Observation of associated W+J/ψ production

Peter Onyisi

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THE UNIVERSITY OF TEXAS AT AUSTIN

ATLAS EXPERIMENT
http://atlas.ch

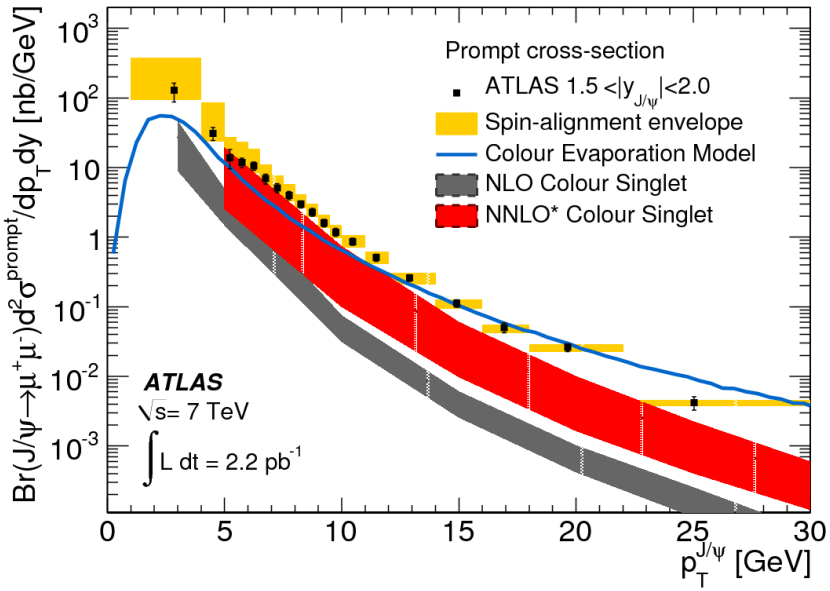
Introduction

- Simultaneous production of charmonium and a weak boson has not been seen at a hadron collider before
- Potentially a good test of production models
- Also sensitive to multiple parton interactions in a single pp collision
- ATLAS has made the first measurement of this process in 4.6 fb^{-1} of 7 TeV pp collisions

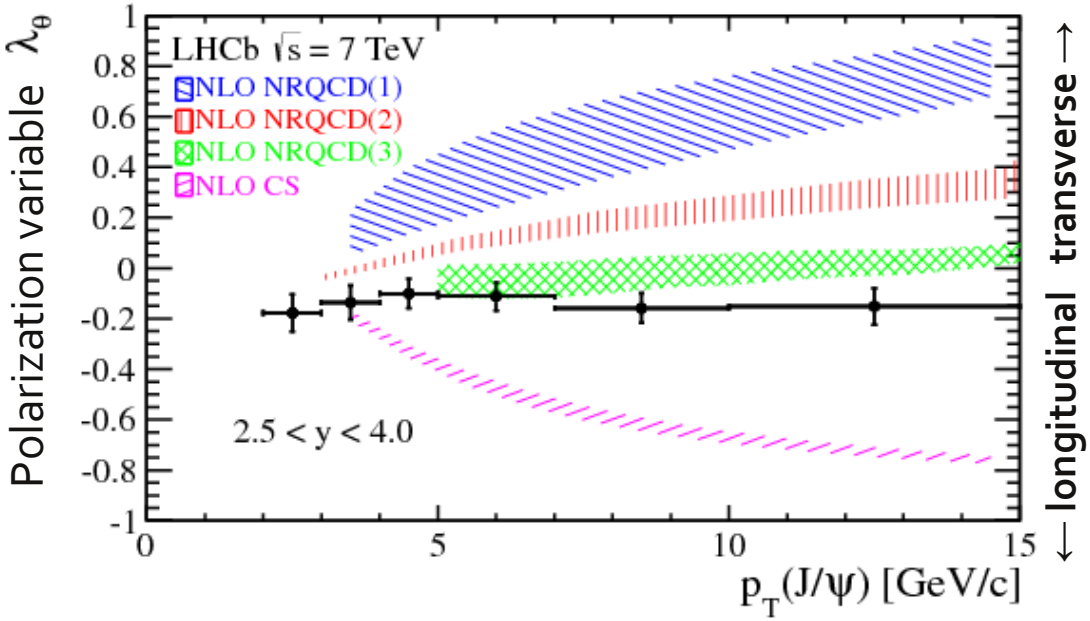
Quarkonium Production

- Quarkonium production in hadron collisions still poorly understood
- Various models fail to predict pt spectrum, polarization, or both

Nucl. Phys. B 850 (2011) 387-444



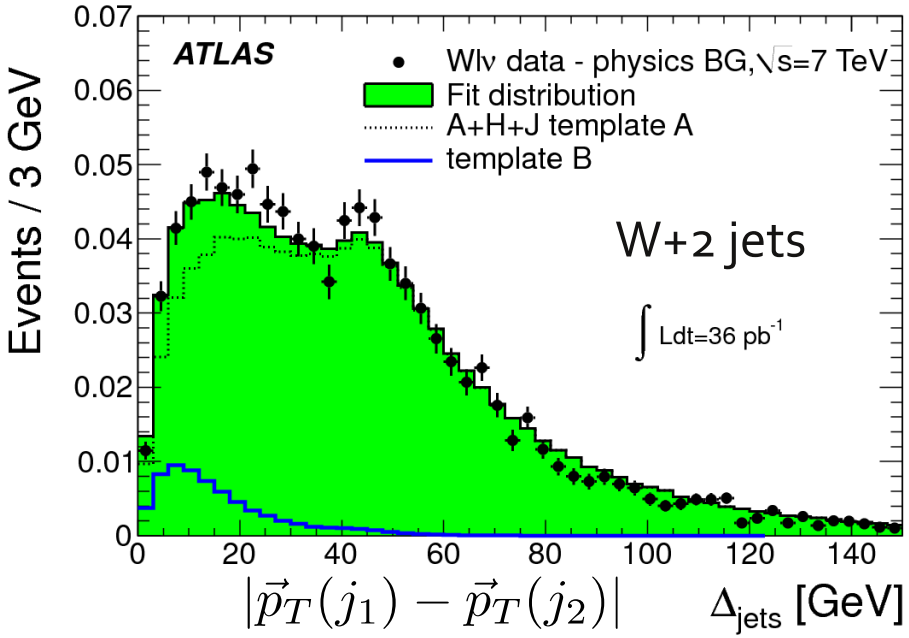
arXiv:1307.6379

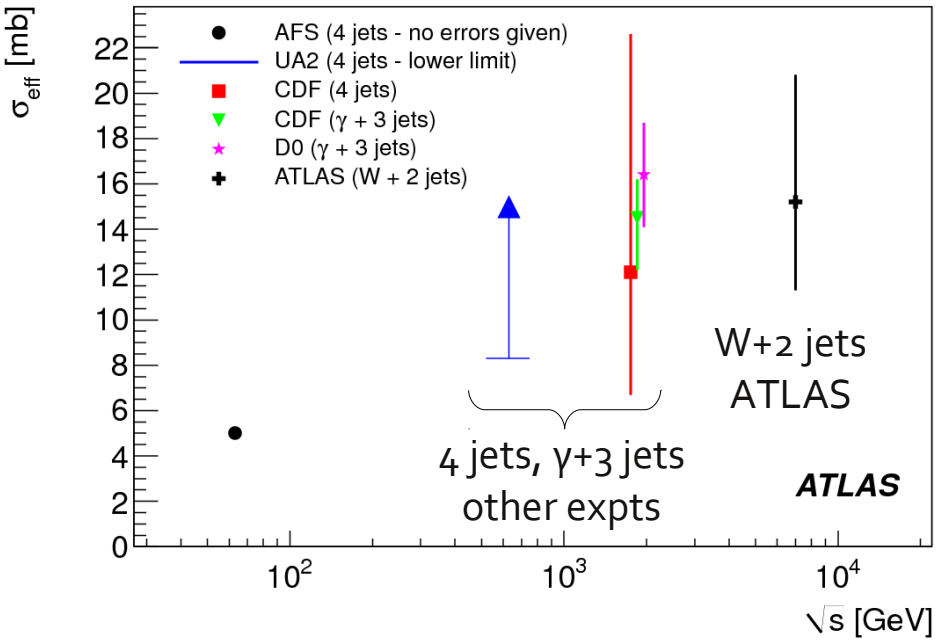


Double Parton Scattering (DPS)

- Background for some rare processes
- Probes the structure of the proton (transverse and momentum correlations of partons)
- Strong evidence, but still want to measure and probe universality

New J. Phys. 15 (2013) 033038



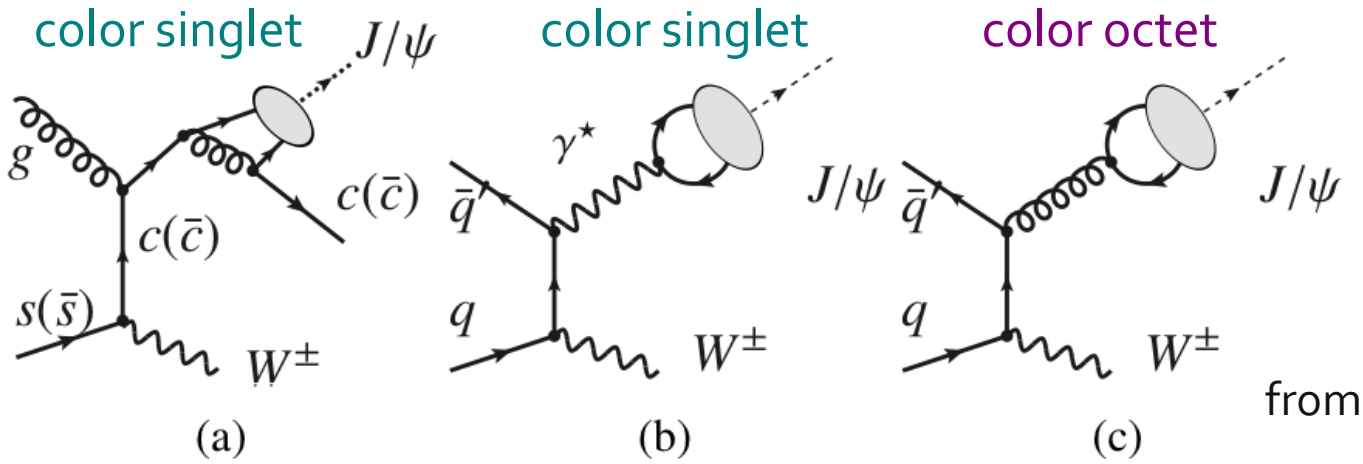


Vector boson + J/ψ

- Interesting probe of both J/ψ production and double parton scattering
  - quark-initiated process selects very different production diagrams than inclusive J/ψ (which is mostly gg)
  - expected single parton scattering production rate small enough that DPS can compete
- Analogous process vector boson+Y(1S) searched for by CDF (PRL 90 (2003) 221803), limits set
- This talk: ATLAS observation of W+J/ψ (ATLAS-CONF-2013-042)

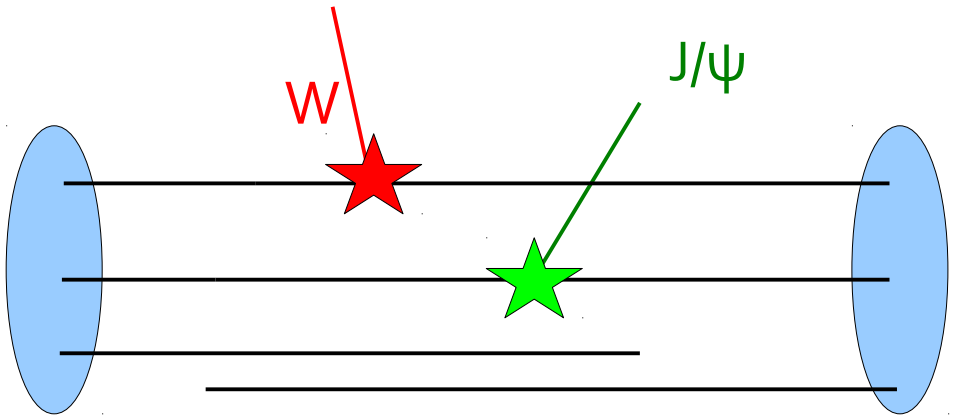
Production Mechanisms

Single parton scattering (SPS)



from arxiv:1303.5327

Double parton scattering (DPS)

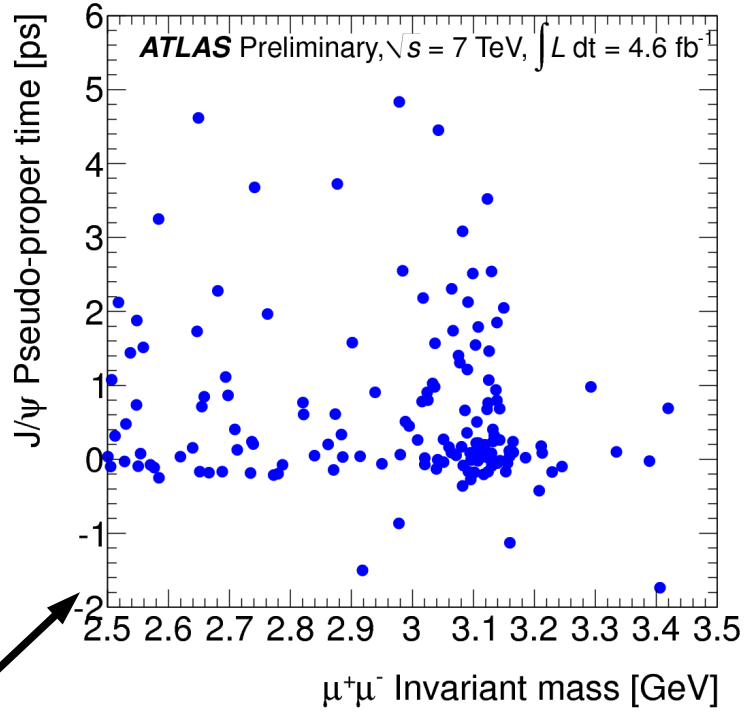


Event Selection

Use the 3μ + MET channel ($J/\psi \rightarrow \mu\mu$, $W \rightarrow \mu\nu$);
$W \rightarrow e\nu$ has more background, less efficient

pseudo-proper time

$$\tau \equiv \frac{\vec{L} \cdot \vec{p}_T^{J/\psi}}{p_T^{J/\psi}} \cdot \frac{m_{\mu^+\mu^-}}{p_T^{J/\psi}}$$

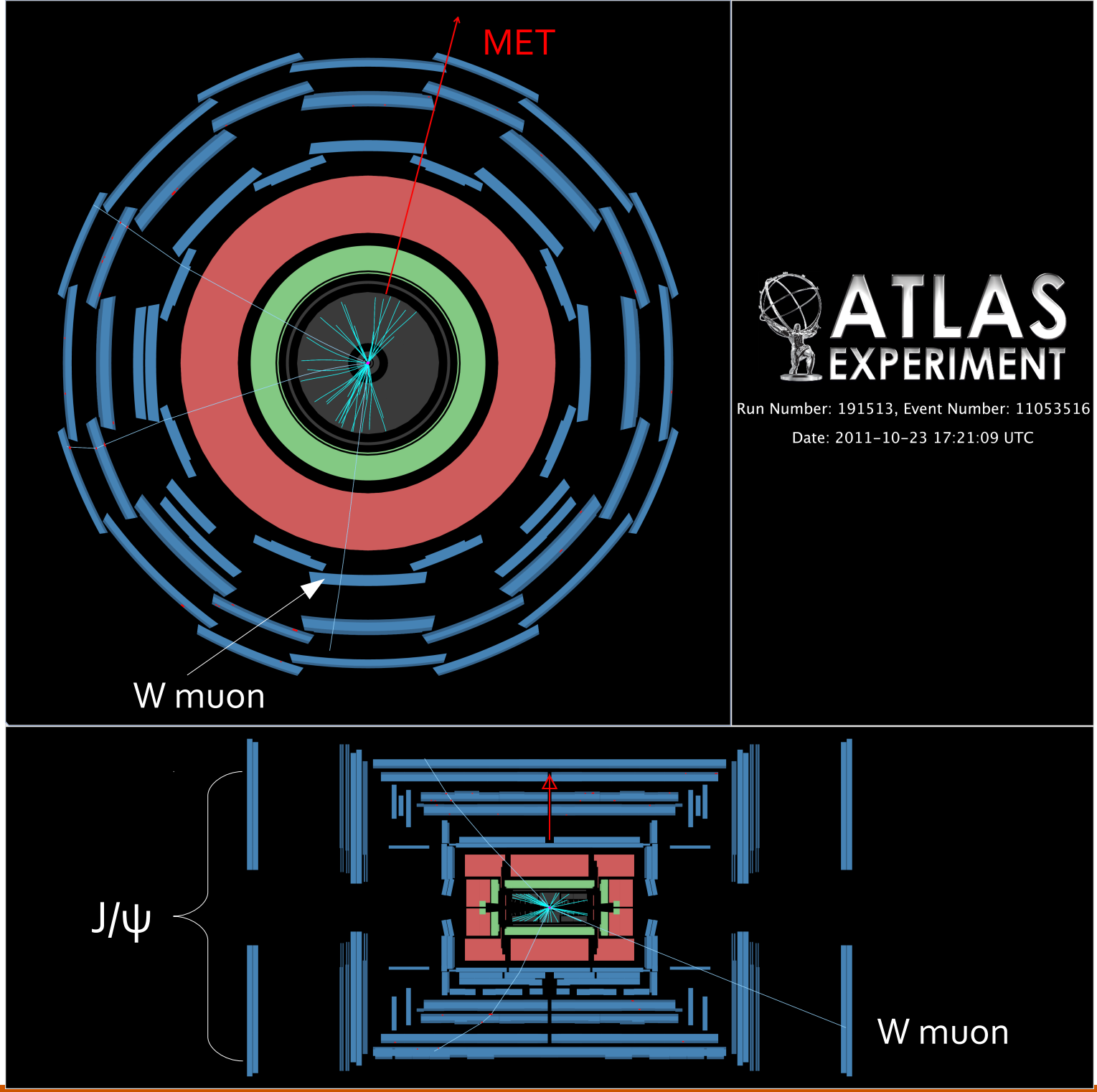


Trigger:
- single muon
- $p_T > 18$ GeV, $|\eta| < 2.4$

All muons:
- $|\eta| < 2.5$
- $pT > 3.5$ (2.5) GeV for $|\eta| < 1.3$ (> 1.3)

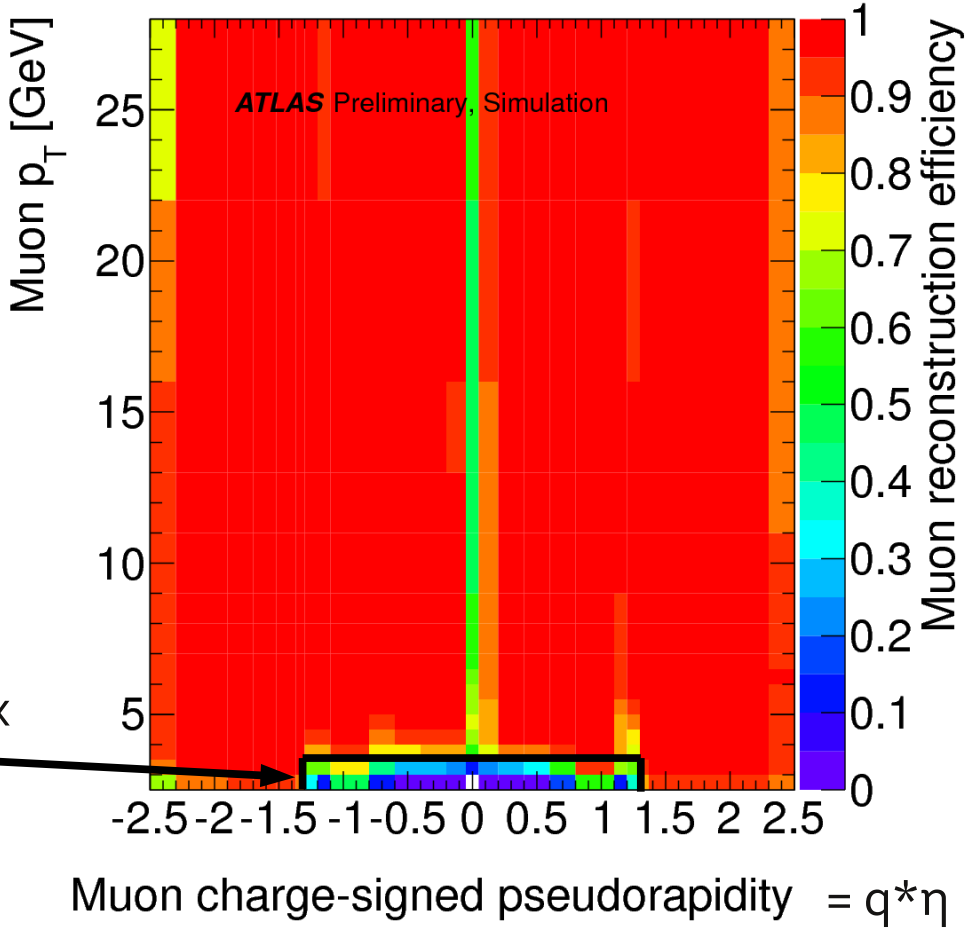
Find J/ψ candidate:
- Two opposite sign μ
- One μ has $p_T > 4$ GeV
- $2.5 < m(\mu\mu) < 3.5$ GeV
- $|y(\mu\mu)| < 2.1$
- $8.5 < p_T(\mu\mu) < 30$ GeV

Find W candidate:
- Use remaining muon
- $p_T > 25$ GeV, $|\eta| < 2.4$, fired trigger
- Impact parameter, isolation cuts
- MET > 20 GeV
- $M_T(W) > 40$ GeV
- Remove events with $|m(\mu\mu) - m_Z| < 10$ GeV


MET
J/ψ
W muon
ATLAS
EXPERIMENT
Run Number: 191513, Event Number: 11053516
Date: 2011-10-23 17:21:09 UTC
J/ψ
W muon

Efficiency Map

- Better low-p_T muon efficiency at high η motivates barrel/endcap separation in fits



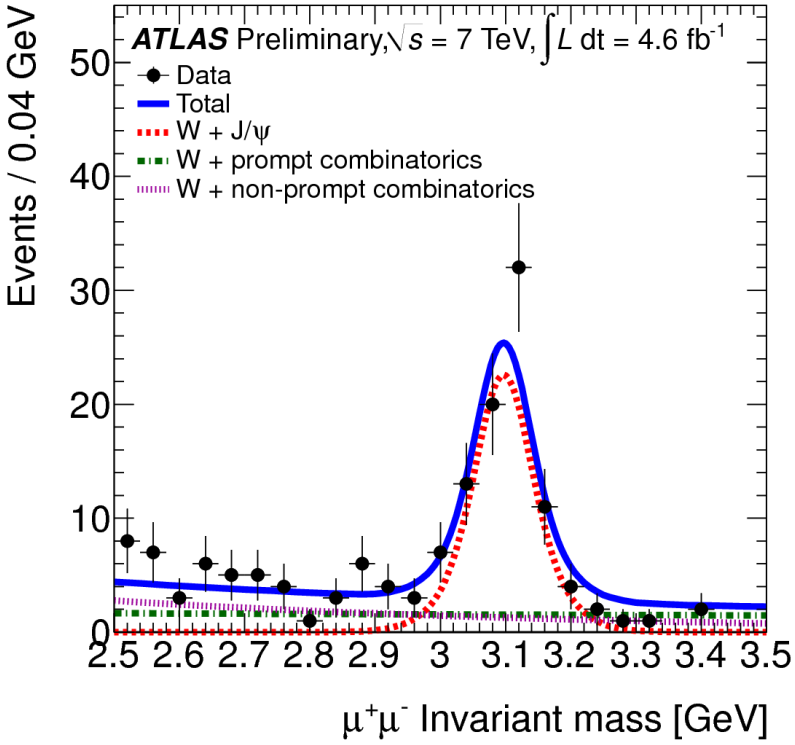
Candidates in box are rejected

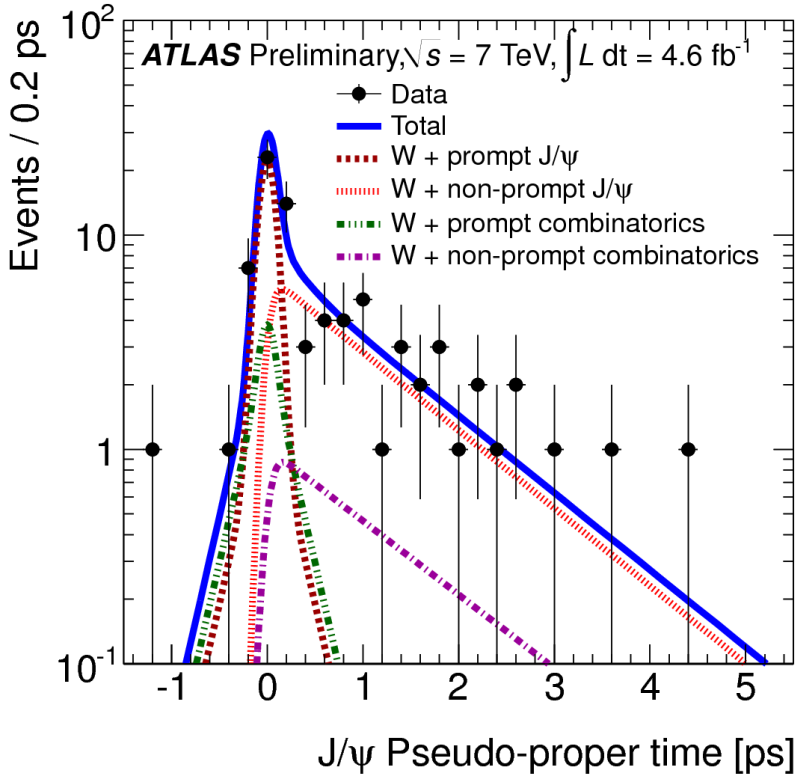
Interpretation

- Do we have prompt J/ψ production in selected 3 μ events?
- Are the prompt J/ψ events compatible with having a W candidate?
  - sPlot technique used to project transverse mass of additional muon + MET
- What do the differential distributions look like?
  - $\Delta\phi$(J/ψ, W) expected to be a good diagnostic for DPS vs single parton scattering process
  - p_T spectrum also interesting

Fits

- Components for J/ψ fit: prompt J/ψ, non-prompt J/ψ, prompt combinatorics, non-prompt combinatorics
- 2D fit in μμ invariant mass and candidate pseudo-proper time $\tau \equiv \frac{\vec{L} \cdot \vec{p}_T^{J/\psi}}{p_T^{J/\psi}} \cdot \frac{m_{\mu^+\mu^-}}{p_T^{J/\psi}}$



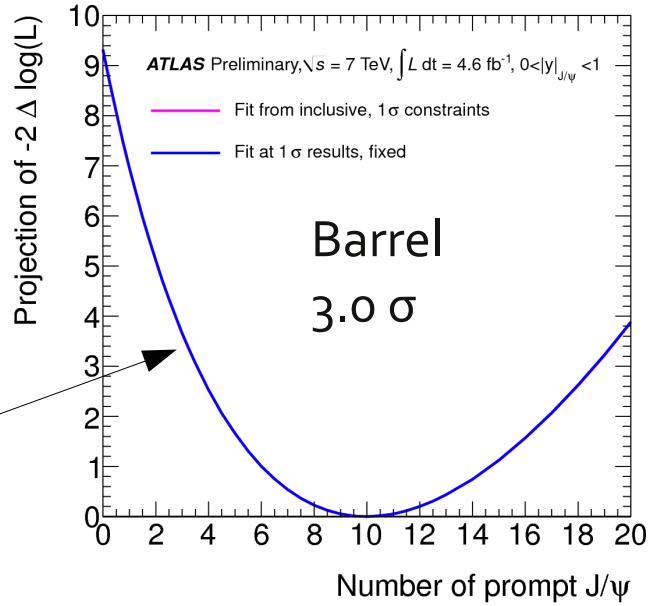


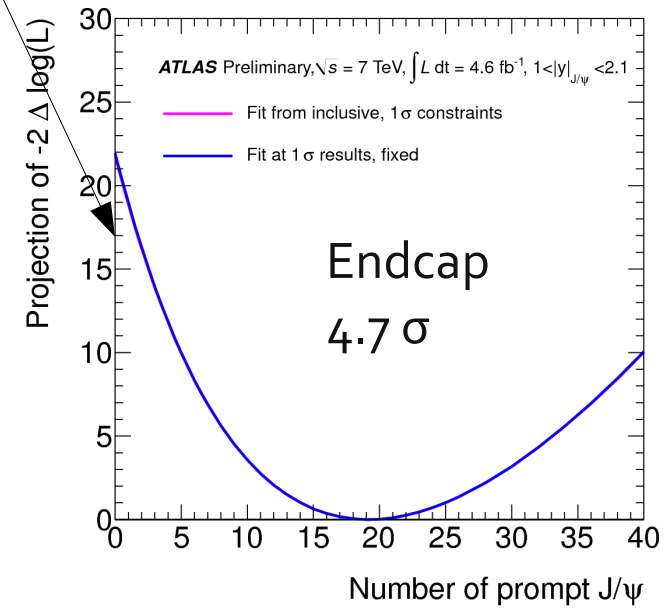
Yields

- Significant prompt J/ψ yields for both barrel and endcap candidates
  - Expect larger yield in endcap due to better acceptance in p_T(J/ψ)
- Combined significance 5.3 σ

Yields from two-dimensional fit			
Process	Barrel	Endcap	Total
Prompt J/ψ	$10.0^{+4.7}_{-4.0}$	$19.2^{+5.8}_{-5.1}$	$29.2^{+7.5}_{-6.5}$
Non-prompt J/ψ	$27.9^{+6.5}_{-5.8}$	$13.9^{+5.3}_{-4.5}$	$41.8^{+8.4}_{-7.3}$
Prompt background	$20.4^{+5.9}_{-5.1}$	$18.8^{+6.3}_{-5.3}$	$39.2^{+8.6}_{-7.3}$
Non-prompt background	$19.8^{+5.8}_{-4.9}$	$19.2^{+6.1}_{-5.1}$	$39.0^{+8.4}_{-7.1}$
p-value	1.5×10^{-3}	1.4×10^{-6}	4.4×10^{-8}
Significance	3.0	4.7	5.3

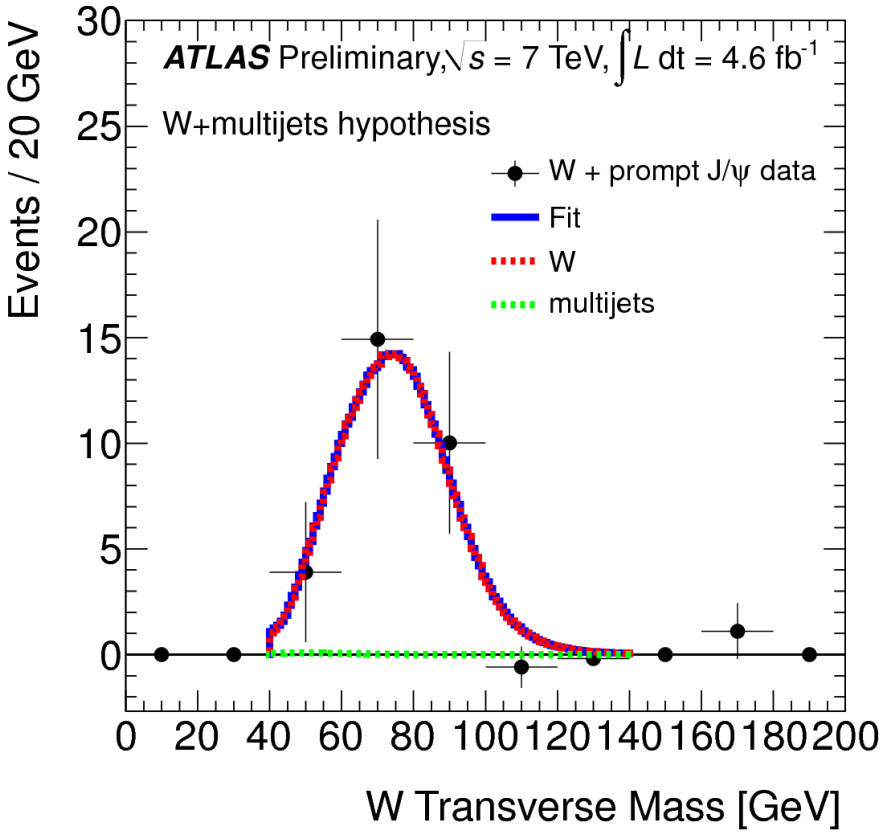
Likelihood contours





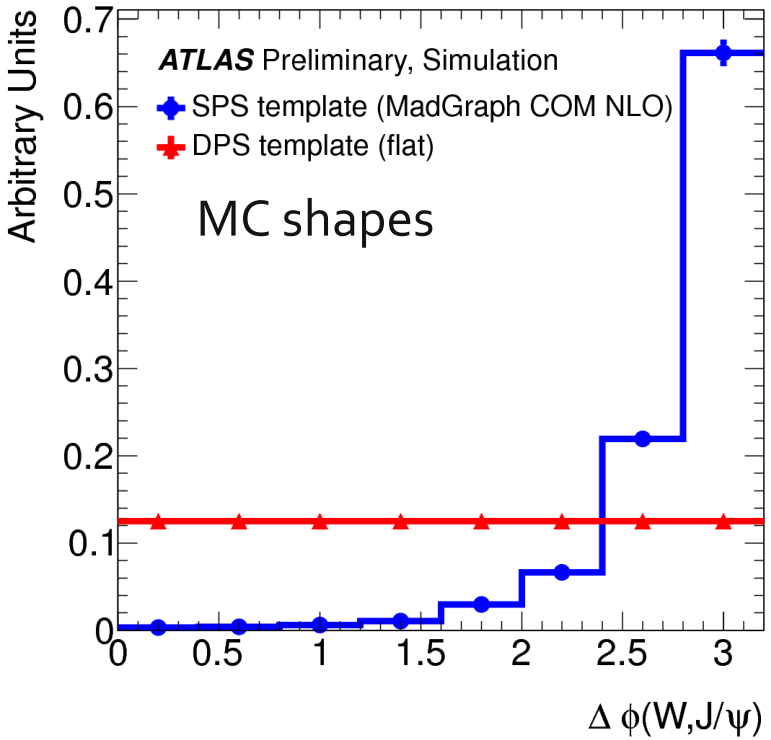
Are these W + J/ψ events?

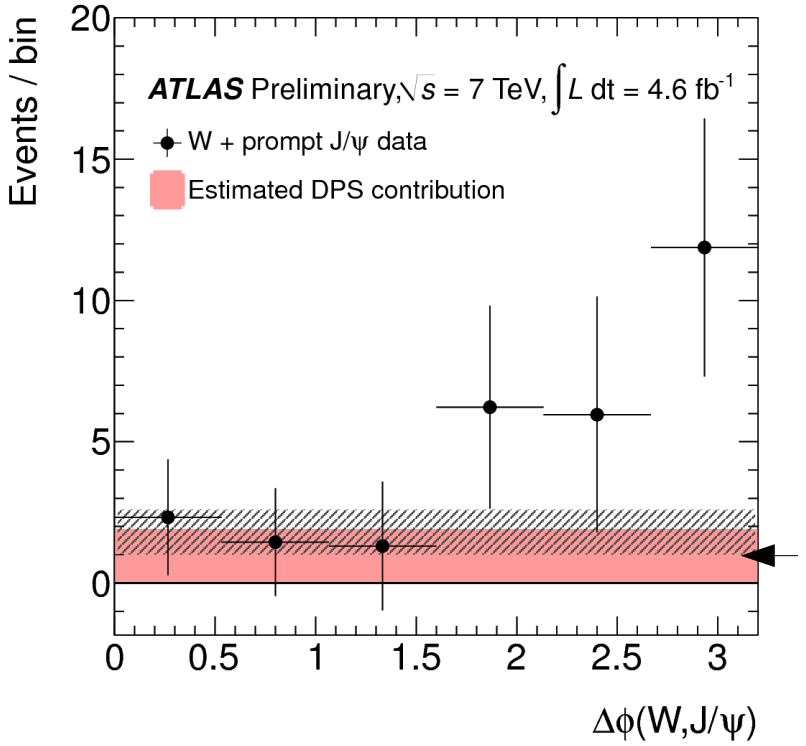
- M_T distributions very consistent with W
  - multijet contribution < 31% at 95% credibility level
  - assume 100% W + J/ψ signal



Azimuthal angle

- Diagnostic for SPS (peak at π) vs DPS (flat)
- Low statistics make interpretation difficult but distribution is suggestive of DPS
  - MC SPS shape very model dependent

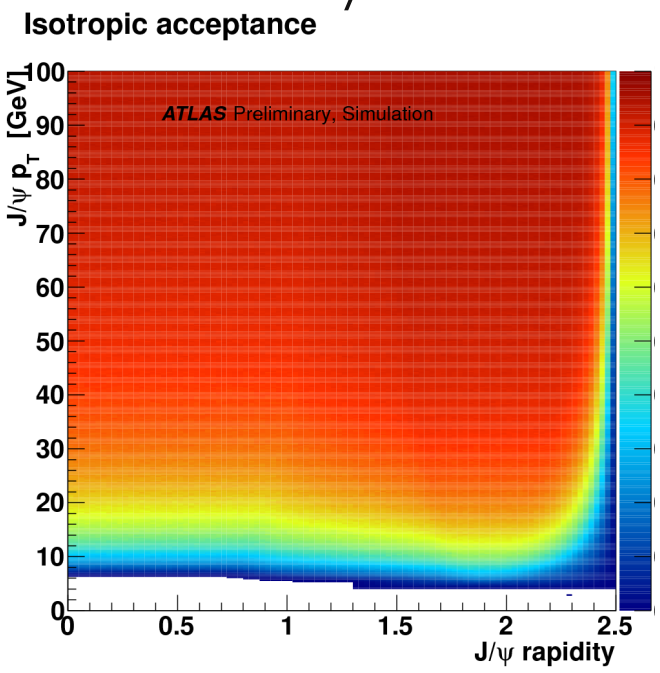


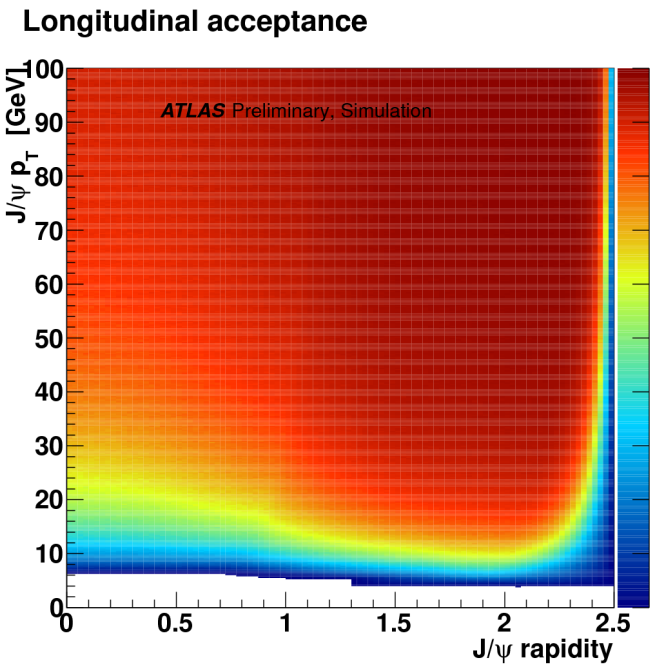


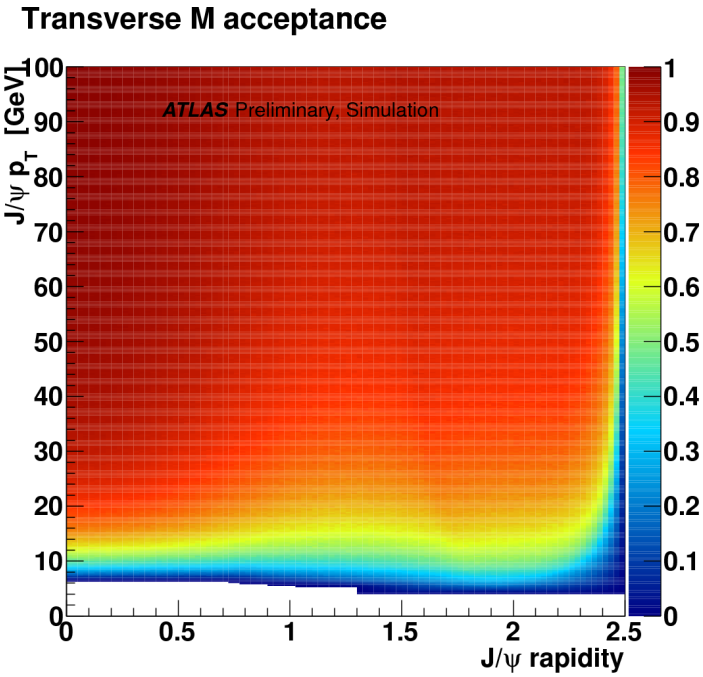
Prediction of total factorization ansatz

Acceptance/Efficiency Unfolding

- Correct for μ efficiency for J/ψ daughters to get "fiducial cross section"
  - i.e. not corrected for μ outside our kinematic cuts
- Then correct for μ falling outside kinematic cuts to get "inclusive cross section"
  - requires assumption on J/ψ decay angular distribution; envelope gives systematic







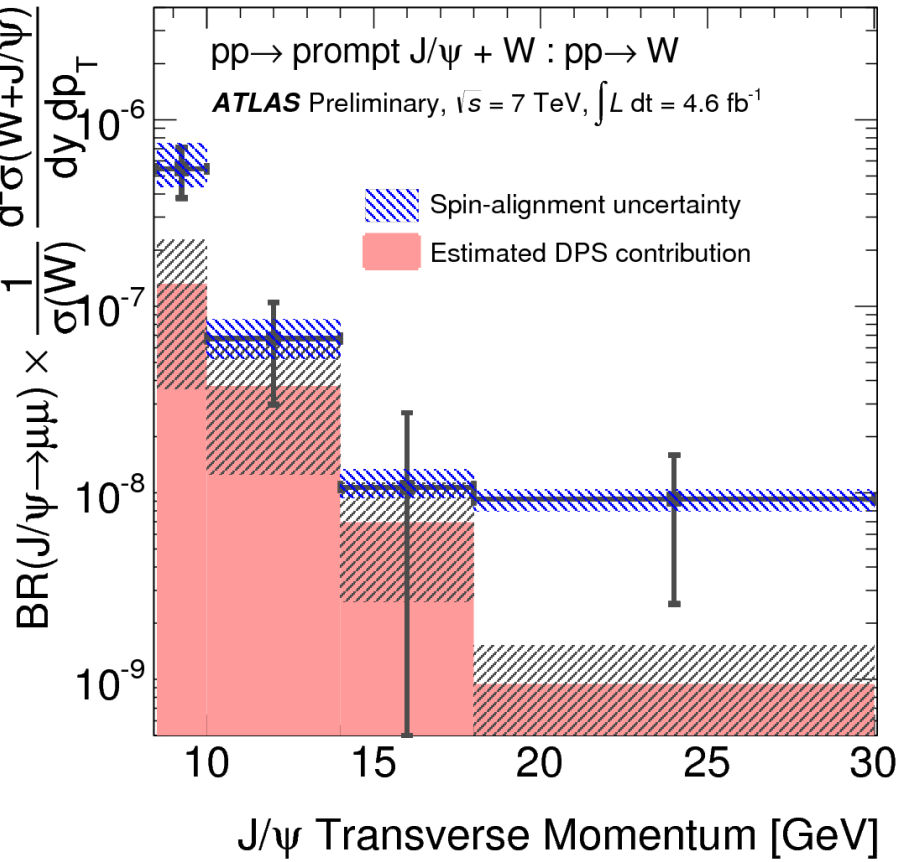
Systematics

- Largest systematic in inclusive measurement from J/ψ decay angular distribution ("spin-alignment")
- Largest systematics for fiducial measurement from muon efficiency and possible W efficiency non-cancellation
  - None of these affect significance of observation, only central value of measurement

Source	Barrel	Endcap
J/ψ muon efficiency	$\approx 5\%$	$\approx 5\%$
$W^{\pm}$ boson kinematics	2%	5%
Fit procedure	$^{+3}_{-2}\%$	$^{+2}_{-1}\%$
Choice of fit nuisance parameters	1%	1%
Choice of fit functional forms	4%	4%
Muon momentum scale	negligible	
J/ψ spin-alignment	$^{+36}_{-25}\%$	$^{+27}_{-13}\%$
Statistical	$^{+47}_{-40}\%$	$^{+30}_{-27}\%$

p_T-differential measurement

- Plotted: ratio of normalized differential σ to σ(W)
- Excess over DPS prediction concentrated in lowest momentum bin [8.5, 10] GeV



Results (1)

- Numbers are ratio to inclusive σ(W)
  - in all cases, $p_T(J/\psi) > 8.5$ GeV, $|y(J/\psi)| < 2.1$
- **Fiducial** ratio (does not correct for muon acceptance):

$$(50 \pm 12(\mathrm{stat}) \pm 4(\mathrm{syst})) \times 10^{-8}$$

- **Inclusive** ratio (corrects for muon acceptance, not for DPS contribution):

$$(123 \pm 31(\mathrm{stat}) \pm 10(\mathrm{syst})^{+40}_{-24}(\mathrm{pol})) \times 10^{-8}$$

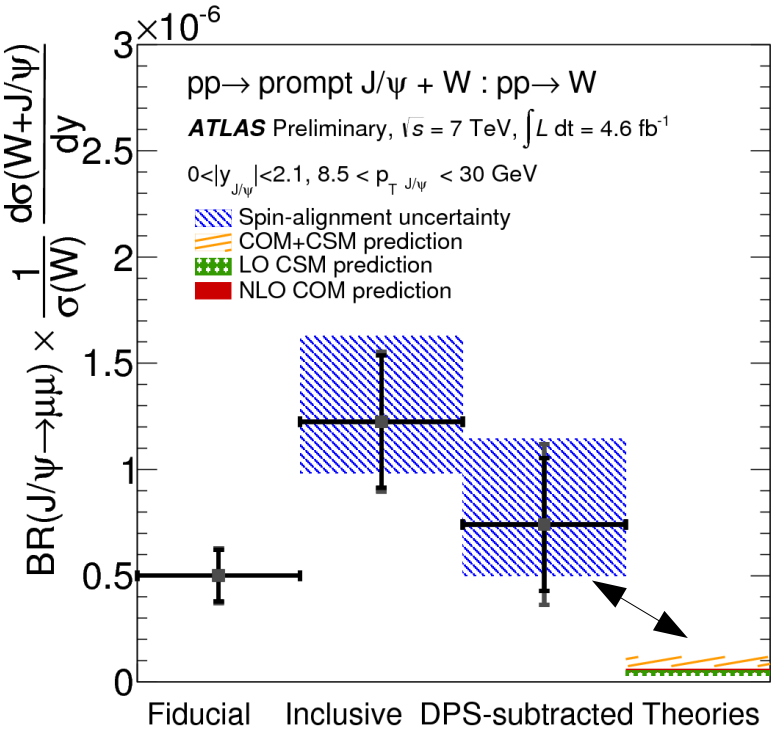
- **DPS-subtracted** ratio (subtracts expected DPS rate from inclusive):

$$(74 \pm 31(\mathrm{stat}) \pm 21(\mathrm{syst})^{+40}_{-24}(\mathrm{pol})) \times 10^{-8}$$

Results (2)

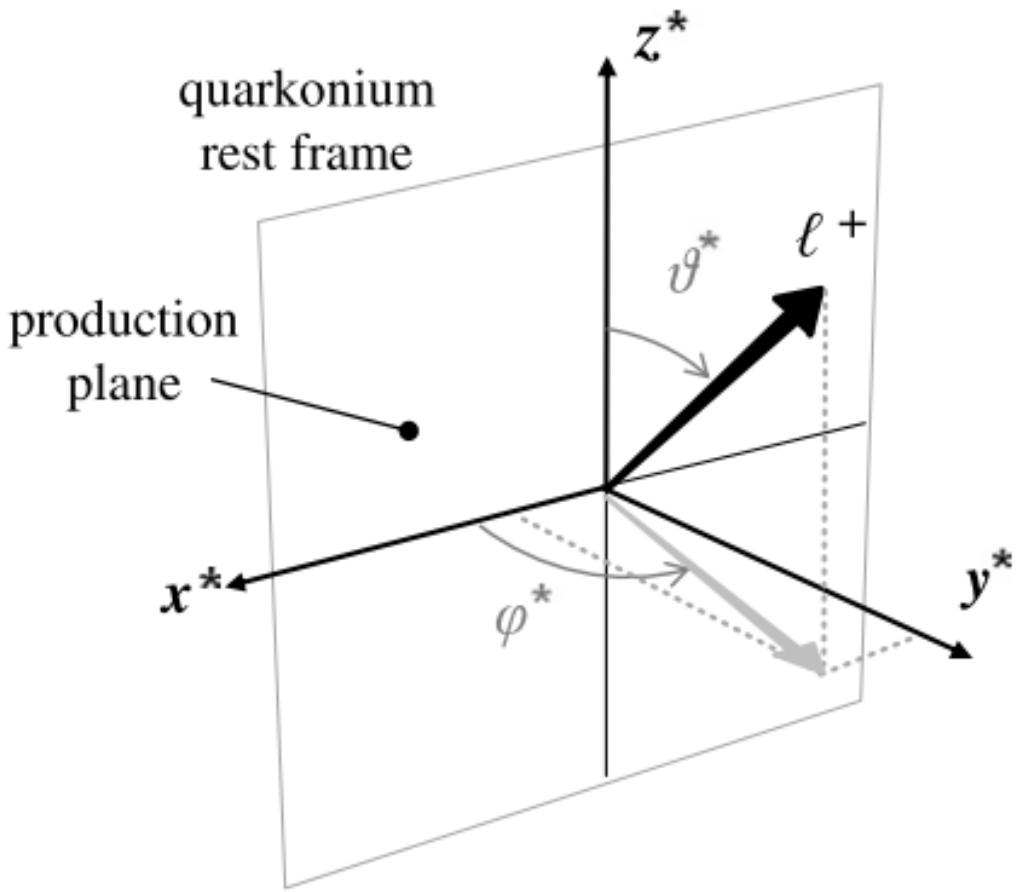
- Theory comparisons of single parton scattering rate:
  - color octet ("NLO COM"): Li, Song, Zhang, Ma, Phys. Rev. D83 (2011) 014001
  - color singlet ("LO CSM"): Lansberg, Lorce, arXiv:1303.5327

- Apparent large disagreement between theory and DPS-subtracted rate
- Suggestions from theory community of large feeddown from χ_c states



Conclusion

- W+J/ψ provides a potentially very interesting window into strong force dynamics, in both quarkonium production and proton structure.
- ATLAS has made a 5.3 σ observation of this process with 4.6 fb^{-1} of 7 TeV data. ATLAS-CONF-2013-042
- Low statistics make it hard to disentangle different components but distributions are suggestive of both SPS and DPS processes.
- Result appears to significantly exceed early theoretical expectations for SPS processes.

Extra

Polarizations