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D-meson nuclear modification factor in Pb-Pb collisions with ALICE

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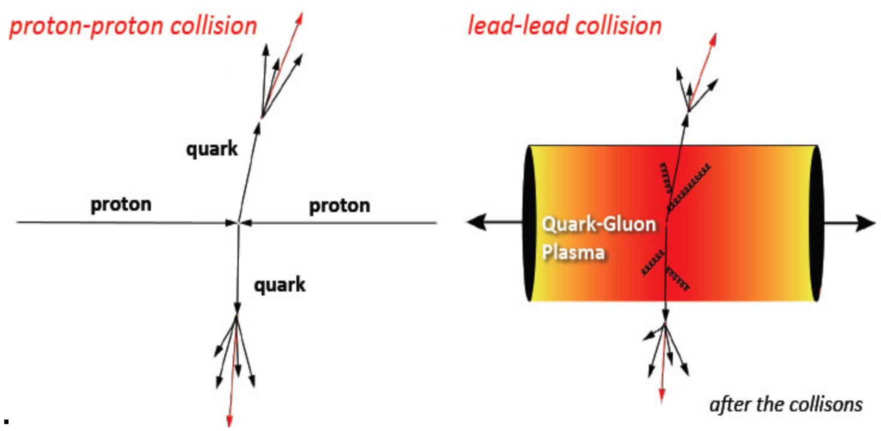
Outline

- Heavy quarks: physics motivations
- The ALICE detector
- Reconstruction of D mesons
- Nuclear modification factor
- Results from Pb-Pb collisions at $\sqrt{s_{NN}}$=2.76 TeV and p-Pb collisions at $\sqrt{s_{NN}}$=5.02 TeV
- Conclusions

Heavy quarks: physics motivations

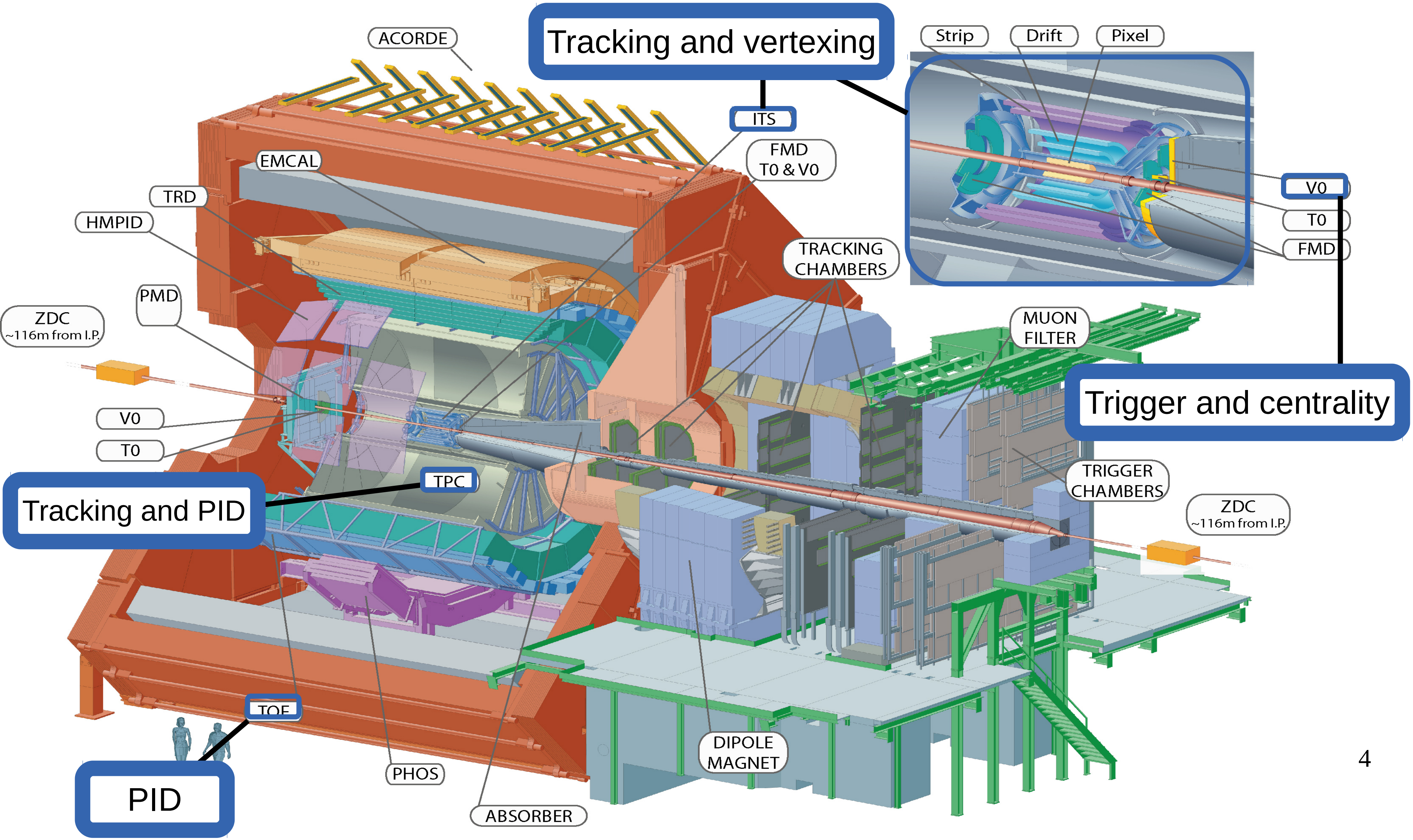
- Heavy quarks are produced in **hard scattering processes in the initial stages of the collision**
- They give us different information in each type of collisions:
  - **pp**: test perturbative QCD
  - **p-Pb**: reference for initial state effects
  - **Pb-Pb**: initial and final state effects due to the interaction with the medium



- In heavy-ion collisions, they pass through all the phases of the medium evolution losing energy via:
  - **gluon radiation**
  - **elastic collisions in the medium**
- They are sensitive to the density of the medium
- **Colour-charge and mass dependence of energy loss** → $\Delta E_g > \Delta E_{u,d} > \Delta E_c > \Delta E_b$

Dokshitzer and Kharzeev, PLB 519 (2001)

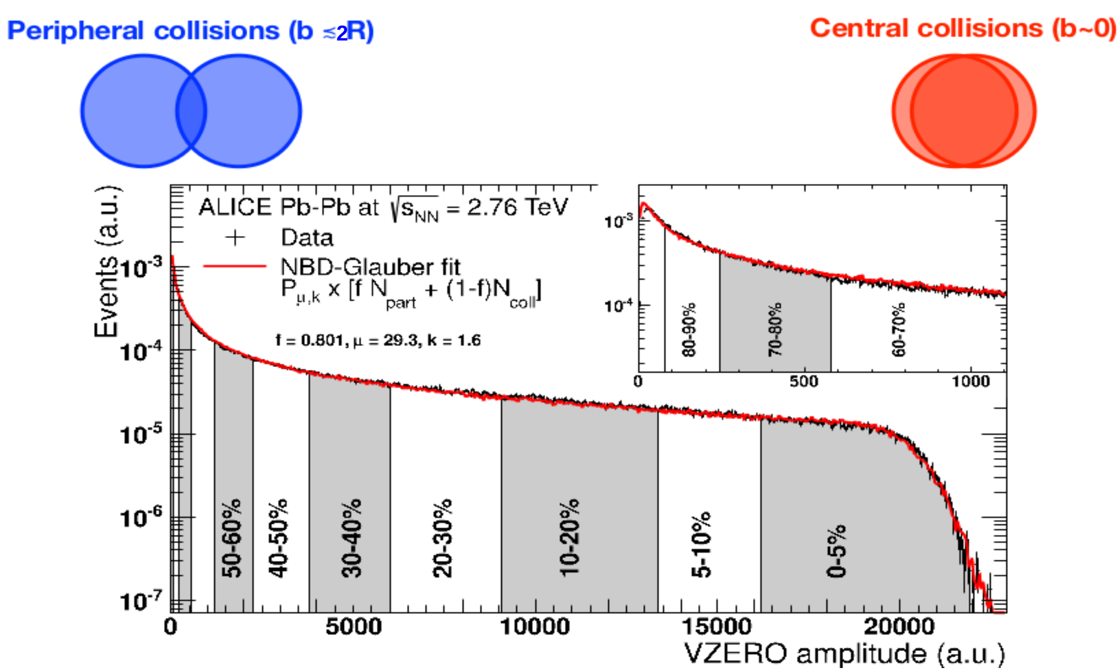
The ALICE detector



Data set

- 2011 Pb-Pb run at $\sqrt{s_{NN}}$=2.76 TeV with integrated luminosity of:
  - 20.9 μb^{-1} in 0-10% centrality (central trigger)
  - 6.2 μb^{-1} in 10-50% centrality (semi-central trigger)

- **Centrality classes** defined on the basis of the Geometrical Glauber model applied to the measured VZERO amplitude



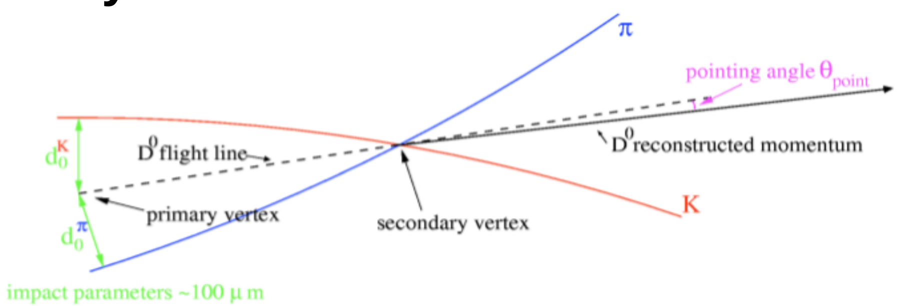
- Prompt D mesons analysed in different centrality classes:

0-7.5% → **study of R_{AA} vs p_T**

0-10%, 10-20%, 20-30%, 30-40%, 40-50%, 50-80% → **study of R_{AA} vs N_{part}**

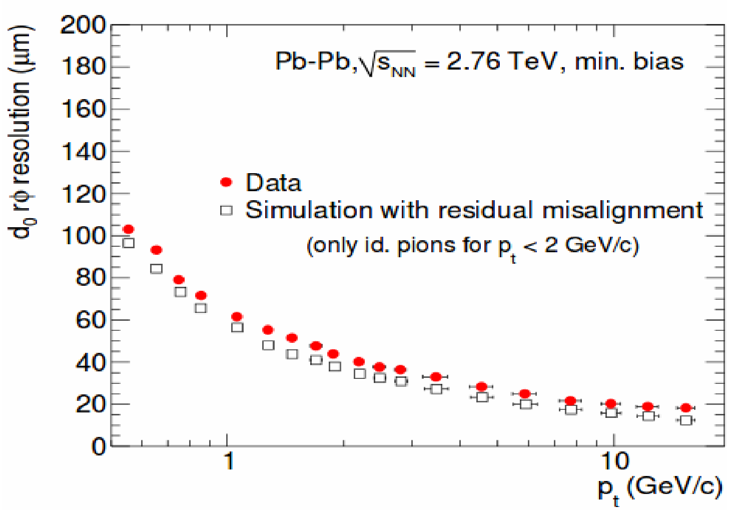
D-meson reconstruction

- D mesons are reconstructed via their **hadronic decay channels**:
  - $\mathbf{D^0 \rightarrow K^- \pi^+}$ BR=3.9%
  - $\mathbf{D^+ \rightarrow K^- \pi^+ \pi^+}$ BR=9.1%
  - $\mathbf{D^{*+} \rightarrow D^0(\rightarrow K^- \pi^+)\pi^+}$ BR=2.6%
  - $\mathbf{D_s^+ \rightarrow \varphi(\rightarrow K^+ K^-)\pi^+}$ BR=2.3%



- Based on the identification of secondary vertices displaced by few hundreds μm

- Main selection criteria:
  - p_T and impact parameter (d_0) of the single tracks
  - PID (π, K, p) for background rejection at low p_T with TPC+TOF
  - Pointing angle (the angle between the candidate momentum and the flight line)
  - Distance primary-secondary vertices

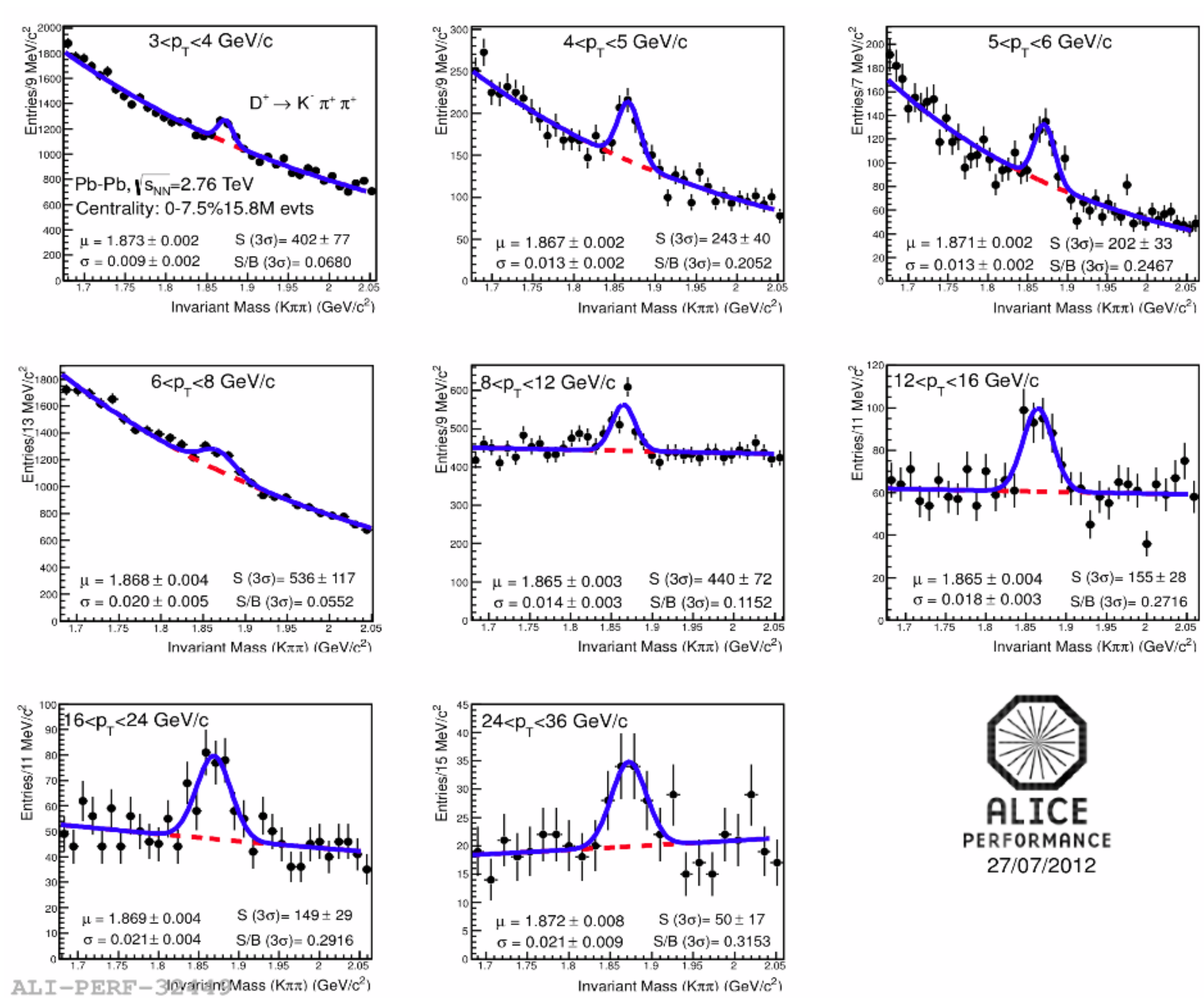


- Signal extracted from fits to invariant mass distributions

- Correction for beauty feed-down to extract results for prompt D mesons based on FONLL arXiv:1205.6344

D mesons in the 0-7.5% centrality class

D^{+}



- Centrality class: 0-7.5%
- Minimum Bias + central trigger based on VZERO
- p_T ranges explored:
  - **D^0 → [1,24] GeV/c**
  - **D^+, D^{*+} → [3,36] GeV/c**
  - **D_s^+ → [4,12] GeV/c**

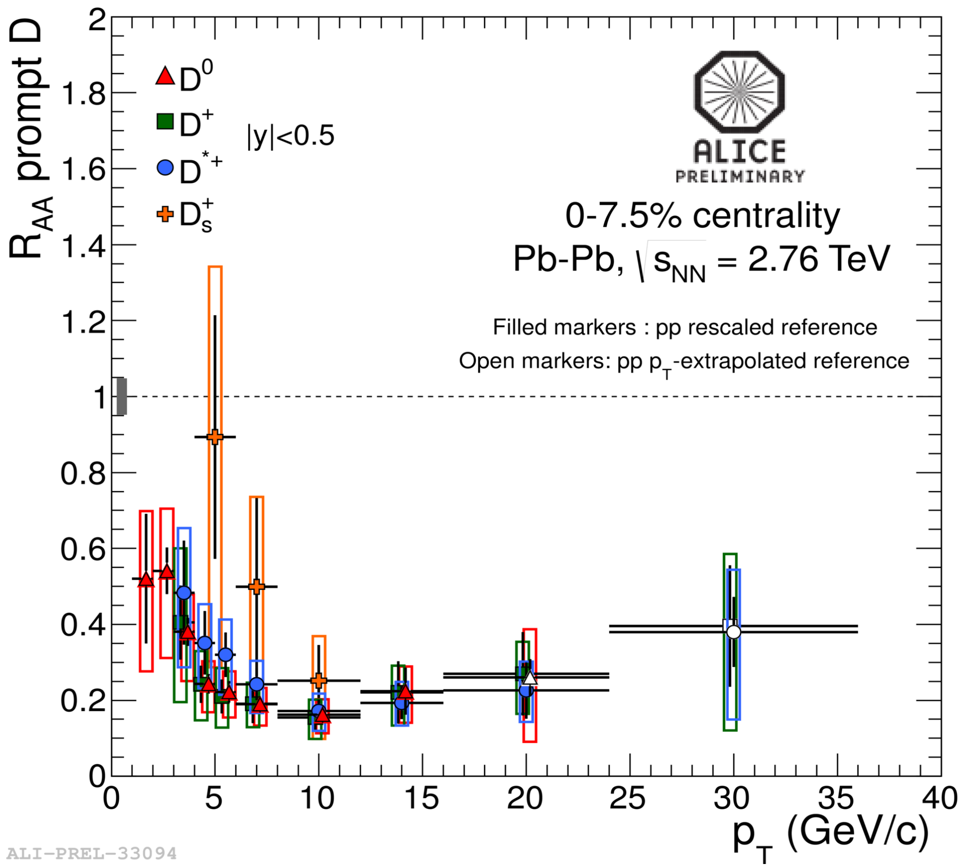
~16x10^6 events analyzed from 2011 Pb-Pb data sample

Nuclear modification factor R_{AA} vs p_T

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

pp reference determined by scaling the cross section measured with ALICE at 7 TeV to 2.76 TeV using FONLL predictions

arXiv:1107.3243, JHEP07(2012)191, arXiv:1205.4007



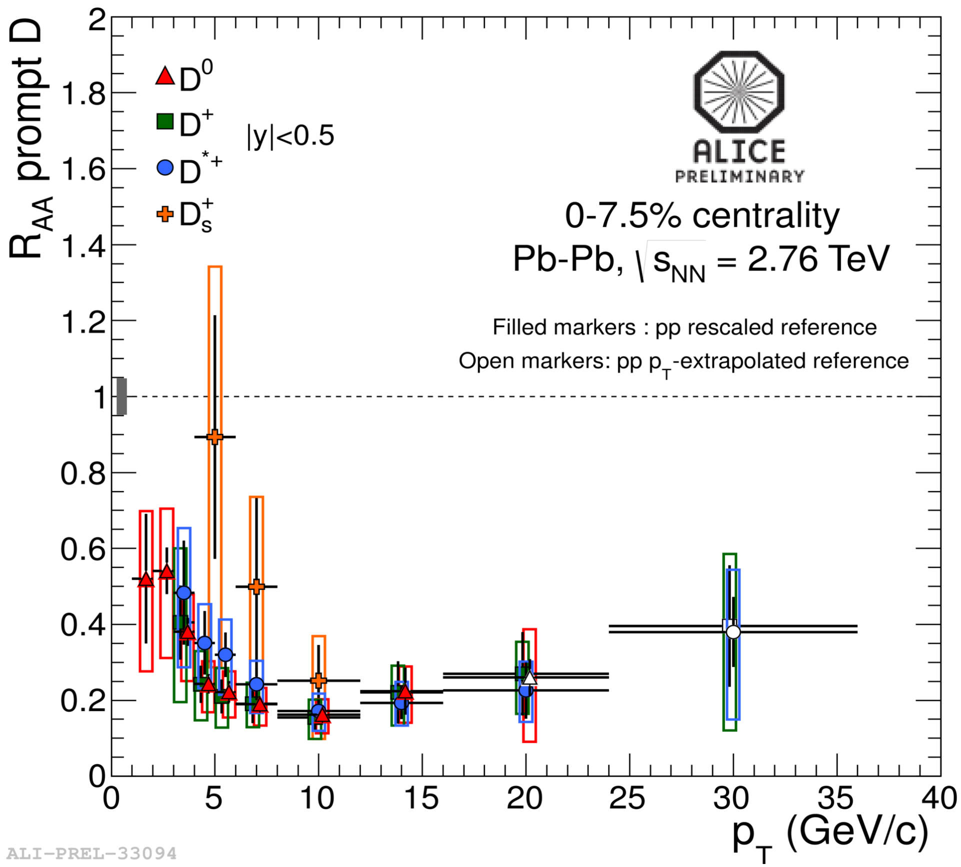
- D^0, D^+, D^{*+} R_{AA} compatible within errors in the whole p_T range
- Large suppression by a factor of 4-5 in $5<p_T<15$ GeV/c for D^0, D^+, D^{*+}
- First measurement of D_s^+ R_{AA} in Pb-Pb collisions with 2011 Run → suppression by a factor of 3-5 in $8<p_T<12$ GeV/c
- more statistics needed to conclude on the enhancement of low-p_T D_s^+, expected in case of charm hadronization via coalescence
(Kuznetsova & Rafelski, EPJ C51(2007)113; He et al., arXiv:1204.4442; Andronic et al., arXiv:0708.1488)

Nuclear modification factor R_{AA} vs p_T

$$R^{D}_{AA}(p_T) = \frac{dN^{D}_{AA}/dp_T}{\langle T_{AA}\rangle \times d\sigma^{D}_{pp}/dp_T}$$

R_{AA} = 1 no nuclear effects

R_{AA} ≠ 1 initial and final nuclear effects



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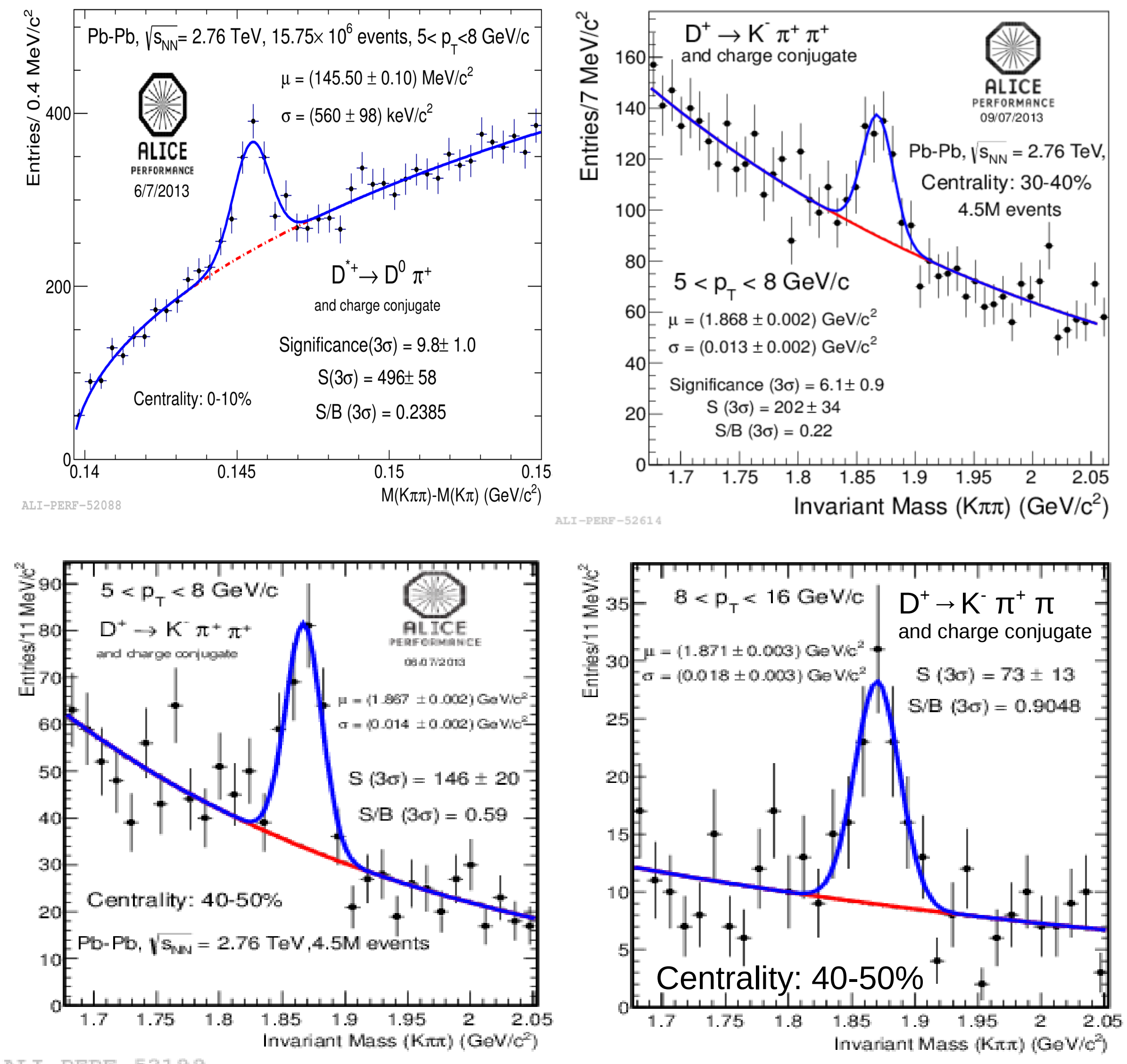
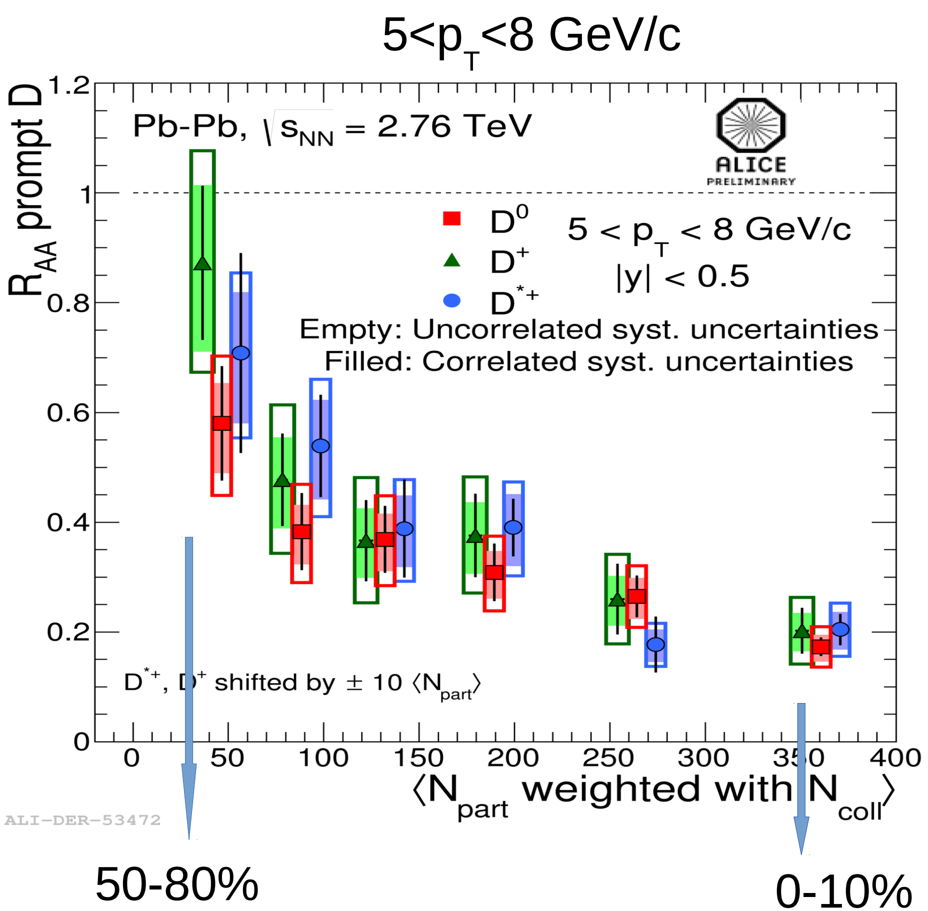
D mesons vs centrality

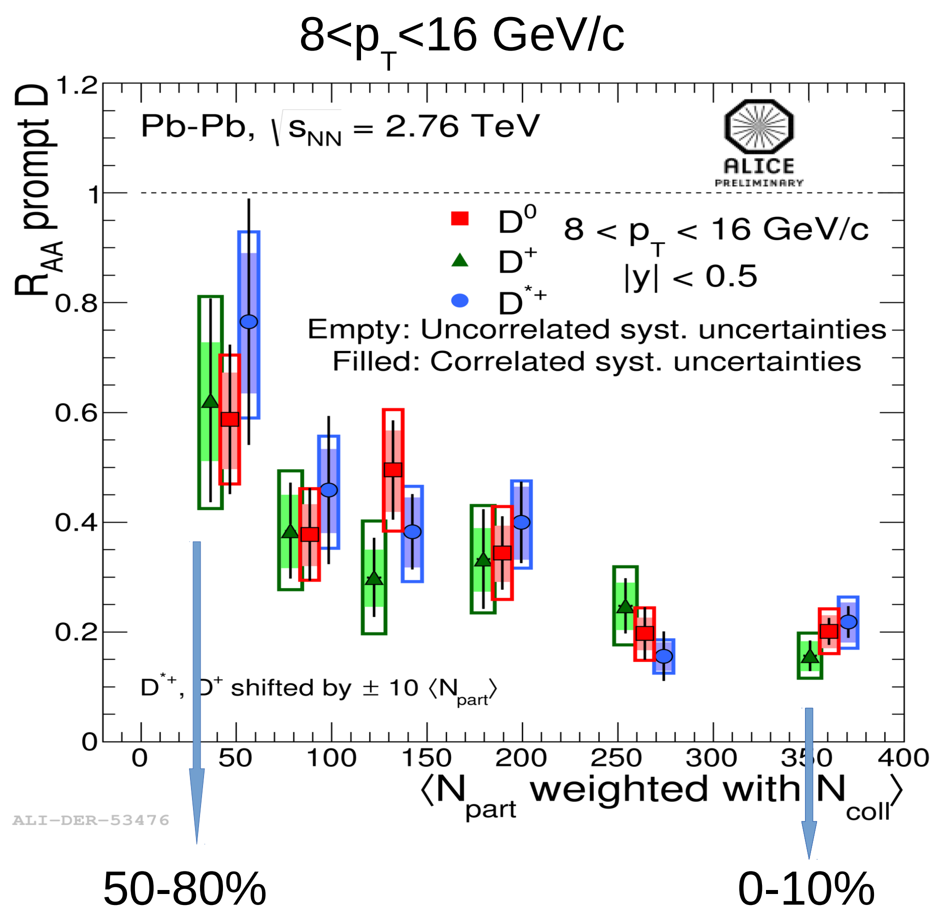


- 6 centrality classes:
- **0-10%, 10-20%, 20-30%, 30-40%, 40-50%, 50-80%**

- 4 p_T intervals studied:
  - **2-3, 3-5 GeV/c for D^0 only** (not shown)
  - **5-8, 8-16 GeV/c for D^0, D^+, D^{*+}**

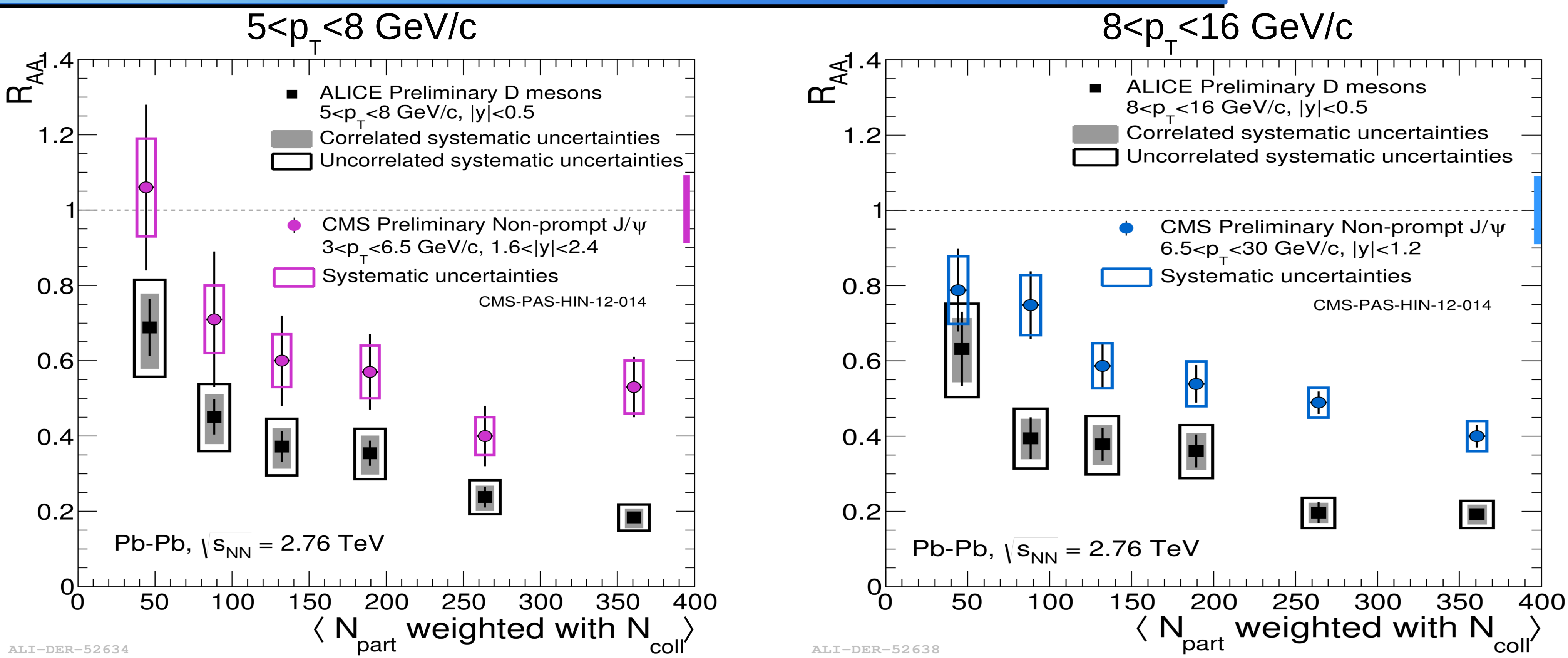
Nuclear modification factor R_{AA} vs centrality





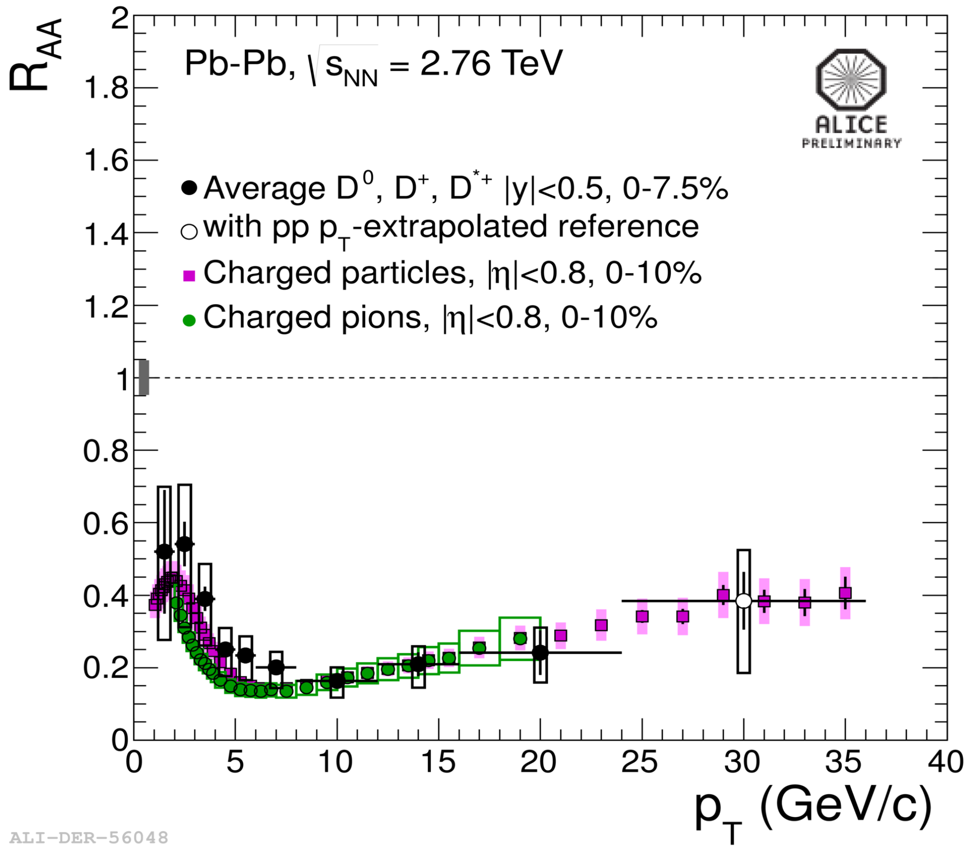
Suppression of D^0, D^+, D^{*+} mesons increases with centrality in $5<p_T<8$ and $8<p_T<16$ GeV/c

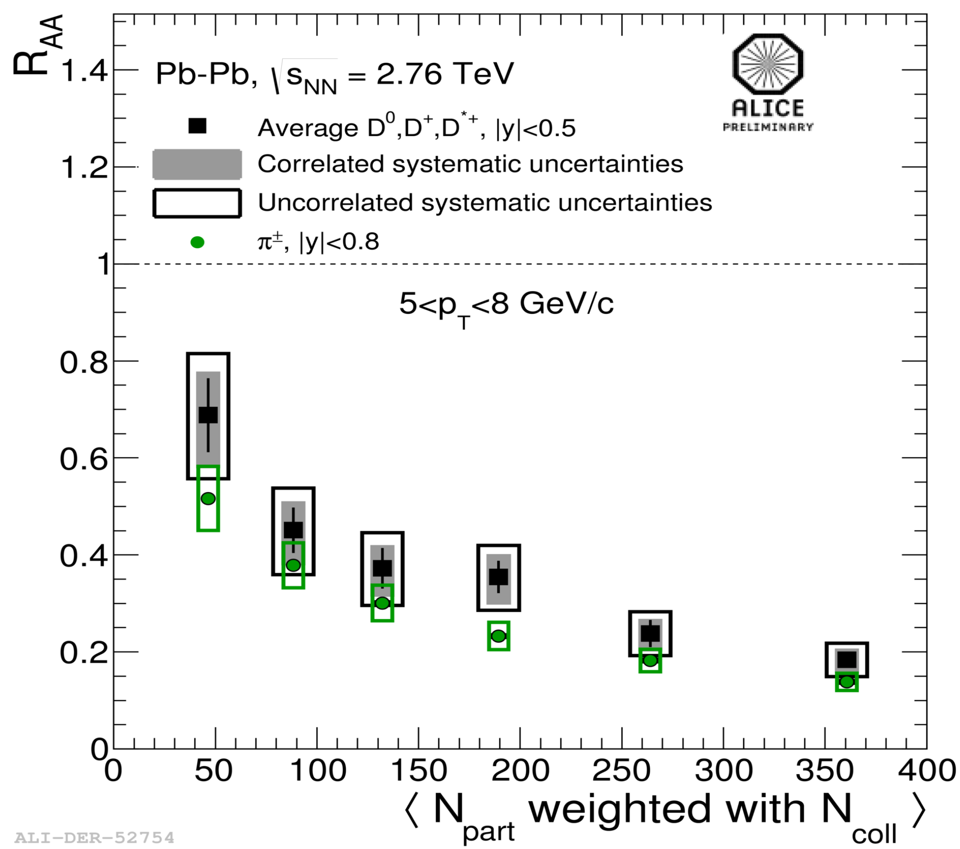
Comparison to non-prompt J/Ψ from B mesons



- p_T ranges chosen to have similar kinematics for D and B mesons measured via non-prompt J/ψ by CMS (arxiv:1201.5069)
- Difference between charm and beauty suppression in central collisions shown both in $5<p_T<8$ and $8<p_T<16$ GeV/c
- Indication of $\mathbf{R_{AA}^{B} > R_{AA}^{D}}$ as expected from the mass hierarchy in the energy loss models

Comparison to light hadrons



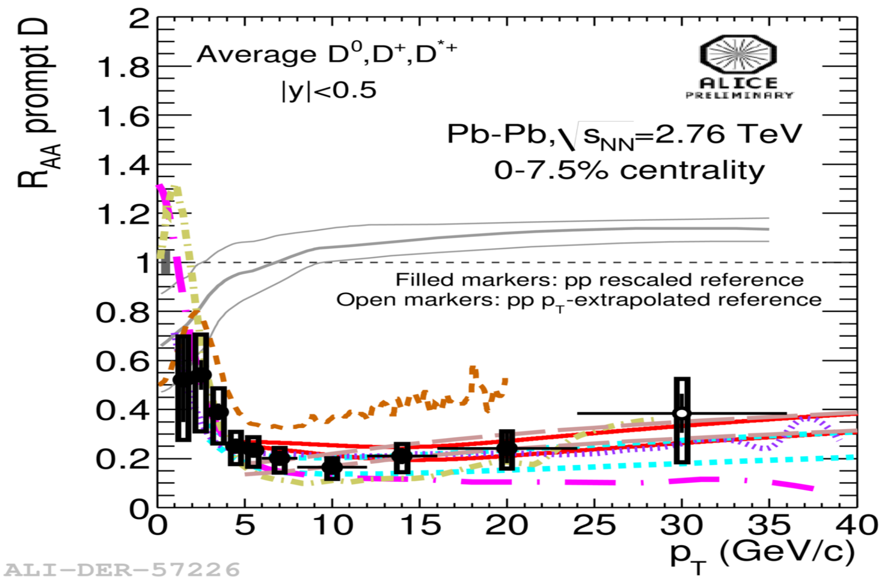


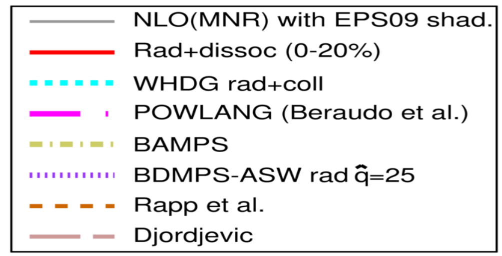
- Similar suppression for D mesons and pions

  $\mathbf{R_{AA}^{D} \approx R_{AA}^{\pi}}$ for p_T >3 GeV/c

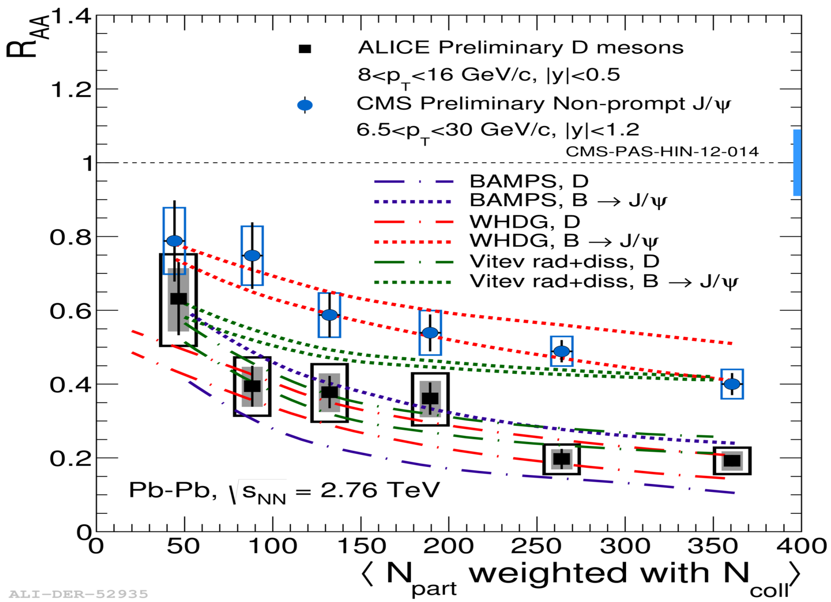
- $R_{AA}^{D} > R_{AA}^{\pi}$ expected from mass hierarchy and colour-charge dependence of energy loss but... **large systematic uncertainties to make a conclusion**

Comparison to energy-loss models





Several theoretical models based on in-medium parton energy loss reproduce R_{AA} of prompt D mesons reasonably well

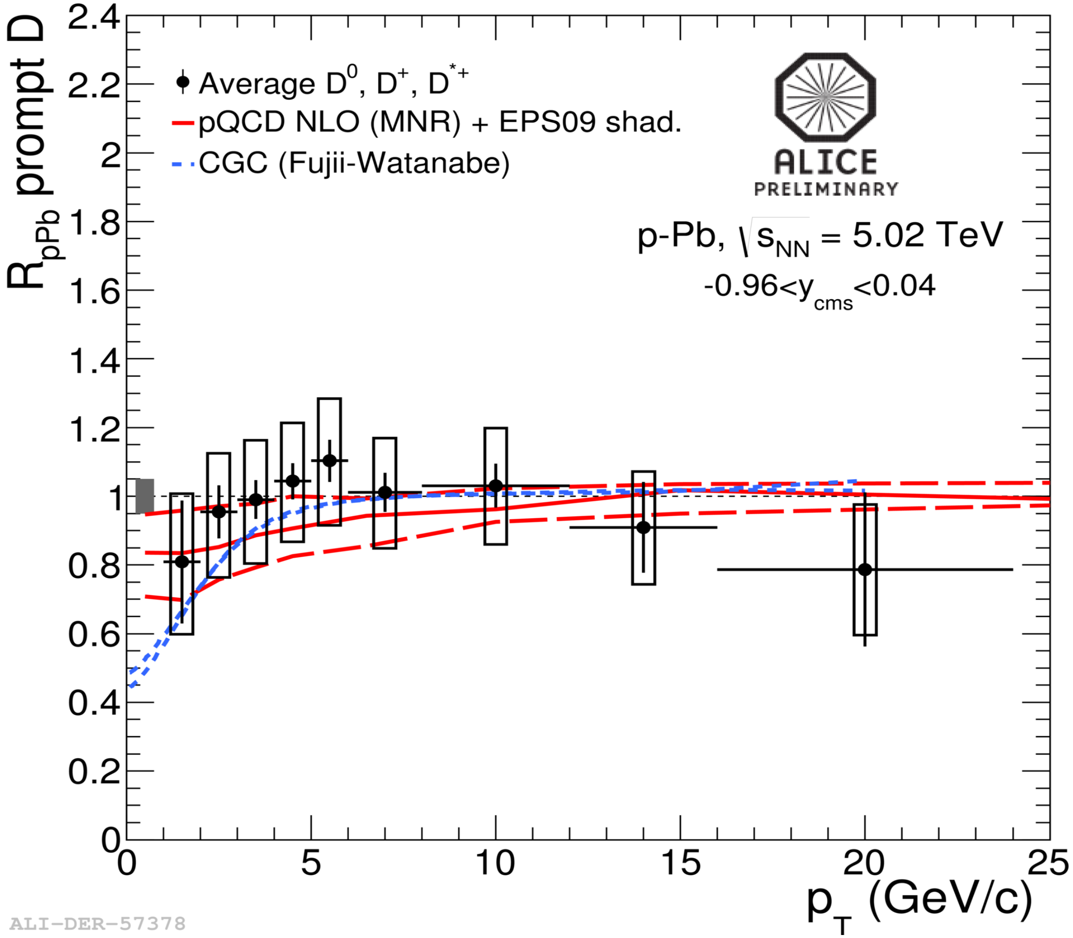


WHDG models in agreement with D meson R_{AA} and with non-prompt J/ψ R_{AA} vs N_{part}

BAMPS: Fochler et al., J. Phys. G38 (2011) 124152
BDMPS: Armesto et al. PRD71 (2005) 054027
POWLANG: Alberico et al., Eur.Phys.J C71 (2011) 1666
UrQMD: T. Lang et al, arXiv:1211.6912 [hep-ph];T. Lang et al., arXiv:1212.0696 [hep-ph].

TAMU: Rapp, He et al., Phys. Rev. C 86 (2012) 014903
WHDG: Horowitz et al., JPhys G38 (2011) 124114
Aichelin et al.:Phys. Rev. C79 (2009) 044906, J. Phys. G37(2010) 094019
Djordjevic et al.: arXiv:1307.4098
Vitev et al.: Phys. Rev. C80 (2009) 054902, Phys. Lett. B 713 (2012) 224

D-meson R_{pPb}



FONLL+EPS09: JHEP 0904:065,2009

- p-Pb collisions → assess cold nuclear matter effects
  - Initial state effects (present also in Pb-Pb): nuclear modification of PDFs (shadowing/saturation at low x), k_T-broadening
- The measured D meson R_{pPb} is close to unity for p_T>3 GeV/c
  - Small nuclear modification in p-Pb
  - Compatible with expectations from pQCD+EPS09 shadowing and from saturation with the Color Glass Condensate approach
- Confirms that the suppression observed in central Pb-Pb collisions at high p_T is an effect of the hot and dense medium

Conclusions

D-meson R_{AA} vs p_T in central (0-7.5%) Pb-Pb collisions:

- strong suppression by a factor of 4-5 in $5<p_T<16$ GeV/c
- First measurement of D_s^+ R_{AA}: suppression by a factor of 3-5 in $8<p_T<12$ GeV/c

D-meson R_{AA} vs centrality Pb-Pb collisions:

- suppression increases with N_{part} for 5-8, 8-16 GeV/c p_T ranges
- observed difference in suppression of D mesons and non-prompt J/ψ from B mesons decays measured by CMS at intermediate/high p_T in central collisions

For the D-meson R_{pPb} measurement in p-Pb collisions data are consistent with small initial-state effects, in particular with pQCD + shadowing

⇓

A suppression in the D meson production yield has been observed in central Pb-Pb collisions due to the presence of the hot and dense medium

More statistics is needed to reduce the uncertainties and provide further constraints to energy-loss models.

Backup slides

B feed-down subtraction

$$f_{prompt} = 1 - (N^{D^+}_{feed-down,raw}/N^{D^+}_{raw}) =$$

$$= 1 - \langle T_{AA} \rangle \cdot \left(\frac{d^2\sigma}{dy dp_T} \right)^{FONLL}_{feed-down} \cdot R^{feed-down}_{AA} \cdot \frac{(Acc \times \varepsilon)_{feed-down} \cdot \Delta y \Delta p_T \cdot BR \cdot N_{evt}}{N^{D+}_{raw}/2}$$

Assumptions on B suppression:

- analysis on R_{AA} vs p_T in 0-7.5% centrality class

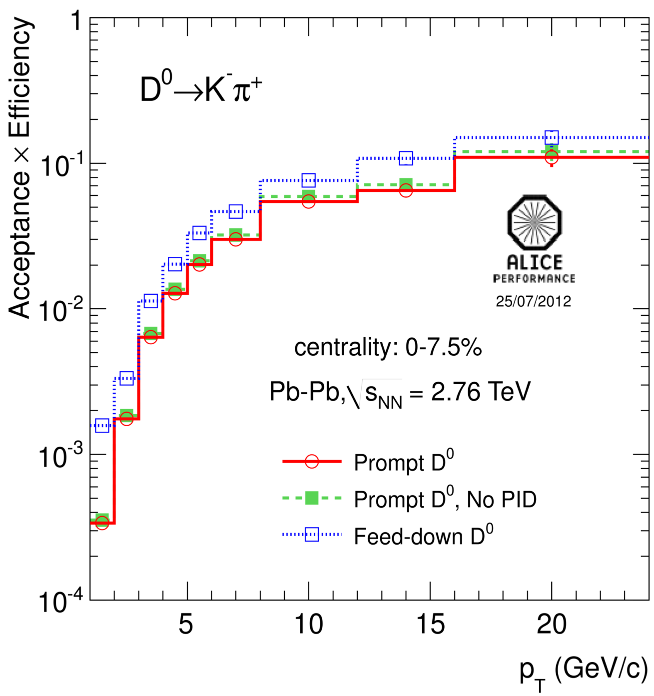
  $R_{AA}^{feed\text{-}down} = R_{AA}^{Prompt\ D}$ and $R_{AA}^{feed\text{-}down}$ ranging from 0.3 to 3 x $R_{AA}^{Prompt\ D}$

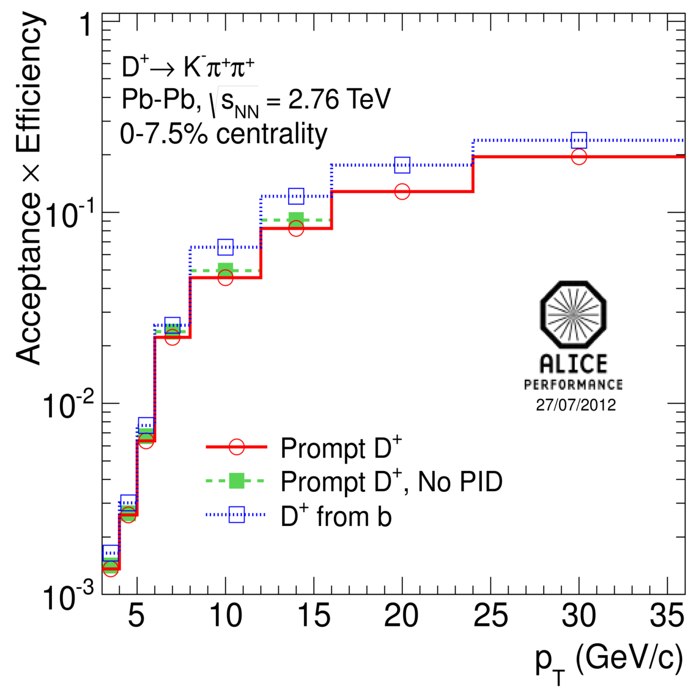
- analysis on R_{AA} vs centrality:

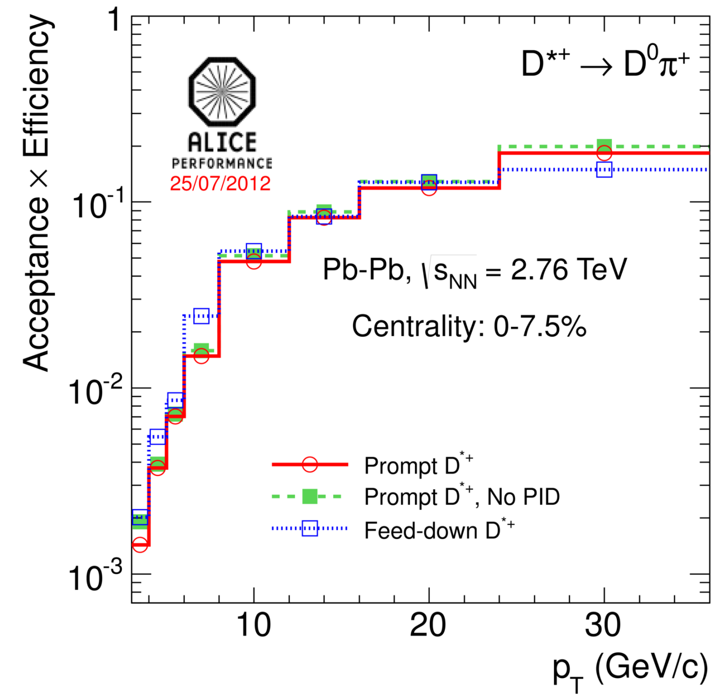
  $R_{AA}^{feed\text{-}down} = 2 \times R_{AA}^{Prompt\ D}$ and $R_{AA}^{feed\text{-}down}$ ranging from 1 to 3 x $R_{AA}^{Prompt\ D}$

Systematic uncertainties from B energy loss ~6-10%

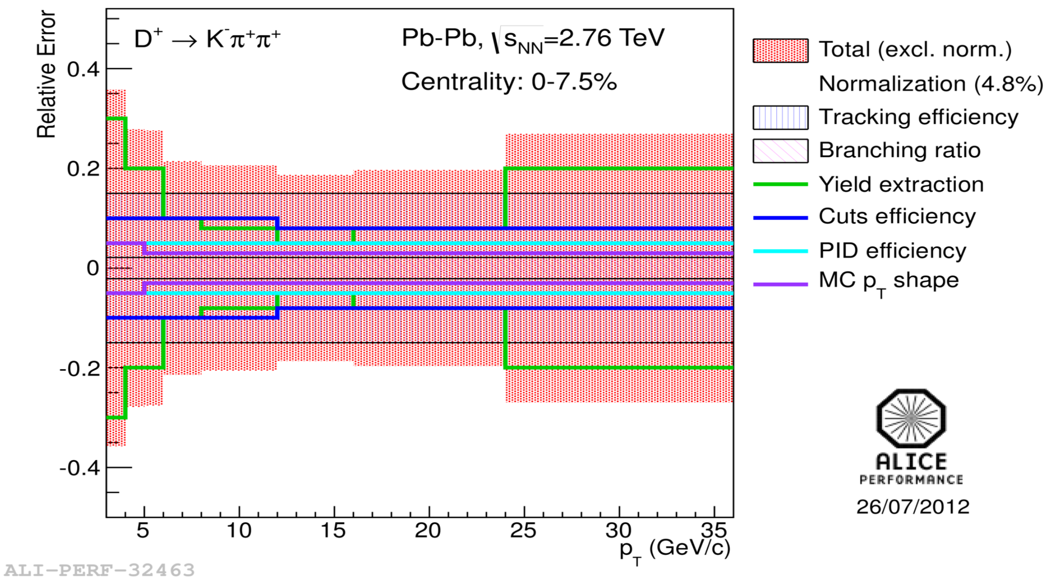
Acceptance x efficiences

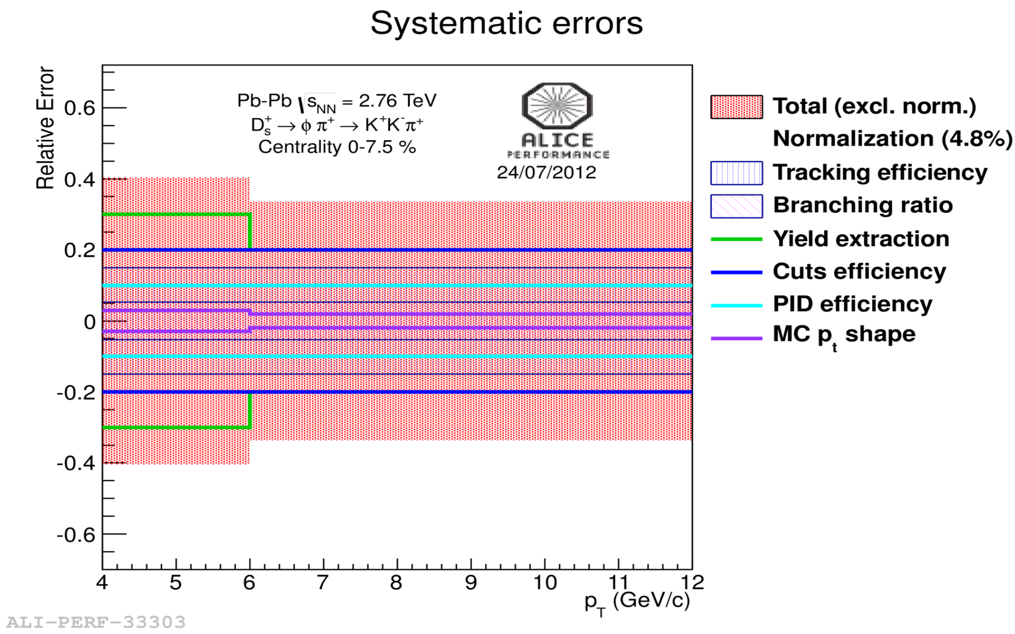




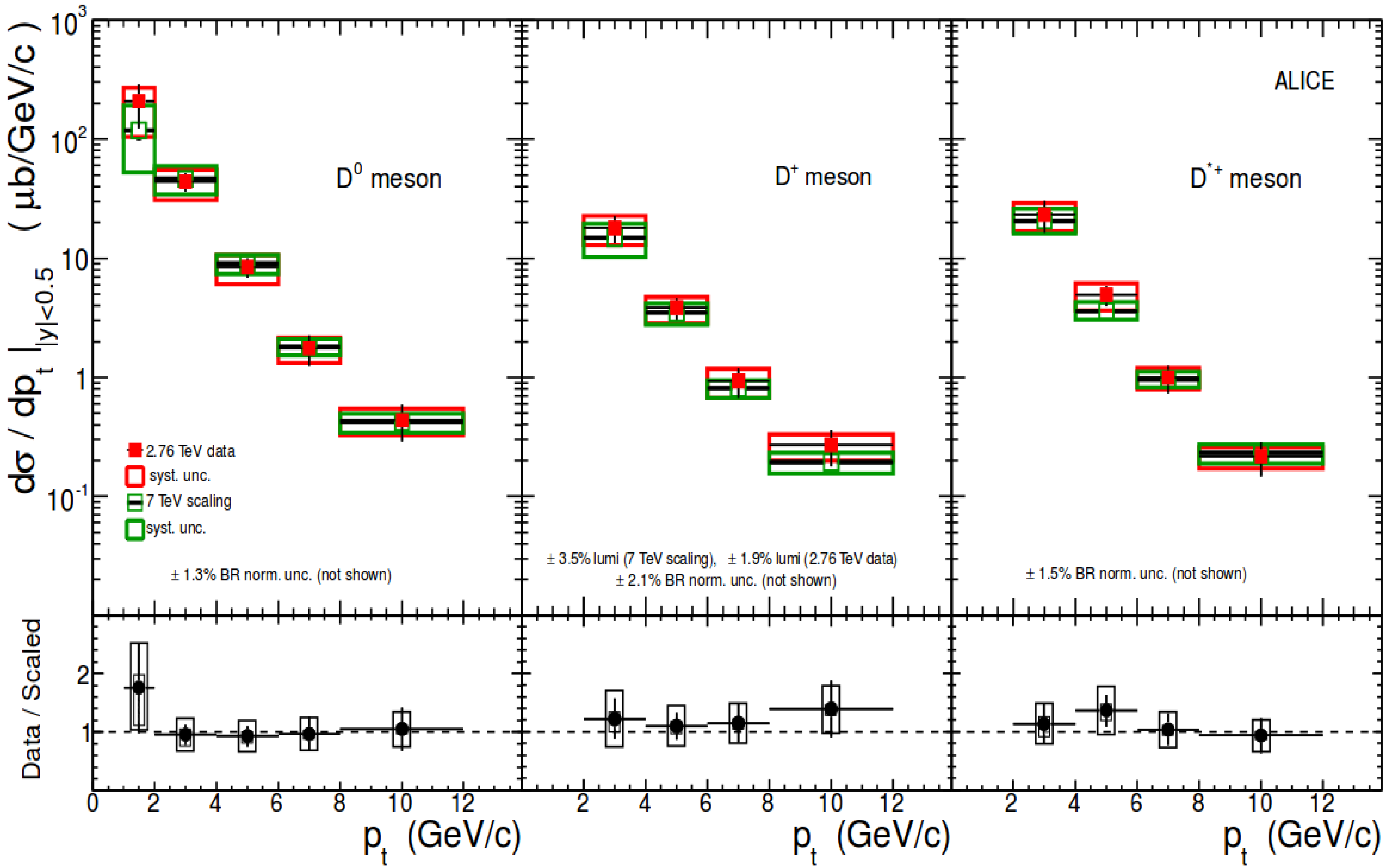


Systematic uncertainties





pp reference



JHEP07(2012)191, arXiv:1205.4007

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