Anisotropic flow fluctuations of identified particles in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV with ALICE

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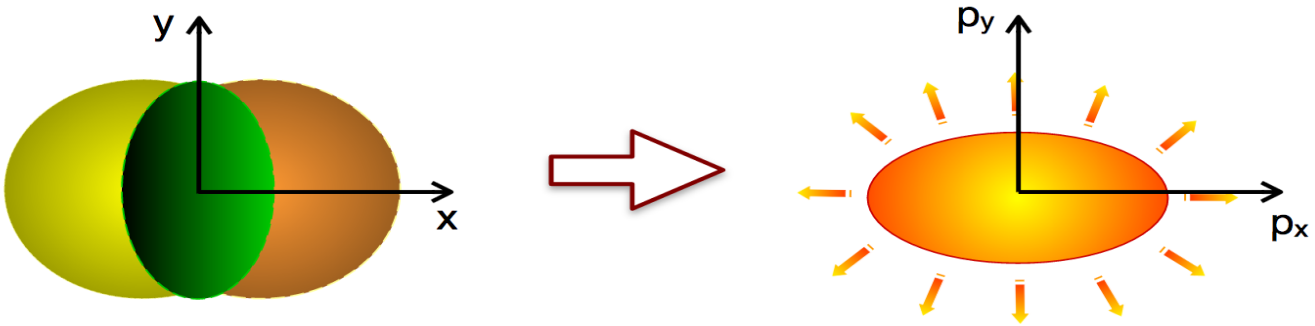
Anisotropic flow v_n

initial spatial anisotropy

momentum-space anisotropy



- Interactions among constituents transform the initial spatial anisotropy into momentum anisotropy
- $E\frac{d^3N}{dp^3} = \frac{d^2N}{2\pi p_T dp_T dy}\left\{1 + \sum_{n=1}^{\infty} 2v_n \cos\left[n\left(\phi - \Psi_n\right)\right]\right\}$
- $v_n = \langle \cos\left[n\left(\phi - \Psi_n\right)\right]\rangle$
- v_n quantify the event anisotropy

  v_2 elliptic flow, v_3 triangular flow...
- v_n are sensitive to the evolution of the collision system
- Anisotropic flow analysis of identified particles furthers the understanding of the hydrodynamic behaviour of the QGP, as well as its initial state, and freeze-out conditions.

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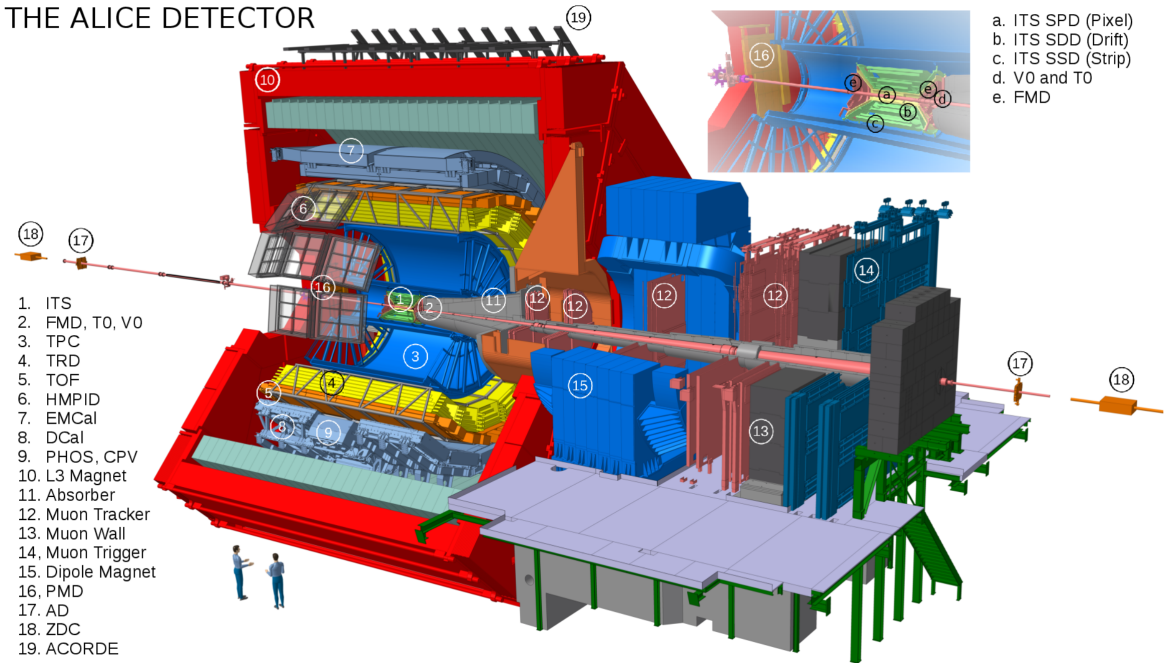
ALICE detector



- Pb–Pb at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV

  $\sim 60 \times 10^6$ minimum bias events

- Inner Tracking System

  Tracking, vertexing, triggering

- Time Projection Chamber

  Tracking, vertexing, particle identification based on specific energy loss

- Time-of-Flight

  Particle identification from flight time and track length

- V0A and V0C

  Triggering, centrality determination

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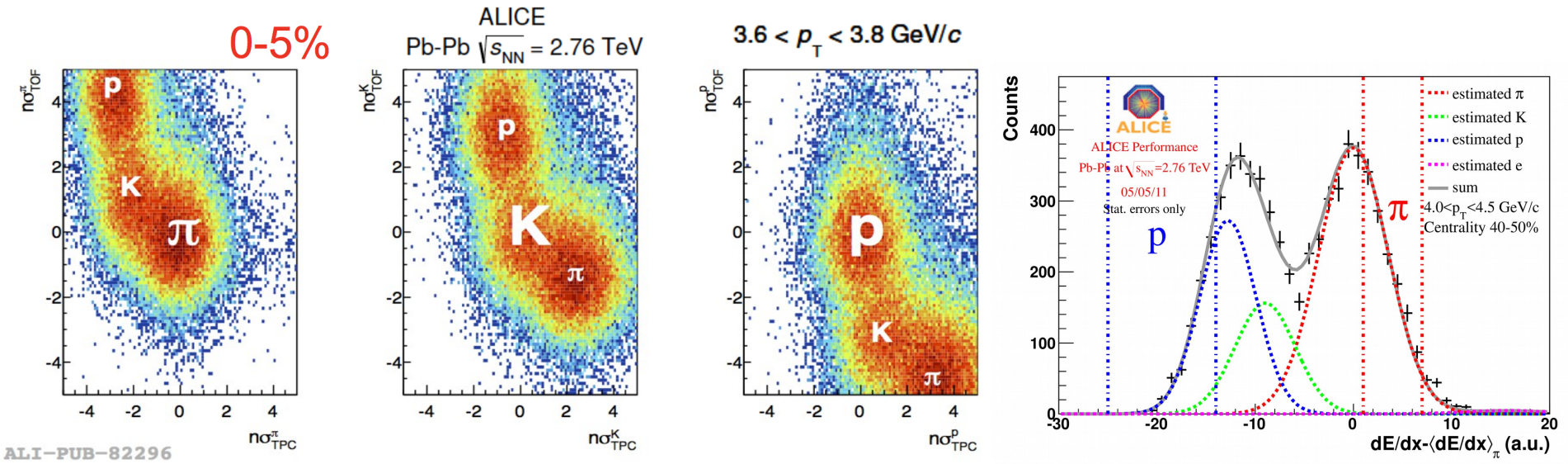
Particle identification



- For $p_{\mathrm{T}} < 4$ GeV/c $\pi^{\pm}$, $K^{\pm}$, p identified using combined TPC and TOF detector response

$$n\sigma^2_{PID} = n\sigma^2_{TPC} + n\sigma^2_{TOF}, \quad n\sigma_{PID} < 3$$

- For $p_{\mathrm{T}} > 4$ GeV/c $\pi^{\pm}$, p identified using TPC detector

$$\Delta_\pi = dE/dx - < dE/dx >_\pi$$

- Track-by-track PID with purity $> 80\%$

[ALICE, Eur.Phys.J.Plus 131 (2016) no.5, 168]

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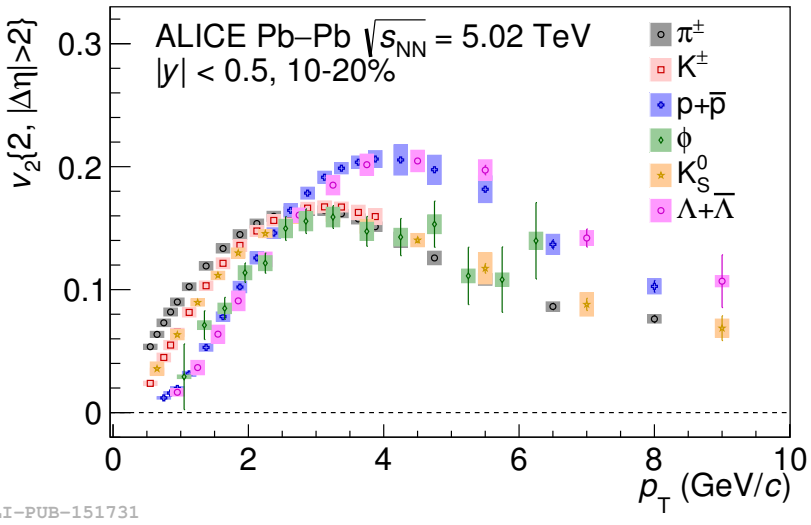
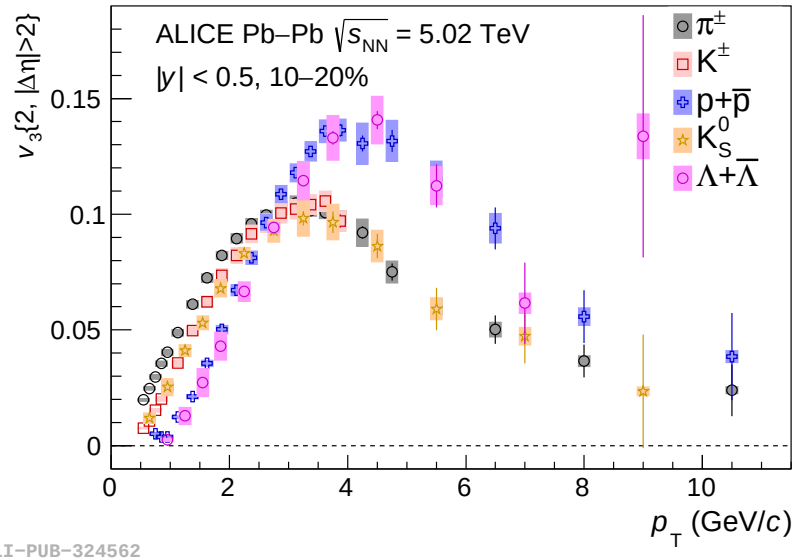
v_2 and v_3 of identified particles





[JHEP 1809 (2018) 006]

- v_n of identified particles was measured by

$$v_n = \frac{\langle\langle \mathbf{u}_n \cdot \mathbf{Q}_n^{V0C} \rangle\rangle}{\sqrt{\frac{\langle \mathbf{Q}_n^{V0C} \cdot \mathbf{Q}_n^{V0A} \rangle \langle \mathbf{Q}_n^{V0C} \cdot \mathbf{Q}_n^{TPC} \rangle}{\langle \mathbf{Q}_n^{V0A} \cdot \mathbf{Q}_n^{TPC} \rangle}}}$$

where $\mathbf{Q}_n$ is defined as $Qn = \sum w_i e^{in\phi}$

  - Hits measured by V0C are used as reference particles (RPs)
  - Large η gap between particles of interest and RPs to suppress non-flow

- Mass ordering is observed for p_T <2-3 GeV/c
- For 3 < p_T < 8-10 GeV/c, particles are grouped into mesons and baryons
- However, 2-particle correlations sensitive to non-flow contaminations (decays, jets, . . .)

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Multi-particle cumulant method

- 4-particle cumulants are obtained using Generic Framework.
  [A. Bilandzic et al., Phys.Rev. C89 (2014) 064904, Phys.Rev. C83 (2011) 044913]
- The differential cumulant is given by

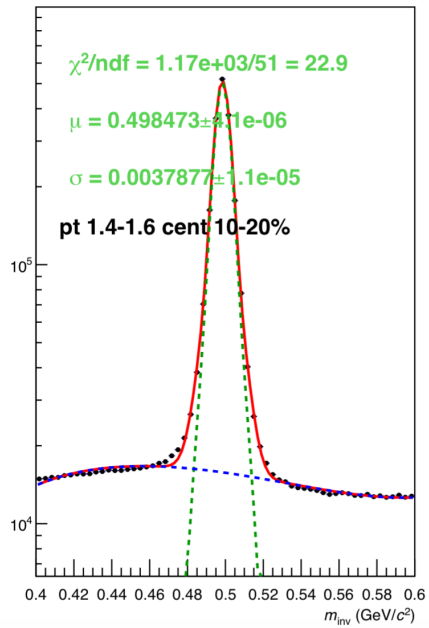
$$d_n\{4\} = \ll 4' \gg - 2 \cdot \ll 2' \gg \ll 2 \gg$$

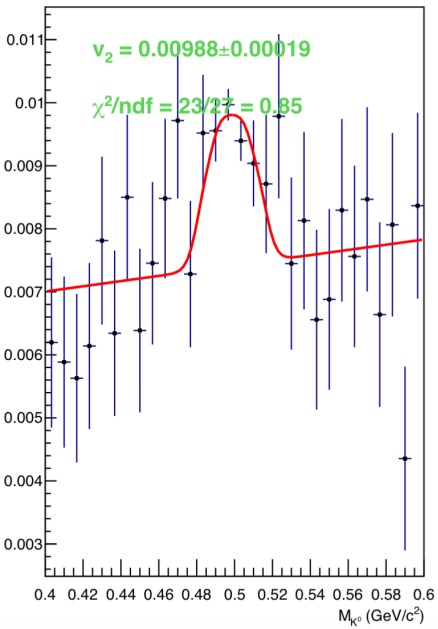
- Estimates of differential flow v_n' are denoted as

$$v_n'\{4\} = -\frac{d_n\{4\}}{(c_n\{4\})^{3/4}}$$

- More effective non-flow effect suppression & More accurate measurements.

K0s





- For reconstructed particles, $\langle\langle n' \rangle\rangle$ can be extracted by $\langle\langle n' \rangle\rangle$ vs inv. mass method:

$$\langle\langle n' \rangle\rangle^{Tot}(m_{inv}) = \langle\langle n' \rangle\rangle^{Sig} \frac{N_{Sig}(m_{inv})}{N_{Tot}(m_{inv})} + \langle\langle n' \rangle\rangle^{Bg}(m_{inv}) \frac{N_{Bg}(m_{inv})}{N_{Tot}(m_{inv})}$$

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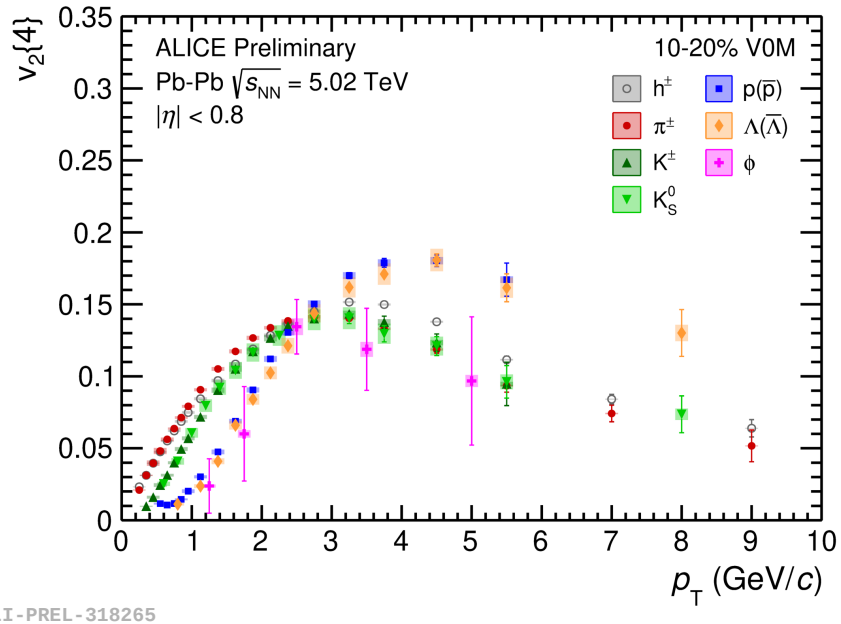
$v_2\{4\}$ of identified particles



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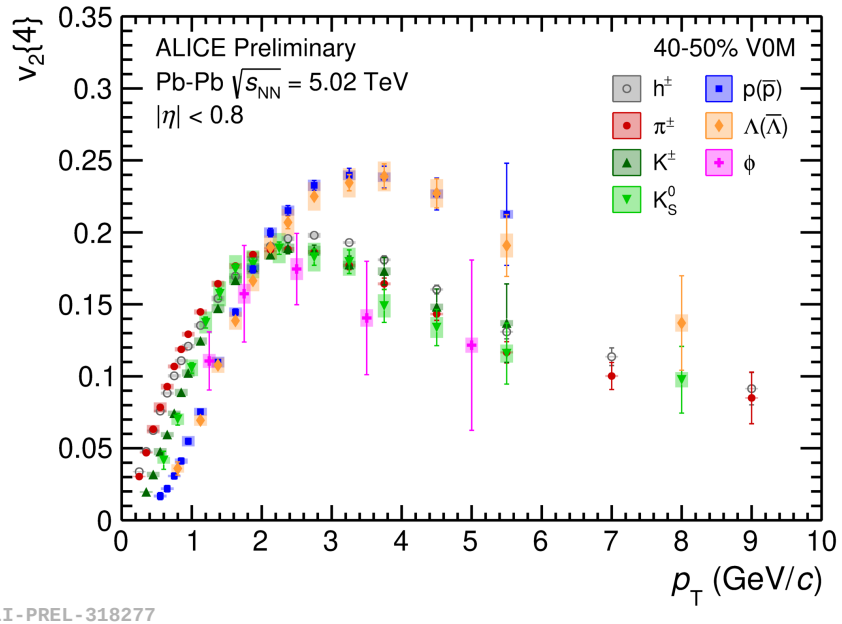

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- Qualitatively similar behaviour as of $v_2\{2\}$ measurements
- Mass-ordering and baryon/meson grouping effects preserved
- Less sensitive to non-flow contamination

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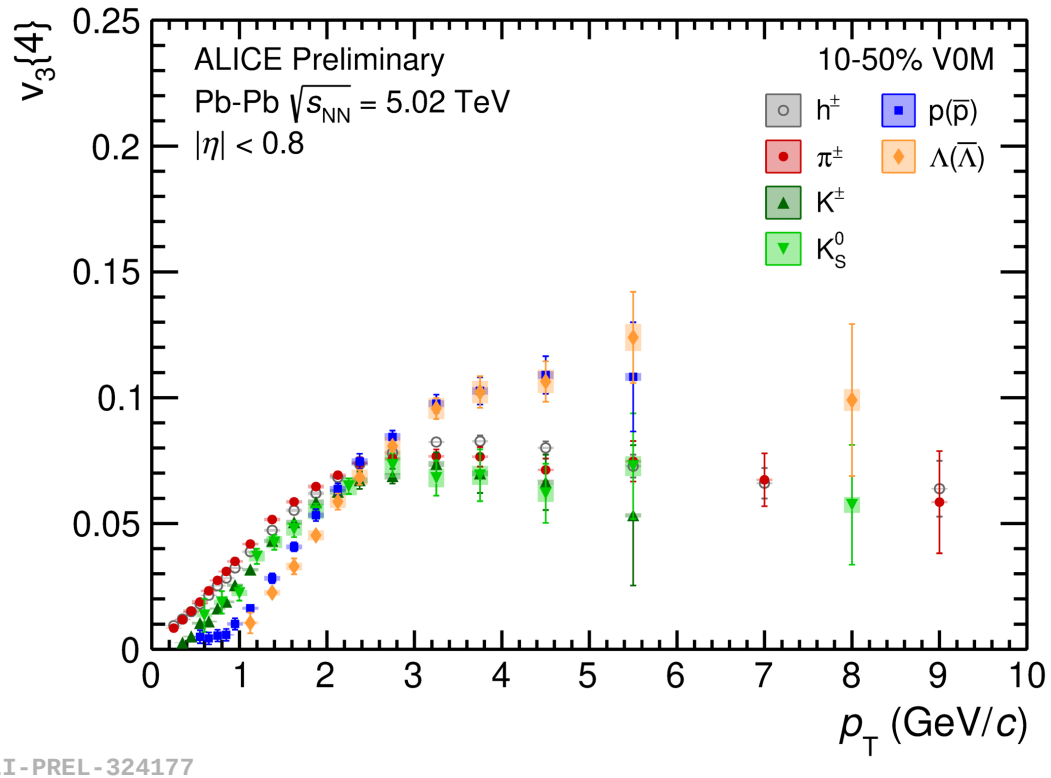
$v_3\{4\}$ of identified particles



- Qualitatively similar behaviour as of $v_3\{2\}$ measurements
- Analysis of large data sample collected in 2018 ongoing to further improve the precision

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Flow and flow fluctuation

- Measurements of 2- & 4-particle correlations used to study v_n fluctuations
  (if non-flow is negligible in 2-PC)
  [Voloshin, Poskanzer, Tang, Wang, PLB 659 (2008) 537-541]

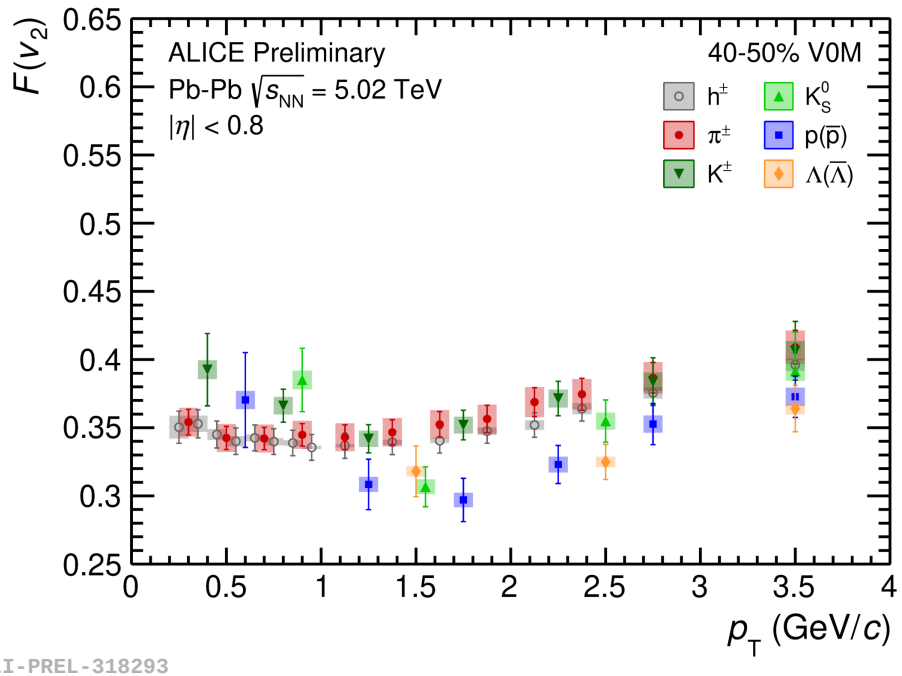
$$v_n\{2\}^2 = \langle v_n \rangle^2 + \sigma_{v_n}^2$$

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

$$\Downarrow$$

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

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



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- Relative v_n fluctuations

$$F(v_n) = \frac{\sigma_{v_n}}{\langle v_n \rangle}$$

- $\langle v_n \rangle$ is the anisotropic flow from the participant plane and σ_{v_n} is the corresponding anisotropic flow fluctuations.

- Non-trivial mass dependence observed
- Would be interesting to see if hydro (or other models) can reproduce the trend

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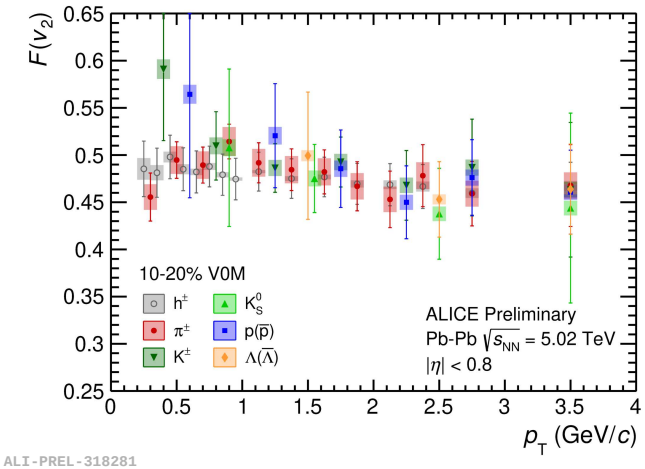
Centrality dependence of F(v_2)



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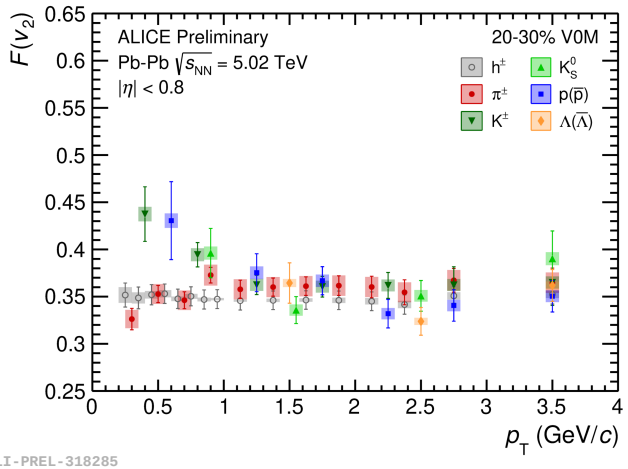

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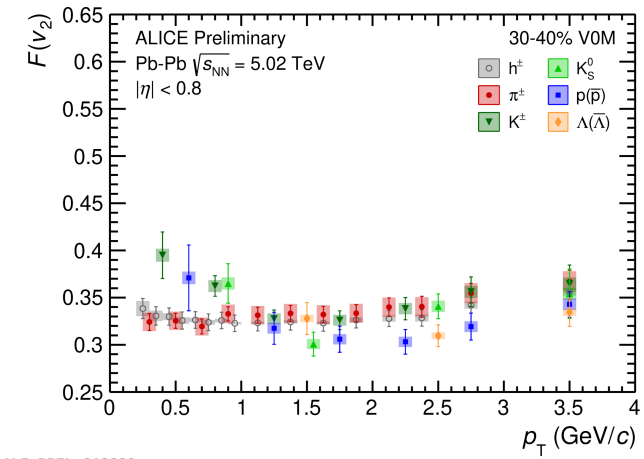

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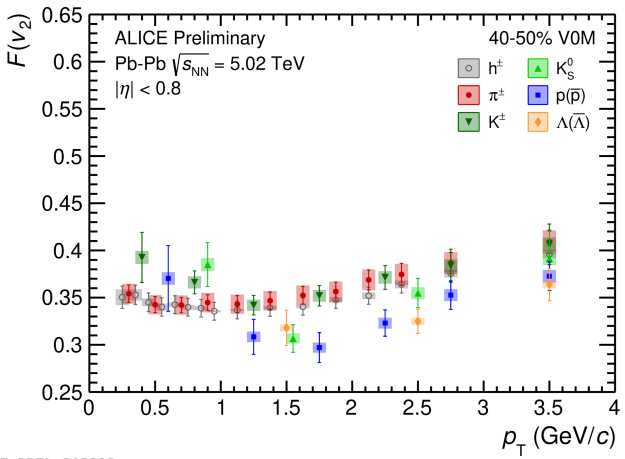

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- Mass dependence less pronounced towards more central collisions

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Summary

- $v_2\{4\}, v_3\{4\}$ of identified particles were measured in Pb-Pb collisions at $\sqrt{s_{\rm NN}} =$ 5.02 TeV
  - Qualitatively similar behaviour as of $v_2\{2\}$ and $v_3\{2\}$ measurements
  - Mass ordering(hydrodynamic flow, hadron re-scattering)
  - Baryon/meson grouping (recombination/coalescence?)
- Measurements of 2- & 4-particle correlations were used to study v_n fluctuations
  - Non-trivial mass dependence observed
  - Mass dependence less pronounced towards more central collisions
- Analysis of large data sample collected in 2018 ongoing
  - More identified particles: Ξ, Ω...

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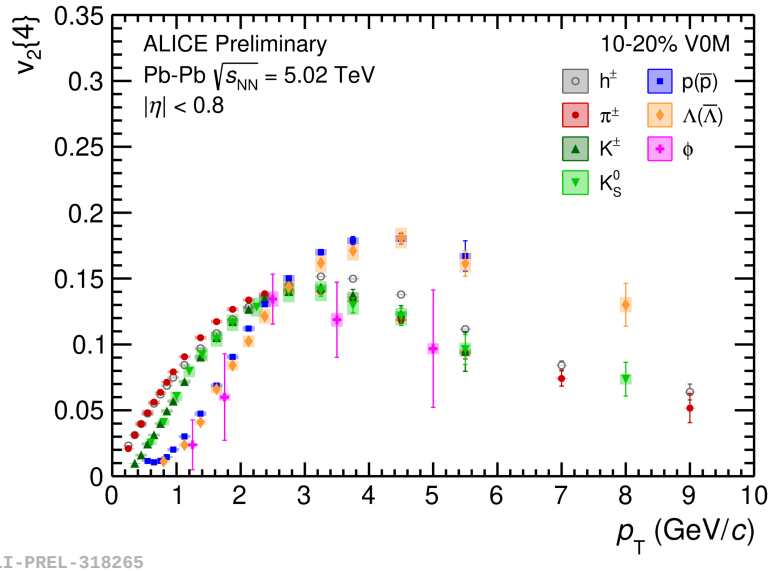
Backup

Centrality dependence of $v_2\{4\}$



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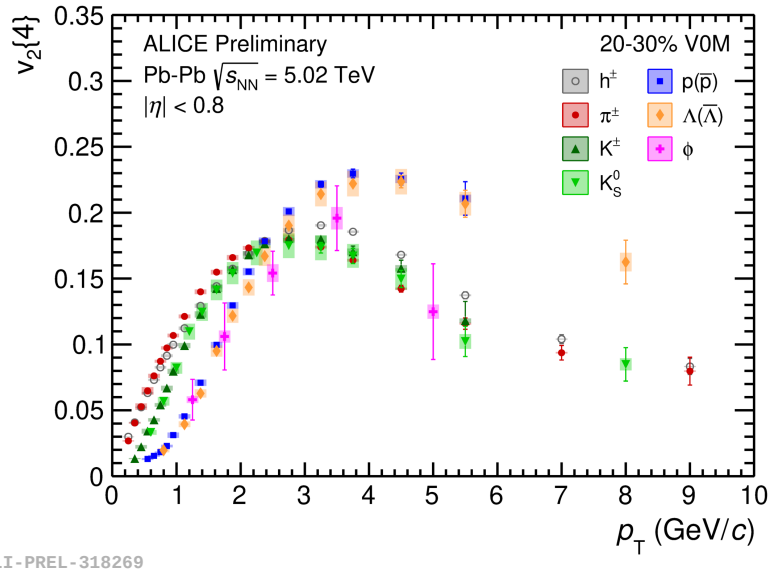

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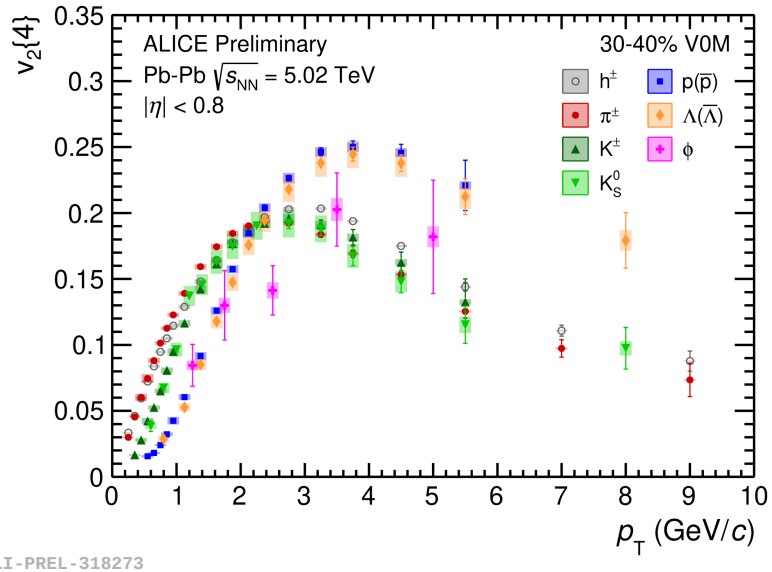

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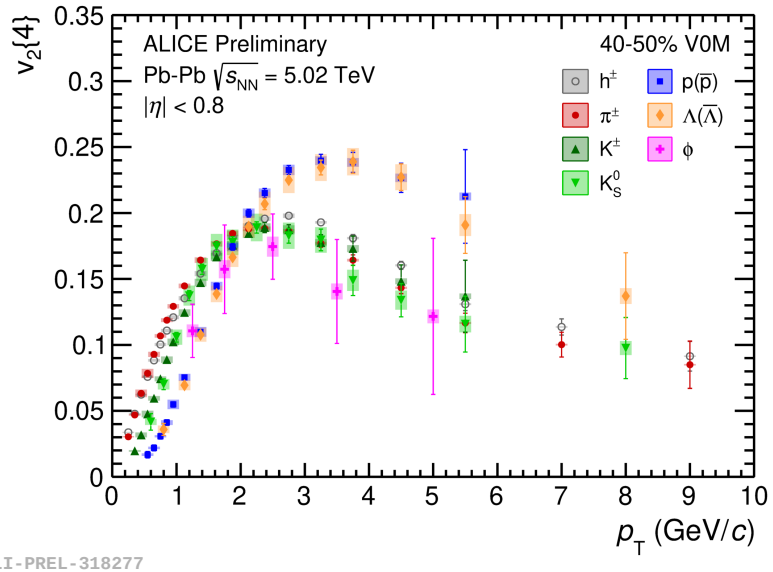

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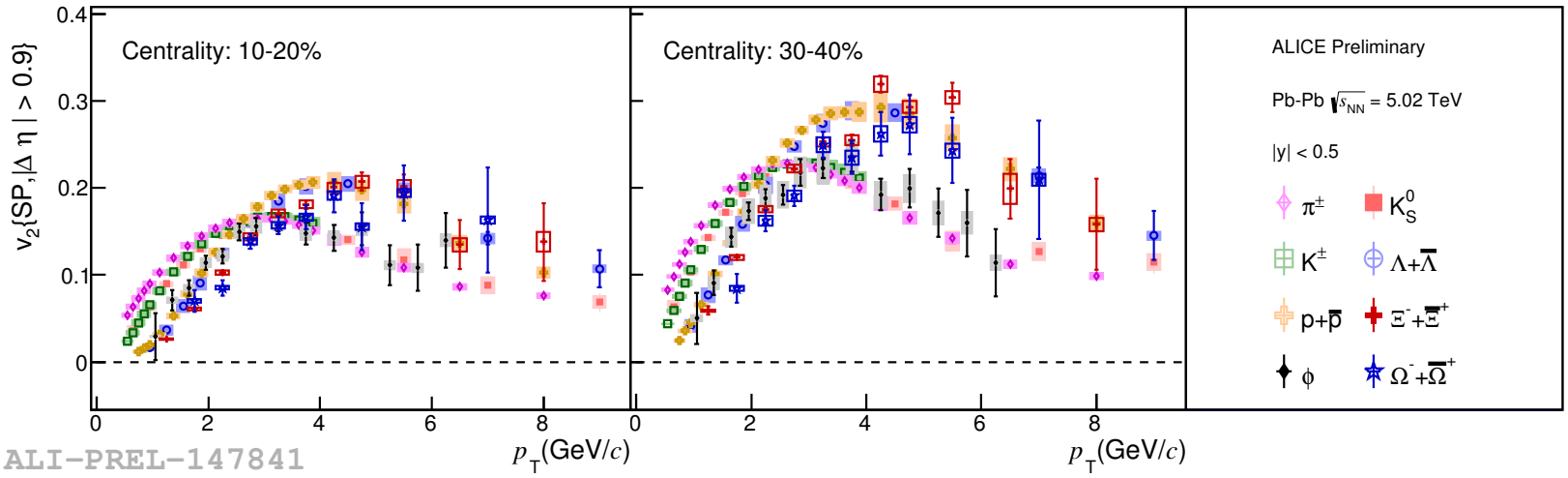
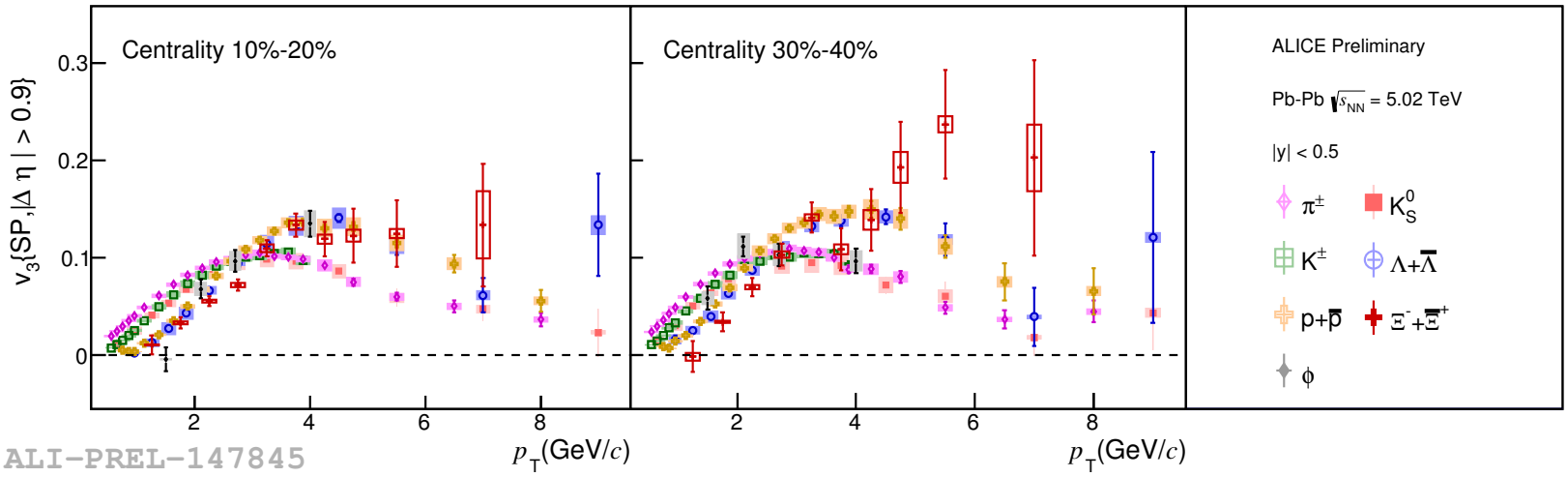
v_2 and v_3 of identified particles(contain Ξ and Ω)





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