Hadron production at LHCb

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On behalf of the LHCb collaboration

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CCNU, Wuhan

Outline

- The LHCb detector
- Heavy flavor production in pp/pPb/PbPb

  JHEP 07 (2018) 134 JHEP 11 (2018) 194 arXiv: 1809.01404

  LHCb-CONF-2018-004 LHCb-CONF-2018-003

- Hadron production in fixed-target experiments

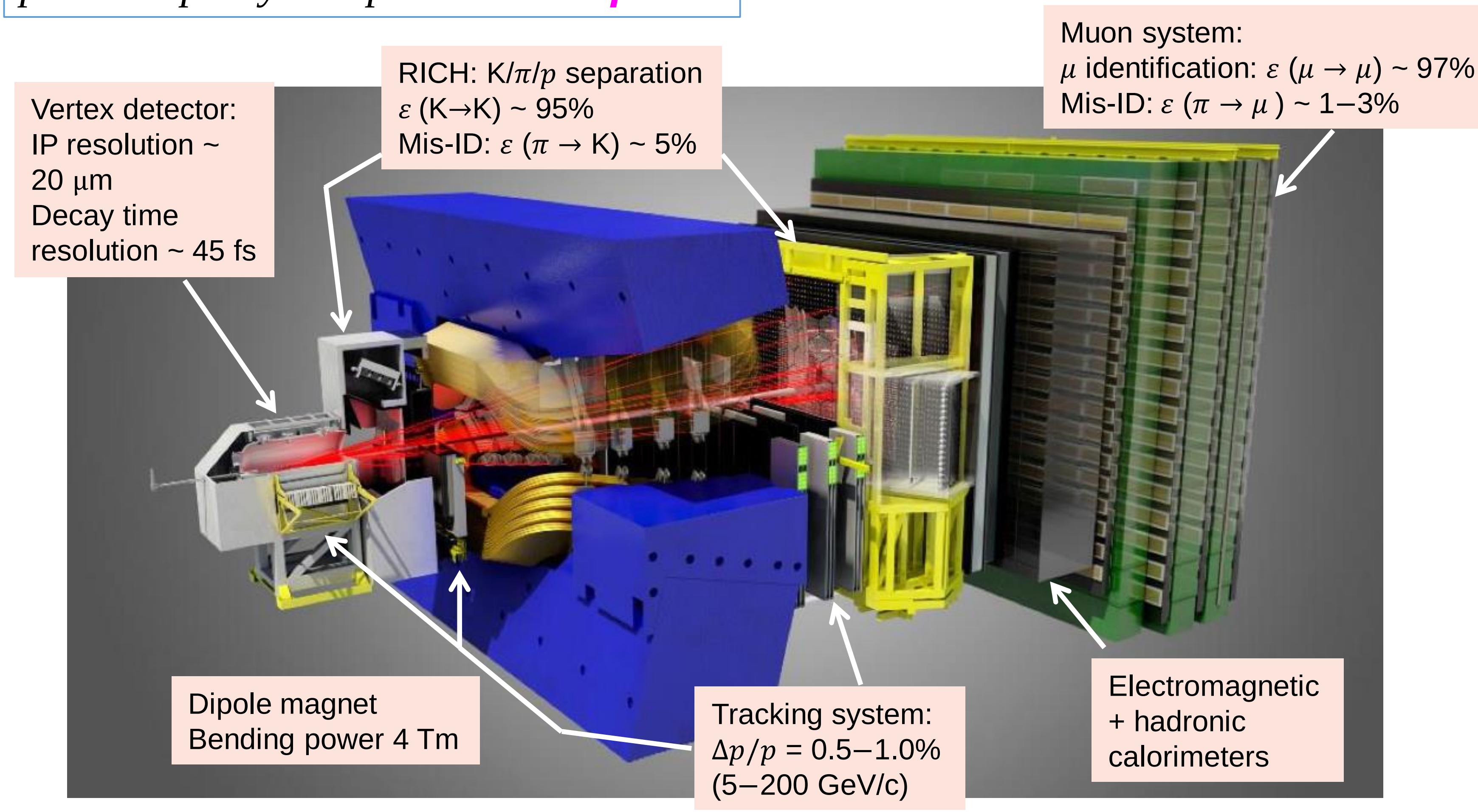
  arXiv:1808.06127 arXiv:1810.07907

- Summary

The LHCb detector

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

pseudorapidity acceptance $\mathbf{2 < \eta < 5}$



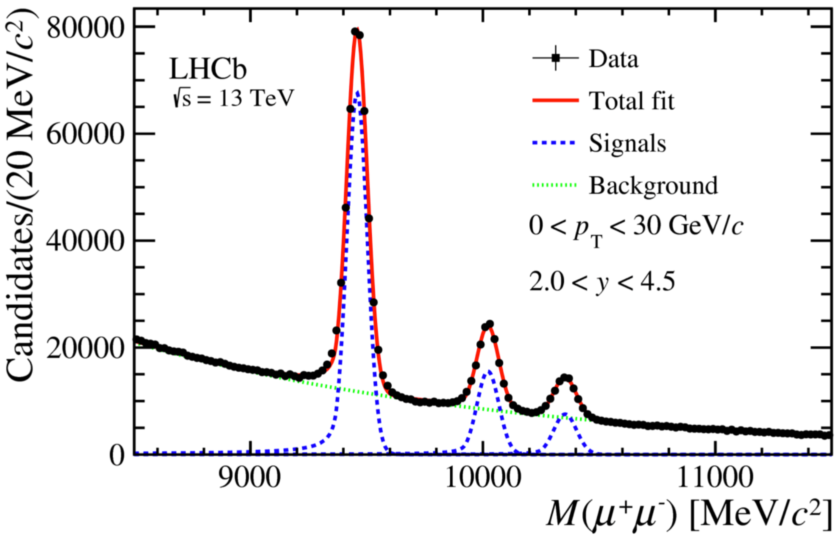
JINST 3 (2008) S08005
IJMPA 30 (2015) 1530022

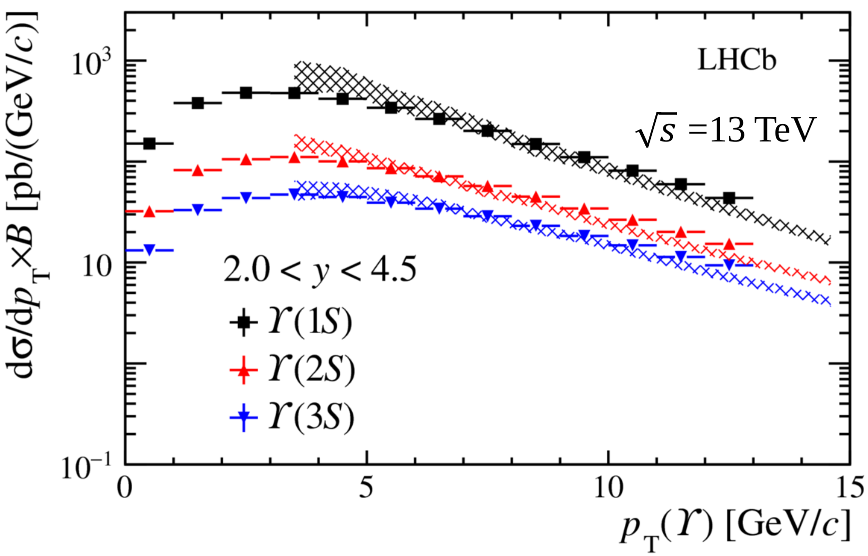
Υ production in pp at 13 TeV with 277 pb^{-1}

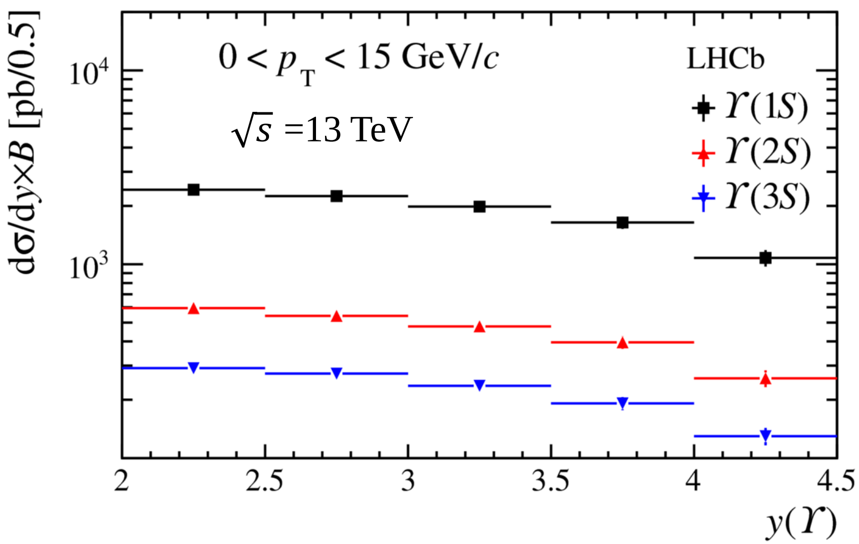
JHEP 07 (2018) 134
Jiajia Qin, HF session

- Compared with NRQCD predictions

Chin. Phys. C 39 (2015) 123102

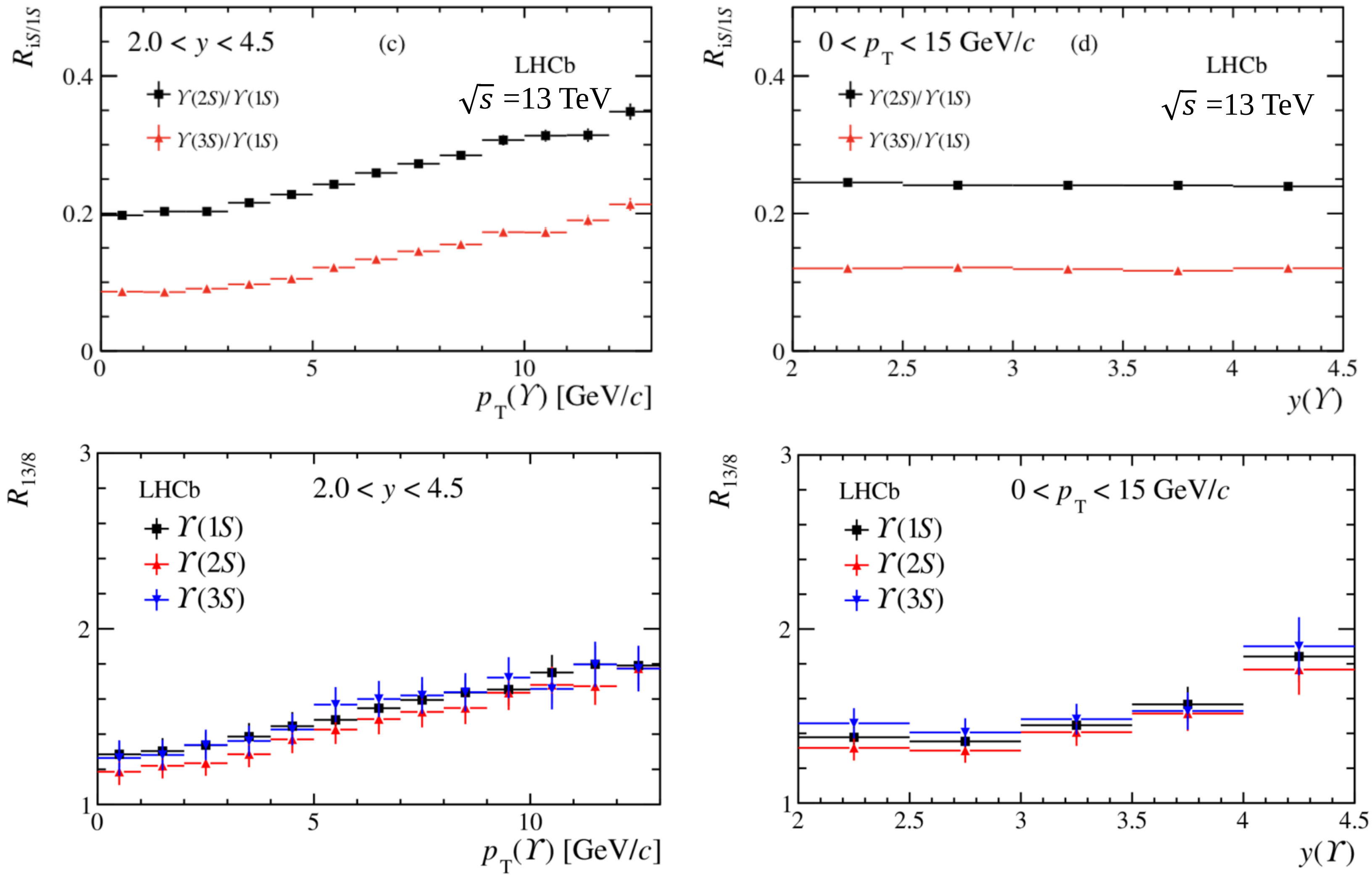




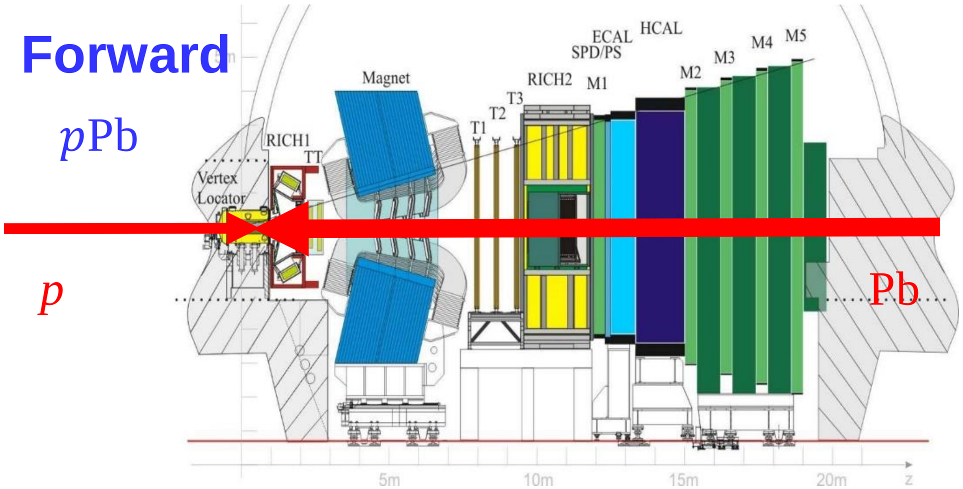


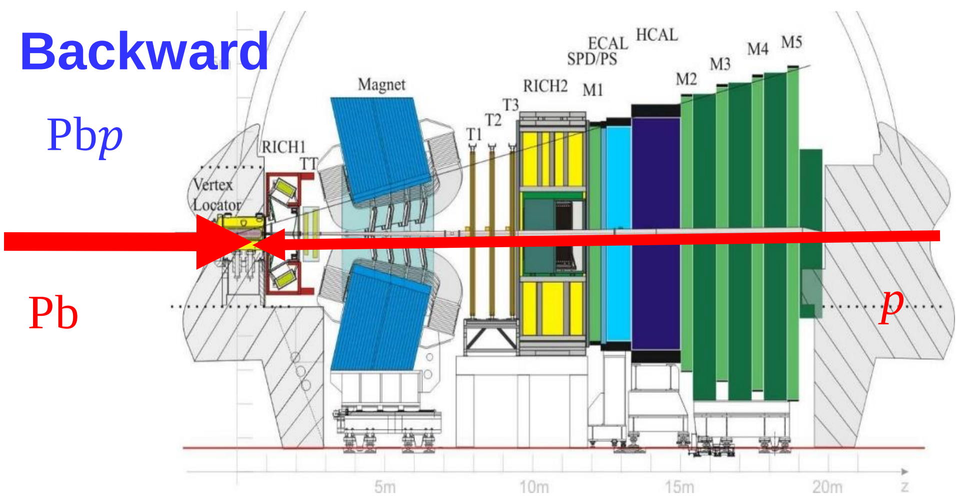
Ratios in pp: $\Upsilon(nS)/\Upsilon(1S)$ and 13/8 TeV

JHEP 07 (2018) 134



LHCb pPb datasets



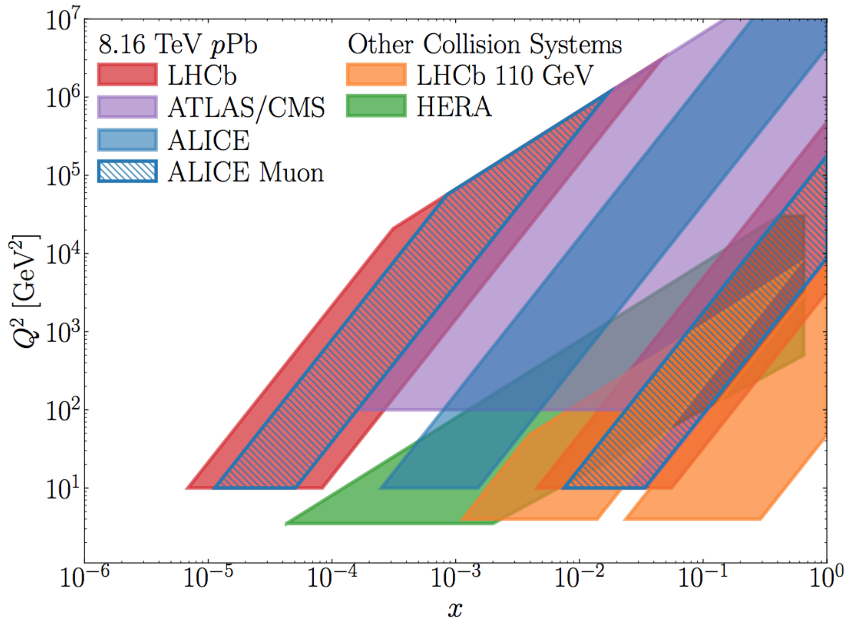


- Rapidity Coverage
  - y^*: rapidity in nucleon-nucleon cms
  - $y_{\text{cms}} = \pm 0.465$
  - Forward: $1.5 < y^* < 4.0$
  - Backward: $-5.0 < y^* < -2.5$
  - Common region: $2.5 < |y^*| < 4.0$

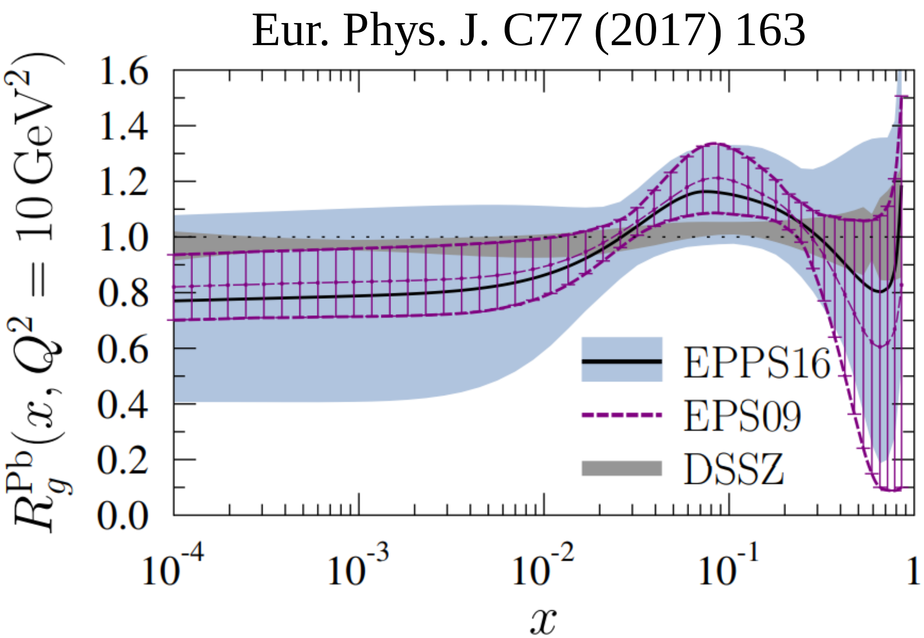
- $\sqrt{s_{\text{NN}}} = 5.02$ TeV (2013, Run I)
  - pPb ($1.06\ \text{nb}^{-1}$) + Pbp ($0.52\ \text{nb}^{-1}$)

- $\sqrt{s_{\text{NN}}} = 8.16$ TeV (2016, Run II)
  - pPb ($13.6\ \text{nb}^{-1}$) + Pbp ($21.8\ \text{nb}^{-1}$)

LHCb: frontier experiment in phase space



Graphic by T. Boettcher



Thanks to the boost, the high resolution, the low-p_{T} reach and the fast read-out

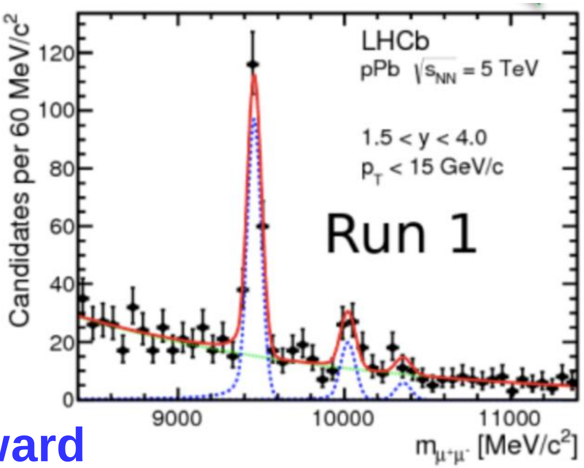
- disentangle initial state from other phenomena
- constrain initial state
- sensitive to the physics on the saturation scale

$\Upsilon(nS)$ signals in pPb at 8.16 TeV

- Run II pPb sample ~20×data w.r.t. Run I
- Cross-section, R_{pPb}, R_{FB} measured for all 3 lowest Υ states

Samples	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$	$\mathcal{L}$
pPb	2705 ± 87	584 ± 49	262 ± 44	$12.5\ \text{nb}^{-1}$
Pbp	3072 ± 82	679 ± 54	159 ± 39	$19.3\ \text{nb}^{-1}$

JHEP 07 (2014) 094



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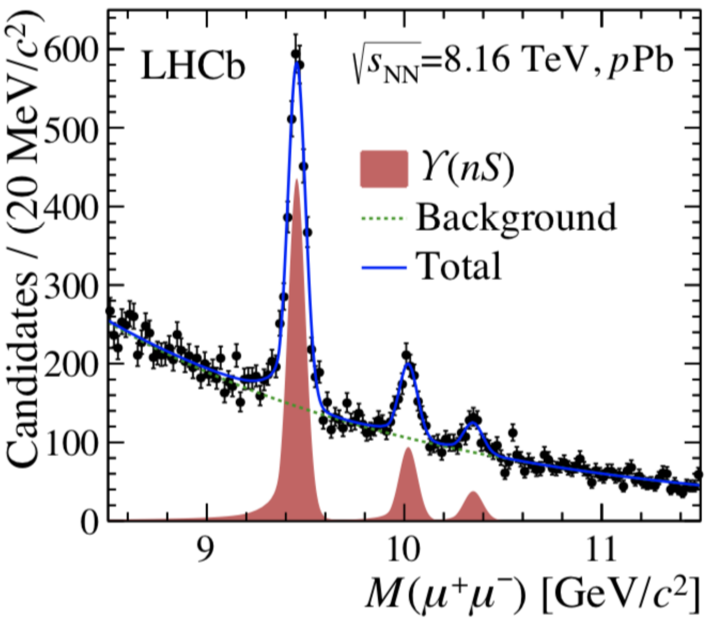
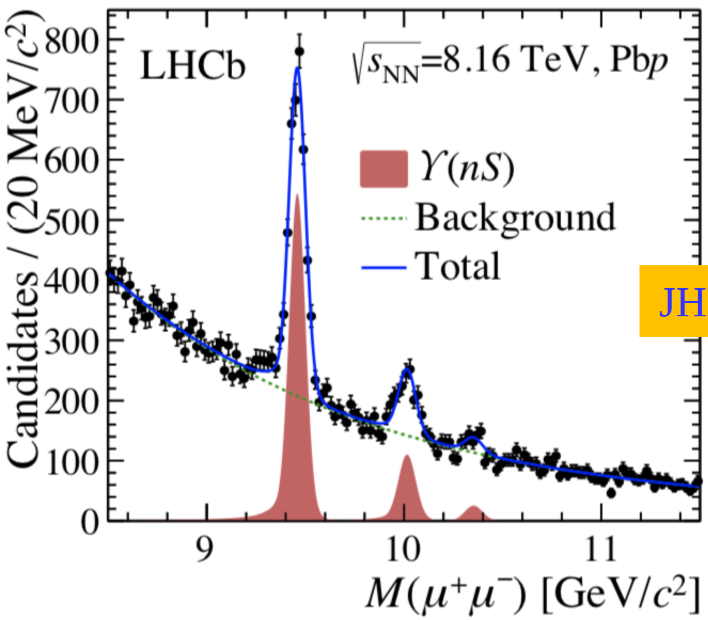


Backward



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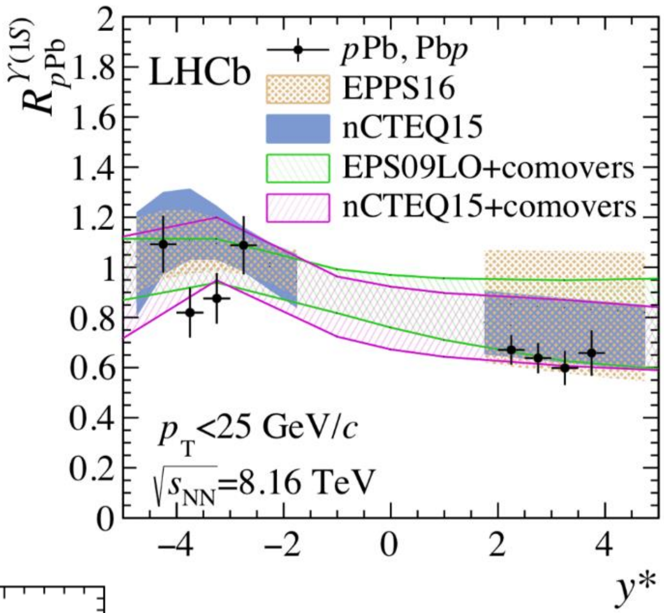
$\Upsilon(1S)$ R_{pPb} at 8.16 TeV

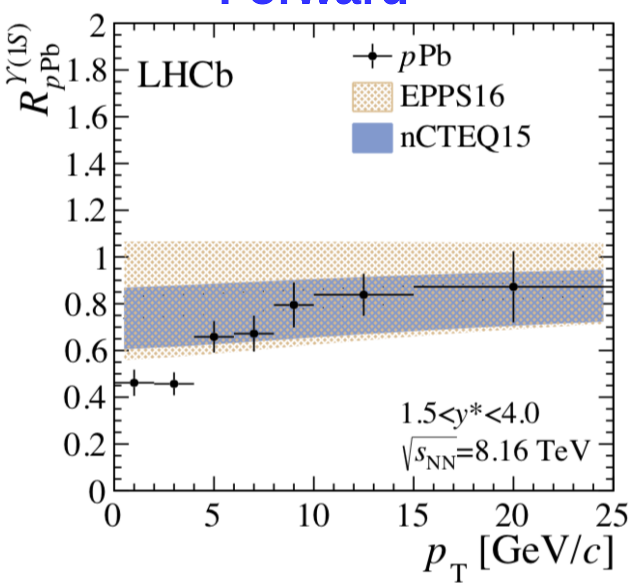
Nuclear modification factor:

$$R_{p\mathrm{Pb}}(p_\mathrm{T}, y^*) = \frac{1}{208}\frac{\mathrm{d}^2\sigma_{p\mathrm{Pb}}(p_\mathrm{T}, y^*)/\mathrm{d}p_\mathrm{T}\mathrm{d}y^*}{\mathrm{d}^2\sigma_{pp}(p_\mathrm{T}, y^*)/\mathrm{d}p_\mathrm{T}\mathrm{d}y^*}$$

- Suppression in the forward pPb region confirmed



Forward



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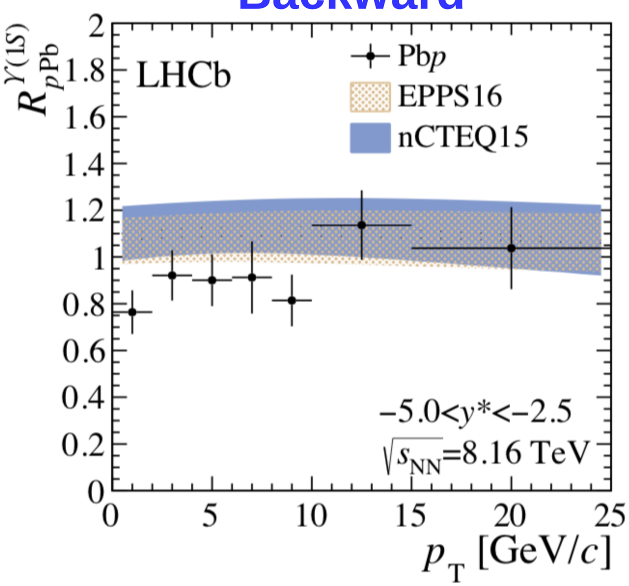

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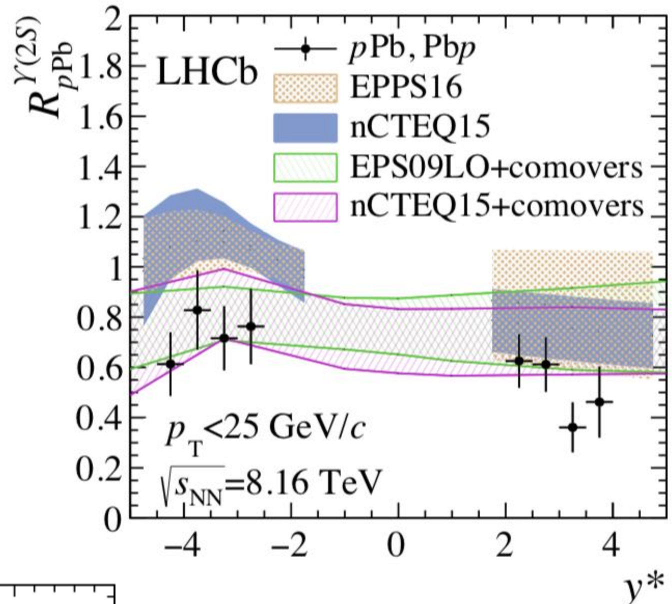
$\Upsilon(2S)\ R_{pPb}$ at 8.16 TeV

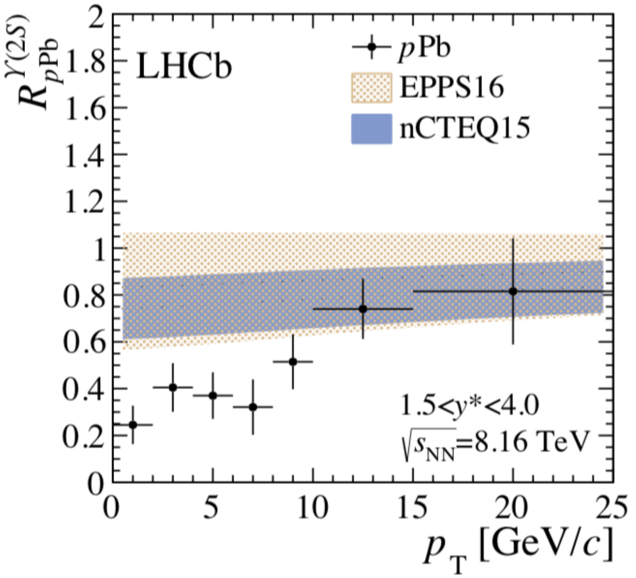
Nuclear modification factor:

$$R_{p\mathrm{Pb}}(p_\mathrm{T}, y^*) = \frac{1}{208}\frac{\mathrm{d}^2\sigma_{p\mathrm{Pb}}(p_\mathrm{T}, y^*)/\mathrm{d}p_\mathrm{T}\mathrm{d}y^*}{\mathrm{d}^2\sigma_{pp}(p_\mathrm{T}, y^*)/\mathrm{d}p_\mathrm{T}\mathrm{d}y^*}$$

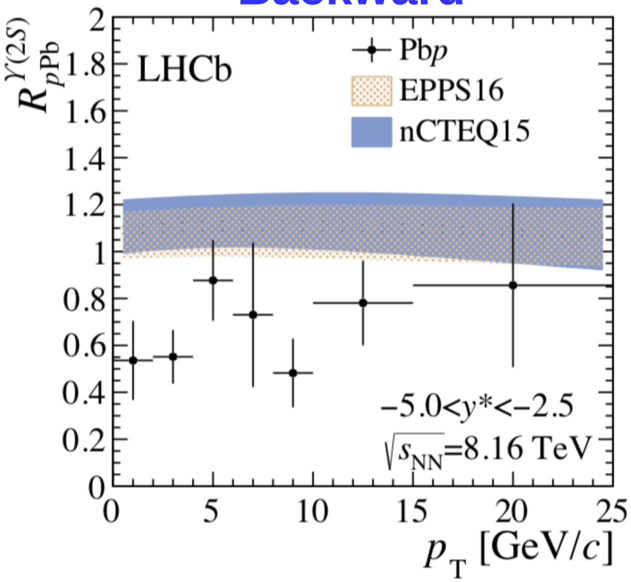
- More suppression in the forward pPb region



Forward



Backward



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$\Upsilon(2S)$ to $\Upsilon(1S)$ ratio in pPb at 8.16 TeV

$$R(\Upsilon(nS)) = \frac{[\mathrm{d}^2\sigma/\mathrm{d}p_\mathrm{T}dy^*]\,(\Upsilon(nS))}{[\mathrm{d}^2\sigma/\mathrm{d}p_\mathrm{T}dy^*]\,(\Upsilon(1S))}$$

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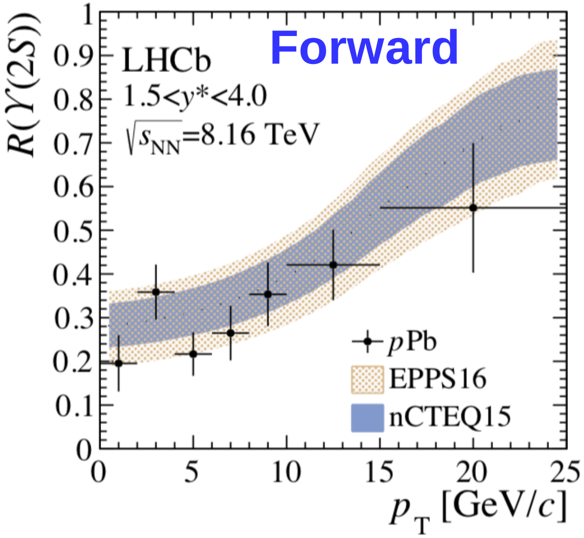
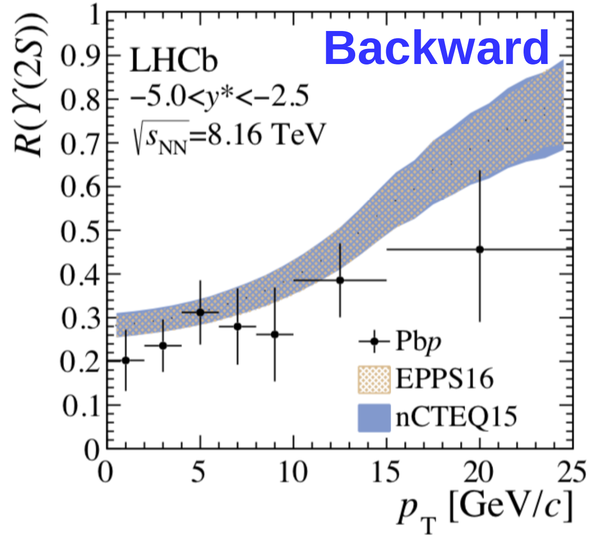
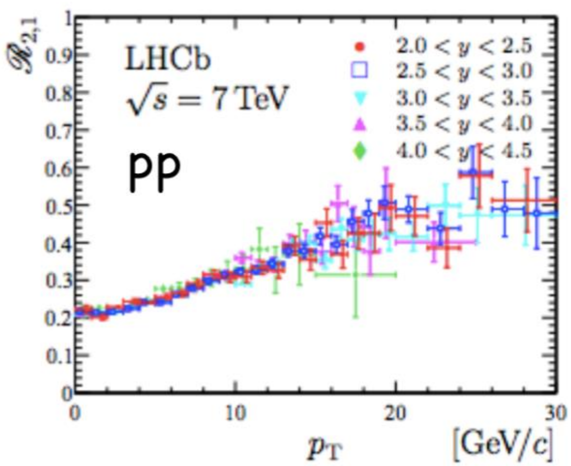
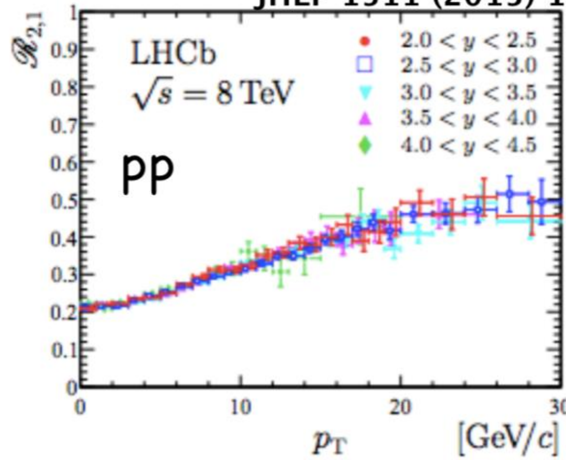
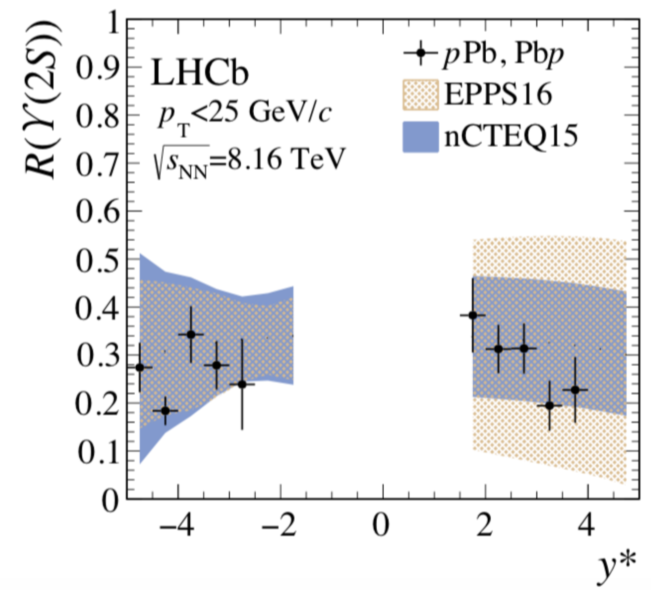






JHEP 1511 (2015) 103





$\Upsilon(nS)$ double ratios in pPb at 8.16 TeV

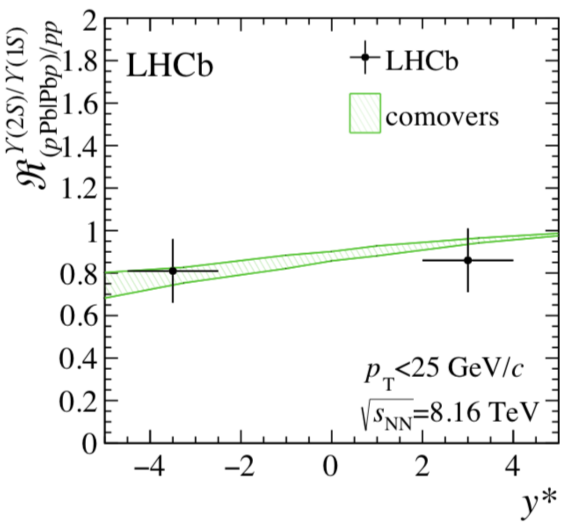
$$\mathfrak{R}^{\Upsilon(nS)/\Upsilon(1S)}_{(p\mathrm{Pb}|\mathrm{Pb}p)/pp} = \frac{R(\Upsilon(nS))_{p\mathrm{Pb}|\mathrm{Pb}p}}{R(\Upsilon(nS))_{pp}}$$

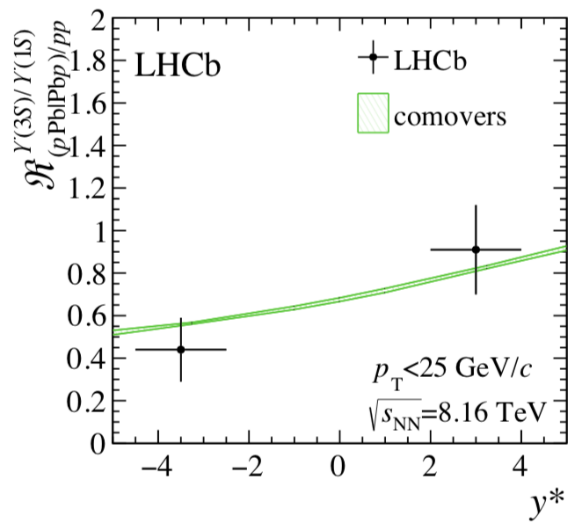
$$\mathfrak{R}^{\Upsilon(2S)/\Upsilon(1S)}_{p\mathrm{Pb}/pp} = 0.86 \pm 0.15,$$

$$\mathfrak{R}^{\Upsilon(3S)/\Upsilon(1S)}_{p\mathrm{Pb}/pp} = 0.81 \pm 0.15,$$

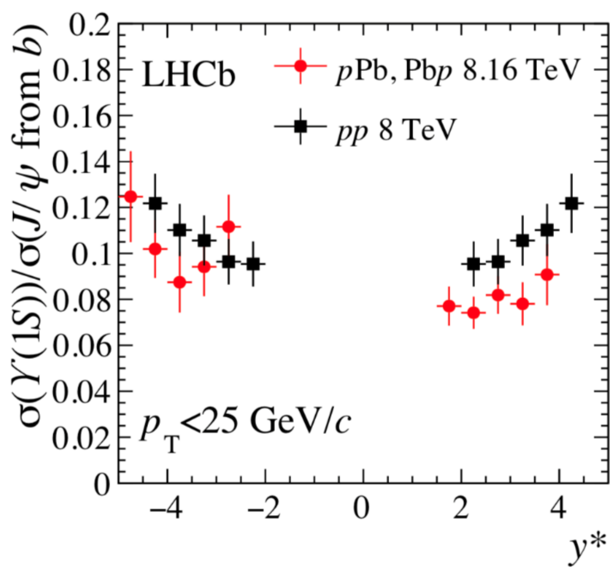
$$\mathfrak{R}^{\Upsilon(2S)/\Upsilon(1S)}_{\mathrm{Pb}p/pp} = 0.91 \pm 0.21,$$

$$\mathfrak{R}^{\Upsilon(3S)/\Upsilon(1S)}_{\mathrm{Pb}p/pp} = 0.44 \pm 0.15.$$





Ratio of $\Upsilon(1S)$ over non-prompt J/ψ



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Open beauty signals in pPb at 8.16 TeV

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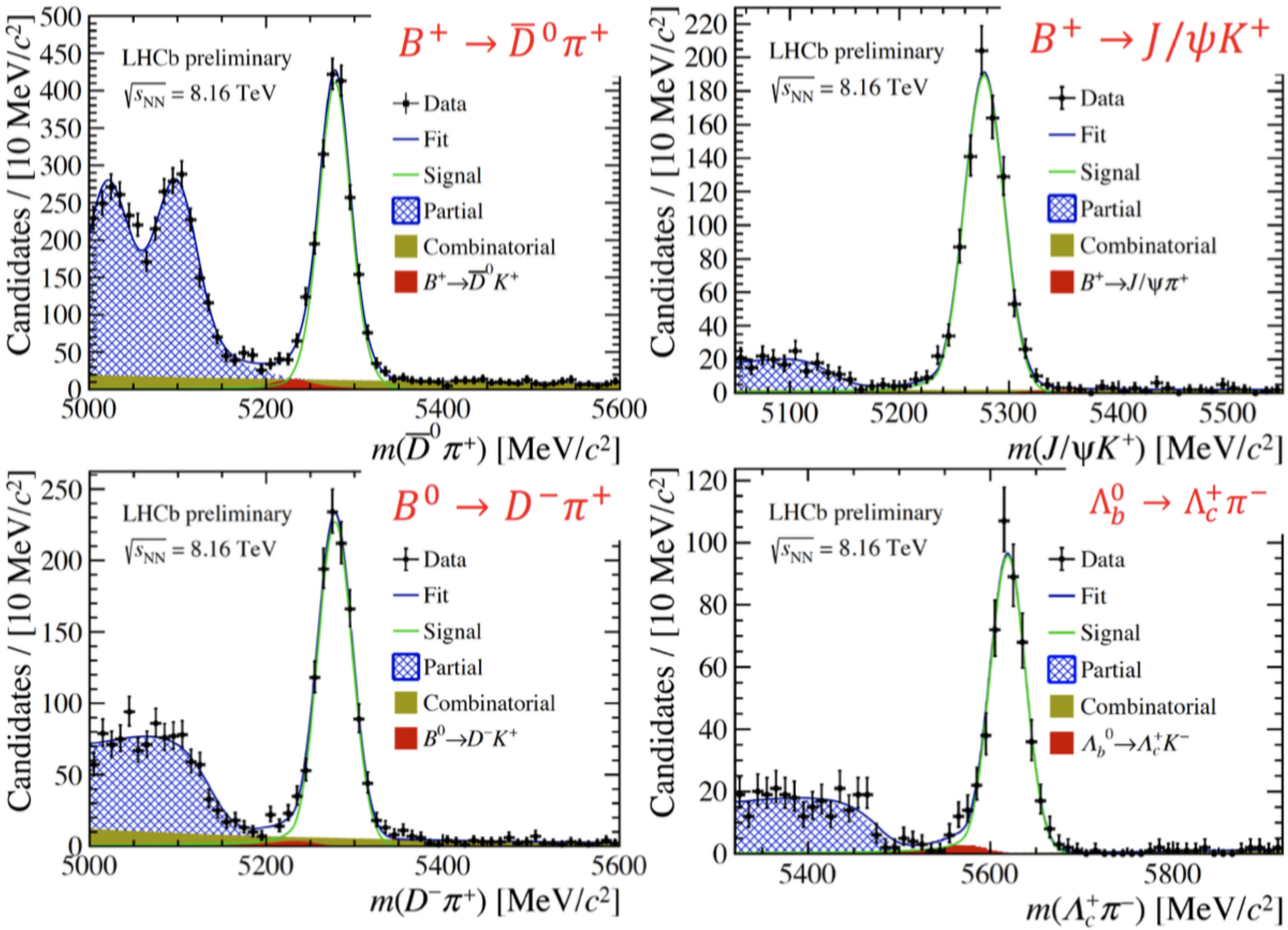
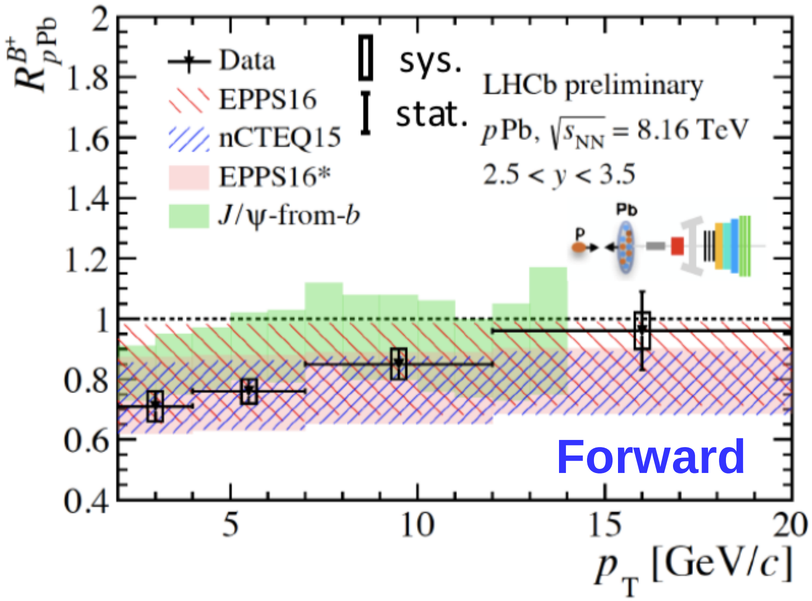
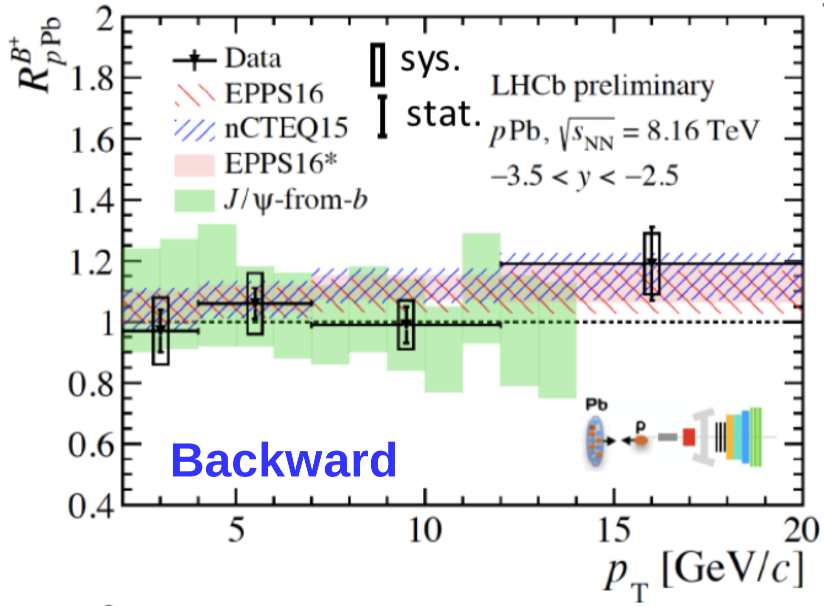


Open beauty R_{pPb} at 8.16 TeV





- Forward: suppressed, increases with p_{T}
- Backward: ≈ 1
- Data are consistent with nPDF calculations and J/ψ from b decay
- Beauty suppression is comparable to charm

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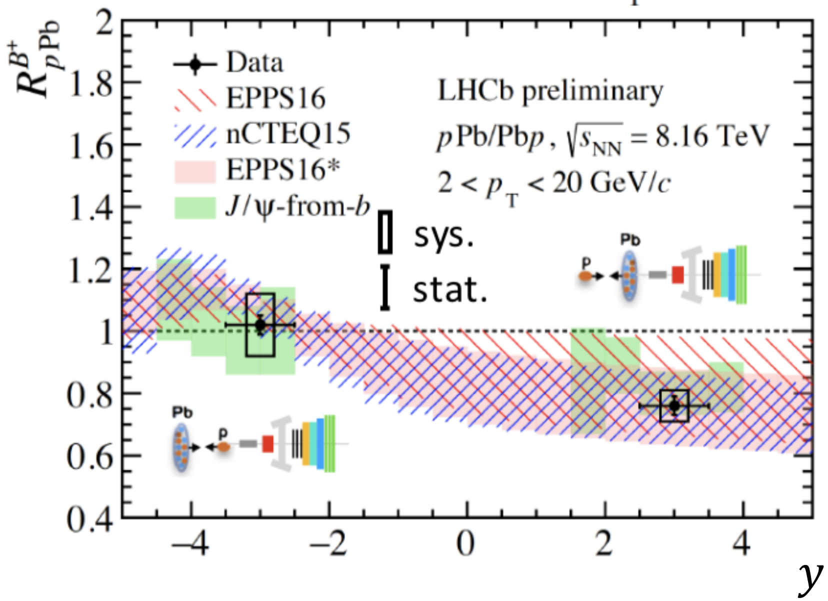
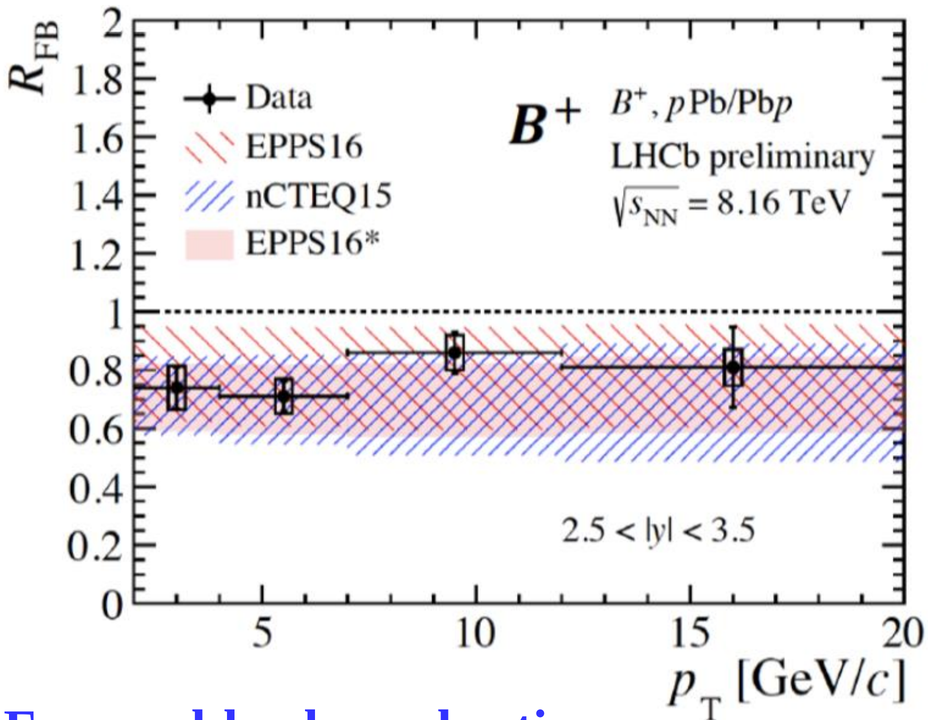
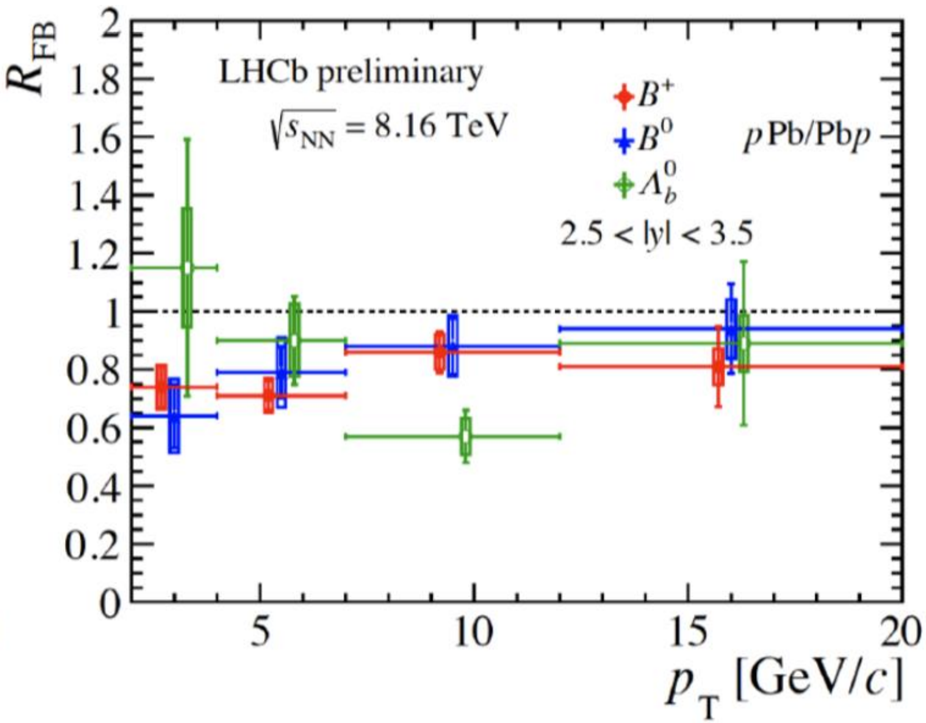


Open beauty forward-backward ratio at 8.16 TeV





Forward-backward ratio:

$$R_{\rm FB} = \frac{\sigma(+|y^*|, p_{\rm T})}{\sigma(-|y^*|, p_{\rm T})}$$

- $R_{\rm FB}$ for B mesons < 1, consistent with nPDF calculations
- $R_{\rm FB}$ for B^0 and B^+ are similar
- $R_{\rm FB}$ for Λ_b^0 suffers larger statistical uncertainty

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Open beauty particle ratios at 8.16 TeV

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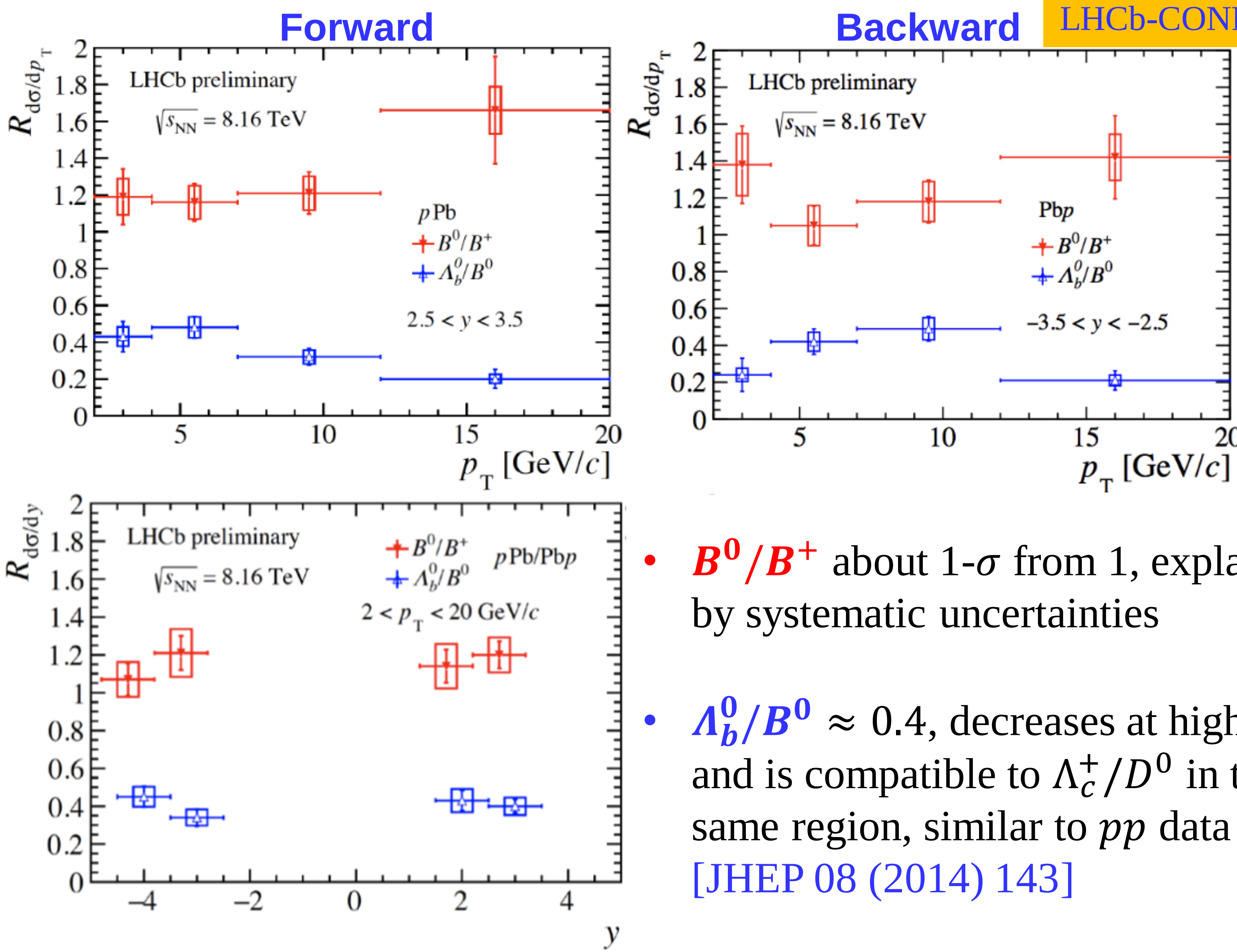
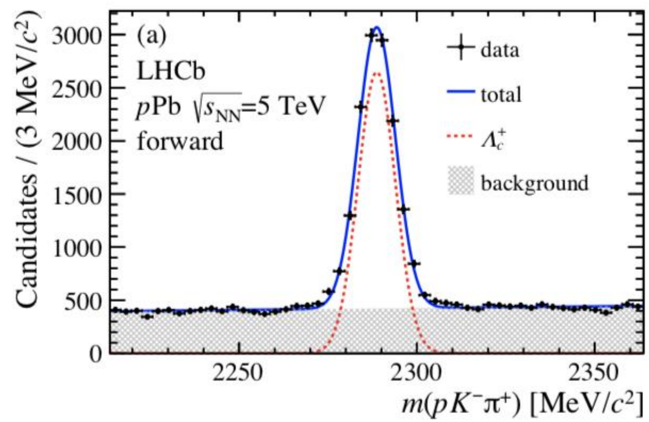
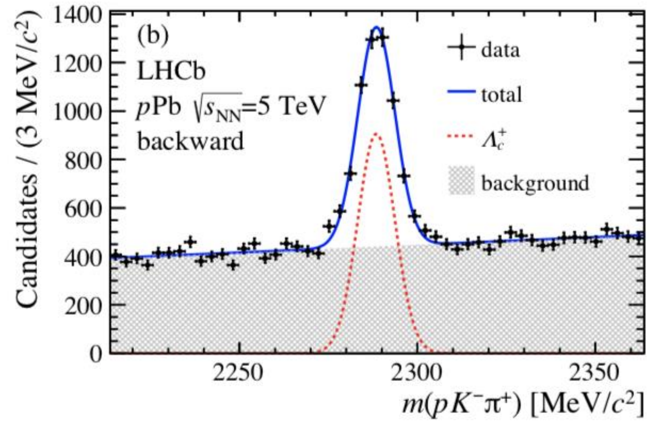


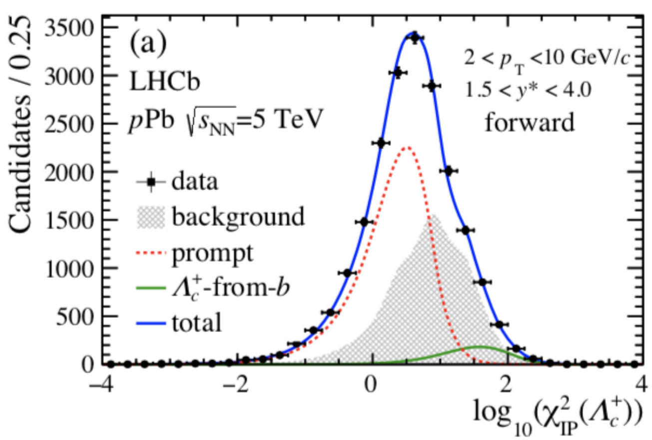
- $\boldsymbol{B^0/B^+}$ about 1-σ from 1, explained by systematic uncertainties
- $\boldsymbol{\Lambda_b^0/B^0} \approx 0.4$, decreases at high p_T, and is compatible to Λ_c^+/D^0 in the same region, similar to pp data [JHEP 08 (2014) 143]

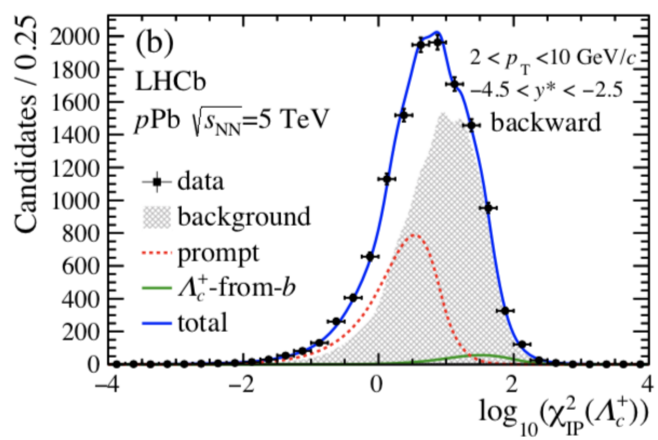
Prompt Λ_c^+ measurement in pPb at 5 TeV

Forward | **Backward**





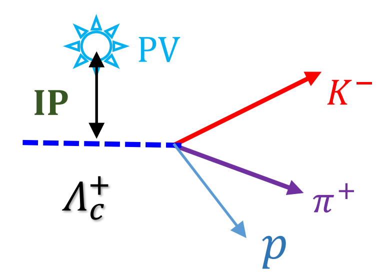




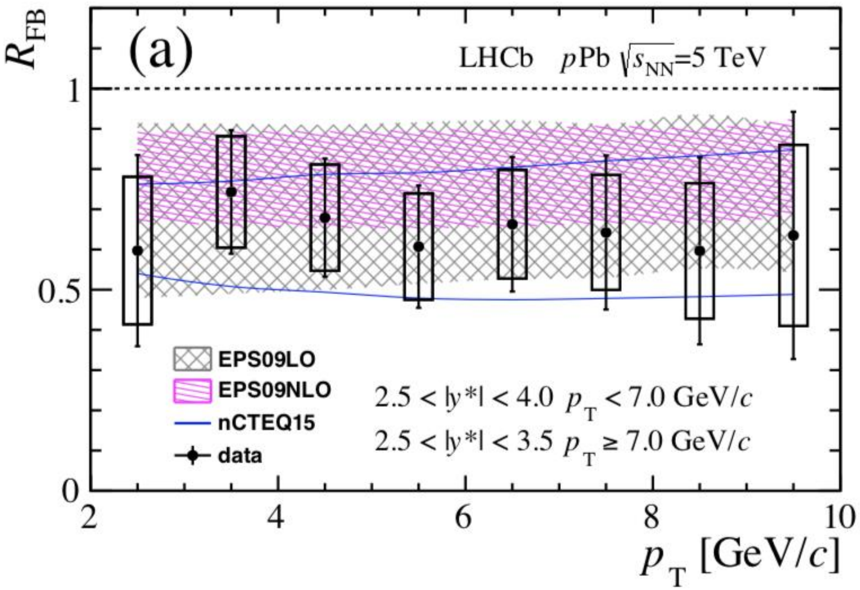
arXiv: 1809.01404,
submitted to JHEP
Jiayin Sun, HI session

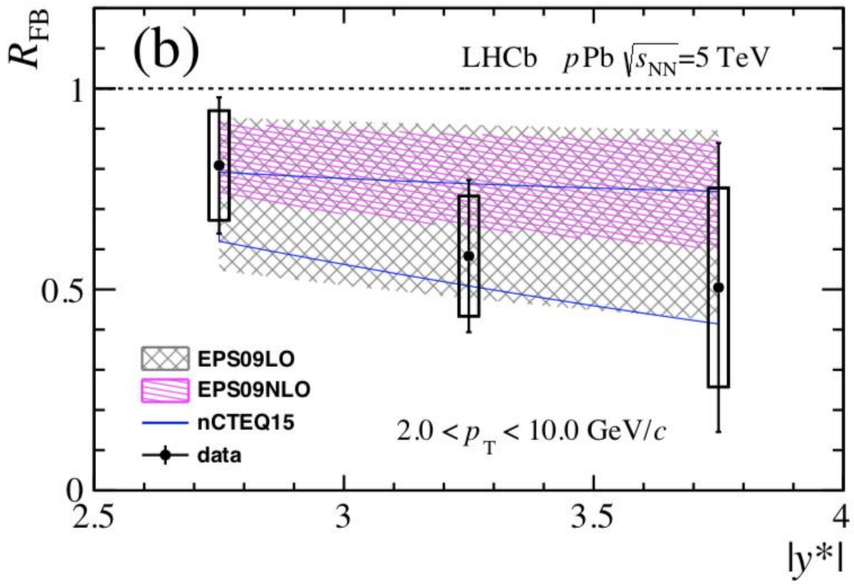
$\Lambda_c^+ \to pK^-\pi^+$

Prompt Λ_c^+ fraction extracted from fitting impact parameter (IP) distribution



Prompt Λ_c^+ forward-backward ratio at 5 TeV





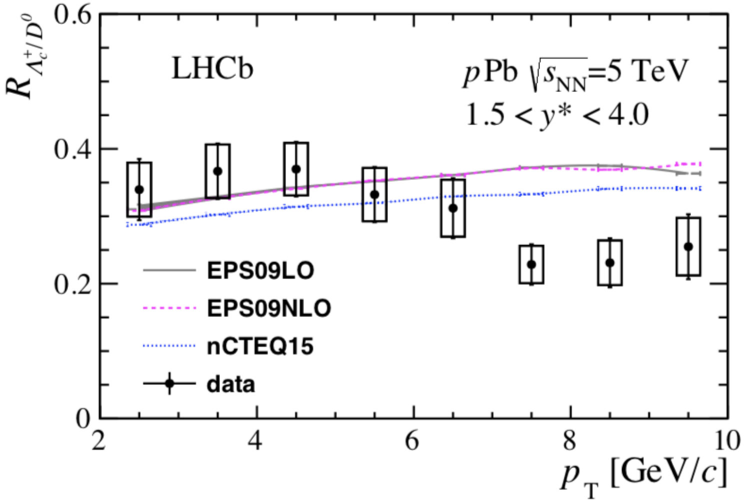
Forward-backward ratio: $$R_{FB} = \frac{\sigma(+|y^*|, p_T)}{\sigma(-|y^*|, p_T)}$$

arXiv: 1809.01404, submitted to JHEP

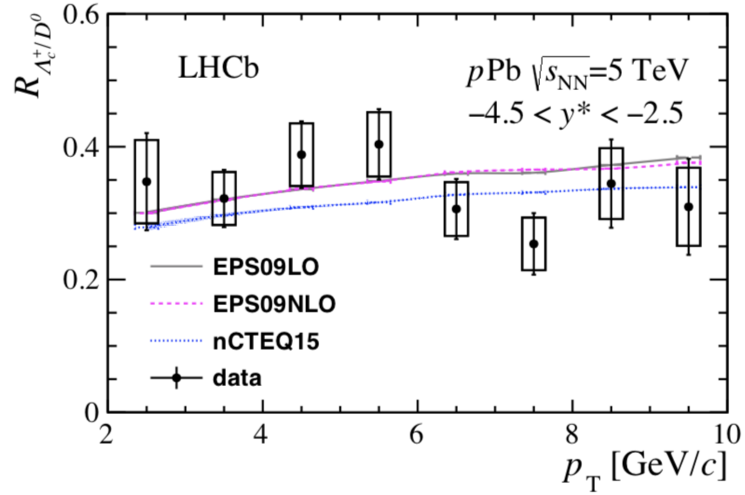
- Consistent with nPDF HELAC-onia calculations within uncertainty

Charmed baryon to meson ratio at 5 TeV

Forward



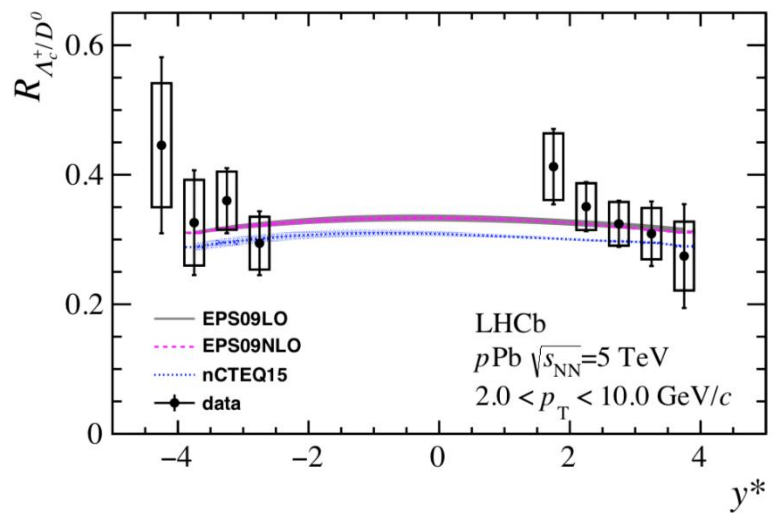
Backward



$$R_{\Lambda_c^+/D^0} = \frac{\sigma_{\Lambda_c^+}(y^*, p_{\mathrm{T}})}{\sigma_{D^0}(y^*, p_{\mathrm{T}})}$$

- Sensitive to charm hadronization mechanisms
- Calculations based on measured *pp* cross-section

arXiv: 1809.01404, submitted to JHEP

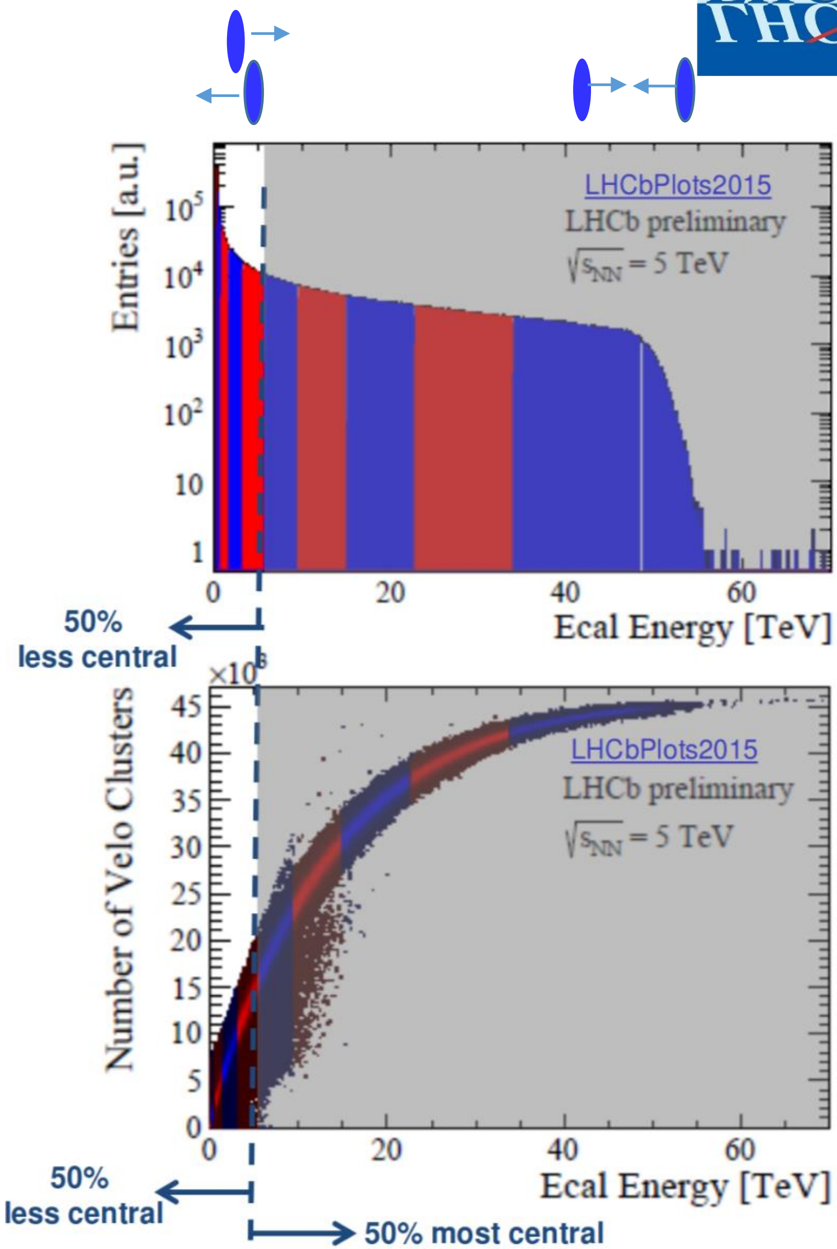


PbPb collisions with LHCb

Ion-Ion runs:

- 10 μb^{-1} PbPb at 5.02 TeV (2015)
- 0.4 μb^{-1} XeXe at 5.44 TeV (2017)
- **~ 200 μb^{-1} PbPb at 5.02 TeV (2018)**

- Collision centrality measured by the calorimeter
- Saturation in the Vertex Locator for the most central PbPb collisions
- LHCb current tracking algorithm efficient up to 50% most central collisions
- Physics studies limited to 50% less central events

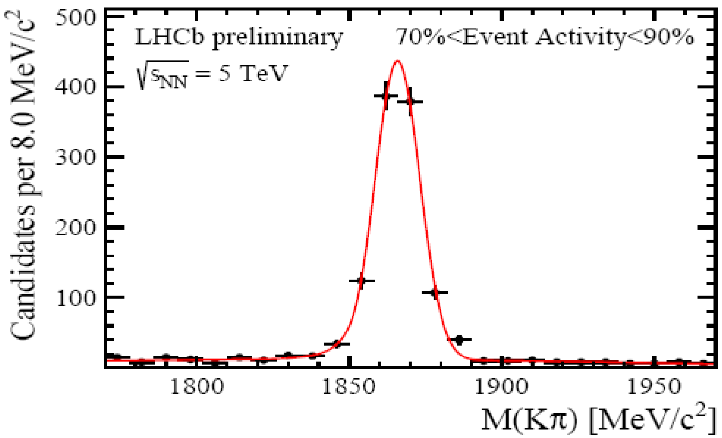


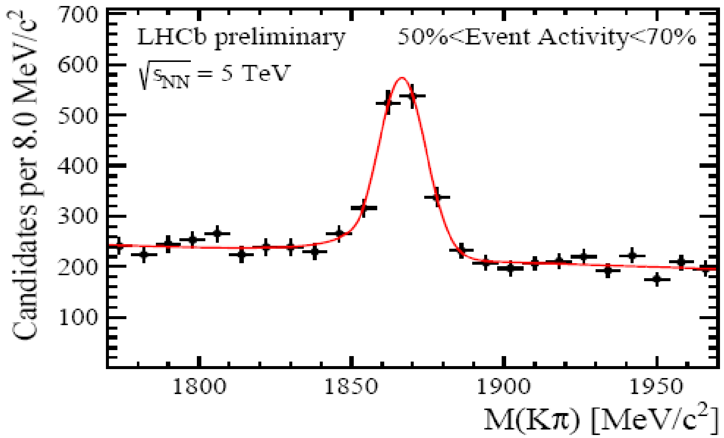
https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbPlots2015

D^0 and J/ψ in PbPb (2015)

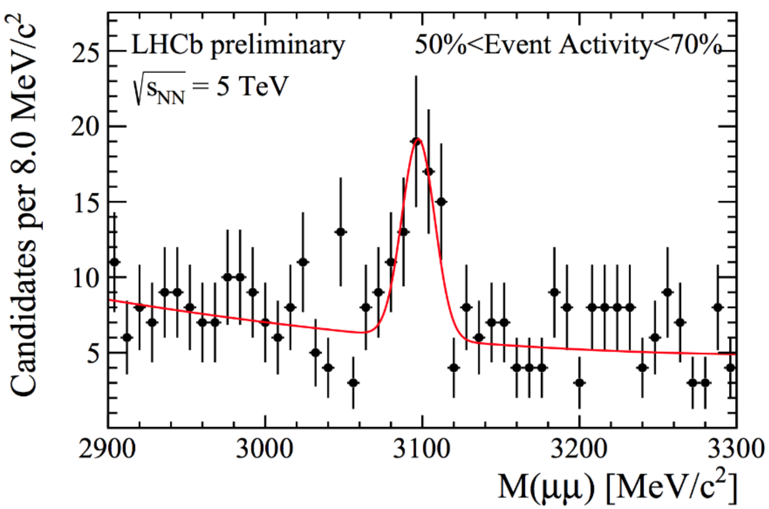
https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbPlots2015

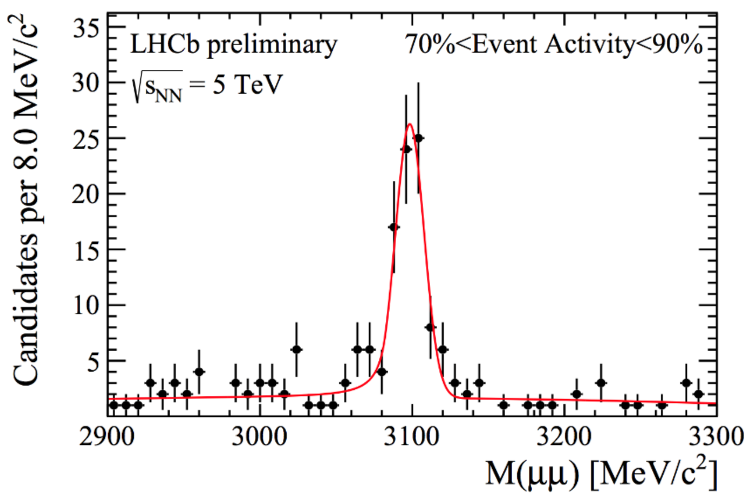
$D^0 \to K^-\pi^+$





$J/\psi \to \mu^-\mu^+$





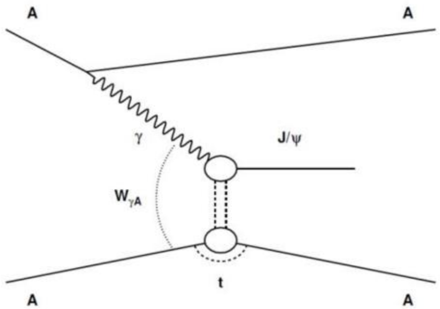
J/ψ in PbPb ultra peripheral collisions

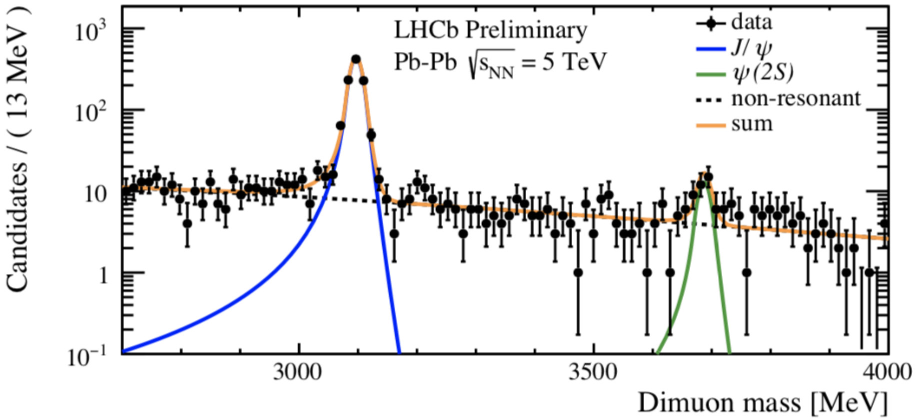
Interaction between the magnetic field of the ions

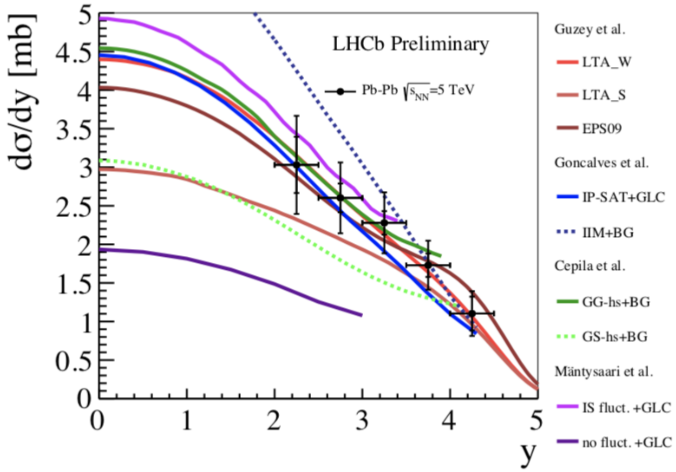
→ Coherent J/ψ photo-production, sensitive to nPDF, …

No additional particle production

LHCb-CONF-2018-003







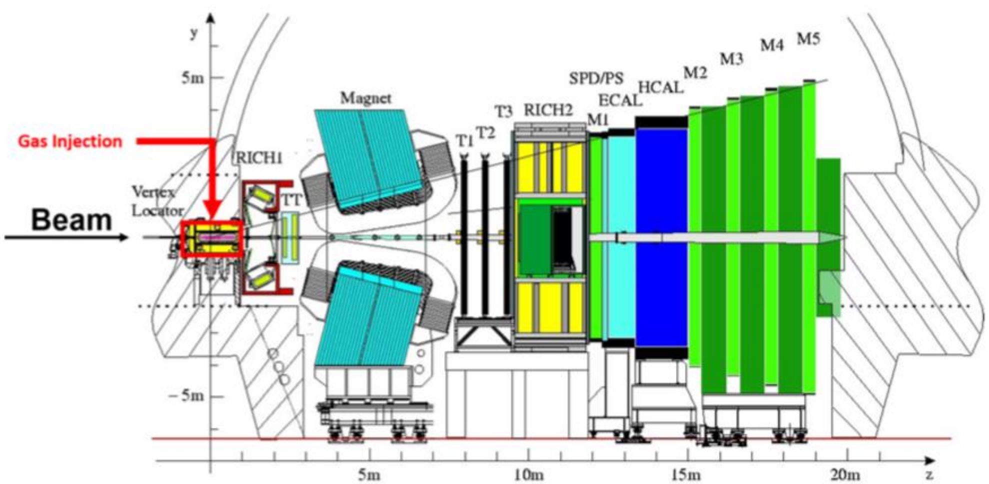
→ Constraint on model space

2018 PbPb run: ~20 times more luminosity and include other final states in exclusive γ-induced reactions

The LHCb fixed-target experiment

Unique fixed-target configuration at the LHC *JINST 9 (2014) P12005*

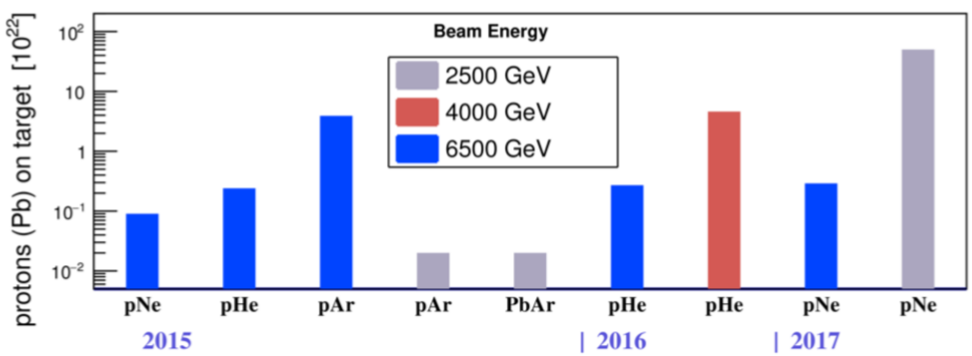
Inject noble gas (He, Ne, Ar, …) inside the Vertex Locator ~ 10^{-7}mbar



- Installed for beam-gas imaging
- In parallel with collider data taking
- Fully benefit from LHCb excellent performance

→ New physics opportunities with p-nucleus and Pb-nucleus collisions

Heavy-ion and cosmic ray related physics



Fixed-target kinematic region

$\sqrt{s_{\rm NN}} \in [69, 115]$ GeV

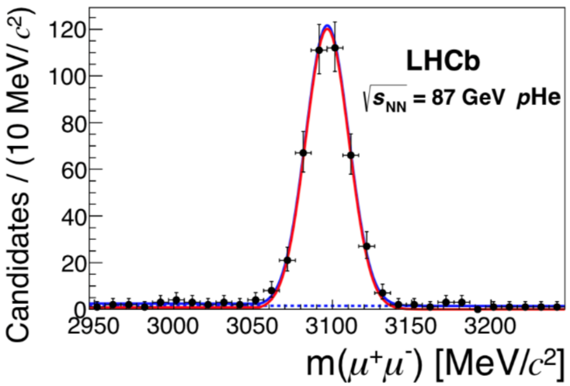
Backward rapidity region

PbNe data were just taken in 2018

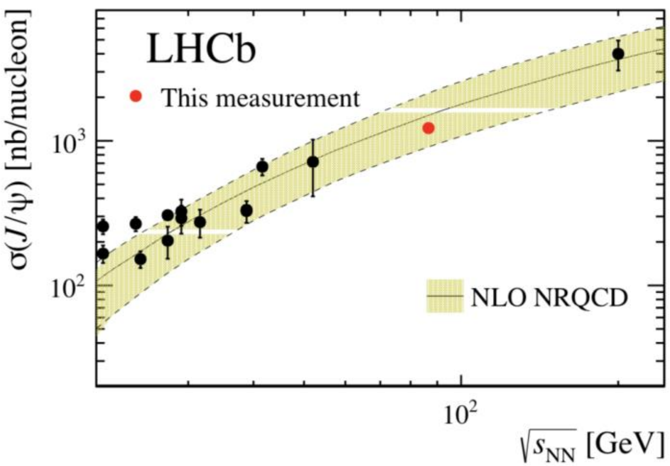
Charm production in fixed-target pHe collisions

arXiv:1810.07907, submitted to PRL

J/ψ

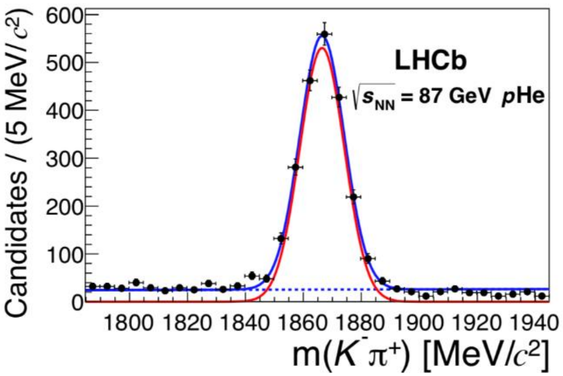


$$\sigma_{J/\psi} = 1225.6 \pm 100.7\,\mathrm{nb/nucleon}$$



LHCb result in good agreement with NRQCD fit and other measurements

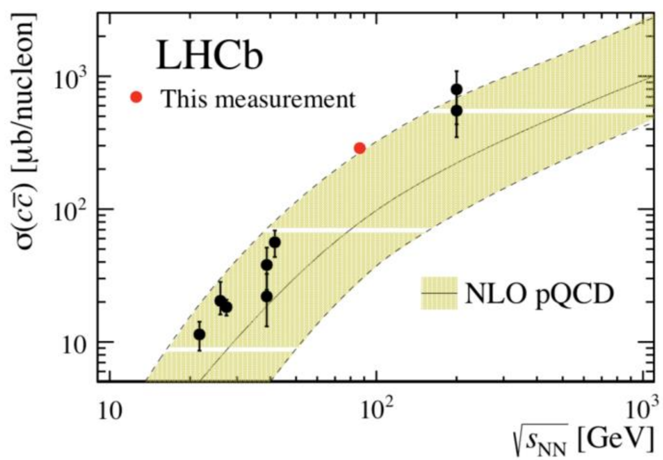
D^0



$$\sigma_{D^0} = 156.0 \pm 13.1\,\mu\mathrm{b/nucleon}$$

with fraction ($c \rightarrow D^0$) = 0.542 ± 0.024

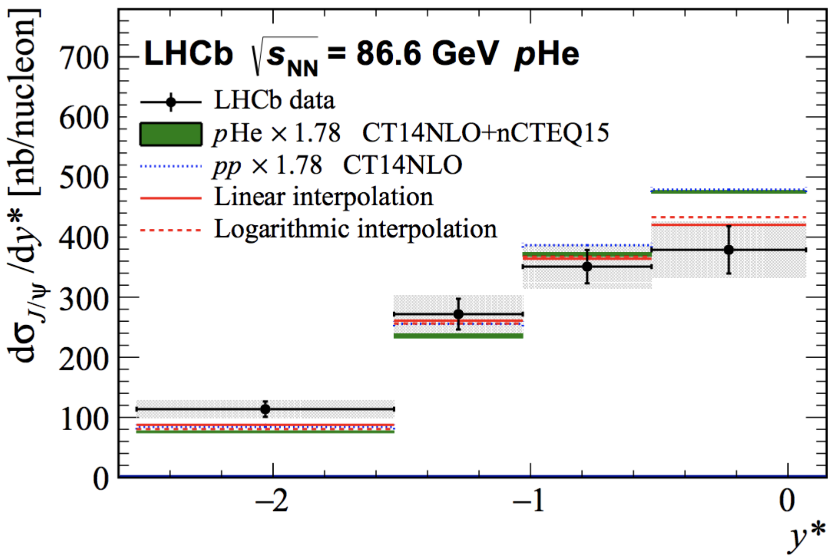
$$\sigma_{c\bar{c}} = 288 \pm 24.2 \pm 6.9\,\mu\mathrm{b/nucleon}$$

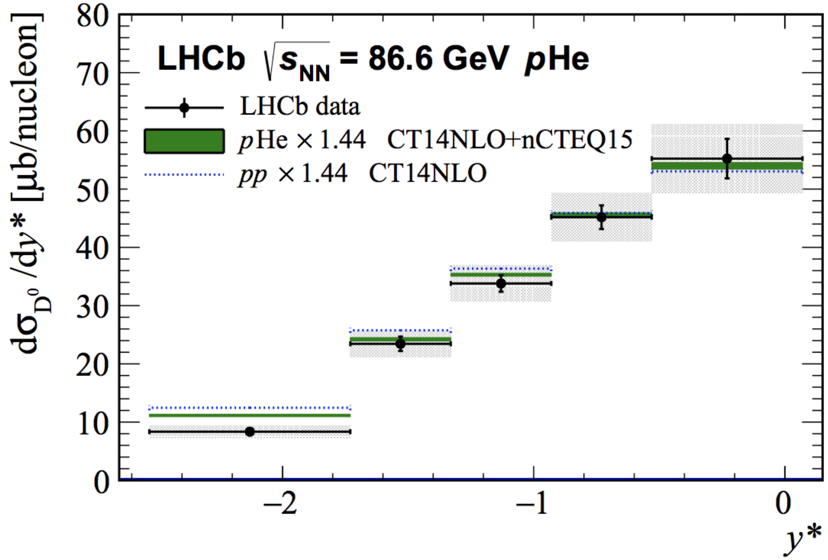


LHCb result in reasonable agreement with NLO pQCD (MNR) predictions and other measurements

Charm production in fixed-target pHe collisions

arXiv:1810.07907, submitted to PRL





Cross-sections are compared with

- Phenomenological parametrisations (JHEP 03 (2013) 122) for J/ψ
  → Shape in agreement
- HELAC-onia model EPJC 77 (2017) designed and tuned for collider data
  → Reasonable agreement

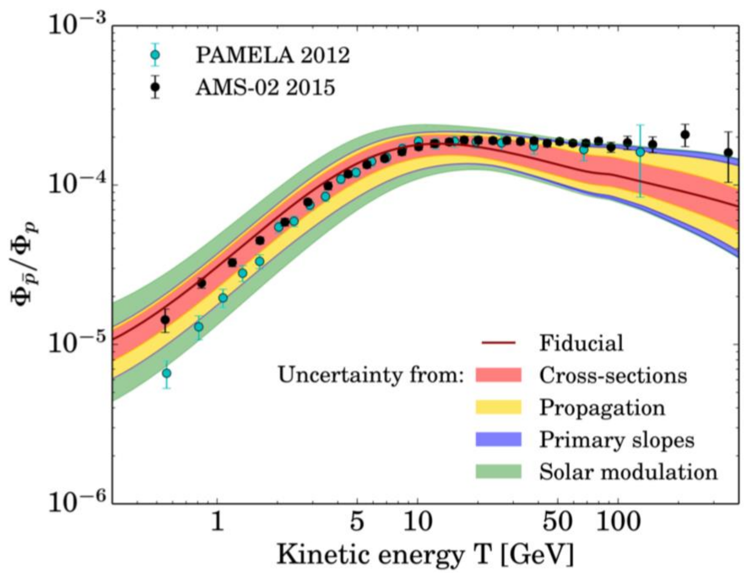
No indication of visible valence-like intrinsic charm in rapidity distribution
Starting point for more detailed proton-Neon and future Lead-Neon collisions

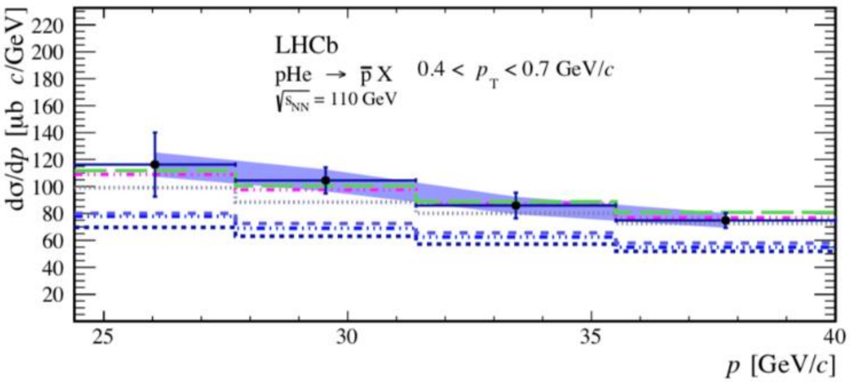
$\bar{p}$ production in fixed-target pHe collisions

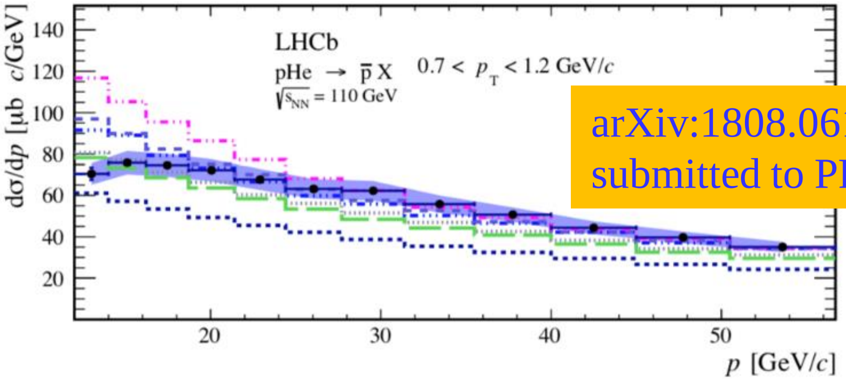
The first direct measurement of antiproton production in pHe collisions

- Incident proton beam energy, 6.5 TeV
- Integrated luminosity, 0.5 nb^{-1}

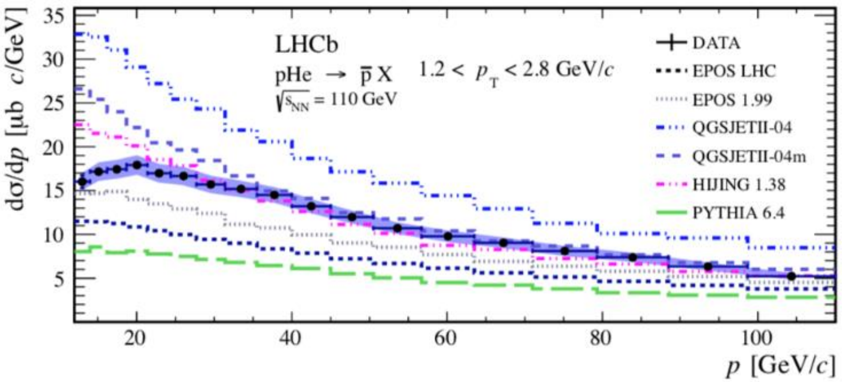
Important input for the study of antiproton cosmic rays from space-borne experiments







arXiv:1808.06127, submitted to PRL



Summary

- The LHCb detector has unique capabilities for heavy flavor measurements at LHC in both collider and fixed-target modes.
- (Selected) recent production measurements in 2018
  - $\Upsilon(nS)$ in pp 13 TeV
  - $\Upsilon(nS)$, B^0, B^+, Λ_b^0, Λ_c^+ in pPb collisions
  - J/ψ in ultra peripheral PbPb collisions
  - First charm and anti-proton measurements in fixed-target collisions
- A lot more results to come with the large data samples of pp/pPb/PbPb and fixed-target collisions collected in Run II.