QCD 17

20th High-Energy Physics International Conference in Quantum Chromodynamics

3rd - 7th July 2017, Montpellier, France

Production and Properties of B-Hadrons with the ATLAS Detector

(Recent Results)

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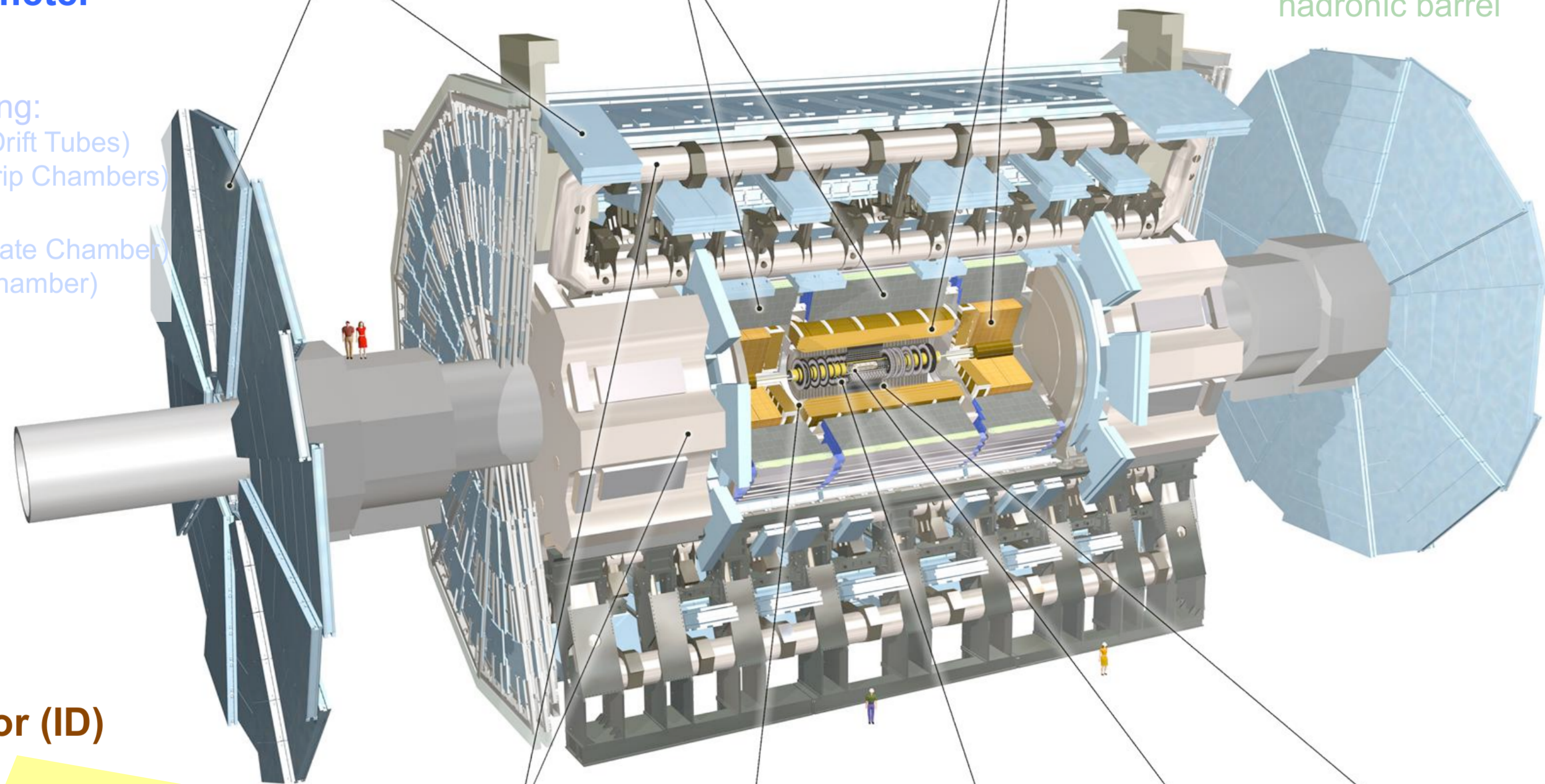
on behalf of the ATLAS collaboration

B-Physics at the ATLAS Experiment

- Triggering |η| < 2.4
- Precision Tracking |η| < 2.7

Muon Specrometer

Calorimeter System



Inner Detector (ID)

- $p_T > 0.4$ GeV, |η| < 2.5
- New for Run2: Insertable B-Layer (IBL): an additional inner-most pixel layer (r = 33mm) => ~30% more precise secondary vertex reconstruction

ATLAS B-Physics Programme

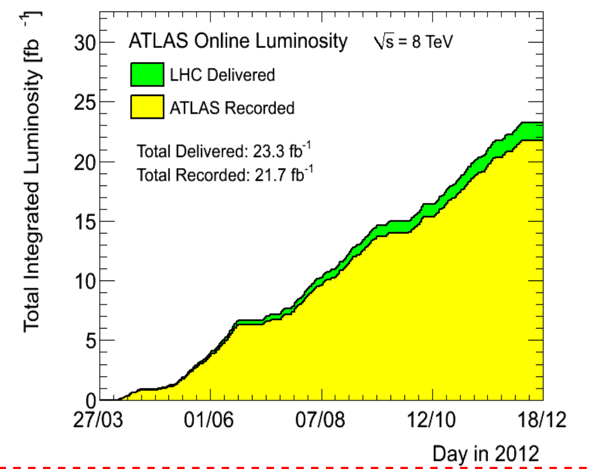
- ATLAS B-physics programme includes:
  - **Precision measurements:** rare decays, b-hadron decay properties, CPV
  - **Heavy flavour production:** b-hadrons, (associated) quarkonia production
  - **Spectroscopy:** new states and decay modes
  - Mostly in fully reconstructable exclusive decays with single/di-/multi-muon final states, which allows to trigger low-p_T objects

- **Outline of the talk (recent results):**
  - Measurement of $X(3872) \rightarrow J/\psi\, \pi^+\pi^-$ and $\psi(2S) \rightarrow J/\psi\, \pi^+\pi^-$ production — JHEP 01 (2017) 117
  - Measurement of the prompt J/ψ pair production in the $J/\psi \rightarrow \mu^+\mu^-$ decay mode — EPJC 77 (2017) 76
  - Measurement of b-hadron pair production with $B \rightarrow J/\psi\, X$ and $B \rightarrow \mu\, X$ decay modes — arXiv:1705.03374 Submitted to JHEP

Datasets and Trigger

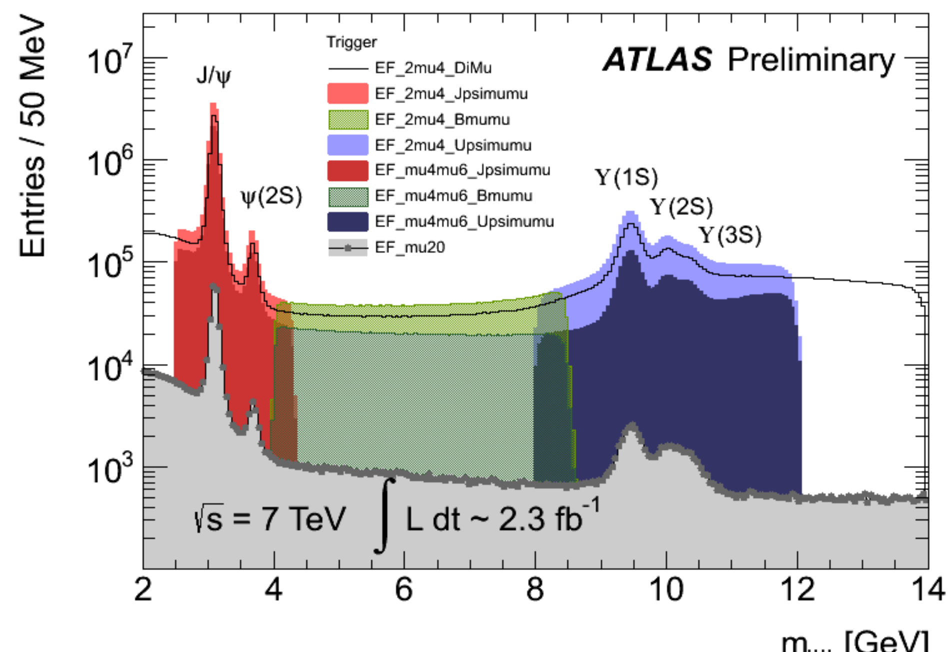
Datasets (pp):

- 7 TeV data, 5.08 fb^{-1}, 50ns, 3.7×10^{33} $cm^{-2}s^{-1}$
- 8 TeV, 21.3 fb^{-1}, 50ns, 7.7×10^{33} $cm^{-2}s^{-1}$
- 13 TeV, 3.9+35.6 fb^{-1}, 50/25ns, 13.8×10^{33} $cm^{-2}s^{-1}$



Trigger:

- 20/40 MHz collision rate → ~400 Hz recording
- B-physics concentrates on low-p_T di-muon signatures; presented analyses use $J/\psi \to \mu\mu$ trigger:
  - $L_{int} = 11.4$ fb^{-1}
  - Trigger on low-p_T (4,6 GeV) di-muon
  - 2 muons at L1 (HW-based)
  - Confirmed at HLT
  - Track vertex fit and mass cuts at HLT
  - 8 TeV data: low-p_T maintained introducing barrel triggers

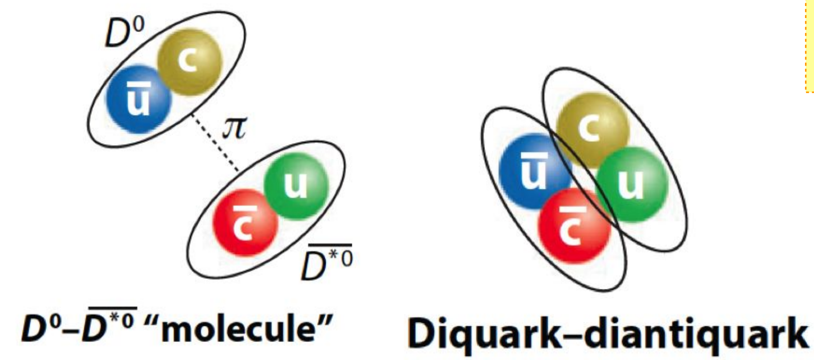


Measurement of $\psi(2S) \to J/\psi\, \pi^+ \pi^-$ and $X(3872) \to J/\psi\, \pi^+ \pi^-$ production

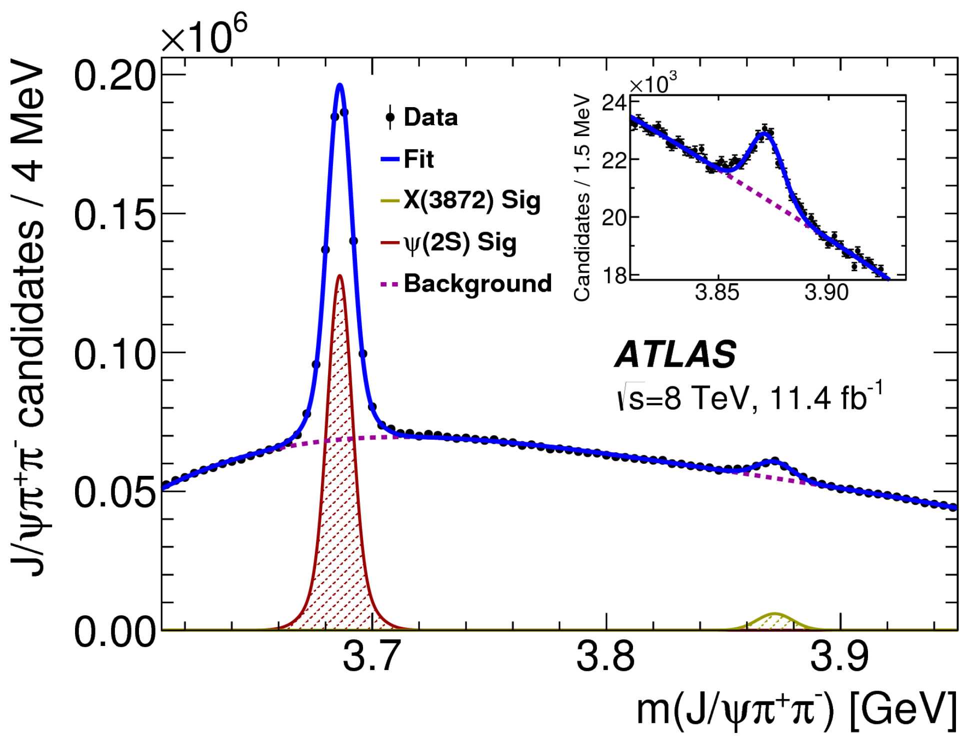
Production of ψ(2S) and X(3872) in J/ψππ

JHEP 01 (2017) 117

- **X(3872) state**: Discovered by Belle, confirmed by CDF, BaBar and D0
  - JPC = 1^{++} by LHCb (and CDF)
  - CMS x-section vs. p_T favors mixed $\chi_{c1}(2P)$-$D^0\overline{D}^{*0}$ state; $\chi_{c1}(2P)$ predominates
  - ψ(2S) measurement for straightforward comparisons



- **Selection**: ~470k of ψ(2S) and ~30k of X(3872)
- **Measurement** in bins of p_T and pseudo-lifetime
  - Prompt / non-prompt production J/ψππ candidate mass fits and pseudolifetime fits
  - Lifetime structure of X(3872)
    - production from B_c ?
  - Di-pion mass spectrum



(Non-)Prompt Production X(3872) vs. ψ(2S)

JHEP 01 (2017) 117

- Relative X(3872)/ψ(2S) non-prompt production significantly smaller than Tevatron measurement

$$R_B^{2L} = \frac{\mathcal{B}(B \to X(3872) + \text{any})\mathcal{B}(X(3872) \to J/\psi\pi^+\pi^-)}{\mathcal{B}(B \to \psi(2S) + \text{any})\mathcal{B}(\psi(2S) \to J/\psi\pi^+\pi^-)} = (3.57 \pm 0.33(\text{stat}) \pm 0.11(\text{sys})) \times 10^{-2}$$

Tevatron: 0.18 ± 0.08 from Phys.Rev.D81 (2010) 114018

- Non-prompt fraction in ψ(2S) and X(3872) production agrees with CMS

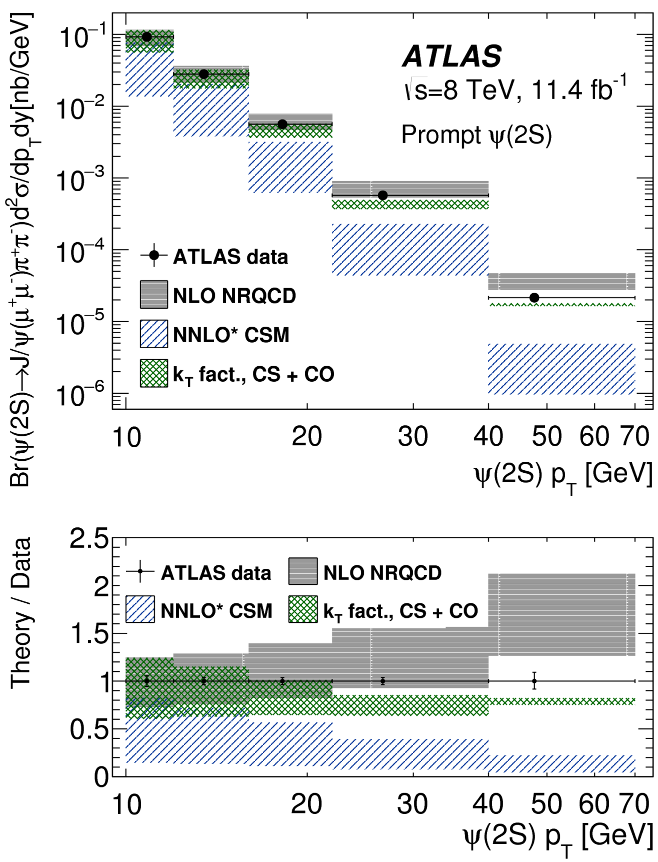
- Suggests strongly enhanced X(3872) production through B_c (account for small f_{Bc})

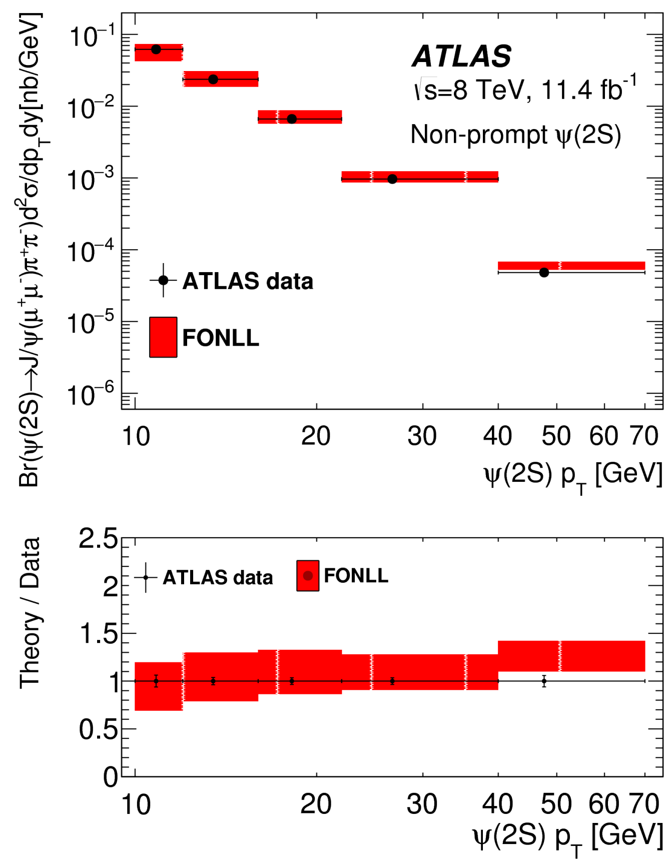
$$\frac{\sigma(pp \to B_c)\mathcal{B}(B_c \to X(3872))}{\sigma(pp \to \text{non-prompt } X(3872))} = (25 \pm 13(\text{stat}) \pm 2(\text{sys}) \pm 5(\text{spin}))\%$$

ψ(2S) Production

JHEP 01 (2017) 117

- Relative X(3872)/ψ(2S) non-prompt production significantly smaller than Tevatron measurement
- Non-prompt fraction in ψ(2S) and X(3872) production agrees with CMS
- Suggests strongly enhanced X(3872) production through B_c (account for small f_{Bc})
- NNLO* CSM underestimates ψ(2S) prompt production, NLO NRQCD, k_T fact. and FONLL agree

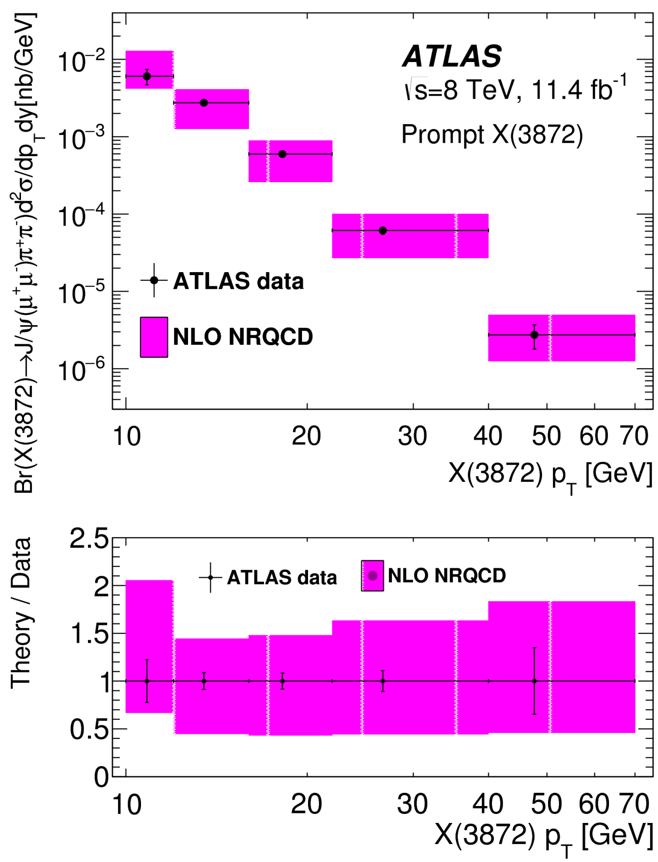


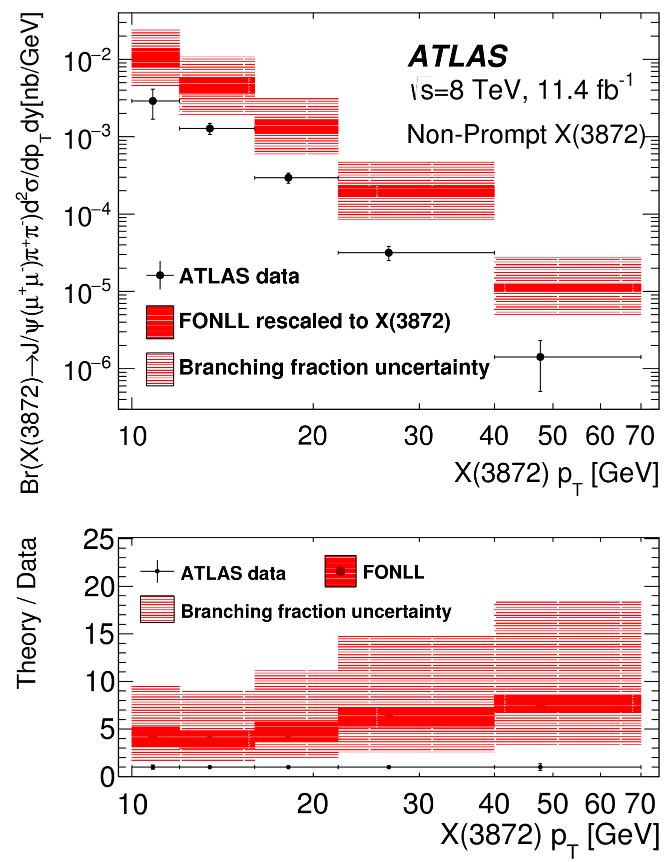


X(3872) Production

JHEP 01 (2017) 117

- Relative X(3872)/ψ(2S) non-prompt production significantly smaller than Tevatron measurement
- Non-prompt fraction in ψ(2S) and X(3872) production agrees with CMS
- Suggests strongly enhanced X(3872) production through B_c (account for small f_{Bc})
- Prompt X(3872) production agrees with NLO NRQCD assuming mixture of $\chi_{c1}(2P)$ with $D^0\overline{D}^{*0}$, but non-prompt prediction accounting for Tevatron result overestimates ATLAS data

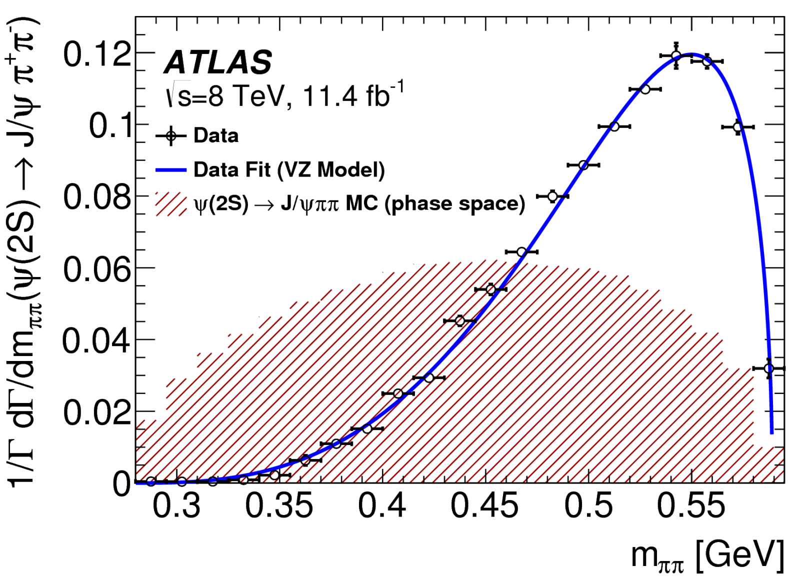


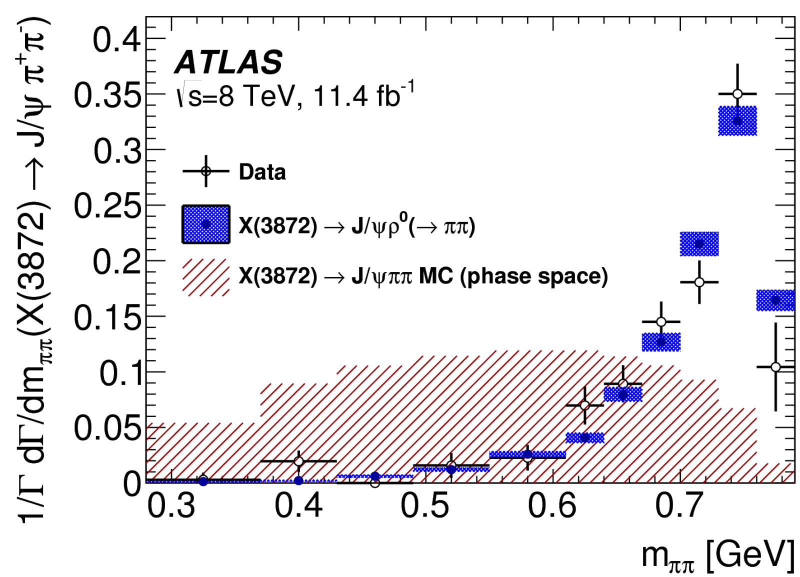


Di-Pion Invariant Mass Spectra

JHEP 01 (2017) 117

- Relative X(3872)/ψ(2S) non-prompt production significantly smaller than Tevatron measurement
- Non-prompt fraction in ψ(2S) and X(3872) production agrees with CMS
- Suggests strongly enhanced X(3872) production through B_c (account for small f_{Bc})
- NNLO* CSM underestimates ψ(2S) prompt production, NLO NRQCD, k_T fact. and FONLL agree
- Prompt X(3872) production agrees with NLO NRQCD assuming mixture of $\chi_{c1}(2P)$ with $D^0\overline{D}^{*0}$, but non-prompt prediction accounting for Tevatron result overestimates ATLAS data
- ψ(2S) di-pion mass spectrum agrees with LHCb and BES measurements
- X(3872) di-pion mass spectrum prefers X(3872) → $J/\psi\rho^0(\to\pi\pi)$ hypothesis



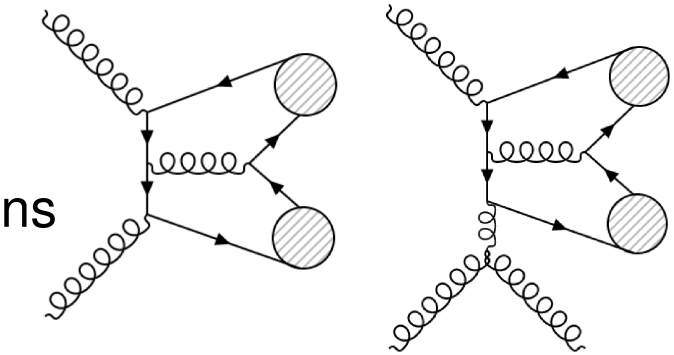


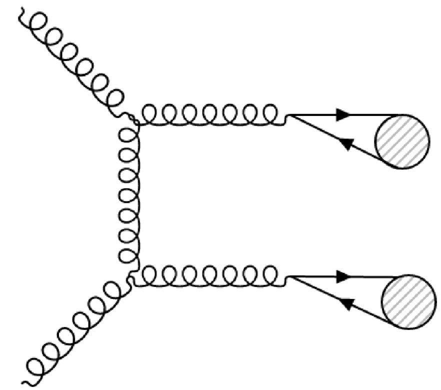
Measurement of the prompt J/ψ pair production in the $J/\psi \to \mu^+\mu^-$ decay mode

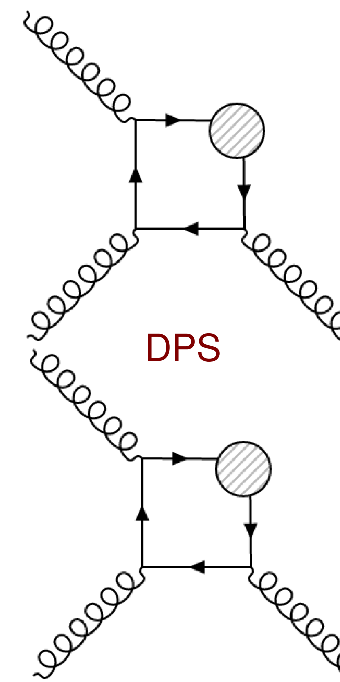
Prompt J/ψ Pair Production

EPJC 77 (2017) 76

- **Motivation**:
  - Understanding of non-perturbative QCD, also sensitive to NLO and higher pQCD corrections
  - Study J/ψ production models
  - Measure double parton scattering (DPS)
    - Important background for NP searches
    - σ_{eff} from gluon-dominated interactions







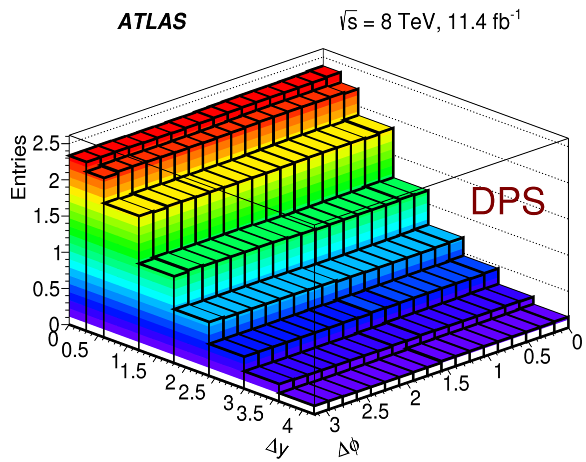
- **Selection**: 1210 di-J/ψ events left
- **Measurement** of the differential x-sections
  - → Selection / efficiencies / acceptance
  - → 2D mass fits
  - → L_{xy} fits (prompt/non-prompt)
  - → pile-up removal (<1%)
  - Barrel (|y|<1.05) / endcap (1.05 < |y| < 2.1)
  - Inclusive J/ψ sample to study pile-up and J/ψ reconstruction performance

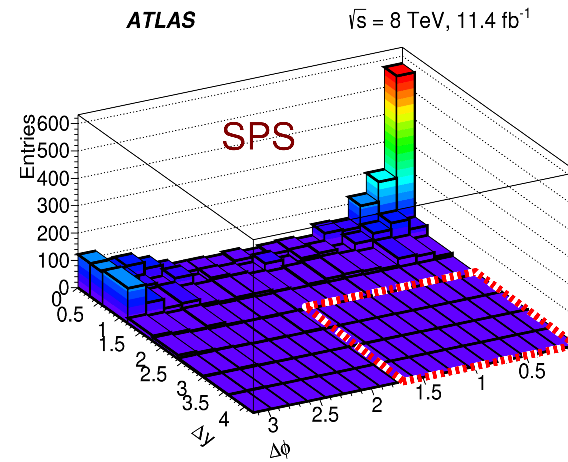
Prompt J/ψ Pair X-Section & DPS

EPJC 77 (2017) 76

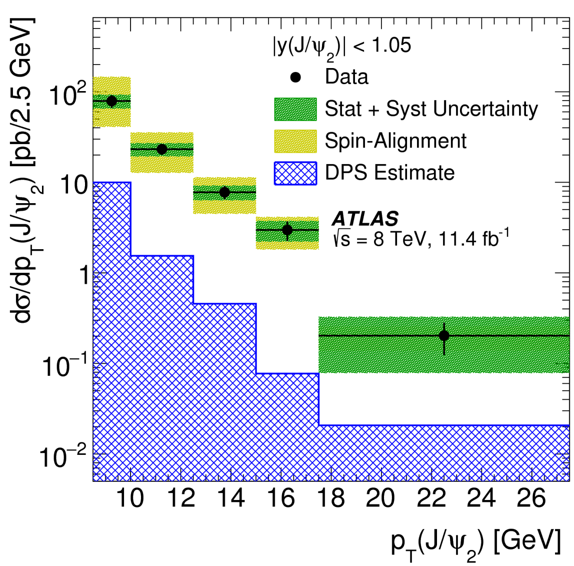
- DPS template from mixed J/ψ candidates in different events
  - dominating in J/ψs |Δy| > 1.8 (and |Δϕ| < π/2)

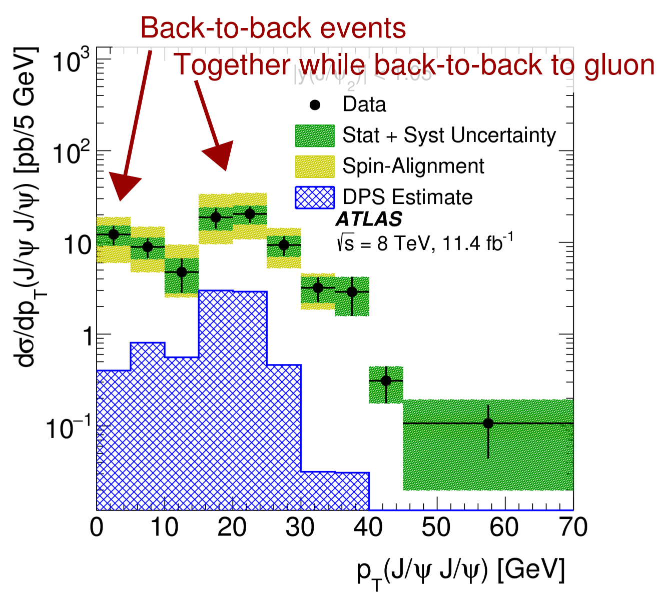
$$f_{DPS} = (9.2 \pm 2.1\,(\text{stat}) \pm 0.5\,(\text{syst}))\%$$

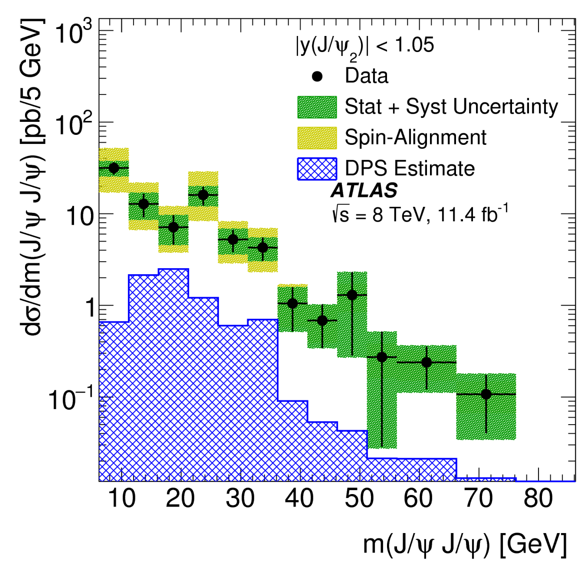




$$\sigma_{Fid}(pp \to J/\psi J/\psi + X) = \begin{cases} 15.6 \pm 1.3\,(\text{stat}) \pm 1.2\,(\text{syst}) \pm 0.2\,(\text{BF}) \pm 0.3\,(\text{lumi})\ \text{pb}, & \text{for } |y| < 1.05, \\ 13.5 \pm 1.3\,(\text{stat}) \pm 1.1\,(\text{syst}) \pm 0.2\,(\text{BF}) \pm 0.3\,(\text{lumi})\ \text{pb}, & \text{for } 1.05 \le |y| < 2.1 \end{cases}$$



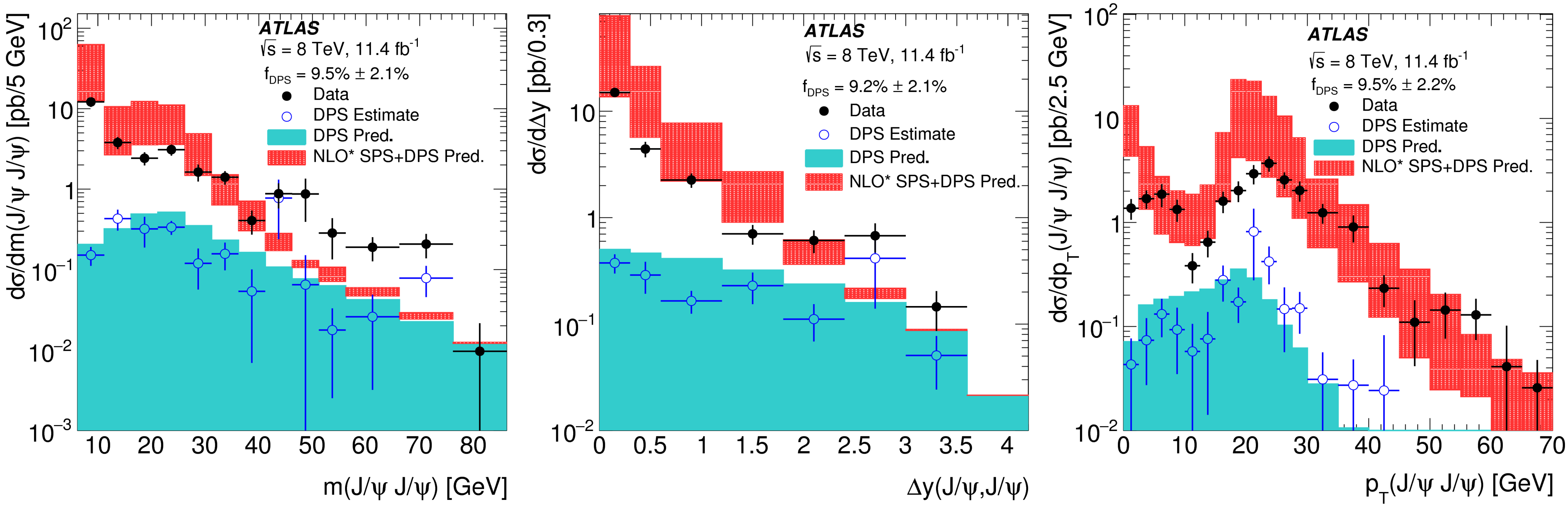




Comparison to Theory Calculations

EPJC 77 (2017) 76

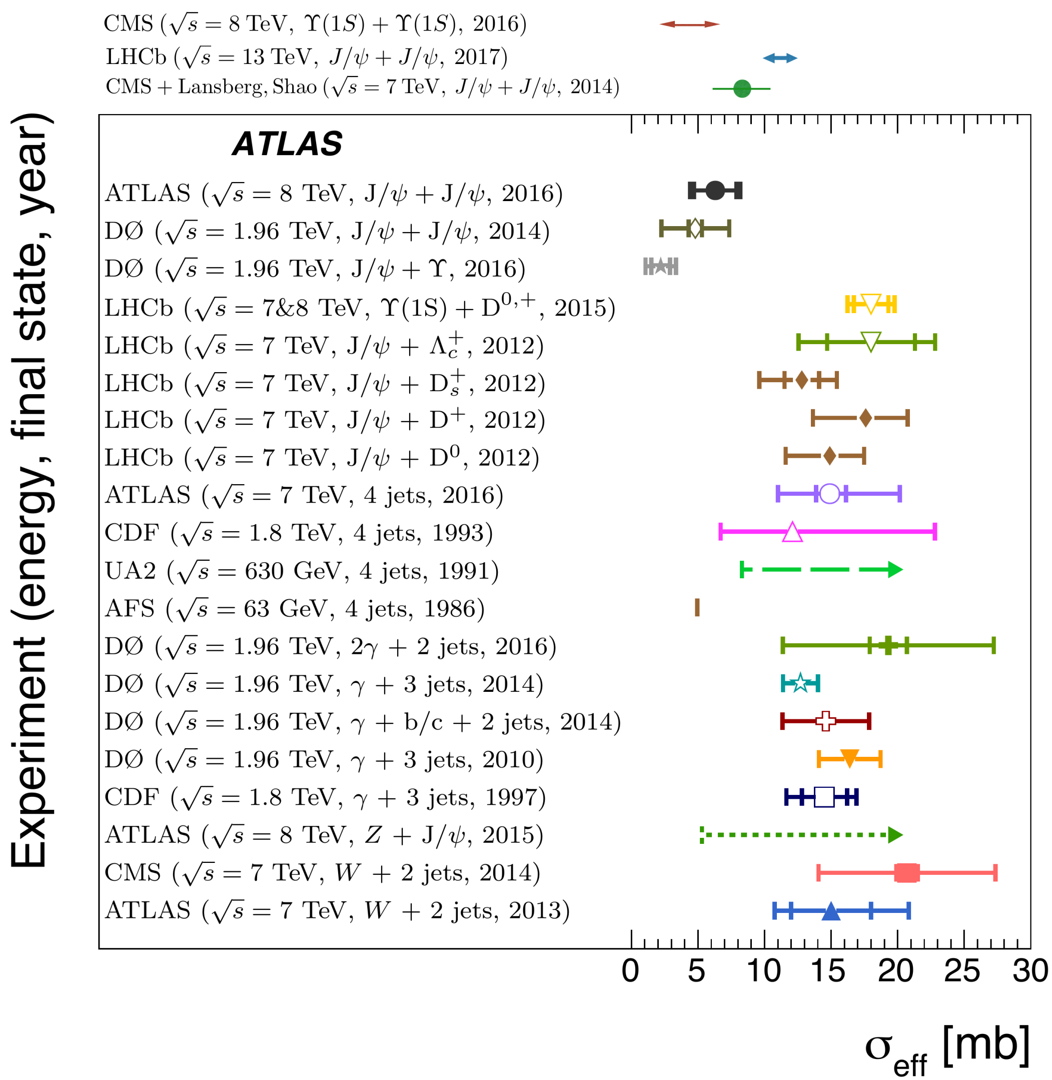
- Largely agreement with NLO* SPS (with a feed-down correction factor) + LO DPS (normalized to measured DPS)
- Except for large invariant di-J/ψ mass, larger Δy and in the low-p_T region
  - Similar feature in CMS di-J/ψ measurement (JHEP 09 (2014) 94)
  - Further cross-checks suggest need of contributions from feed-down and/or intrinsic parton transverse momentum



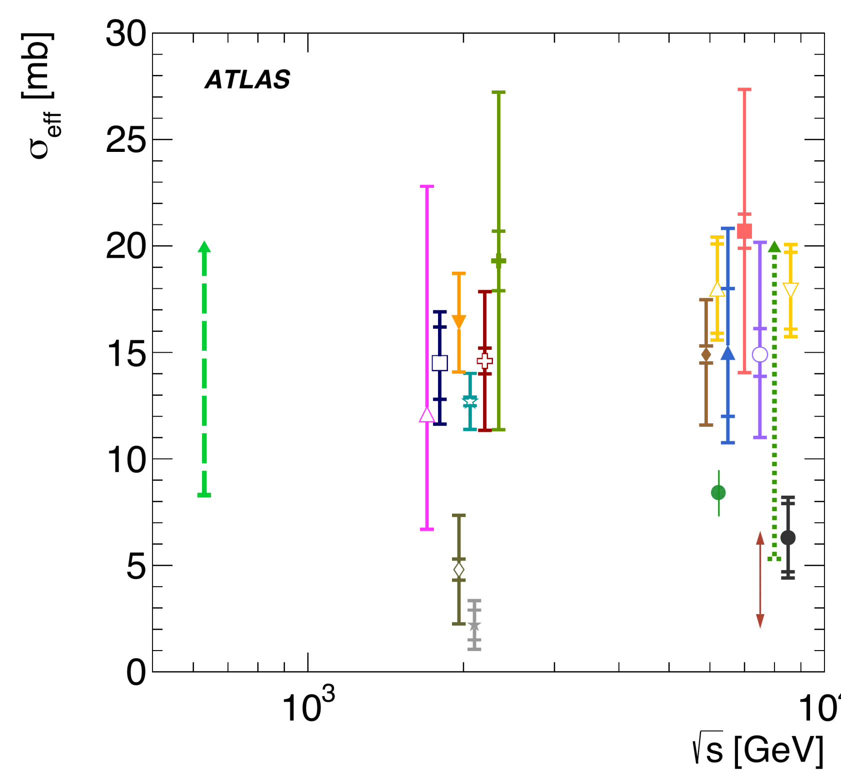
Double Parton Scattering σ_{eff}

EPJC 77 (2017) 76

- Extracted $\sigma_{\text{eff}} = \frac{1}{2}\frac{\sigma^2_{J/\psi}}{\sigma^{J/\psi,J/\psi}_{\text{DPS}}} = \frac{1}{2}\frac{\sigma^2_{J/\psi}}{f_{\text{DPS}} \times \sigma_{J/\psi J/\psi}} = 6.3 \pm 1.6\ (\text{stat}) \pm 1.0\ (\text{syst}) \pm 0.1\ (\text{BF}) \pm 0.1\ (\text{lumi})\ \text{mb}$
- σ_{eff} from di-J/ψ generally lower than from other final states



- Theory prediction for process and energy dependence needed



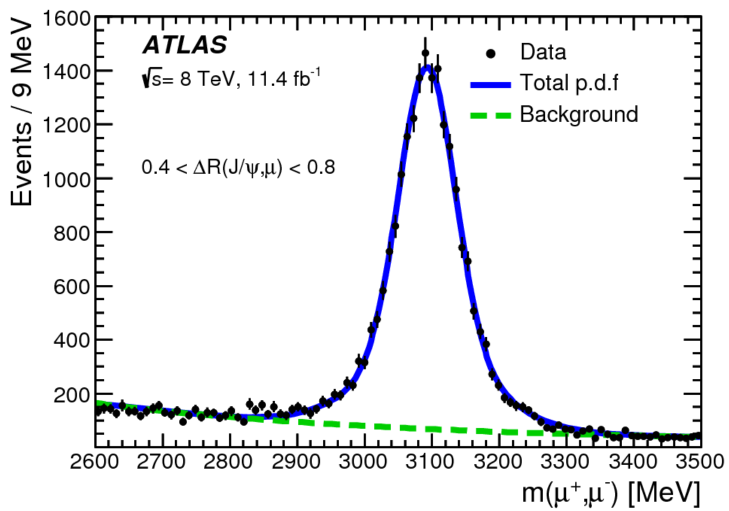
arXiv:1705.03374
Submitted to JHEP

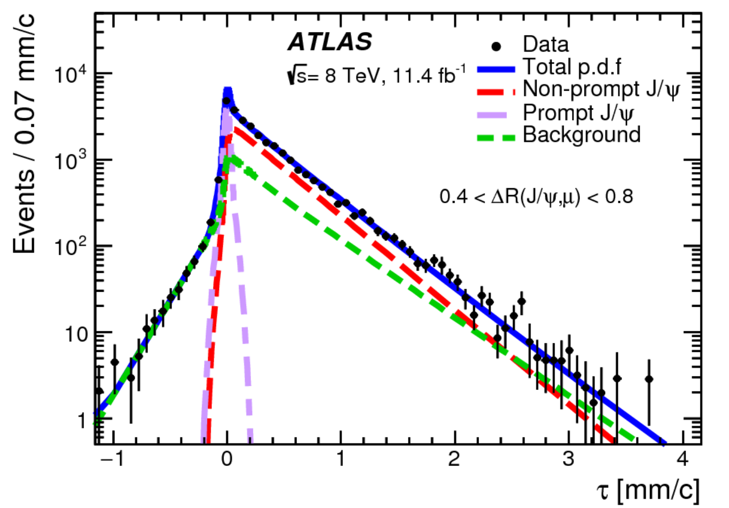
Measurement of b-hadron pair production with $B \to J/\psi X$ and $B \to \mu X$ decay modes

Production of b-Hadron Pairs

arXiv:1705.03374

- **Motivation**: b-production vs. theory
  - especially small-angle $b\bar{b}$ pairs production via gluon splitting
  - Important background for other searches
    - e.g. associated Higgs + vector boson
- Convenient 3-muon signature:
  - $b \to J/\psi(\mu\mu)X + b \to \mu X$
- **Measurement**: in each kinematic bin:
  - J/ψ non-prompt yield from mass & pseudo-lifetime fit
  - 3rd muon event yield from signal-enhanced ($\tau > 0.25$ mm) sample, and 2D fit of muon transverse $d_0/\sigma(d_0)$ & BDT constructed from muon-production sensitive kinematic parameters
  - Irreducible background subtraction
  - Corrections on the τ cut and detector resolution

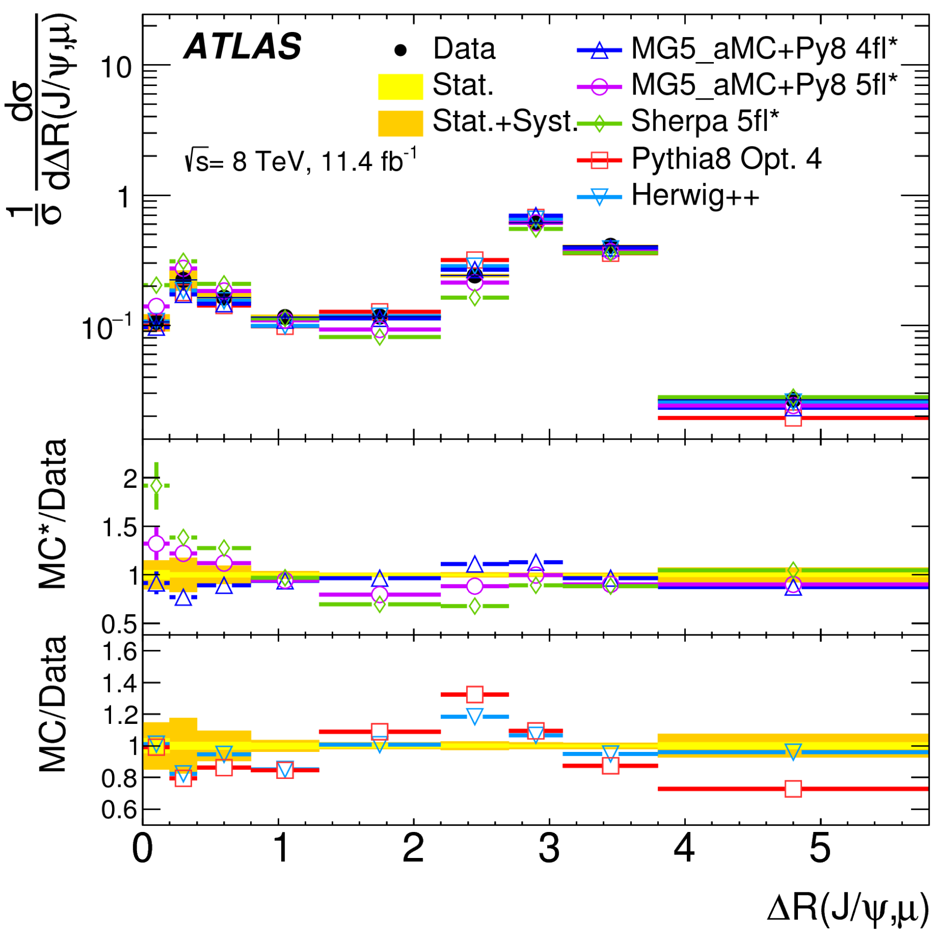


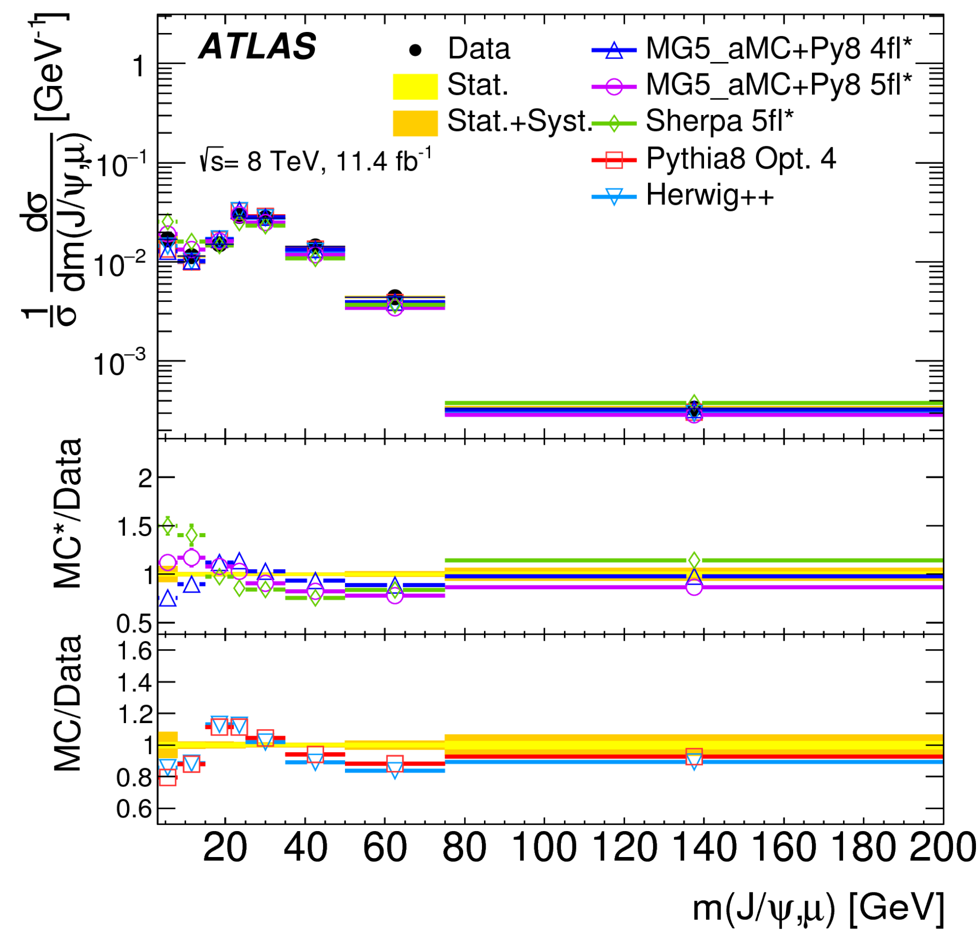


Comparison to MC Generators

arXiv:1705.03374

- Total x-section$_{\text{fiducial}}$: $\sigma(B(\to J/\psi[\to \mu^+\mu^-] + X)B(\to \mu + X)) = 17.7 \pm 0.1(\text{stat}) \pm 2.0(\text{syst})$ nb
- Tested number of Pythia8 $g \to b\bar{b}$ splitting functions (p_T-based kernels best agree at low ΔR)
- Best overall agreement with 4-flavour scheme MadGraph5_aMC@NLO + Pythia8 prediction





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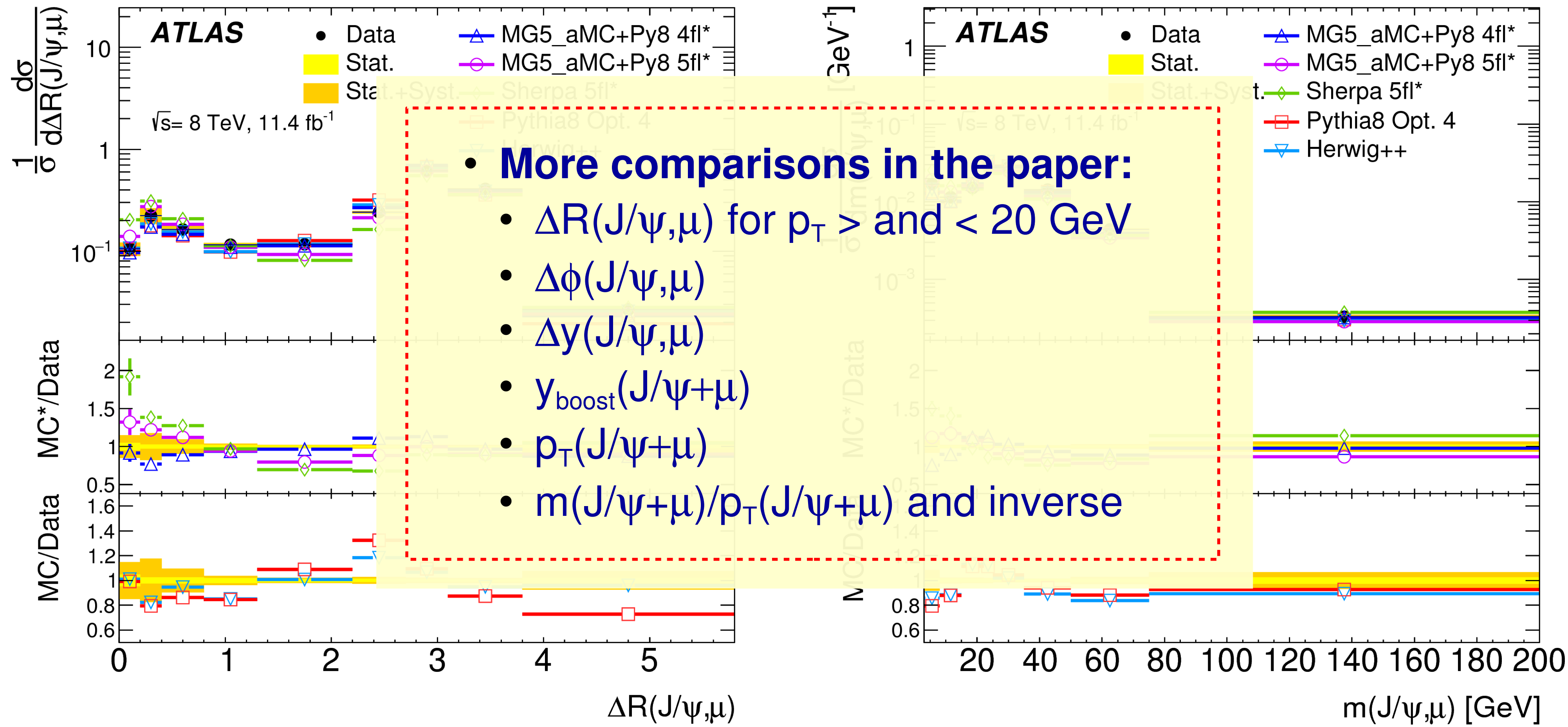


- **More comparisons in the paper:**
  - $\Delta R(J/\psi,\mu)$ for p_T > and < 20 GeV
  - $\Delta\phi(J/\psi,\mu)$
  - $\Delta y(J/\psi,\mu)$
  - $y_{\text{boost}}(J/\psi+\mu)$
  - $p_T(J/\psi+\mu)$
  - $m(J/\psi+\mu)/p_T(J/\psi+\mu)$ and inverse

Summary

- Presented latest ATLAS results probing QCD predictions:
  - Production of $\psi(2S)$ and X(3872) in $J/\psi\pi^+\pi^-$ decay mode
  - Prompt J/ψ pair production; $J/\psi\to\mu^+\mu^-$ decay mode
  - Production of b-hadron pair with $B\to J/\psi X$ and $B\to\mu X$ decay modes

- ATLAS will continue its B-physics program in the Run 2,3 and the HL-LHC era, continue focusing on precision measurements, rare decays and heavy flavour production and spectroscopy
  - Detector upgrades (namely in **tracking** and **muon system**) and new **trigger strategies** and tools will help to cope with the high-luminosity environment

Summary: Run-1 & Run-2 B-Physics Results

Publications

Short Title	Int L	Journal	Preprint
NEW Measurement of b-hadron pair production at $\sqrt{s}$ = 8 TeV	11.4 fb^{-1}	Submitted to JHEP	arXiv:1705.03374
NEW Measurement of the prompt J/ψ pair production cross-section in *pp* collisions at $\sqrt{s}$ = 8 TeV	11.4 fb^{-1}	Eur. Phys. J. C77 (2017) 76	arXiv:1612.02950
Production measurements of ψ(2S) and X(3872) → J/ψ $\pi^+\pi^-$ at $\sqrt{s}$ = 8 TeV	11.4 fb^{-1}	JHEP01(2017)117	arXiv:1610.09303
Measurement of the relative width difference of the B^0-$\bar{B}^0$ system	25 fb^{-1}	JHEP06 (2016) 081	arXiv:1605.07485
Study of the rare decays of B^0_s and B^0 into muon pairs from data collected during the LHC Run 1	25 fb^{-1}	Eur. Phys. J. C 76 (2016) 513	arXiv:1604.04263
Measurement of the CP-violating phase φ_s and the B^0_s meson decay width difference with B^0_s → J/ψ ϕ decays	14.3 fb^{-1}	JHEP 1608 (2016) 147	arXiv:1601.03297
Measurement of the differential cross-sections of prompt and non-prompt production of J/ψ and ψ(2S) in *pp* collisions at $\sqrt{s}$ = 7 and 8 TeV	(2.1 + 11.4) fb^{-1}	Eur.Phys.J. C76 (2016) 5, 283	arXiv:1512.03657
Measurement of $D^{*\pm}$, $D^\pm$ and $D_s^\pm$ meson production cross sections in *pp* collisions at $\sqrt{s}$ = 7 TeV	280 nb^{-1}	Nucl.Phys. B907 (2016) 717	arXiv:1512.02913
Determination of the ratio of *b*-quark fragmentation fractions f_s / f_d in *pp* collisions at $\sqrt{s}$ = 7 TeV	2.47 fb^{-1}	Phys. Rev. Lett. 115, 262001 (2015)	arXiv:1507.08925
Measurement of the branching ratio $\Gamma(\Lambda^0_b \to \psi(2S)\Lambda^0)$ / $\Gamma(\Lambda^0_b \to J/\psi\,\Lambda^0)$	20.6 fb^{-1}	Physics Letters B 751 (2015) 63-80	arXiv:1507.08202
Study of the $B_c^+ \to J/\psi\, D_s^+$ and $B_c^+ \to J/\psi\, D_s^{*+}$ decays	(4.9 + 20.6) fb^{-1}	Eur. Phys. J. C, 76(1), 1 (2016)	arXiv:1507.07099
Observation and measurement of the production of prompt and non-prompt J/ψ mesons in association with a Z boson in *pp* collisions at $\sqrt{s}$ = 8 TeV	20.3 fb^{-1}	Eur. Phys. J. C75 (2015) 229	arXiv:1412.6428
Search for X_b and other hidden-beauty states using $\pi^+\pi^-\Upsilon(1S)$ channel	16.2 fb^{-1}	Phys. Lett. B740 (2015) 199-217	arXiv:1410.4409
Cross-section measurement of ψ(2S) → J/ψ (→ $\mu^+\mu^-$) $\pi^+\pi^-$ at $\sqrt{s}$ = 7 TeV	2.1 fb^{-1}	JHEP 09 (2014) 079	arXiv:1407.5532
φ_s and $\Delta\Gamma_s$ from flavour tagged time dependent angular analysis of B^0_s → J/ψ ϕ	4.9 fb^{-1}	Phys. Rev. D 90 (2014) 052007	arXiv:1407.1796
Observation of an excited $B^\pm_c$ meson state	(4.9 + 19.2) fb^{-1}	Phys. Rev. Lett. 113 (2014) 212004	arXiv:1407.1032
Measurement of χ_{c1} and χ_{c2} production at $\sqrt{s}$ = 7 TeV	4.5 fb^{-1}	JHEP 07 (2014) 154	arXiv:1404.7035
Parity violating asymmetry parameter α_b and the helicity amplitudes for the decay $\Lambda_b^0 \to J/\psi\,\Lambda^0$	4.6 fb^{-1}	Phys. Rev. D 89 (2014) 092009	arXiv:1404.1071
Associated production of prompt J/ψ mesons and W boson at $\sqrt{s}$ = 7 TeV	4.5 fb^{-1}	JHEP 04 (2014) 172	arXiv:1401.2831
Measurement of the differential cross-section of B^+ meson production in *pp* collisions at $\sqrt{s}$ = 7 TeV	2.4 fb^{-1}	JHEP 10 (2013) 042	arXiv:1307.0126
Measurement of upsilon production in $\sqrt{s}$ = 7 TeV *pp* collisions	1.8 fb^{-1}	Phys. Rev. D 87 (2013) 052004	arXiv:1211.7255
Time-dependent angular analysis of the decay B^0_s → J/ψ ϕ and extraction of $\Delta\Gamma_s$ and the CP violating weak phase φ_s	4.9 fb^{-1}	JHEP 12 (2012) 072	arXiv:1208.0572
Measurement of the Λ_b lifetime and mass	4.9 fb^{-1}	Phys. Rev. D 87 (2013) 032002	arXiv:1207.2284
Measurement of the *b*-hadron production cross-section using decays to $D^{*+}\mu^- X$ final states in *pp* collisions at 7 TeV	3.3 pb^{-1}	Nucl. Phys. B 864 (2012) 341-381	arXiv:1206.3122
Search for the decay $B^0_s \to \mu^+\mu^-$	2.4 fb^{-1}	Phys. Lett. B713 (2012) 180-196	arXiv:1204.0735
Observation of a new χ_b state in radiative transitions to Υ(1S) and Υ(2S)	4.4 fb^{-1}	Phys. Rev. Lett. 108 (2012) 152001	arXiv:1112.5154
Υ(1S) fiducial production cross-section	1.1 pb^{-1}	Phys. Lett. B703 (2011) 428-446	arXiv:1106.5325
Differential cross-sections of inclusive, prompt and non-prompt J/ψ production	2.3 pb^{-1}	Nucl. Phys. B 850 (2011) 387-344	arXiv:1104.3038
Analyses performed within other ATLAS Physics Groups:			
$D^{*+/-}$ production in jets	0.3 pb^{-1}	Phys. Rev. D 85, 052005 (2012)	arXiv:1112.4432
Inclusive production of electrons and muons (b/c cross section)	35 pb^{-1}	Phys. Lett. B 707 (2012) 438-458	arXiv:1109.0525
Centrality dependence of J/ψ production in heavy ions collisions	6.7 μb^{-1}	Phys. Lett. B 697 (2011) 294-312	arXiv:1012.5419

CONF notes

Short Title	Int L	Ref./link to ATLAS public pages	Plots
NEW Angular analysis of $B^0_d \to K^* \mu^+\mu^-$ decays in pp collisions at $\sqrt{s}$ = 8 TeV	20.3 fb^{-1}	ATLAS-CONF-2017-023	Link
$B^\pm$ mass reconstruction in $B^\pm \to J/\psi\, K^\pm$ decay at 13 TeV pp collisions	3.2 fb^{-1}	ATLAS-CONF-2015-064	Link
Differential non-prompt J/ψ production fraction at $\sqrt{s}$ = 13 TeV	6.4 pb^{-1}	ATLAS-CONF-2015-030	Link

PUB notes

Short Title	Int L	Ref./link to ATLAS public pages	Plots	Enhancement of
ATLAS B-physics studies at increased LHC luminosity, potential for CP-violation measurement in the B^0_s → J/ψ ϕ decay	(5-3000) fb^{-1}	ATL-PHYS-PUB-2013-010	Link	-
Comparison of D(*) production cross section at $\sqrt{s}$ = 7TeV with FONLL and GM-VFNS predictions	1.1 nb^{-1}	ATL-PHYS-PUB-2011-012	Link	ATLAS-CONF-2011-017

Stand-alone plots

Short Title	Int L / MC	Plots	More info (may be restricted)
NEW B^0_s proper decay time resolution in the $B^0_s \to J/\psi\,(\mu^+\mu^-)\,\phi(K^+K^-)$ decay for Run 1, Run 2 and HL-LHC	2012, 2015 and 2016 data, HL-LHC simulation	Link	ATL-COM-PHYS-2016-1403; $B^0_s \to \mu^+\mu^-$ mass-resolution in ATL-PHYS-PUB-2016-026
J/ψ candidates in pp collisions at 13 TeV	May 2015 commissioning data	Link	ATL-COM-PHYS-2015-458

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/BPhysPublicResults

Backup

The ATLAS Experiment

General purpose detector

Calorimeter System

EM and Hadronic energy

- LAr EM barrel and EC
- LAr Had. Barrel
- Tile Calorimeter (Fe-Scin.) hadronic barrel

Muon Specrometer

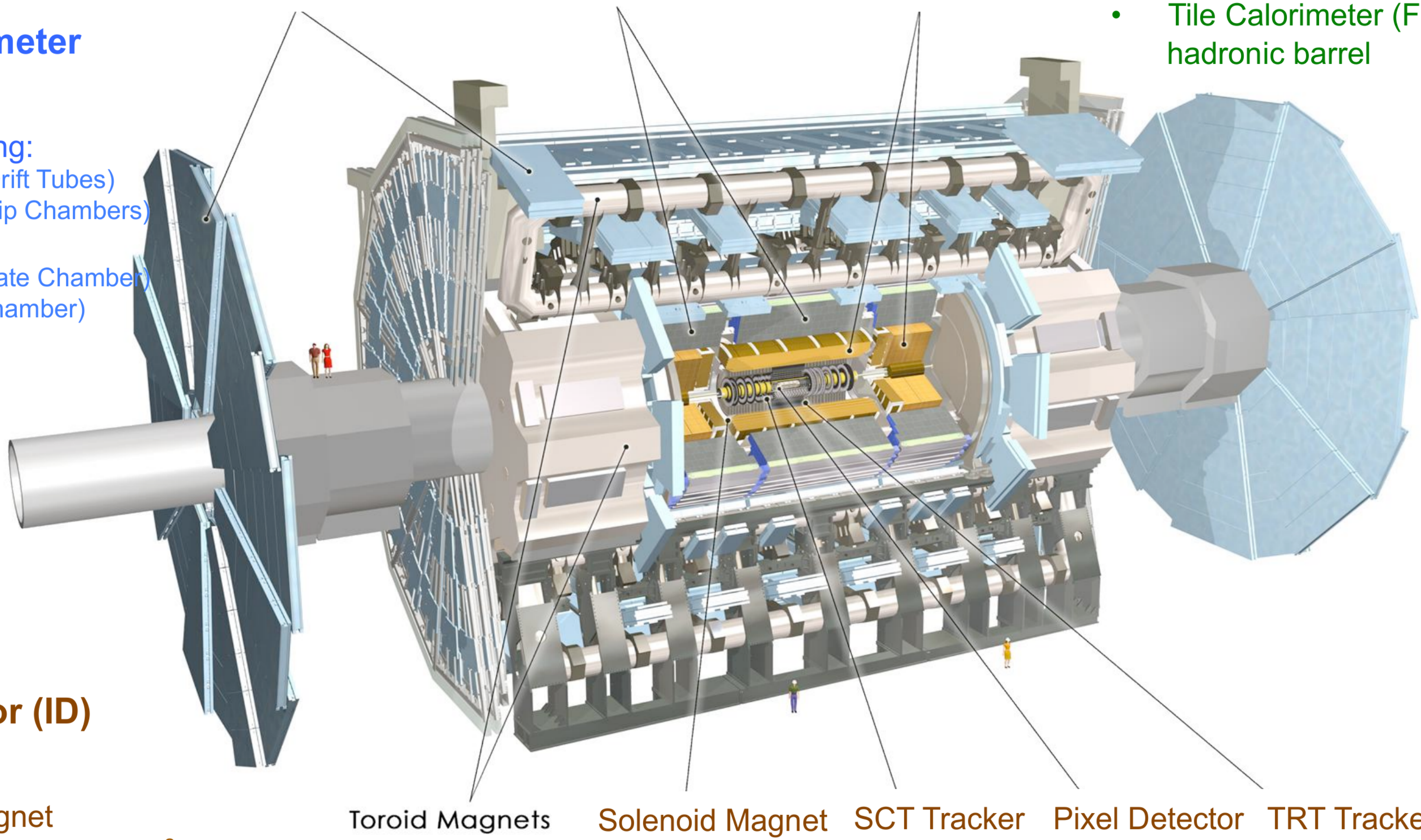
Toroid Magnets

Precision μ tracking:

- MDT (Monitored Drift Tubes)
- CSC (Cathode Strip Chambers)

Trigger:

- RPC (Resistive Plate Chamber)
- TGC (Thin Gas Chamber)



Inner Detector (ID)

Tracking

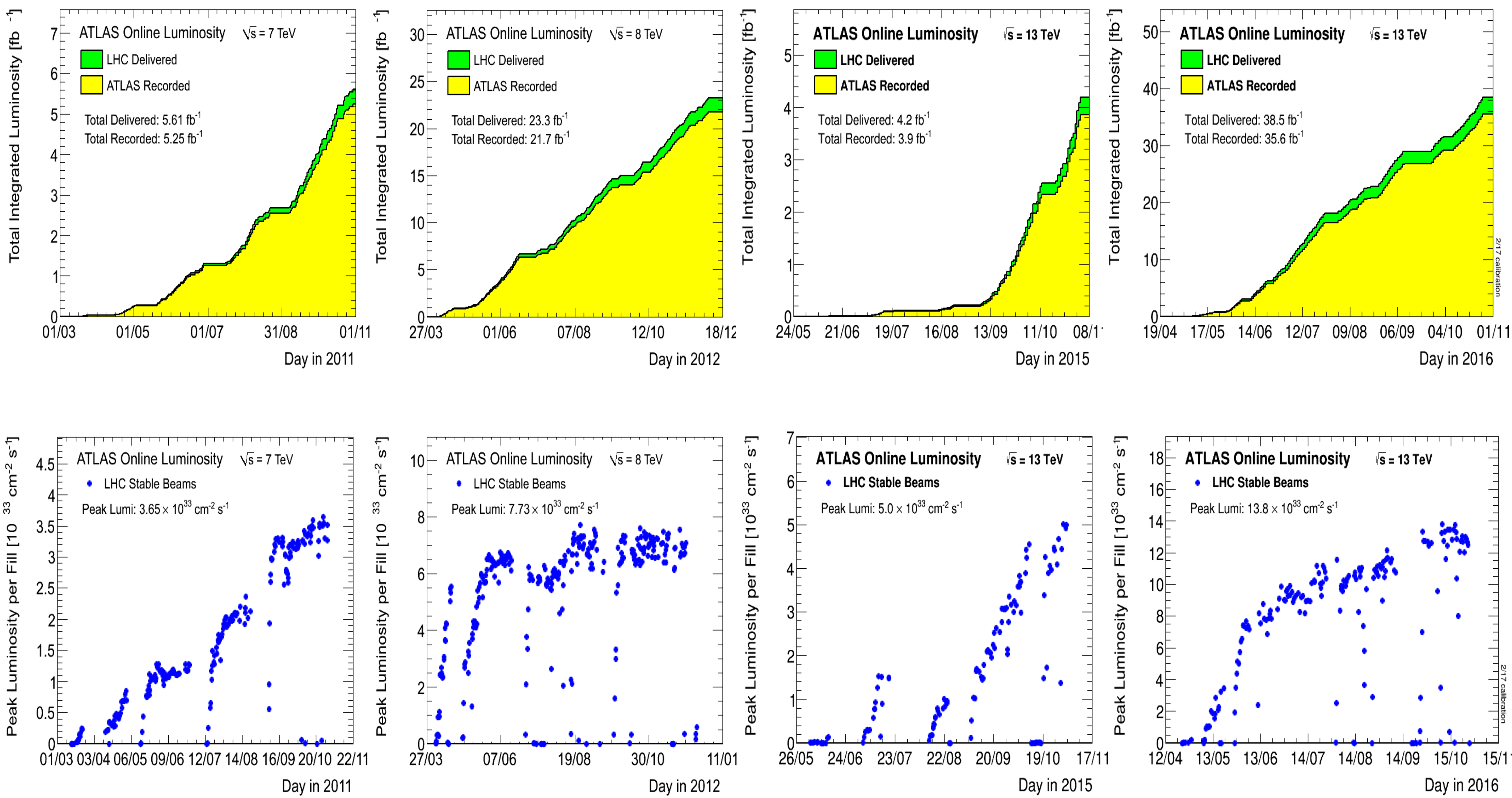
2T Solenoid Magnet

- Silicon Pixels, 50x400 μm^2
- Silicon Strips (SCT), 80 μm stereo
- Transition Ratiation Tracker (TRT) 36 points/track

- Resolution in $m_{\mu+\mu-}$: around 50 MeV for J/ψ and 150 MeV for ϒ(nS)
- Resolution in b-hadron proper decay time around 100 fs (no IBL, ~30% improvement expected)

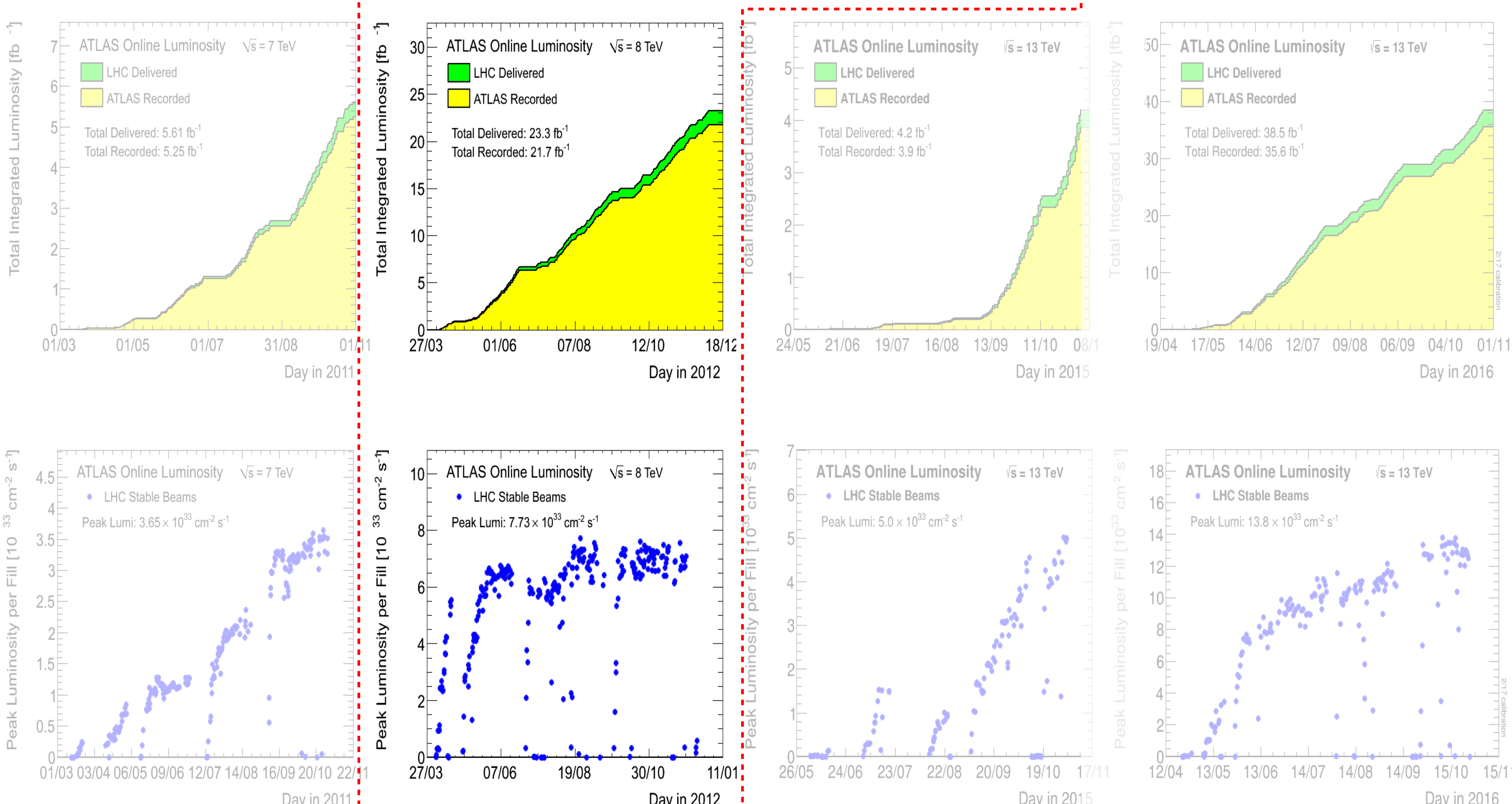
Data Taking

- **Datasets (pp):**
  - 7 TeV data, 5.08 fb^{-1} — 50ns, $3.7\times10^{33}\ cm^{-2}s^{-1}$
  - 8 TeV, 21.3 fb^{-1} — 50ns, $7.7\times10^{33}\ cm^{-2}s^{-1}$
  - 13 TeV, 3.9+35.6 fb^{-1} — 50/25ns, $13.8\times10^{33}\ cm^{-2}s^{-1}$



Data Taking

- **Datasets (pp):** 7 TeV data, 5.08 fb^{-1}, 50ns, 3.7×10^{33} $cm^{-2}s^{-1}$ | 8 TeV, 21.3 fb^{-1}, 50ns, 7.7×10^{33} $cm^{-2}s^{-1}$ | 13 TeV, 3.9+35.6 fb^{-1}, 50/25ns, 13.8×10^{33} $cm^{-2}s^{-1}$

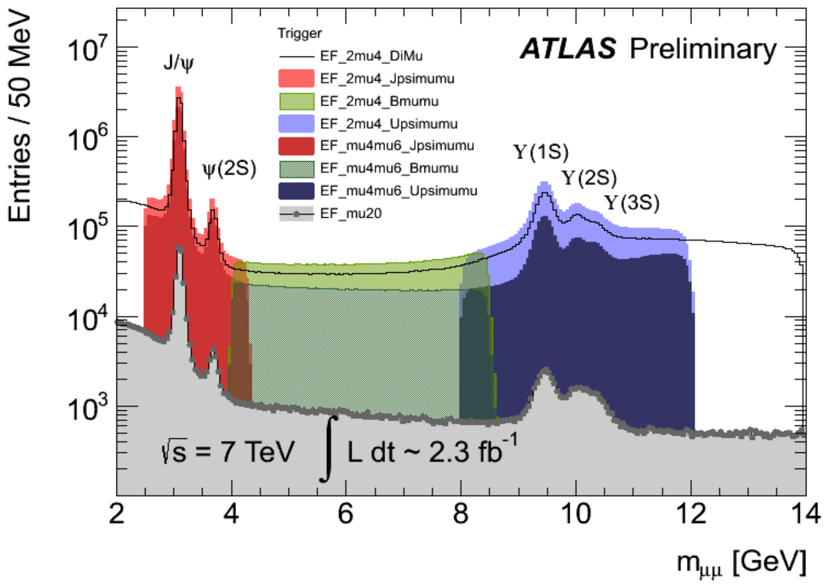


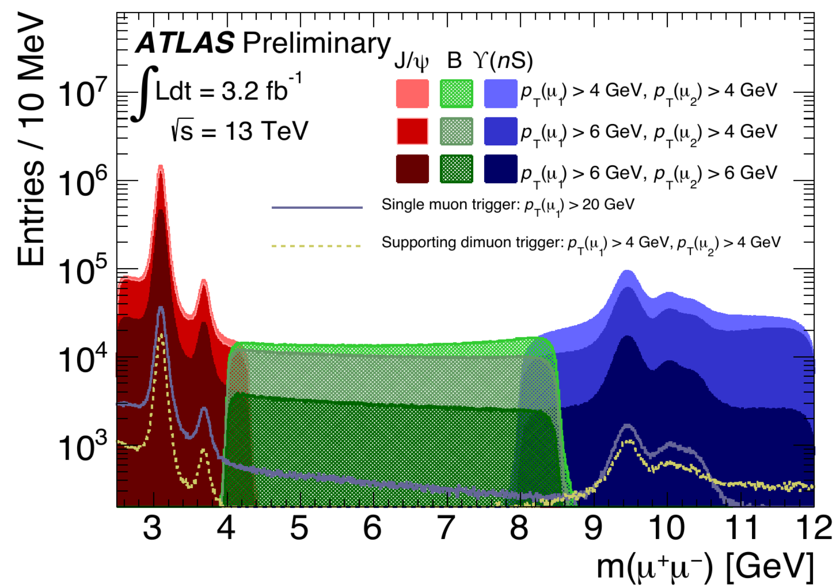
B-Physics Trigger

- **Datasets (pp):**

7 TeV data, 5.08 fb^{-1}	8 TeV, 21.3 fb^{-1}	13 TeV, 3.9+35.6 fb^{-1}
50ns, $3.7 \times 10^{33}\,cm^{-2}s^{-1}$	50ns, $7.7 \times 10^{33}\,cm^{-2}s^{-1}$	50/25ns, $13.8 \times 10^{33}\,cm^{-2}s^{-1}$

- 20/40 MHz collision rate → ~400 Hz recording
- B-physics concentrates on low-p_T di-muon signatures:
  - Quarkonia: $J/\psi \to \mu\mu$, $\Upsilon \to \mu\mu$, etc.
  - Exclusive $B \to J/\psi(\mu\mu)X$ decays
  - Rare and semi-rare $B \to \mu\mu(X)$ decays
- Trigger on low-p_T (4,6 GeV) di-muon
  - 2 muons at L1 (HW-based)
  - Confirmed at HLT
  - Track vertex fit and mass cuts at HLT
- 8 TeV data: low-p_T maintained introducing barrel triggers
- 13 TeV data: low-p_T maintained using barrel triggers, introduce coarse topological cuts (HW, opening angle, inv. mass) in 2016

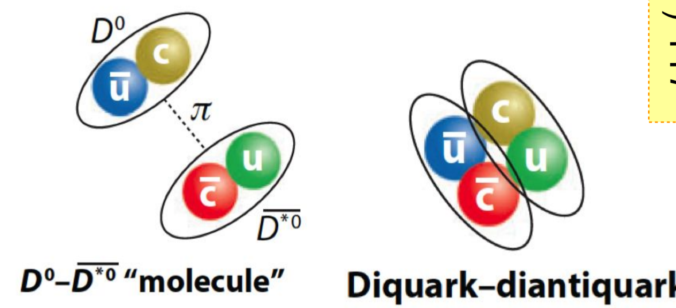




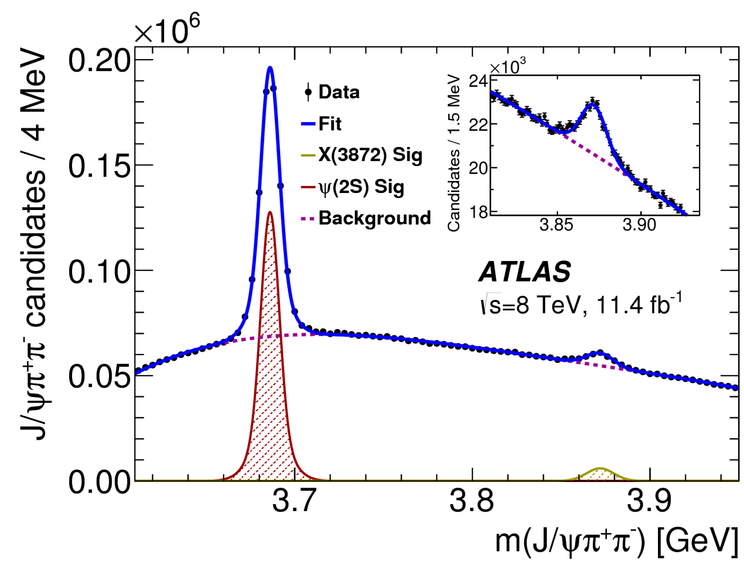
Production of ψ(2S) and X(3872) in J/ψππ

JHEP 01 (2017) 117

- X(3872) state: Discovered by Belle, confirmed by CDF, BaBar and D0
  - JPC = 1^{++} by LHCb (and CDF)
  - CMS x-section vs. p_T favors mixed $\chi_{c1}(2P)$-$D^0\overline{D}^{*0}$ state; $\chi_{c1}(2P)$ predominates
  - ψ(2S) measurement for straightforward comparisons



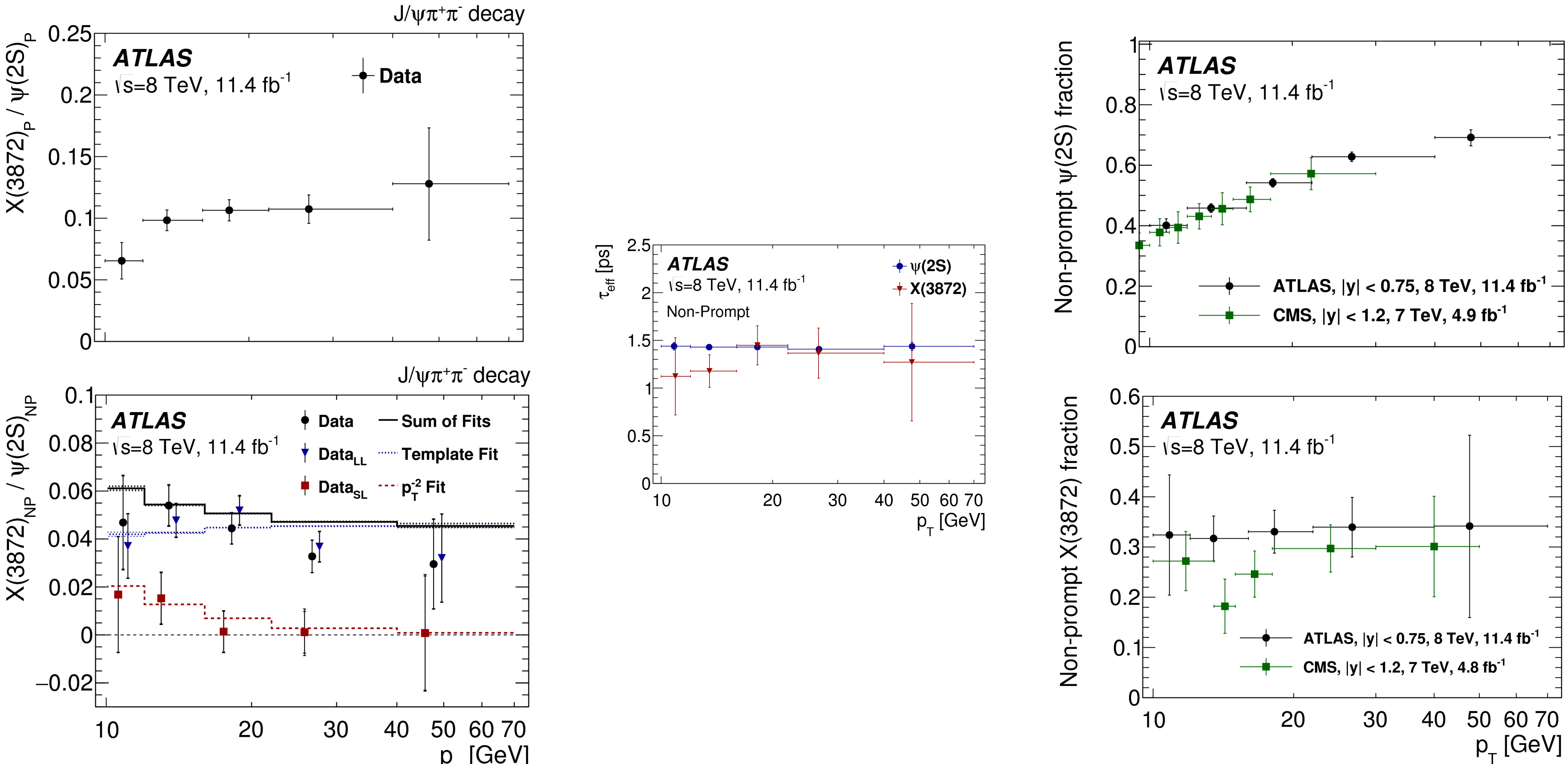
- Selection: 11.4 fb^{-1} of 8 TeV pp data
  - 4-track vertex of $J/\psi\to\mu^+\mu^-$ and $\pi^+\pi^-$ with $p_T(\mu) > 4$ GeV and $p_T(\pi) > 0.6$ GeV
  - $|y(J/\psi\pi\pi)| < 0.75$ (optimal resolution), $\Delta R(J/\psi,\pi) < 0.5$ (background suppression)
  - ~470k of ψ(2S) and ~30k of X(3872)
- Measurement in bins of p_T and pseudo-lifetime
  - Prompt / non-prompt production
    J/ψππ candidate mass fits and pseudo-lifetime fits
  - Lifetime structure of X(3872) – production from B_c ?
  - Di-pion mass spectrum
- Systematics:
  - Detector efficiencies and acceptance, accounting for possible spin-alignment scenarios of the parent state
  - Background suppression by ΔR cut
  - Fit model variations



(Non-)Prompt Production X(3872) vs. ψ(2S)

JHEP 01 (2017) 117

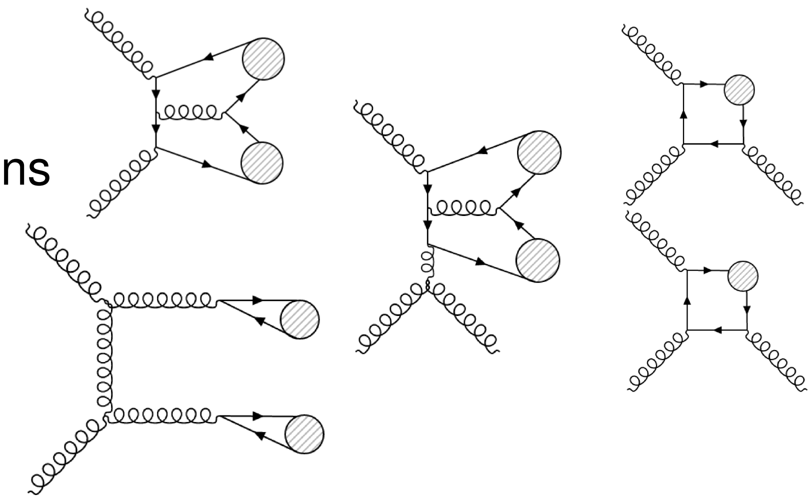
- Relative X(3872)/ψ(2S) non-prompt production (0.0357±0.0033±0.0011) significantly smaller than Tevatron measurement (0.18±0.08 from Phys.Rev.D81 (2010) 114018)
- Non-prompt fraction in ψ(2S) and X(3872) production agrees with CMS
- Suggests strongly enhanced X(3872) production through B_c (account for small f_{Bc})



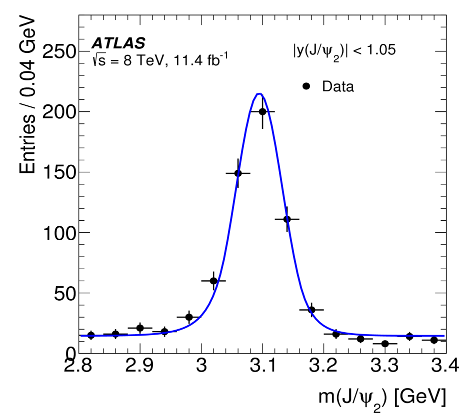
Prompt J/ψ Pair Production

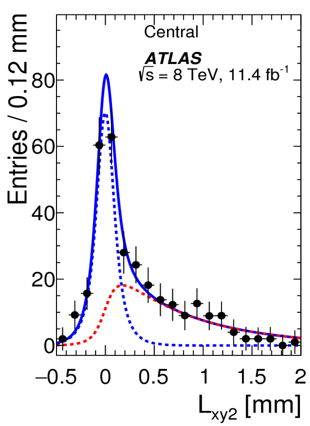
EPJC 77 (2017) 76

- Motivation:
  - Understanding of non-perturbative QCD, also sensitive to NLO and higher pQCD corrections
  - Study J/ψ production models
  - Measure double parton scattering (DPS)
    - Important background for NP searches
    - σ_{eff} from gluon-dominated interactions



- Selection: 11.4 fb^{-1} of 8 TeV pp data
  - Triggered J/ψ $p_T(\mu) > 4$ GeV, the other J/ψ $p_T(\mu) > 2.5$ GeV
  - $|y(J/\psi)| < 2.1$, $p_T(J/\psi) > 8.5$ GeV
  - J/ψ_1 J/ψ_2 ordered by $p_T(J/\psi)$: J/ψ_2 is softer
  - Distance of the two vertices along beam axis $d_z < 1.2$ mm
  - 1210 events
- Measurement of the differential x-sections
  - Selection / efficiencies / acceptance → 2D mass fits → Lxy fits (prompt/non-prompt) → pile-up removal
  - Barrel ($|y|<1.05$) / endcap ($1.05 < |y| < 2.1$)
  - Inclusive J/ψ sample to study pile-up and J/ψ reconstruction performance



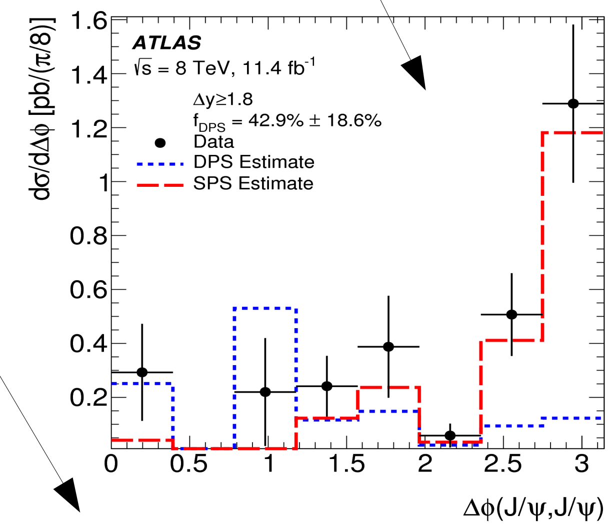


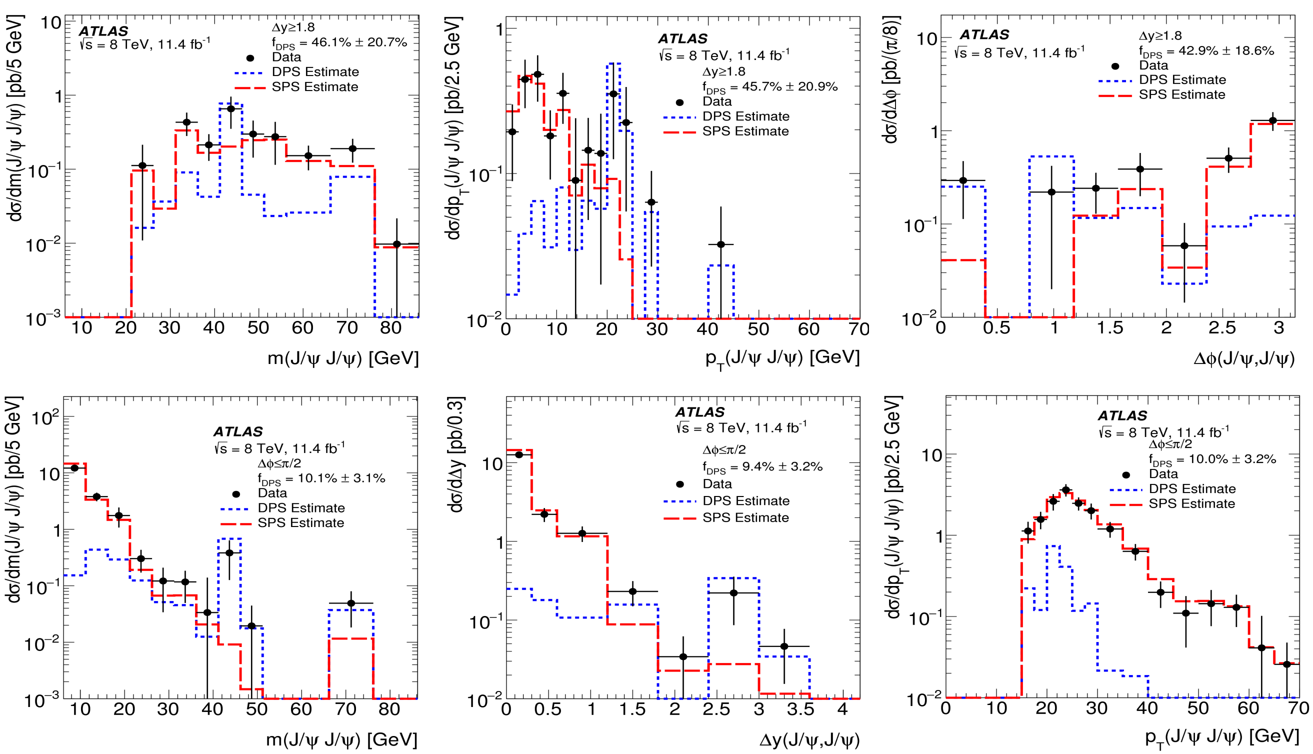
- Systematics: dominated by trigger efficiency (x-sections) and DPS template (DPS fraction)

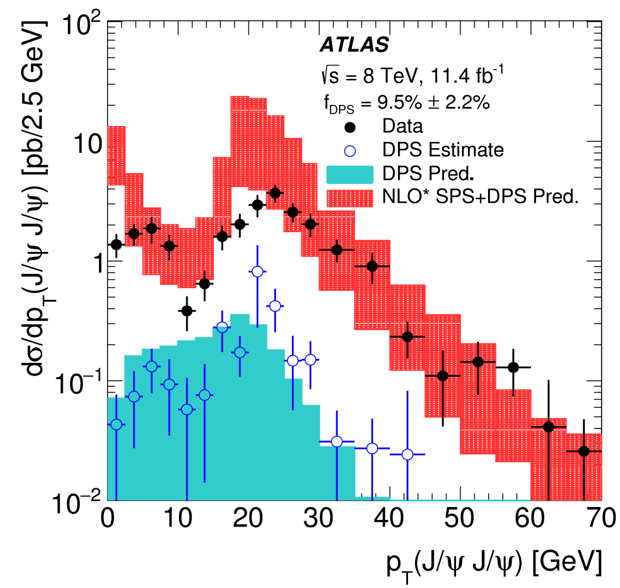
di-J/ψ: Theory-Experiment Discrepancies

EPJC 77 (2017) 76

- Plots for $\Delta y > 1.8$ indicating SPS contribution at $\Delta\phi \sim 3.14$ => non-constant contribution to di-J/ψ final state from feed-down of back-to-back SPS pair production from excited charmonia → can change kinematic properties of the SPS distribution
- Wide peak at low di-J/ψ p_T can be explained by an effect of inclusion of intrinsic parton transverse momentum, (as well as by smearing due to the non-constant feed-down)



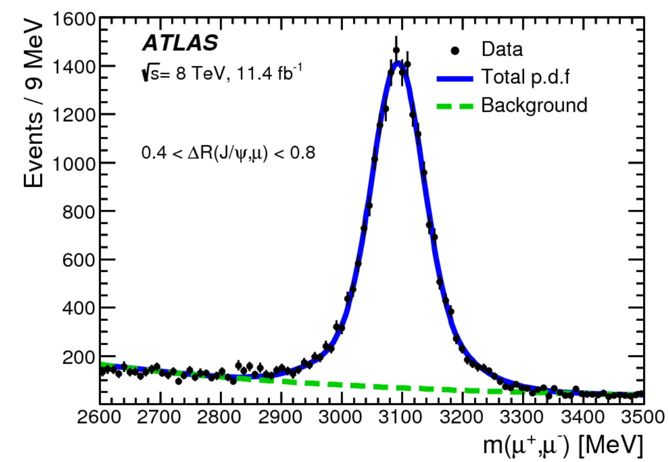


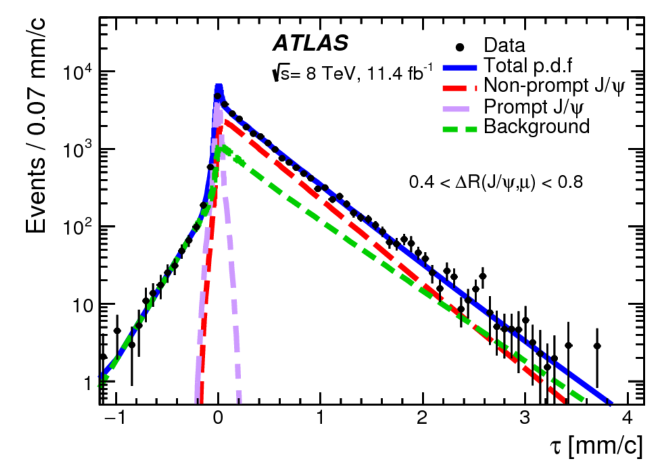


Production of b-Hadron Pairs

arXiv:1705.03374

- Motivation:
  - b-production vs. theory, especially small-angle $b\bar{b}$ pairs production via gluon splitting
  - Important background for e.g. associated Higgs + vector boson searches
- Selection: 11.4 fb^{-1} of 8 TeV pp data
  - 3-muon signature: $b \to J/\psi(\mu\mu)X + b \to \mu X$
  - 2-track $J/\psi \to \mu^+\mu^-$ vertex (and also such a trigger), $|\eta(\mu)| < 2.3$
  - $p_T(\mu) > 6$ GeV, $|\eta(\mu)| < 2.5$
  - > single J/ψ → take the one closest to J/ψ PDG mass
  - > single 3rd muon → take the highest-p_T one
- Measurement: in each kinematic bin:
  - J/ψ non-prompt yield from mass & pseudo-lifetime fit
  - 3rd muon event yield from signal-enhanced ($\tau > 0.25$ mm) sample, and 2D fit of muon transverse $d_0/\sigma(d_0)$ & BDT constructed from muon-production sensitive kinematic parameters
  - Irreducible background subtraction
  - Corrections on the τ cut and detector resolution effects
- Systematics: dominated by muon trigger & reconstruction efficiency

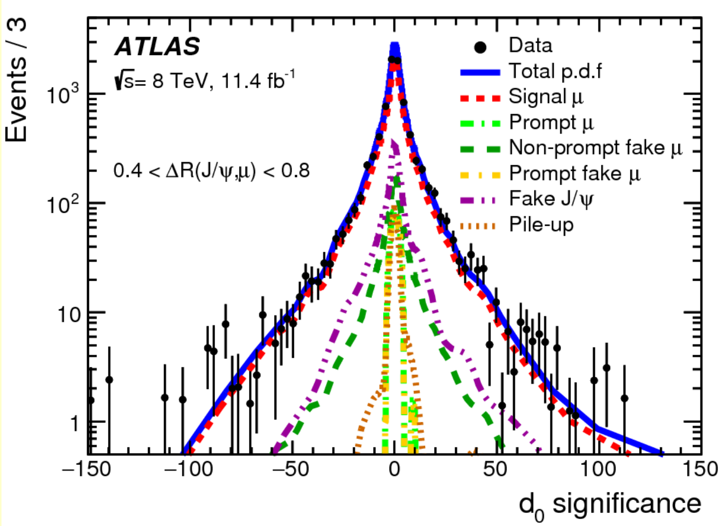


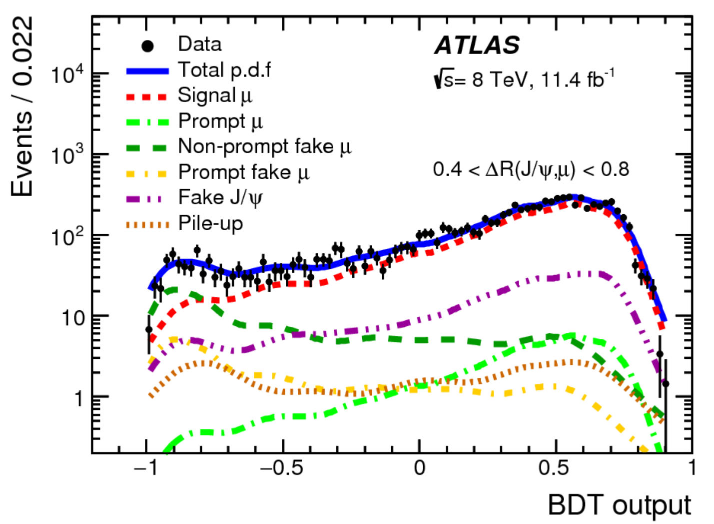


3rd Muon Selection & Backgrounds

arXiv:1705.03374

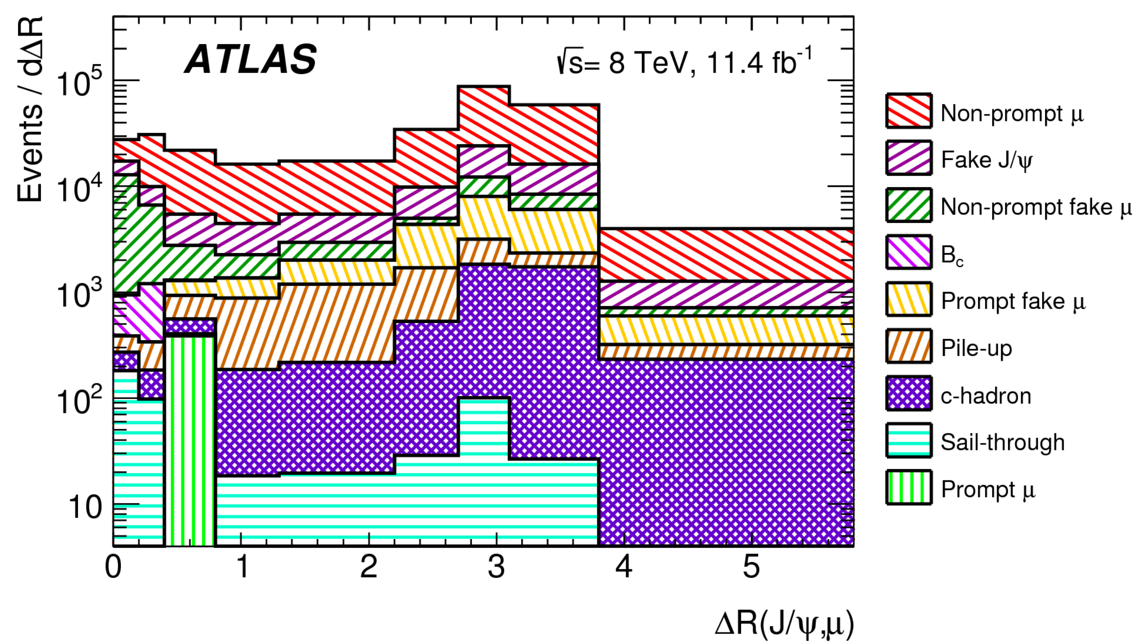
- BDT constructed from:
  - Muon pseudorapidity
  - Tracker / Muon Spectrometer momentum imbalance
  - Track curvature before / after tracker plane
  - Track segments angles





- Irreducible backgrounds
  - Too small to be extracted
  - Or too similar to signal

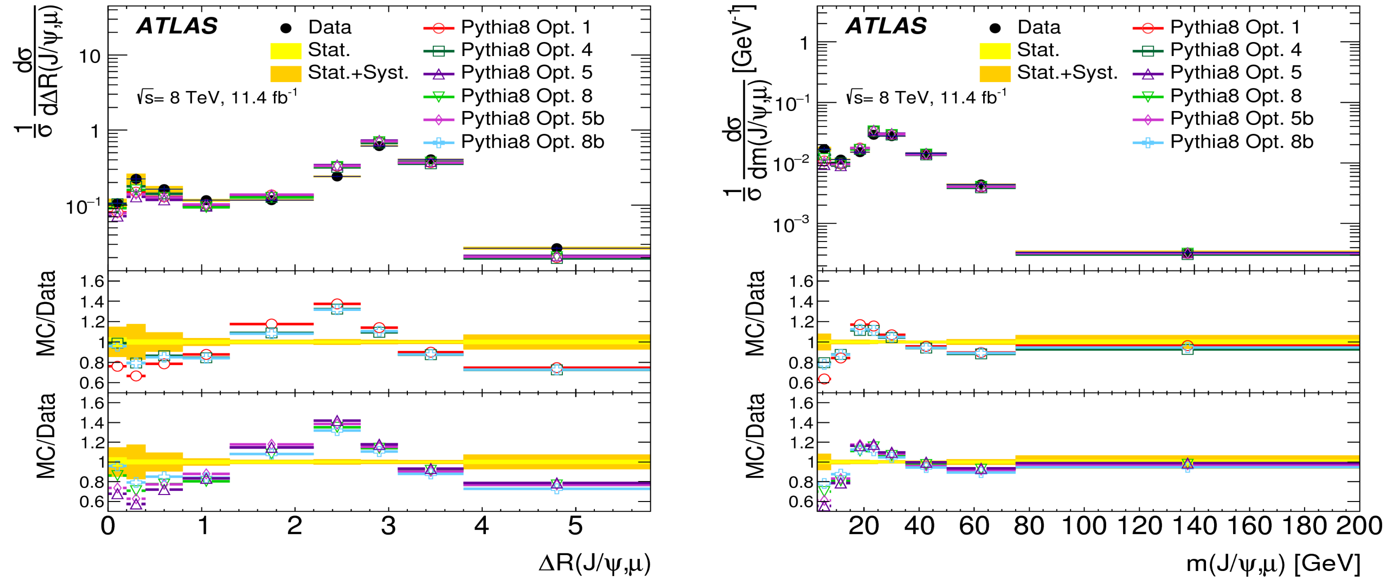
- $B_c \to J/\psi + \mu + X$
- Semileptonic decay of c-hadrons
  - $gg \to b\bar{b}$ and $gg \to c\bar{c}$ in same hard scatter
  - DPS: $b\bar{b} + c\bar{c} + X$
- K/π traversing to muon detectors without interactions



Data vs. Pythia8 $g \to b\bar{b}$ Splitting Options

arXiv:1705.03374

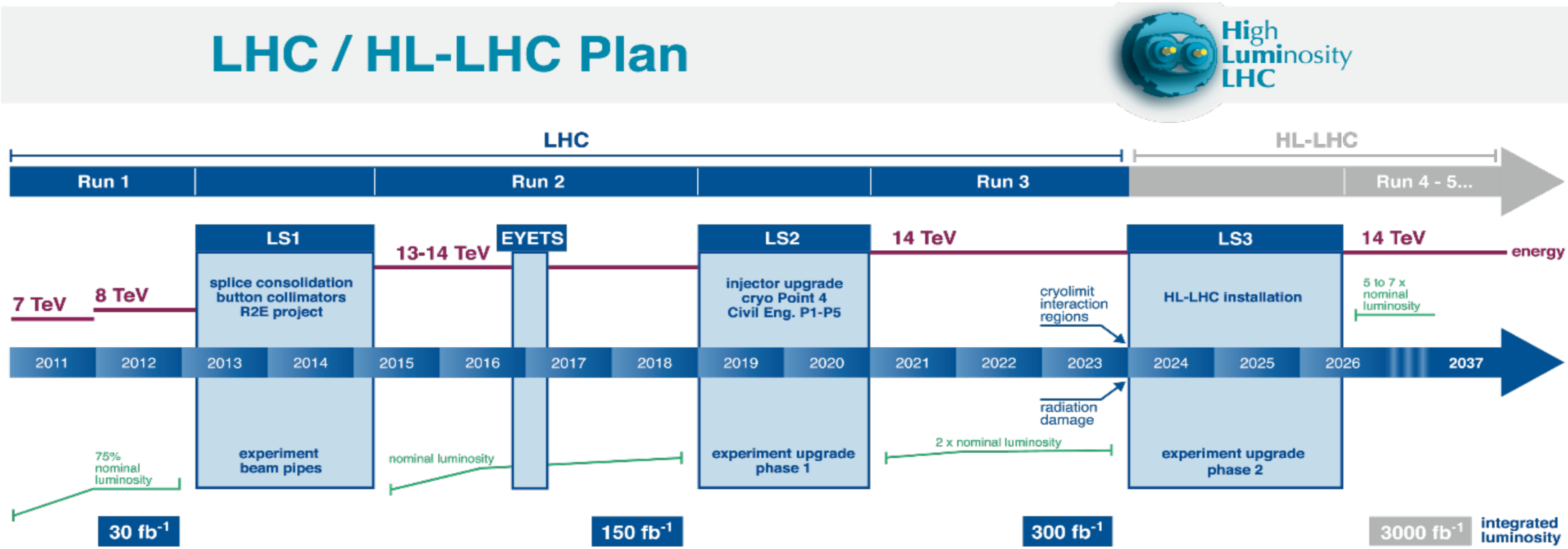
- Pythia8 p_T-based splitting kernel best agreement (and comparably to Herwig++) at low ΔR



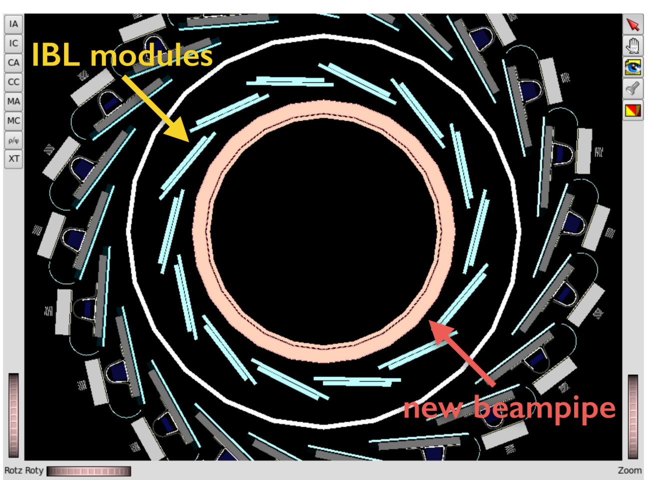
Option label	Descriptions
Opt. 1	The same splitting kernel, $(1/2)(z^2 + (1-z)^2)$, for massive as massless quarks, only with an extra β phase-space factor. This was the default setting in Pythia8.1, and currently must also be used with the MC@NLO [50] method.
Opt. 4	A splitting kernel $z^2 + (1-z)^2 + 8r_q z(1-z)$, normalised so that the z-integrated rate is $(\beta/3)(1+r/2)$, and with an additional suppression factor $(1 - m_{qq}{}^2/m^2_{\text{dipole}})^3$, which reduces the rate of high-mass $q\bar{q}$ pairs. This is the default setting in Pythia8.2.
Opt. 5	Same as Option 1, but reweighted to an $\alpha_s(km^2_{qq})$ rather than the normal $\alpha_s(p^2_T)$, with $k = 1$.
Opt. 5b	Same as Option 5, but setting $k = 0.25$.
Opt. 8	Same as Option 4, but reweighted to an $\alpha_s(km^2_{qq})$ rather than the normal $\alpha_s(p^2_T)$, with $k = 1$.
Opt. 8b	Same as Option 8, but setting $k = 0.25$.

Table 1: Description of Pythia8 options. Options 2, 3, 6 and 7 are less well physically motivated and not considered here. The notation used is as follows: $r_q = m_q^2/m_{qq}^2$, $\beta = \sqrt{1-4r_q}$, with m_q the quark mass and m_{qq} the $q\bar{q}$ pair invariant mass.

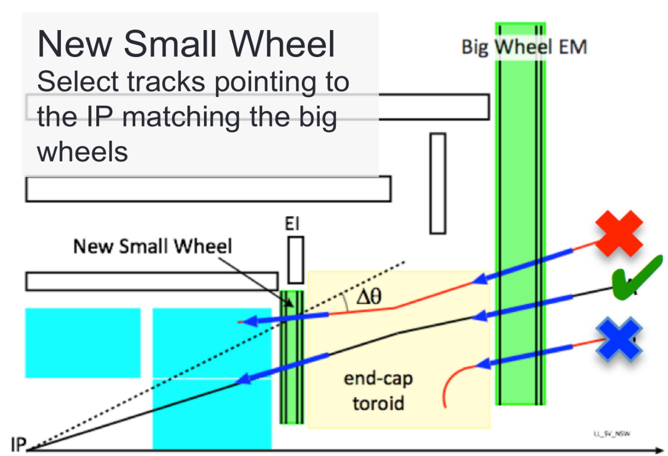
Measurements in Run-2 and Beyond



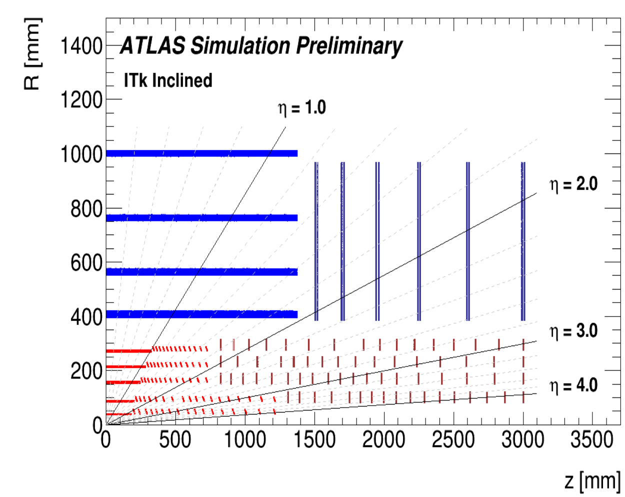
- New pixel layer (IBL, 32-38 mm) + small radius Be beam pipe
- Topological L1 trigger



- New small muon wheel
- Fast tracking trigger (FTK) at LVL 1.5; available in Run-2



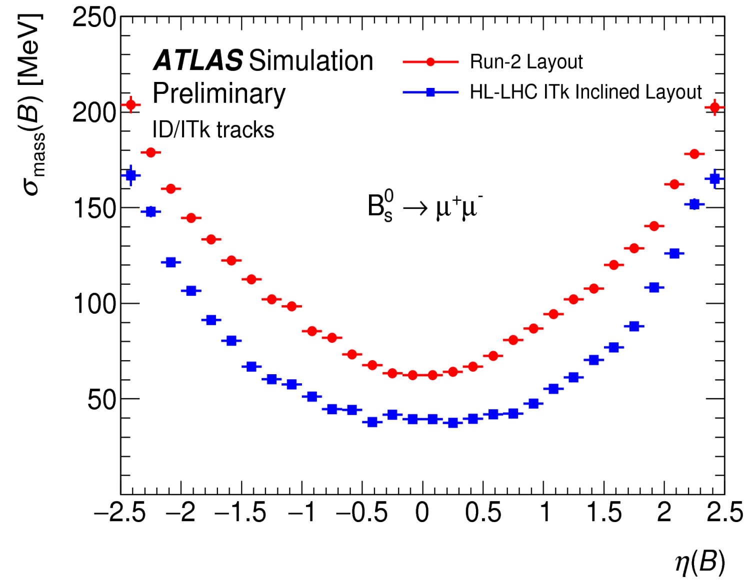
- Completely new Si based tracker (ITK)

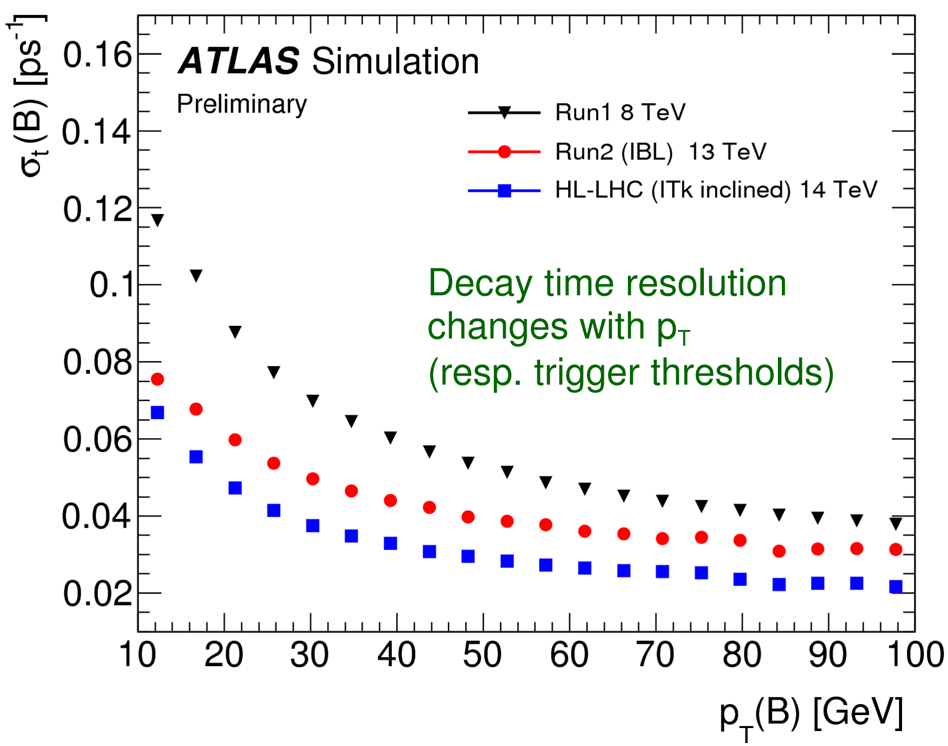


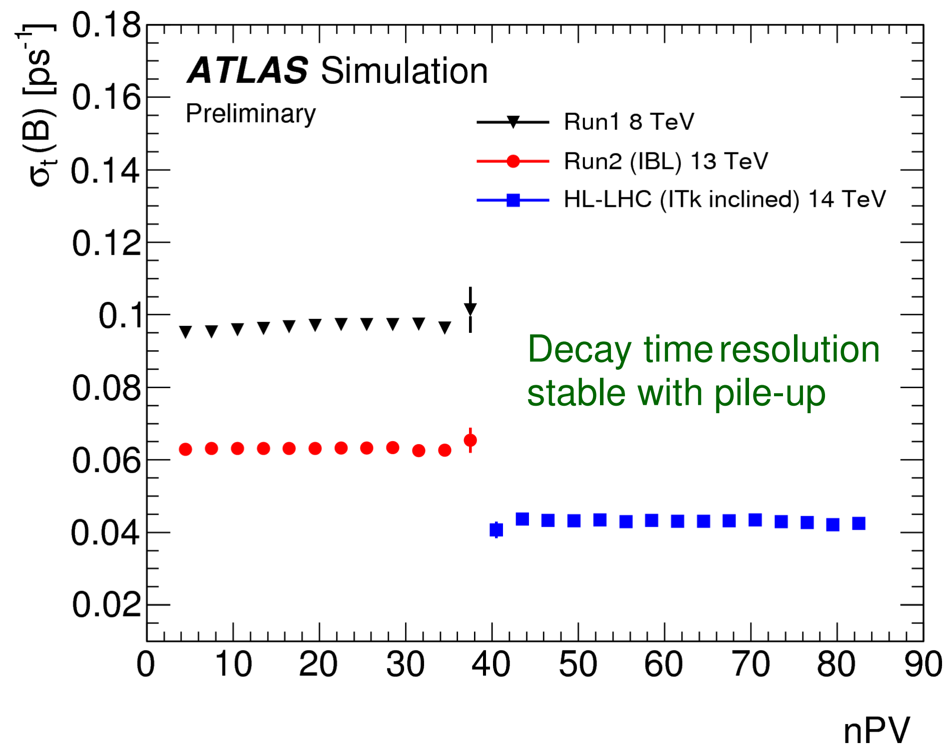
Detector Performance in Run-2 and Beyond

ATL-PHYS-PUB-2016-025

- **Resolution:** invariant mass in decay $B_s \to \mu^+\mu^-$, proper decay time in $B_s \to J/\psi(\mu^+\mu^-)\phi(K^+K^-)$ decay
- Comparison of Run-1, Run-2 (IBL) and HL-LHC (ITk) performances
- **Trigger:** use L1-topo (keep low thresholds at L1) and complicated HLT with full $B_s \to J/\psi(\mu^+\mu^-)\phi(K^+K^-)$ decay topology reconstruction at trigger level



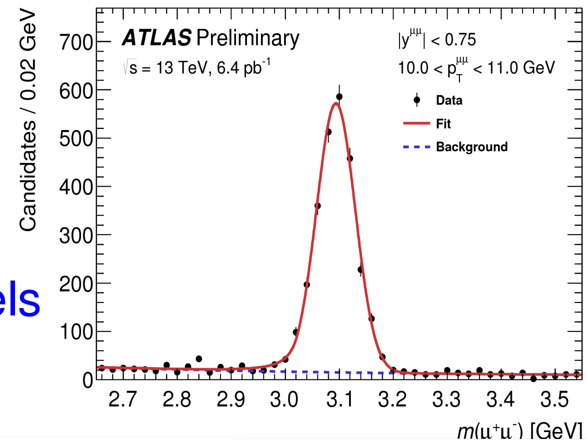


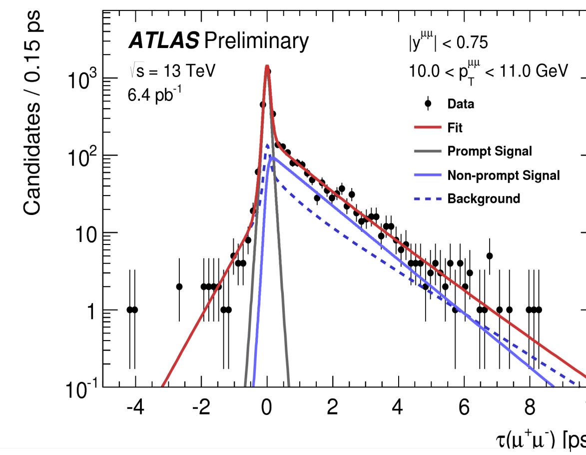


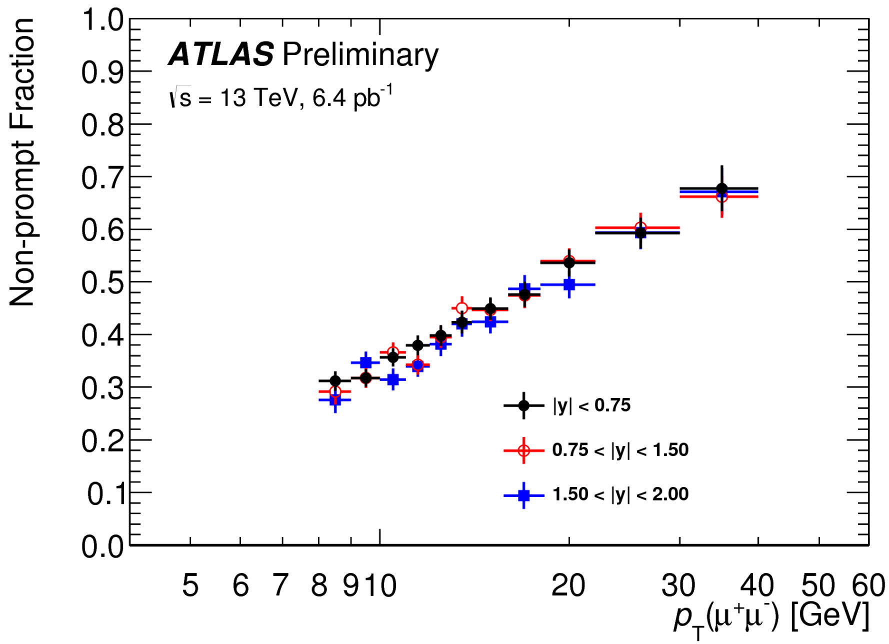
Fraction of Non-Prompt J/ψ at 13 TeV

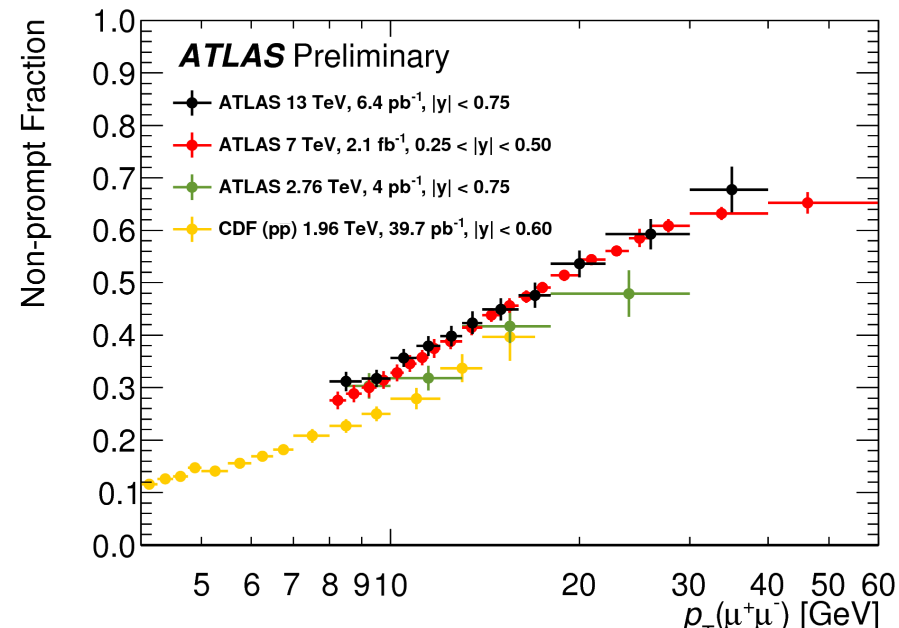
ATLAS-CONF-2015-030

- First ATLAS quarkonium production measurement at 13 TeV (similar techniques to the Run-1 study)
- Early data sample 6.4 pb^{-1} collected with di-muon triggers
- Yields extracted from an un-weighted and unbinned fit to 2D di-muon mass and proper decay time
- Efficiencies and acceptance cancels to a good approximation in the non-prompt fraction







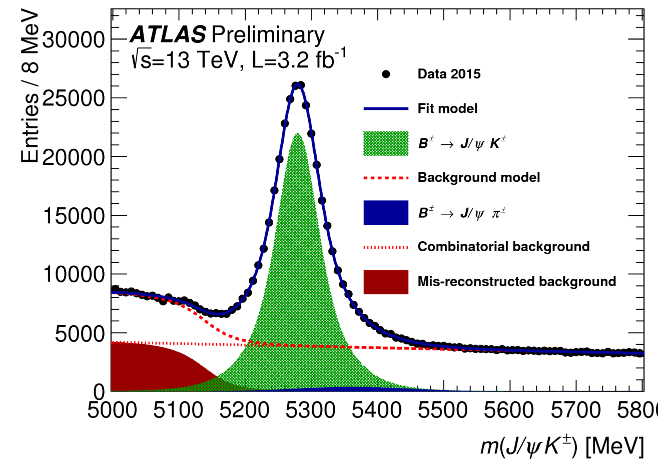


- Interesting trends in dependence on √s, though little change between 7 and 13 TeV

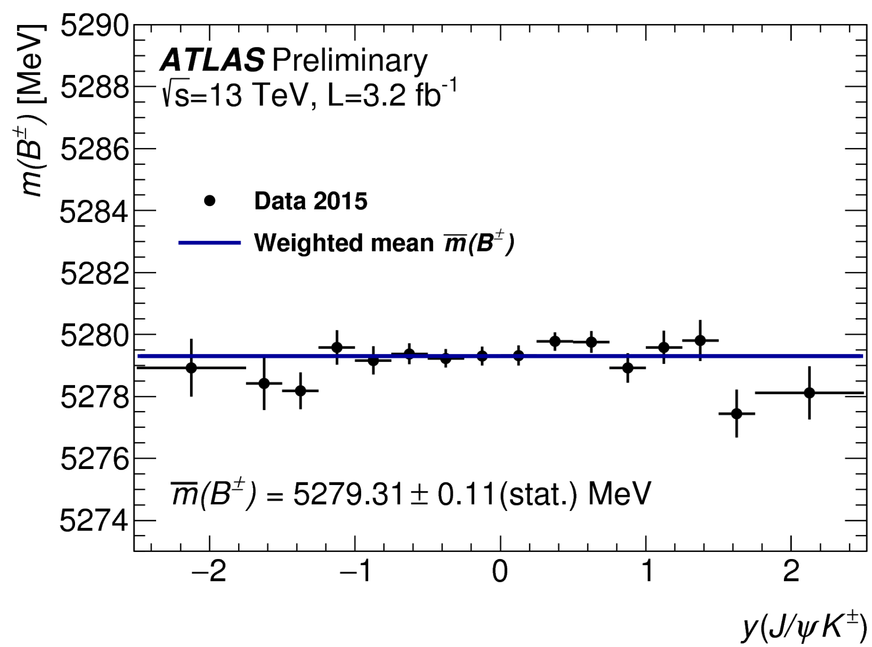
Run2 B-Meson Reconstruction

ATLAS-CONF-2015-064

- $B^{\pm}$ meson mass reconstruction using full 2015 pp dataset at 13 TeV
- Preparation for further detailed b-hadron measurements
  - Reconstruction in $B^{\pm} \to J/\psi K^{\pm}$ decay mode
  - Simple selection ($p_T(\mu) > 4$ GeV, $p_T(K) > 3$ GeV)
  - 3-tracks vertex fit ($\chi^2/NDF < 3$)
  - Independent fits in 16 rapidity regions
  - Model systematics (p_T scale and vertexing not included)



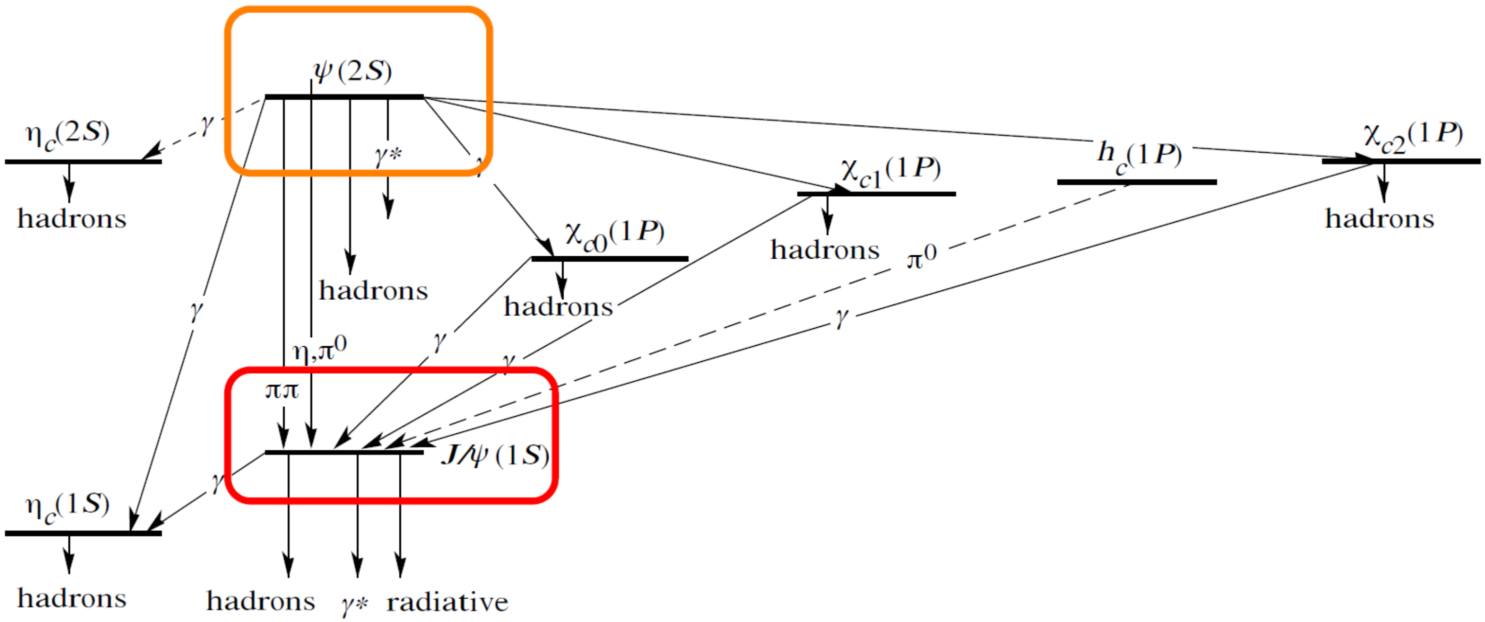
Fit	$B^{\pm}$ mass [MeV]	Fit error [MeV]
Default Fit	5279.31	0.11 (stat.)
$L_{xy} > 0.2$ mm	5279.34	0.09 (stat.)
World Average fit	5279.29	0.15
LHCb	5279.38	0.11 (stat.) ± 0.33 (syst.)



J/ψ and ψ(2S) Production at 7&8 TeV

EPJC 76 (2016) 5, 283

- Quarkonia production at LHC offers unique windows on understanding strong interactions



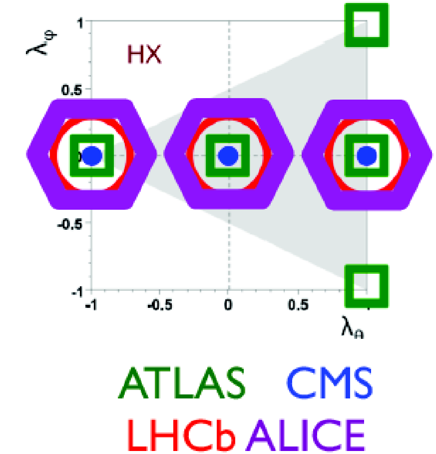
- Two distinct charmonium production mechanisms at LHC:
  - **Prompt:** produced directly in the pp interaction or through feed-down decays of heavier states
    - Theory: Non-relativistic QCD (arXiv:1009.3655) – pQCD $c\bar{c}$ production, soft evolution into quarkonia (data derived)
  - **Non-prompt:** produced in decays of b-hadrons, can be separated experimentally due to the "long" b-hadron lifetime
    - Theory: Fixed Order Next-to-Leading Logarithm (arXiv:1205.6344) – perturbative $b\bar{b}$ prod., data drive fragmentation and b-hadron decay model
- Around 35% of prompt J/ψ come from feed-down, ψ(2S) are almost all direct

J/ψ and ψ(2S) Production at 7&8 TeV

EPJC 76 (2016) 5, 283

- Data (2.1 fb^{-1} @ 7 TeV and 11.4 fb^{-1} @ 8 TeV) collected using di-muon triggers
- Basic di-muon selection ($p_T(\mu_{1,2}) > 4$ GeV, $|\eta(\mu_{1,2})| < 2.3$), di-muon tracks vertex fit
- Weights to correct for trigger efficiency, muon indentification and reconstruction and geometrical acceptance
  - probe various spin-alignment scenarious (not yet measured at ATLAS)

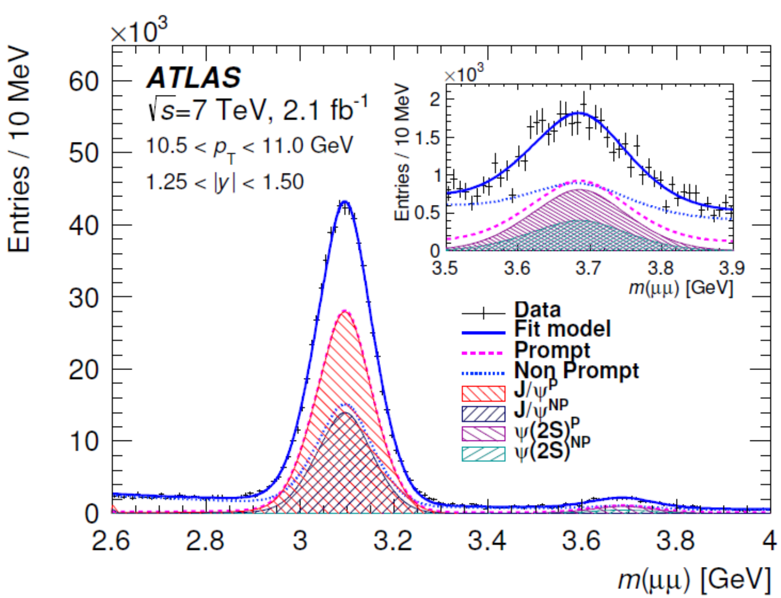
$$\frac{d^2N}{d\cos\theta^\star d\phi^\star} \propto 1 + \lambda_\theta \cos^2\theta^\star + \lambda_\phi \sin^2\theta^\star \cos 2\phi^\star + \lambda_{\theta\phi} \sin 2\theta^\star \cos\phi^\star$$

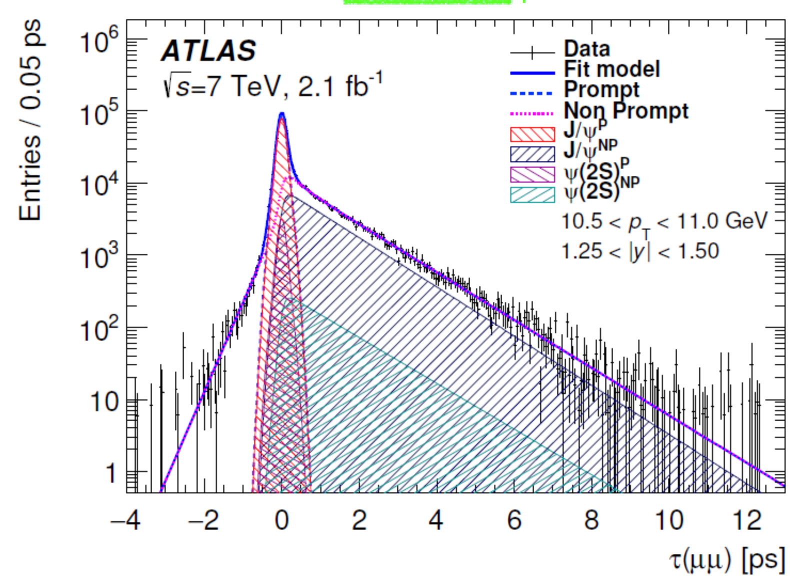


- Corrected prompt and non-prompt J/ψ and ψ(2S) yields determined from an unbinned fit to the 2D di-muon mass and pseudo-lifetime distribution
  - in 22 p_T x 8 rapidity bins

$$\tau = \frac{L_{xy}\, m(J/\psi)}{p_T(J/\psi)}$$

xy displacement of candidate from PV; Invariant mass of candidate; p_T of candidate





J/ψ and ψ(2S) Production at 7&8 TeV

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- Prompt J/ψ compared to NRQCD – good agreement across range of p_T, no y-dependence
- Prompt ψ(2S) (no significant feed-down) compared to NRQCD – mostly well describing data, some deterioration at high-p_T
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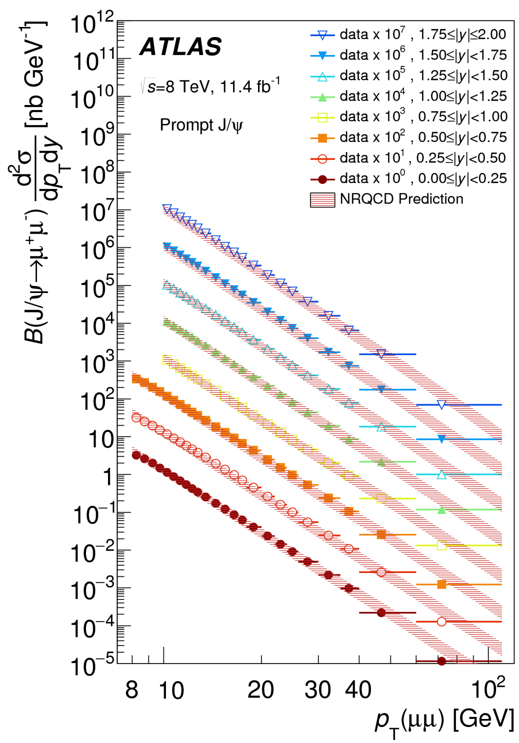
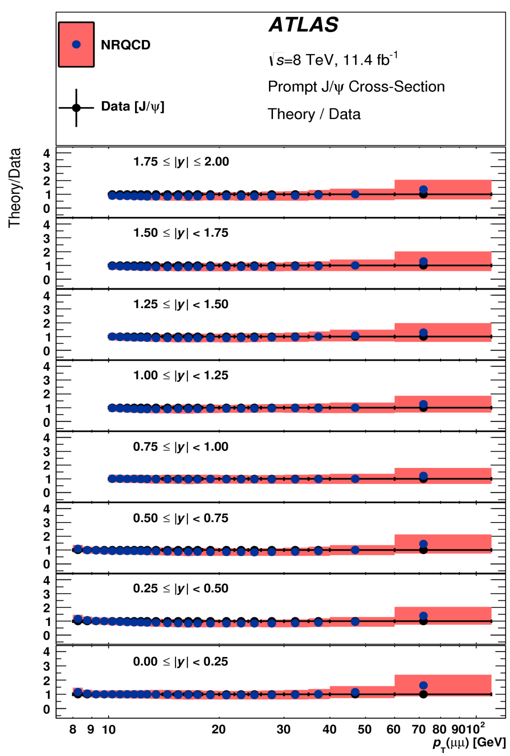
- Ratio of prompt ψ(2S) / J/ψ flat across the whole p_T range
- Prompt J/ψ fraction dominates at low-p_T, but non-prompt exceeds prompt at around 20 GeV





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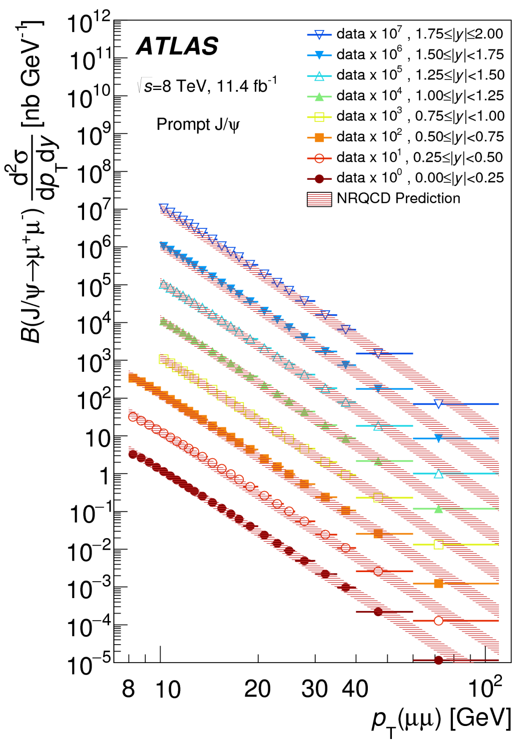

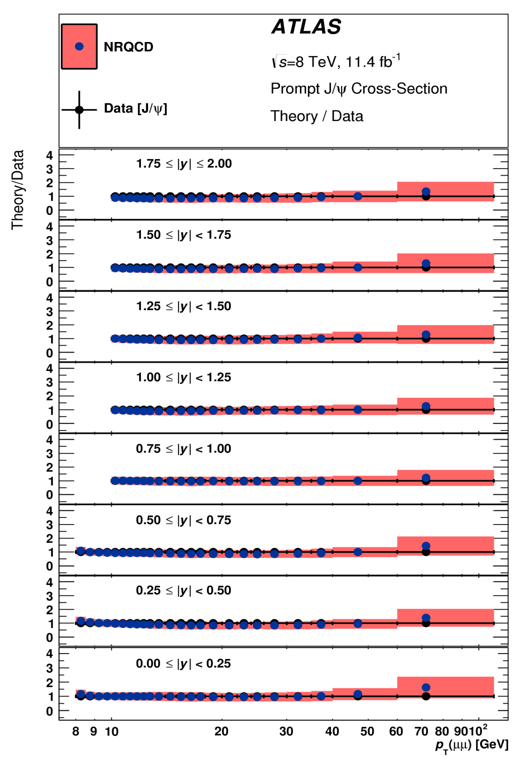

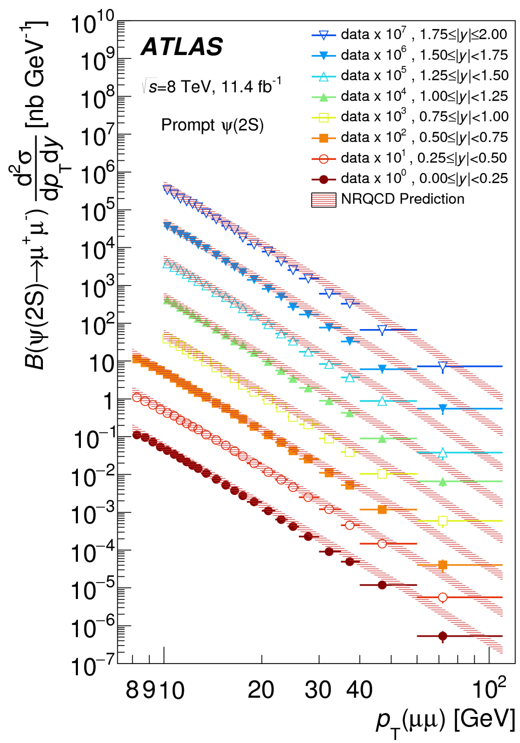

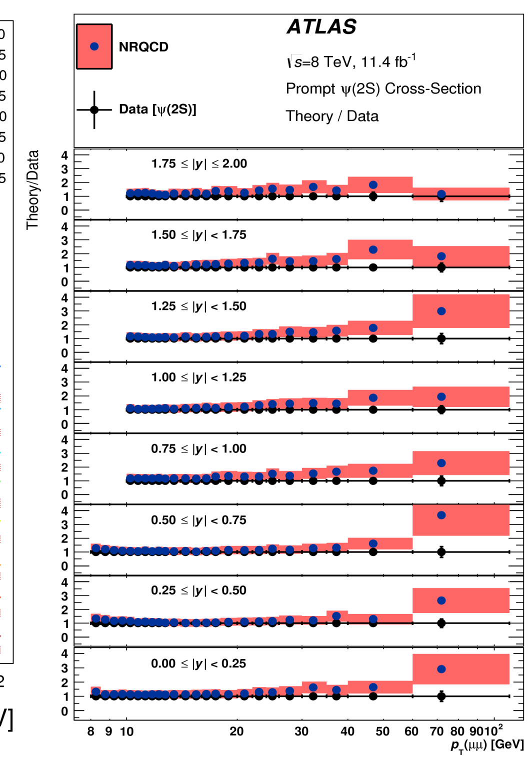

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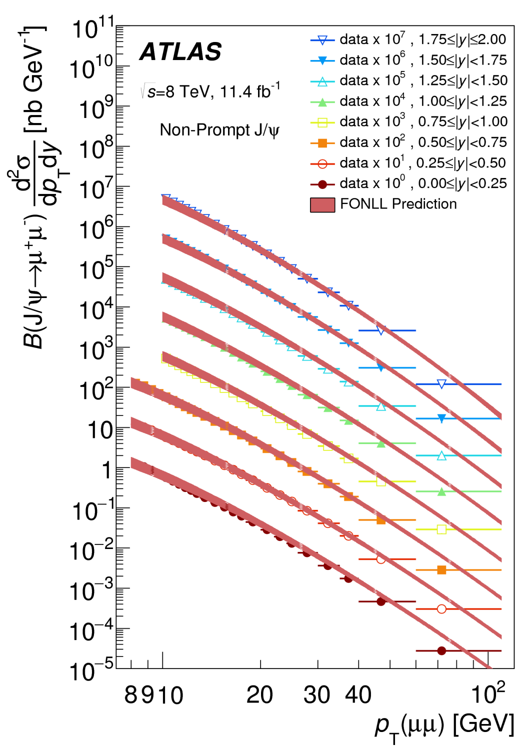

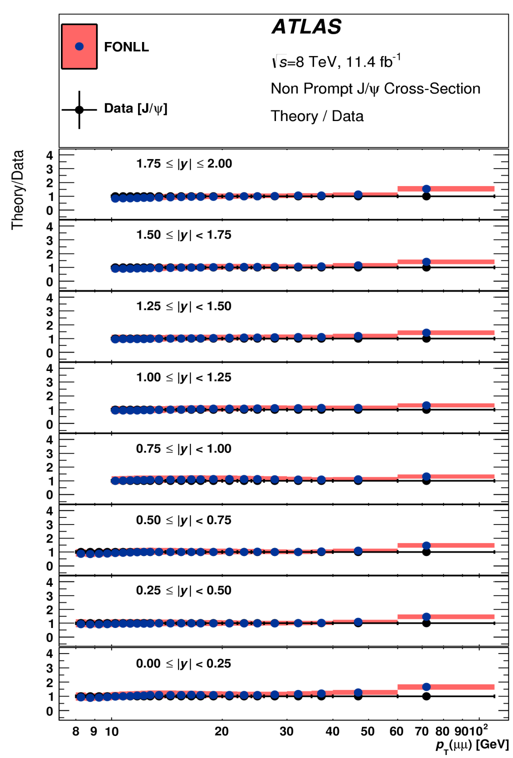

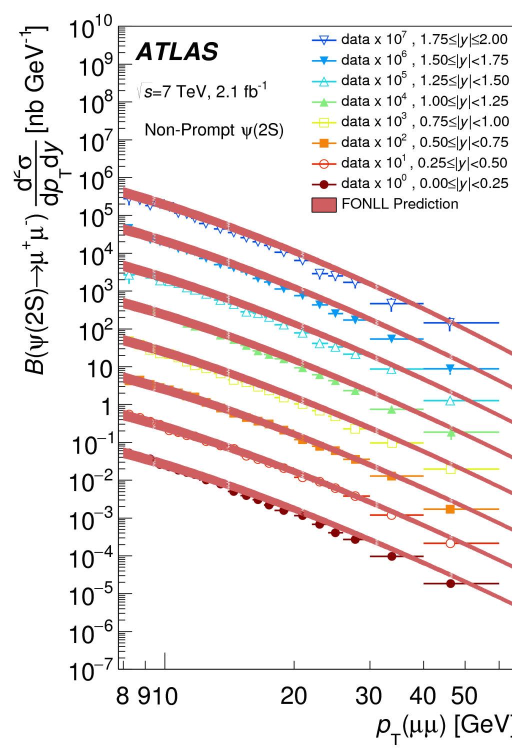

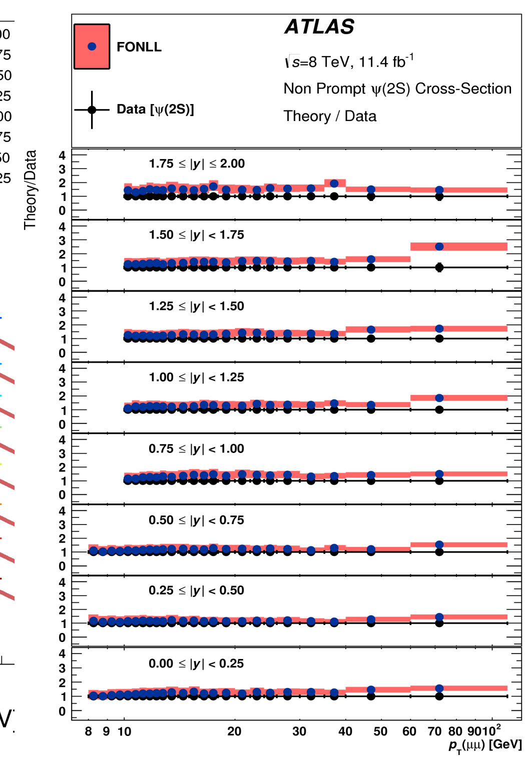

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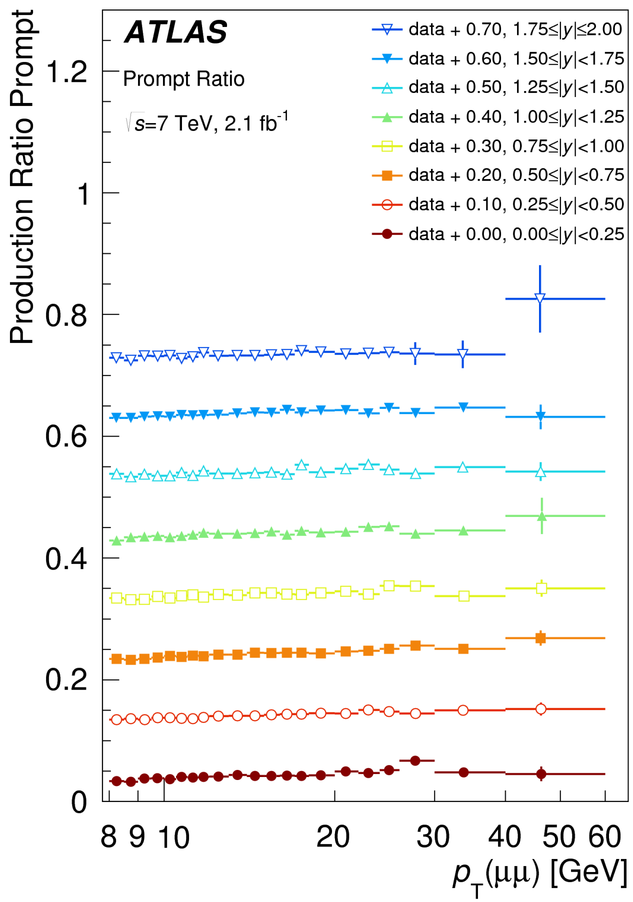

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