Heavy-flavour production and multiplicity dependence in pp and p-Pb collisions with ALICE.

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for the ALICE Collaboration

LHCP Conference, June 2014, NYC, USA

Why Heavy Flavours (charm and beauty)?

Heavy quarks are produced in initial high-Q^2 processes

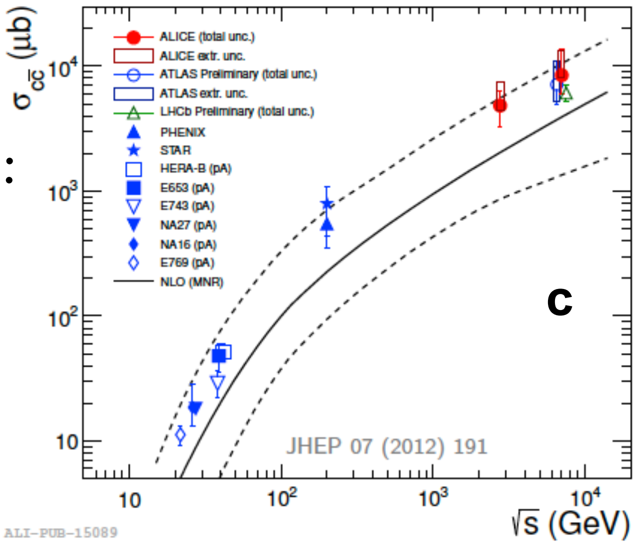
arXiv:1405.4144v1

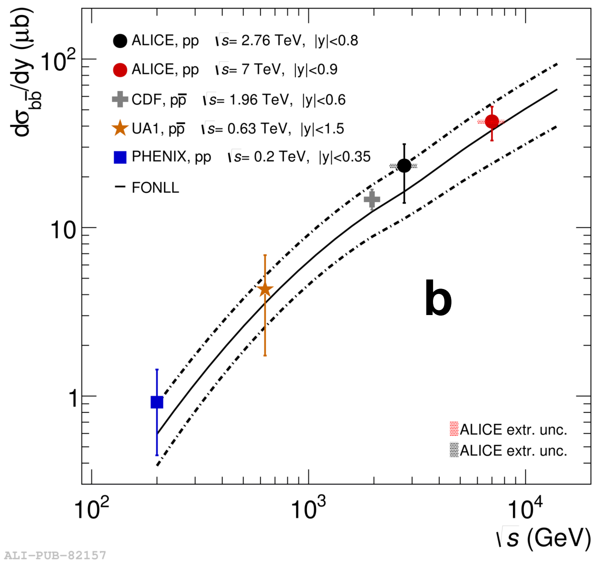
- Test for pQCD

  At LHC, larger cross-section:

  σ_c(LHC)~5-10 σ_c(RHIC)

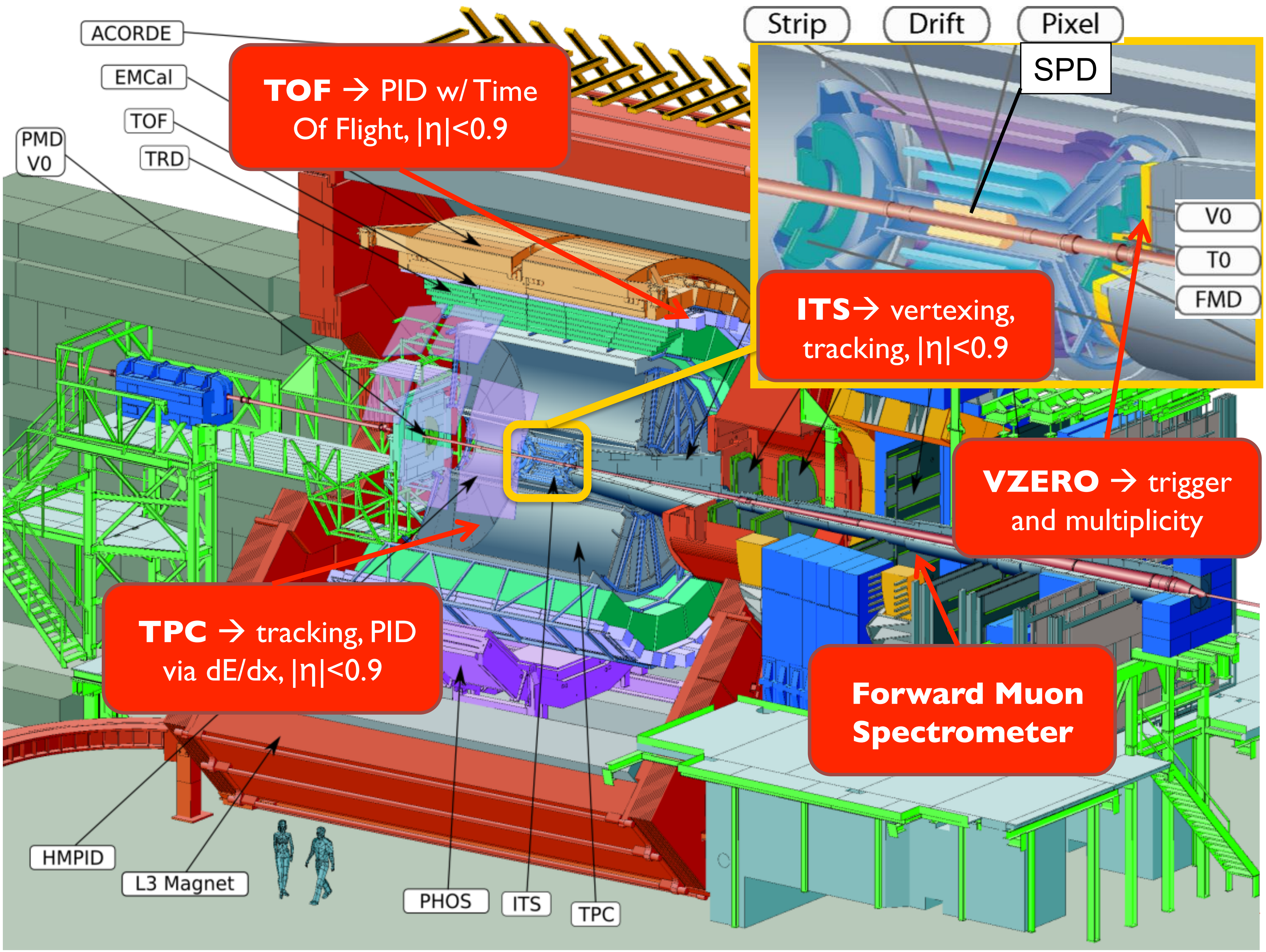
  σ_b(LHC)~ 50 σ_b(RHIC)



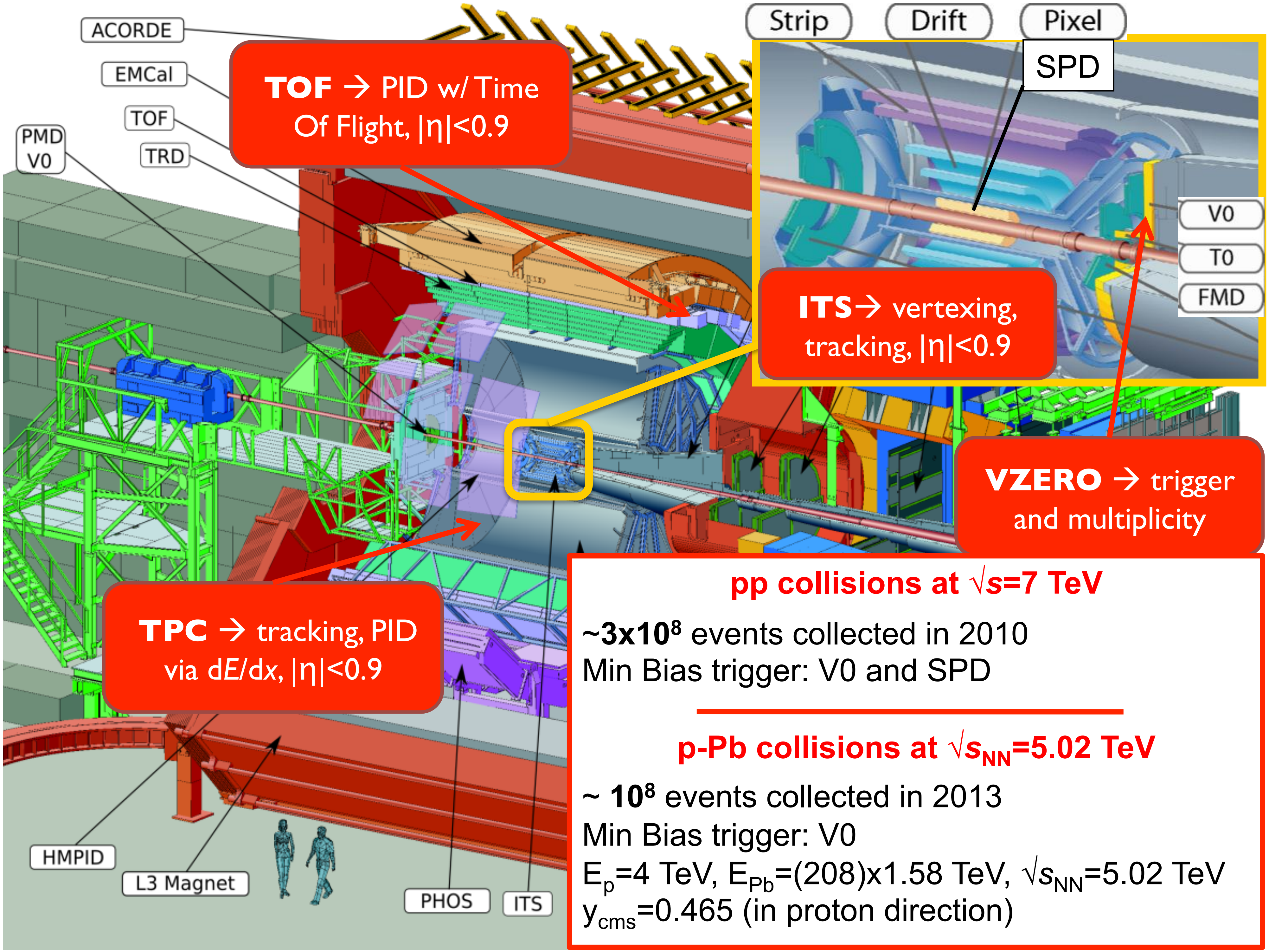


- Effect of multi-parton interactions on the heavy-flavour sector?
- pp is the reference for p-Pb and Pb-Pb collisions
- In p-Pb collisions: study nuclear PDF at small *x*

Can we get more insight into charm production mechanisms in pp and p-Pb collisions?



ACORDE
EMCal
TOF
TRD
PMD
V0
TOF → PID w/ Time Of Flight, |η|<0.9
Strip
Drift
Pixel
SPD
V0
T0
FMD
ITS→ vertexing, tracking, |η|<0.9
VZERO → trigger and multiplicity
TPC → tracking, PID via dE/dx, |η|<0.9
Forward Muon Spectrometer
HMPID
L3 Magnet
PHOS
ITS
TPC



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

~3x10^8 events collected in 2010
Min Bias trigger: V0 and SPD

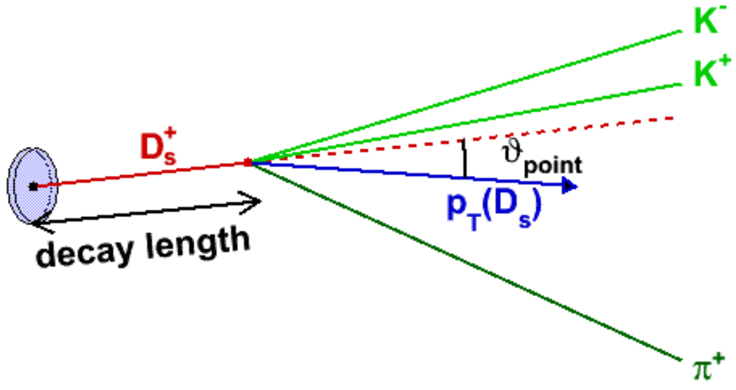
p-Pb collisions at $\sqrt{s_{NN}}$=5.02 TeV

~ **10^8** events collected in 2013
Min Bias trigger: V0
E_p=4 TeV, E_{Pb}=(208)x1.58 TeV, $\sqrt{s_{NN}}$=5.02 TeV
y_{cms}=0.465 (in proton direction)

Measurements of Heavy Flavours in ALICE

Full reconstruction of D-meson hadronic decays

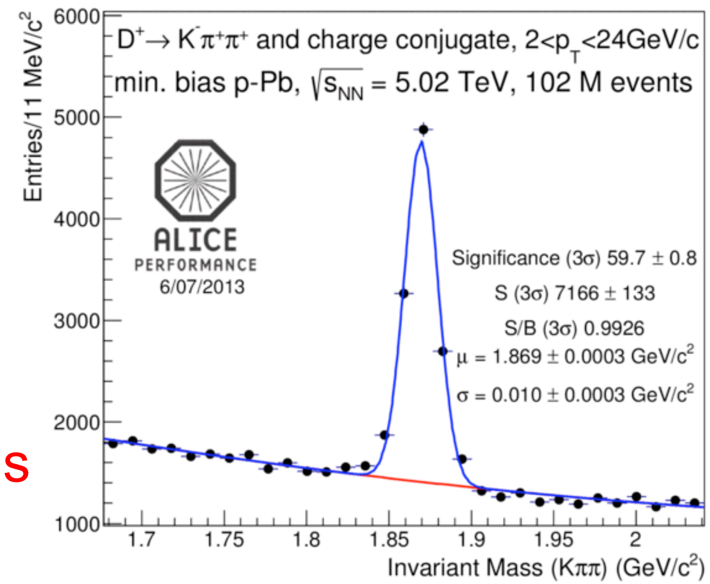
$D^0 \rightarrow K^-\pi^+$
$D^+ \rightarrow K^-\pi^+\pi^+$
$D^{*+} \rightarrow D^0(\rightarrow K^-\pi^+)\pi^+$
$D_s^+ \rightarrow \phi(\rightarrow K^+K^-)\pi^+$



Invariant mass analysis based on displaced secondary vertices, selected with topological cuts and PID

Correction for beauty feed-down (based on FONLL) to extract results for prompt D mesons

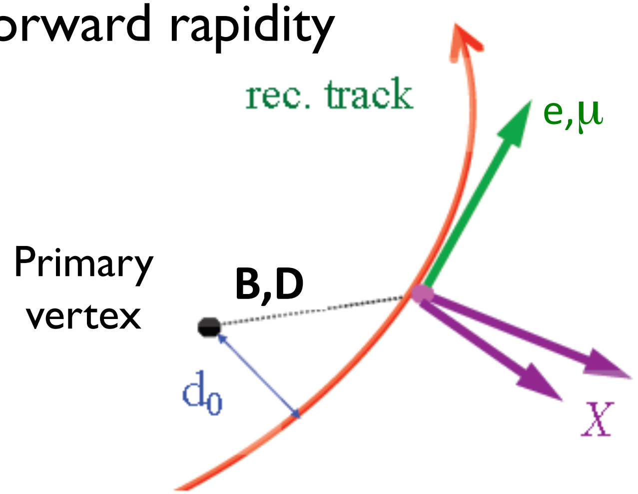
FONLL: JHEP, 1210 (2012) 137



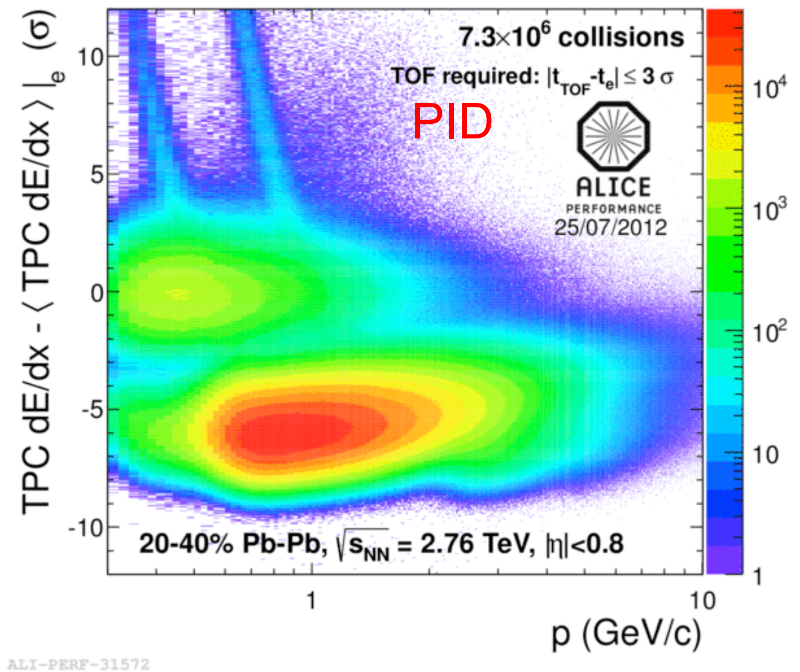
Measurements of Heavy Flavours in ALICE

Semi-leptonic decays of charm and beauty

Electrons: mid-rapidity
Muons: forward rapidity



Example: electrons



Background (π^0 and η Dalitz decays, photon conversions) subtracted with:

→ Invariant mass method: reconstruction of low-mass e^+e^- pairs

→ Cocktail: based on different background sources using Monte Carlo hadron-decay generator

Beauty-decay electrons: extra cut on track impact parameter and/or separation based on e-h correlations

Heavy-flavour production at the LHC: test of pQCD

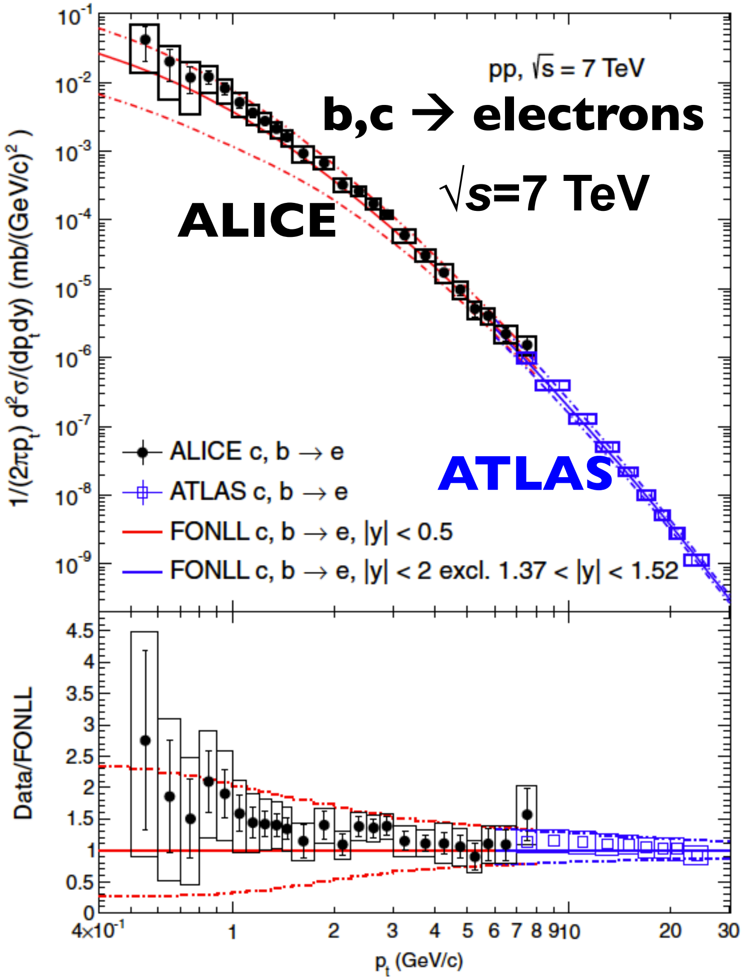
pQCD Factorization:

Collins, Soper, Sterman
Nucl. Phys. B263 (1986) 37

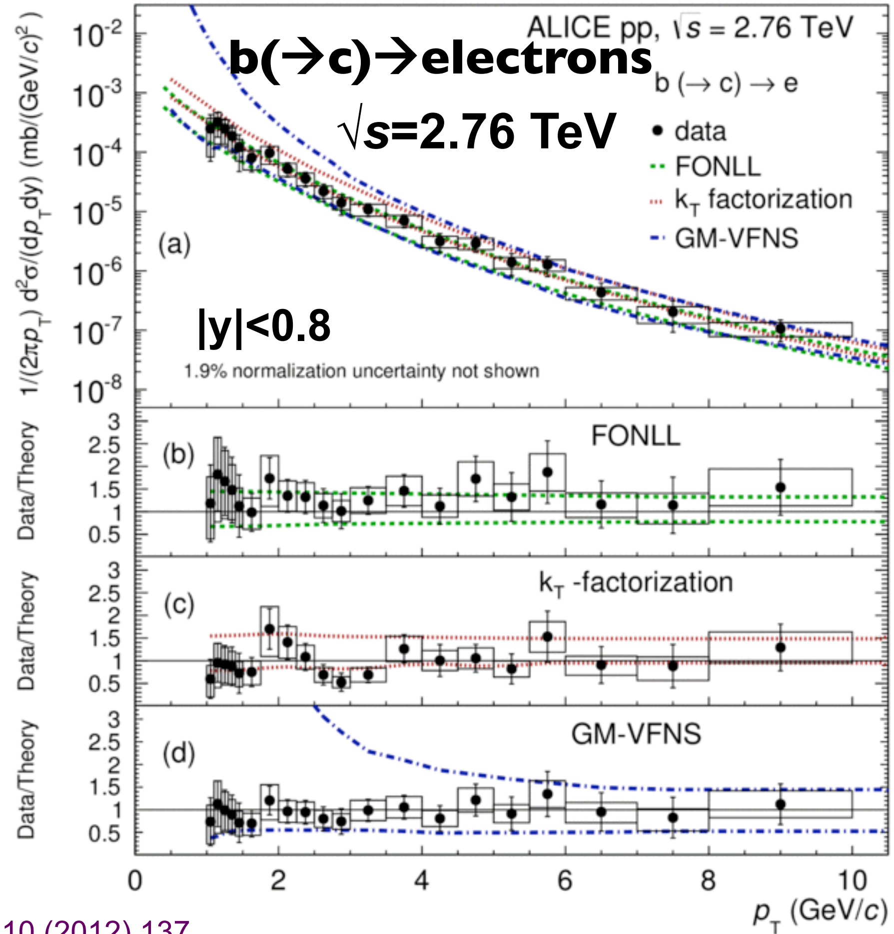
$$E\frac{d^3\sigma}{dp^3} \propto f_{a/A}(x_a, Q^2) \otimes f_{b/B}(x_b, Q^2) \otimes \frac{d\hat{\sigma}^{ab\to cd}}{dt} \otimes D_{h/c}(z_c, Q^2) \otimes D_{h/d}(z_d, Q^2)$$

PDF — Partonic x-section — Fragmentation function

Heavy-flavour decay leptons



(ALICE) Phys. Rev. D86 (2012) 112007
(ATLAS) PLB 707 (2012) 438



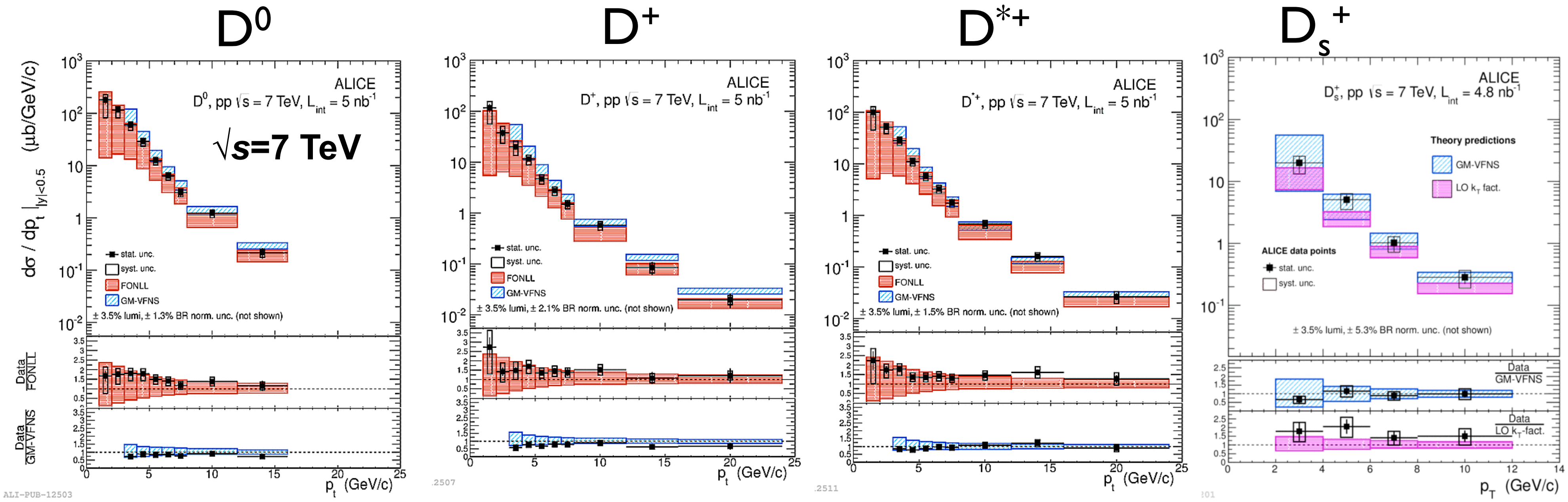
FONLL: JHEP, 1210 (2012) 137
GM-VFNS: Eur.Phys.J., C72(2012)2082
Nucl. Phys. B, 872(2013) 253
k_T factorization: Phys.Rev., D87(2013)094022

arXiv:1405.4117v1

Complementarity with ATLAS measurements at high p_T

Cross sections at both energies (7 and 2.76 TeV) well described by different pQCD predictions

Open charm in pp collisions



Cross sections for D mesons:

D^0 $1<p_T<16$ GeV/c

D^+, D^{*+} $1<p_T<24$ GeV/c

D_s^+ $2<p_T<12$ GeV/c

ALICE Coll. JHEP 01 (2012) 128
ALICE Coll, Phys. Lett. B 718 (2012) 279
ALICE Coll. JHEP 1207 (2012) 191

FONLL: JHEP, 1210 (2012) 137
GM-VFNS: Eur.Phys.J., C72(2012)2082
Nucl. Phys. B, 872(2013) 253
k_T factorization: Phys.Rev., D87 (2013) 094022

Within uncertainties described by FONLL/GM-VFNS pQCD calculations and k_T-factorization approaches

Heavy-flavour production at the LHC: nuclear PDF at small *x*

pQCD Factorization:

Collins, Soper, Sterman
Nucl. Phys. B263 (1986) 37

$$E\frac{d^3\sigma}{dp^3} \propto \underbrace{f_{a/A}(x_a, Q^2) \otimes f_{b/B}(x_b, Q^2)}_{\text{PDF}} \otimes \underbrace{\frac{d\hat{\sigma}^{ab\rightarrow cd}}{dt}}_{\text{Partonic x-section}} \otimes \underbrace{D_{h/c}(z_c, Q^2) \otimes D_{h/d}(z_d, Q^2)}_{\text{Fragmentation function}}$$

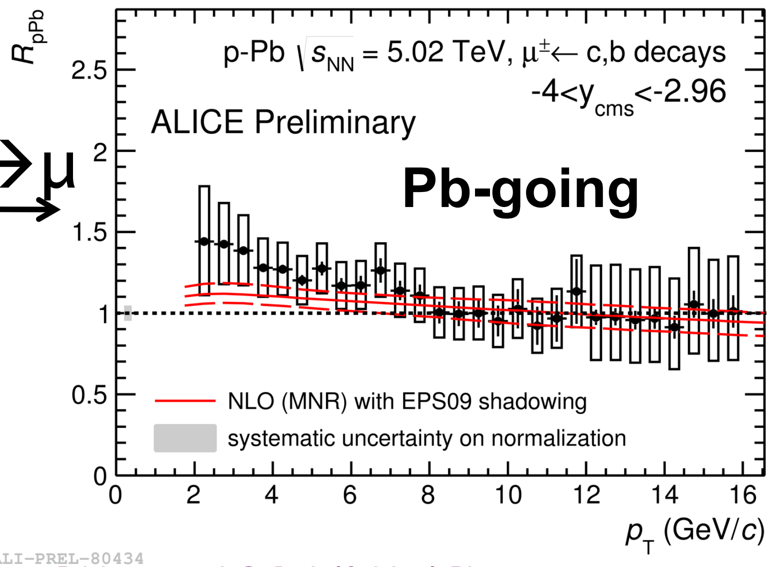
p-Pb: is HF production affected by the nucleus?

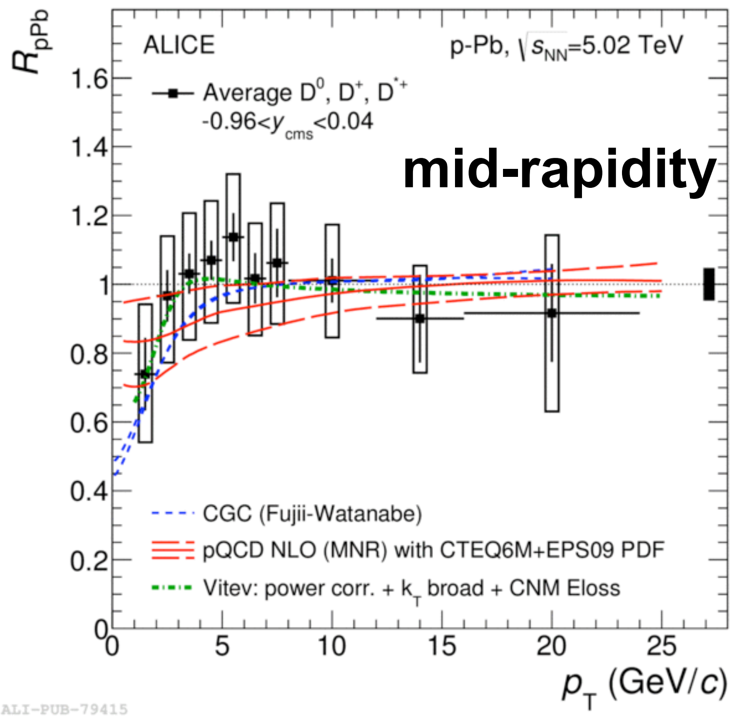
$$R_{pPb} = \frac{(d\sigma/dp_T)_{pPb}}{A \times (d\sigma/dp_T)_{pp}}$$

→ R_{pPb}=1 in absence of nuclear effects

arXiv:1405.3452

c,b→μ





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

M. Mangano, P. Nason and G. Ridolfi, Nucl. Phys. B373 (1992) 295

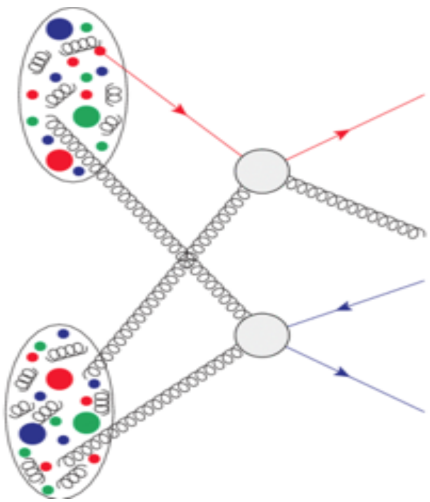
K. J. Eskola, H. Paukkunen and C.A. Salgado, JHEP 0904 (2009) 065

Fujii - Watanabe, private communication

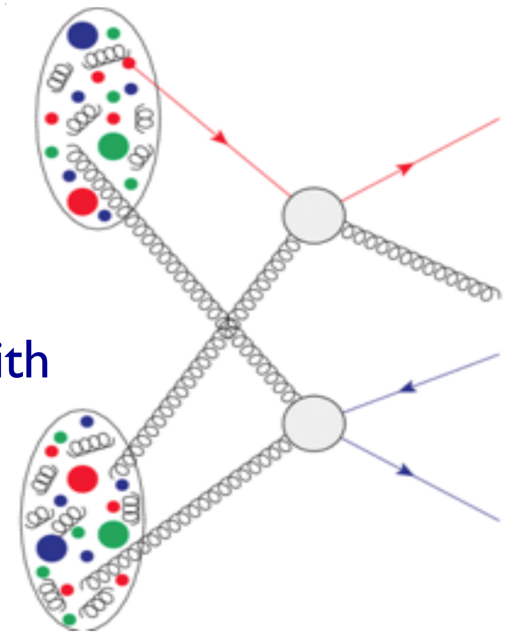
Different *x* regimes explored in different rapidity ranges with HF probes
→shadowing/saturation relevant at low p_T at LHC energies

Data described within uncertainties by different models of initial state effects

Heavy-flavour production at the LHC: interplay between hard and soft processes



Multi-parton interactions (MPI): effects on the hard scale



- NA27 (pp collisions at $\sqrt{s}$ = 28 GeV):

  Events with charm have larger charged particle multiplicity

  NA27 Coll. Z.Phys.C41:191

- CMS (pp collisions at $\sqrt{s}$ = 7 TeV):

  Studies on jets and underlying event are better agreement with models including MPI

  Eur. Phys. J. C 73 (2013) 2674

- LHCb (pp collisions at $\sqrt{s}$ = 7 TeV):

  Double charm production agrees better with models including double parton scattering

  J. High Energy Phys., 06 (2012) 141

- ALICE (pp collisions at $\sqrt{s}$ = 7 TeV):

  Approximately linear increase of J/ψ yield as a function of multiplicity

  Phys.Lett. B712 (2012) 165

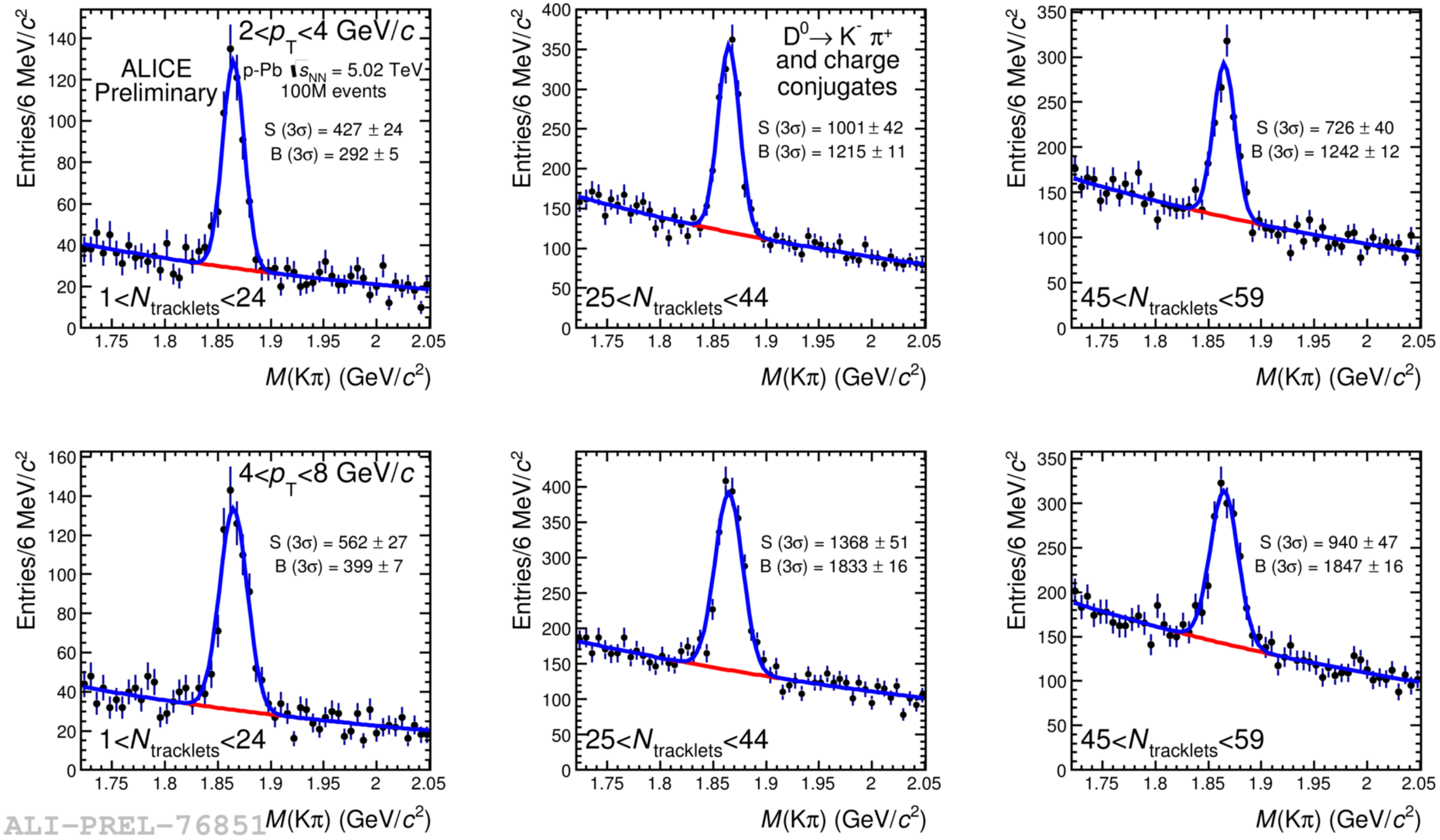
Open-charm production vs multiplicity

Self-normalized D-meson yields (relative to the multiplicity integrated yield)

Multiplicity estimator: N tracklets=n. track segments reconstructed in SPD ($|\eta|<1$)

$$\frac{d^2N^D/dydp_T}{\left\langle d^2N^D/dydp_T \right\rangle} = \frac{\boxed{Y^{mult}/(\varepsilon^{mult}\times N^{mult}_{event})}}{Y^{tot}/(\varepsilon^{tot}\times N^{tot}_{event}/\varepsilon^{trigger})}$$

→ D yield/event in a given multiplicity range, corrected for reconstruction efficiency



Example: D^0 meson

p-Pb $\sqrt{s_{NN}}$=5.02 TeV

multiplicity ranges:
- $1<N_{tracklets}<24$
- $25<N_{tracklets}<44$
- $45<N_{tracklets}<59$

p_T ranges
- $2<p_T<4$ GeV/c
- $4<p_T<8$ GeV/c

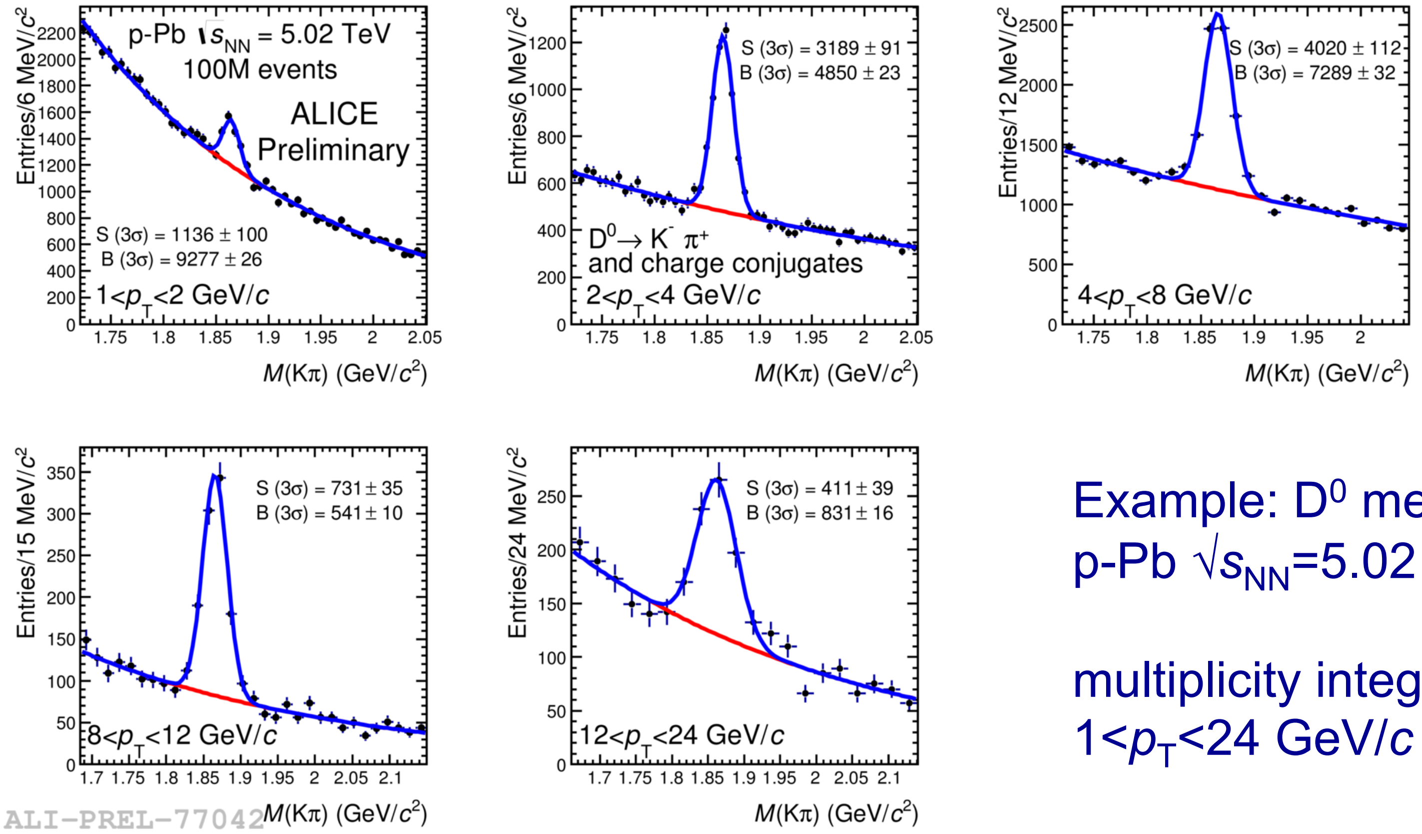
Open-charm production vs multiplicity

D-meson yield in multiplicity intervals (pp and p-Pb)

Multiplicity estimator: N tracklets=n. track segments reconstructed in SPD (|η|<1)

$$\frac{d^2N^D/dydp_T}{\left\langle d^2N^D/dydp_T \right\rangle} = \frac{Y^{mult}/(\varepsilon^{mult} \times N^{mult}_{event})}{\boxed{Y^{tot}/(\varepsilon^{tot} \times N^{tot}_{event}/\varepsilon^{trigger})}}$$

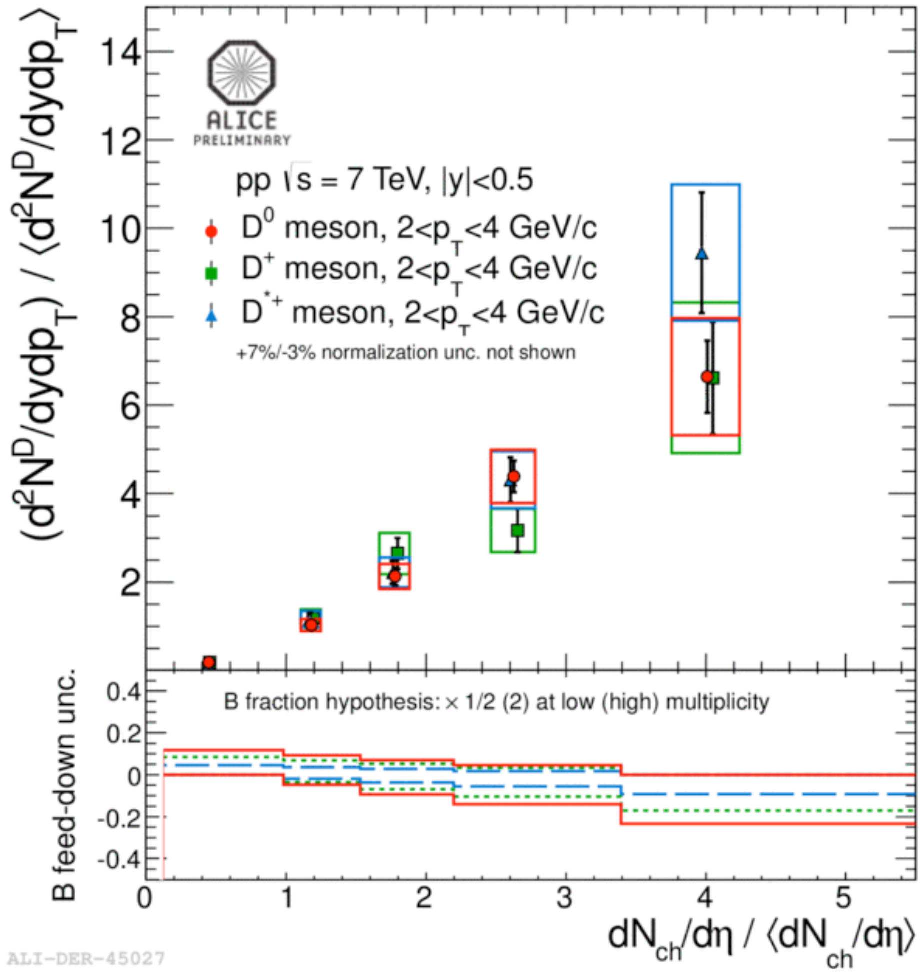
D yield/event integrated in multiplicity, corrected for reconstruction and trigger efficiencies



Example: D^0 meson
p-Pb $\sqrt{s_{NN}}$=5.02 TeV

multiplicity integrated, 5 bins in:
$1<p_T<24$ GeV/c

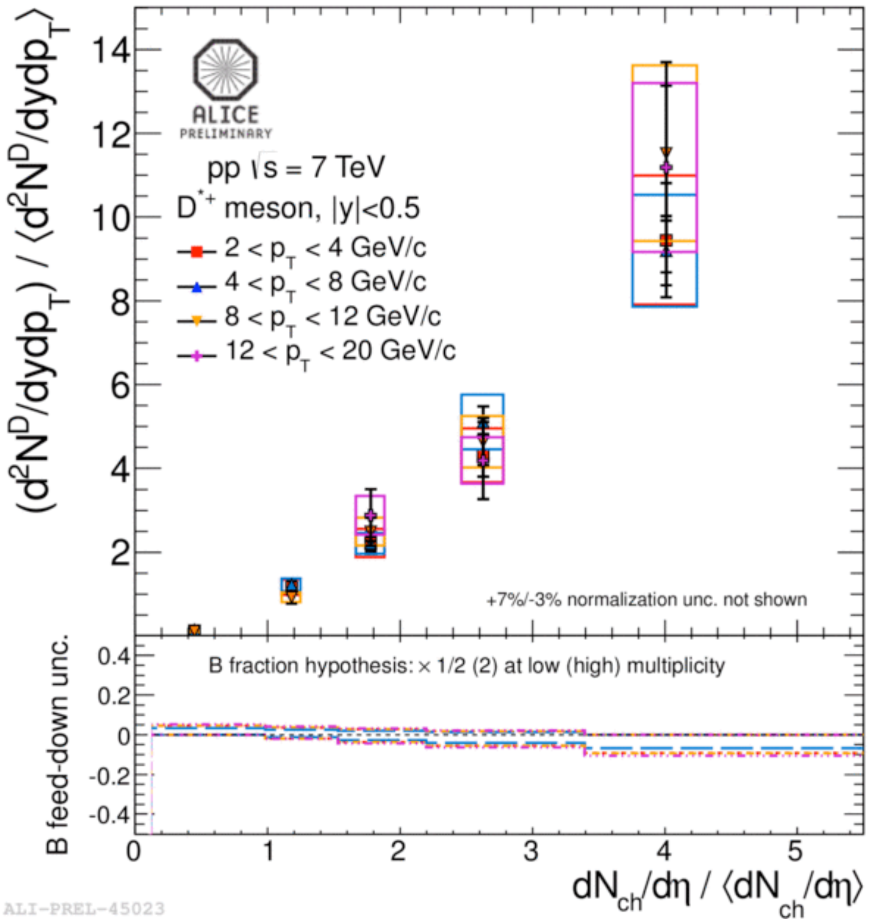
D-meson yield vs multiplicity: pp



Self-normalized D-meson yields (relative to the multiplicity integrated yield)

Increase of self-normalized yields with increasing charged-particle multiplicity
Results for D^0, D^+, D^{*+} mesons in agreement within the uncertainties

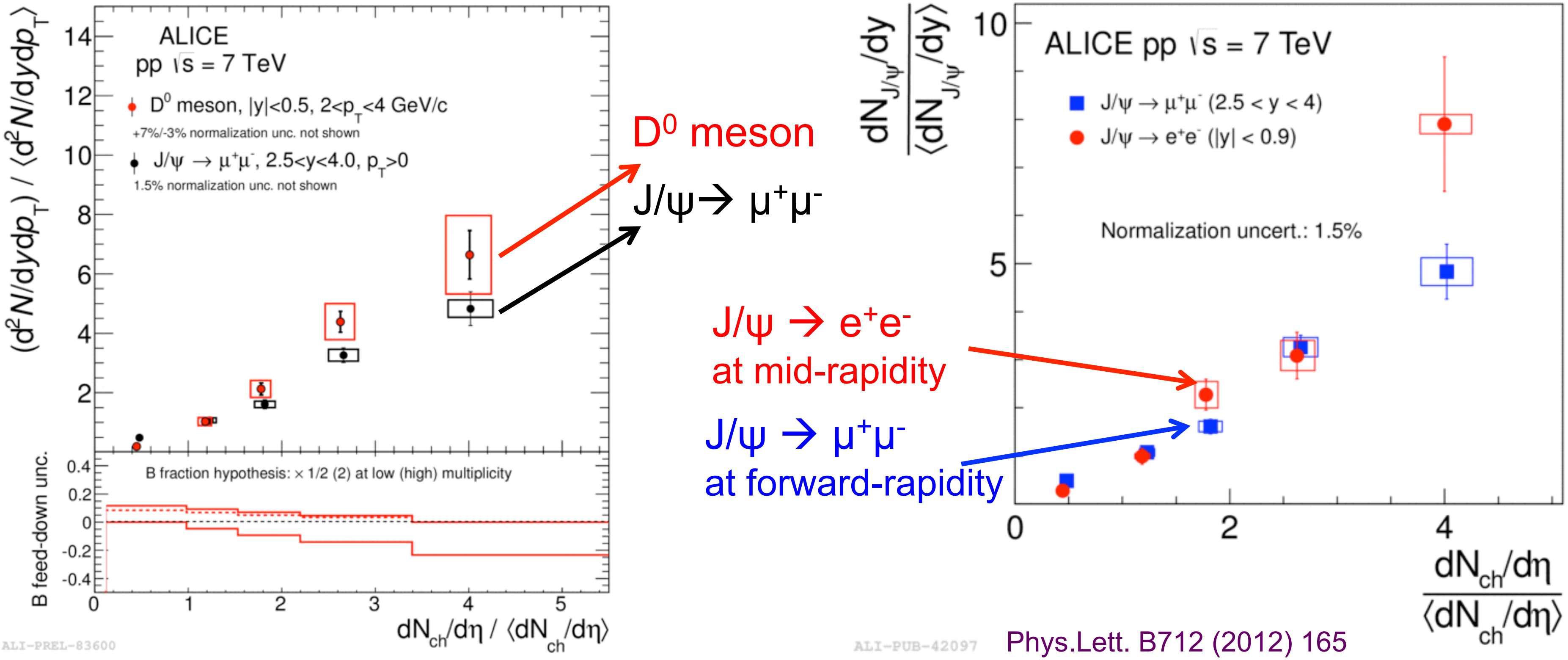
D-meson yield vs multiplicity: pp



Results from different p_T ranges in agreement within the uncertainties

Increasing trend of D-meson yield vs charged multiplicity in pp collisions → MPI are dominating the high-multiplicity events and affecting heavy-flavour production

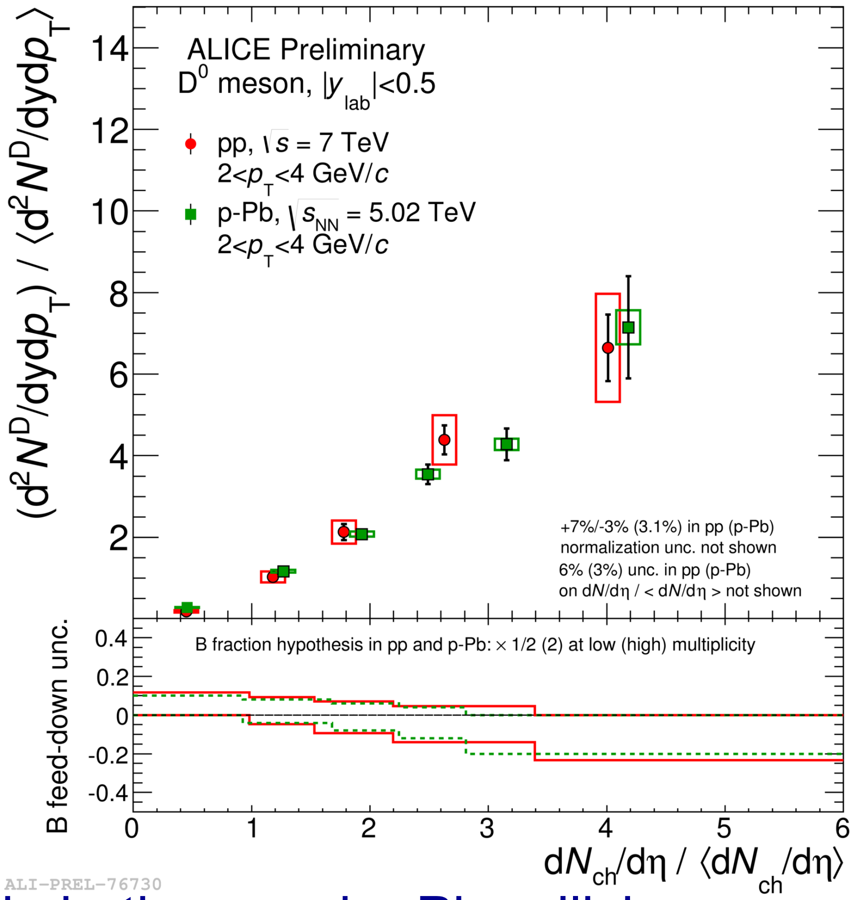
D-meson vs J/ψ yields: pp



Caveat: different rapidity and p_T intervals for D and J/ψ measurements

Increasing trend with multiplicity for both D mesons and J/ψ in pp collisions

D-meson yield vs multiplicity: pp and p-Pb



Compatible trend in both pp and p-Pb collisions

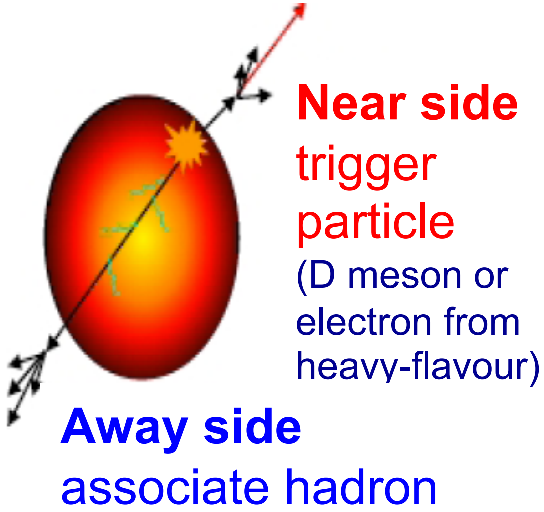
High-multiplicity p-Pb collisions: MPI (like pp) but also higher number of binary nucleon-nucleon collisions

Heavy-flavour production at the LHC:

azimuthal correlations:

b and c fragmentation

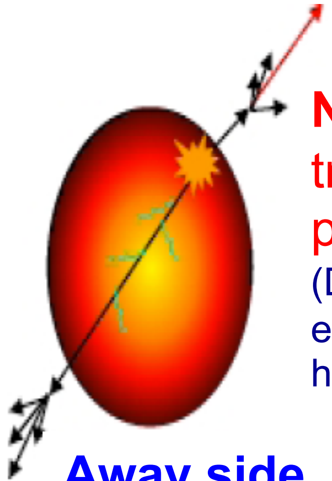
initial/final state effects in p-Pb



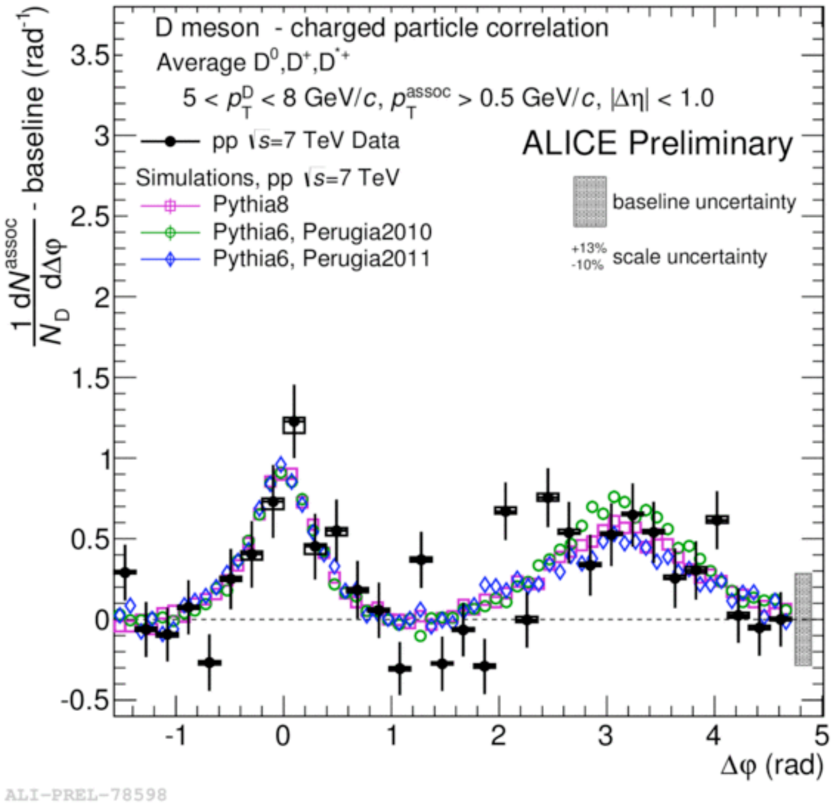
Heavy-flavour azimuthal correlations

In pp collisions:

- Address charm and beauty jet fragmentation
- Reference for comparison with Pb-Pb and p-Pb



D meson-charged hardon azimuthal correlations

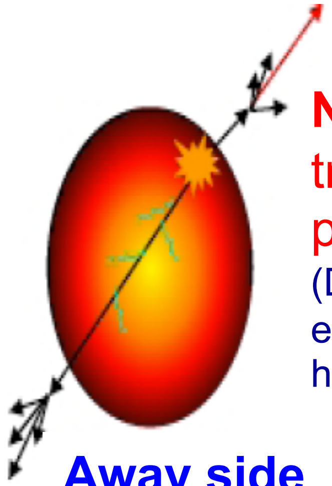


Compatible within uncertainties with expectations from different Pythia tunes

Heavy-flavour azimuthal correlations

In pp collisions:

- Address charm and beauty jet fragmentation
- Reference for comparison with Pb-Pb and p-Pb

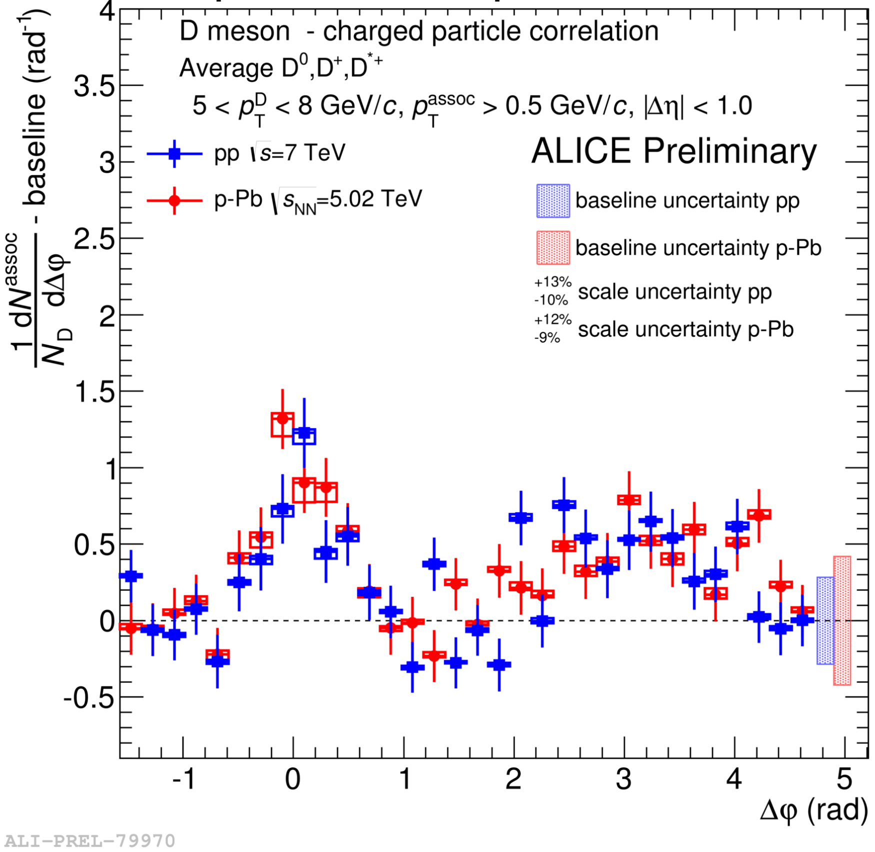


In p-Pb collisions:

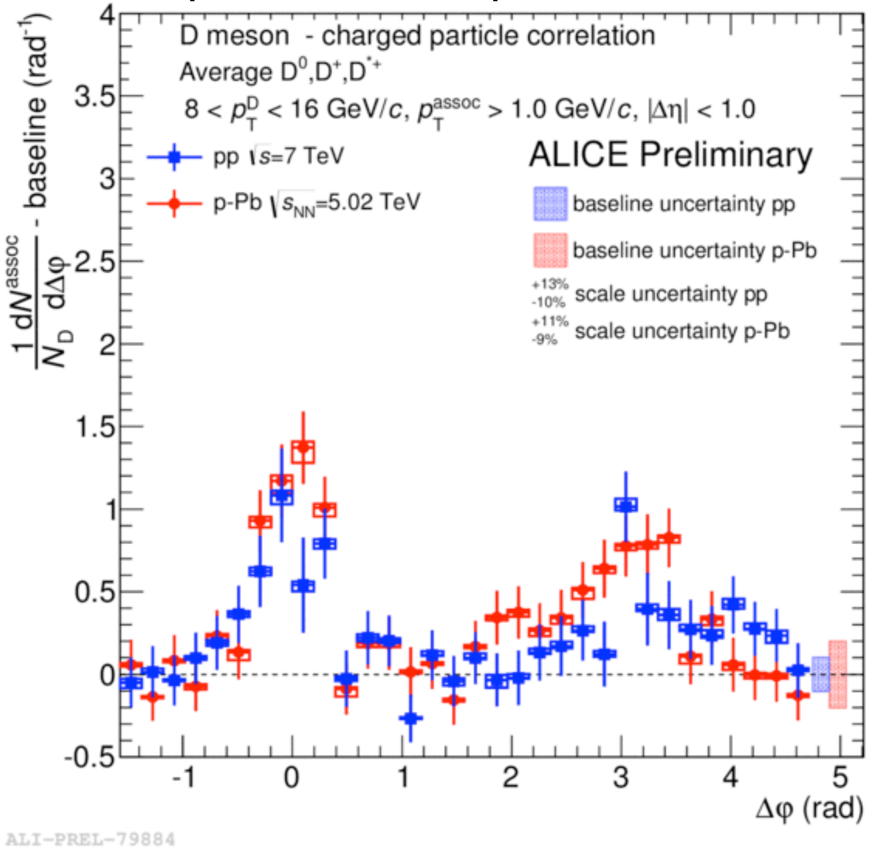
- Are heavy-flavour jet properties affected by nuclear effects due to the Pb nucleus?

D- hadron azimuthal correlations: pp vs p-Pb

$5<p_T^D<8$ GeV/c, $p_T^{assoc}>0.5$ GeV/c



$8<p_T^D<16$ GeV/c, $p_T^{assoc}>1$ GeV/c

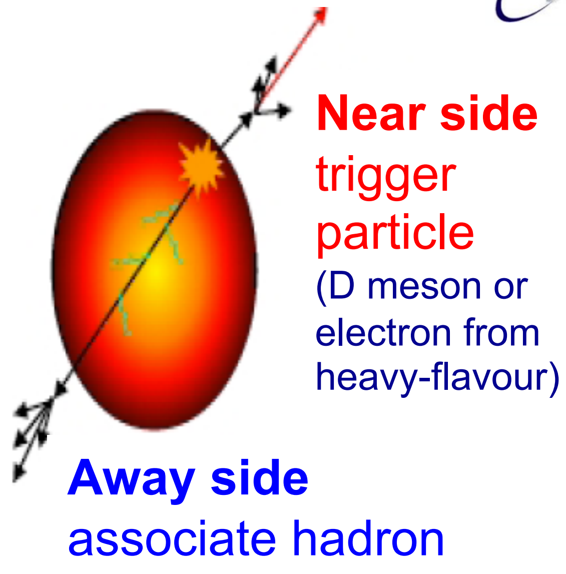


Compatibility within uncertainties between pp collisions at $\sqrt{s}$ = 7 TeV and p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV after baseline subtraction

Heavy-flavour azimuthal correlations

In pp collisions:

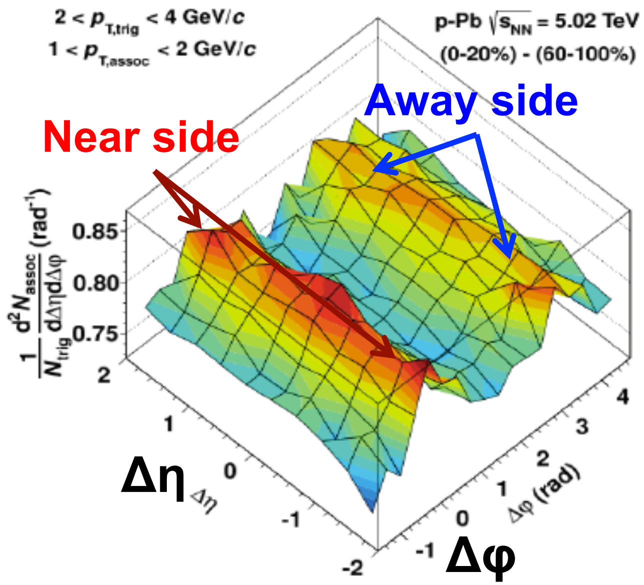
- Address charm and beauty jet fragmentation
- Reference for comparison with Pb-Pb and p-Pb



In p-Pb collisions:

- Are heavy-flavour jet properties affected by nuclear effects due to the Pb nucleus?

- Long range structure observed with light flavours on both near and away side
  - Initial-state effects (i.e. Color Glass Condensate)
    B. Arbuzov et al, Eur.Phys.J. C71 (2011) 1730
    K. Dusling and R. Venugopalan, arXiv:1302.7018 [hep-ph].
  - Final-state effects (i.e. hydro)
    S. Alderweireldt and P. Van Mechelen, arXiv:1203.2048 [hep-ph]
    K. Werner, I. Karpenko, and T. Pierog, P.R.L. 106 (2011) 122004

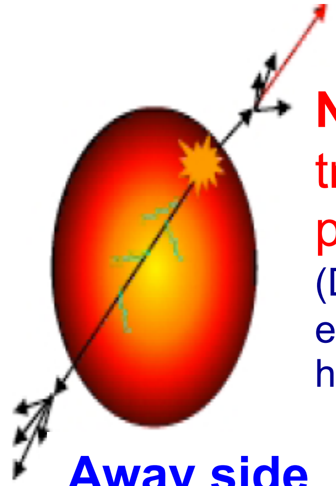


(high multiplicity) - (low multiplicity) to subtract jet contribution

Heavy-flavour azimuthal correlations

In pp collisions:

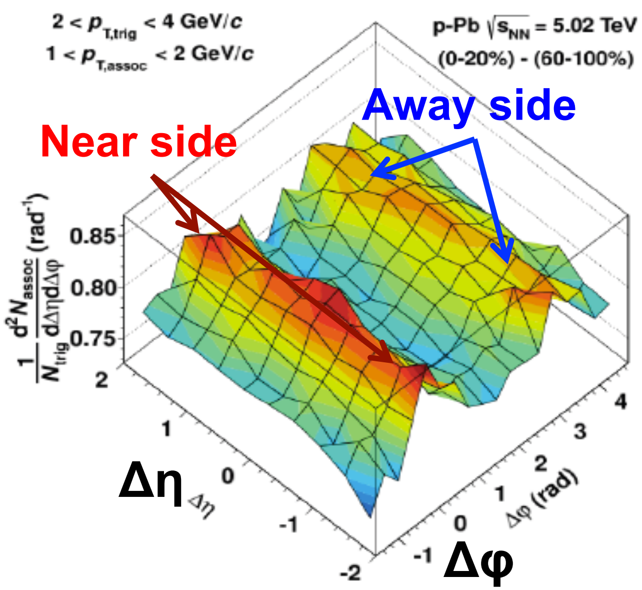
- Address charm and beauty jet fragmentation
- Reference for comparison with Pb-Pb and p-Pb



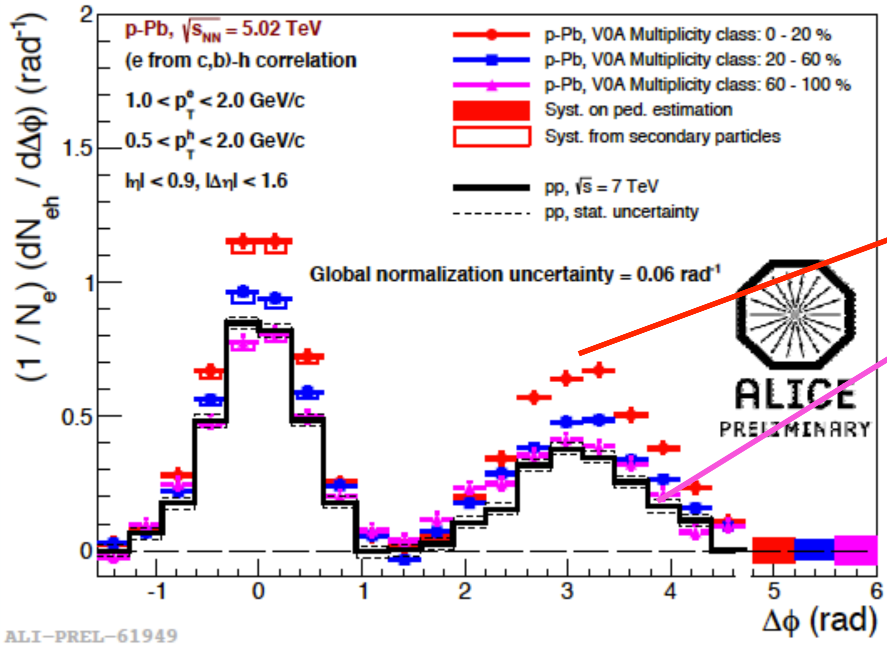
In p-Pb collisions:

- Are heavy-flavour jet properties affected by nuclear effects due to the Pb nucleus?

- Long range structure observed with light flavours on both near and away side
  - – Is this present in the heavy-flavour sector?



HFe-h correlations in p-Pb from ALICE



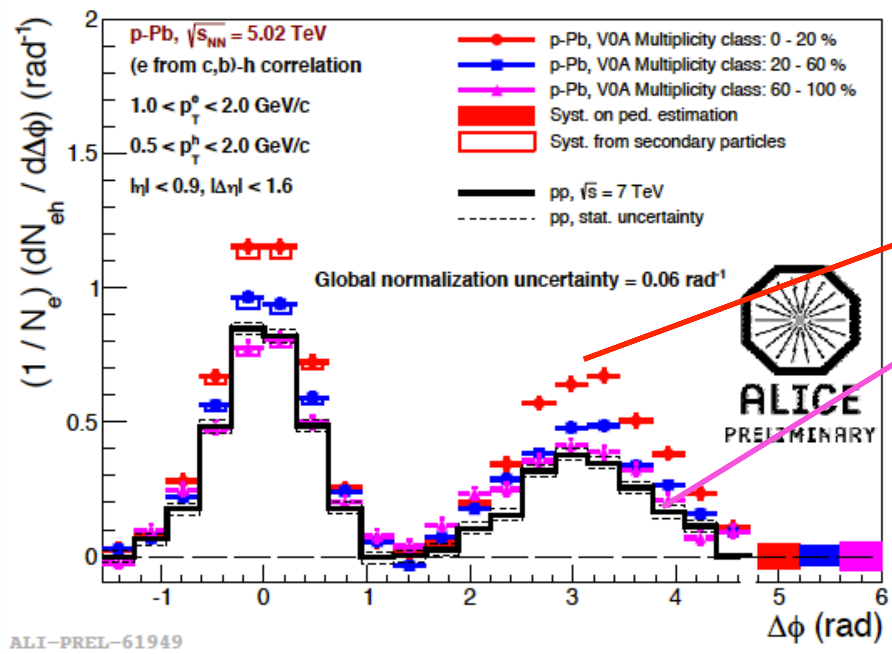
p-Pb collisions in two multiplicity ranges:

0-20% (high multiplicity)

60-100% (low multiplicity)

Jet contribution reduced by subtracting low-multiplicity events

HFe-h correlations in p-Pb from ALICE



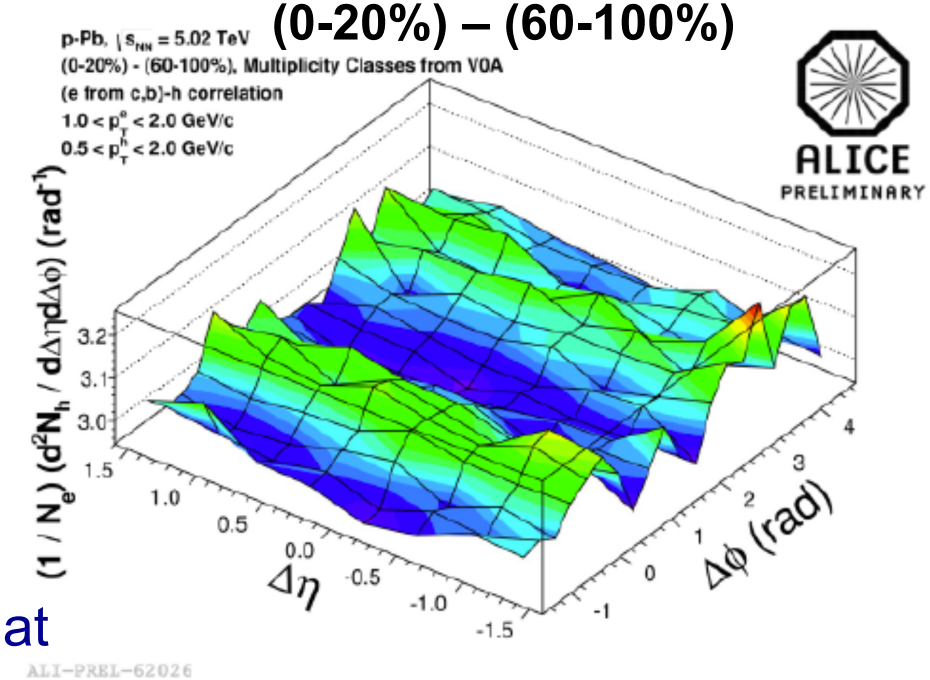
p-Pb collisions in two multiplicity ranges:

0-20% (high multiplicity)

60-100% (low multiplicity)

Jet contribution reduced by subtracting low-multiplicity events

(0-20%) – (60-100%)



$1 < p_T^e < 2$ GeV/c

Indications for long-range correlations in $\Delta\eta$ for two-particle correlations triggered by heavy-flavour decay electrons.

Similar to what was observed for light particles. Same mechanism (CGC/hydro) at work for light and heavy flavours?

Conclusions

Heavy flavours as test for pQCD at LHC energies:

Cross sections at $\sqrt{s}$ =7 and 2.76 TeV for D mesons and leptons from heavy-flavour decays described by pQCD

Nuclear PDFs at small *x*:

Data described within uncertainties by different models of initial state effects

Role of MPI in heavy-flavour production at the LHC:

D-meson yields increase with charged-particle multiplicity → pp trend suggests that MPI affect hard momentum scale relevant for heavy-flavour production

Heavy-flavour jet structure in pp and p-Pb collisions

Good agreement of D-charged hadron correlations with Pythia tunes

Initial/final state effects on heavy-flavour production in p-Pb collisions

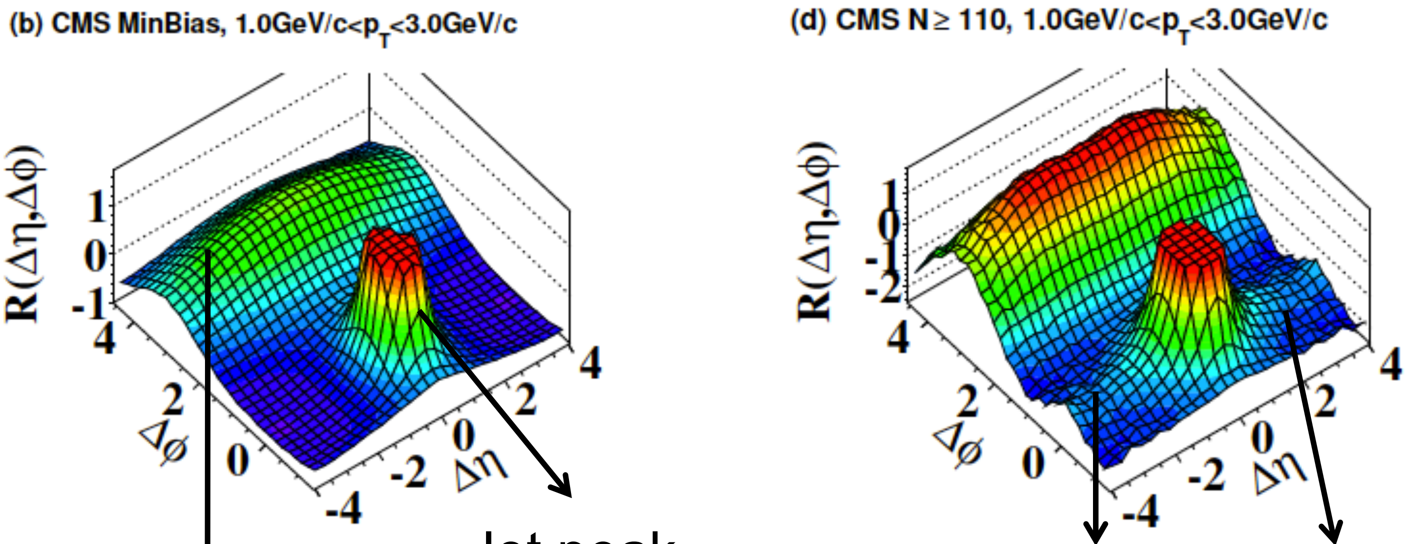
Long range correlations for HF decay electron-hadron correlations at low p_T

Similar to what was observed for light particles.

Same mechanism for light and heavy flavours?

Extra slides

High-multiplicity pp collisions at the LHC



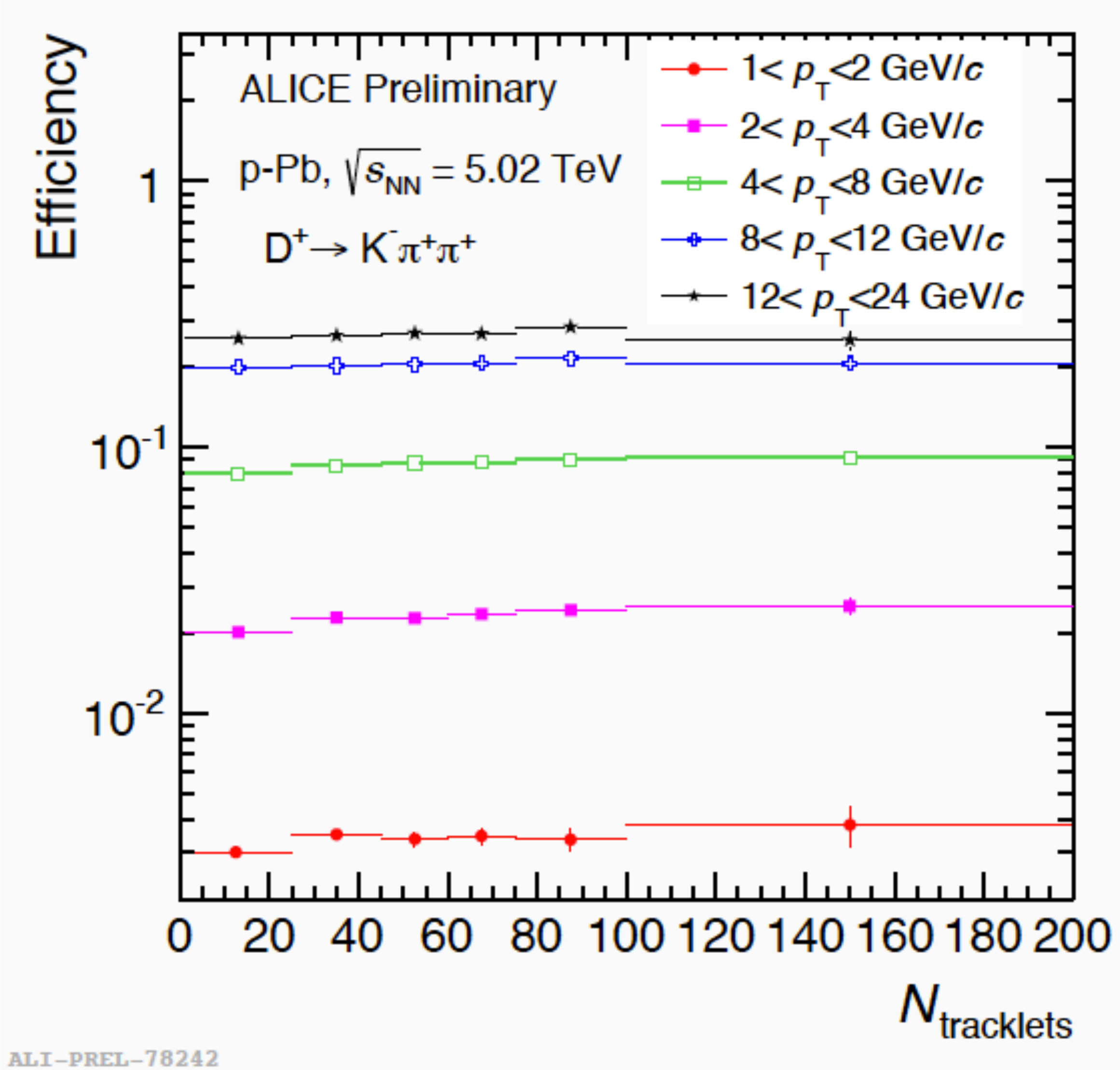
Jet peak

Recoil jet on the away side

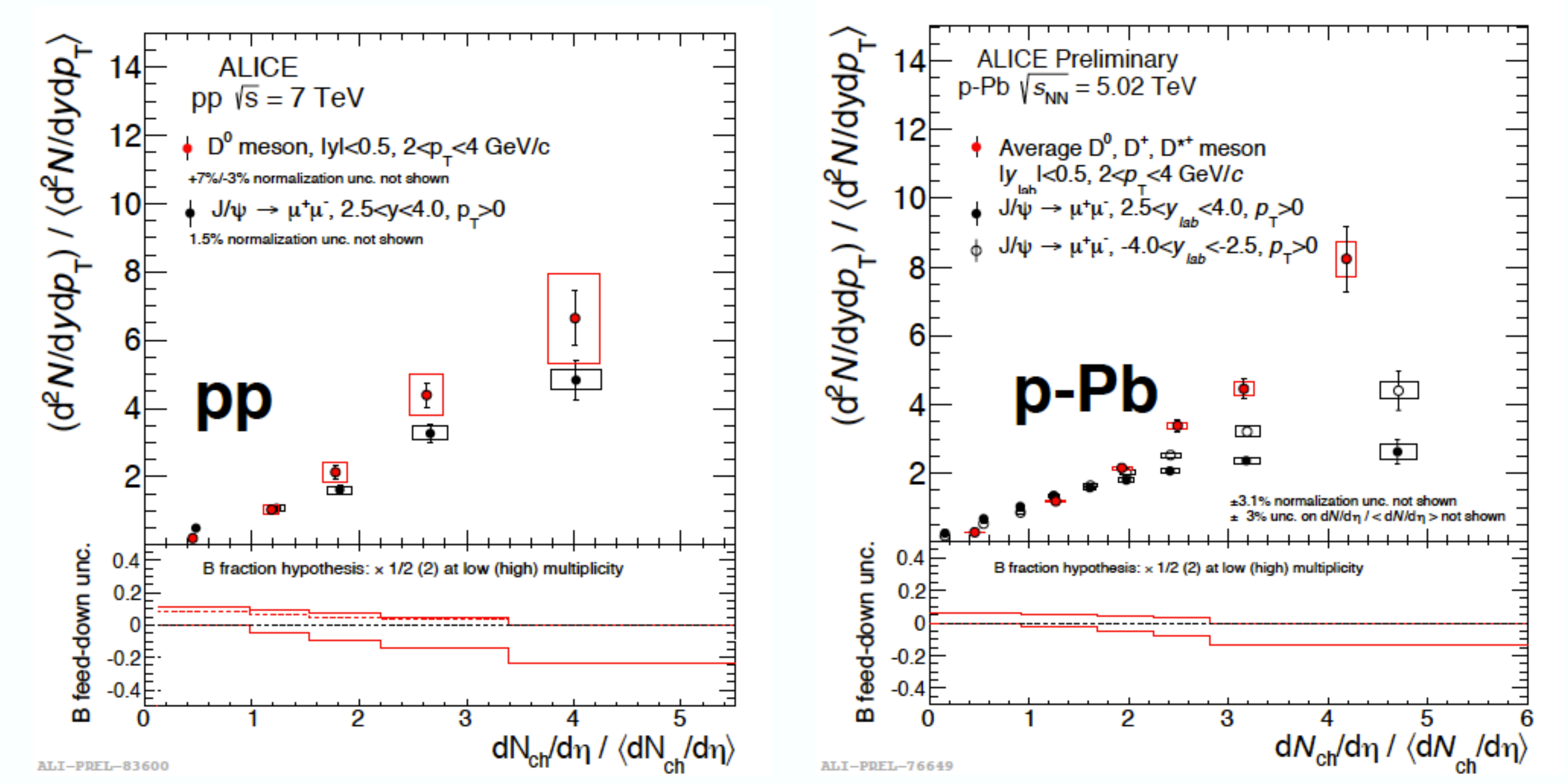
High-multiplicity pp events
(0.0005% of average pp multiplicity):
- near side ridge along Δη: origin?

D-meson reconstruction efficiencies vs multiplicity and p_T

efficiency does not show a strong multiplicity dependence
efficiency increases with increasing p_T

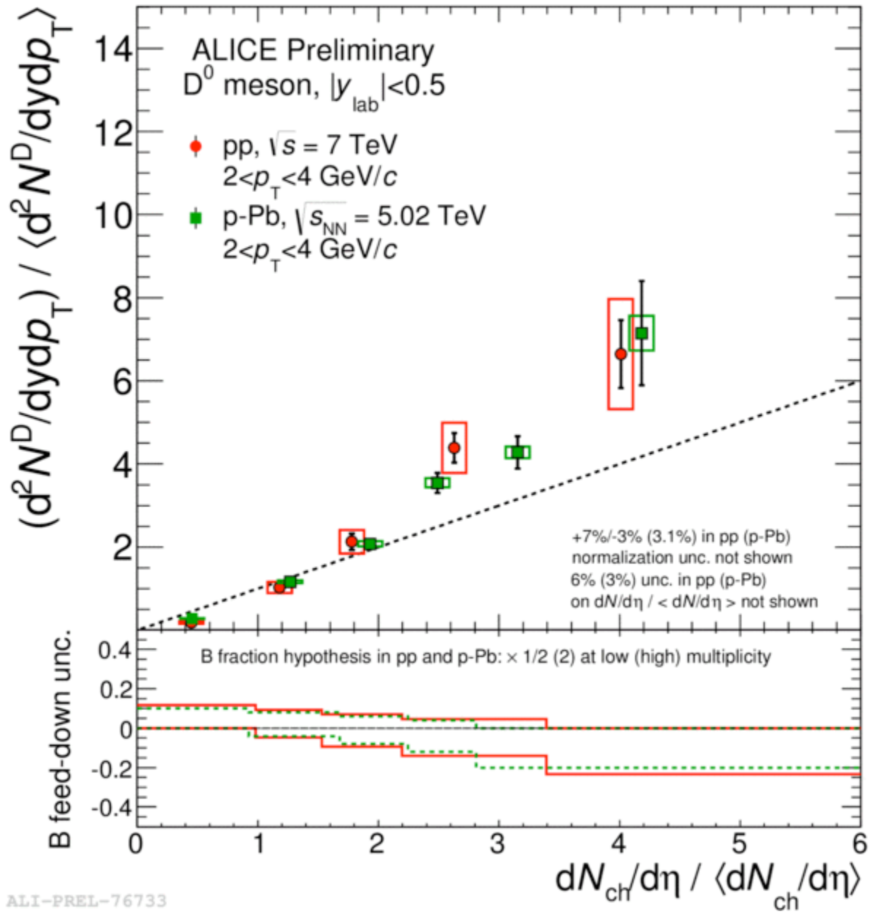


D-meson and J/ψ vs multiplicity: pp and p-Pb

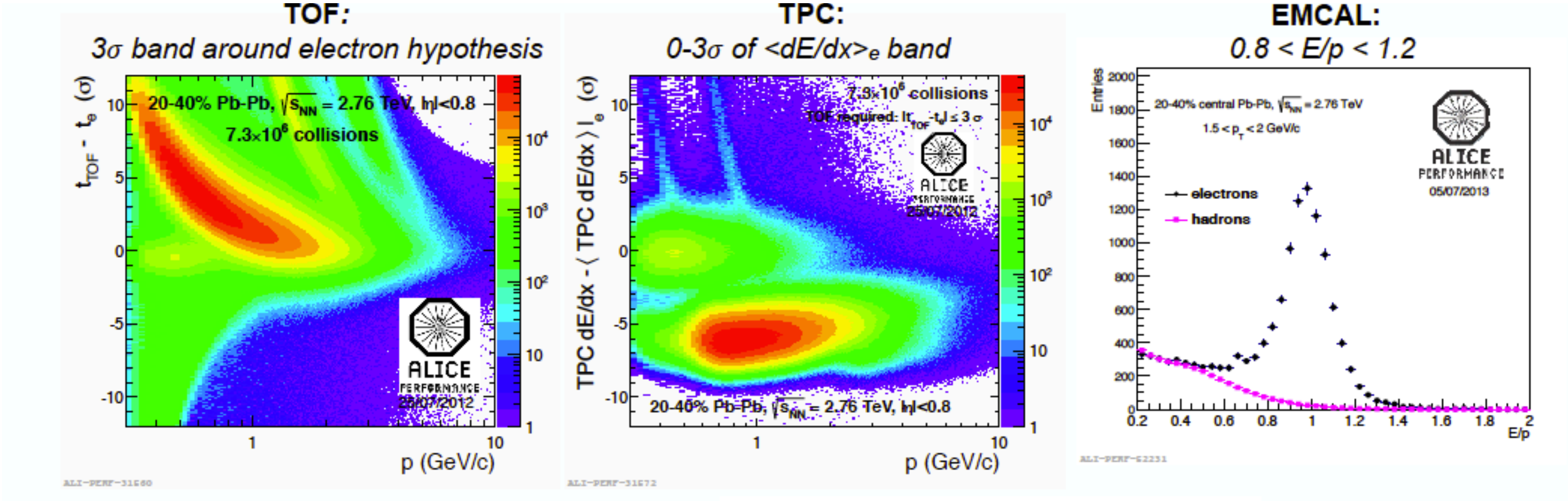


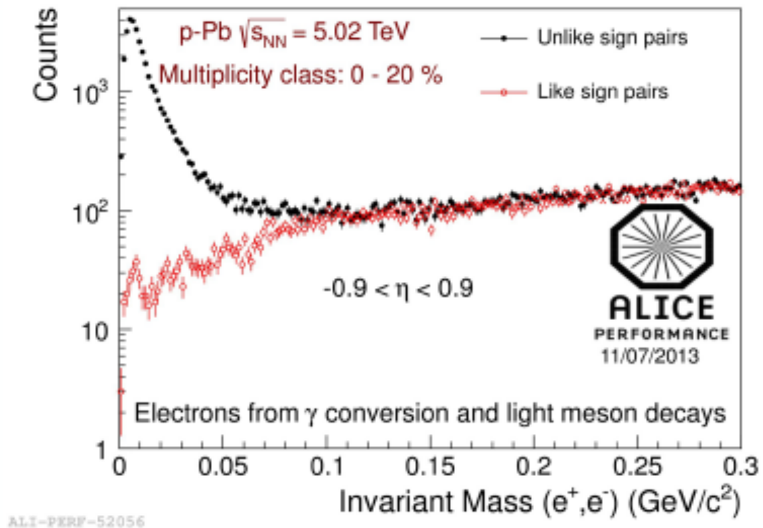
different Cold Nuclear Matter (CNM) effects expected in p-Pb - different Bjorken-x values probed

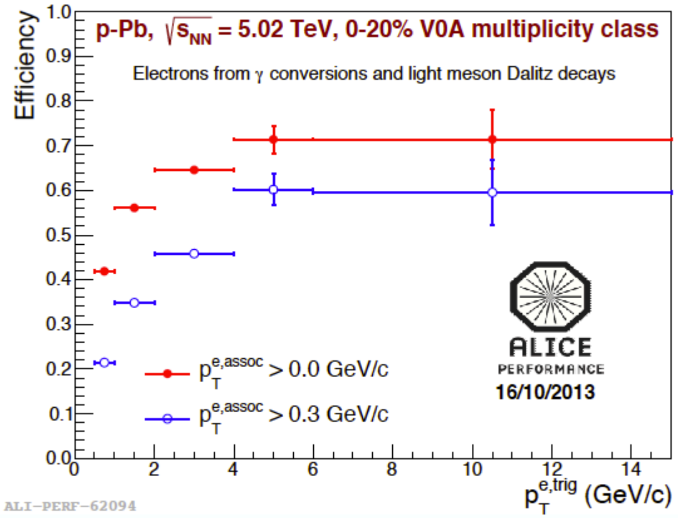
D-meson vs multiplicity: pp and p-Pb



Electron identification



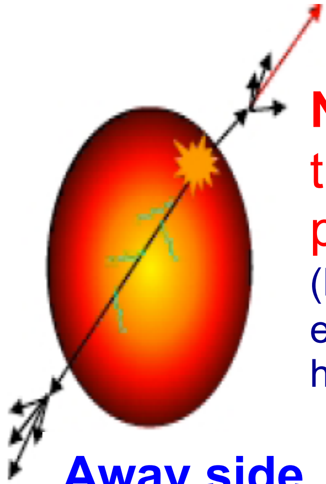




Heavy-flavour azimuthal correlations

In pp collisions:

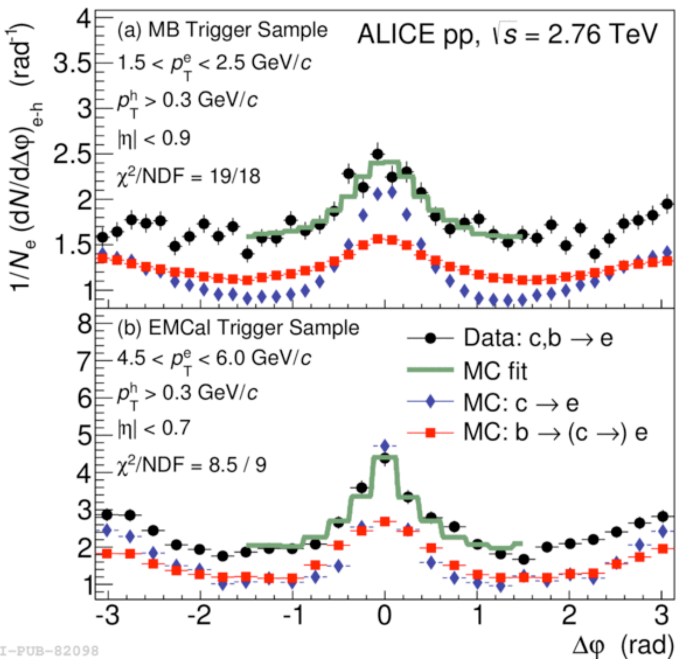
- Extract relative contributions of electrons from charm and beauty decays

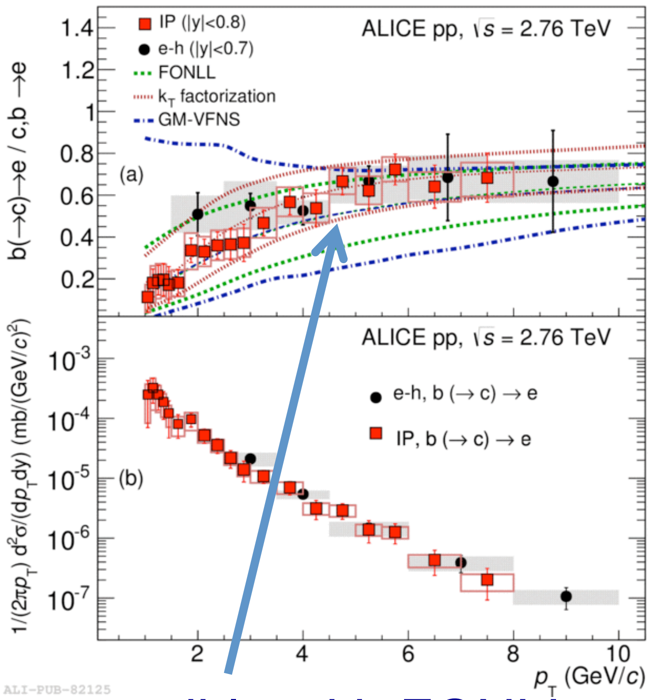


Near side
trigger particle
(D meson or electron from heavy-flavour)

Away side
associate hadron

Heavy-flavour (HF) electron – hadron azimuthal correlations

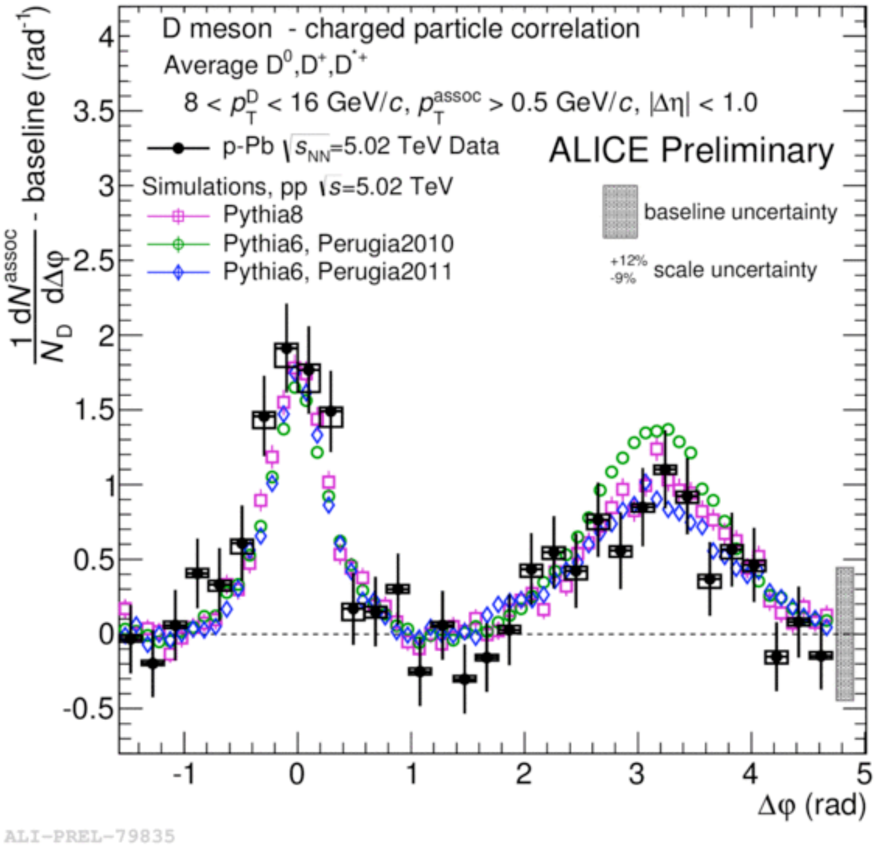




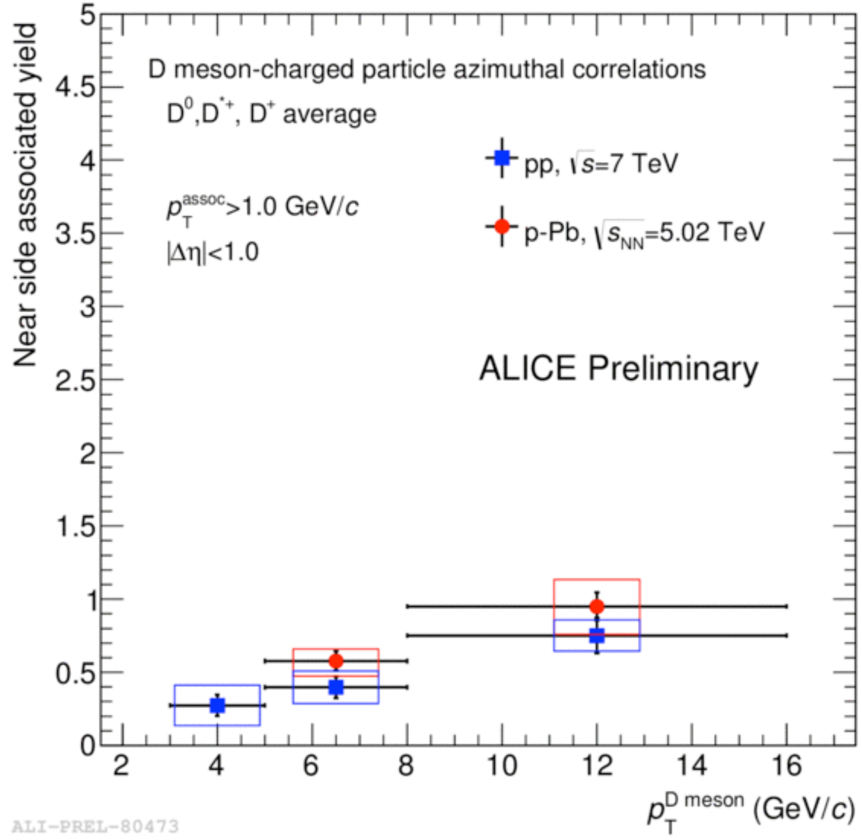
arXiv:1405.4144

b/c ratio compatible with FONLL prediction

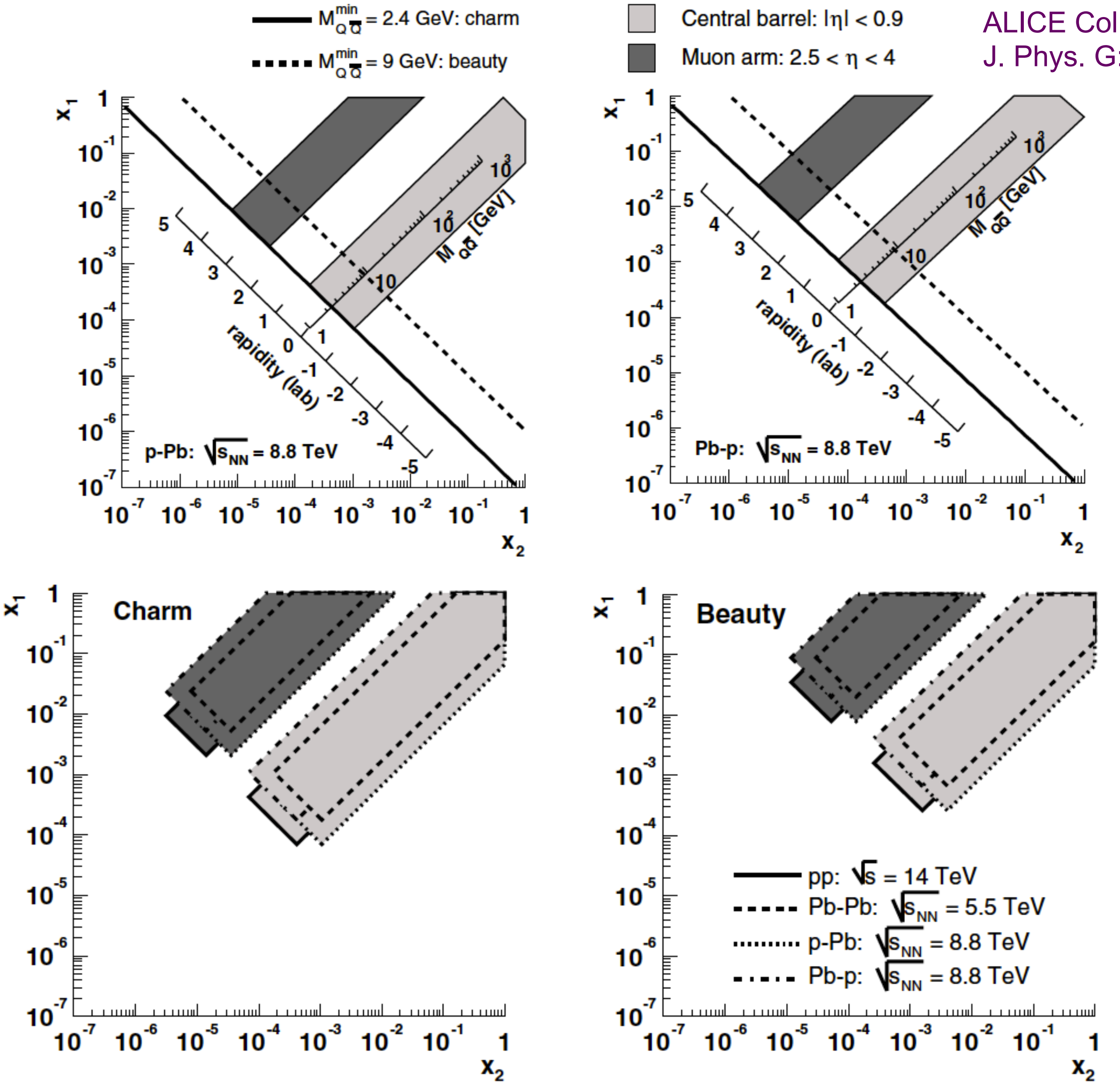
D-h azimuthal correlations in p-Pb



Near side yield vs p_T^D, p_T^{assoc}>1 GeV/c



x regimes at the LHC

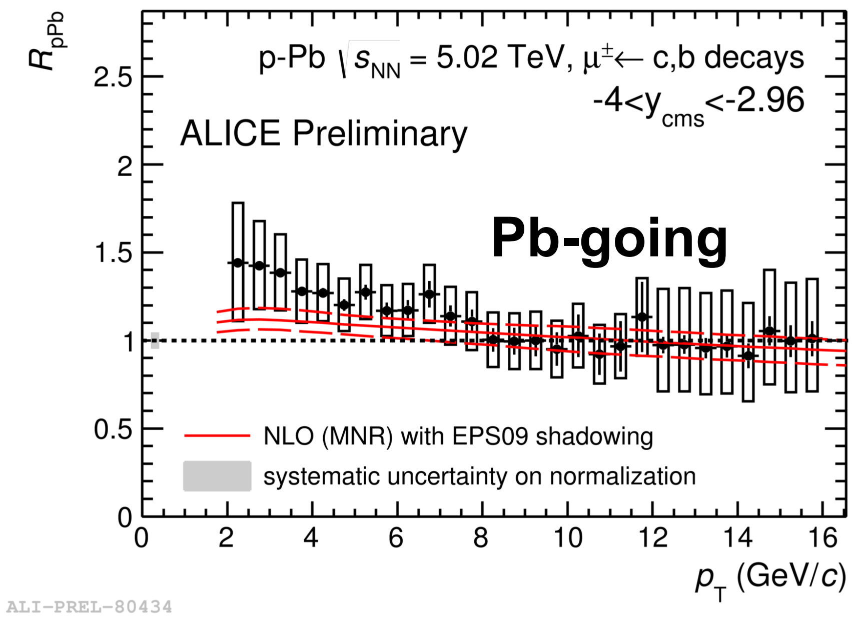


ALICE Coll.,
J. Phys. G: Nucl. Part. Phys. 32 (2006) 1295–2040

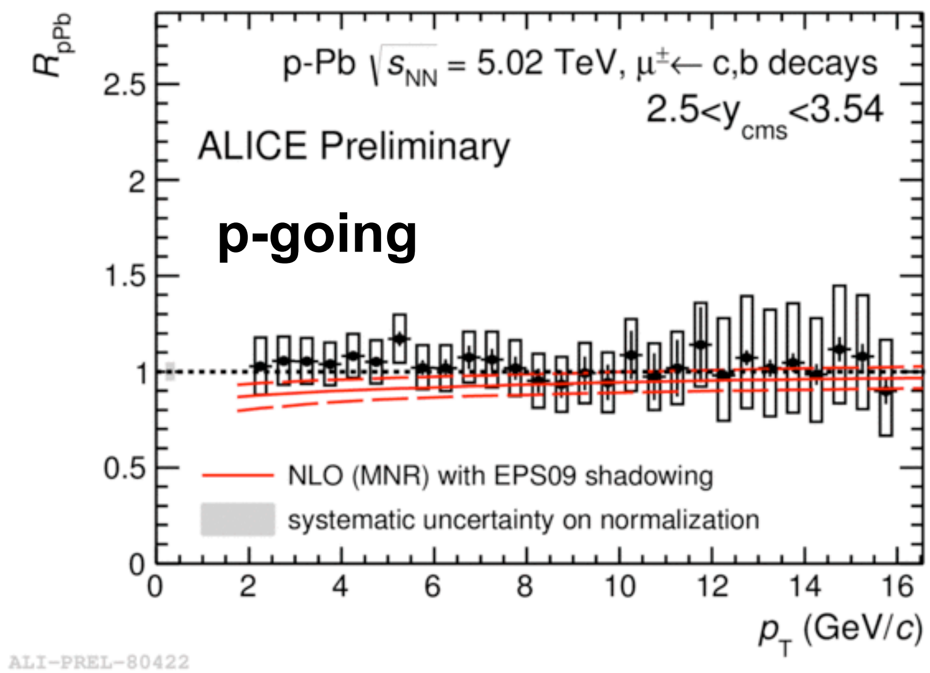
$$x_1 = \frac{A_1}{Z_1} \cdot \frac{M_{Q\overline{Q}}}{\sqrt{s_{pp}}} \exp\left(+y_{Q\overline{Q}}\right)$$

$$x_2 = \frac{A_2}{Z_2} \cdot \frac{M_{Q\overline{Q}}}{\sqrt{s_{pp}}} \exp\left(-y_{Q\overline{Q}}\right)$$

c,b→μ



p-Pb $\sqrt{s_{NN}}$ = 5.02 TeV, $\mu^{\pm} \leftarrow$ c,b decays
$-4<y_{cms}<-2.96$
ALICE Preliminary
Pb-going
NLO (MNR) with EPS09 shadowing
systematic uncertainty on normalization
R_{pPb}
p_T (GeV/c)
ALI-PREL-80434



p-Pb $\sqrt{s_{NN}}$ = 5.02 TeV, $\mu^{\pm} \leftarrow$ c,b decays
$2.5<y_{cms}<3.54$
ALICE Preliminary
p-going
NLO (MNR) with EPS09 shadowing
systematic uncertainty on normalization
R_{pPb}
p_T (GeV/c)
ALI-PREL-80422