First measurement of associated vector boson plus prompt charmonium production at the ATLAS experiment

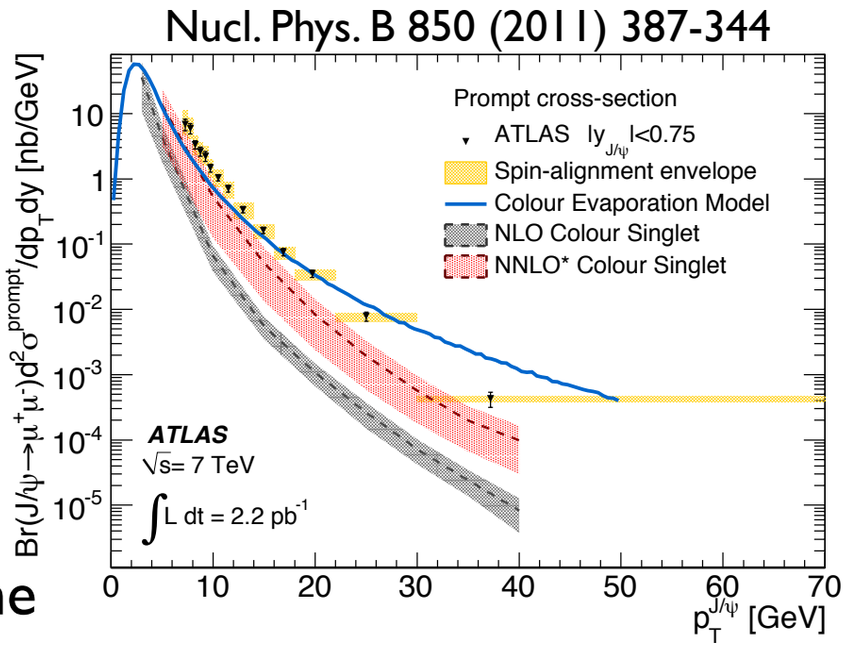
S. Leontsinis
on behalf of the ATLAS collaboration
National Technical University of Athens
Brookhaven National Laboratory

13th International Workshop on Meson Production, Properties and Interaction
KRAKÓW, POLAND
30th May 2014

Associated vector boson plus prompt charmonium production

Introduction

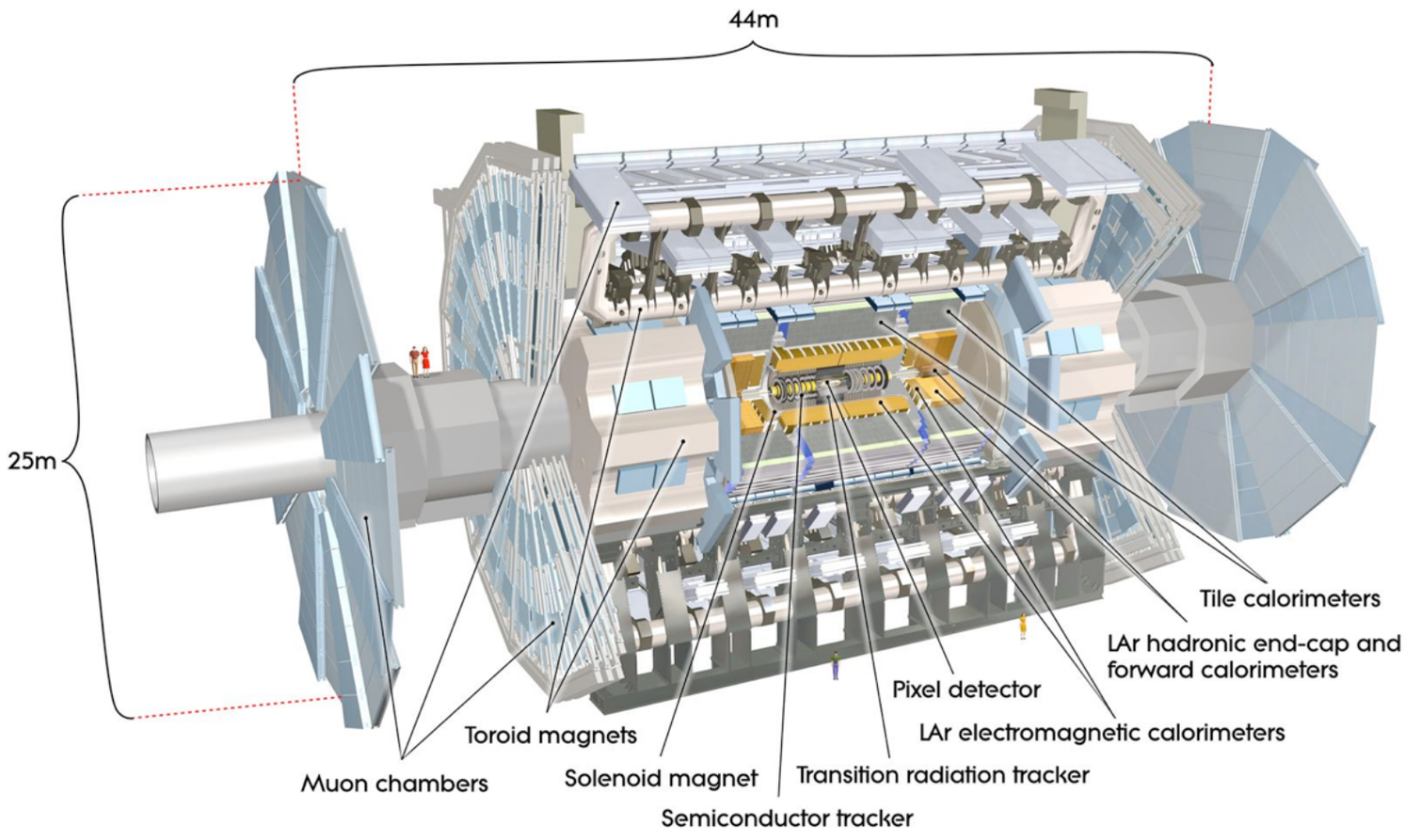
- J/ψ meson is a bound state of $c\bar{c}$
- Production mechanism of prompt J/ψ not well understood
- Production mechanisms:
  - Colour singlet process (CS): quarkonia produced is determined by the state of the original quarks
  - Colour octet process (CO): proposes that the quark pairs produced by the hard process are not produced with the quantum numbers of the physical quarkonia but evolve into the quarkonia state through radiation of soft gluons.



- $W^{\pm}$ + prompt J/ψ is a quark-initiated process with different production mechanisms than the inclusive J/ψ
- Possible scenarios considered prior to ATLAS measurement
  - being dominated by CO processes → test of NRQCD (Phys.Rev. D66 (2002) 114002)
- First measurement of the associated production of $W^{\pm}$ + prompt J/ψ (arxiv.org/1401.2831)
  - $W^{\pm} \to \mu\nu_{\mu}$ and $J/\psi \to \mu\mu$ with ATLAS detector at $\sqrt{s}$ = 7 TeV

The ATLAS detector

- General purpose detector at the LHC
  - Tracking
    - Silicon (Pixel+SemiConductor Tracker) and Transition Radiation Tracker
    - 2 T solenoidal field
- Muon identification:
  - Dedicated tracking chambers
  - 0.5-2T toroidal field

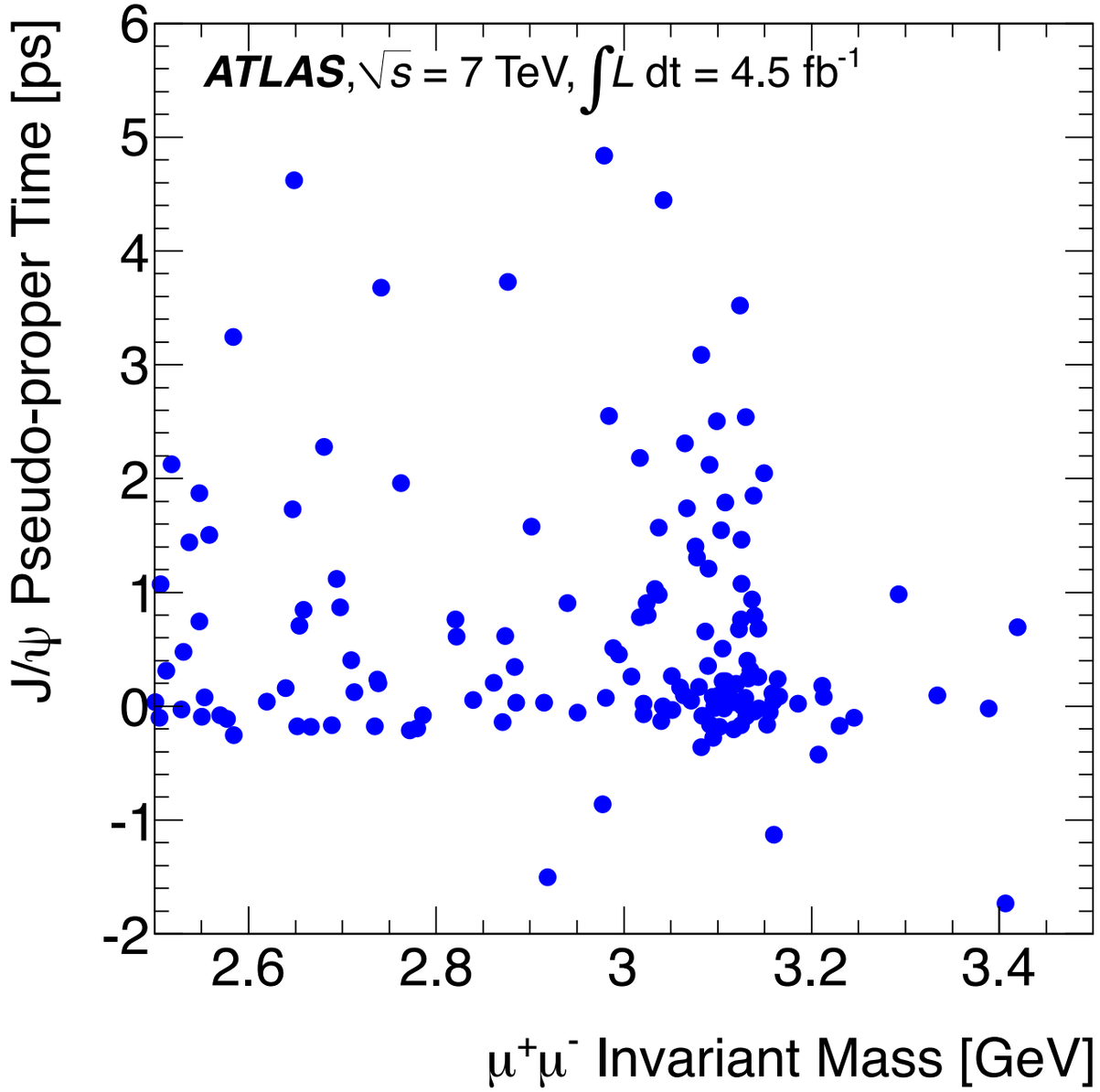


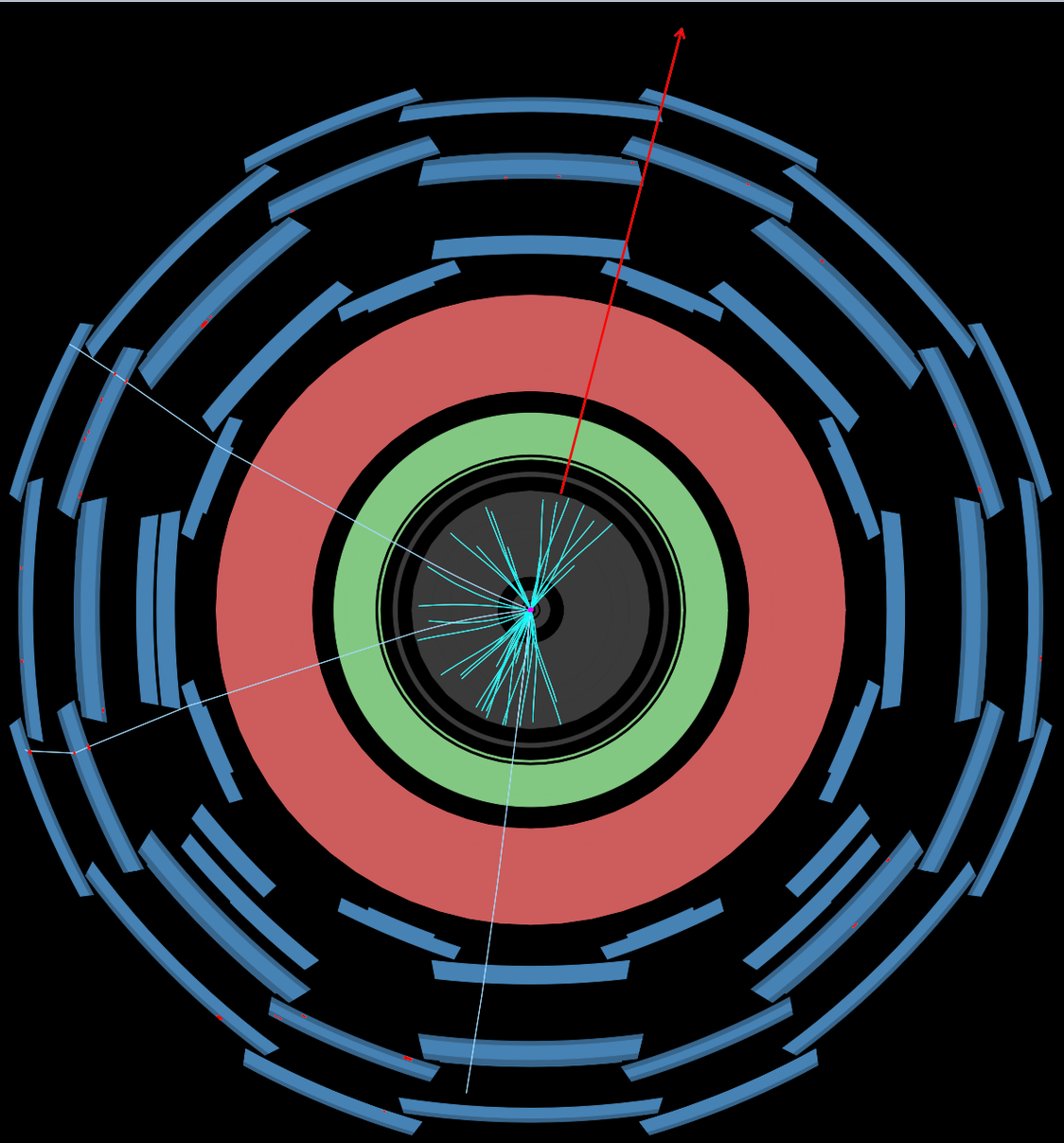
- Neutrinos
  - Not detected
  - Imbalance of transverse momentum

Associated vector boson plus prompt charmonium production

Data analysis

- 2011 dataset, 4.5 fb^{-1} of $\sqrt{s}$ = 7 TeV pp collisions
- Single muon trigger p_T>18 GeV
- $J/\psi \rightarrow \mu^+\mu^-$
  - p_T^{μ} >3.5 (2.5) GeV with $|\eta|$<1.3 (>1.3)
  - common vertex
  - invariant mass 2.5 < $m_{\mu\mu}$ < 3.5 GeV
  - 8.5 < $p_T^{J/\psi}$ < 30 GeV and $|y_{J/\psi}|$<2.1
- $W^{\pm} \rightarrow \mu\nu_{\mu}$
  - isolated muon p_T > 25 GeV and $|\eta|$<2.4
  - missing transverse energy > 20 GeV
  - transverse mass of the $W^{\pm}$ boson > 40 GeV
- Remove events with $|m_{\mu\mu}-m_z|$<10 GeV

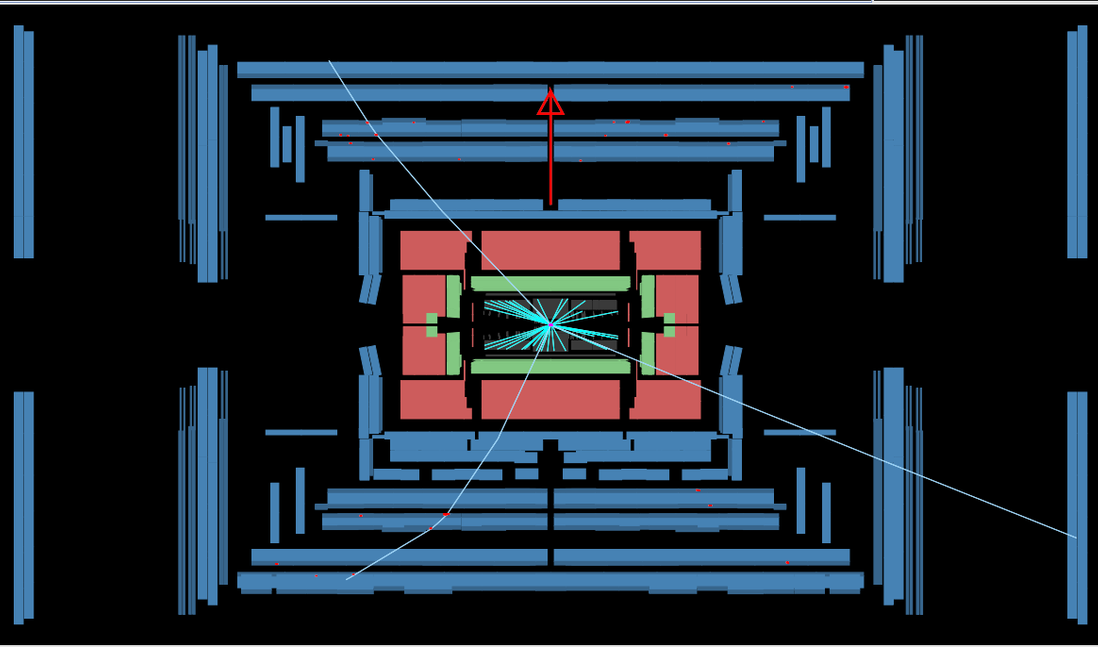




ATLAS EXPERIMENT

Run Number: 191513, Event Number: 11053516

Date: 2011-10-23 17:21:09 UTC

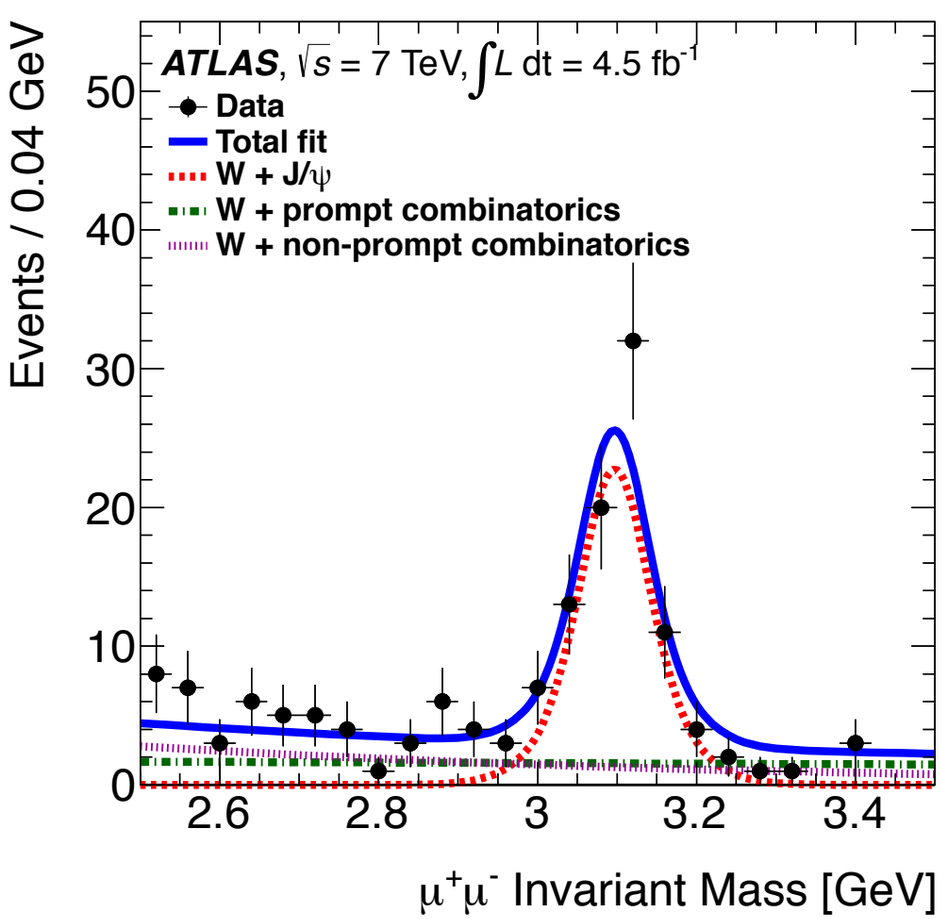


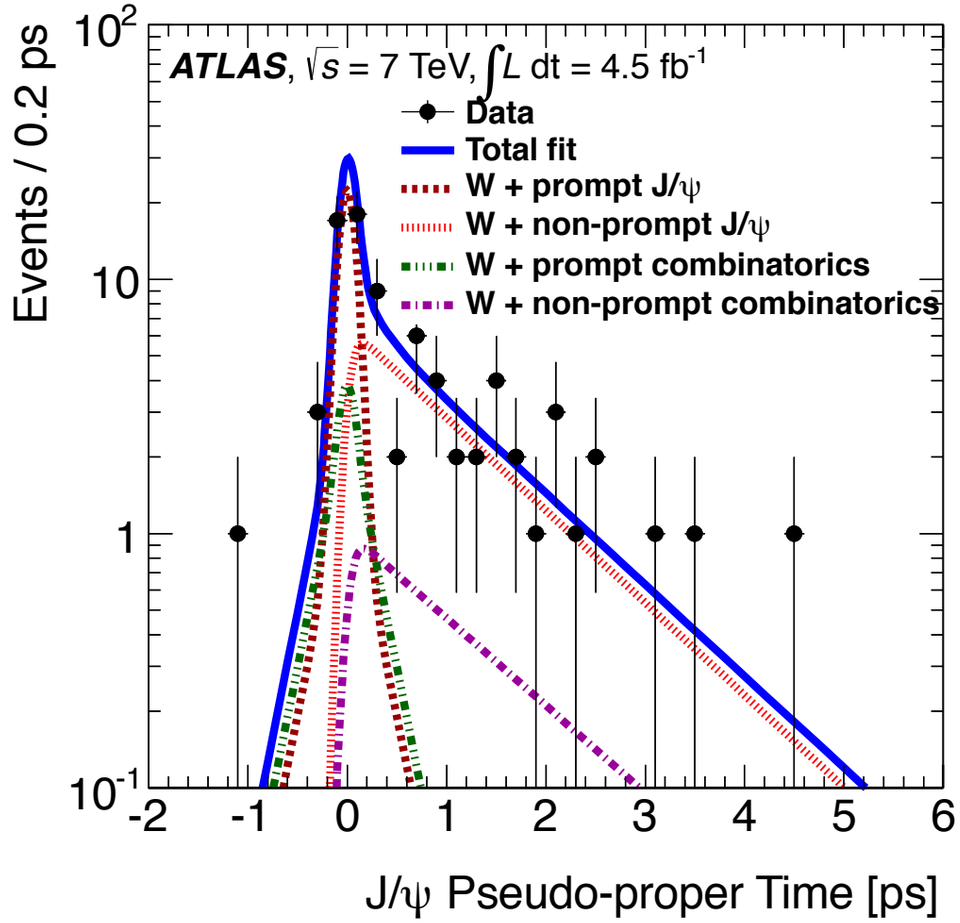
Associated vector boson plus prompt charmonium production

Extraction of prompt J/ψ component

- 2D unbinned maximum likelihood fit in J/ψ invariant mass and pseudo-proper time
- Mass
  - signal: gaussian
  - background: exponential
- Pseudo-proper time
  - prompt: gaussian + double sided exponential
  - non-prompt: single sided exponential

shape parameters taken from a fit in an inclusive J/ψ sample from data





Associated vector boson plus prompt charmonium production

Extraction of prompt J/ψ component

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	8.0×10^{-3}	1.4×10^{-6}	2.1×10^{-7}
Significance (σ)	2.4	4.7	5.1

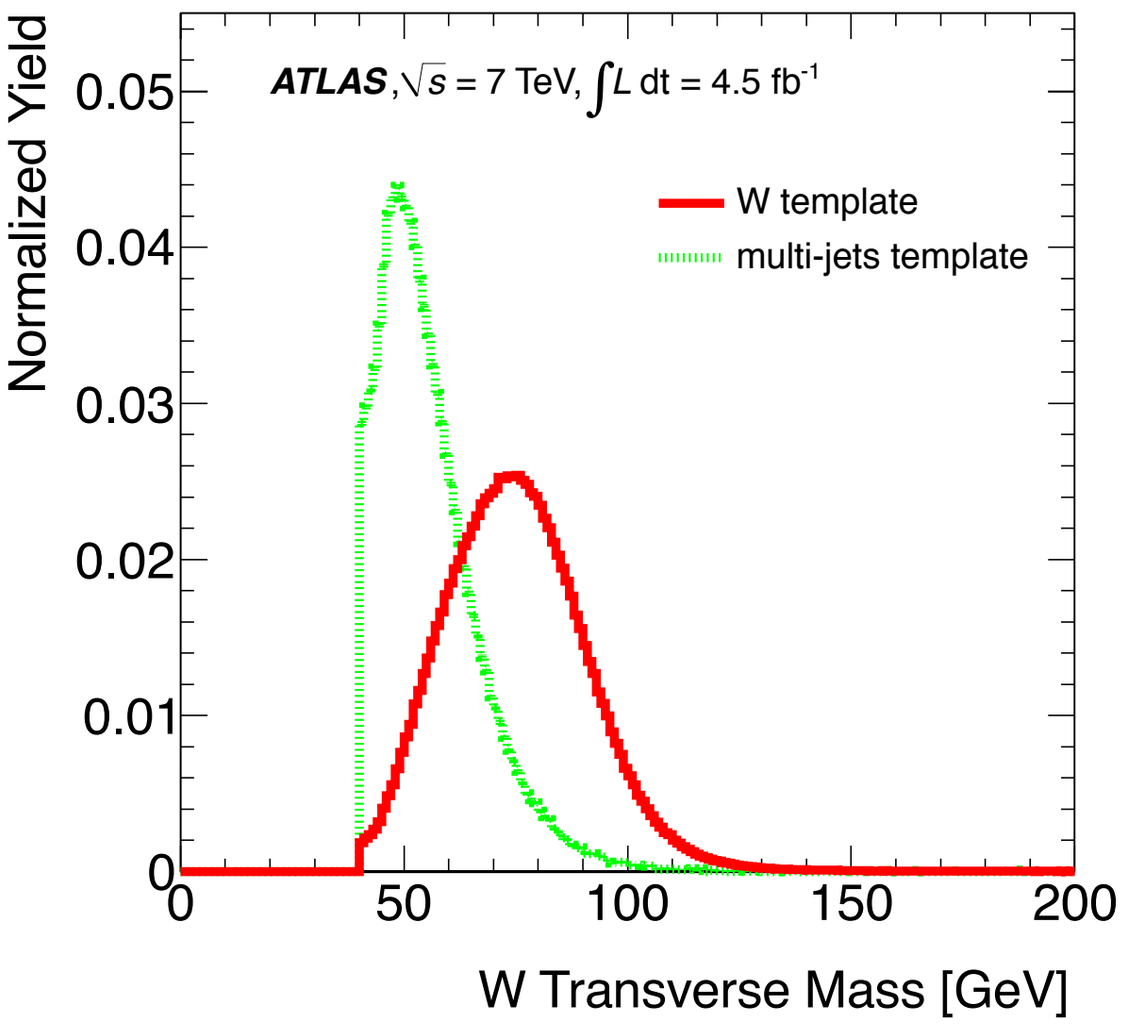
extract m_T^W events based on the prompt J/ψ yield using sPlot

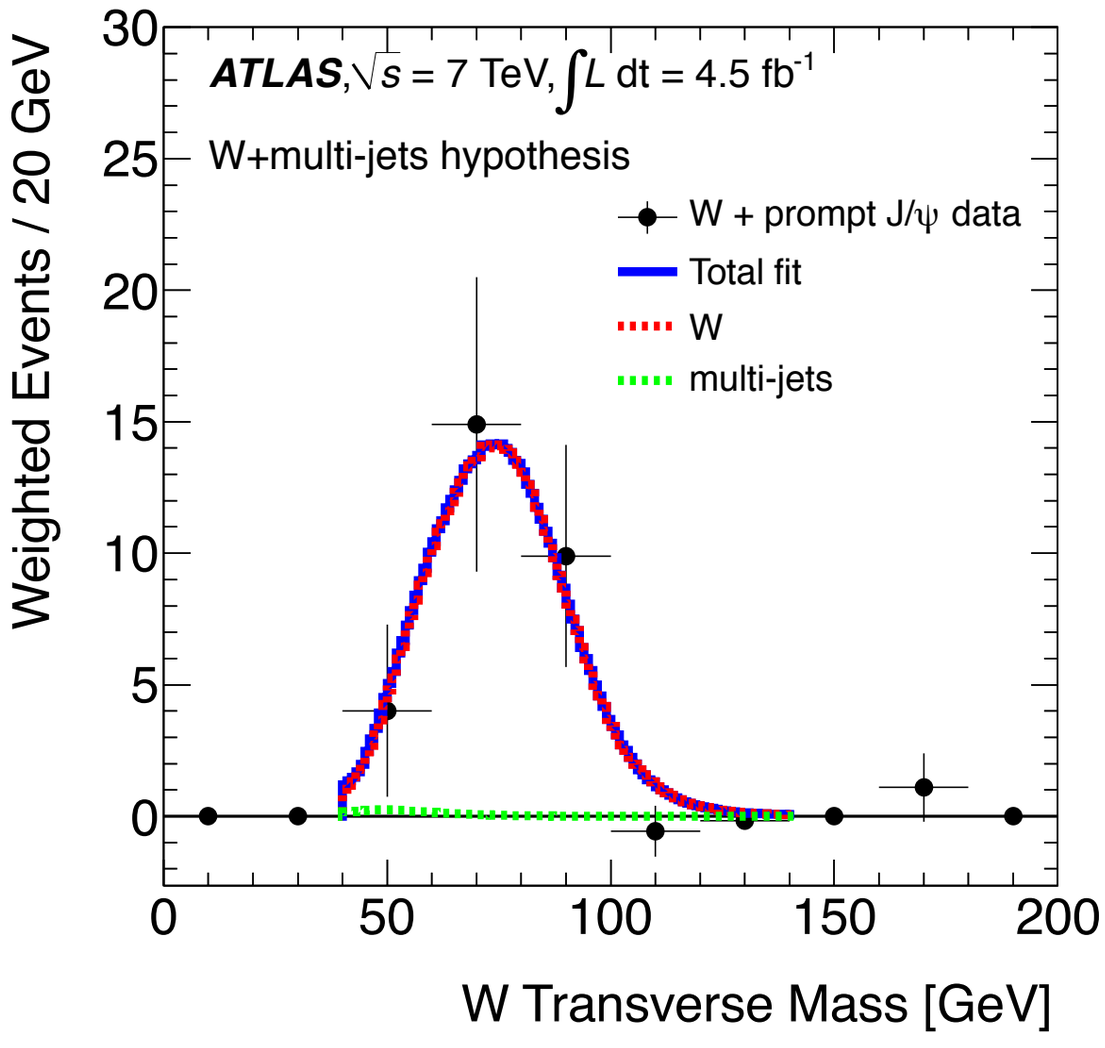
p-value evaluated with pseudo-experiments with B-only hypothesis to determine how often it fluctuates to S+B hypothesis

Associated vector boson plus prompt charmonium production

$W^{\pm}$ events associated with prompt J/ψs

- Confirming the $W^{\pm}$
- Weighted $W^{\pm}$ transverse mass distribution using J/ψ signal yield compared with
  - $W^{\pm}$ signal template
  - data-driven multi-jet template
- Multi-jet yield < 0.3 events at 95% credibility





Associated vector boson plus prompt charmonium production

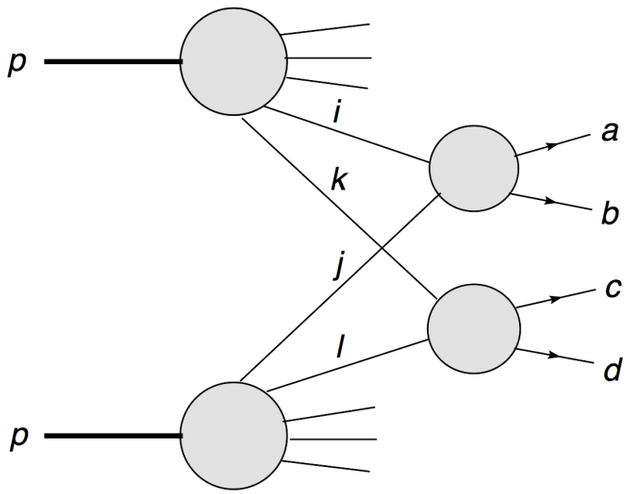
Backgrounds

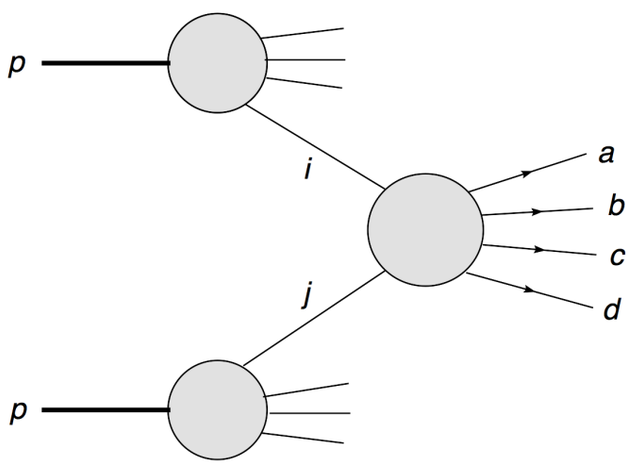
- $W^{\pm}$ + b
  - rejected from the fit
- $B_c \rightarrow J/\psi \mu^{\pm} \nu_{\mu} X$
  - check the three-muon invariant mass below 12 GeV
- Z+jets
  - $|m_{\mu\mu}-m_z|<10$ GeV
- Pileup
  - $W^{\pm}$ + J/ψ candidates might be produced in different pp collisions of the same bunch crossing
  - $N = N^{extra}_{vtx} \times P_{J/\psi} \times N_{W^{\pm}}$
    - N^{extra}_{vtx}: Number of extra vertices near the $W^{\pm}$
    - $P_{J/\psi}$: Probability of producing a J/ψ meson
    - $N_{W^{\pm}}$: number of $W^{\pm}$ candidates in fiducial region
  - Estimated ~ 1.8 ± 0.2 events (subtracted from the cross section measurement)

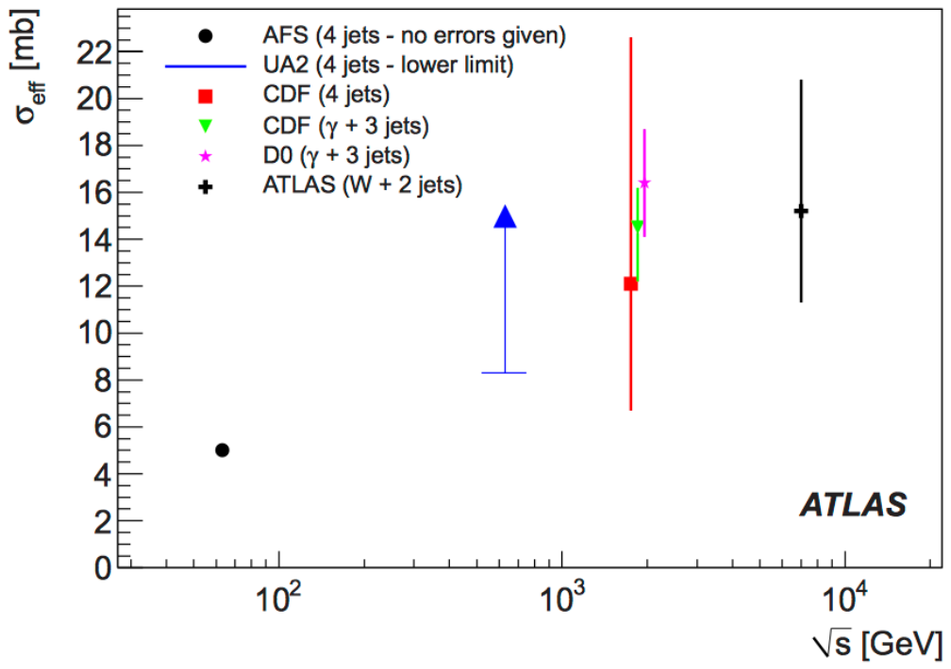
Associated vector boson plus prompt charmonium production

Double parton scattering

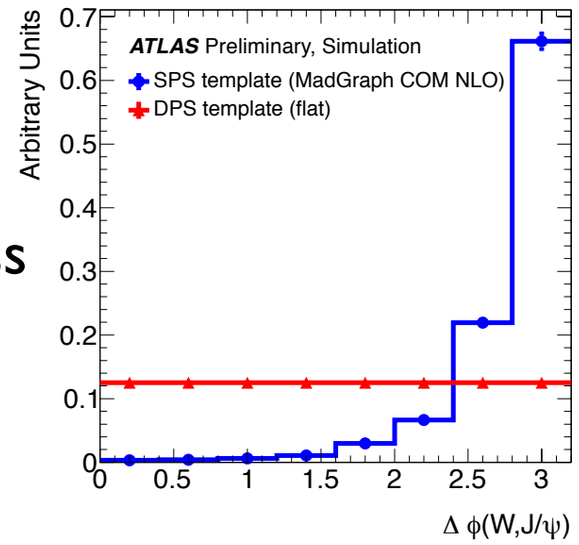
- $W^{\pm}$ and J/ψ candidates originate from two different parton interactions in the same pp collision

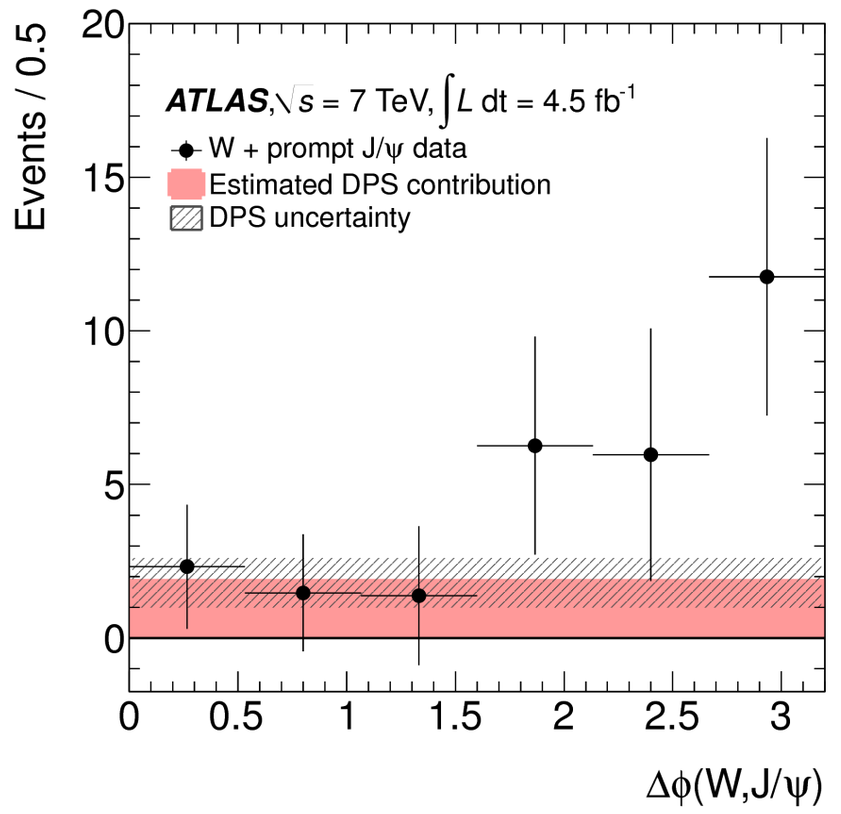






- $N_{DPS} = P_{J/\psi|W^{\pm}} N_{W^{\pm}}$
  - $P_{J/\psi|W^{\pm}} = \sigma_{J/\psi}/\sigma_{eff}$
    - Probability of an additional process to occur (along with the J/ψ)
    - $\sigma_{eff} = 15+3^{+5}_{-3}$ mb (ATLAS measurement arXiv:1301.6872)
  - $N_{W^{\pm}}$: number of $W^{\pm}$ candidates in fiducial region
- $N_{DPS} = 11 \pm 4$





Associated vector boson plus prompt charmonium production

Cross section ratio $W^{\pm}$+J/ψ : $W^{\pm}$

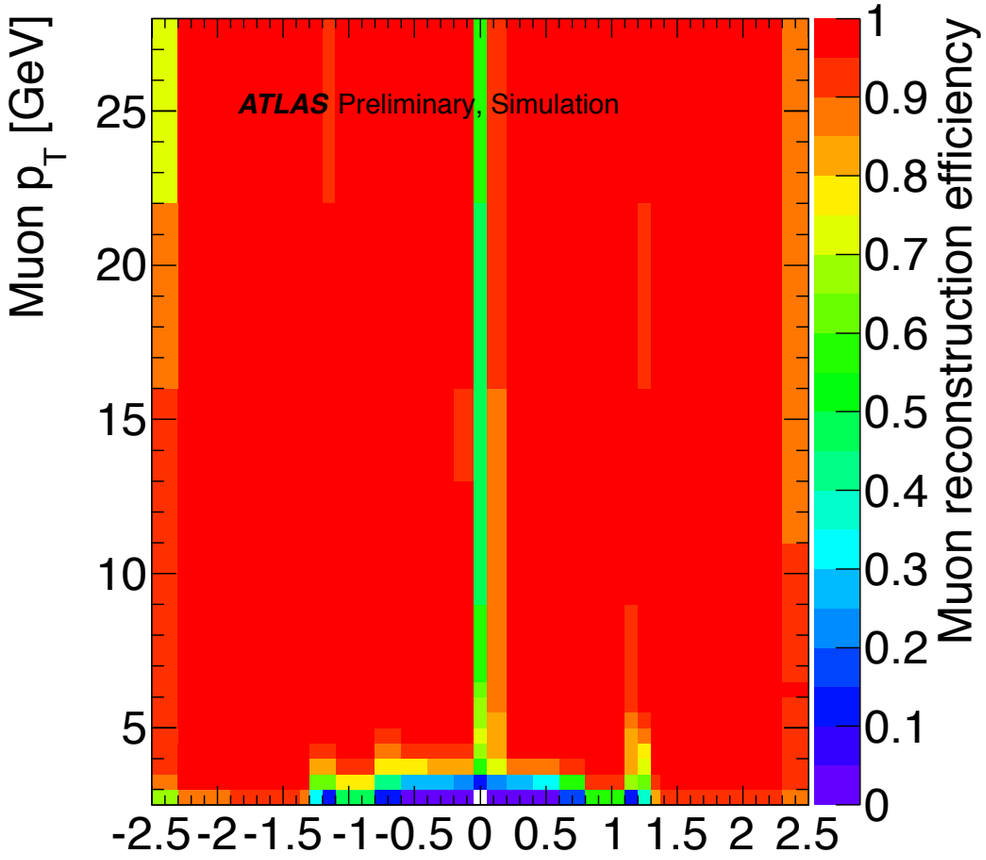
$$\frac{\sigma(pp \to W + \text{prompt} \quad J/\psi)}{\sigma(pp \to W)} = \frac{\frac{N^{W+J/\psi}}{\epsilon^{J/\psi} \cdot \alpha^{J/\psi} \cdot \epsilon^{W} \cdot \mathcal{L}}}{\frac{N^{W}}{\epsilon^{W} \cdot \mathcal{L}}}$$

- Ratio reduces (cancels) systematic uncertainties associated with luminosity and the W boson
- Ingredients missing
  - efficiency ε(J/ψ)
  - acceptance α(J/ψ)

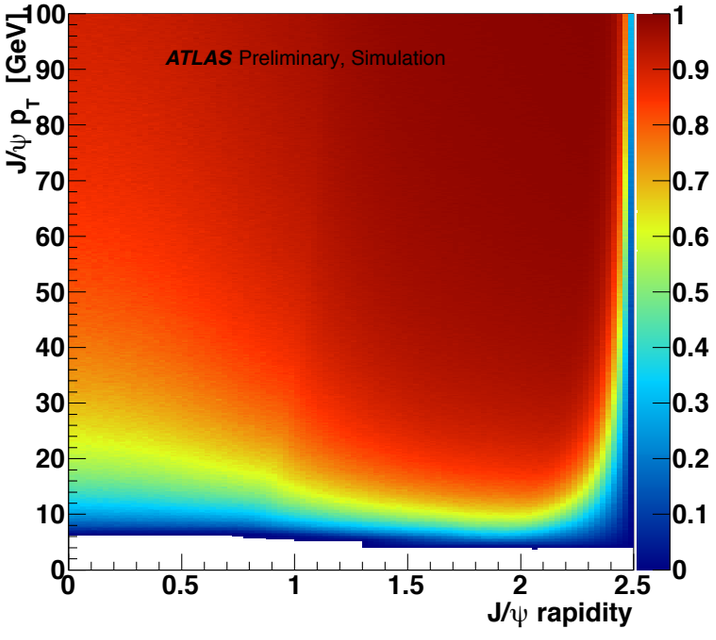
Associated vector boson plus prompt charmonium production

Efficiency - acceptance corrections

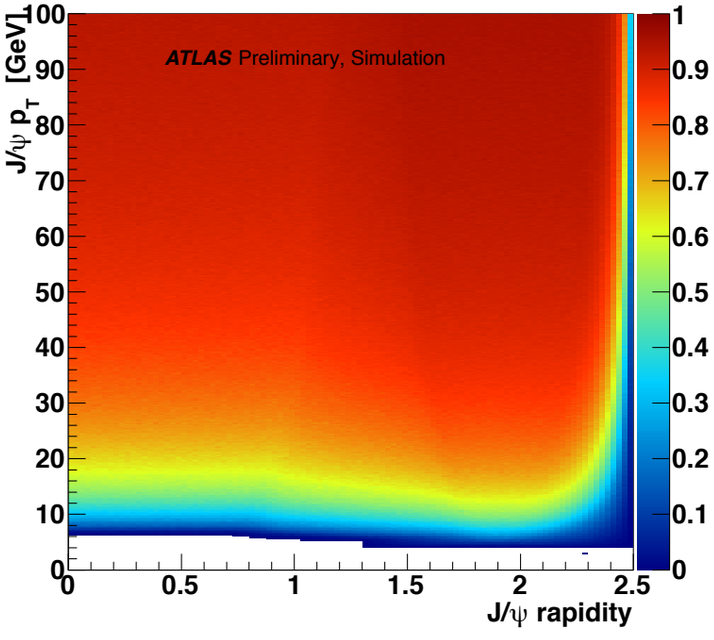
- Muon reconstruction efficiencies calculated using J/ψ "tag-and-probe" method
- Decay muons can follow different paths (depending on the spin-alignment)
- The efficiency for these muons to fall in the fiducial region - acceptance
  - Following different J/ψ spin-alignment scenarios



Longitudinal acceptance



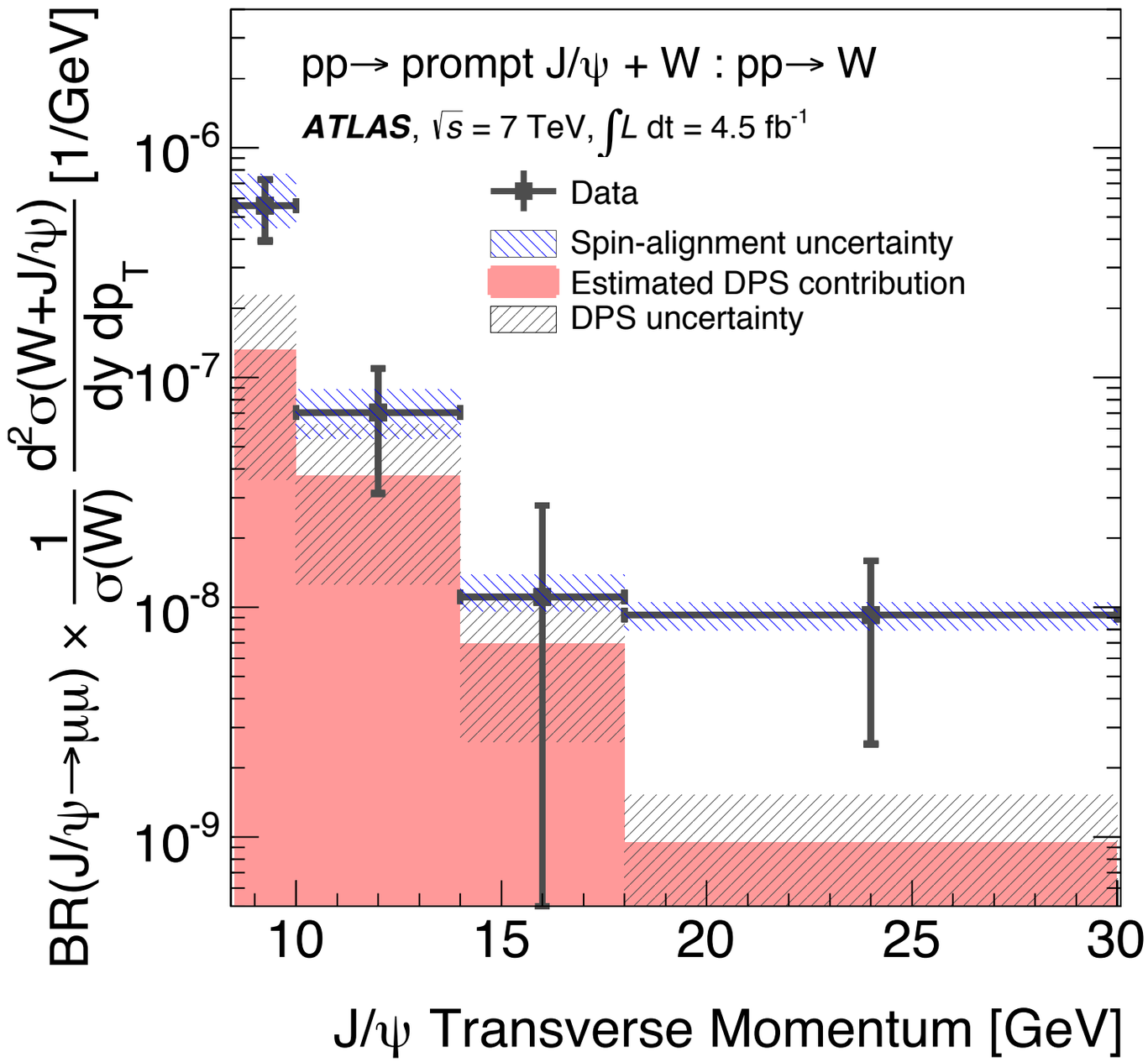
Isotropic acceptance



Associated vector boson plus prompt charmonium production

Inclusive cross section ratio

- Inclusive differential cross section
- Rare process
- Estimation for DPS contribution
  - 40% of the total signal
- SPS dominated low $p_T^{J/\psi}$ production rate



Associated vector boson plus prompt charmonium production

Conclusions

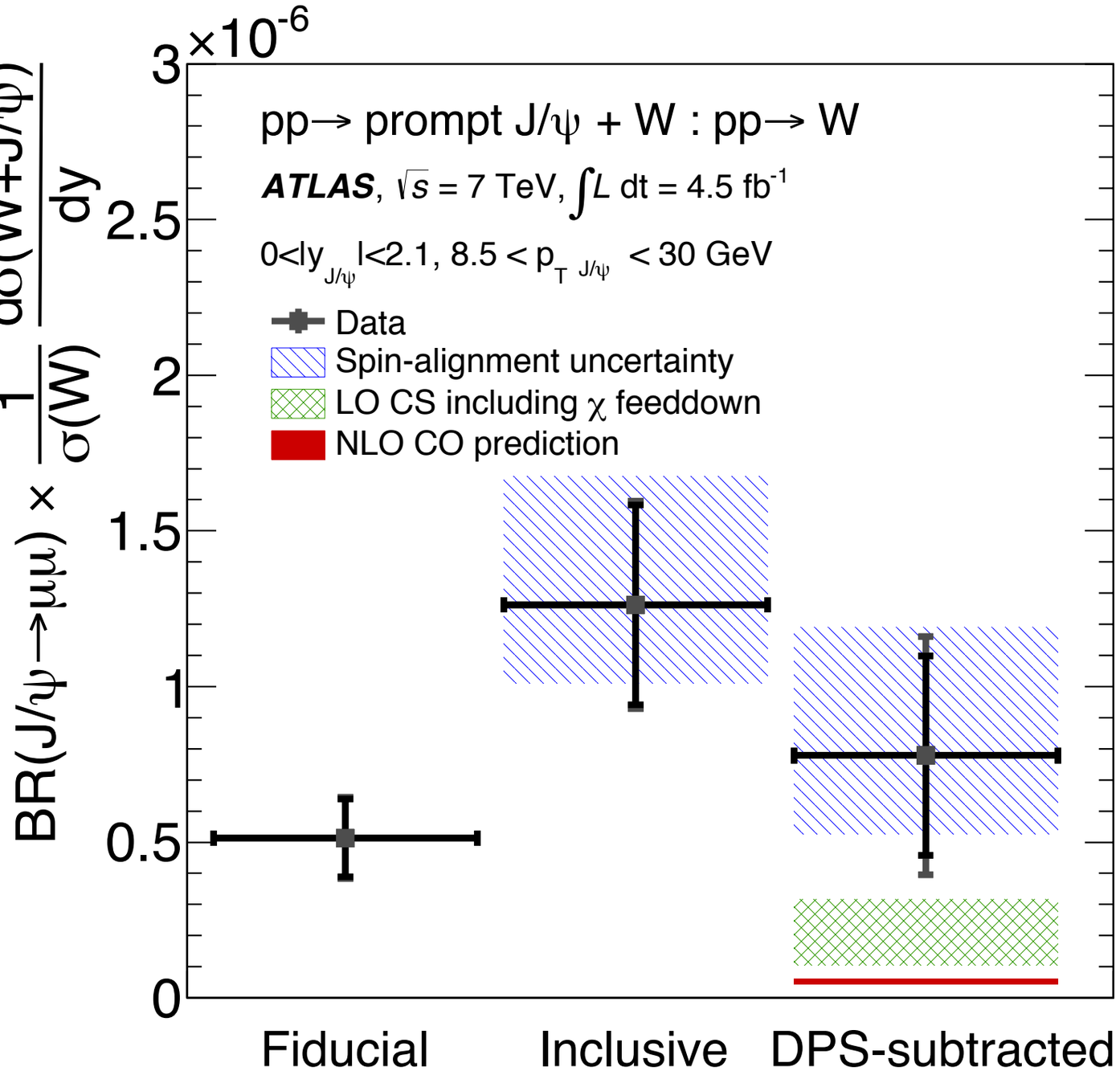
$R_{J/\psi}^{fid} = (51 \pm 13 \pm 4) \times 10^{-8}$

$R_{J/\psi}^{incl} = (126 \pm 32 \pm 9) \times 10^{-8}$

$R_{J/\psi}^{DPS\ sub} = (78 \pm 32 \pm 22^{+41}_{-25}) \times 10^{-8}$

LO CSM contributions: (10-32) x 10^{-8}

NLO COM contributions (4.6-6.2) x 10^{-8}



- First observation of charmonium + vector boson production with a statistical significance of 5.1σ
- Measurement of cross-section ratio $W^{\pm}+J/\psi : W^{\pm}$
- CSM theories revisited
  - CSM contributions larger than COM
- Differential cross section ratio as a function of $p_T^{J/\psi}$ suggests big single parton scattering contribution

European Union
European Social Fund
OPERATIONAL PROGRAMME
EDUCATION AND LIFELONG LEARNING
investing in knowledge society
MINISTRY OF EDUCATION, LIFELONG LEARNING AND RELIGIOUS AFFAIRS
MANAGING AUTHORITY
NSRF 2007-2013
EUROPEAN SOCIAL FUND
Co- financed by Greece and the European Union

Back up

Associated vector boson plus prompt charmonium production

Uncertainties

Source	Barrel	Endcap
J/ψ muon efficiency	(3–5)%	(3–5)%
$W^{\pm}$ 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	$^{+47}_{-40}$%	$^{+30}_{-27}$%