# Double Parton Scattering in $p\bar{p}$ interactions at $\sqrt{s} = 1.96$ TeV

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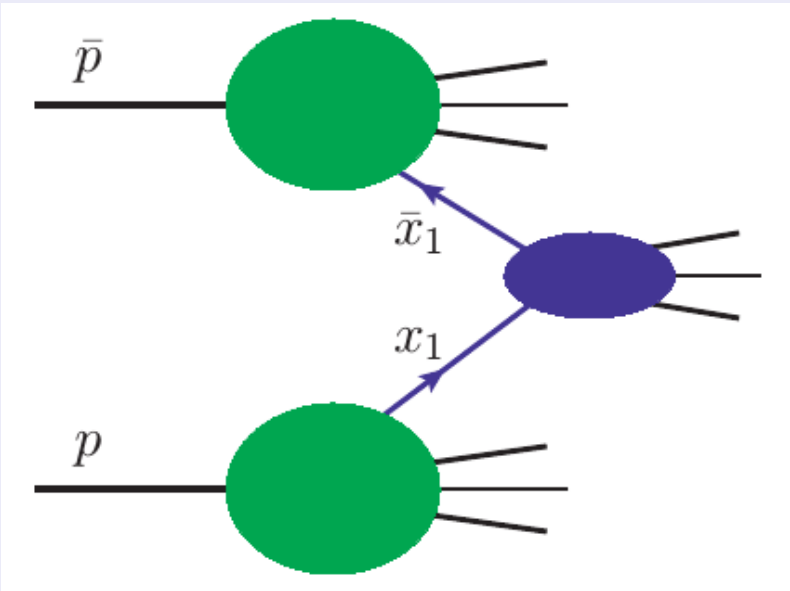
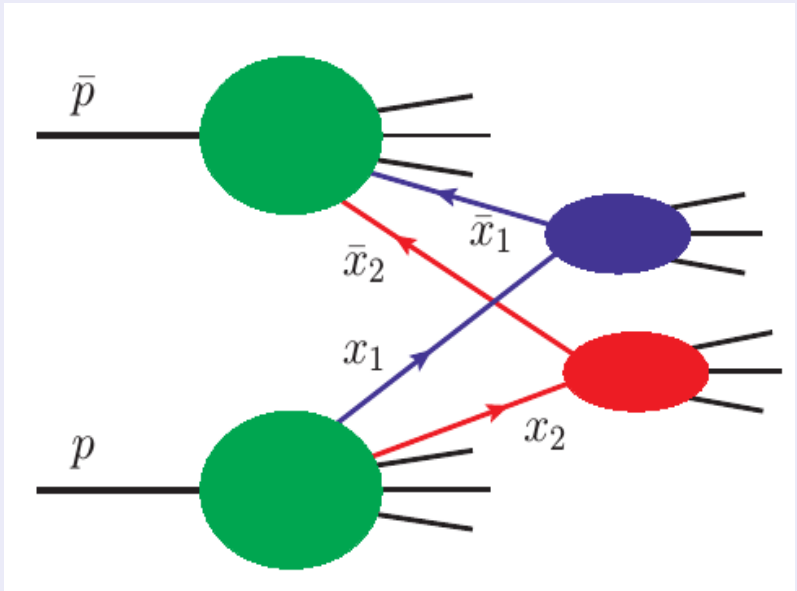
# Motivation: Single Parton Scattering vs Double Parton Scattering

## Single Parton Scattering(SPS,SP)




## Double Parton Scattering(DPS,DP)



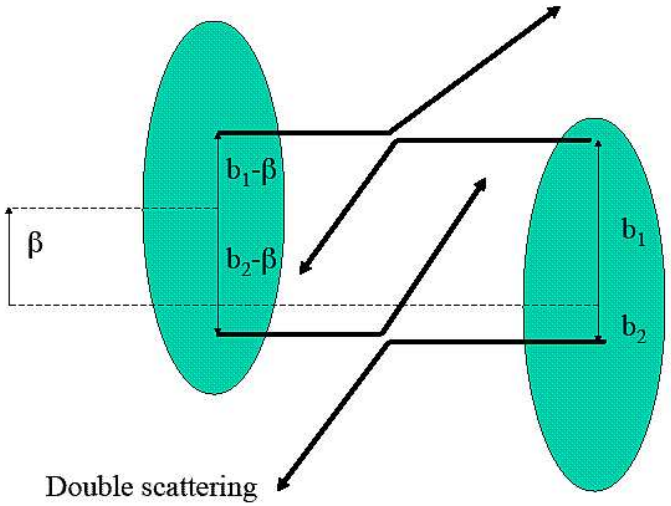

## Double Parton Scattering

| dominated by $q\bar{q}$ | dominated by $gq$ | dominated by $gg$ |
|---|---|---|
| $\gamma\gamma + 2jets$, $W + 2jets$ | $\gamma + 3jets$ | $4jets$, $J/\psi J/\psi$, $J/\psi\Upsilon$ |

# Definition:Effective cross section

$$\sigma_{eff}^{-1} = \int d^2\beta [F(\beta)]^2$$

$F(\beta) = \int f(b) f(b-\beta) d^2 b$,
$\beta$ is the impact parameter for the two colliding hadrons,
$f(b)$ is a function describing the spatial distribution of the parton matter inside a hadron.




Schematic view of the impact parameter $\beta$ for the two colliding hadrons.

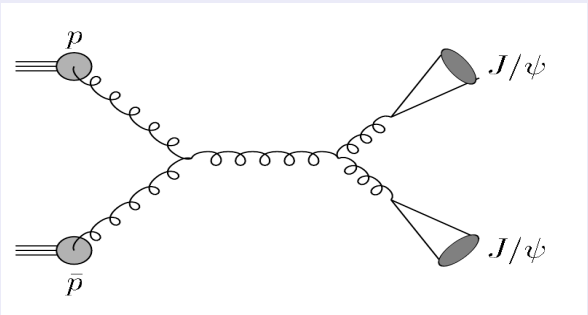
$$\sigma_{\mathrm{DP}}^{(1,2)} = \frac{m}{2} \frac{\sigma^{(1)}\sigma^{(2)}}{\sigma_{\mathrm{eff}}}$$

# Observation and studies of double $J/\psi$ production at D0

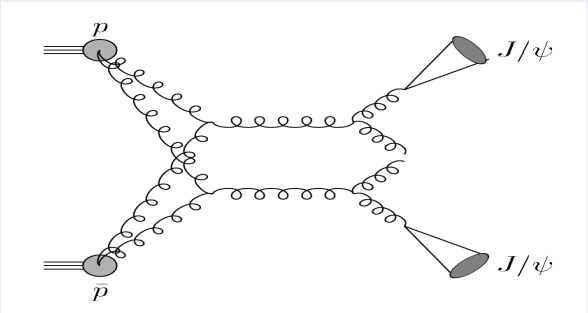
# Motivation:double $J/\psi$

## Main features of analysis:

- Single Parton Scattering




- Double Parton Scattering



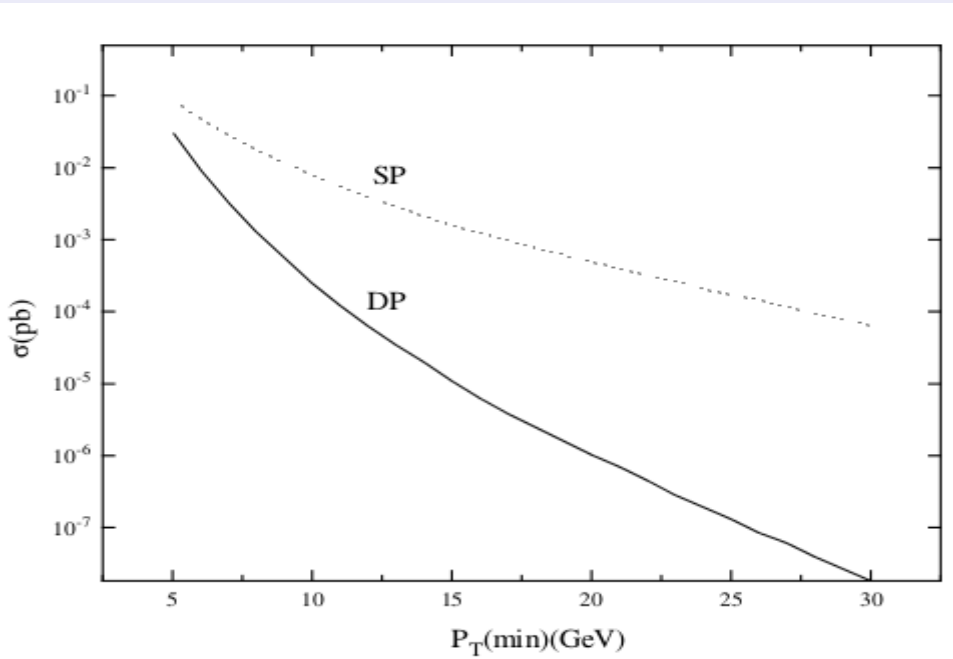

$$\sigma_{\mathit{eff}} = \frac{\sigma^{2}_{J/\psi}}{2\sigma^{DP}_{J/\psi\ J/\psi}}$$

LHCb result:
$5.6 \pm 1.1 nb$.

J. High Energy Phys.06, 141 (2012)

## Prediction for the Tevatron:

$pT(J/\psi) > 4GeV$, $|\eta(J/\psi)| < 0.6$, $J/\psi \to 2\mu$.
Predicted Double Parton Scattering fraction is 10-15%
Should be by $\sim$ 1.8 larger for $|\eta| < 2.0$

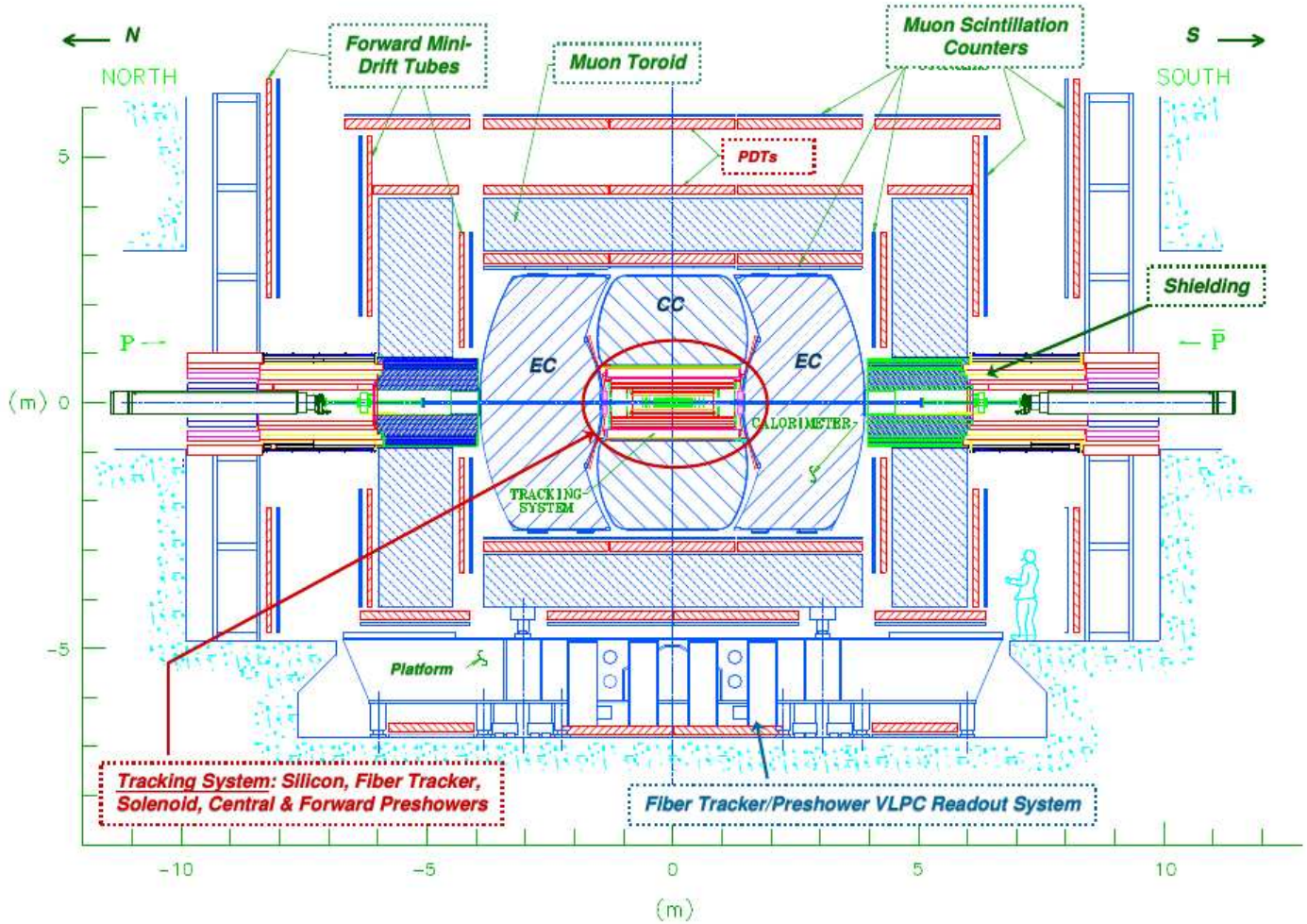



J.Phys. G24 (1998) 1105-1112

Theoretical predictions:
$\sim$4nb of SP and $\sim$2nb of DP cross section

Phys.Lett. B705 (2011) 116-119

# D0 detector




- central tracking system (silicon microstrip tracker, central fiber tracker)
- muon system (3 layers of drift tubes, plastic scintillators)

# Event selection

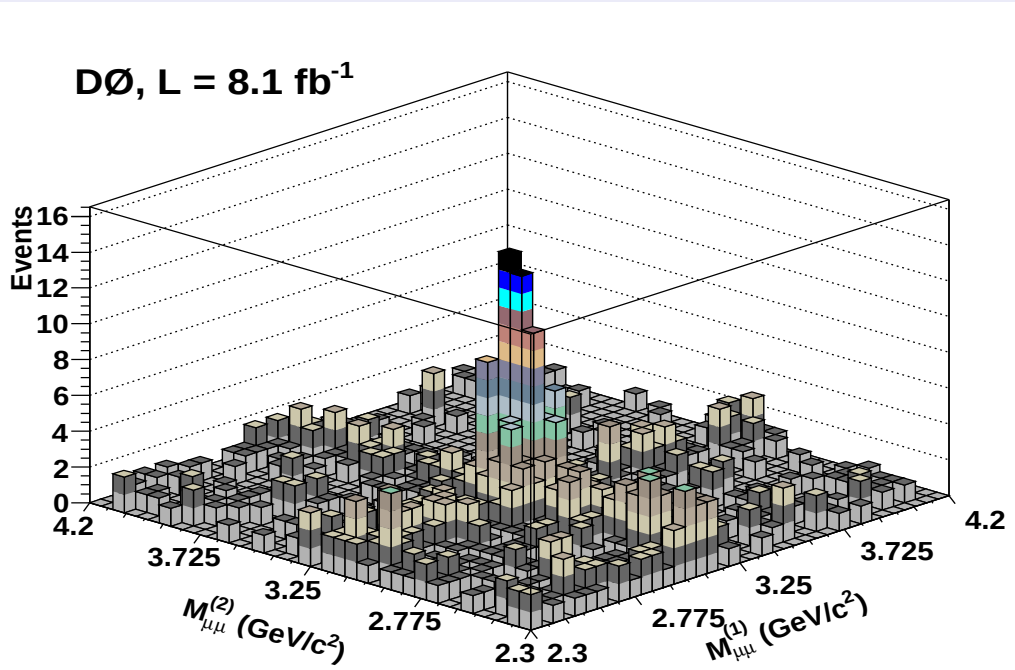
*Offline cuts:*

- $pT_\mu > 2.0 GeV$ if $|\eta_\mu| < 1.35$ OR $p_\mu > 4.0 GeV$ if $1.35 < |\eta_\mu| < 2.0$
- $|\eta_\mu| < 2.0$;
- opposite charges of muons in pair;
- track should be consistent with originating at the $p\bar{p}$ interaction
- muon pair should be in mass window 2.85-3.35 GeV
- $J/\psi$: $pT > 4.0 GeV$ $|\eta| < 2.0$

## Accidental background

We are looking in wide and narrow mass windows.

- 34% for double $J/\psi$
- 12.6% for single $J/\psi$




- After low $p_T$ DiMuon triggers:902 events in $2.3 < M_{eff} < 4.2$ GeV.
- After low $p_T$ DiMuon triggers:242 events in $2.85 < M_{eff} < 3.35$ GeV.

# Acceptance

## Single $J/\psi$

$A\varepsilon_{sel} = 0.221 \pm 0.002(stat) \pm 0.023(syst)$

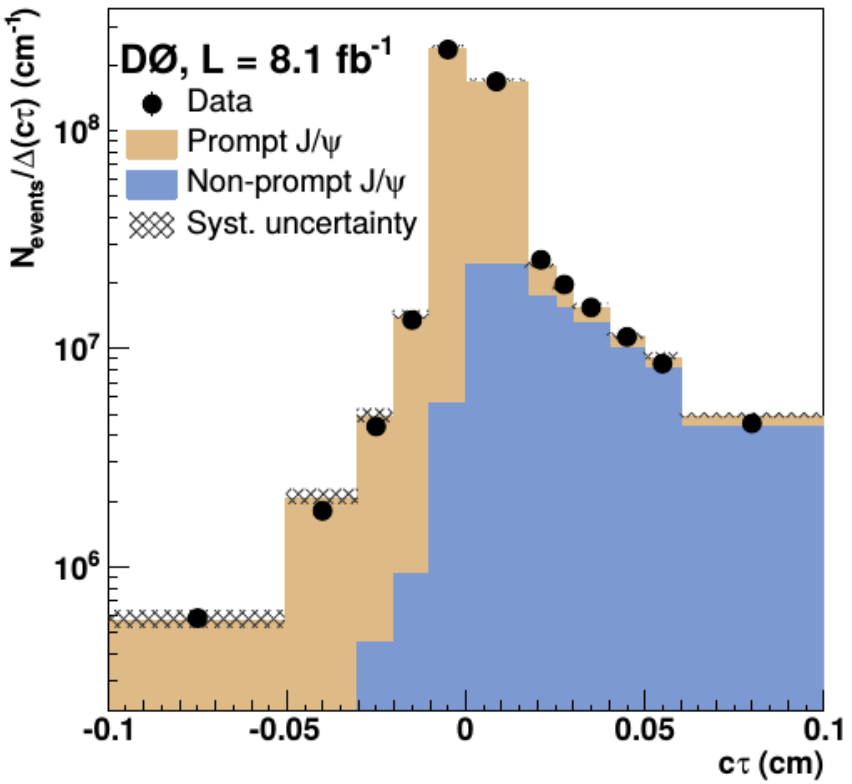
## Double $J/\psi$

$A_{SP}\varepsilon_{sel} = 0.109 \pm 0.002(stat) \pm 0.005(syst)$
$A_{DP}\varepsilon_{sel} = 0.099 \pm 0.006(stat) \pm 0.0051(syst)$

Systematic uncertainties are due to muon identification scale factors and model dependence.

# Prompt fraction

## Single $J/\psi$




$$c\tau = L_{xy} M_{J/\psi} / p^T_{J/\psi}$$

## Single $J/\psi$

$$P = 0.814 \pm 0.009$$

## Double $J/\psi$,2D fit

$$P = 0.592 \pm 0.101$$

# Results:Single $J/\psi$ production

$$\sigma = \frac{N_{data} P}{\varepsilon_{trigg} L A \varepsilon_{sel}}$$

**Cross section**

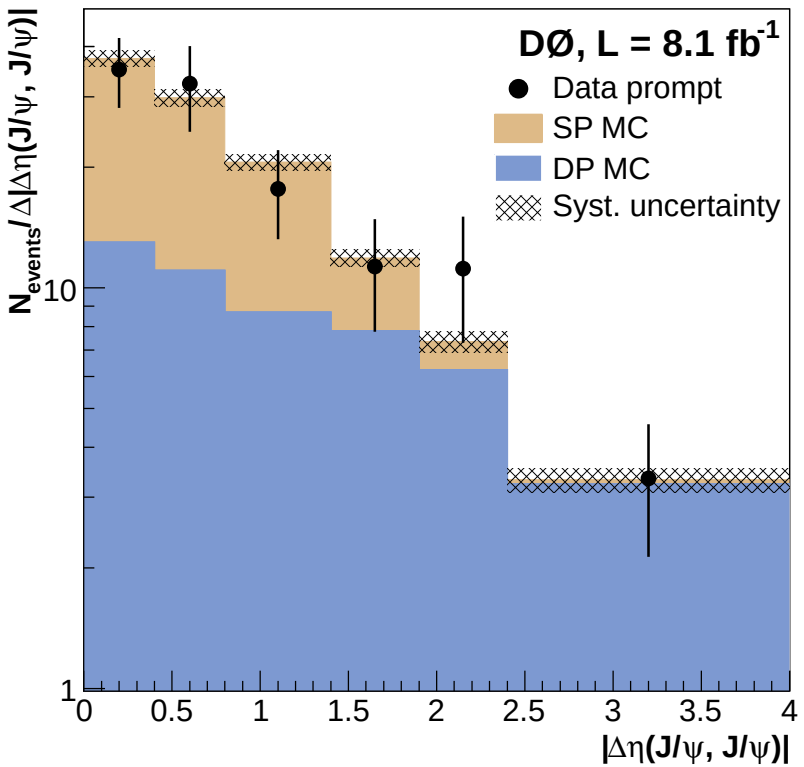
$$\sigma(J/\psi) * Br(J/\psi \to \mu^+\mu^-) = 23.9 \pm 4.6(\text{stat.}) \pm 3.7(\text{syst.})\ \text{nb}$$

**The predicted cross section using the "$k_T$ factorization"**

$$\sigma_{kT}(J/\psi) Br(J/\psi \to \mu^+\mu^-) = 23.0 \pm 8.5\ \text{nb}$$

# Estimation of Double Parton fraction from Prompt signal

Estimated after subtraction from the data of non-prompt and accidental background




$P_{SP} = 0.58 \pm 0.12,\ P_{DP} = 0.42 \pm 0.12$

*Uncertainties are caused by template fitting, model dependence(Herwig++ vs DjpsiFDC, Pythia8 vs Data like Model), variation of non-prompt and accidental backgrounds.*

# Results:SP double $J/\psi$ cross section

$$\sigma_{SP}(J/\psi J/\psi)Br(J/\psi \to \mu^+\mu^-)^2 = 70. \pm 6(\text{stat.}) \pm 22(\text{syst.})\ \text{fb}$$

## The predicted cross section using the "$k_T$ factorization"

$$\sigma_{k_T}(J/\psi J/\psi)Br(J/\psi \to \mu^+\mu^-)^2 = 55.1\ ^{+28.5}_{-15.6}\ (PDF)\ ^{+31.0}_{-17.0}\ (scale)\ \text{fb}$$

## The predicted cross section using the NRQCD

$$\sigma_{NRQCD}(J/\psi J/\psi)Br(J/\psi \to \mu^+\mu^-)^2 = 51.9\ \text{fb}$$

Since the renormalization and factorization scales rely on the charm quark mass, the results are very sensitive to the value of it.

Phys. Rev. D 90, 111101(R) (2014)

# Results:DP double $J/\psi$ cross section

$$\sigma_{DP}(J/\psi J/\psi)Br(J/\psi \to \mu^+\mu^-)^2 = 59 \pm 6(\text{stat.}) \pm 22(\text{syst.})\ \text{fb}$$

The predicted cross section using the "$k_T$ factorization"

$\sigma^0_{\text{eff}} = 15$ mb

$$\sigma^{DP}_{kT}(J/\psi\ J/\psi)Br(J/\psi \to \mu^+\mu^-)^2 = 17.6\ \text{fb} \pm 13.\ \text{fb}$$

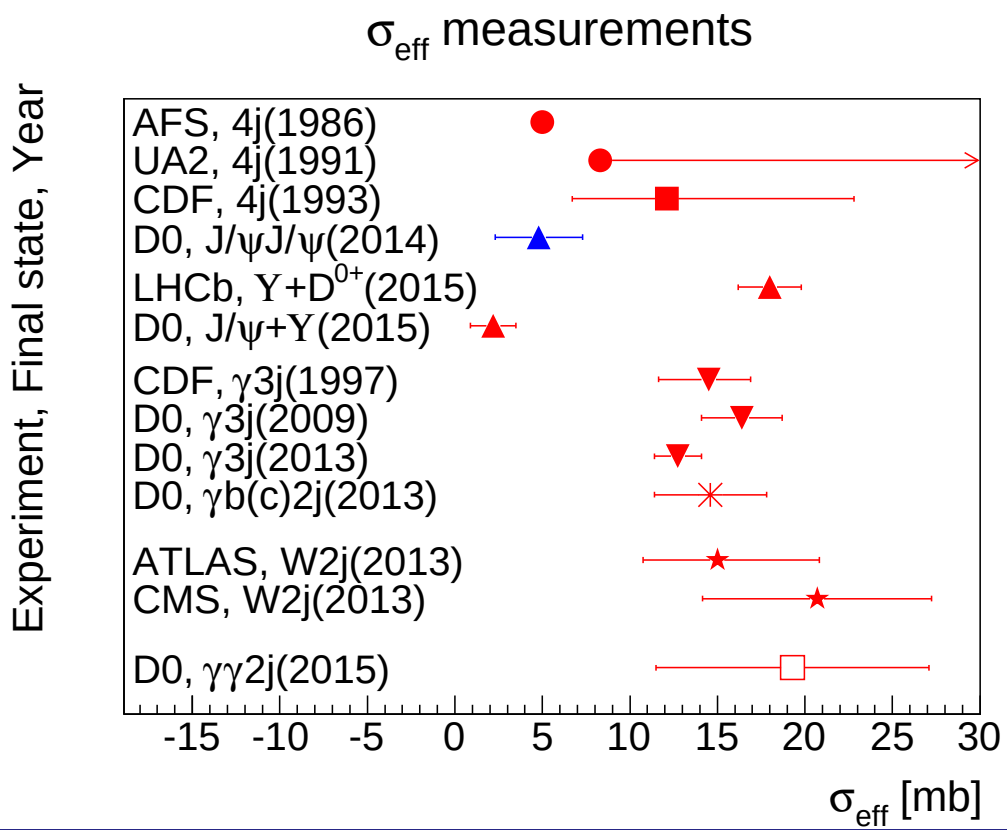
Phys. Rev. D 90, 111101(R) (2014)

# Results:Effective cross section

$$\sigma_{eff} = \frac{\sigma^2_{J/\psi}}{2\sigma_{J/\psi J/\psi_{DP}}}$$

$4.8 \pm 0.5(\text{stat.}) \pm 2.5(\text{syst.})$ mb

Phys. Rev. D 90, 111101(R) (2014)



# Summary

- In this analysis we have measured double $J/\psi$ production cross section in Double Parton Scattering:

$$\sigma_{DP}(J/\psi J/\psi) * Br(J/\psi \to \mu^+\mu^-)^2 = 59 \pm 6(\text{stat.}) \pm 22(\text{syst.}) \text{ fb}$$

It shows much higher rate of double $J/\psi$ events produced in the double parton scattering which might require tuning of spatial parton density models at small energies

- This allowed us to get $\sigma_{eff}$:

$$\sigma_{eff} = 4.8 \pm 0.5(\text{stat.}) \pm 2.5(\text{syst.}) \text{ mb}$$

♦ A smaller $\sigma_{eff}(\sim R^2)$ may indicate a more clumpy gluon density concentrated in a smaller radius.
♦ It is test on energy and flavour dependence of $\sigma_{eff}$.