LHCb实验小系统碰撞中重味测量新进展

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清华大学

2024.4.14

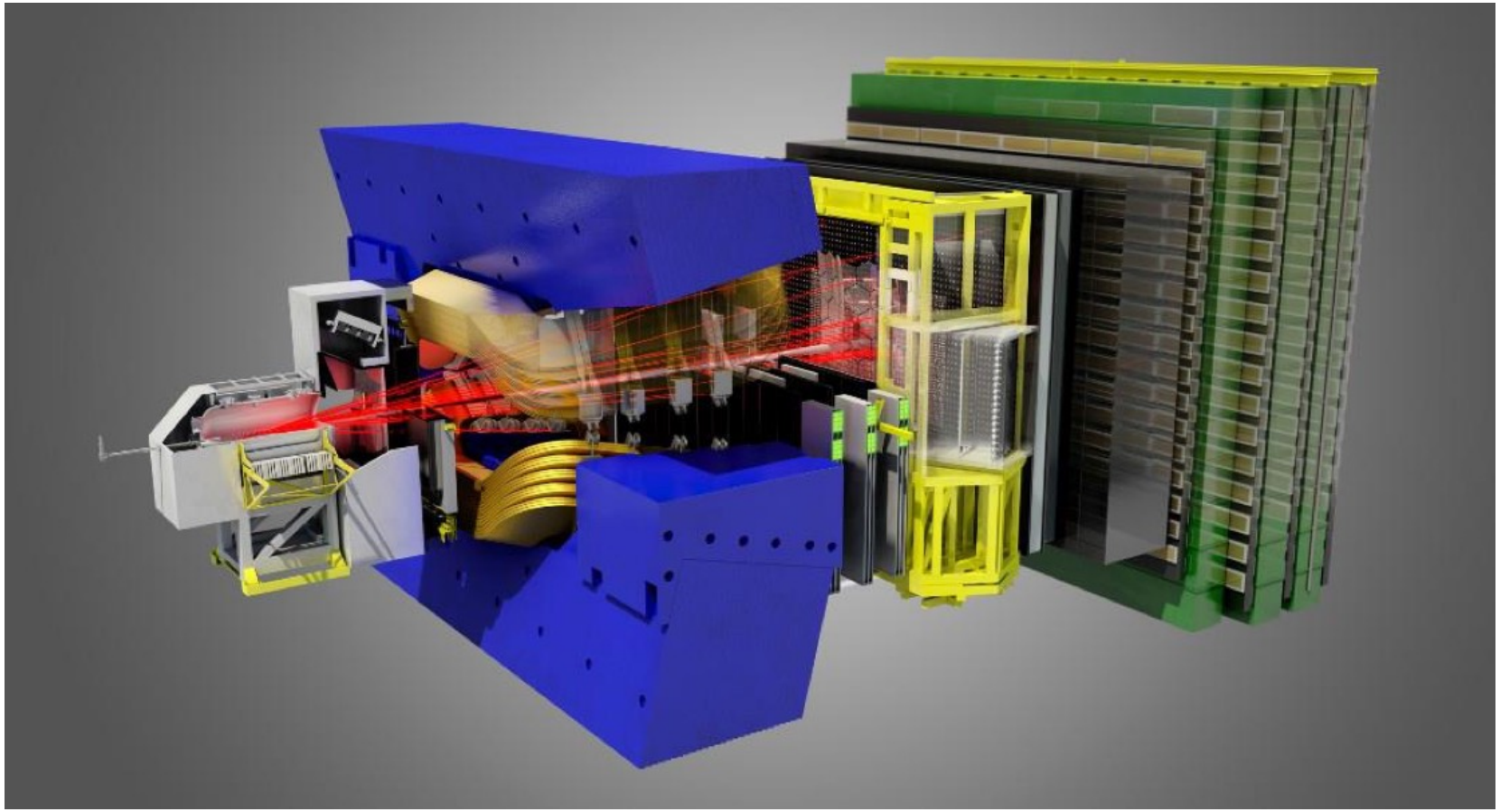
第二届超边缘碰撞物理研讨会
合肥，2024年4月12-15日

The LHCb detector

A single arm **general purpose detector** at **forward** rapidity !

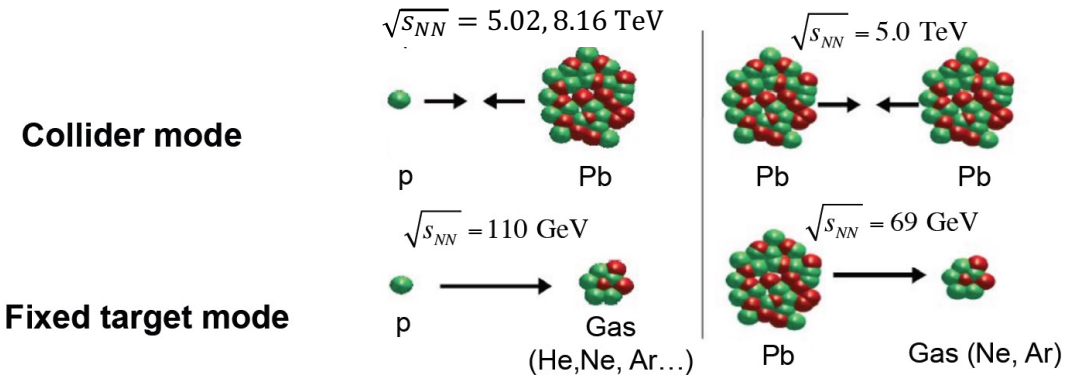
acceptance $2 < \eta < 5$

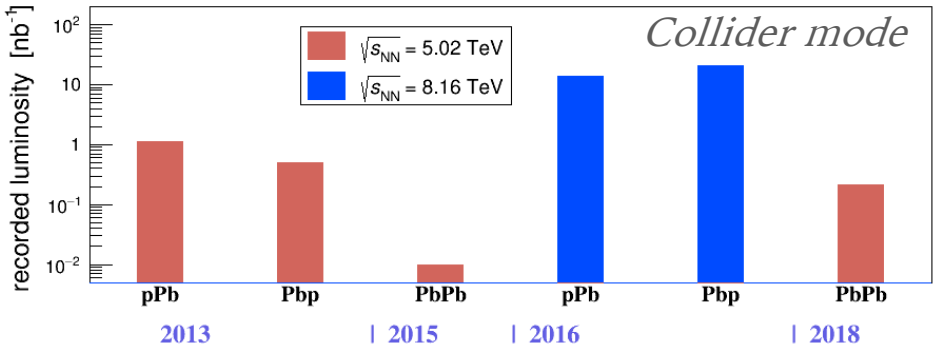
- **Full PID**
  reconstruct resonances to $p_T = 0$
- **Precise tracking system**
  clear separation between primary and displaced vertices
- **Fast DAQ and detectors**
  precision access to rare probes: charm/bottom, higher quarkonia, exotic states
- **Fixed-target system (SMOG)**
  explore p+gas and Pb+gas collisions (He, Ne, Ar gas)

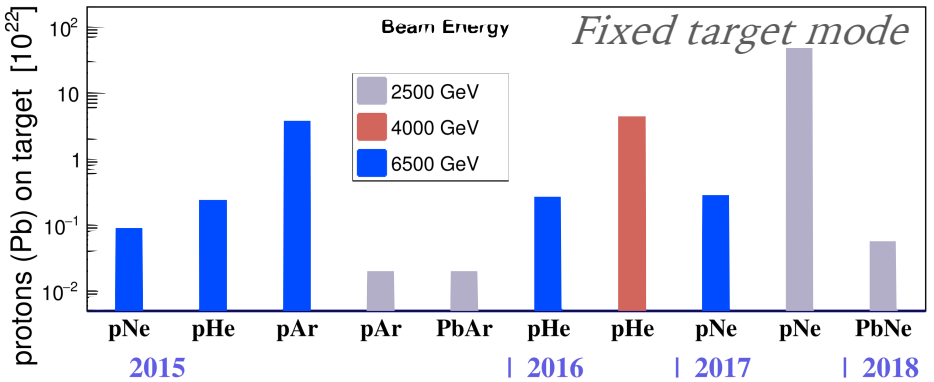


JINST 3 (2008) S08005
IJMPA 30 (2015) 1530022
JINST 9 (2014) P12005

LHCb heavy ion datasets from Run1/Run2



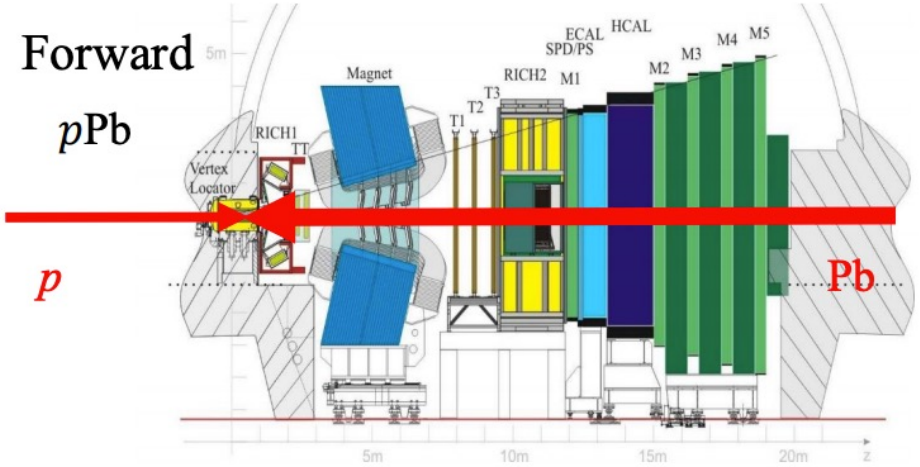




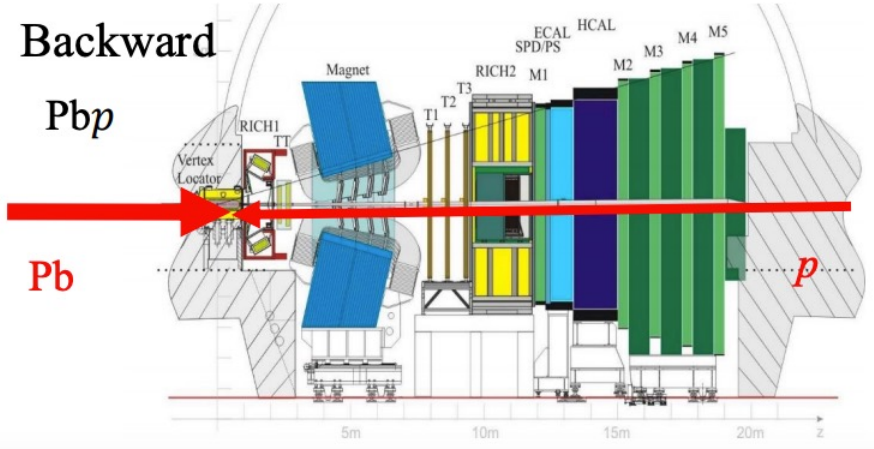
PbPb:
limited to 100-60% centrality

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

*p*Pb data-taking modes:

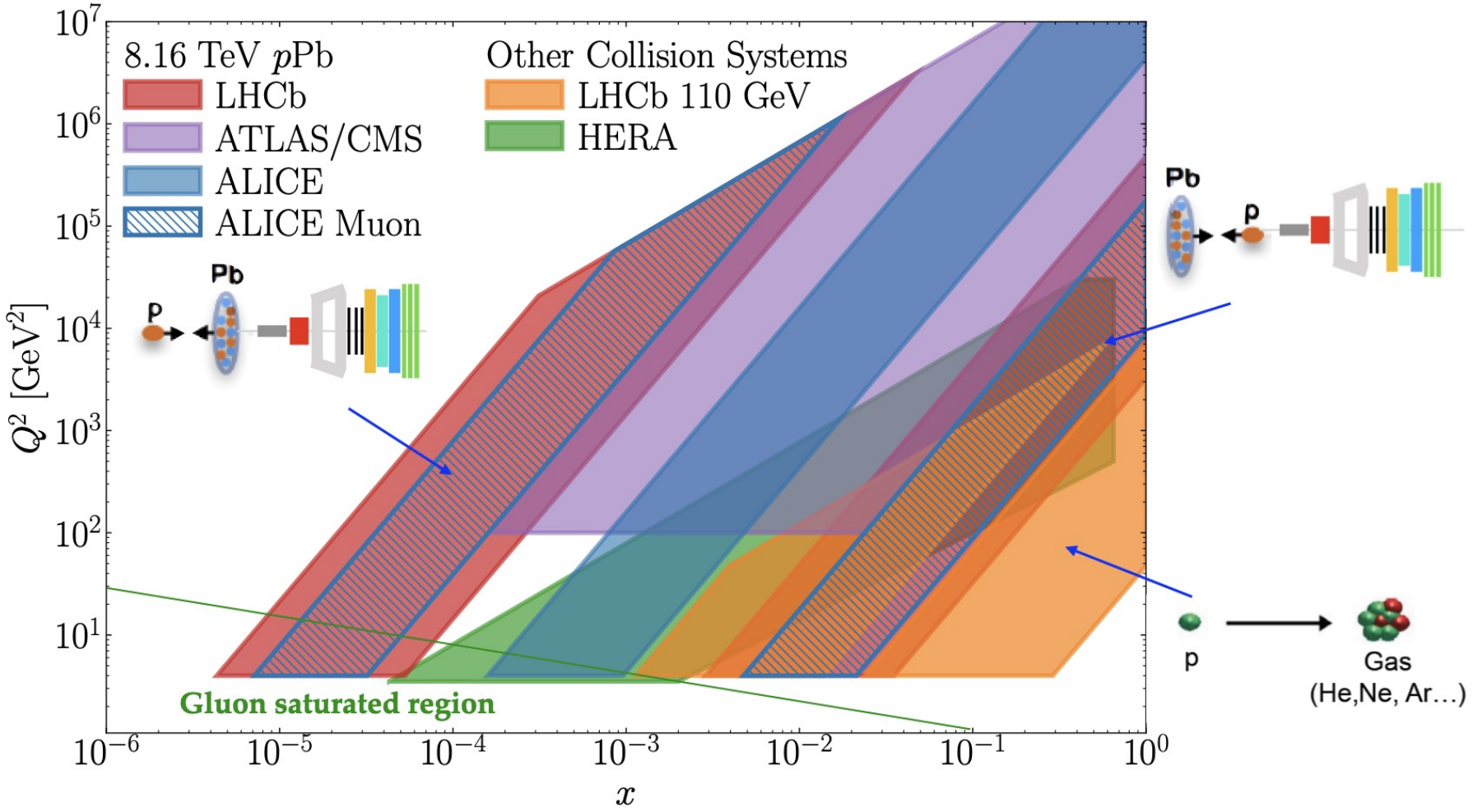


$1.5 < y < 4.0$



$-5.0 < y < -2.5$

Mapping the initial state with LHCb



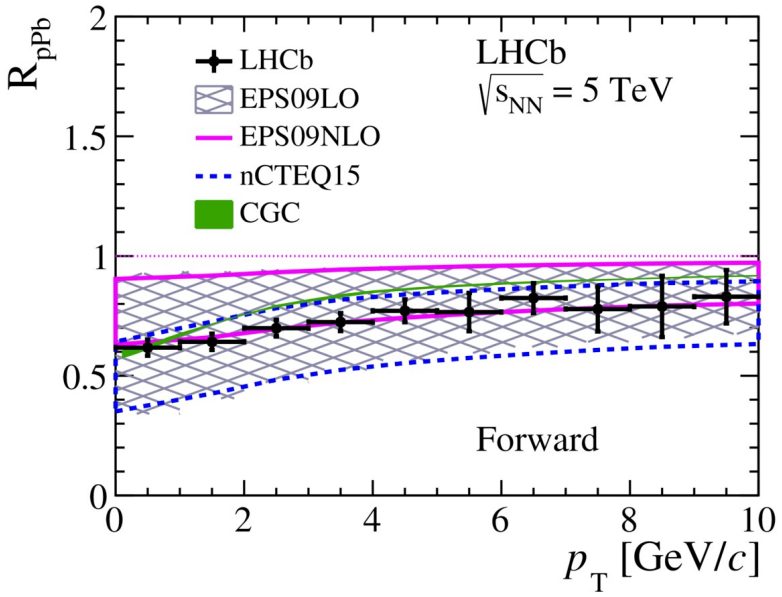
Unique coverage of low-x (pPb), medium-x (Pbp) and large-x (p+gas) regions

Constraining nPDFs with D^0 meson in pPb

- LHCb measurement of prompt D^0 production in pPb collisions at 5TeV makes a stringent constraint on reducing nPDFs uncertainty down to $x \sim 10^{-6}$

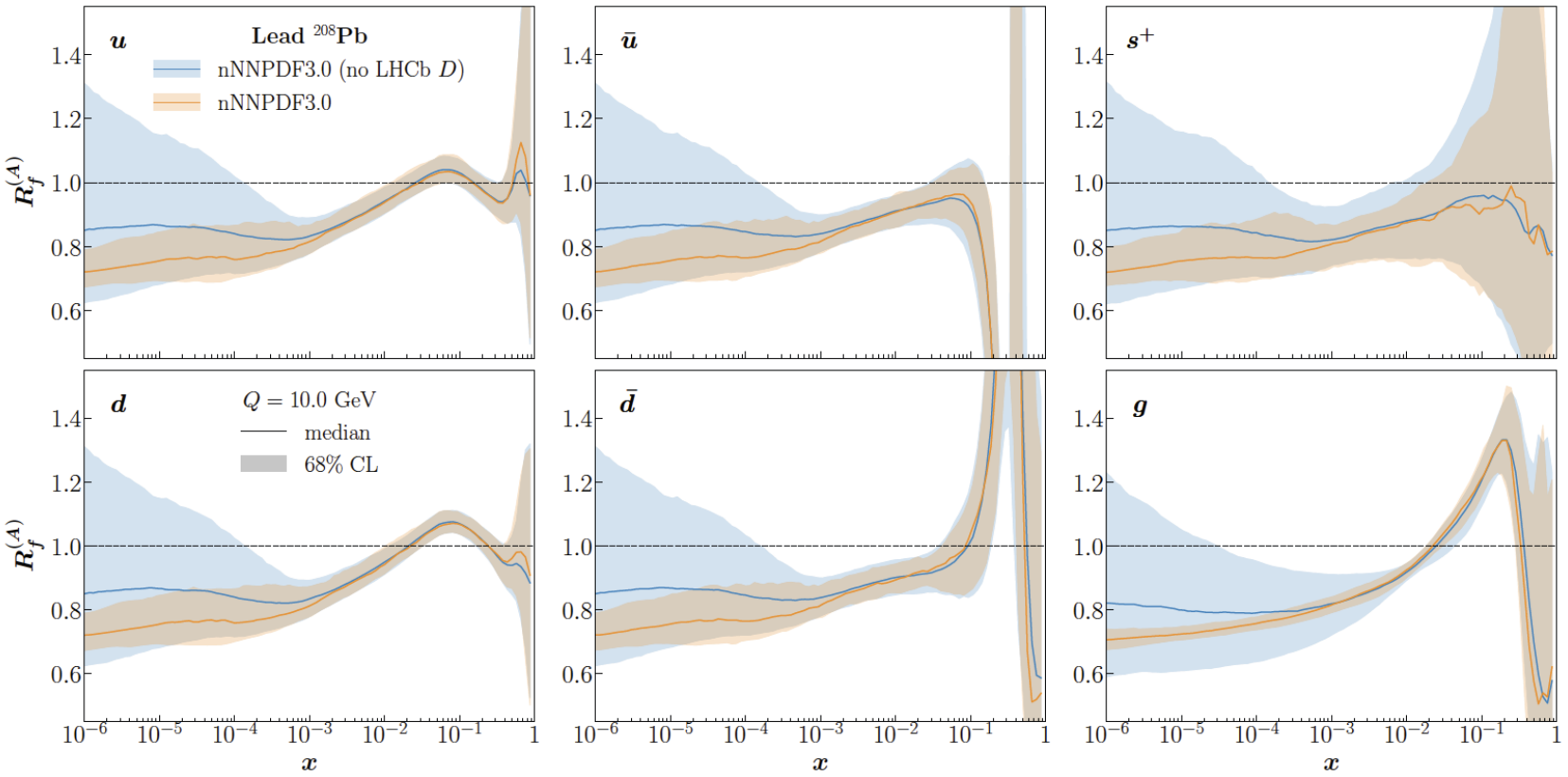
北大，张艳席

JHEP 10 (2017) 090



$$R_{pPb} = \frac{\sigma_{pPb}}{A\sigma_{pp}}$$

nNNPDF3.0, Eur. Phys. J. C 82 (2022) 507



Prompt D_s^+ and D^+ in pPb at 5.02 TeV

- First measurement of prompt D_s^+ and D^+ mesons in forward rapidity in heavy ion collisions
- Forward:
  - significant suppression consistent with nPDFs/CGC
  - consistent between D^0, D_s^+ and D^+
- Backward:
  - consistent with nPDFs
  - D^+ slightly lower

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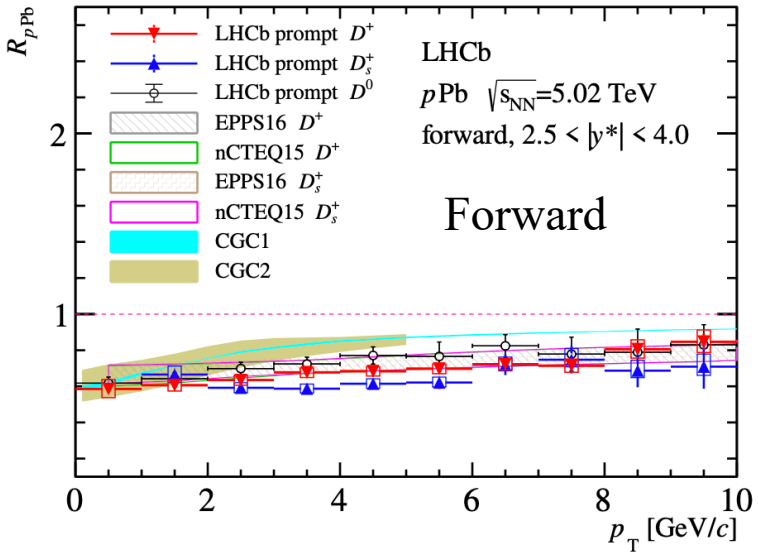
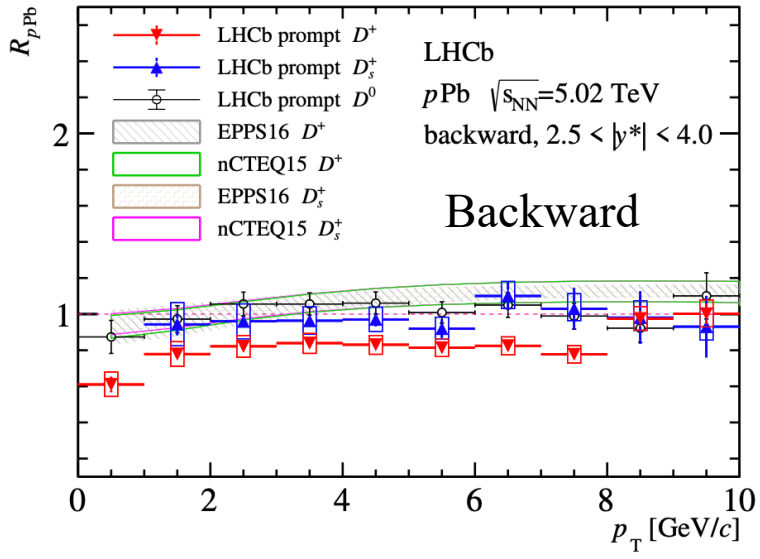
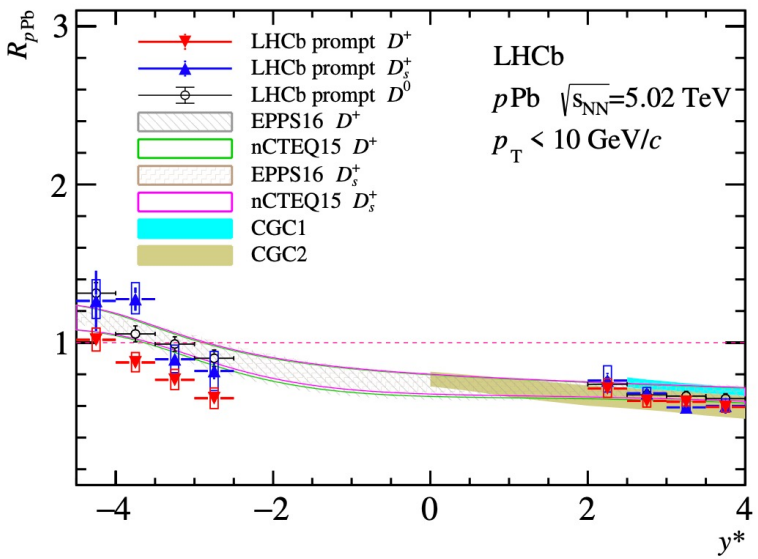
INFN，孙佳音

JHEP 01 (2024) 070







Prompt D^0 in pPb at 8.16 TeV

- 20 times statistics of 5.02 TeV, the most precise charm measurement in heavy ion
- Forward:
  - Suppression consistent with 5.02 TeV result
  - Consistent with nPDFs and CGC
- Backward:
  - Data lower than nPDFs at high p_T
  - Room for additional effects in the backward rapidity

Phys. Rev. Lett. 131 (2023) 102301

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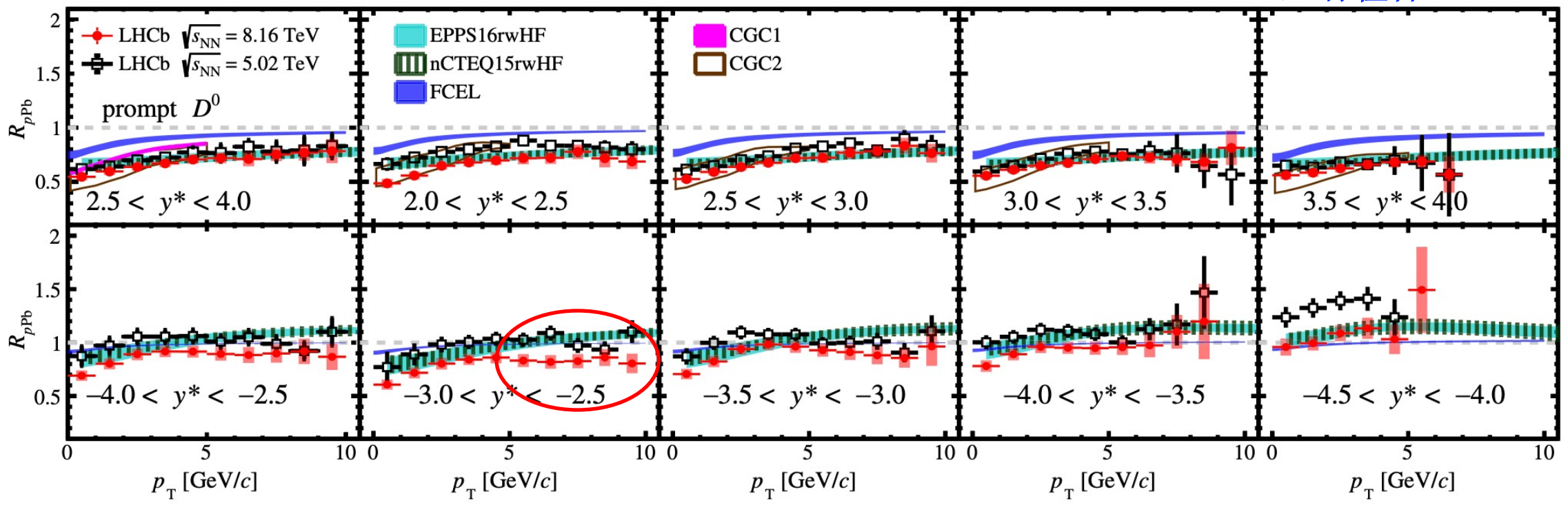
Forward

Backward



Prompt D^0 in pPb at 8.16 TeV

- Lower than binary scaling at high p_T for a backward rapidity range where anti-shadowing effect starts to dominate
  - ➢ Modification of charm hadronization? or other final state effect?

Phys. Rev. Lett. 131 (2023) 102301

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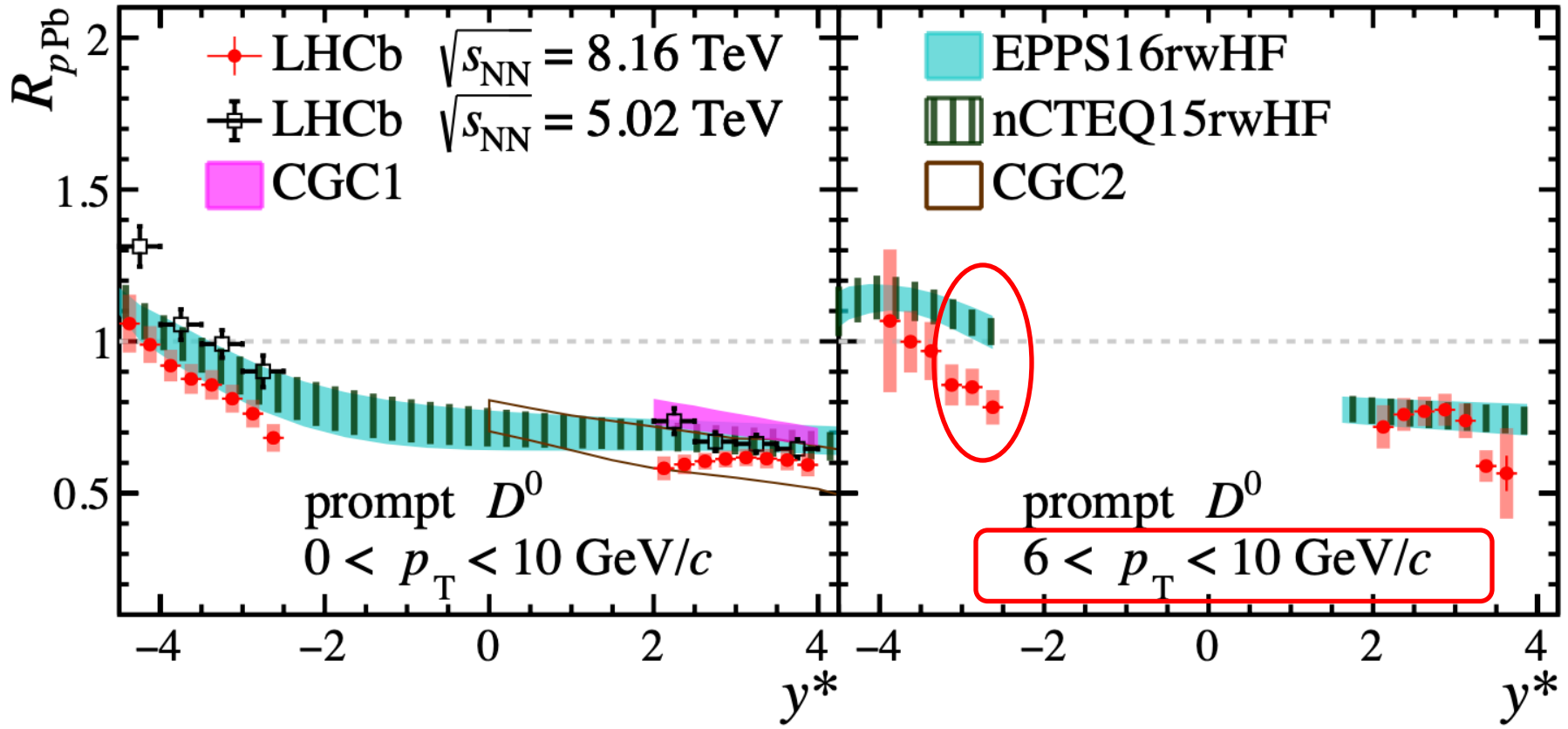

Prompt D_s^+ and D^+ in pPb at 8.16 TeV

- Measured with the same Run2 dataset
  - ➢ Forward: consistent with nPDFs/CGC
  - ➢ Backward: both lower than nPDFs at high p_T

Charm energy loss in (nuclear/parton-) medium before hadronization ?

Need to measure charmed hadrons flow versus rapidity !

arXiv:2311.08490

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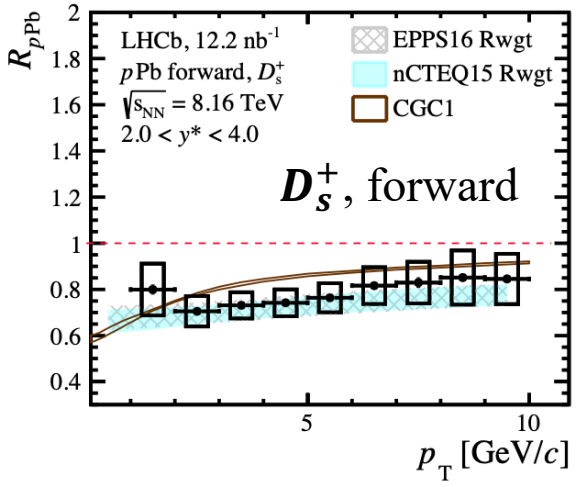
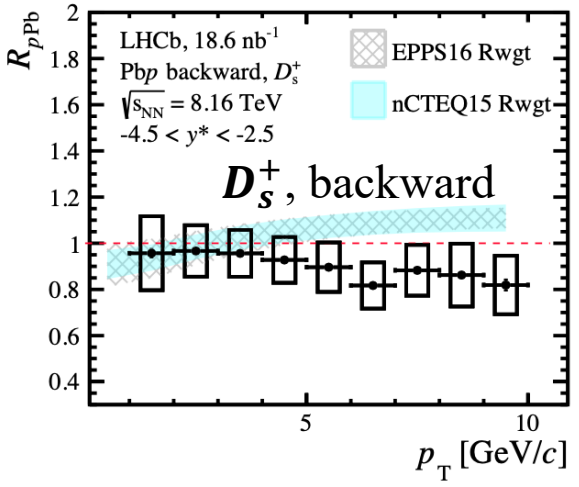
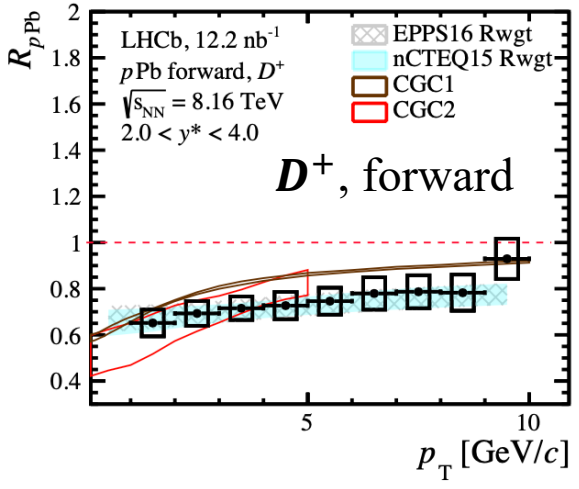
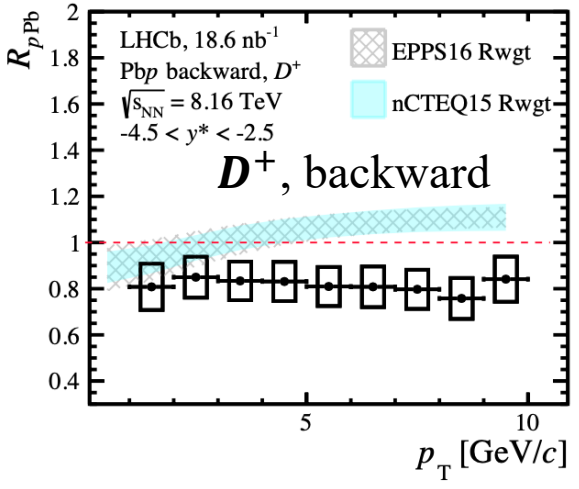


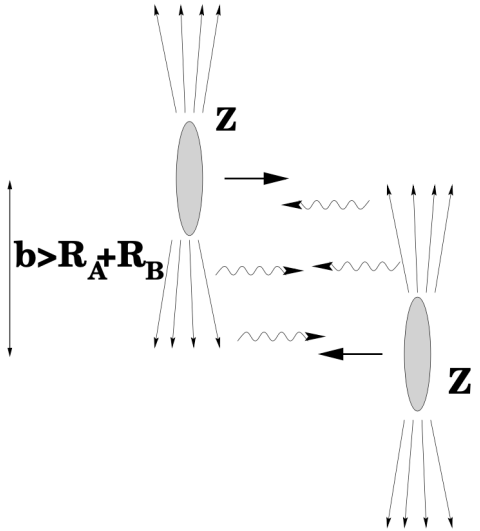




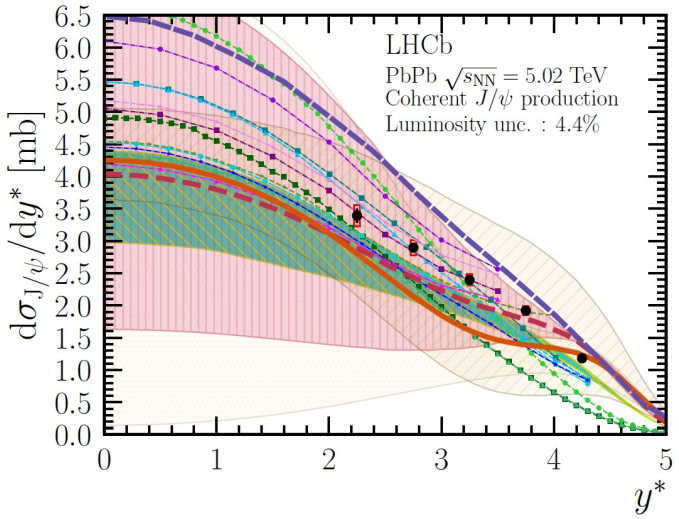


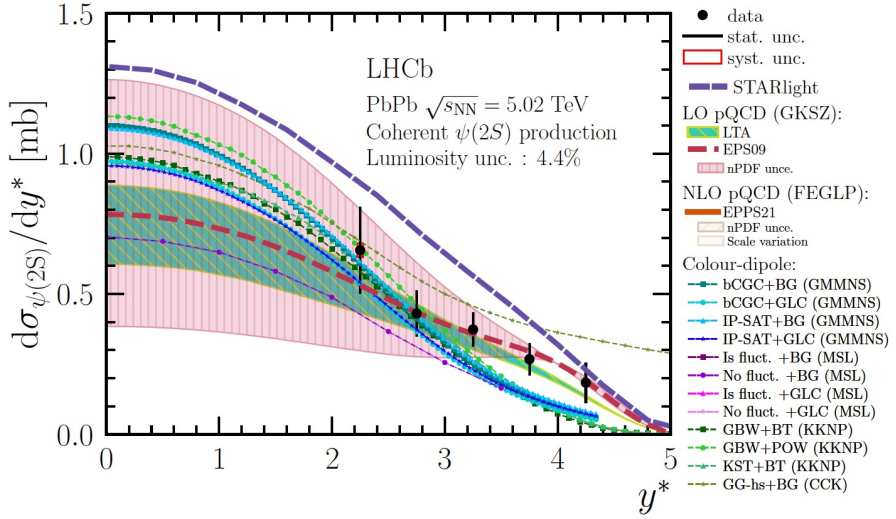
Charmonium in UPC PbPb collisions

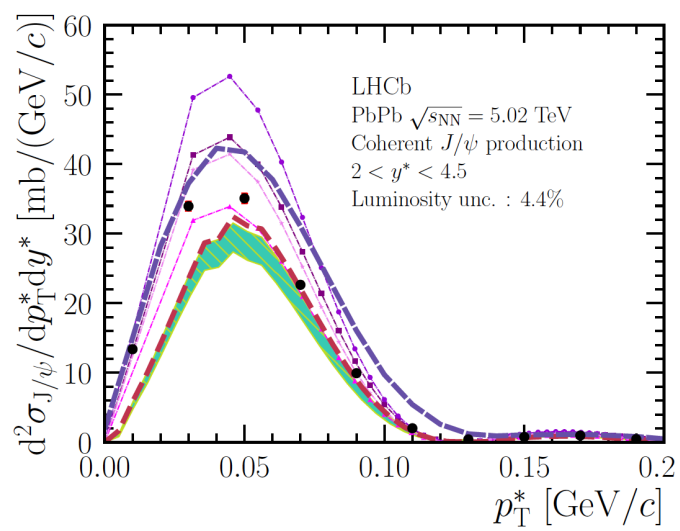
- Most precise coherent J/ψ measurement in forward rapidity at LHC
- First ψ(2S) production measurement in forward rapidity at LHC
- p_T spectra determined for the first time in UPC PbPb
- Set unprecedented constrains to saturation models

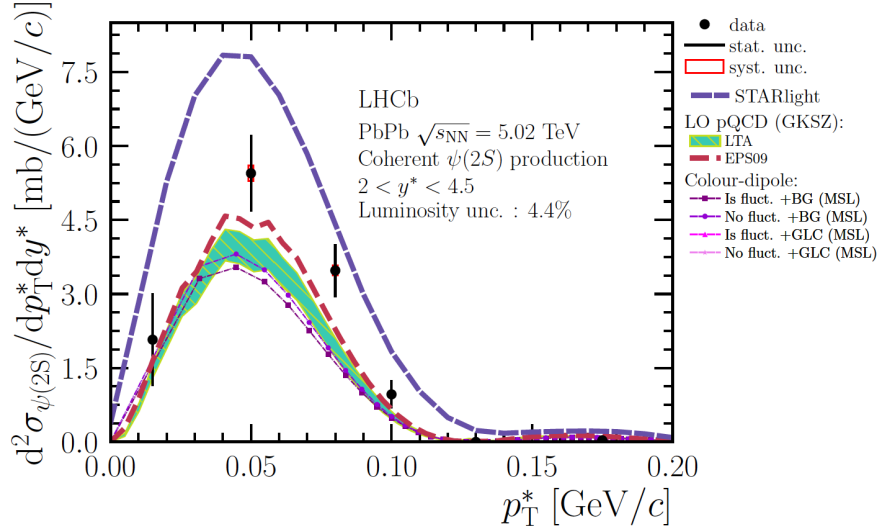


JHEP 06 (2023) 146　华南师大，李衡讷





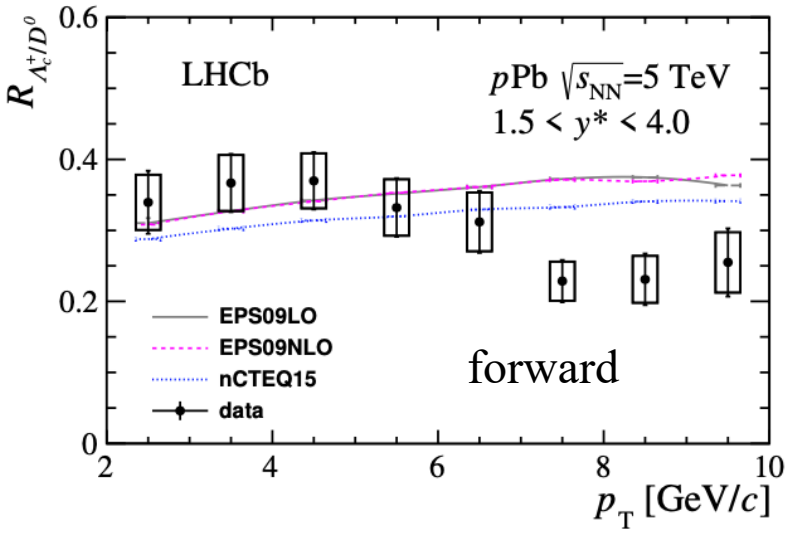


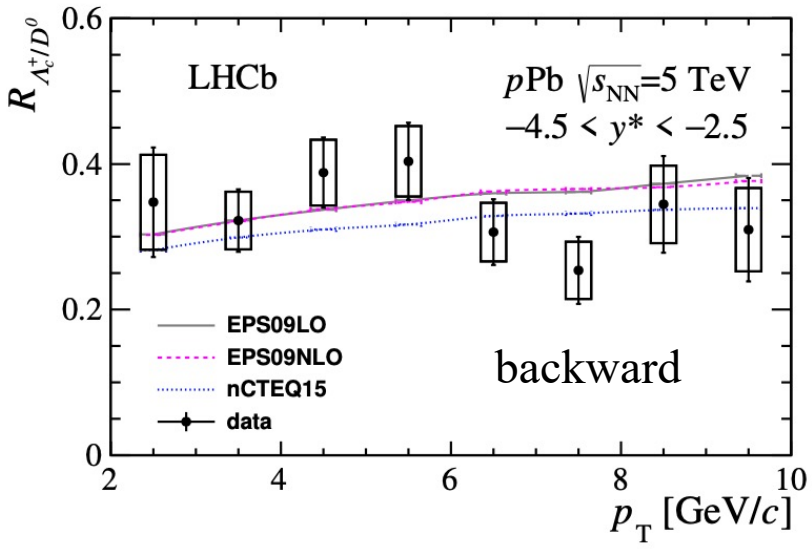


Prompt Λ_c^+/D^0 ratio in pPb at 5.02 TeV

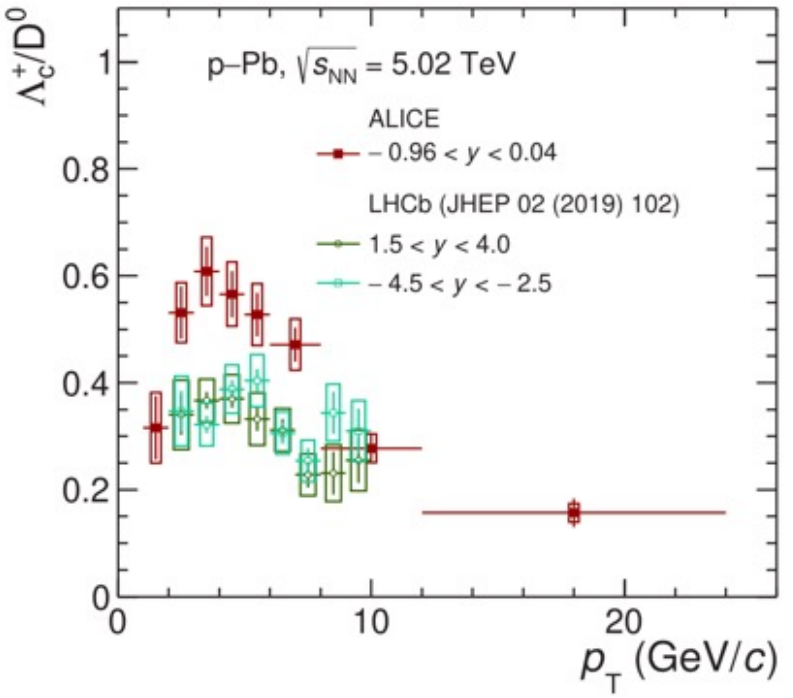
- Charm hadronization mechanism (coalescence versus fragmentation) probed with charm hadron ratios
- LHCb measured Λ_c^+/D^0 in pPb at forward/backward rapidities
- Forward/backward data consistent, but lower than mid-y ALICE data

JHEP 02 (2019) 102 清华，孙佳音





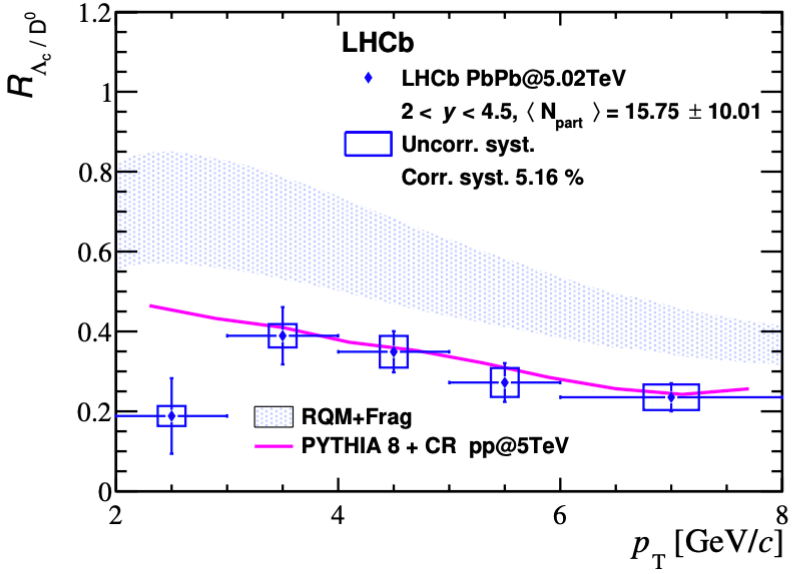
ALICE, Phys. Rev. C 104 (2021) 054905

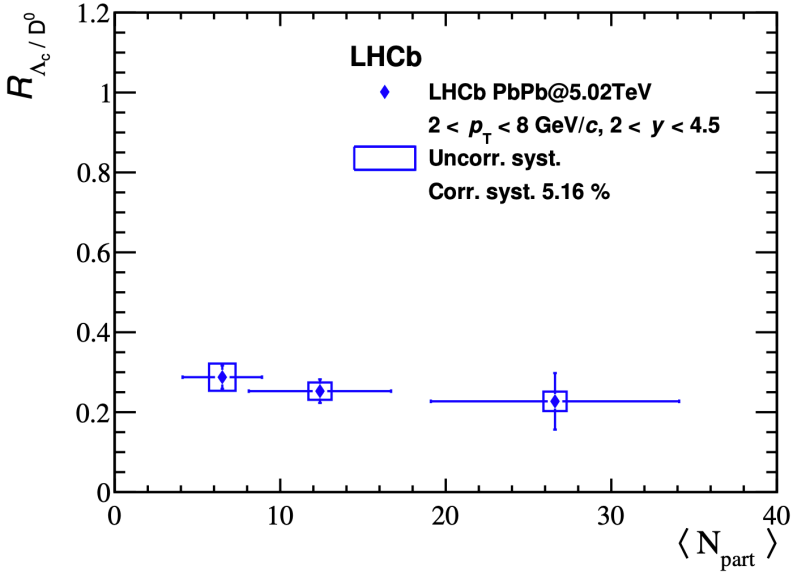


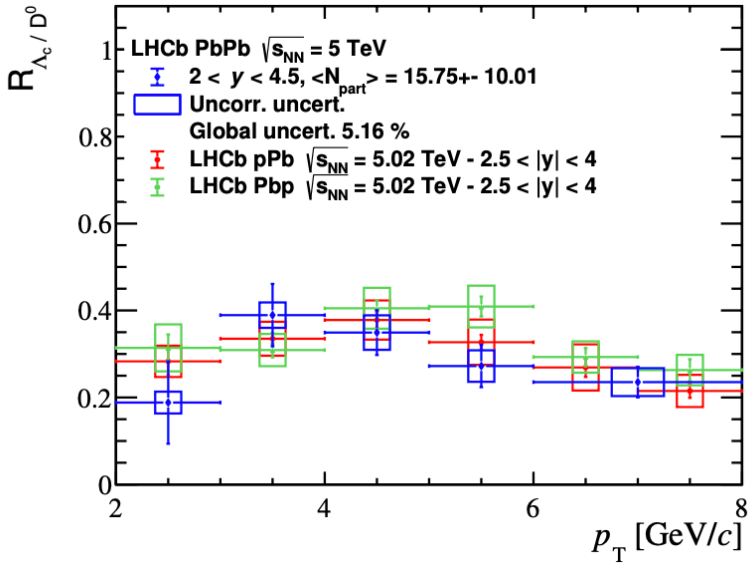
Prompt Λ_c^+/D^0 ratio in PbPb at 5.02 TeV

- First measurement of prompt Λ_c^+/D^0 in forward rapidity in PbPb collisions (up to 60% centrality)
- PYTHIA8 + Color Reconnection: compatible with data within 3σ
- Statistical Hadronization Model is above the data
- No centrality dependence and consistent with LHCb pPb data

JHEP 06 (2023) 132 高能所，陈缮真



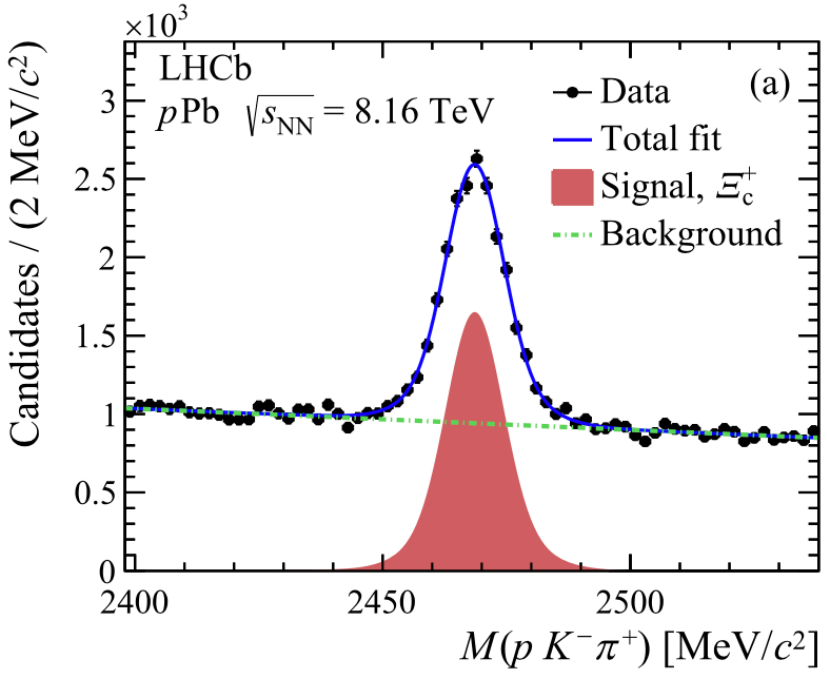


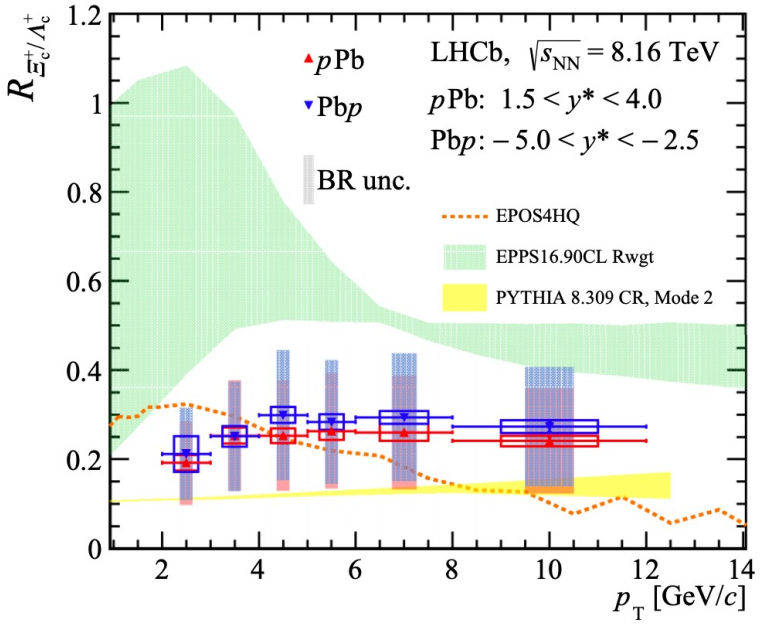


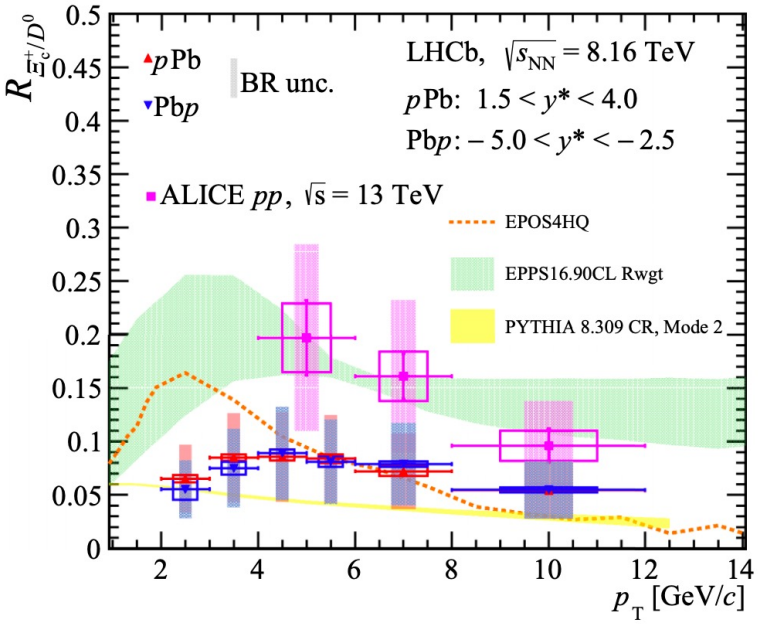
Prompt Ξ_c^+ production in pPb at 8.16 TeV

- 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, but uncertainty is large

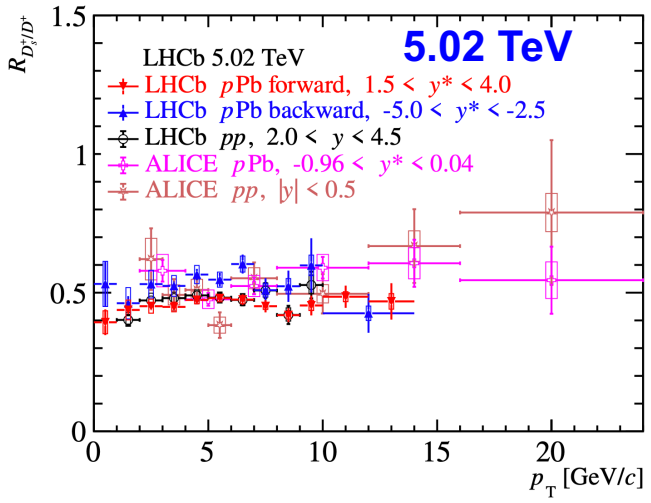
Phys. Rev. C 109 (2024) 044901 INFN，孙佳音

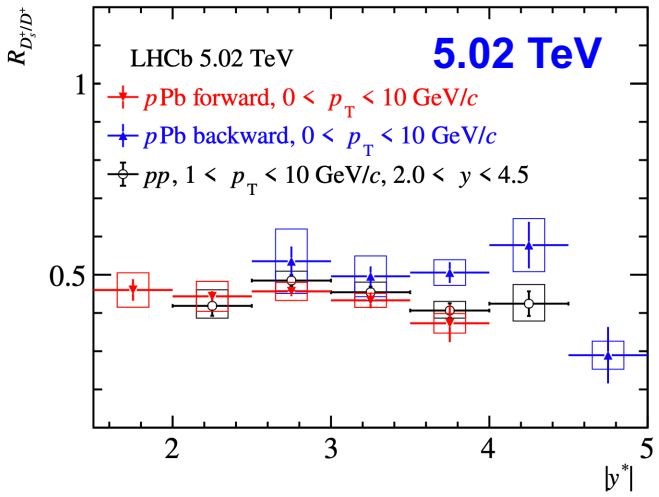




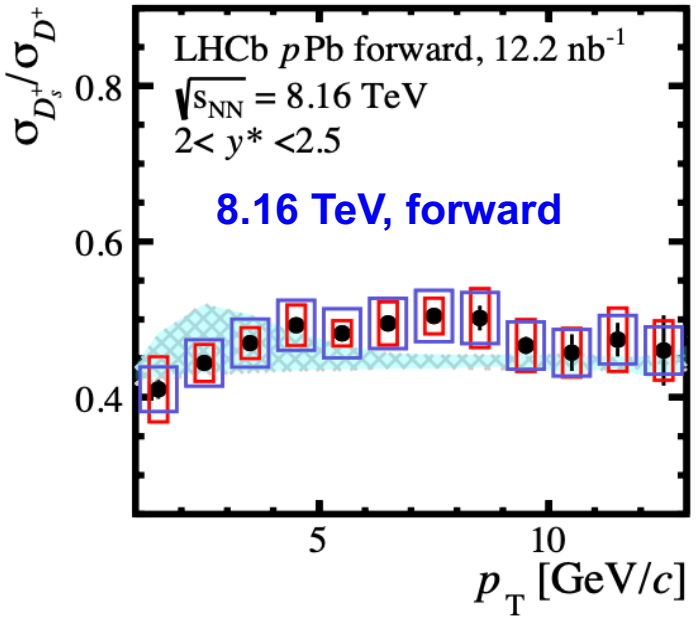


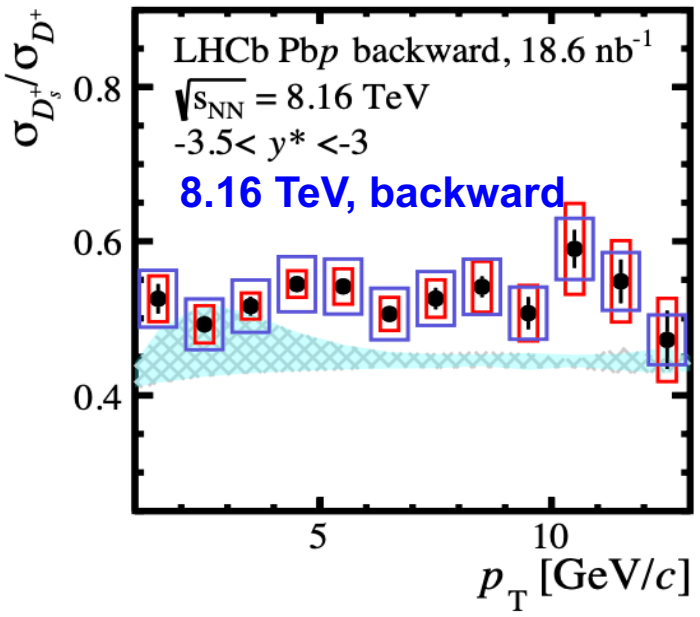
D_s^+/D^+ ratio in pPb at 5.02 and 8.16 TeV

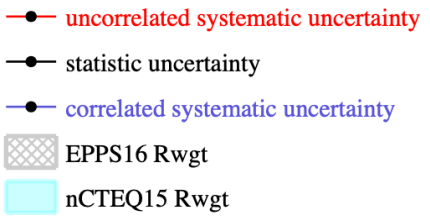




- No or minor p_T dependence
- Consistent with LHCb pp measurements within uncertainties
- Consistent with ALICE measurements (at mid-rapidity) with higher precision
- Consistent with theoretical calculations in forward rapidity at 8.16 TeV.







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

JHEP 01 (2024) 070

arXiv:2311.08490

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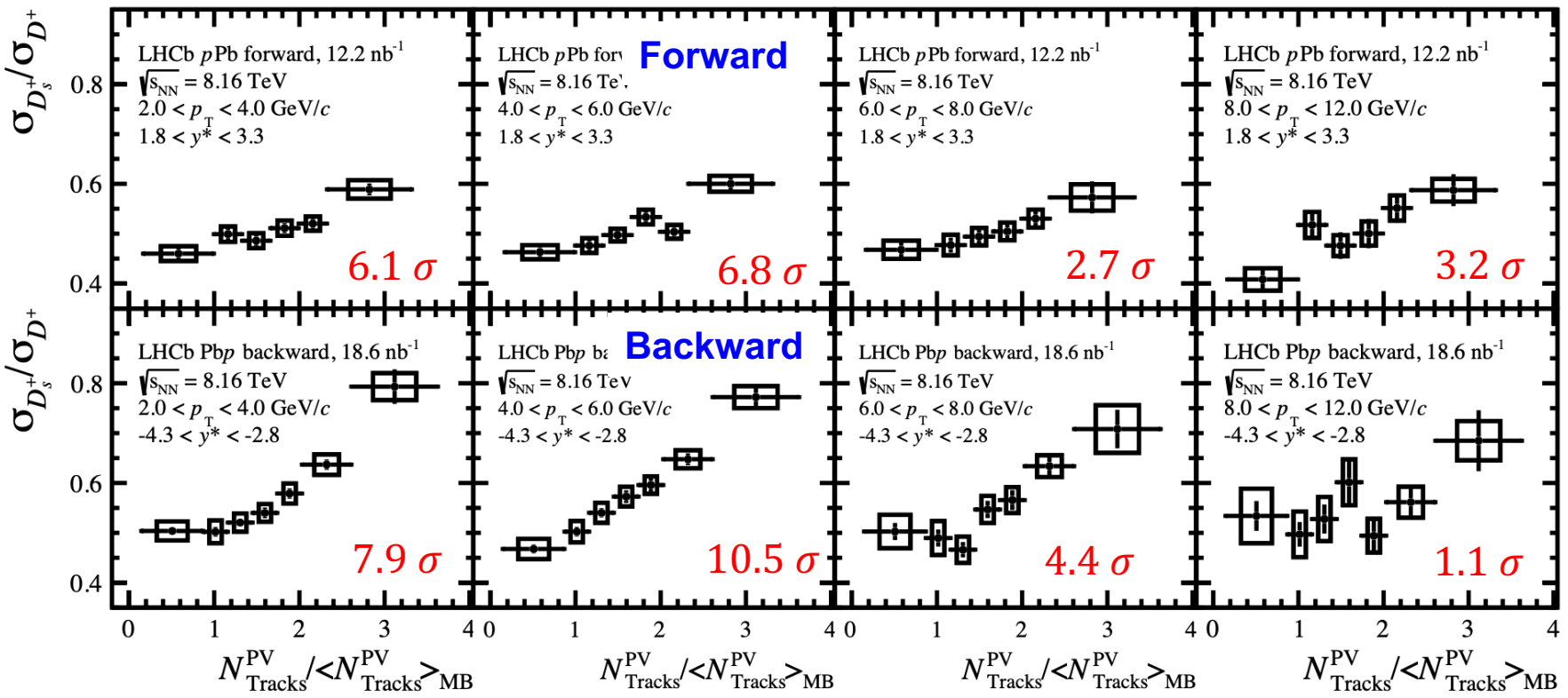
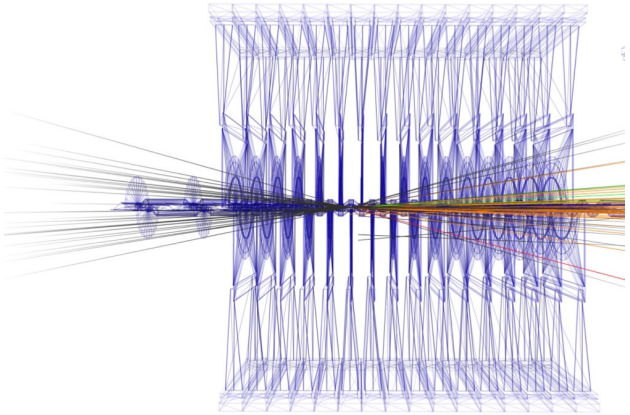
D_s^+/D^+ ratio vs multiplicity in pPb at 8.16 TeV





N_{Tracks}^{PV} :
Number of tracks used in primary vertex reconstruction

- 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.

arXiv:2311.08490
submitted to PRL

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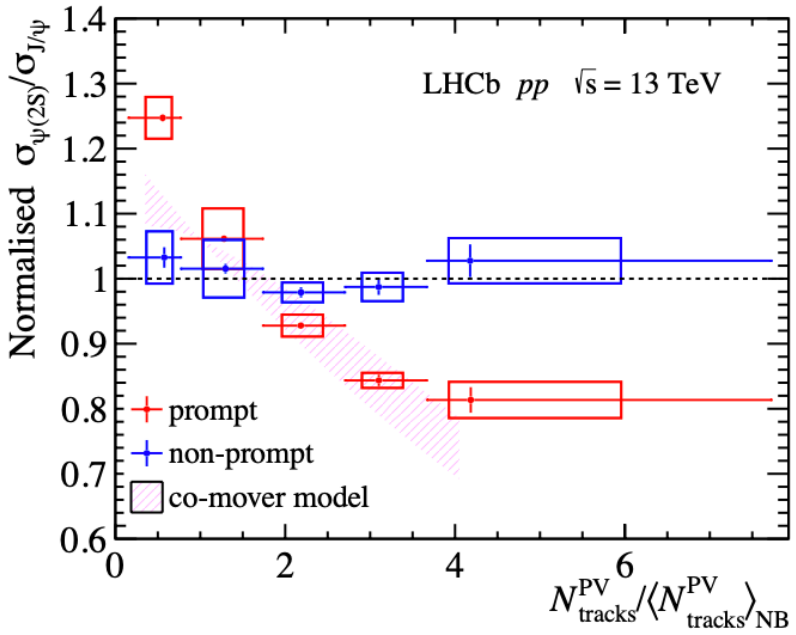
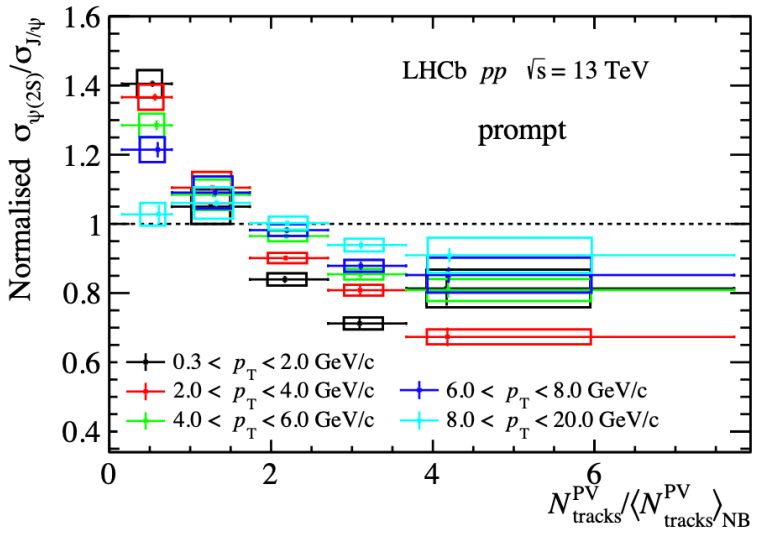
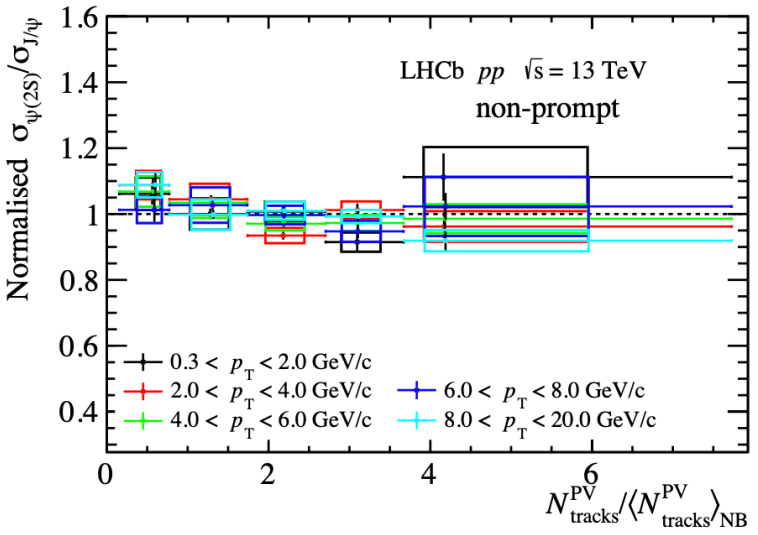
$\psi(2S)$ to J/ψ ratio vs multiplicity in *pp* at 13 TeV

- QGP droplet produced in high multiplicity *pp* collisions (small system) ?
- Search for sequential charmonia suppression in small system !
- Decreasing trend vs multipliticity observed for prompt contributions (in particular for low p_T), consistent with comover interactions
- Independent on multiplicity and p_T for non-prompt contributions



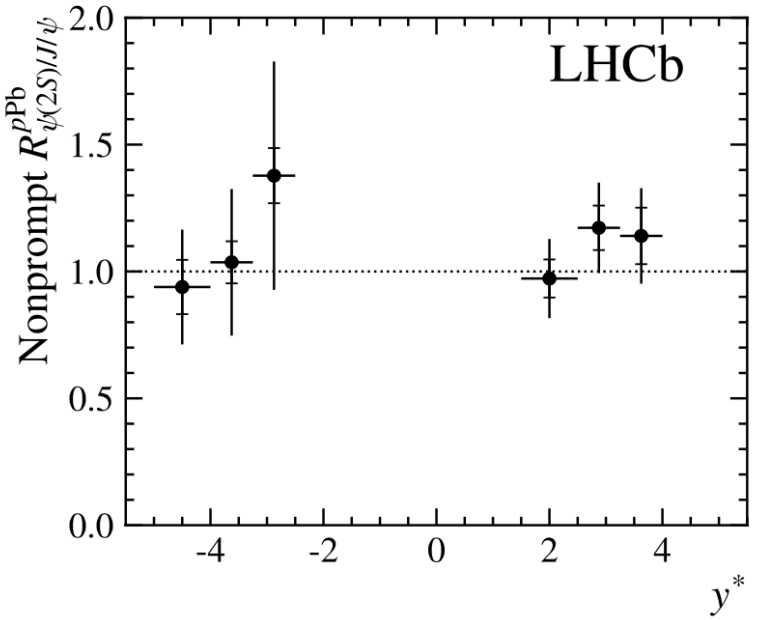


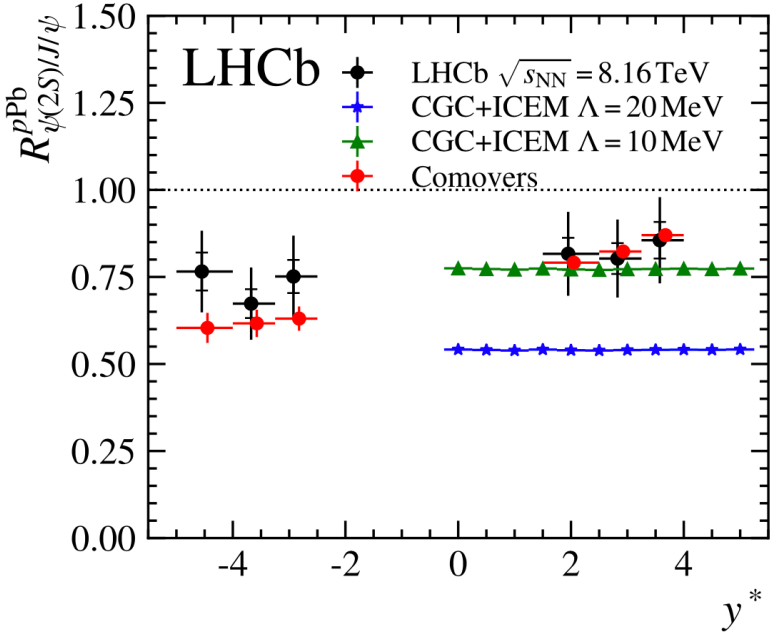


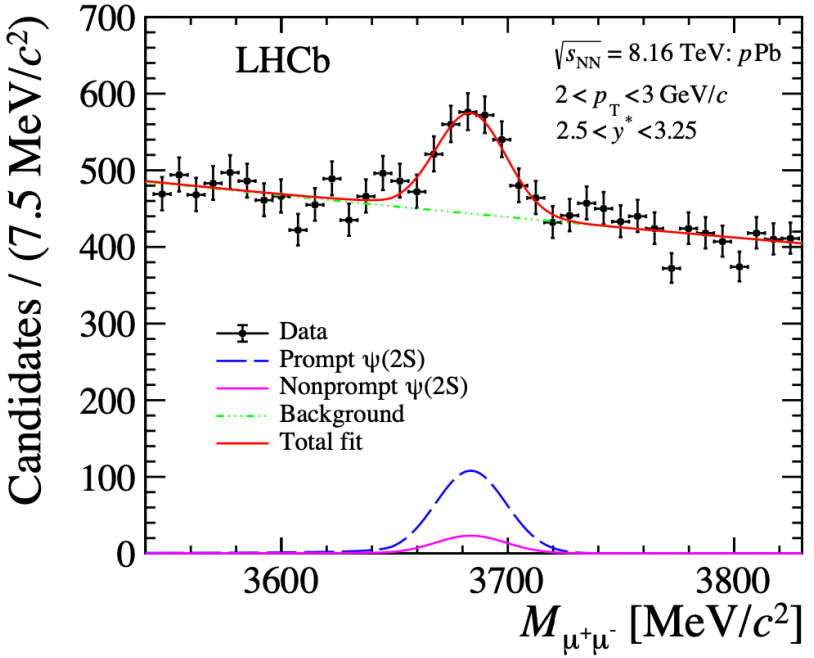
清华，康有恩　arXiv:2312.15201, submitted to JHEP

$\psi(2S)$ 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







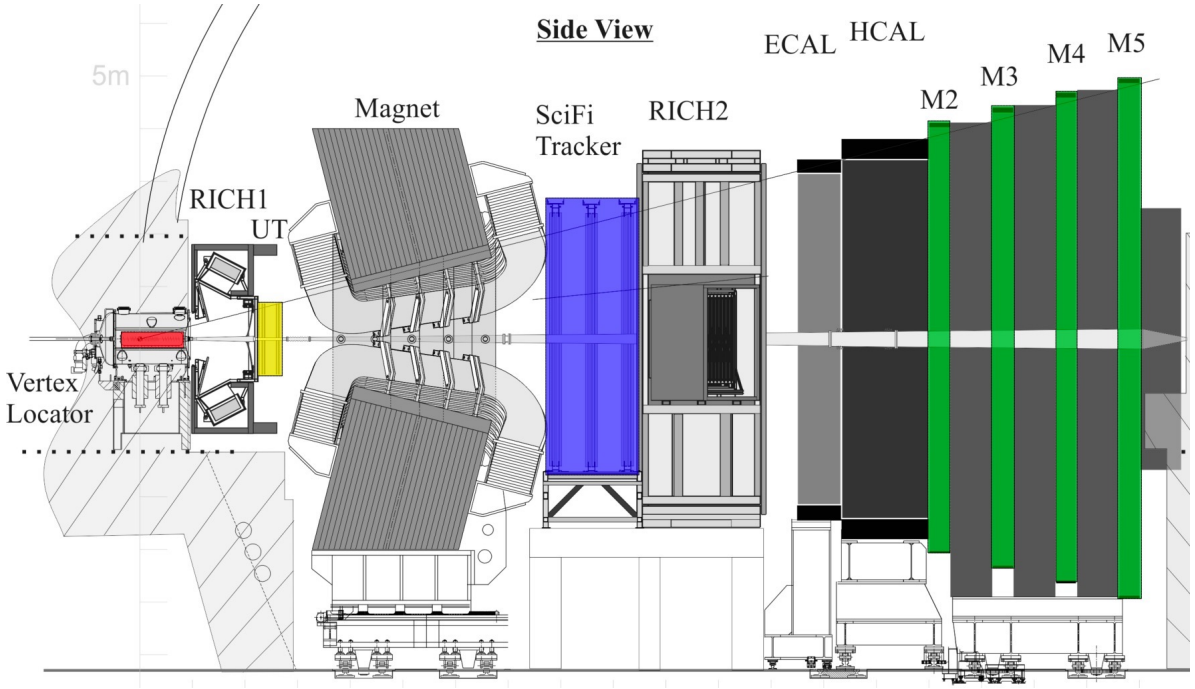
北大，张艳席
华南师大，李衡讷

arXiv:2401.11342

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

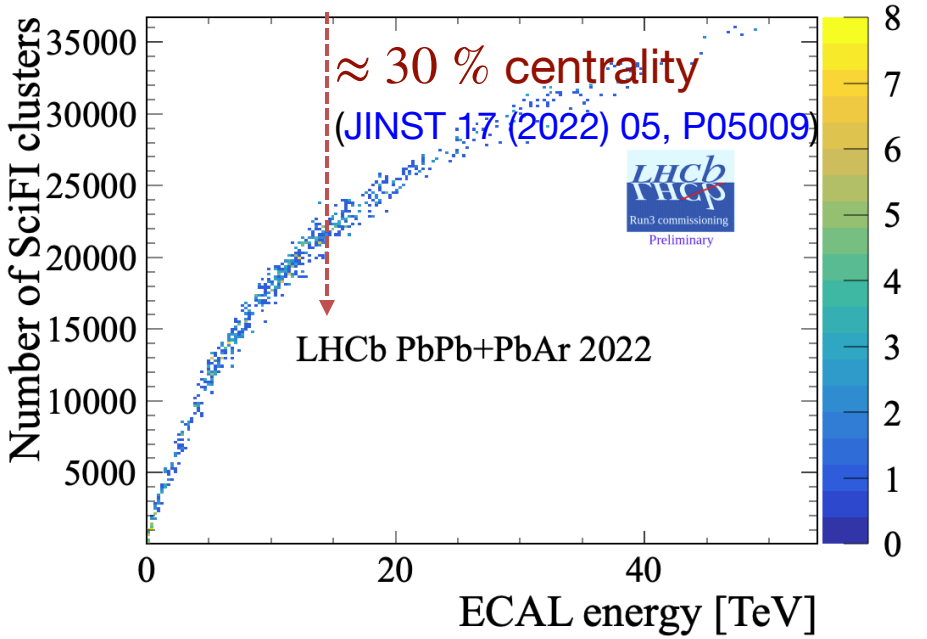
LHCb Upgrade-I installed

- 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



arXiv:2305.10515

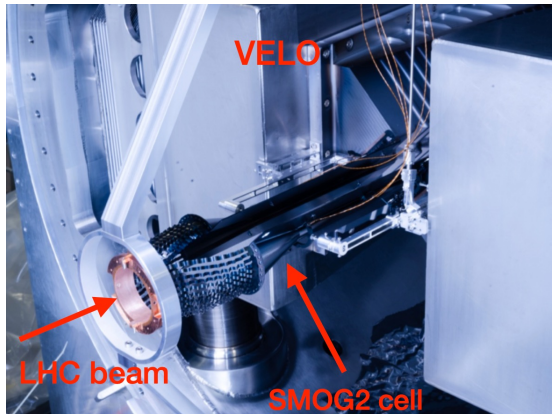
First data from PbPb + PbAr collisions in 2022!



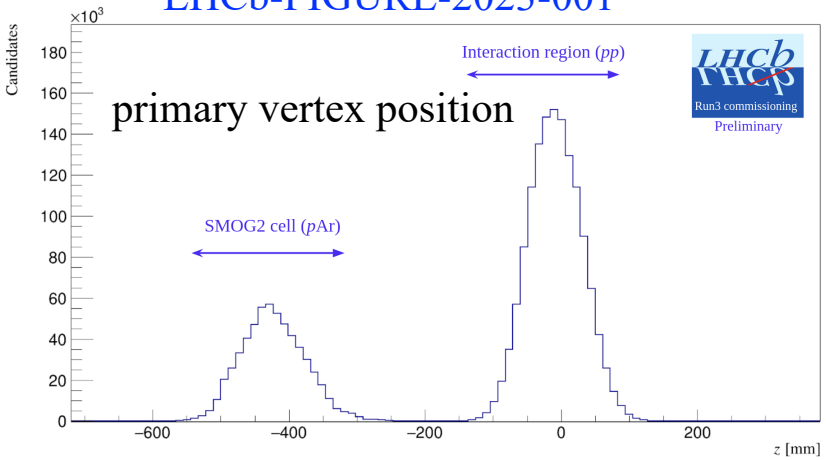
LHCb-FIGURE-2023-022

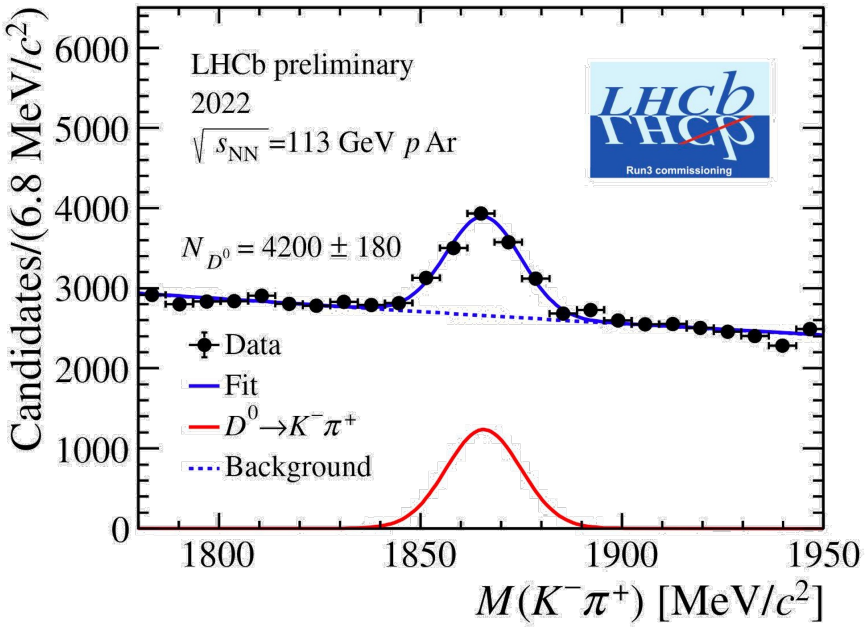
Fixed target upgrade – SMOG2

- Dedicated gas storage cell installed
- Greatly increased rates of beam+gas collisions
- Concurrent running with pp collisions
- New gases: H_2, D_2, O_2 and large nuclei (Kr, Xe)
- Energies: $\sqrt{s_{\mathrm{NN}}} \in [68.5, 110]$ GeV



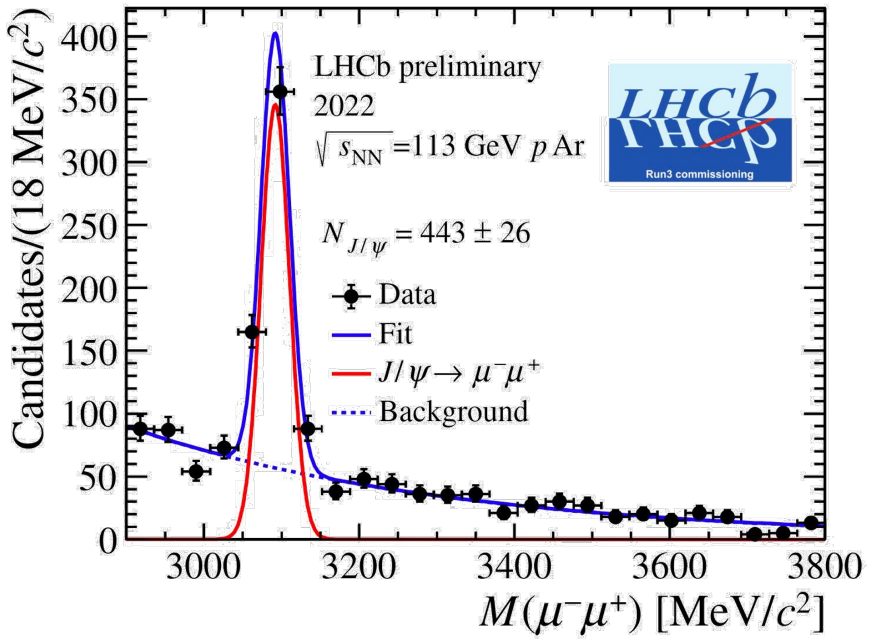
LHCb-FIGURE-2023-001





Reconstructed from **18 minutes** of early 2022 data!

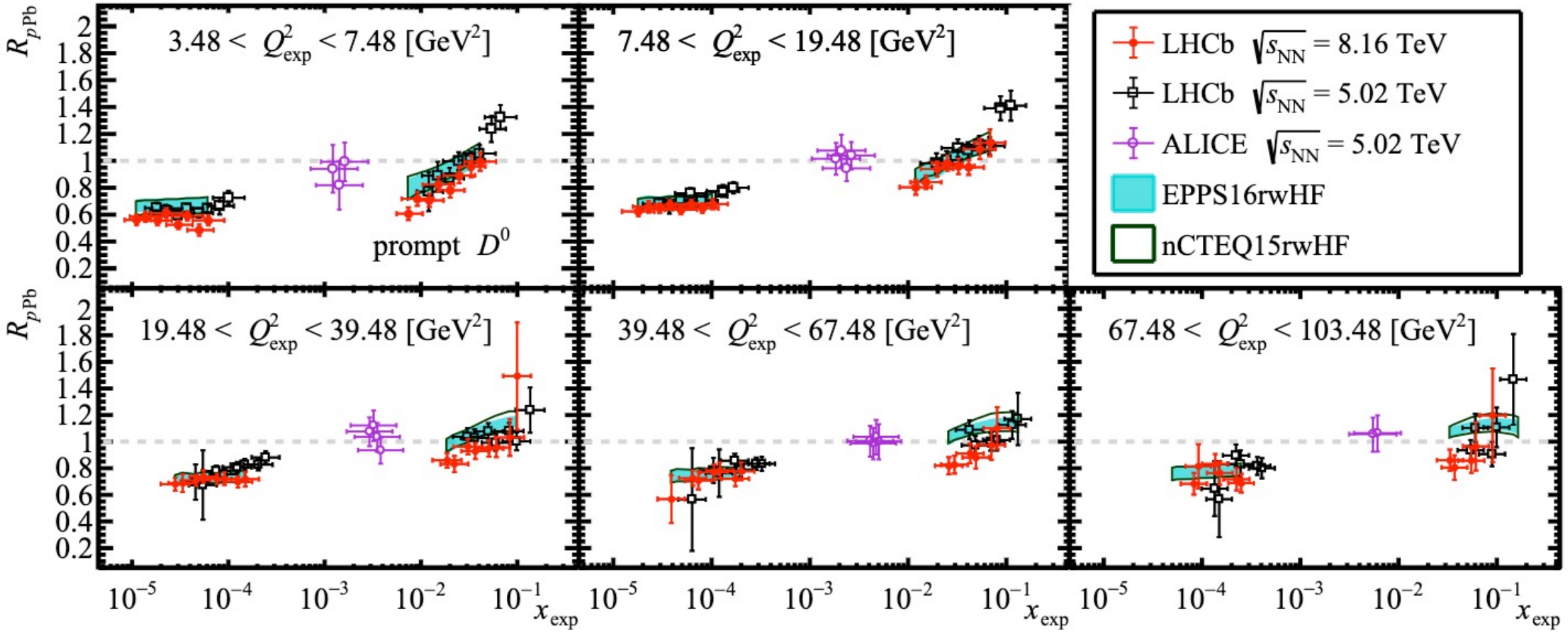
LHCb-FIGURE-2023-008



Summary

- LHCb has a very diverse heavy-ion and fixed target program, which profits of the variety of datasets
- LHCb detector capabilities provide unique access to rare probes of nuclear matter
  - Unprecedented access to low-x region of nuclei with various probes
  - Precise open/hidden charm and bottom measurements in small systems
  - Unique access to higher charmonia and exotics at low p_T
- LHCb heavy-ion program is rapidly expanding with new capabilities
  - Vigorous upgrades that directly impact LHCb heavy ion physics is underway

backup



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

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b hadronization in *pp* at 13 TeV

- Baryon-to-meson ratio measured down to zero p_T with $\Lambda_b^0 \to J/\psi p K$ and $B^0 \to J/\psi \pi K$
- p_T trend compatible with measurement with semileptonic channel and pPb
- A strong baryon enhancement with multiplicity is observed
- Ratio recovers e^+e^- value (QCD-vacuum) at low multiplicity
- Ratio consistent with e^+e^- at high p_T

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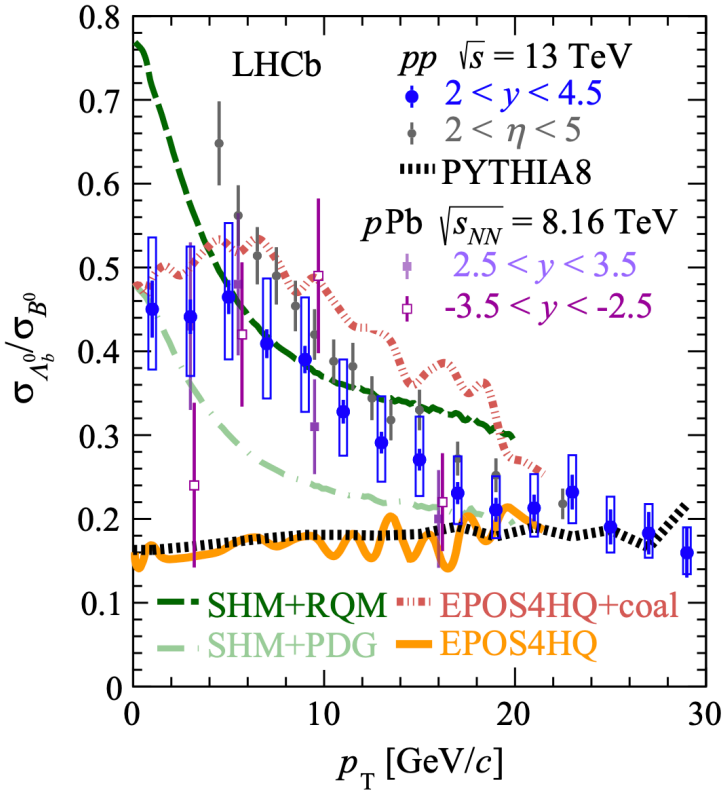
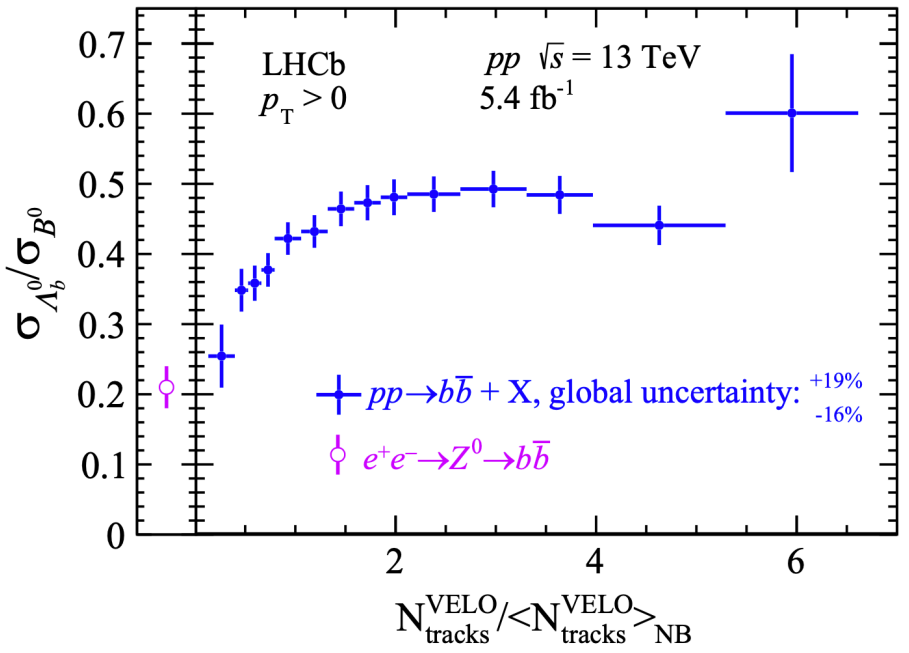
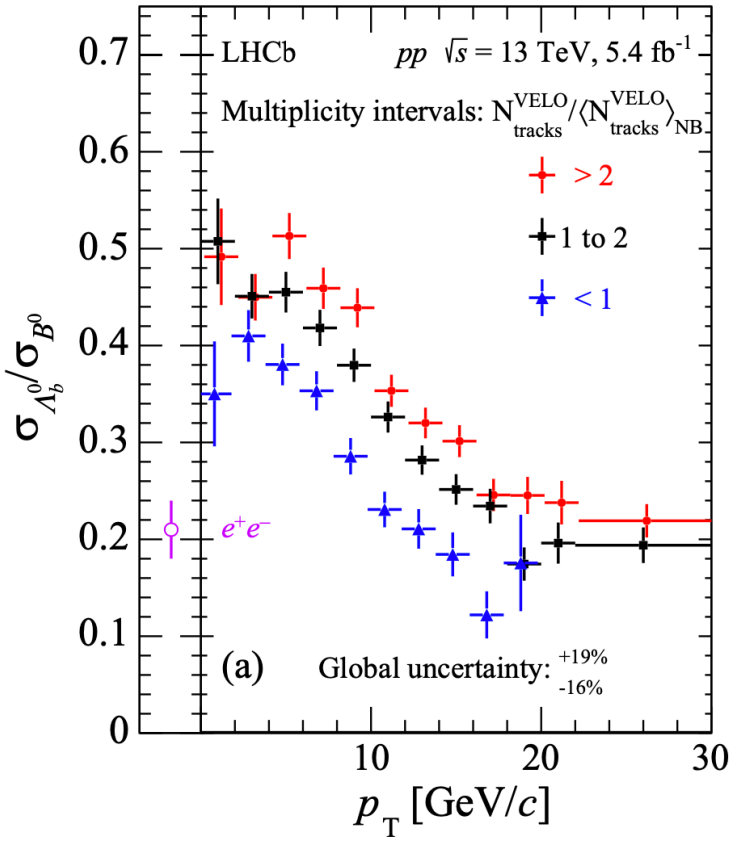


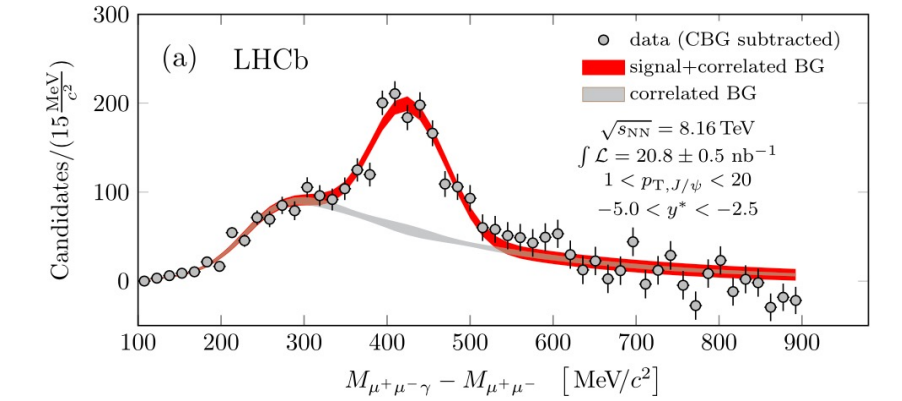


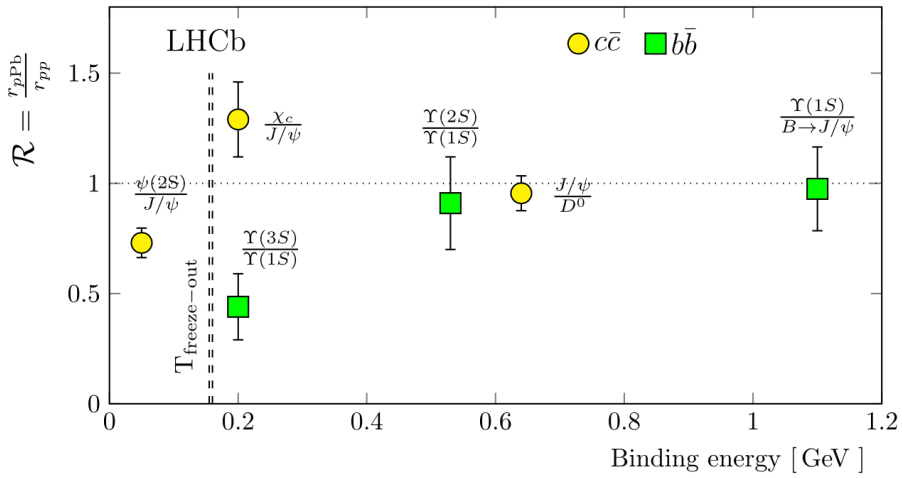


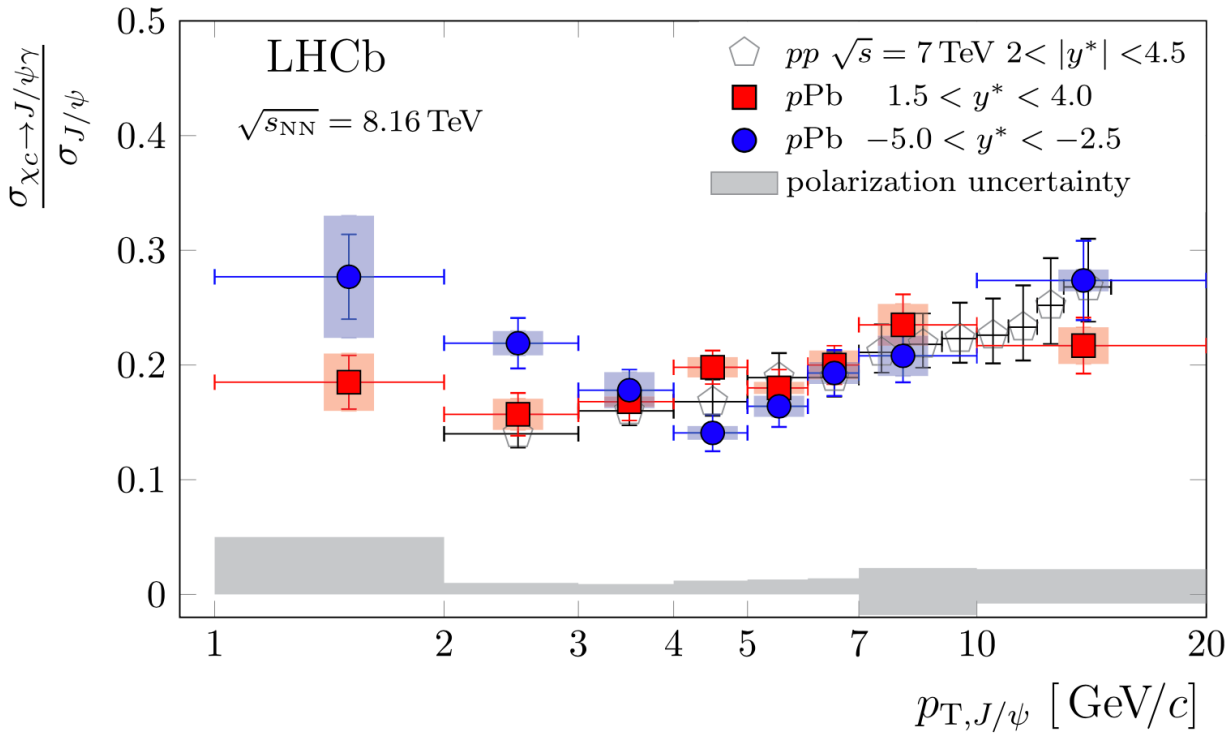
χ_c production in pPb at 8.16 TeV

- 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

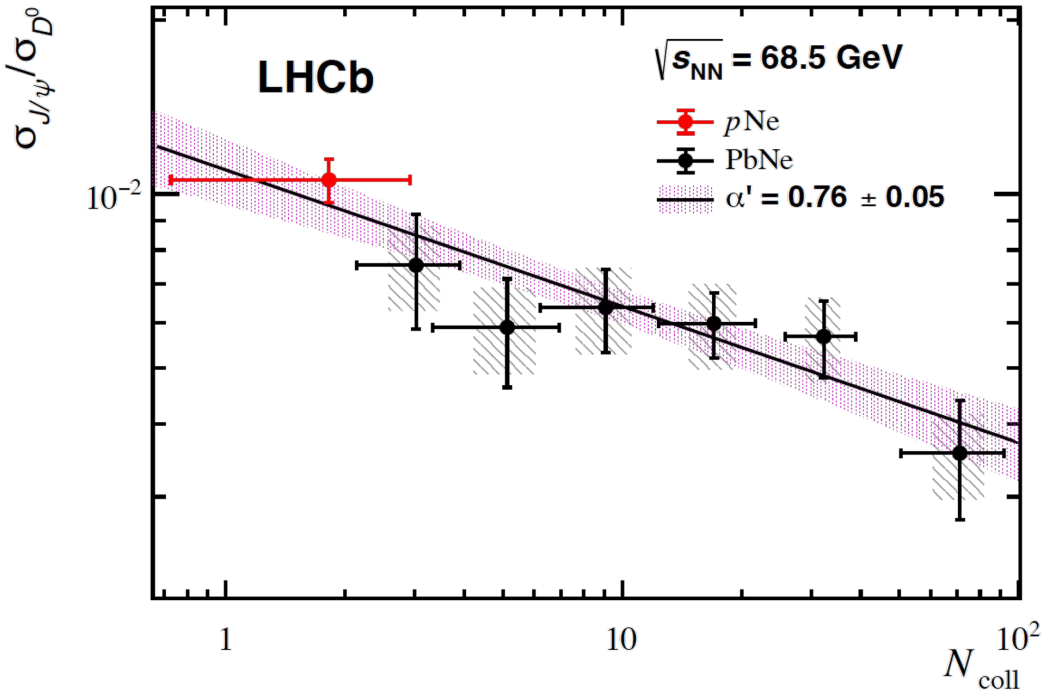


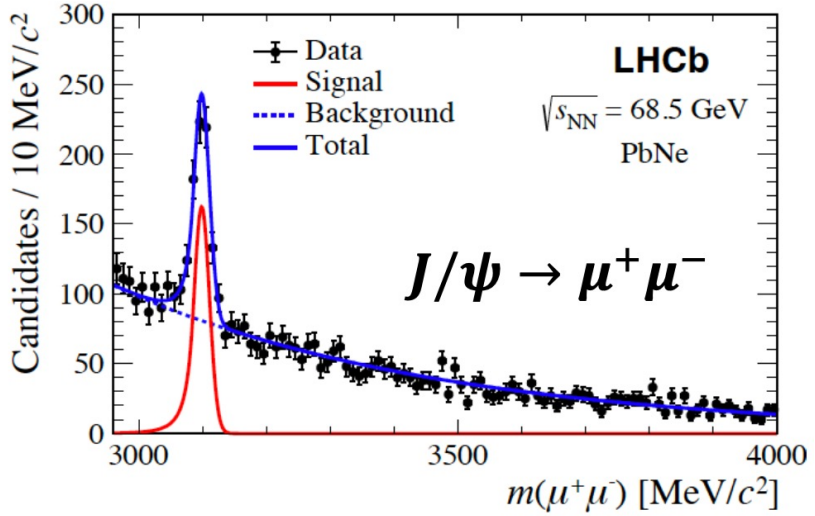


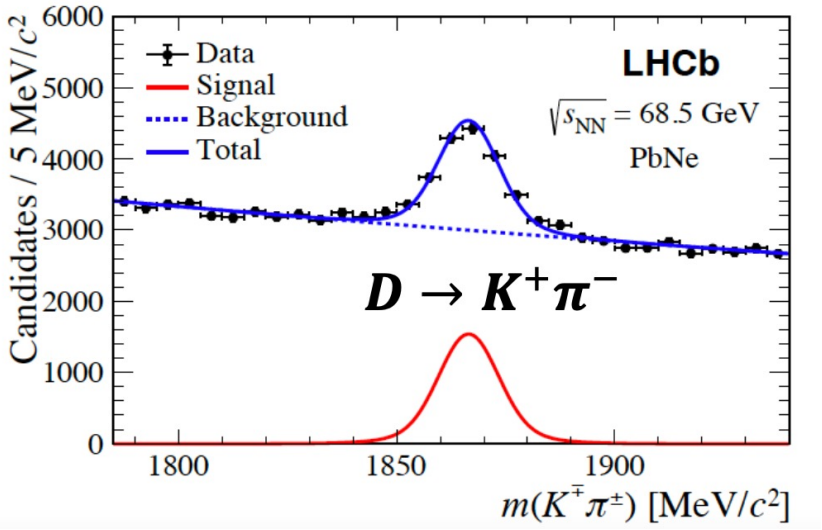


J/ψ to D^0 ratio in fixed-target collisions

- Study PbNe sample at $\sqrt{s_{NN}} = 68.5$ GeV, negligible charm recombination, cleaner to search for "anomalous" suppression
- Use open charm as baseline
- Continuous suppression observed, compatible with no QGP scenario
- Larger system size (PbAr) and precision reachable in Run 3





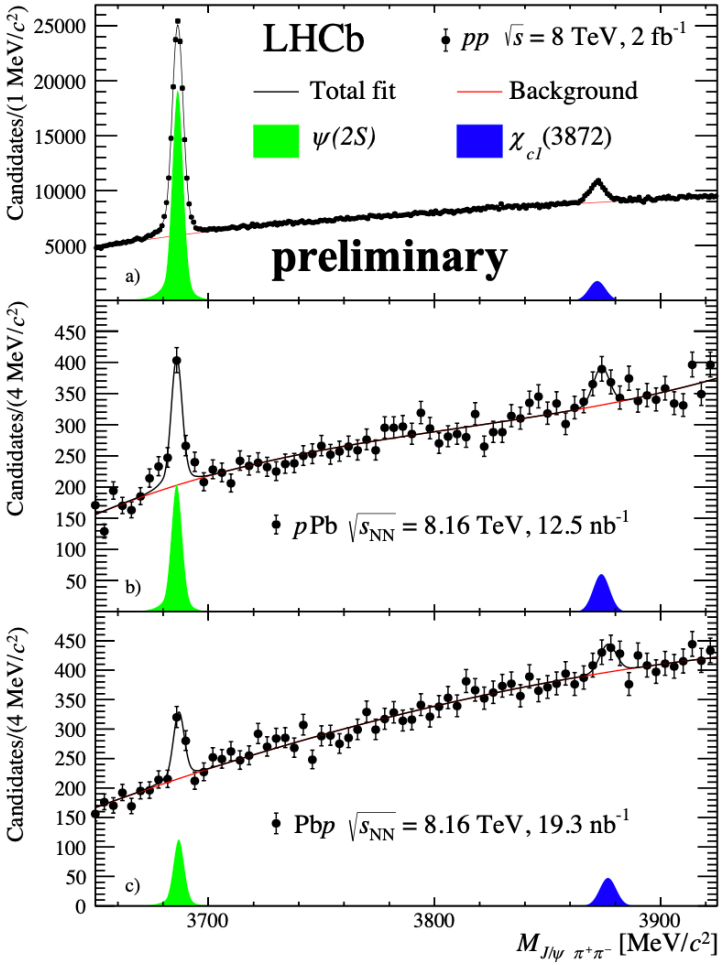


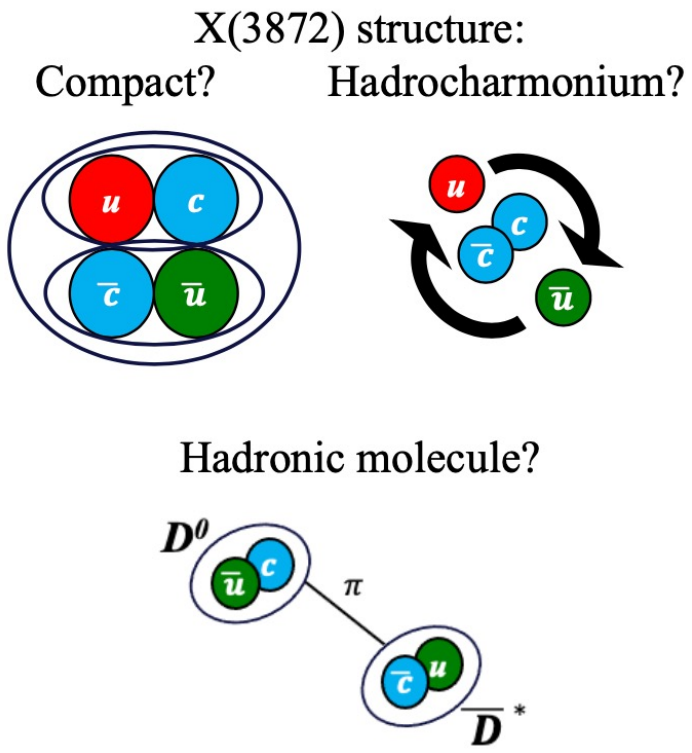
PbNe: Eur. Phys. J. C83 (2023) 658, pNe: Eur. Phys. J. C83 (2023) 625, Eur. Phys. J. C83 (2023) 541

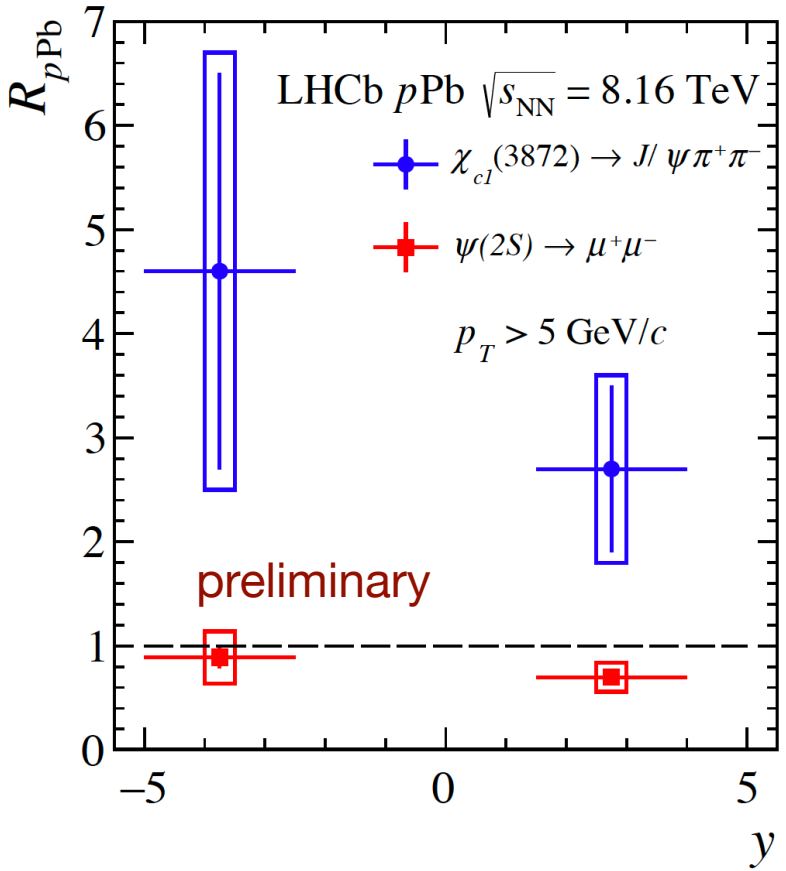
Modification of X(3872) in *p*Pb

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

LHCb-PAPER-2023-026, in preparation







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