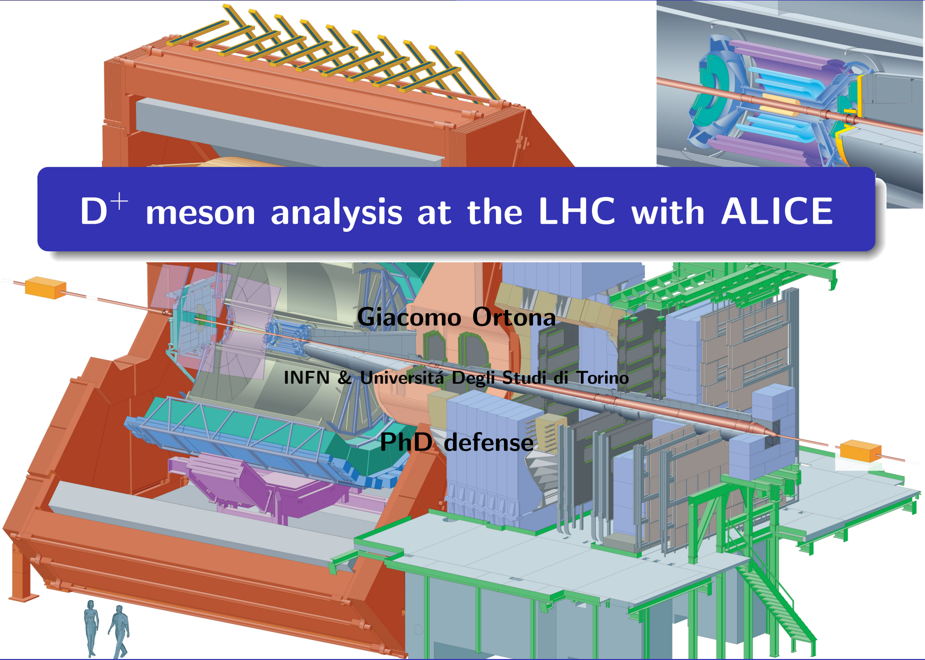


D^+ meson analysis at the LHC with ALICE

Giacomo Ortona

INFN & Universitá Degli Studi di Torino

PhD defense

Outline

1. The ALICE Experiment
2. Physics Motivation
3. D^+ cross section in proton-proton collisions
4. Elliptic Flow
5. D^+ energy loss

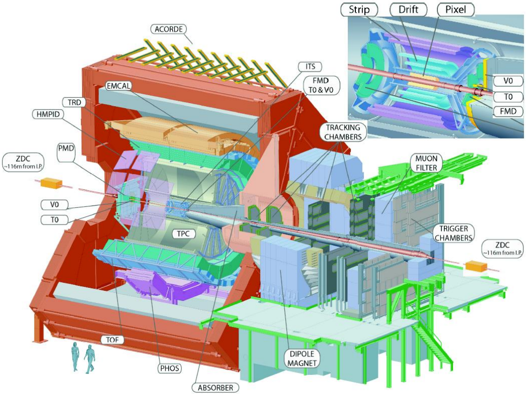
The ALICE Detector

2010 Configuration

- ITS, TPC, TOF, HMPID, Muon arm, V0, T0, FMD, PMD, ZDC 100% ready
- TRD (7/18)
- EMCAL (4/12)
- PHOS (3/5)

HF coverage

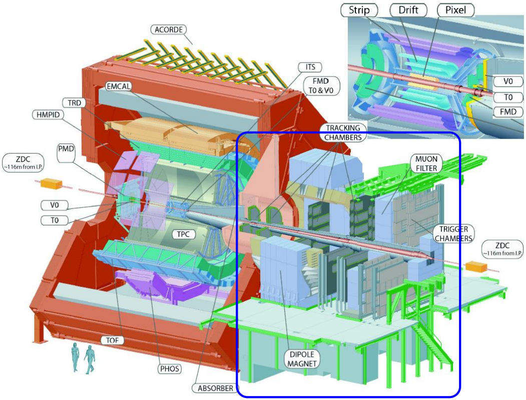
- extends to low p_t
- central (e, hadrons) and forward (μ) rapidity regions
- both for b and c



The ALICE Detector

HF in the muon arm

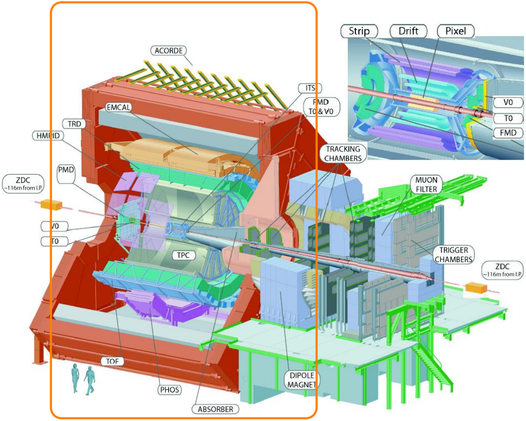
- Muon Tracker and muon trigger
- Single and di-muon channels
- Open heavy flavour and quarkonia



The ALICE Detector

HF at midrapidity:

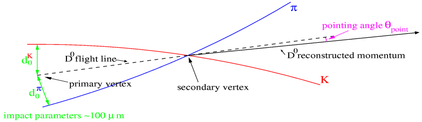
- Inner Tracking System (ITS): Vertexing
  - Silicon Pixel Detector (SPD) (trigger)
  - Silicon Drift Detector (SDD)
  - Silicon Strip Detector (SSD)
- Time Projection Chamber (TPC): Tracking, PID, event plane, centrality
- Time Of Flight (TOF): PID
- Transition Radiation Detector (TRD): PID
- VZERO: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



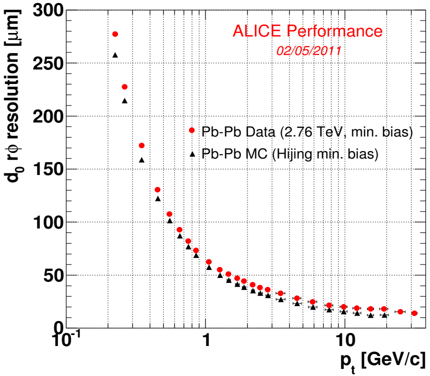
Heavy flavour at ALICE

ALICE has very good performances in HF study:

- Excellent vertexing and tracking
- electronic, hadronic and muonic channels are studied covering different rapidity regions
- very good track impact parameter (d_0) resolution (minimum distance between track and primary vertex) for the tracking in the central barrel
- PID is performed with several techniques ($\frac{dE}{dx}$, TOF, TRD)



d_0 resolution in the rϕ plane in Pb-Pb collisions

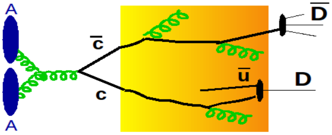


Charm as a probe of QGP

Why studying charm at ALICE?

Charmed particles are a good probe for QGP:

- It is produced at the very beginning of the collision
- Follows the whole fireball evolution
- Interacts strongly with the medium
- Test of thermalization for quarks with large mass



In proton-proton collisions the study of heavy flavours is interesting too

- It provides a crucial reference for Pb-Pb data
- It's a test for pQCD predictions

Datasets

The data presented in this thesis were collected by the ALICE detector in 2010. The data sets consists of

- $314 \cdot 10^6$ proton-proton collisions at $\sqrt{s} = 7$ TeV ($5 nb^{-1}$).
- $58 \cdot 10^6$ proton-proton collisions at $\sqrt{s} = 2.76$ TeV
- $17 \cdot 10^6$ minimum bias Pb-Pb collision at $\sqrt{s_{NN}} = 2.76$ TeV. Of these, $13 \cdot 10^6$ collisions are selected in the 0-80% centrality class ($2.12 \mu b^{-1}$).

Minimum bias trigger defined utilizing VZERO and SPD detector information. Events selection is done asking for the presence of only one reconstructed primary vertex (pile-up events are rejected) with $|z_{vertex}| < 10$ cm from the geometrical centre of the detector. Rejection of beam gas and e.m. background is performed offline using information from ZDC and VZERO detectors.

Analysis Strategy

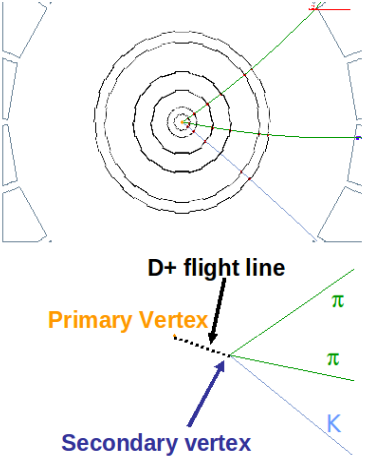
- Apply basic quality cuts to tracks
- Build invariant mass distribution of D^+ candidates from their fully reconstructed purely hadronic decays

⇒ Fit signal and background to extract the signal

- Efficiency and acceptance corrections
- Feed down from B decays subtraction

⇒ Corrected yield

- Normalize and calculate the cross section (proton-proton)



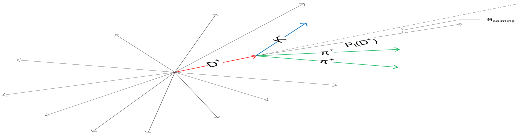
D^+ reconstruction

D^+ properties

$D^+(c\bar{d})$. Decay modes: $D^+ \to K^-\pi^+\pi^+$, $D^+ \to \bar{K^0}{*}\pi^+ \to K^-\pi^+\pi^+$. Branching ratio $9.13 \pm 0.19\%$ with a $c\tau$ $311.8 \pm 2.1\mu m$. Mass$= 1.86957 \pm 0.00016$ GeV/c

$D^+ \to K^-\pi^+\pi^+$

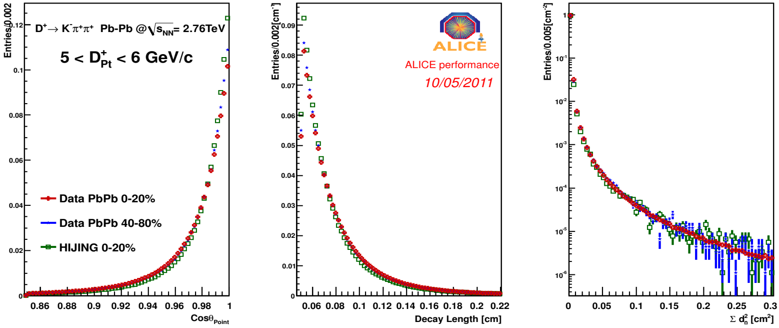
- Triplets of charged tracks with right sign combination
- Large distance between primary and secondary vertex
- Pointing of reconstructed D momentum to primary vertex
- Large impact parameter of the tracks
- conservative PID: Opposite sign particle CAN'T be a pion



Candidate selection

Main cuts to reduce combinatorial background are:

- Dispersion of daughter tracks around secondary vertex
- Distance between primary and secondary vertex (decay length)
- Pointing angle of the reconstructed candidate towards the primary vertex of the event
- large value of the track impact parameters ($\sum d_0^2$)

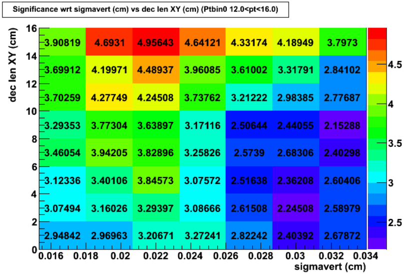


loose topological cuts, mainly background

Cut tuning

Multidimensional optimisation of cut variables

- high statistical significance $\left(\frac{S}{\sqrt{S+B}}\right)$.
- cut efficiencies (from MC) not too small to avoid large corrections.
- signal stable for cut variation around the chosen point.
- Fit peak on the D^+ PDG mass value.
- Fit gaussian σ reproduced in MonteCarlo (and p-p data for the Pb-Pb case).

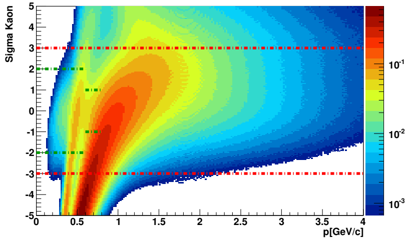


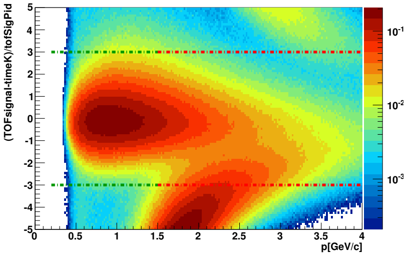
Statistical significance obtained from different values of decay length in the transverse plane and dispersion around secondary vertex ($12 < p_t < 16$ GeV/c)

ALICE

Candidate selection: PID

PID applied in conservative way in order to minimize the loss of signal, particles with no PID information are kept.
We use jointly PID from TOF and TPC and we vary the PID response over p.
For the D^+ we know that the like sign particles must be pions and opposite sign must be kaons.

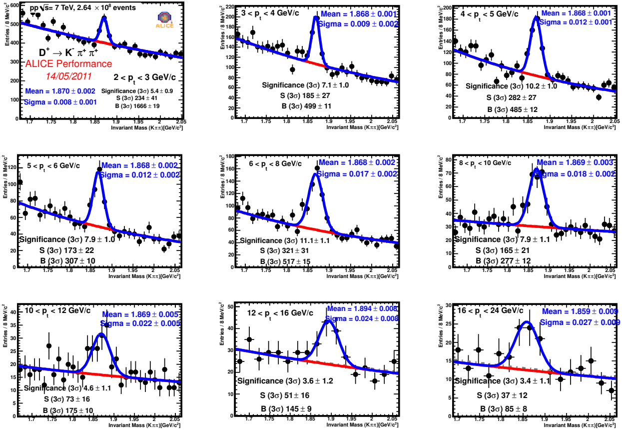




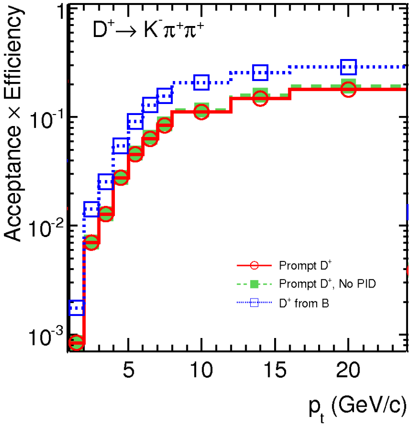
Green identification, red compatibility

Invariant Mass spectra

We can plot the invariant mass distribution of the candidates passing cuts and PID requirements. Then we perform a fit to extract the signal in different p_t bins.



corrections to the raw yield



To obtain the corrected yield, the raw yield extracted from the fit is corrected by efficiencies and acceptance (from MC).
PID almost 100% efficient.

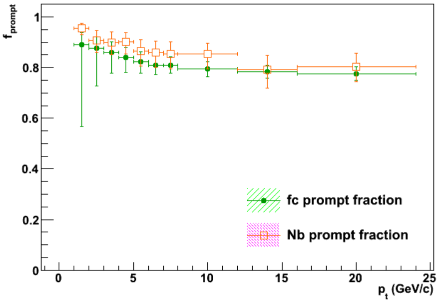
Feed-down subtraction

The feed down contribution from B decays is estimated from FONLL and B and D efficiencies. 2 methods to estimate feed-down:

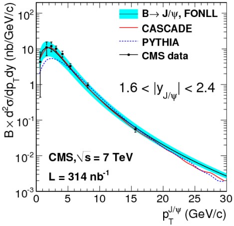
$$f_c:\ f_{prompt} = 1 - \frac{N^{D^{\pm}\,raw}_{from\ B}}{N^{D^{\pm}\,raw}_{all}}$$

$$N_b:\ f_{prompt} = \left(1 + \frac{\epsilon_{from\ B}}{\epsilon_{prompt}} \frac{\left.\frac{d\sigma^{D^{+}from\ B}_{FONLL}}{dp_t}\right|_{|y|<0.5}}{\left.\frac{d\sigma^{D^{+}}_{FONLL}}{dp_t}\right|_{|y|<0.5}}\right)^{-1}$$

FONLL parameters varied to estimate uncertainties:
$0.5 < \frac{\mu_{F/R}}{m_T} < 2$,
$0.5 < \frac{\mu_F}{\mu_R} < 2$,
$4.5 < m_b < 5$ GeV,
$1.3 < m_c < 1.7$ GeV



FONLL gives good B description of LHCb/CMS data



Normalization to cross section

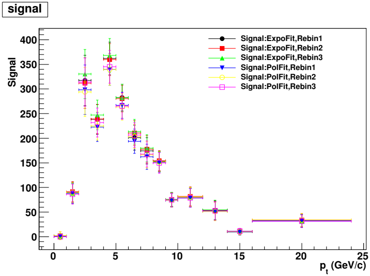
The main goal of D^{+} analysis in p-p is to measure its production cross section $d\sigma/dp_t$. We can extract the cross section from the raw yield using the formula:

$$\frac{d\sigma^{D^+}(p_t)}{dp_t}\Big|_{|y|<0.5} = \frac{1}{2}\frac{1}{\Delta y(p_t)}\frac{f_{prompt}(p_t)}{Acc\times\epsilon_{prompt}}\frac{N^{D^\pm}_{raw}(p_t)|_{y<\Delta y}}{(BR)\Delta p_t}\frac{\sigma^{mb}/\sigma^{V0AND}}{N^{mb}}\sigma^{V0AND}$$

- $f_{prompt}(p_t)$: B feed-down correction
- $\frac{1}{Acc\times\epsilon_c(p_t)}$: efficiency correction
- $N^{D^\pm}_{raw}(p_t)$: Raw signal from the invariant mass fit
- $\frac{\sigma^{mb}/\sigma^{V0AND}}{N^{mb}}\sigma^{V0AND}$: Cross section $\sigma_{minbias}$ measured from the V0AND cross section measured in VdM scans.

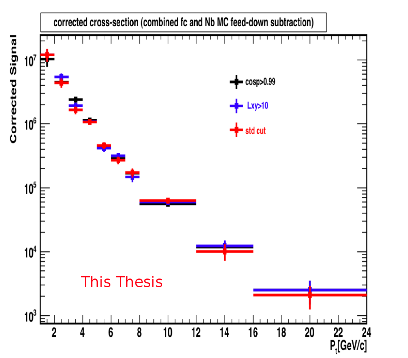
systematic on corrected yields

- Raw yield extraction: change (bkg) fit function, range, binning
- Cut variation
- PID efficiency
- D^{+} - D^{-} comparison.



systematic on corrected yields

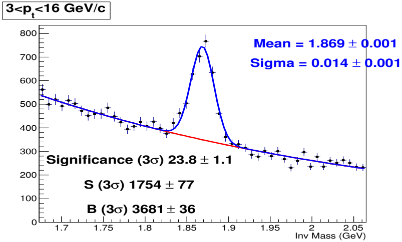
- Raw yield extraction
- Cut variation: 3 different sets of cuts, with large signal variation
- PID efficiency
- D^+ - D^- comparison.



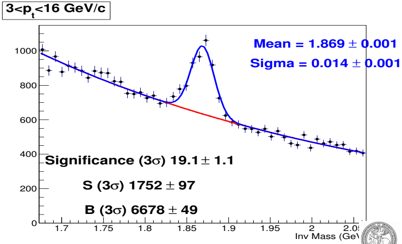
systematic on corrected yields

- Raw yield extraction
- Cut variation
- PID efficiency: analysis performed with and without PID
- D^+ - D^- comparison.

with PID

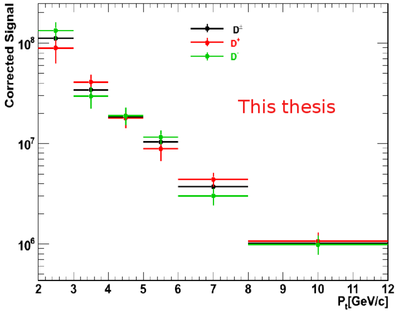


without PID



systematic on corrected yields

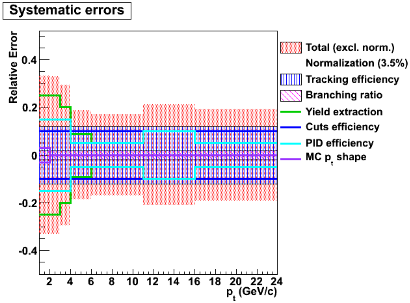
- Raw yield extraction
- Cut variation
- PID efficiency
- D^{+} - D^{-} comparison: corrected yield for particle/antiparticle



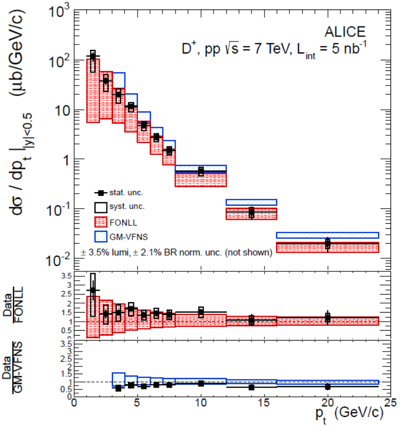
Systematics uncertainties on D^+ cross section

Sources of syst. uncertainty

- Raw yield extraction (5% to 25%)
- cut variation (10%)
- PID efficiency (10-15%)
- cross section normalization (3.5%)
- BR uncertainty (2.1%)
- tracking efficiency (12%)
- MonteCarlo p_t shape (1-5%)



Results: D^+ production cross-section at $\sqrt{s} = 7$ TeV



- measurement in good agreement with pQCD calculations (FONLL, GM-VFNS) within uncertainties.
- FONLL central values underestimate data (pattern already observed at lower energies).
- GM-VFNS central values overestimate data

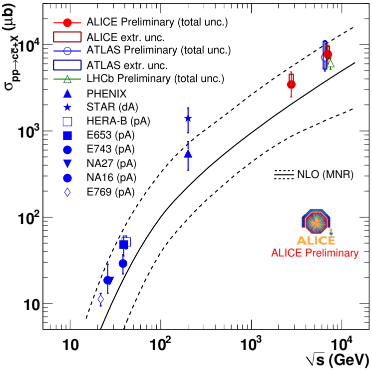
The total D^+ production cross-section is obtained by extrapolating the σ^{D^+} measured in $p_t > 1$ GeV/c (visible) down to $p_t = 0$ GeV/c and full rapidity using the ratio of the FONLL visible cross section to the FONLL total cross section to correct the measured σ^{D^+}:

$$\sigma^{7\text{TeV}}_{D^+} = 2.18 \pm 0.32(\text{stat.})^{+0.36}_{-0.71}(\text{syst.}) \pm 0.15(\text{lumi.})^{+0.66}_{-0.31}(\text{extr.})\text{mb}$$

Results: charm production cross-section

Correcting the total D^+ production by the $c \to D^+$ fragmentation ratio ($\sim$ 15%) it is possible to measure the total charm production cross section.

- measurement performed at $\sqrt{s} = 7$ TeV and $\sqrt{s} = 2.76$ TeV.
- final result from weighted average of results from D^+, D^0 and D^{*+}.
- both measurements in good agreement with pQCD (MNR-NLO) calculations, but central values underestimate data, as happens at lower energies.
- good agreement with the same measurement performed at ATLAS and LHCb experiments at $\sqrt{s} = 7$ TeV.

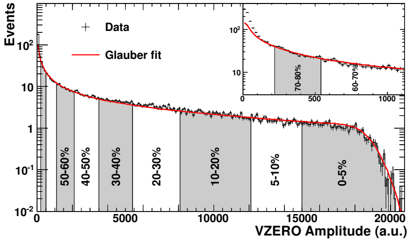


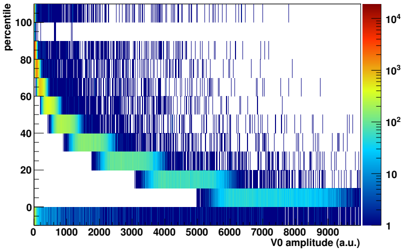
Pb-Pb analysis at $\sqrt{s_{NN}} = 2.76$ TeV

- Similar strategy to proton-proton
  - Cut optimization
  - raw yield extraction from fit to the invariant mass spectra
  - efficiency, acceptance and feed-down corrections to obtain the corrected yield
- Pb-Pb collisions can be classified according to their centrality
  - event multiplicity depends on the centrality
  - cut tuning performed in centrality bin. Looser cuts applied in peripheral events (less background)
- Goal of Pb-Pb analysis is the measurement of D^+ R_{AA} and v_2

Centrality

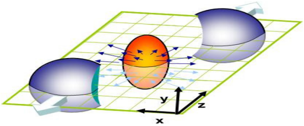
Glauber model: nucleus-nucleus collision as superposition of N_{coll} nucleon-nucleon collisions. Nucleons in the geometrical overlap region of the nuclei are participants. Medium size, event multiplicity and number of participant nucleons depend on the collision geometry (centrality). Centrality estimation at ALICE: VZERO, TPC, ZDC, SPD, FMD.



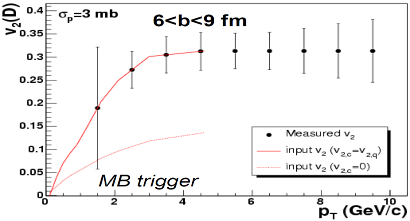


Particle production: $N_{\text{primary}} = f \cdot N_{\text{part}} + (1 - f)\, N_{\text{coll}}$

Open charm at ALICE: Elliptic Flow



Initial spatial anisotropies in the overlap region of the colliding nuclei create asymmetric pressure gradients. Rescatterings translate in momentum anisotropies of final particle production. At midrapidity :
$\frac{dN}{Nd\phi} = 1 + 2v_2 \cos(2(\phi - \Psi_{RP})) + ...$ and



Ko et al., Braz J. Phys 37 (2007) 969.
Simulation of
1 year of data taking, impact parameter range: $6 - 9fm$

Elliptic flow:
$v_2 =< cos[2(\phi - \Psi_{RP})] >$
Elliptic flow of heavy particles can bring useful information about thermalization, thermodynamics of QGP and the hadronization mechanism.

v_2 measurement strategy

measurement of v_2 with event plane

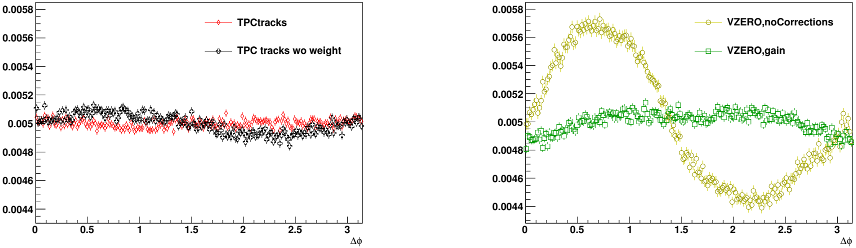
- Event plane determination with TPC tracks and VZERO
- Event plane angle $\Psi = \frac{1}{2}\tan^{-1}\left(\frac{\sum_i w_i \sin(2\phi_i)}{\sum_i w_i \cos(2\phi_i)}\right)$
- Produce the invariant mass spectra of candidates in bins of p_t as a function of $\Delta\phi$ with respect to event plane
- v_2 computed from azimuthal asymmetries in signal distribution:
  - In-plane versus out-of-plane anisotropy
  - Fit of v_2 versus invariant mass for signal and background invariant mass regions
  - side bands subtraction of background v_2

Other methods, based on Q-cumulants and scalar products have been prepared, but results are not shown here.

Event plane determination

The event plane is computed from the amplitudes in each VZERO sector or from azimuthal track distribution inside the TPC. $\Psi = \frac{1}{2}\tan^{-1}\left(\frac{\sum_i w_i \sin(2\phi_i)}{\sum_i w_i \cos(2\phi_i)}\right)$. ϕ dependent weights for TPC (to account for dead sectors). For VZERO weights are the relative integrated amplitude of each sector. Both computed run-by-run.

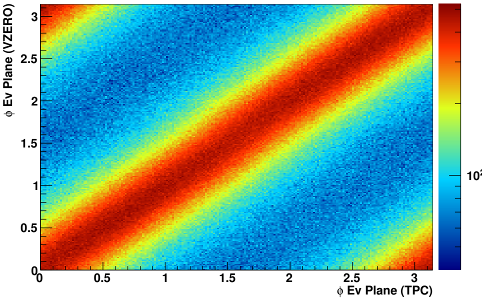
20-80% centrality



recentering and flattening of VZERO to be used for 2011 data.

Event plane determination

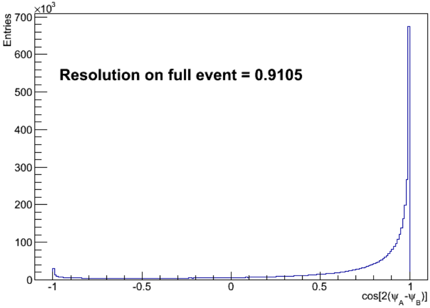
The event plane is computed from the amplitudes in each VZERO sector or from azimuthal track distribution inside the TPC. $\Psi = \frac{1}{2}\tan^{-1}\left(\frac{\sum_i w_i \sin(2\phi_i)}{\sum_i w_i \cos(2\phi_i)}\right)$. ϕ dependent weights for TPC (to account for dead sectors). For VZERO weights are the relative integrated amplitude of each sector. Both computed run-by-run.



Good agreement between VZERO and TPC event planes.

Event plane resolution

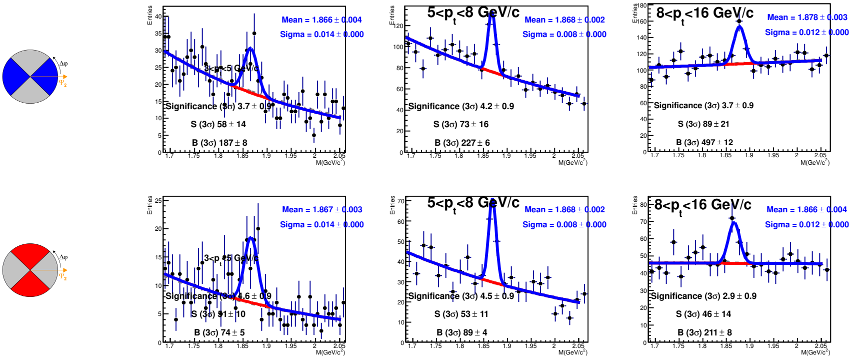
Obtained splitting each event in 2 sub-events and computing for each of them the event plane angle. $\sigma_{\text{EP}} = \langle \cos(2(\Psi^a - \Psi^b)) \rangle$ averaged over many events. It depends on event multiplicity (centrality) and v_2. For 30-50% centrality TPC EP resolution $\sigma_{\text{EP}} \sim 0.91$.



v_2 measured from EP methods must be corrected by EP resolution: $v_2 = v_2^{\text{obs}} / \sigma_{\text{EP}}$.

v_2 from signal anisotropy

Centrality 30-50%

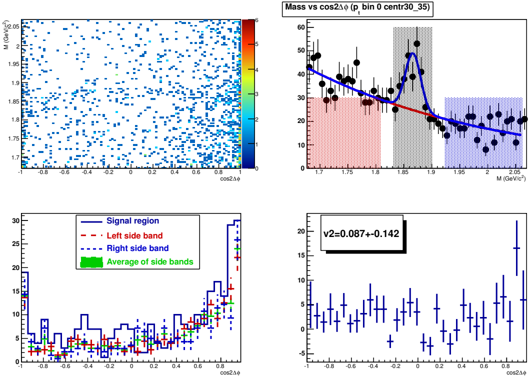


From signal distribution in and out of plane: $v_2 = \frac{\pi}{4}\frac{N_{\text{in-plane}} - N_{\text{out-plane}}}{N_{\text{in-plane}} + N_{\text{out-plane}}}$

(to be corrected for EP resolution)

v_2 from side band subtraction

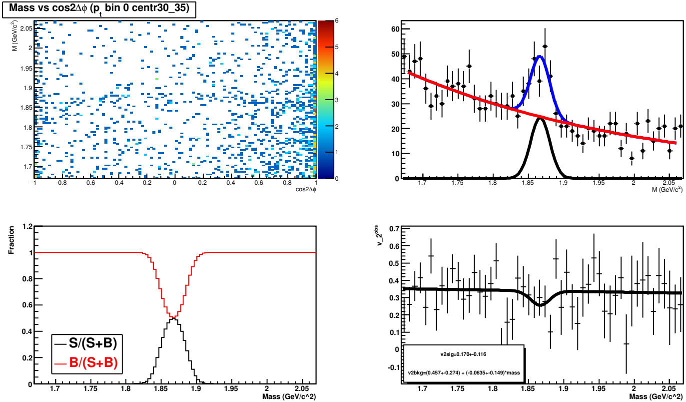
From the 2D distibution of invariant mass vs $\cos 2\Delta\phi$



- Project 2D histogram on $\cos 2\Delta\phi$ in the side bands regions and in signal region
- From subtraction we get the signal $\cos 2\Delta\phi$ distribution
- Get v_2 as $\langle \cos 2(\Psi_2 - \psi_{RP}) \rangle$ from the signal histogram

Fit to v_2 versus mass

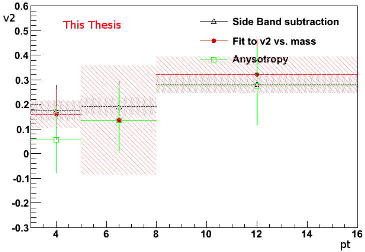
From the 2D distibution of invariant mass vs $\cos 2\Delta\phi$



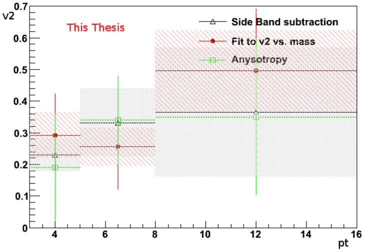
- From invariant mass fit signal and background fraction as a function of mass
- Extract $v_2 = \langle \cos 2(\Psi_2 - \psi_{RP}) \rangle$ vs mass
- Fit it with $v_2^{sgn} * S/(S+B) + v_2^{bkg} * B/(S+B)$

$v_2(p_t)$

30-50% CC



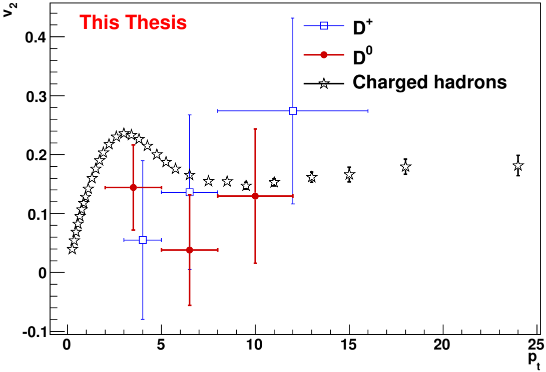
50-80% CC



v_2 corrected by resolution.
Low statistics, difficult signal extraction, high stat. and syst. uncertainties.

$v_2(p_t)$ (II)

30-50% CC

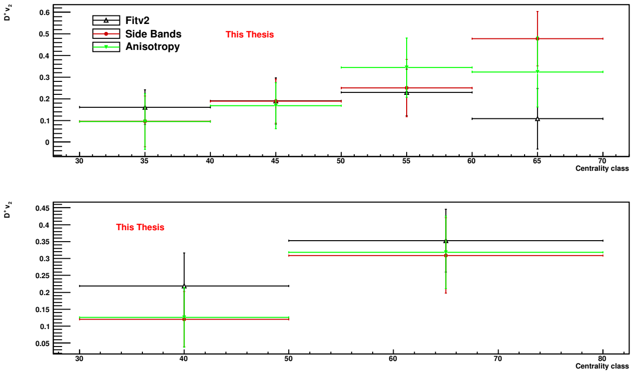


Statistical errors only

Results in agreement with D^0 result within large uncertainties. Compatible with both charged hadron and no-flow. No B feed-down subtraction.

v_2 centrality dependence

To increase fit quality, results be integrated in $3 < p_t < 16$ GeV/c for different centrality classes.

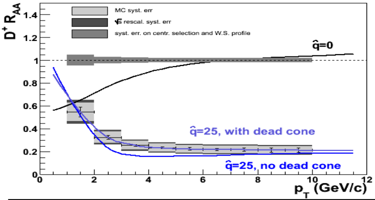


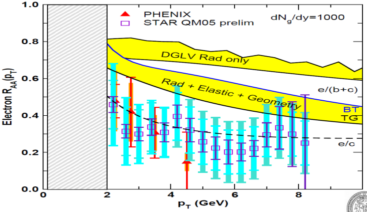
Hint of $v_2 > 0$ above 40% centrality. v_2 seems to increase up to 50% centrality. Coherent with charged hadron behaviour.

Open charm at ALICE: Energy loss

The study of open charm particles (D^0,D^+,D^*,...) can bring helpful information on the nature of QGP. One of the main QCD medium effects is parton energy loss. Radiative energy loss: $\Delta E \propto \alpha_s L^2 C_R \hat{q}$.[1]

- Nuclear Modification factor: $R_{AA}(p_t) = \frac{1}{<N_{coll}>} \frac{dN_{AA}/dp_t}{dN_{pp}/dp_t}$
- An $R_{AA} < 1$, already observed at RHIC, has been interpreted as an effect of the parton energy loss in the medium
- Different colour charges C_R for quark (4/3) and gluons (3). $\Rightarrow R^D_{AA} > R^h_{AA}$. Colour charge dependence of energy loss
- Dead cone effect: gluon emission suppressed for angles $\theta < \frac{M}{E}$ $\Rightarrow R^B_{AA} > R^D_{AA}$. Energy loss mass dependence





[1] Baier, Dokshitzer, Mueller, Peigne, Schiff Nucl.Phys., vol. B484

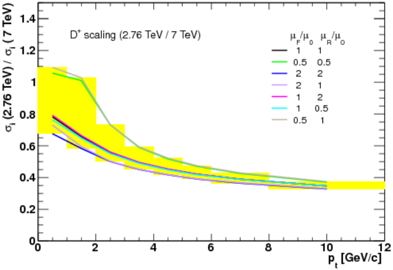
proton-proton reference scaling

The proton-proton cross-section at $\sqrt{s} = 7$ TeV must be scaled to the energy of the Pb-Pb collision ($\sqrt{s} = 2.76$ TeV). From the FONLL cross sections at the two energies:

$$\sigma^{D^+}(p_t; 2.76) = \frac{\sigma^{\text{FONLL}}(p_t;2.76)}{\sigma^{\text{FONLL}}(p_t;7)} \sigma^{D^+}(p_t, 7)$$

Uncertainties and cross-checks

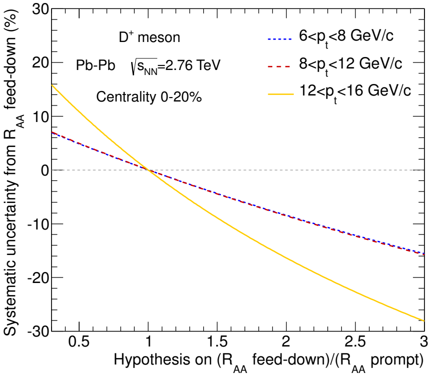
- Systematic uncertainties varying FONLL parameters (as in pp)
- Results compatible when scaling with GM-VFNS
- scaled results compatible with p-p measurement at $\sqrt{s} = 2.76$ TeV



ALICE

Feed-down in Pb-Pb

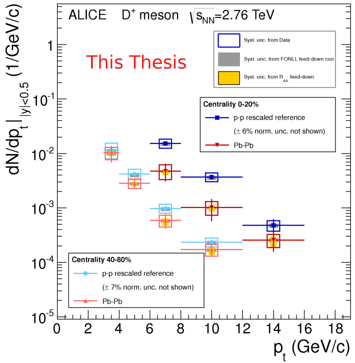
The energy loss of D mesons from B decays affects the feed-down spectra. In principle feed-down and prompt have different energy loss and this must be taken into account for feed-down subtraction.



We assumed $R_{AA}^{\text{feed-down}}/R_{AA}^{\text{prompt}} = 1$ and estimated the systematic uncertainty varying $1/3 < R_{AA}^{\text{feed-down}}/R_{AA}^{\text{prompt}} < 3$ for the different p_t bins.

Corrected yield

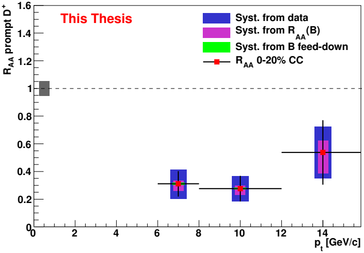
Corrected yield in central (0-20%) and peripheral (40-80%) Pb-Pb collisions



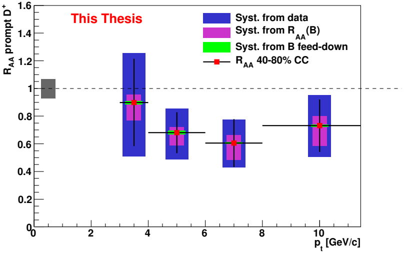
Strong suppression with respect to the observed p-p reference in both centralities in all p_t bins.

D^+ meson R_{AA}

0-20%

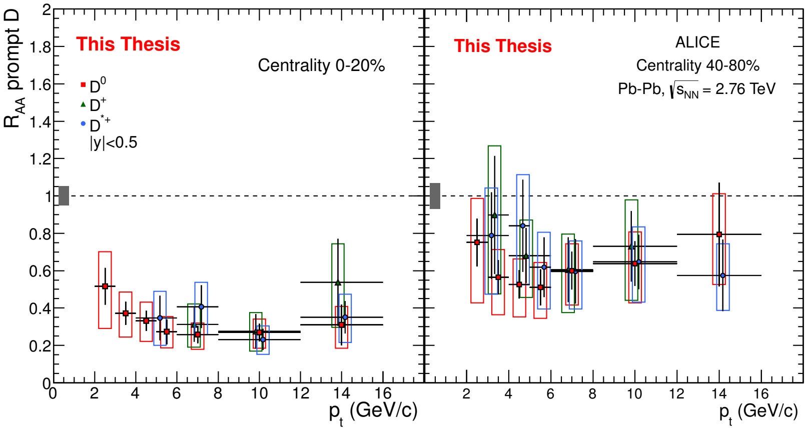


40-80%



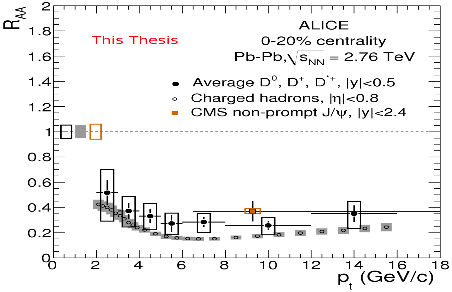
$R_{AA} \sim 0.3$ in central collisions, $R_{AA} \sim 0.6 - 0.7$ in peripheral collisions. Stronger suppression in central events compatible with assumption of a medium effect

Comparison with other D mesons



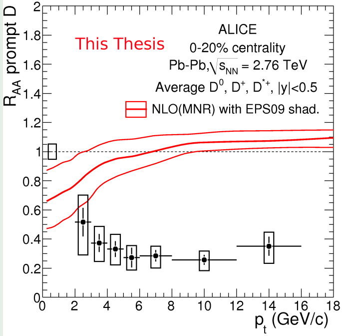
Good agreement between D^+, D^0 and D^{*+} both in central and peripheral events for the whole p_t range. From now on: weighted average of the three mesons.

Comparison with charged hadrons



light hadrons R_{AA} from ALICE compatible with D meson R_{AA} within uncertainty and with the CMS non-prompt J/ψ one ($p_t > 6.5$ GeV/c).

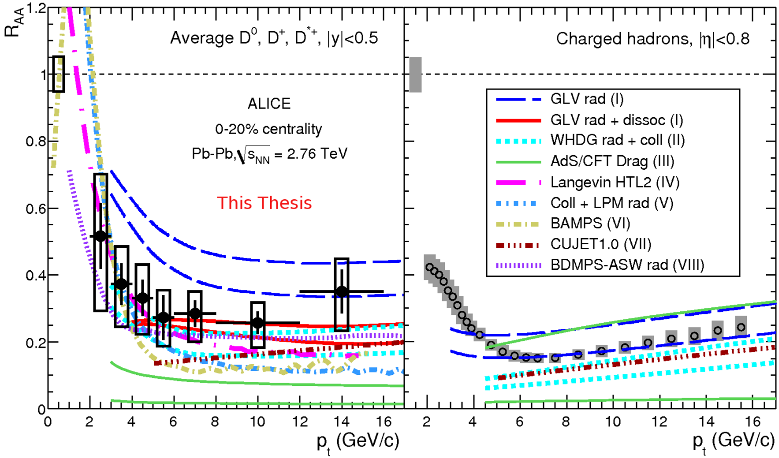
Shadowing is small for $p_t > 5$ GeV/c : hot medium effect



D meson values systematically higher than light hadrons, and below non-prompt J/ψ. Possible hint for $R^B_{AA} > R^D_{AA} > R^\pi_{AA}$ hierarchy?

Comparison with theory

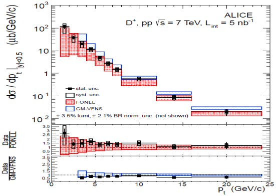
Theoretical models generally compatible within uncertainties, but just a few (I, II, VII) can reproduce well both D meson and light hadrons R_{AA}



Conclusions

The D^+ p_t differential production cross-section was measured in p-p collisions at $\sqrt{s} = 7$ TeV.

- Good agreement between our measurement and pQCD calculation



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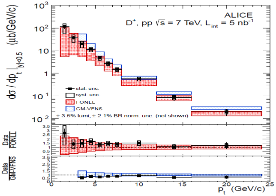
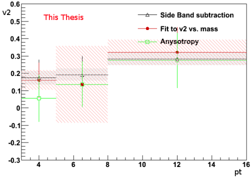
- limited statistics does not allow to have a conclusive results
- Hint of $v_2 > 0$ for p_t integrated v_2
- Good prospects for the analysis of 2011 data, where the available statistics is several times higher





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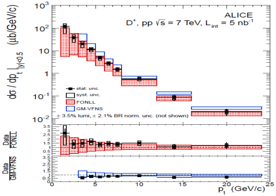
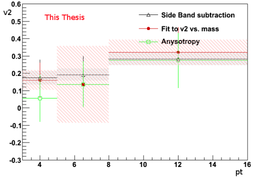
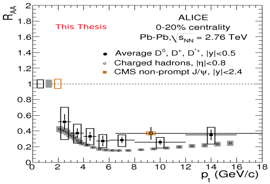
The D^+ R_{AA} show strong suppression

- Hot medium effect
- D R_{AA} higher than charged hadrons, lower than non-prompt J/ψ from CMS
- Possible hint of R_{AA} hierarchy.







THANK YOU FOR YOUR ATTENTION