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D meson azimuthal anisotropy measured with the ALICE experiment

Andrea Festanti (University and INFN, Padova)
for the ALICE Collaboration

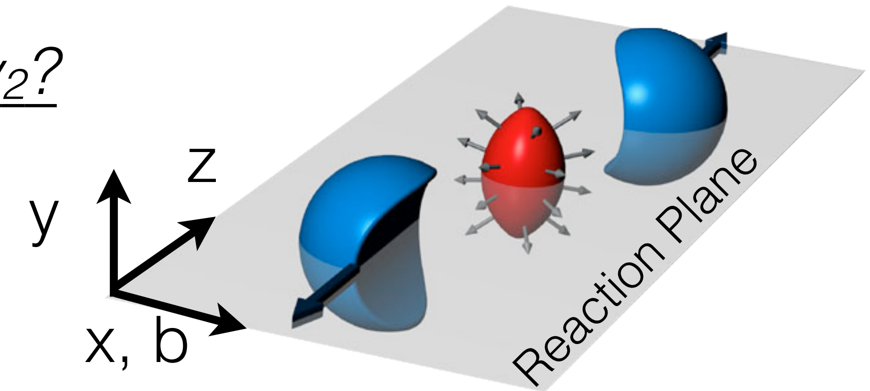
Outline of the talk

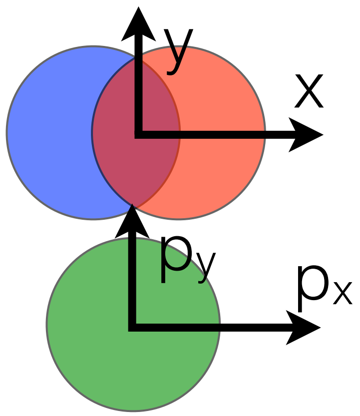
- **Introduction**: why do we measure D meson v_2?
- A Large Ion Collider Experiment - ALICE
- D mesons selection strategy
- **The v_2 measurement**: methods
- Systematic uncertainties
- Results
- Conclusions

Introduction

Why do we measure D meson v_2?

- In non-central heavy ion collisions, the collision region is **anisotropic** in spatial coordinates, while initial momentum distribution is isotropic





Introduction

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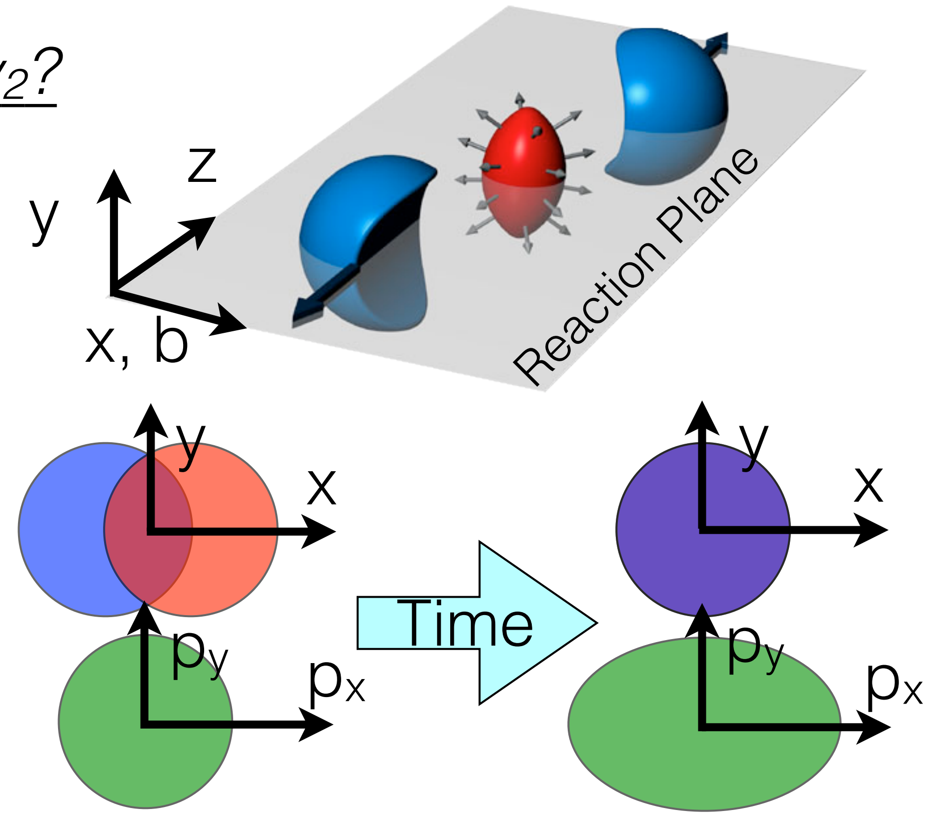

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- **Pressure gradients** generated by interactions among constituents transform initial coordinate space anisotropy into a **momentum anisotropy** of the produced particles

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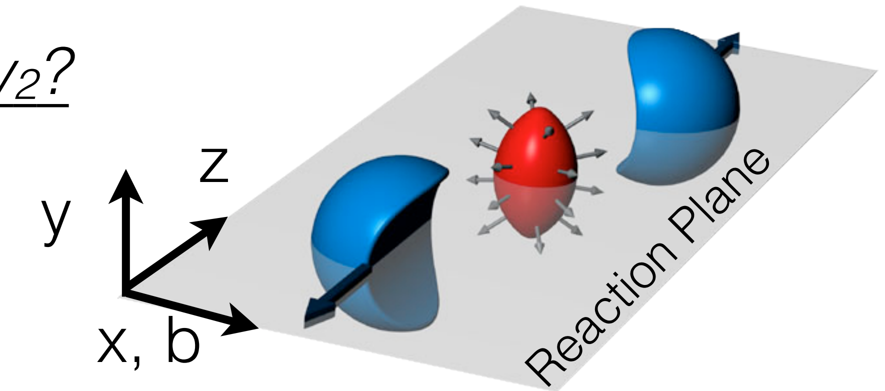

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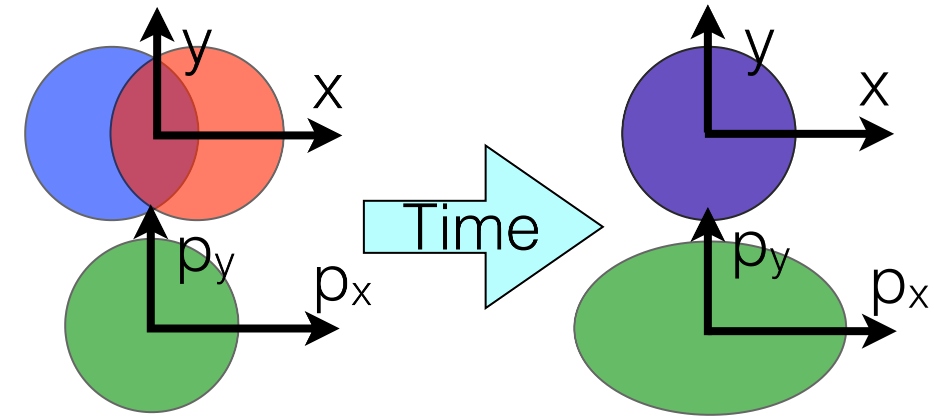


- **Pressure gradients** generated by interactions among constituents transform initial coordinate space anisotropy into a **momentum anisotropy** of the produced particles

- Azimuthal distribution of the final particles can be parametrized by a **Fourier expansion** with respect the n-th order reaction plane angle; coefficients are sensitive to
  - equation of state
  - medium transport properties

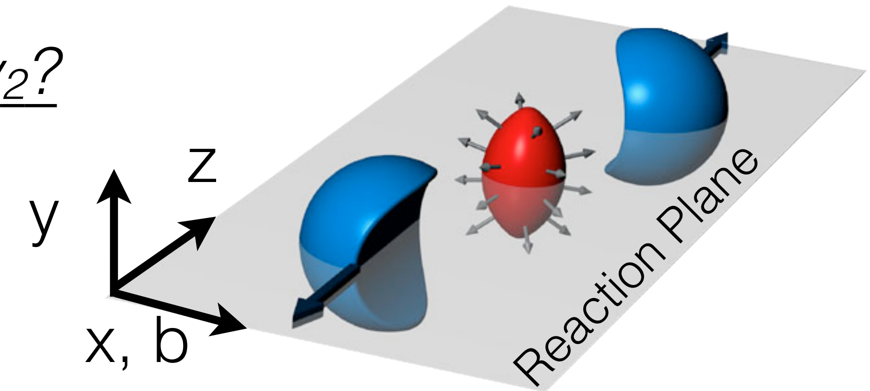
$$E\frac{d^3N}{d^3\overrightarrow{p}} = \frac{1}{2\pi}\frac{d^2N}{p_t dp_t dy}\left(1 + 2\sum_{n=1}^{\infty} v_n \cos[n(\phi - \Psi_{RP})]\right)$$

$$v_n(p_t, y) = \langle \cos[n(\psi - \Psi_{RP})] \rangle$$

ALICE

Introduction

Why do we measure D meson v_2?



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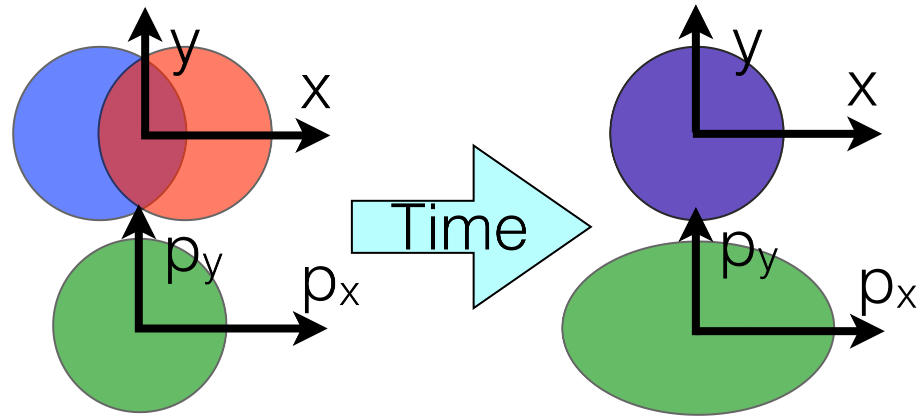

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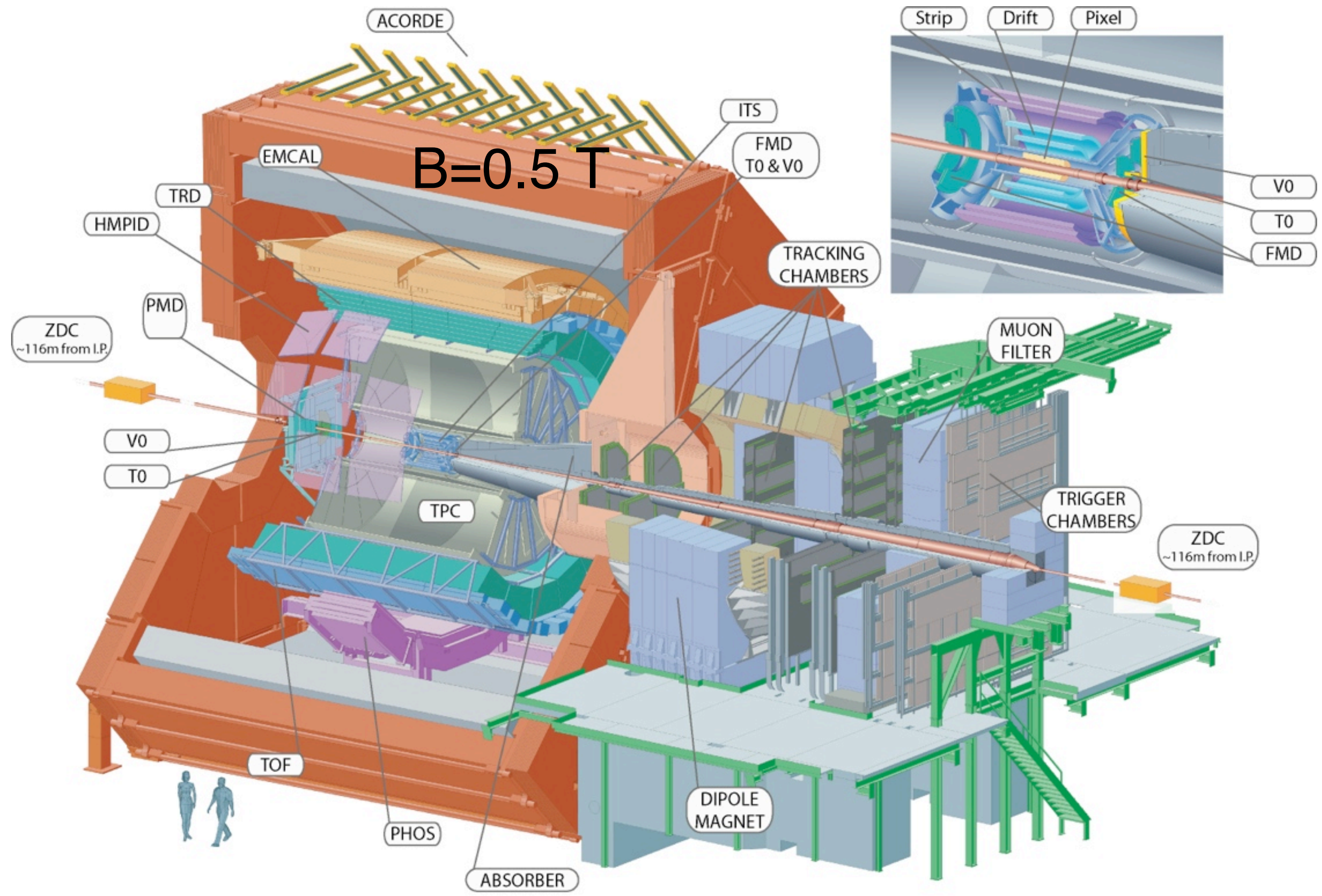
- In particular, the second harmonic **v_2** [**elliptic flow**] of **heavy flavour particles** brings informations about
  - possible **thermalization** of heavy quarks in the medium [low momentum]
  - **path length** dependence of **heavy quark energy loss** [high momentum]

A Large Ion Collider Experiment - ALICE

Detectors used for the analysis

- **Inner Tracking System - ITS:** vertex and track reconstruction
- **Time Projection Chamber - TPC:** tracks reconstruction and particle identification
- **Time Of Flight - TOF:** particle identification
- **VZERO scintillators:** trigger and centrality selection



Data sample

- **2011 Pb-Pb collisions @ $\sqrt{s_{NN}}$=2.76 TeV**

15×10^6 analyzed events in 0-7.5% centrality class

7×10^6 analyzed events in 15-30% centrality class

9.5×10^6 analyzed events in 30-50% centrality class

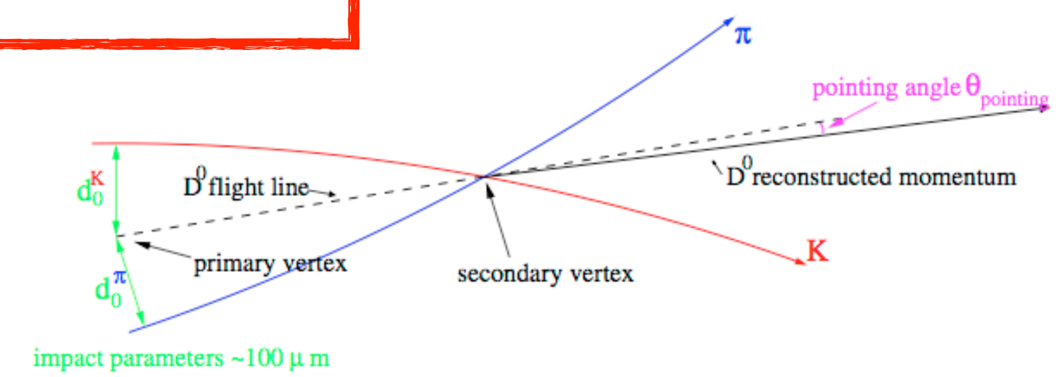
D meson selection strategy

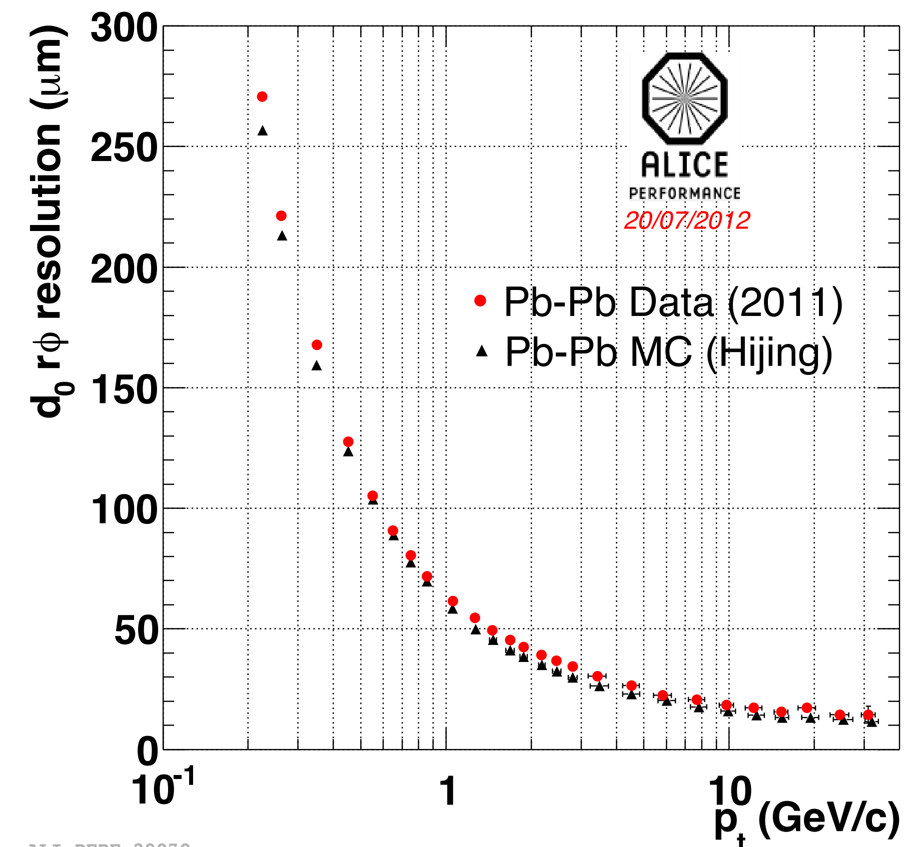
- D^0, D^+ and D^{*+} reconstructed in the central rapidity region [|y|<0.8] from their hadronic decay channel

> $D^0 \rightarrow K^-\pi^+$ [BR 3.88±0.05%, cτ≈123 μm]
> $D^+ \rightarrow K^-\pi^+\pi^+$ [BR 9.13±0.19%, cτ≈312 μm]
> $D^{*+} \rightarrow D^0\pi^+$ [BR 67.7±0.5%]

- Selection of D^0 and D^+ decays is based on the reconstruction of secondary vertex topologies displaced by a few hundred μm from the interaction vertex

- In case of D^{*+}, D^0 candidates were attached to $\pi^{+/-}$ candidate at the primary vertex





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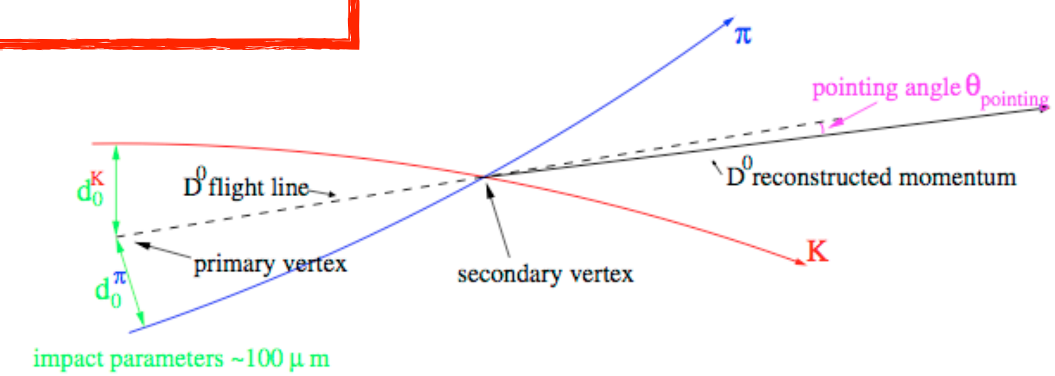
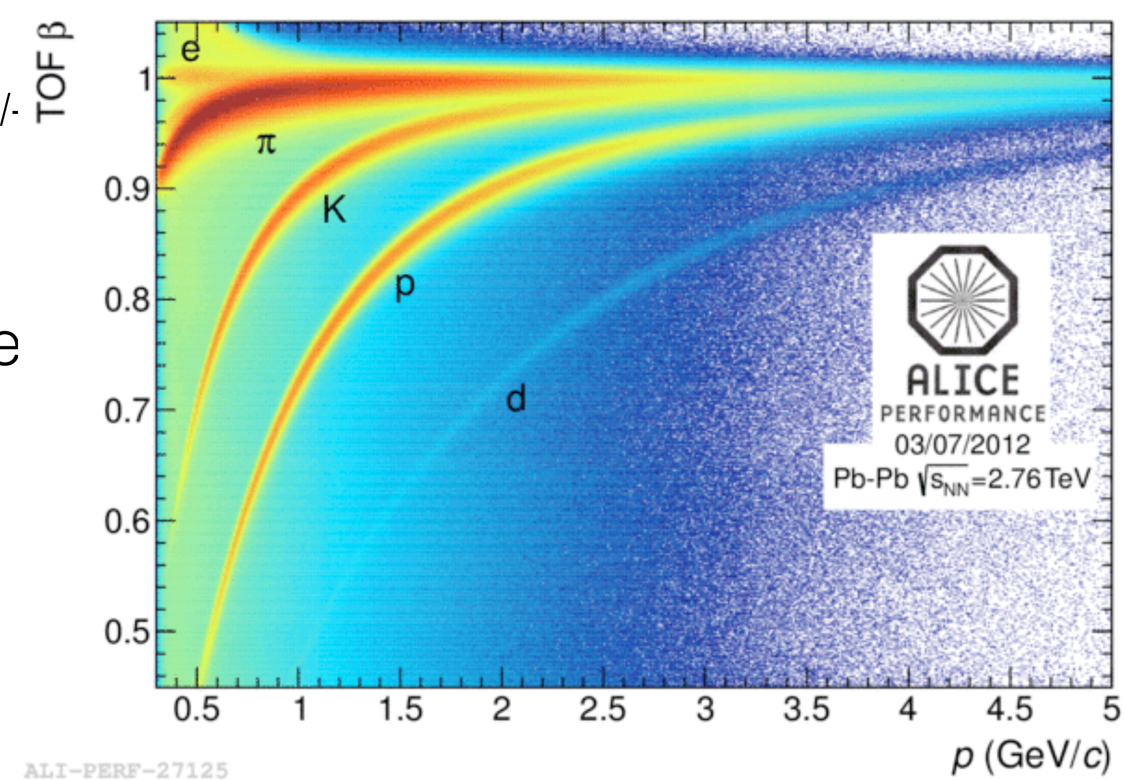


- In case of D^{*+}, D^0 candidates were attached to $\pi^{+/-}$ candidate at the primary vertex
- Particle identification with TPC and TOF to reduce combinatorial background without any loss of signal
- Yields are extracted from an invariant mass analysis



The v_2 measurement

Methods

$$E\frac{d^3N}{d^3\vec{p}} = \frac{1}{2\pi}\frac{d^2N}{p_t dp_t dy}\left(1 + 2\sum_{n=1}^{\infty} v_n \cos[n(\phi - \Psi_{RP})]\right)$$

- **Event plane based methods**
  - reaction plane not known
  - using the event plane as an experimental estimate of the reaction plane
- **Scalar product and Q-Cumulants**
  - flow is a correlation among all particles
  - use of multi-particle correlations
  - current statistics only allows for 2-particle methods for D mesons

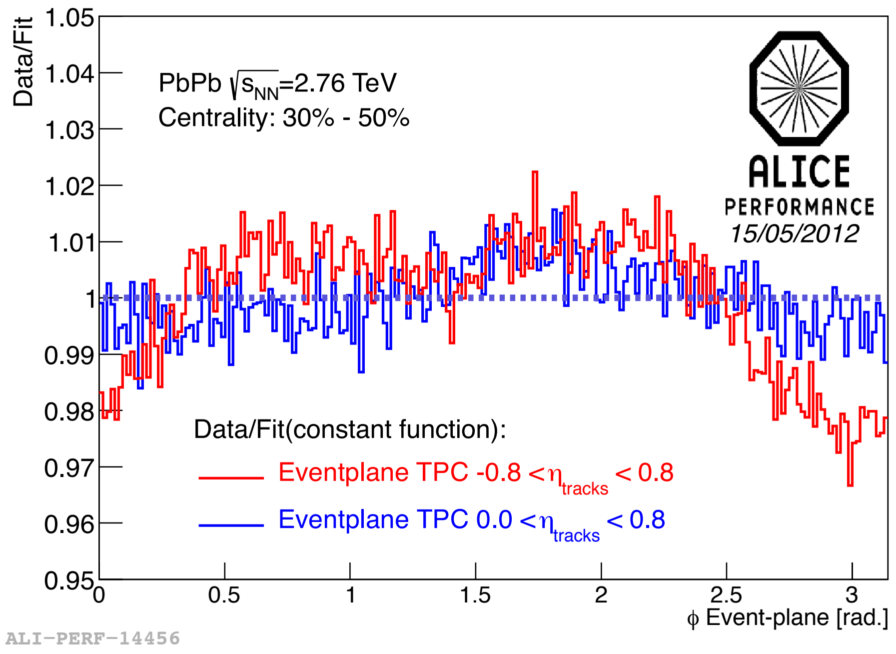
The v_2 measurement

Event plane estimation

- Event plane angle ψ_n for each harmonics n is measured through the Q-vector using TPC tracks with 0< η <0.8 [uniform detector efficiency]

$$Q_n = \begin{pmatrix} \sum_{i=0}^{N} w_i \cos n\phi_i \\ \sum_{i=0}^{N} w_i \sin n\phi_i \end{pmatrix} \qquad \psi_n = \frac{1}{n} \tan^{-1}\left(\frac{Q_{n,y}}{Q_{n,x}}\right)$$

- Tracks weights are determined as a function of p_T, η, track charge and run number from the Φ angle distribution



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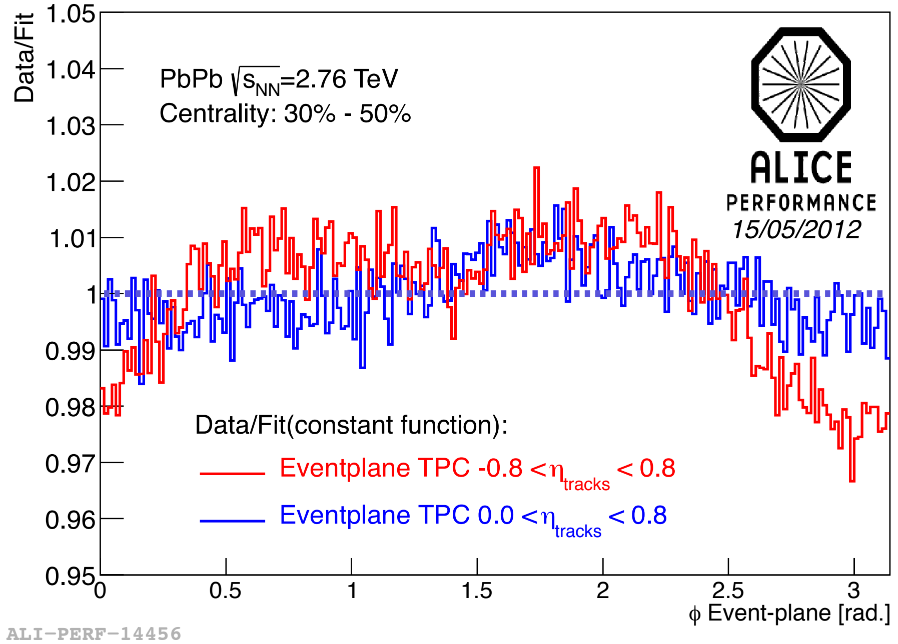


- Due to finite number of detected particles the resolution in angle is limited; to get the real v_n, v_n^{obs} must be corrected for the resolution

$$v_n^{obs} = \langle \cos n(\phi_i - \psi_n)\rangle \qquad v_n = \frac{v_n^{obs}}{\langle \cos n(\psi_n - \Psi_{RP})\rangle}$$

- The event plane resolution is computed using two sub-events obtained from one full event split in two random subsets with same multiplicity and covering equal η regions

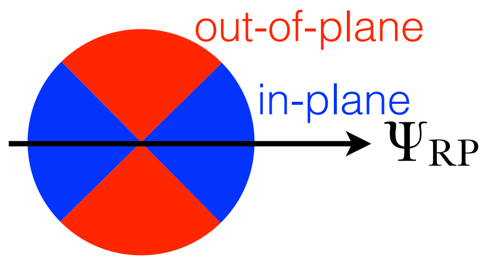
$R_2 = 0.86^{+0.03}_{-0.06}$ for 30-50% centrality

The v_2 measurement

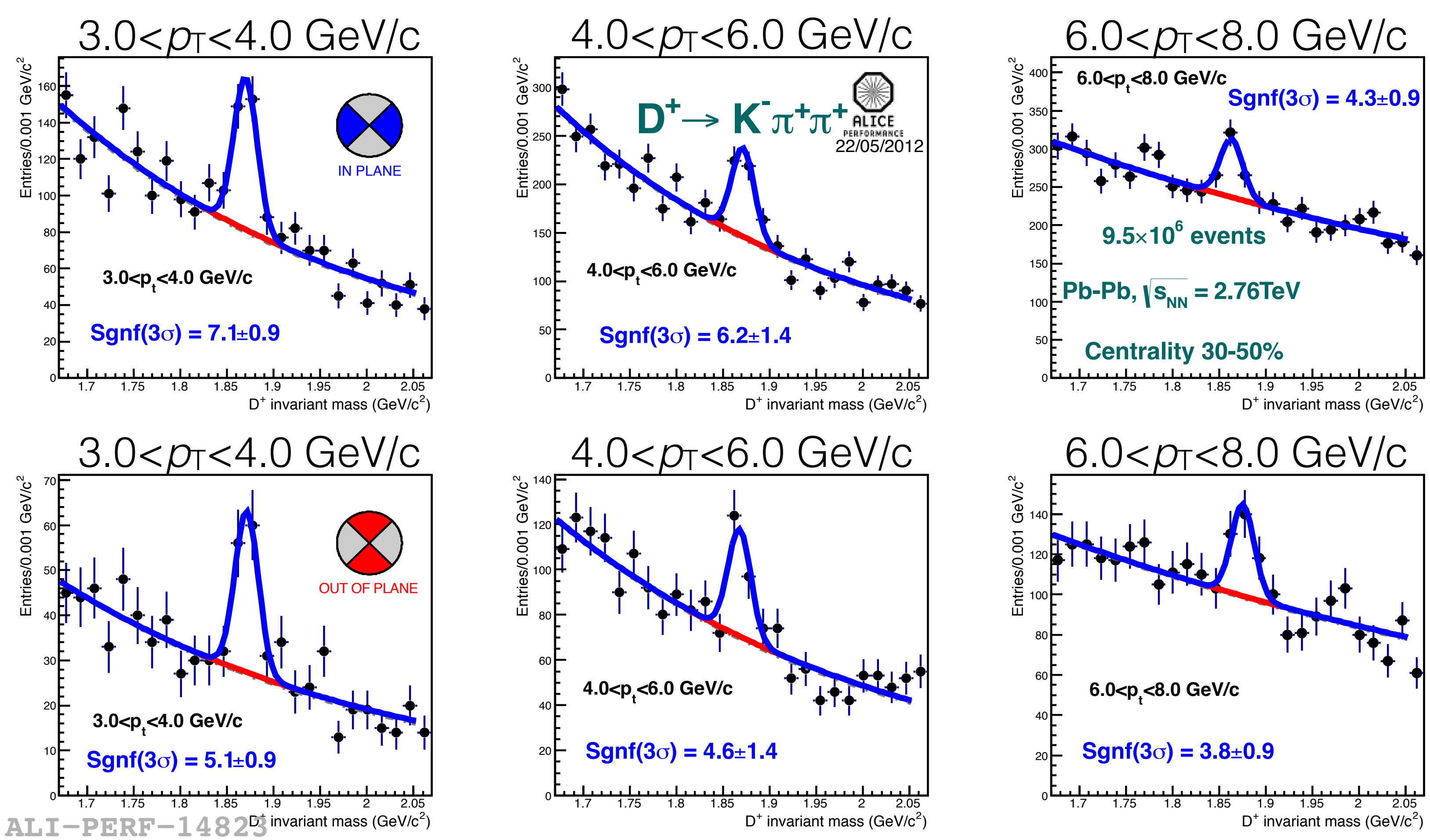
Event plane based method

- Start from invariant mass distributions of D meson candidates in two **ΔΦ** regions centered on the event plane

  - in-plane: (0, π/4] ∪ [3π/4, π)
  - out-of-plane: (π/4, 3π/4]



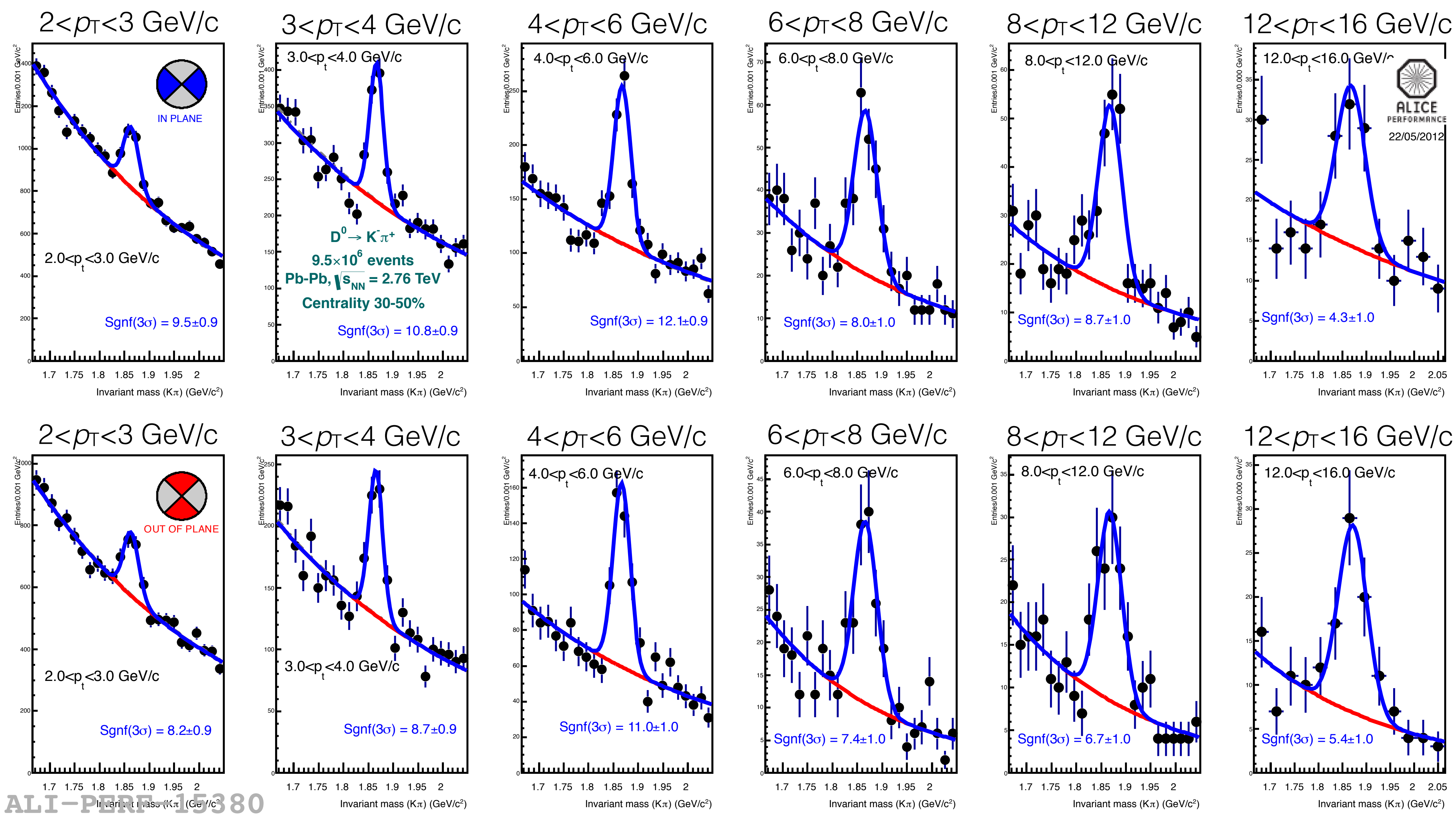
- Fit the invariant mass distributions to extract number of candidates in-plane and out-of-plane [v_2 computed from azimuthal asymmetry]



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

The v_2 measurement

D^0 invariant mass distributions



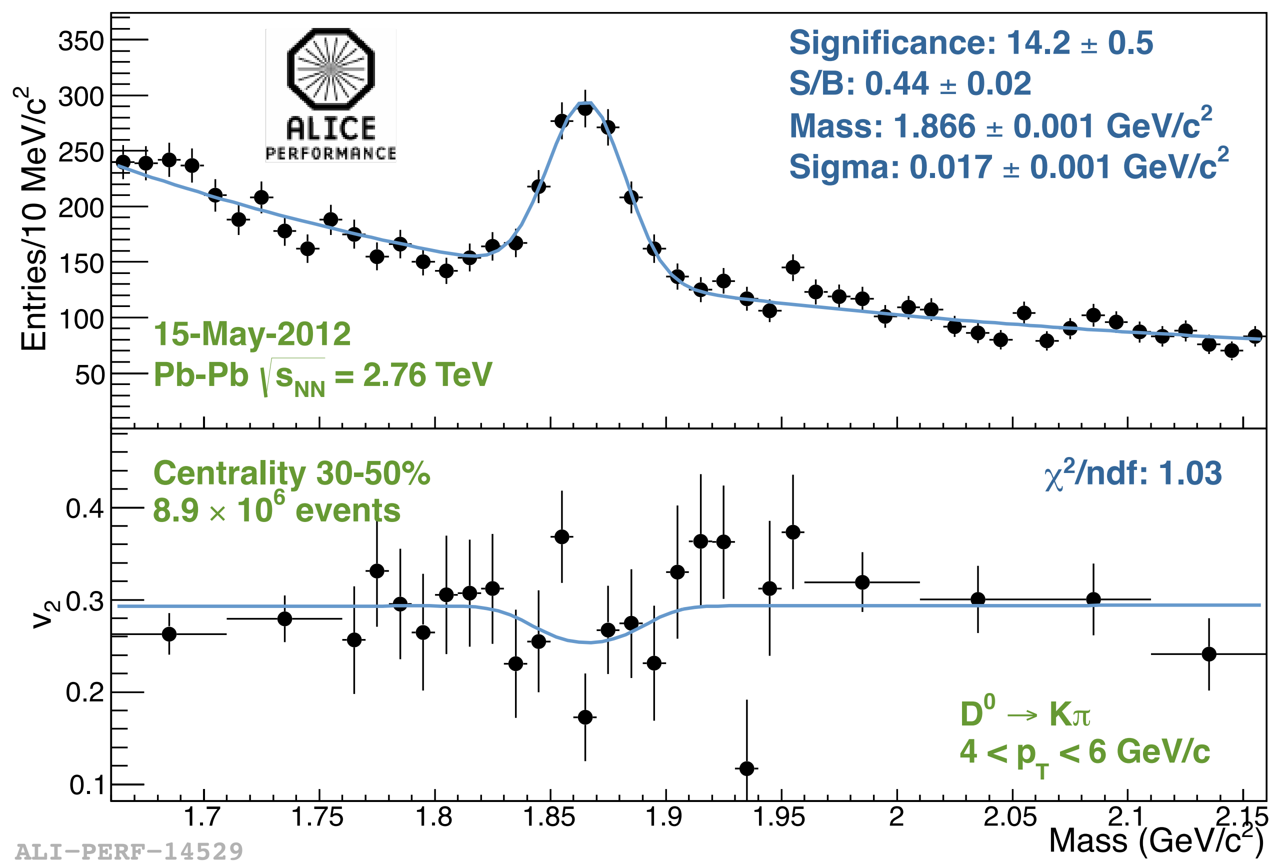
Scalar Product and Q-Cumulants

v_2 fit

- Total v_2 is calculated with multi-particle algorithms as a function of invariant mass
- Simultaneous fit of the yields and v_2 as a function of mass

$$v_2^{sgn} = \frac{N^{tot}}{N^{sgn}} v_2^{mea} - \frac{N^{bkg}}{N^{sgn}} v_2^{bkg}$$

- Invariant mass distributions fitted with a gaussian + background function
- v_2^{bkg} shape is a function linearly dependent on the mass



Systematic uncertainties

Sources

Data systematics

0.01 - 0.04 absolute value

- Yield extraction from the invariant mass distributions
- Cut variation [it tests the stability extraction against variation of significance and S/B of the D meson peak]
- v_2^{bkg} parametrization [scalar product and Q-cumulants]

Event plane resolution

- Centrality dependence
- Difference between R_2 estimation methods

+3% -7% semiperipheral

+7% -16% central

D meson from B feed-down contribution

max +23% uncertainty

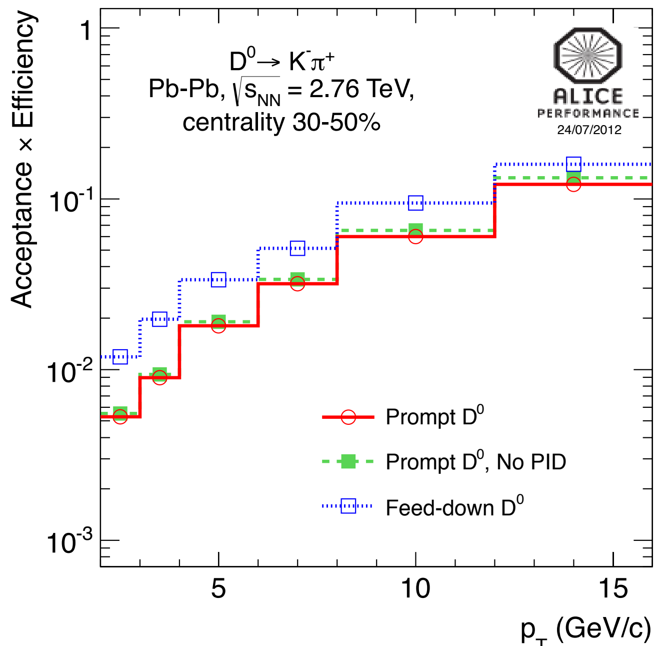
B feed-down

- Measured D meson yield includes
  - prompt D meson
  - D from beauty hadron decay
- The measured v_2 is therefore given by:

$$v_2 = f_{prompt} v_2^{prompt} + (1 - f_{prompt}) v_2^{feed-down}$$

- f_{prompt} is the fraction of D mesons promptly produced in the measured yield [estimated using FONLL predictions and Monte Carlo efficiencies]

$$f_{prompt} = \left(1 + \frac{(Acc \times \epsilon)_{feed-down}}{(Acc \times \epsilon)_{prompt}} \times \frac{\left(\frac{d^2\sigma}{dy dp_t}\right)^{FONLL}_{feed-down}}{\left(\frac{d^2\sigma}{dy dp_t}\right)^{FONLL}_{prompt}} \times \frac{R_{AA}^{feed-down}}{R_{AA}^{prompt}} \right)^{-1}$$



- Hypothesis: $R_{AA}^{feed-down} = R_{AA}^{prompt}$
- Systematic uncertainty determined varying the hypothesis in the range: $0.5 < R_{AA}^{feed-down}/R_{AA}^{prompt} < 2$
- $0.7 < f_{prompt} < 0.95$

B feed-down

- Measured D meson yield includes
  - prompt D meson
  - D from beauty hadron decay
- The measured v_2 is therefore given by:

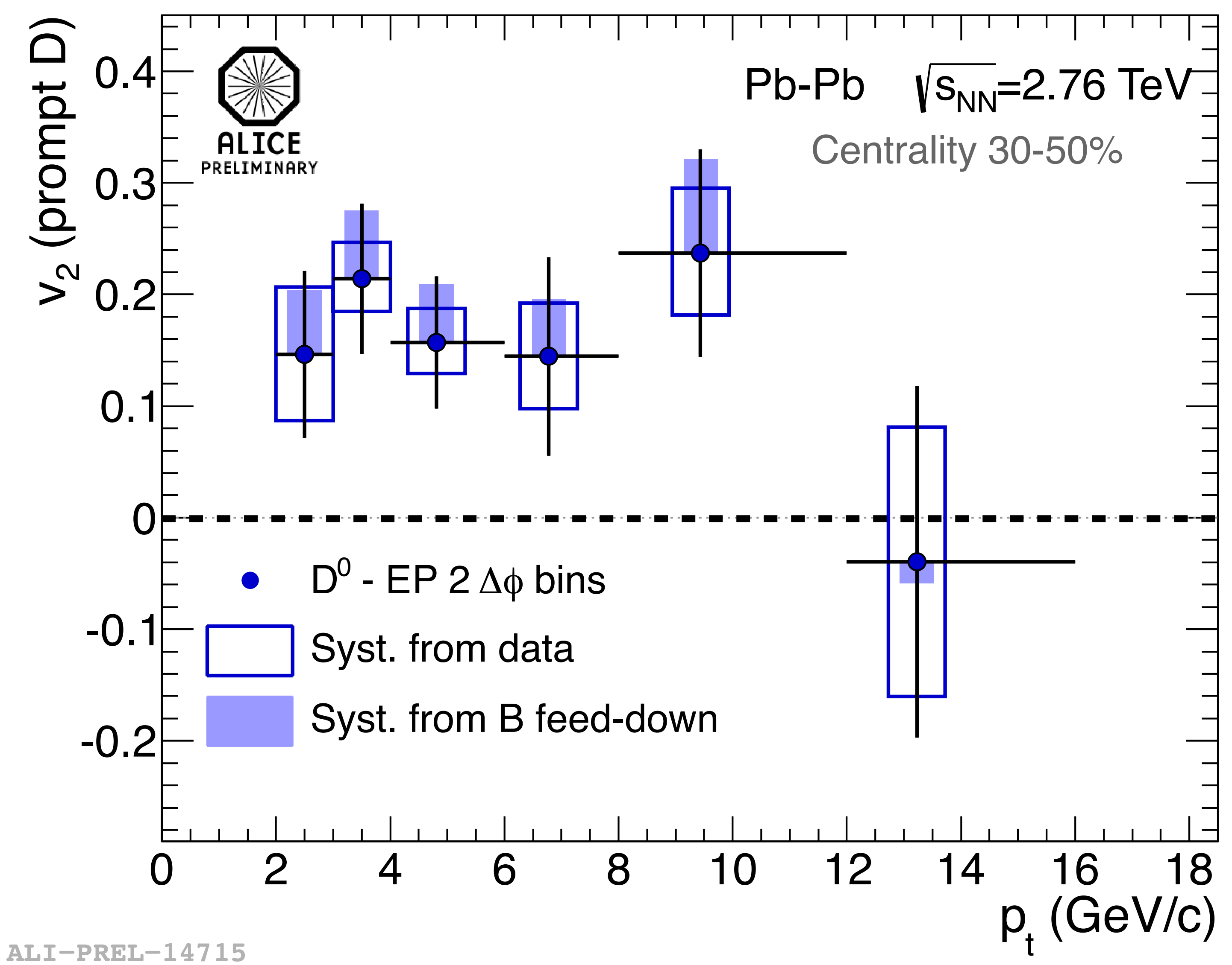
$$v_2 = f_{prompt} v_2^{prompt} + (1 - f_{prompt}) v_2^{feed-down}$$

- $v_2^{feed-down}$ of D mesons from B decays is unknown
- D meson v_2 determined assuming $v_2^{feed-down} = v_2^{prompt}$
- Assigned asymmetric systematic uncertainty that spans the range

$$0 < v_2^{feed-down} < v_2^{prompt}$$

Results

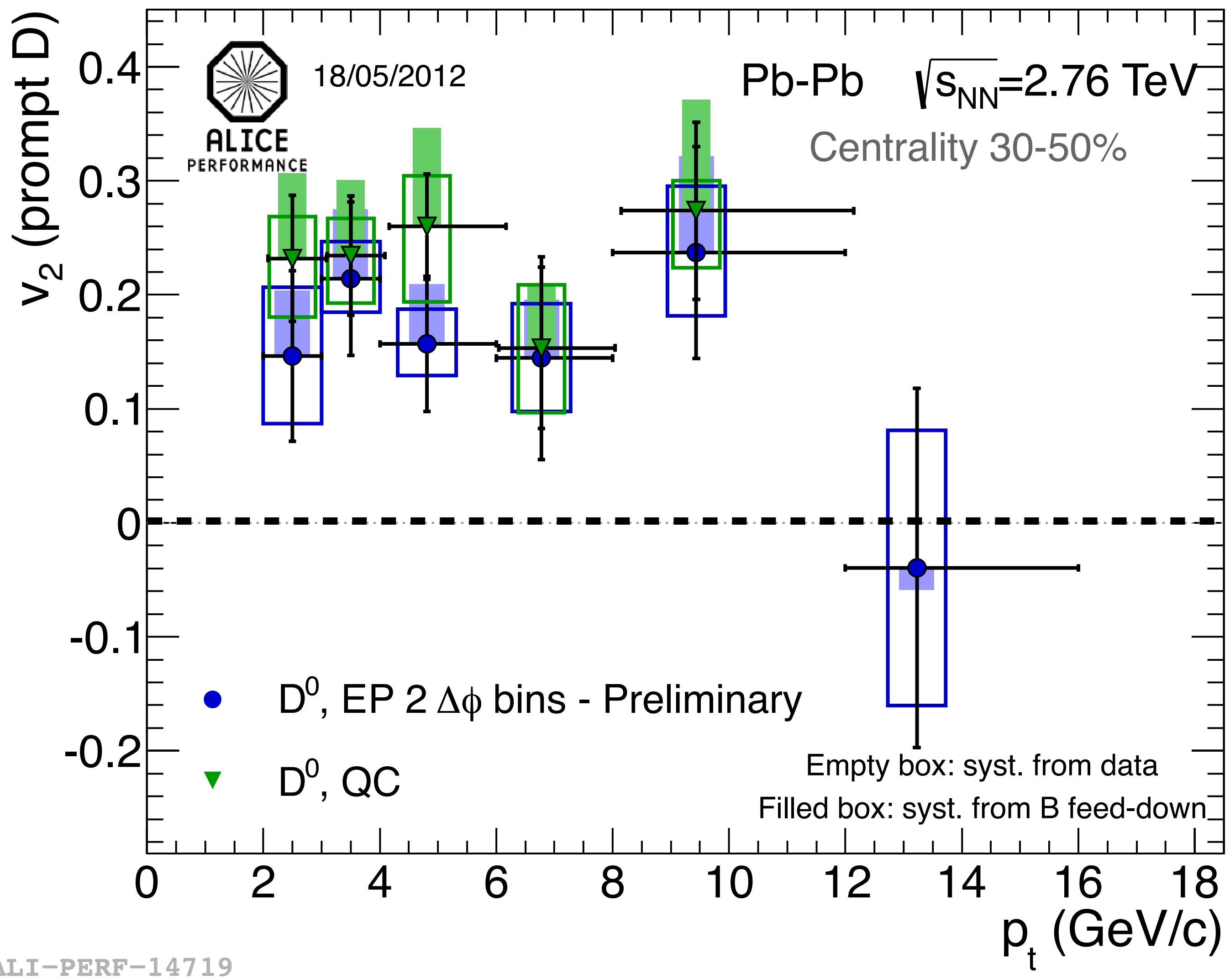
D^0 v_2 - event plane method

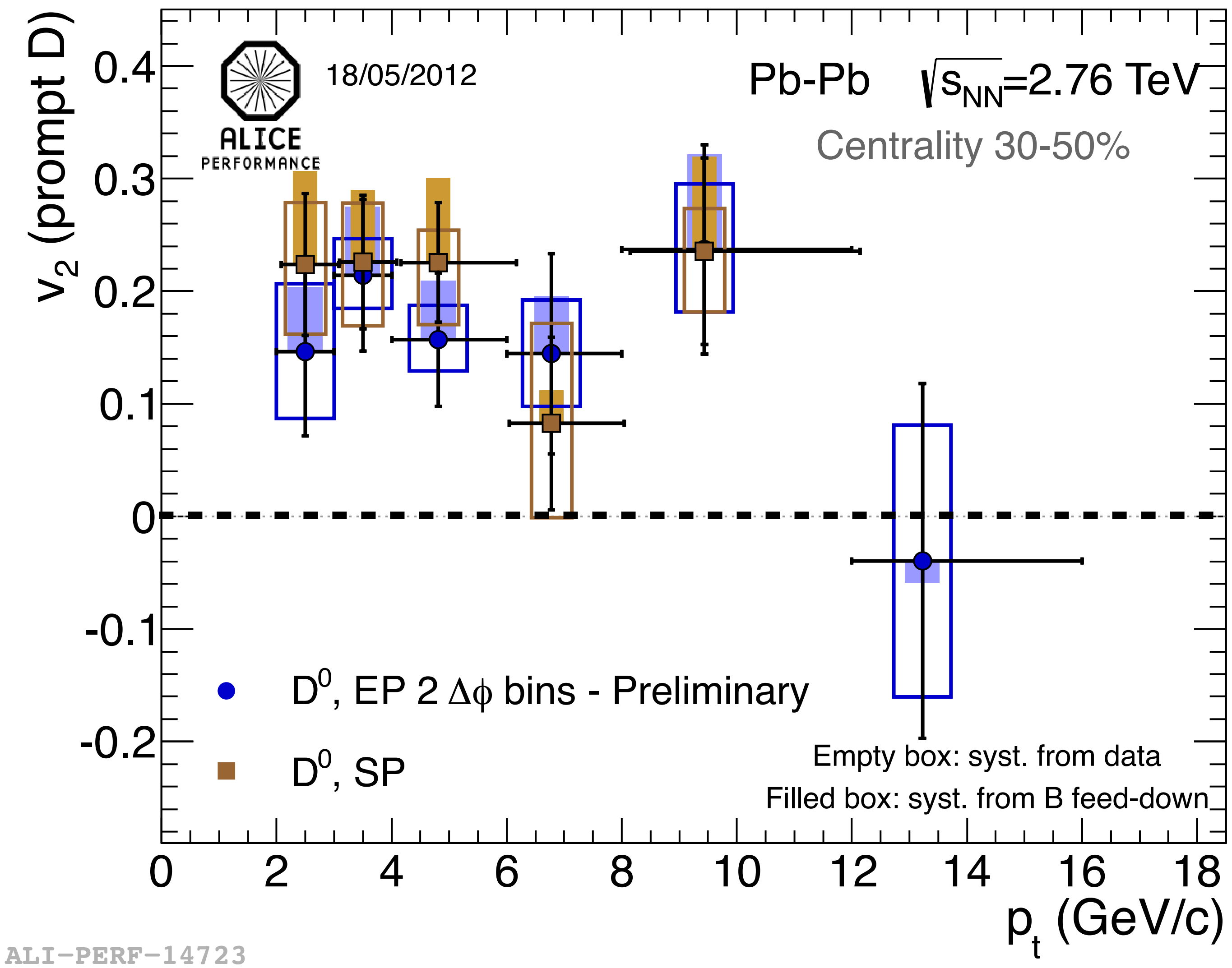


- Indication of non-zero v_2 for D^0 mesons in 2-6 GeV/c in 30-50%

Results

D^0 v_2 - all methods

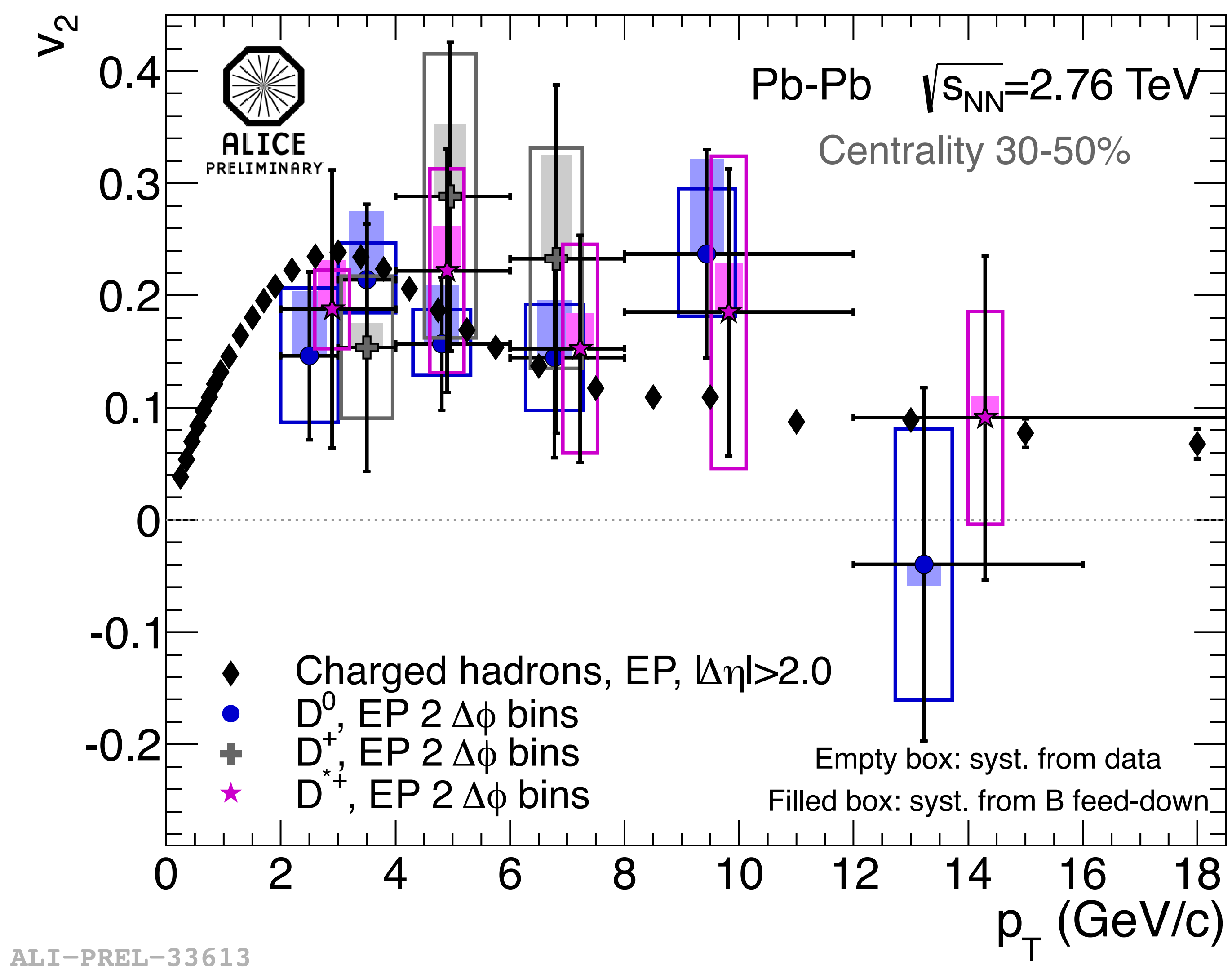




- Consistency of v_2 measurements with the three methods

Results

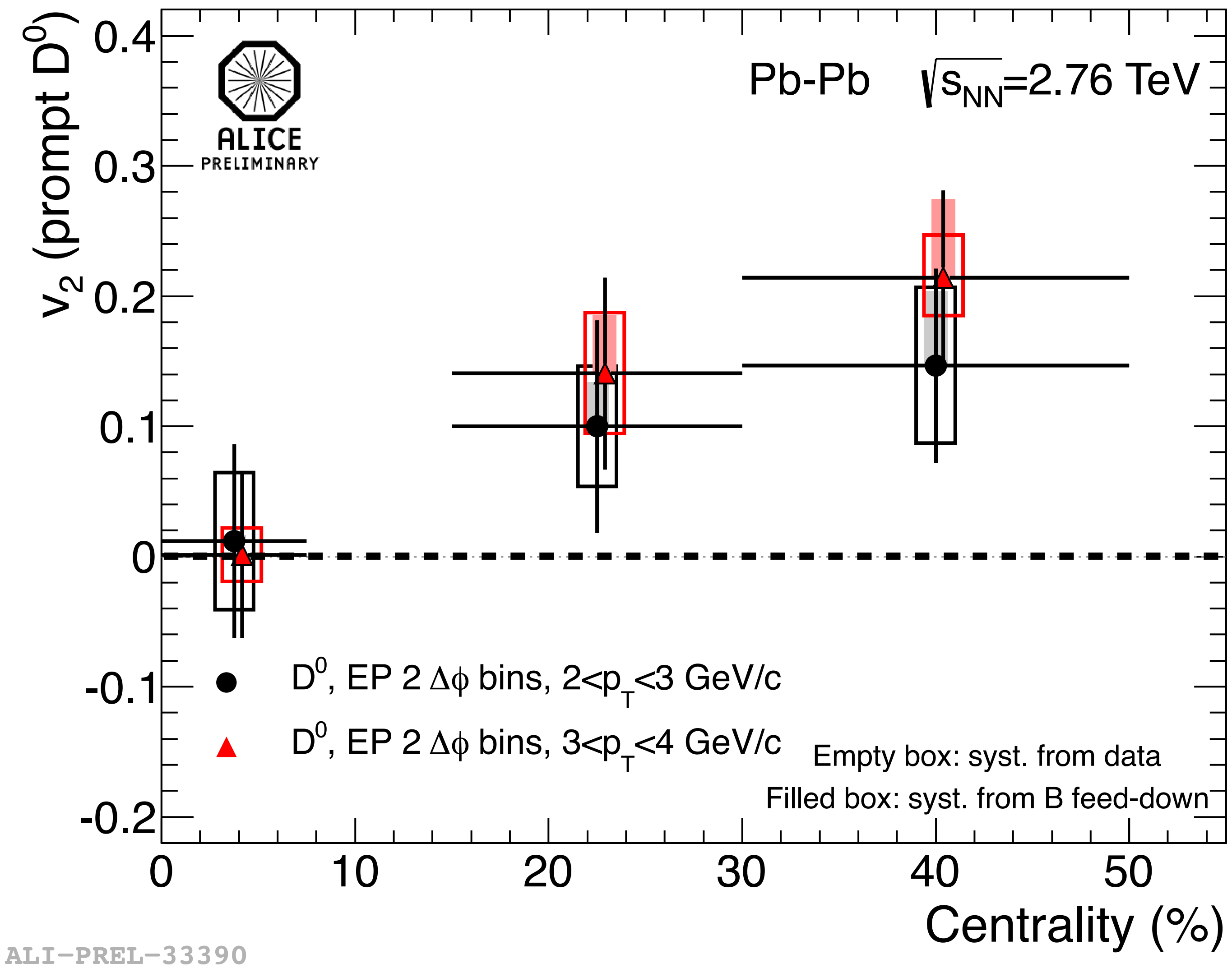
D^0, D^+, D^{*+} and charged hadrons v_2



- Consistency of the measured v_2 of the three different mesons
- D meson v_2 comparable and of the same magnitude of charged hadrons v_2 measured with ALICE

Results

D^0 v_2 centrality dependence

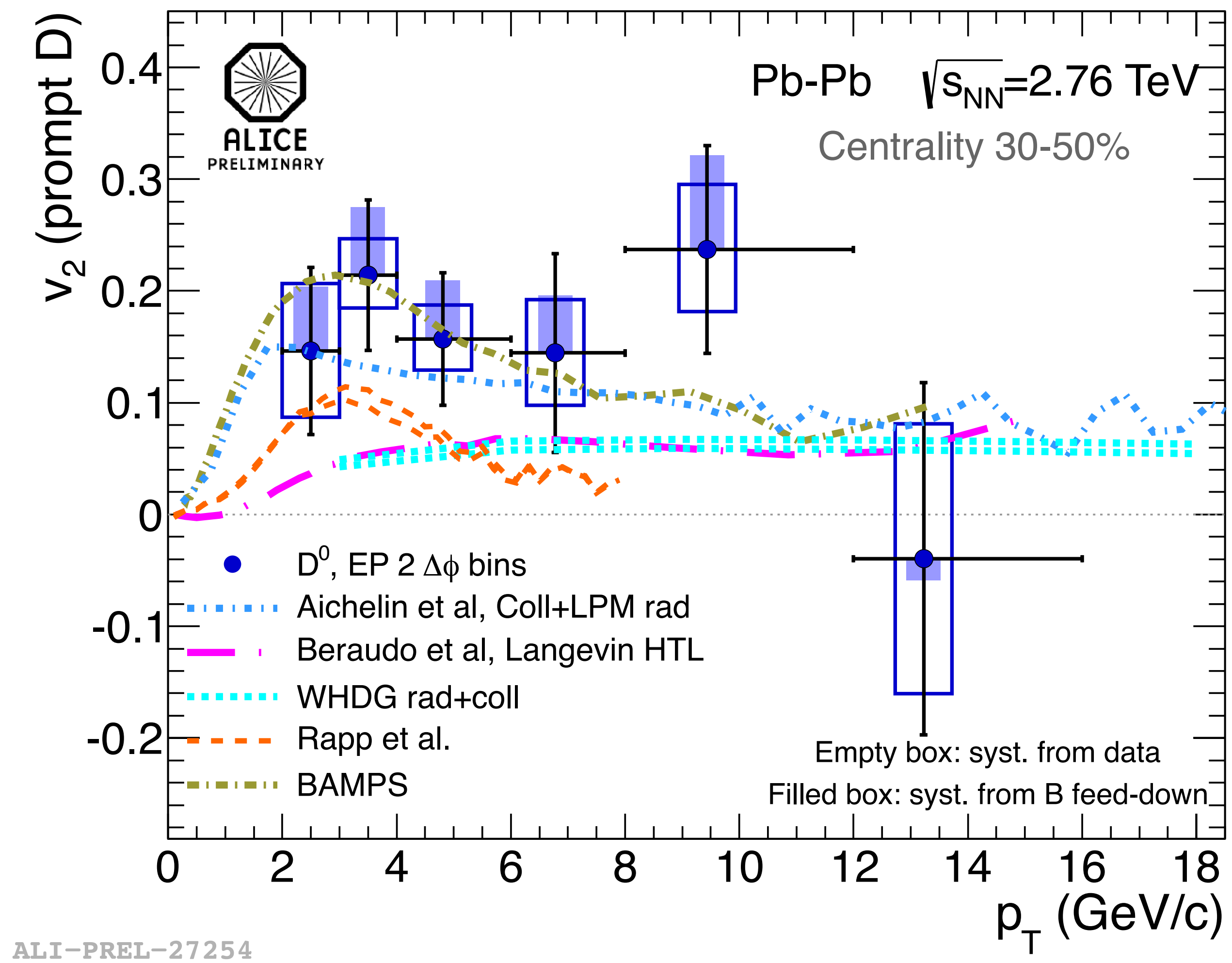


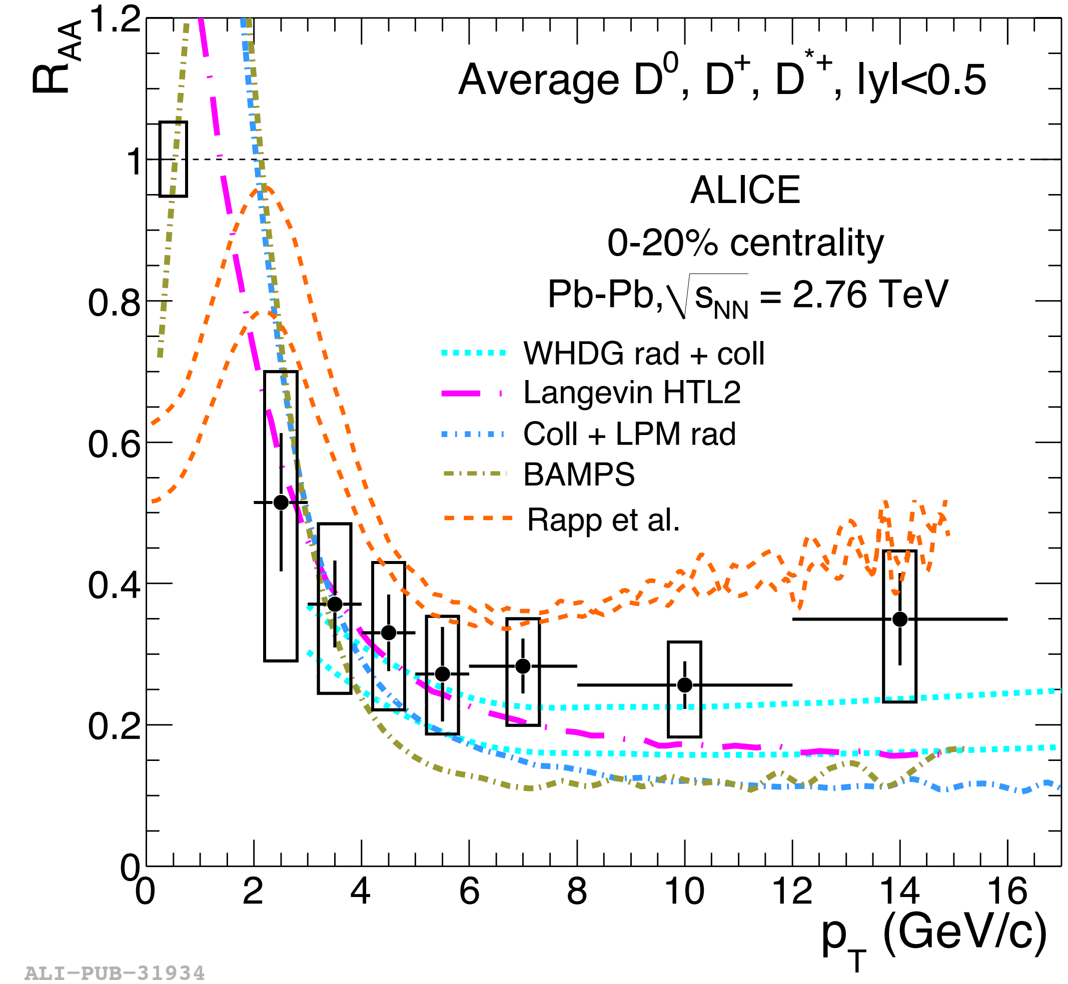
- In 30-50% v_2 larger than in more central collisions
- Hint of v_2 increasing from central to more peripheral collisions [as expected] in 2-3 and 3-4 GeV/c p_T bins

Results

Comparison with models

Simultaneous description of D meson v_2 and R_{AA} → understanding of heavy quark transport coefficient of the medium





- [1]BAMPS and [2]Coll+LPM rad seem to describe consistently v_2 but underestimate R_{AA} [[1]Uphoff et al. arXiv: 1112.1559, [2]Aichelin et al. Phys. Rev. C 79 (2009) 044906]

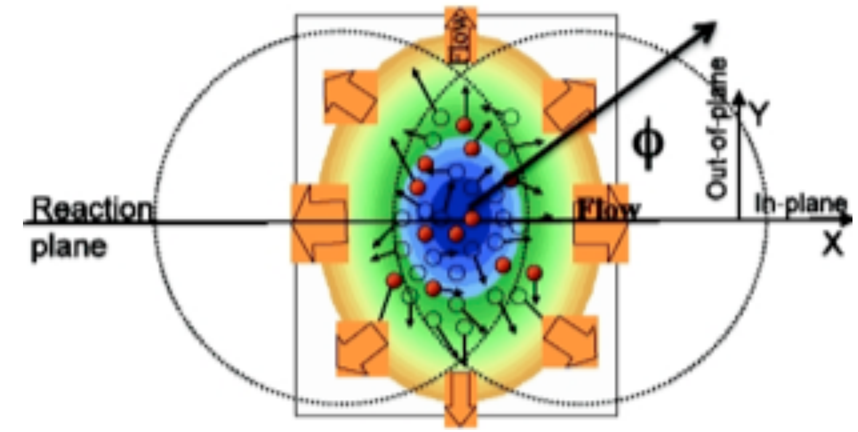
- [3]WHDG and [4]Beraudo et al might underestimate v_2 but describe well R_{AA} [[3]Horowitz et al. J.Phys. G38, 124064 (2011), [4]Alberico et al. Eur. Phys J. C 71, 1666 (2011)]

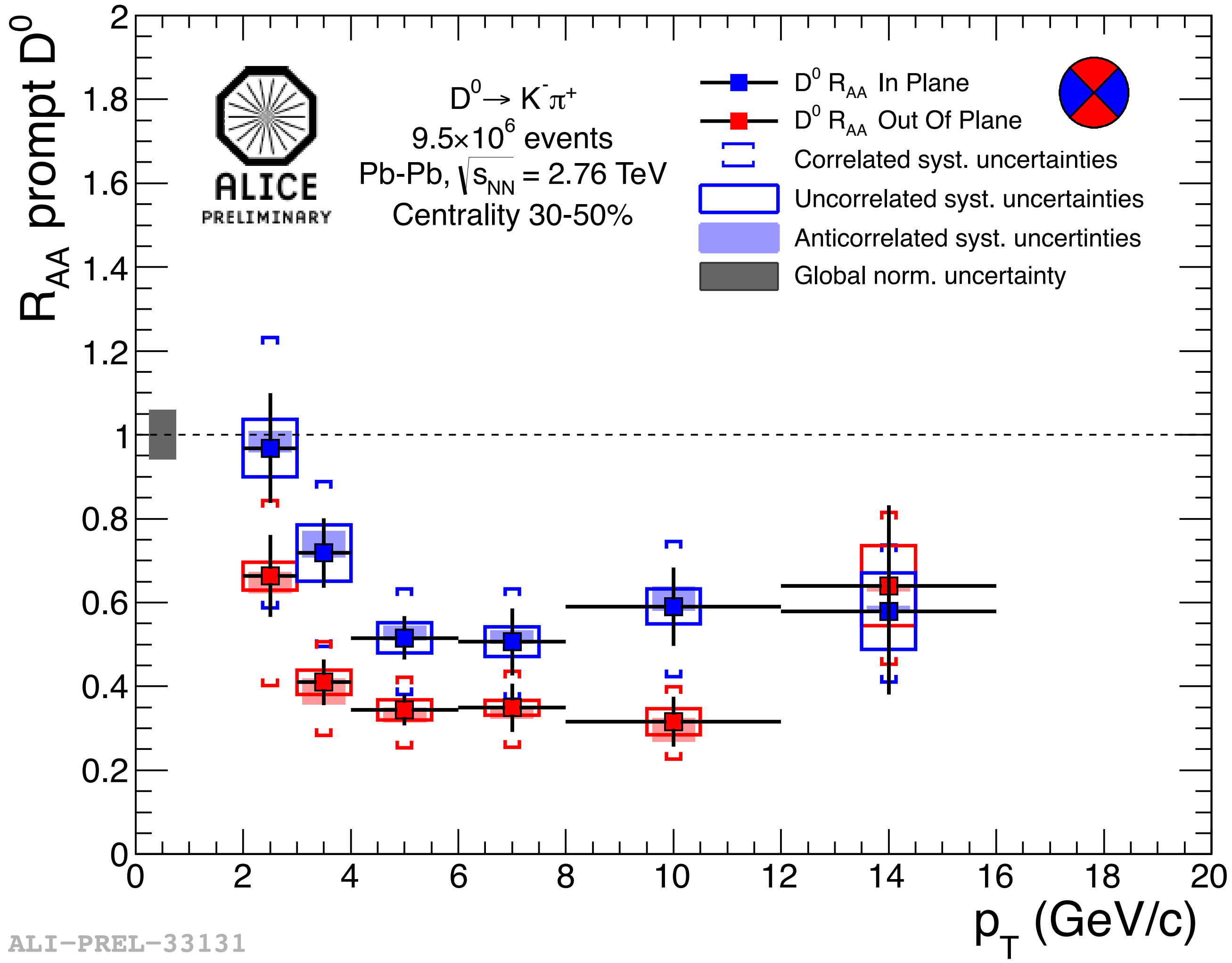
- [5]Rapp et al seems to underestimate both v_2 and suppression [[5]He, Fries and Rapp, arXiv: 1204.4442[nucl-th]]

R_{AA} vs Event Plane

- Raw yields in-plane and out-of-plane in 30-50%
- Efficiency feed-down correction
- pp reference measured at $\sqrt{s}$=7 TeV, scaled to $\sqrt{s}$=2.76 TeV

$$R_{AA}^{in(out)}(p_T) = 2\frac{dN_{AA}^{in(out)}/dp_T}{\langle T_{AA}\rangle \times d\sigma_{pp}/dp_T}$$





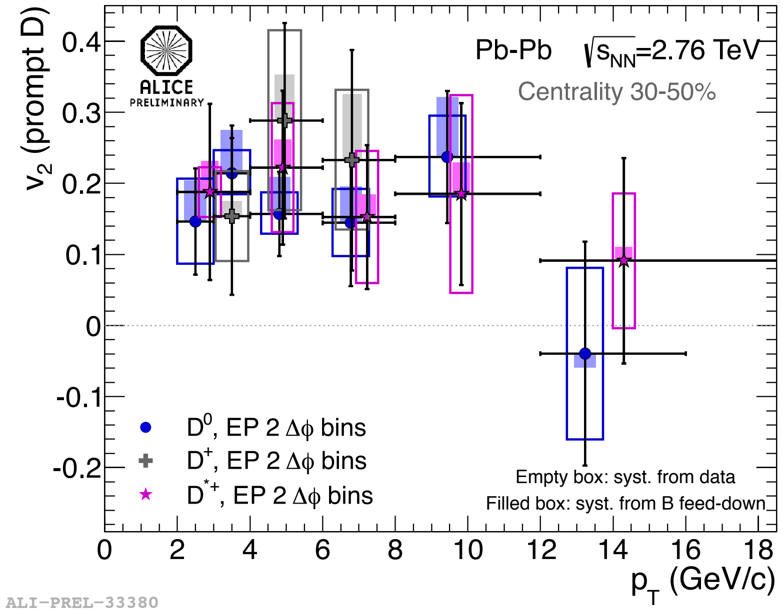
More suppression out-of-plane with respect to in-plane:

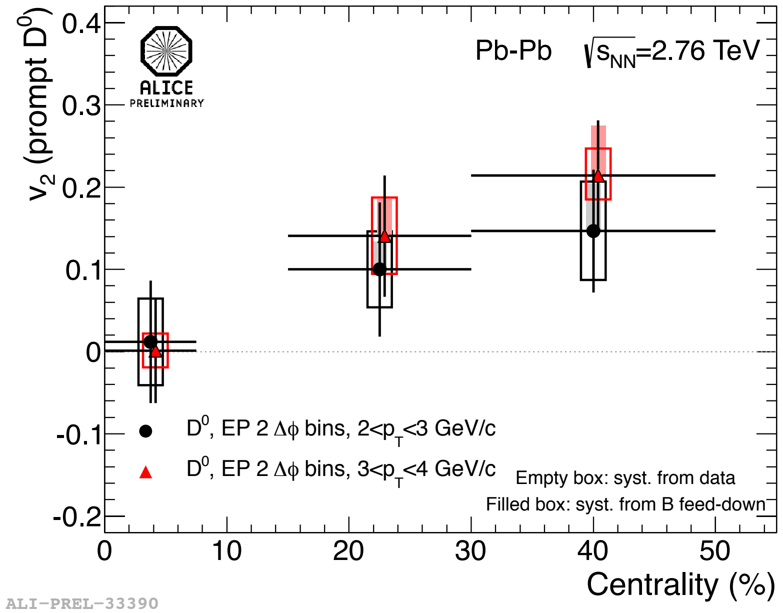
consistent with measured non zero D^0 v_2

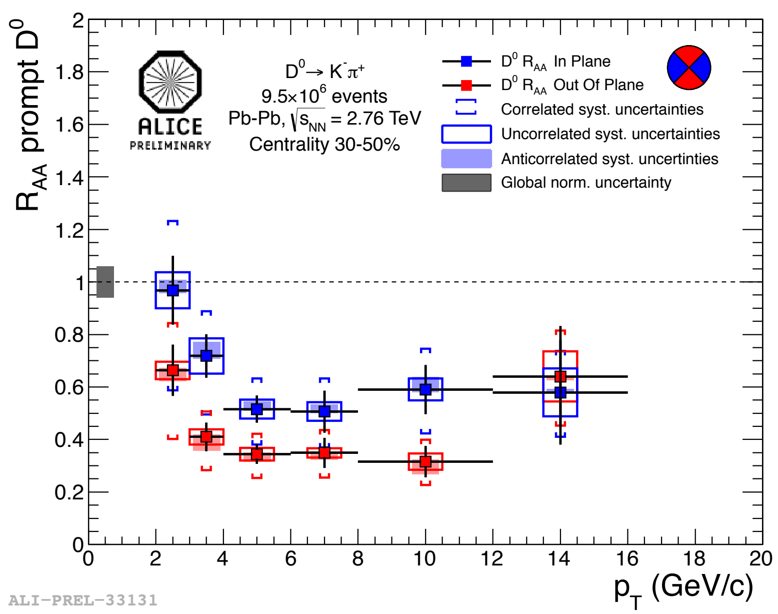
elliptic flow at low p_T ?

longer path length at high p_T ?

Conclusions







- First measurement of D meson azimuthal anisotropy at LHC
  - compatibility of the results obtained with different methods
  - non-zero v_2 in 2-6 GeV/c

- Hint of v_2 increasing from 0-7.5% to 30-50%

- Measurement of D^0 R_{AA} vs event plane: azimuthal dependence of the suppression

Backup

The v_2 measurement

Scalar product and Q-cumulants

Scalar product

- It estimates the v_2 on the basis of the scalar product beetween the unit vector associated to the D meson u and the flow vector Q

$$v_2(\eta, p_t) = \frac{\langle u^*(\eta, p_T)\frac{Q_2}{M}\rangle}{\sqrt{\langle \frac{Q_2^{*a}}{M^a}\frac{Q_2^{*b}}{M^b}\rangle}}$$

$$u = e^{2i\phi}$$

$$Q_2 = \sum_{i=1}^{M} e^{2i\phi_i}$$

- Particles used for computing the flow vector come from TPC
- The decay tracks of the D meson are excluded from the flow vector
- a and b denote two indipendent sub-events

Q-cumulants

- Involve quantities which do not depend on event plane orientation