Recent heavy-ion results from LHCb

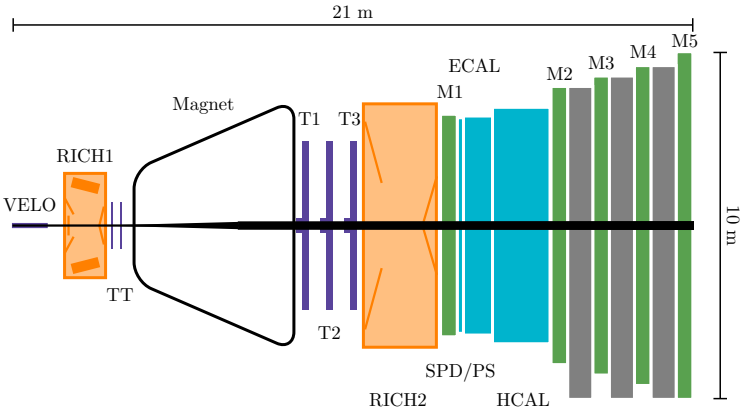
Tom Boettcher

on behalf of the LHCb collaboration

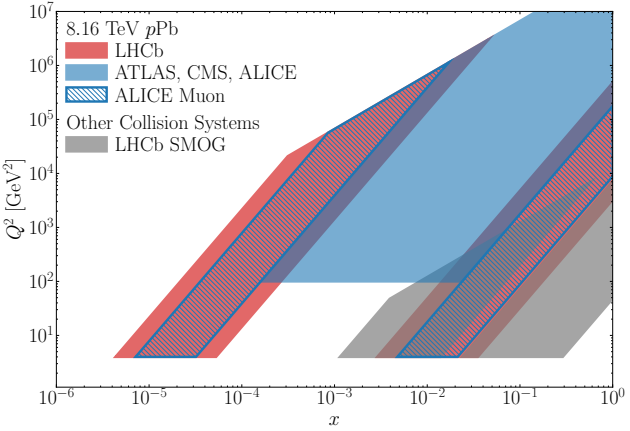
CIPANP
September 1, 2022

The LHCb experiment (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 $\sigma(p)/p \sim 0.5 - 1.0\%$
- Fixed-target mode with the SMOG system



Heavy-ion collisions at LHCb



pPb collisions

- Low- and high-x nuclear parton distributions (nPDFs), exotic production
- $\sqrt{s_{\mathrm{NN}}} = 5\,\mathrm{TeV}$ and $8.16\,\mathrm{TeV}$

PbPb collisions

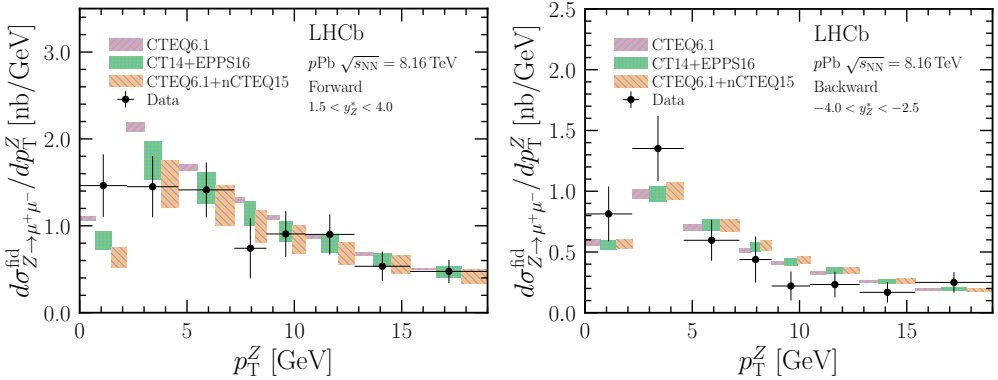
- UPCs, heavy-flavor production
- Limited to peripheral events (60%)

Fixed-target physics (SMOG)

- pHe, pNe, pAr, PbAr, PbNe
- cosmic ray physics, nucleon structure

Z production in pPb collisions (arXiv:2205.10213, accepted by JHEP)

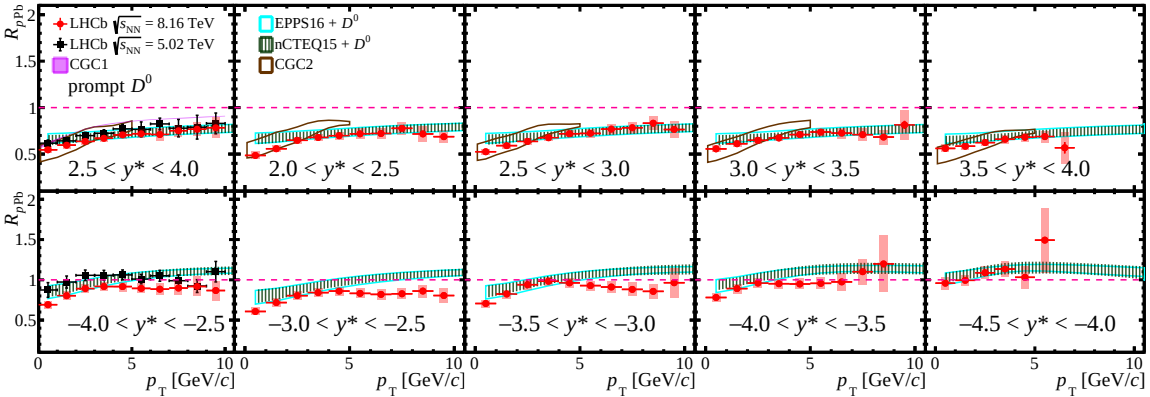
Clean probe of the initial state at $Q^2 \sim m_Z^2$ at low- and high-x. Can be used to study both nPDFs and transverse-momentum-dependent PDFs.



Data agree with NLO pQCD calculations within large uncertainties.

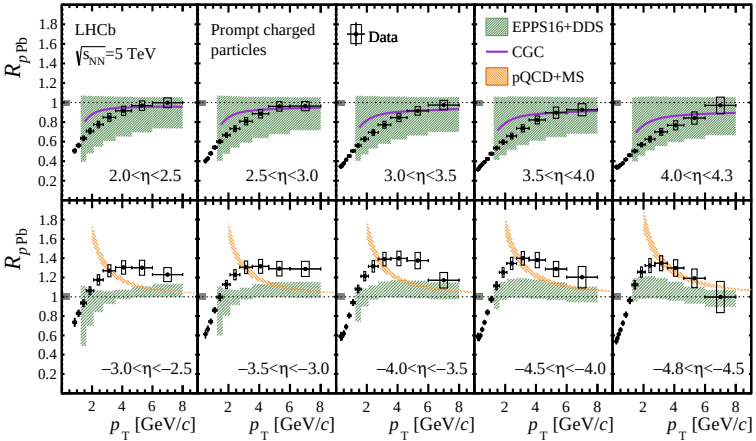
D^0 production at 8.16 TeV (arXiv:2205.03936, accepted by PRL)

Probes low-x partons (mostly gluons) down to $Q^2 \sim 4\,\mathrm{GeV}^2$. Potentially sensitive to gluon saturation.



Good agreement with nPDFs and LHCb D^0 data at 5 TeV at forward rapidity, but some tension at backward rapidity.

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



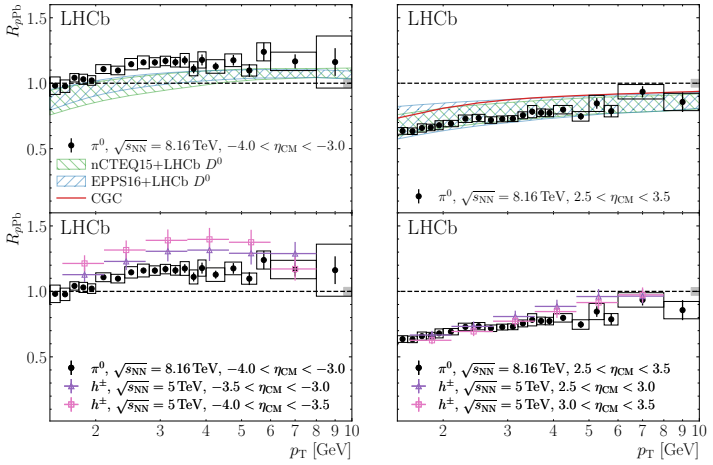
Theory predictions

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

- Probe $x \lesssim 10^{-5}$ and $Q^2 \lesssim 1\,\mathrm{GeV}^2$
- Strong suppression at forward rapidities
- Large enhancement at backward rapidities not explained by nPDF calculations

π^0 production (arXiv:2204.10608, accepted by PRL)

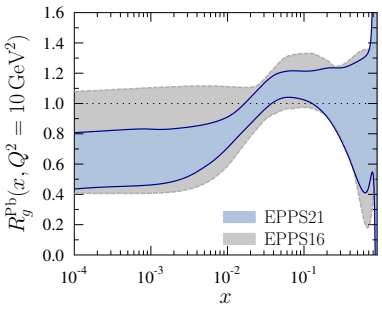
Knowing the particle species provides additional information. Kinematics and production mechanisms are similar to charged particles, but systematics are mostly independent.



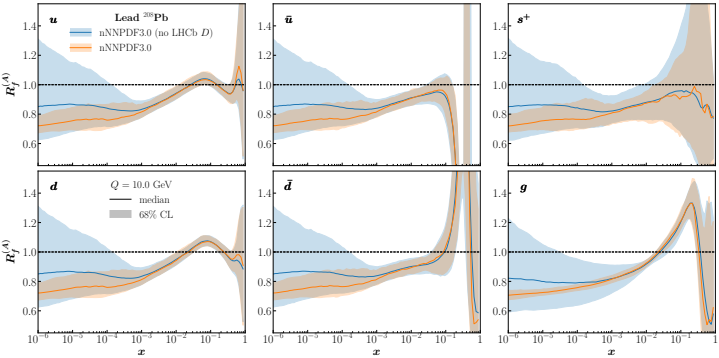
- Backward enhancement is larger than nPDF predictions, but smaller than the LHCb charged particle enhancement
- Studies of other identified particles (p, K, $\eta^{(\prime)}$) will help clarify the picture

LHCb's impact on nPDF fits

EPPS21 (EPJC 82 (2022) 5, 413)



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

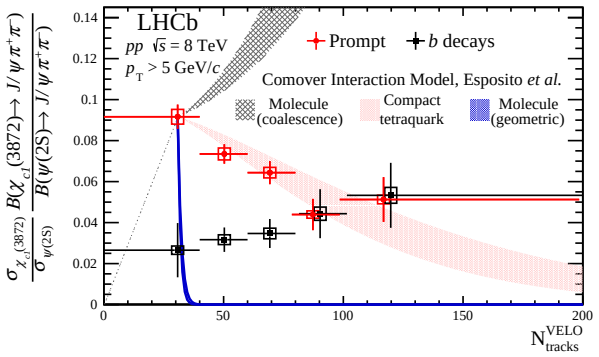


LHCb data has a huge impact in state-of-the-art nPDF fits! Recent LHCb measurements at low x will allow us to overconstrain nPDFs and challenge their built-in assumptions.

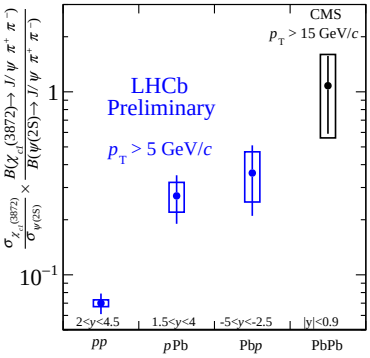
$\chi_{c1}(3872)$ production in pp and pPb collisions

Production mechanism provides information about the structure of exotic hadrons.

PRL 126, 092001 (2021)



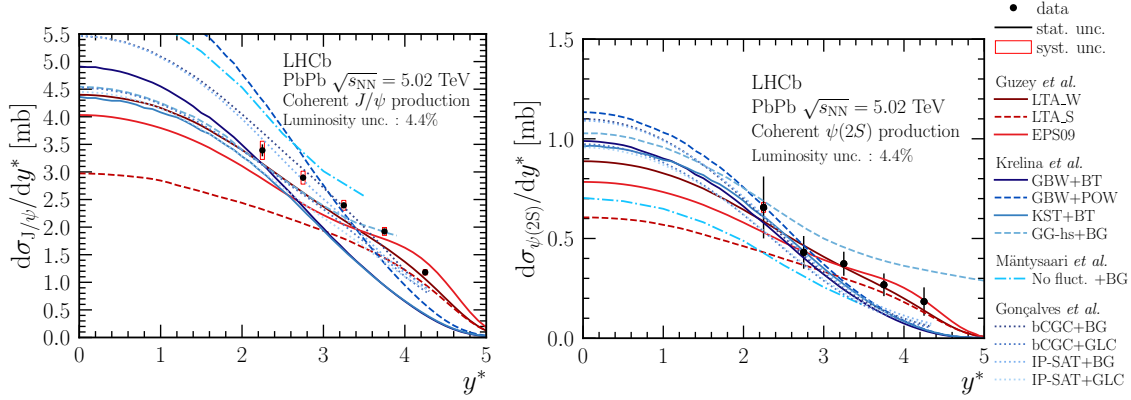
LHCb-CONF-2022-001



First evidence of $\chi_{c1}(3872)$ production in pPb collisions. $\sigma_{\chi_{c1}(3872)}/\sigma_{\psi(2S)}$ appears to decrease with multiplicity in pp, but increase with increasing collision system size.

Coherent charmonium production in ultraperipheral PbPb collisions (arXiv:2206.08221, accepted by JHEP)

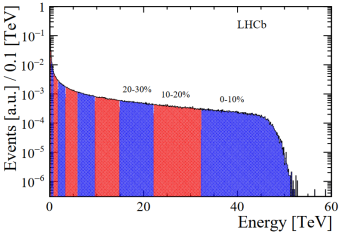
Coherent charmonia production cross-sections $\propto g(x)^2$.

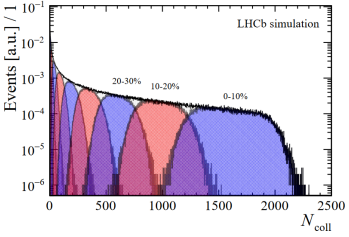


Results provide strong constraints on pQCD and CGC calculations.

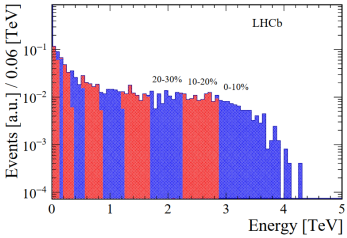
Centrality determination (JINST 17 (2022) 05, P05009)

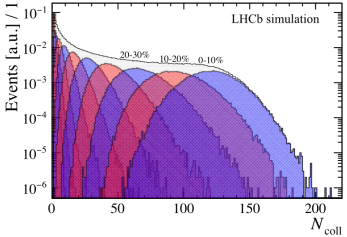
PbPb at $\sqrt{s_{\mathrm{NN}}} = 5.02\,\mathrm{TeV}$





PbNe at $\sqrt{s_{\mathrm{NN}}} = 69\,\mathrm{GeV}$

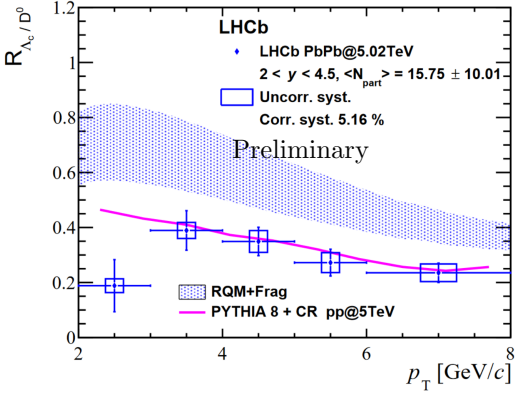


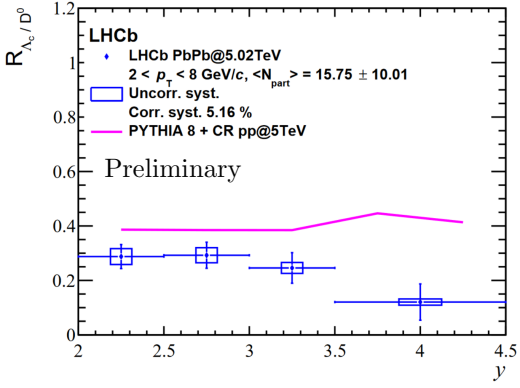


- Use Glauber MC to map total ECAL energy to geometrical quantities
- First centrality determination at LHCb
- First fixed-target centrality determination at the LHC
- Major step towards expanding LHCb's heavy-ion program

Λ_c^+/D^0 ratio in peripheral PbPb collisions (LHCb-PAPER-2021-046, in preparation)

Baryon-to-meson ratios are used to isolate hadronization effects in heavy-ion collisions.

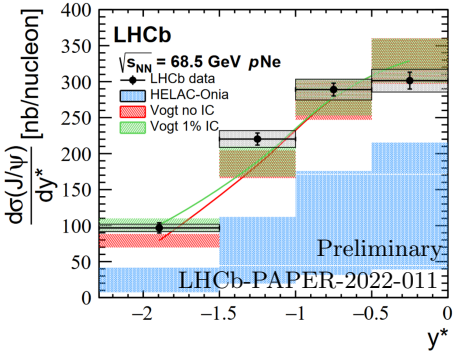




Data agree with PYTHIA8 with color recombination. Smaller than the ratio measured by ALICE in pPb, suggesting strong rapidity dependence.

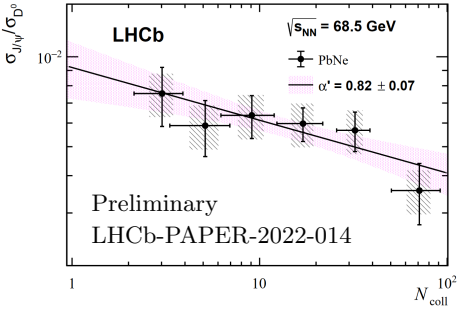
Fixed-target charm production (LHCb-PAPER-2022-011, LHCb-PAPER-2022-014, in preparation)

J/ψ production in pNe. Potentially sensitive to intrinsic charm (IC) in the nucleon.



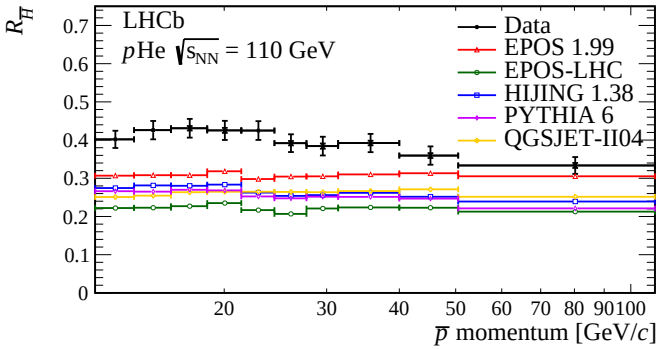
Data are consistent with IC, but uncertainties are large.

J/ψ and D^0 production in PbNe



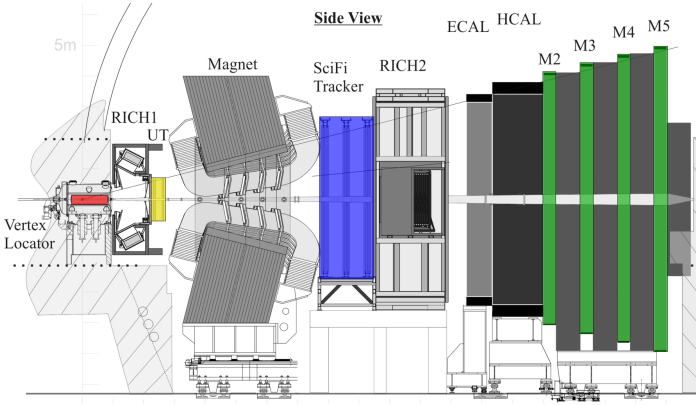
$\sigma_{J/\psi}/\sigma_{D^0} \propto \langle N_{\rm coll}\rangle^{\alpha'-1}$. $\alpha' \neq 1$ implies additional nuclear effects on J/ψ production. Agrees with pA data from NA50.

Fixed-target $\overline{p}$ production from hyperon decays (arXiv:2205.09009, accepted by EPJC)



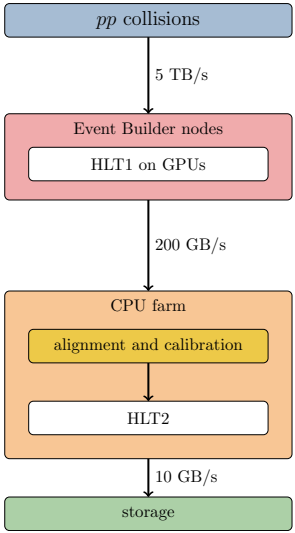
- $R_{\overline{H}}$ = fraction of $\overline{p}$ from hyperon decays
- Important input for $\overline{p}$ flux in cosmic rays.
- Event generators used in cosmic ray physics consistently underestimate the data.
- Consistent with pp results from STAR, ALICE, and CMS

LHCb in Run 3

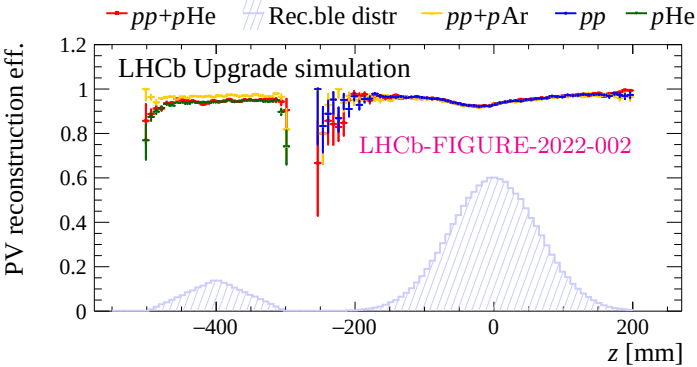


- New tracking system with higher granularity
- Tracking up to 30% centrality
- Data collection with no hardware trigger. New frontend electronics to allow for full detector read out at 40 MHz.
- SMOG2: new gas cell upstream of the interaction point. Up to 100× increase in gas pressure.

Allen: LHCb's GPU-based trigger (CSBS 4, 7 (2020), LHCB-TDR-021)



- Full end-to-end trigger stage on GPUs
- Performs track and ECAL reco, μ/e ID, vertexing, and event selection at 30 MHz with $\sim$ 170 GPUs
- Simultaneously collect pp and SMOG2 data



Final thoughts

LHCb has a thriving heavy-ion physics program!

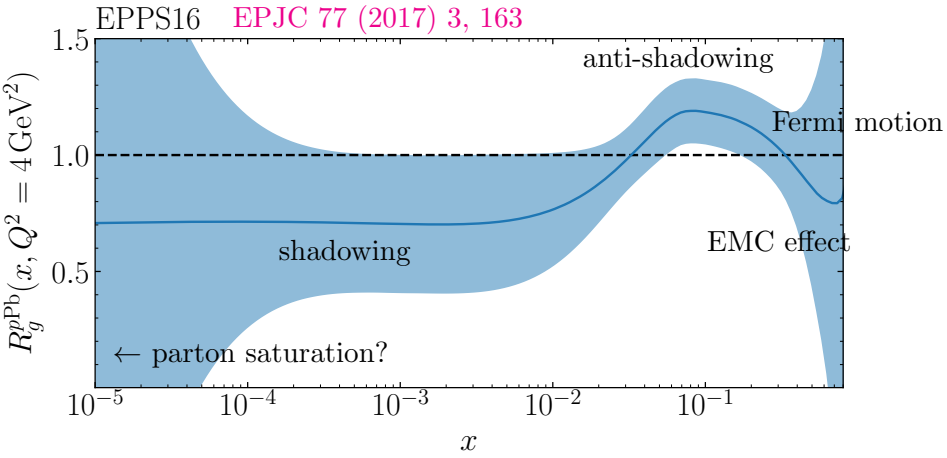
- High- and low-x nulceon structure
- Exotic production
- Hadronization in heavy-ion collisions (see also Sook Hyun Lee's talk tomorrow)
- Cosmic ray physics with fixed-target collisions

I couldn't cover everything...

- b-quark hadronization modification in high-multiplicity pp collisions
- J/ψ photoproduction in peripheral PbPb collisions
- And more: LHCb heavy-ion and fixed-target public results

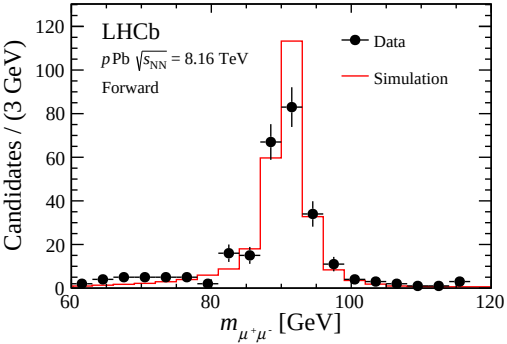
Thank you!

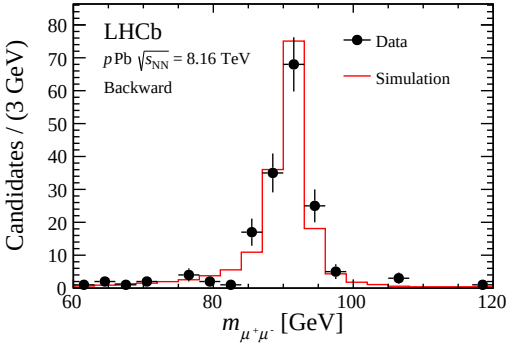
Backup



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

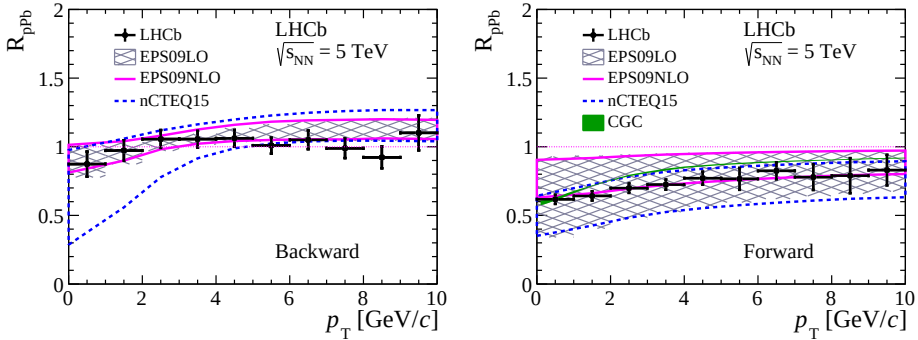
Z production in pPb collisions (arXiv:2205.10213, accepted by JHEP)





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

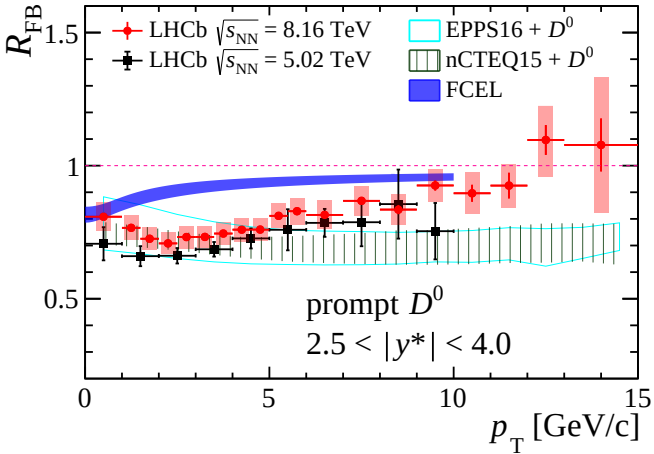
$2.5 < |y_{\rm CM}| < 4.0$ for $p_{\rm T} < 6\,{\rm GeV}$
$2.5 < |y_{\rm CM}| < 3.5$ for $6 < p_{\rm T} < 10\,{\rm GeV}$



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 $p_{\rm T} = 0$
- Backward measurement probes the high(ish)-x antishadowing region
- Forward measurement probes the low-x shadowing region

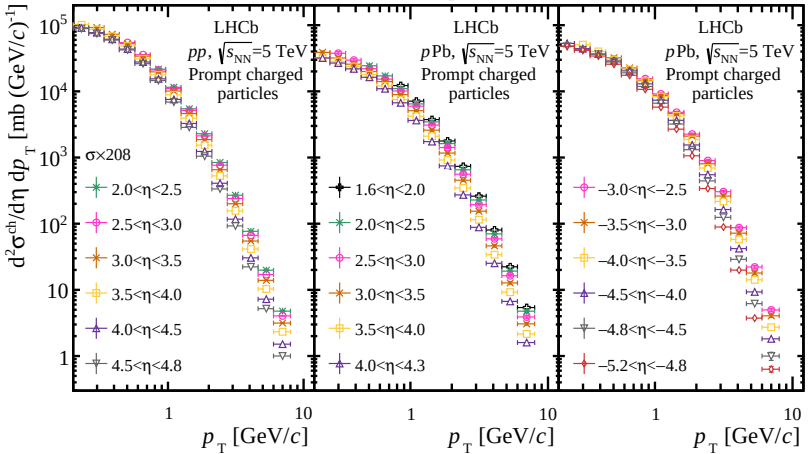
Prompt D^0 production at 8.16 TeV (arXiv:2205.03936)



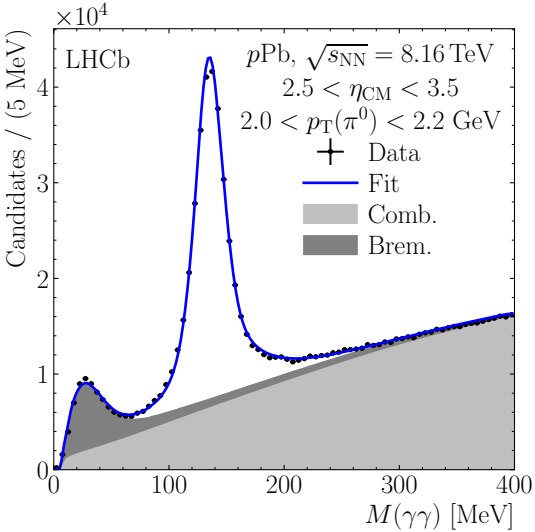
Tension with nPDF predictions is clear in the forward-backward ratio.

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%)

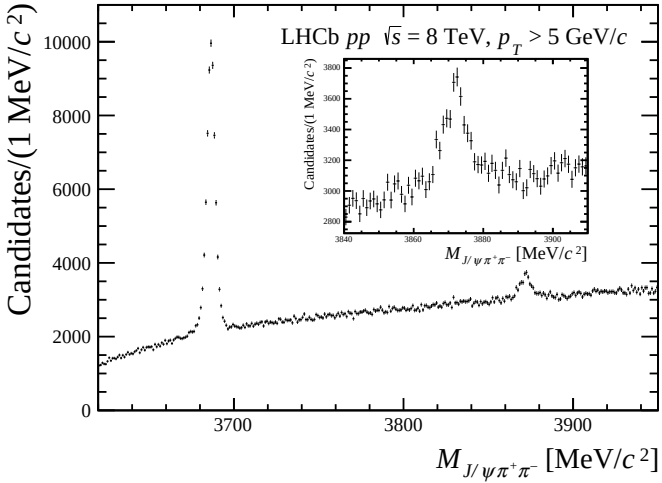


Neutral pion production (arXiv:2204.10608)

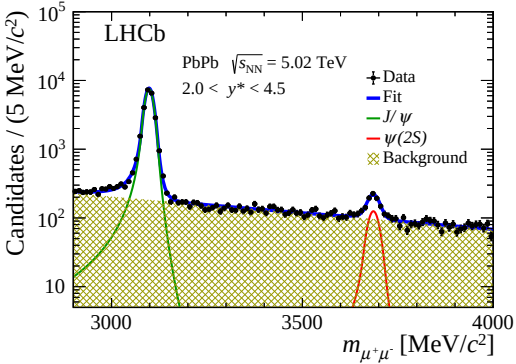


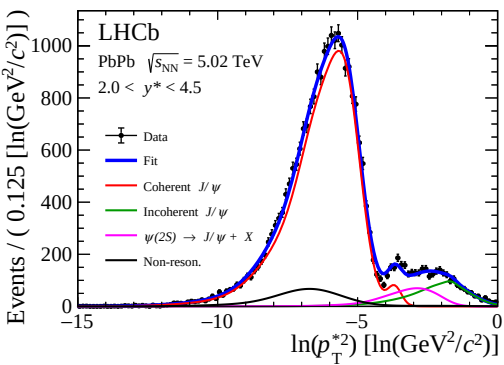
- Charged particles and π^0s share similar production processes and probe similar kinematics
- Systematic uncertainties are mostly independent
- Knowing the hadron species could help untangle the effects nPDFs, saturation, and final state interactions

$\chi_{c1}(3872)$ production in pp collisions PRL 126, 092001 (2021)



Coherent charmonium production in ultraperipheral PbPb collisions (arXiv:2206.08221, accepted by JHEP)





Fixed-target $\overline{p}$ production from hyperon decays (arXiv:2205.09009, accepted by EPJC)