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

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Overview

Motivation

Analysis and Fit Method

J/ψ Analysis and Results

J/ψ and ψ(2S) Analysis and Results

Conclusions

Backup

Motivation

Study fundamental QCD processes in nuclear medium at TeV scale.

Cold Nuclear medium effects as Heavy Ion baseline

- Final state effects due to hot matter not expected in p-A collisions but suppression observed.
- Suppression of Quarkonia production is evidence of Quark Gluon Plasma (J/ψ Suppression by Quark-Gluon Plasma Formation - Matsui, T. et al. Phys.Lett. B178 (1986))

Numerous insights

- J/psi Production Mechanisms
- Saturation scale in QCD
- Medium-induced gluon radiation
- Shadowing and other modifications of the gluon PDFs
- Absorption of qqbar pairs
- Ion-direction observables vs. proton directions observables

Analysis Method

Reconstruct di-muon invariant mass 2.5 (2.6) GeV < m(μμ) < 3.5 (4.1)

Trigger

- L1 Trigger: Single MU0
- High-Level Trigger (no L1 seed): Full-scan Muon spectrometer 2 muons > 2 GeV

Two (almost) independent analyses

- May 2015 J/ψ arXiv: 1505.08141 [hep-ex]
- June 2015 J/ψ and ψ(2S) - ATLAS-CONF-2015-023

Measurement of prompt and non-prompt (b-quarks) fraction of J/ψ and ψ(2S)

Kinematic range: 8.5 GeV < p_T < 30 GeV, $|y^*|$ < 1.94 (1.5)

Perform weighted simultaneous 2D unbinned maximum likelihood fit

- Invariant di-muon mass and lifetime
- Event weights: Trigger and reconstruction efficiency; acceptance
- Parameterise signal and background, non-prompt fraction

Comparison of J/ψ Analyses

Common elements

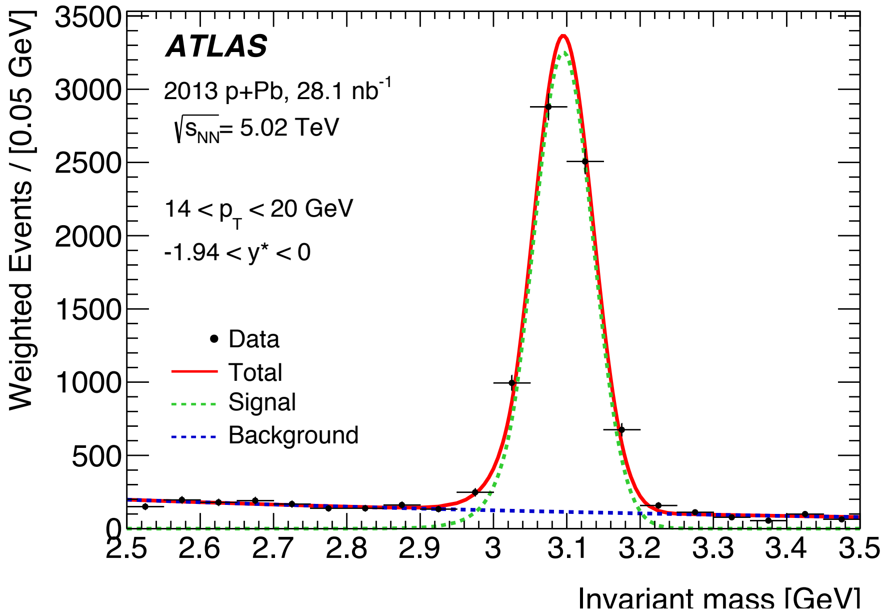
- Same pPb data sample, same triggers, same secondary di-muon vertex fitting
- Same muon selection criteria and reconstruction efficiency corrections
- Same version of J/ψ acceptance map

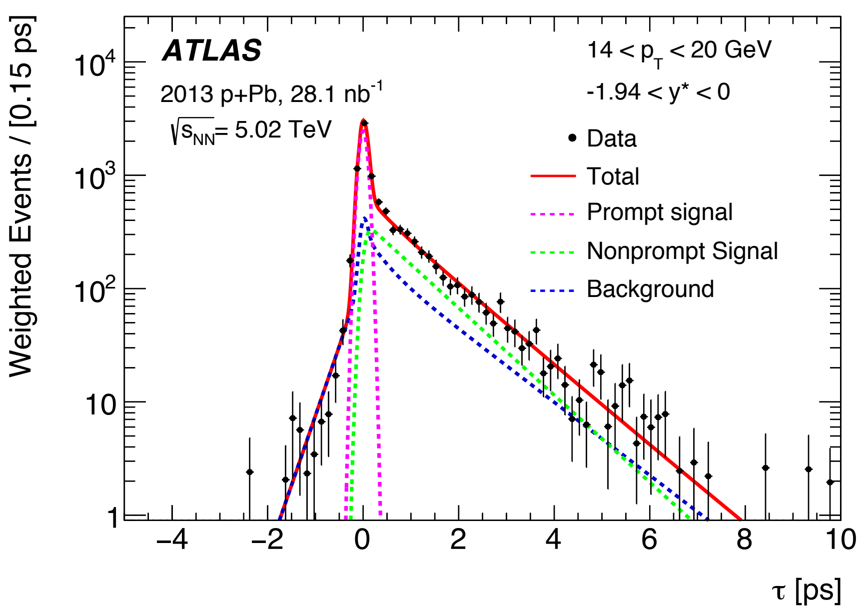
Elements that are different

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

Fit Method

Simulataneous 2D unbinned ML fit to dimuon invariant mass and pseudo proper time





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

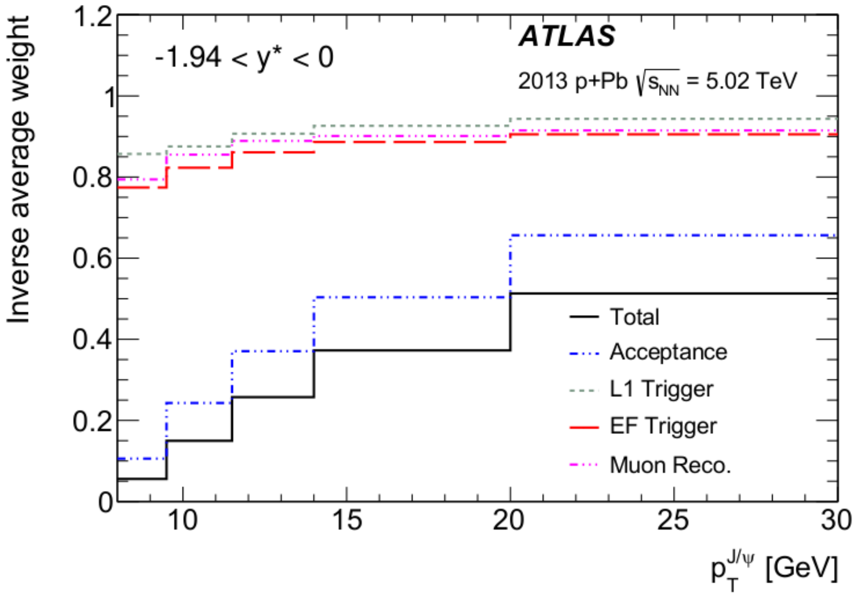
L_{xy} = projection of decay length on the transverse plane

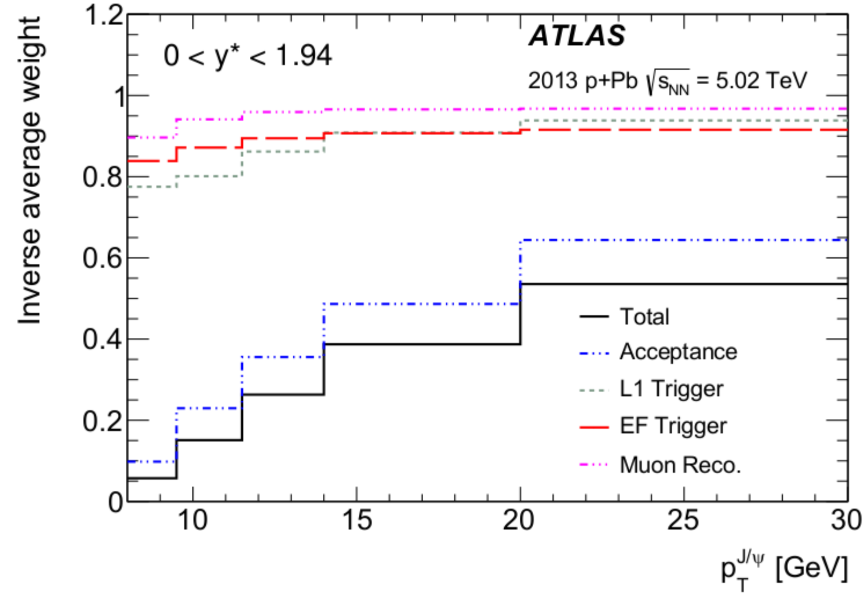
$$\mathrm{PDF}(m,\tau) = \sum_{i=1}^{7} \kappa_i f_i(m) \cdot h_i(\tau) \otimes g(\tau)$$

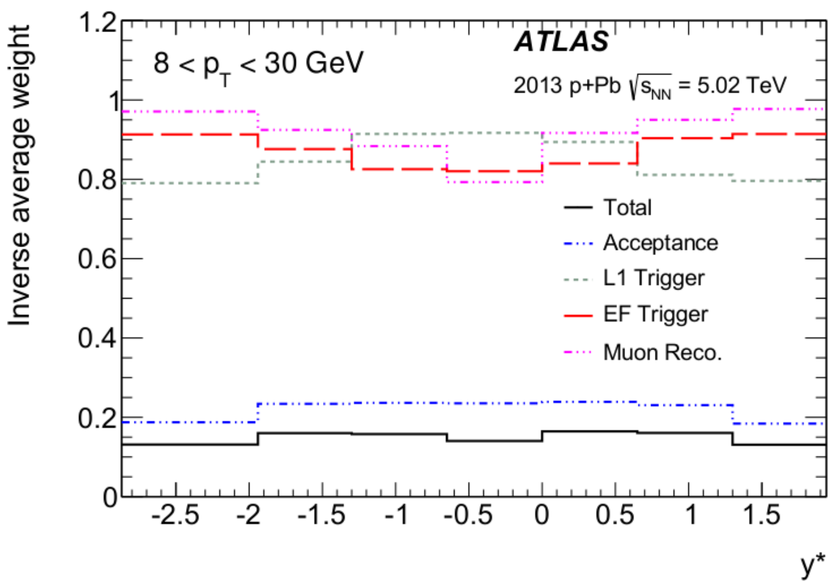
CB: Crystal ball function
G: Gaussian
E: Exponential
g: Double Gaussian
δ: Delta Function

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	$E_5(m)$	$E_6(\|\tau\|)$

Event Weights (Efficiency and Acceptance)







L1 Trigger: Measured with respect to Minimum Bias events

EF Trigger: Measured from pPb events using J/ψ Tag & Probe method (unbiased trigger efficiency measurement)

Muon Reconstruction: Same as proton-proton efficiency correction for 8 TeV

Acceptance: MC simulation for geometric acceptance ($p_T^{\mu} > 4$ GeV and $|\eta_{\mu}| < 2.4$)

J/ψ Analysis pPb 5.02 teV

May 2015: arXiv:1505.08141 [hep-ex]

R_{FB} — Asymmetry of J/psi production between the proton beam direction and lead beam direction

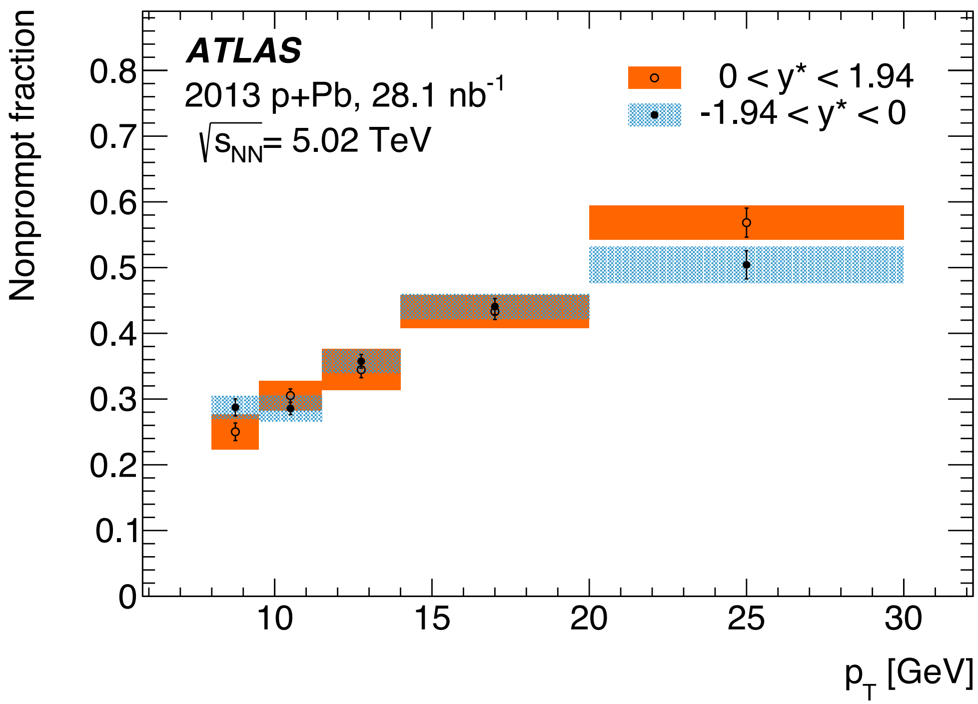
- R_{FB} vs. y^* and p_T, prompt and non-prompt

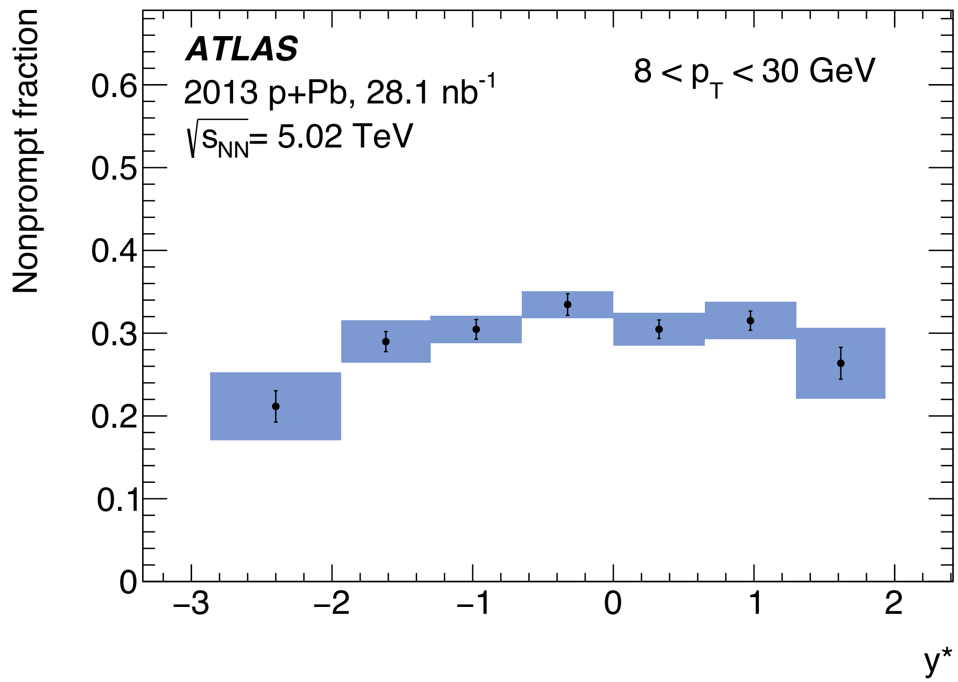
$d^2\sigma/dy^*dp_T$, prompt and non-prompt

Non-prompt fraction vs y^* and p_T

Comparison with FONLL calculations: 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].

Non-Prompt Fraction for J/ψ in p+Pb vs. p_T and y^*





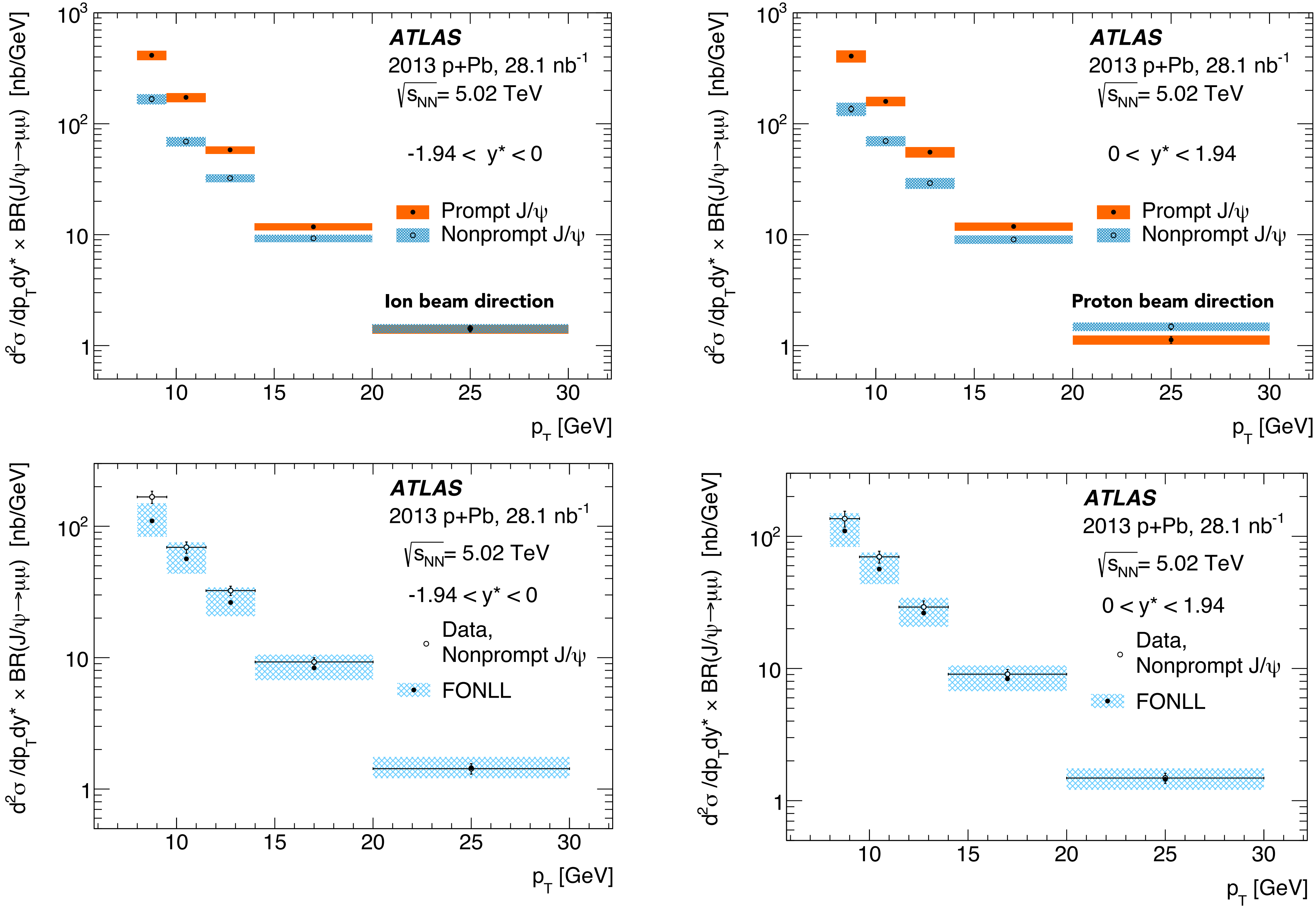
Strong kinematic dependence on p_T

No significant y^* dependence (possible hint of larger b-quark reduction, ion beam direction)

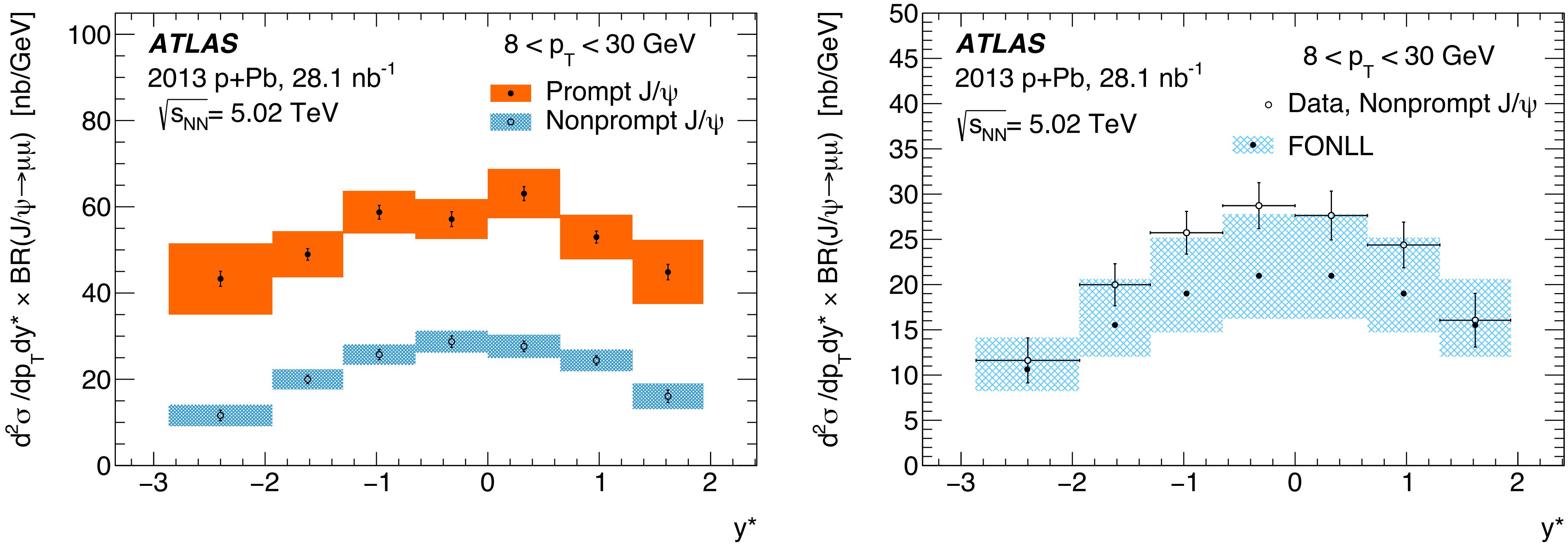
Similar trends observed in pp collisions

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

J/ψ Differential Production Cross Section vs. p_T in p+Pb

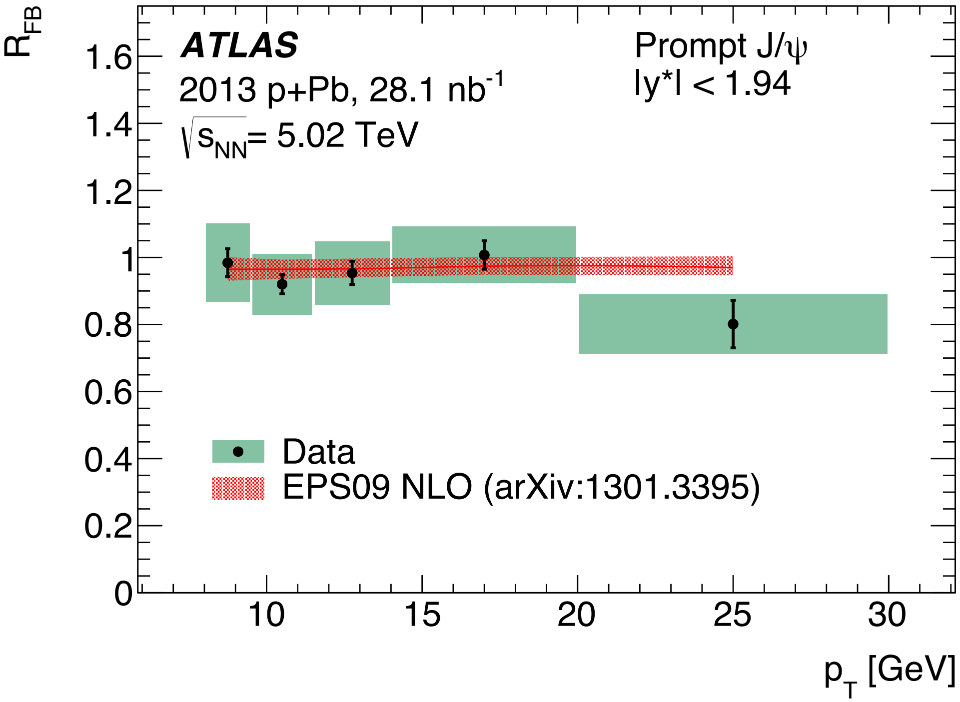


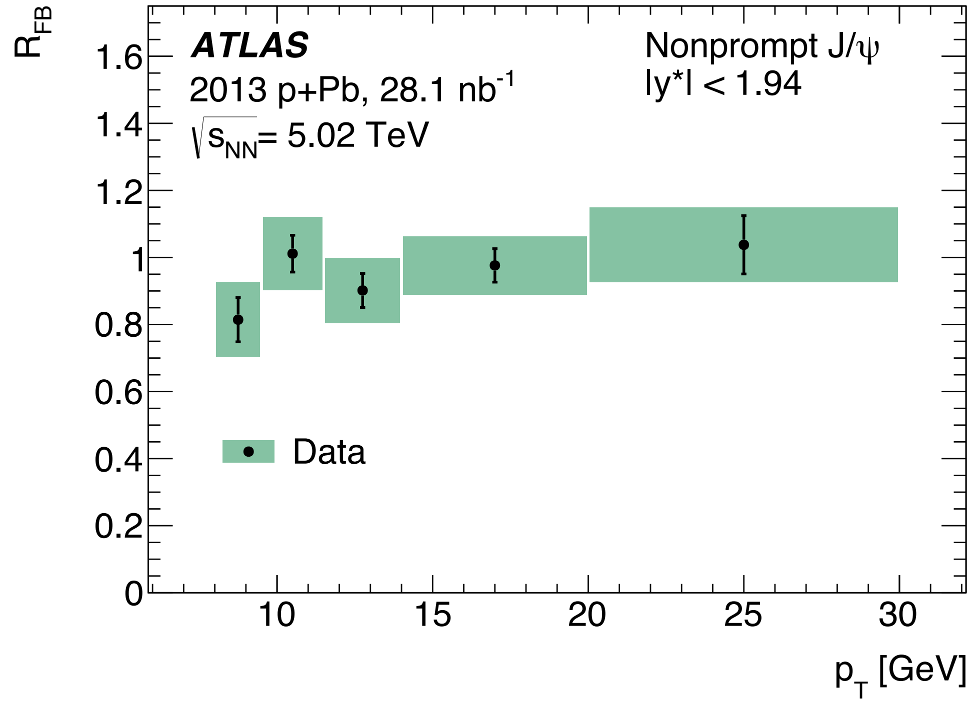
Differential Production Cross-section for J/ψ in pPb vs. y*



Larger variation for J/ψ from b

R_{FB} for Prompt and Non-prompt J/ψ vs p_T

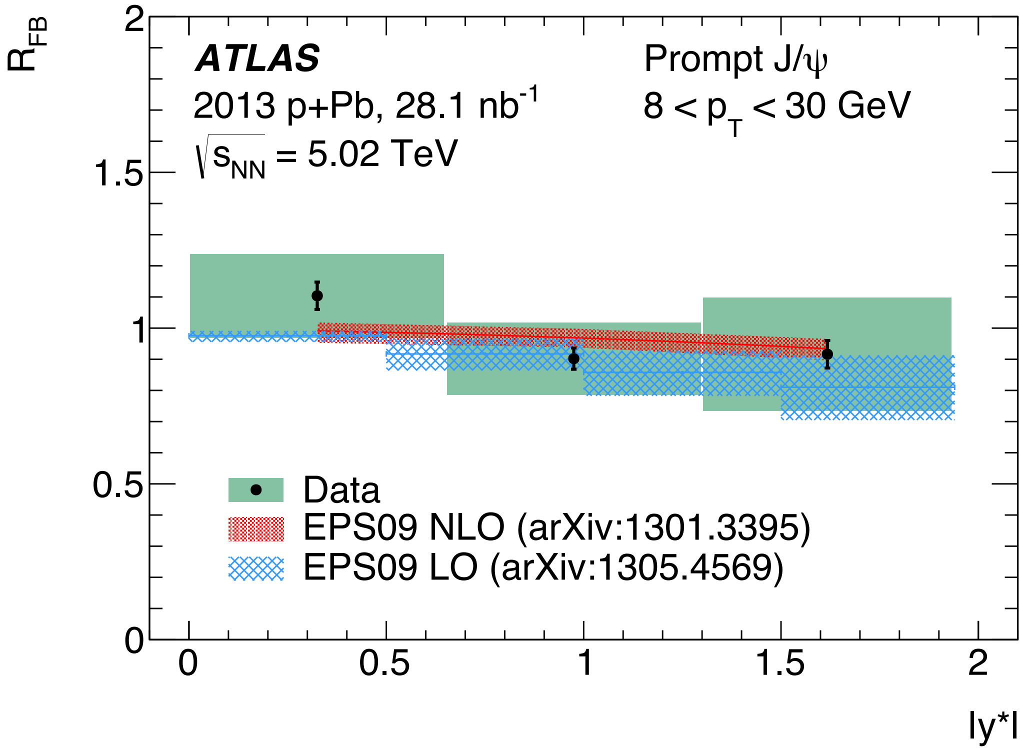


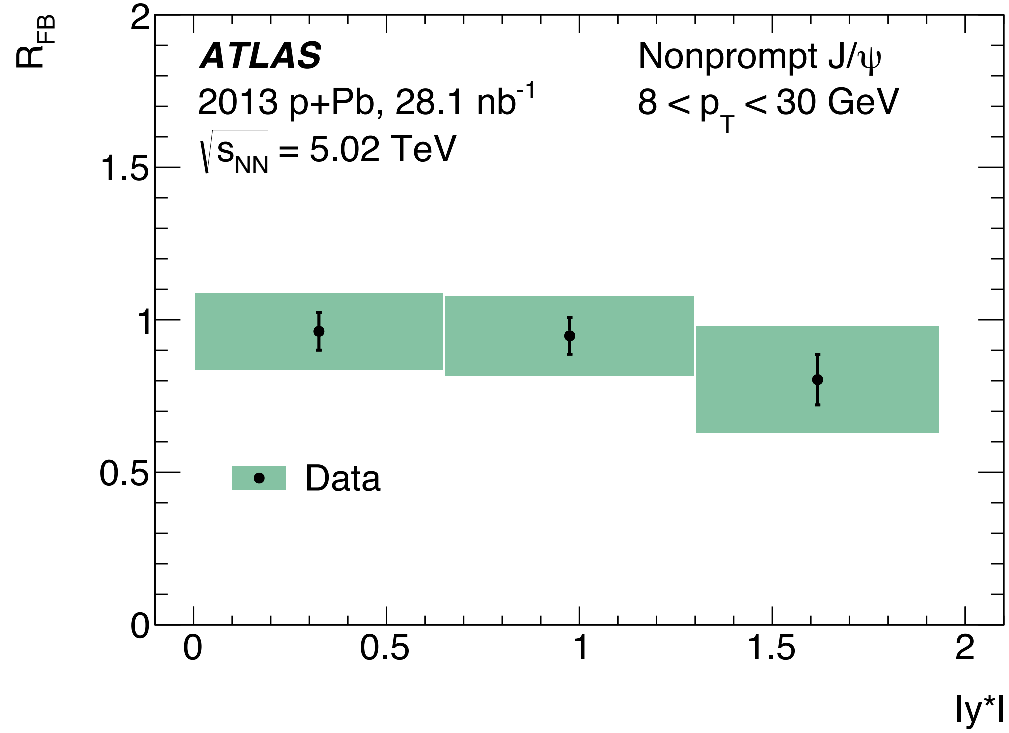


No significant p_T dependence observed.
In agreement with theoretical predications which include shadowing effects.

ALICE: RFB~0.6, y*~3-3.5, pT<15 GeV, inclusive J/ψ Indicates strong kinematic dependence
LHCb results: ~0.9, non-prompt J/ψ, pT<15 GeV

R_{FB} for Prompt and Non-prompt J/ψ vs y^*





No significant y^* dependence observed in the kinematic range 8 < p_T < 30 GeV
Complementary results to LHCb and ALICE which do observe R_{FB} below unity and strong kinematic dependence at low p_T
Suggests a strong kinematic dependence of the cold medium effects on both charmonium and b-quark production.

LHCb results: ~0.75 for y=2.8 for prompt J/ψ, pT<15 GeV
LHCb results: ~0.9 for |y|=2.8 for non-prompt J/ψ, pT<15 GeV

J/ψ and ψ(2S) Analysis pPb 5.02 TeV and pp 2.76 TeV

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

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)

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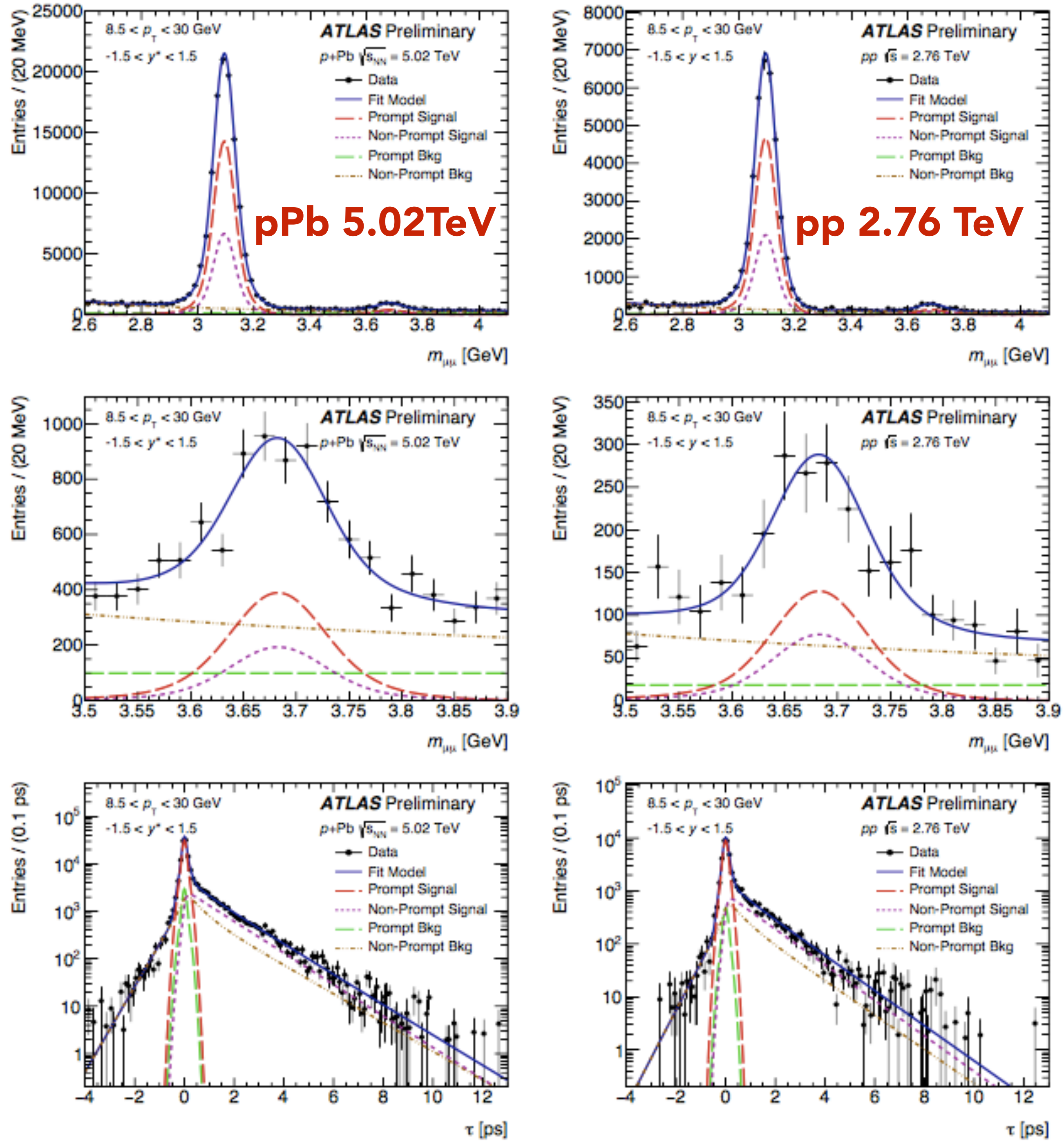
Fit Results

Simultaneous fit in invariant mass and pseudo proper time

Fit model similar to J/ψ fit but includes both J/ψ and ψ(2S)



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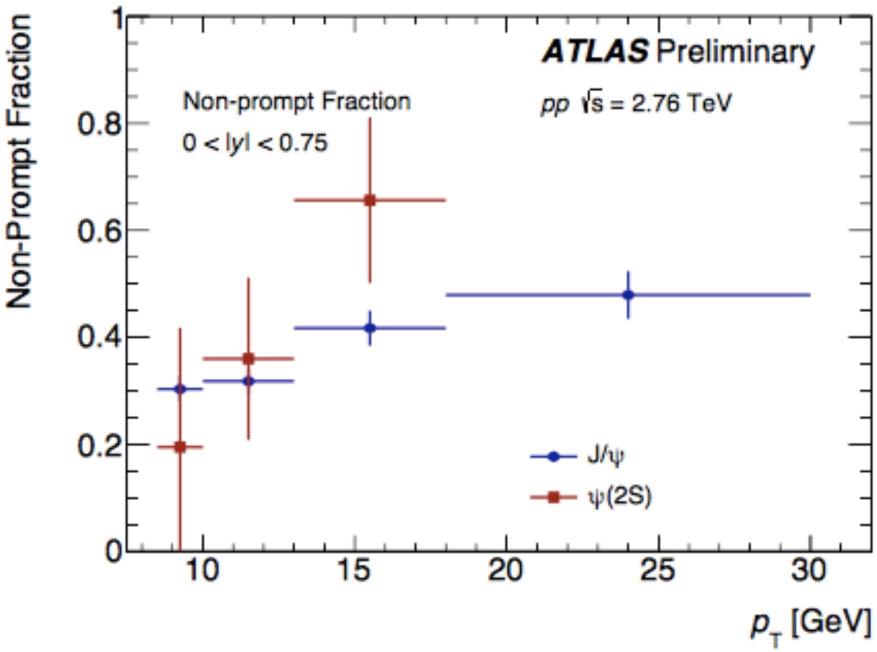
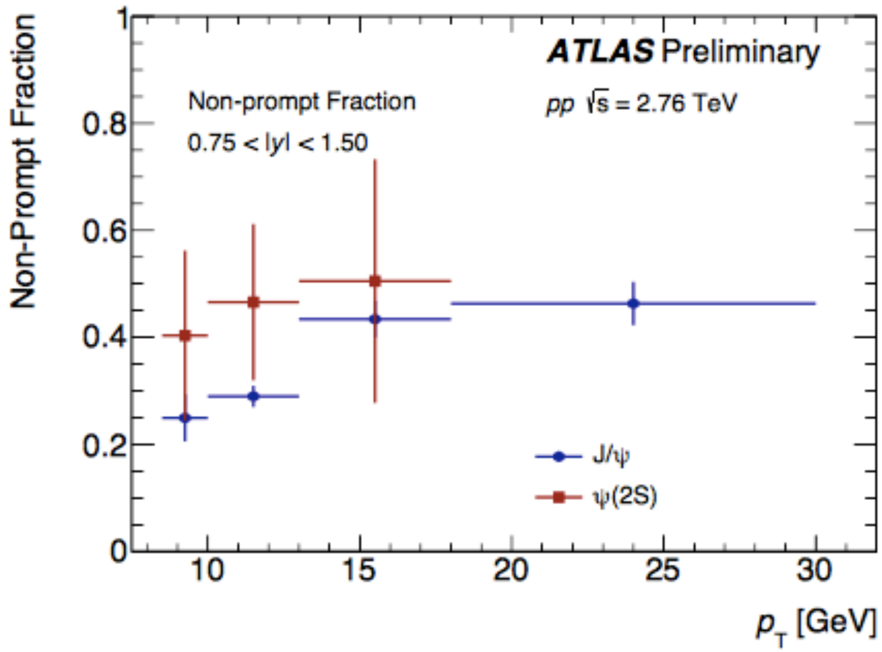
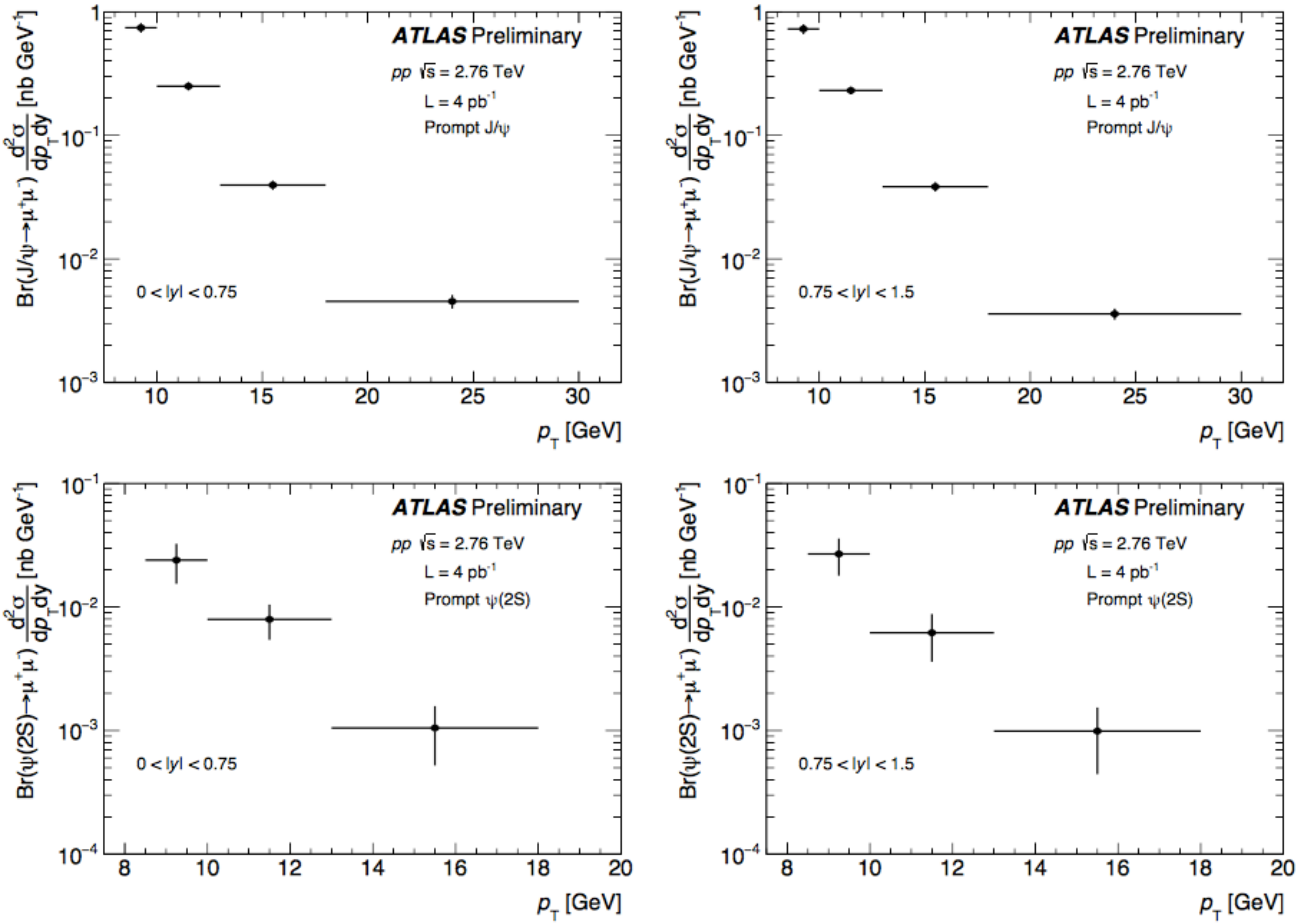
Non-prompt fraction of ψ(2S) and J/ψ in 2.76 TeV pp vs. p_T



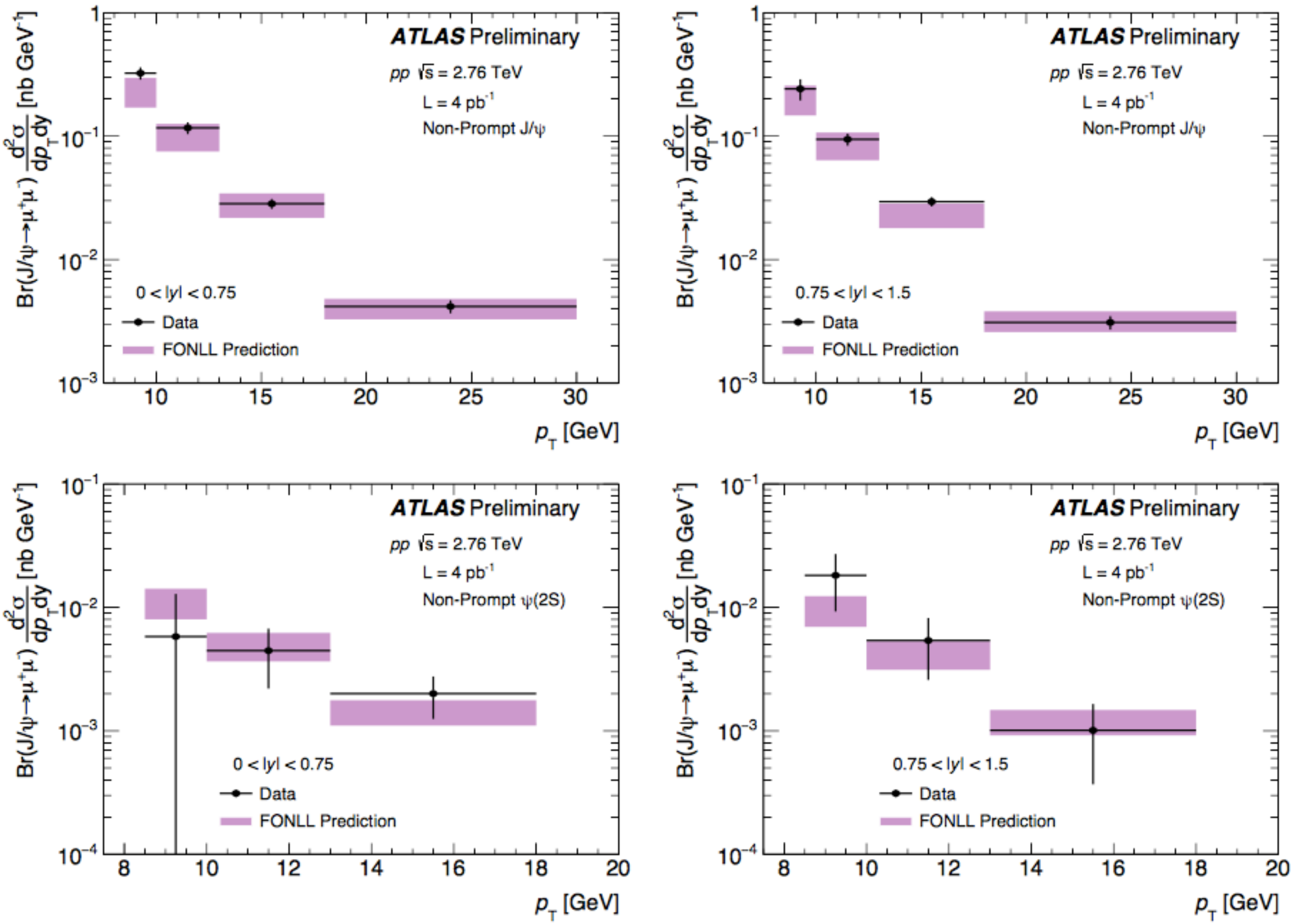


$$nonprompt\ fraction(p_T, y*) = \frac{N^{nonprompt\ \ J/\psi}(p_T, y*)}{N^{total\ \ J/\psi}(p_T, y*)}$$

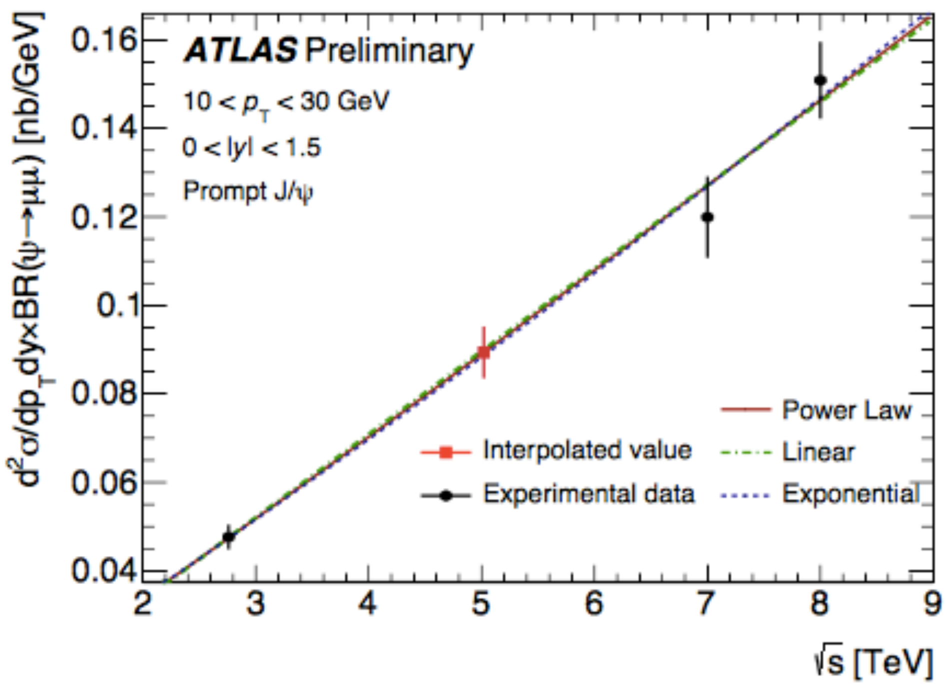
Differential Production cross-section Prompt ψ(2S) and J/ψ in 2.76 TeV pp

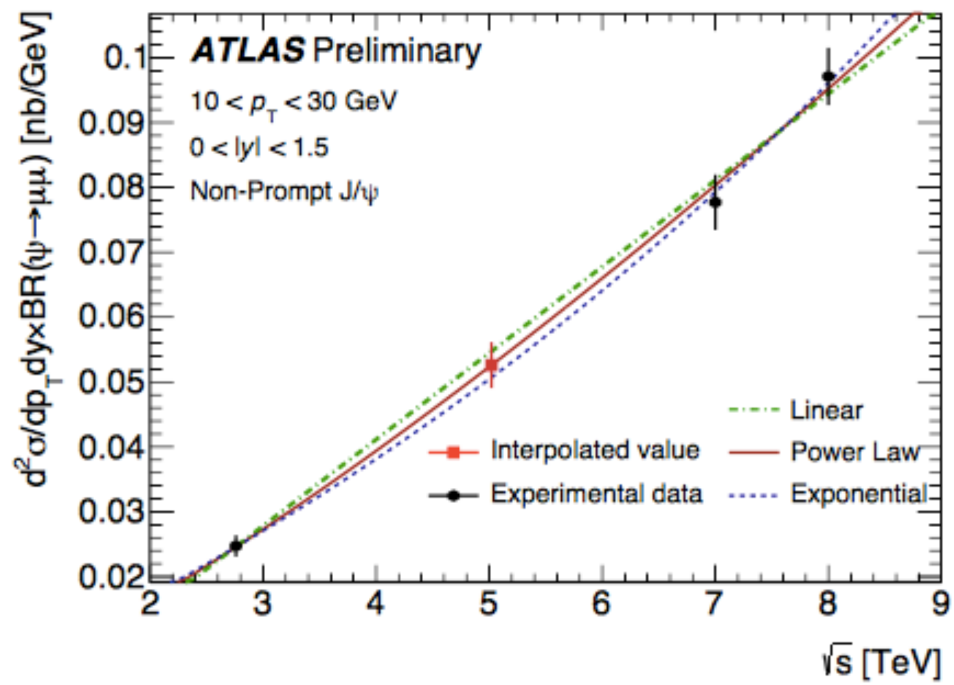


Differential Production cross-section Non-Prompt ψ(2S) and J/ψ in 2.76 TeV pp



Interpolation of pp Cross-Section to 5.02 TeV (R_{pPb})





Interpolation between 2.76 TeV and at 7 TeV and 8 TeV to determine pp cross-section at 5.02 TeV
Interpolation used three functional forms to evaluate systematic uncertainty

R_{pPb} vs. p_T and y^*

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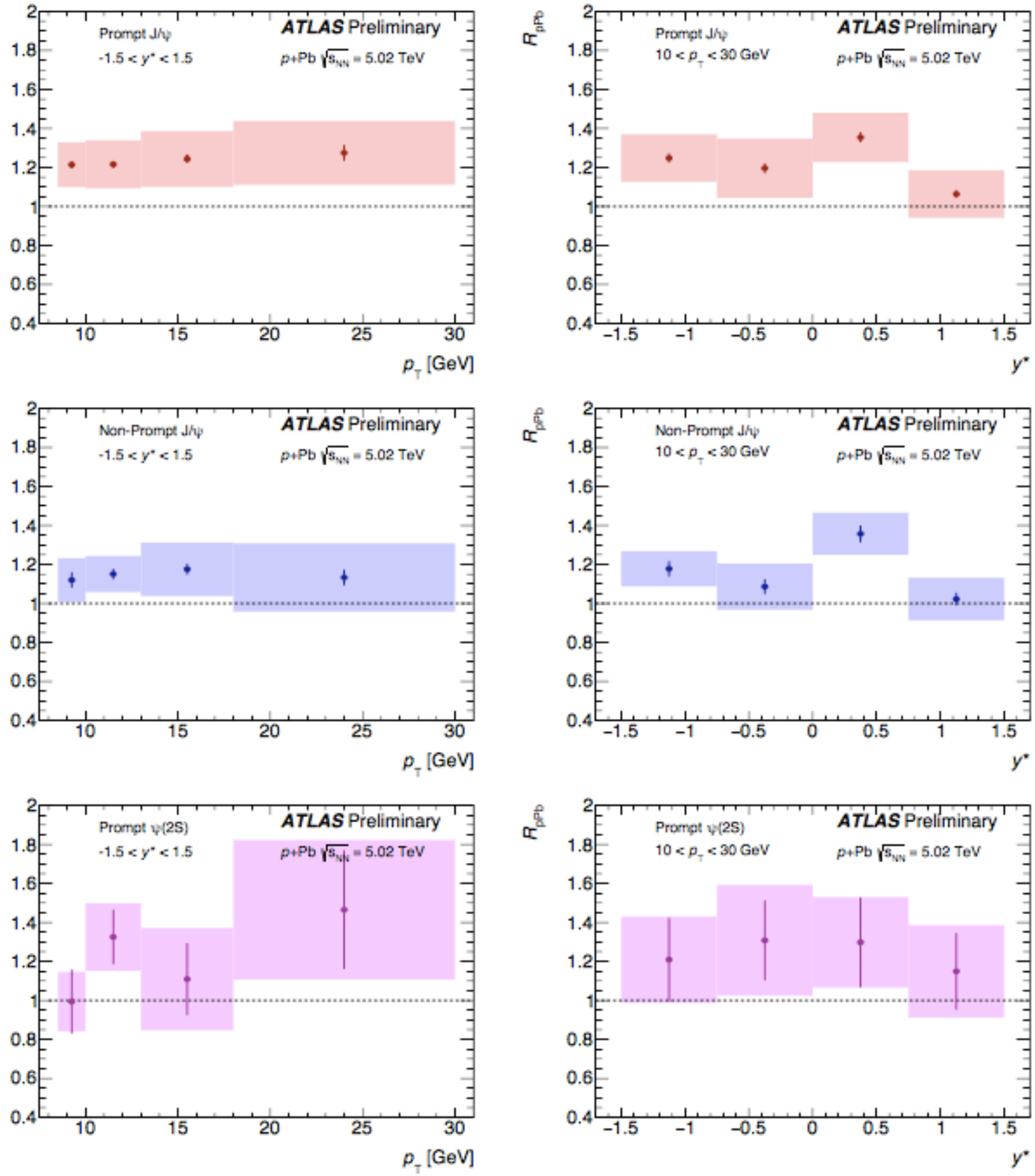
$$R_{pPb} = \frac{1}{A} \cdot \frac{\frac{d^2\sigma_{p+Pb}}{dy^* dp_T}}{\frac{d^2\sigma_{p+p}}{dy^* dp_T}}$$

Prompt J/ψ

Non-Prompt J/ψ

Prompt ψ(2S)



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R_{pPb} vs. centrality

Prompt J/ψ

$R_{pPb} > 1$

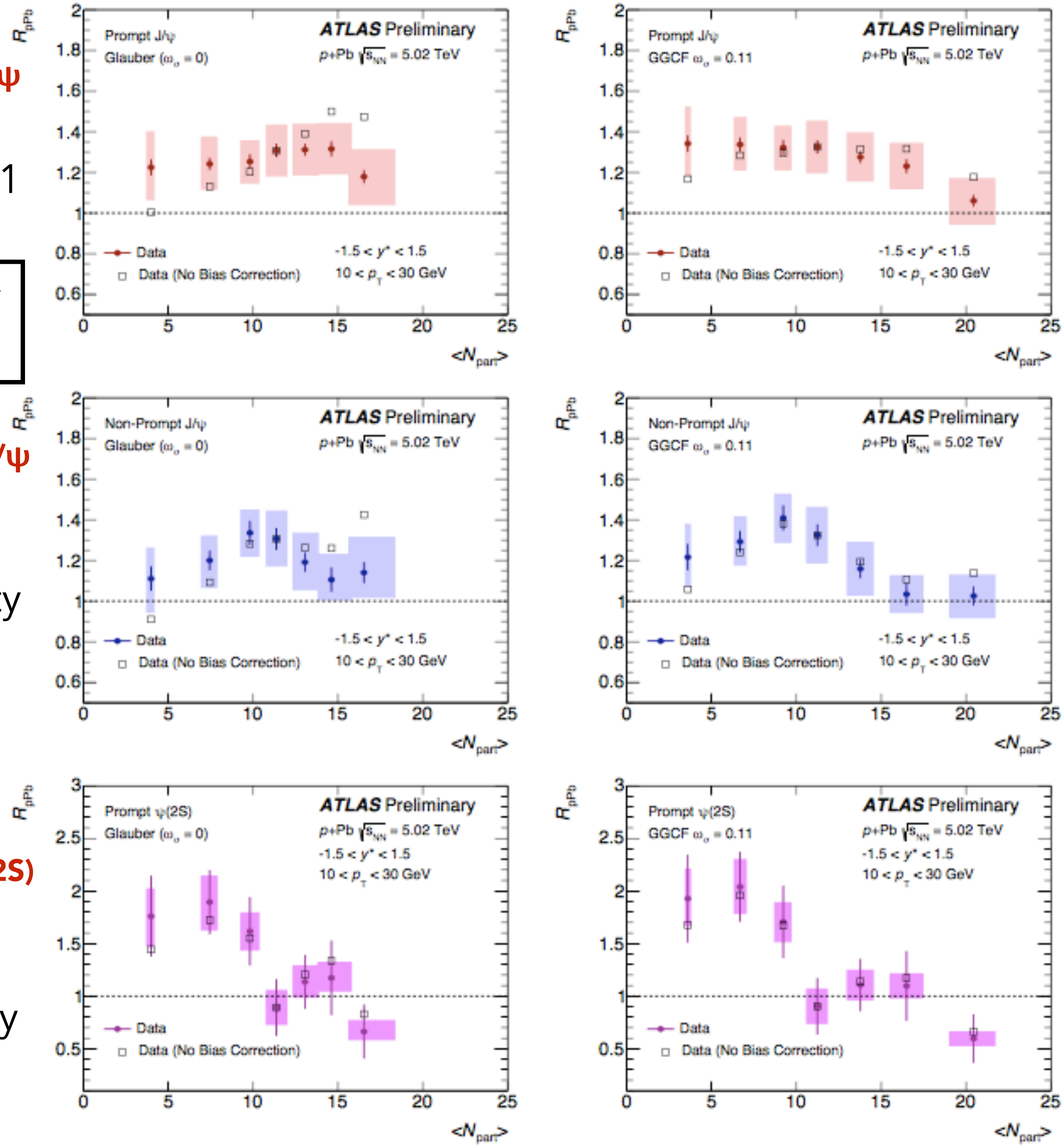
J/ψ independent of centrality
Decreasing trend for the ψ

Non-Prompt J/ψ

$R_{pPb} > 1$
mid-centrality

Prompt ψ(2S)

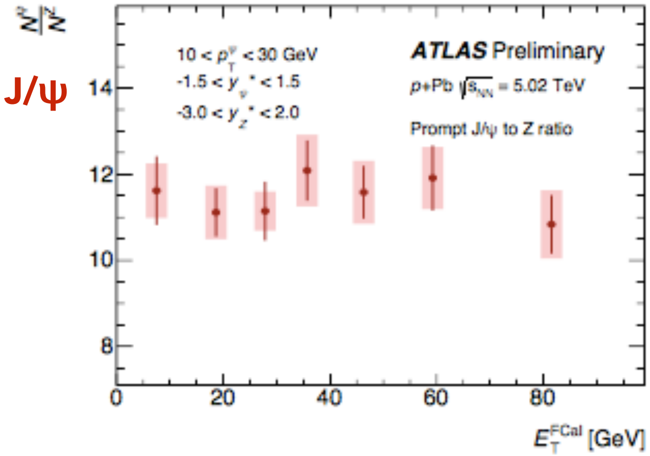
$R_{pPb} > 1$
low-centrality



N_ψ/N_Z vs. FCal E_T

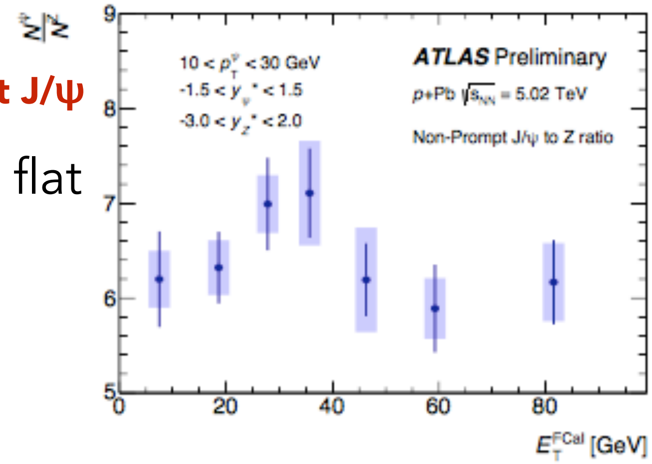
- Number of Z bosons scale with number of nucleon-nucleon interactions.
- Ratio of yields provide a test of production scaling independent of geometric models
- Check of the centrality dependence by normalising to the number of Z bosons
  - ➡ N_ψ/N_Z vs. FCal E_T

Prompt J/ψ



Non-Prompt J/ψ

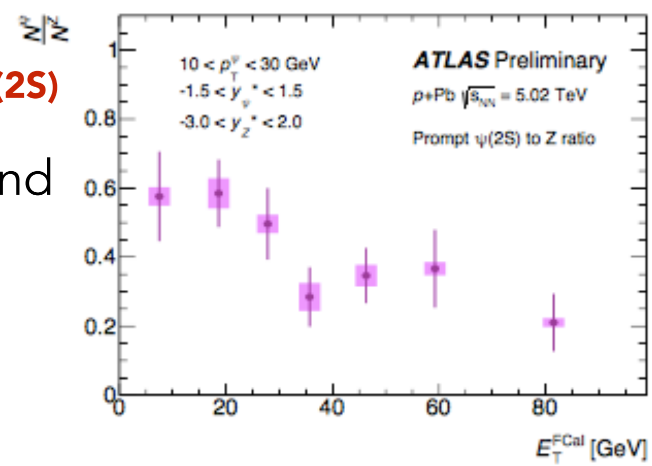
J/ψ appears to be flat



J/ψ to Z ratio independent of event activity, nuclear modification also independent of centrality.

Prompt ψ(2S)

ψ(2S) has a decreasing trend



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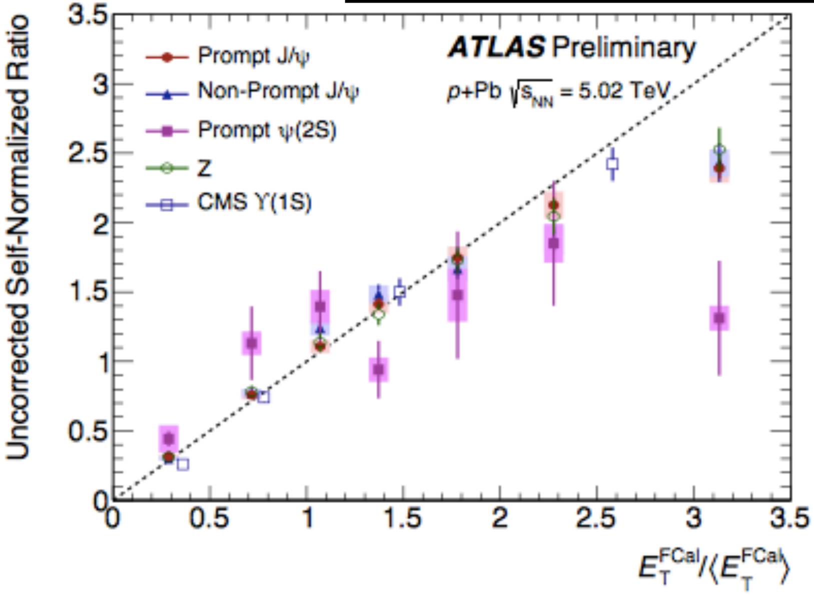
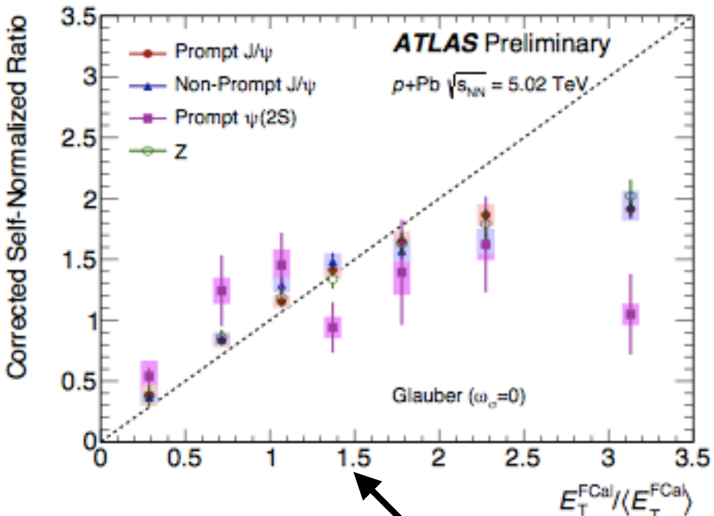
Self-normalising ratios

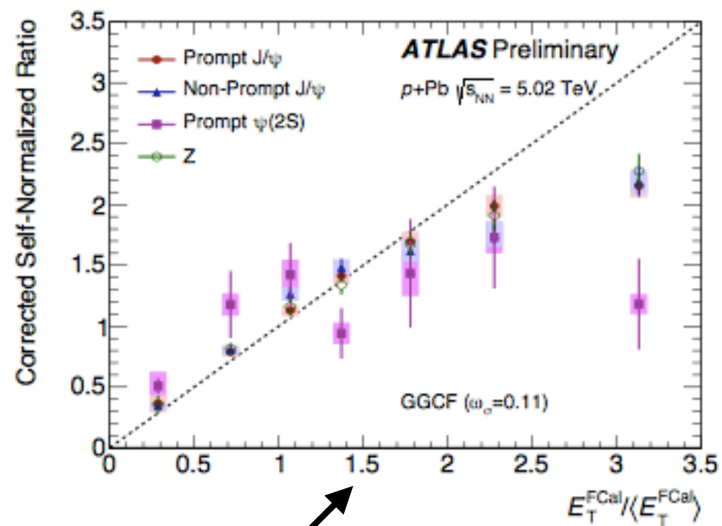
Correlation of charmonium production with size of underlying event activity.
Deviation from linear scaling enhanced when centrality bias corrections applied.



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

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





Centrality bias corrections with standard Glauber model and GGCF

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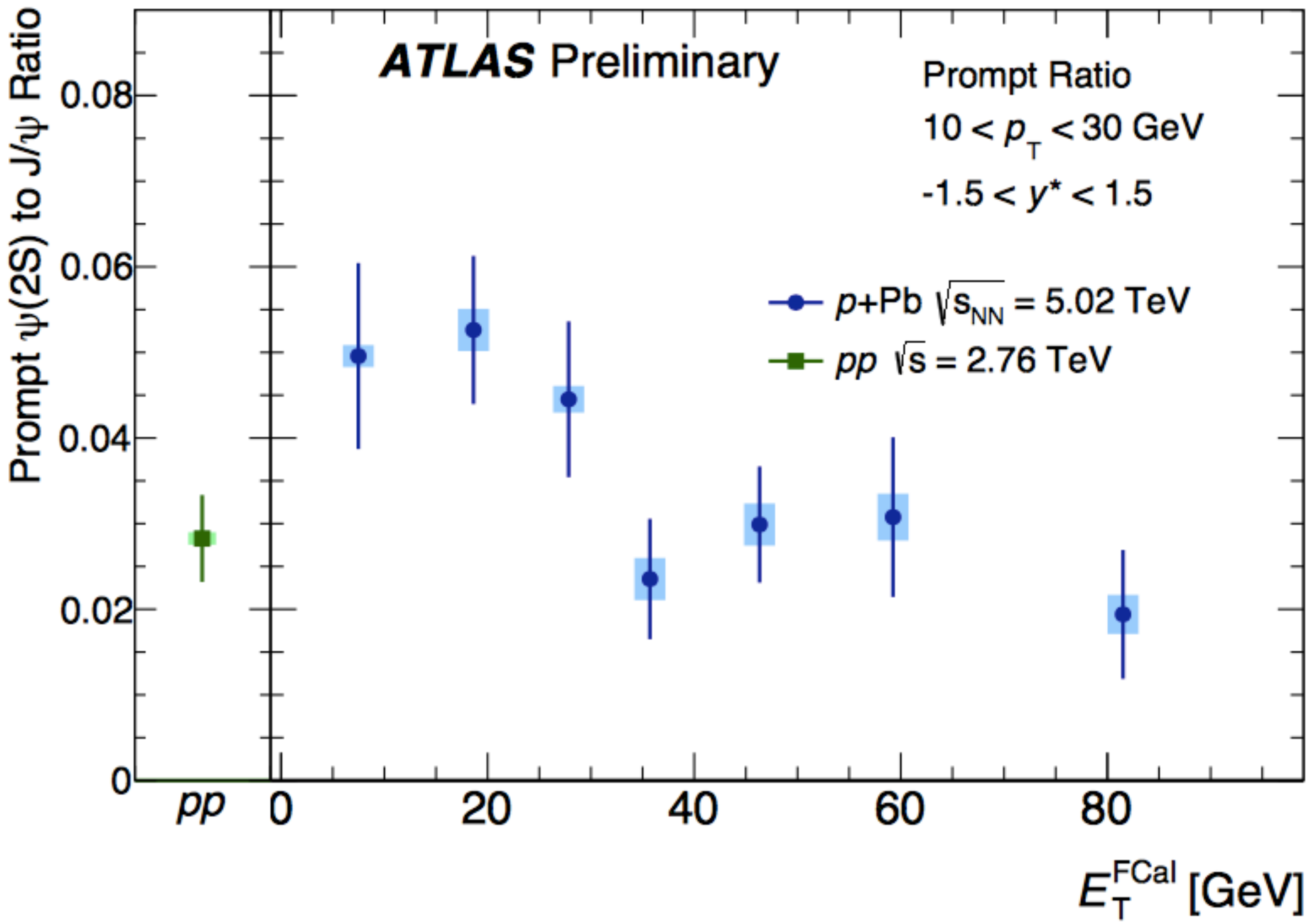
Suppression of ψ(2S) to J/ψ vs FCal E_T

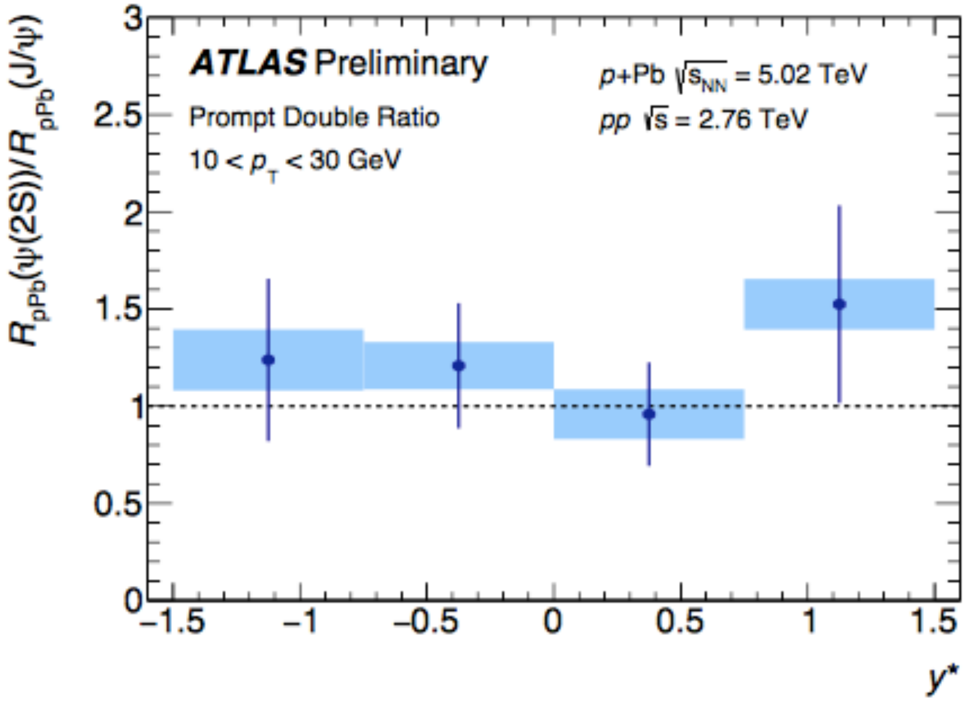


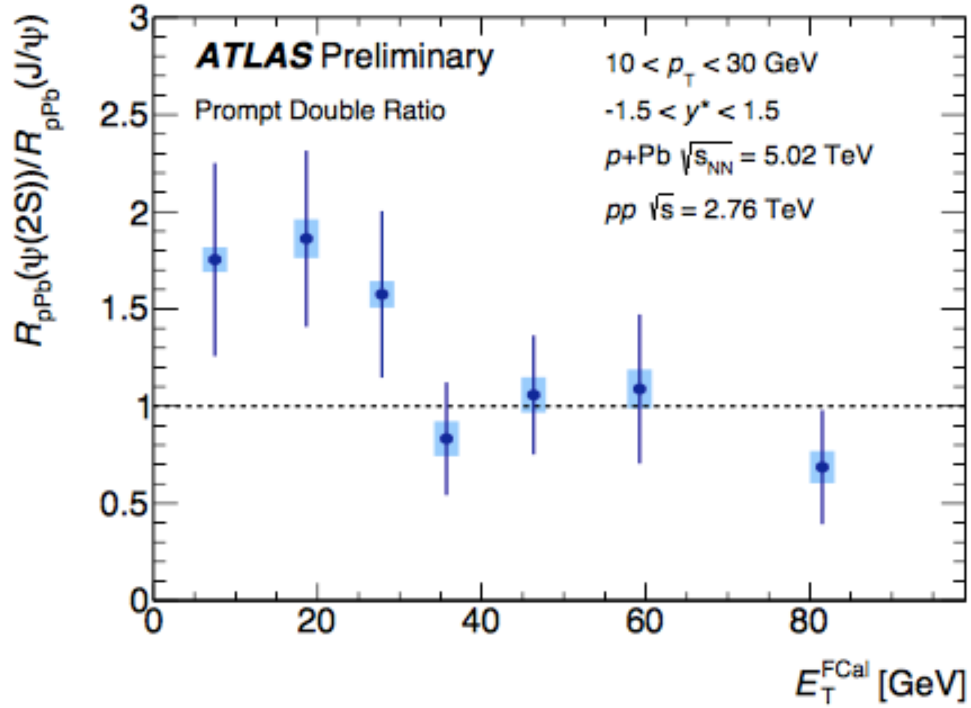
Evidence for centrality dependence

Decreasing trend with centrality; magnitude > ALICE

Prompt double-ratio vs. FCal E_T and y^*

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





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

Conclusions

First precision measurement of quarkonia production with ion beams in ATLAS

- Differential production cross sections
- R_{FB} for J/ψ
- R_{pPb} for J/ψ and ψ(2S) via pp interpolation
- non-prompt fraction
- single and double ratios for J/ψ and ψ(2S)

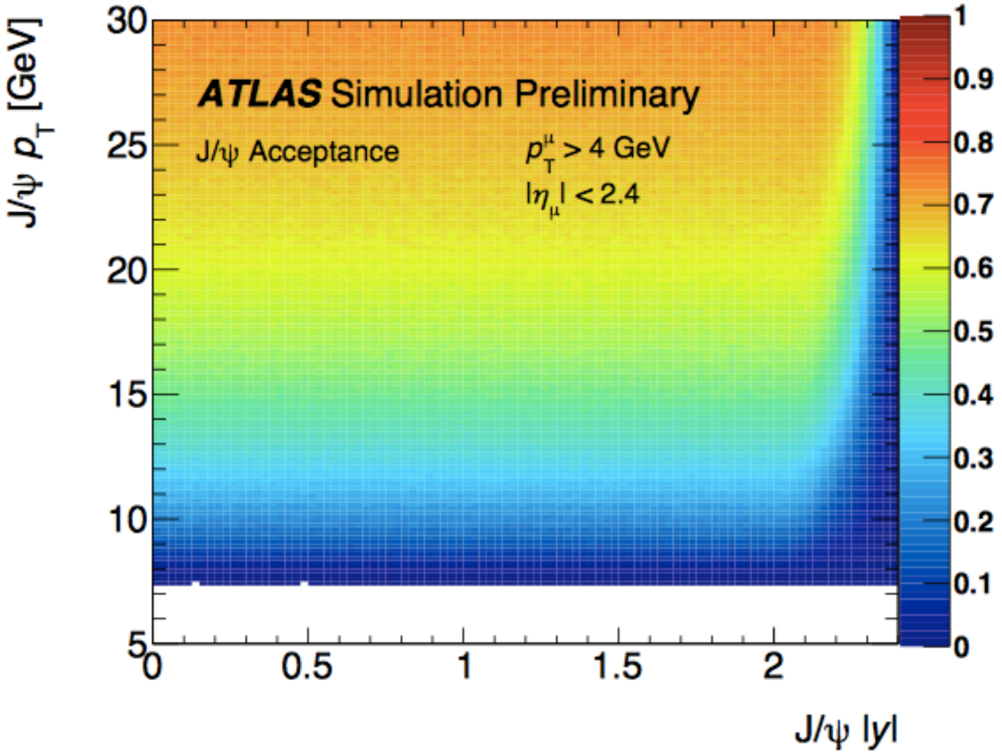
Separation: prompt and non-prompt (b) components

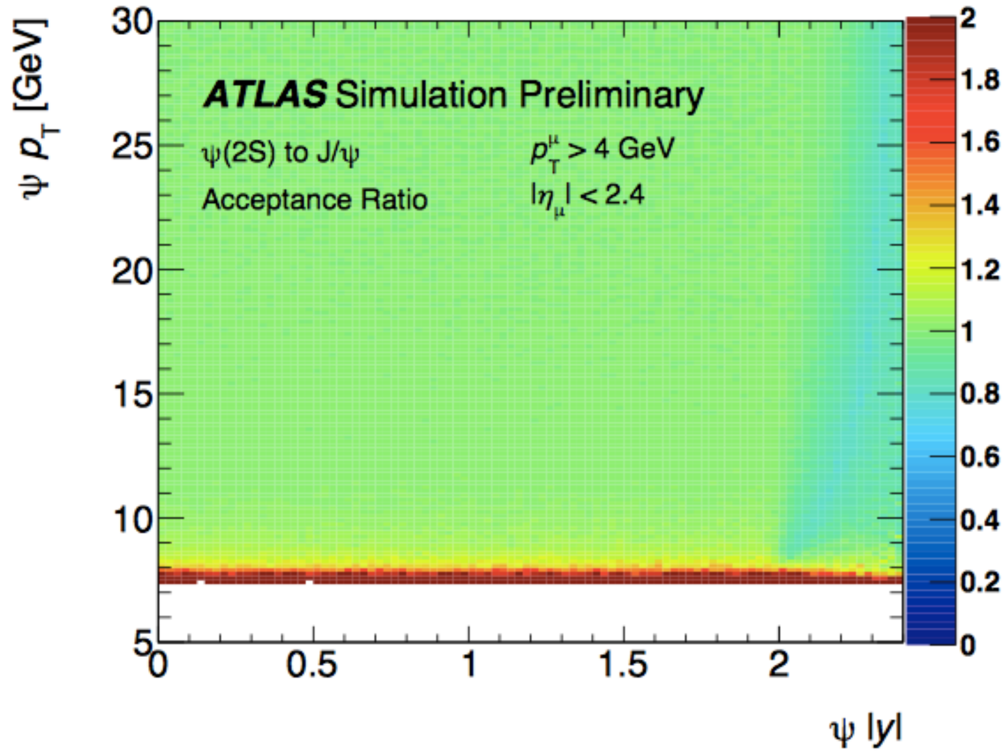
Nuclear medium effects seen in a number of observables and hints in others - most prominently:

- 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

Backup

Acceptance


ATLAS Simulation Preliminary
J/ψ Acceptance
$p_T^\mu > 4$ GeV
$|\eta_\mu| < 2.4$
J/ψ p_T [GeV]
J/ψ |y|
30
25
20
15
10
5
0
0.5
1
1.5
2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0


ATLAS Simulation Preliminary
ψ(2S) to J/ψ
Acceptance Ratio
$p_T^\mu > 4$ GeV
$|\eta_\mu| < 2.4$
ψ p_T [GeV]
ψ |y|
30
25
20
15
10
5
0
0.5
1
1.5
2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0

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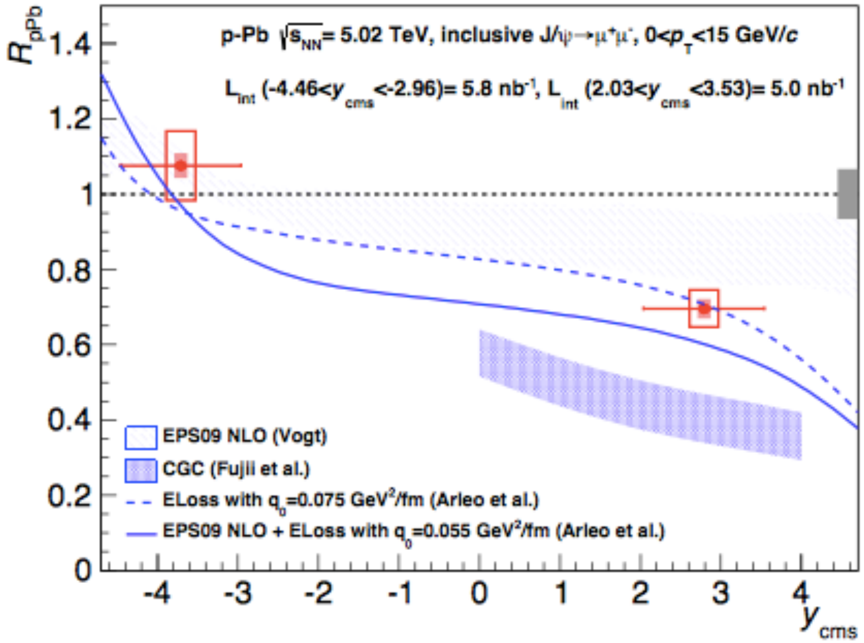
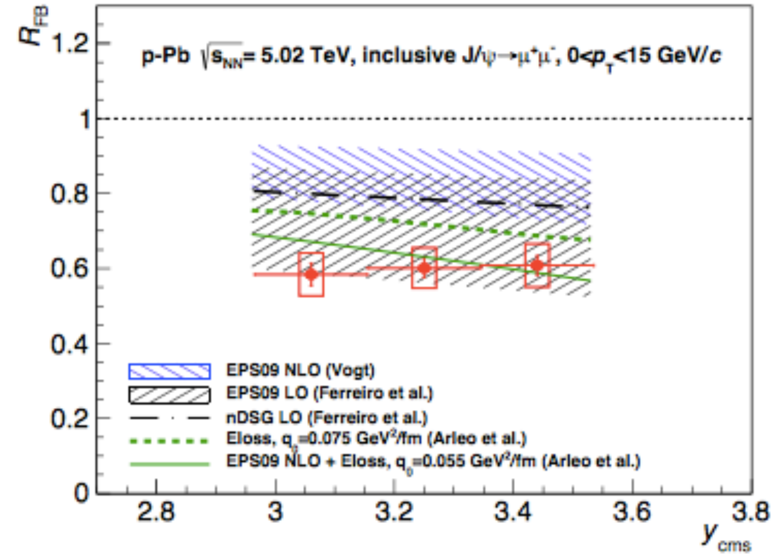
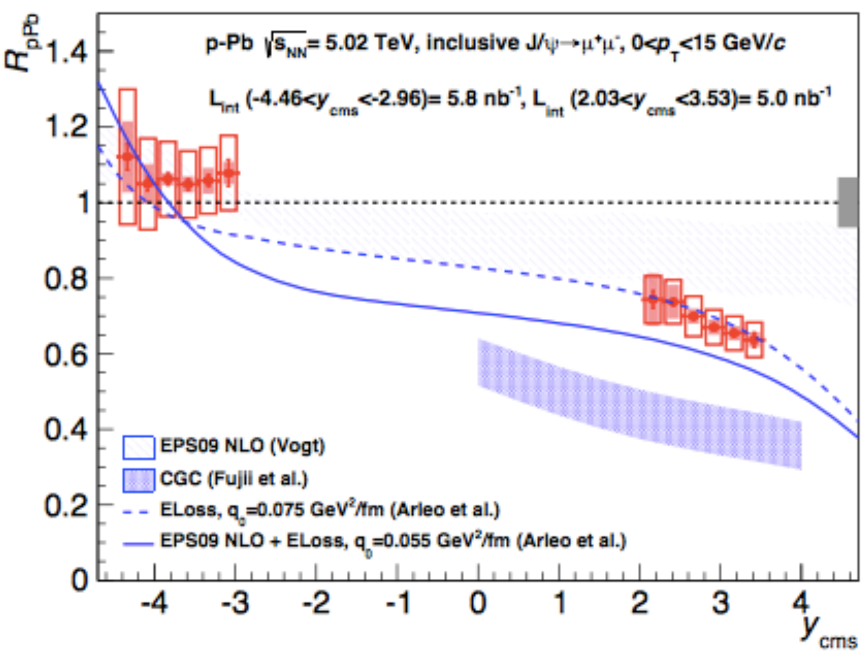
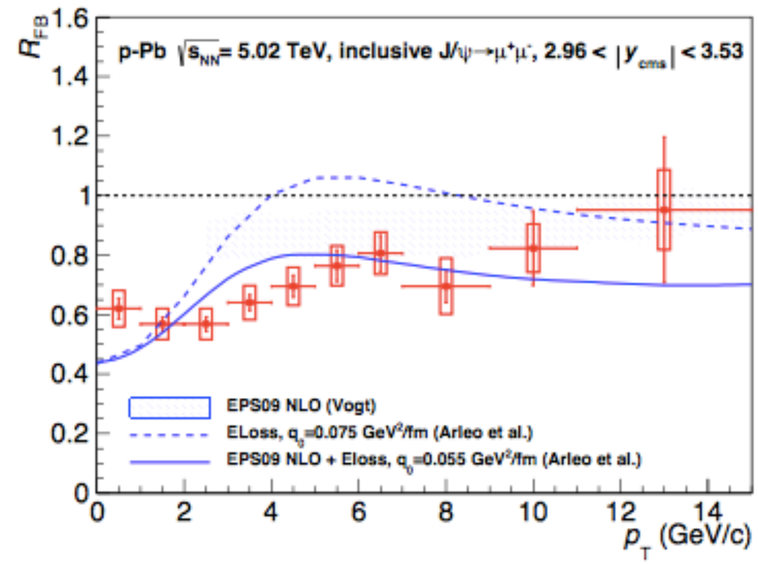
ALICE J/ψ results

arXiv:1308.6726 [nucl-ex]
JHEP 02 (2014) 073







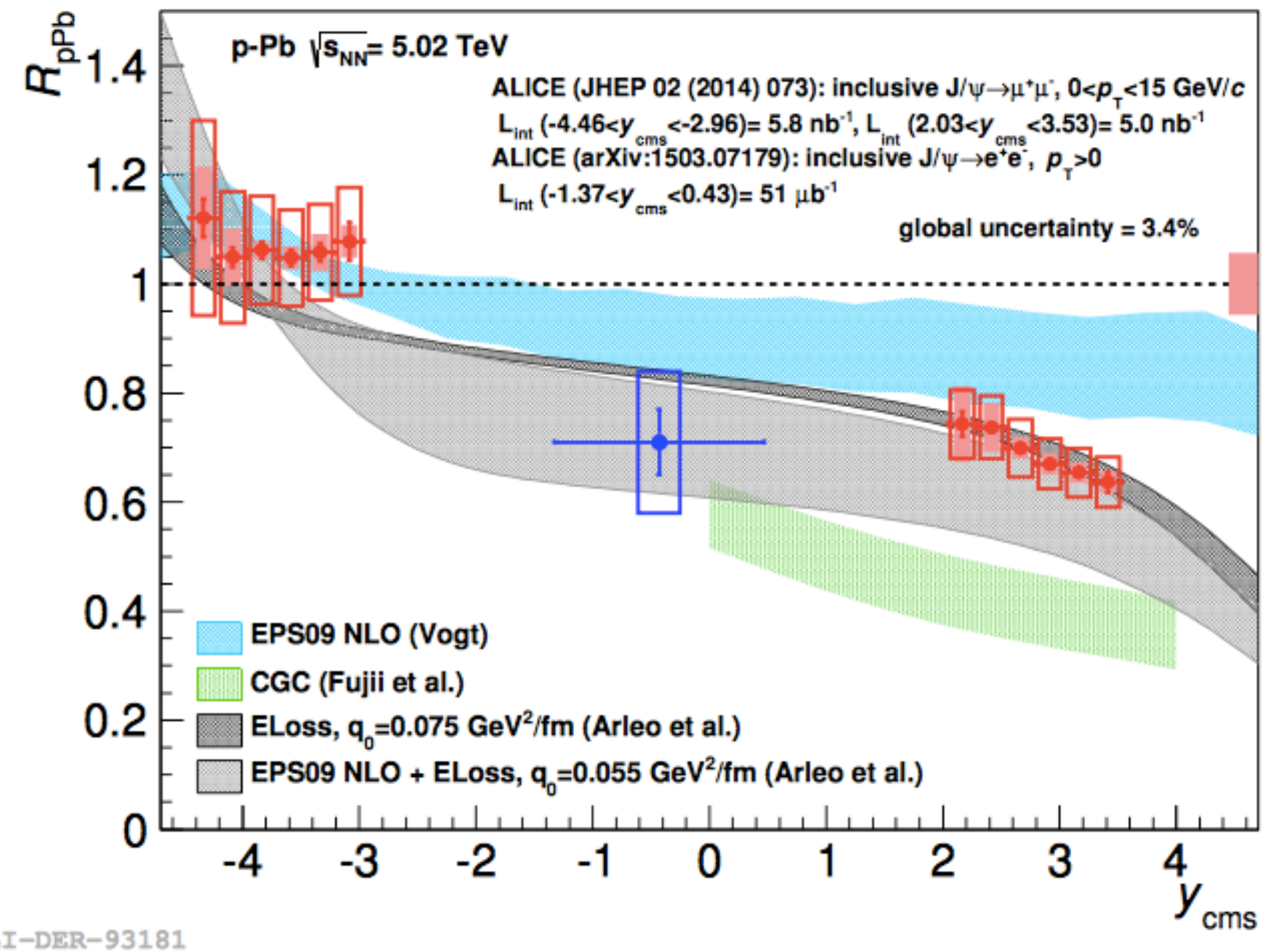


ALICE Results on J/ψ in pPb at 5.02 TeV

J/ψ in pA collisions

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

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

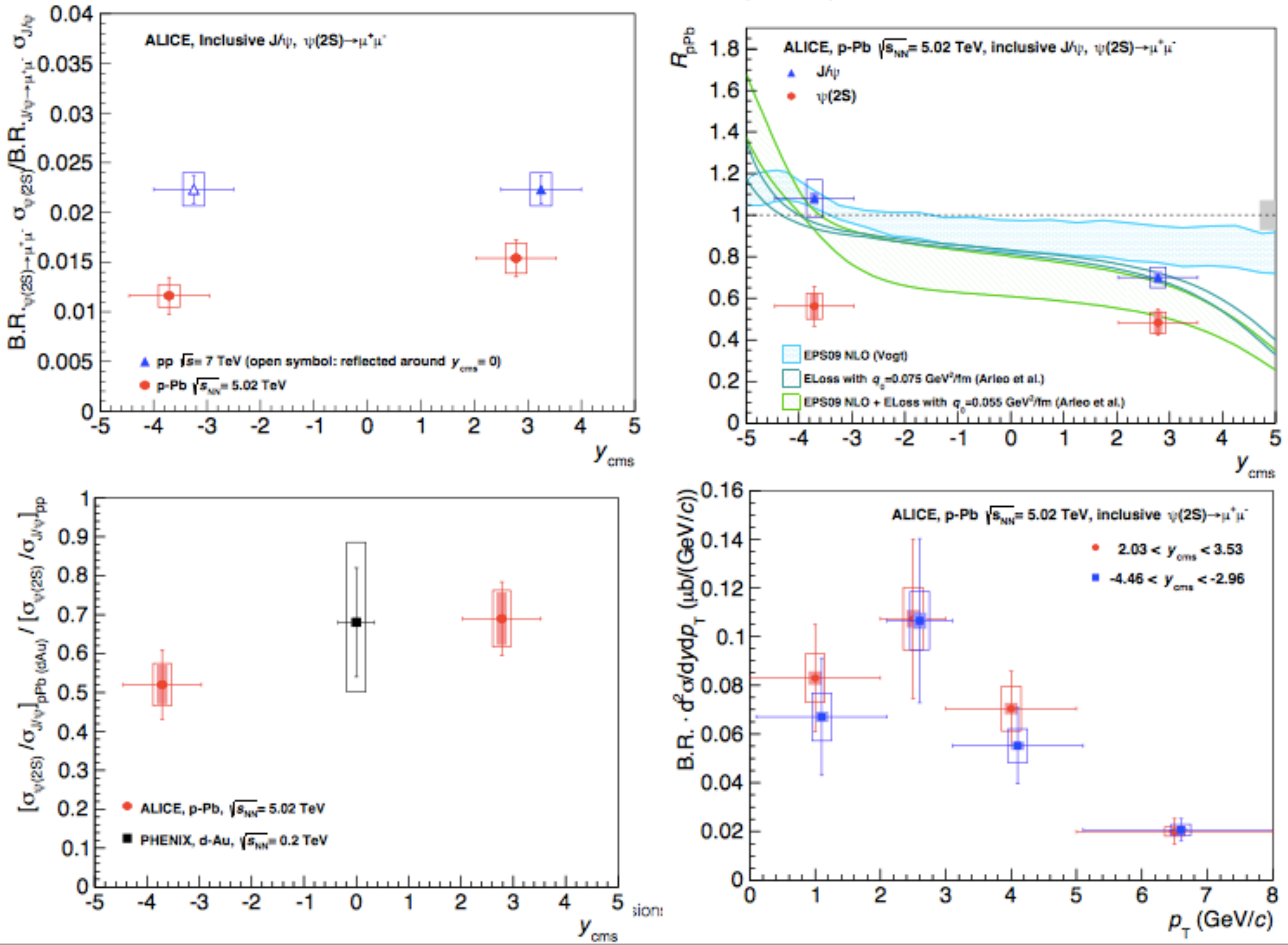


Hard Probes 2015, Mateusz Ploskon

ALICE ψ(2S) results (I)

arXiv:1405.3796 [nucl-ex]

JHEP 1412 (2014) 073



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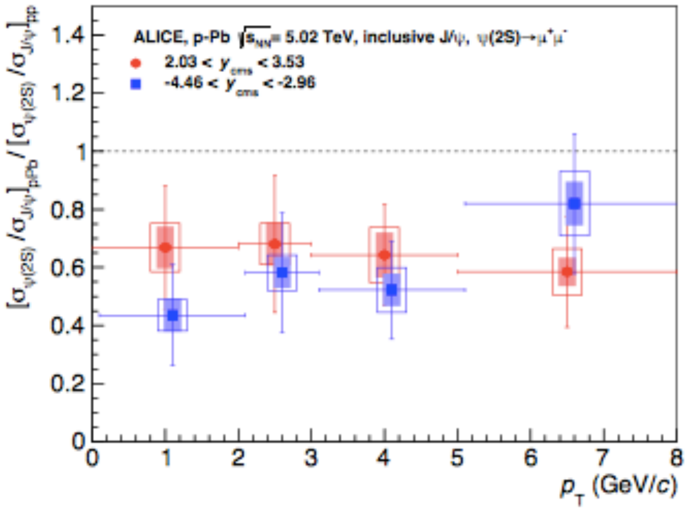
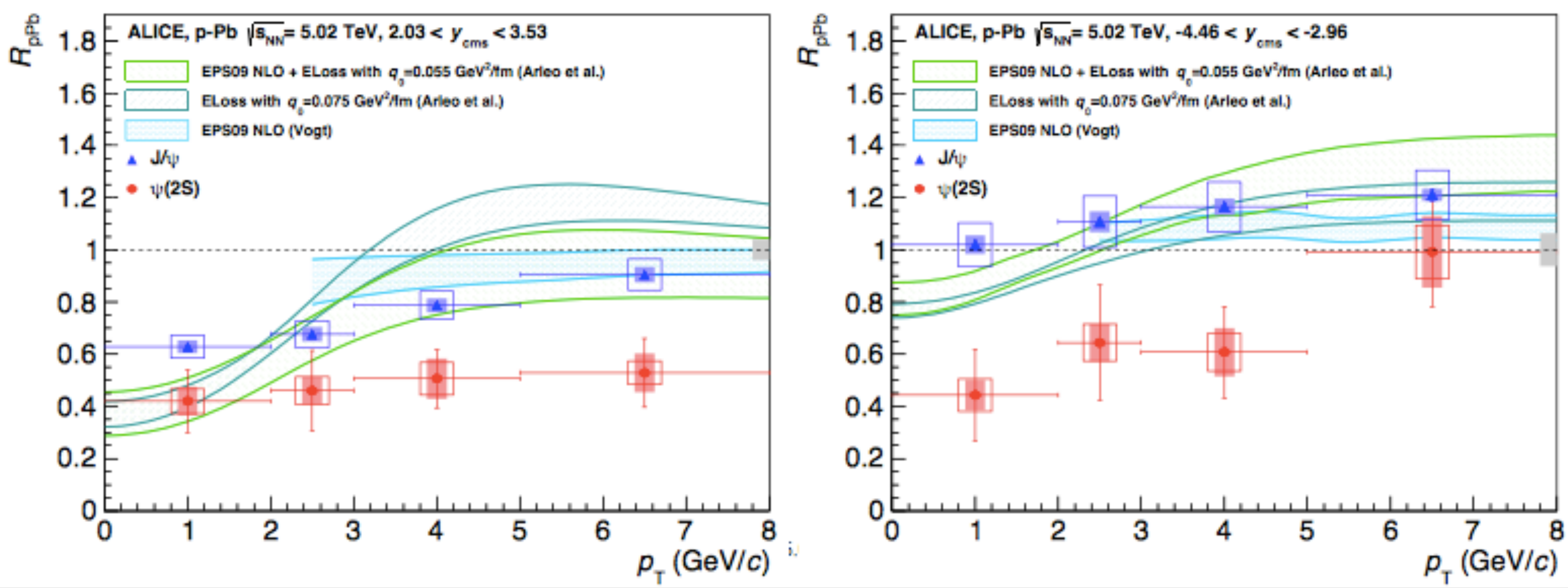
ALICE ψ(2S) results (II)

arXiv:1405.3796 [nucl-ex]
JHEP 1412 (2014) 073





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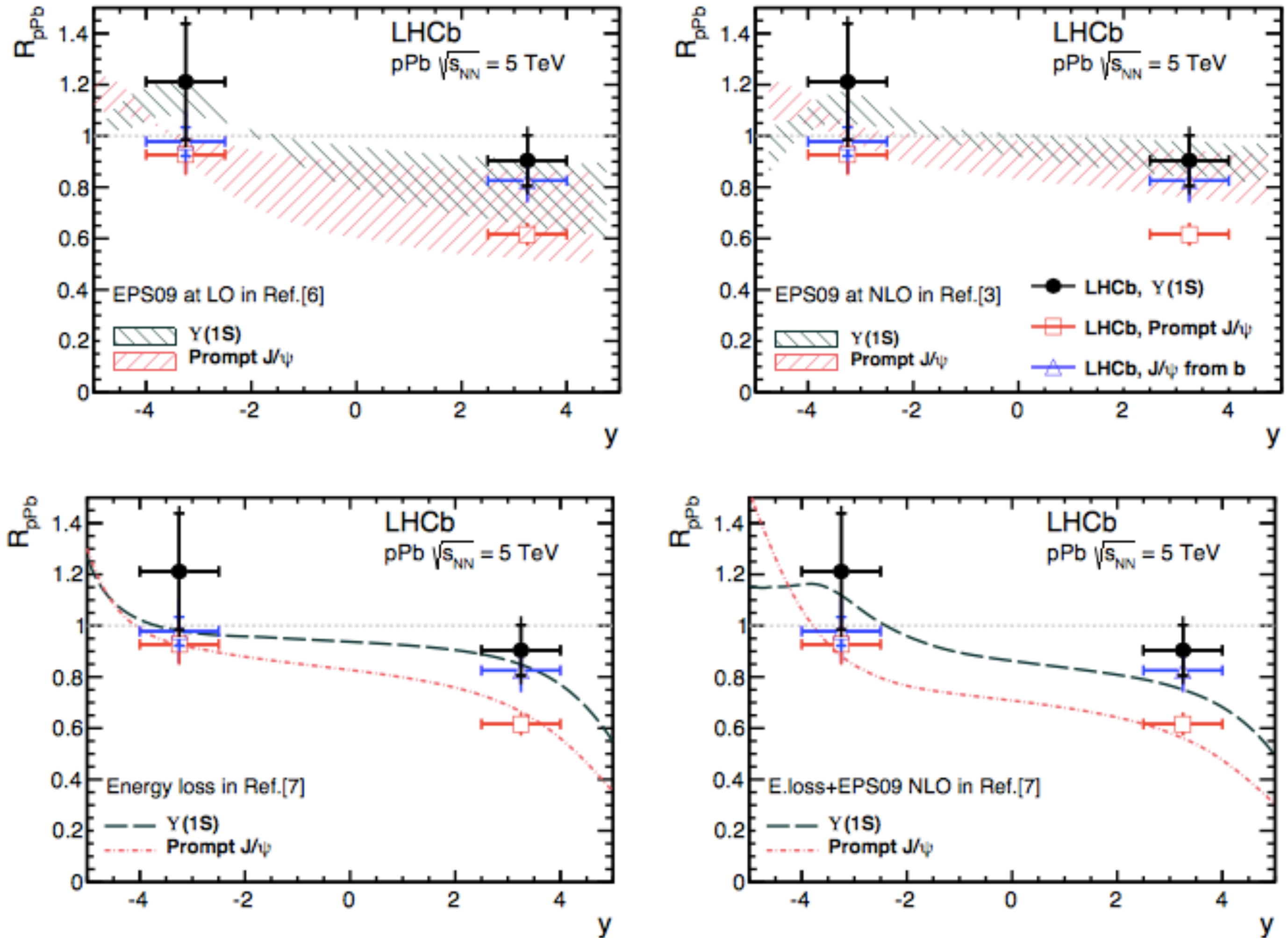
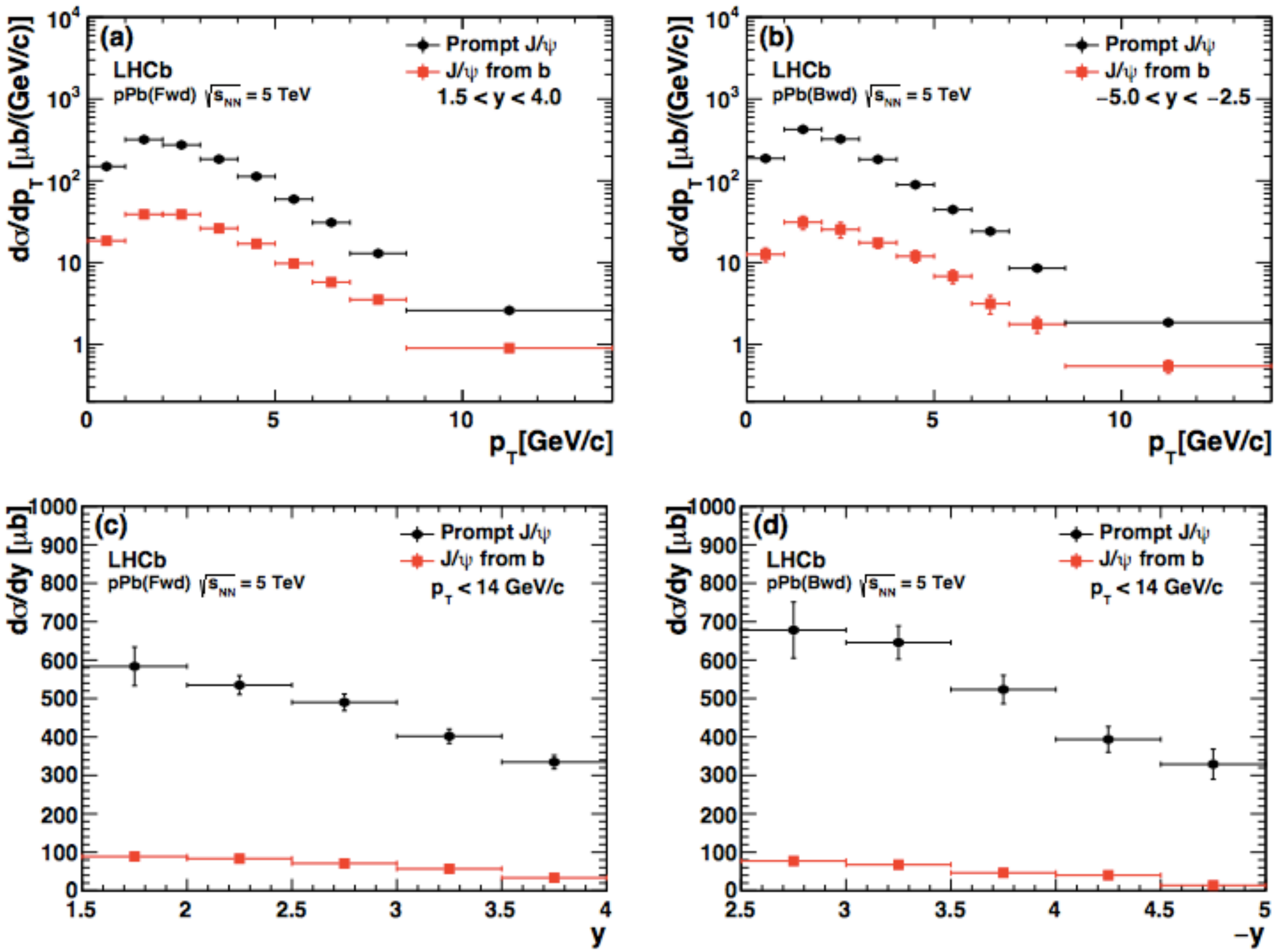
J/ψ and Υ in pPb with LHCb



J/ψ Production in pPb with LHCb



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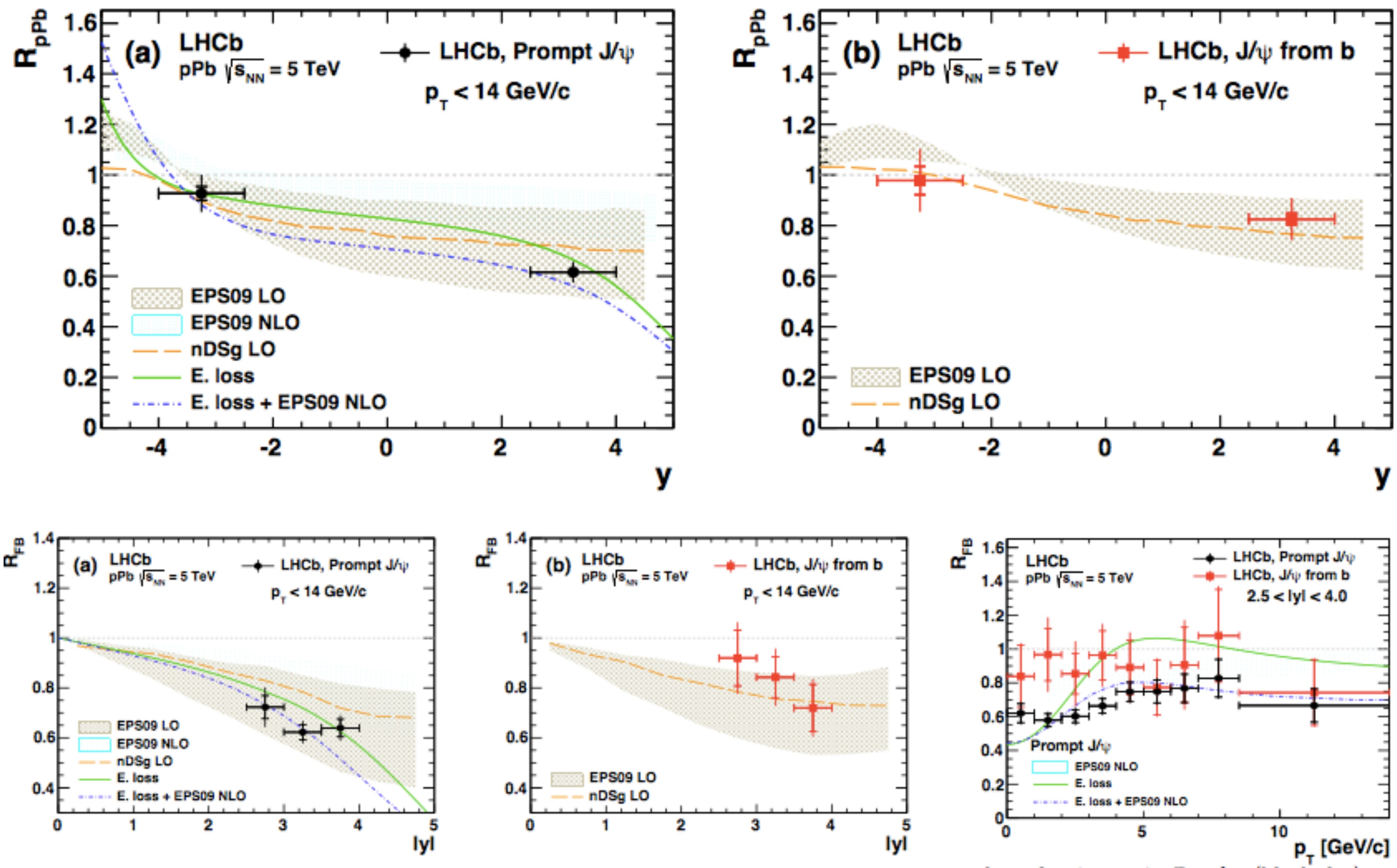
J/ψ R_{pPb} with LHCb



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