Recent heavy ion results at LHCb

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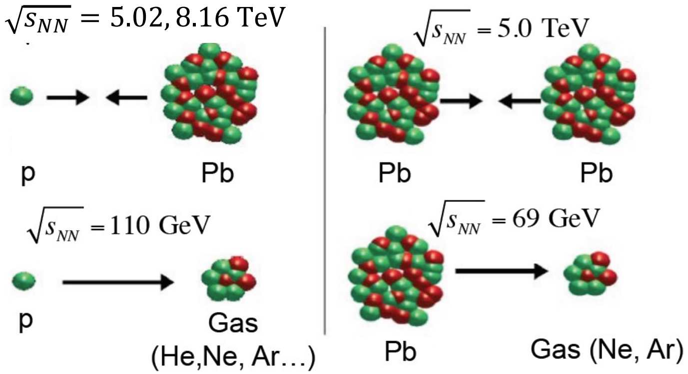
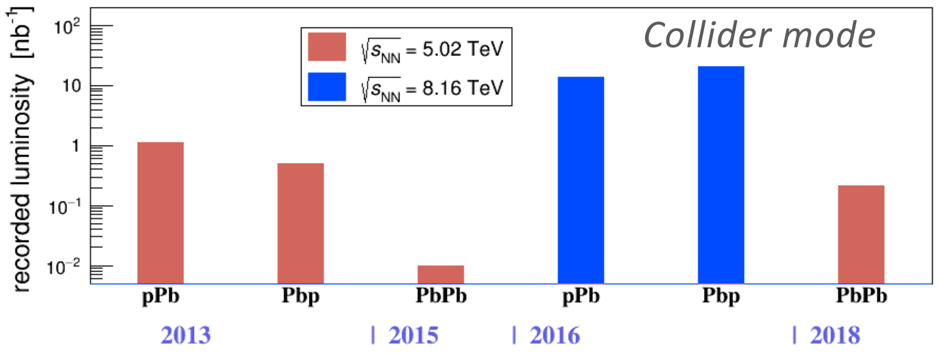
第 5 届 LHCb 前沿物理研讨会
武汉，2025.4.25-28

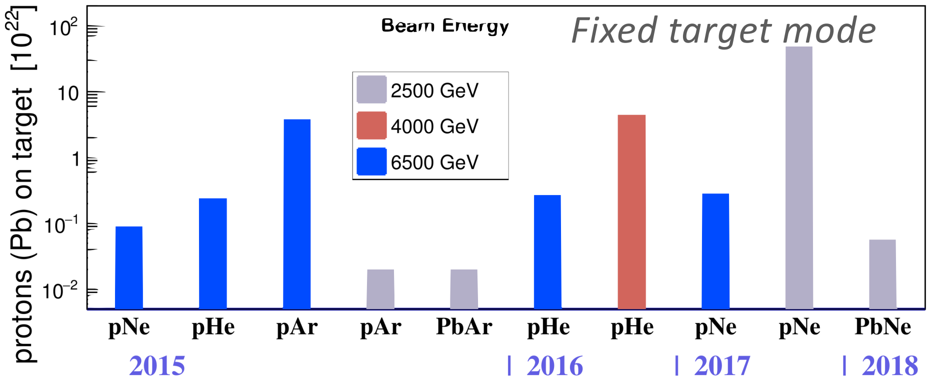
LHCb heavy ion datasets from Run1/Run2

Collider mode

Fixed target mode



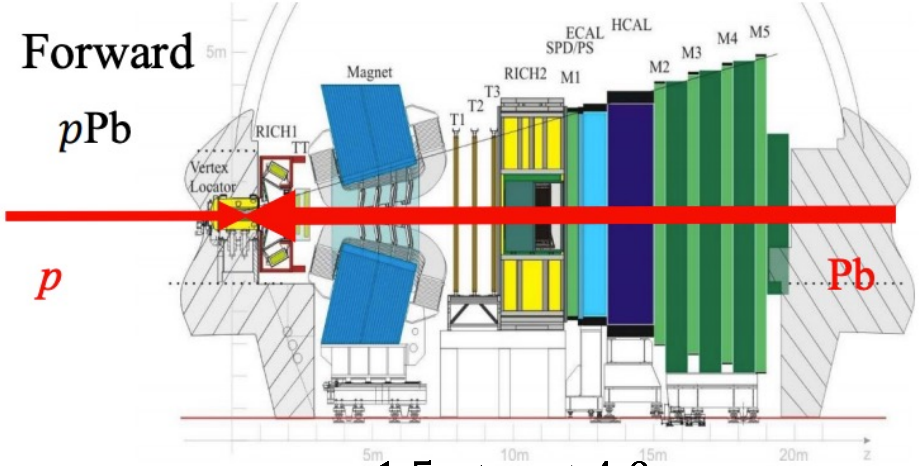




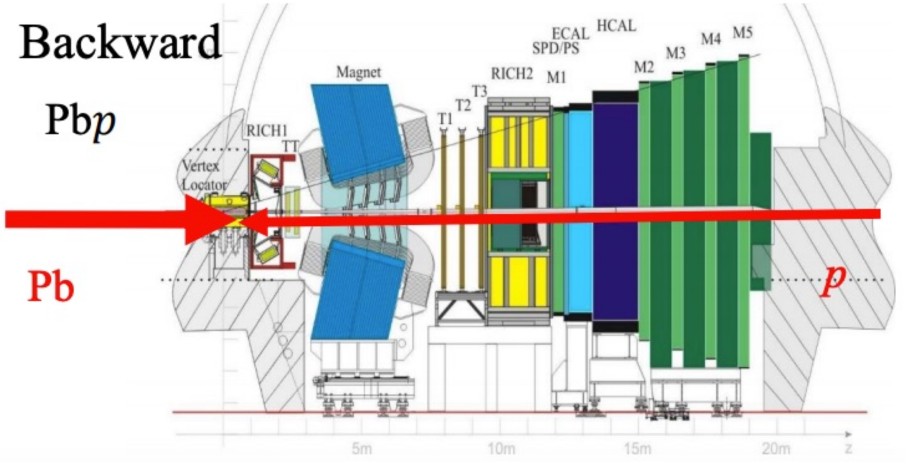
PbPb:
limited to 100-60% centrality

+ huge pp collision datasets at various energies for small-system studies!

Proton-Pb data-taking modes:

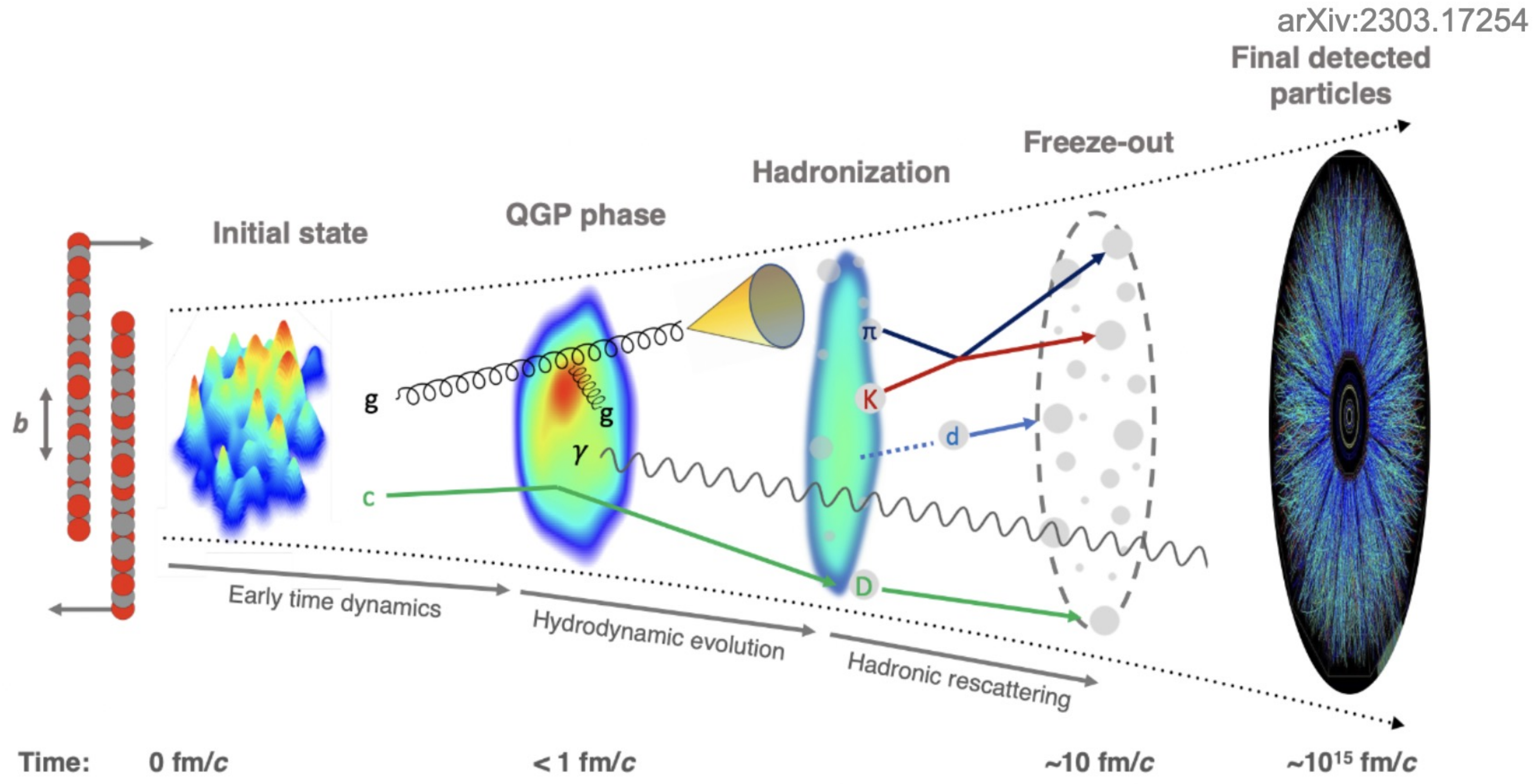


$1.5 < y < 4.0$



$-5.0 < y < -2.5$

Heavy flavor as excellent probes in heavy-ion collisions



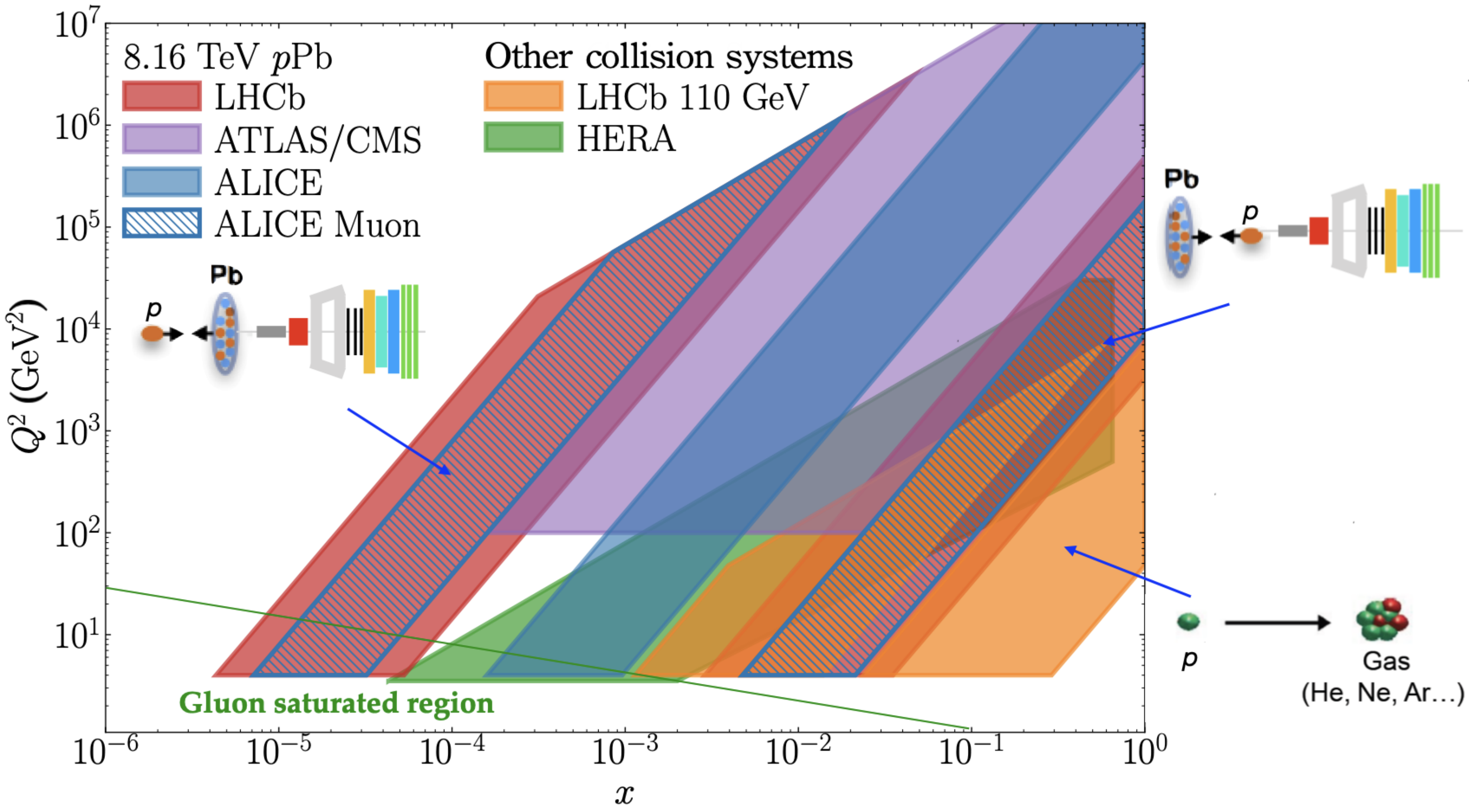
陈缮真，朱相雷，**科学通报** 70 (2025) 70-82

- Produced in hard processes at early stage of collisions, and experience the full evolution of the medium

- Initial state:
  - Nuclear shadowing
  - Gluon saturation
  - Initial-state scatterings
- QGP phase:
  - In-medium energy loss
  - Color screening
  - Collectivity
- Hadronization:
  - Coalescence versus fragmentation
  - Quarkonia regeneration

Cold nuclear matter effects studied in pA collisions

- nPDF; CGC; energy loss; multiple scattering (Cronin effect)



nPDF $(x,\ Q^2)$ coverage of different experiments

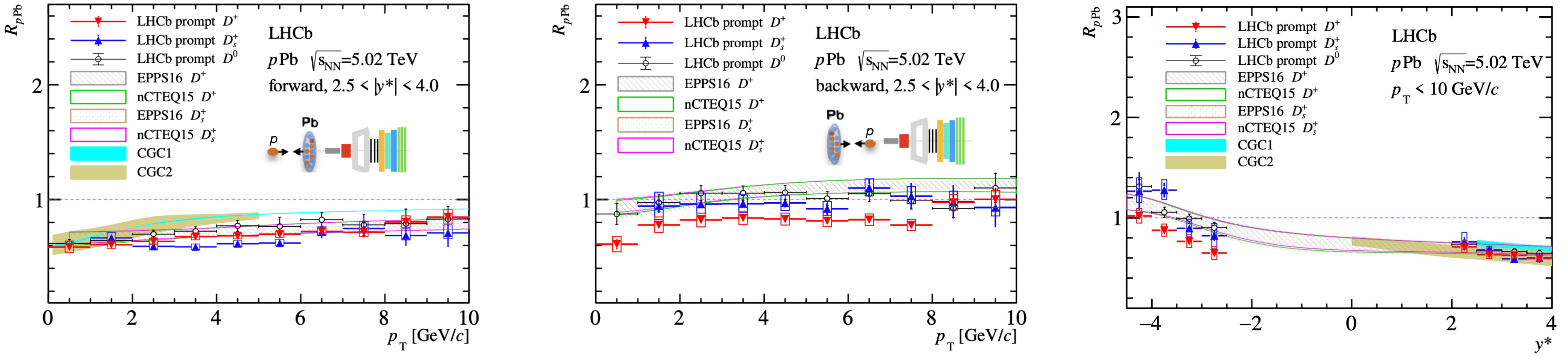
$$R_{p\mathrm{Pb}}(p_\mathrm{T}, y^*) \equiv \frac{1}{A}\frac{\mathrm{d}^2\sigma_{p\mathrm{Pb}}(p_\mathrm{T}, y^*)/\mathrm{d}p_\mathrm{T}\mathrm{d}y^*}{\mathrm{d}^2\sigma_{pp}(p_\mathrm{T}, y^*)/\mathrm{d}p_\mathrm{T}\mathrm{d}y^*}$$

$$x_{\mathrm{exp}} \equiv 2\frac{\sqrt{p_\mathrm{T}^2 + M^2}}{\sqrt{s_{\mathrm{NN}}}}\mathrm{e}^{-y^*}$$

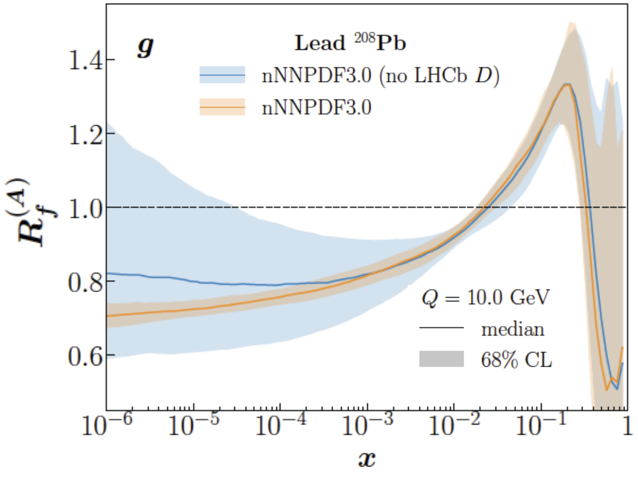
$$Q^2_{\mathrm{exp}} \equiv p_\mathrm{T}^2 + M^2$$

Prompt D meson production in pPb at 5.02 TeV

LHCb, JHEP 01 (2024) 070; JHEP 10 (2017) 090

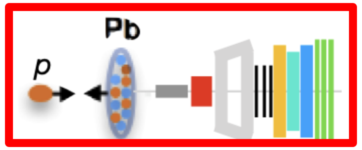


nNNPDF3.0, EPJC 82 (2022) 507

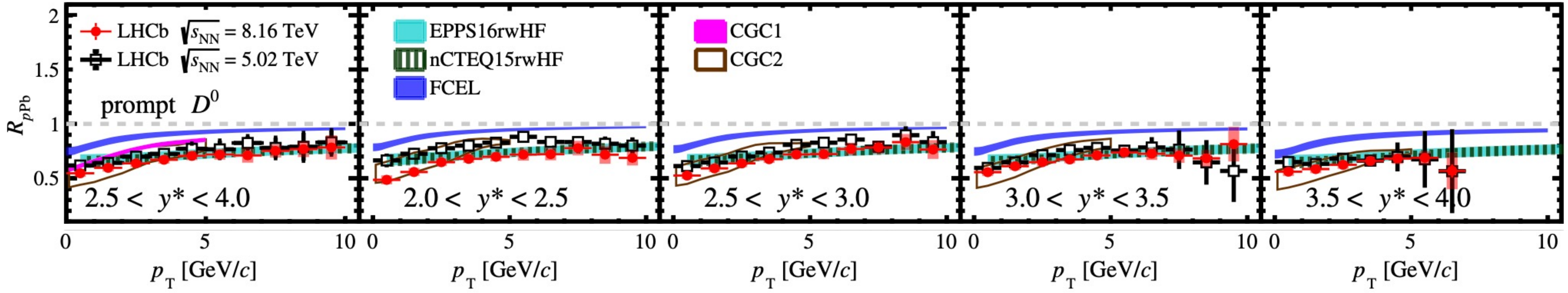


- One of the strongest constraint on gluon nPDF
- All D mesons suppressed at forward rapidity
  → gluon shadowing at small x
- D meson species dependence at backward rapidity
  → final state effects become important

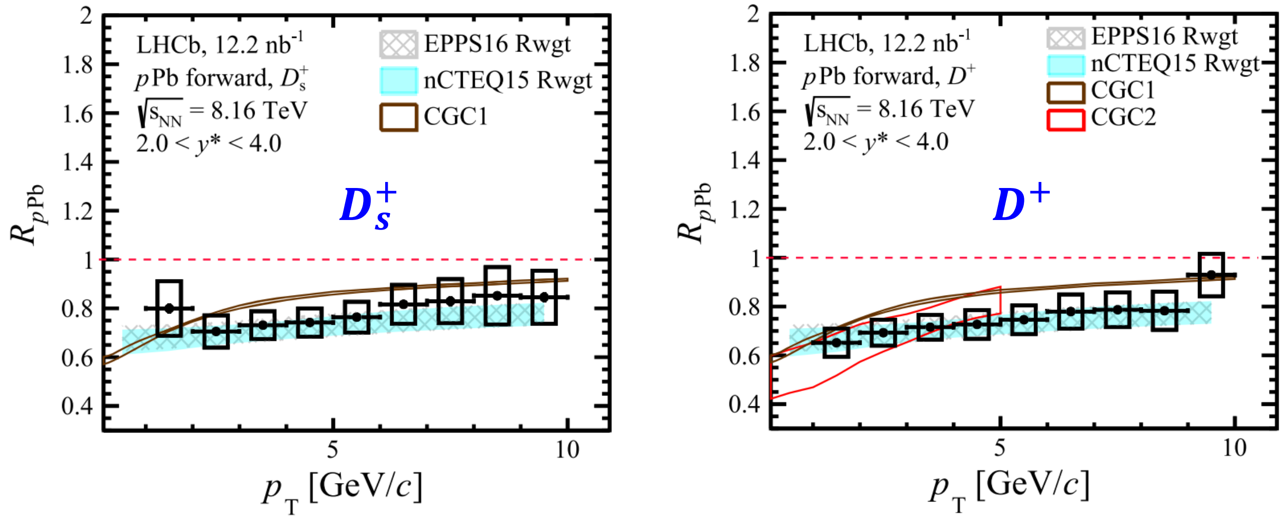
Prompt D meson production in pPb at 8.16 TeV



LHCb, PRL 131 (2023) 102301 D^0

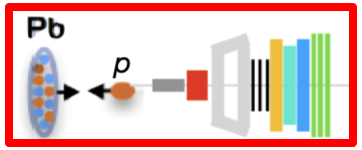


- Precise differential measurements in different rapidity regions → gluon shadowing at forward rapidity
- D^0 data at low p_T closer to CGC prediction, or initial state energy loss becomes more important



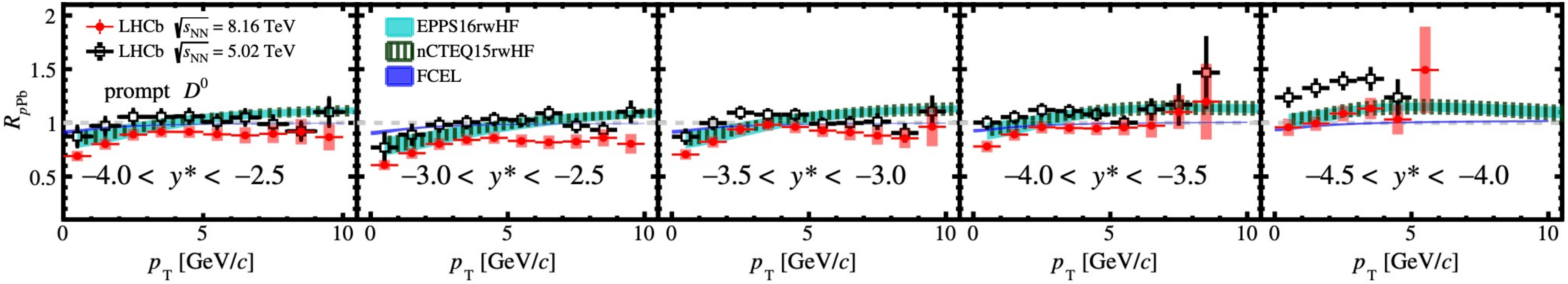
LHCb, PRD 110 (2024) L031105

Prompt D meson production in pPb at 8.16 TeV

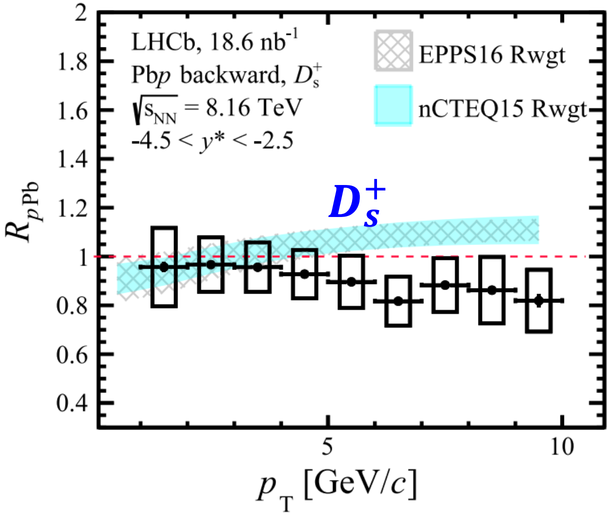


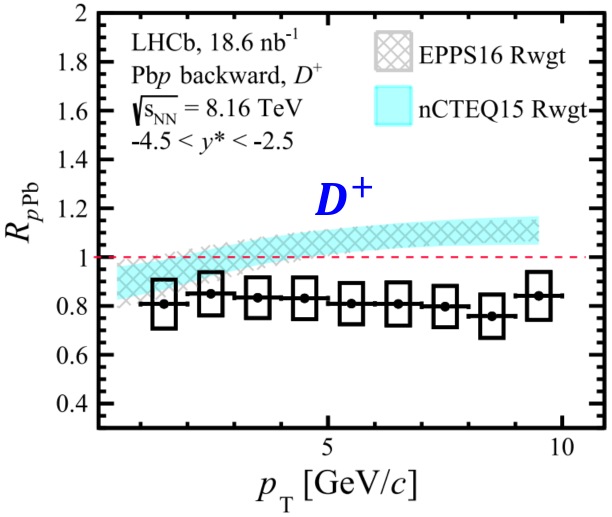
LHCb, PRL 131 (2023) 102301

D^0



- All D meson data lower than nPDF calculations at high p_T !
  → Onset of charm energy loss in cold/hot nuclear matter ?
    Model comparisons desired
  → Or charmed baryon enhanced ?
    More measurements expected

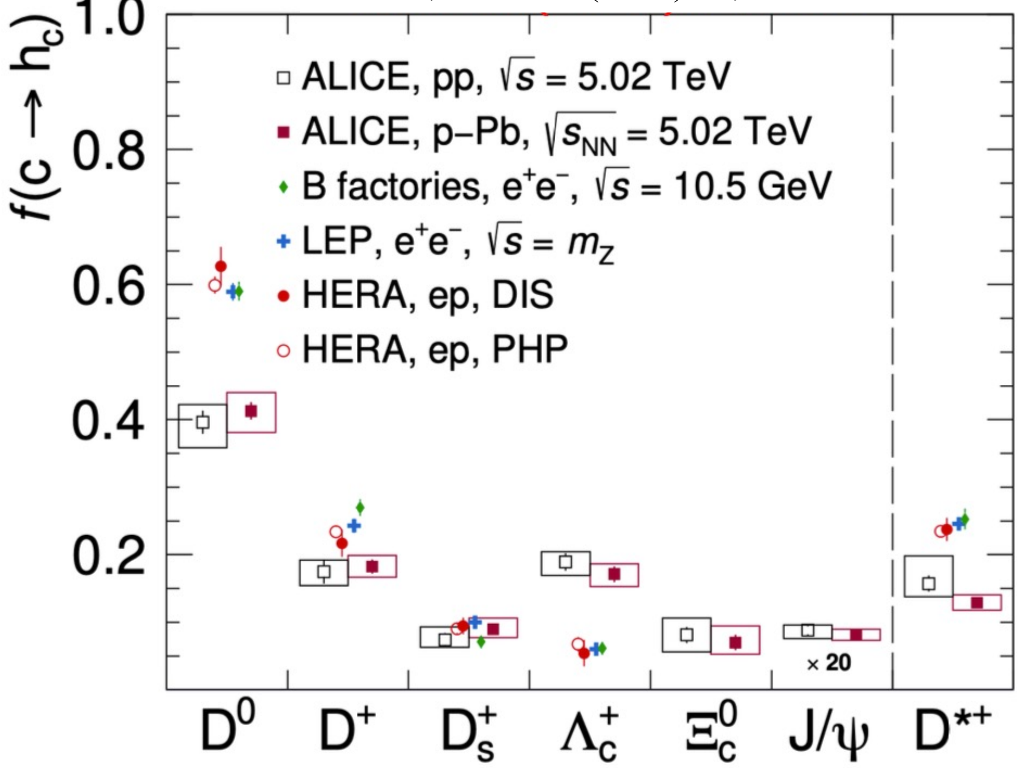




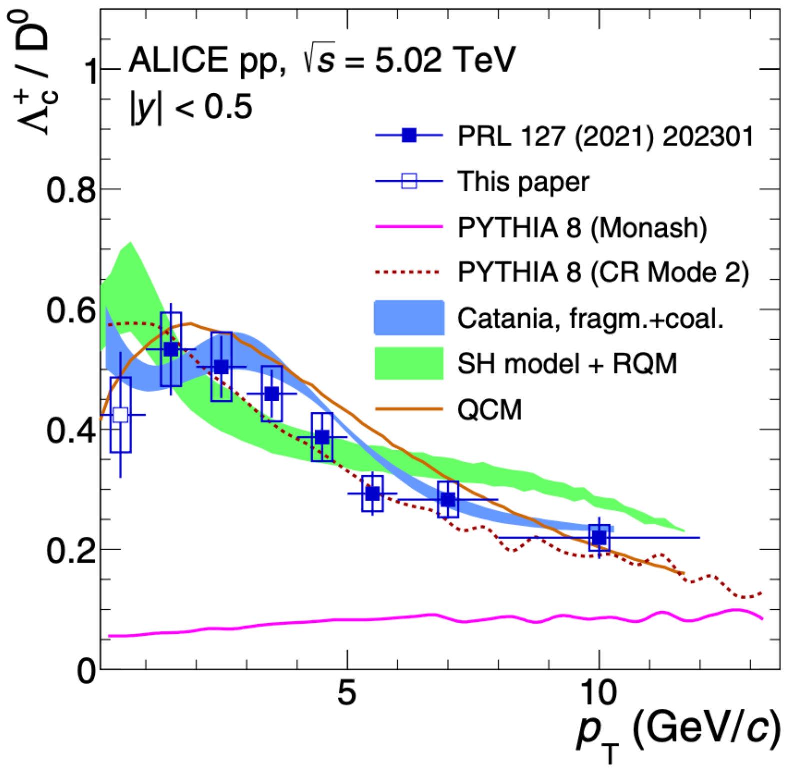
LHCb, PRD 110 (2024) L031105

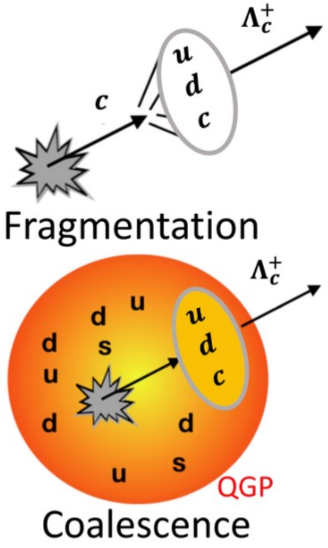
Heavy flavor hadronization

ALICE, EPJC 84 (2024) 12, 1286



ALICE, PRC 107 (2023) 064901

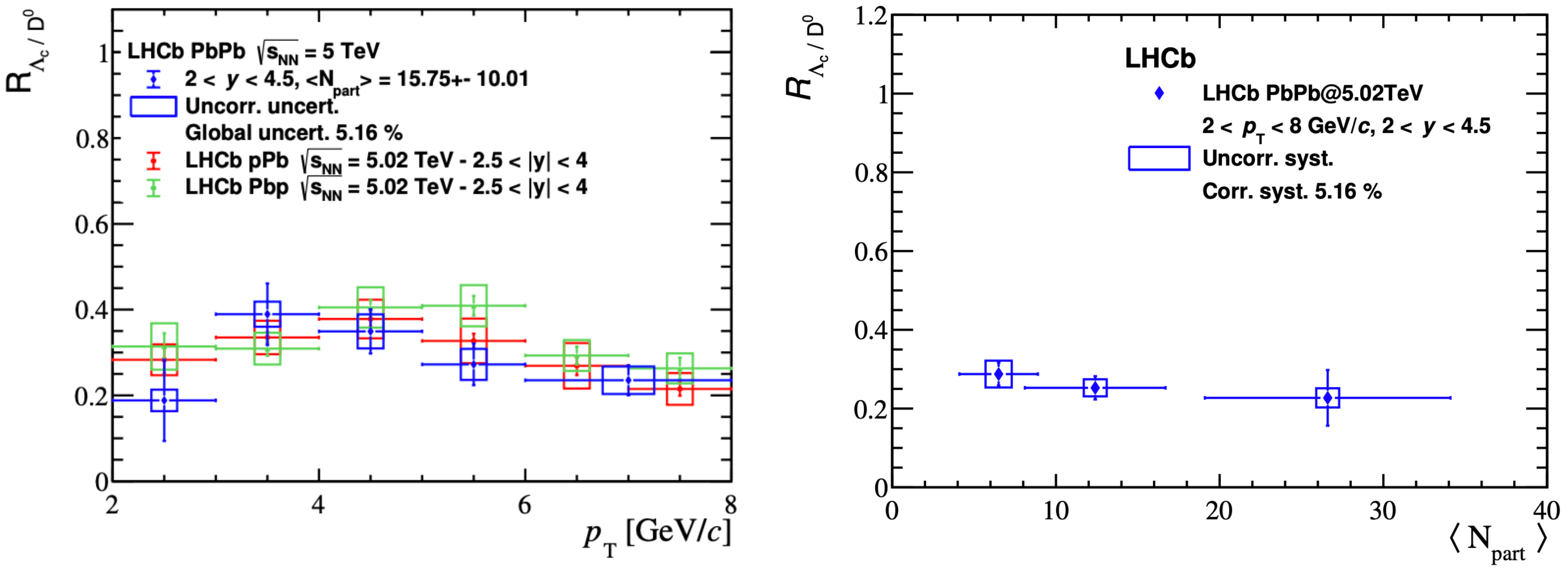




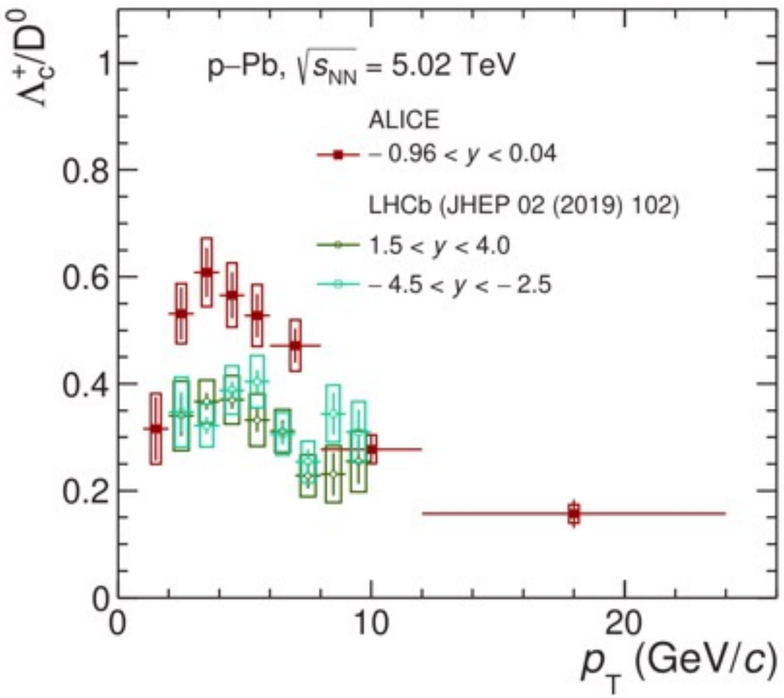
- Charm hadronization modified in pp compared to ee/ep collisions
- Indication of coalescence/stat. hadronization, probed with HF hadron yield ratios

Λ_c^+/D^0 ratio in forward rapidities

LHCb, JHEP 06 (2023) 132



ALICE, PRC 104 (2021) 054905

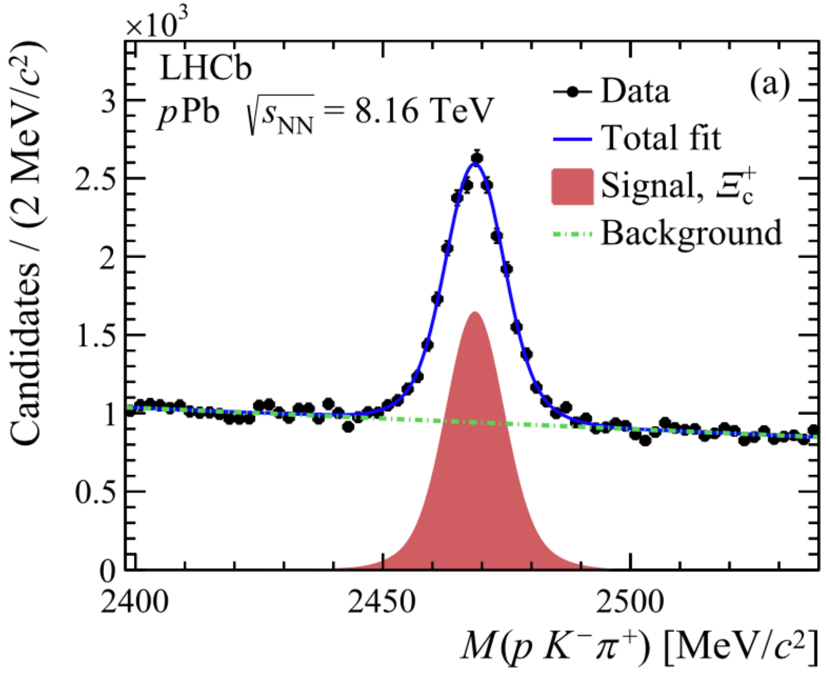


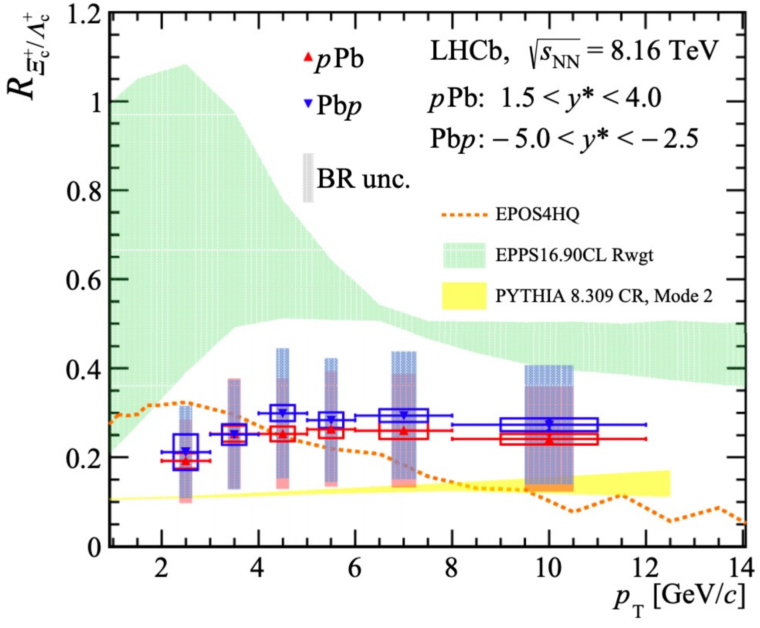
- Stays almost unchanged in pPb/Pbp and peripheral PbPb collisions, much larger than ee/ep, charm hadronization changed in forward rapidity as well
- Tension with values at mid-rapidity, since rapidity independence predicted
- More independent measurements are expected

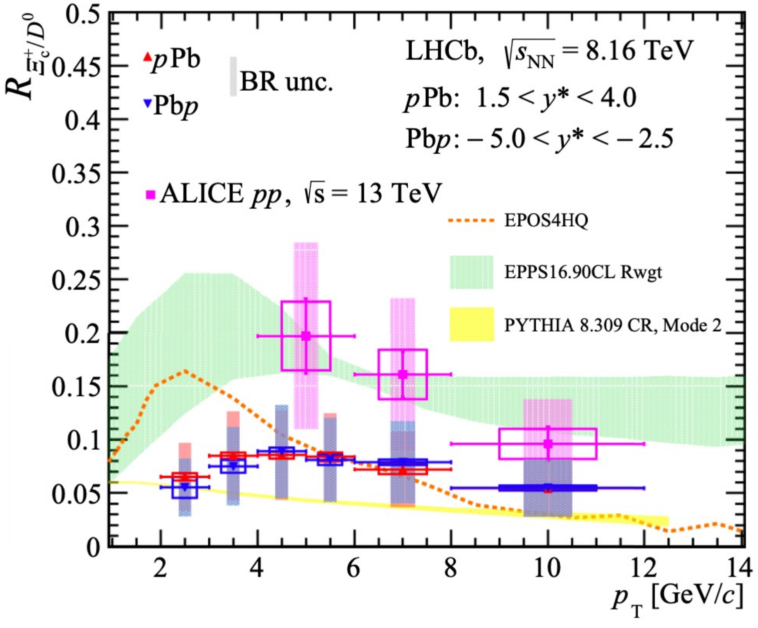
Ξ_c^+/D^0 ratios in pPb at 8.16 TeV

- First measurement of prompt Ξ_c^+ in heavy ion collisions
- Ξ_c^+/Λ_c^+ ratio constant over p_T, consistent between forward and backward
- Ξ_c^+/D^0 ratio generally lower than ALICE pp data at mid-y

Phys. Rev. C 109 (2024) 044901

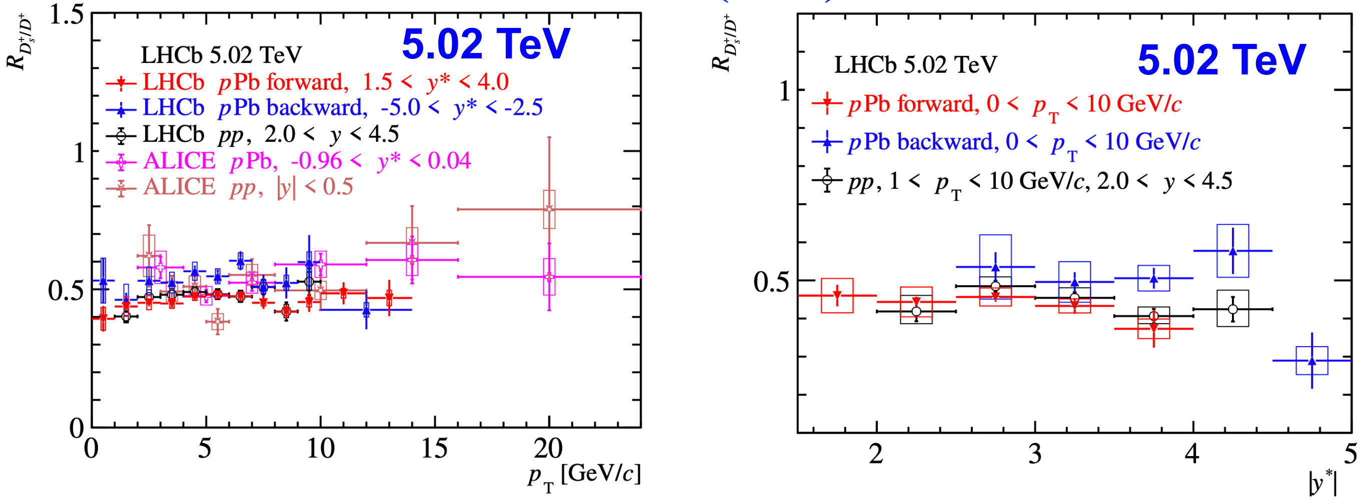




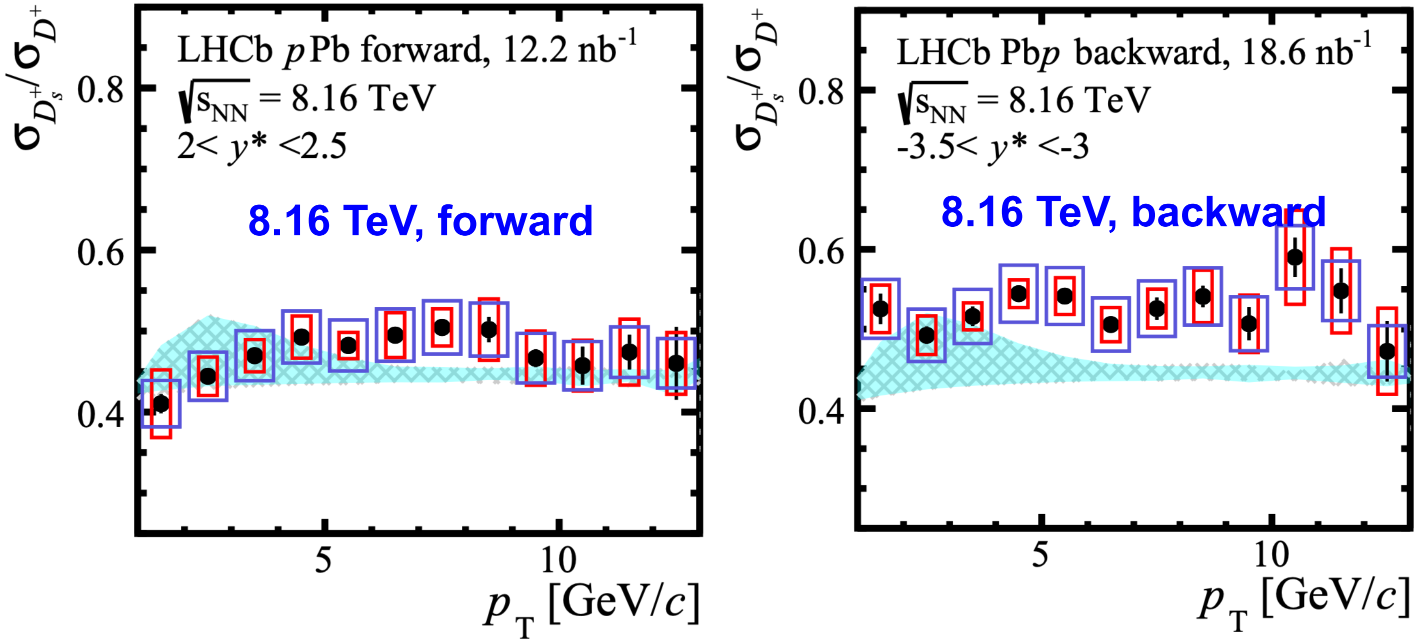


D_s^+/D^+ ratio in pPb at 5.02 and 8.16 TeV

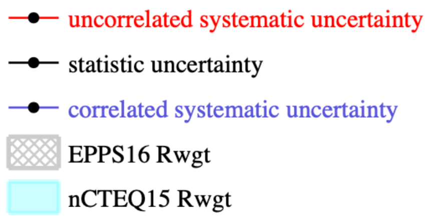
JHEP 01 (2024) 070



- No or minor p_T dependence
- Consistent with LHCb pp measurements within uncertainties
- Consistent with ALICE measurements (at mid-rapidity) with higher precision
- Consistent with theoretical calculations in forward rapidity at 8.16 TeV.

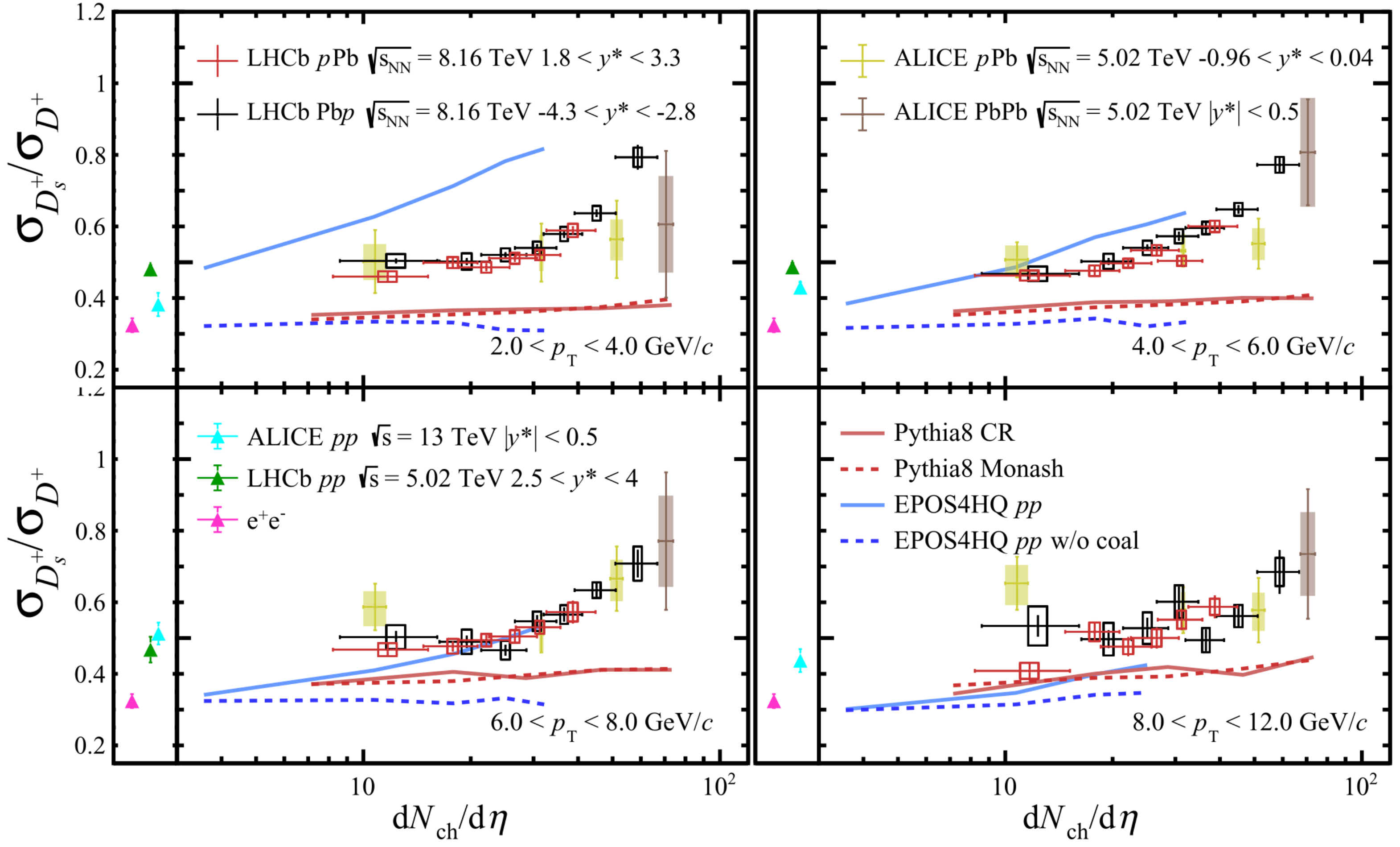


- Slightly higher at backward rapidity than at forward, **multiplicity dependence ?**



Phys. Rev. D 110 (2024) L031105

D_s^+/D^+ ratio vs multiplicity in pPb at 8.16 TeV



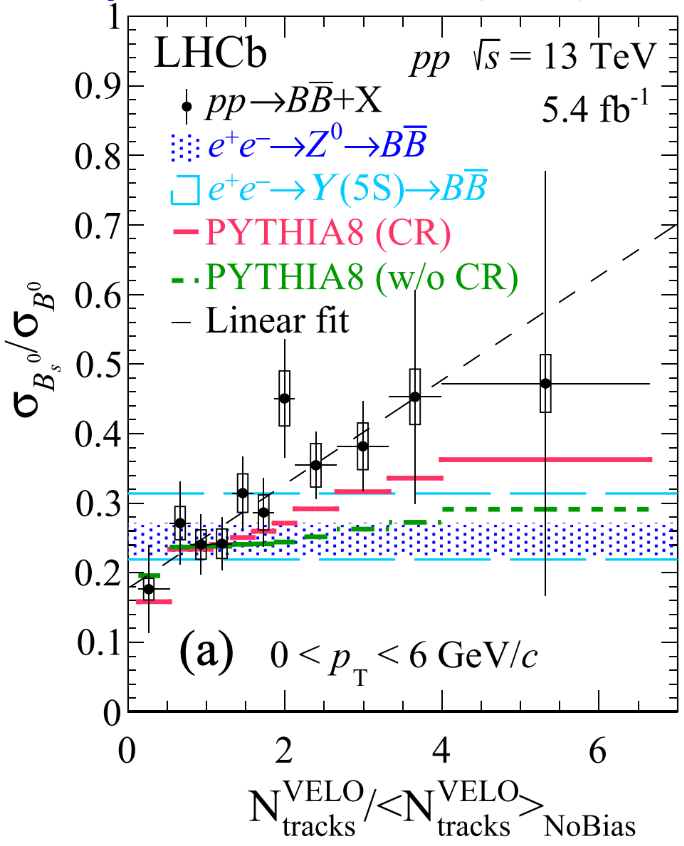
- The ratio increases with multiplicity significantly!
- The enhancement is more pronounced at backward rapidity and lower p_T.
- Modification of charm hadronization/production in high-multiplicity pPb collisions.

Phys. Rev. D 110 (2024) L031105

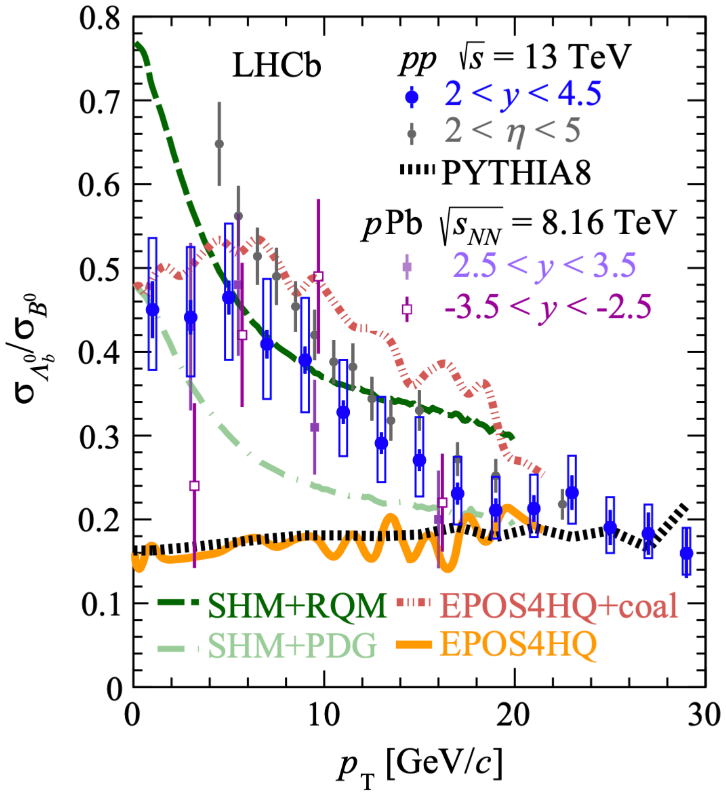
b hadronization in *pp* at 13 TeV

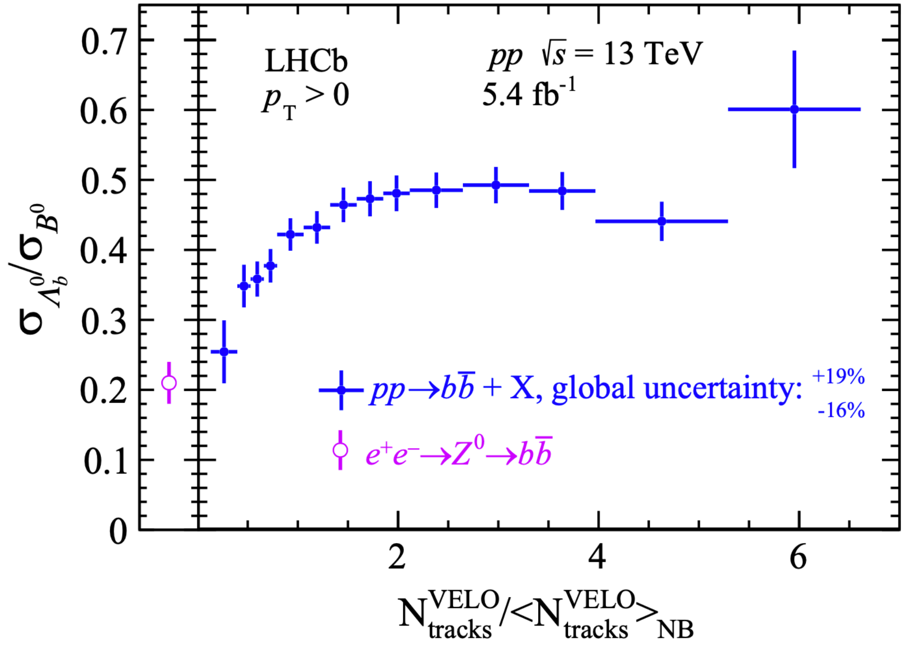
- Evidence of B_s^0/B^0 enhancement (at low p_T) in high multiplicity events
- A strong baryon enhancement of with multiplicity is observed
  - ➢ Ratio recovers e^+e^- value (QCD-vacuum) at low multiplicity
  - ➢ Ratio consistent with e^+e^- at high p_{T}

Phys. Rev. Lett. 131 (2023) 061901

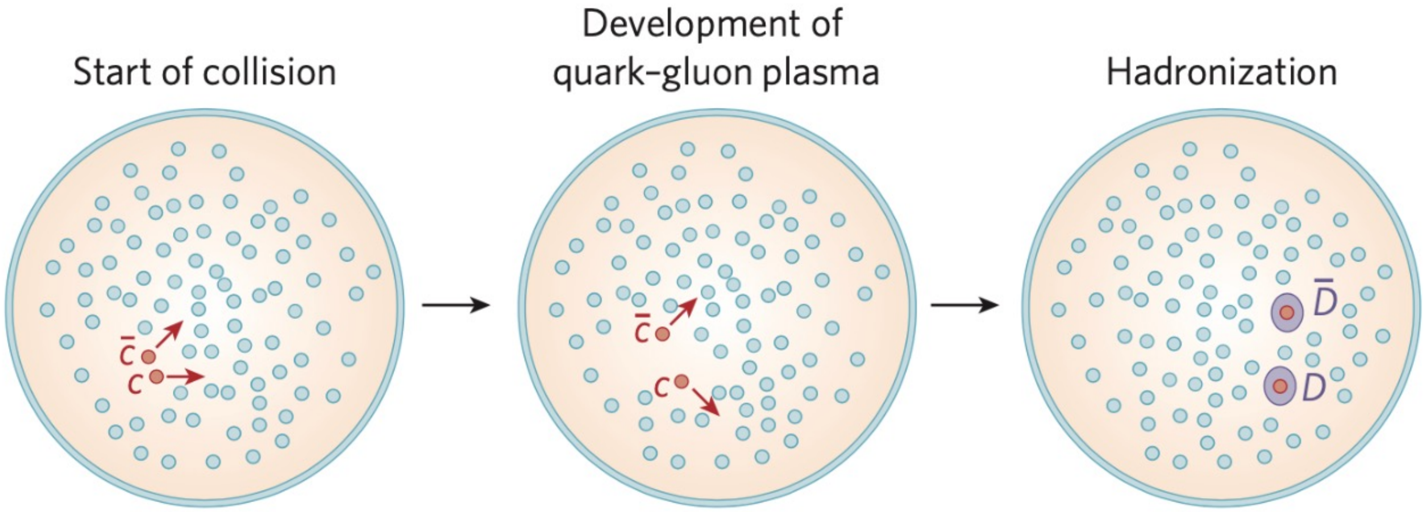


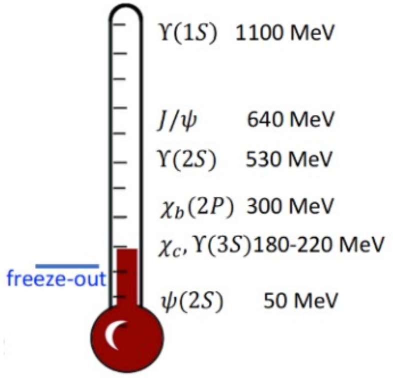
Phys. Rev. Lett. 132 (2024) 081901

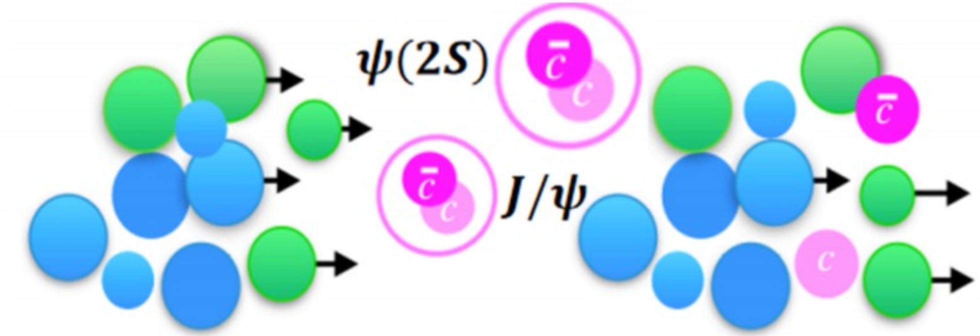




Quarkonia production and dissociation in HIC



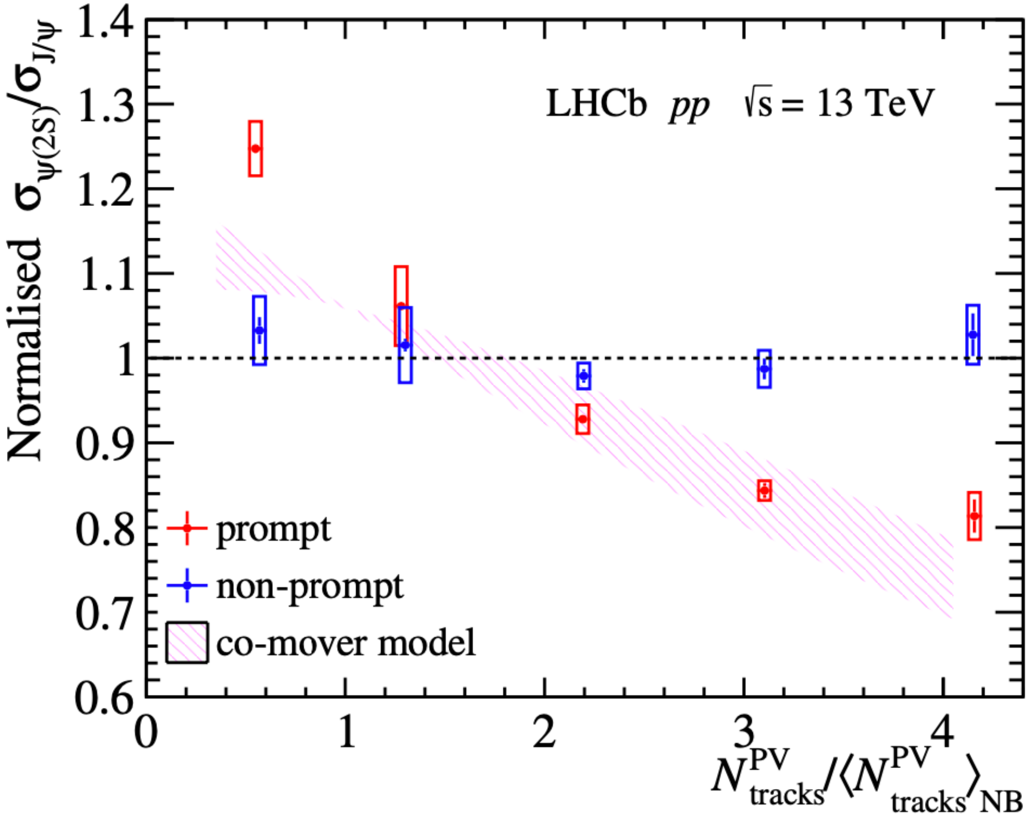


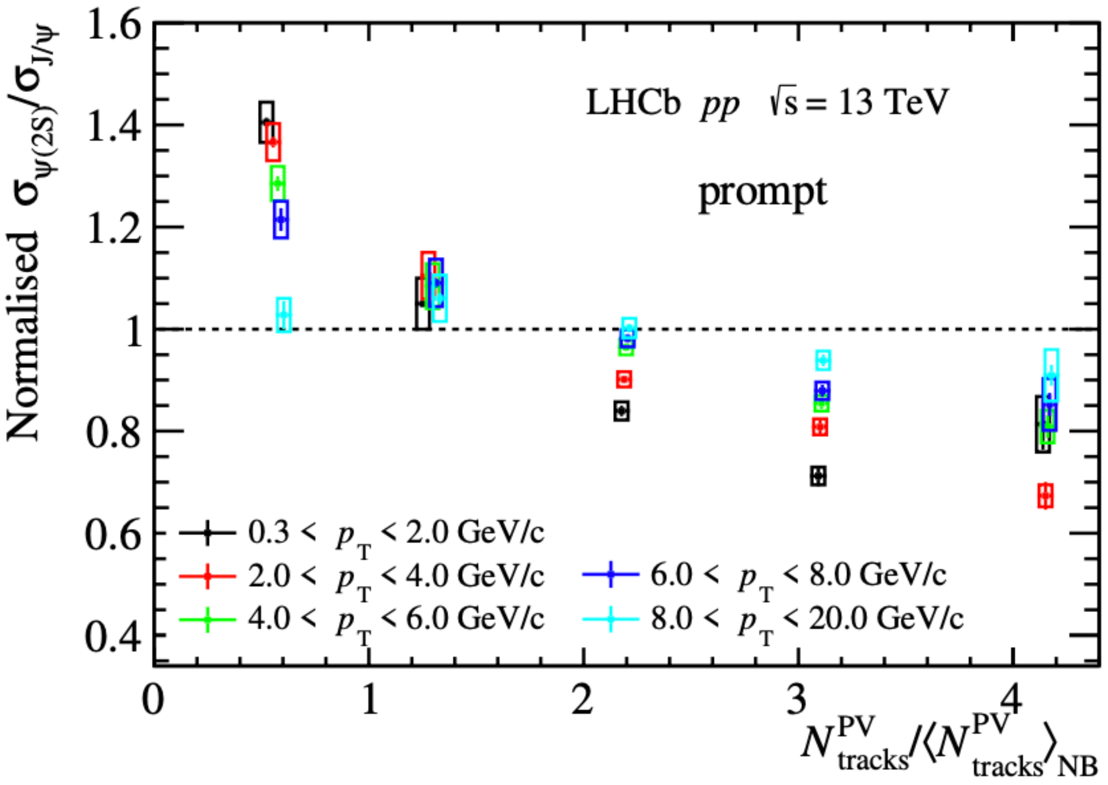


- Color screening in QGP and rescatterings with comoving particles dissociate quarkonia production, **binding energy dependent**
- Probed with production ratios of different quarkonium states

$\psi(2S)$ to J/ψ ratio vs multiplicity in *pp* at 13 TeV

JHEP 05 (2024) 243

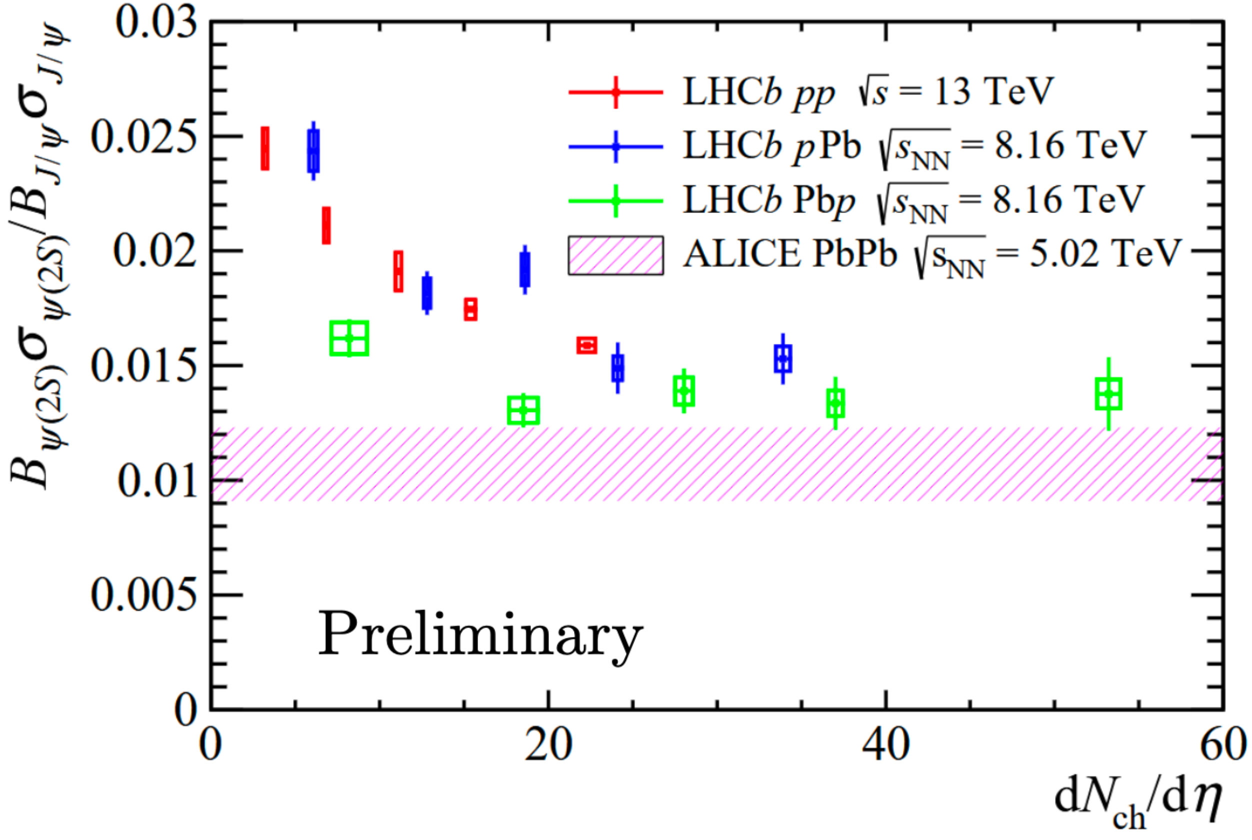




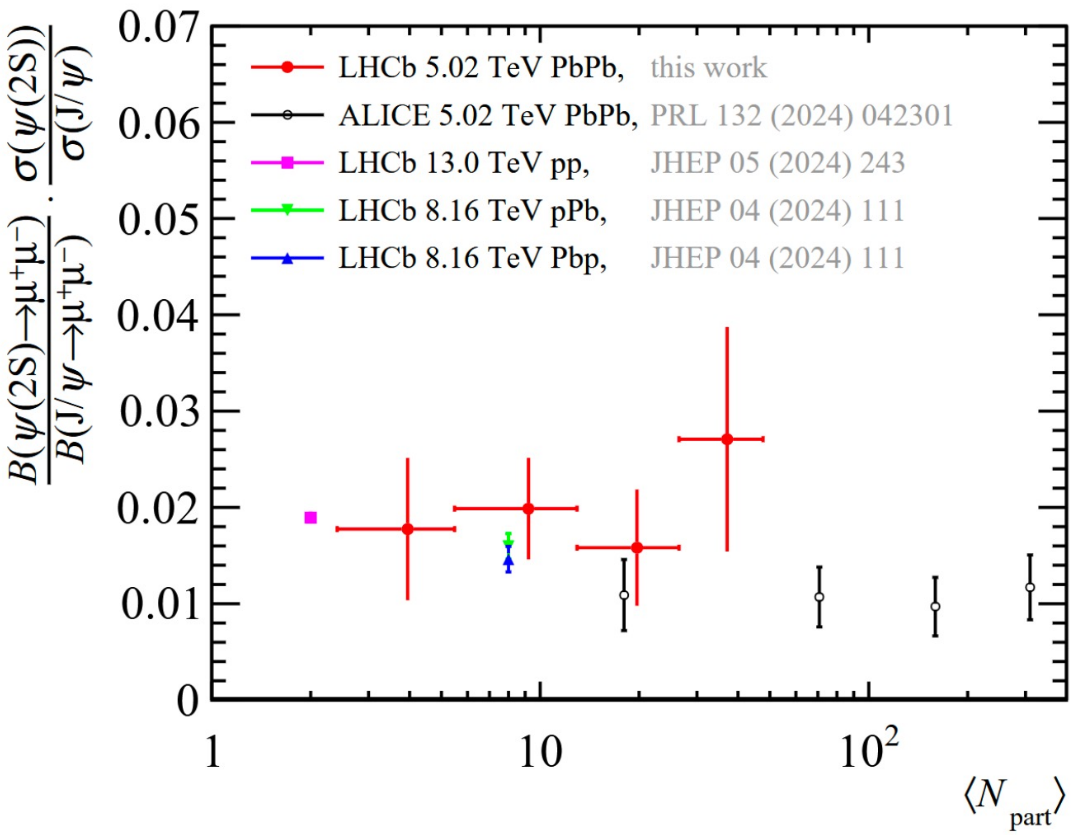
- Decreasing trend vs multiplititicity observed for prompt contributions (in particular for low p_T), consistent with comover interactions

$\psi(2S)$ to J/ψ ratio in pPb and PbPb collisions

LHCb-PAPER-2025-011, in preparation



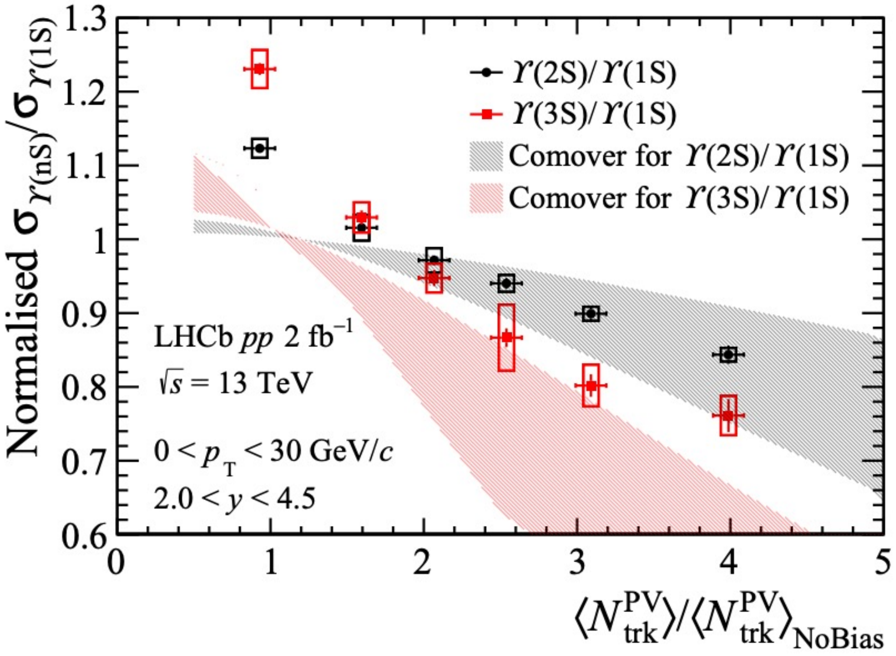
arXiv:2411.05669

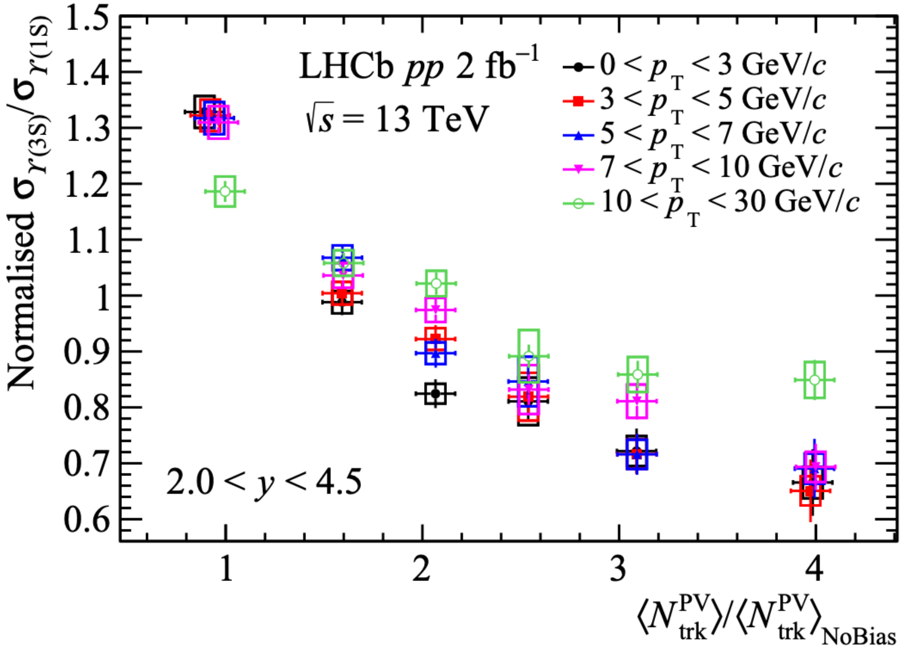


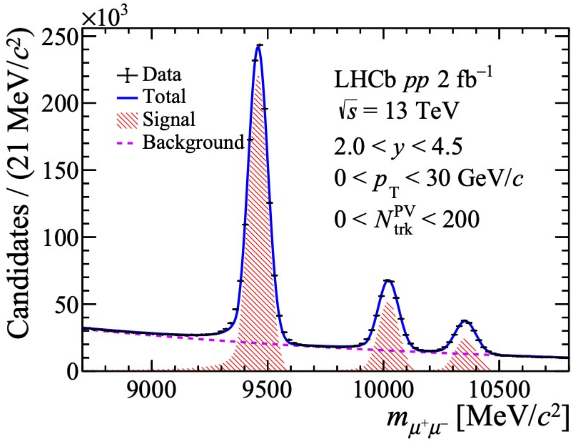
- Stronger suppression in the Pb-going direction, close to PbPb collisions.

$\Upsilon(3S)/\Upsilon(1S)$ and $\Upsilon(2S)/\Upsilon(1S)$ ratios in *pp* at 13 TeV

arXiv:2501.12611





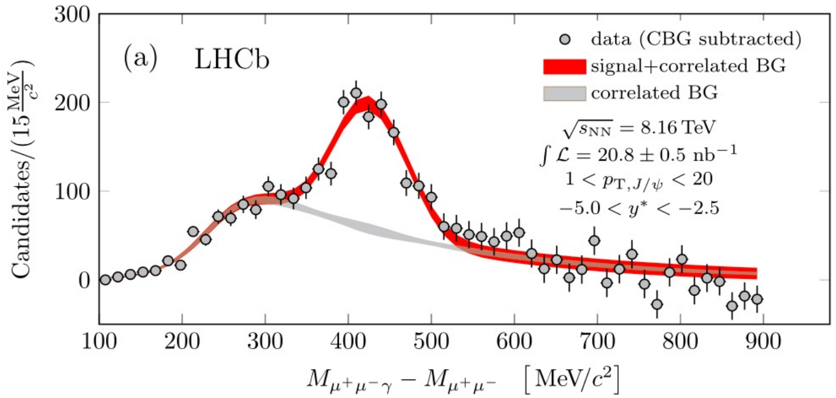


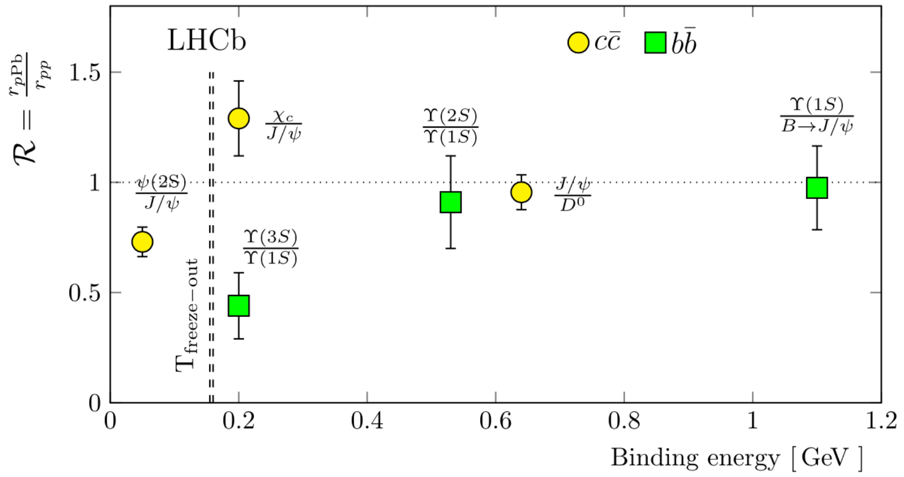
- Sequential suppression pattern observed in high multiplicity events.
- Suppression is more significant for low p_T regions.
- Qualitatively consistent with comover model predictions.

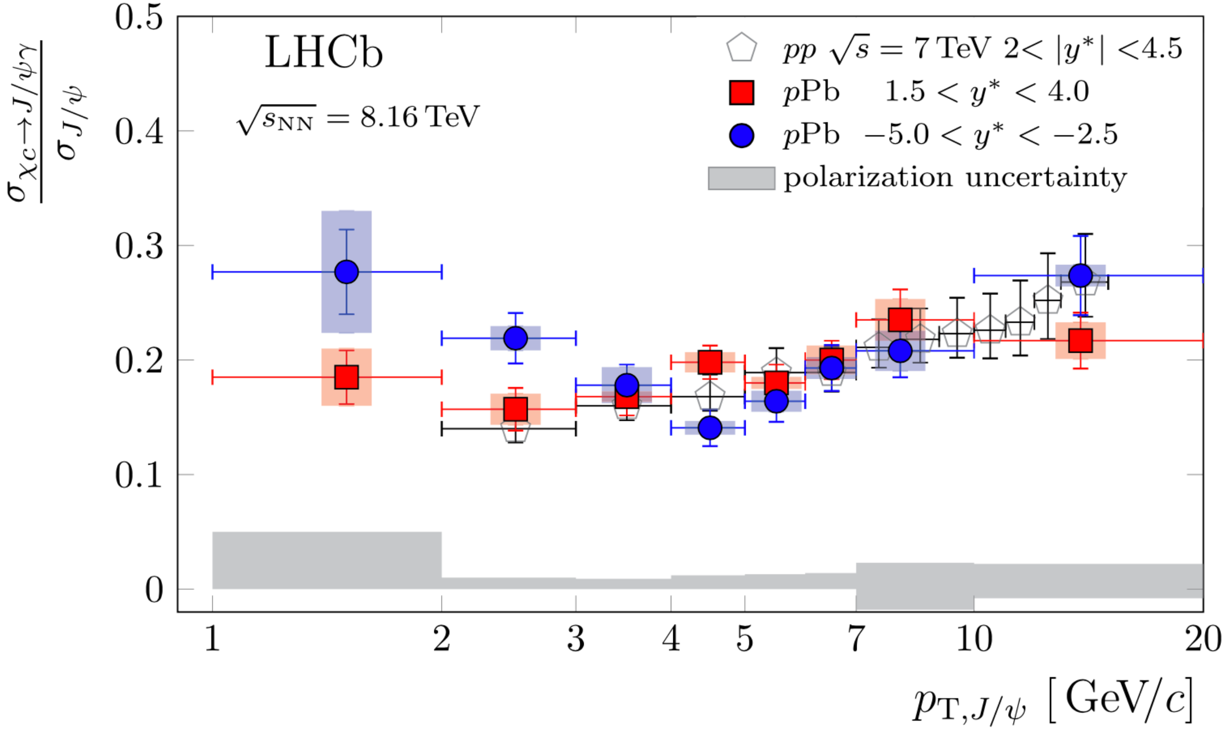
χ_c production in pPb at 8.16 TeV

- First measurement at LHC of $\chi_{c1} + \chi_{c2} \to J/\psi\gamma$ feeddown to J/ψ in pPb
- Data compatible with feeddown from pp at 7 TeV
- No indication of comover break-up for χ_c

Phys. Rev. Lett. 132 (2024) 102302

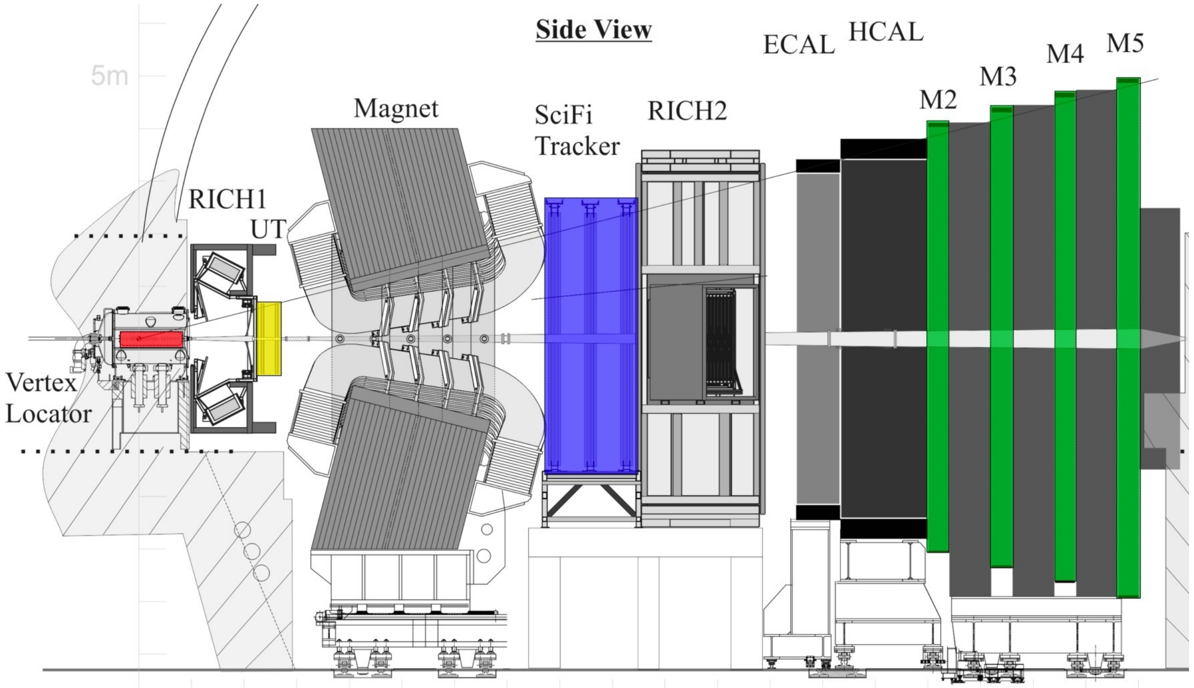




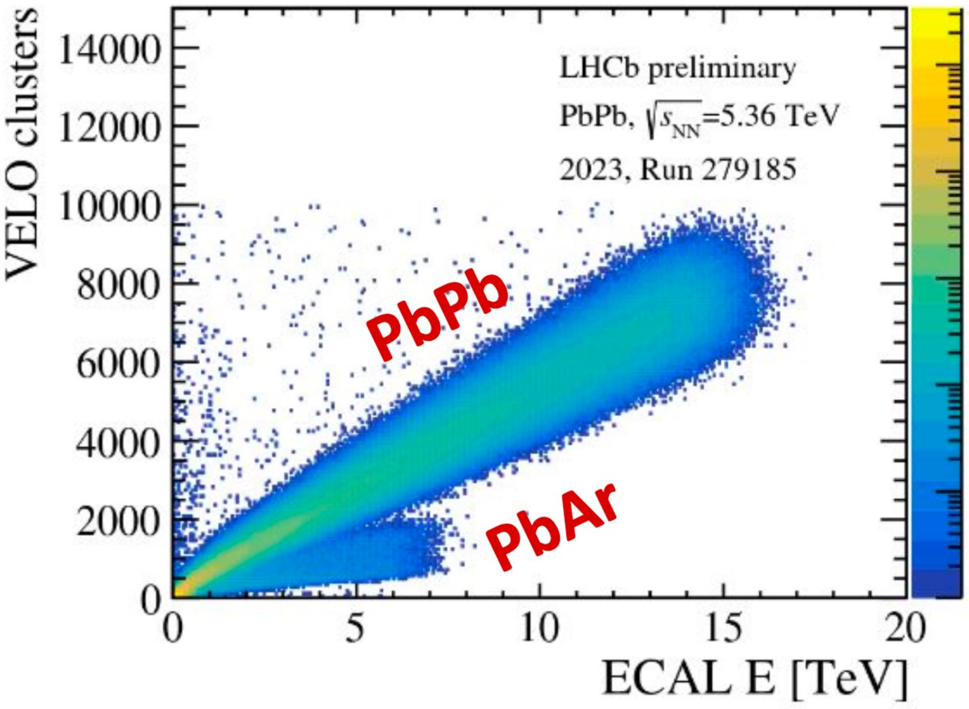


LHCb Upgrade-I installed

- Major upgrade:
  - Replacement of full tracking and RICH1/2 detectors
  - Completely new readout electronics
  - New DAQ & online system at 40 MHz
- New tracking system allows reconstruction up to ~30% most central PbPb collisions



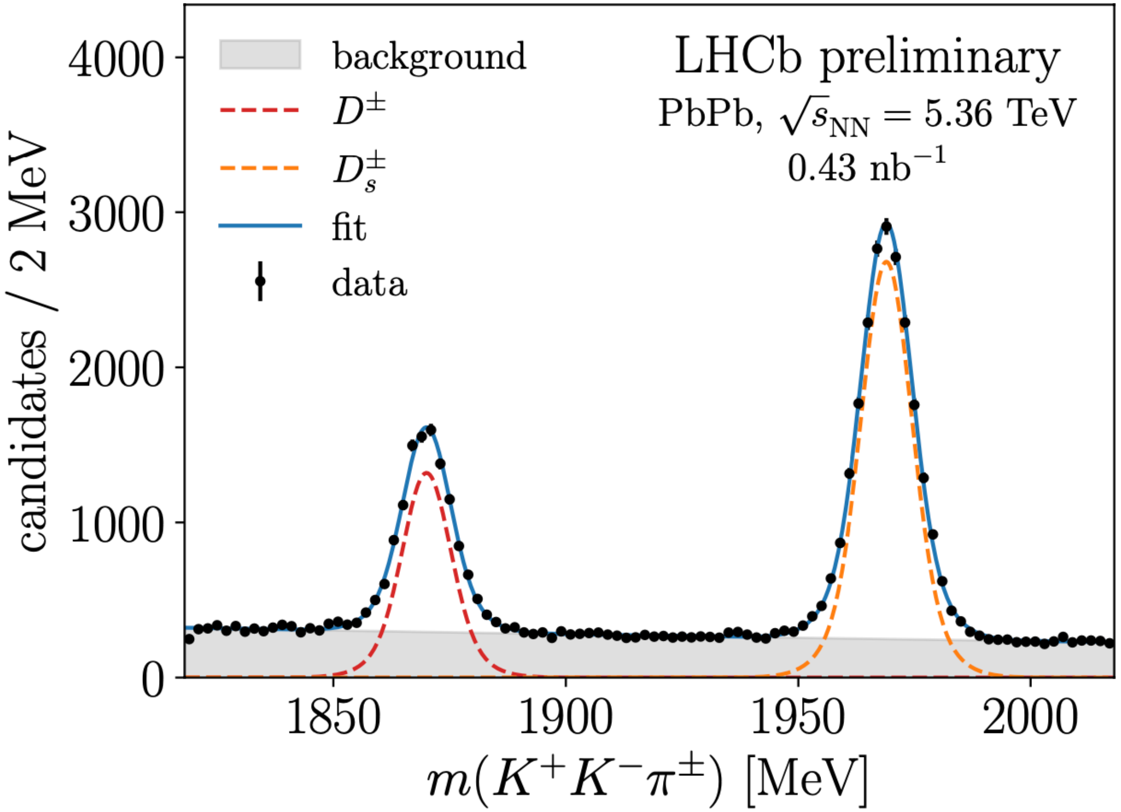
JINST 19 (2024) P05065

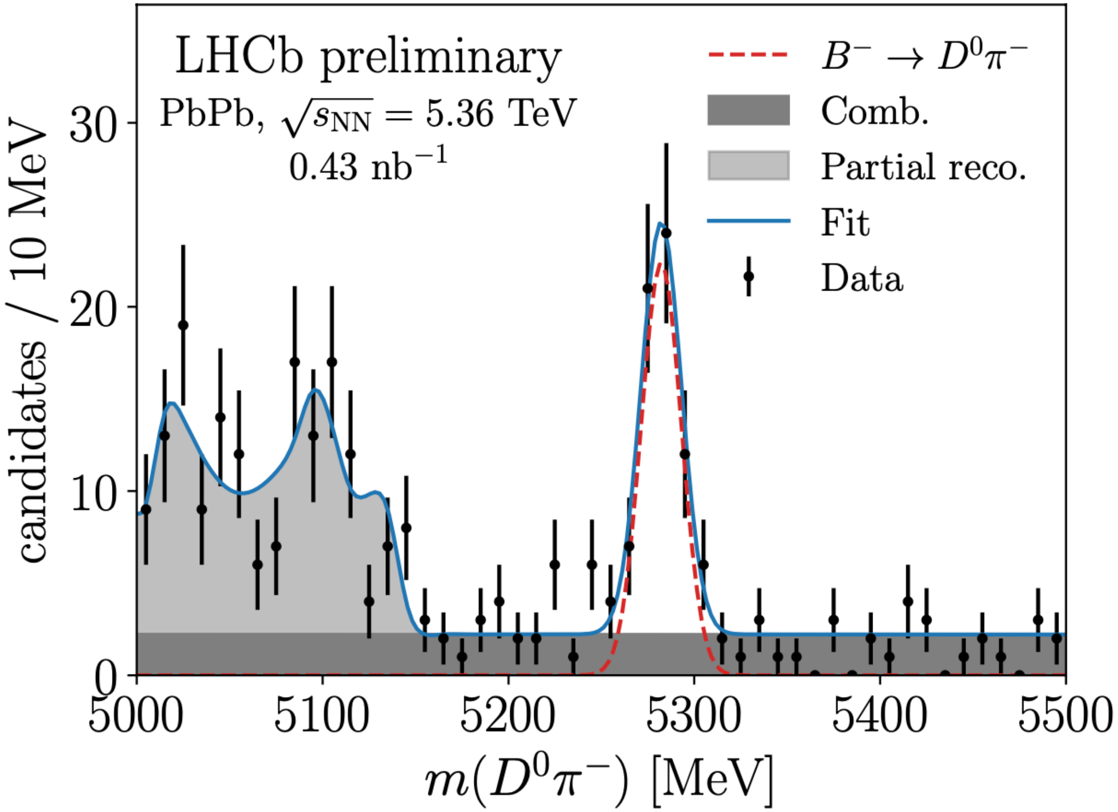


LHCb-FIGURE-2023-030

Early signals from the 2024 PbPb run

LHCb-FIGURE-2025-004

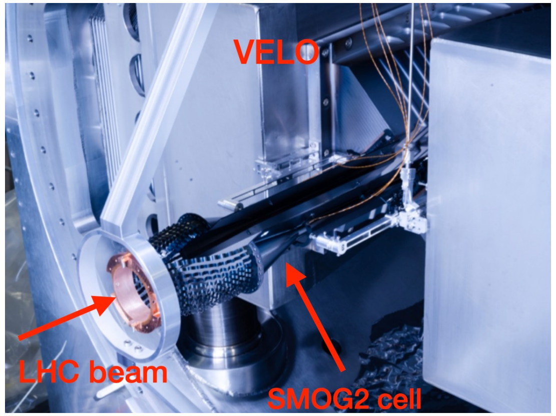




- Clean charm and fully hadronic B decays

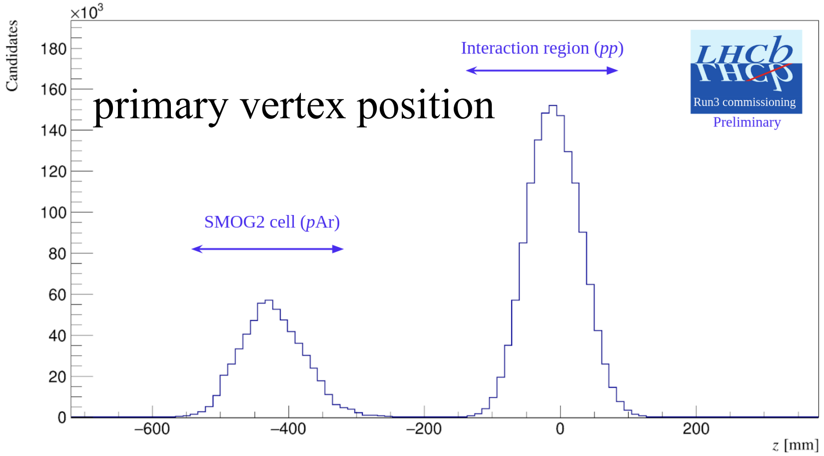
Fixed target upgrade – SMOG2

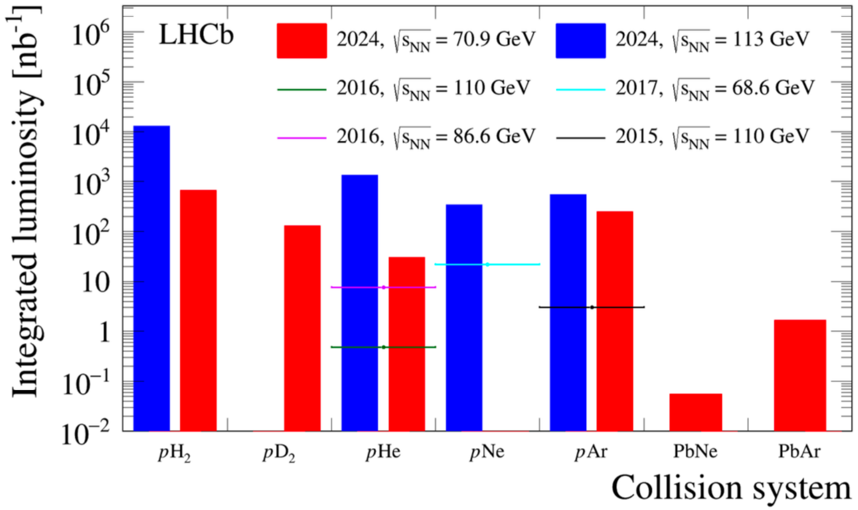
- Dedicated gas storage cell installed
- Greatly increased rates of beam+gas collisions
- Concurrent running with pp collisions
- New gases: H_2, D_2 and large nuclei (Kr, Xe)
- Energies: $\sqrt{s_{NN}} \in [68.5, 110]$ GeV

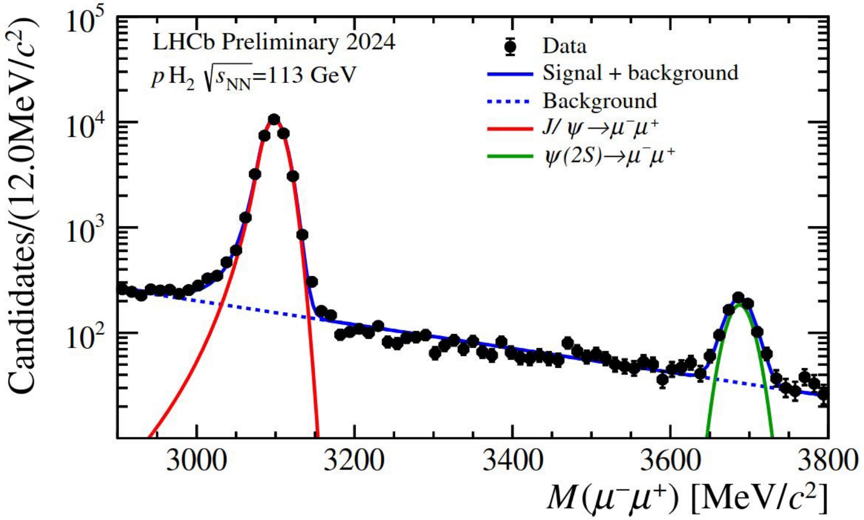


arXiv: 2407.14200

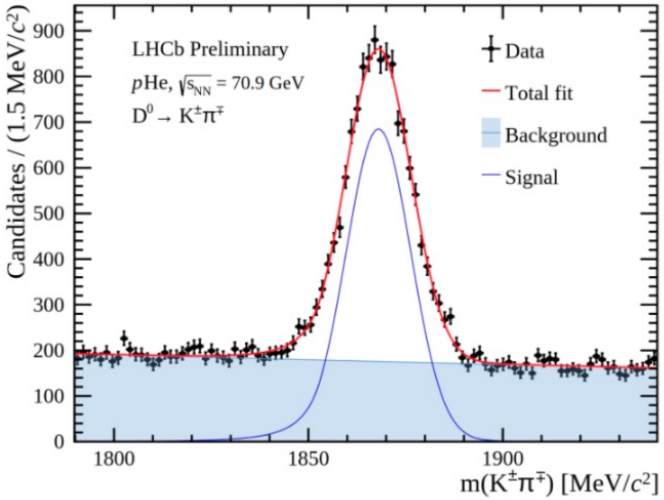
LHCb-FIGURE-2023-001







LHCb-FIGURE-2024-023



LHCb-FIGURE-2025-013

Summary & outlook

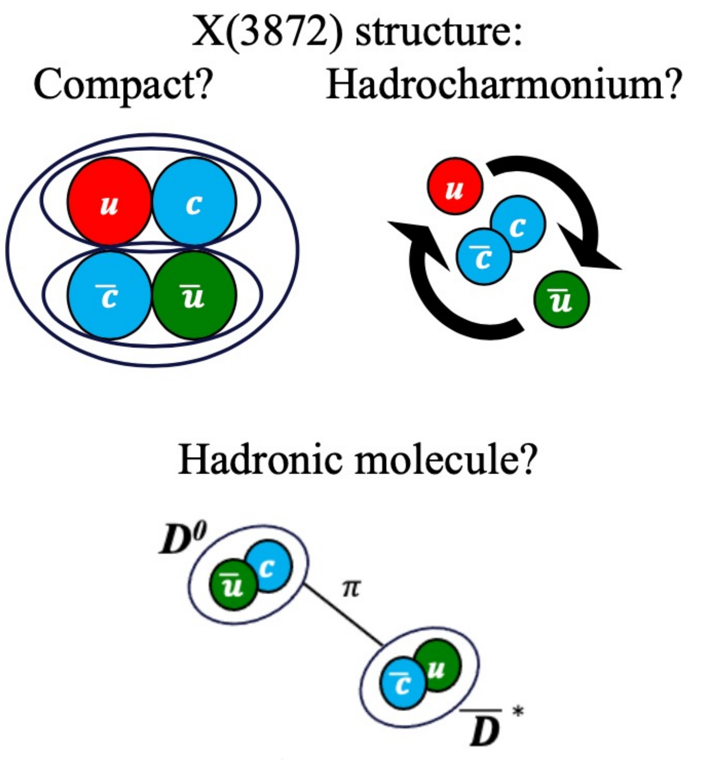
- LHCb has a very diverse heavy-ion and fixed target program, which profits of the variety of datasets
- Provides unique access to heavy flavor probes of nuclear matter
  - Unprecedented access to low-x region of nuclei
  - Modification of hadronization of heavy flavor hadrons
  - Final-state effects in heavy quarkonia production in small system collisions
  - Unique access to higher charmonia and exotics at low p_T
- Started to exploit the Upgrade I detector, i.e. semi-central PbPb collisions and high-statistics pA and PbA datasets at a unique energy scale

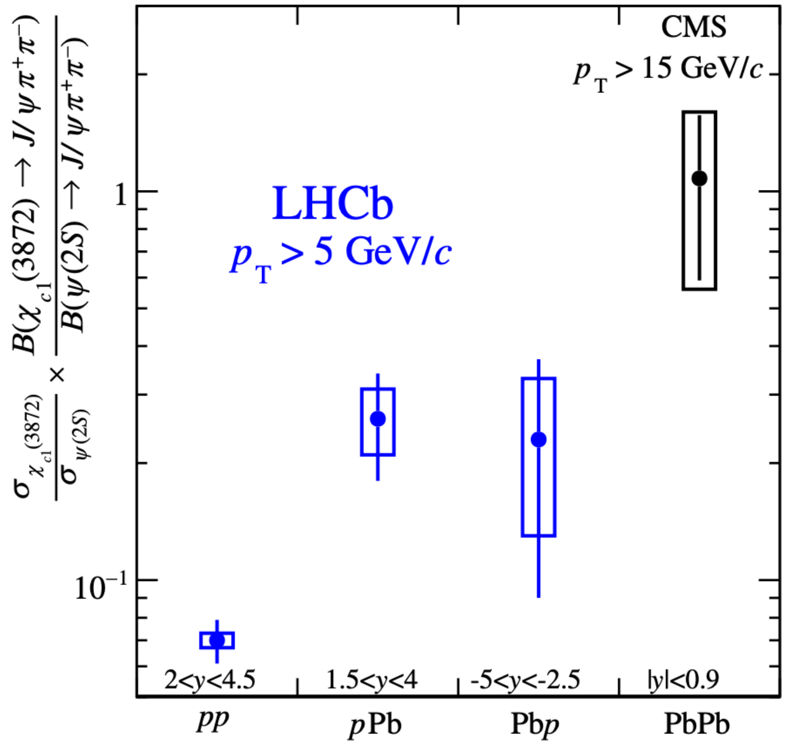
backup

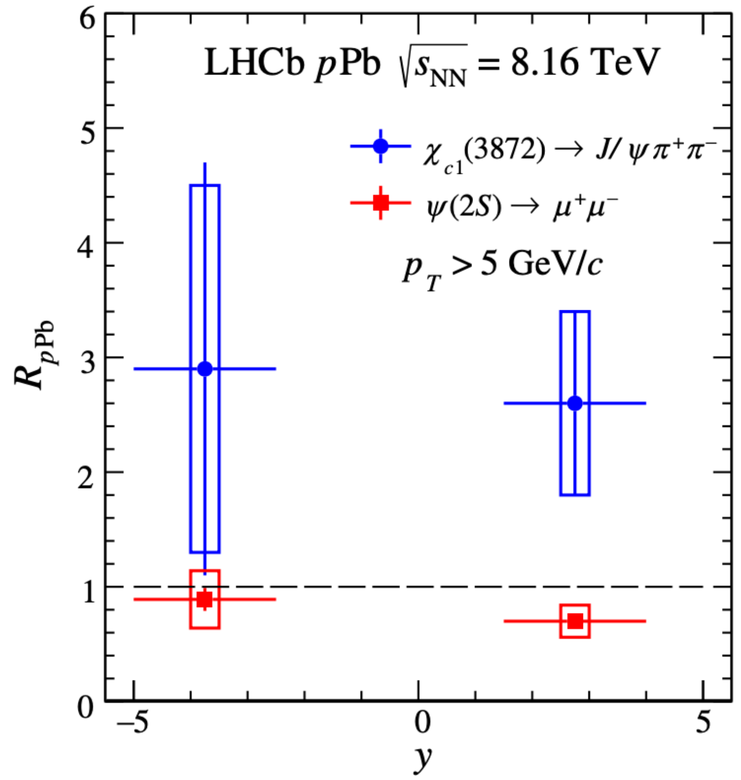
Modification of X(3872) in *p*Pb

- LHCb can uniquely reconstruct exotic hadrons at low p_T
- Exotic multiquark states can give new constraints on hadronization models

Phys.Rev.Lett.132 (2024) 242301



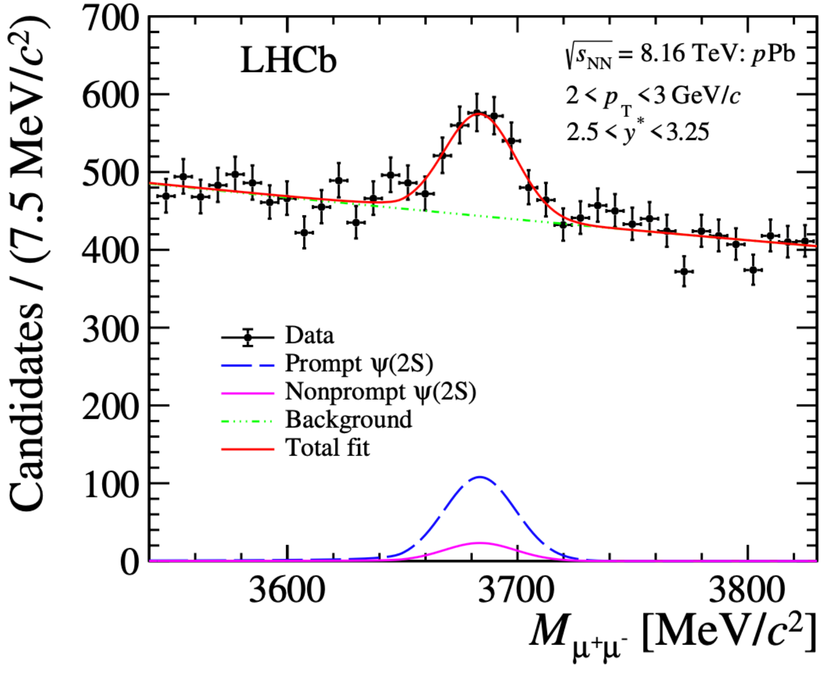


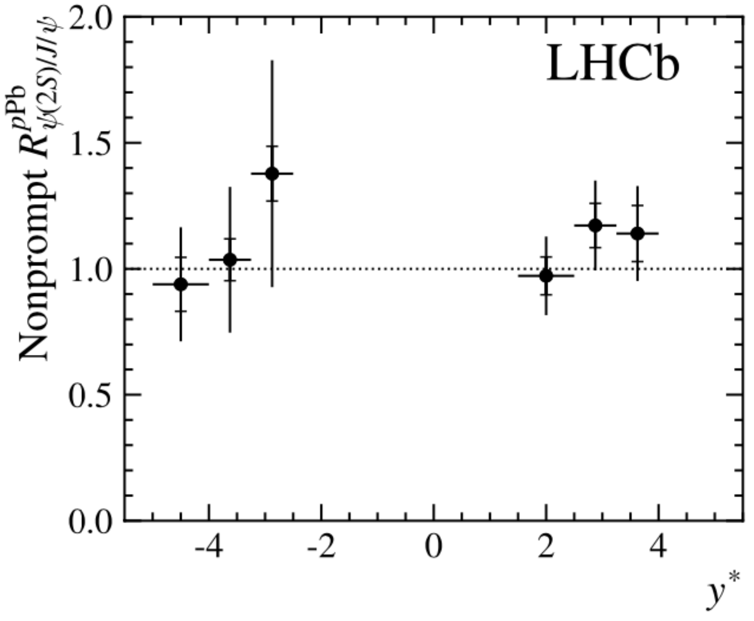


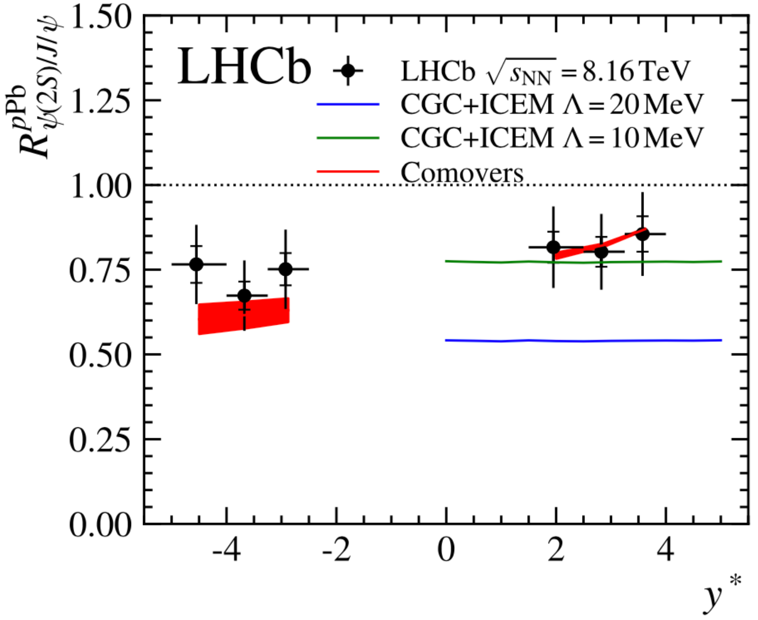
First measurement of nuclear modification factor of an exotic hadron
Different from expectations based on conventional charmonia

$\psi(2S)$ to J/ψ ratio in pPb at 8.16 TeV

- New $\psi(2S)$ precise result with 20 times larger dataset than Run1 (5.02 TeV)
- Nonprompt: compatible with unity
- Prompt: additional suppression of $\psi(2S)$, compatible with comover break-up model







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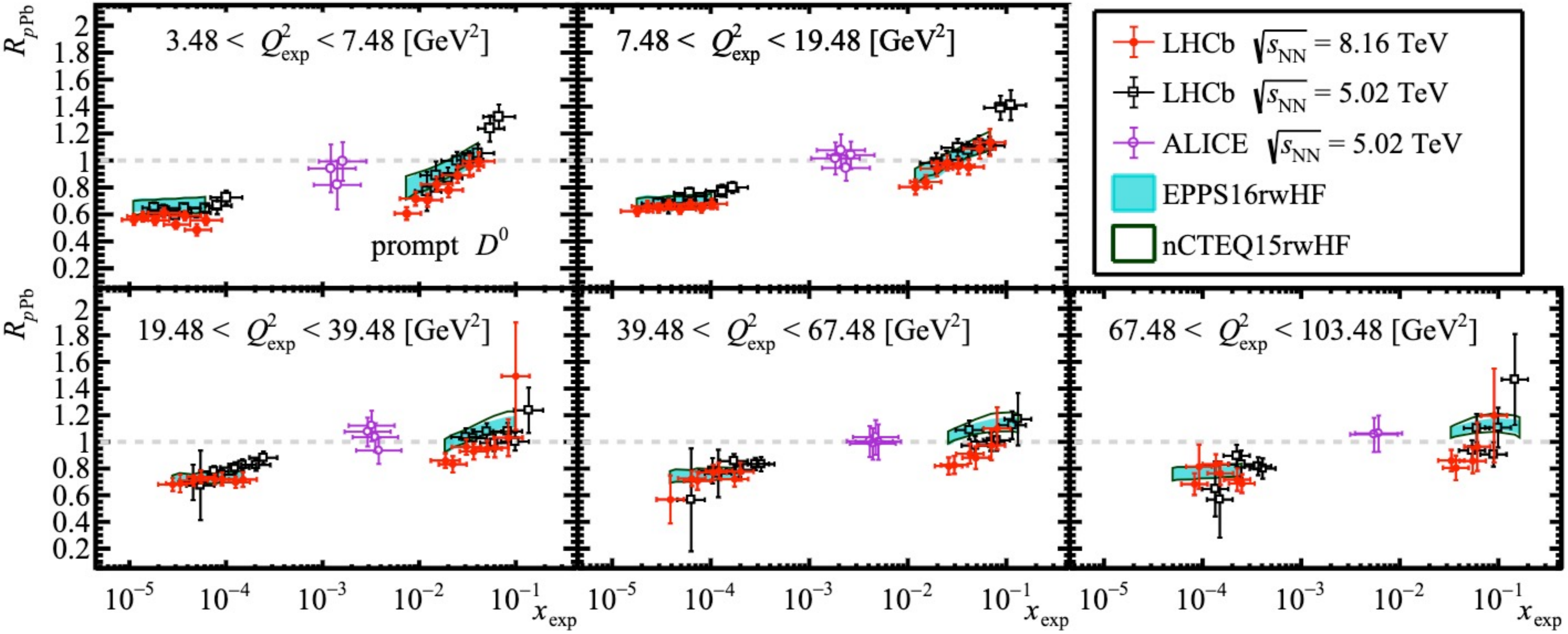
$$R_{\psi(2S)/J/\psi} = \frac{\sigma_{\psi(2S)}/\sigma_{J/\psi}|_{p\mathrm{Pb}}}{\sigma_{\psi(2S)}/\sigma_{J/\psi}|_{pp}}$$



$$x_{\text{exp}} \equiv 2\frac{\sqrt{p_{\text{T}}^2(D^0) + M^2(D^0)}}{\sqrt{s_{\text{NN}}}}e^{-y^*} \text{ and } Q^2_{\text{exp}} \equiv p_{\text{T}}^2(D^0) + M^2(D^0),$$

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