ATLAS results on heavy flavour production and its relation to quark matter

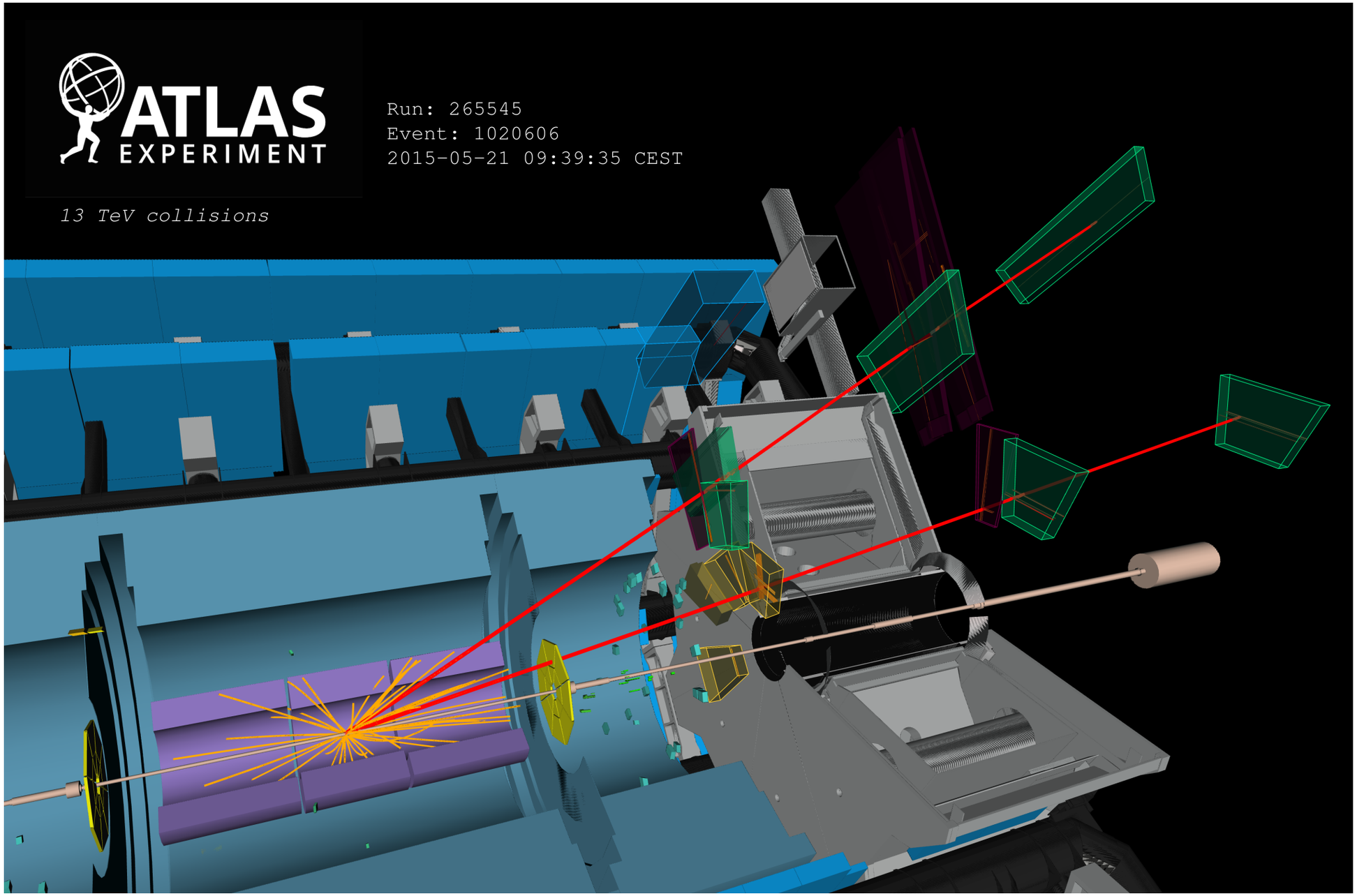
Marisilvia Donadelli

on behalf of the ATLAS Collaboration

Strangeness in Quark Matter 2015

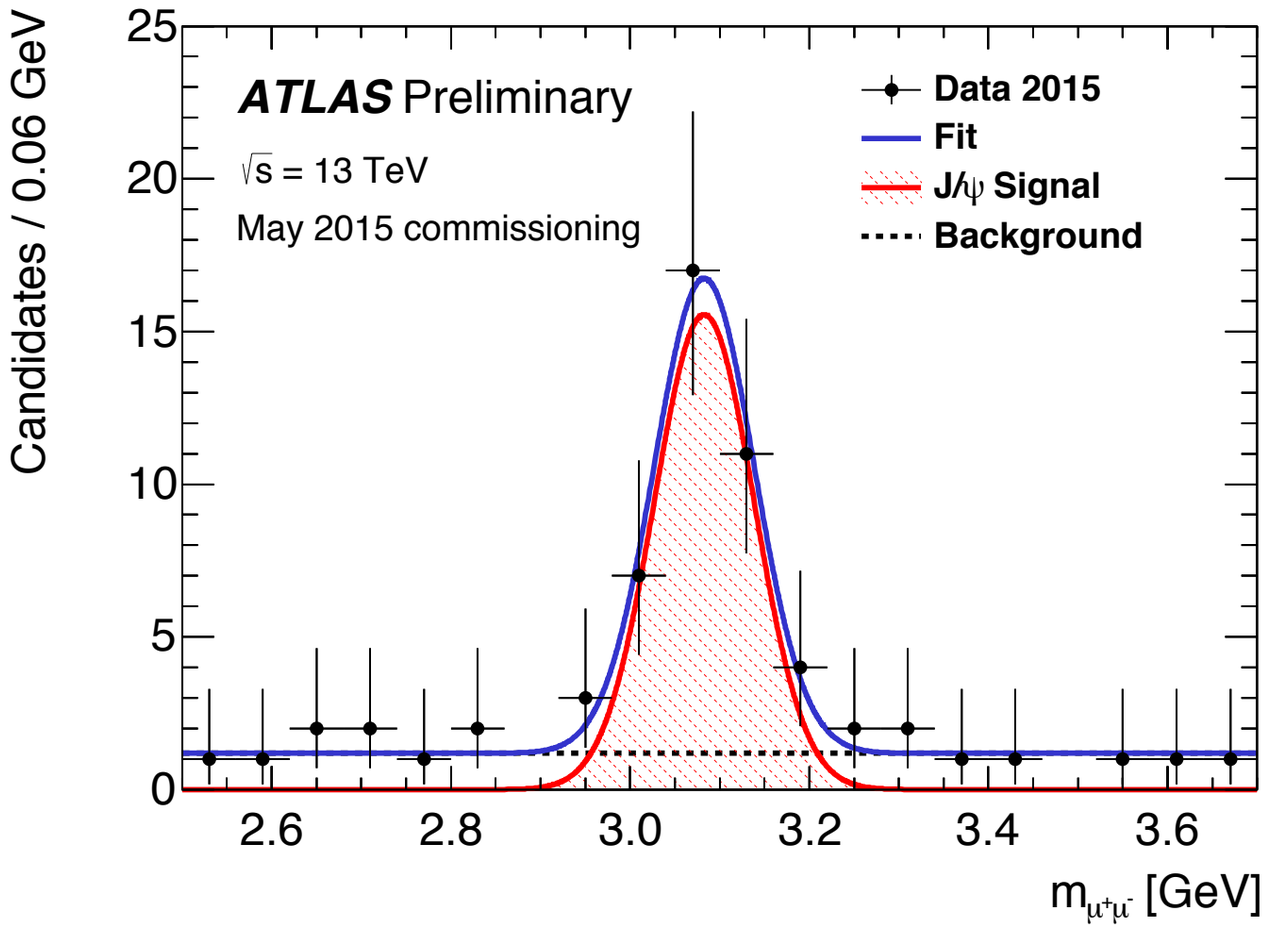
DUBNA 2015

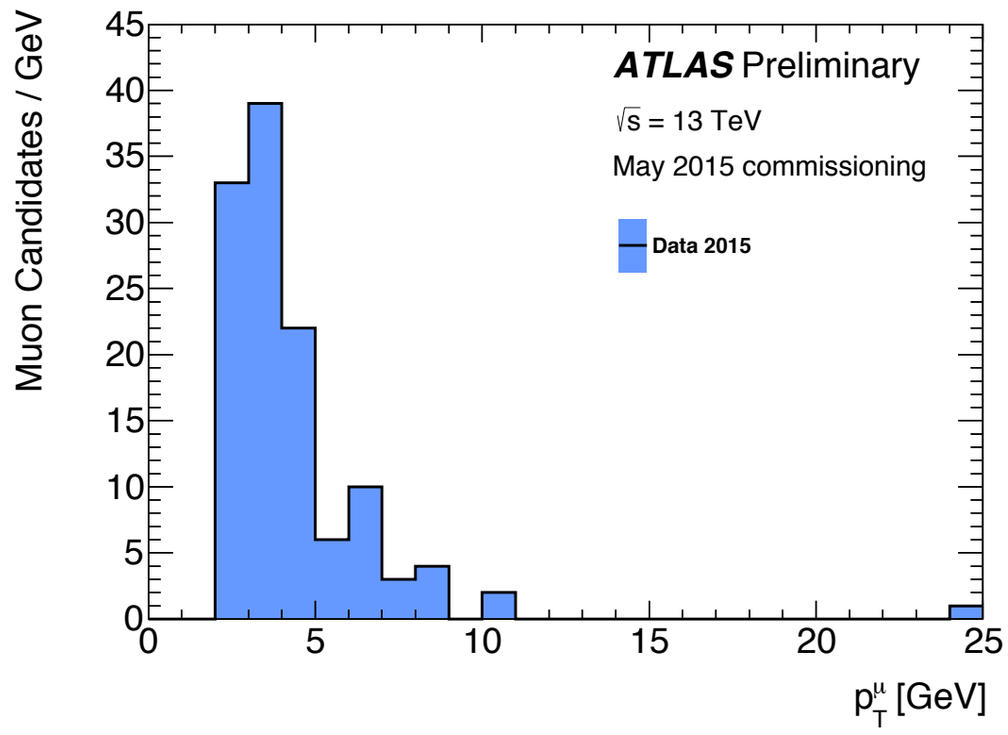
Wetting our appetite…

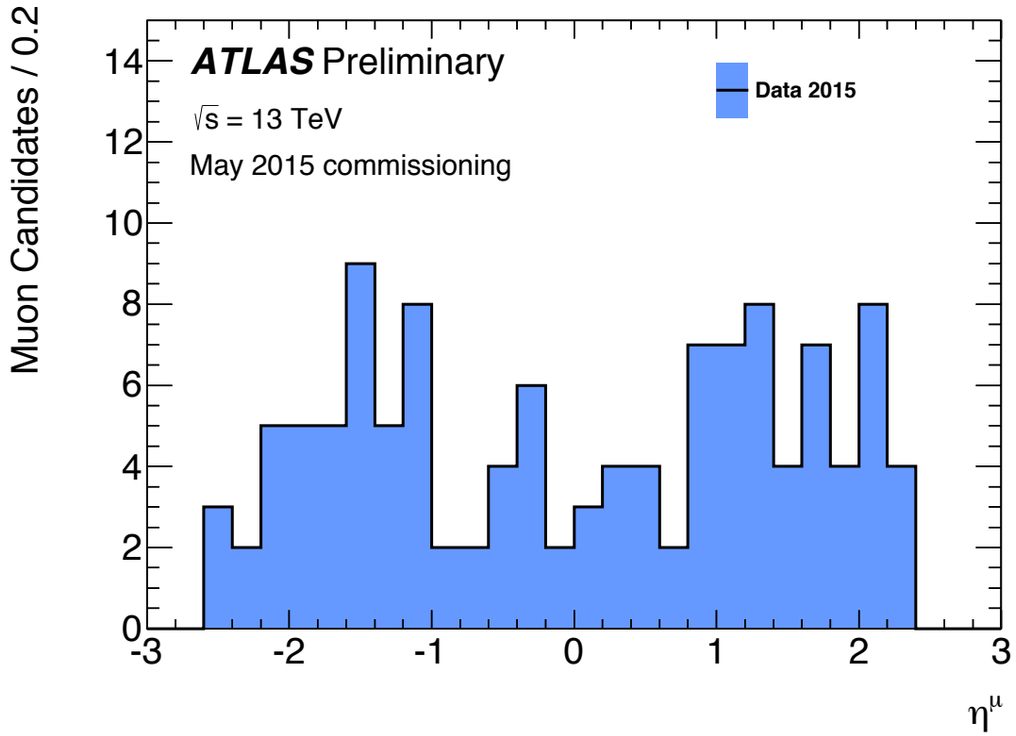


Display of a J/Ψ candidate event from proton-proton collisions recorded by ATLAS on 21 May 2015, with LHC stable beams at a collision energy of 13 TeV. The red lines show the paths of two muons through the detector, with transverse momenta of 5.6 and 8.2 GeV. The green and yellow bars indicate energy deposits in the liquid argon and scintillating-tile calorimeters. Charged particle tracks reconstructed from hits in the inner tracking detector are shown as orange arcs, curving in the solenoidal magnetic field. The reconstructed dimuon invariant mass is 3.12 GeV.

J/ψ→μ+μ- candidates in pp collisions @ 13 TeV pp collisions

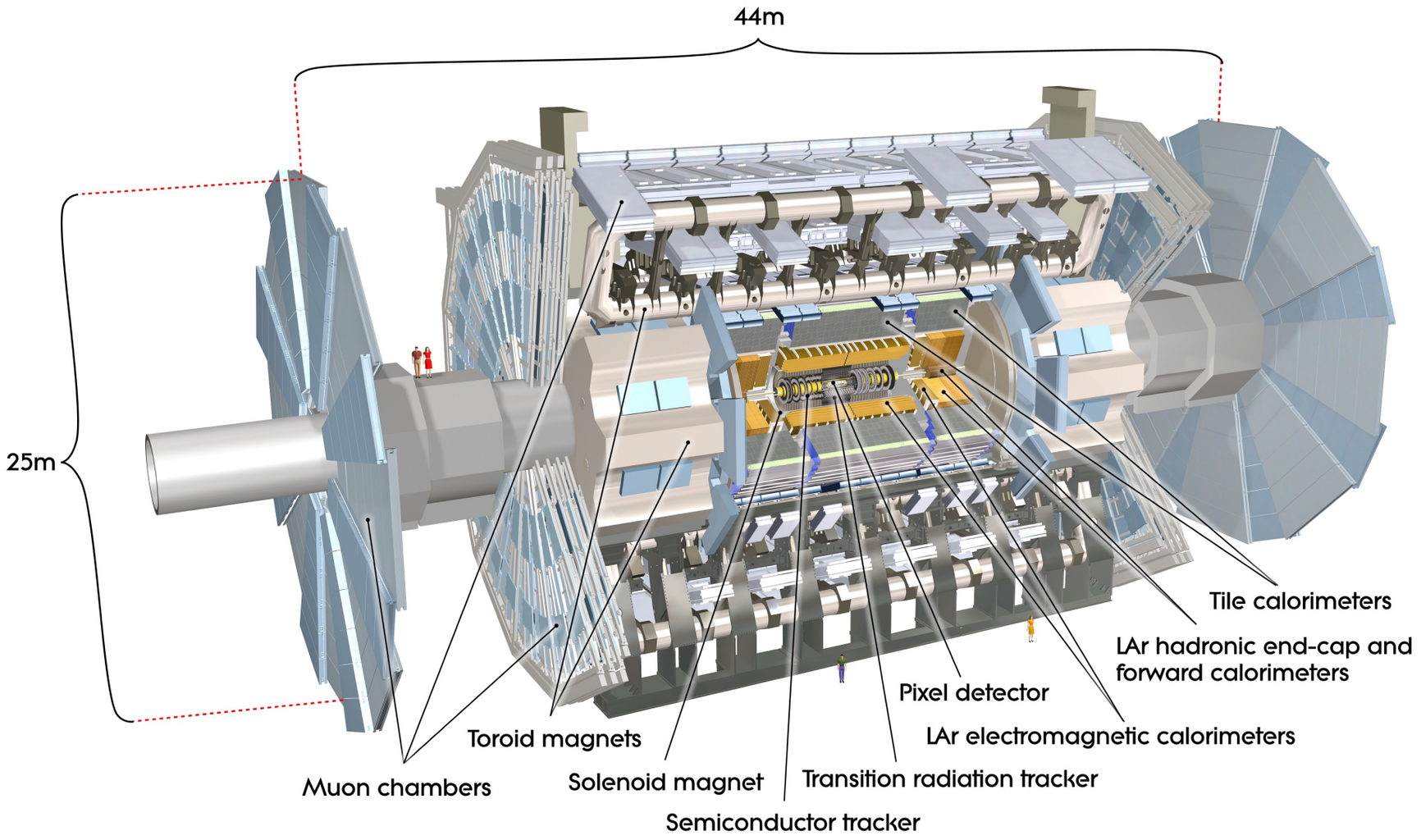






Data taken during "quiet beams" delivered as part of the LHC beam commissioning period in May 2015

ATLAS Detector



Inner Detector – Tracking $|\eta|<2.5$

Calorimetry – $|\eta|<4.9$

Muon Spectrometer - $|\eta|<2.7$

p+Pb @ 5.02 TeV and pp @ 2.76 TeV
Motivations

Why p+Pb collisions?

Suppression of quarkonium yields in nucleus-nucleus collisions is one key feature of the hot quark-gluon plasma (QGP), but the baseline should be determined from Cold Nuclear Matter (CNM) effects.

Several Phenomenological interpretations proposed to explain suppression in p+A, d+A:

nuclear absorption;
modifications of parton distribution functions in nuclei (shadowing),
gluon saturation;
induced medium energy loss.

Why pp collisions?

Tests of QCD calculations at the perturbative / non-perturbative boundary.

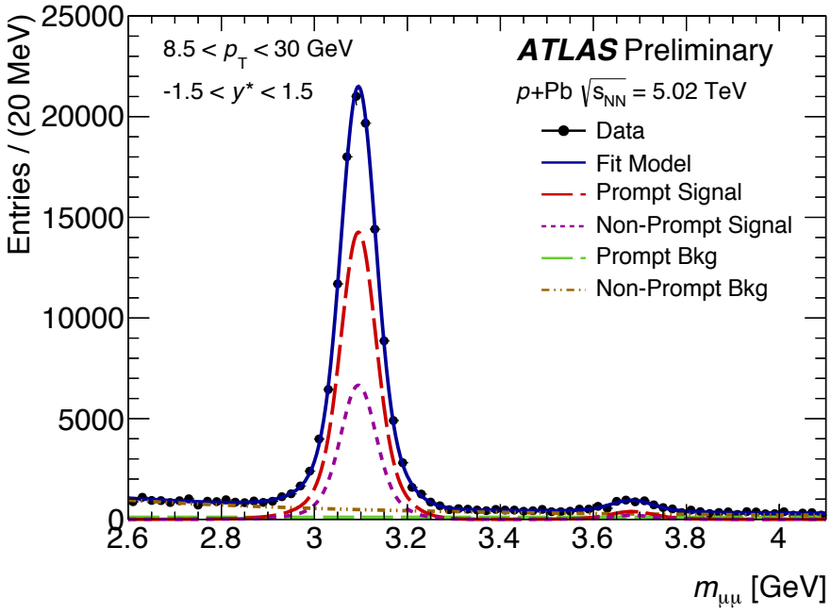
Standard candles for Heavy Ions, B-meson production, backgrounds to SM/BSM processes.

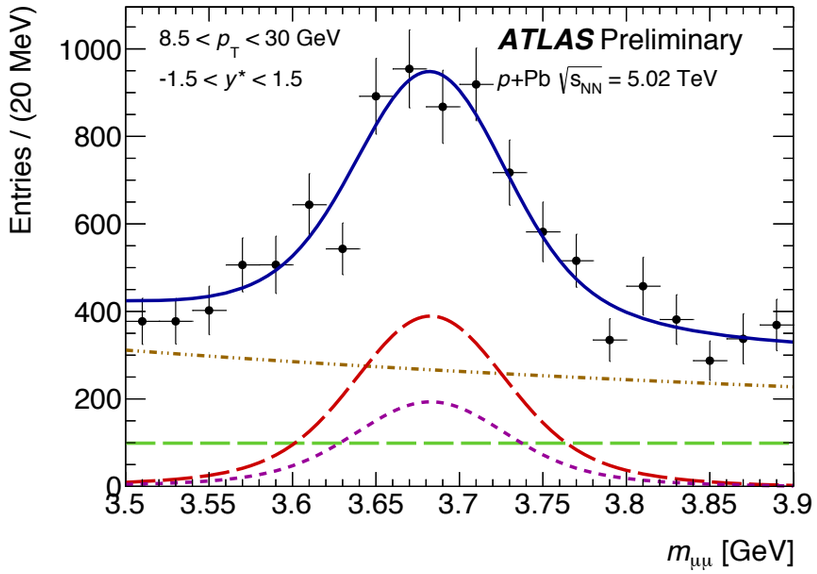
Test multiple parton scattering effects, parton density functions.

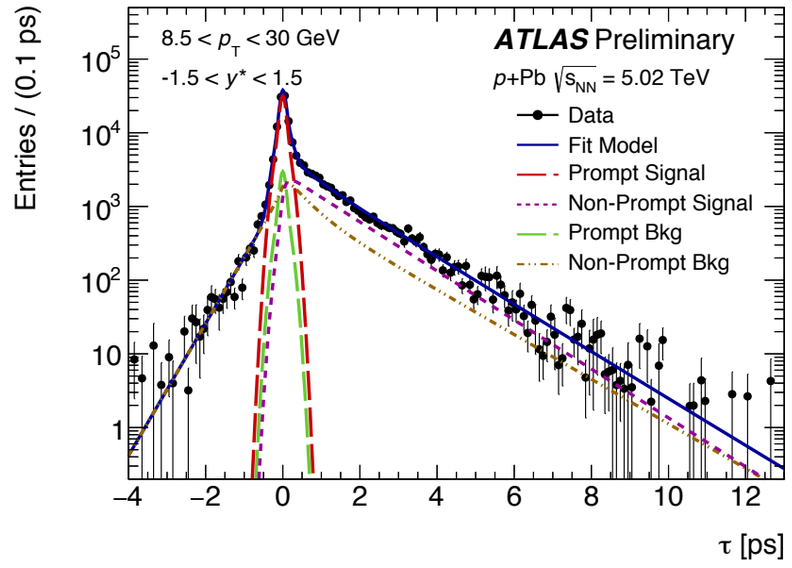
Search for rare decays and probes of new physics.

ψ(2S) and J/ψ @ 5.02 TeV p+Pb and @ 2.76 TeV pp

p+Pb







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	ψ(2S) S	P	$\omega_i CB_2(m) + (1-\omega_i)G_2(m)$	$\delta(\tau)$
4	ψ(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	$E_5(m)$	$E_6(\|\tau\|)$

CB: Crystal Ball function

G: Gaussian

E(τ) - single sided exponential;

E(|τ|) - double sided exponential

δ:delta function

ω: fraction of CB function in the signal

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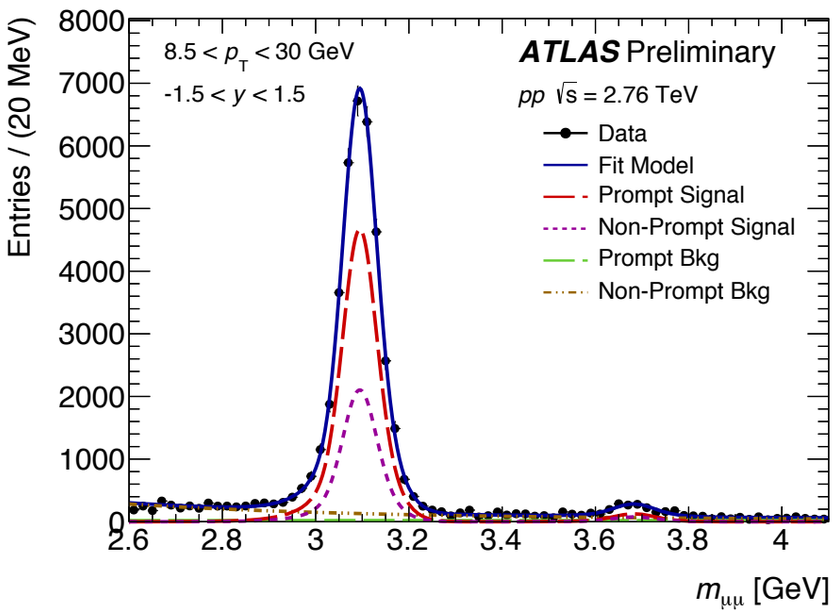
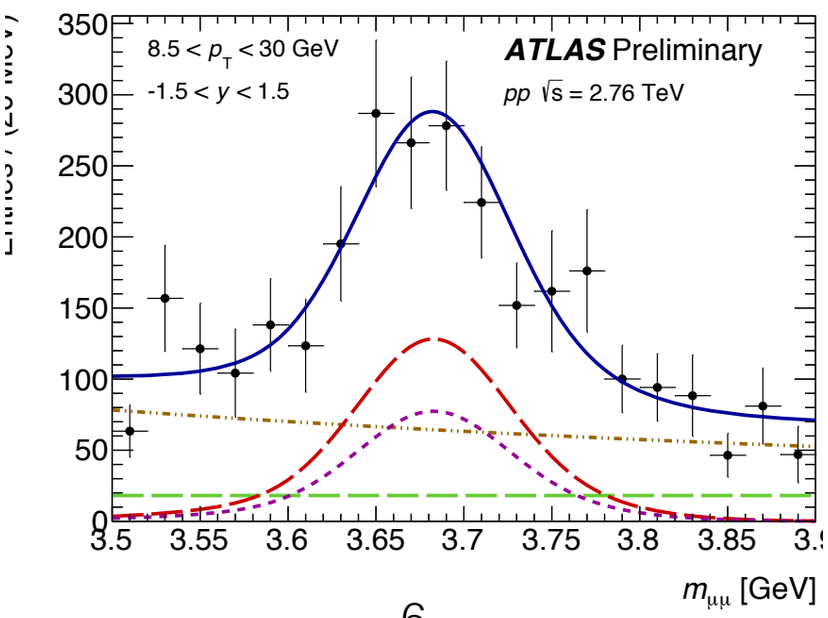
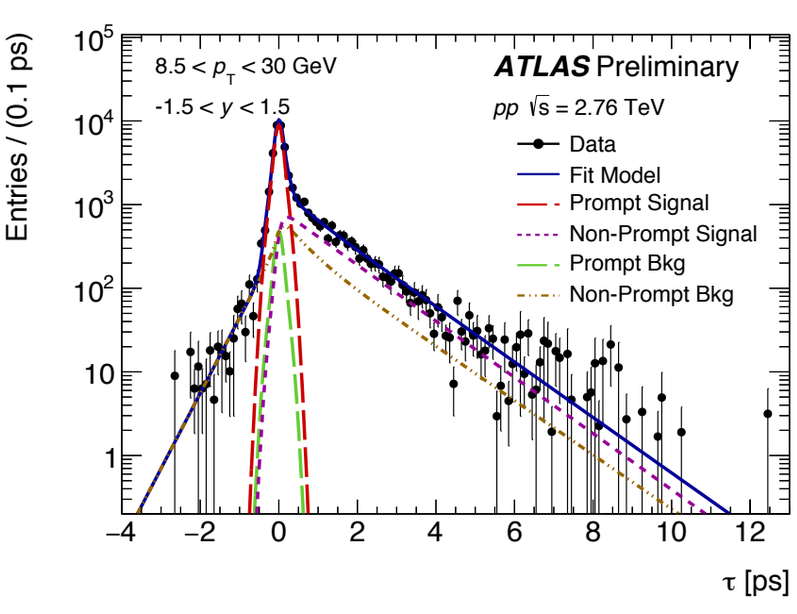
pp

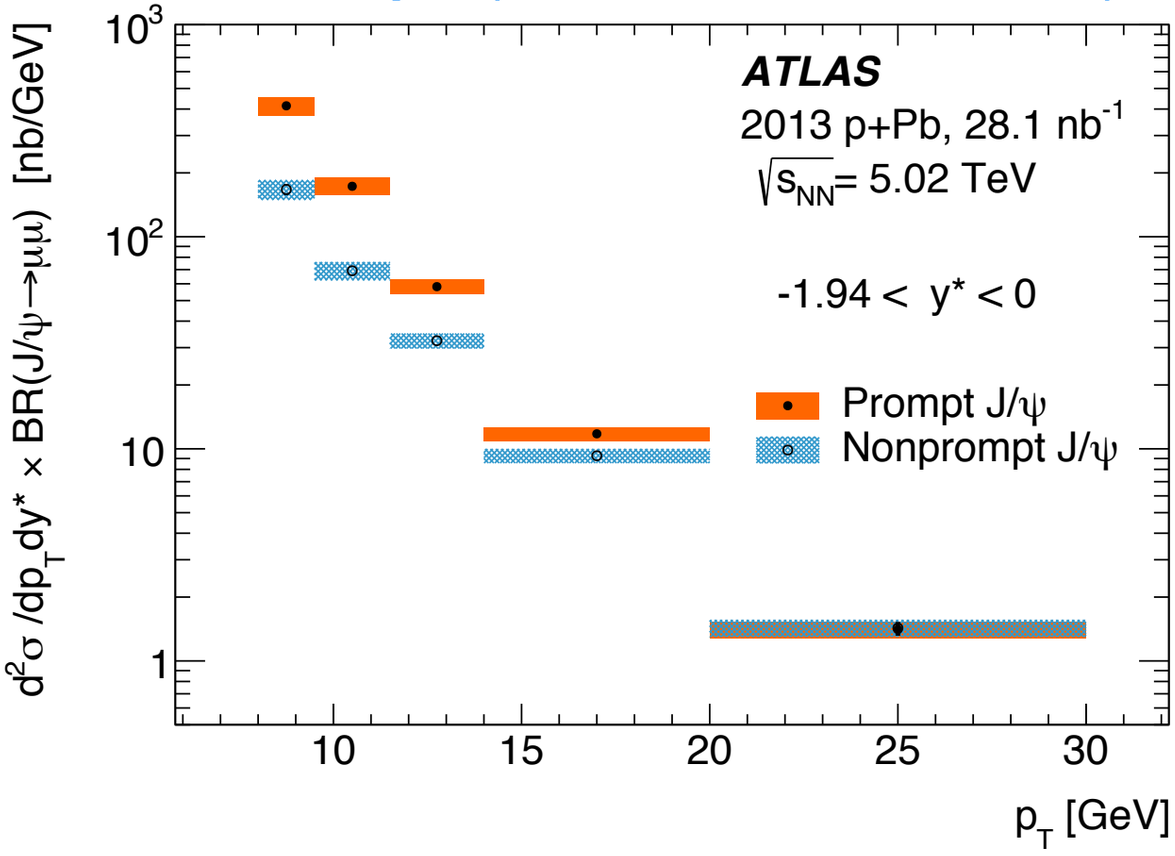




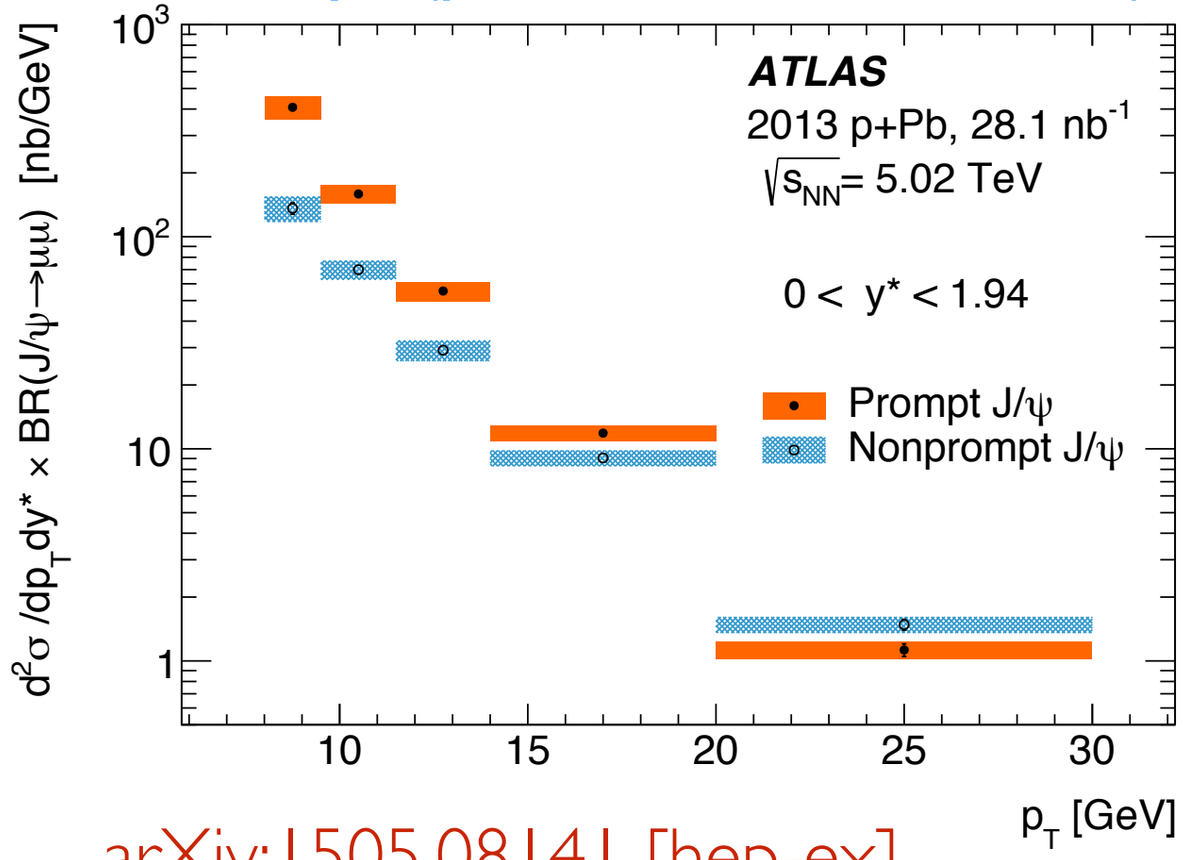


Double differential cross sections for prompt and non-prompt J/ψ @ 5.02 TeV p+Pb

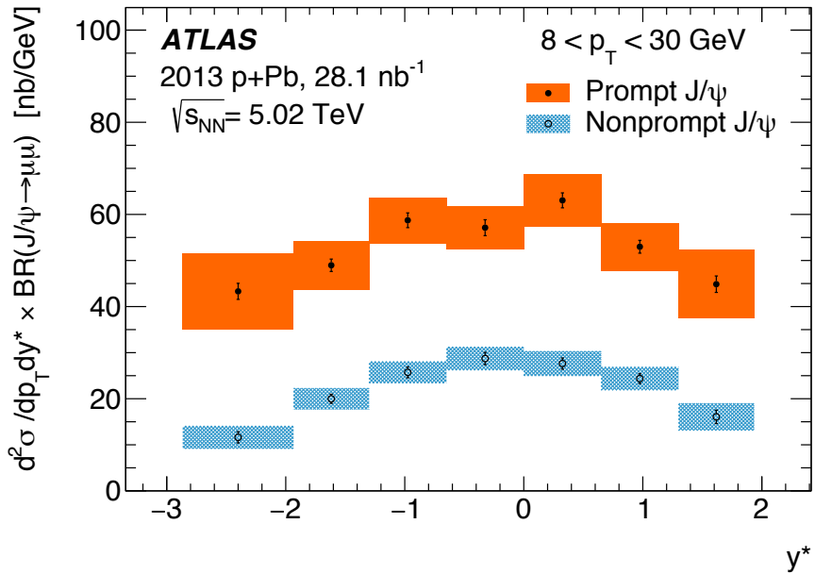
backward y* (lead beam direction)

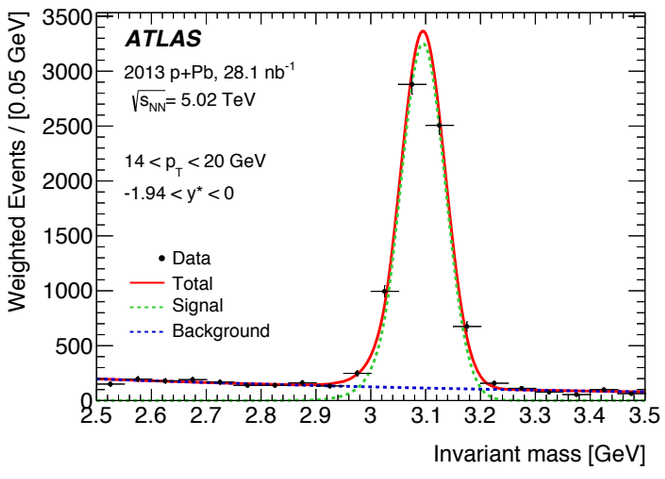


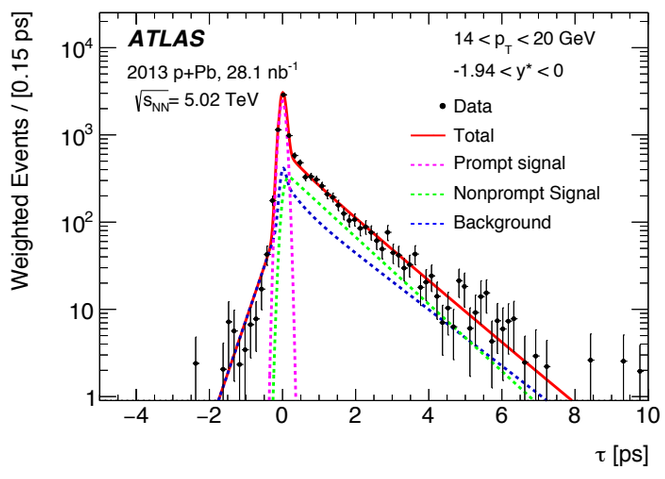
forward y* (proton beam direction)



arXiv:1505.08141 [hep-ex]

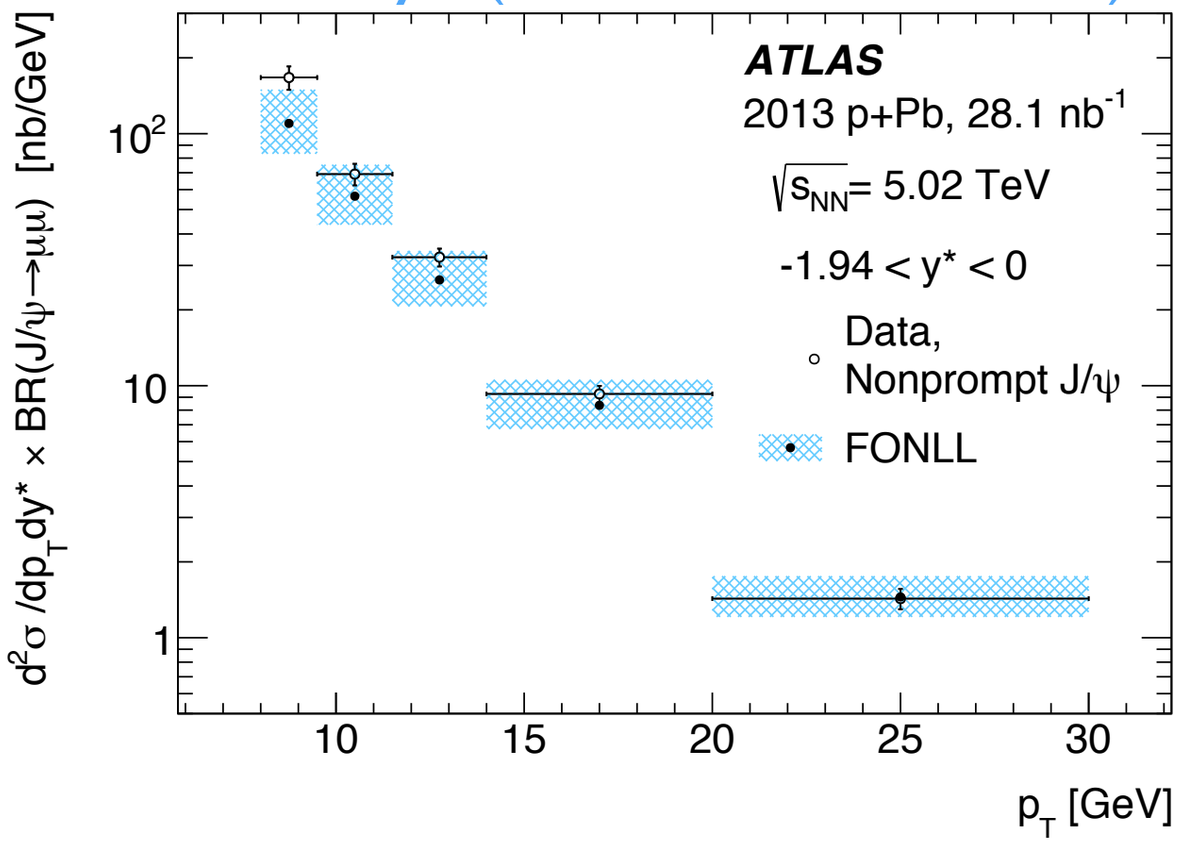




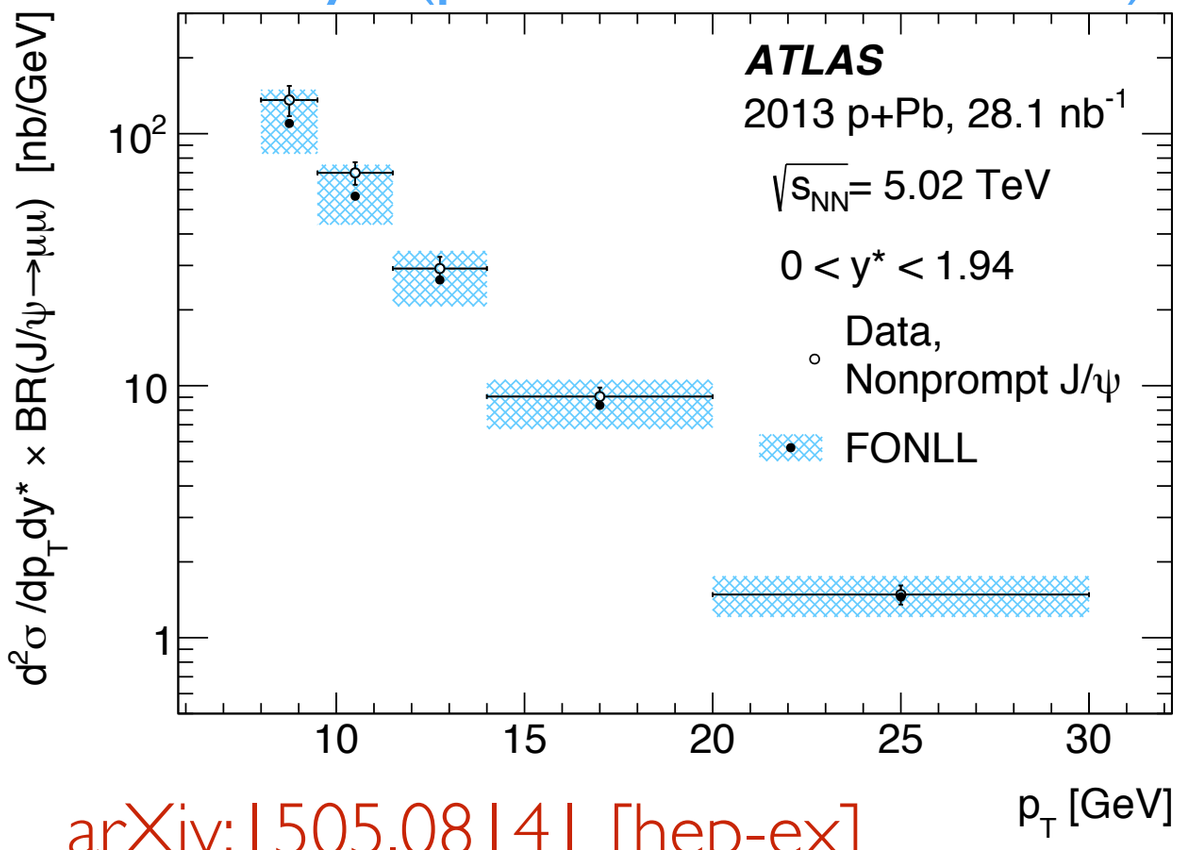


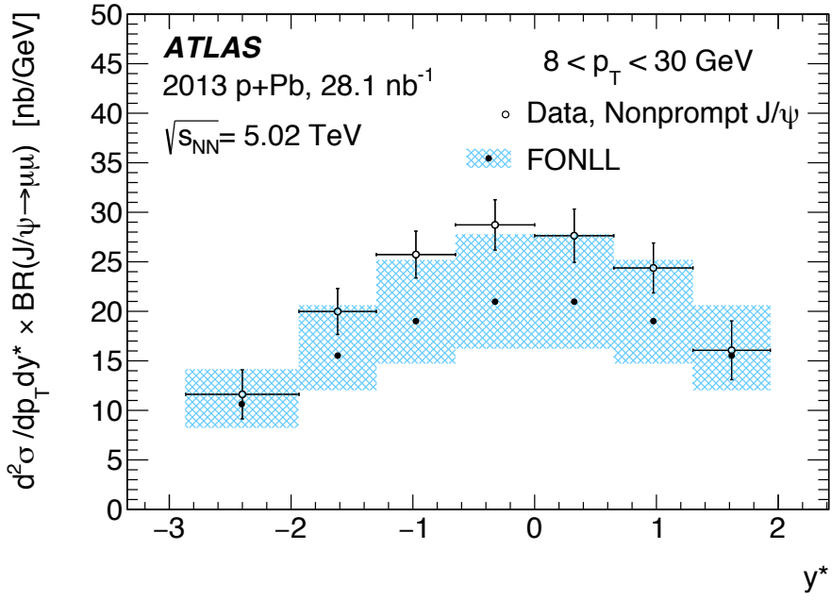
Double differential cross sections for non-prompt J/ψ @ 5.02 TeV p+Pb

backward y* (lead beam direction)



forward y* (proton beam direction)





arXiv:1505.08141 [hep-ex]

Comparison with a FONLL calculation for pp collisions scaled by the number of nucleons in the Pb ion.

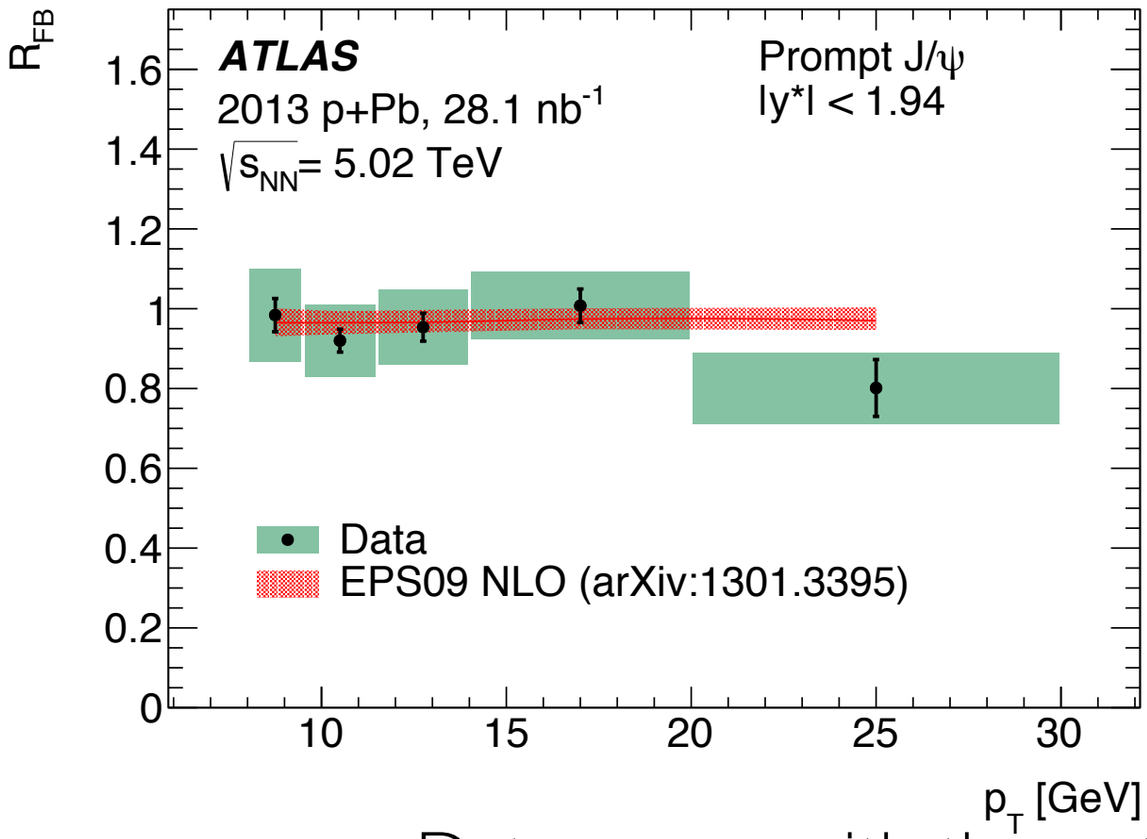
Shaded boxes: theoretical uncertainties on the FONLL predictions, which are strongly correlated between bins.

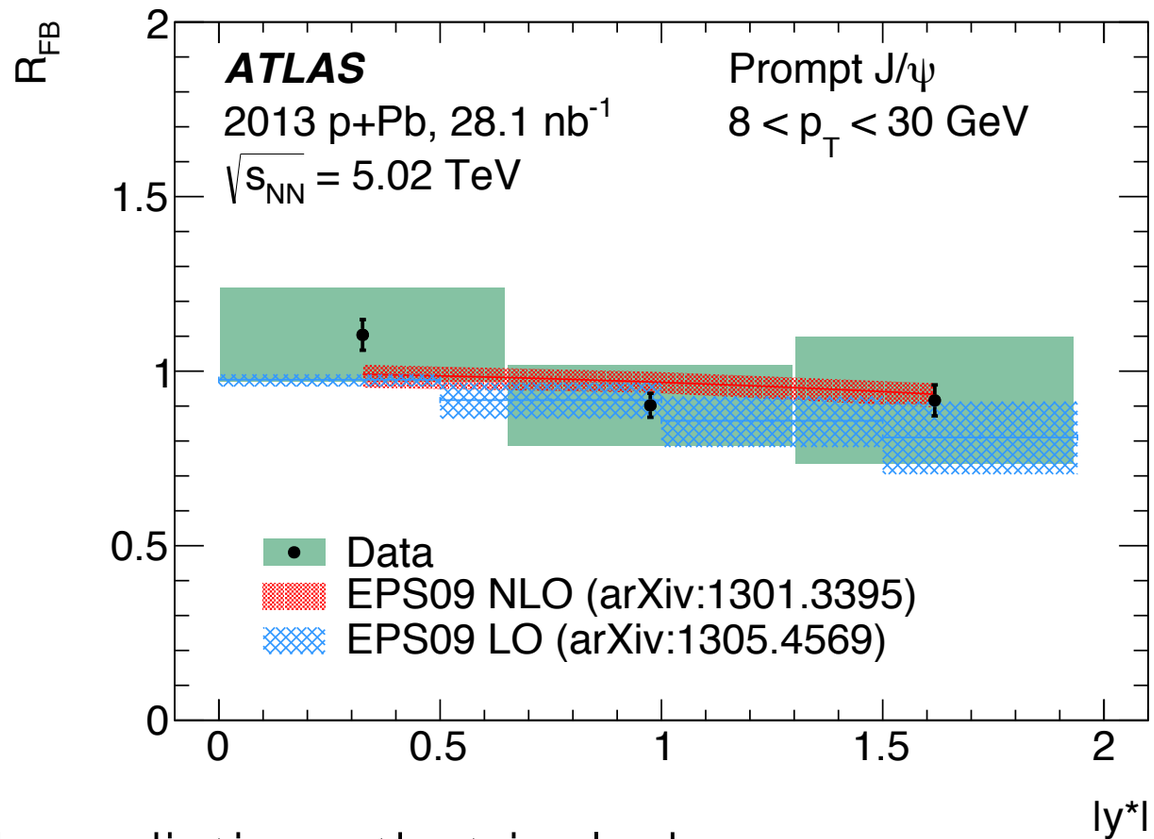
Forward-backward ratios of J/ψ @ 5.02 TeV p+Pb

$$R_{\mathrm{FB}}(p_{\mathrm{T}}, y^*) \equiv \frac{d^2\sigma(p_{\mathrm{T}}, y^* > 0)/dp_{\mathrm{T}}dy^*}{d^2\sigma(p_{\mathrm{T}}, y^* < 0)/dp_{\mathrm{T}}dy^*}$$

arXiv:1505.08141 [hep-ex]

Prompt component





Data agrees with theoretical predictions that include shadowing effects based on EPS09 nPDF

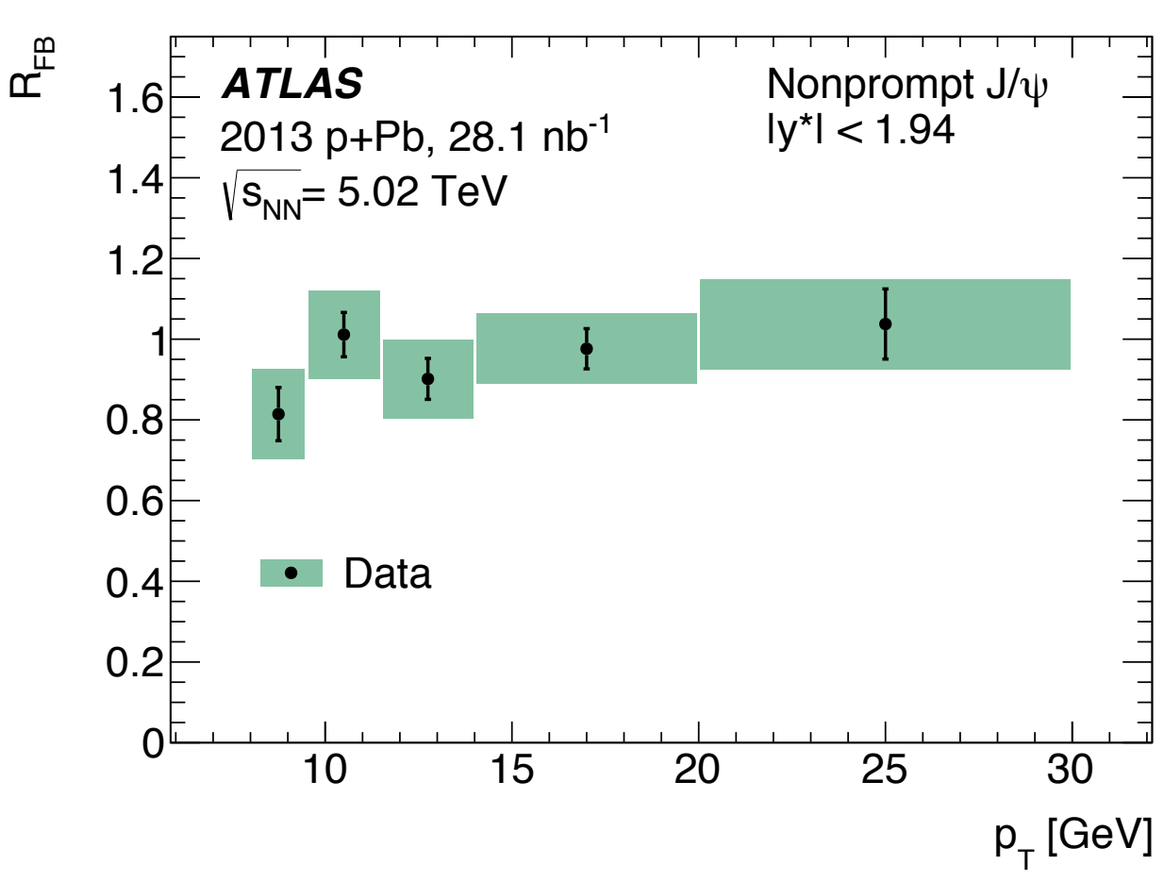
ALICE inclusive J/ψ: R_{FB}~0.6, y*~3-3.5, p_T<15 GeV

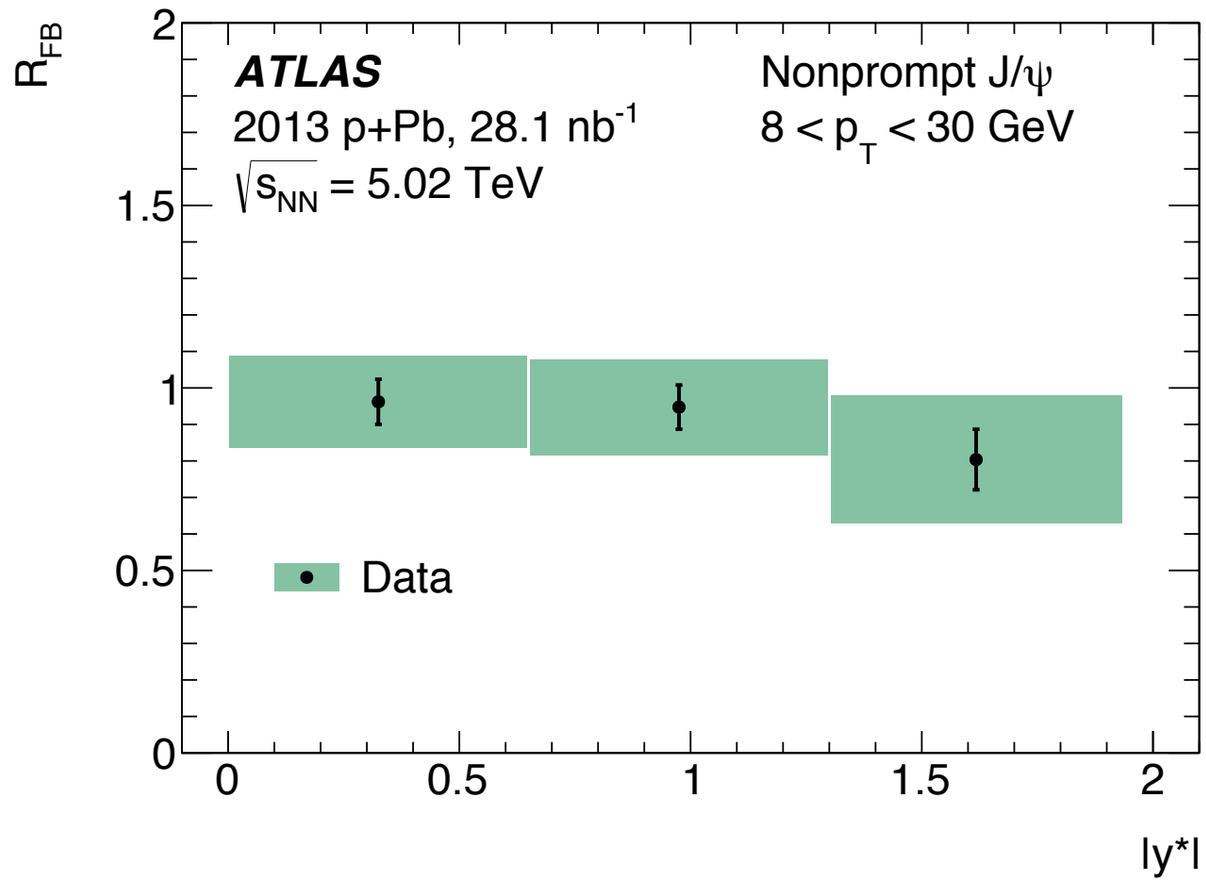
LHCb results: ~0.75 for y=2.8 for prompt J/ψ p_T<15 GeV

Forward-backward ratios of J/ψ @ 5.02 TeV p+Pb

Non-prompt component

arXiv:1505.08141 [hep-ex]





LHCb non-prompt J/ψ: ~0.9, pT<15 GeV

Non-prompt J/ψ and ψ(2S) @ 2.76 TeV pp

$$f_{NP}^{\psi} = \frac{N_{\psi}^{\mathrm{np,\ corr}}}{N_{\psi}^{np,\ corr} + N_{\psi}^{p,\ corr}}$$

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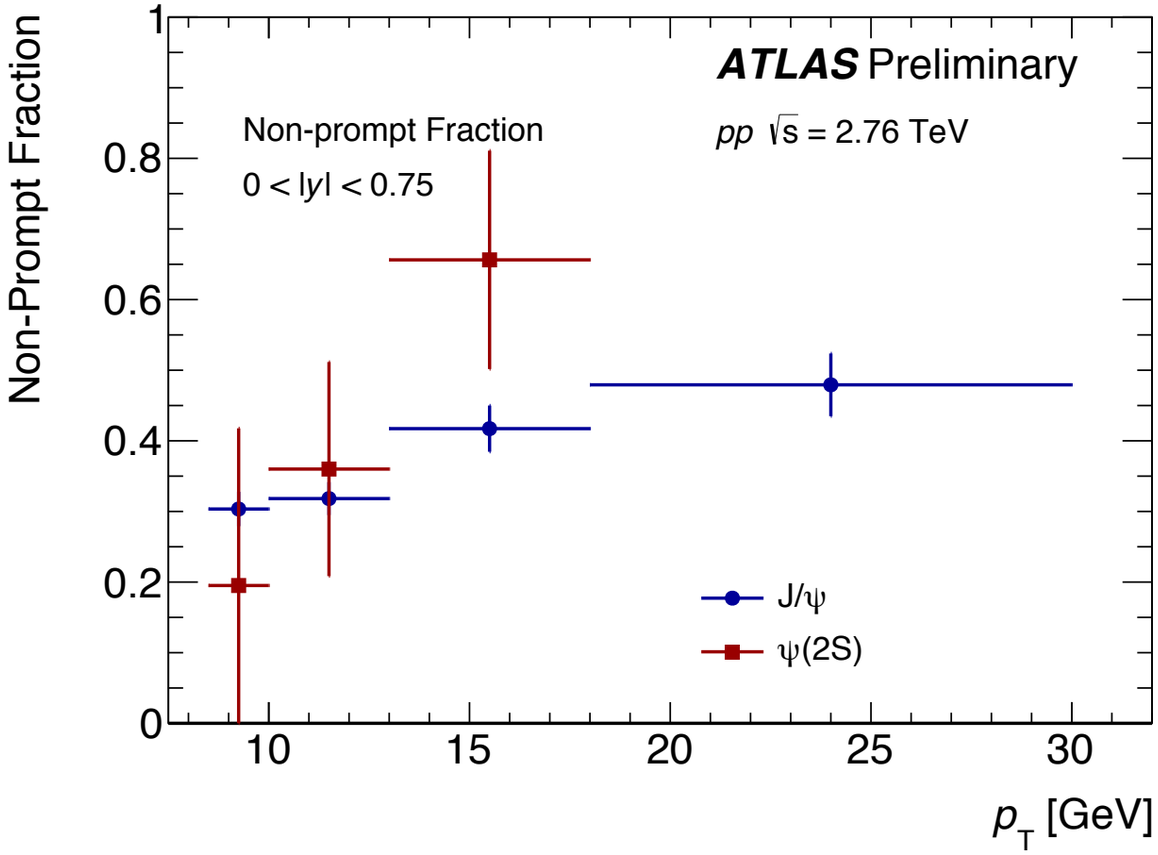
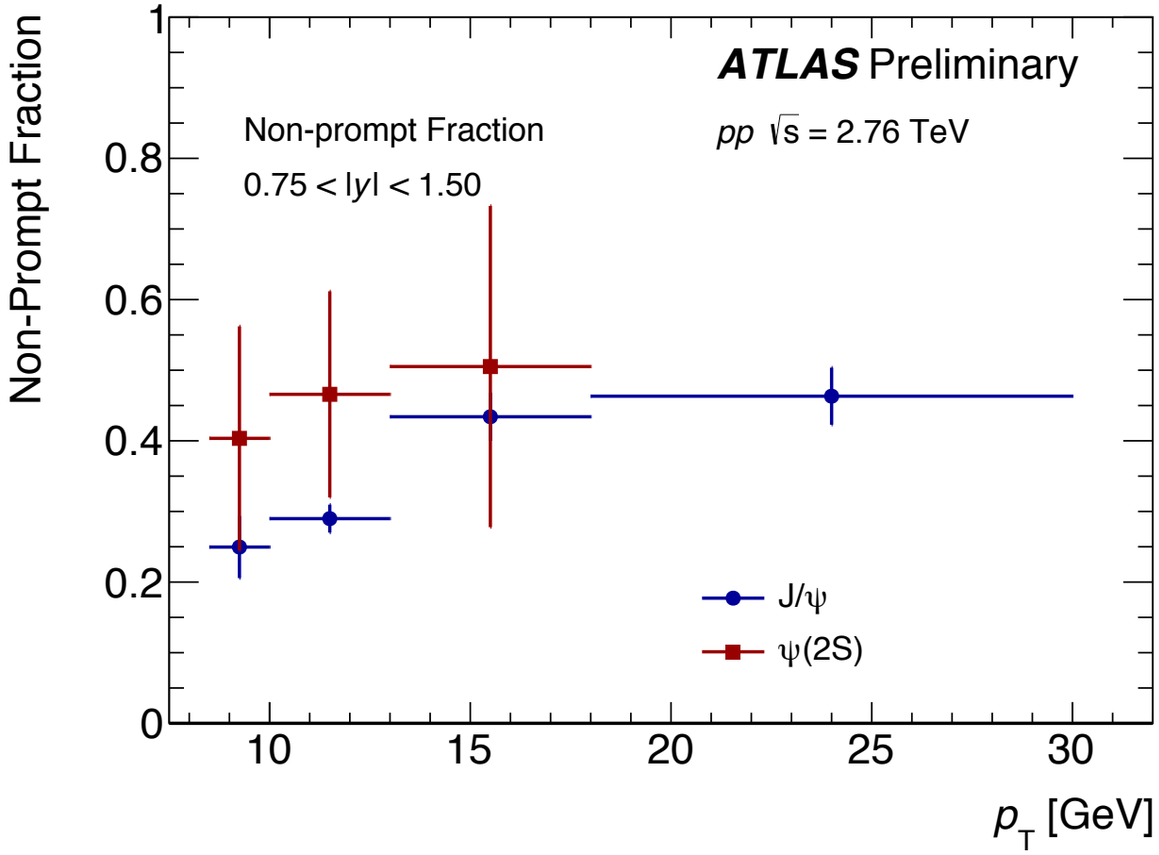
0 < |y| < 0.75



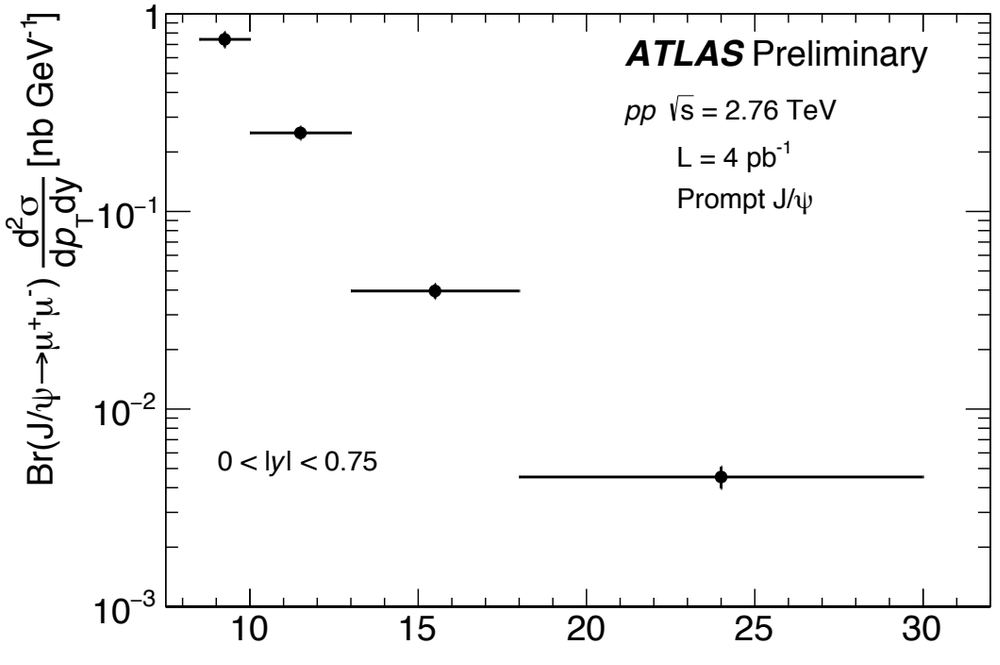
0.75 < |y| < 1.5

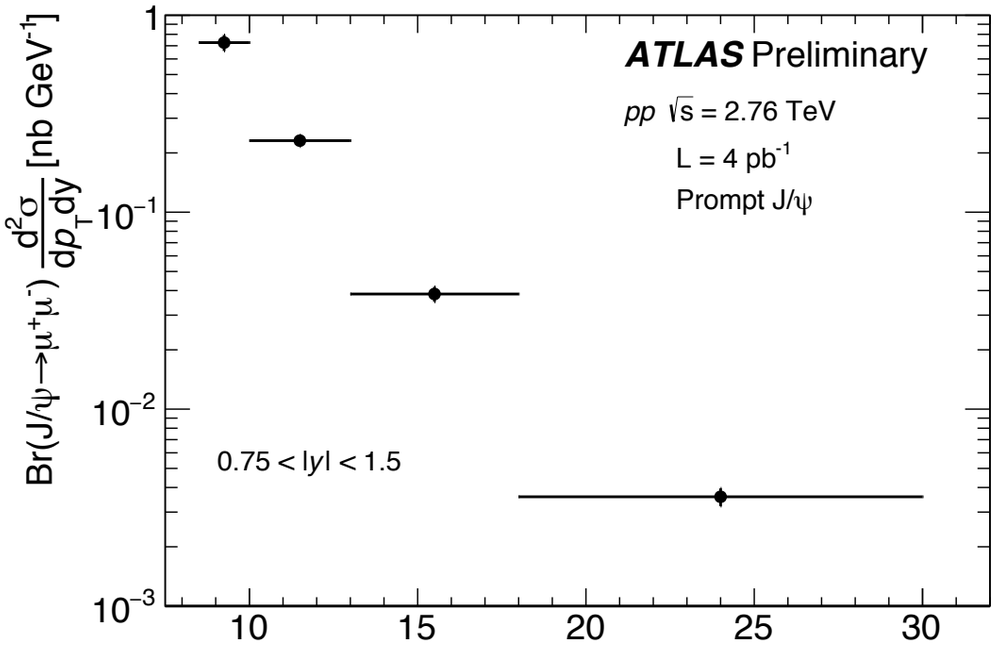


Double differential cross sections for prompt J/ψ and ψ(2S) @ 2.76 TeV pp

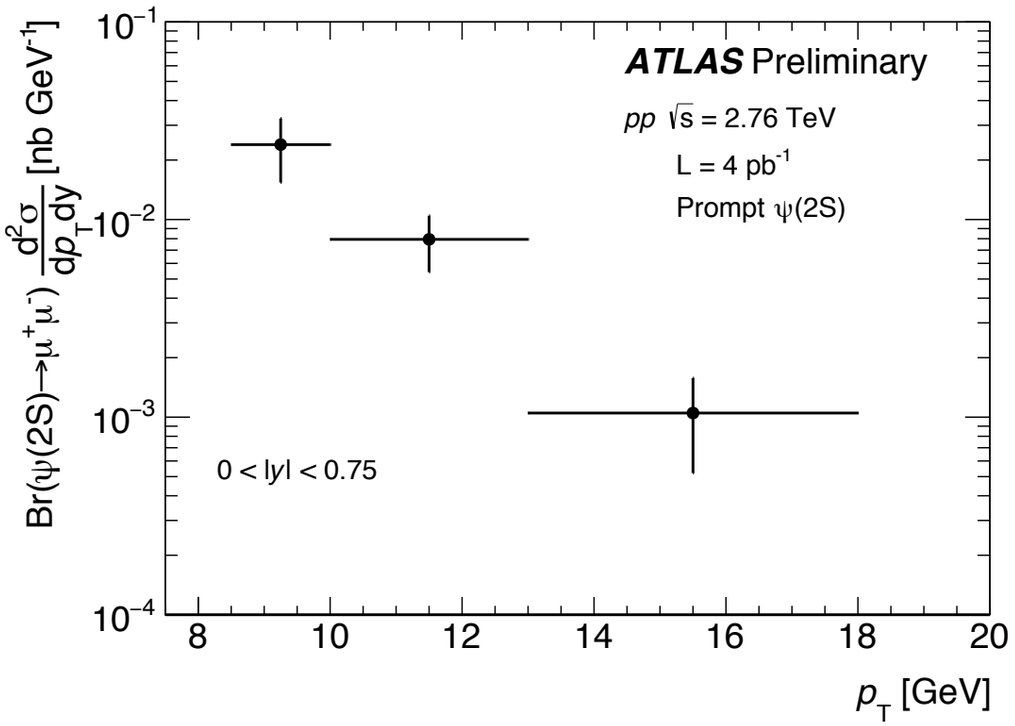
0 < |y| < 0.75 ATLAS-CONF-2015-023 0.75 < |y| < 1.5

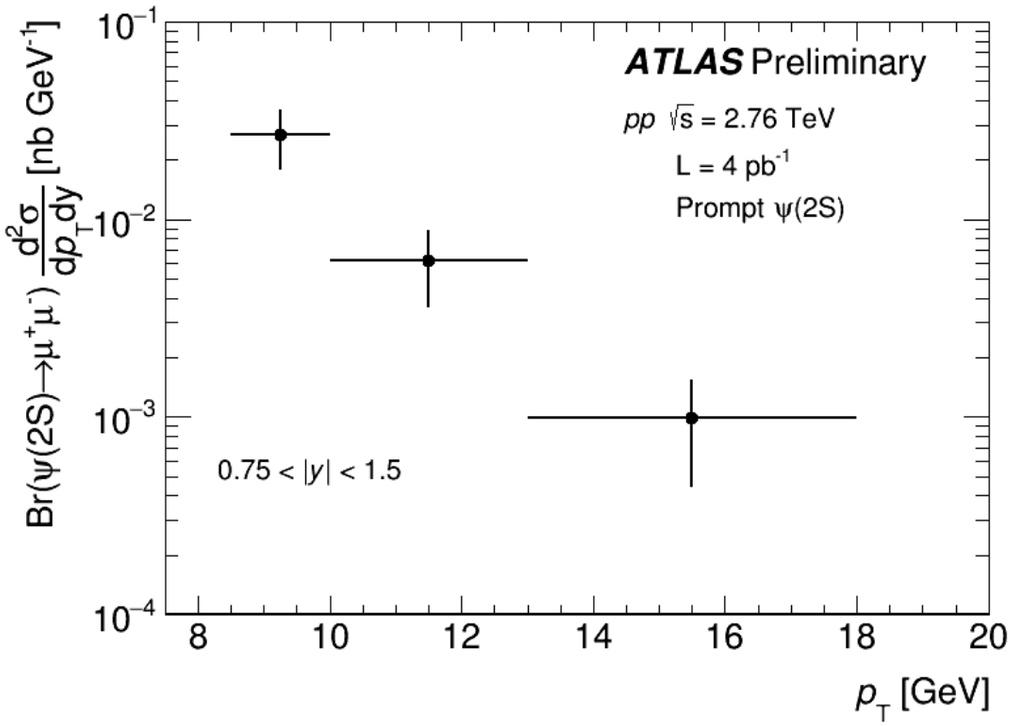
J/ψ





ψ(2S)

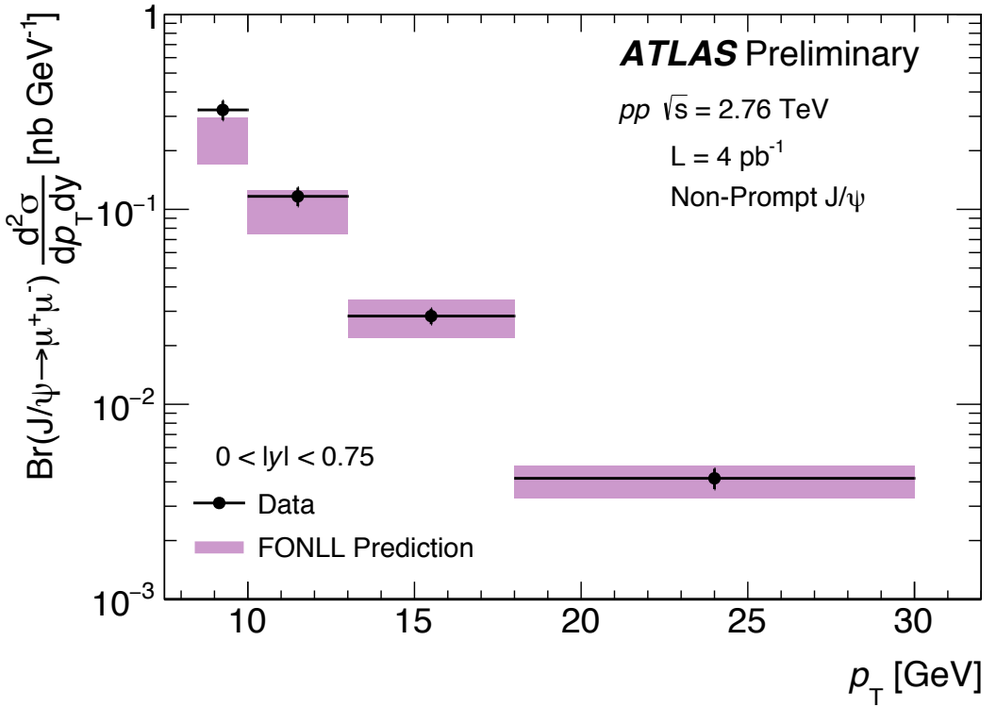


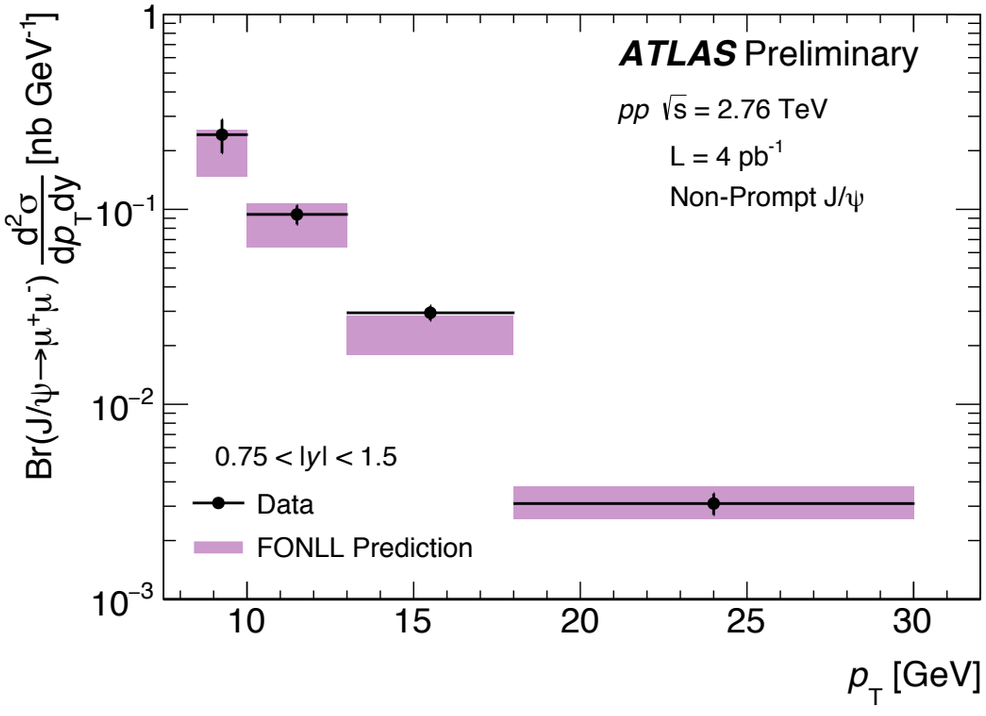


Double differential cross sections for non-prompt J/ψ and ψ(2S) @ 2.76 TeV pp

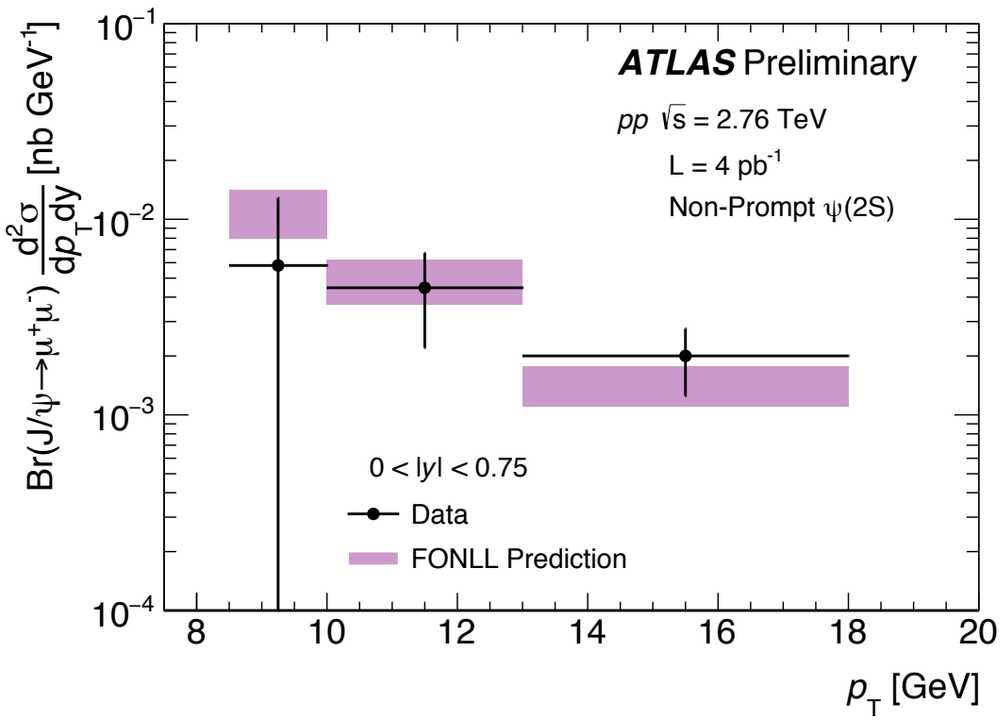
0 < |y| < 0.75 ATLAS-CONF-2015-023 0.75 < |y| < 1.5

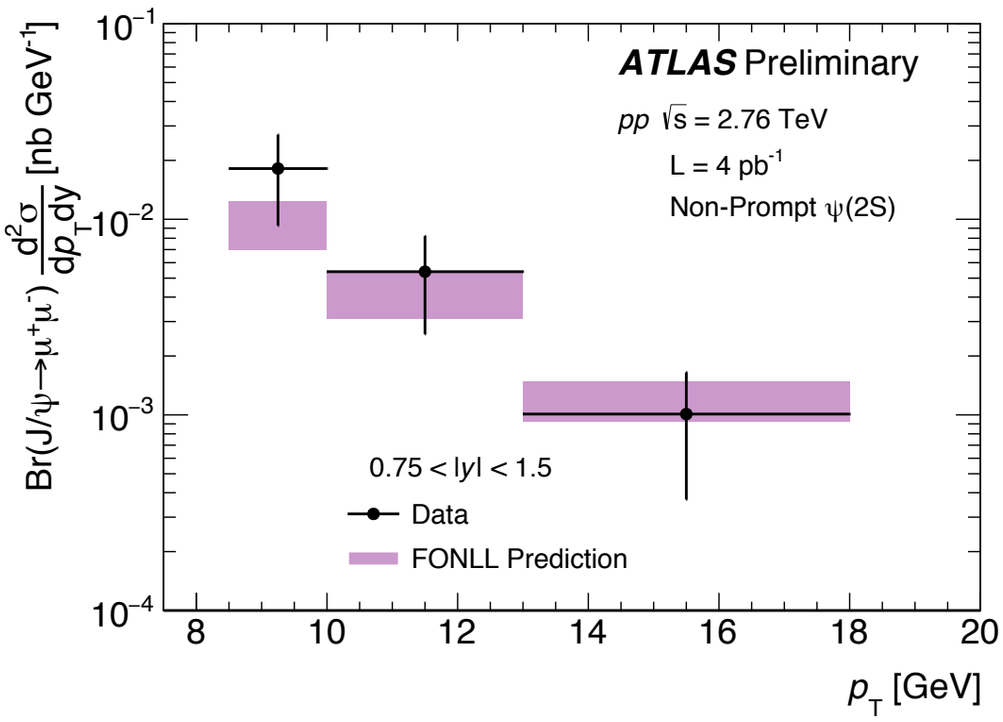
J/ψ





ψ(2S)





Nuclear modification factor J/ψ and ψ(2S) @ 5.02 TeV p+Pb

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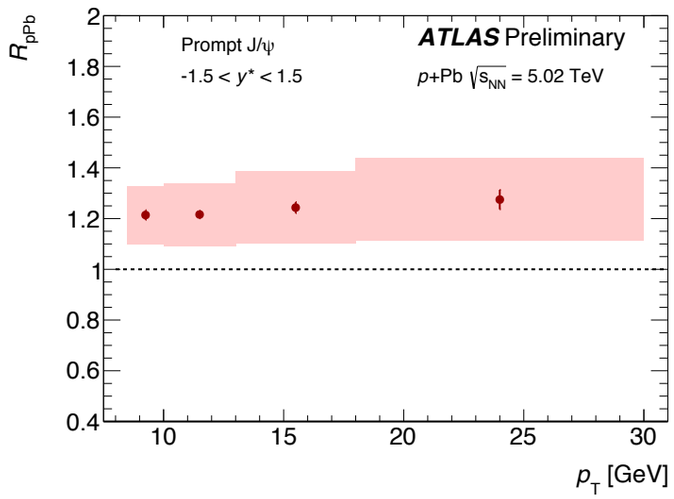
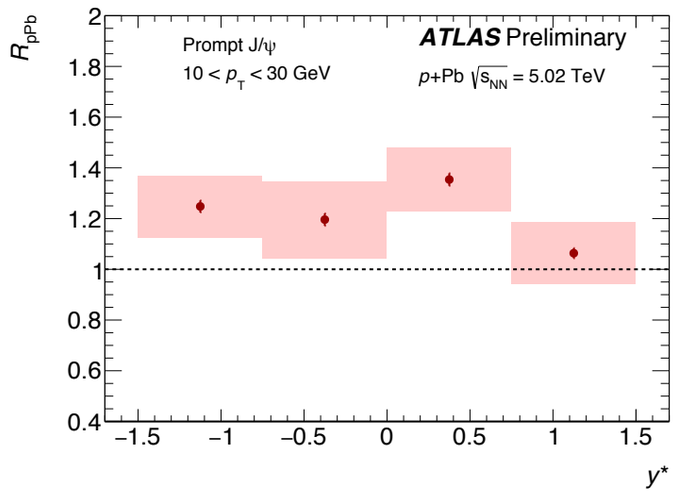
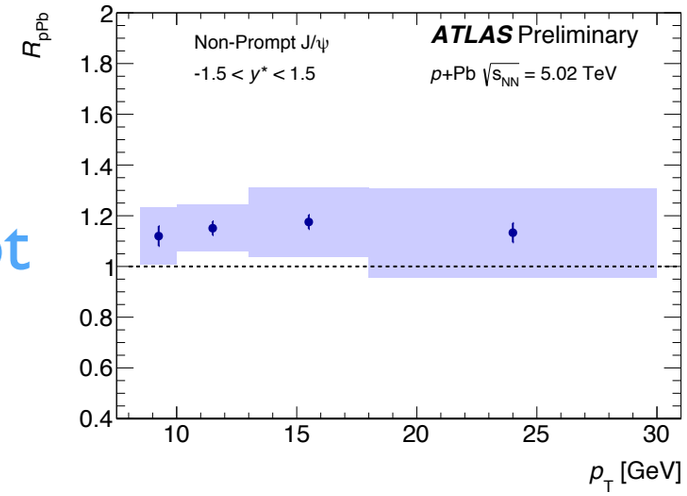
prompt J/ψ

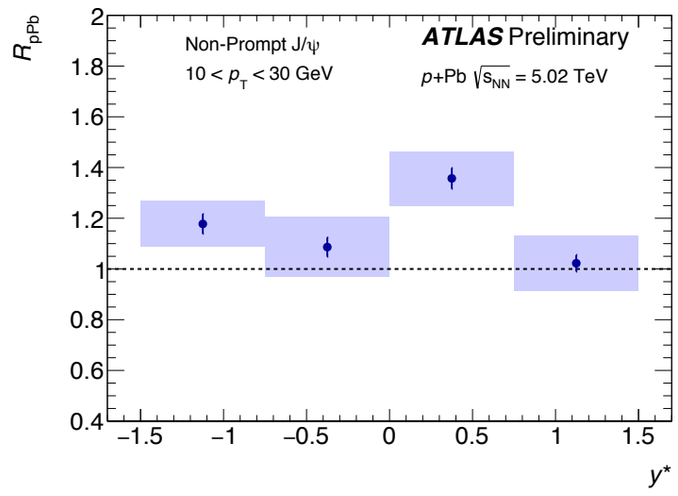
non-prompt J/ψ

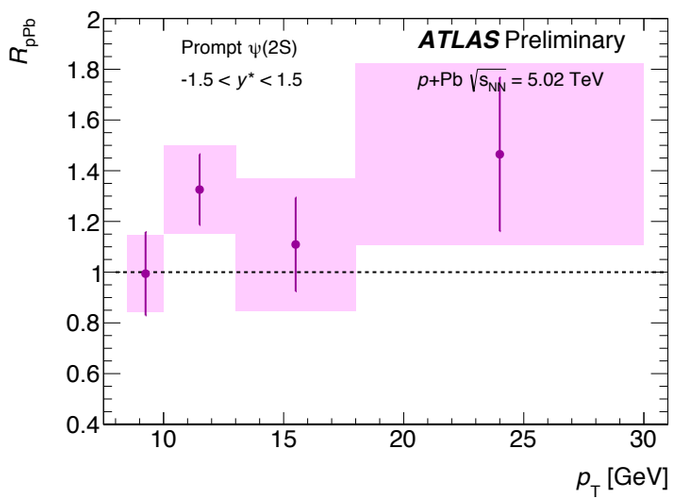
prompt ψ(2S)

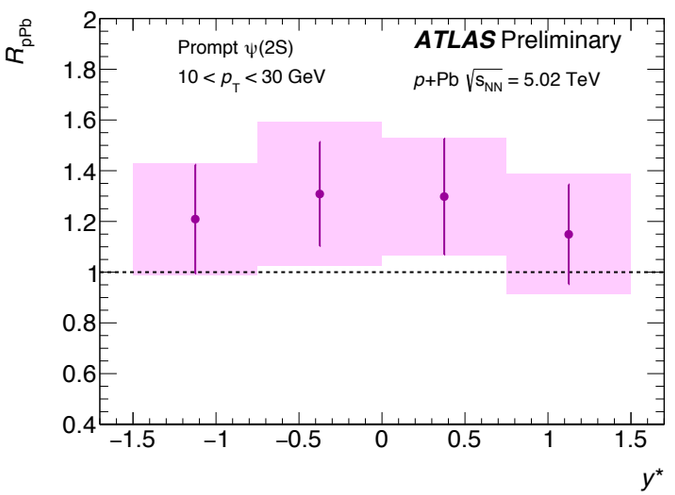












R_{pPb} X p_T , y*

$$R_{p\mathrm{Pb}} = \frac{1}{A^{\mathrm{Pb}}} \frac{d^2\sigma_{\psi}^{p+\mathrm{Pb}}/dy^* dp_{\mathrm{T}}}{d^2\sigma_{\psi}^{pp}/dy dp_{\mathrm{T}}}$$

Nuclear modification factor J/ψ and ψ(2S) @ 5.02 TeV p+Pb

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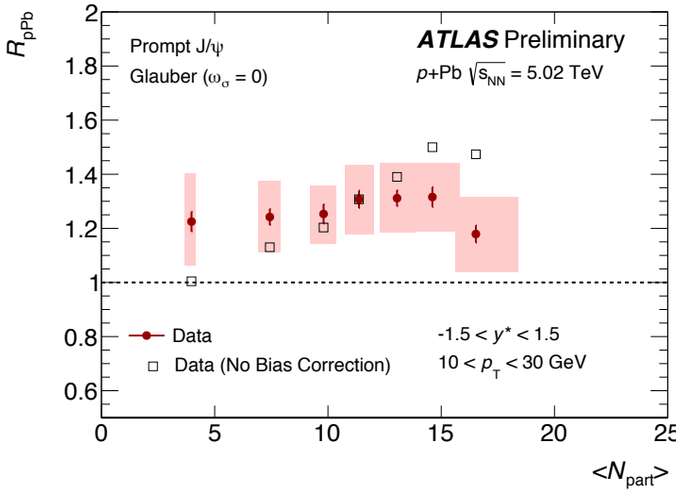
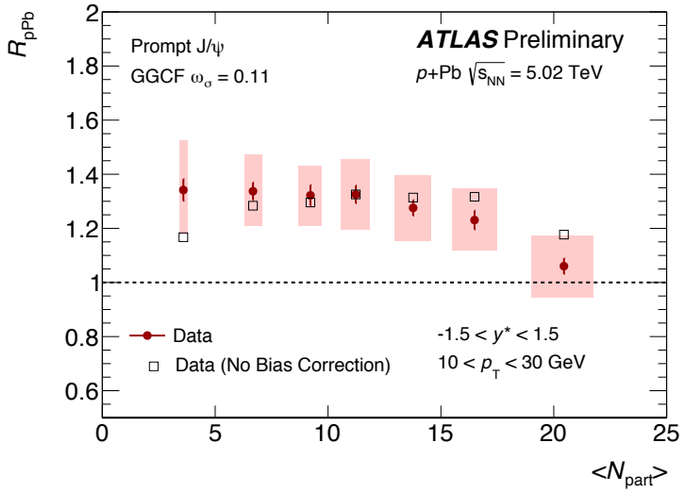
$$R_{pPb} = \frac{1}{\langle T_{pPb} \rangle_{cent}} \frac{1/N_{evt}\, d^2N_{\psi}^{p+Pb}/dy^* dp_T \,\big|_{cent}}{d^2\sigma_{\psi}^{pp}/dy dp_T}$$

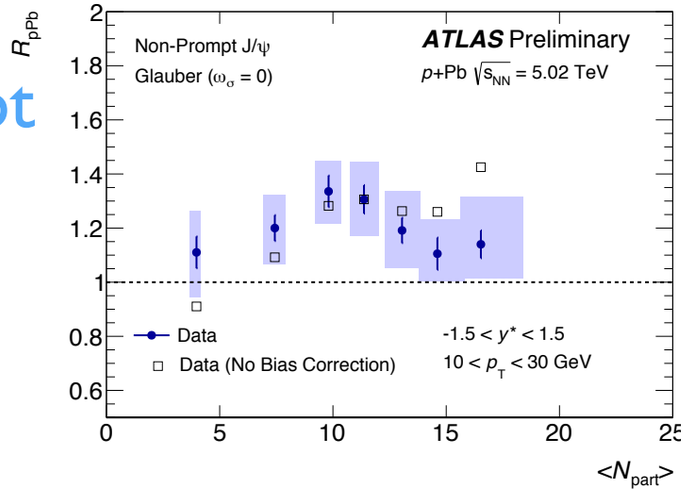
prompt J/ψ $R_{pPb} > 1$

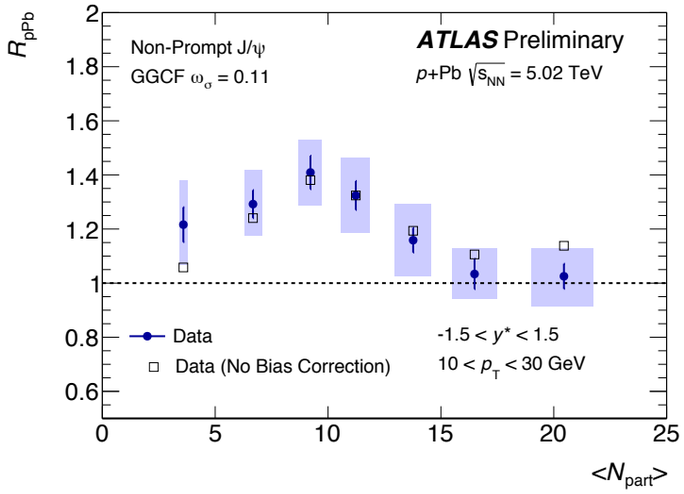




R_{pPb} X $\langle N_{part} \rangle$

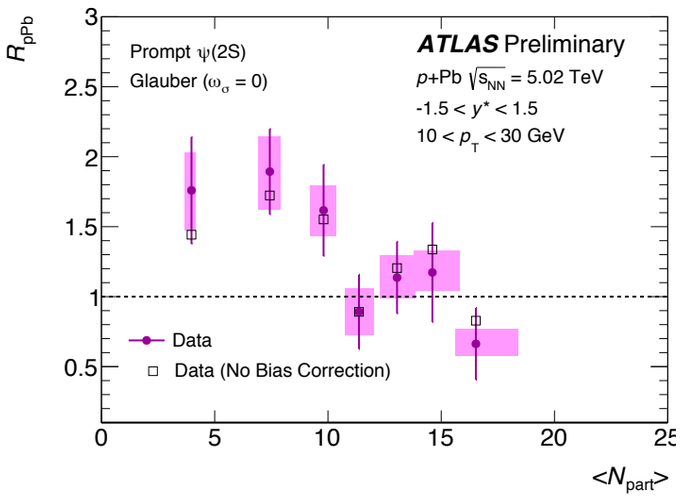
non-prompt J/ψ $R_{pPb} > 1$ mid cent

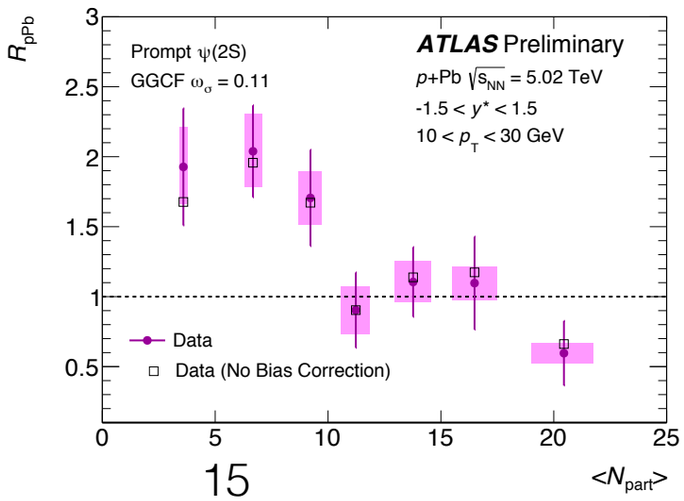




Model dependent:
standard Glauber (left)
GGCF $\boldsymbol{\omega_\sigma}$ = 0.11 (right)

prompt ψ(2S) $R_{pPb} > 1$ low cent





J/ψ and ψ(2S) ratios to Z yields @ 5.02 TeV p+Pb

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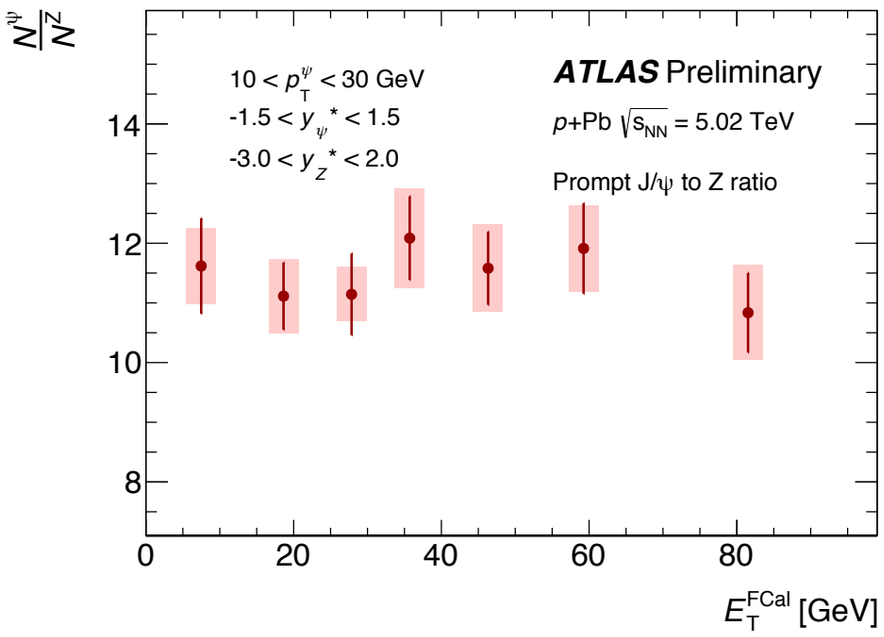
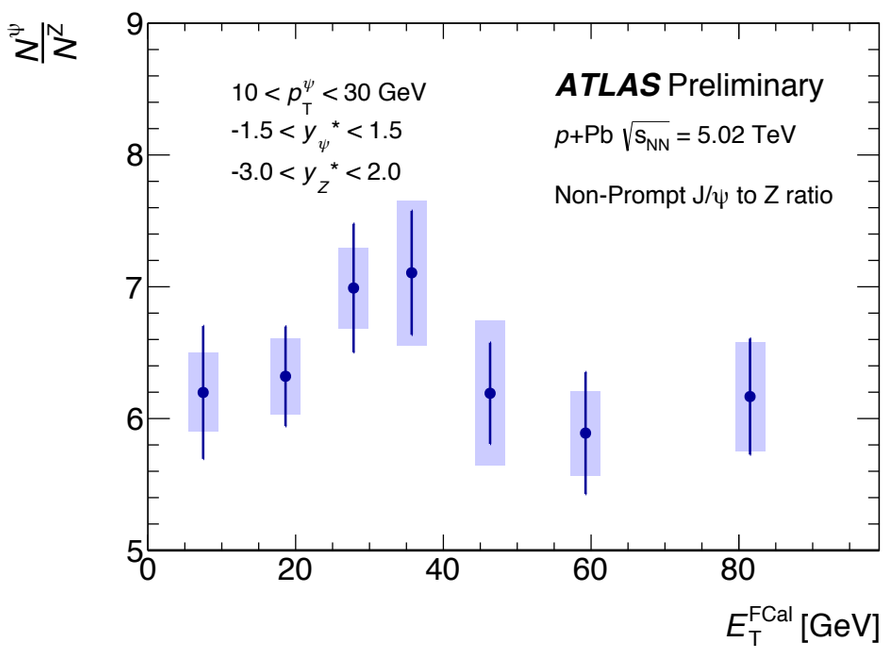
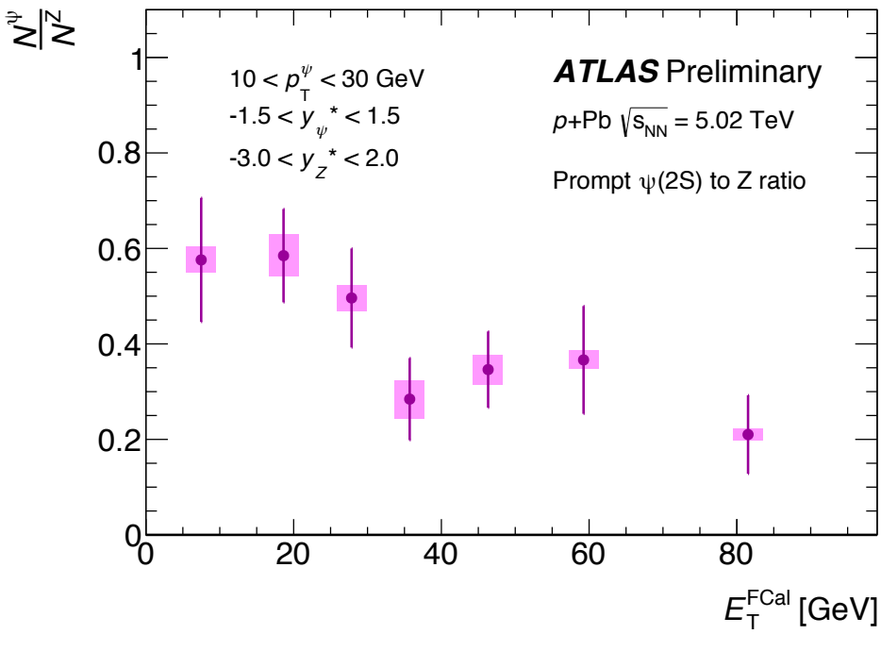
prompt J/ψ to Z



non-prompt J/ψ to Z



prompt ψ(2S) to Z



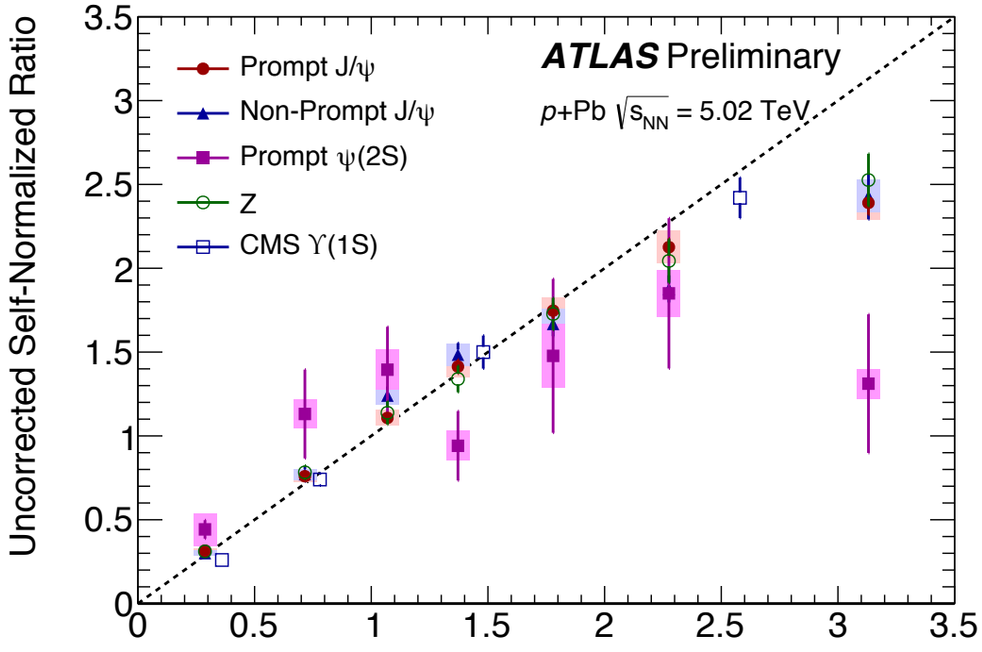
Test of ψ production scaling with the nuclear thickness independently of geometric models

Decreasing trend for ψ(2S)

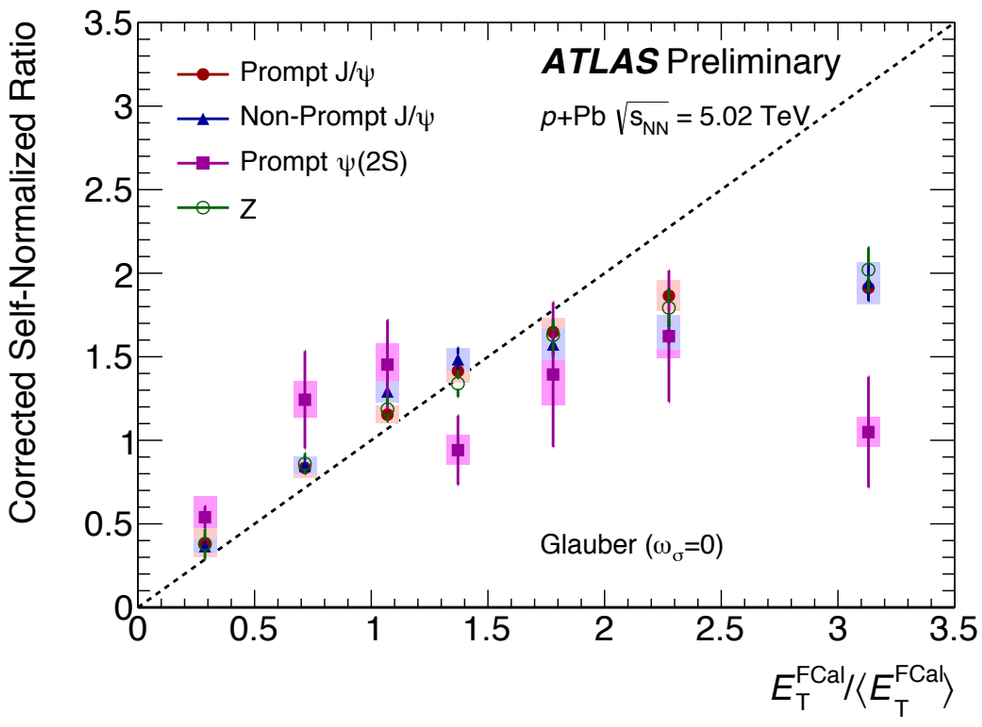
while J/ψ appears to be flat

Self-normalized ratios for ψ(2S) and J/ψ @ 5.02 TeV p+Pb

uncorrected



corrected - Glauber



$$\frac{\psi}{\langle\psi\rangle} = \frac{N_\psi / N_{\mathrm{evt}} \,|\, \mathrm{cent}}{N_\psi^{0-90\%} / N_{\mathrm{evt}}^{0-90\%}}$$

$$\frac{E_{\mathrm{T}}^{\mathrm{FCal}}}{\langle E_{\mathrm{T}}^{\mathrm{FCal}}\rangle} = \frac{\langle E_{\mathrm{T}}^{\mathrm{FCal}}\rangle \,|\, \mathrm{cent}}{\langle E_{\mathrm{T}}^{\mathrm{FCal}}\rangle \,|\, 0-90\%}$$

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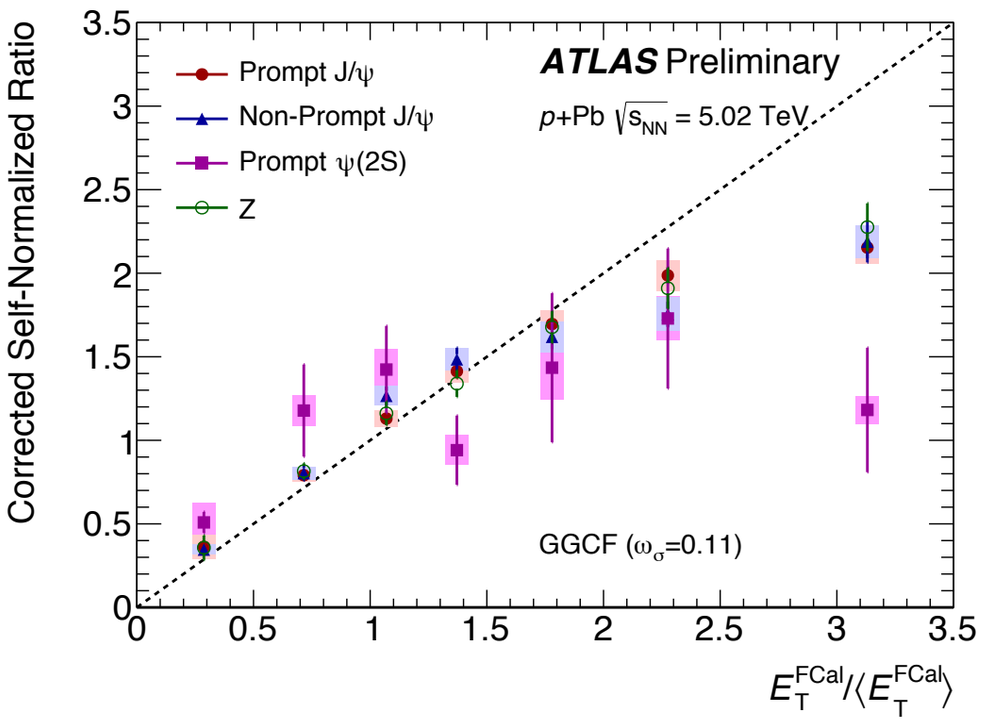
The uncorrected J/ψ and Z self-normalized ratios show similar trend to CMS results for ϒ(1S).

At large E_T^{FCal}, $E_T^{FCal}/\langle E_T^{FCal}\rangle > 3$, significant deviations from the unity are observed for prompt J/ψ non-prompt J/ψ and prompt ψ(2S).

The deviations become more significant when the centrality bias correction is applied.

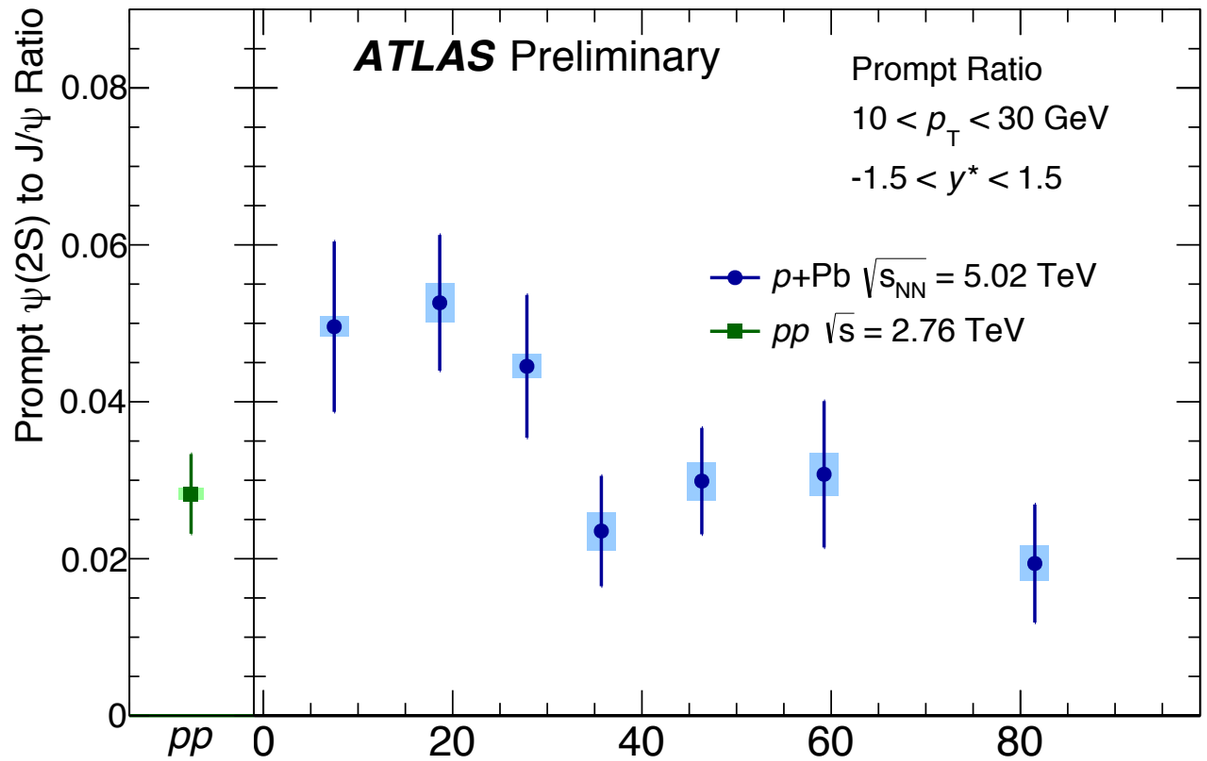
corrected - GGCF



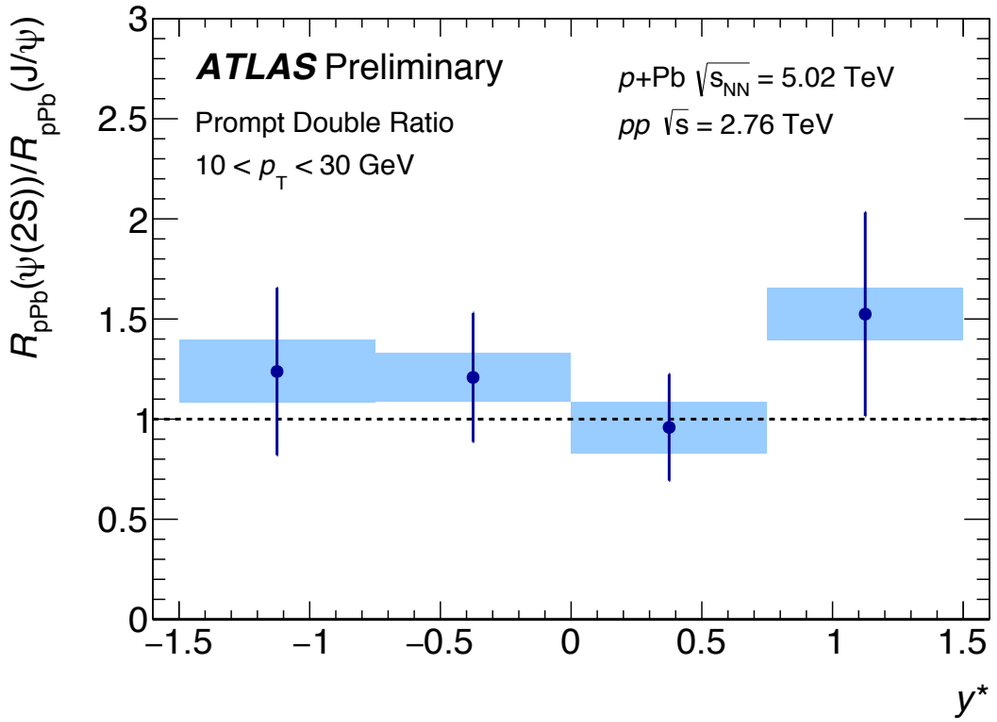
Prompt double ratios @ 5.02 TeV p+Pb

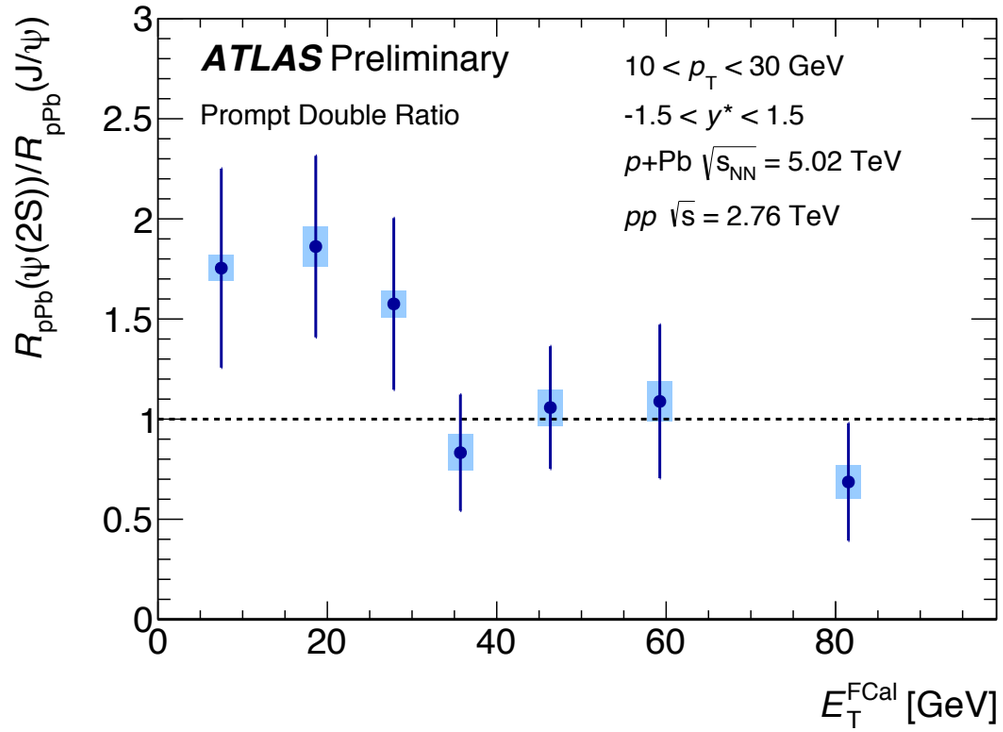
Prompt ratios
X
FCal E_T and y*

Evidence for centrality dependence
Similar pattern as Z-normalized $\Psi(2S)$
Decreasing trend with centrality



ATLAS-CONF-2015-023 $R_{p\mathrm{Pb}}(\psi(2S))/R_{p\mathrm{Pb}}(J/\psi)$





Run 169226, Event 379791
Time 2010-11-16 02:53:54 CET

Pb+Pb @ 2.76 TeV
Motivations

Measurements of heavy quark production and suppression in ultra-relativistic nuclear collisions probe the interactions of heavy quarks with the hot, dense medium created in the collisions.

Measurement of the suppression of quarkonium yields: experimental signature of the QGP formation.

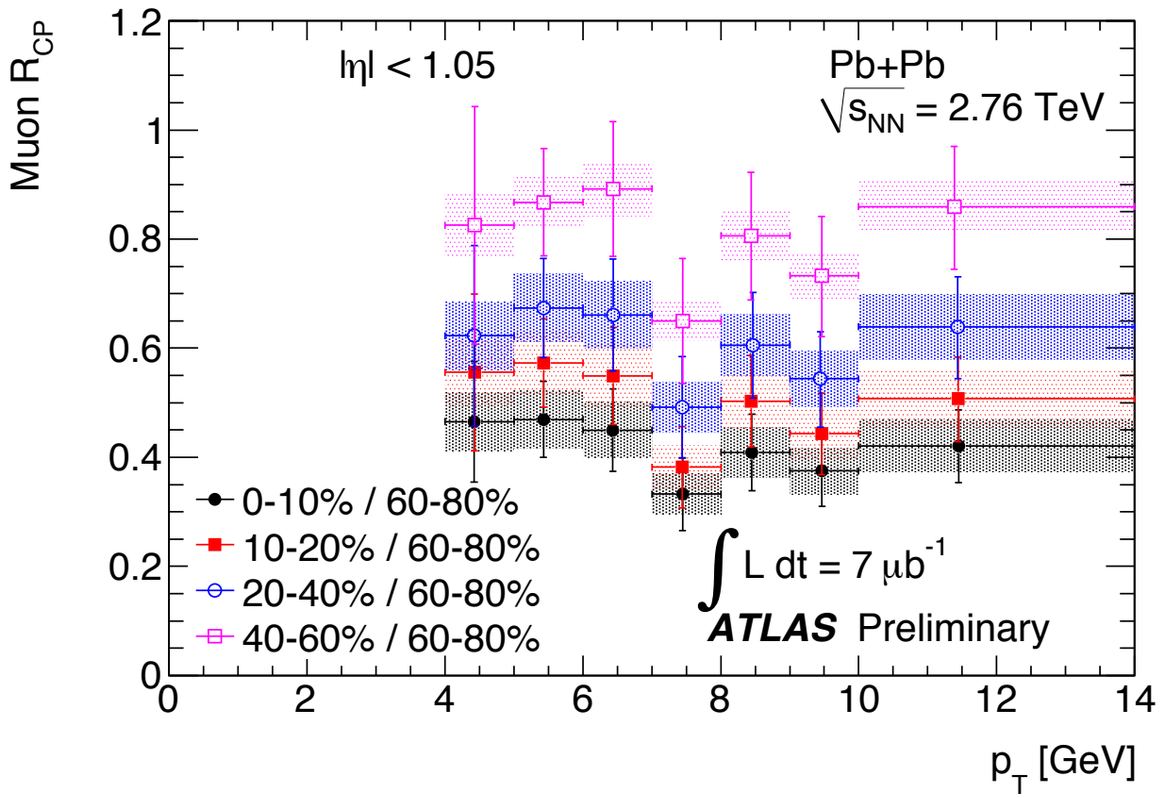
Important complement to studies of light quark and gluon quenching.

Suppression of heavy flavour muons in Pb+Pb @ 2.76 TeV

60-80% reference

$$R_{CP}(p_T)|_{cent} = \frac{1}{R_{coll}^{cent}} \left(\frac{\frac{1}{N_{evt}^{cent}} \frac{N_S^{cent}}{\varepsilon^{cent}}}{\frac{1}{N_{evt}^{60-80}} \frac{N_S^{60-80}}{\varepsilon^{60-80}}} \right)$$

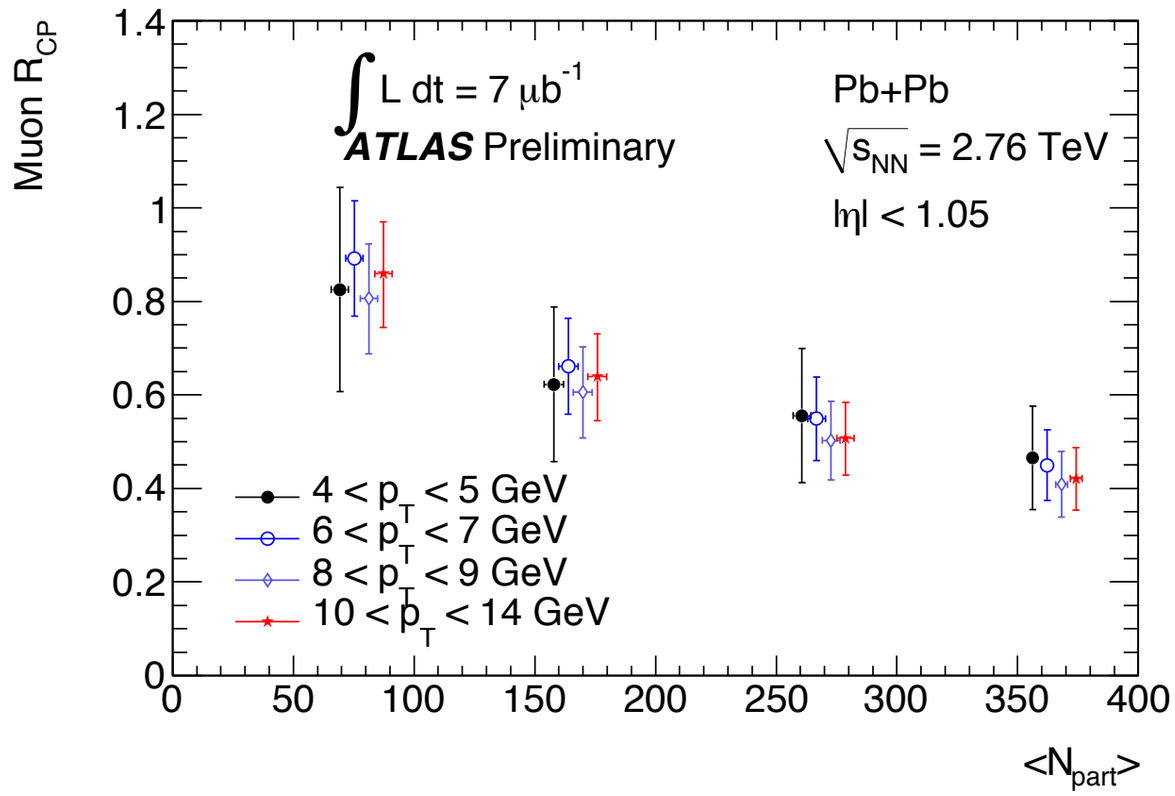
R_{cp} X muon p_T



No significant variation with muon pT

[ATLAS-CONF-2012-050]

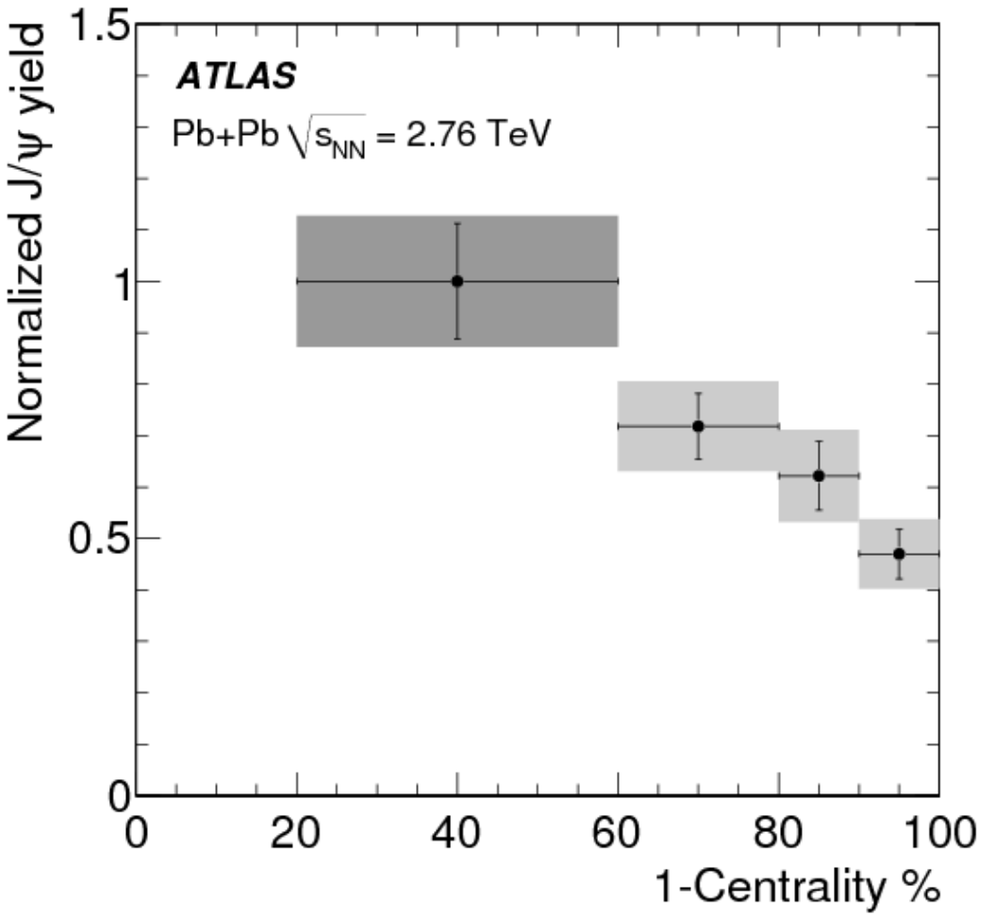
R_{cp} X $\langle N_{part} \rangle$



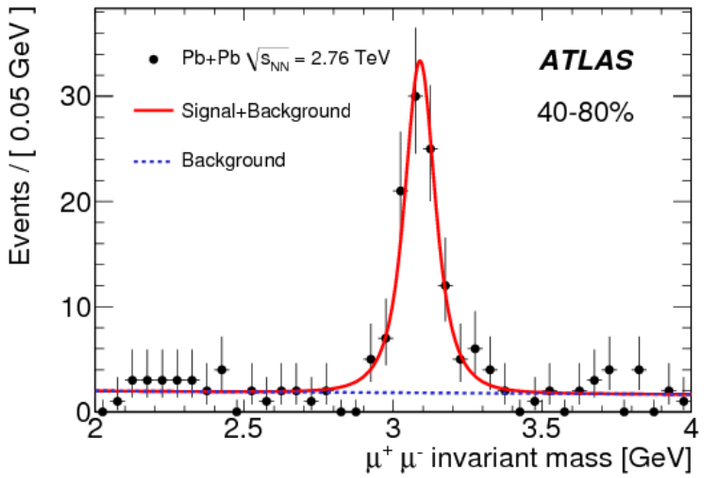
Suppression factor of ~2.5 in the yield of muons in the most central compared to most peripheral

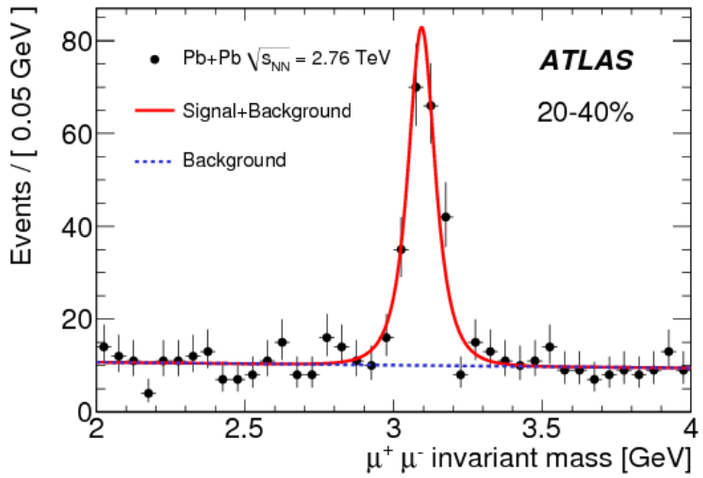
Centrality dependence of J/ψ in Pb+Pb @ 2.76 TeV

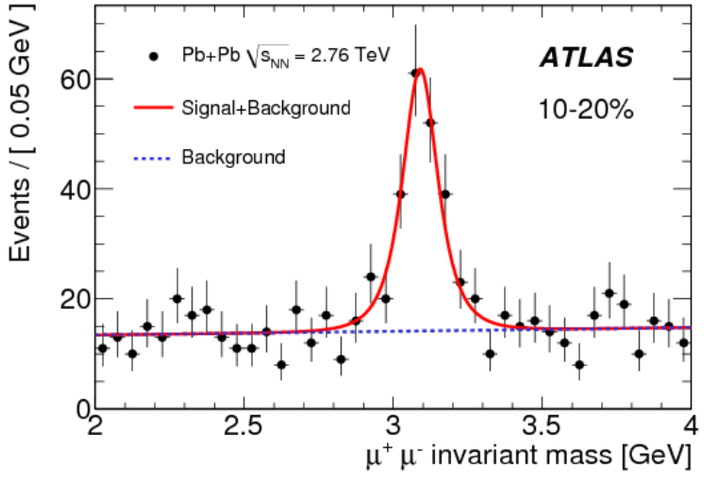
Phys.Lett. B697 (2011)

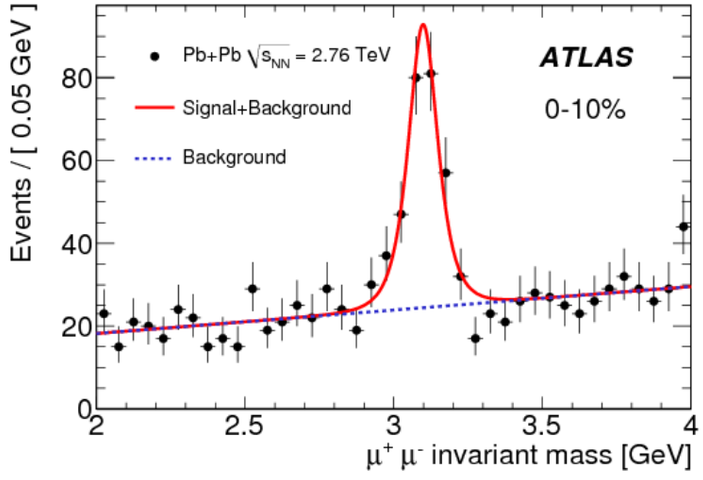


Suppression of J/ψ yield normalized to the number of binary nucleon-nucleon collisions









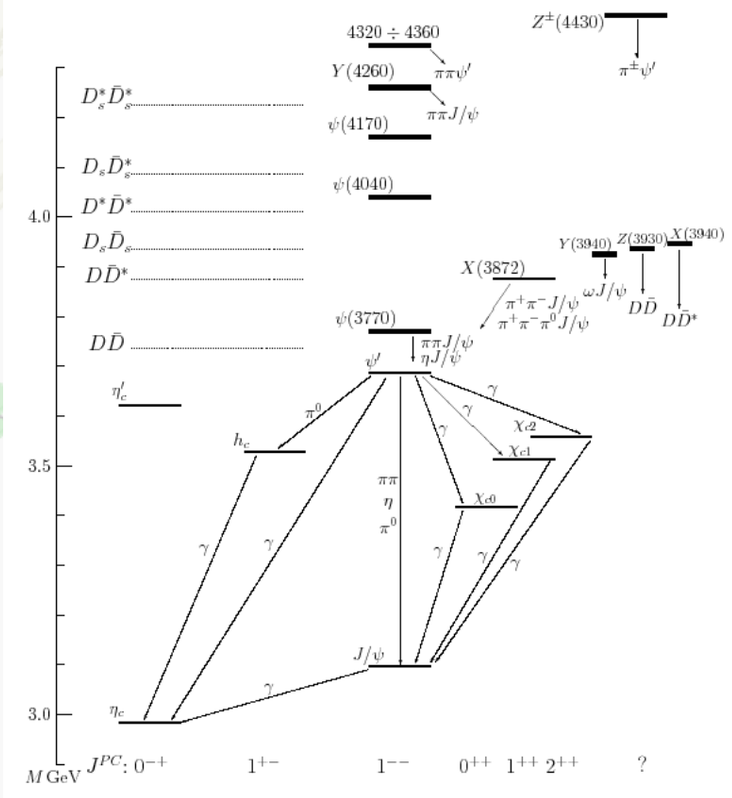
pp @ 7 and 8 TeV
Motivations

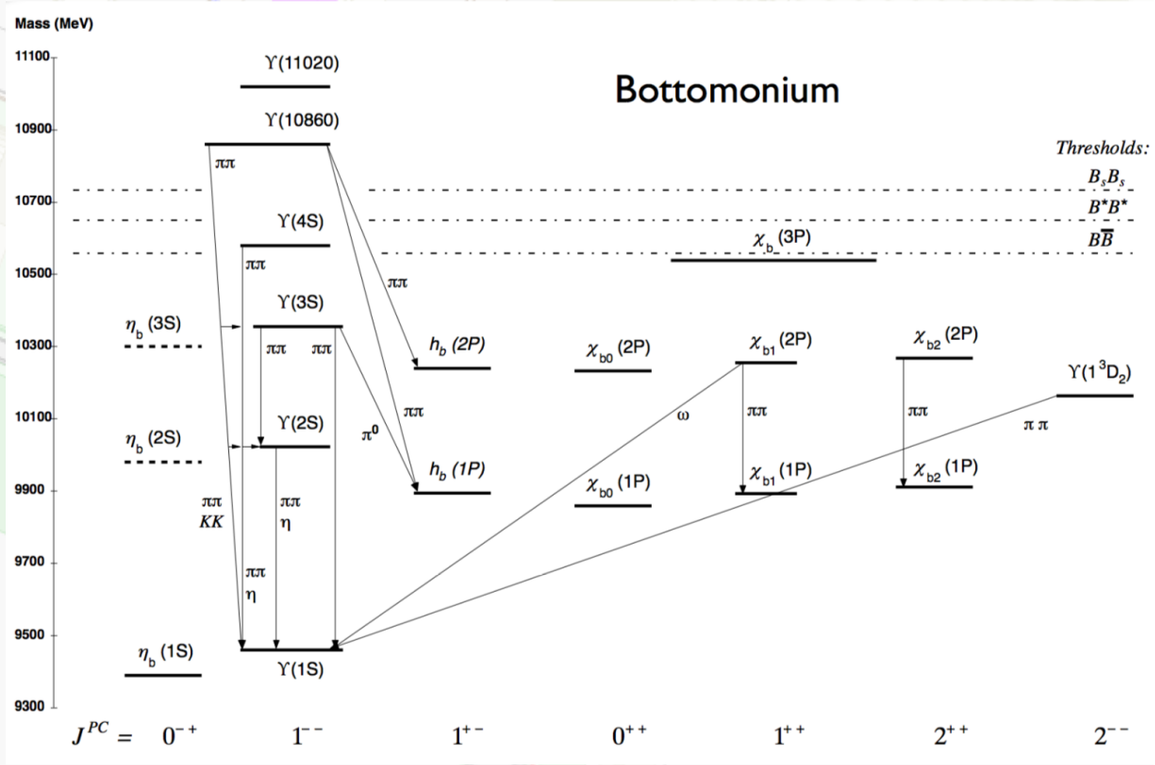
At the LHC possibility to explore kinematic regions of high p_T ~100 GeV:

- test predictions of various theoretical models for both quarkonium and open state production;
- corrections over the LO (NLO, and NLL) + accurate quantitative comparison of data with QCD predictions can be performed to discriminate among various quarkonium production models (color singlet (CS) , color octet (CO or NRQCD), color evaporation (CE) , kT factorization).

Understanding of quarkonium production requires discrimination and understanding of the various modes of production :

Charmonium





J/psi -> μμ candidate in 7 TeV collisions

run #: 152409, evt #:2452006
Inv. Mass=3.1GeV
P(μ+) = 28 GeV, η=0.93
P(μ-) = 15 GeV, η=0.95

Brand new high-statistics measurement of J/ψ and ψ(2S) @ 7 and 8 TeV pp!!!!

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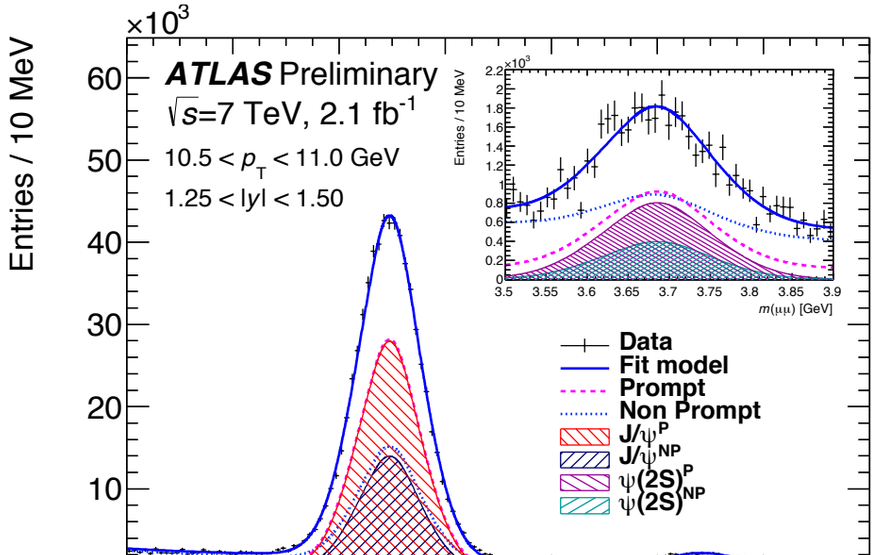
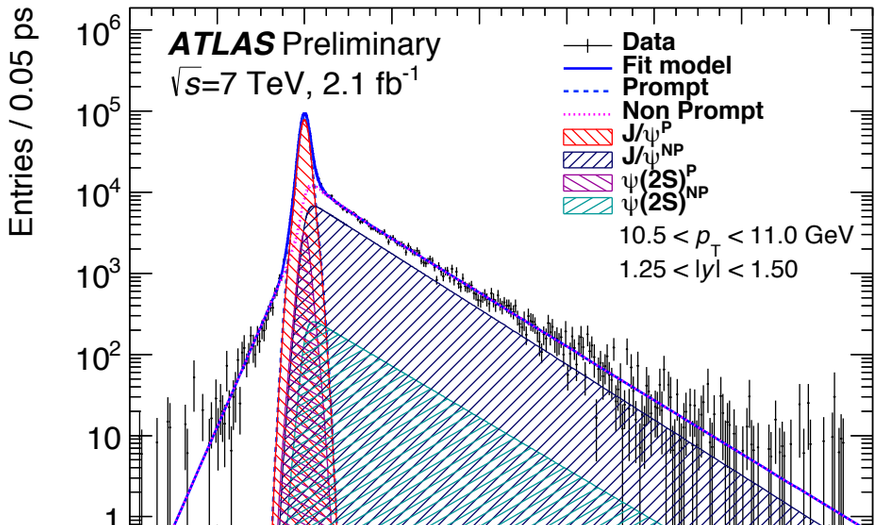
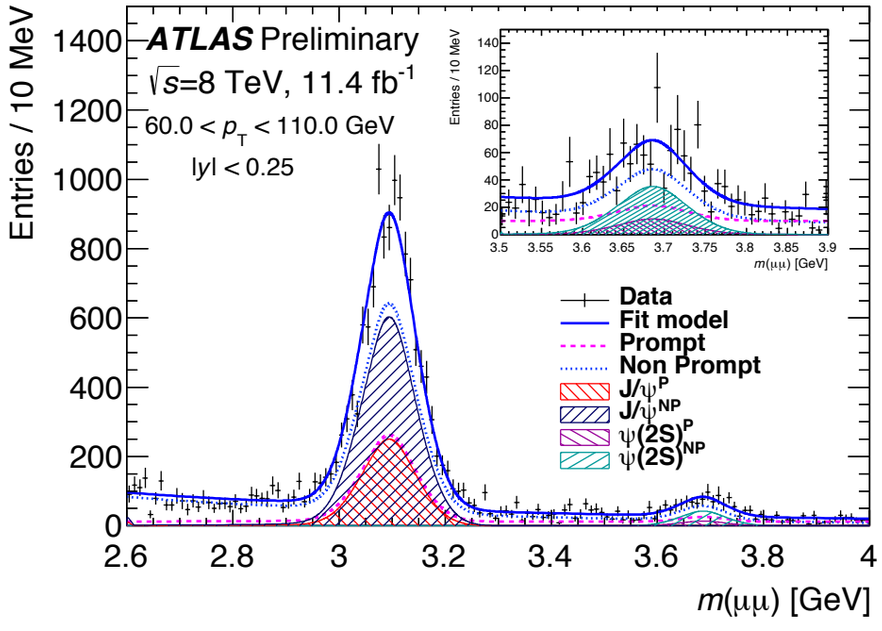
8 < |y| ≤ 110 GeV, |y| < 2.0

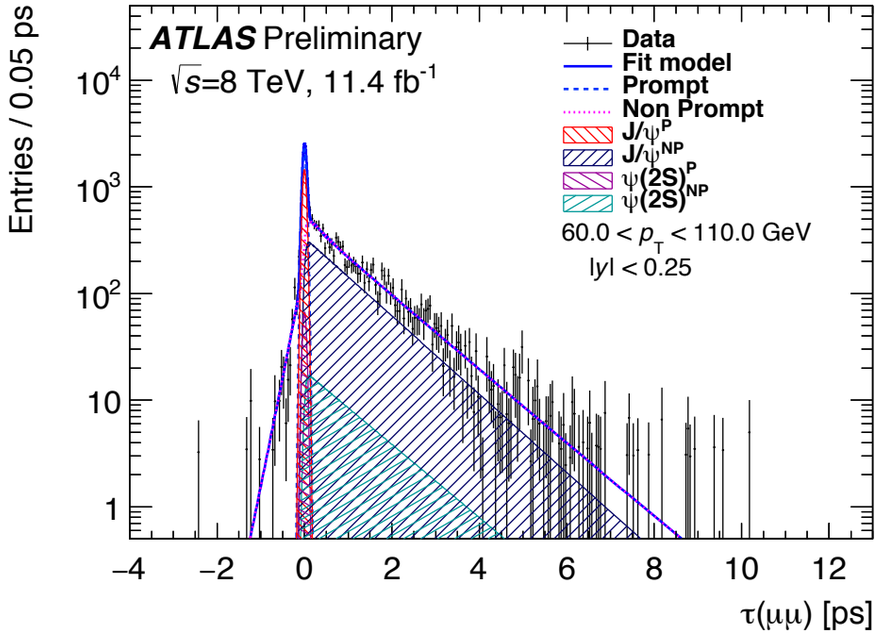
7 TeV





8TeV



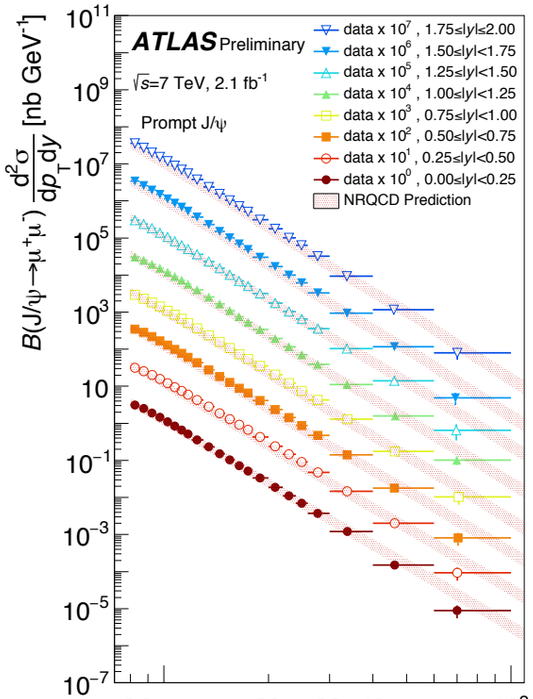


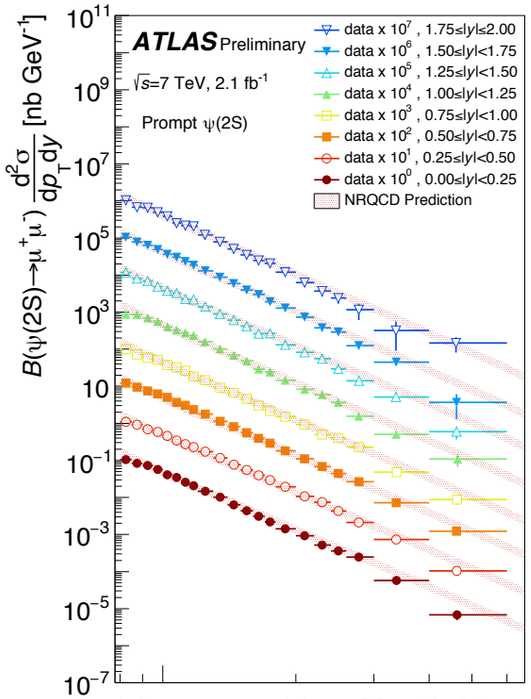
Differential cross-sections of J/ψ and ψ(2S) @ 7 and 8 TeV pp

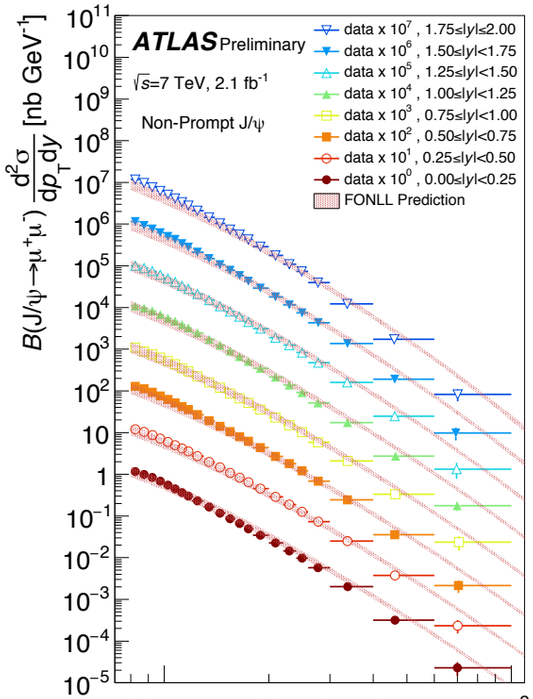
ATLAS-CONF-2015-024

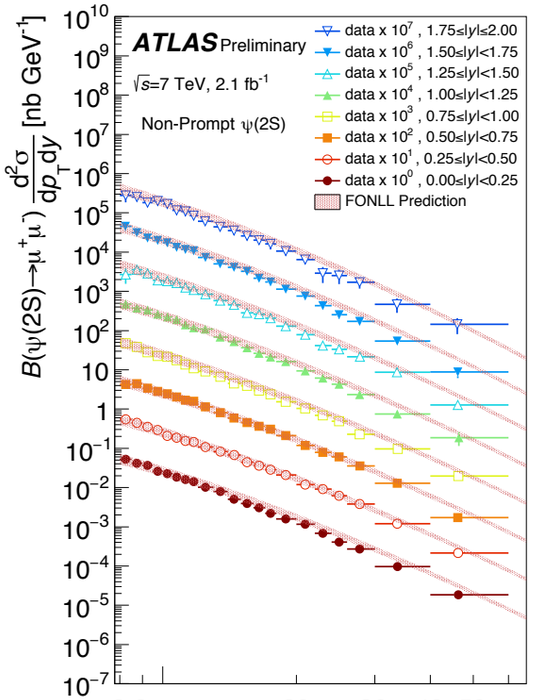
prompt J/ψ | prompt ψ(2S) | non-prompt J/ψ | non-prompt ψ(2S)

7 TeV

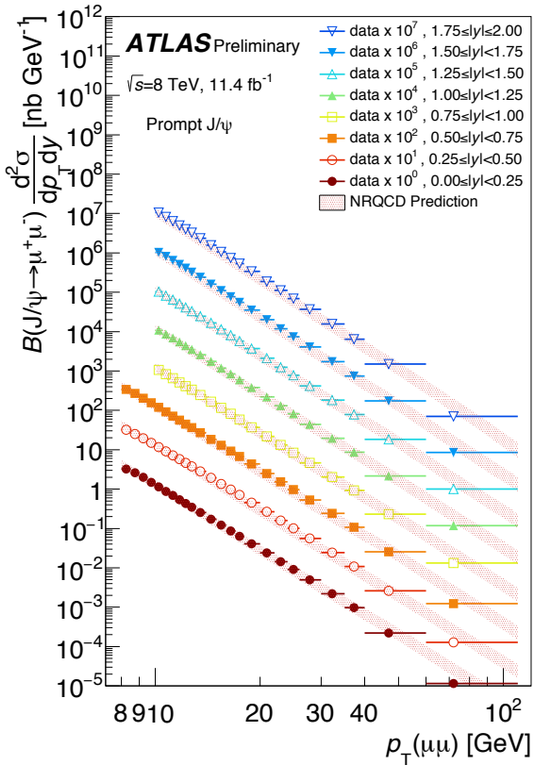


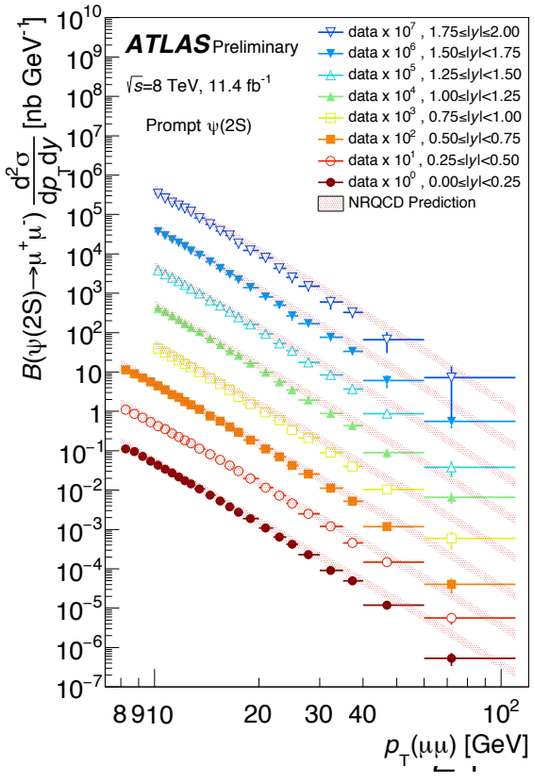


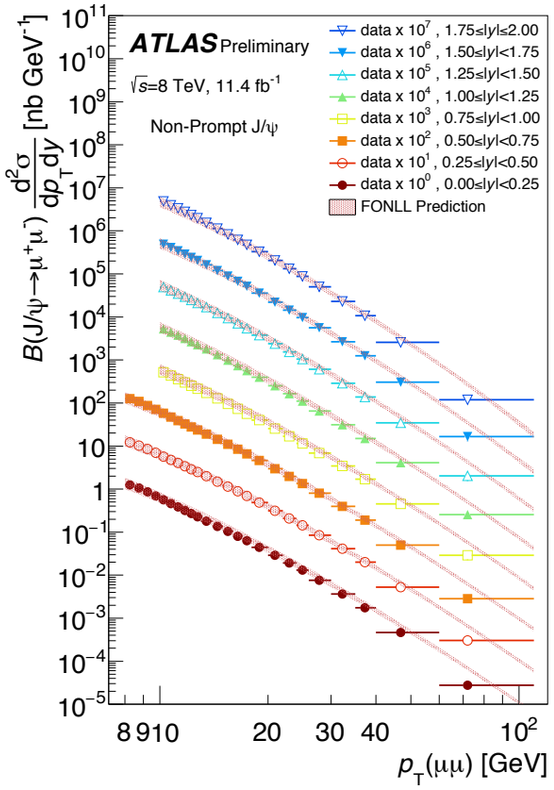


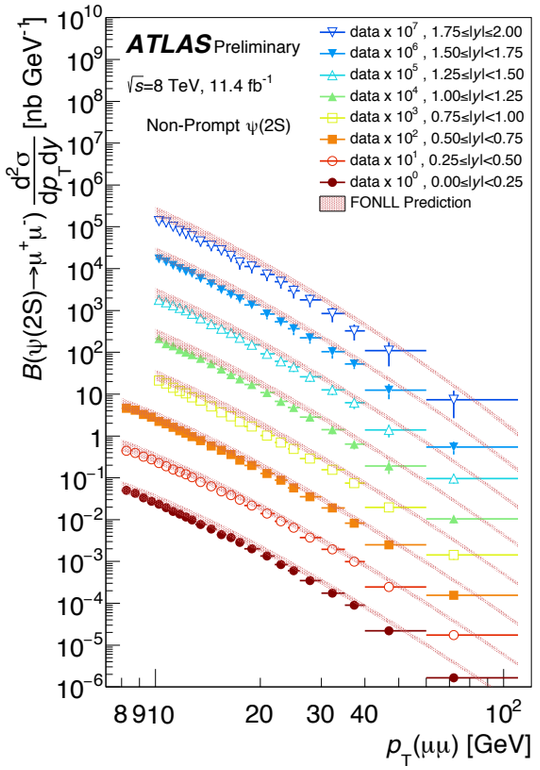


8TeV









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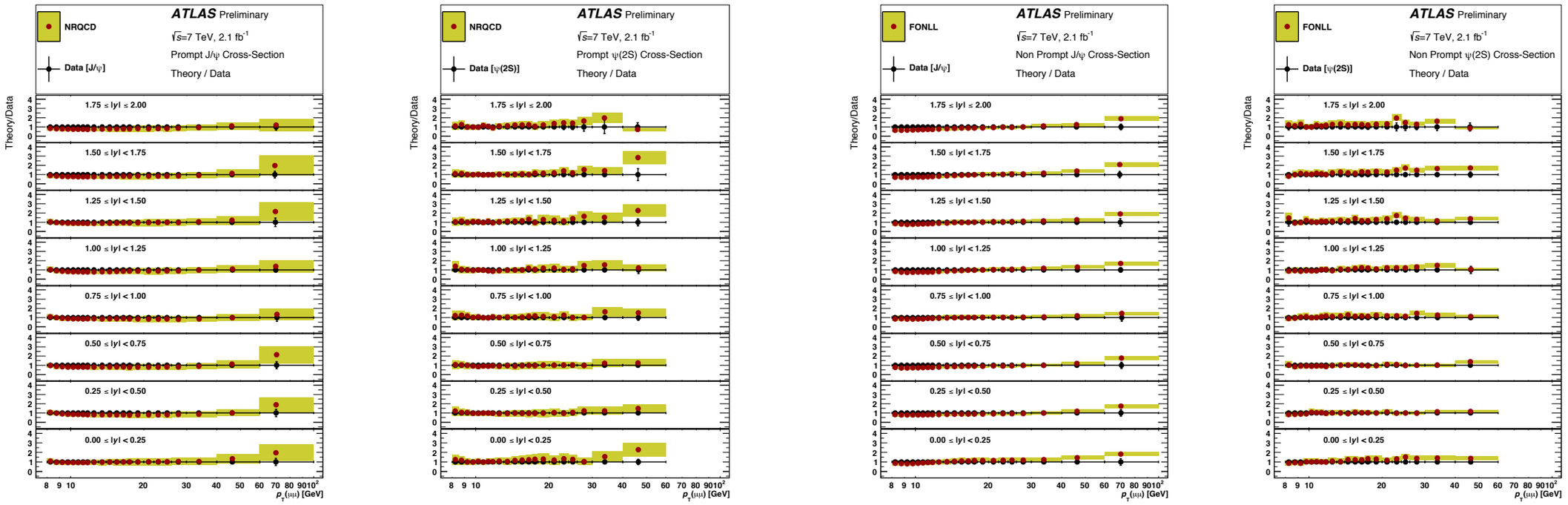
Ratios of theoretical predictions to data

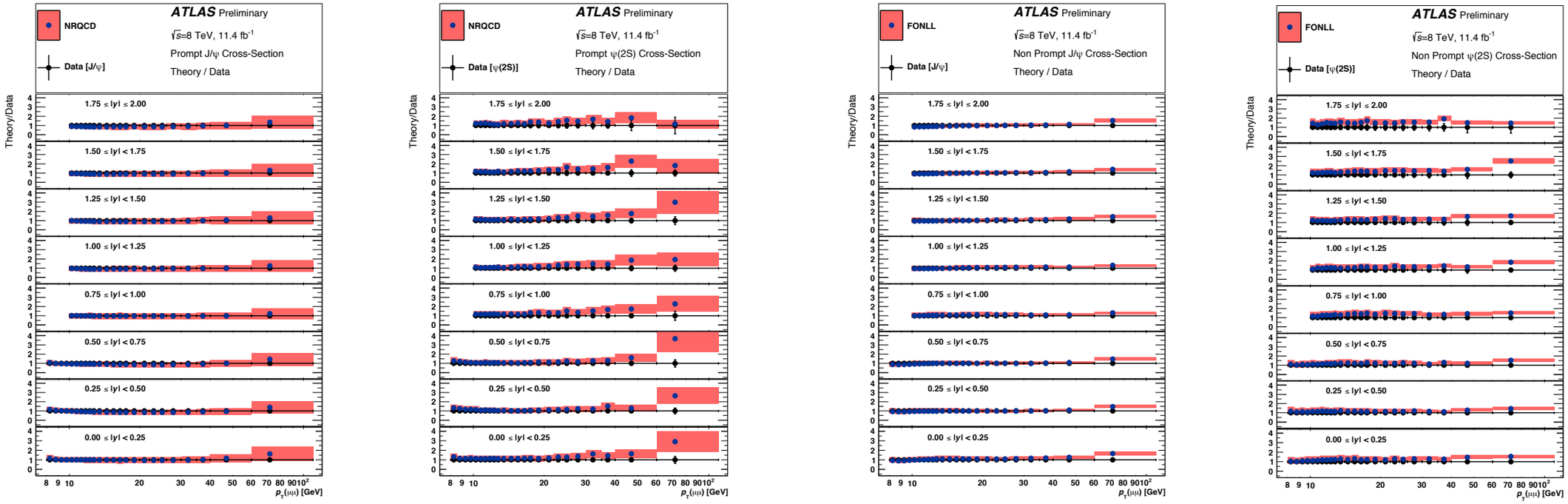
J/ψ NRQCD ψ(2S)

J/ψ FONLL ψ(2S)

7 TeV



8TeV



Fair agreement in the whole p_T range, no ratio dependence in y

Agreement generally good, albeit theory predicts slightly harder p_T spectra for J/ψ and higher yields for ψ(2S) than observed

ψ(2S)→J/ψ(→μ+μ-)π+π- production cross section @ 7 TeV pp

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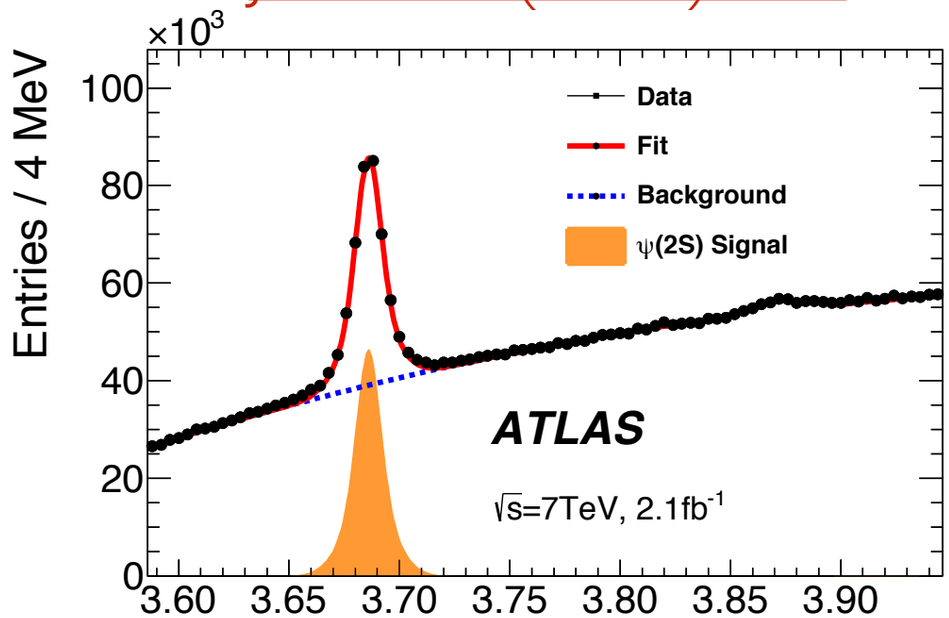
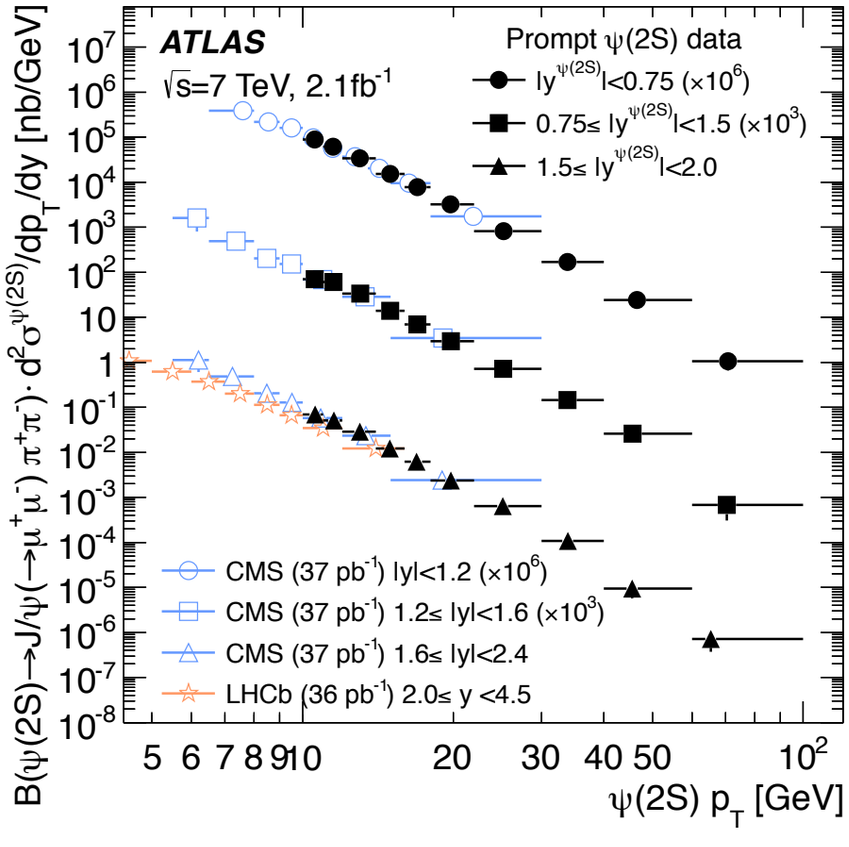
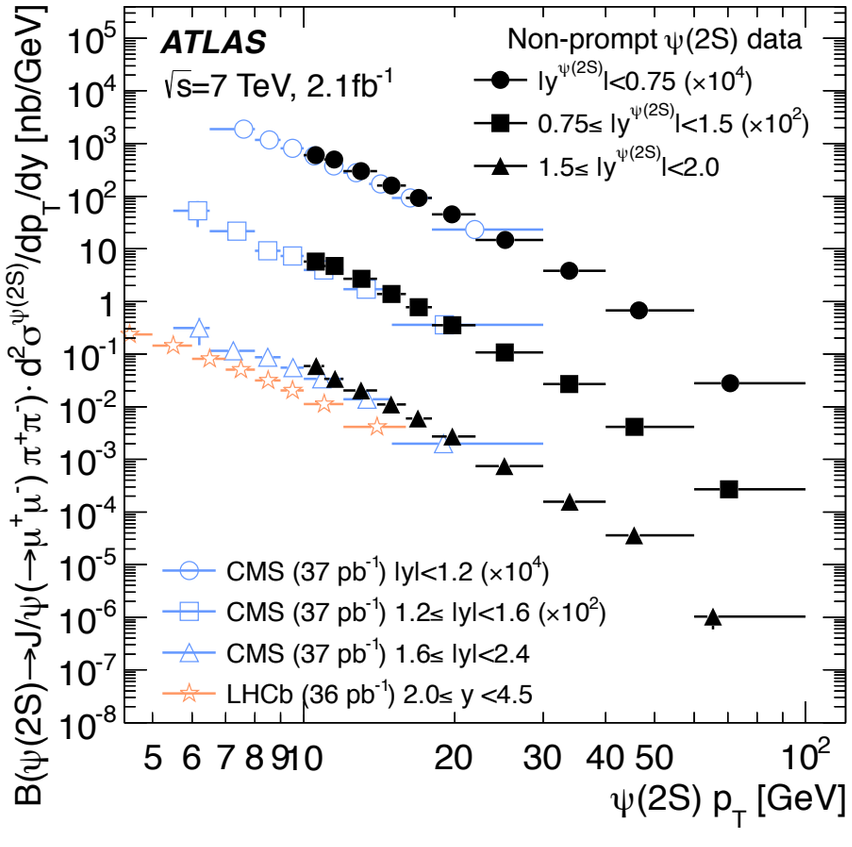
- muon p_T > 4 GeV
- pion candidate tracks p_T> 0.5 GeV
- unbinned mass-lifetime maximum likelihood fit to separate prompt and non prompt production components
- extend p_T range probed to 100 GeV







Prompt ψ(2S)→J/ψ(→μ+μ-)π+π- production @ 7 TeV pp

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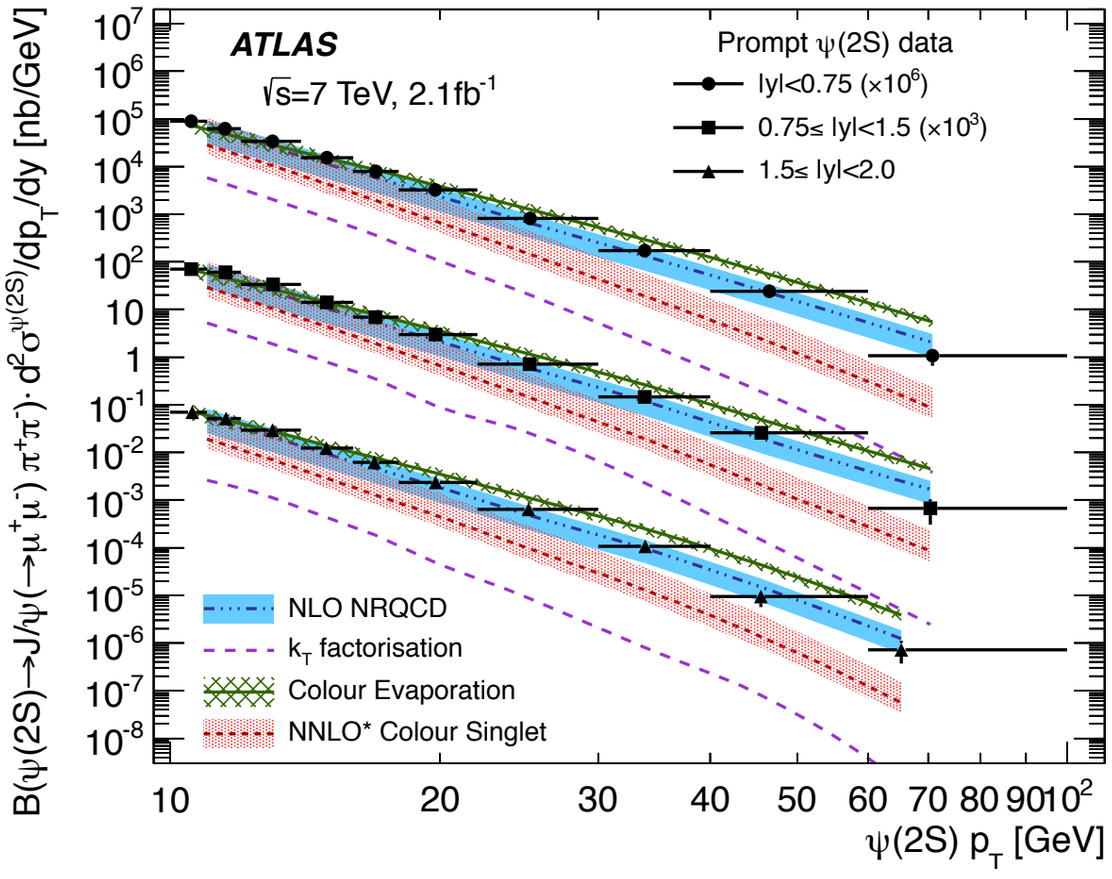

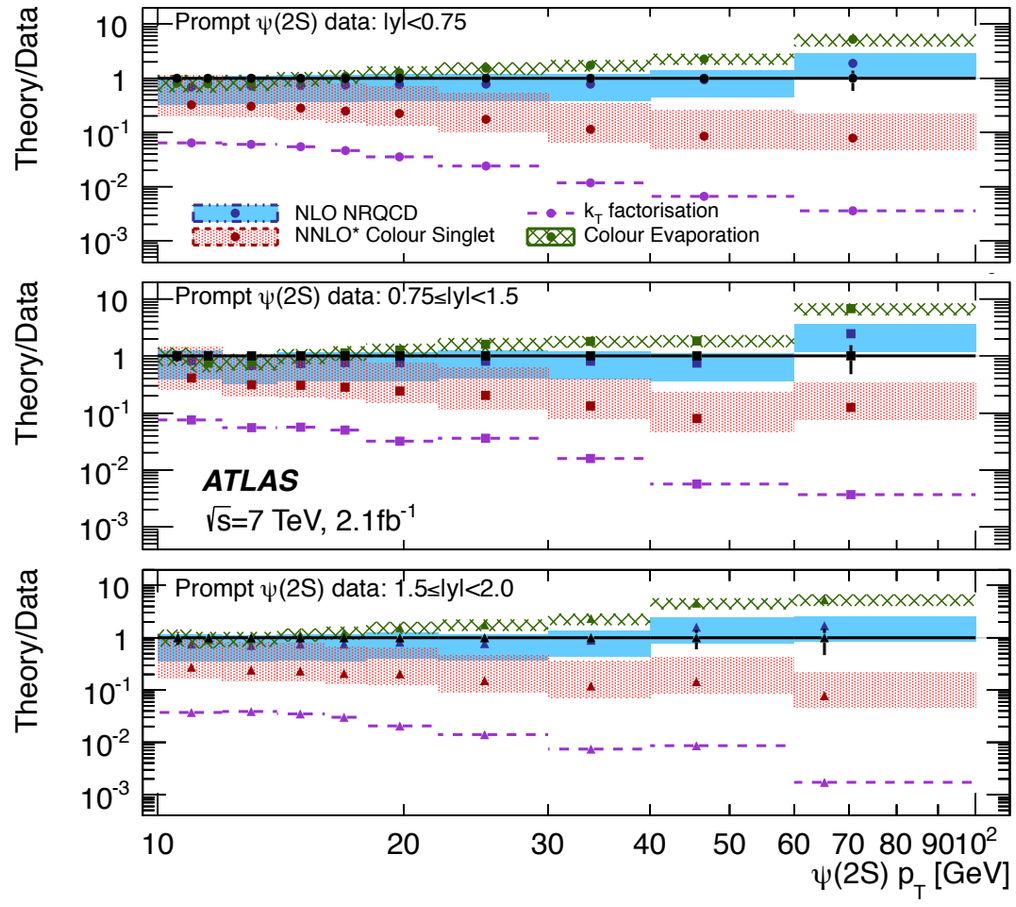

Agreement with NRQCD, overestimate at highest pT never before explored

kT-factorisation model does not describe data well

Colour Singlet NNLO* predictions fall short at highest scales

Non-prompt ψ(2S)→J/ψ(→μ+μ-)π+π- production @ 7 TeV pp

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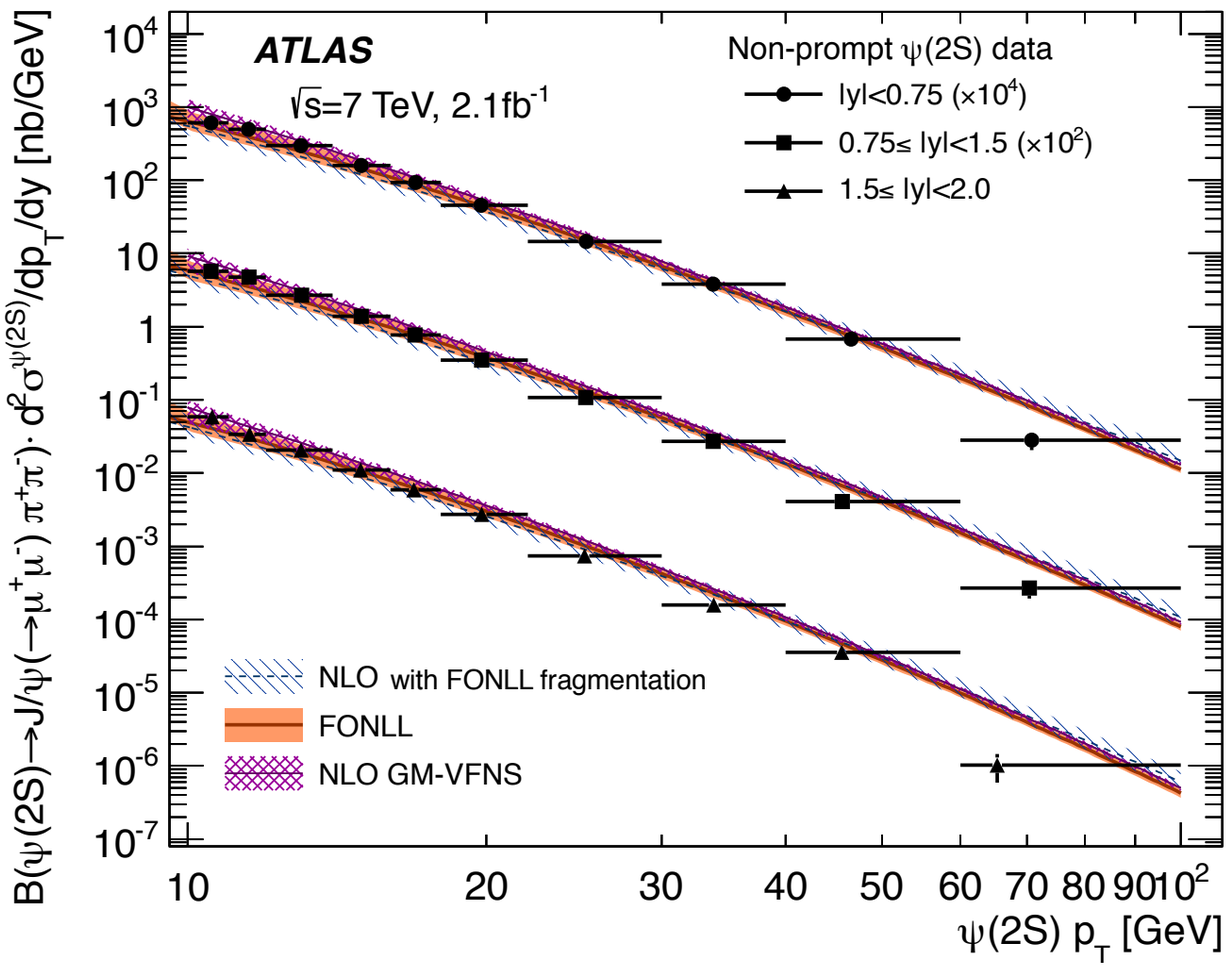
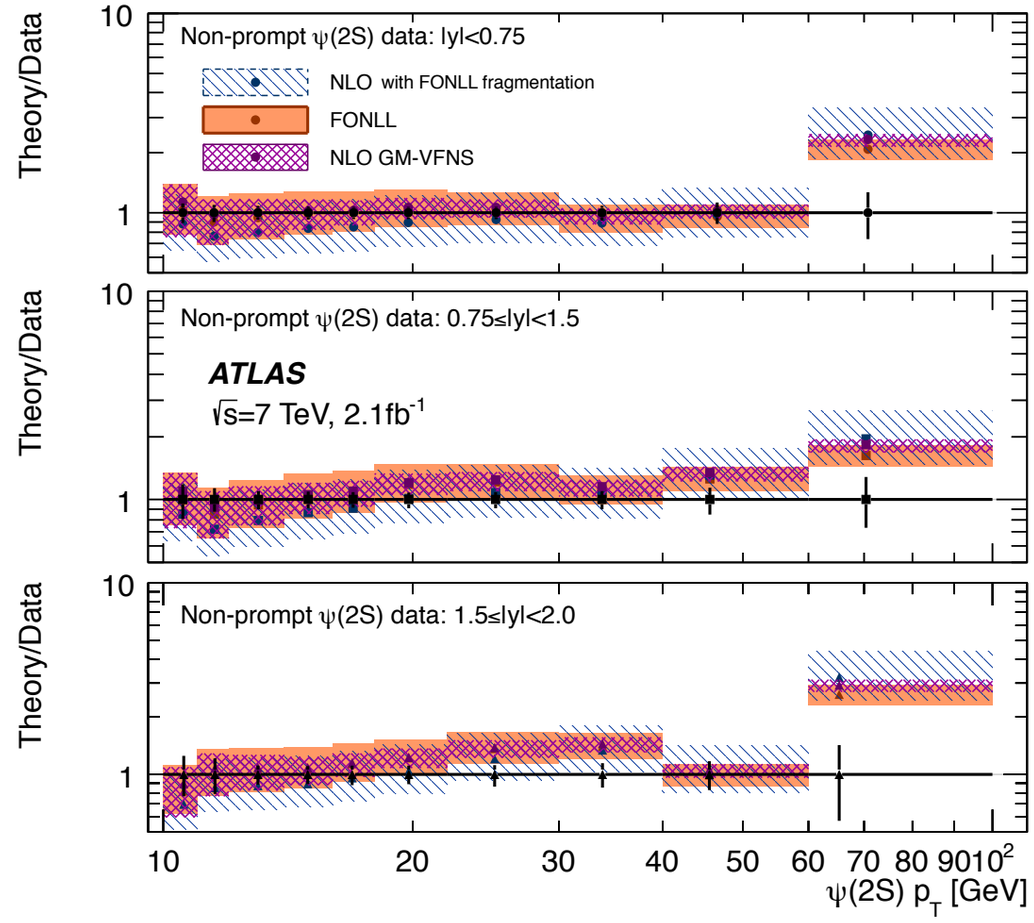
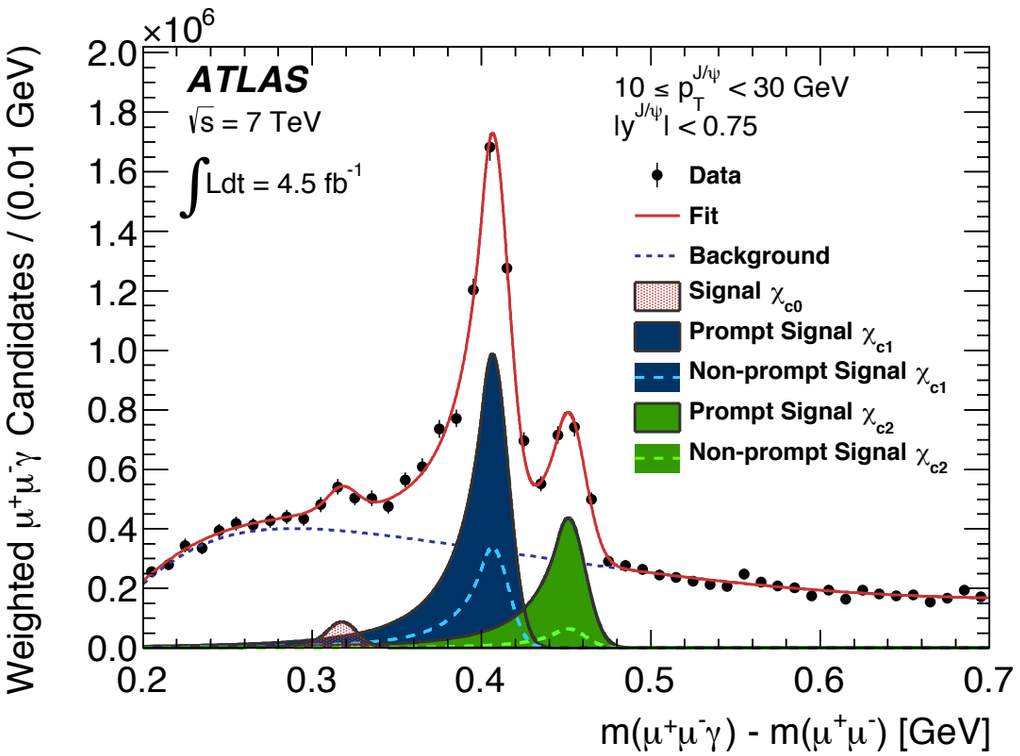
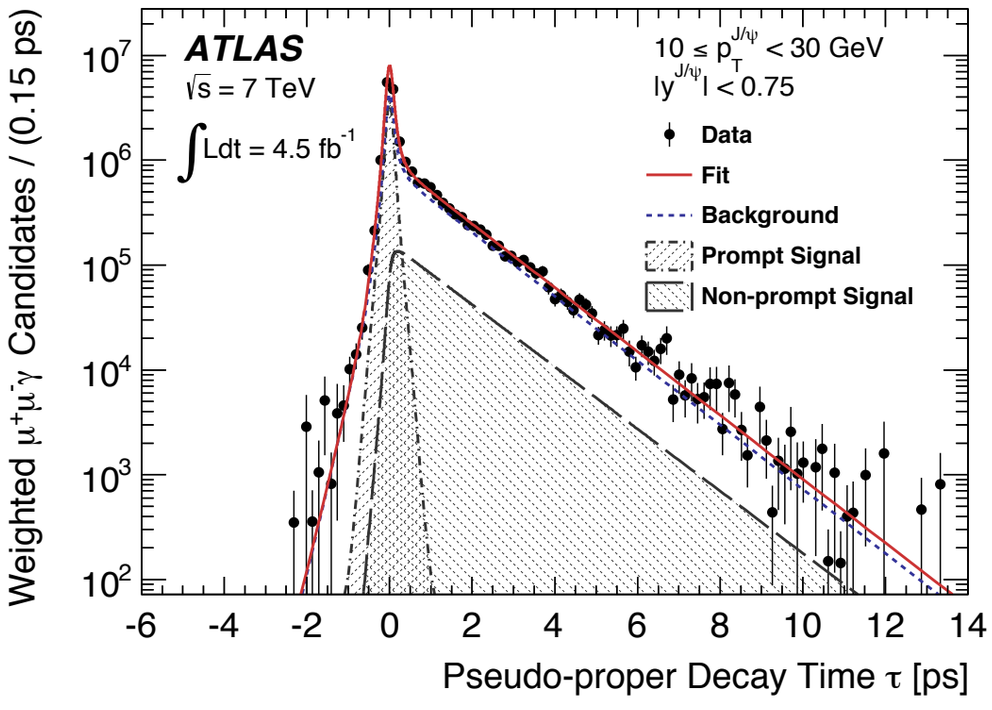




Good agreement with NLO and FONLL predictions at low p_T, but discrepancies observed in both at larger p_T

$\chi_c \rightarrow J/\psi(\rightarrow\mu\mu)\gamma(\rightarrow ee)$ production @ 7 TeV pp





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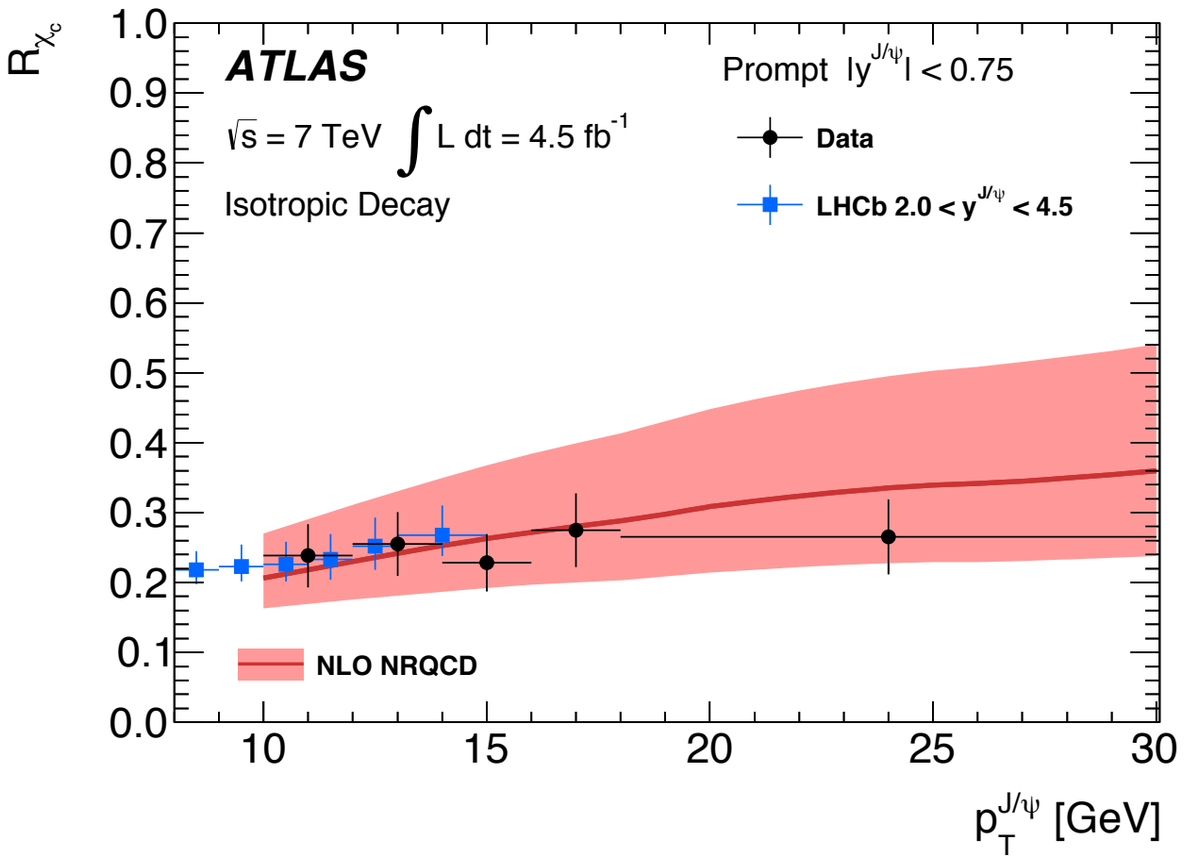
P-wave charmonium production!

Important to understand this production channel to get a complete picture of quarkonium production.

Experimentally challenging:

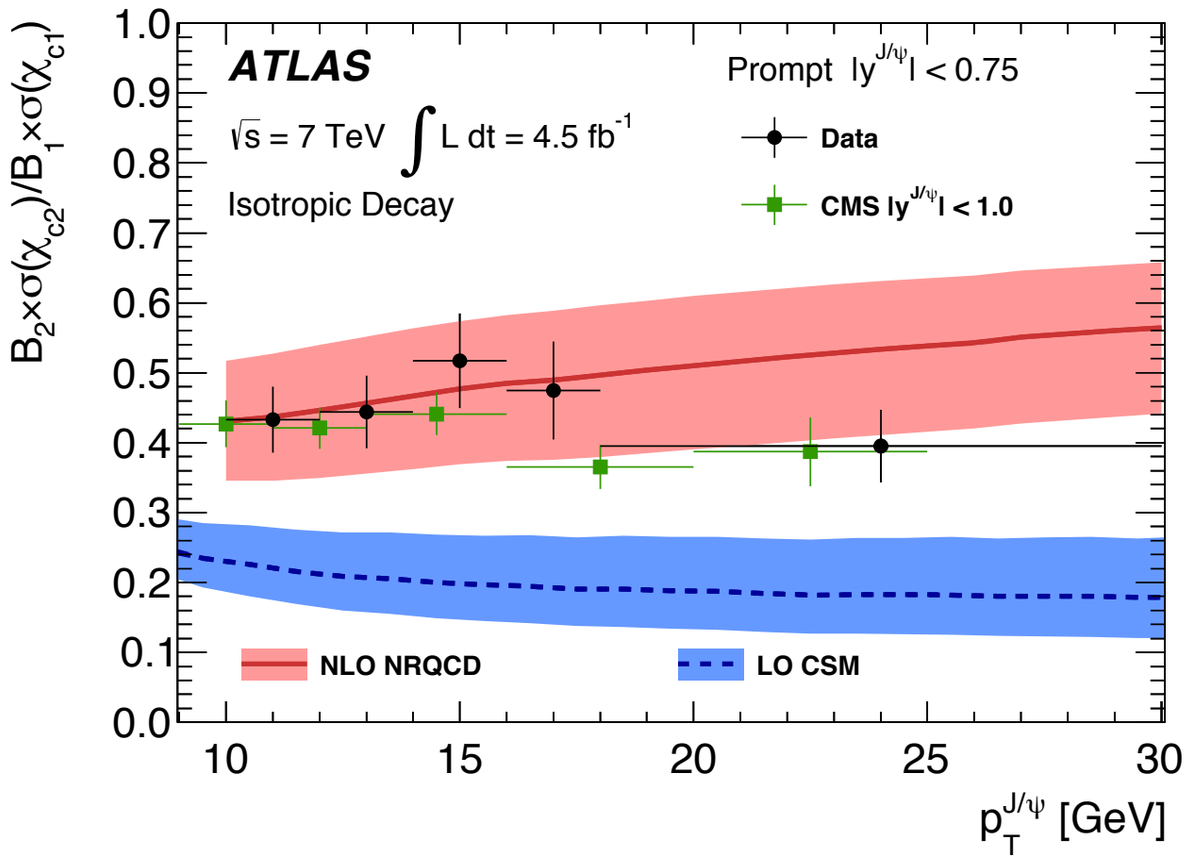
- low p_T muons;
- precise reconstruction of soft (p_T~5 GeV) photon through conversions: low efficiencies
- unbinned maximum likelihood fit on corrected mass and lifetime
- extract the production of the χ_C states

Prompt $\chi_c \rightarrow J/\psi\gamma$ and $\sigma(\chi_{c2})/\sigma(\chi_{c1})$ ratio @ 7 TeV pp



Fraction of prompt J/ψ produced in χ_c feed down

20-30% of prompt J/ψ are produced in χ_c decays



Prompt χ_c cross-section ratio

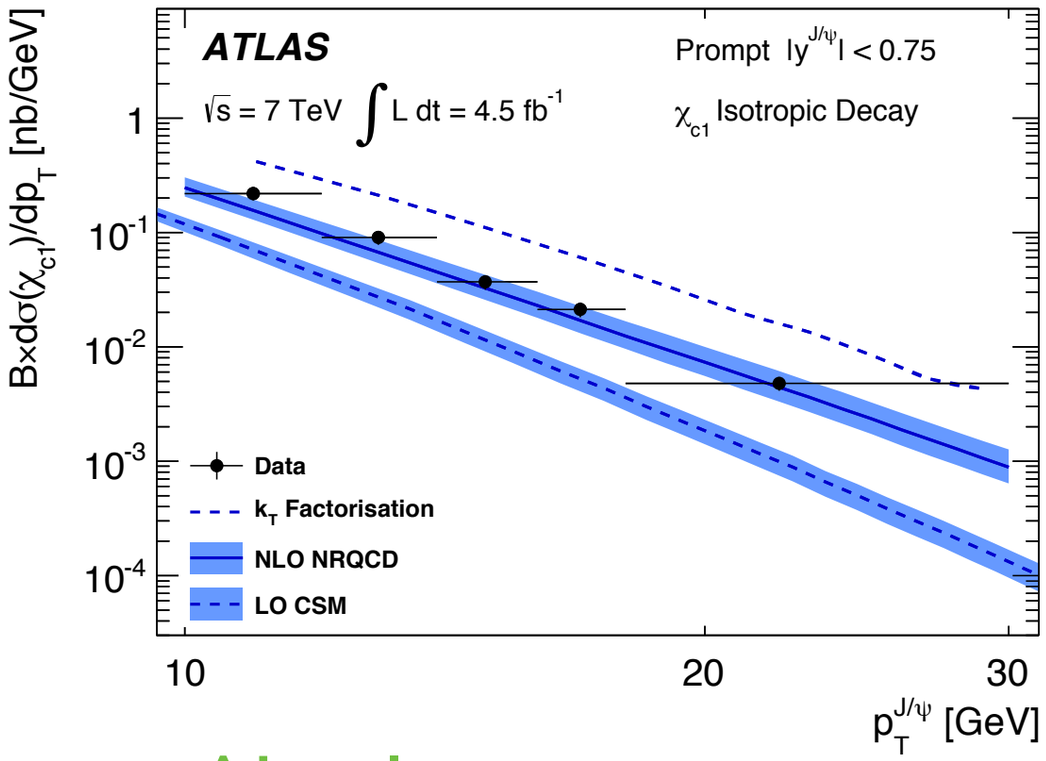
more χ_{c1} than χ_{c2}

ratio sensitive to presence of possible colour octet contributions in NRQCD

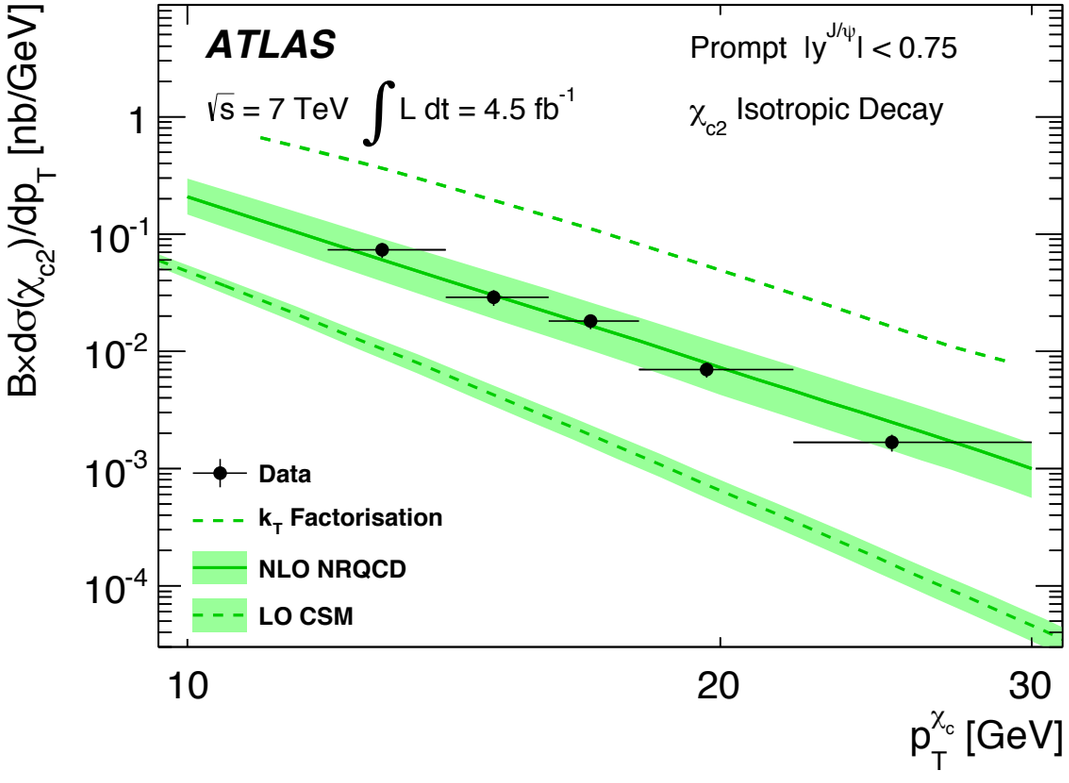
[JHEP 07 (2014) 154]

χ_c production rates @ 7 TeV pp

Absolute prompt χ_{c1}



Absolute prompt χ_{c2}



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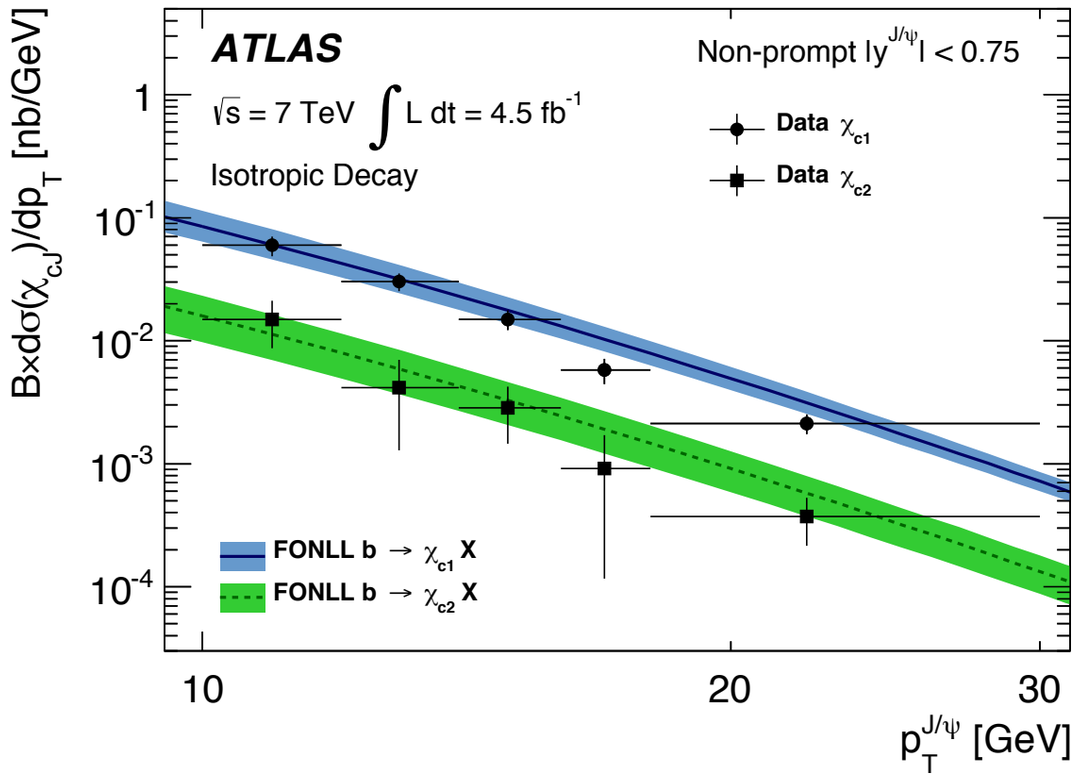
Absolute non-prompt



Summary

p+Pb @ 5.02 TeV and pp @ 2.76 TeV :

- Measured differential cross sections, R_{FB} for J/ψ, R_{pPb} for J/ψ and ψ(2S) via pp interpolation; non-prompt component for J/ψ and ψ(2S).
- **R_{FB}** agrees with theoretical predictions that include shadowing effects based on EPS09.
- **Non-prompt J/ψ and ψ(2S) cross sections in pp:** good agreement with FONLL predictions.
- **R_{pPb} of prompt and non-prompt J/ψ**: independent of centrality with centrality bias corrections.
- **R_{pPb} of prompt and non-prompt J/ψ**: above unity showing no significant dependence on p_T and y*.
- **p_T , y* dependence of prompt ψ(2S) R_{pPb}** : not clear, but there is an overall enhancement integrated over the whole kinematic region.
- **Prompt ψ(2S) R_{pPb}** : decreasing trend from peripheral to central collisions, confirmed by the ψ(2S) to Z ratio.
- **Prompt ψ(2S) to J/ψ double ratio:** no obvious rapidity dependence, but decreases with increasing event activity.

Pb+Pb @ 2.76 TeV:

- **Muons R_{CP}** : factor of ~ 2.5 suppression in the yield for most central compared to most peripheral collisions.
- **Normalized J/ψ yield** : centrality dependent suppression.

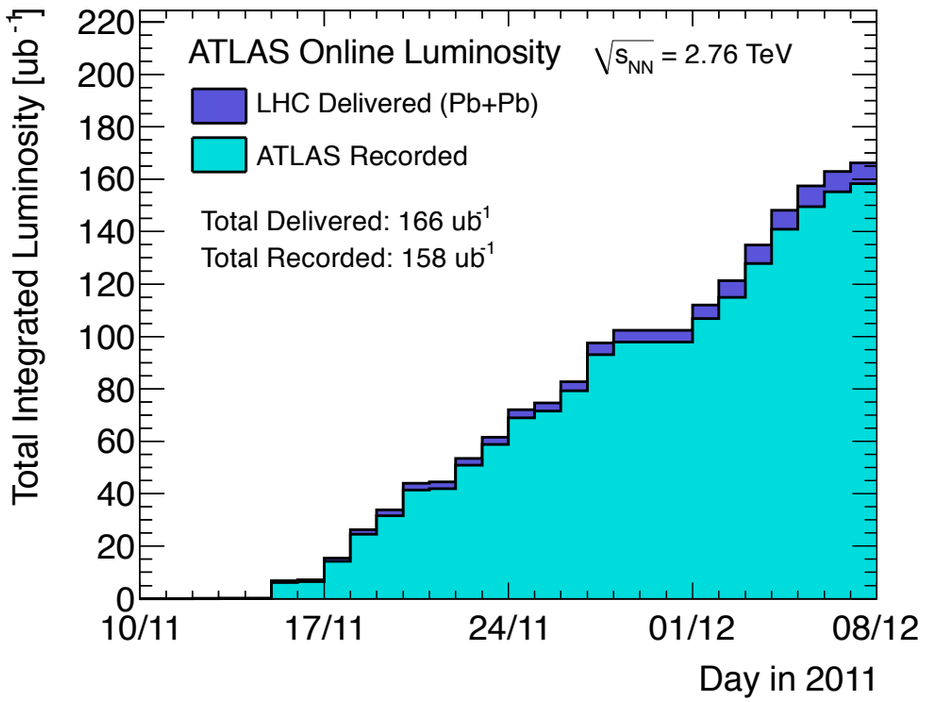
pp @ 7 and 8 TeV:

- J/ψ, ψ(2S) brand new differential cross-sections of prompt and non-prompt production: $8 < |y| \leq 10$ GeV, $|y| < 2.0$.
  - **Prompt production and NRQCD predictions (including colour-octet contributions with various matrix elements tuned to earlier collider data):** good agreement.
  - **Non prompt production and FNOLL predictions**: reasonable agreement across p_T and y.
- **ψ(2S) (S-wave) and χ_c (P-wave)**: study production just below the open charm threshold to undertake feed-down uncertainties.

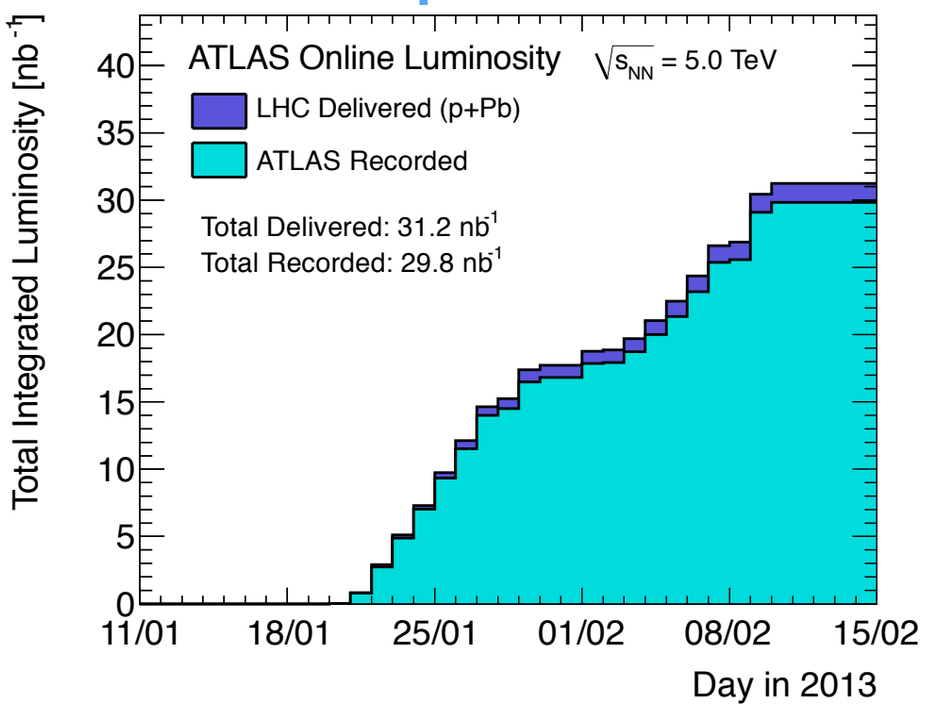
Additional slides

Extraordinary Run 1!!!

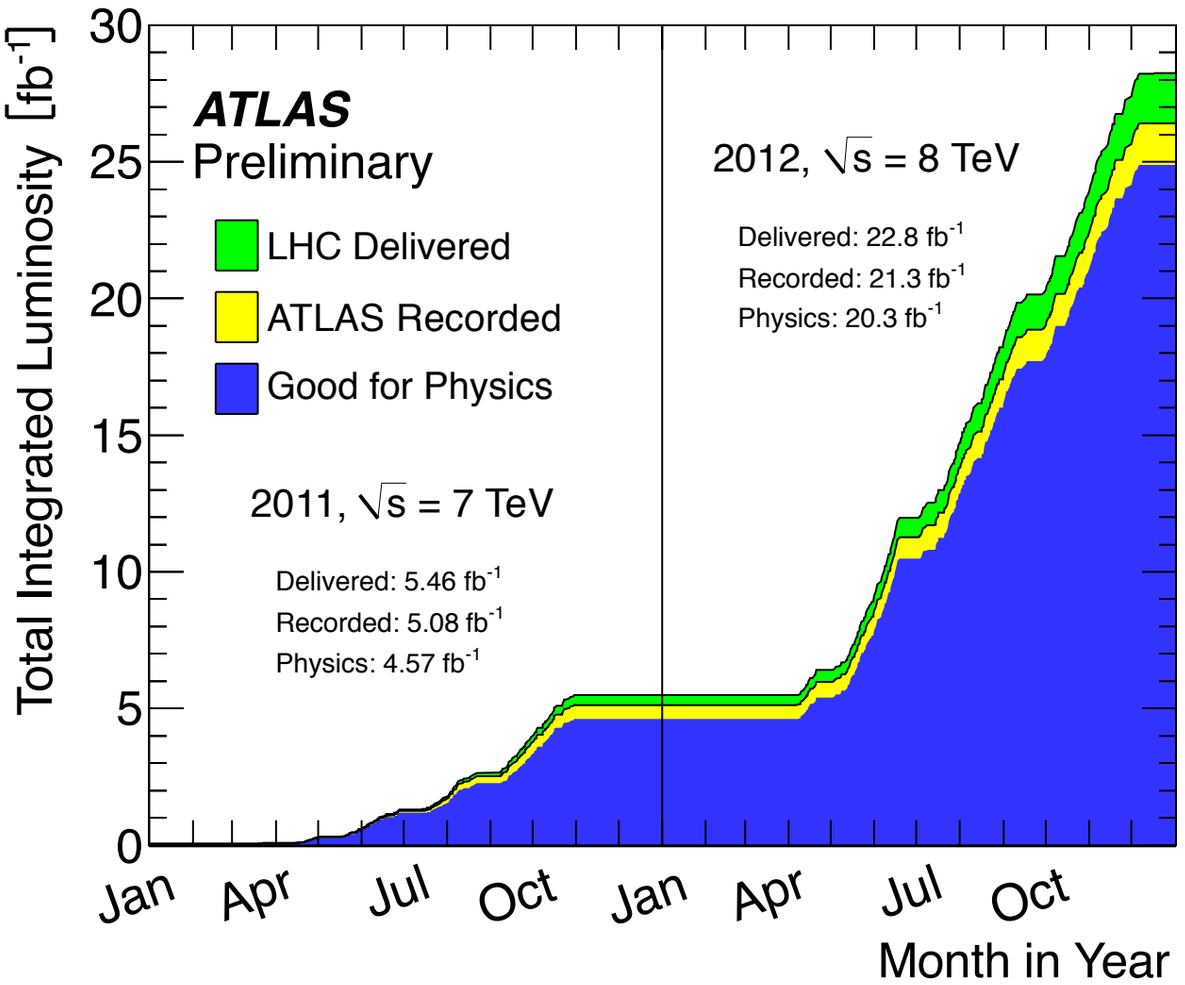
Pb+Pb



p+Pb

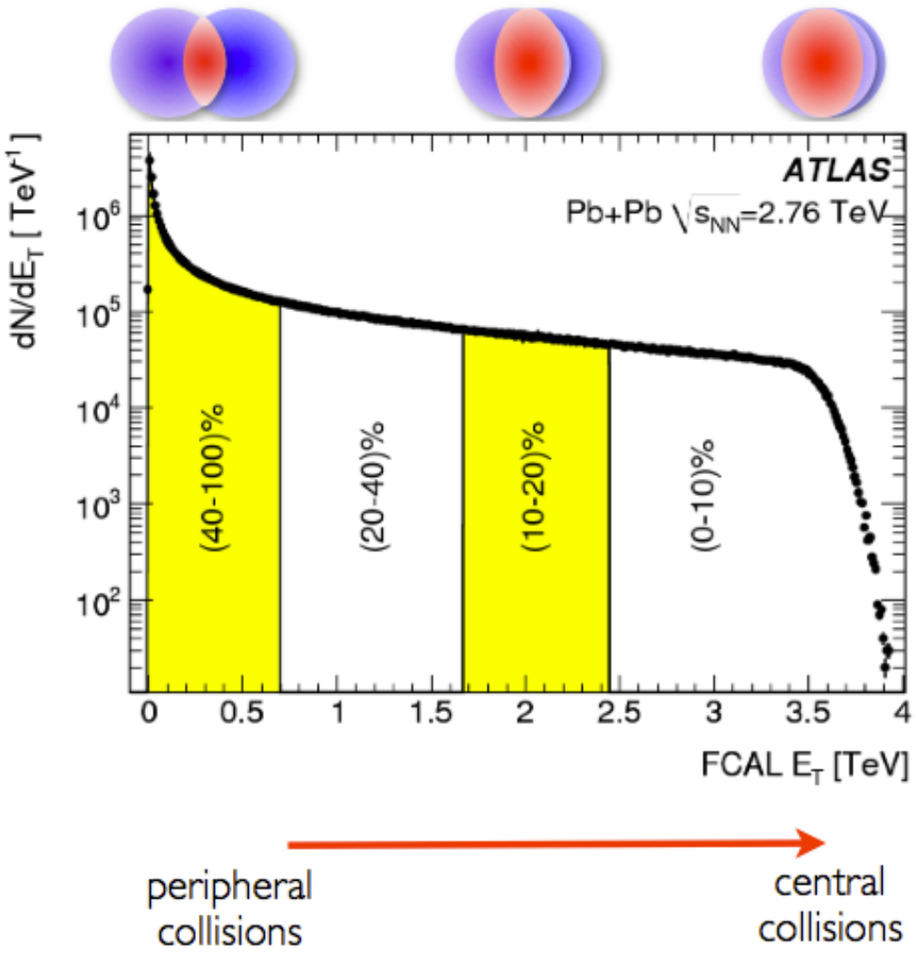


PP



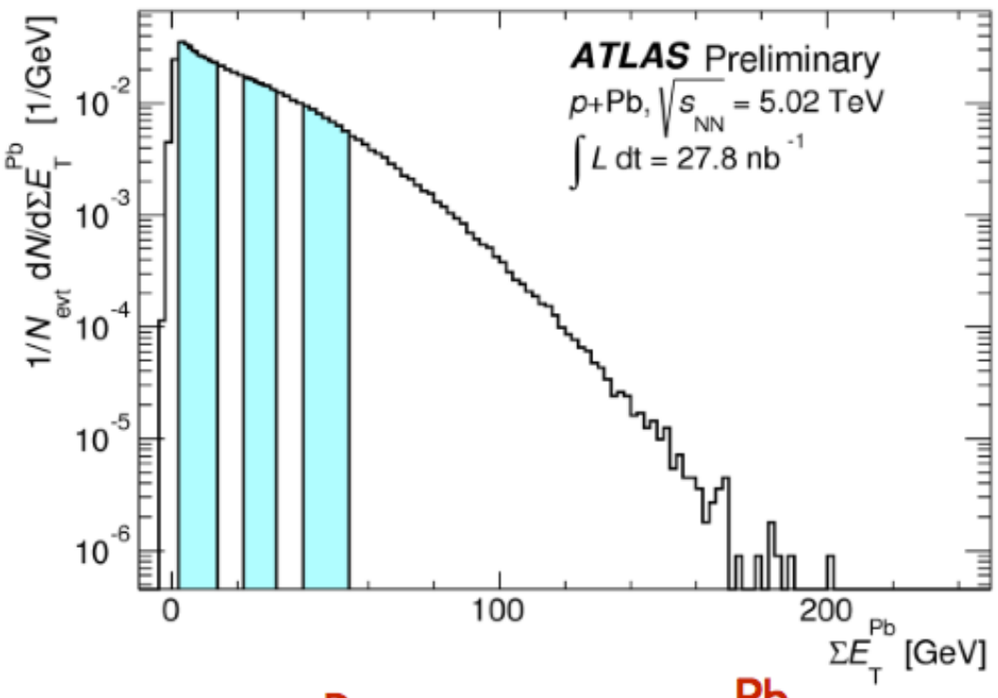
Centrality

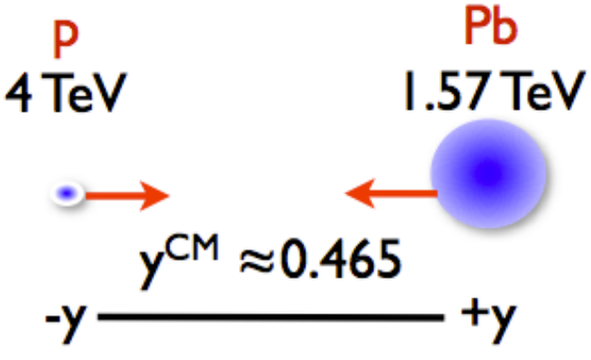
PbPb
total FCal E_T



peripheral collisions → central collisions

pPb
FCal E_T on Pb-going side





Interpolation of pp data

$$\sigma(\sqrt{s}) = \begin{cases} p_0 + \sqrt{s}p_1 & \text{linear} \\ (\sqrt{s}/p_0)^{p_1} & \text{power law} \\ p_0(1 - \exp(-\sqrt{s}/p_1)) & \text{exponential} \end{cases}$$

Interpolation between pp data @ 2.76 TeV with 7 and 8 TeV

8.5-10 GeV in pT, only 2.76 and 7 TeV

10-30 GeV in pT: 2.76, 7 and 8 TeV

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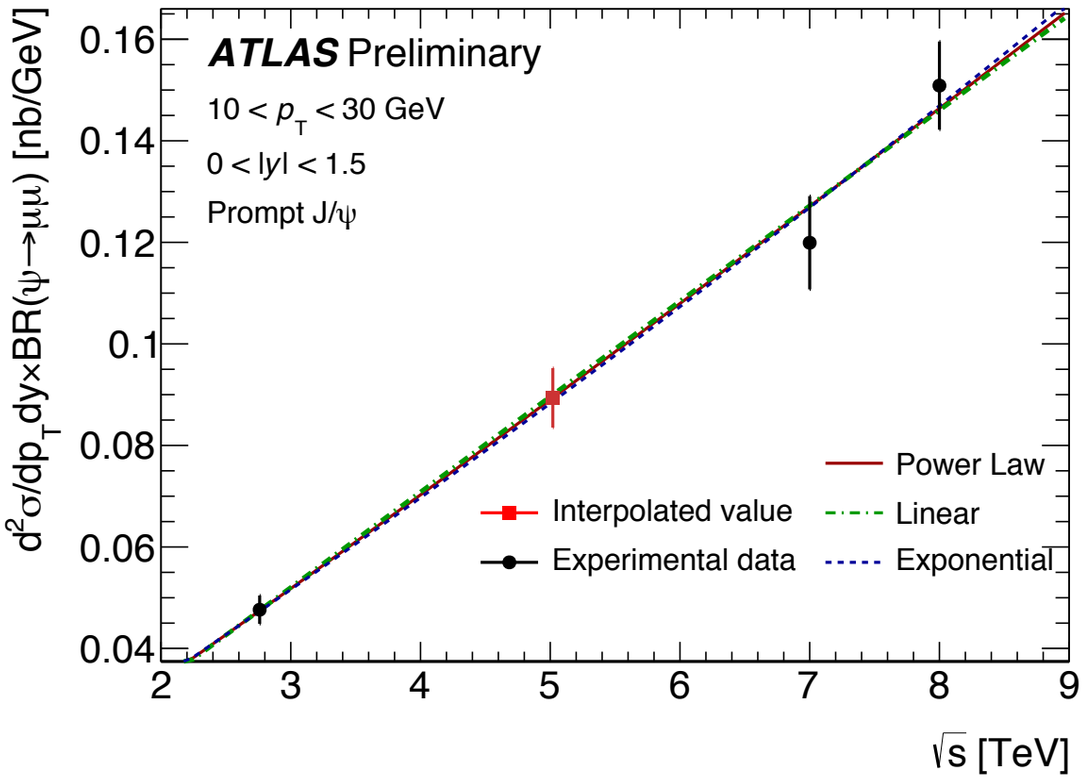
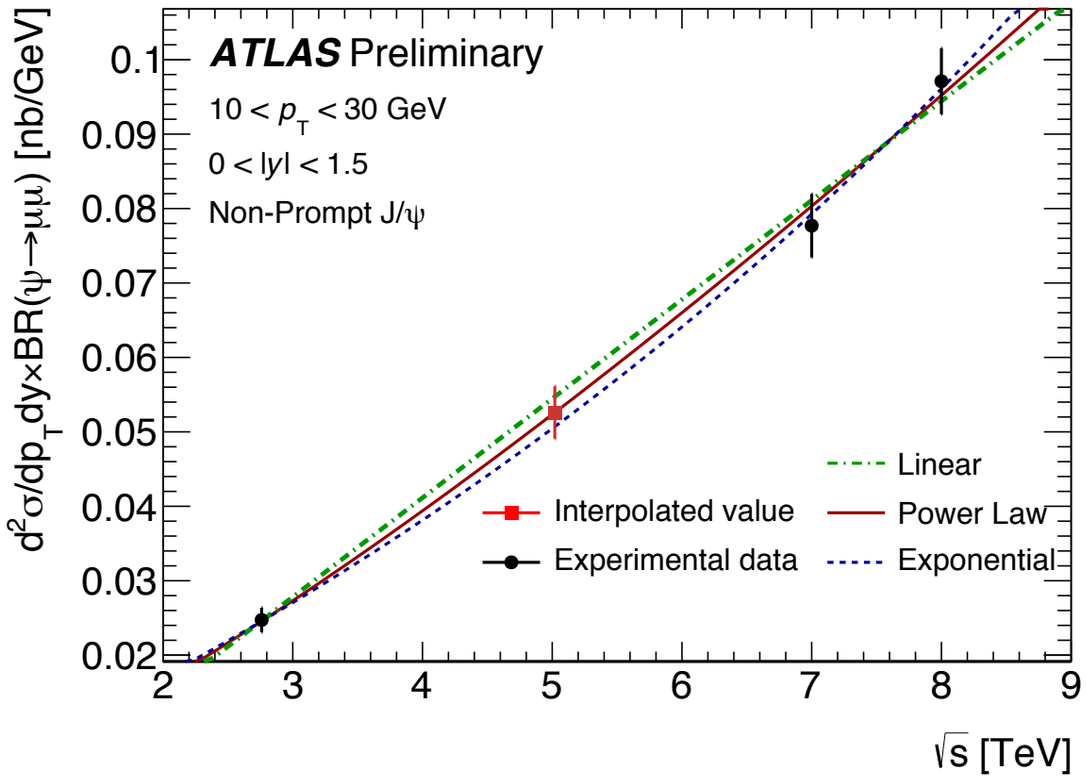
prompt J/ψ

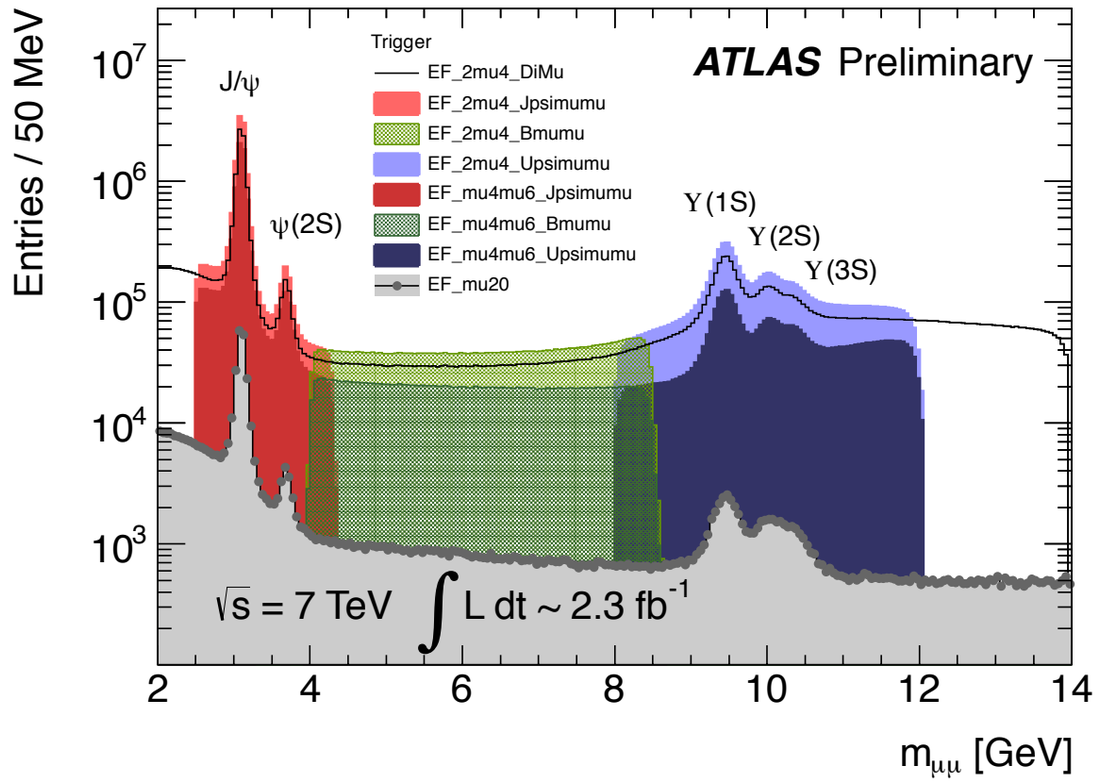


non-prompt J/ψ



Quarkonium/Heavy Flavour trigger @ 7 and 8 TeV pp

Mainly based on dimuon signatures with some analyses using single-muon triggers



Level-1:

HW based, fast muon detectors, coarse resolution "region-of-interest" (RoI), dimuons with p_T > 4 GeV

Level- 2 / Event Filter (EF):

SW based, precise confirmation of the muons with Inner Detector track reconstruction, dimuon vertex construction (inv. mass cut)

Cross section evaluation for quarkonium analyses @ 7 and 8 TeV pp

For each channel $\mathcal{Q}\rightarrow$ final:

$$\frac{d^2\sigma_Q}{dp_t dy} \cdot BR(Q \rightarrow final) = \frac{N_{corr}^{Q\rightarrow final}}{\mathcal{L} \cdot \Delta p_T \cdot \Delta y};$$

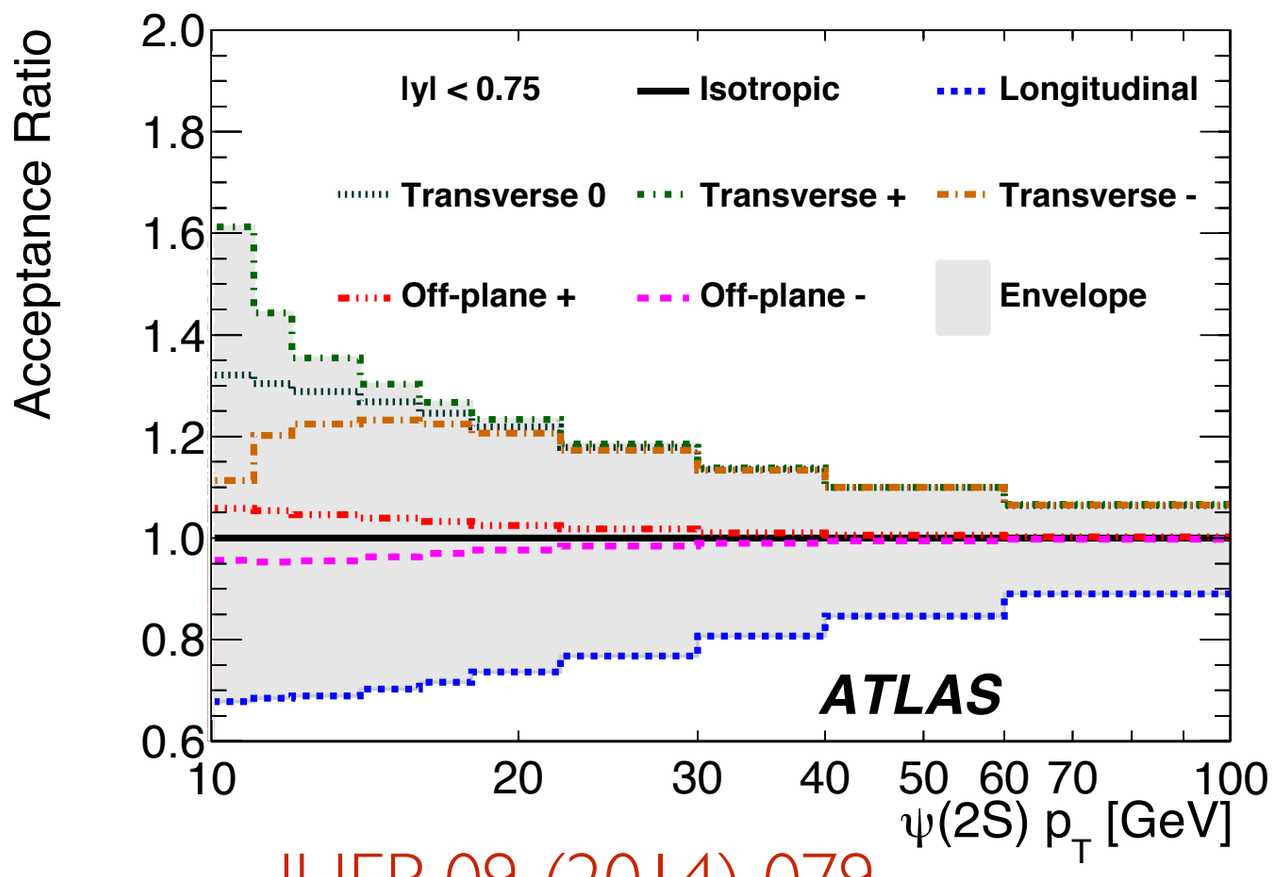
- extraction of the signals is obtained with unbinned maximum likelihood methods;

- efficiency corrections for tracking, reconstruction and triggering are obtained with data driven methods (e.g., tag and probe for the trigger);

- acceptance corrections, to re-cover the visible phase space in p_T and y for comparison with QCD predictions, are obtained with simulation;

- they depend on the unknown polarization status of $\mathcal{Q}$ (spin alignment);
- the correction is evaluated for the isotropic case and an envelope of variations is computed for the various polarizations. Example:

$\psi(2S) \rightarrow J/\psi\pi\pi$



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Charmonia analyses @ 5.02 TeV p+Pb and @ 2.76 TeV pp

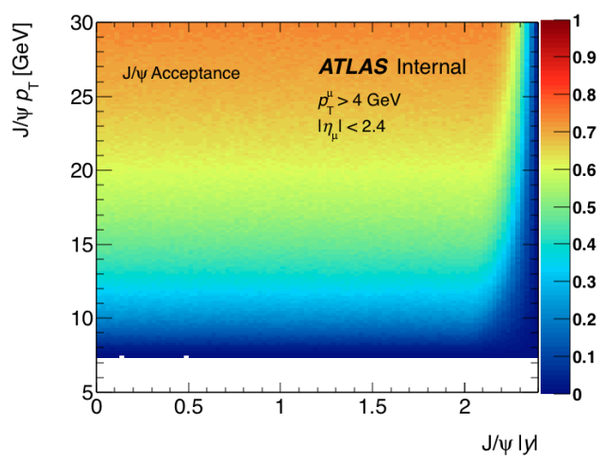
- muon candidates:
  - combination of charged-particle tracks reconstructed in the ID and MS
- muon pairs:
  - opposite sign charges and originating from a common vertex
- prompt and non-prompt processes distinguished by " pseudo-proper time"

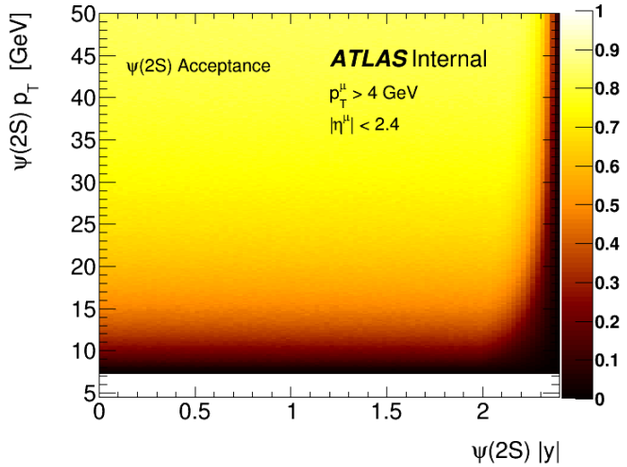
$$\tau = \frac{L_{xy} m_{\mu\mu}}{p_{\mathrm{T}}^{\mu\mu}}$$

- weight applied:

$$w_{\mathrm{total}}^{-1} = A \cdot \varepsilon_{\mathrm{reco}} \cdot \varepsilon_{\mathrm{trig}}$$

- acceptance





- trigger efficiency:

$$\epsilon_{\mathrm{trigger}} = \epsilon_{\mathrm{L1}} \cdot \epsilon_{\mathrm{EF}}$$

$$\epsilon_{\mathrm{L1}} = 1 - [1 - \epsilon_{\mathrm{L1}}^{\mu}(p_{\mathrm{T1}}^{\mu}, q_1^{\mu} \cdot \eta_1^{\mu})] \cdot [1 - \epsilon_{\mathrm{L1}}^{\mu}(p_{\mathrm{T2}}^{\mu}, q_2^{\mu} \cdot \eta_2^{\mu})]$$

$$\epsilon_{\mathrm{EF}} = \epsilon_{\mathrm{EF}}^{\mu}(p_{\mathrm{T1}}^{\mu}, q_1^{\mu} \cdot \eta_1^{\mu}) \cdot \epsilon_{\mathrm{EF}}^{\mu}(p_{\mathrm{T2}}^{\mu}, q_2^{\mu} \cdot \eta_2^{\mu})$$

- unbinned mass-lifetime maximum likelihood fit to separate prompt and non prompt production components

Charmonia analyses @ 5.02 TeV p+Pb

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

Open heavy flavour in Pb+Pb

Muon signal extraction

1) Separate muons (heavy flavour decays) from **pion** and **kaon** decays

2) Momentum balance

$$\frac{\Delta p_{\text{loss}}}{p_{\text{ID}}} = \frac{p_{\text{ID}} - p_{\text{MS}} - \Delta p_{\text{calo}}(p,\eta,\phi)}{p_{\text{ID}}}$$

Muon Spectrometer

Inner Detector

momentum and angle-dependent average energy loss of muons in the calorimeter (from MC simulations)

3) Scattering angle significance:

$$S(k) = \frac{1}{\sqrt{n}}\left(\sum_{i=1}^{k} s_i - \sum_{j=k+1}^{n} s_j\right)$$

deflections in the trajectory resulting from decays in flight

4) Take the maximum:

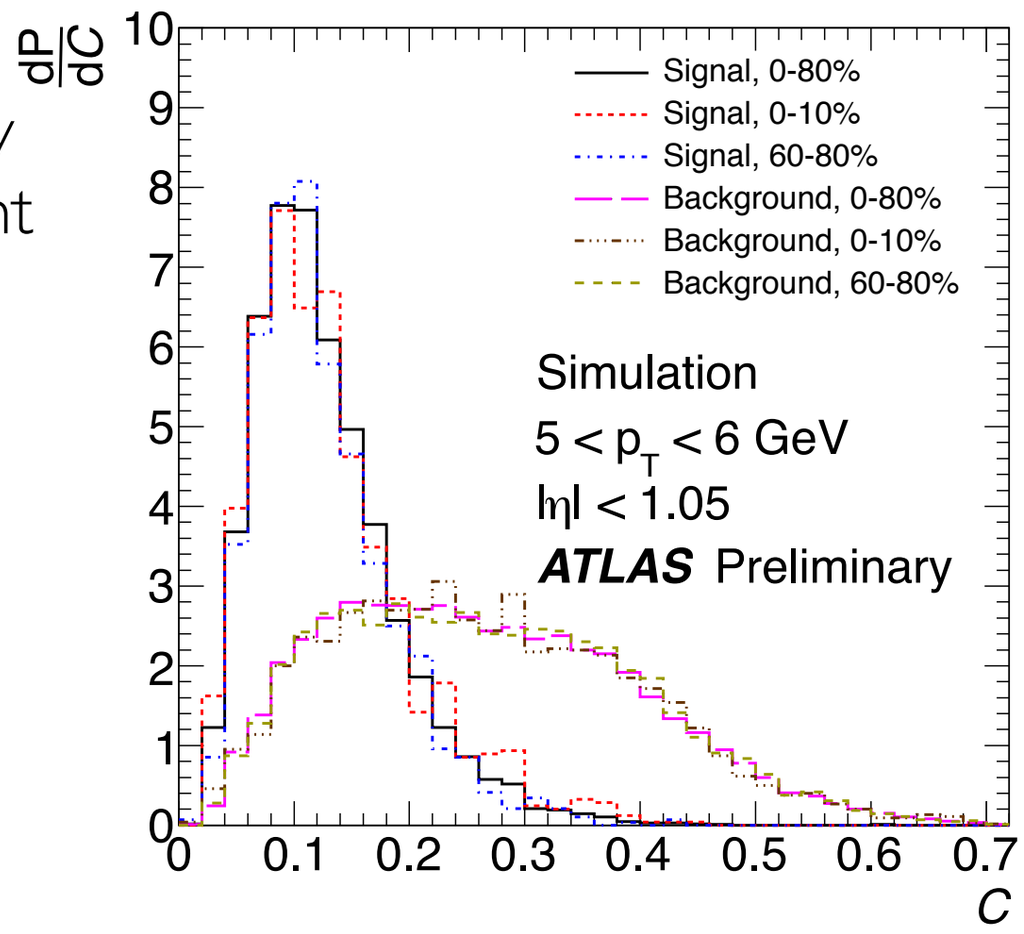
$$S = \max\{|S(k)|, k = 1, 2, ...\}$$

C Distributions

PYTHIA+HIJING

5) Composite discriminant (r = 0.07):

$$C = \left|\frac{\Delta p_{\text{loss}}}{p_{\text{ID}}}\right| + rS$$



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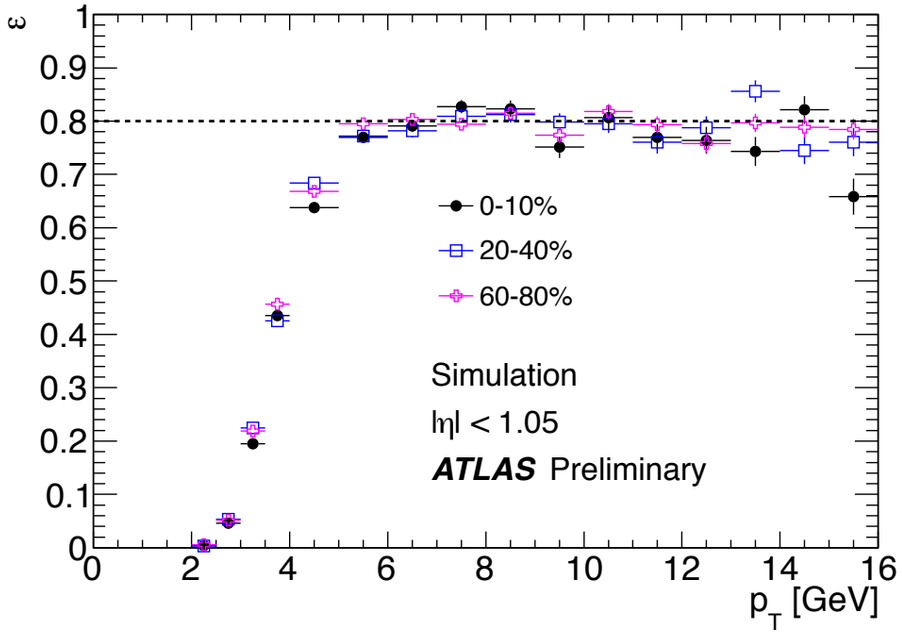
Open heavy flavour in Pb+Pb @ 2.76 TeV

Efficiency for reconstructing muons associated with HF decays

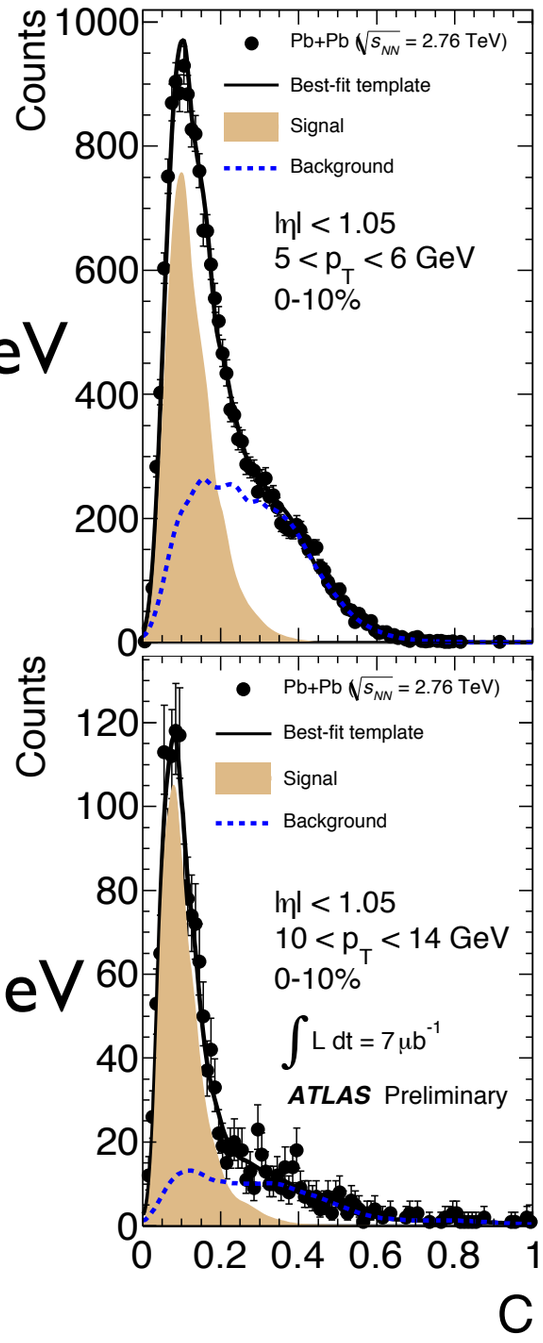


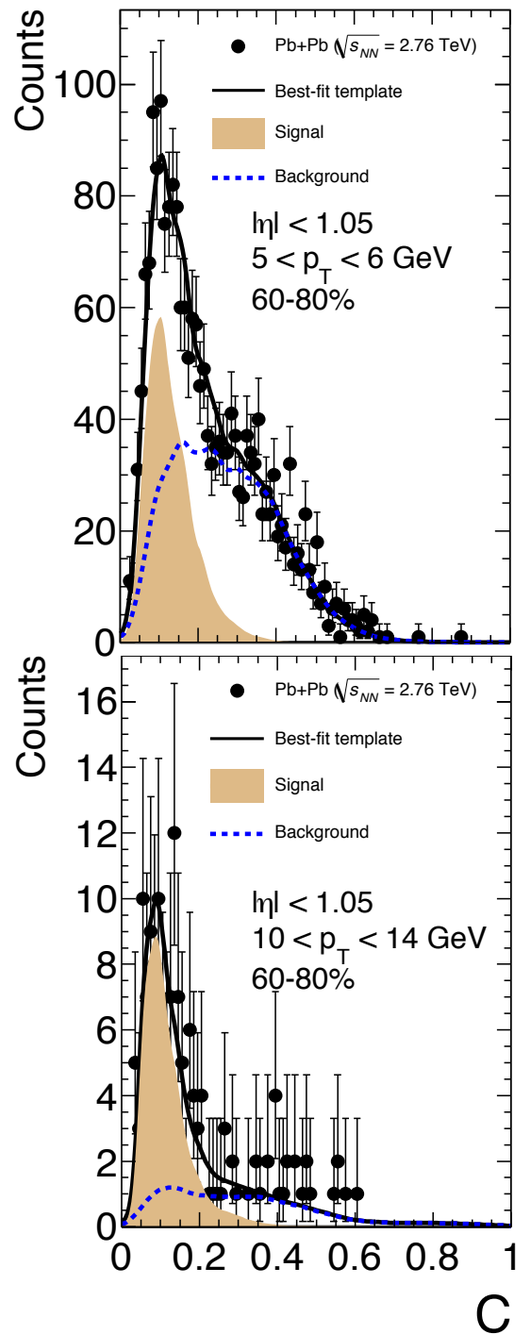
Signal extracted from a template fit

0-10%

60-80%

$5 < p_T < 6$ GeV





$10 < p_T < 14$ GeV

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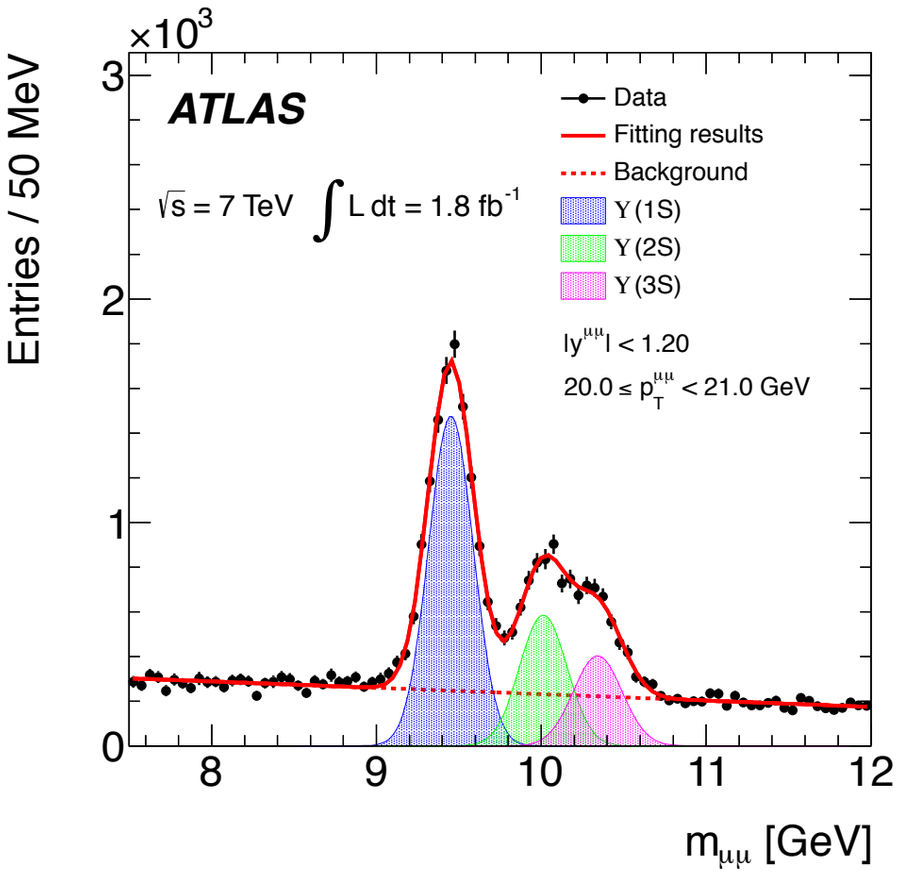
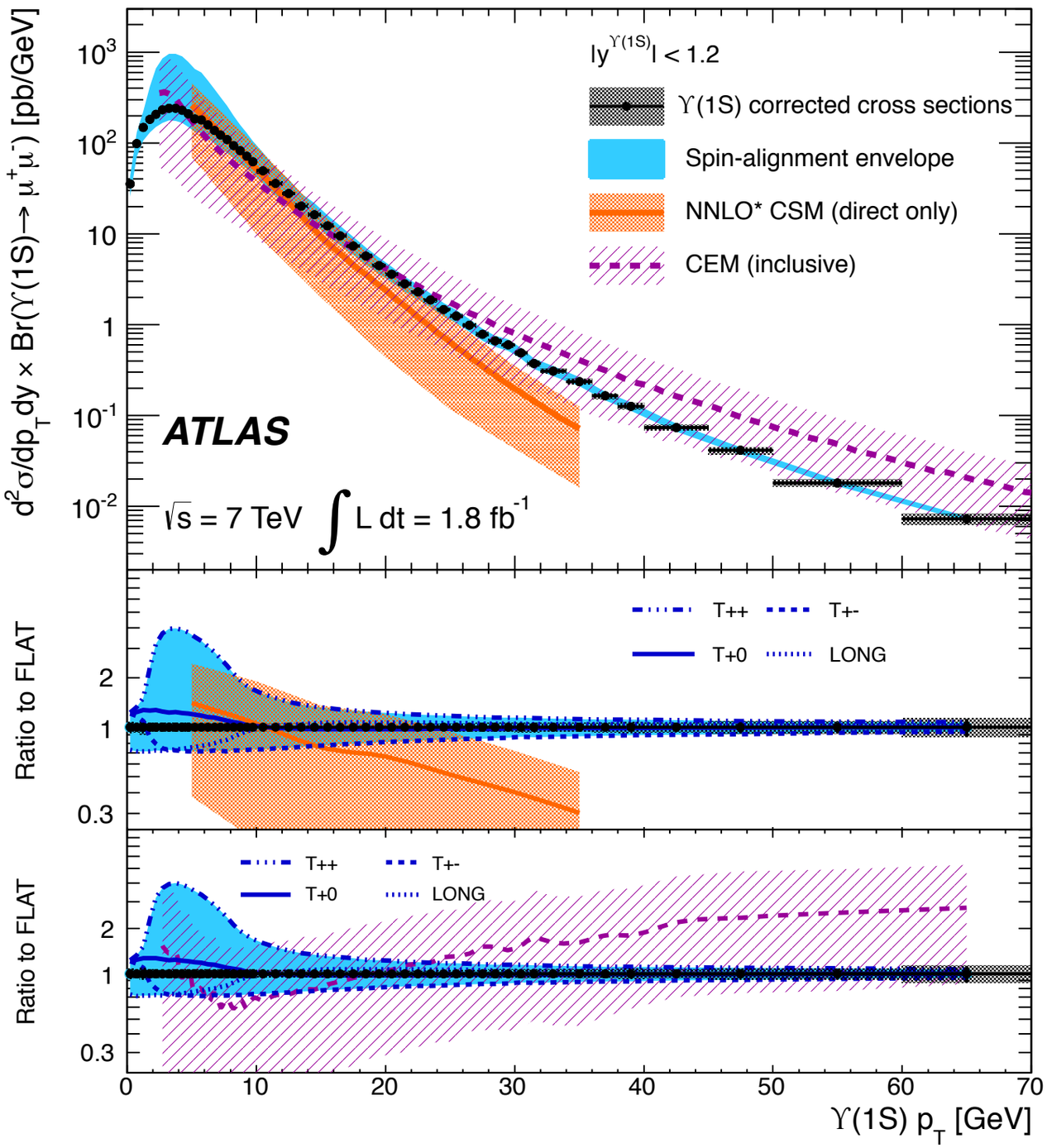
Upsilon (Υn→μμ) production @ 7 TeV pp

Phys. Rev. D 87, 052004 (2013)



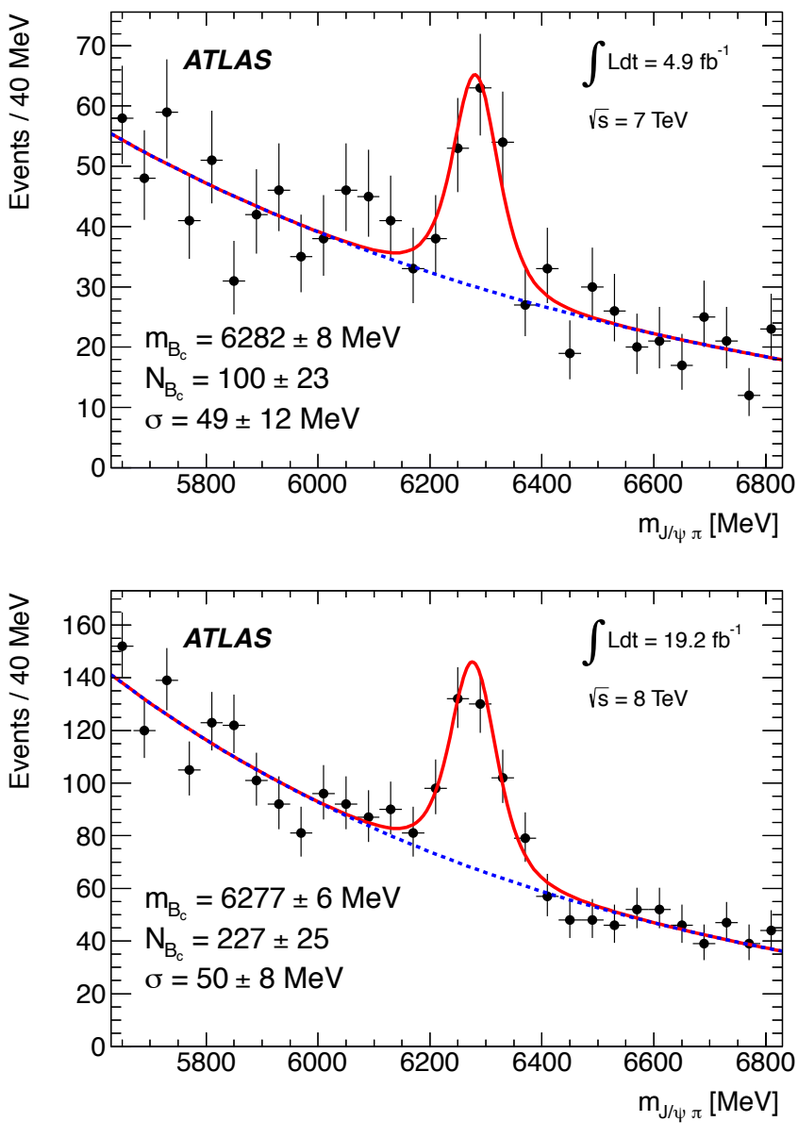
Predictions of direct production with the NNLO* Color Singlet Mechanism (CSM) and inclusive predictions from the Color Evaporation Model (CEM).



Observation an excited of $Bc^{\pm}$ meson state @ 7 TeV and 8 TeV pp

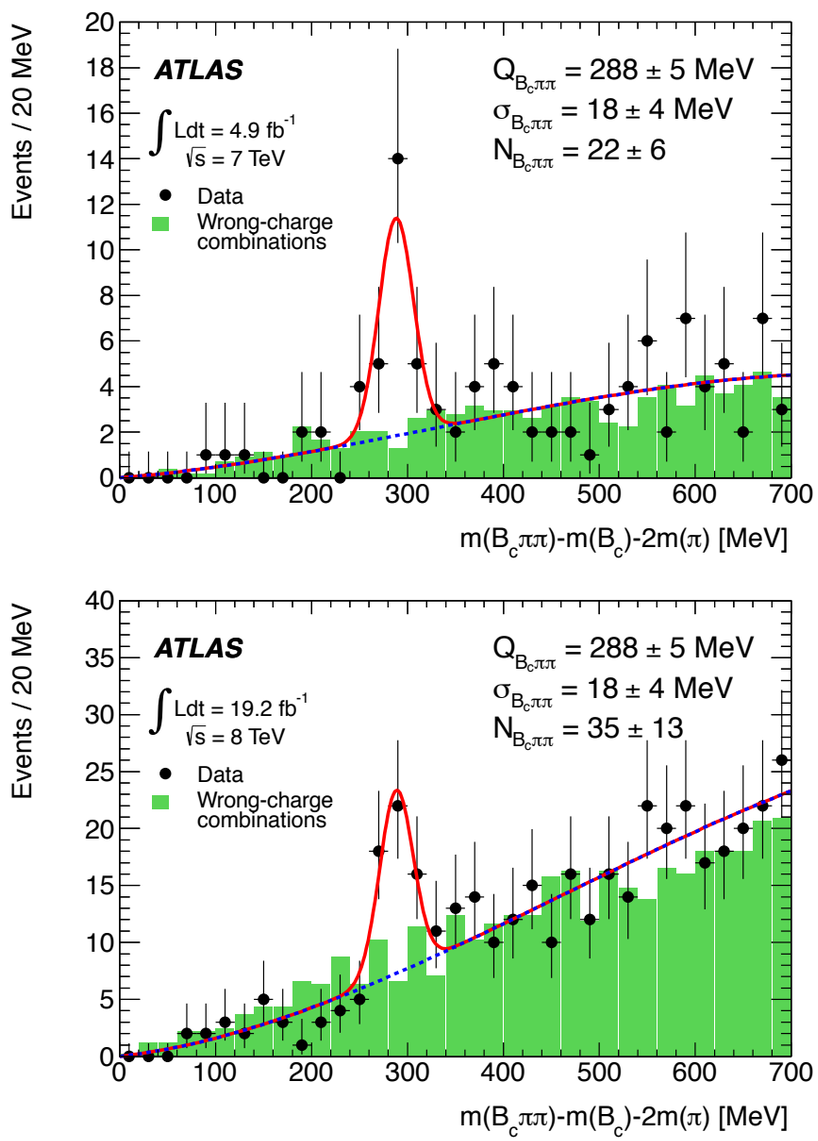
Phys. Rev. Lett. 113, 212004 (2014)

invariant mass distributions of $B^{\pm}c \rightarrow J/\psi\pi^{\pm}$



distributions of the right charge combinations

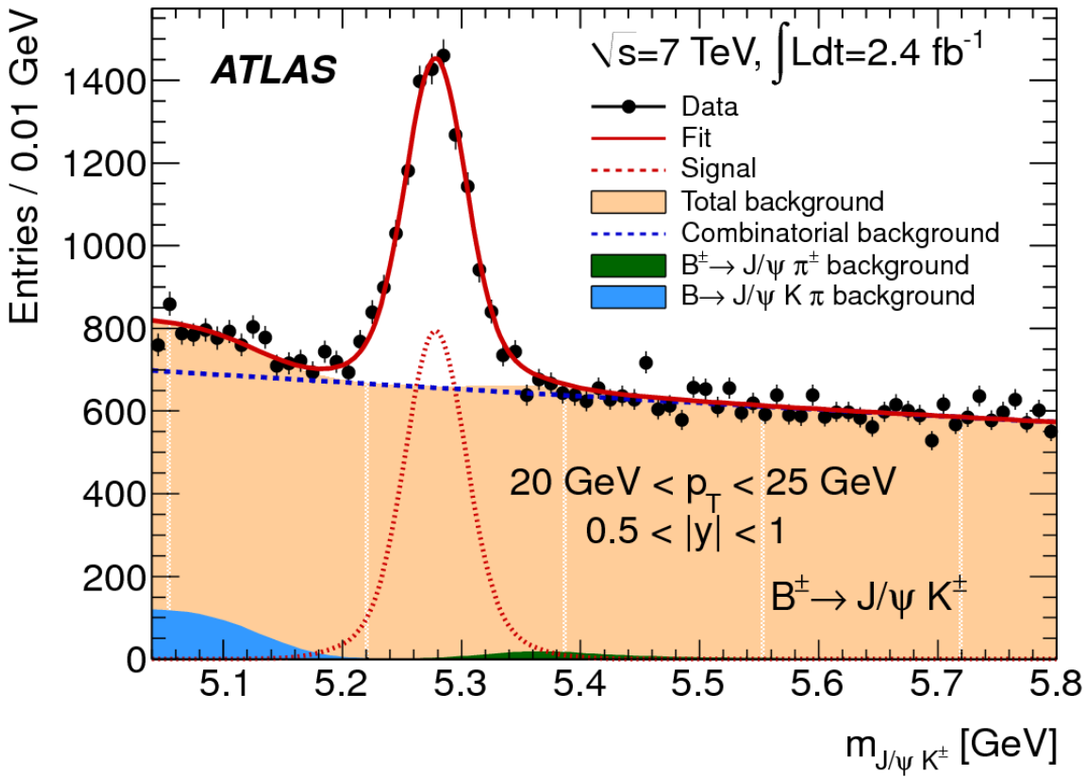
$Q = m(B^{\pm}c\pi\pi) - m(B^{\pm}c) - 2m(\pi^{\pm})$



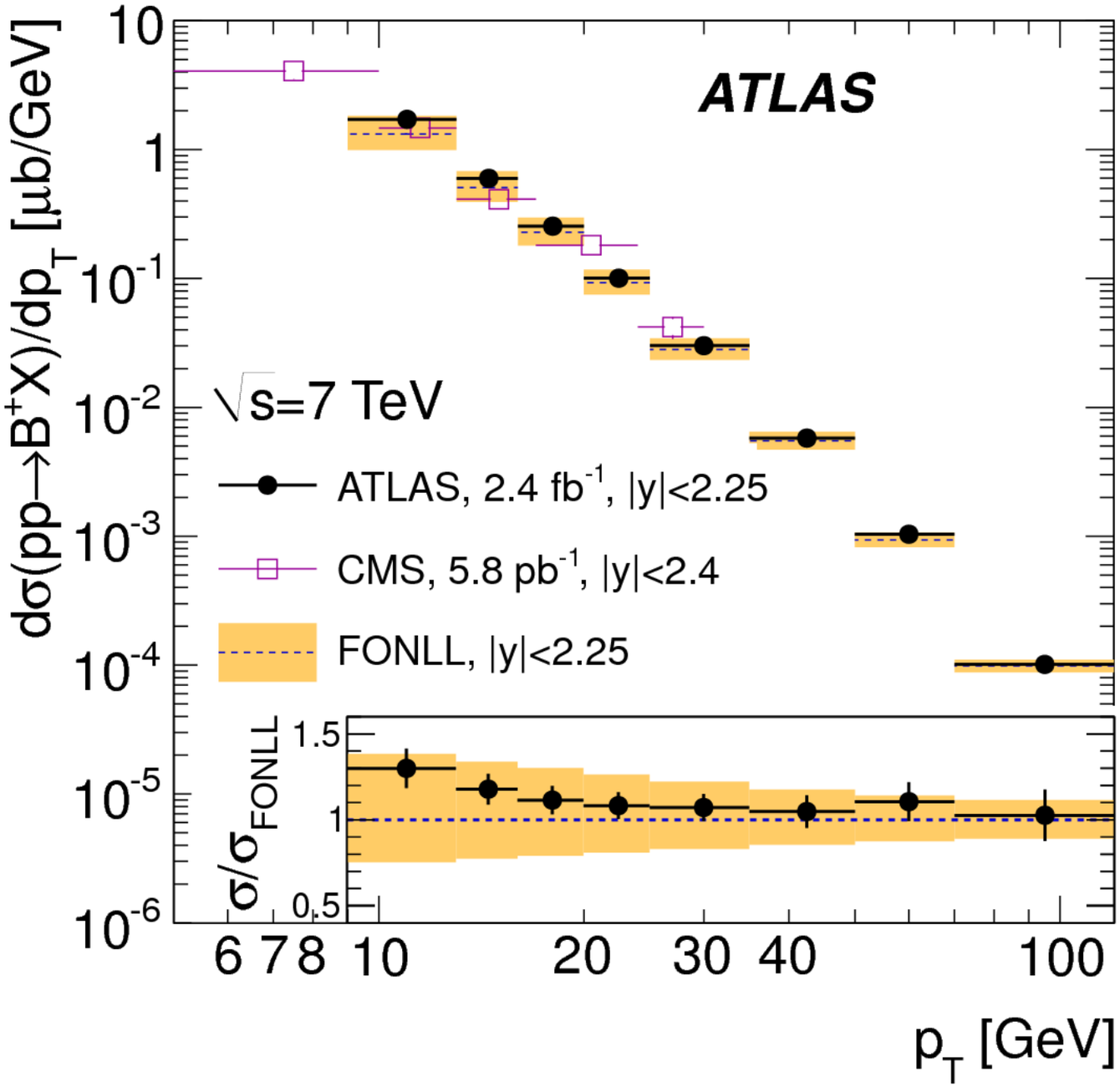
The mass and decay of this state are consistent with expectations for the second S-wave state of the $B^{\pm}c$ meson, $B^{\pm}c(2S)$

B+→ J/ψ(→μμ) K+ production @ 7 TeV pp

JHEP10(2013)042



Predictions of the FONLL calculation for b-quark production compared with the data, assuming a hadronisation fraction of $f_{b\to B^+}$ of (40.1 ± 0.8)%



Measurement of Br($B^{\pm} \to \chi_{c1} K^{\pm}$) @ 7 TeV pp

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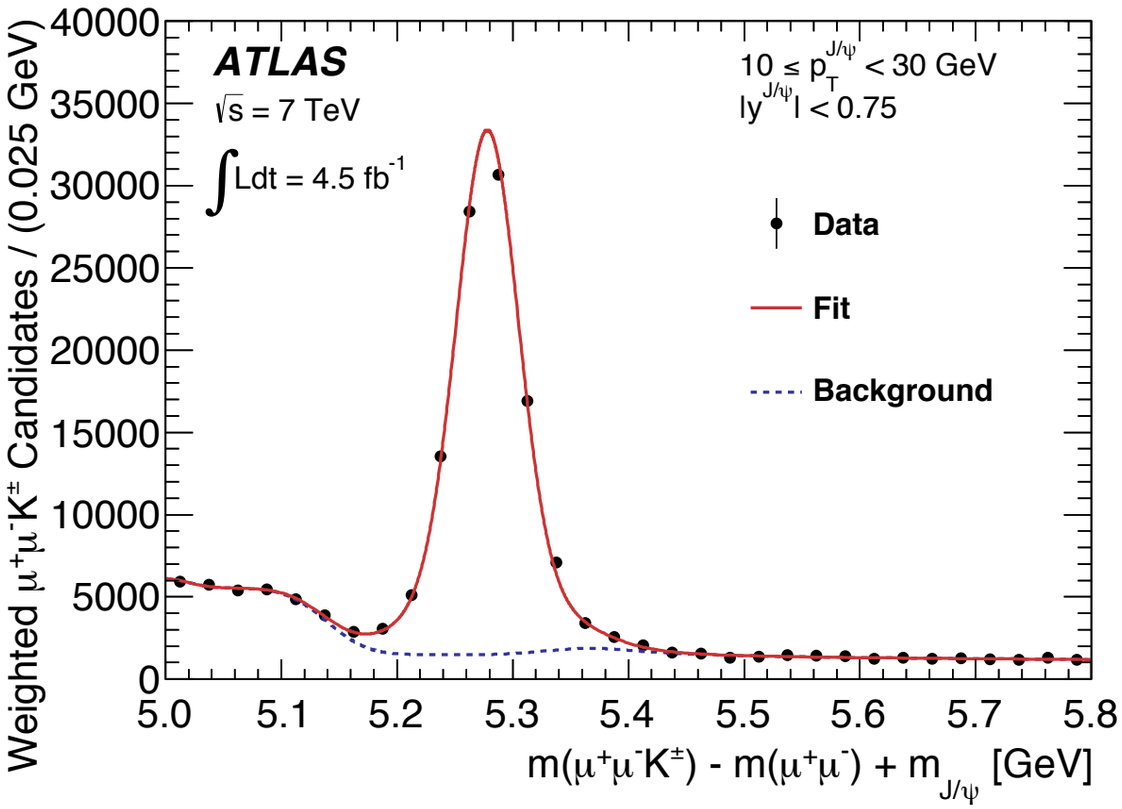
Branching fraction measurement from the $\chi_c \to J/\psi\,\gamma$ sample and the reference $B^+ \to J/\psi\, K^+$

$$BR(B^+ \to \chi_c K^+) = \mathcal{A}_B \cdot \frac{N^B_{\chi_c}}{N^B_{J/\psi}} \cdot \frac{BR(B^+ \to J/\psi K^+)}{BR(\chi_c \to J/\psi\gamma)}$$

$B^{\pm} \to J/\psi\, K^{\pm}$



$B^{\pm} \to \chi_{c1} K^{\pm}$