Heavy flavour and quarkonia measurement with ATLAS detector

Petr Gallus on behalf of the ATLAS Collaboration

4th International Conference on the Initial Stages in High-Energy Nuclear Collisions

Polish Academy of Arts and Sciences, Crakow, Poland

Open and Hidden Heavy Flavours in p+A collisions

- contain heavy c or b quarks
- interact strongly with medium produced in nucleus-nucleus collisions – cold and hot matter effects
- in p+A collisions – should only contain cold matter effects
  - modification of nuclear PDF & parton energy loss as initial-state effect
  - absorption in medium as final state effect
- D^0 and D^* mesons are also used to measure D^*-hadron correlations (see correlation talk by Qipeng Hu)

Nuclear modification factor

$$R_{pPb} = \frac{1}{208}\frac{\sigma_{pPb}^{O(nS)}}{\sigma_{pp}^{O(nS)}}$$

Forward to backward yield ratio

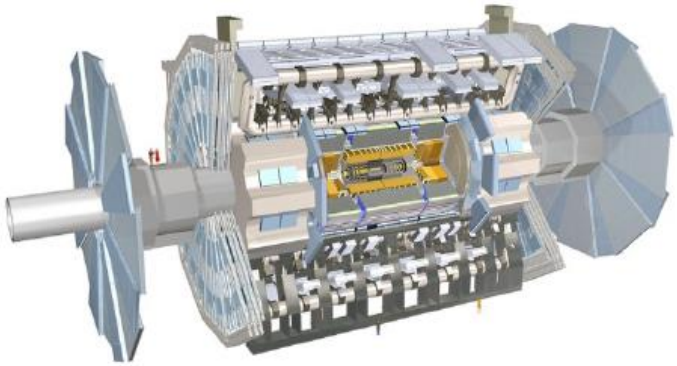
$$R_{FB} = \frac{d\sigma(O(nS))/dp_T dy^*(y^* > 0)}{d\sigma(O(nS))/dp_T dy^*(y^* < 0)}$$

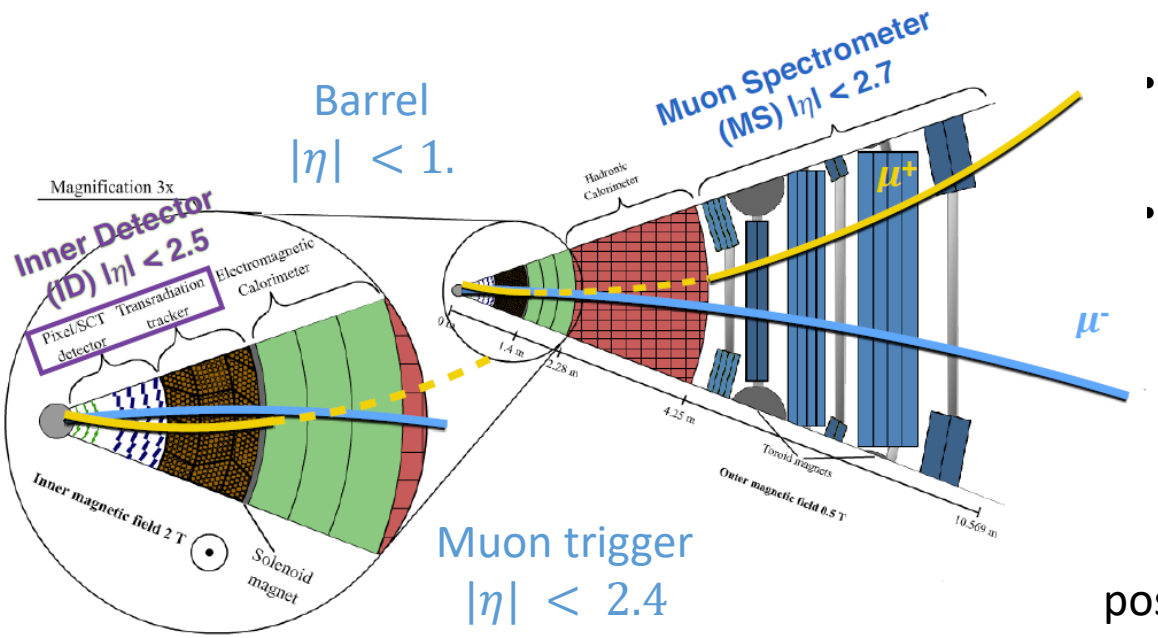
O(nS) = measured meson

double ratio

$$\rho_{pPb}^{O(\mathrm{nS})/O(\mathrm{1S})} = \frac{R_{pPb}^{O(\mathrm{nS})}}{R_{pPb}^{O(\mathrm{1S})}}$$

ATLAS detector





- 2013 p+Pb @ 5.02 TeV
  - $28\ nb^{-1}$
- 2015 p+p @ 5.02 TeV
  - $25.0\ pb^{-1}$
- 2016 p+Pb @ 8.16 TeV
  - $76.3\ \mu b^{-1}$

$$y^* = y_{lab} - 0.465$$

positive in proton beam direction

D meson measurements in p+Pb at $\sqrt{s_{NN}} = 8.16\,TeV$

New results

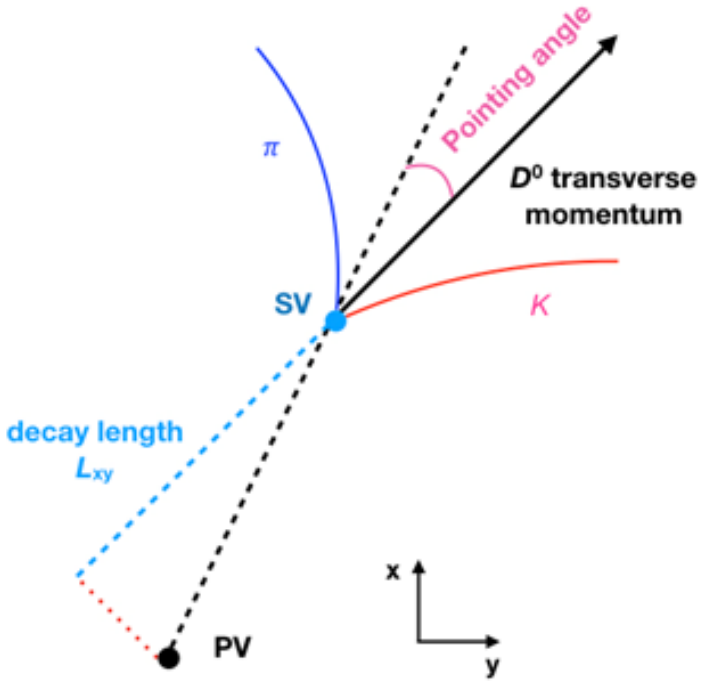
- September 2017 D meson production- ATLAS-CONF-2017-073
  - 2016 p+Pb $\sqrt{s_{NN}} = 8.16\,TeV$
  - correlation part in talk by Qipeng Hu

Prompt D mesons reconstruction

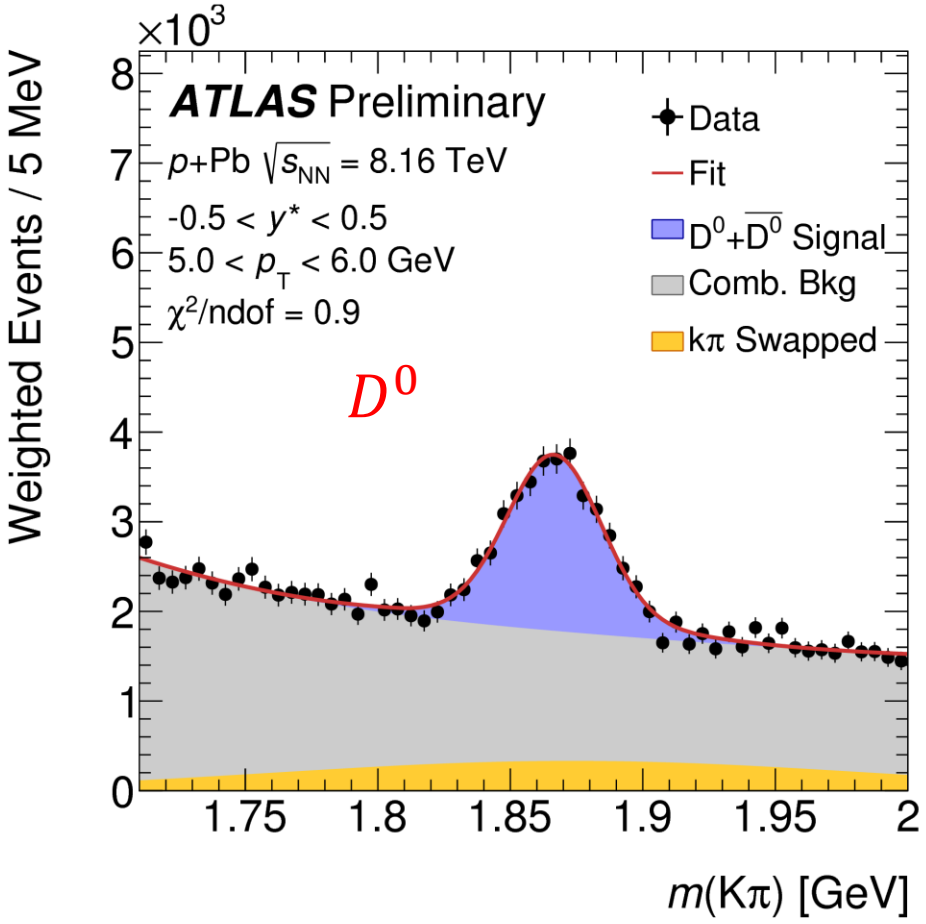
Reconstructed decay channels

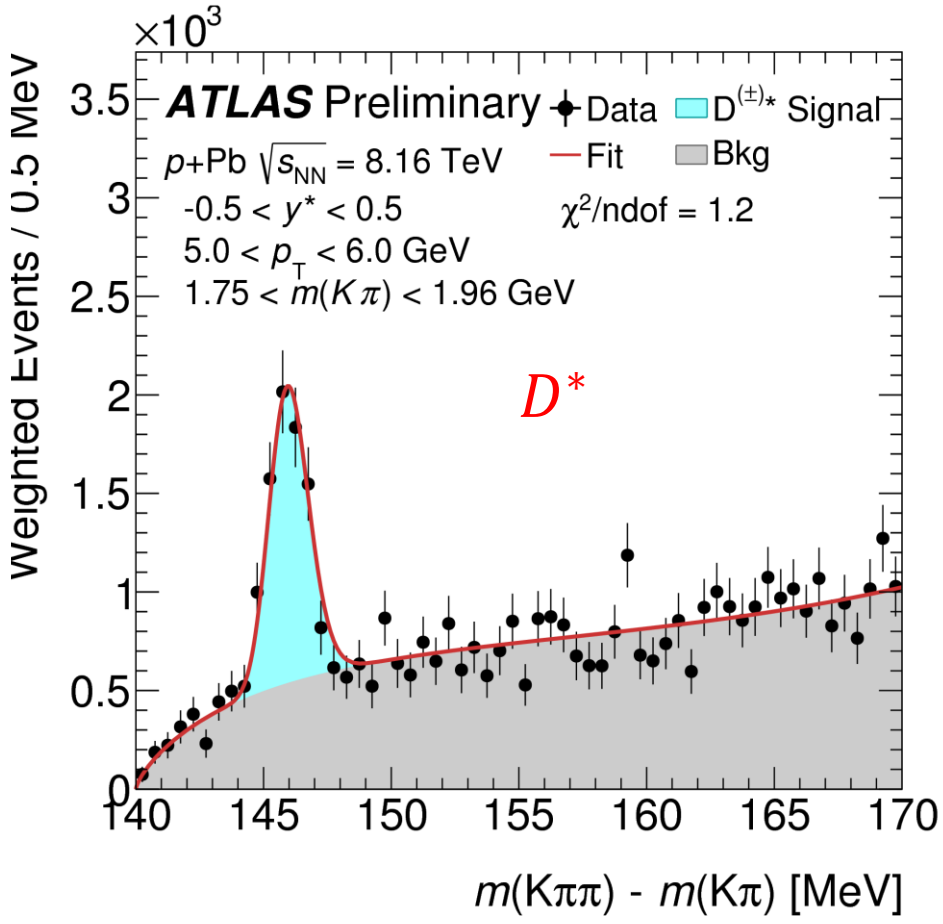
$D^0 \rightarrow K\pi$ and $D^* \rightarrow D^0\pi_s \rightarrow K\pi\pi_s$ (π_s- „soft“ pion)

- Reconstructed primary vertex
- Pairs of oppositely- charged tracks, $p_T^{trk} > 1\ GeV$, combined to form D^0 candidate ($1.7 < m(K\pi) < 2.0\ GeV$)
- D^0 topological cuts
  - secondary vertex probability (χ^2 fit)
  - $cos\ \alpha_{xy}$ - close to 1
  - $L_{xy}/\sigma(L_{xy})$
- „soft“ pion π_s for D^*
  - track with $p_T > 400\ MeV$
- D^* candidate invariant mass distribution for fit
  - $\Delta m = \ m(K\pi\pi_s) - m(K\pi)$
- non- prompt substracted based on pp FONLL
  - $b \rightarrow D$ at the 8 TeV



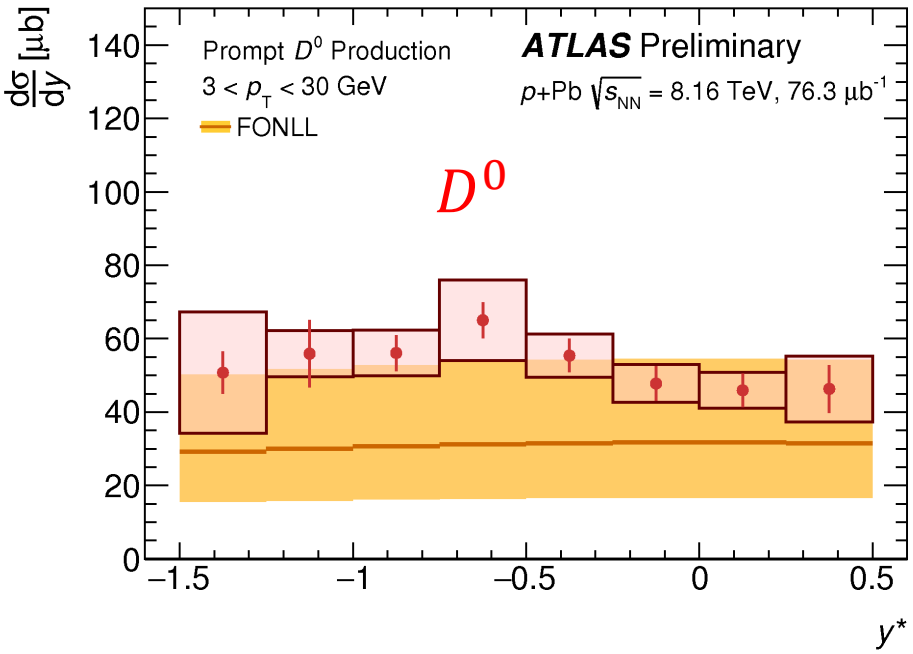
Fit of D^0 and D^* invariant mass distributions

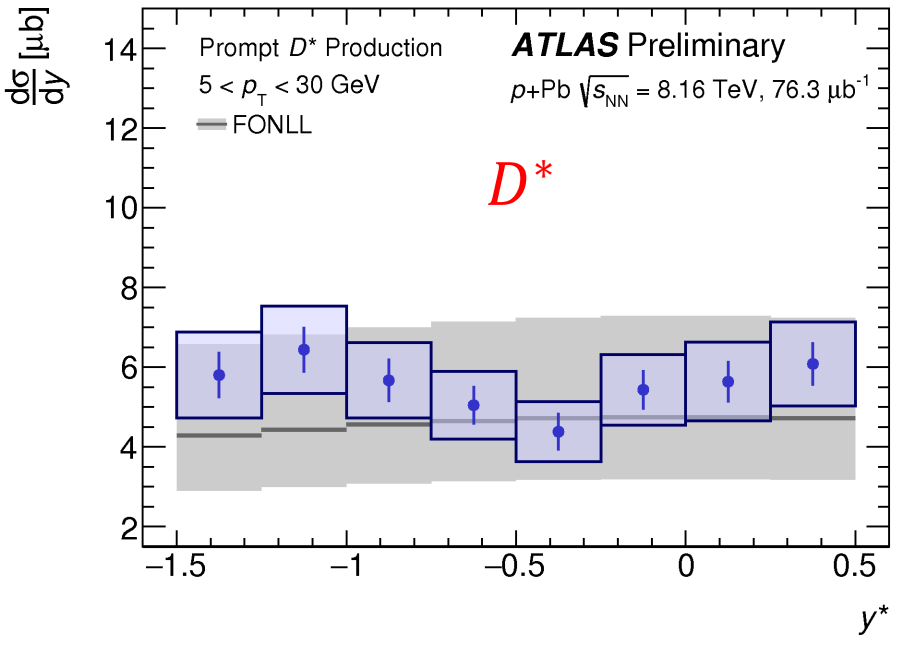




ATLAS-CONF-2017-073

Differential cross section for prompt production



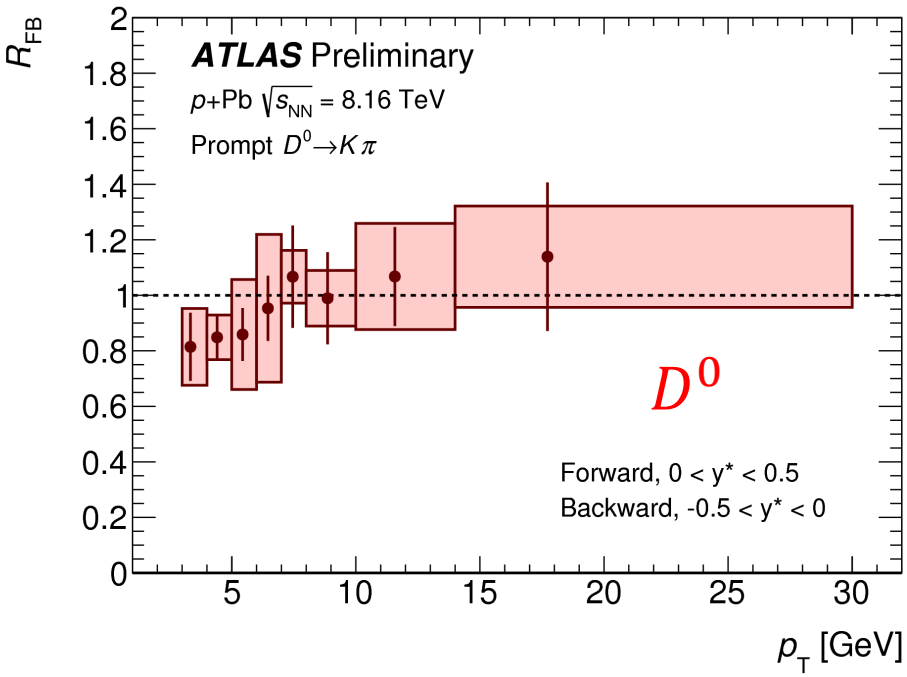


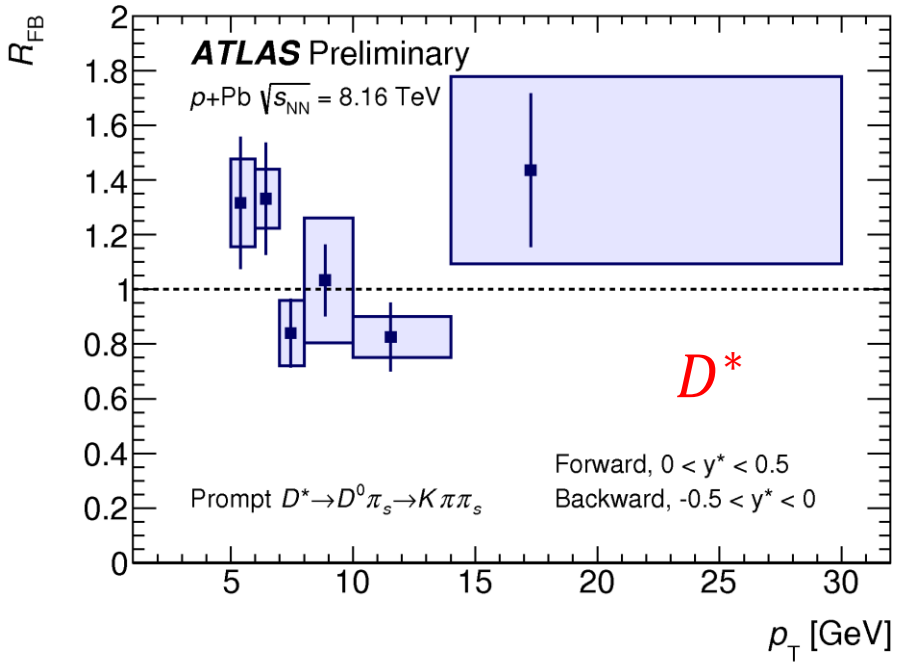
Measured charm meson production cross sections are compatible with extrapolated FONLL x A_{Pb} from 7 & 8 TeV to 8.16 TeV prediction within uncertainties.

ATLAS-CONF-2017-073

FONLL model
arXiv: 1205.6344 [hep-ph]

Forward to backward ratio





No significant modification of D^0 and D^* production in forward direction with respect to backward has been observed. Hint of D^0 relative modification at low p_T, but large uncertainties.

ATLAS-CONF-2017-073

Quarkonia measurements

New results

- September 2017 Quarkonia p+Pb paper – arXiv:1709.03089
  - 2013 p+Pb $\sqrt{s_{NN}} = 5.02\ TeV$ and 2015 p+p $\sqrt{s} = 5.02\ TeV$

Quarkonia candidate selection

Muon trigger : different for p+Pb and pp

- p+Pb: at least one muon at hardware level ($p_T^{\mu} > 0\ GeV, |\eta| < 2.4$), 2 muons with $p_T > 2\ GeV$ in offline trigger
- pp: 2 muons candidates at hardware level ($p_T^{\mu} > 4\ GeV, |\eta| < 2.4$) candidates are muons with opposite charge in offline level

Di-muon range

- p+Pb $\psi(nS)$: $p_T^{\mu\mu} \in \langle 8.5; 30\rangle\ GeV, -2 < y^* < 1.5$
- p+Pb $\Upsilon(nS)$: $p_T^{\mu\mu} \in \langle 0; 40\rangle\ GeV, -2 < y^* < 1.5$

Yield extraction

$\psi(nS)$

Weighted 2D unbinned maximum likelihood fit

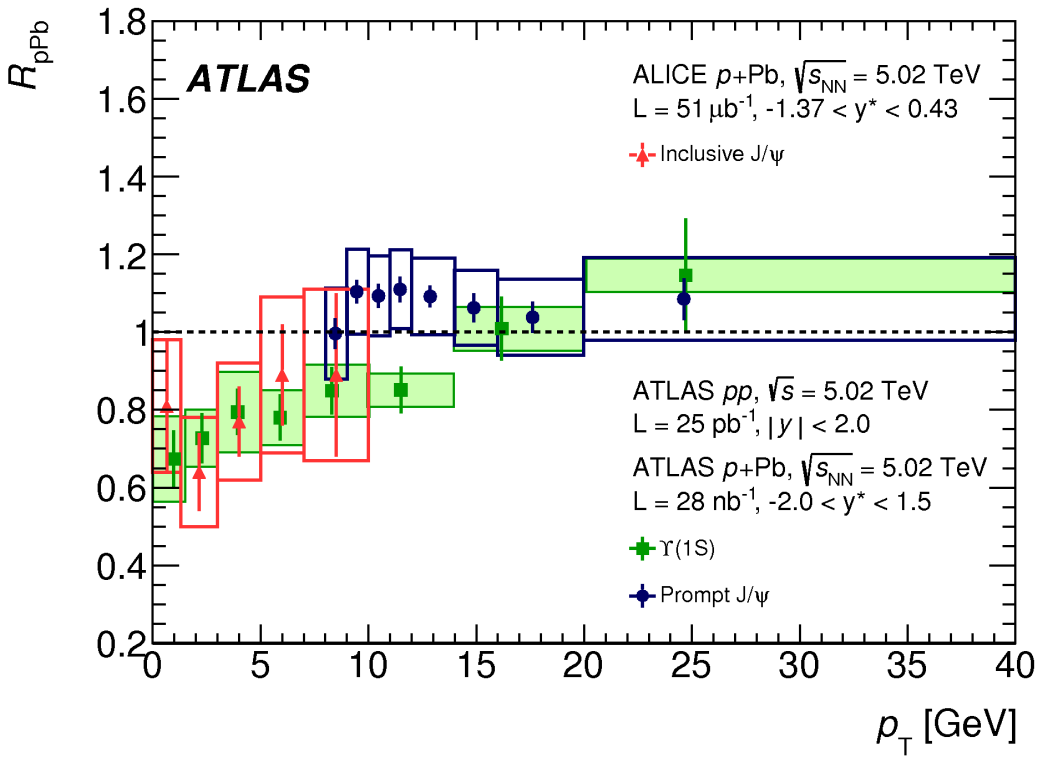
- dimuon invariant mass and lifetime
- per-dimuon weight: trigger, reconstruction, acceptance
- extract fraction of prompt and non-prompt

$\Upsilon\,(nS)$

Weighted unbinned 1D maximum likehood fit

- dimuon invariant mass only
- per-dimuon weight: trigger, reconstruction, acceptance
- different acceptance for each state
- Background parametrisation is p_T dependent.
  Low $p_T^{\mu\mu} < 6\ GeV$ or integrated over p_T range
  High $p_T^{\mu\mu} > 6\ GeV$

Nuclear modification factor of quarkonia (R_{pPb})



ATLAS $\Upsilon\,(1S)$

ATLAS prompt J/ψ

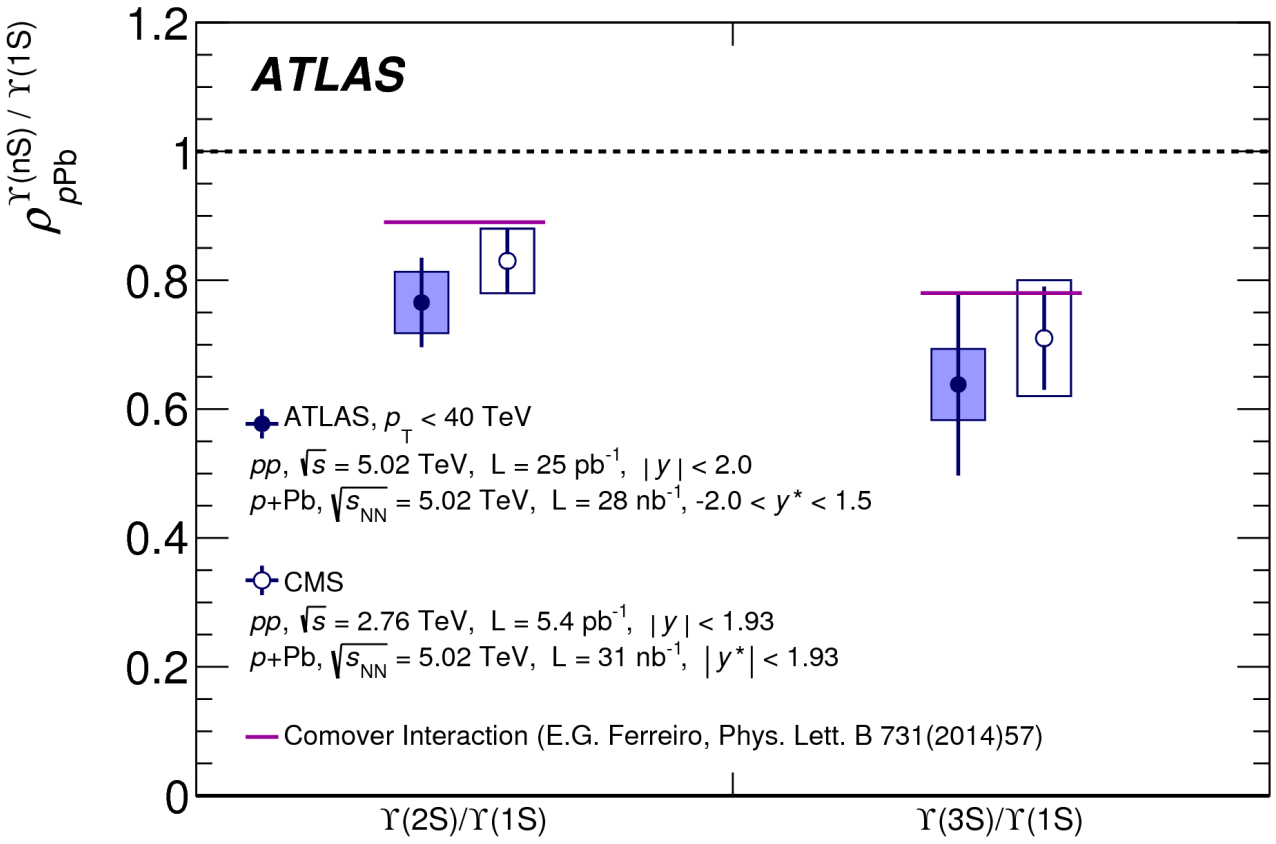
ALICE inclusive J/ψ

The J/ψ R_{pPb} as a function of p_T is consistent with unity across p_T range, for lower p_T both ATLAS $\Upsilon\,(1S)$ and ALICE inclusive J/ψ are showing suppresion comparable to pp.

$R_{pPb} \neq 1$ means modification by nuclear effects

arXiv:1709.03089

Excited states – Double ratio all centralities



$\Upsilon\,(2S)/\Upsilon\,(1S)$ $\Upsilon\,(3S)/\Upsilon\,(1S)$

Double ratio for both excited states shows suppression compared to pp collisions. The measured double ratio agrees with CMS and theory prediction.

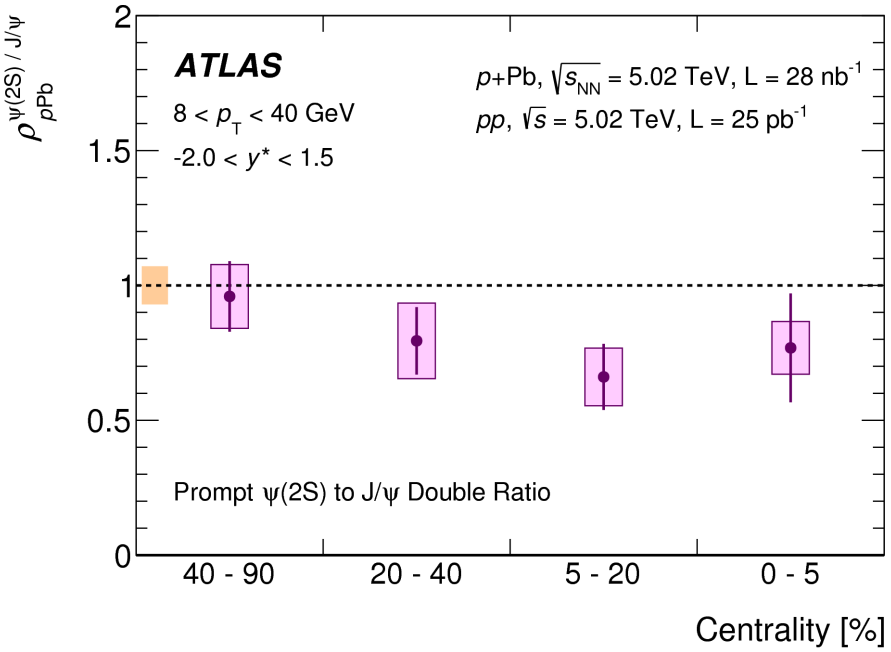
double ratio

$$\rho^{O(\mathrm{nS})/O(1\mathrm{S})}_{pPb} = \frac{R^{O(\mathrm{nS})}_{pPb}}{R^{O(1\mathrm{S})}_{pPb}}$$

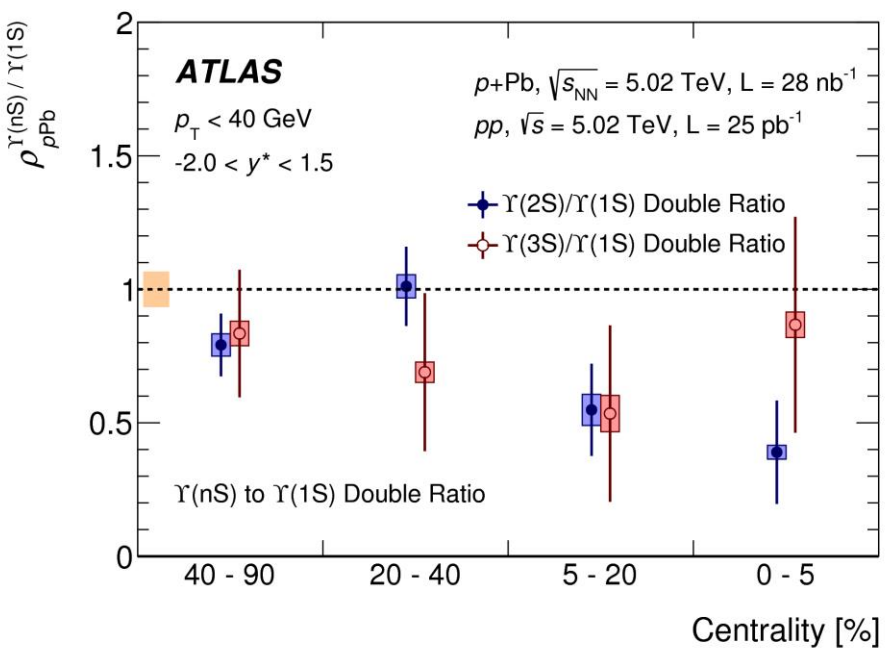
arXiv:1709.03089

Excited states - Double ratios

$\psi(nS)$



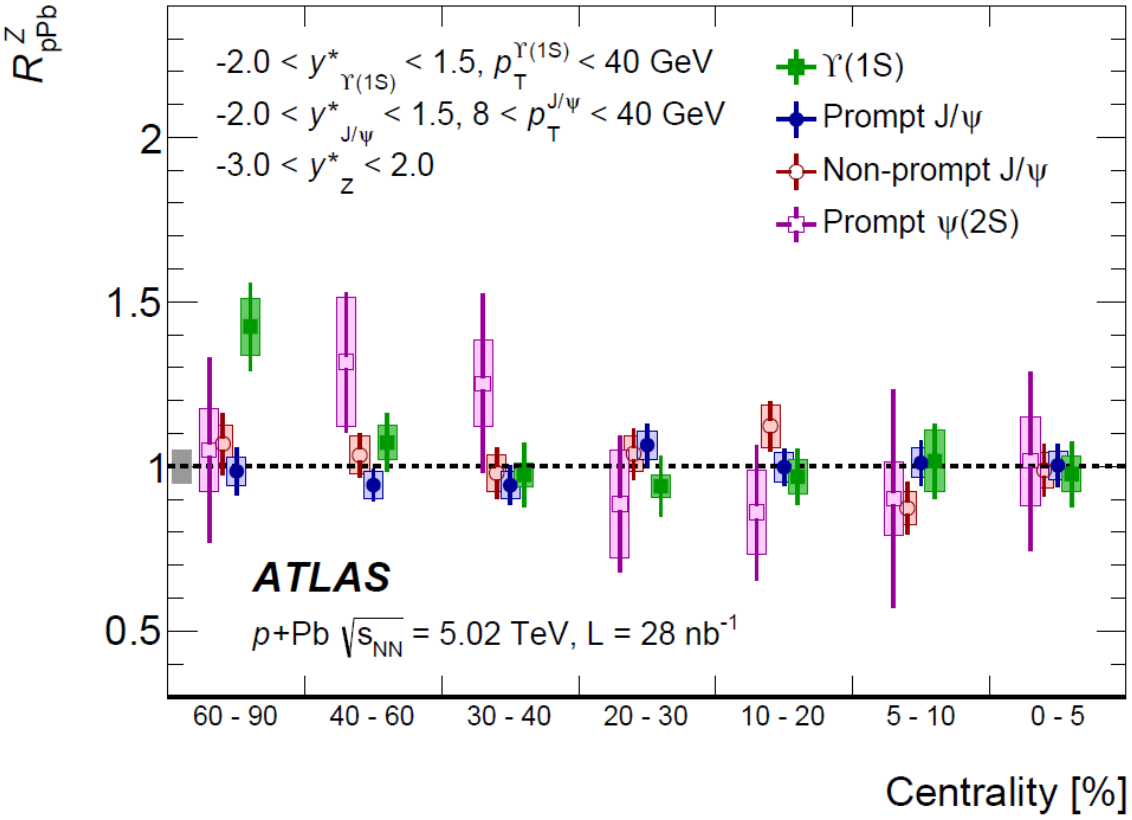
$\Upsilon\ (nS)$



Double ratios of ψ (2S) and $\Upsilon\ (2S)$ are decreasing slightly with centrality with significance level of one sigma.
$\Upsilon\ (3S)$ is inconclusive due to uncertainty.

arXiv:1709.03089

Comparison to Z boson in p+Pb collisions



$$R^{Z}_{pPb}\big(O(nS)\big) = \frac{N^{cent}_{O(nS)}/N^{cent}_{Z}}{N^{0-90\%}_{O(nS)}/N^{0-90\%}_{Z}}$$

Ratios of the yields of Z and quarkonia ground states are consistent with unity except for the most peripheral collisions in case of Y (1S).

arXiv:1709.03089

Summary

Quarkonia and D meson productions in p+Pb collisions are presented.

- D meson
  - Yields are consistent with FONLL prediction from pp after scaling by mass number of Pb nucleus.
  - Forward to background ratio R_{FB} shows no significant asymmetry in production for prompt D^0 and D^* mesons within $|y^*| < 0.5$.
  - The poster D meson production and long-range azimuthal correlation in 8.16 TeV p+Pb collisions with ATLAS by Qipeng Hu.
- Quarkonia
  - Prompt J/ψ R_{pPb} shows no obvious p_T dependence and is consistent with unity.
  - For $\Upsilon\,(1S)$ R_{pPb}, we observe suppression at low p_T.
  - Excited states are more suppressed with respect to the ground state and show slight centrality dependence.
  - Ratios of quarkonia ground states to Z boson are independent on event activity and scale with the number of binary collisions.
- ATLAS HI Public Results

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Additional slides

Pseudo-proper decay time

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

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

Definition of y*

$$y^* = y_{lab} - 0.465$$
$$y^* = -(y_{lab} + 0.465)$$

due to shift of center of mass

y* is defined as positive in proton beam direction

Nuclear modification factor R_{AA} and R_{pA}

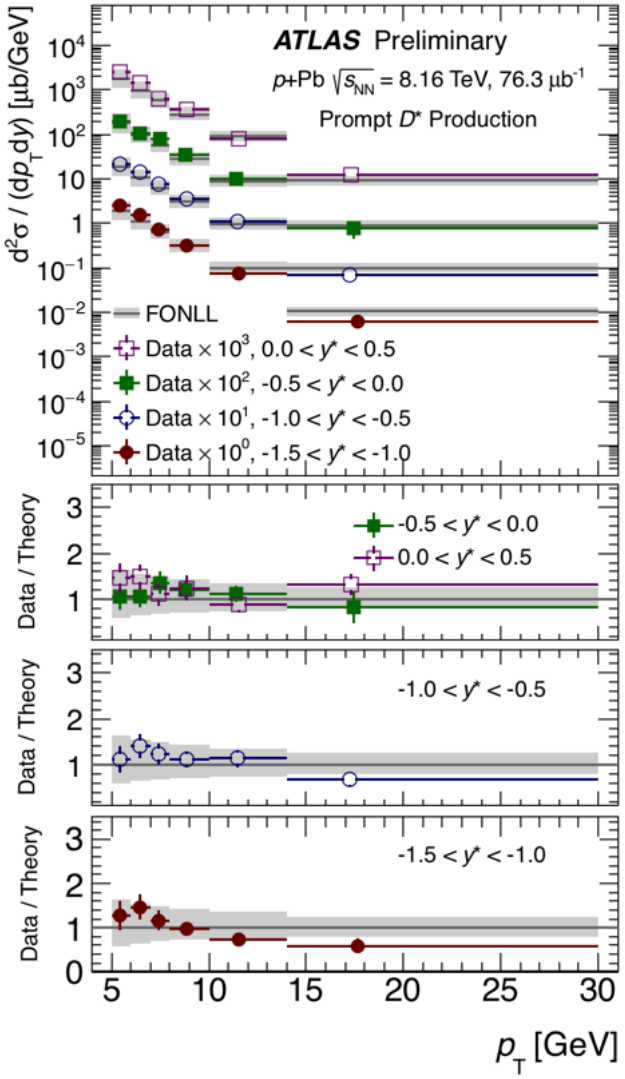
$$R_{AA} = \frac{N^{AA}}{\langle T_{AA} \rangle \times \sigma^{pp}}$$

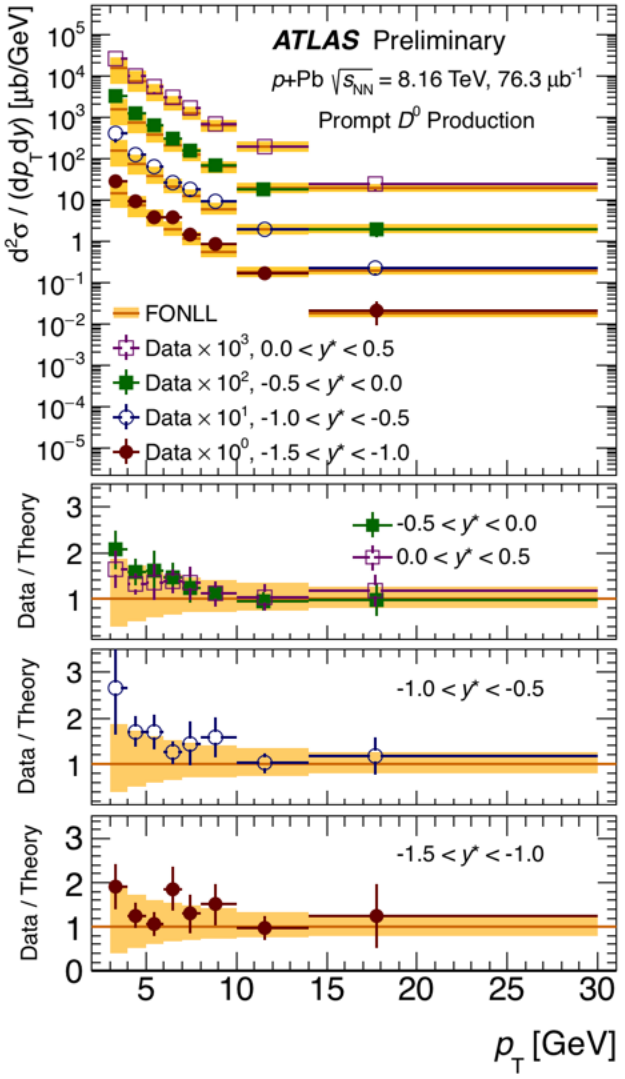
- N^{AA} - per-event yield of quarkonia states in A+A collisions
- $\langle T_{AA} \rangle$ - mean nuclear function ψ
- σ^{pp} - cross section in pp collisions

$$R_{pA} = \frac{1}{A^{Pb}} \frac{d^2\sigma_{\psi}^{p+Pb}/dy * dp_T}{d^2\sigma_{\psi}^{p+p}/dy * dp_T}$$

$$R_{pA}^{cent} = \frac{\langle 1/N_{evt}^{cent} \rangle \; d^2N^{p+Pb}/dydp_T|_{cent}}{\langle T_{pPb} \rangle_{cent} \, d^2\sigma^{pp}/dydp_T}$$

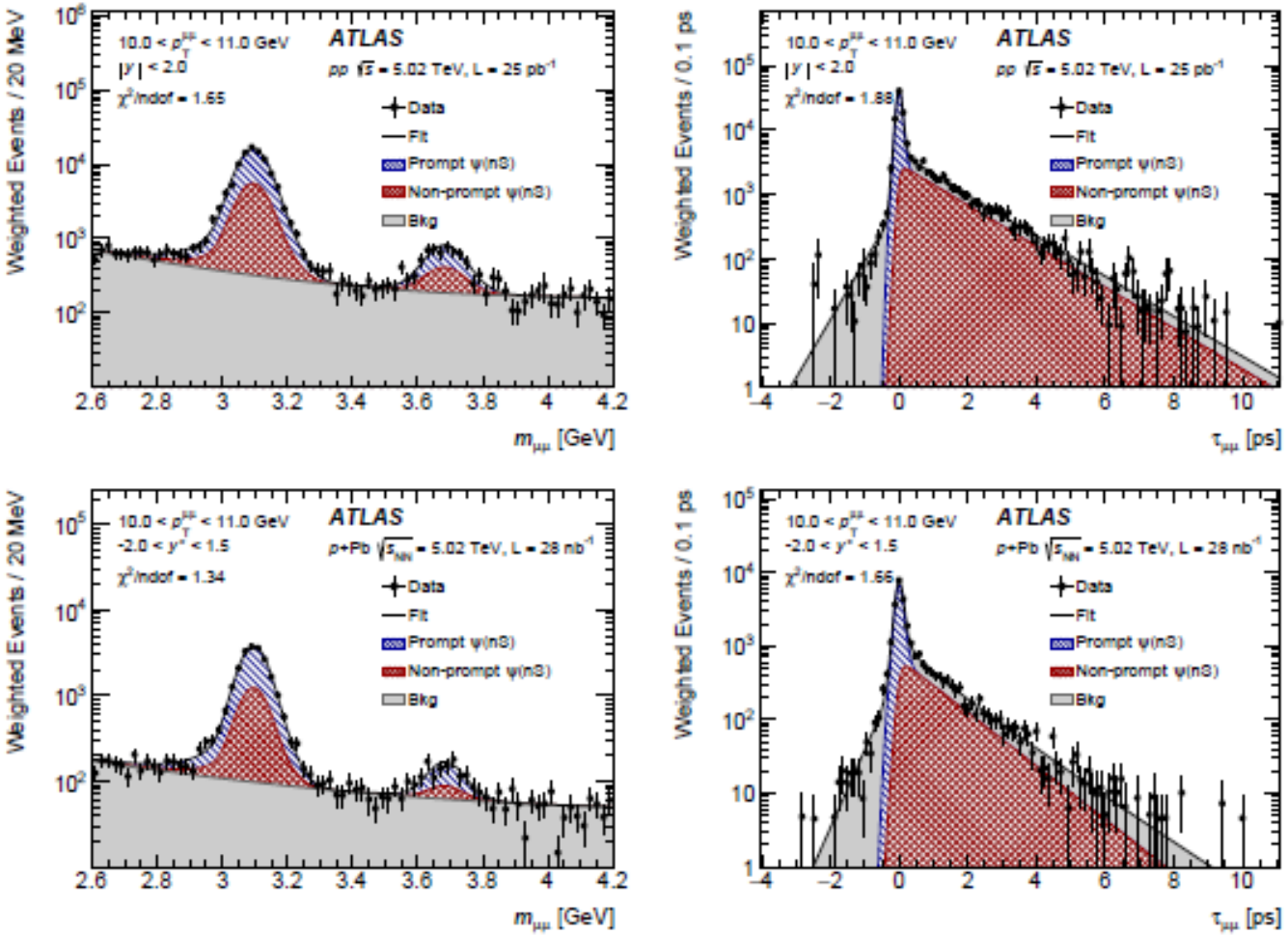
Yields per event scaled by 1/208





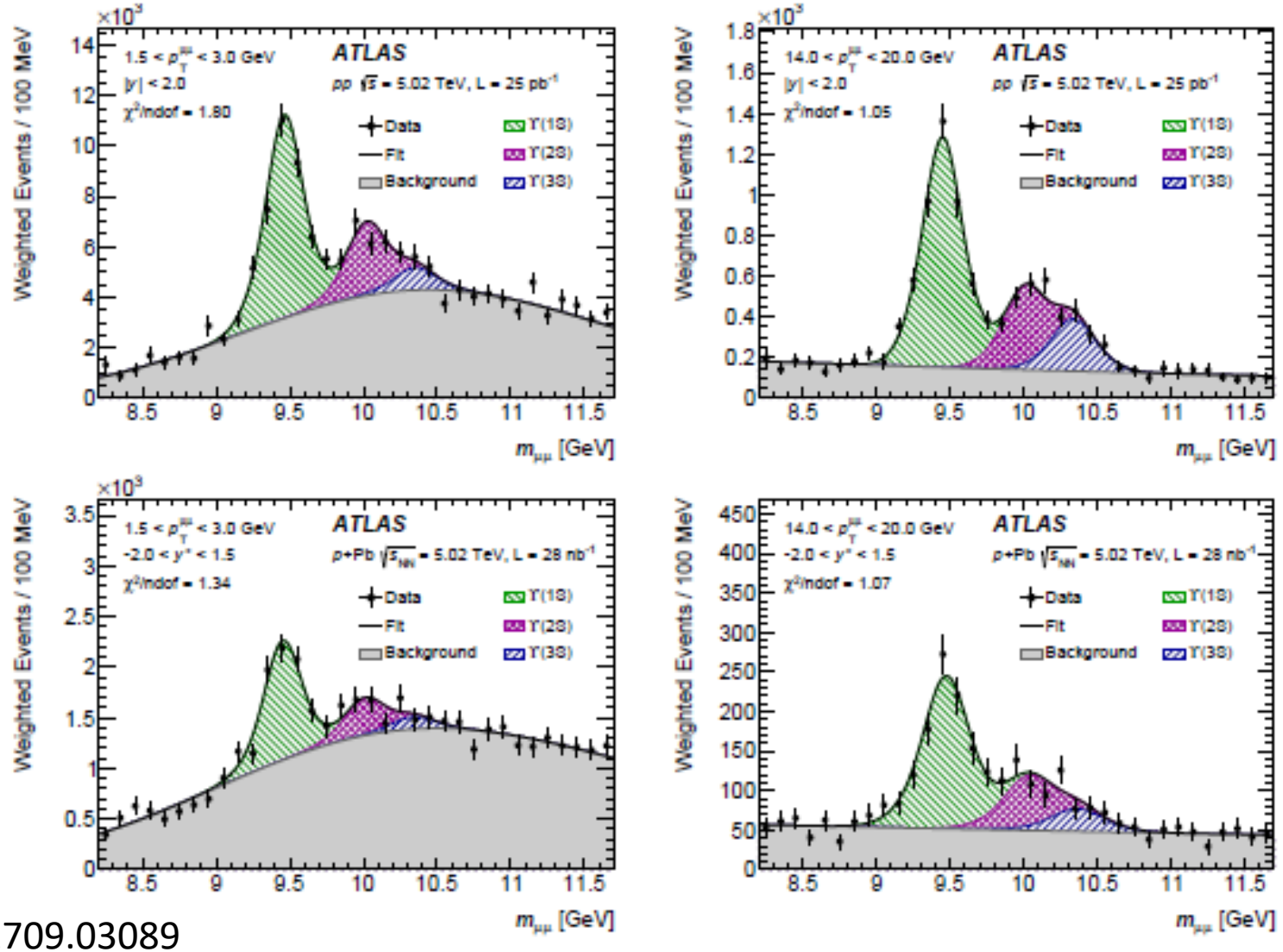
2017-04

Fit of ψ (nS)



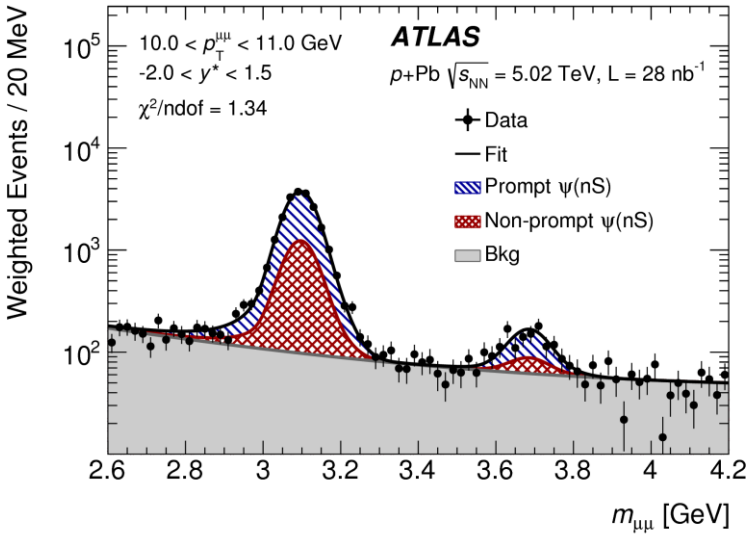
arXiv:1709.03089

Fit of Υ (nS)



arXiv:1709.03089

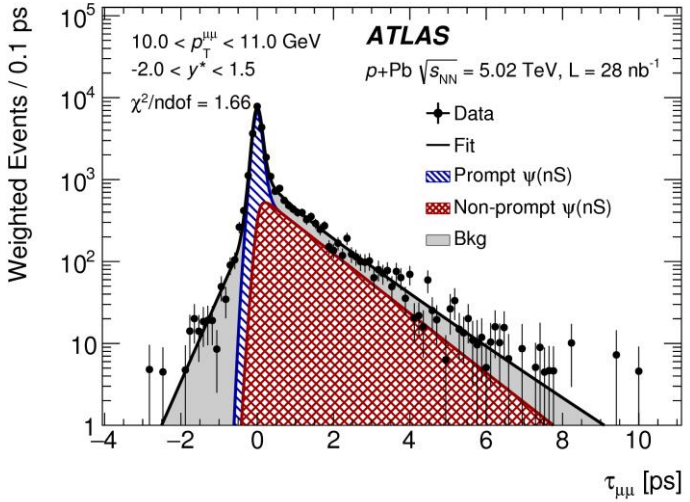
Simultaneous Fit Method



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

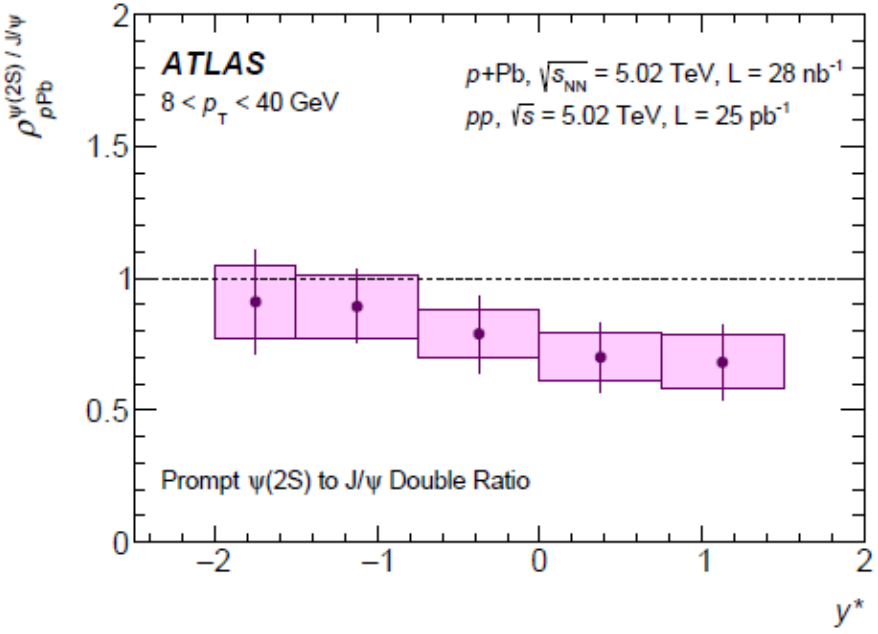
CB: Crystal ball function
G: Gaussian
E: Exponential
g: Double Gaussian
δ: Delta Function

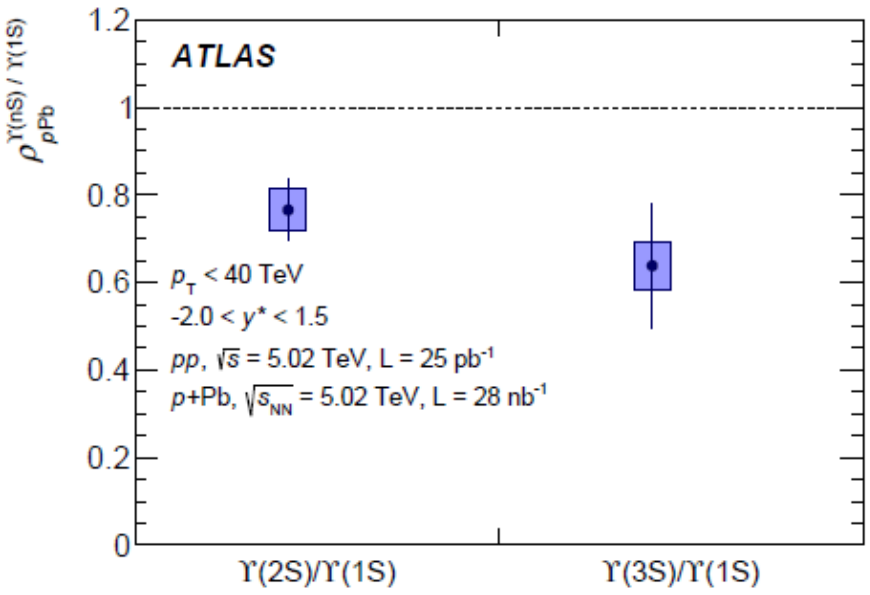
i	Type	Source	$f_i(m)$	$h_i(\tau)$
1	J/ψ S	P	$\omega_i CB_1(m) + (1-\omega_i)G_1(m)$	$\delta(\tau)$
2	J/ψ S	NP	$\omega_i CB_1(m) + (1-\omega_i)G_1(m)$	$E_1(\tau)$
3	$\psi(2S)$ S	P	$\omega_i CB_2(m) + (1-\omega_i)G_2(m)$	$\delta(\tau)$
4	$\psi(2S)$ S	NP	$\omega_i CB_2(m) + (1-\omega_i)G_2(m)$	$E_2(\tau)$
5	Bkg	P	$flat$	$\delta(\tau)$
6	Bkg	NP	$E_3(m)$	$E_4(\tau)$
7	Bkg	NP	$E_5(m)$	$E_6(\|\tau\|)$



arXiv:1709.03089

Exited states - Double ratios

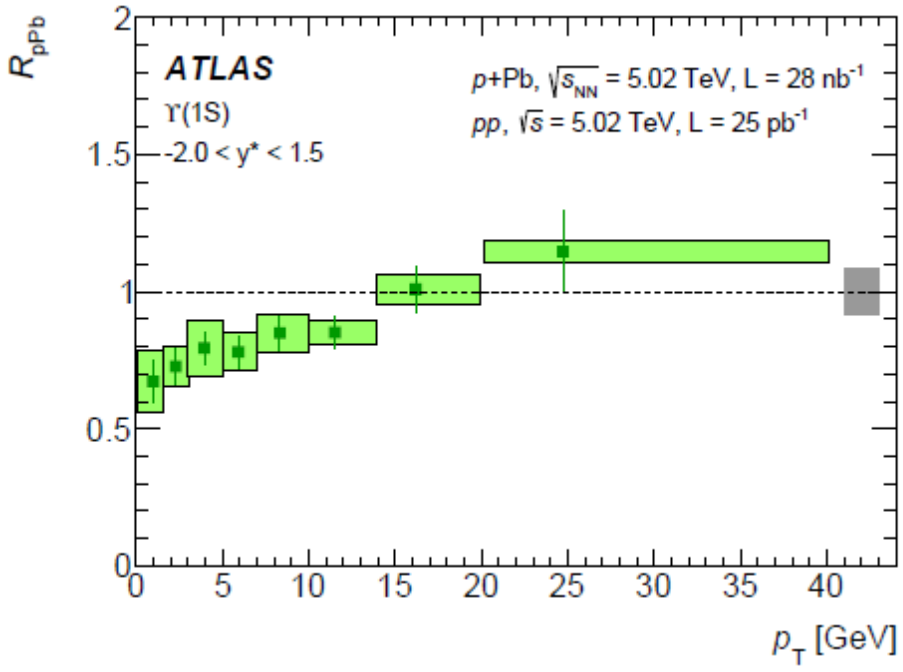


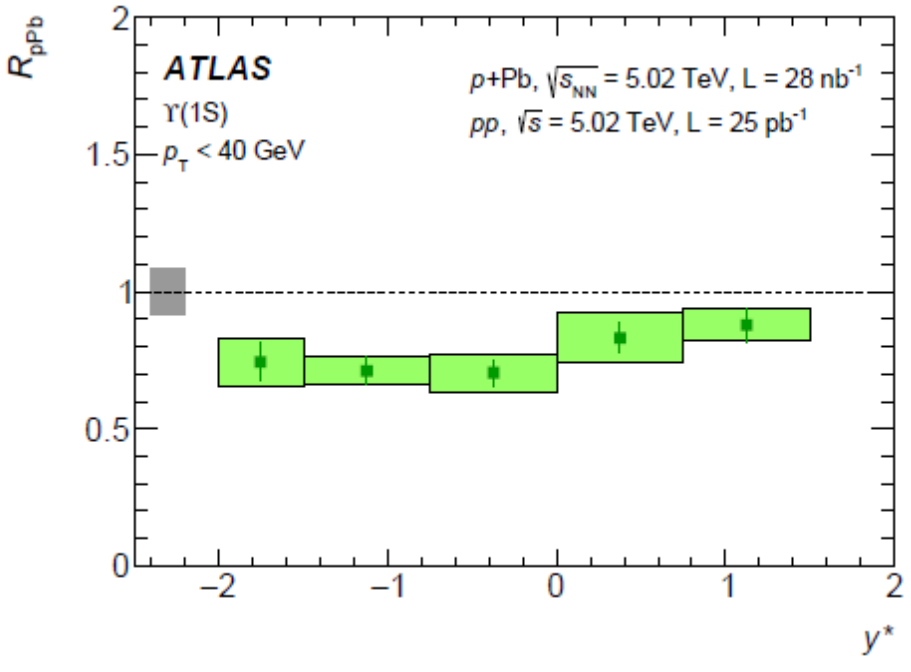


Double ratio of ψ (2S) have decreasing trend with one sigma significance in y^* and Υ (nS) are less than unity by more than 2 sigmas.

arXiv:1709.03089

Nuclear modification factor of $\Upsilon(1S)$ (R_{pPb})

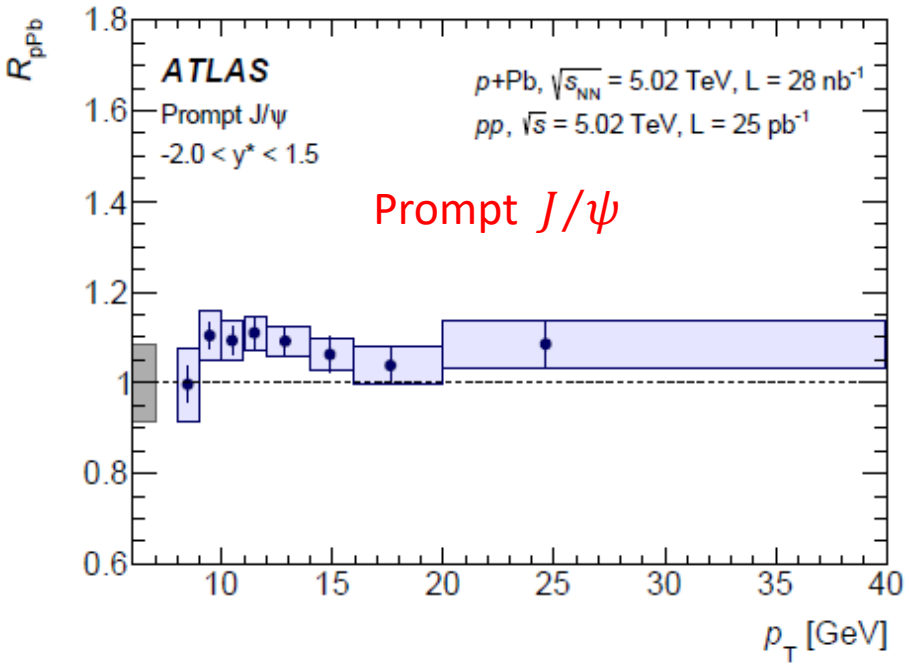


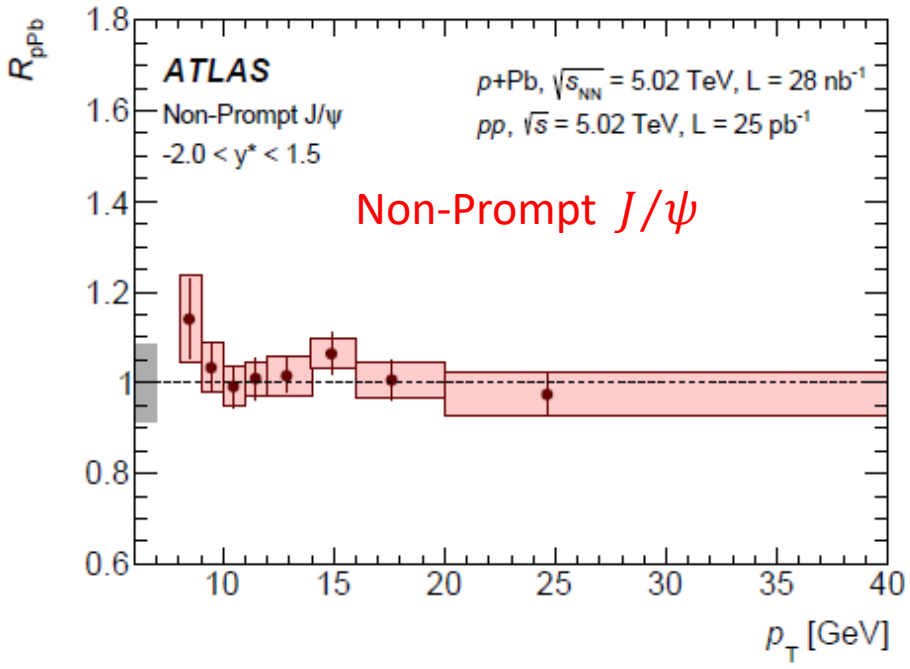


Suppression for low p_T $\Upsilon(1S)$ indicates a modification of nuclear parton distribution functions. No signifcant rapidity dependence.

arXiv:1709.03089

Nuclear modification factor of J/ψ (R_{pPb})



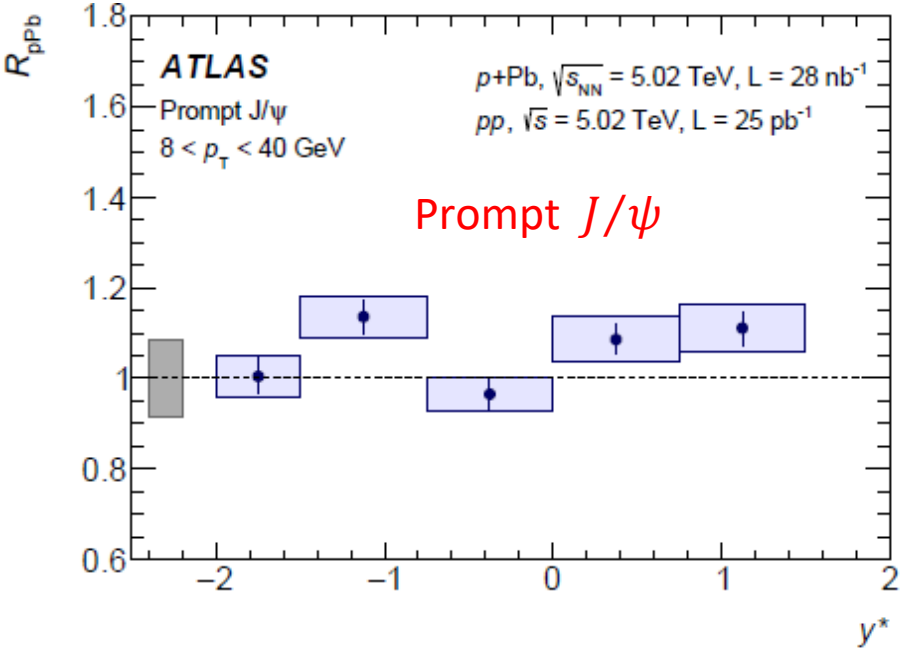


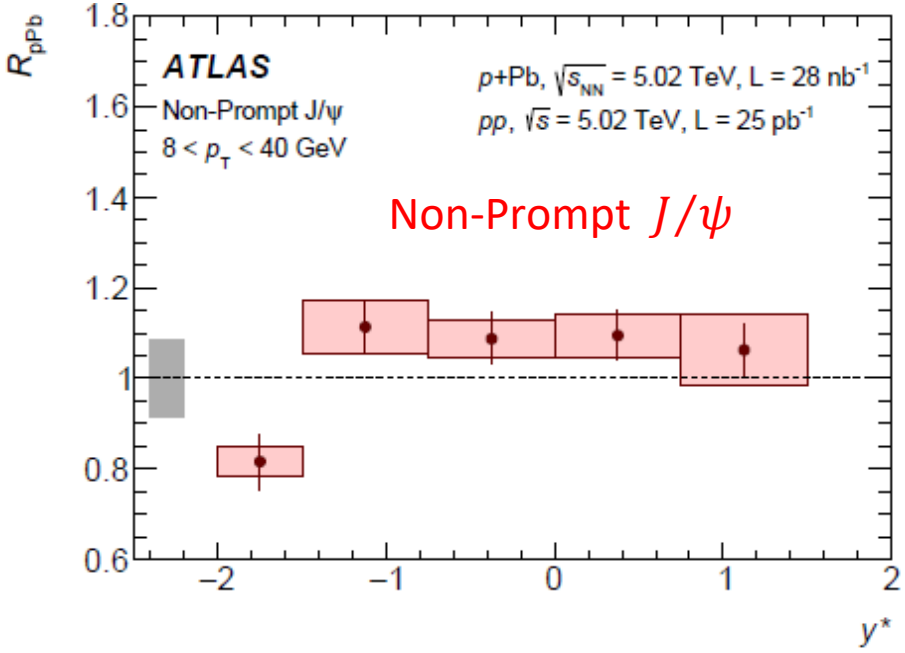
The J/ψ R_{pPb} as a function of p_T are consistent with unity across p_T range within correlated and uncorreletad uncertainties.

R_{AA} < 1 mean suppresion

arXiv:1709.03089

Nuclear modification factor of J/ψ (R_{pPb})





D meson
FNOLL error contributions

- renormalisation & factorisation scale variations
- charm quark mass & PDFs uncertainty

for more reference: arXiv: 1205.6344 [hep-ph]