Associated production of J/ψ pairs with the ATLAS detector

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Introduction

- Simultaneous production of quarkonium with W, Z or other quarkonium
  - Probes mechanism for quarkonium production
  - Sensitive to higher order QCD corrections
  - Allows studies of multiple parton scattering

- ATLAS publications:

	$\sqrt{s}$	$\int L\,dt$	Reference
J/ψ + W	7 TeV	4.6 fb^{-1}	JHEP 04 (2014) 172
J/ψ + Z	8 TeV	20.3 fb^{-1}	Eur. Phys. J. C75 (2015) 229
J/ψ + J/ψ	**8 TeV**	**11.4 fb^{-1}**	**Eur. Phys. J. C77 (2017) 76**

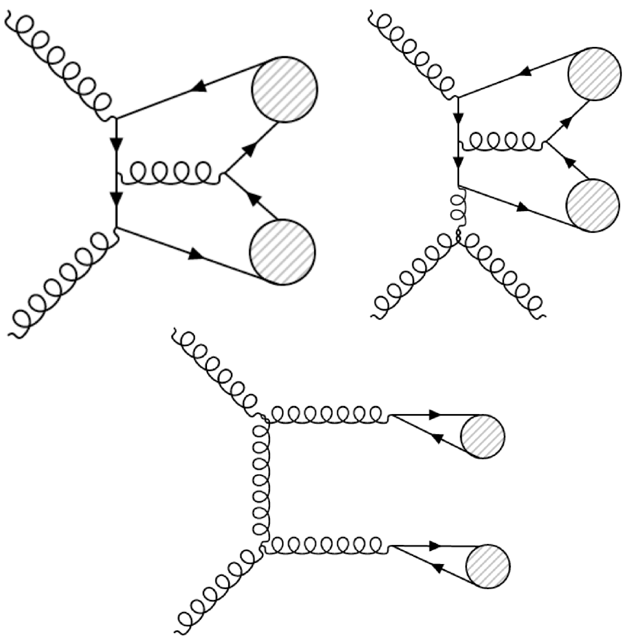
New

- This talk: $J/\psi + J/\psi \rightarrow (\mu^+\mu^-)(\mu^+\mu^-)$ in the 8 TeV data from 2012

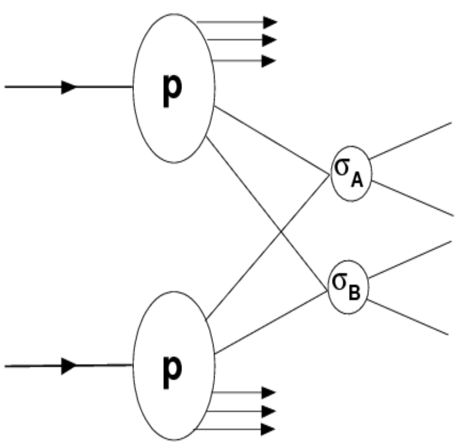
Definitions

- Prompt: Produced directly in the pp interaction or through feed-down decay from higher charmonium states
- Non-prompt: Produced in decay chain of B-hadrons (decay vertex can be displaced from primary pp vertex)

Single parton scattering (SPS):
two J/ψ mesons are produced from a single gluon-gluon collision

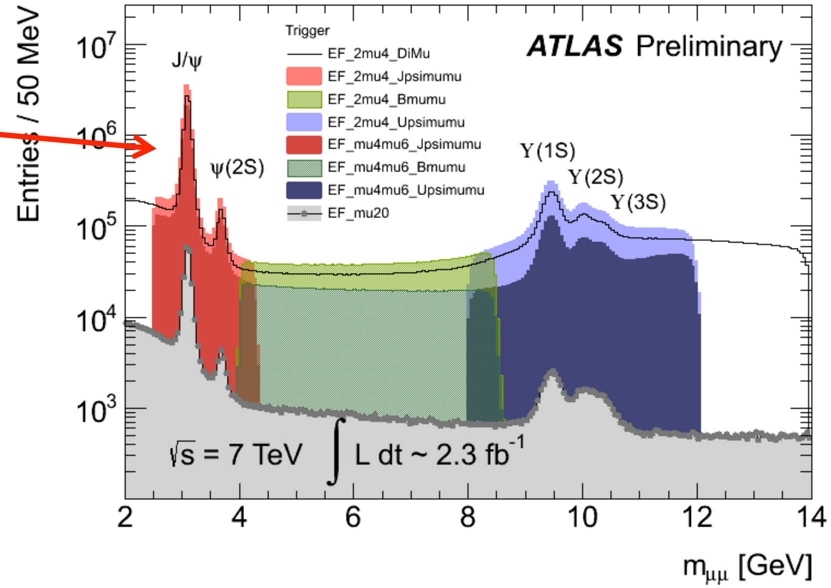


Double parton scattering (DPS):
two independent pairs of partons yield two J/ψ mesons



Extraction of prompt-prompt di-J/ψ signal

- Muon kinematic requirements:
  - Dimuon trigger
  - $|\eta|<2.3$ and $p_T > 2.5$ GeV
  - One J/ψ has muons with $p_T > 4$ GeV



- J/ψ kinematic requirements:
  - $2.8 \leq m_{\mu\mu} \leq 3.4$ GeV for each J/ψ
  - $p_T > 8.5$ GeV and $|y_{J/\psi}|<2.1$

- Per-candidate corrections for
  - Trigger and reconstruction efficiency
  - Detector acceptance

- Sequential background extraction:
  - Non-J/ψ background — 2D mass fits
  - Non-prompt J/ψ from B hadron decays — 2D lifetime fits
  - Pile-up background — 1D vertex separation fit

Invariant mass fits

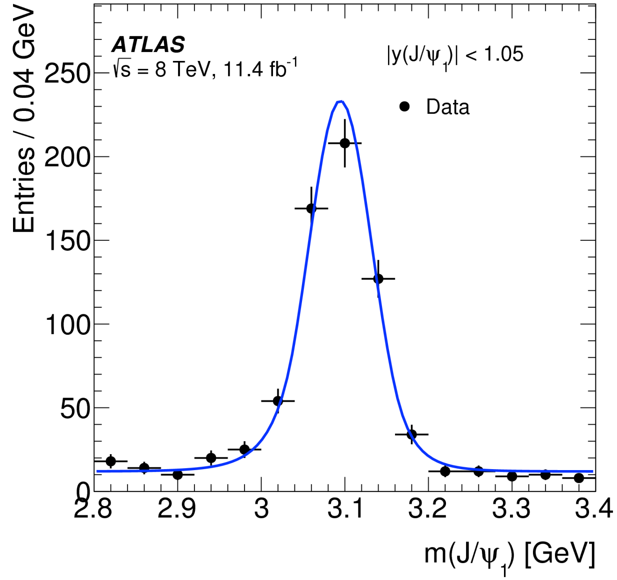
- Examples of 1D projection of 2D fits to m(J/ψ$_1$) vs. m(J/ψ$_2$)
- J/ψ$_1$: leading p_T
- J/ψ$_2$: sub-leading p_T

- Crystal Ball parameters obtained from fits to inclusive J/ψ sample

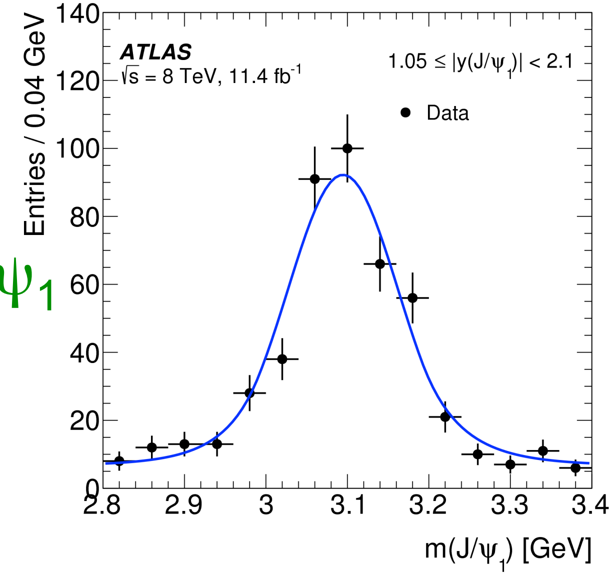
- Separates J/ψ from non-J/ψ background

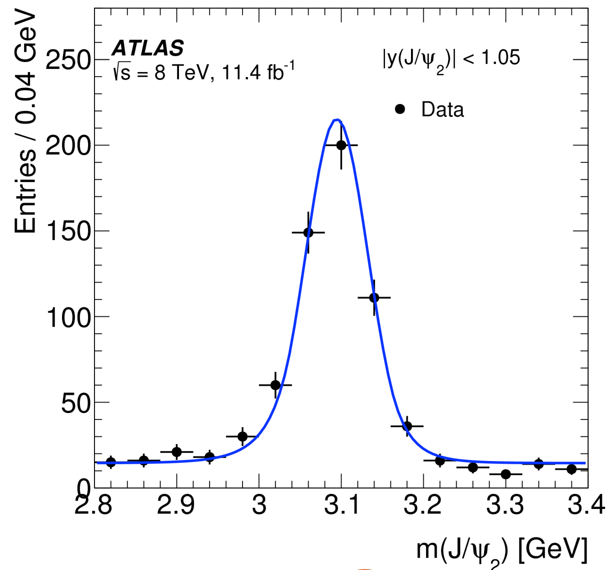
Central

Forward

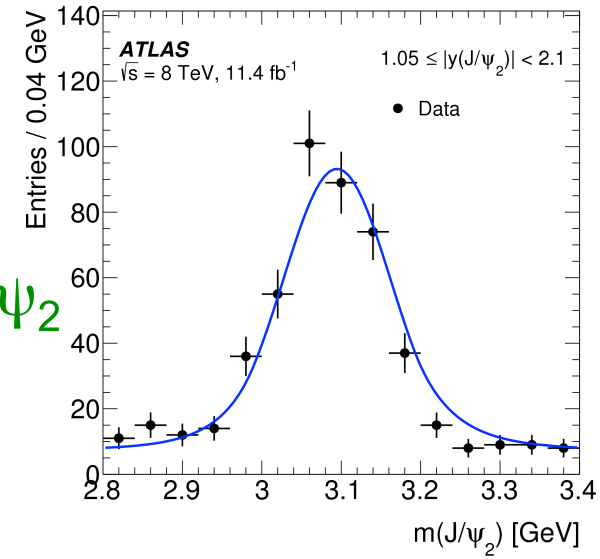


J/ψ$_1$



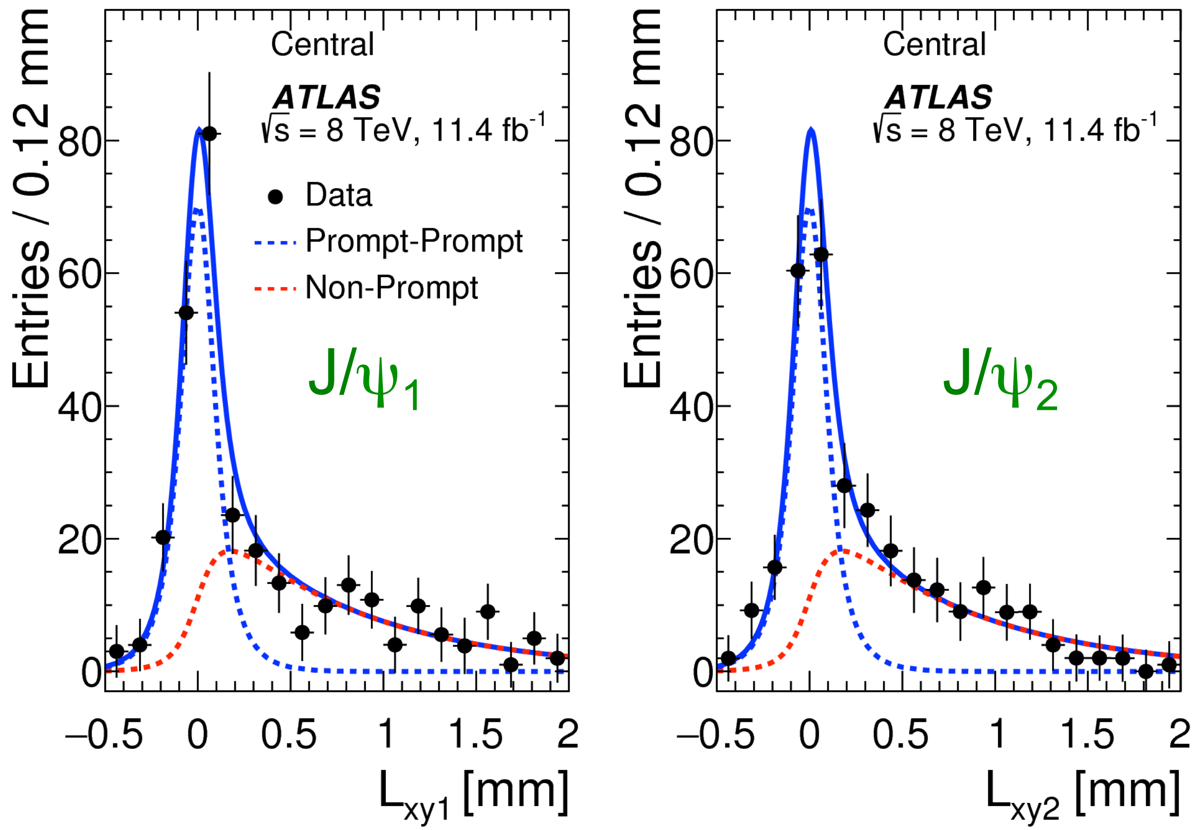


J/ψ$_2$



Decay length fits

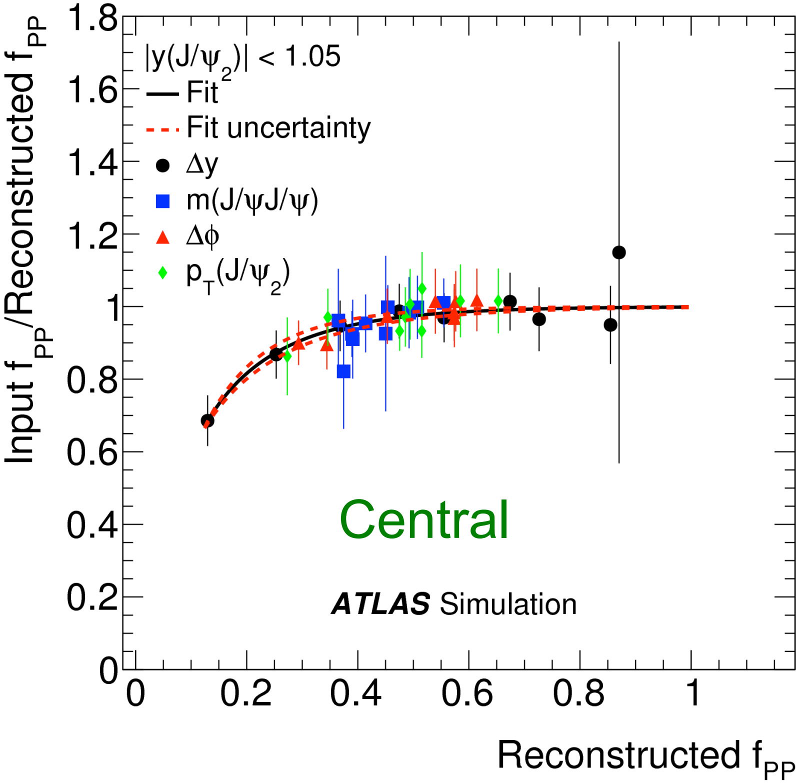
- 1D projection of 2D fits to transverse decay length, L_{xy}
- Resolution function determined from inclusive J/ψ sample
- Separates Prompt-Prompt di-J/ψ from non-prompt background

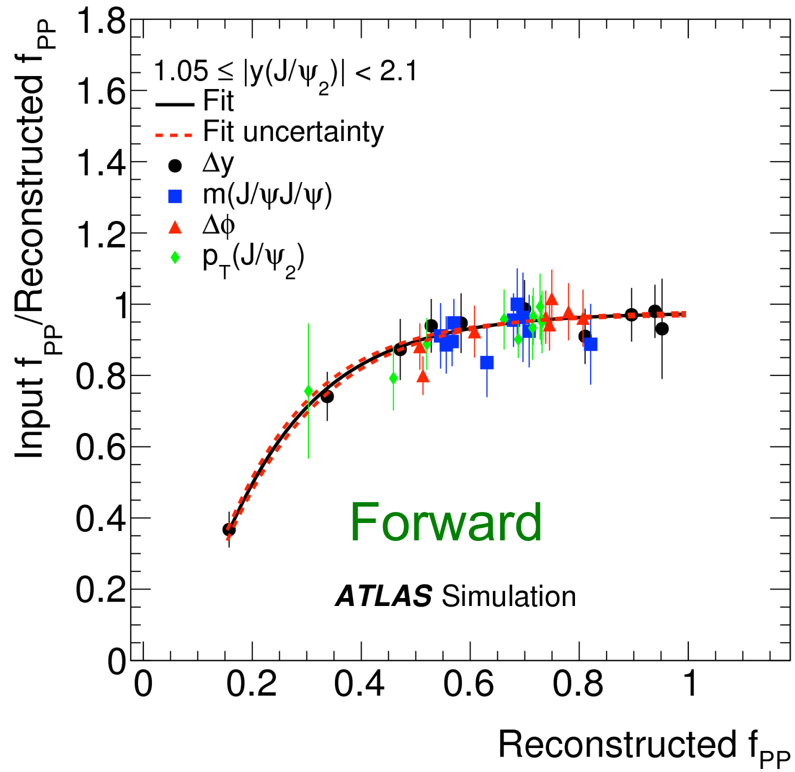


4 fits, based on rapidity of each J/ψ (Central/Forward)

Prompt-prompt di-J/ψ correction factor

- Prompt-prompt fraction f_{PP} extracted in 4 rapidity regions
- Correct for possible bias in PP event weight in differential distributions
- MC samples generated with Pythia8B
- Bias correction shown for all kinematic variables

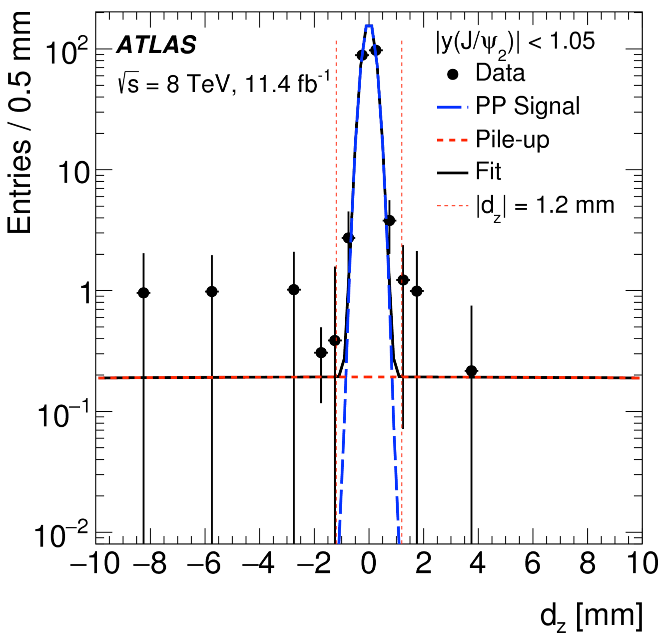




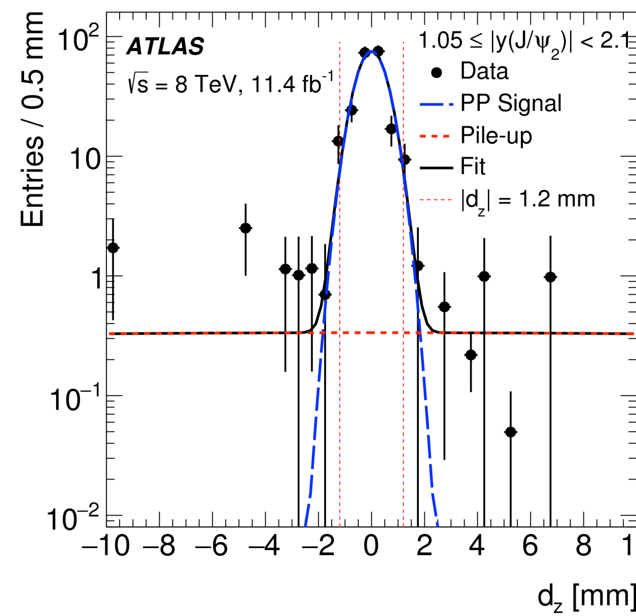
Pile-up background subtraction

- Pile-up contribution: multiple uncorrelated collisions in same beam crossing
- Estimate using d_z distribution: distance between J/ψ mesons along beam direction

Central



Forward

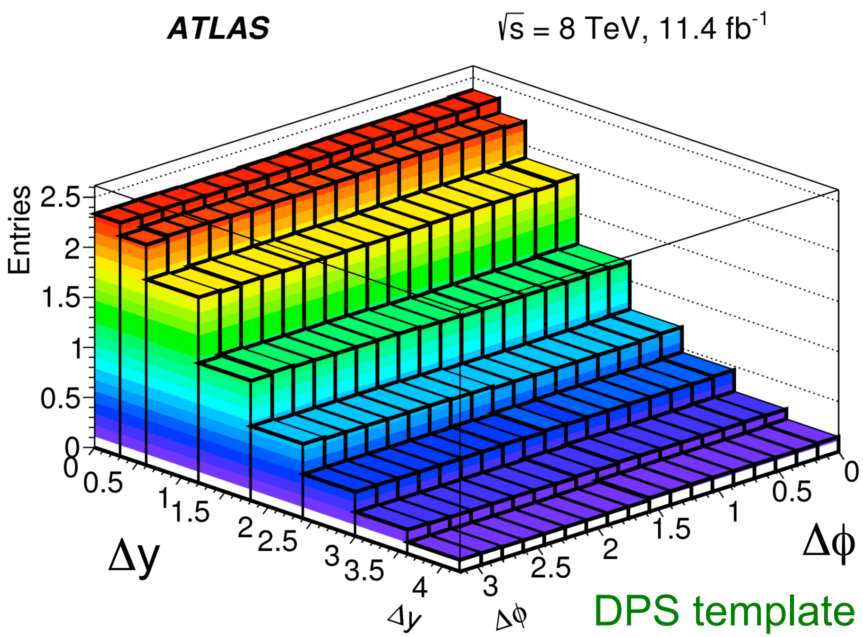


$f_{\text{pile-up}} = (0.466 \pm 0.034\ (\text{stat}) \pm 0.004\ (\text{syst}))\%$

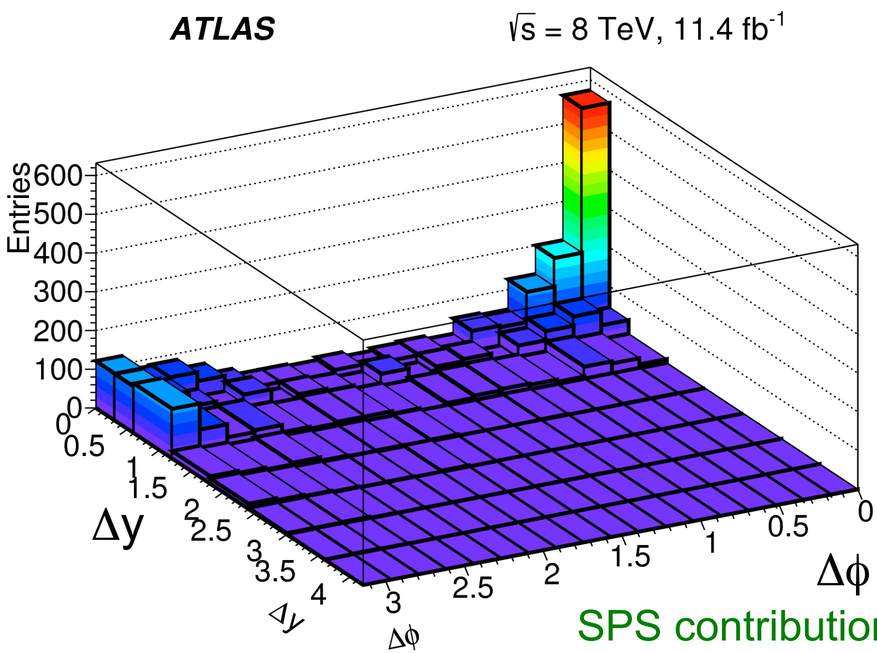
$f_{\text{pile-up}} = (0.802 \pm 0.062\ (\text{stat}) \pm 0.007\ (\text{syst}))\%$

Extracting Double Parton Scattering (DPS) contribution

- Data-driven estimate of DPS:
  - Combine random pairs of J/ψ candidates from different J/ψ events
  - Assume independent kinematics in DPS events
- 2D template of $|\Delta y|$ vs. $|\Delta\phi|$ used to derive DPS event weights:
  - DPS-dominated region $|\Delta y|>1.8$, $|\Delta\phi|>\pi/2$ normalised to data
  - SPS obtained by subtracting DPS from data

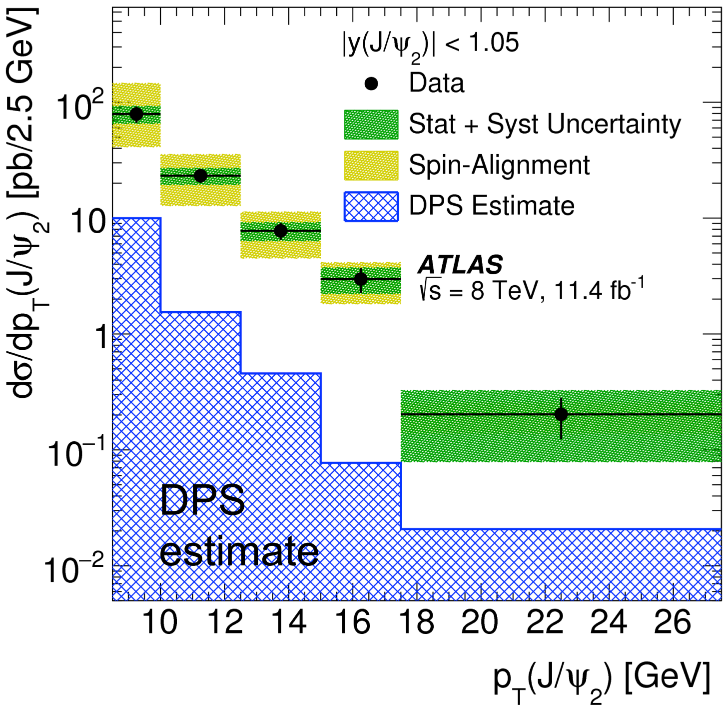


DPS template (mixed events)

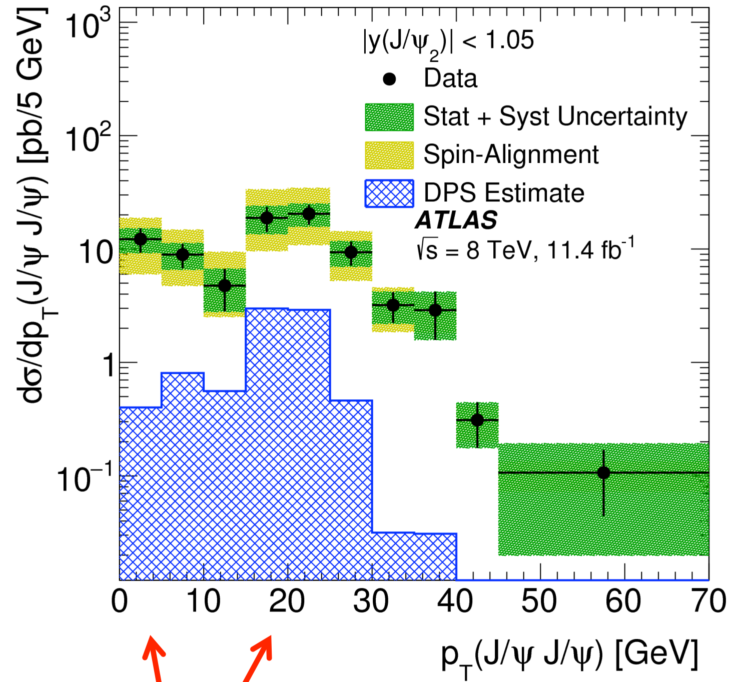


SPS contribution in data

Differential cross-section results (I)



p_T of sub-leading J/ψ

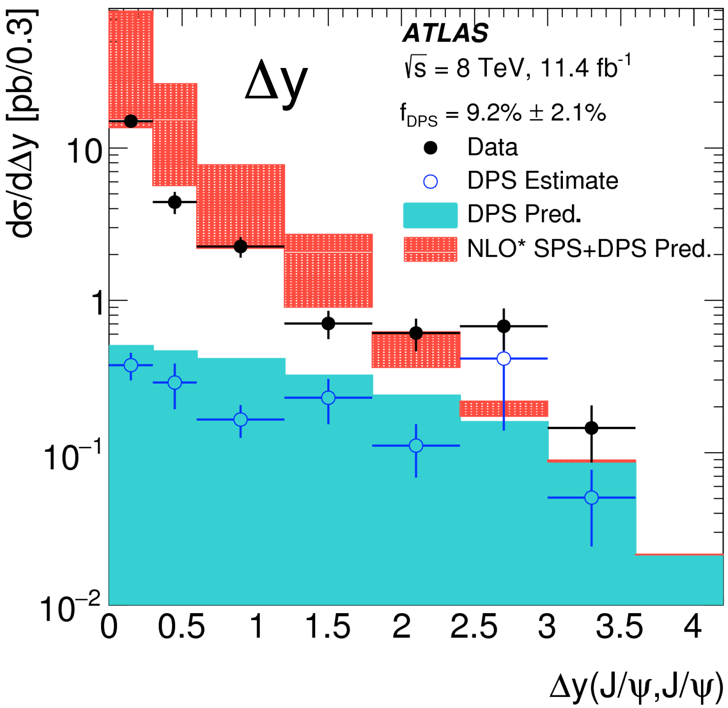


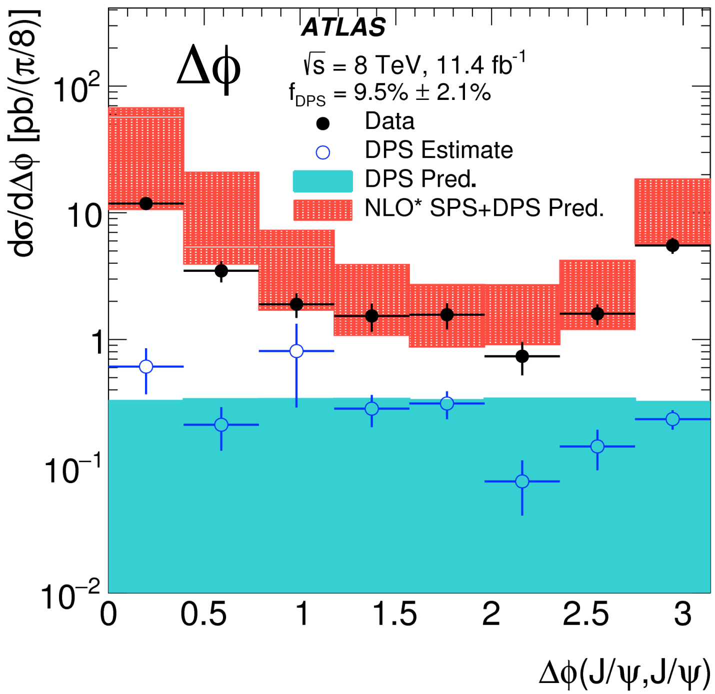
p_T of di-J/ψ

- Measured in J/ψ fiducial volume (p_T > 8.5 GeV and $|y|$<2.1)
- Assume unpolarised J/ψ mesons
- Maximal spin-alignment variations in yellow
- Weighted DPS distributions also shown

- Peak at low p_T: back-to-back J/ψ mesons ("away")
- Peak at higher p_T: J/ψ in same direction (NLO effect)

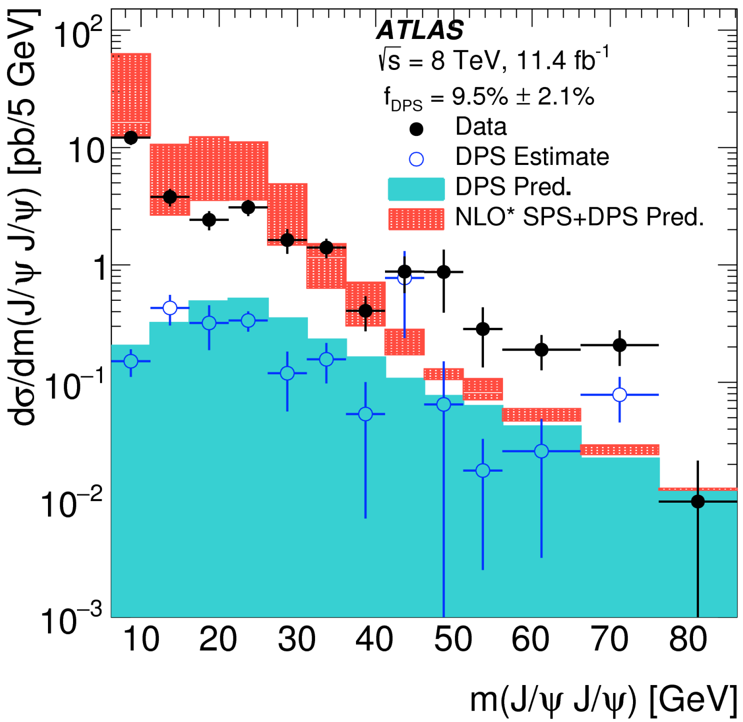
Differential cross-section results (II)

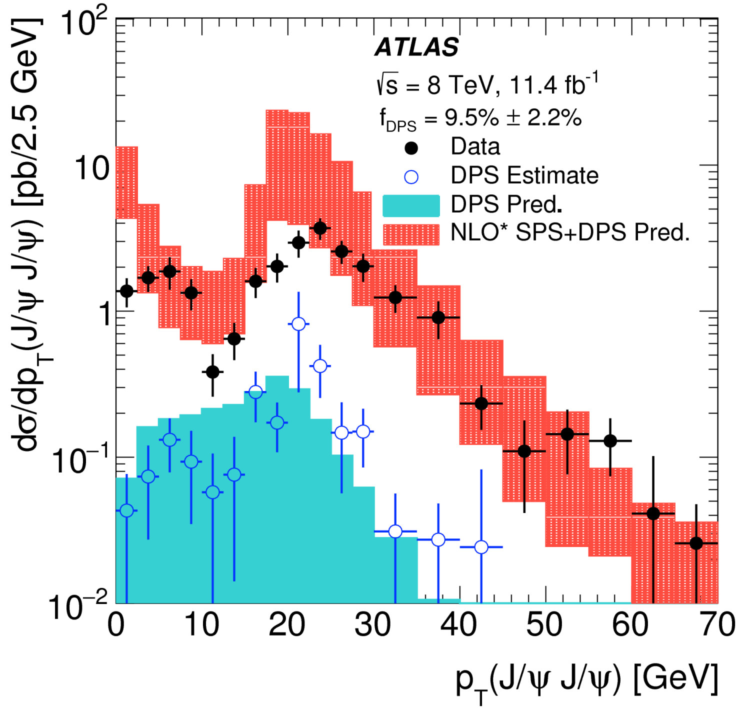




- Measured in muon fiducial volume
- DPS predictions normalised to measured f_{DPS} →shape comparison
  - Phys. Rev. D 95, 034029 (2017)
- NLO* SPS scaled by 1.85 to account for feed-down
  - Phys.Lett. B751 (2015) 479; Phys. Rev. Lett. 111 (2013) 122001

Differential cross-section results (III)





- Measured in muon fiducial volume

- Predicted NLO* SPS + LO DPS cross-section underestimates data at large $m(J/\psi\ J/\psi)$, low $p_T(J/\psi\ J/\psi)$ and large Δy ("away" region)
- Theory does not include feed-down contributions

Inclusive and effective DPS cross-sections

- Inclusive prompt-prompt di-J/ψ cross-section assuming unpolarised J/ψ mesons:

$82.2 \pm 8.3\ (\text{stat}) \pm 6.3\ (\text{syst}) \pm 0.9\ (\text{BF}) \pm 1.6\ (\text{lumi})\ \text{pb},\ \text{for } |y| < 1.05$

$78.3 \pm 9.2\ (\text{stat}) \pm 6.6\ (\text{syst}) \pm 0.9\ (\text{BF}) \pm 1.5\ (\text{lumi})\ \text{pb},\ \text{for } 1.05 \leq |y| < 2.1$

- Effective DPS cross-section measurement:

$$\sigma_{\text{eff}} = \frac{1}{2}\frac{\sigma^2_{J/\psi}}{\sigma^{J/\psi,J/\psi}_{\text{DPS}}} = \frac{1}{2}\frac{\sigma^2_{J/\psi}}{f_{\text{DPS}} \times \sigma_{J/\psi J/\psi}}$$

From ATLAS prompt J/ψ
Eur. Phys. J. C 76 (2016) 283

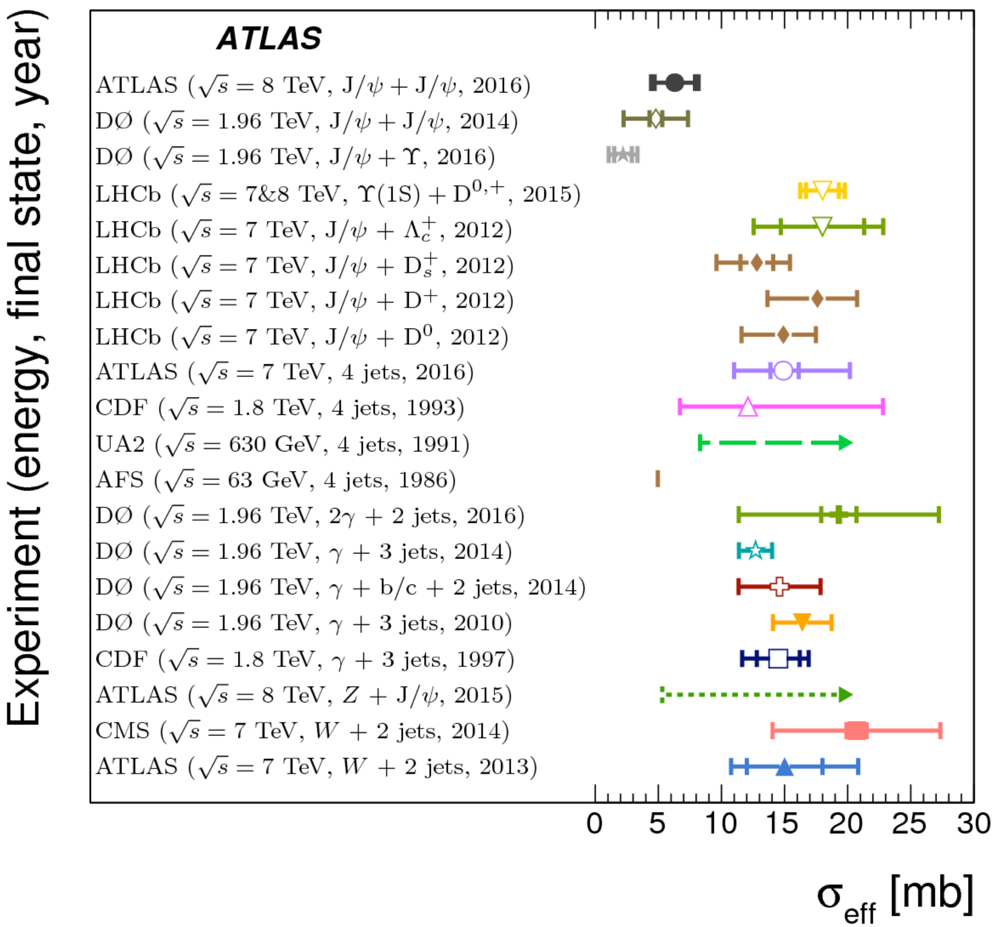
Measured in this analysis

From Δy distribution:
f_{DPS}=(9.2±2.1(stat)±0.5(syst)) %
in muon fiducial region

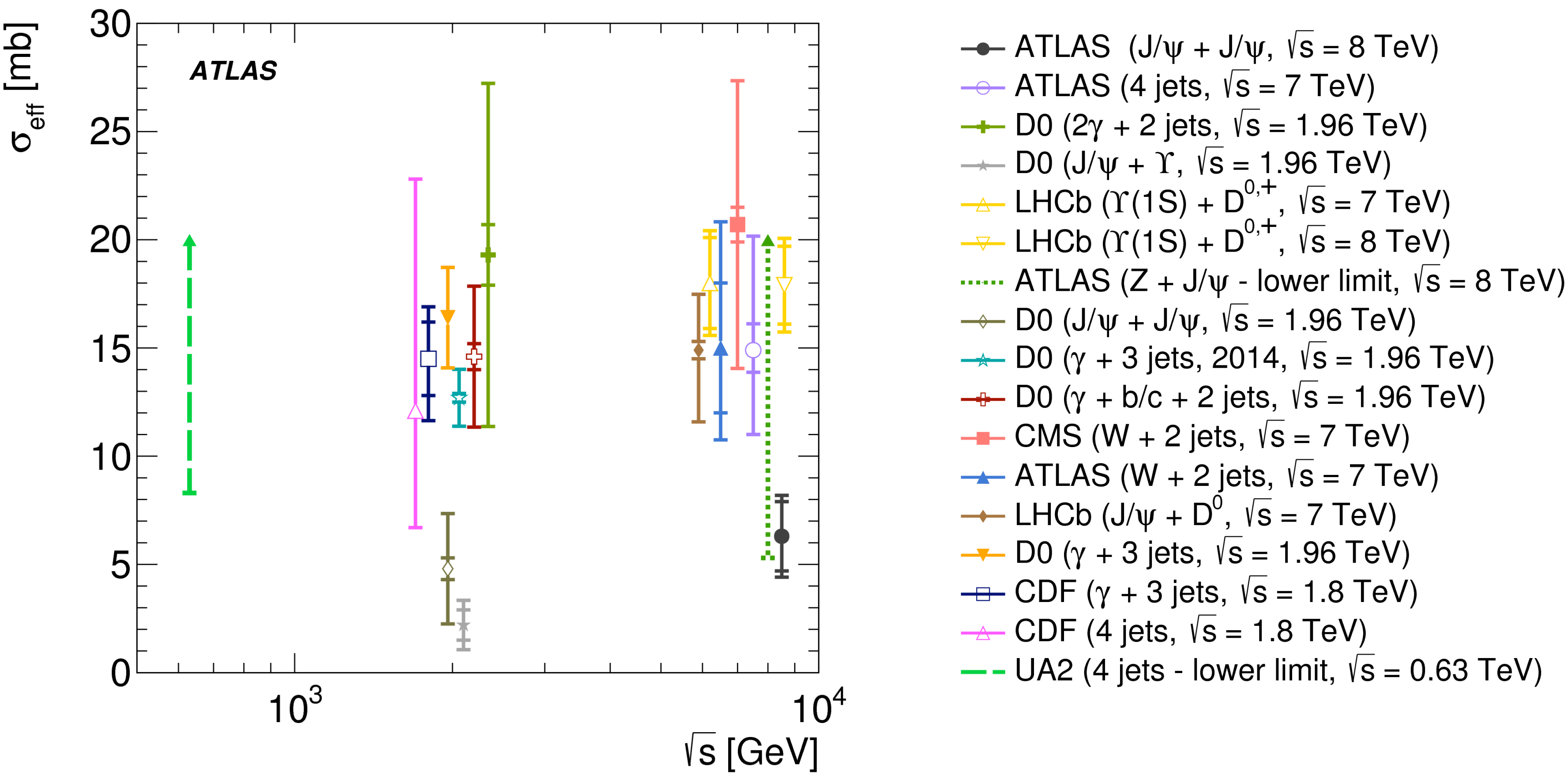
Effective cross-section of DPS

$$\sigma_{\text{eff}} = 6.3 \pm 1.6\ (\text{stat}) \pm 1.0\ (\text{syst}) \pm 0.1\ (\text{BF}) \pm 0.1\ (\text{lumi})\ \text{mb}$$

- Close to D0 quarkonium results, lower than other measurements
- Assumptions on process and energy independence in extracting σ_{eff}
- Di-J/ψ, J/ψ−Υ and 4-jet processes dominated by gluon interactions → probe gluon distribution in proton
- Recent LHCb result, 13 TeV:
  - $\sigma_{\text{eff}} \sim 9.2 - 14.4$ mb
  - $p_T(J/\psi)<10$ GeV, $2.0<y<4.5$
  - arXiv:1612.07451 [hep-ex]



Effective cross-section as a function of √s



- More measurements will help to test process and energy (in)dependence

Summary

- Prompt di-J/ψ production has been measured with 8 TeV ATLAS data:
  - Differential cross-section for J/ψ and di-J/ψ observables
  - Data-driven DPS estimate
  - NLO SPS + LO DPS describes data well, except for regions at low p_T and high mass
  - Effective DPS cross-section, σ_{eff}
- Substantial dataset already recorded at 13 TeV and more to come:
  - Further measurements, higher precision
  - Additional comparisons with theory

Backup slides

Example of f_{PP} bias correction

- A comparison of the PP MC input, MC reconstructed, and MC reconstructed distribution, corrected for the f_{PP} bias, for $p_T(J/\psi_2)$