Elliptic flow of identified particles in Pb-Pb collisions at the LHC

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for the ALICE Collaboration

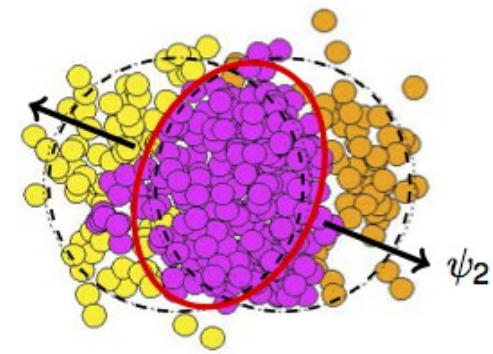
- Why elliptic flow?
- ALICE
  - Particle identification
- Flow analysis methods
- Results
- Summary

XXIV QUARK MATTER DARMSTADT 2014

Why elliptic flow?

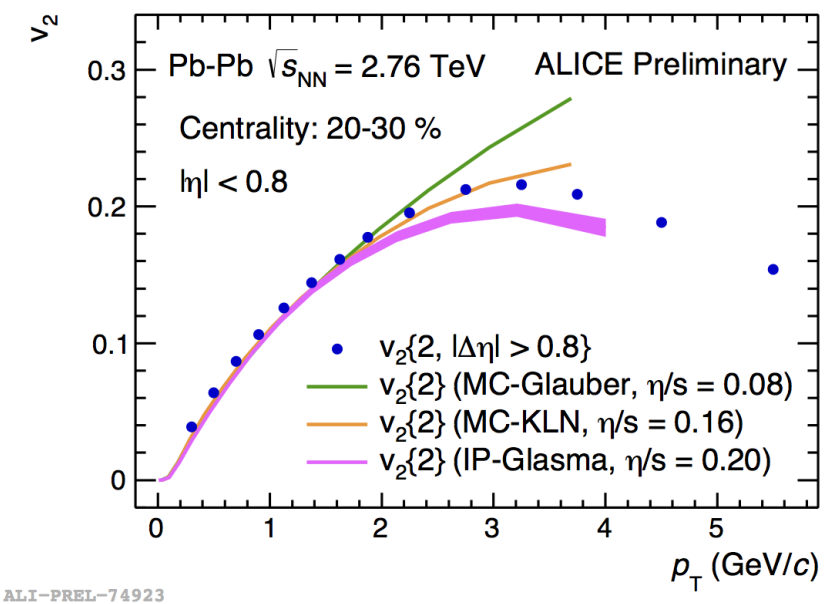
$$E\frac{d^3N}{d^3p}=\frac{1}{2\pi}\frac{d^2N}{p_T\,dp_T\,dy}\left(1+\sum_{n=1}^{\infty}2v_n\cos\left(n\left(\varphi-\Psi_n\right)\right)\right)$$

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

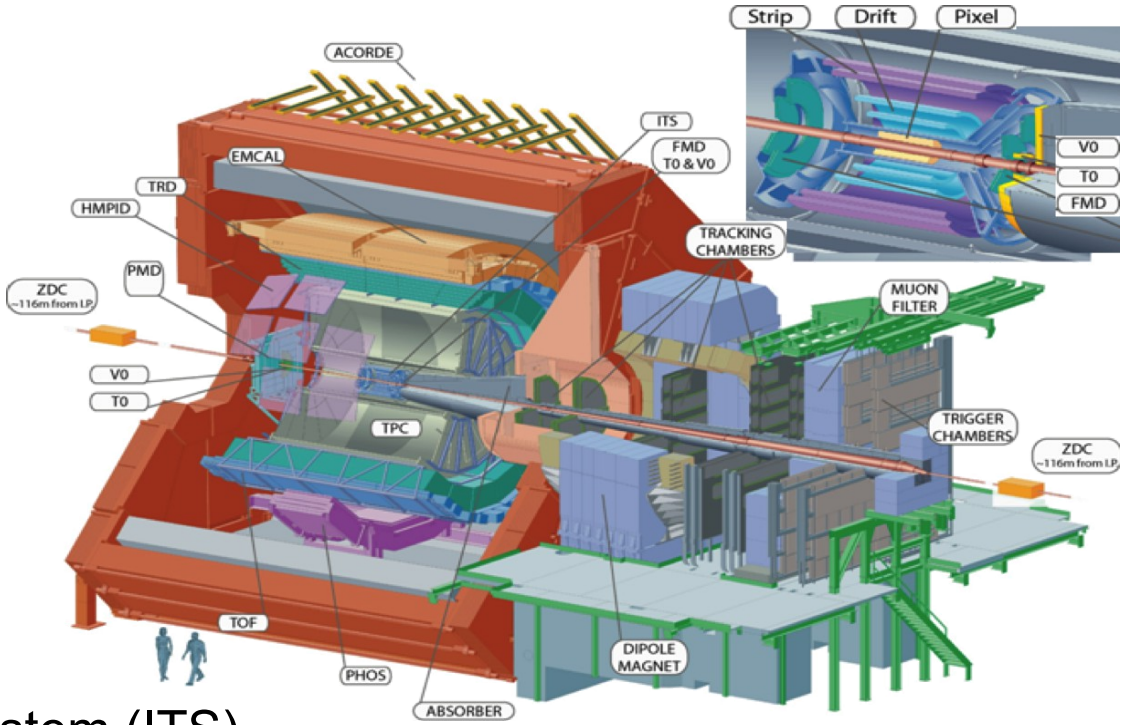


M. Luzum,
J. Phys. G: Nucl. Part. Phys. 38 (2011) 124026

- Elliptic flow (v_2) is sensitive to the system evolution
  - Constrains the initial conditions, deconfined phase, particle production mechanisms
- Identified particle v_2 allows for precision measurements
  - Adds further constraints to initial conditions, deconfined phase, particle production mechanisms
  - Probes the freeze-out conditions of the system (temperature, radial flow, ...)
  - Checks the number of constituent quarks (NCQ) scaling



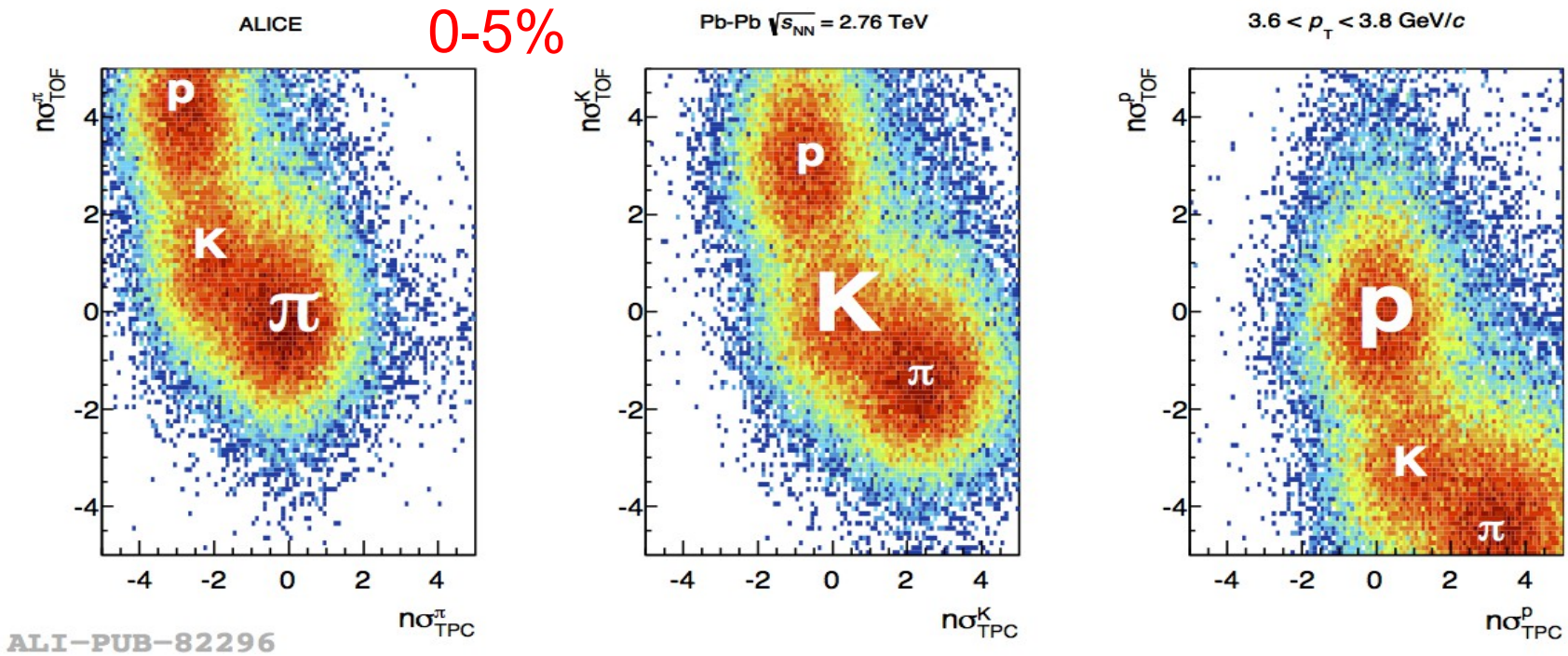
A Large Ion Collider Experiment



- Inner Tracking System (ITS)
  - Tracking, triggering and vertex determination
- Time Projection Chamber (TPC)
  - Tracking and particle identification based on specific energy loss
- Time-of-Flight (TOF)
  - Particle identification based on the arrival time
- V0-A ($2.8<\eta<5.1$) and V0-C ($-3.7<\eta<-1.7$)
  - Triggering and centrality determination

- Data sample:
  - Pb-Pb at $\sqrt{s_{NN}}$ = 2.76 TeV
    - ~15M events analyzed
- Tracks used:
  - $-0.8 < \eta < 0.8$ ($\pi^{\pm}$, $K^{\pm}$, p, ϕ)
  - $-0.5 < y < 0.5$ (K_s^0, Λ, Ξ, Ω)
  - $0.2 < p_T < 6$ GeV/c
- Do not differentiate between particle and antiparticle

Particle identification

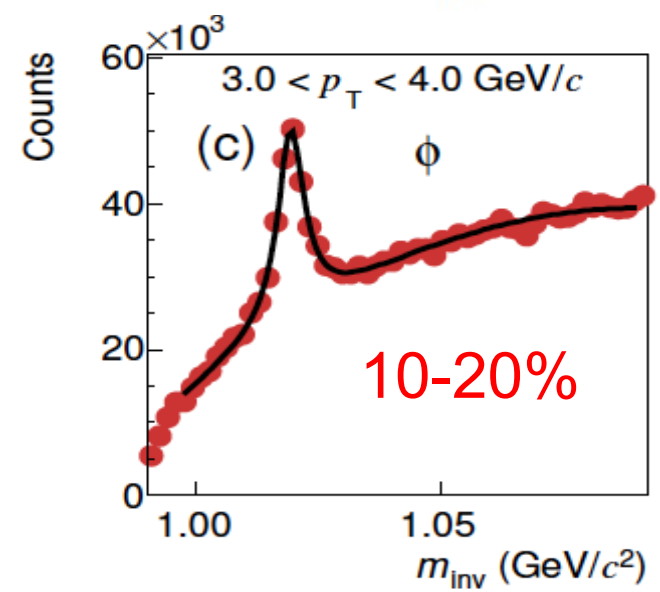


- π±, K±, p identified using TPC and TOF

$$N^2_{\sigma,PID} = N^2_{\sigma,TPC} + N^2_{\sigma,TOF}$$

$$N_{\sigma,PID} < 3$$

- Topological reconstruction for strange and multi-strange particles



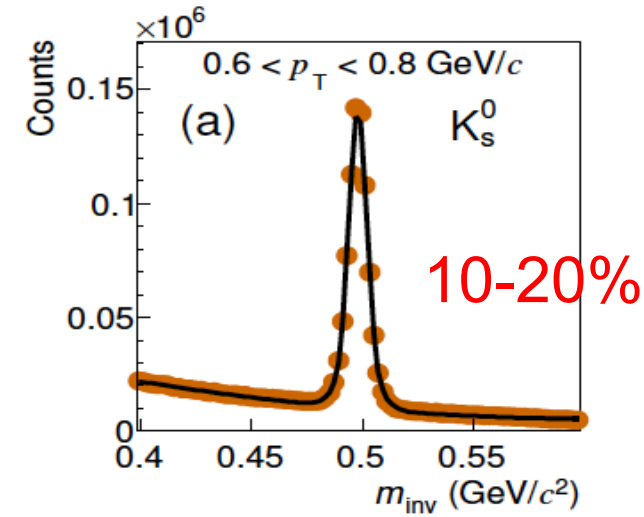
Flow analysis methods

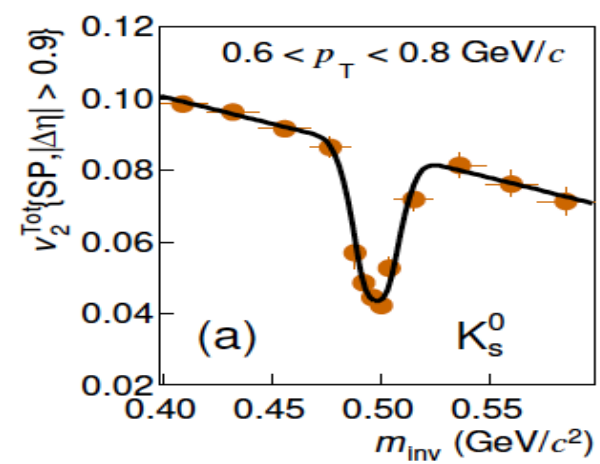
- v_2 of $\pi^{\pm}$, $K^{\pm}$, p is directly measured using the scalar product method
  - Hits measured by V0-A (2.8<η<5.1) and V0-C (-3.7<η<-1.7) detectors are used as reference particles (RPs)
    - Large η gap between particles of interest and RPs to suppress non-flow
- v_2 of K_s^0, Λ, ϕ, Ξ, Ω is determined using the v_2 vs invariant mass method:

$$v_2^{\mathrm{Tot}}(m_{\mathrm{inv}}) = v_2^{\mathrm{Sgn}} \frac{N^{\mathrm{Sgn}}}{N^{\mathrm{Tot}}}(m_{\mathrm{inv}}) + v_2^{\mathrm{Bg}}(m_{\mathrm{inv}}) \frac{N^{\mathrm{Bg}}}{N^{\mathrm{Tot}}}(m_{\mathrm{inv}})$$

  - The yields N^{Sgn} and N^{Bg} are extracted from fits of the invariant mass distributions
  - The $v_2^{\mathrm{Tot}}(m_{\mathrm{inv}})$ is measured using the scalar product method

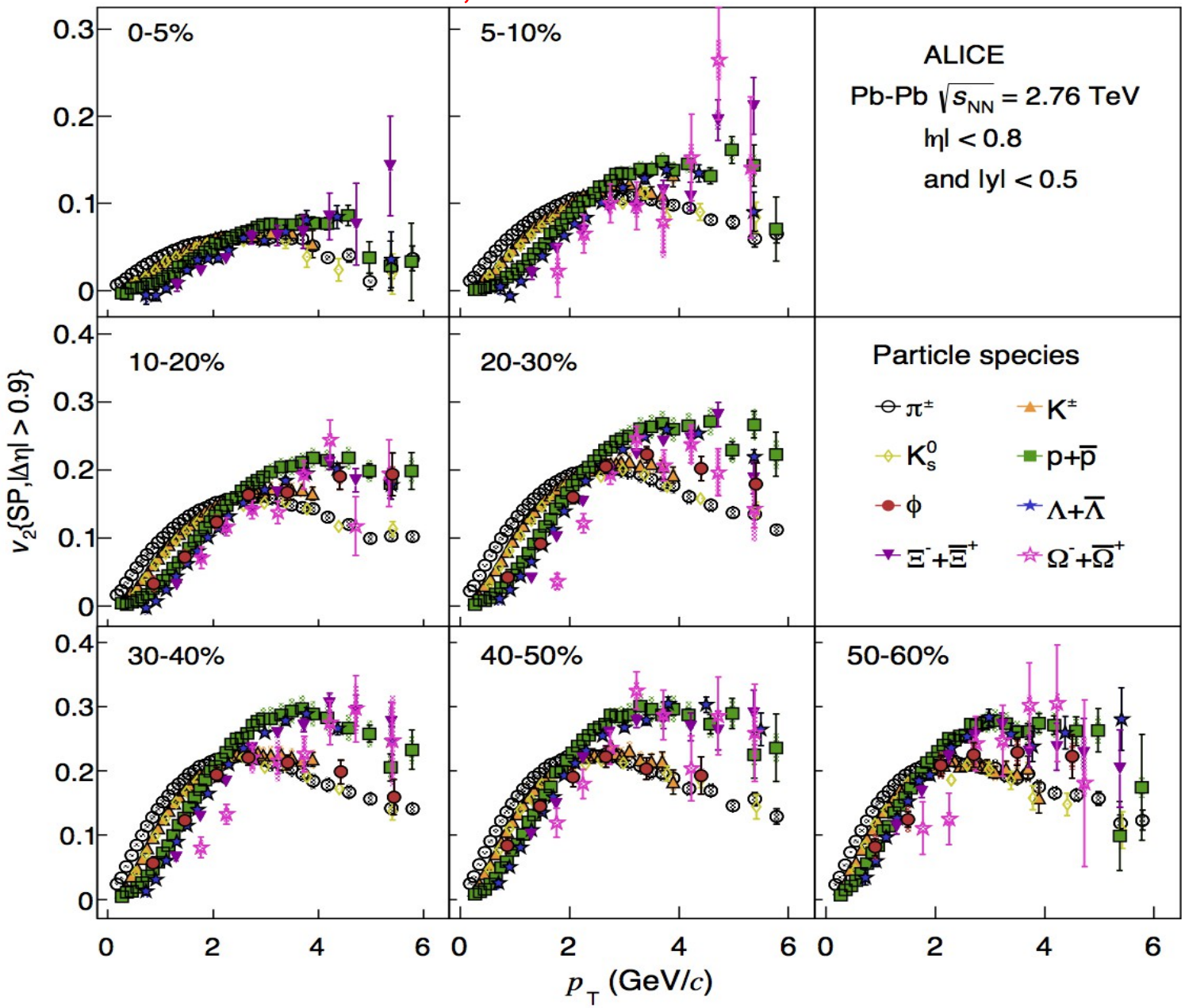
$$v_2 = \sqrt{\frac{\left\langle\left\langle \vec{u}_2^{\mathrm{B}} \cdot \frac{\vec{Q}_2^{\mathrm{A}*}}{M_{\mathrm{A}}} \right\rangle\right\rangle \left\langle\left\langle \vec{u}_2^{\mathrm{B}} \cdot \frac{\vec{Q}_2^{\mathrm{C}*}}{M_{\mathrm{C}}} \right\rangle\right\rangle}{\left\langle \frac{\vec{Q}_2^{\mathrm{A}}}{M_{\mathrm{A}}} \cdot \frac{\vec{Q}_2^{\mathrm{C}*}}{M_{\mathrm{C}}} \right\rangle}}$$



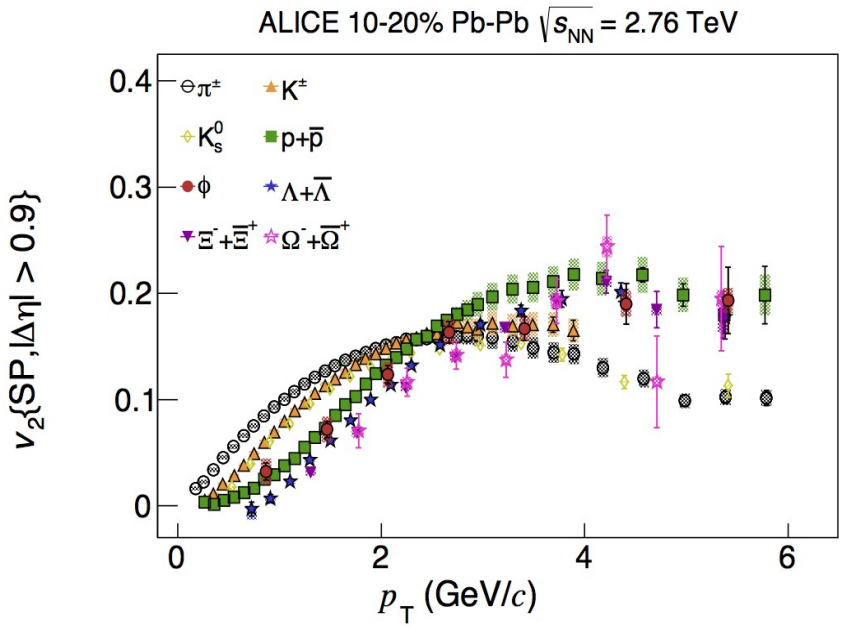


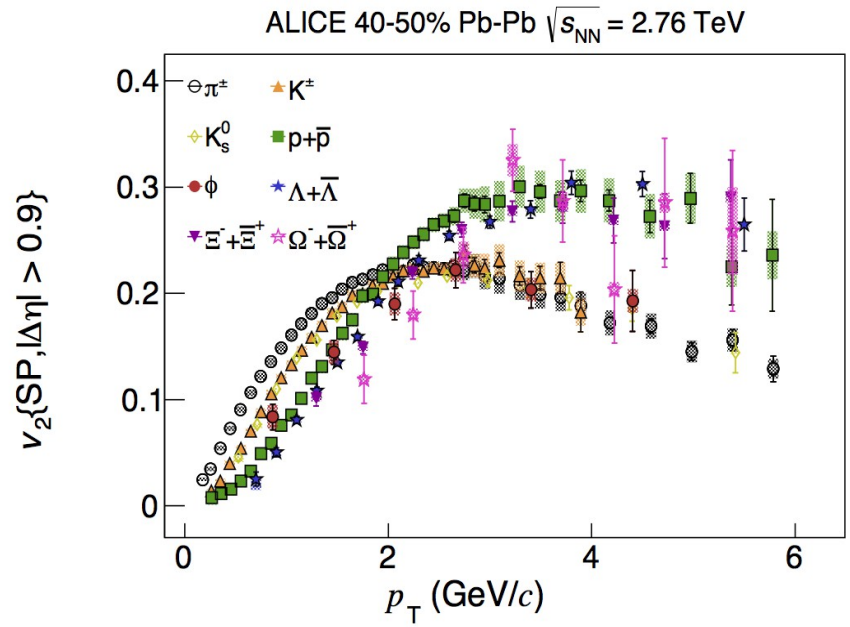
Identified particle v_2

ALICE, arXiv:submit/0981508



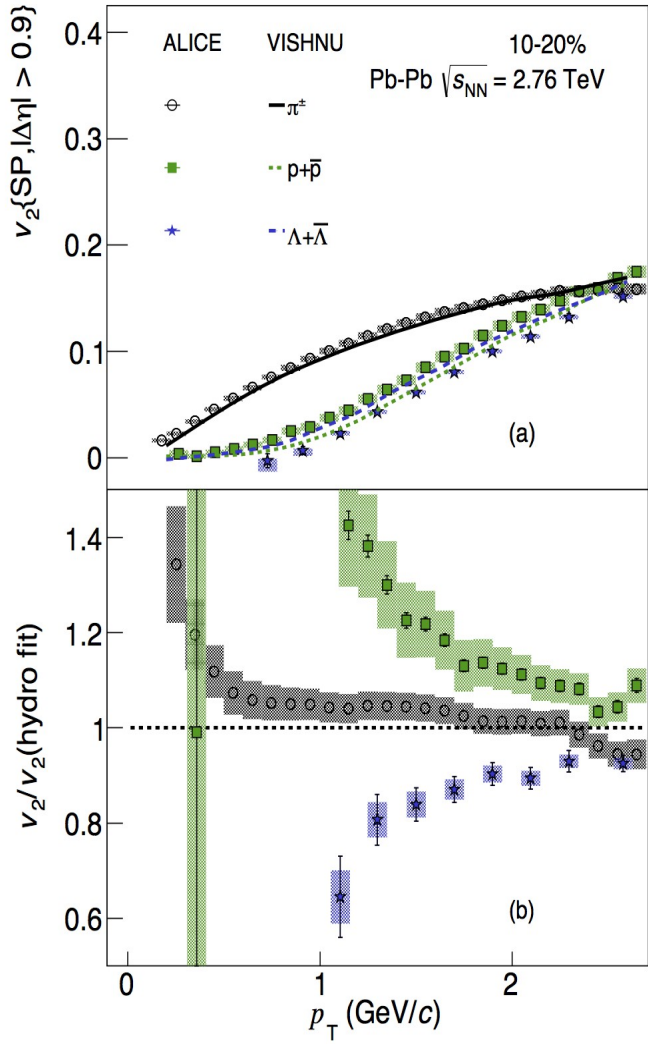
Identified particle v_2



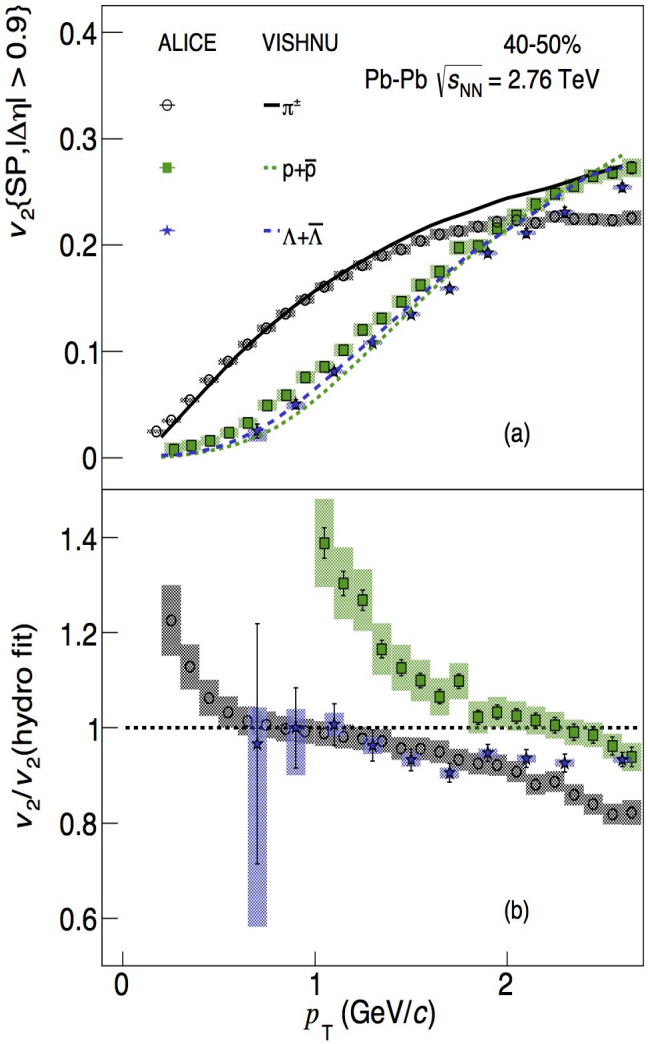


- Small difference between v_2 for $K^{\pm}$ and K_s^0
  - Physics mechanism/detector effect responsible not understood yet
  - v_2 for $K^{\pm}$ and K_s^0 averaged for p_T<4.0 GeV/c in the following slides
- For p_T<2 GeV/c: observe mass ordering indicative of radial flow
- For p_T~2-3.5 GeV/c: crossing between v_2 of p and $\pi^{\pm}$
- For p_T>3 GeV/c: particles tend to group into mesons and baryons
  - v_2 of ϕ follows baryons for central collisions and shift progressively to mesons for peripheral collisions

Comparison with hydrodynamical calculations ($\pi^{\pm}$, p, Λ)



ALI-PUB-82695

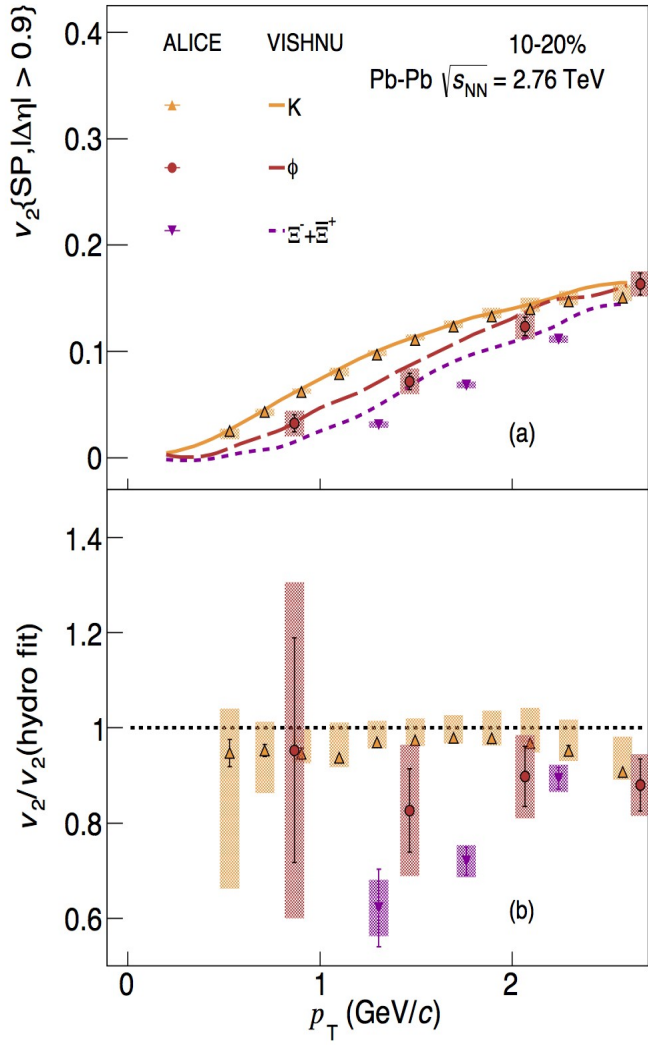


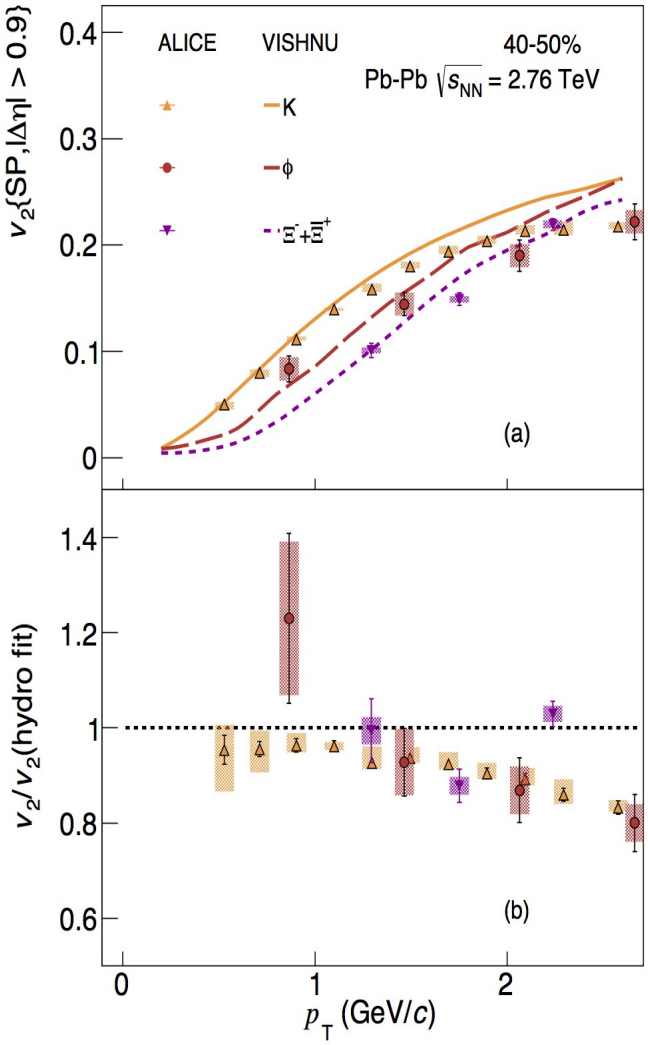
ALI-PUB-82699

- Hydrodynamical calculations (MC-KLN, η/s=0.16) coupled to a hadronic cascade model (VISHNU) reproduce the main features of v_2 for p_T<2 GeV/c
  - Underestimates the v_2 for $\pi^{\pm}$
  - Underpredicts the v_2 for p
  - Overestimates the v_2 for Λ
    - Mass ordering is broken in the model

VISHNU: PRC 89, 034919 (2014)

Comparison with hydrodynamical calculations (K, ϕ, Ξ)

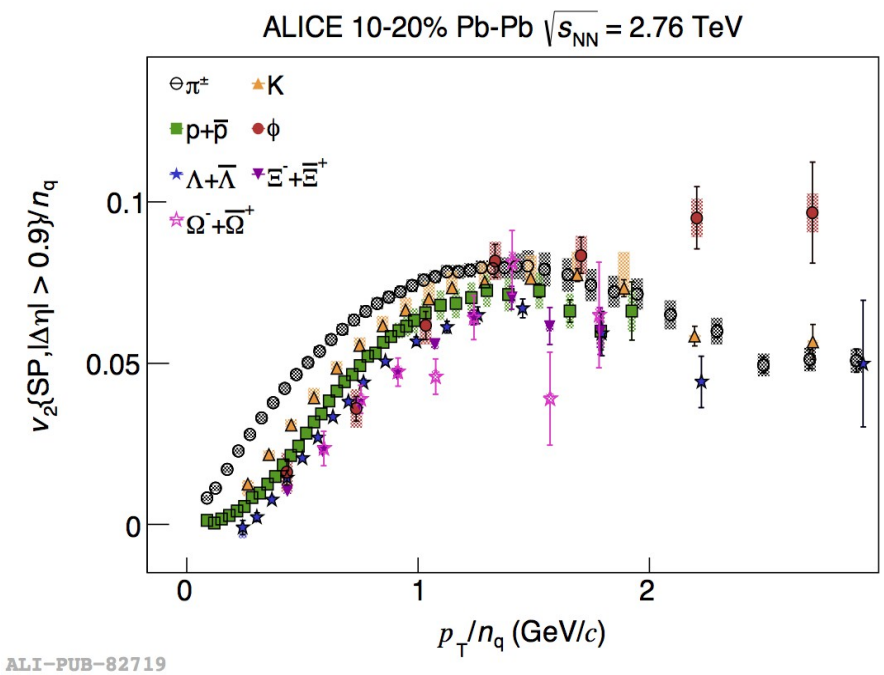


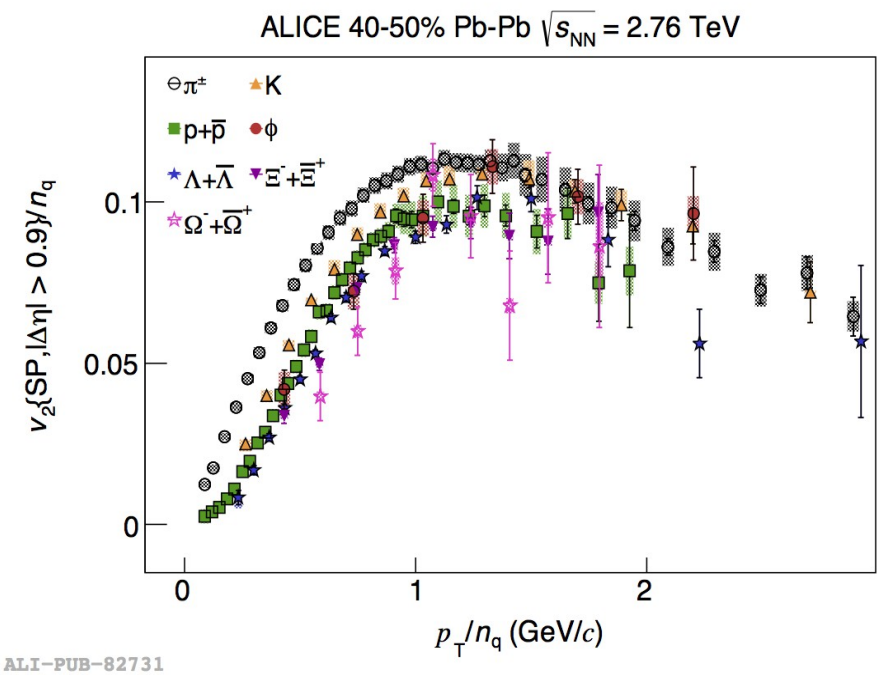


- Hydrodynamical calculations (MC-KLN, η/s=0.16) coupled to a hadronic cascade model (VISHNU) reproduce the main features of v_2 for p_T<2 GeV/c
  - Describes fairly well the v_2 for K
  - Overestimates the v_2 for Ξ
  - Overpredicts the v_2 for ϕ
    - Mass ordering is broken in the model

VISHNU: PRC 89, 034919 (2014)

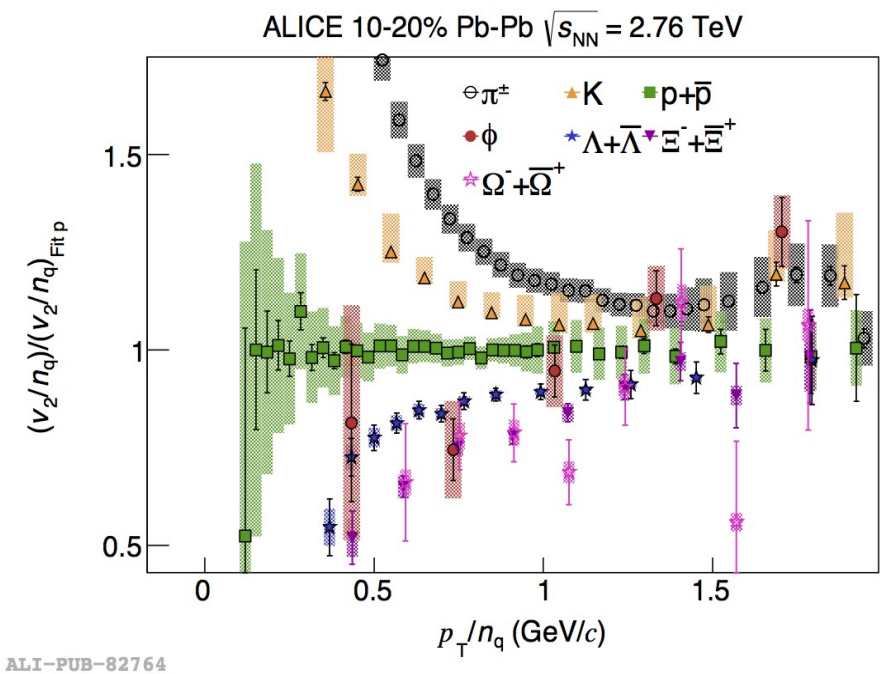
p_T/n_q scaling?

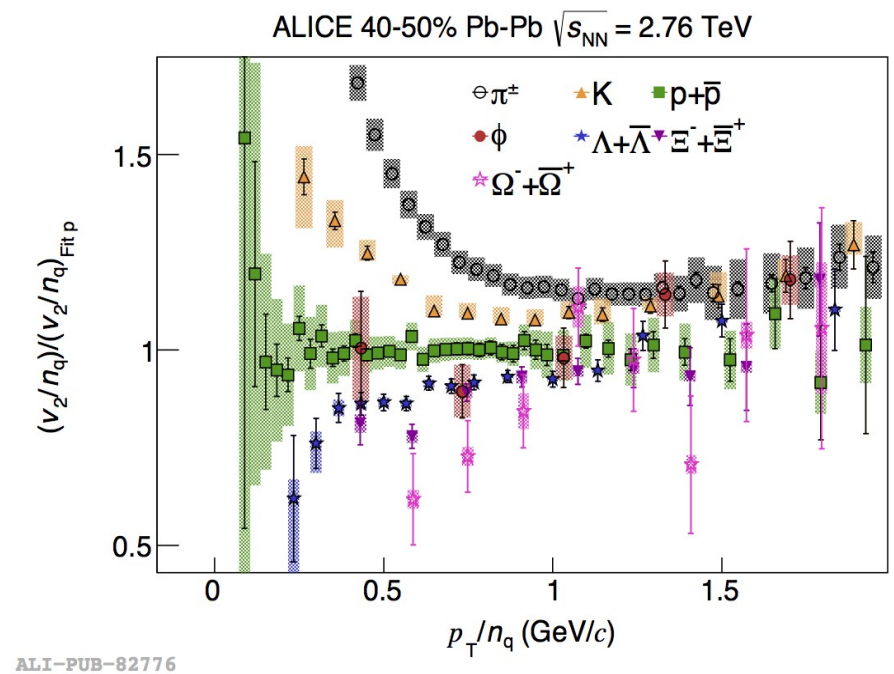




- For p_T/n_q>1-1.5 GeV/c: particles tend to group according to their type
  - ϕ does not follow the band of mesons for central collisions
- For p_T/n_q>1 GeV/c: NCQ scaling is only approximate

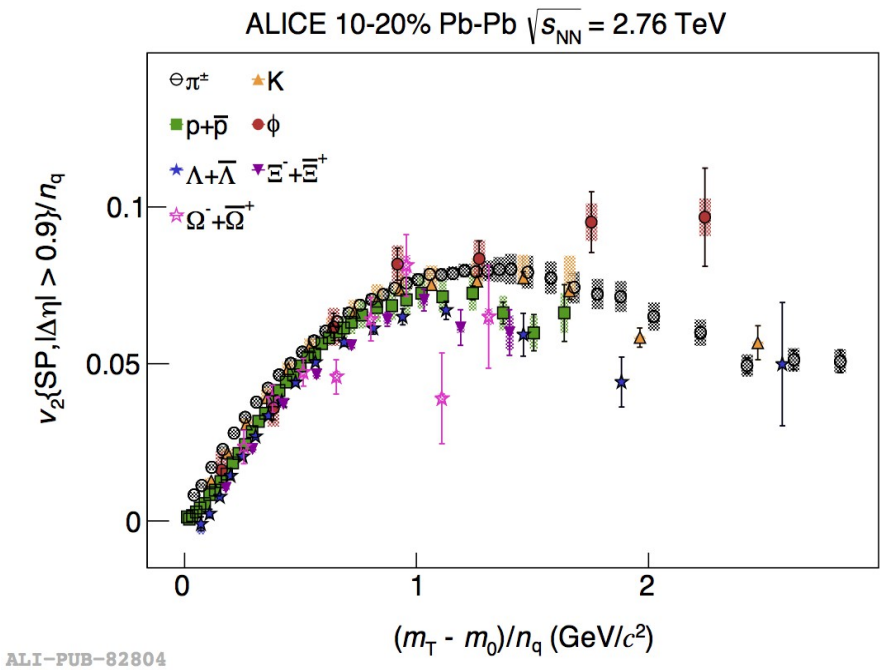
p_T/n_q scaling?

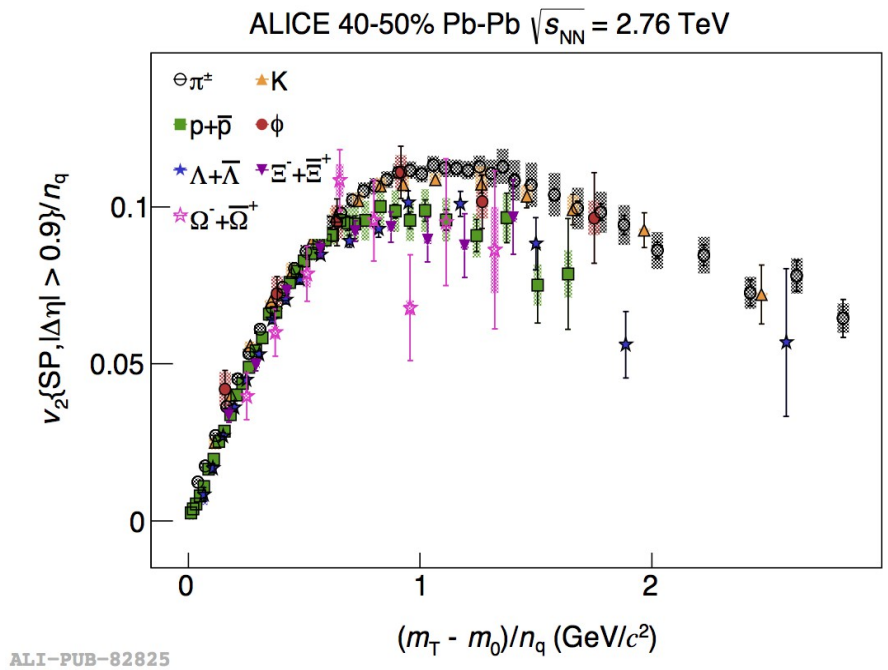




- For p_T/n_q>1 GeV/c: NCQ scaling deviations at the order of ±20%
  - Similar magnitude for all centrality classes

KE_T/n_q scaling?

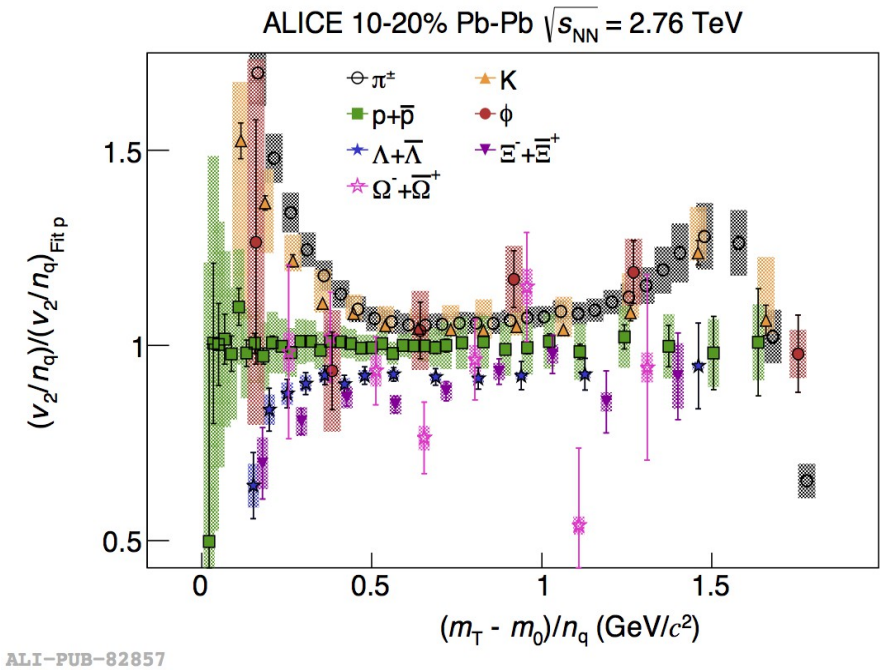


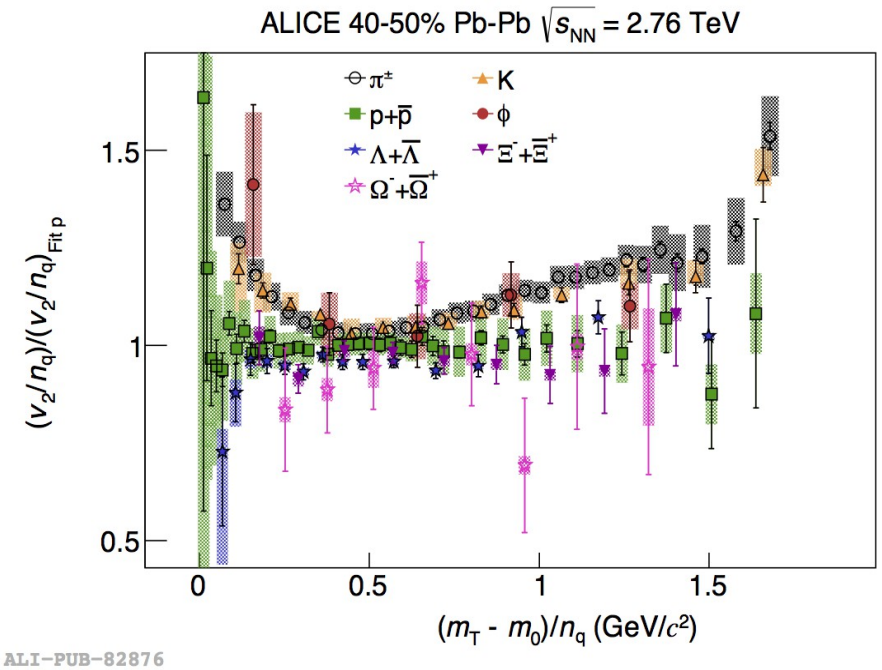


$$KE_T = m_T - m_0 \quad m_T = \sqrt{p_T^2 + m_0^2}$$

- For KE_T/n_q<0.6-0.8 GeV/c^2: significant deviations from NCQ scaling are seen in data
- For KE_T/n_q>0.8 GeV/c^2: NCQ scaling, if any, is only approximate

KE_T/n_q scaling?

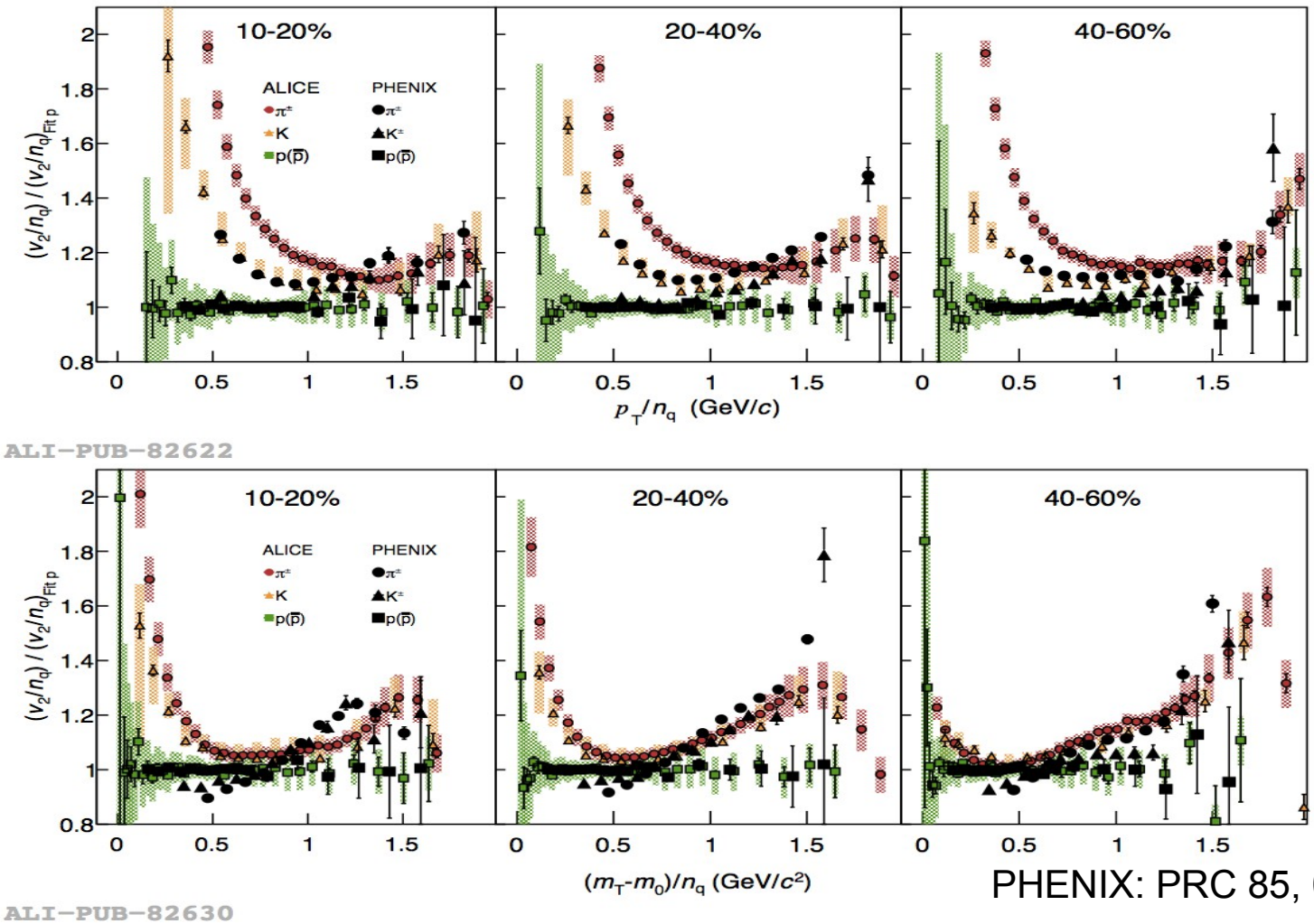




$$KE_T = m_T - m_0 \quad m_T = \sqrt{p_T^2 + m_0^2}$$

- For KE_T/n_q<0.6-0.8 GeV/c^2: NCQ scaling is broken at the LHC
- For KE_T/n_q>0.8 GeV/c^2: NCQ scaling deviations at the level of ±20%
  - Similar magnitude for all centrality classes

“NCQ Scaling” from RHIC to LHC

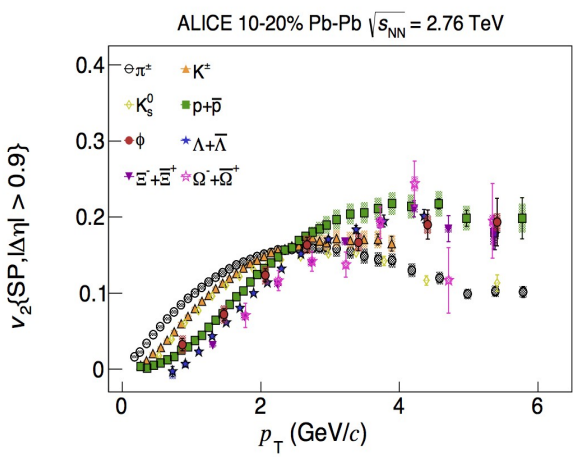


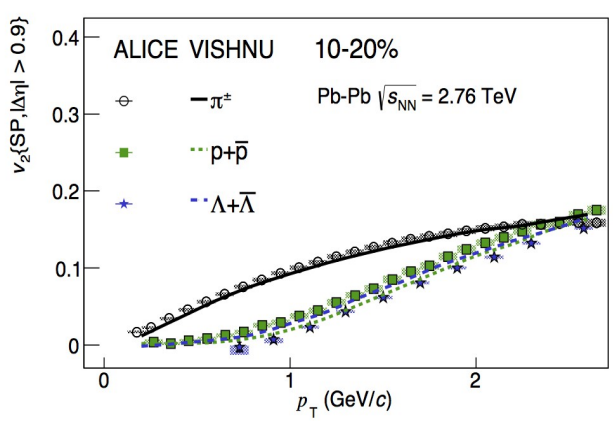
PHENIX: PRC 85, 064914 (2012)

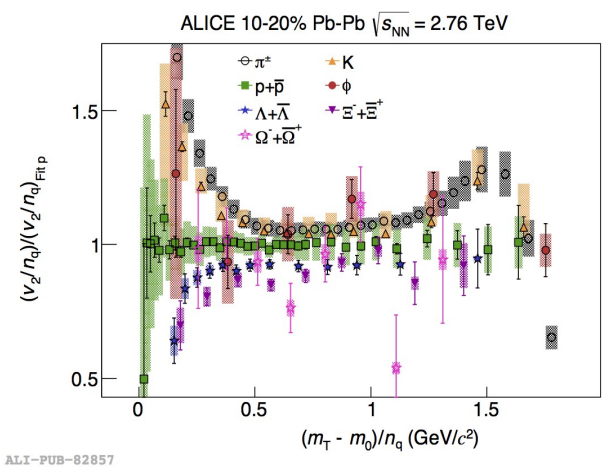
- Deviations at intermediate p_T are qualitatively similar at LHC and RHIC
  - Evolution is different for π and K

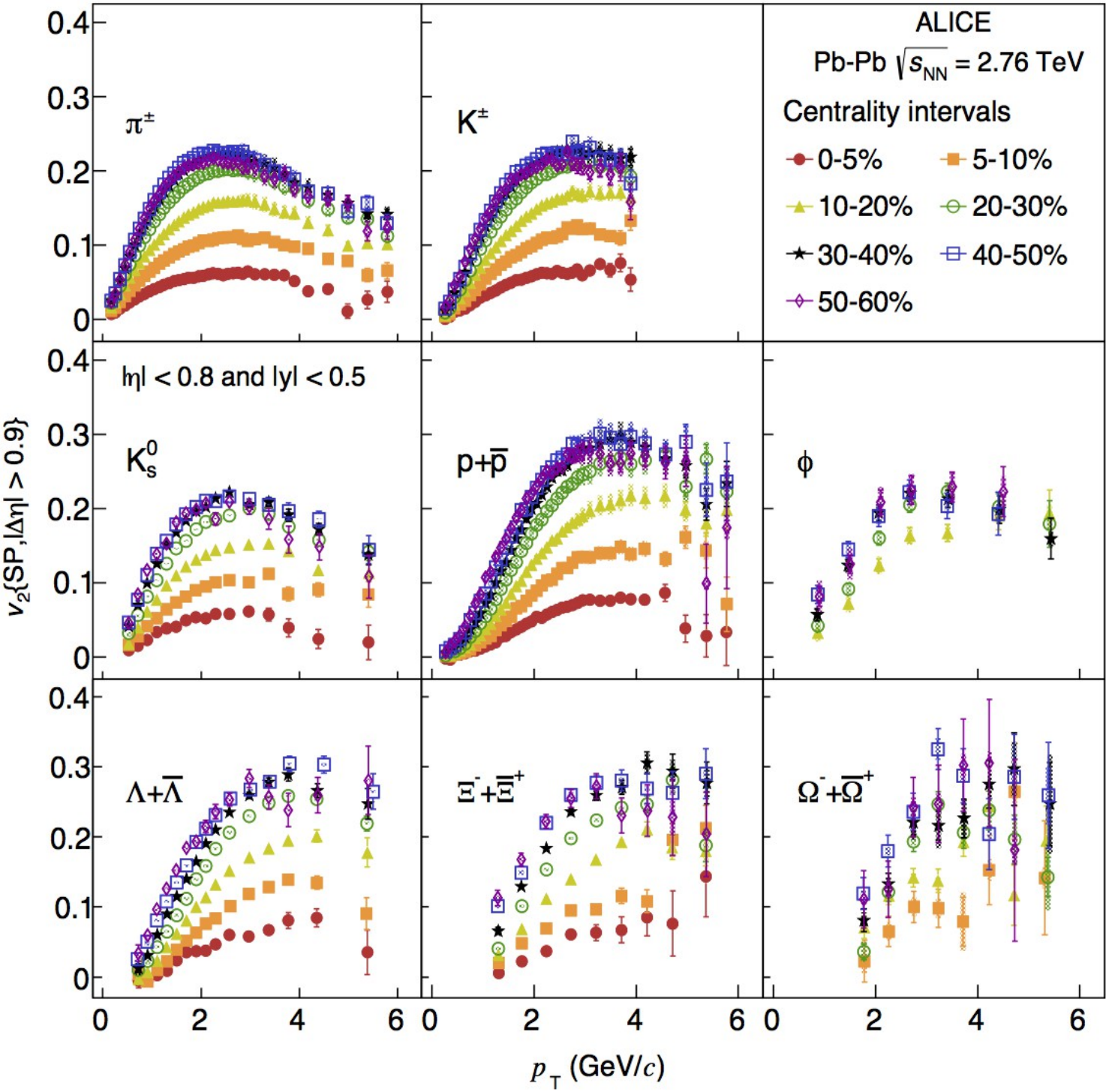
Summary

- v_2 for $\pi^{\pm}$, $K^{\pm}$, p, K_s^0, Λ, ϕ, Ξ, Ω is measured in Pb-Pb collisions using the ALICE detector
  - Observe mass ordering for p_T<2 GeV/c
  - Crossing between v_2 of p and π for p_T~2-3.5 GeV/c
  - Particles tend to group into mesons and baryons for p_T>3 GeV/c
    - v_2 of ϕ follows baryons for central collisions and shift to mesons for peripheral collisions
  - Hydrodynamical calculations (MC-KLN, η/s=0.16) coupled to a hadronic cascade model describe qualitatively the measurements
  - Observe deviations from NCQ scaling at the level of ±20%









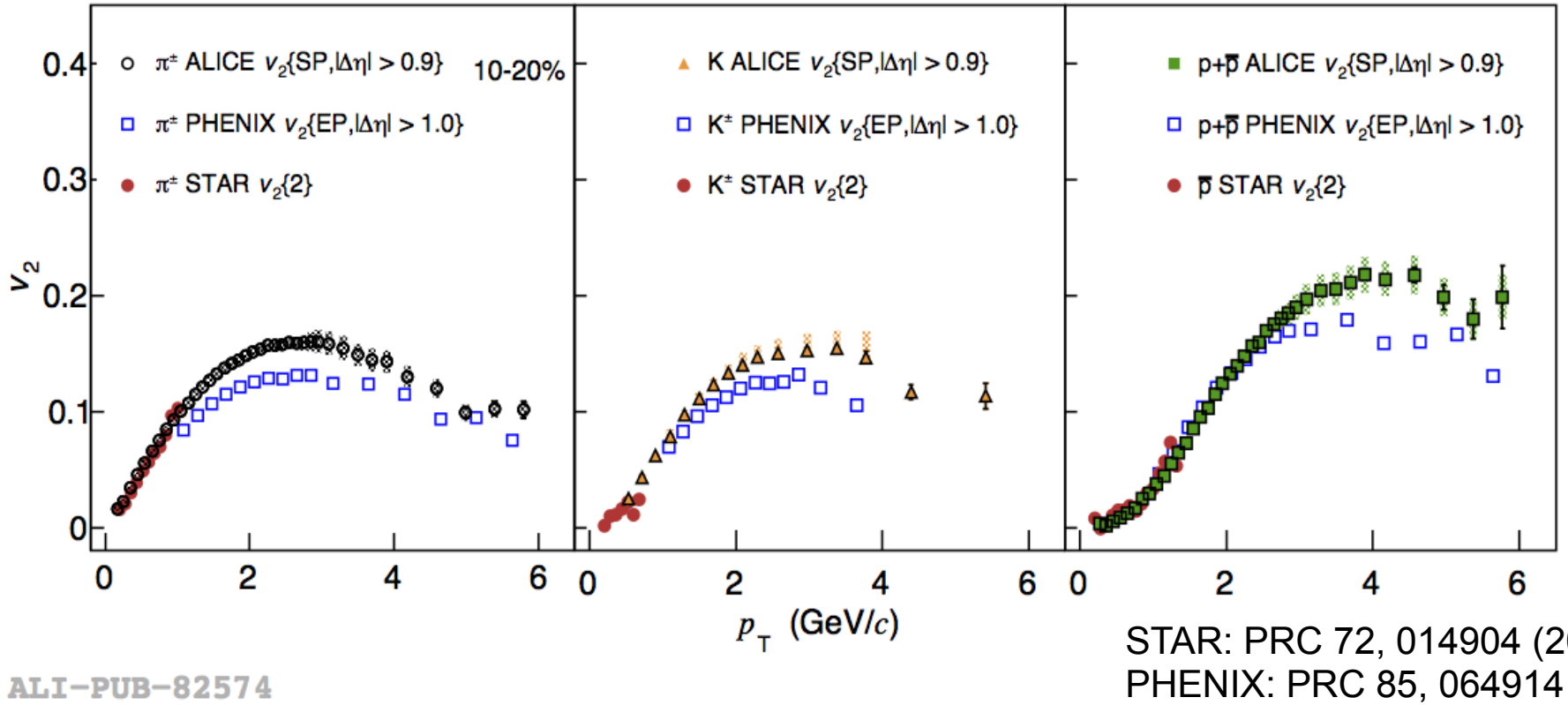
Thanks!

ALICE

ALI-PUB-82414

Back up

v_2 from RHIC to LHC



STAR: PRC 72, 014904 (2005)
PHENIX: PRC 85, 064914 (2012)

- Different methods used → comparison difficult
  - v_2 for π± and K measured at the LHC is above the RHIC results
  - v_2 of p is slightly lower for p_T<2.0-2.5 GeV/c, but higher for p_T>2.5 GeV/c at LHC than at RHIC