Quarkonia production in pPb collisions at LHCb

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on behalf of the LHCb collaboration

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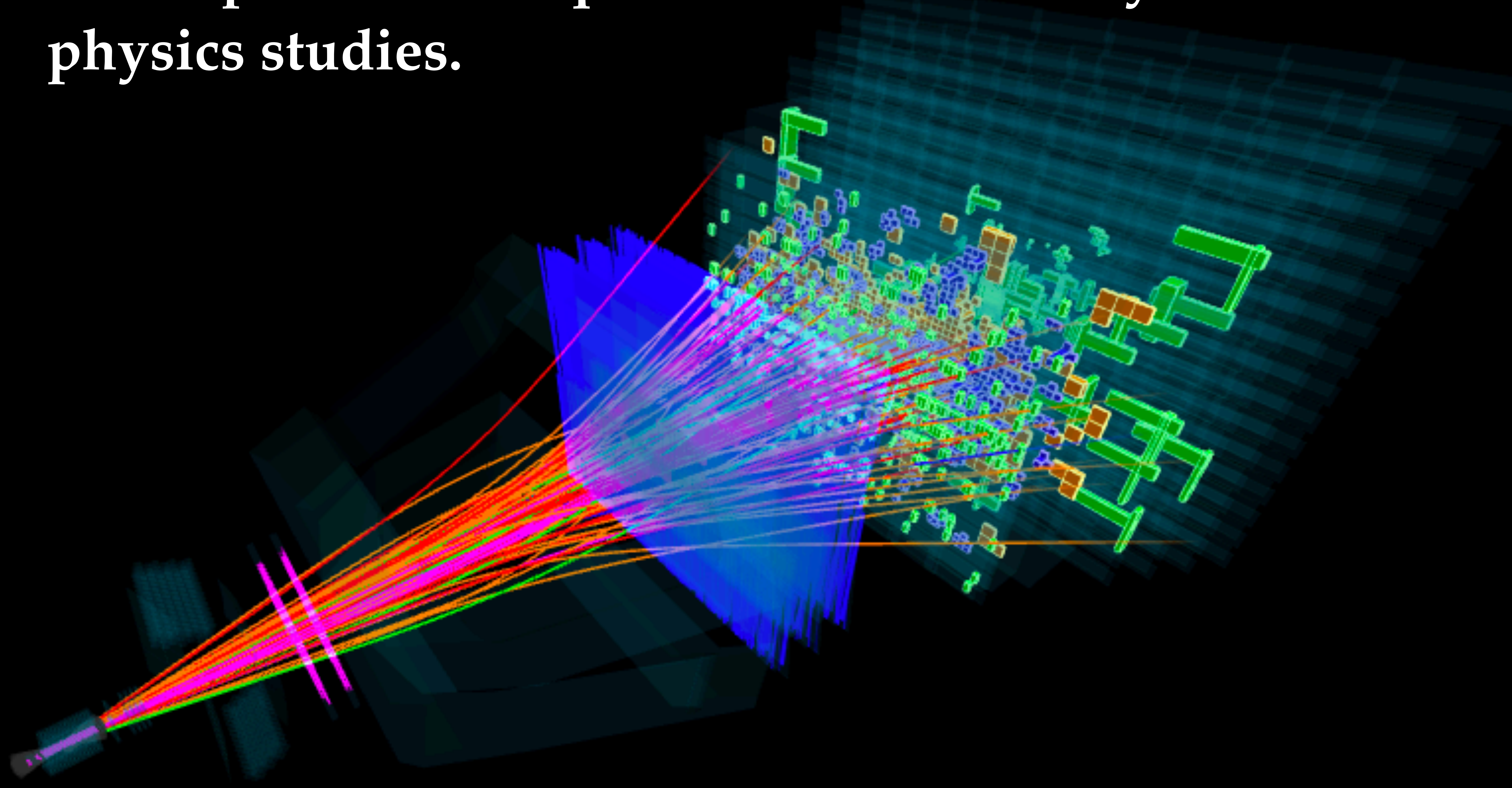
LHCb

LHCb provides unique datasets for Heavy Ion physics studies.

Event 21079095

Run 217709

Thu, 08 Nov 2018 22:56:35



Event display from the first lead-lead LHC collisions in 2018

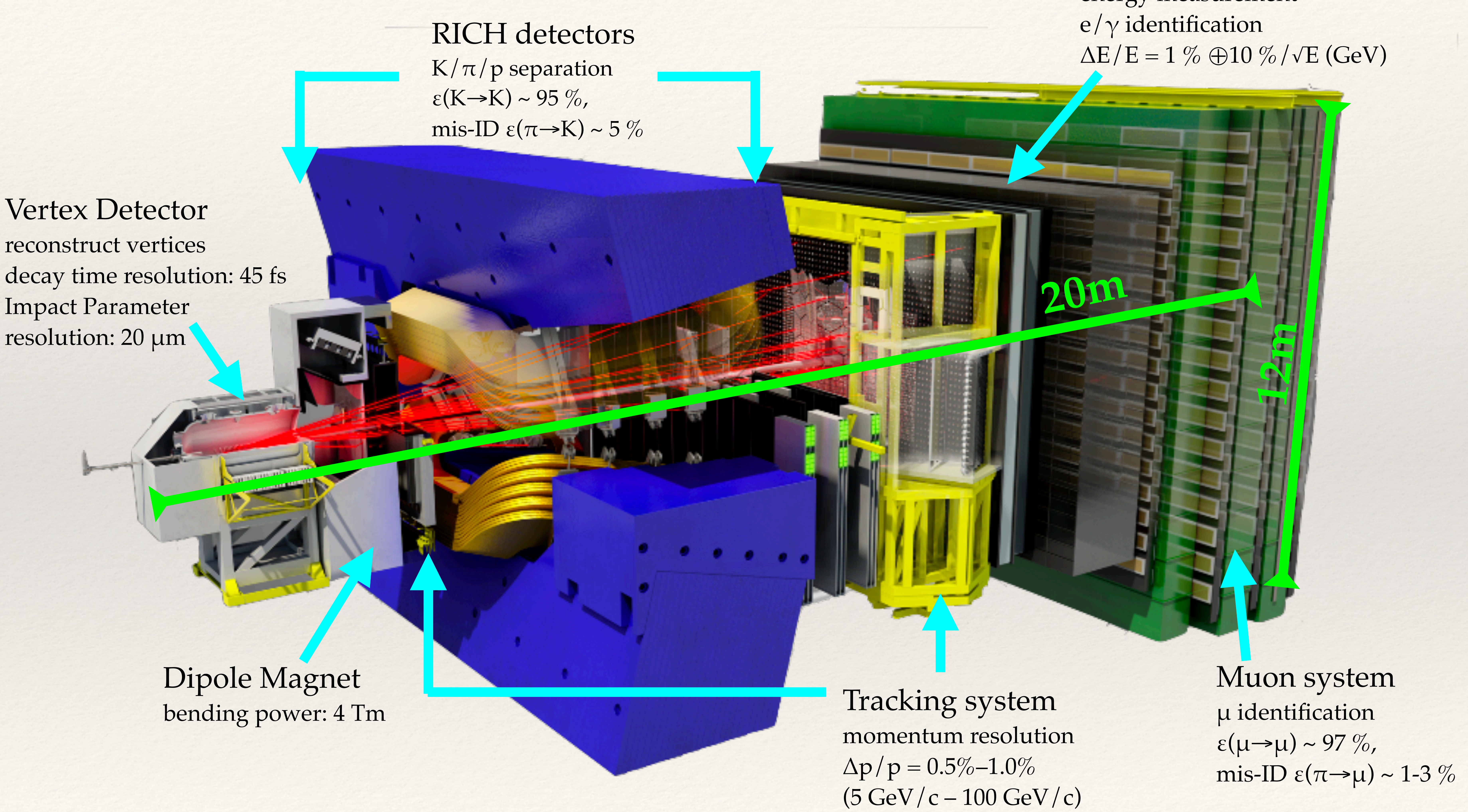
The LHCb detector is special

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

- LHCb is the only detector fully instrumented in forward region
- Unique kinematic coverage

  $2 < \eta < 5$

- A high precision device, down to very low-p_T, excellent particle ID, precision vertex reconstruction and tracking.

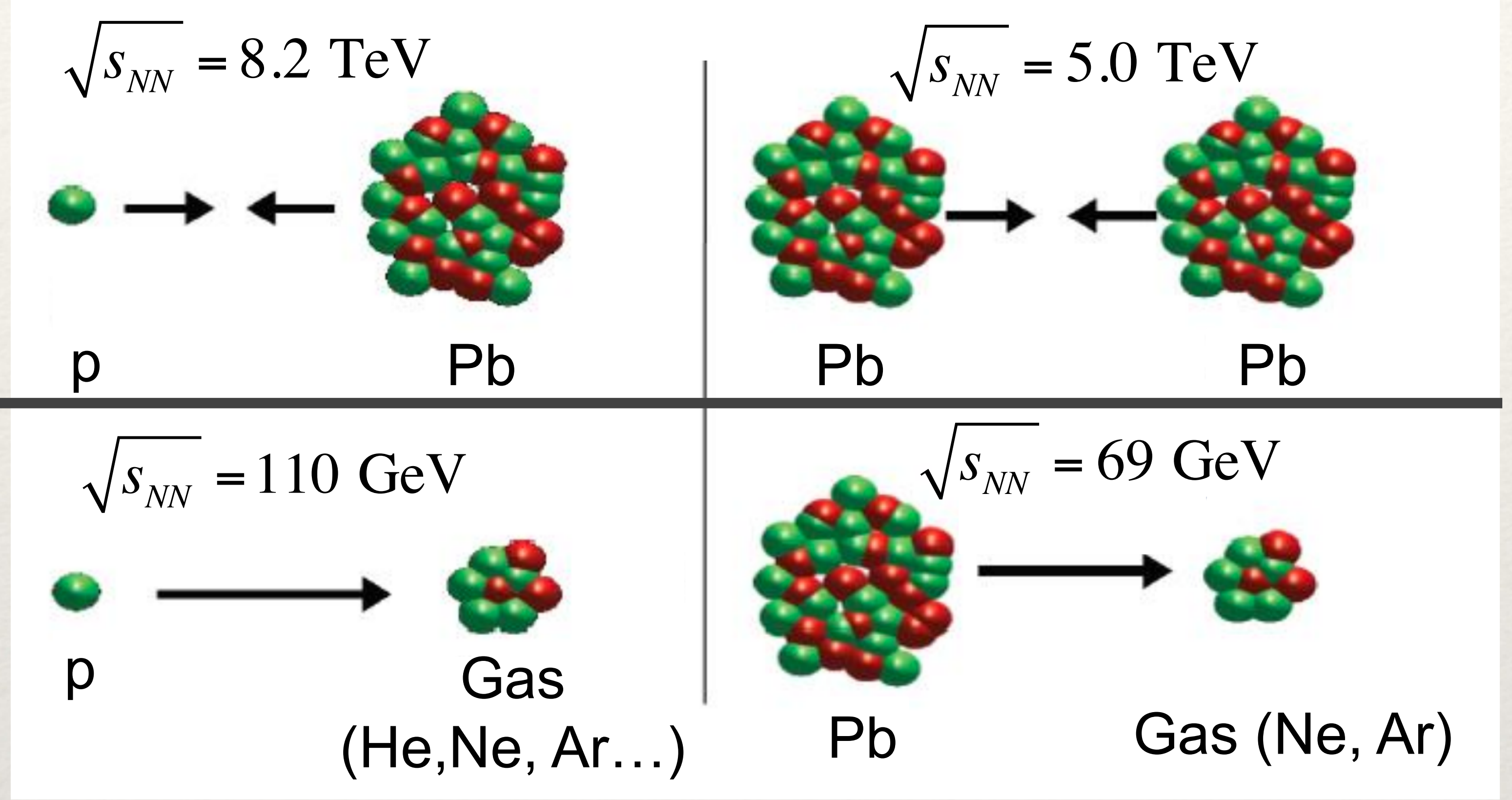


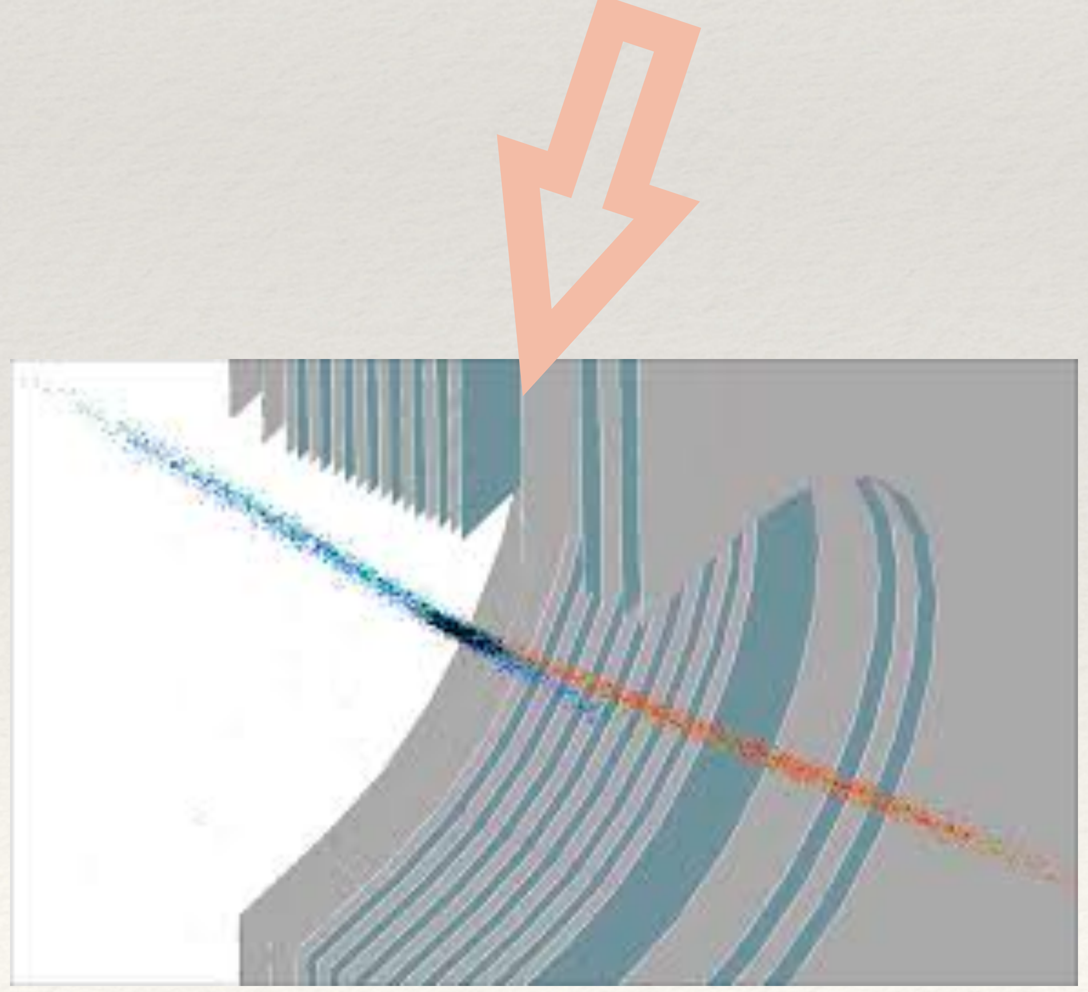
LHCb running modes and kinematic coverage

Both the collider mode and fixed-target mode running at the same time:

Collider Mode

Fixed-target Mode (SMOG)





Collider mode:

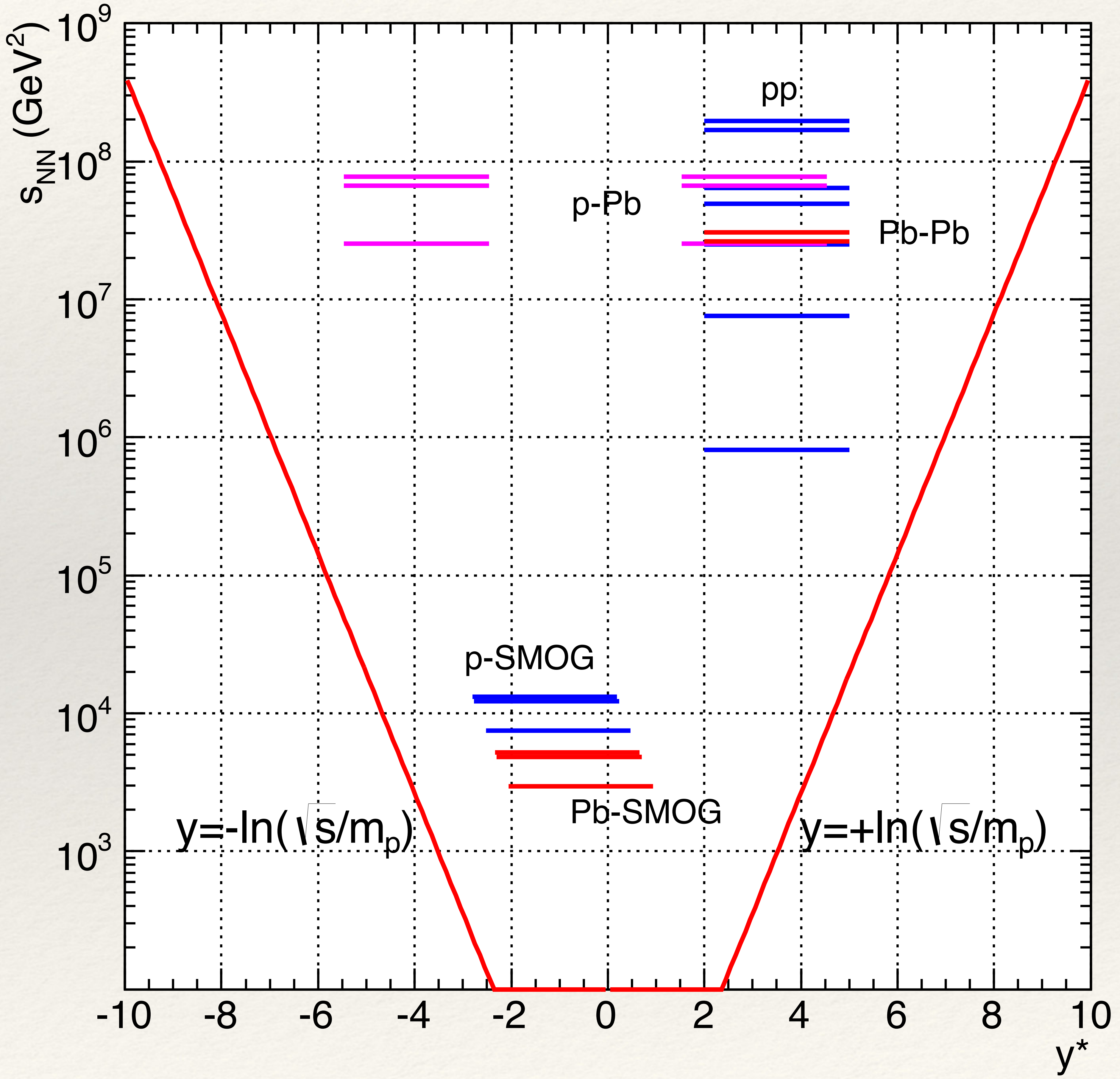
Forward and backward coverage

Fixed-target mode:

Central and backward coverage

$\sqrt{s_{NN}}$: 69 - 110 GeV, fills the gap between SPS (20 GeV) and RHIC (200 GeV) energy scales

Kinematic Acceptance



Data samples

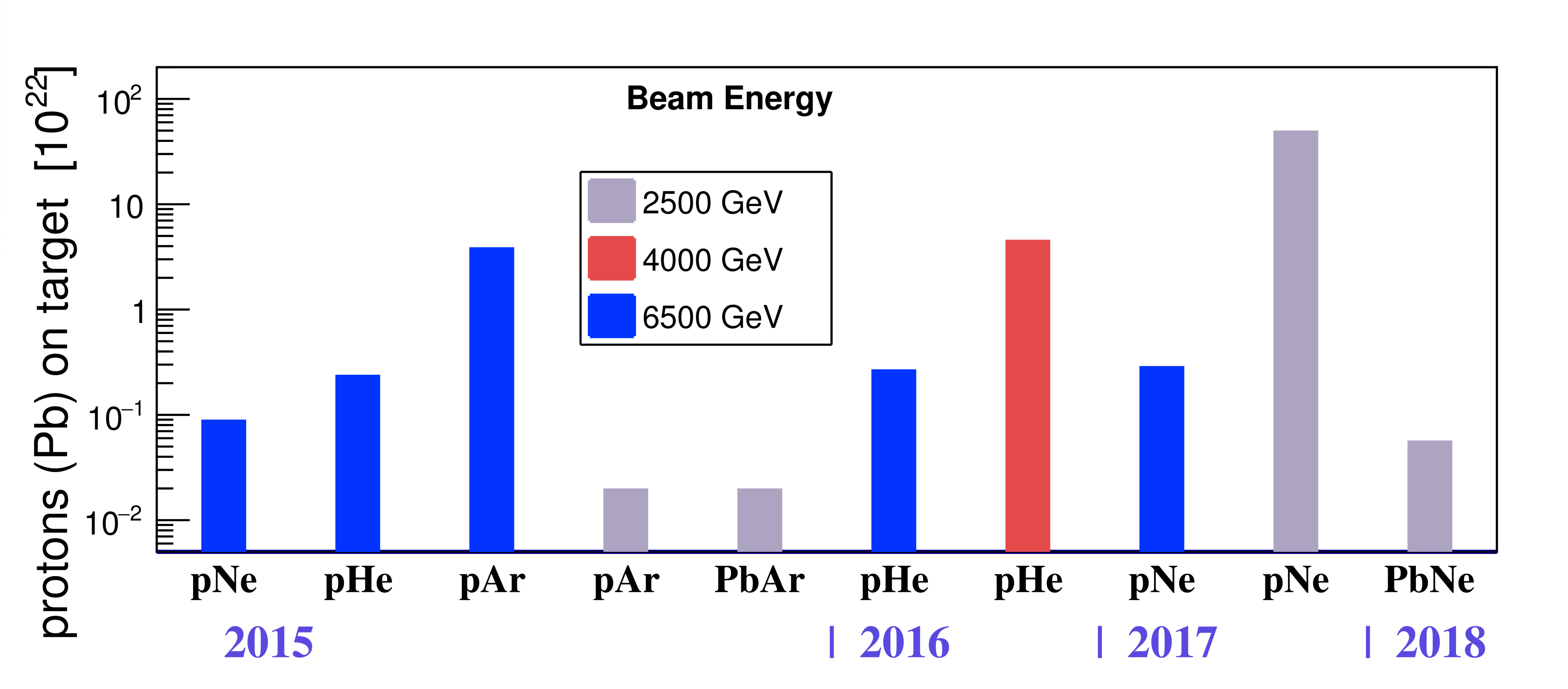
- **Colliding beam mode (pPb and PbPb):**

$\sqrt{s_{NN}}$	2013 5.02 TeV		2016 8.16 TeV		2015 5.02 TeV	2017 5.02 TeV	2018 5.02 TeV
	pPb	Pbp	pPb	Pbp	PbPb	XeXe	PbPb
$\mathcal{L}$	1.1 nb^{-1}	0.5 nb^{-1}	13.6 nb^{-1}	20.8 nb^{-1}	10 μb^{-1}	0.4 μb^{-1}	$\sim$ 210 μb^{-1}

Samples used in this talk

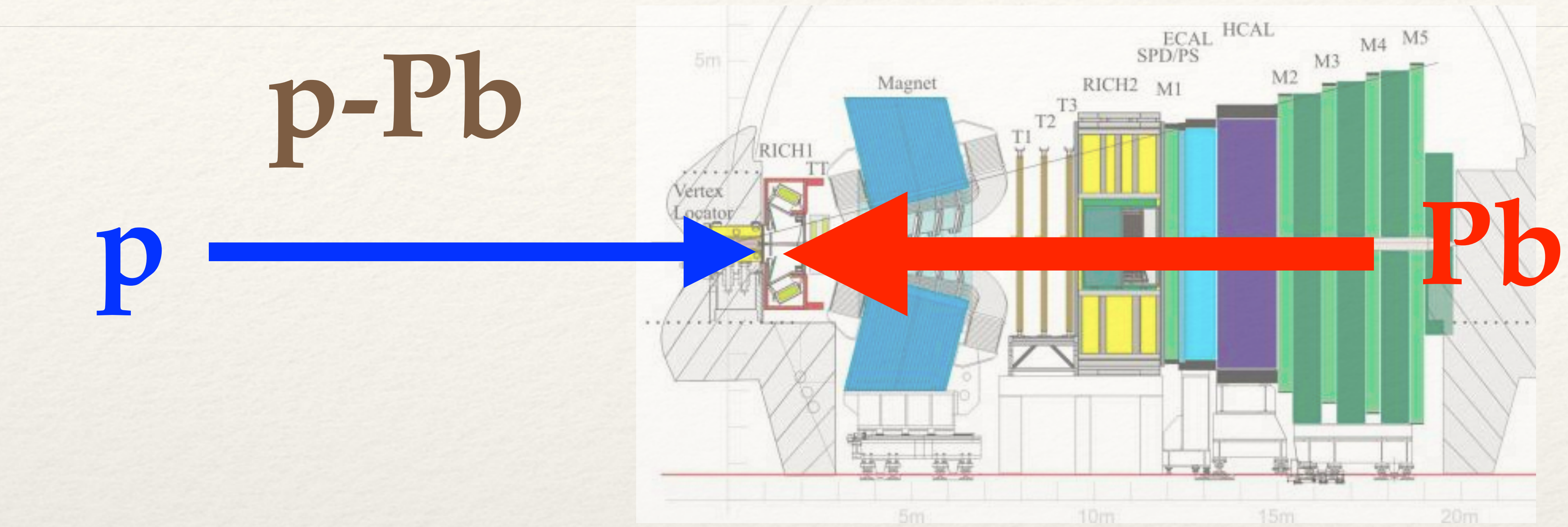
- **Fixed Target mode (SMOG):**
  - **$\sqrt{s_{NN}}$: 69-110 GeV**

$$\int \mathcal{L}dt \sim 5\text{nb}^{-1} \times \frac{(protons\ on\ target)}{10^{22}} \times \frac{p_{gas}}{2 \times 10^{-7}\text{mbar}} \times \text{Exp\_efficiency}$$

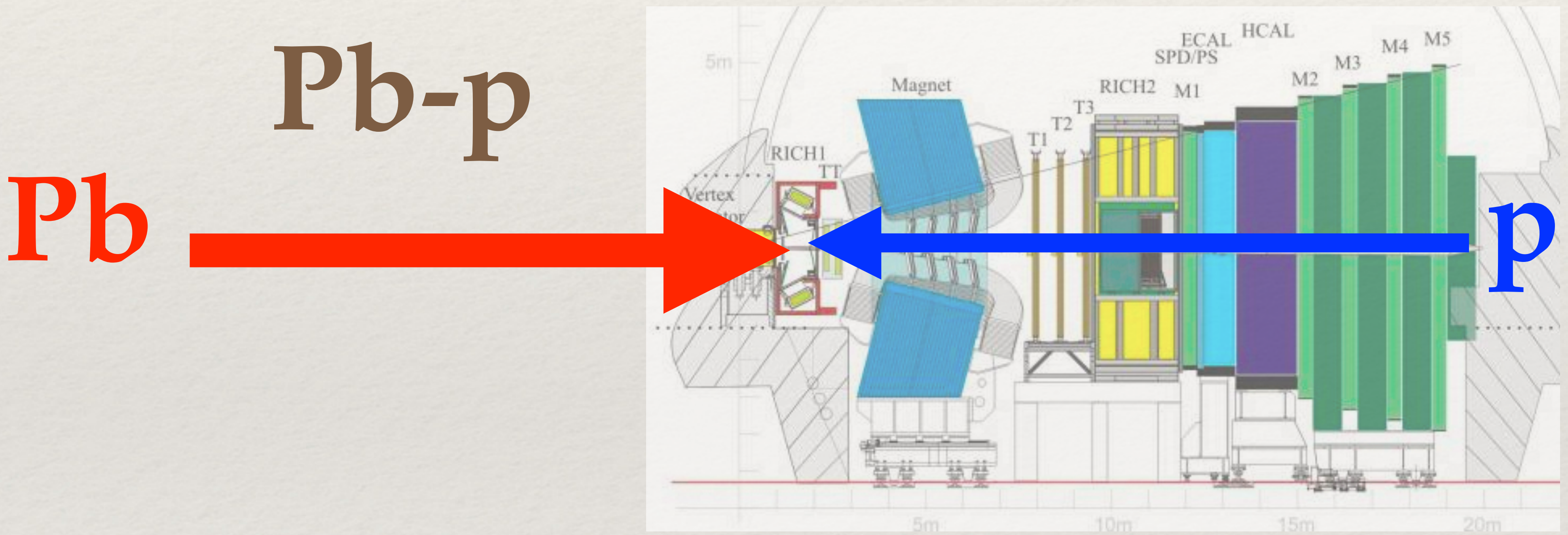


Setups for proton-ion collisions

p-Pb



Pb-p

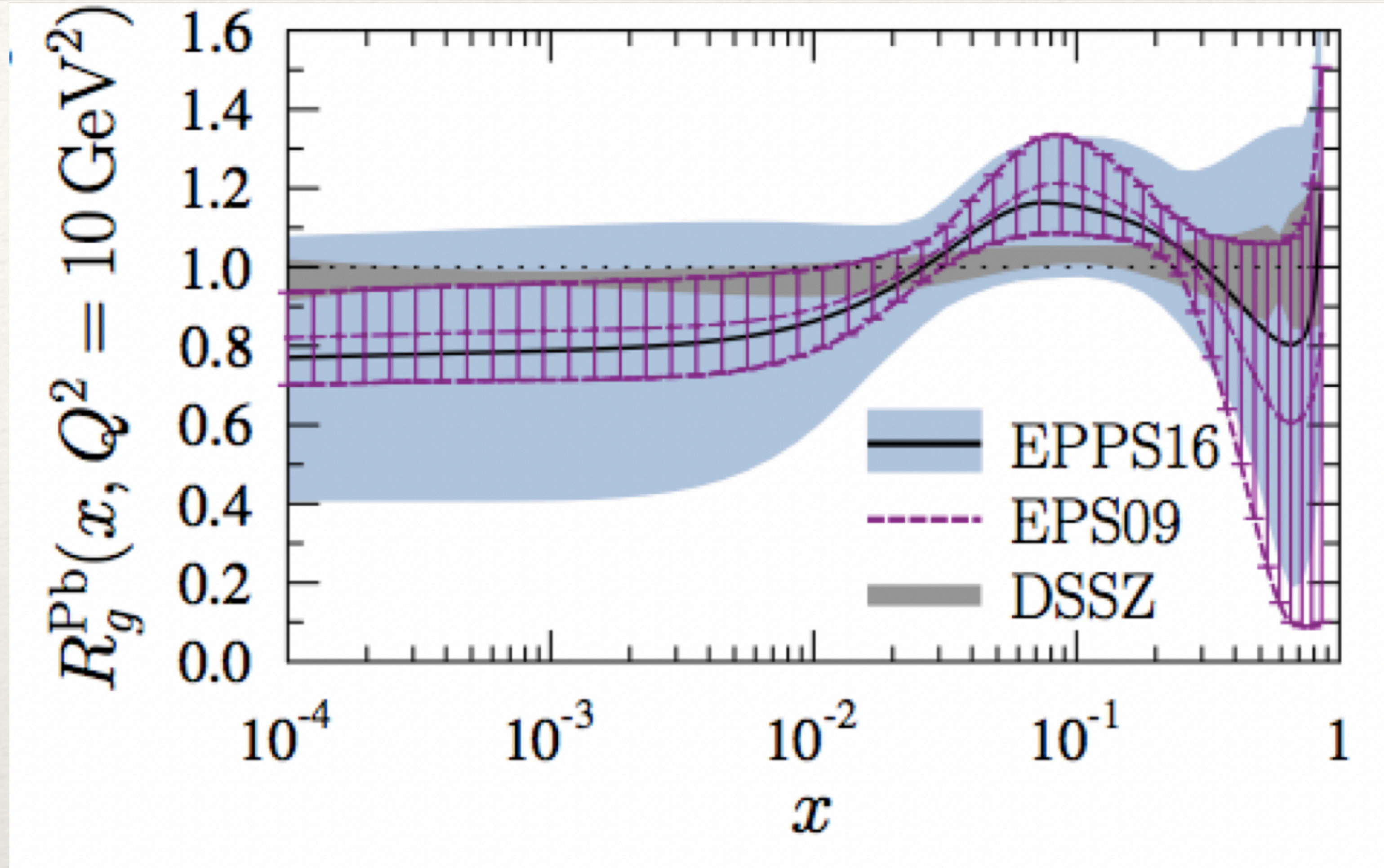


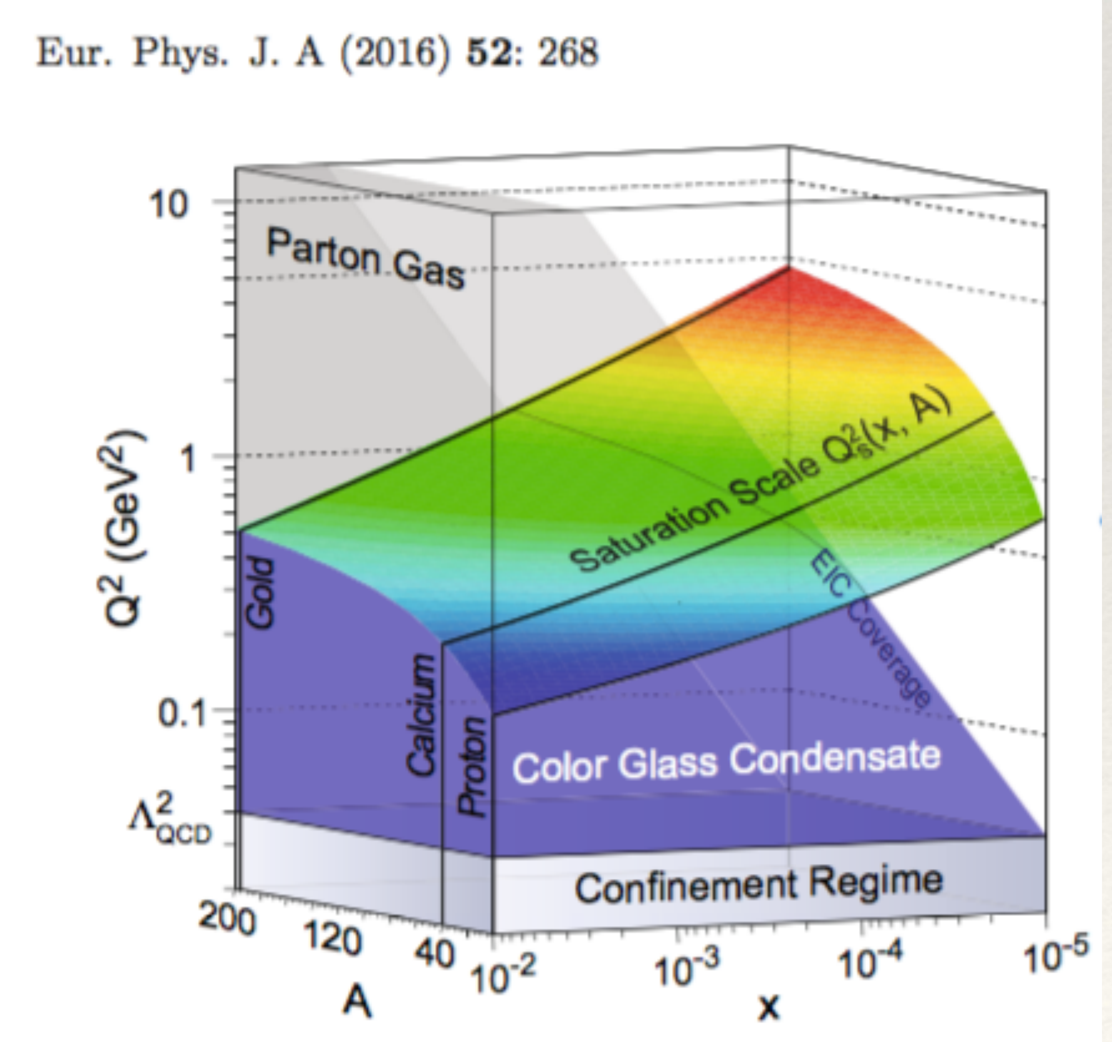
- **Forward production:**
  - Center of mass rapidity coverage: $1.5 < y^* < 4.0$
  - $L = 13.5\ nb^{-1}$
- **Backward production:**
  - Center of mass rapidity coverage: $-5.0 < y^* < -2.5$
  - $L = 20.8\ nb^{-1}$

- Rapidity coverage in center of mass frame considers a rapidity shift of about 0.47 w.r.t. the lab frame coverage $2.0 < y < 4.5$
- Common range for the measurements: $2.5 < |y^*| < 4.0$
- Center of mass energy in 2016: 8.16 TeV, $L=34\ pb^{-1}$, about 20 times of that in 2013 (5.02 TeV)

Quarkonium production in pPb collisions

- For PbPb collisions, deconfined states such as QGP give suppression of heavy quarkonia production (lower binding energies)
- For pPb collisions, suppression is also observed due to cold nuclear matter effects (CNM), and possibly also hot media effects:
  - Nuclear effects on parton densities (shadowing/anti-shadowing) [Eur. Phys. J. C77 (2017) 77: 163, also arXiv:1906.02512 [hep-ph]]
  - Energy loss of incident partons [JHEP 03 (2013) 122]
  - Saturation: Color Glass Condensate [Ann. Rev. Nucl. Part. Sci. 60:463-489, 2010]
  - Nuclear break-up, Comovers [PLB 749 (2015) 98]
  - Hot nuclear matter effects only on excited states [PLB 765 (2017) 323-327]
- Parton density largely unconstrained at the LHC energy in the forward region
  - ==> LHCb can explore low Bjorken-x region with high precision, especially at low Q^2 down to 0 p_T



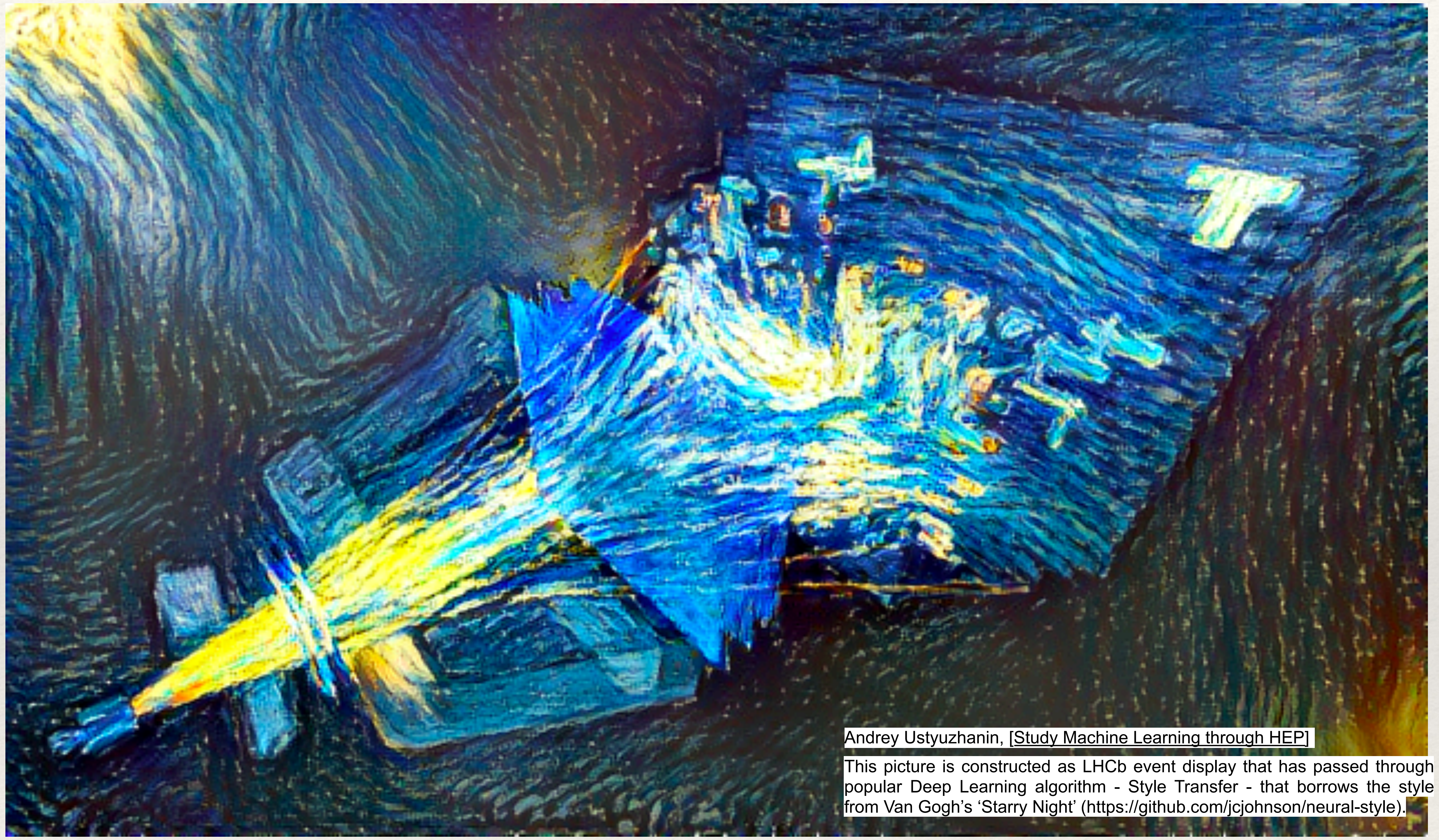


LHCb pPb Quarkonium Results

- **$\sqrt{s_{NN}}$ = 8.16 TeV results:**
  - Upsilon production: [JHEP 11 (2018) 194]
  - Prompt and nonprompt J/ψ production: [PLB 774 (2017) 159]
- **$\sqrt{s_{NN}}$ = 5.02 TeV results:**
  - ψ(2S) production: [JHEP 03 (2016) 133]
  - Upsilon production: [JHEP 07 (2014) 094]
  - J/ψ production: [JHEP 02 (2014) 72]

Will focus on 8.16 TeV results in this talk

Upsilon production



Andrey Ustyuzhanin, [Study Machine Learning through HEP]

This picture is constructed as LHCb event display that has passed through popular Deep Learning algorithm - Style Transfer - that borrows the style from Van Gogh's 'Starry Night' (https://github.com/jcjohnson/neural-style).

Υ(nS) production in pPb

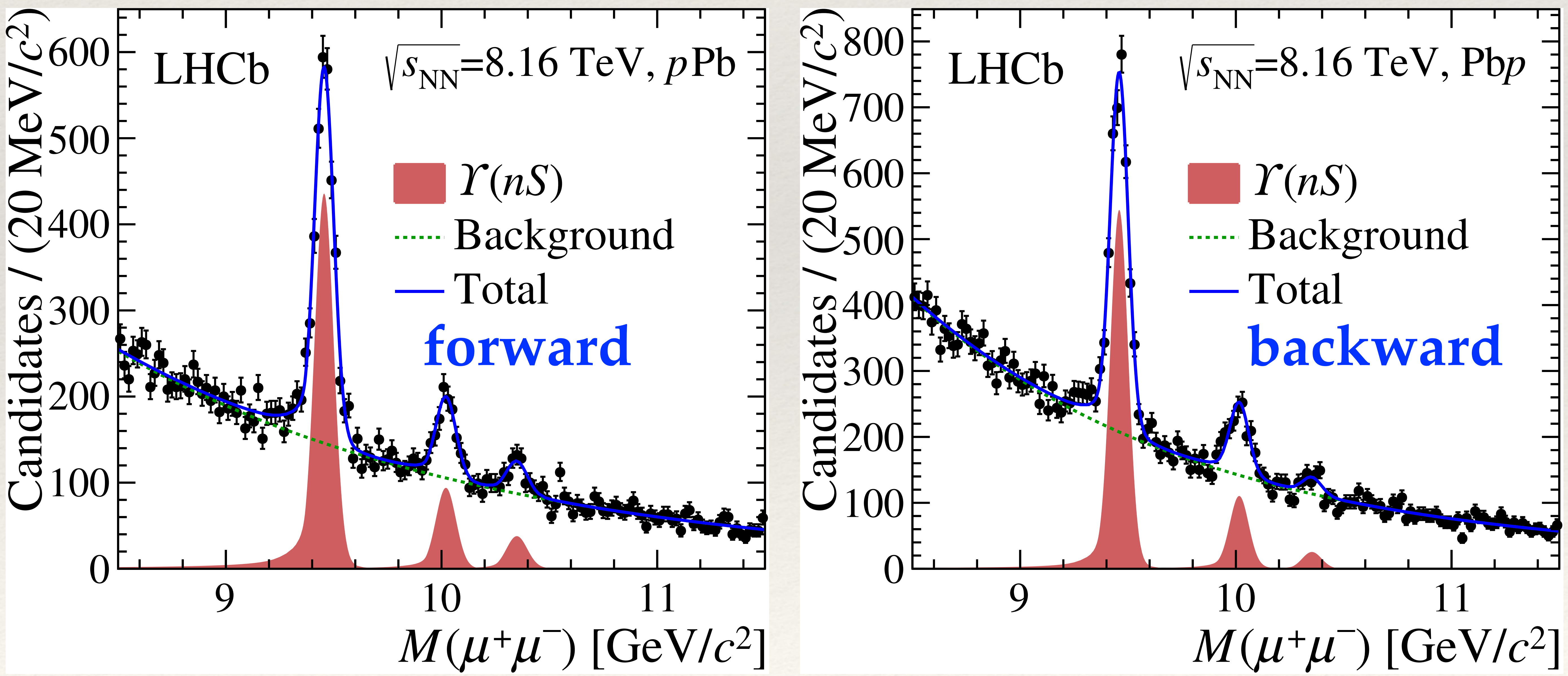
JHEP 11 (2018) 194

- $\sqrt{s_{NN}}$ = 8.16 TeV new Run II pPb results:
  - Cross-section, R_{pPb}, R_{FB} measured for all Υ(nS) states
  - Double / single differential in y and p_T for Υ(nS)
- Comparing with models:
  - EPPS16: Eur. Phys. J. C77 (2017) 163
  - EPS09: JHEP 04 (2009) 065
  - nCTEQ15: Phys. Rev. D93 (2016) 085037
  - Comovers: Phys. Lett. B749 (2015) 98

Signal yields

Samples	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$
pPb	2705 ± 87	584 ± 49	262 ± 44
Pbp	3072 ± 82	679 ± 54	159 ± 39

Di-muon invariant mass

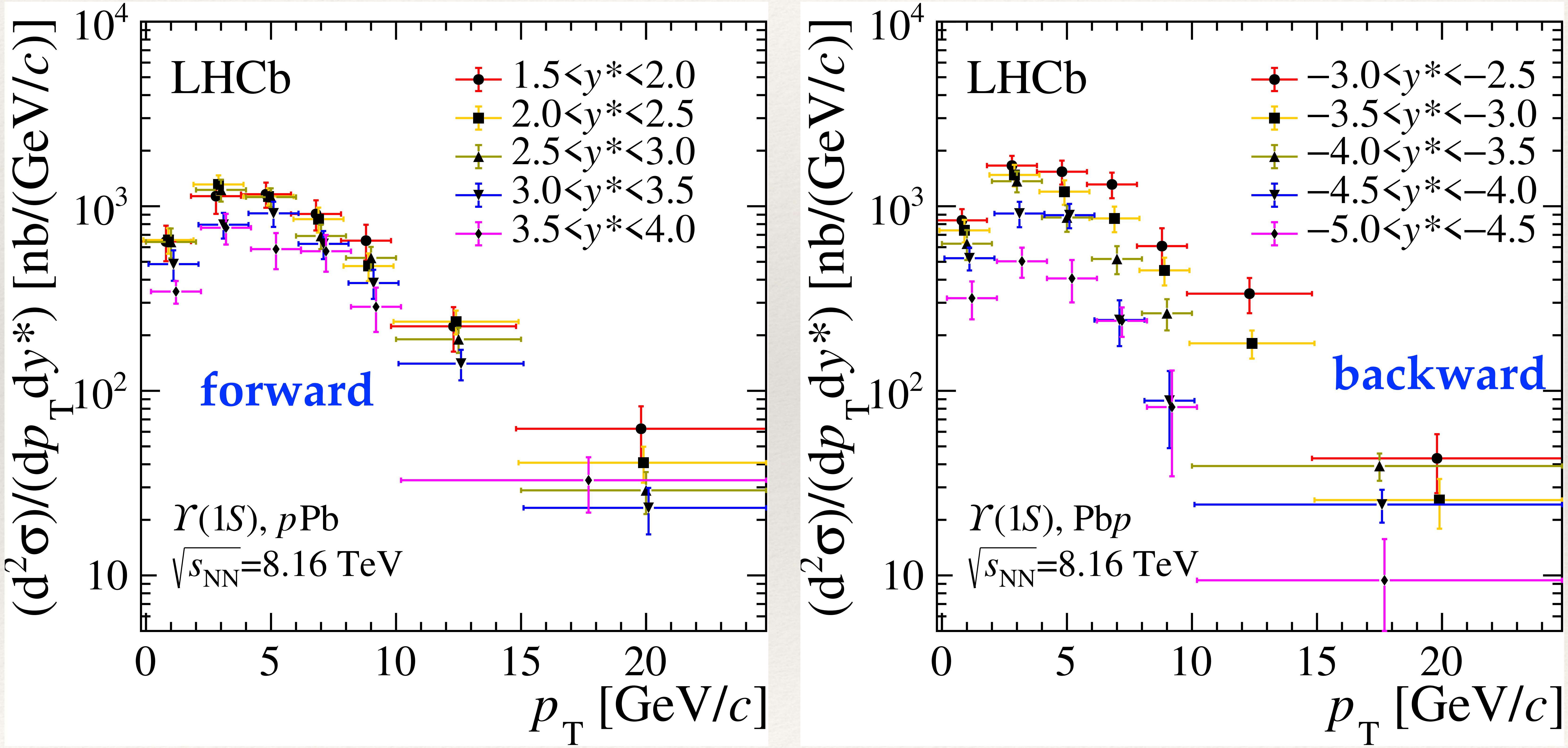


Υ(1S) double differential cross-section

JHEP 11 (2018) 194

In bins of p_T and y*

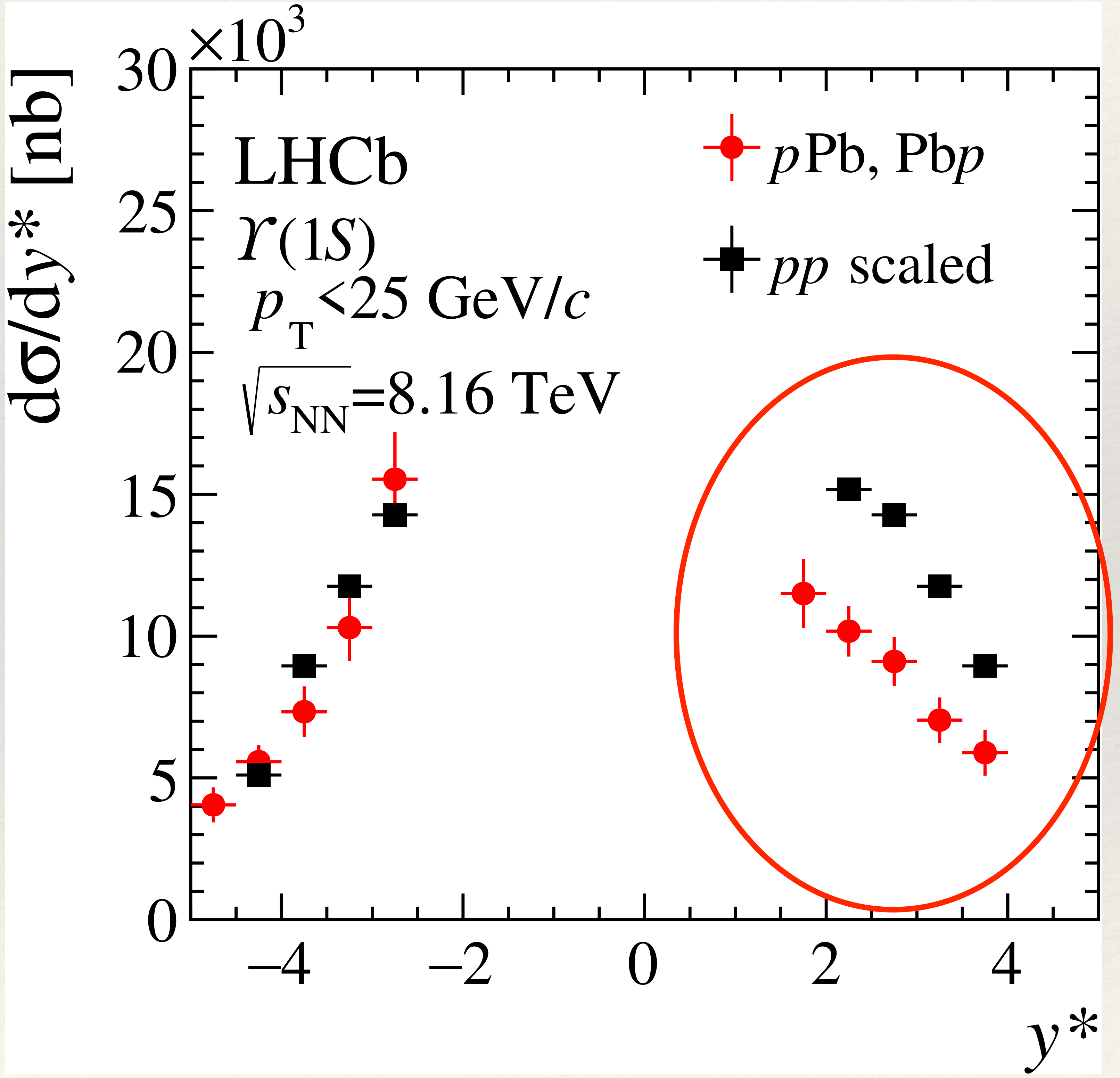
$$\frac{d^2\sigma}{dp_T dy^*} = \frac{N(\Upsilon(nS) \to \mu^+\mu^-)}{\mathcal{L} \times \varepsilon_{tot}^{\Upsilon(nS)} \times \mathcal{B}_{\mu\mu}^{\Upsilon(nS)} \times \Delta p_T \times \Delta y^*},$$



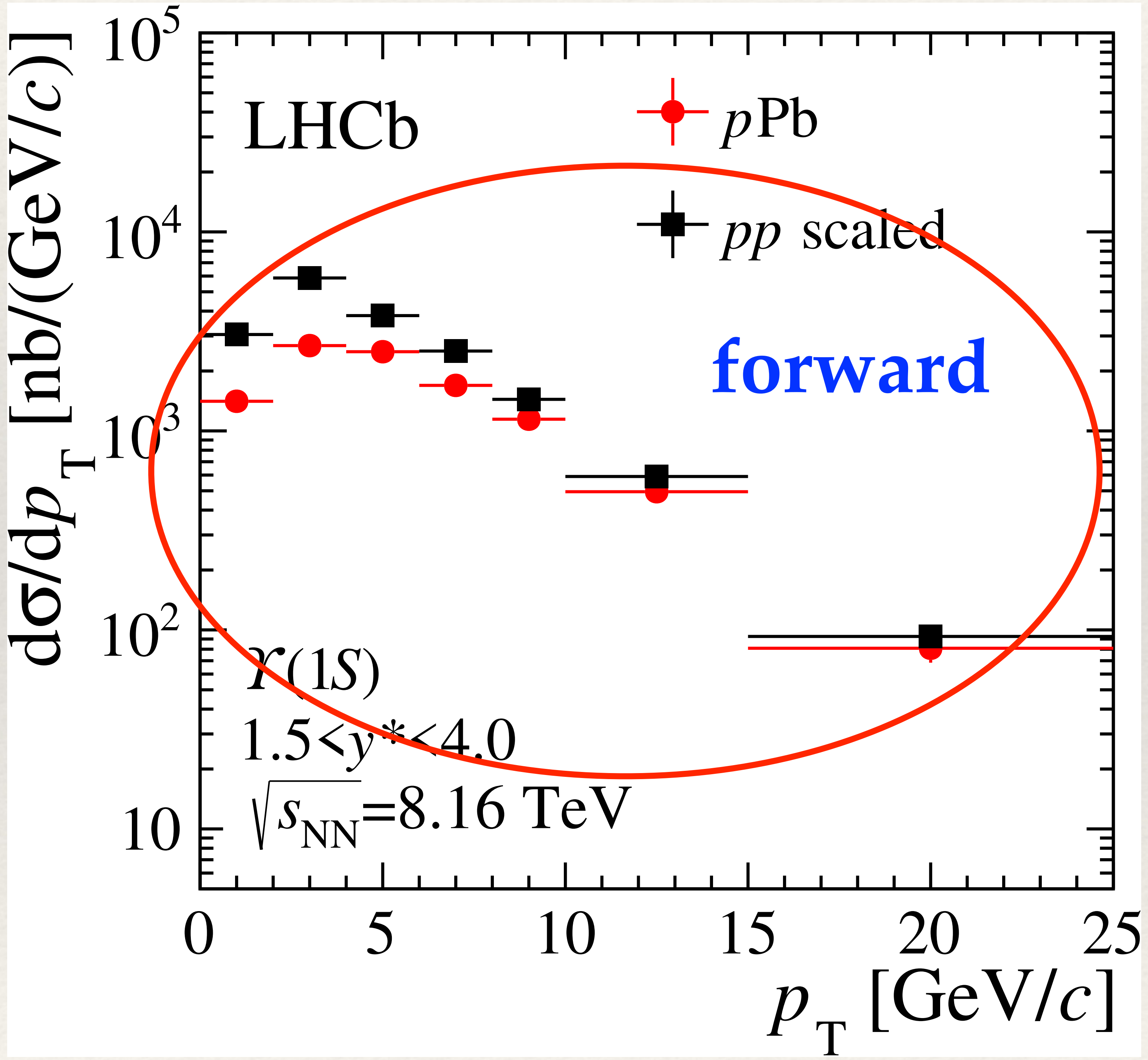
Υ(1S) integrated cross-section

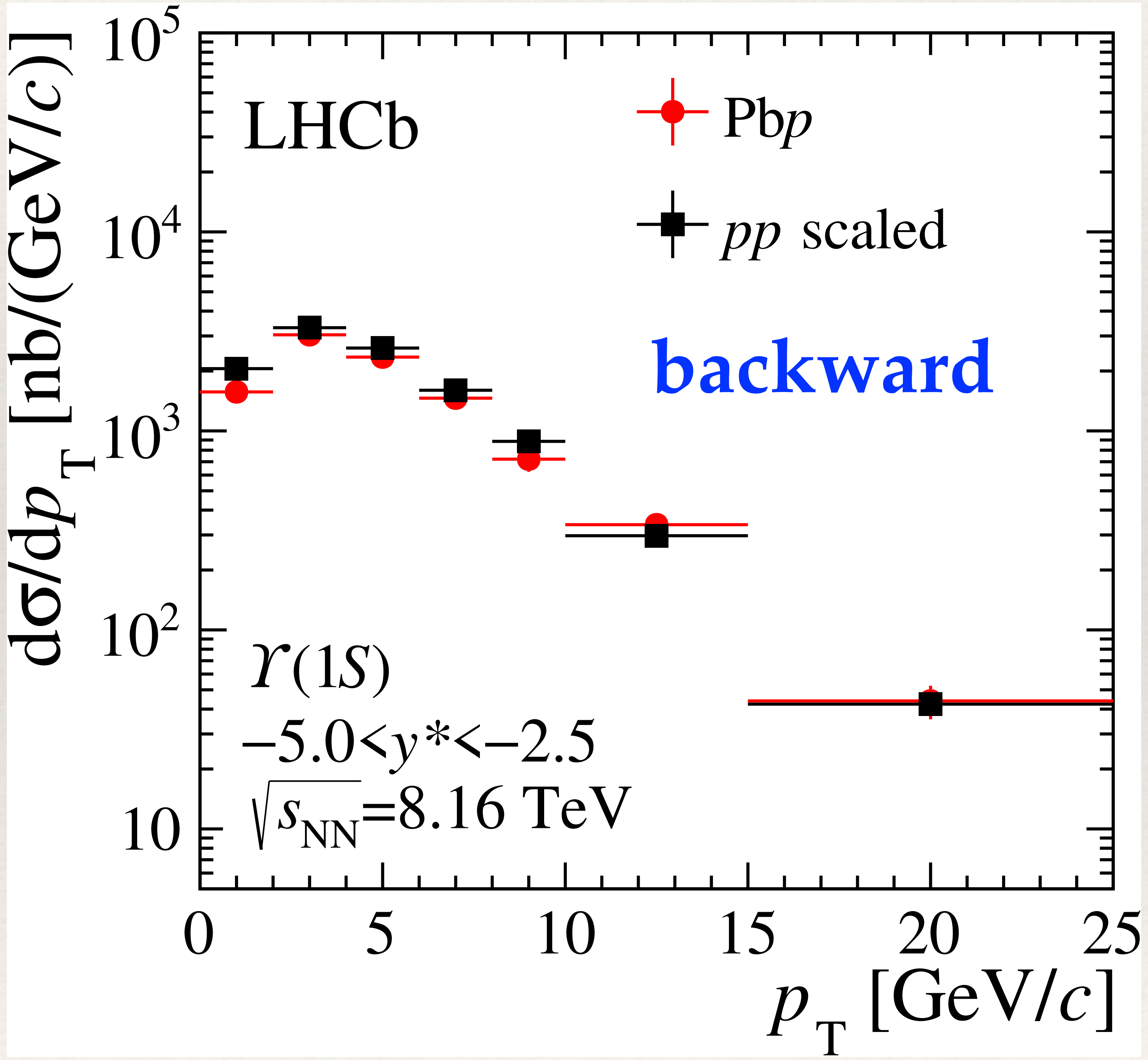
JHEP 11 (2018) 194

As a function of y*



As a function of p_T





suppression in the forward region

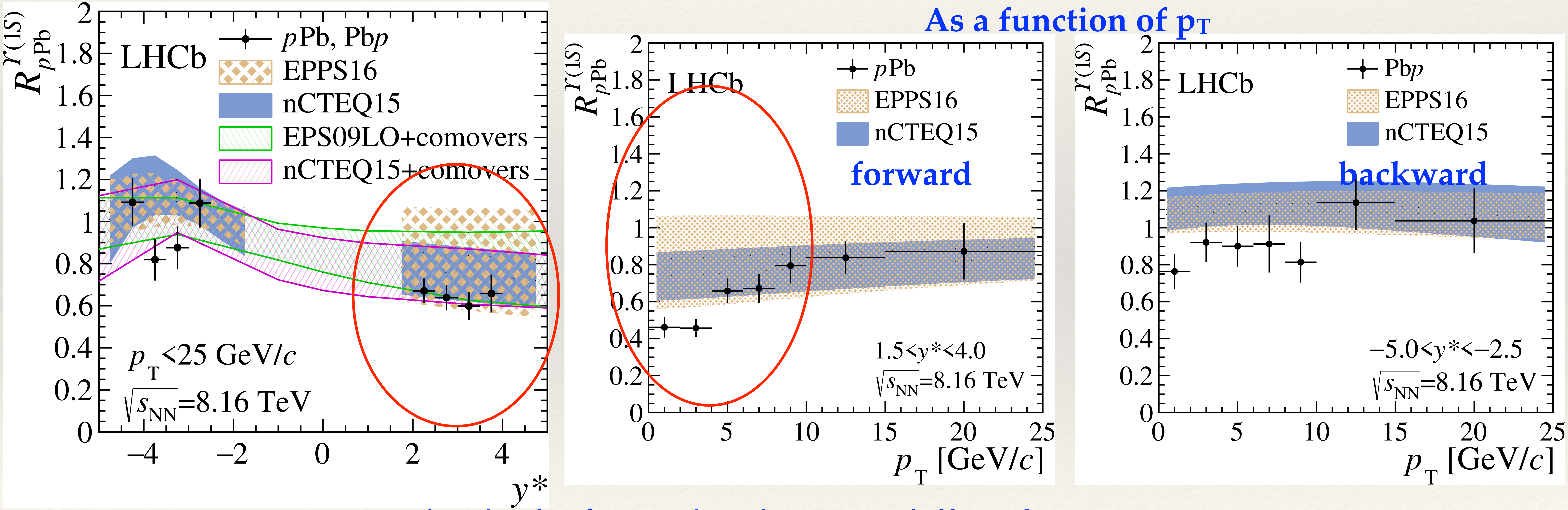
Υ(1S) Nuclear Modification Factors

JHEP 11 (2018) 194

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

As a function of y*

As a function of p_T

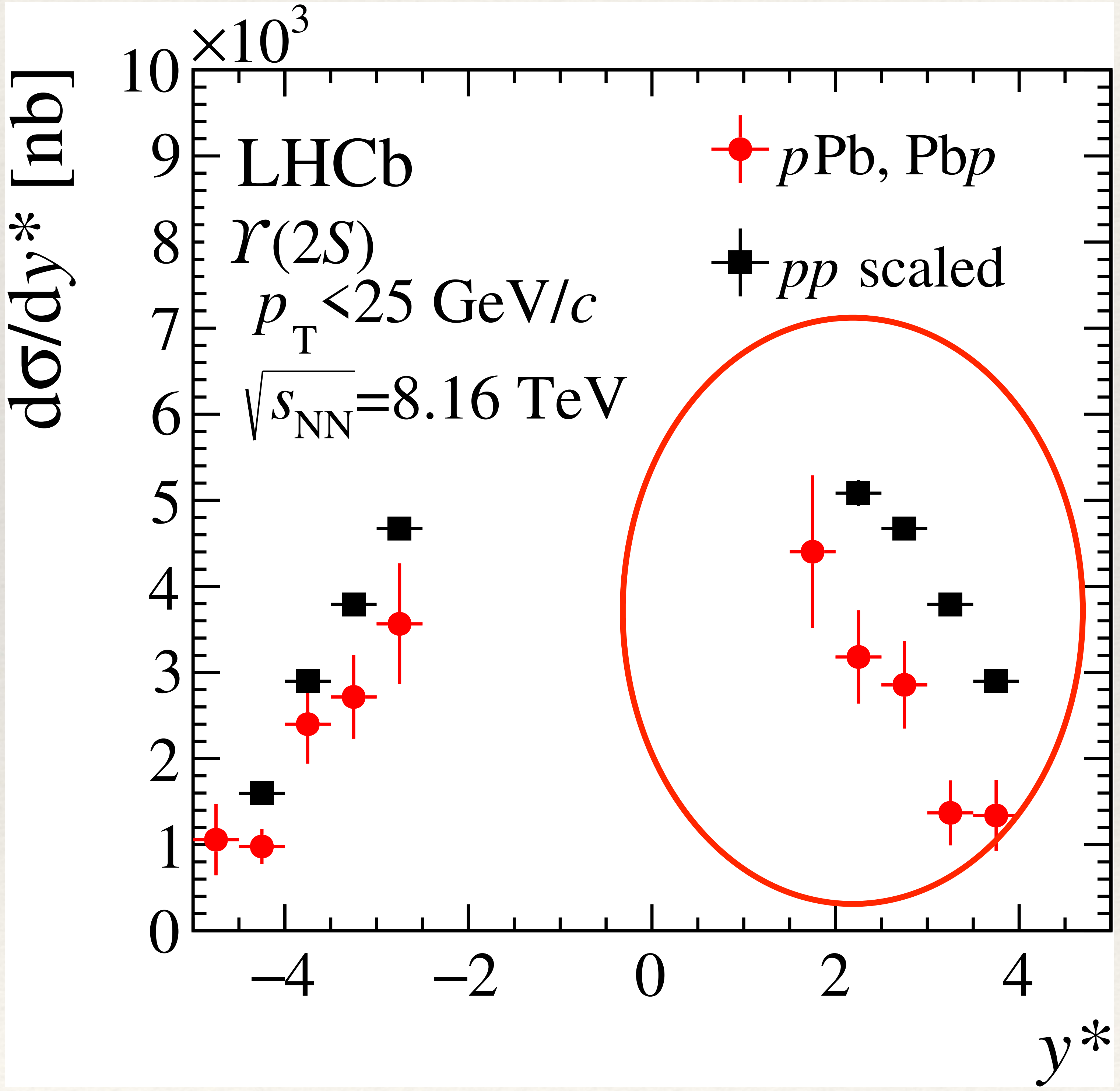


suppression in the forward region, especially at low p_T

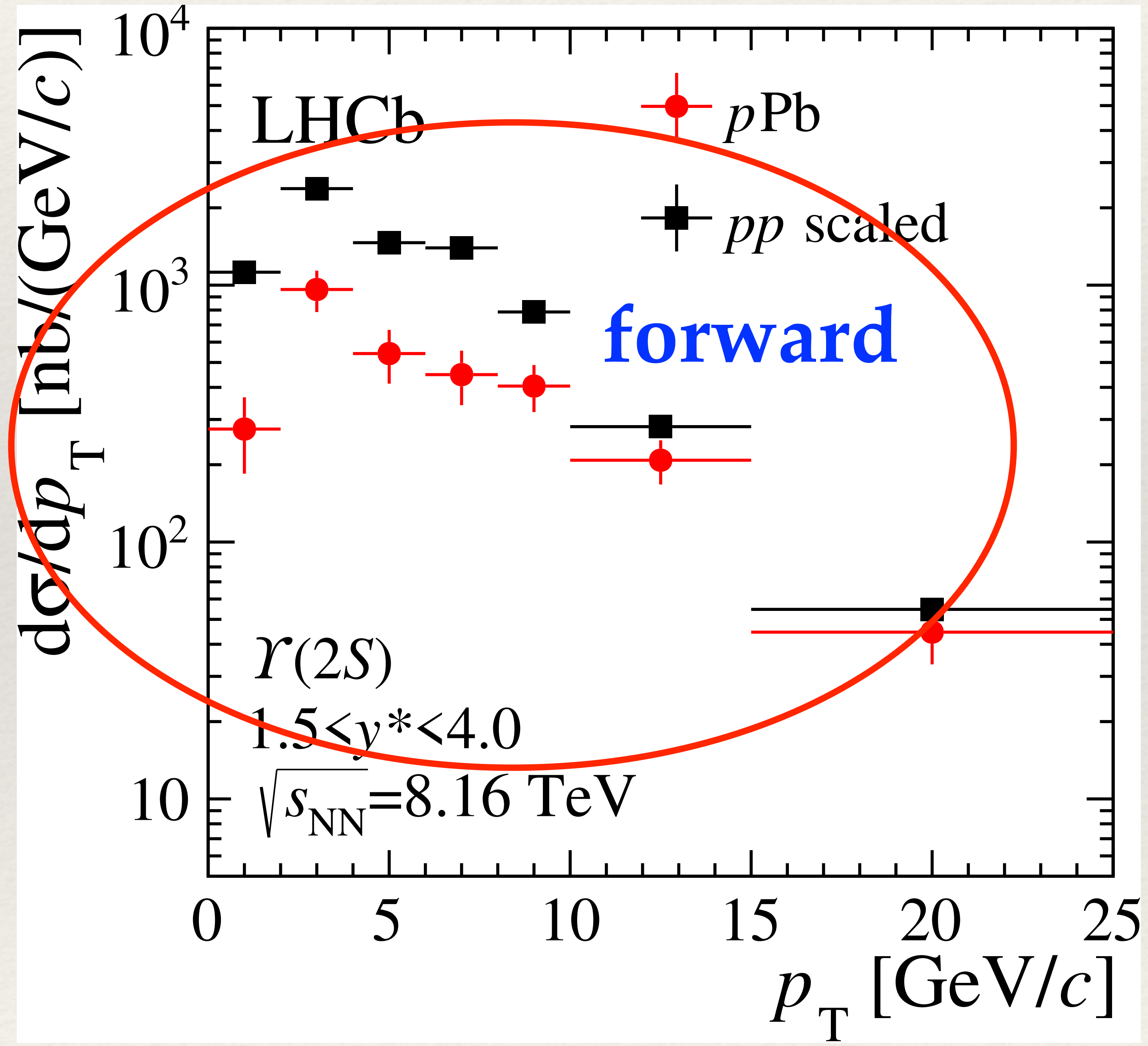
Υ(2S) integrated cross-section

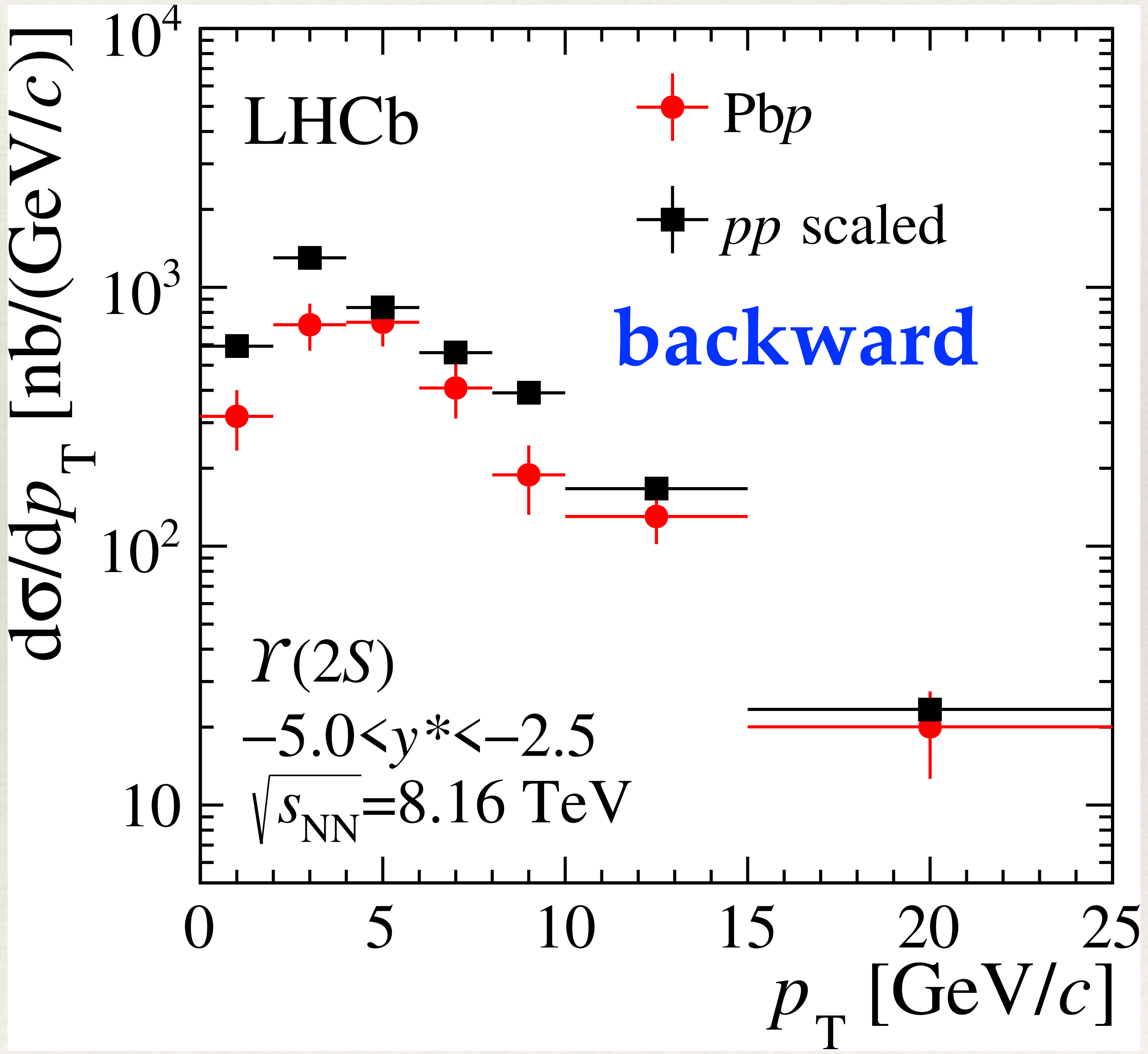
JHEP 11 (2018) 194

As a function of y*



As a function of p_T





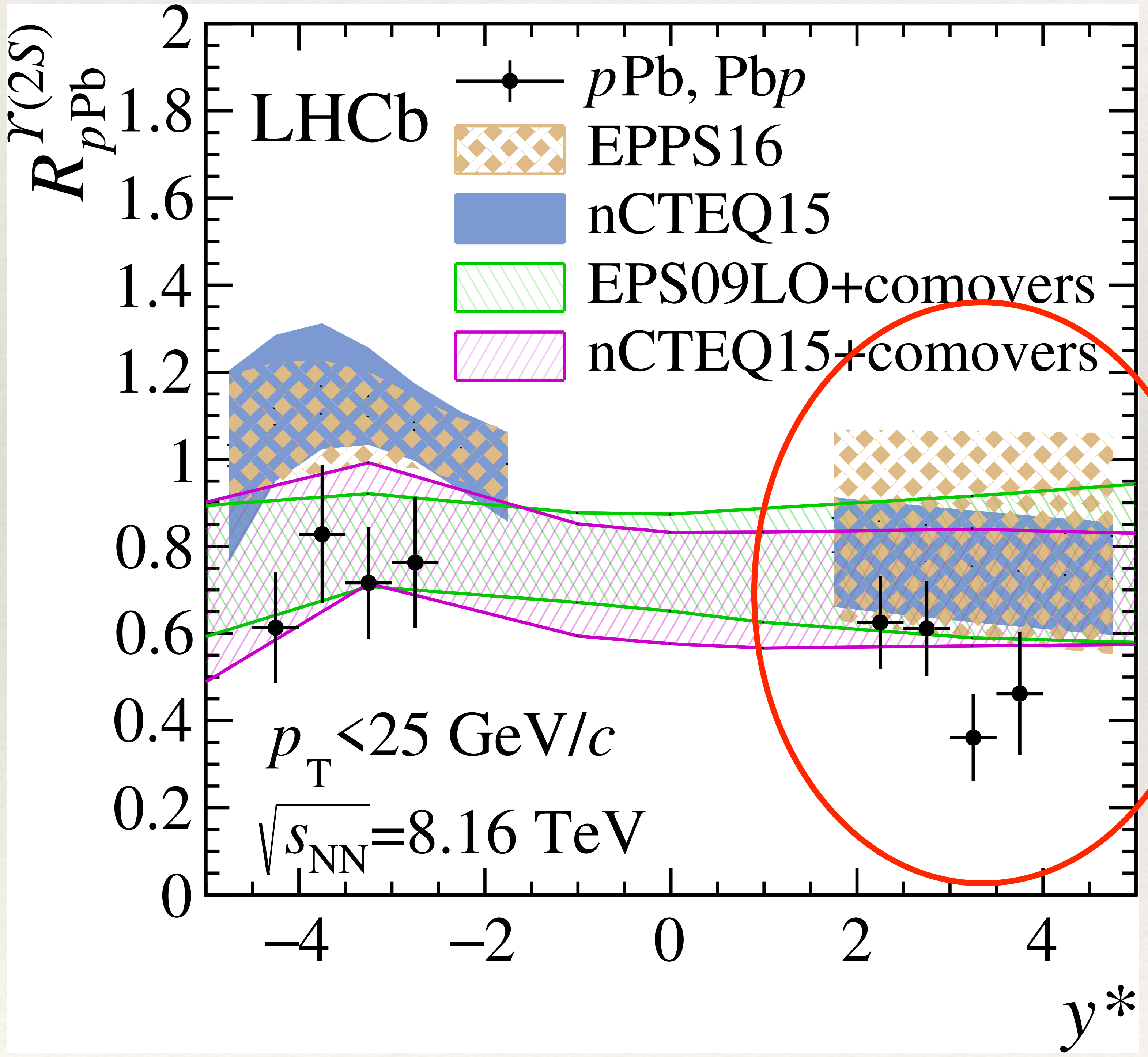
suppression in the both forward and backward regions at low p_T

Υ(2S) Nuclear Modification Factors

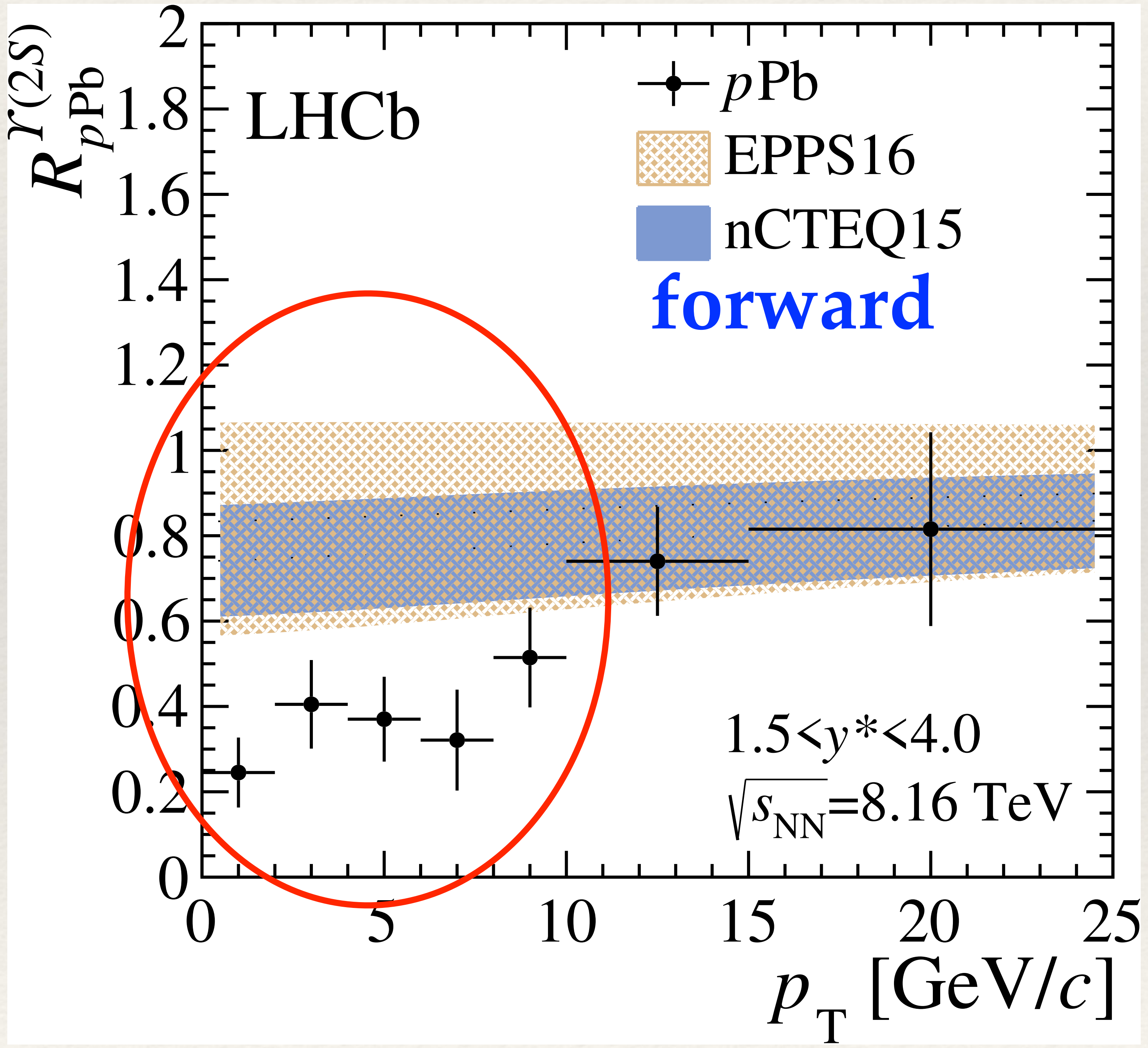
JHEP 11 (2018) 194

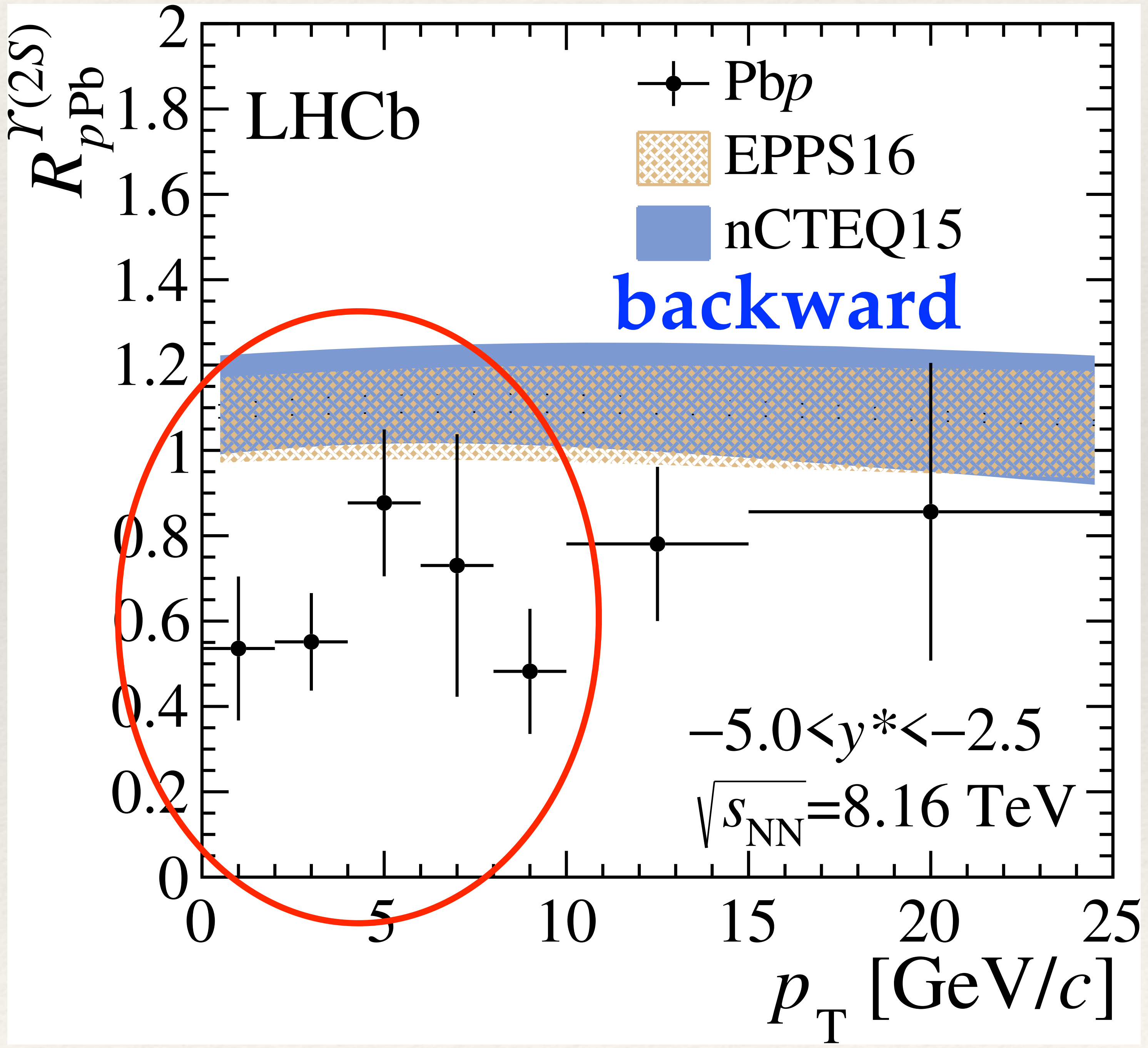
$$R_{p\mathrm{Pb}}(p_\mathrm{T}, y^*) = \frac{1}{208}\frac{\mathrm{d}^2\sigma_{p\mathrm{Pb}}(p_\mathrm{T}, y^*)/\mathrm{d}p_\mathrm{T}\mathrm{d}y^*}{\mathrm{d}^2\sigma_{pp}(p_\mathrm{T}, y^*)/\mathrm{d}p_\mathrm{T}\mathrm{d}y^*},$$

As a function of y*



As a function of p_T





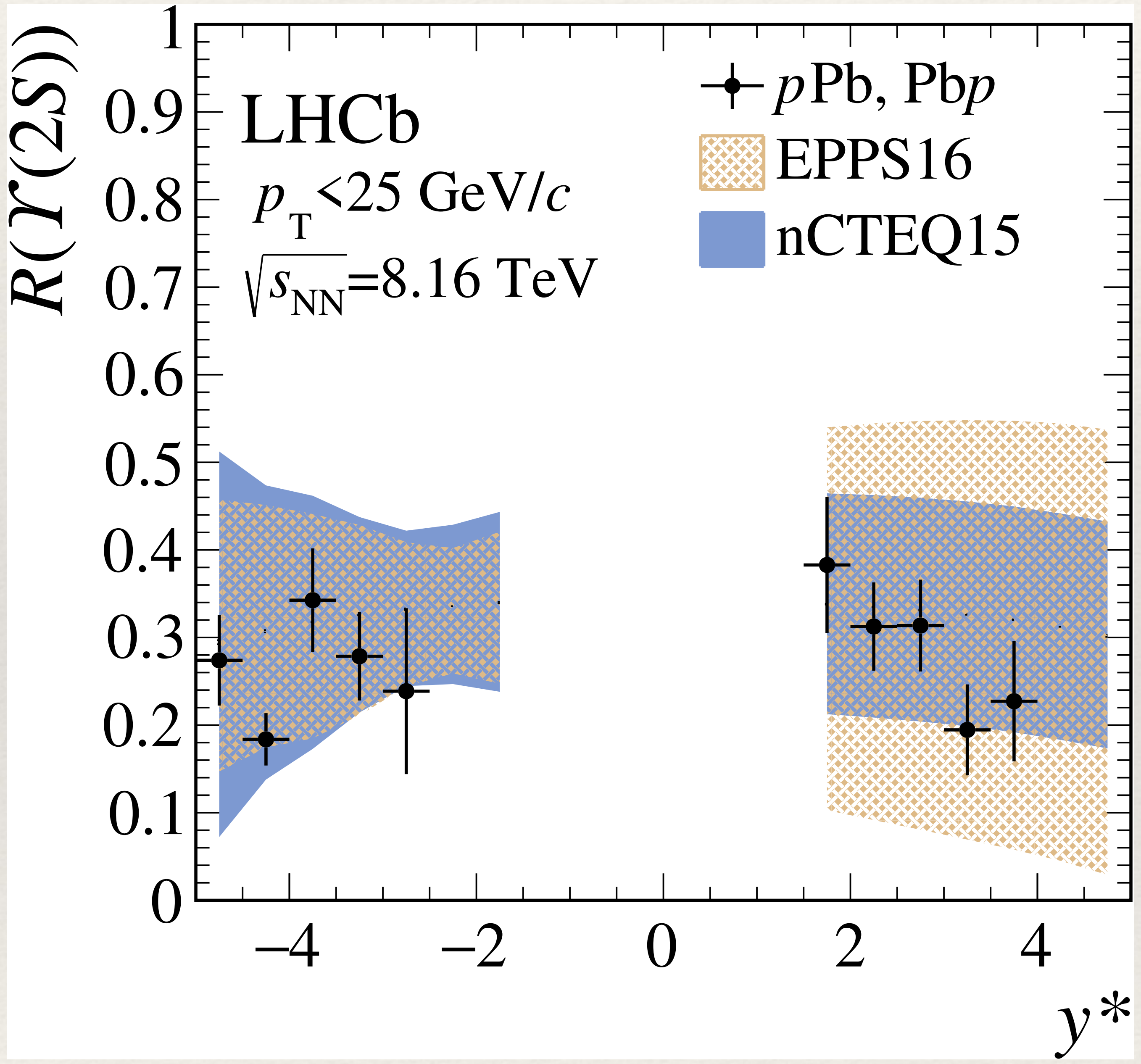
suppression in both forward and backward regions at low p_T

Ratio between Υ(2S) and Υ(1S)

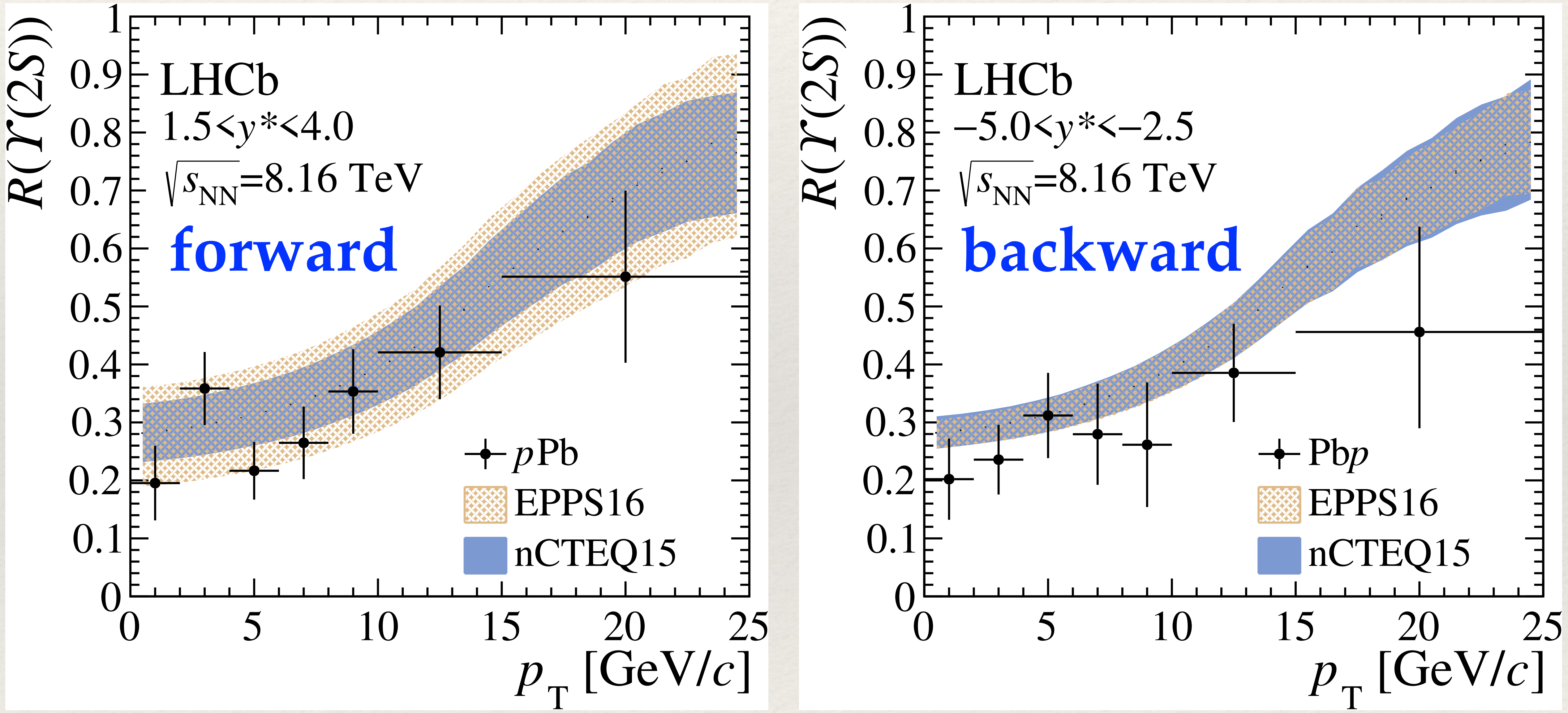
JHEP 11 (2018) 194

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

As a function of y*



As a function of p_T



ratio between Υ(2S) and Υ(1S) looks consistent with theoretical models

==> similar suppression for both Υ(2S) and Υ(1S)

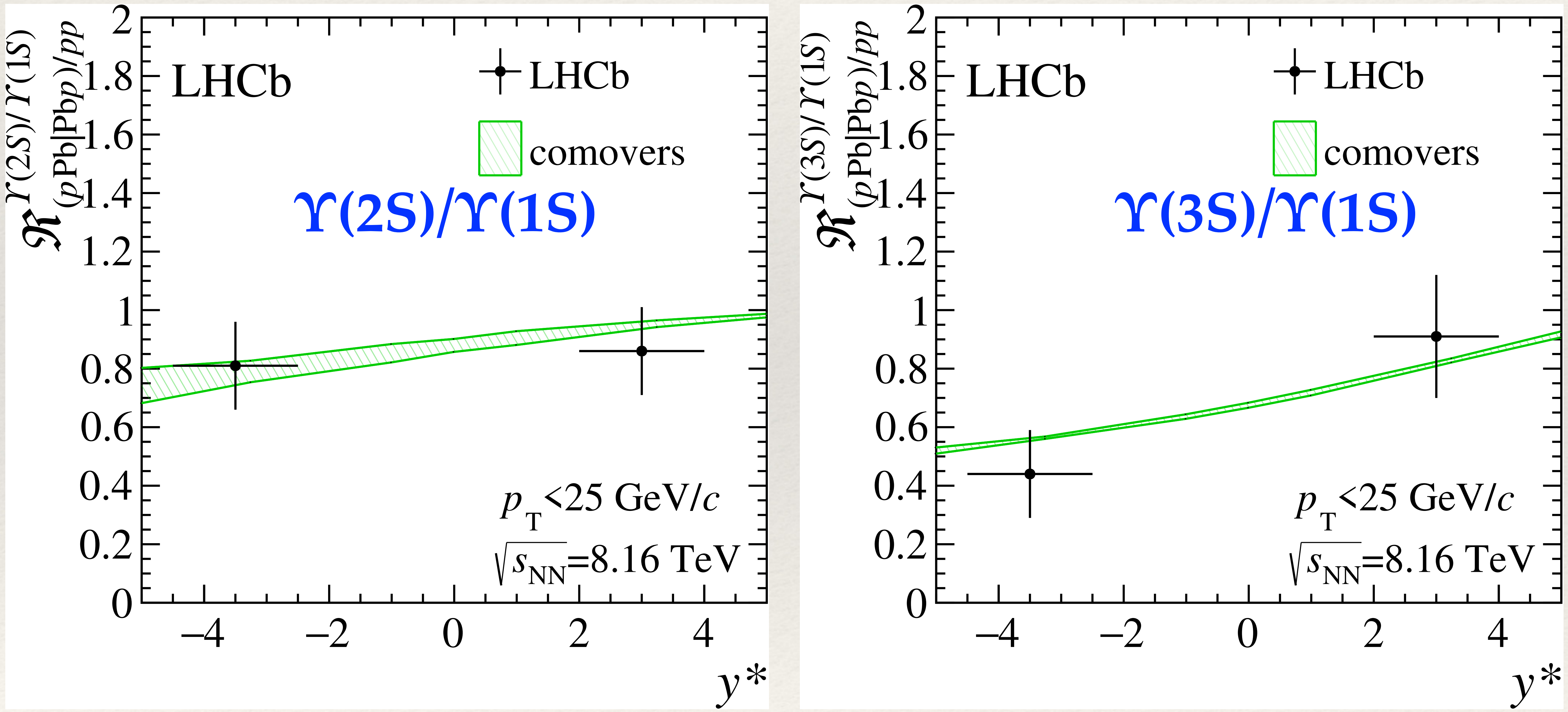
nPDFs predicts similar nuclear modification for Υ(nS), n=1,2,3..

Double ratios, Υ(1S) over non-prompt J/ψ

JHEP 11 (2018) 194

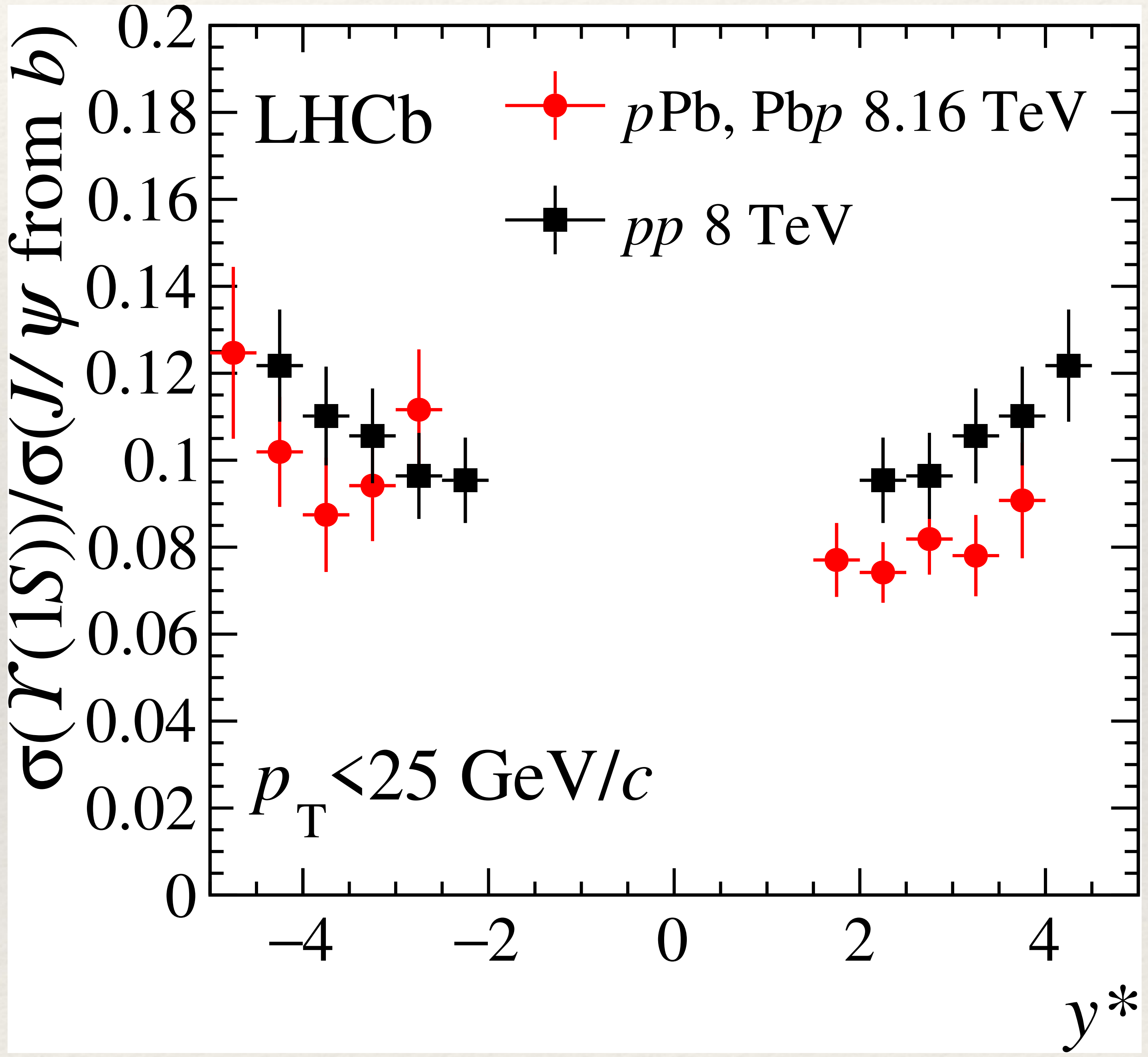
Υ(nS)/Υ(1S) of pPb over that of pp:

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



consistent with "comovers" model

Ratio of Υ(1S) over non-prompt J/ψ



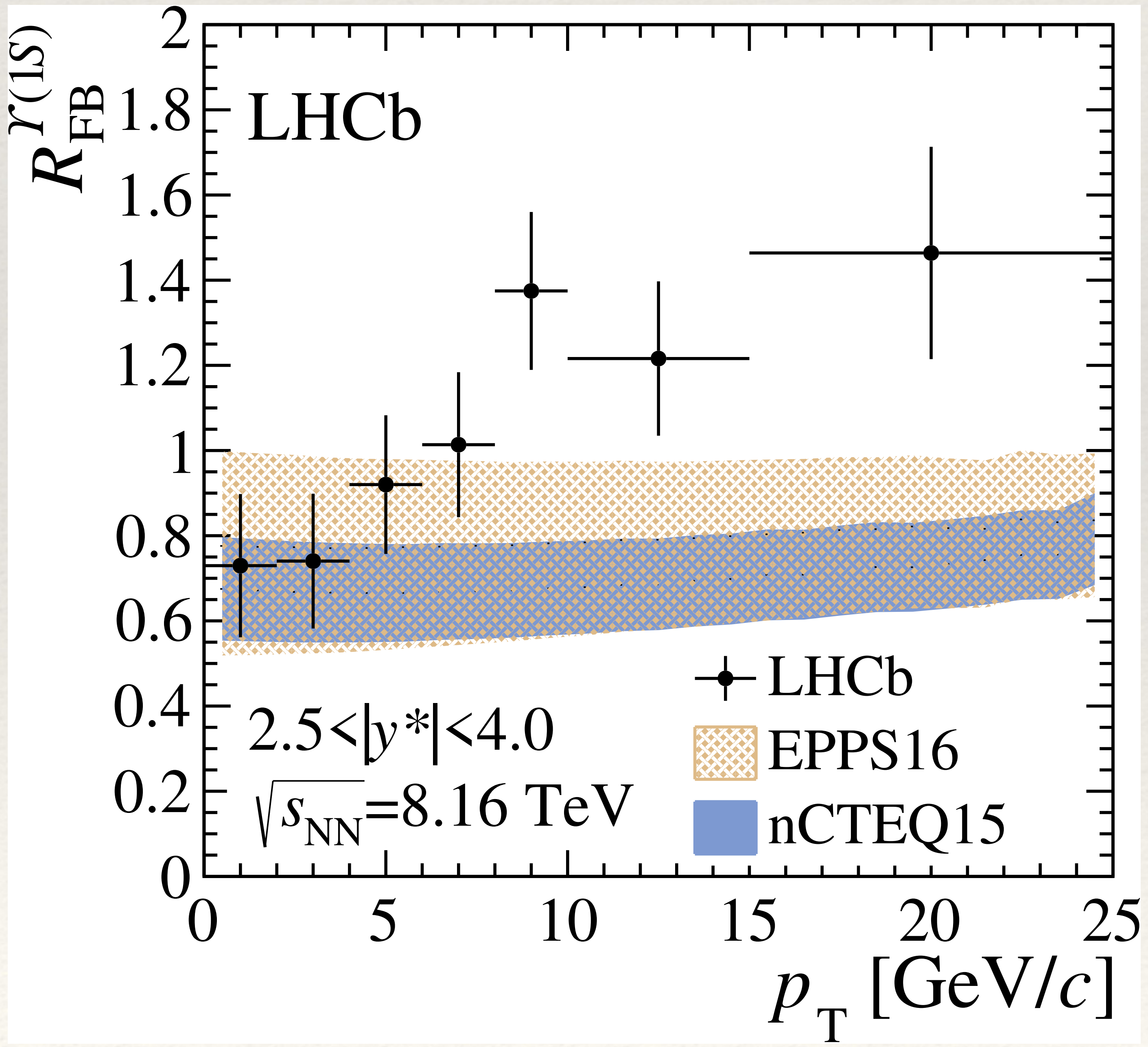
Forward/Backward Ratio

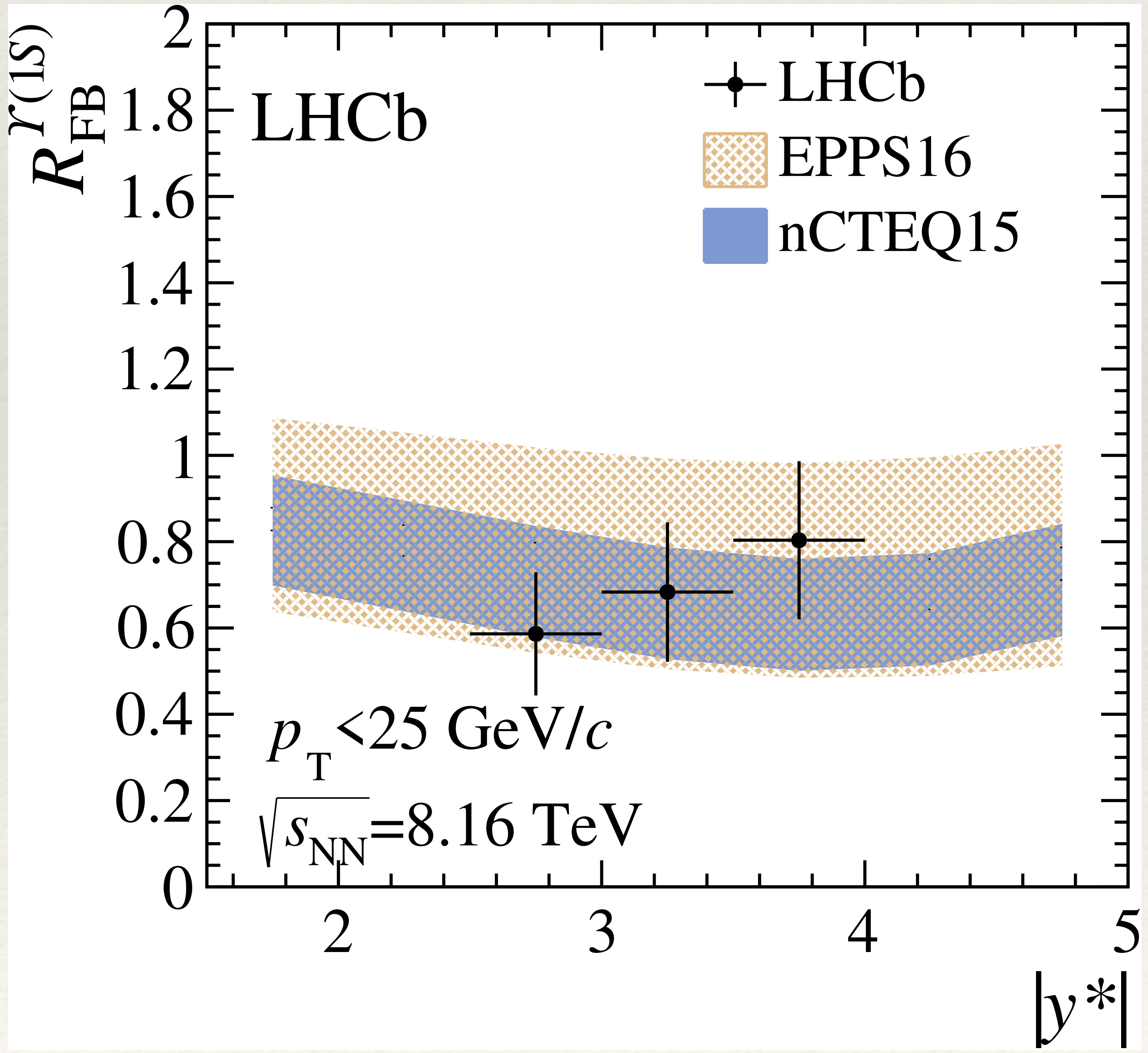
JHEP 11 (2018) 194

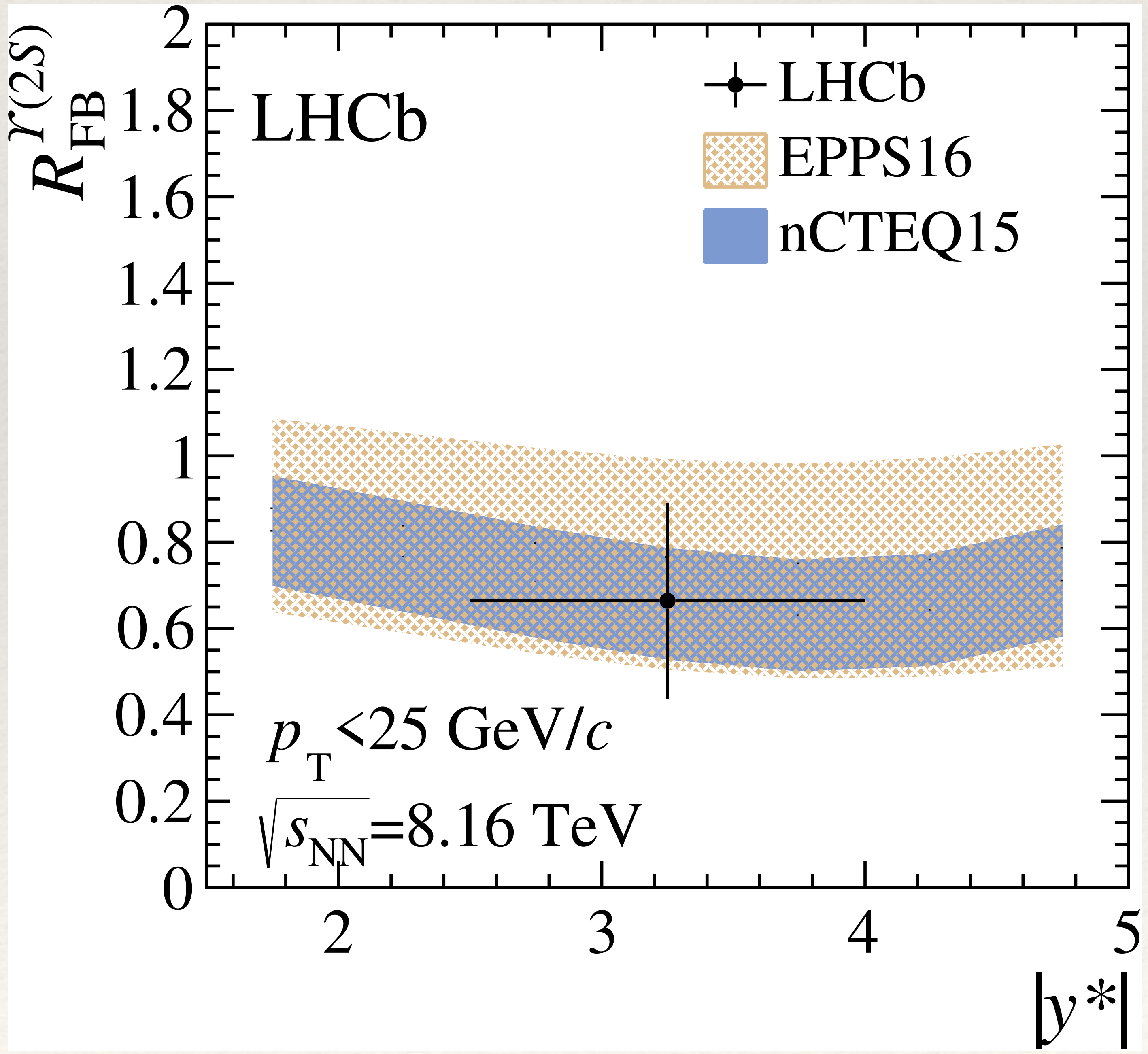
Forward/Backward Ratio $$R_{\rm FB}(p_{\rm T},|y^*|) = \frac{{\rm d}^2\sigma_{p{\rm Pb}}(p_{\rm T},+|y^*|)/{\rm d}p_{\rm T}{\rm d}y^*}{{\rm d}^2\sigma_{{\rm Pb}p}(p_{\rm T},-|y^*|)/{\rm d}p_{\rm T}{\rm d}y^*},$$

compared in common rapidity range: 2.5 < | y* | < 4.0

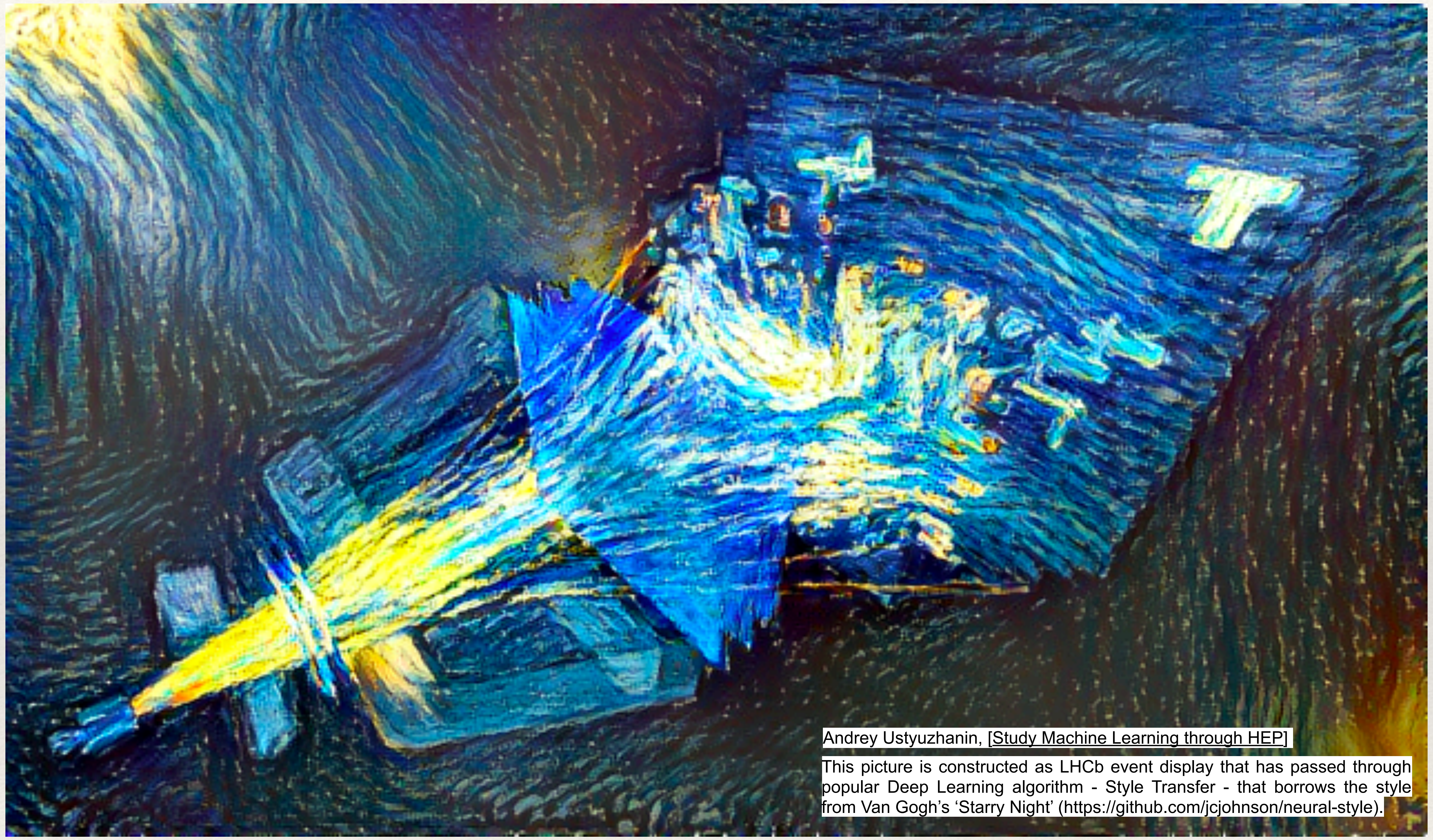
ϒ(1S) vs. p_T **ϒ(1S) vs y*** **ϒ(2S) vs y***







J/ψ production



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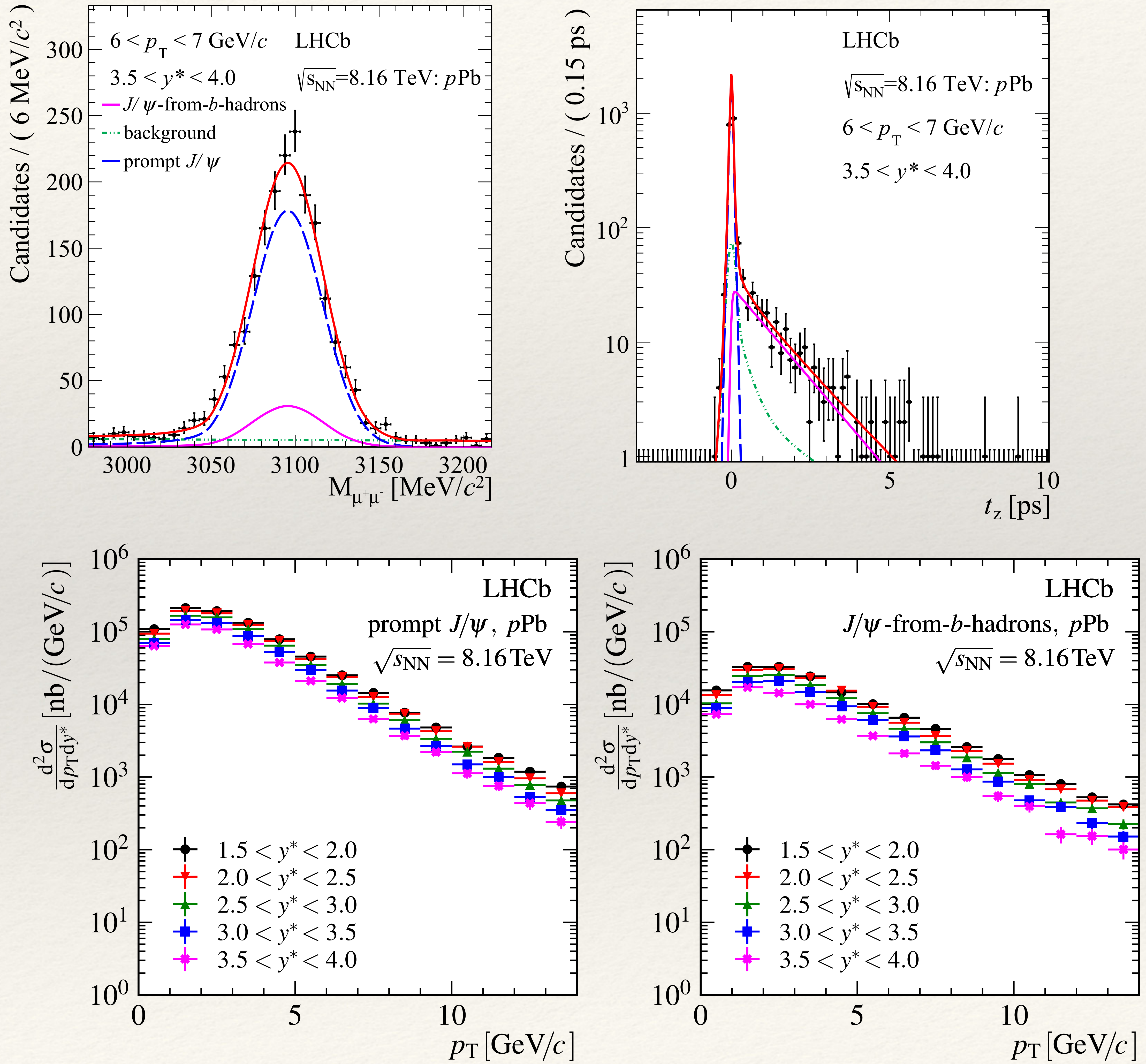
J/ψ production in pPb collisions PLB774 (2017) 159

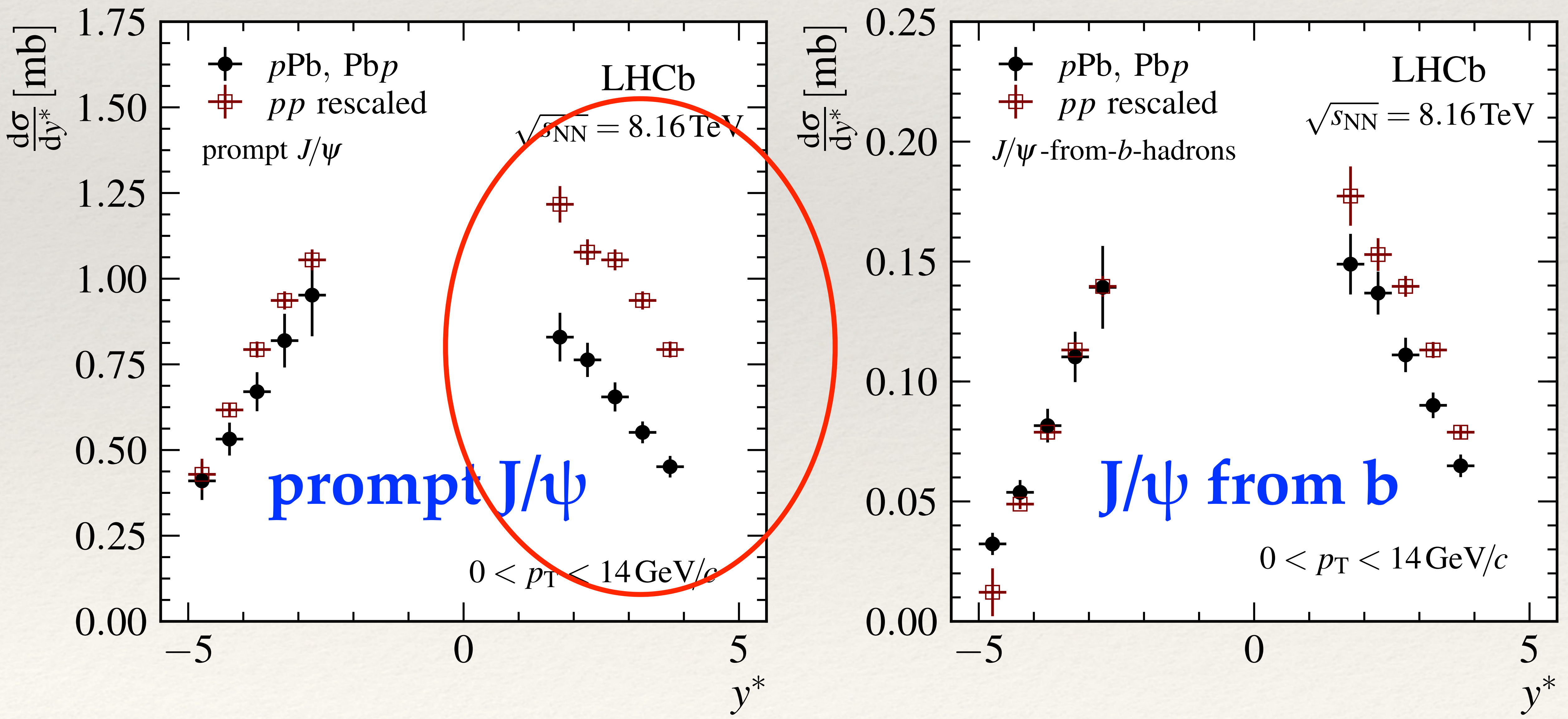
forward as example

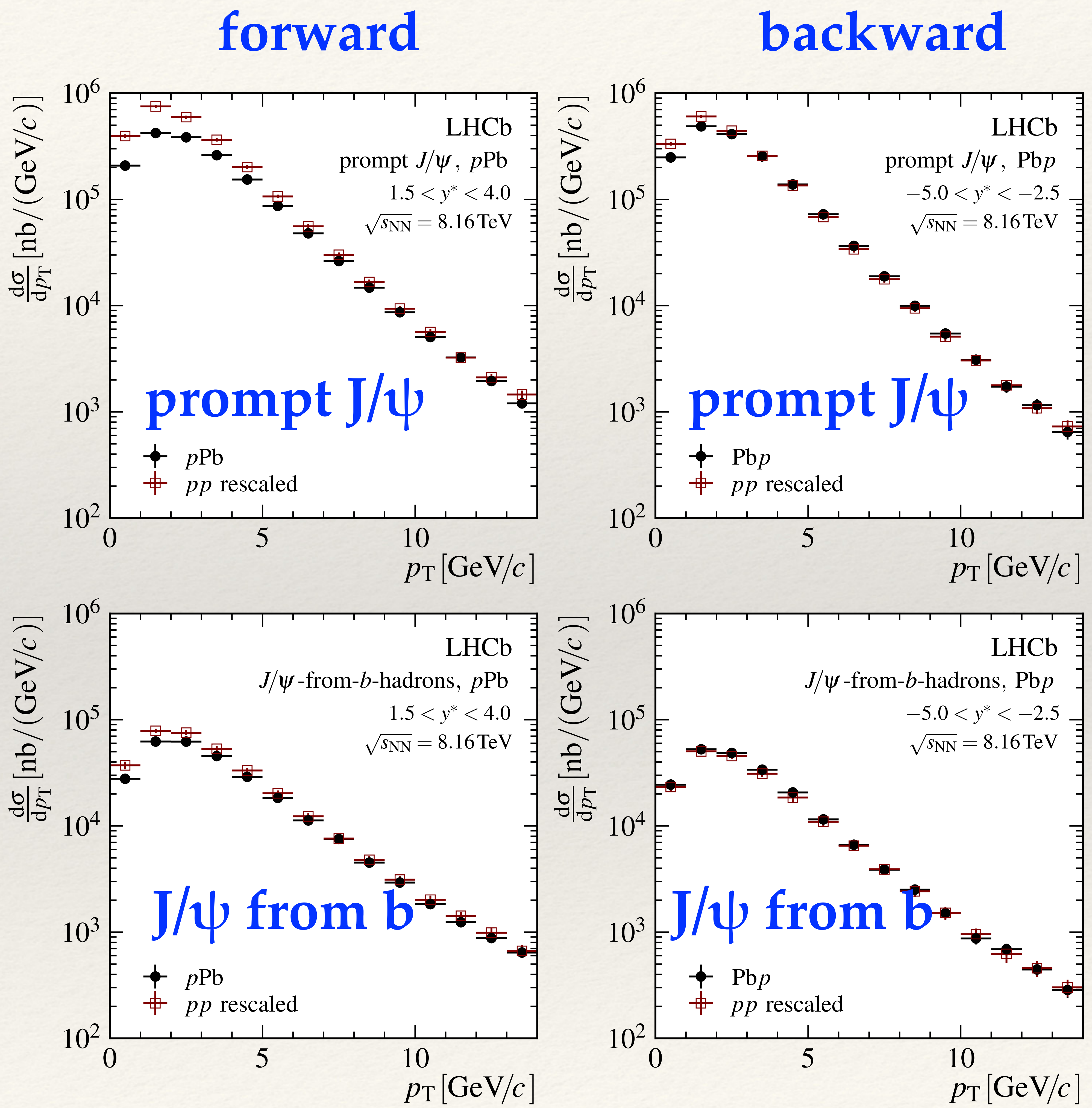
- $\sqrt{s_{NN}}$ = 8.16 TeV results:
  - Double differential in y and p_T
  - Prompt and non-prompt J/ψ separated through pseudoproper time distribution
- Compared with
  - HELAC: Eur. Phys. J. C77 (2017) 1; Comput.Phys.Comm. 184(2013) 2562, Comput. Phys. Comm.198 (2016) 238. EPS09: JHEP 04 (2009) 065.
  - nCTEQ15: Phys. Rev. D93 (2016) 085037.
  - EnergyLoss: JHEP 03 (2013) 122.
  - FONLL: JHEP 05 (1998) 007, JHEP03 (2001) 006
  - CGC: Phys. Rev. D91 (2015) 114005



J/ψ production in pPb collisions PLB774 (2017) 159

- Differential cross-section in y and p_T
  - visible suppression in forward for prompt J/ψ

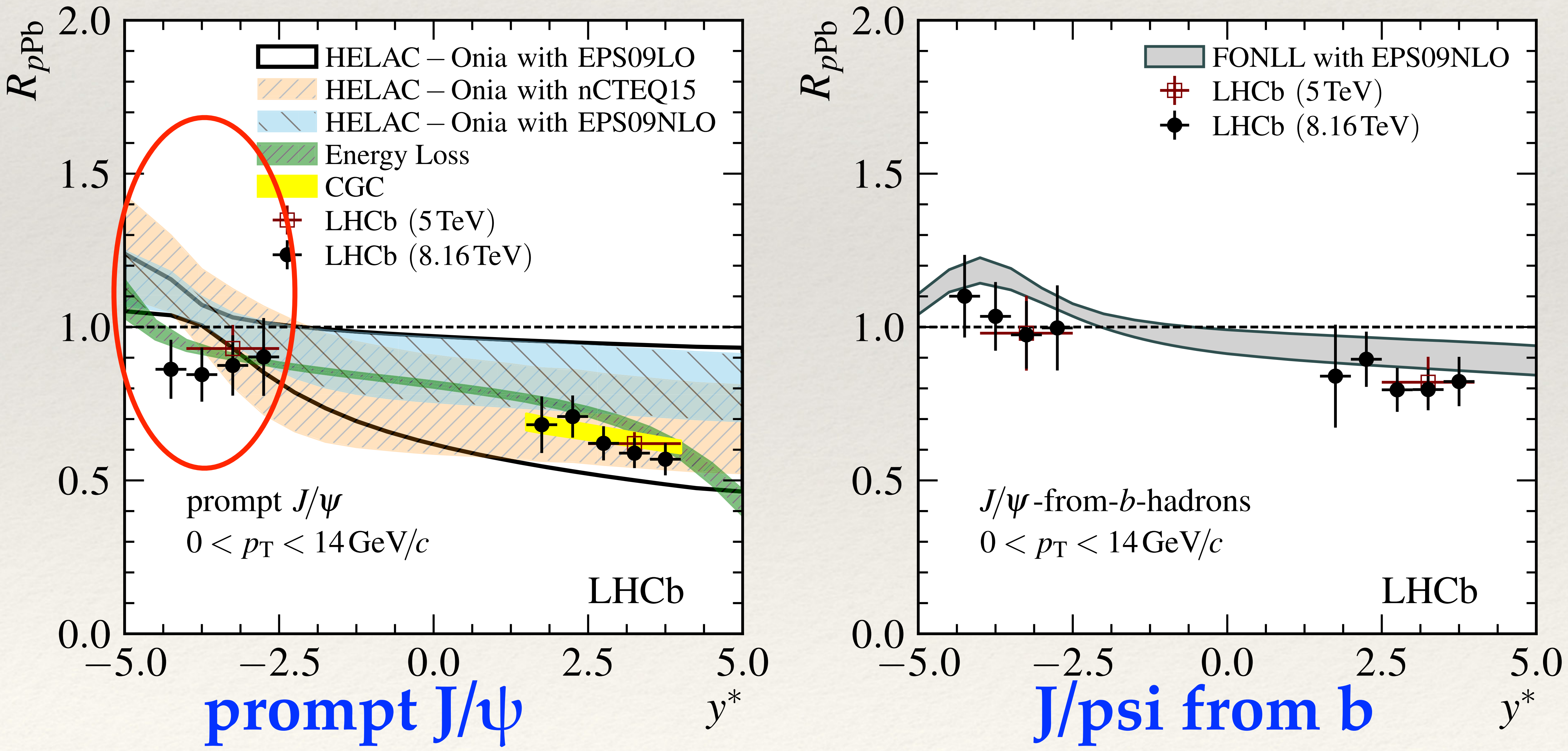


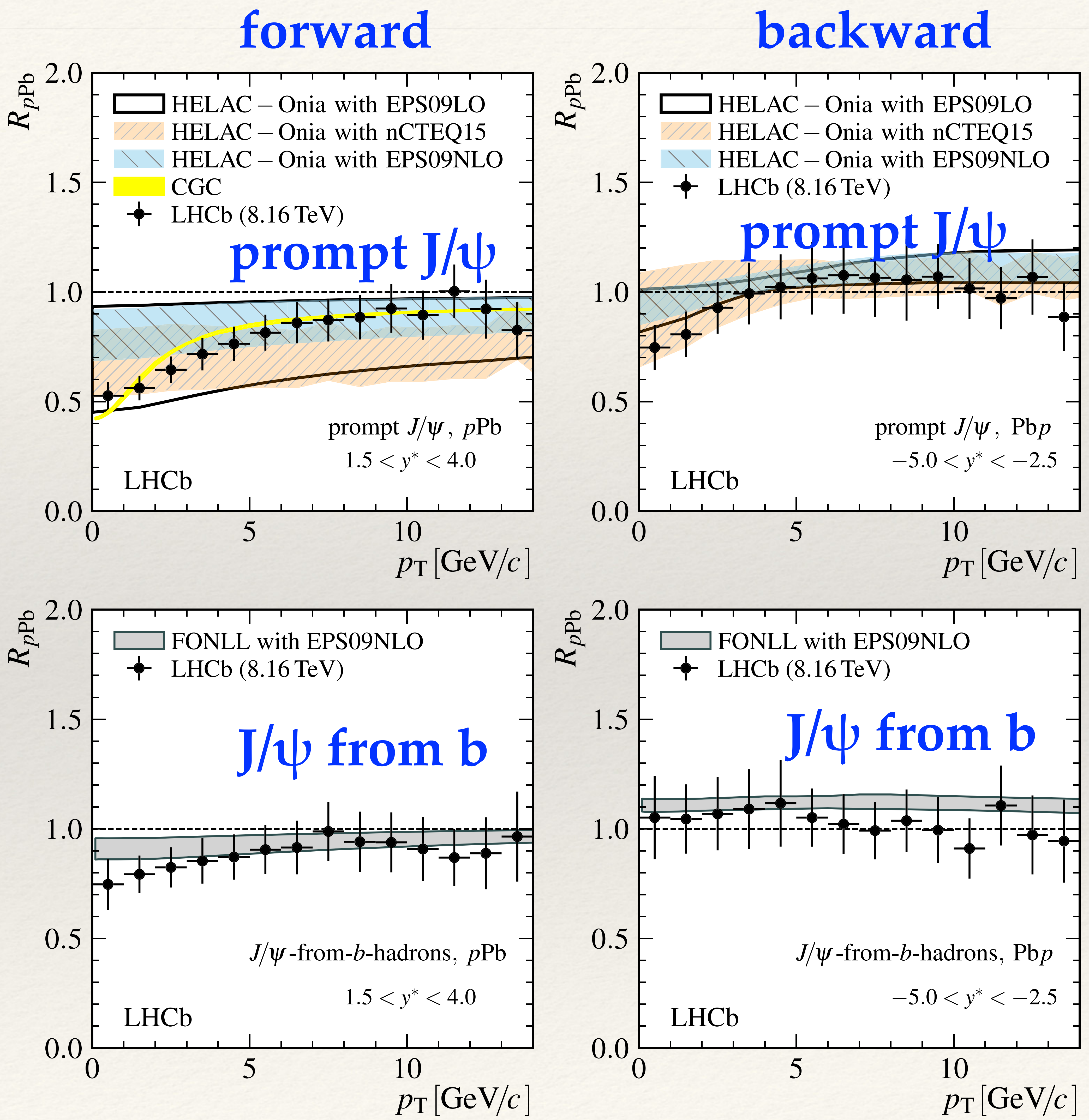


J/ψ production in pPb collisions

PLB774 (2017) 159

- Nuclear modification factors R_{pPb}
  - suppression in forward region is compatible with theory models
  - instead, visible difference in backward region with theory models (certain enhancement is expected but not observed)



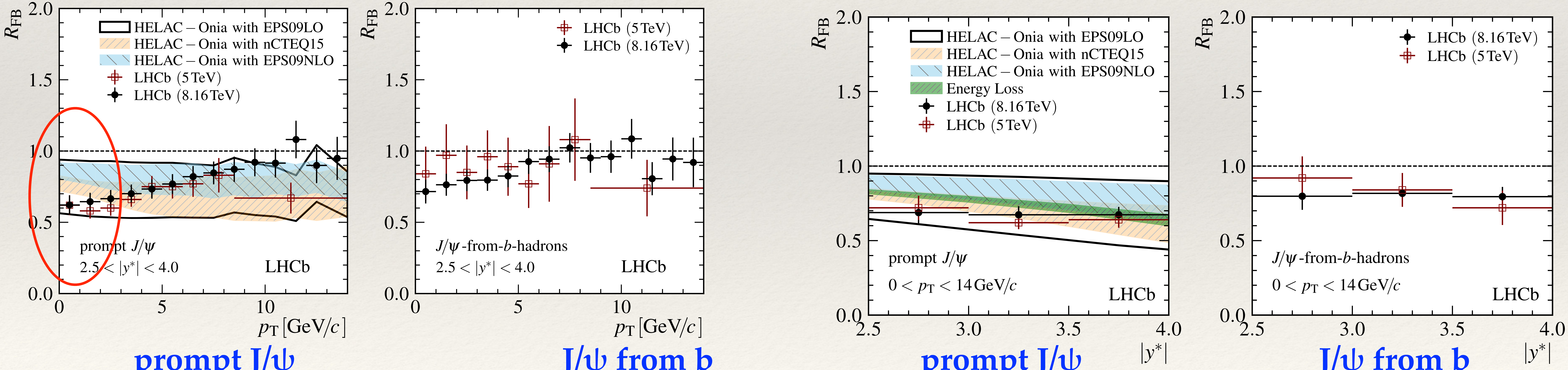


J/ψ production in pPb collisions PLB774 (2017) 159

- Forward and backward ratio
- Certain inconsistency is observed at low p_T

$$R_{FB}(p_T, y^*) \equiv \frac{d^2\sigma_{pPb}(p_T, +y^*)/dp_T dy^*}{d^2\sigma_{pPb}(p_T, -y^*)/dp_T dy^*}.$$

R_{FB} vs p_T **R_{FB} vs $|y^*|$**



prompt J/ψ J/ψ from b prompt J/ψ J/ψ from b

Summary and Outlook

- **LHCb successfully participated in pPb data-taking in 2013 and 2016**
- **Collected good statistics: benefit from larger data samples in 2016**
- **Measurement of J/ψ and $\Upsilon(nS)$ performed**
- **$\psi(2S)$ and χ_c production upcoming and others are ongoing**
- **Results compared with several theoretical predictions**

Backup slides

Why study ultra-relativistic heavy ion collisions?

- It's about understanding our Universe.
- Ultra-relativistic heavy ion collisions can help us to understand what happened in the very beginning after the Big Bang.
  - Explore phase diagram of nuclear matter
  - Study QCD matter under extreme conditions
    - Formation of Quark Gluon Plasma at high T and/or energy density.
  - Many other things to explore in pA/AA: nucleon structure, intrinsic charm, QED at extreme field strengths, diffractive processes...