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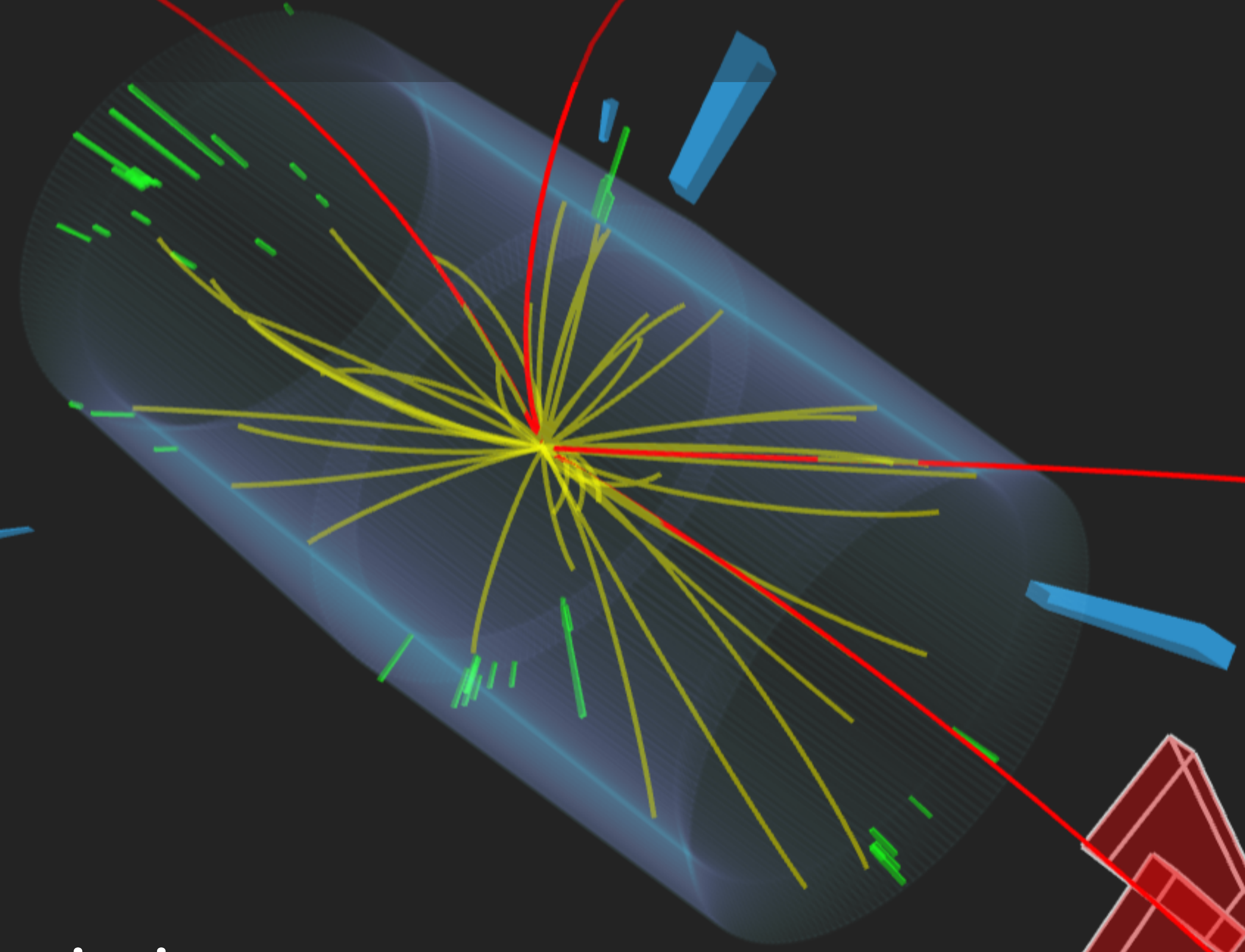
CMS NEW RESULT SQM24

Observation of double-J/ψ meson production in pPb collisions at 8.16 TeV

CMS-PAS-HIN-23-013



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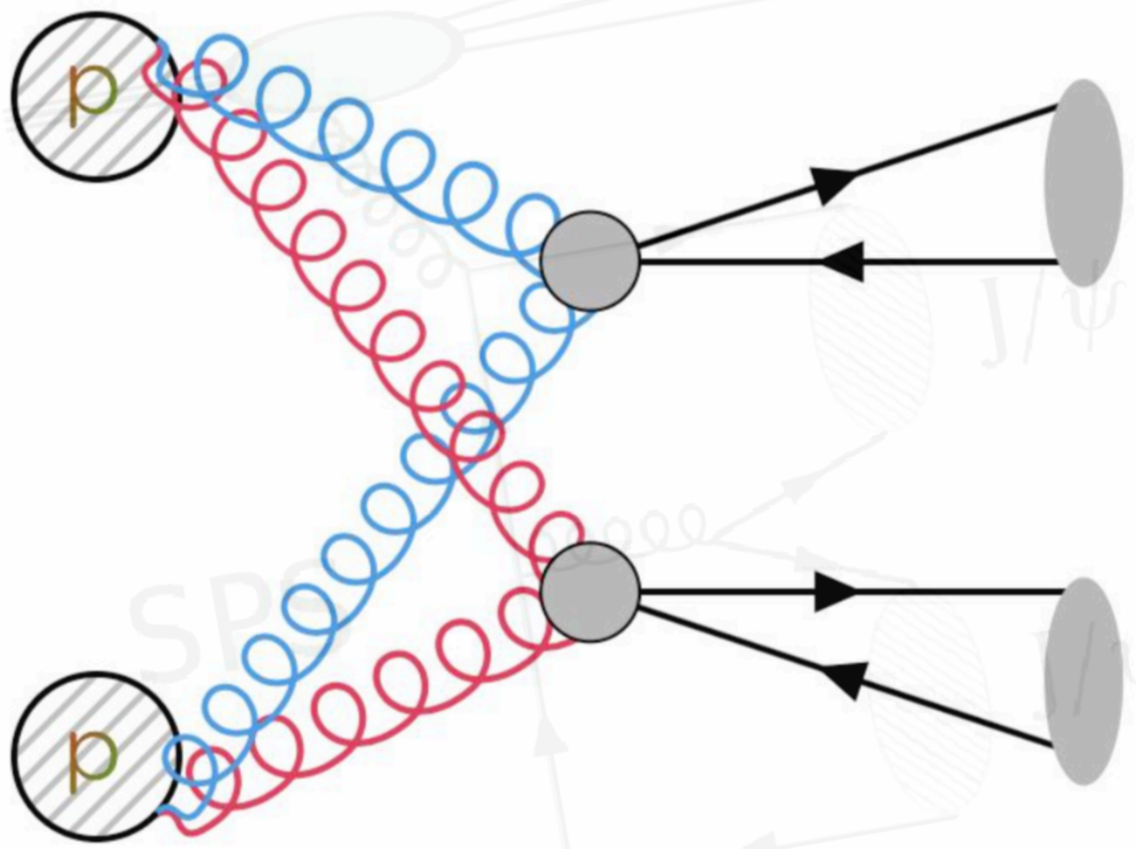
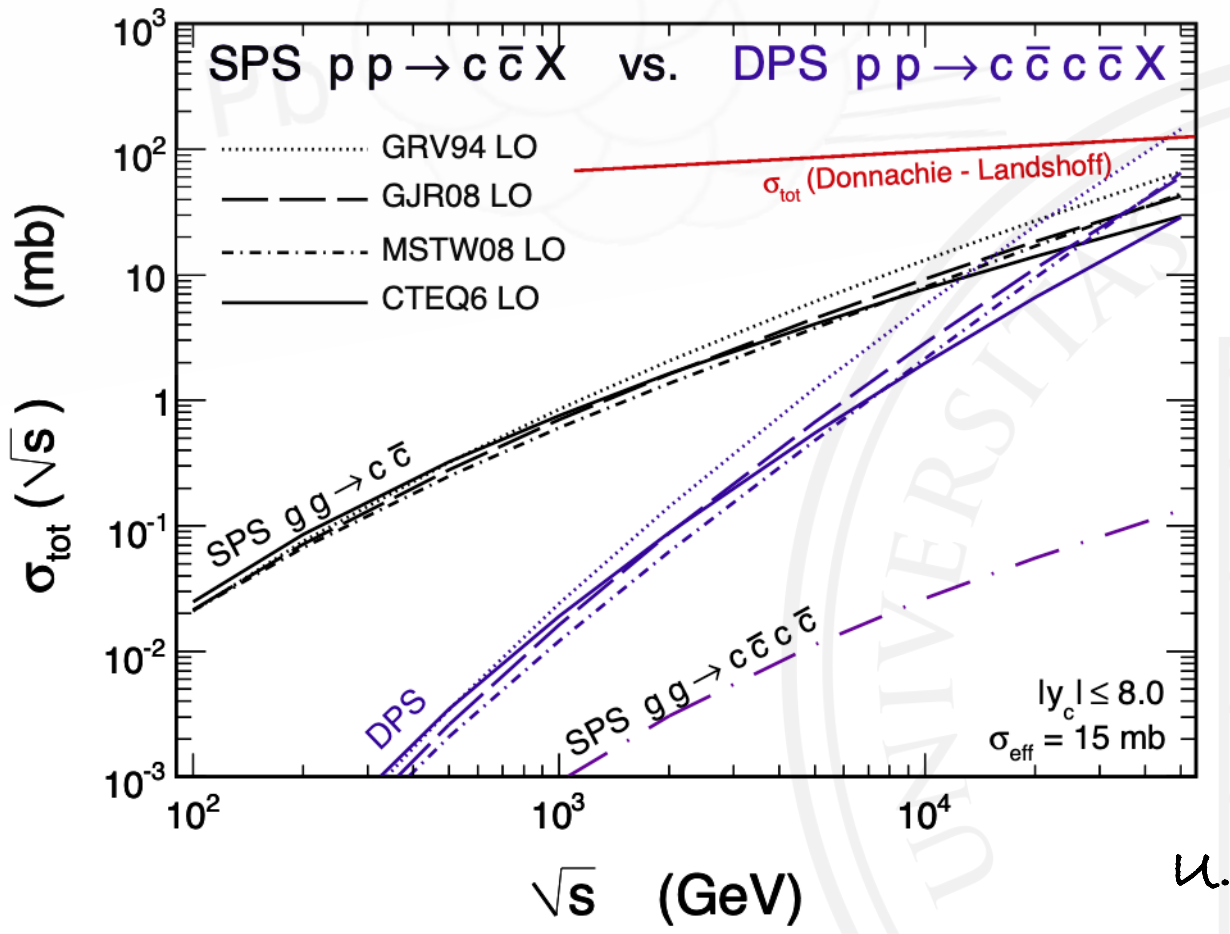
SQM 2024
4th June 2024

Observation of double-J/ψ meson production in pPb collisions at 8.16 TeV

Introduction

- **nPS processes are important for fundamental studies**
  - probe of the partonic structure of the proton
  - input for the tuning of MC generators
  - background of new physics signatures
- **nPS sensitive to interplay between perturbative and non-perturbative QCD**
  - models can be tuned using data measurements
- Rate of nPS processes increases with √s
  - parton densities increase
  - cross section of nPS
    - $$\frac{\sigma_{\mathrm{nPS}}}{\sigma_{\mathrm{SPS}}} \sim \left(\frac{\Lambda^2}{Q_h^2}\right)^{(n-1)}$$
  - in certain processes and/or regions of phase space, contributions from DPS are significant
- We have results from many experiments, using many final states and in different √s





arXiv:1212.5427

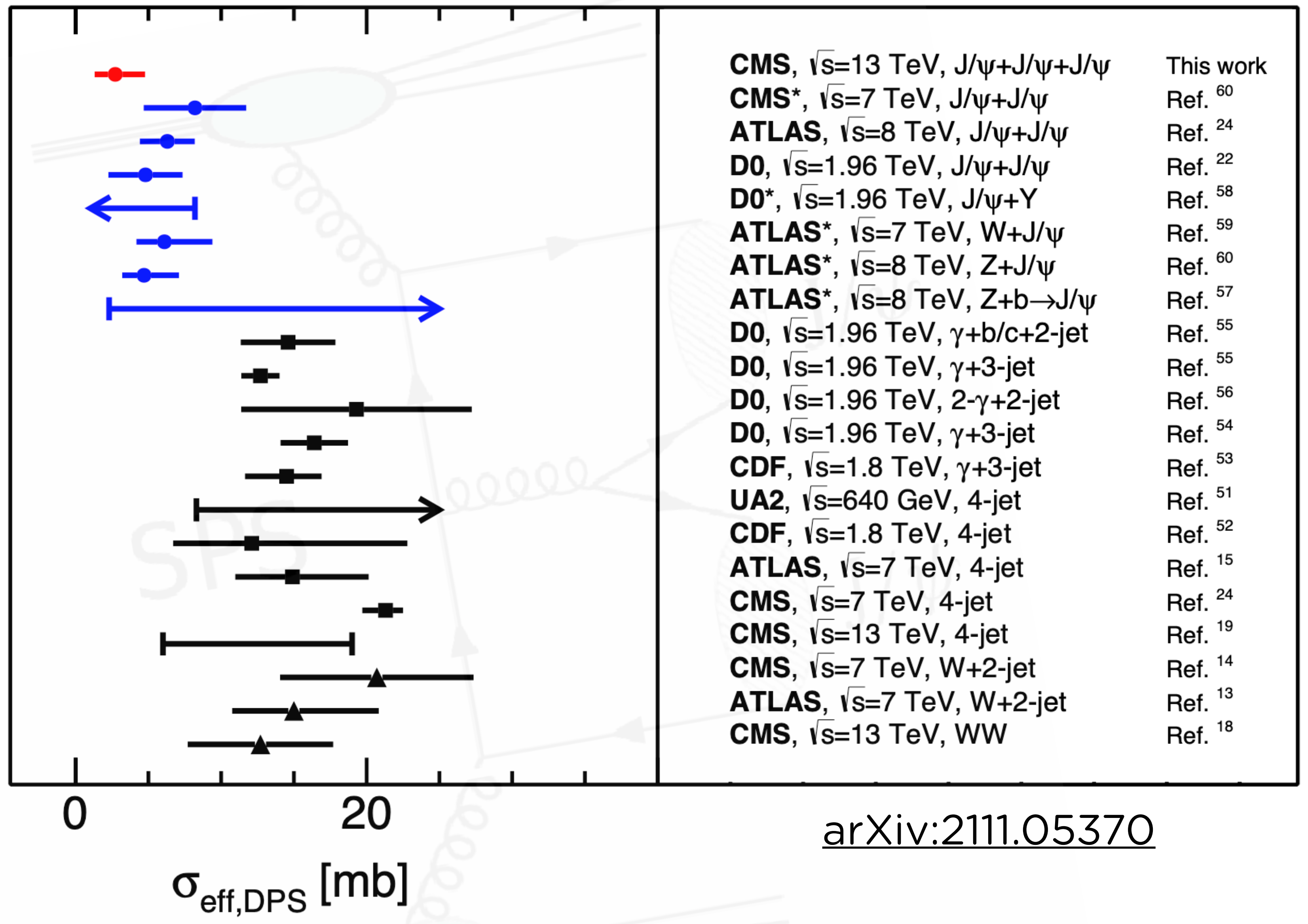
Observation of double-J/ψ meson production in pPb collisions at 8.16 TeV

DPS effective cross section

- **DPS is a proton-proton scattering process where two partons from each proton interact separately**
- DPS cross section can be expressed as:

$$\frac{d\sigma_{\text{DPS}}}{dx_1\, dx_2\, d\bar{x}_1\, d\bar{x}_2} = \frac{1}{C}\int_{x_1}^{1-x_2}\frac{dx_1'}{x_1'}\int_{x_2}^{1-x_1'}\frac{dx_2'}{x_2'}\int_{\bar{x}_1}^{1-\bar{x}_2}\frac{d\bar{x}_1'}{\bar{x}_1'}\int_{\bar{x}_2}^{1-\bar{x}_1'}\frac{d\bar{x}_2'}{\bar{x}_2'}$$
$$\times \sum_{a_1 a_2 b_1 b_2} {}^{R}\hat{\sigma}^{(1)}_{a_1 b_1}(x_1'\bar{x}_1' s, \mu_1)\, {}^{R}\hat{\sigma}^{(2)}_{a_2 b_2}(x_2'\bar{x}_2' s, \mu_2)$$
$$\times \int d^2\boldsymbol{y}\, {}^{R}F_{a_1 a_2}(x_1', x_2', \boldsymbol{y}, \mu_1, \mu_2, \zeta)\, {}^{R}F_{b_1 b_2}(\bar{x}_1', \bar{x}_2', \boldsymbol{y}, \mu_1, \mu_2, \bar{\zeta})$$

From Riccardo Nagar's thesis



- Assumption 1:
  - Generalized PDFs factorize into longitudinal & transverse components
    - introducing the transverse overlap function
- Assumption 2:
  - The longitudinal double-PDF is the product of 2 single PDF
    - i.e. no parton correlations in colour, momentum, flavour, spin, ...

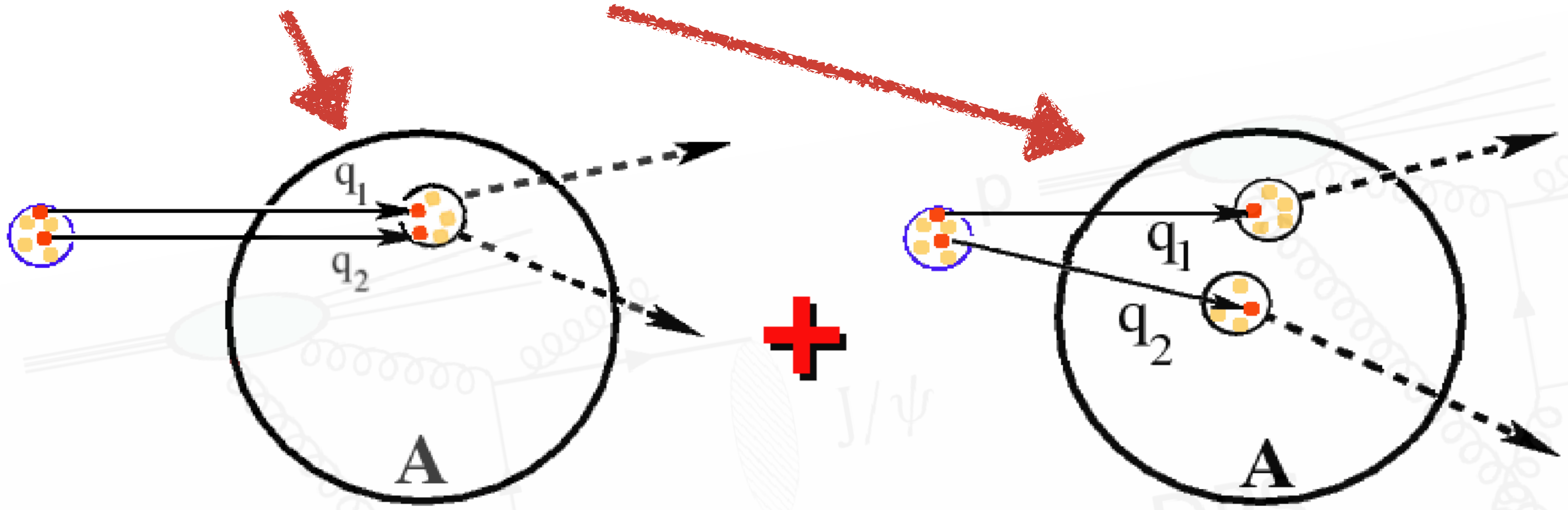
$$\sigma_{\text{DPS}}^{hh'\to ab} = \frac{m}{2}\frac{\sigma_{\text{SPS}}^{hh'\to a}\,\sigma_{\text{SPS}}^{hh'\to b}}{\sigma_{\text{eff}}}$$

- σ_{eff} = <Interparton transverse separation>^{2}.
  - derivable from the geometric p-p overlap with naive expected size of $\sigma_{\text{eff}} \approx 30$ mb
  - experimentally σ_{eff} ~ 15 mb, derived from DPS of jets, photons, EWK bosons and σ_{eff} ~ 5 mb, derived from di-quarkonia final states

Observation of double-J/ψ meson production in pPb collisions at 8.16 TeV

DPS effective cross section

- Two contributions to DPS x-section in pA
- $\sigma^{\rm DPS}_{{\rm pA}\to ab} = \sigma^{\rm DPS,1}_{{\rm pA}\to ab} + \sigma^{\rm DPS,2}_{{\rm pA}\to ab}$

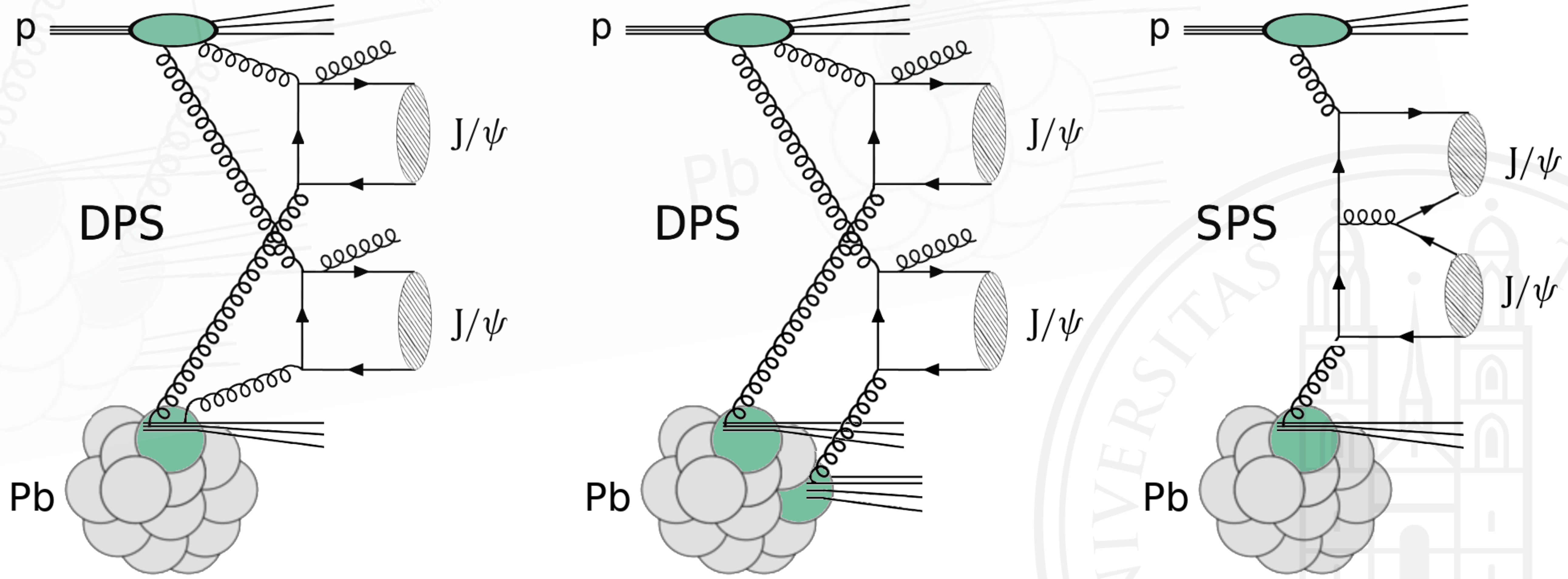


$$\sigma_{\rm eff,pA} = \frac{\sigma_{\rm pp}}{{\rm A} + \sigma_{\rm pp} F_{\rm pA}} = 21.5 \pm 1.1\,\mu{\rm b}$$

- Ratio of DPS pPb / pp cross sections
  - about ${\rm A} + {\rm A}^{4/3}/\pi \sim 600$
- DPS is enhanced by **x600 factor in pPb compared to pp**
- pPb provide **new useful independent extractions of $\sigma_{\rm eff,\,pp}$**

- $\sigma^{\rm DPS,1}_{{\rm pA}\to ab} = {\rm A} \cdot \sigma^{\rm DPS}_{{\rm pN}\to ab}$
- $\sigma^{\rm DPS,2}_{{\rm pA}\to ab} = \sigma^{\rm DPS}_{{\rm pN}\to ab} \cdot \sigma_{\rm eff,pp} \cdot F_{\rm pA}$
  - $F_{\rm pA}$ the Pb transverse density ~ 30 mb[-1] (Glauber MC)

$$\sigma^{\rm DPS}_{{\rm pA}\to ab} = \frac{m}{2} \frac{\sigma^{\rm SPS}_{{\rm pN}\to a}\sigma^{\rm SPS}_{{\rm pN}\to b}}{\sigma_{\rm eff,pA}}$$

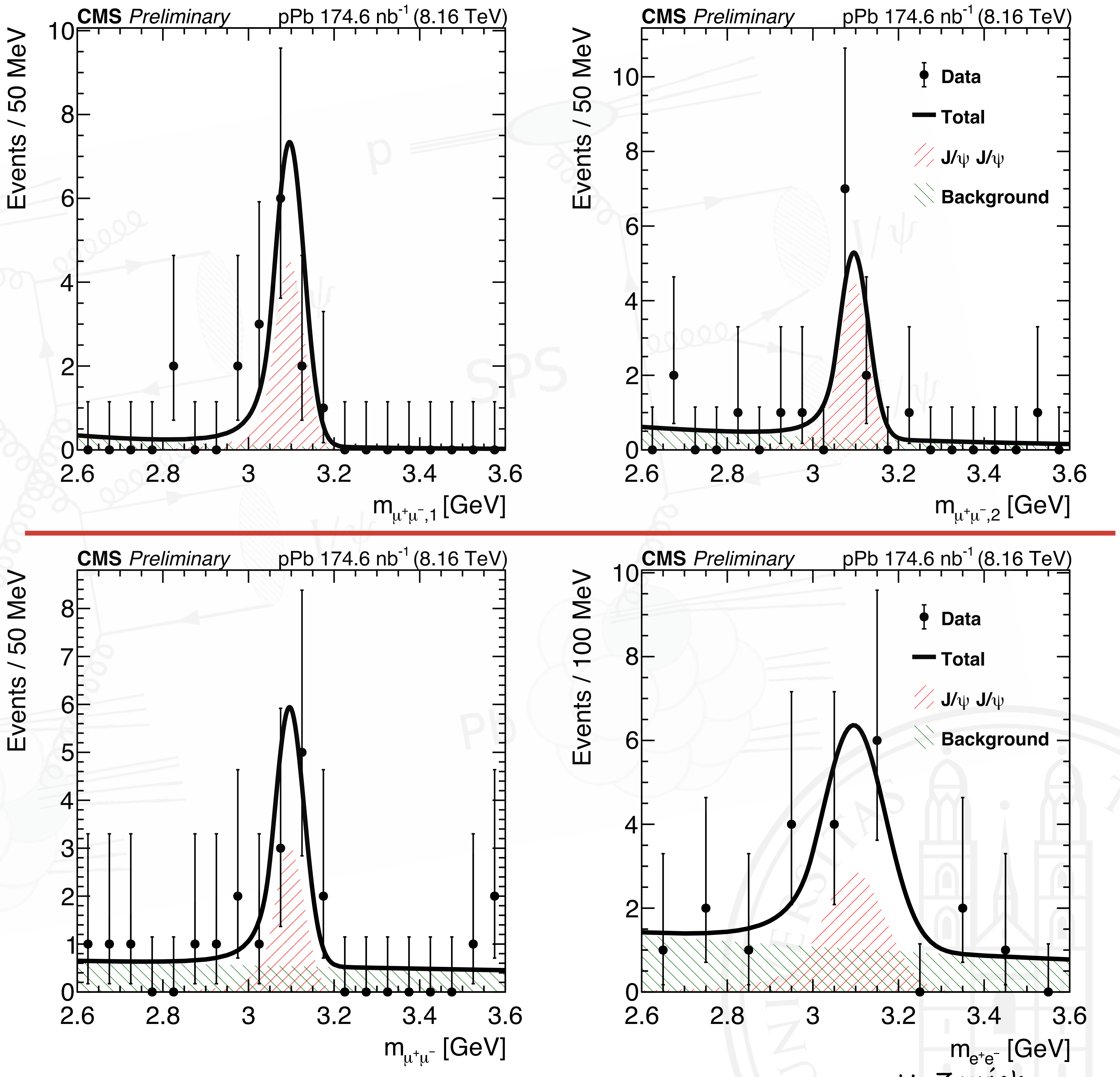


Observation of double-J/ψ meson production in pPb collisions at 8.16 TeV

Signal extraction

Fiducial requirement		
For all muons	$p_T > 3.4\,\mathrm{GeV}$	for $0 < \lvert\eta\rvert < 0.3$
	$p_T > 3.3\,\mathrm{GeV}$	for $0.3 < \lvert\eta\rvert < 1.1$
	$p_T > 5.5\text{–}2.0\lvert\eta\rvert\,\mathrm{GeV}$	for $1.1 < \lvert\eta\rvert < 2.1$
	$p_T > 1.3\,\mathrm{GeV}$	for $2.1 < \lvert\eta\rvert < 2.4$
For the two J/ψ mesons	$p_T > 6.5\,\mathrm{GeV}$ and $\lvert y\rvert < 2.4$	

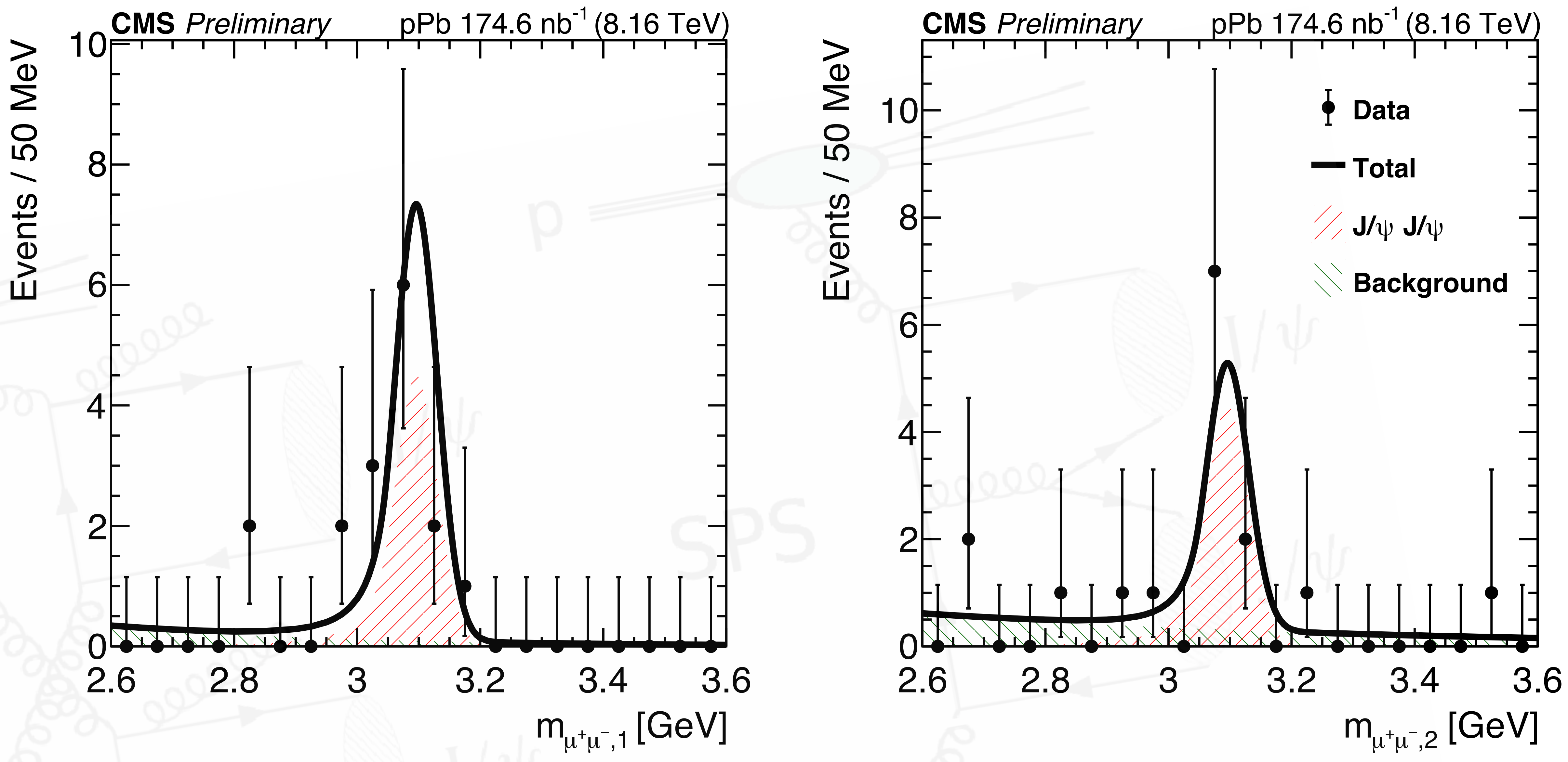
- Yield extraction
  - 2D unbinned extended ML fit
    - crystal ball function for signal
    - exponential for background
- μμ+μμ channel
  - **$N_{J/\psi J/\psi}$ = 8.5 ± 3.4** and 4.9σ significance
- μμ+ee channel
  - **$N_{J/\psi J/\psi}$ = 5.7 ± 4.0** and 2.3σ significance
- Total significance of 5.3σ



Observation of double-J/ψ meson production in pPb collisions at 8.16 TeV

Cross section measurement

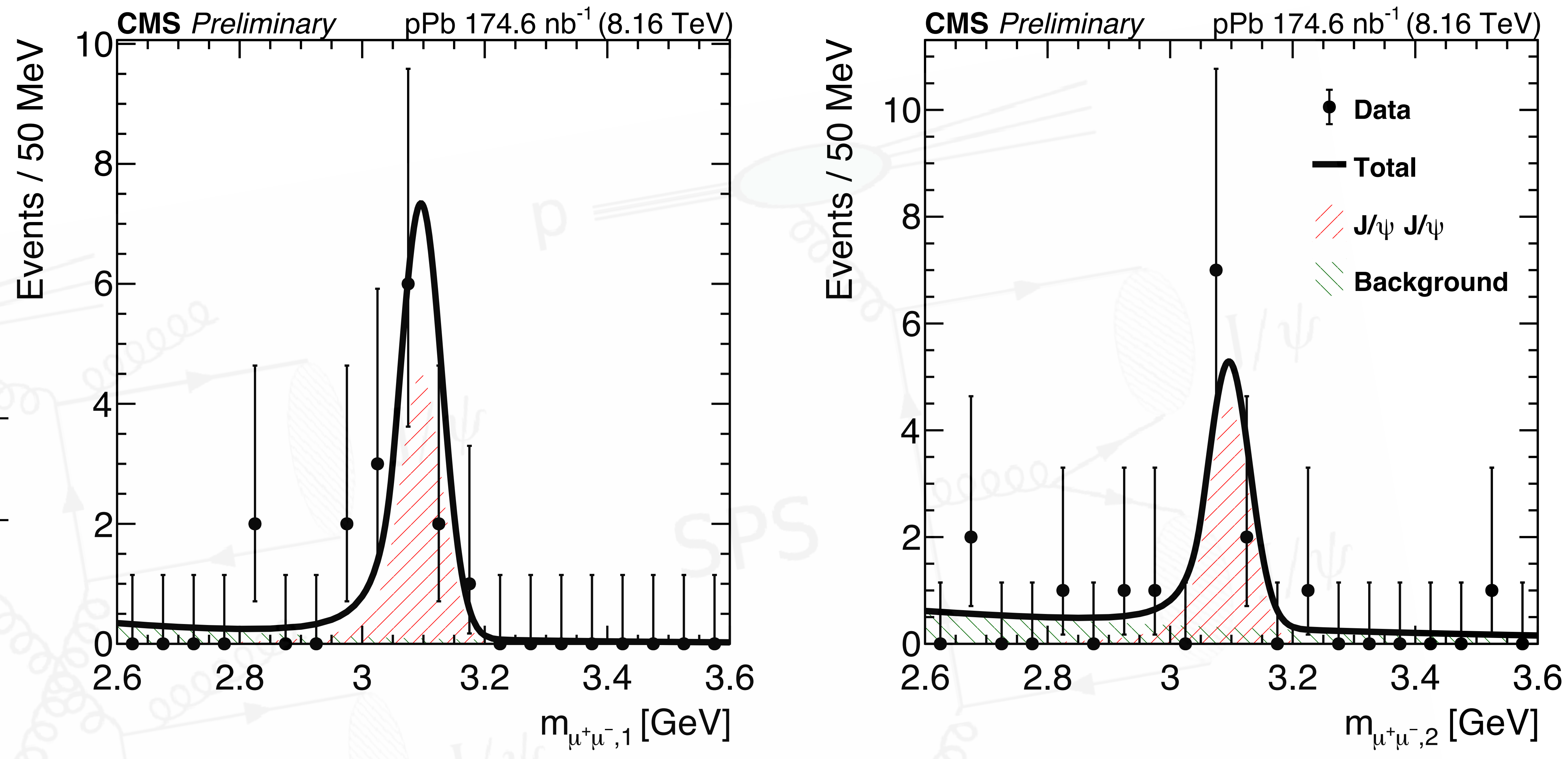
- Measured fiducial cross section to be determined from single-J/ψ MC-based efficiency in (p_T,y) plane
  - $\sigma(\text{pPb} \rightarrow \text{J}/\psi\,\text{J}/\psi + X) = N_{\text{sig}}/(\epsilon \mathcal{L}_{\text{int}} \mathcal{B}^2_{\text{J}/\psi\rightarrow\mu\mu})$
  - considering **only J/ψ→μμ J/ψ→μμ mode**
- $N_{\text{sig}}/\varepsilon = \Sigma_i N^i_{\text{sig}}/\varepsilon^i$
  - N^i_{sig} is the per event signal weight
  - $\epsilon^i = \epsilon^i_{\mu\mu,1}\epsilon^i_{\mu\mu,2}$ is the product of the two J/ψ efficiencies
  - $\epsilon = 62.1\,\%$



Observation of double-J/ψ meson production in pPb collisions at 8.16 TeV

Systematic uncertainties

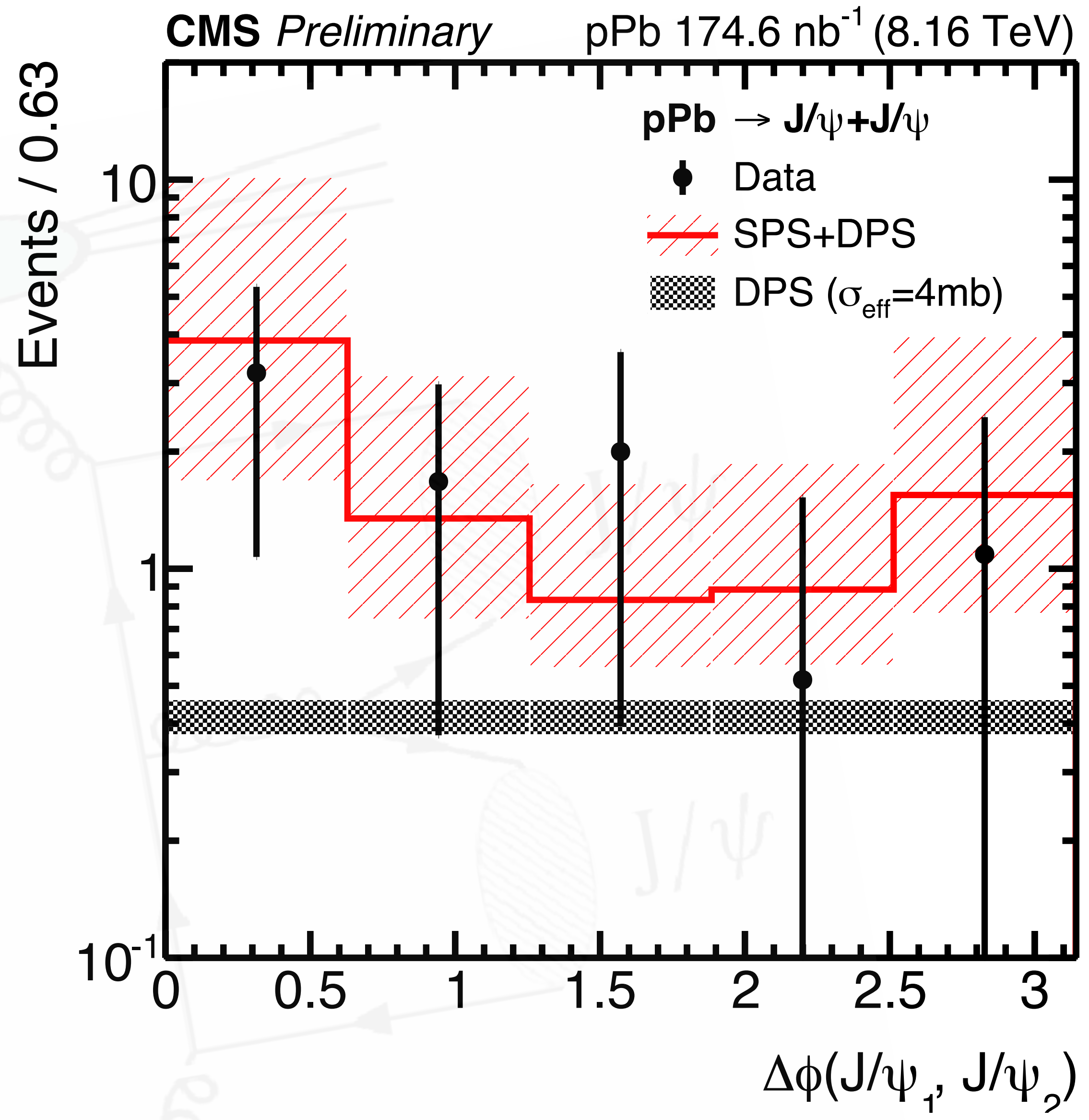
Source of uncertainty	$\sigma(\mathrm{pPb} \to \mathrm{J}/\psi\mathrm{J}/\psi + \mathrm{X})$
J/ψ meson signal shape	4.0%
Dimuon continuum background shape	2.5%
Luminosity	3.5%
Branching fraction	1.1%
Scale factors	1.3%
Total	6.1%

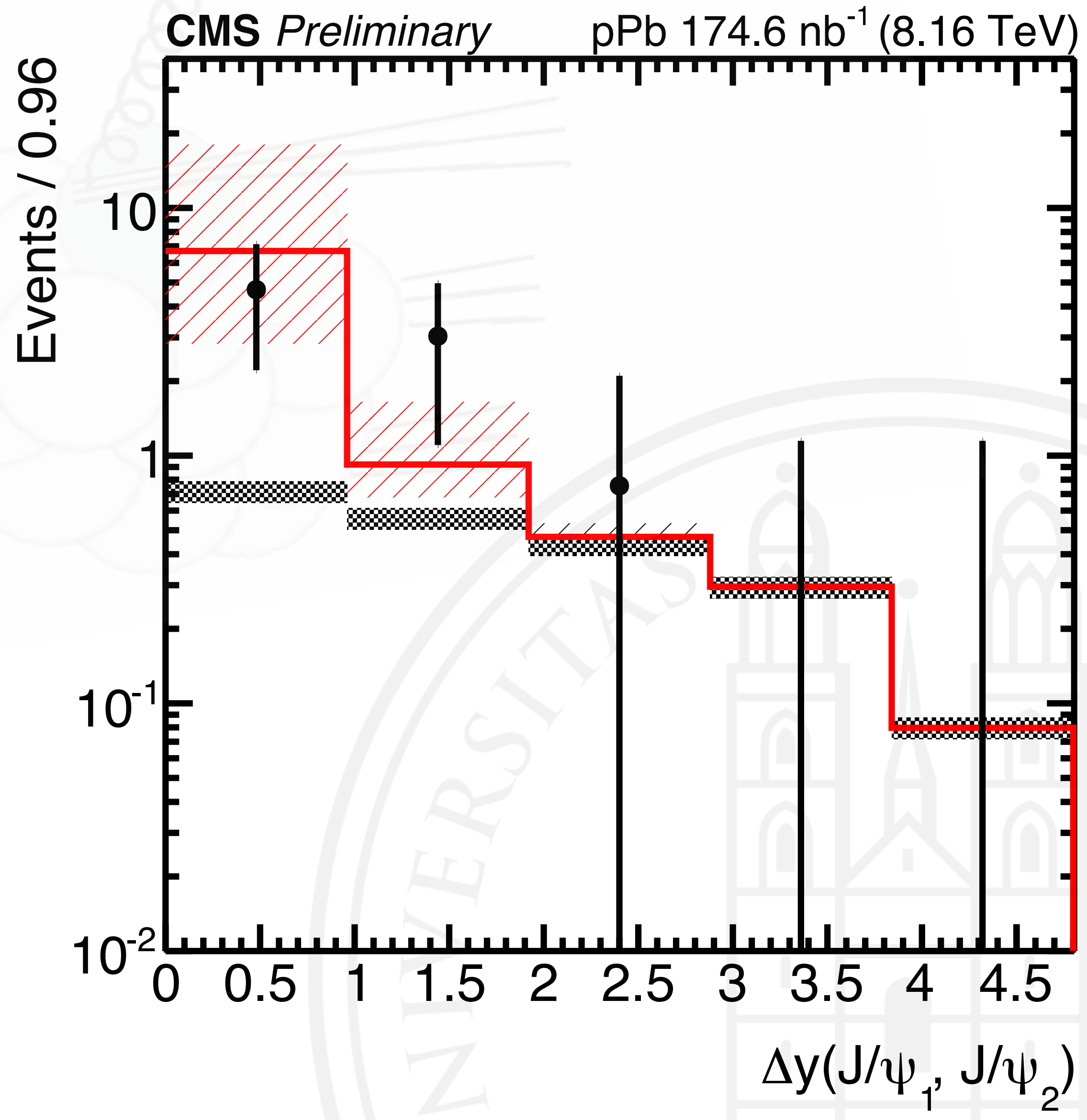


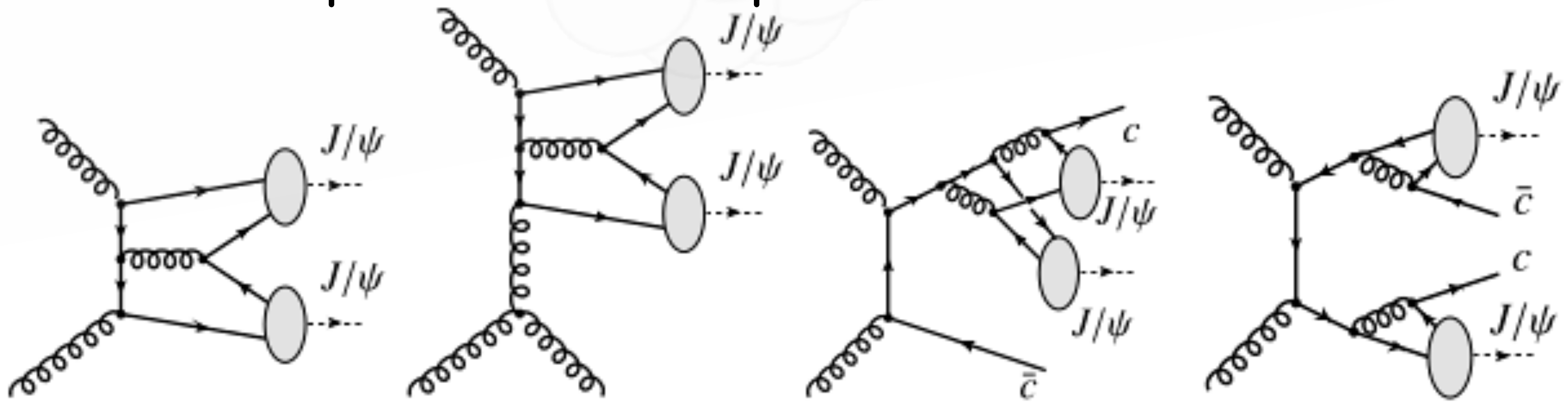
Observation of double-J/ψ meson production in pPb collisions at 8.16 TeV

SPS/DPS discrimination

- $\sigma(\mathrm{pPb} \rightarrow J/\psi J/\psi + X) = 22.0 \pm 9.0\,(\mathrm{stat}) \pm 1.5\,(\mathrm{syst})\,\mathrm{nb}$
- Cross section includes both SPS and DPS components
  - need to separate to measure DPS effective cross section
  - $\sigma_{\mathrm{eff,pA}} = \frac{1}{2} \frac{(\sigma_{\mathrm{SPS}}^{J/\psi})^2}{\sigma_{\mathrm{DPS}}^{J/\psi J/\psi}}$
- **Most discriminating variables in DPS/SPS processes are Δφ and Δy**
- sPlot weights applied to data to acquire signal only Δφ and Δy distributions
- For the SPS/DPS separation we start from Δy
  - SPS calculation shows steep $\Delta y(J/\psi_1, J/\psi_2)$ decrease
- Safe to assume and fit the Δy>1.92 region, where SPS contamination is negligible
  - DPS template derived from event combinatorics
  - **N_{DPS} = 2.1 ± 2.4 events**
  - using this normalisation, the DPS template is compared with data
  - **N_{SPS} = 6.4 ± 4.2 events**







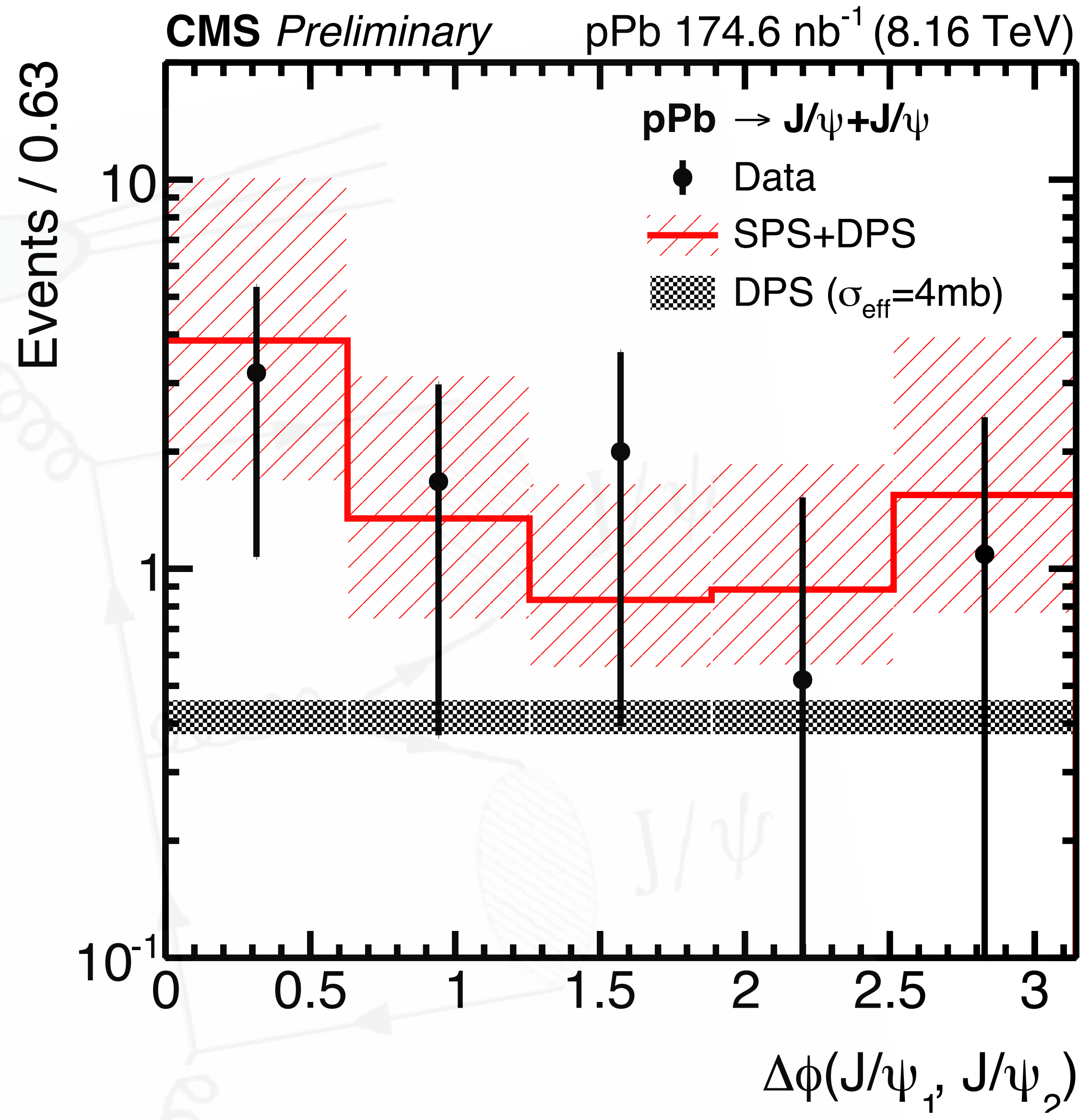
Observation of double-J/ψ meson production in pPb collisions at 8.16 TeV

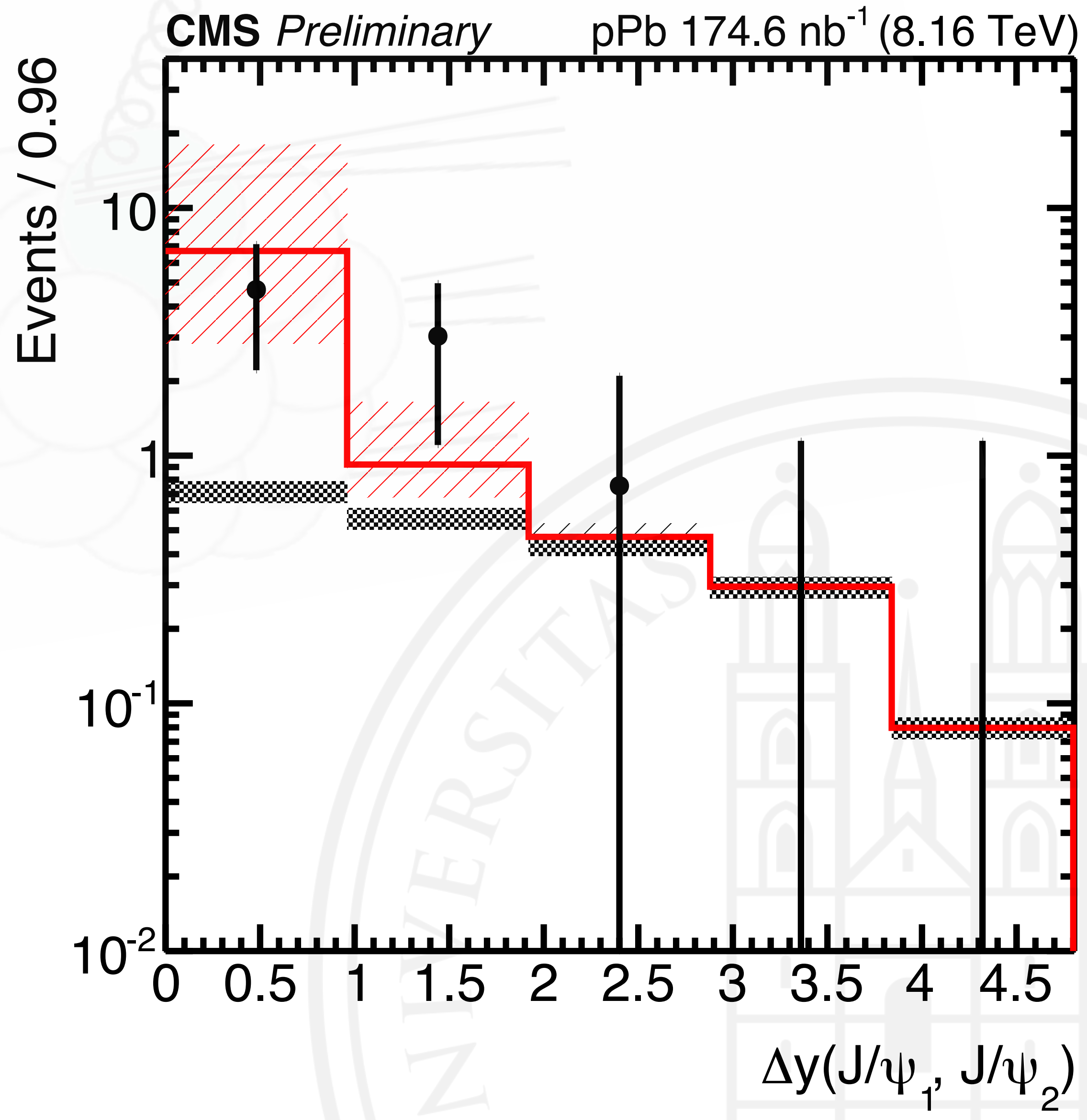
DPS effective cross section measurement

- $\sigma_{\text{SPS}}^{\text{pPb}\to J/\psi J/\psi+X} = 16.5 \pm 10.8\,(\text{stat}) \pm 0.1\,(\text{syst})\,\text{nb}$
- $\sigma_{\text{DPS}}^{\text{pPb}\to J/\psi J/\psi+X} = 5.4 \pm 6.2\,(\text{stat}) \pm 0.4\,(\text{syst})\,\text{nb}$
- $\sigma_{\text{eff,pA}} = \left(\frac{1}{2}\right) \frac{\sigma_{\text{SPS}}^{\text{pPb}\to J/\psi+X}\sigma_{\text{SPS}}^{\text{pPb}\to J/\psi+X}}{\sigma_{\text{DPS}}^{\text{pPb}\to J/\psi J/\psi+X}}$
- $\sigma_{\text{eff,pA}} = 0.53^{+\infty}_{-0.2}\ \text{b}$
- $\sigma_{\text{eff}} = \frac{\sigma_{\text{eff,pA}}}{A - \sigma_{\text{eff,pA}} F_{\text{pA}}/A}$
  - $A = 208$ for a Pb nucleus and $F_{\text{pA}} = 29.5\,\text{mb}^{-1}$ is derived from the pPb thickness function with a Glauber MC model
- $\sigma_{\text{eff}} = 4.0^{+\infty}_{-1.5}\ \text{mb}$

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

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





Observation of double-J/ψ meson production in pPb collisions at 8.16 TeV

Conclusion

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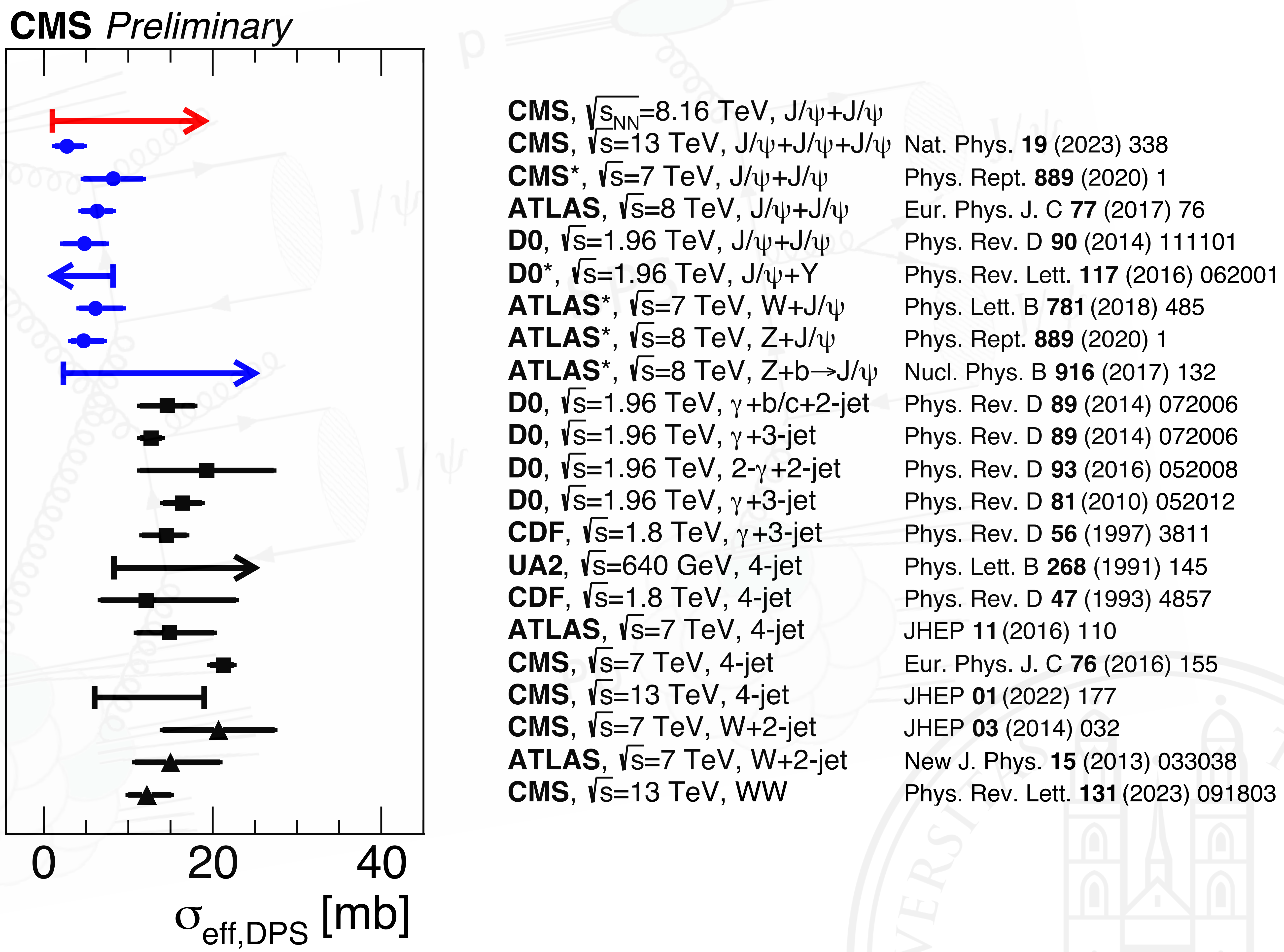
- **First observation of the associated production of two J/ψ mesons in pPb** at $\sqrt{s_{NN}}$ = 8.16 TeV and measurement of the fiducial cross sections
  - $\sigma_{SPS}^{pPb\to J/\psi J/\psi+X} = 16.5 \pm 10.8\,(\mathrm{stat}) \pm 0.1\,(\mathrm{syst})\,\mathrm{nb}$
  - $\sigma_{DPS}^{pPb\to J/\psi J/\psi+X} = 5.4 \pm 6.2\,(\mathrm{stat}) \pm 0.4\,(\mathrm{syst})\,\mathrm{nb}$
  - extraction of σ_{eff} lower limit
    - $\sigma_{eff} > 1.0\,\mathrm{mb}$ at 95% CL
- Future pPb data will provide more accurate σ_{eff} extractions that can help clarify the observed span of σ_{eff} in pp collisions.



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Double J/ψ production diagrams