Recent studies of open charm production at LHCb

Yiheng Luo (on behalf of the LHCb collaboration)

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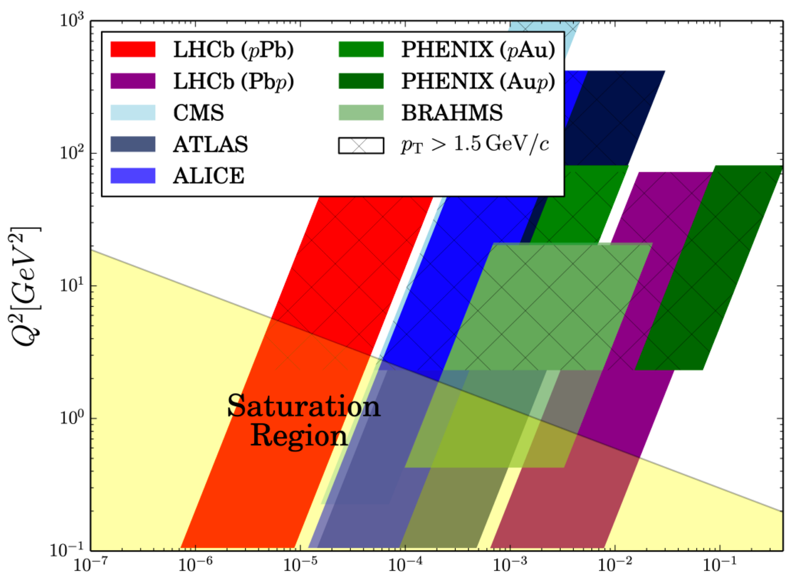
1. Introduction

- Cold nuclear matter effects are dominant in pPb collisions
  - ➢ Modification of nuclear parton distribution functions (nPDFs)
  - ➢ Other initial/final state effects
- Open charm productions precisely constrain nPDFs within LHCb unique small-x and mid-x coverages and are sensitive to the charm quark hadronization mechanisms



LHCb forward: small-x — Shadowing

LHCb backward: mid-x — Anti-Shadowing

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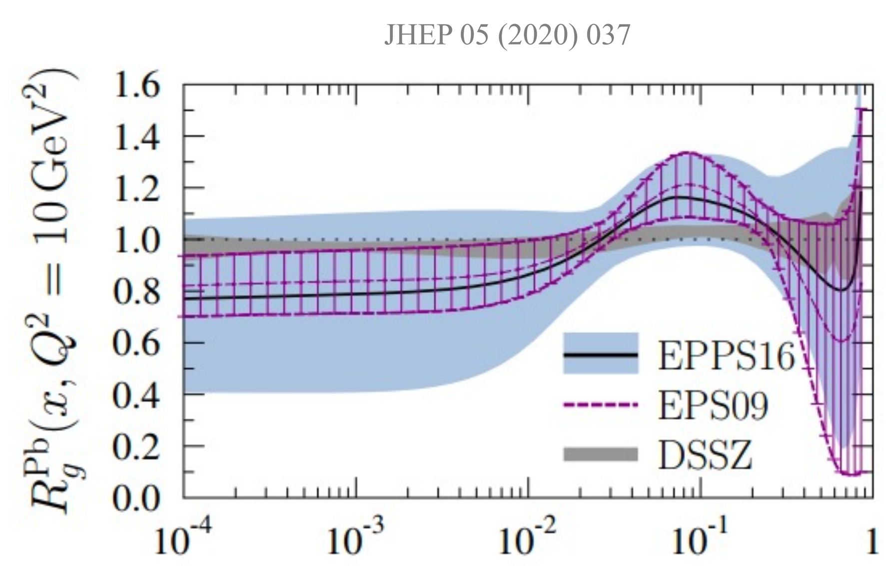
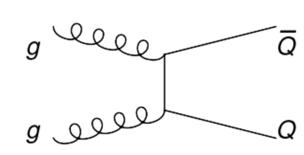


Shadowing — Anti-Shadowing

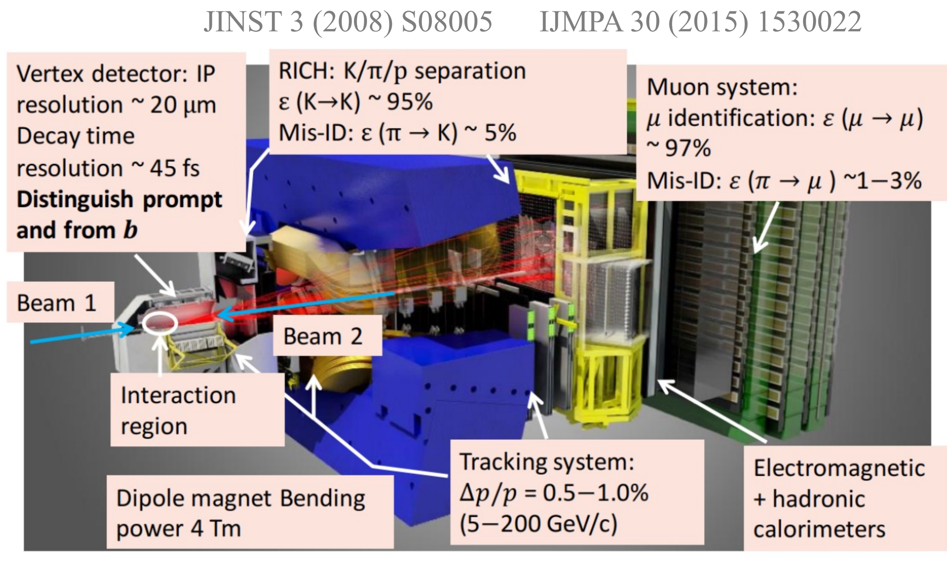
$$R_i^{\rm Pb}(x,Q^2)=\frac{f_i^{\rm Pb}(x,Q^2)}{Af_i^p(x,Q^2)}, i=g,q,\bar{q}$$

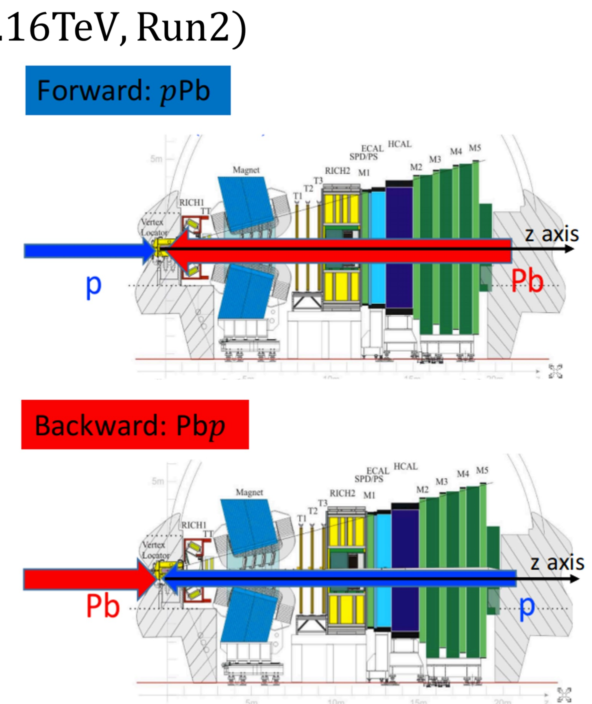


2. LHCb Detector and Datasets

- A single-arm forward spectrometer within the pseudo-rapidity range $2<\eta<5$; designed for studying particles with charm quarks down to low-$p_{\rm T}$
- Datasets ($D^{0,+}$, D_s^+, Λ_c^+ and Ξ_c^+) collected in pPb collisions at $\sqrt{s_{NN}}=5.02$ or 8.16TeV
  - ➢ Rapidity coverage: $1.5<y^*<4.0$ (forward), $-5.0<y^*<-2.5$ (backward)
  - ➢ Luminosity: ~1.5nb^{-1}(5.02TeV, Run1), ~30nb^{-1}(8.16TeV, Run2)

JINST 3 (2008) S08005 IJMPA 30 (2015) 1530022





3. Analysis Strategy

- **Differential cross-sections:** $\frac{d^2\sigma}{dp_{\rm T}dy^*}=\frac{N(p_{\rm T},y^*)}{\mathcal{L}\times\varepsilon(p_{\rm T},y^*)\times\mathcal{B}\times\Delta p_{\rm T}\times\Delta y^*}$

➢$N(p_{\rm T},y^*)$: prompt signal yields in $(p_{\rm T},y^*)$ ➢$\mathcal{B}$: branching fractions ➢$\mathcal{L}$: luminosity

➢$\varepsilon(p_{\rm T},y^*)$: efficiency corrections ➢$\Delta p_{\rm T}$ and Δy^*: width of transvers momenta and rapidity

- **Nuclear modification factors:**

$$R_{p\rm Pb}=\frac{{\rm d}^2\sigma_{p\rm Pb}/{\rm d}p_{\rm T}{\rm d}y^*}{208\times\sigma_{pp}/{\rm d}p_{\rm T}{\rm d}y^*}$$

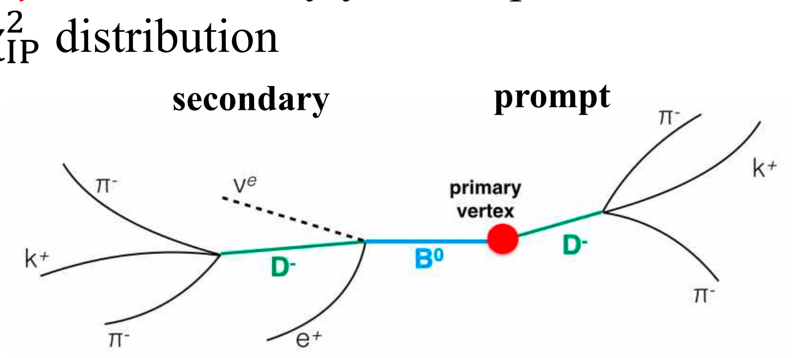
- **Forward-backward ratios:**

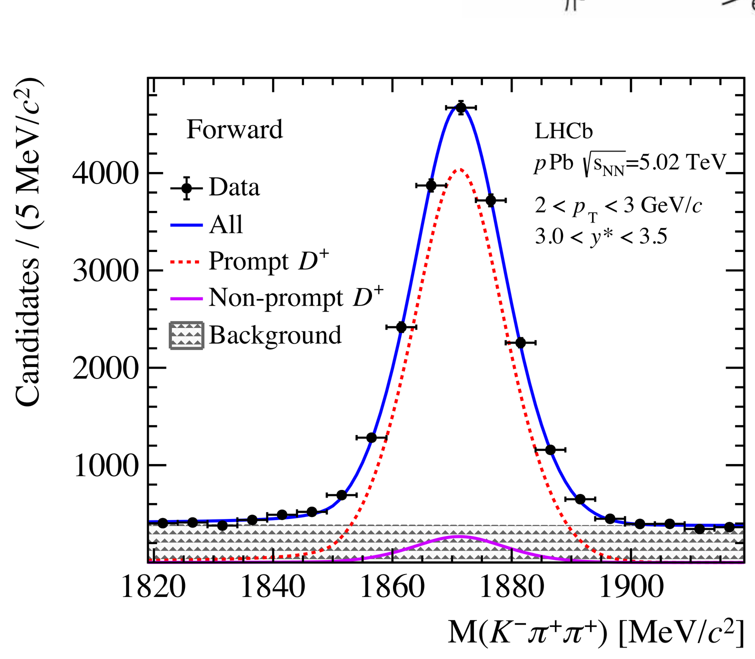
$$R_{\rm FB}(p_{\rm T},y^*)=\frac{{\rm d}^2\sigma_{\rm Forward}(p_{\rm T},|y^*|;y^*>0)/{\rm d}p_{\rm T}{\rm d}y^*}{{\rm d}^2\sigma_{\rm Backward}(p_{\rm T},|y^*|;y^*<0)/{\rm d}p_{\rm T}{\rm d}y^*}$$

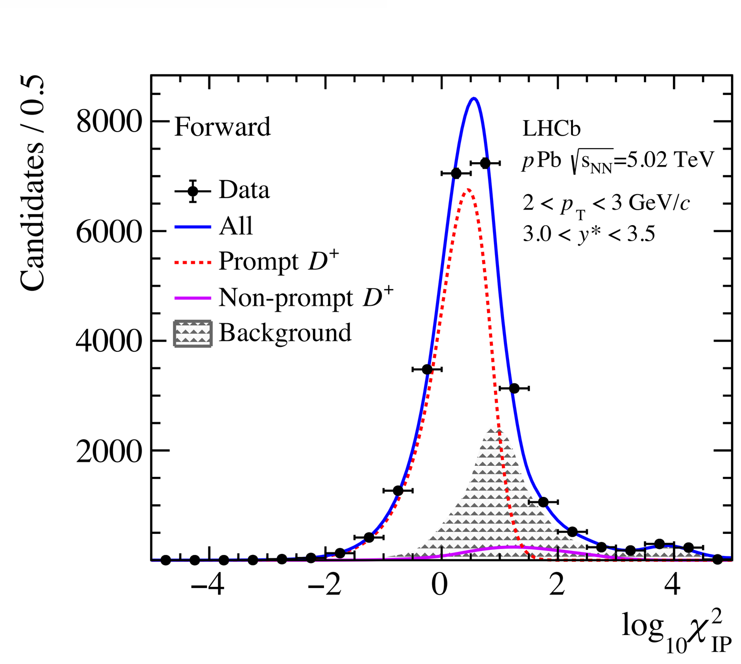
- **Production ratios:**

$$R_{D_s^+/D^+}\equiv\frac{{\rm d}^2\sigma_{D_s^+}}{{\rm d}^2\sigma_{D^+}}, R_{\Lambda_c^+(\Xi_c^+)/D^0}\equiv\frac{{\rm d}^2\sigma_{\Lambda_c^+(\Xi_c^+)}}{{\rm d}^2\sigma_{D^0}}$$

- Background components are subtracted by invariant mass fitting
- Prompt yields $N(p_{\rm T},y^*)$ and secondary yields separated with impact parameter (IP) related variable $\log_{10}\chi^2_{\rm IP}$ distribution





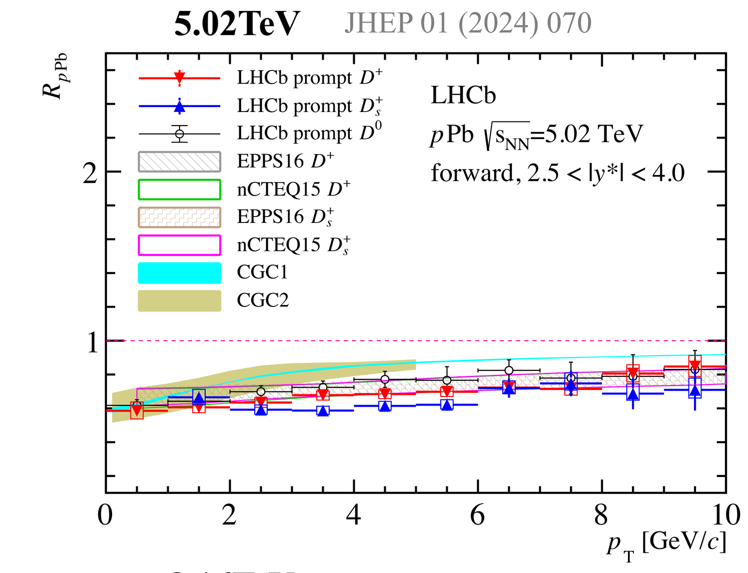


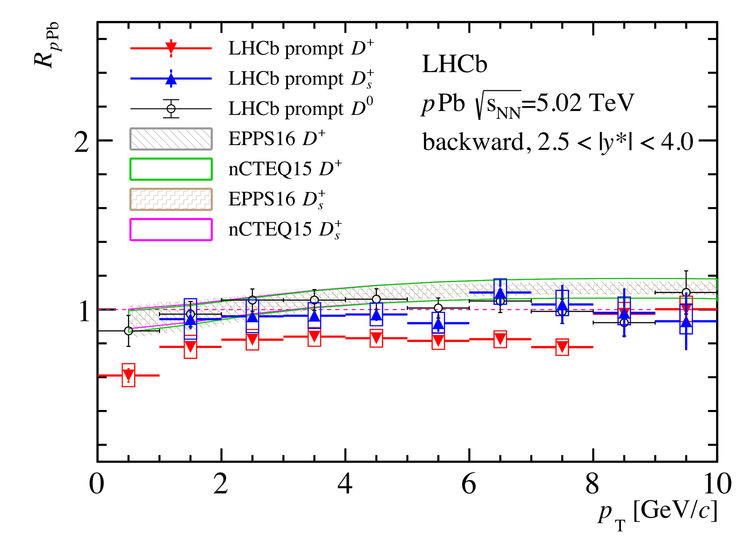
- Total efficiency $\varepsilon(p_{\rm T},y^*)$ are calculated with Monte Carlo simulated samples

4. Nuclear modification factors

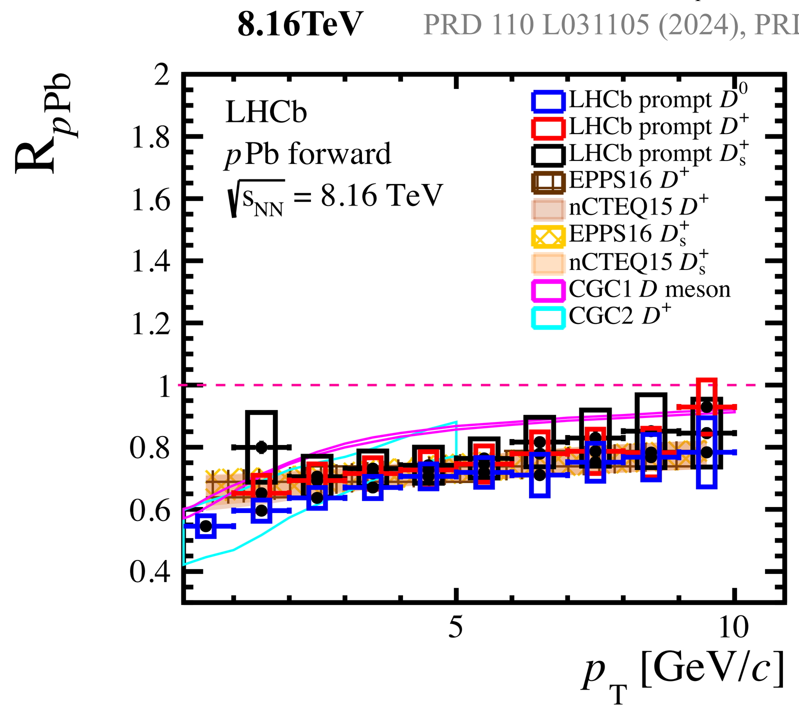
- At forward rapidity
  - ➢ $R_{p\rm Pb}(D^{0,+},D_s^+)$: consistent with nPDFs and CGC (**5.02 & 8.16TeV**)
- At backward rapidity
  - ➢ $R_{p\rm Pb}(D^{0,+},D_s^+)$: lower than predictions (**8.16TeV**), possible other nuclear effects (final-state energy loss, multiple parton scattering…)

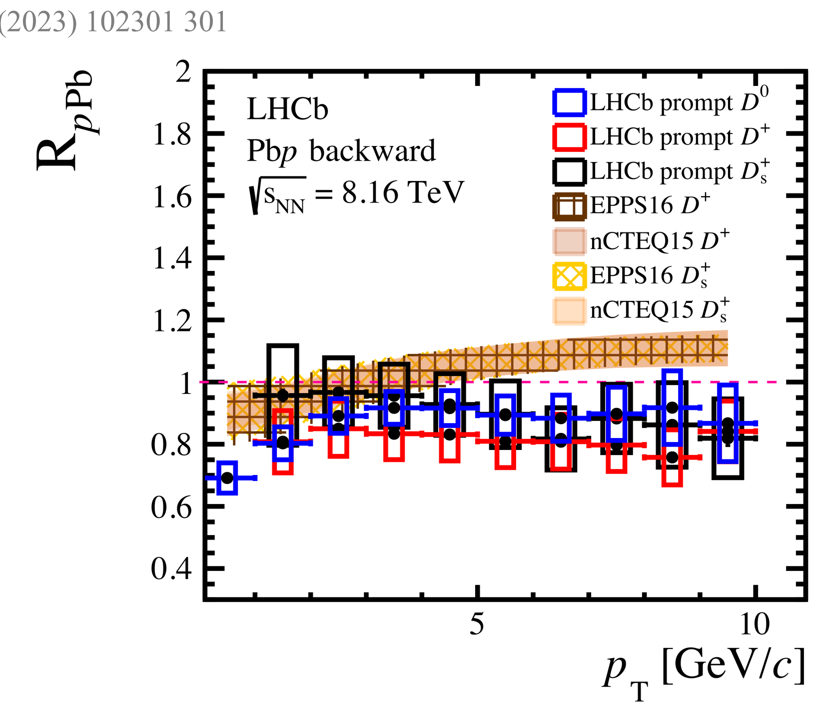
5.02TeV JHEP 01 (2024) 070





8.16TeV PRD 110 L031105 (2024), PRL 131 (2023) 102301 301

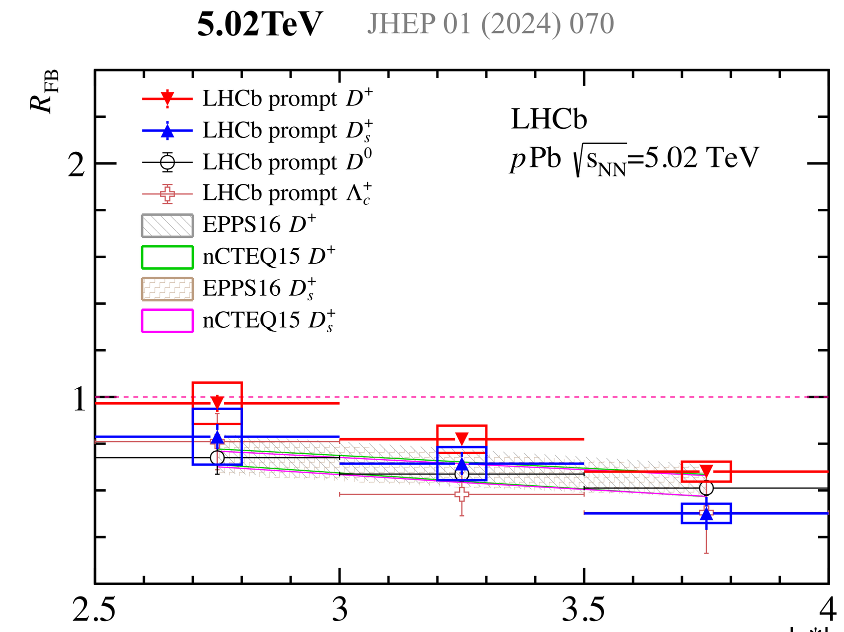




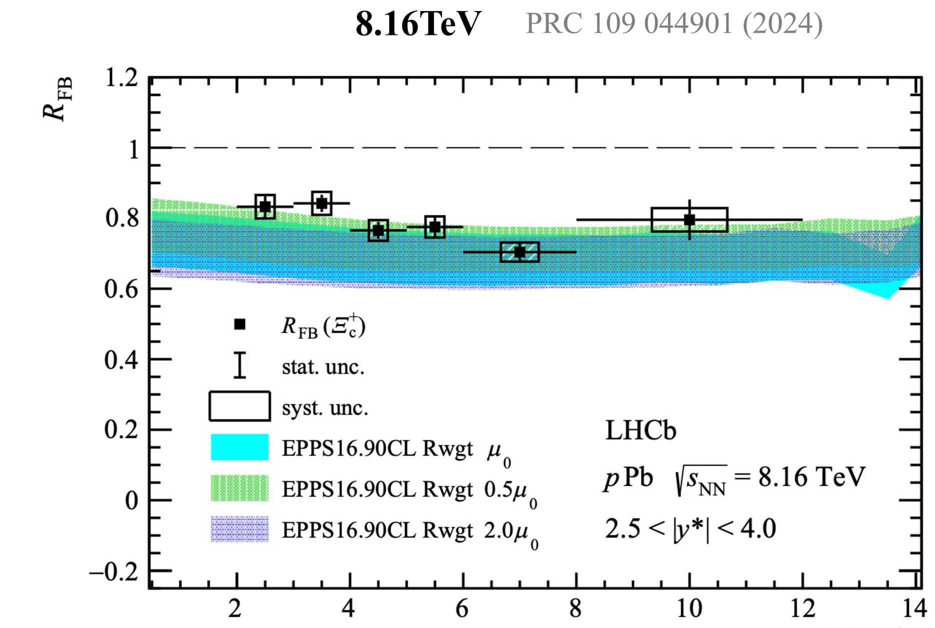
5. Forward-backward ratios

- $R_{\rm FB}(D^{0,+},D_s^+,\Lambda_c^+)$: a slight y^*dependence, consistent with nuclear shadowing. Cold nuclear matter effects are suggested
- $R_{\rm FB}(\Xi_c^+)$: well described by nPDFs and no major final-state effects are indicated

5.02TeV JHEP 01 (2024) 070



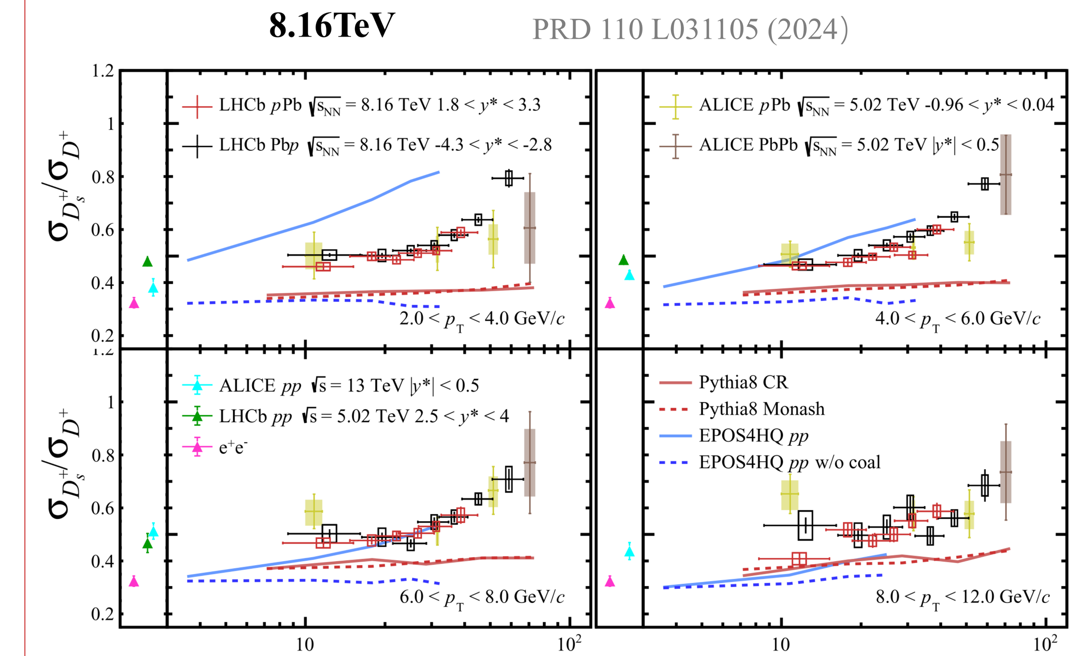
8.16TeV PRC 109 044901 (2024)



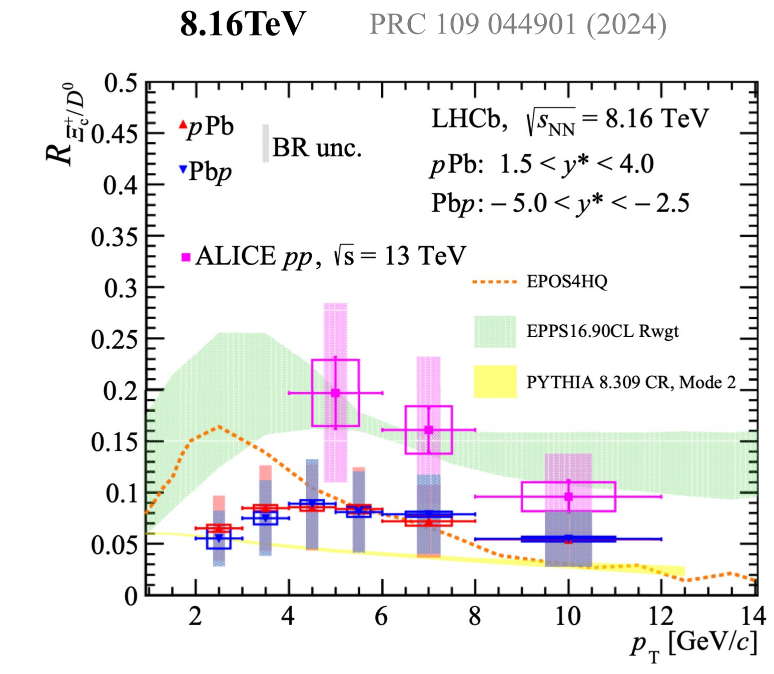
6. Production ratios

- $R_{D_s^+/D^+}$: first observation of strangeness enhancement with charmed mesons in high-multiplicity pPb events, consistent with additional coalescence mechanism
- $R_{\Xi_c^+/D^0}$: similar at forward and backward rapidity, but different trends compared to pp

8.16TeV PRD 110 L031105 (2024)



8.16TeV PRC 109 044901 (2024)



7. Summary and outlook

- Prompt open charm productions are studied with LHCb Run1 & Run2 data samples, constraining theoretical models
- Measured $R_{p\rm Pb}$, $R_{D_s^+/D^+}$ and $R_{\Xi_c^+/D^0}$ suggest the existence of CNM effects and possible changes in charm hadronization in pPb collisions
- During Run3 data-taking, more precise charm measurements will be performed in LHCb pp, pPb, and fixed-target collisions