Niels Bohr Institute

KØBENHAVNS UNIVERSITET

Anisotropic flow fluctuations of charged and identified hadrons in Pb-Pb collisions with the ALICE detector

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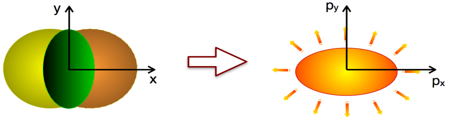
Quark Matter 2019

Anisotropic flow and flow fluctuations



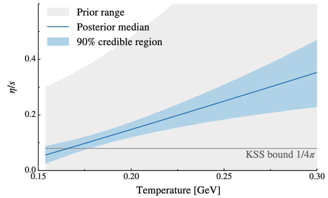
- Interactions among constituents transform the initial spatial anisotropy into momentum anisotropy

$$E\frac{d^3N}{dp^3} = \frac{d^2N}{2\pi p_{\mathrm{T}}\, dp_{\mathrm{T}}\, dy}\left\{1 + \sum_{n=1}^{\infty} 2v_n \cos\left[n\left(\phi - \Psi_n\right)\right]\right\}$$

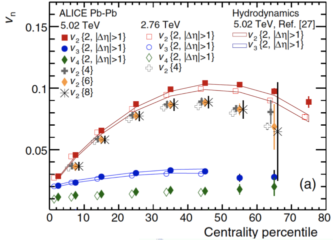
- v_n are sensitive to the evolution of the collision system.(η/s, Initial conditions…)
- Initial geometry fluctuations lead to flow fluctuations in the final state

$$\langle v_n^k \rangle \neq \langle v_n \rangle^k$$

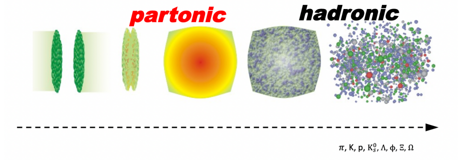
[J.E. Bernhard et al, Phys. Rev. C 94 (2016) 024907]



[ALICE, PRL 116 (2016) 132302)]

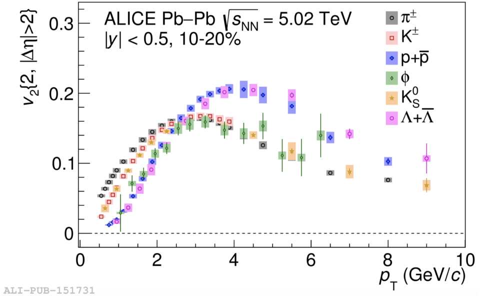


Anisotropic flow and flow fluctuations of identified particles



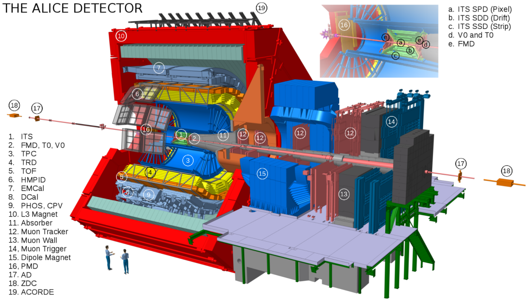
- Anisotropic flow of identified particles:
  - ♦ Further constraints to initial conditions, particle production mechanisms
  - ♦ Probes the freeze-out conditions of the system
- Multi-strange baryons:
  - ♦ Expect small hadronic cross-sections.

[JHEP 1809 (2018) 006]



- First measurement of $v_2\{4\}$ (Less sensitive to non-flow) and flow fluctuations of identified hadrons with the ALICE detector

ALICE detector



- Tracks:
  $|\ \eta\ | < 0.8$ (unidentified)
  $|\ y\ | < 0.5$ (identified)

- ALICE Pb–Pb at $\sqrt{s_{\mathrm{NN}}}$ =5.02 TeV
  320M events(2015 + 2018 data)

- ITS: Tracking, vertexing, triggering
- TPC: Tracking, PID
- TOF: PID
- V0: Triggering, multiplicity estimation

- Identification of $\pi^{\pm}$, $\mathrm{K}^{\pm}$, $\mathrm{p}(\bar{\mathrm{p}})$:

  ◆ Utilising combined TPC & TOF detectors
  ◆ Track-by-track basis with purity > 80%

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

Multi-particle cumulant method

- 2- & multi-particle cumulants are obtained using Generic Framework
  [A. Bilandzic et al, Phys. Rev. C 89 (2014) 064904]
- The 2- & 4-particle cumulant are given by

$$c_n\{2\} = \langle\langle 2 \rangle\rangle$$

$$d_n\{2\} = \langle\langle 2' \rangle\rangle$$

$$c_n\{4\} = \langle\langle 4 \rangle\rangle - 2\cdot \langle\langle 2 \rangle\rangle^2$$

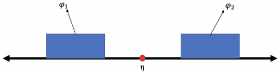
$$d_n\{4\} = \langle\langle 4' \rangle\rangle - 2\cdot \langle\langle 2' \rangle\rangle \langle\langle 2 \rangle\rangle$$

- Estimates of differential flow v_n are denoted as

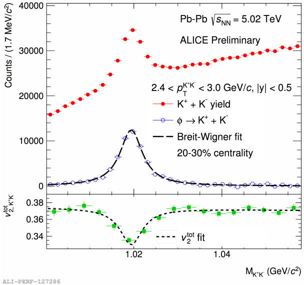
$$v_n\{2\}(p_{\mathrm{T}}) = \frac{d_n\{2\}(p_{\mathrm{T}})}{\sqrt{c_n\{2\}}}$$

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

- Multi-particle cumulant effectively suppress non-flow effect



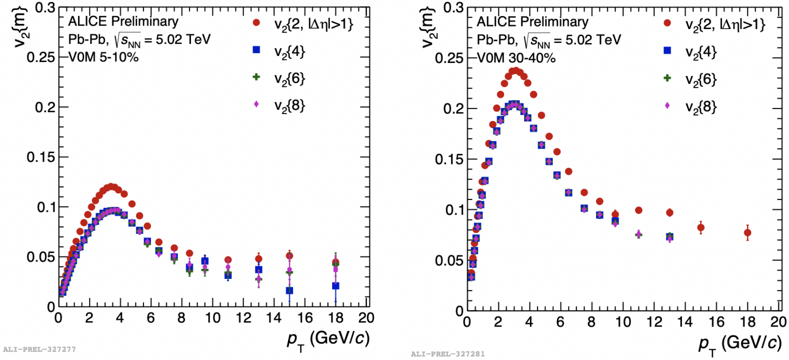
- η gap suppress short-range correlations



- For reconstructed particles:

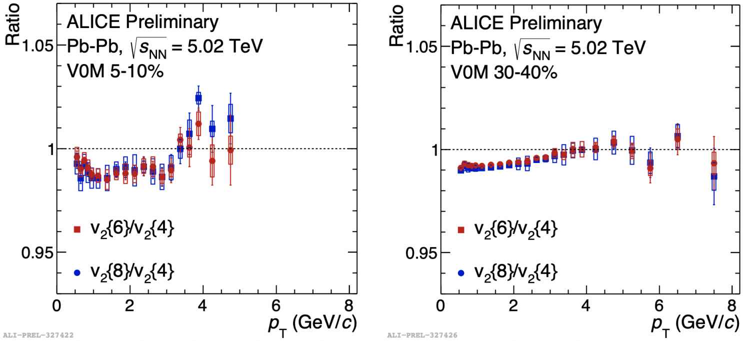
$$\langle\langle n' \rangle\rangle^{Tot}(m_{inv}) = \langle\langle n' \rangle\rangle^{Sig}\frac{N_{Sig}(m_{inv})}{N_{Tot}(m_{inv})} + \langle\langle n' \rangle\rangle^{Bg}(m_{inv})\frac{N_{Bg}(m_{inv})}{N_{Tot}(m_{inv})}$$

p_T-differential $v_2\{2\}$, $v_2\{4\}$, $v_2\{6\}$, $v_2\{8\}$



- Plethora of charged particles $v_2\{2\}$, $v_2\{4\}$, $v_2\{6\}$ and $v_2\{8\}$ measurements in 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



- Deviation of $v_2\{4\}/v_2\{6\}$ and $v_2\{4\}/v_2\{8\}$ from unity at low p_{T} $\rightarrow$ Bessel-Gaussian parametrisation of v_n p.d.f. is not valid
- Non-trivial evolution with p_{T}

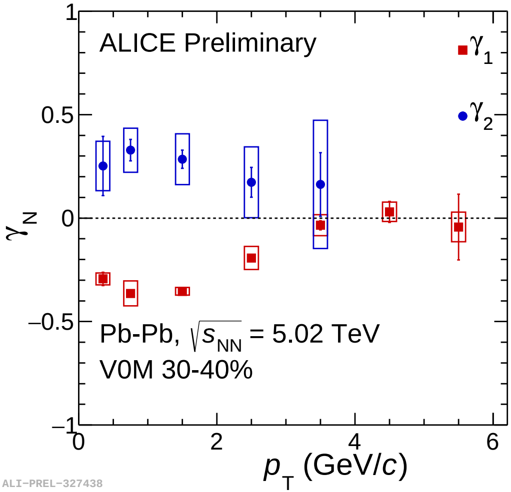
p_T-differential v_2 PDFs

- 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]

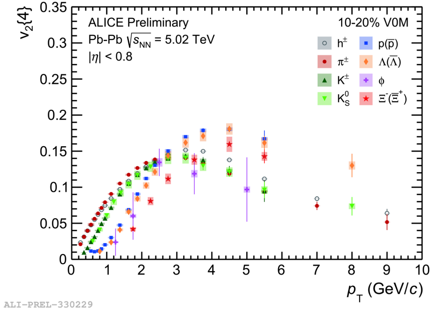
$$\gamma_1 \simeq -2^{3/2}\frac{v_2\{4\}^3 - v_2\{6\}^3}{(v_2\{2\}^2 - v_2\{4\}^2)^{3/2}}$$

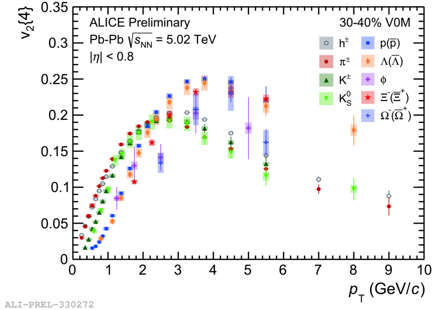
$$\gamma_2 \simeq -\frac{3}{2}\frac{v_2\{4\}^4 - 12v_2\{6\}^4 + 16v_2\{8\}^4}{(v_2\{2\}^2 - v_2\{4\}^2)^2}$$

- Dependence of the v_n p.d.f. on p_T is not constant
- Higher p_T (> 3 GeV/c): γ_1 and γ_2 are consistent with 0



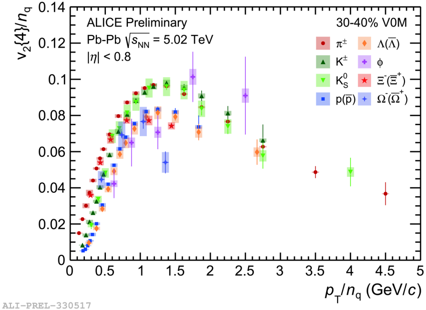
$v_2\{4\}$ of identified particles

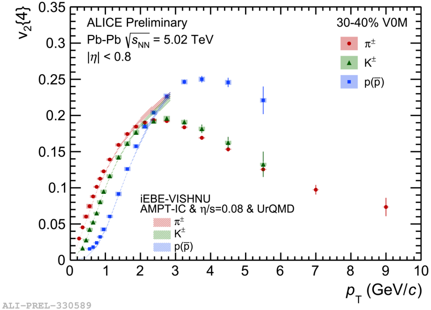




- First measurement of $v_2\{4\}$ of identified hadrons
- Qualitatively similar behaviour as of $v_2\{2\}$ measurements
  Clear mass ordering at low p_T and baryon/meson grouping at intermediate p_T

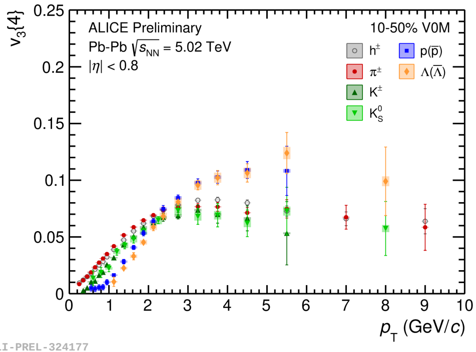
n_q scaling test for $v_2\{4\}$ of identified particles & hydro calculations





- 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)
- Hydro calculations can describe $v_2\{4\}$ of π, K, p well

$v_3\{4\}$ of identified particles



ALI-PREL-324177

- $v_3\{4\}$ of identified hadrons has been measured in a wider centrality interval
- Qualitatively similar behaviour as of $v_3\{2\}$ measurements
  Clear mass ordering at low p_T and baryon/meson grouping at intermediate p_T

Flow and flow fluctuation

- 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]

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

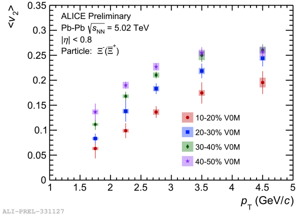
$$v_n\{4\}^2 \approx \langle v_n \rangle^2 - \sigma_{v_n}^2$$

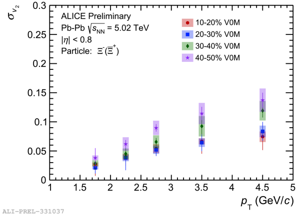
$$\Downarrow$$

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

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

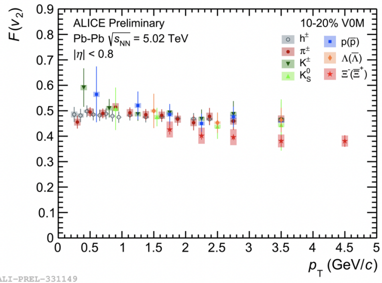
- Non-flow effect of 2-particle cumulant was suppressed by η gap
- $\langle v_n \rangle$ is the anisotropic flow from the symmetry plane and σ_{v_n} is the corresponding anisotropic flow fluctuations





- Obvious centrality dependence of $\langle v_2 \rangle$ and σ_{v_2} for Ξ

Relative flow fluctuations



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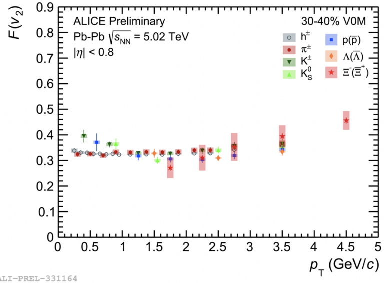

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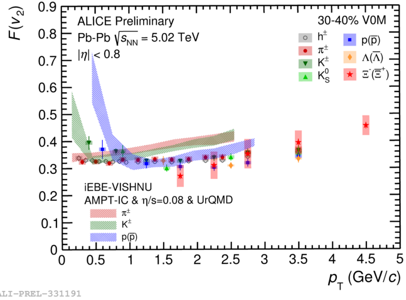
- Relative v_n fluctuations

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

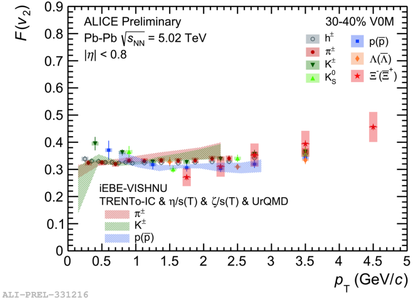
- First measurement of relative flow fluctuations for identified hadrons
- No definite particle species dependence

Relative flow fluctuations of identified particles compared with hydro calculations

Hydro calculations with AMPT-IC



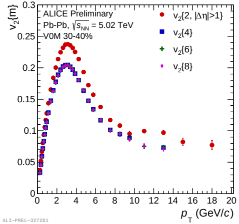
Hydro calculations with TRENTo-IC

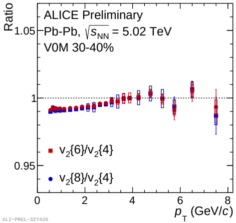


- Hydro can describe $F(v_2)$ of π, K, p well in 30-40%
- Hydro calculations with AMPT initial state describe a $F(v_2)$ distribution with obvious particle species dependence at low p_T

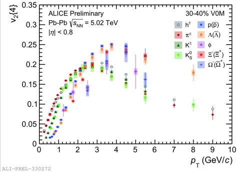
Summary

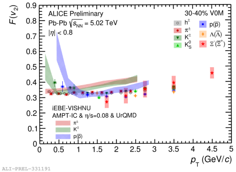
- p_{T}-differential measurements of charged particles flow coefficients using 6- and 8-particle cumulants are done for the first time in ALICE.
- v_2 distribution is not described well by the Bessel-Gaussian distribution.
- Non-trivial evolution with p_{T}.





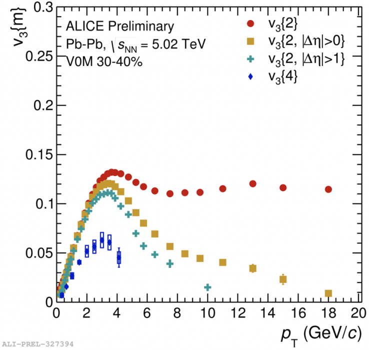
- The first measurement of $v_2\{4\}$ and flow fluctuations of identified hadrons.
- No definite particle species dependence observed for relative flow fluctuations of identified particles.

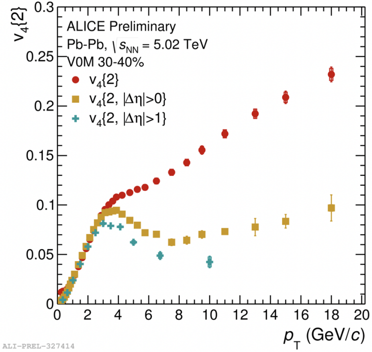




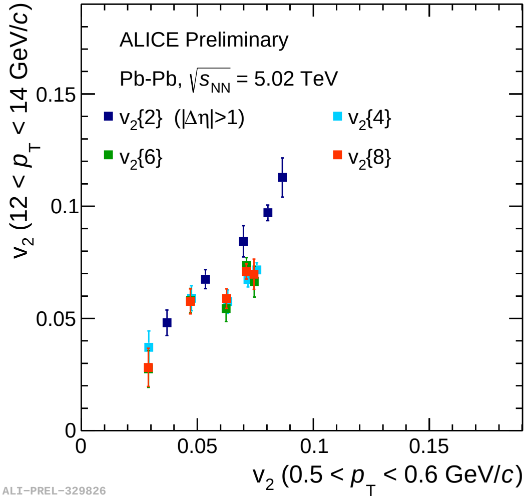
Back up

p_T-differential $v_3\{2,4\}$ and $v_4\{2\}$

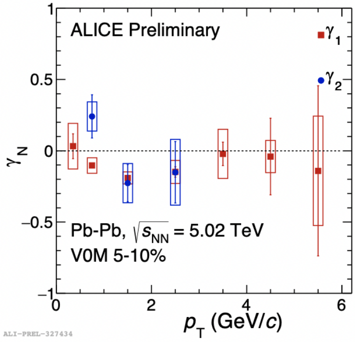


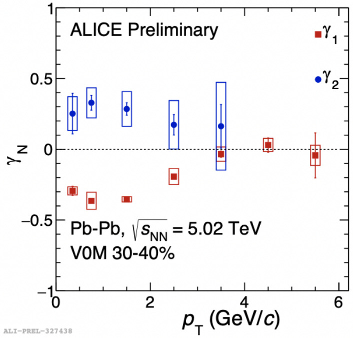


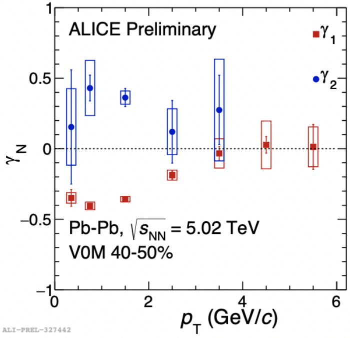
Correlation between soft and hard $v_2\{m\}$



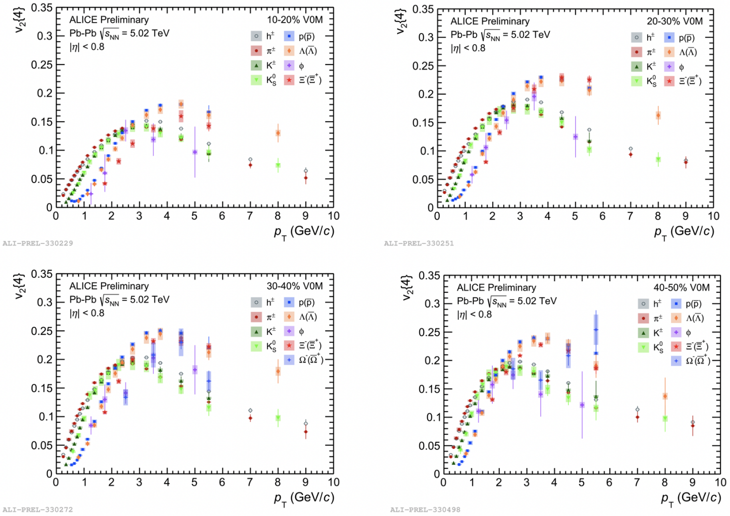
p_T-differential γ_1 and γ_2



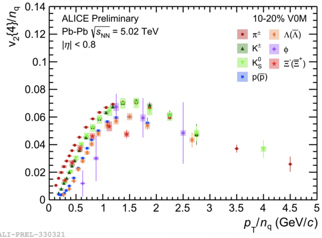




$v_2\{4\}$ of identified particles



$v_2\{4\}/n_q - p_T/n_q$



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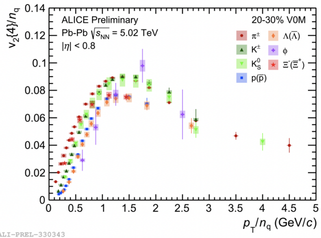

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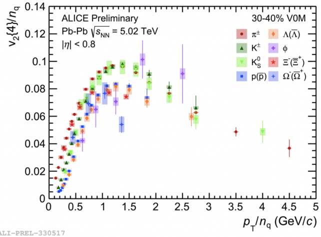

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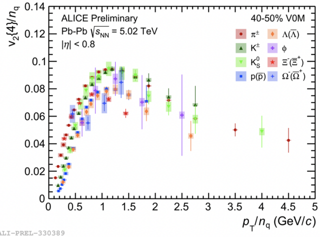
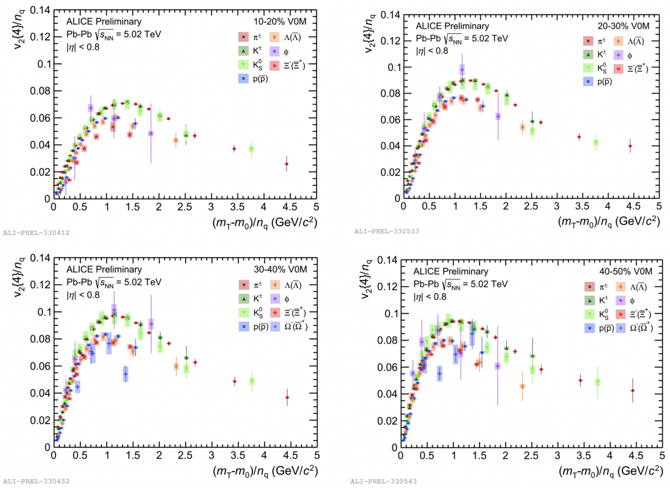
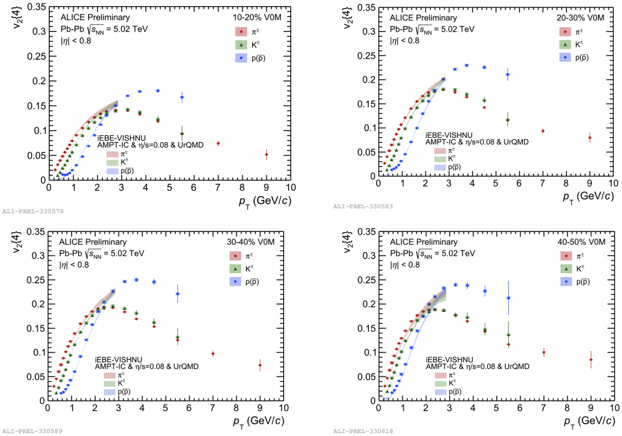


ALI-PREL-330389

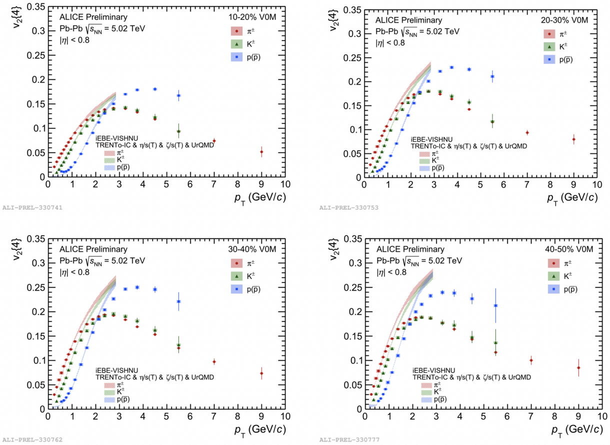
$v_2\{4\}/n_q - KE_T/n_q$


ALICE Preliminary
Pb-Pb $\sqrt{s_{NN}}$ = 5.02 TeV
$|\eta| < 0.8$
10-20% V0M
20-30% V0M
30-40% V0M
40-50% V0M
$\pi^{\pm}$
$K^{\pm}$
K^0_S
$p(\bar{p})$
$\Lambda(\bar{\Lambda})$
ϕ
$\Xi^-(\bar{\Xi}^+)$
$\Omega^-(\bar{\Omega}^+)$
$v_2\{4\}/n_q$
$(m_T-m_0)/n_q$ (GeV/c^2)
ALI-PREL-330412
ALI-PREL-330533
ALI-PREL-330452
ALI-PREL-330543

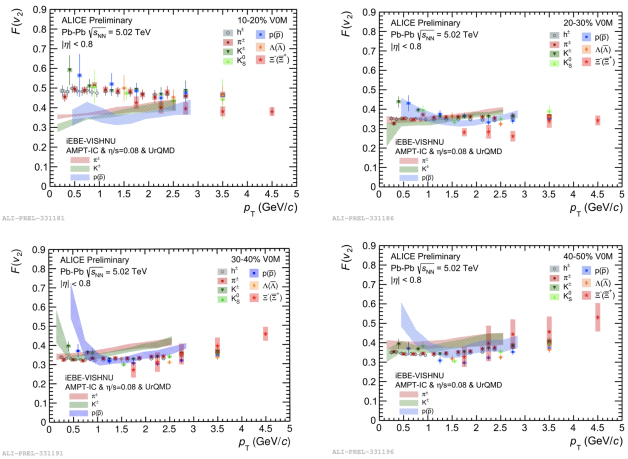
$v_2\{4\}$ of identified particles compared with hydro calculations using AMPT-IC



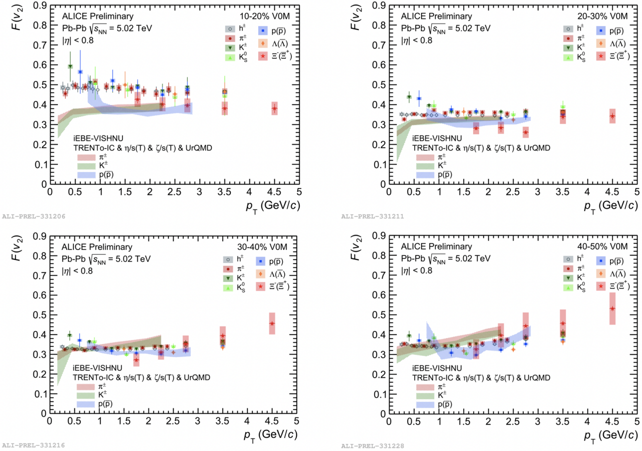
$v_2\{4\}$ of identified particles compared with hydro calculations using TRENToIC



$F(v_2)$ of identified particles compare with hydro calculations using AMPT-IC



$F(v_2)$ of identified particles compare with hydro calculations using TRENTo-IC



Thank you