

Experimental overview on heavy flavour in small systems

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CERN

Strangeness in Quark Matter 2019
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- Modifications of the **initial state**
 - **Gluon saturation**: nuclear PDFs, Color Glass Condensate (CGC)...
- **Interpretation of PbPb results**: intermediate size system
 - Different interplay of initial state and other cold nuclear matter (CNM) effects, QGP?
- Insights on **collectivity**
 - **Heavier quark mass**: do HF hadrons flow? + comparison with light flavours
- **Helping look for QGP in small systems**



Charm quark



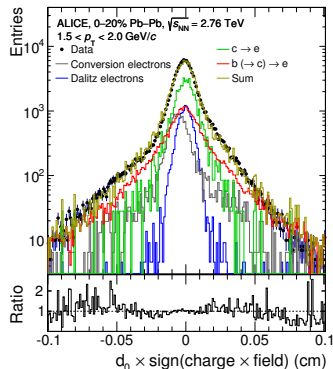
Bottom quark



Top quark

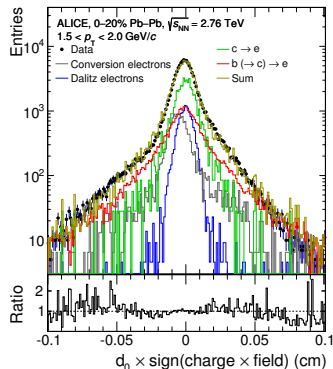
Experimental methods: how to measure heavy flavour?

- Heavy flavour leptons: $b(\rightarrow c) \rightarrow e, \mu, c \rightarrow e, \mu$
- Exclusive decays: resonances
- HF jets: HF-tagged jets, HF-hadron correlations
- In all cases: make use of the long HF hadron lifetime
 - $c\tau \approx 150 \mu\text{m}$ (charm), $c\tau \approx 500 \mu\text{m}$ (beauty)



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Related topics not covered in this talk

- Closed heavy flavour (quarkonia): [R. Araldi's talk](#)
- Open heavy flavour in AA: [C. Terrevoli's talk](#)
- Strangeness and LF in small systems: [R. Preghenella's talk](#)

Production

Production

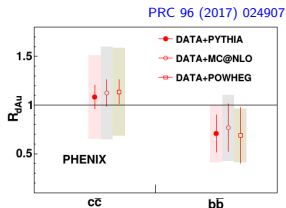
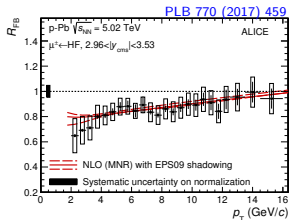
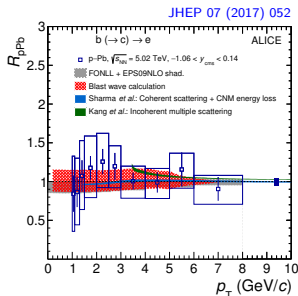




Heavy flavour leptons

Heavy flavour electrons and muons: inclusive semi-leptonic HF hadron decays

- Signal extraction: impact parameter selection, non HF (non b) background subtraction
- Consistent with expectations from nPDF
- Extraction of inclusive $c\bar{c}$, $b\bar{b}$: some model dependence





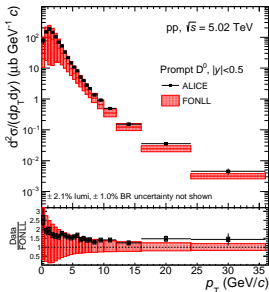
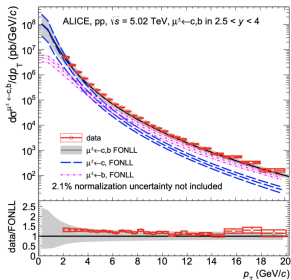
Charm: D mesons (cross sections in pp)

Identified hadrons ($D^0 \rightarrow K^- \pi^+ \dots$): non ambiguous p_T , meson vs hadron...

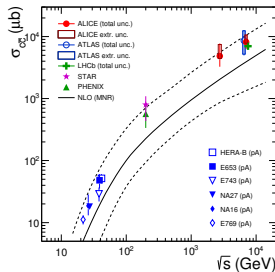
- Differential cross sections for **inclusive HF** and **identified D mesons**
- Total cross section**
- Very precise data: incentive to **improve models?**

EPJC 79 (2019) 388

arXiv:1905.07207



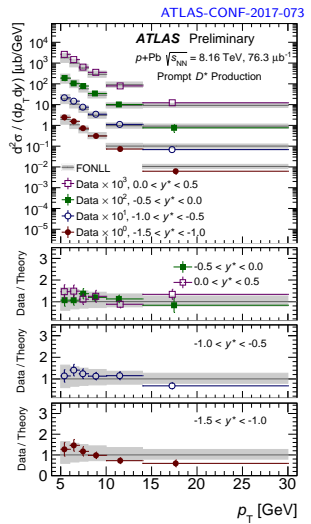
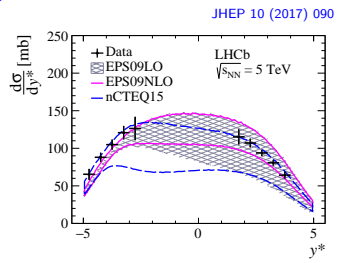
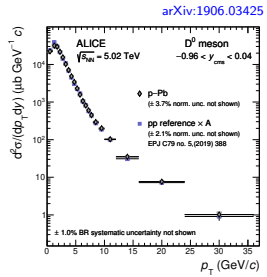
PRC 94 (2016) 054908





Charm: D mesons (cross sections in pPb)

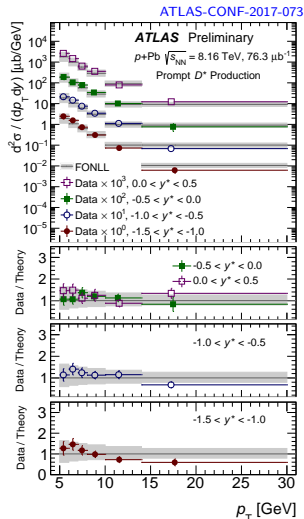
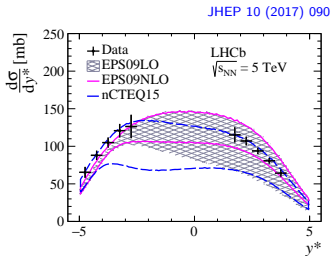
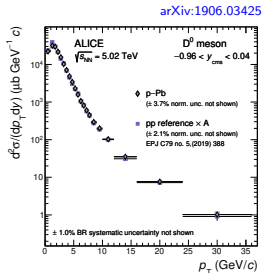
Measuring cross sections for a **direct comparison to models**





Charm: D mesons (cross sections in pPb)

Measuring cross sections for a **direct comparison to models**



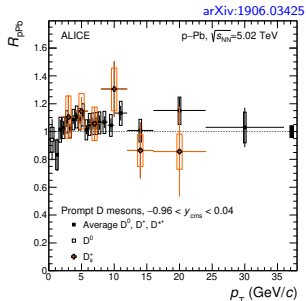
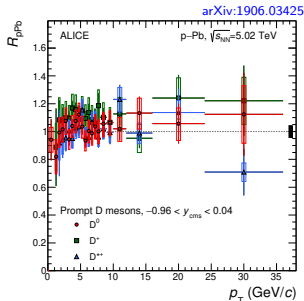
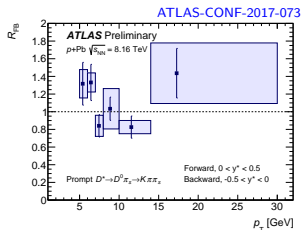
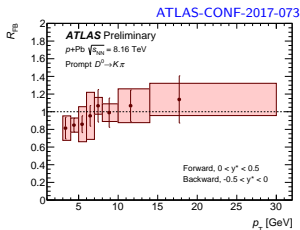
Large uncertainties from theory (scale uncertainties from FONLL, gluon shadowing at low x): use pp data as reference





Charm: D mesons (ratios)

Similar results for D^+ ($\rightarrow K^- \pi^+ \pi^+$), D^0 ($\rightarrow K^- \pi^+$), D^{*+} ($\rightarrow D^0 \pi^+$)... even D_s^+ ($\rightarrow \phi \pi^+$)!

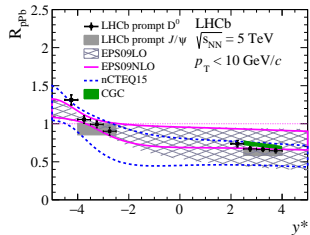
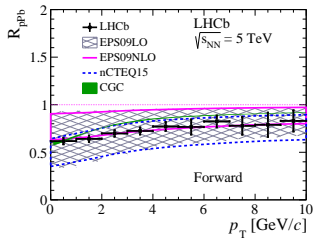
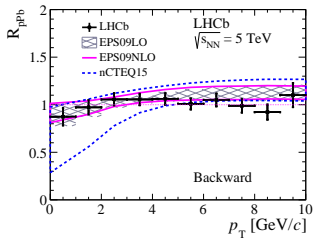




Charm: D mesons (ratios)

JHEP 10 (2017) 090

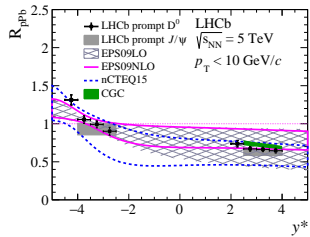
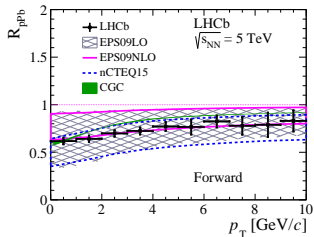
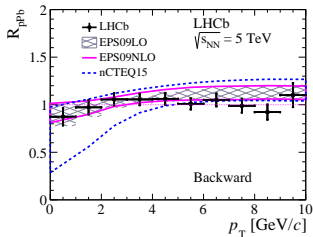
- Modification consistent with nPDF expectations (also CGC at forward)





Charm: D mesons (ratios)

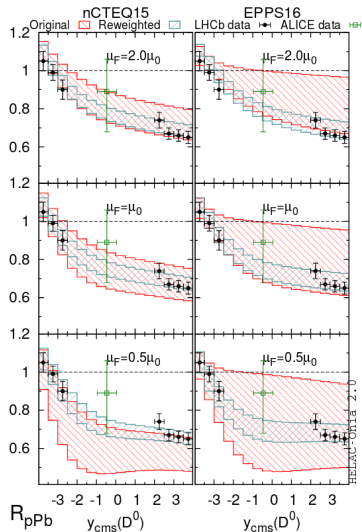
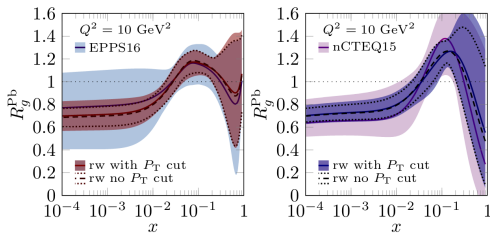
- Modification consistent with nPDF expectations (also CGC at forward)
- Precise data: can it be used to constrain nPDF? (gluon shadowing at forward, antishadowing at backward)



Note on nPDF

Recent investigations towards the use of HF data for constraining small x gluon shadowing

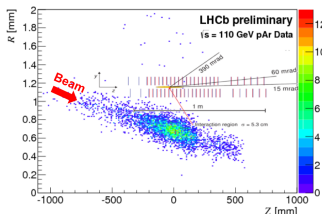
- “nCTEQ” ([PRL 121 \(2018\) 052004](#)): data-driven parametrisation of matrix elements, Bayesian reweighting of MC replicas
- EPPS ([arXiv:1906.02512](#)): SACOT- m_T scheme in GM-VFNS approach, Hessian reweighting





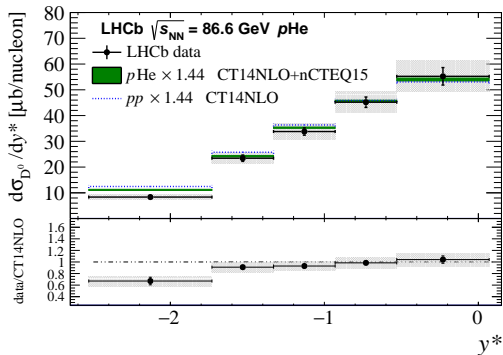
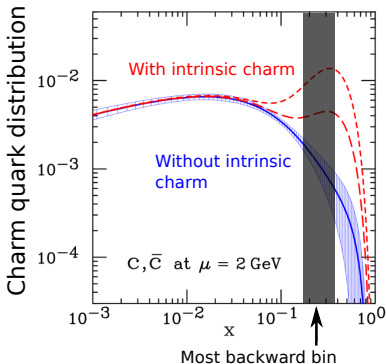
Charm: D^0 mesons in fixed target mode

- Probing **large x** with LHCb in fixed-target mode (SMOG)
- Select events with beam 1 only at interaction point
- **No evidence** for substantial valence-like intrinsic charm contribution



PRD 75 (2007) 054029

PRL 112 (2019) 132002

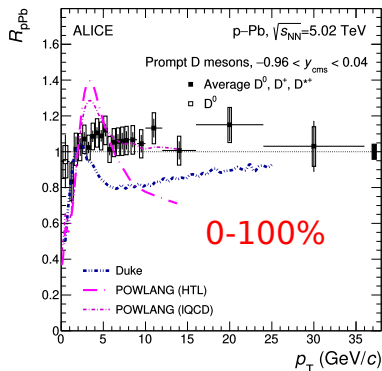
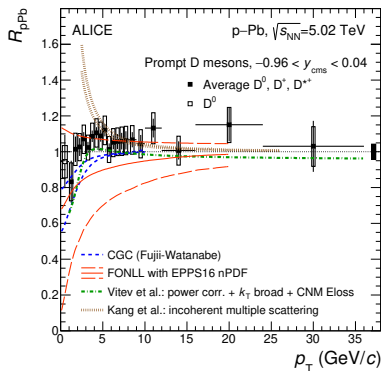




Charm: D mesons

Comparing combined (D^+ , D^0 , D^{*+}) ALICE data with more models

- CGC
- FONLL with nPDF
- Vitev et al: k_T broadening, shadowing, CNM Eloss
- Kang et al: higher twist with incoherent multiple scattering
- Transport models **assuming QGP**: Duke, POWLANG
 - Disfavoured: no hint for peak or high p_T suppression in data

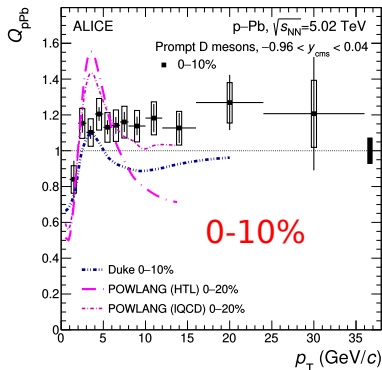
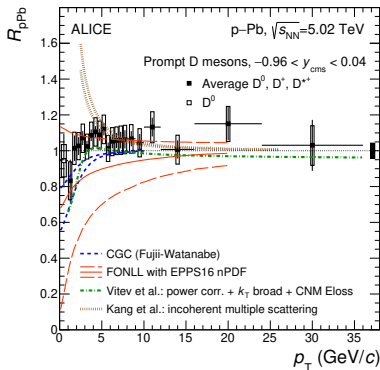




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 - Not even most central collisions



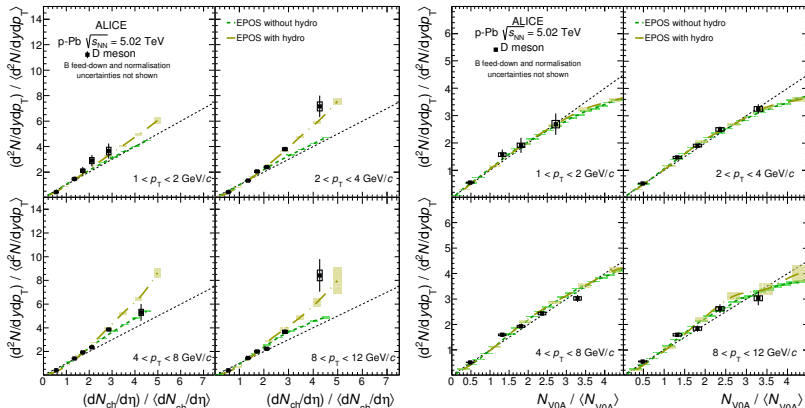


Charm: D mesons vs multiplicity

JHEP 08 (2016) 078

Definitions of multiplicity:

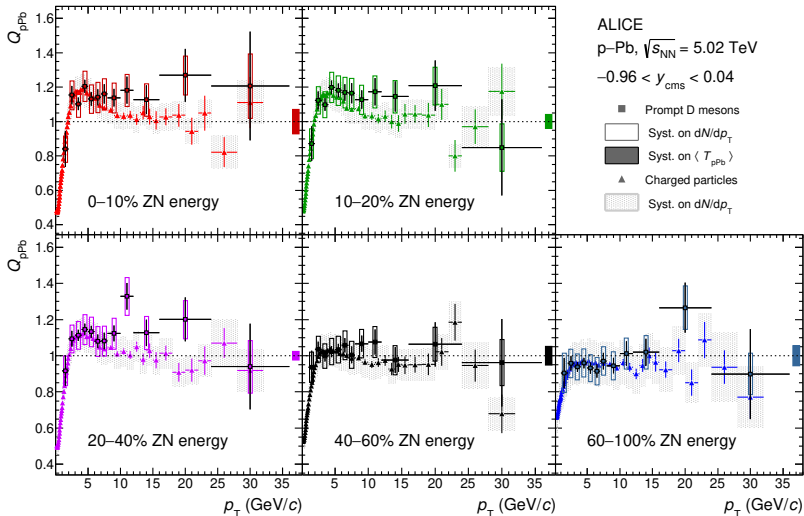
- Midrapidity: faster than linear increase
- Forward rapidity: \approx linear
- Better description by EPOS 3 with hydro than without





Charm: D mesons vs multiplicity

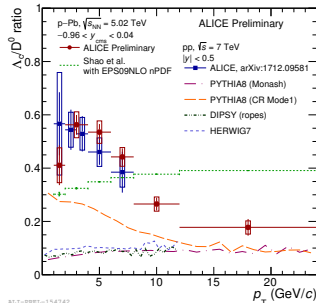
- Hint of **suppression at low p_T** in central collisions
- Hint of **enhancement at high p_T** in central collisions
- Similar trend as for charged particles



Charm baryons

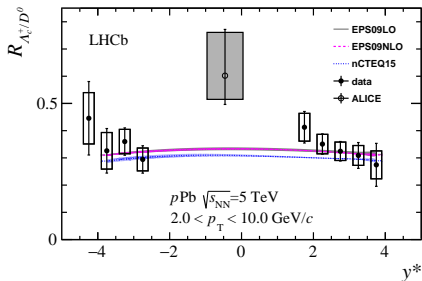
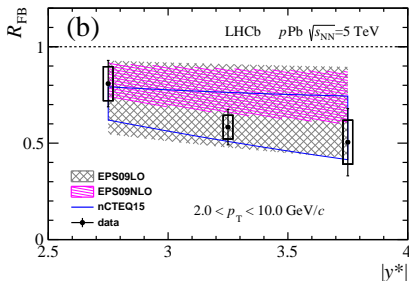


- Forward-backward ratio well described by models with nPDF (large uncertainties)
- Λ_c/D^0 in pPb:
 - Similar as in pp
 - Better description by Shao et al (parametrisation of pp data) than MC generators
 - nPDF uncertainties almost fully cancel
 - Decreasing trend at high p_T



JHEP 02 (2019) 102

JHEP 02 (2019) 102

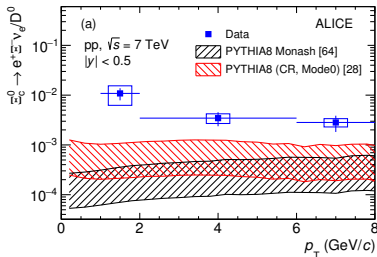




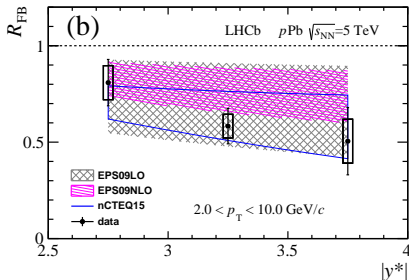
Charm baryons

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 - Similar as in pp
 - Better description by Shao et al (parametrisation of pp data) than MC generators
 - nPDF uncertainties almost fully cancel
 - Decreasing trend at high p_T
 - Remember also: Ξ_c^0/D^0 in pp

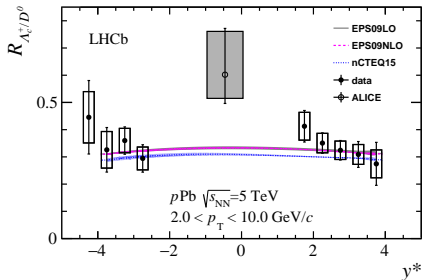
PLB 781 (2018) 8



JHEP 02 (2019) 102



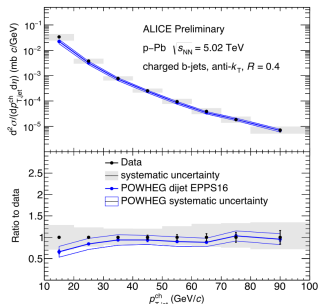
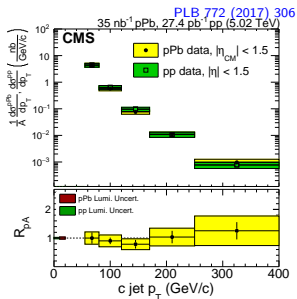
JHEP 02 (2019) 102



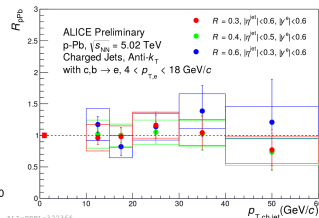


Heavy flavour jets

- Comparing heavy flavour tagged jets in pp and pPb:
 - c jets (CMS)
 - b jets (ALICE)
 - heavy flavour electron jets (ALICE)
- Consistent results in pp and pPb



ALI-PREL-322367

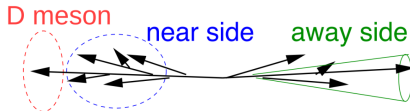


ALI-PREL-322365

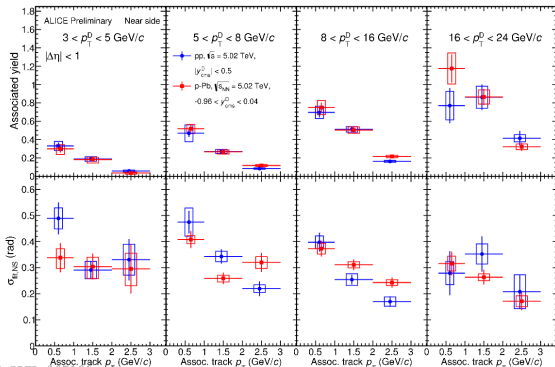
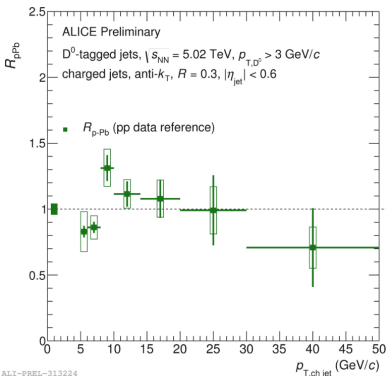




D-tagged jets, D-hadron correlations



- **D⁰-tagged jets:** anti- k_T jets including a D⁰ meson
- **D⁰-hadron correlations:** near and away side production of charged hadrons
- No evidence for CNM effects within uncertainties



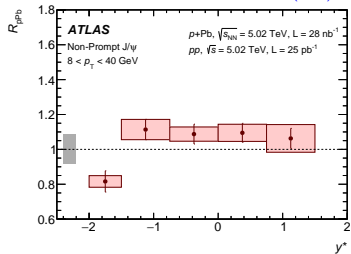


Beauty: nonprompt J/ψ

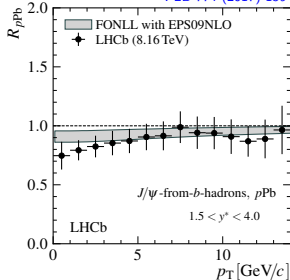
Nonprompt J/ψ : inclusive beauty measurement

- Measured by all 4 LHC experiments
- Results consistent with nPDF expectations

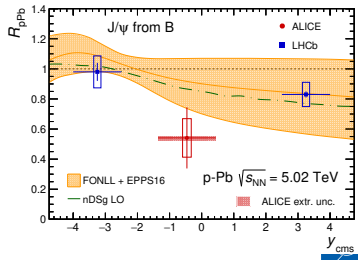
EPJC 78 (2018) 171



PLB 774 (2017) 159



EPJC 78 (2018) 466



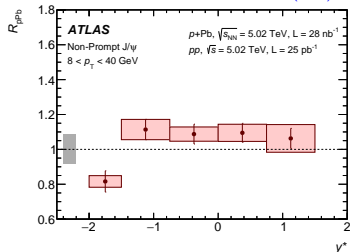
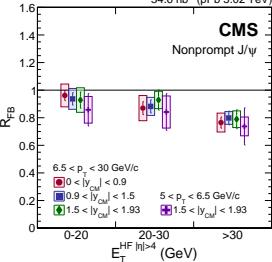


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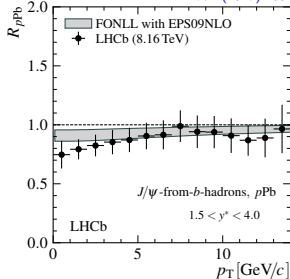
Nonprompt J/ψ : inclusive beauty measurement

- Measured by all 4 LHC experiments
- Results consistent with nPDF expectations
- Hint of suppression in high activity events

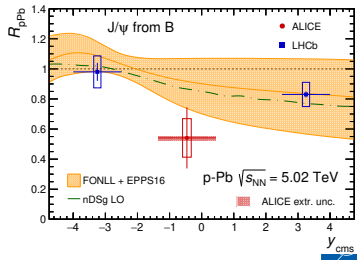
EPJC 78 (2018) 171

EPJC 77 (2017) 269
34.6 nb $^{-1}$ (pPb 5.02 TeV)

PLB 774 (2017) 159



EPJC 78 (2018) 466

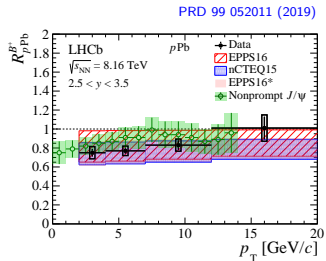
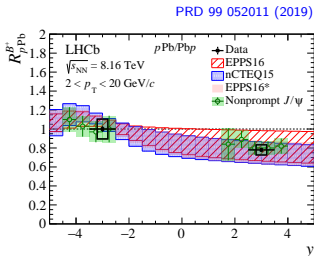
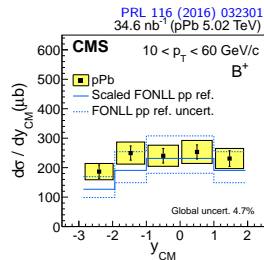




B mesons

Identified B mesons ($B^+ \rightarrow J/\psi K^+$): smaller yields, but unambiguous kinematics and particle identification

- Consistent with **nonprompt J/ψ** results
- Consistent with **nPDF** expectations



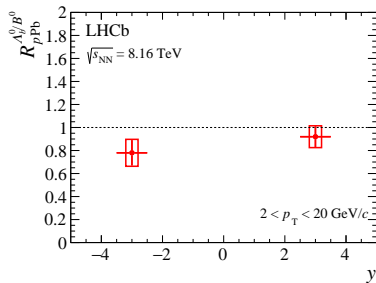
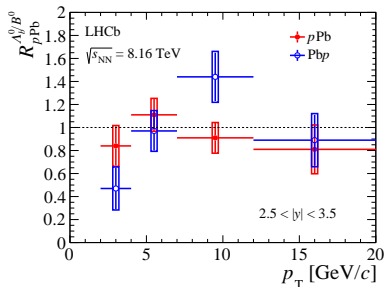
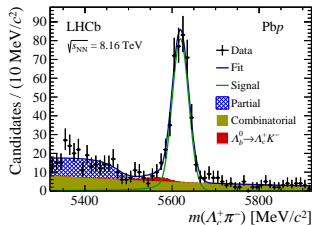


b baryon: Λ_b^0

PRD 99 052011 (2019)

First measurement of b baryon in pPb collisions!

- Constrain fragmentation of b quark in a nuclear environment
- Baryon-to-meson ratio compatible with pp value



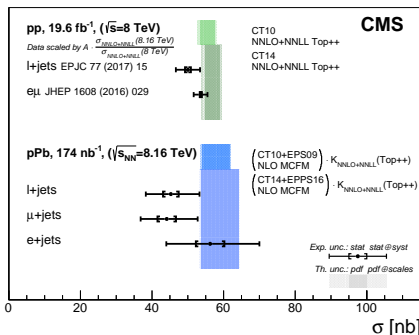
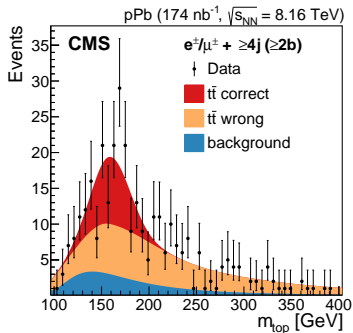
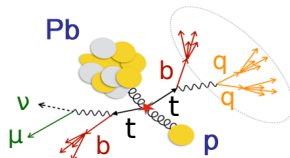


Even heavier flavour: top

PRL 119 (2017) 242001

First measurement of top quarks in pPb!

- Too short-lived to hadronise
- Prospects for gluon nPDF constraints



Flow and correlations

Flow and correlations



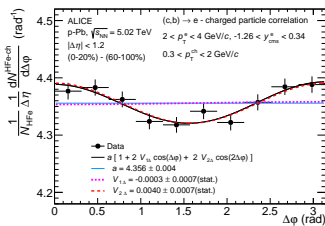
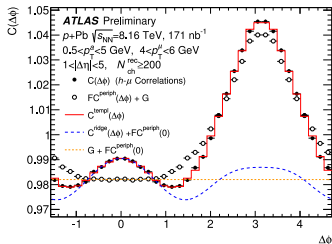
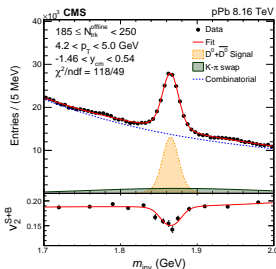
Flow and correlations: experimental methods

Heavy flavour hadron flow in small systems: **challenges**

- Account for **nonflow contribution**
 - Estimate it using **low multiplicity events**
- Extract **signal v_2** from **signal + background**

Different experiments have different strategies:

- ALICE, CMS**: 2-particle correlation (Fourier fit) with nonflow subtraction
- ATLAS**: template fit of $\Delta\phi$, accounting for nonflow from peripheral
- PHENIX**: using event plane



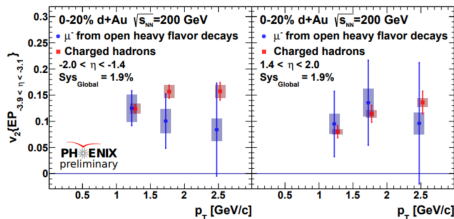
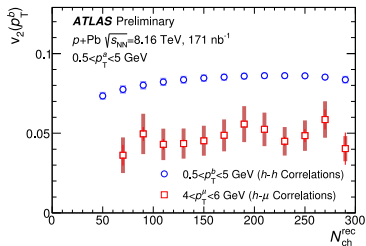
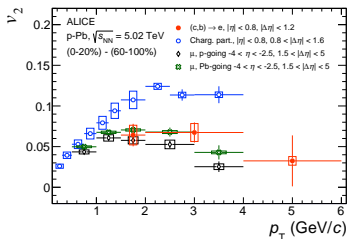


Flow and correlations: heavy flavour leptons

- Non-zero v_2 for heavy flavour leptons
- Smaller v_2 for heavy flavour than charged hadrons
- Consistent results from ALICE, ATLAS, PHENIX

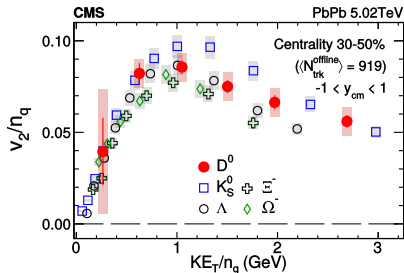
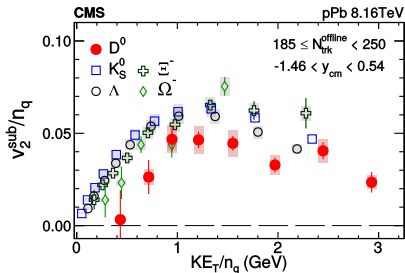
PRL 122 (2019) 072301

ATLAS-CONF-2017-006





- Number of constituent quarks scaling is motivated by [quark coalescence model](#)
- **In pPb:** $D^0 v_2/n_q$ is smaller than strange hadrons for $KE_T/n_q < 2$
- **In PbPb,** $D^0 v_2/n_q$ follows the same trend as other particle species
- Also D^{*+} long-range correlation (ridge) from ATLAS ([ATLAS-CONF-2017-073](#))

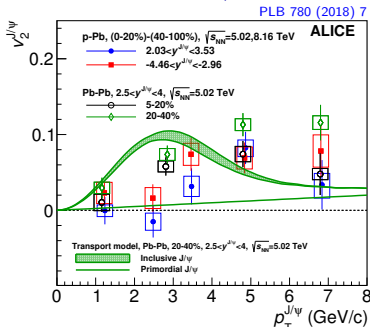




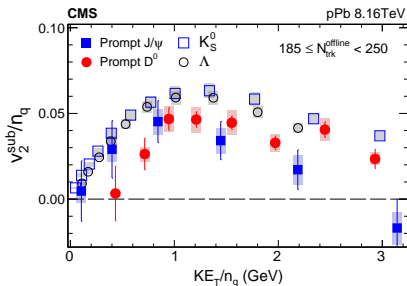
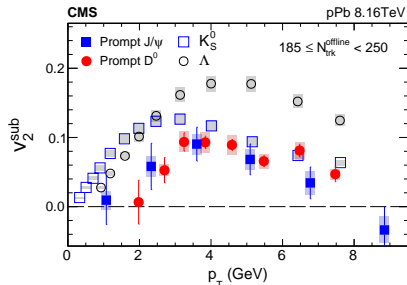
Elliptic flow: J/ψ

Large J/ψ flow in pPb!

- 2-particle correlation, subtracting peripheral
- Comparable to PbPb values
- Similar values at forward and backward
- Lower v_2 than light (strange)
 - But similar at low KE_T/n_q ?
- Similar v_2 as D^0 mesons!
- Collective behaviour of J/ψ in pPb



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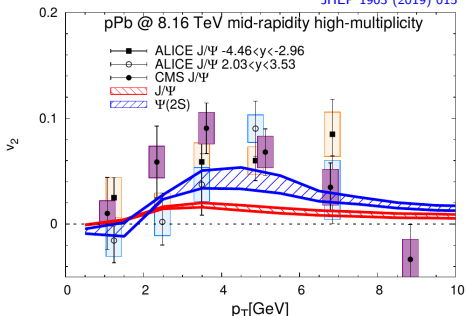


Elliptic flow: J/ψ

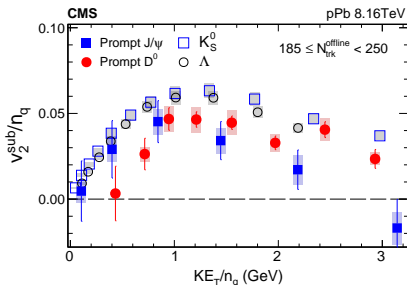
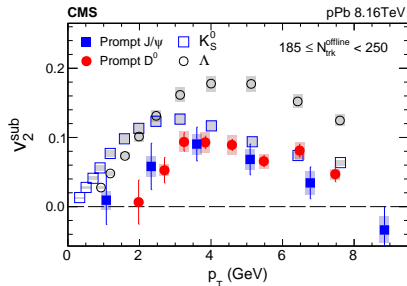
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JHEP 1903 (2019) 015



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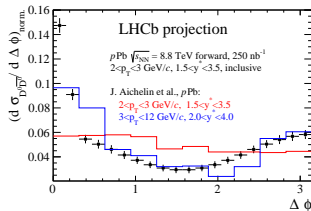
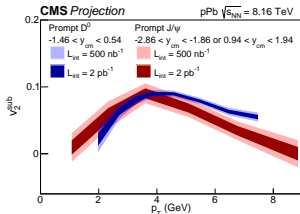
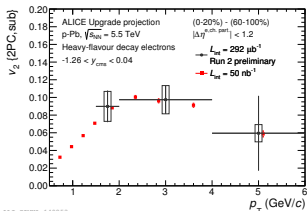
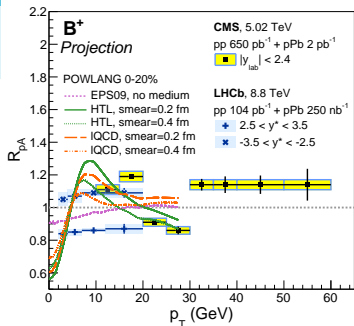
A look into the future

WG5 YR and references therein: ALICE-PUBLIC-2019-001, CMS-PAS-FTR-18-026, CERN-LHCb-CONF-2018-005...

Very precise data expected from Runs 3–4 (detector upgrades, more data)

New ways to understand HQ dynamics in small systems and look for QGP:

- Precise R_{pPb} (e.g. B^+)
- v_2 for HF electrons, D^0 , J/ψ
- $D^0\bar{D}^0$ correlations
- See also [M. Weber's talk](#)



- **Modest modifications of HF production in pPb with respect to pp**
 - Consistent with **initial state modifications (nPDF / CGC)**
 - Potential nPDF constraints
 - No sign of expectations from QGP + transport models (flow peak, high p_T suppression)
- **Large HF flow**
 - **Larger than predicted by transport models**
 - Initial state fluctuations missing in models

- HF production in small systems sheds light on the initial state modifications and final state interactions
- No clear sign of QGP in small systems up to now