J/ψ and ψ(2S) Production in p-Pb Collisions at 5.02 TeV with ATLAS

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Seventh International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions

McGill University
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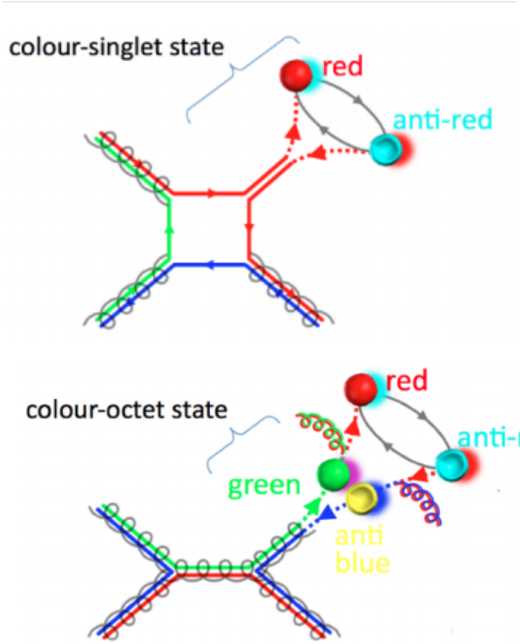
Motivations

- Naïvely: “Cold Nuclear Matter effects as HI baseline”
- Now, numerous new insights:



➡ J/ψ production mechanisms

➡ saturation scale in QCD

➡ medium-induced gluon radiation

➡ shadowing + other modifications of gluon PDFs

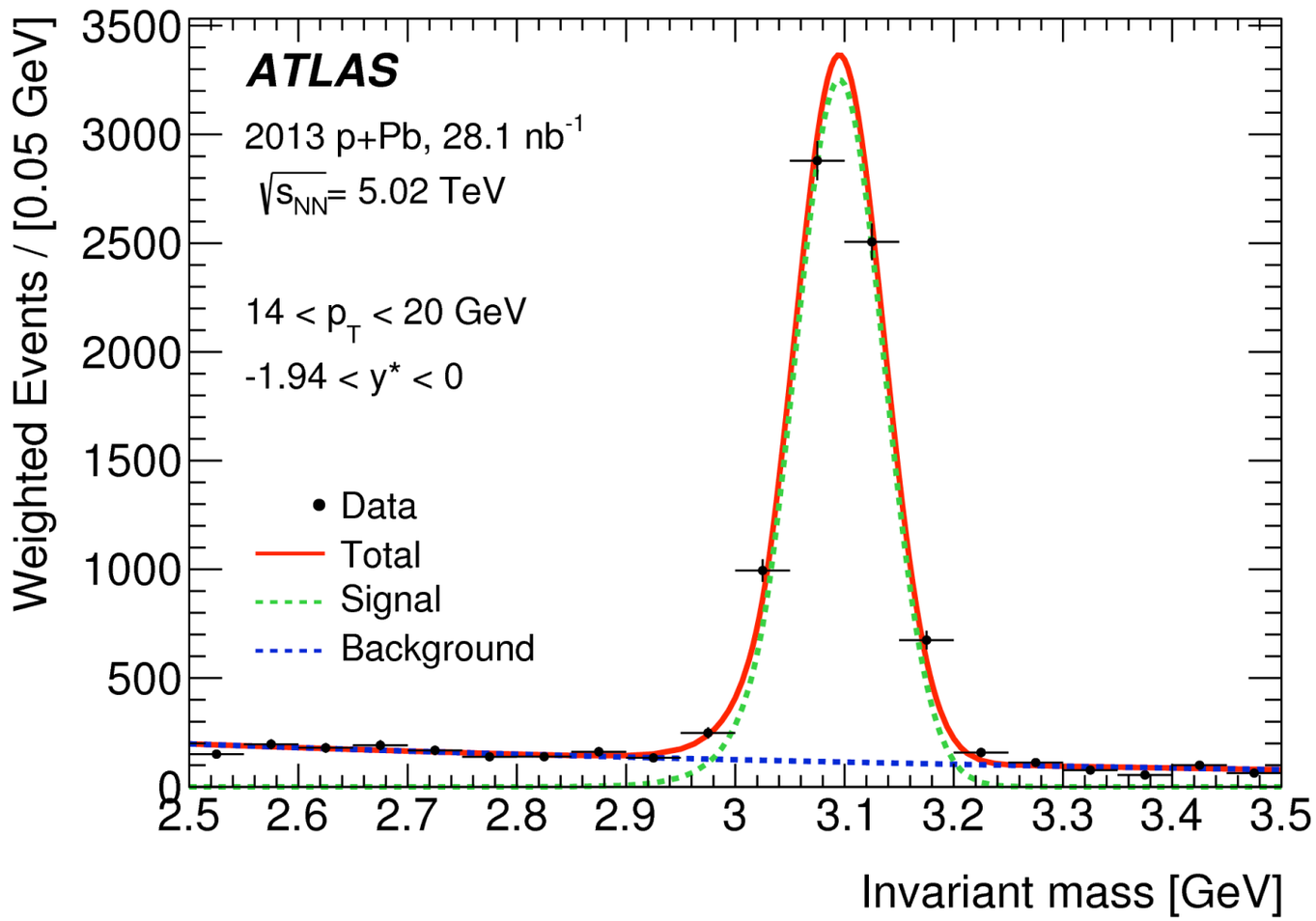
➡ absorption of the $Q\bar{Q}$ pair

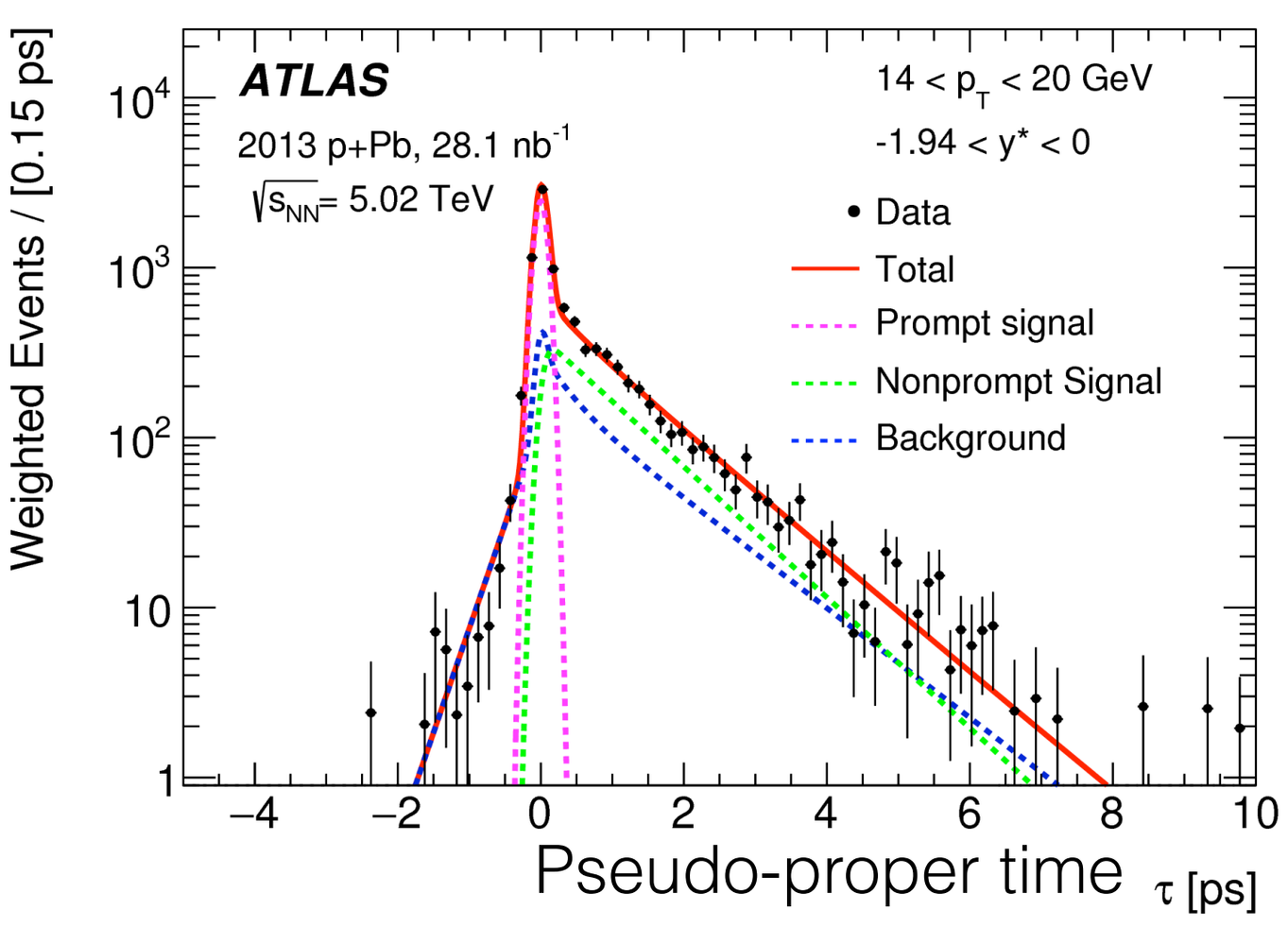
➡ ion-direction observables vs. proton-direction

Method

- Measure dimuons
- Trigger: 1+ MU0 at L1; 2 muons > 2 GeV, full scan Event Filter
- Two largely independent analyses:
  - ➡ May 2015 J/ψ paper - arXiv:1505.08141 [hep-ex]
  - ➡ June 2015 J/ψ and ψ(2S) - ATLAS-CONF-2015-023

- Separate prompt from non-prompt (b-quarks) J/ψ and ψ(2S)
- Analysis ranges: 8.5 < pT < 30 GeV, |y*| < 1.94 (1.5)
- Perform *weighted simultaneous fit* to invariant mass and lifetime to subtract background, separate prompt/non-prompt charmonia
- Weights: L1 trigger, Event Filter, reconstruction efficiency, acceptance





Ingredients of simultaneous fit

$$\mathrm{PDF}(m,\tau) = \sum_{i=1}^{7} \kappa_i f_i(m) \cdot h_i(\tau) \otimes g(\tau)$$

CB: Crystal ball function
G: Gaussian
E: Exponential
g: Double Gaussian
δ: Delta Function

Type	Source	$f_i(m)$	$h_i(\tau)$
J/ψ S	P	$\omega_i CB_1(m) + (1-\omega_i) G_1(m)$	$\delta(\tau)$
J/ψ S	NP	$\omega_i CB_1(m) + (1-\omega_i) G_1(m)$	$E_1(\tau)$
$\psi(2S)$ S	P	$\omega_i CB_2(m) + (1-\omega_i) G_2(m)$	$\delta(\tau)$
$\psi(2S)$ S	NP	$\omega_i CB_2(m) + (1-\omega_i) G_2(m)$	$E_2(\tau)$
Bkg	P	$flat$	$\delta(\tau)$
Bkg	NP	$E_3(m)$	$E_4(\tau)$
Bkg	NP	$E_5(m)$	$E_6(\|\tau\|)$

J/ψ-only Analysis
p+Pb at 5.02 TeV

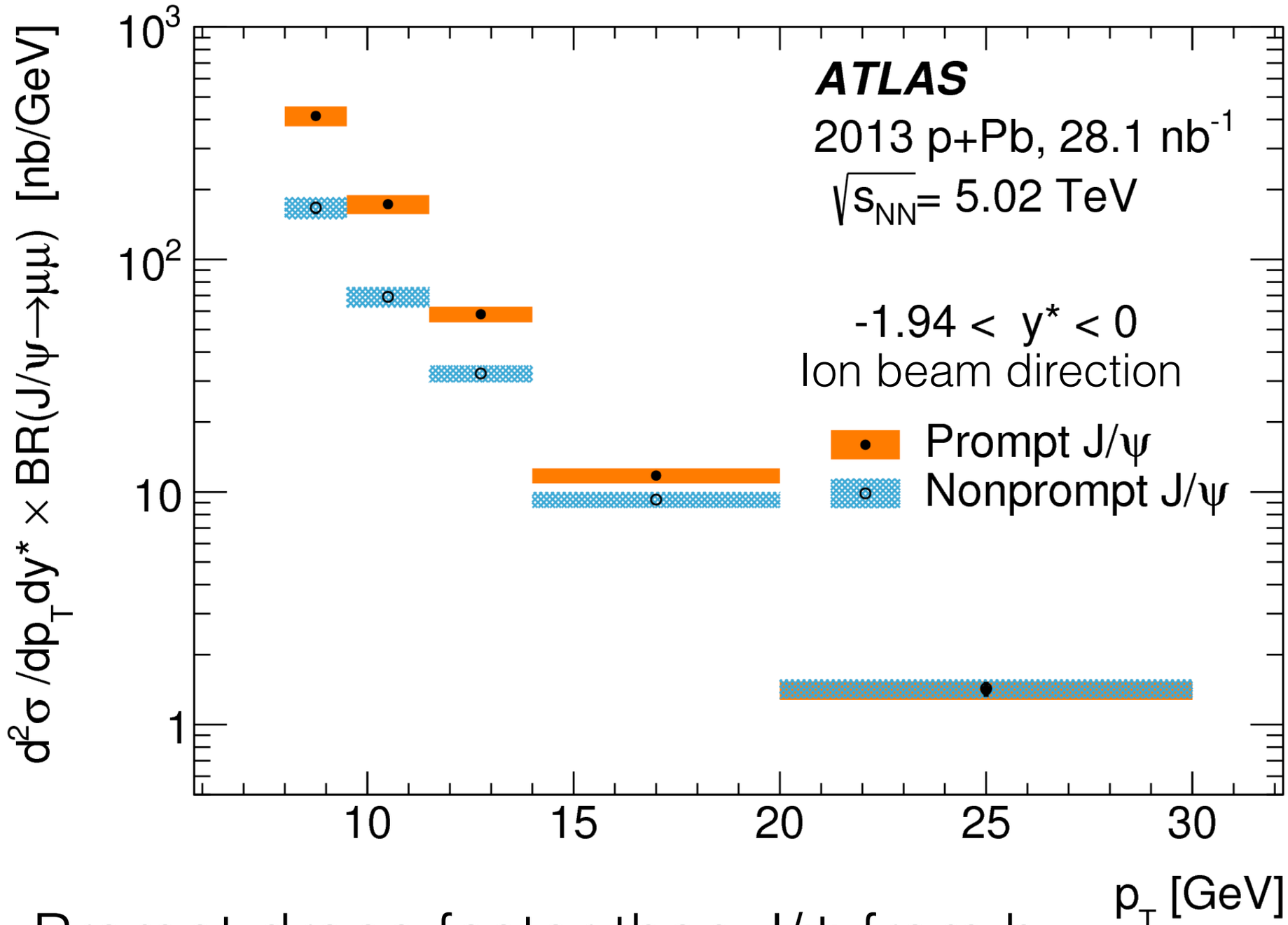
May 2015 J/ψ paper - arXiv:1505.08141 [hep-ex]

$d^2\sigma/dy^*dp_T$, prompt and non-prompt

Non-prompt fraction vs. y^* and p_T

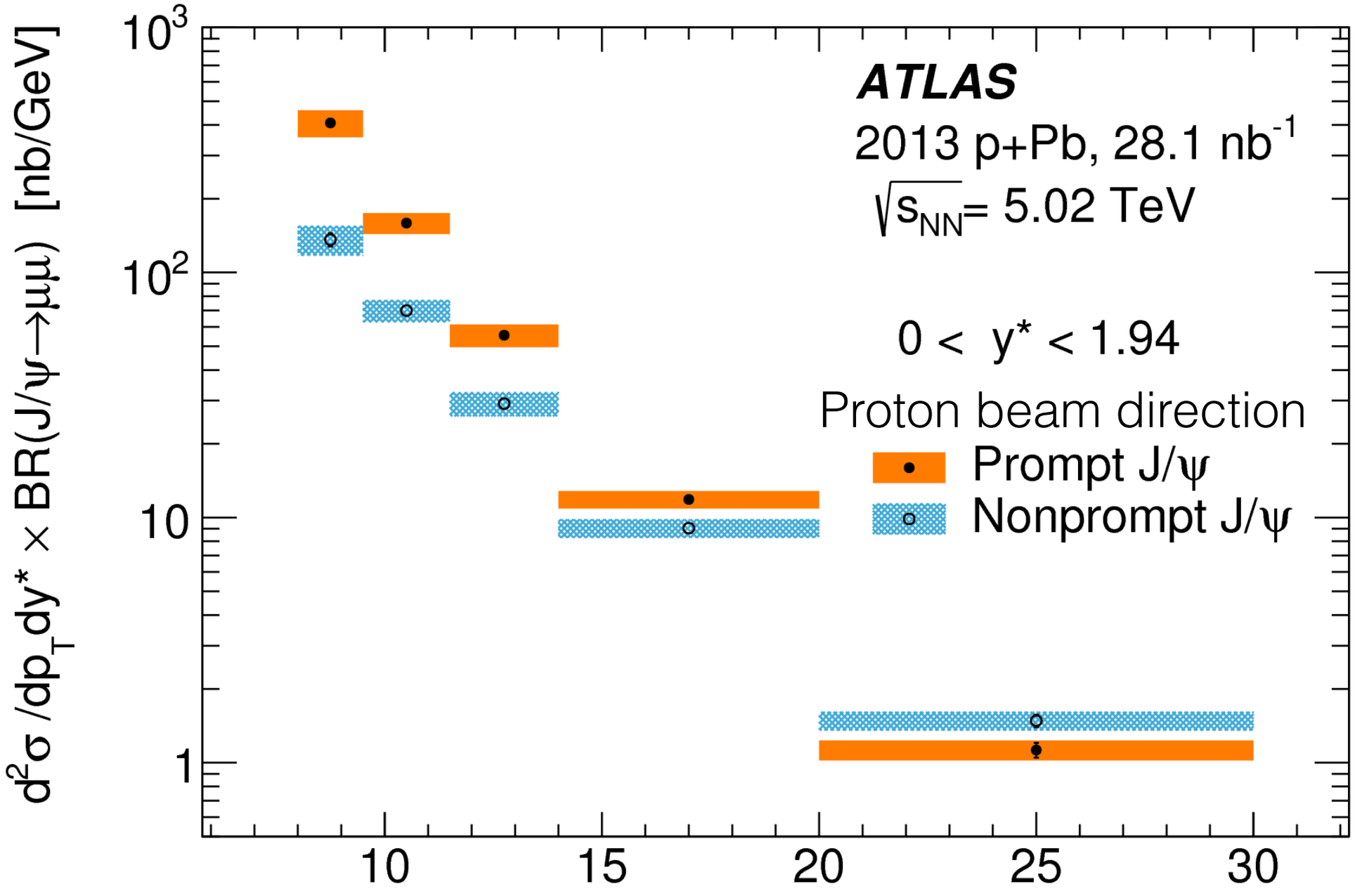
R_{FB} vs. y^* and p_T, prompt and non-prompt

Differential production cross section vs. p_T J/ψ in p+Pb, in ion beam direction



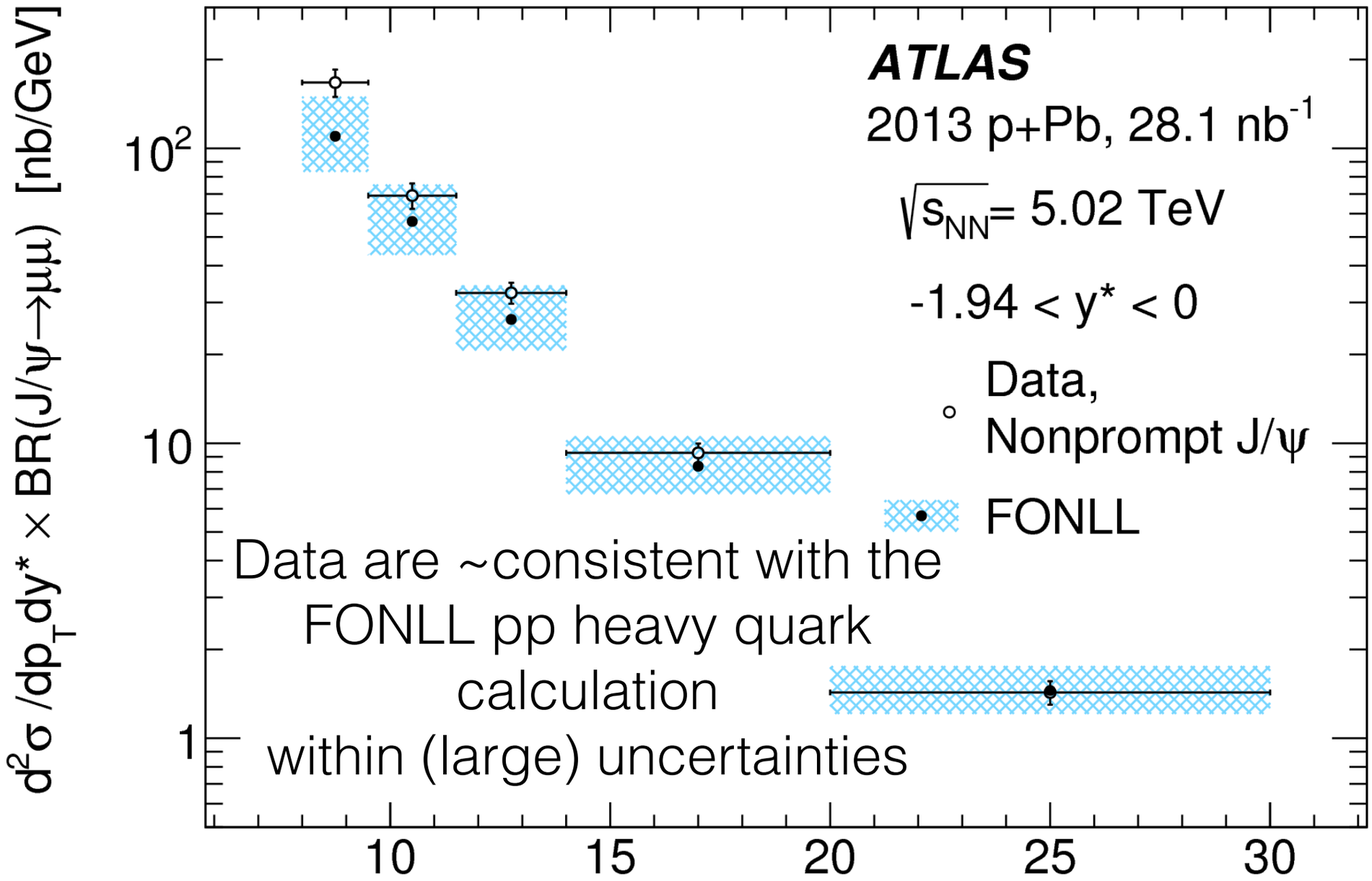
Prompt drops faster than J/ψ from b
Measurement precision quite good!

Differential production cross section vs. p_T
J/ψ in p+Pb, in proton beam direction



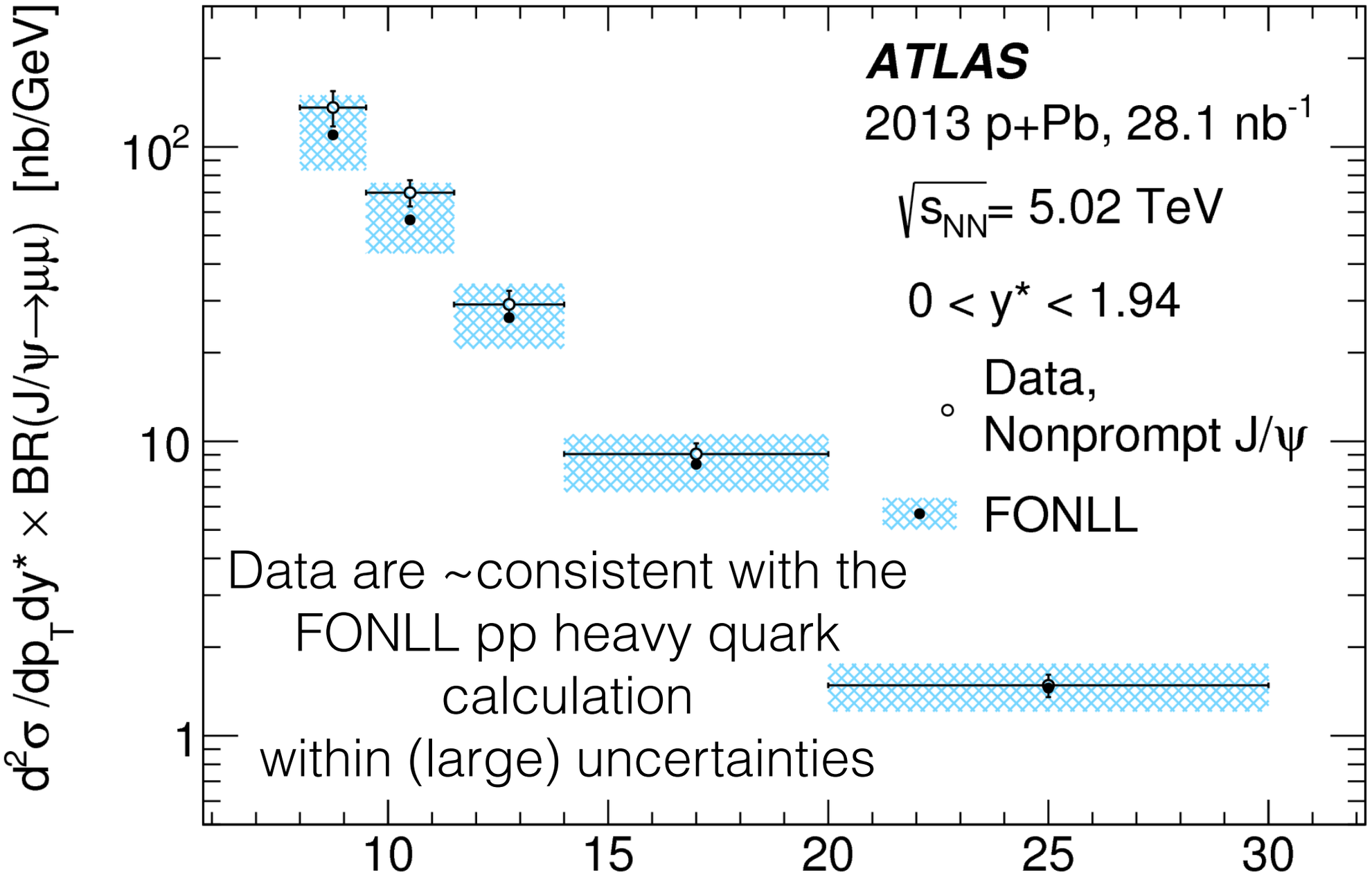
Prompt drops faster than J/ψ from b

Comparison to FONLL (pp) calculation
Nonprompt J/ψ in p+Pb, in ion beam direction



FONLL: M. Cacciari, M. Greco and P. Nason, JHEP 9805 (1998) 007 [arXiv:hep-ph/9803400]; M. Cacciari, S. Frixione and P. Nason, JHEP 0103 (2001) 006 [arXiv:hep-ph/0102134].

Comparison to FONLL (pp) calculation
Nonprompt J/ψ in p+Pb, in proton beam direction



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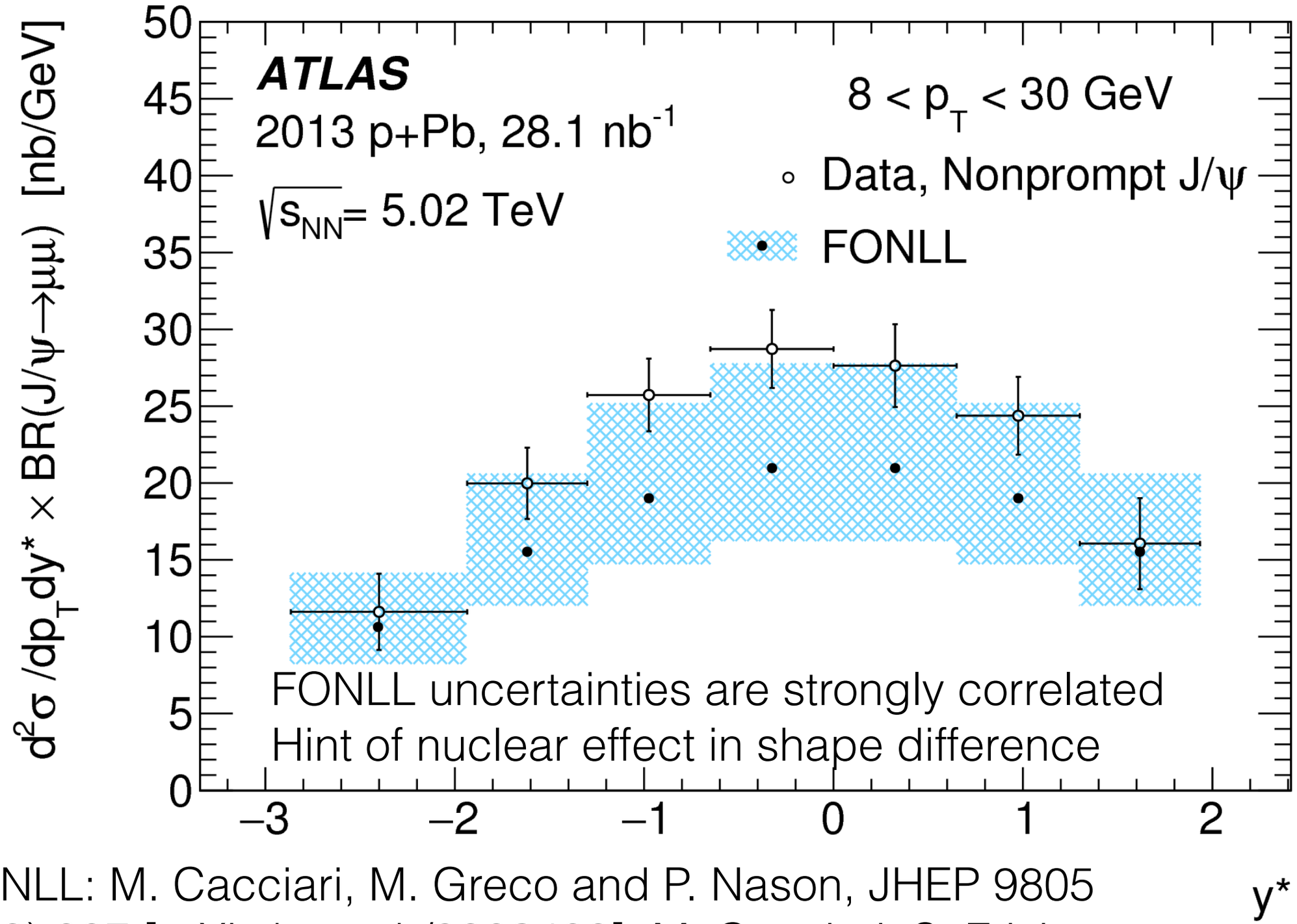
Comparison to FONLL (pp) calculation
Nonprompt J/ψ in p+Pb vs. y*



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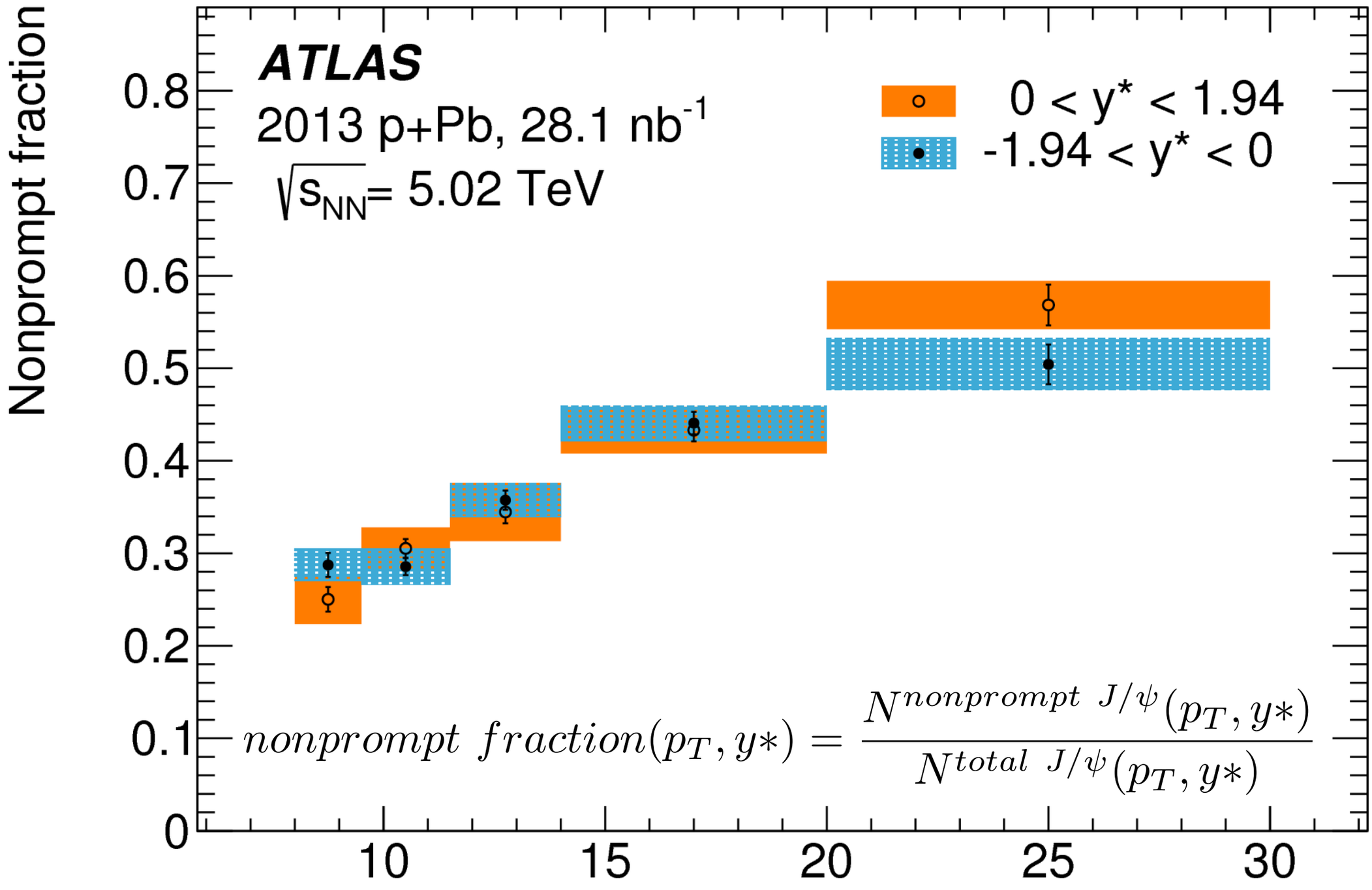
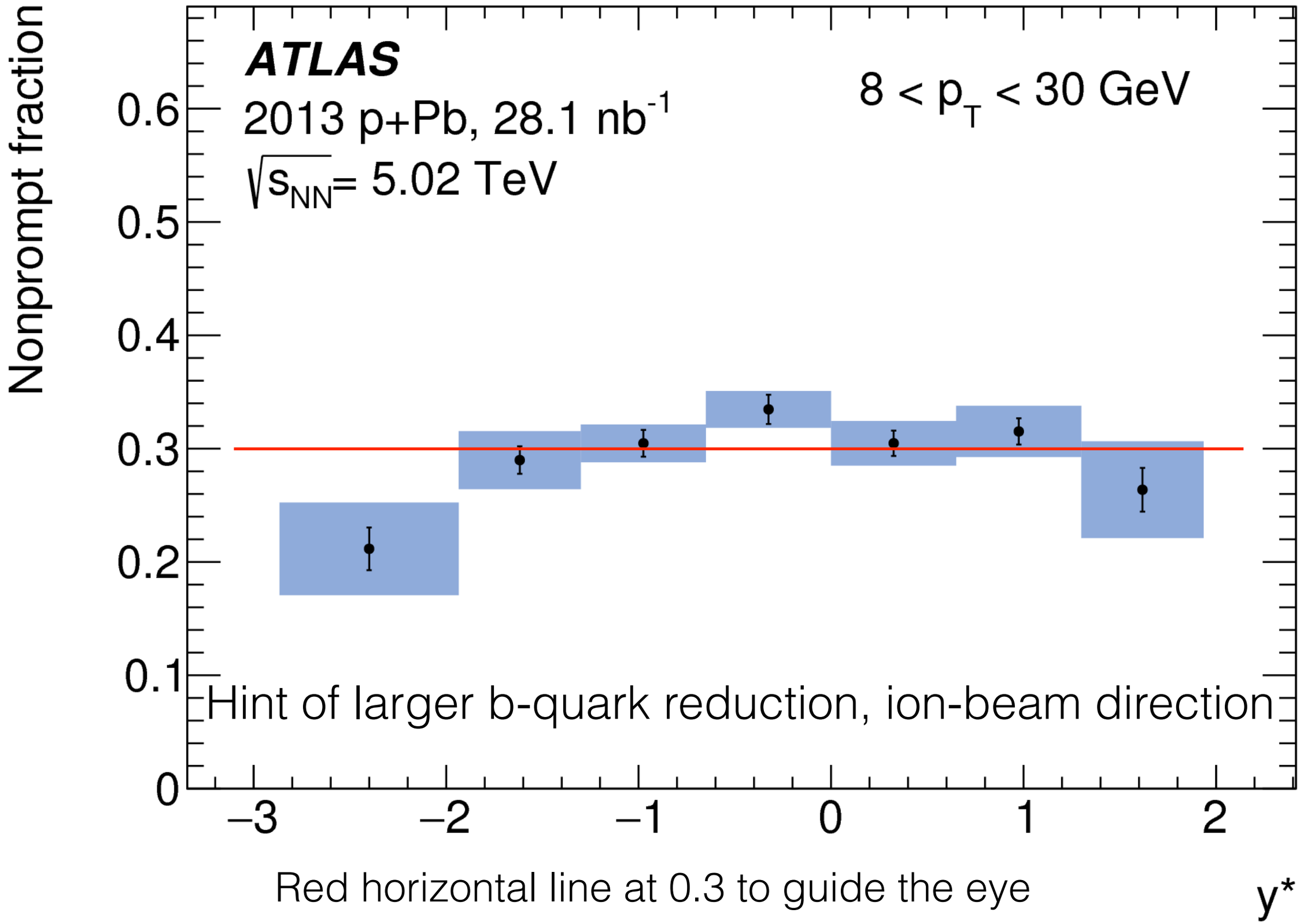
Nonprompt fraction for J/ψ in p+Pb vs. p_T



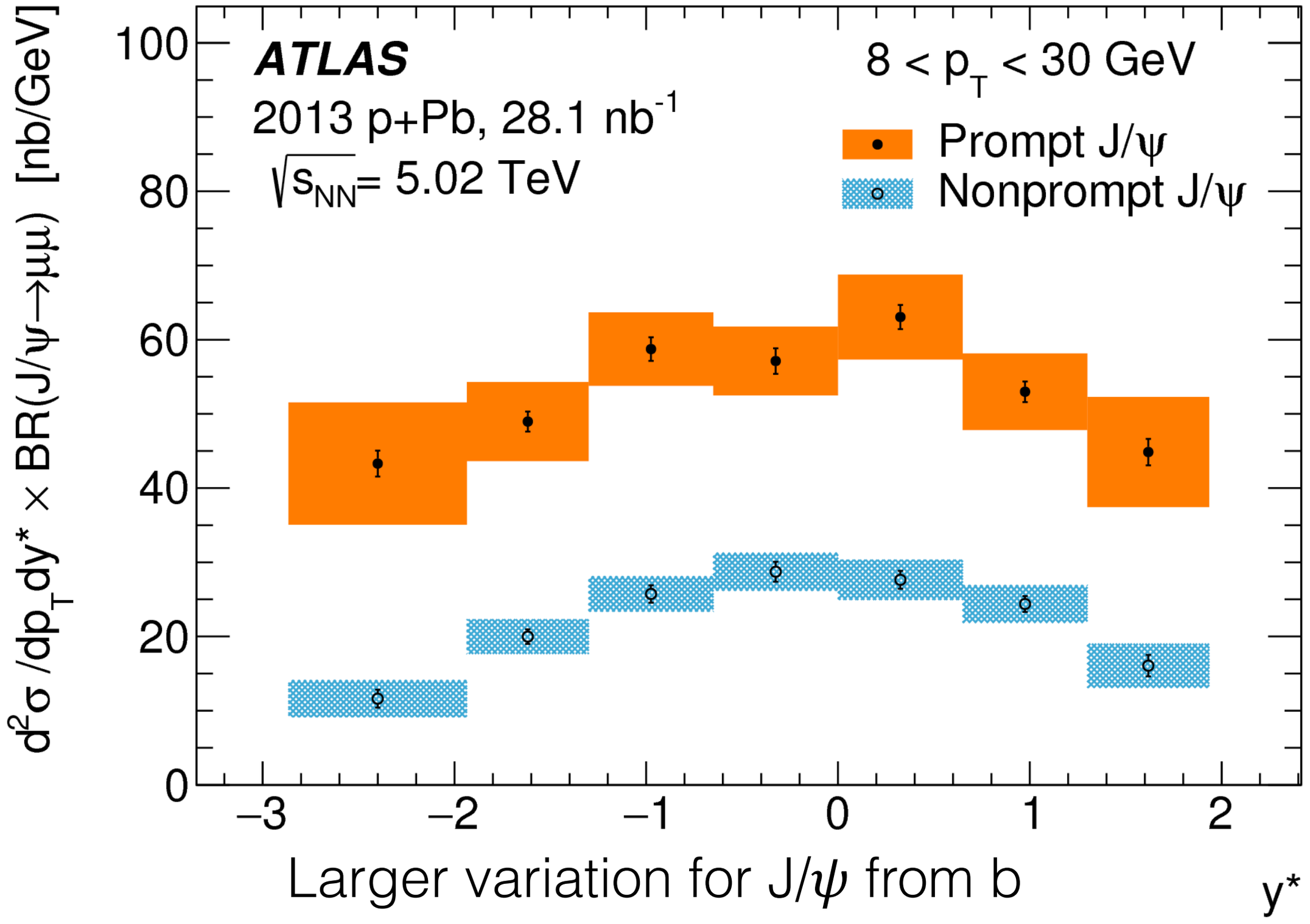
Relatively precise measurement

Hint of b-quark reduction in ion-beam direction, high p_T

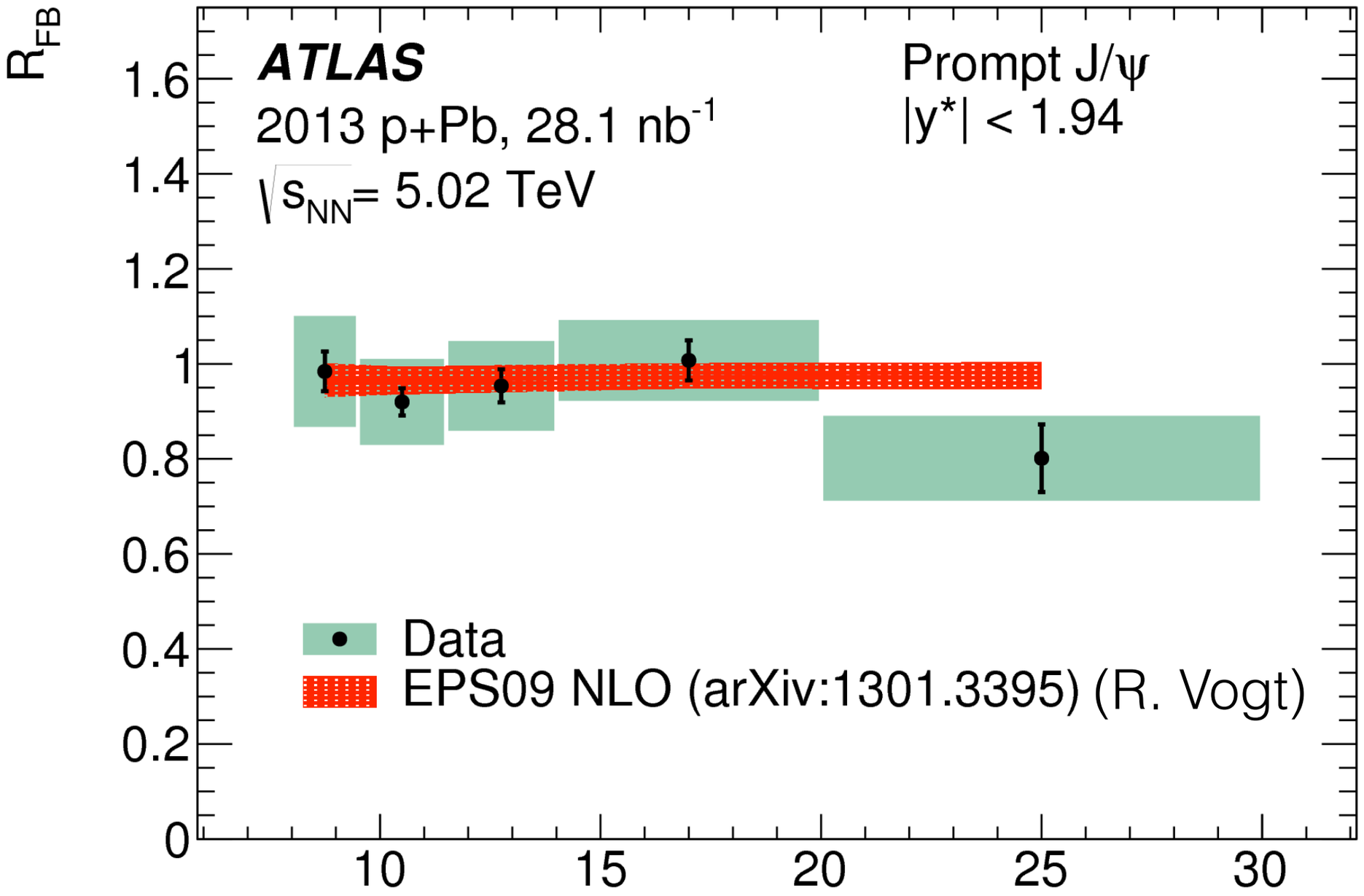
Nonprompt fraction for J/ψ in p+Pb vs. y*



Differential production cross section for prompt and nonprompt J/ψ in p+Pb vs. y*



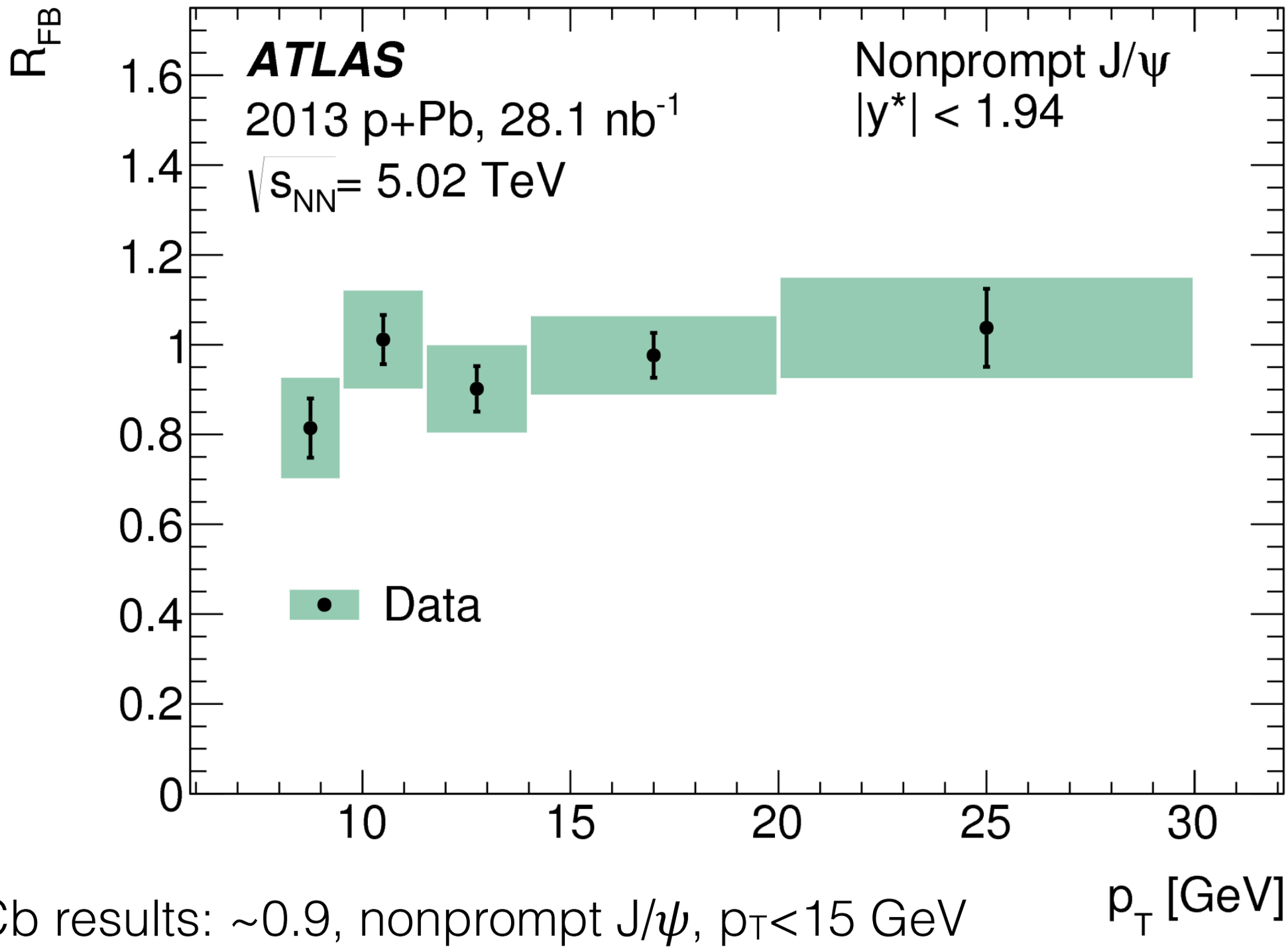
Forward-backward ratio
Prompt J/ψ in p+Pb vs. p_T



ALICE: R_{FB}~**0.6**, y*~3-3.5, p_T<15 GeV, inclusive J/ψ

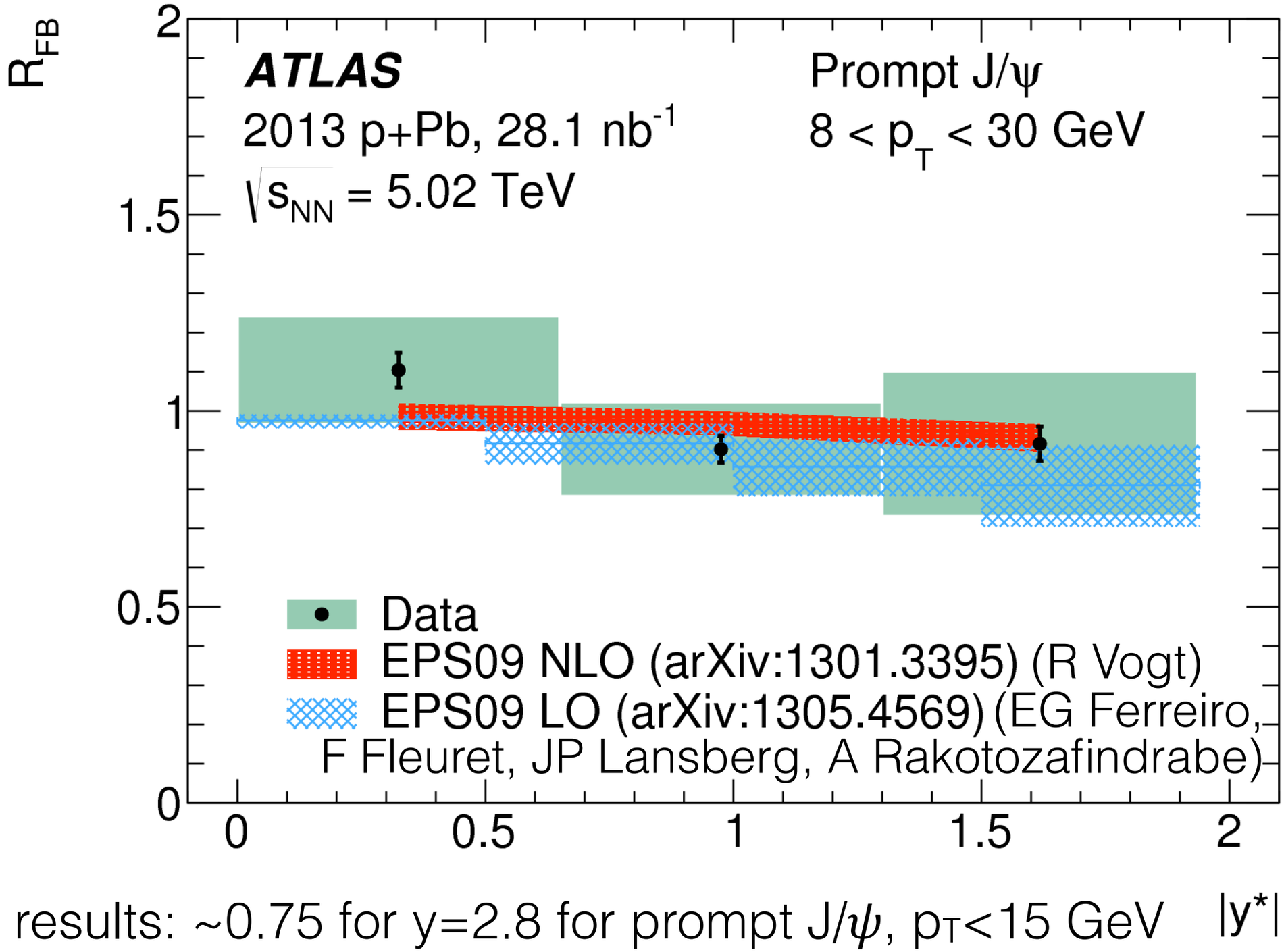
Indicates strong kinematic dependence

Forward-backward ratio
Nonprompt J/ψ in p+Pb vs. p_T



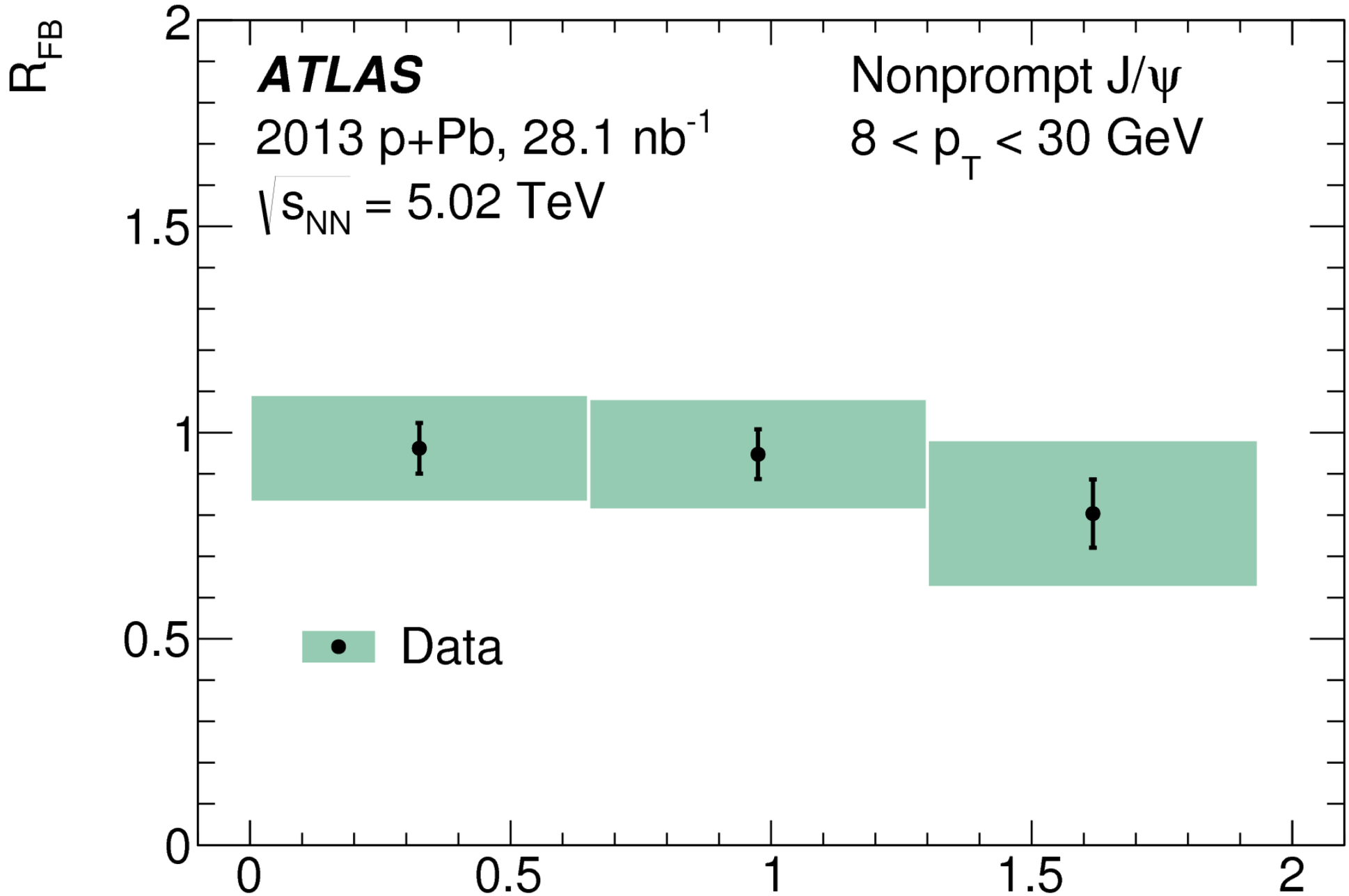
LHCb results: ~0.9, nonprompt J/ψ, p_T<15 GeV

Forward-backward ratio
Prompt J/ψ in p+Pb vs. y*



LHCb results: ~0.75 for y=2.8 for prompt J/ψ, p_T<15 GeV

Forward-backward ratio
Nonprompt J/ψ in p+Pb vs. y*



LHCb results: ~0.9 for |y|=2.8 for nonprompt J/ψ, p_T<15 GeV

J/ψ + ψ(2S) Analysis
p-Pb at 5.02 TeV

June 2015 J/ψ and ψ(2S) - ATLAS-CONF-2015-023

$d^2\sigma/dy^*dp_T$, prompt and non-prompt, J/ψ and ψ(2S)

pp interpolation to 5.02 GeV

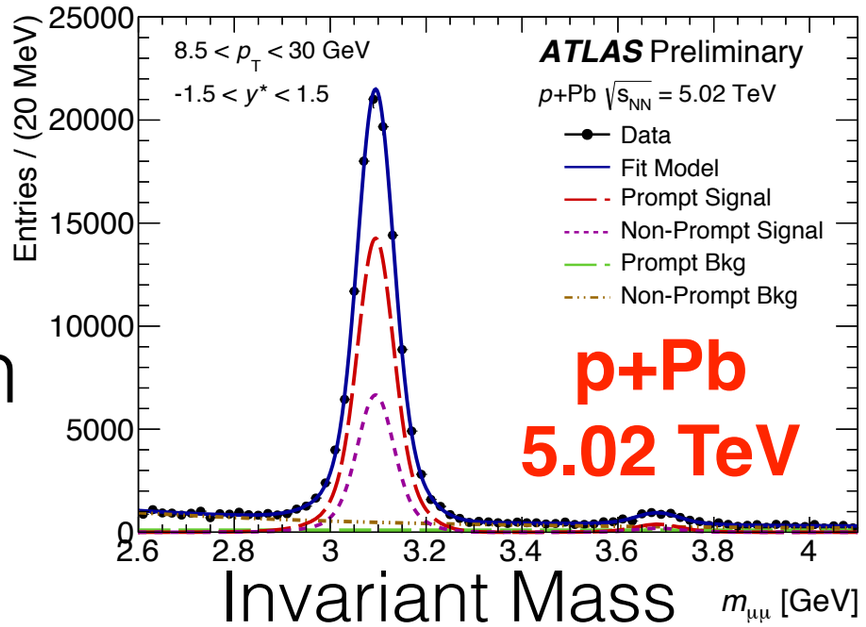
Non-prompt fraction vs. y^* and p_T, J/ψ and ψ(2S)

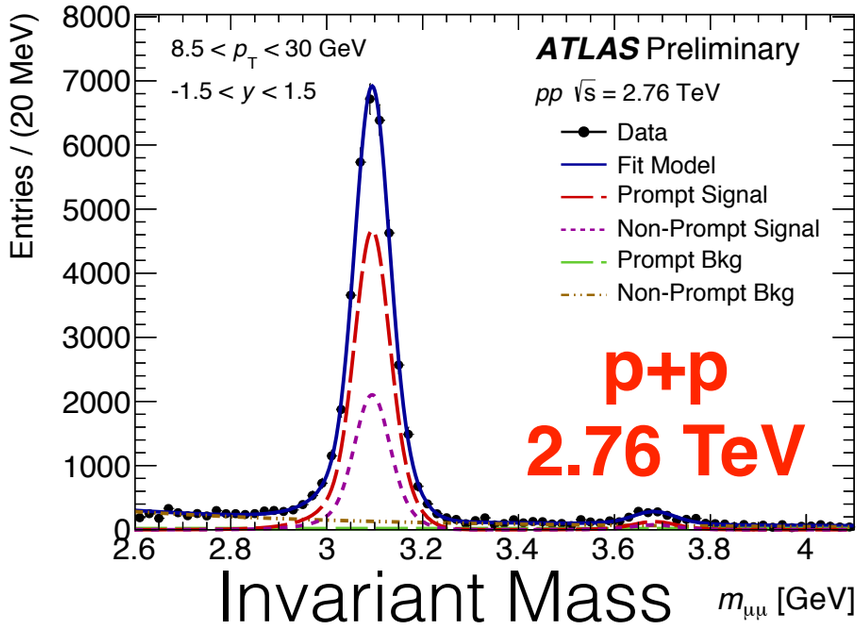
R_{pPb} vs. y^* and p_T, prompt and non-prompt, J/ψ and ψ(2S)

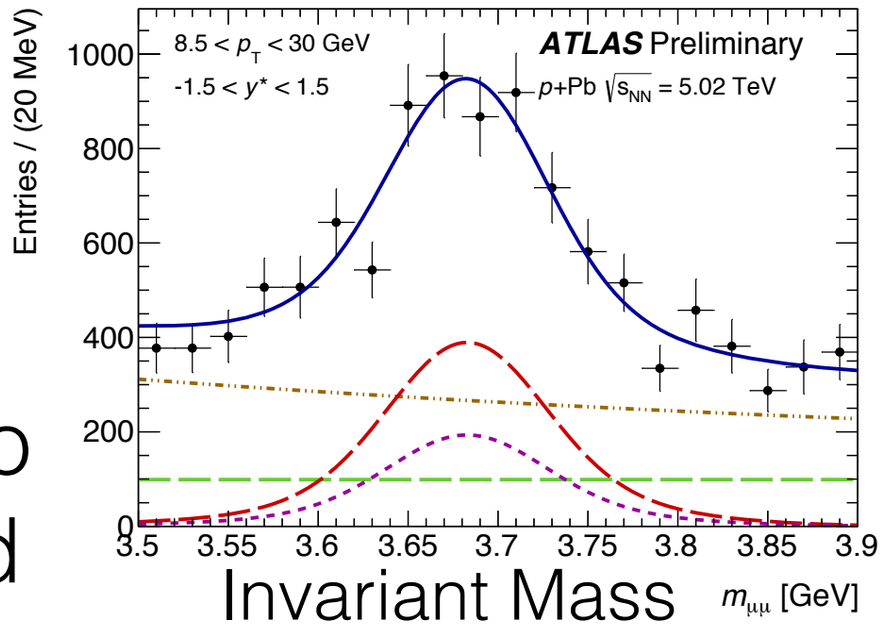
Single and double ratio, prompt J/ψ and ψ(2S)

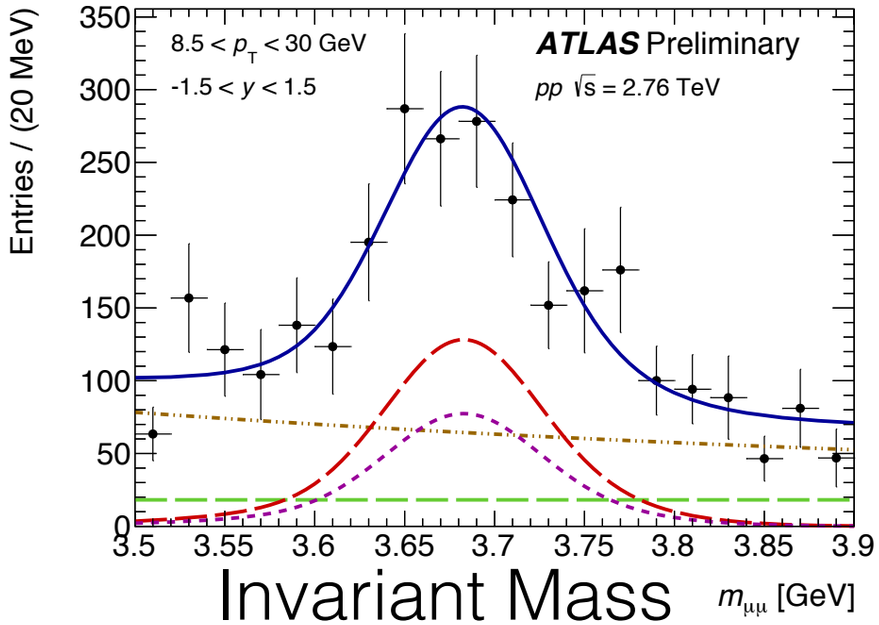
Simultaneous fit in invariant mass and pseudo-proper time

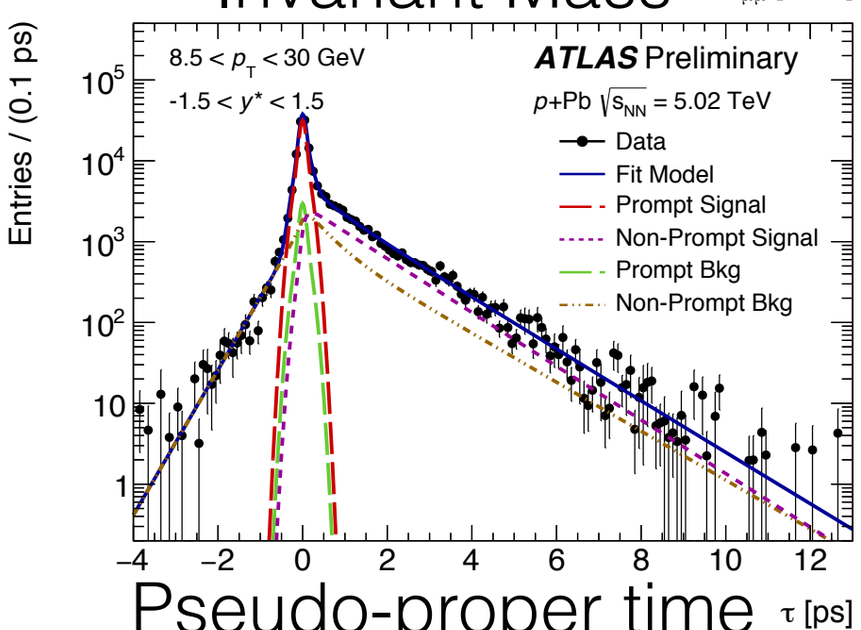
Fit model similar to the one described earlier, but now includes both J/ψ and ψ(2S)

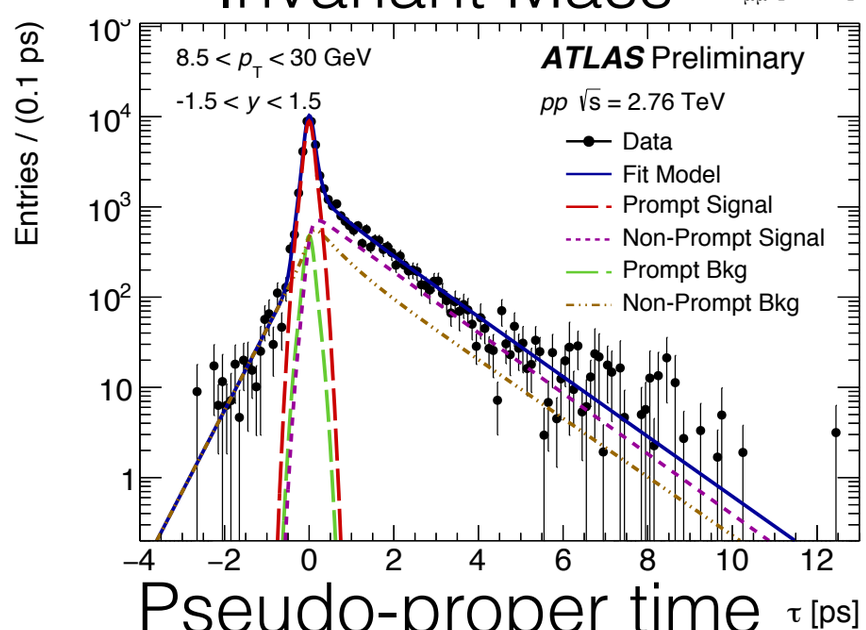




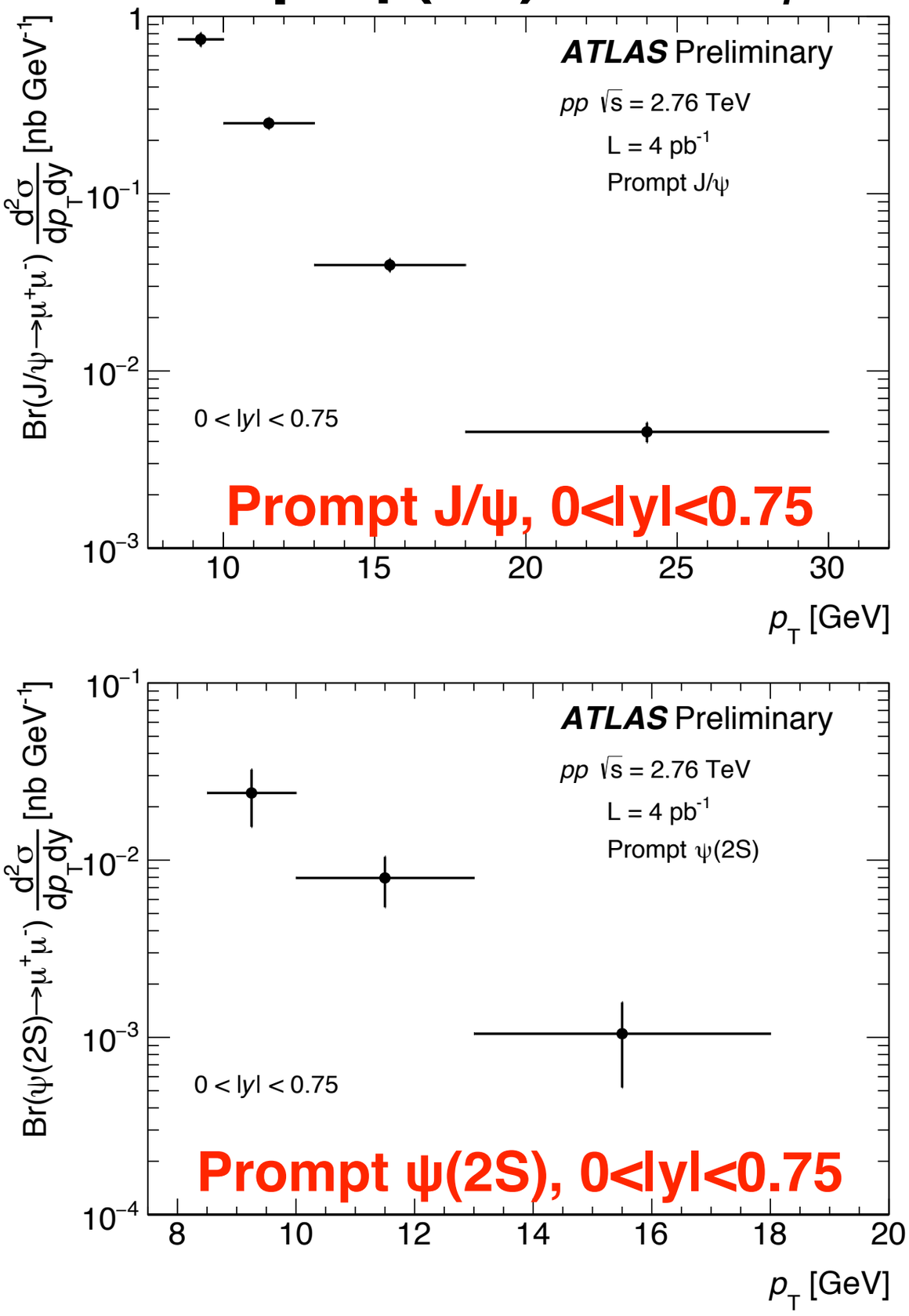




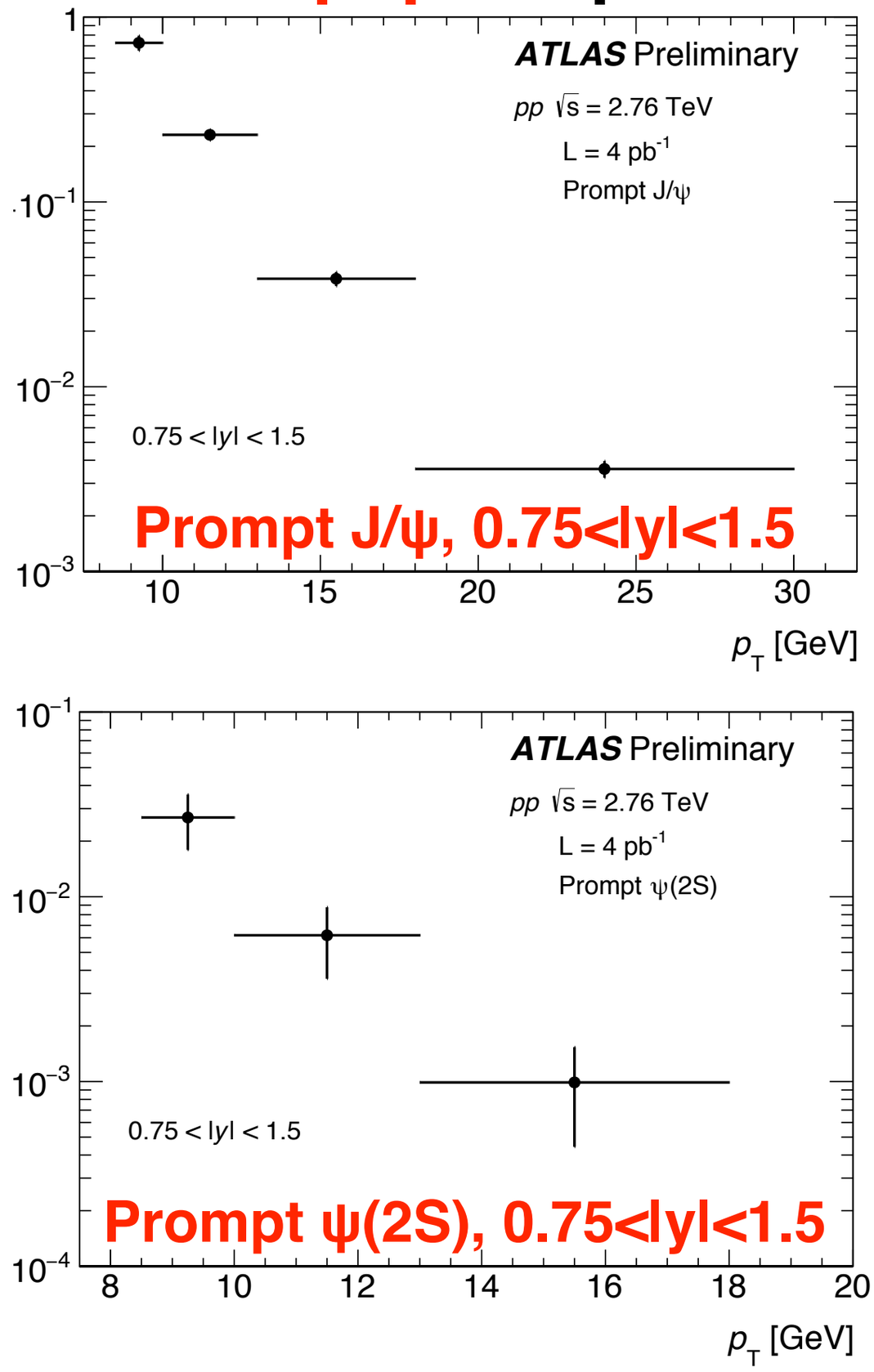




Differential production cross sections
Prompt ψ(2S) and J/ψ in 2.76 TeV p+p vs. p_T



Prompt J/ψ, 0<|y|<0.75

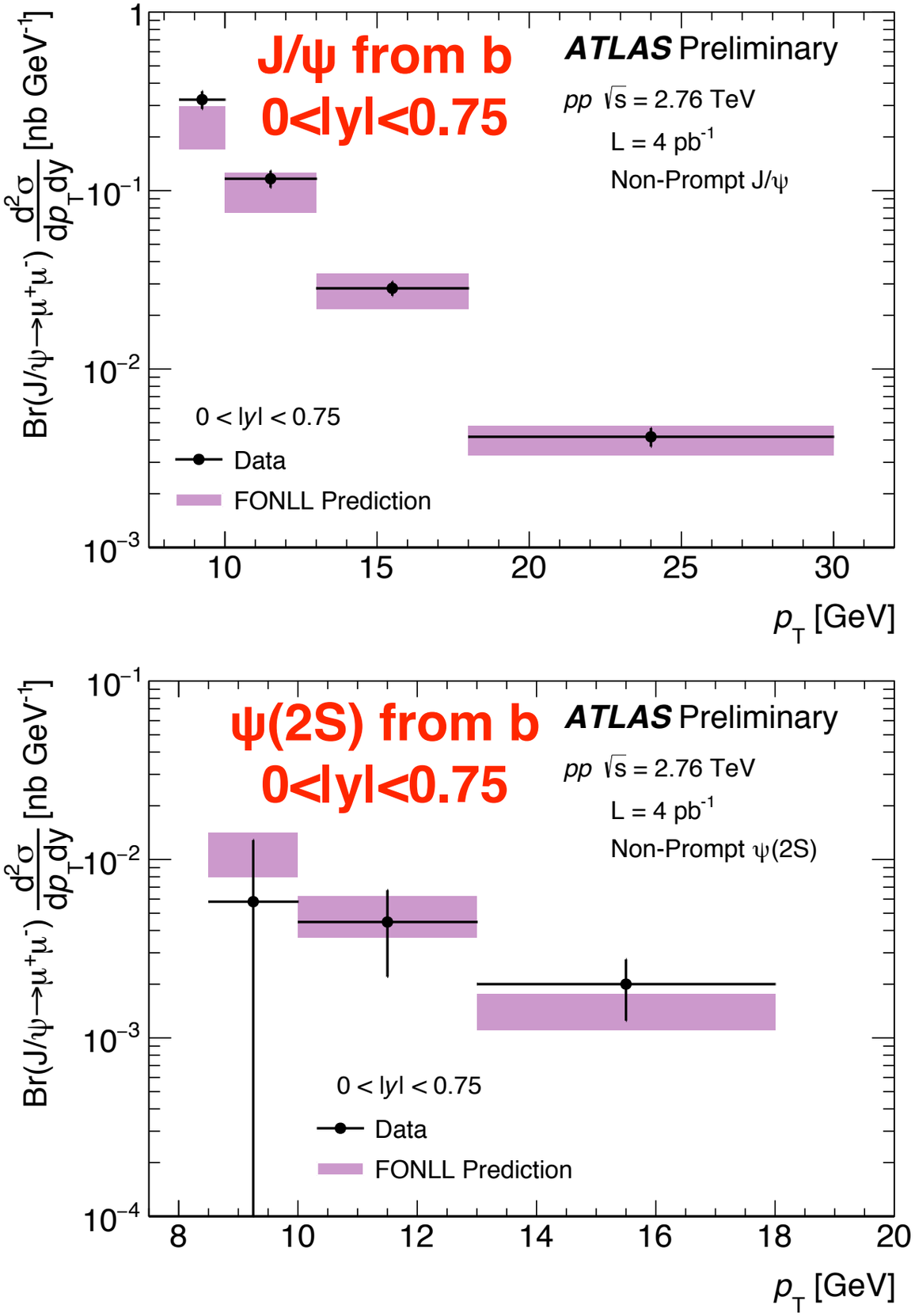


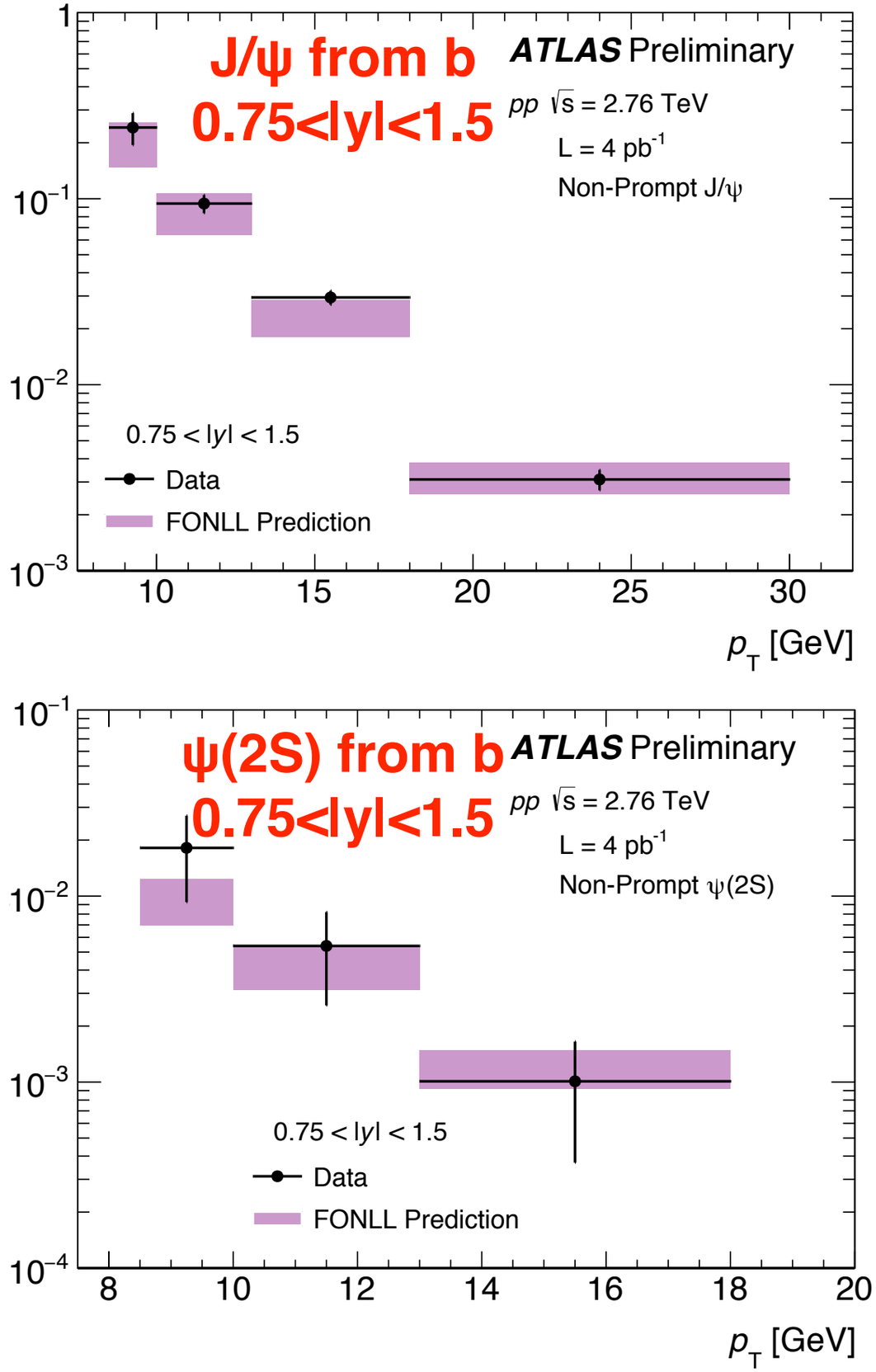
Prompt J/ψ, 0.75<|y|<1.5

Prompt ψ(2S), 0<|y|<0.75

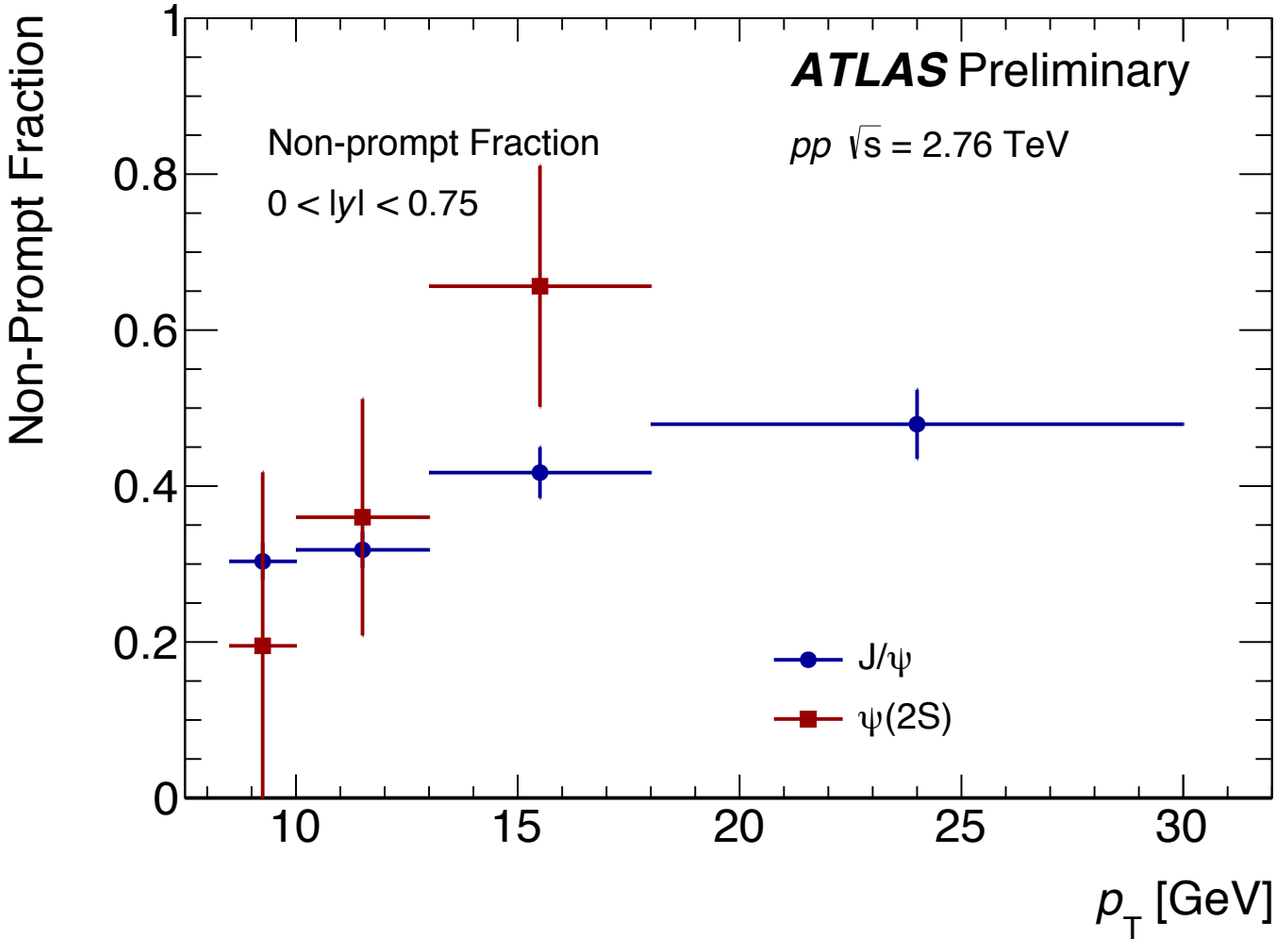
Prompt ψ(2S), 0.75<|y|<1.5

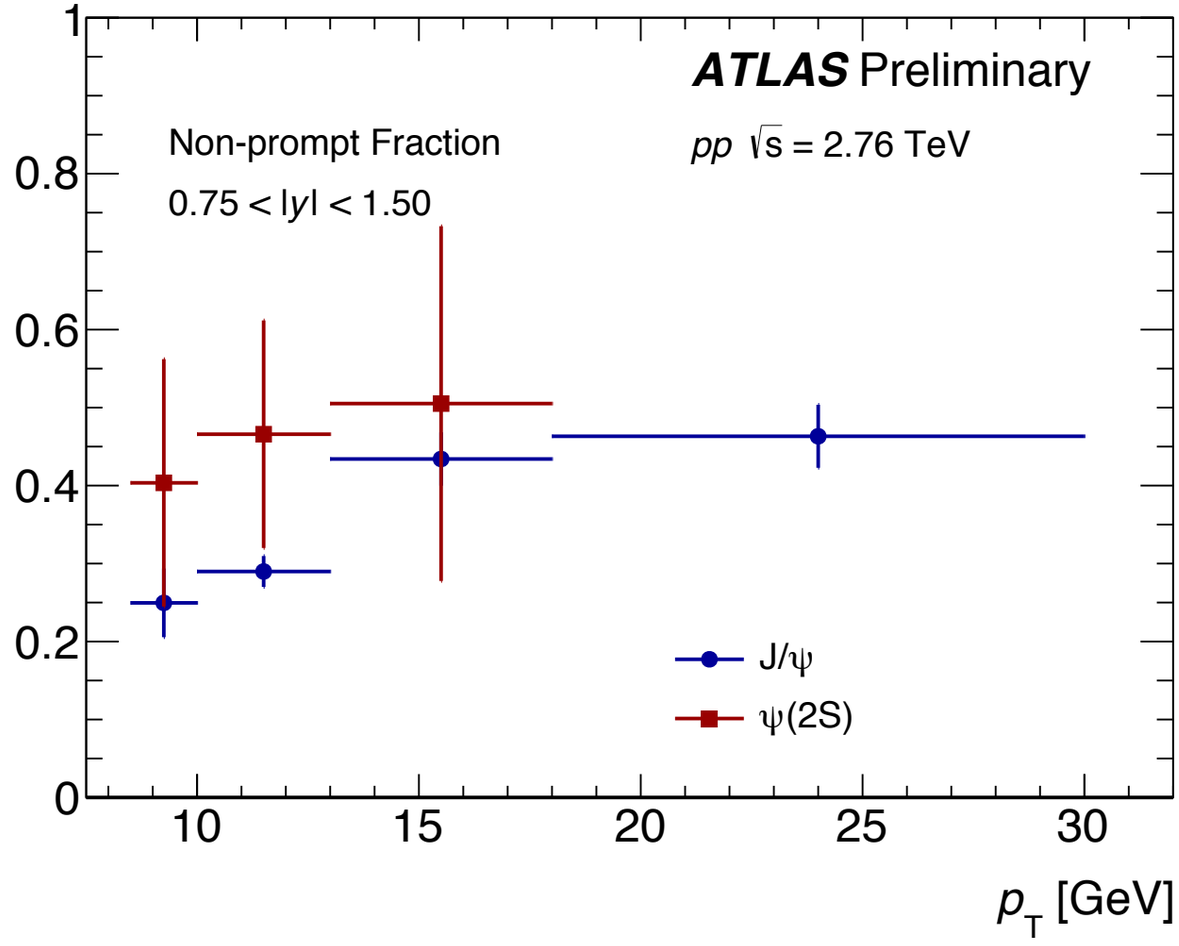
Differential production cross sections
Non-prompt ψ(2S) and J/ψ in 2.76 TeV p+p vs. p_T





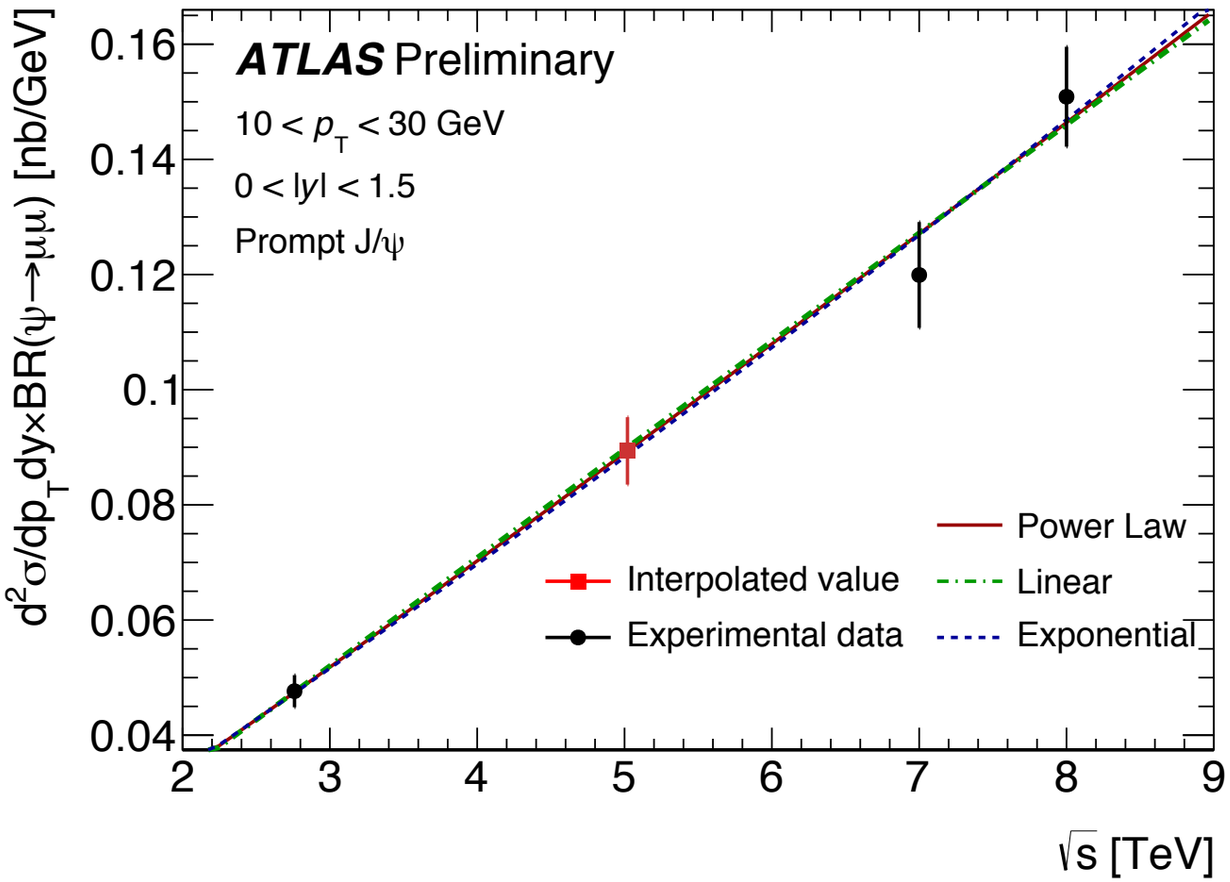
Non-prompt Fraction
ψ(2S) and J/ψ in 2.76 TeV p+p vs. p_T

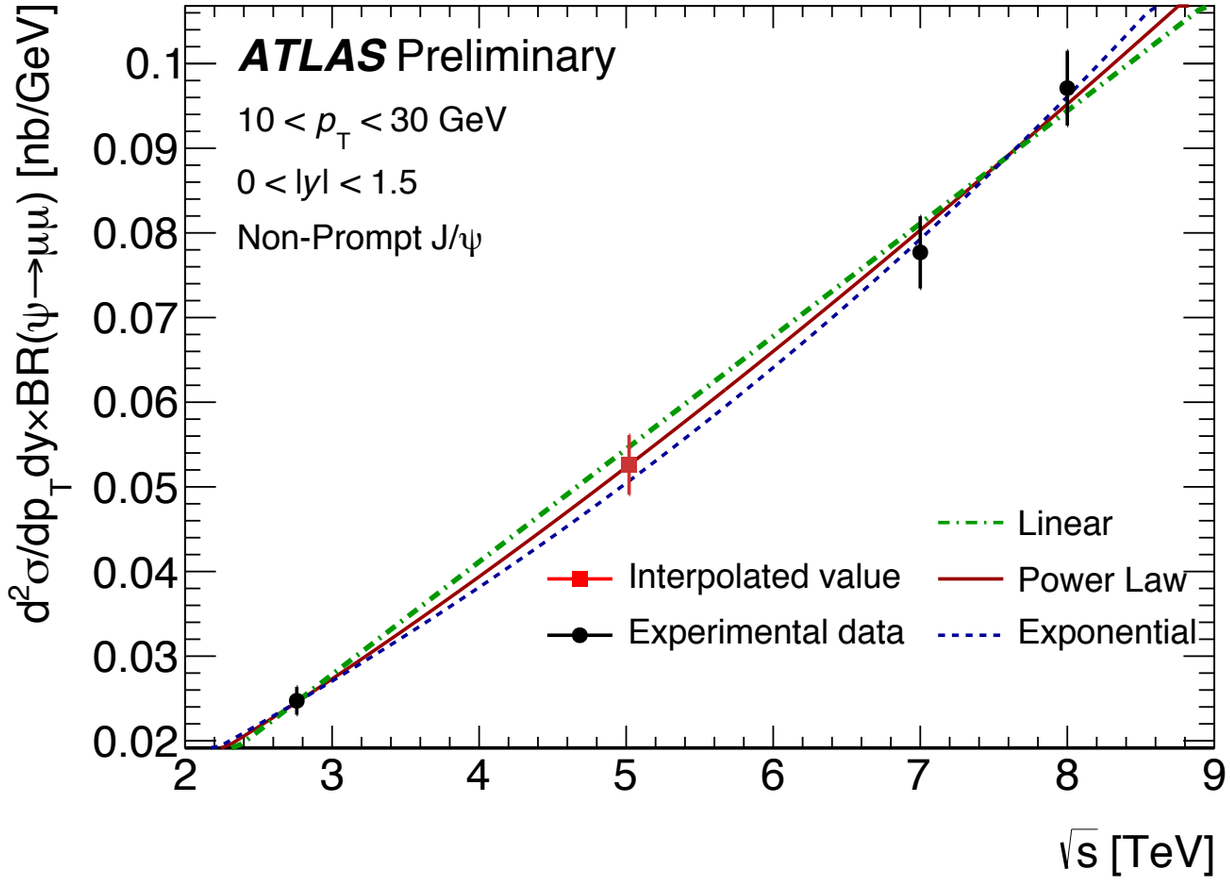




$$nonprompt\ fraction(p_T, y*) = \frac{N^{nonprompt\ J/\psi}(p_T, y*)}{N^{total\ J/\psi}(p_T, y*)}$$

Interpolation of pp data

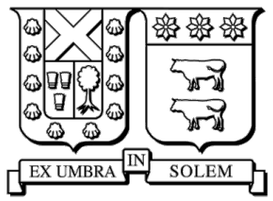


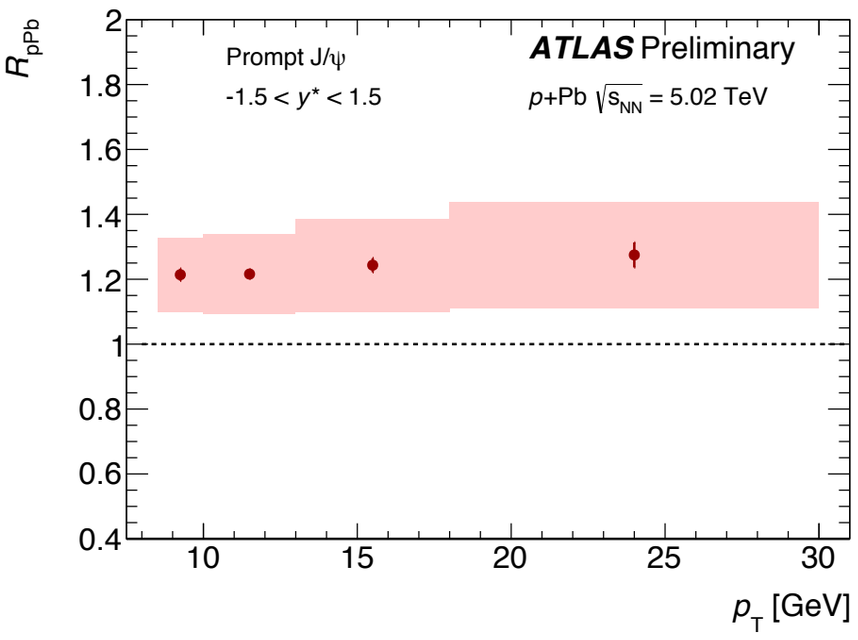


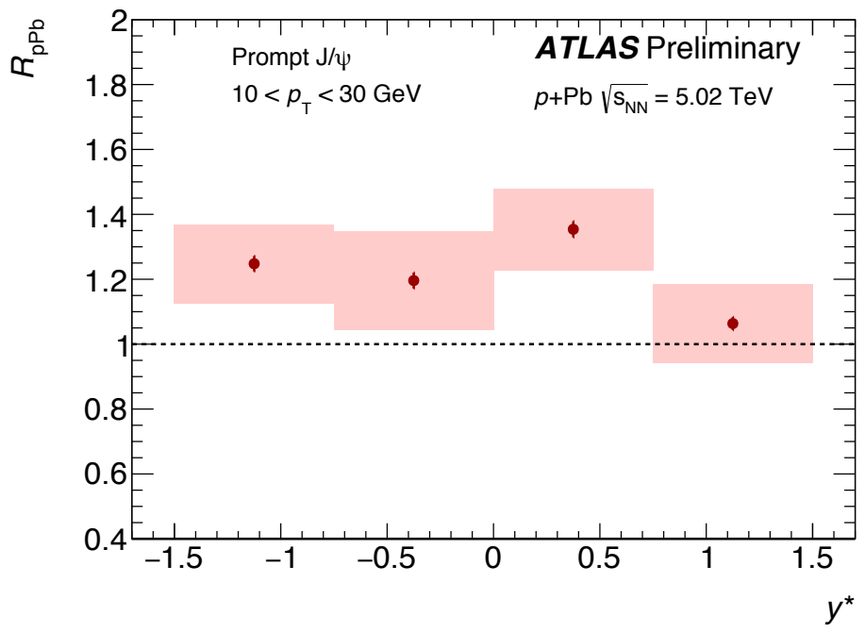
Interpolation between pp at 2.76 TeV and at 7 and 8 TeV

Interpolation used three functional forms to evaluate systematic uncertainty

R_{pPb} vs. pT, y*

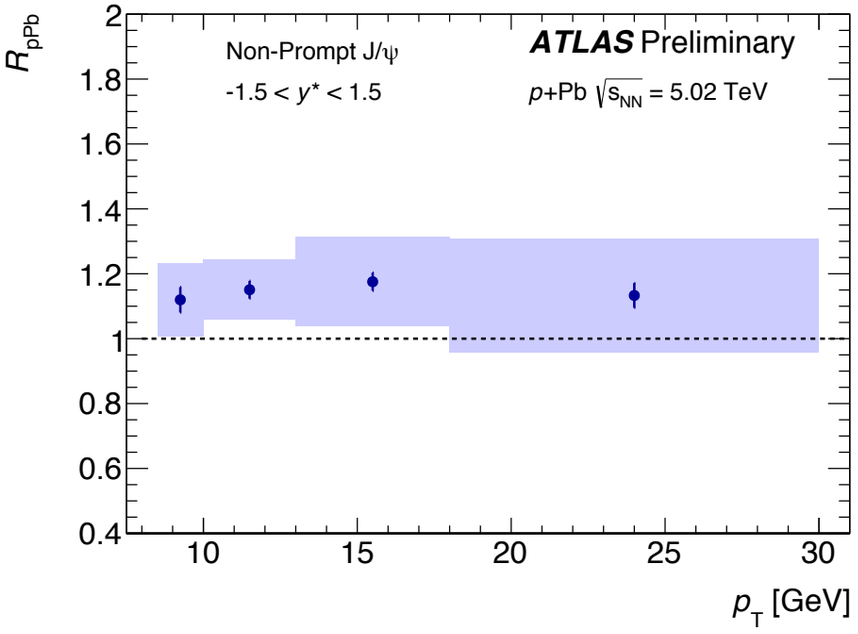


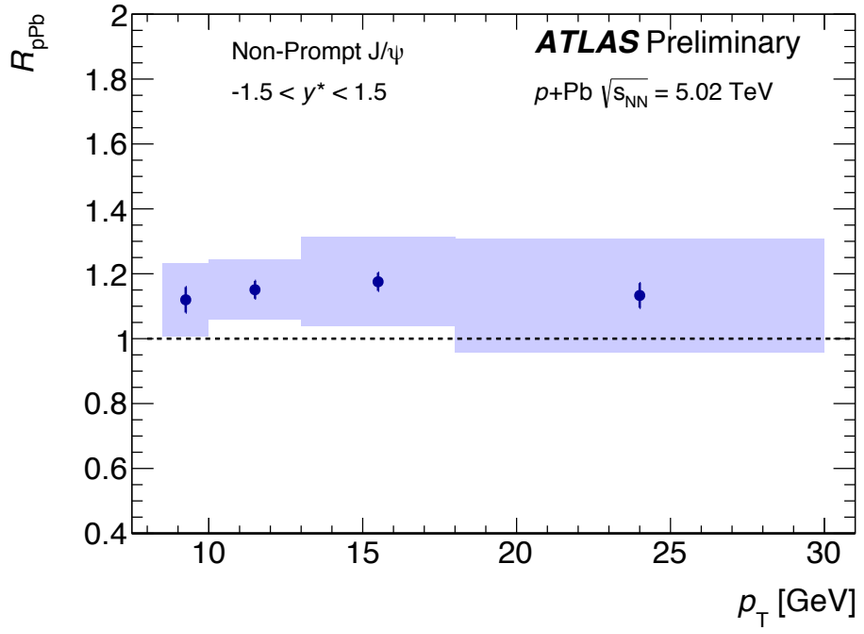




Prompt J/ψ

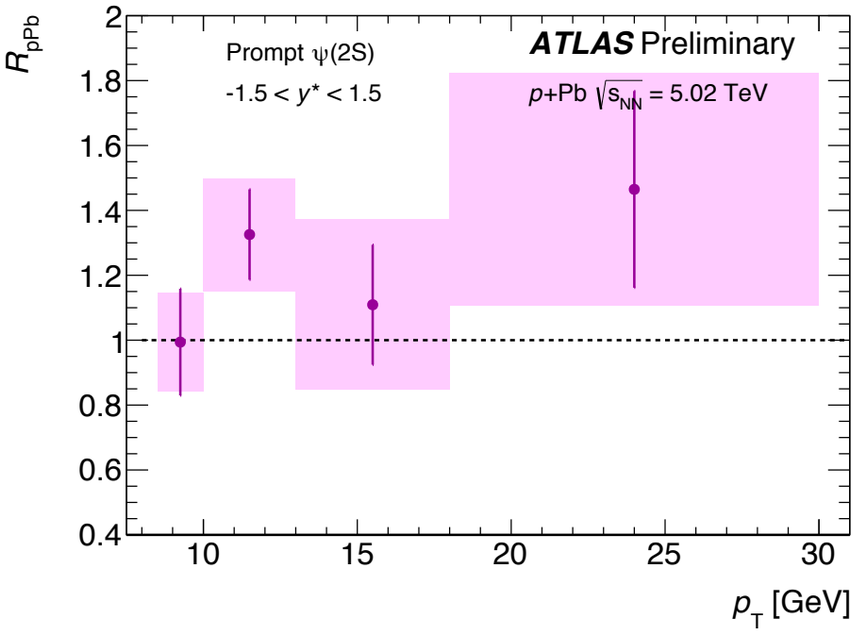
$$R_{pPb} = \frac{1}{A} \cdot \frac{\frac{d^2\sigma_{p+Pb}}{dy^* dp_T}}{\frac{d^2\sigma_{p+p}}{dy^* dp_T}}$$

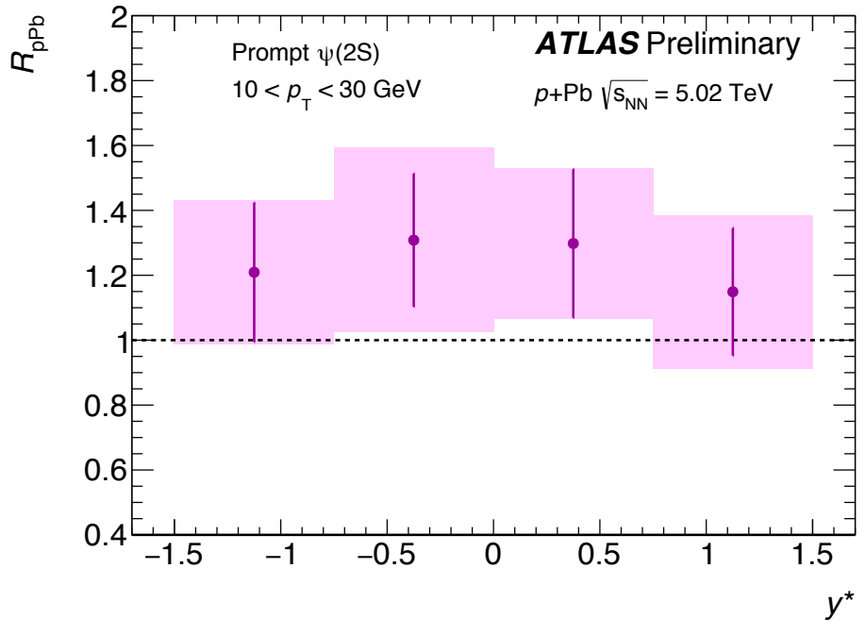




J/ψ from b

(Note: these plots are independent of centrality modeling)





Prompt ψ(2S)

R_{pPb} vs. ~centrality

Prompt J/ψ

$R_{pPb}>1$

J/ψ from b

$R_{pPb}>1$

mid-centrality

Prompt ψ(2S)

Phenix:

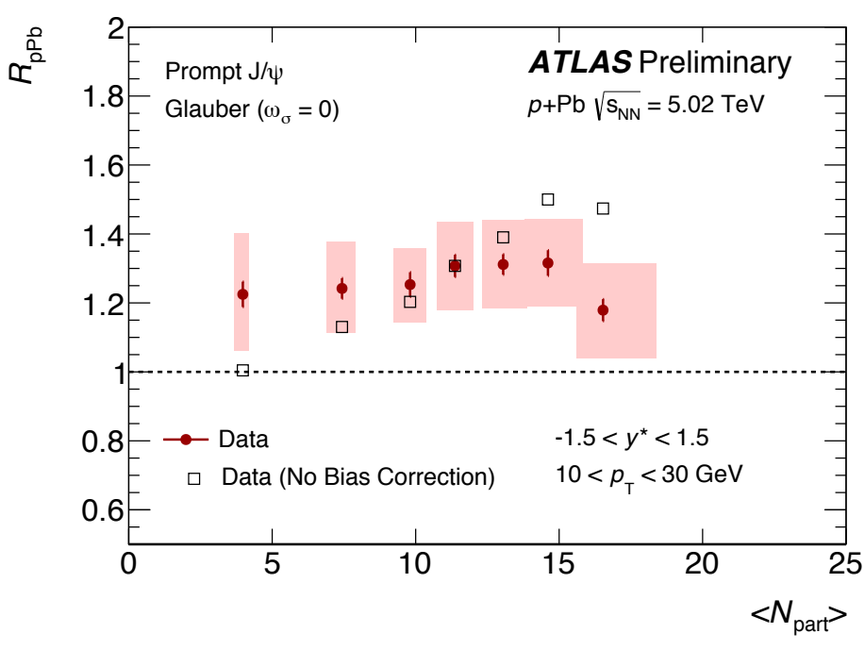
R_{dAu} =**1** *(NColl=3)*

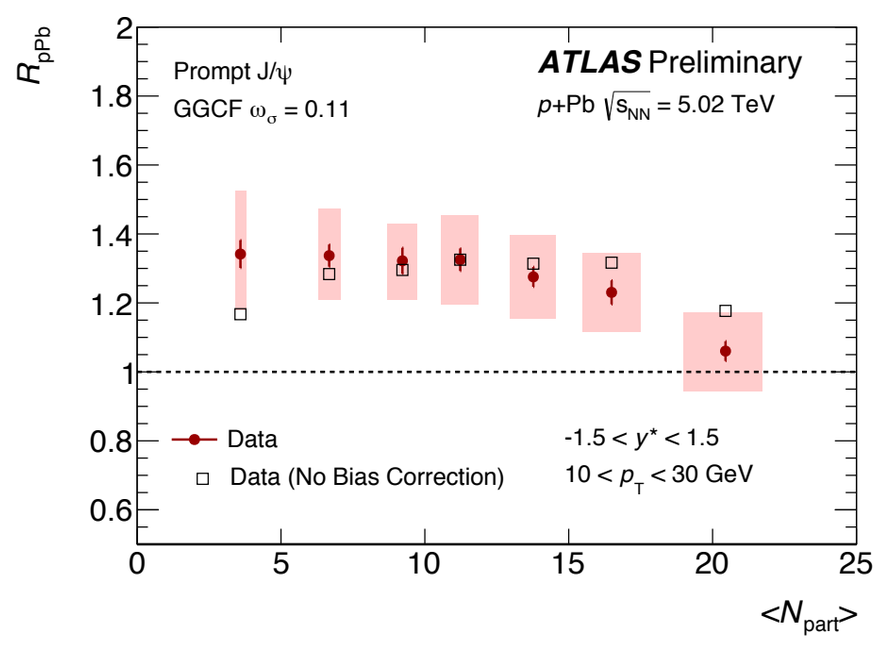
R_{dAu} =**0.2** *(NColl=15)*

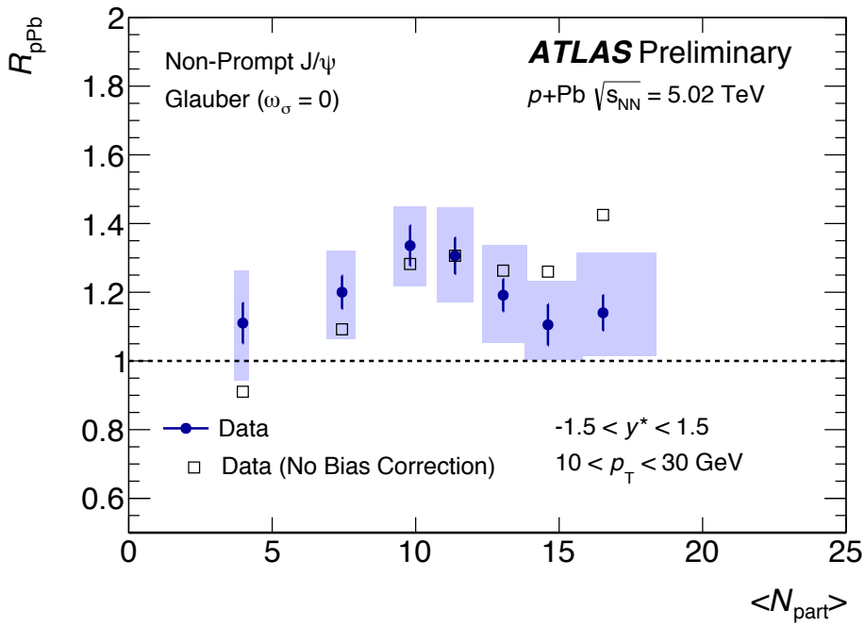
$R_{pPb}>1$

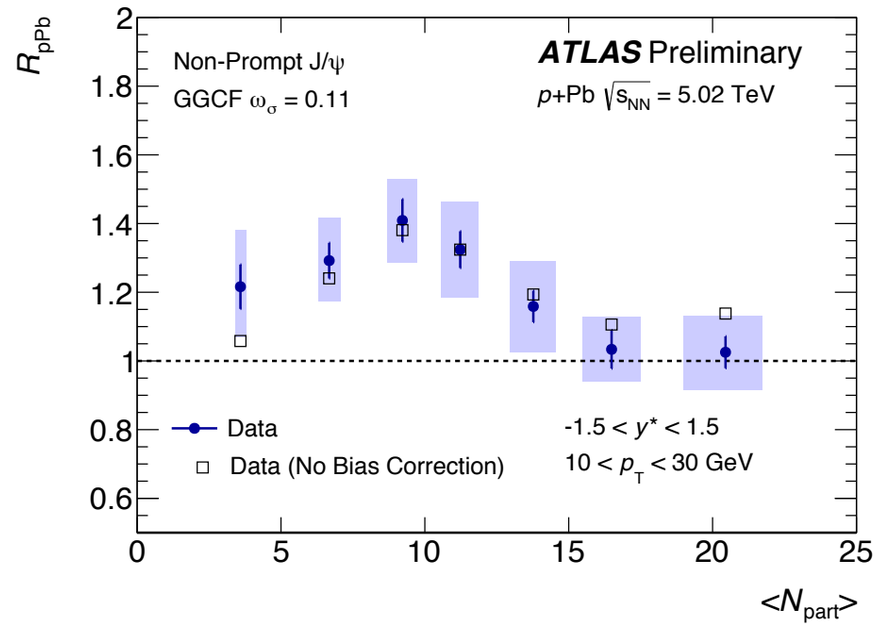
low-centrality

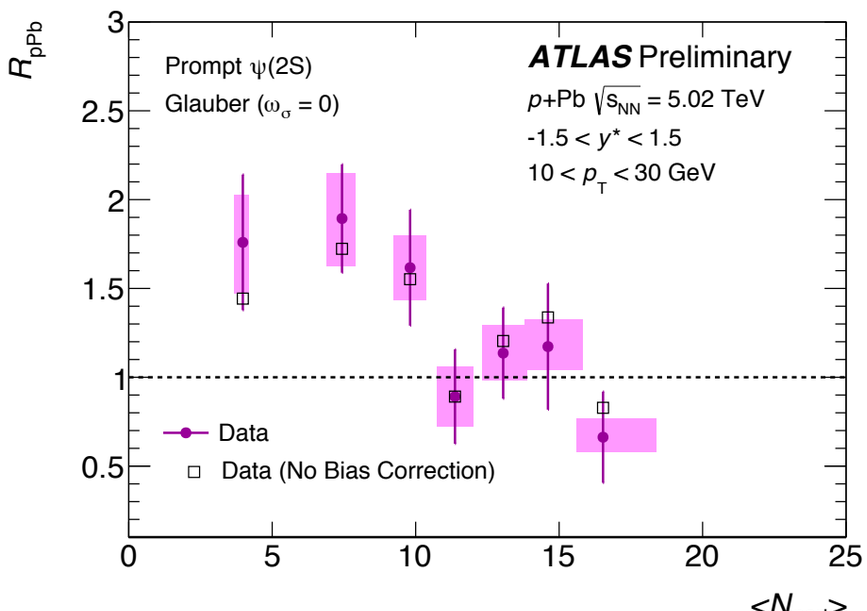
(note vertical scale change

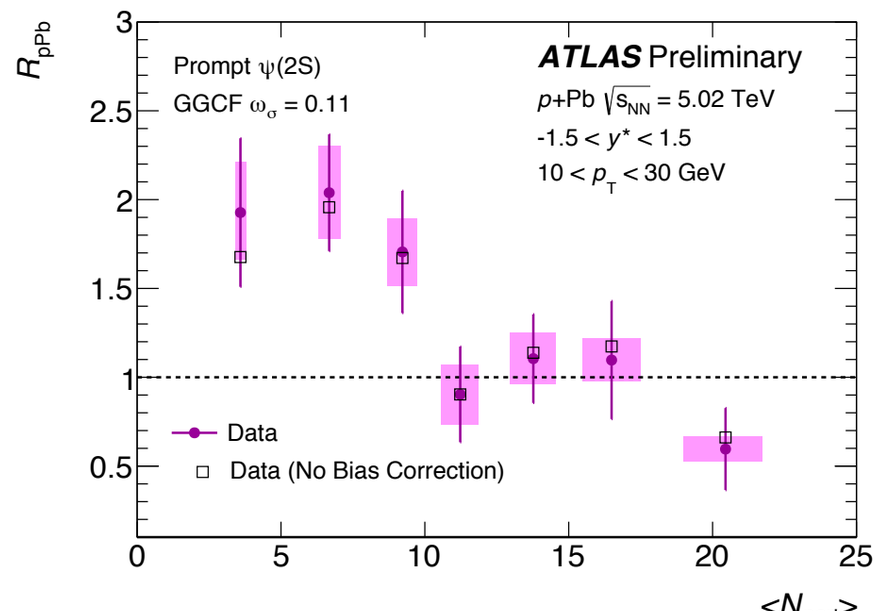










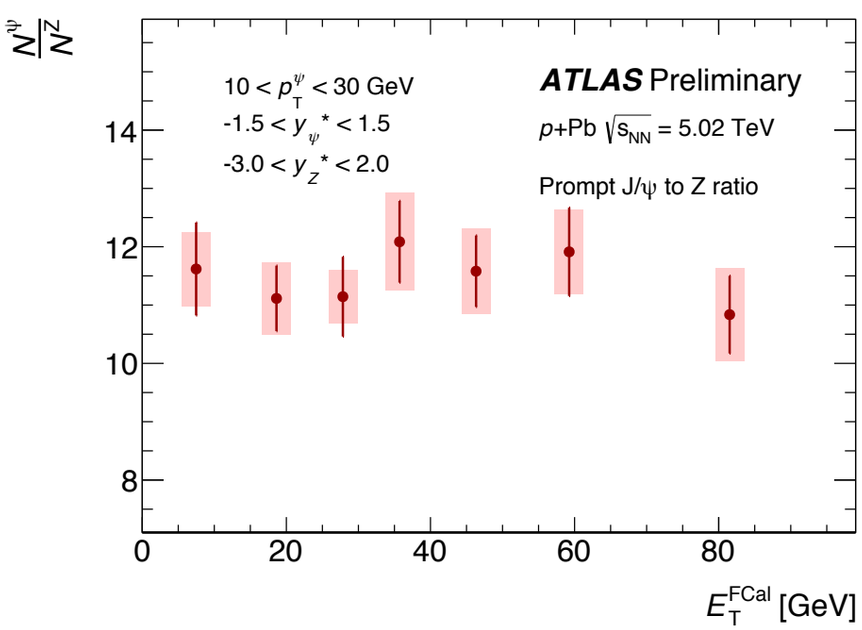


Check of centrality behavior by normalizing to number of Z bosons:

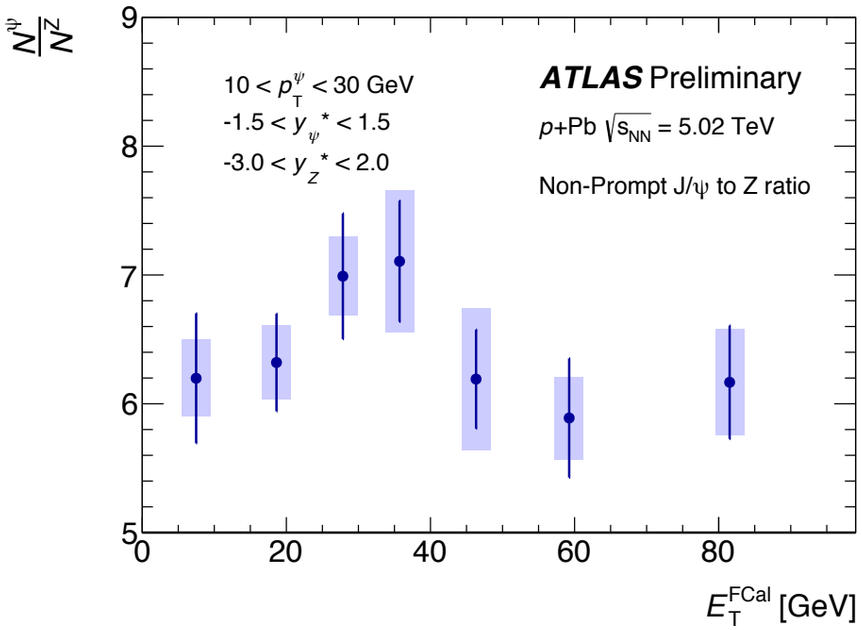
N_ψ/N_Z vs. FCal E_T

J/ψ appears to be flat

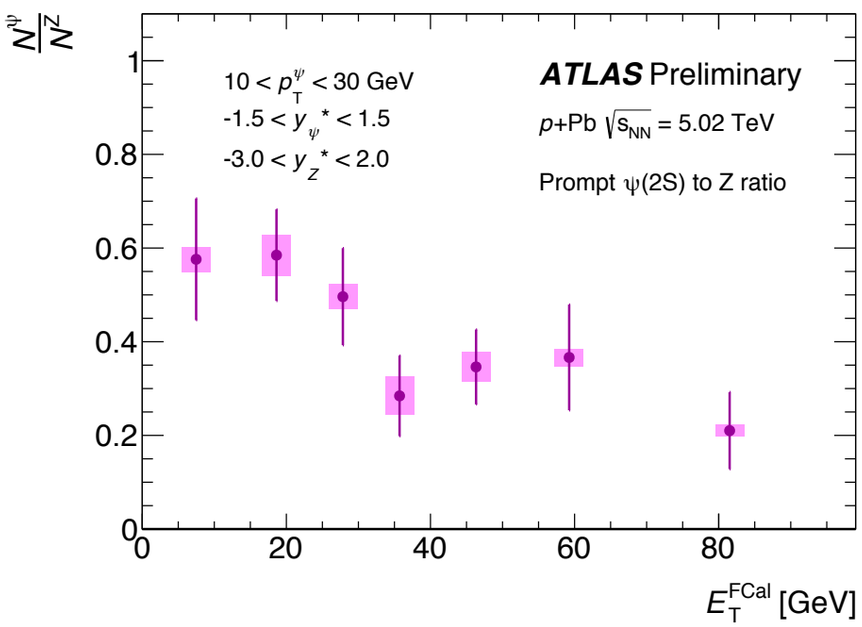
Decreasing trend for ψ(2S)



Prompt J/ψ

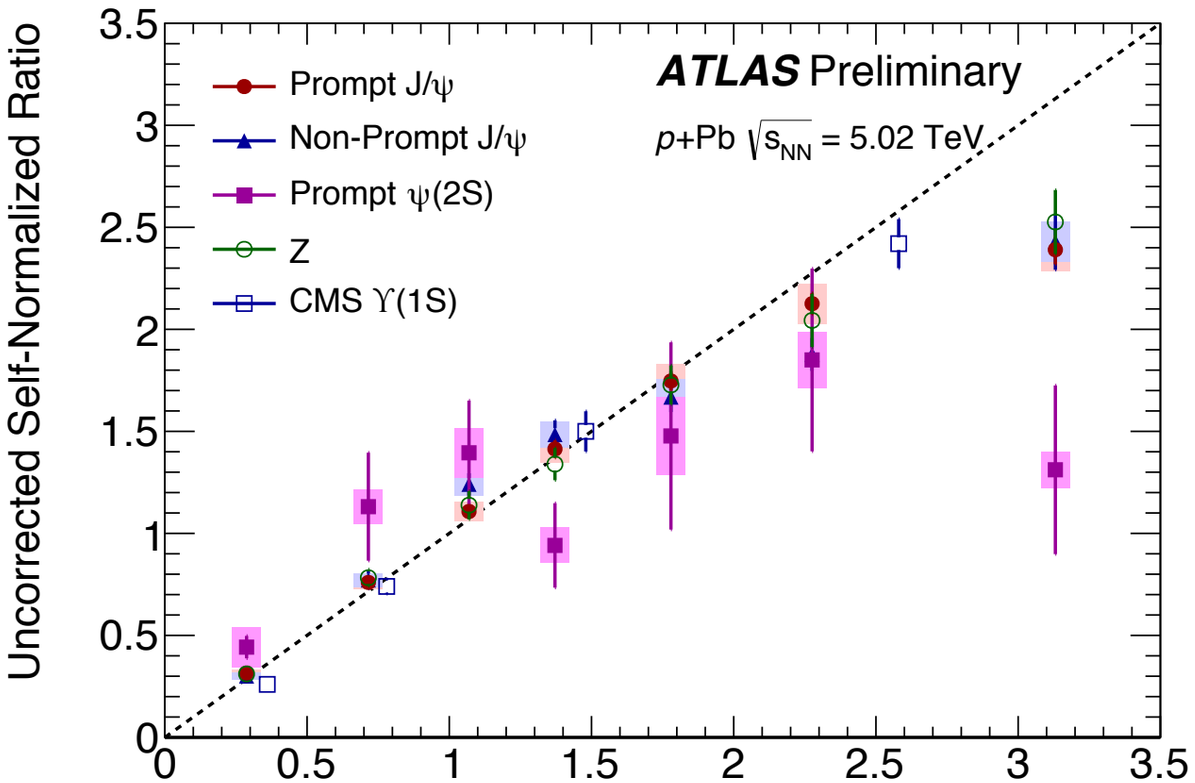


J/ψ from b



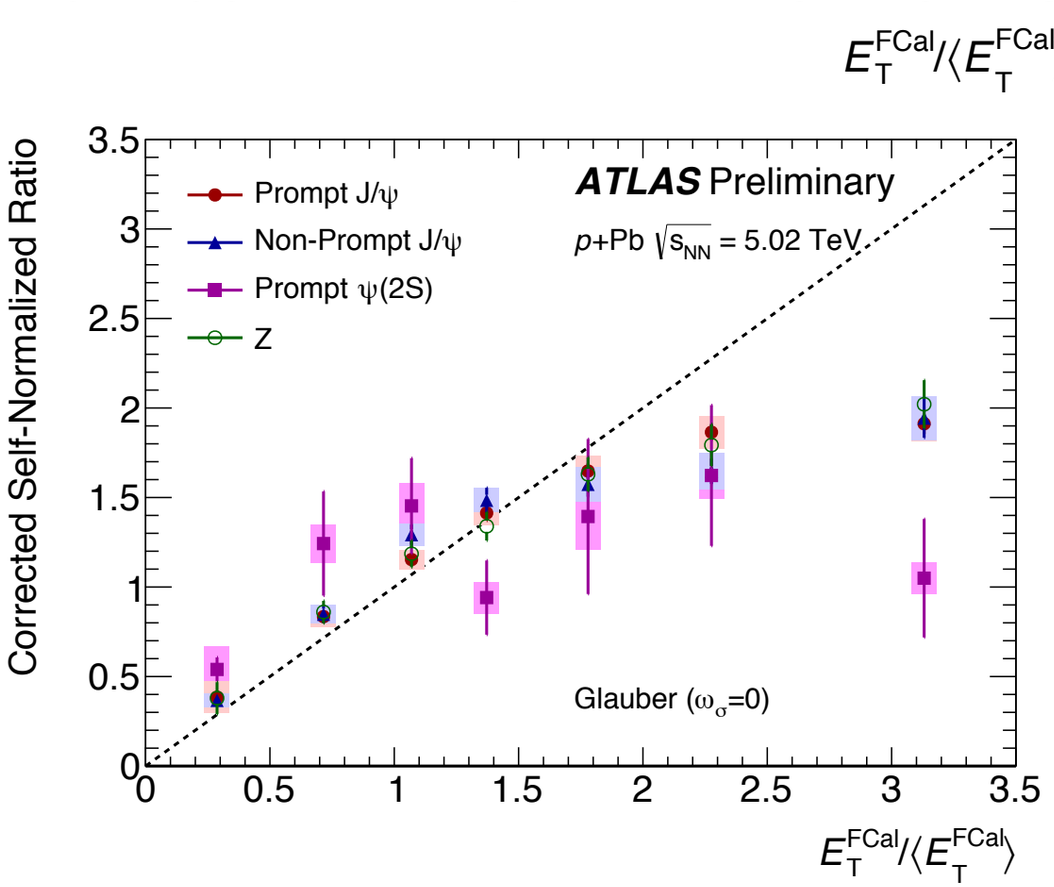
Prompt ψ(2S)

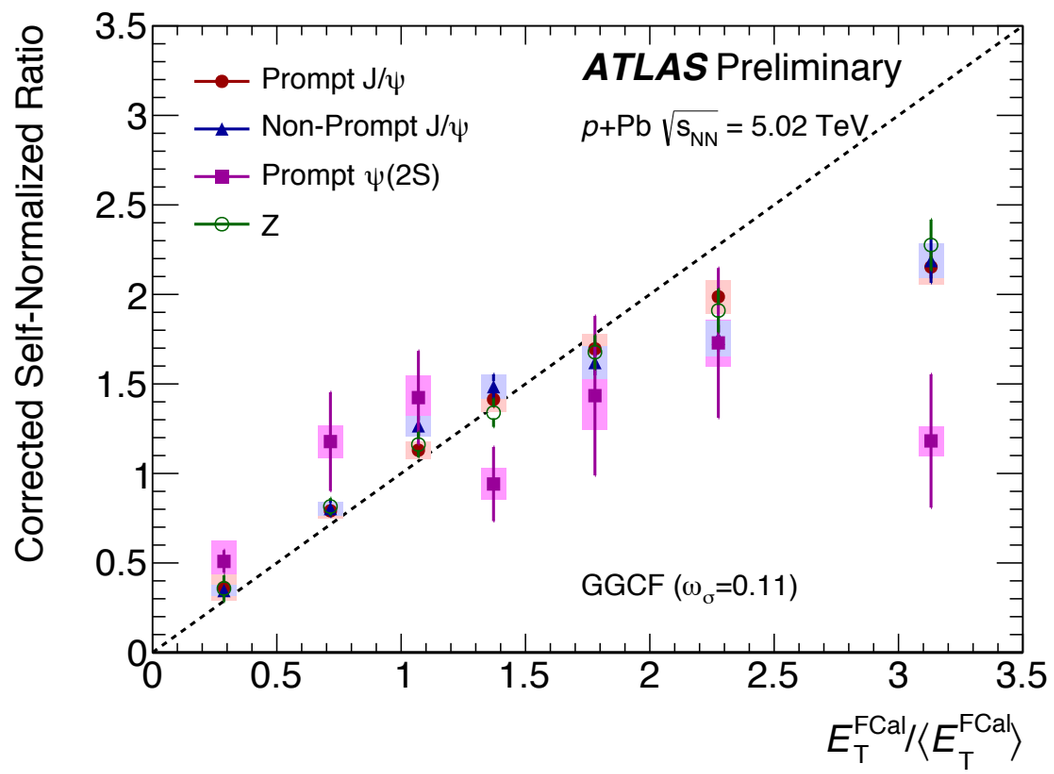
Check of centrality behavior using ‘self-normalized ratios’



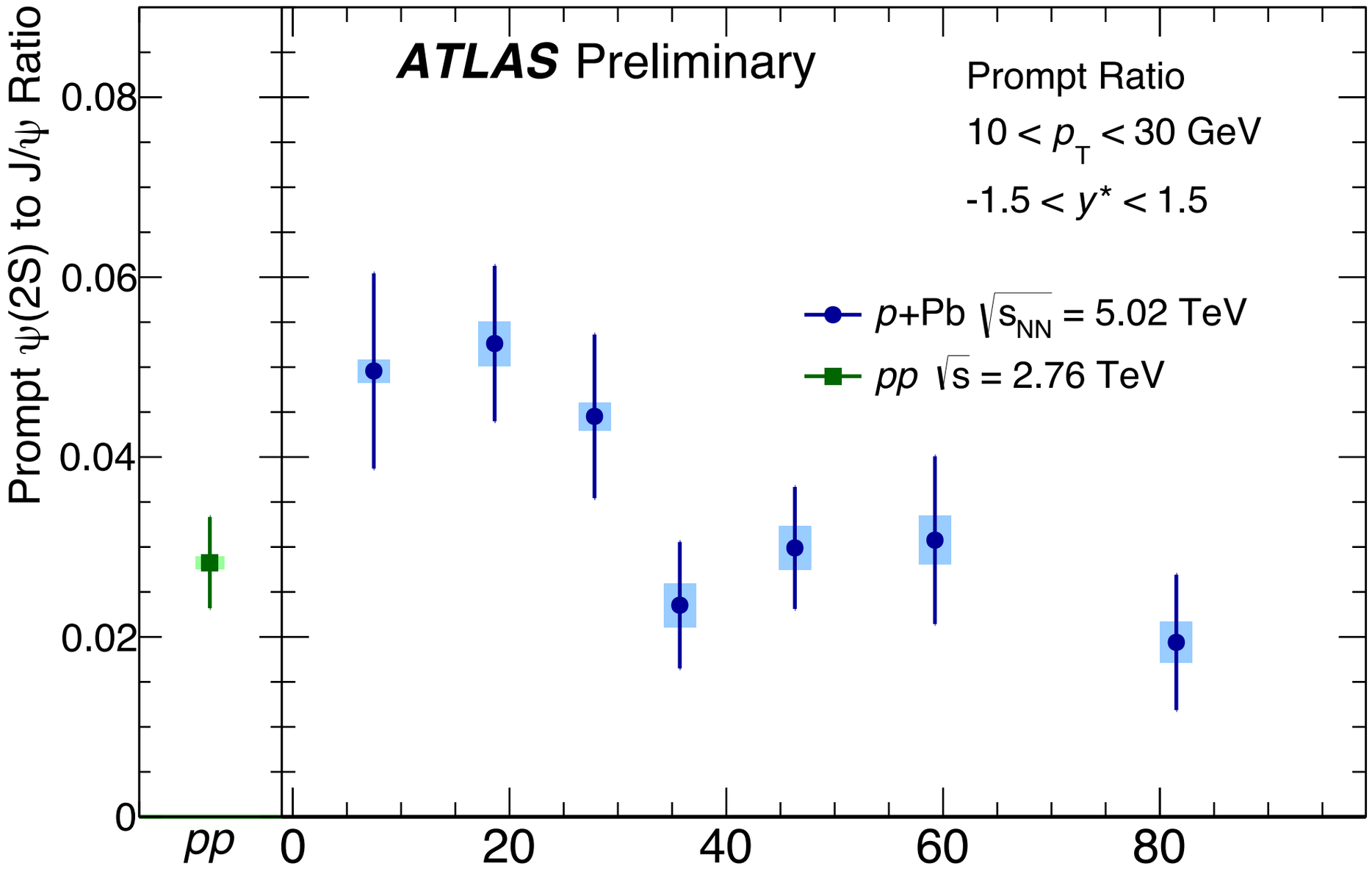
$$\frac{\psi}{\langle\psi\rangle} = \frac{\frac{N_\psi}{N_{evt}}}{\frac{N_\psi^{0-90\%}}{N_{evt}^{0-90\%}}}$$

$$\frac{E_T^{FCal}}{\langle E_T^{FCal}\rangle} = \frac{\langle E_T^{FCal}\rangle|_{cent}}{\langle E_T^{FCal}\rangle|_{0-90\%}}$$





Ratio of prompt ψ(2S) to J/ψ vs. FCal E_T



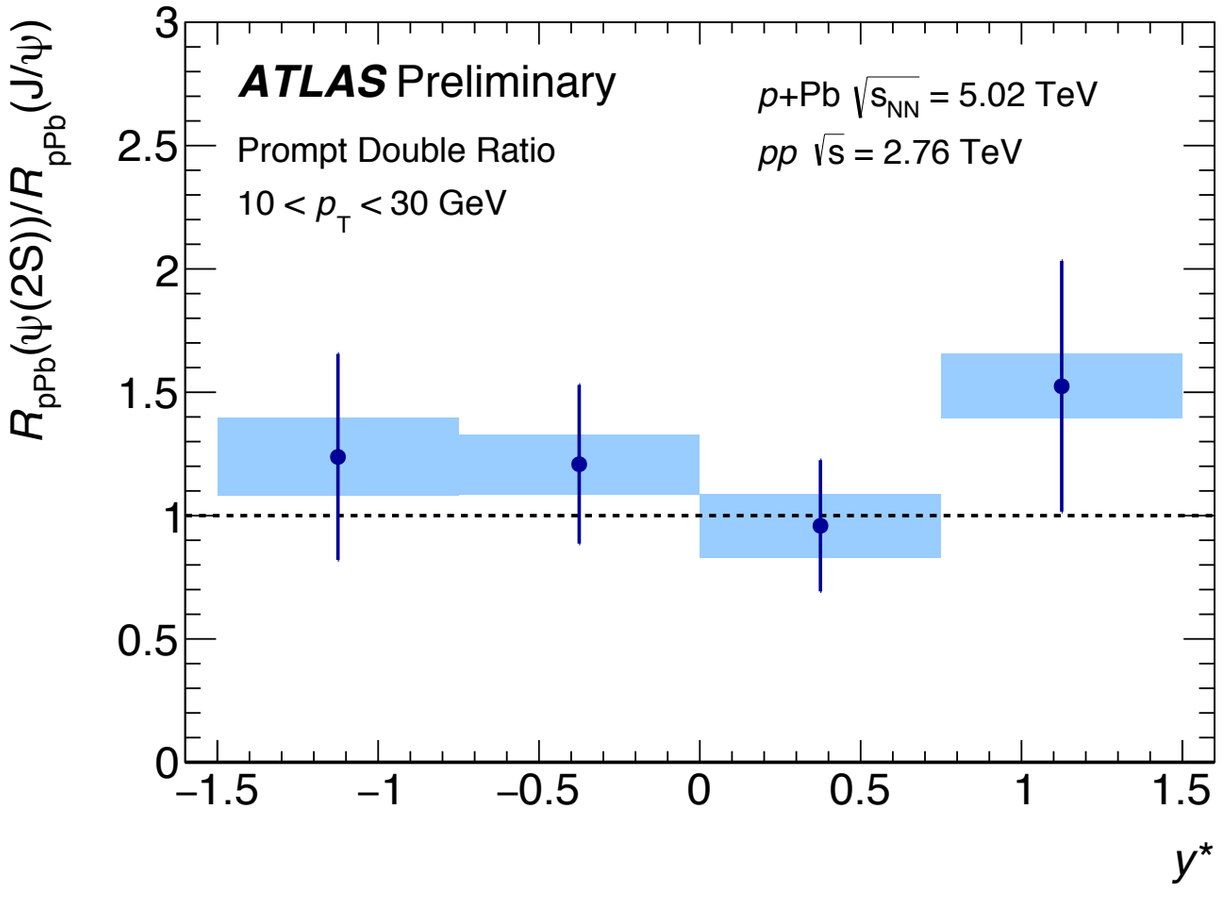
Evidence for centrality dependence

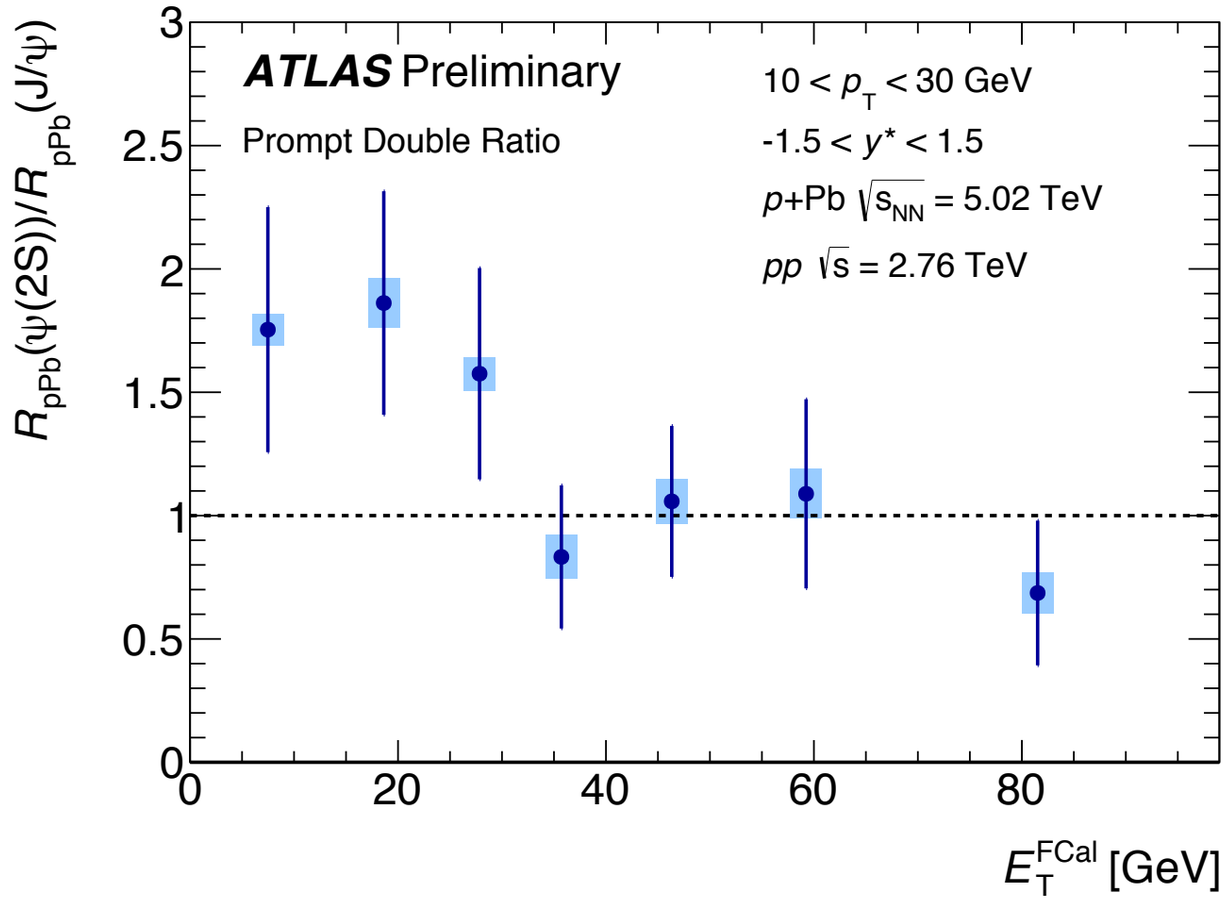
Similar pattern as Z-normalized ψ(2S)

Decreasing trend with centrality; magnitude > ALICE's

Prompt double ratio vs. FCal ET and y*

$$\text{Prompt double ratio} \equiv \frac{\left.\frac{N^{\psi(2S)}}{N^{J/\psi}}\right|_{pPb}}{\left.\frac{N^{\psi(2S)}}{N^{J/\psi}}\right|_{pp}}$$





Shape in E_T is compatible with Z-normalized and R_{pPb}

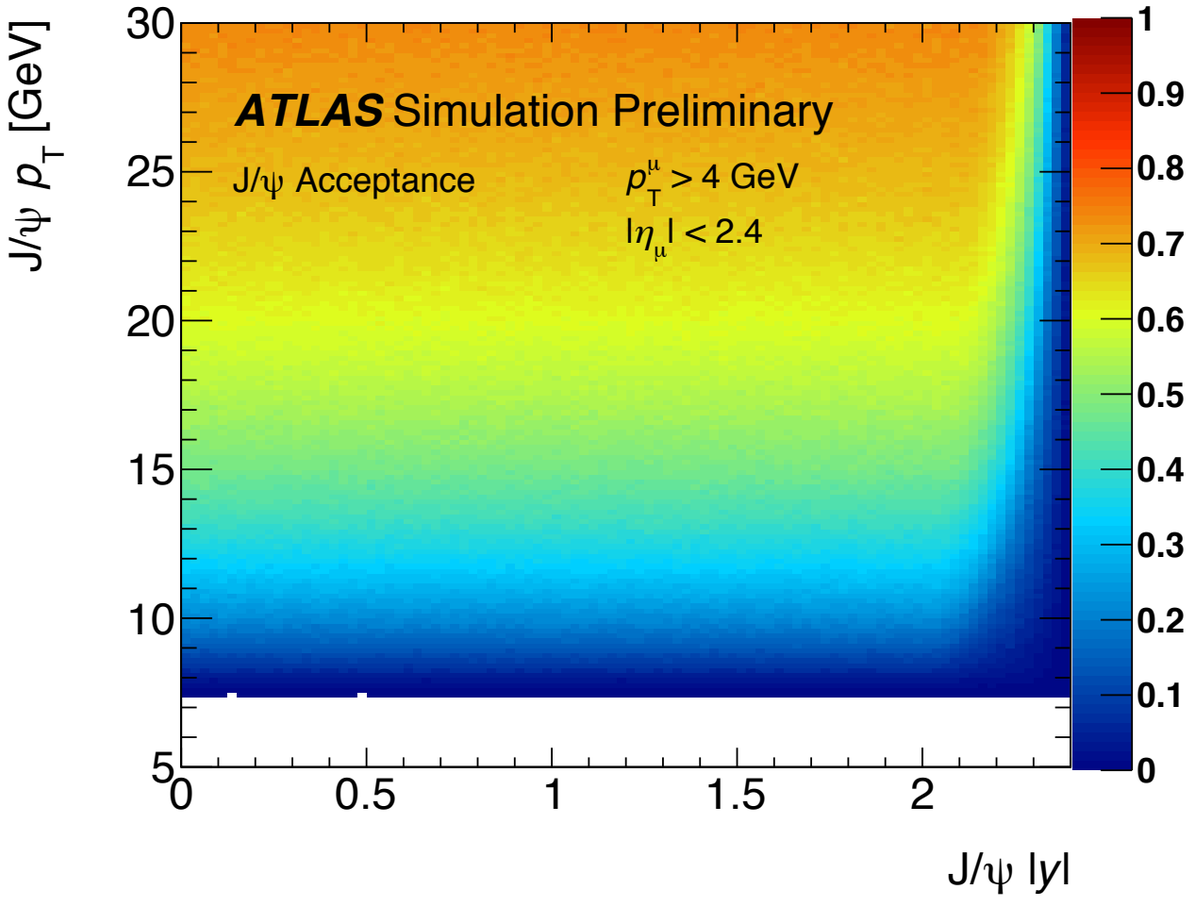
Clear *enhancement* at low FCal E_T, consistent with R_{pPb}

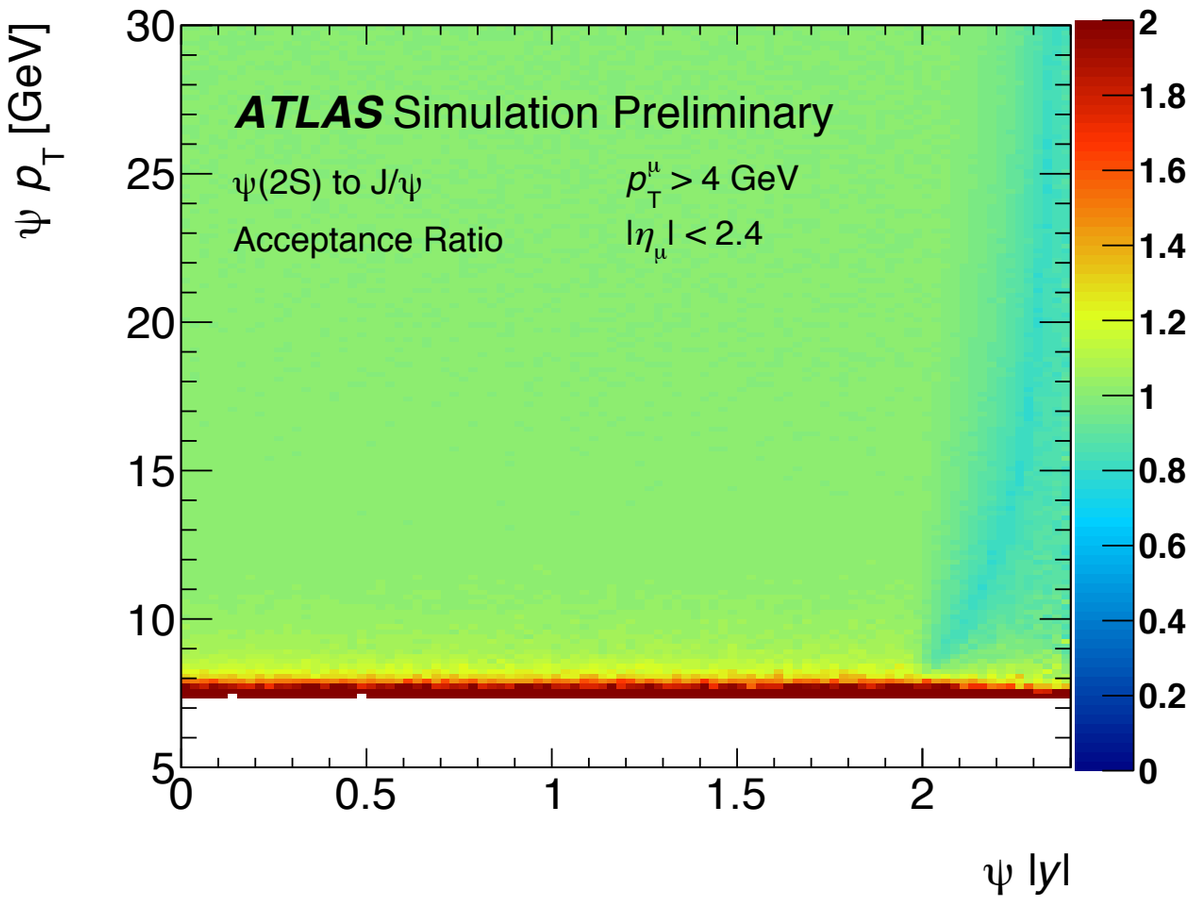
Conclusions

- Measurement of J/ψ and ψ(2S) production in p-Pb collisions at 5.02 TeV - first precise quarkonia results from ion beams in ATLAS!
- Measured differential cross sections, R_{FB} for J/ψ, R_{pPb} for J/ψ and ψ(2S) via pp interpolation; nonprompt fraction, single and double ratios, for J/ψ and ψ(2S)
- Separation: prompt and nonprompt (b) components
- Nuclear medium effects seen in a number of observables and hints in others - most prominently:
  - ➡ R_{FB} significantly larger than ALICE's (at forward y*)
  - ➡ R_{pPb}>1 for J/ψ and ψ(2S), ~all measured kinematics
  - ➡ Double ratio of ψ(2S)/J/ψ enhanced at low centrality

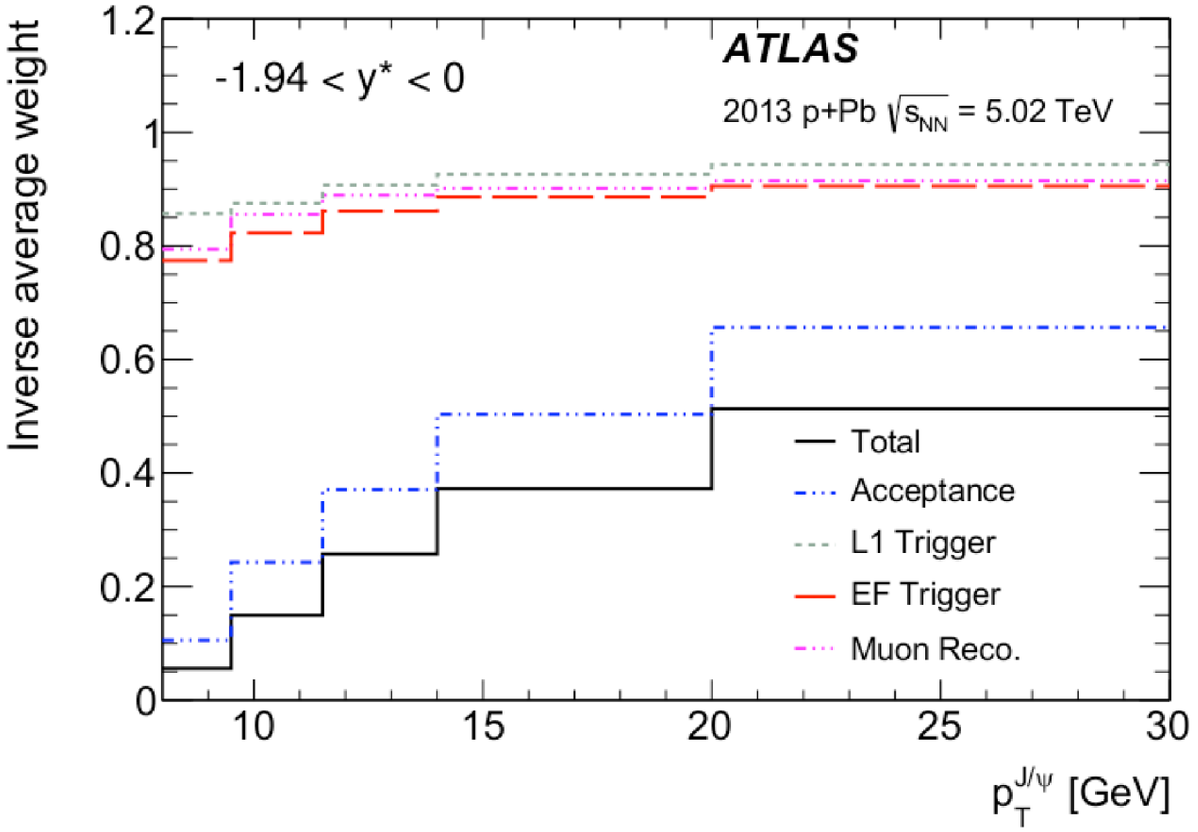
Additional slides

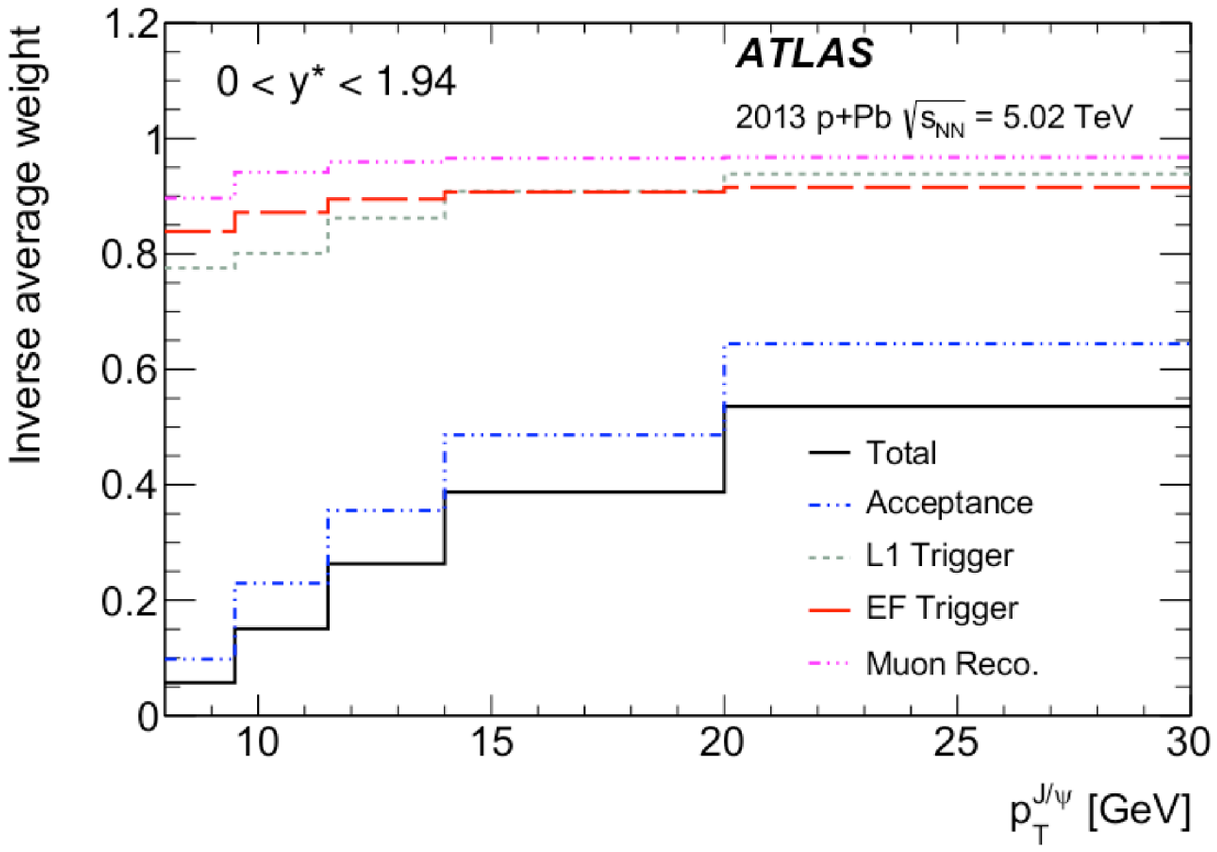
Acceptance of J/ψ and ψ(2S) in ATLAS

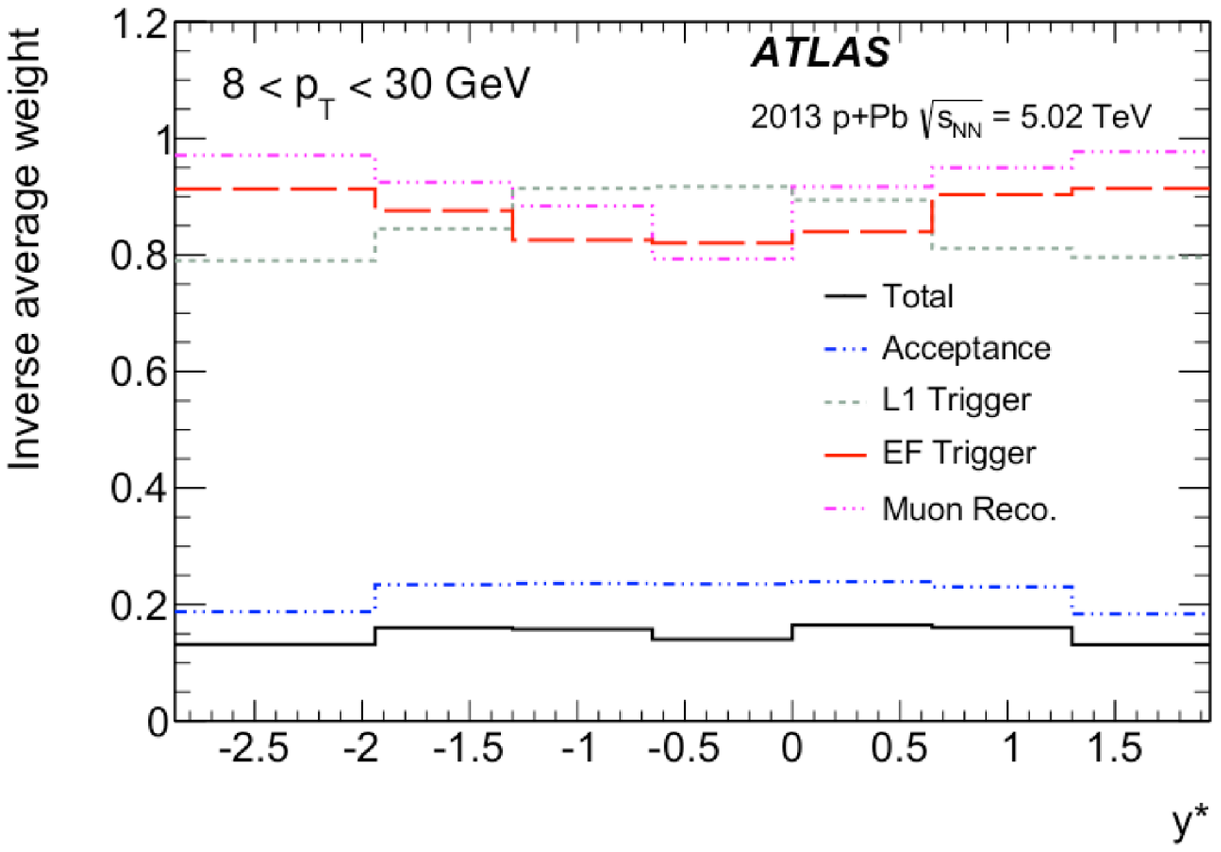




Fitting weights for J/ψ



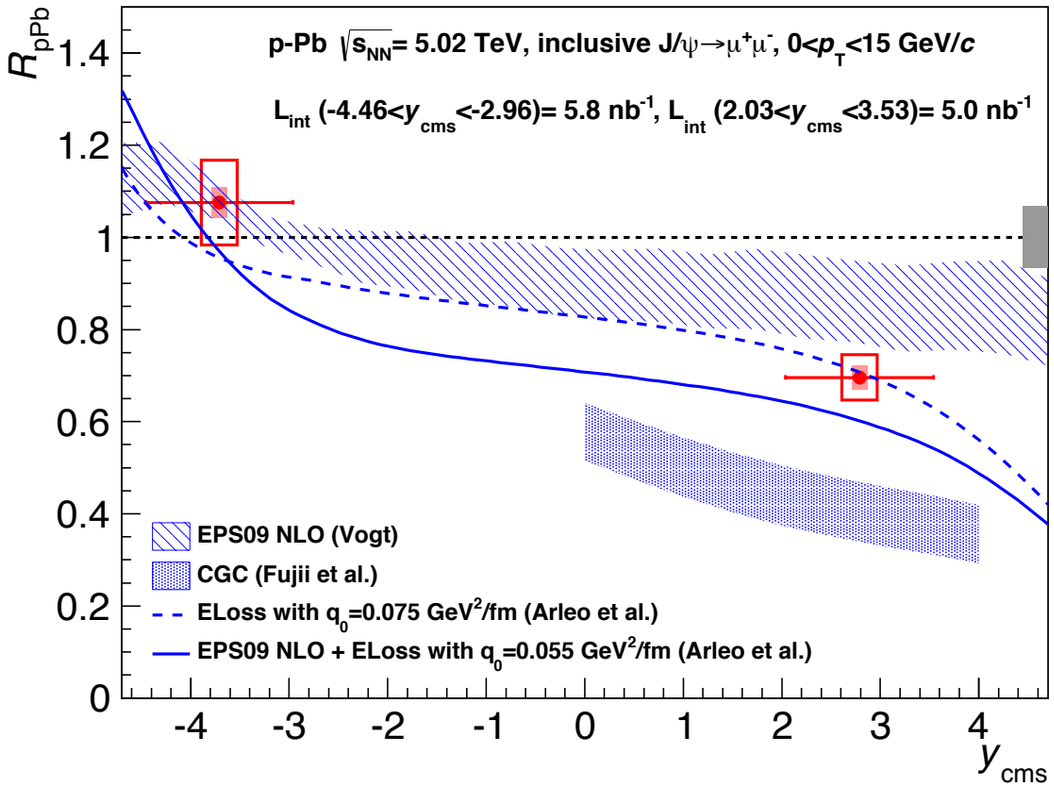


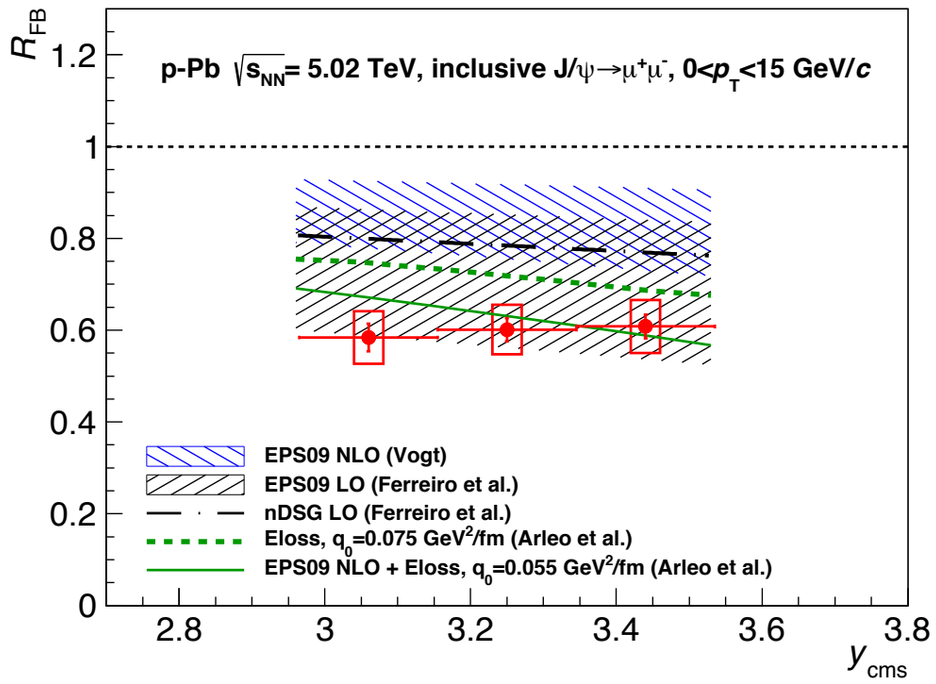


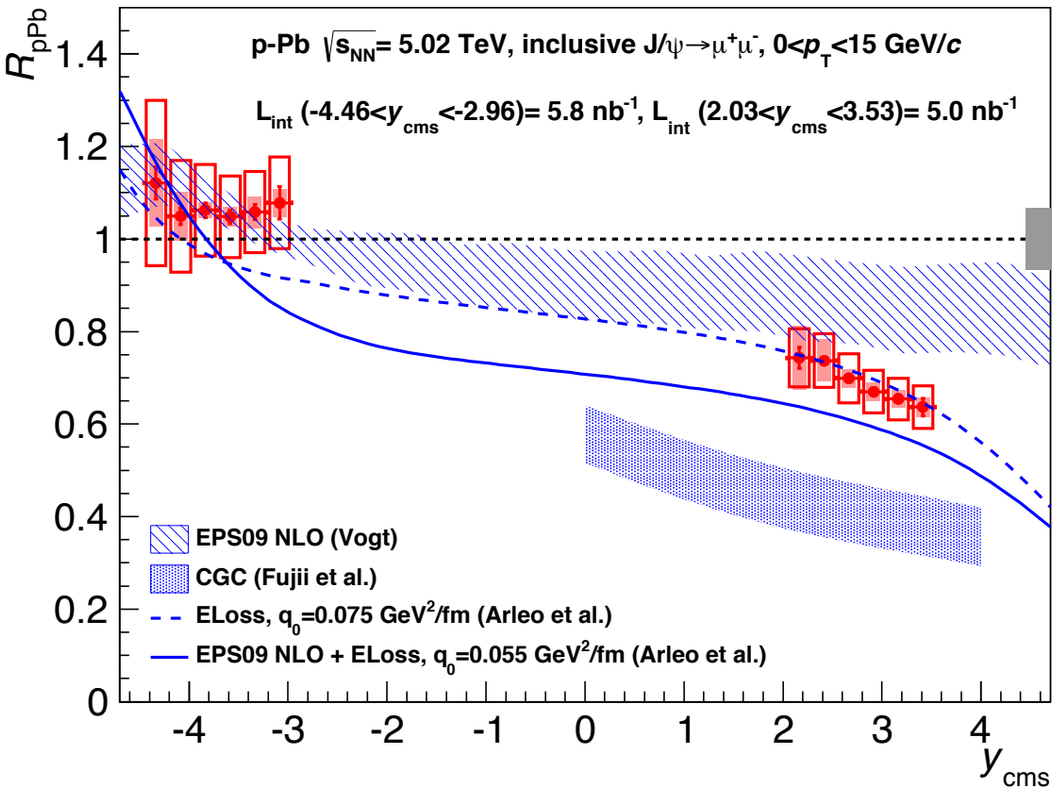
ALICE J/ψ results

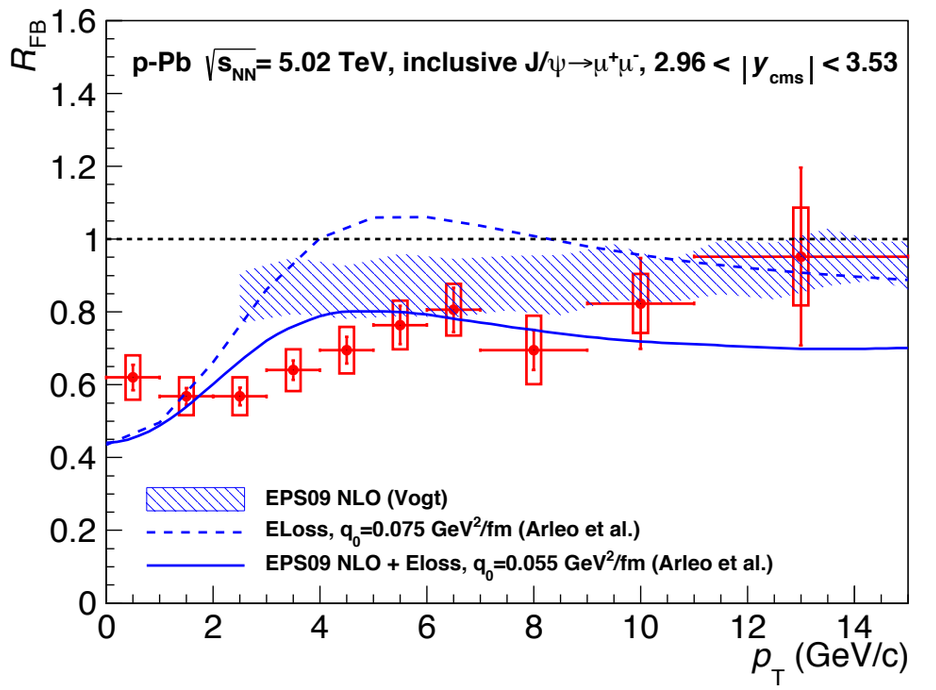
arXiv:1308.6726 [nucl-ex]

JHEP 02 (2014) 073





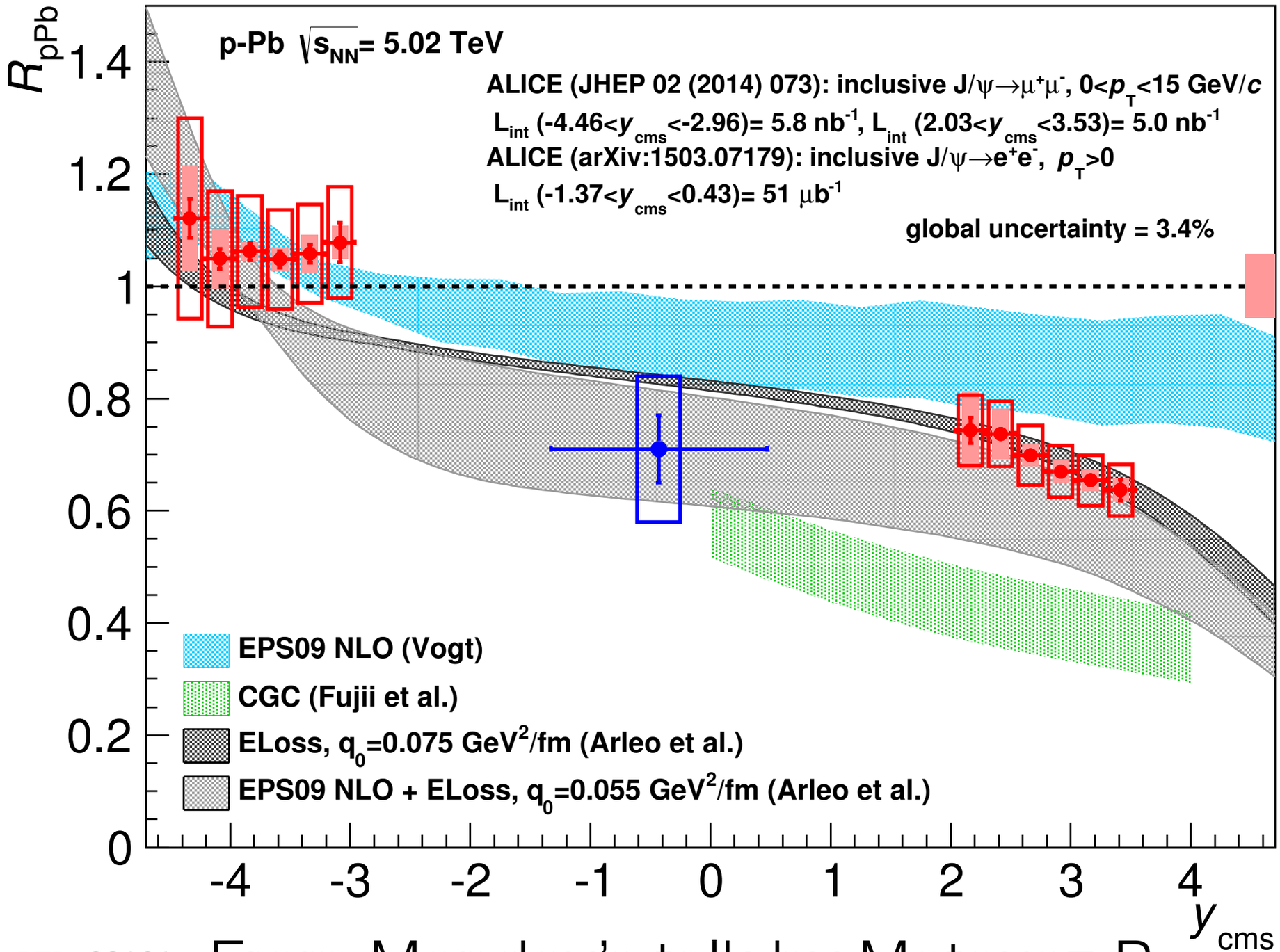




J/ψ in pA collisions

R_{pPb} close to unity at backward (Pb-going) rapidity

CNM effects at mid- and forward (p-going) rapidity

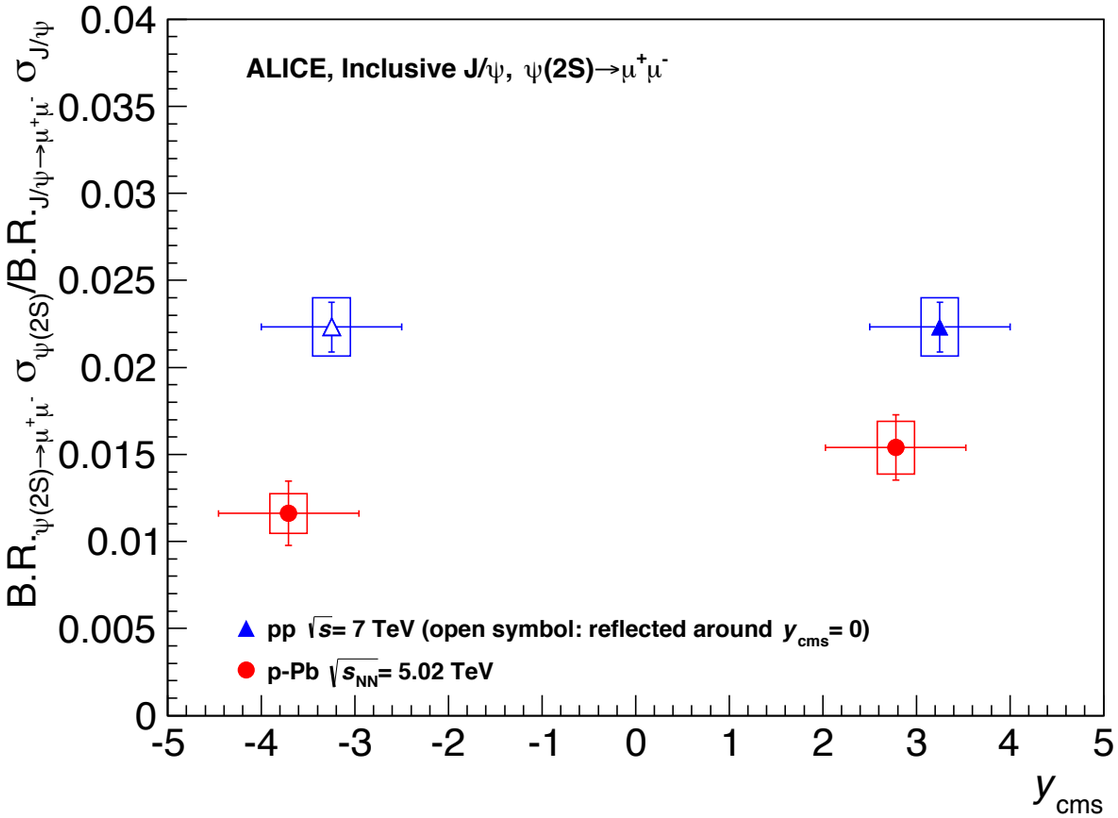


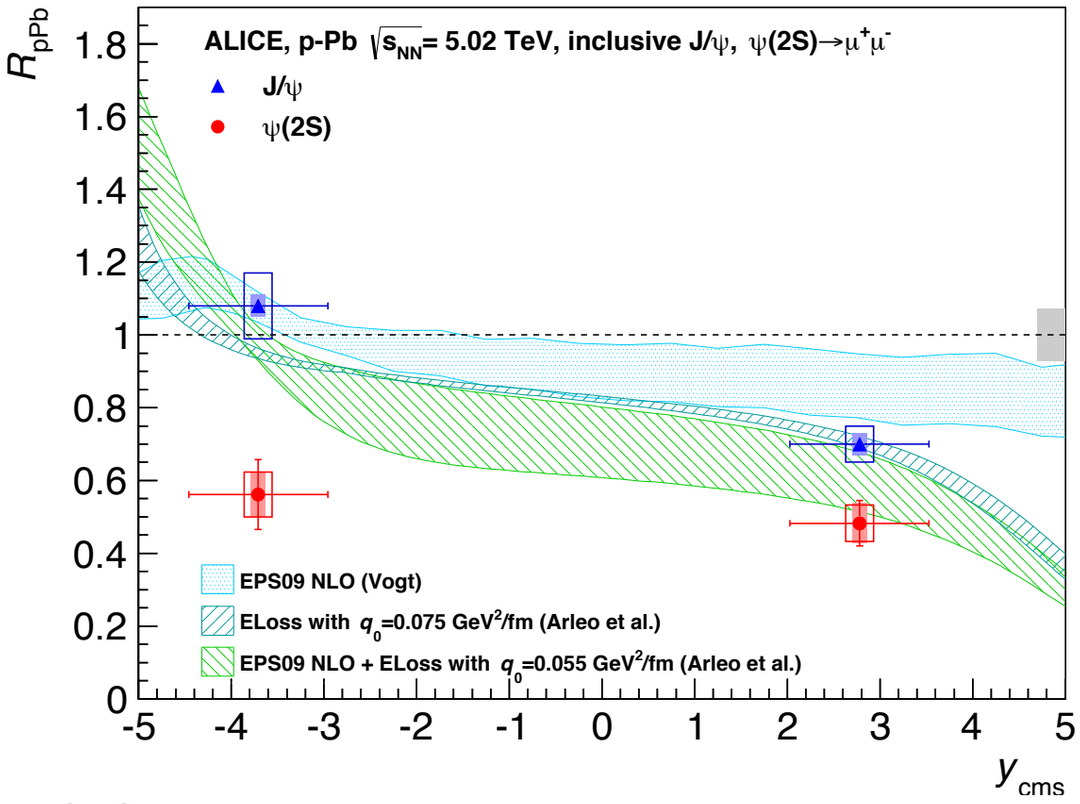
From Monday's talk by Mateusz P.

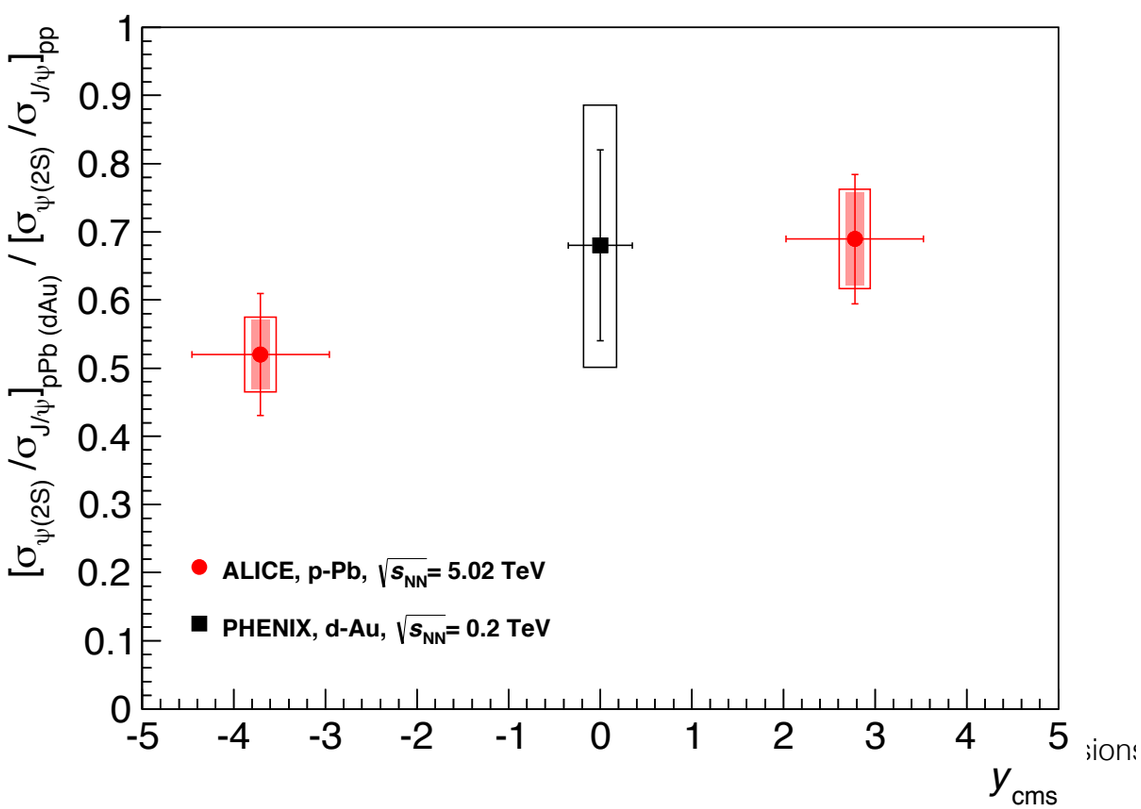
ALICE ψ(2S) results (I)

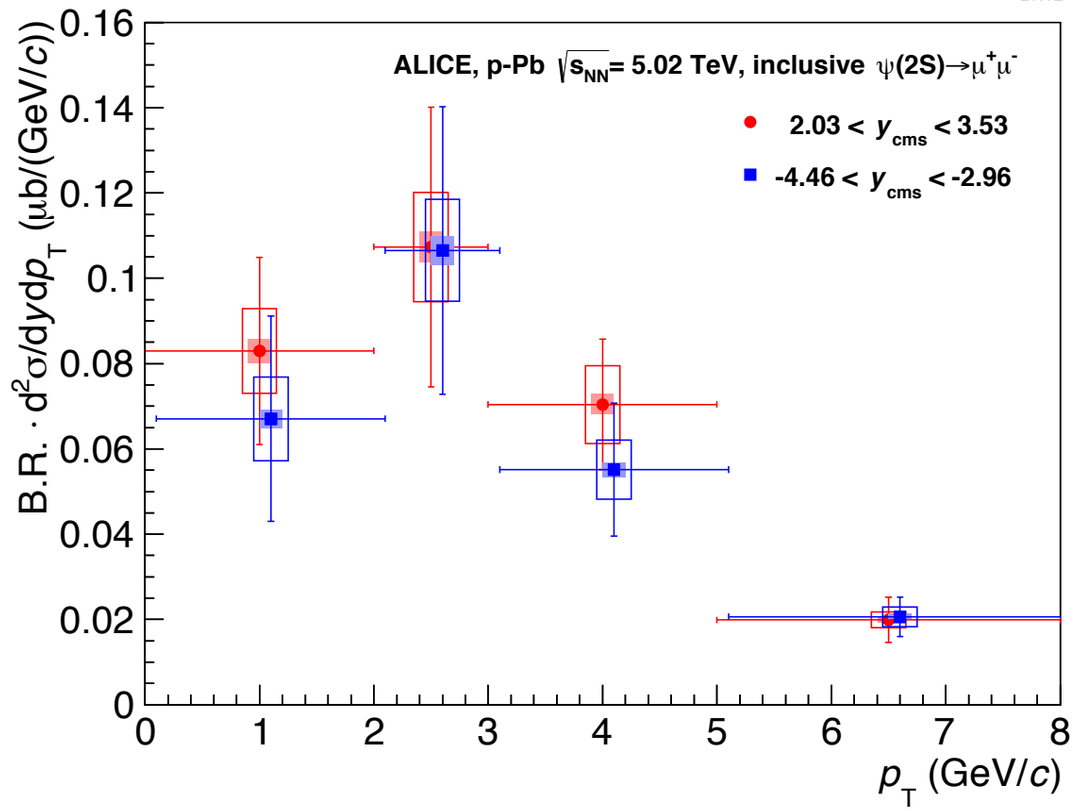
arXiv:1405.3796 [nucl-ex]

JHEP 1412 (2014) 073





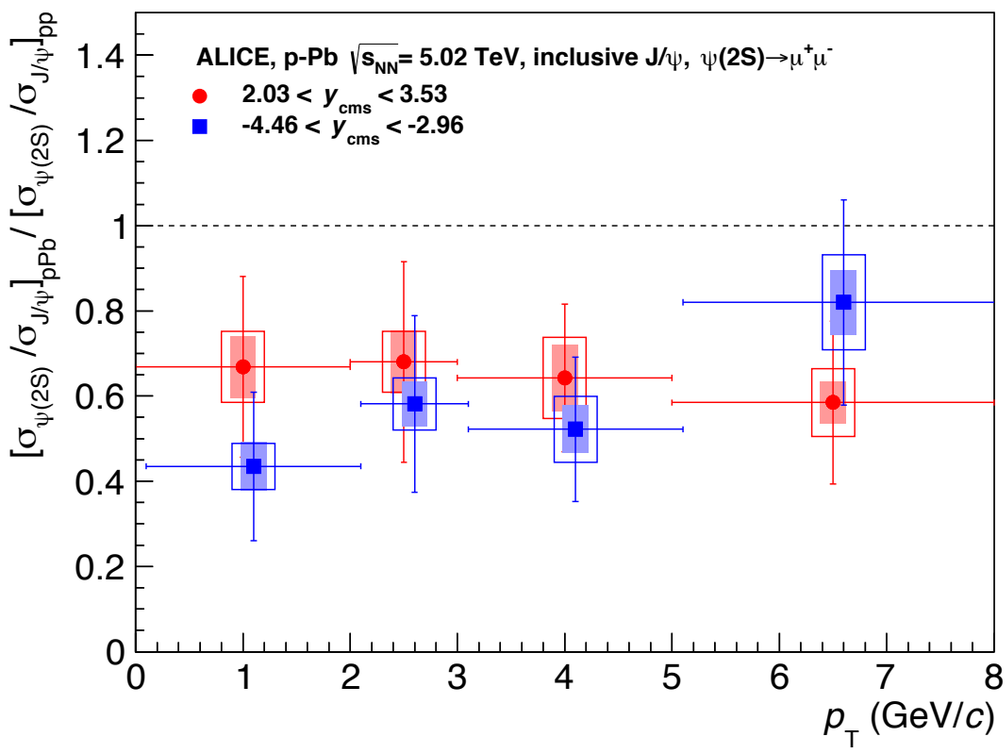


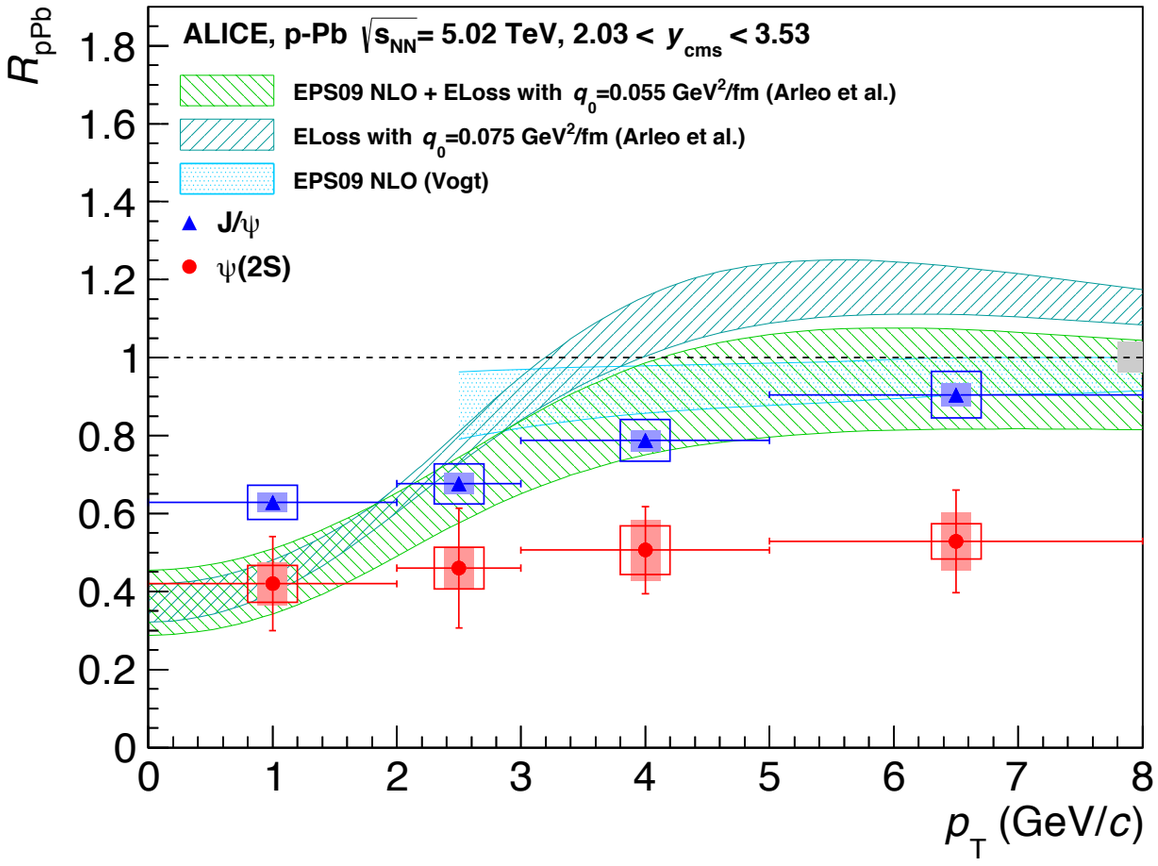


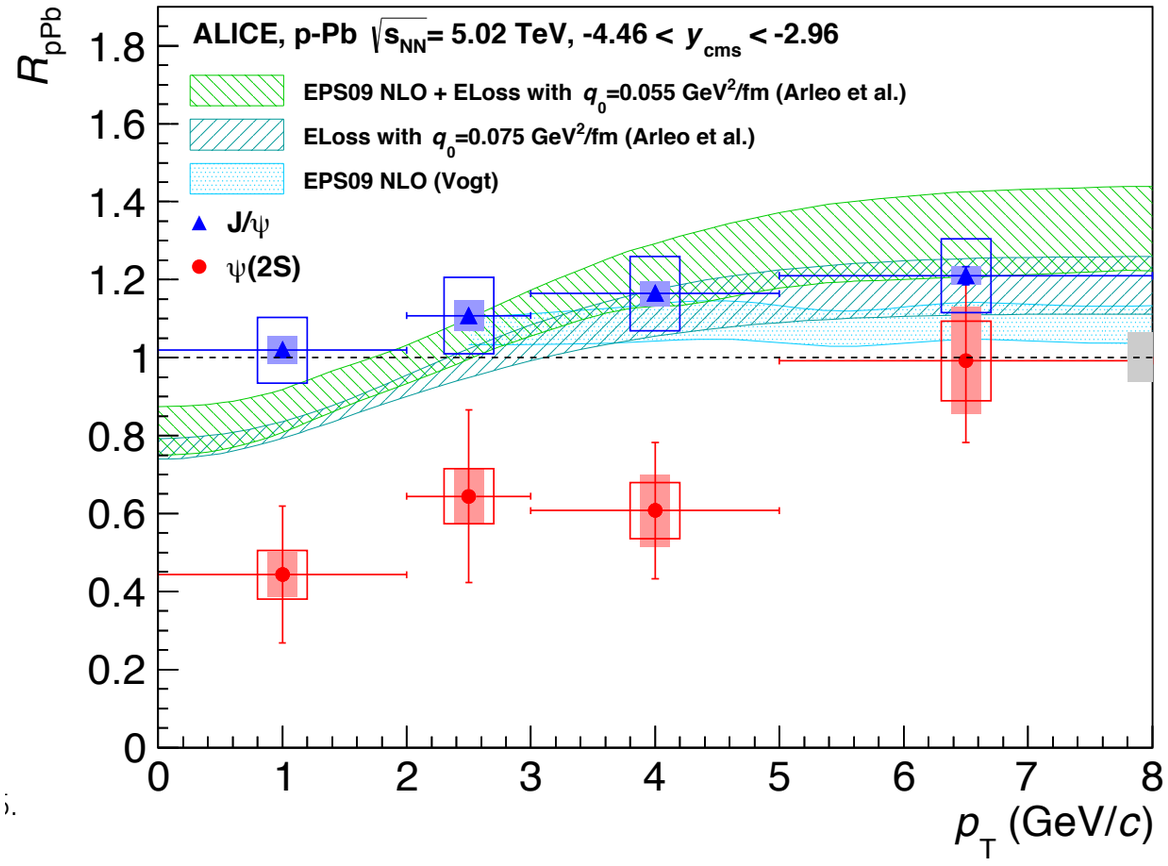
ALICE ψ(2S) results (II)

arXiv:1405.3796 [nucl-ex]

JHEP 1412 (2014) 073







Comparison of the two ATLAS J/ψ analyses

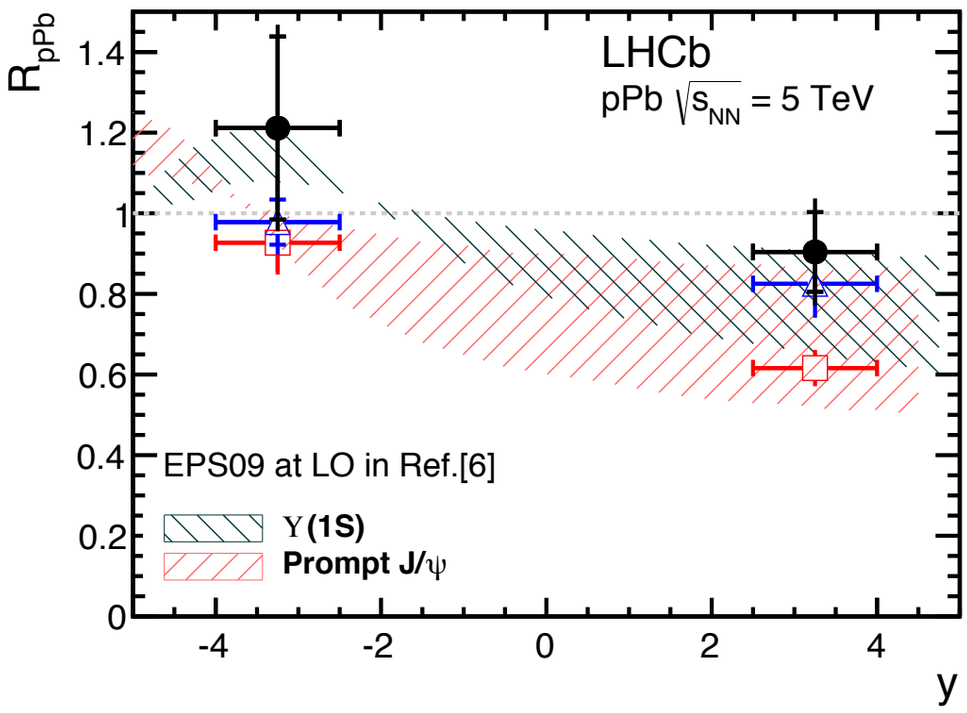
Elements in common:

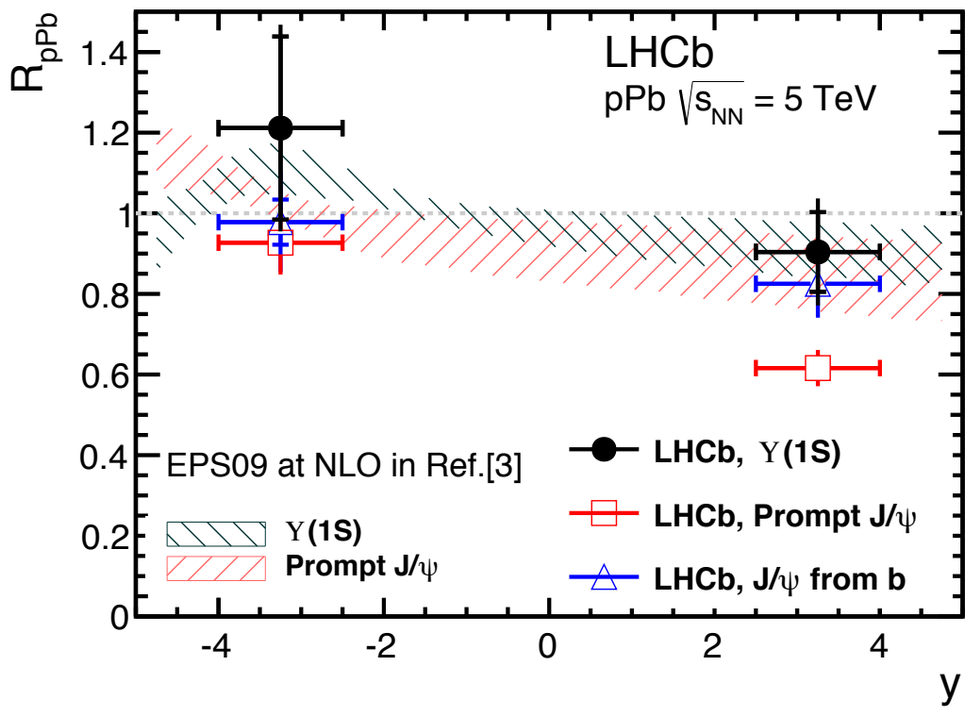
- Same pPb data sample, same triggers, secondary dimuon vertex refitting
- Same muon selection criteria and reconstruction efficiency corrections
- Same version of J/ψ acceptance map

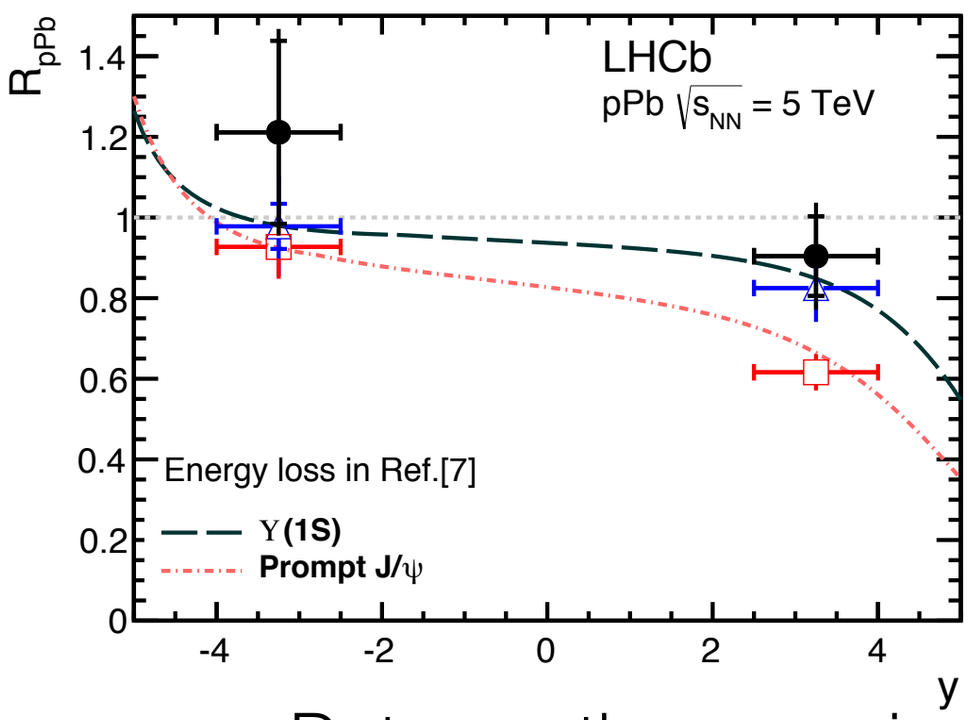
Elements that are different:

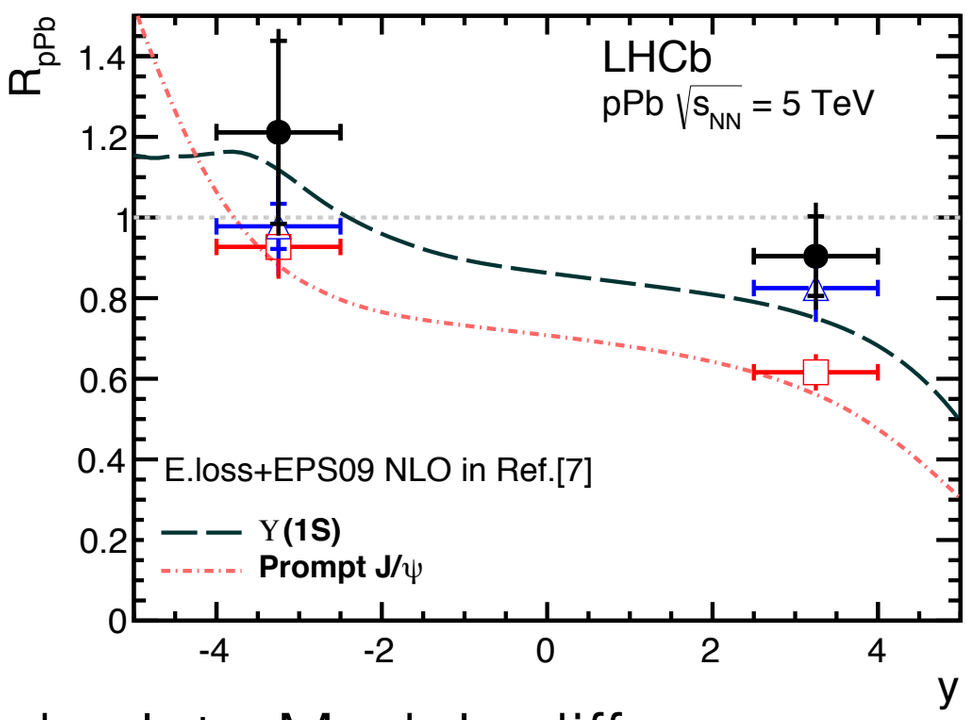
- Included ψ(2S) in fit model; fit model was kept as similar as possible to 7 and 8 TeV analyses to reduce interpolation uncertainties
- Included 2.76 TeV pp data for calculation of R_{pPb}
- Updated efficiency map from 8 TeV pp was used for L1 trigger correction
- Finer-binned Event Filter efficiency map was used
- Centrality dependence was studied using several centrality estimators

J/ψ and Upsilon in pPb from LHCb





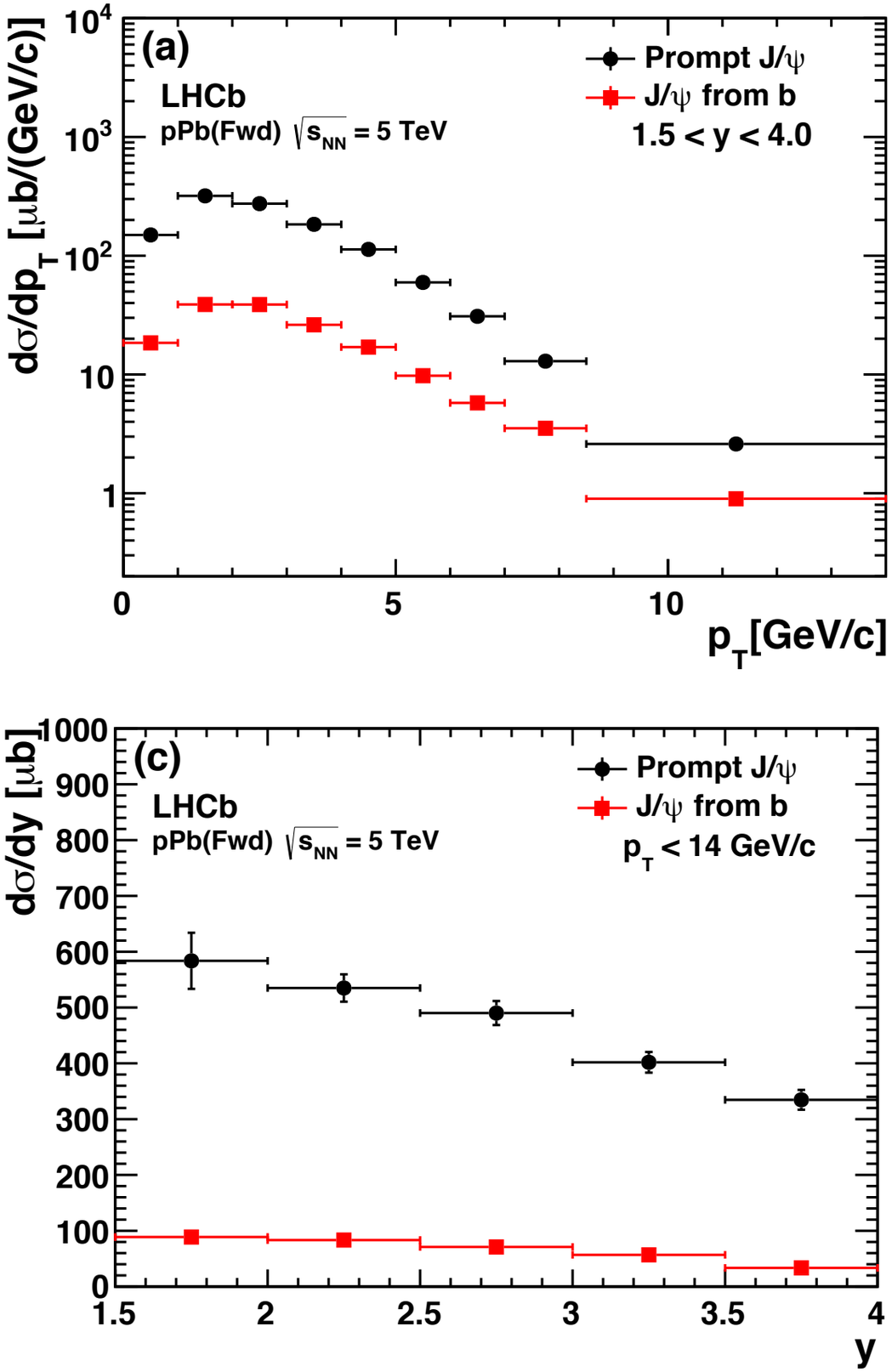


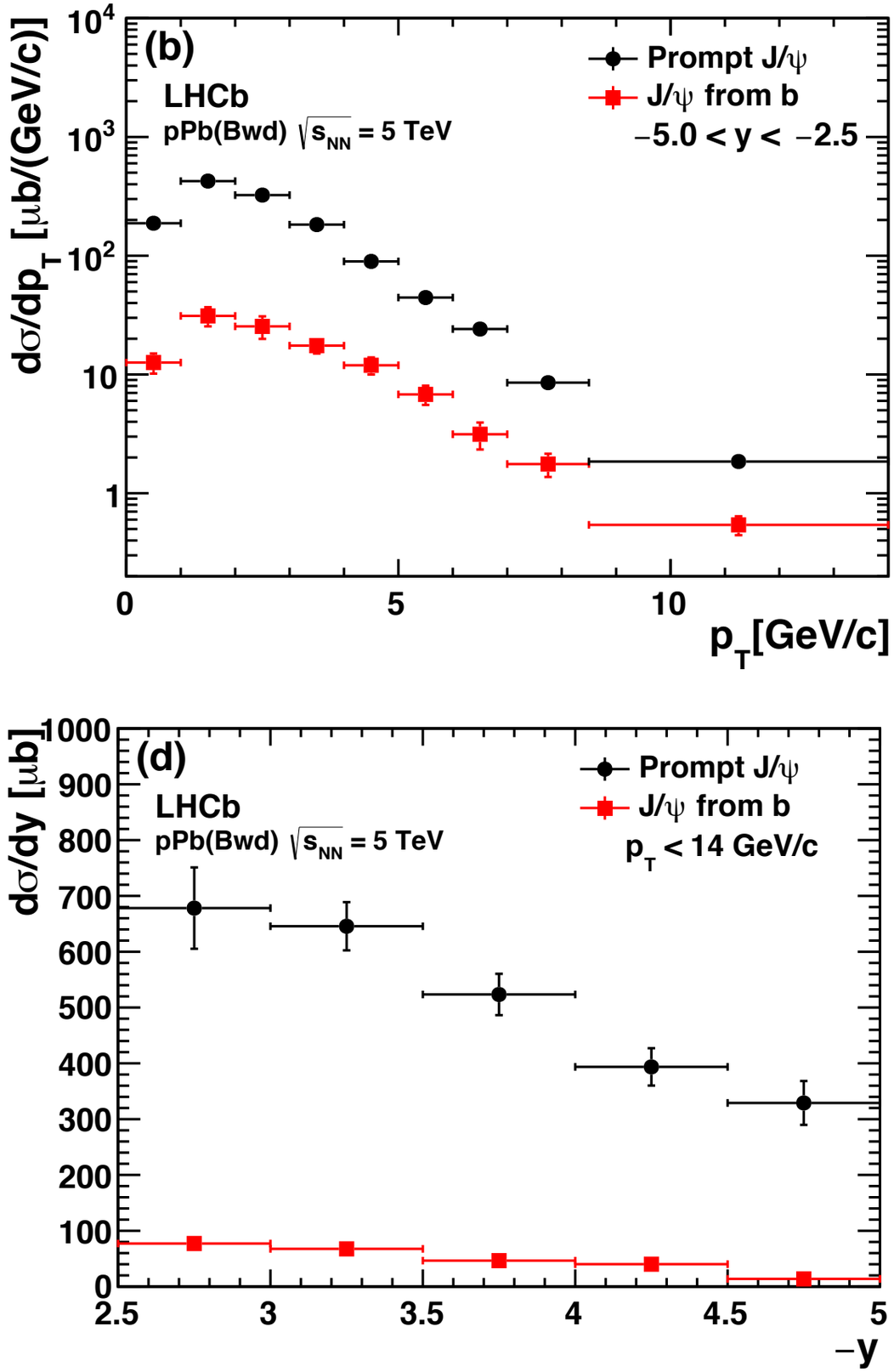


Data are the same in each plot - Models differ

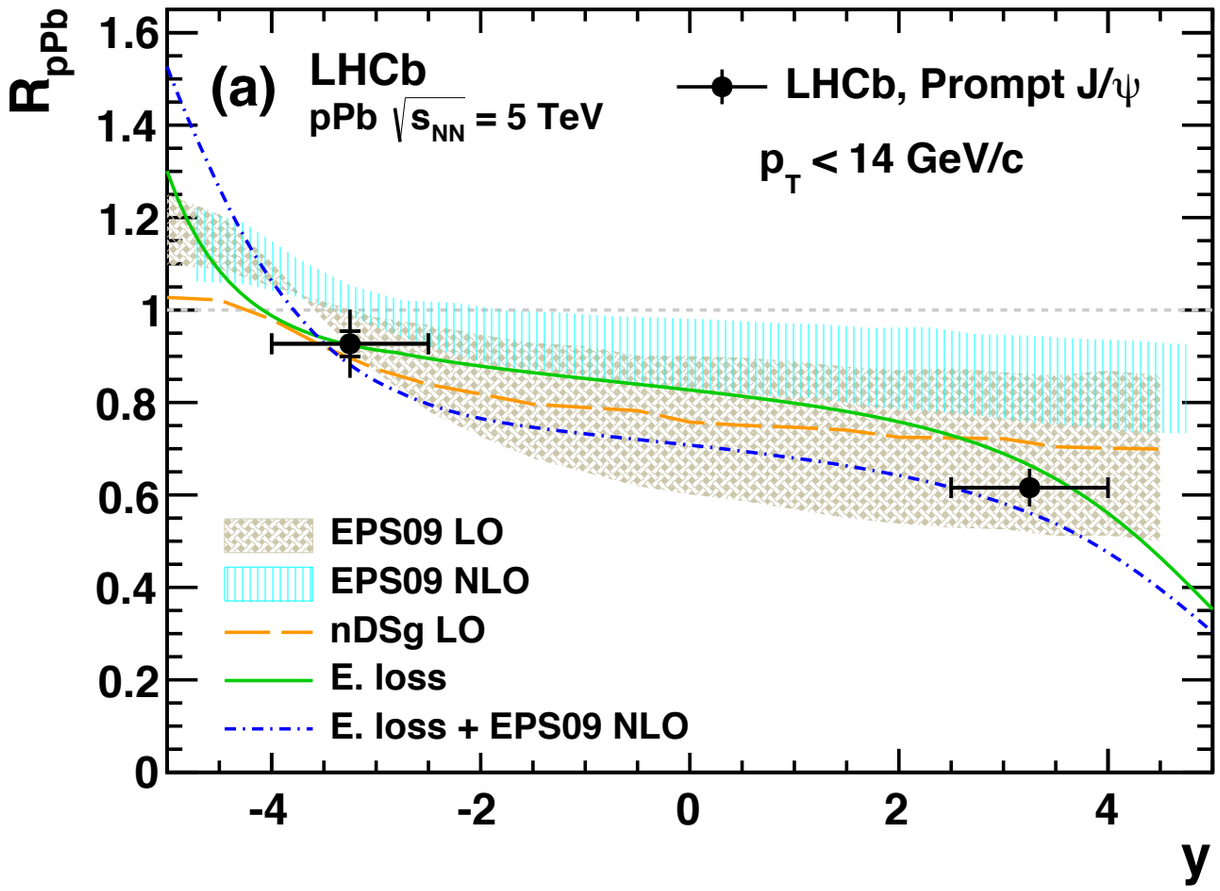
Black circles - Υ(1S), red squares - prompt J/ψ, blue triangles - J/ψ from b

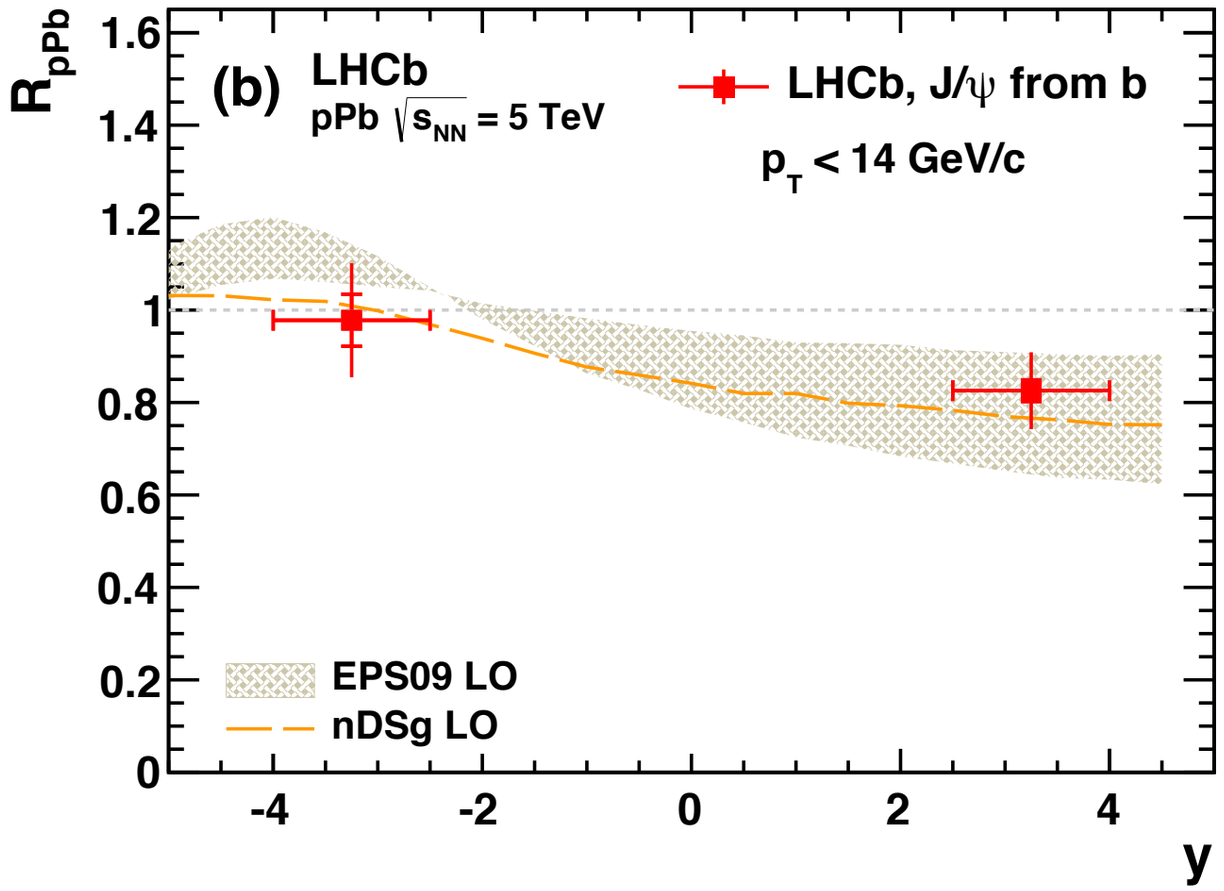
J/ψ in pPb from LHCb

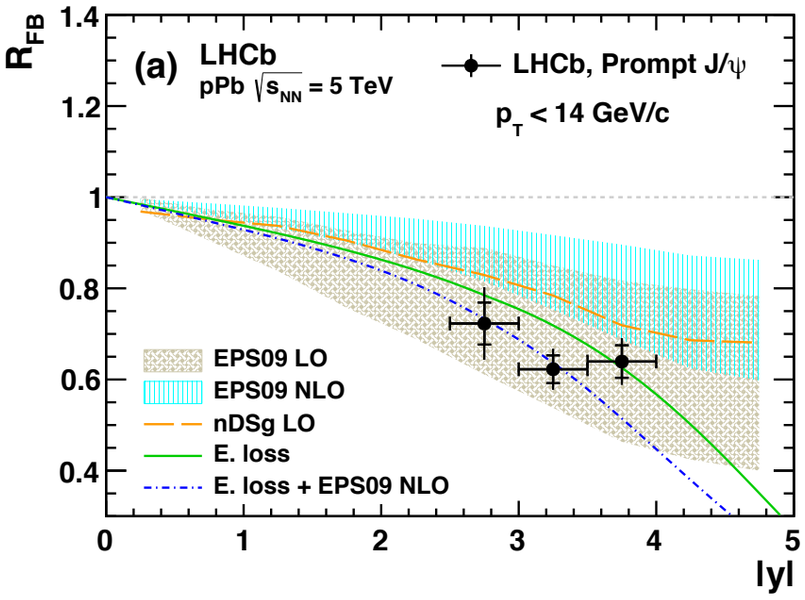


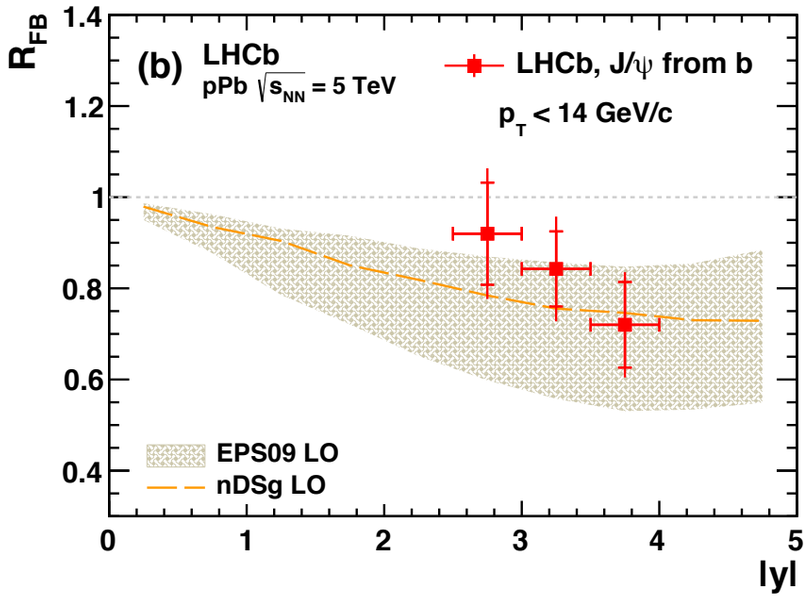


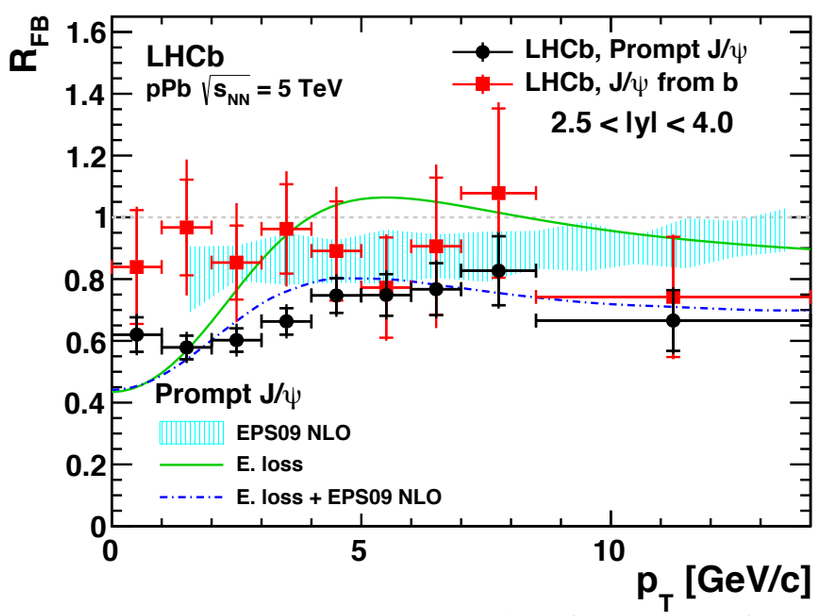
J/ψ in pPb from LHCb

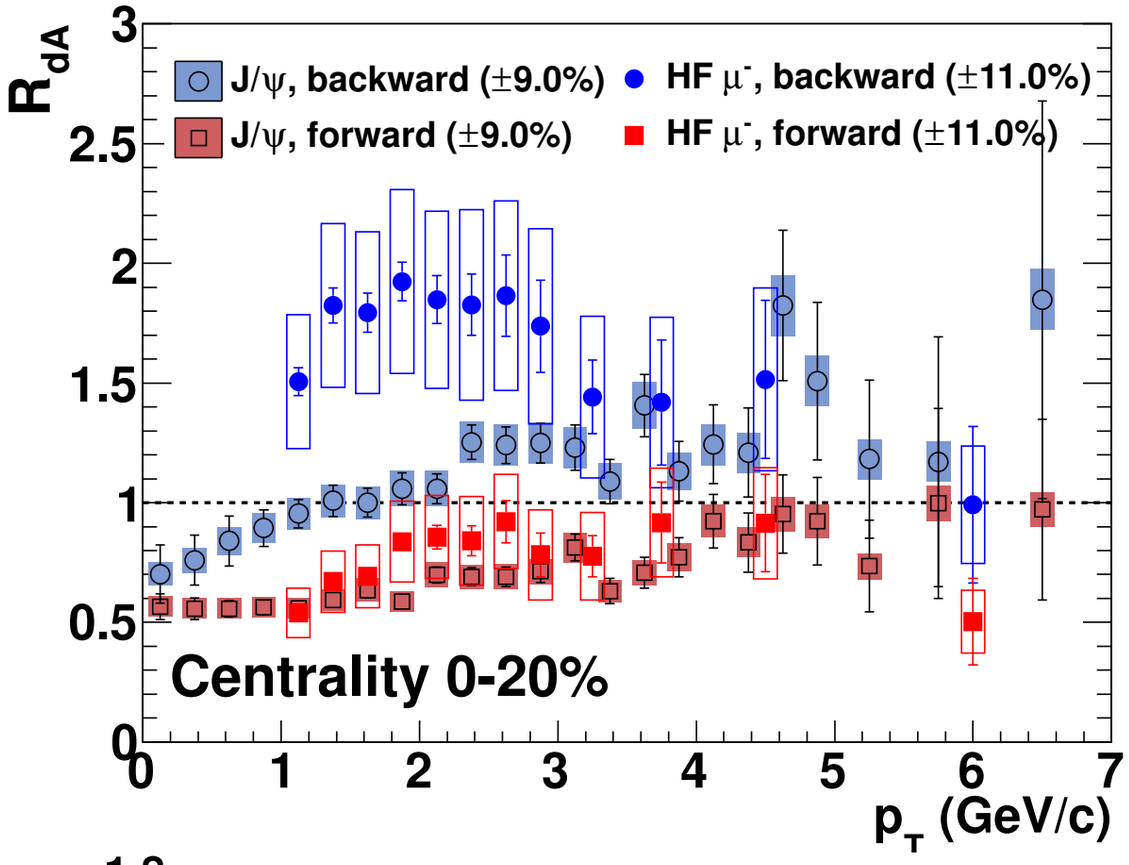


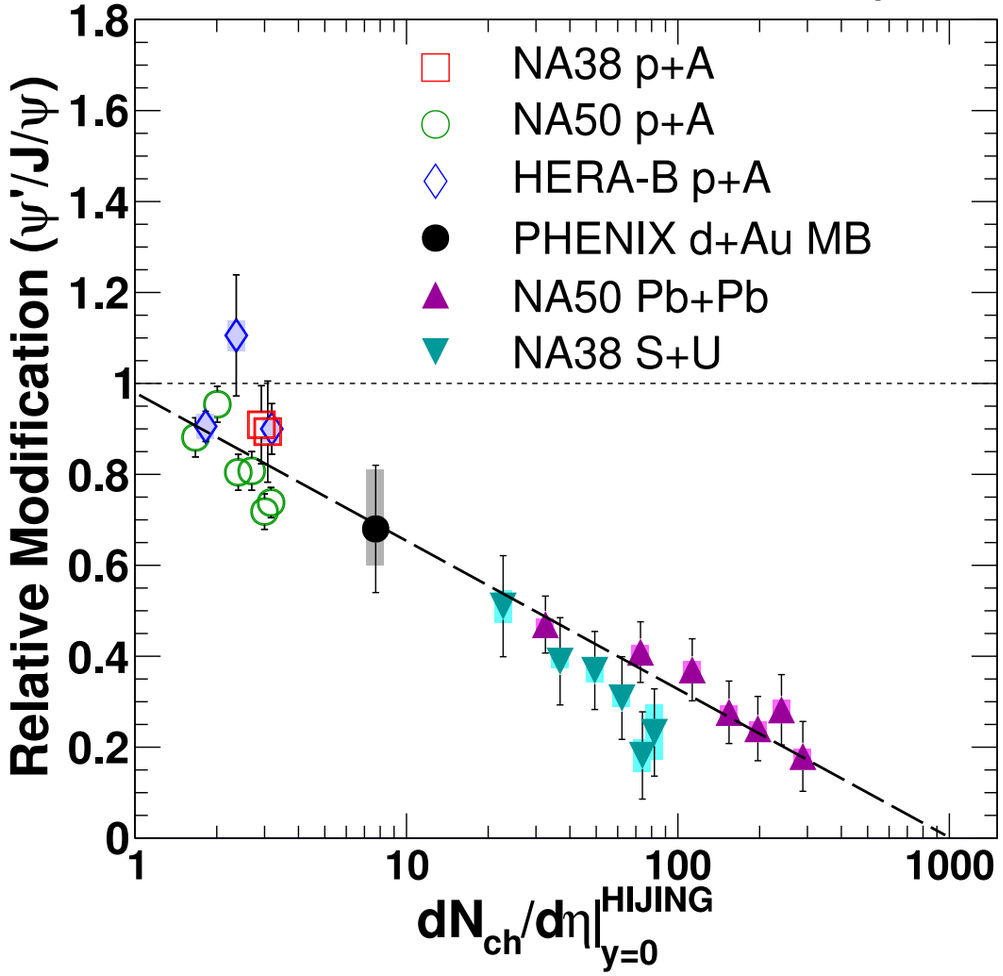




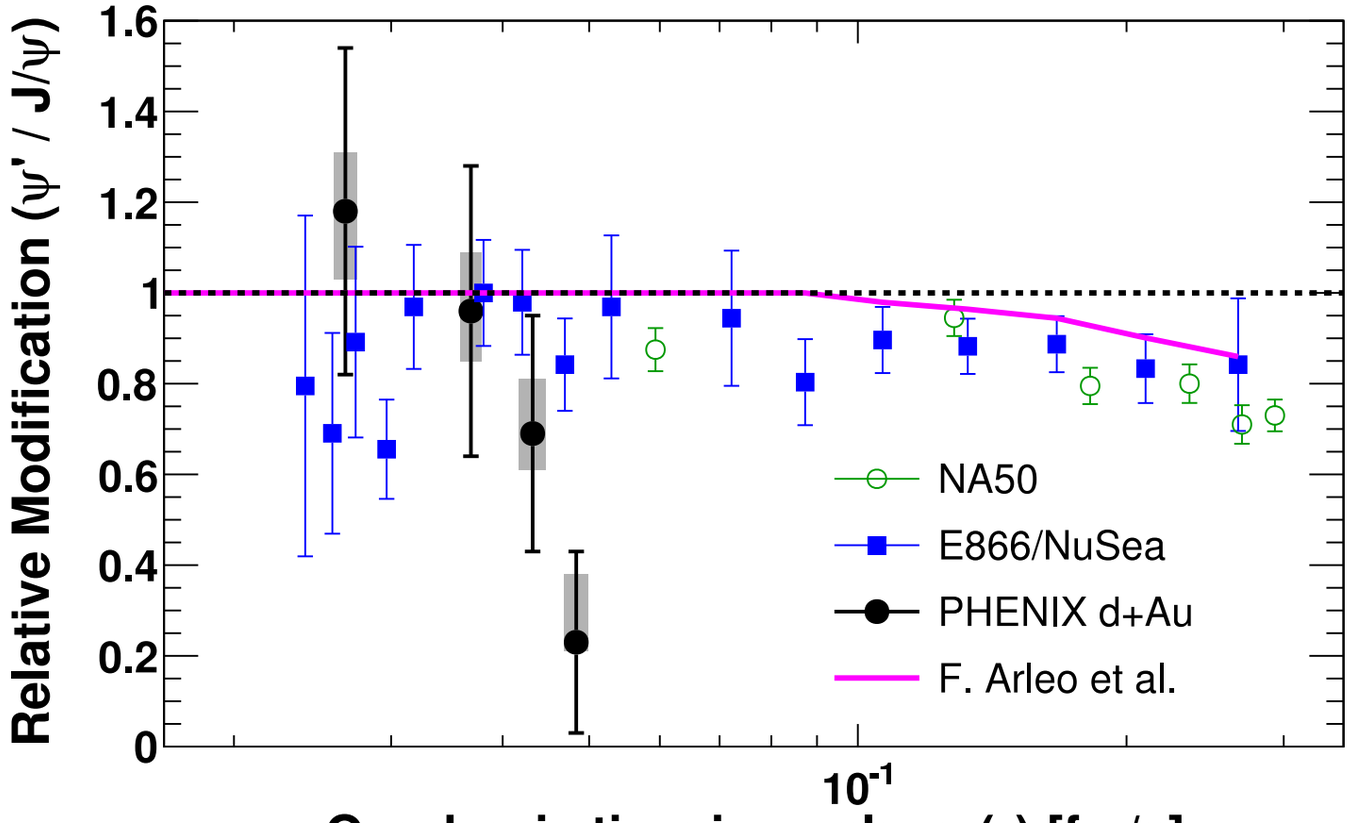


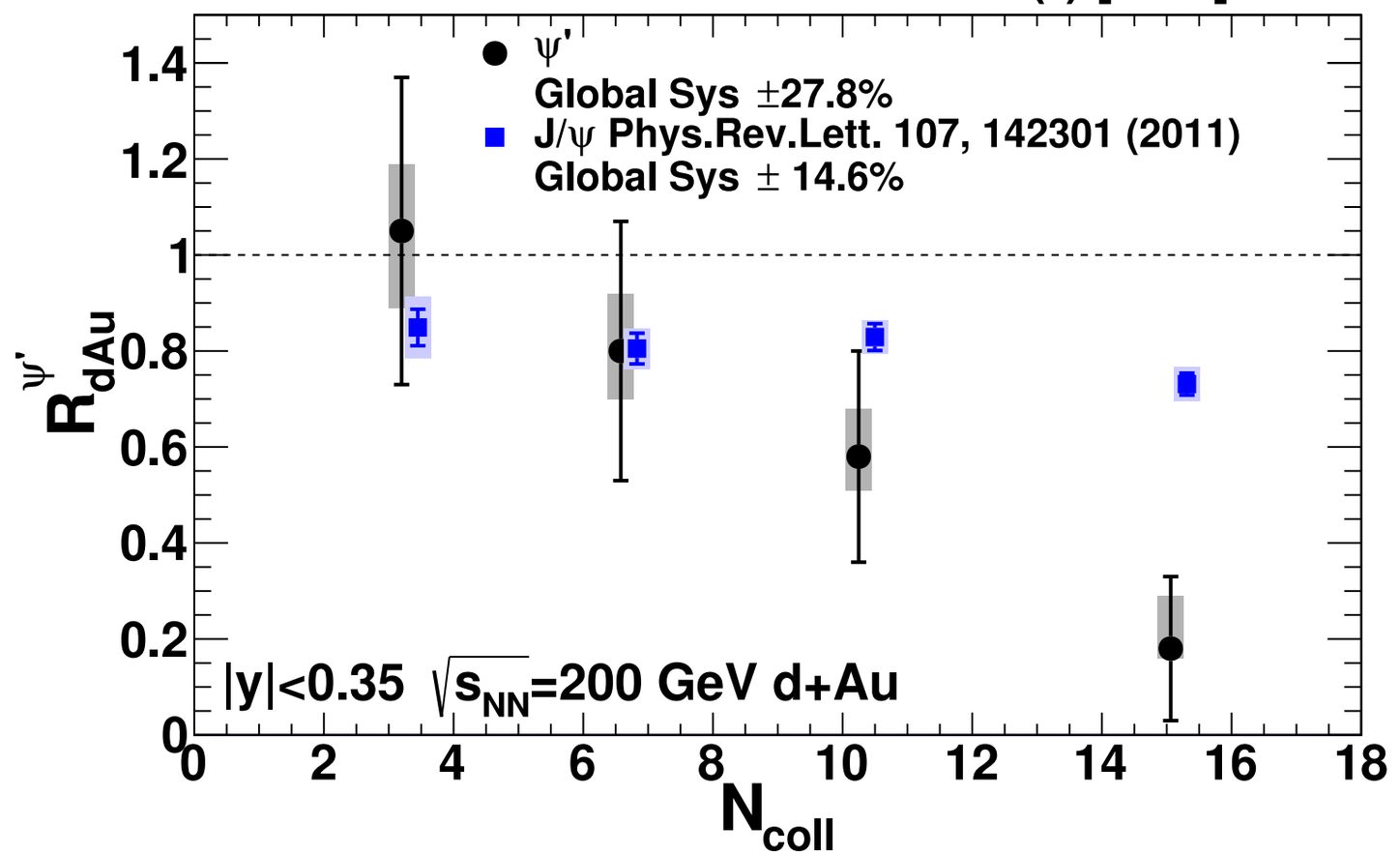




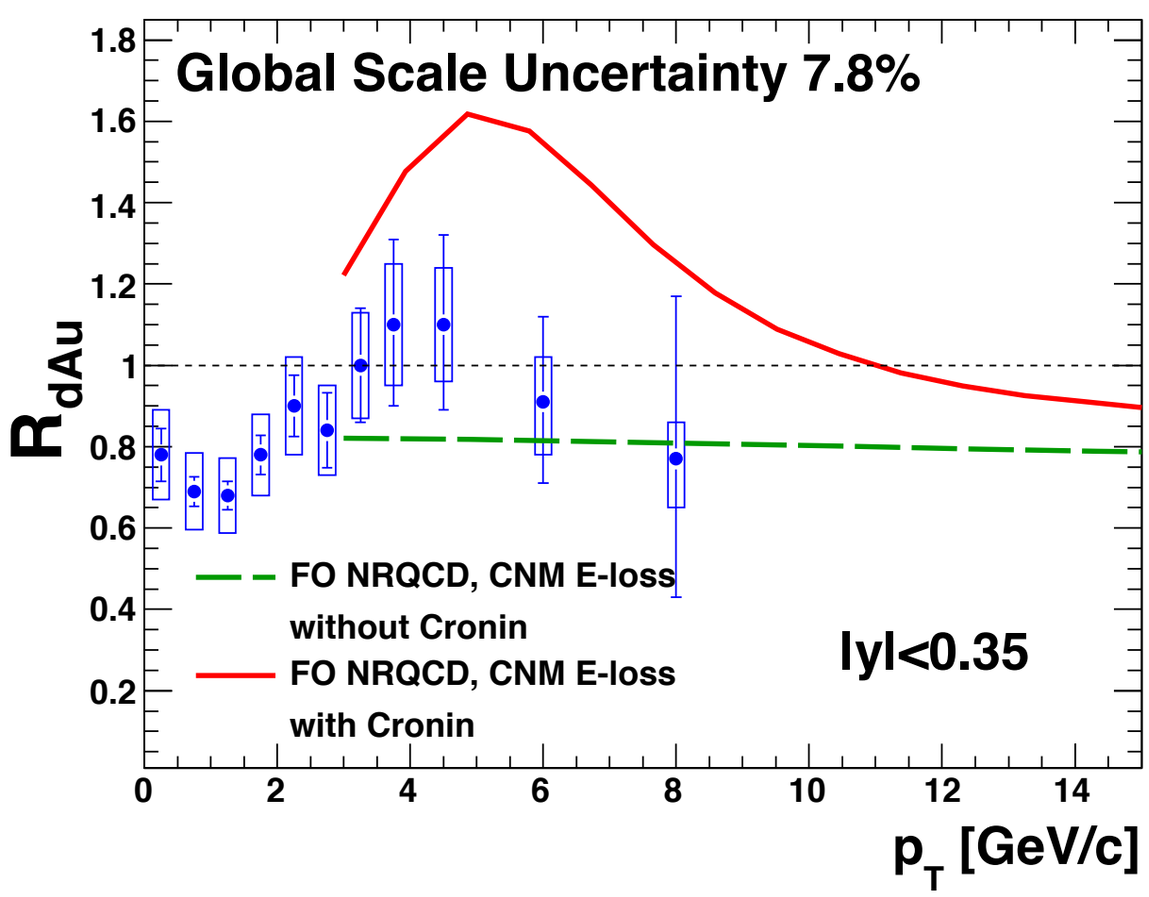


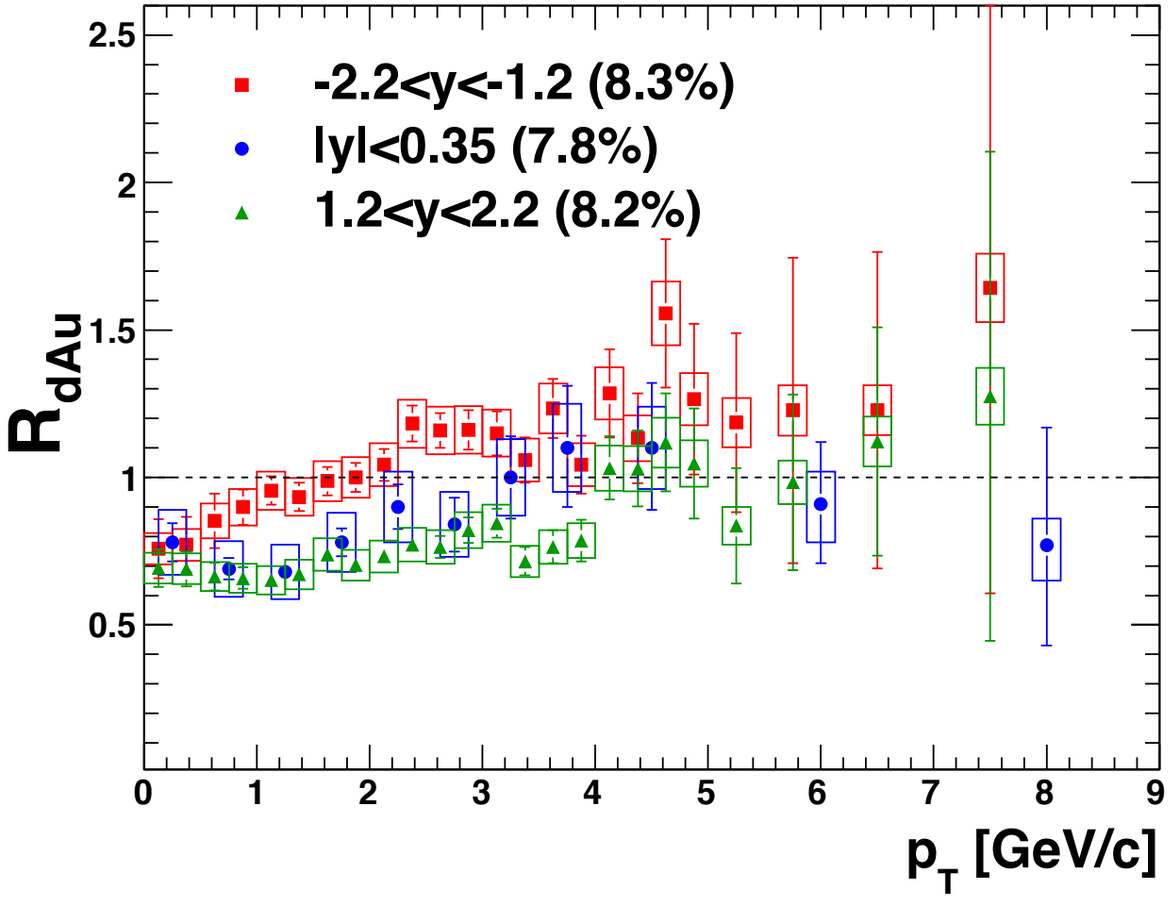
Phenix/RHIC J/ψ, ψ(2S)





Phenix/RHIC J/ψ





Definition of y*

$$y^* = -(y_{lab} + 0.465)$$ p+Pb run period A

$$y^* = y_{lab} - 0.465$$ p+Pb run period B

y* is defined as positive in the proton beam direction

Definition of pseudo-proper time

$$\tau = \frac{L_{xy} m_{\mu\mu}}{p_T^{\mu\mu}}$$

where L_{xy} is the projection of the decay length on the transverse plane