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D meson production with ALICE

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Outline

- Physics motivations for D meson study in Pb-Pb collisions
- Nuclear modification factor in 2011 Pb-Pb data
  - analysis method
  - results
- Elliptic flow in 2011 Pb-Pb data
  - analysis method
  - results
- Conclusions

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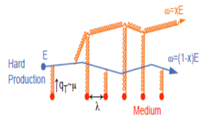
Hard Probes

- produced in high Q^2 interactions $\rightarrow$ pQCD regime, short timescale $\propto 1/Q^2$
- high p_{T} partons, heavy flavors, quarkonia
- predictions: in dense partonic matter they suffer from
  - in-medium dissociation due to binding potential screening (quarkonia)
  - in-medium parton energy loss

Energy loss mechanism

- elastic collisions
- gluon radiation
  - e.g. BDMPS model
    Armesto et al., PRD 71 (2005) 054027

$$< \Delta E >_{parton} = \alpha_s L^2 \widehat{q}\ C_r$$



L distance transversed in the medium
$\widehat{q}$ transport coefficient (medium properties)
C_r Casimir factor
- 3 for gluons
- 3/4 for quarks

Observables related to these effects:

✓ high p_{T} hadrons, jets ✓ Open Heavy Flavors ✓ Quarkonia

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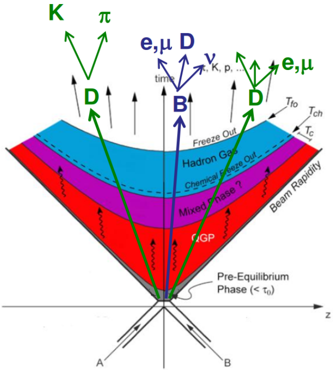
Open Heavy Flavors

D and B mesons, baryons



c and b quarks and evolution of the medium

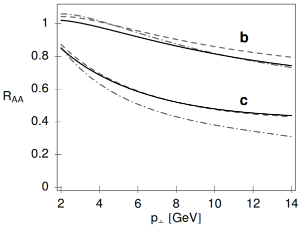
- they can be identified from their hadronic or semileptonic decays
- fragmentation functions for D and B peaked at 1 $\rightarrow$ open heavy-flavour kinematic close to the one of parent quark

Open Heavy Flavors - R_{AA}

- nuclear modification factor

$$R_{AA}(p_{\mathrm{T}}) = \frac{1}{N_{coll}} \frac{dN_{AA}/dp_{\mathrm{T}}}{dN_{pp}/dp_{\mathrm{T}}}$$

- for heavy flavors $R_{AA} = 1$ if no nuclear effects are present
- $R_{AA} \neq 1$ may indicate the presence of:
  - **initial state effects** (observed in pA collisions): PDF nuclear modification (shadowing), Cronin enhancement, ...
  - **final state effects**: collisional and radiative energy loss in the medium



prediction for b and c quarks R_{AA}
Djordjevic et al, arXiv:0410372

- gluon radiation suppressed for angles $\theta < M_Q/E_Q$ (dead cone effect)

  $$R_{AA}(\pi) < R_{AA}(D) < R_{AA}(B)$$

  (pions come mainly from gluon fragmentation $\rightarrow$ higher C_r - $< \Delta E >= \alpha_s L^2 \hat{q} C_r$)

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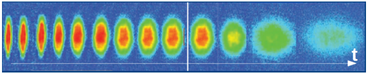
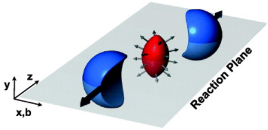
Open Heavy Flavors - Elliptic Flow

Spatial anisotropy of the fireball converted into **momentum anisotropy** of final state particles due to multiple interactions among the medium constituents





$$\frac{dN}{d(\varphi-\Psi_{RP})} \propto 1 + 2v_1 \cos(\varphi - \Psi_{RP}) + 2v_2 \cos(2(\varphi - \Psi_{RP})) + \ldots$$

- D meson $v_2 \neq 0$ at low p_{T} $\rightarrow$ c quark thermalization in the medium
- D meson $v_2 \neq 0$ at high p_{T} $\rightarrow$ path length dependance of the energy loss

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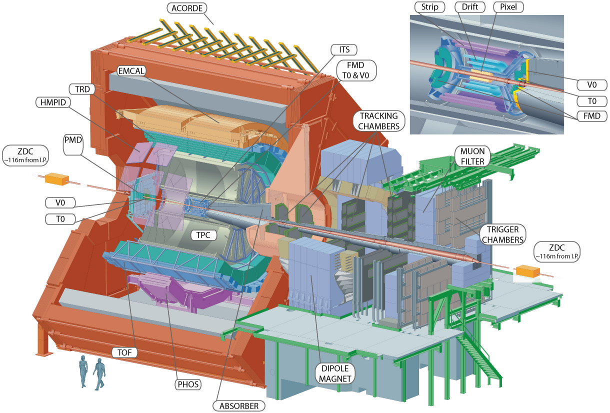
ALICE detector

- Inner Tracking System: 6 layers of silicon detectors for tracking and vertex position
- Time Projection Chamber provides tracking and particle identification
- Time of Flight detector provides particle identification

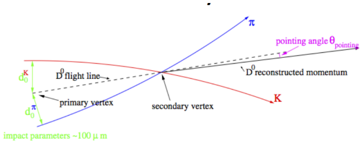


- trigger based on VZERO detector (array of scintillators) and Silicon Pixel Detector (inner layer of ITS)
- centrality provided by VZERO amplitude

D meson reconstruction

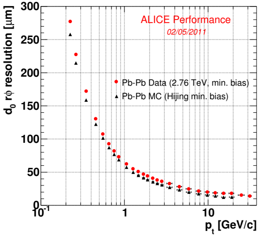
The decay kinematic is fully reconstructed through the hadronic decays of D mesons

- $D^0 \to K^- \pi^+$
- $D^+ \to K^- \pi^+ \pi^+$
- $D^{*+} \to D^0 \pi^+$
- $D_s \to \pi^+ \phi \to K^+ K^- \pi^+$

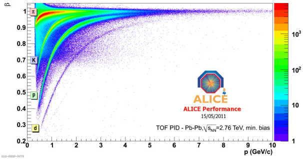


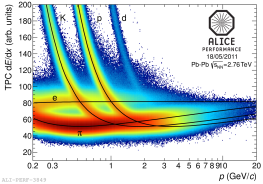
The reconstruction of these decays requires:

Excellent vertex and impact parameter resolution ($c\tau$ of the D mesons $\sim$ 100-300μm)



Particle Identification





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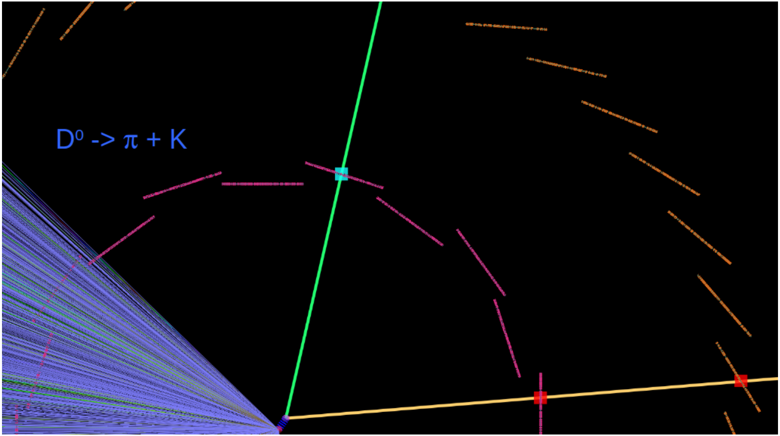
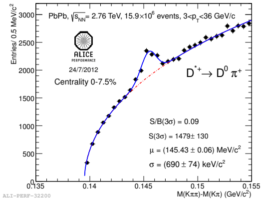
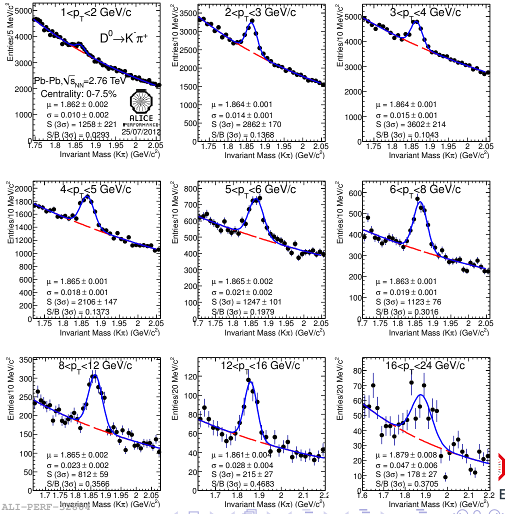
D^0 reconstruction



Analysis of Pb-Pb 2011 data

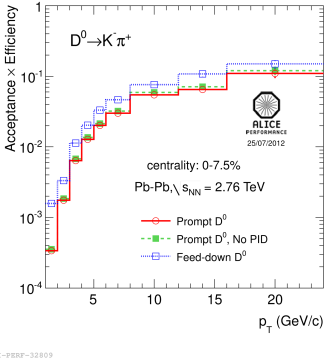
- 16 M events collected with central triggers **0-7.5% centrality**
- Invariant mass analysis of fully reconstructed decay topologies displaced from the primary vertex
- selection strategy based on:
  - topological cuts: decay length, cosine of the pointing angle...
  - particle identification for decay tracks





Analysis of Pb-Pb 2011 data - Efficiencies

Reminder: we are looking for the prompt D mesons R_{AA} in different p_T bins $\rightarrow$ D meson from B decay are more displaced from the primary vertex (B meson decay length + D meson decay length) $\rightarrow$ different efficiencies



- HIJING+Pythia
- simulated data reconstructed taking into account detector conditions for each run
- higher efficiency for D mesons from B $\rightarrow$ analysis cuts select preferentially more displaced vertex

Analysis of Pb-Pb 2011 data - Beauty feed-down subtraction

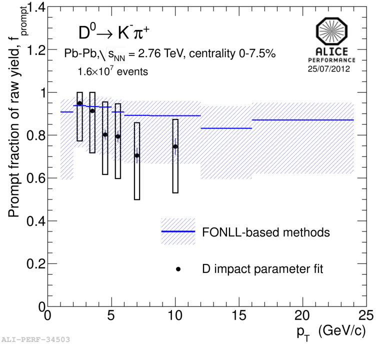
Reminder: we are looking for the prompt D mesons R_{AA} in different p_{T} bins $\rightarrow$ need to subtract the fraction of D mesons coming from B meson decay (beauty feed-down)

- FONLL predictions for non-prompt D meson cross section in pp
- the number of non-prompt D in a given p_{T} bin is

$$\frac{dN^{theory}_{DfromB}}{dp_{\mathrm{T}}} = \Delta p_{\mathrm{T}} \times eff_{DfromB} \times T_{AA} \times R^{DfromB}_{AA} \times \frac{d\sigma^{pp}_{DfromB}}{dp_{\mathrm{T}}}$$

T_{AA} nuclear overlap function (from Glauber Model)

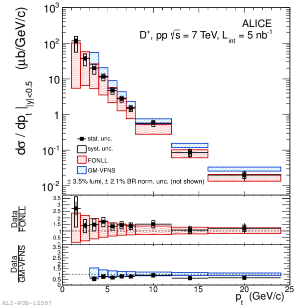
- hypothesis: $0.3 < R^{DfromB}_{AA} < 3$ in general we expect R_{AA} of D mesons from B to be different from that of prompt D mesons, accordingly to the different energy loss hypothesis of c and b q



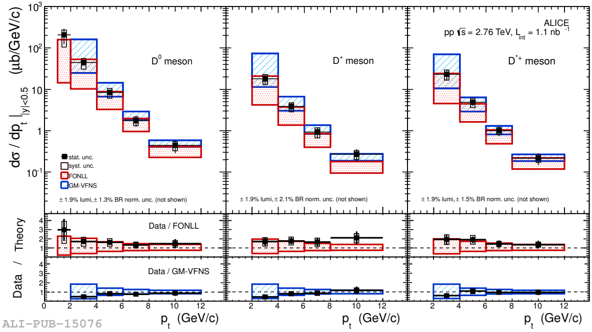
pp reference

- pp @ 7TeV: 316 M events
- pp @ 2.76TeV: 68 M events

- 7 TeV data extrapolated to 2.76 TeV using FONLL predictions
- 2.76 TeV data used to validate results



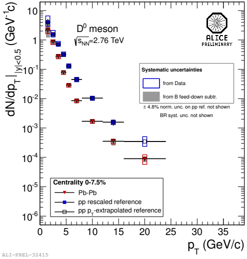
7 TeV

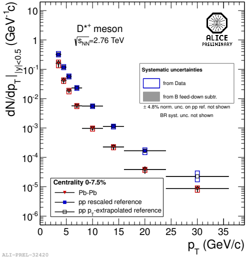


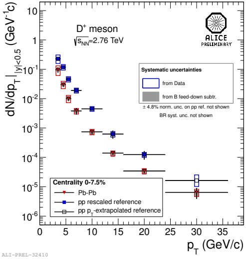
2.76 TeV

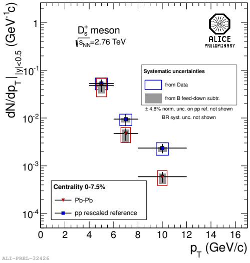
- pp reference for R_{AA} at higher p_T obtained with p_T-extrapolation using FONLL/data ratios in the measured region

p_T spectrum - pp and Pb-Pb









- pp spectra multiplied by $< T_{AA} >$ in 0-7.5%
- main sources of systematic uncertaintes:
  - yield extraction ($\sim$ 10%)
  - PID ($\sim$ 5%)
  - topological cut variation ($\sim$ 10%)
  - B feed-down uncertaintes ($\sim$ 10%)

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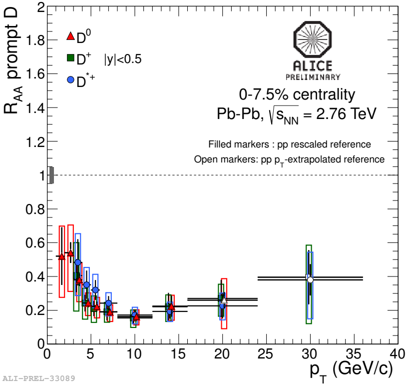
R_{AA} results

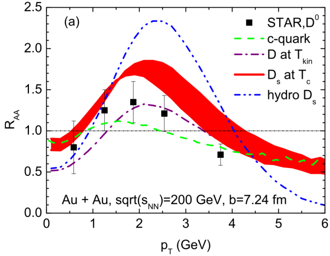


- R_{AA} measurements up to 36 GeV/c
- D^0, D^+ and D^{*+} mesons show a suppression by a factor of 4-5 above a transverse momentum of 5 GeV/c

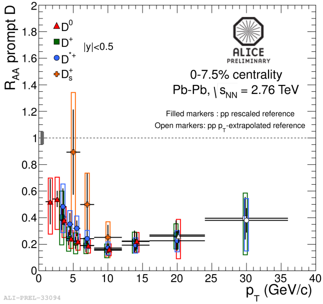
R_{AA} results - focus on D_s

Physics motivation

The relative yield of D_s with respect to that of non-strange D meson expected to be enhanced in Pb-Pb collisions at low-intermediate p_T if charm quarks hadronize via recombination in the medium

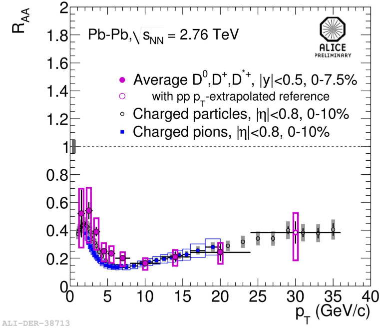


arXiv:1204.4442



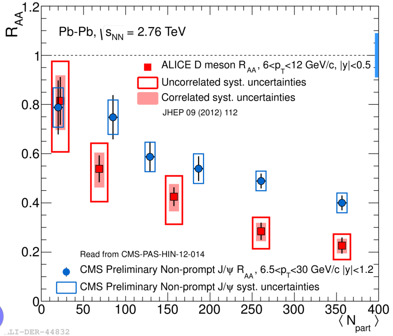
- large statistical and systematic uncertainties with the present data sample do not allow to conclude about low and intermediate p_T region
- for $8 < p_T < 12$ GeV/c suppression similar to the one of non-strange D mesons

$R_{\rm AA}$ results - Comparison to charged hadrons



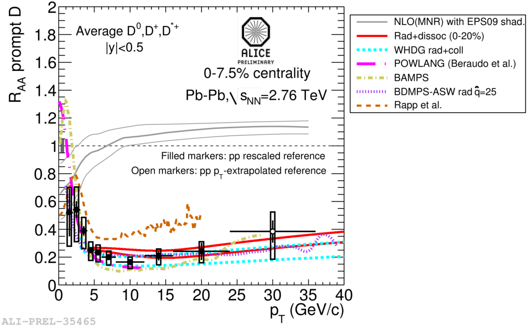
- D meson $R_{\rm AA}$ similar to that of charged hadrons and pions (**caveat** slightly different centrality for charged hadrons and pions: 0-10%)
- maybe a hint for $R_{AA}(D) > R_{AA}(\pi)$ at low $p_{\rm T}$

R_{AA} results - Comparison to non prompt J/ψ



- non-prompt J/ψ from B meson decay (CMS data - CMS-PAS-HIN-12-014)
- hints for stronger D meson suppression in central collisions

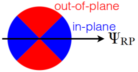
R_{AA} results - Comparison to models



- shadowing alone (**NLO(MNR)** model) cannot explain such a strong suppression
- models including in-medium parton energy loss can give a reasonable description of the data

v_2 - Analysis

Candidates are divided into 2 sub-groups, depending on the reconstructed track angle φ w.r.t. event plane Ψ_{EP} (estimator of the reaction plane is defined by the impact parameter and the beam direction)

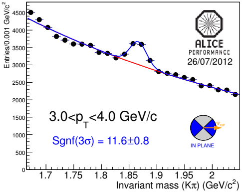


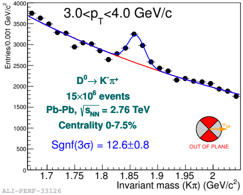
- $|\Delta\varphi| = \varphi - \Psi_{EP}$
  - in plane: $|\Delta\varphi| < \frac{\pi}{4}$
  - out of plane: $\frac{\pi}{4} < |\Delta\varphi| < \frac{3\pi}{4}$
- fit to mass spectra in the 2 regions to get total in-plane(N_{in}) and out of plane(N_{out}) yields

Determine v_2 as

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

- R_2: event plane resolution





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Event plane

Event plane is evaluated from the tracks azimuthal distribution in the TPC
TPC tracks are used to compute the 2 dimensional Q_n vector, in particular the 2nd harmonic Q_2

$$Q_2 = \begin{pmatrix} \sum_{i=0}^{N} w_i \cos\phi_i \\ \sum_{i=0}^{N} w_i \sin\phi_i \end{pmatrix}$$

$$\Psi_{EP} = \frac{1}{2}\tan^{-1}\left(\frac{Q_{2_x}}{Q_{2_y}}\right)$$

- ϕ_i azimuthal angle of the ith reconstructed track of the event
- w_i weight of the ith track
- Weights depend on azimuth and account for efficiency discrepancies among different TPC sectors $\rightarrow$ they are computed in order to have a flat event plane distribution.

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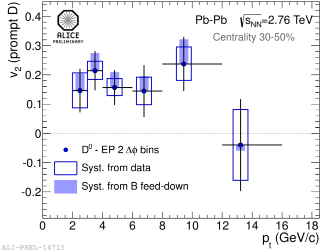
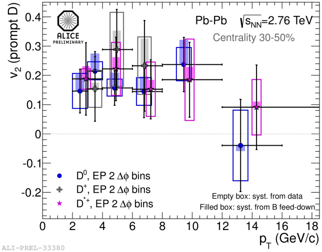
v_2 - results in 30-50%



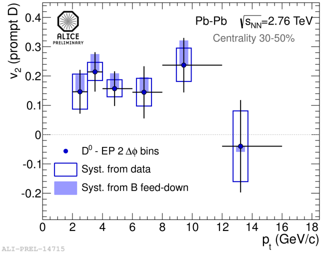
Systematic uncertaintes:

- yield extraction (different fitting functions, bin counting)
- different topological cuts
- B feed-down subtraction (here we need an hypothesis on both feed-down R_{AA} and v_2)
- event plane resolution evaluation



- indication for non-zero D^0 v2 (3σ for 2< p_T <6 GeV/c)
- D^0 v_2 in agreement with D^+ and D^{*+} within uncertaintes

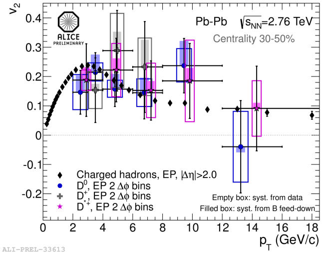
v_2 - results in 30-50%



Systematic uncertaintes:

- yield extraction (different fitting functions, bin counting)
- different topological cuts
- B feed-down subtraction (here we need a hypothesis on both feed-down R_{AA} and v_2
- event plane resolution evaluation

- indication for non-zero D^0 v2 (3σ for $2 < p_T < 6$ GeV/c)
- D^0 v_2 in agreement with D^+ and D^{*+}
- D meson v_2 compatible with that of charged hadrons in the same centrality 30-50%



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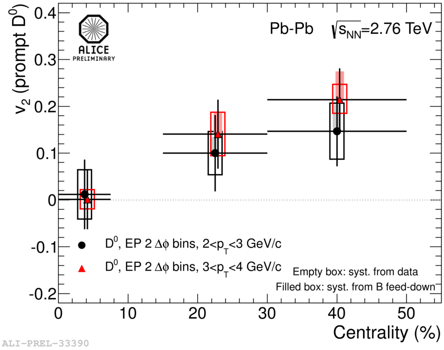
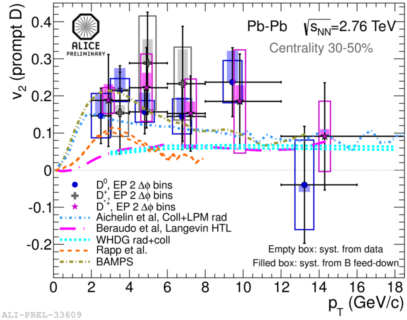
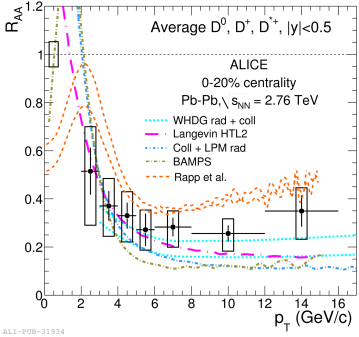
v_2 - other centralities



- p_{T} bins [2,3] and [3,4] GeV/c for 0-7.5%, 15-30% and 30-50%
- v_2 enhancement going from central to semiperipheral collisions
- expected from the small initial geometrical anisotropy in central collisions

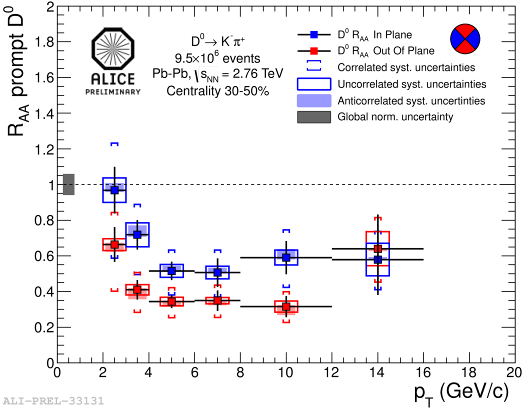
v_2 - Comparison to models





Challenging for the models to reproduce simulataneously R_{AA} and v_2

R_{AA} vs event plane



- access different informations to the relative contribution of partonic energy loss and anisotropic flow to the suppression

Conclusions

- $R_{\rm AA}$ measurement in central collisions has shown a strong suppression (factor 4÷5) of heavy flavours yield w.r.t. pp collisions
- D_s measured for the 1st time in heavy-ion collisions. Intriguing result, although not conclusive on the predicted enhancement at low and intermediate $p_{\rm T}$
- D meson v_2 measured for the 1st time; positive v_2 with 3σ significance in $2 < p_{\rm T} < 6$ GeV/c
- different theoretical models agree with elliptic flow and nuclear modification factor results separately, but simultaneous description of both effects is challenging
- strong suppression of yield at high $p_{\rm T}$ and v_2 comparable to that of charged hadrons indicate that charm quarks are strongly affected by the medium and are good probes for testing its characteristics

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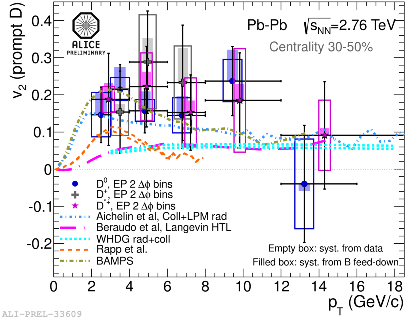
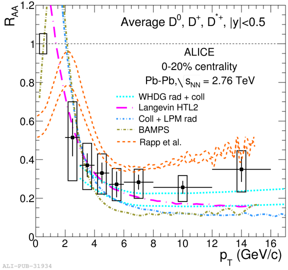
Backup

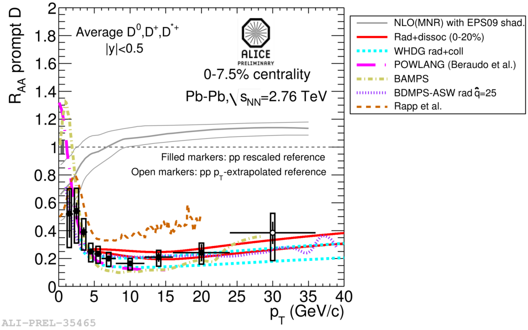




Two models seem in better agreement with data, based on

- Boltzmann Approach Multi-Parton Scattering (**BAMPS**), but underestimate R_{AA} (see slide 13)
- collisional + radiation with **LPM** effect (QCD coherence effect arising from the interference of radiated quanta with medium), but it also underestimates R_{AA}

R_{AA} results - Comparison to models



- shadowing alone (**NLO(MNR)** model) cannot explain such a strong suppression
- the following models show better agreement with data
  - **Vitev**: radiative energy loss supplemented with in-medium D meson dissociation
  - **WHDG**: energy loss + pQCD - includes elastic, inelastic and path length fluctuations contributions
  - **CUJET1.0**: MonteCarlo pQCD tomographic model