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

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Outline

- Physics motivation
- Open heavy-flavour measurements with the ALICE muon spectrometer
- Analysis strategy
- Results
- Summary and outlook

ALICE

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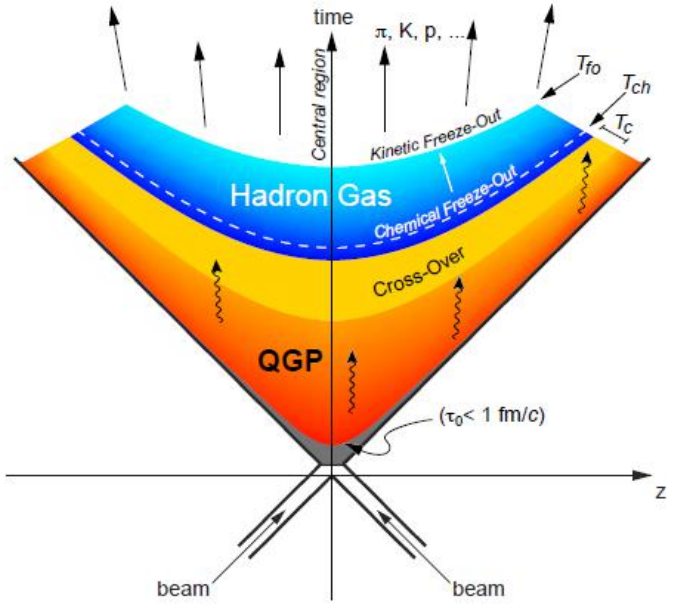
Open heavy flavours in heavy-ion collisions at the LHC

- **Charm and beauty quarks** produced in initial hard scatterings with a short formation time
  $\tau_f \sim 1/m_{c/b}$ (~ 0.02-0.1 fm/c) << τ_{QGP} (~ 5-10 fm/c)
- Involved in the full evolution of the QCD medium
  - **Sensitive probes of the medium properties**



- **Open heavy flavours in AA collisions:**

Investigate the hot nuclear matter effects

- ✓ Energy loss in the medium via gluon radiation and elastic collisions:
  - Parton color-charge and mass dependence
    Dokshitzer & Kharzeev, Phys. Lett. B *519 (2001) 199*
  - Expected: $\Delta E_g > \Delta E_{u,d,s} > \Delta E_c > \Delta E_b$
    $R_{AA}(\pi) < R_{AA}$ (D) < R_{AA} (B)?
- ✓ Participation in the collective expansion of the system

Observables

- ✓ Nuclear modification factor: $R_{AA}(p_T) = \frac{1}{< T_{AA} >} \times \frac{dN_{AA}/dp_T}{d\sigma_{pp}/dp_T}$
- ✓ Central-to-peripheral nuclear modification factor: $R_{CP}(p_T) = < T_{AA} >_p / < T_{AA} >_C \times \frac{dN^C_{AA}/dp_T}{dN^P_{AA}/dp_T}$
- ✓ Elliptic flow, v_2: $\frac{2\pi}{N}\frac{dN}{d\varphi} = 1 + \sum_{n=1}^{\infty} 2v_n \cos[n(\varphi - \psi_n)]$ with $v_2 = < \cos[2(\varphi - \psi_n)] >$

Open heavy flavours in pp and p-Pb collisions at the LHC

- **Heavy flavours in pp collisions:**
  Test of pQCD calculations and reference for p-Pb and Pb-Pb collisions

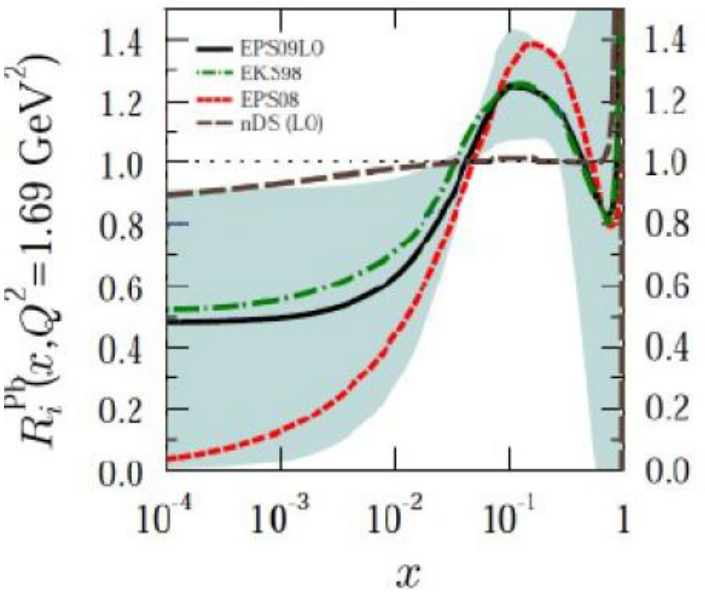
- **Heavy flavours in pA collisions:**

✓ Control experiment for Pb-Pb collisions

✓ Cold nuclear matter effects :

- nuclear modification of parton distribution functions: shadowing/ gluon saturation
- energy loss
- k_T broadening via multiple soft scatterings in the initial state

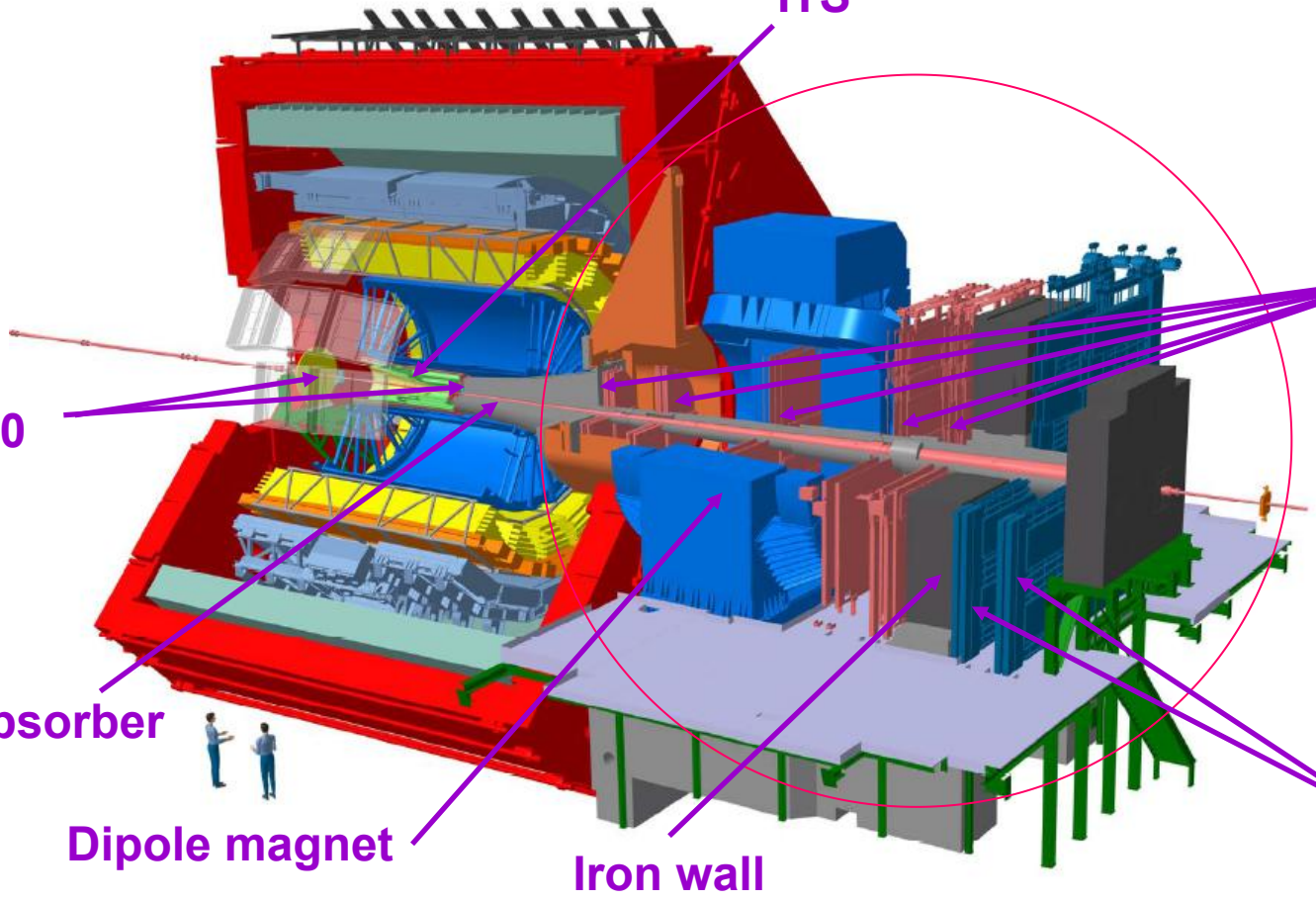
Ratio of PDF (gluons) in the nucleus and in the nucleon



K.J. Eskola et al., JHEP 0904 (2009) 65
F. Dominguez et al., Phys. Lett. B 710 (2012) 182
R. Vogt, Phys. Rev. C 81 (2010) 044903
F. Arleo et al., Phys. Rev. Lett. 109 (2012) 122301
C. Lourenco et al., JHEP 0902 (2009) 014

ALICE setup

V0: trigger, collision centrality
ITS: vertex determination



min. muon momentum: p ~ 4 GeV/c
min. trigger p_T: ~0.5 GeV/c

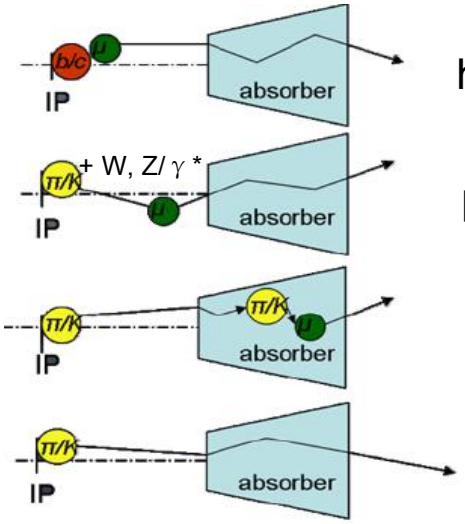
Data sample and Muon selection

Data sample: 2015 Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

- **Trigger condition: signal in the two V0 arrays (minimum bias trigger) with**
  - ✓ at least one muon with a low p_T trigger threshold of ~1 GeV/c
    ($L_{int} \approx 21.9\ \mu b^{-1}$, 0-90% centrality class)
  - ✓ at least one muon with a high p_T trigger threshold of ~4.2 GeV/c
    ($L_{int} \approx 202.3\ \mu b^{-1}$, 0-90% centrality class)

Muon track selection

- **Acceptance & geometrical cuts**
  select tracks in the spectrometer acceptance
- **p_T cut at 2 GeV/c**
  reject μ from secondary π, K
- **Tracks matched with trigger**
  reject hadrons crossing the absorber
- **p×DCA in 6 σ**
  reject beam-gas interactions & particles produced in the absorber



μ from heavy flavours

μ from primary π, K, W,Z/ γ *

μ from secondary π, K

punch through hadrons

$\mu^{\pm} \leftarrow$ b, c studies

- **Main remaining background:**
  μ ← primary π, K decays;
  μ ← W, Z/ γ *

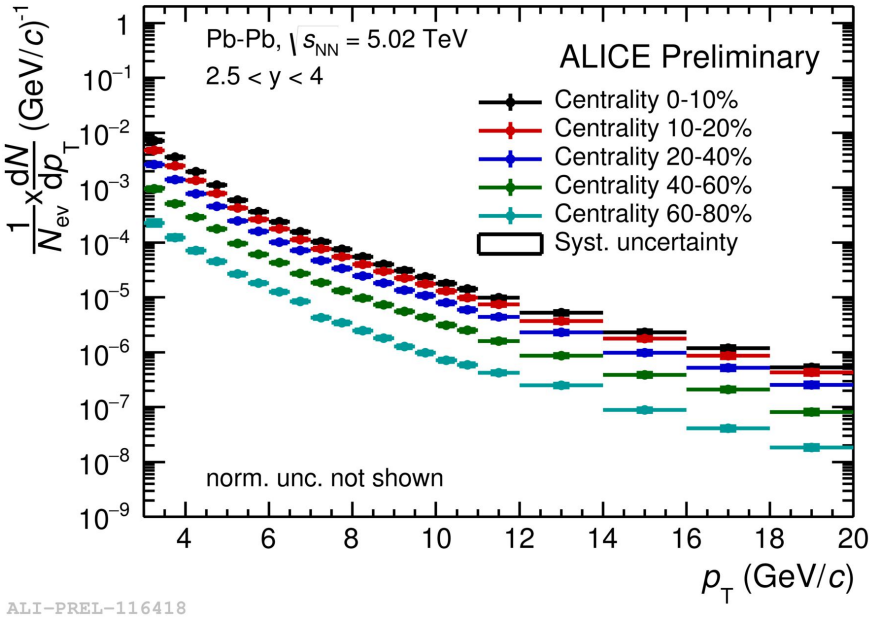
Analysis strategy in Pb-Pb collisions

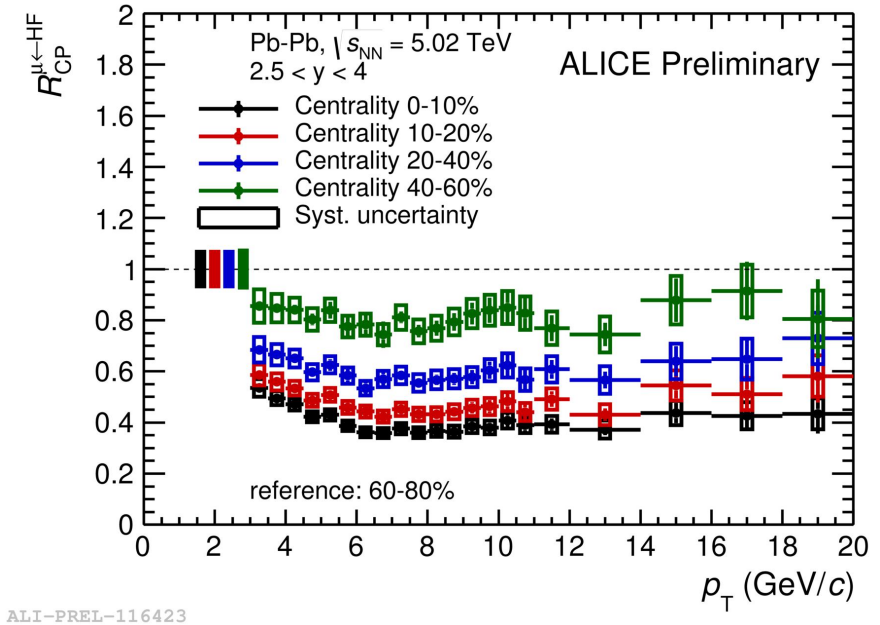
- **Normalize to minimum-bias events**
  - ✓ Normalization of muon samples to equivalent number of MB events on a run by run basis
- **Acceptance x efficiency correction**
  - ✓ From simulations using heavy-flavour signals from NLO pQCD predictions as inputs
  - ✓ Centrality dependence of tracking efficiency estimated via embedding procedure, ~6% difference from 60-80% to 0-10% centrality classes
- **Background: μ←π/K（dominant background contribution at low p_T）**
  - ✓ Data-tuned Monte-Carlo cocktail as previously done (Phys. Rev. Lett. 109 (2012) 112301) (Contribution: ~16% (10%) in 0-10% (60-80%) centrality class at 3 GeV/*c*)
- **Background: μ←W, Z/γ *（dominant background contribution at high p_T）**
  - ✓ Pb-Pb templates obtained by combining pp, pn, np and nn collisions with Monte Carlo (POWHEG) simulation (contribution: ~38% (19%) in 0-10% (60-80%) centrality class at 20 GeV/*c*)

$$\frac{d\sigma_{Pb-Pb}}{dp_T} \approx \frac{Z^2}{A^2} \times \frac{d\sigma_{pp}}{dp_T} + \frac{(A-Z)^2}{A^2} \times \frac{d\sigma_{nn}}{dp_T} + \frac{Z\cdot(A-Z)}{A^2}\left\{\frac{d\sigma_{pn}}{dp_T} + \frac{d\sigma_{np}}{dp_T}\right\} \qquad (A = 208,\ Z = 82)$$

Normalized p_T-differential yields and p_T-differential R_{CP}

$$R_{CP}(p_T) = \langle T_{AA} \rangle_p / \langle T_{AA} \rangle_C \times \frac{dN^C_{AA}/dp_T}{dN^P_{AA}/dp_T}$$

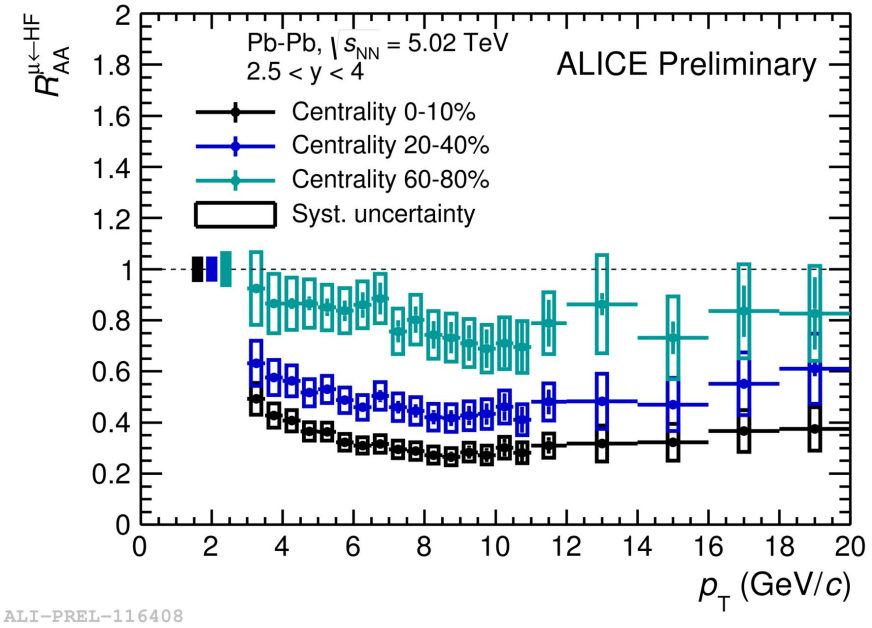


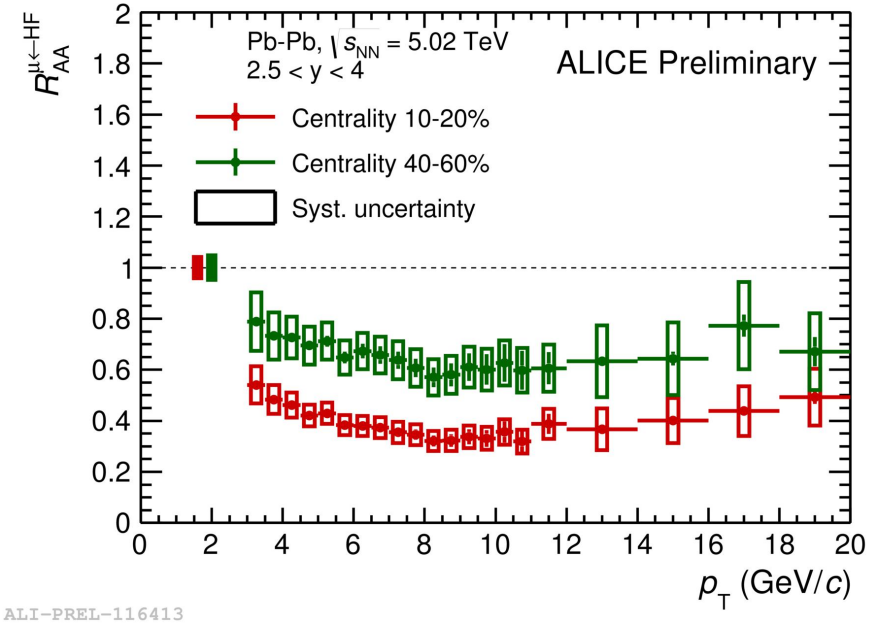


- Measurement over a wide p_T interval, in $3 < p_T < 20$ GeV/c, in all centrality classes with muon triggered events
- Clear increase of the suppression for more central events, about a factor 2.5 in 0-10% w.r.t. 60-80% for $7 < p_T < 12$ GeV/c

p_T-differential R_{AA} of heavy-flavour decay muons in different centrality classes

$$R_{AA}(p_T) = \frac{1}{< T_{AA} >} \times \frac{dN_{AA}/dp_T}{d\sigma_{pp}/dp_T}$$

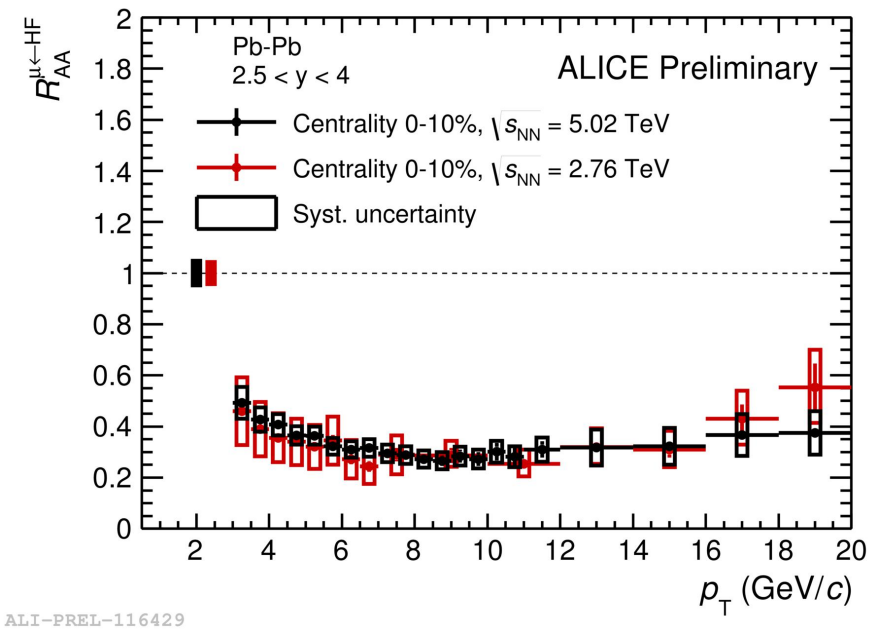




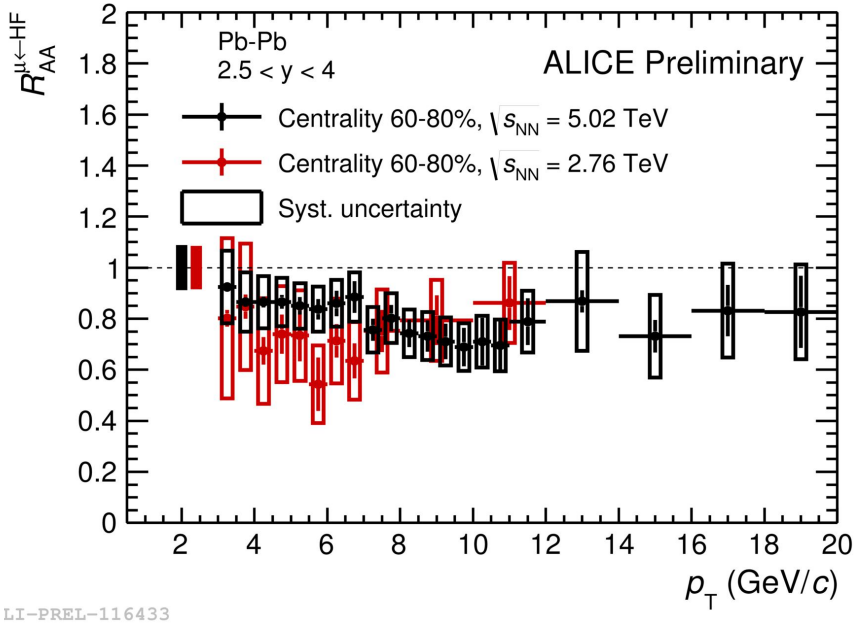
- Clear increase of the suppression for more central events: about a factor 3 in 0-10% at p_T (7< p_T< 12 GeV/c)
- pp reference:
  - ✓ In 3 < p_T < 12 GeV/c, published p_T differential cross section of heavy-flavour decay muons at $\sqrt{s}$ = 7 TeV (PLB 708 (2012) 265) scaled to $\sqrt{s}$ = 5.02 TeV with FONLL (R. Averbeck et al., arXiv:1107.3243) ;
  - ✓ In p_T > 12 GeV/c, scale FONLL predictions according ratio between data & FONLL in 3 < p_T < 12 GeV/c

Comparison of the two energies

Centrality: 0-10%

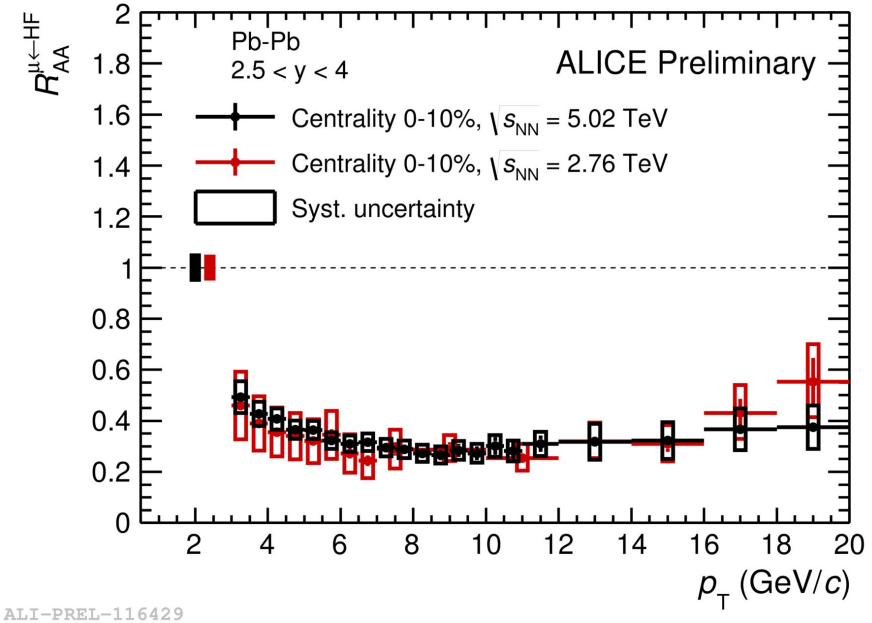


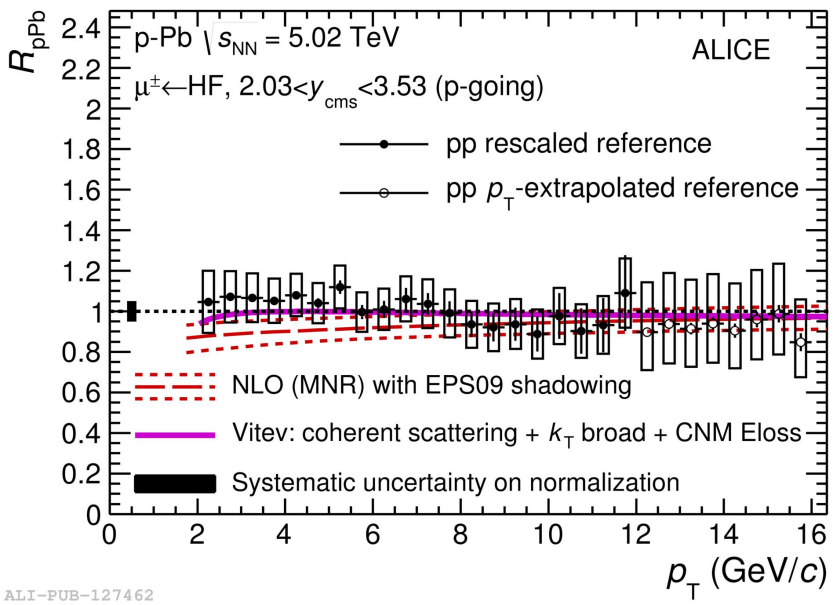
Centrality: 60-80%



- Similar suppression at 5.02 TeV and at 2.76 TeV for both central and peripheral collisions within uncertainties
- Better precision in Run 2 ($\sqrt{s_{NN}}$ = 5.02 TeV)

Comparison with p-Pb measurements

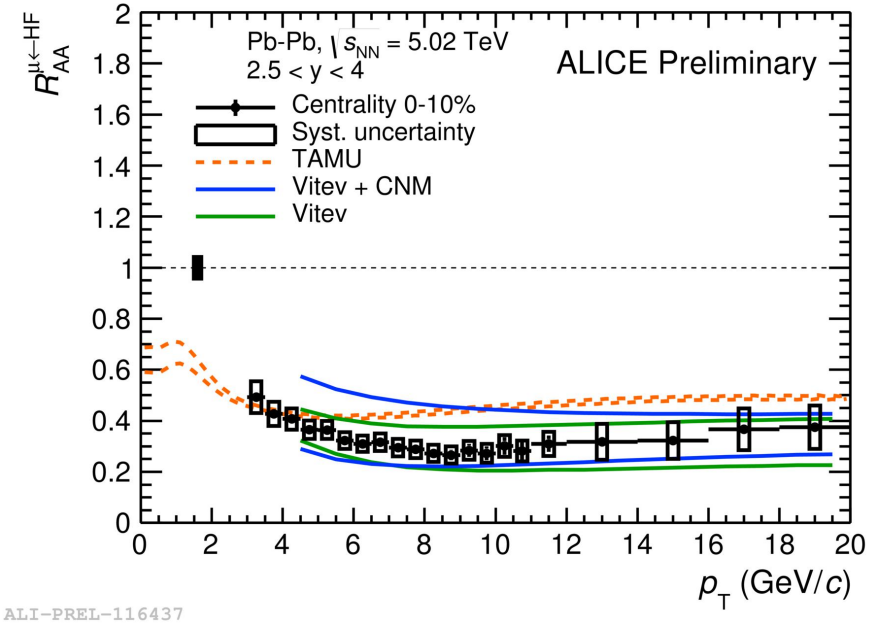


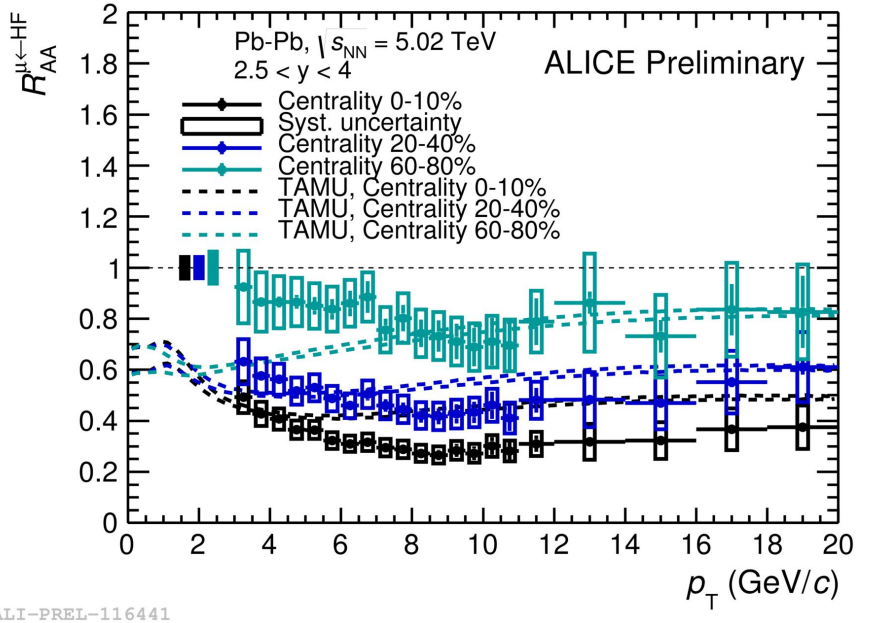


p-Pb: ALICE Collaboration, arXiv:1702.01479

- R_{pPb}: consistent with unity within uncertainties over the whole p_T range
- The suppression observed at high p_T in central Pb-Pb collisions results from final-state effects related to parton energy loss

Comparison with models at $\sqrt{s_{NN}}$ = 5.02 TeV





- R_{AA} measurements at $\sqrt{s_{NN}}$ = 5.02 TeV provide new constraints on energy loss models

Vitev: Phys. Rev. C 80 (2009) 054902
TAMU: Phys. Lett. B 735 (2014) 445

Summary and outlook

Summary

- **First measurement of R_{AA} of muons from heavy-flavour decays measured in a wide p_T range ($3 < p_T < 20$ GeV/c) in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV**
  - ✓ A strong suppression in the 10% most central collisions reaching a factor ~3 in $7 < p_T < 12$ GeV/c
  - ✓ Results compatible within uncertainties with those obtained at $\sqrt{s_{NN}} = 2.76$ TeV
  - ✓ The measured suppression is due to final-state effects ($R_{pPb} \sim 1$)
  - ✓ R_{AA} measurements of muons from heavy-flavour decays at $\sqrt{s_{NN}} = 5.02$ TeV provide new constraints on energy loss models

Outlook

- **More to come soon**
  - ✓ The p_T-differential cross section of heavy-flavour decay muons in pp colllisions at $\sqrt{s} = 5.02$ TeV

Thank you for your attention

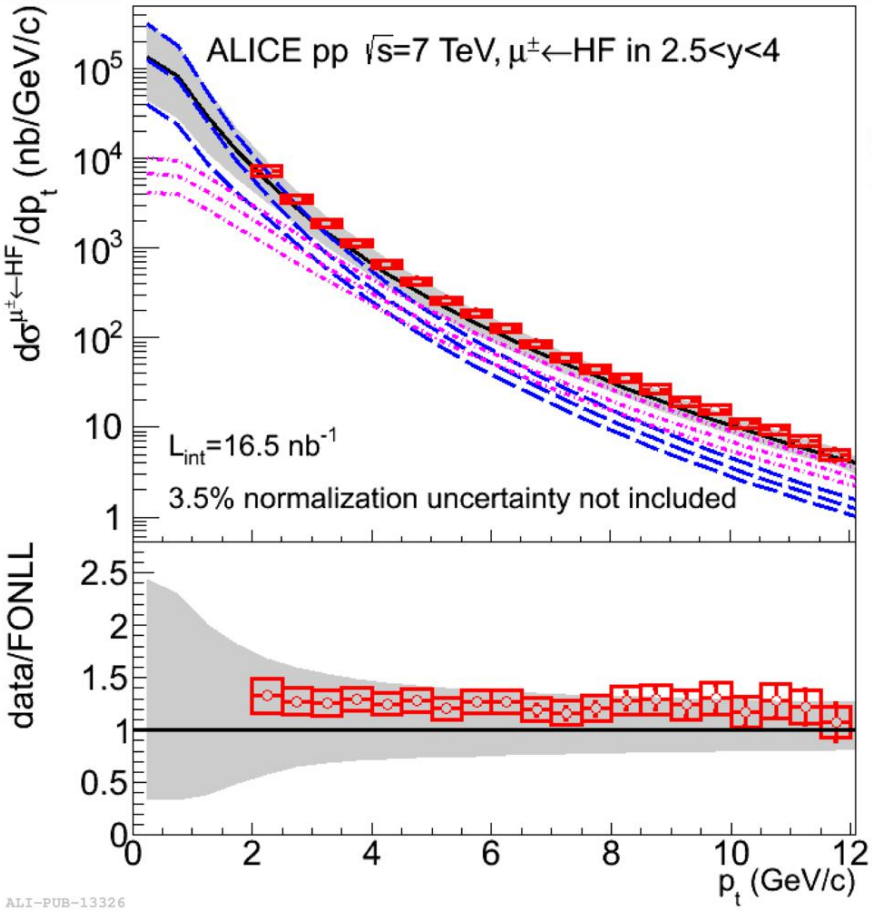
Backup

pp reference

- Published p_T differential cross section of heavy-flavour decay muons at $\sqrt{s}$ = 7 TeV measured in 2 < p_T < 12 GeV/c (PLB 708 (2012) 265) scaled to $\sqrt{s}$ = 5.02 TeV with FONLL (R. Averbeck et al., arXiv:1107.3243)
. Systematic uncertainty: 9-15% (data and energy scaling)

- p_T differential cross section of heavy-flavour decay muons in p_T > 12 GeV/c: scale FONLL predictions according ratio between data & FONLL

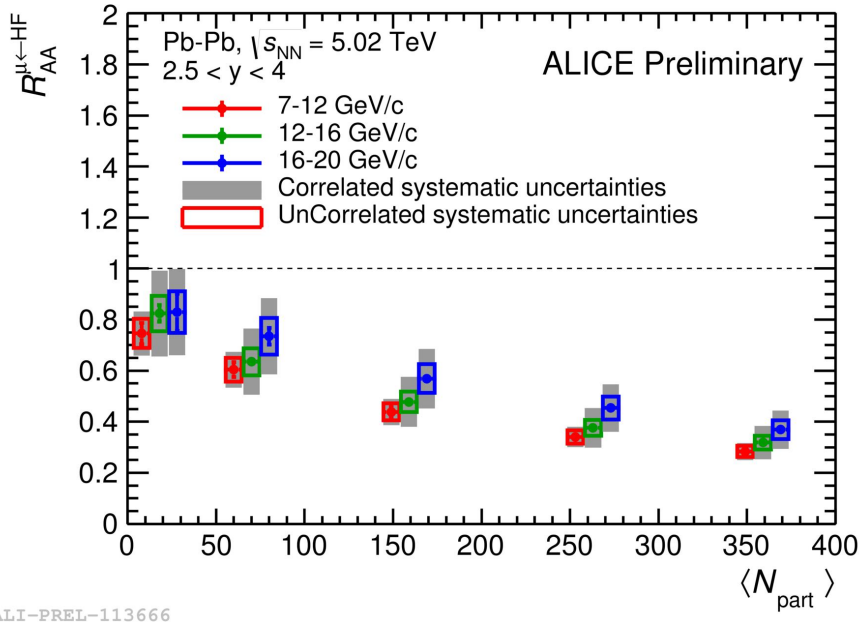
- Total systematic uncertainty: 20-21% (FONLL and fit (11%))



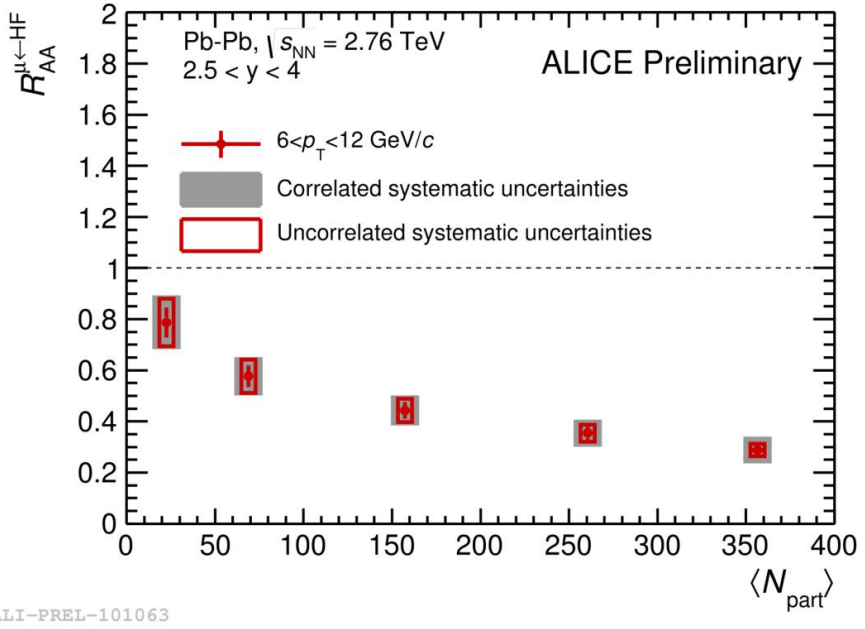
Phys. Lett. B 708 (2012) 265

Centrality dependence of R_{AA} of heavy-flavour decay muons

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



Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV



- The suppression increases from peripheral to central collisions in the domain $7 < p_T < 20$ GeV/c
- Similar suppression to that measured at $\sqrt{s_{NN}}$ = 2.76 TeV within uncertainties (different p_T interval)