MEASUREMENT OF THE PRODUCTION OF PAIRS OF PROMPT J/Ψ MESONS AT √S = 8 TEV WITH THE ATLAS DETECTOR

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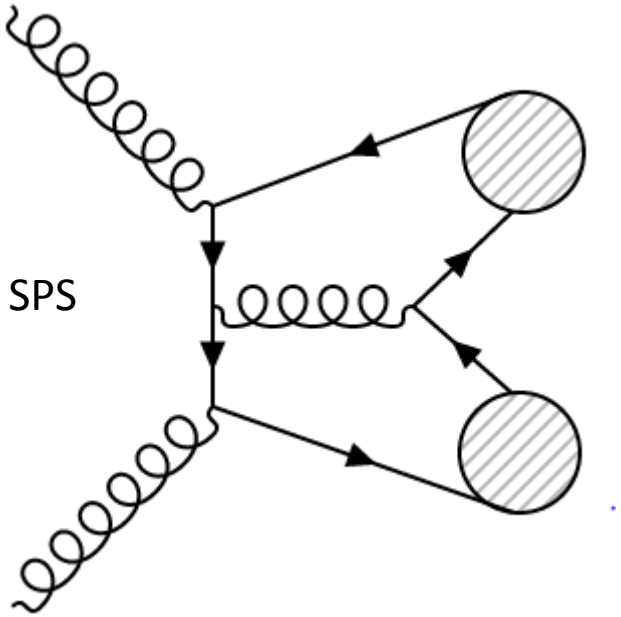
Interest in Di-J/ψ

- Single Parton Scattering (SPS).
  - Color Singlet Model (CSM), Color Octet Model (COM), and Color Evaporation Model (CEM).
  - Importance/effects of feed-down events.
  - LO, NLO, NNLO effects.



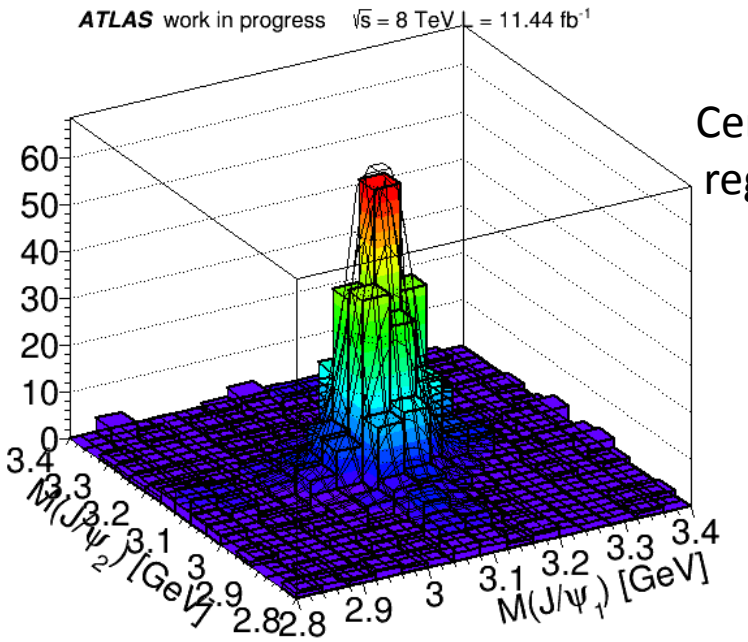
- Double-Parton Scattering (DPS).
  - Likely to play a larger role at high energies, especially for $c\bar{c}c\bar{c}$ production (arXiv:1504.06491)
  - Helps explain observations like the cross-section of multi-jet production and the large rapidity differences in hard diffraction (arXiv:1111.0469)
  - Background to Higgs searches ($WH \rightarrow ll\nu b\bar{b}, H \rightarrow \nu\nu ll$), SUSY and exotics searches (arXiv:0909.1586).
  - Non-perturbative QCD.
  - Insight into the structure of the proton.

- Bose-Einstein Correlations, Non-Relativistic QCD Models, and four-charm-quark states

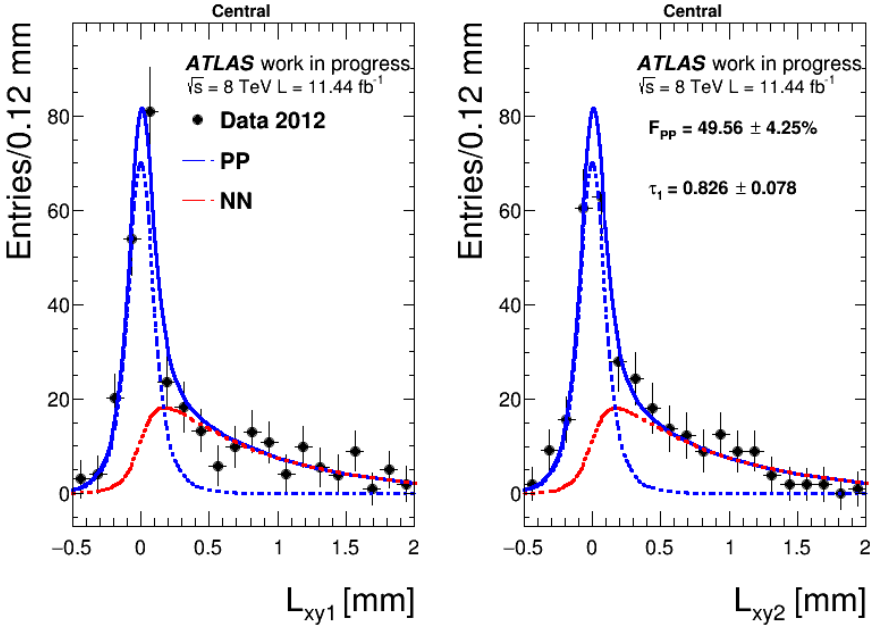
Analysis

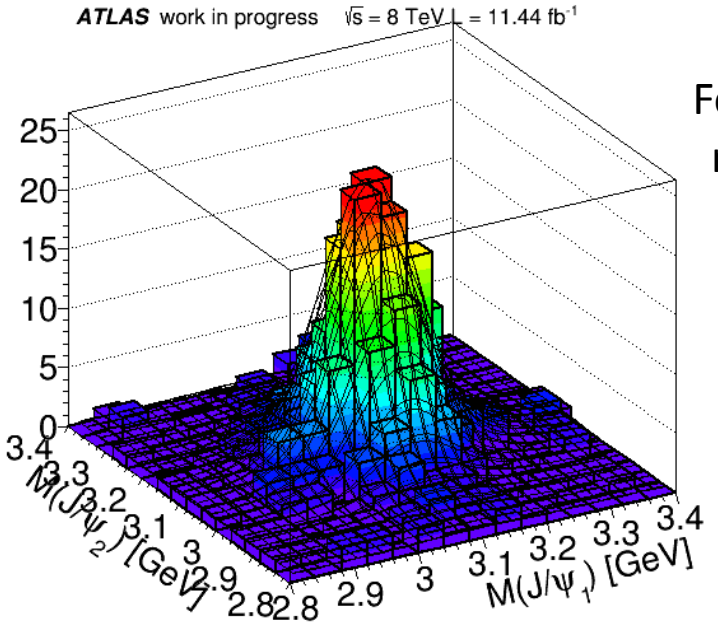
- First look at prompt J/ψ pair production using ATLAS 8 TeV data with decay mode J/ψ→$\mu^+\mu^-$.

- Goals:
  - Measure the differential cross-section in two rapidity regions.
  - Study and extract the fraction of DPS events using a data-driven method.
  - Calculate the effective cross-section of DPS.



Central region





Forward region

Analysis

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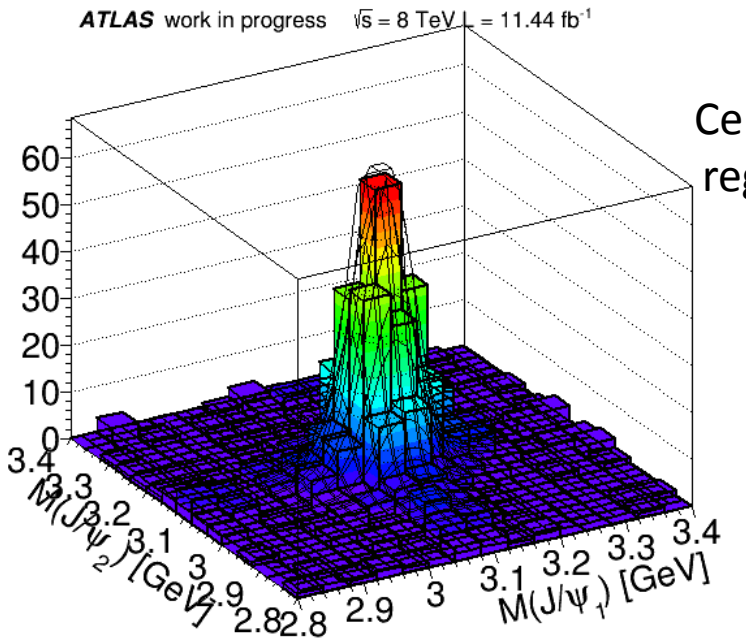
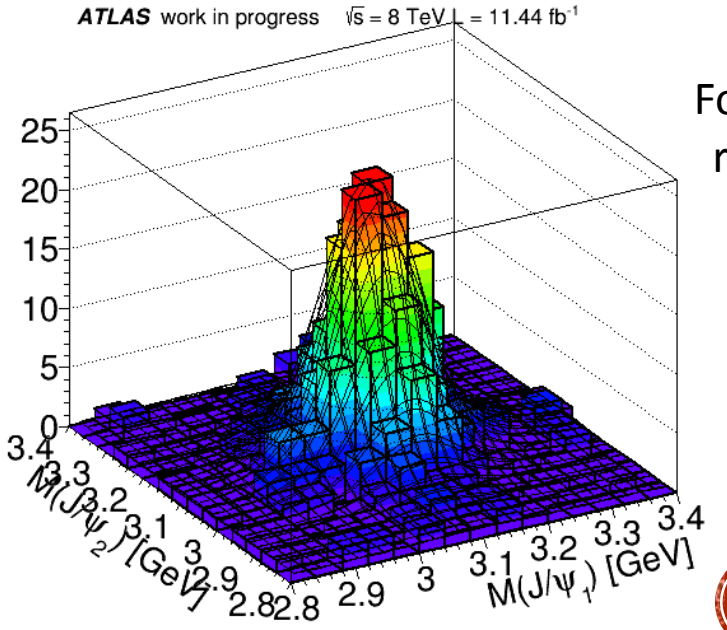
- Goals:
  - Measure the differential cross-sections in two rapidity regions.
  - Study and extract the fraction of DPS events using a data-driven method.
  - Calculate the effective cross-section of DPS.

- Muon Volume:
  - $|y|<2.3$ and $p_T > 2.5$ GeV.
  - One J/ψ must have both muons with $p_T > 4$ GeV.

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

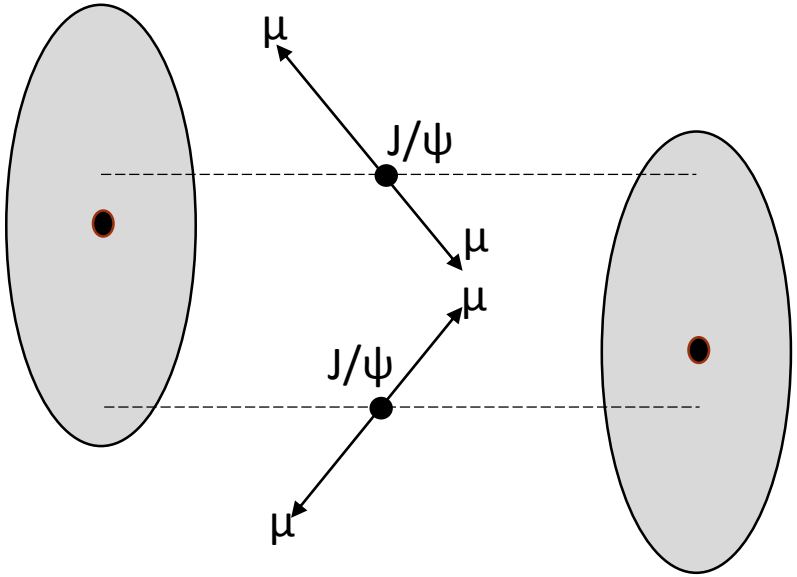


Central region



Forward region

Double Parton Scattering (DPS)



- DPS requires large c.m. energies and low values of incoming fractional momenta (x_F).

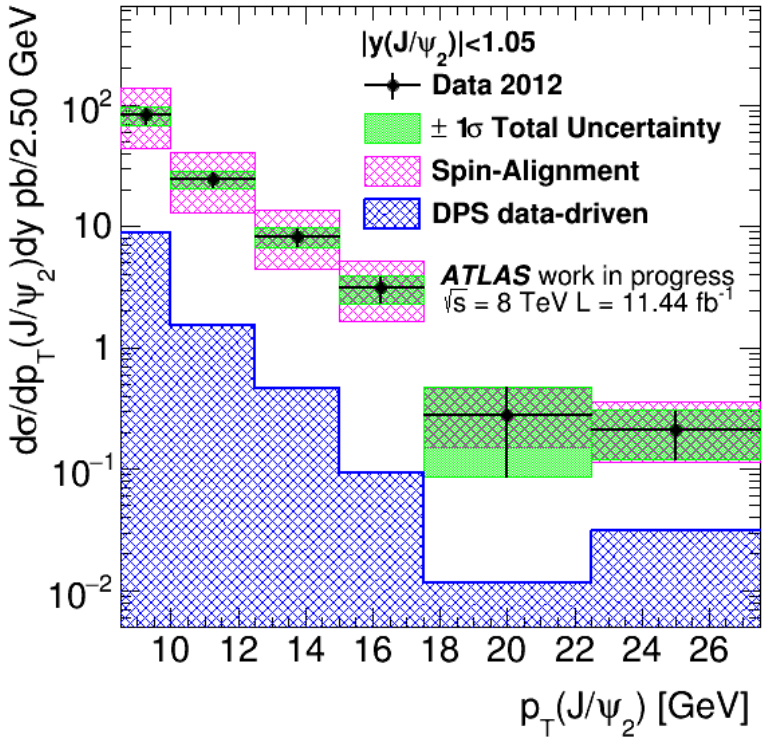
- Assuming that the two processes are independent of each other, DPS cross section can be written as: $\sigma_{DPS} = \frac{1}{2}\frac{\sigma_{J/\psi}\sigma_{J/\psi}}{\sigma_{eff}}$.

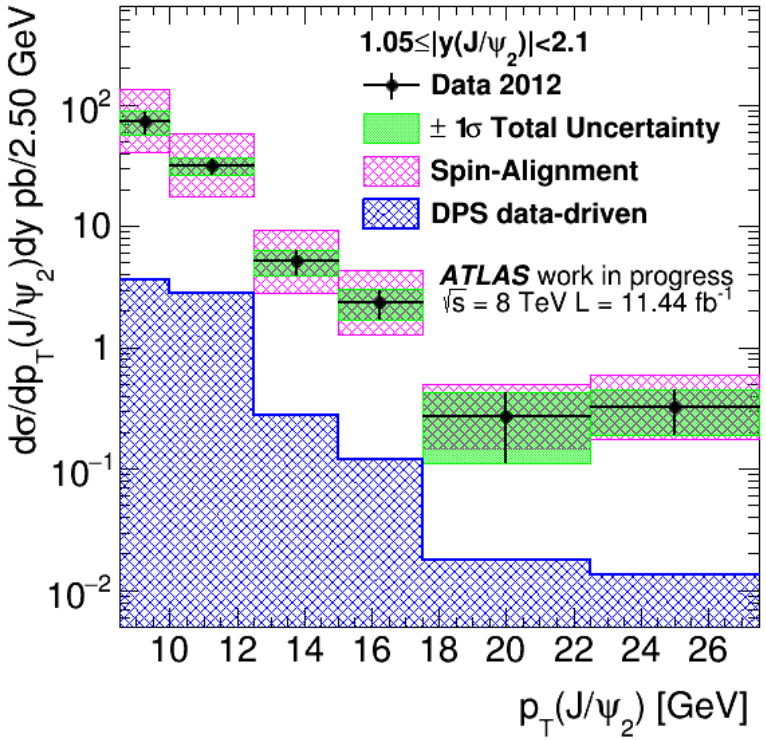
- σ_{eff} measures the size in impact parameter space of the incident hadron's partonic core.

- σ_{eff} ~ 1/4 σ_{Inel}.

- A constant value of σ_{eff} has been able to describe results in different kinematical regions. CDF (PRL.79.584) tested the dependence of σ_{eff} on x_F and had compatible results with being independent of x_F.

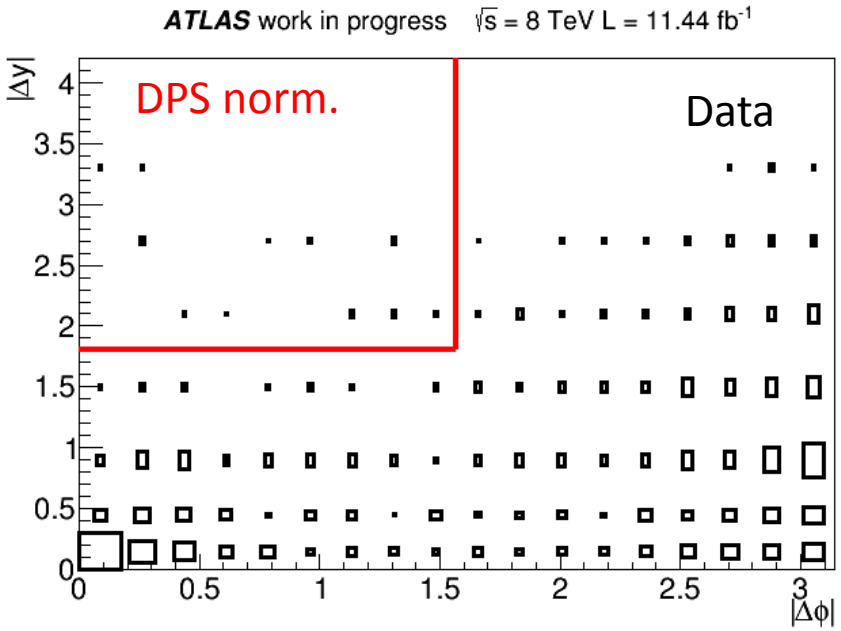
$\frac{d\sigma}{dp_T}$ for Prompt di-J/ψ



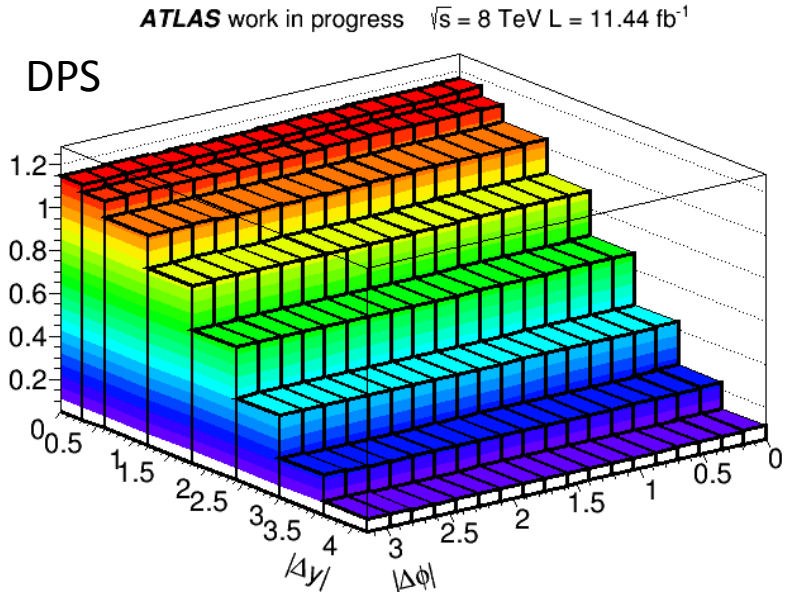


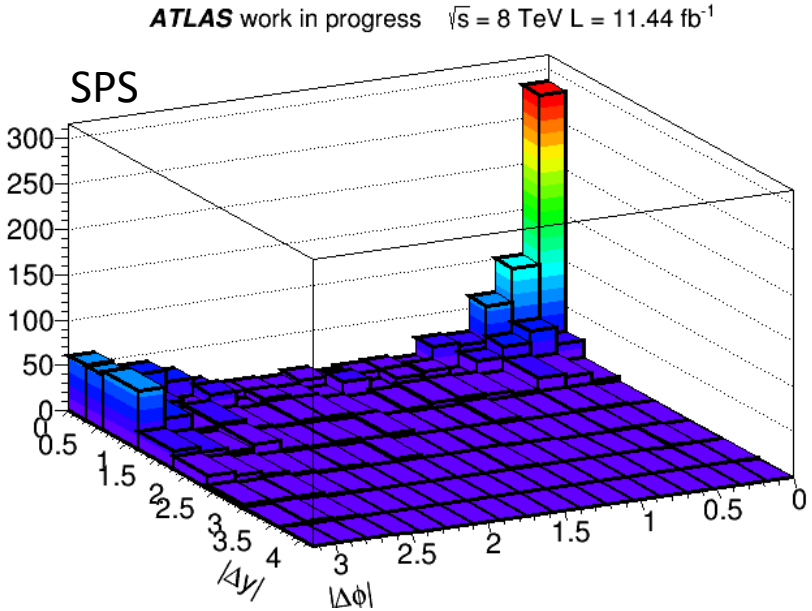
- Differential cross-section as a function of the sub-leading J/ψ p_T assuming unpolarized J/ψ mesons.
- Weighted to get the inclusive cross-section: $p_T(J/\psi) > 8.5$ GeV, $|y(J/\psi)|<2.1$.
  - Central Region: $\sigma = 86.07 \pm 8.63(\text{stat}) \pm 7.21(\text{syst})$ pb for $|y(J/\psi_2)|< 1.05$.
  - Forward Region: $\sigma = 84.50 \pm 9.90(\text{stat}) \pm 7.70(\text{syst})$ pb for $1.05\leq|y(J/\psi_2)|< 2.1$.
- Also included are the DPS-enriched distributions from the data-driven method.
- Comparison to CMS in back-up slides.

Extracting DPS



- DPS events are modeled by using randomized J/ψ pairs from different di-J/ψ events.
- We use a 2-D map of |Δφ| vs. |Δy| to extract the DPS distribution.
  - Define a DPS dominated region to normalize randomized J/ψ to DPS: $|\Delta y| \geq 1.8$ and $0 \leq |\Delta\phi| \leq \pi/2$.

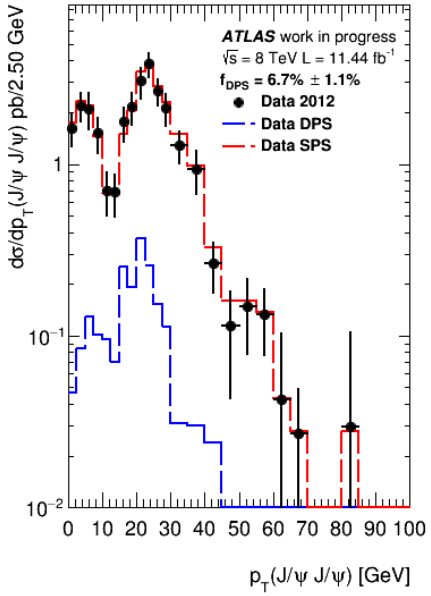




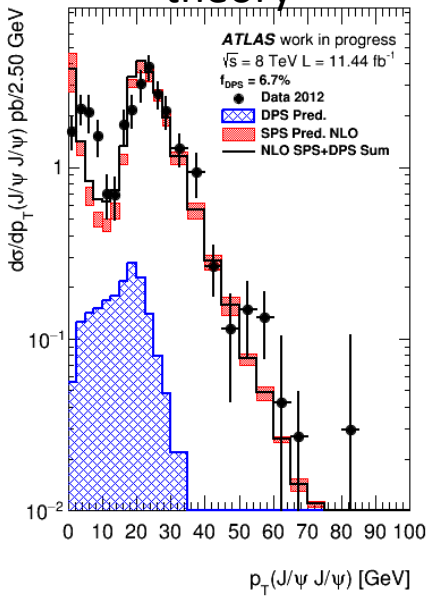
- By subtracting the DPS distribution, we get the SPS distribution.

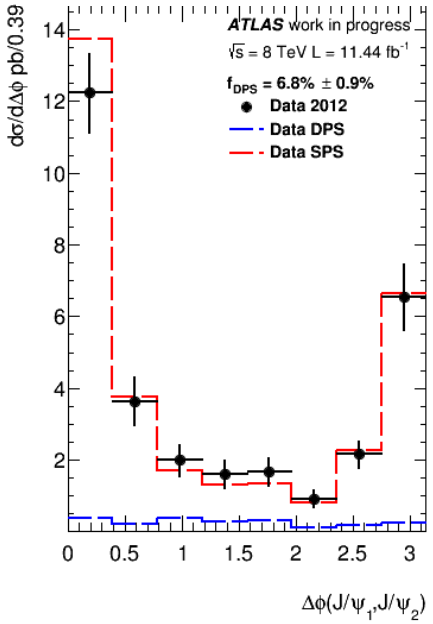
DPS Distributions: $p_T(J/\psi\ J/\psi)$ and $\Delta\phi$

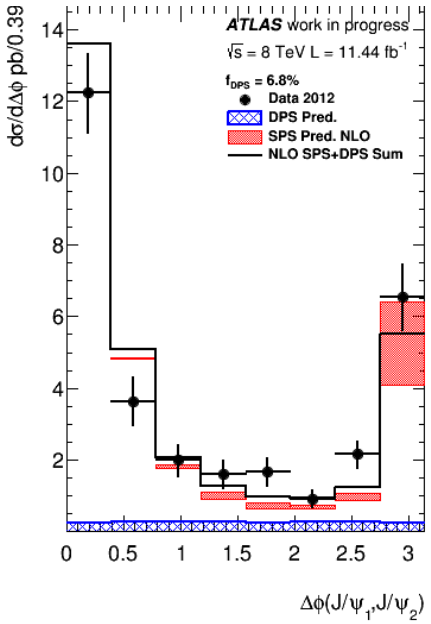
data-driven



theory







- (left)The data-driven SPS/DPS-enriched distributions plotted with data, used to measure f_{DPS}.
- (right) QCD predictions for LO DPS (arxiv: 1105.4186) and NLO SPS (arxiv:1410.8822) normalized to the value f_{DPS} measured in the data.
  - To compare the shape of the SPS/DPS distributions.
- DPS plots show a good agreement to the predictions within fluctuation (low p_T for $p_T(J/\psi\ J/\psi)$ and uniform for $\Delta\phi$).
- SPS shows a larger disagreement, the predictions don't include contribution due to feed down.
- Two peak structure is present in both distributions. Due to LO events when the two J/ψ are back-to-back (low $p_T(J/\psi\ J/\psi)$ and $|\Delta\phi|=\pi$) and NLO events when the two J/ψ are produced back-to back with an additional gluon (higher $p_T(J/\psi\ J/\psi)$ and $|\Delta\phi|=0$).

Effective Cross-section

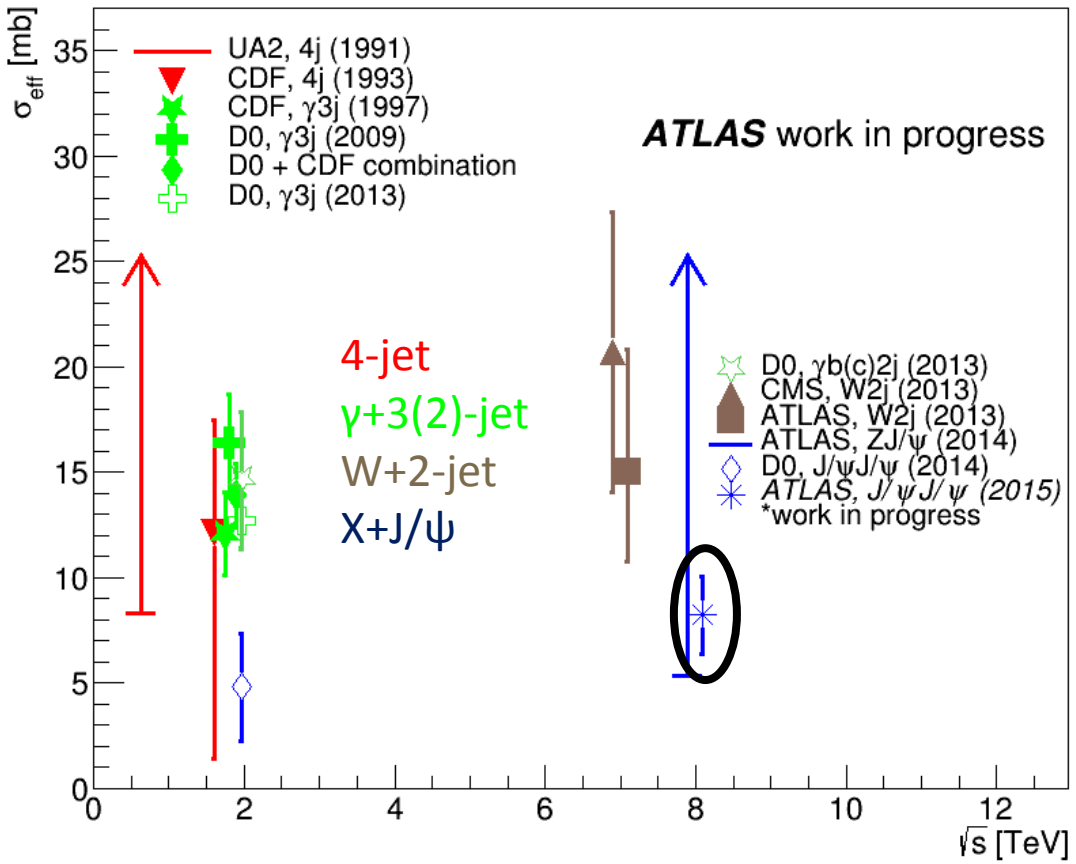
- The effective cross-section is a measure of the hadronic structure and has been reported by multiple experiments using different processes.

- $\sigma_{eff} = \frac{1}{2}\frac{\sigma_{J/\psi}\sigma_{J/\psi}}{\sigma_{DPS}} = \frac{1}{2}\frac{\sigma_{J/\psi}\sigma_{J/\psi}}{f_{DPS}*\sigma_{J/\psi J/\psi}}$

  $= 8.24 \pm 1.30\ (\text{stat})\ ^{+1.30}_{-1.32}(\text{syst})\text{mb}.$

- Di-J/ψ events are dominated by gluon-gluon production unlike most of the other processes.

- Our measurement is within the range of the D0 Di-J/ψ measurement and the 4-jet measurements.



- According to the D0 paper (arXiv:1406.2380), this could indicate a smaller transverse distance between gluons in the hadronic structure as predicted by the pion cloud model (arXiv: 0906.3267).

Summary

- Using 11.44 fb^{-1} of ATLAS 8 TeV data, we present the first ATLAS measurement of the prompt J/ψ pair cross-section.
  - $\sigma(pp \rightarrow J/\psi + J/\psi + X) = 86.07 \pm 8.63(stat) \pm 7.21(syst)$ pb; for $|y(J/\psi_2)|<1.05$.
  - $\sigma(pp \rightarrow J/\psi + J/\psi + X) = 84.50 \pm 9.90(stat) \pm 7.70(syst)$ pb ; for $1.05 \leq |y(J/\psi_2)|<2.1$.

- Using randomized J/ψ pairs as a model for Double Parton Scattering, and defining a DPS-heavy region, we were able to make SPS/DPS weights as a function of $|\Delta\phi|$ and $|\Delta y|$.
  - Our model does not rely on Monte Carlo and therefore does not depend on the production model (CS, CO, CEM).
  - $f_{DPS} = (6.6 \pm 0.9\ (stat) \pm 0.2\ (syst))\%$.

- The effective cross-section is measured to be: $\sigma_{eff} = 8.24 \pm 1.30\ (stat)\ ^{+1.30}_{-1.32}(syst)mb$. It is within range of the D0 prompt Di-J/ψ measurement and the 4-jet measurements. As stated in the D0 paper, this could indicate that the transverse distance between gluons is smaller than that of quarks or quarks and gluons.

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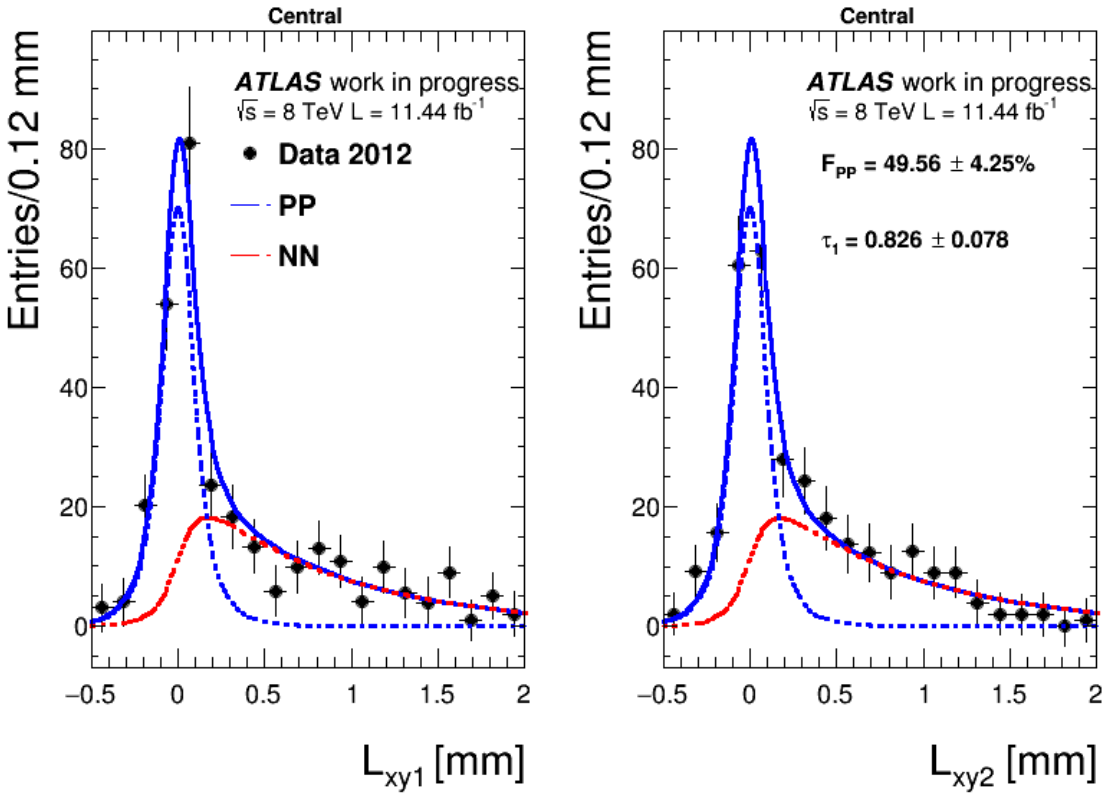
BACKUP SLIDES

Signal Extraction

- Now that we have the signal distributions from the mass fit, we need to extract the prompt-prompt signal (PP) using a 2-D fit of the transverse decay length, L_{xy}.
- The data are split into four rapidity regions and fit to separate the PP signal from the non-prompt-non-prompt (NN) background.
- From this fit, we calculate can calculate the probability that an event is PP as a function of the L_{xy} and rapidity of each J/ψ.
- Finally, to get the PP signal distribution of any variable, we perform 2-D mass fits in bins of the desired variable weighted by the PP probability.



Systematic Uncertainty

- Sources of systematic uncertainty:
  - Trigger
  - Muon Reconstruction
  - Acceptance
  - Mass Model
  - Mass Bias
  - Prompt-Prompt Model
  - Fitting Procedure
  - Double Interactions
  - DPS Model
  - Branching Fraction
  - Luminosity
  - Spin-Alignment

Comparison to CMS

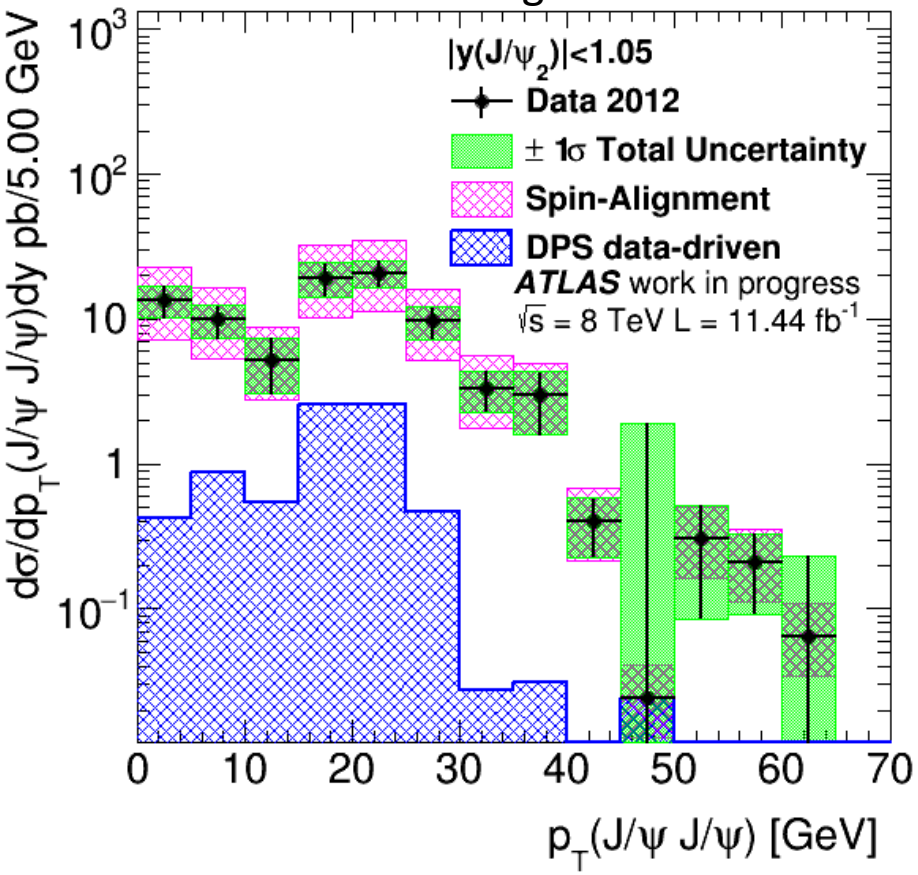
- Using 7 TeV data, CMS measured the cross-section to be:
  $\sigma = 1.59 \pm 0.07(\text{stat}) \pm 0.14(\text{syst})$ nb (arXiv:1406.0484).

- The CMS cross-section used a different inclusive volume which scaled with p_T and included lower p_T where J/ψ production is enhanced.

- Using MC predictions (arxiv:1410.8822) for the 7 TeV CMS results and 8 TeV ATLAS results, we found the values to be equal when accounting for the inclusive volume.

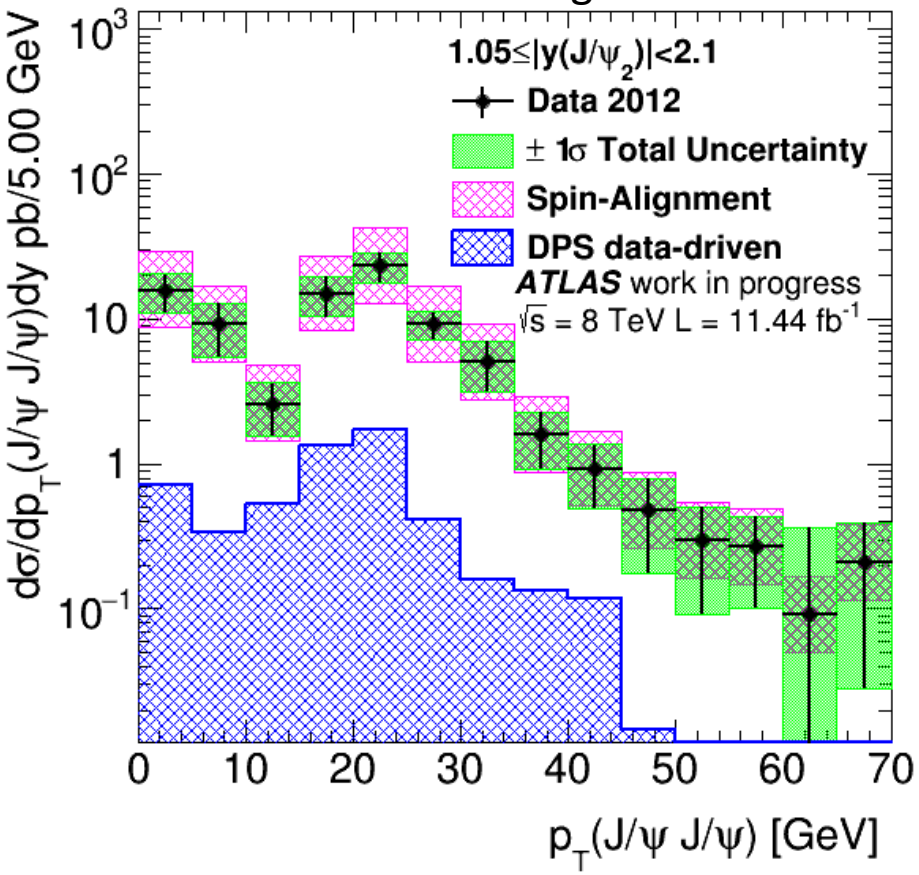
$\frac{d\sigma}{dp_T(\mathrm{J/\psi J/\psi})}$ for Prompt di-J/ψ

Central Region



σ = 85.93 ± 8.54 (stat) ± 7.20 (syst) pb

Forward Region



σ = 84.22 ± 9.45 (stat) ± 7.67 (syst) pb