Anisotropic Flow of Identified Particles in Pb-Pb Collisions with the ALICE detector

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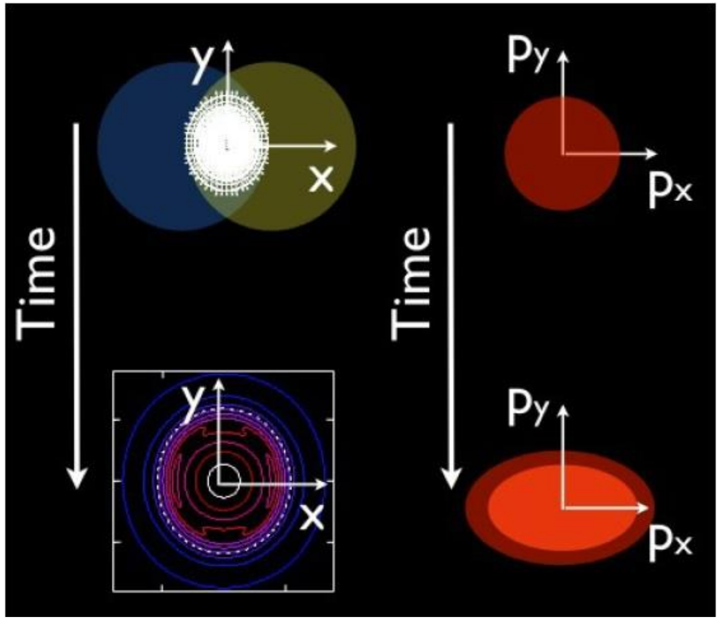
Winter School on Heavy Ion Physics

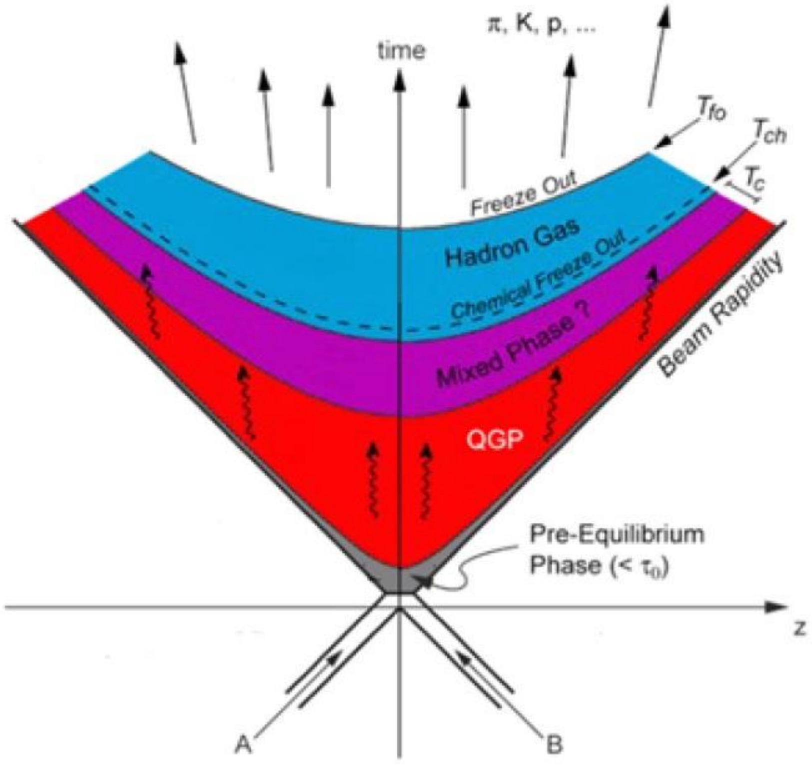
Collective phenomena and flow

- Hot QCD matter is created in HIC: strongly interacting phase
- No direct experimental access to it
- One of the main probes to this phase is **anisotropic flow**



Anisotropic flow:

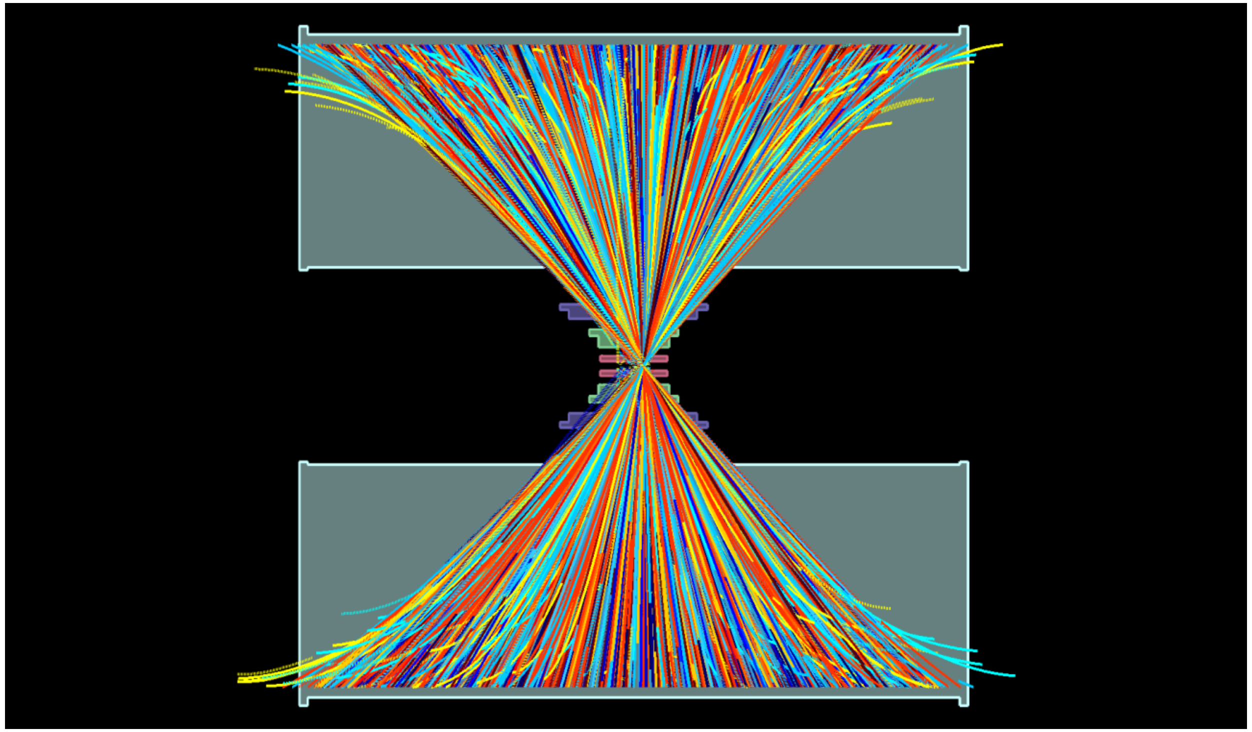
- Initial space asymmetry is converted into momentum anisotropy of the produced particles
- This anisotropy is quantified by Fourier decomposition of azimuthal distribution

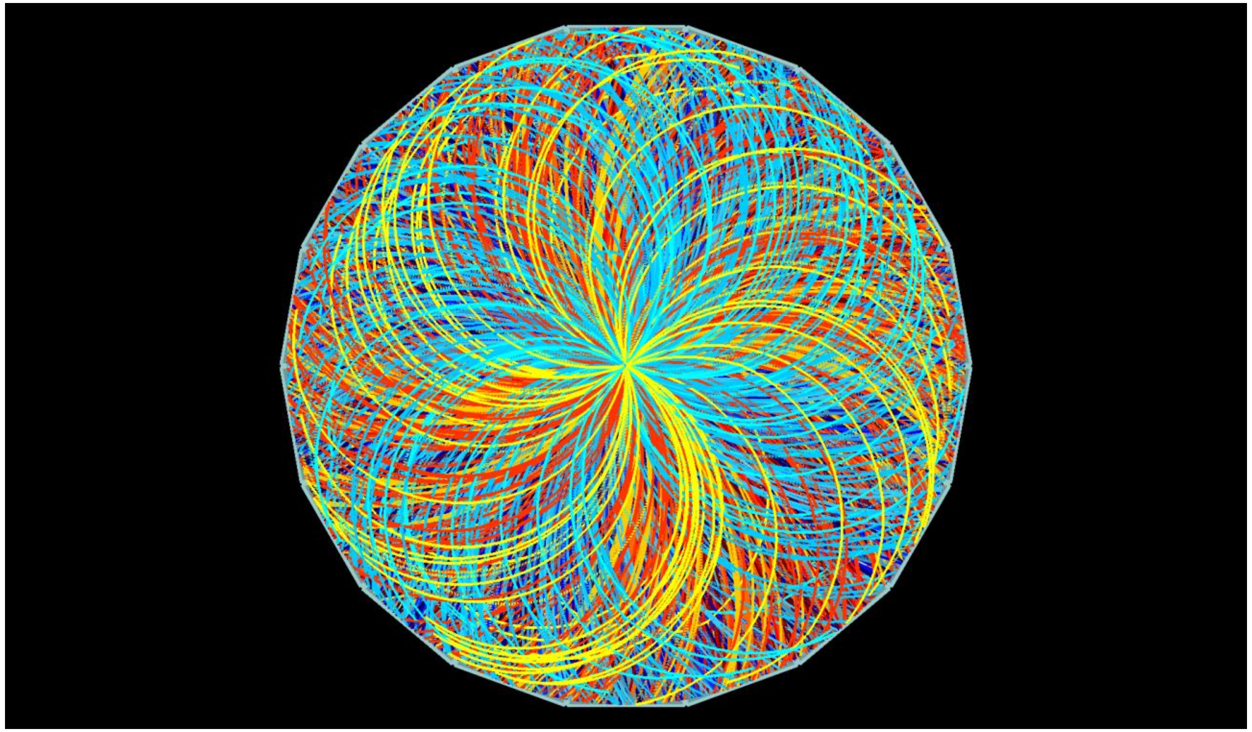


$$v_n = \langle \cos[n(\varphi - \Psi_n)] \rangle$$

How do we measure anisotropic flow in ALICE?

See also: PRL 105:252302,2010





$$v_n = \langle \cos[n(\varphi - \Psi_n)] \rangle \qquad \vec{Q}_n = \sum_{i=1}^{M} \cos n\varphi_i \, \hat{x} + \sin n\varphi_i \, \hat{y} \qquad v_n = \left\langle \hat{u}.\frac{\vec{Q}_n}{M} \right\rangle_{m;ev} \times \left\langle \frac{\vec{Q}_n^a . \vec{Q}_n^b}{M_a M_b} \right\rangle_{ev}^{-1/2}$$

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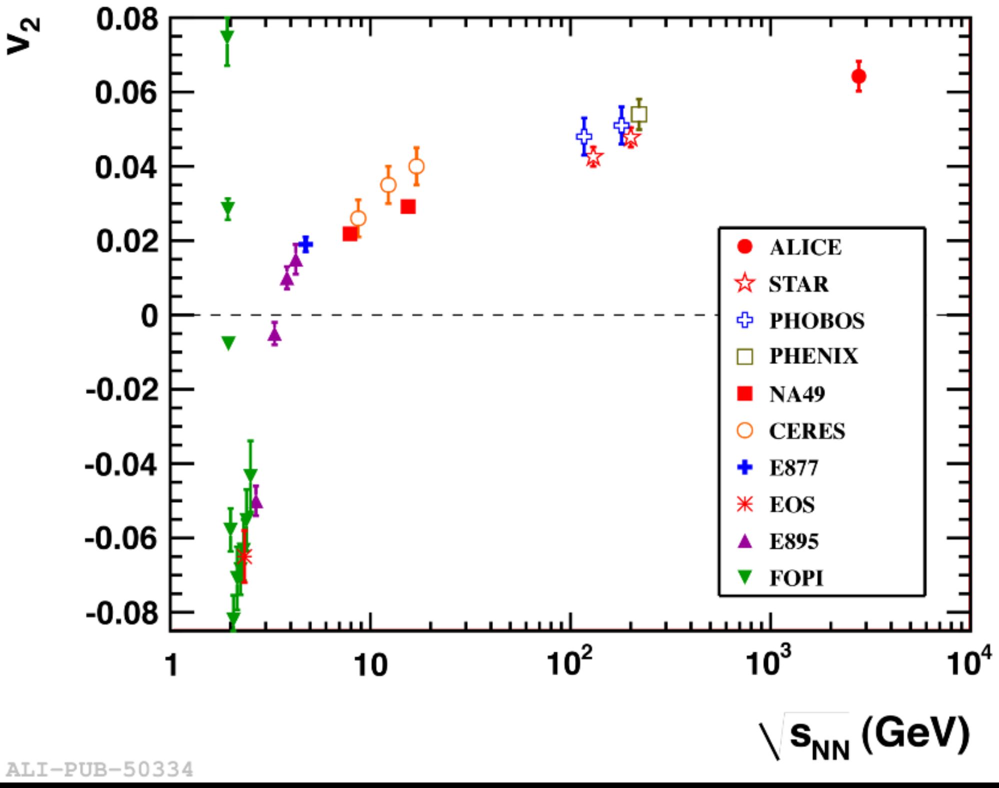
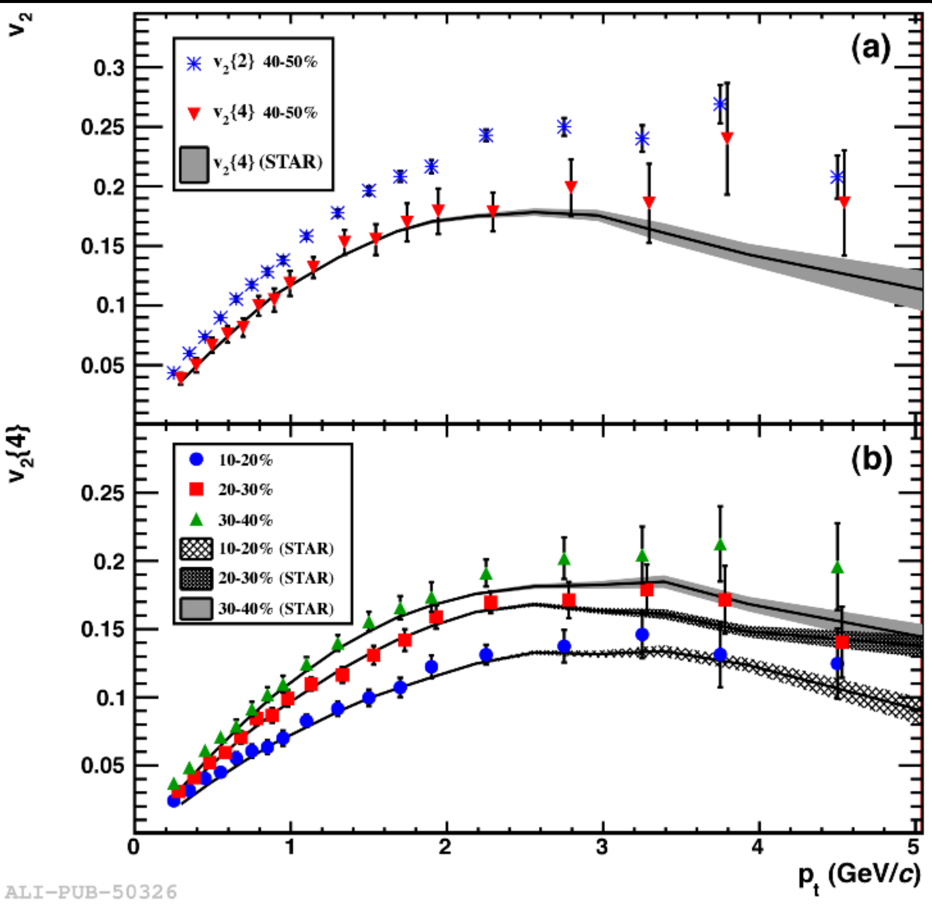
What do we learn from elliptic (n=2) flow?

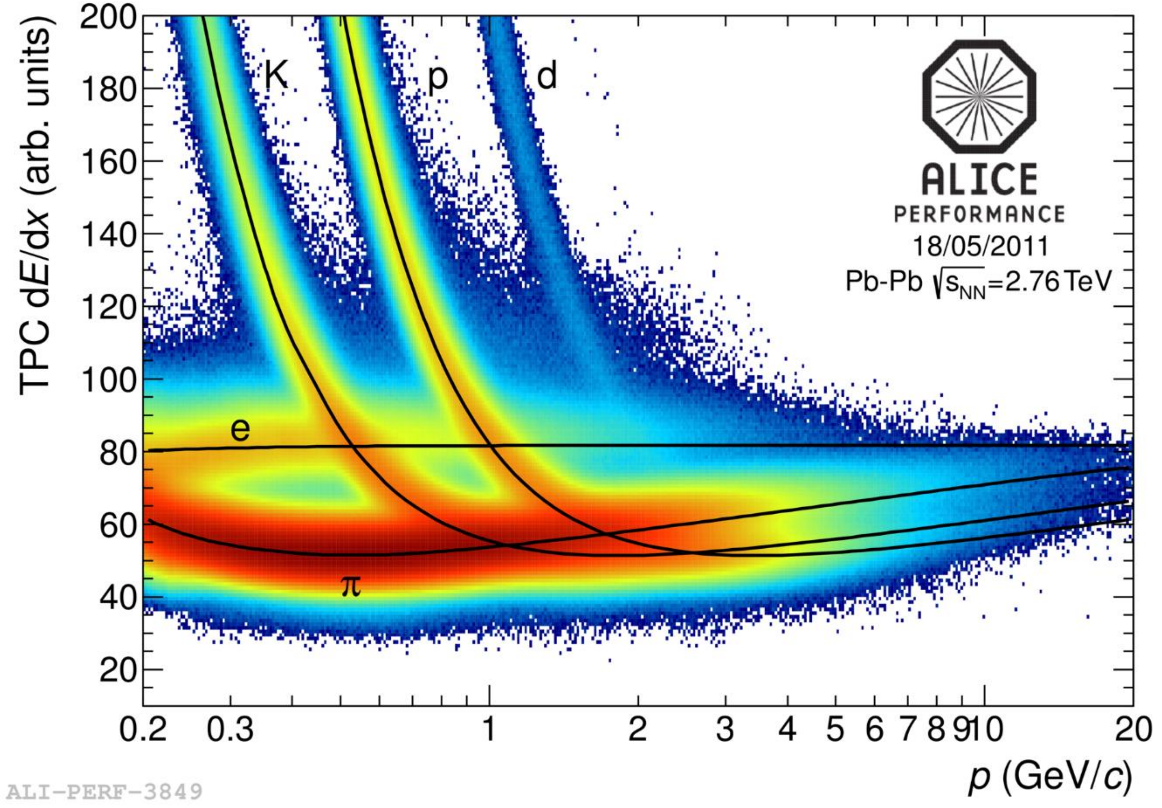
- Fluid with very low viscosity
- At LHC integrated v_2 increases by 30% w.r.t. RHIC
- Constrains η/s

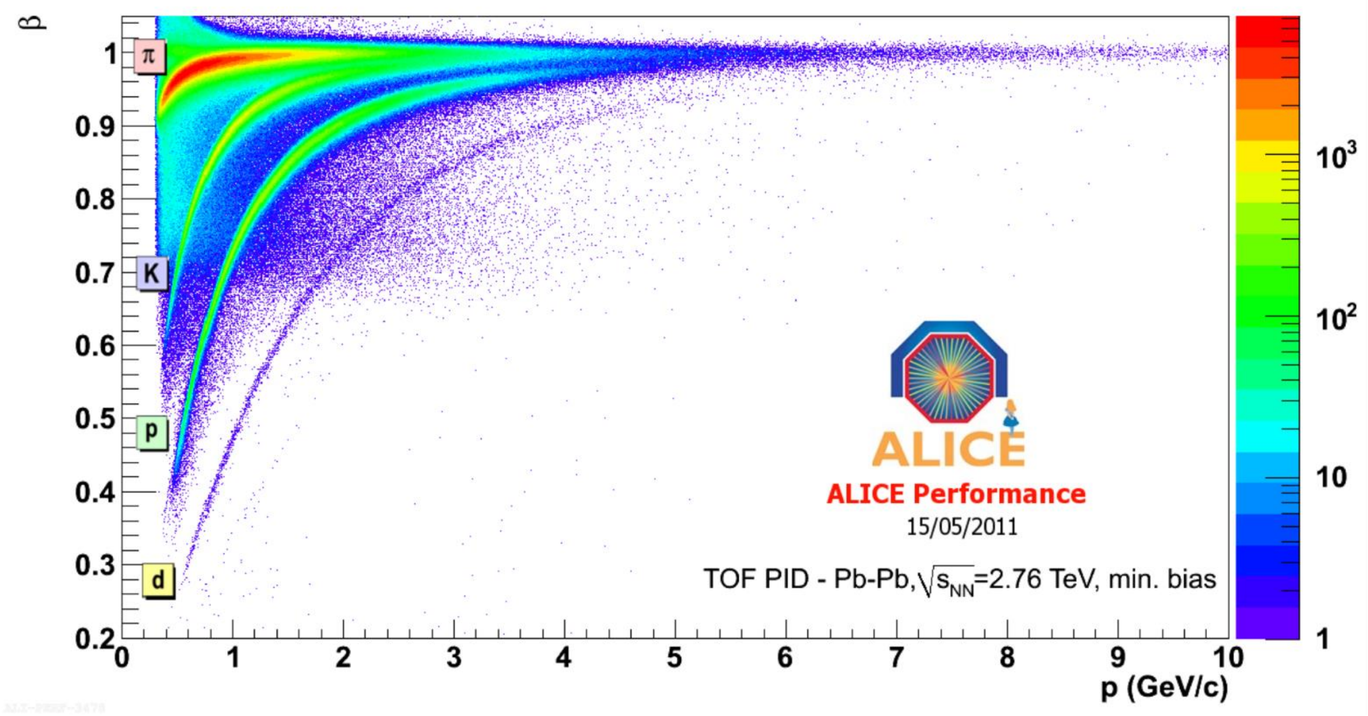


- Differential v_2 similar to RHIC
- Sensitivity to <β>
- PID v_2 : Better understanding of the system behaviour



Particle identification techniques for charged species

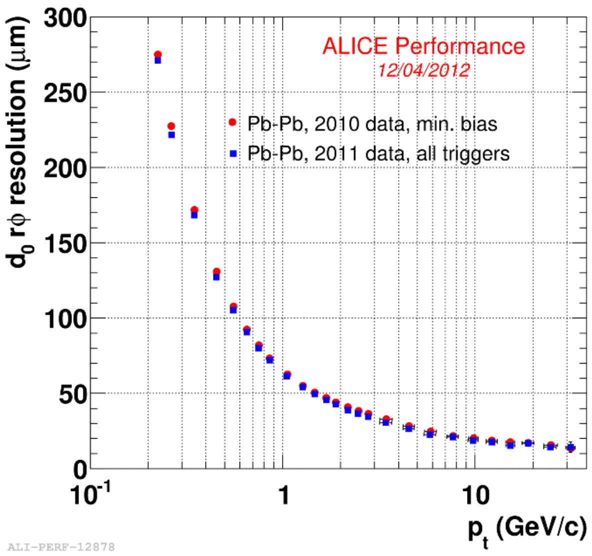


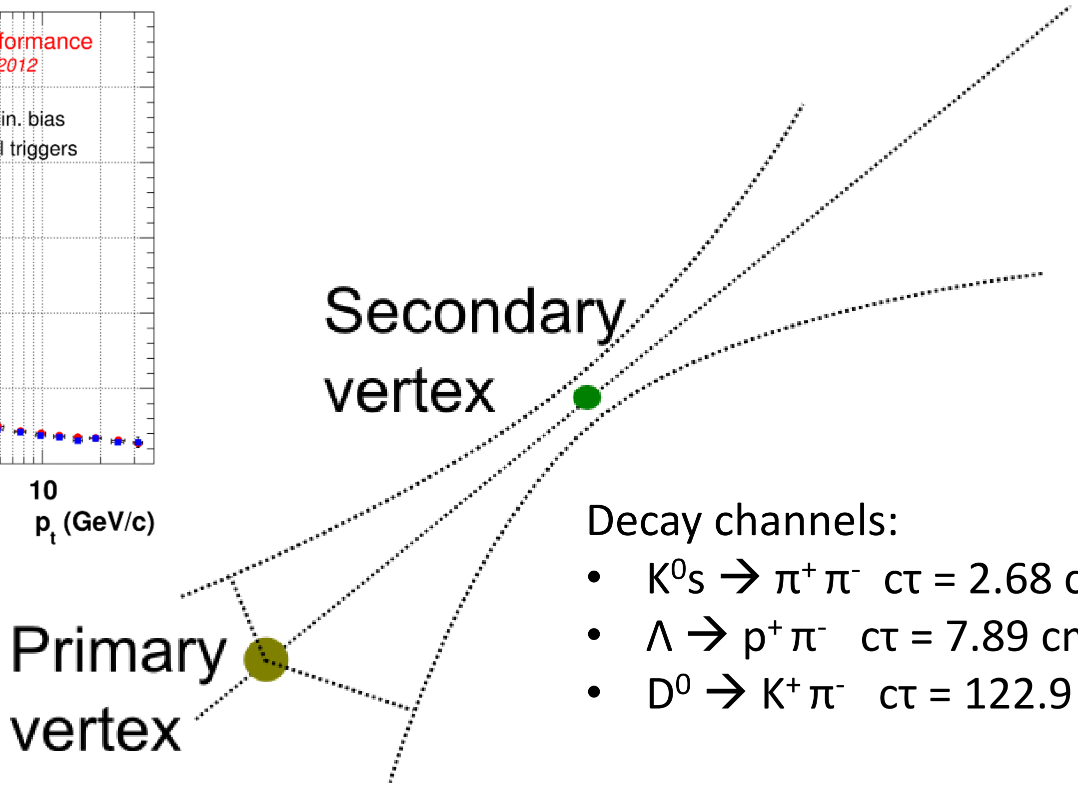


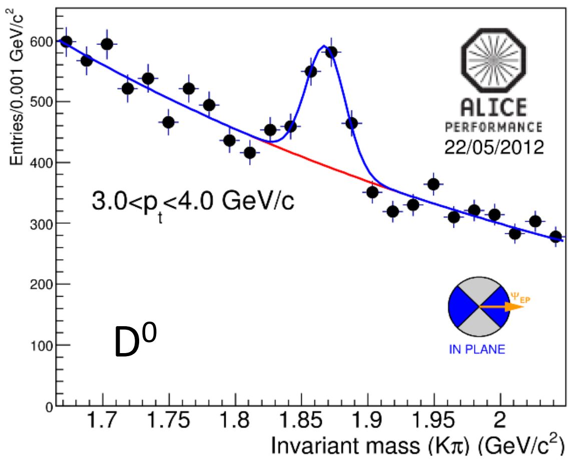
- Excellent PID capabilities using Time Projection Chamber (TPC) and Time of Flight (TOF) detectors

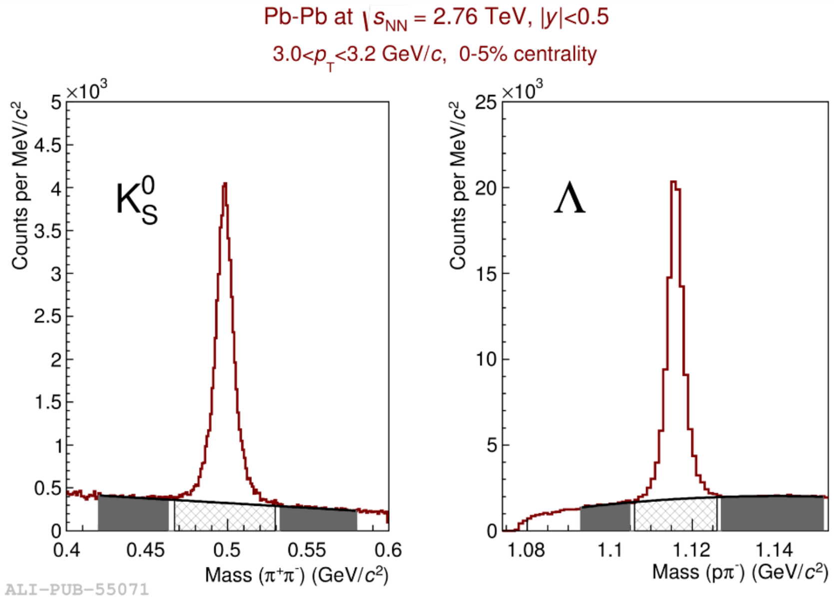
Particle identification techniques for neutral species

- TPC and Inner Tracking System (ITS) provide clear identification based on decay topology
  - Reconstruction of secondary vertex from decay products







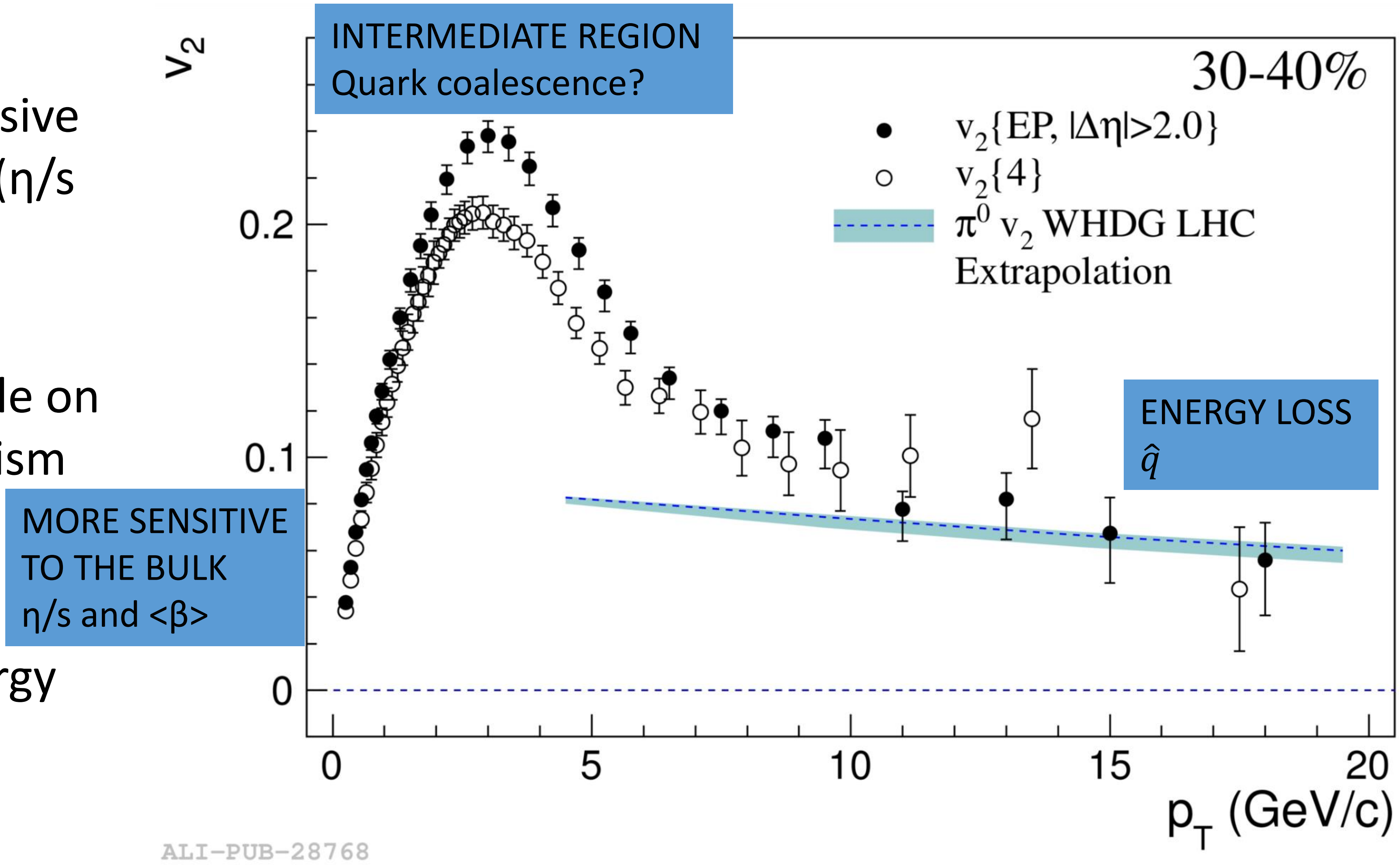


Decay channels:

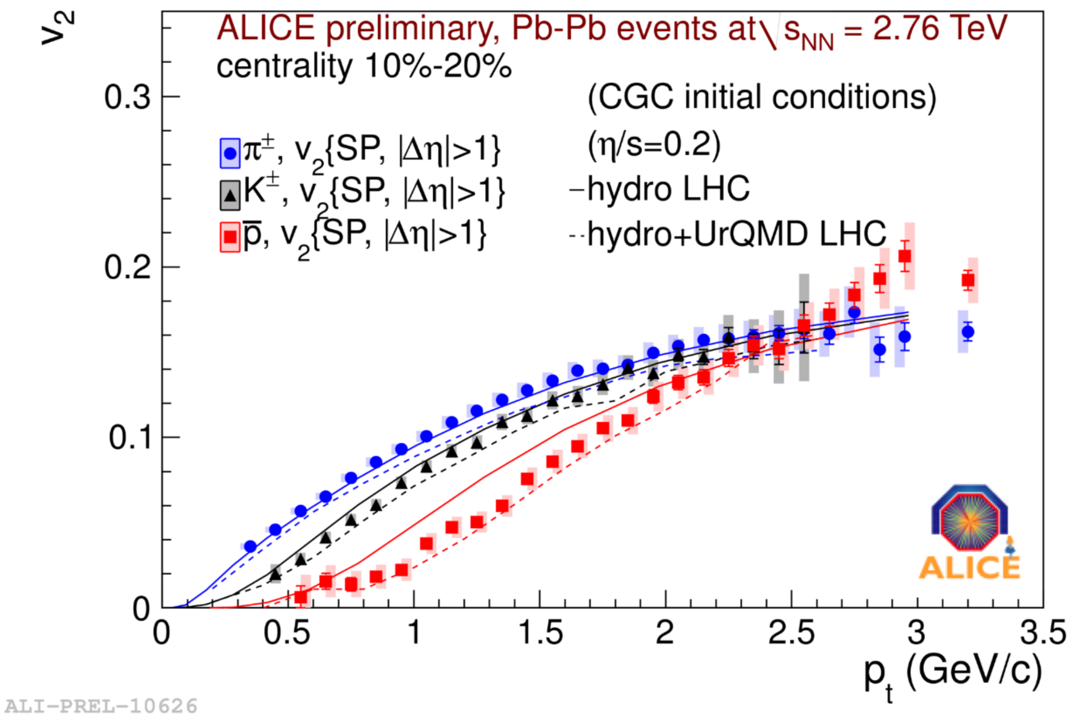
- $K^0s \rightarrow \pi^+\pi^-$ $c\tau$ = 2.68 cm
- $\Lambda \rightarrow p^+\pi^-$ $c\tau$ = 7.89 cm
- $D^0 \rightarrow K^+\pi^-$ $c\tau$ = 122.9 μm

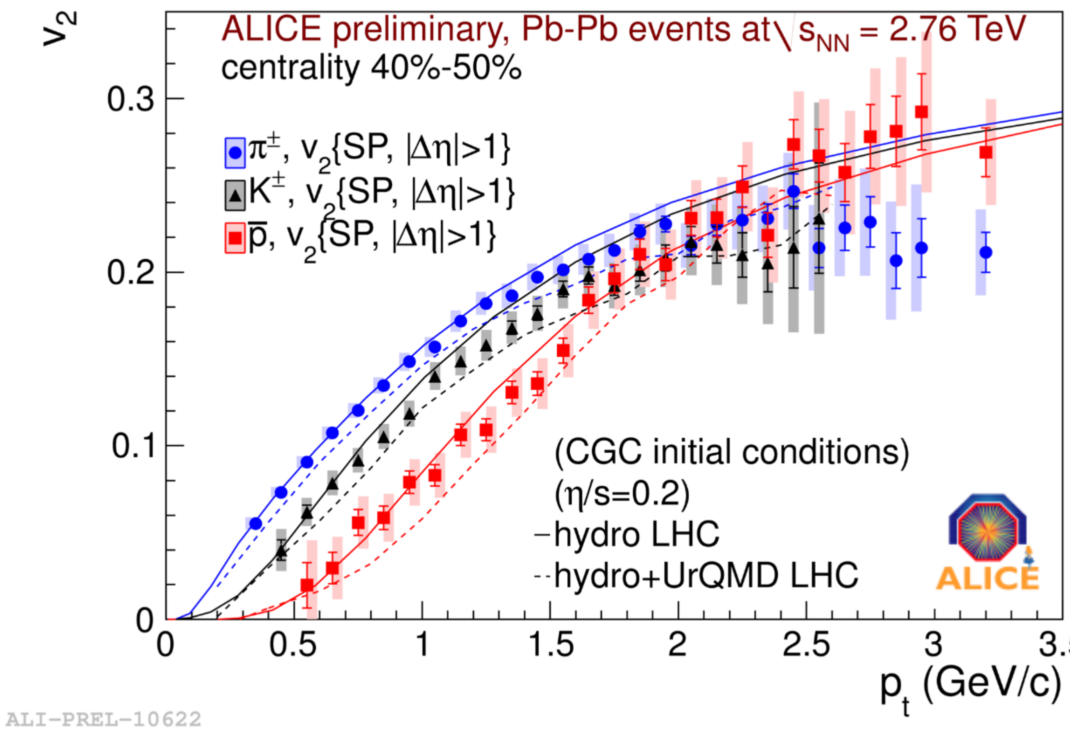
Differential elliptic flow: three regions for analysis

- [low p_T] measure the intensive properties of the medium (η/s and β)
- [intermediate p_T] get handle on the hadronisation mechanism
- [high p_T] measure the path length dependence of energy loss in medium



Probe for properties of the bulk



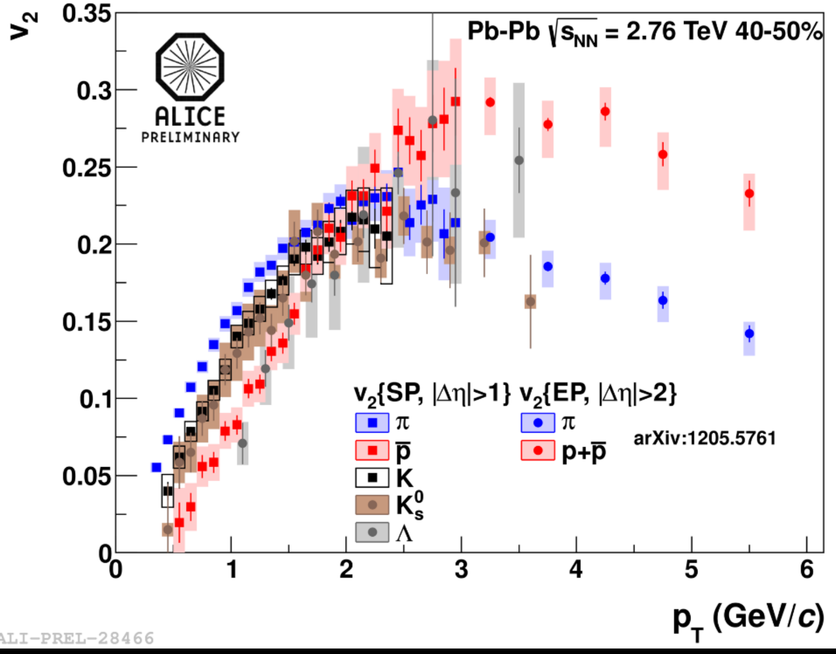


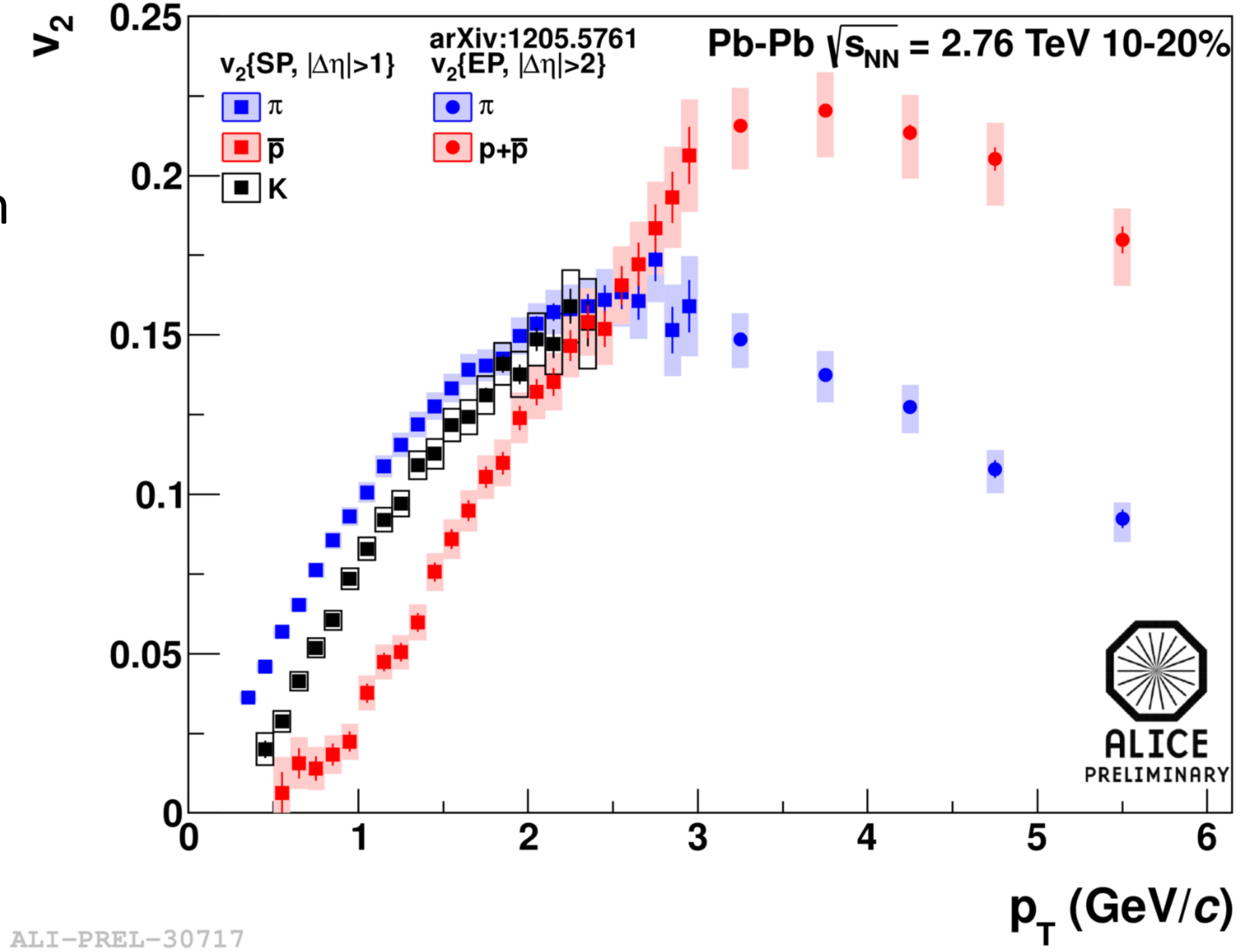
Hydro: Shen, Heinz, Huovinen & Song, arXiv:1 105.3226

- Mass dependence of elliptic flow observed at LHC energies
- Viscous-hydrodynamical calculations reproduce v_2 for pions, kaons
- Hydro by itself does not reproduce protons for most central collisions
  - Transport models in hadronic phase might explain difference

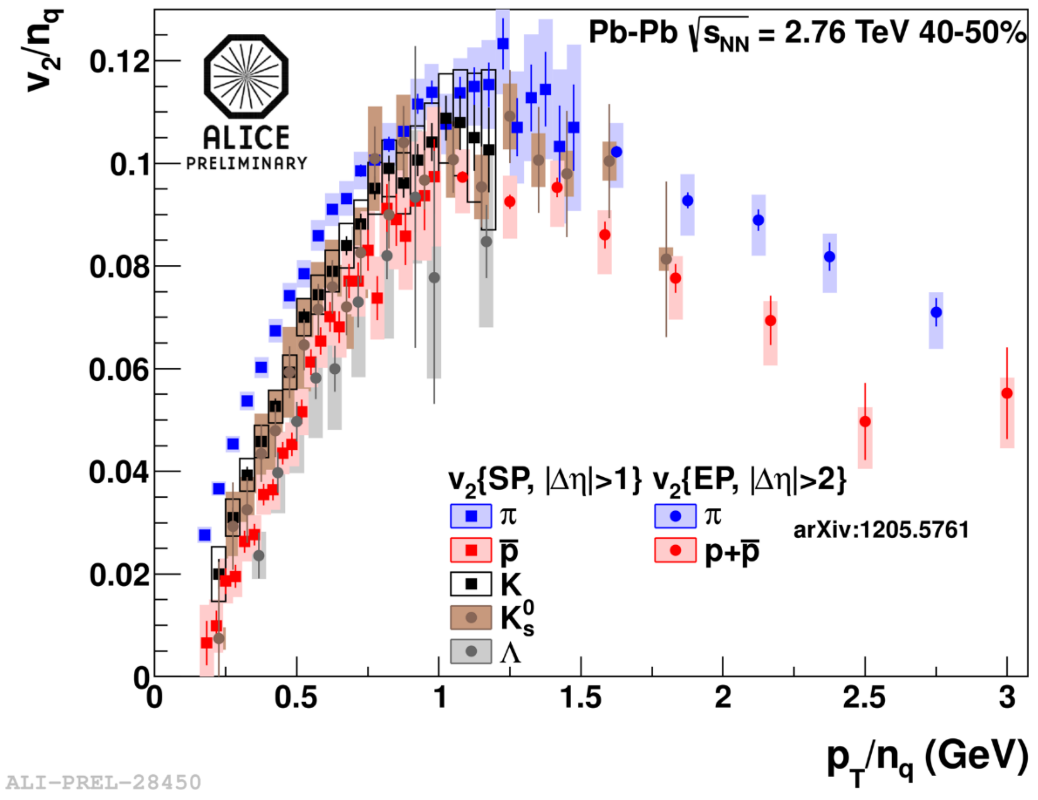
Baryon - Meson splitting

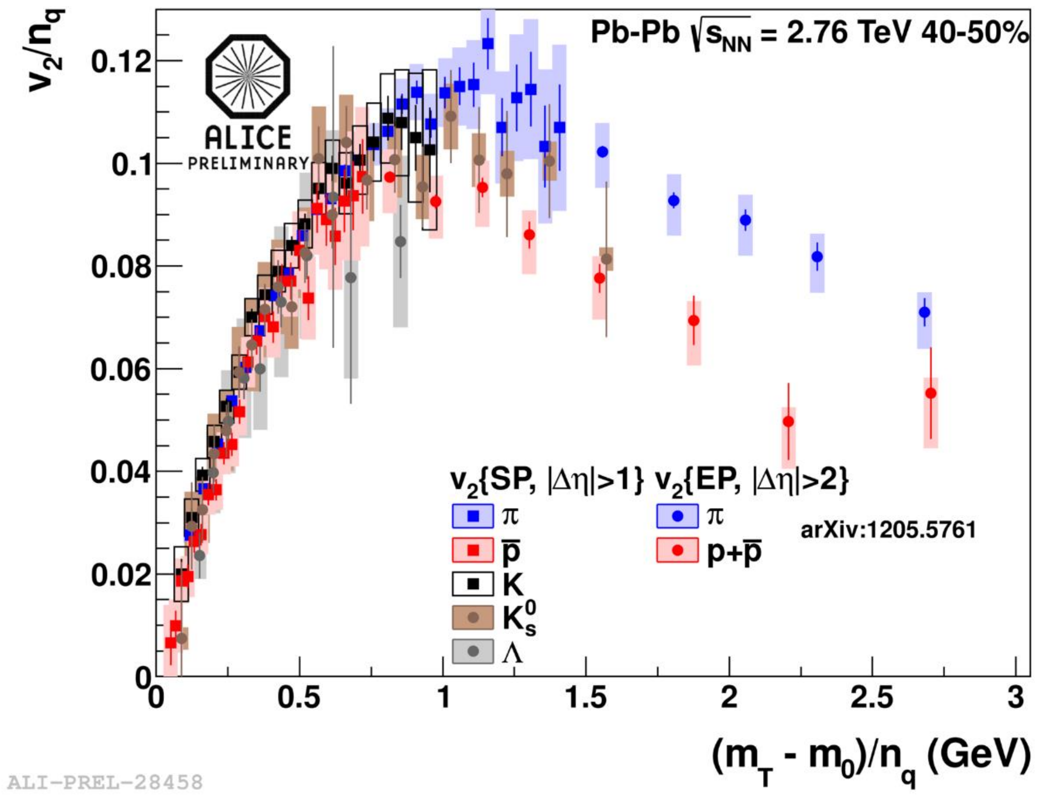
- Mass dependence of elliptic flow observed at LHC energies
- Baryons develop higher elliptic flow than mesons → Hadronisation mechanism(s)





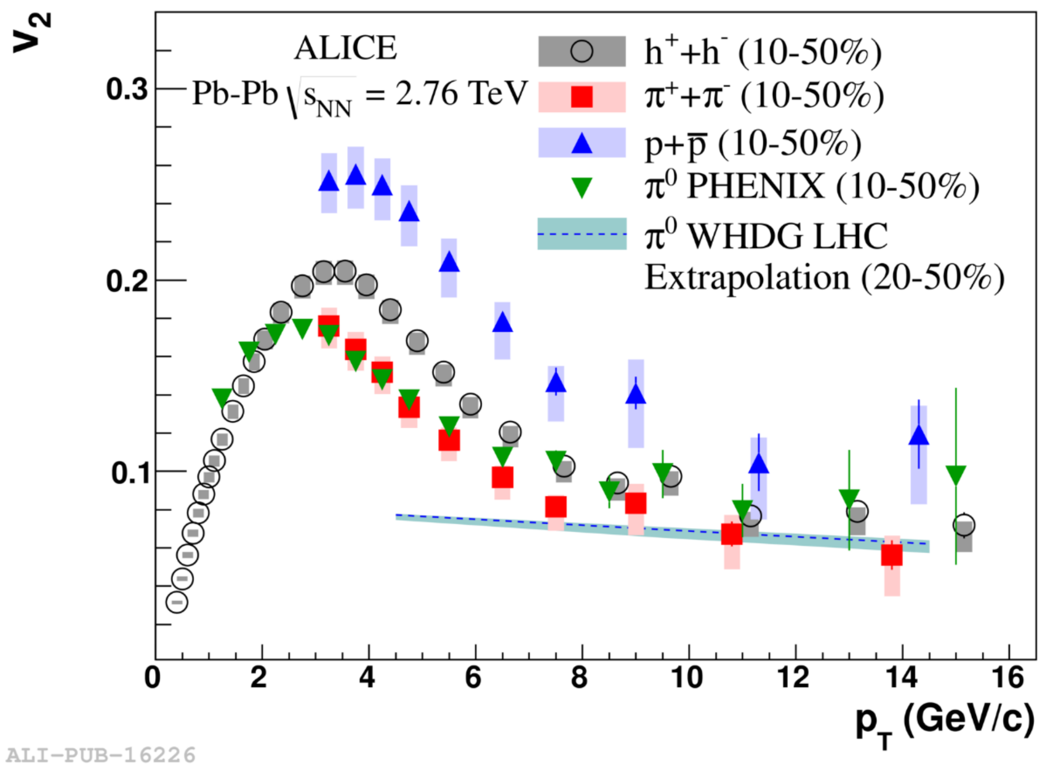
Coalescence?

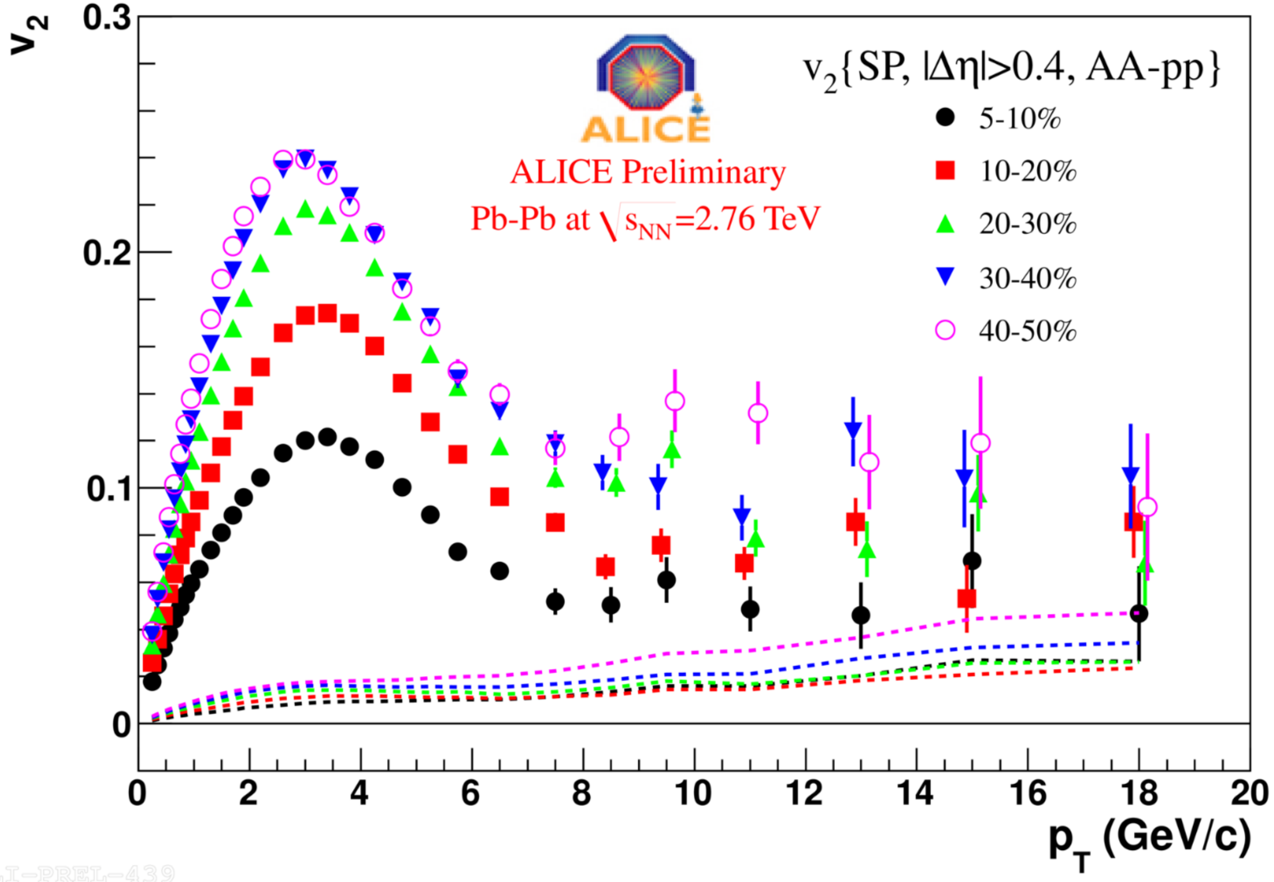




- Deviation from constituent quark scaling observed
- Original coalescence picture broken

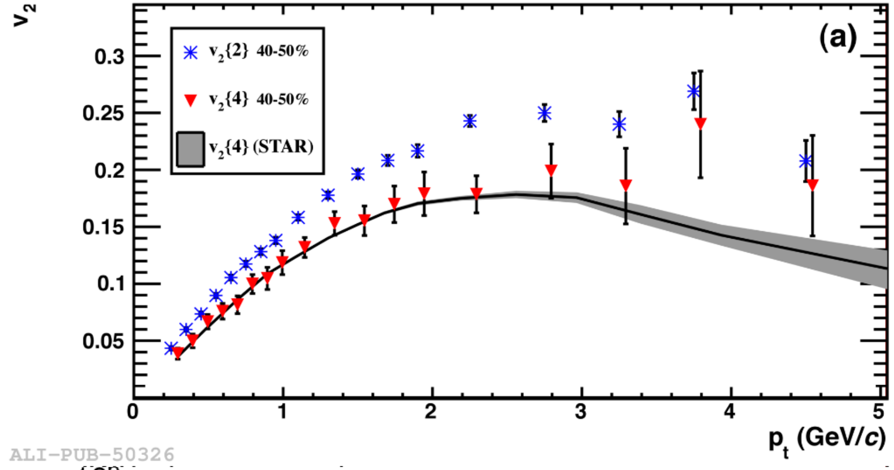
Path dependence in medium

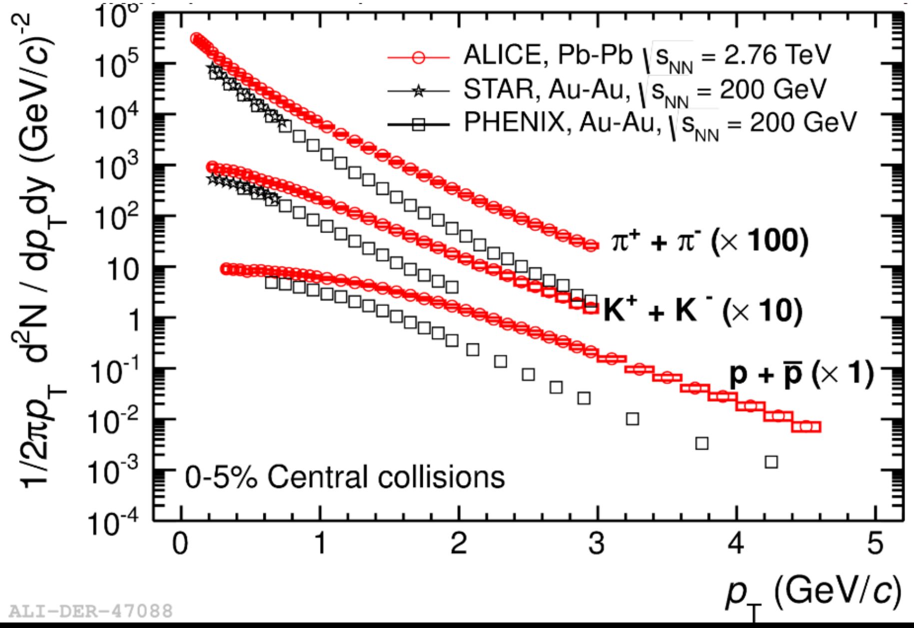


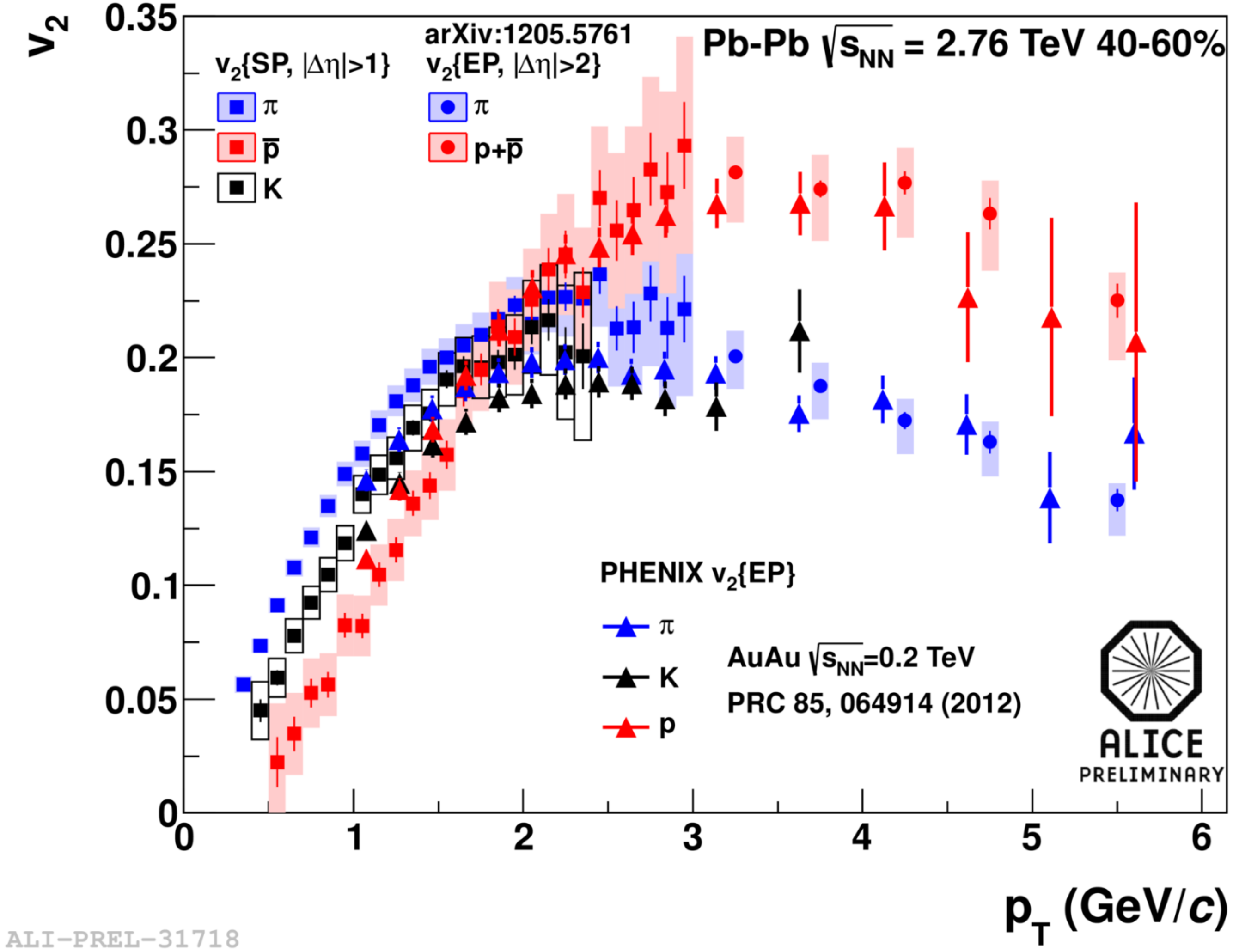


- Sizeable positive plateau develops from 9 GeV/c for all centralities
- WHGD (coll & rad energy loss of partons) explains the data fairly well

Comparison to RHIC

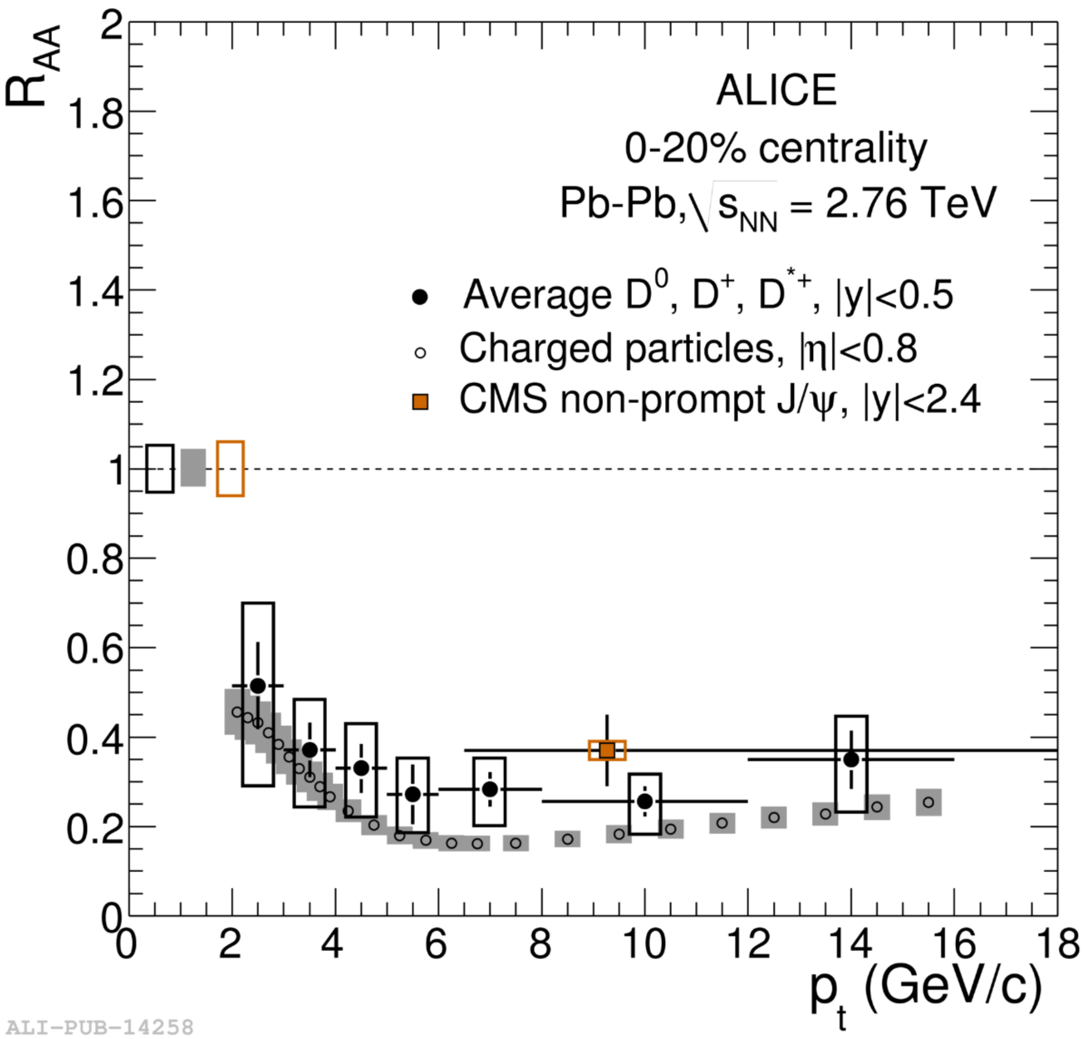






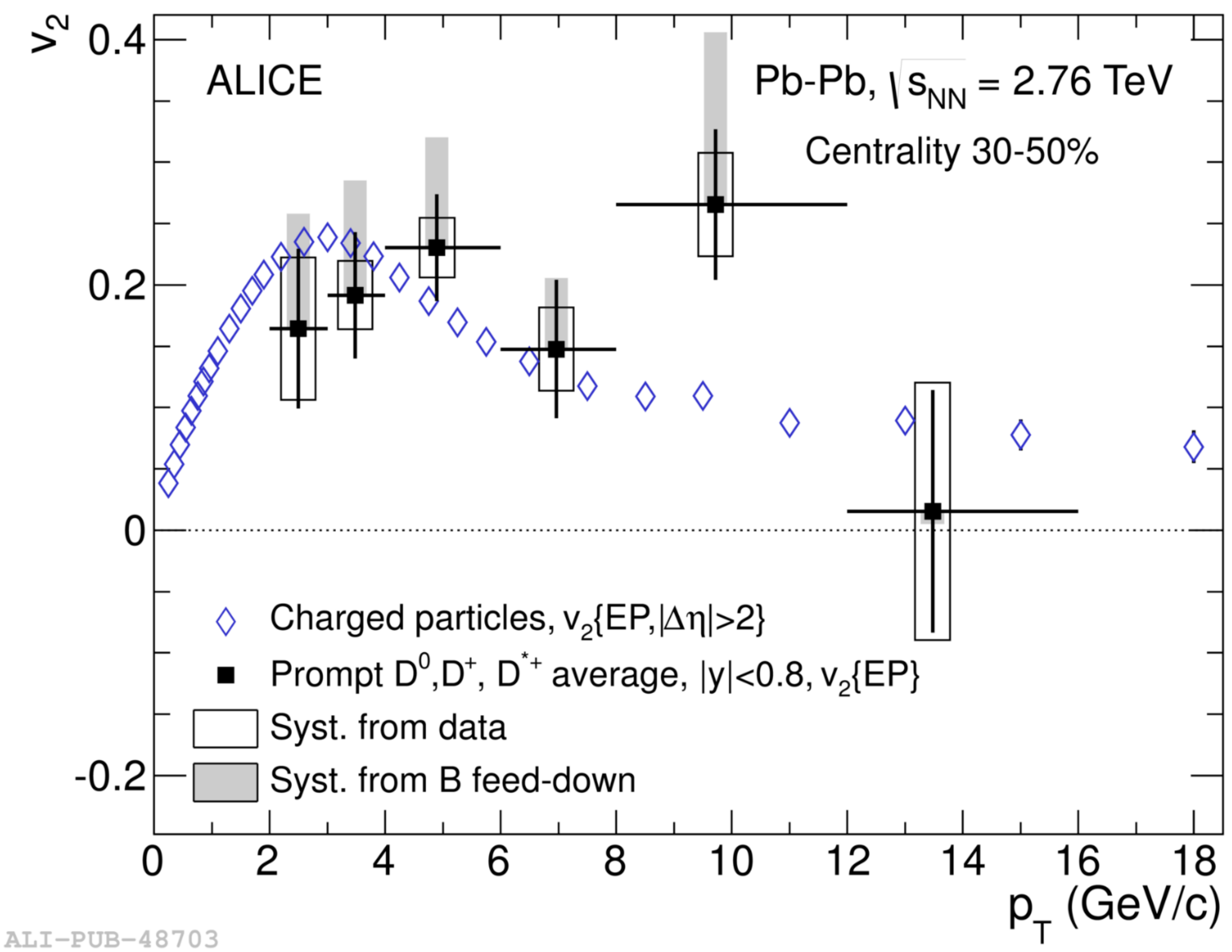
Charm: an insightful probe

- Charm is produced in the initial collision (not in medium): High sensitivity to the early state of system
- Smaller QCD radiation than lighter quarks while going through the medium?
- Path dependence attenuation in medium might depend on azimuthal direction wrt symmetry plane



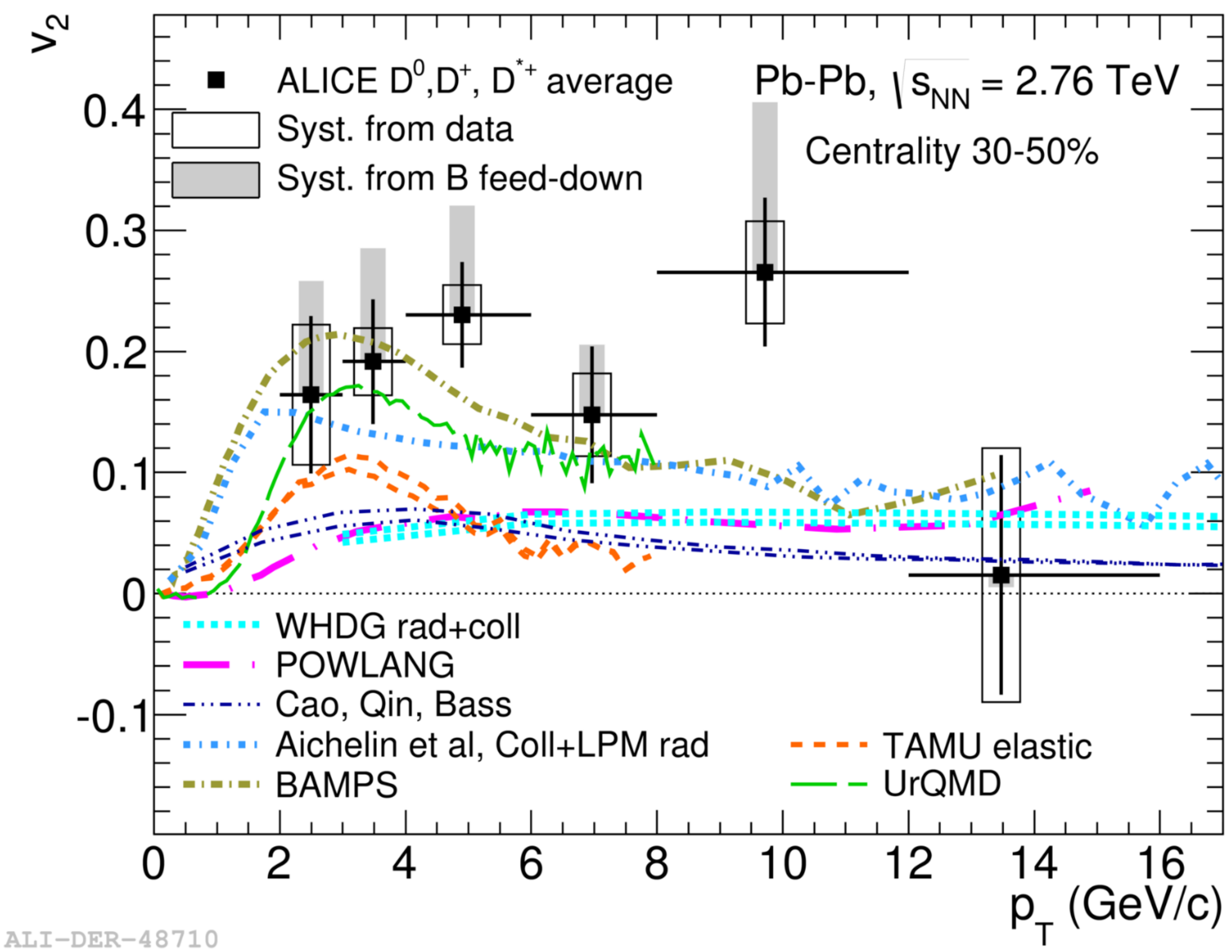
Does charm flow?

- Significant positive elliptic flow for charm mesons at low p_T

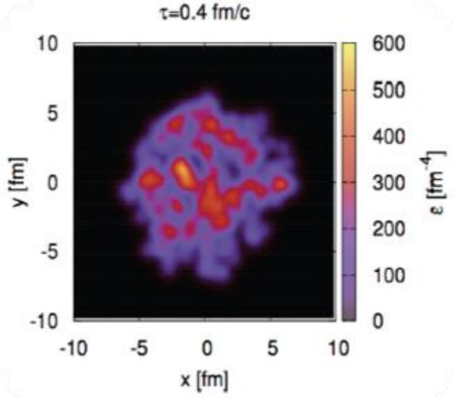


Does charm flow?

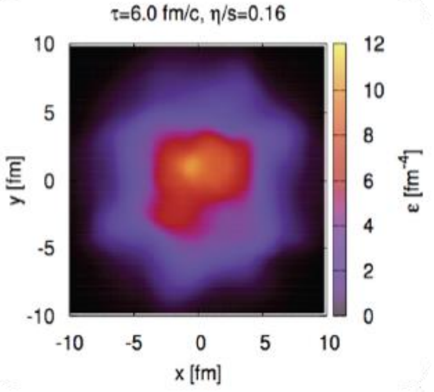
- Significant positive elliptic flow for charm mesons at low p_T
- Models using collisional and radiative energy loss only do not account for low p_T anisotropy
- Models which include medium expansion modelled by Hydro much closer to describe low p_T regime
- There is room for sensitivity to the bulk

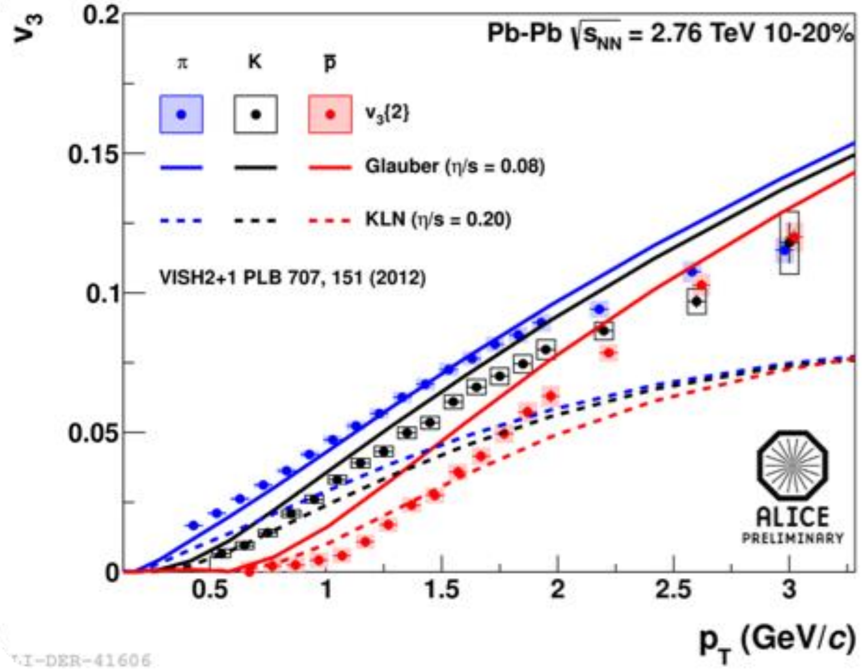


Higher harmonics (n>2)



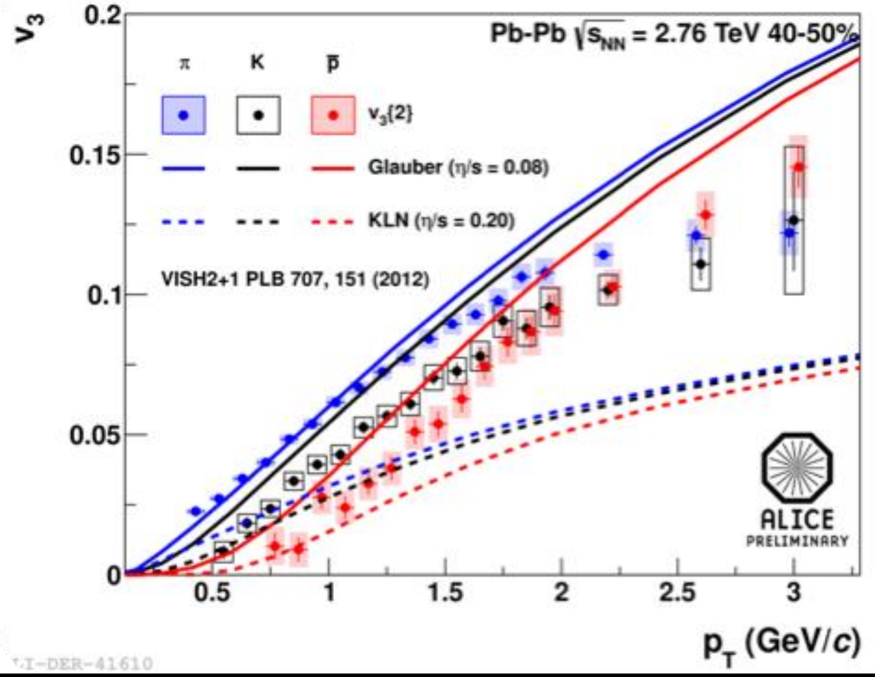
- Higher order harmonics are sensitive to the initial energy/pressure profile lumpiness
  - They are much sensitive to shear viscosity





- Triangular flow (n=3) present mass splitting

- VISH 2+1 using Glauber initial conditions and η/s =0.08 describes better the triangular flow



Concluding remarks

Köszönöm
Thanks
Gracias

- PID v_2 provides strong constrains on η/s, β and ρ of the hot deconfined matter.
- PID v_2 signals a larger radial boost at LHC energies that at RHIC energies.
- Constituent quark scaling is partially violated.
- At small $(m_t\text{-}m_0)/n_q$ the scaling in data resemble the scaling as observed in hydro calculations.
- Viscous hydrodynamic predictions are in good agreement with the data.
  - Protons reconciled once hadronic phase is included.
- Charm is a very clean channel and its elliptic flow opens window to new developments in characterisation of the bulk.
  - More studies on the charm sector will be conducted in the second run of LHC.