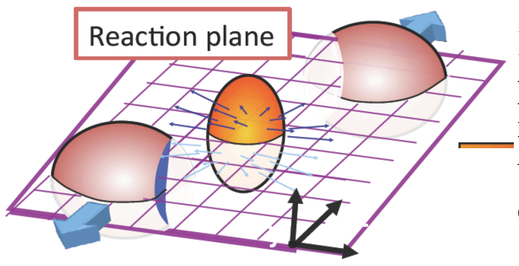
# Measurement of $D^0$-meson elliptic flow in Pb-Pb collisions at $\sqrt{s_{NN}}$=5.02 TeV with ALICE

A. Rossi, Padua University and INFN
on behalf of the ALICE Collaboration

## Physics goals and current status

**Charm quarks**, produced in the early stage of the collision, probe the **whole evolution of the deconfined system (Quark-Gluon Plasma)** formed in ultra-relativistic heavy-ion collisions.




In **semi-central collisions** with non-zero impact parameter, the spatial asymmetry of the colliding region gives rise to asymmetric pressure gradients that result in an **anisotropy of the azimuthal distribution** of the particles produced.

The **elliptic flow** ($v_2$) is the coefficient of the 2nd-order harmonic of the Fourier expansion of the particle azimuthal distribution:

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

$\Psi_n$: $n^{th}$ harmonic symmetry plane $\qquad v_n=\langle\cos[n(\varphi-\Psi_n)]\rangle$

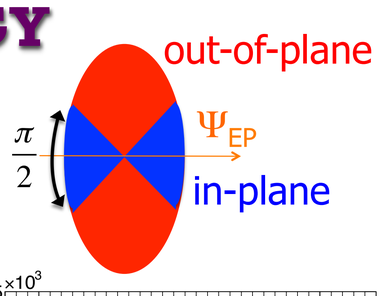
The measurement of D-meson $v_2$ is **crucial to understand charm-quark coupling to the system and in-medium energy loss.** At high $p_T$ constraints can be set to the path-length dependence of energy loss.

ALICE measured a positive D-meson elliptic flow ($D^0$,$D^+$,$D^{*+}$ meson average) in centrality 30-50% in Pb-Pb collisions at $\sqrt{s_{NN}}$=2.76 TeV, using a sample of ~9.5M events from **Run 1 at the LHC** [0,1]. The data suggest that **charm quarks with low transverse momentum are influenced by the system collective motion.** An indication for a decrease of $v_2$ towards more central events was observed for $3<p_T<6$ GeV/$c$ for the $D^0$ meson.

## Analysis Strategy

The $D^0$-meson $v_2$ is measured with the "Event Plane" method (EP) using the formula:

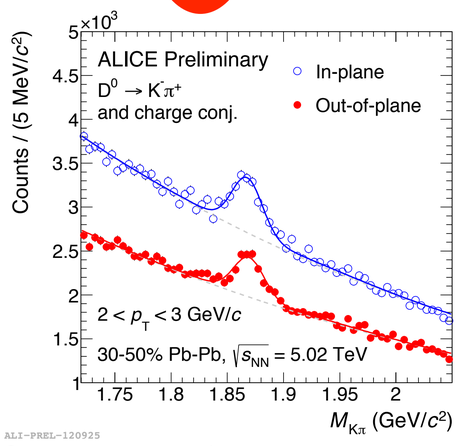
$$v_2\{\mathrm{EP}\} = \frac{1}{R_2}\frac{\pi}{4}\frac{N_{\text{in-plane}}-N_{\text{out-of--plane}}}{N_{\text{in-plane}}+N_{\text{out-of--plane}}}$$




$N_{\text{in-plane}}$ [$N_{\text{out-of-plane}}$] is the yield in the φ region defined by the two quadrants containing [not-containing] the event-plane angle $\Psi_{EP}$, which is an estimator of the 2nd-harmonic symmetry plane. $R_2$ is the event-plane angle resolution (about 0.77). $\Psi_{EP}$ is calculated from the $Q_2$-vector:

$$\vec{Q}_2 = \left( \sum_1^M \cos 2\varphi_i \ , \ \sum_1^M \sin 2\varphi_i \right)$$

$$\Psi_2 \approx \Psi_{EP} = \frac{1}{2}\arctan\left(\frac{Q_{2,y}}{Q_{2,x}}\right) \qquad M = \text{multiplicity of reference particles}$$




In order to **minimize the impact of "non-flow" effects**, the signal in the V0 detectors is used, assuring a minimum **η-gap** of 0.9 with respect to the $D^0$-meson decay tracks.

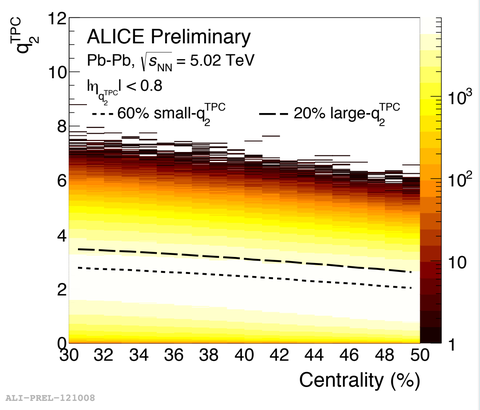
The measured $v_2$ is a combination of **prompt $D^0$ mesons and feed-down $D^0$ mesons** from B-meson decays. The assumption $v_2^{\text{feed-down}} = v_2^{\text{prompt}} = v_2^{\text{all}}$ is used. By varying $v_2^{\text{feed-down}}$ in the range $0 < v_2^{\text{feed-down}} < v_2^{\text{prompt}}$ a systematic uncertainty on $v_2^{\text{prompt}}$ is estimated using the formula:

$$v_2^{\text{prompt}} = \frac{1}{f_{\text{prompt}}}v_2^{\text{all}} - \frac{1-f_{\text{prompt}}}{f_{\text{prompt}}}v_2^{\text{feed-down}}$$

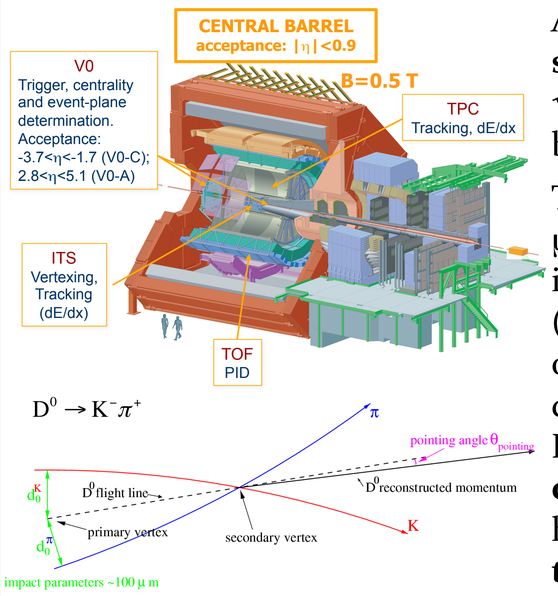
$f_{\text{prompt}}$: prompt fraction, estimated on the basis of the prompt and feed-down D-meson reconstruction efficiency, FONLL feed-down cross-section [2], and assuming $1<R_{AA}(\text{feed-down})/R_{AA}(\text{prompt})<3$.

### $v_2$ with Event-shape Engineering

The D-meson $v_2$ was measured also separately **in two classes of events** defined on the basis of the "reduced" $Q_2$-vector, $q_2=Q_2/\sqrt{M}$. For a given centrality, **in events with larger $q_2$ the "bulk" particle $v_2$ is, on average, larger.** The measurement probes up to what extent charm production is influenced by the initial event shape. In this analysis $q_2$ was calculated using tracks reconstructed in the TPC (thus with no eta gap w.r.t. D-meson daughters), while for $v_2$ was calculated using the event-plane angle from the V0.



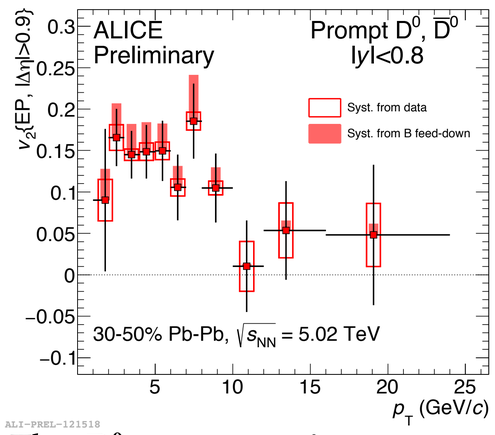

## Alice apparatus, data set and $D^0$-meson reconstruction

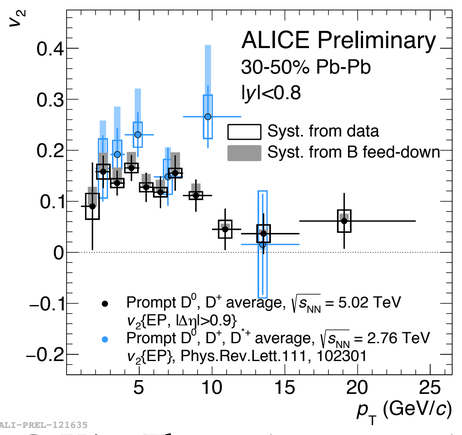



A sample of **~24M** events from **30-50% semi-central** Pb-Pb collisions at $\sqrt{s_{NN}}$=5.02 TeV collected with a minimum bias trigger was used.

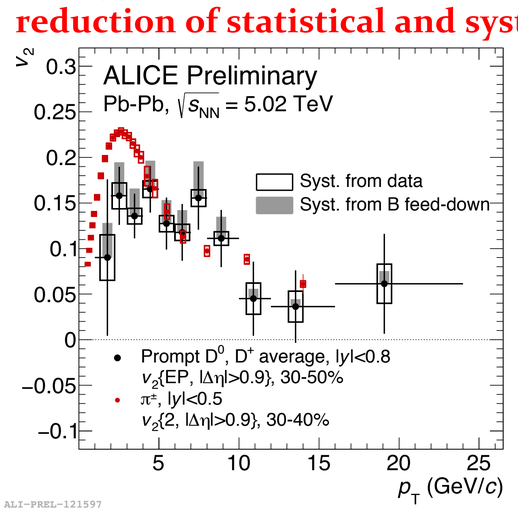
The $D^0$-meson ($M$=1.865 GeV/$c^2$, $c\tau$~123 μm) yield and that of its charge conjugate is extracted in the $D^0 \to K^-\pi^+$ decay channel (BR 3.93%) via an invariant mass analysis of reconstructed decay vertices. The combinatorial background is reduced via **PID** and by selecting vertices with a **displaced topology**, typical of decays happening a few **hundred microns from the primary vertex.**

## Results

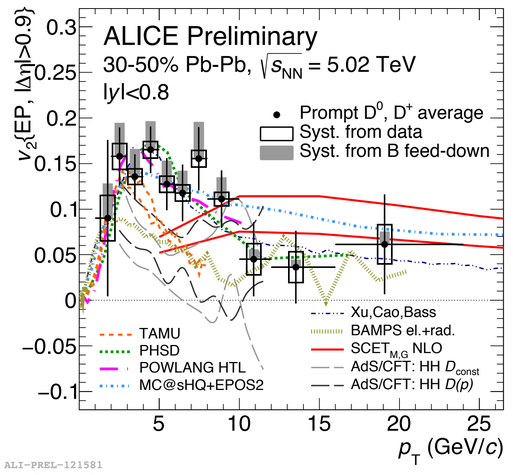


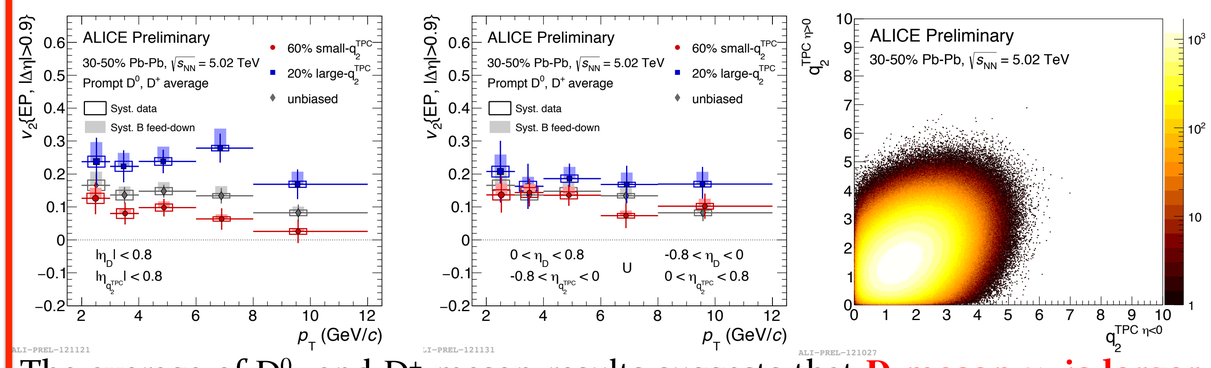

The **$D^0$-meson $v_2$ is measured in $1<p_T<24$ GeV/$c$**. The main systematic uncertainties derive from the yield extraction and the feed-down subtraction. The average of $D^0$- and $D^+$-meson **$v_2$ is larger than 0 in the range $2<p_T<10$ GeV/$c$**, indicating a **significant interaction of charm quarks with the medium constituents** and the presence of mechanisms that transfer to charm quarks the azimuthal anisotropy of the system. A similar $v_2$ is observed at $\sqrt{s_{NN}}$=5.02 and 2.76 TeV. The Run-2 data allowed for a **significant reduction of statistical and systematic uncertainties**.




The D-meson $v_2$ is **similar to that of charged pions**.




The data set **stringent constraints to theoretical models**.




The average of $D^0$- and $D^+$-meson results suggests that **D-meson $v_2$ is larger (smaller) in events with larger (smaller) average elliptic flow.** Non-flow effects and auto-correlations are not removed. If a eta gap is introduced between the particles used to determine the $q_2$-vector and the D mesons, removing auto-correlations and reducing non-flow effects, the separation reduces. It was verified that this reduction is comparable with what expected from the deterioration of the $q_2$-vector resolution implied by the smaller number of particles used for its calculation.

## References

[0] PRL 111 (2013) 102301
[1] PRC 90 (**2014**) 034904
[2] JHEP0407 (2004) 033

Models
TAMU:Phys.Lett. B735 (2014) 445-450
PHSD: Phys. Rev. C 93, 034906 (2016);
POWLANG: EPJ C 75 (2015) 121;
MC@HQ+EPOS: PRC 89 (2014) 014905;
Xu,Cao,Bass: Phys.Rev. C94 (2016) no.2, 024907; PRC 88 (2013);
BAMPS: PLB 717 (2012) 430; J.Phys.Conf.Ser. 509 (2014) 012077;
$SCET_{M,G}$ NLO: arXiv:1610.02043;
Ads/CFT HH $D(r)$: Phys. Rev. D 91, 085019 (2015);
Ads/DCF HH $D_{const}$: arXiv:1605.09285v1.