



Washington August 13-18, 2012

Anisotropic flow of identified particles in Pb-Pb collisions at 2.76 TeV

F. Noferini

for the ALICE Collaboration

17th Aug 2012



CENTRO STUDI E RICERCHE E MUSEO STORICO DELLA FISICA



Motivation

Fourier expansion $\frac{dN}{d\varphi} \propto 1 + 2v_1 \cos[\varphi - \Psi_1] + 2v_2 \cos[2(\varphi - \Psi_2)] + 2v_3 \cos[3(\varphi - \Psi_3)] + \dots$

Anisotropic flow coefficients covered in this talk

Anisotropic flow of identified particles is sensitive to the partonic degrees of freedom at the early times of a heavy-ion collision;

studied vs. transverse momentum allows to quantify:

- rate of hydrodynamic radial expansion (mass dependence of v_n vs. p_T)
- properties of the deconfined phase (e.g. viscosity)
- details of hadronization mechanism (e.g. coalescence)

Outline

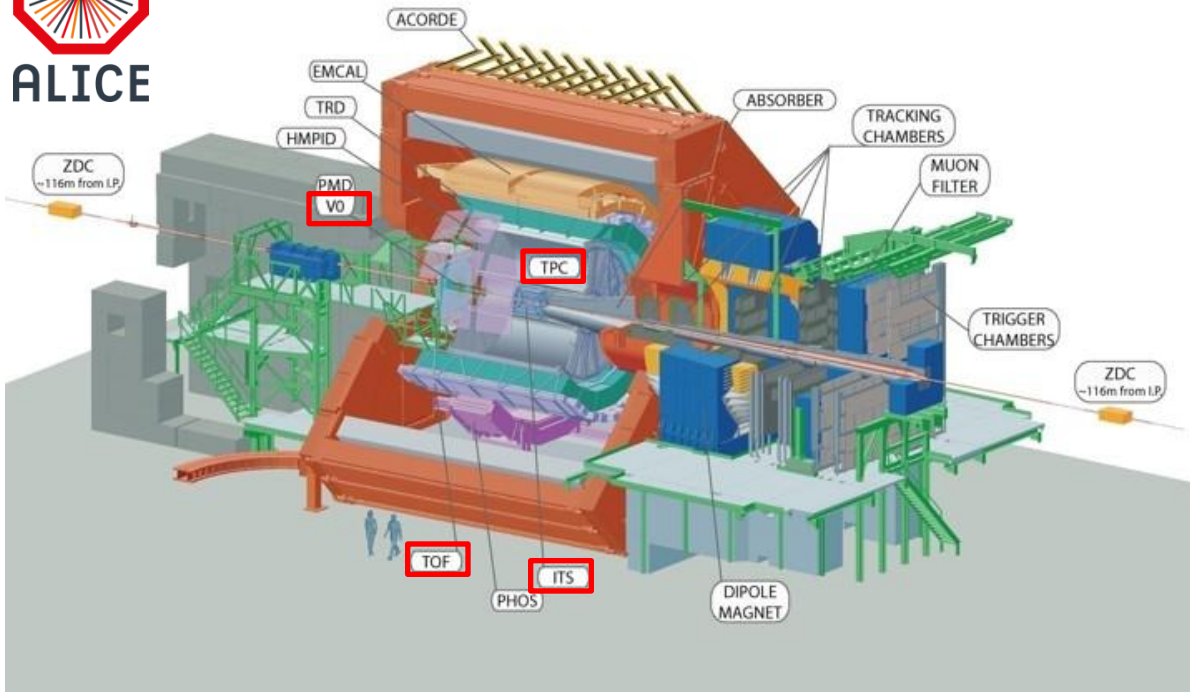
In this talk we present anisotropic flow of π , K, p, Λ , Ξ , Ω and ϕ -meson and investigate the properties of v_2 and v_3 vs. transverse momentum:

- particle mass dependence
- quark (light/strange) content
- comparison with hydrodynamic model calculations
- comparison with measurements at RHIC
- v_2/v_3 scaling properties with number of quarks and transverse kinetic energy.
- Does v_3 (originating from fluctuations) scale similar to v_2 ?

Analysis details



ALICE



VZERO detector
Two forward scintillator
arrays
($-3.7 < \eta < -1.7$, $2.8 < \eta < 5.1$):
centrality / event plane

**Inner Tracking System
(ITS) and Time Projection
Chambers (TPC):**
tracking / event plane

DATA sample:

- Pb-Pb at $\sqrt{s_{NN}} = 2.76$ TeV
- 2010 data
- ~ 10 M events

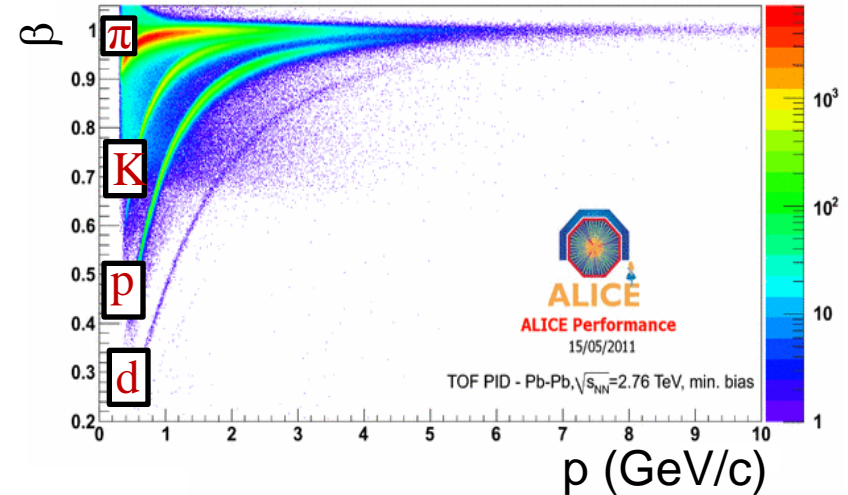
Acceptance: $|\eta| < 0.8$

**Time Of Flight (TOF) and
TPC:** particle identification

π , K and p/ \bar{p} identification

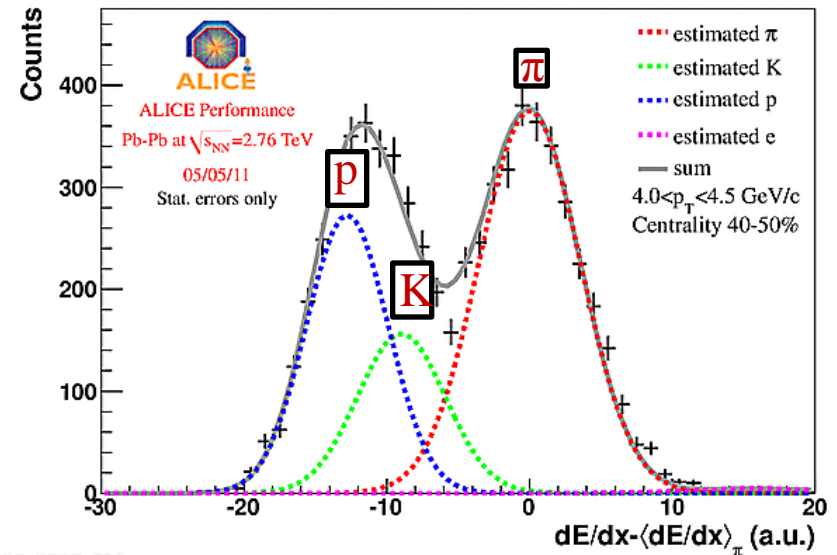
Particle identification with TOF & TPC:

- asymmetric β -cut to select a high purity sample of π , K and p.
- 2σ cut in the TPC dE/dx .
- p_T range (in GeV/c):
 - $\pi \rightarrow 0.3 < p_T < 3.5$
 - $K \rightarrow 0.4 < p_T < 2.5$
 - $p \rightarrow 0.5 < p_T < 4.0$
- purity: $> 90\%$

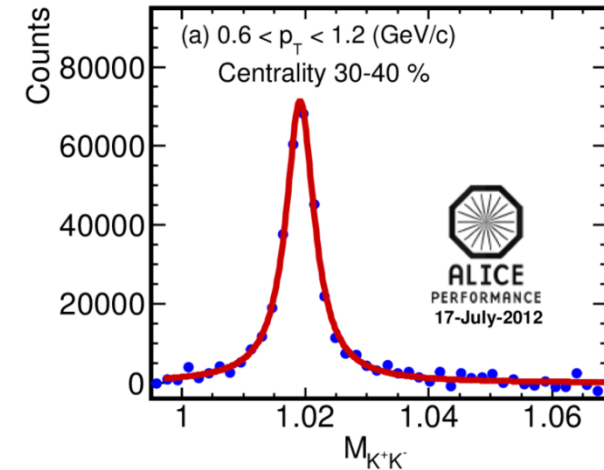
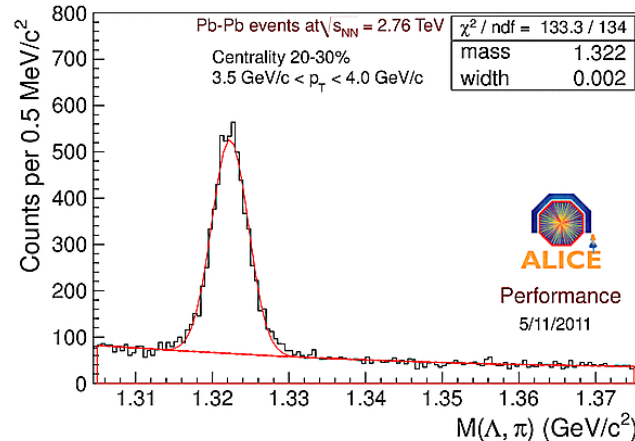
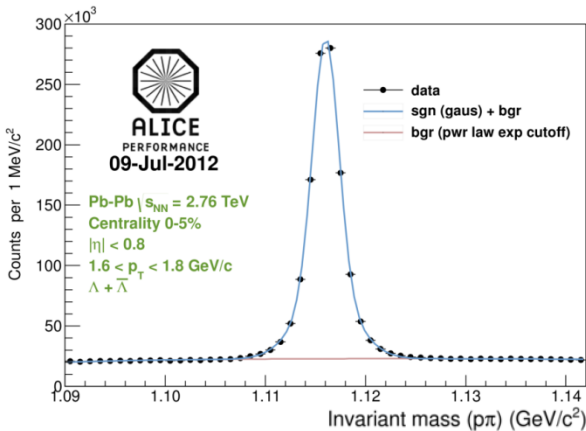
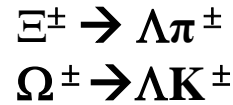
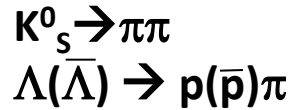


Identification at high p_T with TPC:

- purity cut on the TPC dE/dx signal:
- p_T range (in GeV/c):
 - π and p $\rightarrow 3 < p_T < 16$
- purity: $> 90\%$ for pions, $> 80\%$ for protons



K^0_s , Λ , Ξ , Ω and ϕ reconstruction

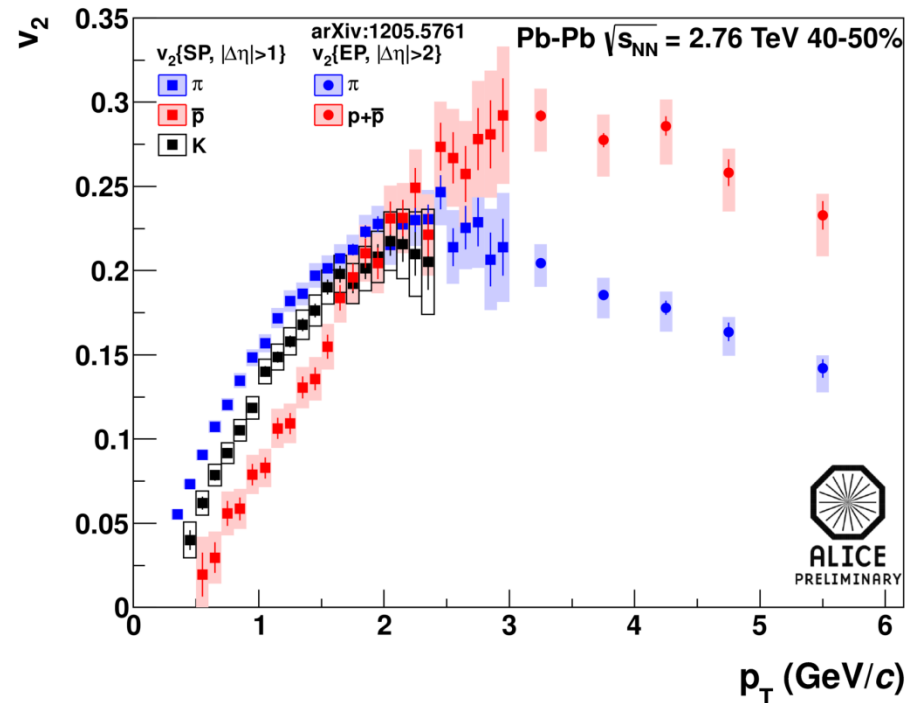
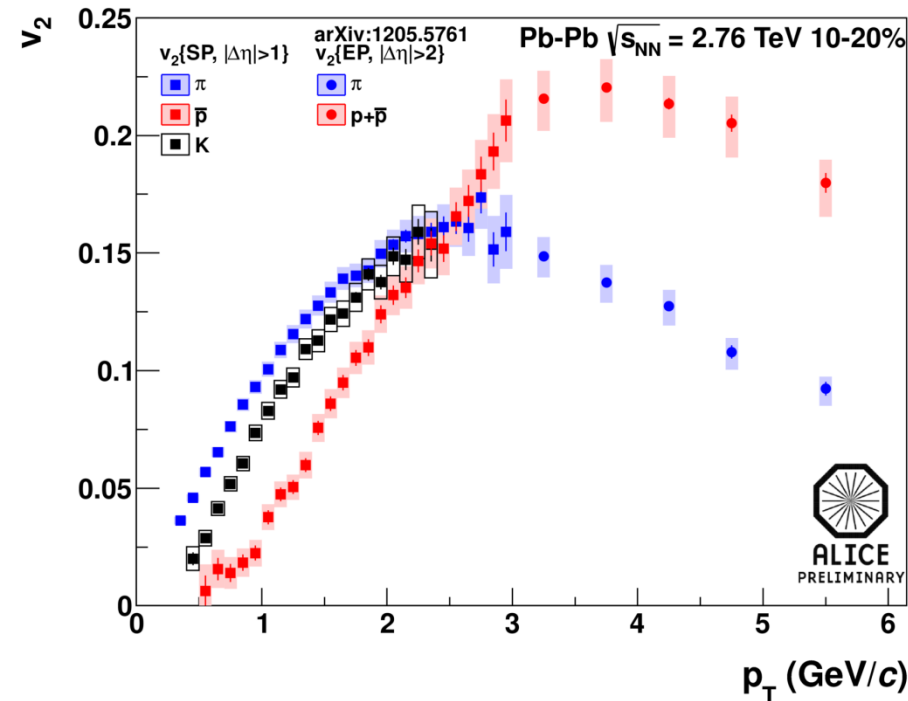


Details on v_2 of K^0_s , Λ , Ξ and Ω :
 See poster #147 by C. Perez Lara

Details on ϕ -meson v_2 :
 See poster #414 by Y. Zhou

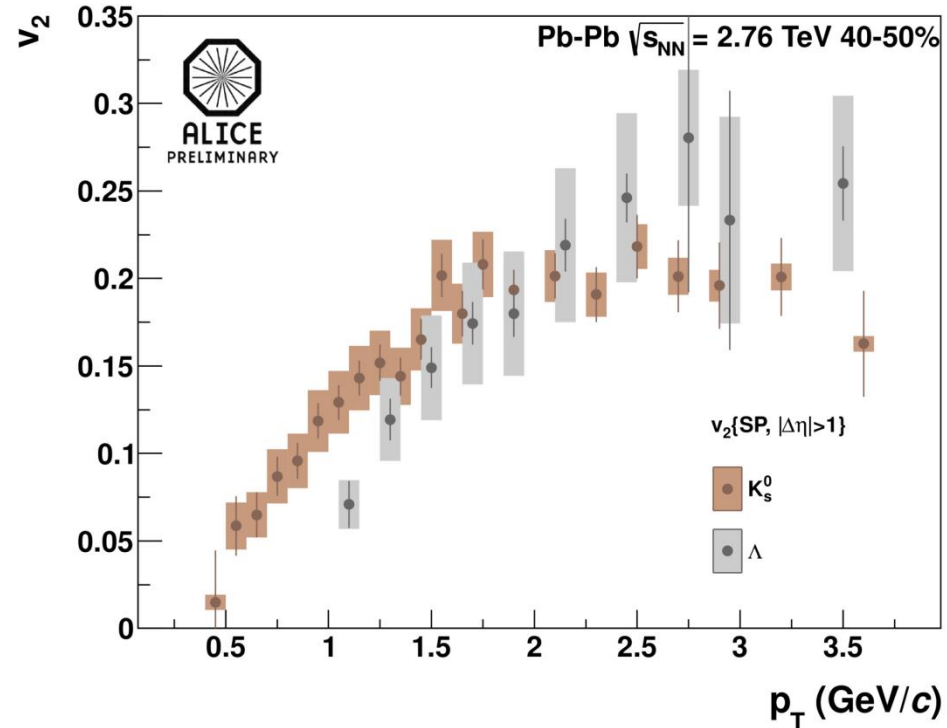
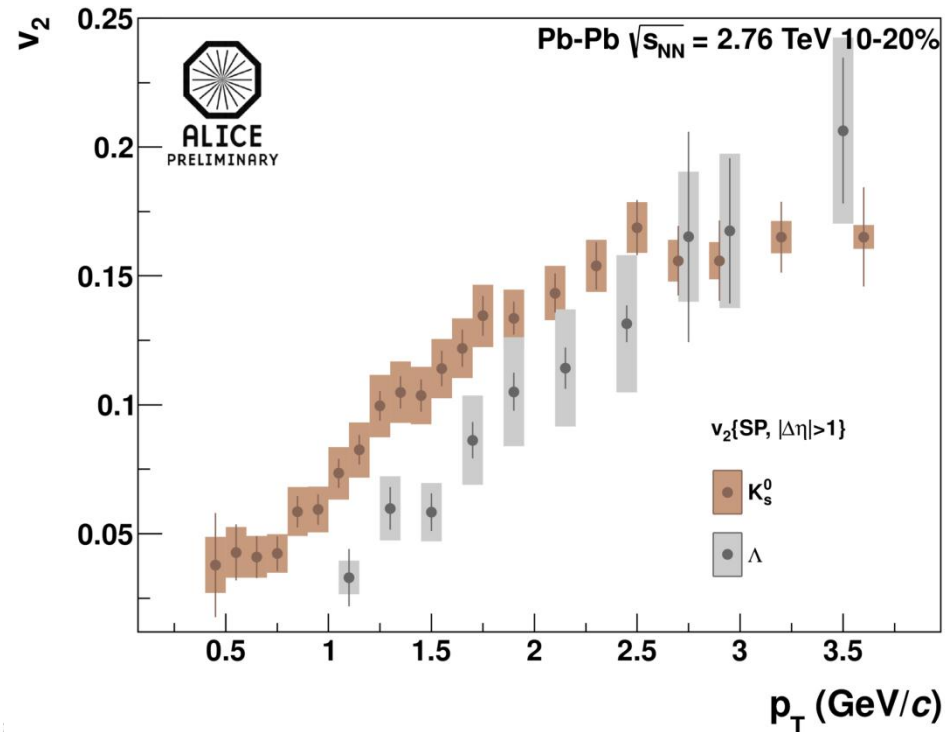
Elliptic flow of identified particles

Elliptic flow of π , K and p



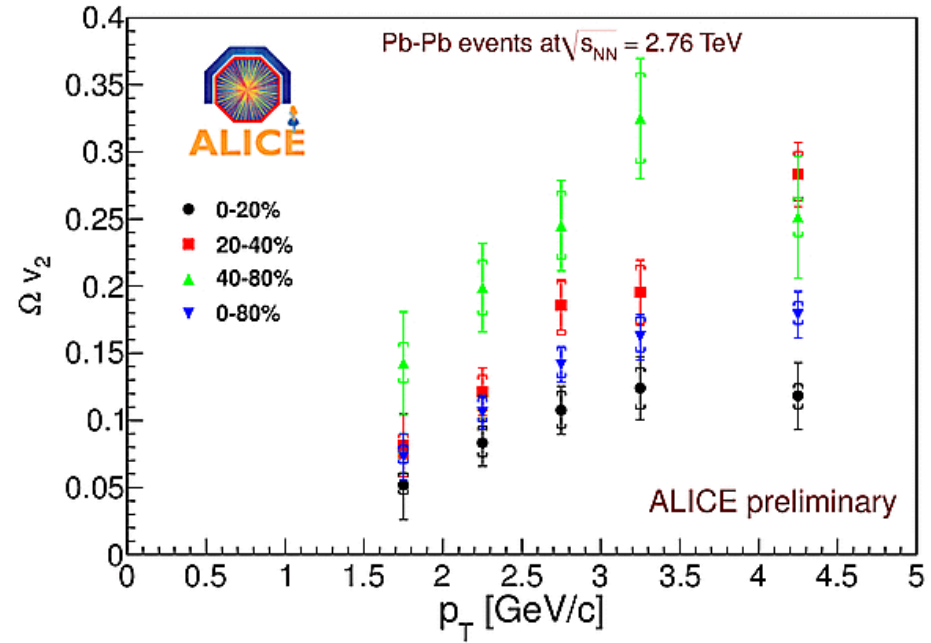
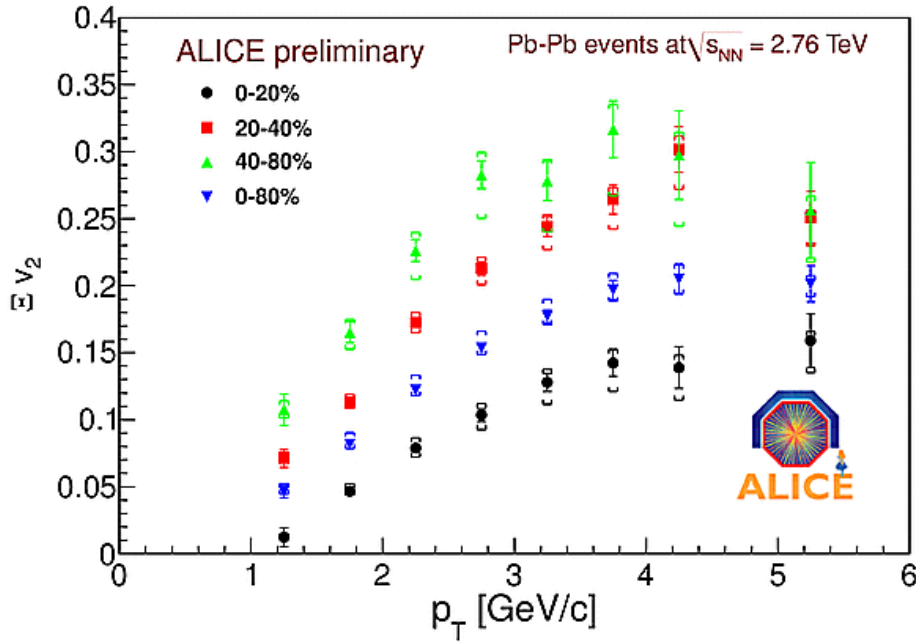
- Mass ordering observed for different species. p_T value at which v_2 is the same for all species is higher for heavier particle (in the region $p_T < 2-3$ GeV/c)
- Mass dependence persists up to high transverse momenta

Elliptic flow of K_s^0 and Λ



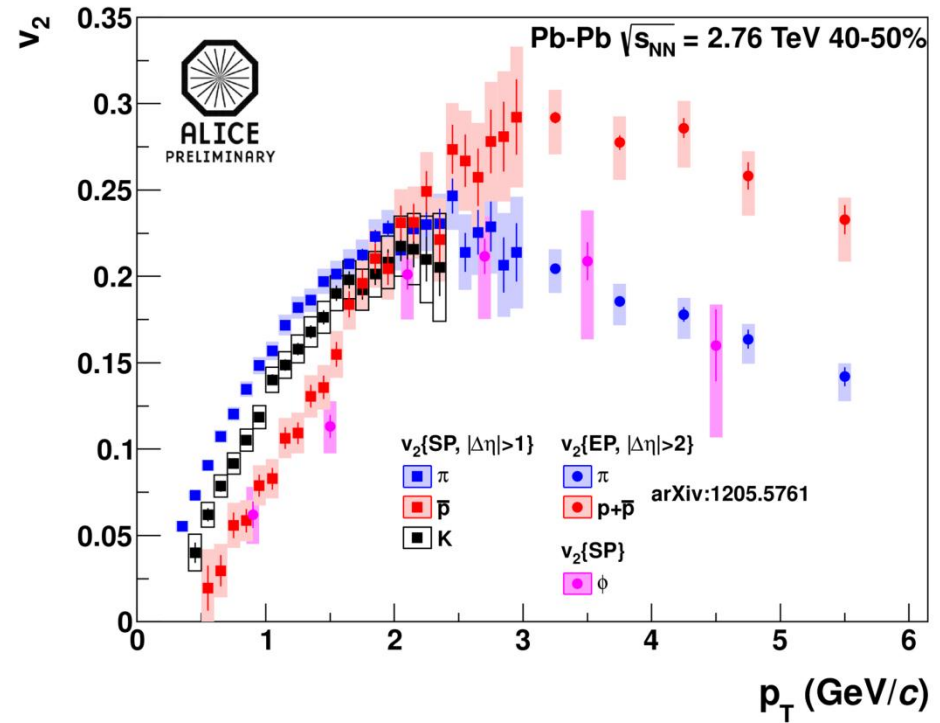
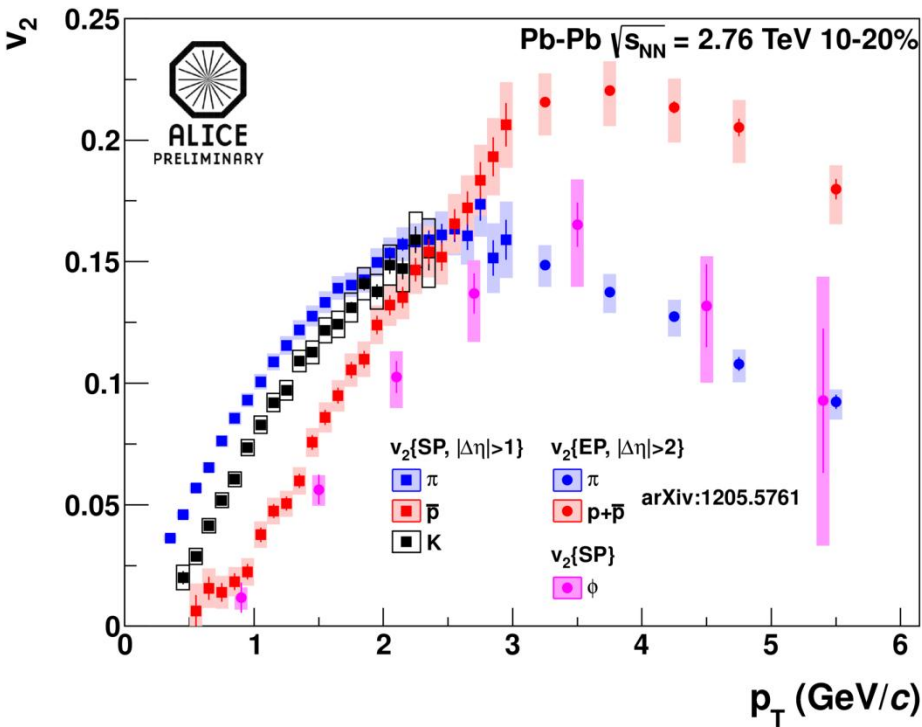
Mass ordering is similar to v_2 of charged kaons and protons

Elliptic flow of Ξ and Ω



v_2 of heavier particles (Ξ and Ω) are shifted more to higher p_T

v_2 of ϕ -meson

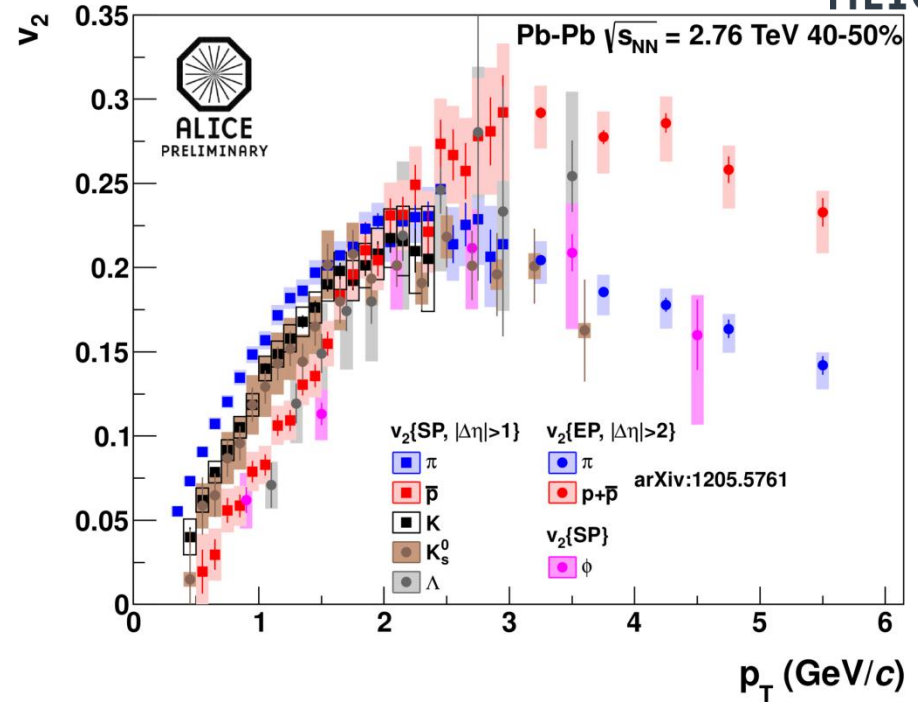
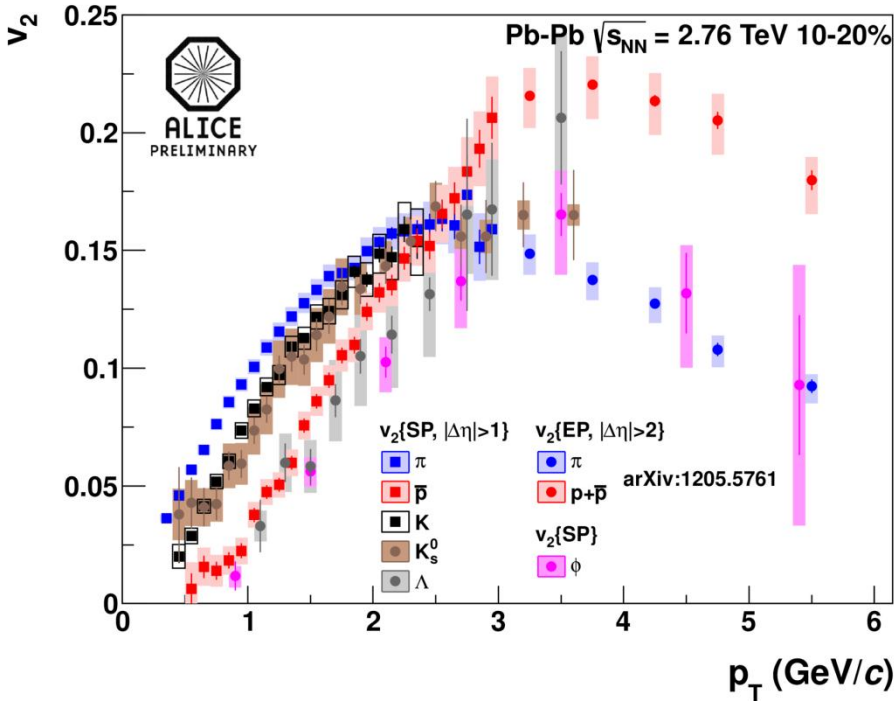


- at low p_T (where flow is affected by radial boost): ϕ -meson v_2 is similar to v_2 of (anti-)protons which has a similar mass
- at high p_T (where coalescence expected to be applicable) ϕ -meson v_2 is similar to v_2 of pions (light quark flavour mesons)

Overview of v_2 of all measured species



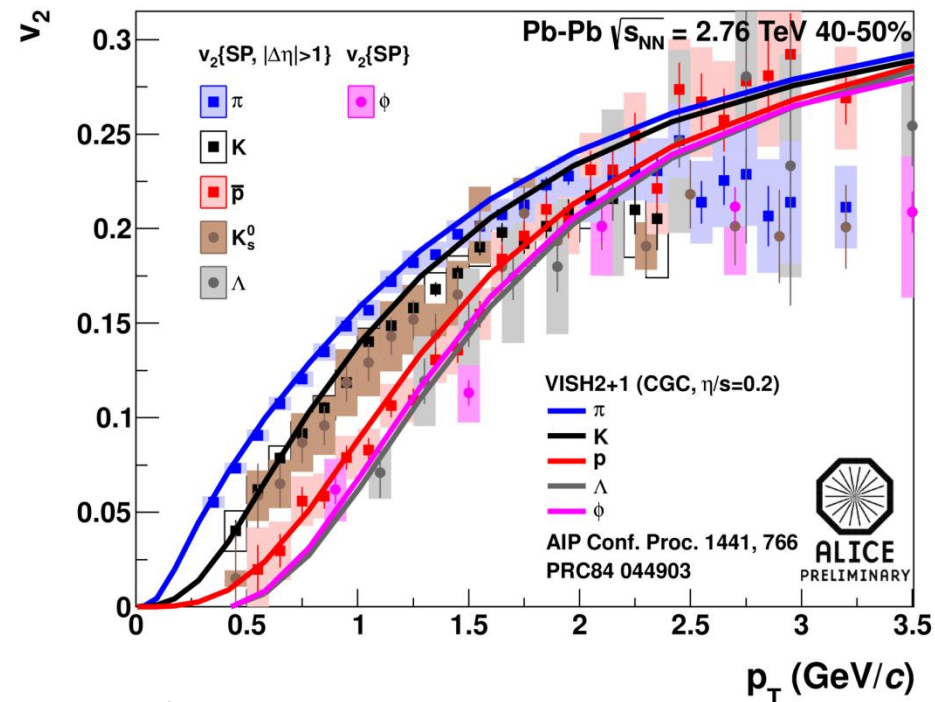
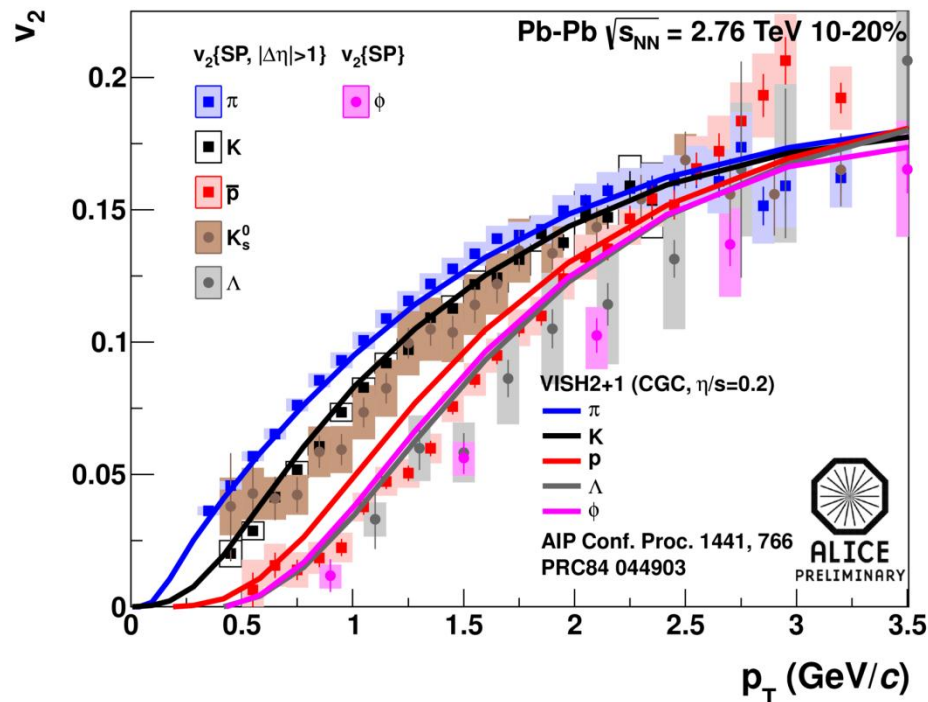
ALICE



- v_2 is measured for a number of particles with light and strange quark content: $\pi, K, p/\bar{p}, K_s^0, \Lambda, \Xi, \Omega$ and ϕ
- Evident mass hierarchy at low and high p_T which changes with the collision centrality
- For v_2 of particles with heavy quark content see:
 - D-meson: talk #460 by D. Caffarri
 - Poster #413 by G. Luparello
 - J/Ψ : talk #473 by H. Yang
 - Heavy flavour electrons: talk #470 by S. Shingo
 - Poster #410 by T. Raascanu and Poster #416 by D. Moreira de Godoy

Comparison with hydrodynamic model calculations

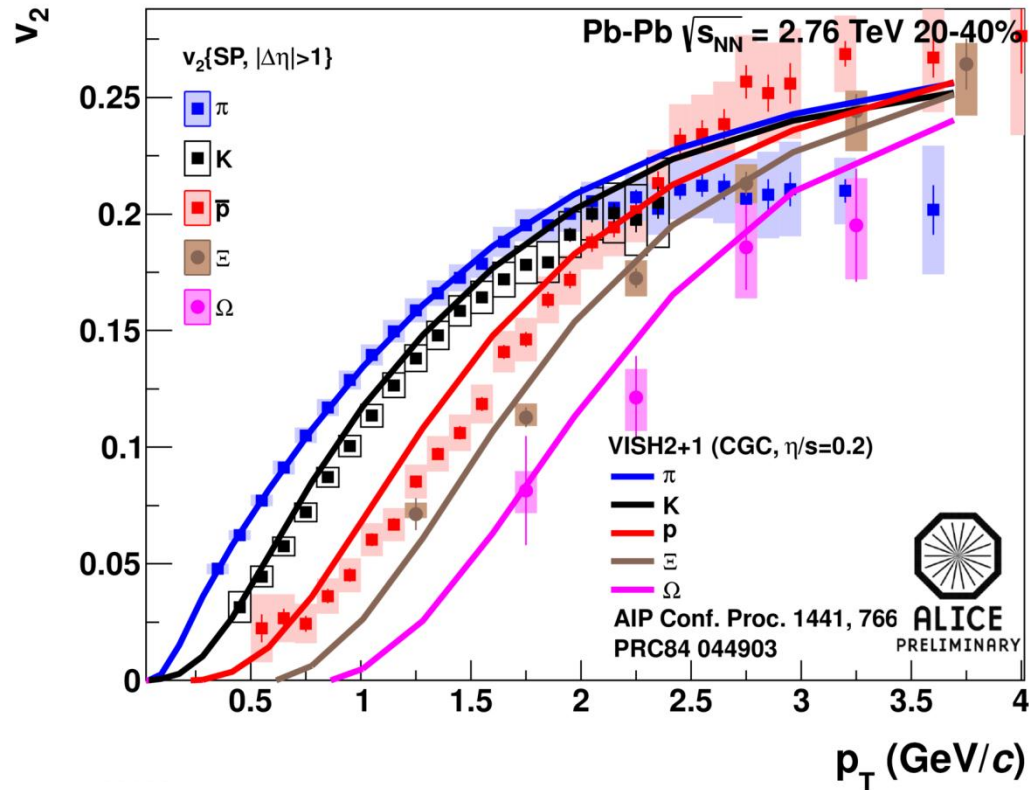
Identified particle v_2 vs. hydro



Viscous hydrodynamic model calculations reproduce the main features of v_2 at low transverse momentum:

- mass dependence is better modelled for peripheral collisions
- for central collisions overestimate proton flow
- Adding hadronic rescattering phase improves the agreement with data
Heinz, Shen, Song, AIP Conf. Proc. 1441, 766 (2012)

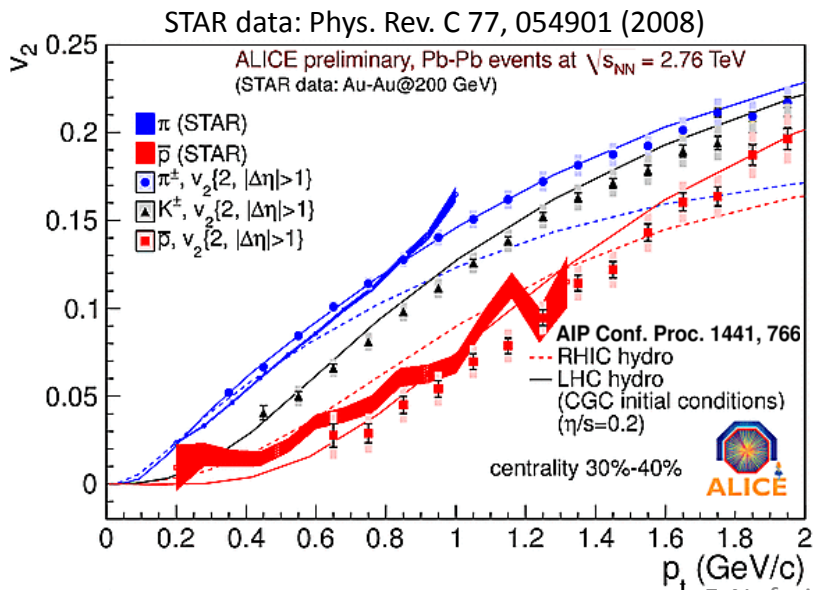
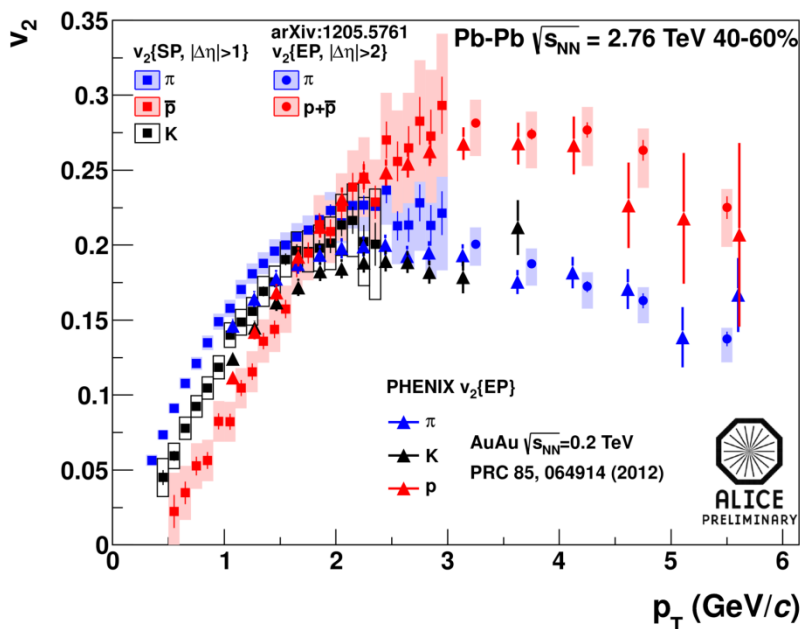
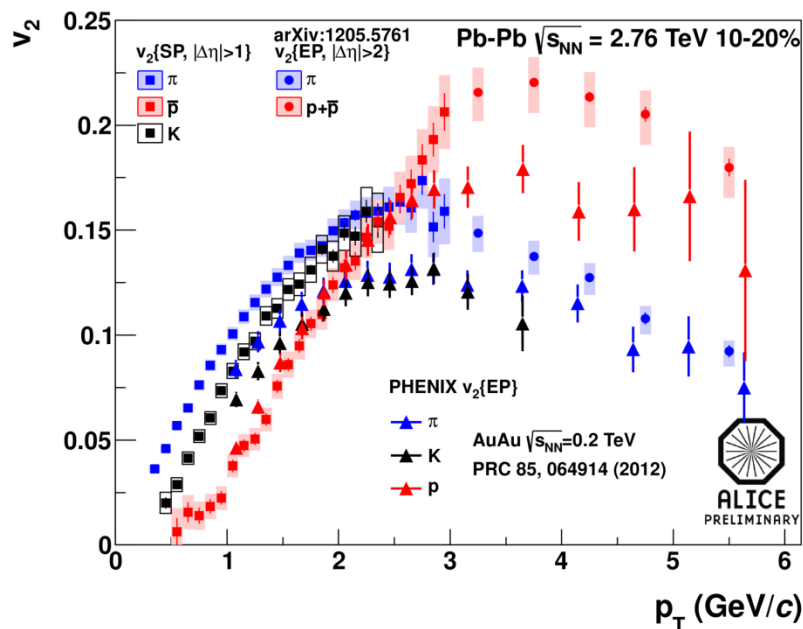
v_2 and Ω flow vs. hydro



Hydrodynamic model calculations reproduce larger boost towards higher p_T for Ξ and Ω (Heinz, Shen, Song, AIP Conf. Proc. 1441, 766 (2012); PRC84 044903)

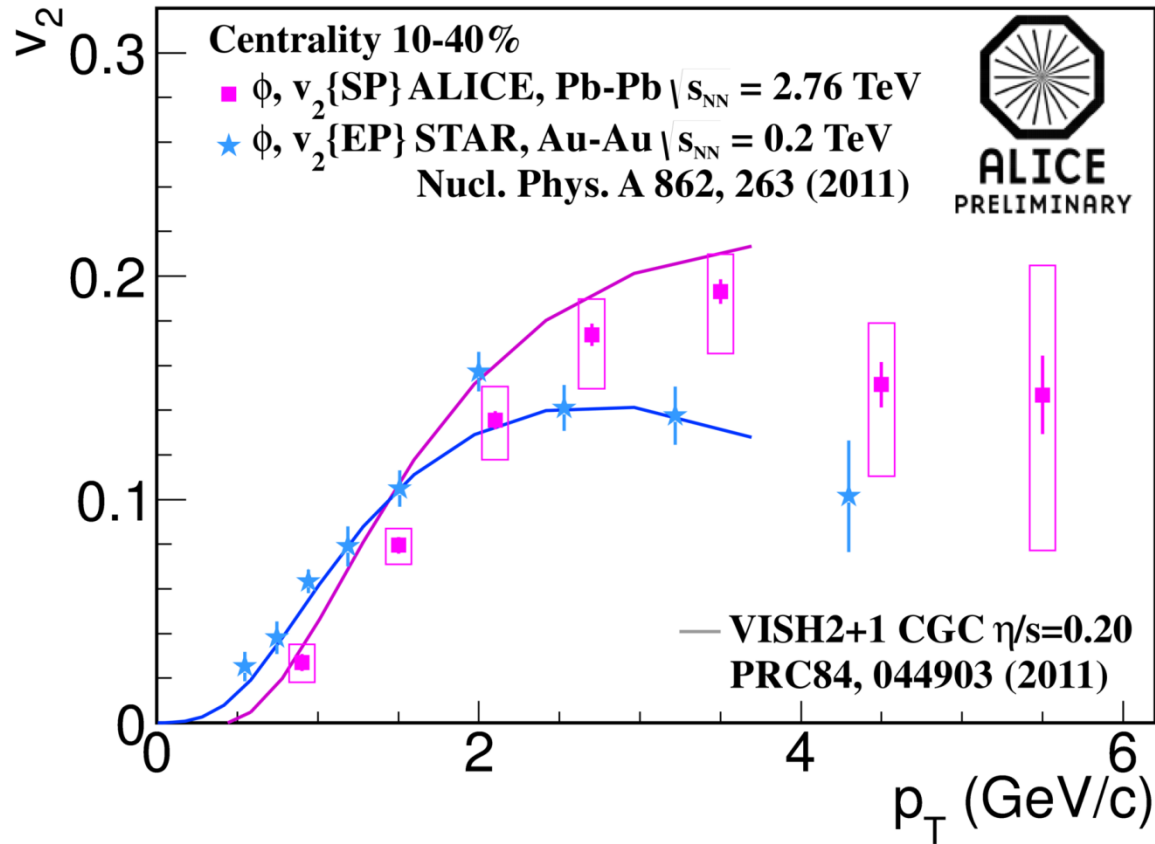
Comparison with RHIC data

v_2 of π , K, p at LHC vs. RHIC



- v_2 measured at the LHC is slightly above the RHIC v_2 for pions and kaons
- v_2 of (anti-)protons reflects effect of larger radial flow at LHC

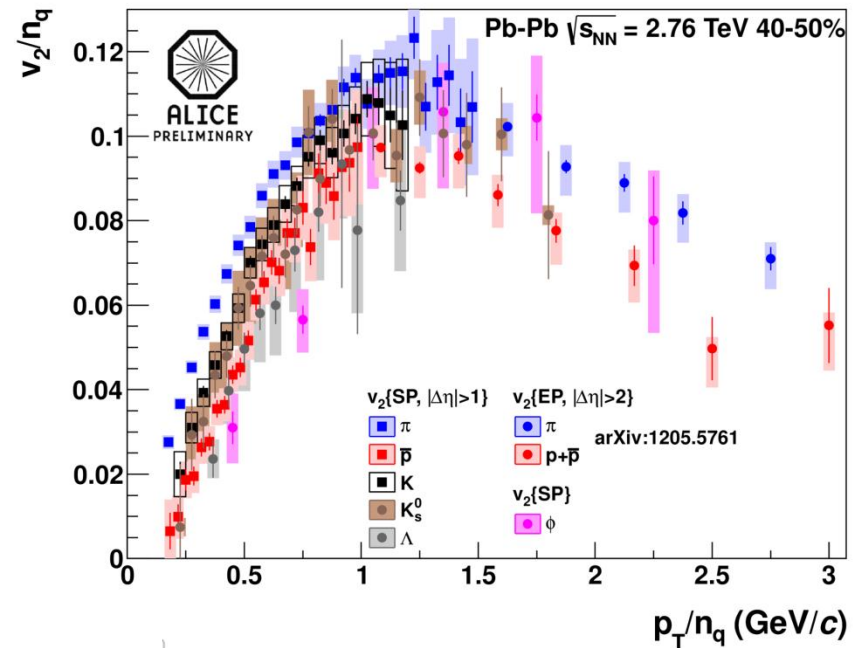
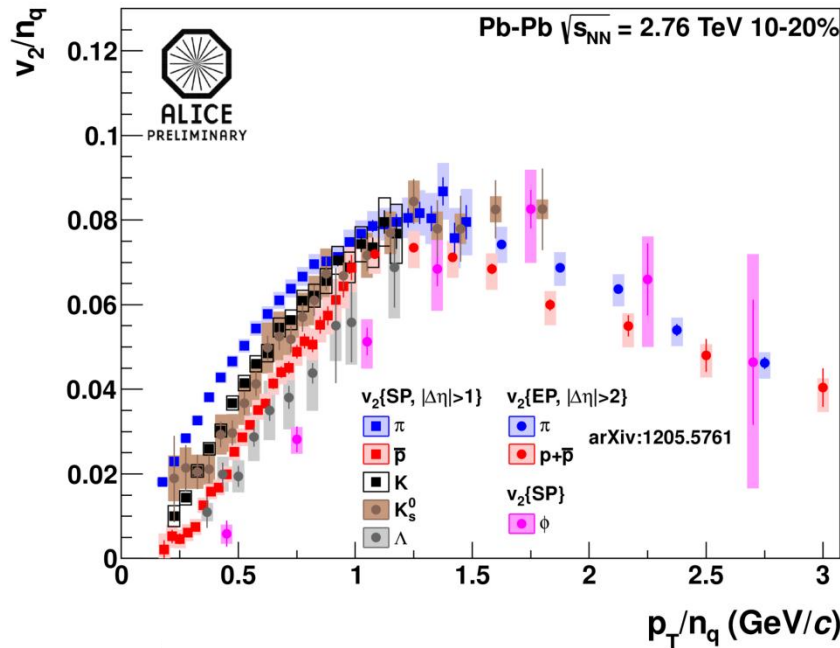
v_2 of ϕ -meson at LHC vs. RHIC



Similarly, the ϕ meson v_2 is compatible with larger radial flow at LHC

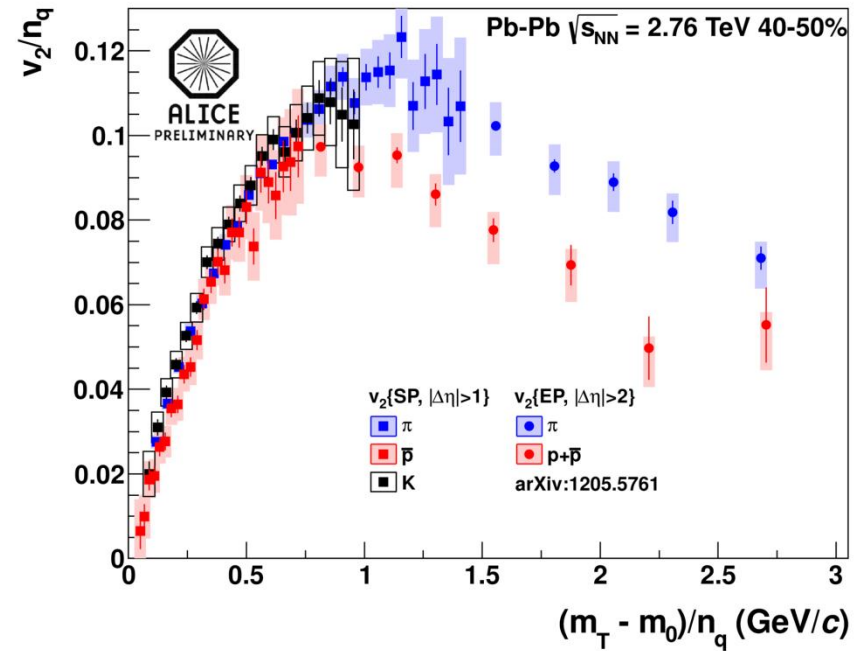
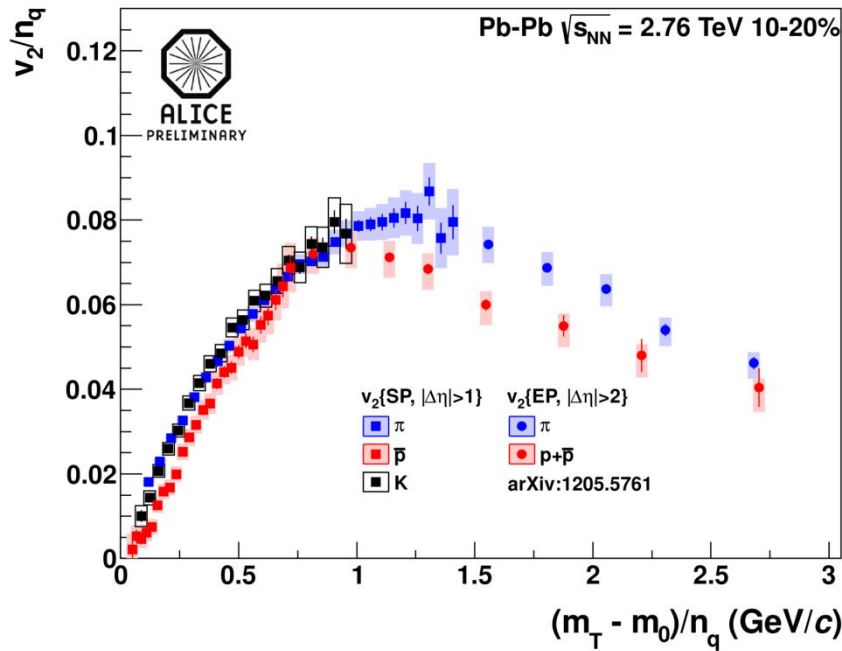
Elliptic flow scaling properties

Number of Constituent Quarks (NCQ) scaling of v_2



- v_2 measured in the p_T region of 3-6 GeV/c can be used to test the model of the hadron production via quark coalescence
- v_2/n_q vs. p_T/n_q (n_q is the number of quarks per meson/baryon) shows that if such scaling exists it is only approximate (holds within 20%)

NCQ scaling of v_2 vs. transverse kinetic energy



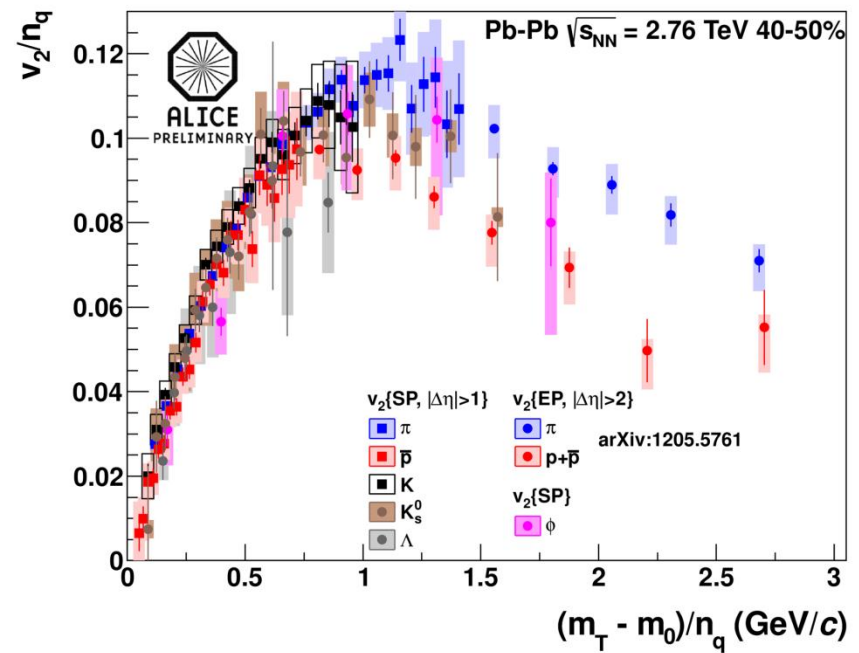
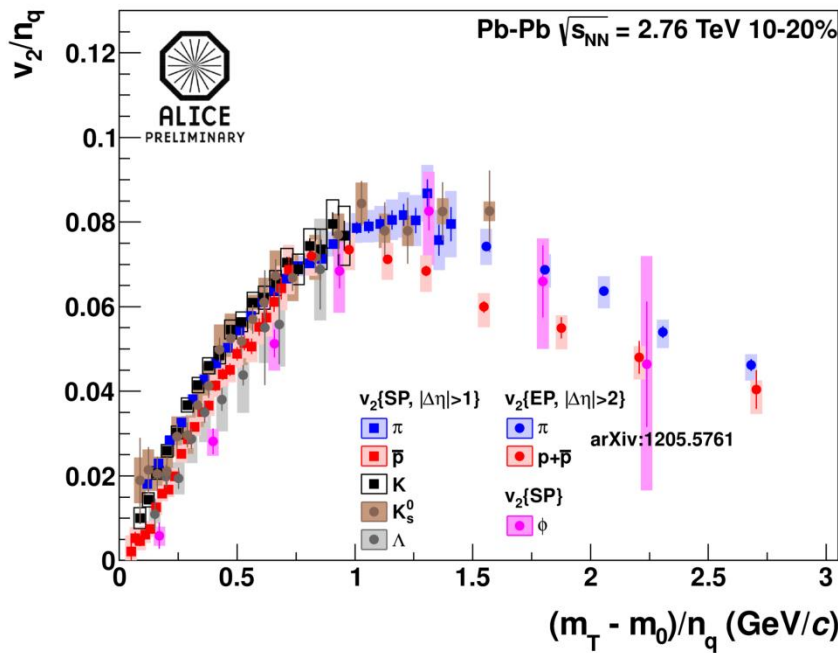
$$m_T = \sqrt{m^2 + p_T^2}$$

$KE_T = \text{Transverse Kinetic Energy} = m_T - m_0$

- For low p_T : v_2/n_q together with KE_T scaling is violated at LHC
- For $KE_T/n_q > 1$ GeV/c antiproton's v_2 is lower than that of pions



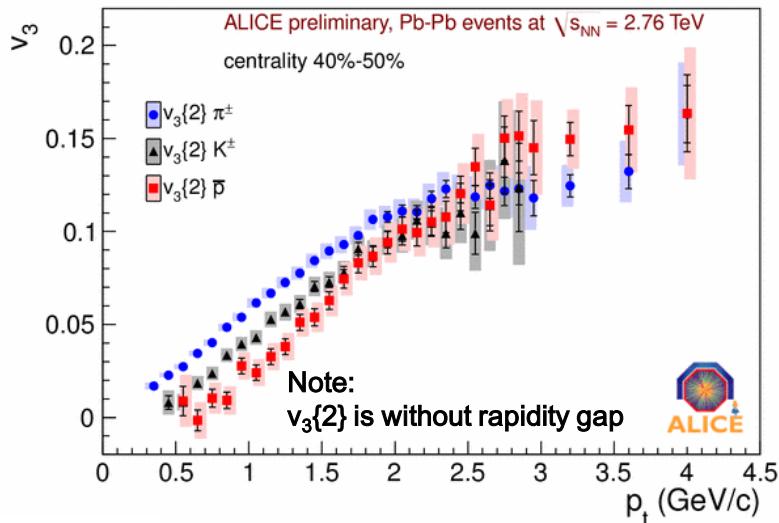
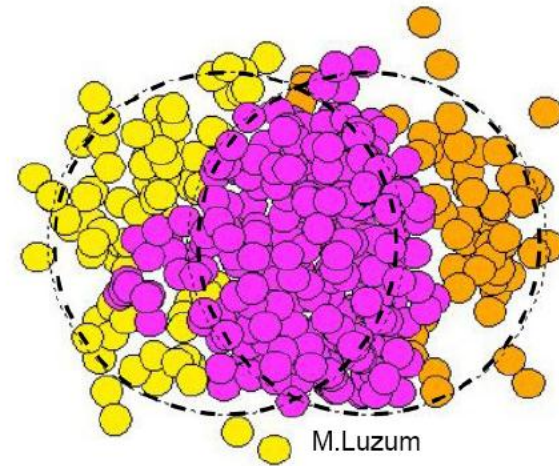
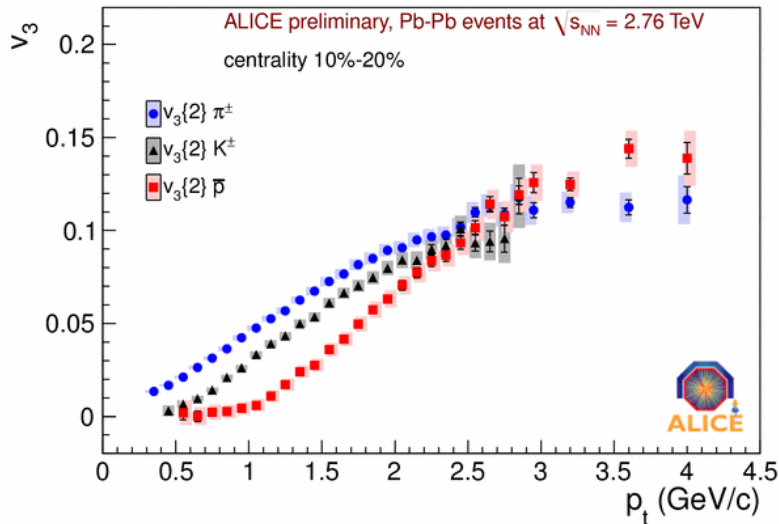
v_2/n_q and KE_T scaling for all species



NCQ scaling maybe violated also for heavier particles, including the ϕ -meson

Identified particle triangular flow

Triangular flow

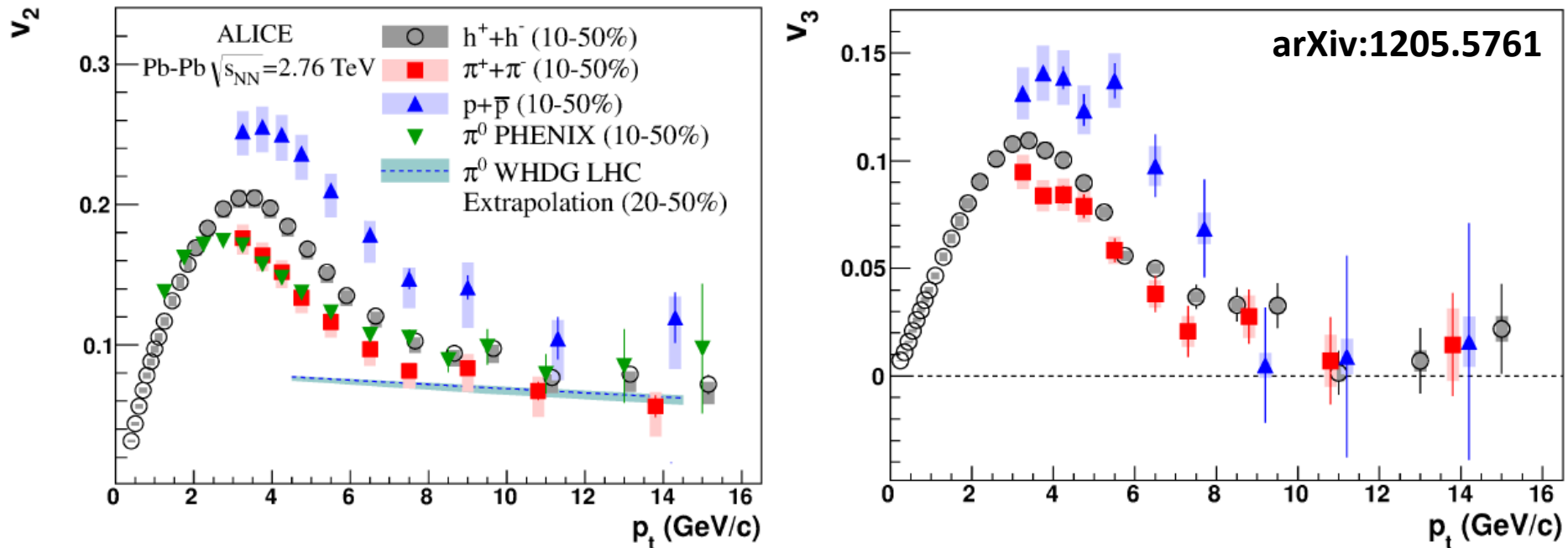


- v_3 (which originates solely from flow fluctuations) exhibits similar particle mass dependence as that of v_2
- The value of p_T at which v_3 of all species cross looks similar to that for v_2

Elliptic and triangular flow at high transverse momentum



WHDG: Horowitz, Gyulassy, J. Phys. G **38**, 124114 (2011)



- up to $p_T \sim 8$ GeV/c, proton v_2 and v_3 is larger than that of pion
- pion/proton v_2 at high transverse momenta ($p_T > 10$ GeV/c) is significant and non-zero, while within experimental uncertainties v_3 is consistent with zero

Summary

Elliptic flow of π , K, p, Λ , Ξ , Ω and ϕ is measured vs. transverse momentum for different collision centrality classes for Pb-Pb collision at 2.76 TeV:

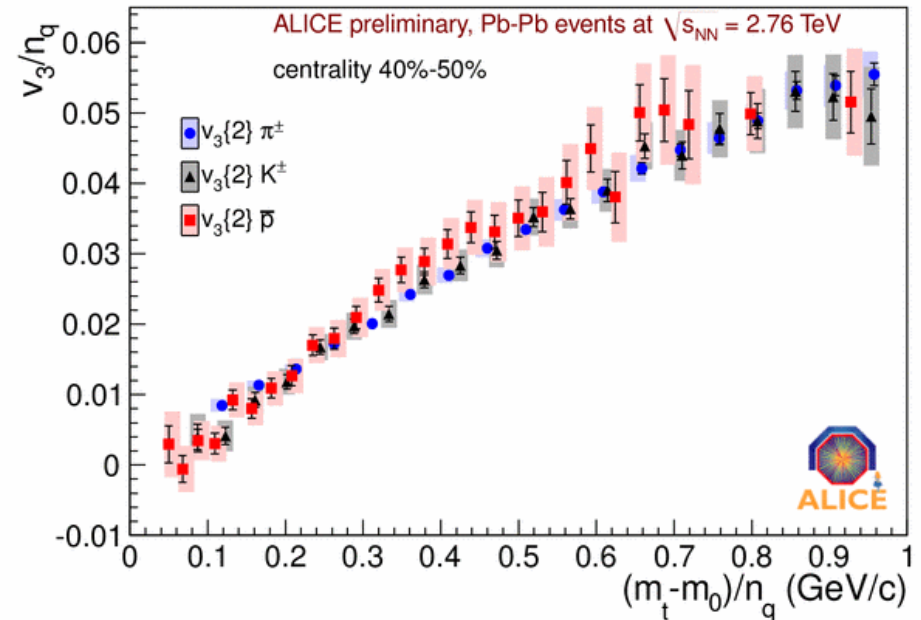
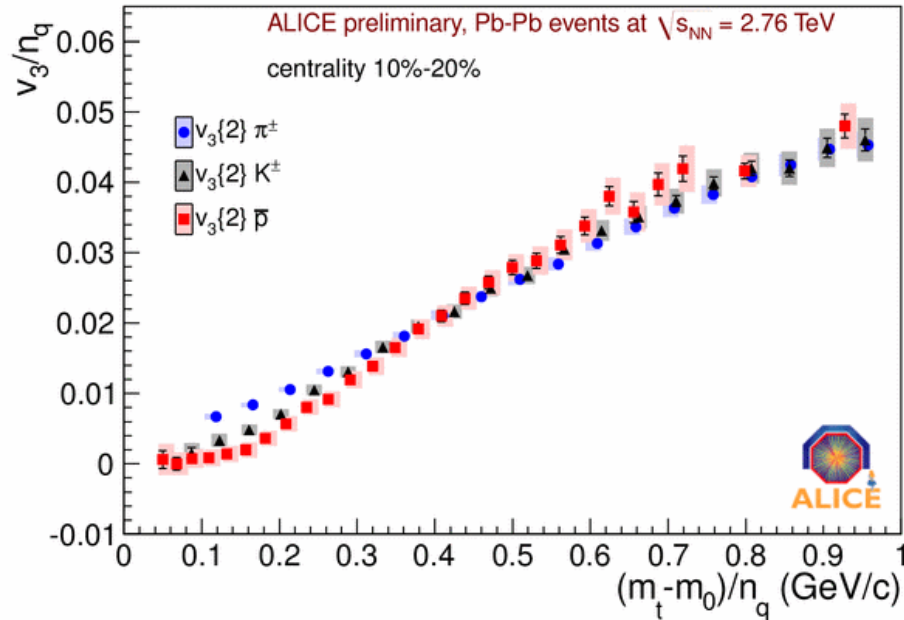
- $p_T < 3$ GeV/c: observed mass dependence is reproduced by the hydrodynamic model calculations (VISH2+1 CGC, VISHNU)
- The larger mass splitting of v_2 to higher p_T observed by ALICE is consistent with stronger radial flow at the LHC
- KE_T scaling does not hold at the LHC
- $p_T \sim 3-6$ GeV/c: constituent number of quark scaling holds only approximately (within 20%)
- $p_T \sim 6-8$ GeV/c: mass dependence persist up to high transverse momenta with proton flow being larger than that of pion up to $p_T \sim 8$ GeV/c
- v_3 of π , K, and p/\bar{p} has a similar mass dependence and crossing point as that of v_2



ALICE

Backup

NCQ scaling of triangular flow



NCQ scaling of v_3 works better than for v_2 but it is still only approximate