Studies of low-x phenomena with the LHCb detector

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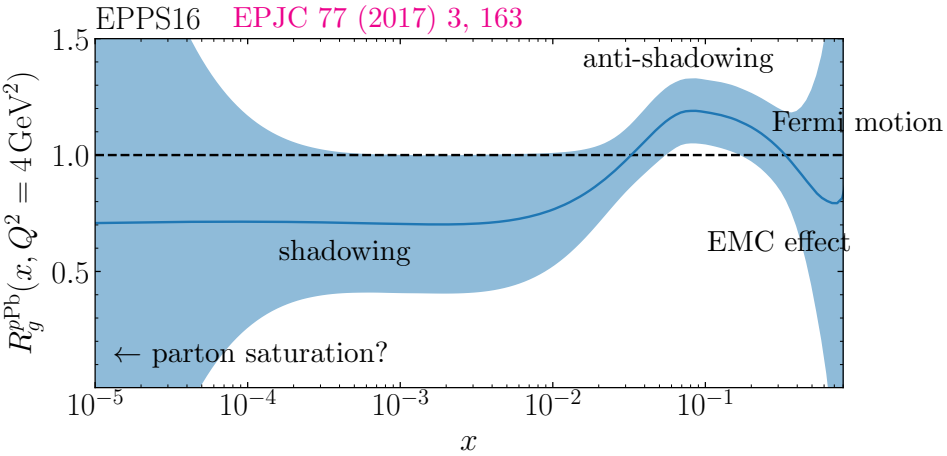
on behalf of the LHCb collaboration

Strangeness in Quark Matter
June 15, 2022

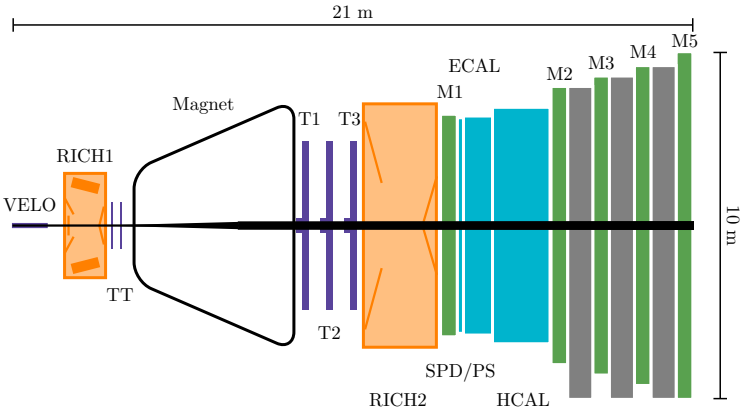
Nuclear PDFs



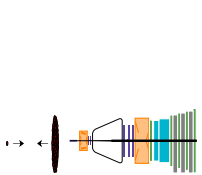
Built-in assumptions: parameterizations, collinear factorization, DGLAP evolution
Collective phenomena and parton saturation violate these assumptions!

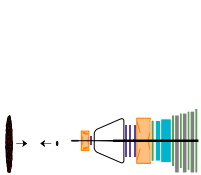
The LHCb detector (Int. J. Mod. Phys. A 30, 1530022 (2015))

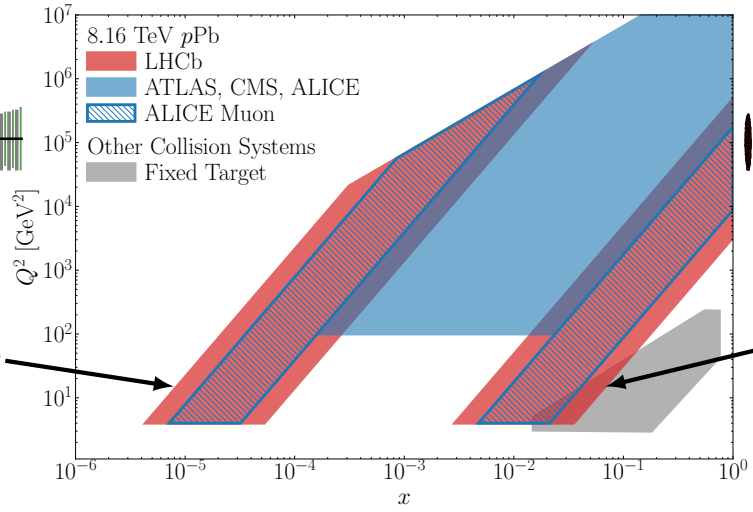
- Forward spectrometer: $2 < \eta < 5$
- **tracking**, **calorimetry**, **RICH**, **muon** systems
- Excellent vertex resolution ($10 - 50$ μm in x and y)
- Track $\sigma(p)/p \sim 0.5 - 1.0\%$



LHCb kinematic coverage





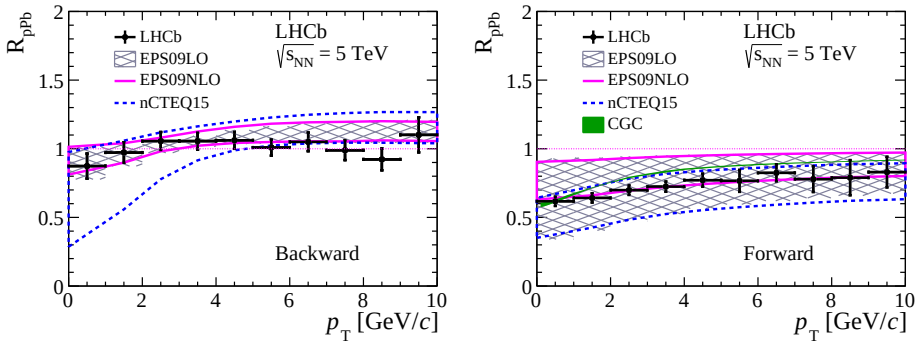


Forward
$y^*/\eta^* > 0$,
shadowing,
saturation?

Backward
$y^*/\eta^* < 0$,
anti-shadowing

Prompt D^0 production at 5 TeV (JHEP **10**, 090 (2017))

$2.5 < |y_{\mathrm{CM}}| < 4.0$ for $p_{\mathrm{T}} < 6\,\mathrm{GeV}$
$2.5 < |y_{\mathrm{CM}}| < 3.5$ for $6 < p_{\mathrm{T}} < 10\,\mathrm{GeV}$

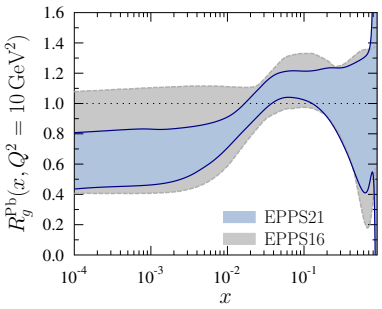


EPS09: JHEP **04**, 065 (2009), nCTEQ15: PRD **93**, no.8, 085037 (2016), CGC: PRD **91**, no.11, 114005 (2015)

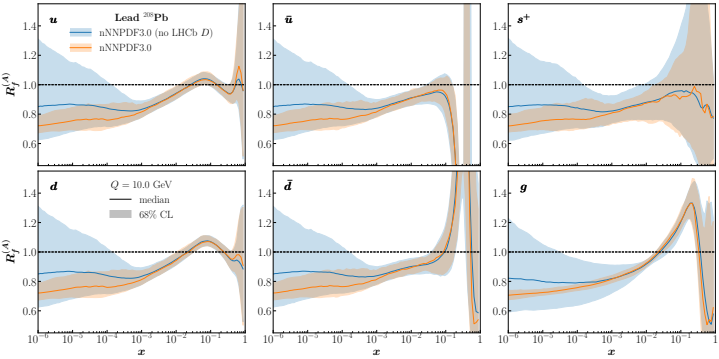
- Measured D-meson production in pp and pPb down to $p_{\mathrm{T}} = 0$
- Backward measurement probes the high(ish)-x antishadowing region
- Forward measurement probes the low-x shadowing region

The impact on nPDFs

EPPS21 (EPJC 82 (2022) 5, 413)

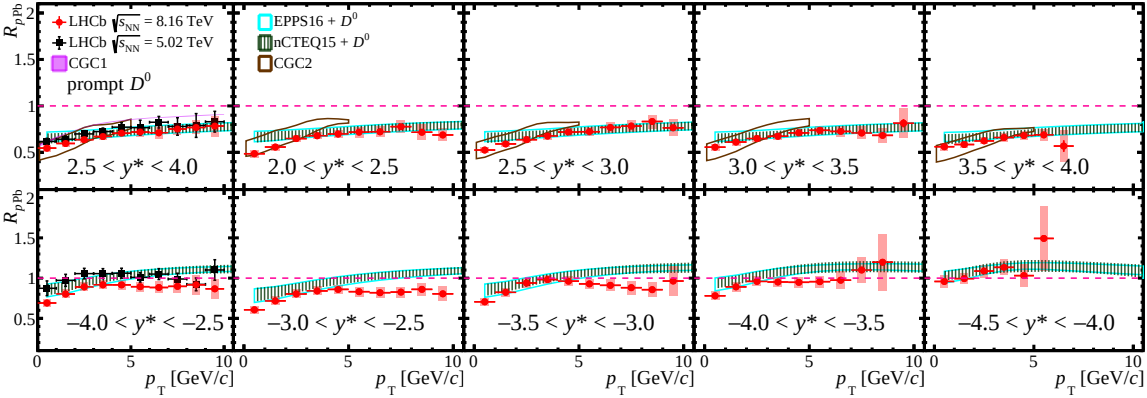


nNNPDF3.0 (EPJC 82 (2022) 6, 507)



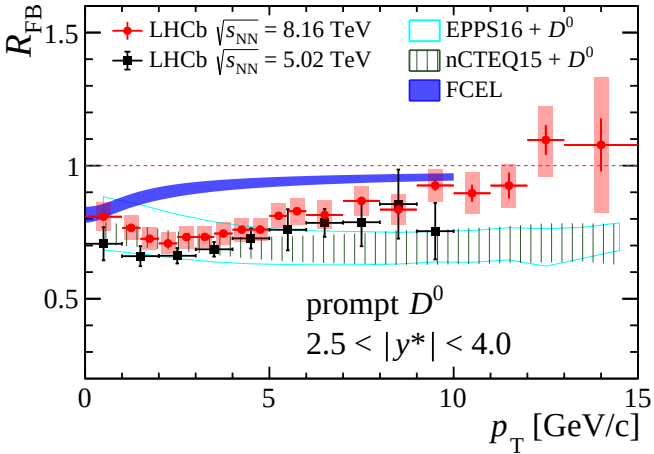
LHCb data has a huge impact in state-of-the-art nPDF fits! More precise studies at low-x will allow us to overconstrain nPDFs and challenge their built-in assumptions.

Prompt D^0 production at 8.16 TeV (arXiv:2205.03936)



Measured D^0 production at 8.16 TeV down to $p_{\mathrm{T}} = 0$ over a wide rapidity range.

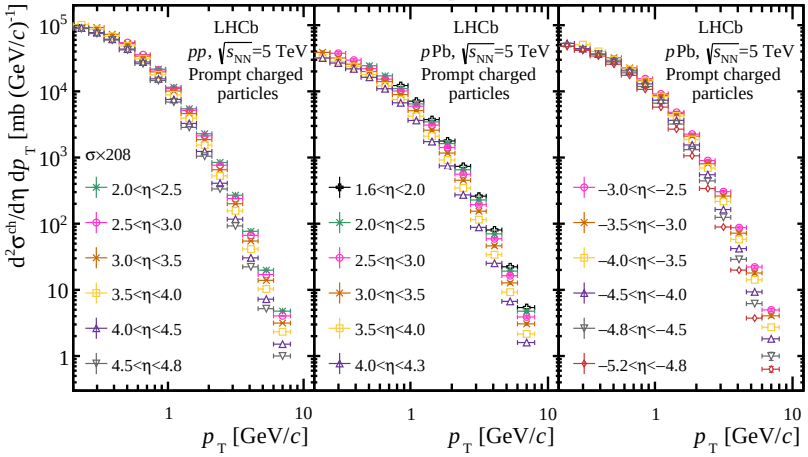
Prompt D^0 production at 8.16 TeV (arXiv:2205.03936)



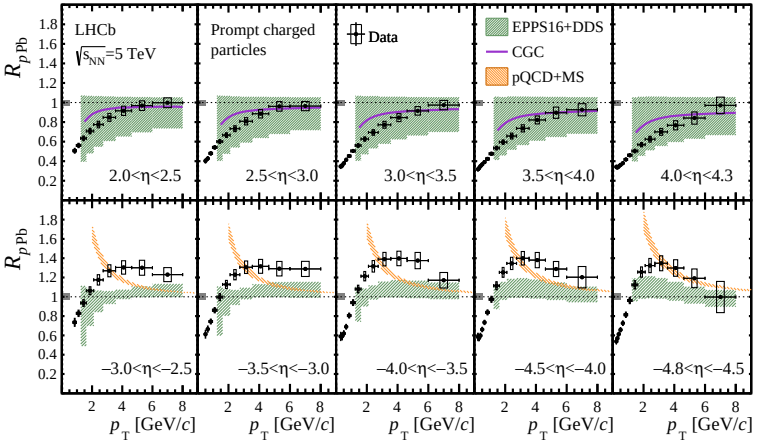
Tension with nPDF predictions is clear in the forward-backward ratio.

Prompt charged particle production (PRL 128 (2022) 14, 142004)

- Forward measurement probes unexplored x: $10^{-6} \lesssim x \lesssim 10^{-4}$
- Potentially probes the saturation region at low p_{T}
- Measurement is very precise: $\mathrm{d}^2\sigma/\mathrm{d}p_{\mathrm{T}}\mathrm{d}\eta$ ($R_{p\mathrm{Pb}}$) uncertainties as small as 3% (4%)



Prompt charged particle production (PRL 128 (2022) 14, 142004)

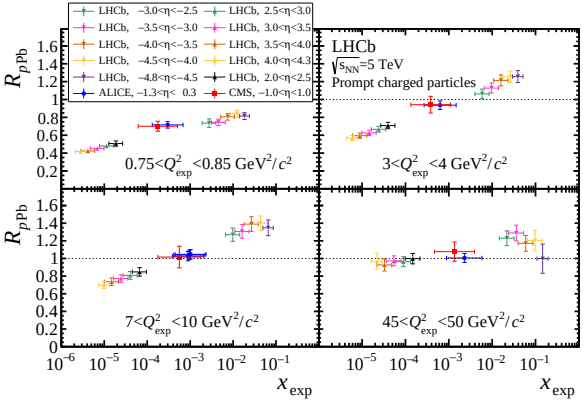


Theory predictions

- EPPS16+DDS
  JHEP **09**, 138 (2014)
- CGC
  PRD **88**, 114020 (2013)
- pQCD+MS
  PRD **88**, 054010 (2013)

- Strong suppression at forward rapidities
- Large enhancement at backward rapidities not explained by nPDF calculations
- Radial flow? Recombination? Competition between enhancing effects and saturation?

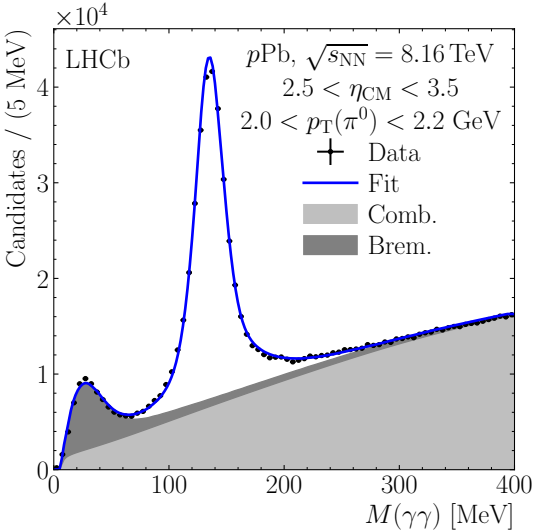
Prompt charged particle production (PRL 128 (2022) 14, 142004)



ALICE: JHEP **11**, 013 (2018)
CMS: JHEP **04**, 039 (2017)

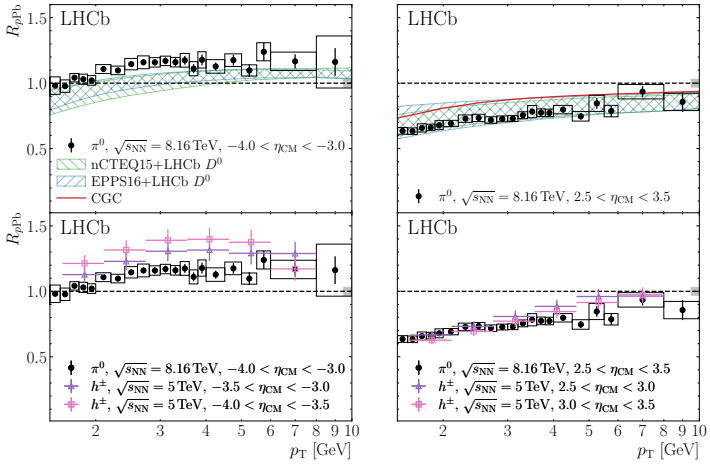
- Study the evolution of $R_{p\mathrm{Pb}}$ using experimental proxies for x and Q^2
- $Q^2_{\mathrm{exp}} = m^2 + p^2_{\mathrm{T}}$,
  $x_{\mathrm{exp}} = \frac{Q_{\mathrm{exp}}}{\sqrt{s_{\mathrm{NN}}}} e^{-\eta_{\mathrm{CM}}}$
- Continuous evolution in x_{exp} at various Q^2_{exp} across multiple experiments

Neutral pion production (arXiv:2204.10608)



- Charged particles and π^0s share similar production processes and probe similar kinematics
- Systematic uncertainties are mostly independent
- Knowing the hadron species could help untangle the effects nPDFs, saturation, and final state interactions

Neutral pion production (arXiv:2204.10608)



- Forward results agree with nPDF predictions and LHCb charged particle results
- Backward enhancement is larger than nPDF predictions, but smaller than the LHCb charged particle enhancement
- Studies of other identified particles (p, K, $\eta^{(\prime)}$) will help clarify the picture

Final thoughts

- In the last 5 years, nPDFs at low-x have gone from unconstrained to overconstrained thanks to LHCb data!

- LHCb measurements in multiple channels present tension with nPDF predictions.
  - D^0 production at 8.16 TeV (arXiv:2205.03936)
  - Charged particle production at 5 TeV (PRL 128 (2022) 14, 142004)
  - π^0 production at 8.16 TeV (arXiv:2204.10608)
  - Quarkonia production in UPCs! See talk by Weisong Duan

- Studies of low-x phenomena at LHCb are just starting to challenge our underlying physical assumptions about QCD in heavy-ion collisions.

Thank you!