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Xacobeo 2021 galicia

Quarkonia production in pPb collisions

Óscar Boente García on behalf of the LHCb collaboration

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Hard Probes 2020 - Austin, Texas (Online)

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Why quarkonia in pPb?

- Quarkonia states are a benchmark for QCD studies
  - produced in the initial state of the collision
  - probe of QGP in PbPb ➡ Sequential melting $\Upsilon(nS) \rightarrow \chi_{cn} \rightarrow \psi(2S) \rightarrow J/\psi$
  - simpler systems (pPb) gateway to more complex (PbPb)

- Many effects might play a role in pPb:
  - nPDF modification → (anti)shadowing effects — HELAC-ONIA: CPC 198 (2016) 238; FONLL: JHEP 05 (1998) 007
  - gluon saturation → Color Glass Condensate — B. Ducloué et al., PRD 91 (2015) 114005, PRD 94 (2016) 074031
  - parton propagation in medium → Energy loss — F. Arleo, S. Peigné, JHEP 03 (2013) 122

  } **Initial state effects**

  - break up in nuclear matter
  - break up by comoving particles — E. G. Ferreiro *et* al., arXiv:1804.04474; Phys. Lett. B749 (2015) 98, arXiv:1411.0549

  } **Final state effects**

- Different models can describe data, look at
  - dependencies (η, p_{T}, $\sqrt{s_{NN}}$, multiplicity …)
  - (excited) states

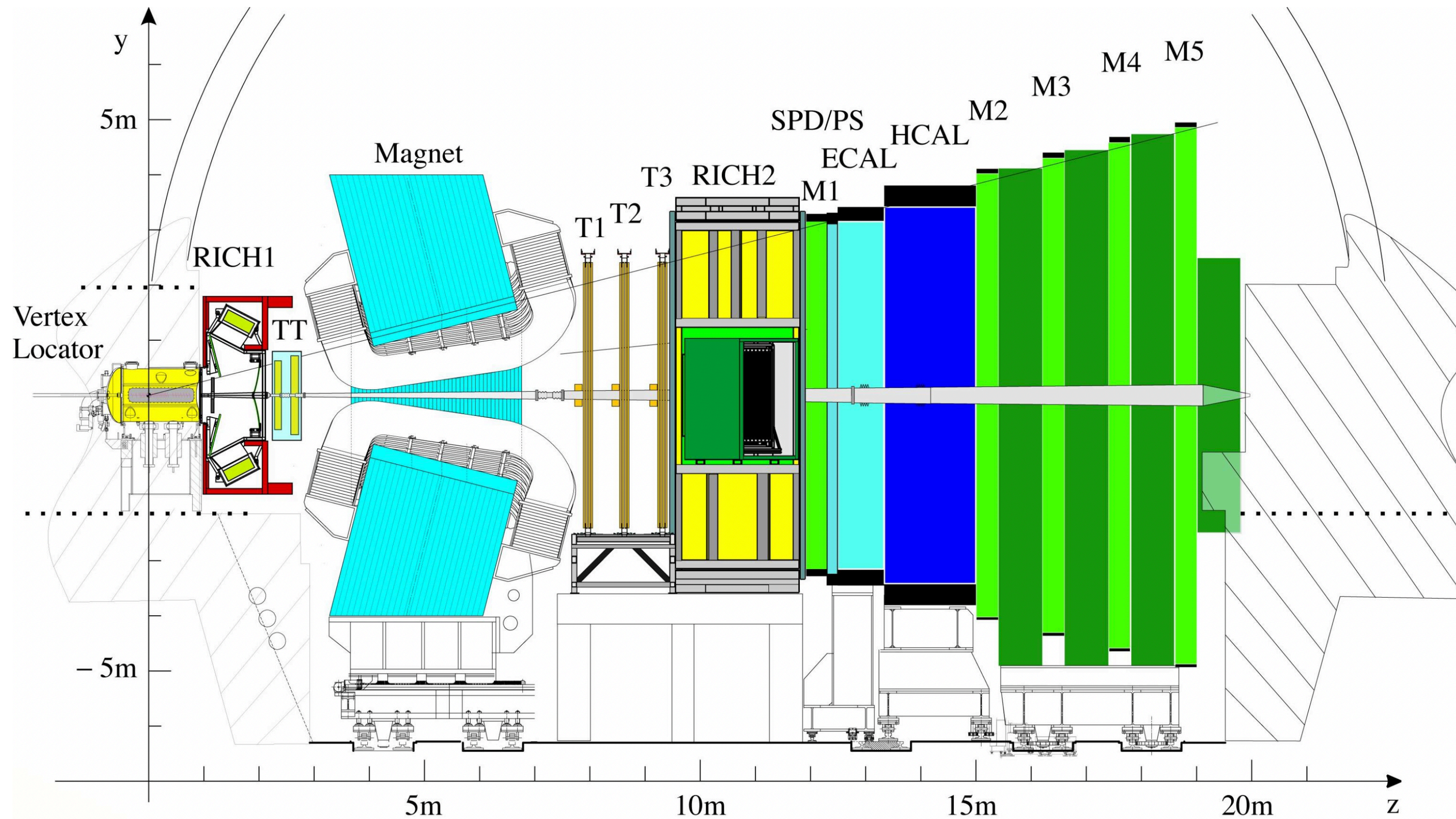
The LHCb detector

- One-arm spectrometer at LHC fully instrumented in $2 < \eta < 5$
  - Tracking system with momentum resolution
    $$\Delta p/p = 0.5 - 1\,\%$$
  - Excellent hadron and muon ID

Muon $\begin{cases} \varepsilon(\mu \to \mu) & \sim 97\,\% \\ \text{misID } \varepsilon(\pi \to \mu) & \sim 1-3\,\% \end{cases}$

Hadron $\begin{cases} \varepsilon(K \to K) & \sim 95\,\% \\ \text{misID } \varepsilon(\pi \to K) & \sim 5\,\% \end{cases}$

  - Precise vertexing



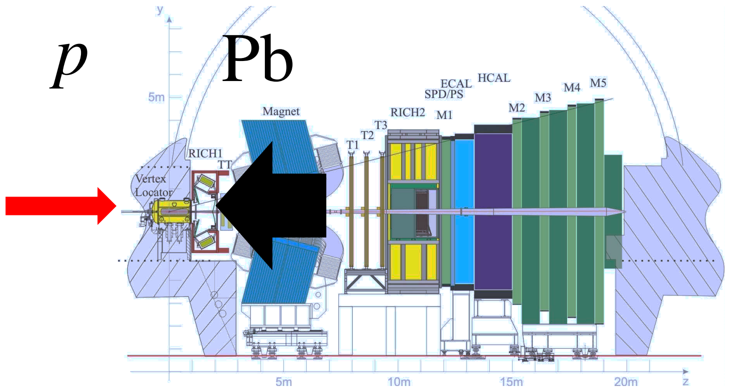
LHCb JINST 3 (2008) S08005

LHCb performance IJMPA 30 (2015) 1530022

➡ LHCb specially suited for quarkonia studies:

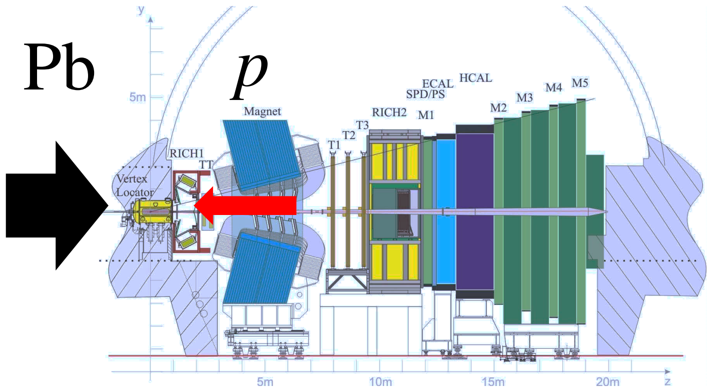
- Excellent mass resolution even at low p_{T} $\longrightarrow$ Disentangle $\Upsilon(nS)$ and χ_{cn} states
- Decay time resolution ~ 45 fs $\longrightarrow$ Separation of prompt vs non-prompt contributions

Datasets and acceptance



Forward configuration

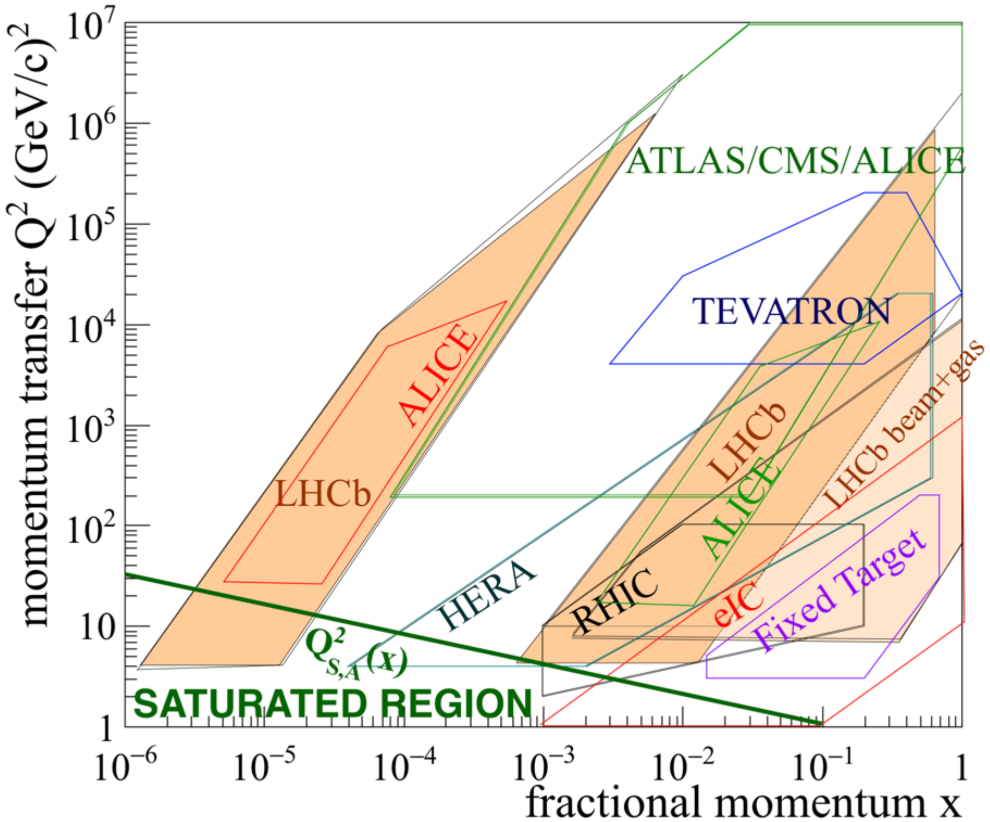
- $1.5 < y^* < 4.0$
- $\mathscr{L}_{int} = 1.1\,\text{nb}^{-1}$ at $\sqrt{s_{NN}} = 5.02\,\text{TeV}$ (2013)
- $\mathscr{L}_{int} = 13.6\,\text{nb}^{-1}$ at $\sqrt{s_{NN}} = 8.16\,\text{TeV}$ (2016)
- Down to $x_{\text{Pb}} \sim 10^{-5}$ (gluon saturation)



Backward configuration

- $-5.0 < y^* < -2.5$
- $\mathscr{L}_{int} = 0.5\,\text{nb}^{-1}$ at $\sqrt{s_{NN}} = 5.02\,\text{TeV}$ (2013)
- $\mathscr{L}_{int} = 20.8\,\text{nb}^{-1}$ at $\sqrt{s_{NN}} = 8.16\,\text{TeV}$ (2016)
- $x_{\text{Pb}} \sim 10^{-2}$ region (anti-shadowing)

y^*: rapidity in center-of-mass system
x_{Pb}: Bjorken x in the colliding nucleus



Prompt and non-prompt J/ψ production at $8.16\,\mathrm{TeV}$

PLB 774 (2017) 159

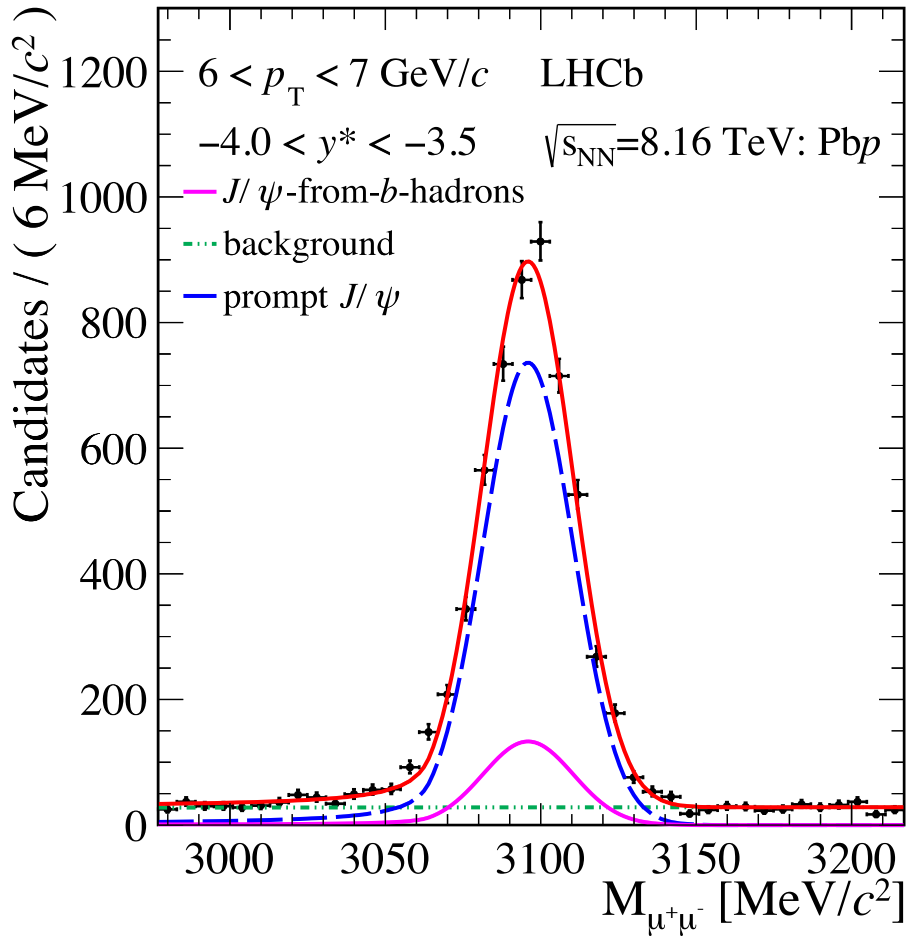
- Measuring $J/\psi \to \mu^+\mu^-$ at $\sqrt{s_{NN}} = 8.16\,\mathrm{TeV}$
- Improved sample size and precision from $5\,\mathrm{TeV}$ analysis (JHEP 02 (2014) 72)
- Discrimination of prompt and non-prompt contribution with pseudo proper time: $t_z \equiv \dfrac{(z_{J/\psi} - z_{\mathrm{PV}}) \times M_{J/\psi}}{p_z}$
- Simultaneous fit to $M_{\mu^+\mu^-}$ and t_z:

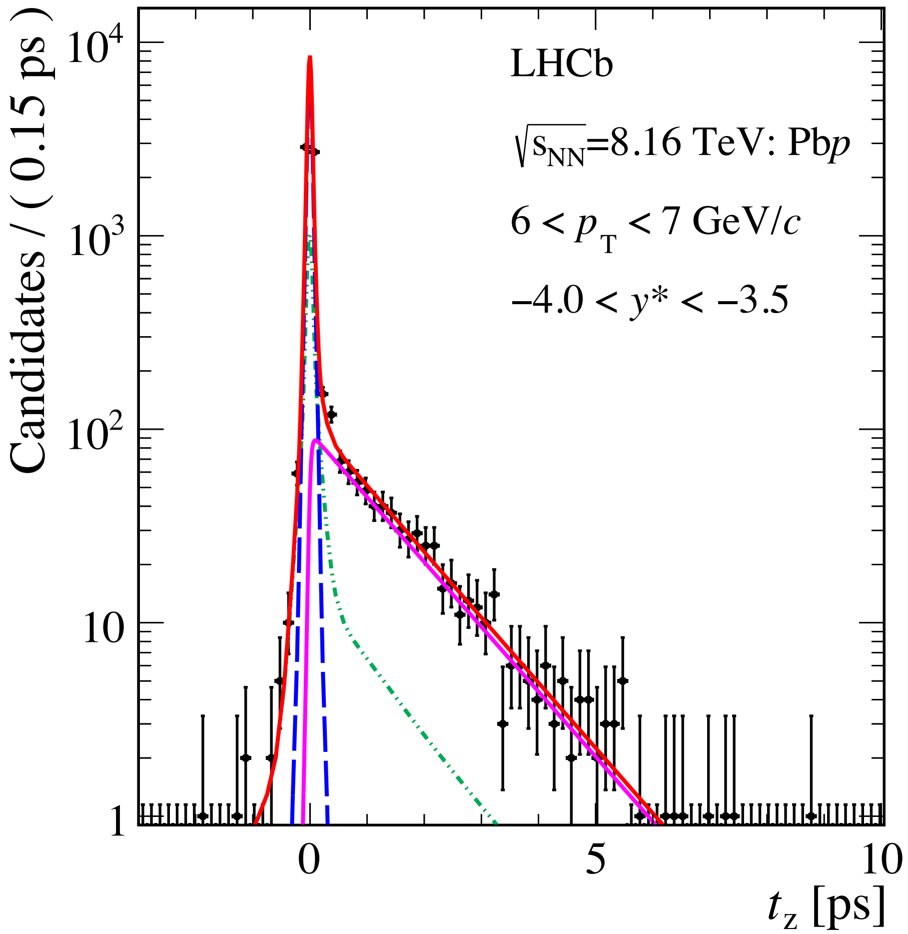
Kinematic coverage:

$0 < p_{\mathrm{T}} < 14\,\mathrm{GeV}/c$

$1.5 < y^* < 4.0$ (forward)

$-5.0 < y^* < -2.5$ (backward)





Prompt and non-prompt J/ψ production at $8.16\,\mathrm{TeV}$

$R^{prompt}_{p\mathrm{Pb}}$ and $R^{from-b}_{p\mathrm{Pb}}$ vs y^*

$$R_{p\mathrm{Pb}} \equiv \frac{\sigma_{p\mathrm{Pb}}}{208 \cdot \sigma_{pp}}$$

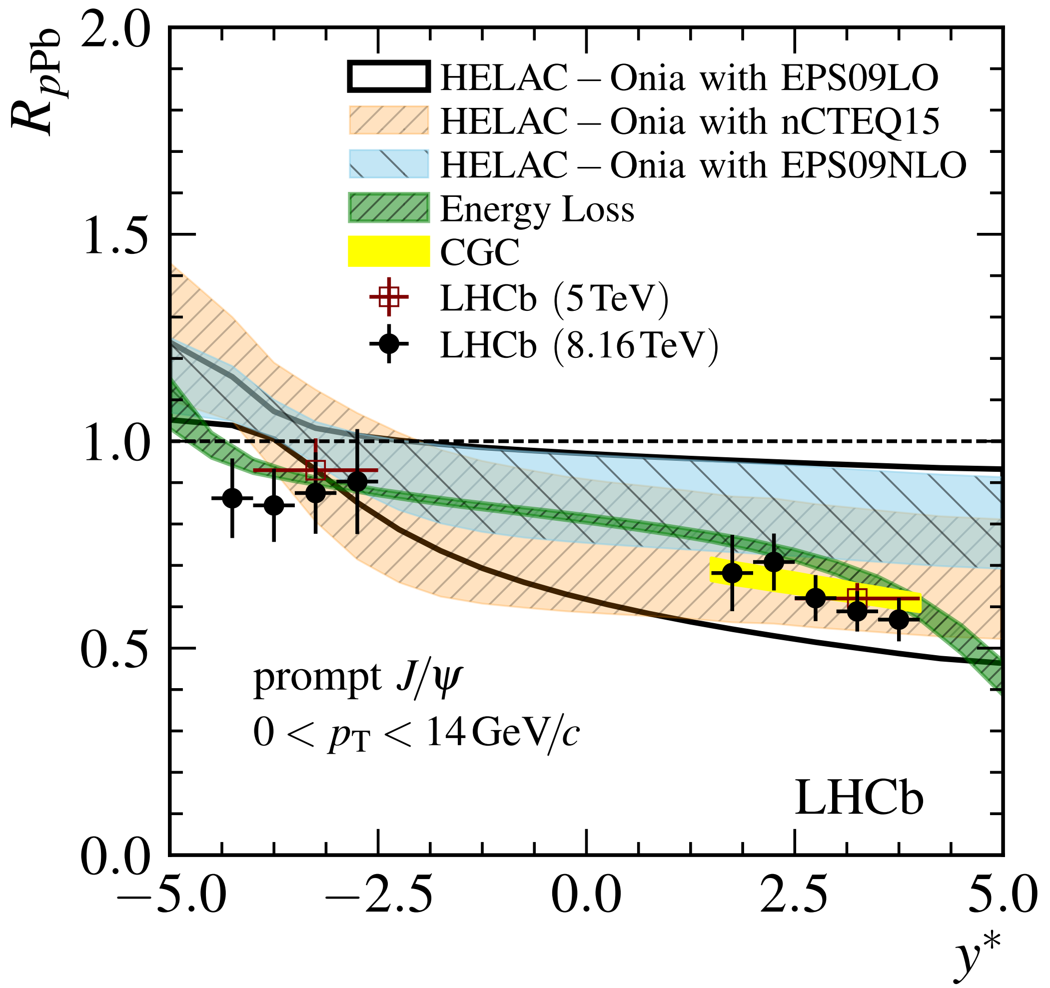
PLB 774 (2017) 159

- Clear suppression in forward region
- Higher suppression in prompt vs non-prompt
- Compatible with $5.02\,\mathrm{TeV}$ result (JHEP 02 (2014) 72)
- Compatible with $R_{p\mathrm{Pb}}$ of B hadrons (Phys. Rev. D99 052011 (2019))

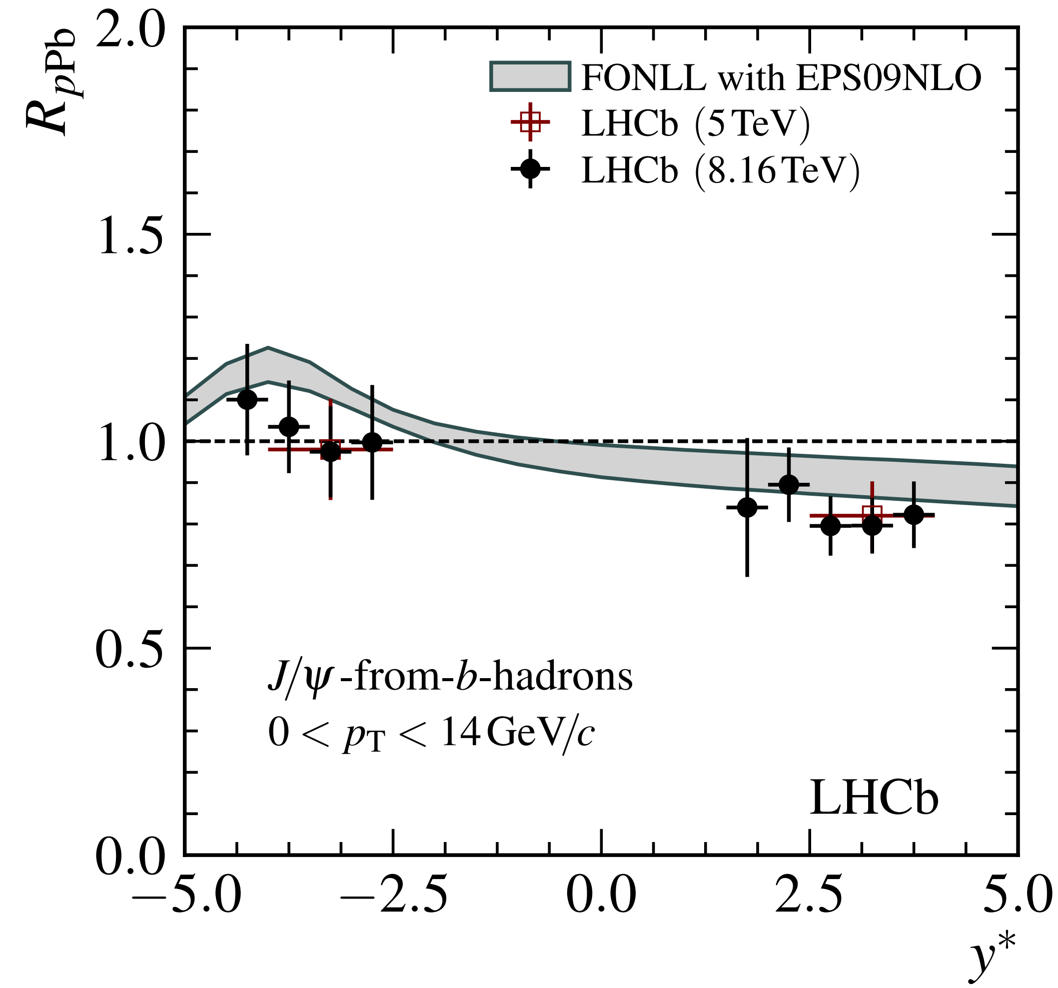
Models for prompt
- HELAC-Onia +nPDF: Comp. Phys. Comm. 198 (2016) 238
- Energy Loss F. Arleo, S. Peigné, JHEP 03 (2013) 122
- CGC (forward) B. Ducloué et al., PRD 91 (2015) 114005 PRD 94 (2016) 074031

Model for non-prompt
- FONLL with EPS09NLO M. Cacciari *et al.*, JHEP 05 (1998) 007

Prompt J/ψ



Non-prompt J/ψ



Prompt and non-prompt J/ψ production at $8.16\,\mathrm{TeV}$

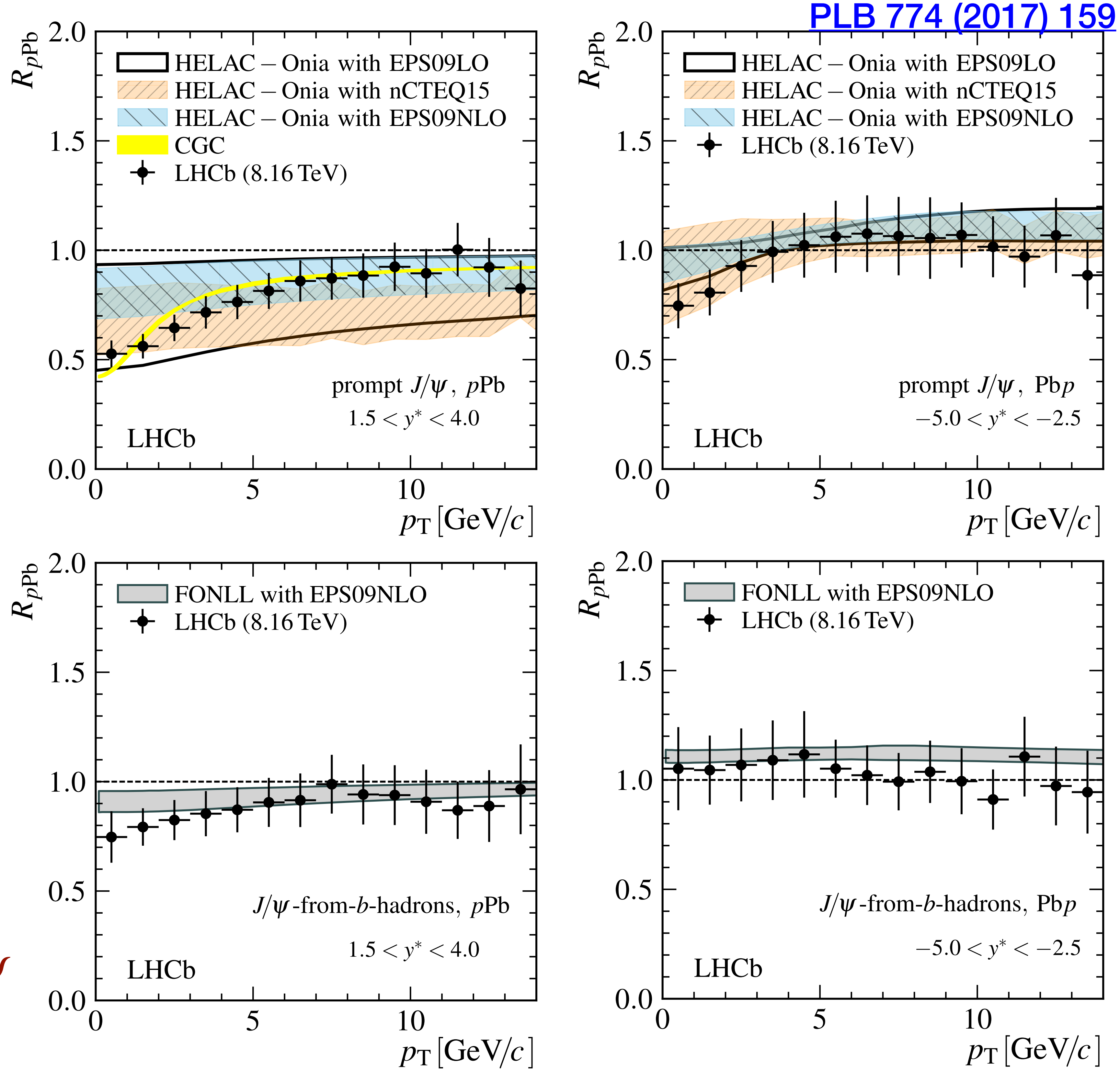
R_{pPb}^{prompt} **and** R_{pPb}^{from-b} **vs** p_T

PLB 774 (2017) 159

- Stronger suppression at lower p_T
- Models describe p_T dependence
- Small tensions at low p_T

Prompt J/ψ

Non-prompt J/ψ

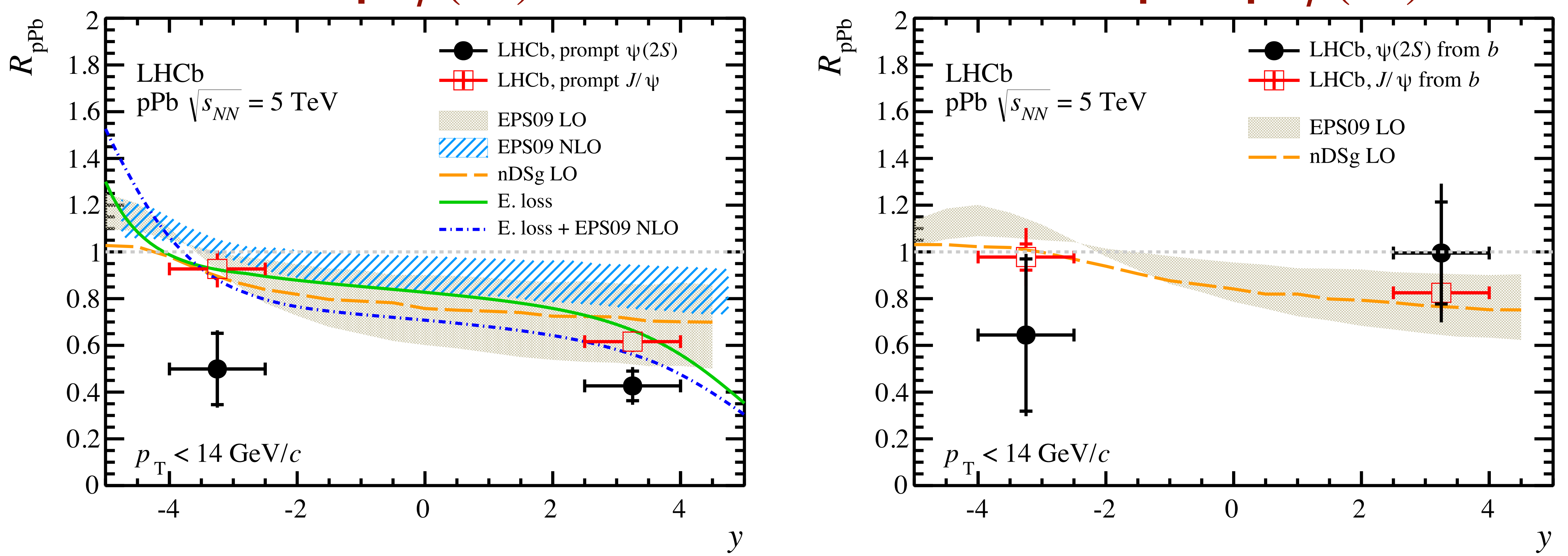


$\psi(2S)$ production at 5.02 TeV

JHEP 03 (2016) 133

- $\psi(2S) \rightarrow \mu^+\mu^-$ measured with 2013 sample ($\mathscr{L}_{int} = 1.6\,\text{nb}^{-1}$)
- Measured ratio $R \equiv \dfrac{\sigma_{pPb}^{\psi(2S)}(5\text{ TeV})}{\sigma_{pPb}^{J/\psi}(5\text{ TeV})} \times \dfrac{\sigma_{pp}^{J/\psi}(7\text{ TeV})}{\sigma_{pp}^{\psi(2S)}(7\text{ TeV})} \longrightarrow R_{pPb}^{\psi(2S)} = R_{pPb}^{J/\psi} \times R$
- Stronger suppression of prompt $\psi(2S)$ with respect to J/ψ in backward
- Observed also in inclusive measurements of PHENIX, ALICE, CMS, ATLAS → PRC 95, 034904 (2017); JHEP 12 (2014) 073; PLB 790 (2019) 509; EPJC 78 (2018) 171
- Fraction from b limited by statistical uncertainties → stay tuned for update with 8 TeV data! (x20)

Prompt $\psi(2S)$ / **Non-prompt $\psi(2S)$**



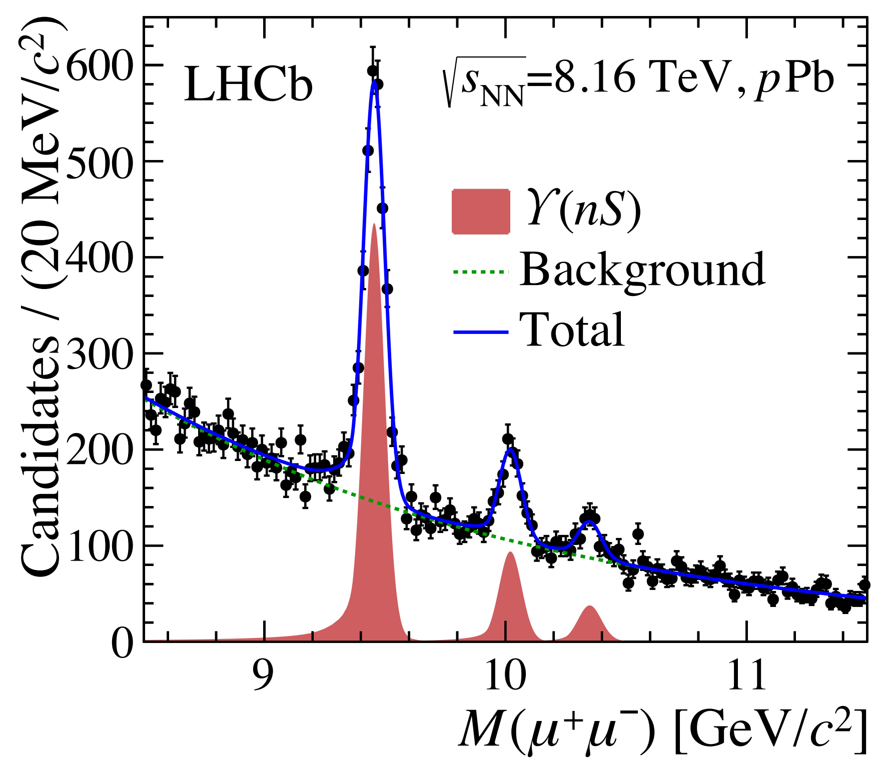
$\Upsilon(nS)$ production at 8.16 TeV

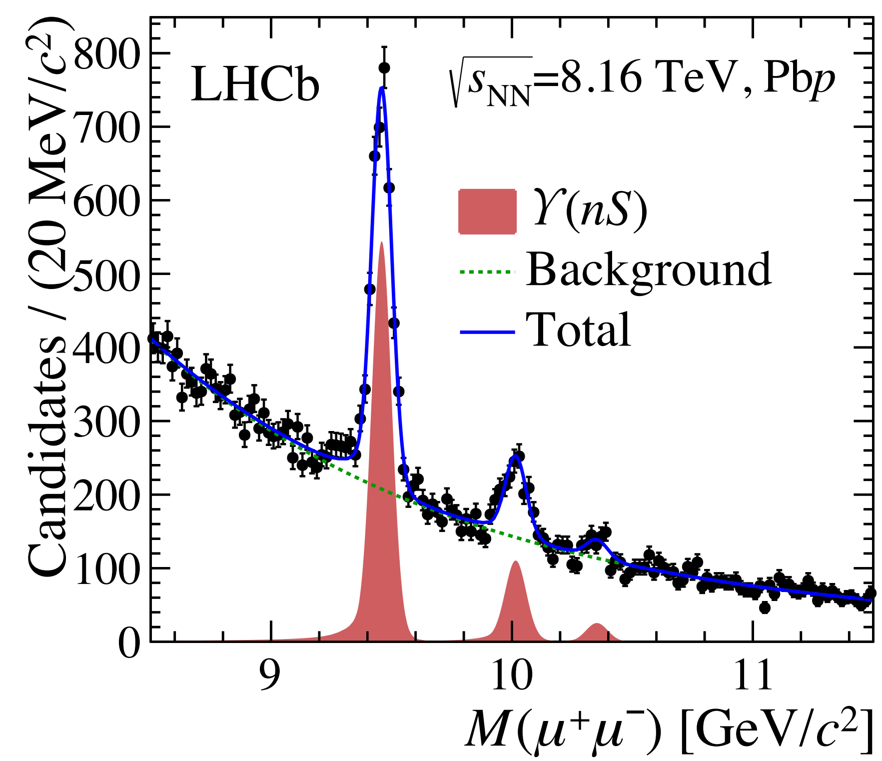
JHEP 11 (2018) 194

- Quarkonium suppression probes deconfinement in PbPb
- $\Upsilon(nS)$ sequential suppression observed in PbPb by CMS and ALICE (PLB 790 (2019) 270, PLB 790 (2019) 89)

➡ **Important to explore CNM effects in pPb to understand results**

- Double differential analysis with 2016 sample
- Measured differential cross-sections, $R_{p\mathrm{Pb}}$ and R_{FB} for all $\Upsilon(nS)$ states
- $\Upsilon(3S)$ signal in forward and backward rapidities





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

Kinematic coverage:

$0 < p_{\mathrm{T}} < 25\,\mathrm{GeV}/c$

$1.5 < y^* < 4.0$ (forward)

$-5.0 < y^* < -2.5$ (backward)

$\Upsilon(nS)$ production at 8.16 TeV

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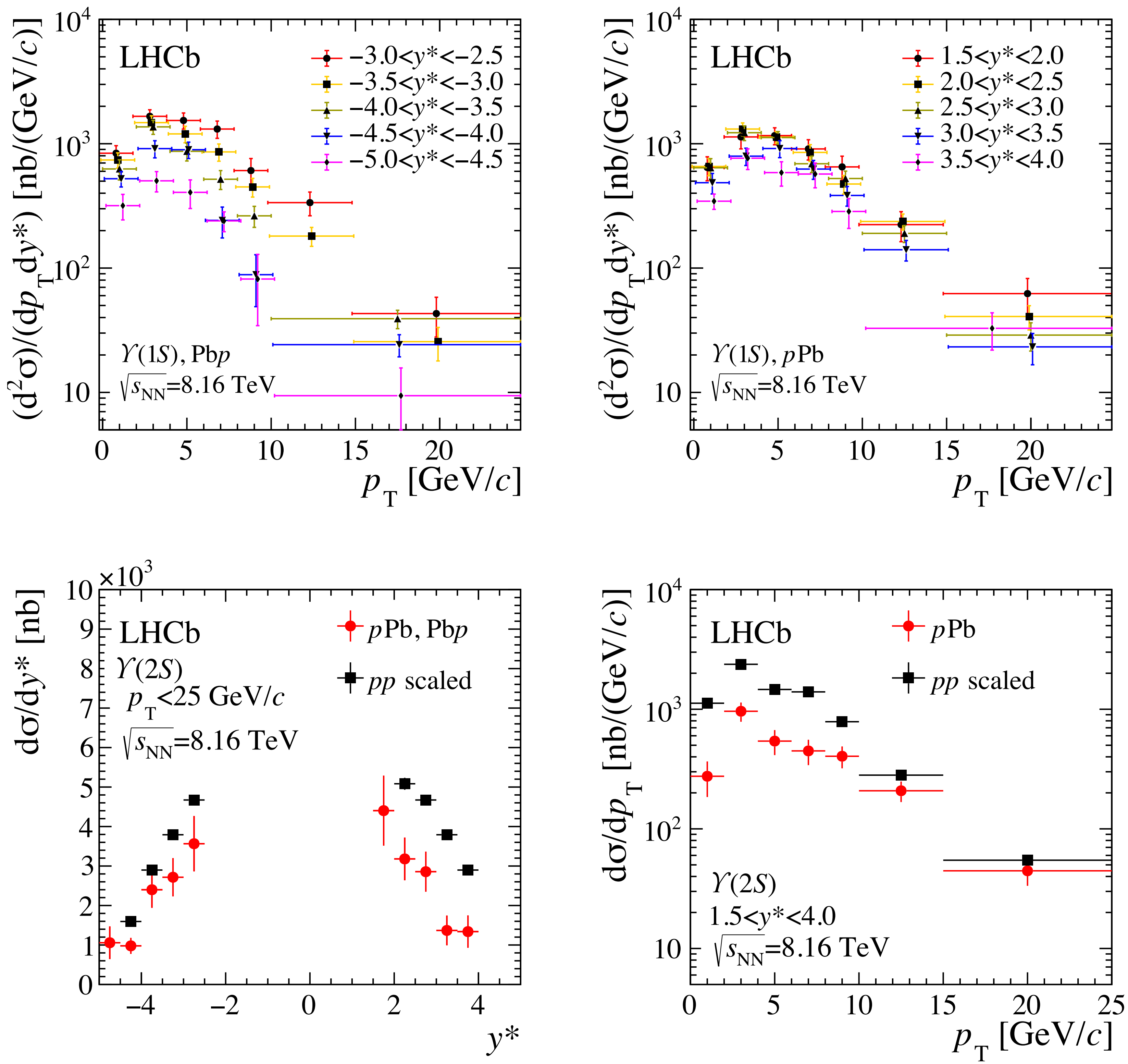
$\frac{d\sigma}{dy^{*}dp_{\mathrm{T}}}$ for $\Upsilon(1s)$

$\frac{d\sigma}{dy^{*}}$ and $\frac{d\sigma}{dp_{\mathrm{T}}}$ for $\Upsilon(2s)$



$\Upsilon(nS)$ production at 8.16 TeV

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$R_{pPb}^{\Upsilon(1S)}$ and $R_{pPb}^{\Upsilon(2S)}$ vs y^*

- Forward: suppression for both states, compatible with nPDFs
- Backward: enhanced suppression for $\Upsilon(2S)$, predicted by nPDFs+comovers

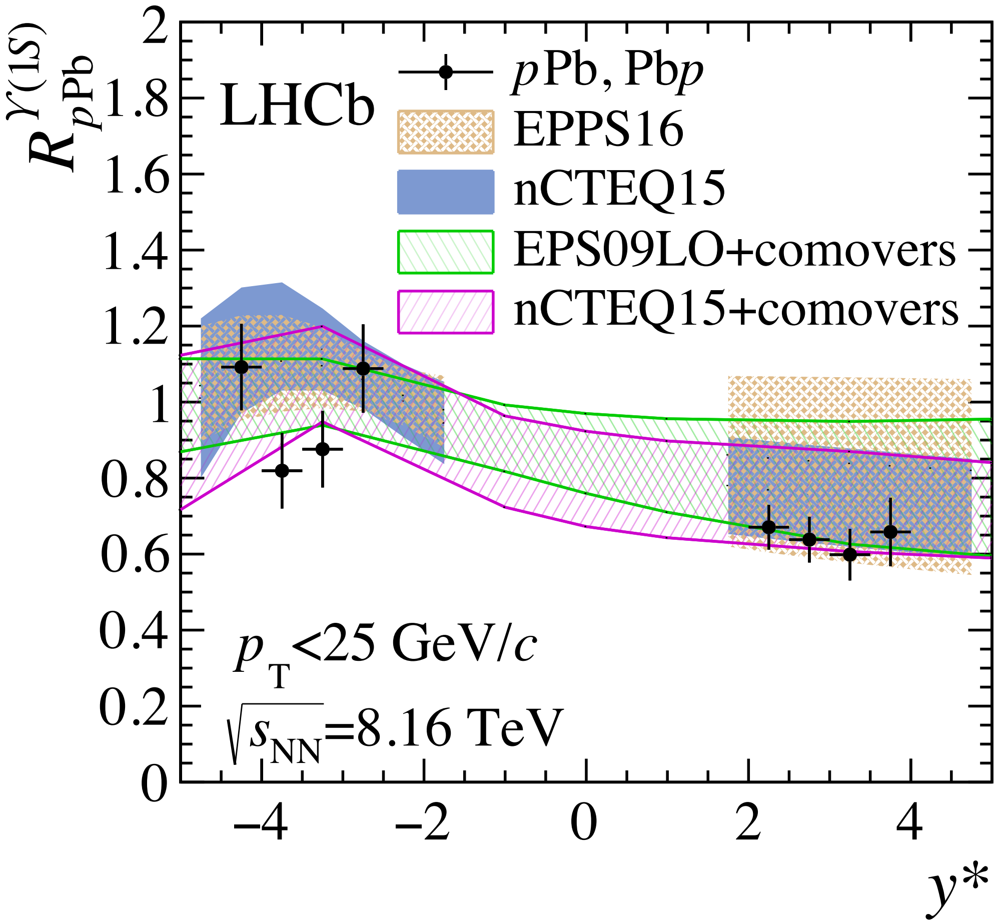
Predictions:

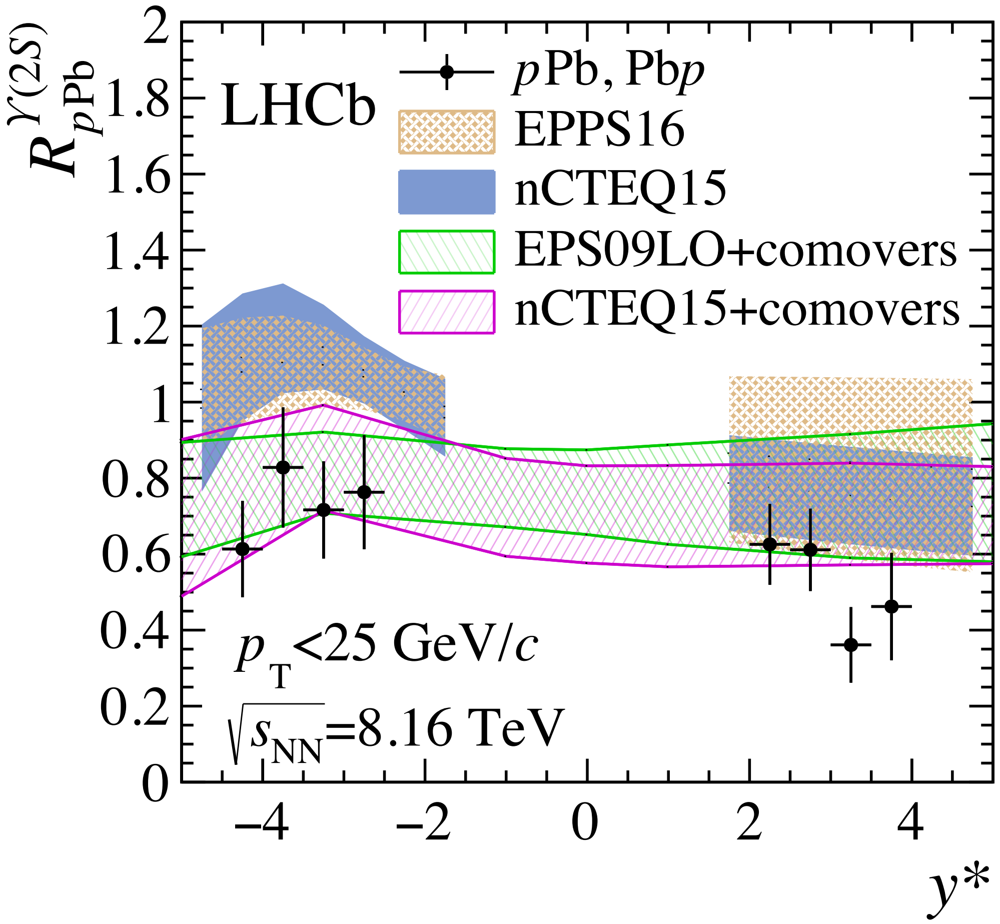
EPPS16: Eur. Phys. J. C (2017) 77: 163

EPPS09: JHEP 04 (2009) 065, arXiv:0902.4154

nCTEQ15: Phys. Rev. D93 (2016) 085037

Comovers: arXiv: 1804.04474; Phys. Lett. B749 (2015) 98, arXiv: 1411.0549





$\Upsilon(nS)$ production at $8.16\,\mathrm{TeV}$

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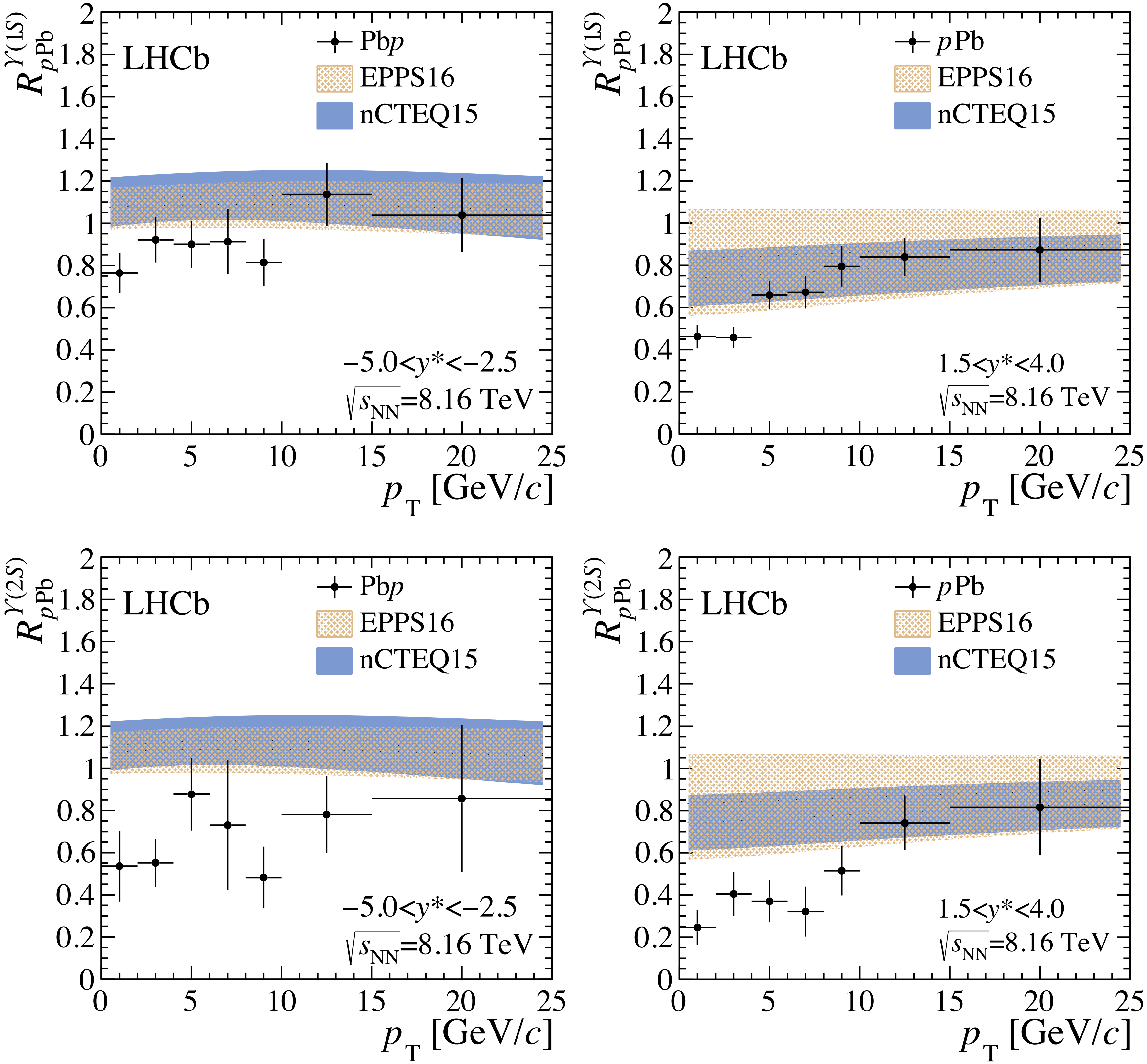
$R_{p\mathrm{Pb}}^{\Upsilon(1S)}$ and $R_{p\mathrm{Pb}}^{\Upsilon(2S)}$ vs p_T

- Clear suppression in forward region
- Compared with nPDF predictions (same for $\Upsilon(1S)$ and $\Upsilon(2S)$)

  EPS16: Eur. Phys. J. C (2017) 77: 163

  nCTEQ15: Phys. Rev. D93 (2016) 085037

- Discrepancies at low p_T in forward region for both states



$\Upsilon(nS)$ production at 8.16 TeV

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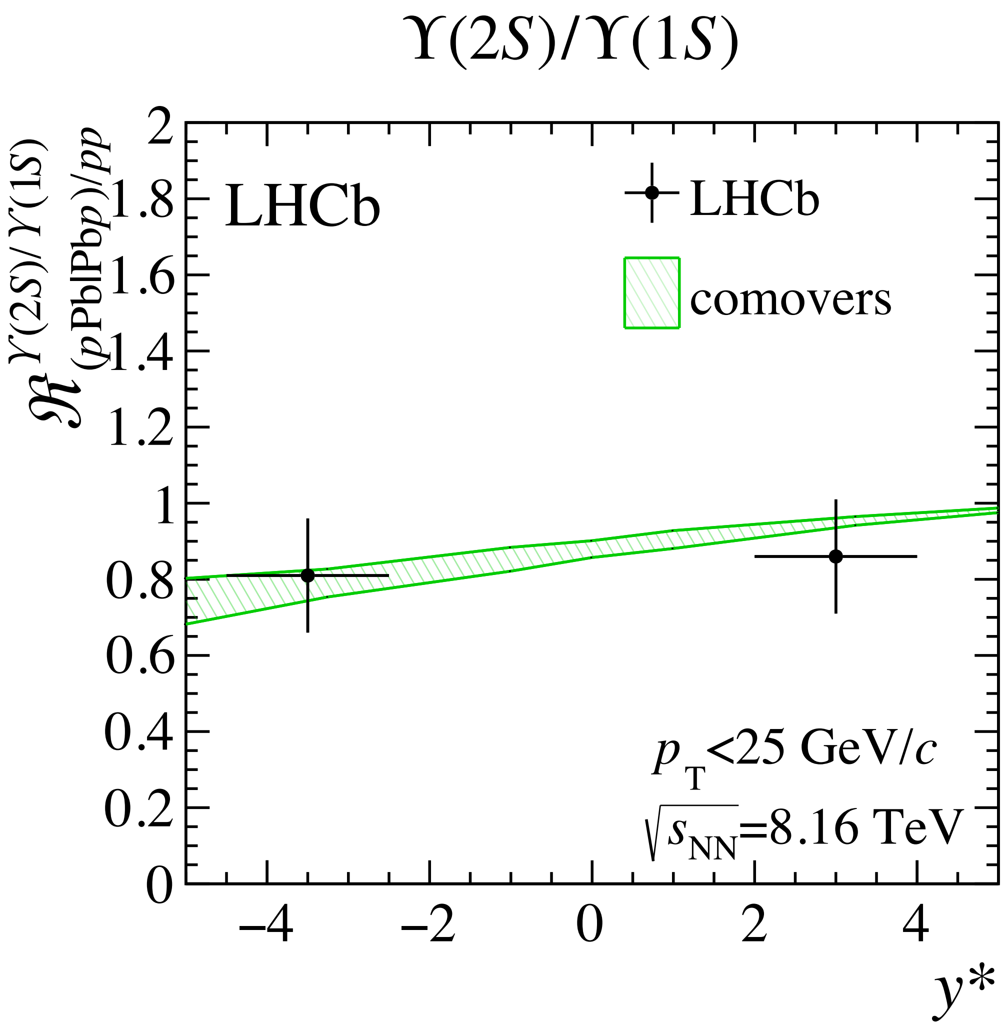
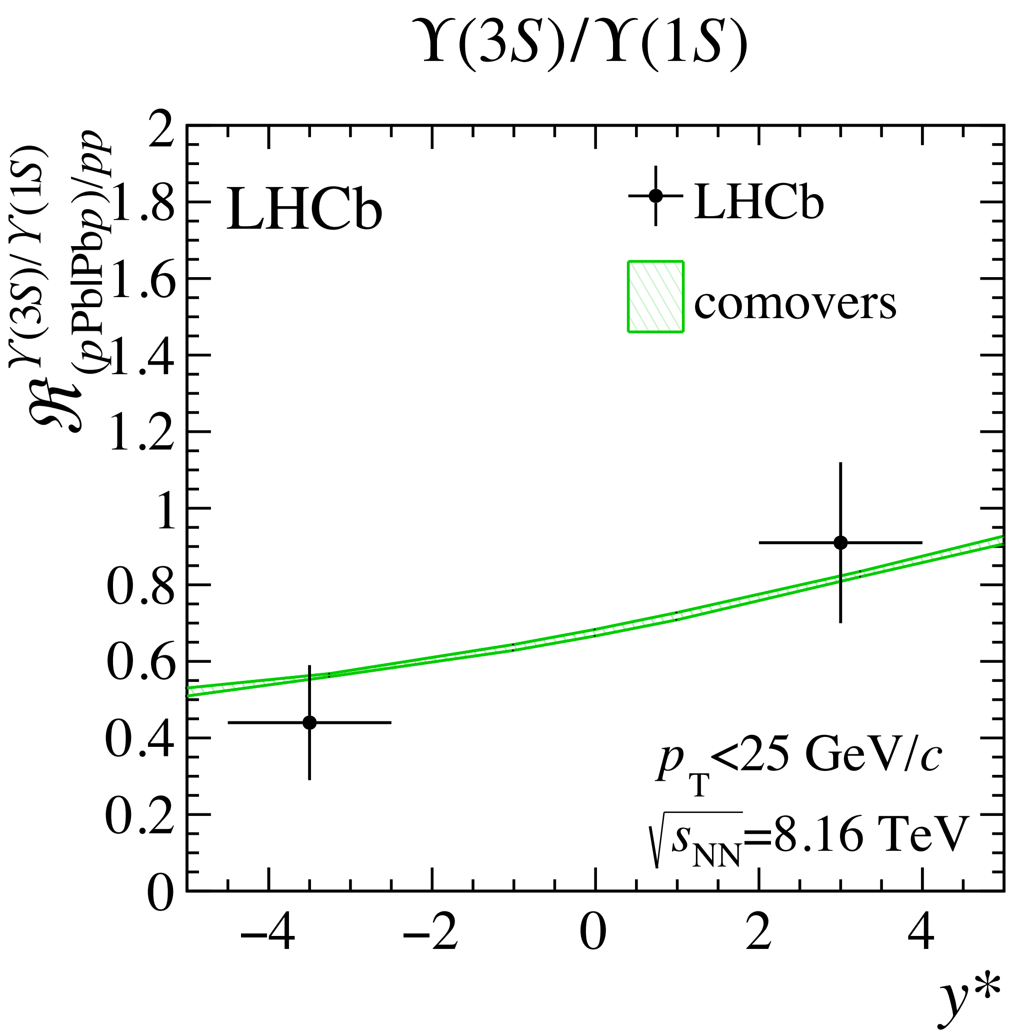
$$\mathfrak{R}^{\Upsilon(ns)/\Upsilon(1s)}_{(p\mathrm{Pb}|\mathrm{Pb}p)/pp} = \frac{R(\Upsilon(nS))_{p\mathrm{Pb}|\mathrm{Pb}p}}{R(\Upsilon(nS))_{pp}}$$

- Double ratio of $\Upsilon(2S)$ and $\Upsilon(3S)$ over $\Upsilon(1S)$ in pp and pPb
- Consistent with *comovers* model
  - Interaction with particles close in phase space dissociates the bound states
  - Suppression linked to comover density



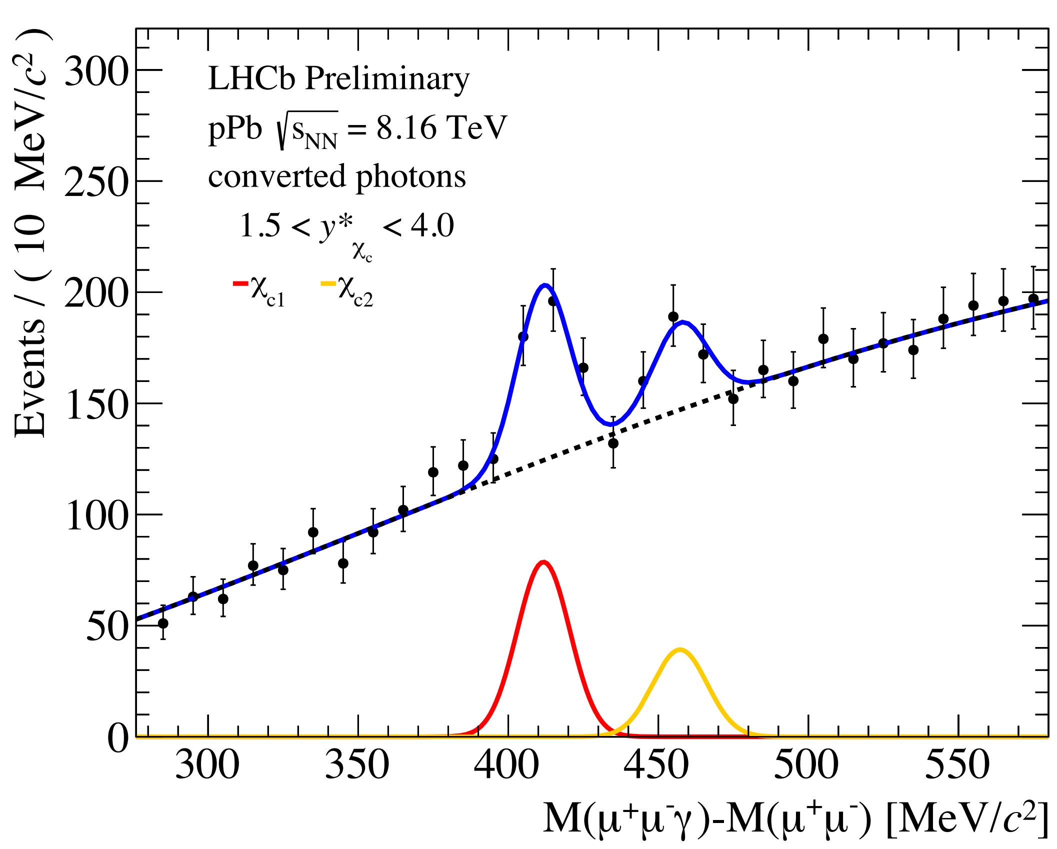


χ_{c1} and χ_{c2} studies at LHCb

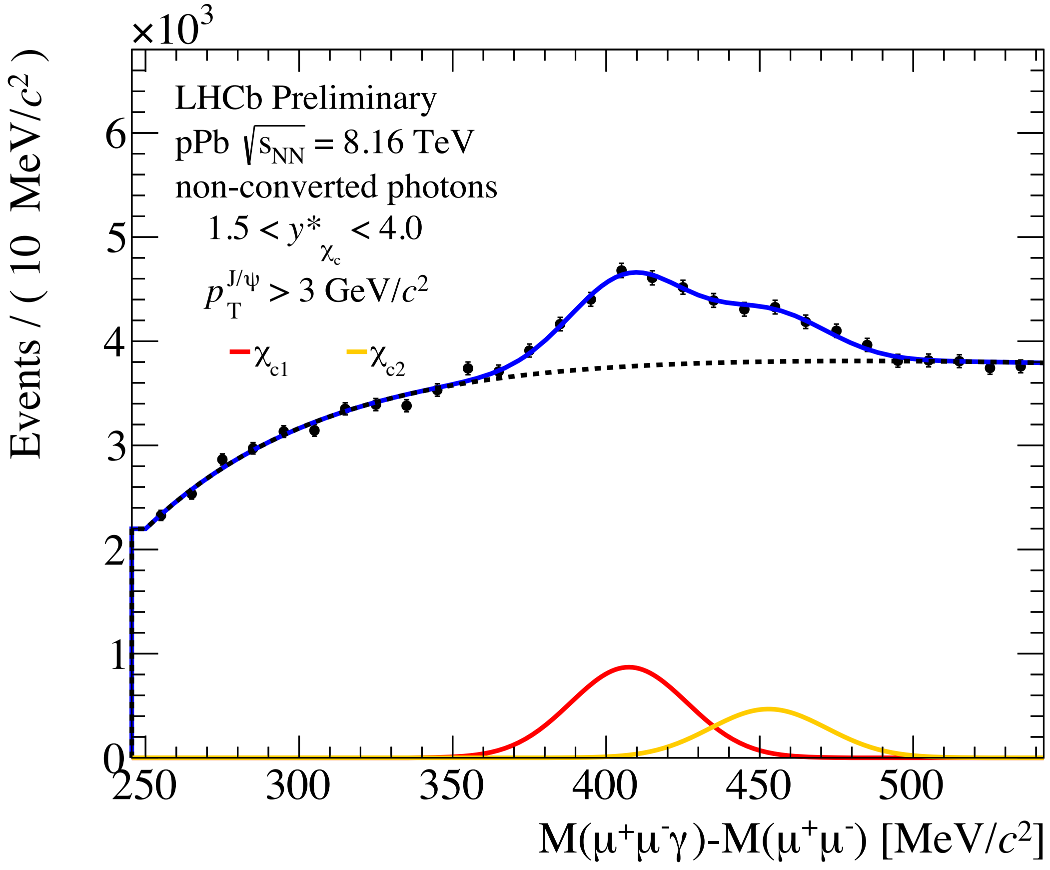
- Measuring $\chi_{c1,c2} \to J/\psi(\to \mu^+\mu^-)\gamma$ with $\sqrt{s_{NN}} = 8.16\,\text{TeV}$ dataset
- Analyzing pPb and Pbp datasets
- Two strategies to identify the γ :

Analysis ongoing… stay tuned

- **converted photons** ($\gamma \to e^{\pm}$, material interaction)



- **non-converted photons** (using calorimeter)



LHCB-FIGURE-2019-020

Conclusions

- **LHCb has an unique program on quarkonia studies in proton-lead collisions**
  - J/ψ, $\psi(2S)$ and $\Upsilon(nS)$ at 5 and $8\,\mathrm{TeV}$ with dimuon decay channel
  - Stronger suppression at backward rapidity for both charm and beauty excited states $\rightarrow$ described adding final state effect
  - Crucial to understand sequential suppression in PbPb
  - Updates on $\psi(2S)$ and χ_{cn} expected soon

- Just the tip of the iceberg! Many possibilities ahead…
  - Studies vs multiplicity? See Cameron Thomas Dean talk on $X(3872)$ vs multiplicity (Wed. at 12:25)

Backup slides

Prompt and non-prompt J/ψ production at $8.16\,\text{TeV}$

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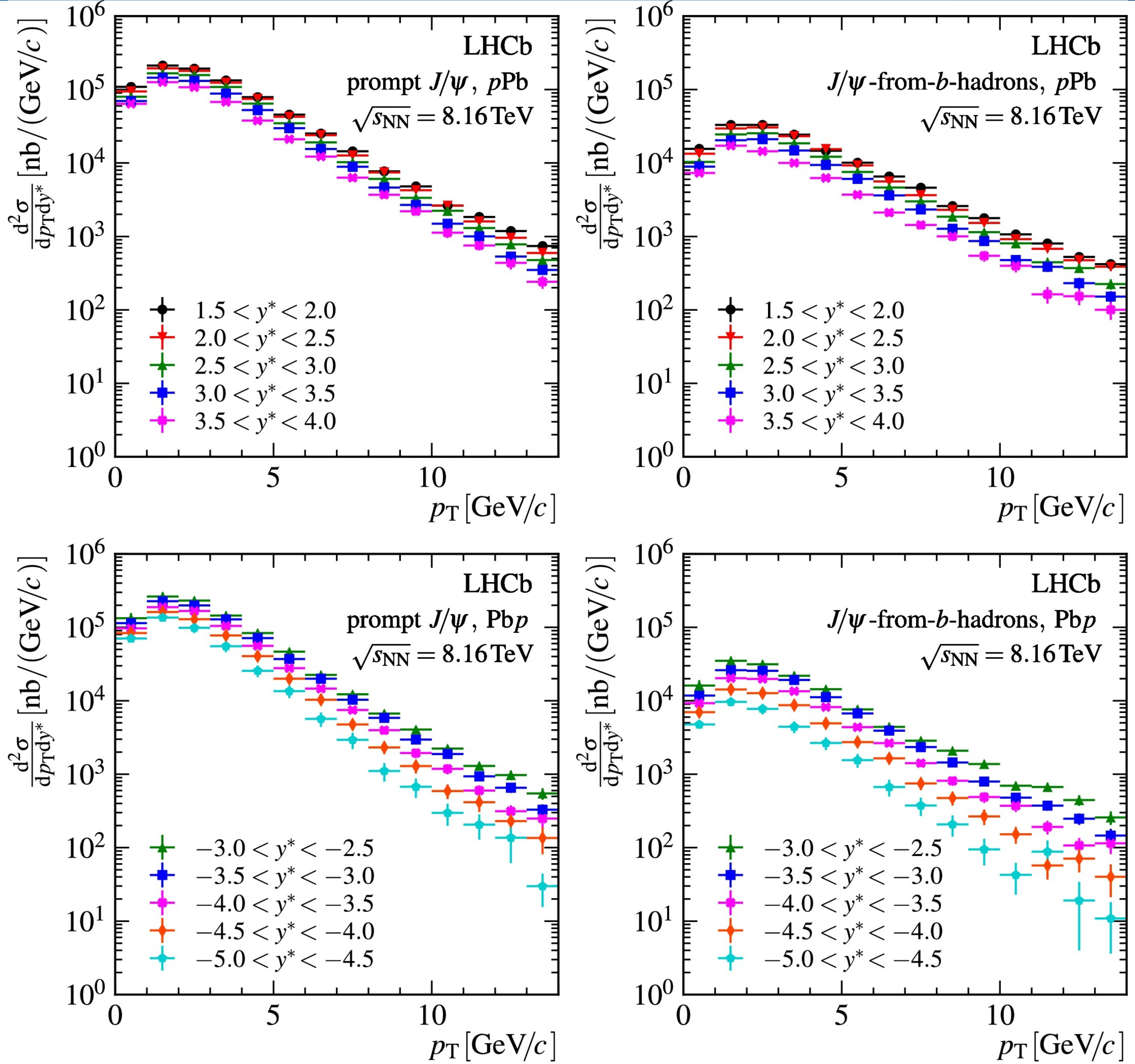
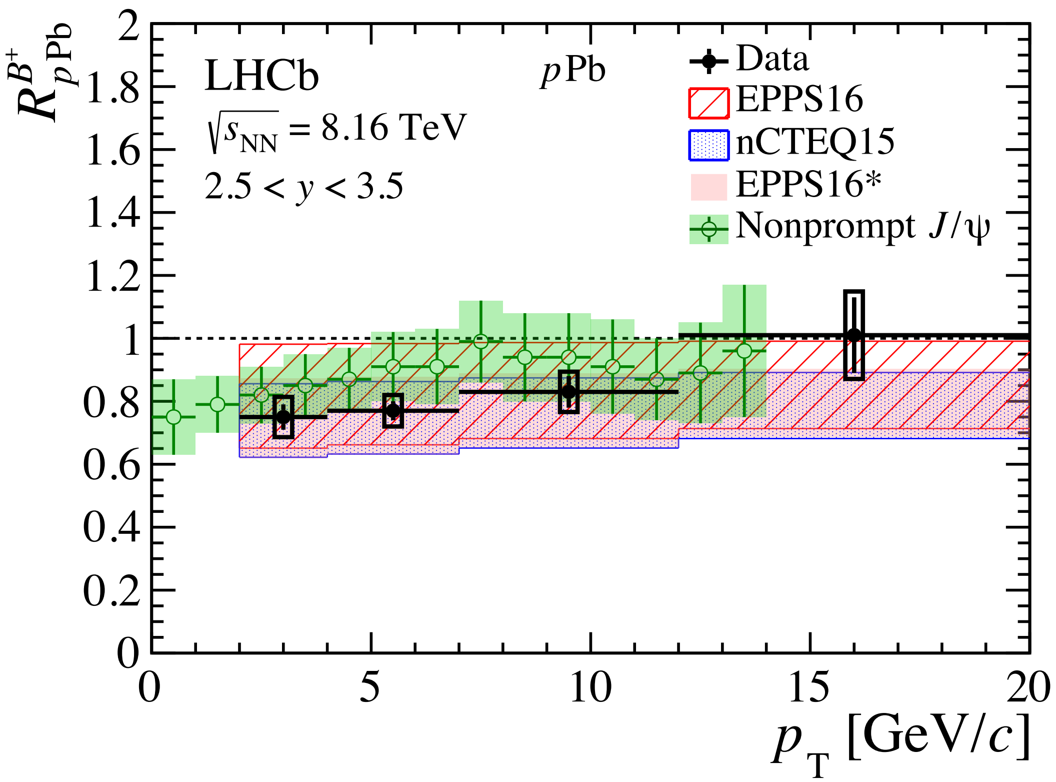
$\frac{d\sigma}{dp_{\mathrm{T}}dy^*}$ for prompt J/ψ

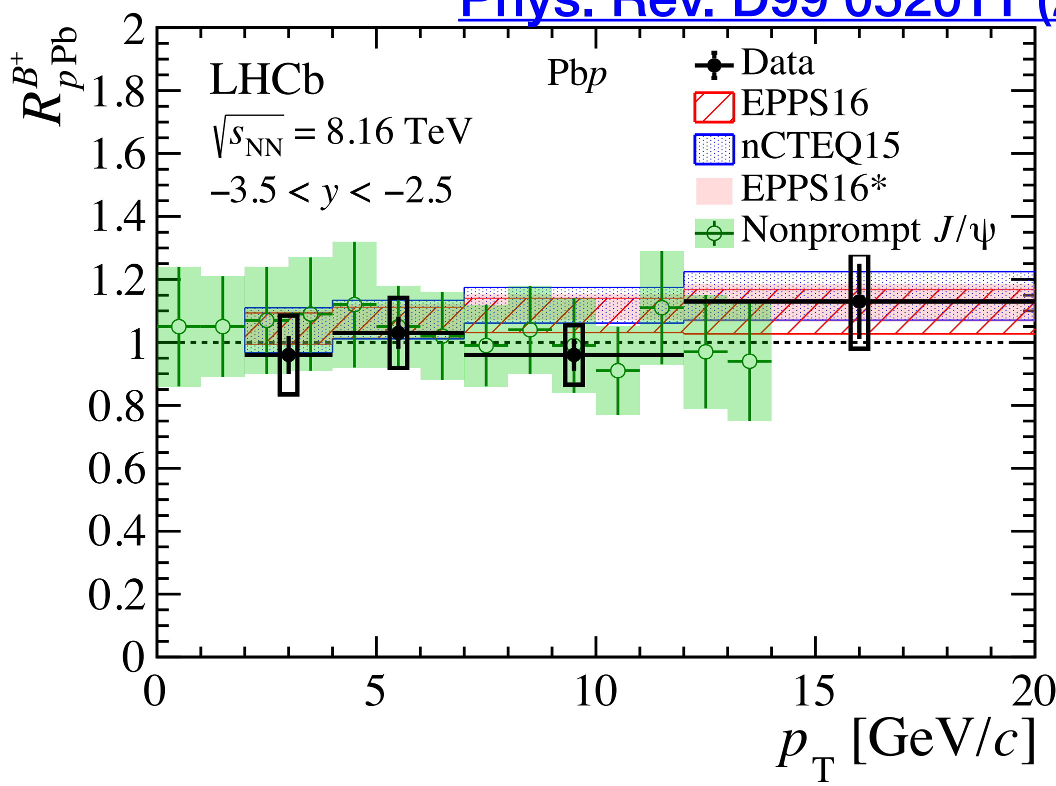
$\frac{d\sigma}{dp_{\mathrm{T}}dy^*}$ for non prompt J/ψ

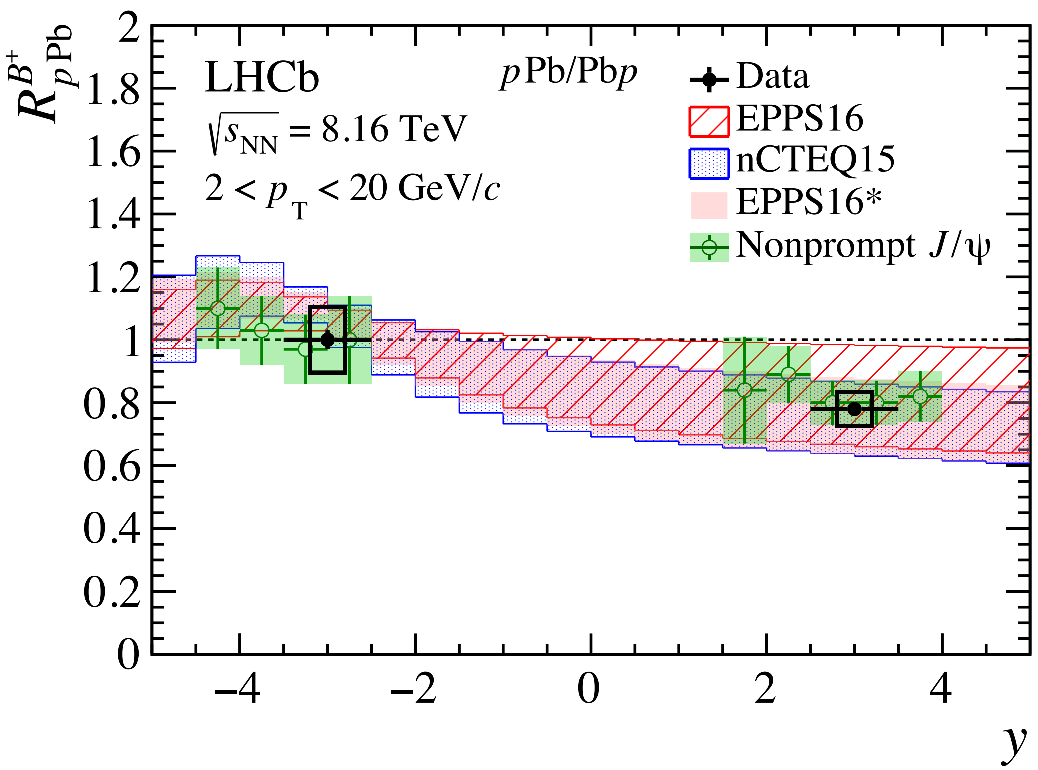


Comparison non-prompt $R_{p\mathrm{Pb}}$ of non-prompt J/ψ and B^+

Phys. Rev. D99 052011 (2019)







$\psi(2s)$ production at $5.02\,\mathrm{TeV}$

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- Inclusive $\psi(2s)$ (prompt + non-prompt)