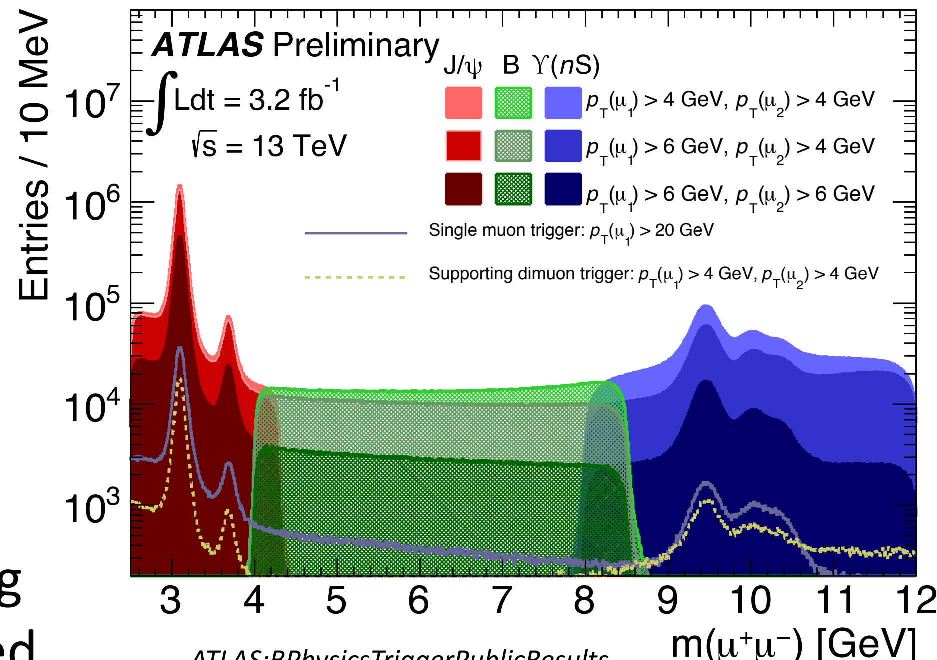
Quarkonium and heavy flavour production at ATLAS

Roger Jones
On Behalf of the ATLAS Collaboration

QCD@LHC 2016, Zurich, Switzerland

Triggering for B-physics: Run-1

- 3-level system O(20MHz) -> O(400Hz) (2-Level for Run-2, @ 1kHz)
  - Level 1 - hardware O(75)kHz
  - Level 2 and Event Filter
    - Software-based
    - Offline-like reconstruction software
- Primary B-physics triggers:
  - Two muon signals at L1
  - confirmed at L2/EF with vertexing and invariant mass criteria applied



ATLAS:BPhysicsTriggerPublicResults

- Varying thresholds and prescaling applied to maximise signal rate
  - Two muons; $p_T(\mu) > 4$ GeV ($\mu4\mu4$) , $\mu4\mu6$
- *(2015+ Requirements of higher thresholds / prescales.)*

Quarkonium production

- Many relevant ATLAS results now available
- Recent ATLAS Results in this talk:

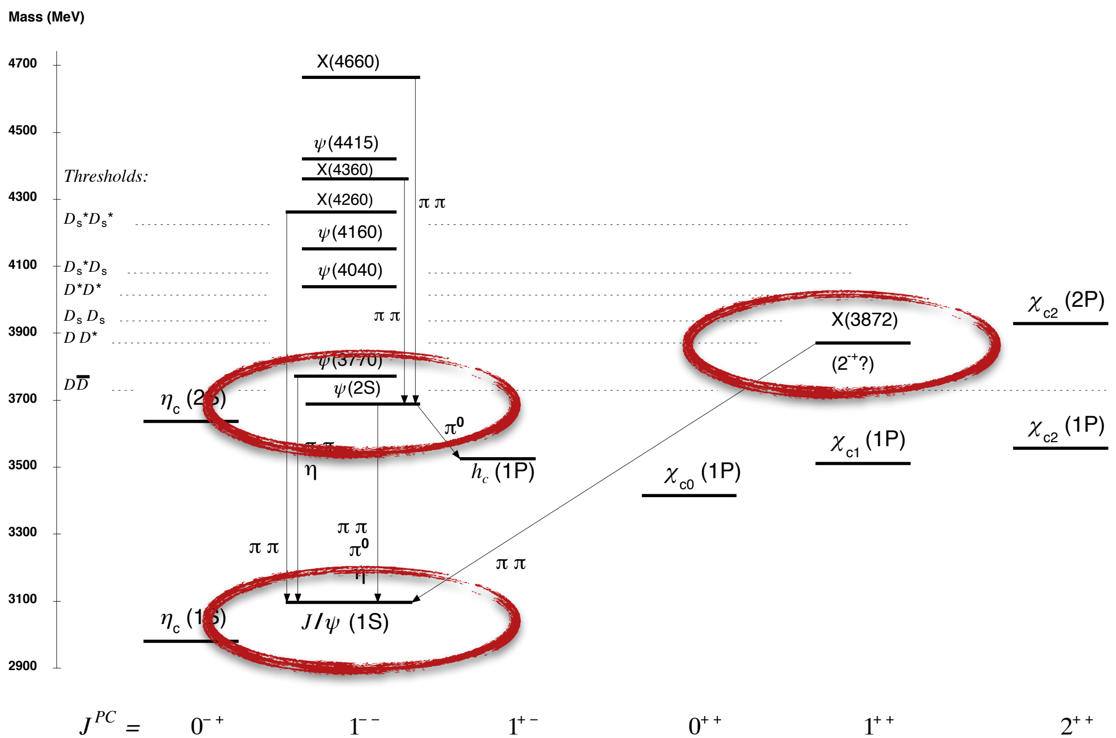
- *For open beauty, see Gabriele Chiodini 's talk on Tuesday*
- *Di-J/ψ in David Bartsch's talk after tea*

Production Cross-sections	
Differential non-prompt J/ψ production fraction at 13 TeV	ATLAS-CONF-2015-030
J/ψ and ψ(2S) → μμ at 7 and 8 TeV	Eur.Phys.J. C76 (2016) 5, 283
ψ(2S), X(3872) → J/ψππ	ATLAS_CONF-2016-028
Search for X_b	PRL B740 (2015) 199
Open HF Production	
f_s/f_d	PRL 115 (2015) 262001
Charm production	Nucl. Phys. B907 (2016) 717

Comprehensive set of measurements across variety of decay modes and states

Heavy Quarkonia Production Cross-Sections

- Measurement of the **prompt** and **non-prompt** **differential cross-sections** of **heavy quarkonia,** typically in the dimuon decay mode
  - Measured in **7 TeV** (2011, 2.1 fb^{-1}), and **8 TeV** (2012, 11.4 fb^{-1}), now **13 TeV**
  - **Here I concentrate on the recent charmonia results**



K.A. Olive et al. (Particle Data Group), Chin. Phys. C38, 090001 (2014)

Example: J/ψ and ψ(2S)

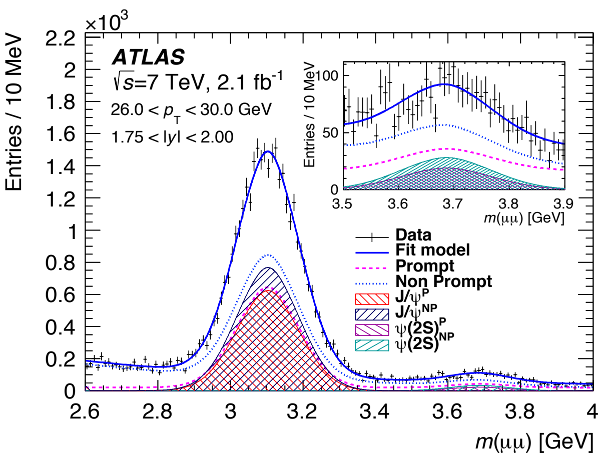
- ψ(2S) meson: no significant feed-down from higher mass quarkonia,
  - unique possibility to study $J^{PC}=1^{--}$ states.
- J/ψ production: contributions from 1^{--} and J^{++} in comparable amounts.
- Non-prompt fraction and Ratio of ψ(2S) to J/ψ also extracted.
- Use displacement from PV for (non)-prompt separation
- Prompt: $\delta(\tau) \otimes R(\tau)$
- non-prompt decays: $1/\tau_\psi \cdot \exp\left(\tau/\tau_\psi\right) \otimes R(\tau)$
- Crystal-ball + Gaussian for mass description
- Weighted unbinned maximum log-likelihood fits to each $p_T - |y|$ slice.

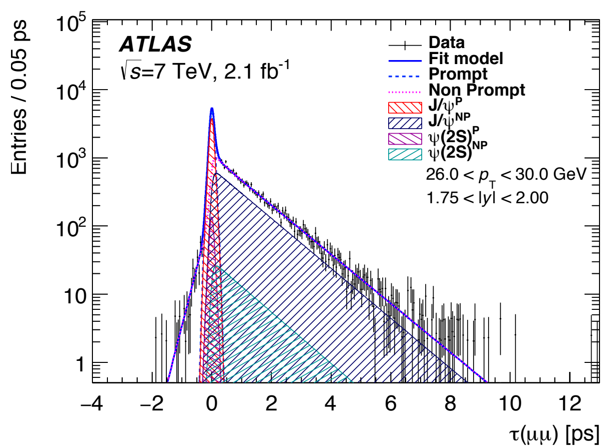
$$\tau(\mu\mu) = \frac{L_{xy} \cdot m(\mu\mu)}{p_T(\mu\mu)}$$

Transverse

Invariant

Transverse





- Default: assume no spin alignment

Eur.Phys.J. C76 (2016) 5, 283

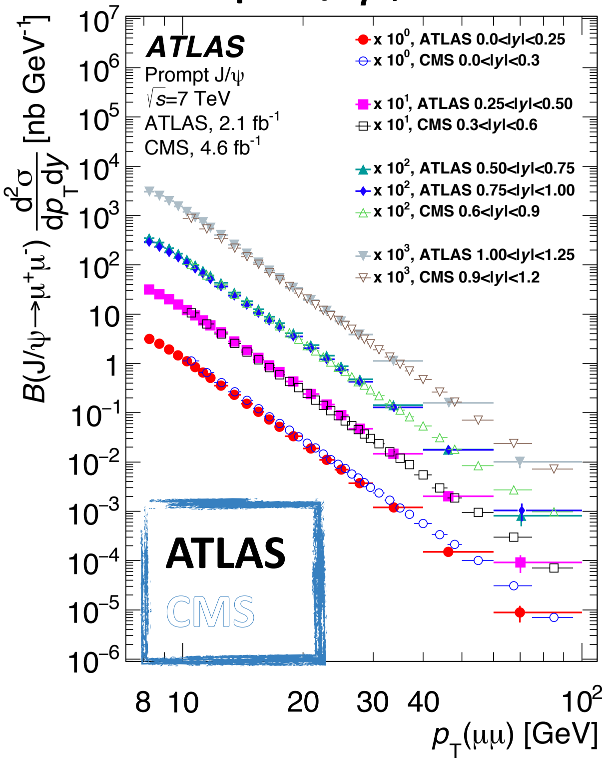
arXiv: 1512.03657

J/ψ and $\psi(2S)$: LHC Comparison

- Comparison of ATLAS data to other LHC experiments.
- Good agreement between **CMS** for overlapping rapidity and p_T (@ 7TeV),

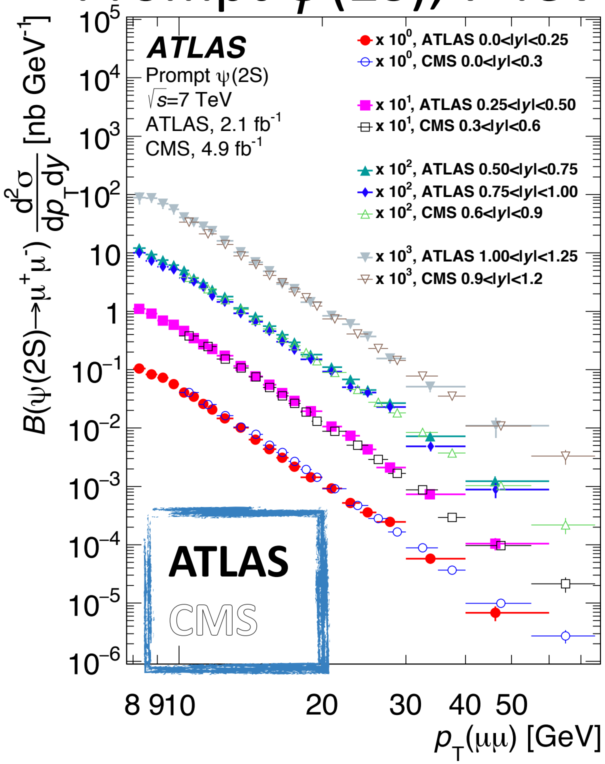
- Also compared to **LHCb**, in overlapping p_T, but adjoining slices of rapidity (@ 8TeV).
  - Comprehensive suite of measurements, now covering areas of p_T: 0 - 120 GeV, y: 0 – 4.5 at LHC energies

Prompt J/ψ, 7 TeV

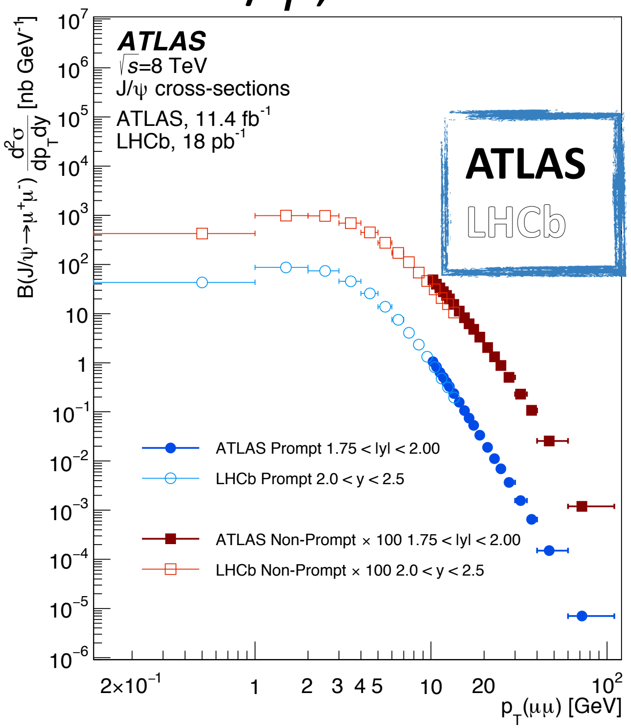


CMS: Phys. Rev. Lett. 114.19 (2015) 191802,

Prompt $\psi(2S)$, 7 TeV



J/ψ, 8 TeV



(LHCb) JHEP 1306 (2013) 064,

J/ψ and $\psi(2S)$: Prompt cross-section

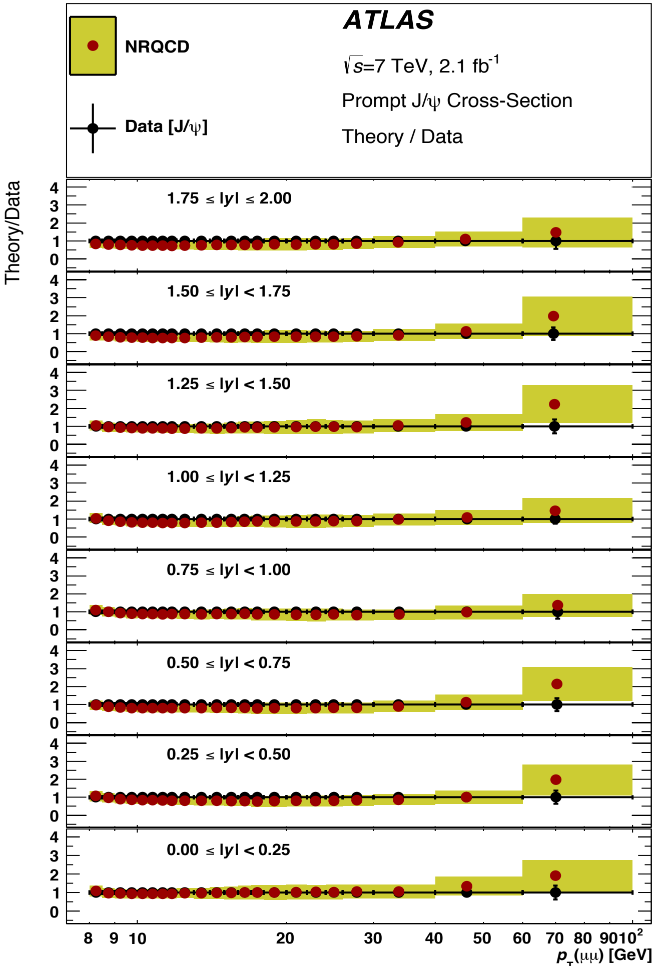
- Double-differential cross-sections times BR:
  - **Prompt** – compared to **NRQCD**,
  - Good agreement across range of p_T,
    - Although data a little softer
  - No observed dependence with rapidity

$$\frac{d^2\sigma(pp \to \psi)}{dp_T dy} \times \mathcal{B}(\psi \to \mu^+\mu^-) = \frac{N_\psi^p}{\Delta p_T \Delta y \times \int \mathcal{L} dt}$$

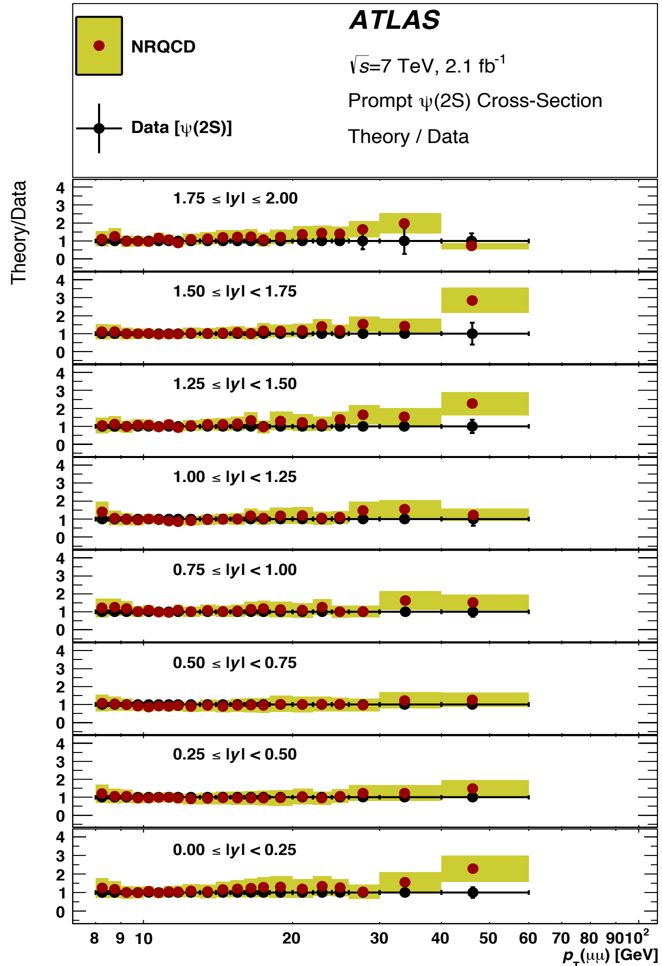
7 TeV

NLO derived using HELAC-ONIA tuned from Tevatron data

J/ψ



$\psi(2S)$



J/ψ and ψ(2S): Prompt cross-section

- Double-differential cross-sections times BR:

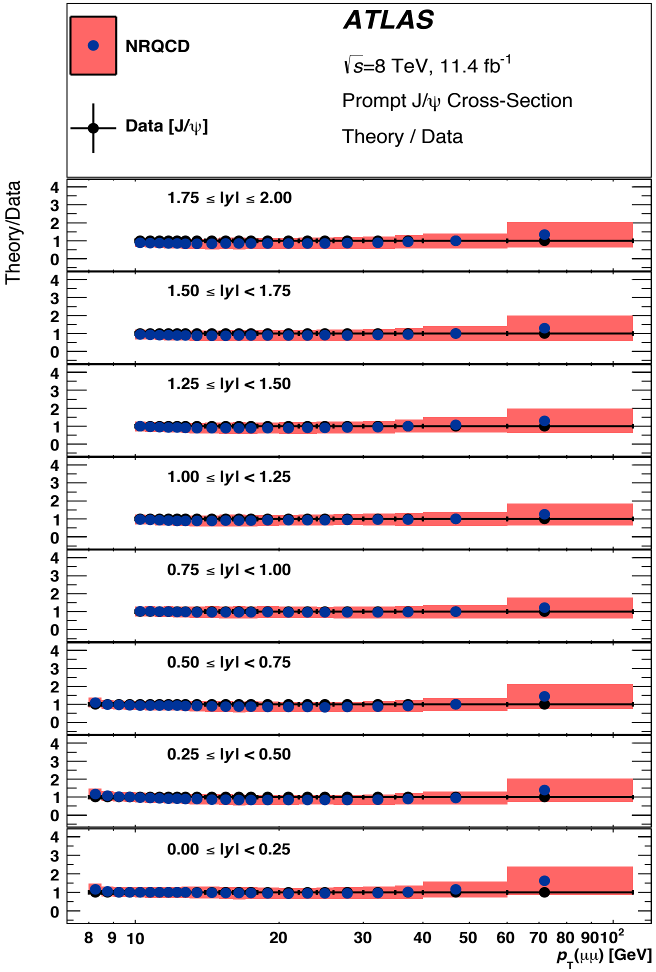
$$\frac{d^2\sigma(pp \to \psi)}{dp_T dy} \times \mathcal{B}(\psi \to \mu^+\mu^-) = \frac{N_\psi^p}{\Delta p_T \Delta y \times \int \mathcal{L}dt}$$

  - **Prompt** – compared to **NRQCD**,
  - Good agreement across range of p_T,
    - Although data a little softer
  - No observed dependence with rapidity

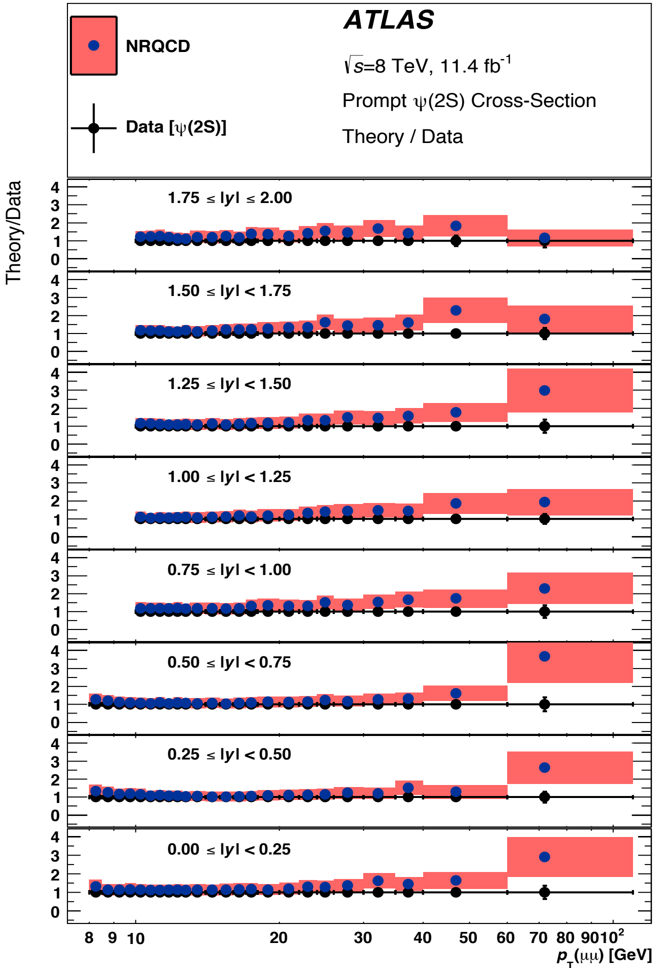
8 TeV

NLO derived using HELAC-ONIA tuned from Tevatron data

J/ψ



ψ(2S)



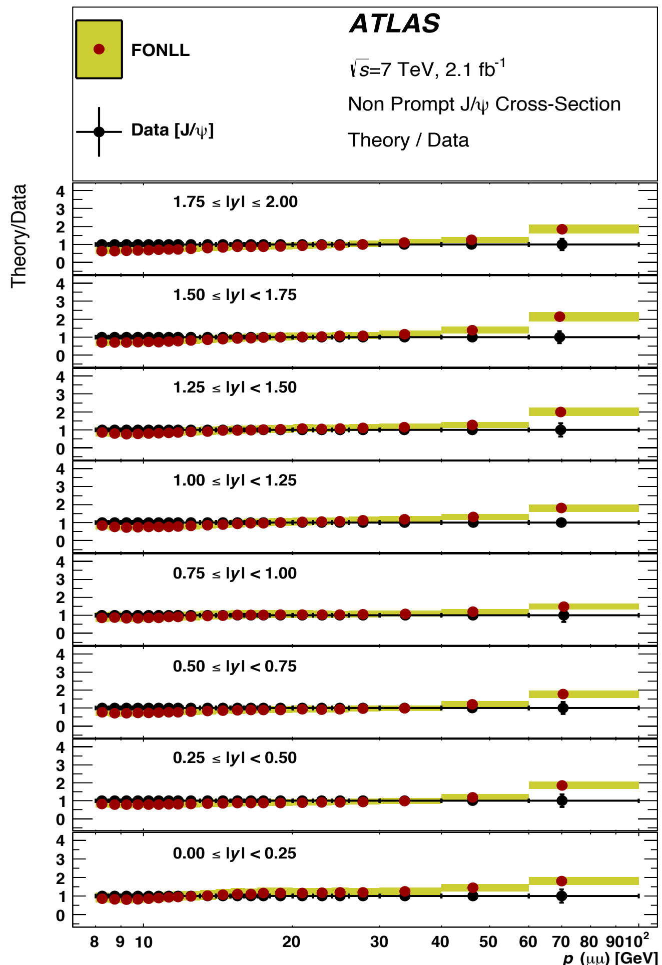
J/ψ and $\psi(2S)$: Non-Prompt cross-section

- Double-differential cross-sections times BR: $$\frac{d^2\sigma(pp \to b\bar{b} \to \psi)}{dp_T dy} \times \mathcal{B}(\psi \to \mu^+\mu^-) = \frac{N_\psi^{np}}{\Delta p_T \Delta y \times \int \mathcal{L} dt}$$
  - **Non-Prompt** – compared to **FONLL**,
  - Small tendency for $\psi(2S)$ prediction to overestimate data

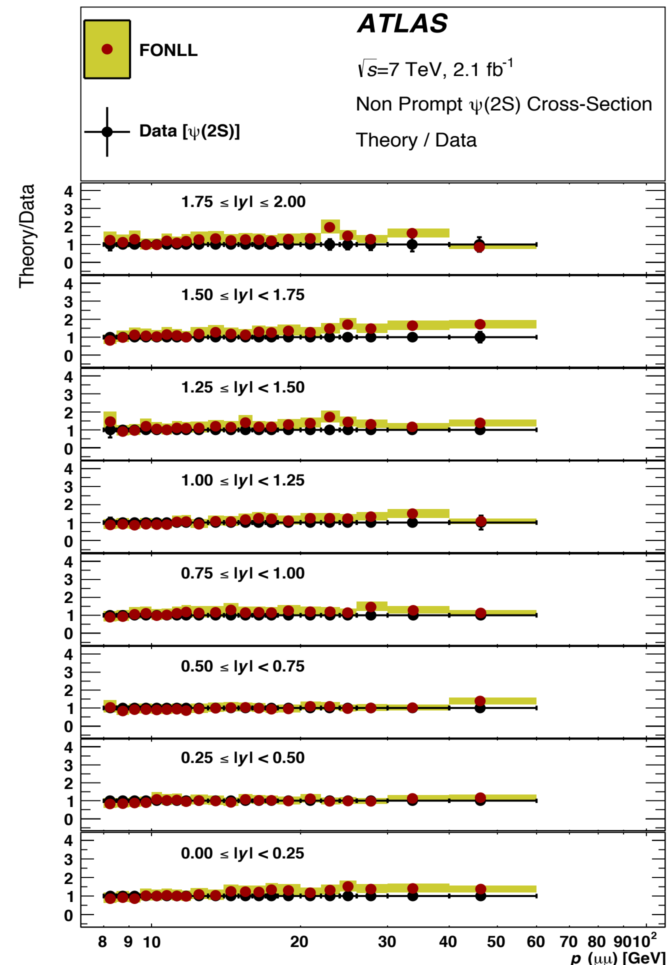
7 TeV

- FONLL predicts a harder spectrum than data.
- General trend appearing across several final states.

J/ψ



$\psi(2S)$



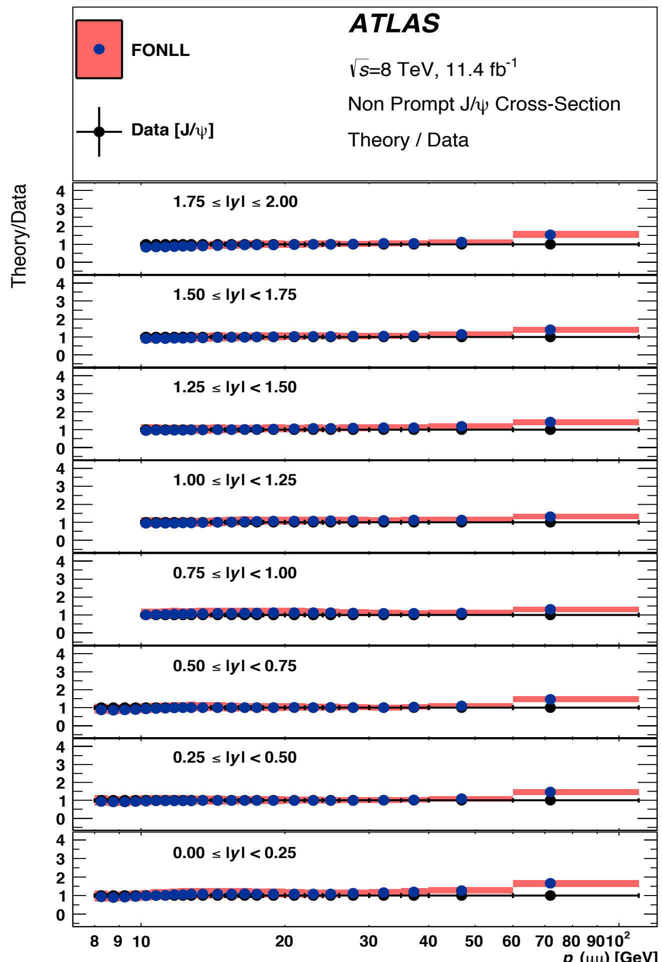
J/ψ and ψ(2S): Non-Prompt cross-section

- Double-differential cross-sections times BR: $$\frac{d^2\sigma(pp \to b\bar{b} \to \psi)}{dp_T dy} \times \mathcal{B}(\psi \to \mu^+\mu^-) = \frac{N_\psi^{np}}{\Delta p_T \Delta y \times \int \mathcal{L} dt}$$
  - **Non-Prompt** – compared to **FONLL**,
  - Small tendency for ψ(2S) prediction to overestimate data

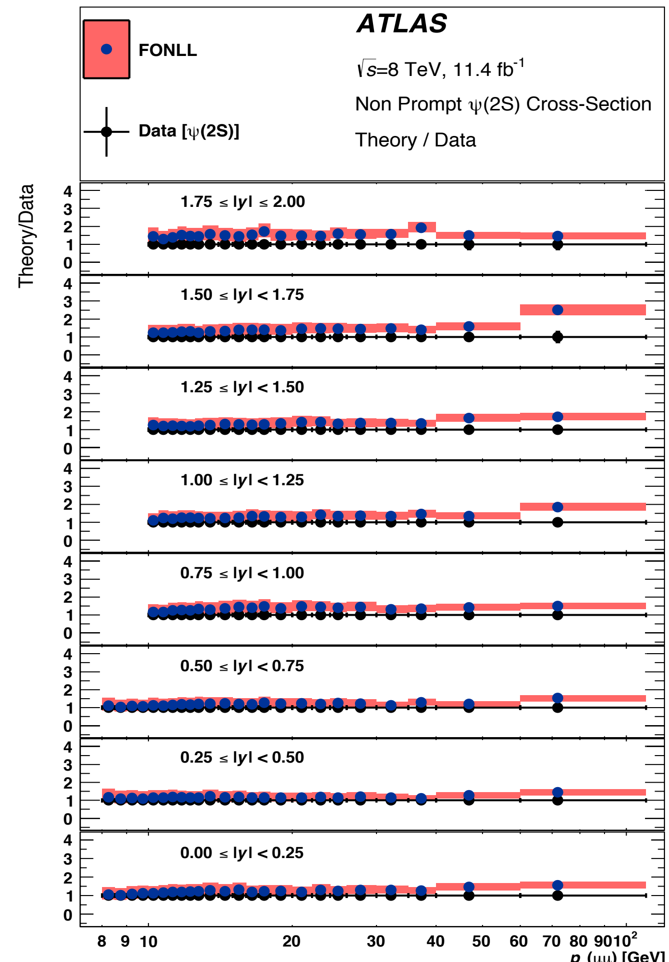
8 TeV

- FONLL predicts a harder spectrum than data.
- General trend appearing across several final states.

J/ψ



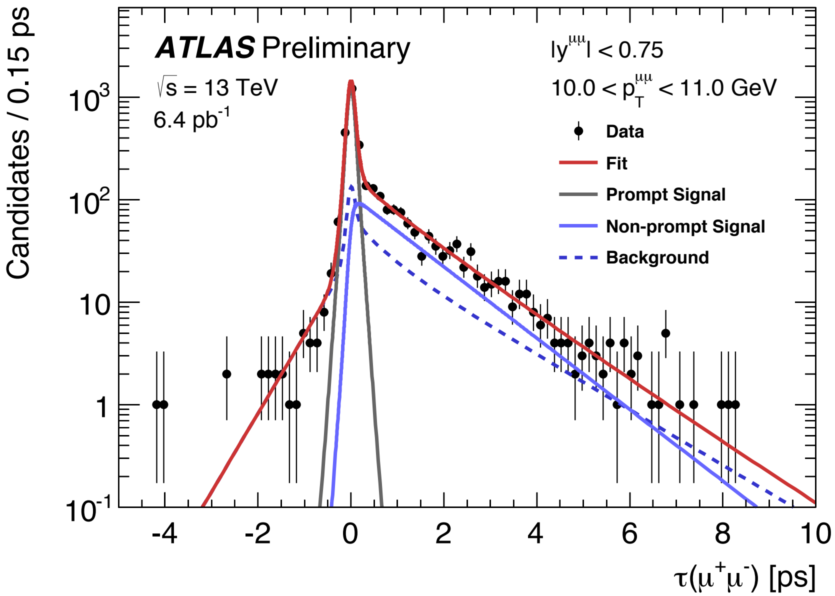
ψ(2S)

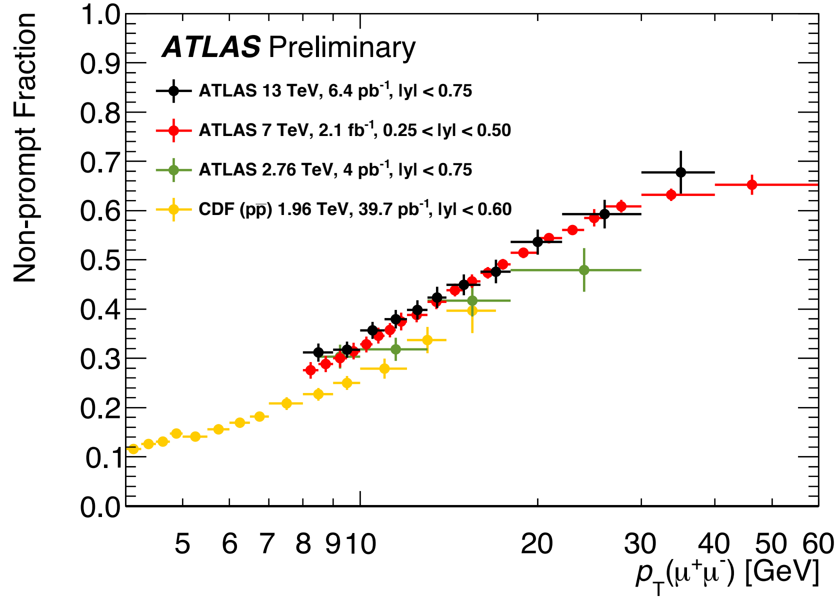


J/ψ Production at 13 TeV

ATLAS-CONF-2015-030

- Non-prompt production fraction:
  - 6.4 pb^{-1} of early 2015 data-taking (Run-2).
  - Simplified analysis to 7/8 TeV:
    - Efficiencies largely assumed to cancel in ratio.
  - Strong dependence on p_T.
  - No dependence on |y|
    - 3 |y| bins 0–0.75–1.50–2.0.
  - Similar behaviour between 7/13 TeV; some variation wrt. lower energies.



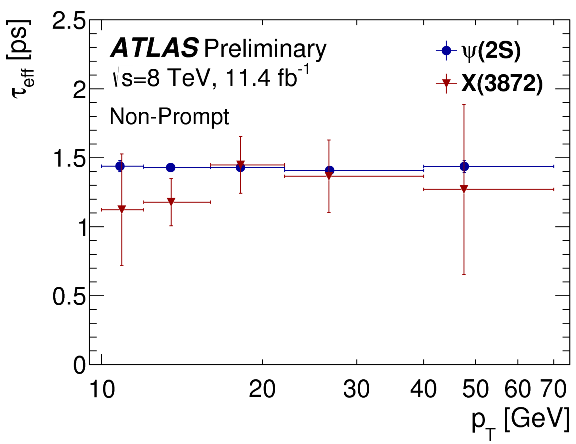


ψ(2S) and X(3872) in J/ψππ mode

ATLAS-CONF-2016-028

- X(3872) narrow & close to DD threshold
  - Decays to ρψ and ωψ with comparable rate, violating isospin symmetry.
  - Tetra quark? Molecule? Mixed state
- $J/\psi\pi\pi$ (10<pT<70 GeV) studied using 11.4fb-1 of 8TeV data
- Measure in 5 pT bins.

- No spin alignment assumed, but extremes used to set systematic
- In each pT bin, fit in 4 intervals of τ(J/ψππ) to separate the prompt/non-prompt



- ψ(2S) consistent with a single lifetime component
- X(3872) requires a second short lifetime component (from decay of B_c)
- Form ratio of X to ψ(2S) product BRs

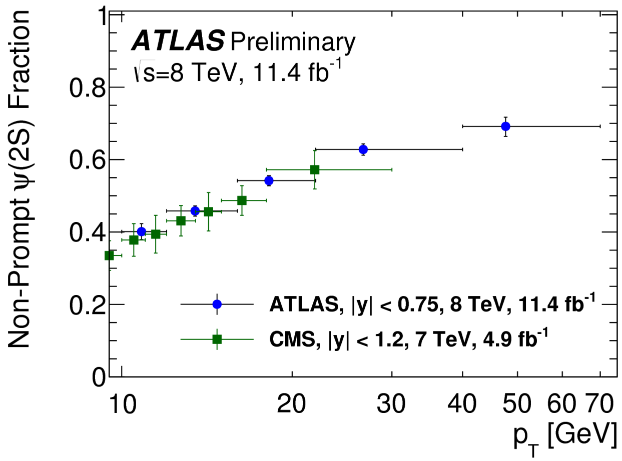
$$R_B^{2L} = \frac{Br(B \to X(3872))Br(X(3872) \to J/\psi\pi^+\pi^-)}{Br(B \to \psi(2S))Br(\psi(2S) \to J/\psi\pi^+\pi^-)} = (3.57 \pm 0.33(\text{stat}) \pm 0.11(\text{sys}))\%.$$

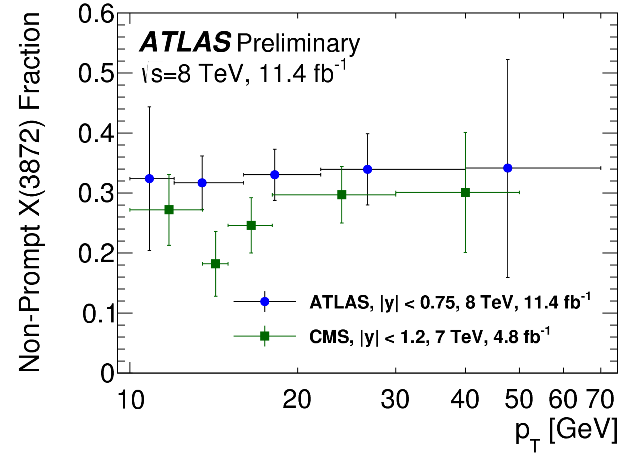
ψ(2S) and X(3872) non-prompt fractions

ATLAS EXPERIMENT

Lancaster University

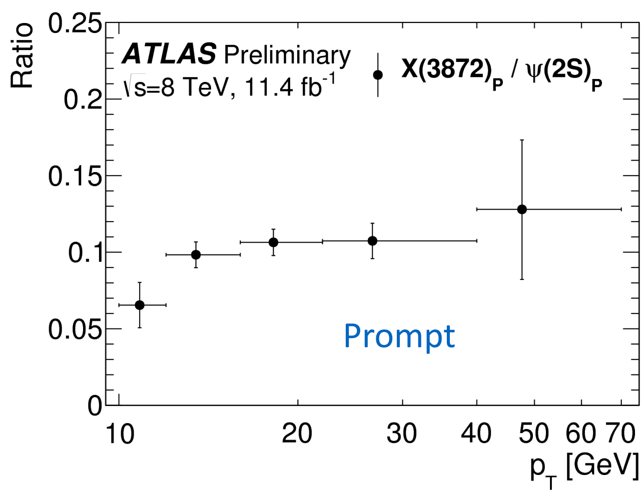
ATLAS-CONF-2016-028

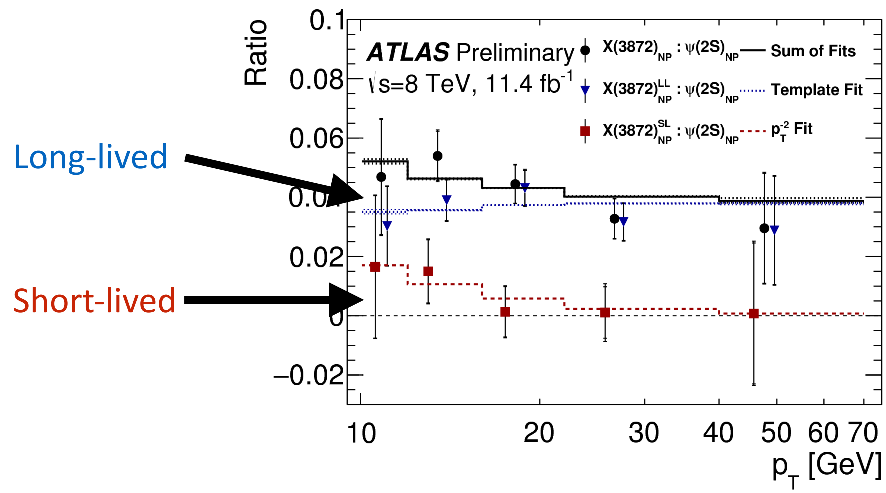




CMS: JHEP 04 (2013) 154

- Reasonable agreement with CMS (different rapidity & com energy)
- Relative production also measured

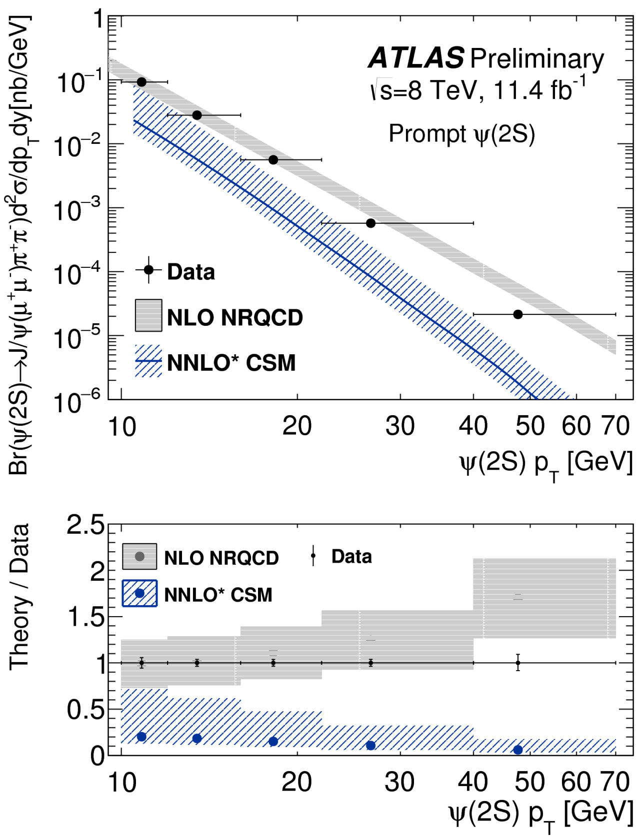


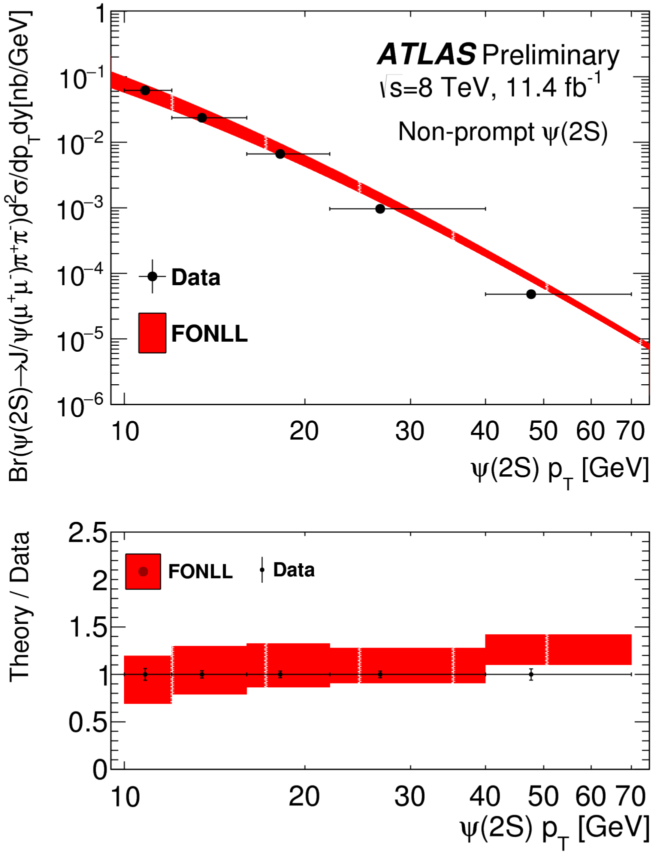


ψ(2S) Production

ATLAS-CONF-2016-028

- Differential cross sections (times BRs) measured
- NLO+NRQCD gives reasonable agreement for prompt
- FONLL matches non-prompt well

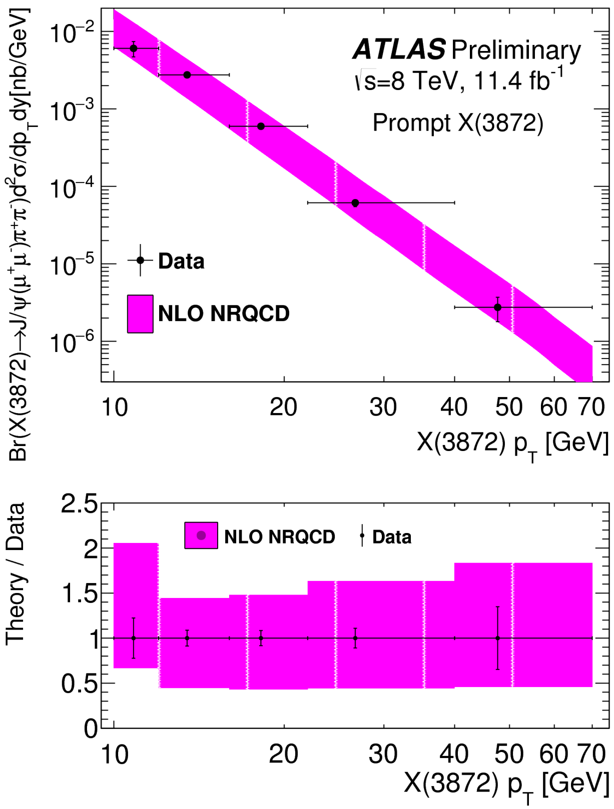


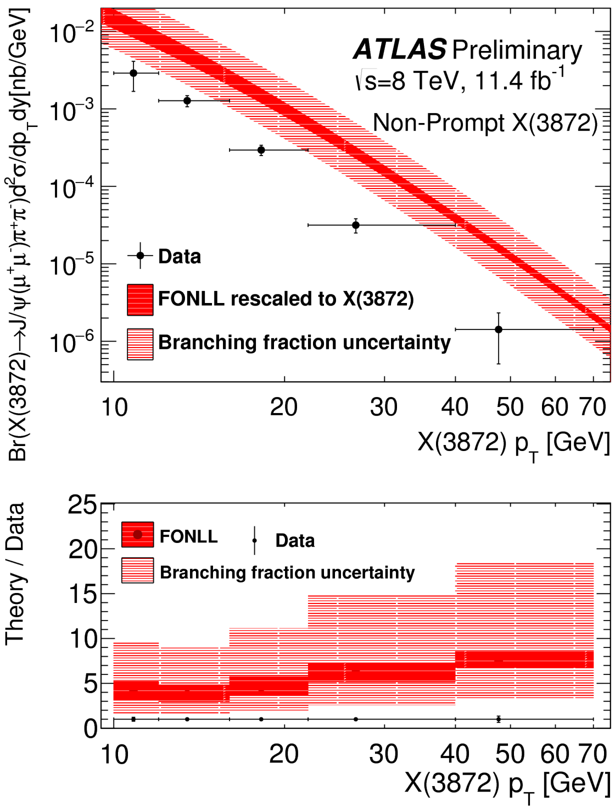


ψ(2S) Production

ATLAS-CONF-2016-028

- Differential cross sections (times BRs) measured
- NLO+NRQCD gives reasonable agreement for prompt
- FONLL overshoots data
- X(3872) modelled as mixture of $\chi_{c1}(2P)$ and D^0/anti-D^0 molecular state

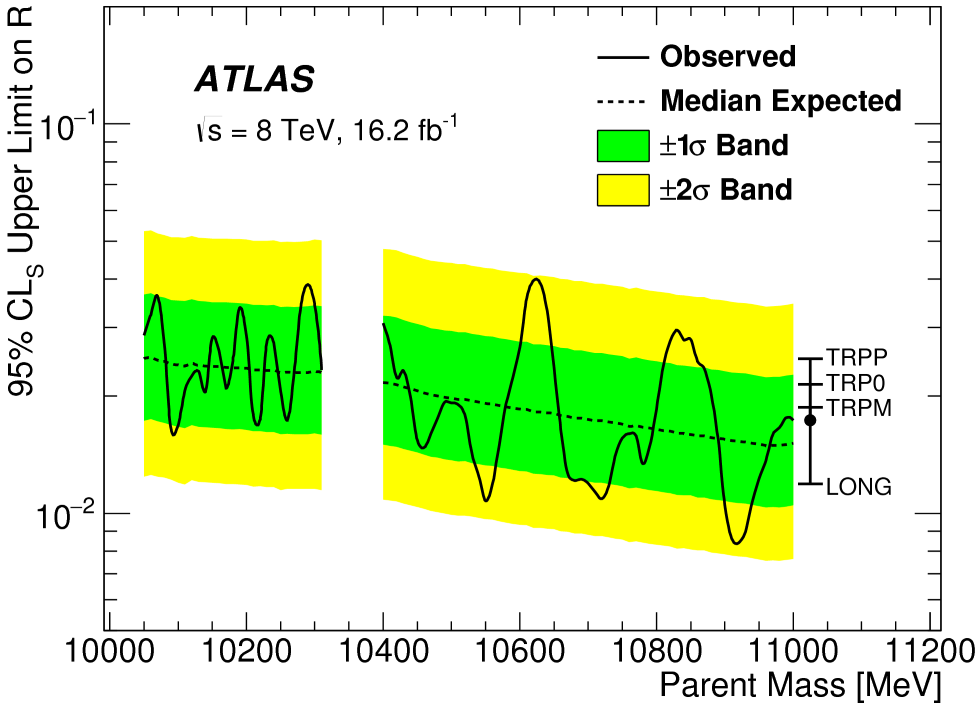




Search for X_b Production

PRL B740 (2015) 199

- Look for analogous hidden beauty states in $\Upsilon(1S)\pi\pi$ decays
- $16.2 fb^{-1}$ of 8TeV data
- 8 bins of y, pT and angle between dipion and lab fame momentum of parent in parent COM frame
- Calibrate with $\Upsilon(2S)$, validate with $\Upsilon(3S)$
- No evidence for narrow states between 10.05-10.31 GeV and 10.40-11.00 GeV



- $R = (\sigma.B)/(\sigma.B)_{\Upsilon(2S)}$

Open Heavy Flavour

Fragmentation function ratio f_s/f_d

PRL 115 (2015) 262001

arXiv:1507.08925

- Integrated fragmentation function important for studies like $B_s \to \mu\mu$
- Obtained as a function of η and p_T from $B_s \to J/\psi\phi$ & $B_d \to J/\psi K^*$

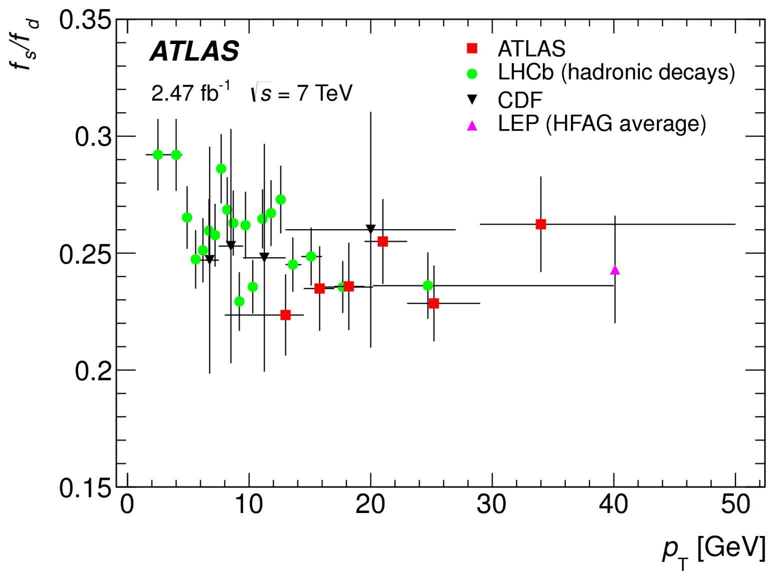
$$\frac{f_s}{f_d}\frac{\mathcal{B}(B_s^0 \to J/\psi\phi)}{\mathcal{B}(B_d^0 \to J/\psi K^{*0})} = 0.199 \pm 0.004(\text{stat}) \pm 0.010(\text{sys}).$$

c.f.

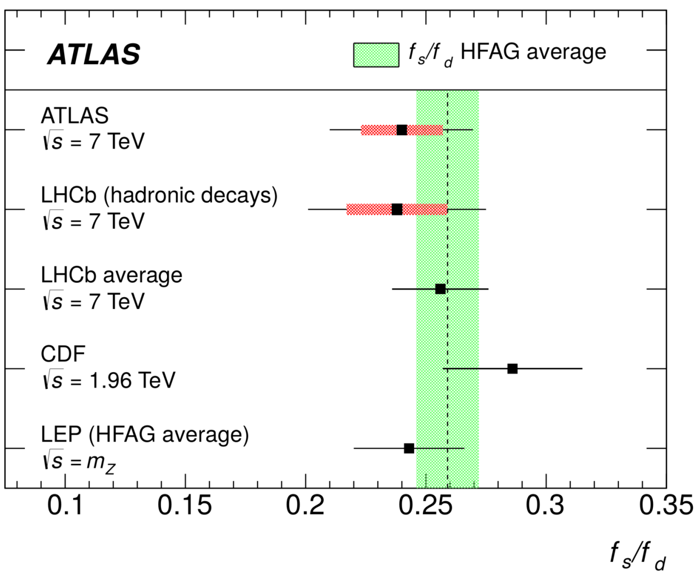
$$\frac{\mathcal{B}(B_s^0 \to J/\psi\phi)}{\mathcal{B}(B_d^0 \to J/\psi K^{*0})} = 0.83^{+0.03}_{-0.02}(\omega_B)^{+0.01}_{-0.00}(f_M)^{+0.01}_{-0.02}(a_i)^{+0.01}_{-0.02}(m_c)$$

$$\frac{f_s}{f_d} = 0.240 \pm 0.004(\text{stat}) \pm 0.013(\text{sys}) \pm 0.017(\text{th}).$$

pert. QCD Liu, Wang & Xie PRD89 (2014) 094010
http://arxiv.org/abs/1309.0313v2



ende



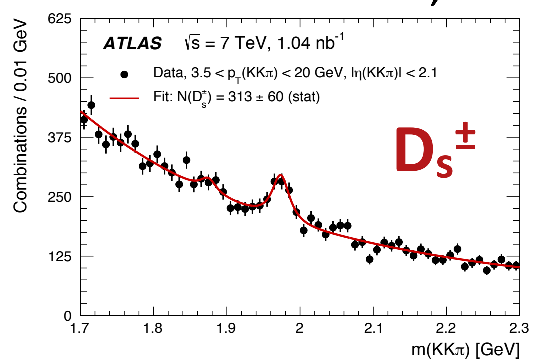
Charm Production Cross-Section

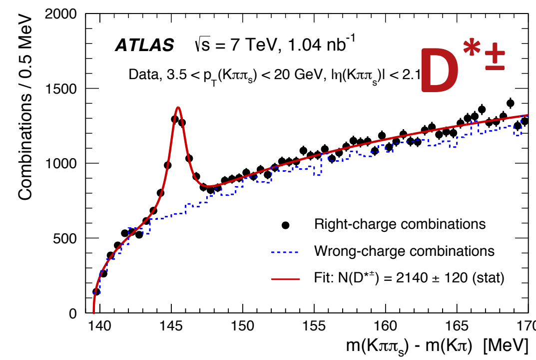
Nucl. Phys. B907 (2016) 717
arXiv:1512.02913

- Differential and fiducial cross-sections of: $D^{*\pm}$, $D^{\pm}$ and $D_s^{\pm}$ mesons measured at 7 TeV;

$$D^{*\pm} \to D^0 \pi_s^{\pm}$$
$$D^0 \to K^- \pi^+$$

$$D^+ \to K^- \pi^+ \pi^+$$
$$D_s^{\pm} \to \phi \pi^{\pm}$$
$$\phi \to K^+ K^-$$





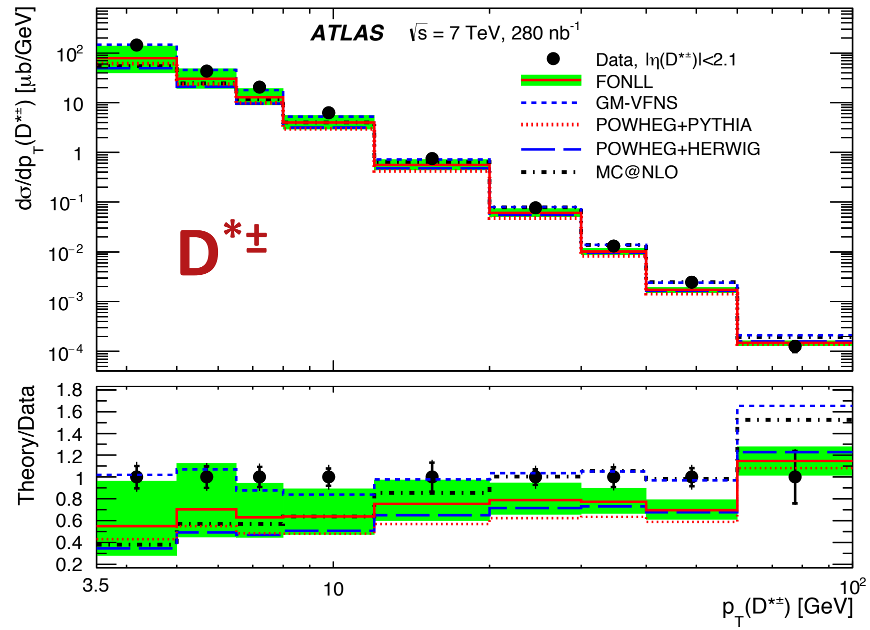
  – Fiducial region: $3.5 < p_T(D) < 100$ GeV, $|\eta(D)| < 2.1$.
  – Extrapolated to full phase space (for $D^{*\pm}$ and $D^{\pm}$)
  - Compared to FONLL, GM-VFNS and NLO-MC (MC@NLO and HERWIG)

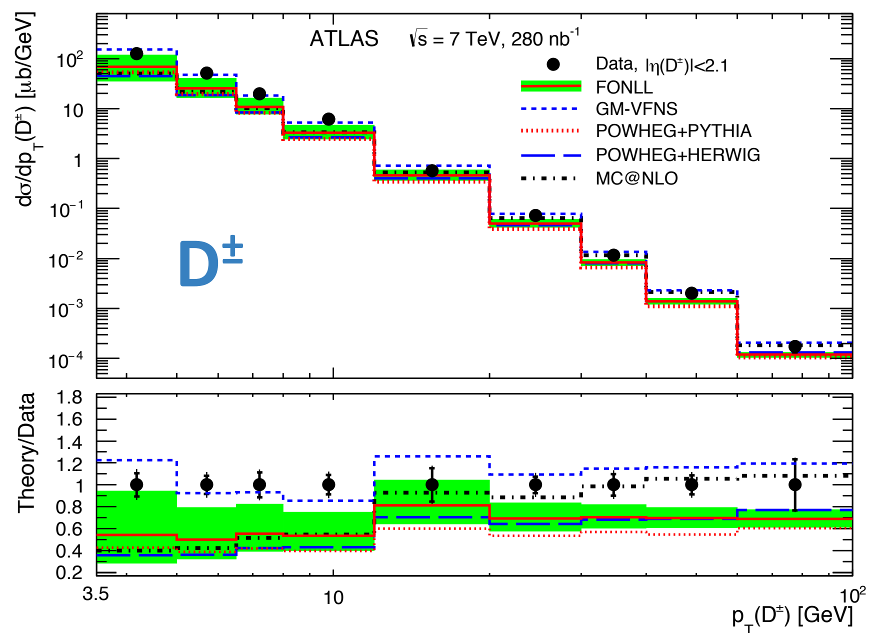
	$\sigma^{vis}(D^{*\pm})$		$\sigma^{vis}(D^{\pm})$		$\sigma^{vis}(D_s^{*\pm})$	
Range	low-p_T	high-p_T	low-p_T	high-p_T	low-p_T	high-p_T
[units]	[μb]	[nb]	[μb]	[nb]	[μb]	[nb]
ATLAS	331 ± 36	988 ± 100	328 ± 34	888 ± 97	160 ± 37	512 ± 104
GM-VFNS	340^{+130}_{-150}	1000^{+120}_{-150}	350^{+150}_{-160}	980^{+120}_{-150}	147^{+54}_{-66}	470^{+56}_{-69}
FONLL	202^{+125}_{-79}	753^{+123}_{-104}	174^{+105}_{-66}	617^{+103}_{-86}	-	-
POWHEG+PYTHIA	158^{+179}_{-85}	600^{+300}_{-180}	134^{+148}_{-70}	480^{+240}_{-130}	62^{+64}_{-31}	225^{+114}_{-69}
POWHEG+HERWIG	137^{+147}_{-72}	690^{+380}_{-160}	121^{+129}_{-64}	580^{+280}_{-140}	51^{+50}_{-25}	268^{+107}_{-62}
MC@NLO	157^{+125}_{-72}	980^{+460}_{-290}	140^{+112}_{-65}	810^{+390}_{-260}	58^{+42}_{-25}	345^{+175}_{-87}

Differential Cross-sections

- $D^{*\pm}$ and $D^{\pm}$ differential cross-sections.
- Shapes of data well reproduced by FONLL and POWHEG;
  - MC@NLO predicts harder pT spectra.
  - Overall normalisations sit below data.
- GM-VFNS in good agreement in shape and normalisation.
- dσ/dη differential cross-section shows similar trends for data and MC:
  - Some discrepancy in shape for MC@NLO for high-pT (20–100 GeV) data.

3.5% luminosity uncertainty not included in figures.





Extrapolated Cross-sections

- Extrapolation to full phase space using low-pT dataset.
  - Total cross-section from FONLL (with $D^{*\pm}$ and $D^{\pm}$ data):

ATLAS $\sigma_{c\bar{c}}^{\text{tot}} = 8.6 \pm 0.3\,(\text{stat}) \pm 0.7\,(\text{syst}) \pm 0.3\,(\text{lum}) \pm 0.2\,(\text{ff})^{+3.8}_{-3.4}\,(\text{extr})\ \text{mb}$

ALICE $\sigma_{c\bar{c}}^{\text{tot}} = 8.5 \pm 0.5\,(\text{stat})^{+1.0}_{-2.4}\,(\text{syst}) \pm 0.3\,(\text{lum}) \pm 0.2\,(\text{ff})^{+5.0}_{-0.4}(\text{extr})\ \text{mb}$

JHEP 07 (2012) 191, arXiv:1205.4007 [hep-ex]

- In good agreement with ALICE measurement.

- POWHEG + PYTHIA used in extrapolation of:
  - Strangeness suppression factor;

$$\gamma_{s/d} = \frac{\sigma_{c\bar{c}}^{\text{tot}}(D_s^+)}{\sigma_{c\bar{c}}^{\text{tot}}(D^+) + \sigma_{c\bar{c}}^{\text{tot}}(D^{*+}) \cdot \mathcal{B}_{D^{*+}\to D^0\pi^+}} = 0.26 \pm 0.05\,(\text{stat}) \pm 0.02\,(\text{syst}) \pm 0.02\,(\text{br}) \pm 0.01\,(\text{extr})$$

$$\gamma_{s/d}^{\text{LEP}} = 0.24 \pm 0.02 \pm 0.01(\text{br})$$ Eur. Phys. J. C 75 (2015) 19

  - Fraction of charmed non-strange D mesons in vector state;

$$P_{\text{V}}^{d} = \frac{\sigma_{c\bar{c}}^{\text{tot}}(D^{*+})}{\sigma_{c\bar{c}}^{\text{tot}}(D^+) + \sigma_{c\bar{c}}^{\text{tot}}(D^{*+}) \cdot \mathcal{B}_{D^{*+}\to D^0\pi^+}} = 0.56 \pm 0.03\,(\text{stat}) \pm 0.01\,(\text{syst}) \pm 0.01\,(\text{br}) \pm 0.02\,(\text{extr})$$

$$P_{\text{V}}^{\text{LEP}} = 0.61 \pm 0.02 \pm 0.01(\text{br})$$ Eur. Phys. J. C 75 (2015) 19

Summary

- Run-1 provided a comprehensive suite of quarkonium measurements at 7/8 TeV in range of decay modes;
  - Synergy with other LHC experiments; allows improved understanding of quarkonia production in hadronic collisions.
    - Still some Run-1 results to come,
    - Run-2 allows new energy regime to explore, results already emerging.
- Heavy flavour production measurements largely in agreement with theory:
  - Some shape and normalisation differences.
- Exploring the nature of the X(3872)
- Associated production of quarkonia and di-quarkonium provide good tests of DPS processes
- Expect many interesting results to come.

Backup

f_s/f_d Fragmentation Ratio

PRL: 115.262001

- Ratio of b-quark fragmentation fractions: f_s/f_d
- Necessary input to rare decays / searches =>
  - Improvement in constraints / sensitivity.

- ATLAS measurement with 7 TeV data, 2.47 fb^{-1}, through decays of:

$B_s \to J/\psi\phi$ and $B_d^0 \to J/\psi K^{*0}$

$$\frac{f_s}{f_d} = \frac{N_{B_s^0}}{N_{B_d^0}} \frac{\mathcal{B}(B_d^0 \to J/\psi K^{*0})}{\mathcal{B}(B_s^0 \to J/\psi\phi)} \frac{\mathcal{B}(K^{*0} \to K^+\pi^-)}{\mathcal{B}(\phi \to K^+K^-)} \mathcal{R}_{\text{eff}},$$

- $\mathcal{R}_{\text{eff}}$ is MC derived ratio of Acceptance and Efficiency corrections.

Observable	Value	σ
$N_{B_s^0}$	$6640 \pm 100 \pm 220$	3.3%
$N_{B_d^0}$	$36290 \pm 320 \pm 650$	1.8%
$\mathcal{R}_{\text{eff}}$	$0.799 \pm 0.001 \pm 0.010$	1.3%
$\mathcal{B}(\phi \to K^+K^-)$	0.489 ± 0.005	1.0%
$\mathcal{B}(K^{*0} \to K^+\pi^-)$	0.66503 ± 0.00014	0.02%
Total		4.1%

f_s/f_d: results

- From experiment:

$$\frac{f_s}{f_d}\frac{\mathcal{B}(B_s^0 \to J/\psi\phi)}{\mathcal{B}(B_d^0 \to J/\psi K^{*0})} = 0.199 \pm 0.004(\text{stat}) \pm 0.008(\text{sys}).$$

- Recent theory result of ratio of BF:

  Phys. Rev. D 89 (2014) 094010 and update in:

  arXiv:1309.0313v2

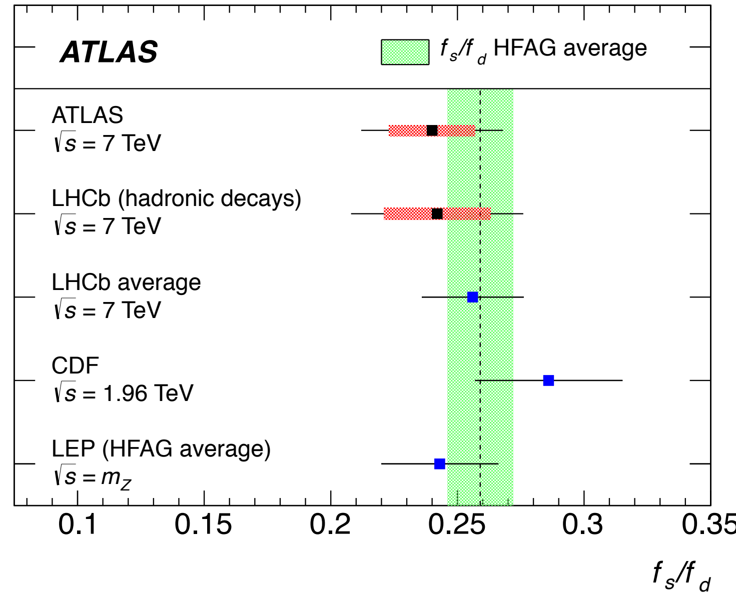
  – Perturbative QCD gives 7.1% theory uncertainty on BF ratio:

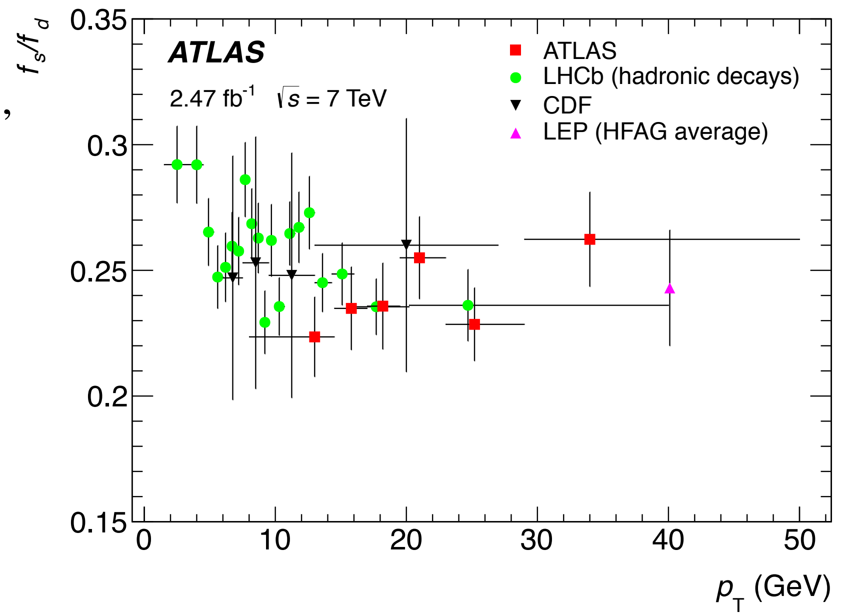
$$\frac{\mathcal{B}(B_s^0 \to J/\psi\phi)}{\mathcal{B}(B_d^0 \to J/\psi K^{*0})} = 0.83^{+0.03}_{-0.02}(\omega_B)^{+0.01}_{-0.00}(f_M)^{+0.01}_{-0.02}(a_i)^{+0.01}_{-0.02}(m_c),$$

- Resulting ratio:

$$\frac{f_s}{f_d} = 0.240 \pm 0.004(\text{stat}) \pm 0.010(\text{sys}) \pm 0.017(\text{th}).$$

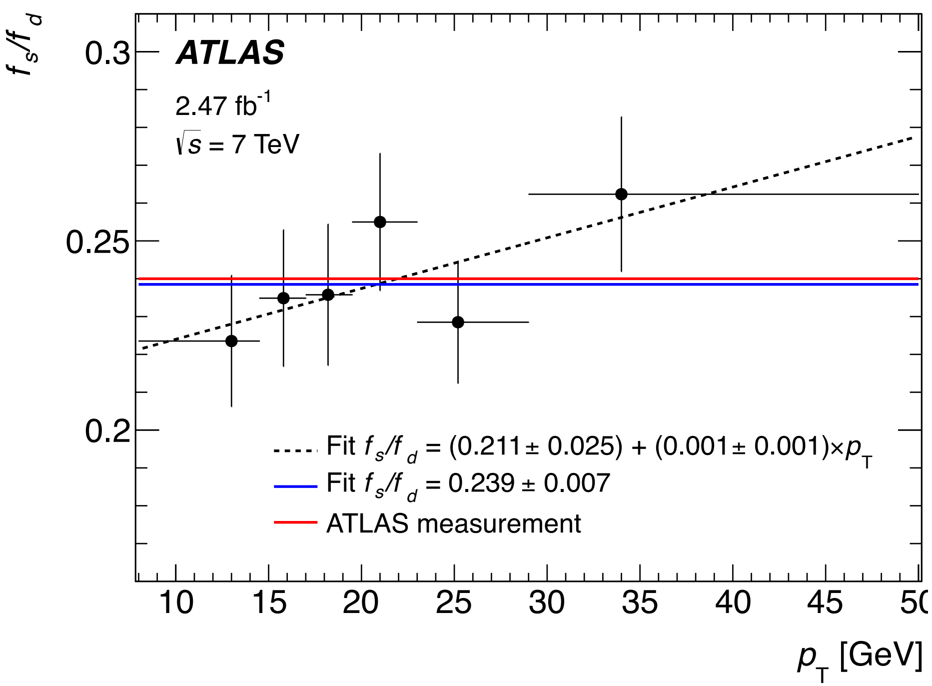
- No p_T or |y| dependence within the measured kinematic range.

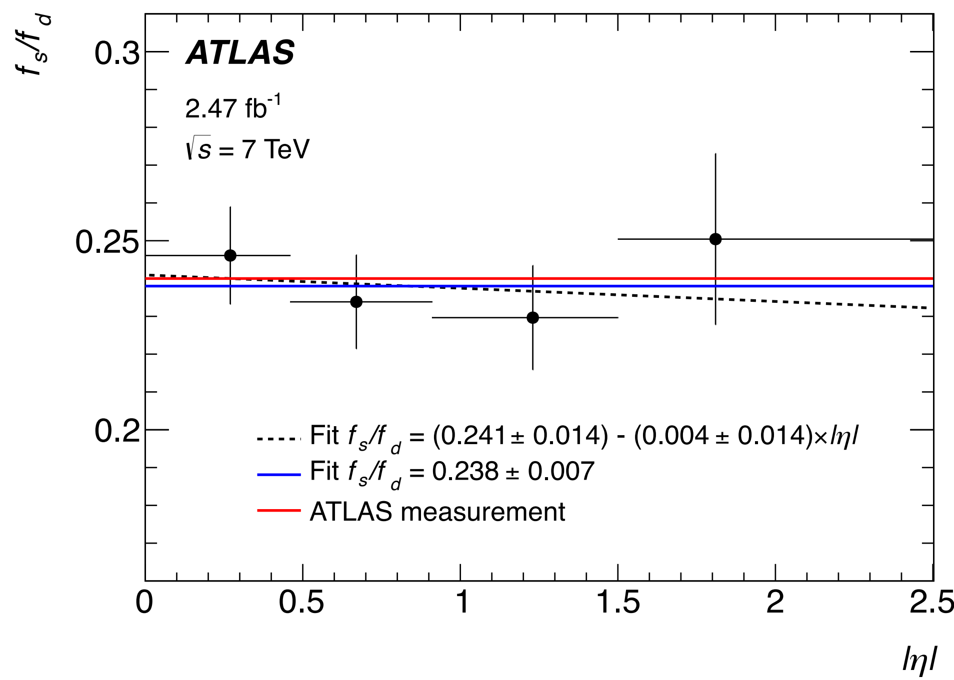




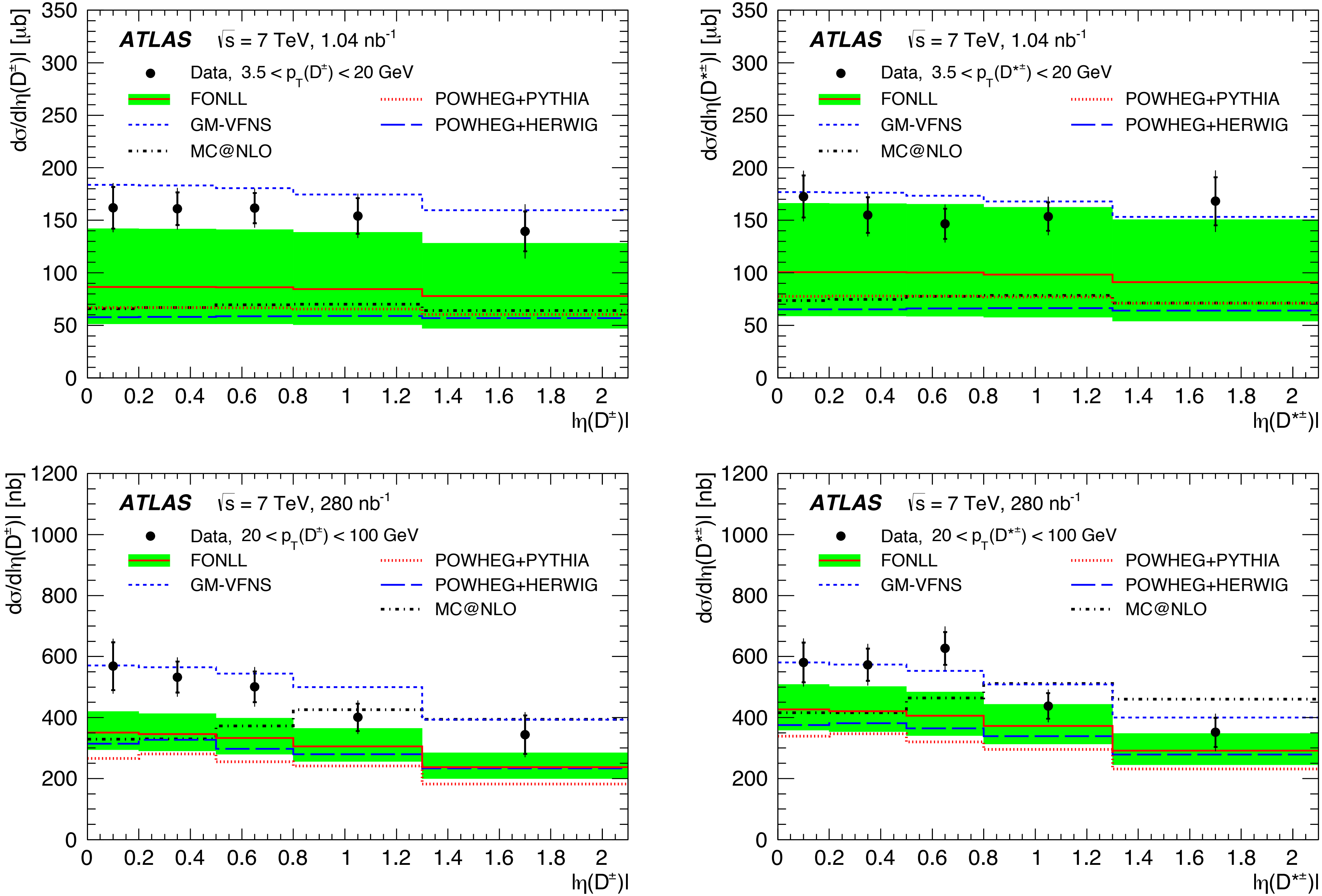
fs/fd

- Dependencies on |η| and p_T.





D*± and D± Differential Cross-sections in η



Systematics

- Charm production
- Systematic uncertainties in visible region.

Source	$\sigma^{vis}(D^{*\pm})$		$\sigma^{vis}(D^{\pm})$		$\sigma^{vis}(D_s^{*\pm})$	
	low-p_T	high-p_T	low-p_T	high-p_T	low-p_T	high-p_T
Trigger	-	$^{+0.9}_{-1.0}\%$	-	$^{+0.9}_{-1.0}\%$	-	$^{+0.9}_{-1.0}\%$
Tracking	$\pm7.8\%$	$\pm7.4\%$	$\pm7.7\%$	$\pm7.4\%$	$\pm7.6\%$	$\pm7.4\%$
$D^{(*)}$ selection	$^{+2.8}_{-1.6}\%$	$^{+1.7}_{-1.4}\%$	$^{+1.6}_{-1.0}\%$	$^{+0.9}_{-0.6}\%$	$^{+2.6}_{-1.6}\%$	$^{+1.1}_{-0.9}\%$
Signal fit	$\pm1.3\%$	$\pm0.9\%$	$\pm1.3\%$	$\pm1.5\%$	$\pm6.4\%$	$\pm5.3\%$
Modelling	$^{+1.0}_{-1.7}\%$	$^{+2.7}_{-2.3}\%$	$^{+2.3}_{-2.6}\%$	$^{+2.9}_{-2.4}\%$	$^{+1.7}_{-2.4}\%$	$^{+2.8}_{-2.4}\%$
MC statistics	$\pm0.6\%$	$\pm0.9\%$	$\pm0.8\%$	$\pm0.8\%$	$\pm2.9\%$	$\pm3.1\%$
Luminosity	$\pm3.5\%$	$\pm3.5\%$	$\pm3.5\%$	$\pm3.5\%$	$\pm3.5\%$	$\pm3.5\%$
Branching fraction	$\pm1.5\%$	$\pm1.5\%$	$\pm2.1\%$	$\pm2.1\%$	$\pm5.9\%$	$\pm5.9\%$

Theory Uncertainties

- POWHEG+PYTHIA:

3.5 < p_T(D) < 20 GeV

$$\sigma^{\text{vis}}(D^{*\pm}) = 158^{+176}_{-81}\,(\text{scale})^{+15}_{-16}\,(m_Q)\,^{+14}_{-13}\,(\text{PDF}\oplus\alpha_s)^{+19}_{-16}\,(\text{hadr})\,\mu\text{b}\,,$$

$$\sigma^{\text{vis}}(D^{\pm}) = 134^{+145}_{-67}\,(\text{scale})^{+12}_{-13}\,(m_Q)\,^{+12}_{-11}\,(\text{PDF}\oplus\alpha_s)^{+21}_{-12}\,(\text{hadr})\,\mu\text{b}\,,$$

$$\sigma^{\text{vis}}(D_s^{\pm}) = 62\,^{+63}_{-29}\,(\text{scale}) \pm 6\,(m_Q) \pm 5\,(\text{PDF}\oplus\alpha_s)\,^{+7}_{-8}\,(\text{hadr})\,\mu\text{b}\,,$$

20 < p_T(D) < 100 GeV

$$\sigma^{\text{vis}}(D^{*\pm}) = 600^{+269}_{-137}\,(\text{scale})^{+15}_{-21}\,(m_Q)^{+25}_{-34}\,(\text{PDF}\oplus\alpha_s)^{+126}_{-111}\,(\text{hadr})\,\text{nb}\,,$$

$$\sigma^{\text{vis}}(D^{\pm}) = 480^{+208}_{-109}\,(\text{scale})\,^{+6}_{-11}\,(m_Q)^{+20}_{-27}\,(\text{PDF}\oplus\alpha_s)^{+121}_{-71}\,(\text{hadr})\,\text{nb}\,,$$

$$\sigma^{\text{vis}}(D_s^{\pm}) = 225^{+106}_{-47}\,(\text{scale})\,^{+9}_{-8}\,(m_Q)^{+9}_{-13}\,(\text{PDF}\oplus\alpha_s)\,^{+40}_{-49}\,(\text{hadr})\,\text{nb}\,.$$

- FONLL:

3.5 < p_T(D) < 20 GeV

$$\sigma^{\text{vis}}(D^{*\pm}) = 202^{+119}_{-73}\,(\text{scale})^{+36}_{-27}\,(m_Q) \pm 21\,(\text{PDF}) \pm 5\,(\text{ff})\,\mu\text{b}\,,$$

$$\sigma^{\text{vis}}(D^{\pm}) = 174\,^{+99}_{-60}\,(\text{scale})^{+33}_{-24}\,(m_Q) \pm 18\,(\text{PDF}) \pm 7\,(\text{ff})\,\mu\text{b}\,,$$

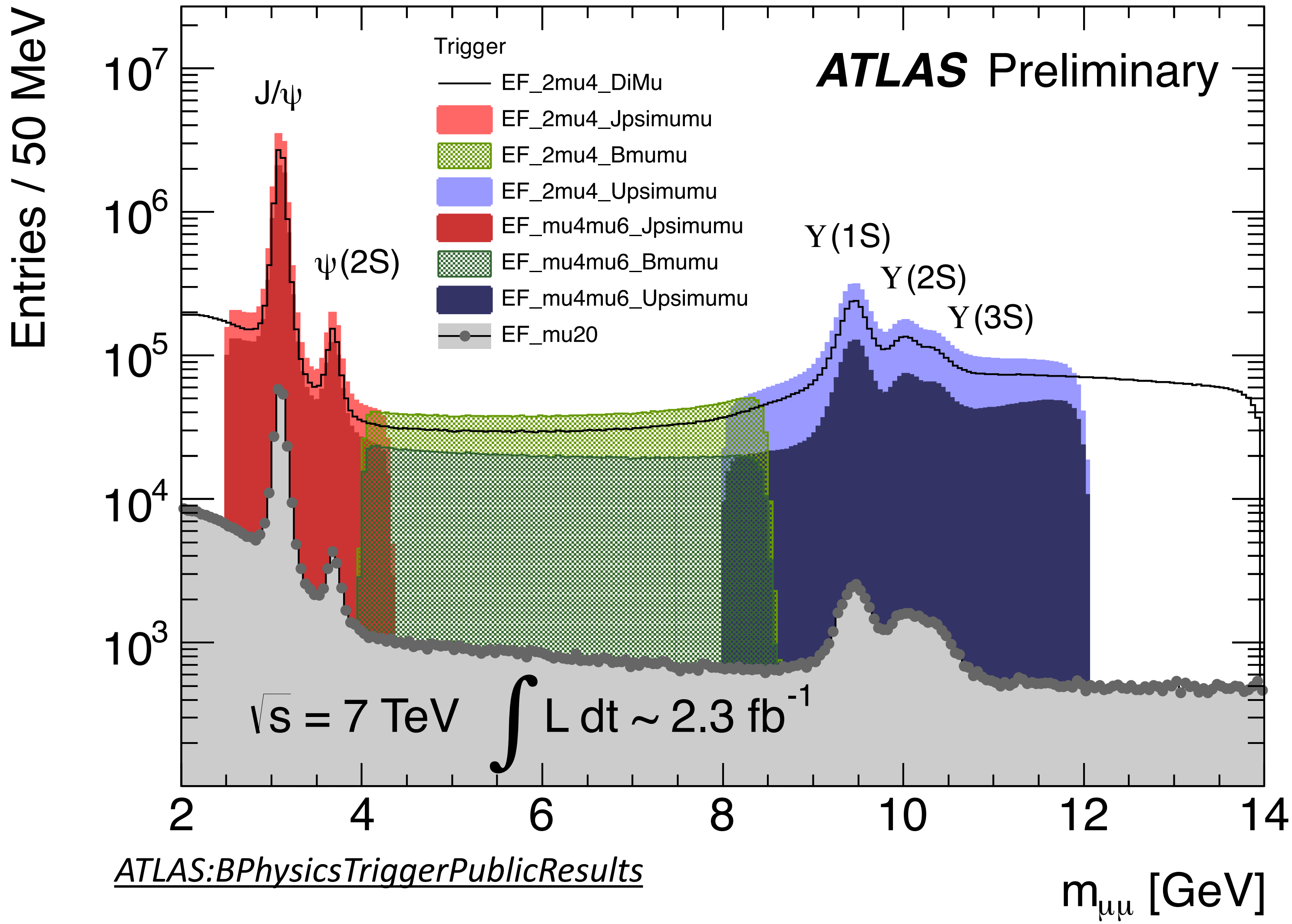
20 < p_T(D) < 100 GeV

$$\sigma^{\text{vis}}(D^{*\pm}) = 753^{+116}_{-98}\,(\text{scale})^{+28}_{-18}\,(m_Q) \pm 41\,(\text{PDF}) \pm 17\,(\text{ff})\,\mu\text{b}\,,$$

$$\sigma^{\text{vis}}(D^{\pm}) = 617\,^{+92}_{-78}\,(\text{scale})^{+37}_{-21}\,(m_Q) \pm 33\,(\text{PDF}) \pm 23\,(\text{ff})\,\mu\text{b}\,.$$

- scale uncertainty: x0.5 – x2.0 variation
- m_Q: Variation in b and c quark masses
- PDF uncertainty from CTEQ6.6 PDF error eigenvectors
- Fragmentation fraction uncertainty from LEP data
- hadr: quadrature sum of fragmentation fraction and function uncertainties (from Peterson fragmentation function).

Run-I Trigger Performance



ATLAS:BPhysicsTriggerPublicResults