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

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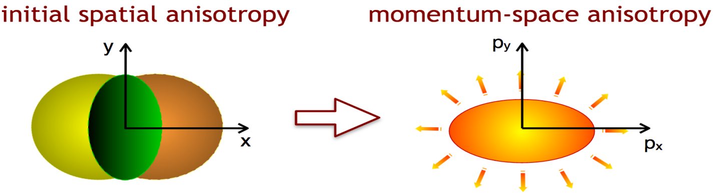
Anisotropic flow v_n

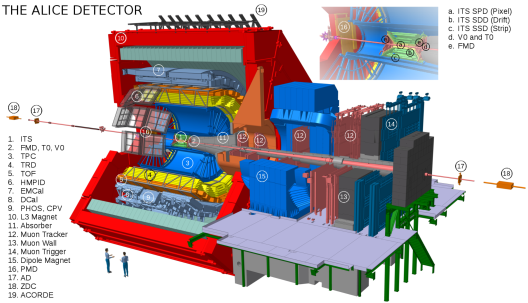


- Interactions among constituents transform the initial spatial anisotropy into momentum anisotropy
- $E\frac{d^3N}{dp^3} = \frac{d^2N}{2\pi p_T dp_T dy}\left\{1 + \sum_{n=1}^{\infty} 2v_n \cos\left[n\left(\phi - \Psi_n\right)\right]\right\}$
- $v_n = \langle\cos\left[n\left(\phi - \Psi_n\right)\right]\rangle$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

Results from JHEP:10.1007/JHEP09(2018)006

ALICE detector



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

  $\approx 60 \times 10^6$ minimum bias events
- Tracks:
  $|\ \eta\ | < 0.8$ (unidentified)
  $|\ y\ | < 0.5$ (identified)

- Inner Tracking System

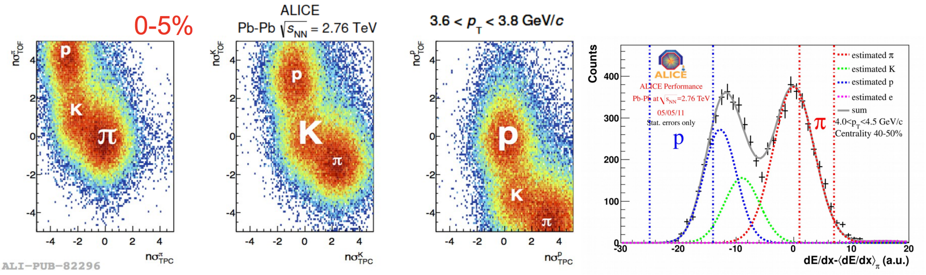
  Tracking, vertexing, triggering
- Time Projection Chamber

  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, Q-vector

Particle identification



- For $p_{\mathrm{T}} < 4$ GeV$/c$ $\pi^{\pm}$, $K^{\pm}$, p are 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 are 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]

Flow analysis methods

- v_n of identified particles is measured using the scalar product method

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

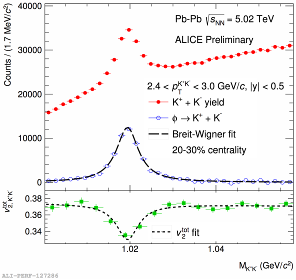
where $\mathbf{Q}_n$ is defined as $\mathbf{Q}n = \sum w_i e^{in\phi}$

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

- v_n of $\pi^{\pm}$, $\mathrm{K}^{\pm}$, $\mathrm{p}+\bar{\mathrm{p}}$ is directly measured using the scalar product method
- v_n of ϕ, $\mathrm{K}^0_{\mathrm{S}}$, $\Lambda+\bar{\Lambda}$, $\Xi^-+\bar{\Xi}^+$, $\Omega^-+\bar{\Omega}^+$ is extracted using the v_n vs invariant mass method

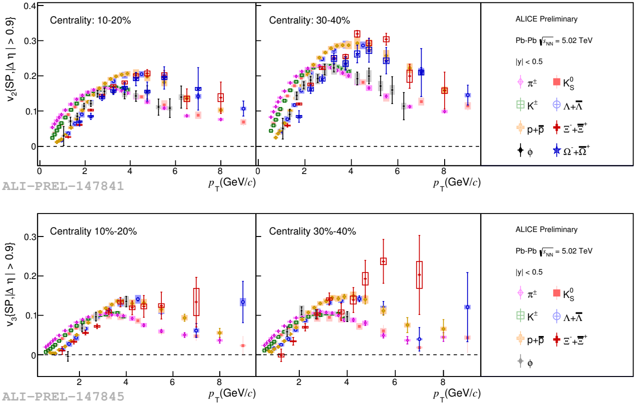
$$v_n^{Tot}(m_{inv}) = v_n^{Sig}\frac{N_{Sig}(m_{inv})}{N_{Tot}(m_{inv})} + v_n^{Bg}(m_{inv})\frac{N_{Bg}(m_{inv})}{N_{Tot}(m_{inv})}$$

Yields N_{Sig} and N_{Bg} are extracted from fitting the invariant mass distributions. v_n^{Sig} is extracted from fitting the v_n distribution.



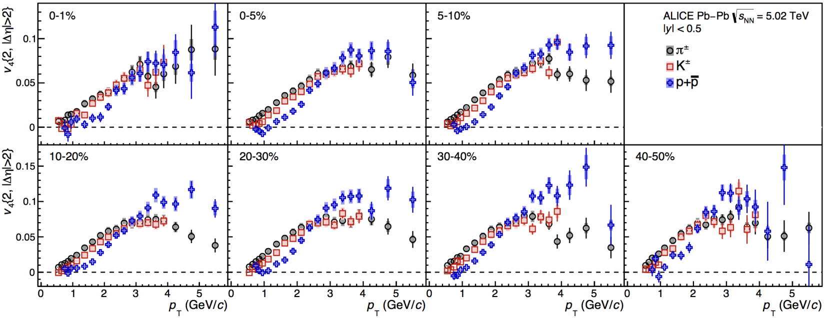
- Reconstruction of $\phi, \mathrm{K}^0_{\mathrm{S}}$, Λ, Ξ, Ω via decay products on statistical basis
  - $\phi \to K^+ + K^-$
  - $\mathrm{K}^0_{\mathrm{S}} \to \pi^+ + \pi^-$
  - $\Lambda \to p + \pi^-$
  - $\bar{\Lambda} \to \bar{p} + \pi^+$
  - $\Xi^- \to \Lambda + \pi^- \to p + \pi^- + \pi^-$
  - $\bar{\Xi}^+ \to \bar{\Lambda} + \pi^+ \to \bar{p} + \pi^+ + \pi^+$
  - $\Omega^- \to \Lambda + K^- \to p + \pi^- + K^-$
  - $\bar{\Omega}^+ \to \bar{\Lambda} + K^+ \to \bar{p} + \pi^+ + K^+$

v_2 and v_3 of identified particles



- Mass ordering of $v_2(p_T)$ and $v_3(p_T)$ is observed for p_T <2-3 GeV/c
- For $3 < p_T < 8$-10 GeV/c, v_2 and v_3 of particles are grouped into mesons and baryons

v_4 of π, K, p



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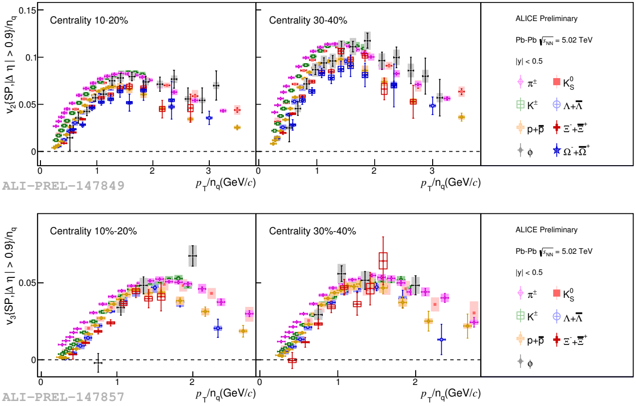
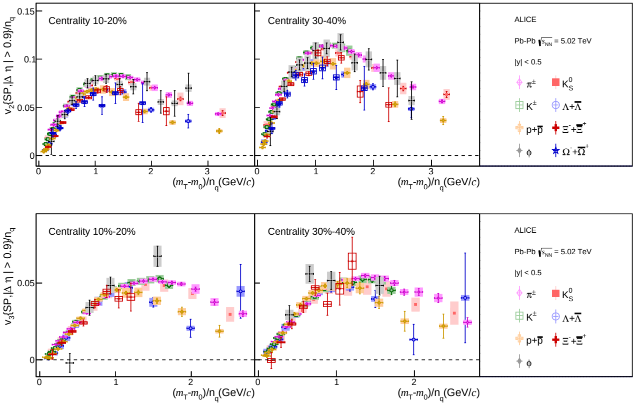
- A clear mass ordering of $v_4(p_{\mathrm{T}})$ is observed for $p_{\mathrm{T}} < 2\text{-}3$ GeV/c
- $3 < p_{\mathrm{T}} < 6$ GeV/c, v_4 of particles are grouped into mesons and baryons

n_q scaling test — p_{T}/n_q dependence



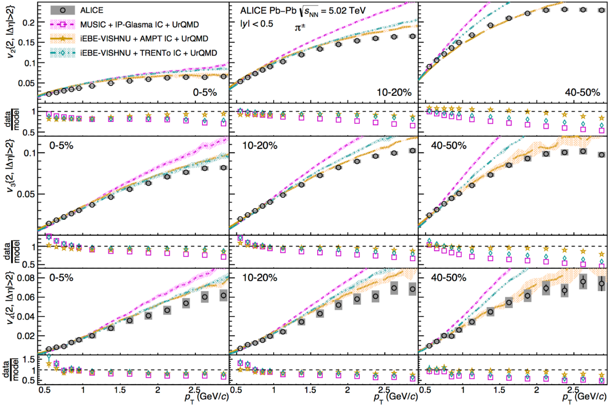
- Both v_n and p_{T} are scaled by the number of constituent quarks (n_q)
- NCQ scaling of v_2 and v_3 has not been accurately observed at the LHC

n_q scaling test — $(m_{\mathrm{T}} - m_0)/n_q$ dependence



- NCQ scaling of v_2 illustrate significant deviations for $(m_{\mathrm{T}} - m_0)/n_q$ < 0.6–0.8 GeV$/c$.
- NCQ scaling of v_3 of the various identified hadron species approximately follow a common behaviour at low p_{T}.

Comparison with model calculations



- **MUSIC** (hydrodynamic) + **IP-Glasma** (initial conditions of the collision) + **UrQMD** (hadronic cascade)
- **iEBE-VISHNU** + **AMPT** (initial conditions of the collision) + **UrQMD** (hadronic cascade)
- **iEBE-VISHNU** + **TRENTo** (initial conditions of the collision) + **UrQMD** (hadronic cascade)

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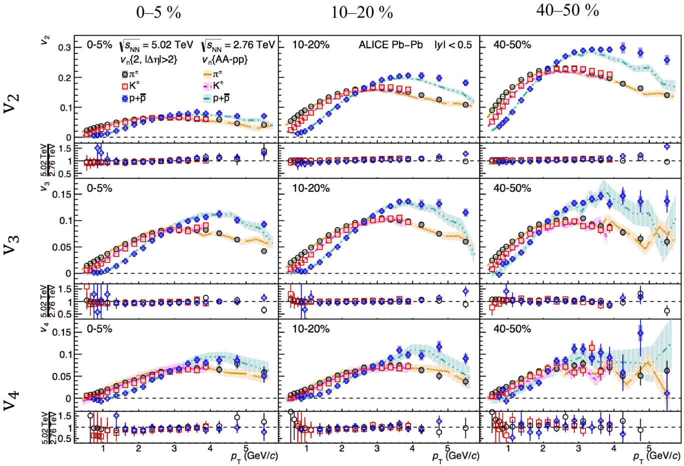
- The v_n measurements are compared to hydrodynamical calculations (K, p in backup)
- Good agreement between v_n for p_T < 1-3 GeV/c (proton v_n is described fairly well up to $p_T = 3$ GeV/c (in backup))

Collision energy dependence of v_n



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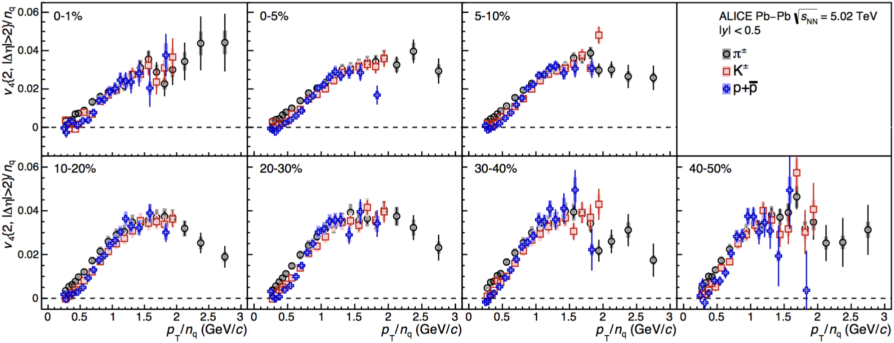
- No significant energy dependence is observed for the $p_{\rm T}$ differential v_n

Summary

- Anisotropic flow of identified particles have been measured in Pb-Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV
- Mass ordering of $v_n(p_{\rm T})$ is observed for $p_{\rm T}$ <2-3 GeV/c
- The NCQ scaling is broken both for v_2 and v_3 for all centrality intervals
- Good agreement with hydrodynamical calculations($p_{\rm T} < 1$ GeV/c for π, K; $p_{\rm T} < 3$ GeV/c for p)
- The measurements are compatible with those performed in Pb–Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV

Backup

n_q scaling test for identified particle v_4



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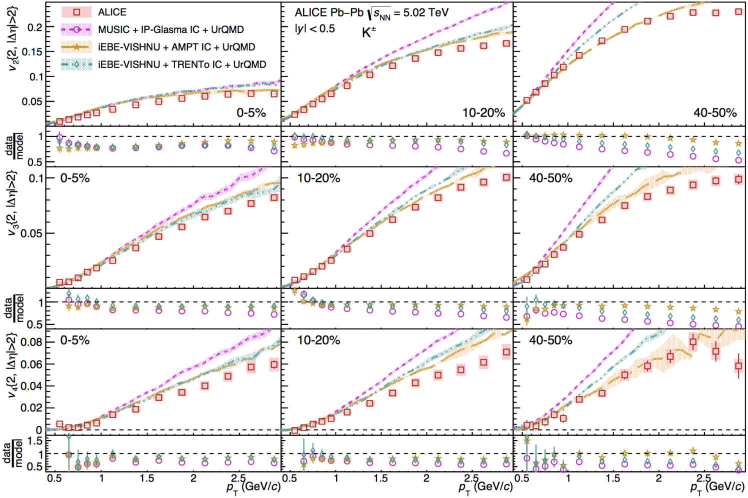
Comparison with model calculations for K



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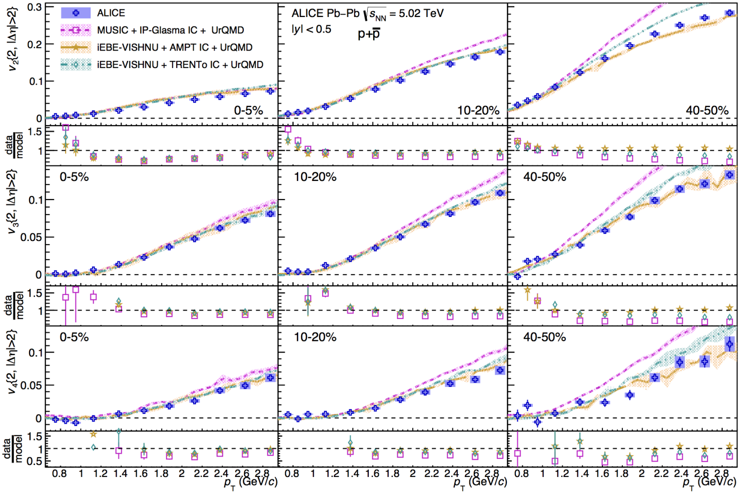
Comparison with model calculations for p



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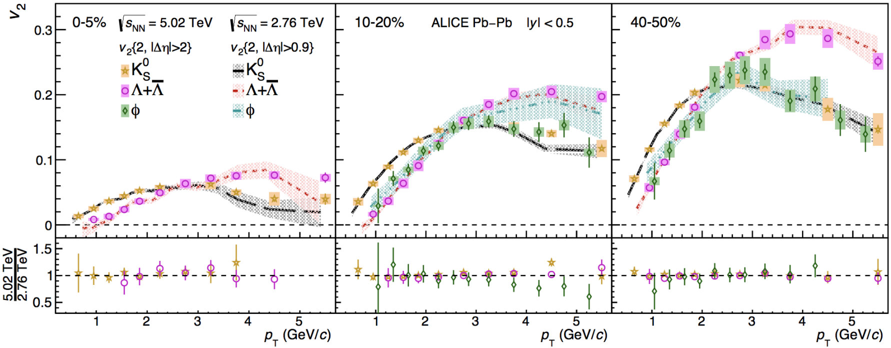
Collision energy dependence of v_n (K_S^0, Λ, ϕ)



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