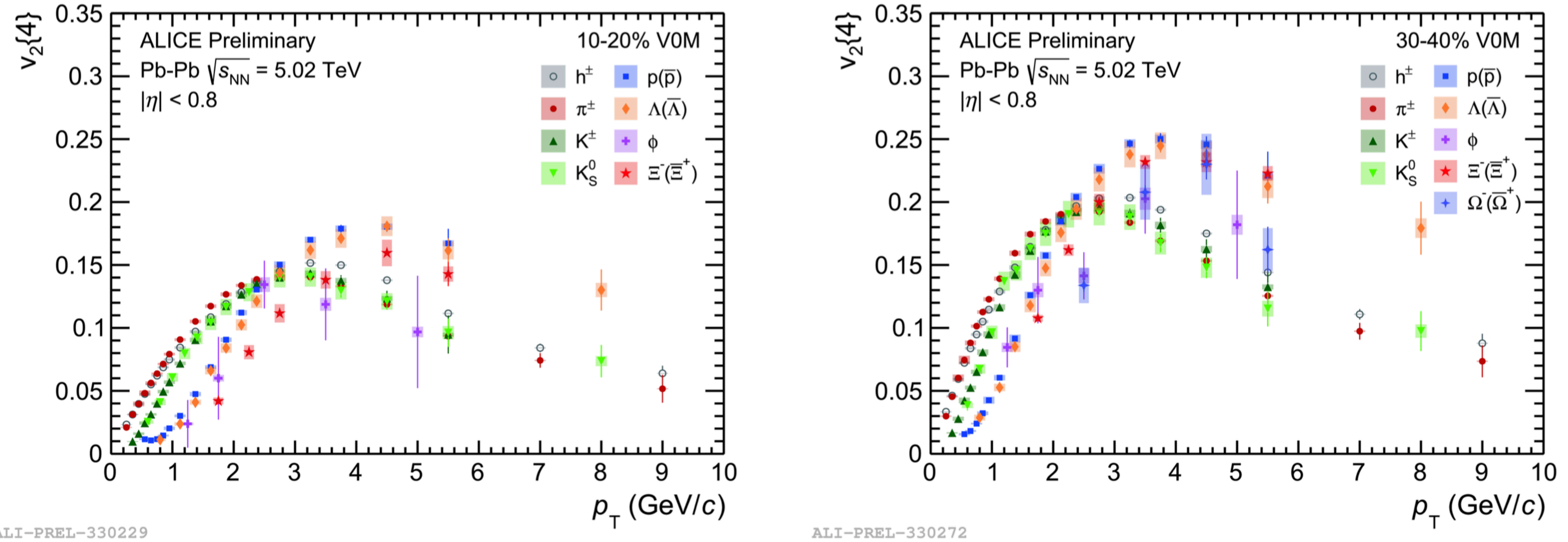
The fit can be performed to construct the probability density function of v_2 by the relation between the cumulants $c_2\{m\}$:[S. Acharya et al. In: JHEP 1807 103 (2018).]

$$P(v_2) = \frac{2\alpha v_2}{\pi k_2}(1-\varepsilon_0^2)^{\alpha+1/2}\int_0^{\pi}\frac{(1-v_2^2/k_2^2)^{\alpha-1}}{(1-v_2\varepsilon_0\cos\phi/\mathrm{k}_2)^{2\alpha+1}}d\phi$$

- Event Shape Engineering (ESE): select large/small eccentricities
- Underlying PDFs more skewed for higher q_2 percentiles, suggesting a significant amount of fluctuations is picked up by ESE



PID Flow



- Measurement of $v_2\{4\}$of identified hadrons
- Qualitatively similar behaviour as of $v_2\{2\}$ measurement

  Clear mass ordering at low p_T and baryon/meson grouping at intermediate p_T

PID Flow Fluctuations

- Measurements of 2- & 4-particle cumulant are used to study flow and flow fluctuations (if non-flow is negligible in 2-PC): [S.A. Voloshin et al.PLB 659 (2008) 537]

$$v_n\{2\}^2 = \langle v_n \rangle^2 + \sigma_{v_n}^2$$

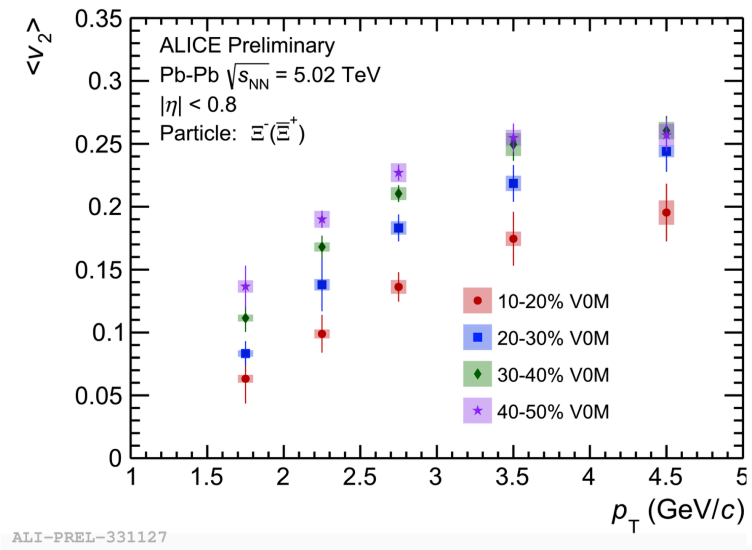
$$v_n\{4\}^2 \approx \langle v_n \rangle^2 - \sigma_{v_n}^2$$

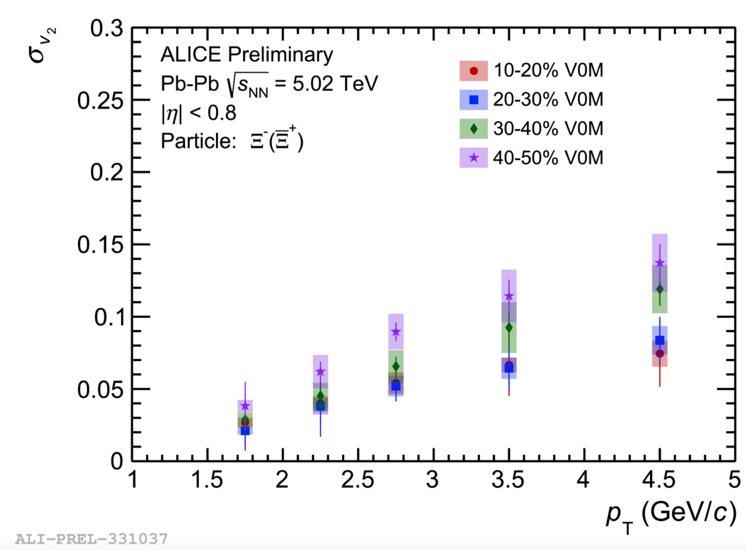
$$\Downarrow$$

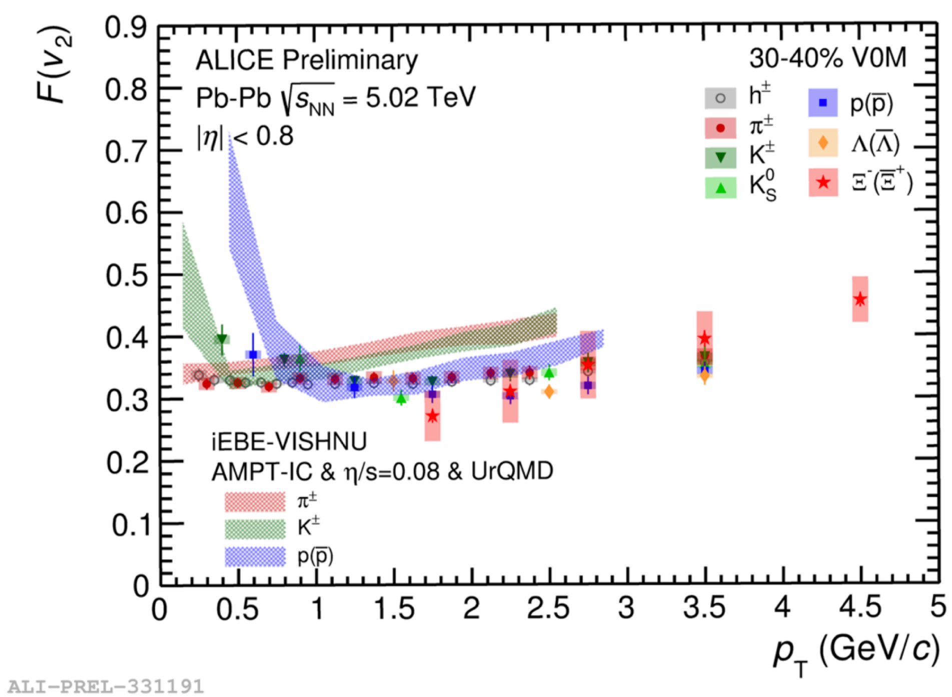
$$\langle v_n \rangle \approx ((v_n\{2\}^2 + v_n\{4\}^2)/2)^{1/2}$$

$$\sigma_{v_n} \approx ((v_n\{2\}^2 - v_n\{4\}^2)/2)^{1/2}$$

- Relative v_n fluctuations : $F(v_n) = \dfrac{\sigma_{v_n}}{< v_n >}$







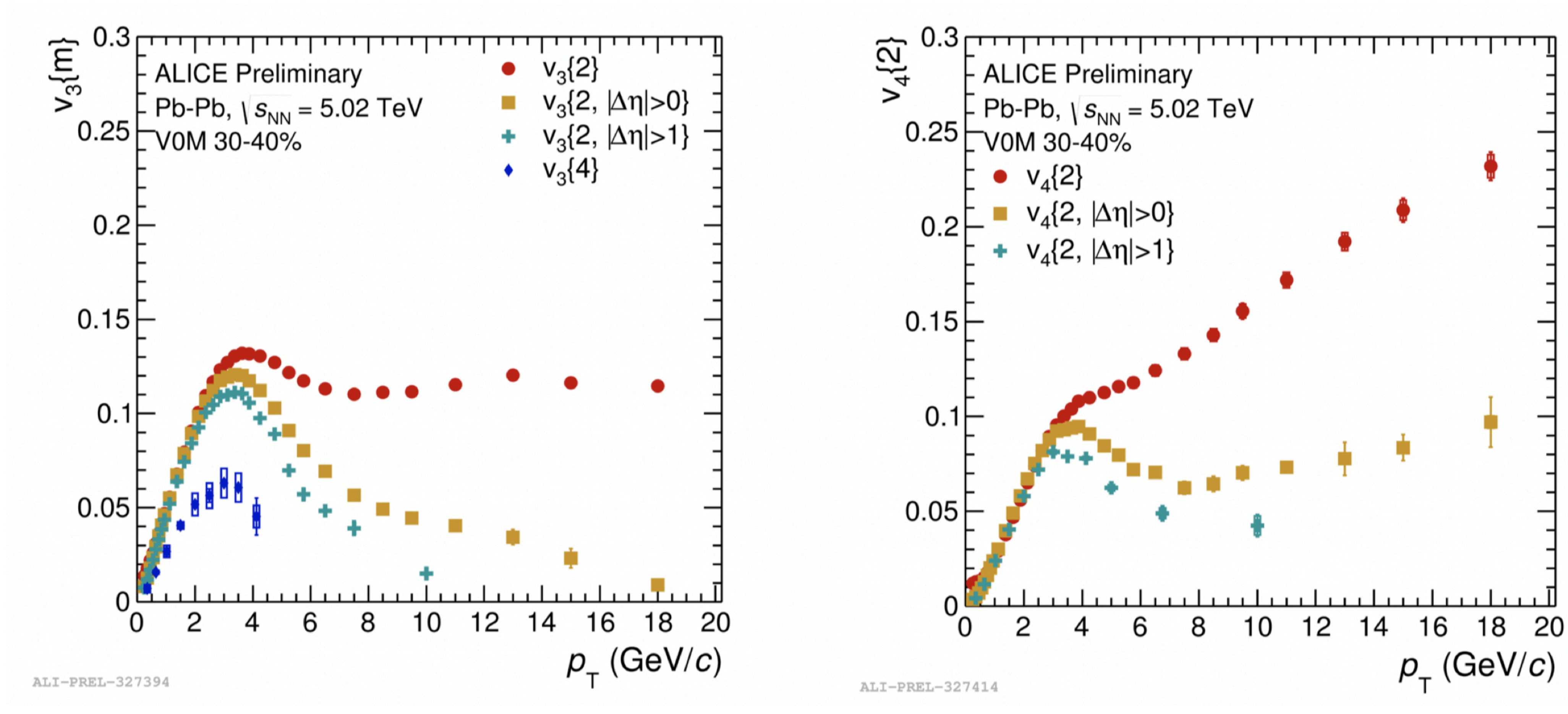
- Non-flow effect of 2-particle cumulant was suppressed by η gap
- $< v_n >$ is the anisotropic flow from the symmetry plane and σ_{v_n} is the corresponding anisotropic flow fluctuations
- Obvious centrality dependence of $< v_n >$ and σ_{v_n} for Ξ
- No definite particle species dependence on $F(v_2)$

Summary

- v_2 distribution is not described well by the Bessel-Gaussian distribution. Non-trivial evolution with p_{T}
- Precision measurements of flow vector fluctuations indicate they are driven by flow magnitude fluctuations
- Flow fluctuation further understood and quantified by unfolding the underlying v_2 PDFs
- No definite particle species dependence observed for relative flow fluctuations of identified particles

Back up

p_T-differential $v_3\{m\}$ and $v_4\{2\}$

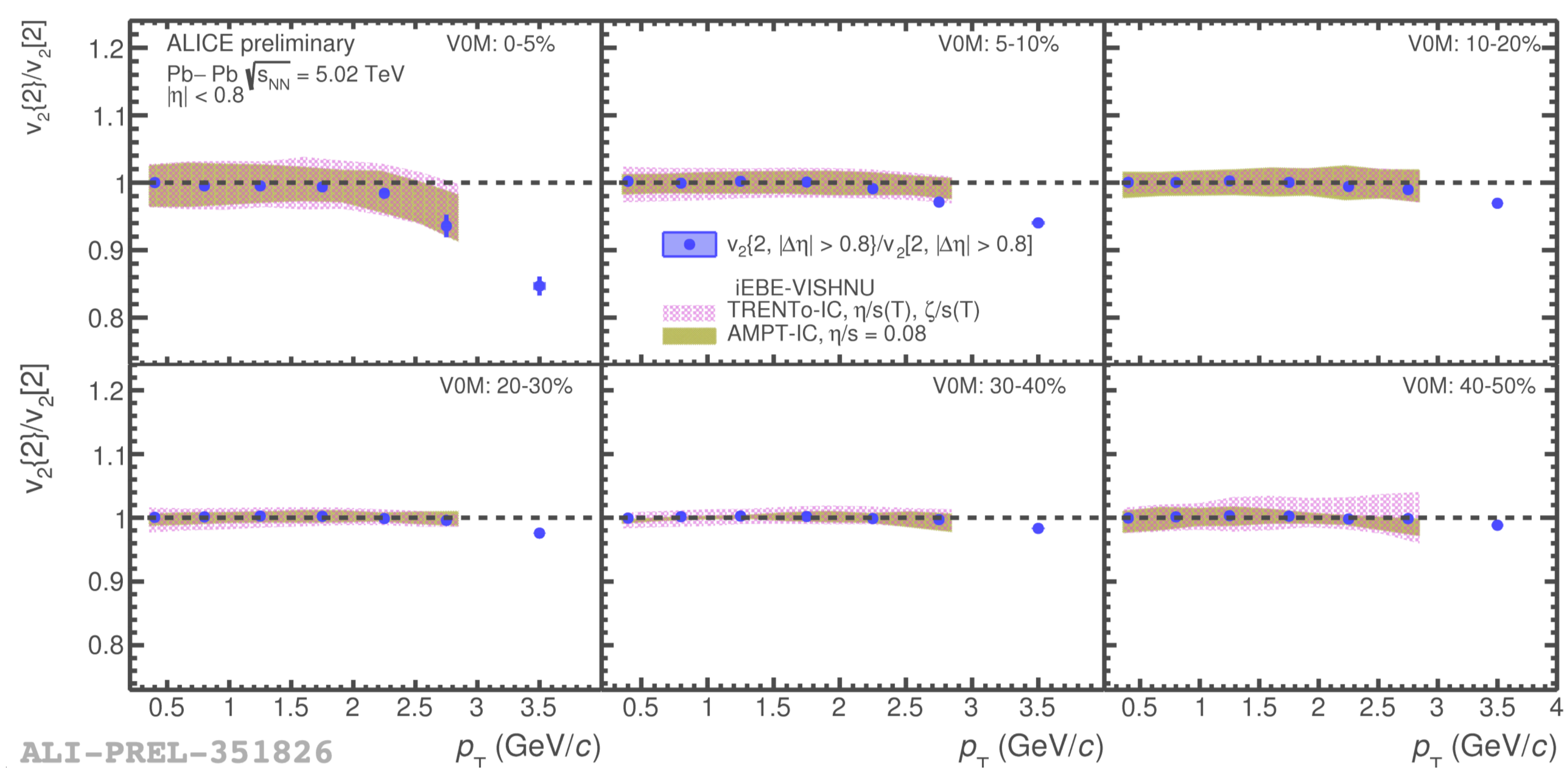


- Precision measurements of v_3 and v_4
- Large η gap was used to suppress non-flow

Flow vector fluctuations

- $v_2\{2\} = \frac{d_n\{2\}(p_T)}{\sqrt{c_n\{2\}}} = \frac{< v_n^a(p_T) \cdot v_n^T \cdot cos[n(\phi_1^a - \phi_2^T)] >}{< v_n^T \cdot v_n^T >^{1/2}}$, affected by decorrelation
- $v_2[2] = \sqrt{c_n\{2\}(p_T)} = < v_n^a \cdot v_n^a >^{1/2}$, not affected by decorrelation

- $\frac{v_2\{2\}}{v_2[2]}$ is a special case for r_n (if one selects the associated particle 'b' from entire 'T')
- $\frac{v_2\{2\}}{v_2[2]}$ carries similar information with that from r_n

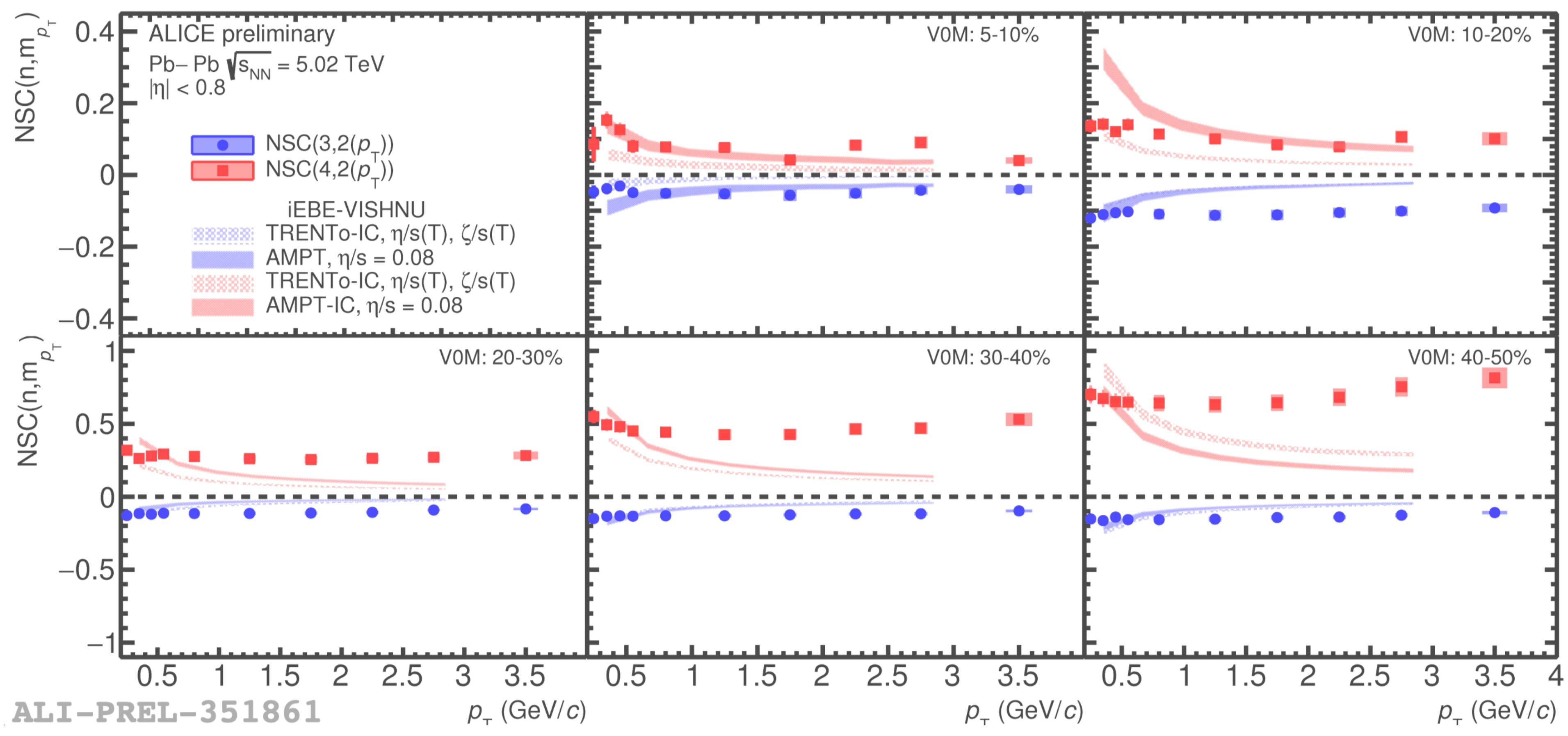


Flow magnitude fluctuations

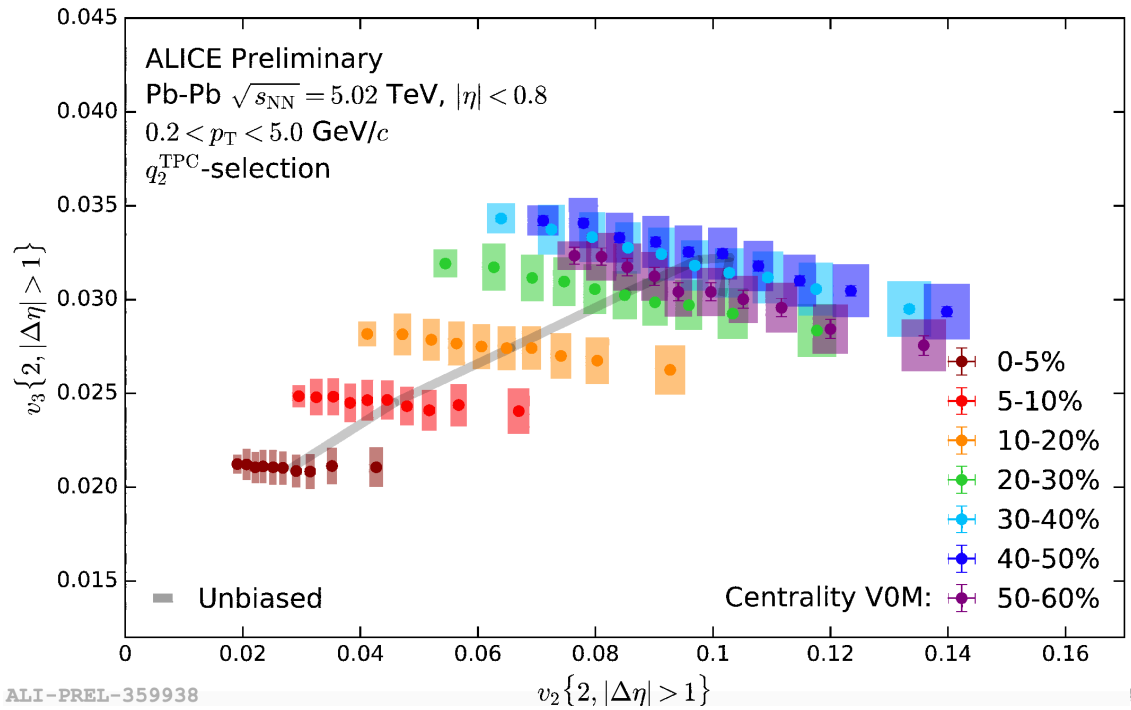
Normalised symmetric cumulant can be probed by the correlation between different harmonics:

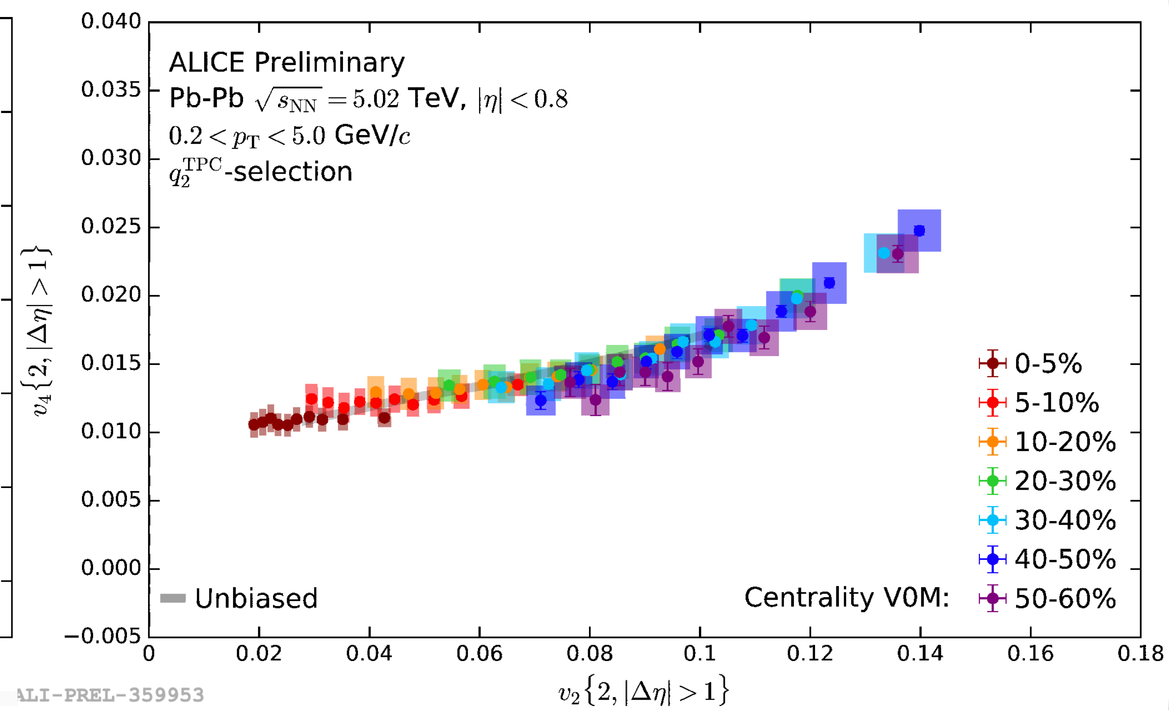
$$NSC(n,m) = \frac{< v_n^2 \cdot v_m^2 > - < v_n^2 > < v_m^2 >}{< v_n^2 > < v_m^2 >}$$

- Shows p_{T} dependence, especially in central collisions.
- AMPT gives a better description in most central collisions
- Both generators fail when going more peripheral collisions



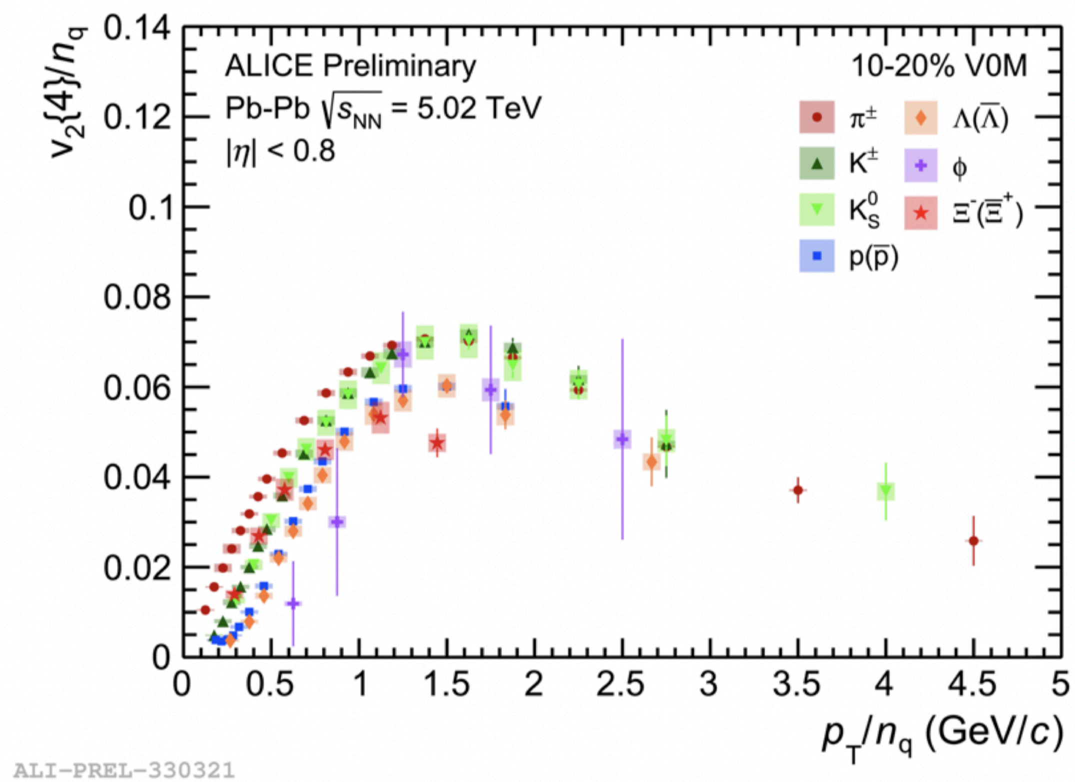
Correlation flow with Event Shape Engineering

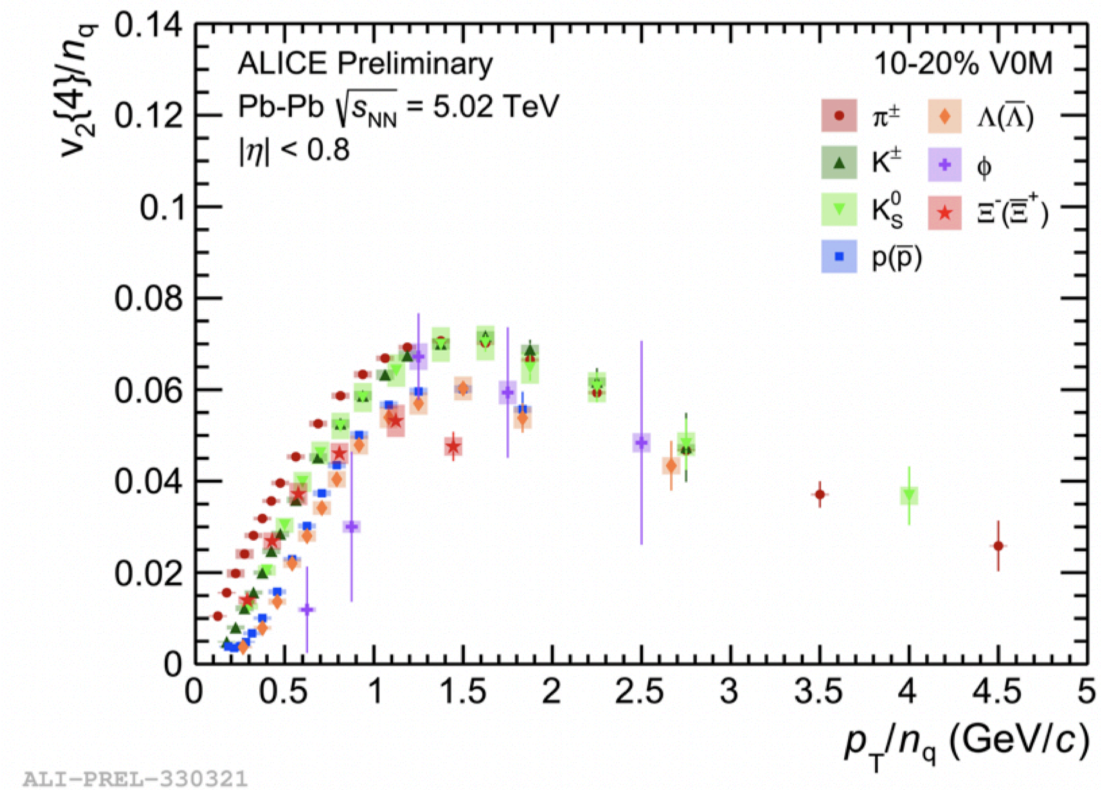




- The correlation between the different harmonics was exposed in each centrality bin.
- Split each bin into its 10% portions of the q_2-distribution

n_q scaling test for $v_2\{4\}$ of identified particles





- Both v_2 and p_T are scaled by the number of constituent quarks (n_q)
- The various hadron species approximately follow a common trend at intermediate p_T (About 20% deviation)