Measurement of muons from heavy-flavour hadron decays in p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV with ALICE at the LHC

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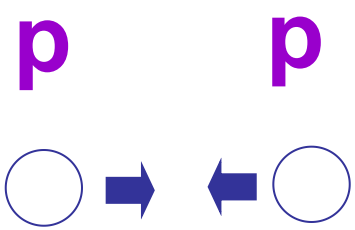
Outline

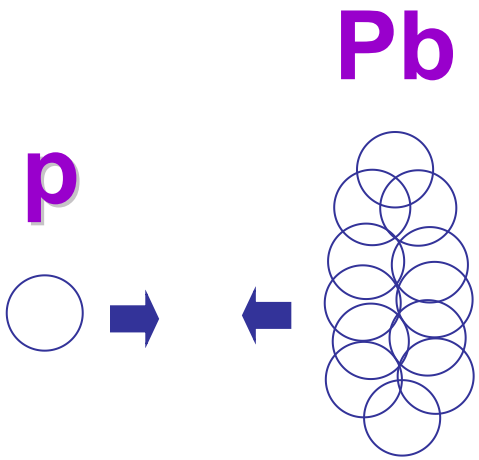
- Physics motivations
- Open heavy-flavour measurements with the ALICE muon spectrometer
- Analysis strategy
- Results
  - p_T-differential cross sections
  - p_T-differential nuclear modification factor R_{pPb}
  - p_T-differential forward-to-backward ratio R_{FB}
- Conclusion and outlook

Physics motivations

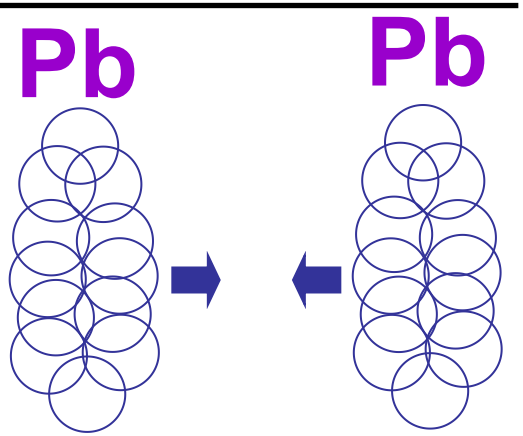
ALICE goal: study the properties of the hot and dense Quark-Gluon Plasma (QGP) formed in Pb-Pb collisions at the LHC



Test of pQCD calculations and reference for p-Pb and Pb-Pb collisions



Cold Nuclear Matter effects in the initial and final state



Initial-state effects + QGP

- To get a precise understanding of the properties of the hot and dense system, one needs to understand Cold Nuclear Matter effects (CNM) in the initial and final state that can be accessed by studying p-Pb collisions

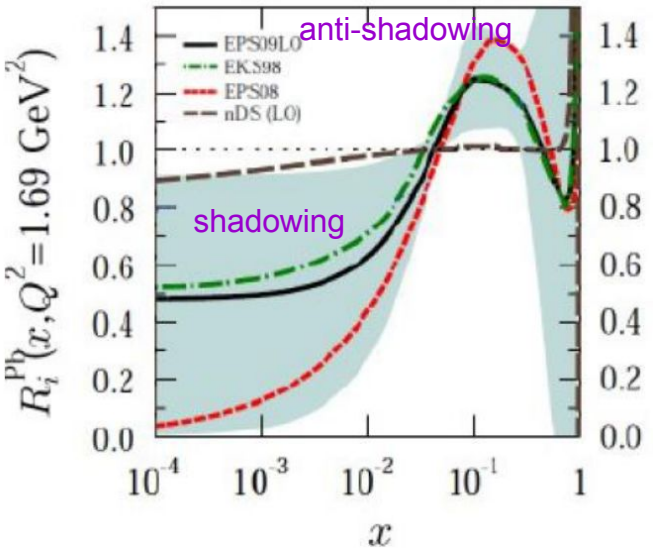
➢ Heavy quarks (charm and beauty) produced in initial hard scatterings and experience the full evolution of the medium, efficient probes of the medium properties

Open heavy-flavours in p-Pb collisions

- **Control experiment for Pb-Pb**

- **Investigate cold nuclear matter effects**
  - nuclear modification of parton distribution functions: shadowing/ gluon saturation at low Bjorken-x[1]

    [1]H.Fujii and K.Watanabe, Nucl.Phys.A915(2013) 1
  - energy loss[2] [2]I. Vitev, Phys. Rev. C75(2007) 064906
  - k_T broadening via multiple soft scatterings in the initial state[3] [3] X.N. Wang, Phys.Rev. C61(2000) 064910

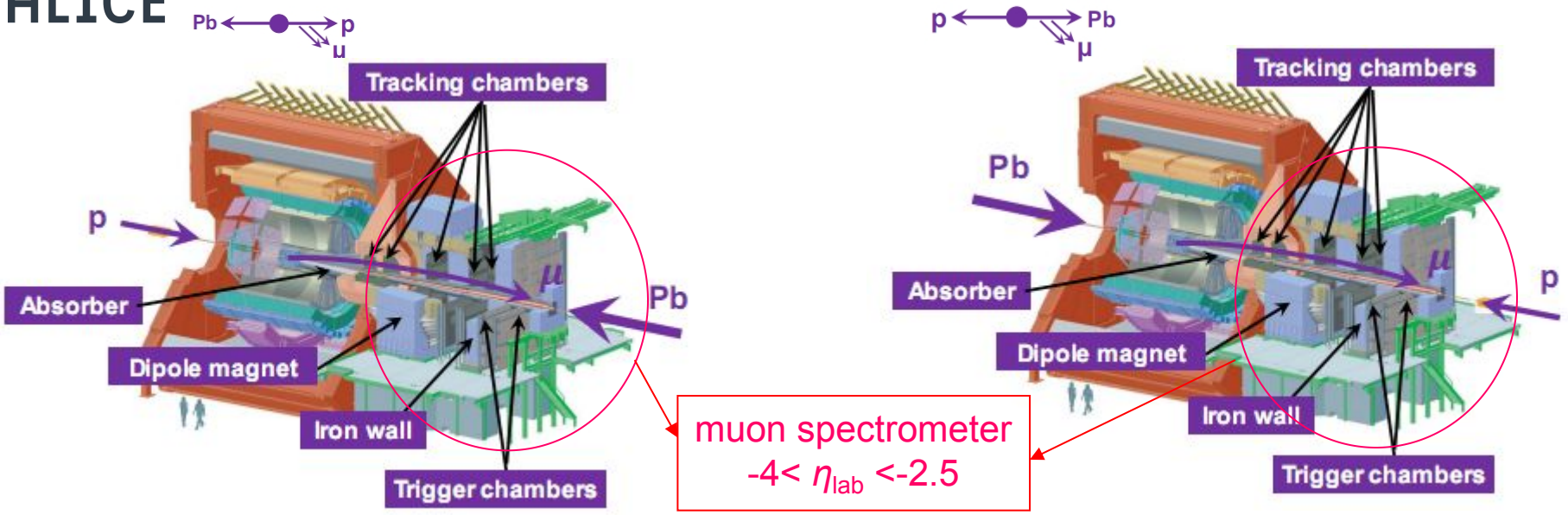


- **Investigation by means of the nuclear modification factor**

$$R_{\mathrm{pA}} = \frac{1}{\mathrm{A}} \frac{\mathrm{d}\sigma_{\mathrm{pA}}/\mathrm{d}p_{\mathrm{T}}}{\mathrm{d}\sigma_{\mathrm{pp}}/\mathrm{d}p_{\mathrm{T}}}$$

K.J. Eskola et al., JHEP 0904(2009) 65
D.E. Kharzeev et al.,arXiv:1025.1554[hep-ph]
F.Dominguez et al., arXiv: 1109.1250[hep-ph]
R.Vogt, Phys.Rev C81 (2010) 044903
F. Arleo et al., arXiv: 1204.4609[hep-ph]
C. Lourenco et al., JHEP 0902 (2009) 014

Open heavy-flavour measurements with the ALICE muon spectrometer



Rapidity shift of the center-of-mass of 0.456 units in the p direction

- **forward rapidity (p-going direction, $2.03<y_{CMS}<3.53$)**

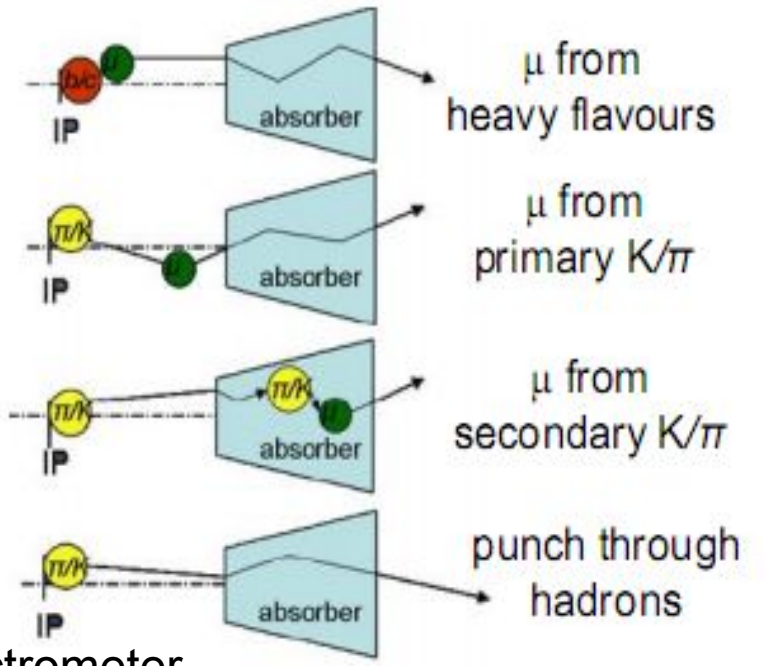
Integrated luminosity
196 μb^{-1} (low p_T μ trigger)
4.9×10^3 μb^{-1} (high p_T μ trigger)

- **backward rapidity (Pb-going direction, $-4.46<y_{CMS}<-2.96$)**

Integrated luminosity
145 μb^{-1} (low p_T μ trigger)
5.8×10^3 μb^{-1} (high p_T μ trigger)

Muon selection

- **Muon triggers**
  - MSL (Muon Single Low):
    p_T threshold of about 0.5 GeV/c
  - MSH (Muon Single High):
    p_T threshold of about 4.2 GeV/c



- **Track selection cuts**
  - -4< η_{lab} <-2.5: acceptance of ALICE muon spectrometer
  - 170º< θ_{abs} <178º: geometry of the spectrometer
  - muon trigger matching: reject hadrons that cross the absorber
  - pointing angle to the vertex via pXDCA in 6σ
    (DCA: distance of closest approach of a muon track to the interaction vertex):
    remove beam-gas and particles produced in the absorber

Heavy-flavour decay muons: background subtraction (1/2)

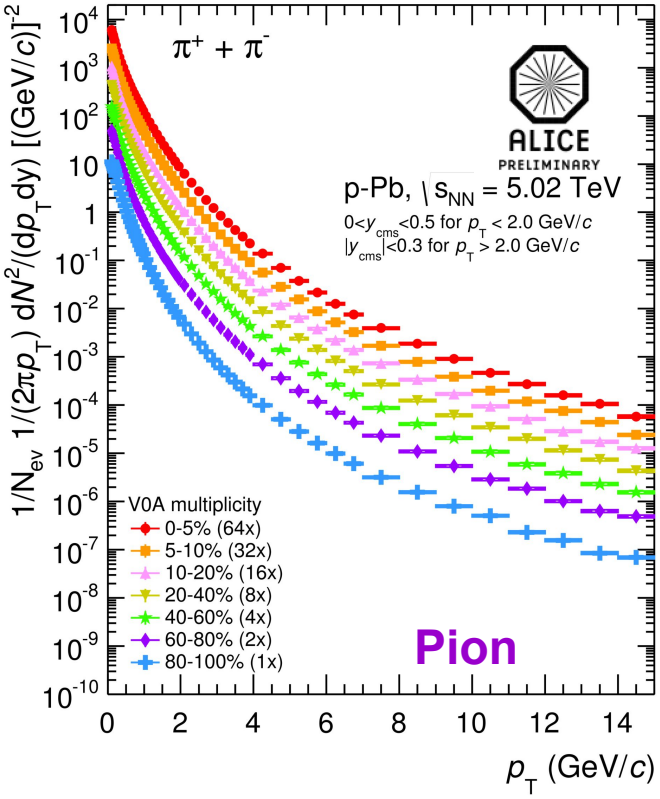
- **Estimated using a data-based cocktail of background sources (mainly π± and K± decays)**

- **Forward rapidity (p-going direction, $2.5<y_{CMS}<3.53$)**

  - inputs: charged hadron spectra (π± and K±) measured at mid-rapidity ($|y_{CMS}|<0.3$) with ALICE

  - extrapolate the measured distributions to forward rapidity according to the d*N*/d*y* shape from Monte-Carlo generators

  - produce the K±/π± decay muon background via fast simulation of the decay kinematics and absorber effect



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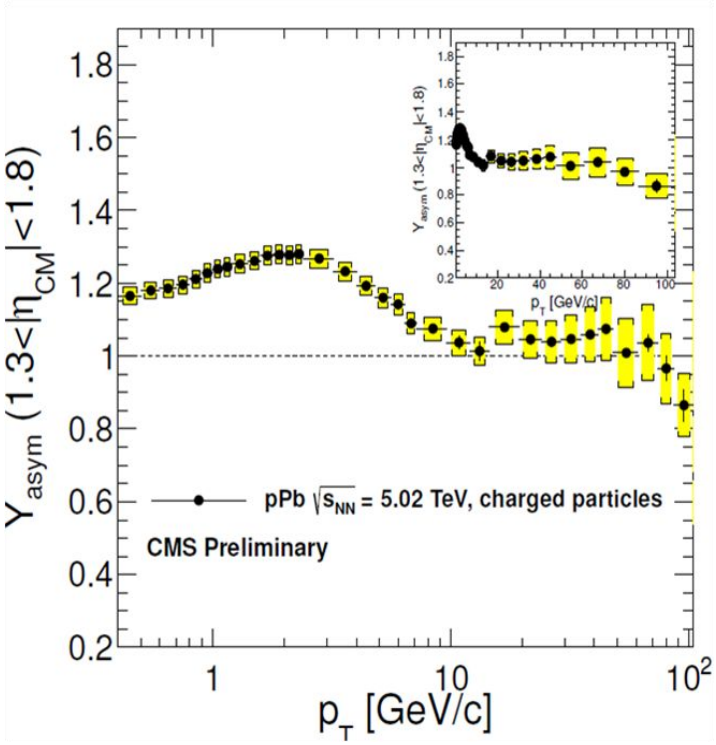
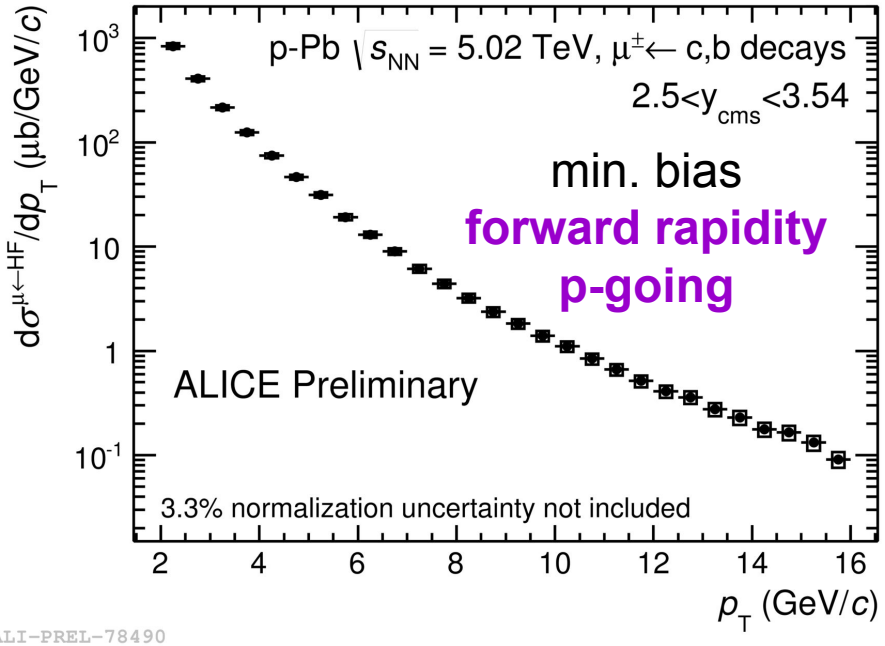
Heavy-flavour decay muons: background subtraction (2/2)

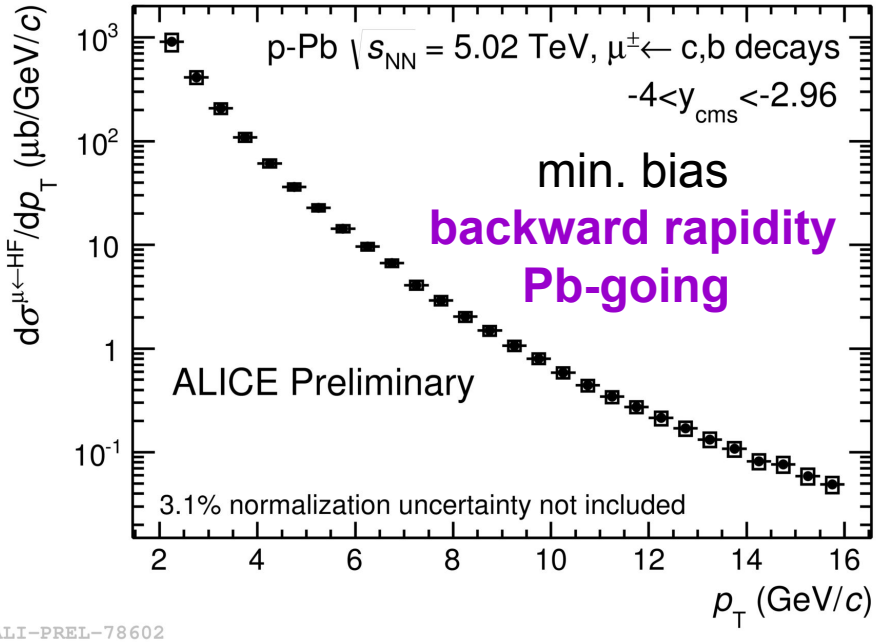


- **Backward rapidity (Pb-going direction, $-4<y_{CMS}<-2.96$)**
  - scale estimated charged hadron spectra at forward rapidity to backward rapidity according to the forward-to-backward ratio measured by the CMS Collaboration
  - produce the $K^{\pm}/\pi^{\pm}$ decay muon background via fast simulation

CMS PAS HIN-12-017

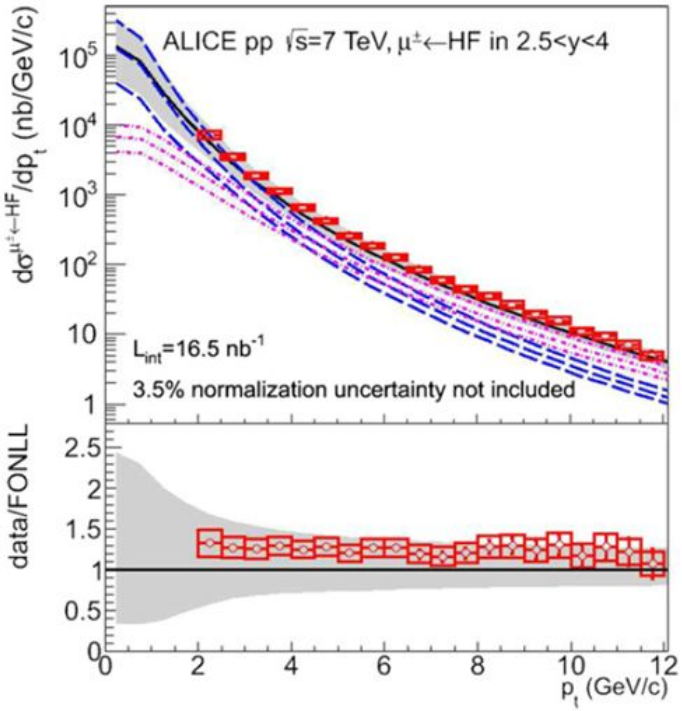
Heavy-flavour decay muons: p_T-differential cross sections





- p_T-differential production cross sections measured for heavy-flavour decay muon at forward and backward rapidities in 2< p_T <16 GeV/*c*

pp reference



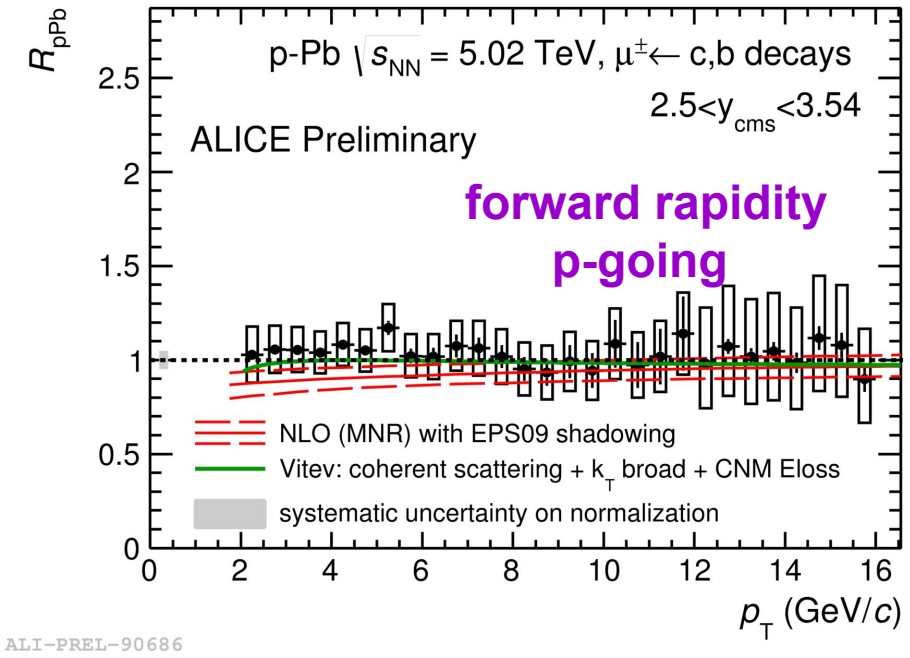
- **The nuclear modification factor:**

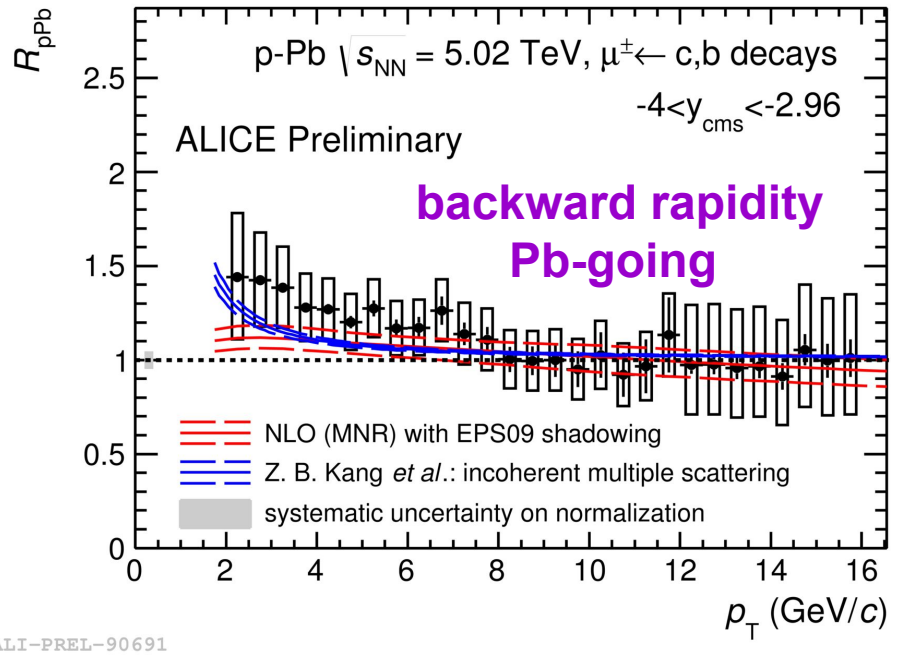
$$R_{\mathrm{pA}} = \frac{1}{\mathrm{A}} \frac{\mathrm{d}\sigma_{\mathrm{pA}}/\mathrm{d}p_{\mathrm{T}}}{\mathrm{d}\sigma_{\mathrm{pp}}/\mathrm{d}p_{\mathrm{T}}}$$

- FONLL pQCD calculations are in agreement within uncertainties with the measured cross sections of muons from HF decays
- pp reference obtained by a pQCD-based energy scaling of the p_T-differential cross sections measured at 7 TeV[1] and, extrapolated to higher p_T by using pQCD calculations[2] when no measurement is available

[1] Phys. Lett. B 708 (2012) 265
[2] arXiv: 1107.3243[hep-ph]

Heavy-flavour decay muons: p_T-differential R_{pPb}



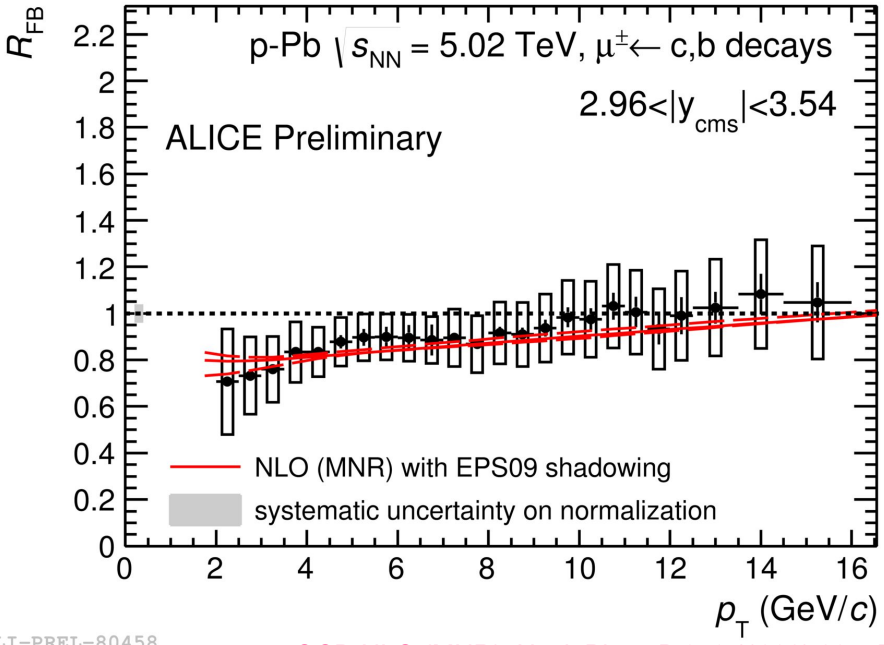


- R_{pPb} at forward rapidity: consistent with unity within uncertainties over whole p_T range
- R_{pPb} at backward rapidity: slightly larger than unity in $2 < p_T < 4$ GeV/c and compatible with unity at higher p_T
- Within uncertainties, data can be described by models implementing cold nuclear matter effects

Heavy-flavour decay muons: p_T-differential R_{FB}

Forward-to-backward ratio

$$R_{FB}(2.96 < |y_{CMS}| < 3.54) = \frac{d\sigma/dp_T[\text{Forward}(2.96 < y_{CMS} < 3.54)]}{d\sigma/dp_T[\text{Backward}(-3.54 < y_{CMS} < -2.96)]}$$

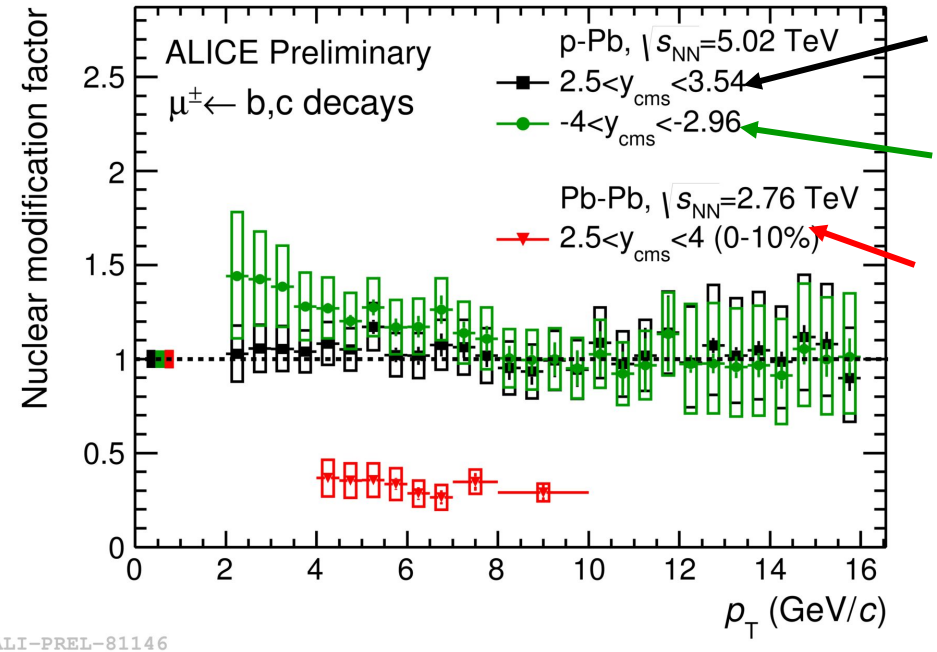


pQCD NLO (MNR): Nucl. Phys. B 373 (1992) 295; EPS09: K. J. Eskola et al., JHEP 04 (2009) 065

- R_{FB}: systematically smaller than unity in 2<p_T<4 GeV/c and close to unity at higher p_T
- Within uncertainties, data can be described by perturbative QCD calculations with EPS09

Comparison with R_{AA} measurement

Pb-Pb: ALICE Collaboration, Phys. Rev. Lett: 109, 112301 (2012)



p-Pb forward rapidity

p-Pb backward rapidity

Pb-Pb central

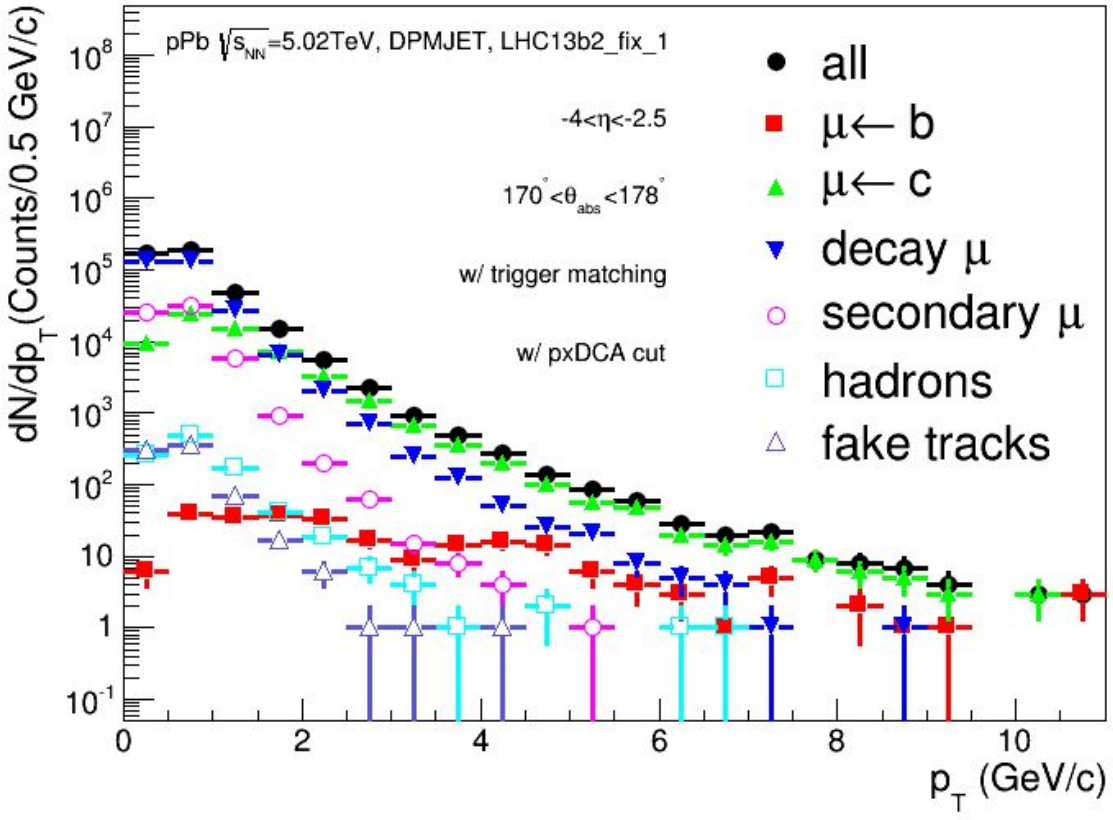
- R_{AA}: suppression up to a factor of about 4 in 4< p_T < 10 GeV/c in the 10% most central Pb-Pb collisions,
- R_{pPb} being consistent with unity, the suppression observed in central Pb-Pb collisions results from final-state effects related to parton energy loss

Conclusion and Outlook

- Cold nuclear matter effects on heavy-flavour production assessed at forward and backward rapidity via the nuclear modification factor R_{pPb} and forward-to-backward ratio R_{FB} of muons from heavy-flavour hadron decays
- Models implementing initial state effects describe the data within uncertainties
- Small cold nuclear matter effects -> suppression in central Pb-Pb collisions results from medium effects.
- **Outlook:** R_{AA} measurement at higher p_T, analysis being finalized, paper proposal to come soon; Study production of heavy-flavour decay muons as a function of the event activity

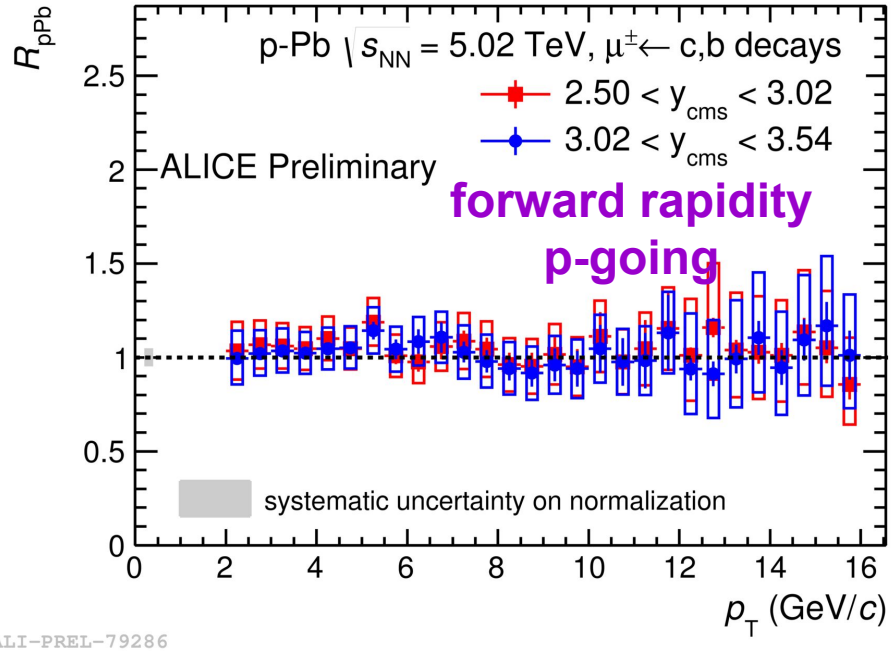
Backup

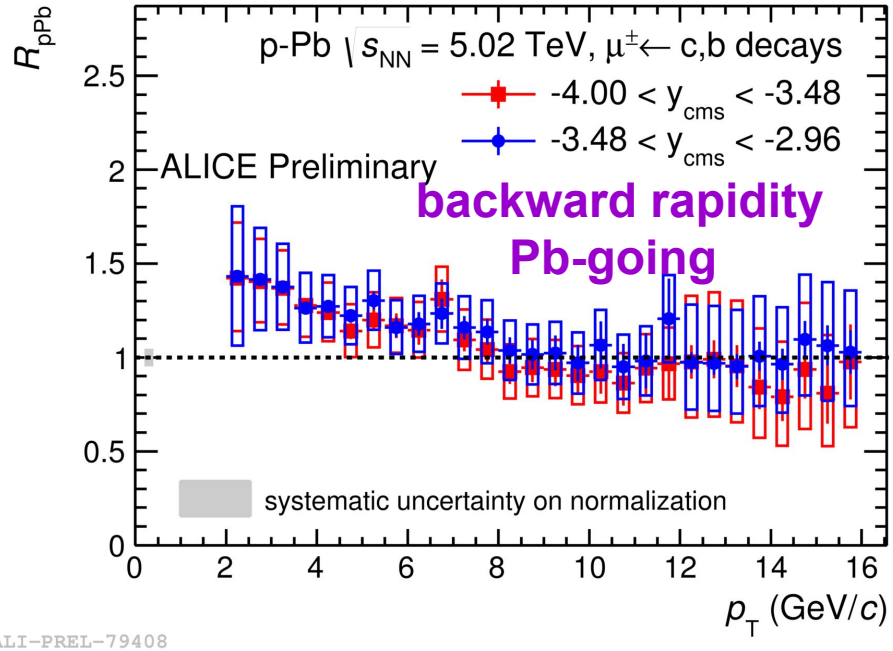
Background source



- In the following, we will focus on the region p_T > 2 GeV/*c* where the background contribution consists of muons from primary pion and kaon decays, mainly.

Heavy-flavour decay muons: R_{pPb} within sub-rapidity bins



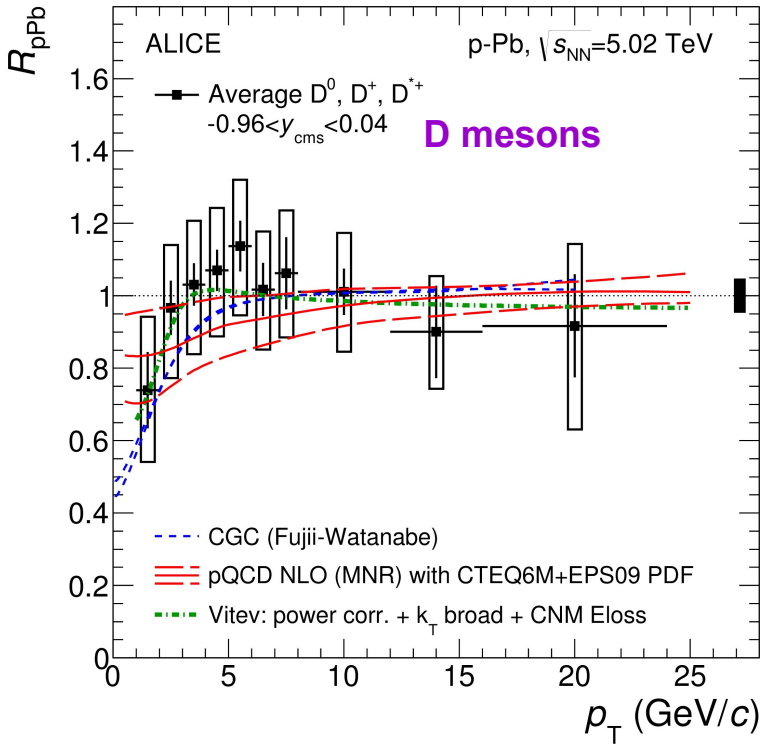


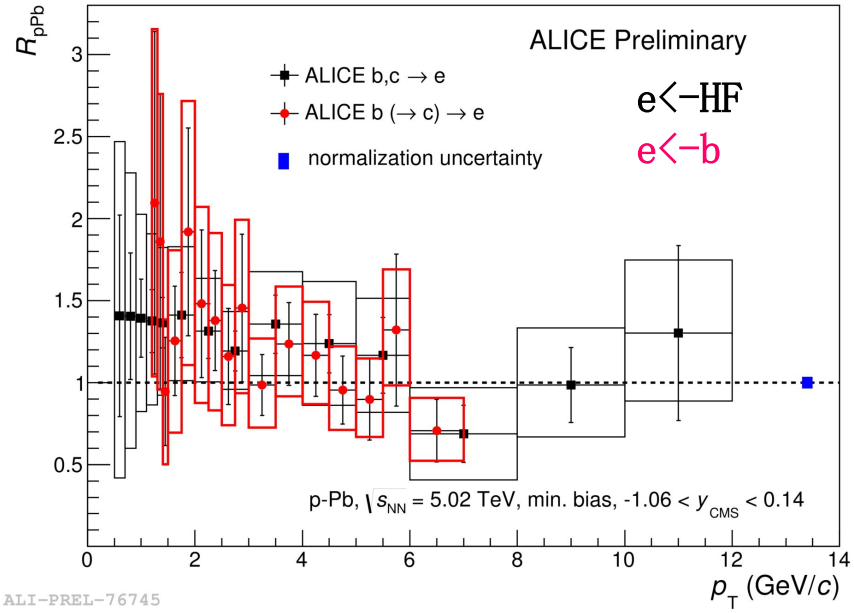
$2.50 < y_{CMS} < 3.02$
$3.02 < y_{CMS} < 3.54$

$-4.00 < y_{CMS} < -3.48$
$-3.48 < y_{CMS} < -2.96$

- Similar results in sub-rapidity bins for R_{pPb} at both forward and backward rapidity

Open heavy-flavour R_{pPb} at midrapidity

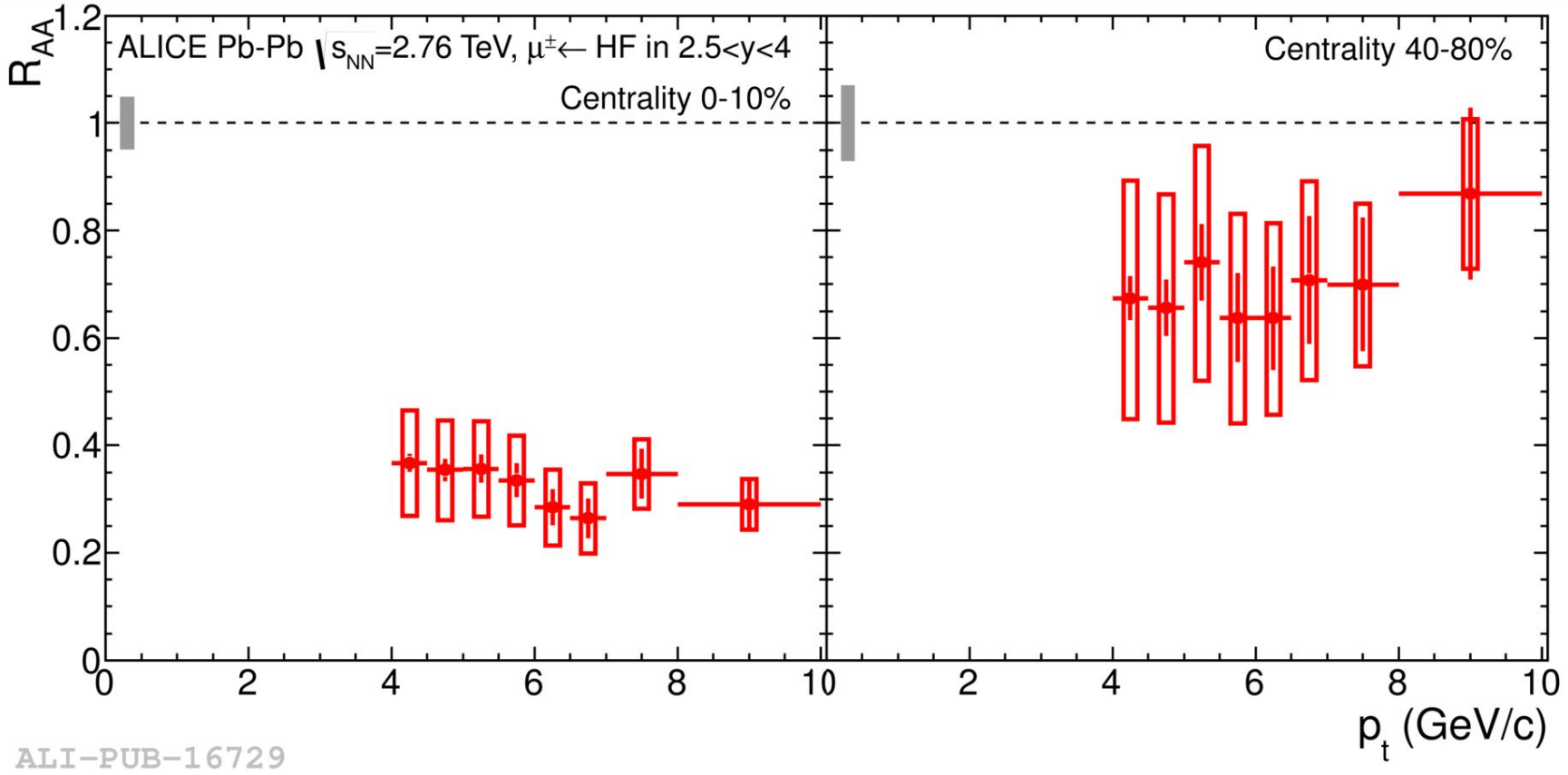




ALICE Collaboration, Phy. Rev. Lett. 113 (2014) 232301

- Small cold nuclear matter effects observed also at mid-rapidity for D mesons and heavy-flavour (beauty) decay electrons

The HFM R_{AA} plot in the two centrality classes



- The HFM R_{AA} plot in the two centrality (0-10%, 40-80%) classes measured in ALICE muon spectrometer in Pb-Pb collisions at $\sqrt{s_{NN}}$= 2.76 TeV.