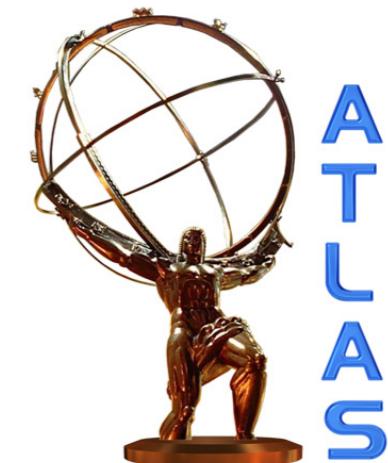


Observation and measurements of the production of prompt and non-prompt J/ψ mesons in association with a Z boson in pp collisions at $\sqrt{s} = 8\text{TeV}$ with the ATLAS detector

S. Leontsinis
on behalf of the ATLAS Collaboration

National Technical University of Athens
Brookhaven National Laboratory

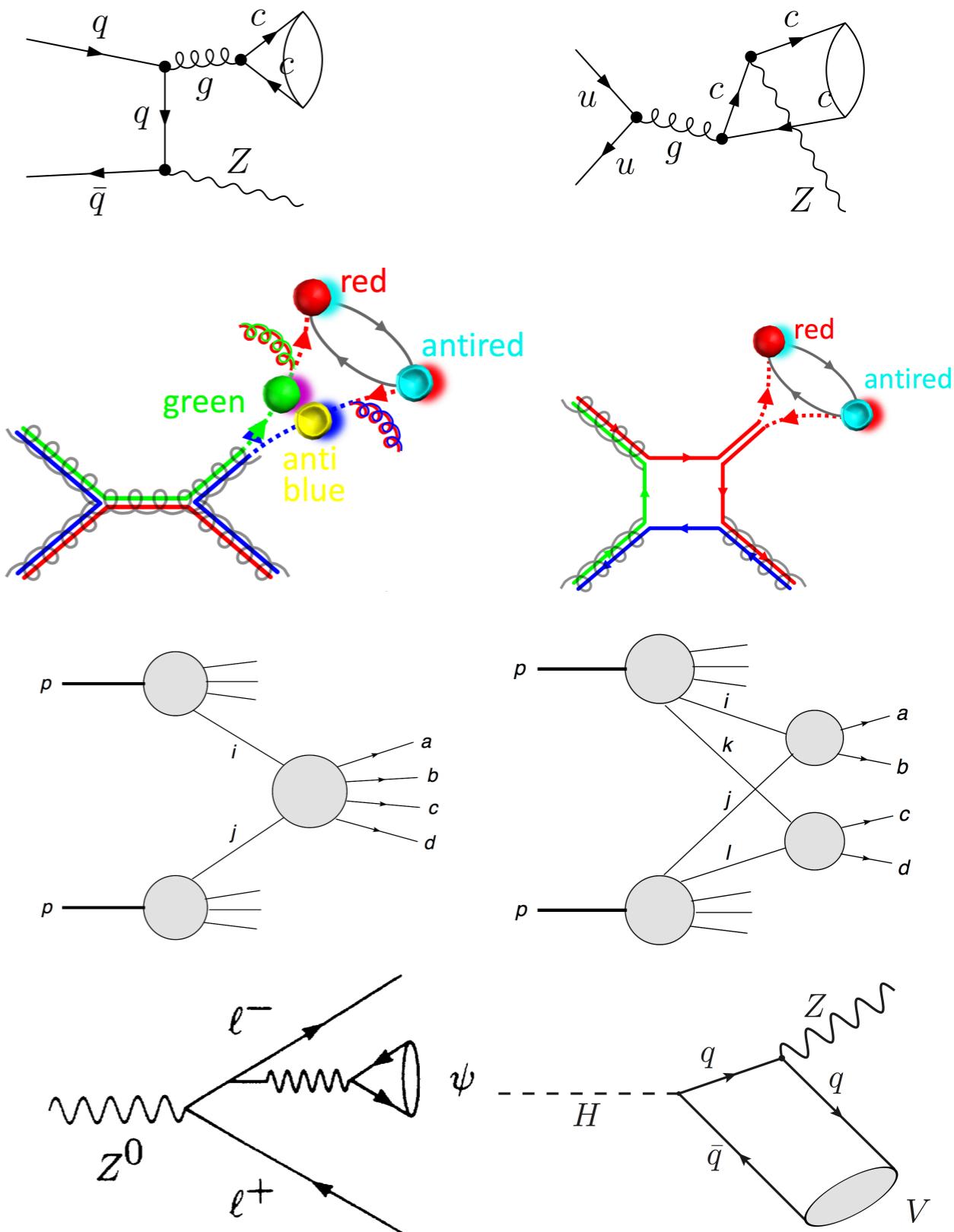
15th April 2015



Associated production of $Z+J/\psi$

Introduction

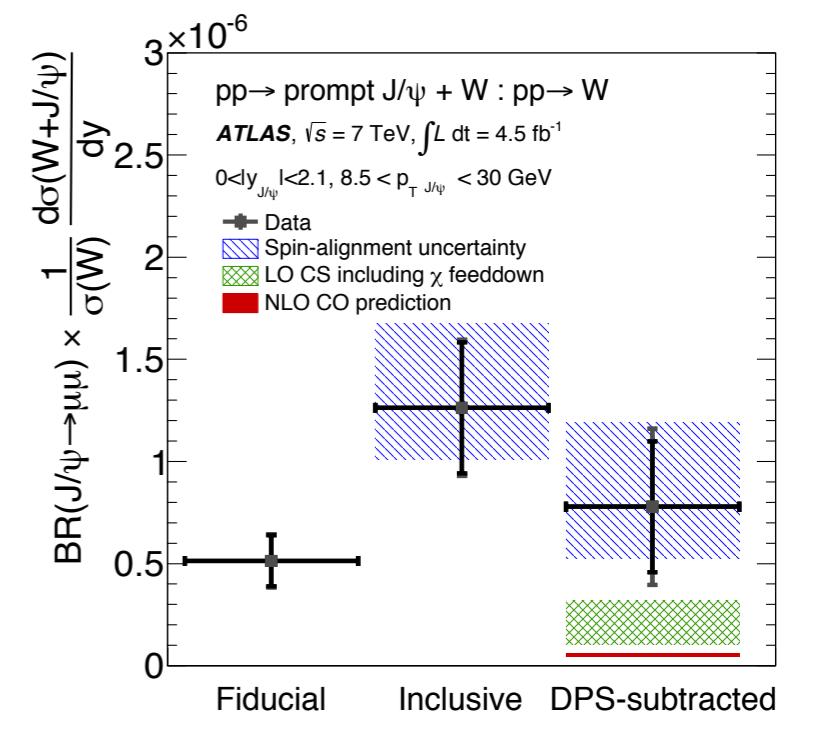
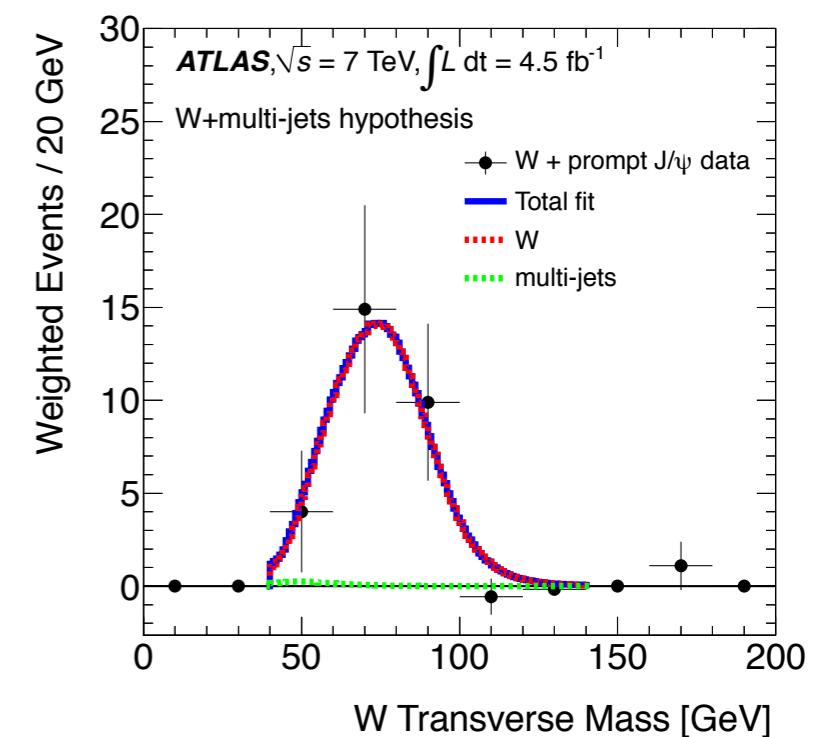
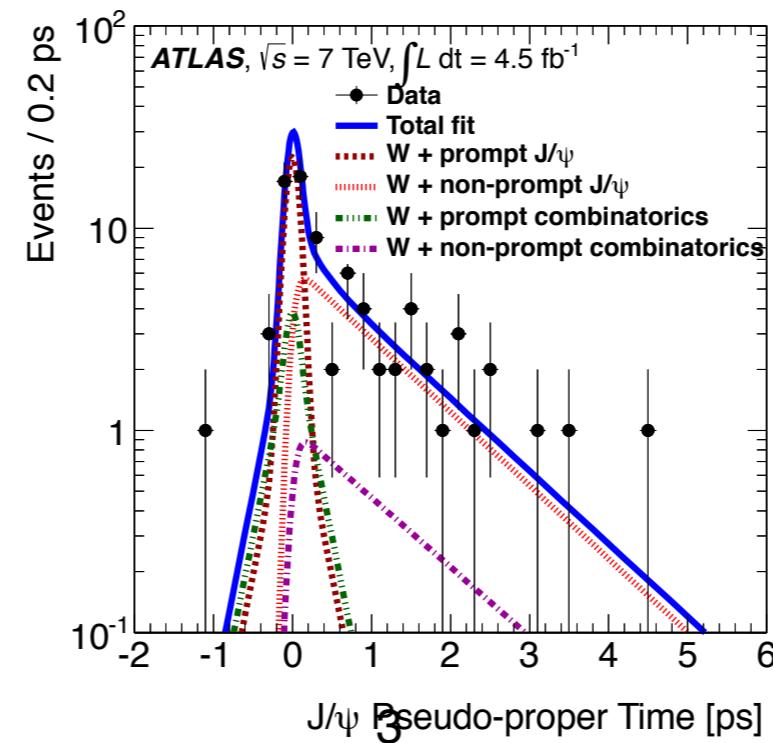
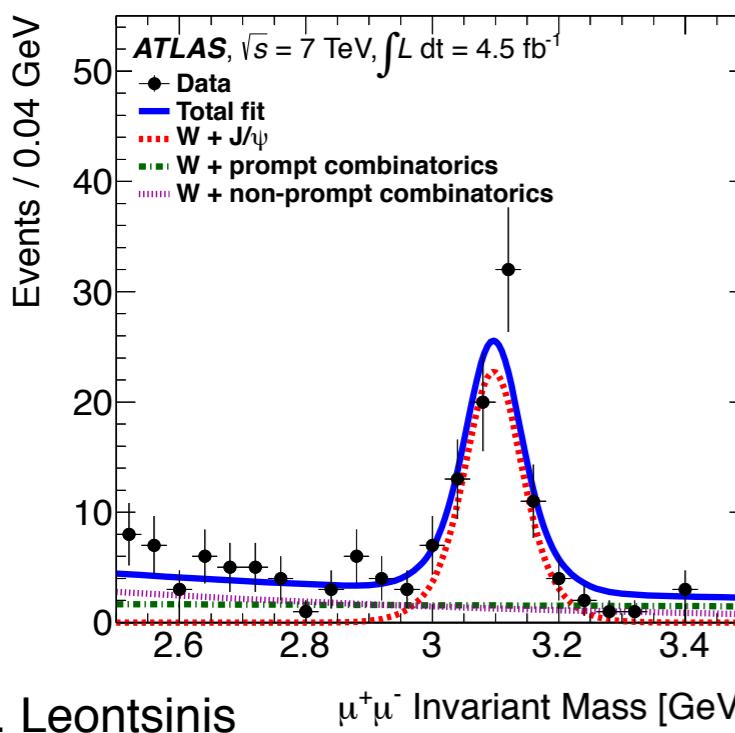
- Associated production of $Z+J/\psi$ is an attractive final state
 - clean signature (muons, electrons)
 - J/ψ is a $c\bar{c}$ bound state
 - provides insight in the production/formation mechanism of the J/ψ meson
 - colour-octet contributions were thought to dominate at high p_T
 - higher order colour-singlet contributions may play a comparable role
- study of Single Parton Scattering (SPS) and Double Parton Scattering (DPS)
- search for the rare decay of $Z \rightarrow J/\psi + ll$
- performance of the muon reconstruction in the low p_T region
- search for $H \rightarrow Z+J/\psi$
- BSM processes:
 - light higgs $Zh \rightarrow Z\mu\mu$



Associated production of $Z + J/\psi$

Introduction

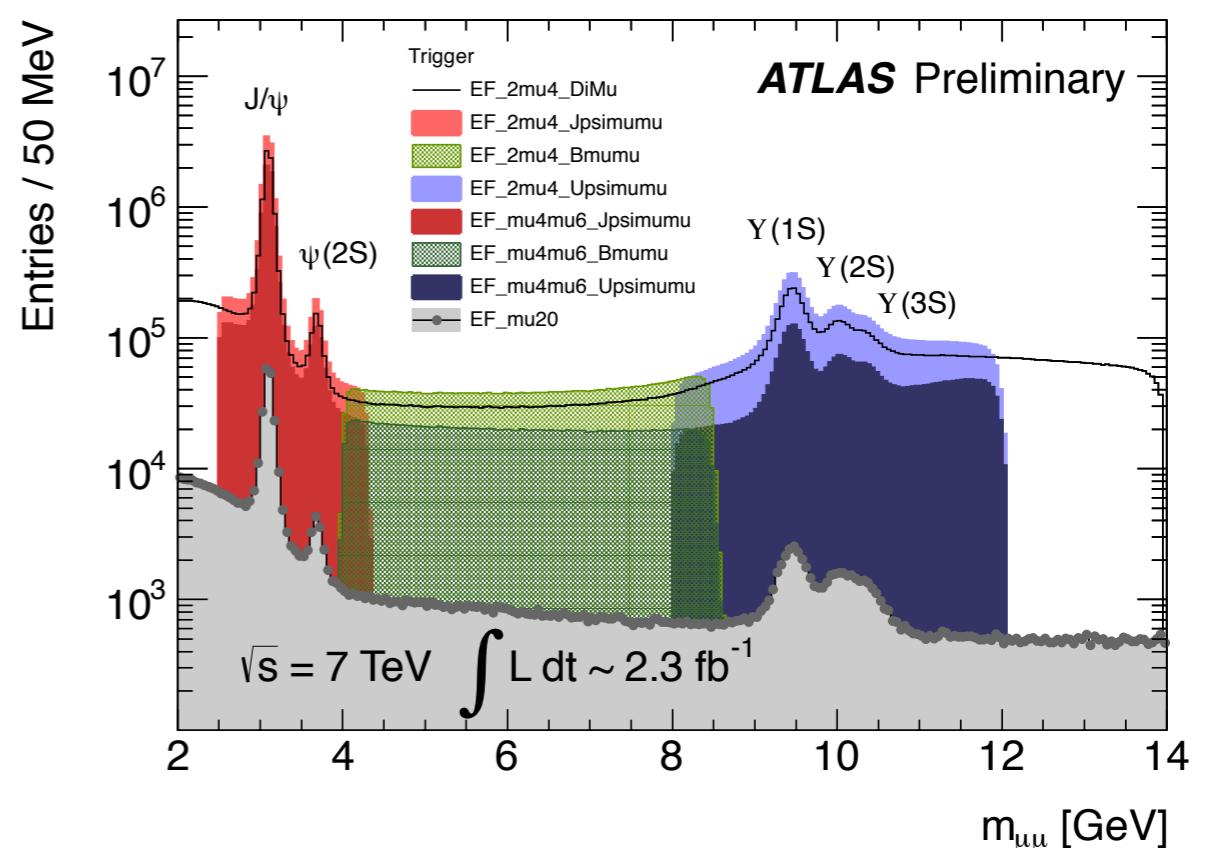
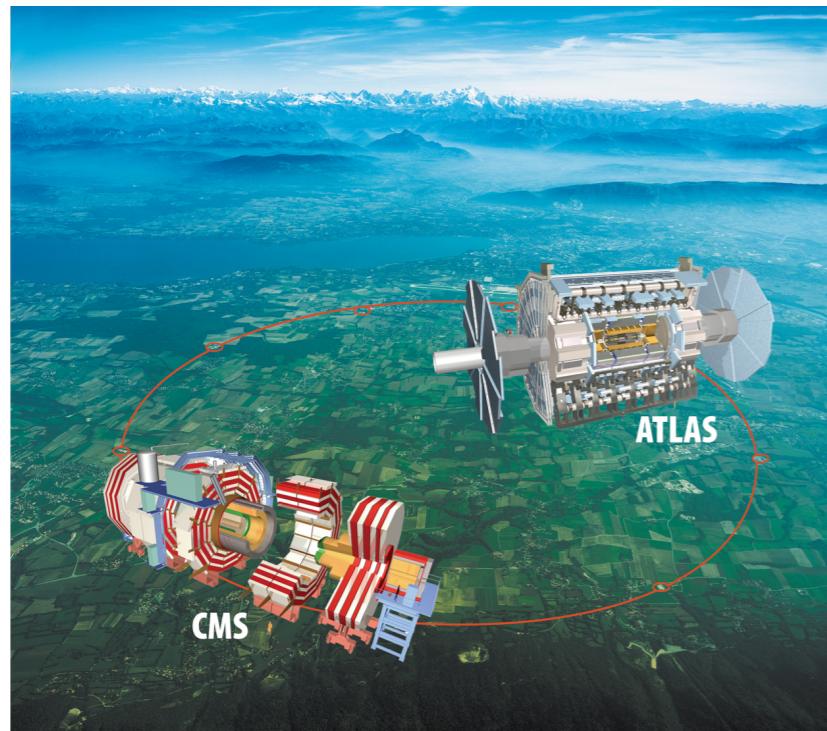
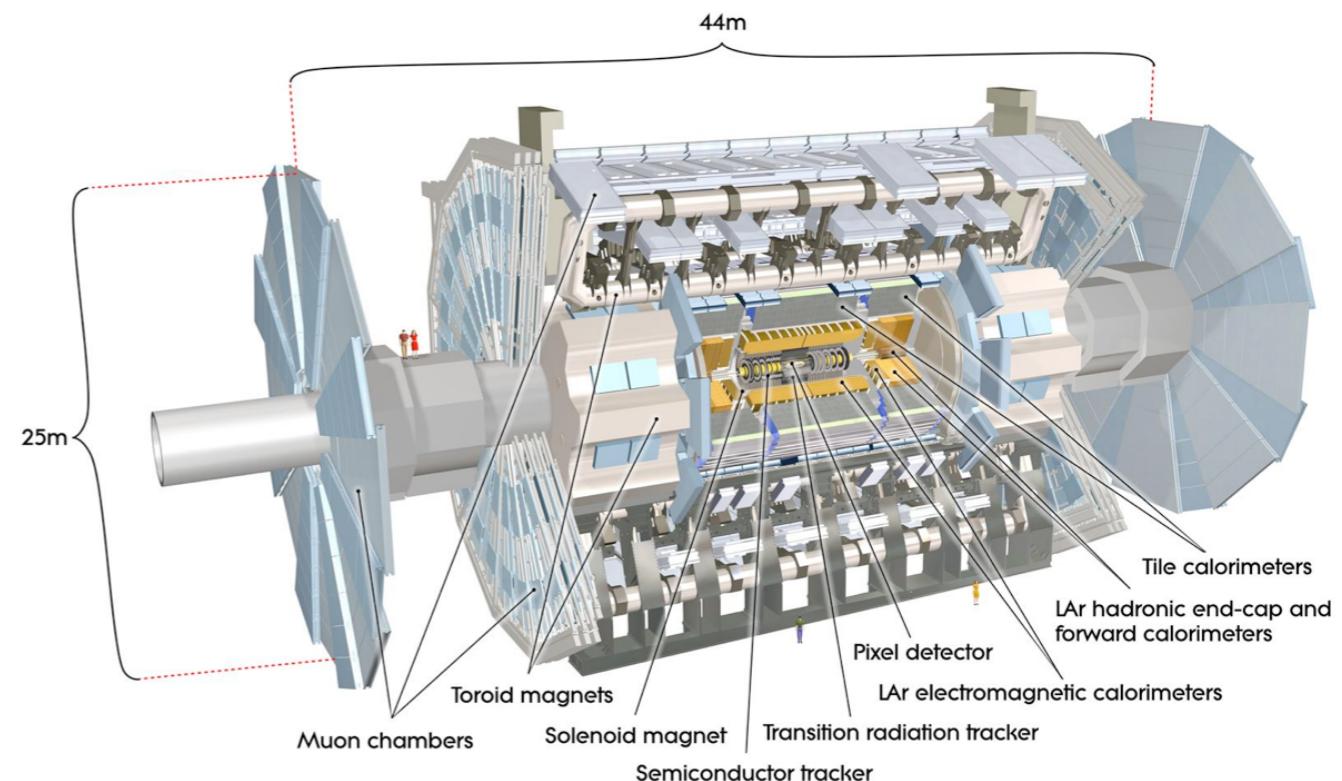
- First search of the associated production of $\Upsilon(1S) + W(Z)$ by CDF
 - No signal - set limit
- First observation of such process
 - $W(\rightarrow \mu\nu_\mu) + \text{prompt } J/\psi(\rightarrow \mu\mu)$ by ATLAS at $\sqrt{s}=7$ TeV
- Today:
 - $Z(\rightarrow ll) + J/\psi(\rightarrow \mu\mu)$ (either prompt or non-prompt) at $\sqrt{s}=8$ TeV ($ll: e$ or μ)
 - arXiv:1412.6428



Associated production of $Z + J/\psi$

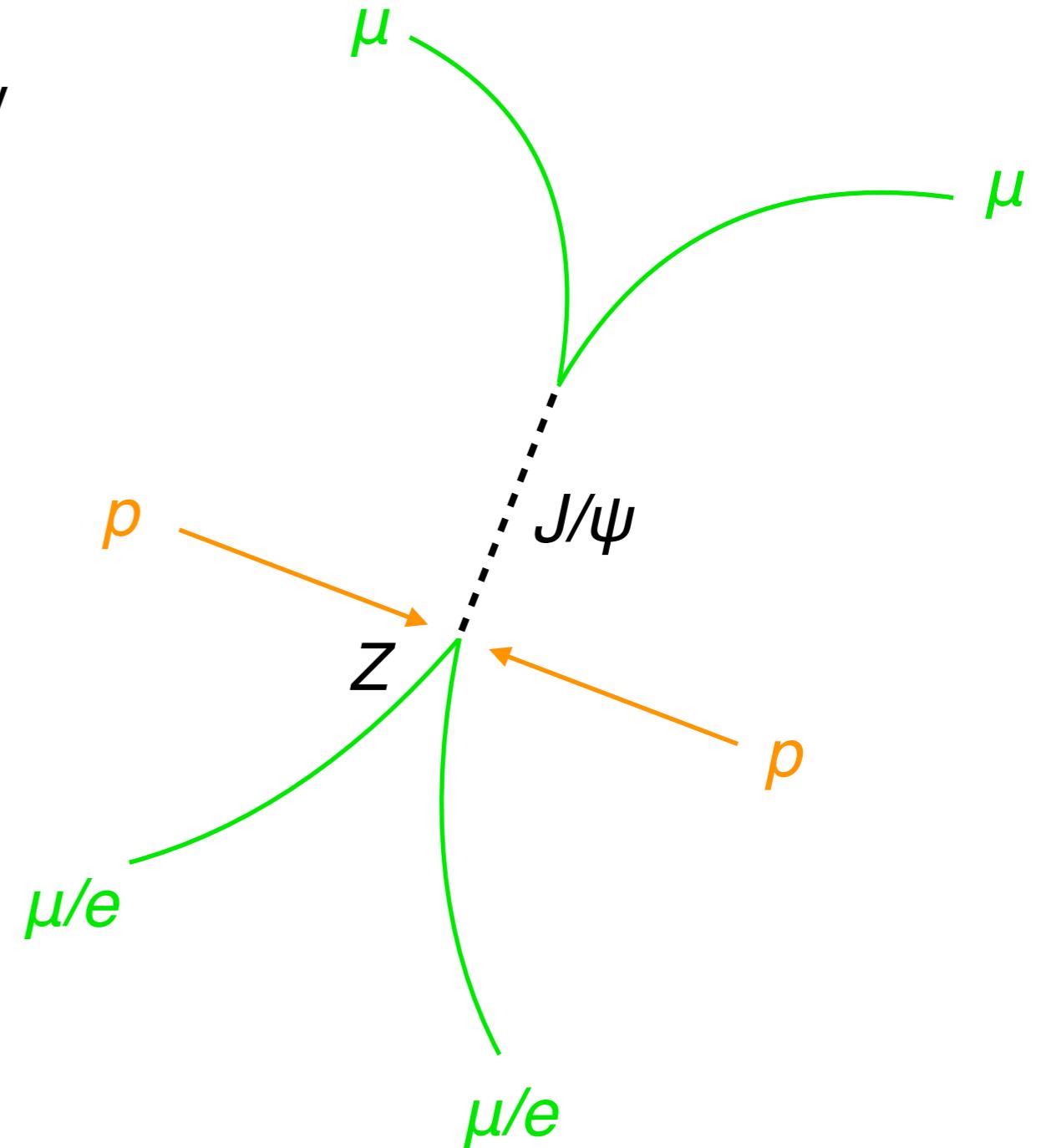
The ATLAS detector

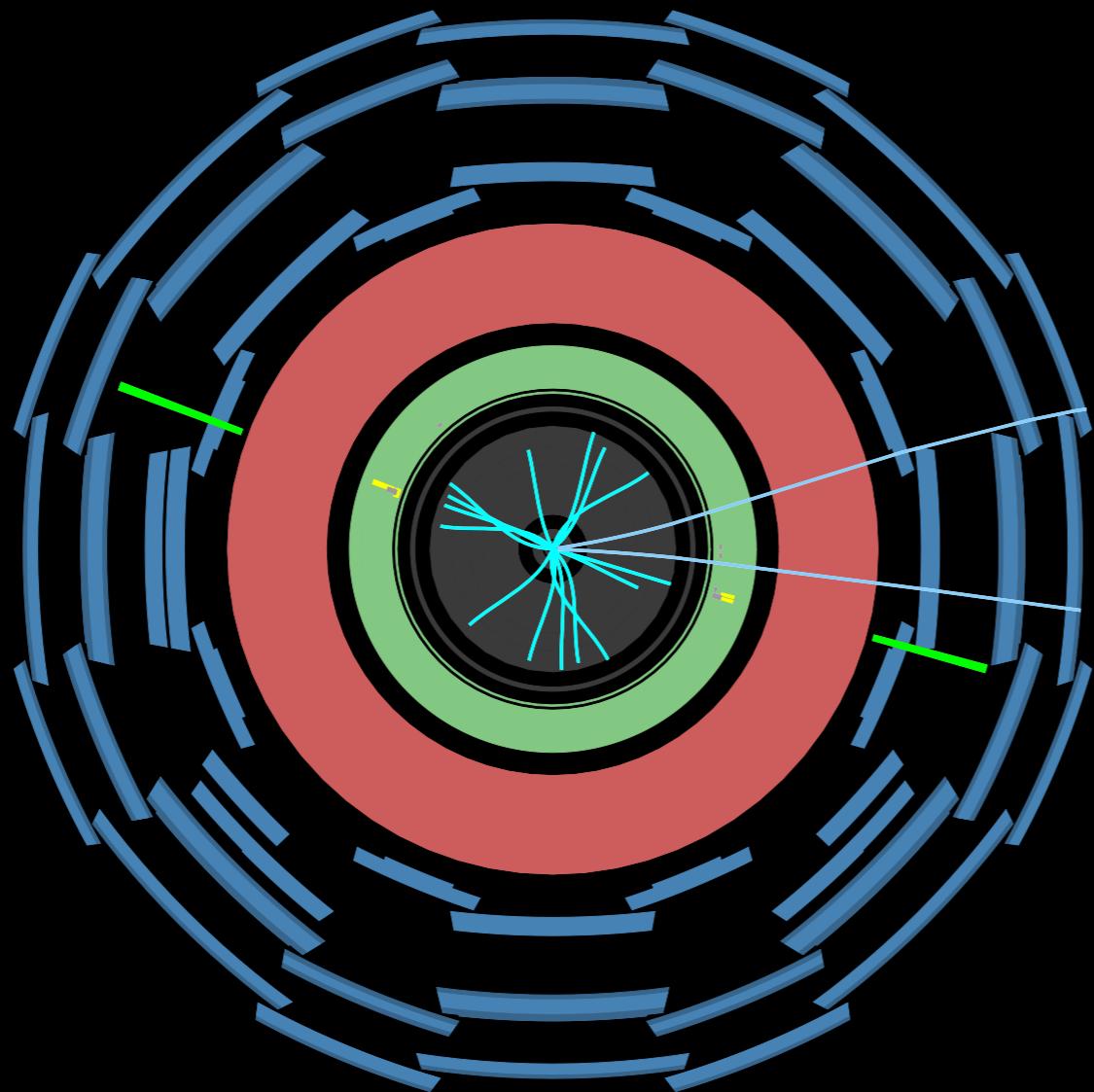
- General purpose detector at the LHC
 - tracking
 - silicon (Pixel+Semiconductor Tracker) and Transition Radiation Tracker
 - 2 T solenoidal field
 - Muon identification:
 - dedicated tracking chambers
 - 0.5-2T toroidal field



Analysis overview

- High p_T triggers
- Z
 - trigger match lepton p_T greater than 25 GeV
 - sub-leading lepton p_T greater than 15 GeV
 - $|\eta| < 2.5$
- J/ψ
 - $p_{T\mu} > 2.5$ GeV
 - $|\eta^\mu| < 2.5$
 - $p_{TJ/\psi} > 8.5$ GeV and $|y^{J/\psi}| < 2.1$
- J/ψ vertex must be separated by more than 10mm in the z direction from the Z vertex

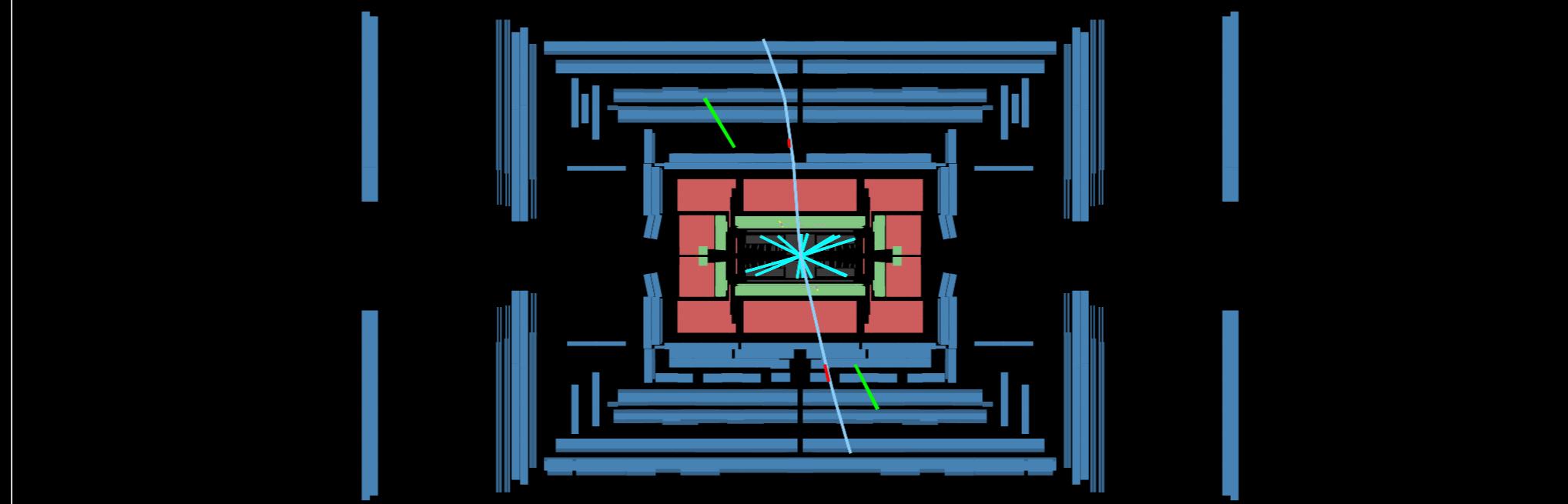


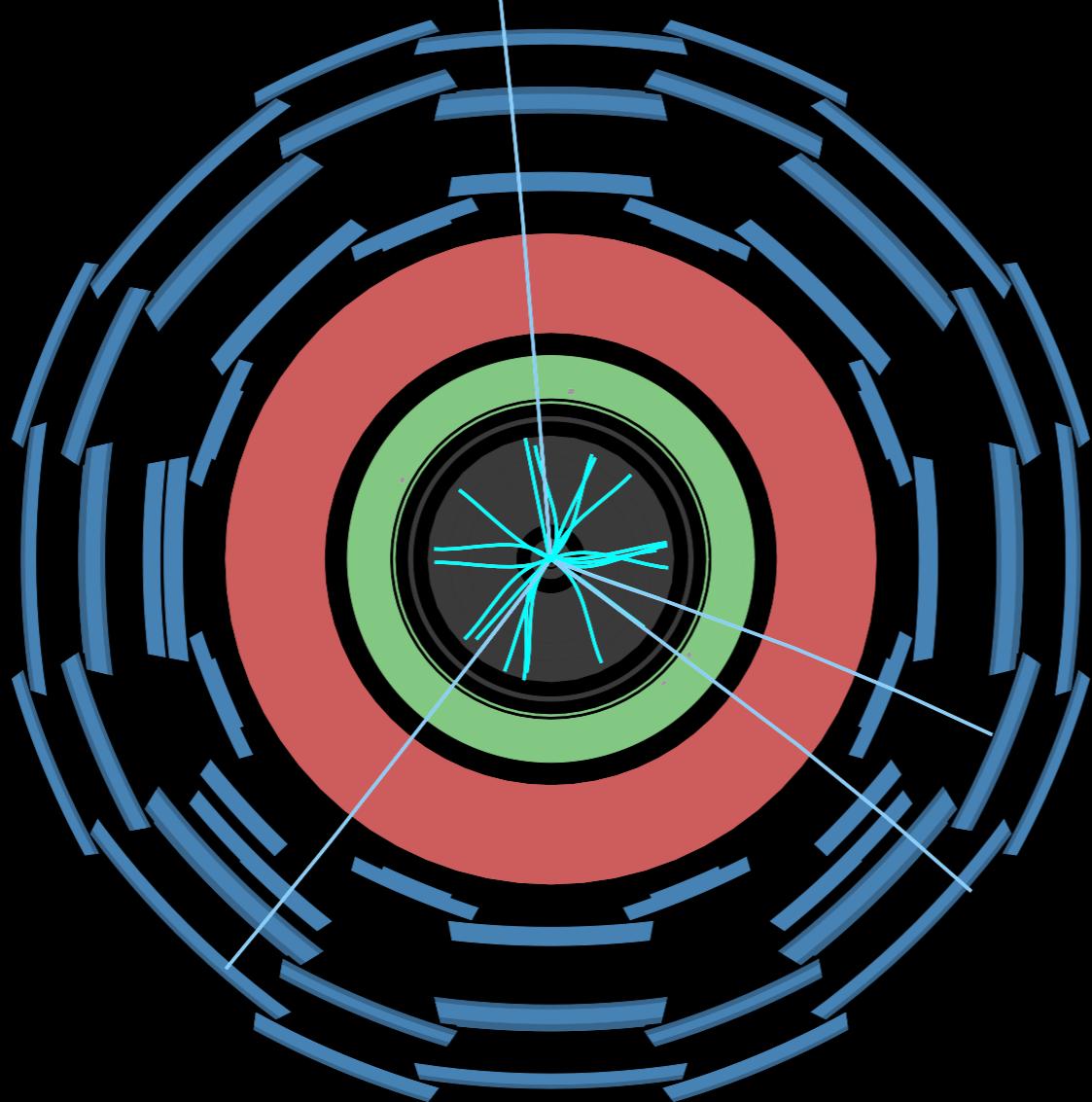


ATLAS EXPERIMENT

Run Number: 200967, Event Number: 71279004

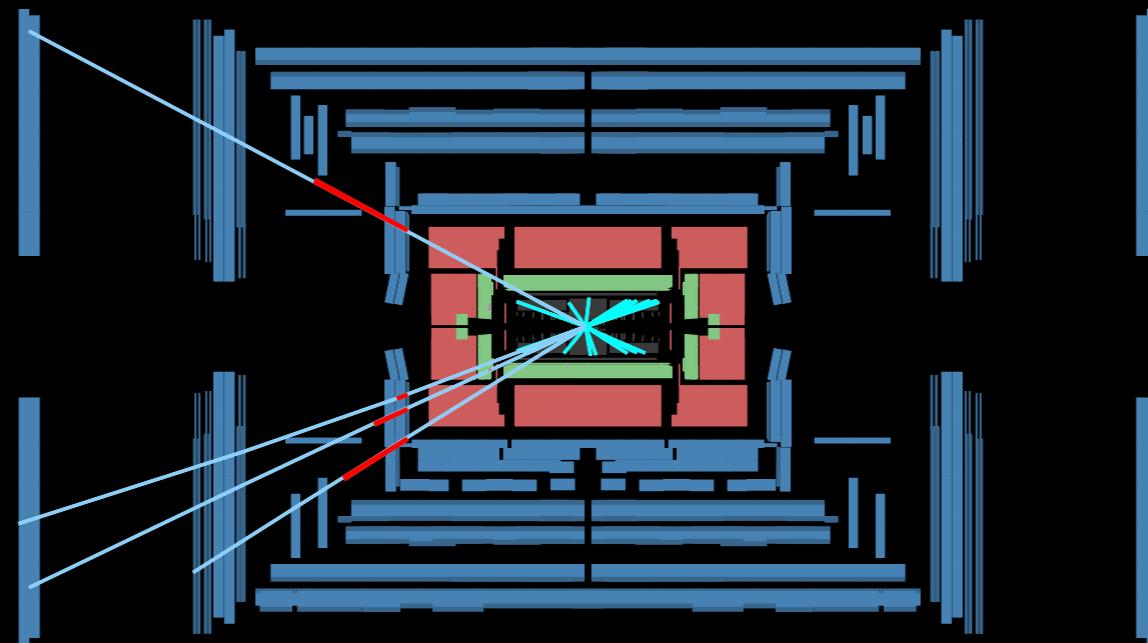
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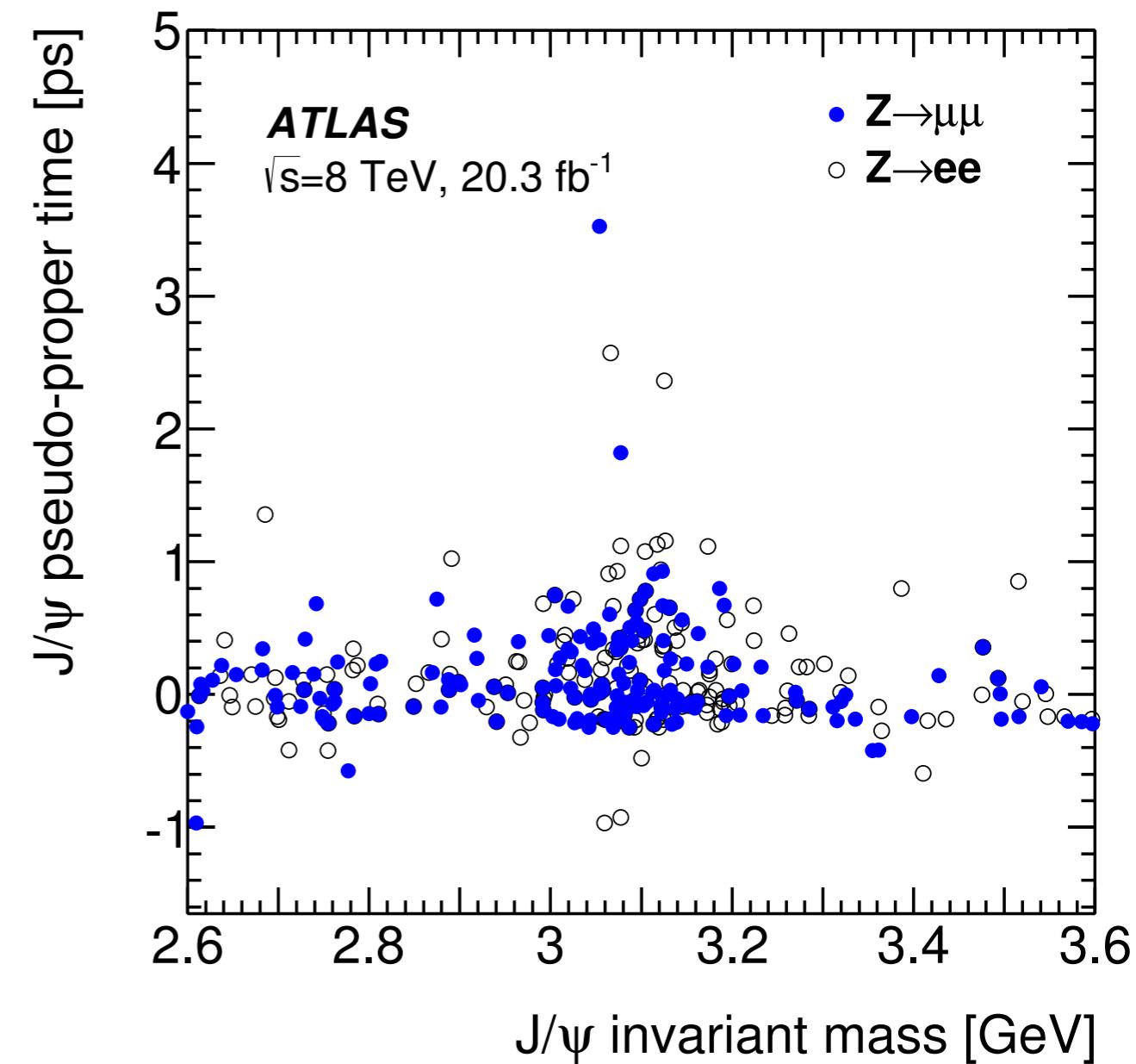
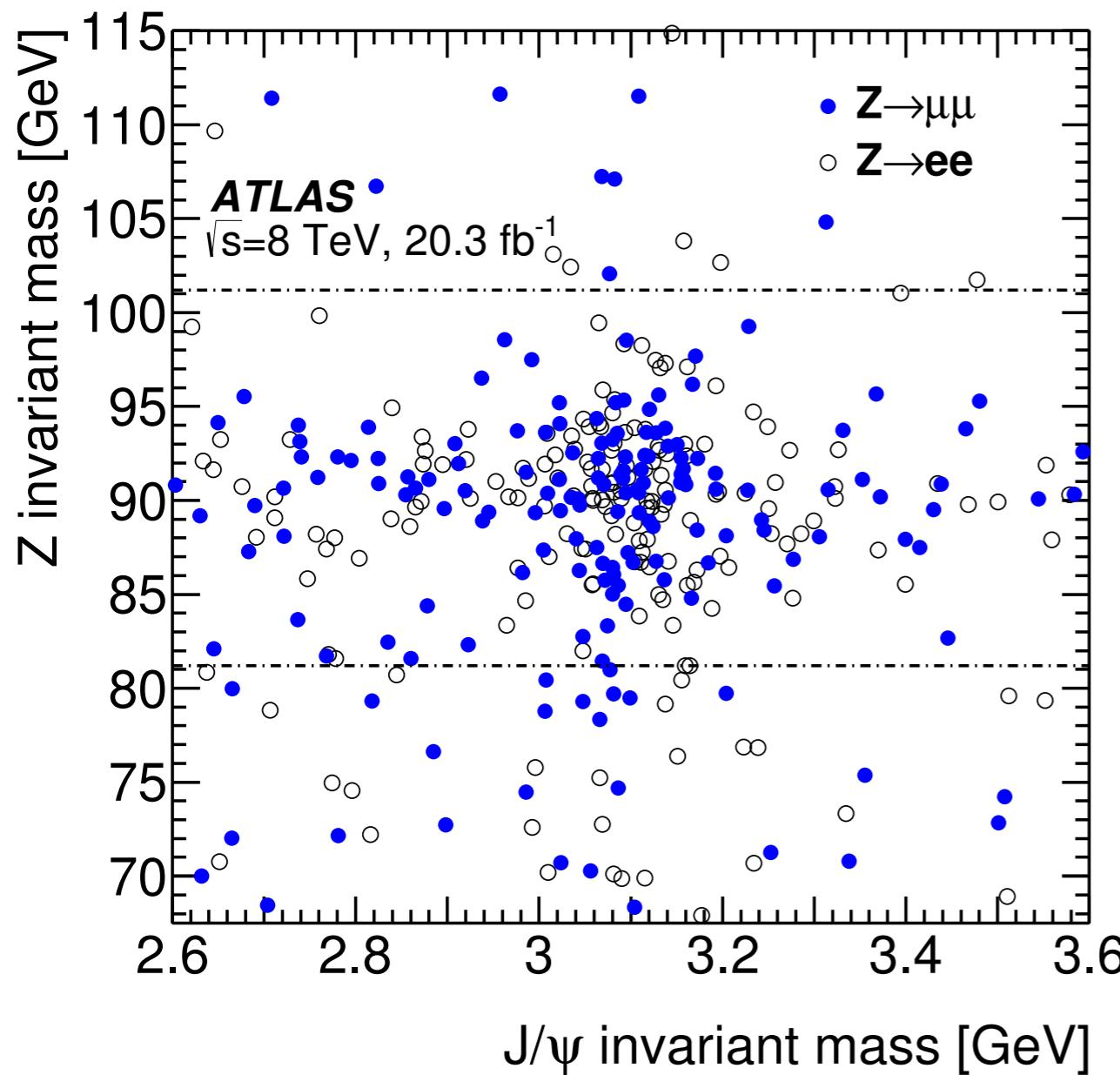
Run Number: 204564, Event Number: 108362933

Date: 2012-06-07 02:21:12 CEST



Associated production of $Z + J/\psi$

Candidates

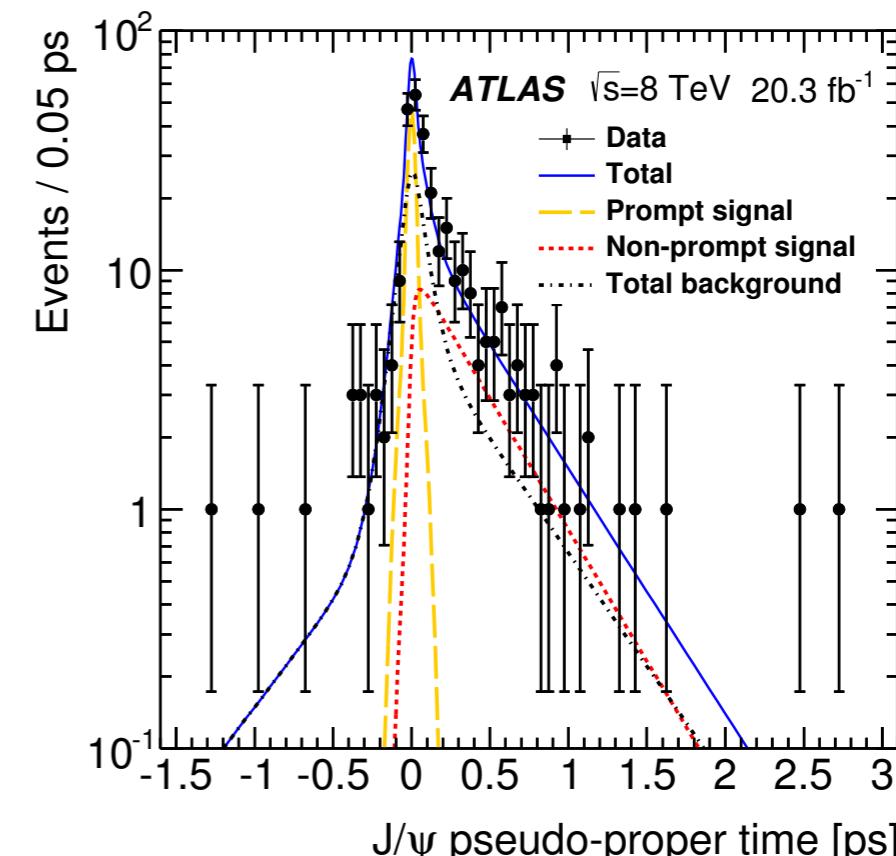
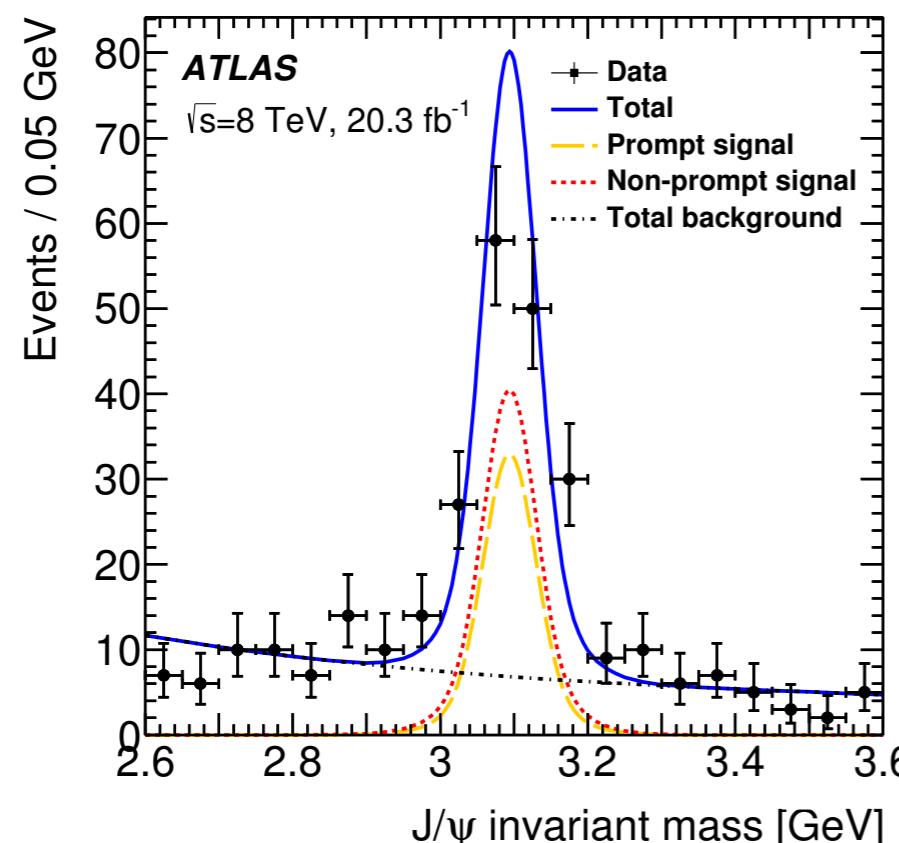


Associated production of $Z + J/\psi$

Yield extraction

- Unbinned maximum likelihood fit
 - mass
 - lifetime
 - 4 components
 - signal prompt
 - signal non-prompt
 - backgrounds (x2)
- More than 5 sigma significance
- Due to limited statistics - shape related parameters are driven by a inclusive J/ψ sample

Process	$ y_{J/\psi} < 1.0$	$1.0 < y_{J/\psi} < 2.1$	Total	
	Events found	From pileup		
Prompt signal	$24 \pm 6 \pm 2$	$32 \pm 8 \pm 5$	$56 \pm 10 \pm 5$	$5.2^{+1.8}_{-1.3}$
Non-prompt signal	$54 \pm 9 \pm 3$	$41 \pm 8 \pm 7$	$95 \pm 12 \pm 8$	$2.7^{+0.9}_{-0.6}$
Background	$61 \pm 11 \pm 6$	$77 \pm 13 \pm 7$	$138 \pm 17 \pm 9$	

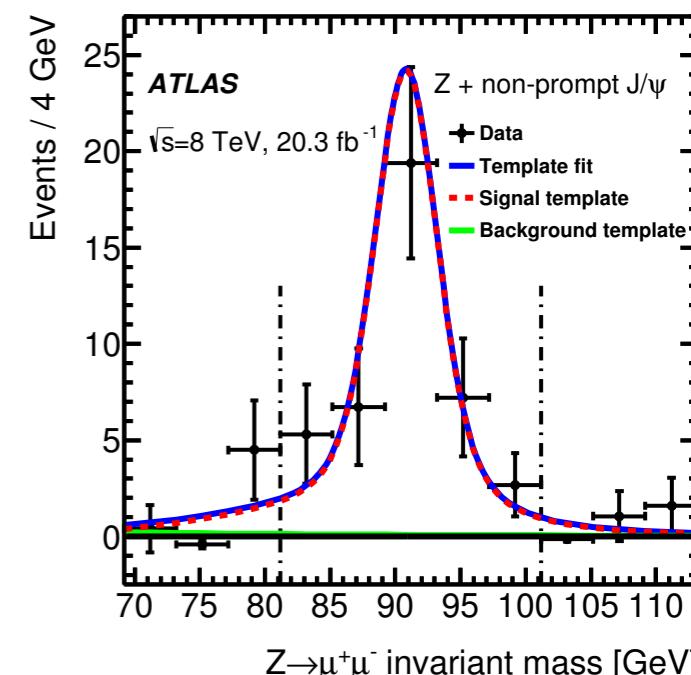
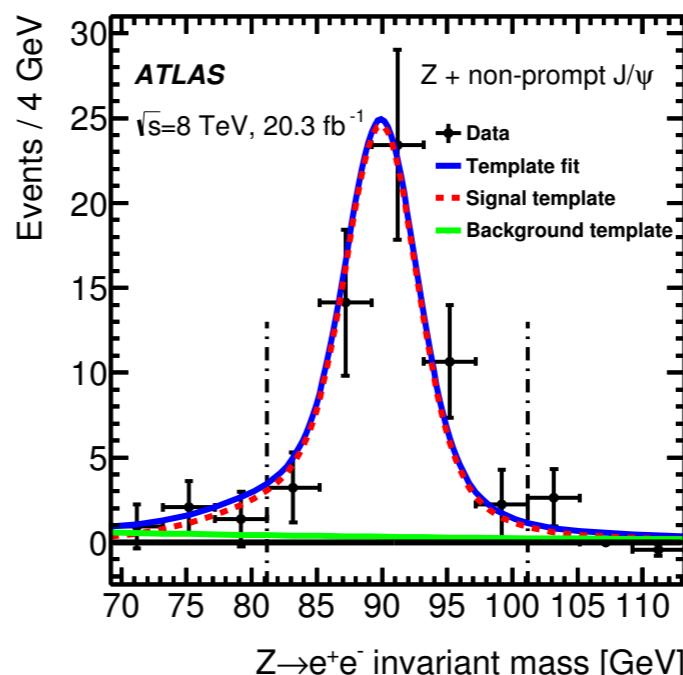
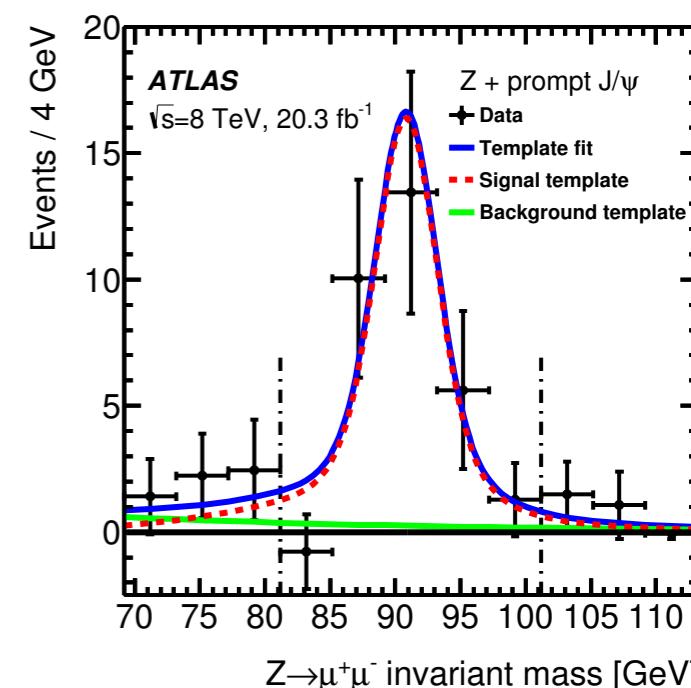
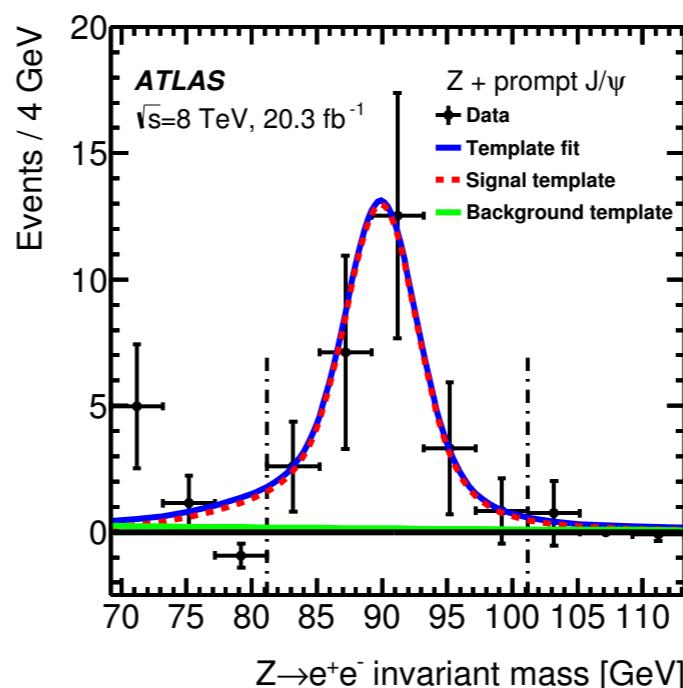


Associated production of $Z + J/\psi$

Yield extraction

- Fit allows to extract weights from each component (sPlot technique)
 - caveat: discriminating variable and variable that the weights are going to be applied to must be un-correlated
- Apply weights to $Z \rightarrow ee$ and $Z \rightarrow \mu\mu$
- Compare
 - sWeighted distributions
 - mujet backgrounds
 - signal templates

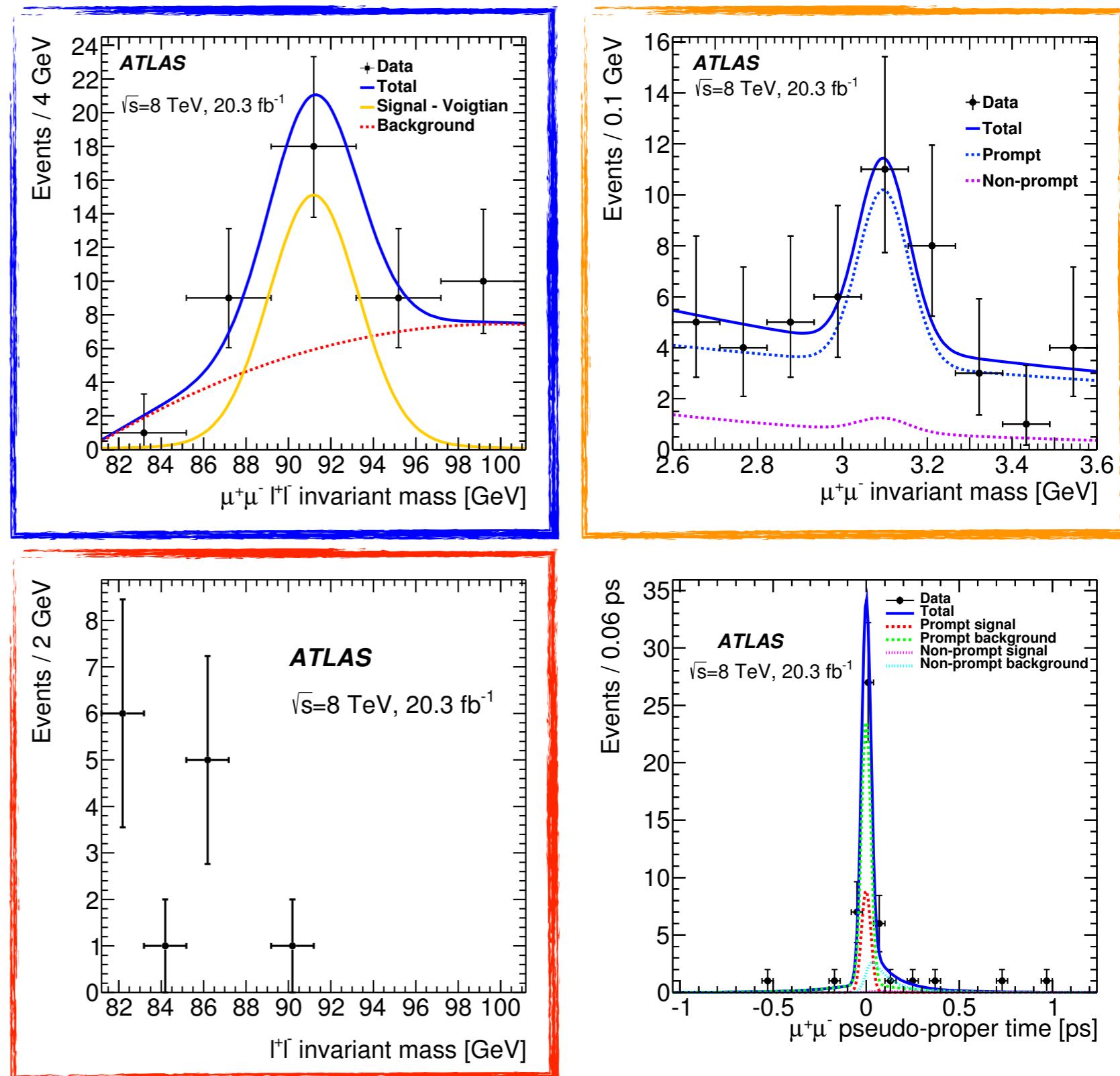
	$Z \rightarrow ee$	$Z \rightarrow \mu\mu$
Prompt	0 ± 4	1 ± 4
Non-prompt	1 ± 5	0 ± 5



Associated production of $Z + J/\psi$

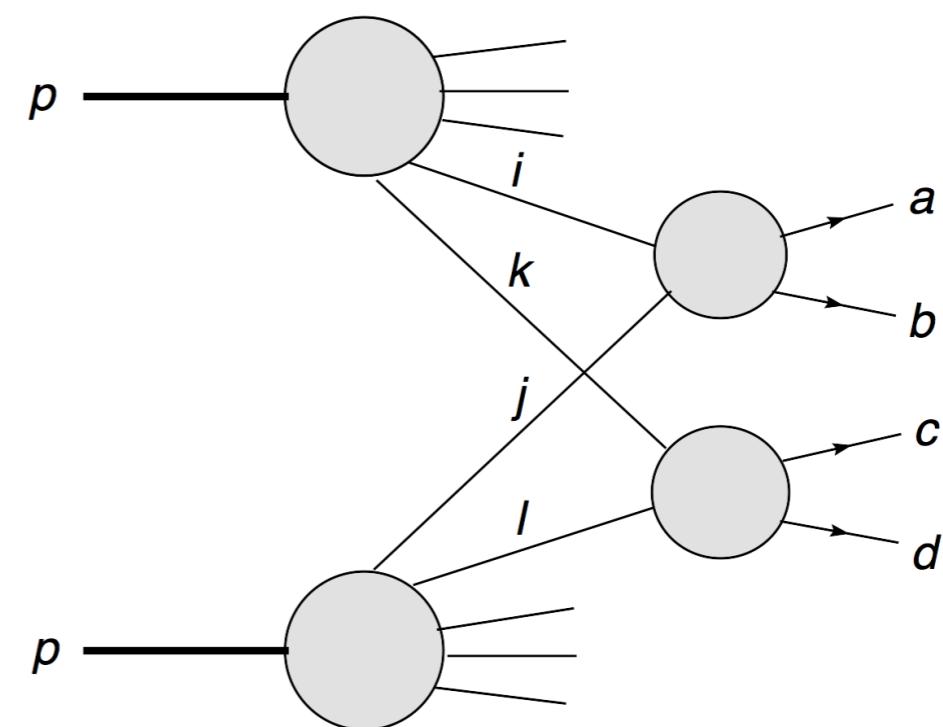
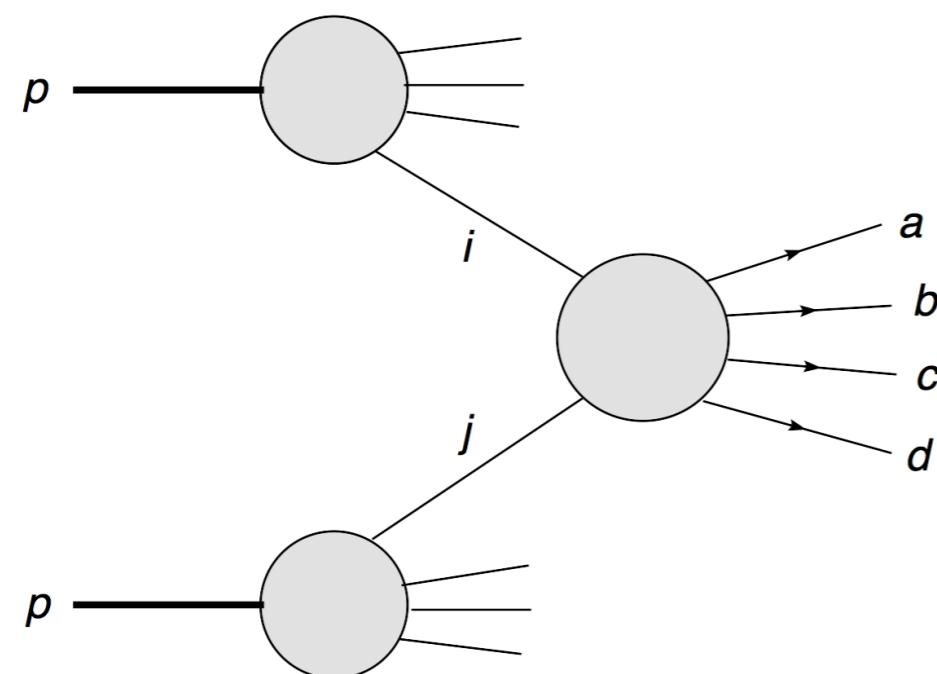
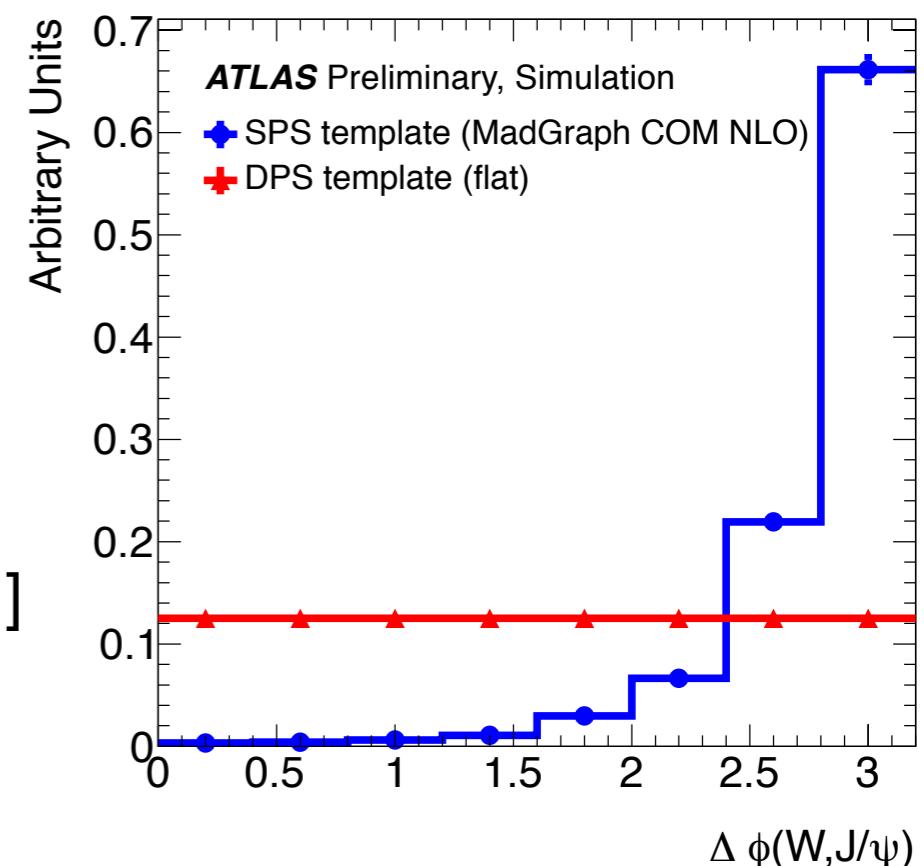
Hint of $Z \rightarrow J/\psi + \text{ll}$ (?)

- Final state of analysis: Z and J/ψ
- Check possible contamination from rare $Z \rightarrow \text{ll} J/\psi$ decay
- Calculate the $\text{ll}\mu\mu$ invariant mass
- for events with $|m_Z^{\text{PDG}} - m_{\text{ll}\mu\mu}| < 10 \text{ GeV}$
 - plot
 - $\mu\mu$ invariant mass
 - ll invariant mass
- Excluding the events with $|m_Z^{\text{PDG}} - m_{\text{ll}}| < 10 \text{ GeV}$
 - negligible effect in measurement



Single/Double Parton Scattering

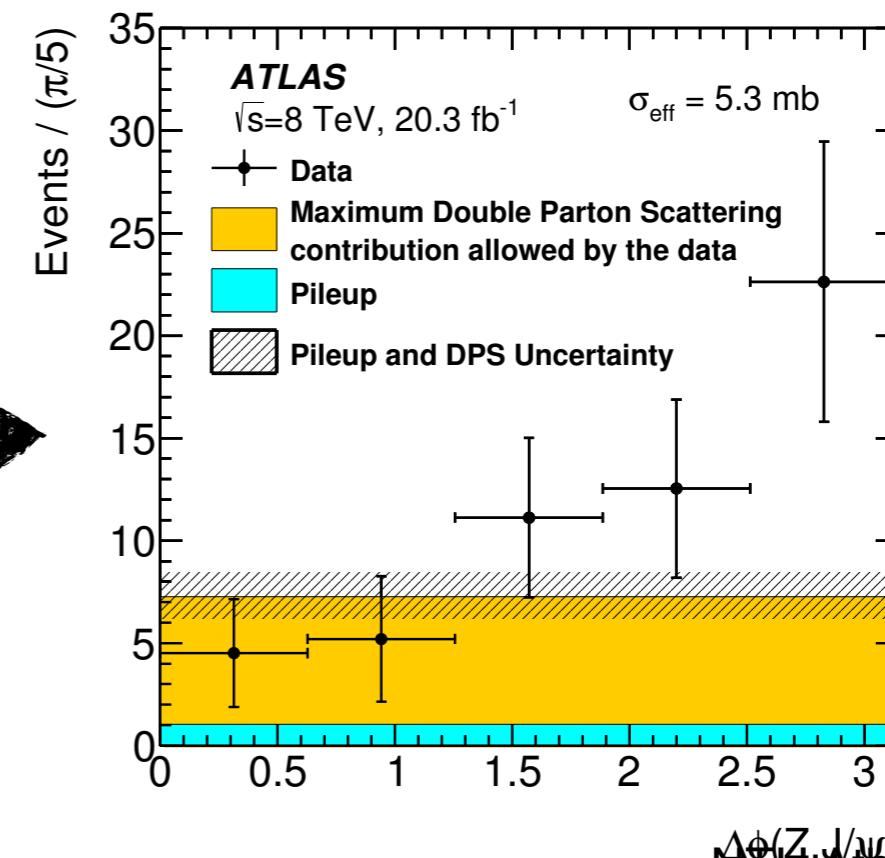
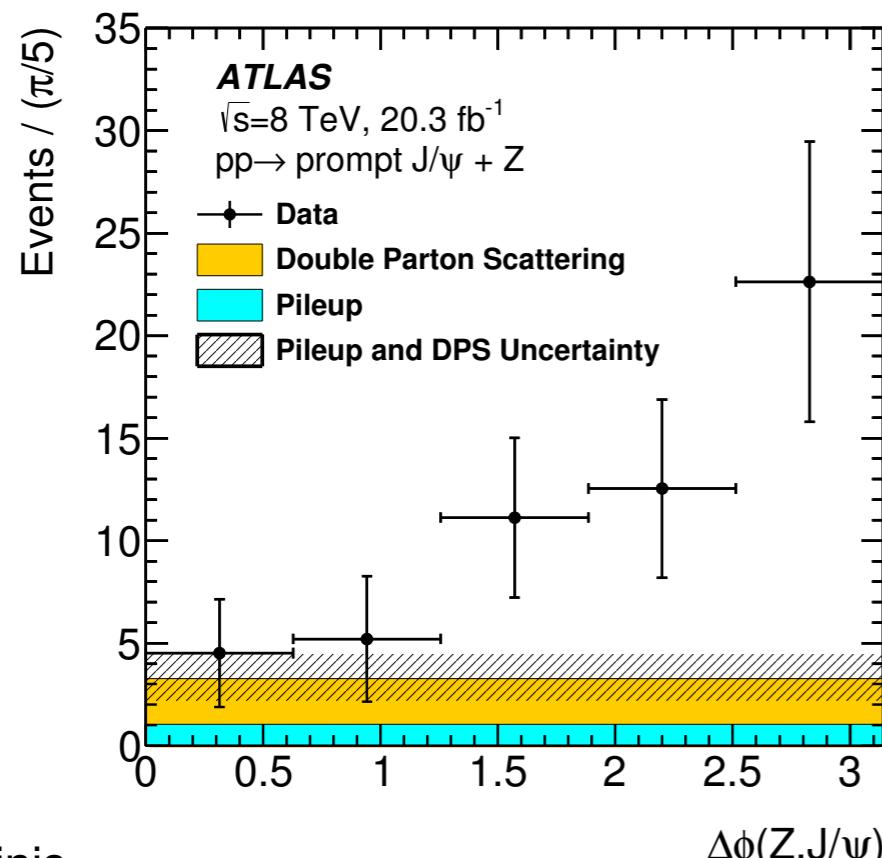
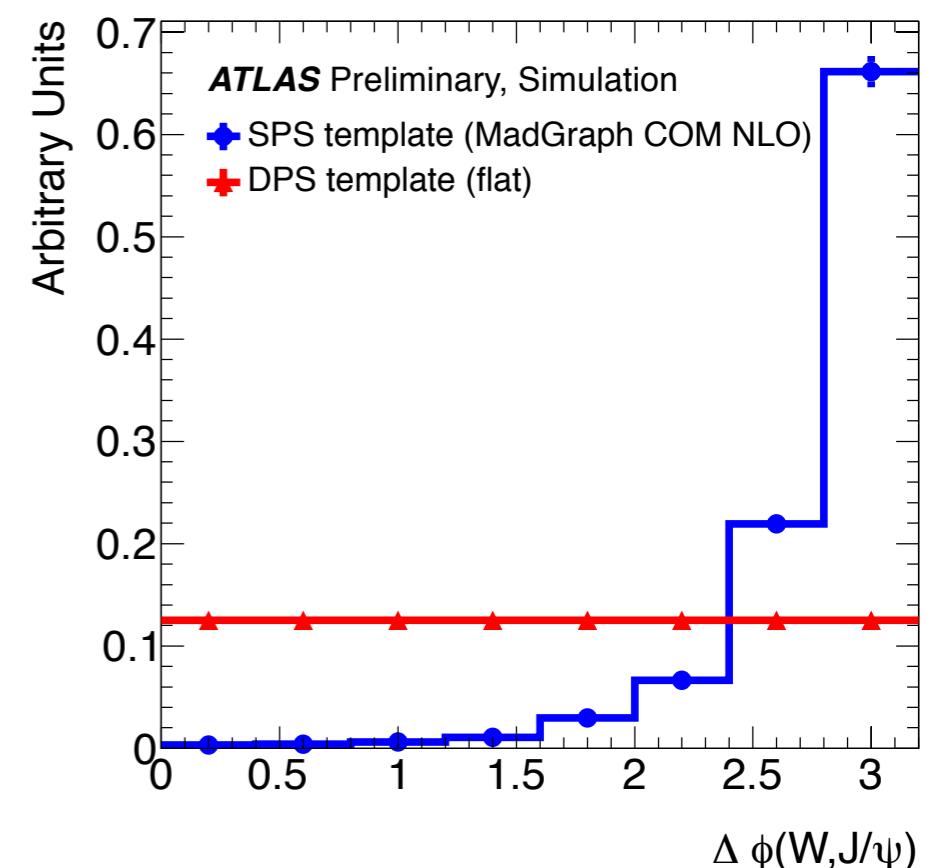
- Single parton scattering
 - both objects from the same diagrams
- Double parton scattering
 - each object from independent scatter
- Indistinguishable on an event-by-event basis
- Use of discriminating variables
 - azimuthal angle between the two particles [$\Delta\phi(Z, J/\psi)$]
 - flat contribution from DPS
 - peak at $\Delta\phi = \pi$, from SPS back-to-back production
 - smeared due to detector effects



Associated production of $Z + J/\psi$

Results - lower limit on σ_{eff}

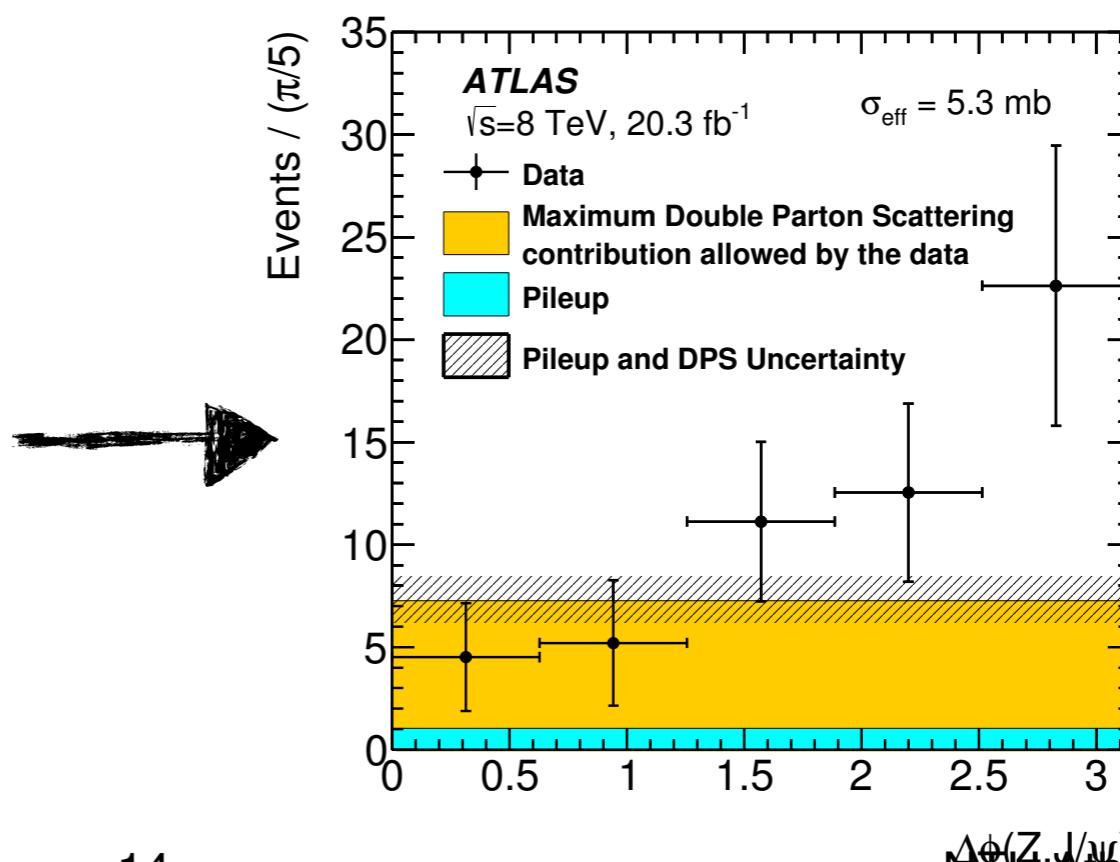
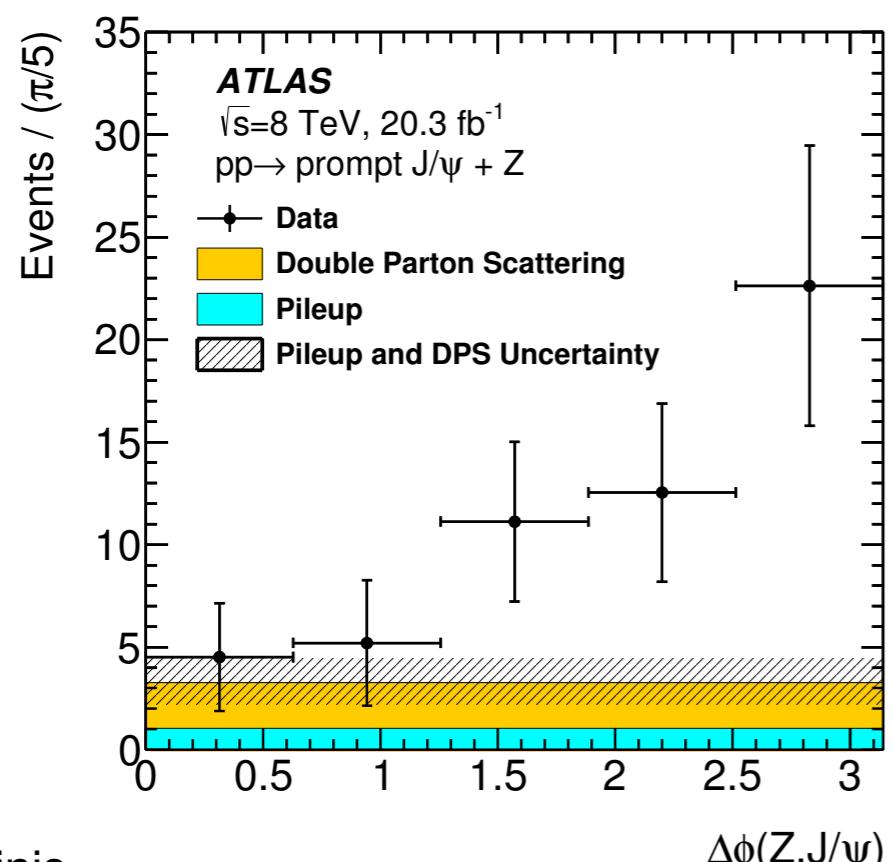
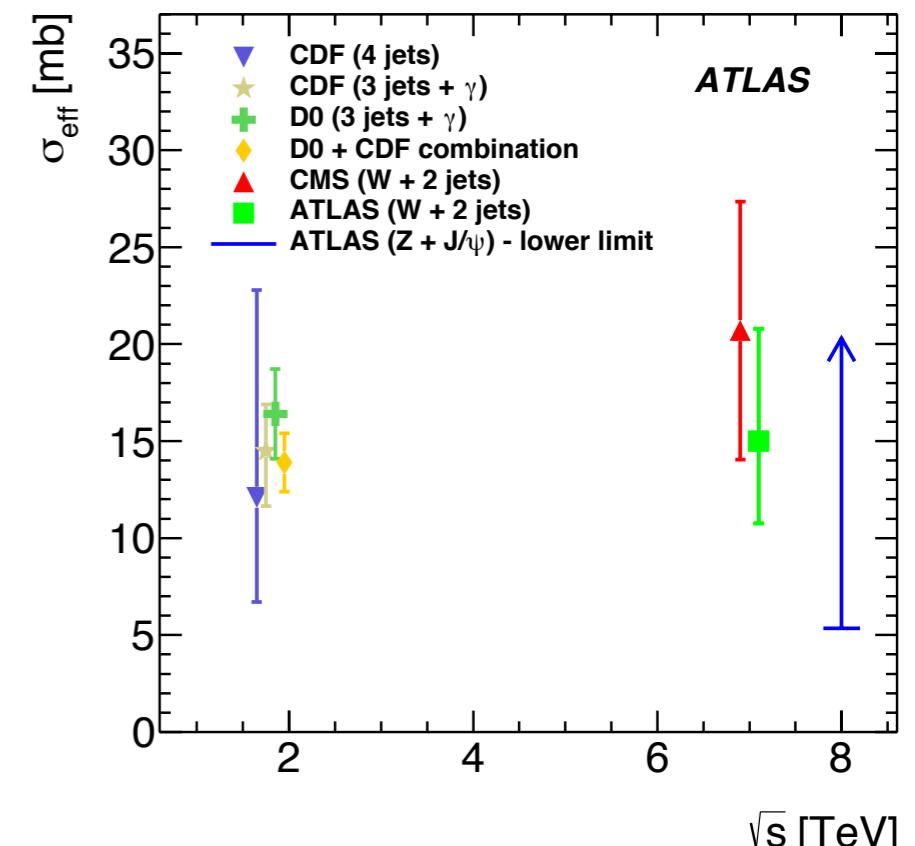
- Estimation of DPS events follows:
 - $N_{\text{DPS}} = P_{J/\psi}^{\text{DPS}} N_{\text{fid}}^{\text{Z}}$
 - $P_{J/\psi}^{\text{DPS}} = \sigma_{J/\psi}^{\text{bin}} / \sigma_{\text{eff}}$
- Set a lower limit on level of DPS contributing to the observed signal
- Assuming that the first bin is DPS dominated
- Fluctuate the σ_{eff} up to how much the data supports



Associated production of $Z + J/\psi$

Results - lower limit on σ_{eff}

- Lower limit of σ_{eff} 5.3 mb is extracted
- In agreement with other experiments
 - Small dependence with \sqrt{s}
 - Process independent
- Quarkonia for studying DPS is a realistic prospect

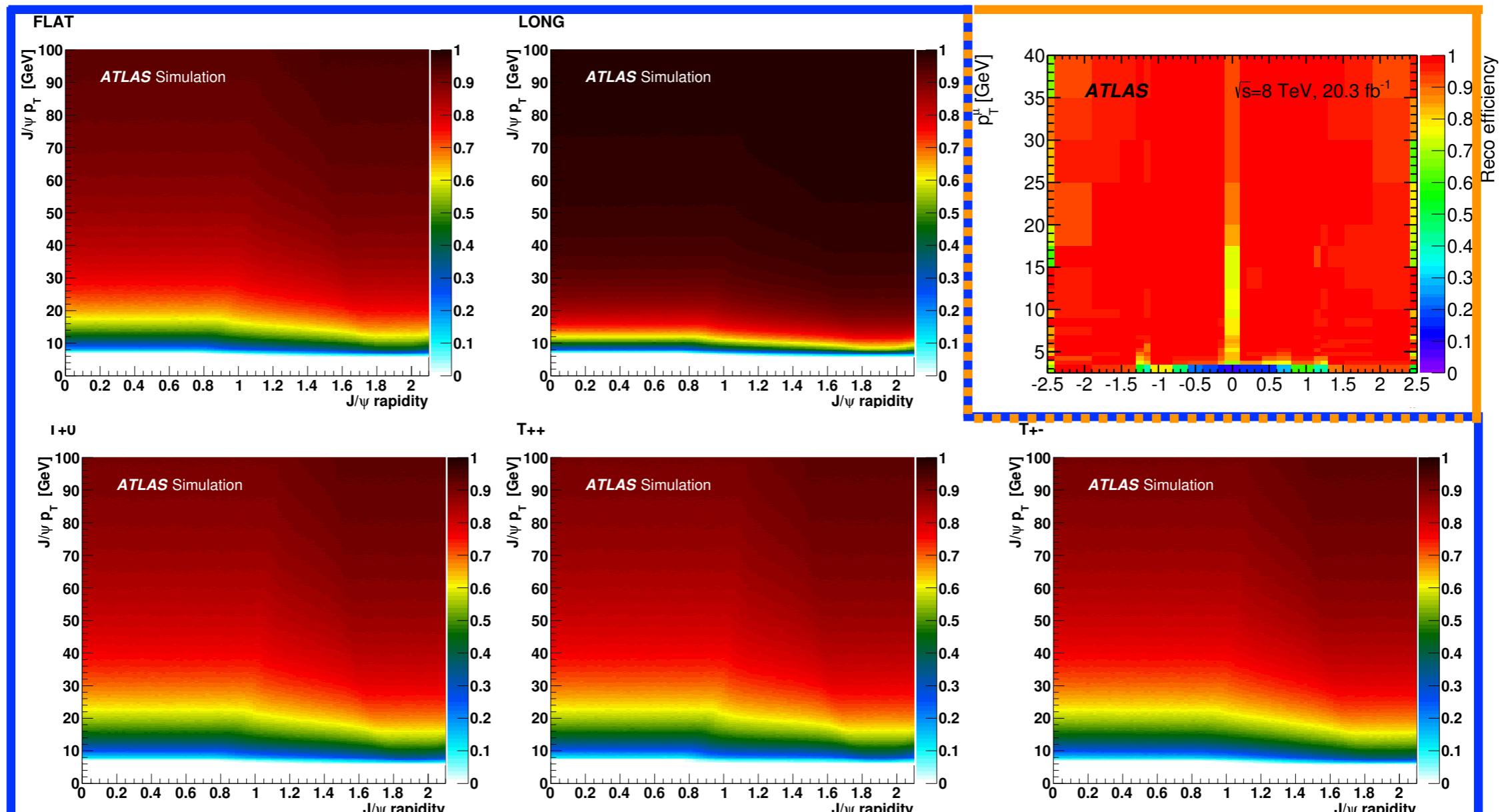


Associated production of $Z + J/\psi$

Corrections - detector efficiency and acceptance

- Muon reconstruction efficiency using tag-and-probe method with J/ψ decays
- Acceptance depends on spin-alignment, i.e. angular distributions of muons
 - Calculate maps for kinematic cuts on p_T and $|\eta|$ of J/ψ muons
 - Correct for muon losses within this fiducial region
 - Use unpolarised (isotropic) spin-alignment as default

$$\frac{\sigma(pp \rightarrow Z + J/\psi)}{\sigma(pp \rightarrow Z)} = \frac{\frac{N^{Z+J/\psi}}{\epsilon^{J/\psi} \alpha^{J/\psi} \epsilon^Z \mathcal{L}}}{\frac{N^Z}{\epsilon^Z \mathcal{L}}}$$



Systematic uncertainties

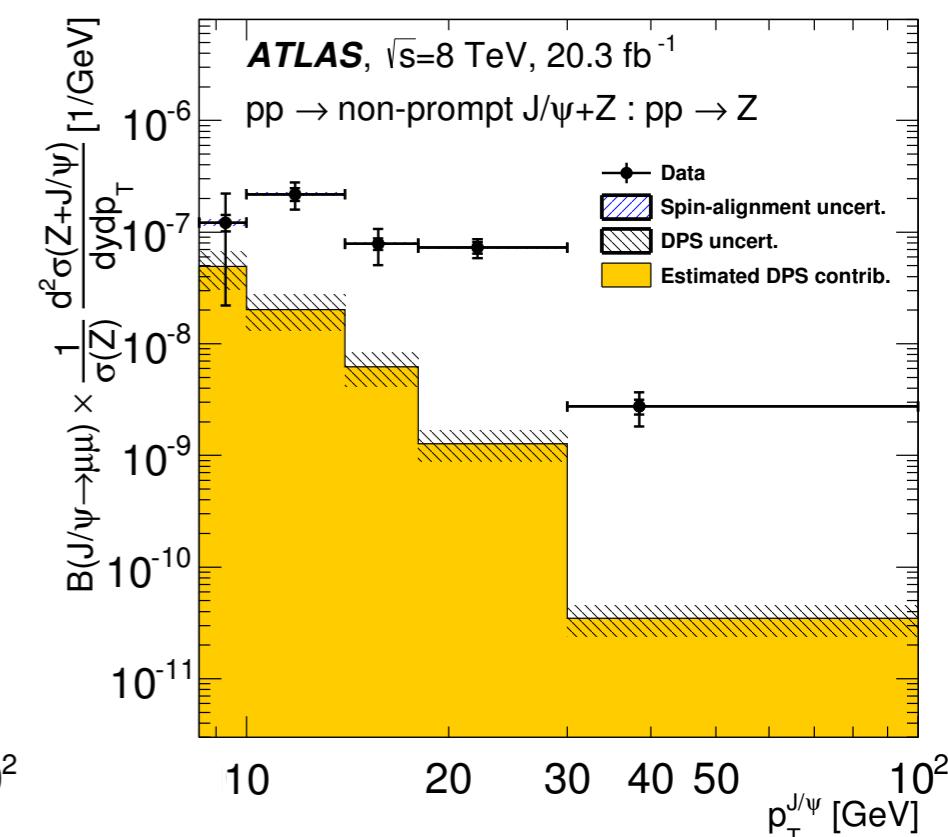
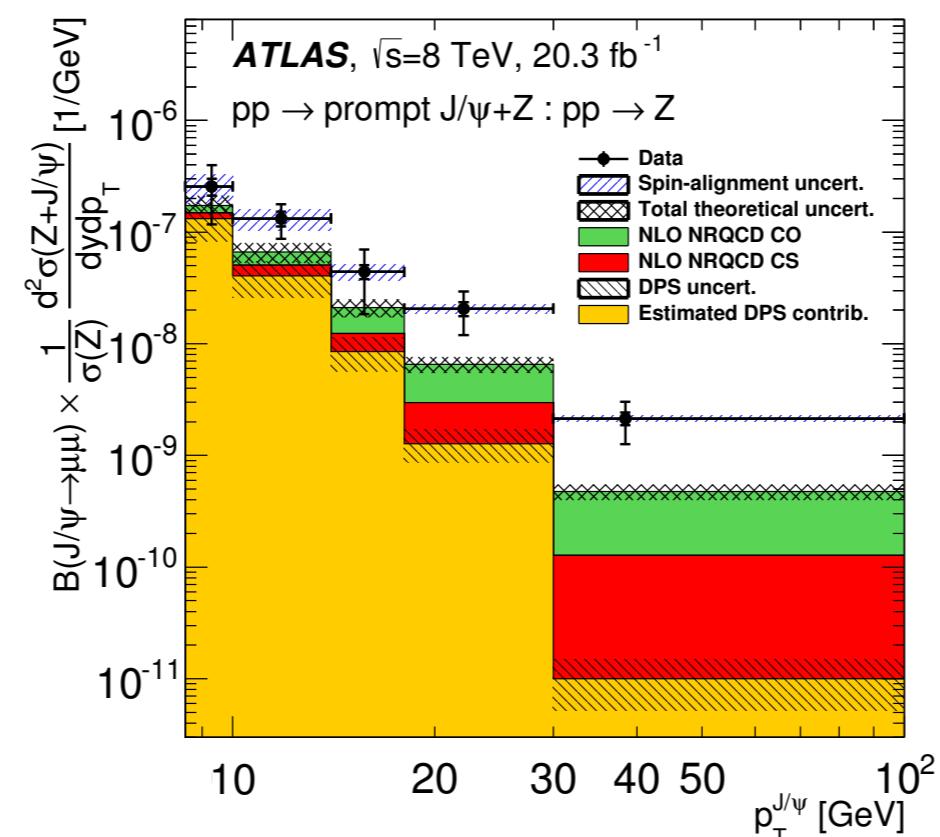
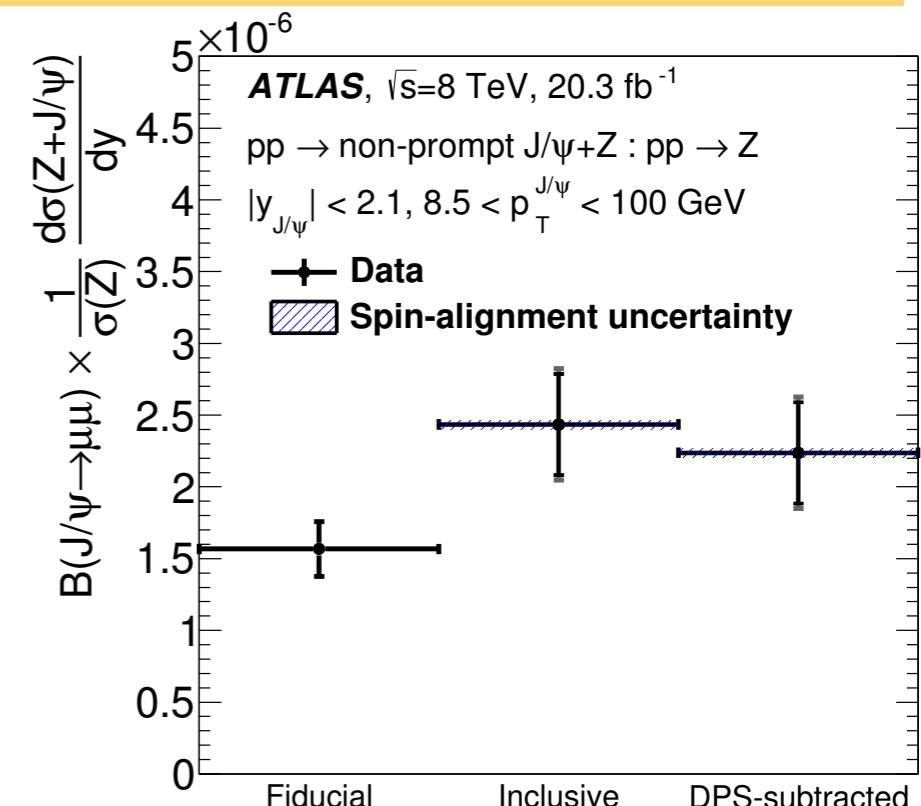
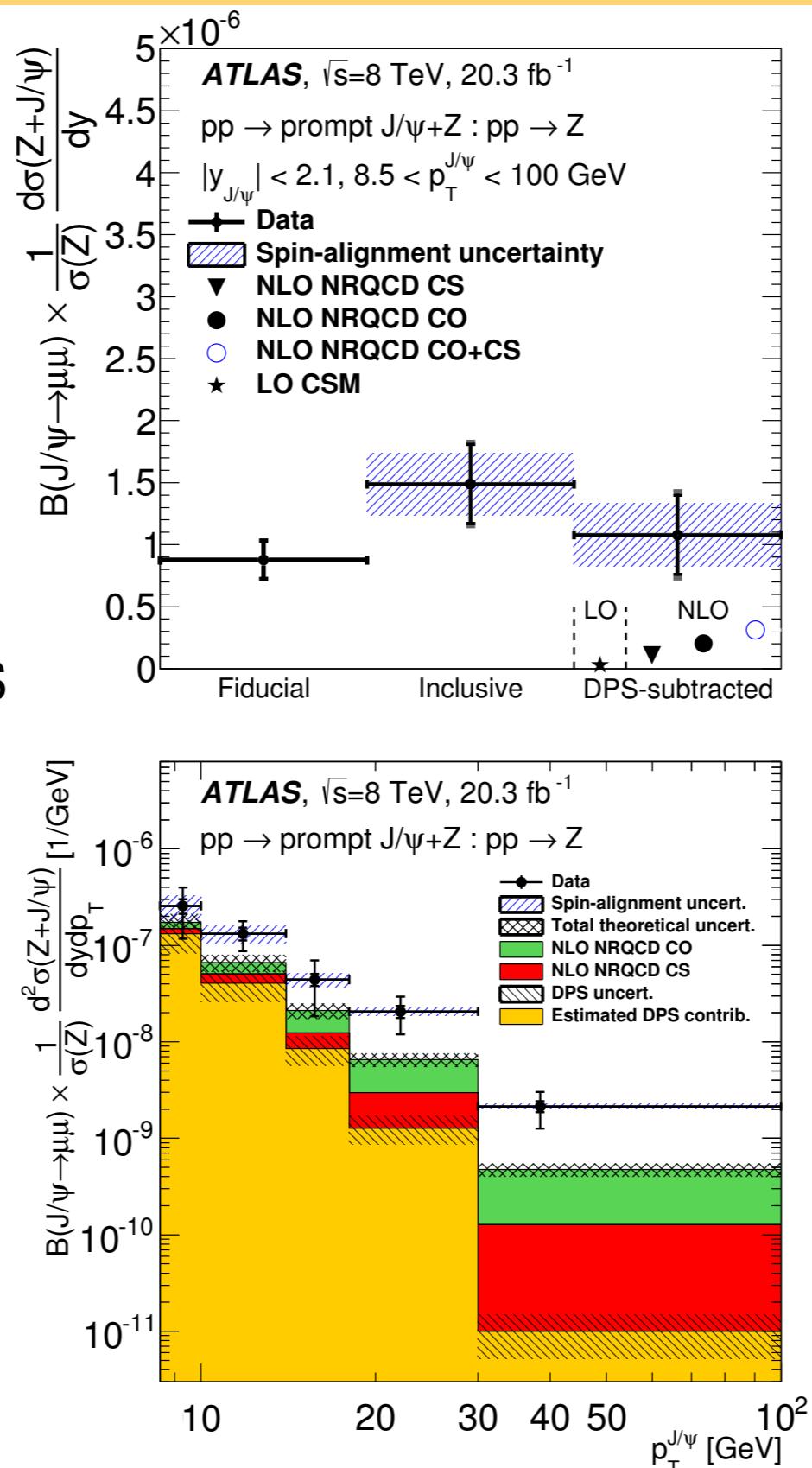
- Fit procedure
 - variation of the fit model
 - removing link between associated production and inclusive sample
- Z boson kinematics
 - assume for central value that the Z efficiency and acceptance cancel in cross-section ratio
 - systematics assessed for differences in Z boson kinematics between inclusive Z and $Z + J/\psi$ processes that would invalidate this assumption
- J/ψ muon efficiencies
 - create 1000 different muon reconstruction efficiency maps, smearing each bin according to the uncertainty in that bin
- Vertex separation
 - This choice could cause a potential bias in the measurement of the prompt and the non-prompt yield since it affects the pseudo-proper time distribution of the J/ψ

Source	Prompt		Non-prompt	
	$ y_{J/\psi} < 1.0$	$1.0 < y_{J/\psi} < 2.1$	$ y_{J/\psi} < 1.0$	$1.0 < y_{J/\psi} < 2.1$
Fit procedure	3%	3%	4%	8%
Z boson kinematics	1%	1%	1%	1%
$\mu_{J/\psi}$ efficiency	1%	1%	1%	1%
Vertex separation	7%	16%	2%	15%

Associated production of $Z+J/\psi$

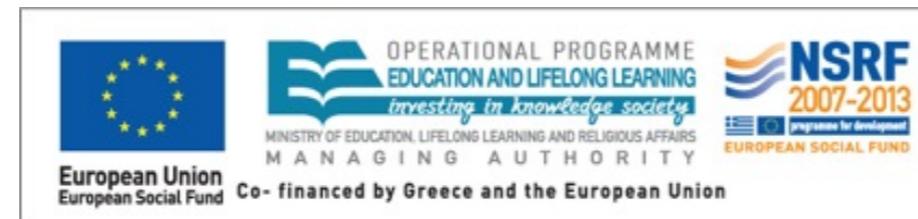
Results - cross section ratios

- Total cross sections
 - theory is underestimating the SPS production
- Differential cross sections
 - low p_T dominated by DPS
 - SPS drops off less steeply with p_T than DPS
 - Theory discrepancy more pronounced with higher p_T
- DPS fraction is
 - 29% for the prompt $J/\psi + Z$
 - 8% for the non-prompt $J/\psi + Z$



Outlook and conclusions

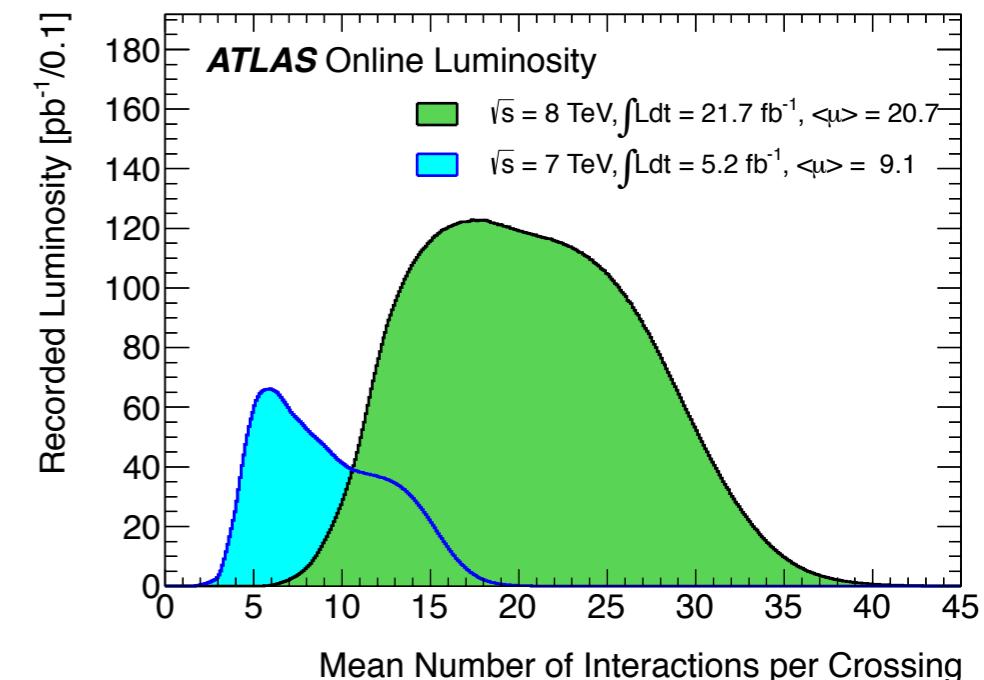
- One of the most rare processes observed in LHC
 - Production of a J/ψ meson in association with a Z boson occurs approximately twice per million Z
- $Z + J/\psi$ (either prompt or non-prompt) cross section ratio relative to inclusive Z
- Estimation of the SPS and DPS contributions
- Measurement of the $\Delta\phi(Z, J/\psi)$ distribution
- Help address issues like:
 - singlet vs octet production of quarkonia
 - double parton scattering
 - resonant production



backup

Pileup

- True J/ψ and Z particles are produced in different proton-proton collisions in the same bunch crossing
- Mean number of interactions per crossing
 - $\langle \mu \rangle = 20.7$ at $\sqrt{s}=8\text{TeV}$
- Pileup estimation
 - calculate N_{extra} pileup vertices around the Z
 - $N_{\text{extra}} = 2.3 \pm 0.2$
 - calculate the probability of any of these yielding a J/ψ
 - $P_{J/\psi}^{ij} = \sigma_{J/\psi}^{ij} / \sigma_{\text{inel}}$
 - Prompt: $5.2^{+1.8}_{-1.3}$
 - Non prompt: $2.7^{+0.9}_{-0.6}$

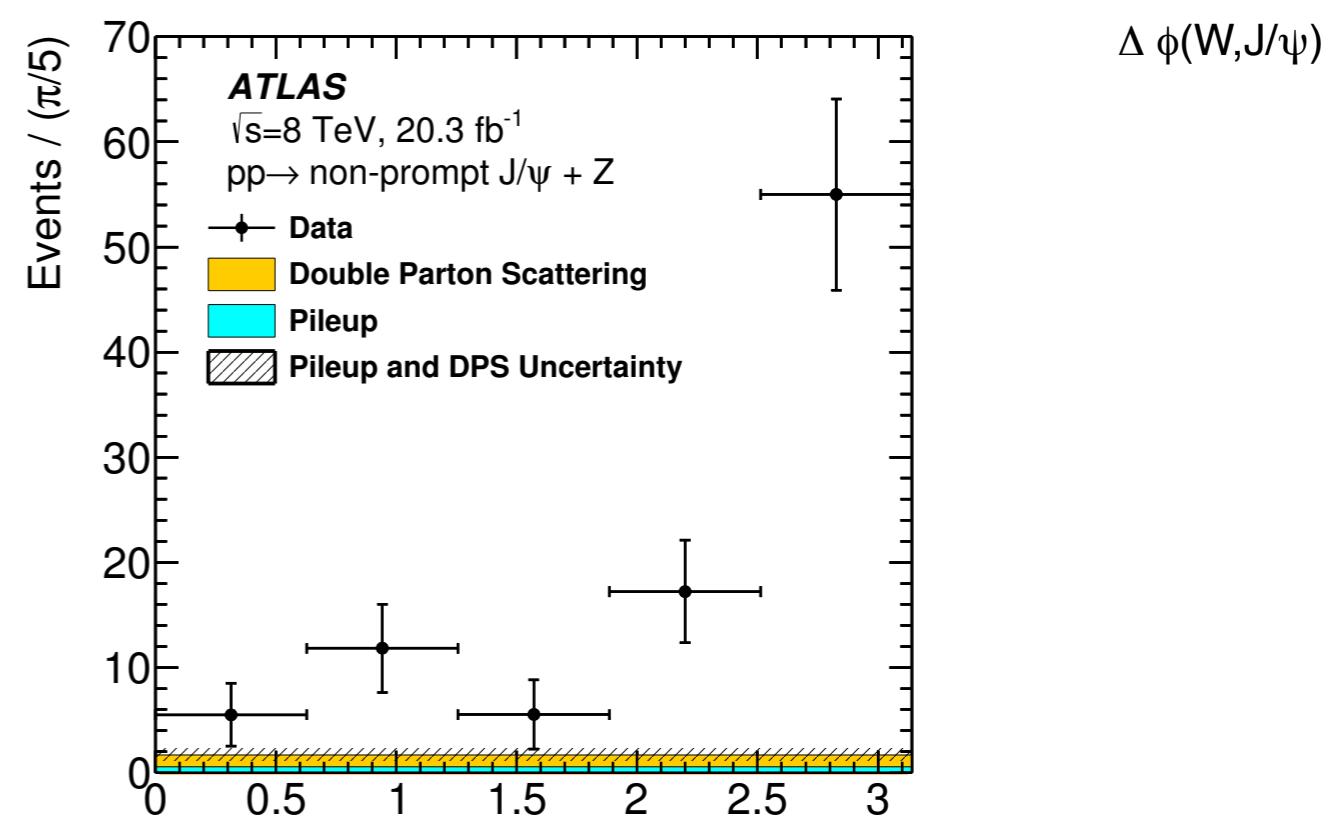
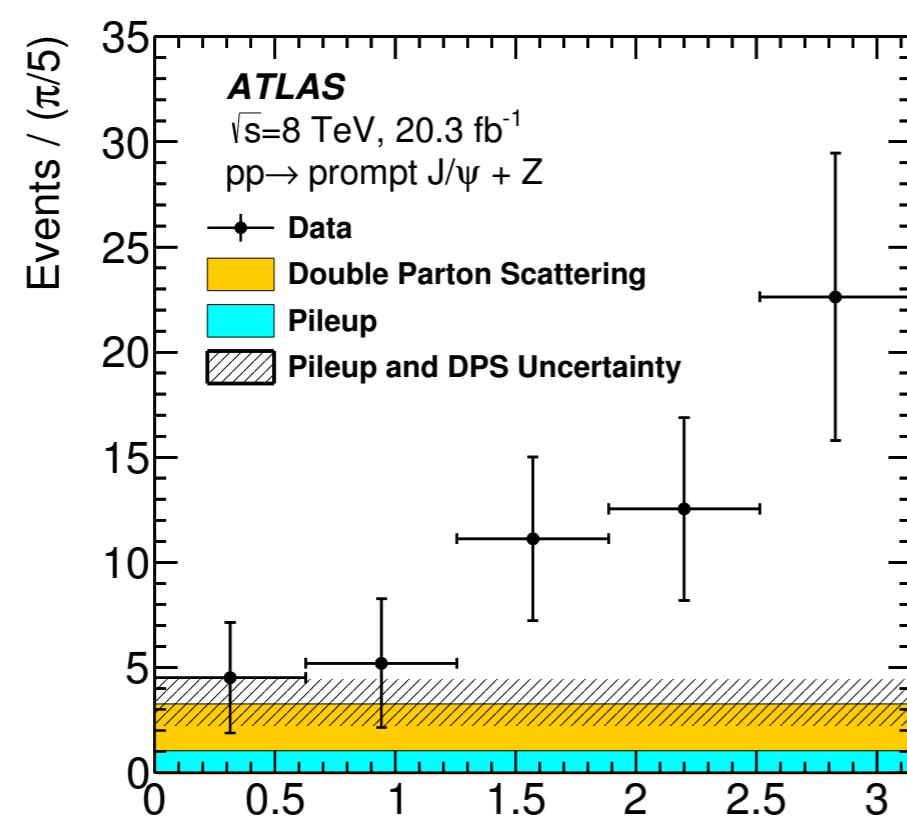
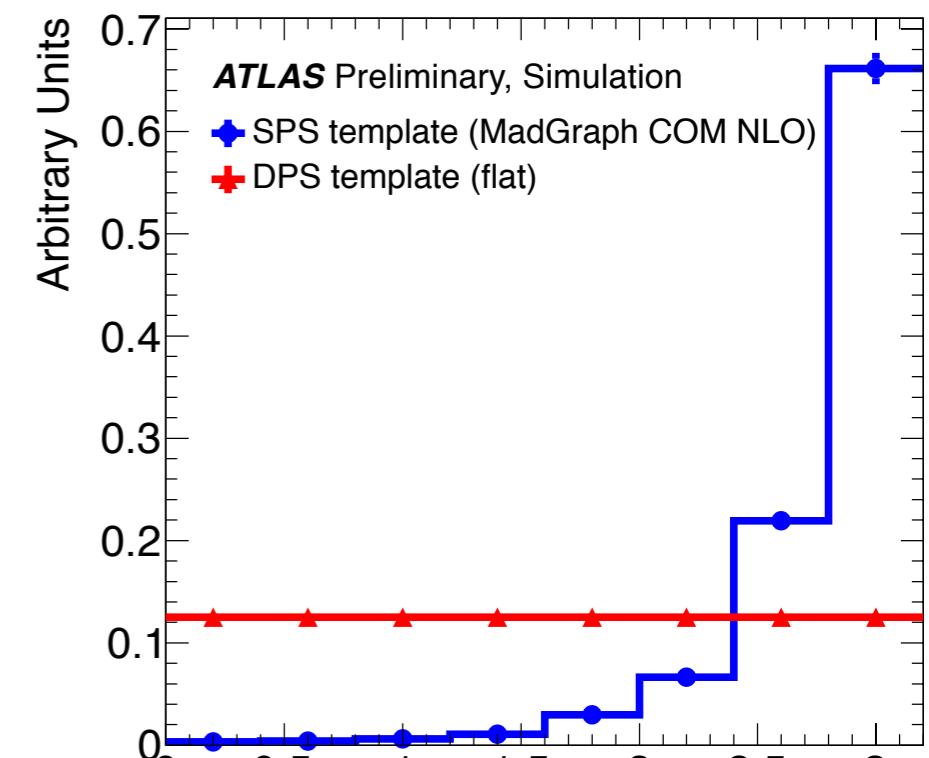


Process	$ y_{J/\psi} < 1.0$	$1.0 < y_{J/\psi} < 2.1$	Total	
			Events found	From pileup
Prompt signal	$24 \pm 6 \pm 2$	$32 \pm 8 \pm 5$	$56 \pm 10 \pm 5$	$5.2^{+1.8}_{-1.3}$
Non-prompt signal	$54 \pm 9 \pm 3$	$41 \pm 8 \pm 7$	$95 \pm 12 \pm 8$	$2.7^{+0.9}_{-0.6}$
Background	$61 \pm 11 \pm 6$	$77 \pm 13 \pm 7$	$138 \pm 17 \pm 9$	

Associated production of $Z + J/\psi$

Single/Double Parton Scattering

- DPS governed by a “universal” effective cross-section, σ_{eff}
- Estimation follows:
 - $N_{\text{DPS}} = P^{\text{DPS}}_{J/\psi} N_{\text{fid}}^{\text{Z}}$
 - $P^{\text{DPS}}_{J/\psi} = \sigma^{\text{bin}}_{J/\psi} / \sigma_{\text{eff}}$
- σ_{eff} taken from ATLAS W+2jets measurement
- Prompt: $11.1^{+5.7}_{-5.0}$
- Non prompt: $5.8^{+2.8}_{-2.6}$



Analysis procedure

- Pair of muons fitted in a common vertex that reconstruct a J/ψ
 - $p_T^\mu > 2.5(3.5)$ GeV for $|\eta^\mu| > (<) 1.3$
 - both $|\eta^\mu| < 2.5$, at least one with $p_T^\mu > 4$ GeV
 - $2.6 < m_{\mu\mu} < 3.6$ GeV
 - $p_T^{\mu\mu} > 8.5$ GeV and $|y^{\mu\mu}| < 2.1$
- Second pair of muons that form a $Z \rightarrow l l$ ($l = \mu, e$)
 - $p_T^l > 15$ GeV
 - $|\eta^\mu| < 2.5 - |\eta^e| < 2.47$
 - $|m_Z^{\text{PDG}} - m_{ll}| < 10$ GeV
 - lepton track isolation: $p_T^{\text{cone}20}/p_T < 0.15$
($\Delta R < 0.2$ around lepton)
 - at least one leg of the Z must match to a trigger object that fired the trigger
 - $p_T^l > 25$ GeV
 - $|\eta^l| < 2.4$
- Triggers used:
 - $Z \rightarrow \mu\mu$: EF_mu24i_tight \parallel EF_mu36_tight
 - $Z \rightarrow ee$: EF_e24vhi_medium1 \parallel EF_e60_medium1

