Measurements of open heavy-flavour production in pp and p-Pb collisions with ALICE

Sarah LaPointe
INFN Torino

For the ALICE collaboration

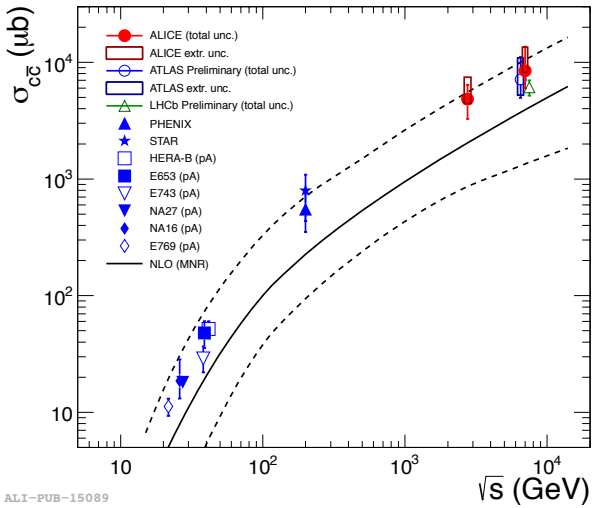
The 7th international workshop on charm physics
May 18-22, 2015

Why study open heavy flavour?

- Heavy quarks (charm and beauty) are produced via initial high-Q^2 parton scattering processes
- Abundant production of heavy quarks

  Increase in $\sigma_{Q\bar{Q}}$ from RHIC to the LHC:
  ~ $10^* \sigma_{c\bar{c}}$ (RHIC)
  ~ $50^* \sigma_{b\bar{b}}$ (RHIC)

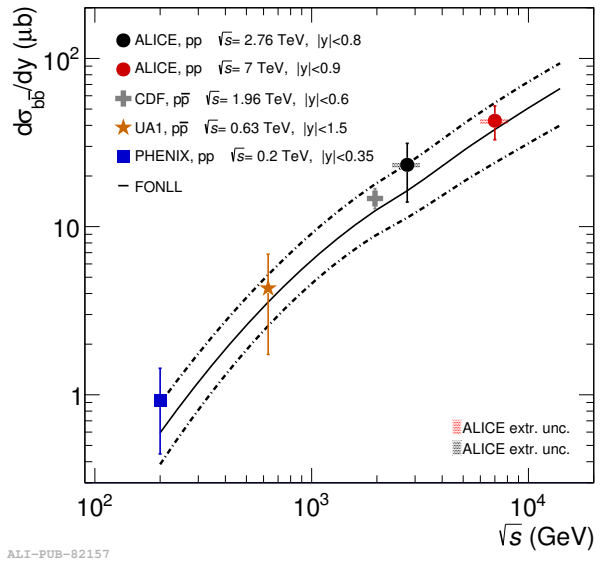
JHEP 1207 (2012) 191



pp collisions

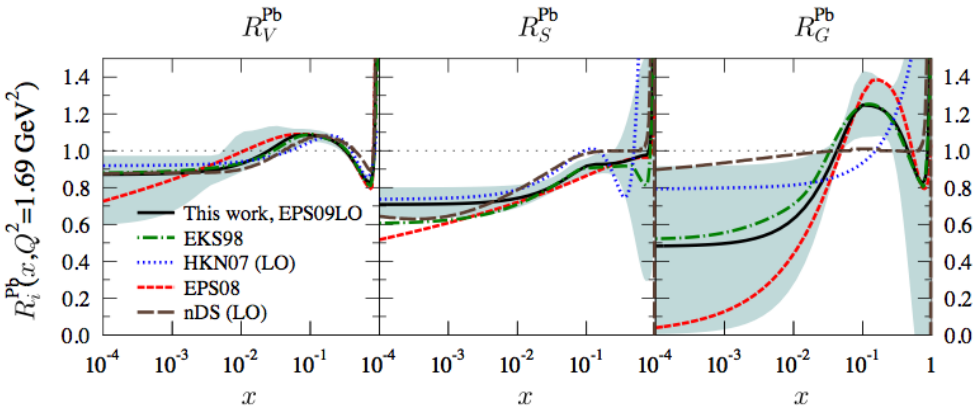
- Tests of perturbative QCD (pQCD)
- Multi-parton interactions (MPI) influence heavy-flavour (HF) production at the LHC
- Reference system for p-Pb and Pb-Pb collisions
- Study jet structure and fragmentation

Phys.Lett. B738 (2014) 97



Why study open heavy flavour?

p-Pb collisions

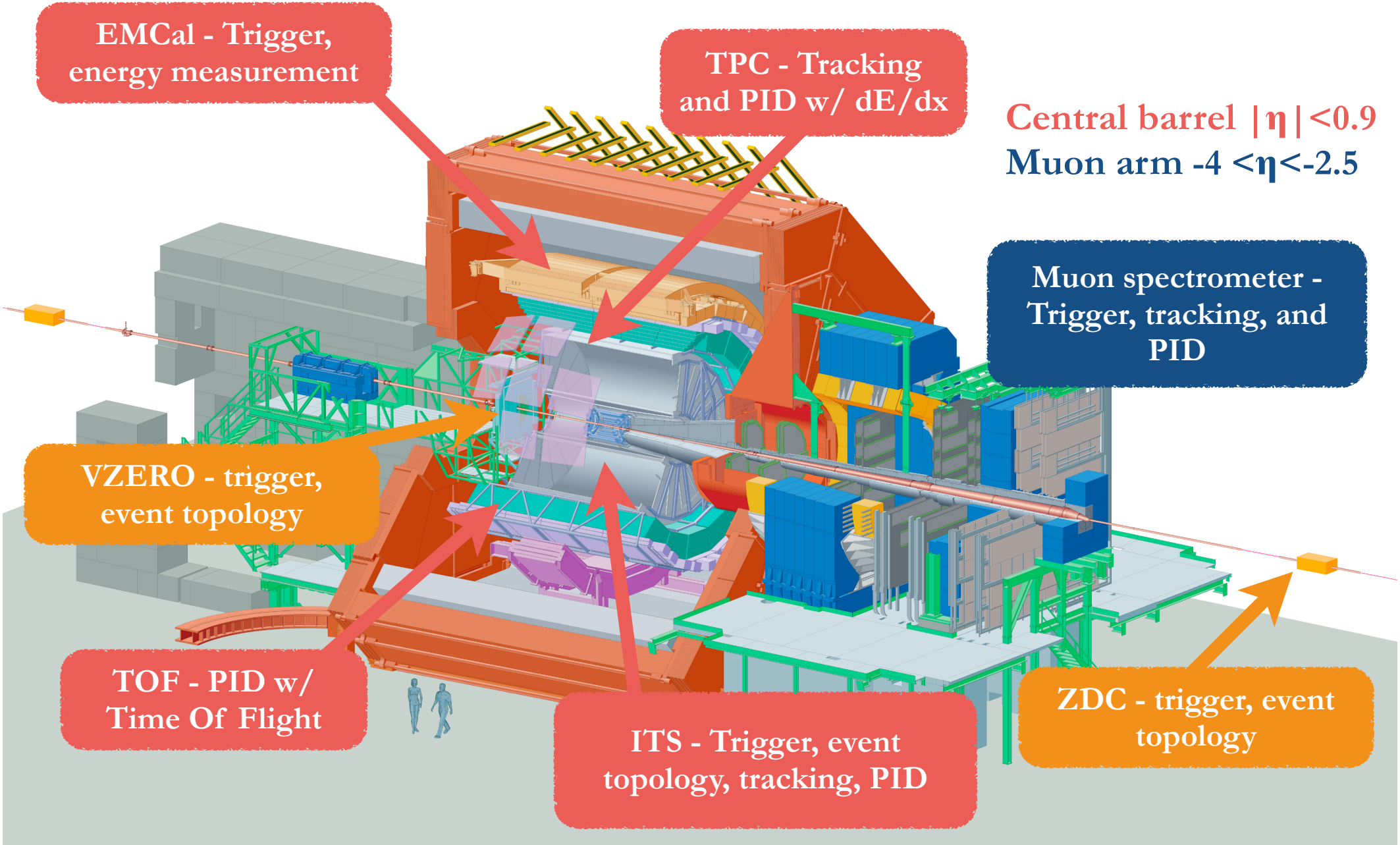


JHEP 0904(2009) 65

- Study cold nuclear matter effects, to better evaluate hot matter effects in Pb-Pb collisions
  - Modification of parton distributions in nuclei
    - shadowing / gluon saturation at low Bjorken x
  - k_T-broadening from multiple soft scatterings
- Study partonic energy loss from initial- and final-state radiation
- Investigate potential final-state effects

Results from Pb-Pb collisions C. Bianchin (this session)
Experimental overview ➜ A. Dainese (this morning)

A Large Ion Collider Experiment



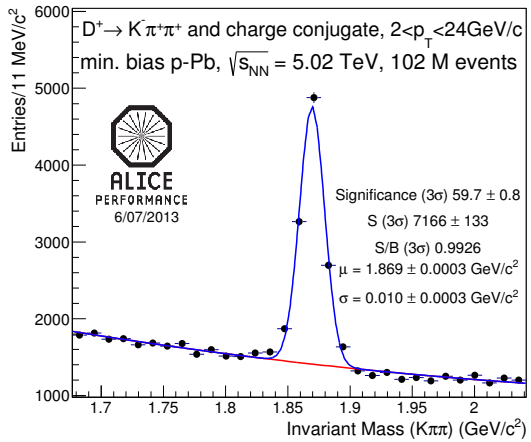
Open heavy-flavour program

Mid-rapidity

D mesons (D^0, D^+, D^*, D_s) via **hadronic** decays

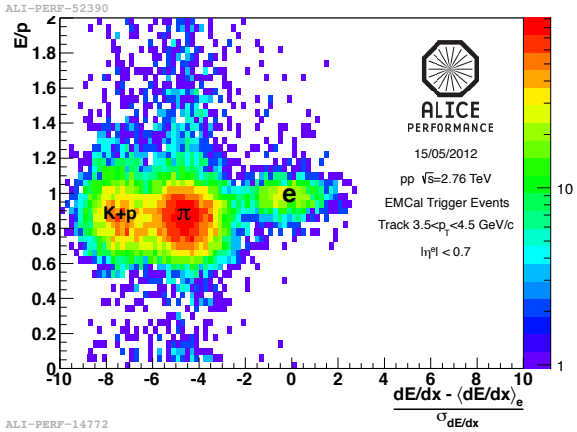
- Select displaced vertex topologies using TPC and ITS
- Particle ID using TPC and TOF
- Invariant mass analysis
- FONLL-pQCD based correction for beauty feed-down

  JHEP, 1210 (2012) 137



Single electrons from **semi-leptonic** HF-hadron decays

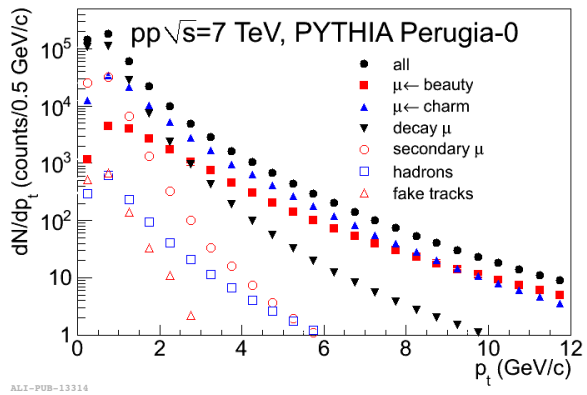
- Electron ID using TPC, TOF, and EMCal (high p_T)
- Background estimation:
  - MC cocktail
  - e^+e^- invariant-mass method
- Beauty-decay electrons using ITS - exploiting displacement from primary vertex



Forward rapidity

Single muons from **semi-leptonic** HF-hadron decays

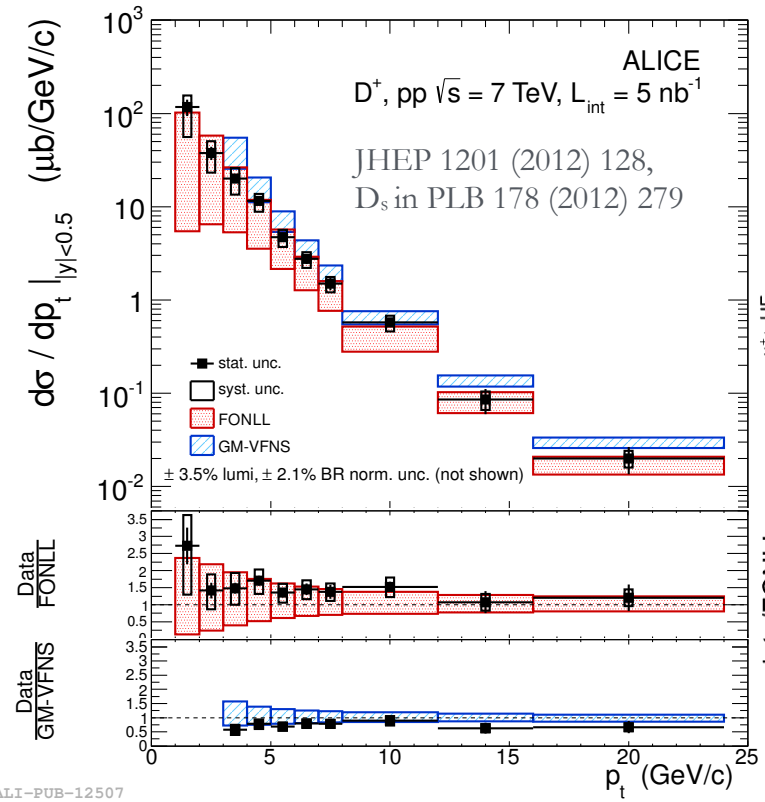
- Muon spectrometer
- Estimation of background sources
  - For pp collisions a MC simulation is used
  - For p-Pb collisions, data-tuned MC cocktail



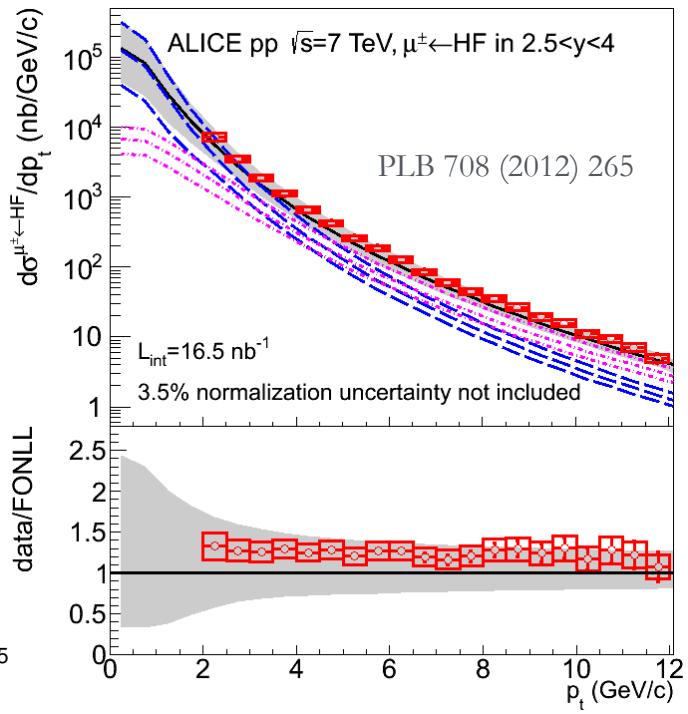
Heavy-flavour production cross sections

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

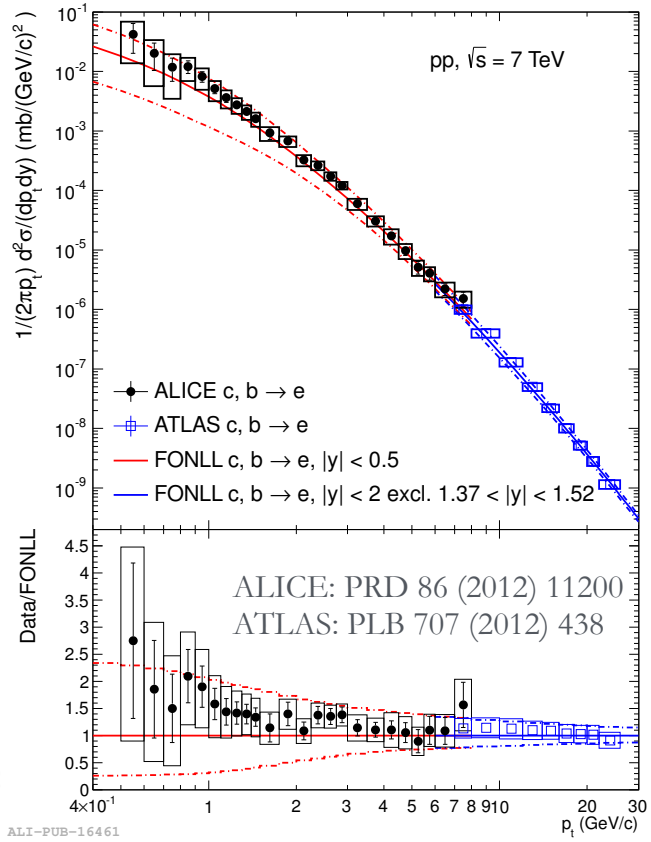
D mesons



HF-decay muons



HF-decay electrons



- **pQCD predictions describe the data within uncertainties**
  FONLL: JHEP 1210 (2012) 37, GM-VFNS: EPJ C72 (2012) 2082, k_T-factorization: PRD 87 (2013) 094022
- **Measurements of HF-decay electrons complementary to the high-p_T ATLAS result**
- **Similar situation for pp collisions at $\sqrt{s}$ = 2.76 TeV**

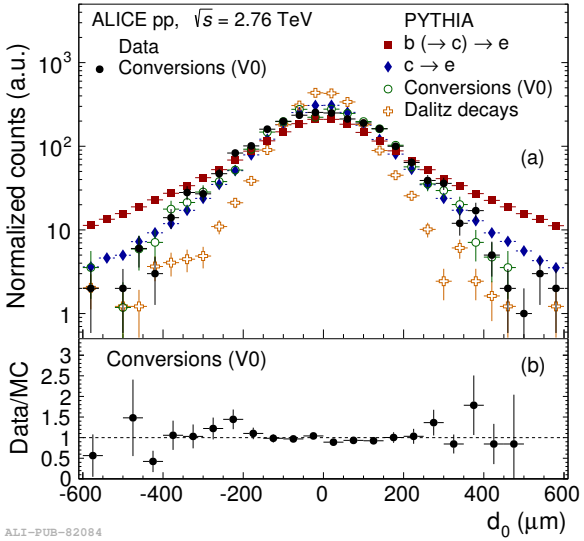
Electrons from beauty-hadron decays

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

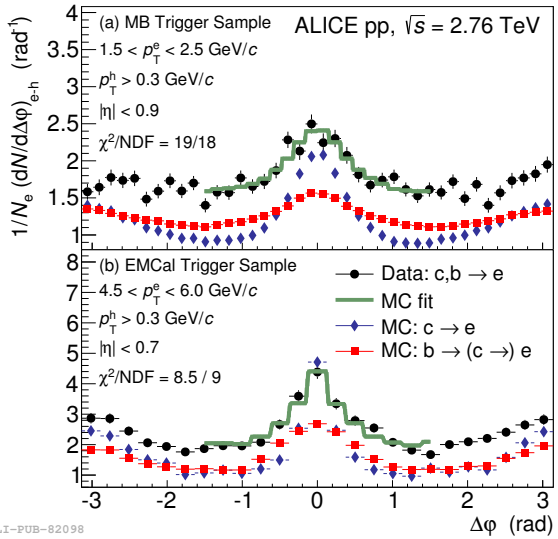
Beauty-hadron decays

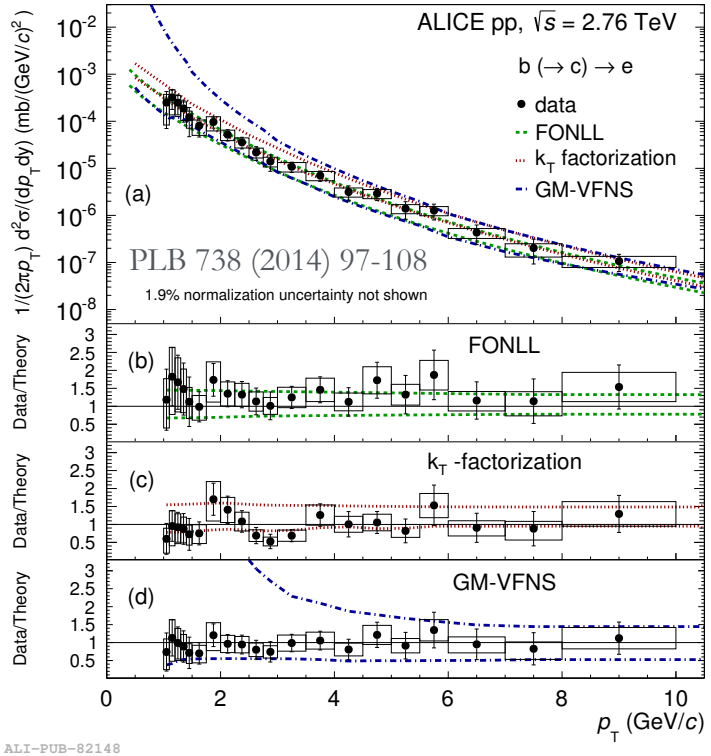
- relatively long lifetime ($c\tau$~500 μm) ➜ broad impact parameter distribution
- decay kinematics ➜ Δφ between electron-hadron wider than for other sources

Impact-parameter analysis



electron-hadron azimuthal correlation





- **p_T-differential production cross section of electrons from beauty-hadron decays**
- **Compatibility with FONLL, GM-VFNS and k_T-factorization calculations**

FONLL: JHEP 1210 (2012) 37, GM-VFNS: EPJ C72 (2012) 2082, k_T -factorization: PRD 87 (2013) 094022

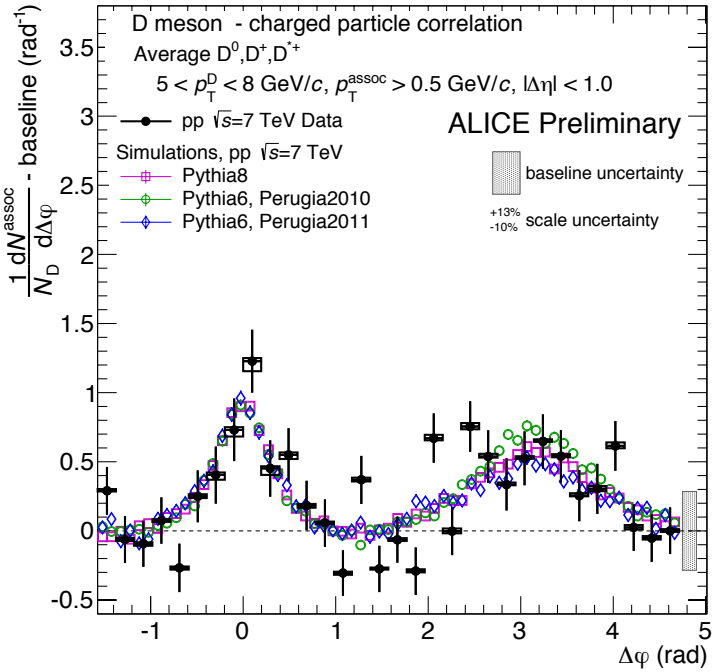
D meson-hadron azimuthal correlations

Measure the associated hadron yield on the near (Δφ around 0) and away side (Δφ around π)

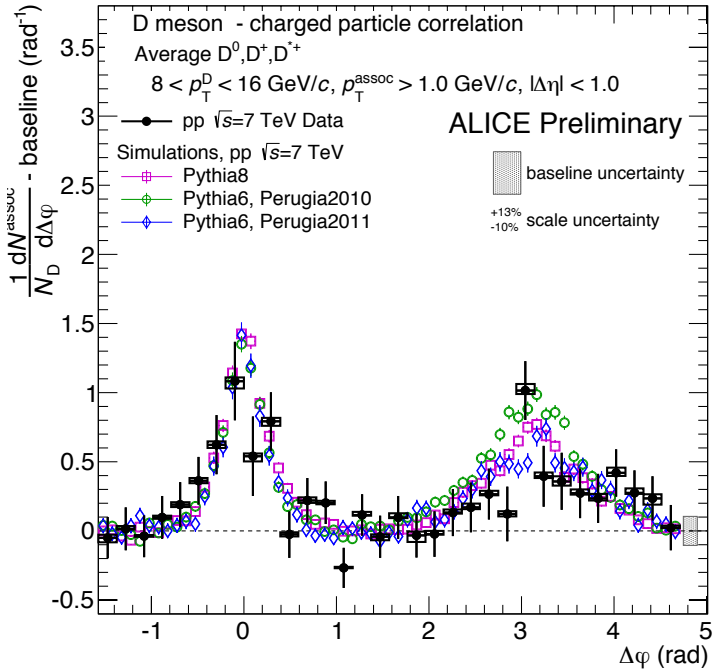
- Sensitive to quark fragmentation
- Insight into $c\bar{c}$ production mechanisms

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

$5 < p_T^D < 8$ GeV/c
$p_T^{Assoc.} > 0.5$ GeV/c



$8 < p_T^D < 16$ GeV/c
$p_T^{Assoc.} > 1$ GeV/c



PYTHIA8
Perugia 2010
Perugia 2011

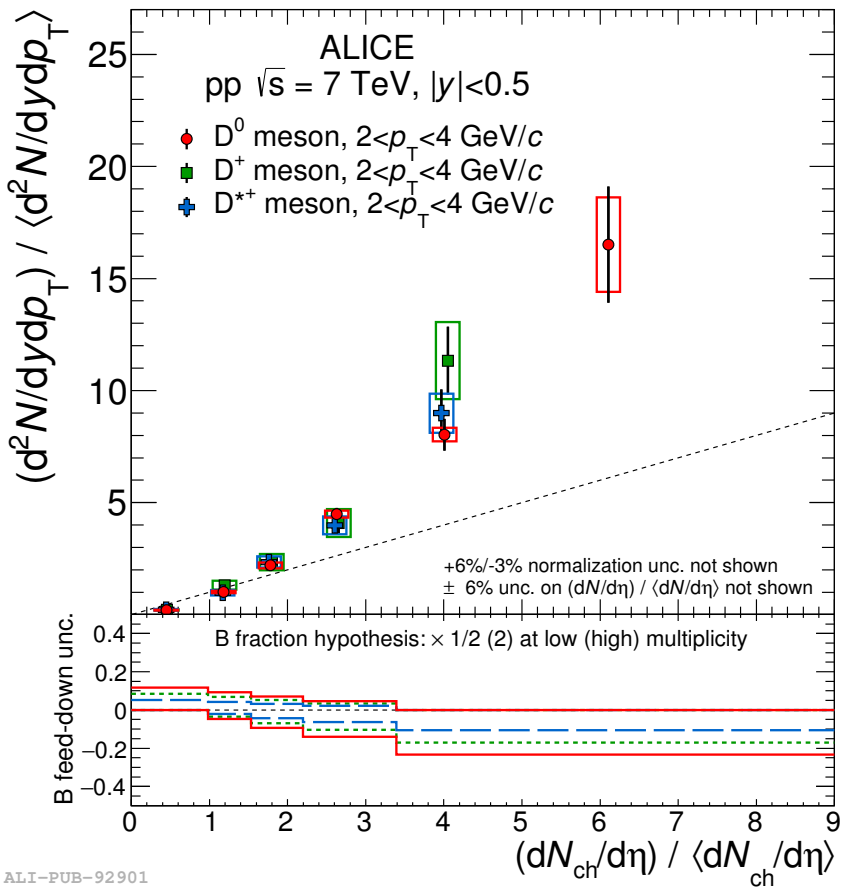
- Baseline subtracted azimuthal correlation of D mesons and charged hadrons
- Different PYTHIA tunes consistent with the measurement
- Data from Run-II at the LHC will provide more precision ➜ constrain models

Multiplicity dependence of D-meson production

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

Self-normalized D-meson yields as a function of charged-particle multiplicity

arXiv:1505.00664



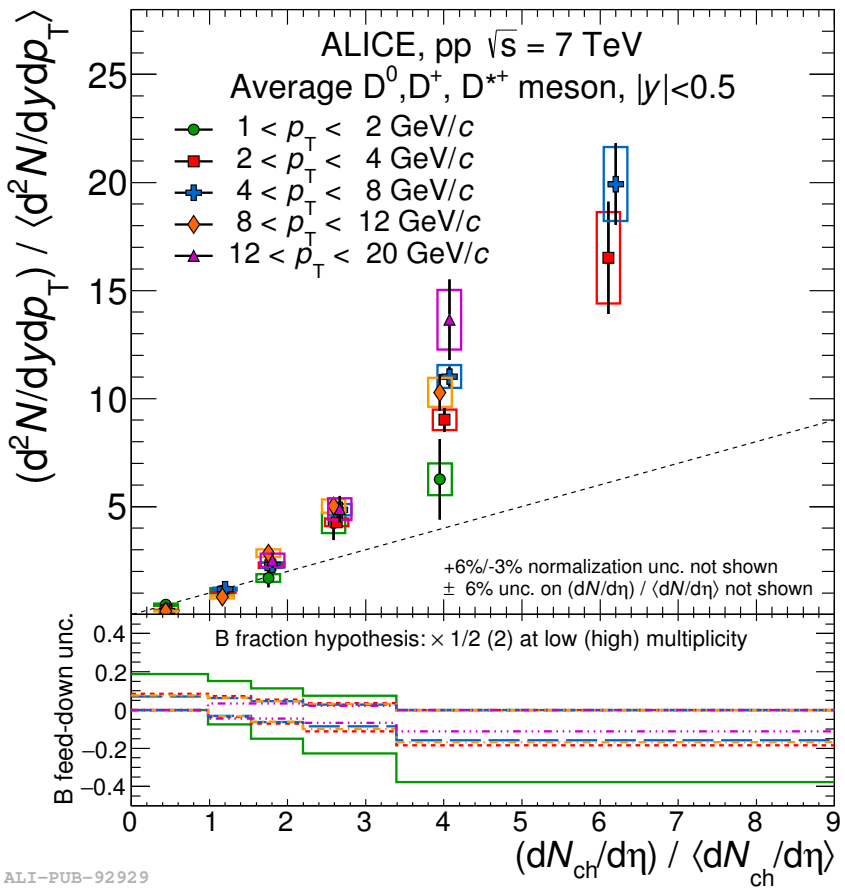
- **Measured for different D-meson species**
- **Increase of D-meson per-event yield with increasing charged-particle yield**

Multiplicity dependence of D-meson production

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

Self-normalized D-meson yields as a function of charged-particle multiplicity

arXiv:1505.00664



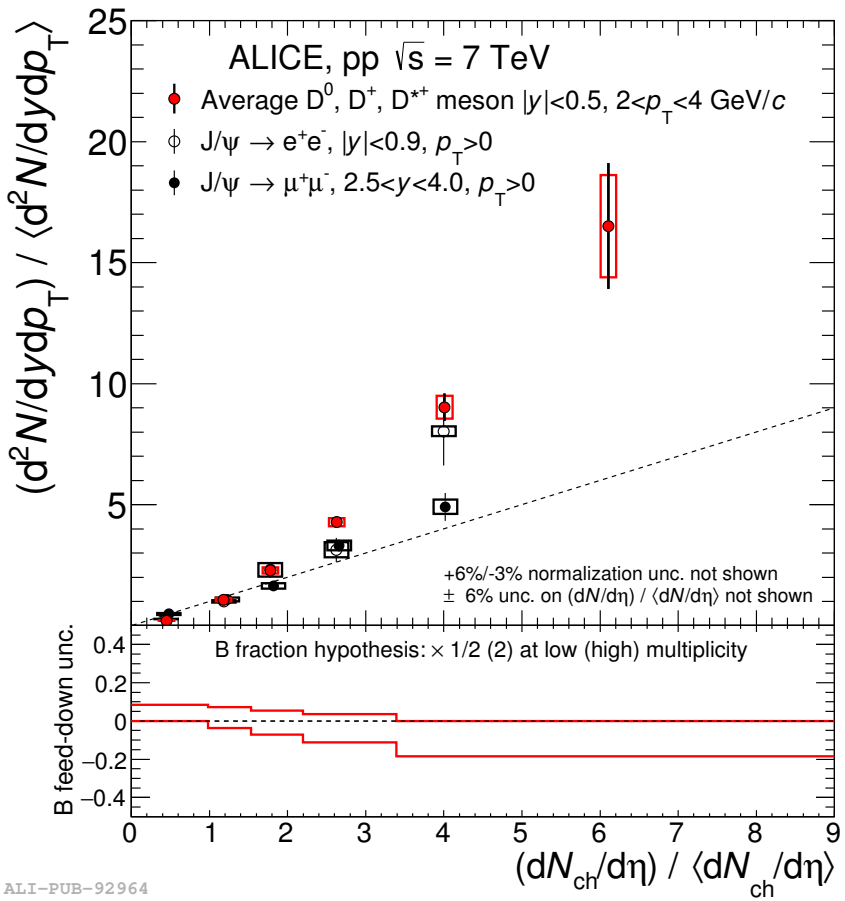
- **Measured for different D-meson species**
- **Increase of D-meson per-event yield with increasing charged-particle yield**
- **Within the uncertainties, no p_T-dependence of D-meson yield vs. multiplicity observed**

Multiplicity dependence of D-meson production

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

Self-normalized D-meson yields as a function of charged-particle multiplicity

arXiv:1505.00664



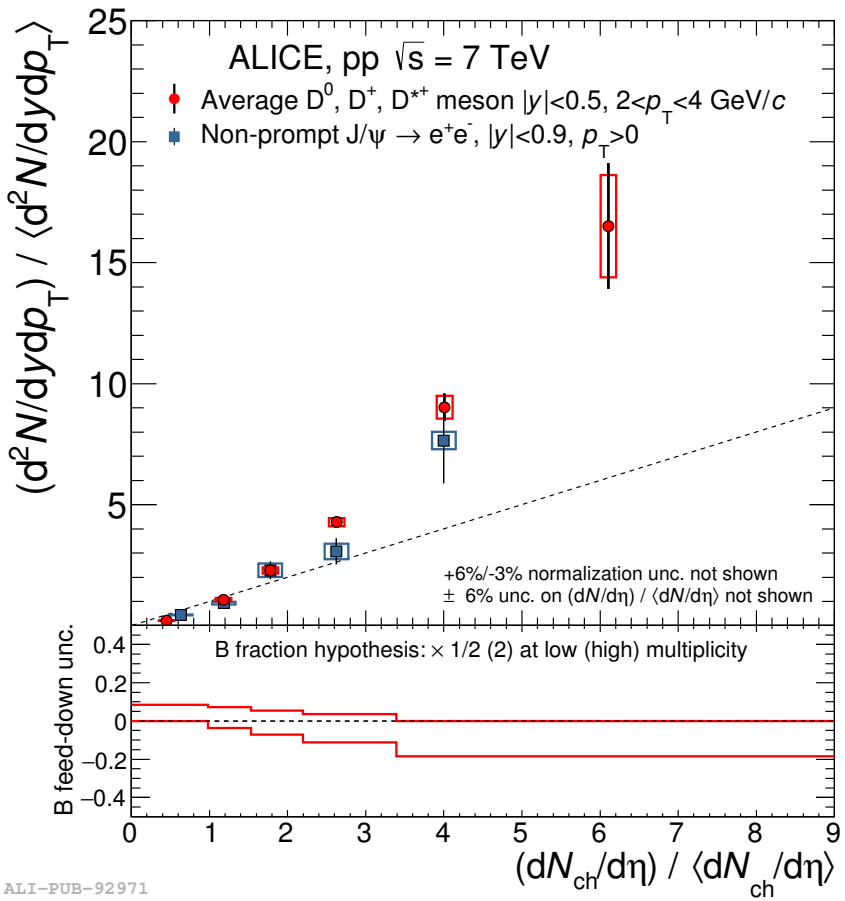
- **Measured for different D-meson species**
- **Increase of D-meson per-event yield with increasing charged-particle yield**
- **Within the uncertainties, no p_T-dependence of D-meson yield vs. multiplicity observed**
- **Similar rising trend observed for J/ψ mesons at central and forward rapidity**
  PLB 712(2012)165

Multiplicity dependence of D-meson production

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

Self-normalized D-meson yields as a function of charged-particle multiplicity

arXiv:1505.00664

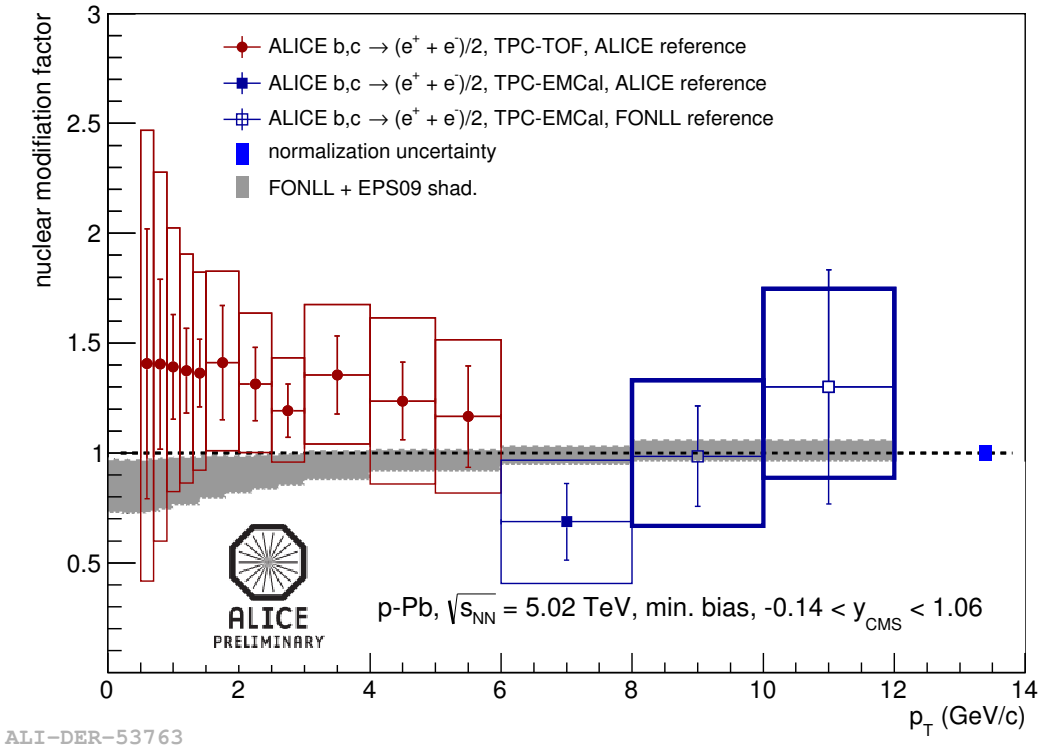


- **Measured for different D-meson species**
- **Increase of D-meson per-event yield with increasing charged-particle yield**
- **Within the uncertainties, no p_T-dependence of D-meson yield vs. multiplicity observed**
- **Similar rising trend observed for J/ψ mesons central and forward rapidity**
  PLB 712(2012)165
- **Increase of beauty production with increasing multiplicity**

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

- Assessment of initial-state, cold nuclear matter effects
- Investigate possible final-state effects

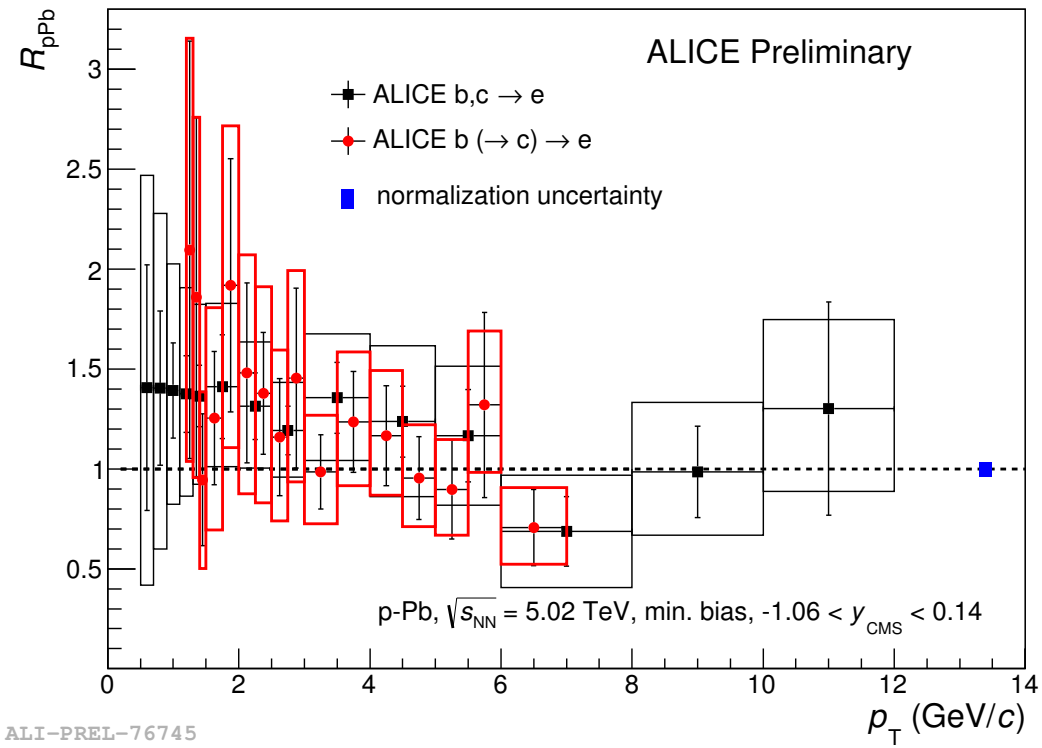
Nuclear modification factor for HF-decay electrons



$$R_{\mathrm{pPb}} = \frac{d\sigma_{\mathrm{pPb}}/dp_{\mathrm{T}}}{A \times d\sigma_{\mathrm{pp}}/dp_{\mathrm{T}}}$$

- R_{pPb} of HF-decay electrons compatible with unity
- Data described by FONLL+EPS09 parametrization of shadowing, within the uncertainties NPB 373(1992)295, JHEP 0904 (2009) 065

Nuclear modification factor for HF-decay electrons

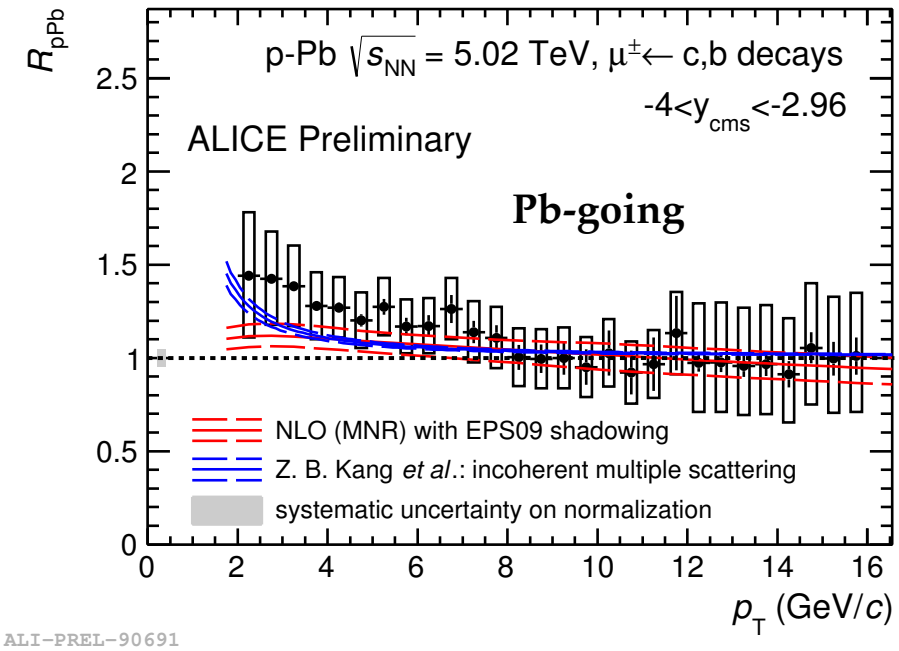


$$R_{\mathrm{pPb}} = \frac{d\sigma_{\mathrm{pPb}}/dp_{\mathrm{T}}}{A \times d\sigma_{\mathrm{pp}}/dp_{\mathrm{T}}}$$

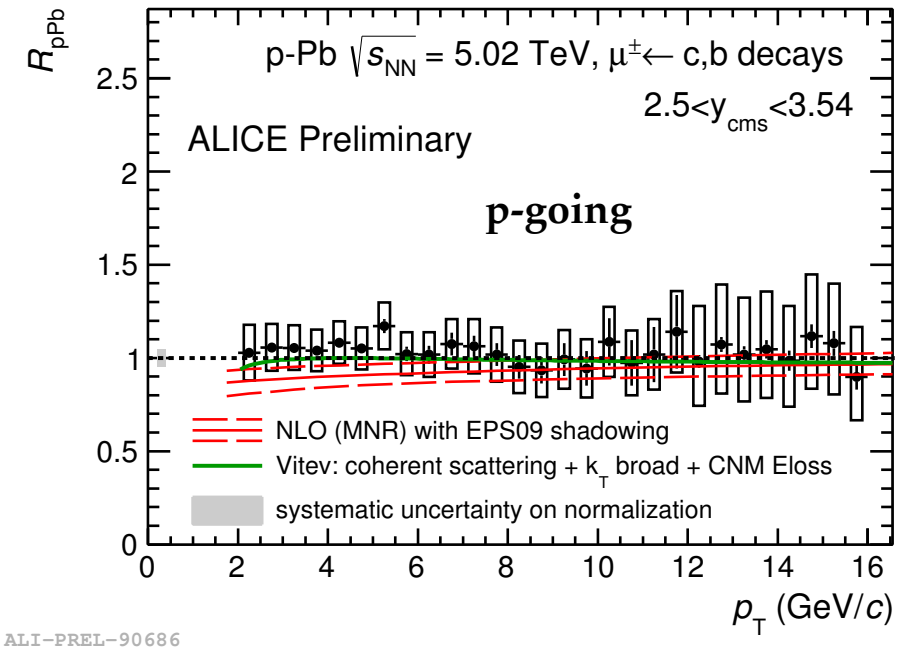
- R_{pPb} of HF-decay electrons compatible with unity
- Data described by FONLL+EPS09 parametrization of shadowing, within the uncertainties NPB 373(1992)295, JHEP 0904 (2009) 065
- R_{pPb} of electrons from beauty-hadron decays is also compatible with unity

Nuclear modification factor for HF-decay muons

Backward probe high Bjorken x in Pb



Forward probe low Bjorken x in Pb



- R_{pPb} of HF-decay muons at forward rapidity compatible with unity
- R_{pPb} of HF-decay muons at backward slightly greater than unity at low p_T
- Data described by models that include cold nuclear matter effects

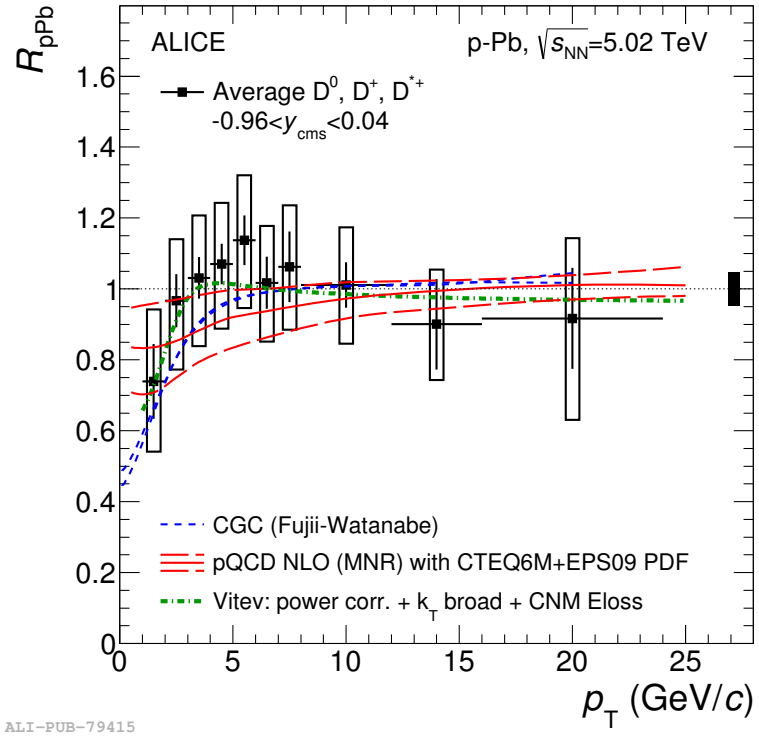
MNR pQCD calculation with EPS09 parametrization of shadowing NPB 373(1992)295, JHEP 0904 (2009) 065

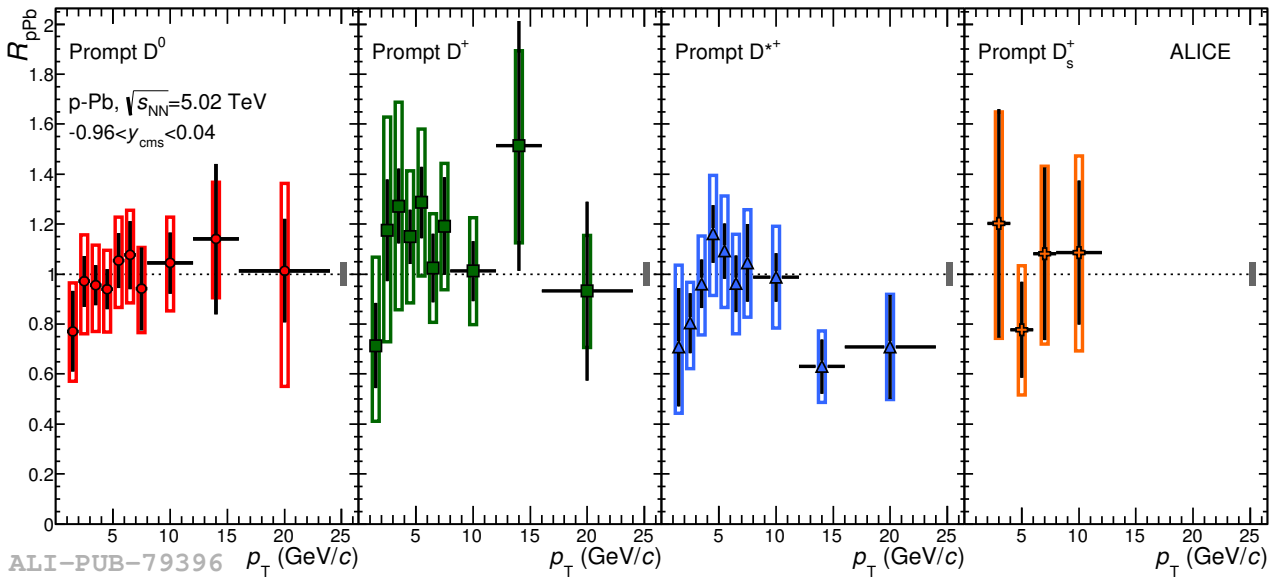
I. Vitev - coherent scattering, k_T-broadening, and energy loss in cold nuclear matter PRC 75 (2007) 064906

Z. B. Zhang et. al. - incoherent multiple scattering PLB 740 (2015) 23

Nuclear modification factor for D mesons

PRL 113 (2014) 232301





- R_{pPb} of D mesons compatible with unity within the p_T range covered
- The R_{pPb} can be described by:

  MNR pQCD calculation with EPS09 parametrization of shadowing NPB 373(1992)295, JHEP 0904 (2009) 065

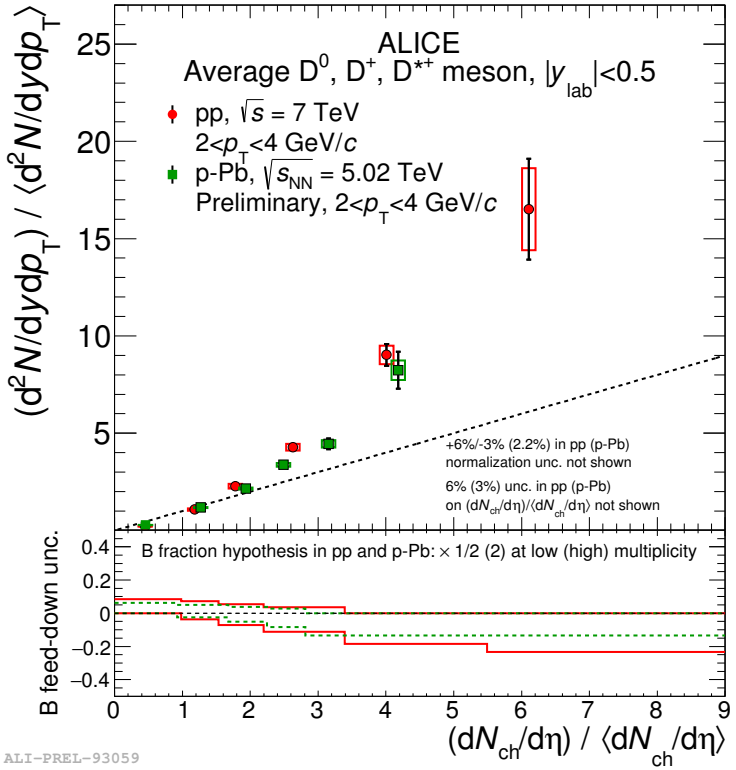
  I. Vitev - coherent scattering, k_T-broadening, and energy loss in cold nuclear matter PRC 75 (2007) 064906

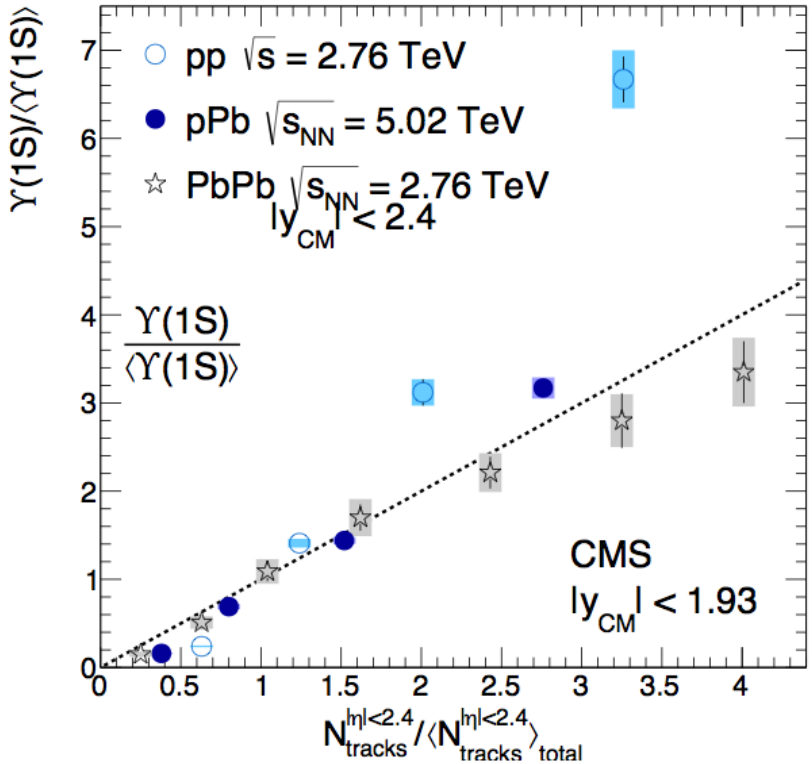
  CGC - color glass condensate NPA 920 (2013) 78

  .

Multiplicity dependence of D-meson production

JHEP 04 (2014) 103

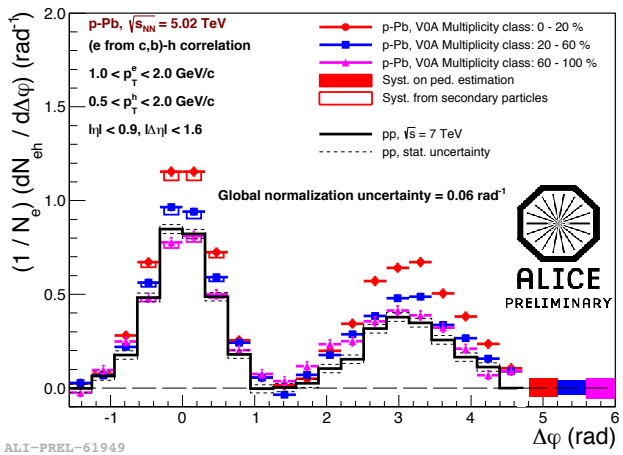




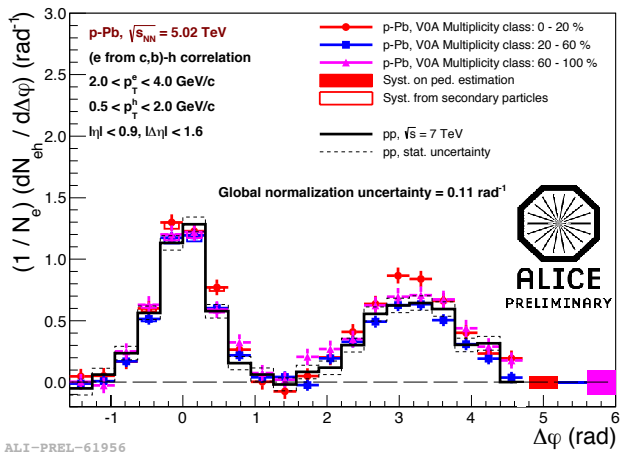
- D-meson production vs. multiplicity ➜ similar trend in pp and p-Pb collisions
  - pp collisions: high multiplicity events attributed to MPI
  - p-Pb collisions: high multiplicity events also from multiple binary nucleon-nucleon collisions
  - CMS reports similar trend from ϒ measurements in pp and p-Pb collisions

HF electron-hadron correlations in p-Pb collsions

$1 < p_{\mathrm{T}}^{\mathrm{trigger}} < 2\ \mathrm{GeV}/c$



$2 < p_{\mathrm{T}}^{\mathrm{trigger}} < 4\ \mathrm{GeV}/c$



— pp $\sqrt{s}$ = 7 TeV

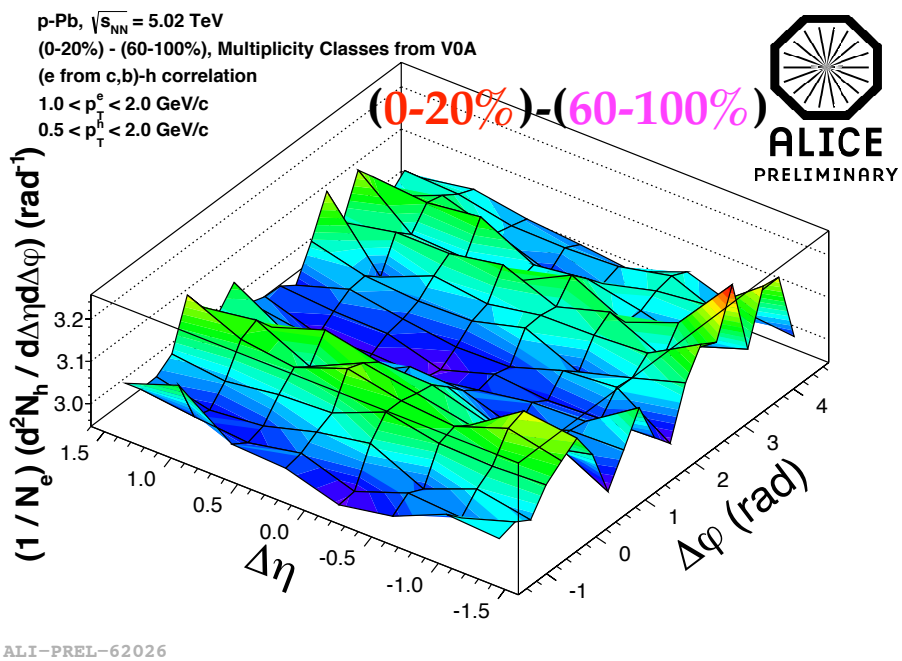
p-Pb multiplicity classes

0-20%

20-60%

60-100%

For all: $0.5 < p_{\mathrm{T}}^{\mathrm{Assoc.}} < 2$ GeV/c



In high multiplicity events:

At low electron p_{T} a hint of near- and away-side enhancement

Remove jet contribution by subtracting low multiplicity events

Indication for double-ridge structure, as observed for light-flavor two particle correlations. PLB 719 (2013) 29, PLB 726 (2013) 164

HF possibly affected by the processes consistent with long-range correlations in Δη of light-flavour hadrons

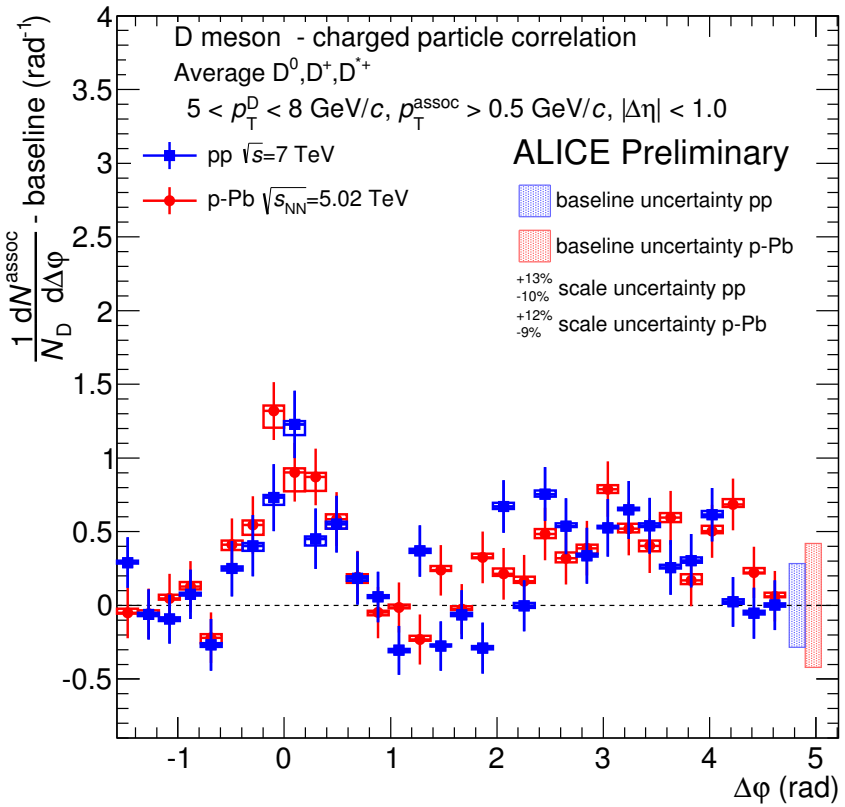
Initial state: CGC arXiv:1302.7018

Final state: Hydrodynamics PLB 718 (2013) 1557

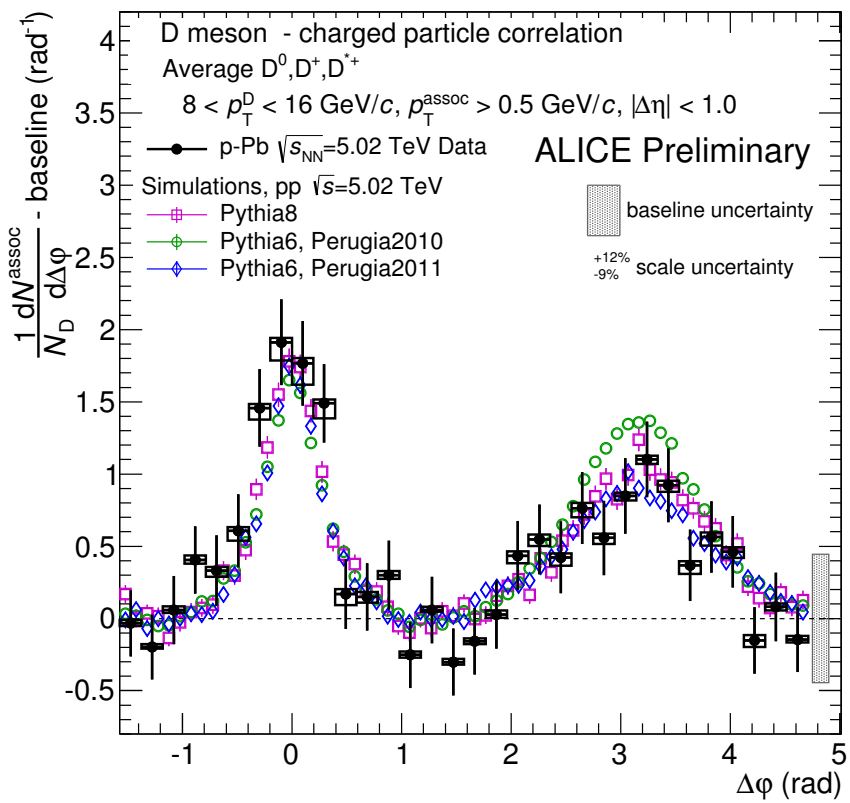
D meson-hadron correlations in p-Pb collisions

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

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



$8 < p_T^D < 16$ GeV/c, $p_T^{Assoc.} > 0.5$ GeV/c



- Distributions from pp and p-Pb collisions are comparable
- Within the uncertainties the p-Pb measurement is consistent with various PYTHIA tunes
- Better constraints of PYTHIA tunes with improved statistics available in Run-II at the LHC

Summary and outlook

pp collisions

- Measured production cross sections allow us to test various pQCD predictions
  - FONLL, GM-VFNS, k_T-factorization predictions are in agreement with data
- Heavy quark fragmentation studies via D-meson azimuthal correlations
  - Consistent with various PYTHIA tunes
- Heavy-flavour hadron yield vs. multiplicity
  - With increasing multiplicity, yield increases more than linearly
  - Models including MPI contributions reproduce the observed trend

p-Pb collisions

- Heavy-flavour hadron yields
  - No strong suppression observed with respect to pp collisions
  - Increasing yields with increasing event multiplicity, as observed in pp collisions
- D-meson azimuthal correlations
  - Consistent with various PYTHIA tunes
- Electron-hadron azimuthal correlations at low p_T
  - Double-ridge structure observed. CGC, hydrodynamic expansion, some other mechanism?

Outlook

- Statistically larger data sample from Run-II at the LHC
- More precise measurements of azimuthal correlations, beauty, and heavy flavour in jets

Extras

Q_{pPb} dependence of event activity