

ALICE results on heavy-flavour production at the LHC

Raphaelle Bailhache-Roemer
on behalf of the ALICE collaboration



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R.Bailhache IKF, Goethe Universität Frankfurt, 20.11.2012

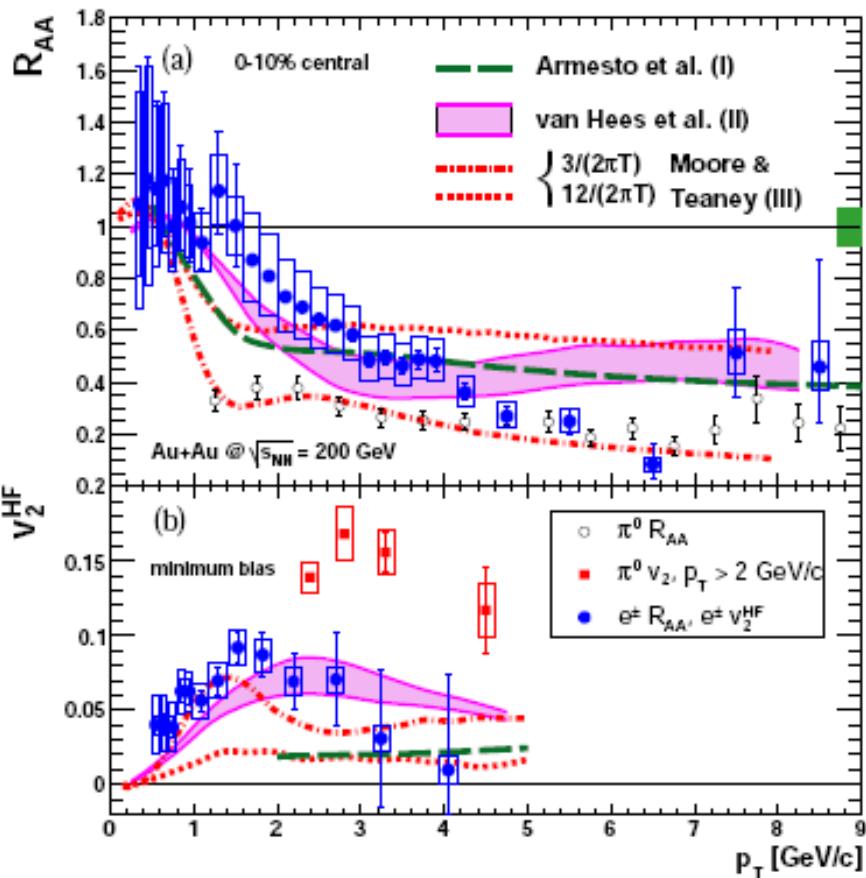
Outline

- Motivation
- Heavy-flavour measurements with ALICE
- Results in pp collisions at 7 and 2.76 TeV
 - Differential and total production cross sections
- Results in Pb-Pb collisions at 2.76 TeV
 - Suppression compared to pp: nuclear modification factors
 - Azimuthal anisotropy
- Summary and Outlook

Motivation

- **Heavy quarks in pp collisions:** produced in hard partonic collisions
 - Test **perturbative QCD calculations**
 - Provide a **reference for Pb-Pb studies**
- **Heavy quarks in p-Pb collisions:** sensitive to nuclear modification of PDFs
 - Test **shadowing models**
 - low- p_T can be modified by gluon shadowing/ saturation: test **gluon saturation models**
- **Heavy quarks in Pb-Pb collisions:** interact strongly with the medium
 - Test models of **in-medium parton energy-loss ΔE**
 - Dependence on the volume and density of the medium
 - Color charge dependence: $\Delta E_g > \Delta E_q$
 - Mass dependence (dead-cone effect): $\Delta E_{u,d,s} > \Delta E_c > \Delta E_b$
(Dokshitzer and Kharzeev, PLB 519 (2001) 199)
 - Probe the level of heavy quark **thermalization** at low momentum
 - Provide a **reference for quarkonia studies**

Introduction Results from RHIC



Adare A et al., PRC 84 (2011) 044905

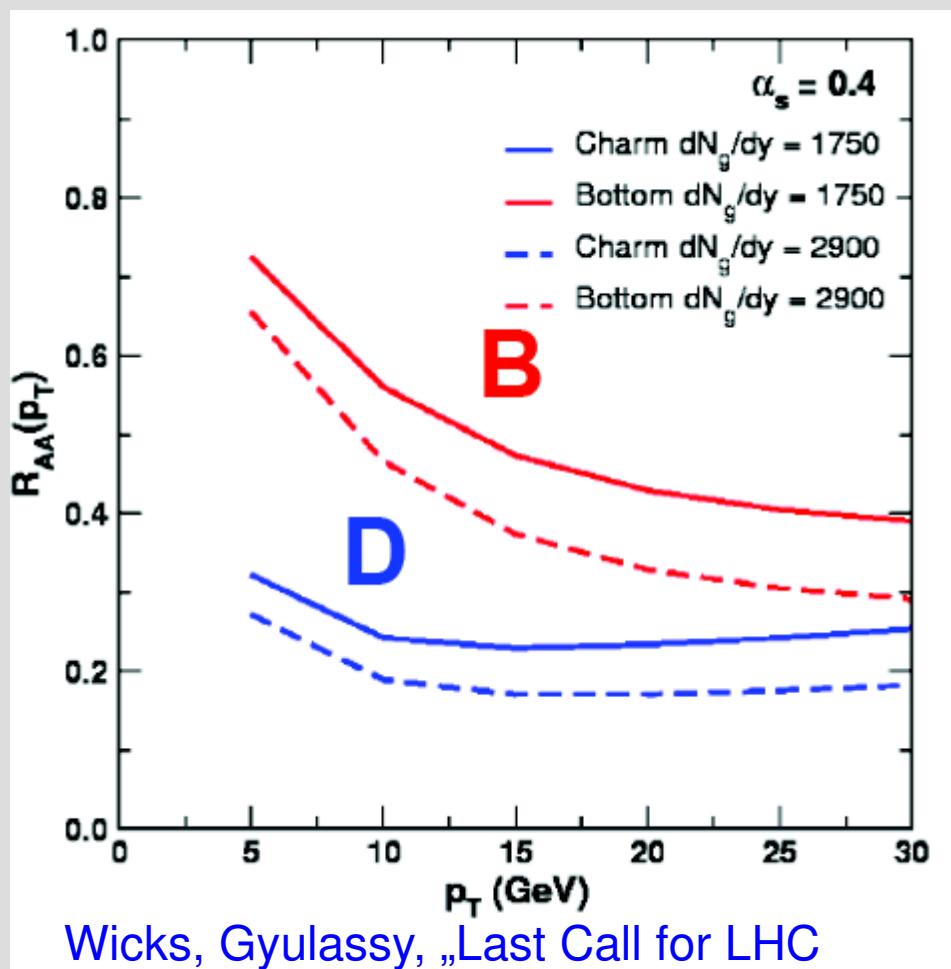
$$R_{AA} = \frac{1}{\langle T_{AA} \rangle} \frac{dN_{AA}/dp_T}{d\sigma_{pp}/dp_T}$$

In Au-Au collisions at 200 GeV/c electrons from heavy-flavour decays show:

- A suppression of HF e similar to light mesons at high p_T
 → Large energy loss of heavy quarks
- A non-zero elliptic flow v_2 at low p_T
 → Certain level of thermalization of heavy quarks

Challenging for models to reproduce simultaneously both results

Introduction Predictions for LHC



$$R_{AA} = \frac{1}{\langle T_{AA} \rangle} \frac{dN_{AA}/dp_T}{d\sigma_{pp}/dp_T}$$

- Energy loss based predictions: factor 3-5 suppression for D mesons
- Significantly smaller suppression for B
- Suppression of D mesons expected to be smaller than for light hadrons at low p_T

Wicks, Gyulassy, „Last Call for LHC Predictions“ workshop, 2007

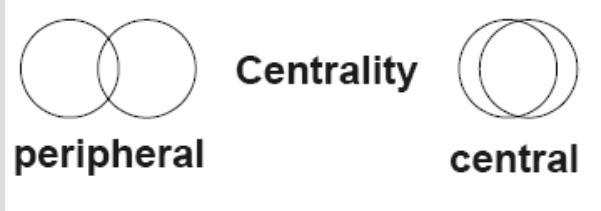
ALICE

Data Sample

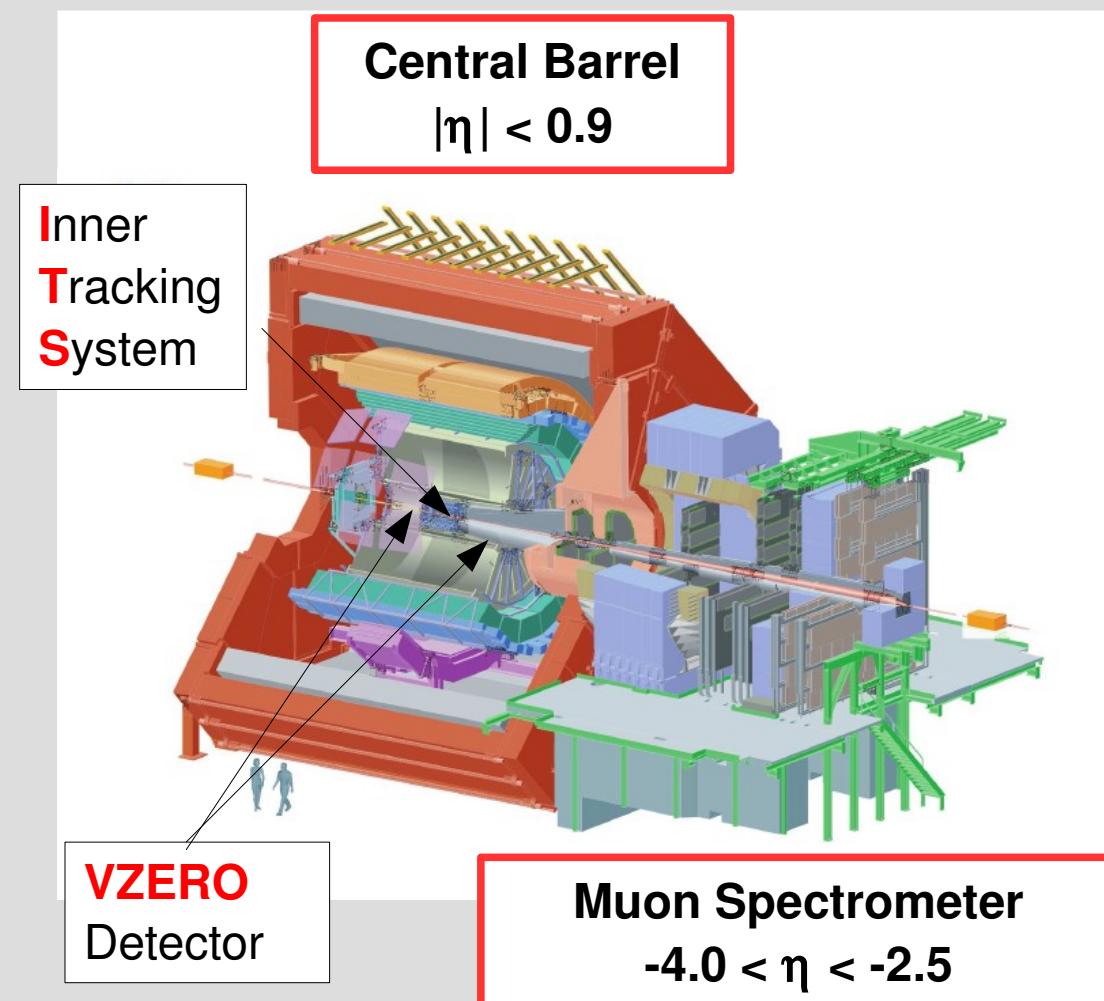
- Minimum-bias trigger: with VZERO and the 2 pixel layers of the ITS
- EMCal trigger
- Muon trigger

system, $\sqrt{s_{NN}}$ (TeV)	pp 7	pp 2.76	Pb-Pb 2.76
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Centrality in Pb-Pb



Use for this analysis the summed amplitudes in VZERO scintillator tiles
 → increase with centrality



Heavy-flavour measurements with ALICE



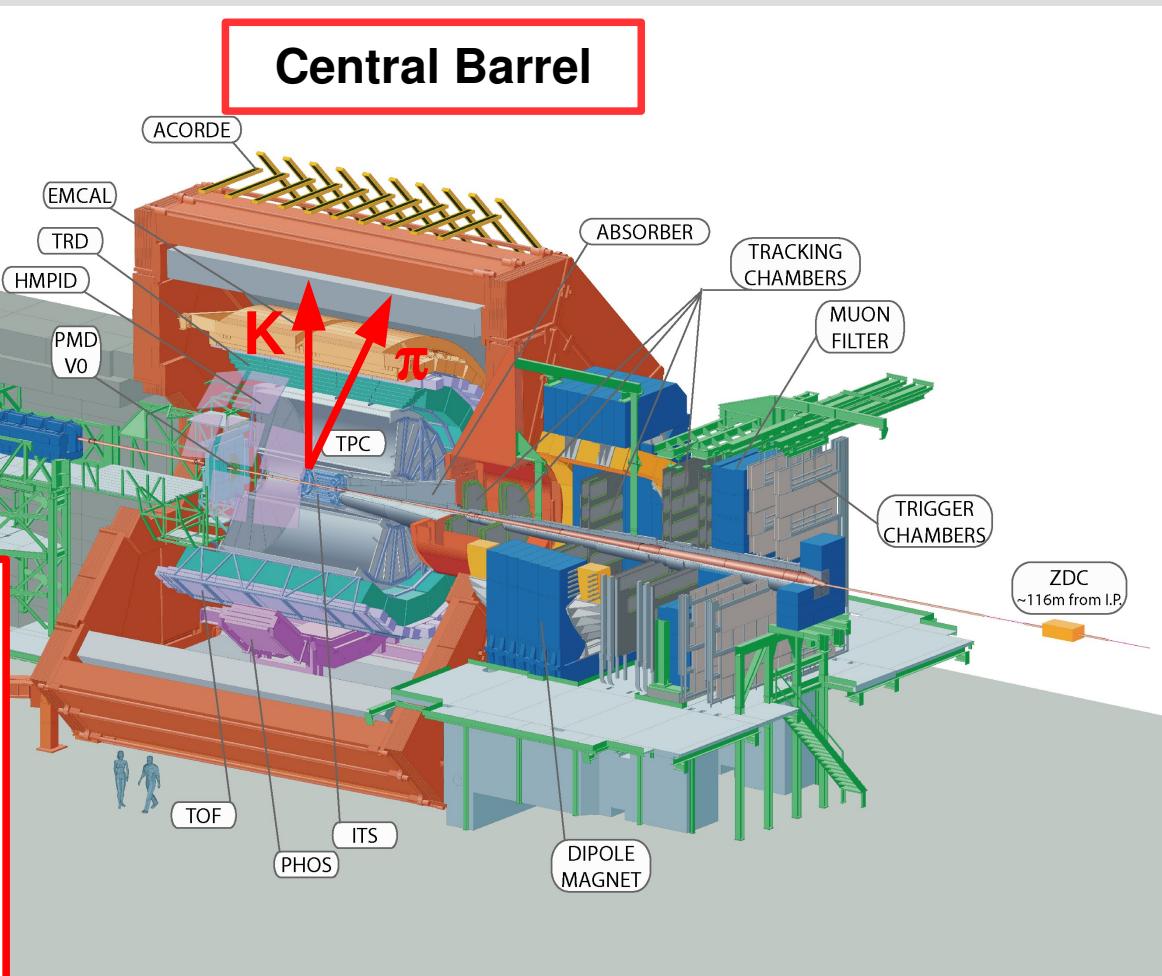
D mesons, $|y| < 0.5$

ITS: vertexing

TPC: tracking + PID

TOF: PID

$D^0 \rightarrow K\pi$	$c\tau \sim 123 \mu m$
$D^+ \rightarrow K\pi\pi$	$c\tau \sim 312 \mu m$
$D^{*+} \rightarrow D^0\pi$	
$D_s^+ \rightarrow KK\pi$	$c\tau \sim 150 \mu m$
$b/c \rightarrow e + X$	
$b \rightarrow e + X$	$c\tau \sim 500 \mu m$
$b/c \rightarrow \mu + X$	



Heavy-flavour measurements with ALICE

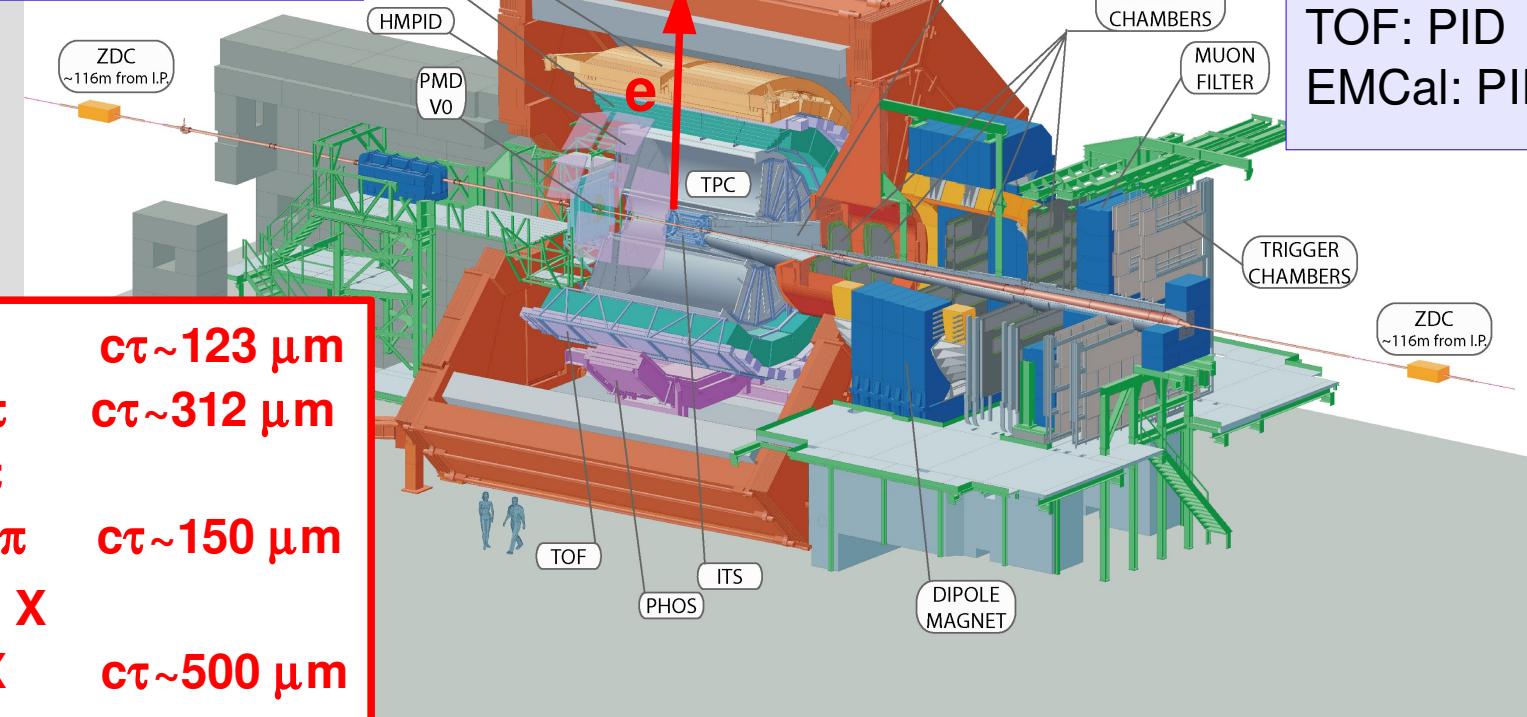


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$b/c \rightarrow e + X$

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$b/c \rightarrow \mu + X$

$b/c \rightarrow e + X, |y| < 0.8$

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TPC: PID + tracking

TRD: PID

TOF: PID

EMCal: PID + trigger

Heavy-flavour measurements with ALICE

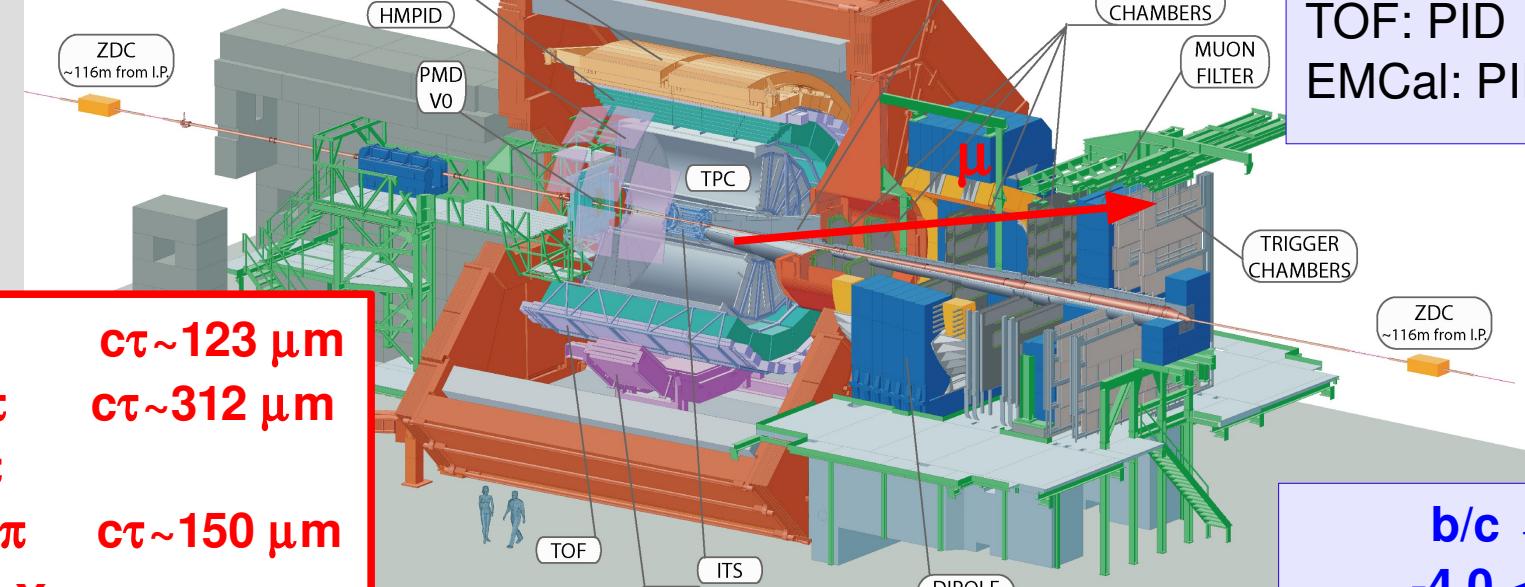


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Muon Spectrometer

$b/c \rightarrow \mu + X$

$-4.0 < y < -2.5$

Tracking chambers

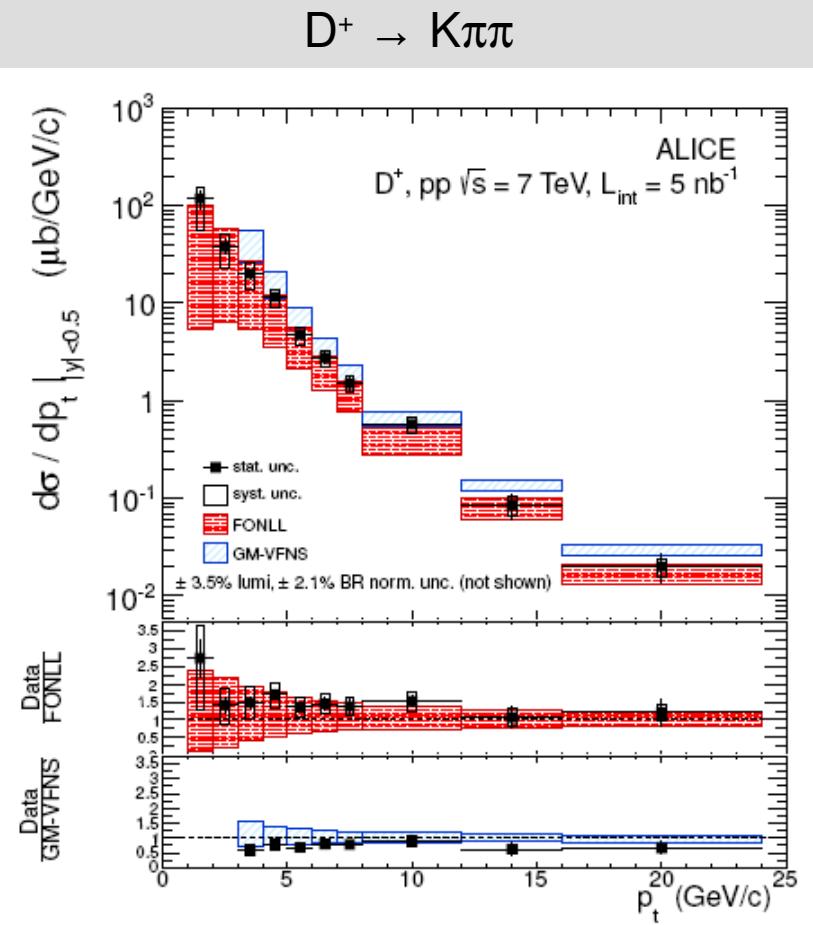
Trigger chambers

Results in pp collisions

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R.Bailhache IKF, Goethe Universität Frankfurt, 20.11.2012

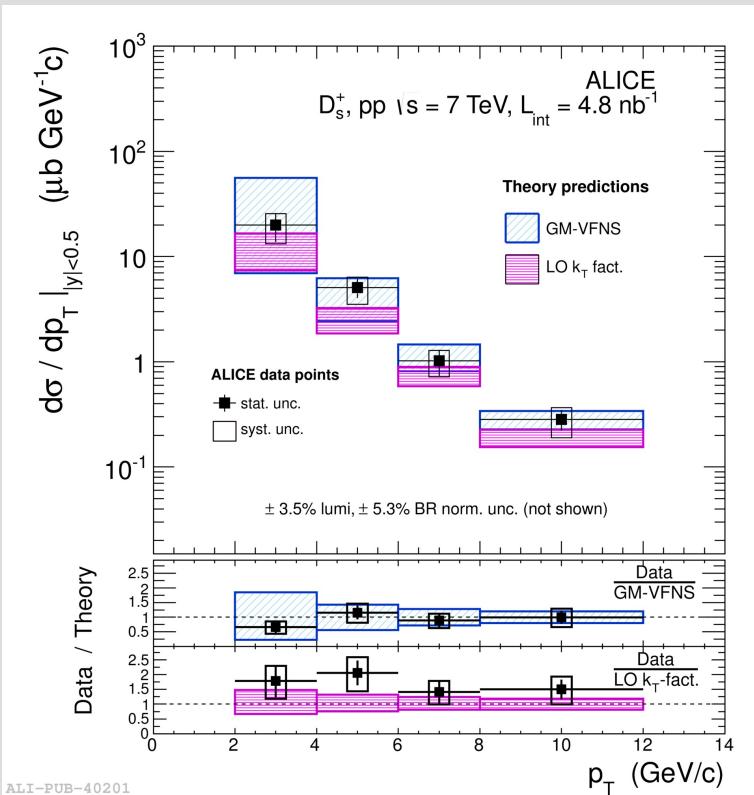
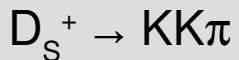
D meson cross sections in pp at 7 TeV, $|y|<0.5$



B.Abelev et al., JHEP 01 (2012) 128

- Prompt D mesons measured at mid-rapidity, $|y|<0.5$
 - D^0 : $1 < p_T < 16 \text{ GeV}/c$
 - D^+ and D^{*+} : $1 < p_T < 24 \text{ GeV}/c$
 - D_s^{*+} : $2 < p_T < 12 \text{ GeV}/c$
- pQCD calculations in agreement with the data
 - Fixed-Order-Next-to-Leading-Log (FONLL, Cacciari et al., arXiv:1205.6344)
 - GM-VFNS (Kniehl et al., arXiv:1202.0439)
 - LO with k_T -factor (R.Maciula et al., arXiv:1208.6126)

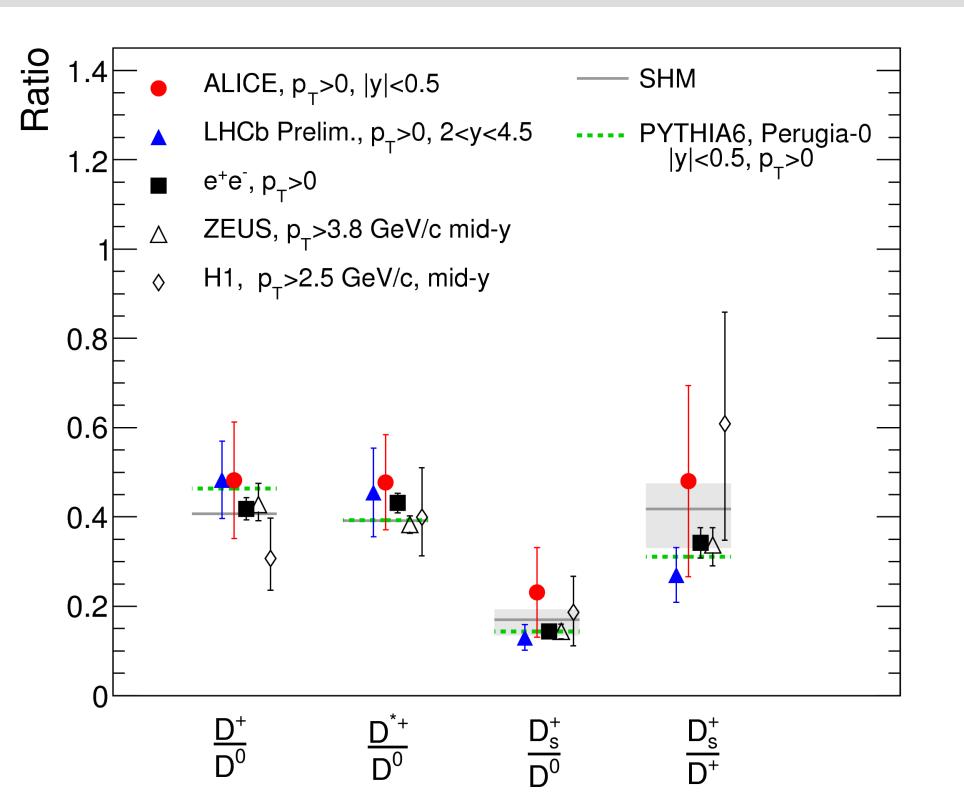
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B. Abelev et al., ArXiv:1208.1948 accepted by PLB

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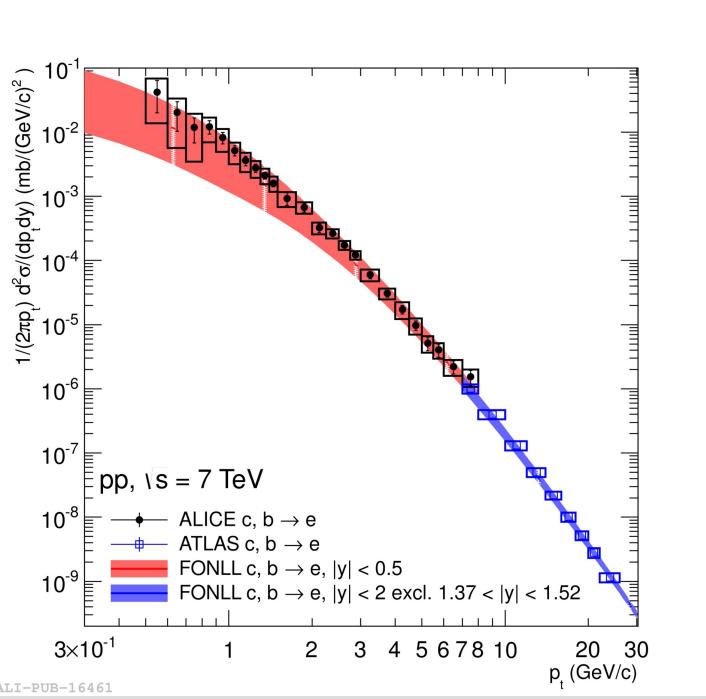


B. Abelev et al., ArXiv:1208.1948 accepted by PLB

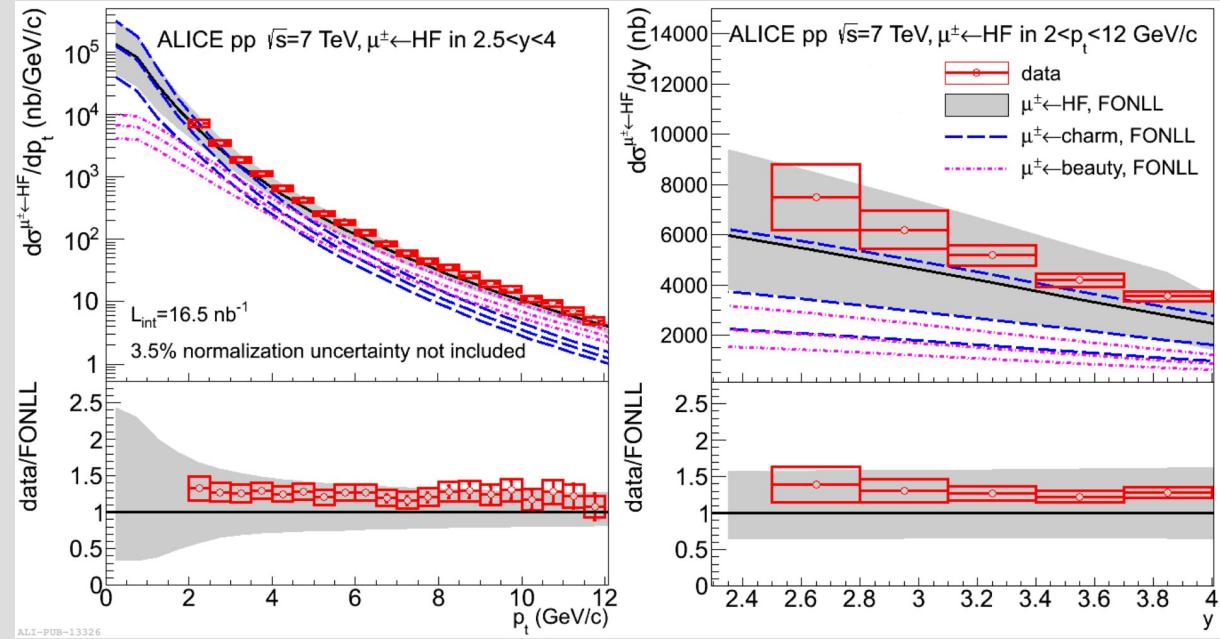
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b/c → l + X cross sections in pp at 7 TeV

b/c → e + X, $|y| < 0.5$



b/c → μ + X, $-4.0 < y < -2.5$



B.Abelev et al., PLB 708 (2012) 265

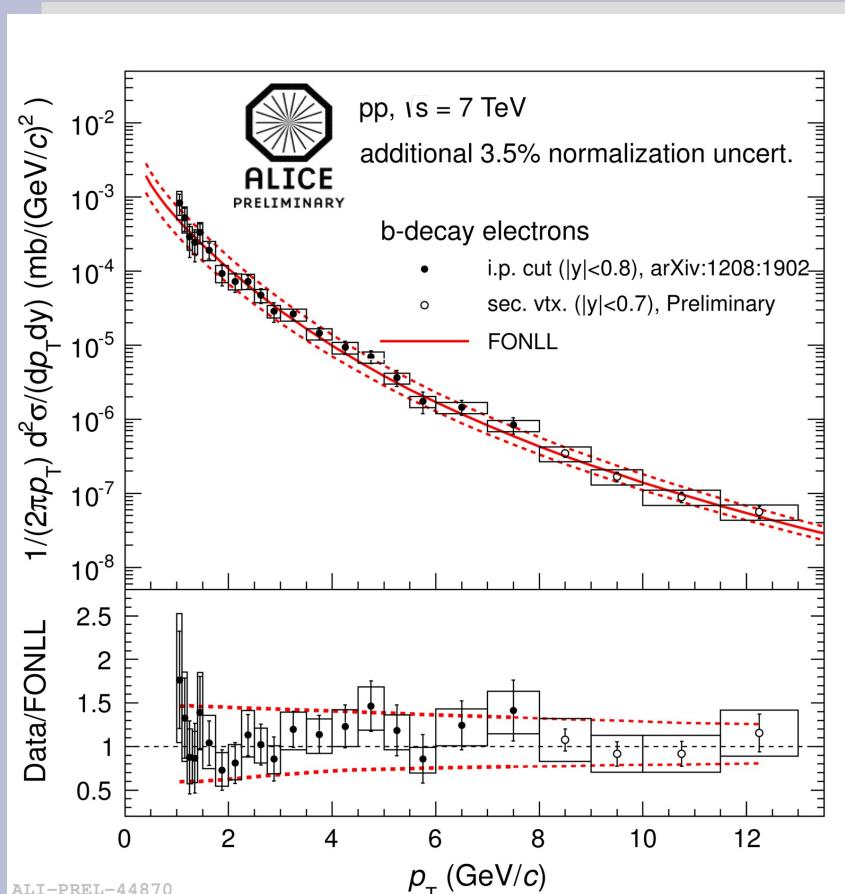
B.Abelev et al., ArXiv:1205.5423, accepted by PRD

ATLAS with complementary acceptances:

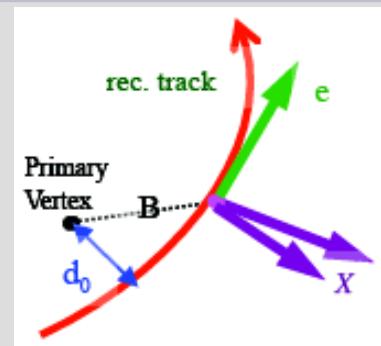
G.Aad et al., PLB 707 (2012) 438

FONLL calculations describe relatively well the measured HF decay lepton differential cross-sections

$b \rightarrow e + X$ cross sections in pp at 7 TeV, $|y|<0.8$



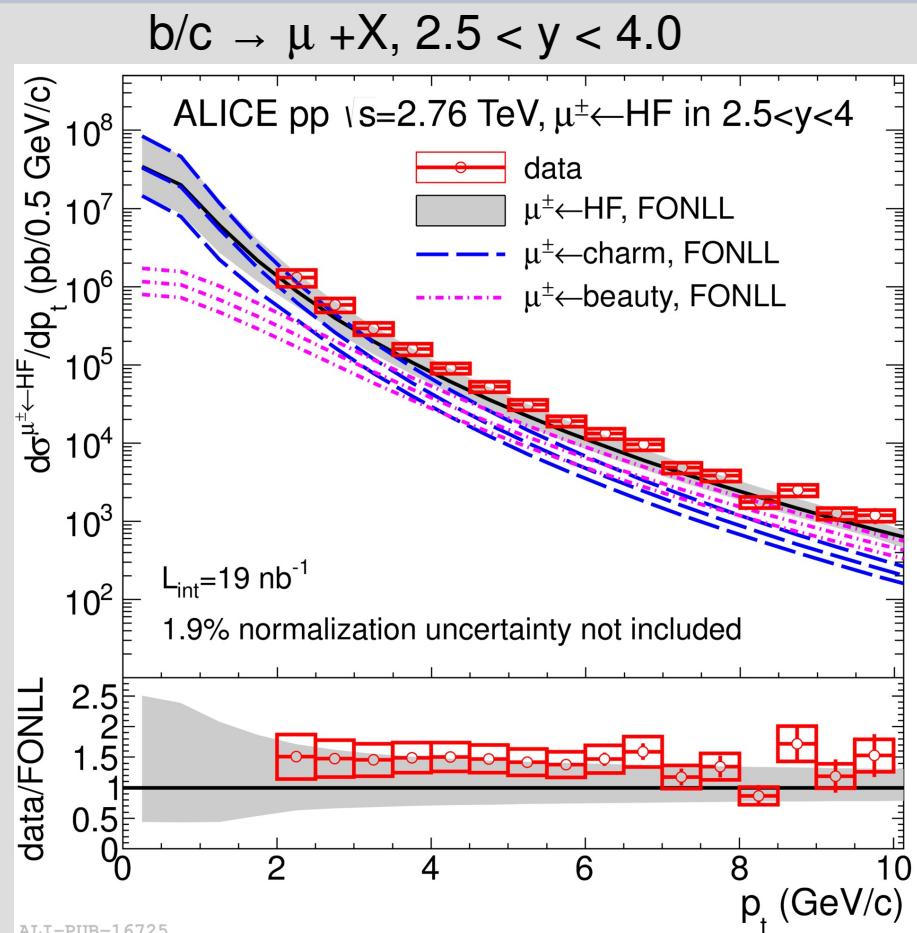
FONLL describes well the data



Measured electrons from B hadron decays
 $c\tau \sim 500 \mu\text{m}$ for B hadrons

- Impact parameter analysis
Select e via p_T dependent minimum impact parameter cut d_0 (e.g. $|d_0| > 250 \mu\text{m}$ for $p_T \sim 2.5 \text{ GeV}/c$)
- B-tagging analysis
Reconstruct a secondary vertex
- e-hadron correlation analysis:
Use the shape of the angular e-h correlation

Heavy-flavour in pp at 2.76 TeV

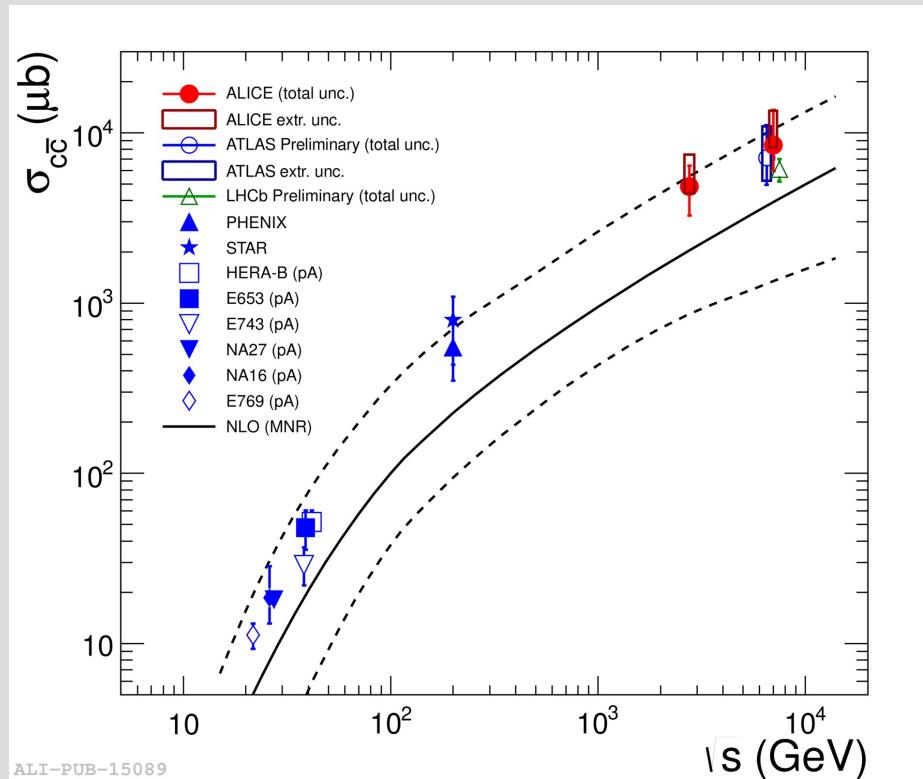


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 - $D^0: 1 < p_T < 12 \text{ GeV}/c$
 - $D^+ \text{ and } D^{*+}: 2 < p_T < 12 \text{ GeV}/c$
- $b/c \rightarrow e + X$ measured at mid-rapidity $2 < p_T < 12 \text{ GeV}/c$
- $b/c \rightarrow \mu + X$ measured at foward-rapidity $2 < p_T < 10 \text{ GeV}/c$
- **Data well reproduced by FONLL and GM-VFNS**
- **Limited statistics for e and D mesons**

B.Abelev et al., PRL 109 (2012) 112301

Total charm cross section

B.Abelev et al., JHEP 07 (2012) 191

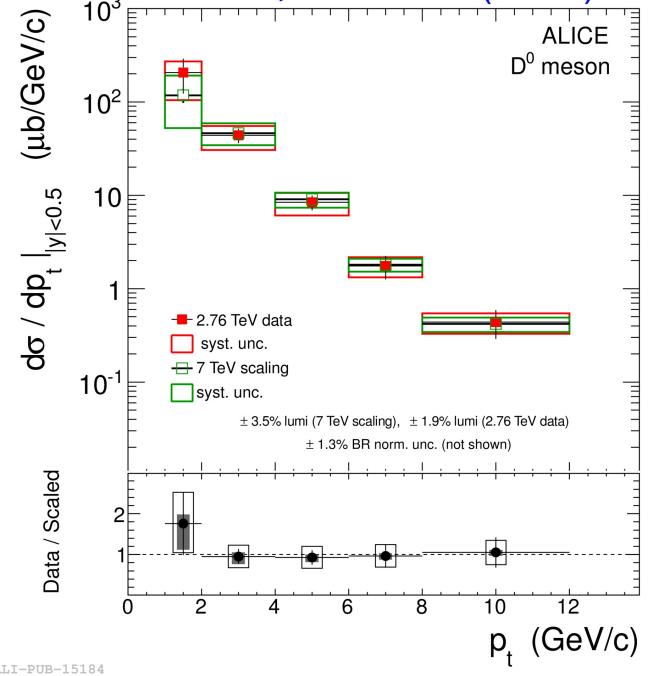


From the D mesons measured at mid-rapidity ,estimate the total charm cross section
NLO reproduces relatively well the data

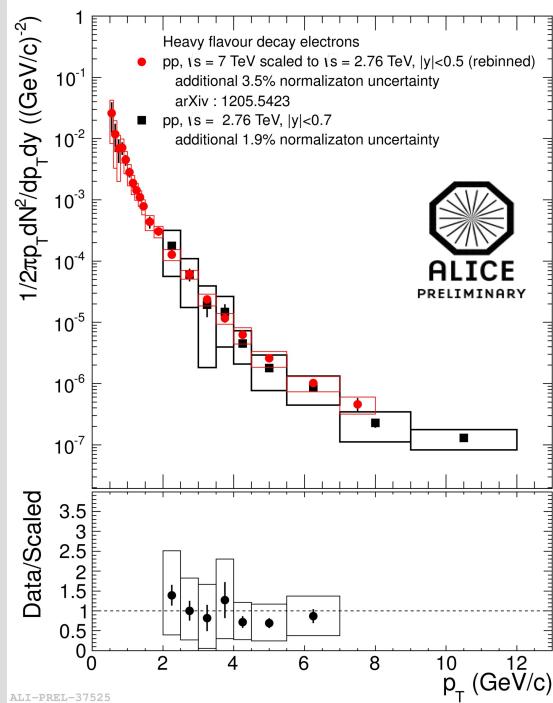
Baseline for Pb-Pb studies at 2.76 TeV

$D^0 \rightarrow K\pi$

B.Abelev et al., JHEP 07 (2012) 191



$b/c \rightarrow e + X$

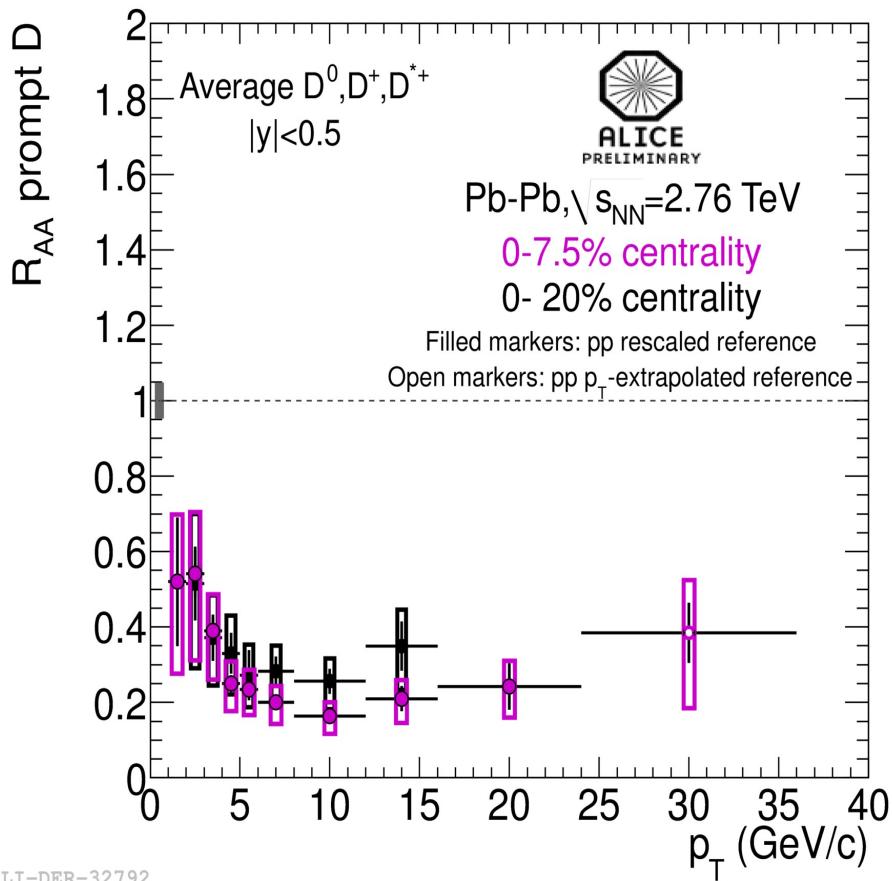


- D for $p_T < 24 \text{ GeV}/c$ and e for $p_T < 8 \text{ GeV}/c$: measurements at 7 TeV scaled to 2.76 TeV
 - Scaling Ratio = FONLL cross sections at 2.76 TeV and 7 TeV
 - Scaled and measured cross sections consistent
- D above $p_T > 24 \text{ GeV}/c$ and e above $p_T > 8 \text{ GeV}/c$: use FONLL calculations
- μ in all the p_T range: measured cross section at 2.76 TeV

Results in Pb-Pb collisions

- Nuclear Modification factor
- Azimuthal anisotropy

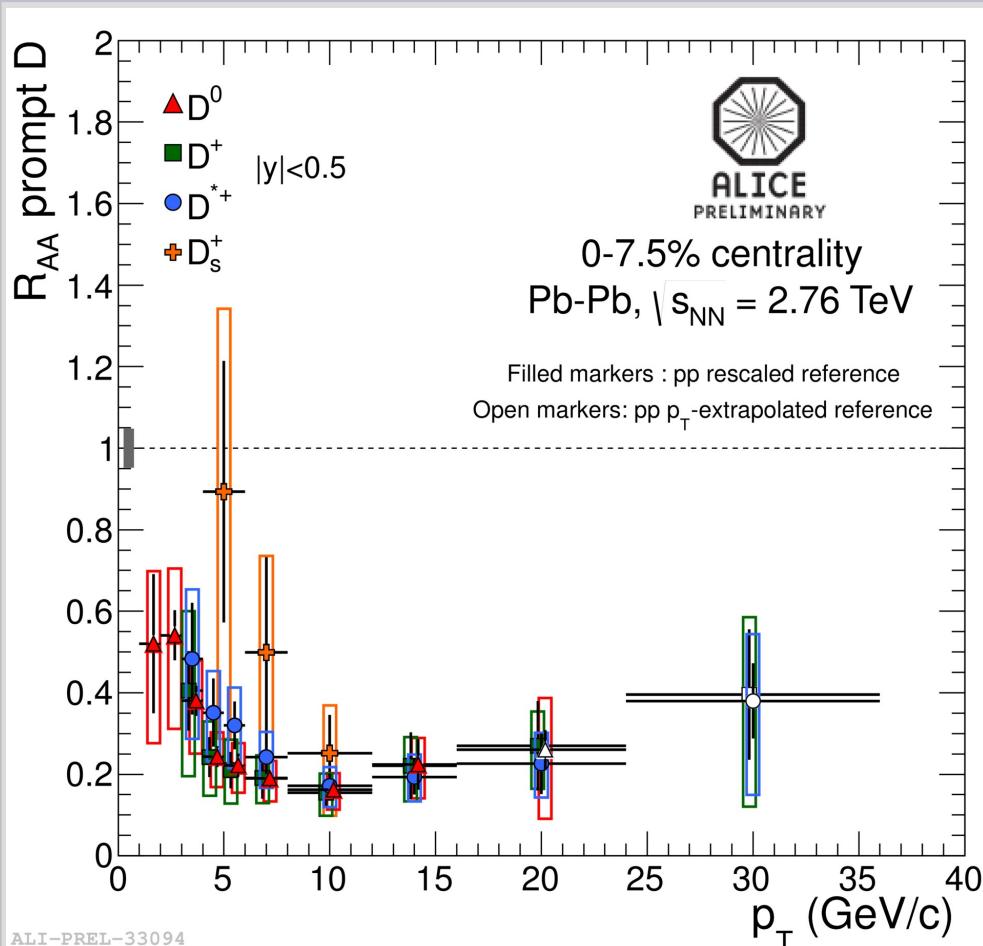
D mesons in 0-7.5% central Pb-Pb at 2.76 TeV, $|y| < 0.5$



$$R_{AA} = \frac{1}{\langle T_{AA} \rangle} \frac{dN_{AA}/dp_T}{d\sigma_{pp}/dp_T}$$

- Prompt D mesons
- 2010 and 2011 data:
 - 0-7.5% centrality: 2011 data
 - 0-20% centrality: 2010 data
 (B.Abelev et al., JHEP 09 (2012) 112)
- Strong suppression observed

D mesons in 0-7.5% central Pb-Pb at 2.76 TeV, $|y| < 0.5$



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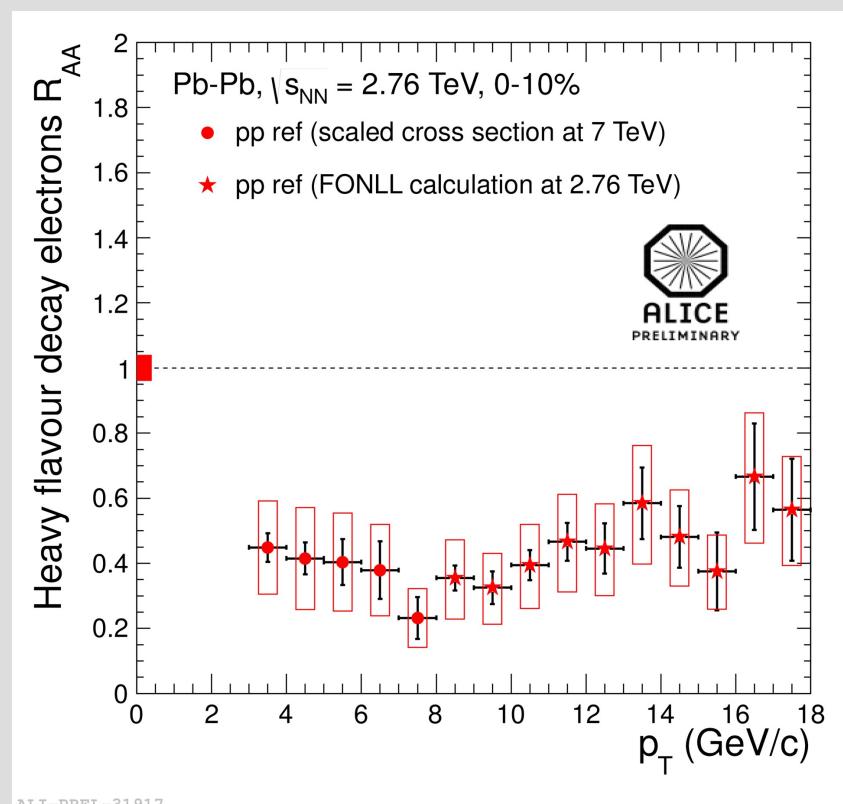
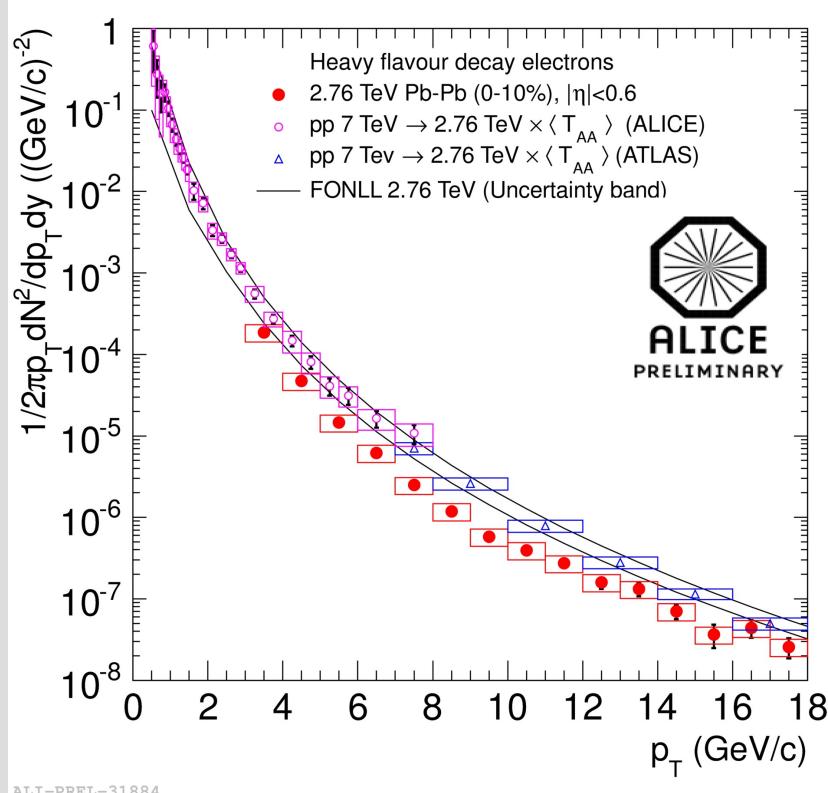
Similar suppression observed for D_s^+

- Predicted enhancement of strange w.r.t. non-strange D mesons at intermediate p_T (Kuznetsova & Rafelski, EPJ C51(2007)113; He et al., arXiv:1204.4442; Andronic et al., arXiv:0708.1488)
- Need better precision for conclusive statement

b/c → e + X in 0-10% central Pb-Pb

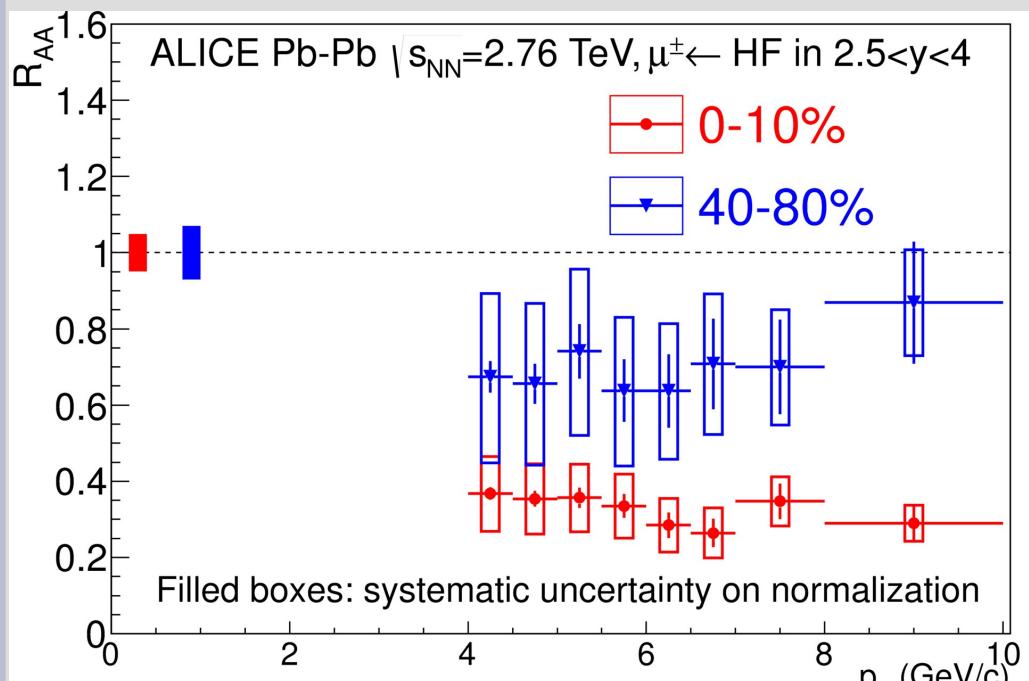


Background subtracted via invariant mass method (Dalitz decays and γ conversion) and cocktail (J/ψ)



Strong suppression observed

$b/c \rightarrow \mu + X$ in 0-10% central Pb-Pb

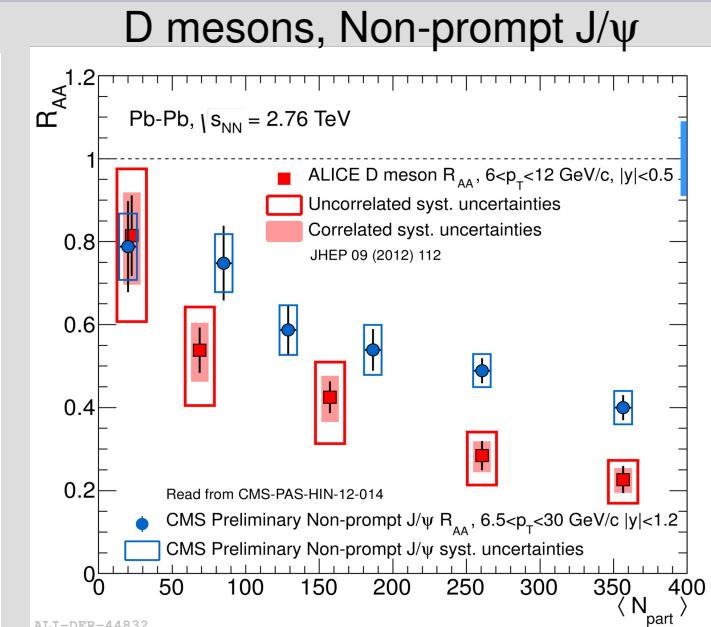
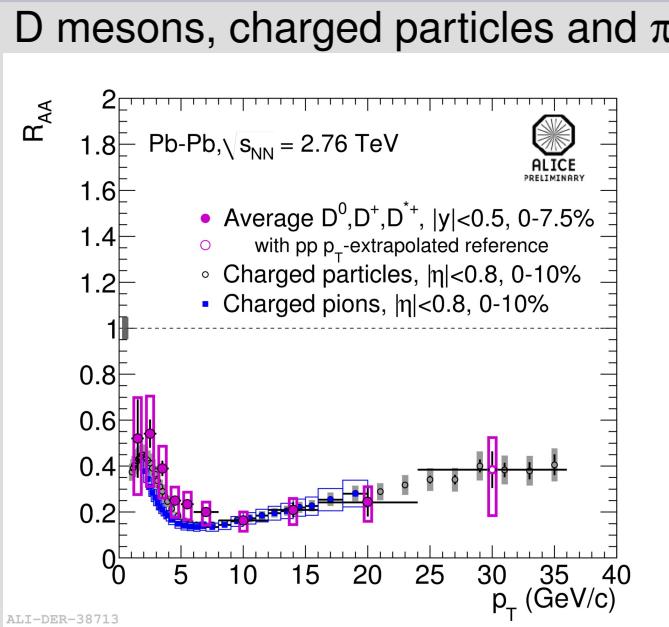
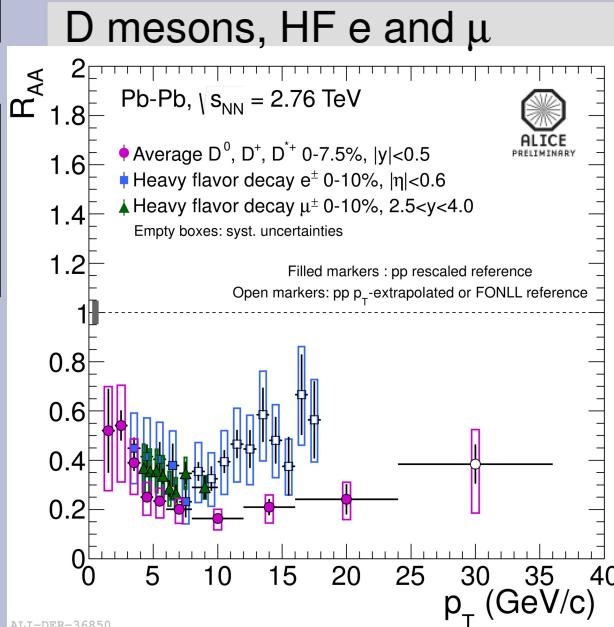


B. Abelev et al., PRL 109 (2012) 112301

- Background from π^- and K^- decays subtracted via:
 - π^- and K^- cross-section extrapolated from mid-rapidity
 - Assumption: $0 < R_{AA}^{\pi,K}(-4.0 < y < -2.5) < 2 R_{AA}^{\pi,K}(y \sim 0)$
- Strong suppression observed in central Pb-Pb collisions
- Less suppression observed in peripheral Pb-Pb collisions

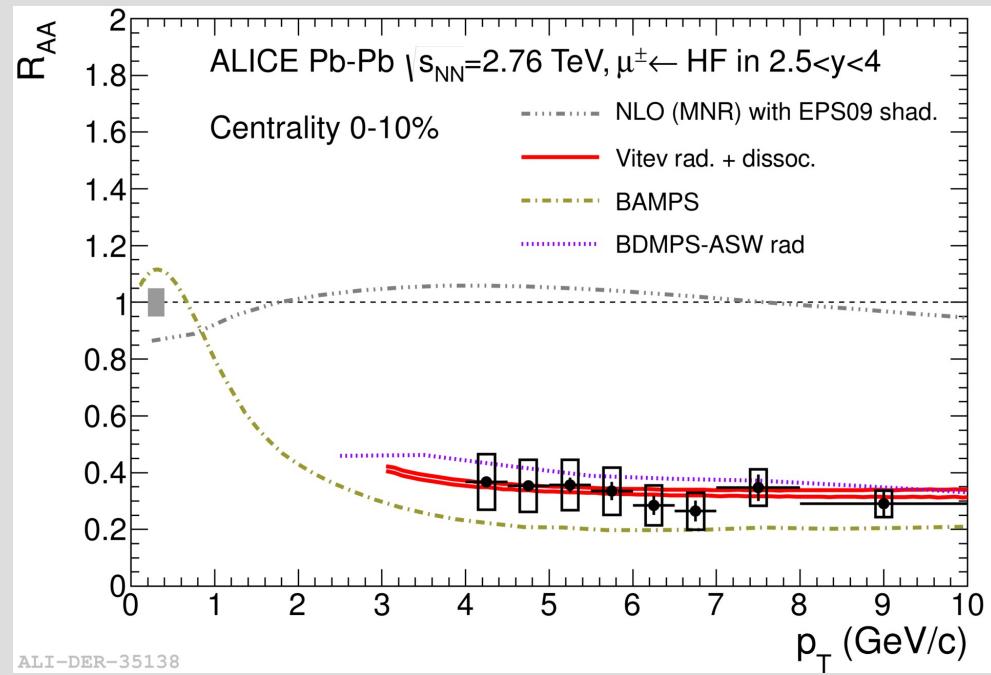
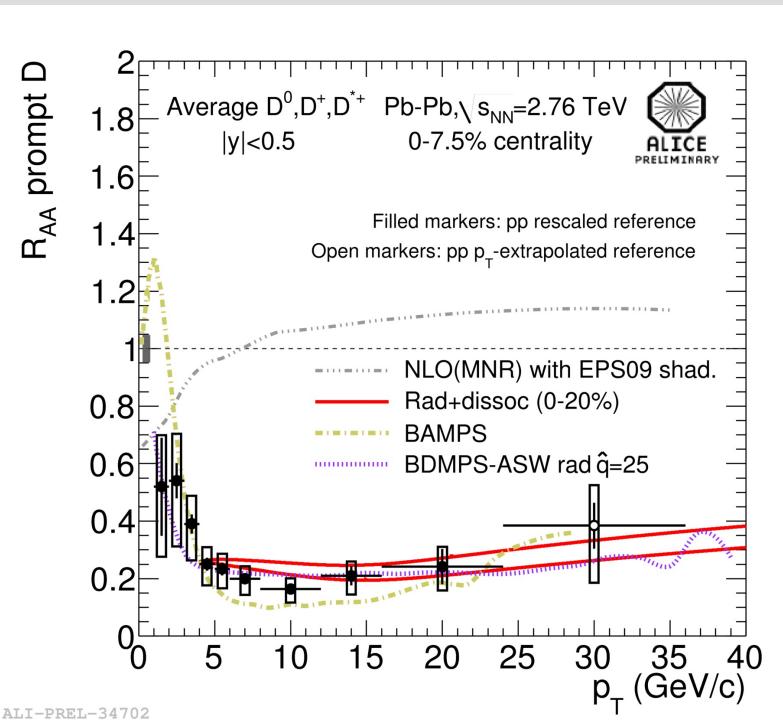


Heavy-flavour R_{AA} compared to other particles



- R_{AA} of HF decay e ($|\eta|<0.6$) and μ ($-4.0<|y|<-2.5$) similar
- R_{AA} of HF decay e ($|\eta|<0.6$) compatible with R_{AA} of D mesons, taking into account the decay kinematics ($p_T^e \sim 0.5 p_T^{B/D}$ at high p_T)
- R_{AA} of D mesons, charged particles and π similar
- Hint for $R_{AA}^\pi < R_{AA}^D$ at low p_T
- Beauty R_{AA} : non-prompt J/ ψ (CMS) less suppressed than D mesons for $p_T > 6$ GeV/c

R_{AA} of D mesons and heavy-flavour μ



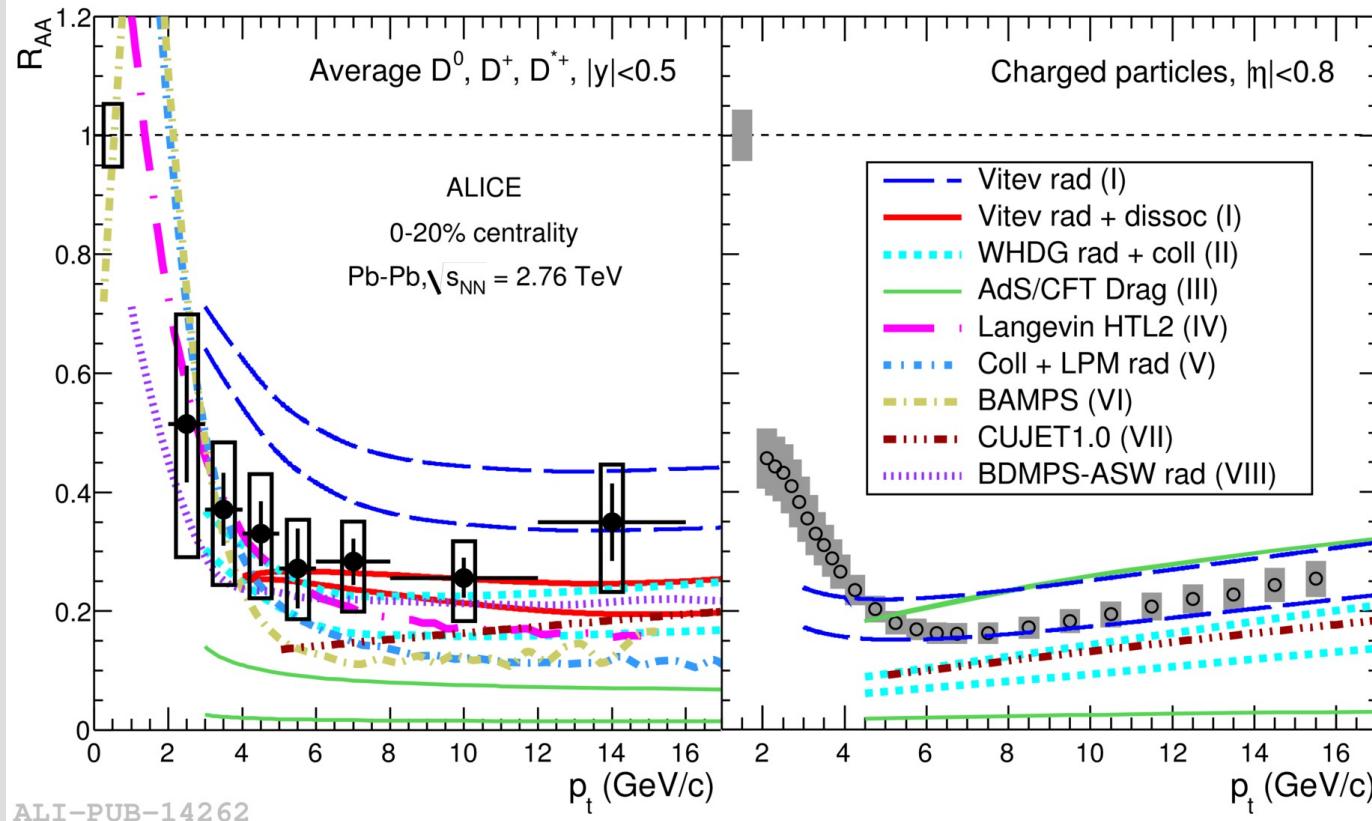
B.Abelev et al., , PRL 109 (2012) 112301

- The large suppression observed is most likely a final state effect
- Models with various parton energy loss mechanisms can describe the data
 - Small initial state (shadowing) effect expected at high momentum
 - p-Pb data (January 2013) needed to quantify initial state effects

R_{AA} of D mesons and charged particles

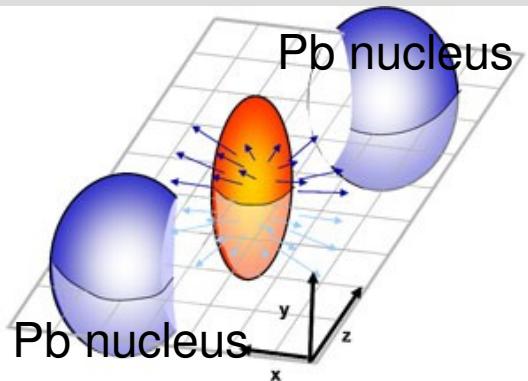


B.Abelev et al., JHEP 09 (2012) 112



Models describe reasonably well R_{AA} of D mesons and charged particles

Elliptic flow measurement



- Almond shape of the overlap region
→ Anisotropic pressure gradients during system expansion
- Evolves into momentum space via multiple collisions → can be measured experimentally
- Probes/scans the medium
- Reveals the level of thermalization of heavy quarks at low p
- Reveals path length dependence of the heavy-quark energy loss in the medium at high p

Fourier decomposition of particle azimuthal distribution wrt. the reaction plane

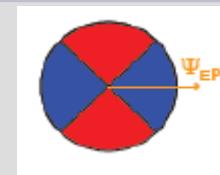
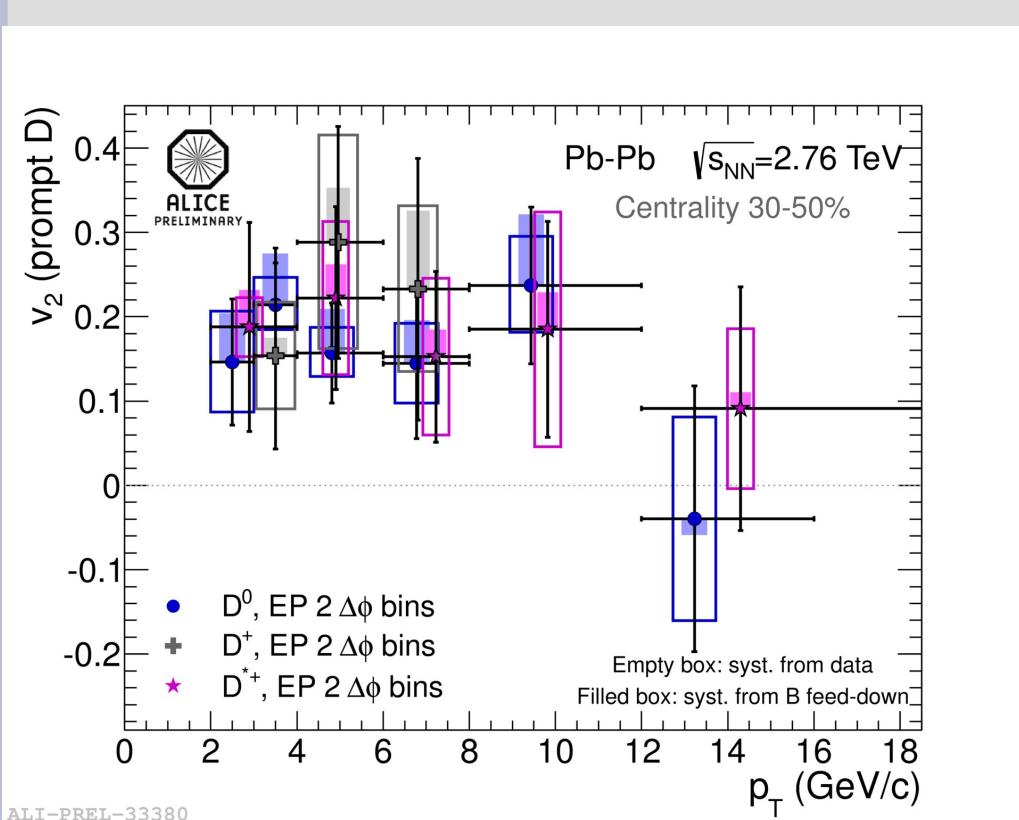
$$\frac{dN}{d\phi} \sim 1 + 2 \sum_{n=1} v_n(p_T, \eta) \cos(n[\phi - \Psi_{RP}])$$

v₂ elliptic flow particle azimuthal angle
 reaction plane (RP) angle

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D meson v_2 non-central Pb-Pb collisions



$$v_2 = \frac{1}{R} \frac{\pi}{4} \frac{N_{in-plane} - N_{out-of-plane}}{N_{in-plane} + N_{out-of-plane}}$$

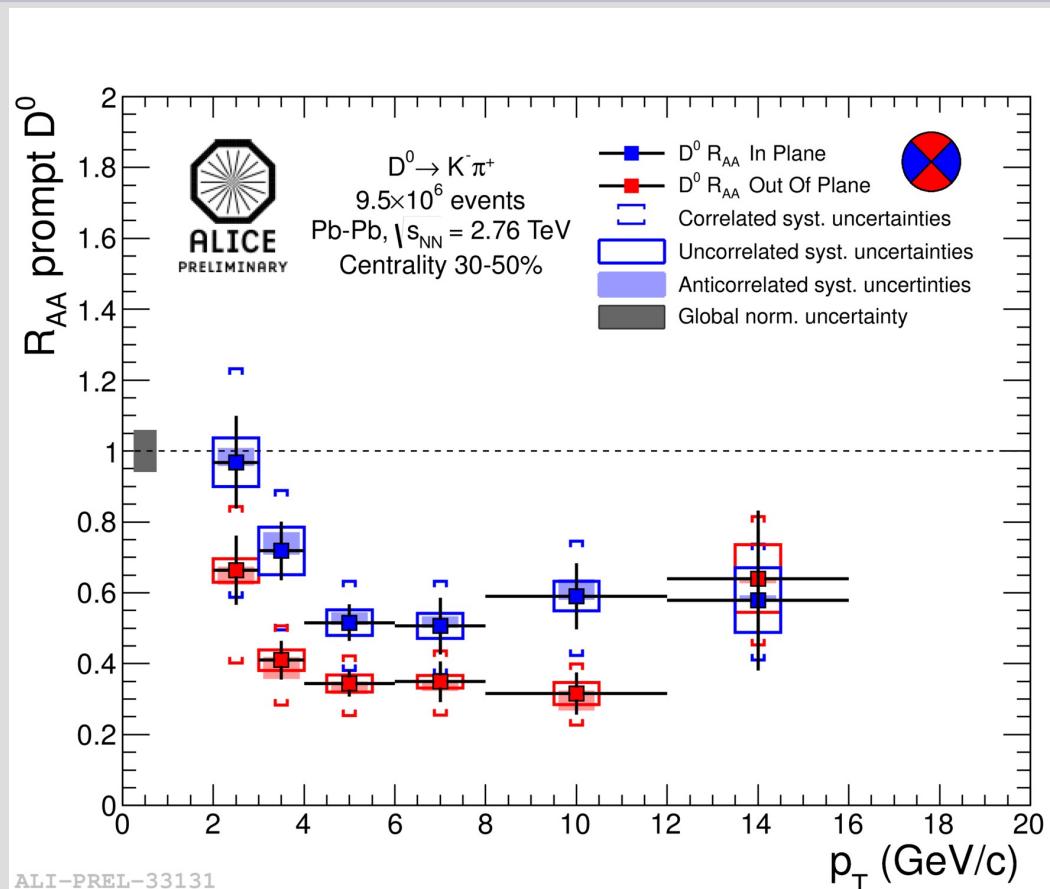
with R = event plane resolution

Event plane method used:

- Determine the event plane in each event with a given resolution
- Measure the yield of D mesons in- and out-of-plane

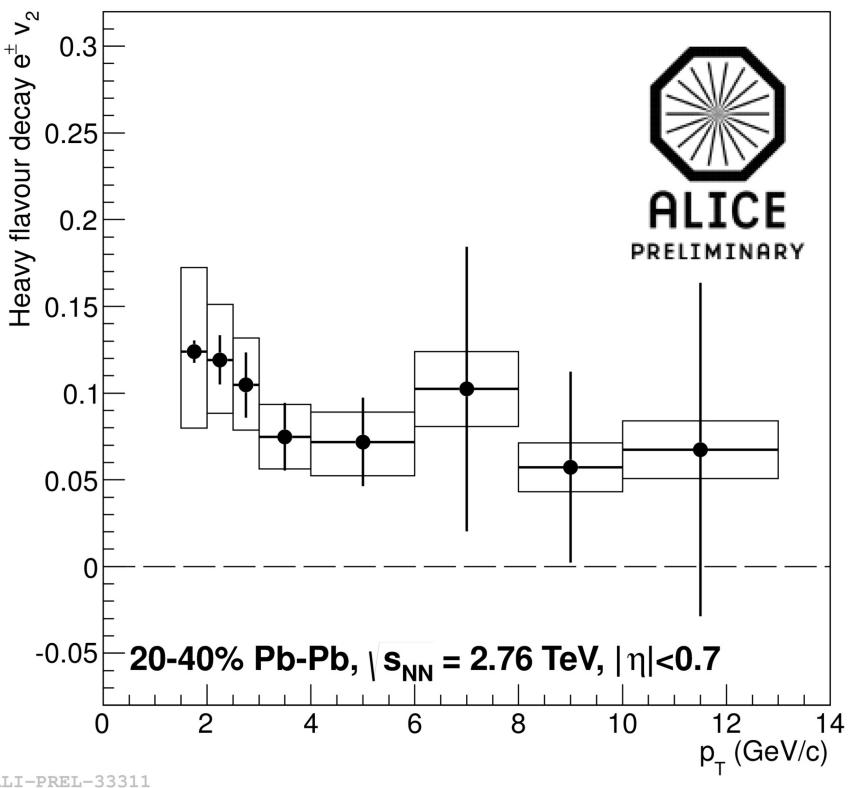
Indication for $v_2 > 0$, consistent for all D meson species

D meson suppression vs event plane



For $p_T < 10$ GeV/c: suppression out-of-plane larger than in-plane:
elliptic flow at low p_T , energy loss path length dependence at high p_T ?

b/c → e +X in 20-40% central Pb-Pb



Heavy-flavour electron $v_2 > 0$ at low p_T

- Electron identification:
 - TPC-TOF
 - TPC-EMCal
- Event plane method

$$v_2^{e HF} = \frac{(1+\alpha)v_2^e \text{ incl.} - v_2^e \text{ backg.}}{\alpha}$$

with $\alpha = N^{e HF} / N^{e \text{ backg.}}$

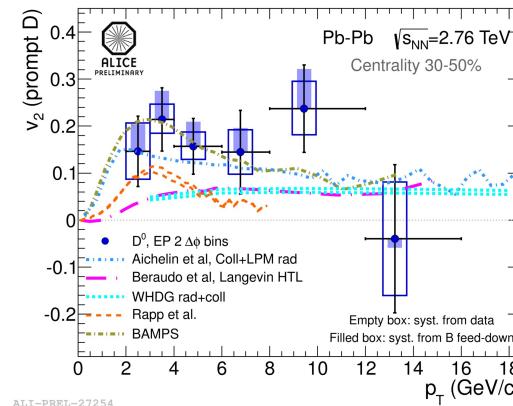
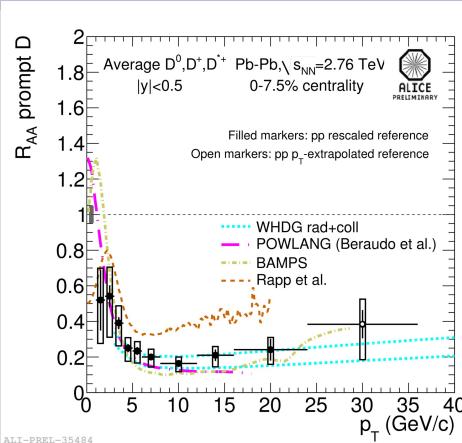
- Background subtraction:
 - Mainly from γ conversion, π^0 , η Dalitz decays
 - v_2 calculated with cocktail using measured v_2 of mesons

R_{AA} and v_2

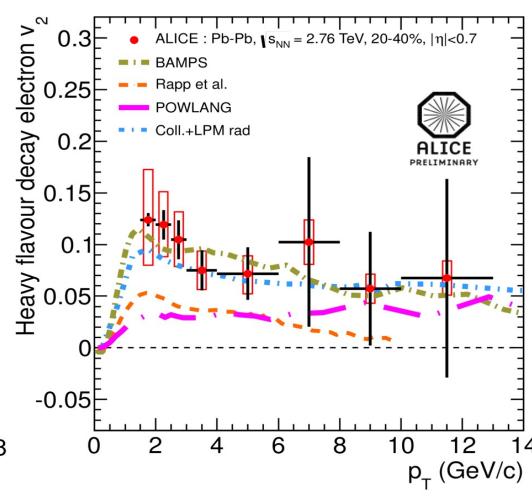
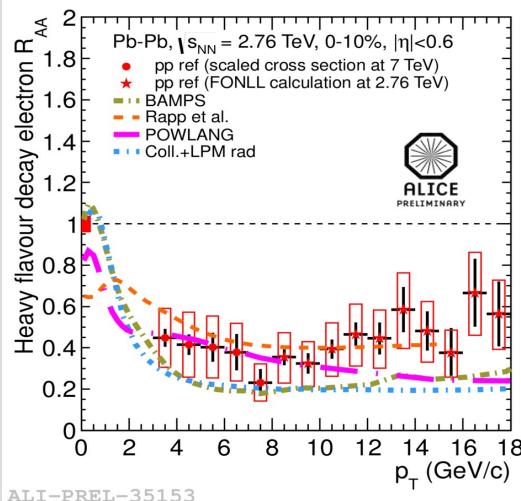
R_{AA}

v_2

D mesons



HF electrons



Simultaneous description of R_{AA} and v_2 challenging for models

Summary

- Unique acceptance of ALICE at low p_T with a broad η acceptance
- In pp collisions: differential and total cross-sections reasonably well reproduced by pQCD
- Several measurements with different D meson species and semi-leptonic channels in Pb-Pb
 - Large suppression of HF production at high momentum observed along with azimuthal anisotropy with respect to the event plane
 - At mid-rapidity: $R_{AA}^\pi \sim R_{AA}^D$ compatible with $R_{AA}^{HF\ e}$
 - $R_{AA}^{HF\ e}$ at mid-rapidity $\sim R_{AA}^{HF\ \mu}$ at forward-rapidity
 - Observation of non-zero v_2 of D mesons and HF e at low p_T

Challenge for the models

