Recent B-Physics Results from ATLAS

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On behalf of the ATLAS Collaboration

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II. Differential cross section measurement of $D^{\pm}$ and $D_s^{\pm}$ meson production

III. Precision measurement of the B^0 meson lifetime using $B^0 \rightarrow J/\psi K^{*0}$ decays

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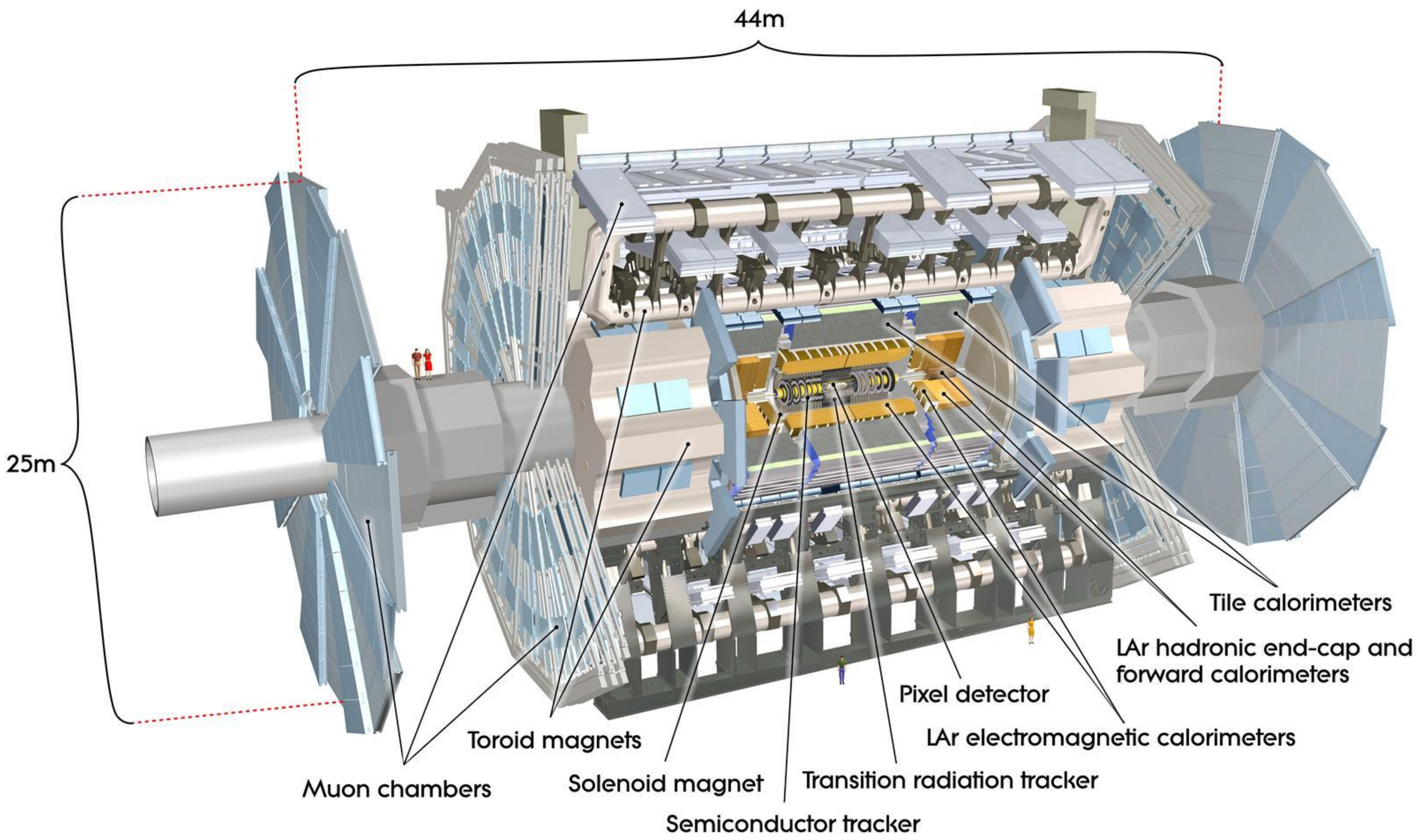
V. Conclusion

Three recent results on charm and beauty production from ATLAS, using LHC pp data.



ATLAS from inside to out:

- Inner detector (pixel, silicon microstrips, straw-tube TRT) $|\eta| < 2.5$, surrounded by a 2T axial B field from the solenoid
- Sampling calorimeters (LAr EM $|\eta| < 3.2$; Scint tile HAD $|\eta| < 3.2$; LAr HAD $1.5 < |\eta| < 4.9$)
- Air core toroids provide B field for Muon drift tubes + cathode strip chambers (muon tracking to $|\eta| < 2.7$) and resistive plate + thin gap chambers (triggering to $|\eta| < 2.4$)

Differential cross section measurement of $D^{\pm}$ and $D_s^{\pm}$ meson production at $\sqrt{s} = 13$ TeV *

Message: Heavy quark production in proton-proton collisions provides a test of perturbative QCD. Predictions in which the masses of heavy quarks are comparable to the typical energy scale of a hard scattering process have large uncertainties.[1,2] Predictions are also challenged by the difficulty of modeling non-perturbative effects (hadronization) and by uncertainties in fragmentation functions.

Experimental data can constrain calculations and contribute to New Physics searches, both as signal and as background.[3] *D* meson decays to $\phi(\mu\mu)\pi$ are sought for this differential cross section measurement.

The outcome –

Production cross sections of $D^{\pm}$ and $D_s^{\pm}$ are measured differentially in p_T and $|\eta|$ at $\sqrt{s} = 13$ TeV and compared to NLO QCD predictions. This is the first such measurement by ATLAS for the $D_s^{\pm}$, and the first time such a measurement has been reported up to p_T ~100 GeV. This provides a benchmark for theoretical calculations in a new kinematical regime. The results are mostly consistent with the GM-VFNS (General Mass – Variable Flavour Number Scheme) and FONLL within uncertainties, with increasing deviation toward high-p_T.

*arXiv:2412.15742 (submitted to JHEP)

[1] B. A. Kniehl et al., PRL 96 (2006) 012001.

[2] B.A. Kniehl et al., EPJ C 72 (2012) 2082.

[3] One example New Physics search involves b and c decays to tau); these impact lepton-flavor-violating tau decay analyses. ATLAS Collab., https://cds.cern.ch/record/2647956.

Context:

- Measurements distinguish between *promptly* produced (hadronization of charm quarks from the primary hard scatter) and non-promptly produced (c produced through decays of b-hadrons). ATLAS measures inclusive (prompt and non-prompt) production here at $\sqrt{s} = 13$ TeV.

- ALICE measured differential cross sections at $\sqrt{s} = 13$ TeV for promptly and non-promptly produced D and D_s mesons and reported the prompt fraction.

- CMS measured differential cross sections for prompt production of D mesons at $\sqrt{s} = 13$ TeV on a partial Run-2 dataset (collected up to 2016).

- LHCb measured prompt production cross sections for D and D_s mesons in the forward region at $\sqrt{s} = 13$ TeV.

- ATLAS previously measured these quantities at $\sqrt{s} = 7$ TeV.

- ATLAS has not previously measured the production cross section of the D_s differentially.

The method uses:

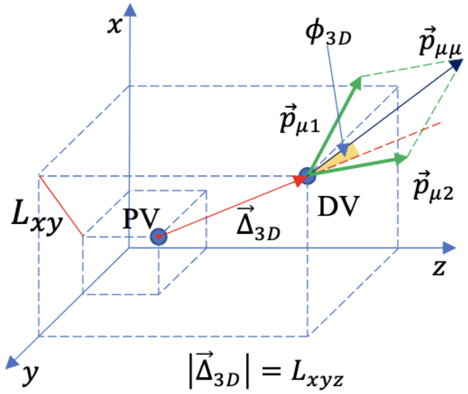
- ***Collision dataset***
  - size 137 fb^{-1} from 2016-2018 at $\sqrt{s} = 13$ TeV

- ***Monte Carlo***
  - events modeling inelastic *pp* collisions were generated separately for prompt ($pp \rightarrow c\bar{c}$) and non-prompt ($pp \rightarrow b\bar{b}$) production of $D_{(s)}$ mesons.
  - Simulation includes all 2→2 QCD processes; higher order processes via initial- and final-state parton showering.
  - Generated D and D_s mesons were decayed to $\phi(\mu\mu)\pi^{\pm}$
  - Generation includes multiple interactions per crossing (pile-up) and detector effects related to prior or subsequent events.

- ***Two theoretical models***
  - General-mass Variable-flavor-number (GM-VFNS)* - charm quark PDF evolves with massless evolution, heavy quark mass retained in the hard-scattering calculation.
  - Fixed-order next-to-leading-log (FONLL)** - heavy quark production x-section calculated in perturbative QCD, heavy flavor fragmentation is non-perturbative, and a decay function describes the heavy hadron decay into leptons.

*B.A. Kniehl et al. PRL 96 (2006) 012001; B.A. Kniehl et al., PRD 71 (2005) 014018; B.A. Kniehl et al., PRD 79 (2009) 094009; M. Benzke et al., JHEP 12 (2017) 021; B.A. Kniehl et al., PRD 71 (2005) 094013.
**M. Cacciari et al., JHEP 05 (1998) 007; M. Cacciari et al., JHEP 10 (2012) 007.

The method, continued:



- ***Select the data:***
  - require 2 muons with opposite charge, with $p_{1,T} > 6$ and $p_{2,T} > \{6 \text{ or } 11\}$, and each $|\eta| < 2.5$
  - dimuon invariant mass consistent with ϕ-meson (inside a window of width that scales with $|\eta|$)
  - Pion candidate track reconstructed in the Inner Detector, and various reconstruction quality requirements.

- For all possible μμπ candidates: remove those 3 tracks, ***refit the primary vertex (PV)***, then use those 3 to attempt *D* meson ***secondary vertex (SV) reconstruction.***

- ***Use the SV-PV displacement to reject background*** based on L_{xy} and a^0_{xy}.
  - $L_{xy}/\sigma_{L_{xy}} > 3$ and $|a^0_{xy}/\sigma_{a^0_{xy}}| < 4$

- ***Suppress combinatorial background*** through goodness of the SV fit.

- To ***match detector coverage and trigger acceptance***, final candidate must have $p_T > 12$ GeV and $|\eta| < 2.5$.

- In case of multiple candidates per event, the one with the ***best SV is selected.***

$$L_{xy} = |\vec{L}_T| cos\theta_{xy}$$
$$a^0_{xy} = |\vec{L}_T| sin\theta_{xy}$$

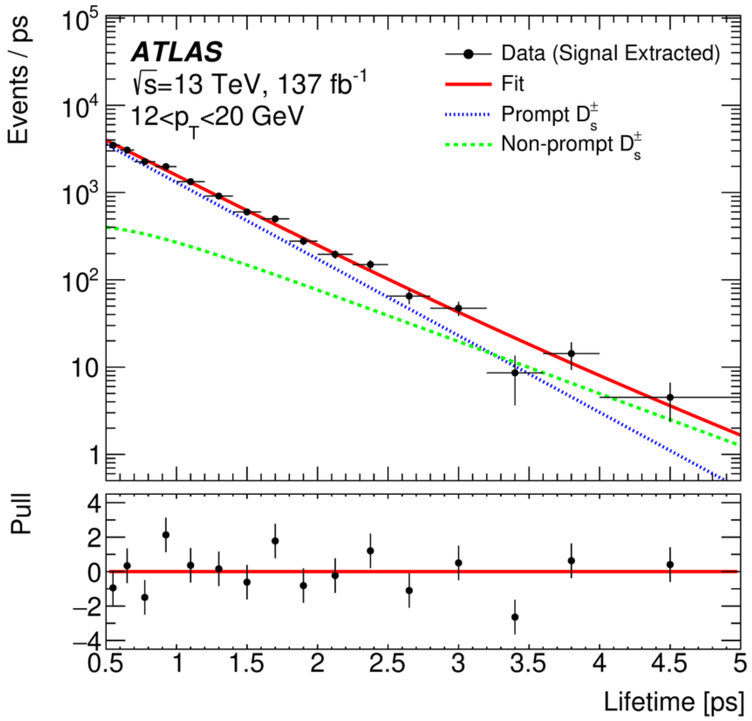
$|\vec{L}_T|$ connects the SV and PV in the transverse plane.

θ_{xy} is the angle between $\vec{L}_T$ and the $\vec{p}_T$ of the μμπ candidate

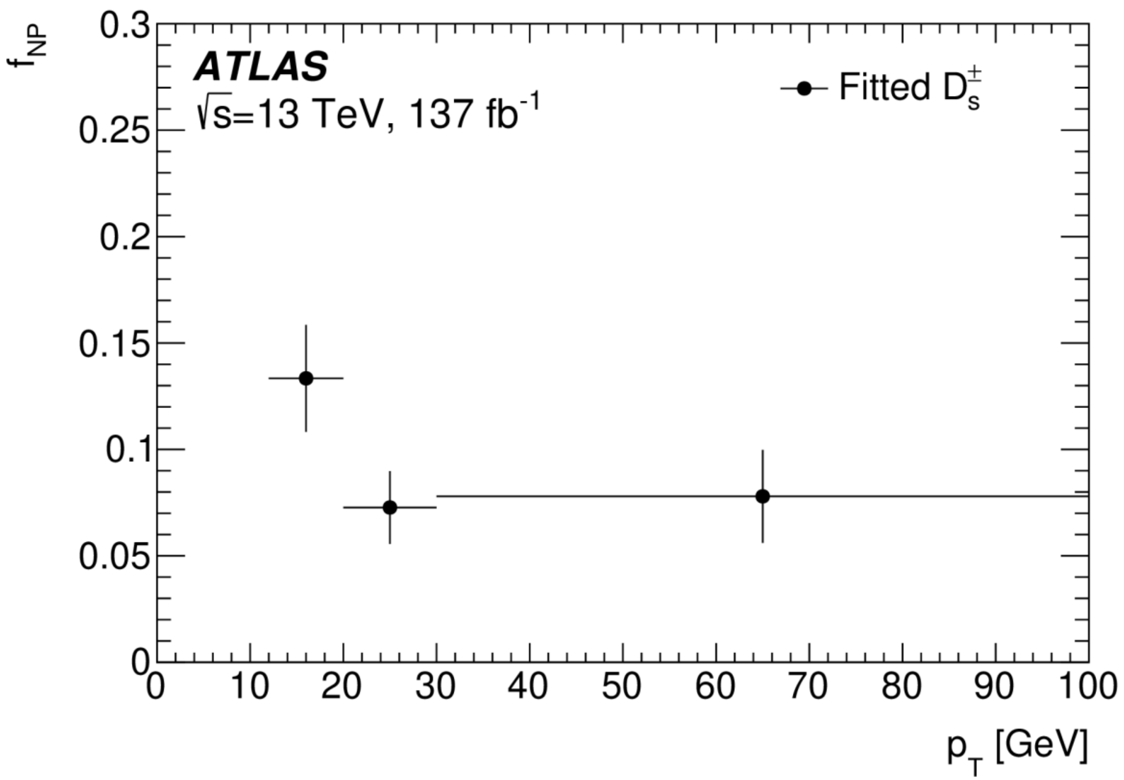
The method, continued:

- Reconstruction efficiency depends on prompt vs non-prompt, so ***constrain the non-prompt fraction*** by comparing data to lifetime templates from simulation.

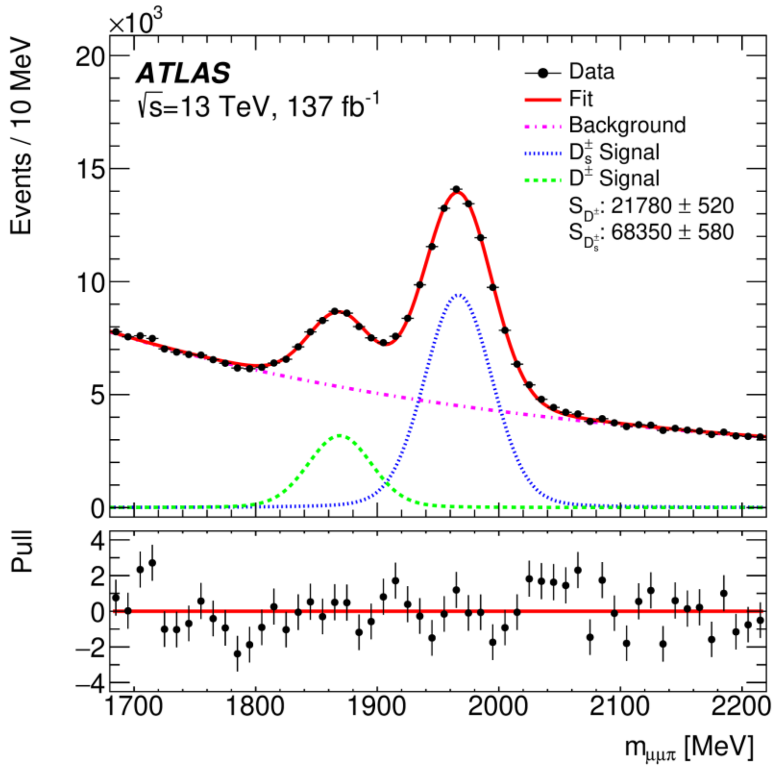
Example template for D_s:



Example non-prompt fraction for D_s:



- ***Reconstruct $m_{\mu\mu\pi}$ ...***



- ***...and bin in p_T and $|\eta|$....9 bins in p_T $\times$ 5 bins in $|\eta|$***

- ***Apply reconstruction efficiencies*** based on simulated events.

- ***Unbinned maximum likelihood fit to the data, modeled with***:
  - *for signal*: a Voigtian distribution (convolution of Breit-Wigner and gaussian).
  - *for bkg* (combinatorial): quadratic exponential

- ***Extract the number of signal events.***

Method, continued:

- $$\left.\frac{d\sigma}{dp_T}\right|_i = \frac{\text{Signal } (D \text{ or } D_s) \text{ in bin } i}{\text{Lumi} \times \text{eff} \times BR[\rightarrow \phi(\mu\mu)\pi] \times \text{bin width}}$$

> - $BR(D^\pm \to \phi(\mu\mu)\pi^\pm) = BR(D^\pm \to \phi\pi^\pm) \times BR(\phi \to \mu\mu)$
> - $BR(D_s^\pm \to \phi(\mu\mu)\pi^\pm) = \frac{BR(D_s^\pm \to \phi(K^+K^-)\pi^\pm)}{BR(\phi \to K^+K^-)} \times BR(\phi \to \mu\mu)$

- Similarly for $\left.\frac{d\sigma}{d|\eta|}\right|_i$
- Systematics:
  - Detector effects: muon recon, track recon, pile-up re-weighting, trigger, luminosity
  - Modeling: non-prompt fraction, production kinematics
  - Other: External BR's, MC sample size, fit model

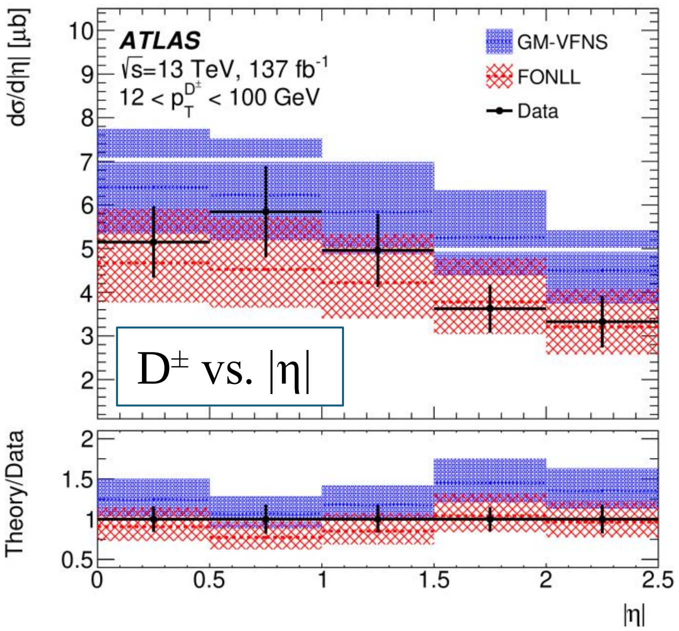
- Also compare these data to ATLAS data at $\sqrt{s}$ = 7 TeV, and compare inclusive differential x-section of data to both models.

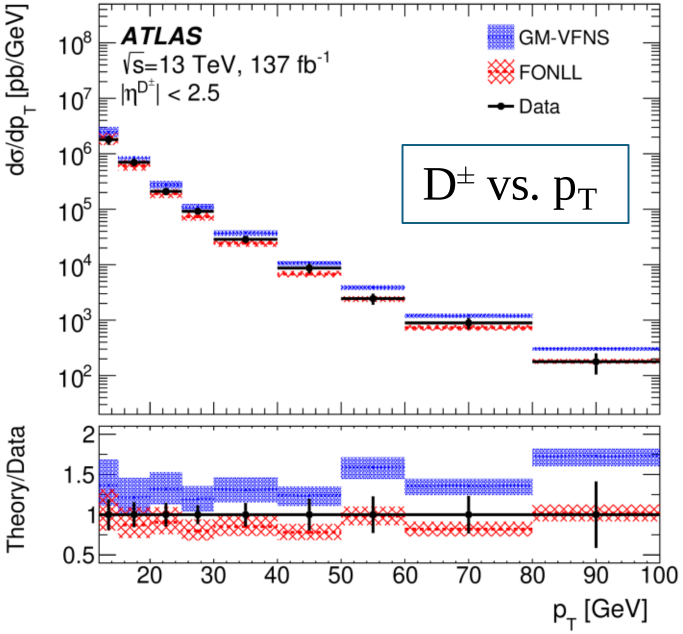
Differential cross section Results:

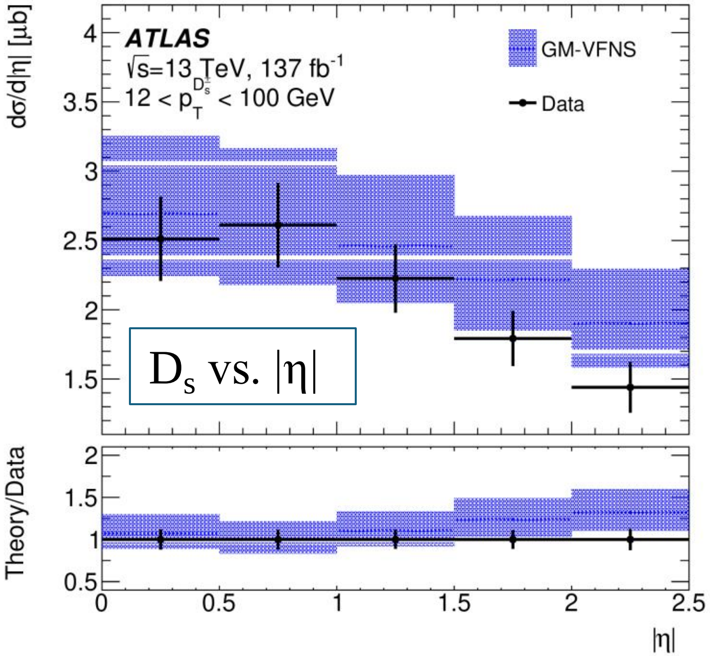
For $D^{\pm}$, good agreement with both models at low p_T. At higher p_T, GM-VFNS is higher; FONLL remains consistent with data.

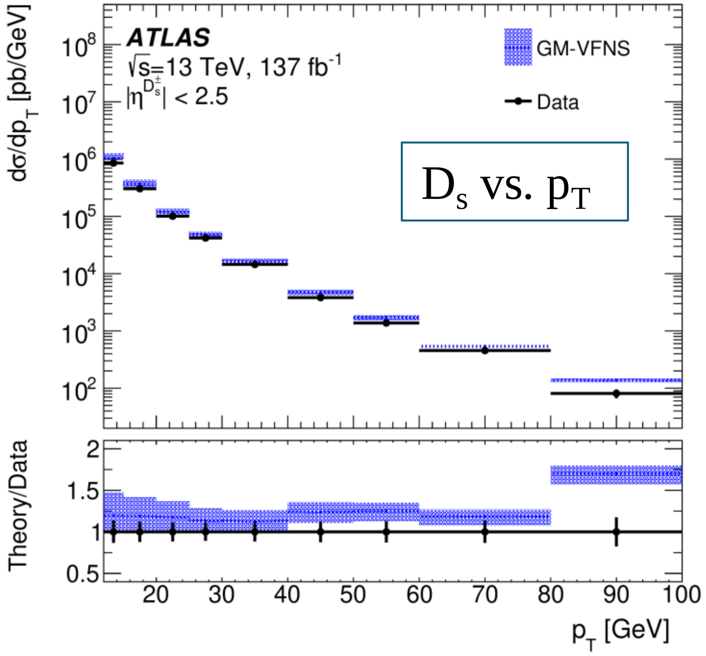
For D_s, only GM-VFNS is available, and it predicts higher x-section throughout range, trending larger with p_T.

Both models agree well with data in $|\eta|$.









For the D_s, this is the first measurement in the differential cross section reported by ATLAS, and the first time such a measurement is reported up to p_T ~100 GeV.

Inclusive $D_{(s)}$ production cross section results at √s = 7 TeV and 13 TeV, and their ratio, in the fiducial volume given by

- $|\eta| < 2.1$
- $20 < p_T < 100$ GeV

for data and theoretical models.

The D_s uncertainty of 12% at √s = 13 TeV improved relative to the 20% uncertainty at √s = 7 TeV.

The $D^{\pm}$ uncertainty of 14% at √s = 13 TeV is higher than the 11% uncertainty at √s = 7 TeV due to background uncertainty driven by low signal yield.

Data are mostly consistent with models within uncertainties, although the ratios predicted by GM-VFNS and FONLL are significantly different.

	$D^{\pm}$ inclusive fiducial cross-section [nb]		
	ATLAS	GM-VFNS	FONLL
	$\sigma \pm \delta_{\text{total}}$	$\sigma \pm \delta_{\text{theory}}$	$\sigma \pm \delta_{\text{theory}}$
$\sqrt{s}$ = 13 TeV	$1\,690 \pm 270$	$2\,200^{+310}_{-290}$	$1\,480^{+230}_{-190}$
$\sqrt{s}$ = 7 TeV	888 ± 97	980^{+120}_{-150}	620^{+100}_{-80}
Ratio (13 TeV/7 TeV)	1.9 ± 0.4	2.24 ± 0.04	2.38 ± 0.01

	$D_s^{\pm}$ inclusive fiducial cross-section [nb]	
	ATLAS	GM-VFNS
	$\sigma \pm \delta_{\text{total}}$	$\sigma \pm \delta_{\text{theory}}$
$\sqrt{s}$ = 13 TeV	810 ± 100	950^{+140}_{-130}
$\sqrt{s}$ = 7 TeV	510 ± 100	470^{+56}_{-69}
Ratio (13 TeV/7 TeV)	1.6 ± 0.4	2.02 ± 0.05

Precision measurement of the B^0 meson lifetime using $B^0 \to J/\psi K^{*0}$ decays[*]

Message: Particle lifetime is a fundamental property of primary phenomenological importance. The b-hadron lifetimes can be computed in the heavy-quark expansion (HQE) framework[†] perturbatively through an expansion in powers of m_b^{-1}. Models typically provide predictions in ratios of b-hadron lifetimes. Lifetime differences are largely attributable to corrections for Pauli interference and weak annihilation which are enhanced by a phase space factor. That factor includes a non-perturbative matrix of four-quark operators recently calculated[‡] using QCD sum rules formulated in HQET.

The outcome:

- The B^0 effective lifetime is measured through the channel $B^0 \to J/\psi K^{*0}$ to be:

$$\tau_{B^0} = 1.5053 \pm 0.0012(stat.) \pm 0.0035(syst.)\ \text{ps}$$

This is the most precise measurement to date, and it is consistent with other measurements.

- The measured average decay width of the heavy and light B^0 eigenstates is:

$$\Gamma_d = 0.6639 \pm 0.0005(stat.) \pm 0.0016(syst) \pm 0.0038(ext.{**})\ \text{ps}^{-1}$$

This is in good agreement with the theoretical prediction.

- The measured Γ_d is combined with the average Γ_s previously measured by ATLAS to obtain:

$$\Gamma_d/\Gamma_s = 0.9905 \pm 0.0022(stat.) \pm 0.0036(syst.) \pm 0.0057(ext.)$$

This result is compatible with predictions from HQE and lattice QCD and with the experimental average.

[*]arXiv:2411.09962 (submitted to JHEP).
[†]V.A. Khoze et al., Phys. Usp. 26 (1983) 387; M.A. Shifman et al., Sov. J. Nucl. Phys. 41 (1985) 120; M.A. Shifman et al., Sov. Phys. JEPT 64 (1986) 698; I.I. Bigi et al., Phys. Lett. B 280 (1992) 271; I.I. Bigi et al., Phys. Lett. B 293 (1992) 430; I.I. Bigi, arXiv:hep-ph/9508408; N. Uraltsev, arXiv:hep-ph/9804275; M. Neubert, arXiv:hep-ph/9702375.
[‡]M. Kirk et al., arXiv:hep-ph/1711.02100.
** "ext." are external systematics associated with Heavy Flavor Averaging Group information.

The concept:

The effective lifetime τ_{B^0} is related to the decay widths of the light (Γ_L) and heavy (Γ_H) mass eigenstates of the $B^0 - \bar{B}^0$ system as:

$$\tau_{B^0} = \frac{1}{\Gamma_d}\frac{1}{1-y^2}\left(\frac{1+2Ay+y^2}{1+Ay}\right)$$

where

$$\Gamma_d = (\Gamma_L + \Gamma_H)/2$$
$$y = (\Gamma_L - \Gamma_H)/2\Gamma_d$$

and A is related to decay rates to final state f through

$$A = \frac{R_H^f - R_L^f}{R_H^f + R_L^f}$$

for

$$\langle\Gamma(B^0(t))\rangle = \Gamma(B^0(t)) + \Gamma(\bar{B}^0(t)) = R_H^f exp(-\Gamma_H t) + R_L^f exp(-\Gamma_L t)$$

The method uses:

- ***Collision data:*** 140.1 fb^{-1} collected at $\sqrt{s}$ = 13 TeV. Typical pileup per crossing is 31.

- ***Monte Carlo:***
  - signal: includes pairs of oppositely charged muons with p_T > 3.5 GeV and $|\eta|$ < 2.6, produced with PYTHIA 8.244 and CTEQ6L1.

- ***The data reconstruction:***
  - The goal is to select $B^0 \rightarrow J/\psi K^{*0}$
  - $\geq$ 4 Inner Detector tracks
  - $\geq$ 1 pair of oppositely charged muon candidates forming a vertex with χ^2/ndof < 10
  - *Form the J/ψ* – for pairs of oppositely charged muon candidates, require invariant mass consistent with PDG
  - *Form the K^{*0}* - for all tracks except the muon-candidates from the J/ψ: apply $K^+\pi^-$ mass hypothesis and reconstruct $K^{*0} \rightarrow K^+\pi^-$. In case of multi-candidates, choose the one with the best K^* mass.
  - *Form the B^0* - Combine J/ψ K^{*0} and require χ^2/ndof < 3. In case of multi-candidates, choose the one with the best B^0 mass.

- 10.6M B^0 candidates are obtained in the mass range 5.00 – 5.65 GeV.

- To choose the best candidate per event, reconstruct the primary vertex (PV) with B^0 tracks removed. Choose the PV candidate with the smallest impact parameter extrapolated from the B^0 vertex in the direction of the B^0 momentum.

The goal is to find the *proper decay time t* of every candidate:

$$t = \frac{L_{xy} m_B}{p_{T_B}}$$

- Identify 2 backgrounds:
  - "prompt": J/ψ comes from $pp \rightarrow J/\psi$X and K^{*0} comes from something else
  - "combinatorial": J/ψ comes from a b-hadron decay, and K^{*0} comes from something else

Backgrounds are modelled from collision data sidebands.

Again, L_{xy} is the distance in the transverse plane from the primary vertex to the B^0 meson decay vertex, projected onto the direction of the B^0 p_T

- Extract the lifetime of the B^0 from a two-dimensional unbinned maximum likelihood fit to signal and background.
  - Mass and proper decay time are simultaneously fitted using a log-likelihood function.

    - The probability distribution function (PDF) describing t for each event i is composed of 2 terms:

$$\tau_j(t_i, \sigma_{t_i}, p_{T_i}) = P_j(t_i | \sigma_{t_i}, p_{T_i}) \cdot C_j(\sigma_{t_i}, p_{T_i}) \quad \text{where } j \in \text{(signal, background)}$$

    The $C_j(\sigma_{t_i}, p_{T_i})$ are 2-dim distributions that describe the difference between signal and background for per-candidate time uncertainty σ_{t_i} and transverse momentum p_{T_i}.

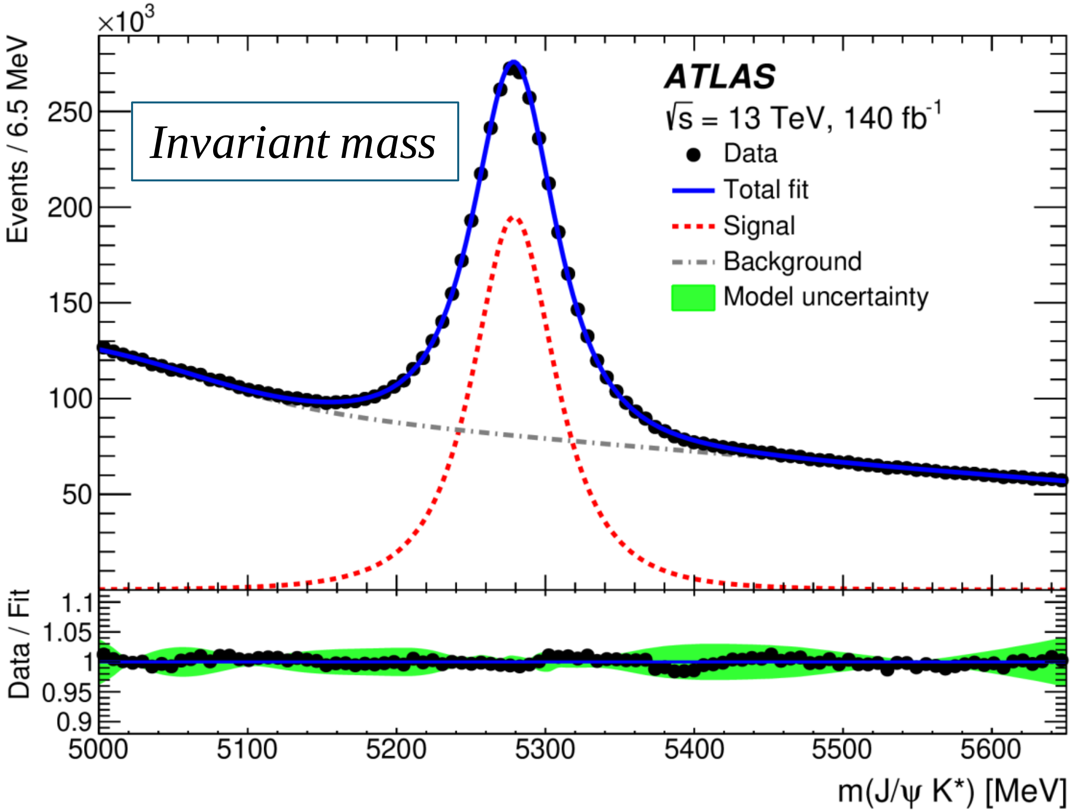
    - Fit using the following data for every event i: mass m_i, t_i, uncertainty σ_{ti}, efficiency w_i, and $p_{T(B)}$
    - Fit parameters: signal fraction, mass probability distribution function (PDF), time PDF

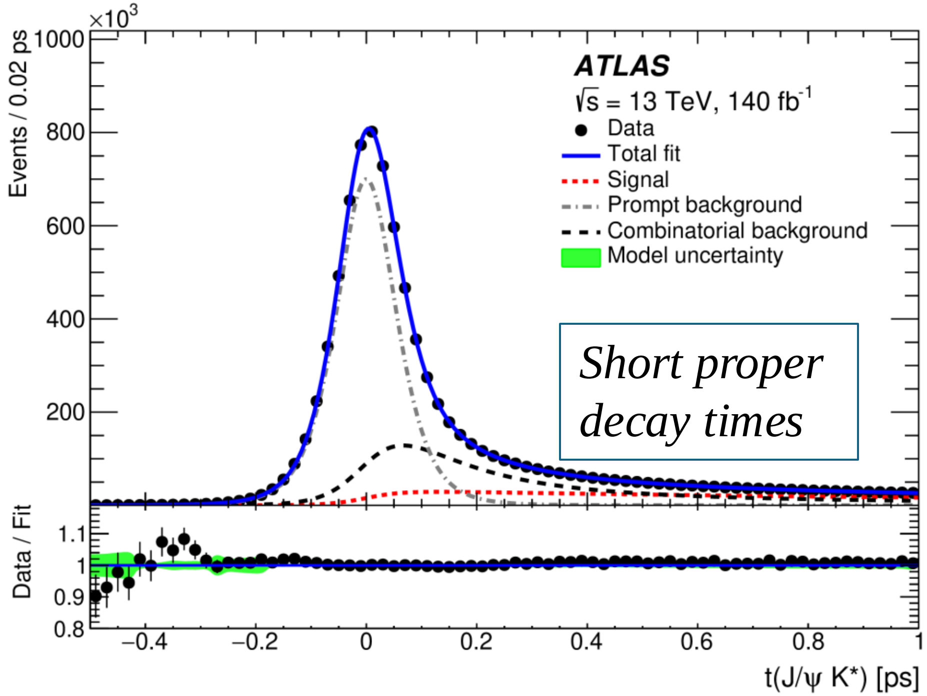
  - Signal mass is modeled by a Johnson-SU
  - Background mass is modeled by a polynomial (for relative size of 2 background components) + sigmoid (partially reconstructed decays)
  - Signal decay time is modeled by an exponential function
  - Background decay time is modeled by a gaussian (prompt, just resolution) + 3 exponentials

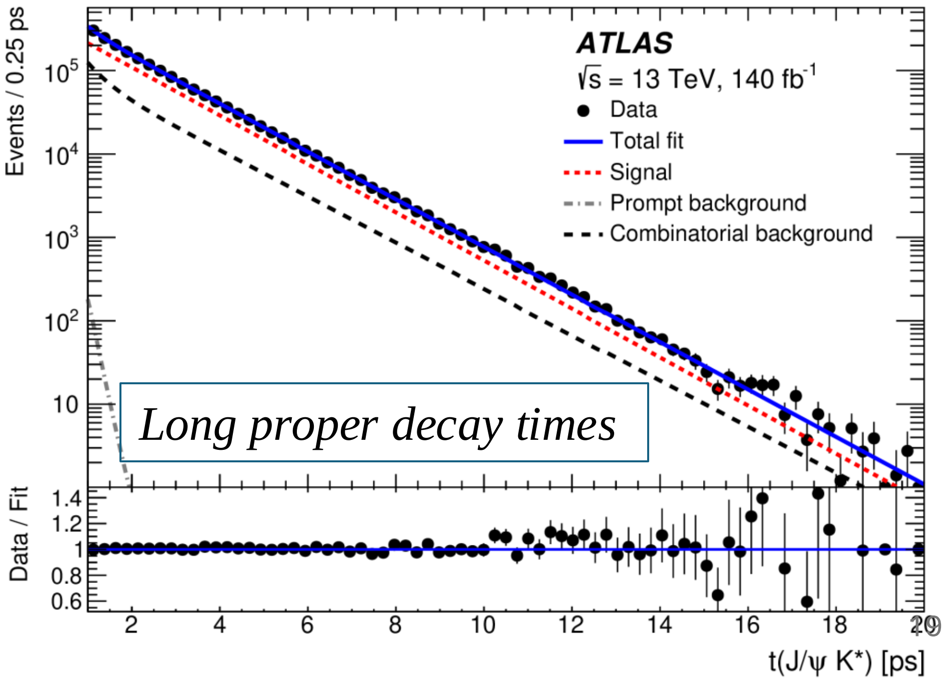
▪ *Systematics*

Source of uncertainty	Systematic uncertainty [ps]
ID alignment	0.00108
Choice of mass window	0.00104
Time efficiency	0.00130
Best-candidate selection	0.00041
Mass fit model	0.00152
Mass-time correlation	0.00229
Proper decay time fit model	0.00010
Conditional probability model	0.00070
Fit model test with pseudo-experiments	0.00002
Total	0.0035

The measurements:



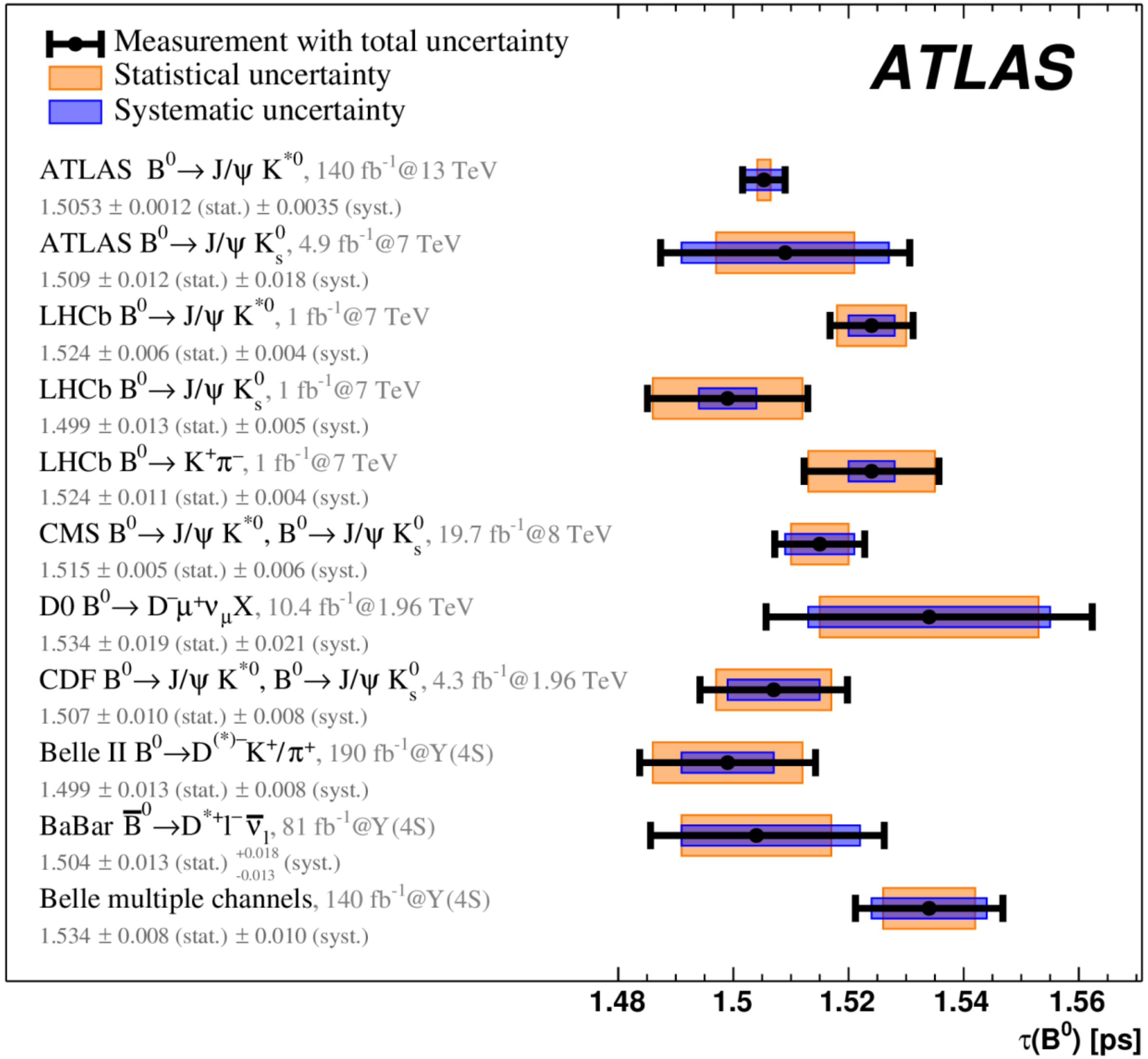




Results:

- $\tau_{B^0} = 1.5053 \pm 0.0012(stat.) \pm 0.0035(syst.)$ ps
- $\Gamma_d = 0.6639 \pm 0.0005(stat.) \pm 0.0016(syst) \pm 0.0038(ext.)$ ps^{-1}
- $\Gamma_d/\Gamma_s = 0.9905 \pm 0.0022(stat.) \pm 0.0036(syst.) \pm 0.0057(ext.)$

- Compatible with most other world measurements
- Reduced systematic uncertainty by factor 4.7 relative to previous (7 TeV, $B^0 \to J/\psi K_s{}^0$) ATLAS measurement
- Improvement due to data from the Insertable B-Layer, improved alignment, and increased statistics
- Γ_d is compatible with the HQE prediction* of $0.63^{+0.11}_{-0.07}$ ps^{-1}.
- Γ_d/Γ_s is compatible with predictions by HQE* (within 1.3σ) and lattice QCD** (within 0.4σ) and with the world average*** (within 1.3 σ)



* A. Lenz et al., JHEP 01 (2023) 004.
** D. Becirevic, arXiv:hep-ph/0110124.
*** HFLAV, PRD 107 (2023) 052008.

Measurement of the production cross section of J/ψ and ψ(2S) mesons with pp collisions at $\sqrt{s}$ = 13 TeV*

Message: Quarkonium states can be produced promptly (from short-lived QCD sources) or non-promptly (from long-lived sources such as decays of beauty hadrons). *A satisfactory model of prompt production mechanism within the framework of perturbative QCD is being sought.* Measurements of both cases require correction for feed-down from higher charmonium states. Data can compared to predictions from non-relativistic QCD (NRQCD) and from the Colour Evaporation Model (CEM).

The kinematic range of quarkonium production measurements is extended. Measurements of charmonium production via decay in the dimuon channel are presented at $\sqrt{s}$ = 13 TeV for meson p_T in the ranges 8 - 360 GeV (for J/ψ) and 8-140 GeV (for ψ(2S)), both for rapidity $|y| < 2$.

Cross sections are reported separately for prompt and non-prompt production. Non-prompt fractions are measured. Production ratios for ψ(2S) relative to J/ψ are given.

The outcome – In the high-p_T regime, the results show similar p_T dependence for the prompt and non-prompt differential cross sections. The non-prompt fraction is nearly constant for both J/ψ and ψ(2S). Comparisons with predictions indicate varying degrees of success. The extended p_T range provides new input for future tuning of models.

* Eur. Phys. J. C 84 (2024) 169; arXiv:2309.17177

The method:

Collect the data, reconstruct the event:

- Selected with single- or di-muon triggers
- Consider pairs of oppositely charged muon candidates with $p_T > 4$ GeV and $|\eta| < 2.4$
- The muon tracks in the Inner Detector fit to a common vertex producing an invariant mass in the range 2.6 – 4.2 GeV.
- The primary vertex (PV) is the collision interaction whose z-coordinate is nearest to the point of closest approach of the dimuon system trajectory to the beam axis.
- L_{xy} is the distance in the transverse plane from the primary vertex to the dimuon system's decay vertex, projected onto the direction of the dimuon system's p_T.
- Use these to calculate the pseudo-proper lifetime τ of the decaying meson:

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

Determine the cross sections:

- Divide the data into 34 bins of dimuon p_T × 3 bins of dimuon |y|.
  - For each bin apply a two-dimensional unbinned maximum likelihood fit to the distributions of $m_{\mu\mu}$ and $\tau_{\mu\mu}$.

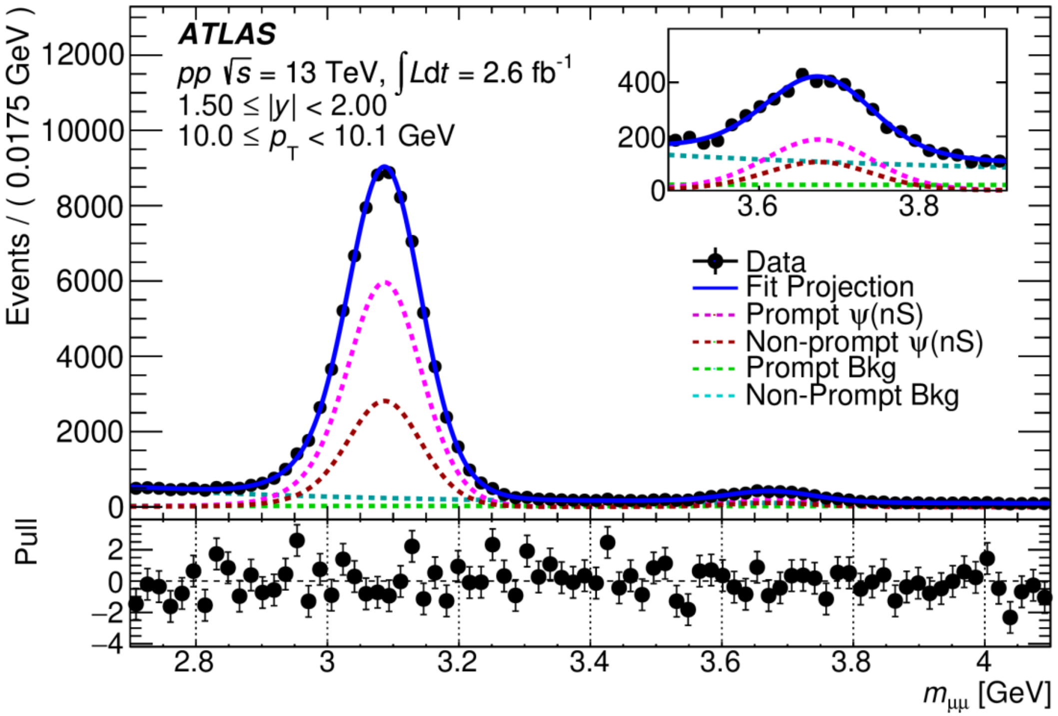
- Fit model includes:
  - 4 signal terms (prompt J/ψ, non-prompt J/ψ, prompt ψ(2S), non-prompt ψ(2S))
  - 3 bkg terms (prompt bkg from non-resonant dimuons from the PV [Drell-Yan] – 2nd-order polynomial; non-prompt dimuons from cascade decay of a b-hadron – exponential fn; non-prompt dimuons from separate b-hadrons – exponential fn.)
  - Each term is factorized into 2 fitting parameters: $f_1(m_{\mu\mu})$ – 2 Gaussians + Crystal Ball fn; and $f_2(\tau_{\mu\mu})$ – delta fn for prompt and single-sided exponential fns for non-prompt.
  - Fit includes decay time resolution and mass-time correlations in the peak.

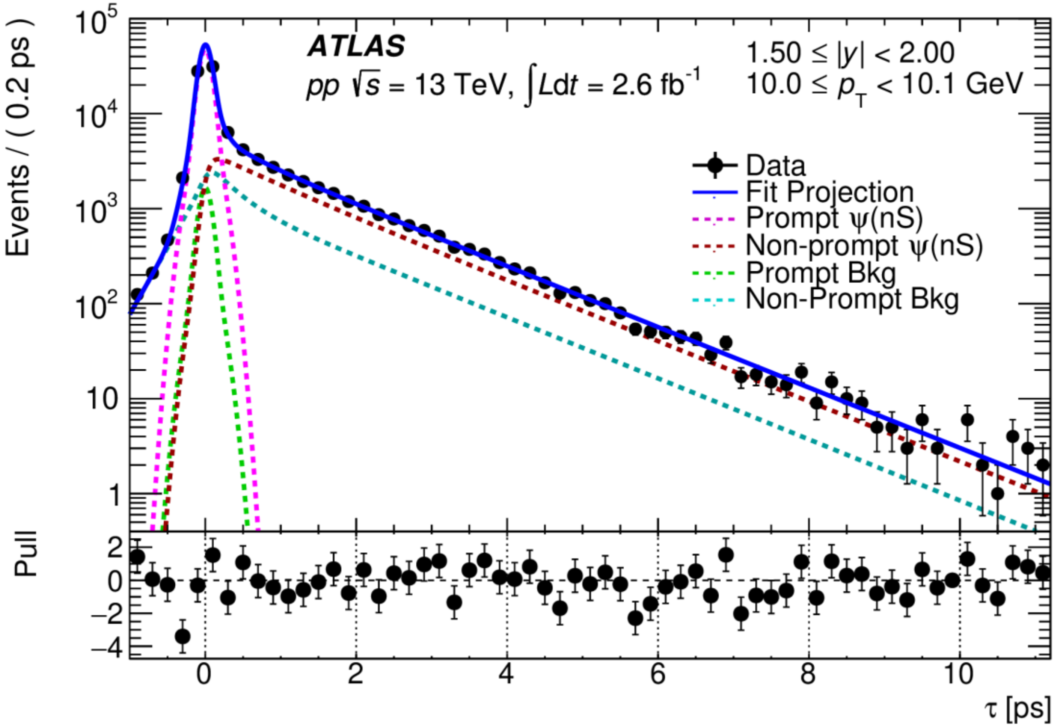
- Extract yields N for prompt (P) and non-prompt (NP) ψ mesons.
- Correct yields for efficiency and acceptance
- The cross sections are:

$$\frac{d^2\sigma(pp\rightarrow\psi)}{dp_T dy} \times BR(\psi \rightarrow \mu^+\mu^-) = \frac{\mathrm{N}}{\mathrm{Acceptance} \cdot \mathrm{Efficiencies} \cdot \Delta p_T \cdot \Delta y \cdot \mathrm{Lumi}}$$

- Compute the non-prompt fraction relative to the total.
- Compute the ratio of ψ(2S) production relative to J/ψ production, separately for prompt and non-prompt

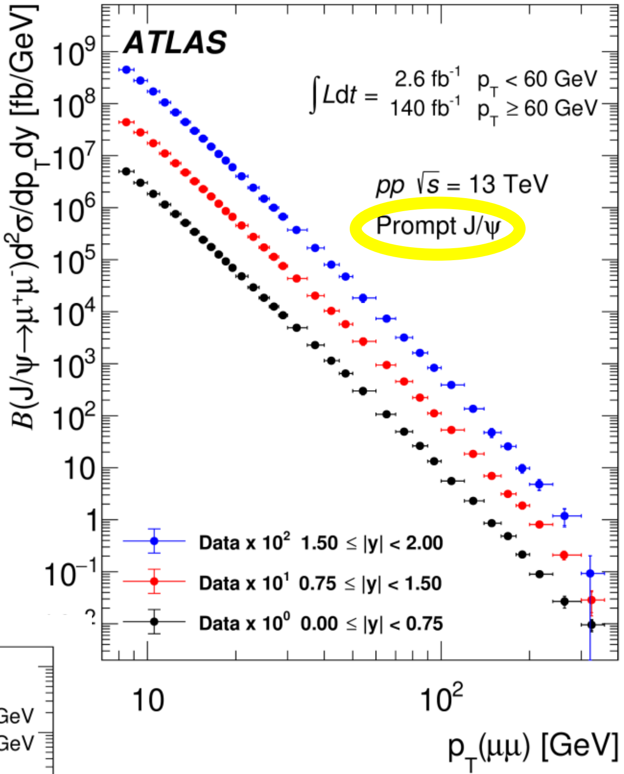
Fit results for example bins:

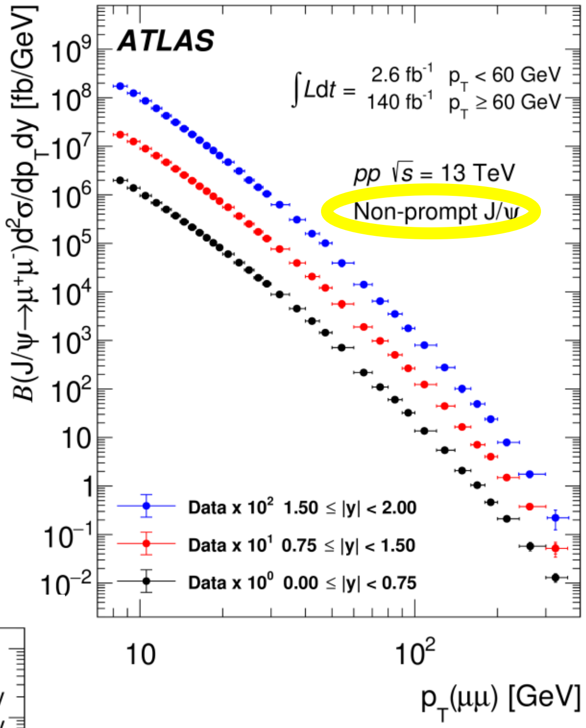


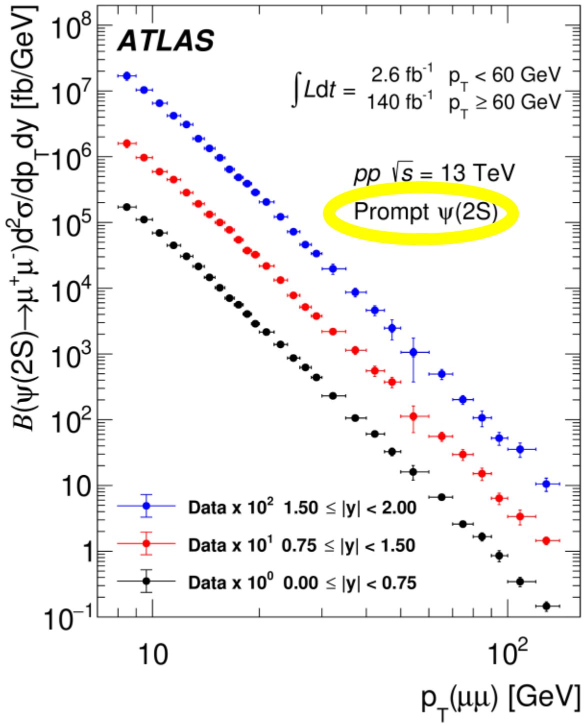


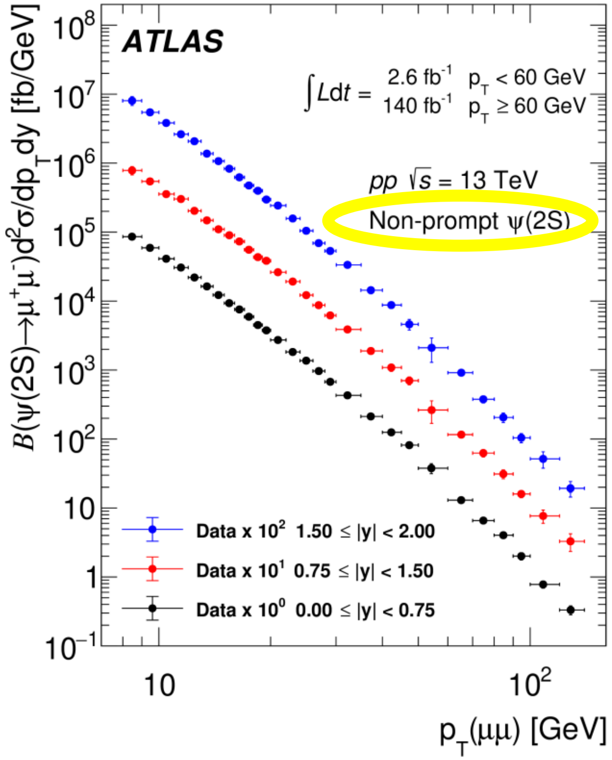
Systematic uncertainties are associated with fit model, reconstruction, trigger, and acceptance corrections.

Double-differential cross-section results:



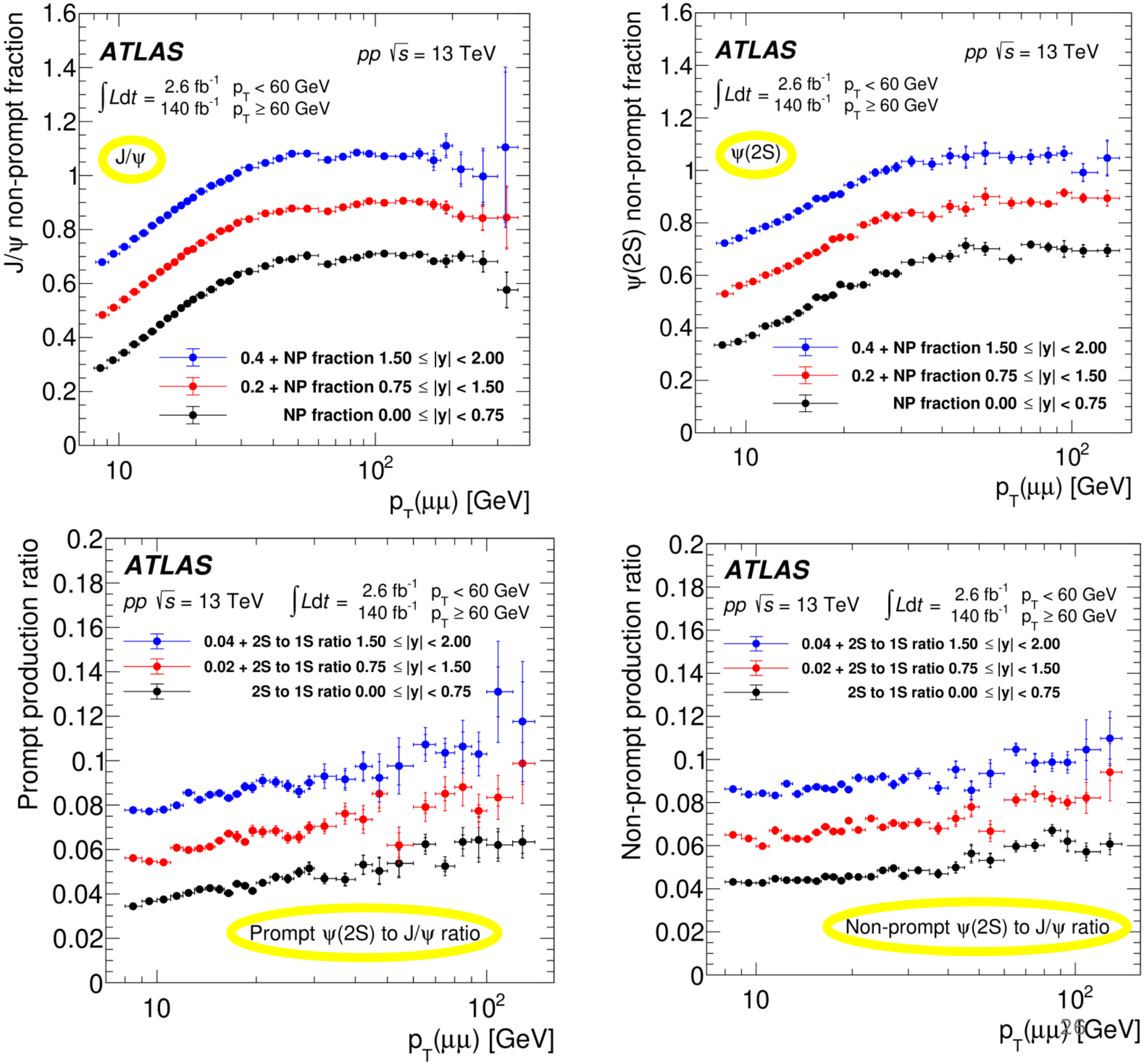






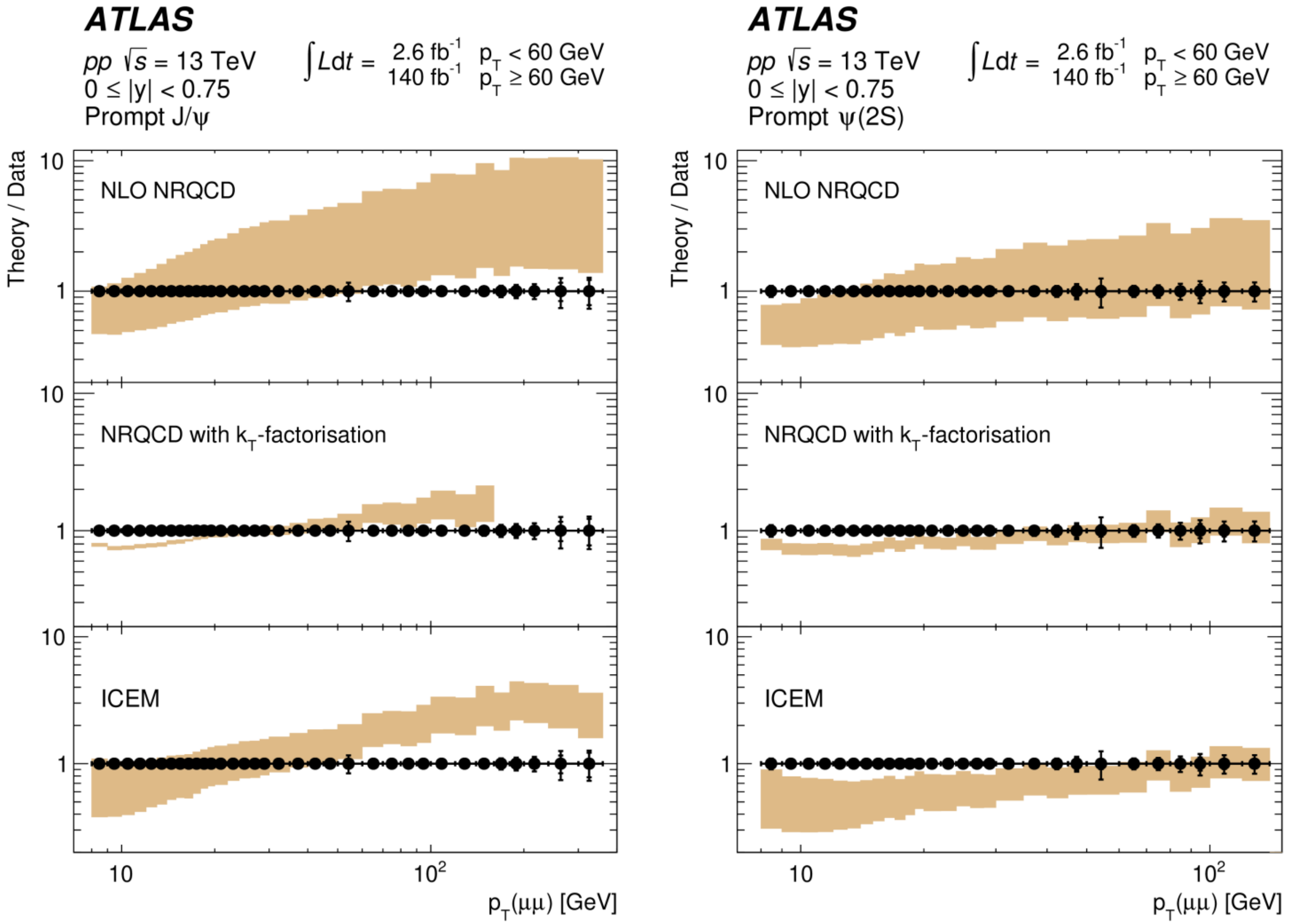
Non-prompt production fractions

Production cross section ratio for ψ(2S) : J/ψ



Comparison of data to theory for *prompt* production:

- *For NRQCD*[†]: Predictions and data largely overlap within theoretical uncertainties, which relate to renormalization, factorization, and NRQCD scales. Predictions overestimate data cross sections at high p_T.
- *For k_T-factorization model*[‡]: aims to improve the description by taking into account the transverse degrees of freedom of the initial gluons in the colliding protons. Uncertainties include only the renormalization scale. Prediction underestimates data at low p_T. High-p_T comparison is limited by availability* of the p_T-dependent gluon PDF.
- *Improved Colour Evaporation Model (ICEM)*[††] assigns a fixed fraction of the $c\bar{c}$ production cross section below the open charm threshold to individual charmonium states. Predictions use parameter values previously determined from LHCb 7 TeV data.** Predicts harder p_T spectra and underestimates the ψ(2S) cross section.

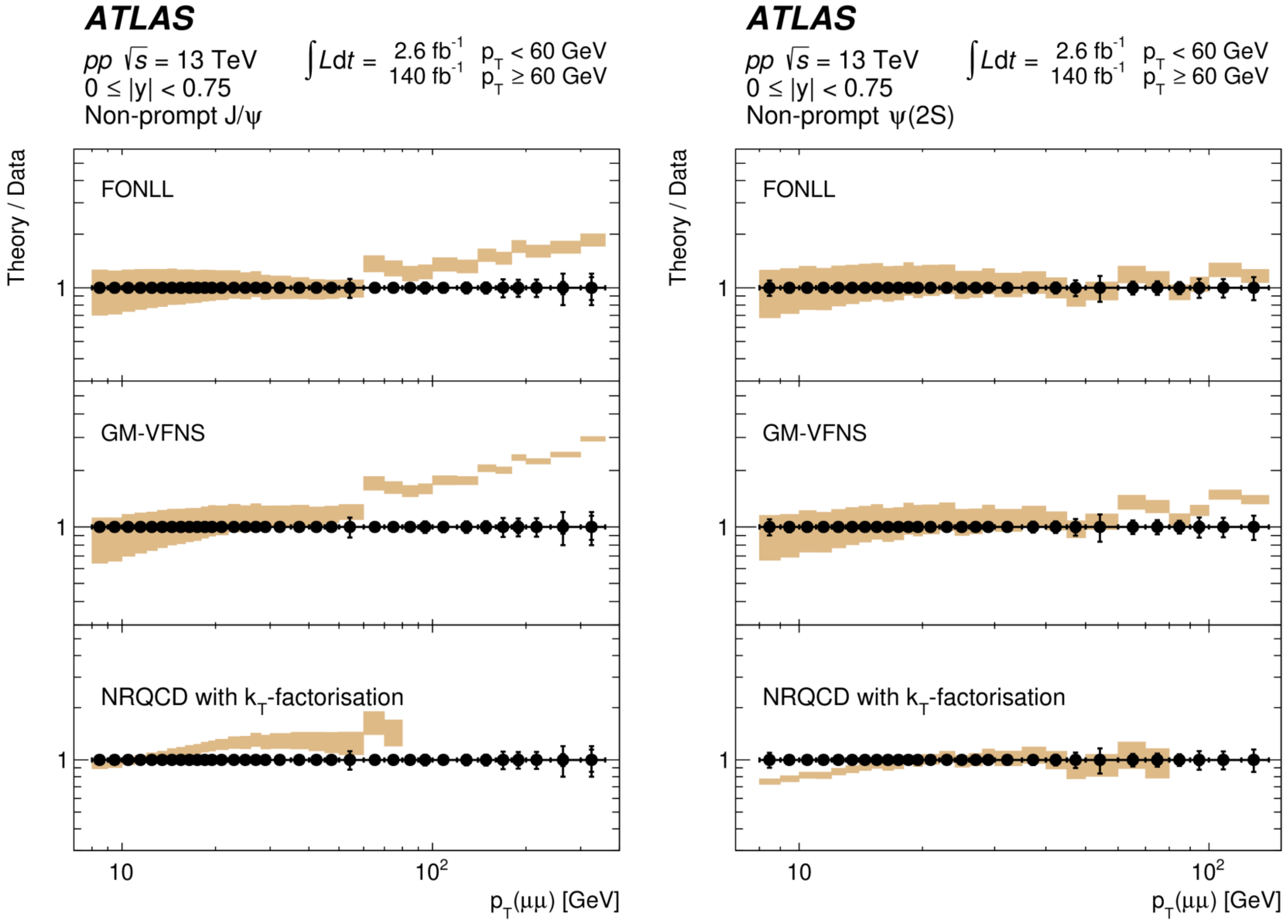


† M. Butenschoen et al., PRL 106 (2011) 022003.
‡ S.P. Baranov et al., EPJ C 75 (2015) 455; S.P. Baranov et al., PRD 96 (2017) 034019.
†† V. Cheung et al., PRD 104 (2021) 094026.
*H. Jung, arXiv:hep-ph/0411287.
** LHCb Collab., EPJ C 74 (2014) 2872; LHCb Collab., EPJ C 71 (2011) 1645.

Comparison of data to theory for *non-prompt* production:

Model based on PQCD for production of the $b\bar{b}$-pair, their hadronization, and their decay to charmonium.

- *FONLL*[*] uncertainties cover renormalization scale and c-quark mass. Agreement at low p_T; prediction diverges at high p_T for J/ψ.
- *GM-VFNS*[**] uncertainties originate from renormalization scale dependence. Result similar to FONLL but with increased deviation at high p_T.
- *NRQCD with k_T-factorization*[†] can be used to predict p_T distributions of vector charmonia through non-prompt production. Shapes are produced well but are limited by the available gluon PDF.



[*] M. Cacciari et al., JHEP 03 (2001) 006; M. Cacciari et al., JHEP 10 (2012) 137.
[**] P. Bolzoni et al., PRD 88 (2013) 074035.
[†] A.V. Lipatov et al., EPJ C 80 (2020) 330; S.P. Baranov et al., EPJ C 78 (2018) 820.

Summary

ATLAS presents recent results on:

- *Differential cross section measurement of $D^{\pm}$ and $D_s^{\pm}$ meson production* – some ATLAS firsts, and comparisons to theory in a new kinematical regime.

- *Precision measurement of the B^0 meson lifetime using $B^0 \to J/\psi K^{*0}$ decays* – most precise measurement of this lifetime thus far.

- *Measurement of the production cross section of J/ψ and $\psi(2S)$ mesons in pp collisions at $\sqrt{s} = 13$ TeV* – comparison to models in a new p_T regime.