Observation of double J/Ψ production in pPb collisions

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Sunil Bansal
Panjab University, India
(for CMS Collaboration)

Outline

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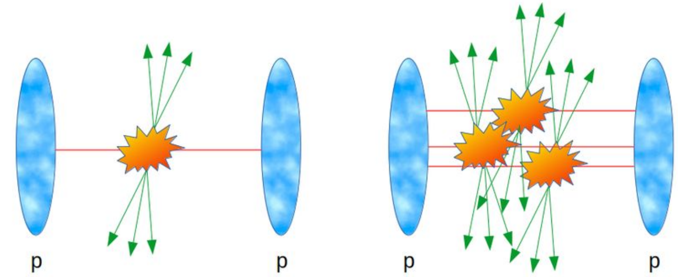
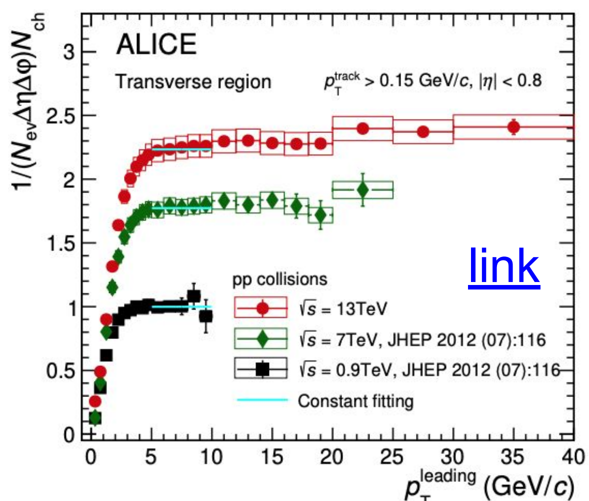
- Dataset and Event Selection
- Signal Extraction
- Double J/Ψ Production Cross Section
- Extraction of DPS Contributions
  - production cross section and effective cross section
- Summary

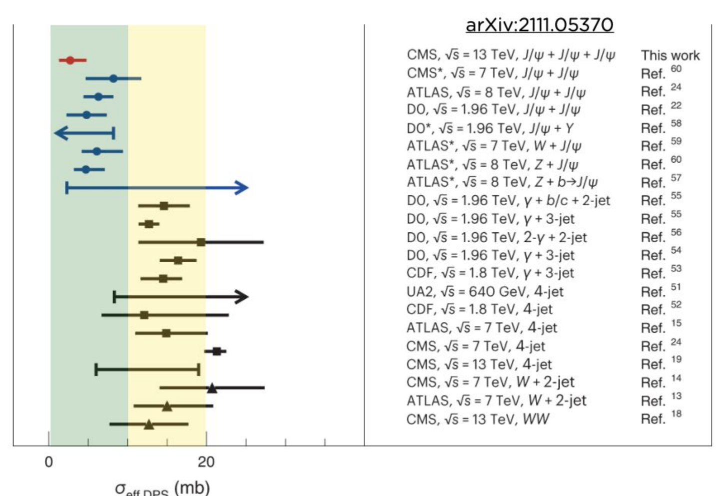
Introduction

- 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

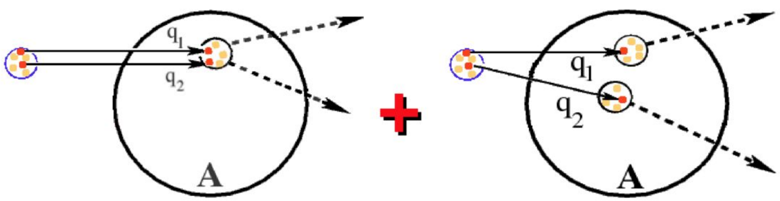


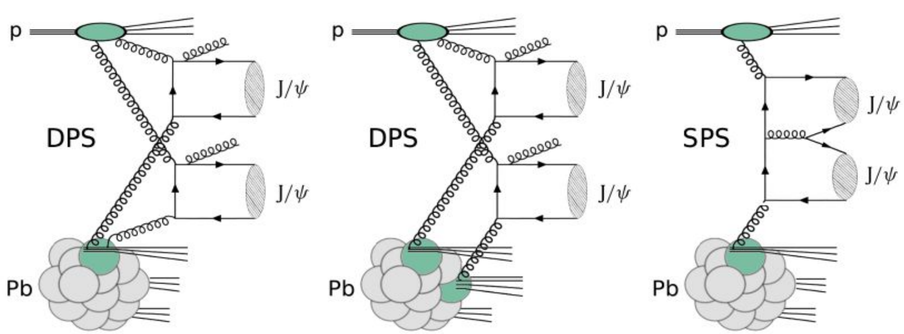


Introduction

- DPS cross section can be written as $$\sigma_{\rm DPS}^{hh'\to ab} = \frac{m}{2}\frac{\sigma_{\rm SPS}^{hh'\to a}\,\sigma_{\rm SPS}^{hh'\to b}}{\sigma_{\rm eff}}$$
    - 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 $\sigma_{\rm eff} \equiv$ (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 $\sigma_{\rm eff}$
- DPS is enhanced by a factor of 600 in pPb collisions as compared to pp

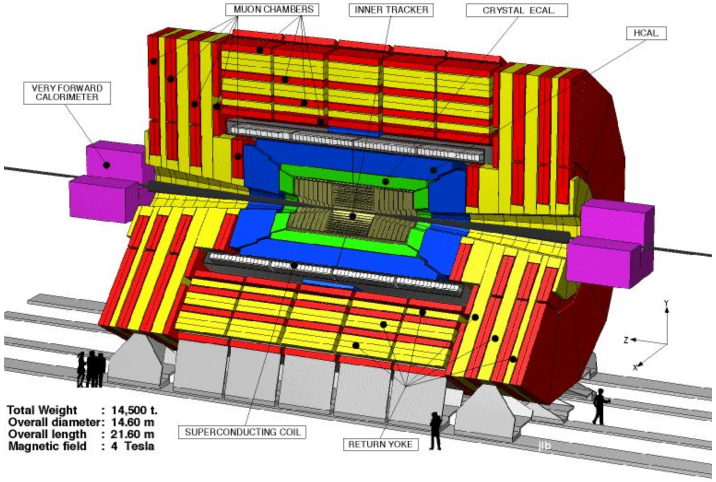




Studies with J/Ψ meson has advantage of higher production rate and clean signature with leptonic final state e.g. Triple J/Ψ[link], J/Ψ + D^0 [link]

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



$p_T > 3.4\,\text{GeV}$	for $0 < \lvert\eta\rvert < 0.3$
$p_T > 3.3\,\text{GeV}$	for $0.3 < \lvert\eta\rvert < 1.1$
$p_T > 5.5 - 2.0\lvert\eta\rvert\,\text{GeV}$	for $1.1 < \lvert\eta\rvert < 2.1$
$p_T > 1.3\,\text{GeV}$	for $2.1 < \lvert\eta\rvert < 2.4$

- 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

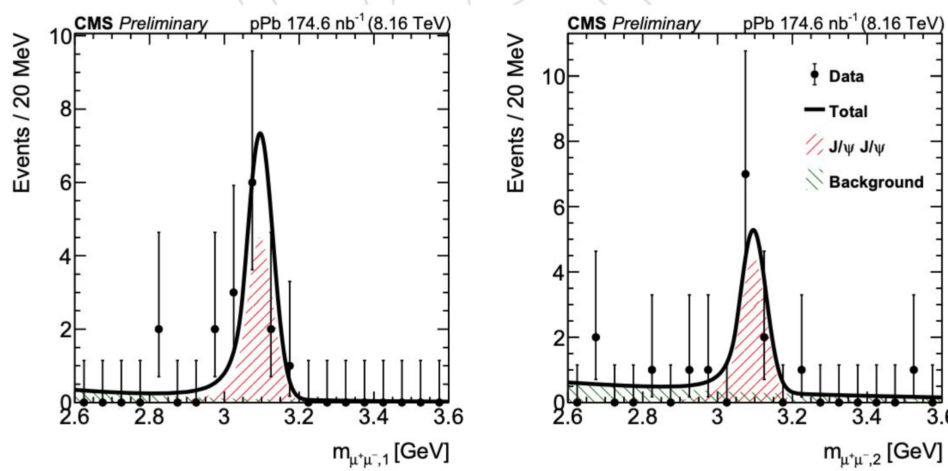
- 2D unbinned extended ML fit
  - Crystal ball function for signal: common mean and width from simulation
  - Exponential function for background

- Signal Yield
  - $J/\psi(\to\mu\mu)J/\psi(\to\mu\mu)$: 8.5 ± 3.4
  - $J/\psi(\to\mu\mu)J/\psi(\to ee)$: 5.7 ± 4.0

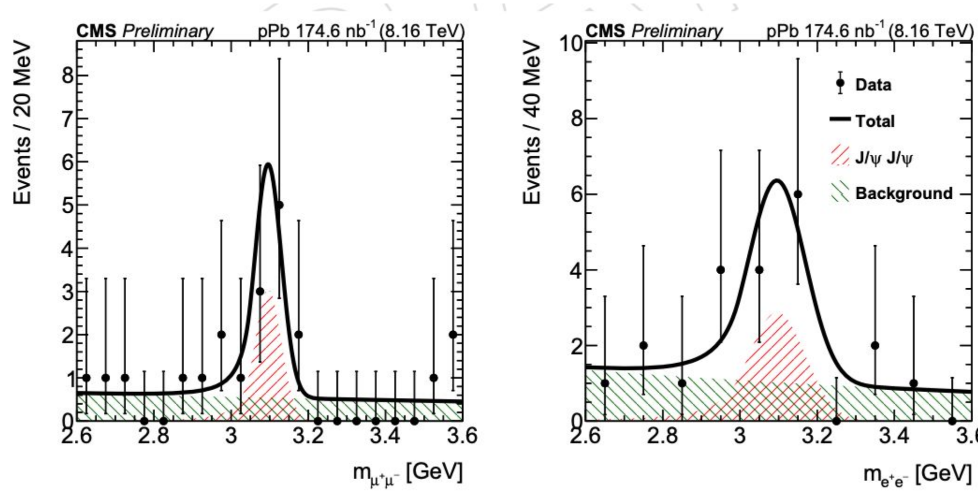
- Significance is 4.9 std. dev. for 4 muon channel: Likelihood ratio of the fits + asymptotic formula under Wilks theorem

- 5.3σ (combination with Fischer Formalism)

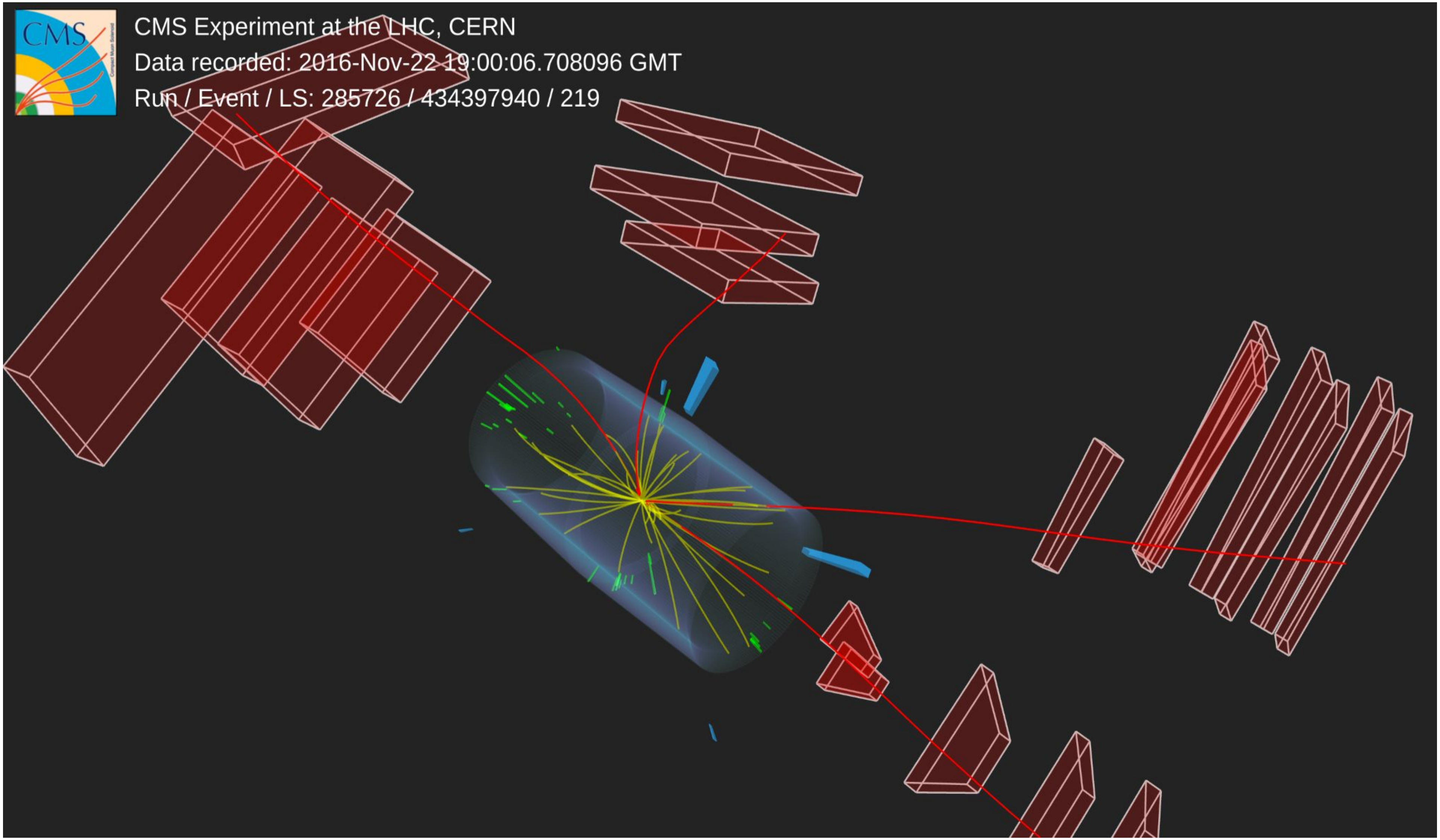
$J/\psi(\to\mu\mu)J/\psi(\to\mu\mu)$



$J/\psi(\to\mu\mu)J/\psi(\to ee)$



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

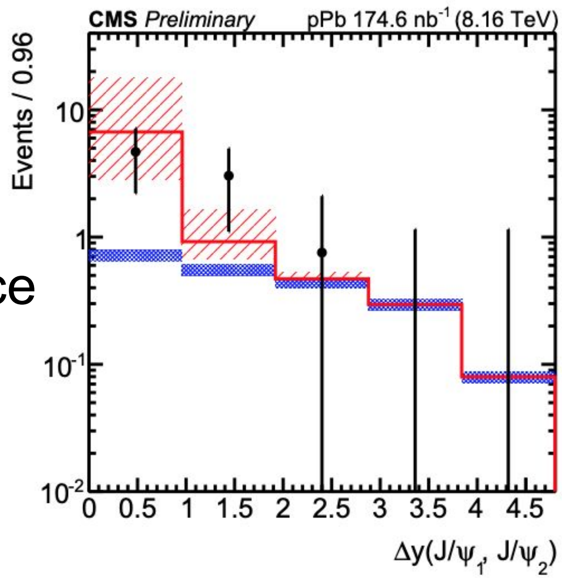
Source of uncertainty	$\sigma(\mathrm{pPb} \to \mathrm{J}/\psi\mathrm{J}/\psi + \mathrm{X})$
J/ψ meson signal shape	4.0%
Dimuon continuum background shape	2.5%
Luminosity	3.5%
Branching fraction	1.1%
Scale factors	1.3%
Total	6.1%

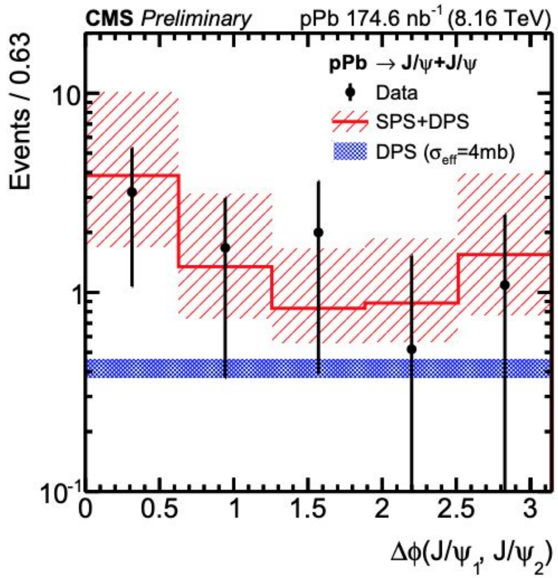
Measured cross section is DPS + SPS which needs to be separated for the measurement of the effective cross section

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 i.e. > 2 is dominated by DPS



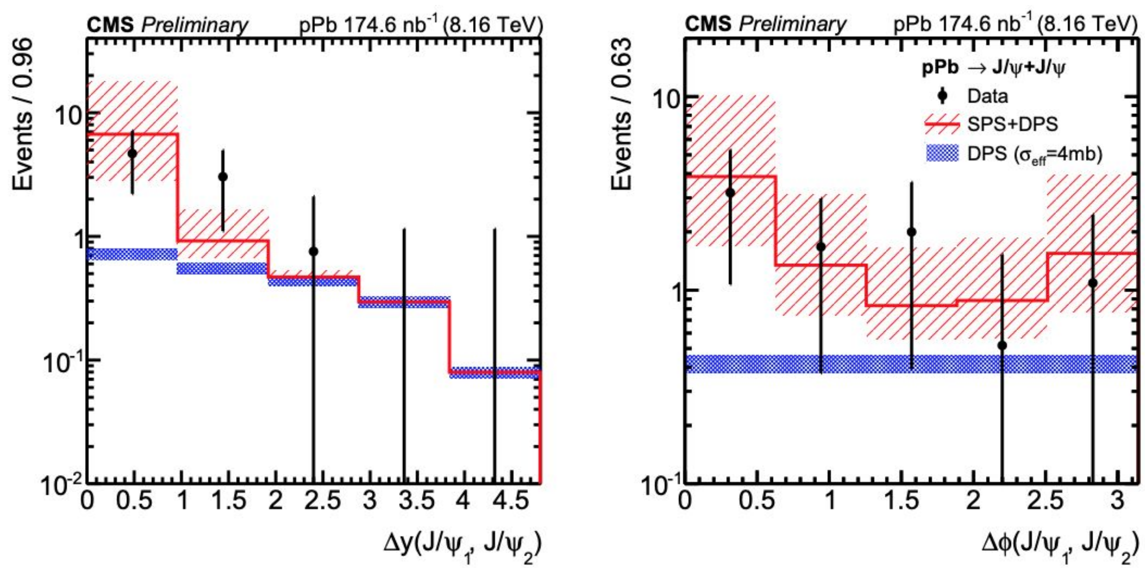


Extraction DPS Contributions (II/II)

- 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

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

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

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

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

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

- Neglecting parton correlations, factorization of double PDF in transverse and longitudinal components; σ_{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

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

Summary

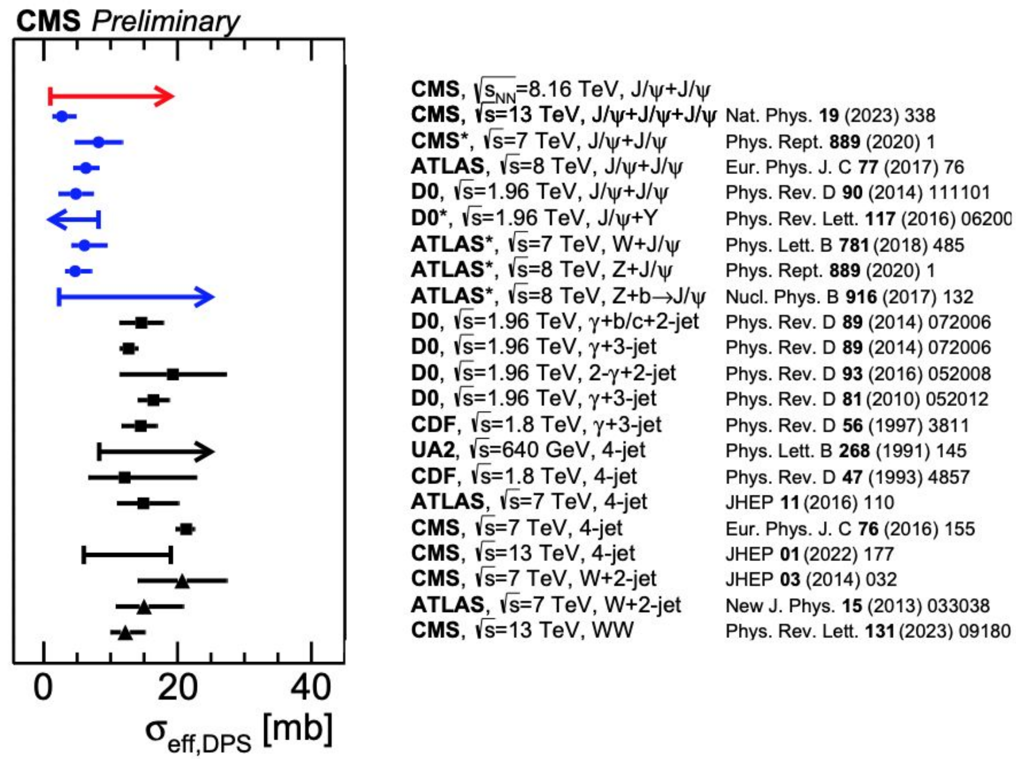
- First observation of double J/ψ production in pPb collisions at the energy of 8.16 TeV

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

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

  With σ_{eff} > 1.0 mb @ 95% CL

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




thank you
danke
рахмат
謝謝
ngiyabonga
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Баярлалаа
спасибо
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merci