Heavy-flavour and W-boson production measurements via leptonic decay channels with ALICE at the LHC

Francesco Bossù
for the ALICE collaboration

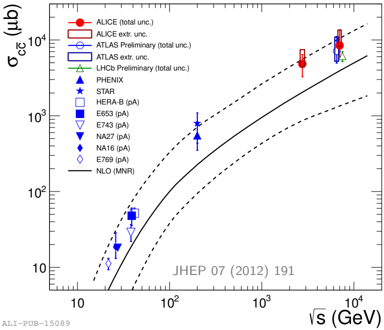
iThemba LABS, Cape Town

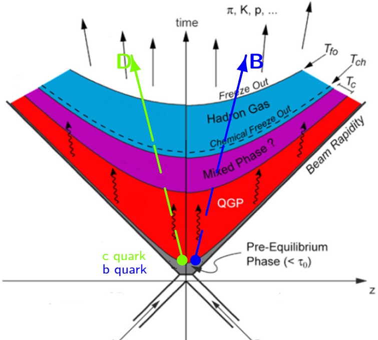
THE 15H INTERNATIONAL CONFERENCE ON STRANGENESS IN QUARK MATTER
DUBNA, 6-11 JULY 2015

Why heavy flavours in ALICE?

In proton-proton collisions:

- charm and beauty quarks produced in high-Q^2 partonic scattering processes
- higher cross section at the LHC
  $\sigma_{c\bar{c}}(LHC) \sim 10 \cdot \sigma_{c\bar{c}}(RHIC)$
  $\sigma_{b\bar{b}}(LHC) \sim 50 \cdot \sigma_{b\bar{b}}(RHIC)$
- test bench for pQCD calculations
- reference for heavy-ion data





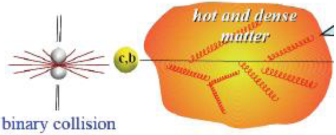
... and being "heavy-ion"-minded:

- heavy quarks dominantly produced in the early stages of the collision
- exposed to the medium evolution
- no additional production in the hadronic phase

⇒ Ideal probes

- Partons lose energy in the medium via elastic collisions and gluon radiation
- Medium-induced gluon radiation depends on:
  - ⋆ medium properties and path length in the medium
  - ⋆ parton colour charge (Casimir factor)
  - ⋆ parton mass (dead-cone effect)

  Dokshitzer and Kharzeev, PLB 519 (2001), 199



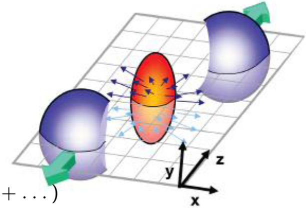
$$\Delta E_{\rm g} > \Delta E_{\rm u,d} > \Delta E_{\rm c} > \Delta E_{\rm b}$$

- Tools:
  - ⋆ Nuclear modification factor

$$R_{\rm AA} = \frac{1}{\langle T_{\rm AA}\rangle} \frac{{\rm d}N_{\rm AA}/{\rm d}p_{\rm T}}{{\rm d}\sigma_{\rm pp}/{\rm d}p_{\rm T}}$$

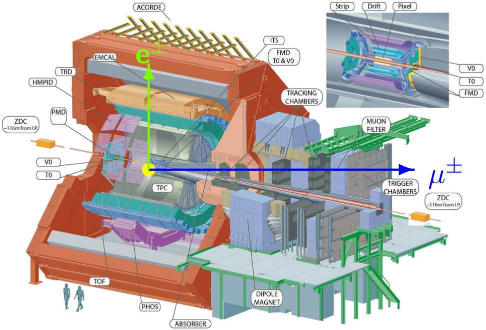
$$R_{\rm AA}(B) > R_{\rm AA}(D) > R_{\rm AA}(\pi)?$$

  - ⋆ Azimuthal anisotropy



$$\frac{{\rm d}N}{{\rm d}\varphi} = \frac{N_0}{2\pi}\left(1 + 2\cdot v_1 cos(\varphi - \Psi_1) + 2\cdot v_2 cos[2(\varphi - \Psi_2)] + \ldots\right)$$

collective motion at low $p_{\rm T}$ and path-length dependence of parton energy loss at high $p_{\rm T}$



Why leptons?

- Possible trigger particles
- BR $\approx 10\%$ for $\mathrm{c, b} \to \mathrm{e}(\mu) + \mathrm{X}$
- Clean signature in calorimeters for high-momentum electrons
- At high p_{T}, muon sample has low background from non-heavy flavour sources

Electrons

- $|\eta| \leq 0.9$
- down to very low p_{T}
- Tracking, vertexing and PID
- Bkg: MC cocktails and $\mathrm{e^+e^-}$ invariant mass analysis

Muons

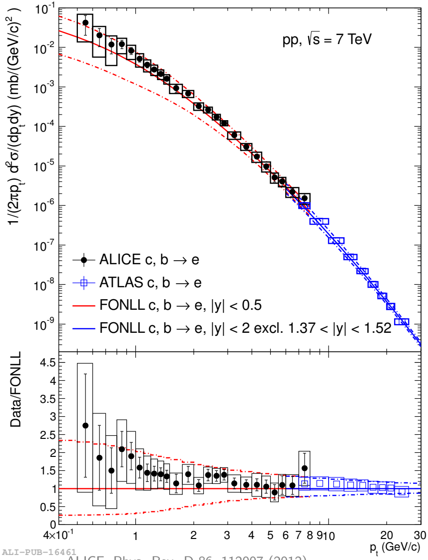
- $-4 \leq \eta \leq -2.5$
- $p > 4$ GeV/c
- Bkg: π and K decays subtraction via MC in pp or data-tuned MC cocktail in p-Pb and Pb-Pb

Forward Detectors

- Large η
- Interaction trigger
- Event characterization

- Combined two PID strategies: TPC+TRD+TOF and TPC+EMCal
- FONLL calculations describe the data within uncertainties over the full p_T range

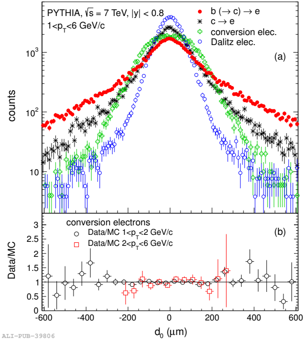
  (Cacciari et al., arXiv:1205.6344)
- Complementary with corresponding ATLAS measurement which is restricted to high p_T



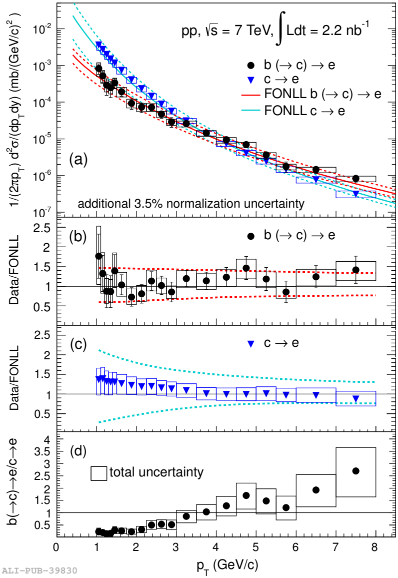
ALICE, Phys. Rev. D 86, 112007 (2012)
ATLAS, PLB 707 (2012) 438

- Long lifetime for beauty hadrons $c\tau \approx 500\mu$m
- Further e track rejection via p_{T}-dependent impact parameter d_0 cut
- Charm extraction: subtraction of the beauty-decay contribution from the inclusive spectrum of electrons from heavy-flavour decays
- FONLL pQCD predictions are in agreement within uncertainties both with the charm and the beauty differential cross section down to low p_{T}

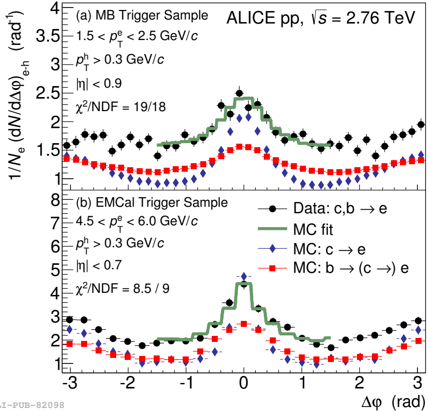
(Cacciari et al., arXiv:1205.6344)



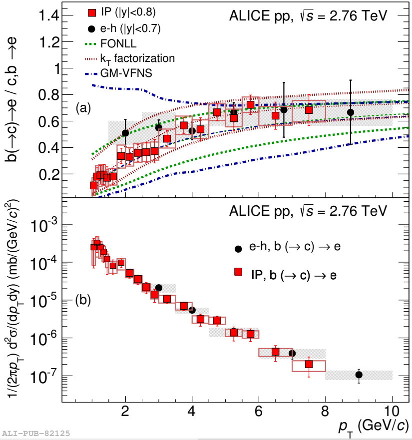
PLB 721 (2013) 13-23



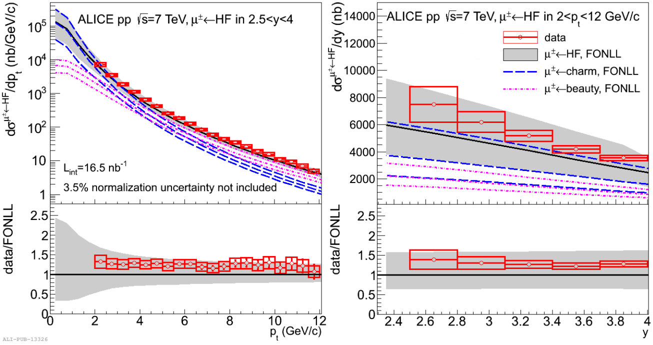
- Azimuthal electron-hadron correlations, complementary technique to impact-parameter method
- Broader near-side correlation for $e \leftarrow$ b compared to $e \leftarrow$ c
- Fit templates for charm and beauty obtained with Pythia
- pQCD predictions describe within uncertainties the beauty differential cross section (FONLL: JHEP 1210 (2012) 37, GM-VFNS : EPJ C72 (2012) 2082, k_T-factorization : PRD 87 (2013) 094022



PLB 738 (2014) 97



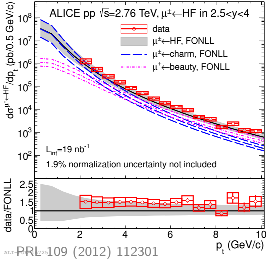
pp collisions: $\mu \leftarrow$ heavy flavours at $\sqrt{s} = 2.76$ and 7 TeV



PLB 708 (2012) 265

Muons from HF decays

- $2.5 < y < 4$
- background ($\mu \leftarrow \pi, K$) subtracted via MC simulation normalised to data at low p_T
- pQCD calculations describe both the p_T and y distributions within the uncertainties at both energies Cacciari et al., arXiv:1205.6344

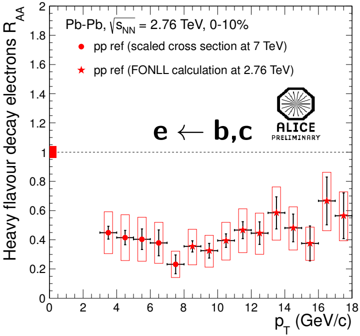


PRL 109 (2012) 112301

$$R_{AA}(p_T) = \frac{1}{\langle T_{AA} \rangle} \cdot \frac{dN_{AA}/dp_T}{d\sigma_{pp}/dp_T}$$

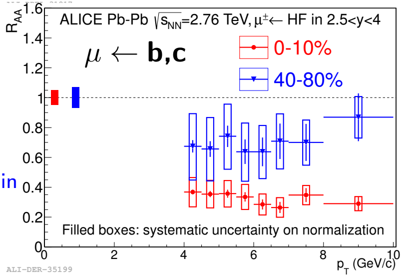
◇ Heavy-flavour decay electrons at mid-rapidity ($|y| < 0.6$)

- pp reference:
  - p_T<8 GeV/c: FONLL-based data rescaling from 7 TeV to 2.76 TeV
  - p_T>8 GeV/c: FONLL pQCD calculations
- Clear suppression in $3 < p_T < 18$ GeV/c

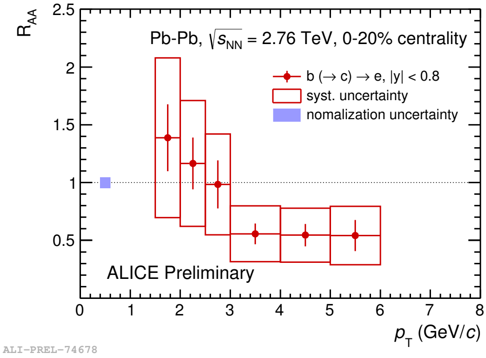


◇ Heavy-flavour decay muons at forward rapidity ($2.5 < y < 4$)
PRL 109 (2012) 112301

- pp reference measured at $\sqrt{s}$ =2.76 TeV
- Suppression by a factor 3-4 for $p_T > 5$ GeV/c in the 10% most central collisions
- Less suppression in peripheral collisions

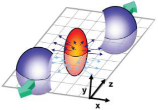


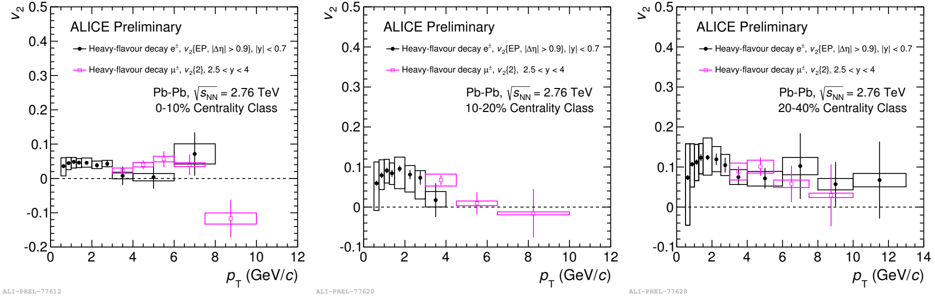
Pb-Pb collisions: beauty-decay electrons $R_{AA}(p_T)$



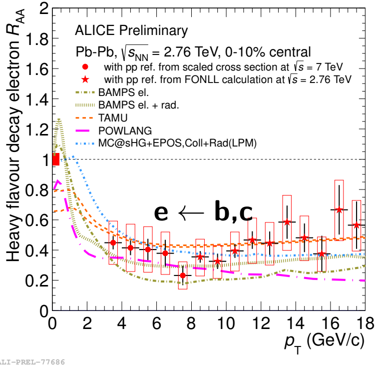
- Separation of charm and beauty contributions based on fits to the electron impact-parameter distribution
- $R_{AA} < 1$ for $p_T > 3\text{GeV}/c$: hints for b-quark energy loss in the medium

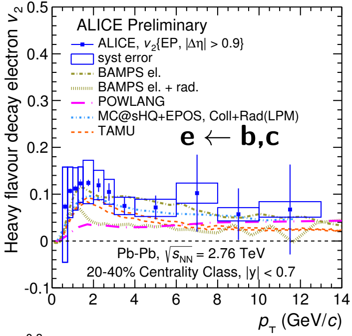
$$\frac{dN}{d\varphi} = \frac{N_0}{2\pi}\left(1 + 2\cdot v_1 cos(\varphi - \Psi_1) + 2\cdot v_2 cos[2(\varphi - \Psi_2)] + \ldots\right)$$





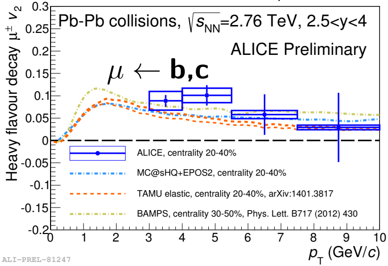
- Similar v_2 for electrons (mid-rapidity) and muons (forward rapidity)
- Both in electron and muon channels, positive v_2 at low p_T (3σ effect)
- Indication of increase of v_2 from central to semi-central collisions
- Heavy quarks (mostly charm at low p_T) participate in the collective expansion of the medium





- R_{AA} and v_2 of heavy-flavour decay electrons (top) and v_2 of muons (right)
- Models challenged to reproduce simultaneously R_{AA} and v_2

POWLANG: Eur. Phys. J. C 71 (2011) 1666, J. Phys. G 38 (2011) 124144
BAMPS: Phys. Lett. B 717 (2012) 430
TAMU elastic: arXiv: 1401.3817
MC@ sHQ+EPOS, Coll + Rad (LPM): Phys. Rev. C 89 (2014) 014905

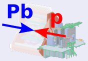


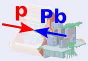
Open questions:

- Are the Pb-Pb results due to QGP formation?
- What is the role of cold nuclear matter?
- How are parton distribution functions modified in nuclei?
- Do we have a control experiment?

Heavy flavours

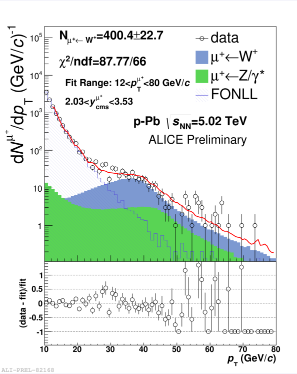
- Nuclear modification factor: R_{pPb}
- Electron-hadron angular correlations to look for collective behaviour
- Exploit two beam configurations to explore backward and forward rapidity regions

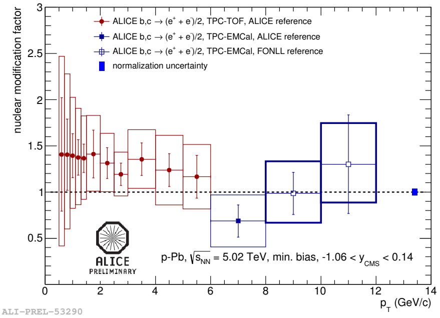


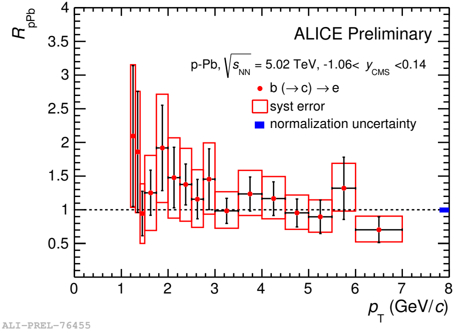


$\mu^{\pm} \leftarrow W^{\pm}$

- Main source of high-p_{T} muons ($p_{\mathrm{T}} \gtrsim 30\text{GeV}/c$) are decays of $W^{\pm}$ and Z^0
- $W^{\pm}$ created in hard scattering, decay muons are insensitive to the strong interaction
- Ideal probes for PDF modification and binary-scaling tests



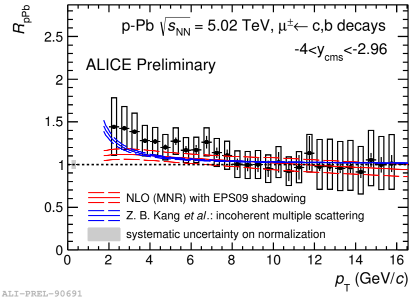


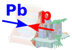


- Nuclear modification factor consistent with unity for heavy-flavour decay electrons
- Electrons from beauty-hadron decays also show an R_{pPb} consistent with unity
- Cold nuclear matter effects are not the cause of the strong suppression at high p_{T} in Pb–Pb collisions

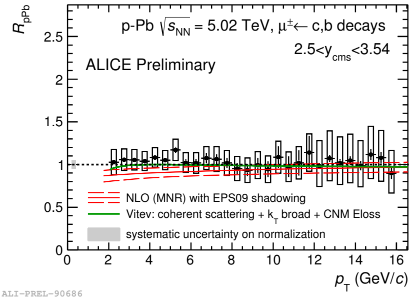
p-Pb collisions: muon ← heavy flavours - R_{pPb}

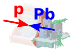
Backward rapidity





Forward rapidity



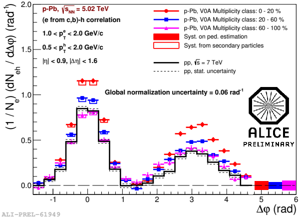


- Beam-energy asymmetry: different rapidity coverage for the two beam configurations
- Forward: $2.5 < y_{\mathrm{cms}} < 3.54$, R_{pPb} consistent with unity
- Backward: $-4 < y_{\mathrm{cms}} < -2.96$, R_{pPb} slightly larger than unity in 2< p_{T} <4 GeV/c
- Different models including cold nuclear matter effects reproduce the data:

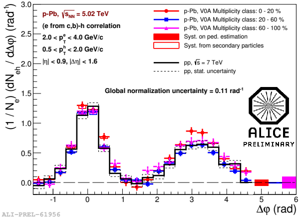
  pQCD with EPS09 nPDF NPB 373(1992)295, JHEP 04467(2009)065
  I. Vitev: coherent scattering, k_{T}-broadening and CNM energy loss PRC 75(2007)064906
  Z.B. Kang et al.: incoherent multiple scattering PLB 740 (2015) 23

p-Pb collisions: electron-charged particle angular correlations

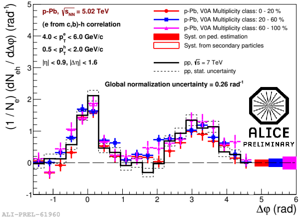
$1 < p_{\mathrm{T}}^{e} < 2$ GeV/c



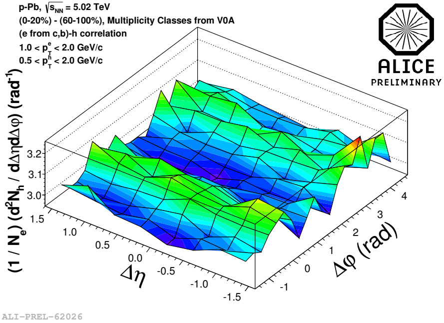
$2 < p_{\mathrm{T}}^{e} < 4$ GeV/c

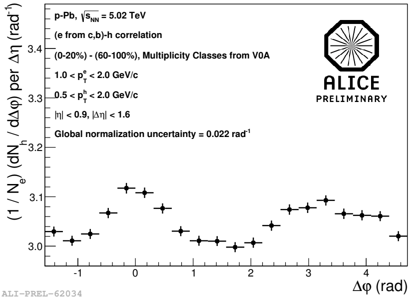


$4 < p_{\mathrm{T}}^{e} < 6$ GeV/c



- Goal: search for long-range correlations (effect already observed with light flavours [PLB 719(2013)29])
- Measurement performed in three event-activity classes: 0-20%, 20-60%, 60-100%
- Measurement in pp collisions at 7 TeV also shown here
- High p_{T}: near and away-side yields are similar in different p–Pb event-activity classes and in pp data
- Low p_{T}: for the highest event-activity classes, enhancement of the yields with respect to pp both on the near and the away side

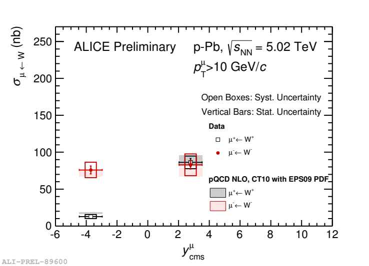




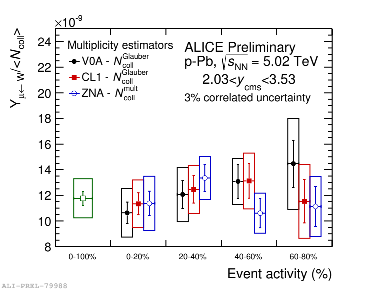
- Jet contribution removed by subtracting 60-100% from 0-20% p–Pb event-activity classes
- Double-ridge structure observed, as for the light flavours
- Do potential explanations for light-flavour results hold also for heavy-flavour decay electrons? (CGC and/or final state hydrodynamics [PRD 87 (2013) 094034], [PLB 718 (2013) 1557])

p-Pb collisions: muons from W-boson decays

- $\mu^+ \leftarrow W^+$ and $\mu^+ \leftarrow W^+$ cross sections measured both at backward and forward rapidities
- Isospin effect visible at backward rapidity
- NLO pQCD calculation using CT10 + EPS09 PDF set reproduce the measurements within uncertainties [JHEP 1103 (2011) 071]



- $\mu^\pm \leftarrow W^\pm$ yields normalized to $\langle N_{coll} \rangle$ measured in four event-activity bins with different estimators
- Within uncertainties, consistent results obtained with different estimators
- Within uncertainties, $Y / \langle N_{coll} \rangle$ is constant in different event-activity bins



Summary

pp collisions

- Measurements of heavy-flavour decay muons (at forward rapidity) and electrons (at mid-rapidity)
- pQCD calculations reproduce measurements within uncertainties

Pb–Pb collisions

- Strong suppression of heavy-flavour yields both in the electron and in the muon channels in central collisions
- Similar R_{AA} for electrons (mid-rapidity) and muons (forward rapidity)
- Positive v_2 values: charm quarks participate in the collective expansion of the medium
- Together, R_{AA} and v_2 represent a challenging test for model calculations

p-Pb collisions

- Leptons from heavy-flavour decays show a R_{pPb} compatible with unity: the suppression measured in Pb-Pb is then due to final-state effects. Models reproduce the data within uncertainties.
- electron-charged particle correlations show a double-ridge structure like in the light-flavour sector
- High-p_T muons can be used to measure $W^{\pm}$: cross-section measurements are reproduced by a NLO calculation that includes nuclear PDFs
- $\mu \leftarrow W$ yields show a flat behaviour versus event activity: confirm the binary-collision scaling for hard processes