

MEASUREMENTS OF OPEN HEAVY-FLAVOUR PRODUCTION IN PP AND P-PB COLLISIONS WITH ALICE AT THE LHC

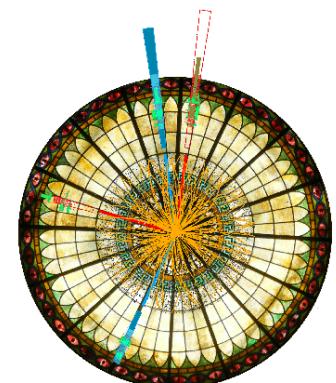
Deepa Thomas
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For the ALICE Collaboration

27th April – 1st May 2015

DIS 2015
XXIII International Workshop on
Deep-Inelastic Scattering and
Related Subjects

Dallas, Texas
April 27 – May 1, 2015





Outline

- Motivation
- ALICE detector
- Heavy-flavour measurements
- Results from pp and p-Pb collisions
- Summary and outlook



Motivation

Why study heavy quarks?

pp collisions

- Test pQCD calculations of the production of heavy quarks at LHC energies.
- Study Multi-Parton Interactions (MPIs) in pp collisions which are relevant at the LHC.
- Study jet structure and fragmentation.
- Provide reference for p-Pb and Pb-Pb collisions.

p-Pb collisions

- Address cold nuclear matter effects in initial and final state
 - Initial state effects :
 - The nuclear environment affects quark and gluon distribution functions
→ described by calculations based on phenomenological modifications of the Parton Distribution Functions (PDF).
 - Gluon saturation at low x → affects particle production at low p_T .
→ described by Color Glass Condensate (CGC) theory.
 - Partons lose energy via initial and final state radiation.
 - k_T -broadening due to multiple soft collisions.
- Study potential collective effects.



ALICE

ALICE detector

Inner Tracking System

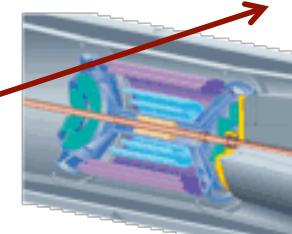
- Trigger
- Primary vertex reconstruction
- Event topology
- Tracking
- PID

Time Of Flight

- PID

Central barrel coverage: $|\eta| < 0.9$

Muon spectrometer coverage: $-4 < \eta < -2.5$



VZERO

- Trigger and Event topology

Electromagnetic calorimeter

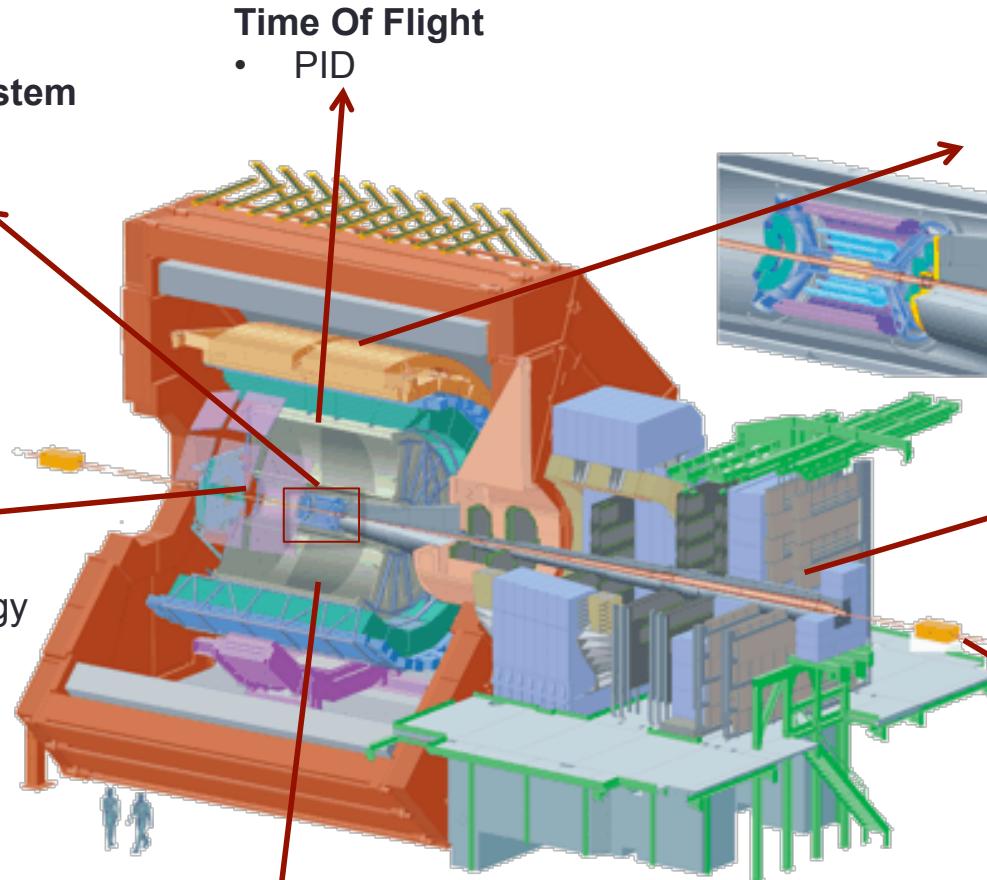
- Trigger and PID

Muon Spectrometer

- Trigger, tracking and PID

ZDC

- Trigger and Event topology



Time Projection Chamber

- Tracking and PID

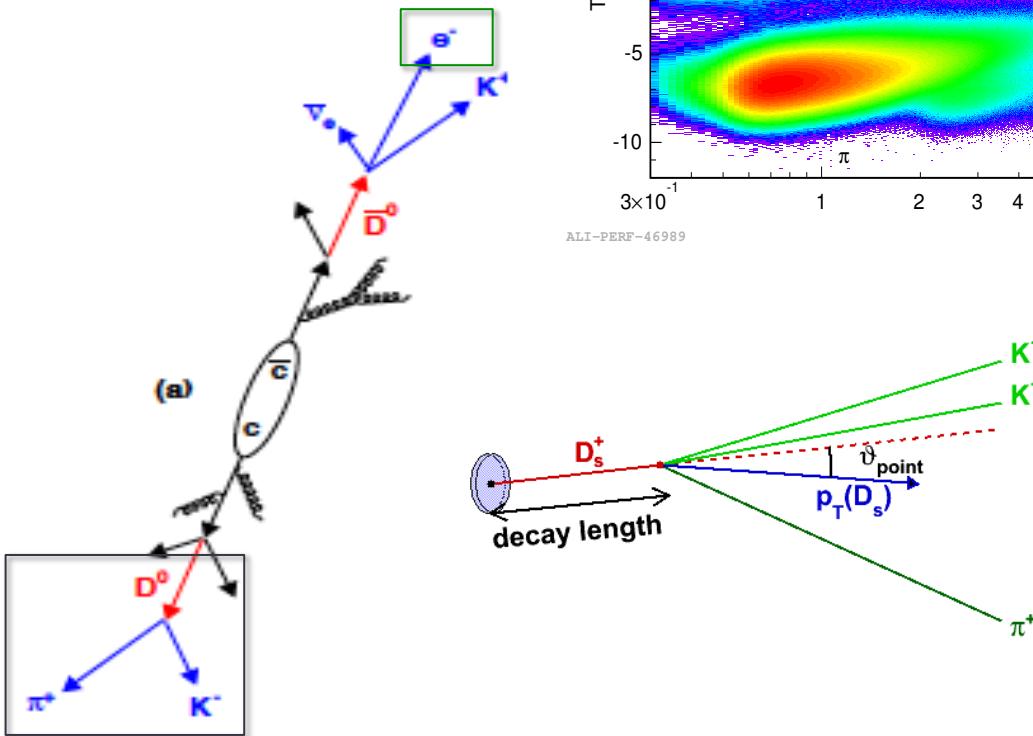


ALICE Heavy-flavour measurements

Heavy quarks studied via semi-leptonic and hadronic decay channels.

Decay channels used

- $c, b \rightarrow l$ (BR = 10%)
- $D^0 \rightarrow K^- \pi^+$ (BR = 3.88%)
- $D^+ \rightarrow K^- \pi^+ \pi^+$ (BR = 9.13%)
- $D^{*+} \rightarrow D^0 \pi^+$ (BR = 67.7%)
- $D_s^+ \rightarrow \phi(\rightarrow K^- K^+) \pi^+$ (BR = 2.28%)

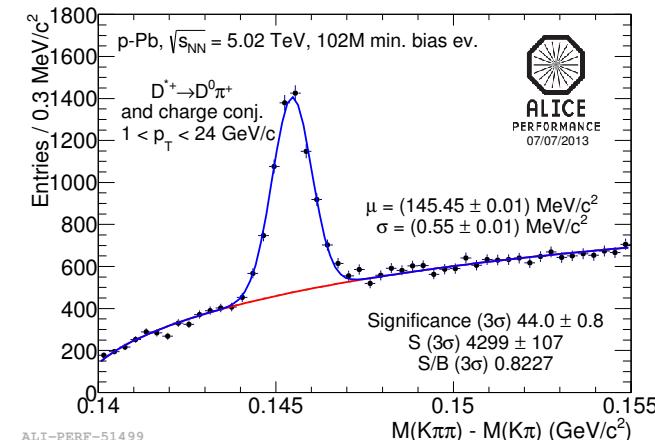


Electrons identified at mid rapidity using various PID detectors.

Muons identified at forward rapidity.

D-meson reconstruction:

- Identify secondary vertex, apply topological cuts.
- Calculate invariant mass.





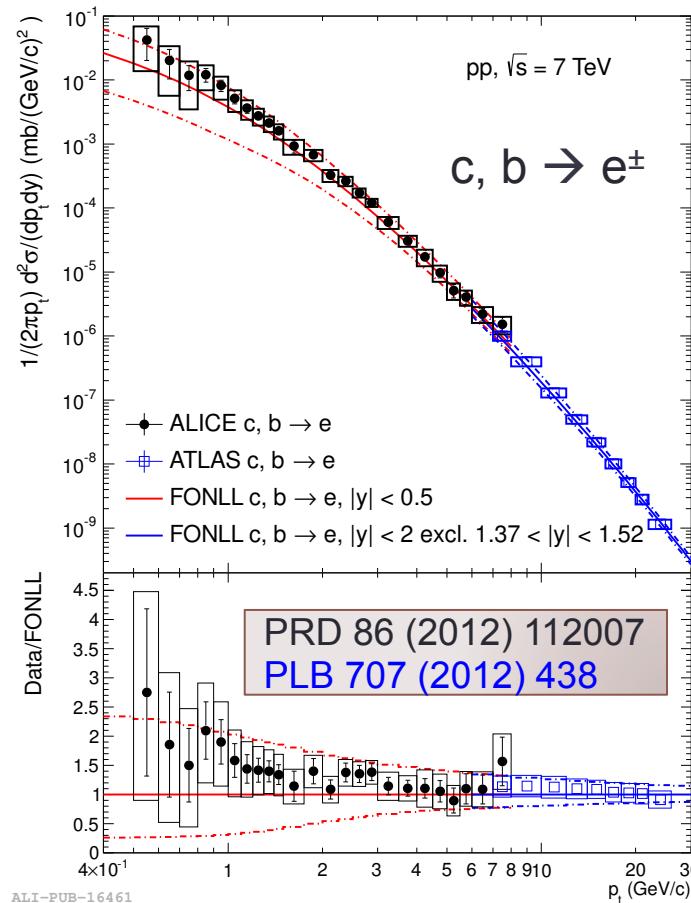
Results from pp collisions

- Cross-section measurements
- D-meson yield in different multiplicity ranges
- Collision energies
 - $\sqrt{s} = 2.76 \text{ TeV}$ and 7 TeV
(only results at 7 TeV discussed in this presentation)



ALICE Heavy-flavour decay lepton cross sections

pp @ $\sqrt{s}=7$ TeV



PLB 708 (2012) 265

p_T -differential cross sections of heavy-flavour decay electrons.

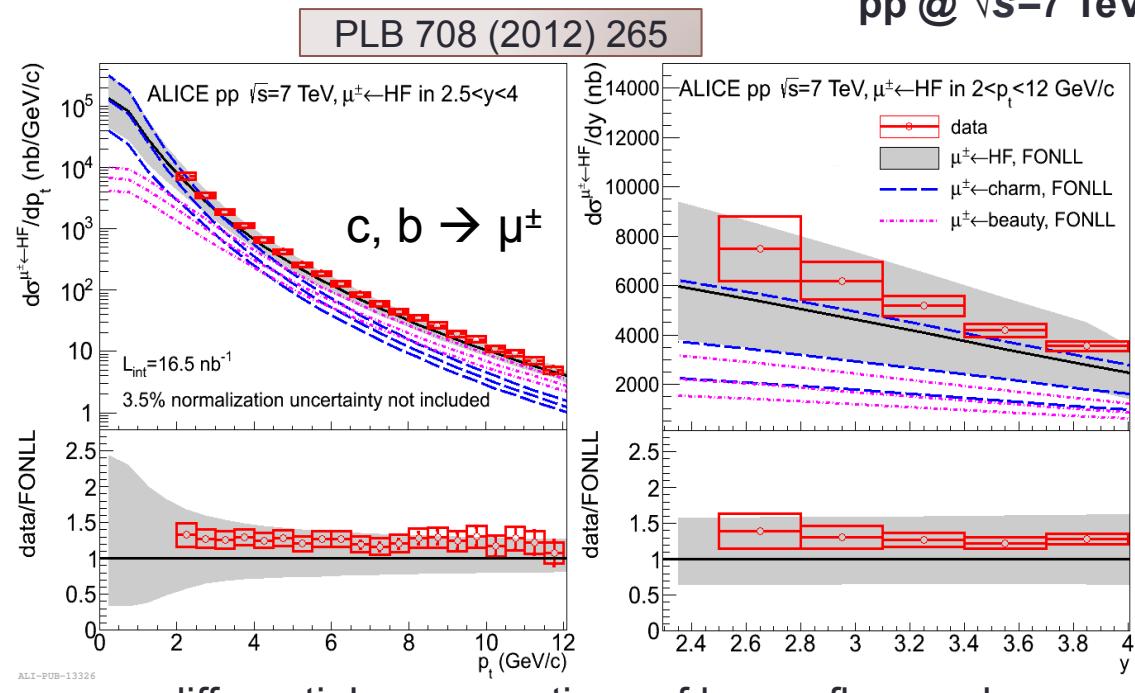
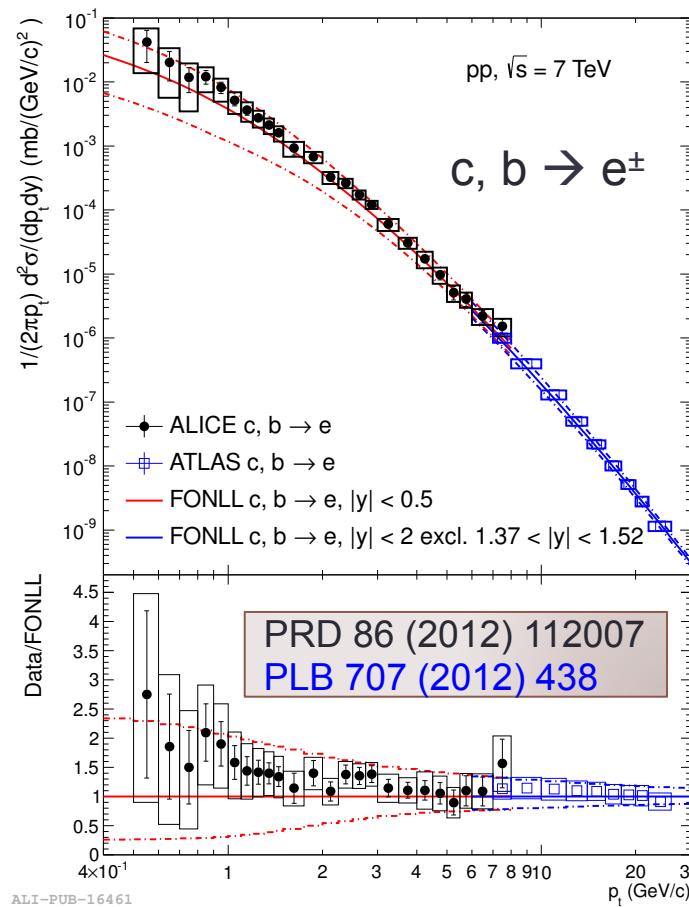
- Consistent with pQCD calculations^[1].

ALICE : low p_T

ATLAS : high p_T

[1]. FONLL : JHEP 1210 (2012) 137
GM-VFNS : EPJ C72 (2012) 2082
 k_T factorization : PRD 87 (2013) 094022

Heavy-flavour decay lepton cross sections



p_T -differential cross sections of heavy-flavour decay electrons and muons.

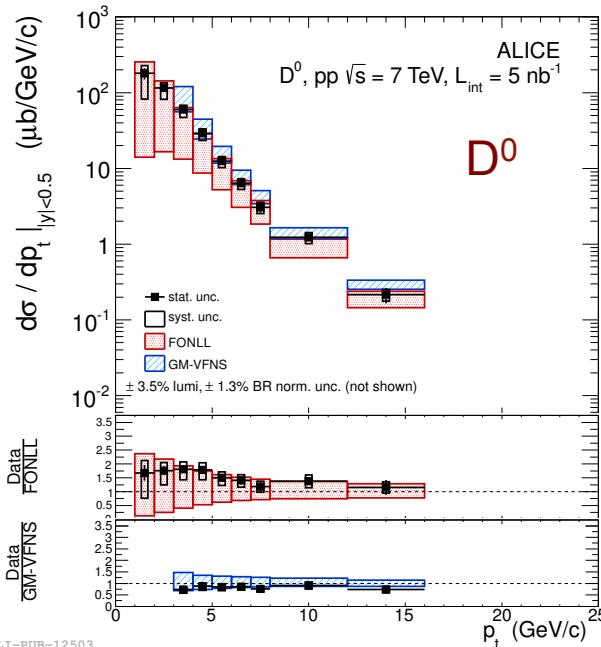
- **Consistent with pQCD calculations^[1].**

Rapidity-dependent measurement of HF decay muons ($2.5 < y < 4$)

- **Consistent with pQCD calculations.**

[1]. FONLL : JHEP 1210 (2012) 137
GM-VFNS : EPJ C72 (2012) 2082
 k_T factorization : PRD 87 (2013) 094022

D-meson cross sections



ALI-PUB-12503

 p_T -differential cross sections $D^0 : 1 < p_T < 16 \text{ GeV}/c$ $D^+, D^{*+} : 1 < p_T < 24 \text{ GeV}/c$ $D_s^+ : 2 < p_T < 12 \text{ GeV}/c$

- Consistent with pQCD calculations^[1].

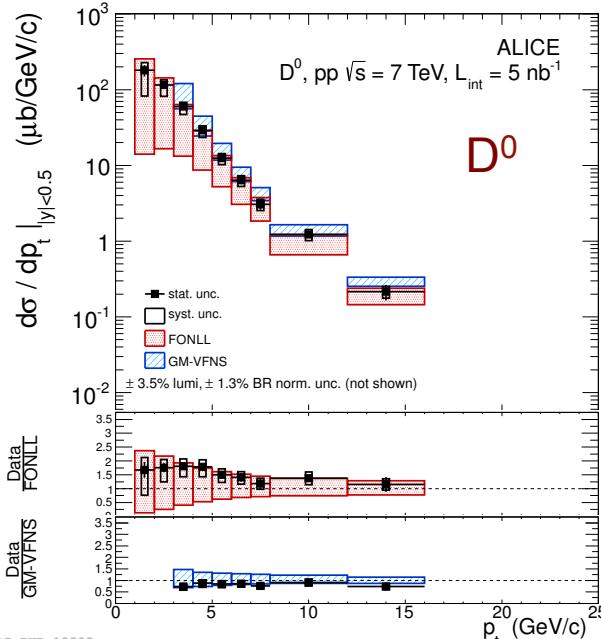
JHEP 01 (2012) 128
 Phys. Lett. B 718 (2012) 279

[1]. FONLL : JHEP 1210 (2012) 137

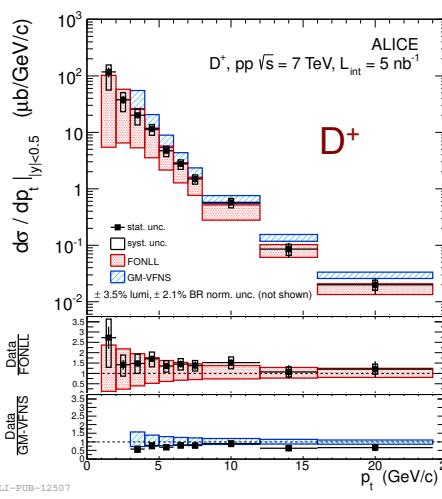
GM-VFNS : EPJ C72 (2012) 2082

 k_T factorization : PRD 87 (2013) 094022

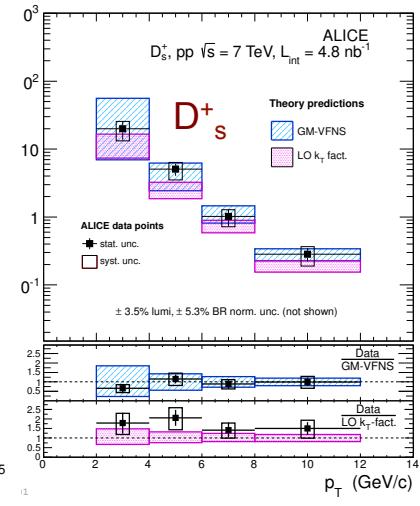
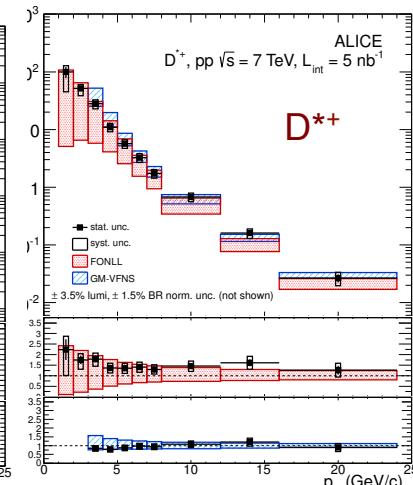
D-meson cross sections



ALI-PUB-12503



ALI-PUB-12507



JHEP 01 (2012) 128
 Phys. Lett. B 718 (2012) 279

 p_T -differential cross sections $D^0 : 1 < p_T < 16 \text{ GeV}/c$ $D^+, D^{*+} : 1 < p_T < 24 \text{ GeV}/c$ $D_s^+ : 2 < p_T < 12 \text{ GeV}/c$

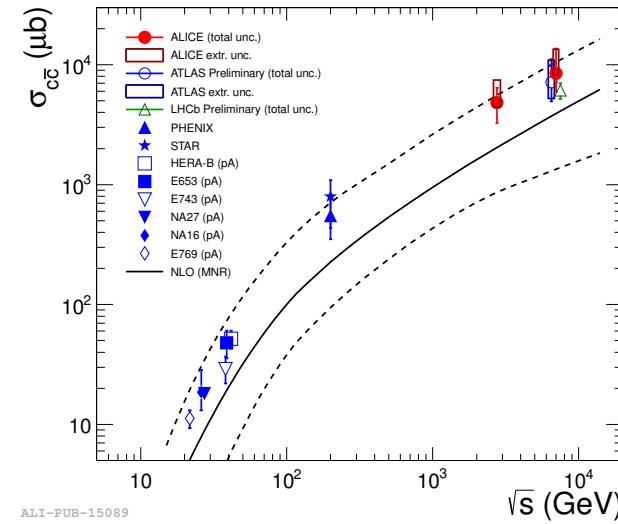
- Consistent with pQCD calculations^[1].

Total charm cross section

- In good agreement with other LHC experiments.
- Consistent with NLO pQCD-based calculations (MNR)

[1]. FONLL : JHEP 1210 (2012) 137

GM-VFNS : EPJ C72 (2012) 2082

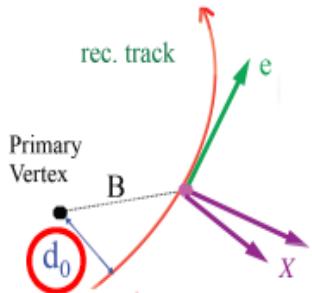
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ALICE Beauty-decay electron cross sections

pp @ $\sqrt{s}=7$ TeV

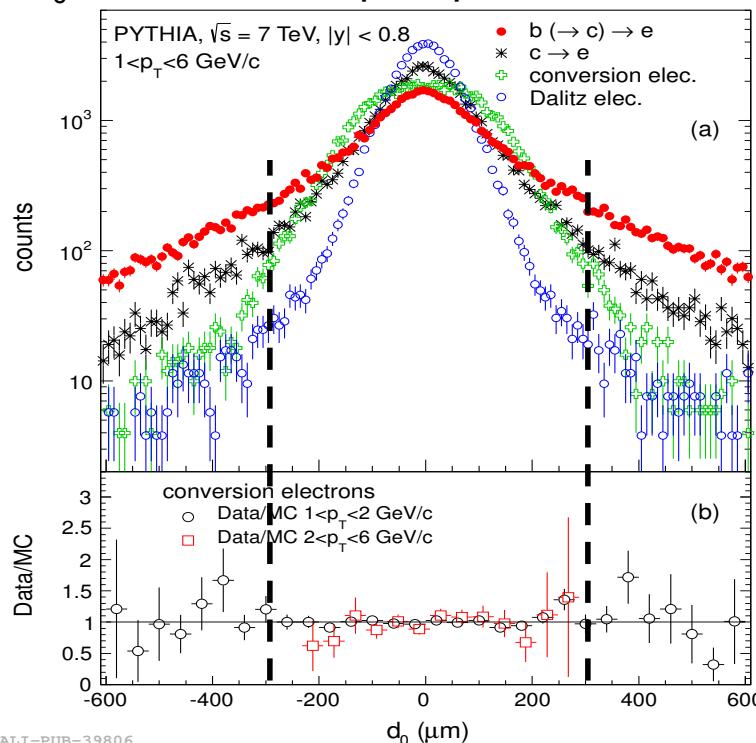
PLB 721 (2013) 13-23



Select electrons with large impact parameter to primary vertex

Subtract remaining background using simulations

d_0 : transverse impact parameter



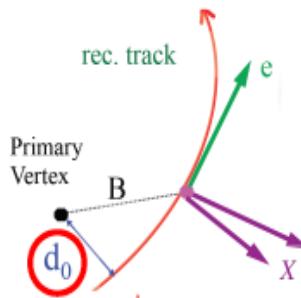
- p_T -differential cross section of $b \rightarrow e$.
- **Well described by pQCD calculations^[1].**
- Beauty takes over as dominant source of HF decay electrons at $p_T \sim 4$ GeV/c

[1]. FONLL : JHEP 1210 (2012) 37

ALICE Beauty-decay electron cross sections

pp @ $\sqrt{s}=7$ TeV

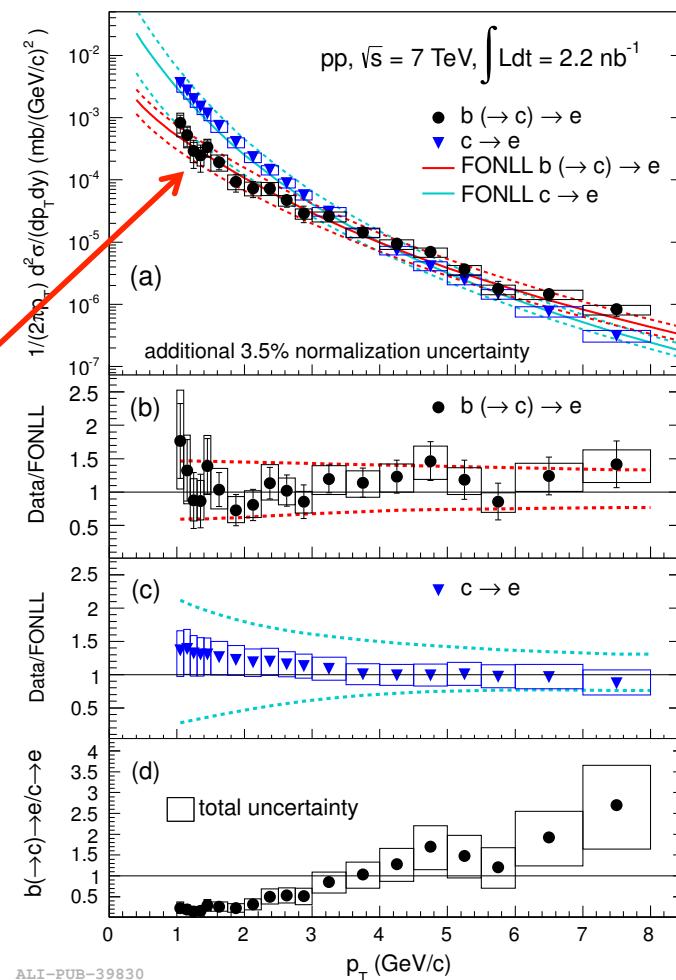
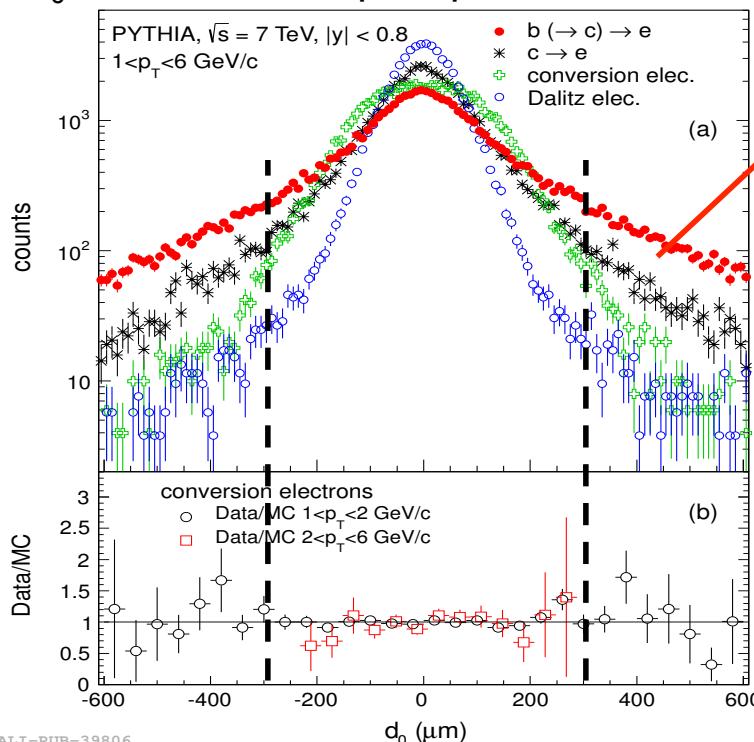
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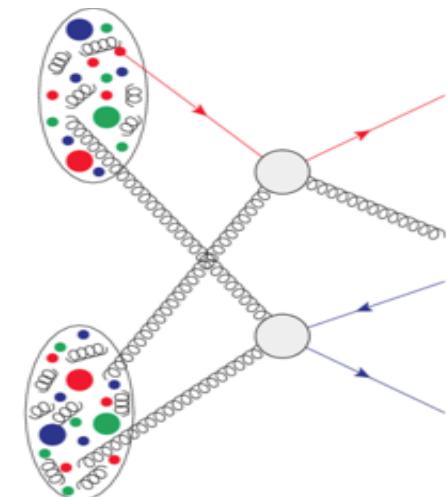
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[1]. FONLL : JHEP 1210 (2012) 37

Multiplicity dependence of D-meson production

MPIs are expected to be relevant at the LHC

- NA27 (pp collisions at $\sqrt{s} = 28$ GeV)
→Events with charm have larger charged-particle multiplicity^[2].
- CMS measurement of jets and underlying events
→better agreement with models including MPIs^[3].
- LHCb measurement of double charm production
→better agreement with models including double-parton scattering^[4].
- ALICE measurement of increase of J/ ψ yields with increasing charged-particle multiplicity^[5].



[2] : NA27 Coll. Z.Phys.C41:191

[3] : Eur.Phys.J.C 73 (2013) 2674

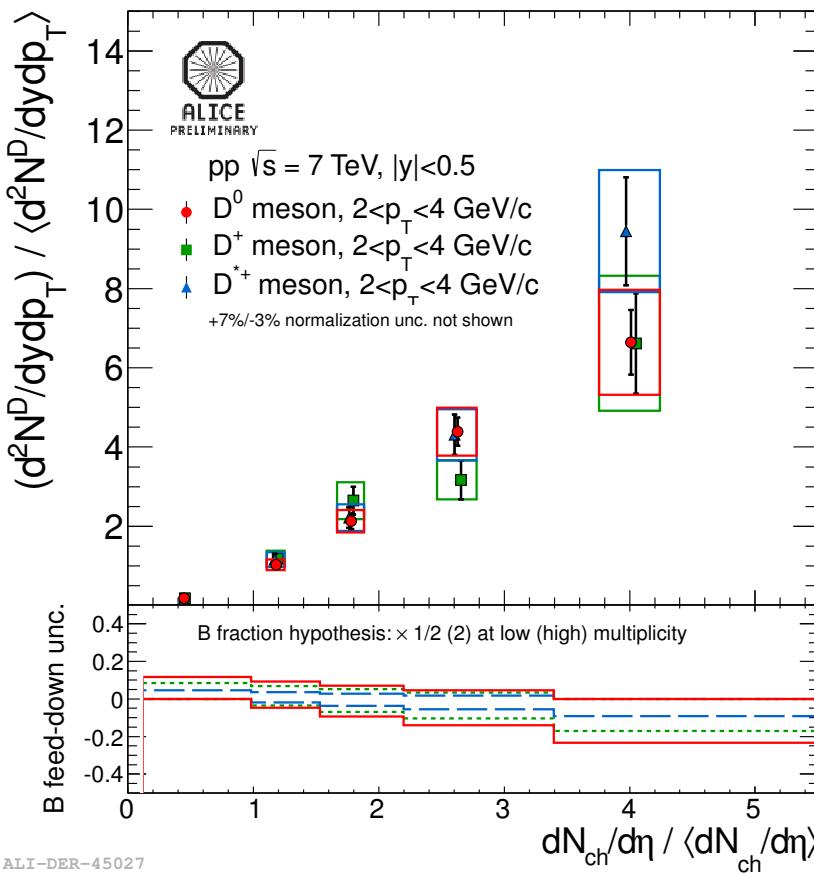
[4] : J. High Energy Phys., 06 (2012) 141

[5] : Phys.Lett. B 712 (2012) 165

ALICE Multiplicity dependence of D-meson production

Study self-normalized yield in multiplicity intervals relative to the multiplicity integrated one

$$\frac{d^2 N^D / dy dp_T}{\langle d^2 N^D / dy dp_T \rangle} = \frac{(d^2 N^D / dy dp_T)^{multi} / (\epsilon^{multi} \times N_{event}^{multi})}{(d^2 N^D / dy dp_T)^{tot} / (\epsilon^{tot} \times N_{event}^{tot})}$$



Increase of D-meson yield with increasing charged-particle yields.

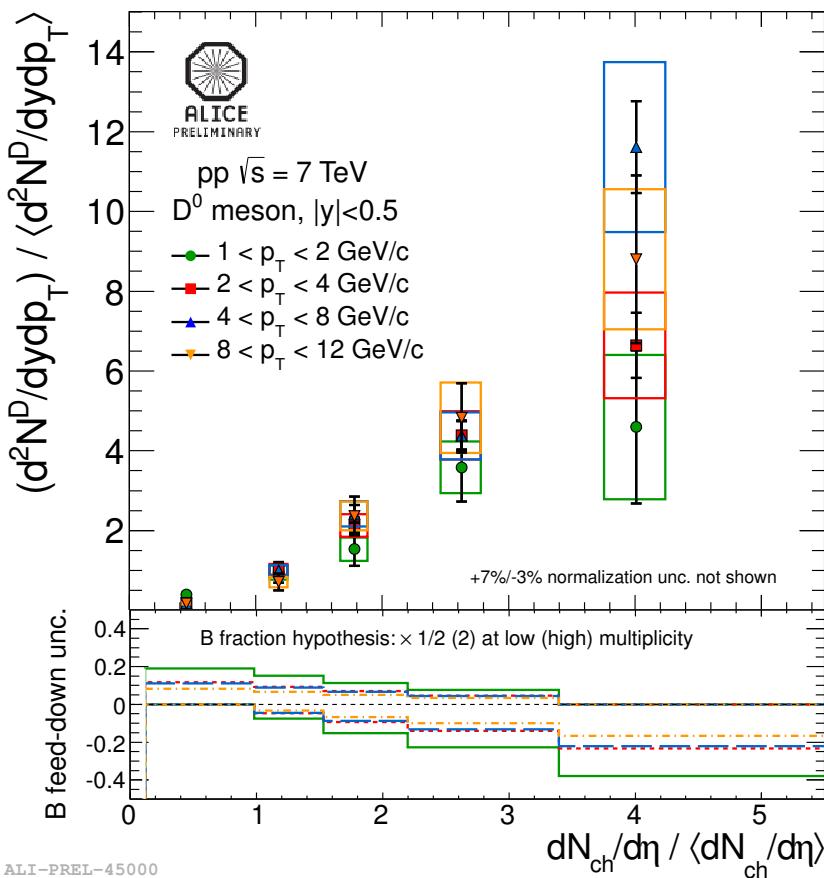
Measurements for different D mesons

- Consistent within uncertainties.

Multiplicity dependence of D-meson production

Study self-normalized yield in multiplicity intervals relative to the multiplicity integrated one

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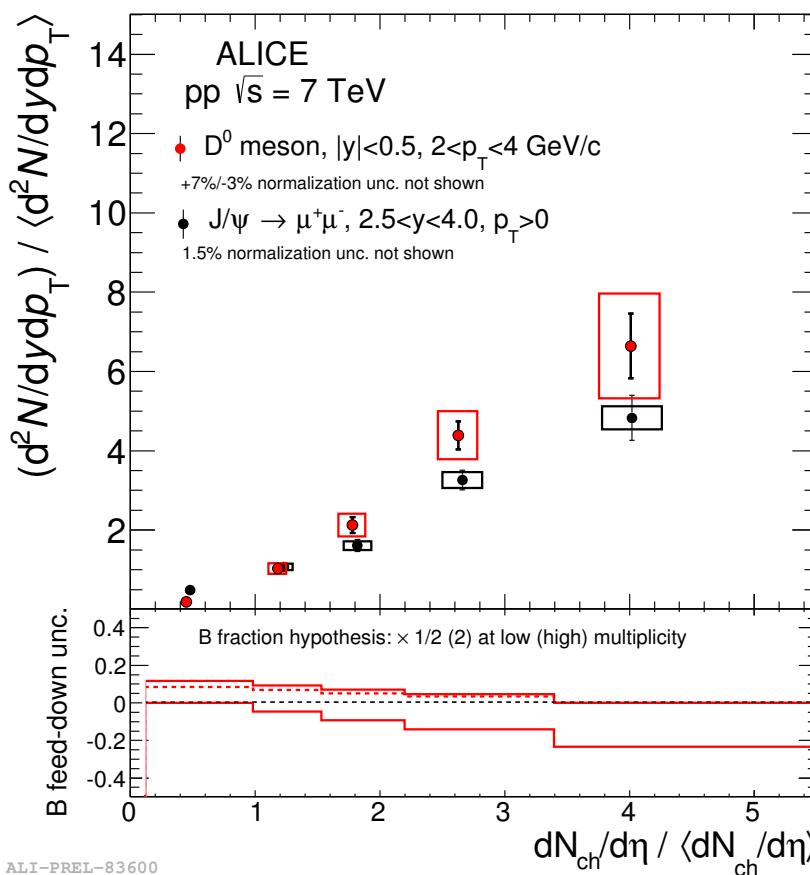
No visible p_T dependence of D-meson yield observed.



Multiplicity dependence of D-meson production

Study self-normalized yield in multiplicity intervals relative to the multiplicity integrated one

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Increase of D-meson yield with increasing charged-particle yields.

Measurements for different D mesons

- Consistent within uncertainties.

No visible p_T dependence of D-meson yield observed.

Comparison with J/Ψ ($2.5 < y < 4.0$):

- Similar trend compared to D mesons.

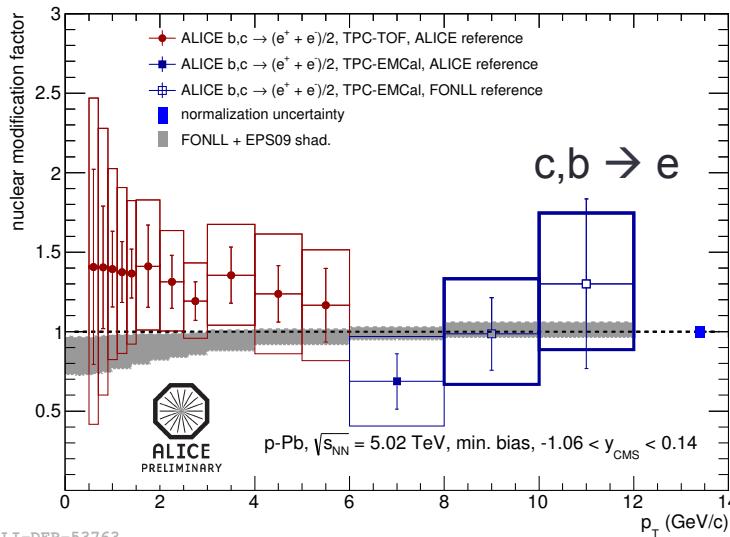


Results from p-Pb collisions

- Nuclear modification factor ($R_{p\text{Pb}}$).
- D-meson yield in different multiplicity ranges.
(Multiplicity dependence of D-meson nuclear modification factor is not shown here)
- Azimuthal angular correlations between HF hadrons and charged particles.
- Collision energy
 $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}$

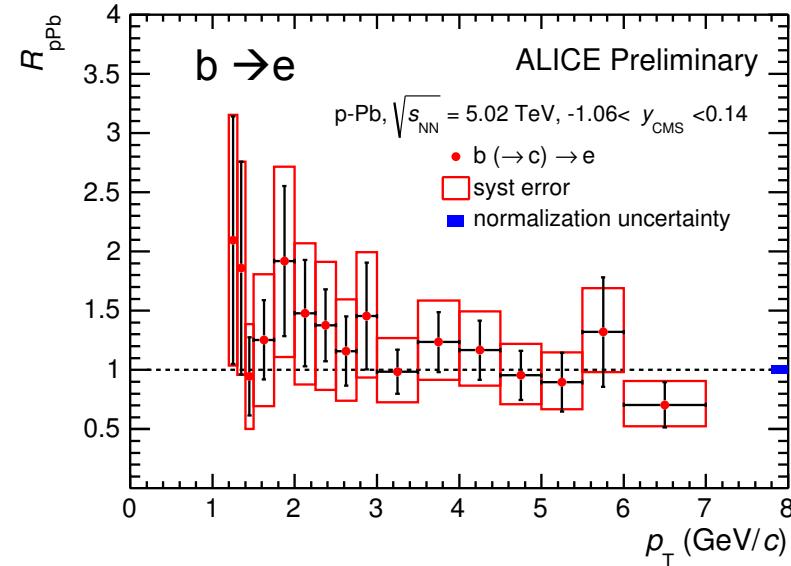
Nuclear modification factor for HF decay electrons

$$R_{pPb} = \frac{d\sigma_{pPb}/dp_T}{A \times d\sigma_{pp}/dp_T}$$



ALI-DER-53763

$b \rightarrow e$ measurement : Impact parameter method

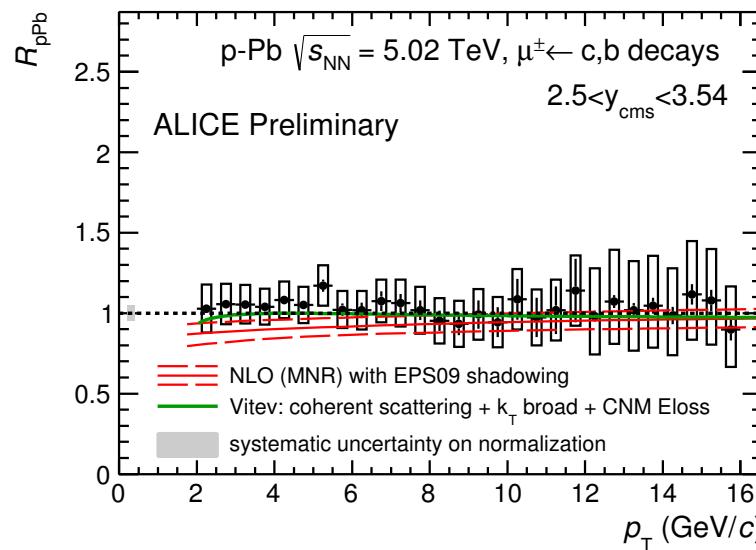


ALI-PREL-76455

- R_{pPb} of HF decay electrons consistent with unity.
 - Consistent with FONLL pQCD calculations with EPS09 shadowing parameterization^[6] within uncertainties.
- R_{pPb} of electrons from beauty decays is also consistent with unity.
- **Cold nuclear matter effects are small at high $p_T \rightarrow$ no large suppression of the yields in the measured p_T range.**

[6] M. Cacciari et al., JHEP 006(2001)0103; K. Eskola et al., JHEP 04(2009)065

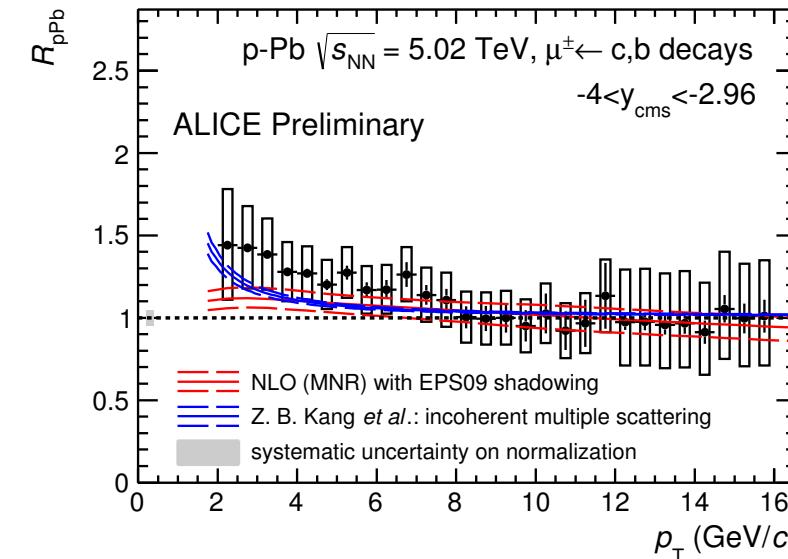
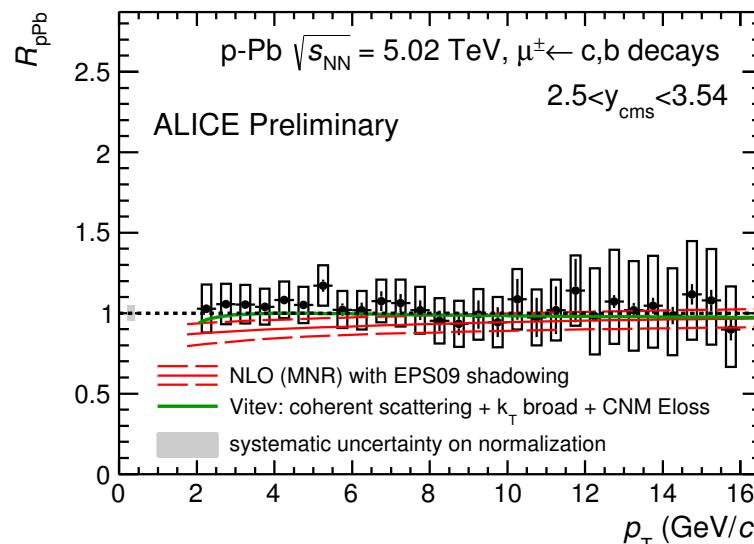
ALICE Nuclear modification factor for HF decay muons



- R_{pPb} at forward rapidity: consistent with unity within uncertainties.
- Data described well by theory calculations^[7].
 - MNR pQCD calculation with EPS09 shadowing parameterization.
 - I. Vitev : coherent scattering, k_T -broadening and energy loss in cold nuclear matter.
 - Z. B. Kang et al : incoherent multiple scattering

[7] M. Mangano et al., NPB 373(1992)295; K. Eskola et al., JHEP 04467(2009)065;
I. Vitev, PRC 75(2007)064906; Z. B. Kang et al., Phys. Lett. B 740 (2015) 23.

ALICE Nuclear modification factor for HF decay muons



- $R_{p\text{Pb}}$ at forward rapidity: consistent with unity within uncertainties.
- $R_{p\text{Pb}}$ at backward rapidity: slightly larger than unity at low p_T .
- Data described well by theory calculations^[7].
 - MNR pQCD calculation with EPS09 shadowing parameterization.
 - I. Vitev : coherent scattering, k_T -broadening and energy loss in cold nuclear matter.
 - Z. B. Kang et al : incoherent multiple scattering

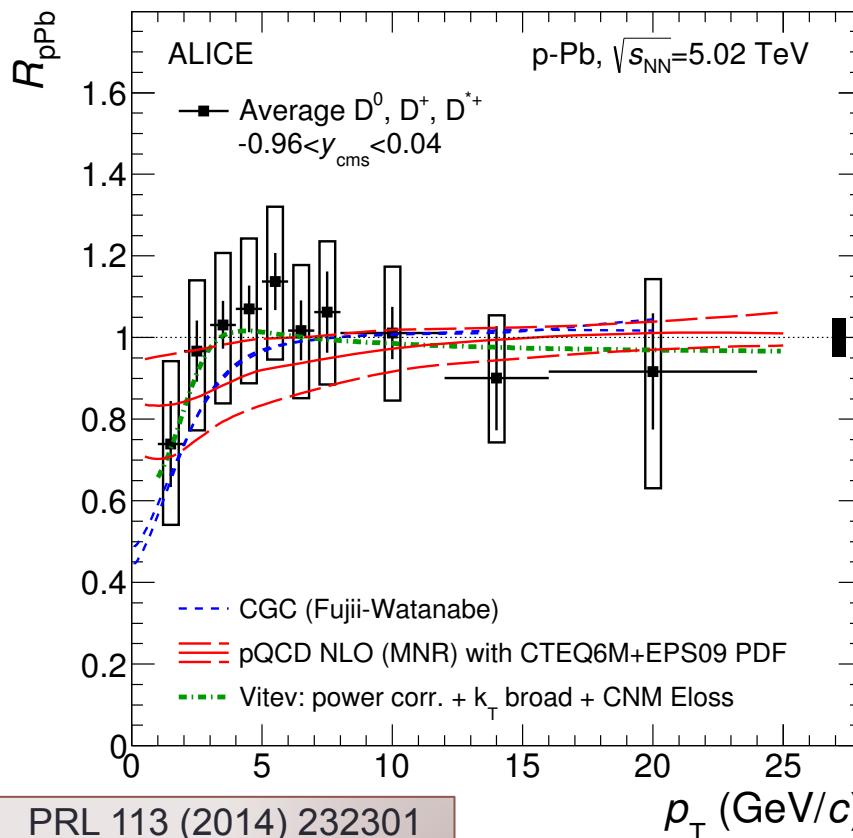
[7] M. Mangano et al., NPB 373(1992)295; K. Eskola et al., JHEP 04467(2009)065;
I. Vitev, PRC 75(2007)064906; Z. B. Kang et al., Phys. Lett. B 740 (2015) 23.



ALICE

Nuclear modification factor for D mesons

Average of D^0 , D^+ , D^{*+} mesons



PRL 113 (2014) 232301

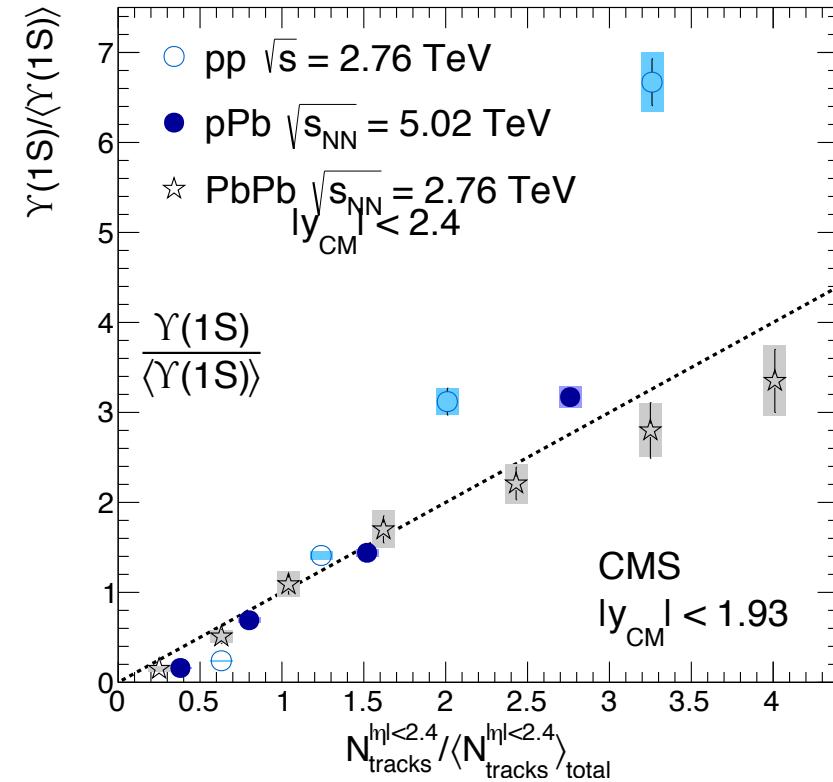
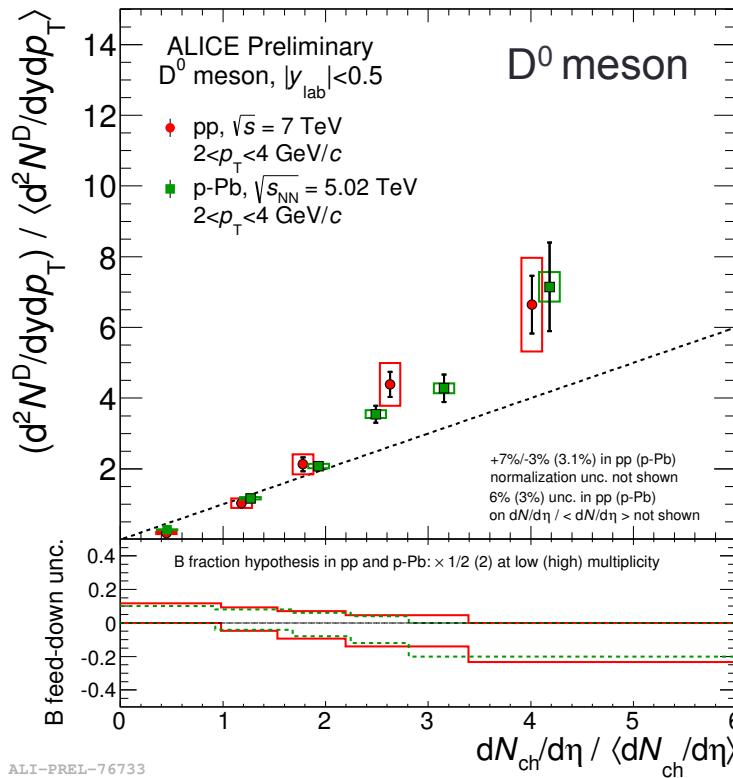
[8] arXiv:1308.1258

[9] NPB 373 (1992) 295 , JHEP 04 (2009) 065

[10] PRC 75 (2007) 064906

- R_{pPb} for D mesons consistent with unity for $p_T > 2 \text{ GeV}/c$
- Consistent with
 - Color Glass Condensate (CGC) calculations^[8].
 - MNR pQCD calculations with EPS09 nuclear PDF^[9].
 - Model including energy loss in cold nuclear matter, nuclear shadowing and k_T broadening^[10].
- **Cold nuclear matter effects are small at high p_T**

Multiplicity dependence of D-meson production

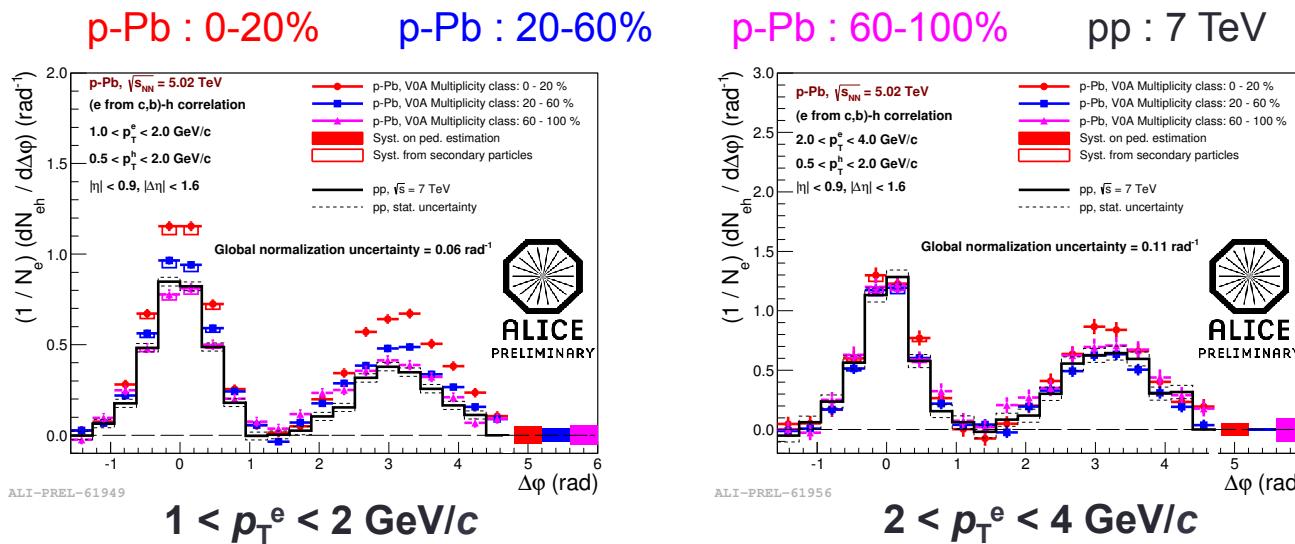
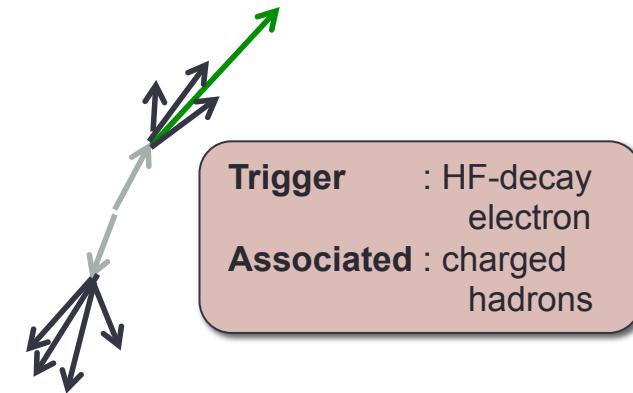


JHEP 04 (2014) 103

- Similar trend of D-meson production vs. multiplicity in pp and p-Pb collisions.
- In pp collisions: high multiplicity events from MPIs.**
- In p-Pb collisions: high multiplicity events also from $N_{\text{coll}} > 1$.**
- CMS : Y measurement shows similar trend in pp and p-Pb collisions.

ALICE Heavy-flavour decay electron - hadron correlations

- Near- and away-side angular correlations
 - p-Pb collisions in different multiplicity classes at $\sqrt{s_{NN}} = 5.02 \text{ TeV}$.
 - pp collisions at $\sqrt{s} = 7 \text{ TeV}$.
- Search for long-range angular correlations as observed in the light-flavour sector (PLB 719(2013)29).

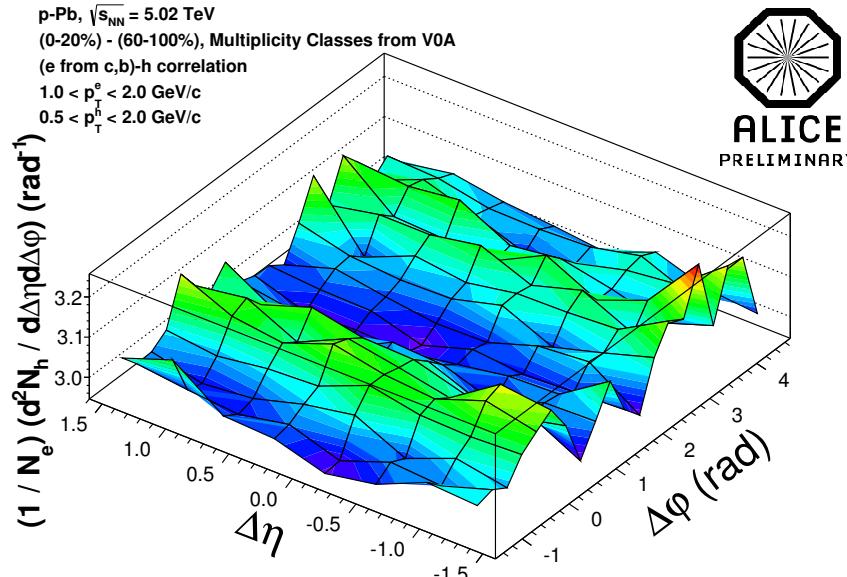


- Low p_T^e : enhanced yield on near and away side for the highest multiplicity class in p-Pb collisions.
- High p_T^e : near- and away-side yields are consistent in different multiplicity classes in p-Pb collisions at $\sqrt{s_{NN}} = 5.02 \text{ TeV}$ and pp collisions at $\sqrt{s} = 7 \text{ TeV}$.



ALICE Heavy-flavour decay electron - hadron correlations

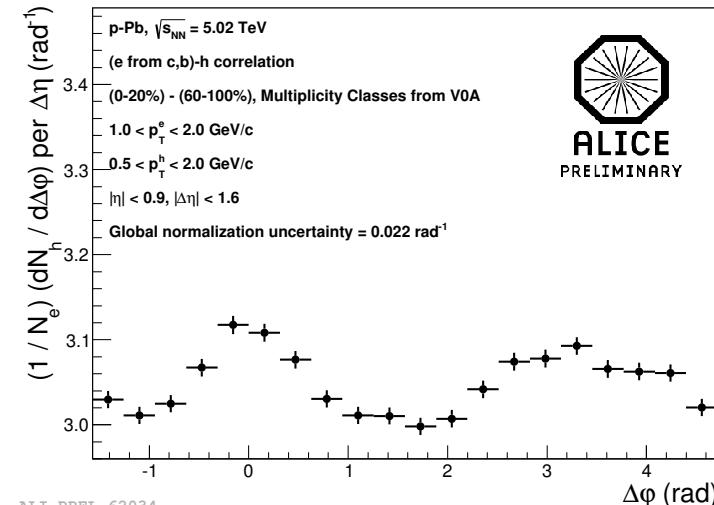
p-Pb, $\sqrt{s_{NN}} = 5.02$ TeV
 (0-20%) - (60-100%), Multiplicity Classes from V0A
 (e from c,b)-h correlation
 $1.0 < p_T^e < 2.0$ GeV/c
 $0.5 < p_T^h < 2.0$ GeV/c



ALI-PREL-62026



Remove jet contribution by subtracting multiplicity classes : **0-20% – 60-100%**



ALI-PREL-62034



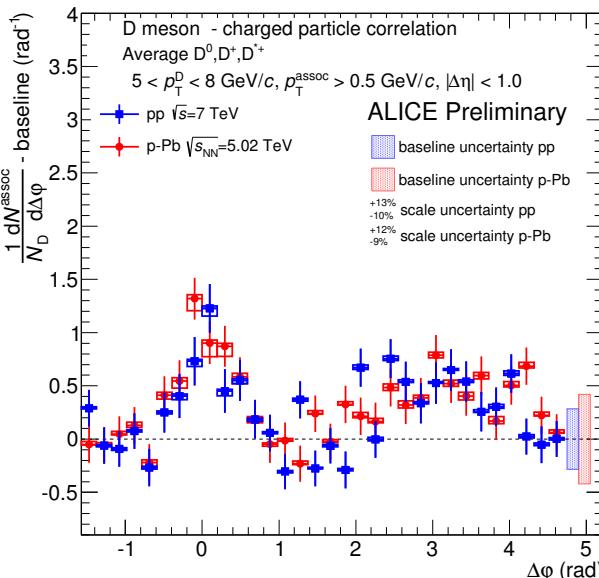
- Double-ridge structure is observed in heavy-flavour decay electron azimuthal angular correlations with charged particles in high multiplicity p-Pb collisions at low p_T^e after the baseline subtraction.
- Correlations in the light-flavour sector could be explained by initial-state effect or collective flow^[11]
 - CGC in initial state.
 - Hydrodynamics in final state.
 - Does it explain the double-ridge structure in the heavy-flavour sector as well??

[11] Dusling & Venugopalan, PRD 87 (2013) 094034;
 Bozek & Broniowski, PLB 718 (2013) 1557.

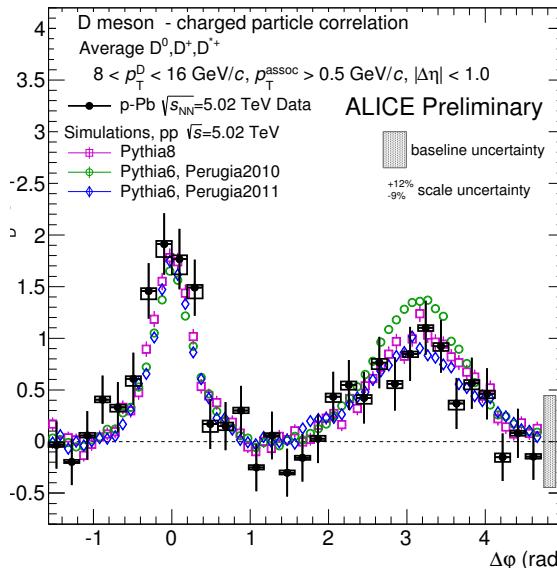


ALICE

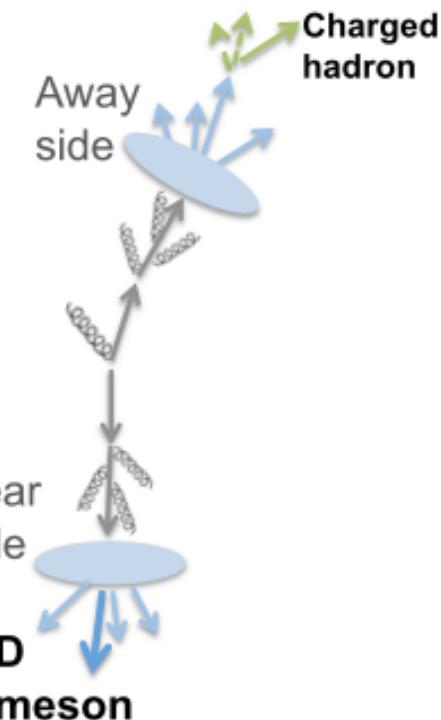
D meson - hadron correlations

pp : $\sqrt{s} = 7 \text{ TeV}$ p-Pb : $\sqrt{s_{NN}} = 5.02 \text{ TeV}$ $6 < p_T^D < 8 \text{ GeV}/c, p_T^{\text{Asso}} > 0.5 \text{ GeV}/c$ 

p-Pb Comparison with PYTHIA
 $8 < p_T^D < 16 \text{ GeV}/c, p_T^{\text{Asso}} > 0.5 \text{ GeV}/c$



Trigger : D meson
Associated : charged hadrons



Azimuthal angular correlation of D mesons with charged hadrons in pp and p-Pb collisions.

- Distributions from pp and p-Pb collisions compatible with each other.

Comparison with PYTHIA :

Consistent with different PYTHIA tunes within uncertainties.



ALICE Summary

- **pp collisions**
 - Cross-section measurements consistent with various pQCD calculations.
 - Increase of D-meson yield with increasing charge-particle multiplicity → suggesting MPIs in pp collisions.
- **p-Pb collisions**
 - No strong suppression observed for heavy-flavour yields at high p_T .
 - $R_{p\text{Pb}}$ well described by models which include cold nuclear matter effects.
 - Increase of D-meson yields with increasing charged-particle multiplicity → similar trend in pp and p-Pb collisions.
 - Double-ridge structure observed in HF-decay electron angular correlations with charged hadrons.
 - D-meson angular correlations with charged hadrons in p-Pb collisions consistent with pp collisions and various PYTHIA tunes.

Outlook

- Large data sample at higher \sqrt{s} expected in Run II from June 2015 onwards.
- Among others new and precise measurements of beauty, heavy-flavour angular correlations and heavy flavour in jets.

Back up



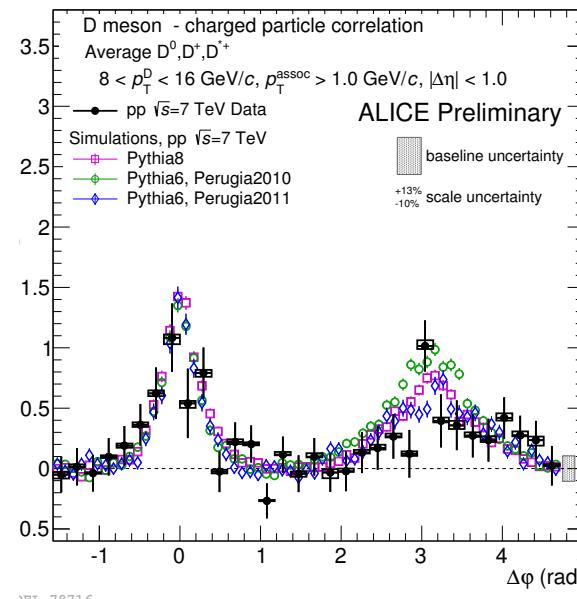
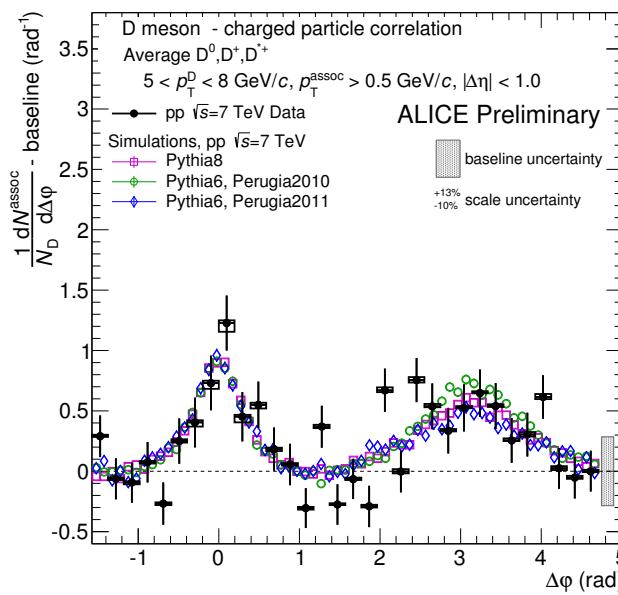
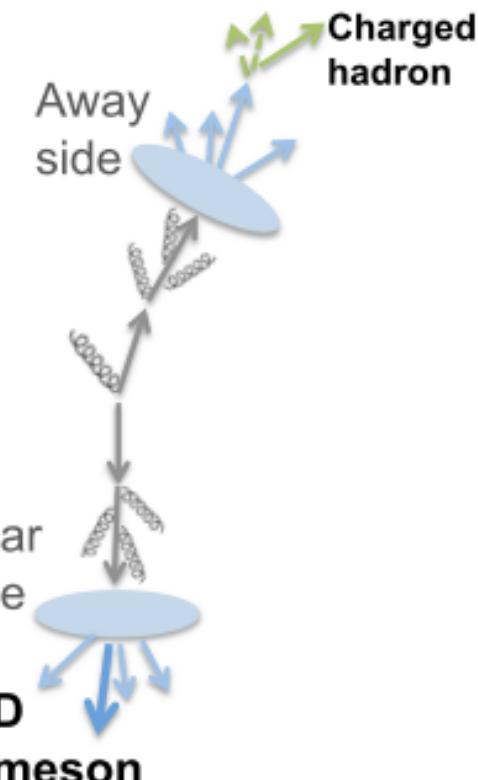
ALICE

D meson-hadron correlations

Measure hadron yield associated with D mesons on the near and away side.

pp at $\sqrt{s} = 7$ TeV

Trigger : D meson
Associated : charged hadrons



Azimuthal angular correlation of D mesons with charged hadrons in pp collisions at $\sqrt{s} = 7$ TeV.

Comparison with PYTHIA :

Consistent with different PYTHIA tunes within uncertainties.



ALICE Q_{pPb} for D mesons

- Test any multiplicity-dependent modification of p_T spectra in p-Pb collisions.

$$Q_{pPb}(p_T) = \frac{dN_{multi}^{pPb}/dp_T}{\langle N_{coll} \rangle dN^{pp}/dp_T}$$

- Determination of $\langle N_{coll} \rangle$ biased in p-Pb collisions.
 - Multiplicity bias
 - Geometrical bias
 - Jet-veto bias
- Two different estimators (V0A and ZNA) used to determine $\langle N_{coll} \rangle$.

V0A

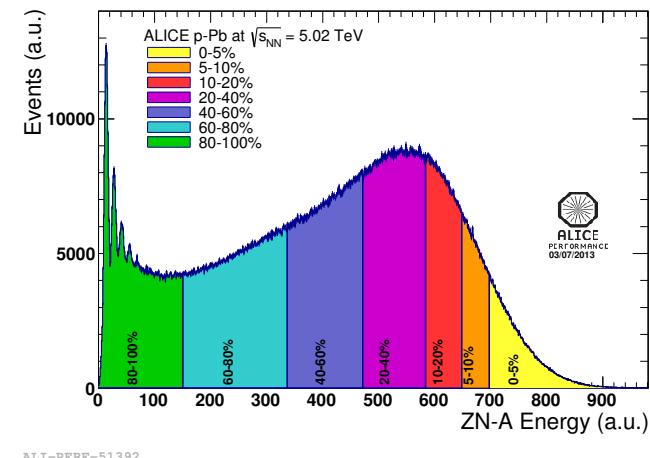
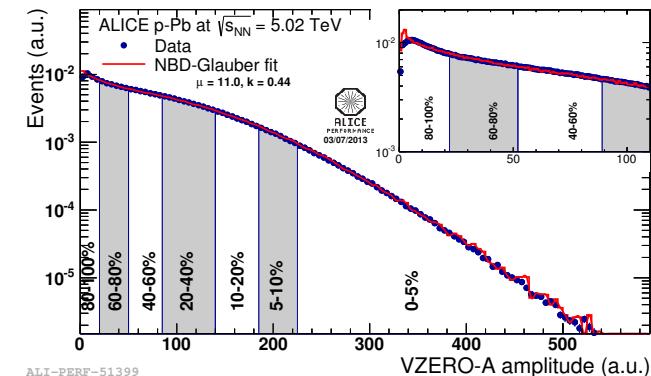
- $\langle N_{coll} \rangle$ from Glauber fit to V0A amplitude.
- Multiplicity from Negative Binomial distribution (NBD)

ZNA

ZN defined as energy deposited by Pb-spectator neutrons in the ZDC.

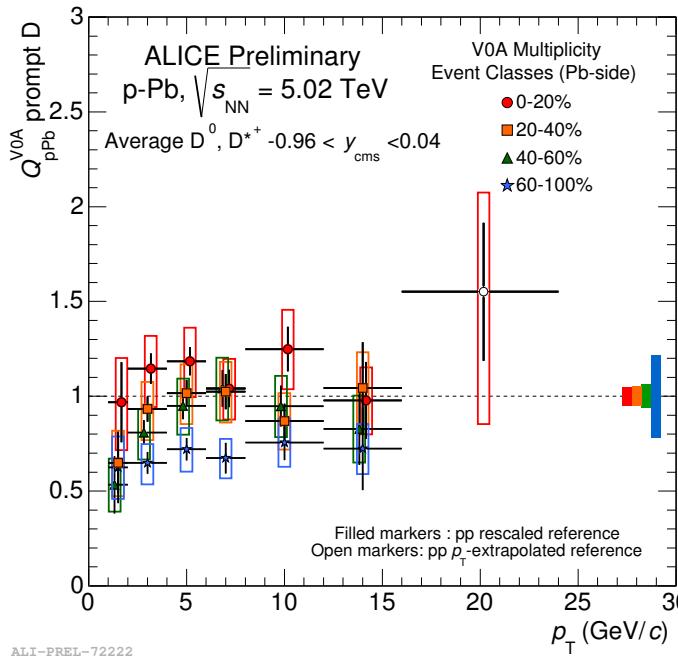
$\langle N_{coll} \rangle$ obtained with a hybrid method.

- Slice events in ZN energy (Pb-going side).

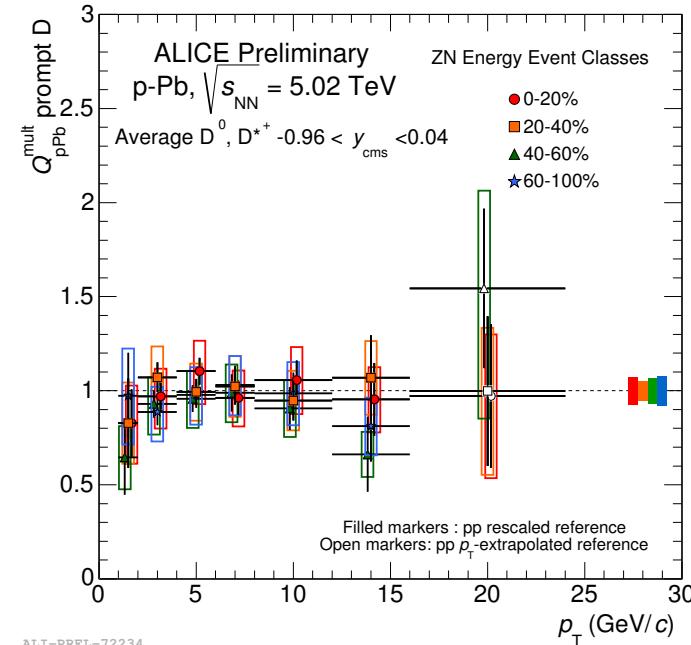




$Q_{p\text{Pb}}$ for D mesons



ALI-PREL-72222



ALI-PREL-72234

- V0A estimator: shows a residual bias in $Q_{p\text{Pb}}$ distribution of averaged D^0 and D^{*+} mesons.
- ZN estimator: No multiplicity-dependent modification of D-meson production relative to pp collisions within uncertainties.
- Patterns for both V0A and ZN estimators are consistent with those observed for charged hadrons.