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ALICE

The 5th China LHC Physics Workshop

Study of D meson collectivities with ALICE at the LHC

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Outline

- Physics Motivation
- The ALICE Experiment
- D-meson flow in heavy-ion collisions
- Summary

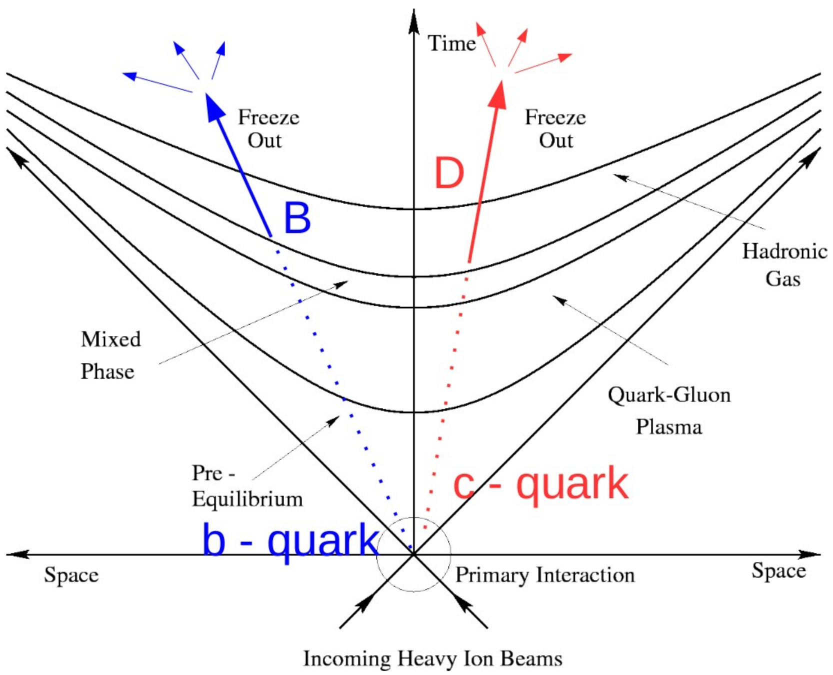
Heavy flavour study in heavy-ion collisions

ALICE

ALICE (A Large Ion Collider Experiment) is dedicated to the study of the Quark-Gluon Plasma (the deconfined partonic medium created in heavy-ion collisions)

Heavy quarks (charm and beauty quarks):

- Due to the large mass ($m_c \approx 1.3$ GeV/c, $m_b \approx 4.5$ GeV/c), their production occurs mainly via hard parton scattering in the initial stages of the collisions
- Heavy-quark production calculable with perturbative QCD ($m_Q >> \Lambda_{QCD}$) over the full p_T range → well calibrated probe
- In Pb-Pb collisions they experience the full evolution of the QGP → sensitive probes to the properties of this medium, interacting with the medium constituents via
  - ➡ Elastic scatterings
  - ➡ Gluon radiations



Observables:

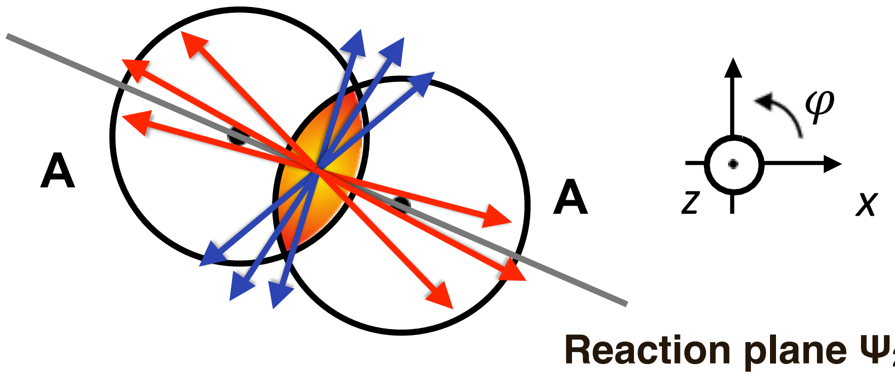
- ➡ Nuclear modification factor
- ➡ Azimuthal anisotropies

Elliptic flow and event-shape engineering (ESE)

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

$$v_2 = \langle\cos[2(\varphi - \Psi_2)]\rangle$$

second harmonic coefficient, elliptic flow



- Asymmetry between the in-plane (parallel to Ψ_2) and out-of plane (orthogonal to Ψ_2) regions
- At low p_T: participation in the collective motion and thermalisation of heavy quarks in the medium
- At high p_T: path-length dependence of energy loss

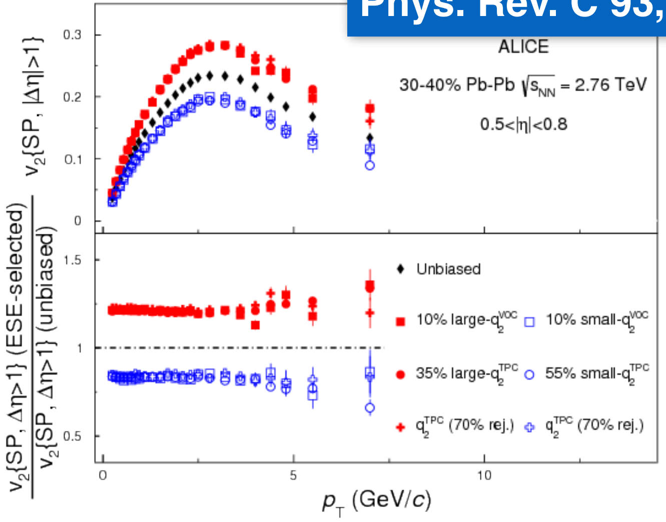
$$v_2\{EP\} = \frac{1}{R_2}\frac{\pi}{4}\frac{N_{\text{in-plane}} - N_{\text{out-of-plane}}}{N_{\text{in-plane}} + N_{\text{out-of-plane}}}$$

Event shape engineering that allows us to study various observables in classes of events corresponding to the same centrality, but different eccentricity

✦ In the recent study of Pb-Pb collisions, we found that the charged particle spectra gets modified in different events samples using the constraints of 2nd order reduced *q*-vector (q_2)

✦ The effect of the ESE selection on the single particle p_T distribution may show the interplay between the initial configuration of the system and the dynamics of the expansion of the fireball and could give us the effect of radial flow in different collision systems.

Phys. Rev. C 93, 034916

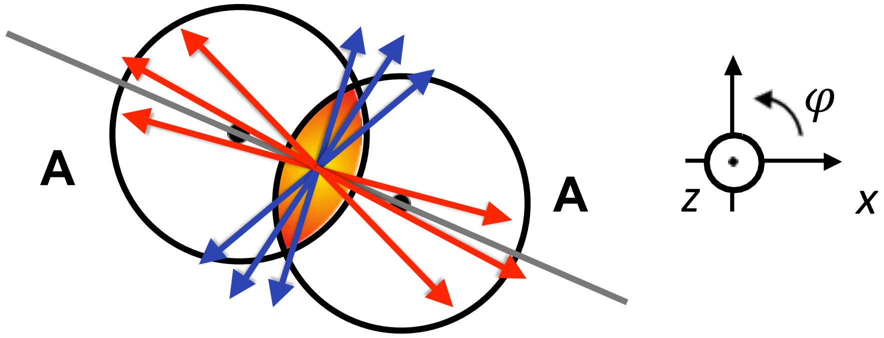


Charge-dependent directed flow

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

$$v_1 = \langle \cos(\varphi - \Psi_1) \rangle$$

first harmonic coefficient, directed flow



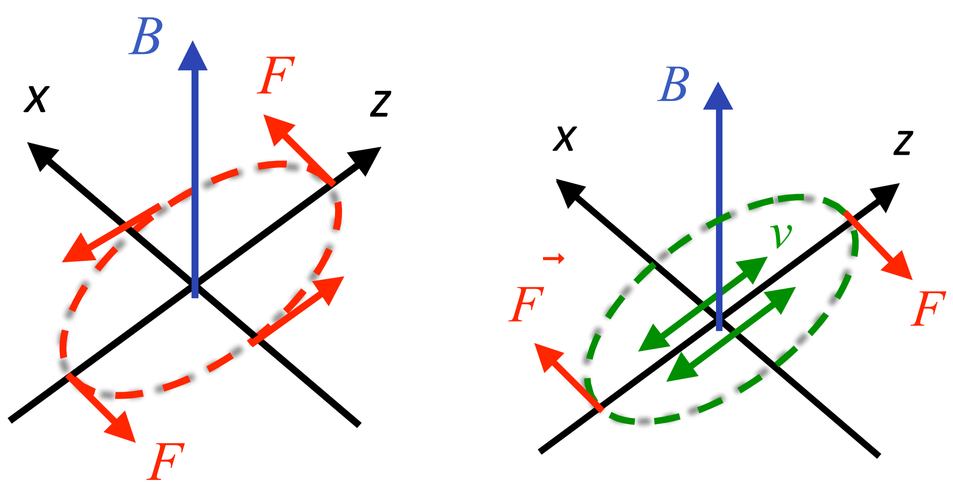
Reaction plane Ψ_2

Charge-dependent v_1 can be used to study the magnetic field created in heavy-ion collisions

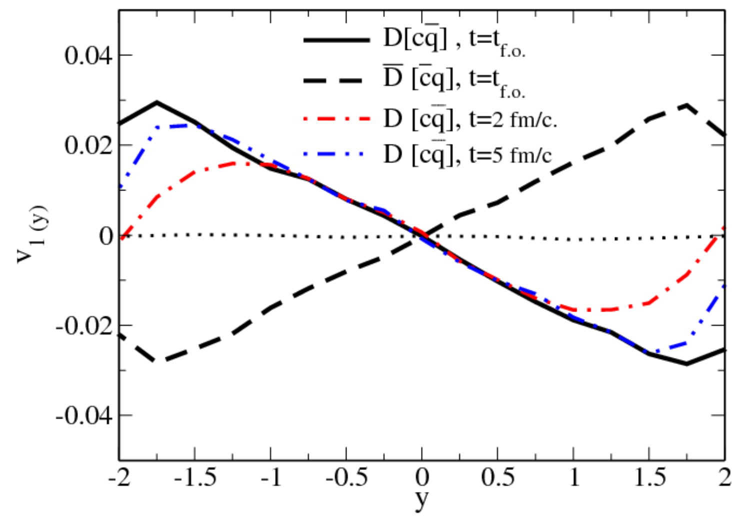
Originated by two competing effects:

- ☑ **Faraday effect: Electric field induced by decreasing B**
- ☑ **Hall effect: Lorentz force induced moving charges**

$$\vec{F} = q\,\vec{v} \times B$$



S. K. Das et all, PLB 768 (2017) 260-264



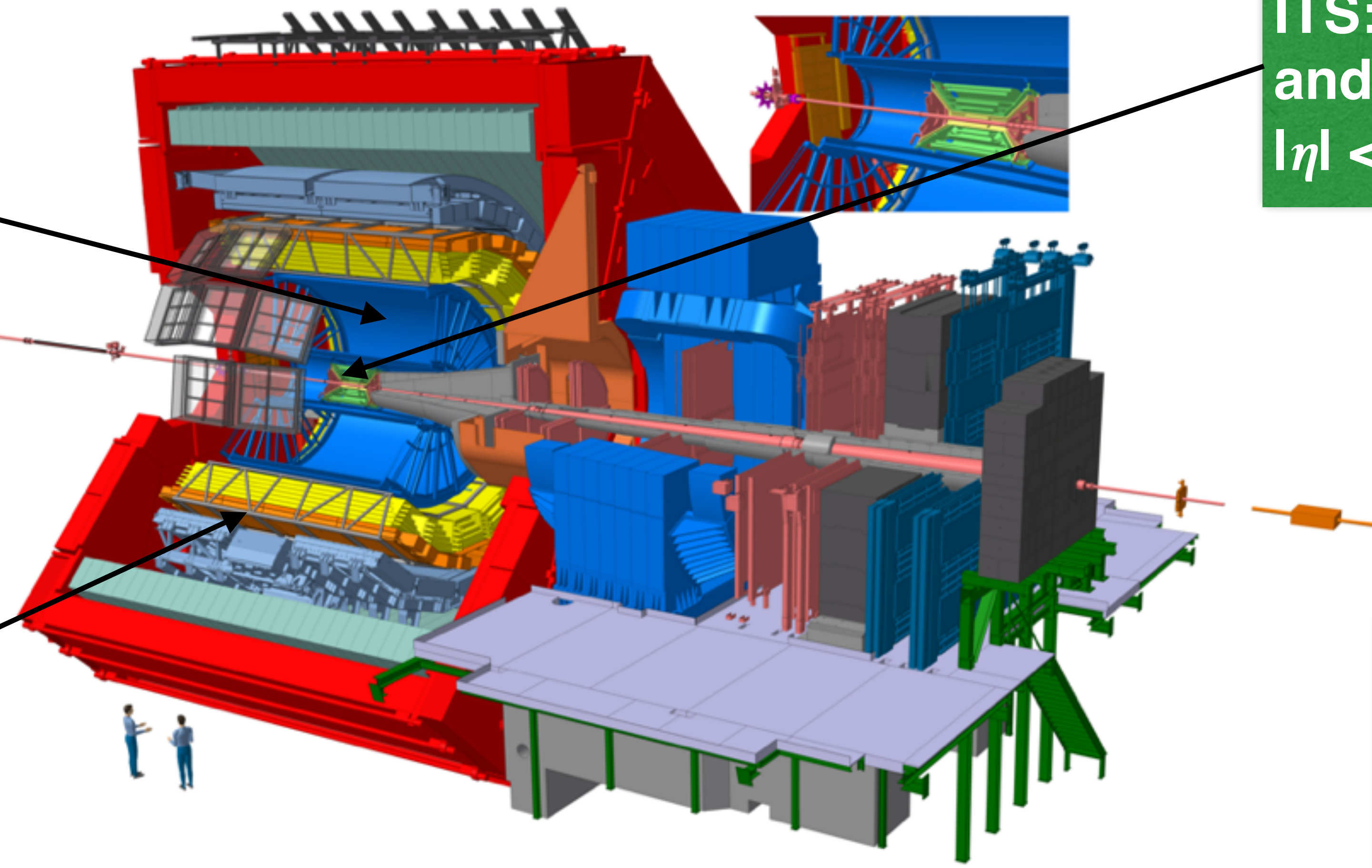
Charm quark is an ideal probe

➡ formation time is comparable to the time scale when the magnetic field reaches its maximum value

➡ relaxation time is similar to the QGP life-time

➡ expected larger effect compared to light hadrons

ALICE Detector



Heavy-flavour detection with ALICE:

Tracking and secondary vertex reconstruction:

- ❖ The Inner Tracking System (ITS) and the Time Projection Chamber (TPC) embedded in a magnetic field of 0.5 T, allow track reconstruction in the pseudorapidity range $-0.9 < \eta < 0.9$.
- ❖ This allows an excellent detection of heavy-flavour meson decay vertices displaced few hundred μm from the collision vertex.
- ❖ VZERO detector is used for triggering.

Particle identification:

- ❖ This has been done using TPC and TOF via the measurement of the specific energy loss dE/dx and and time of flight, respectively to reduce the background-candidate contribution to the D-meson invariant mass distribution.

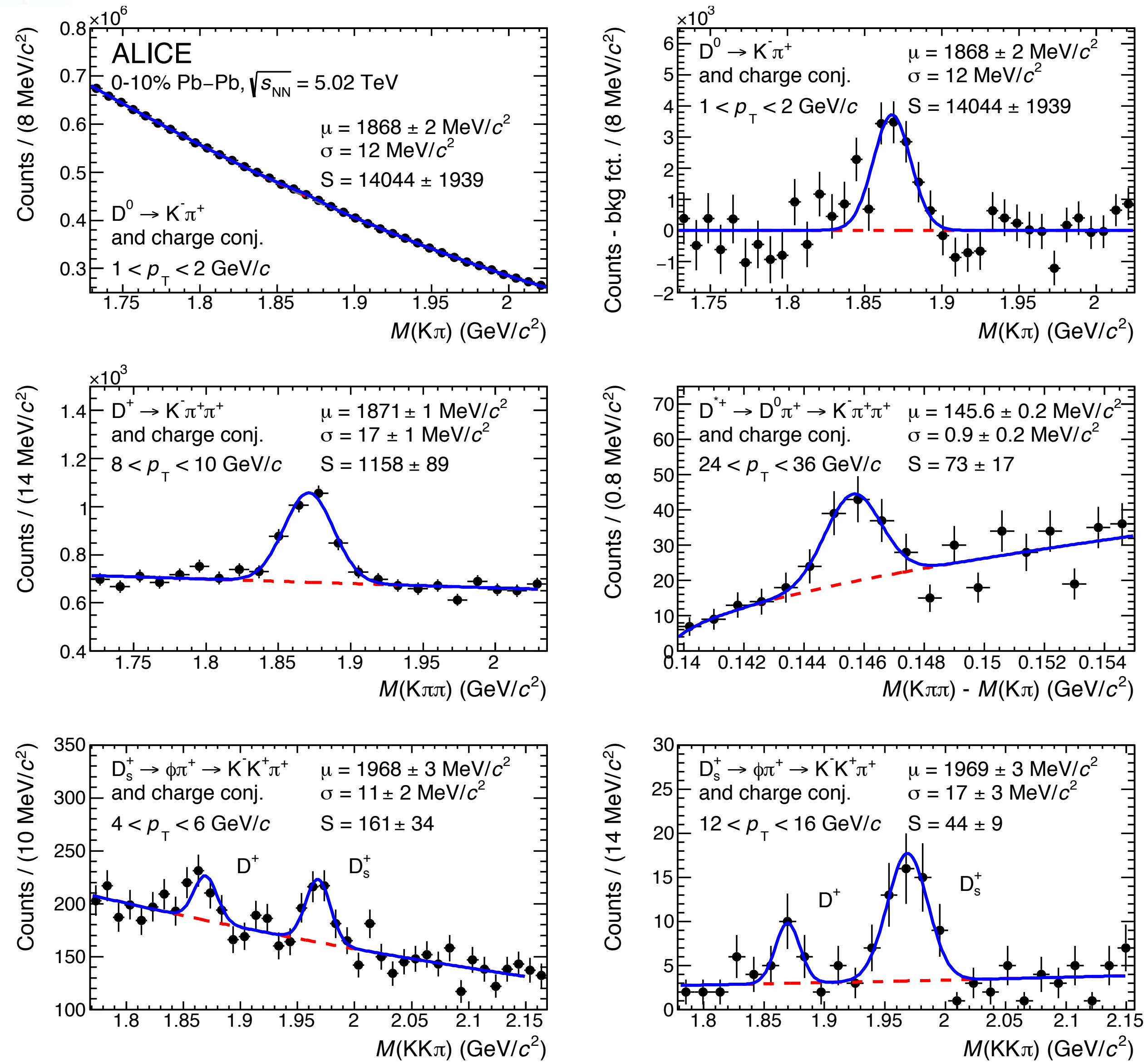
Data sample

~10^8 Pb-Pb MB collisions
$\sqrt{s_{NN}}$ = 5.02 TeV

D-meson reconstruction

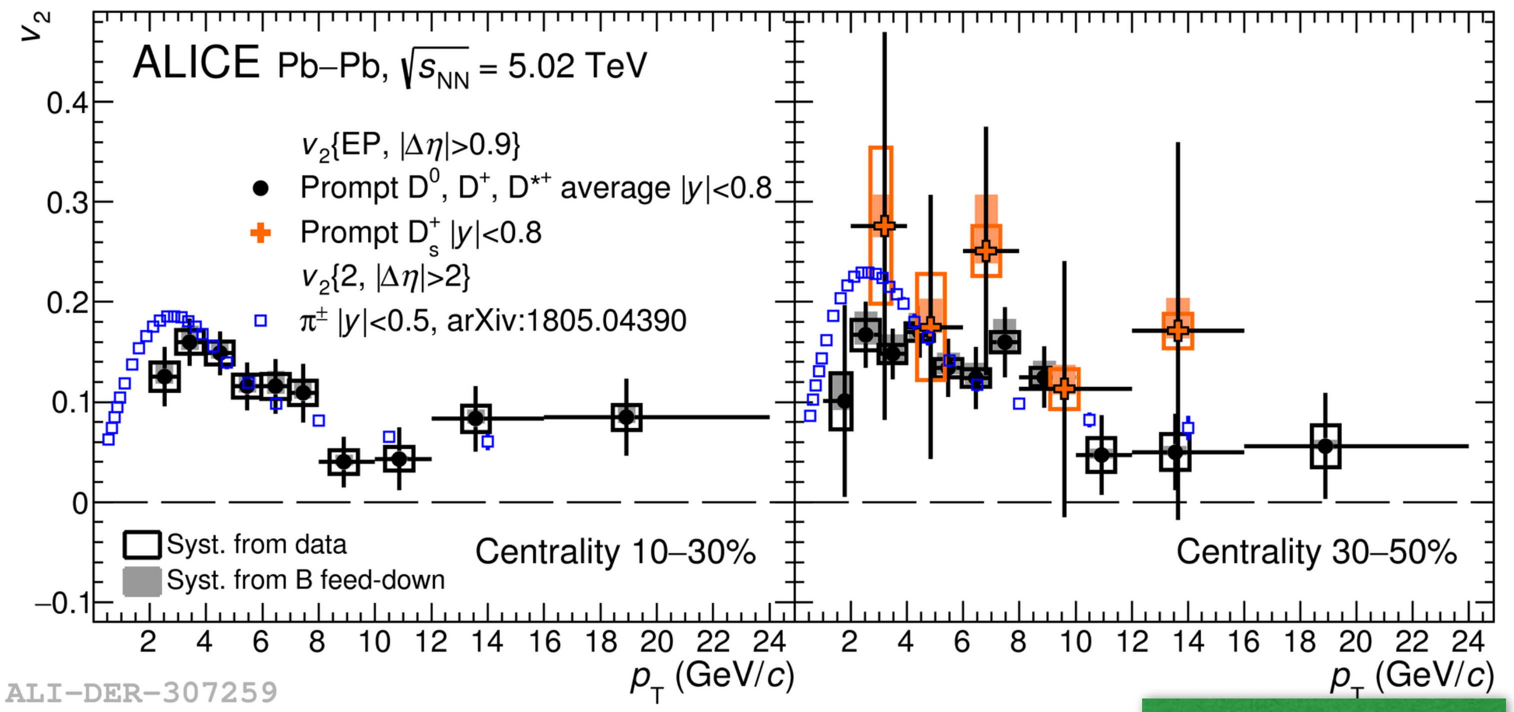
Meson	Mass (GeV/c^2)	decay channel	$c\tau$ (μm)
D^0 ($c\bar{u}$)	1.865	$K^-\pi^+$	123
D^+ ($c\bar{d}$)	1.870	$K^-\pi^+\pi^+$	312
D^{*+} ($c\bar{d}$)	2.010	$D^0(\rightarrow K^-\pi^+)\,\pi^+$	strong decay
D_s^+ ($c\bar{s}$)	1.968	$\phi\,(\rightarrow K^-K^+)\,\pi^+$	150

- Full reconstruction of decay topologies displaced few hundred microns from the interaction vertex
- Reduction of the combinatorial background achieved applying:
  - ✓ geometrical selection of displaced decay-vertex topology
  - ✓ particle identification (PID) of decay tracks
- Signal extracted from invariant-mass analysis
- Feed-down from b-hadrons subtracted with a FONLL-based method.

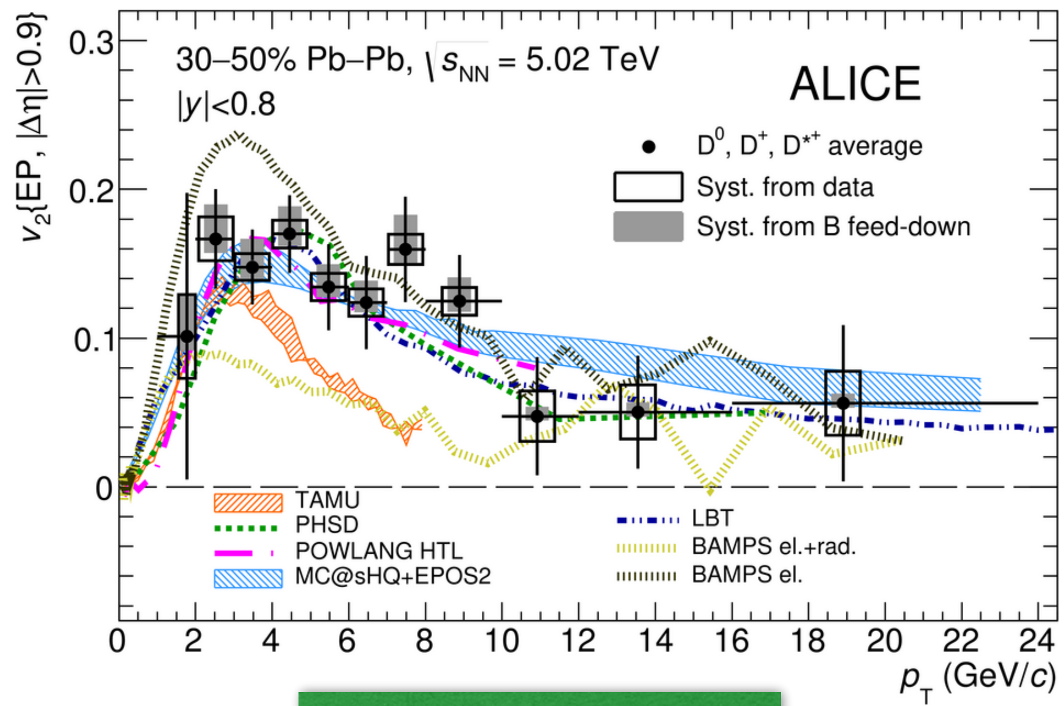


JHEP 1810 (2018) 174

D-meson v_2



JHEP 09 (2018) 006

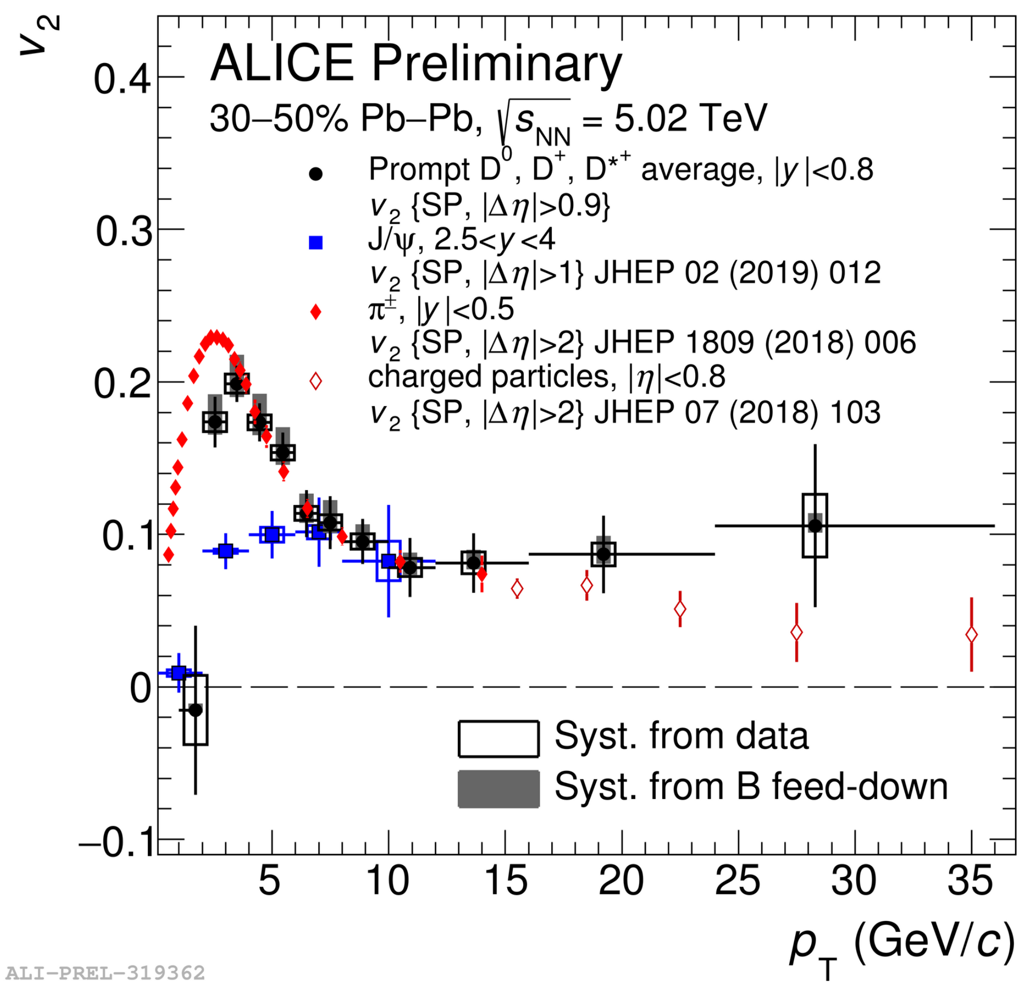


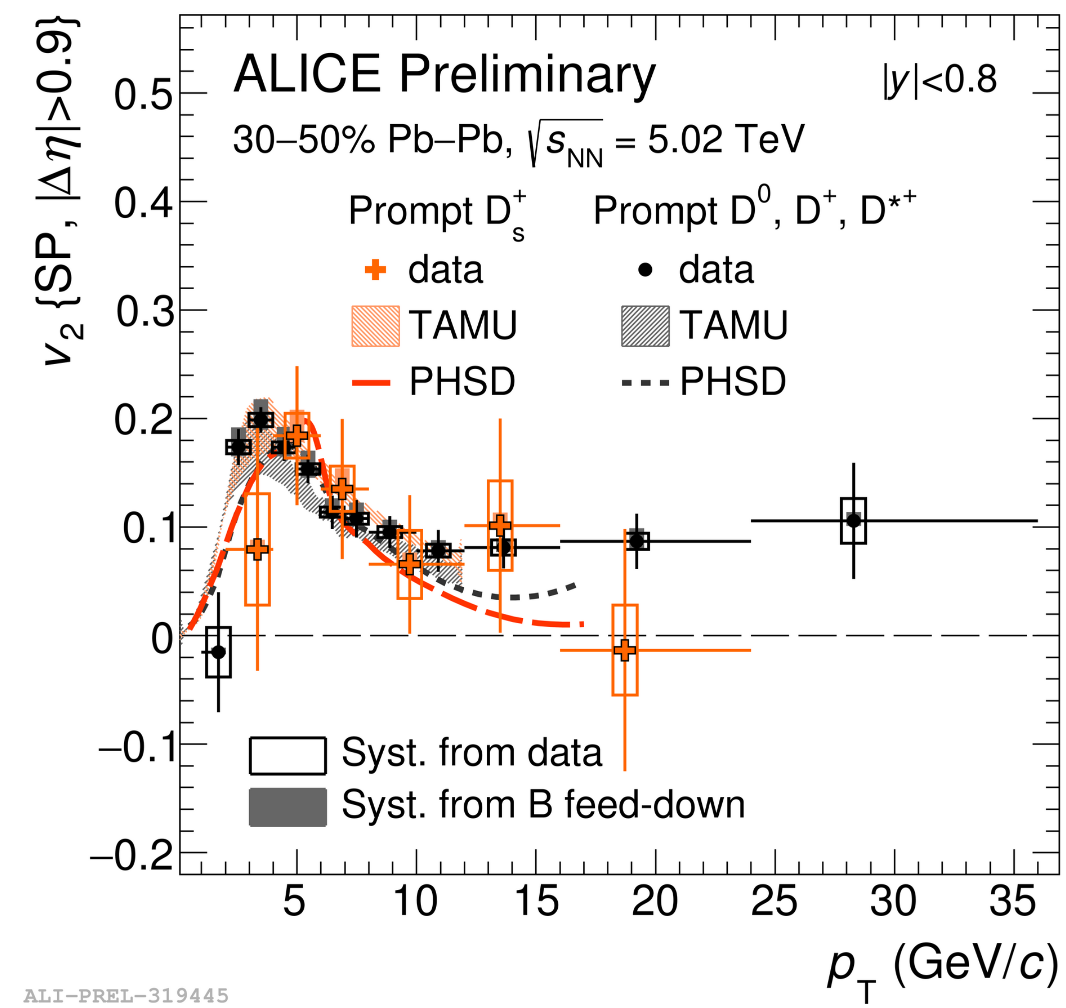
Phys. Rev. Lett. 120, 102301

- Positive non-strange D-meson v_2 for 2 < p_T < 8-10 GeV/c in mid-central (10-30% and 30-50%) Pb-Pb collisions
- D_s^+ v_2 in 30-50% compatible within uncertainties with non-strange D-meson v_2
- D_s^+ v_2 in 30-50% larger than zero in 2 < p_T < 8 GeV/c with
- v_2 (D) ≃ v_2 ($\pi^{\pm}$) for p_T > 4 GeV/c in the 10-30% and 30-50% centrality classes
- Hint of v_2 (D) < v_2 ($\pi^{\pm}$) for p_T < 4 GeV/c in the 10-30% and 30-50% centrality classes
- Data compared to different model predictions (TAMU, PHSD, BAMPS etc.)
- From the study we see that low momentum charm quarks take part in the collective motion of the QGP.

TAMU: PLB 735, 445-450(2014)
PHSD: PRC92, 014910 (2015)
POWLANG: EPJC75, 121 (2015)
MC@sHQ+EPOS: PRC 89,014905 (2014)
LBT: PLB 777 (2018)255-259
BAMPS: JPG 42, 115106(2015)

D-meson v_2





- Positive non-strange D-meson v_2 in 30-50% Pb-Pb collisions using Scalar Product method
- D mesons v_2 in 30-50% compatible within uncertainties with the J/Ψ measured by ALICE for $p_T > 8$ GeV/c
- v_2 (D){SP} ≃ v_2 ($\pi^{\pm}$) and charged particles for $p_T > 4$ GeV/c in 30-50% centrality class
- Hint of v_2 (J/Ψ) < v_2 (D) < v_2 (π±) for $p_T < 4$ GeV/c
- Data (both for strange and non-strange D mesons) compared to different model predictions

Event shape engineering (ESE)

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

✓ Mathematical parameter is the reduced *q* vector of different order of flow.

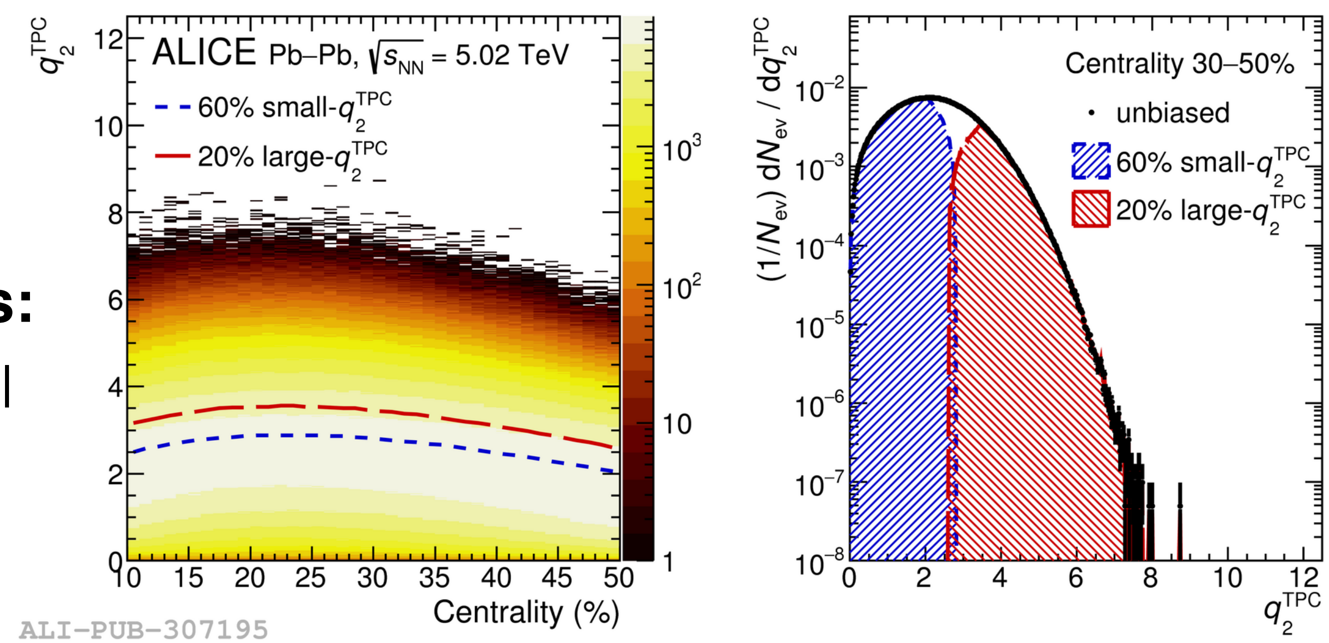
✓ Reduced flow vector increases roughly linearly with the actual flow coefficients giving us the flexibility to determine different event classes based on its values.

- The second order reduced flow vector is defined as: → $q_2 = |Q_2|/\sqrt{M}$
  where the Q-vector is determined from particles azimuth and M is the total multiplicity

$$Q_{2,x} = \sum_i^M \cos 2\varphi_i, Q_{2,y} = \sum_i^M \sin 2\varphi_i$$

D-meson v_2 for different q_2 samples: investigate correlations between flow coefficients of D mesons and soft hadrons

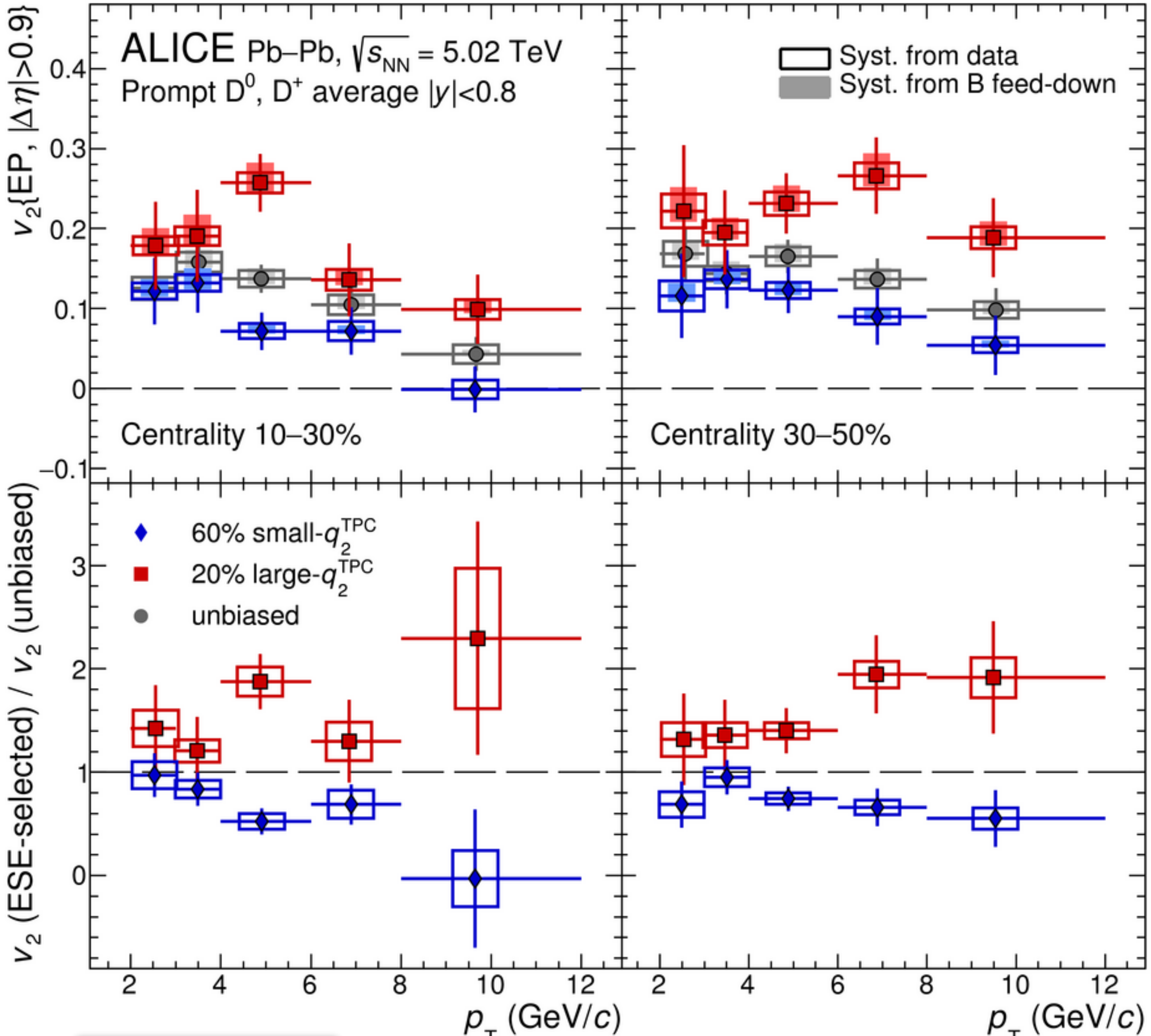
D-meson p_T spectra for different q_2 samples: study interplay between elliptic flow and radial flow (at low/intermediate p_T) and in-medium energy loss (high p_T)



arXiv:1809.09371

Event shape engineering (ESE)

q_2 estimator: TPC



arXiv:1809.09371

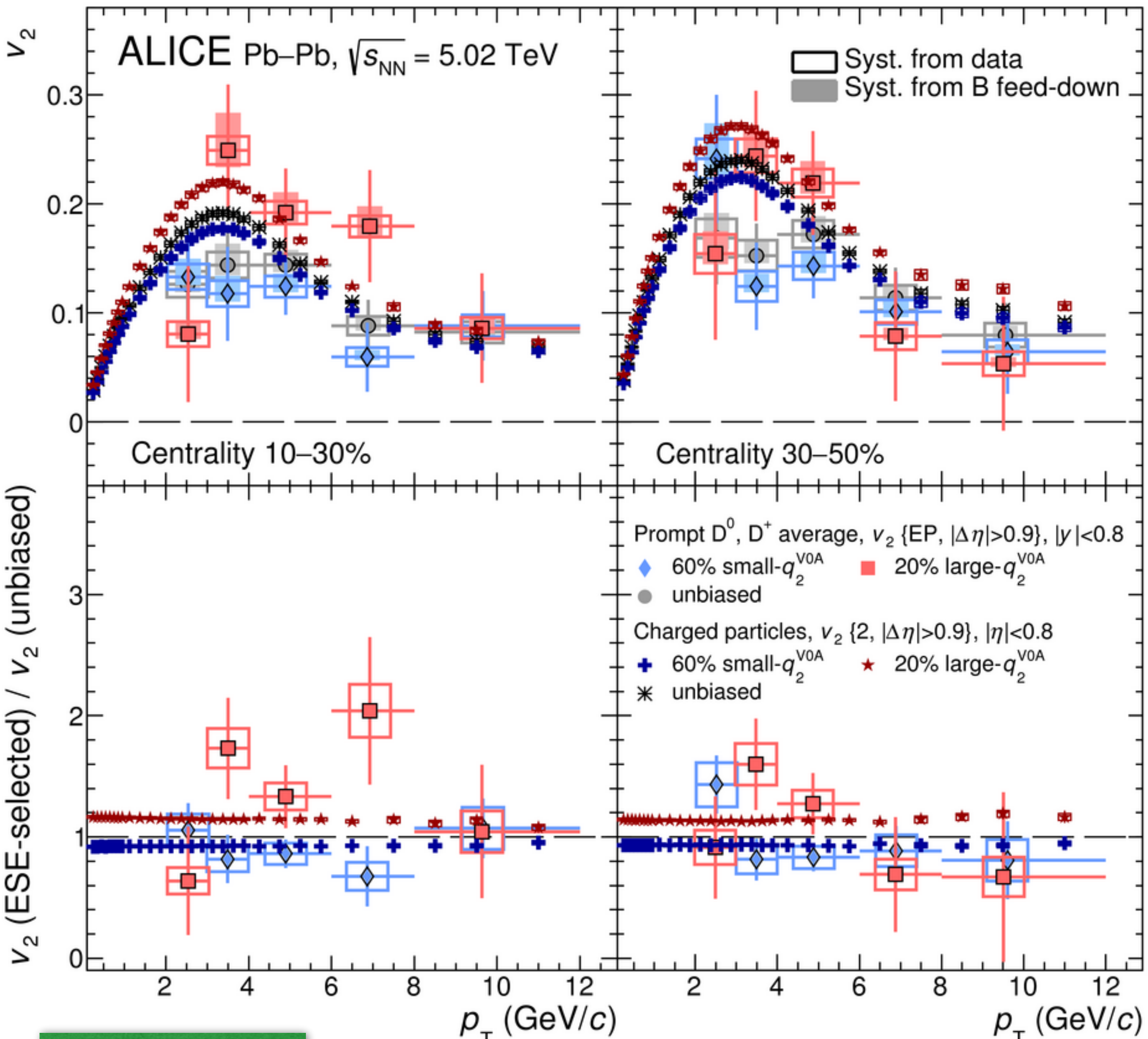
- Measurement of D-meson v_2 in ESE-selected samples using TPC-q_2
- Similar effect in the 10-30% and 30-50% centrality classes within uncertainties

➡ v_2 (large-q_2) > v_2 (unbiased) of about 40%
➡ v_2 (small-q_2) < v_2 (unbiased) of about 25%

Note: *Effect could be slightly enlarged by non-flow correlations (D mesons and q_2 measured in the same η region)*

ESE selected D meson v2

q_2 estimator: V0A



arXiv:1809.09371

- Measurement of D-meson v_2 in ESE-selected samples using V0A-q_2
- Compared to charged particle ESE-selected v_2 in 10-30% and 30-50% centrality for 20% (60%) large-q_2 (small-q_2)
- The ratio of ESE selected v_2 to the unbiased sample found to be compatible with charged particle within uncertainly for 30-50% centrality
- Due to large uncertainly no farm conclusion can be drawn

D^0 ($\overline{D^0}$)-meson v_1 measurement (ongoing)

Directed flow measured with the scalar-product method

$$v_1\{A,C\} = \frac{\langle \vec{u}_1 \cdot \vec{Q}_1^{A,C} \rangle}{\sqrt{\langle \vec{Q}_1^{A} \cdot \vec{Q}_1^{C} \rangle}}$$

spectator plane reconstructed with ZDC ($|\eta| > 8.8$)

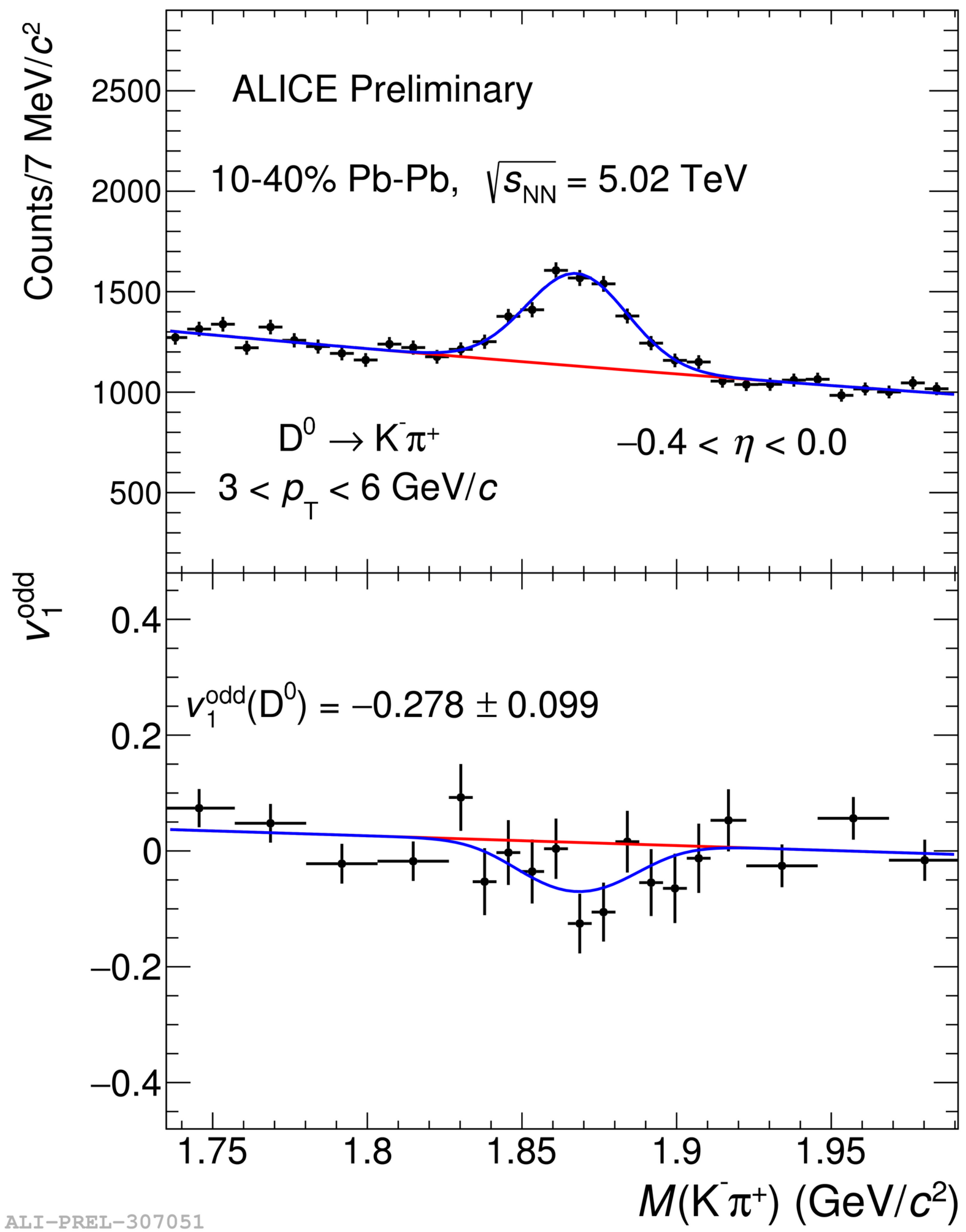
➡ A, C denotes the ZDC side

A: $\eta > 8.8$

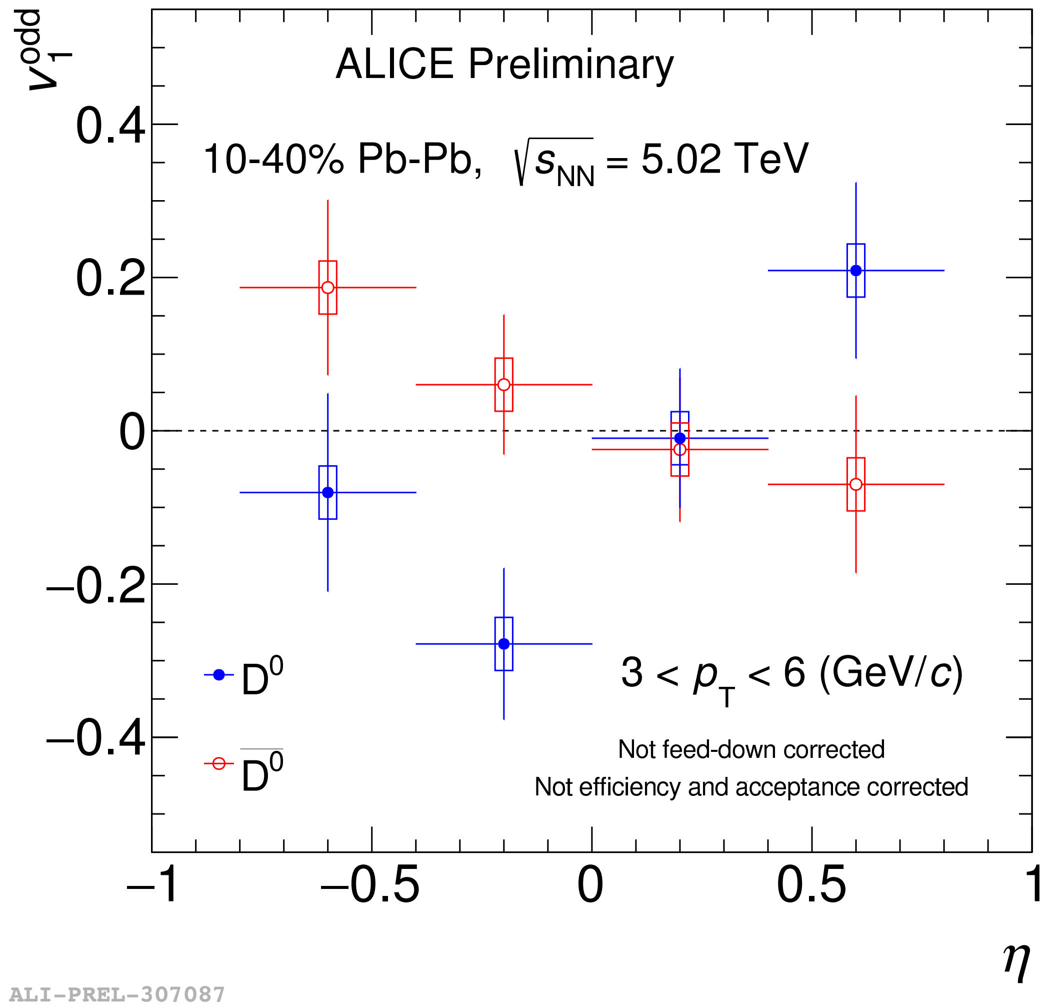
C: $\eta < -8.8$

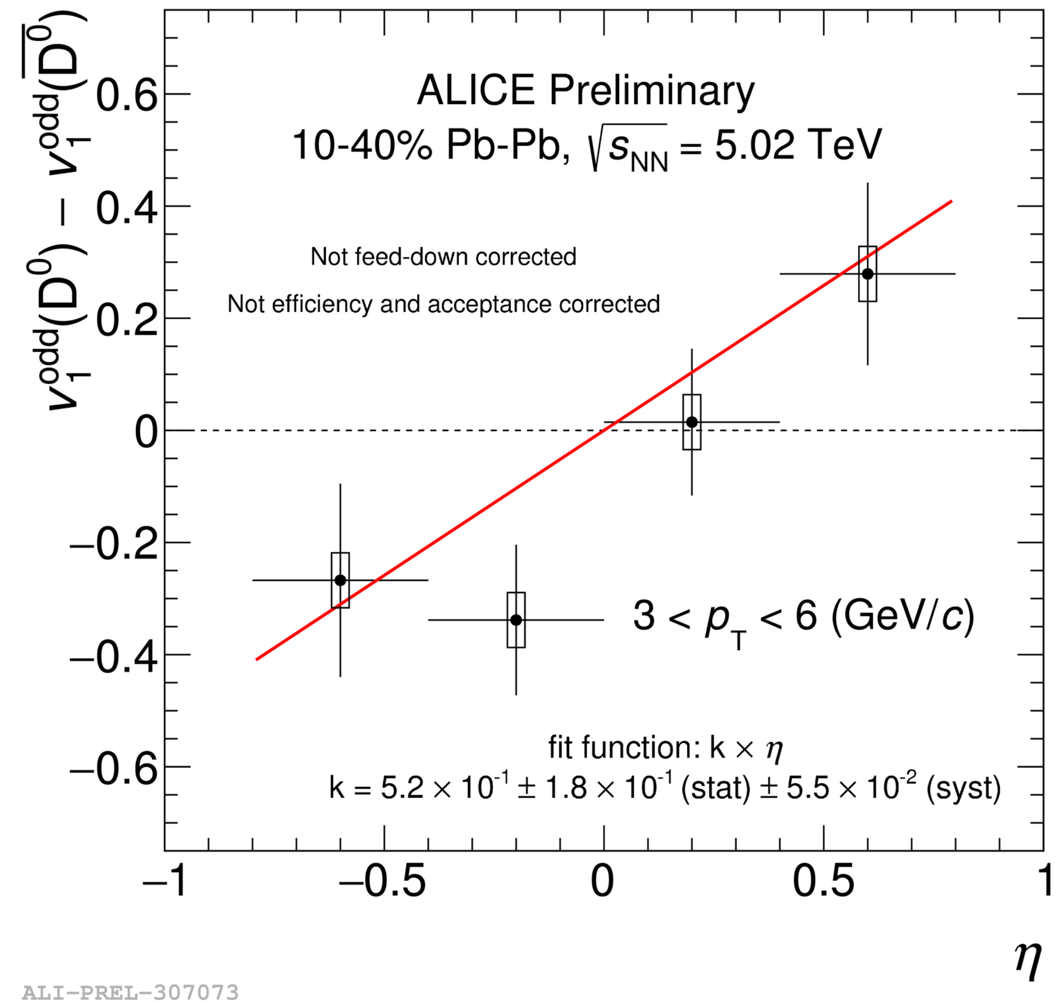
Computed rapidity-odd component, for D^0 and $\overline{D^0}$ separately

$$v_1^{odd} = \frac{1}{2}(v_1\{A\} - v_1\{C\})$$



D^0 ($\overline{D^0}$)-meson v_1 measurement



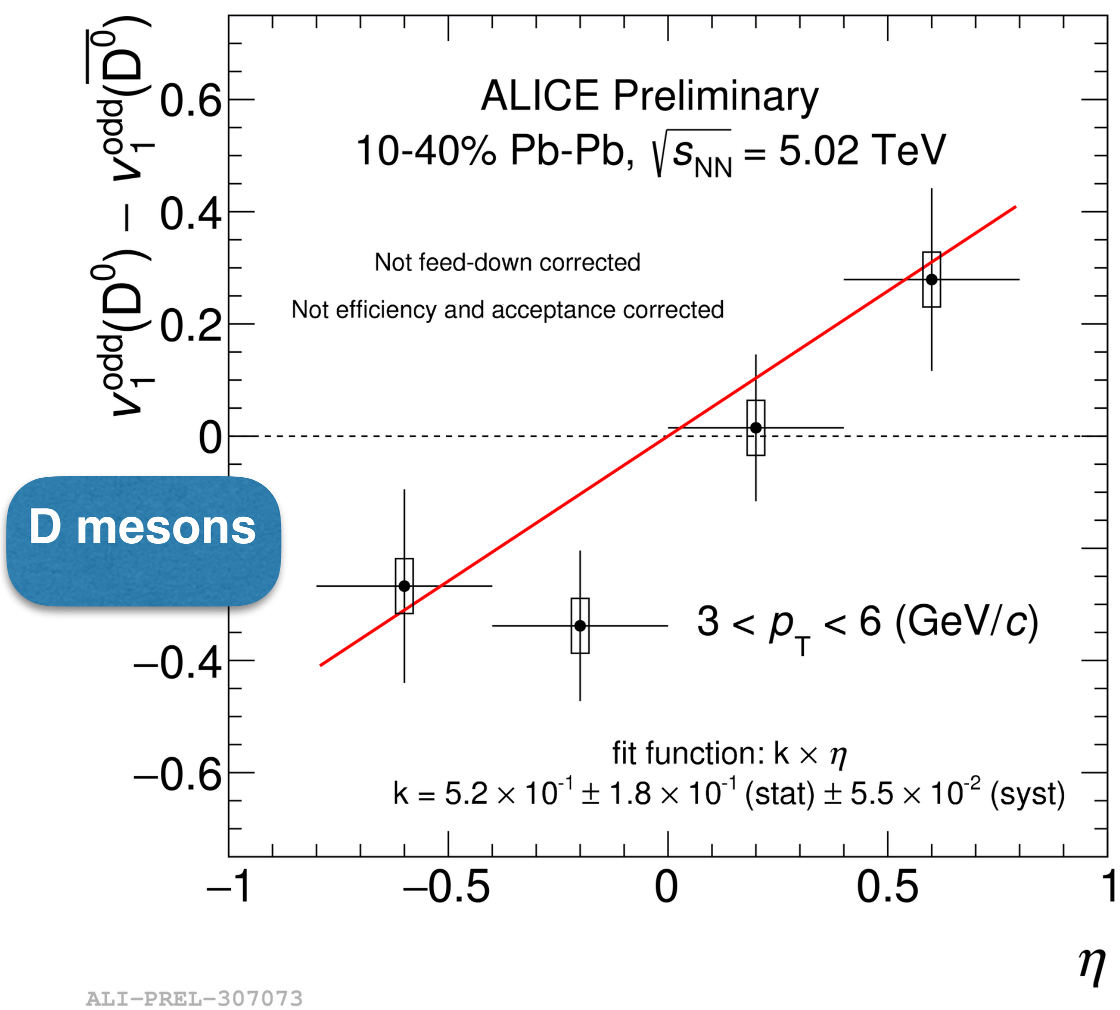


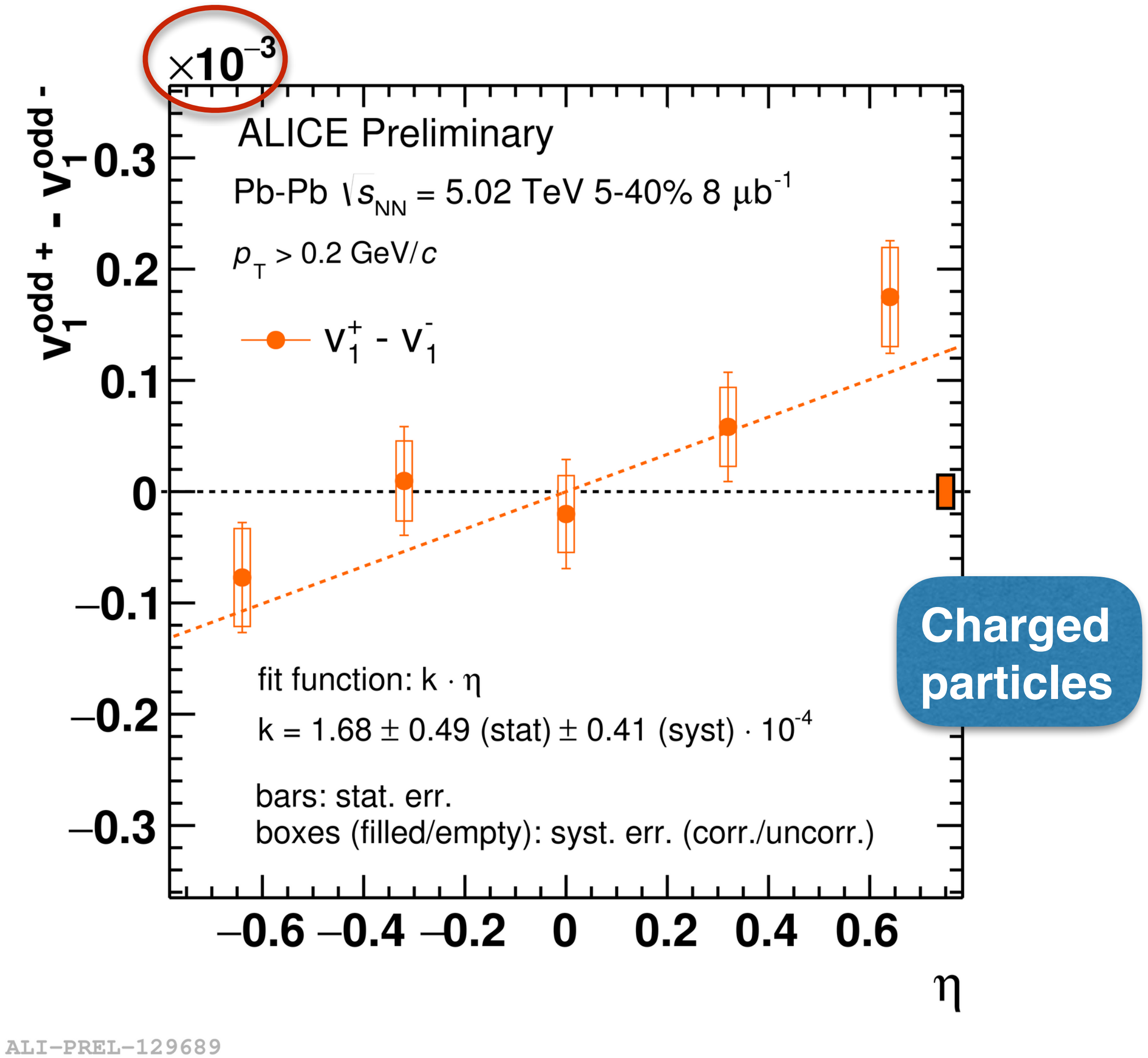
- v_1^{odd} component of D^0 (blue) and $\overline{D^0}$ (red) in the centrality range 10-40% and in $3 < p_T < 6$ GeV/c
- A hint of different trend is observed i.e negative v_1^{odd} for D^0 in positive pseudo rapidity

$$\Delta v_1^{odd} = v_1^{odd}(D^0) - v_1^{odd}(\overline{D^0})$$

➡ effect of a charge separation due to the presence of an electromagnetic field
➡ fitted with a linear function to quantify the effect
➡ Hint of positive slope with a significance of 2.7σ in $3 < p_T < 6$ GeV/c

D^0 ($\overline{D}^0$)-meson v_1 measurement





$$\Delta v_1^{odd} = v_1^{odd}(D^0) - v_1^{odd}(\overline{D}^0)$$

➡ Similar trend observed for charged particles, but different magnitude

Summary

ALICE

- **ALICE measures D-meson anisotropic flow using Pb-Pb data at 5.02 TeV**
  - ☑ Positive v_2 for $2 < p_T < 10$ GeV/c in 10-30% and 30-50% centrality has been observed
  - ☑ Statistically improved results are w.r.t 2015 PbPb data, compatible with the charged particle v_2 within uncertainty.
  - ☑ Event shape dependent study indicates a positive correlations between D-meson and light-hadron v_2.
  - ☑ First measurement of charged dependent difference of directed flow of HF particle at the LHC energies —> similar to charged particle v_1

Thank you!