

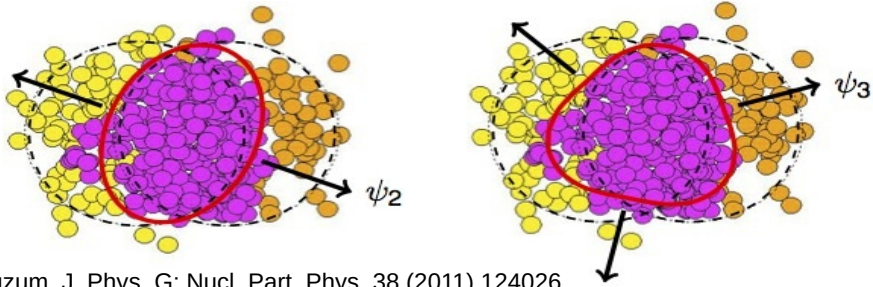
Event shape dependence of anisotropic flow for inclusive and identified hadrons in Pb-Pb and Xe-Xe collisions with ALICE

Mihaela Besoiu for the ALICE Collaboration
(Institute of Space Science)

- Anisotropic flow
- ALICE
 - Particle identification
- Results for Pb-Pb collisions
- Results for Xe-Xe collisions
- Summary



Anisotropic flow



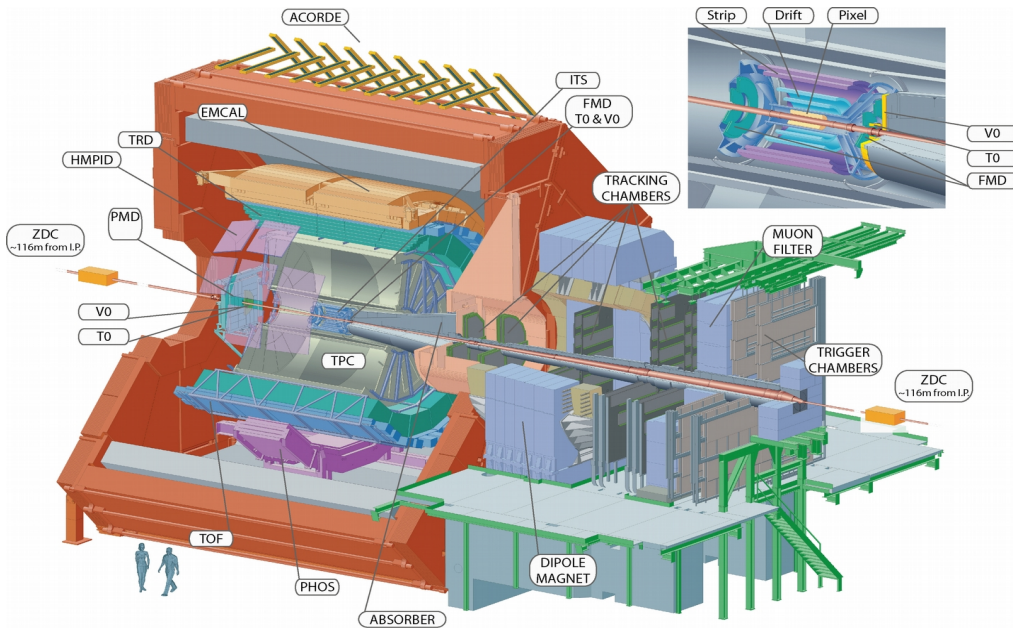
M. Luzum, J. Phys. G: Nucl. Part. Phys. 38 (2011) 124026

$$E \frac{d^3 N}{d^3 p} = \frac{1}{2\pi} \frac{d^2 N}{p_T dp_T dy} \left(1 + \sum_{n=1}^{\infty} 2v_n \cos(n(\varphi - \Psi_n)) \right)$$

$$v_n = \langle \cos(n(\varphi - \Psi_n)) \rangle$$

- v_n quantify the event anisotropy
 - v_2 elliptic flow, v_3 triangular flow, ...
- Anisotropic flow is sensitive to initial conditions and system evolution
- Identified particle v_n allows for more detailed measurements
 - Adds constraints to deconfined phase, particle production mechanisms
 - Probes radial flow and hadronic rescattering phase
 - Checks the number of constituent quarks scaling

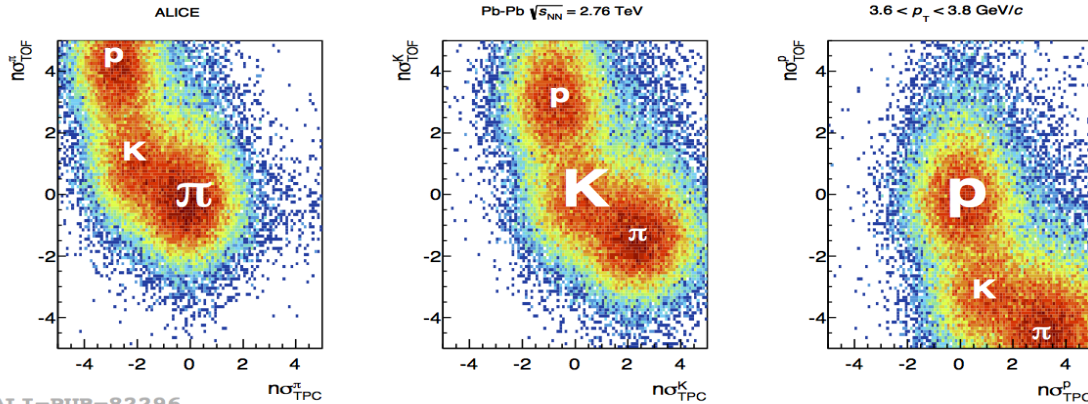
A Large Ion Collider Experiment



- Inner Tracking System (ITS)
 - Tracking, triggering, vertexing
- Time Projection Chamber (TPC)
 - Tracking, vertexing, particle identification based on specific energy loss
- Time-of-Flight (TOF)
 - Particle identification based on the flight time
- V0A ($2.8 < \eta < 5.1$) and V0C ($-3.7 < \eta < -1.7$)
 - Triggering, centrality determination, Q-vector, event-shape selection
- Track selection
 - $|\eta| < 0.8$ (unidentified)
 - $|y| < 0.5$ ($\pi^\pm, K^\pm, p+\bar{p}, K^0_S, \Lambda+\bar{\Lambda}, \Xi^-+\bar{\Xi}^+$)

- Pb-Pb at $\sqrt{s_{NN}} = 5.02$ TeV
 - ~ 320 M events
- Xe-Xe at $\sqrt{s_{NN}} = 5.44$ TeV
 - ~ 1.3 M events

Particle identification (PID)



ALI-PUB-82296

- PID @ $p_T < 4$ GeV/c (left)
 - π^\pm , K^\pm , $p+\bar{p}$ identified using TPC and TOF (purity >90%)

$$n_{\sigma, \text{PID}}^2 = n_{\sigma, \text{TPC}}^2 + n_{\sigma, \text{TOF}}^2$$

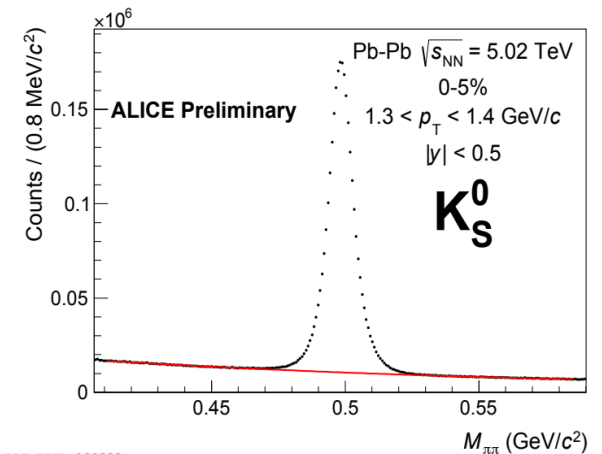
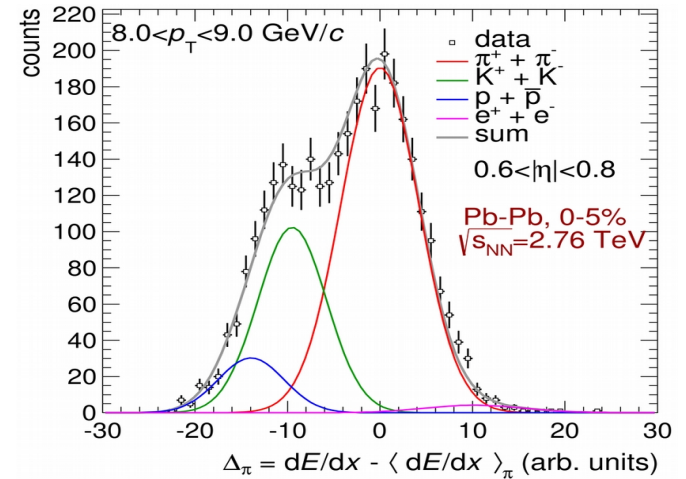
$$n_{\sigma, \text{PID}} < 3$$

- PID @ $p_T > 4$ GeV/c (right)
 - π^\pm and $p+\bar{p}$ identified using TPC (purity >80%)

$$\Delta_\pi = dE/dx - \langle dE/dx \rangle_\pi$$

- Topological reconstruction for K_S^0 , $\Lambda+\bar{\Lambda}$ and $\Xi+\bar{\Xi}$

ALICE, Int. J. Mod. Phys. A 29 (2014) 1430044



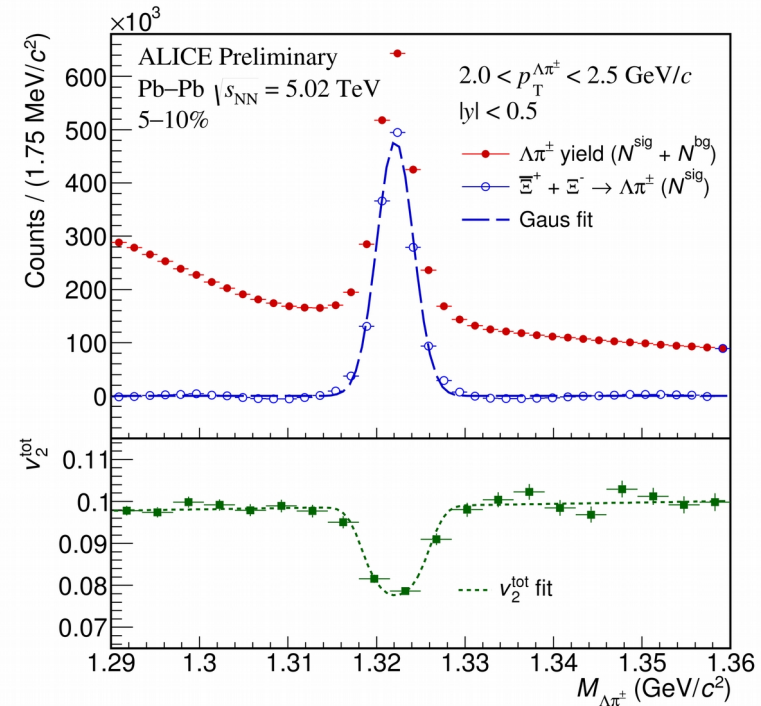
Flow analysis method

- v_n of inclusive, π^\pm , K^\pm , $p+\bar{p}$ is evaluated using the scalar product method
 - Particle of interest (POI) is taken from TPC and hits measured by V0A are used as reference particles (RPs)
 - Large η gap between POI and RPs to suppress non-flow
- v_n of K^0_S , $\Lambda+\bar{\Lambda}$, $\Xi^-+\bar{\Xi}^+$ is determined using the v_n vs invariant mass method

$$v_n^{\text{Tot}}(m_{\text{inv}}) = v_n^{\text{Sgn}} \frac{N^{\text{Sgn}}}{N^{\text{Tot}}}(m_{\text{inv}}) + v_n^{\text{Bg}} \frac{N^{\text{Bg}}}{N^{\text{Tot}}}(m_{\text{inv}})$$

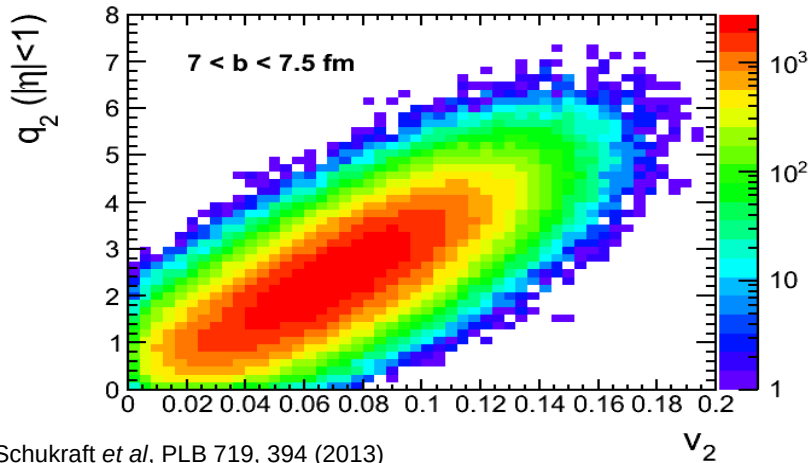
- The yields N^{Sgn} and N^{Bg} are extracted from fits of the invariant mass distribution
- The $v_n^{\text{Tot}}(m_{\text{inv}})$ is measured using the scalar product method

$$v_n = \frac{\langle u Q_n^{\text{V0A}} \rangle}{\sqrt{\frac{\langle Q_n^{\text{V0A}} Q_n^{\text{V0C}} \rangle \langle Q_n^{\text{V0A}} Q_n^{\text{TPC}} \rangle}{\langle Q_n^{\text{V0C}} Q_n^{\text{TPC}} \rangle}}$$

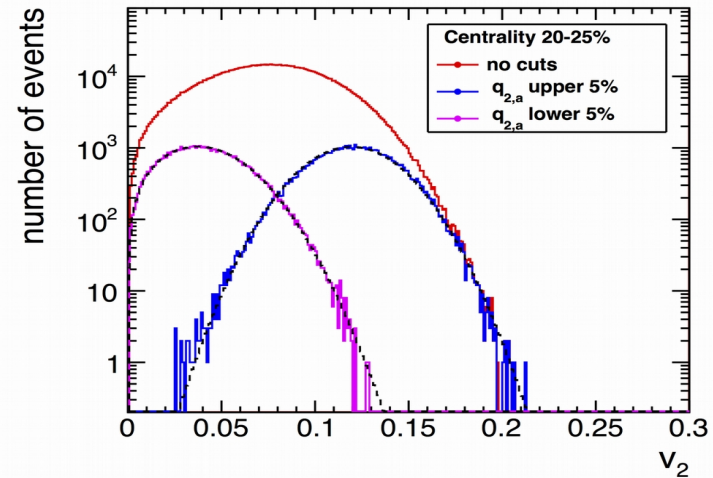


v_n of inclusive and identified hadrons with ESE in Pb-Pb collisions

Event Shape Engineering (ESE)



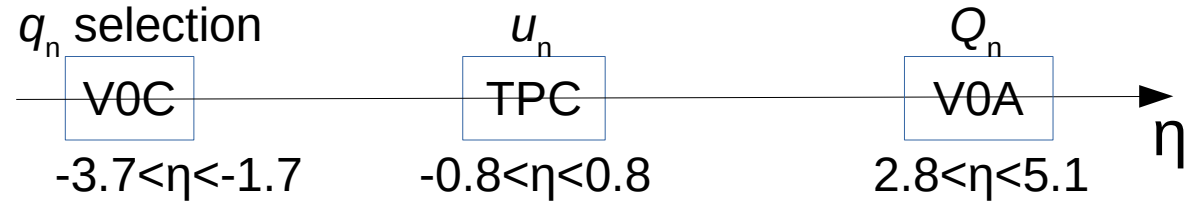
J. Schukraft *et al*, PLB 719, 394 (2013)
 H. Petersen *et al*, PRC 88, 044918 (2013)
 P. Huo *et al*, PRC 90, 024910 (2014)



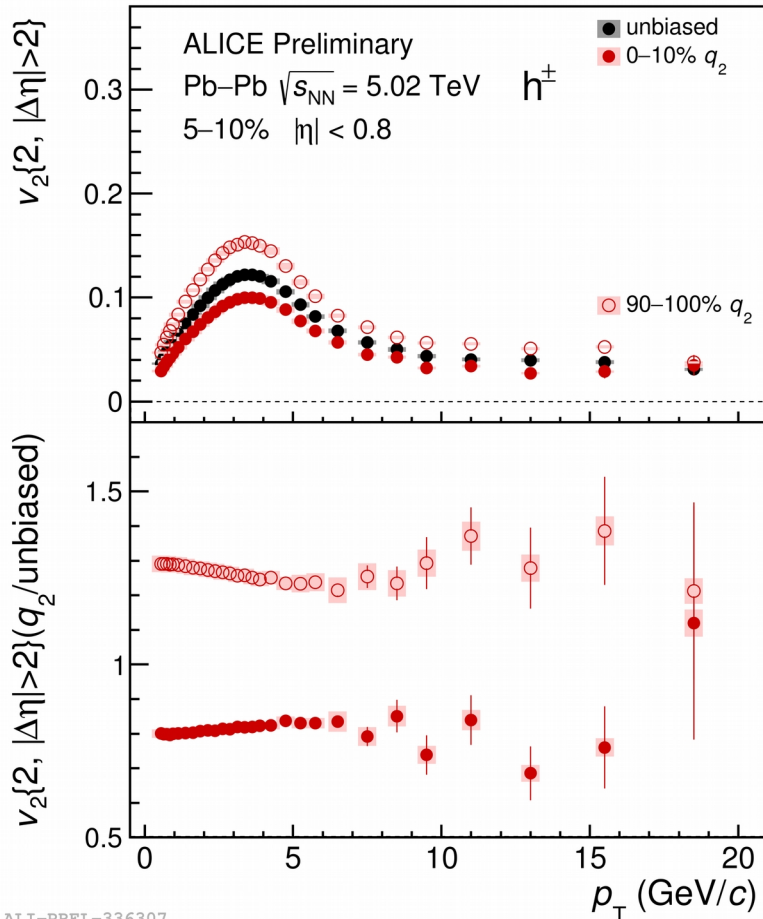
- Select events with similar centralities and different shapes based on the event-by-event flow/eccentricity fluctuations


<p>Flow vector</p> $Q_{n,x} = \sum_i \cos(n\varphi_i)$ $Q_{n,y} = \sum_i \sin(n\varphi_i)$	<p>→</p>	<p>q_n distribution</p> $Q_n = Q_{n,x} + iQ_{n,y}$ $q_n = Q_n / \sqrt{M}$
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Unidentified particle $v_2(p_T)$ with q_2 selection: 5-10% centrality



Unidentified particle $v_2(p_T)$ with q_2 selection: 5-10% centrality

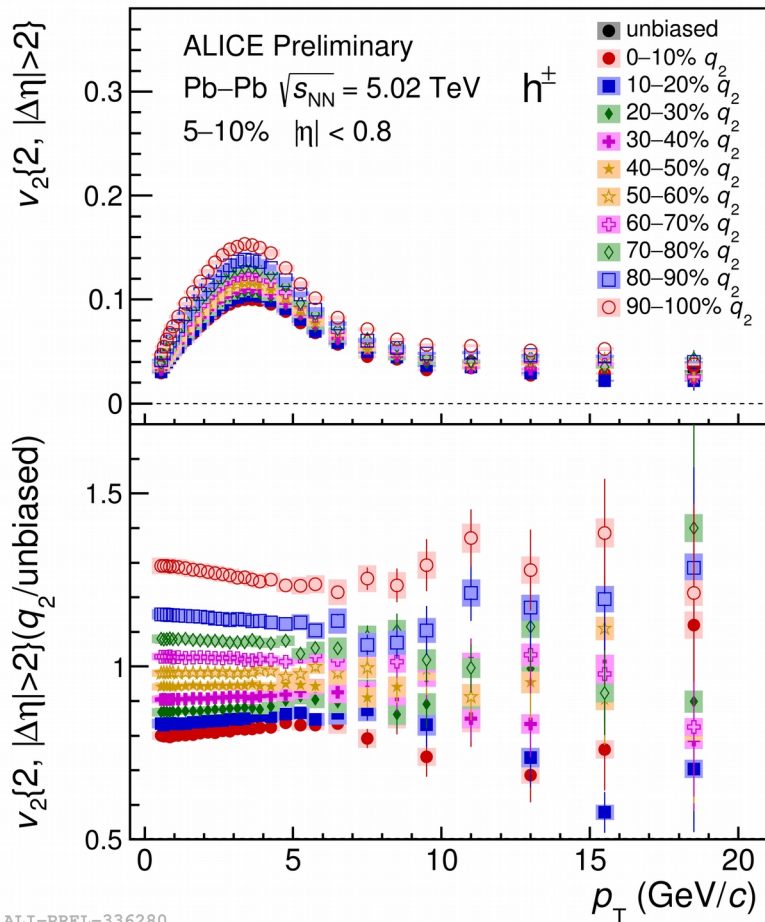




Large q_2 : 10% high



Small q_2 : 10% low

- q_2^{VOC} selects events up to 30% larger or smaller v_2 than the average
- $p_T > 3$ GeV/c: ratios almost flat \rightarrow same source of flow fluctuations
- $p_T < 3$ GeV/c: weak p_T dependence \rightarrow different ellipticity for various q_2 classes

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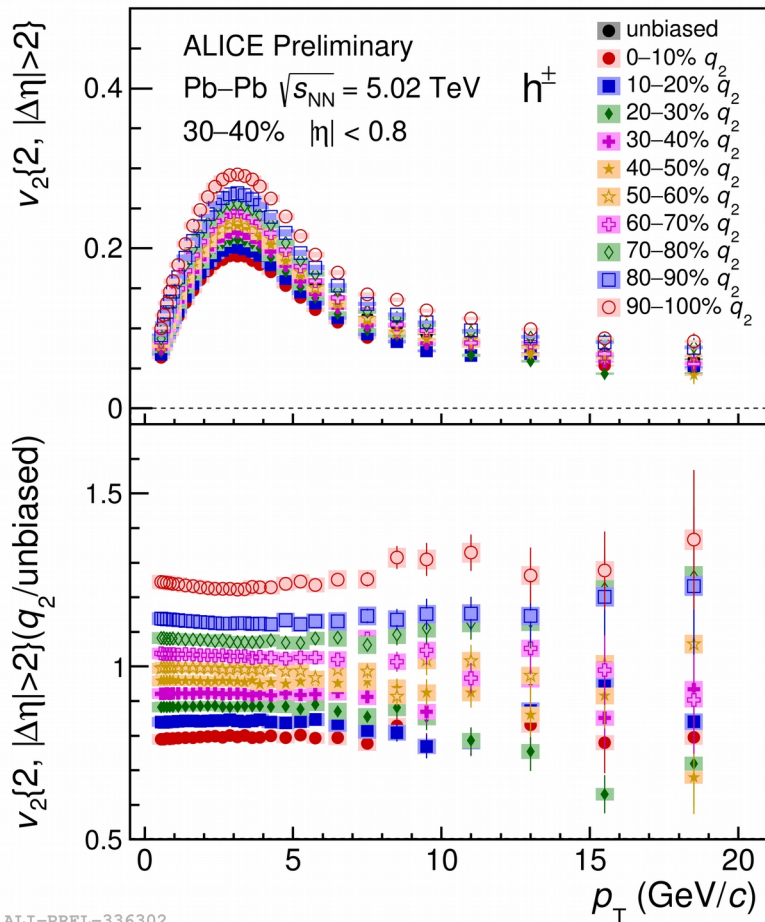



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Unidentified particle $v_2(p_T)$ with q_2 selection: 30-40% centrality

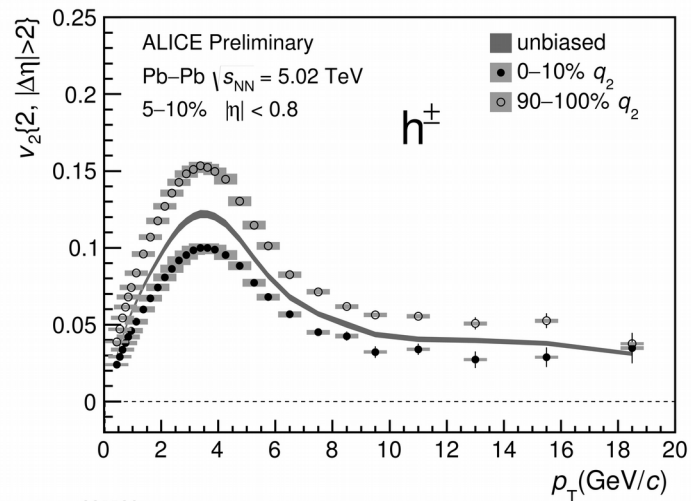


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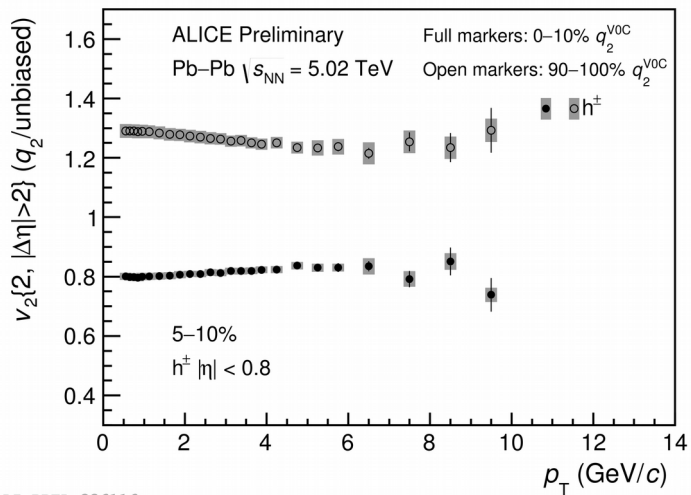
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PID $v_2(p_T)$ with q_2 selection: 5-10% centrality

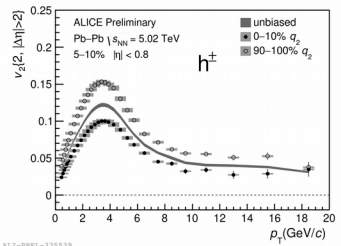


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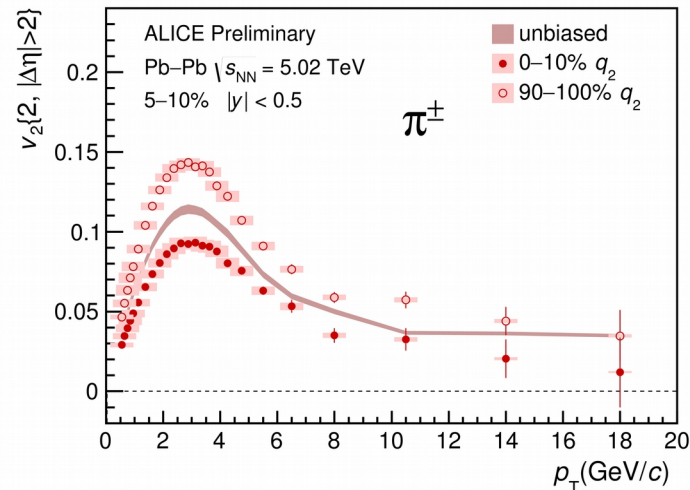


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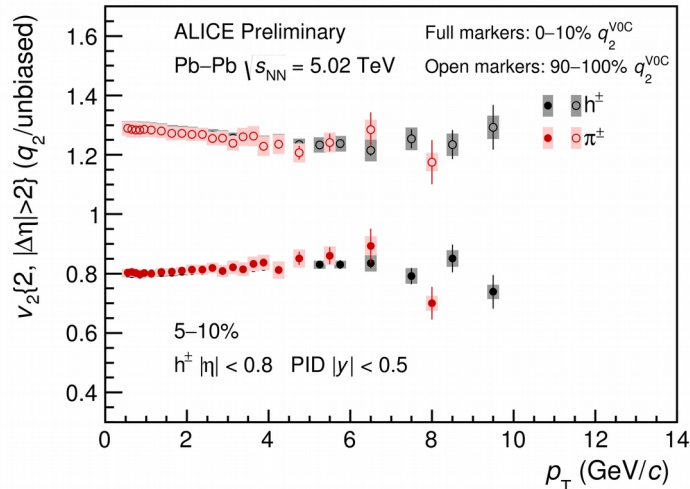
PID $v_2(p_T)$ with q_2 selection: 5-10% centrality



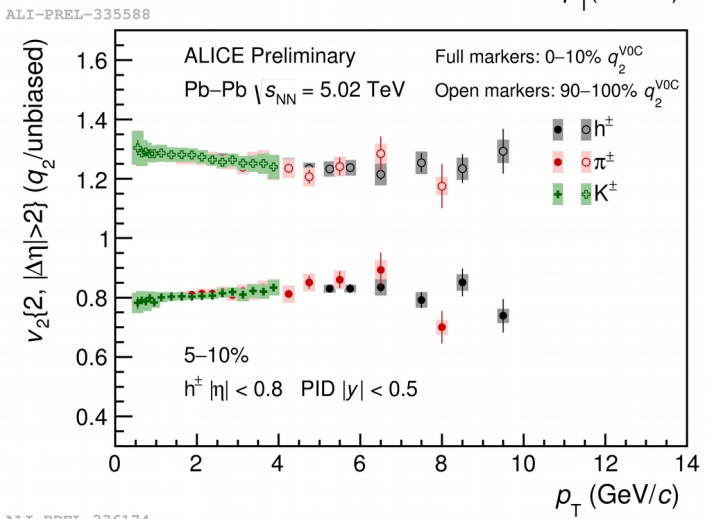
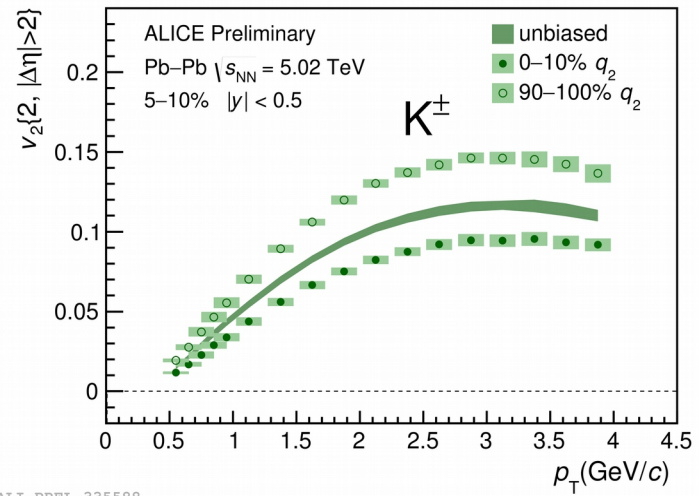
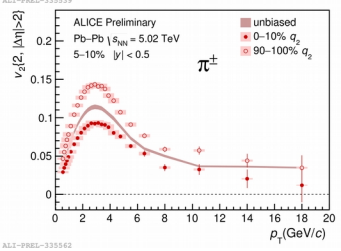
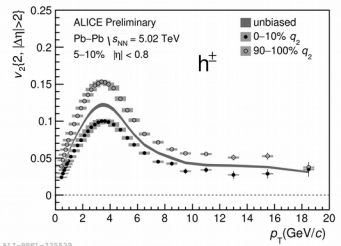
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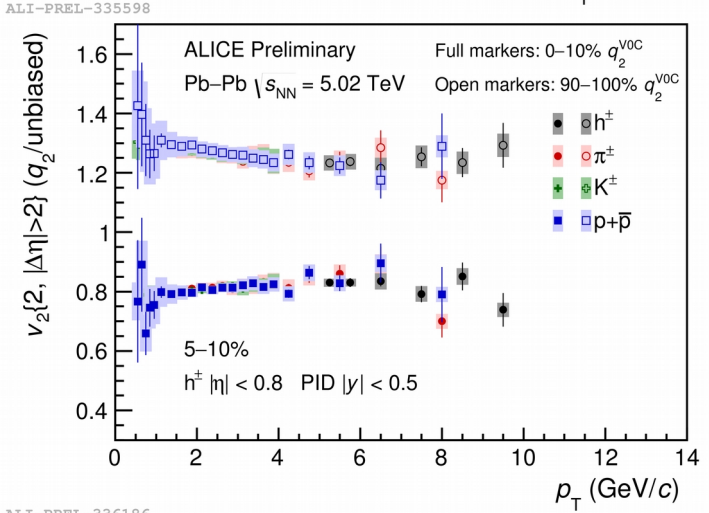
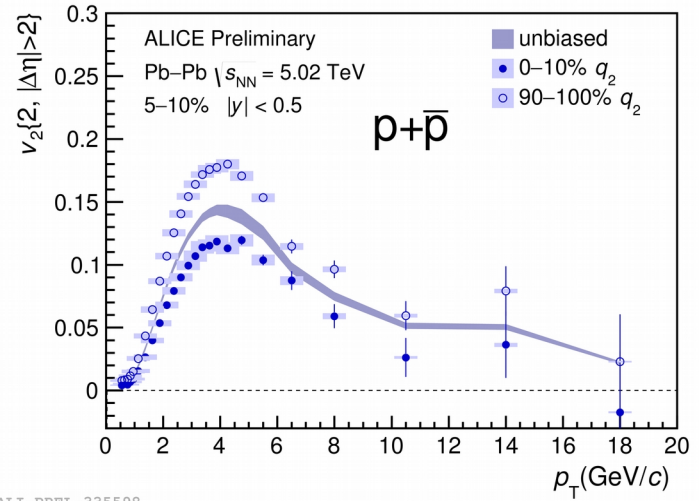
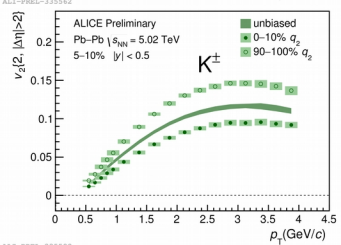
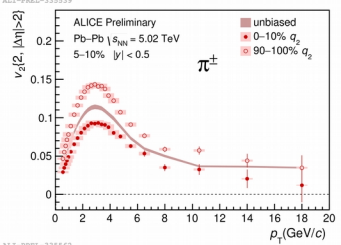
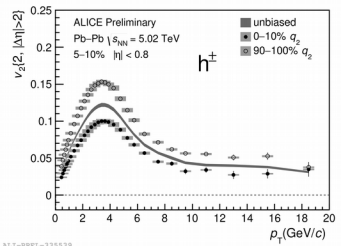
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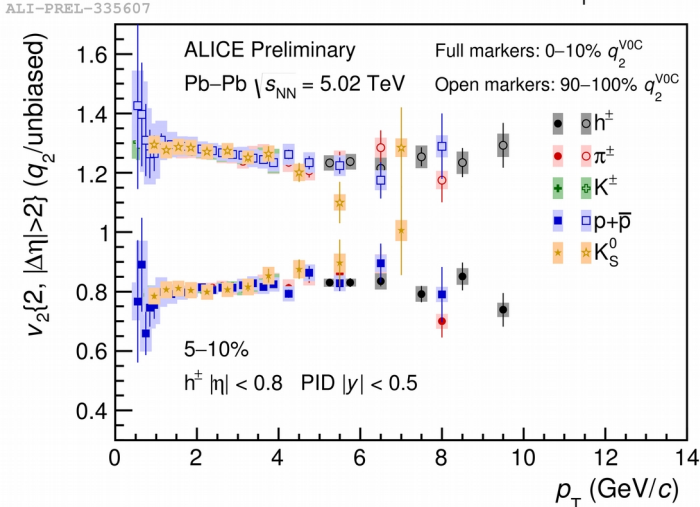
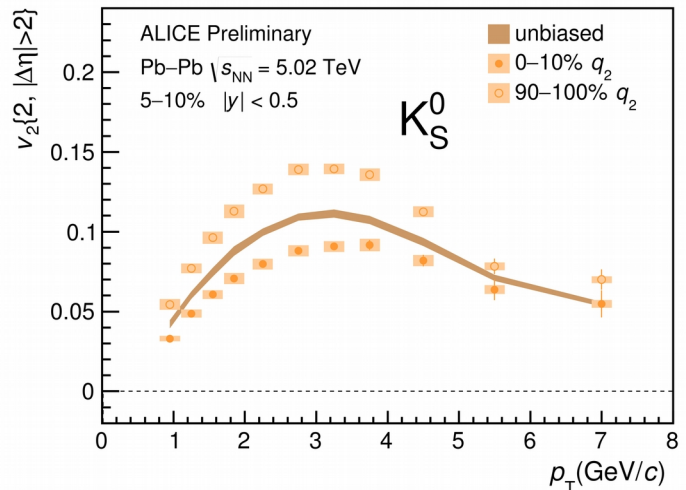
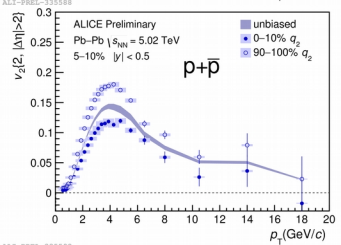
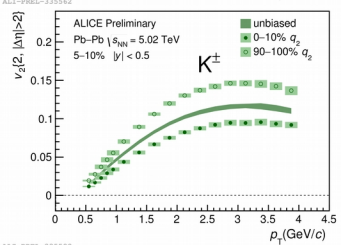
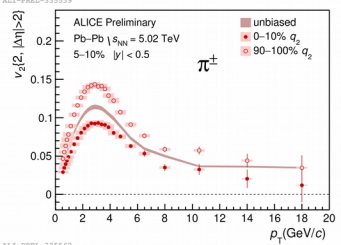
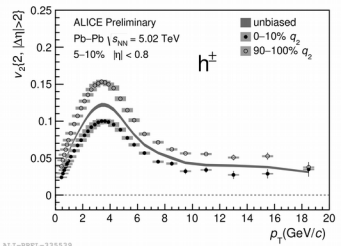
PID $v_2(p_T)$ with q_2 selection: 5-10% centrality



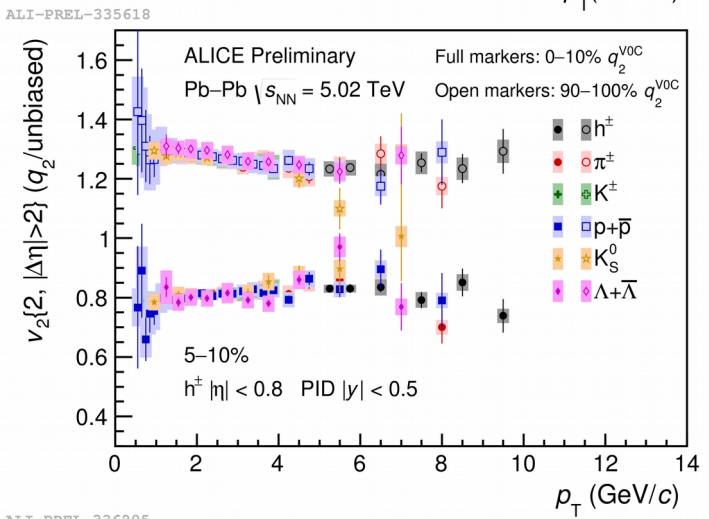
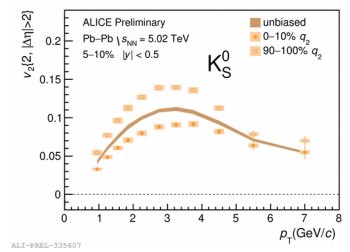
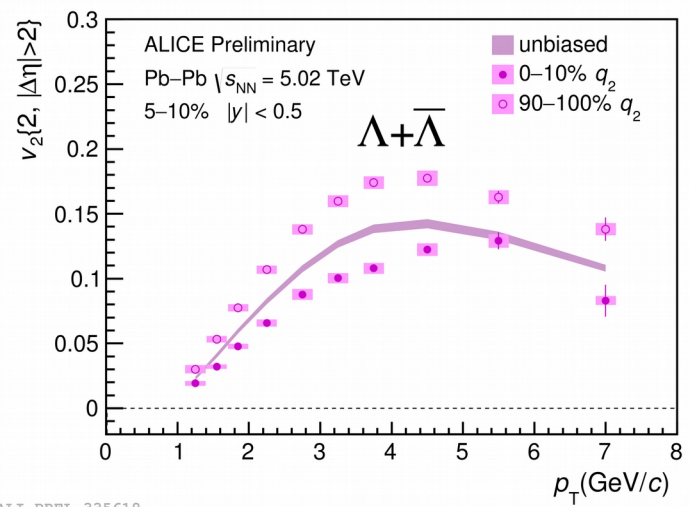
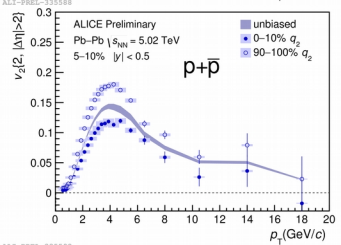
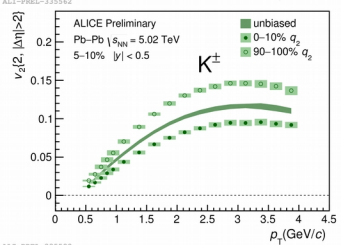
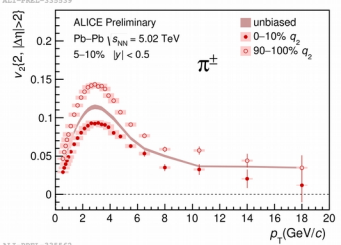
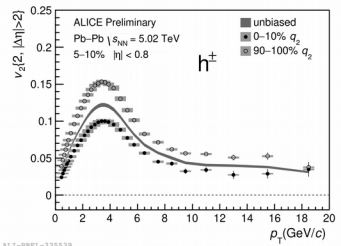
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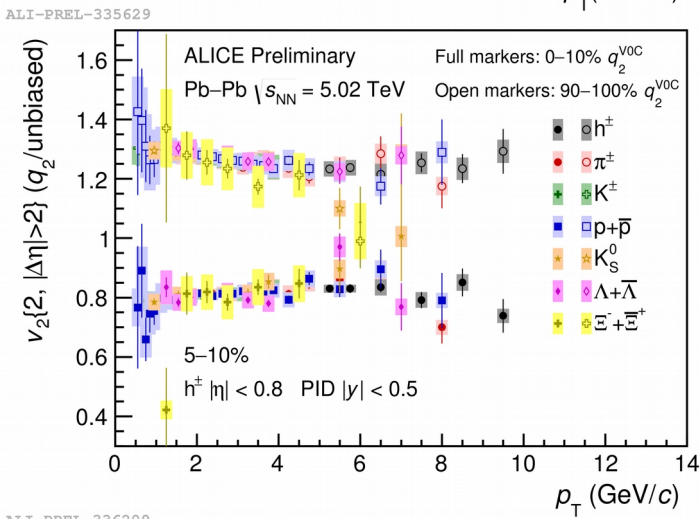
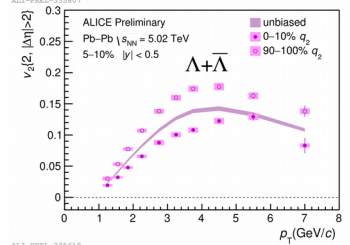
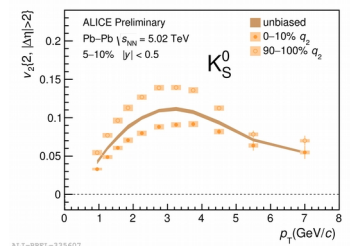
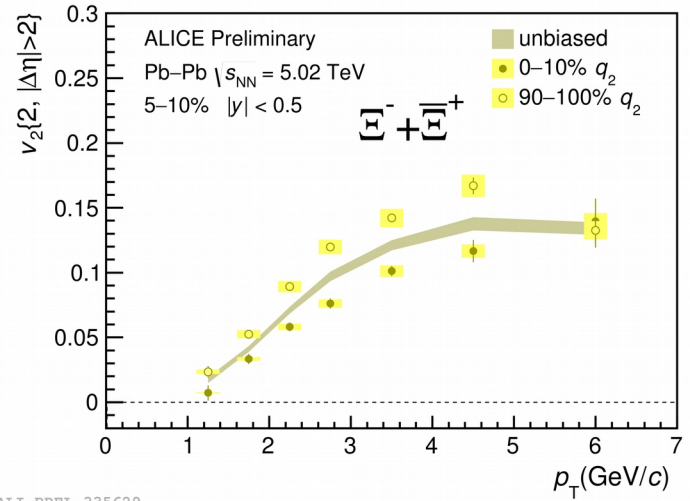
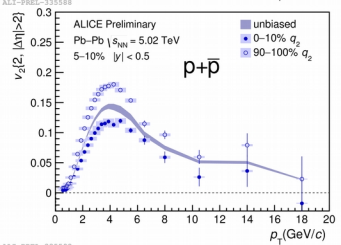
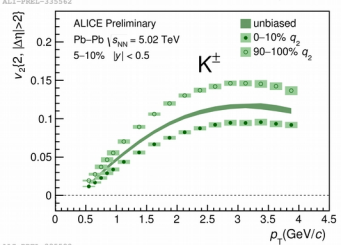
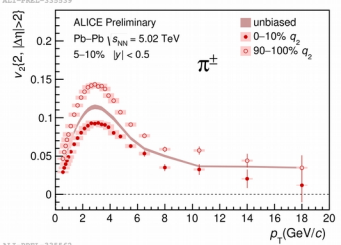
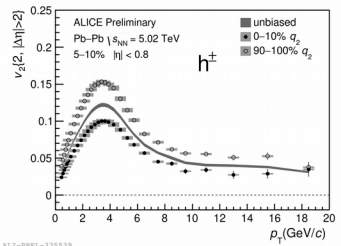
PID $v_2(p_T)$ with q_2 selection: 5-10% centrality



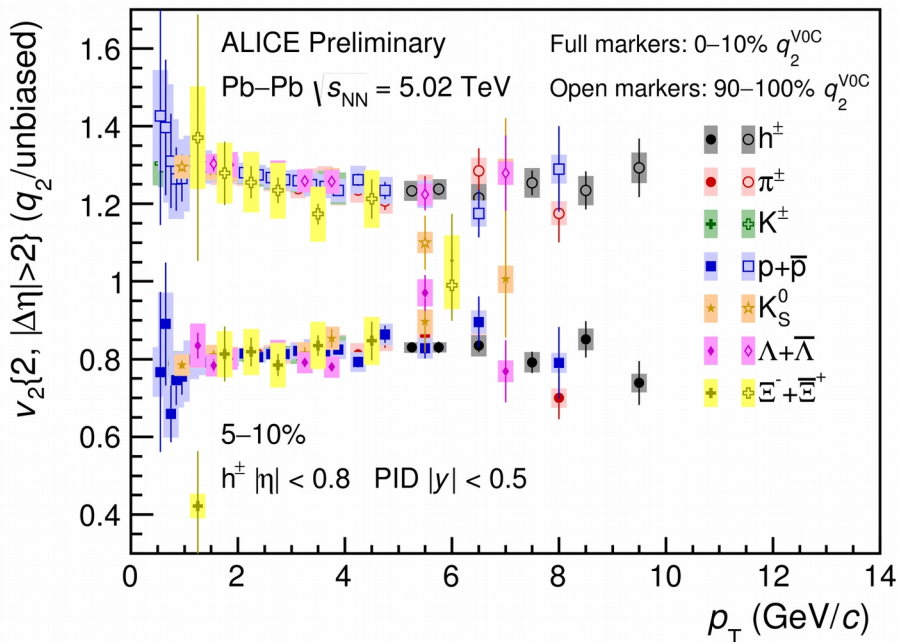
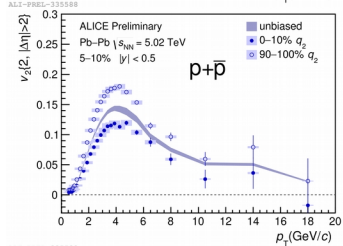
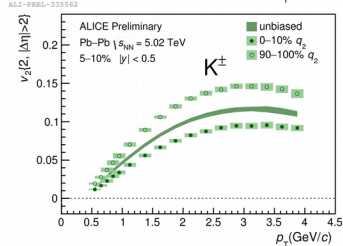
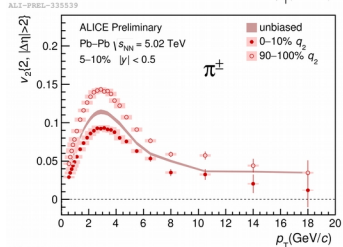
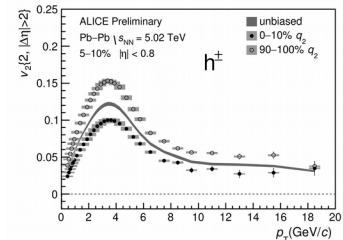
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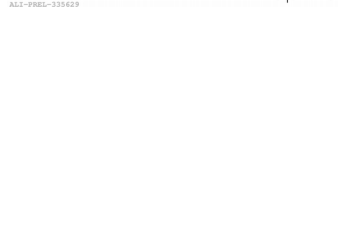
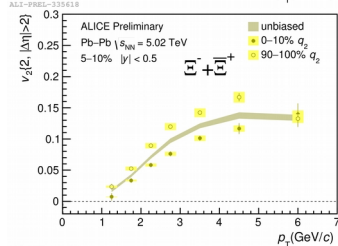
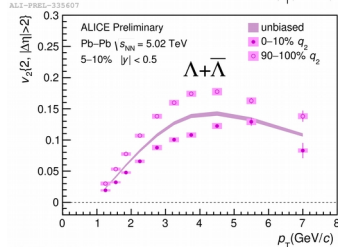
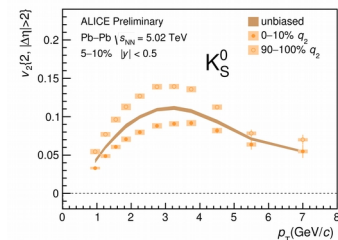


PID $v_2(p_T)$ with q_2 selection: 5-10% centrality

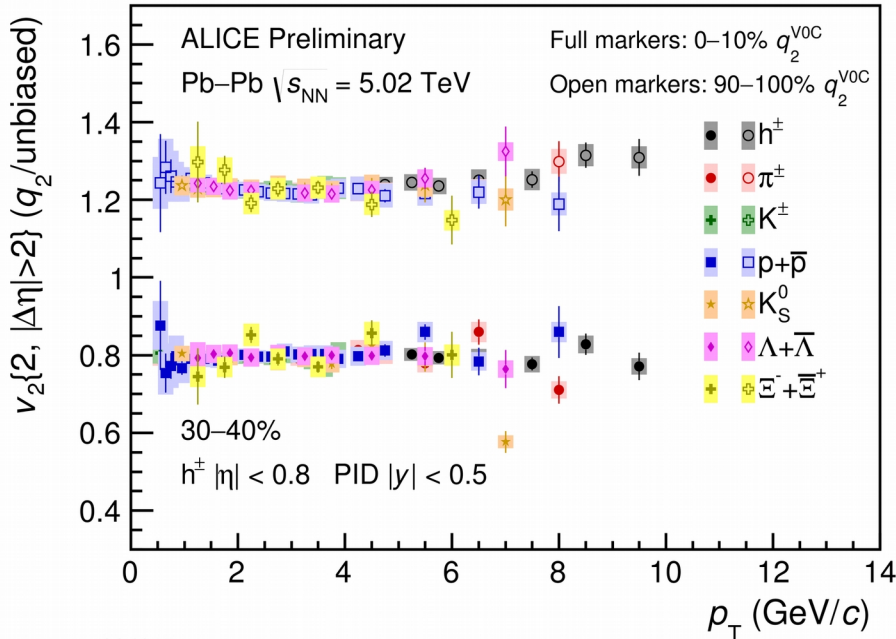
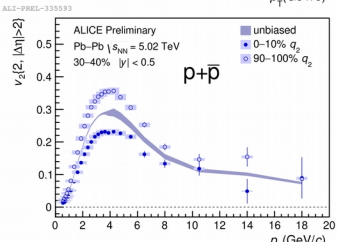
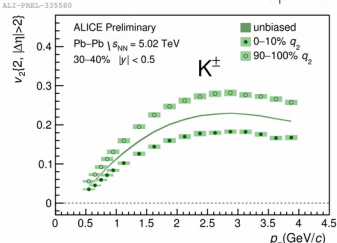
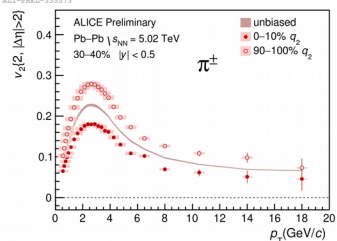
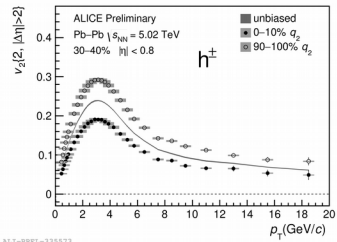


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- $p_T > 3 \text{ GeV}/c$: ratios almost flat \rightarrow same source of flow fluctuations
- $p_T < 3 \text{ GeV}/c$: weak p_T dependence \rightarrow different ellipticity for q_2 classes
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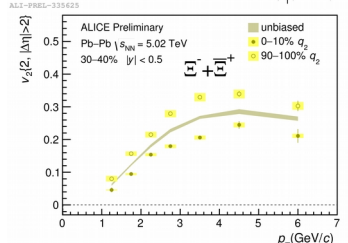
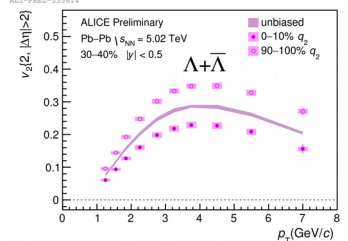
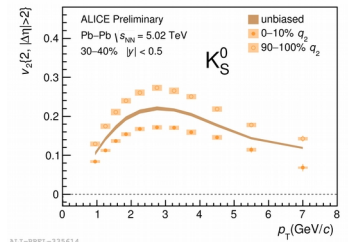


PID $v_2(p_T)$ with q_2 selection: 30-40% centrality

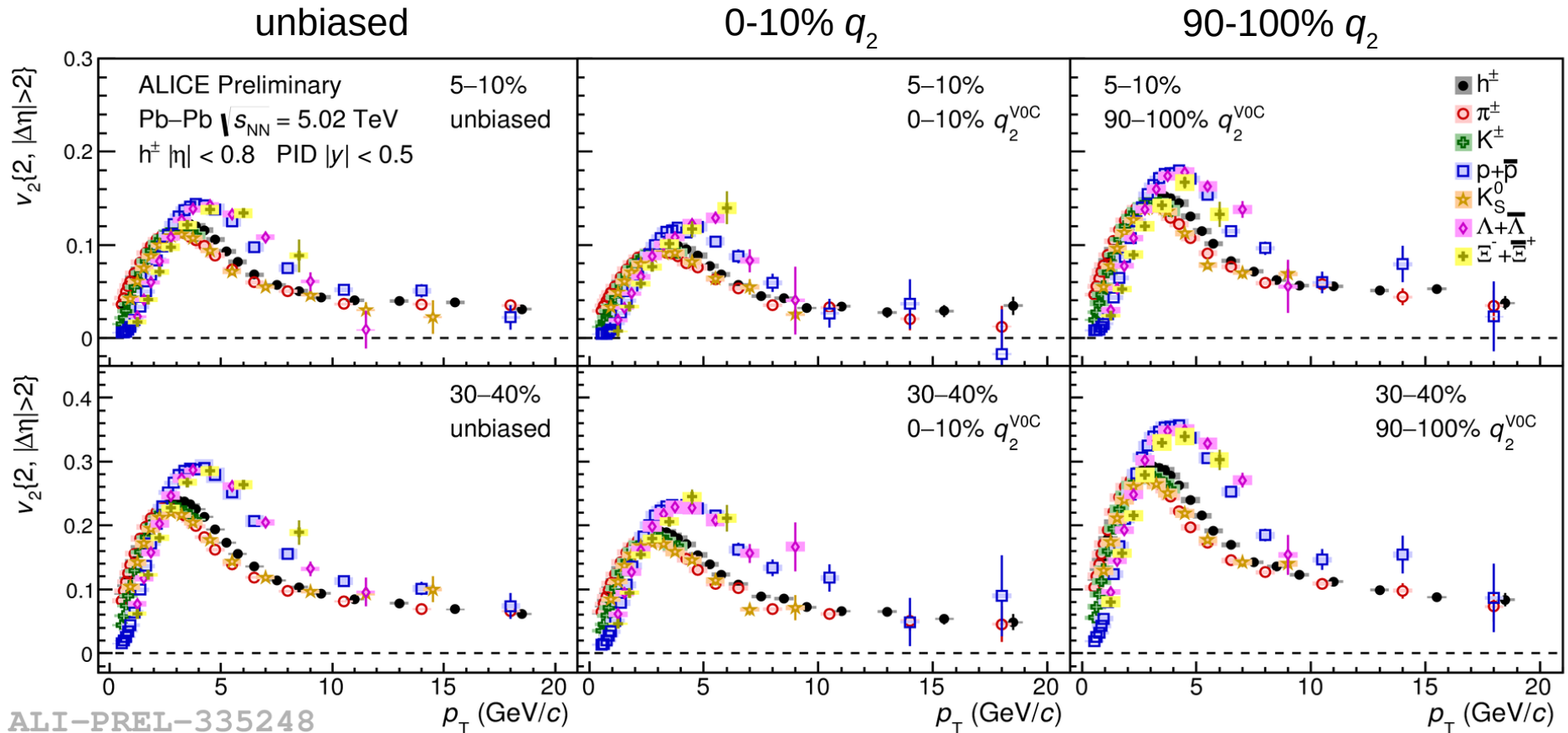


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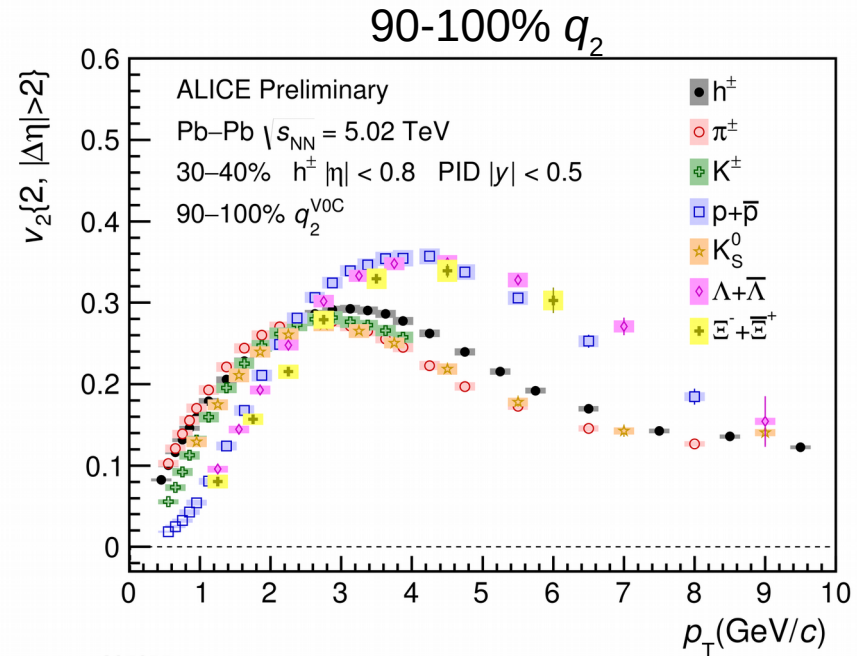
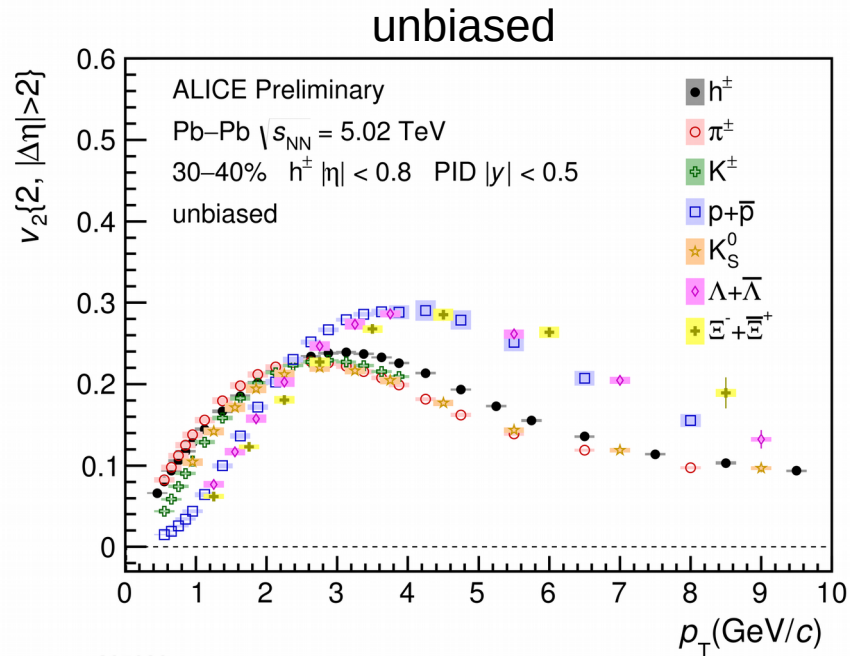
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PID $v_2(p_T)$ with q_2 selection: 5-10% and 30-40% centrality



PID $v_2(p_T)$ with q_2 selection: 30-40% centrality

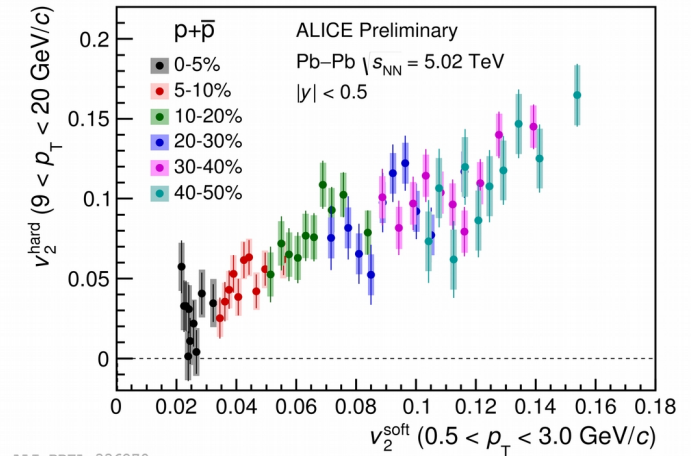
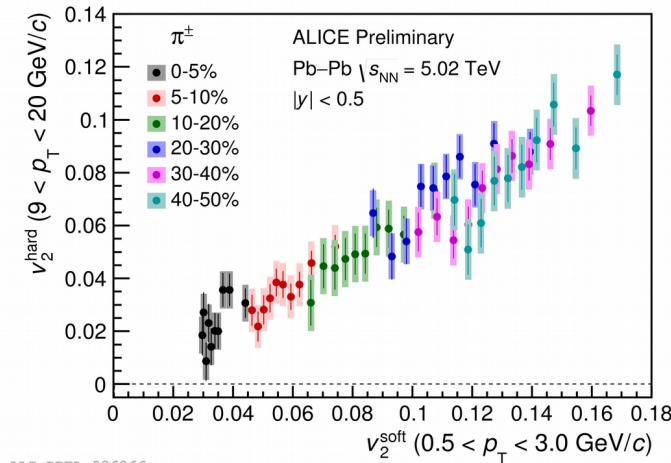
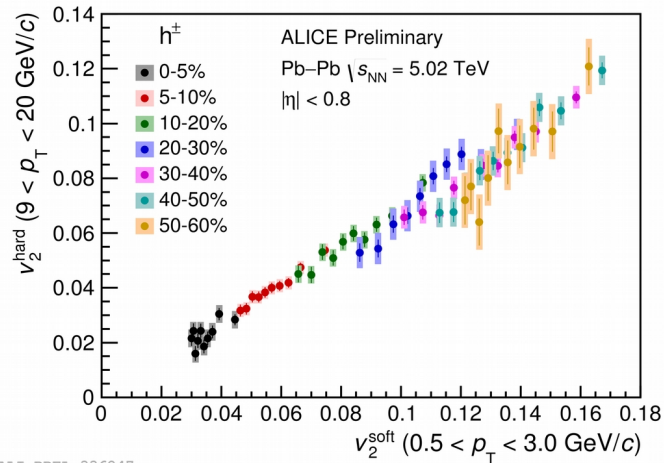


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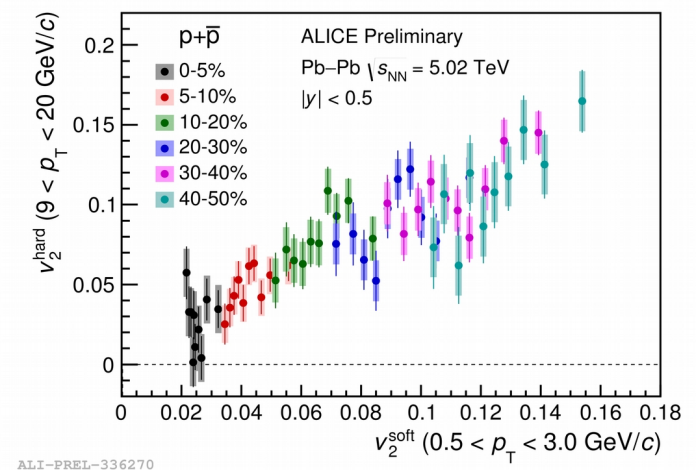
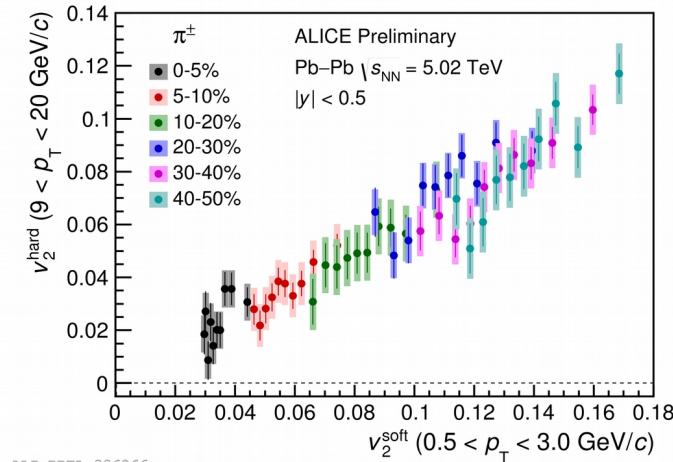
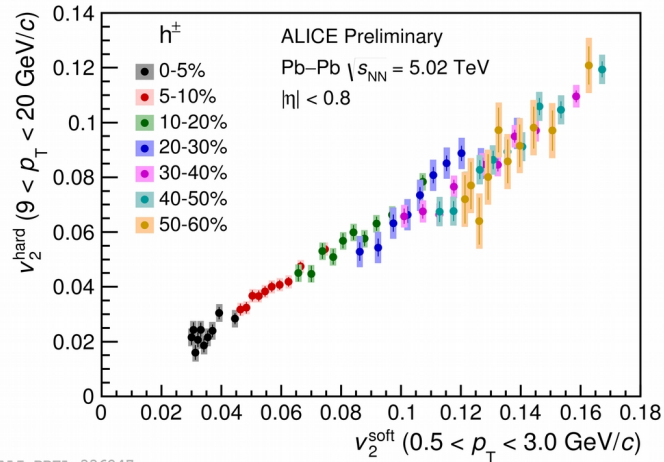
- $p_T < 2$ GeV/c: mass ordering due to interplay between radial flow and anisotropic geometry
- $p_T \sim 2-3$ GeV/c: crossing between mesons and baryons
- $3 < p_T < 10$ GeV/c: particles grouping according to their type ($v_2^{\text{baryons}} > v_2^{\text{mesons}}$)
- $p_T > 10$ GeV/c: no particle type dependence within uncertainties

v_2^{hard} vs v_2^{soft} with q_2 selection

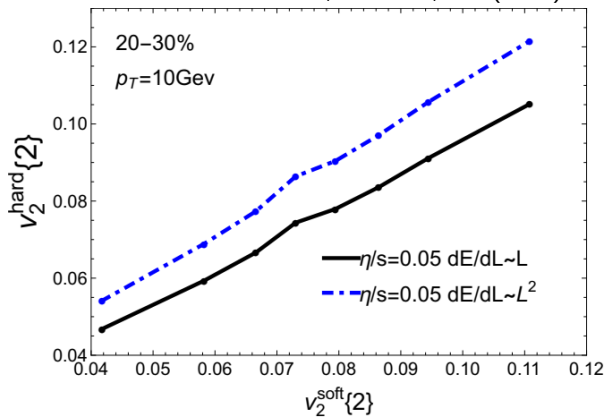


- An almost linear dependence between soft and hard
 - Hint of different slope for protons

v_2^{hard} vs v_2^{soft} with q_2 selection

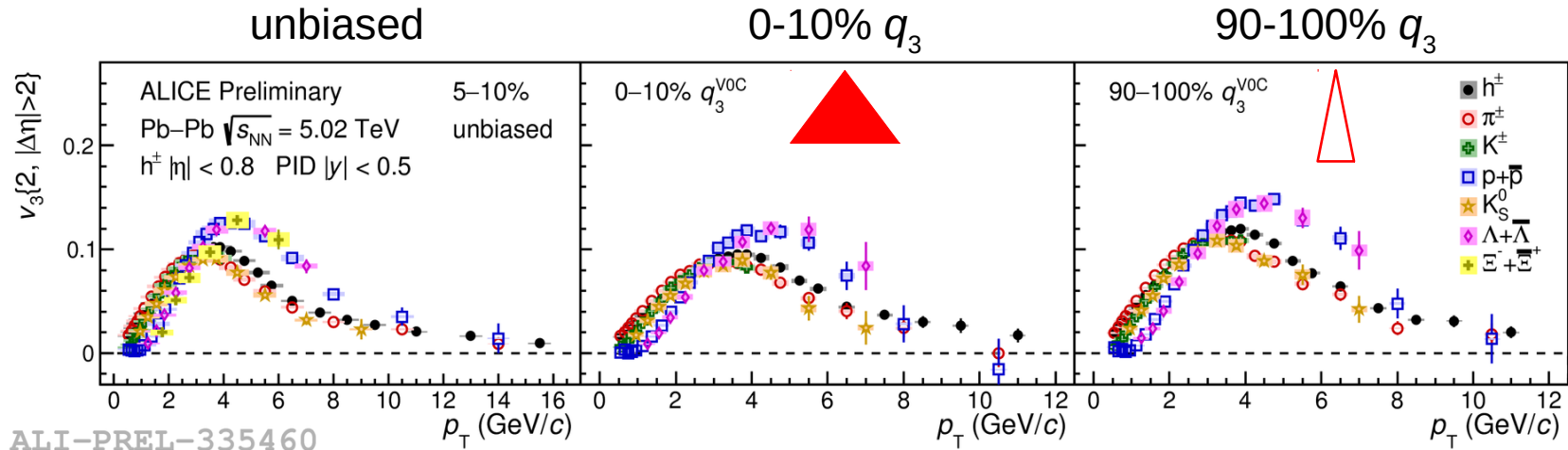


J. Noronha-Hostler, NPA 967, 161 (2017)



- An almost linear dependence between soft and hard
 - Hint of different slope for protons
- Constrain parton's energy loss
 - Input from theory needed

PID $v_3(p_T)$ with q_3 selection: 5-10% centrality



ALI-PREL-335460

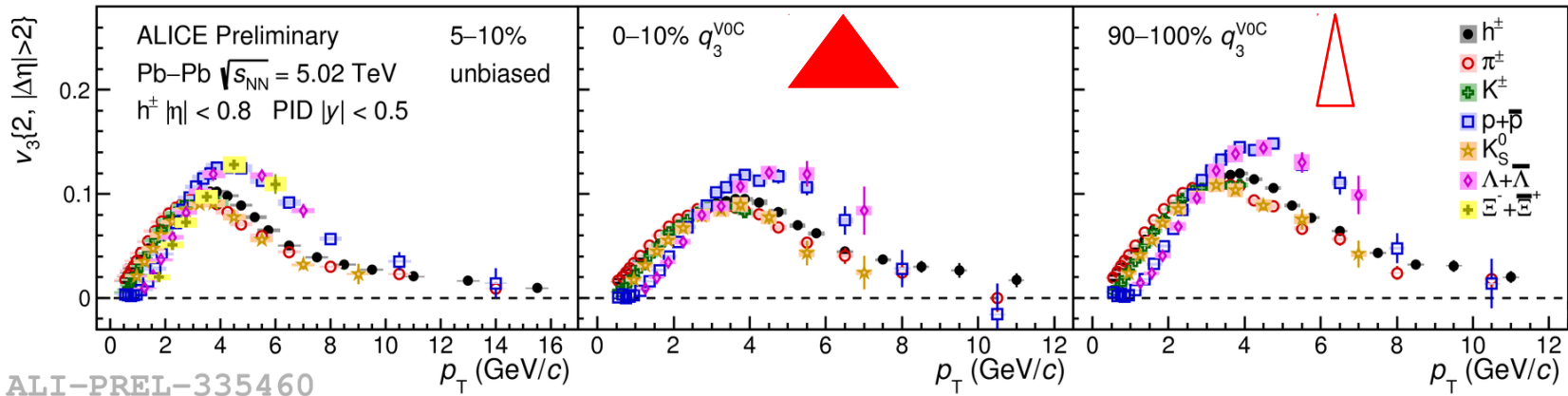
- $p_T < 2$ GeV/c: mass ordering due to interplay between radial flow and anisotropic geometry
- $p_T \sim 2-3$ GeV/c: crossing between mesons and baryons
- $3 < p_T < 10$ GeV/c: particle type dependence ($v_3^{\text{baryons}} > v_3^{\text{mesons}}$)

PID $v_3(p_T)$ with q_3 selection: 5-10% centrality

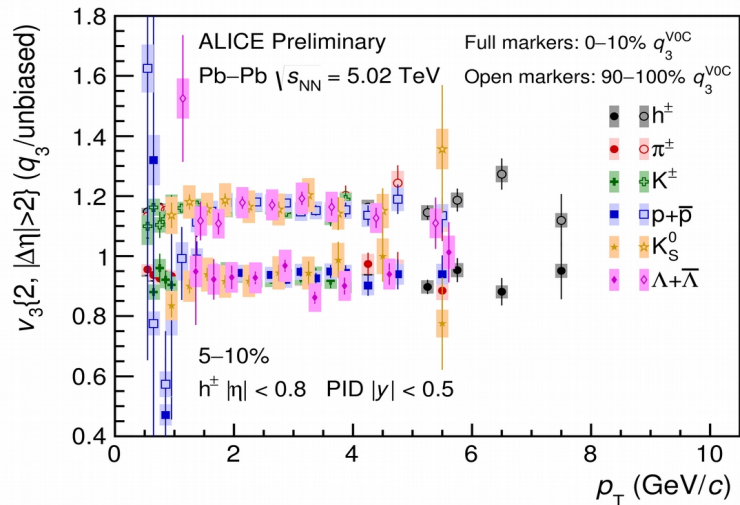
unbiased

0-10% q_3

90-100% q_3

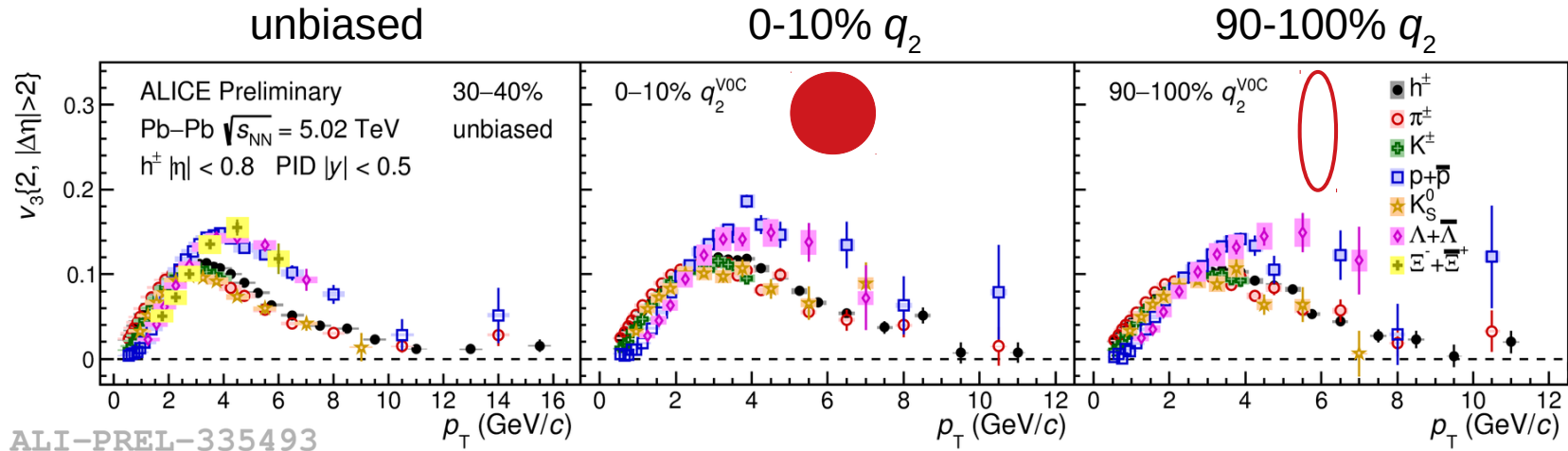


ALI-PREL-335460



- $p_T < 2$ GeV/c: mass ordering due to interplay between radial flow and anisotropic geometry
- $p_T \sim 2-3$ GeV/c: crossing between mesons and baryons
- $3 < p_T < 10$ GeV/c: particle type dependence ($v_3^{\text{baryons}} > v_3^{\text{mesons}}$)
- Ratios almost flat up to $p_T = 8$ GeV/c \rightarrow same source of flow fluctuations
- Same values for inclusive and PID
 - No dependence on particle species

PID $v_3(p_T)$ with q_2 selection: 30-40% centrality



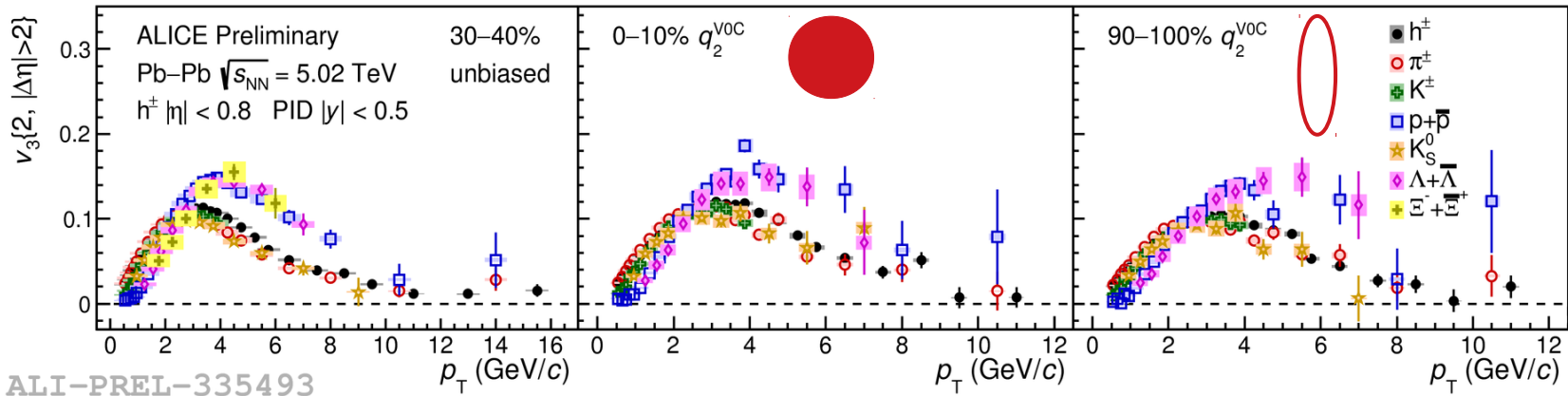
- $p_T < 2$ GeV/c: mass ordering due to interplay between radial flow and anisotropic geometry
- $p_T \sim 2-3$ GeV/c: crossing between mesons and baryons
- $3 < p_T < 10$ GeV/c: particle type dependence ($v_3^{\text{baryons}} > v_3^{\text{mesons}}$)

PID $v_3(p_T)$ with q_2 selection: 30-40% centrality

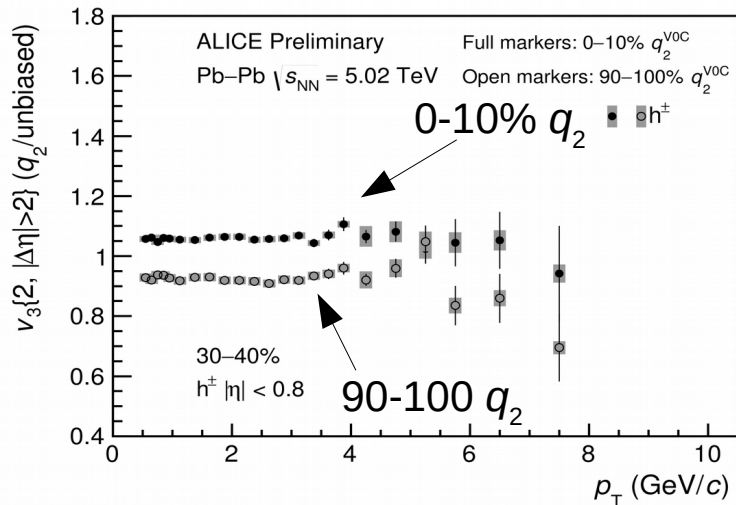
unbiased

0-10% q_2

90-100% q_2

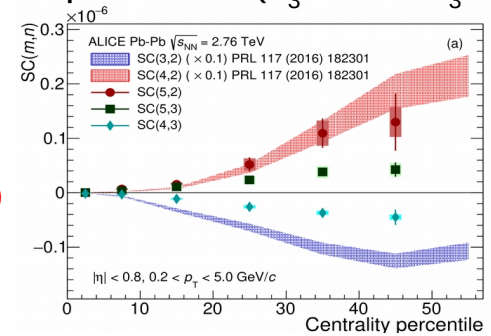


ALI-PREL-335493



- $p_T < 2$ GeV/c: mass ordering due to interplay between radial flow and anisotropic geometry
- $p_T \sim 2-3$ GeV/c: crossing between mesons and baryons
- $3 < p_T < 10$ GeV/c: particle type dependence ($v_3^{\text{baryons}} > v_3^{\text{mesons}}$)
- v_3 anti-correlated with q_2

ALICE, PRC 97, 024906 (2018)

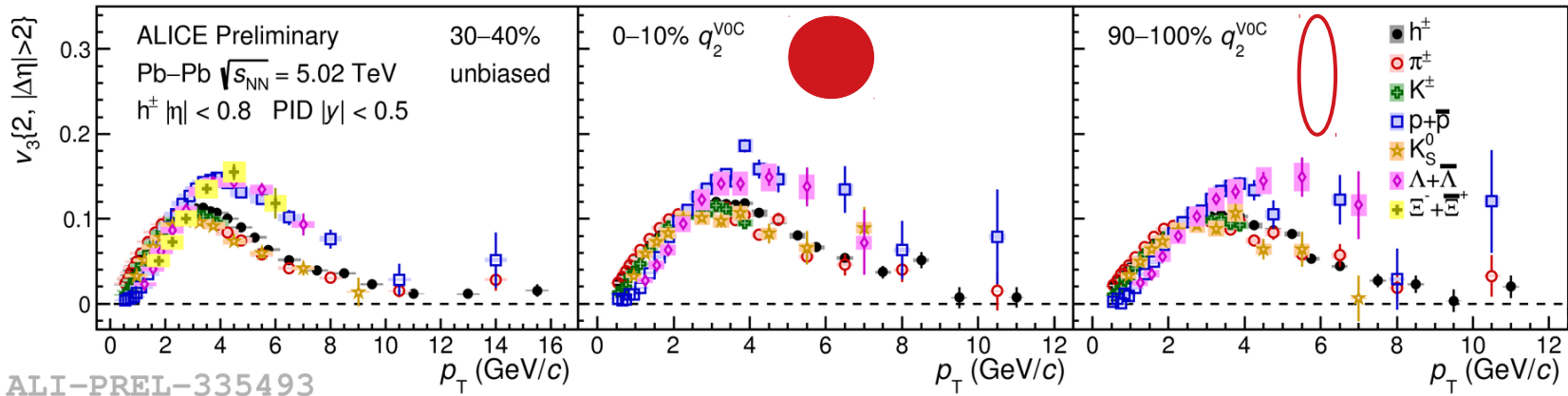


PID $v_3(p_T)$ with q_2 selection: 30-40% centrality

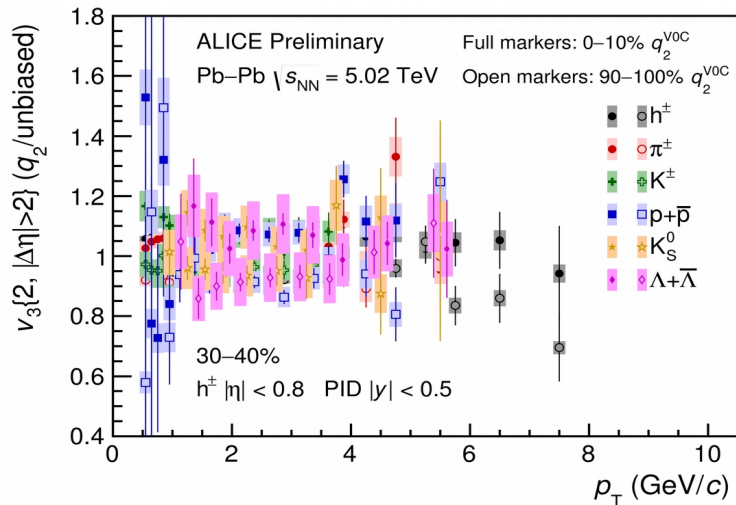
unbiased

0-10% q_2

90-100% q_2



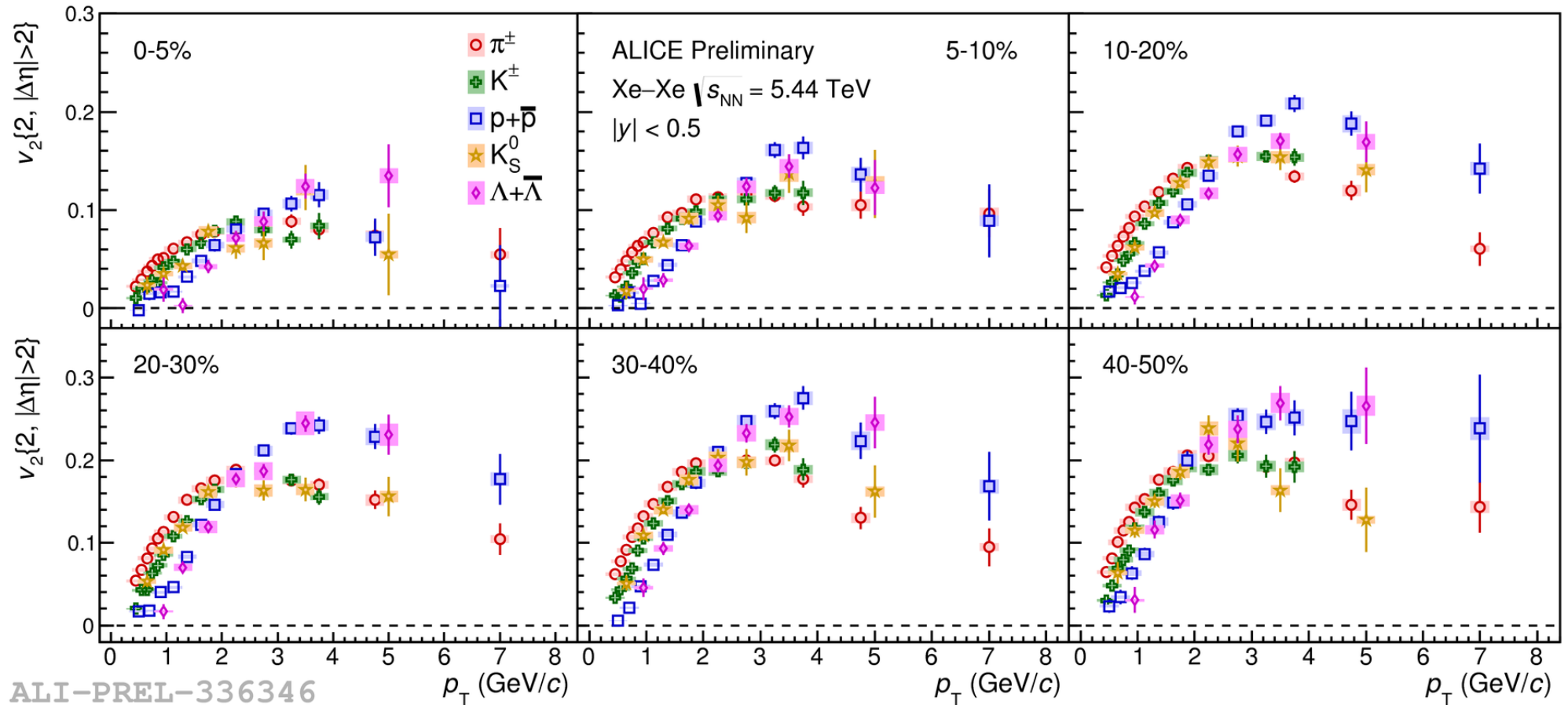
ALI-PREL-335493



- $p_T < 2$ GeV/c: mass ordering due to interplay between radial flow and anisotropic geometry
- $p_T \sim 2-3$ GeV/c: crossing between mesons and baryons
- $3 < p_T < 10$ GeV/c: particle type dependence ($v_3^{\text{baryons}} > v_3^{\text{mesons}}$)
- v_3 anti-correlated with q_2
- Ratios almost flat up to $p_T = 8$ GeV/c → same source of flow fluctuations
- Same values for inclusive and PID
 - No dependence on particle species

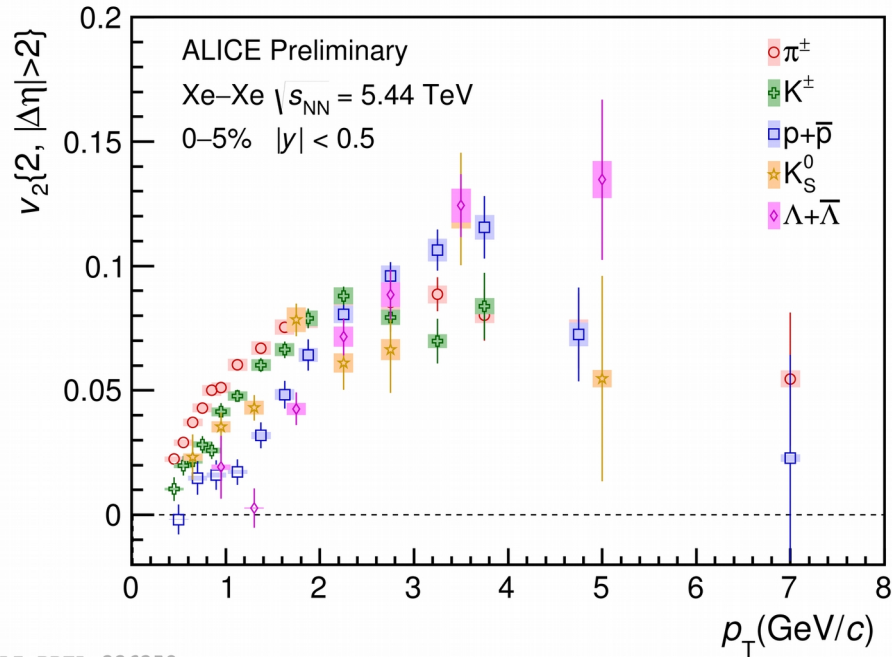
v_n of PID in Xe-Xe collisions

Identified particle $v_2(p_T)$

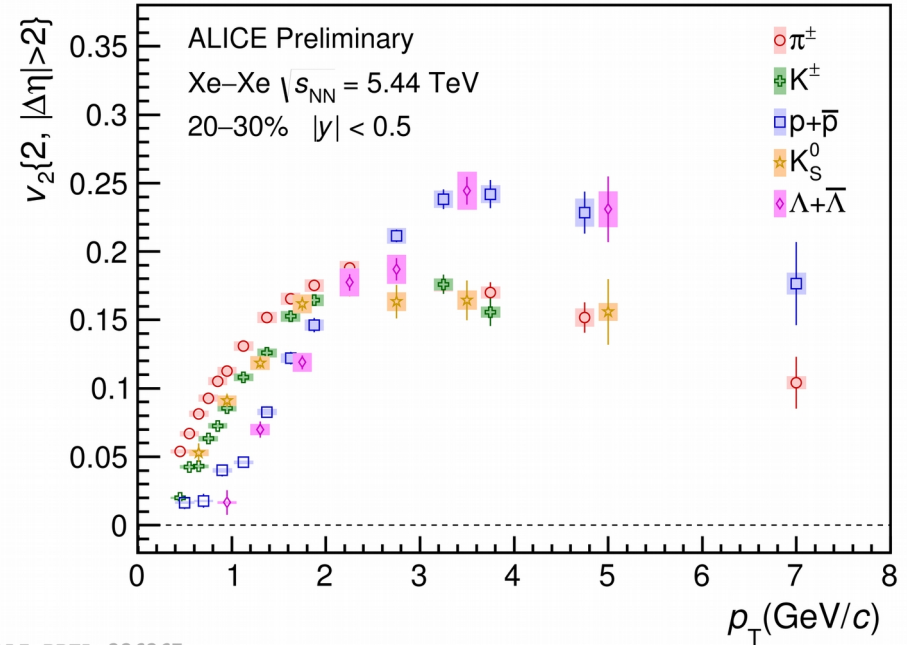


ALI-PREL-336346

Identified particle $v_2(p_T)$



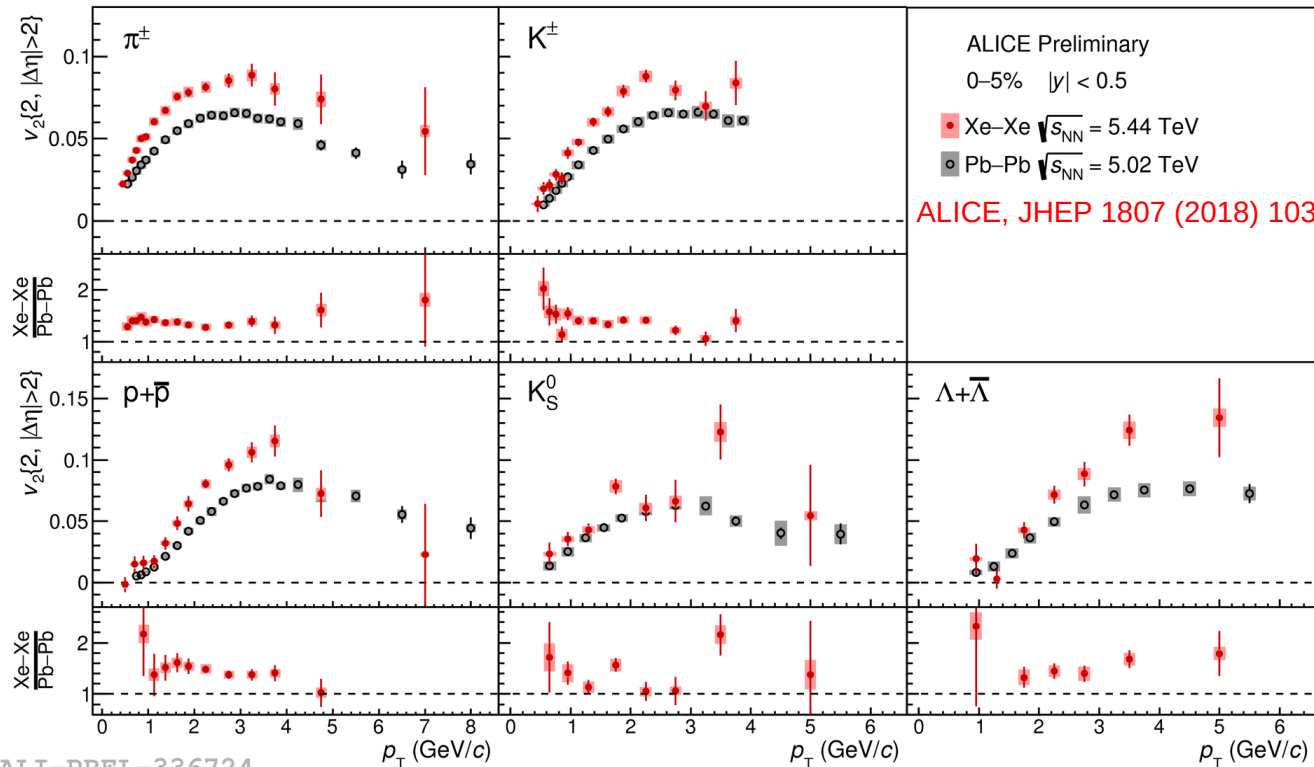
ALI-PREL-336358



ALI-PREL-336367

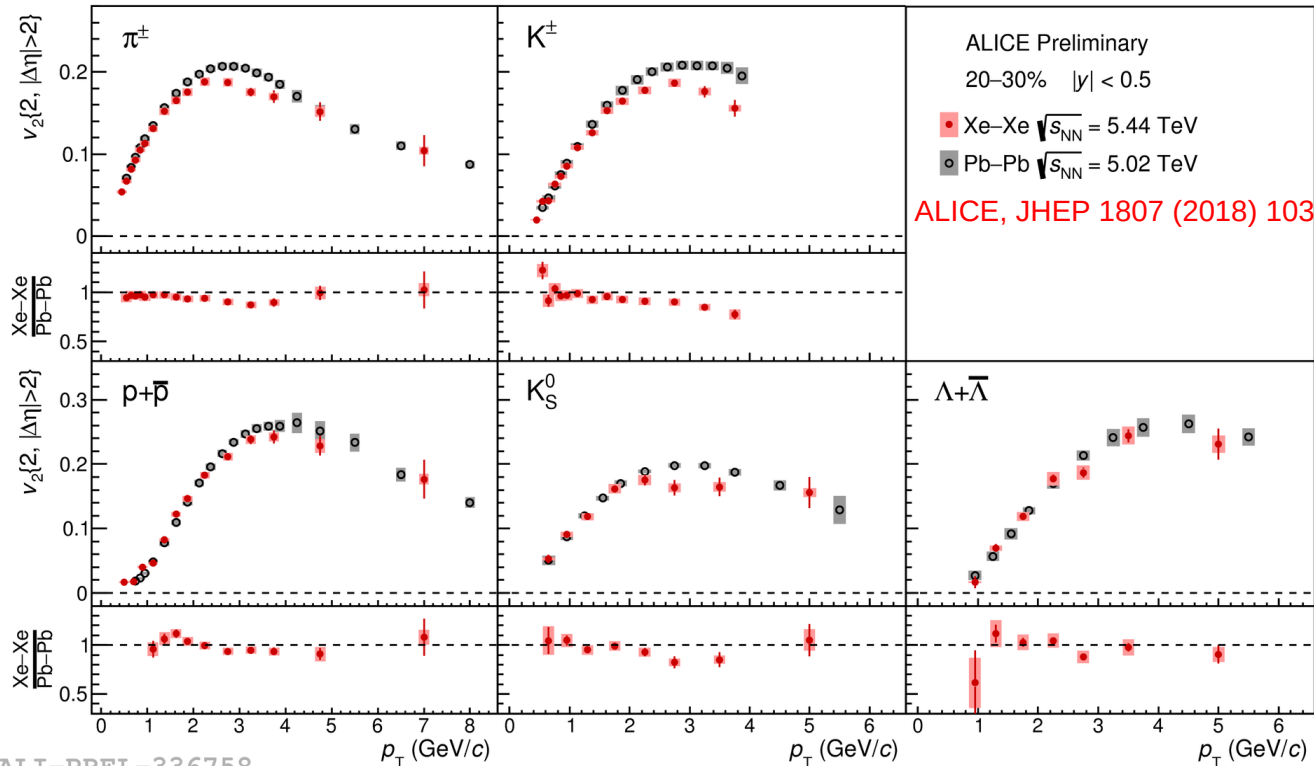
- $p_T < 2$ GeV/c: mass ordering due to interplay between radial flow and anisotropic geometry
- $p_T \sim 2$ -3 GeV/c: crossing between v_2 of mesons and baryons
- $p_T > 3$ GeV/c: particles grouping according to their type ($v_2^{\text{baryons}} > v_2^{\text{mesons}}$)

PID $v_2(p_T)$ Xe-Xe vs Pb-Pb: 0-5% centrality



- Constrain initial geometry and transport coefficients (e.g., η/s)
 - 0-5%: $v_2^{\text{Xe}} > v_2^{\text{Pb}} \rightarrow$ Xe deformation

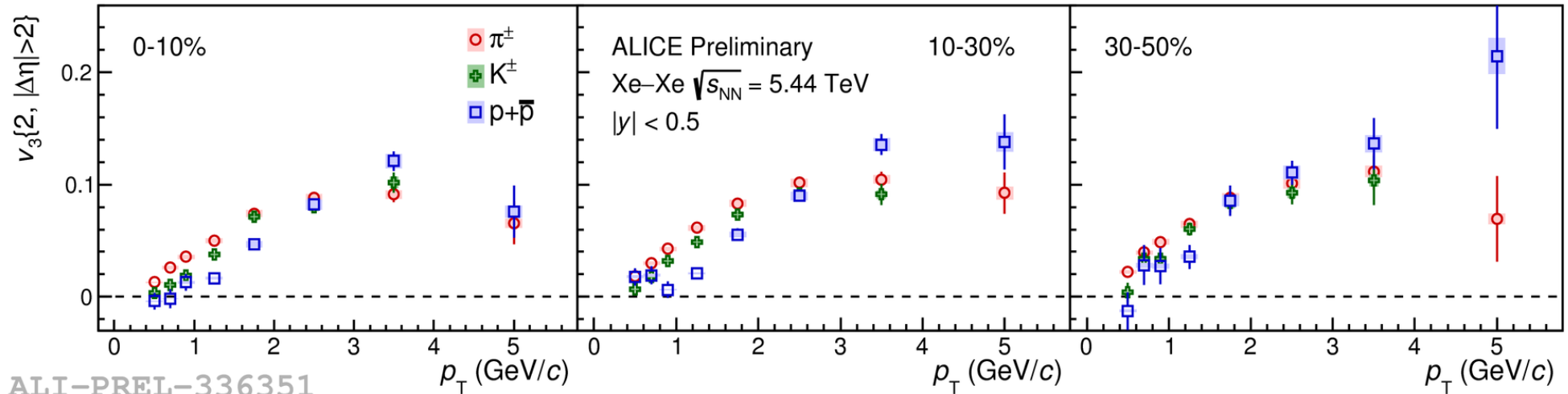
PID $v_2(p_T)$ Xe-Xe vs Pb-Pb: 20-30% centrality



ALI-PREL-336758

- Constrain initial geometry and transport coefficients (e.g., η/s)
 - 0-5%: $v_2^{\text{Xe}} > v_2^{\text{Pb}} \rightarrow$ Xe deformation
 - 20-30%: $v_2^{\text{Pb}} > v_2^{\text{Xe}}$ for $p_T > 2$ GeV/c

Identified particle $v_3(p_T)$



ALI-PREL-336351

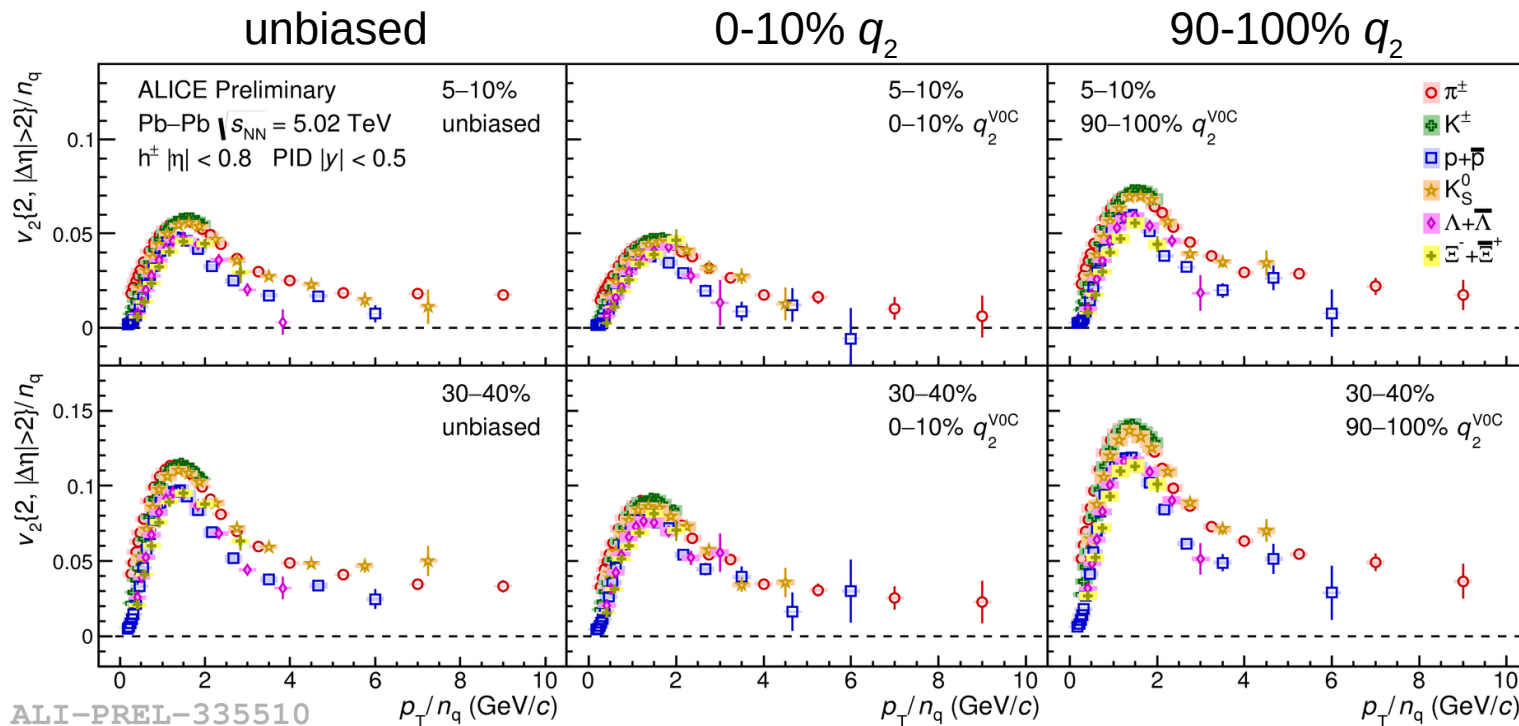
- $p_T < 2$ GeV/c: mass ordering due to interplay between radial flow and anisotropic geometry
- $p_T \sim 2-3$ GeV/c: crossing between mesons and baryons

Summary

- v_n coefficients of unidentified particles and π^\pm , K^\pm , $p+\bar{p}$, K_S^0 , $\Lambda+\bar{\Lambda}$, $\Xi^-+\bar{\Xi}^+$ have been measured in Xe-Xe collisions and with ESE in Pb-Pb collisions
 - Mass ordering for $p_T < 2$ GeV/c
 - Crossing between mesons and baryons for $p_T \sim 2-3$ GeV/c
 - Particle type dependence for $p_T > 3$ GeV/c
 - ESE analysis
 - v_n larger or smaller than the average
 - v_3 is anti-correlated with q_2 classes
 - Same source of flow fluctuations up to 20 GeV/c
 - No dependence on particle species
 - See poster #80, C. Ristea

Backup

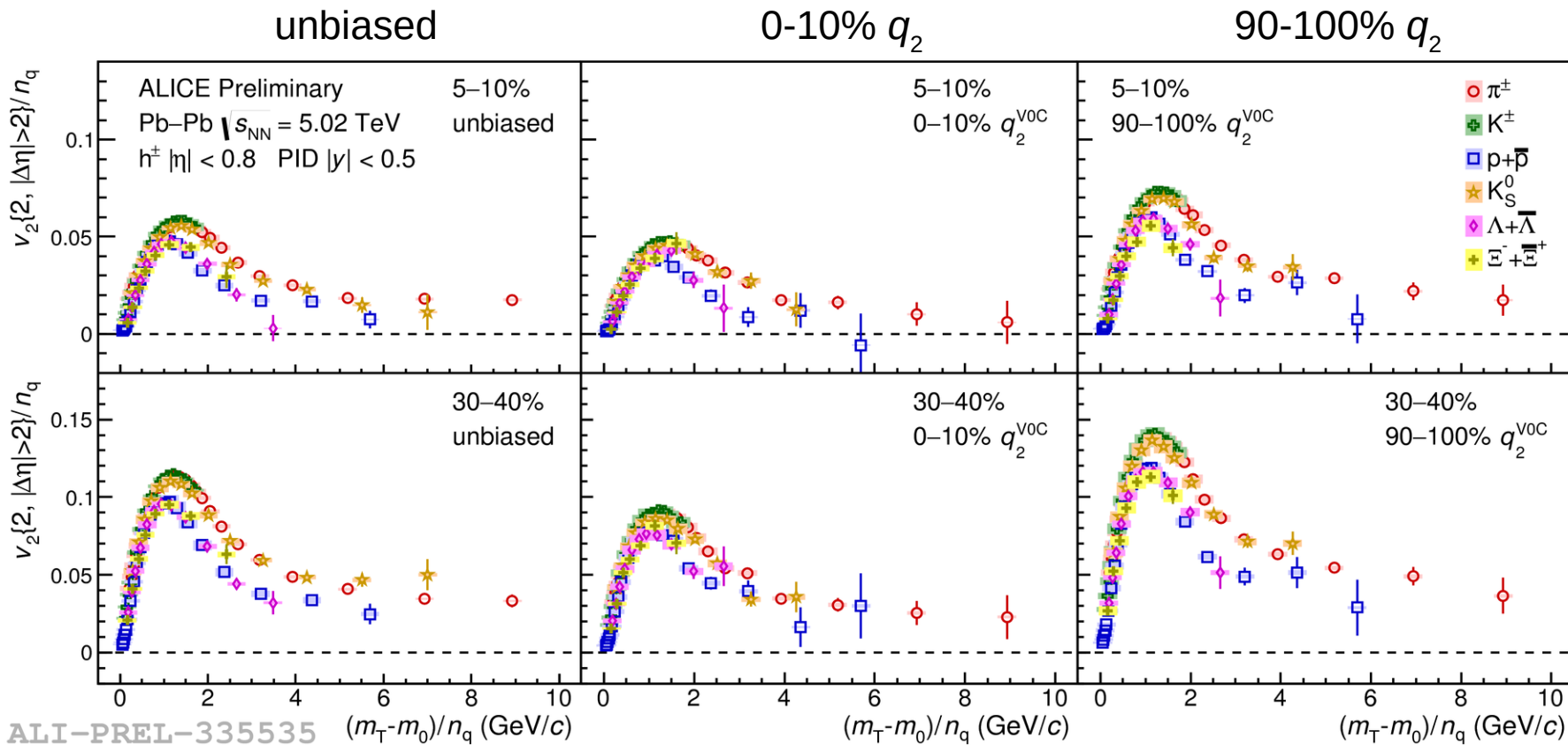
p_T/n_q scaling with q_2 selection: 5-10%, 30-40% centrality (Pb-Pb collisions)



ALI-PREL-335510

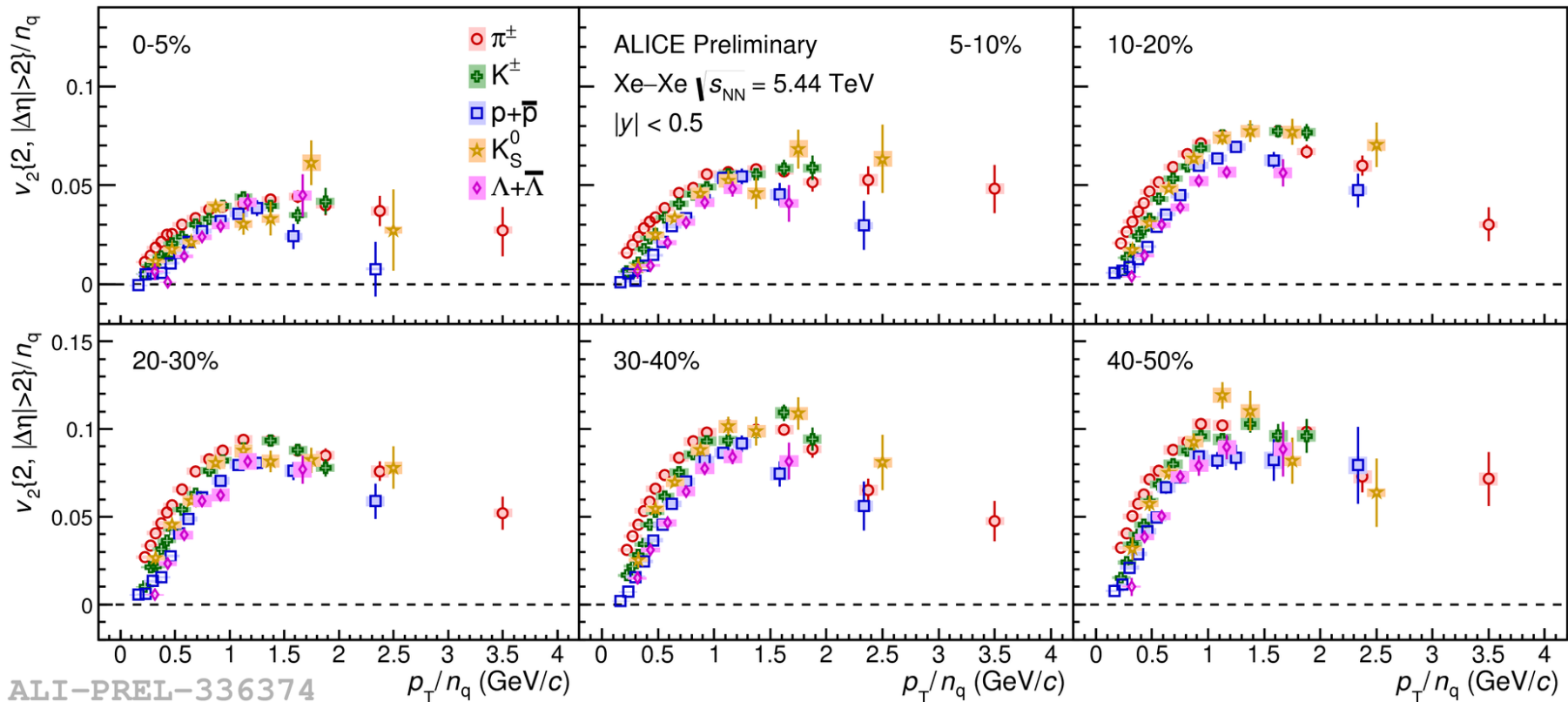
- Test particle production via coalescence using number of constituent quarks (NCQ) scaling
- $p_T/n_q > 1-1.5$ GeV/c: NCQ scaling is only approximate
 - No dependence on q_2

$(m_T - m_0)/n_q$ scaling with q_2 selection: 5-10%, 30-40% centrality (Pb-Pb collisions)



ALI-PREL-335535

p_T/n_q scaling (Xe-Xe collisions)



- $p_T/n_q > 1-1.5$ GeV/c: NCQ scaling is only approximate

$(m_T - m_0)/n_q$ scaling (Xe-Xe collisions)

