2×J/ψ production at LHCb

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Double Quarkonia

- Important test of QCD **SPS**
  - *Colour Singlet vs Colour Octet*
  - LO, NLO*, NLO NR QCD calculations
  - Probe *linearly-polarized gluons* in proton
  - TMD gluon distributions
  - ….
- **DPS**: puzzle of double quarkonia
  - σ_{eff} is very small: Non-universal? Process dependent?
- 4c tetraquarks: there are models of (narrow) 4c-*tetraquark(s)* near the threshold

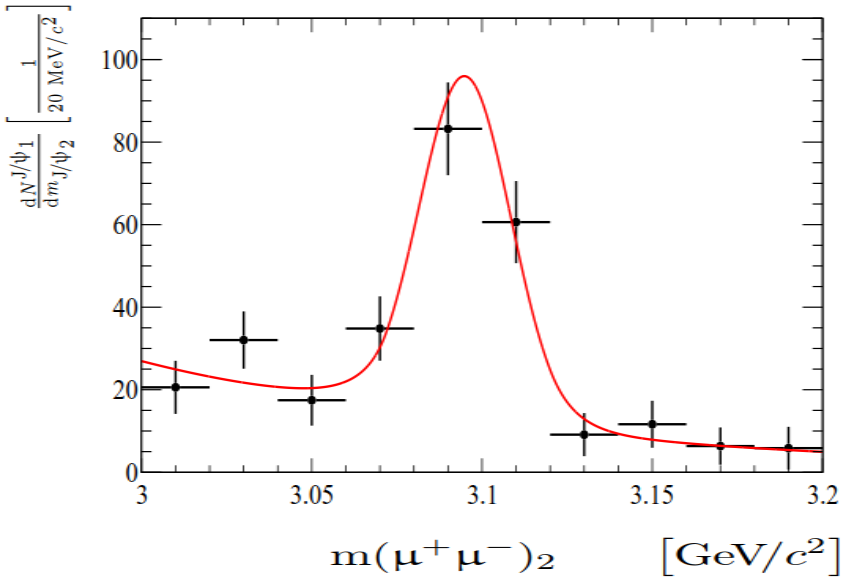
2×J/ψ @ 7TeV

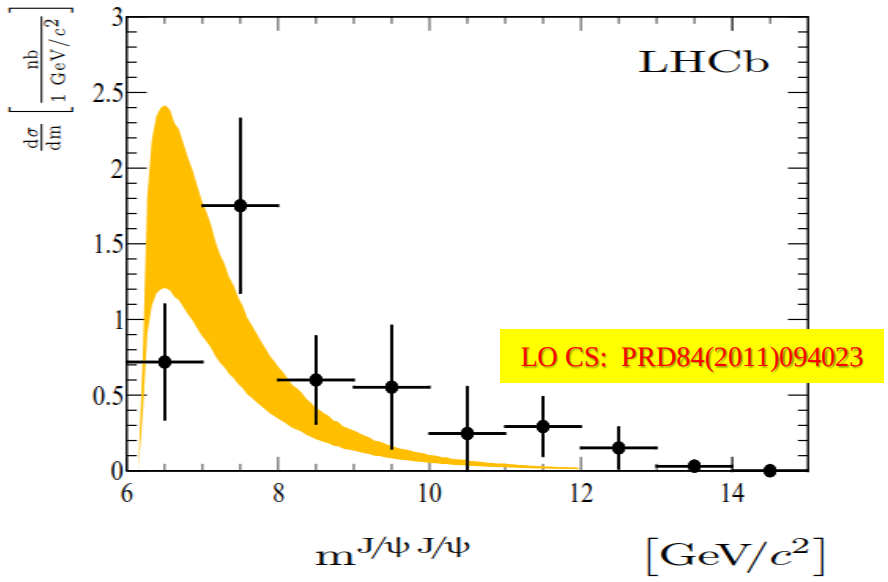
- 37pb^{-1}
  - 2010 (1.2% from Run-I)
- 141±19 signal events
  - $2<y(J/\psi)<4.5$, $p_T(J/\psi)<10$GeV/c

SPS:
4.0± 1.2 nb LO PRD84(2011)094023
4.6 ±1.1 nb LO PRD94(2016) 074033
$5.4^{+2.7}_{-1.1}$ nb NLO PRD94(2016) 074033
DPS: 3.8±1.3 nb

$\sigma(J/\psi J/\psi) = 5.1\pm1.0\pm1.1$ nb

PLB707(2012)52





2×J/ψ @ 13TeV

- 279pb^{-1} 2015
  - $2<y(J/\psi)<4.5$, $p_T(J/\psi)<10$GeV/c
- Good muons
- 4μ vertex

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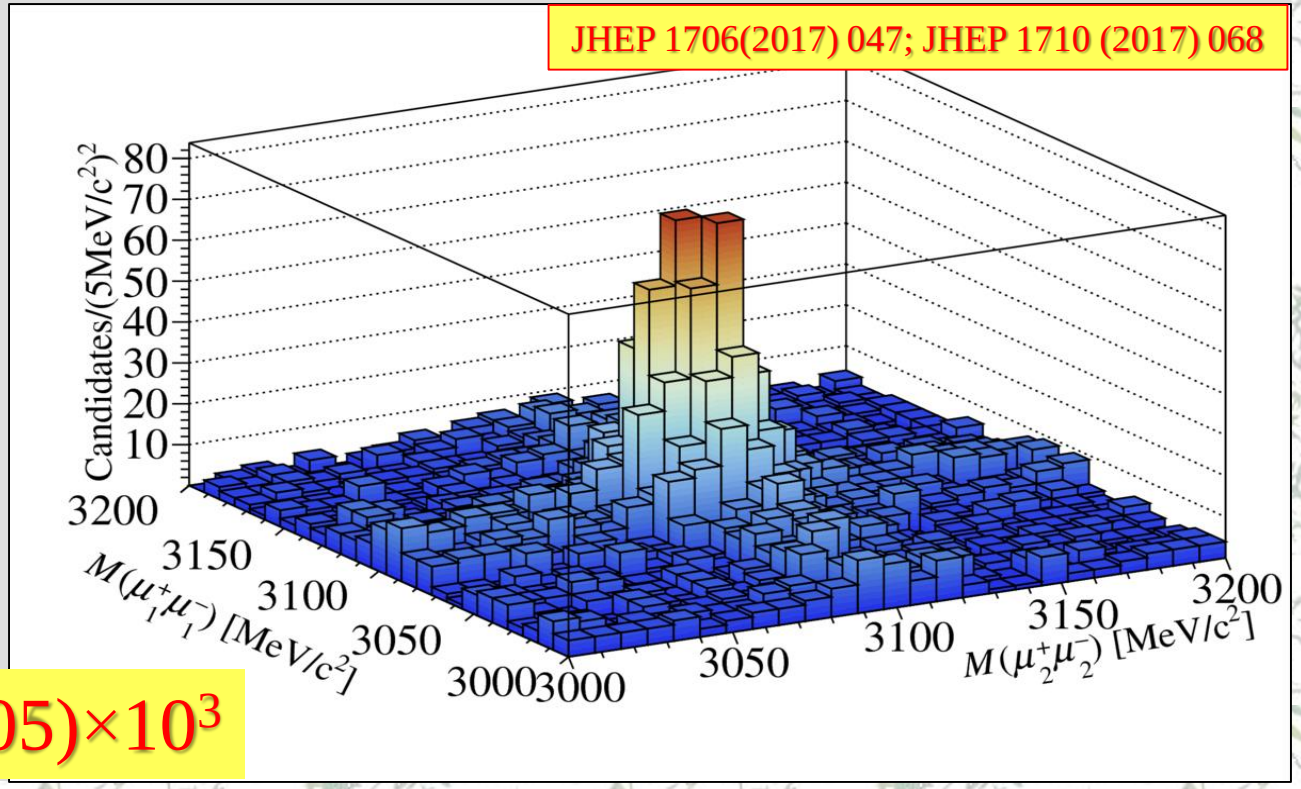

Signal: (1.05±0.05)×10^3

Cross section

- 2D fit to efficiency-corrected dataset

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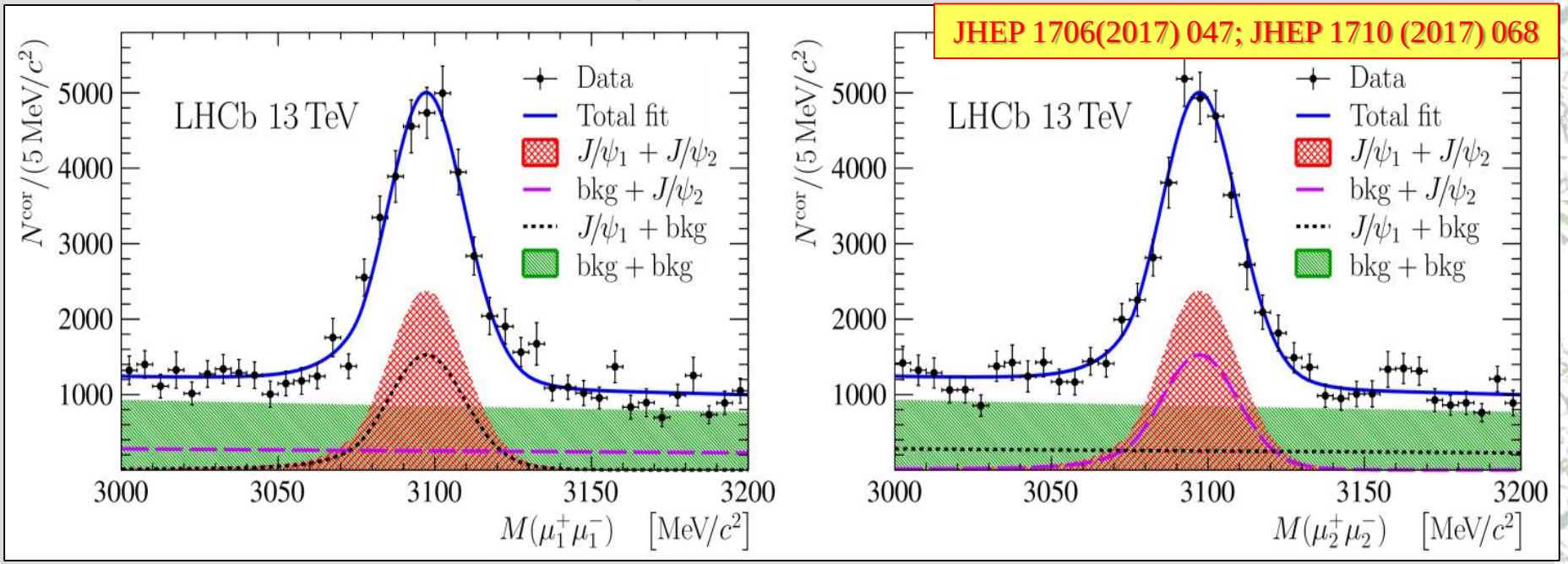

$\sigma(J/\psi J/\psi)=15.2 \pm 1.0 \pm 0.9$ nb

Cross section

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	$\sigma(J/\psi\, J/\psi)$ [nb]		
	no p_T cut	$p_T > 1\,\text{GeV}/c$	$p_T > 3\,\text{GeV}/c$
LO CS PRD94 (2016) 054017	$1.3 \pm 0.1^{+3.2}_{-0.1}$	—	—
LO CO CPC 198 (2016) 238	$0.45 \pm 0.09^{+1.42+0.25}_{-0.36-0.34}$	—	—
LO k_T PRD84 (2011) 054012	$6.3^{+3.8+3.8}_{-1.6-2.6}$	$5.7^{+3.4+3.2}_{-1.5-2.1}$	$2.7^{+1.6+1.6}_{-0.7-1.0}$
NLO* CS′ PRD94 (2016) 054017	—	$4.3 \pm 0.1^{+9.9}_{-0.9}$	$1.6 \pm 0.1^{+3.3}_{-0.3}$
NLO* CS″ CPC 198 (2016) 238	$15.4 \pm 2.2^{+51}_{-12}$	$14.8 \pm 1.7^{+53}_{-12}$	$6.8 \pm 0.6^{+22}_{-5}$
NLO CS PRD94 (2016) 074033	$11.9^{+4.6}_{-3.2}$	—	—
DPS LHCb data, σ_{eff} from CDF	$8.1 \pm 0.9^{+1.6}_{-1.3}$	$7.5 \pm 0.8^{+1.5}_{-1.2}$	$4.9 \pm 0.5^{+1.0}_{-0.8}$
Data	$15.2 \pm 1.0 \pm 0.9$	$13.5 \pm 0.9 \pm 0.9$	$8.3 \pm 0.6 \pm 0.5$

$p_T(J/\psi J/\psi)$

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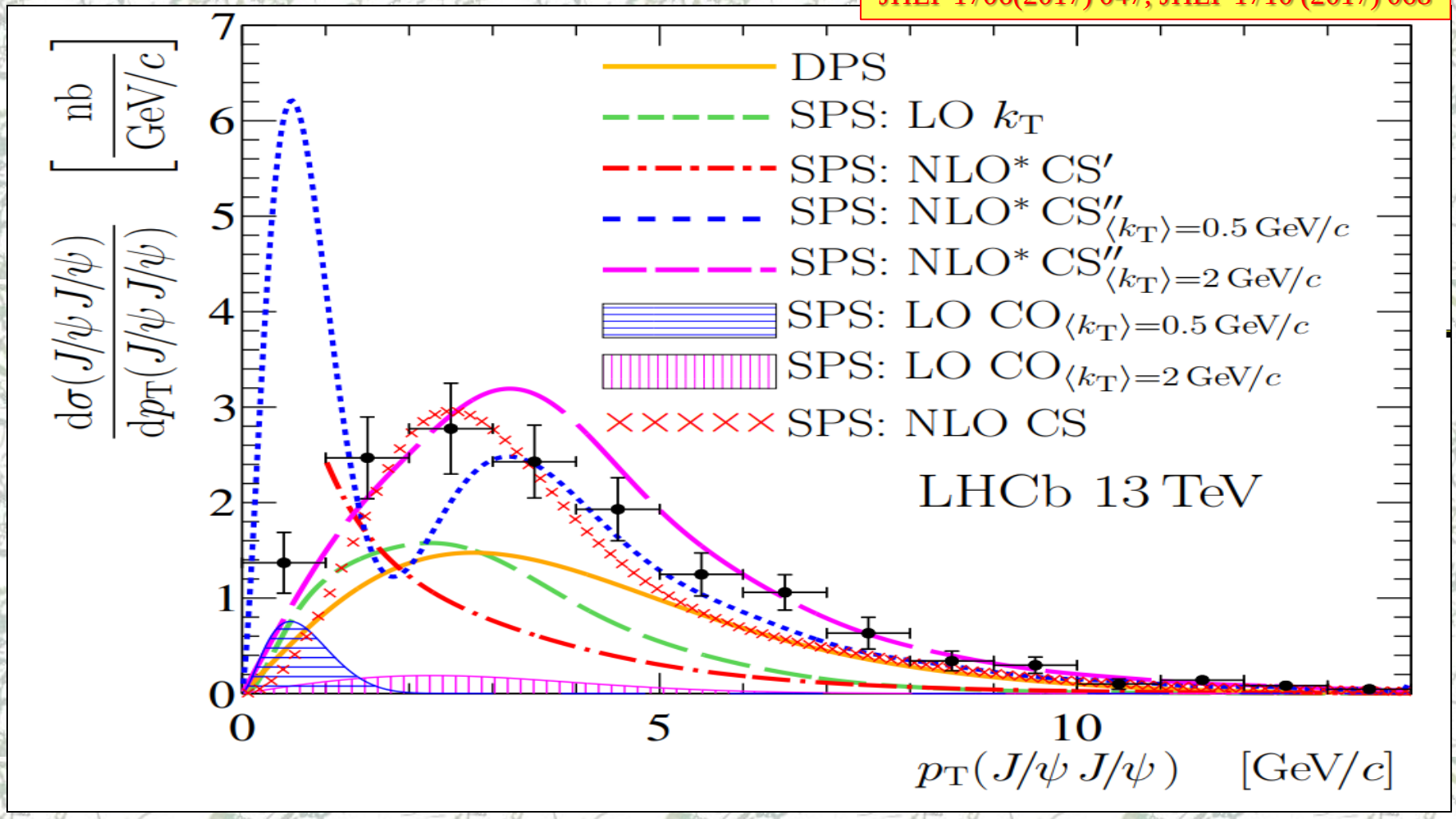

$p_T(J/\psi)$, $y(J/\psi)$, $y(J/\psi J/\psi)$

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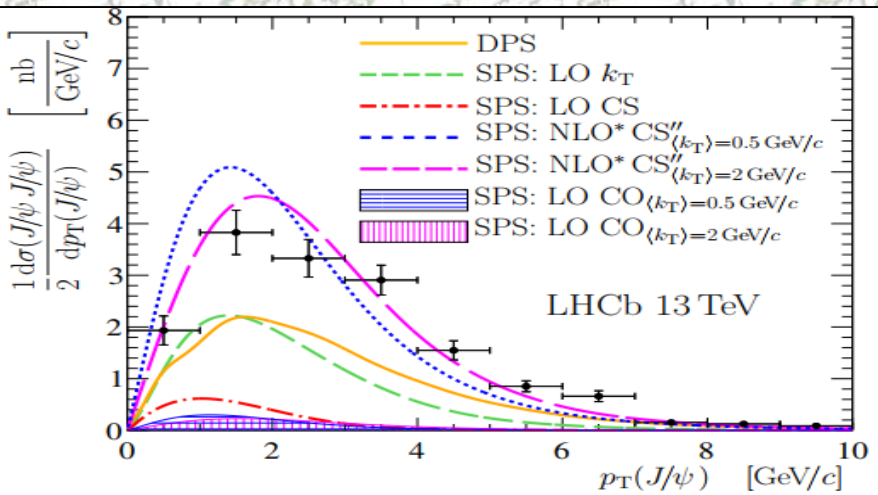

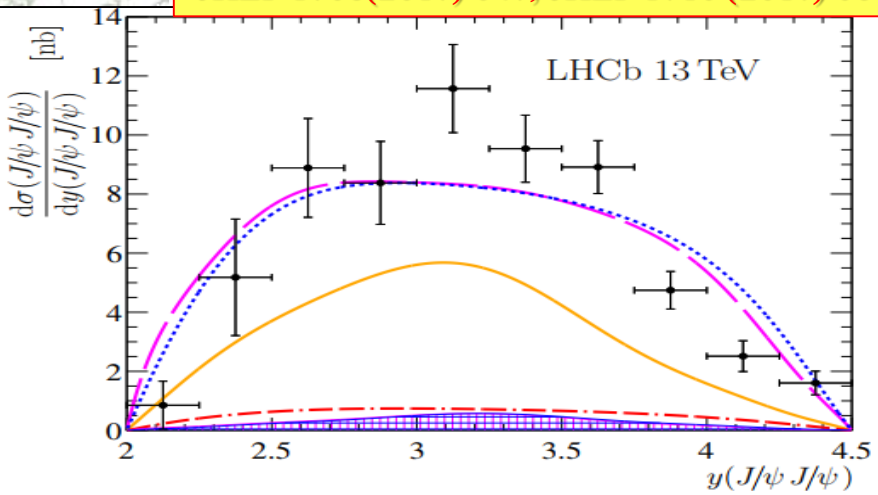

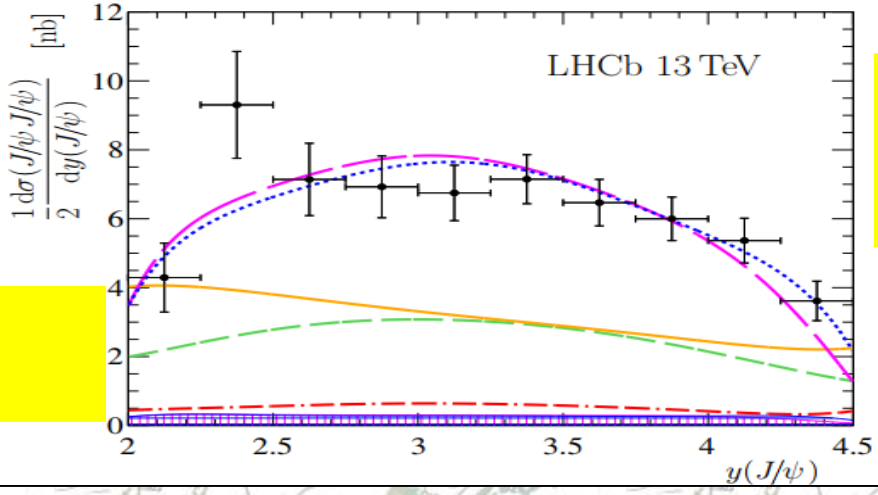

No discrimination between different SPS models

No discrimination between SPS/DPS

Δy, $\Delta\phi$, A_T, m(J/ψJ/ψ)

These are discriminative variables!

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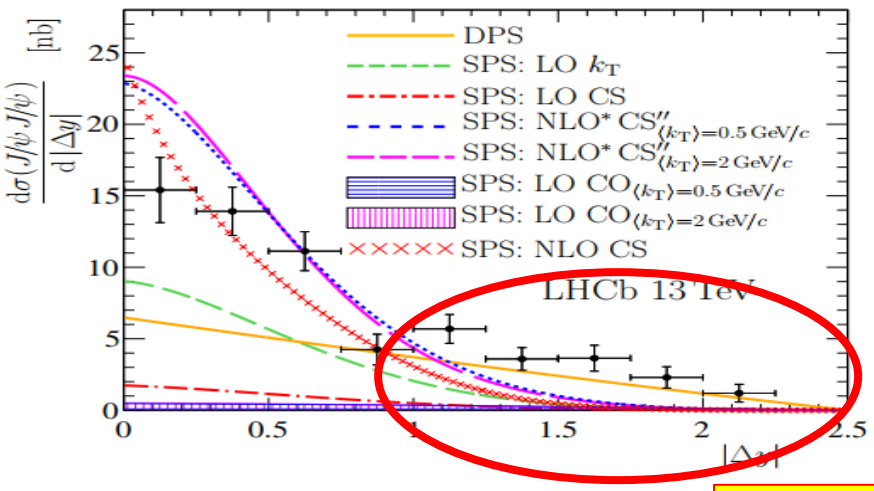
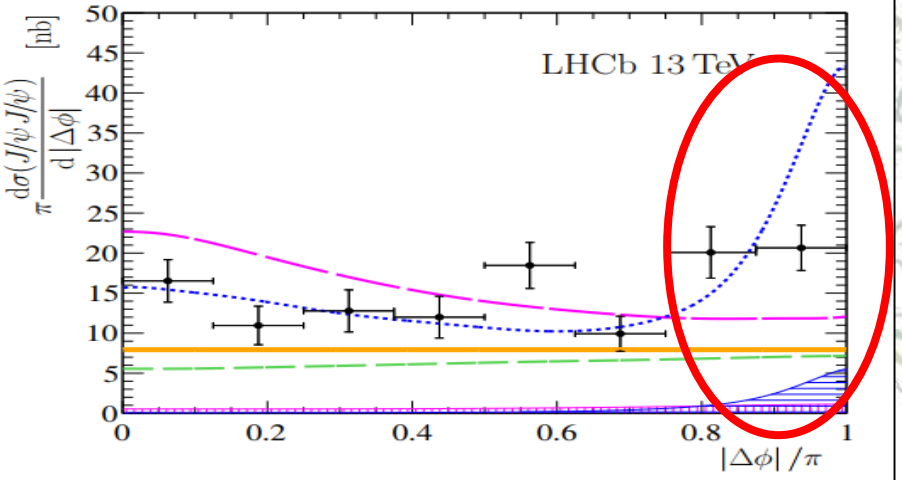
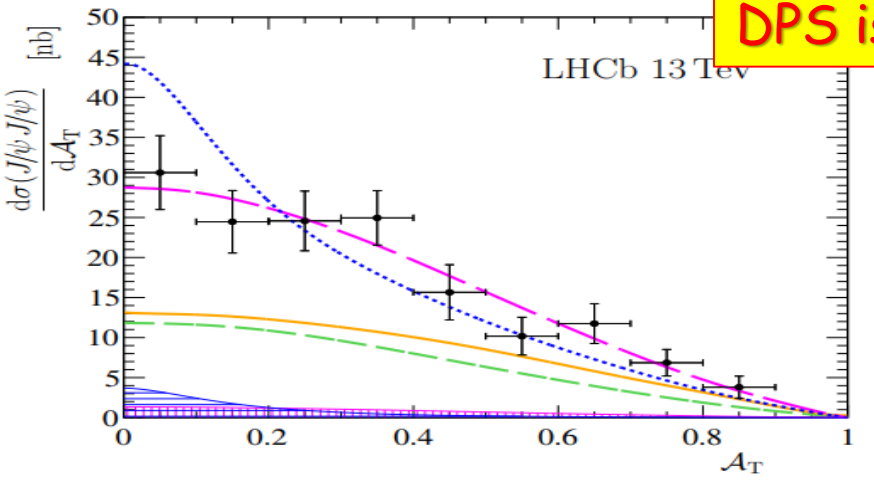
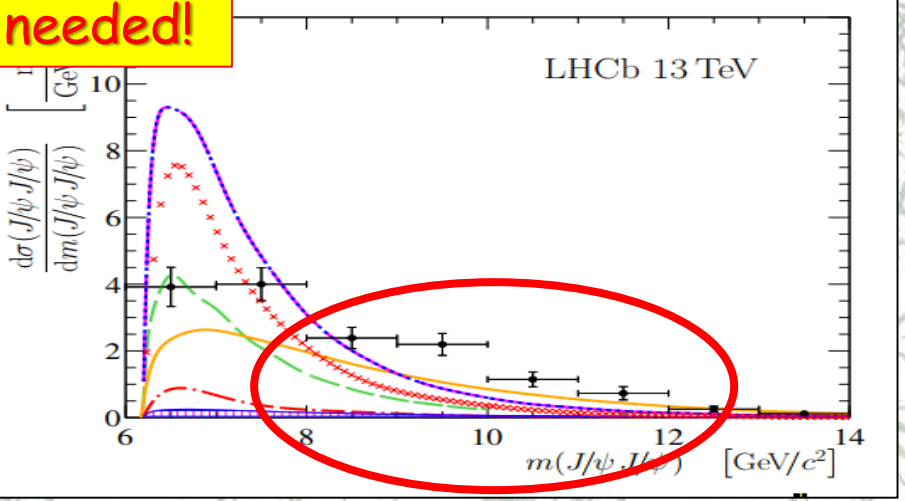




DPS is needed!





DPS fits:

$$\frac{d\sigma}{dv} = \sigma_{DPS} F_{DPS}(v) + \sigma_{SPS} F_{SPS}(v),$$

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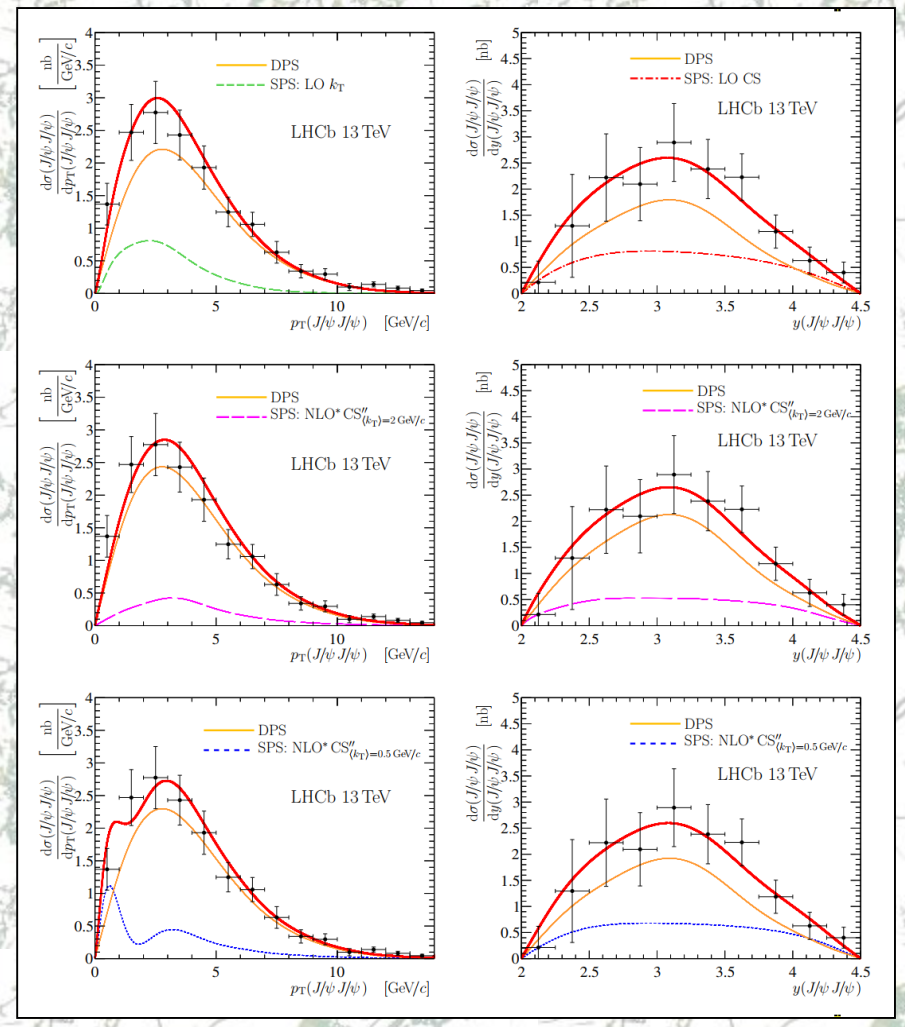

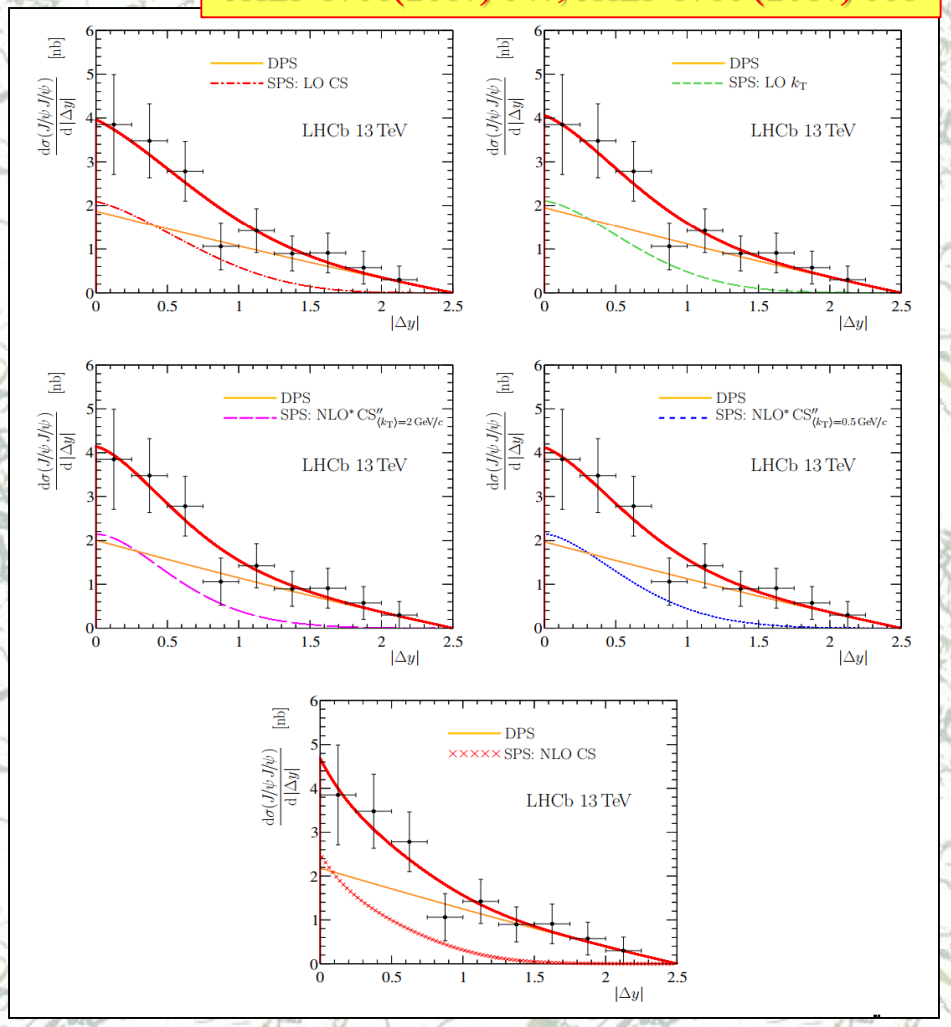

DPS fits

$$f_{\mathrm{DPS}} \equiv \frac{\sigma_{\mathrm{DPS}}}{\sigma_{\mathrm{SPS}} + \sigma_{\mathrm{DPS}}}.$$

DPS is not small!

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Variable	LO CS	LO k_{T}	NLO* CS′	NLO* CS″ $\langle k_{\mathrm{T}} \rangle = 2\,\mathrm{GeV}/c$	NLO* CS″ $\langle k_{\mathrm{T}} \rangle = 0.5\,\mathrm{GeV}/c$	NLO CS
no $p_{\mathrm{T}}(J/\psi\,J/\psi)$ cut						
$p_{\mathrm{T}}(J/\psi\,J/\psi)$	—	78 ± 2	—	86 ± 55	81 ± 7	—
$y(J/\psi\,J/\psi)$	83 ± 39	—	—	75 ± 37	68 ± 34	—
$m(J/\psi\,J/\psi)$	76 ± 7	74 ± 7	—	78 ± 7		77 ± 7
$\lvert\Delta y\rvert$	59 ± 21	61 ± 18	—	63 ± 18	61 ± 18	69 ± 16
$p_{\mathrm{T}}(J/\psi\,J/\psi) > 1\,\mathrm{GeV}/c$						
$y(J/\psi\,J/\psi)$	—	—	75 ± 24	71 ± 38	68 ± 34	—
$m(J/\psi\,J/\psi)$	—	73 ± 8	76 ± 7	88 ± 1		—
$\lvert\Delta y\rvert$	—	57 ± 20	59 ± 19	60 ± 18	60 ± 19	—
$p_{\mathrm{T}}(J/\psi\,J/\psi) > 3\,\mathrm{GeV}/c$						
$y(J/\psi\,J/\psi)$	—	—	77 ± 18	64 ± 38	64 ± 35	—
$m(J/\psi\,J/\psi)$	—	76 ± 10	84 ± 7	87 ± 2		—
$\lvert\Delta y\rvert$	—	42 ± 25	53 ± 21	53 ± 21	53 ± 21	—

DPS fits: σ_{eff}

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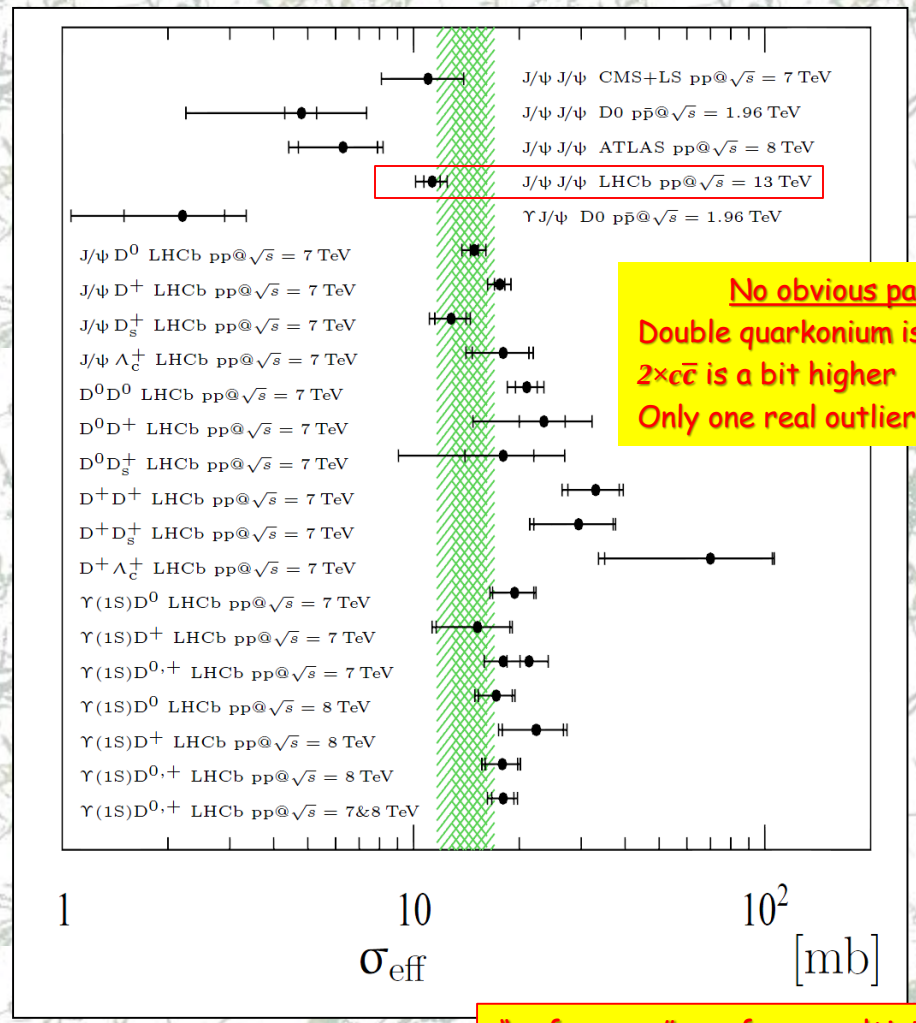
Variable	LO k_T	NLO* CS″		NLO CS
		$\langle k_T \rangle = 2\,\text{GeV}/c$	$\langle k_T \rangle = 0.5\,\text{GeV}/c$	
$p_T(J/\psi\,J/\psi)$	9.7 ± 0.5	8.8 ± 5.6	9.3 ± 1.0	—
$y(J/\psi\,J/\psi)$	—	11.9 ± 7.5	10.0 ± 5.0	—
$m(J/\psi\,J/\psi)$	10.6 ± 1.1	10.2 ± 1.0		10.4 ± 1.0
$\lvert\Delta y\rvert$	12.5 ± 4.1	12.2 ± 3.7	12.4 ± 3.9	11.2 ± 2.9

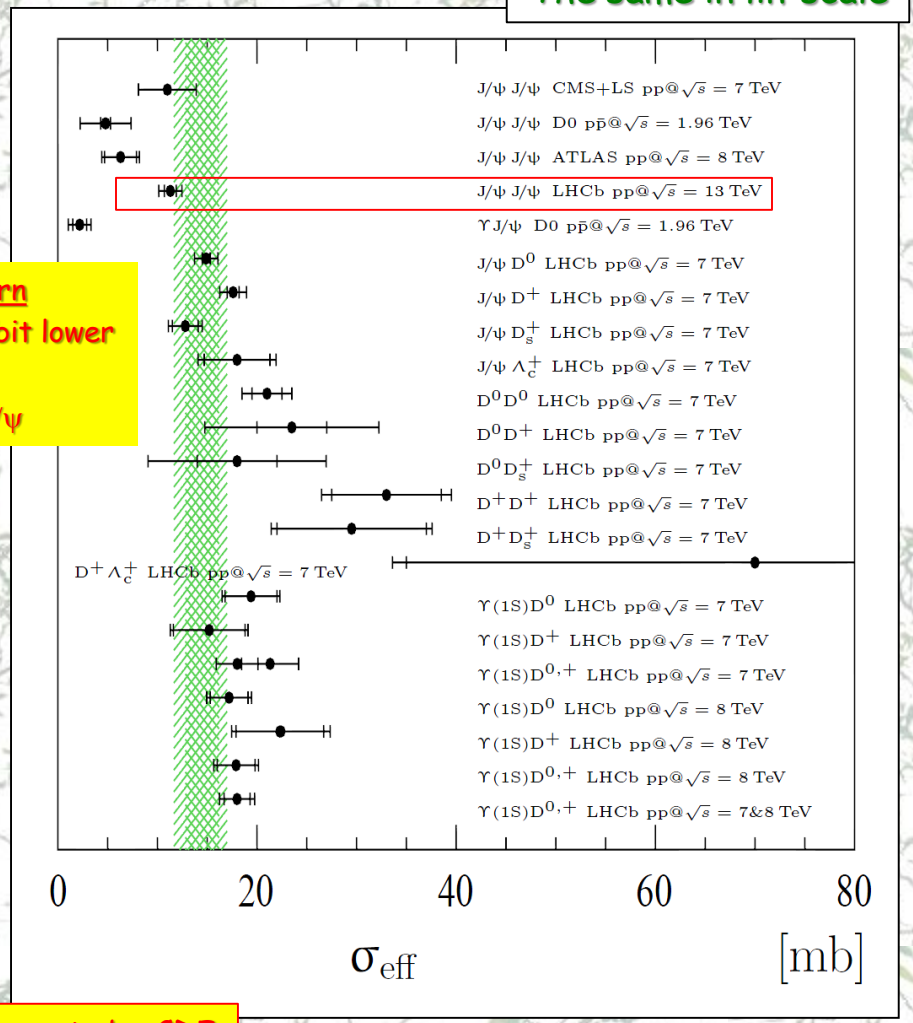
- σ_{eff} for f_{DPS}=100% 7.3±0.5±1.0 mb
- For all cases σ_{eff} is relatively small
  - smaller than σ_{eff} for $c\bar{c}c\bar{c}$, J/ψ $c\bar{c}$, $b\bar{b}c\bar{c}$
  - similar to ATLAS, CMS, …

σ_{eff}



No obvious pattern
Double quarkonium is a bit lower
$2\times c\bar{c}$ is a bit higher
Only one real outlier ϒJ/ψ

The same in lin-scale



"reference" σ_{eff} from multi-jet events by CDF

Summary

- $2\times J/\psi$ production at $\sqrt{s}=13$TeV is studied
- Large statistic allows study of differential distributions
- Results indicate (large) DPS component
- σ_{eff} is measured using SPS+DPS template fits
  - Consistent values for different SPS models
    - LO CS, LO CO, NLO* CS, NLO CS
  - σ_{eff} is small
- SPS theory uncertainties are still too large to make strong conclusions
- More data is available for more precise measurements