Open-charm meson elliptic flow measurement in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV with ALICE at the LHC.

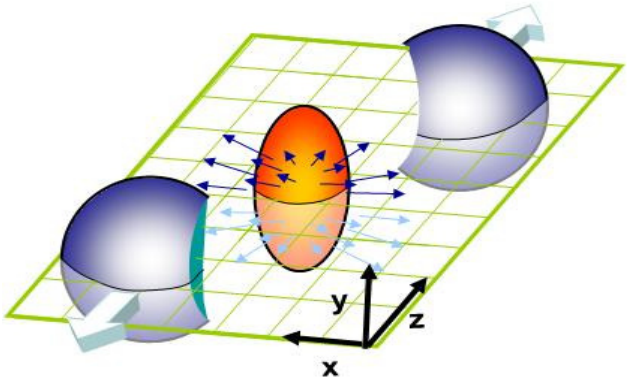
Giacomo Ortona for the ALICE collaboration

INFN & University of Torino

Hard Probes 2012 (Cagliari) - 27th May - 1st June 2012

Outline

Motivations



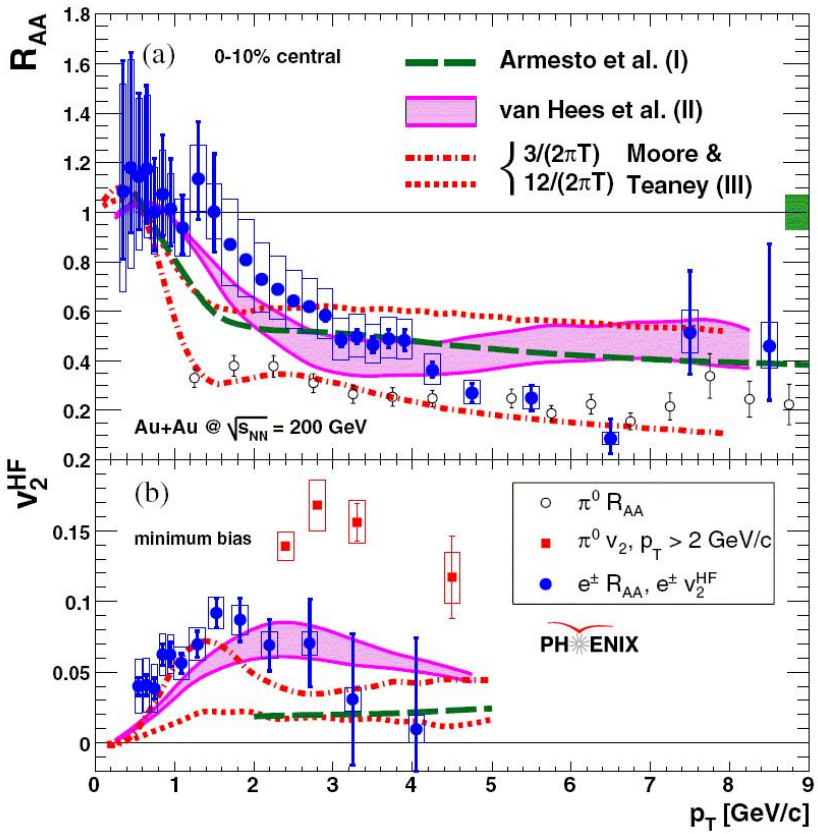
- Initial spatial anisotropies in the overlap region of the colliding nuclei create asymmetric pressure gradients that give rise to momentum anisotropies.
- Given the reaction plane angle Ψ_{RP}, at midrapidity:
  $\frac{dN}{Nd\phi} = 1 + 2v_2 \cos\left(2(\phi - \Psi_{RP})\right) + \ldots$ and
  Elliptic flow: $v_2 = < cos[2(\phi - \Psi_{RP})] >$

- Elliptic flow of heavy particles can bring useful information about the medium. Hydro models predict v_2 of charm to be smaller than the one of light hadrons at low p_t, where v_2 comes from charm flow (sensitive to c thermalization). At high p_t dominant effects are path length dependence of energy loss.
- R_{AA}[1] and v_2 both are sensitive to medium transport properties and are complementary measurements.

[1] See talk by Z. Conesa del Valle

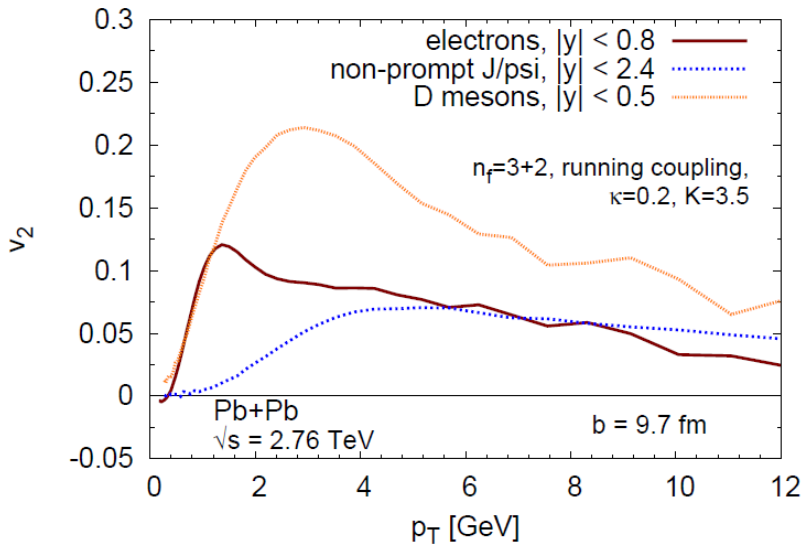
RHIC results and LHC predictions

Phenix collaboration, Phys. Rev. Lett. 98, 172301 (2007)



- Not all models reproduce R_{AA} and v_2 simultaneously.
- We expect $v_2^B < v_2^D$.

Uphoff et al., arXiv:1205.4945



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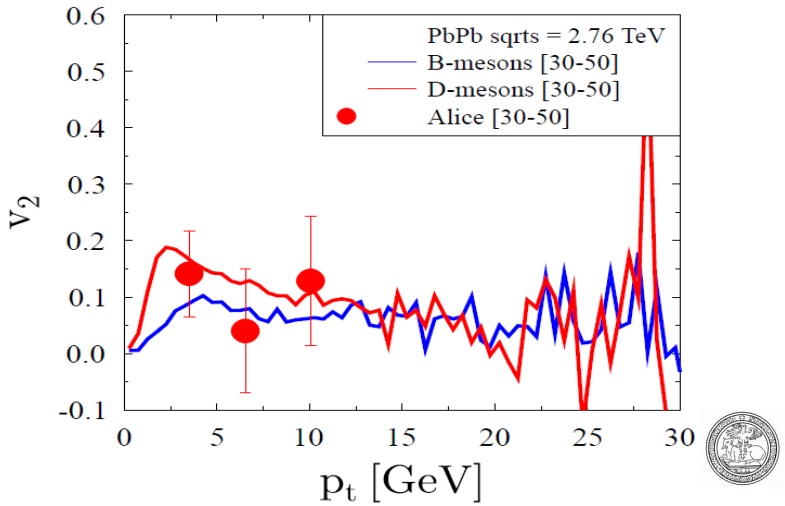
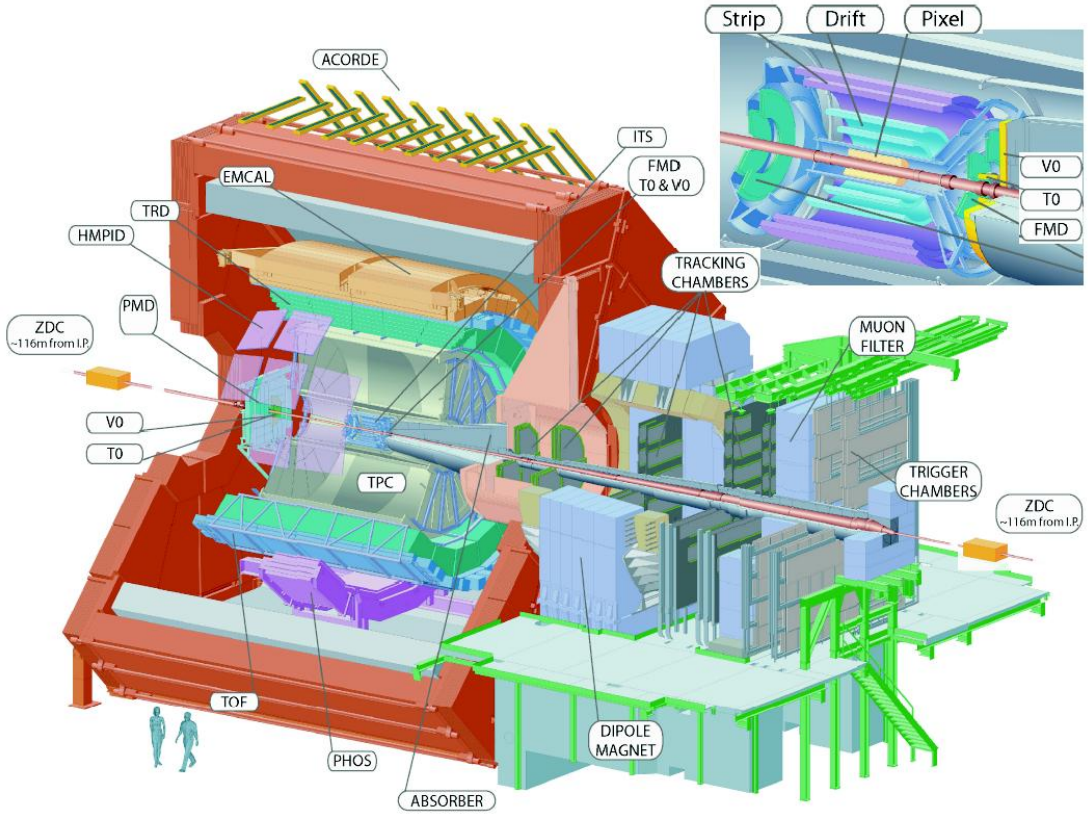


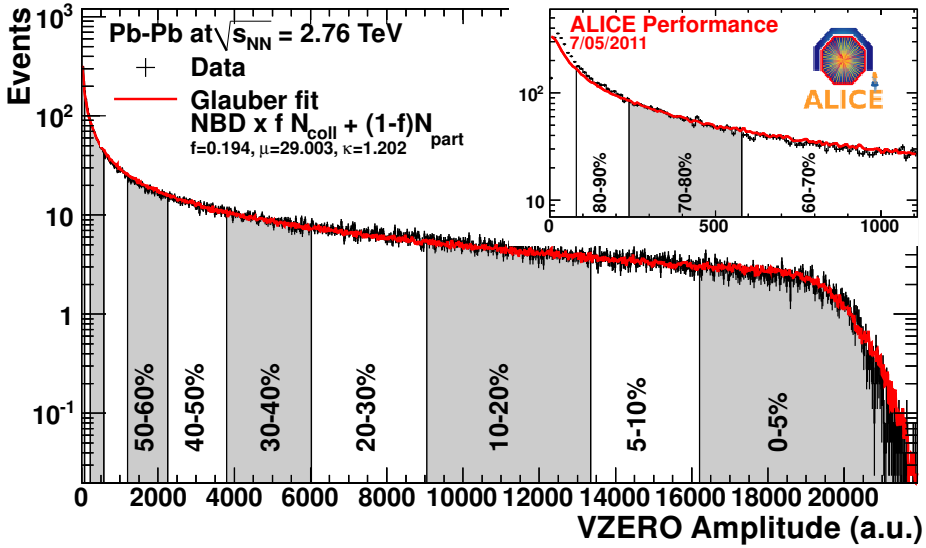
ALICE at the LHC

- Inner Tracking System (ITS): Vertexing, tracking
  - Silicon Pixel Detector (SPD)
  - Silicon Drift Detector (SDD)
  - Silicon Strip Detector (SSD)
- Time Projection Chamber (TPC): Tracking, PID, event plane, centrality
- Time Of Flight (TOF): PID
- VZERO scintillators: trigger, event plane, centrality



Data sample

- We present results from Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV collected in November 2011.
- 2 triggers used:
  - Minimum bias trigger
  - SemiCentral trigger: selects events in the 0-50% centrality range.
- Event centrality determination using VZERO amplitudes. Glauber-MC model to extract the total cross-section and normalize.
- Two centrality classes considered:
  - $\sim 9.5 \times 10^6$ collisions in 30-50% centrality
  - $\sim 7.1 \times 10^6$ collisions in 15-30% centrality

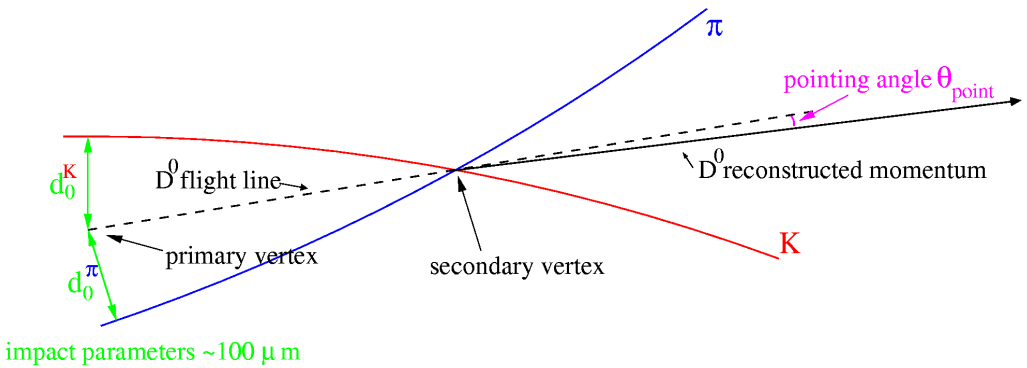


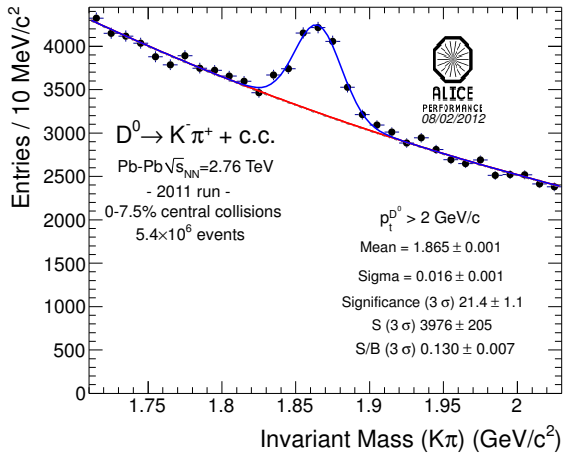
D meson reconstruction

- Analysis strategy based on invariant mass analysis of fully reconstructed decay topologies displaced from the interaction vertex.

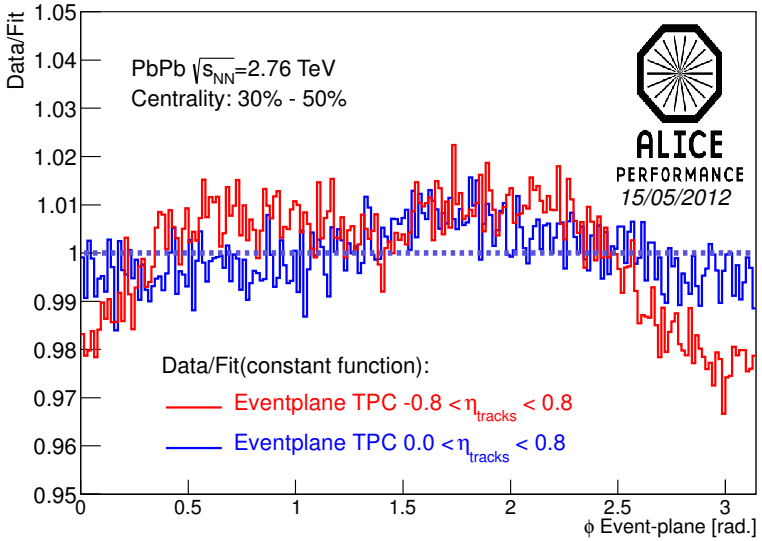
Meson	Decay channel	$c\tau$	BR
D^0	$D^0 \rightarrow K^-\pi^+$	$\sim 120\mu m$	$\sim 3.8\%$
D^+	$D^+ \rightarrow K^-\pi^+\pi^+$	$\sim 310\mu m$	$\sim 9.2\%$
D^{*+}	$D^{*+} \rightarrow D^0\pi^+$		$\sim 67.7\%$

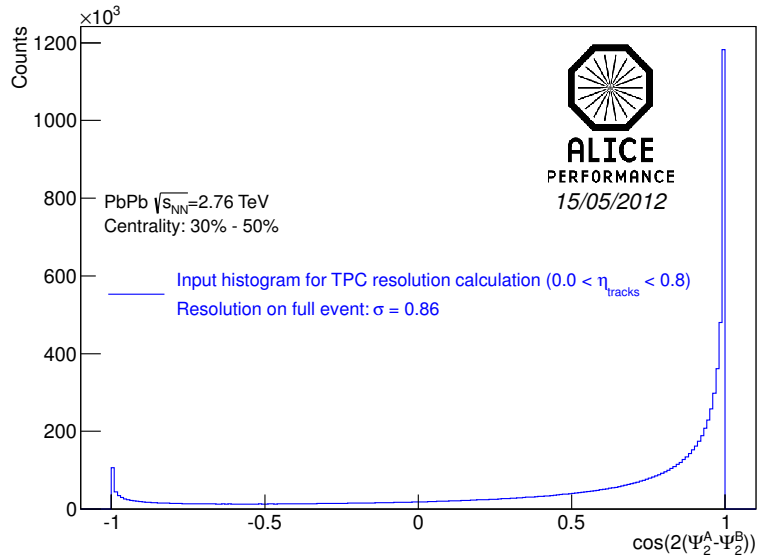
- Main topological cuts: Pointing of the reconstructed D meson to the primary vertex of the event, large impact parameter, decay length.
- Particle IDentification (PID) from TPC and TOF.



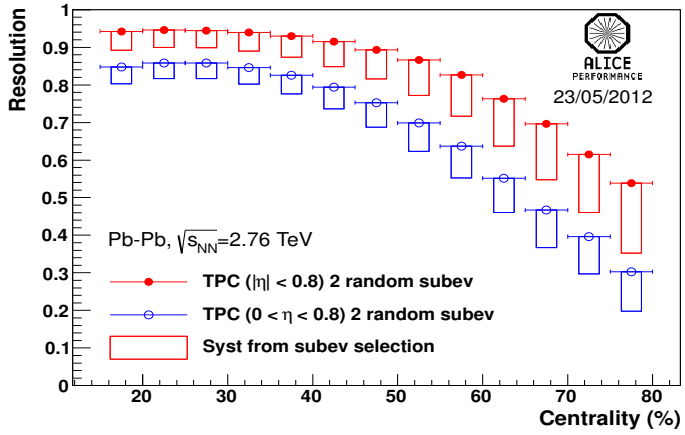


Event plane

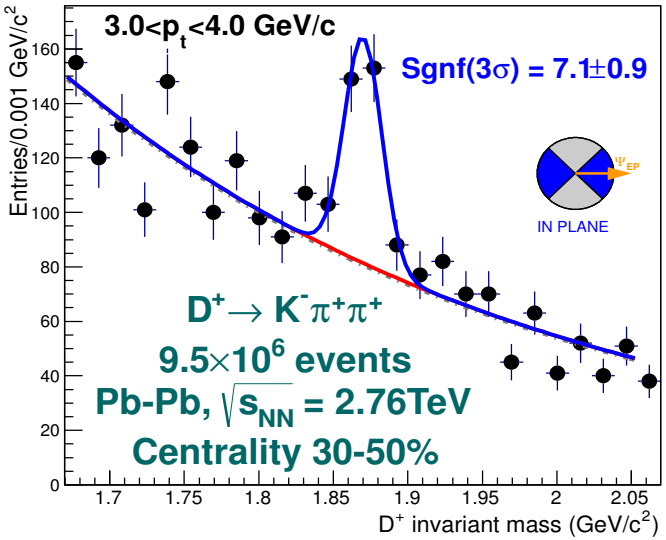


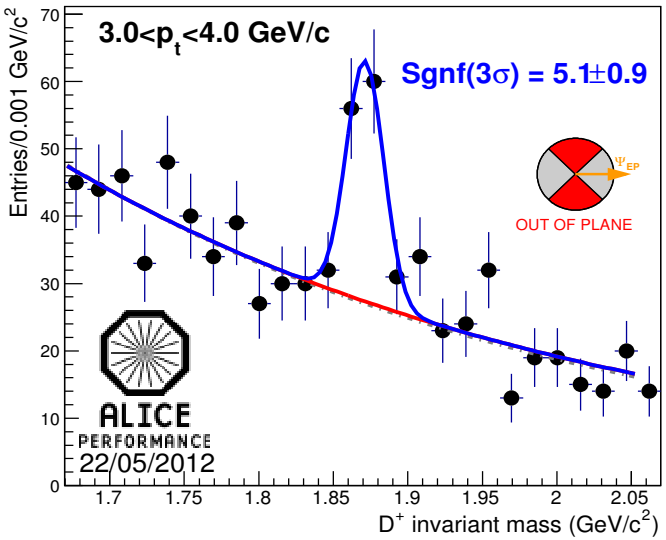


- Event plane determination with TPC tracks with $\eta > 0$ or with VZERO detector.
- from the Q vector of the event: $\Psi_n = \frac{1}{n} \tan^{-1}\left(\frac{\sum_{i=0}^{N} w_i \sin n\phi_i}{\sum_{i=0}^{N} w_i \cos n\phi_i}\right)$
- ϕ-weights applied to improve TPC-EP flatness.
- Resolution: 2 random sub-events (TPC). Used to correct v_2



D^0 and D^+ v_2 extraction: $2\Delta\phi$ bins





- Fit the In-plane and out-of-plane invariant mass spectra of candidates to extract the yield (N_{IN} and N_{OUT}) in the two regions.
- From azimuthal asymmetries in signal compute

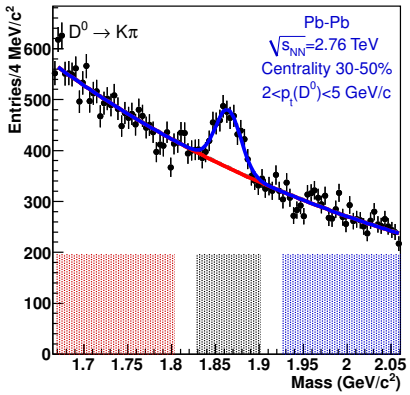
$$v_2 = \frac{\pi}{4} \frac{N_{IN} - N_{OUT}}{N_{IN} + N_{OUT}}$$

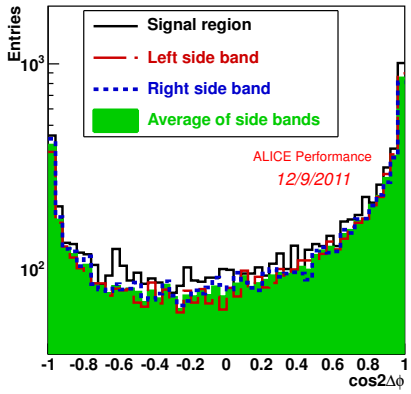
v_2 extraction: $\cos 2(\Delta\phi)$ vs mass

Alternative methods are used to check the robustness of the measurement.

Side bands subtraction

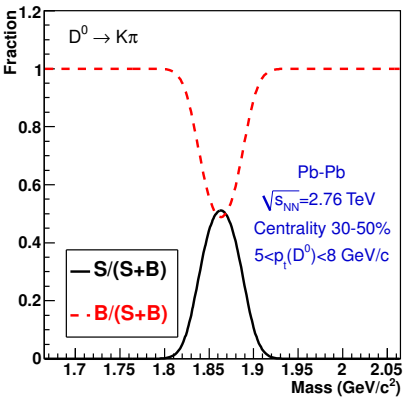
- D meson v_2 as $\langle \cos 2(\Delta\phi) \rangle$ after background subtraction from the side-bands.

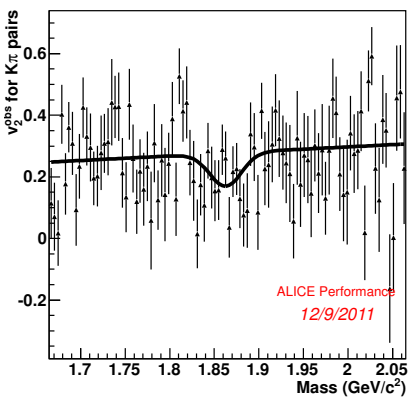




Fit of v_2 versus mass:

- $\frac{S}{S+B}$, $\frac{B}{S+B}$ vs mass from the fit
- Extract $v_2 = \langle \cos 2(\Delta\phi) \rangle$ for each mass bin
- Fit with $v_2^{sgn} \cdot \frac{S}{S+B} + v_2^{bkg} \cdot \frac{B}{S+B}$



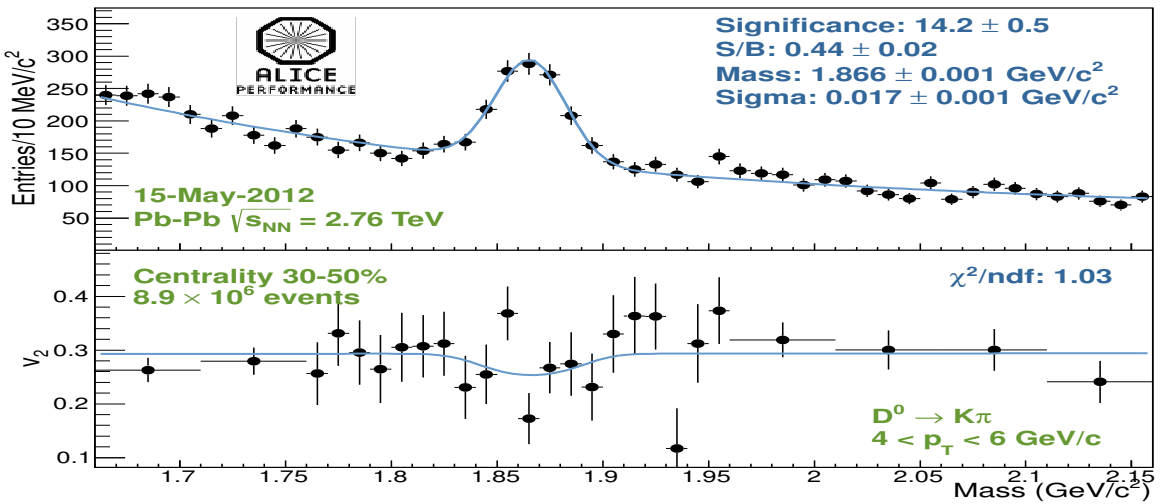


v_2 extraction: Q-cumulants and scalar products

Alternative methods are used to check the robustness of the measurement.

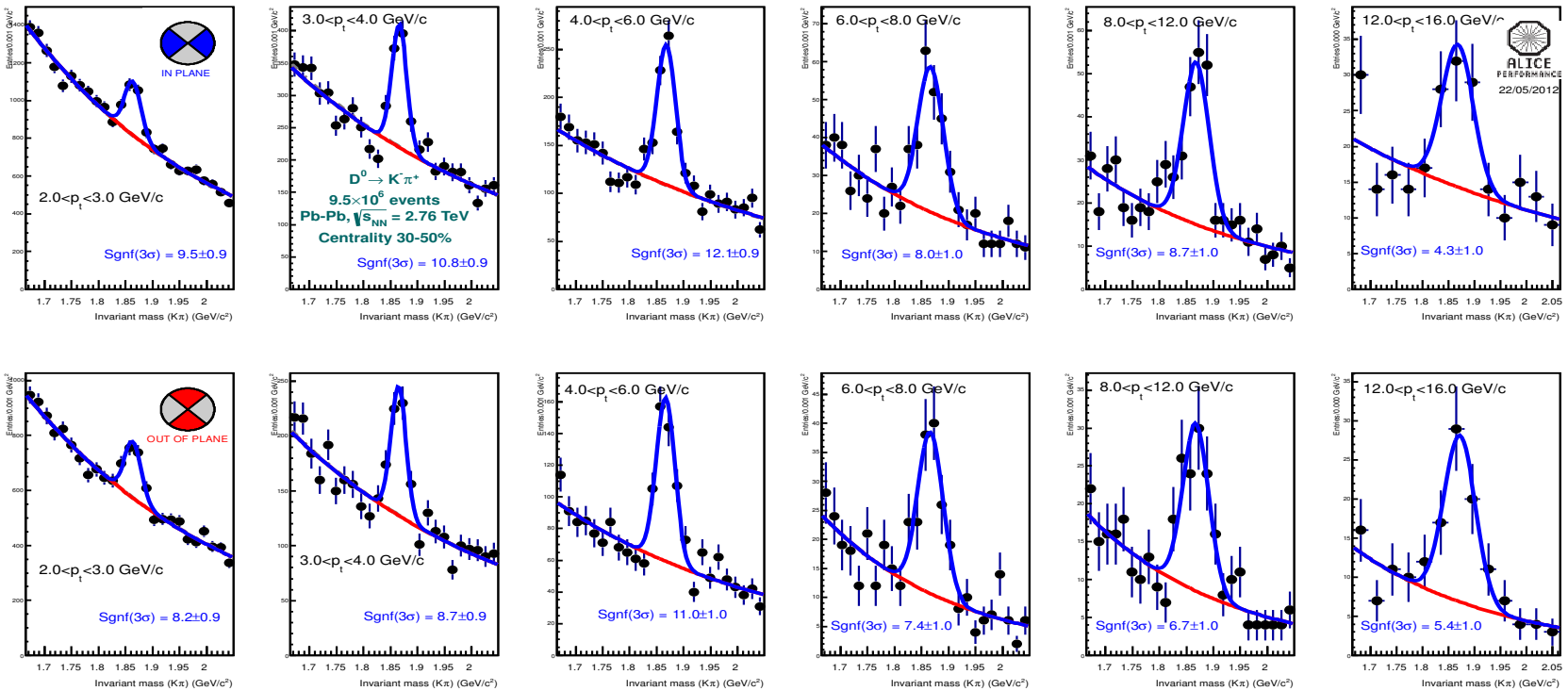
- 2 particle correlations Bilandzic, Snellings, Voloshin, Phys.Rev. C83
- TPC tracks used as Reference Flow Particles
- v_2^D extracted from a fit of v_2 vs mass
- Q-cumulants: $v_2 = \sqrt{\left\langle \frac{1}{P_{M,2}} \sum_{i \neq j} e^{2i(\phi_i - \phi_j)} \right\rangle}$
- Scalar products: $v_2 = \frac{\left\langle \left\langle \hat{u} \cdot \frac{\vec{Q}}{M} \right\rangle \right\rangle}{\sqrt{\left\langle \frac{\vec{Q^A}}{M^A} \cdot \frac{\vec{Q^B}}{M^B} \right\rangle}}$, where $Q = \sum_i^M e^{2i\phi_i}$

Q-Cumulants method, simultaneous fit of invariant mass and v_2 vs mass



Signal extraction for EP: D^0 in 30-50%

- The signal yield in each bin is obtained from a fit of the invariant mass distribution of the candidates.
- The gaussian σ of the signal fit is fixed by the fit of the full ϕ distribution.
- Topological cuts are applied to improve the significance.



D^0 signal is visible in 6 p_t bins in the range $2 < p_t < 16$ GeV/c

See D. Caffarri's poster

Systematic uncertainties

The following sources of systematic uncertainty have been considered:

- Yield extraction (background fitting, free or fixed gaussian width, 0.02/0.03 absolute unc.)
- Different sets of topological cuts for D selection (0.02/0.04 absolute unc.)
- Feed-down from B contribution (see next slide)
- Centrality dependence of the event plane resolution within the classes 15-30% and 30-50% (EP methods only, 3%)
- Definition of sub-events for the event plane resolution (EP methods only, 7%)
- QC/SP methods: Background fitting functions (v_2 vs mass and yield extraction: 0.01/0.04 absolute unc.)

B feed-down

- Our sample contains D from B decays. To obtain the v_2^{prompt} of D mesons from prompt c quarks we need to subtract their contribution.
- The v_2^{obs} we measure is $v_2^{\text{obs}} = f_{\text{prompt}} v_2^{\text{prompt}} + (1 - f_{\text{prompt}}) v_2^{\text{feed-down}}$. f_{prompt} is the fraction of prompt D mesons in the sample.
- To subtract the B feed-down contribution contribution, we need an hypothesis on $v_2^{\text{feed-down}}$. All models predict $v_2^B \leq v_2^D$.
- We assume $v_2^{\text{feed-down}} = v_2^{\text{prompt}}$
  - This assumption on $v_2^{\text{feed-down}}$ is a source of (asymmetric) systematic uncertainty. Its limit for the case $v_2^{\text{feed-down}} = 0$ is given by $\frac{v_2^{\text{prompt}}}{f_{\text{prompt}}}$
  - $0.7 < f_{\text{prompt}} < 0.95$ computed from MonteCarlo and FONLL[2] prediction.
  - f_{prompt} depends on the relative R_{AA} suppression of feed-down and prompt D: we vary $0.5 < \frac{R_{AA}^{\text{prompt}}}{R_{AA}^{\text{feed-down}}} < 2$

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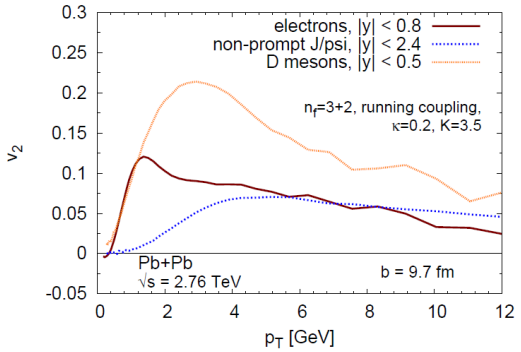

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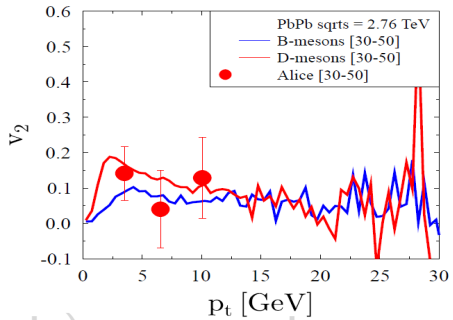

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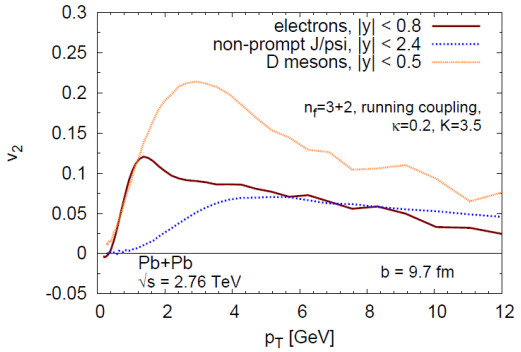

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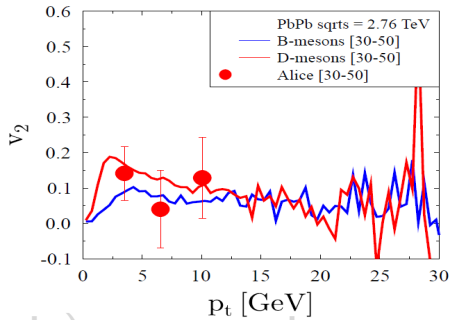

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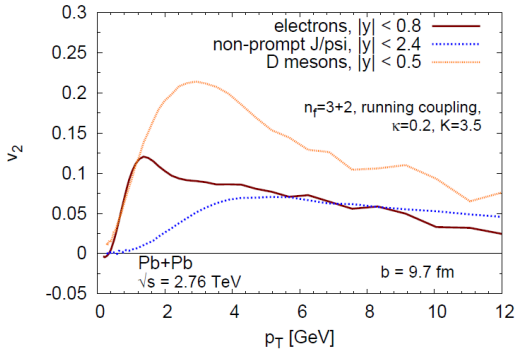

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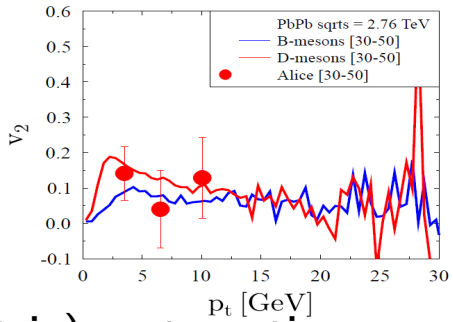

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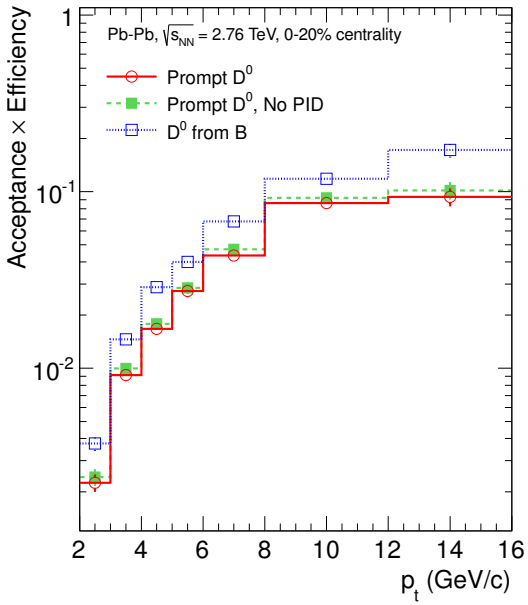
arXiv:1203.2160v1



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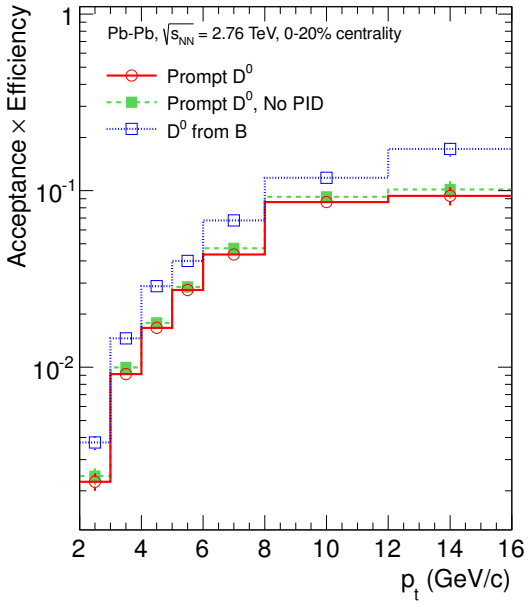

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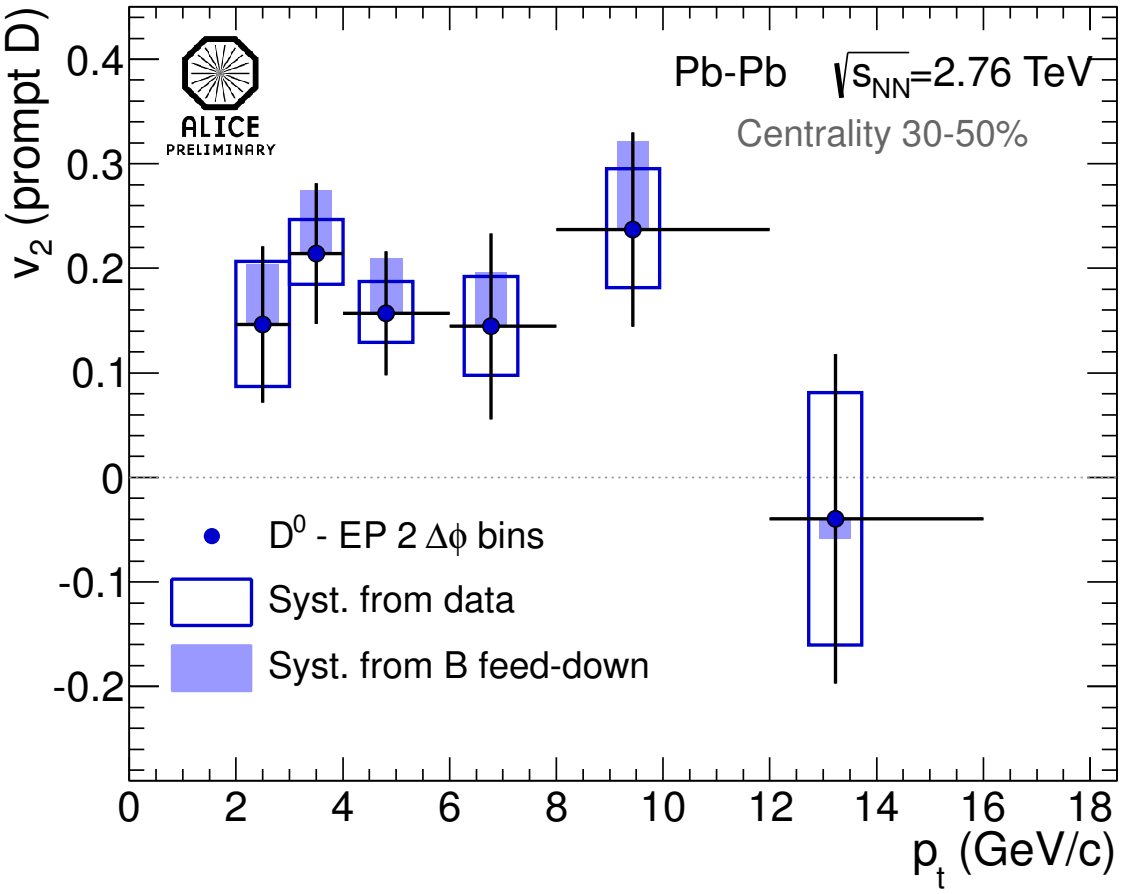
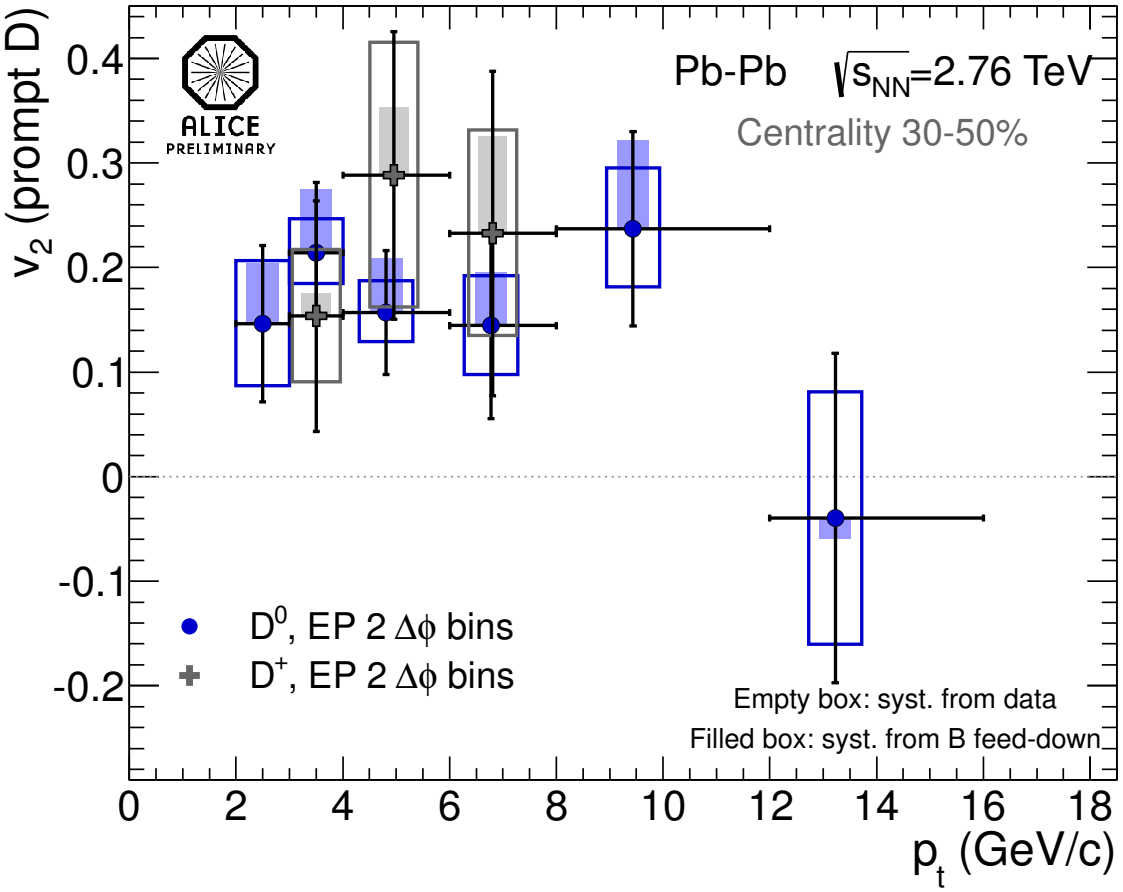
D^0 v_2 in 30-50% centrality



- Indication for non-zero v_2 (3 σ effect in $2 < p_t < 6$ GeV/c)

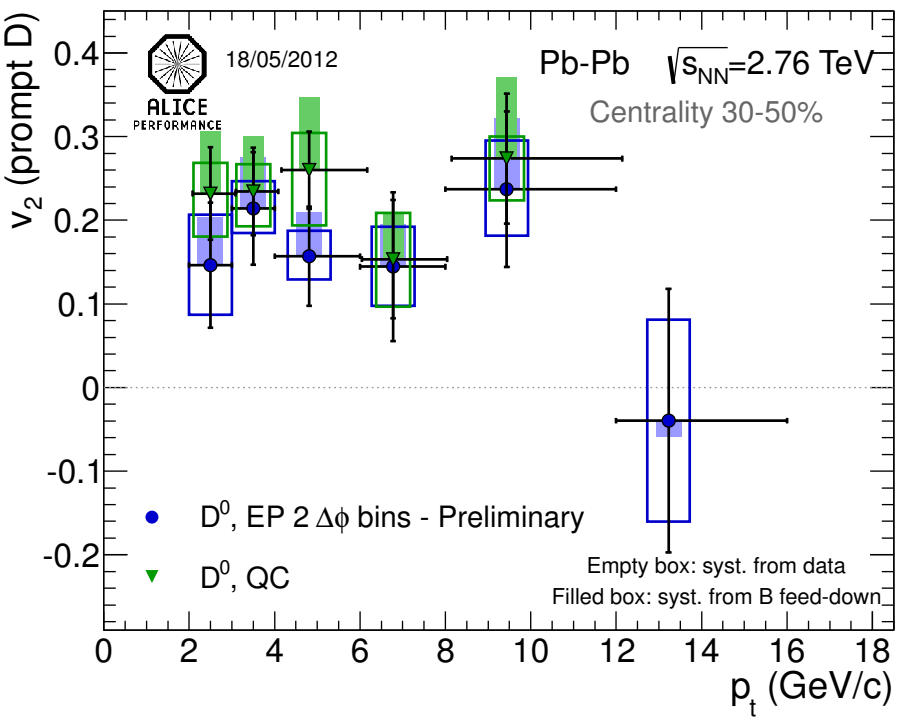
D^0 and D^+ v_2 in 30-50% centrality



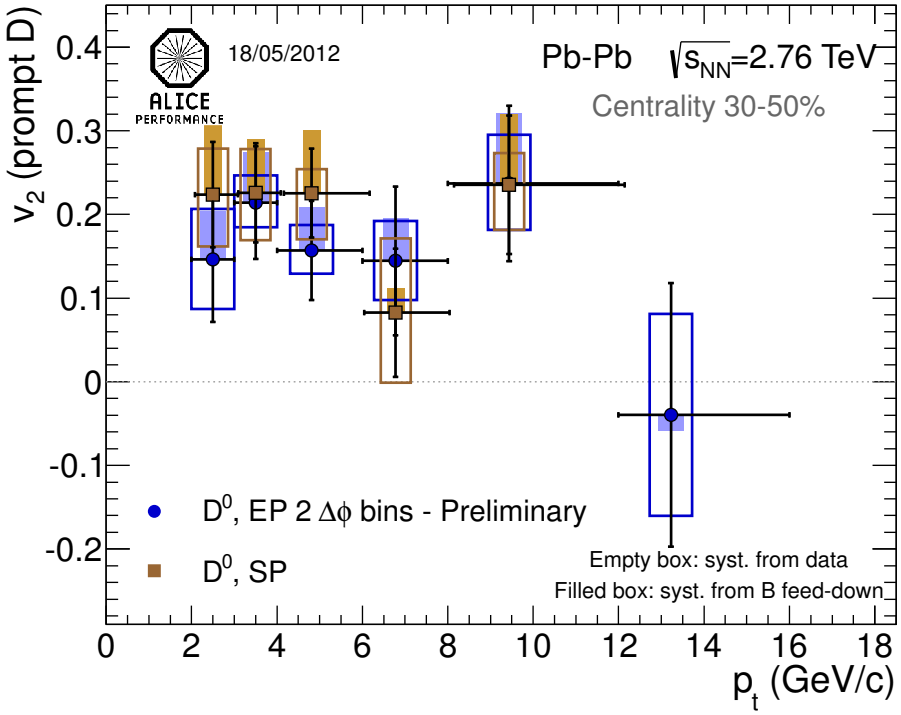
- D^0 and D^+ v_2 are compatible within uncertainties.

D^0: comparison with QC and SP

Q-Cumulants (2^{nd} order)

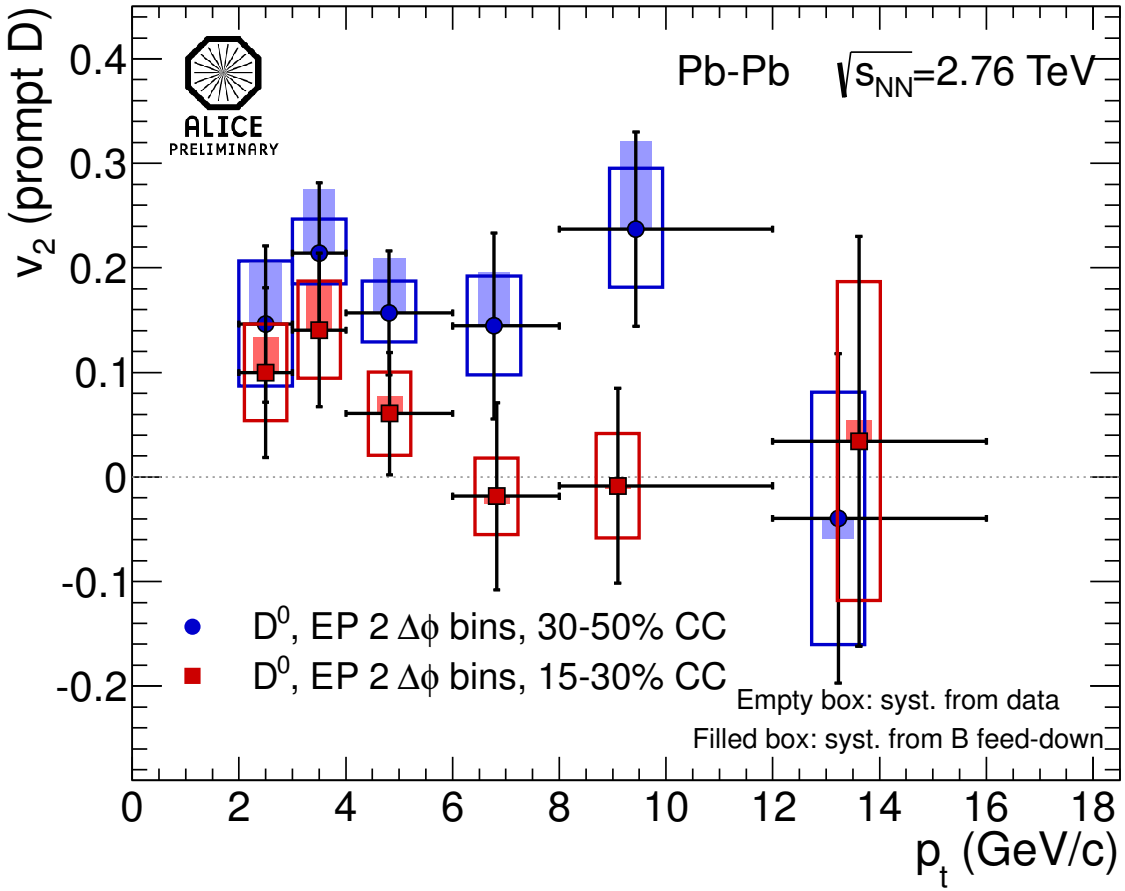


Scalar product



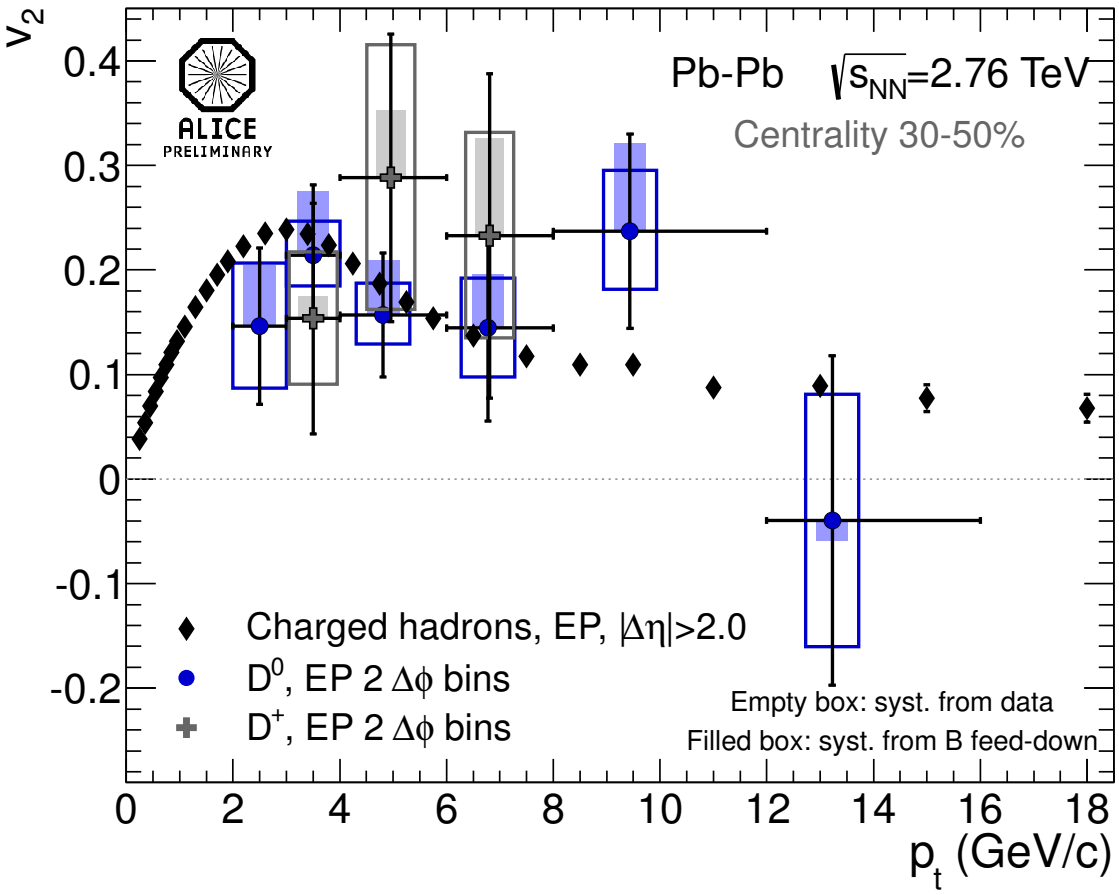
- All methods give consistent results

D^0 centrality dependence



- D^0 v_2 larger in 30-50% CC than in 15-30% CC in all p_t bins.
- Hint of v_2^D centrality dependence, consistent with v_2 larger in more peripheral events

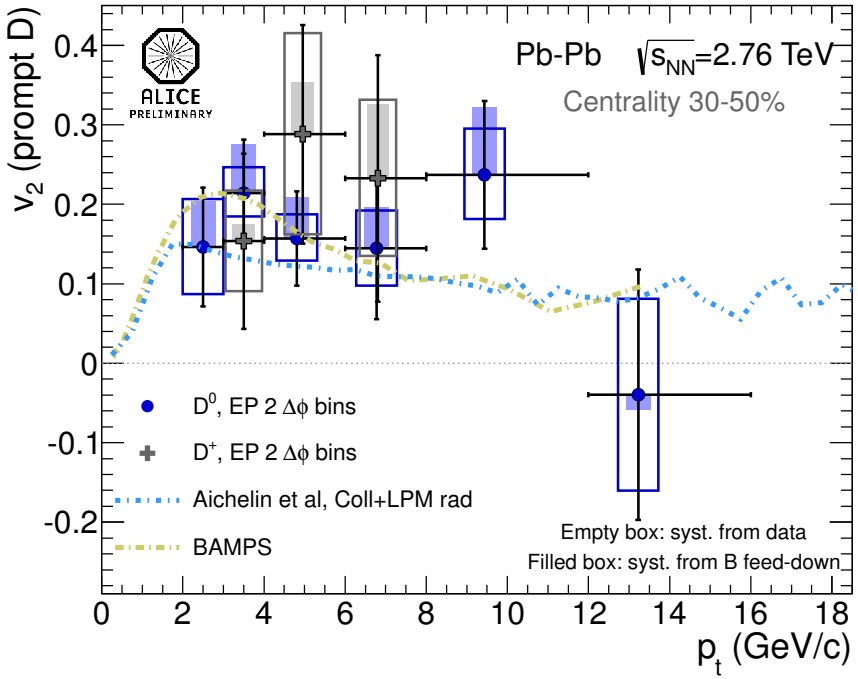
Comparison with charged hadrons...

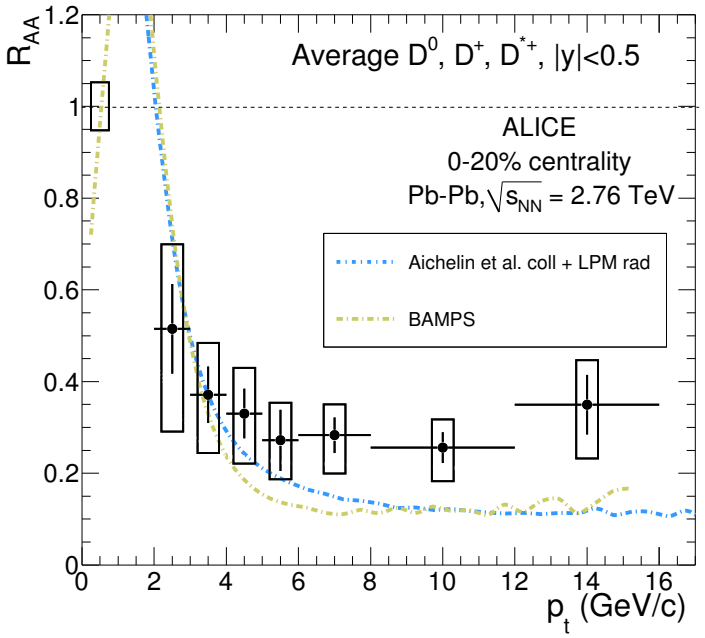


- D meson v_2 compatible within uncertainties with charged hadrons elliptic flow measured at ALICE in the same rapidity region.

... and with theory

arXiv:1203.2160v1



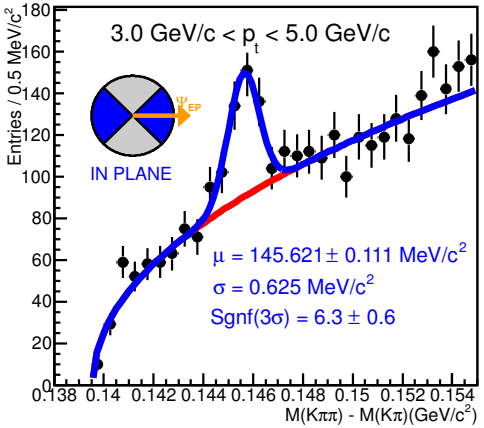


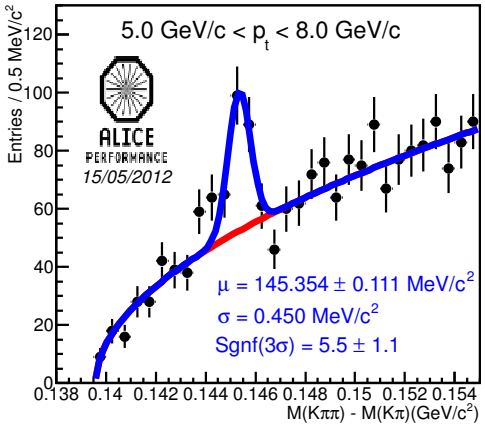
- BAMPS[3] and Gossiaux et al.[4] transport models can describe D v_2 although they underestimate the R_{AA}.

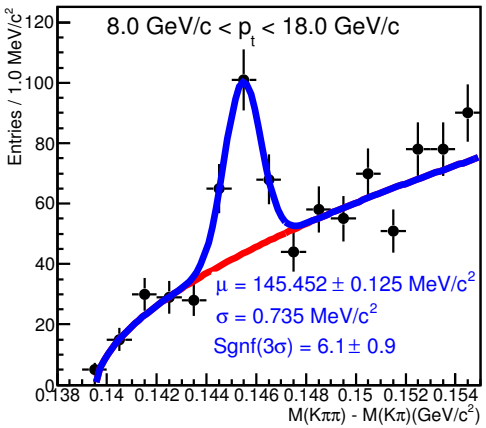
[3] Uphoff et al., arXiv:1112.1559
[4] Phys. Rev. C79 (2009) 044906.

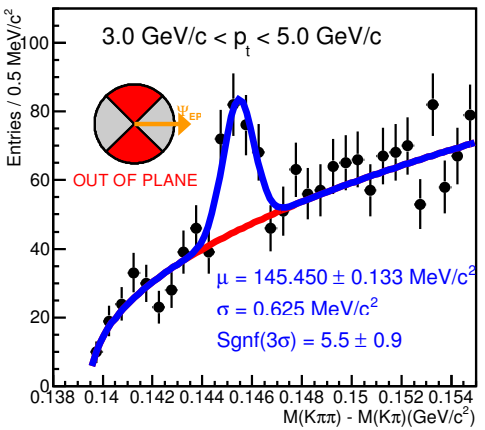
Coming soon...

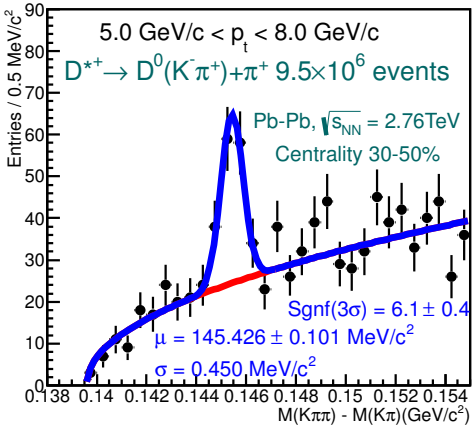
- D^* analysis is well advanced

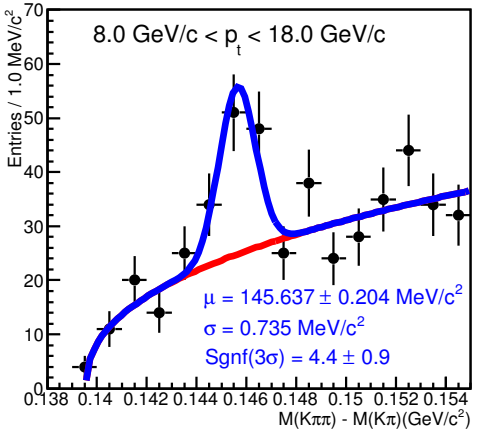










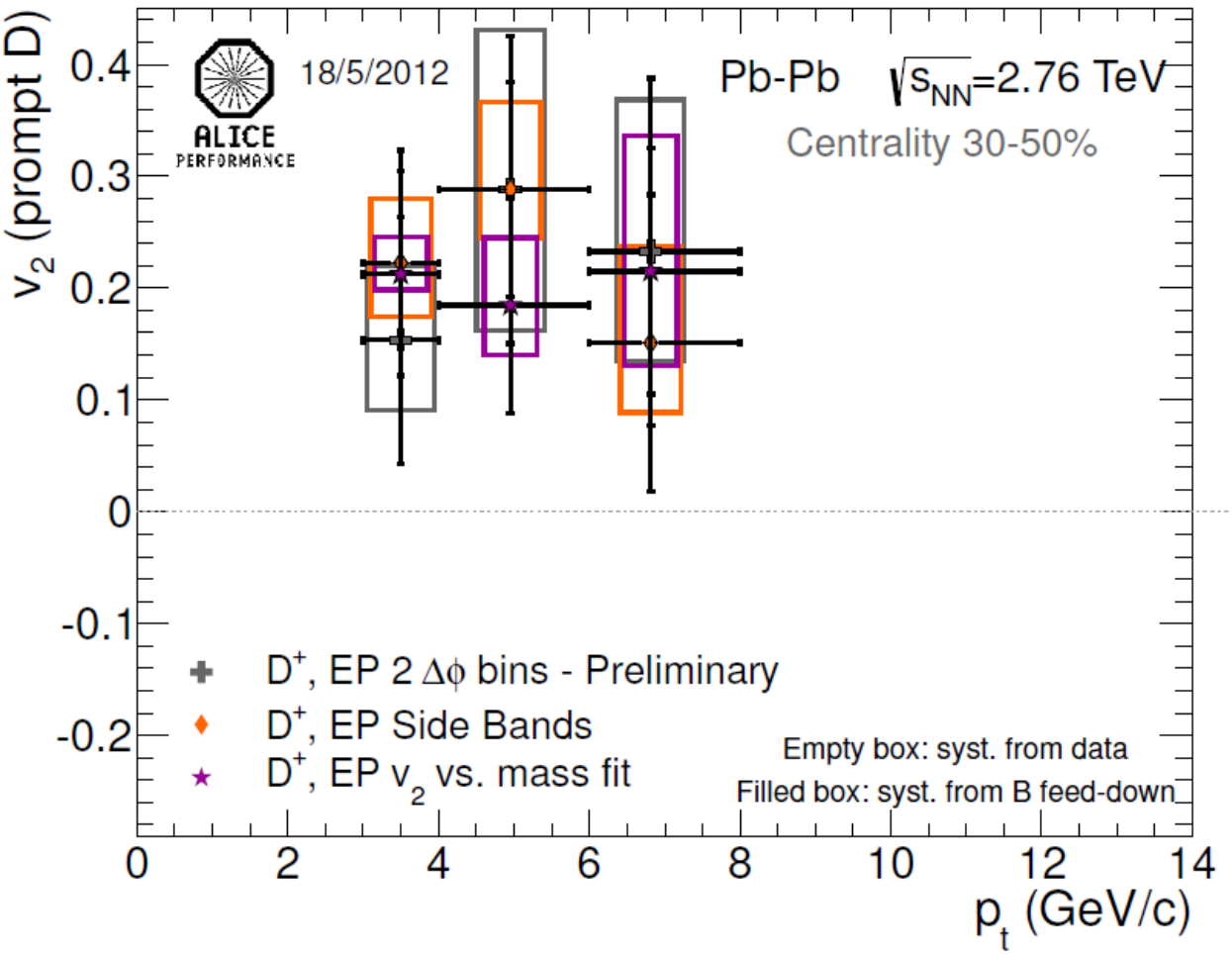


Conclusions

- The D meson v_2 measurement by the ALICE collaboration was shown using the $D^0 \rightarrow K^-\pi^+$ and $D^+ \rightarrow K^-\pi^+\pi^+$ channels
- Results are consistent among the different mesons (D^0,D^+) and several v_2 extraction methods:
  - Event plane (in-plane/out-of-plane anisotropy, side bands, fit v_2 vs mass), 2^{nd} order Q-Cumulants, Scalar product
- The results hint to $v_2^D > 0$ ($3\ \sigma$) in the p_t range $2 < p_t < 6$ GeV/c
- The measured v_2 is compatible within uncertainties with the v_2 of the charged hadrons
- A possible dependence of v_2^D on centrality was observed between the centrality classes 15-30% and 30-50%
- The measurement is described by models of heavy-quark transport in the medium, however a simultaneous description of R_{AA} and v_2 is still lacking.

BACKUP

Alternative methods: event plane, 2D methods



- Compatible results for all the methods