# Observation of double J/Ψ production in pPb collisions

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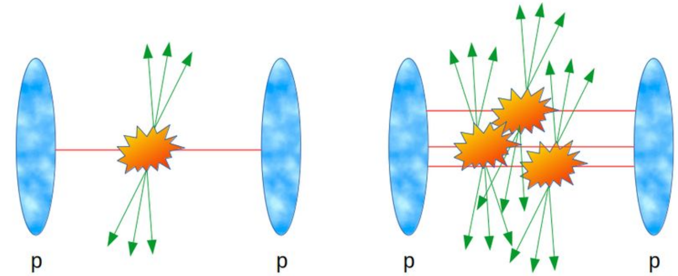
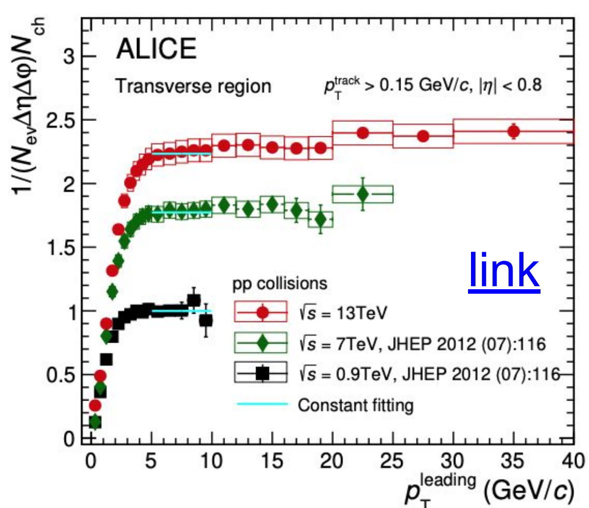
- Signal Extraction
- Double J/Ψ Production Cross Section
- Extraction of DPS Contributions
    - production cross section and effective cross section
- Summary

# Introduction

- MPI (multiple parton scattering) studies are important for
  - Probing partonic structure of proton
  - Tuning of Monte Carlo event generators
  - Background for new physics searches




- Sensitive to interplay between perturbative and non-perturbative QCD
- MPI cross section increases with $\sqrt{s}$; increased parton densities
- DPS: two hard scatterings within the same collision
  - Many measurements from UA2 to LHC
    - Different processes and collision energies

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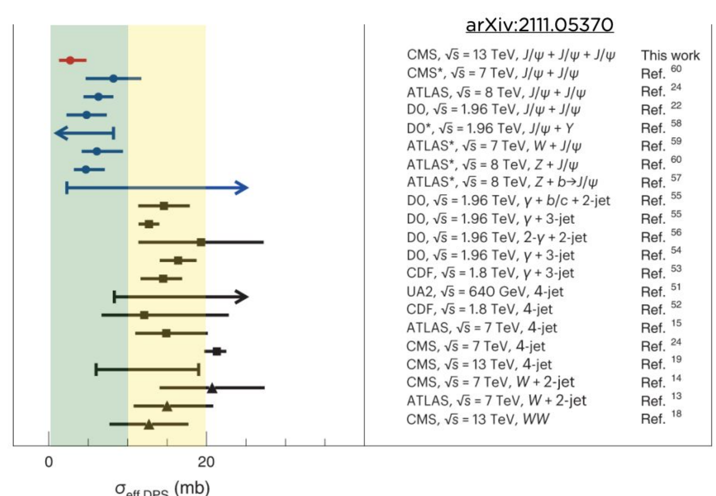
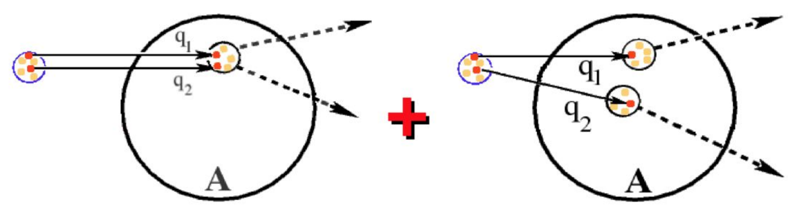
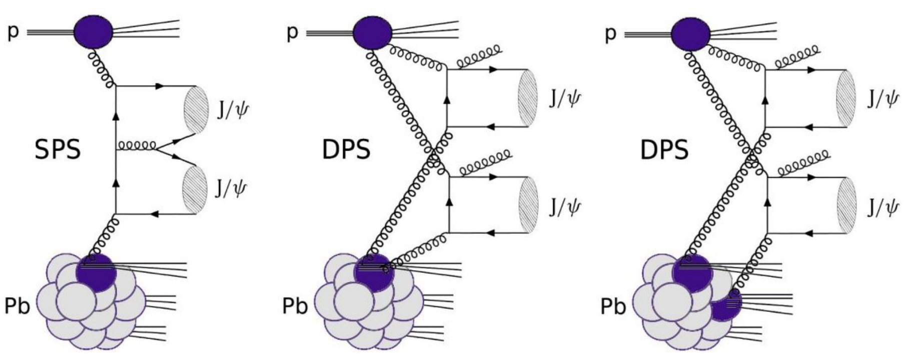


# Introduction

- DPS cross section can be written as $$\sigma_{\mathrm{DPS}}^{hh'\to ab} = \frac{m}{2}\frac{\sigma_{\mathrm{SPS}}^{hh'\to a}\,\sigma_{\mathrm{SPS}}^{hh'\to b}}{\sigma_{\mathrm{eff}}}$$
  - assumptions; PDFs factorization in the transverse and longitudinal components, no parton correlations i.e. double PDF can be expressed as as a product of single PDFs
  - The $\sigma_{eff}$ ≡ (Interpretation transverse distance)$^2$
    - Measurements: ~15 mb for jet, photon, W/Z and ~5 mb for quarkonia states.
    - MC predicts 20-30 mb ⇒ presence of correlations

- pPb data provide an independent tool to extract $\sigma_{eff}$
- DPS is enhanced by a factor of 600 in pPb collisions as compared to pp

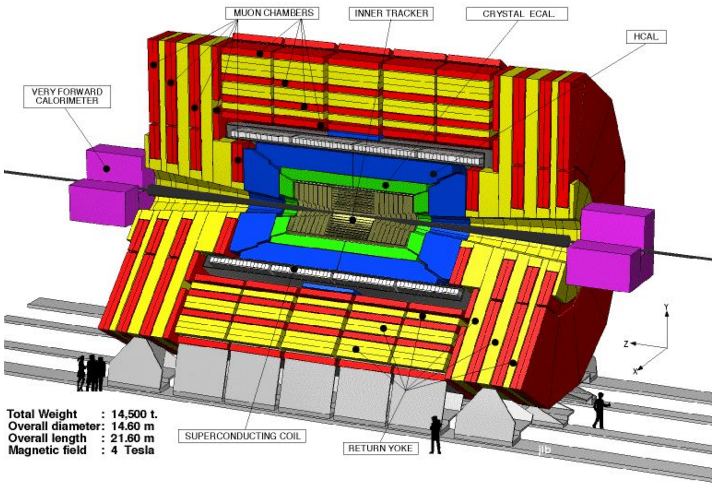



*Studies with J/Ψ meson has advantage of higher production rate and clean signature with leptonic final state e.g. Triple J/Ψ[link], J/Ψ + $D^0$ [link]*

# Dataset and Event Selection

- pPb data sample collected at $\sqrt{s_{NN}}$ = 8.16 TeV during 2016
  - Integrated luminosity: 174.56 $nb^{-1}$
- Channels considered
  - $J/\psi(\rightarrow\mu\mu)J/\psi(\rightarrow\mu\mu)$
  - $J/\psi(\rightarrow\mu\mu)J/\psi(\rightarrow ee)$
- 4 leptons with common vertex
- Soft Muons



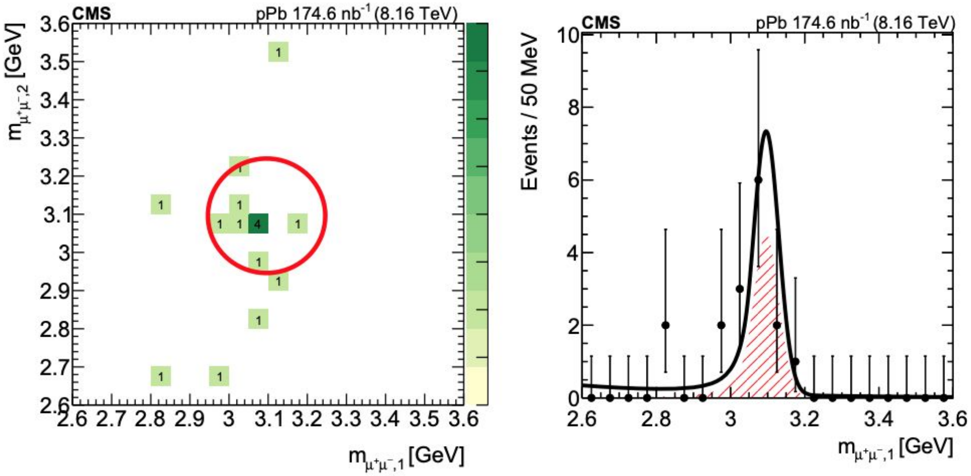

$$
\begin{aligned}
p_T &> 3.4\,\text{GeV} && \text{for } 0 < |\eta| < 0.3 \\
p_T &> 3.3\,\text{GeV} && \text{for } 0.3 < |\eta| < 1.1 \\
p_T &> 5.5 - 2.0|\eta|\,\text{GeV} && \text{for } 1.1 < |\eta| < 2.1 \\
p_T &> 1.3\,\text{GeV} && \text{for } 2.1 < |\eta| < 2.4
\end{aligned}
$$

- Electrons with $p_T$ > 2.5 GeV and $|\eta|$ < 2.5
- **J/Ψ** mesons with $p_T$ > 6.5 GeV and $|y|$ < 2.4, decay length < 0.01 cm to reduce non-prompt contribution. Invariant mass: 2.6–3.6 GeV

# Signal Extraction

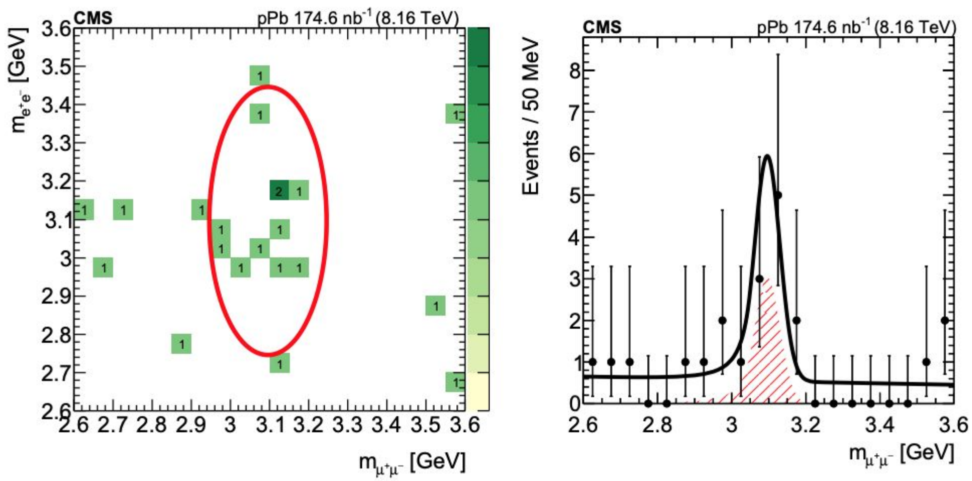
- 2D unbinned extended ML fit
  - ➢ Crystal ball function for signal: common mean and width from simulation
  - ➢ Exponential function for background

**J/ψ(→μμ)J/ψ(→μμ)**




- Signal Yield
  - ➢ J/ψ(→μμ)J/ψ(→μμ) : 8.5 ± 3.4
  - ➢ J/ψ(→μμ)J/ψ(→ee) : 5.7 ± 4.0

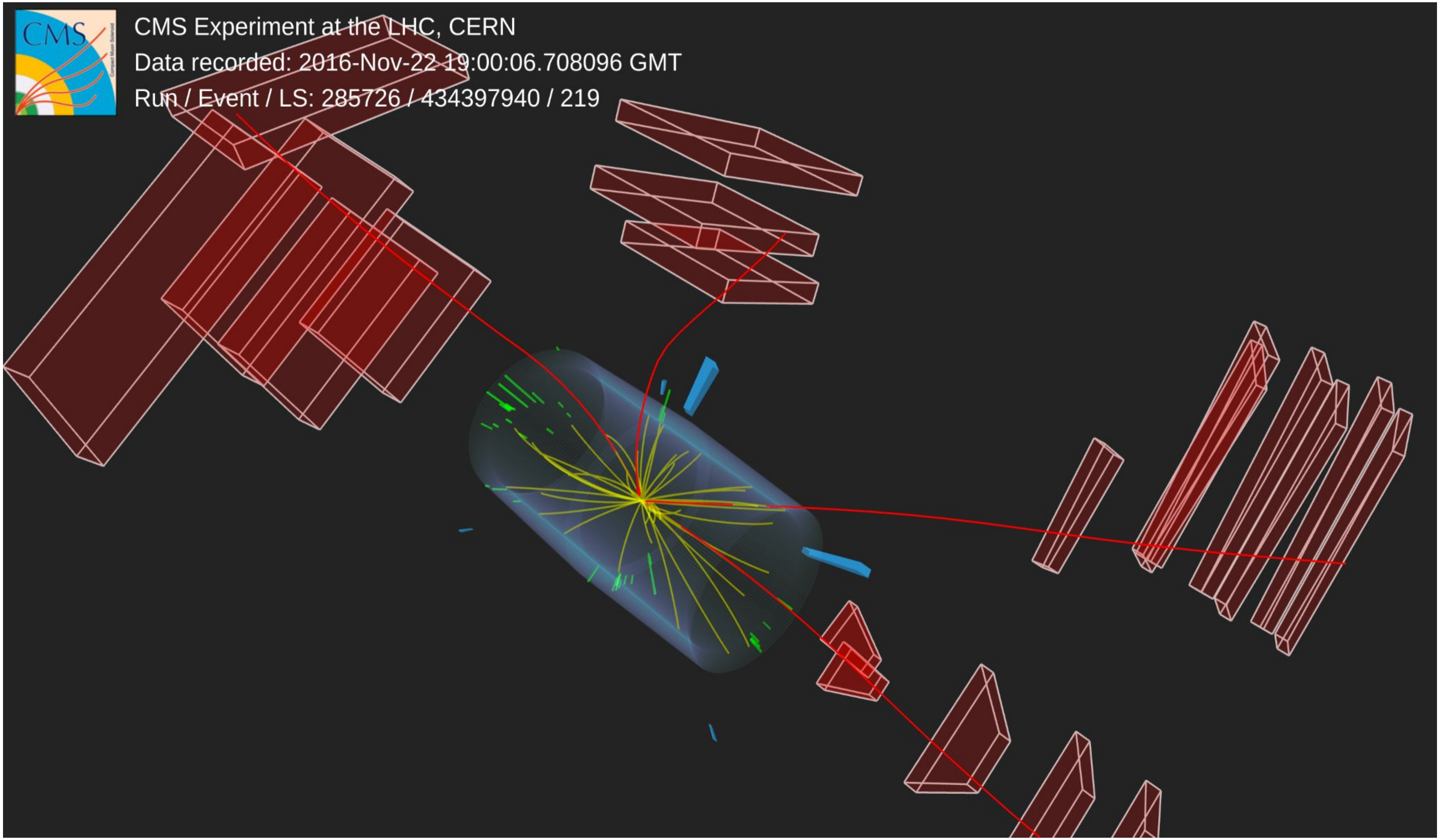
**J/ψ(→μμ)J/ψ(→ee)**




- Significance is 4.9 std. dev. for 4 muon channel: Likelihood ratio of the fits + asymptotic formula under Wilks theorem

- 5.3σ (combination with Fischer Formalism)

# Event Display



# Double J/Ψ Production Cross Section

- Measured, using J/ψ(→μμ)J/ψ(→μμ) only, fiducial cross section as

$$\sigma(\mathrm{pPb} \to \mathrm{J}/\psi\mathrm{J}/\psi + \mathrm{X}) = N_{\mathrm{sig}} / (\epsilon\, \mathcal{L}_{\mathrm{int}}\, \mathcal{B}^2_{\mathrm{J}/\psi \to \mu^+\mu^-})$$

- $N_{sig}$ = 8.5 ± 3.4
- Efficiency = 62.1% (same as squared efficiency of single J/ψ(→μμ))
- B.R. (J/ψ(→μμ)) = 5.961%

$$\sigma(\mathrm{pPb} \to \mathrm{J}/\psi\mathrm{J}/\psi + \mathrm{X}) = 22.0 \pm 8.9\,(\mathrm{stat}) \pm 1.5\,(\mathrm{syst})\,\mathrm{nb}$$

- Systematic uncertainty is dominated by signal, background PDFs and luminosity
  - Signal with CB + Gaussian, background with first order polynomial

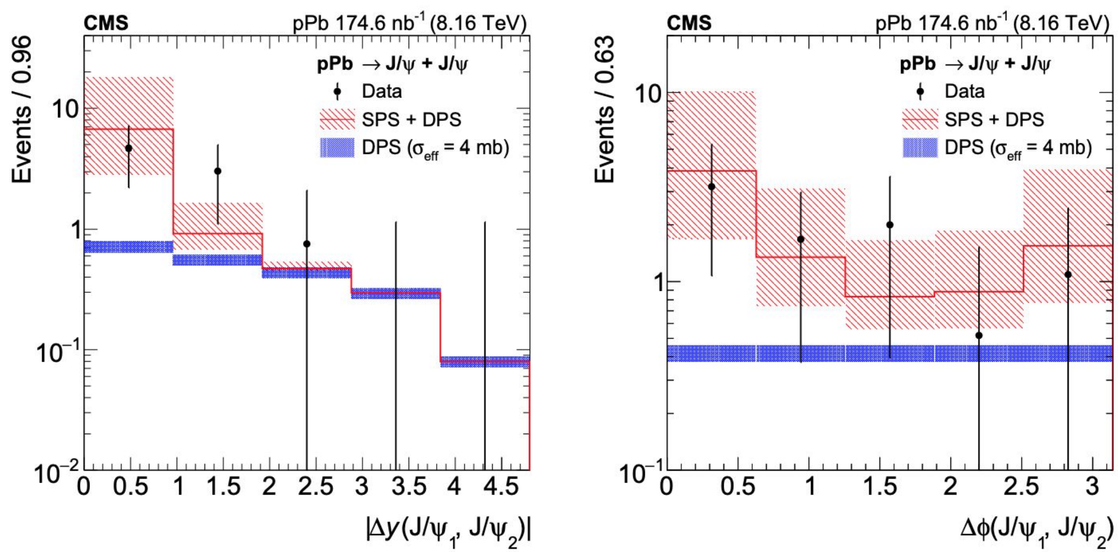
| Source of uncertainty | $\sigma(\mathrm{pPb} \to \mathrm{J}/\psi\mathrm{J}/\psi + \mathrm{X})$ |
|---|---|
| J/ψ meson signal shape | 4.0% |
| Dimuon continuum background shape | 2.5% |
| Luminosity | 3.5% |
| Branching fraction | 1.1% |
| Scale factors | 1.3% |
| Total | 6.1% |

*Measured cross section is DPS + SPS which needs to be separated for the measurement of the effective cross section*

# Extraction DPS Contributions (I/II)

- Discriminating variables between DPS and SPS; Δy and Δφ
  - Decorrelated J/ψ pair in DPS: flat Δy and Δφ
  - Correlated J/ψ pair in SPS: peaking Δy (~0) and Δφ (~0, π)

- Limited data sample to perform 2D fit Δy-Δφ
- Look for the phase-space dominated by SPS/DPS
  - Large Δy is dominated by DPS

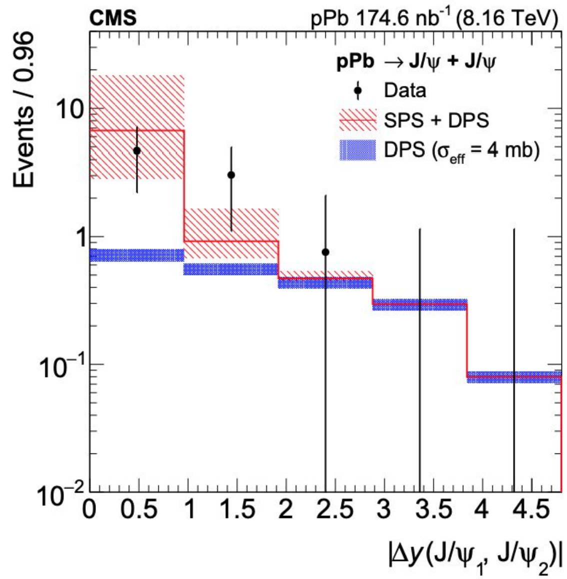


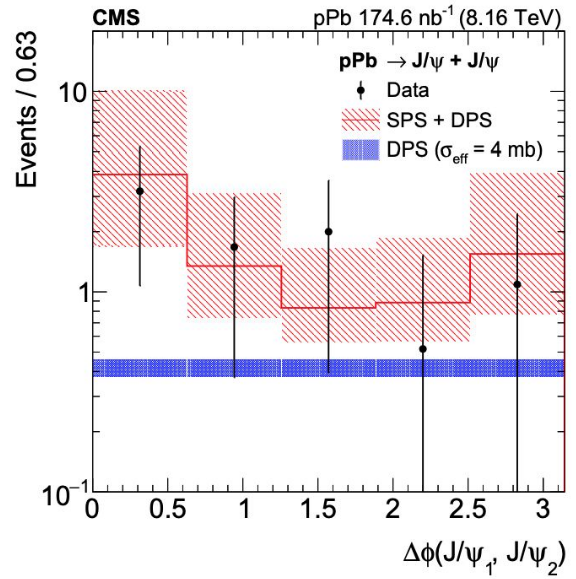
# Extraction DPS Contributions (II/II)

- 1D fit of Δy variable in the DPS dominated region Δy > 1.92
  - A data driven DPS templated is constructed using two J/ψ from independent events
  - SPS template derived using simulated events

- Yields:

events (DPS) = 2.1 ± 2.4
events (SPS) = 6.4 ± 4.2




- Fiducial cross section:

SPS: 16.5 ± 10.8 (stat) ± 0.1 (syst) nb
DPS: 5.4 ± 6.2 (stat) ± 0.4 (syst) nb

*These measurements can be used to measure the effective cross-section*

# Effective Cross Section

- $\sigma_{eff,pA}$ can be extracted using formula

from theory

$$\sigma_{eff,pA} = \left(\frac{1}{2}\right) \frac{\sigma_{SPS}^{pPb\to J/\psi+X}\,\sigma_{SPS}^{pPb\to J/\psi+X}}{\sigma_{DPS}^{pPb\to J/\psi J/\psi+X}}$$

from data

Theoretical cross section with HELAC-ONIA code + CT14nlo proton PDF + reweighted EPPS16 lead nPDF

| | |
|---|---|
| $\sigma_{SPS}^{pPb\to J/\psi+X}\mathcal{B}(J/\psi\to\mu^+\mu^-)$ | $4.51 \pm 0.42\ \mu b$ |
| $\sigma_{SPS}^{pPb\to J/\psi J/\psi+X}\mathcal{B}^2(J/\psi\to\mu^+\mu^-)$ | $20.2^{+38.5}_{-13.1}\,\mathrm{pb}$ |

$$\sigma_{eff,pA} = 0.53^{+\infty}_{-0.2}\,\mathrm{b}$$

large upper uncertainty indicates the possibility of the absence of DPS contribution

- Neglecting parton correlations, factorization of double PDF in transverse and longitudinal components; $\sigma_{eff}$ (pp) can be calculated

$$\sigma_{eff} = \frac{\sigma_{eff,pA}}{A - \sigma_{eff,pA}\, F_{pA}/A}$$

A = 208, and $F_{pA}$ = 29.5 $mb^{-1}$ from Glauber MC Model

$$\sigma_{eff} = 4.0^{+\infty}_{-1.5}\,\mathrm{mb}$$ → $\sigma_{eff}$ > 1.0 mb at 95% CL

# Summary

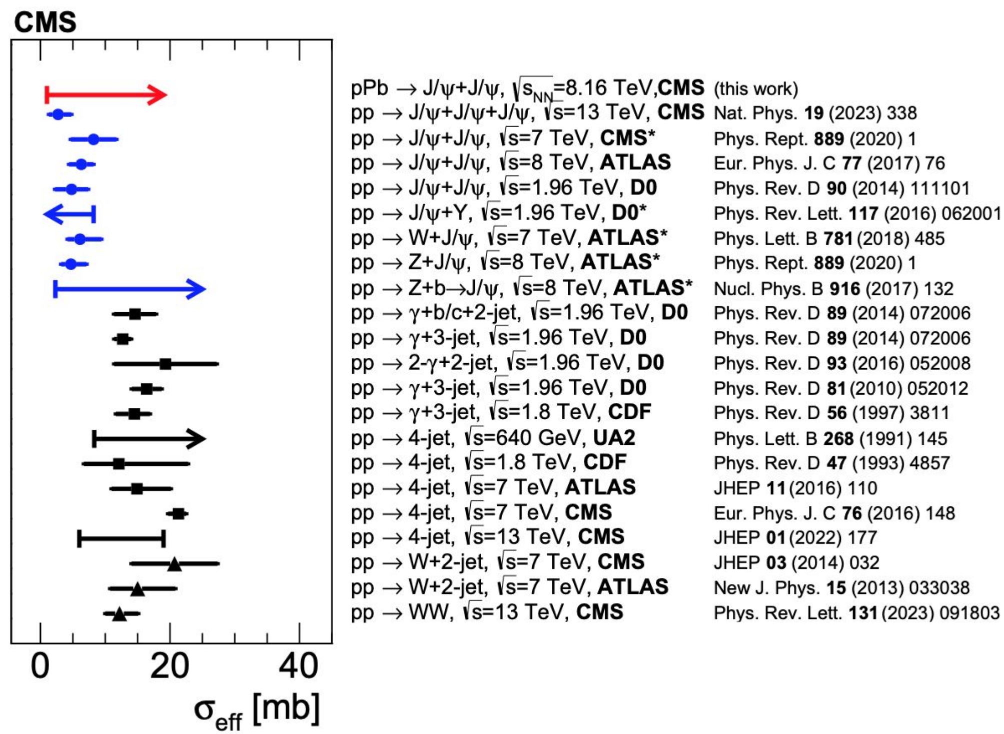
- First observation of double J/ψ production in pPb collisions at the energy of 8.16 TeV

$$\sigma(\mathrm{pPb} \rightarrow \mathrm{J}/\psi\mathrm{J}/\psi + \mathrm{X}) = 22.0 \pm 8.9\,(\mathrm{stat}) \pm 1.5\,(\mathrm{syst})\,\mathrm{nb}$$

- DPS cross section is measured to be:
  5.4 ± 6.2 (stat) ± 0.4 (syst) nb

  With $\sigma_{eff}$ > 1.0 mb @ 95% CL

- Future pPb data will be useful in the measurement of effective cross section with better accuracy.




https://arxiv.org/abs/2407.03223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