New observables in quarkonium production

J.P. Lansberg
IPN Orsay – Paris-Sud U. –CNRS/IN2P3 – Université Paris-Saclay

work done in collaboration with Hua-Sheng Shao (CERN)

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- Colour-Singlet Model (CSM) back in the game

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- All this motivates the study of new observables which can be more discriminant for specific effects
- Examples for which data exists: quarkonium-pair production, $J/\psi + Z$, ...

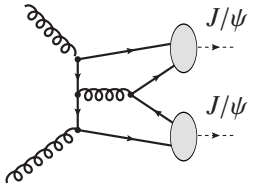
Part I

Quarkonium-pair production

On the importance of α_s^5 contributions to $J/\psi + J/\psi$ & $J/\psi + \eta_c$

JPL, H.S. Shao PRL 111, 122001 (2013)

- LO to $J/\psi + J/\psi$ at α_S^4



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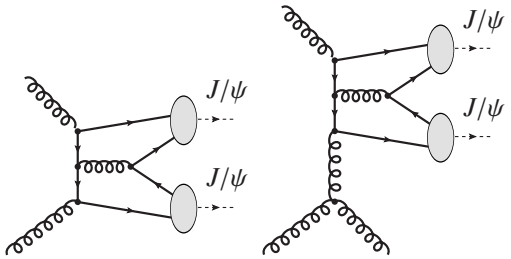

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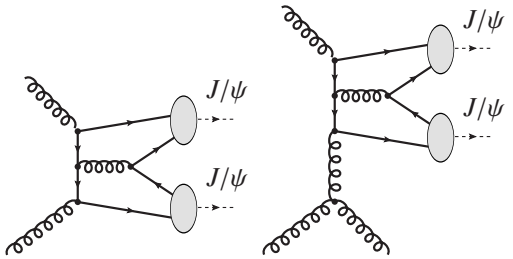

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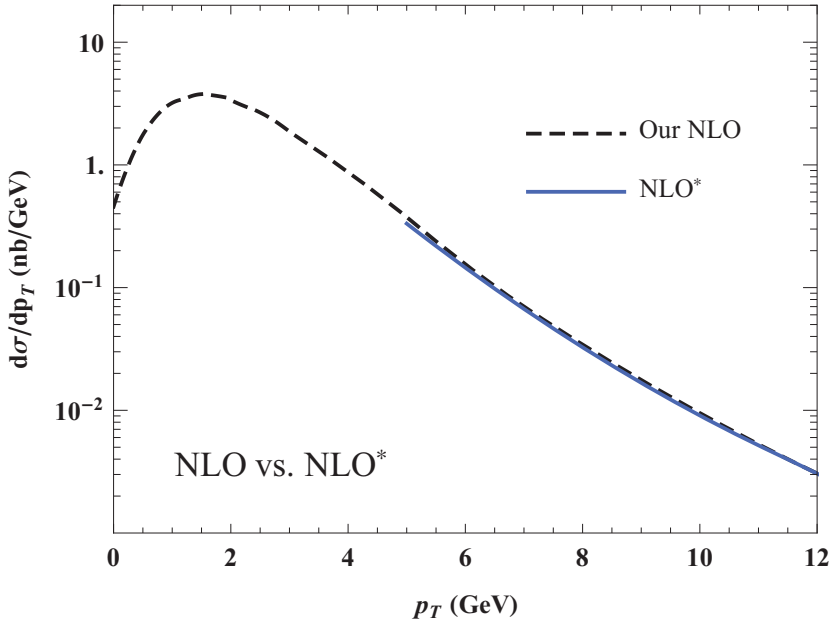

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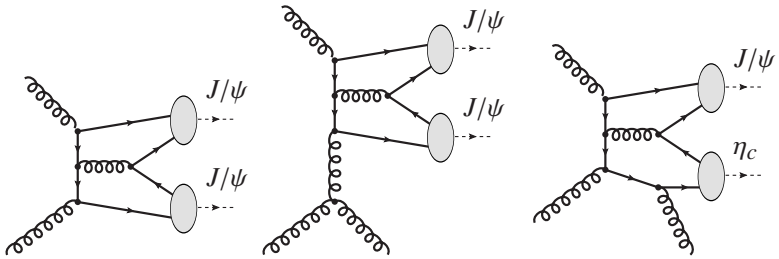

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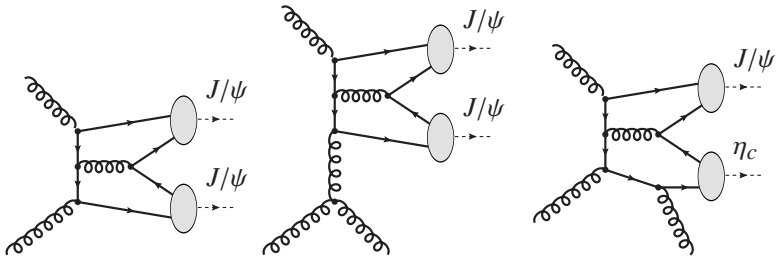

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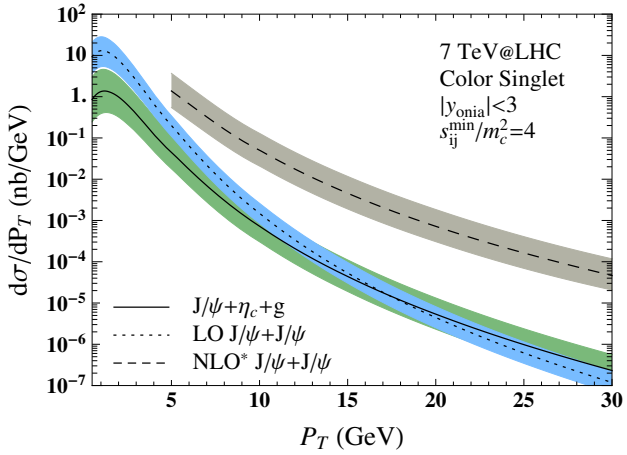

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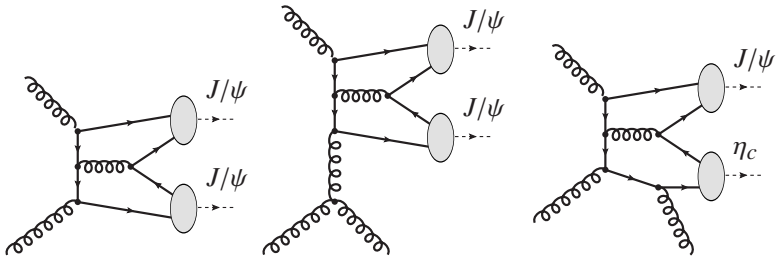

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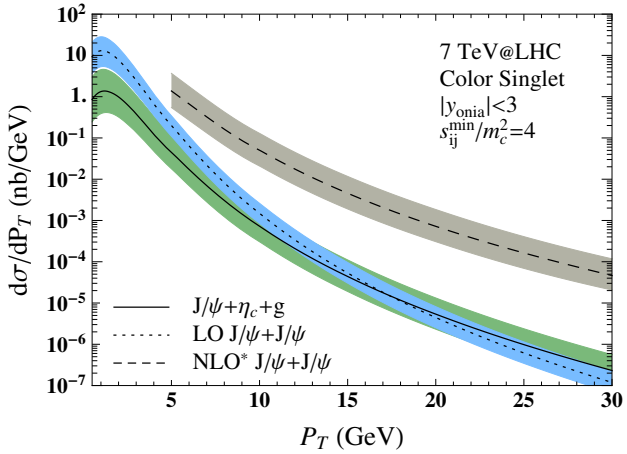

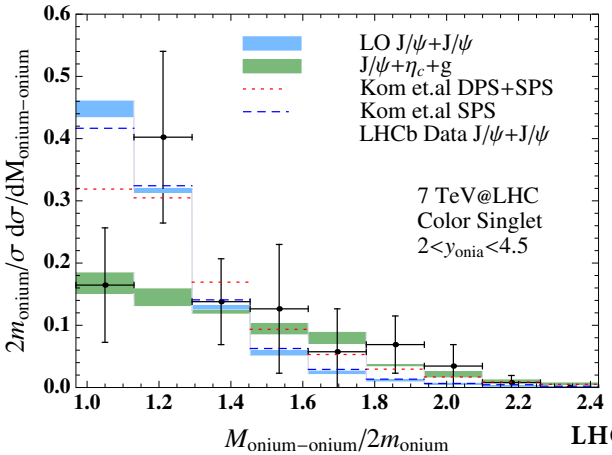

LHCb PLB 707 (2012) 52

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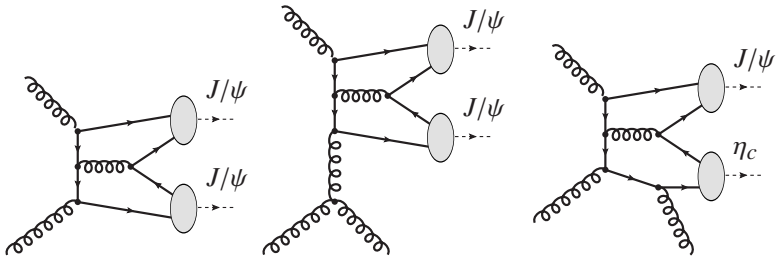

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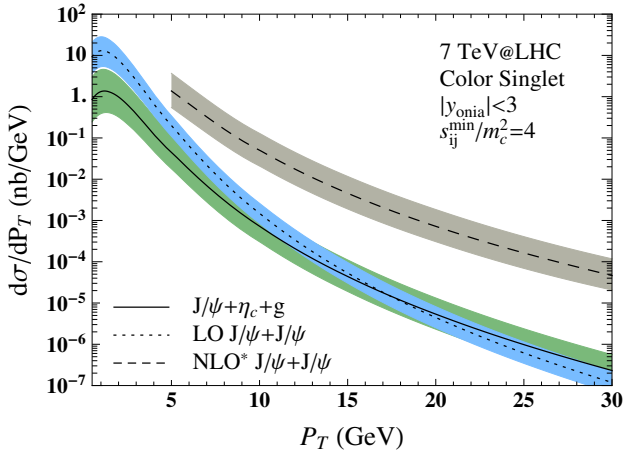

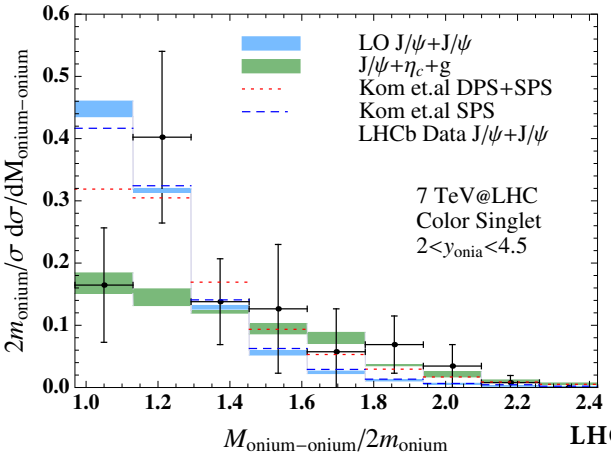

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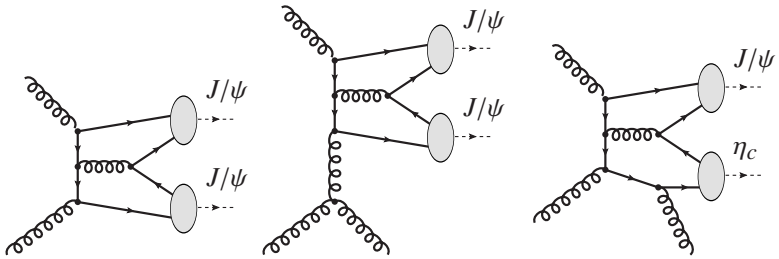

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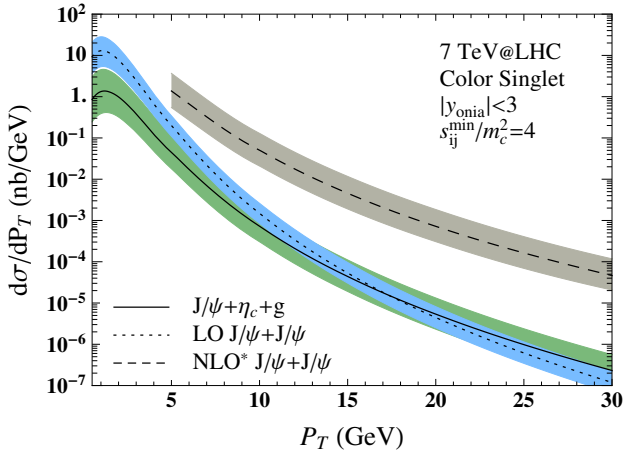

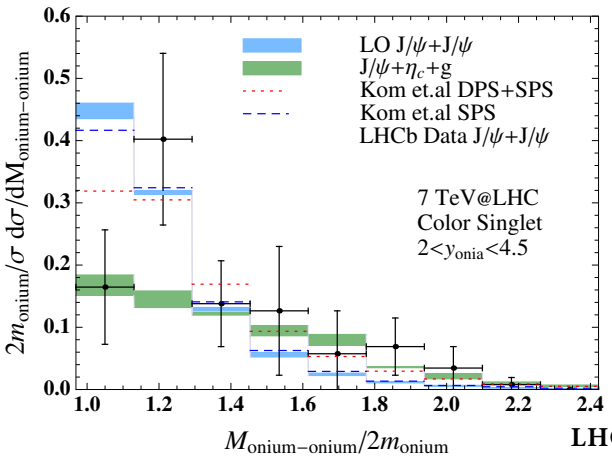

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- Large enhancement at high P_T

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On the importance of QCD corrections : P_T enhanced topologies

JPL, H.-S.Shao PLB 751 (2015) 479

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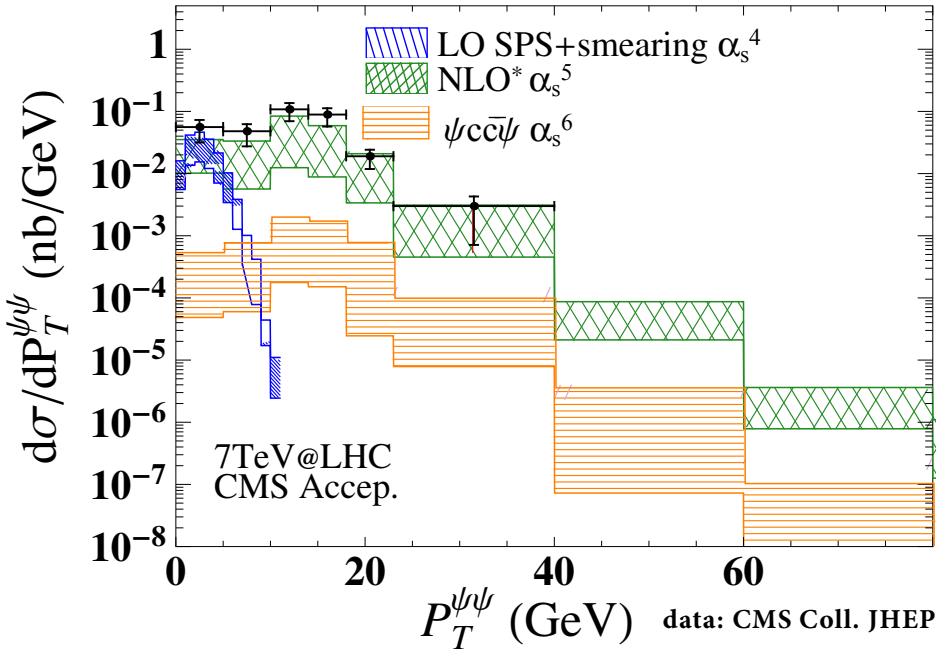

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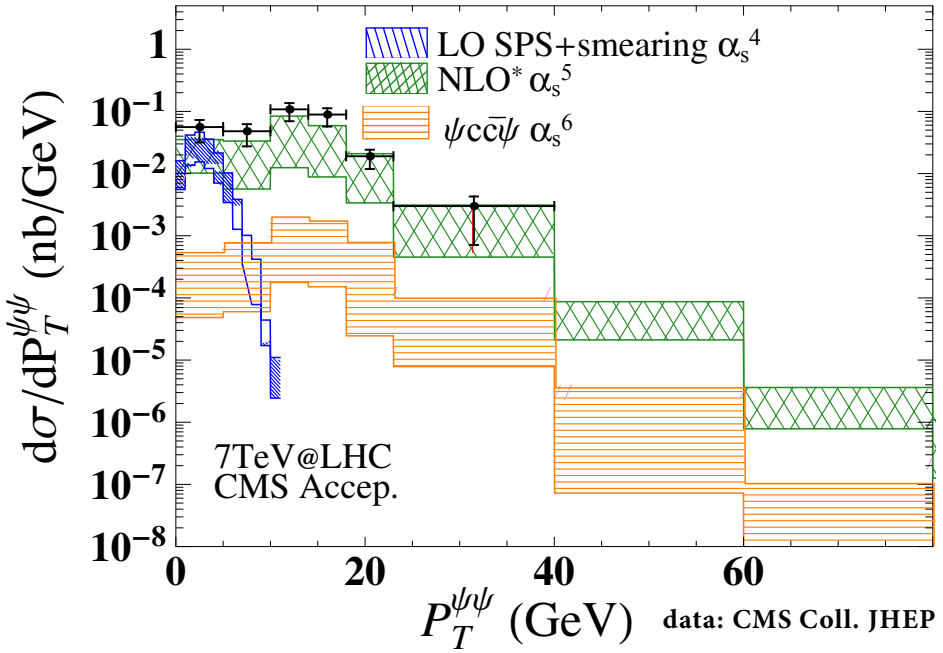

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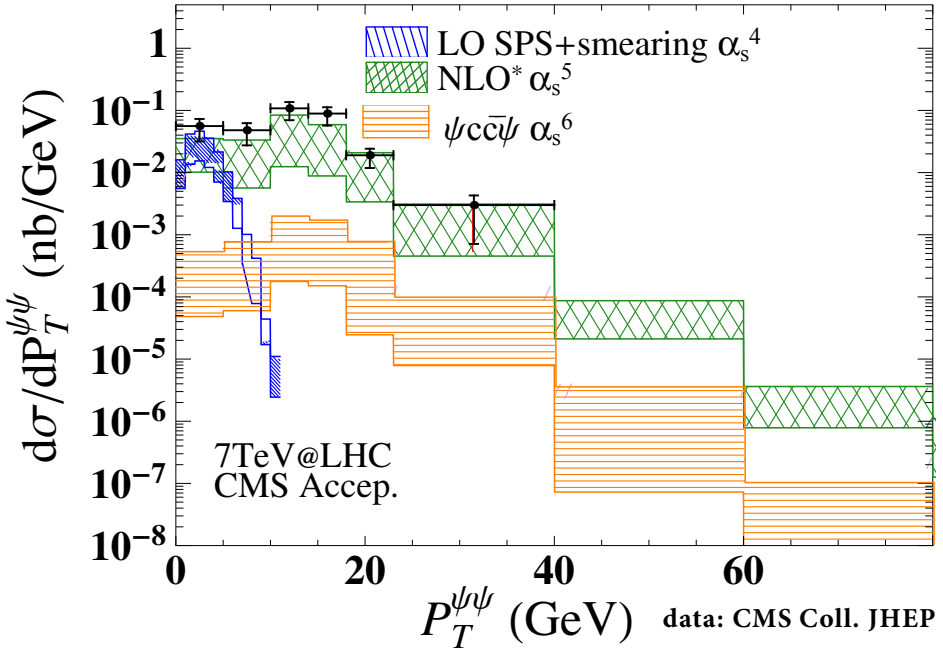

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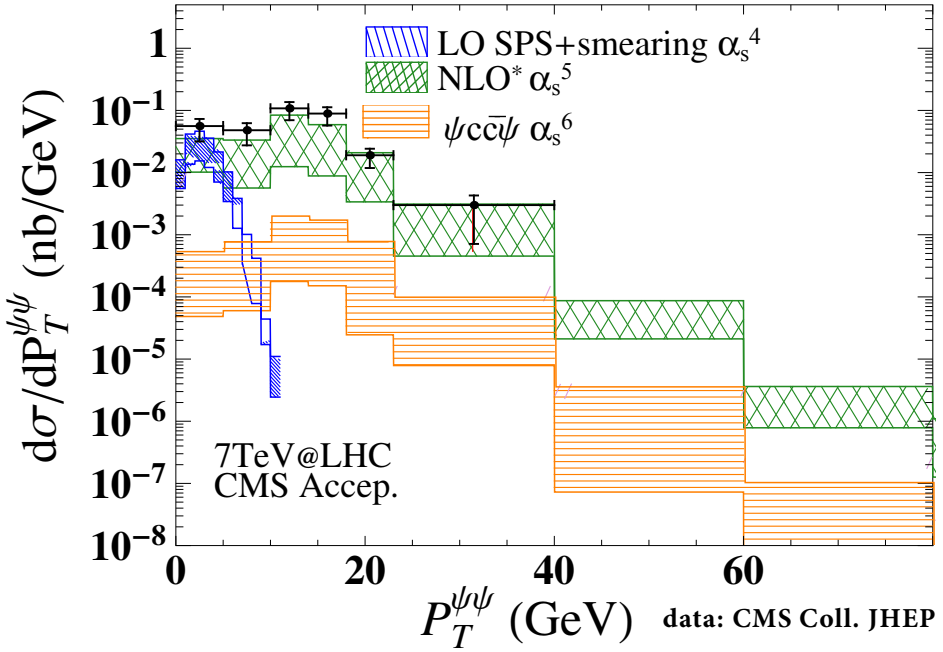

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- We do not expect NNLO (α_s^6) contributions to matter where one currently has data

[the orange histogram shows one class of leading P_T α_s^6 contributions]

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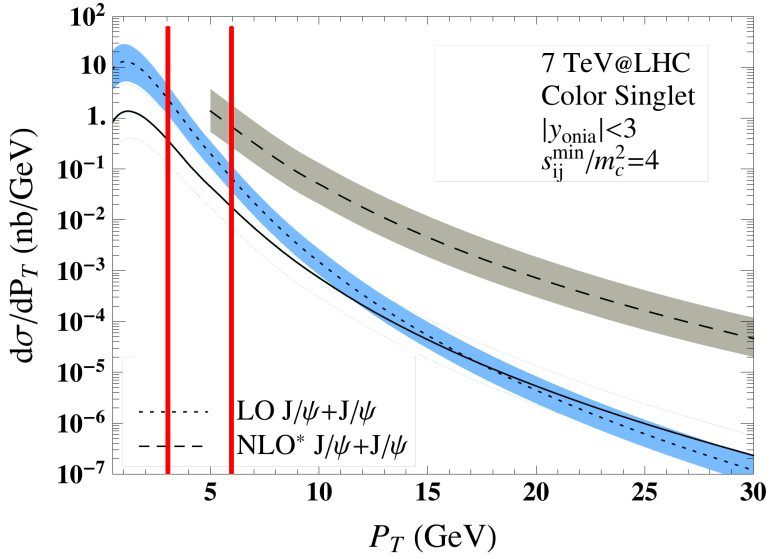

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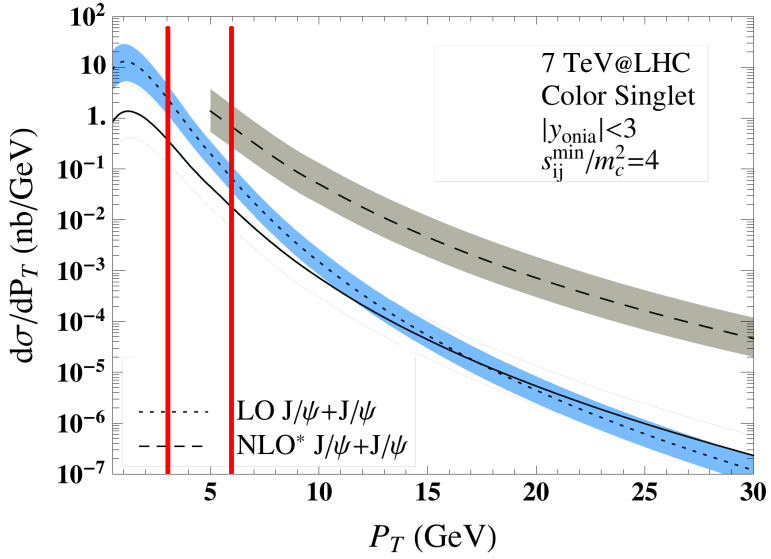

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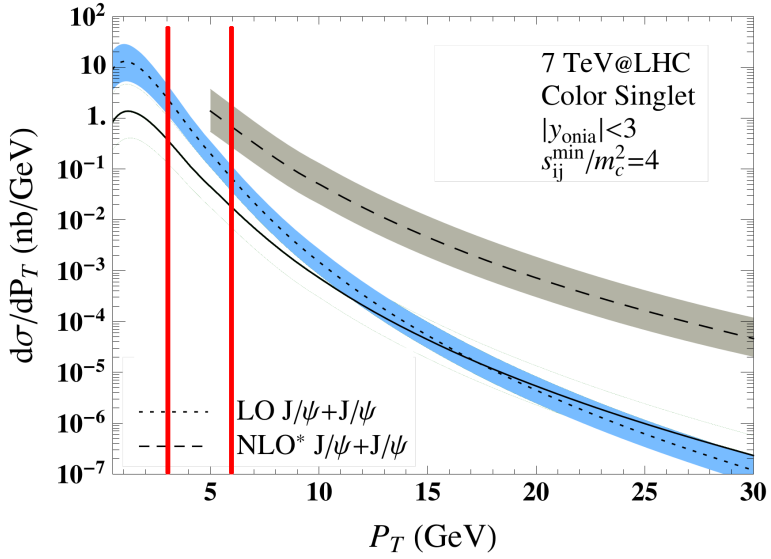

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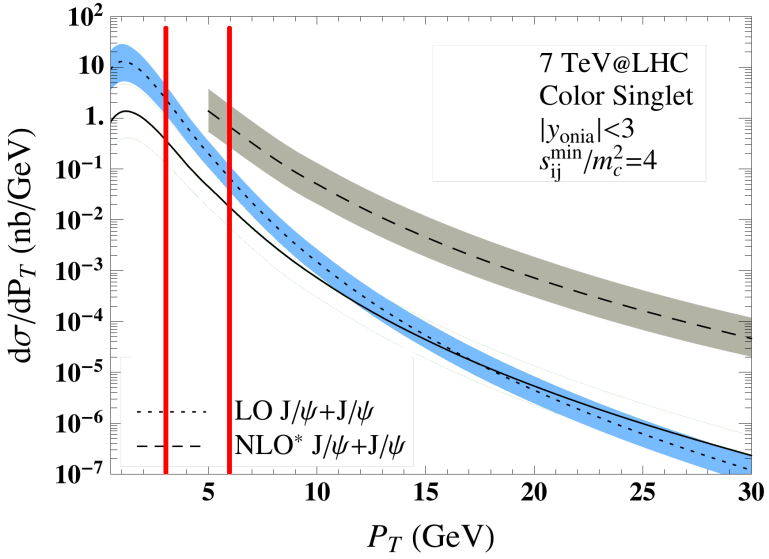
- As we will see, some kinematical distributions are also problematic → the so-called CMS puzzle



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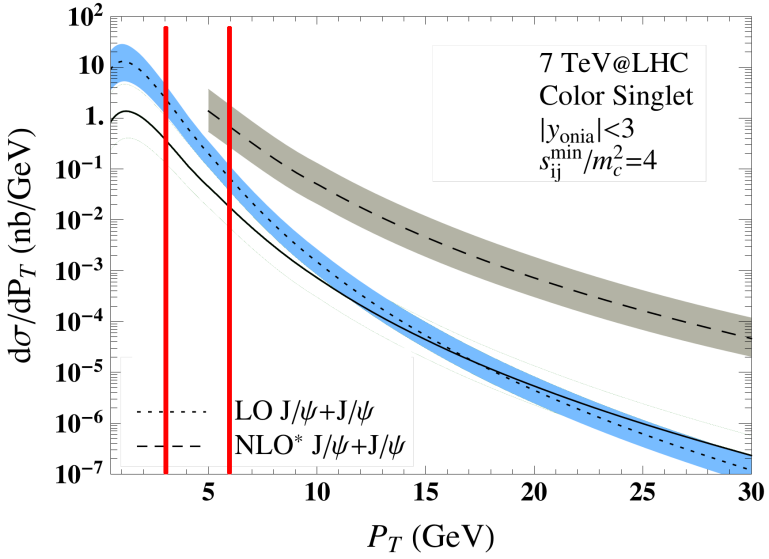
LO	$0.35^{+0.26}_{-0.17}$ pb	53^{+57}_{-27} fb
NLO*	$1.5^{+2.2}_{-0.87}$ pb	170^{+340}_{-110} fb
Data	5.25 ± 0.52 pb	129 ± 46 fb

On the importance of QCD corrections (III)

- CMS sample affected by an acceptance P_T cut (4-6 GeV) CMS Coll. JHEP 1409 (2014) 094
- D0 sample has a slightly lower P_T cut (3 GeV) D0 Coll. PRD 90 (2014) 111101
- We expect the corresponding P_T-integrated x-section to receive large real α_s^5 contributions (NLO*)
- The α_s^5 contributions are however insufficient to describe the CMS data
- As we will see, some kinematical distributions are also problematic → the so-called CMS puzzle
- As we will also see, this was foreseeable (this should not have been a puzzle at all)



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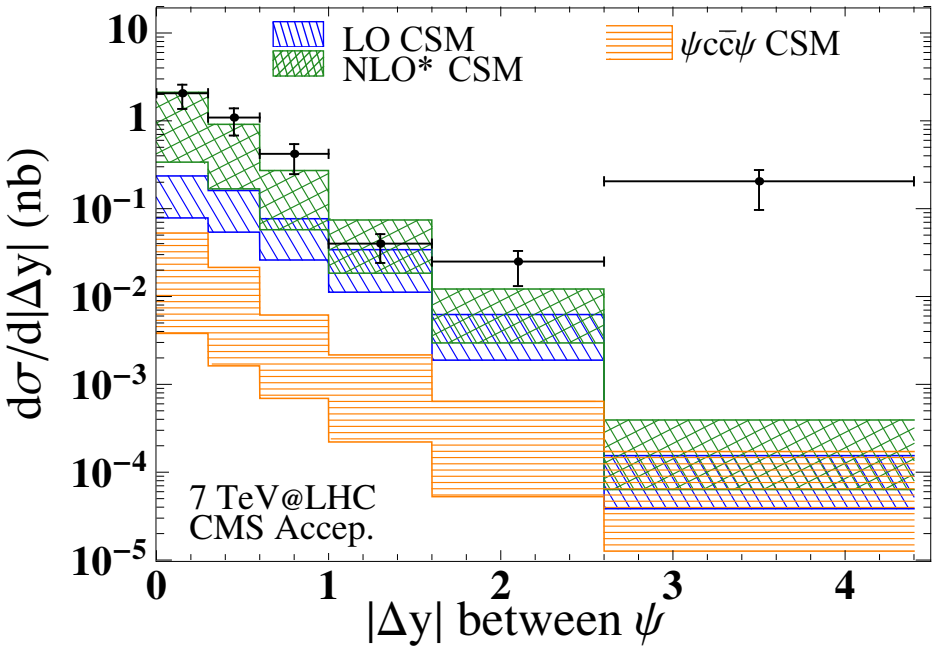
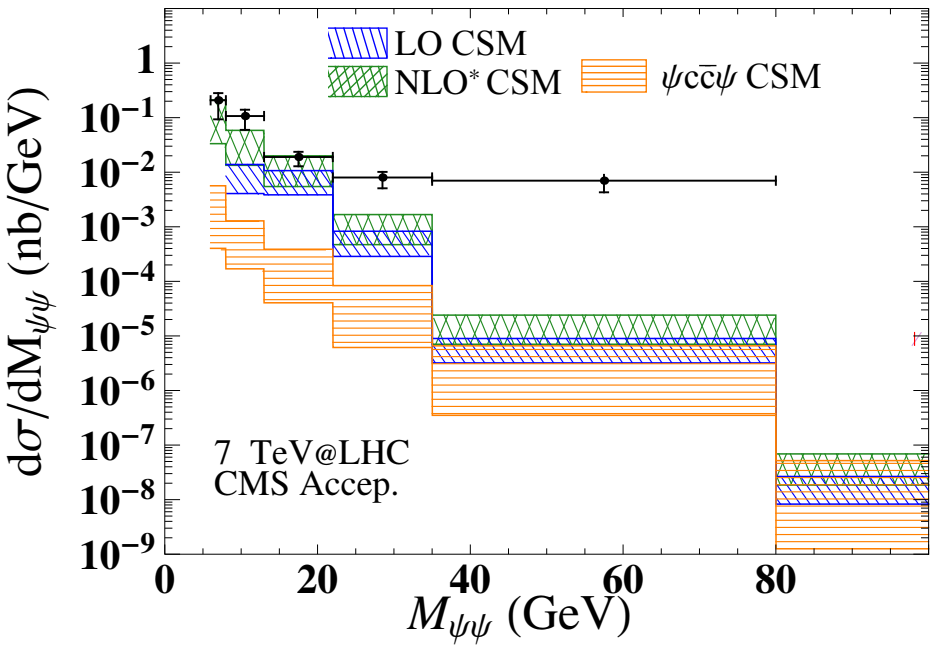
The so-called CMS puzzle





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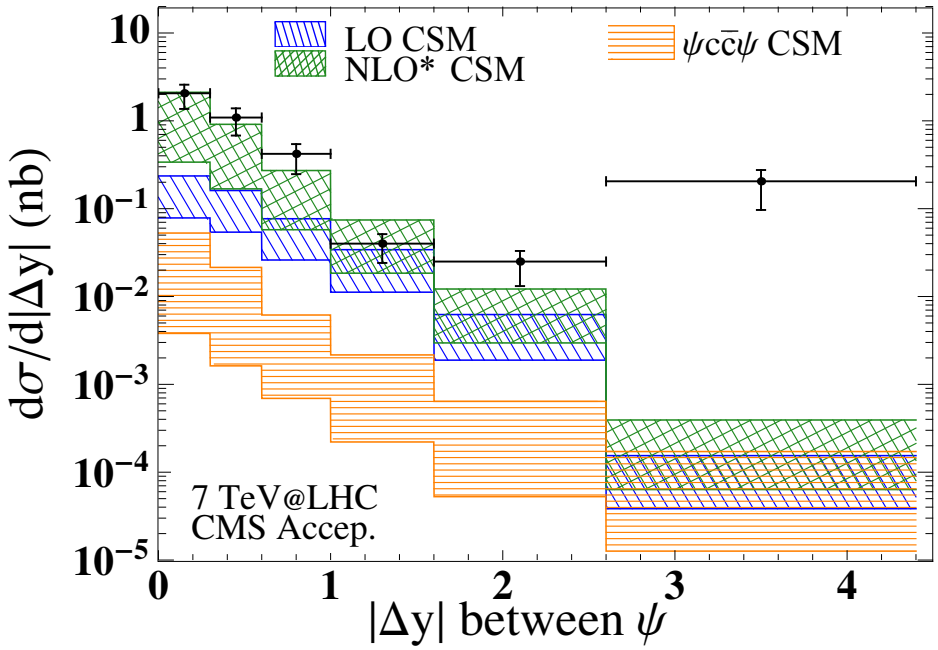

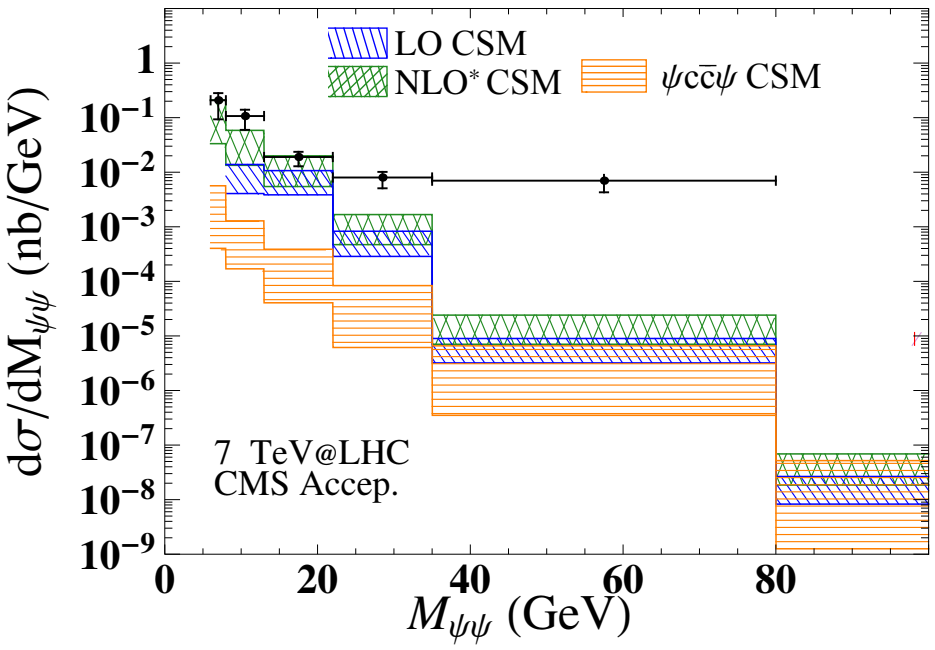

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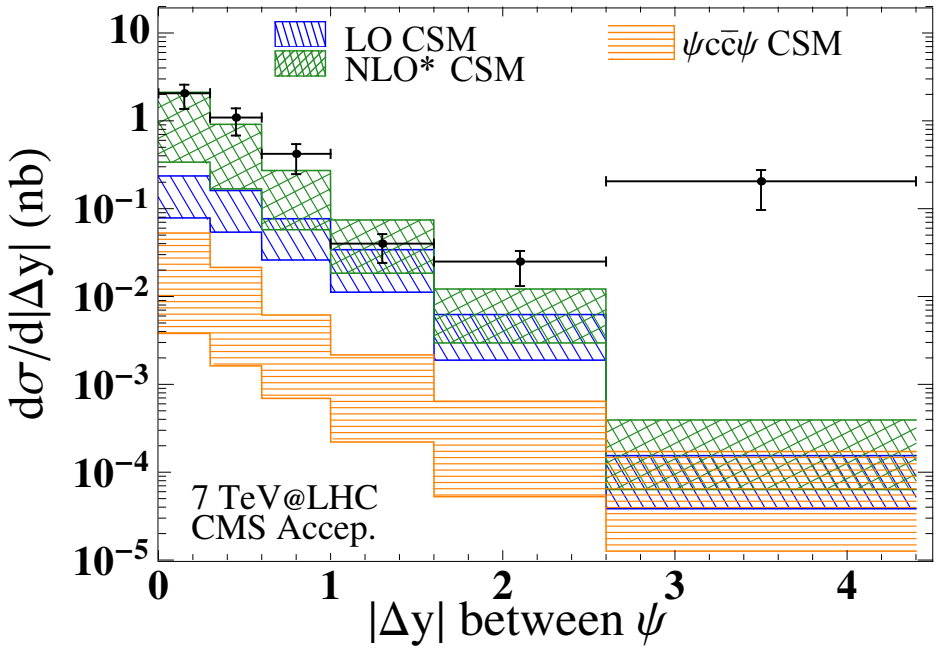

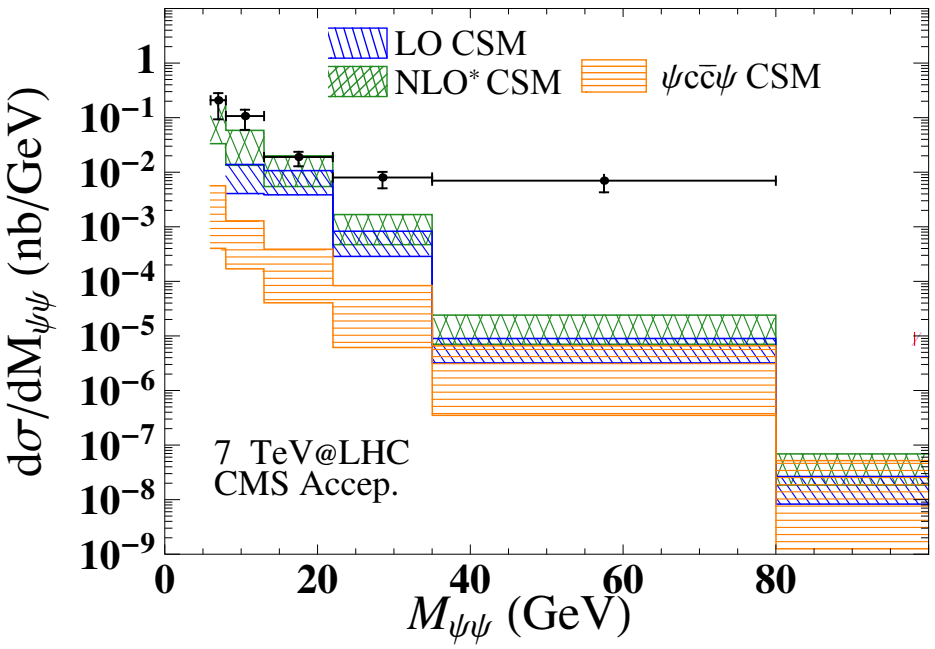

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[At $\Delta y = 3.5$ and $P_T = 6$ GeV, $M_{\psi\psi} \simeq 40$ GeV.]

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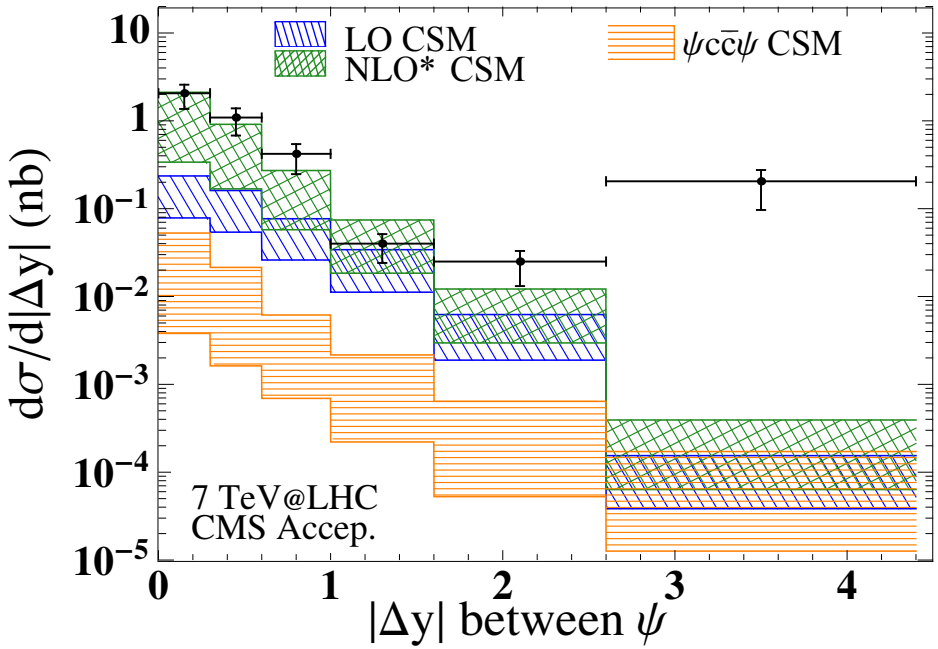

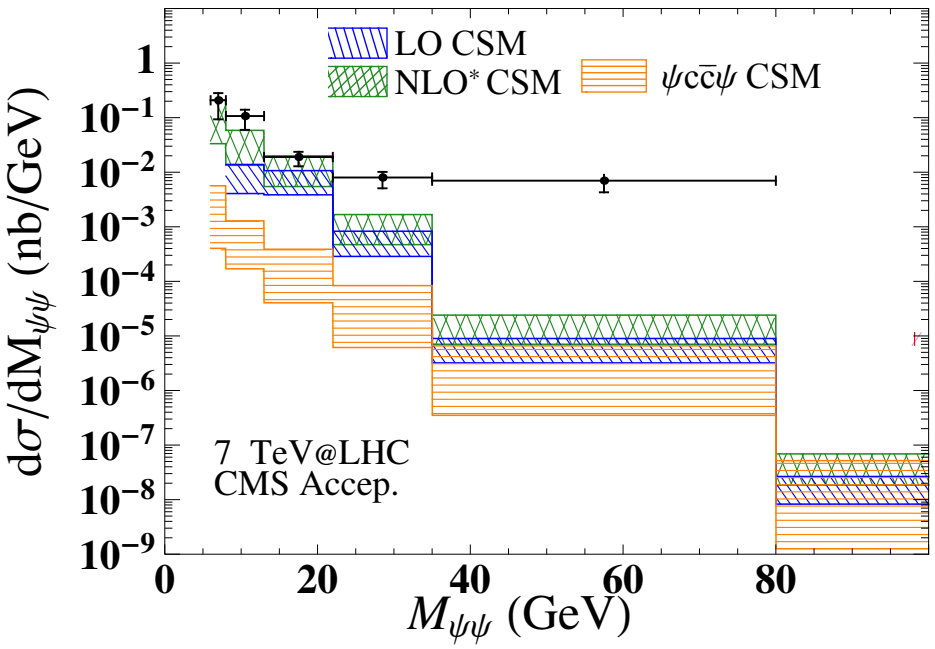

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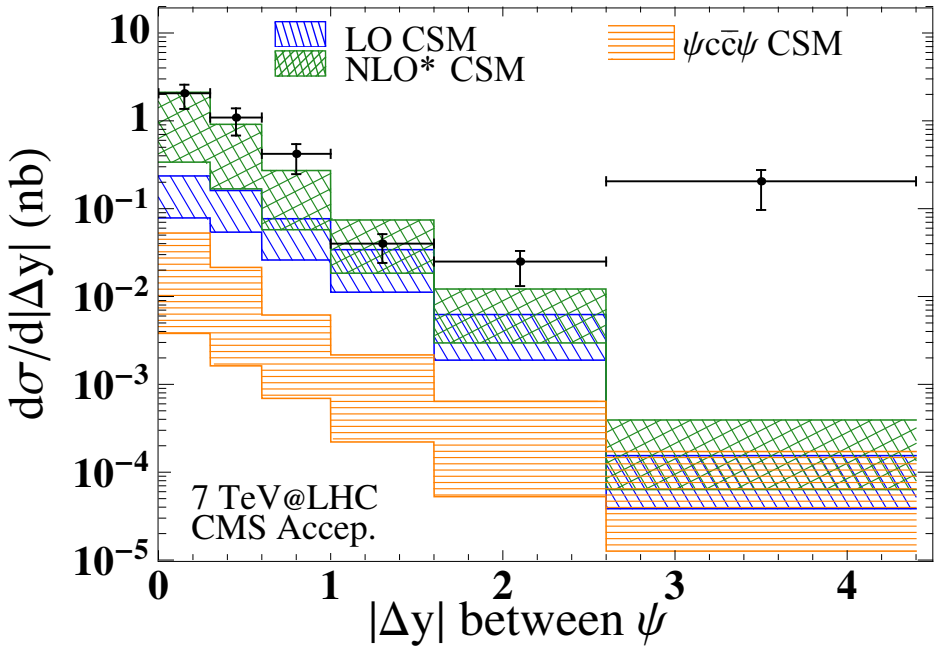

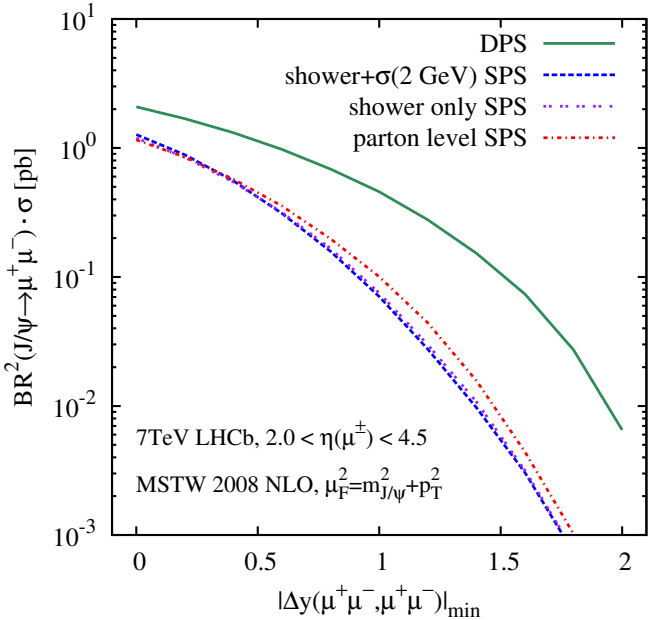

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C.H. Kom, A. Kulesza, W.J. Stirling PRL 107 (2011) 082002

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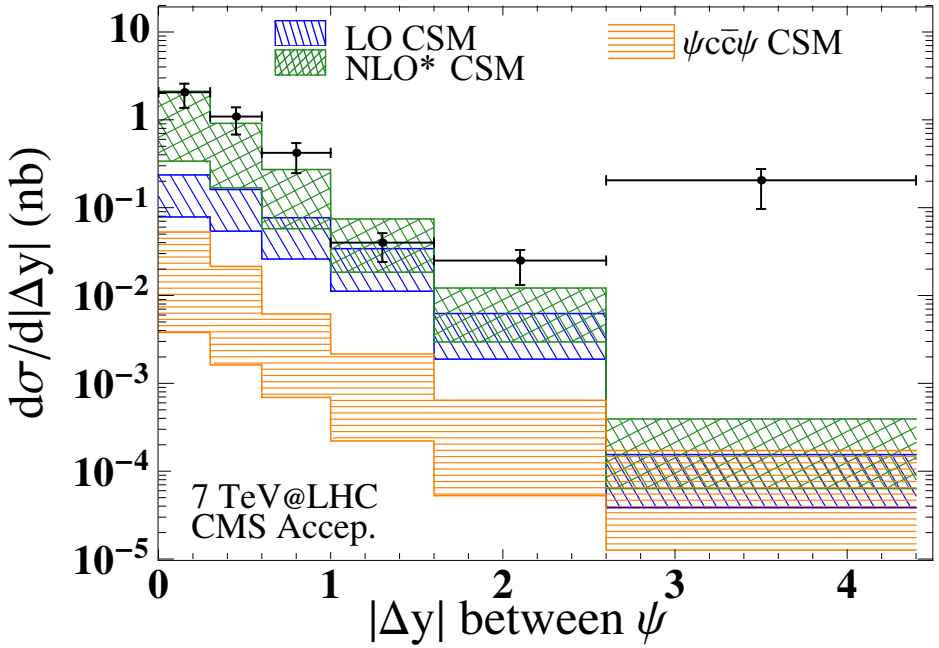

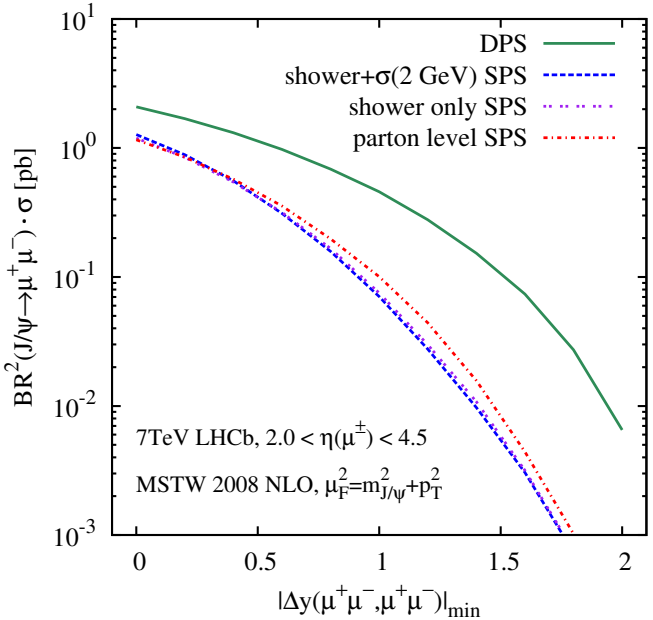

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- He & Kniehl found at LO that CO ≫ CS at large Δy; yet still in disagreement with the data; NLO needed ! — Z. He, B. Kniehl PRL 115, 022002 (2015)

On the importance of double parton scatterings at large Δy I

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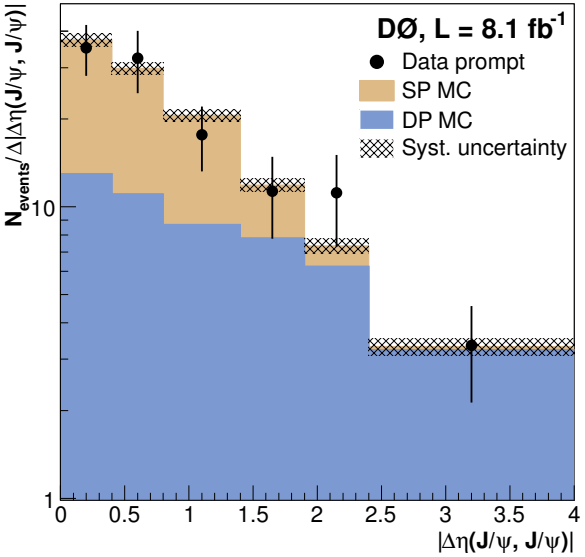

D0 Coll. PRD 90 (2014) 111101

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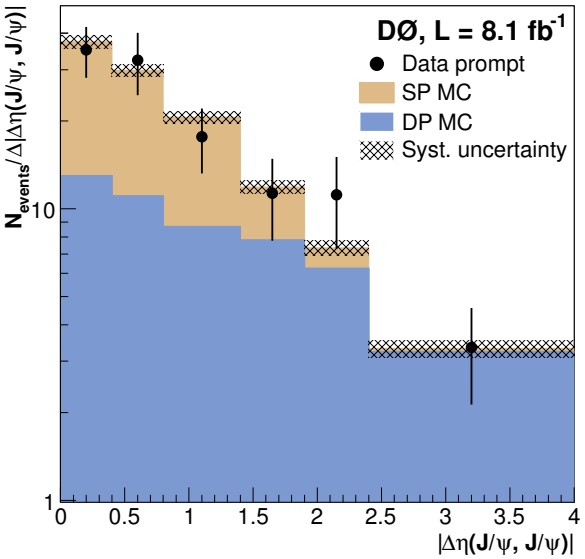

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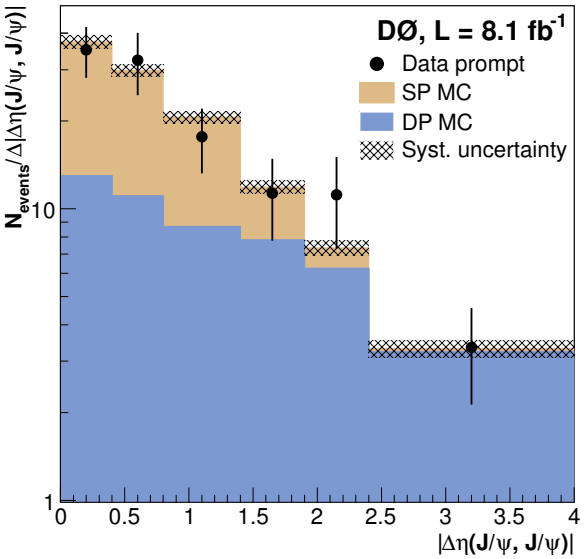

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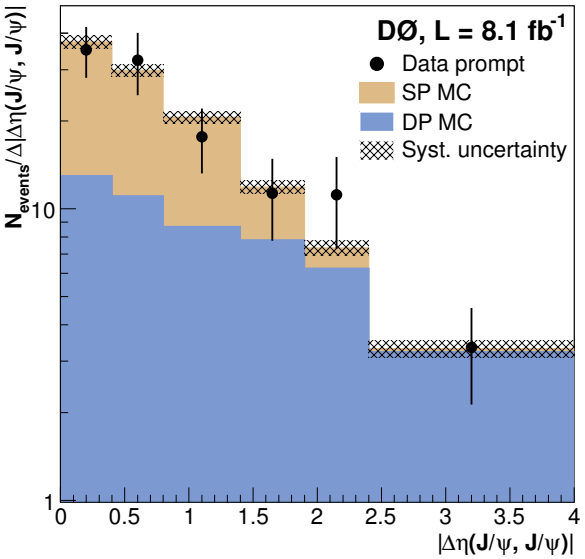

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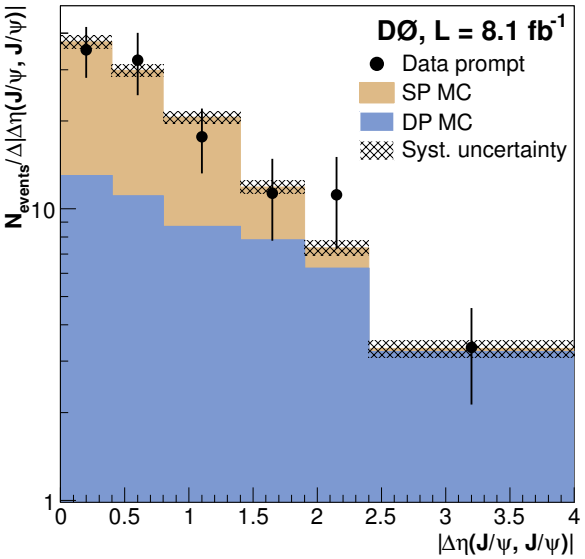

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- A natural question arises: using $\sigma^{\rm DPS} = \frac{1}{2}\frac{\sigma_\psi \sigma_\psi}{\sigma_{\rm eff}}$ and $\sigma_{\rm eff}$ = 4.8 ± 2.5 mb, can one account for the large Δy CMS data ?

On the importance of double parton scatterings at large Δy II

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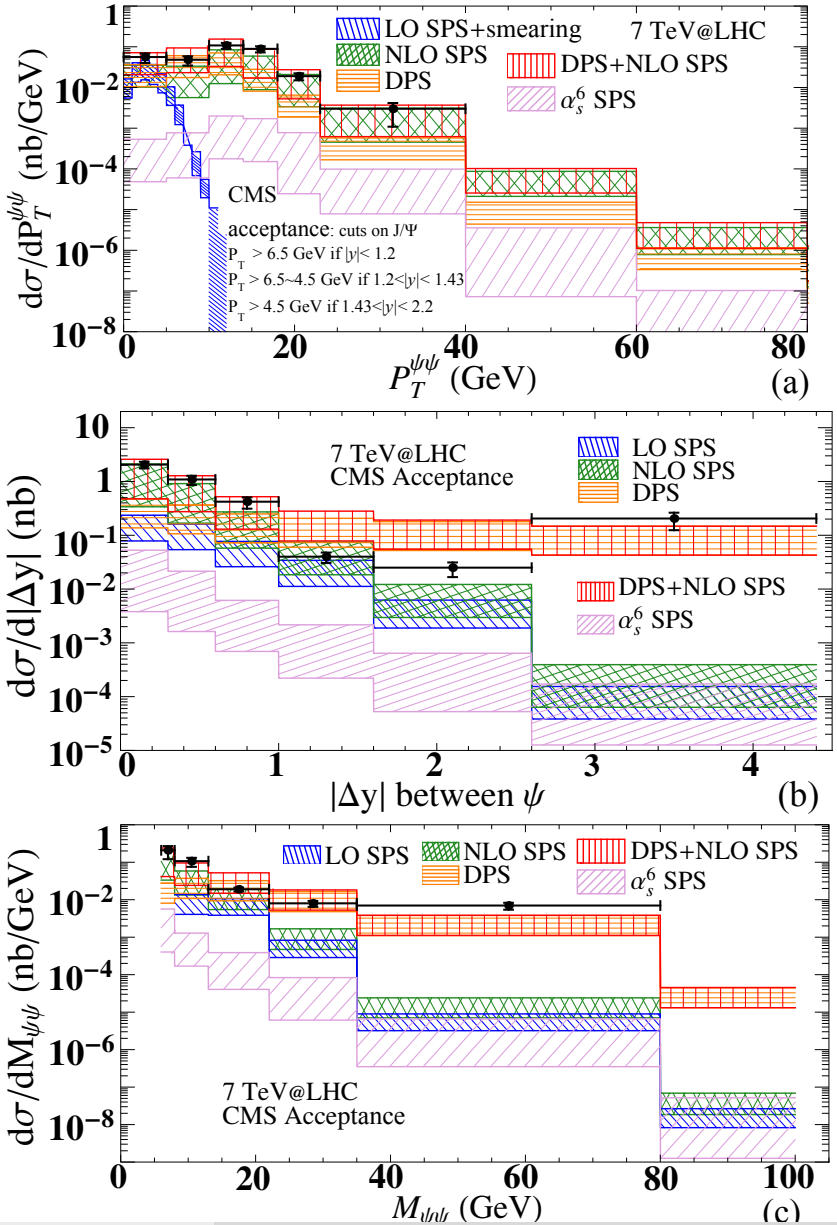

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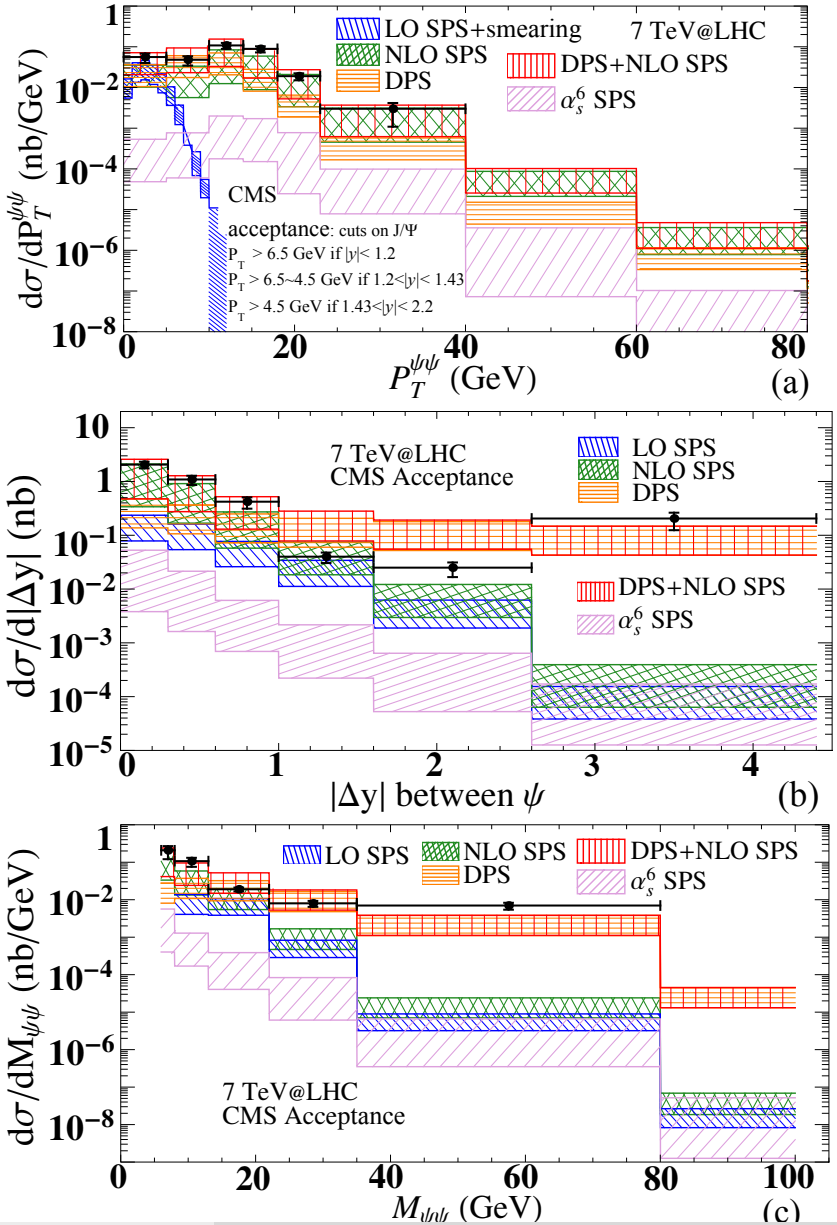

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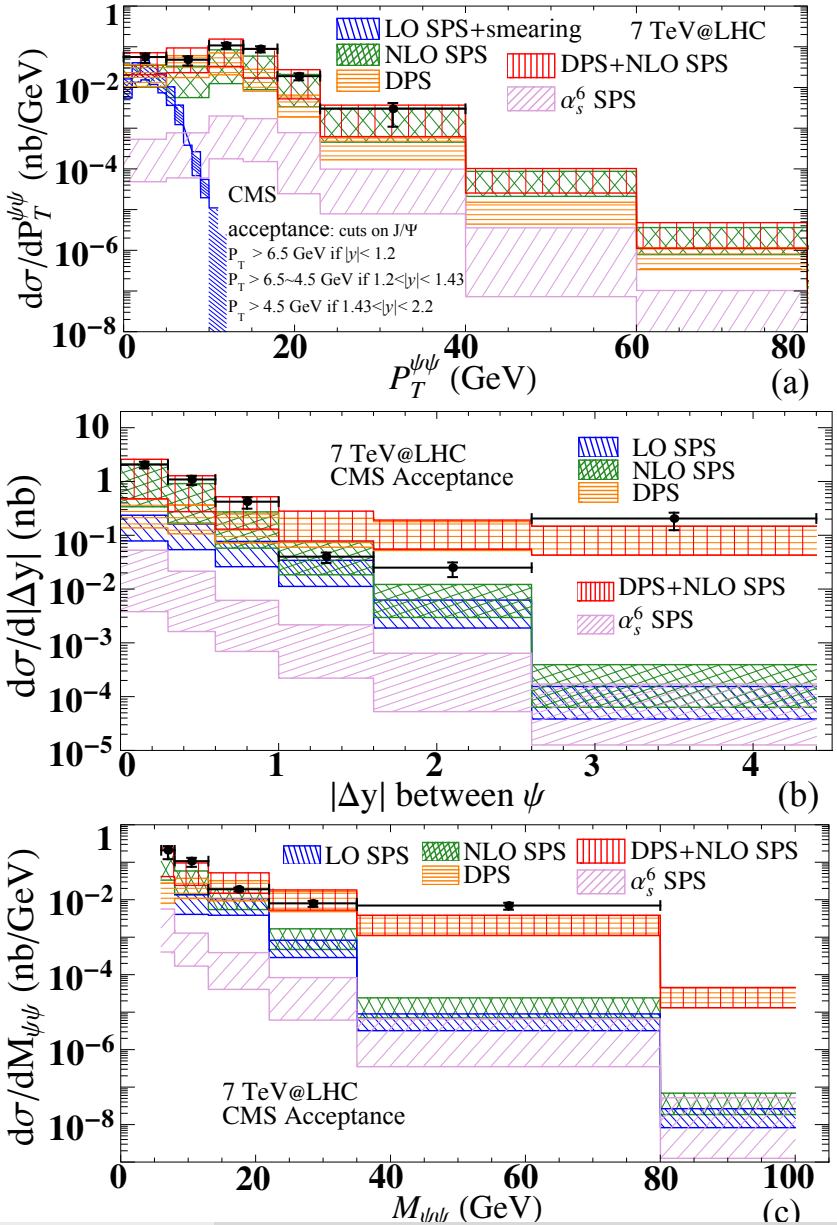
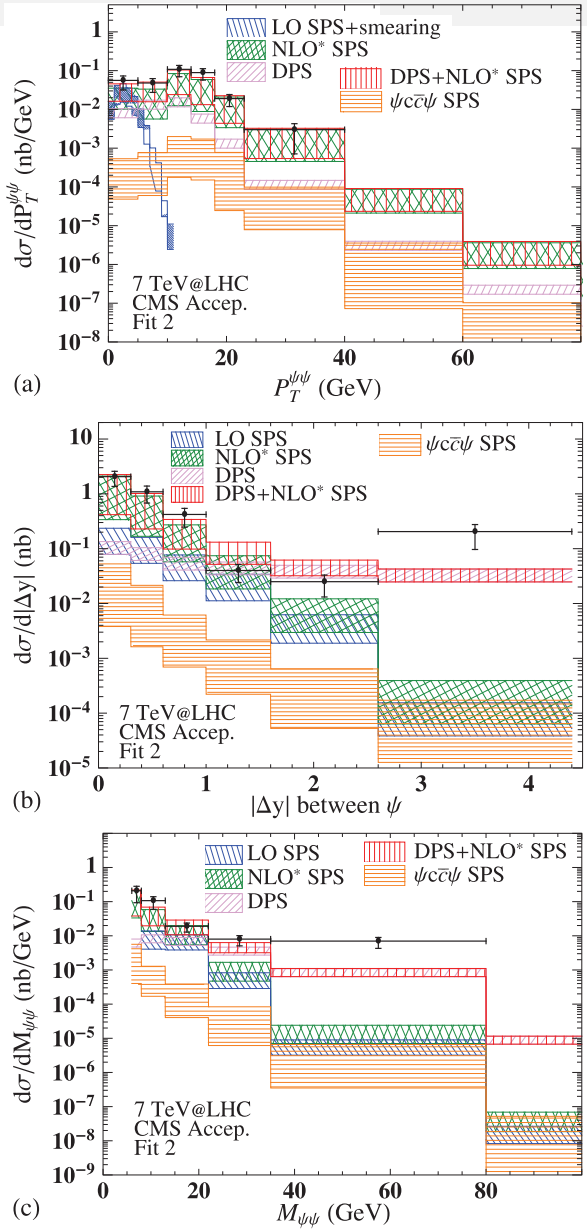


Our fit of the double parton scatterings



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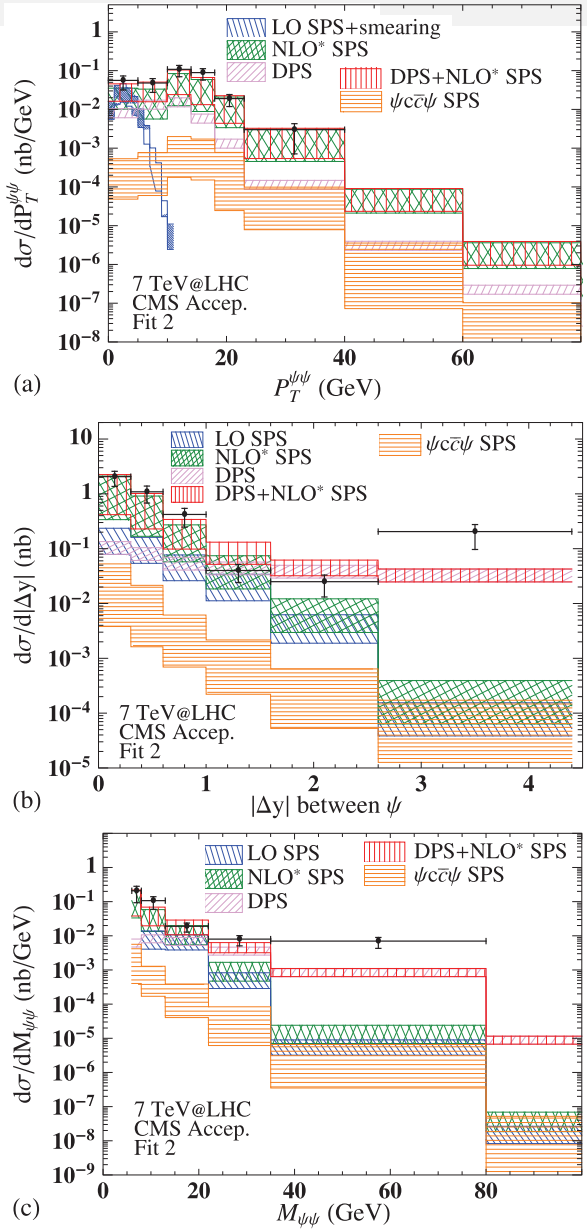

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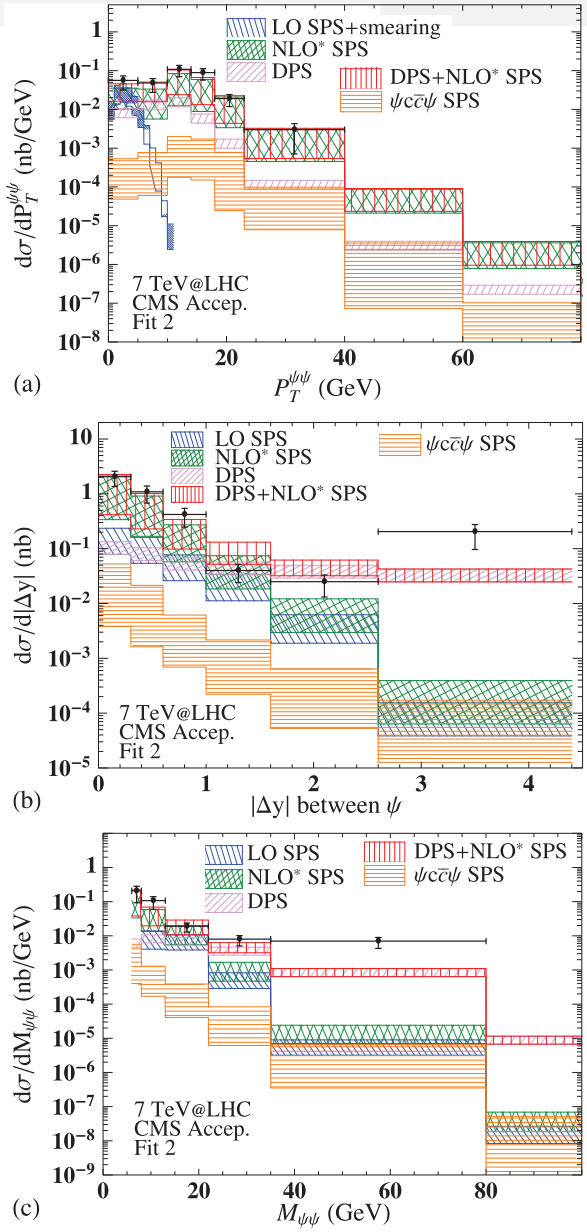

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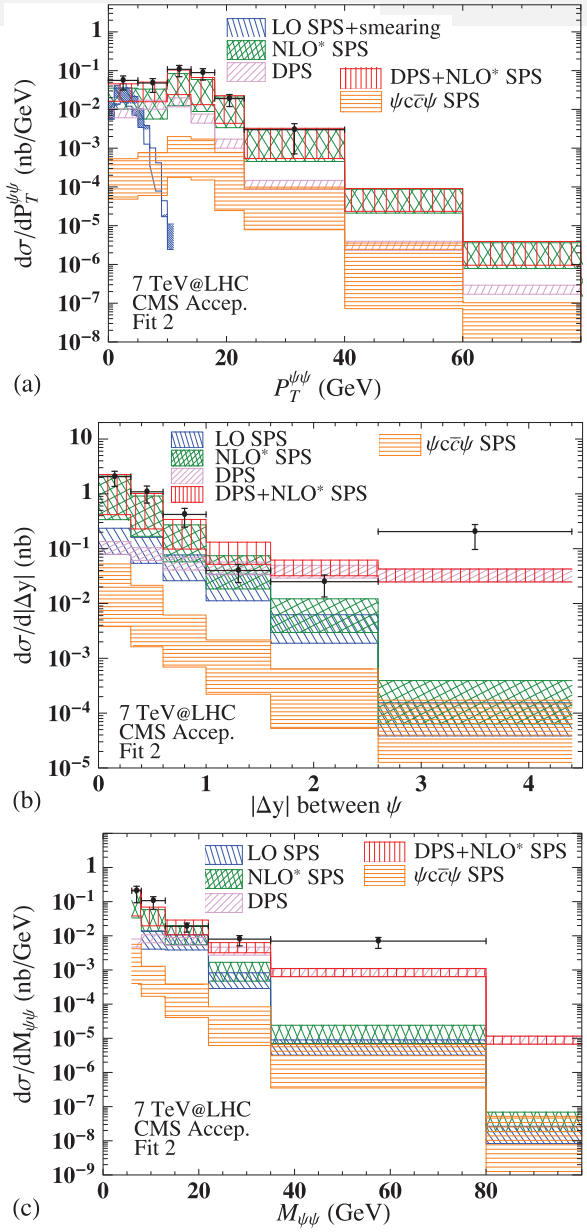

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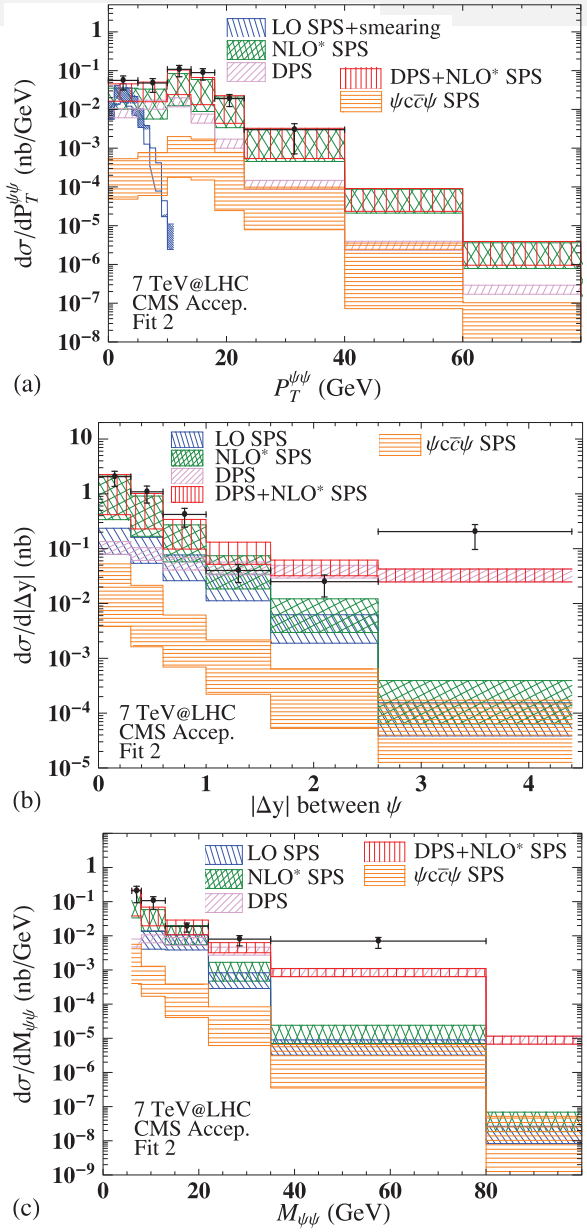

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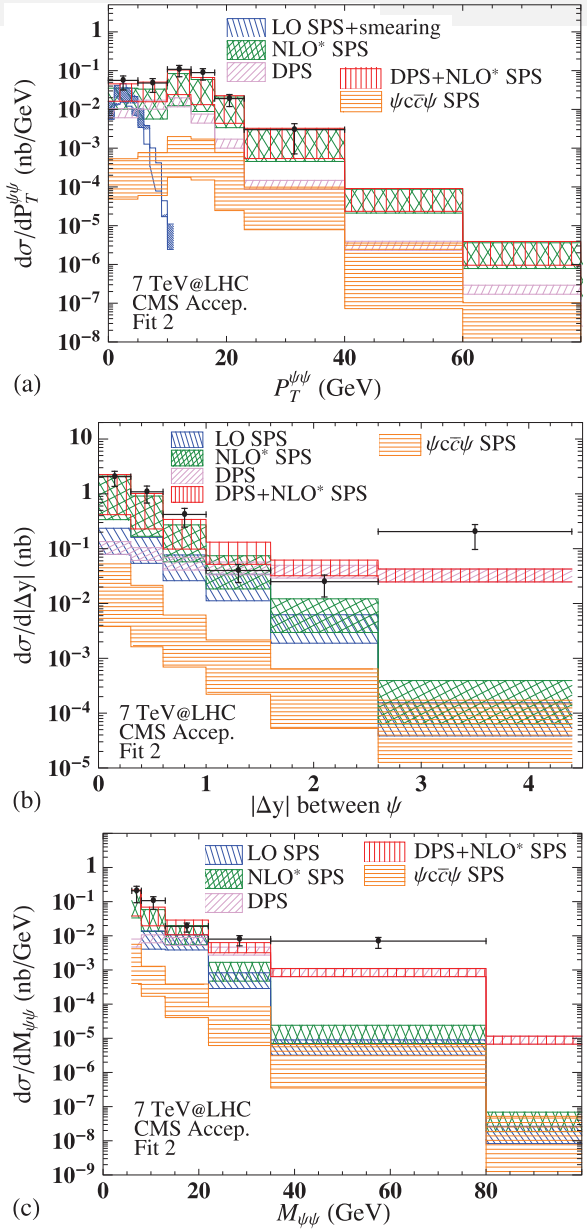
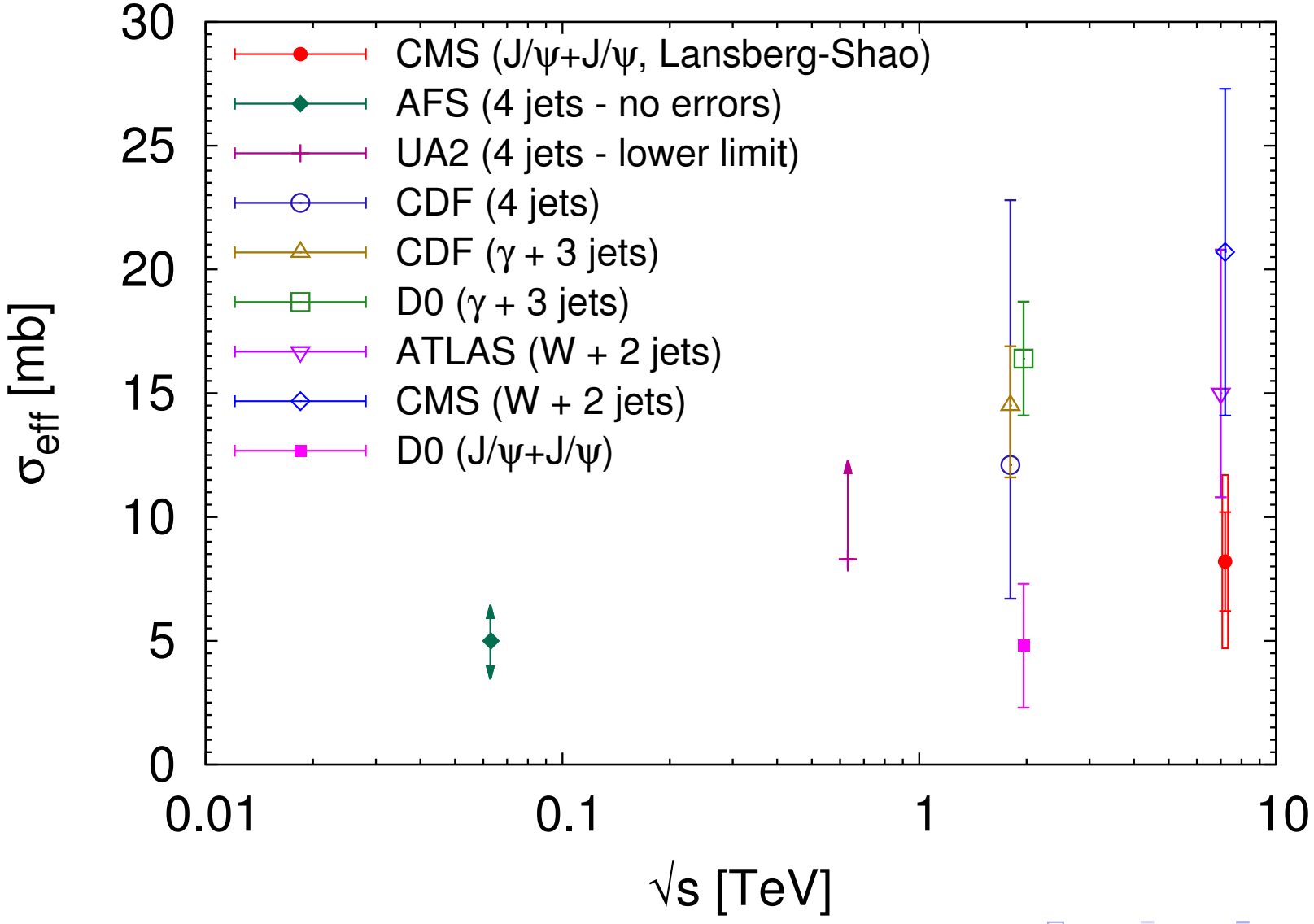
- Best agreement with Fit 3 confirming the consistency: $\sigma_{\rm eff} = 4.8 \pm 2.5$ mb vs $\sigma_{\rm eff} = 5.3 \pm 1.4$ mb



Our fit value for σ_{eff} : 8.2 ± 2.0 ± 2.9 mb



Predictions: excited states

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- Overall :

	(CSM) SPS	DPS
$F^{\psi'}_{\psi\psi}$	45%	20%
$F^{\chi_c}_{\psi\psi}$	small	50%

Part II

$J/\psi + Z$ production

ATLAS analyses

ATLAS analyses

- Following the pioneering searches by CDF, for the first time
  ATLAS recently observed associated production of $J/\psi + W$ and $J/\psi + Z$

CDF Coll., PRL 90 (2003) 221803; PRD 91 (2015) 052011
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- The discrepancy is largest for $J/\psi + Z$, which I discuss now

based on JPL, H.S. Shao arXiv:1608.03198 [hep-ph]

The ATLAS puzzle

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- Assuming a DPS yield with $\sigma_{\text{eff}} = 15$ mb (because of their 4 jet analysis)

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{}^{\text{prompt}}R^{\text{DPS subtracted}}_{J/\psi+Z} &= \mathcal{B}(J/\psi \to \mu^+\mu^-)\,\sigma(pp \to Z + J/\psi)/\sigma(pp \to Z) \\
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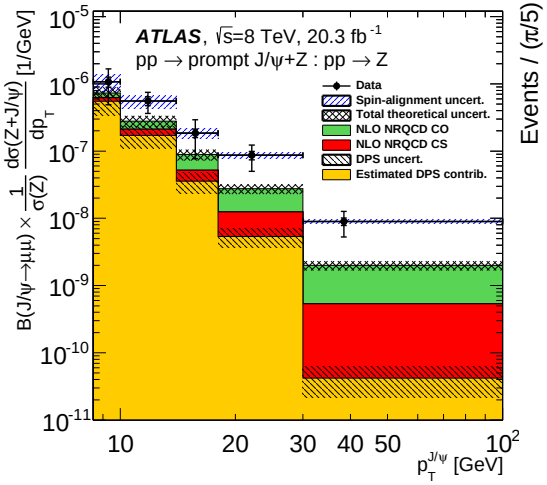

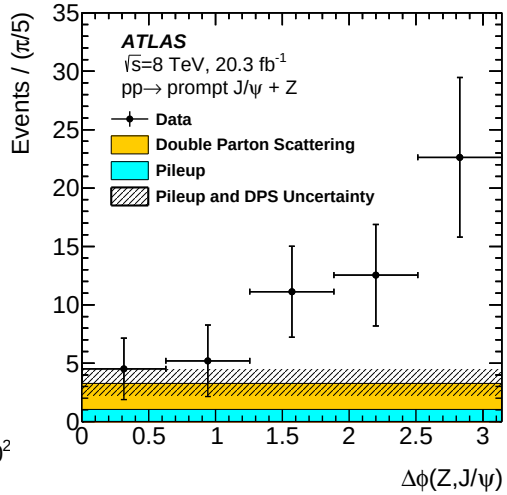

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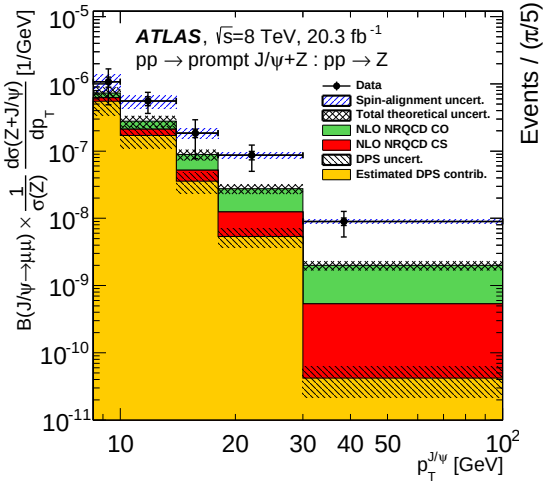

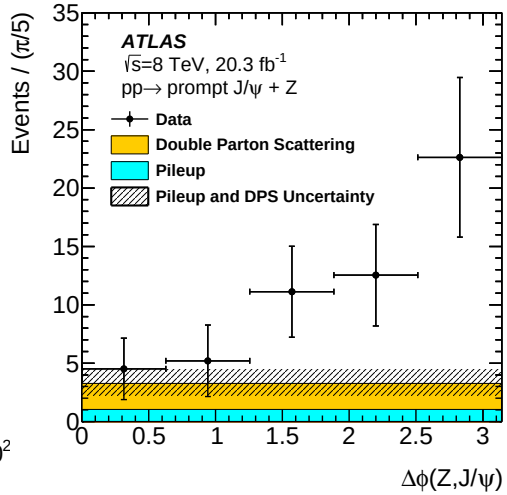

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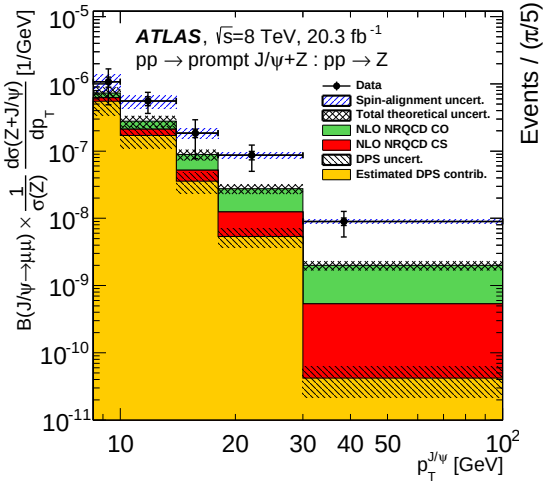

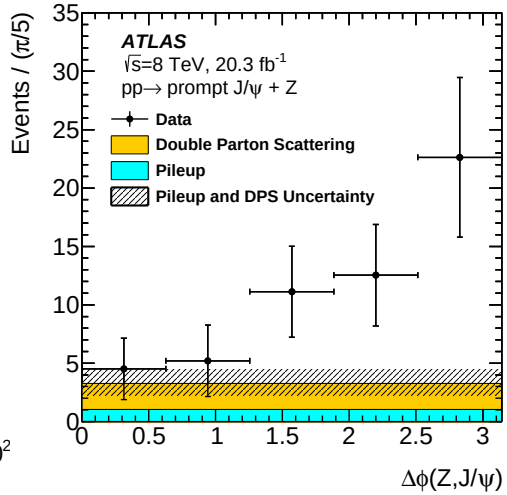

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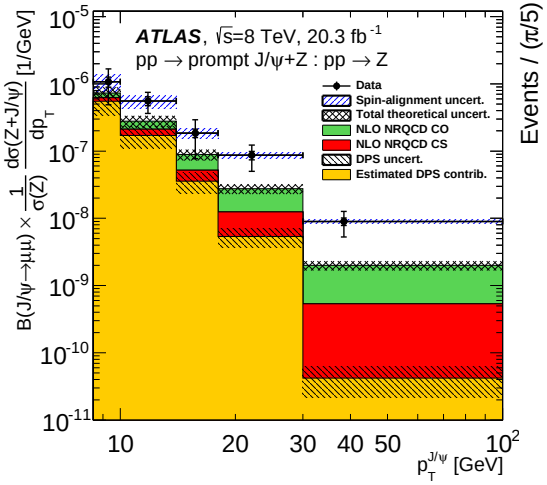

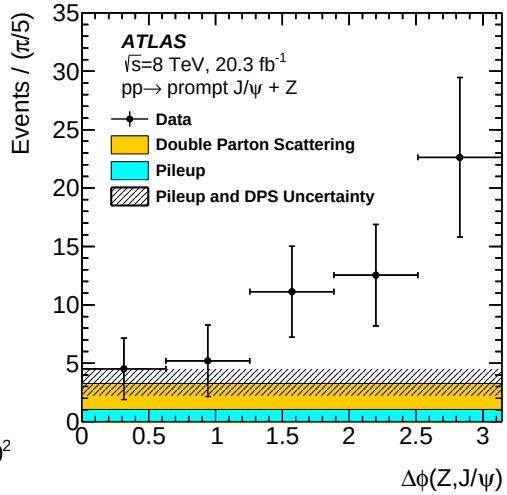

  - A priori, the $\Delta\phi$ distribution hints at a significant SPS yield (peak at π)
  - Gap opening at large P_T^ψ
- We have thus decided to re-analyse the SPS theory with the Colour-Evaporation Model (CEM) which usually overshoots data at large P_T^ψ ($\leftrightarrow$ upper SPS limit)

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- This gives a 2-σ discrepancy with a DPS contribution set by $\sigma_{\text{eff}} = 15$ mb

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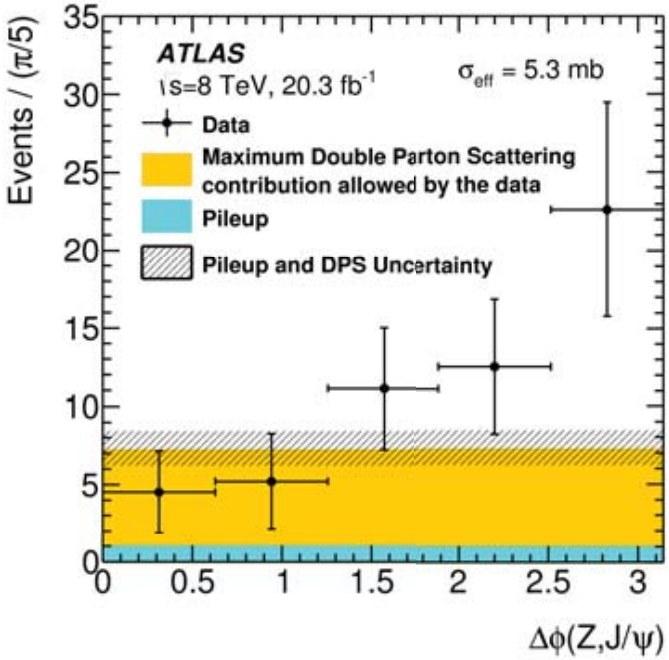

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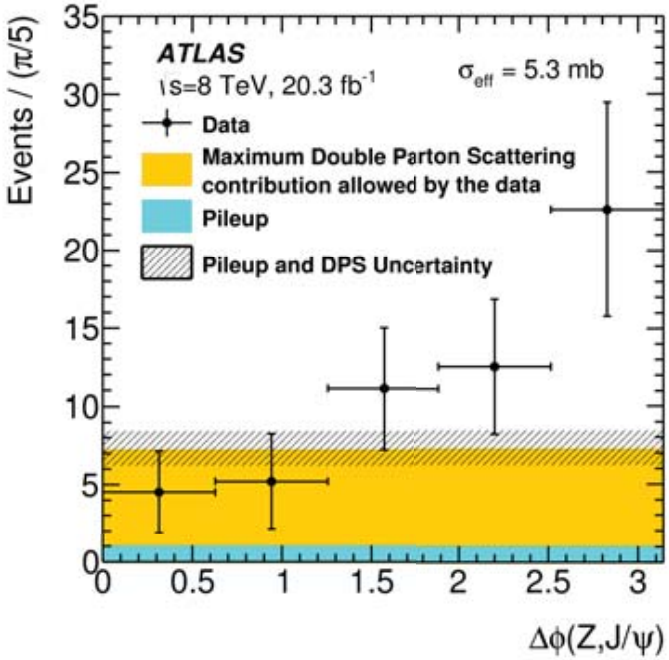

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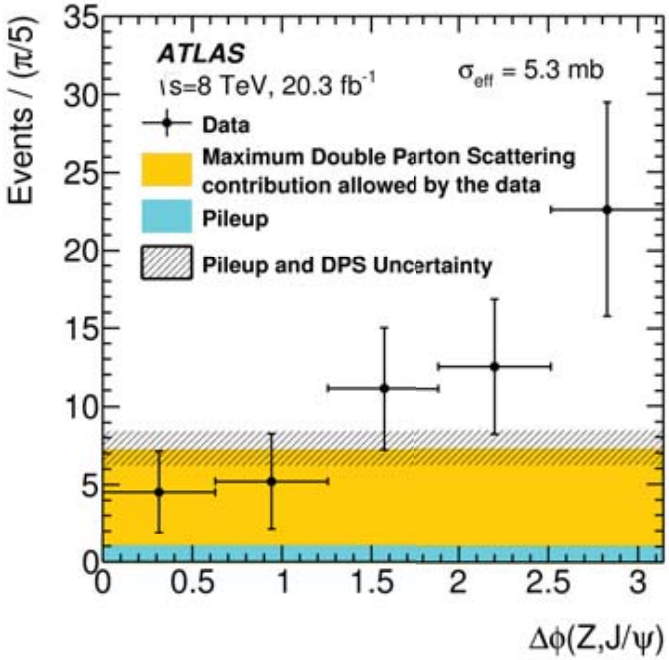

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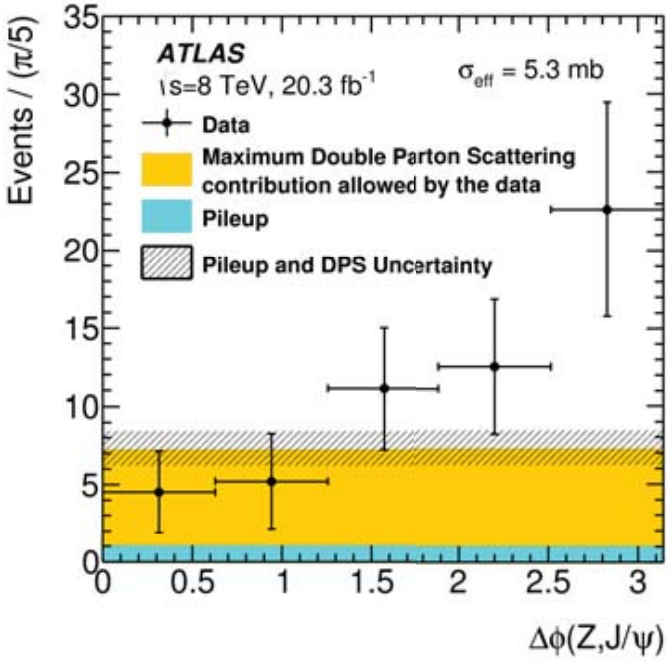

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- What about the azimuthal spectrum if the SPS yield is 1/6 of the ATLAS yield ?

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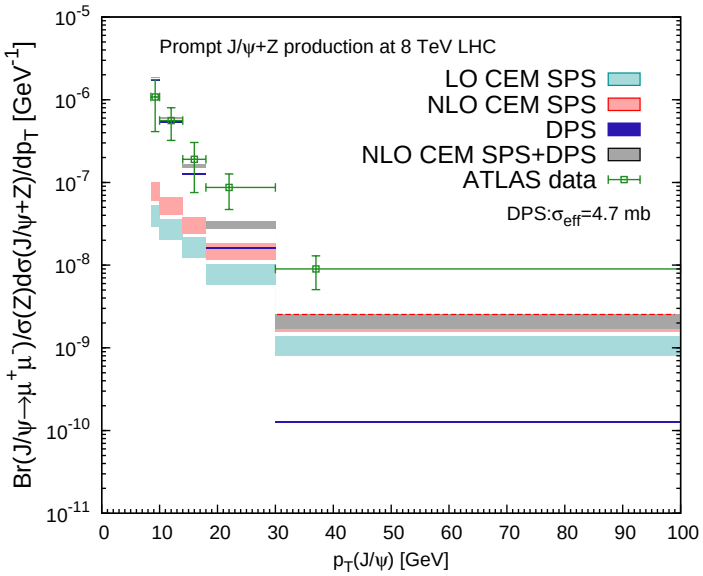

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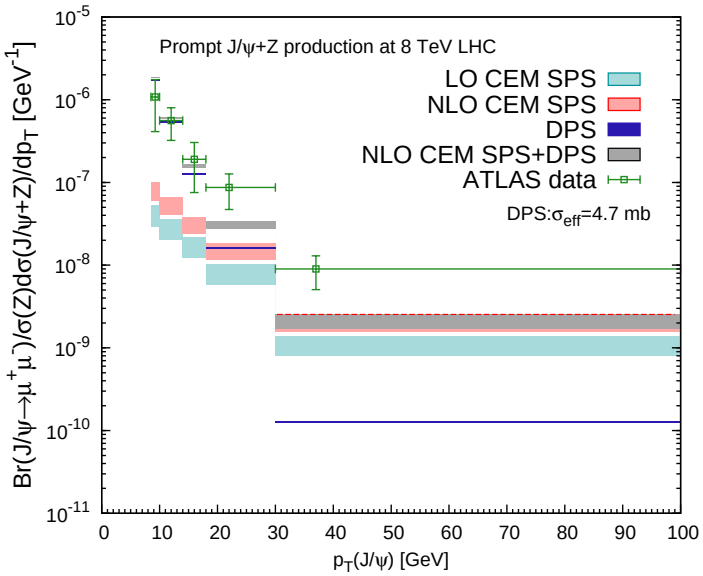

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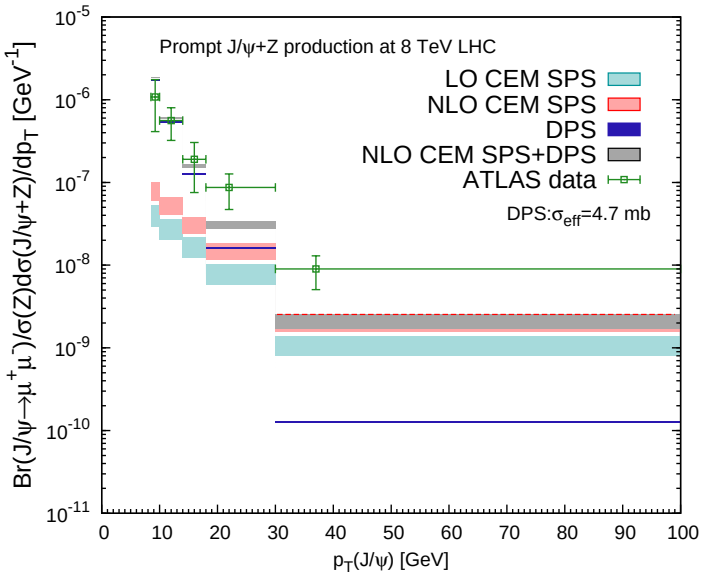

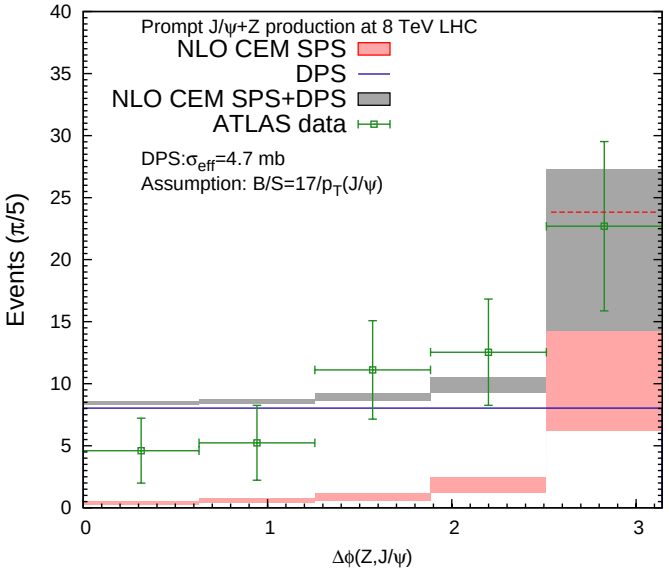

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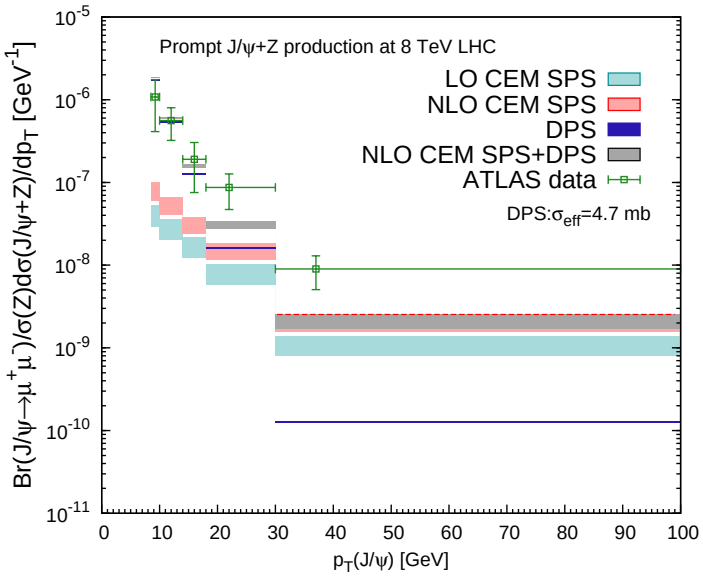

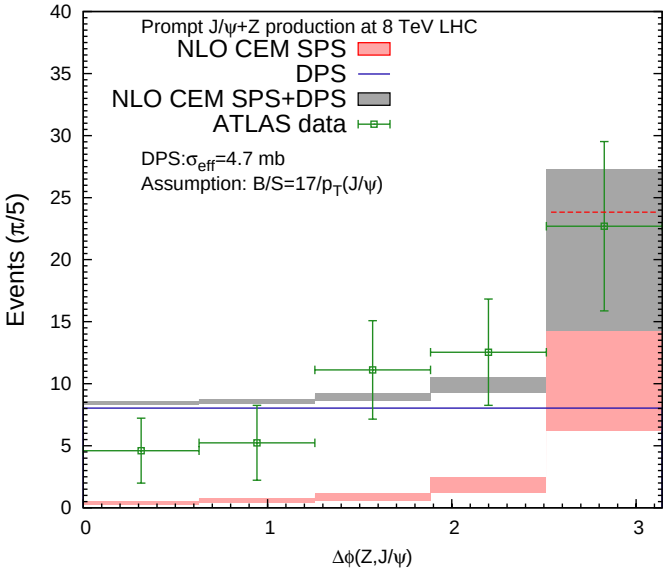

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- The last plot has been made by folding our DPS and SPS cross sections by an estimation of the ATLAS efficiency, and **it works.**

Part III

Conclusion

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ICHEP NEWS : Confirmation by the recent ATLAS study using our predictions: ATLAS-CONF-2016-047

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  ICHEP NEWS : Confirmation by the recent ATLAS study using our predictions: ATLAS-CONF-2016-047

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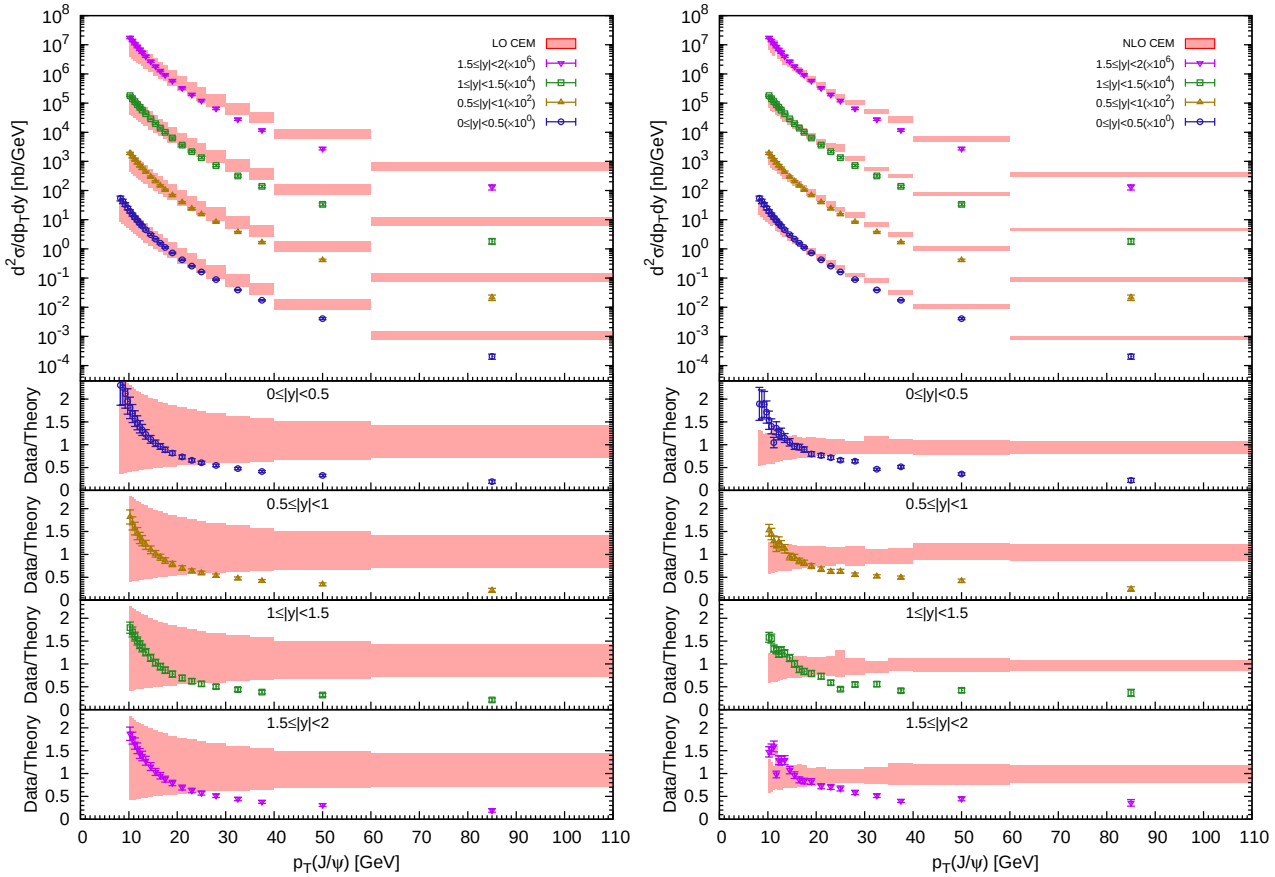
  D0 PRL 116 (2016) 082002 + H.S. Shao - Y. J. Zhang PRL 117 (2016) 062001

Part IV

Back-up slides

CEM results for single J/ψ



Comparison between the ATLAS data (EPJC 76 (2016) 283)and the CEM results for $d\sigma/dy/dP_T$ of J/ψ + a recoiling parton at (left) LO and (right) NLO at $\sqrt{s}$ = 8 TeV. [The theoretical uncertainty band is from the scale variation.]

On the (non-)importance of CO channels for di-J/ψ

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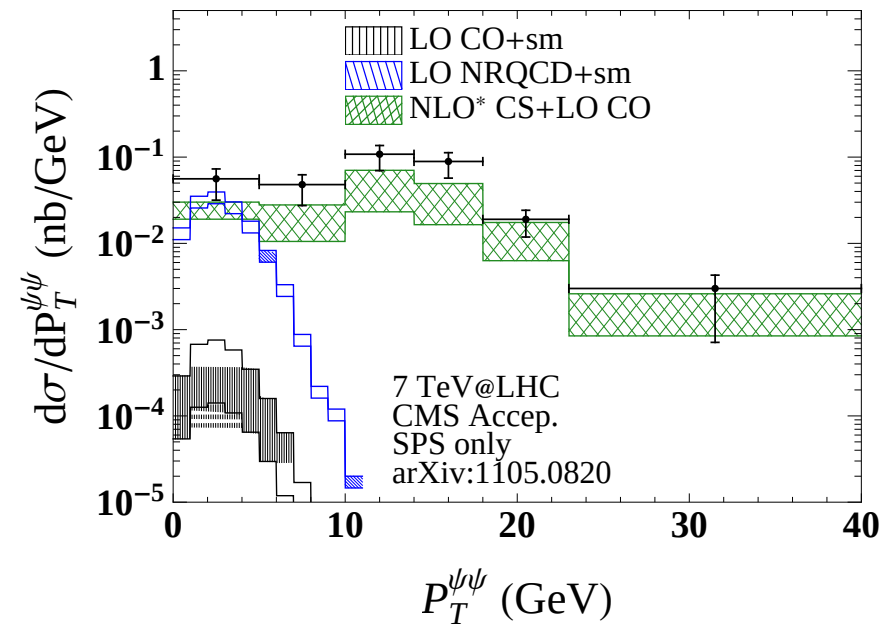

Single J/ψ LDME fit: M. Butenschoen, B. Kniehl arXiv:1105.0820, PRD 84 (2011) 0515

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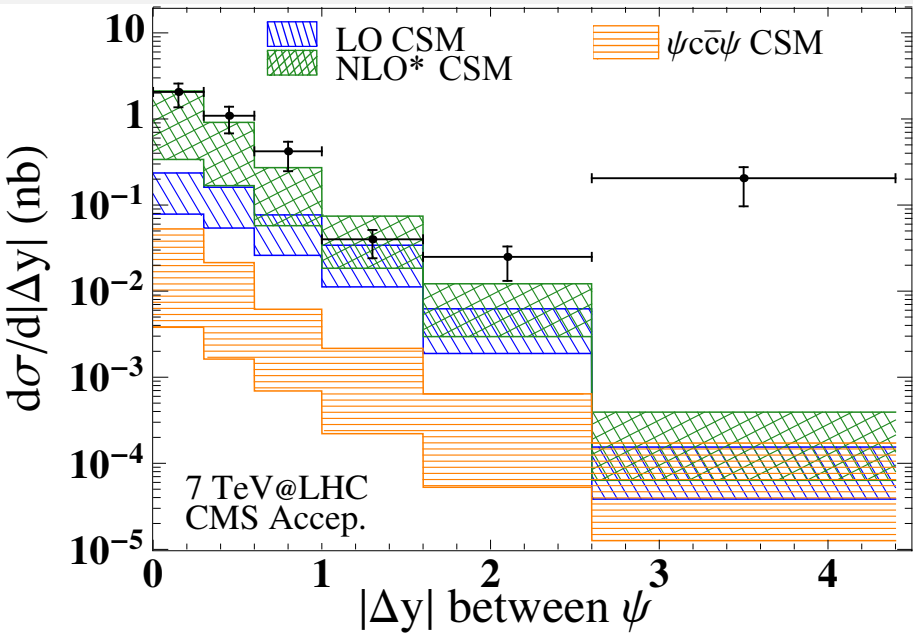

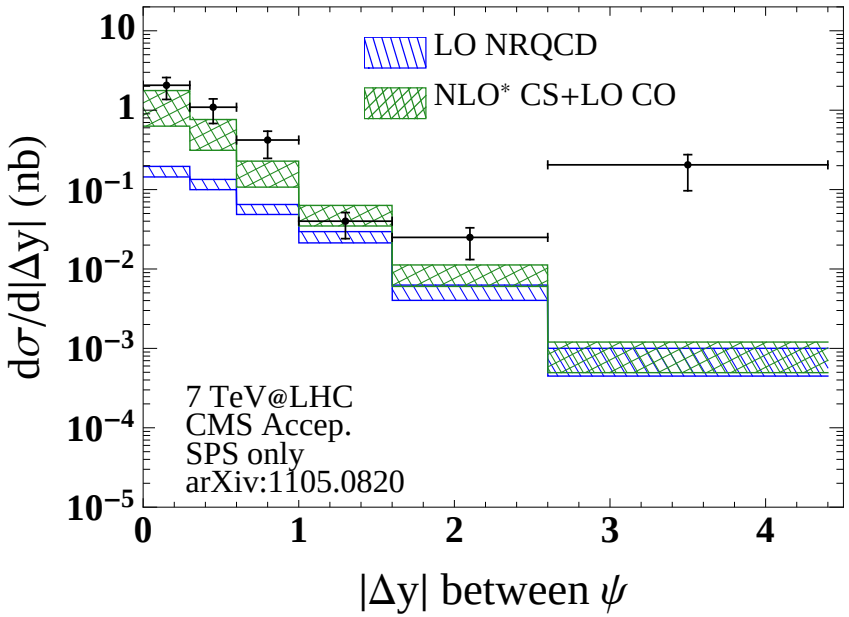

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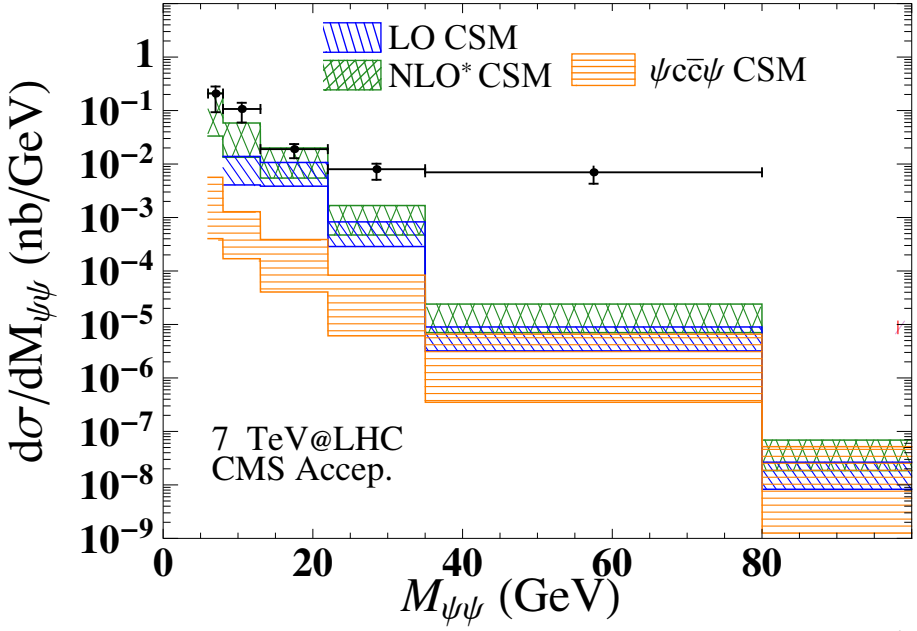

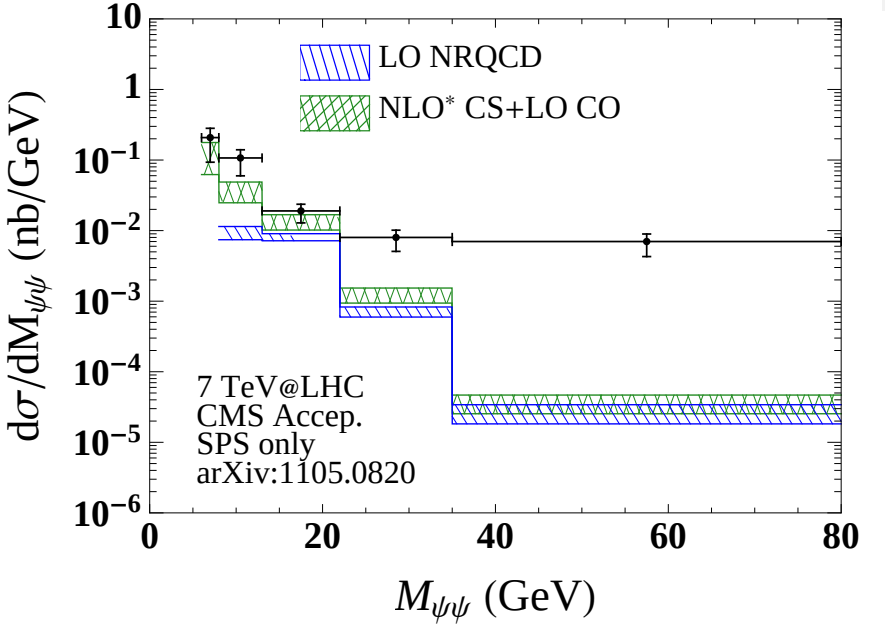

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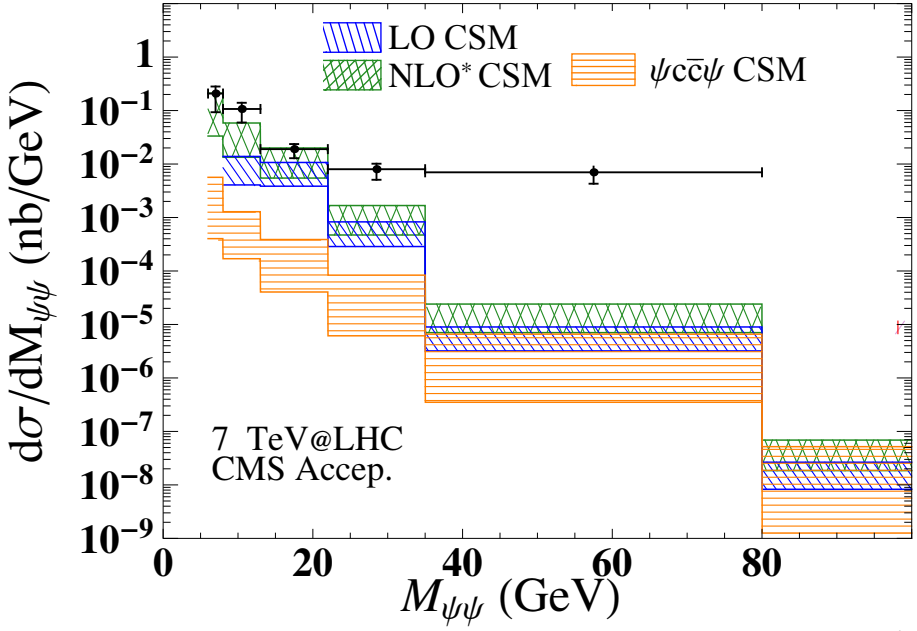

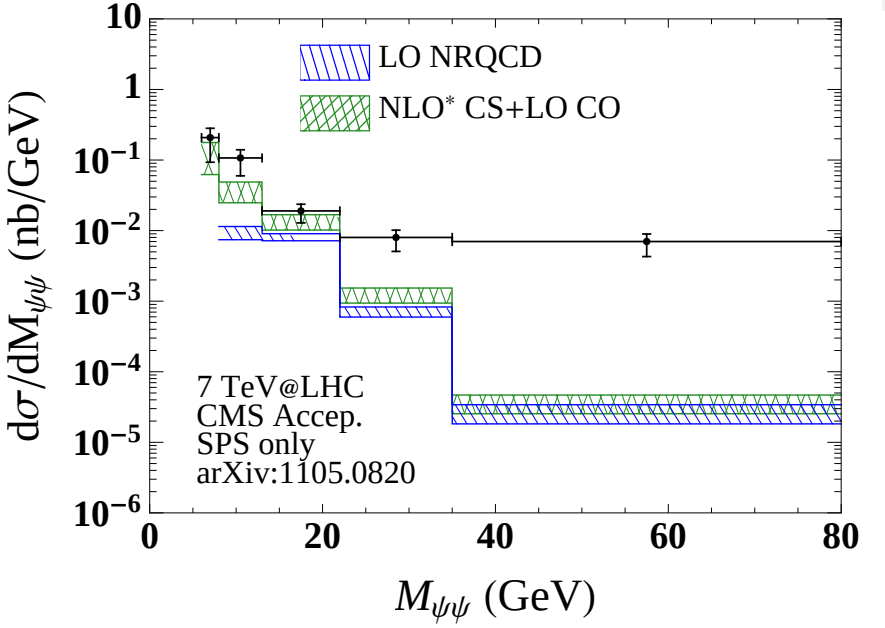

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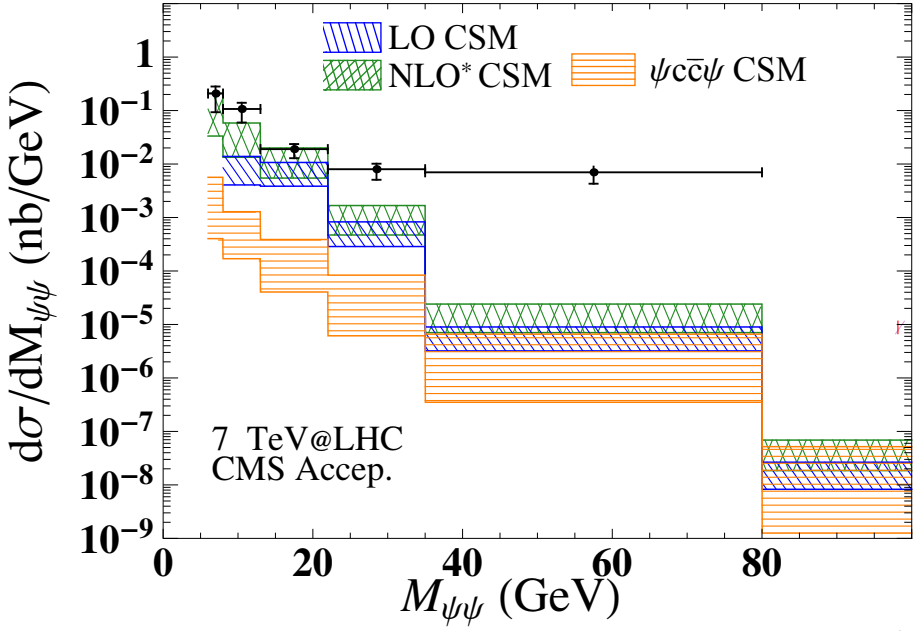

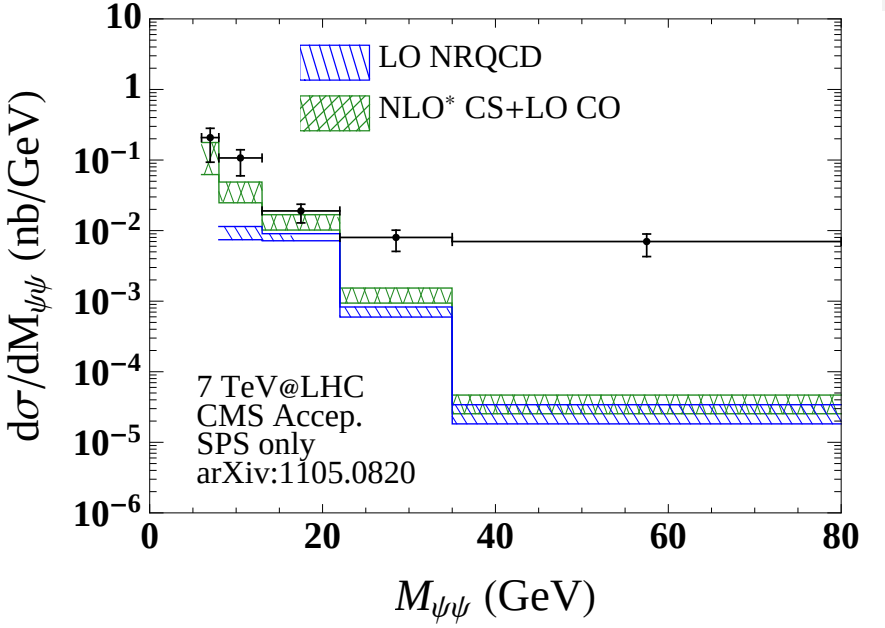

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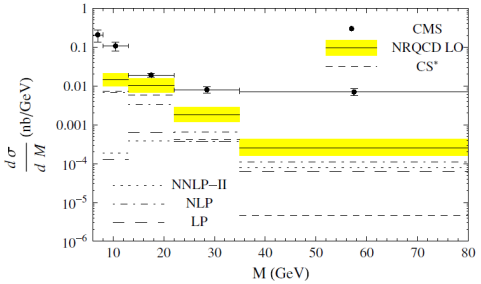

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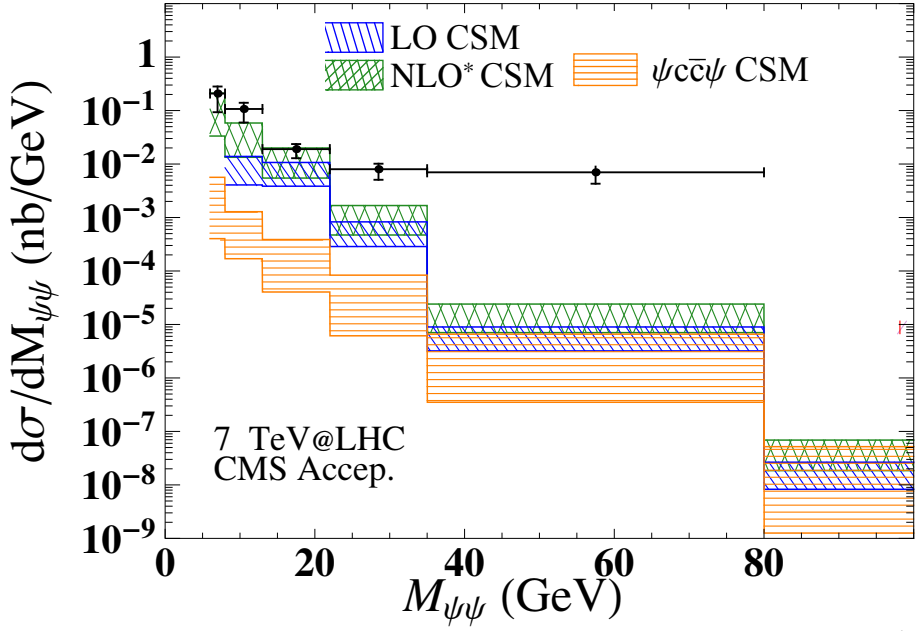

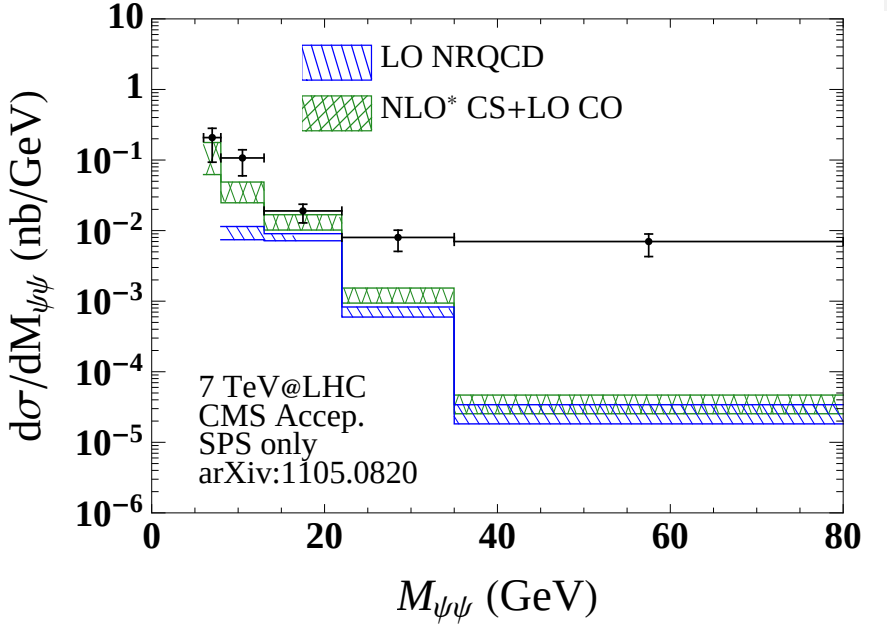

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- In terms of $\chi^2_{\mathrm{d.o.f}}$:

	LO CO+ NLO* CSM w/o DPS	NLO* CSM w DPS
$\chi^2_{\mathrm{d.o.f}}$	3.0	1.9

Another way to see this with 2 CO channels

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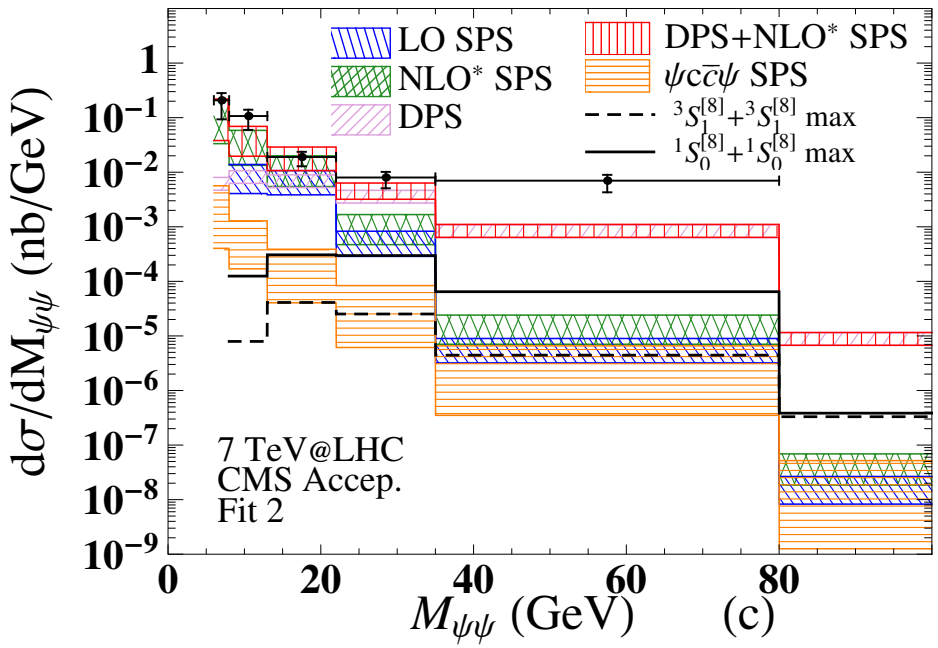

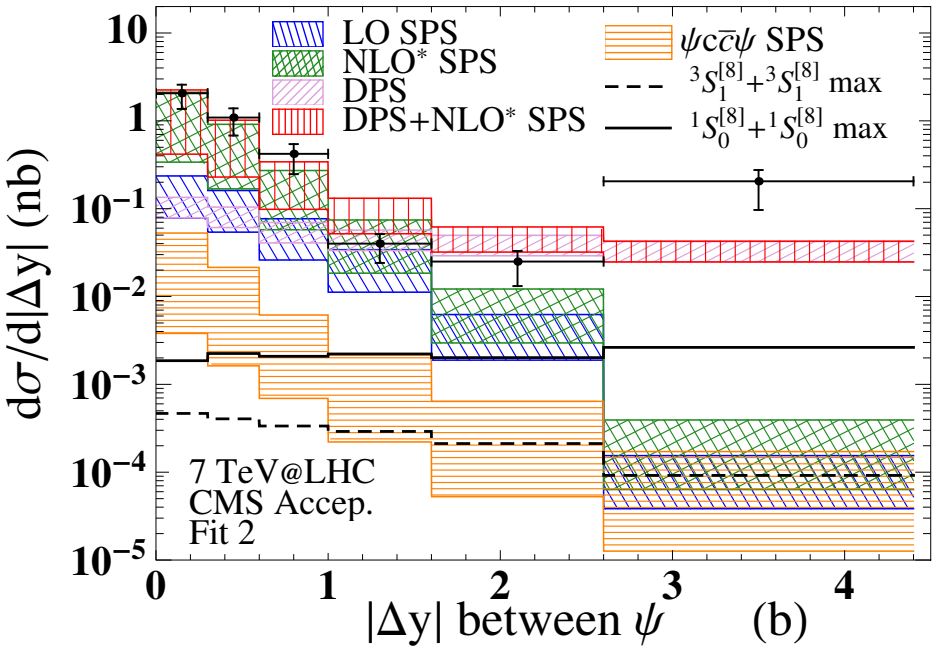

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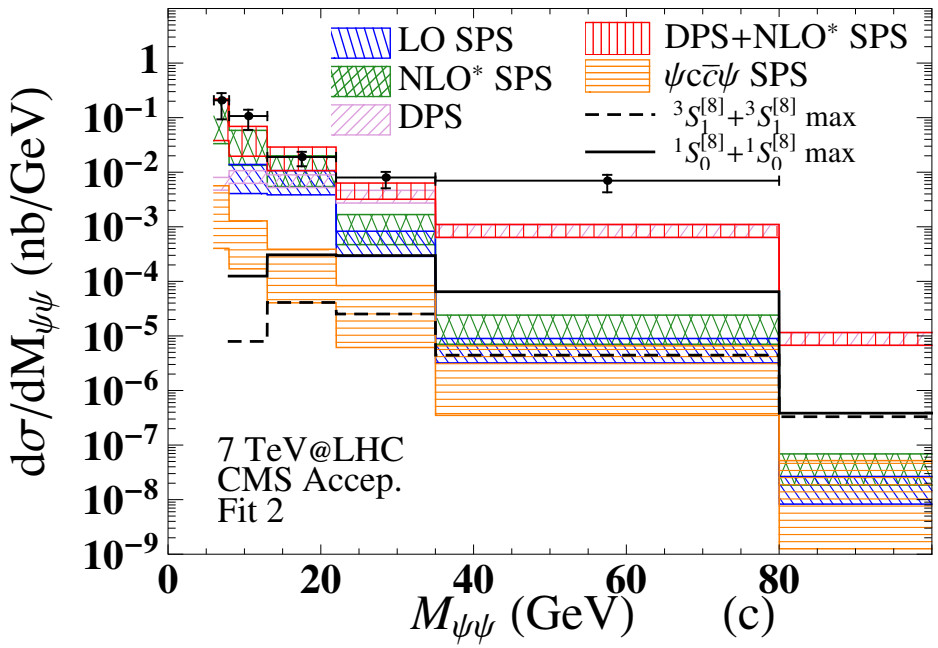
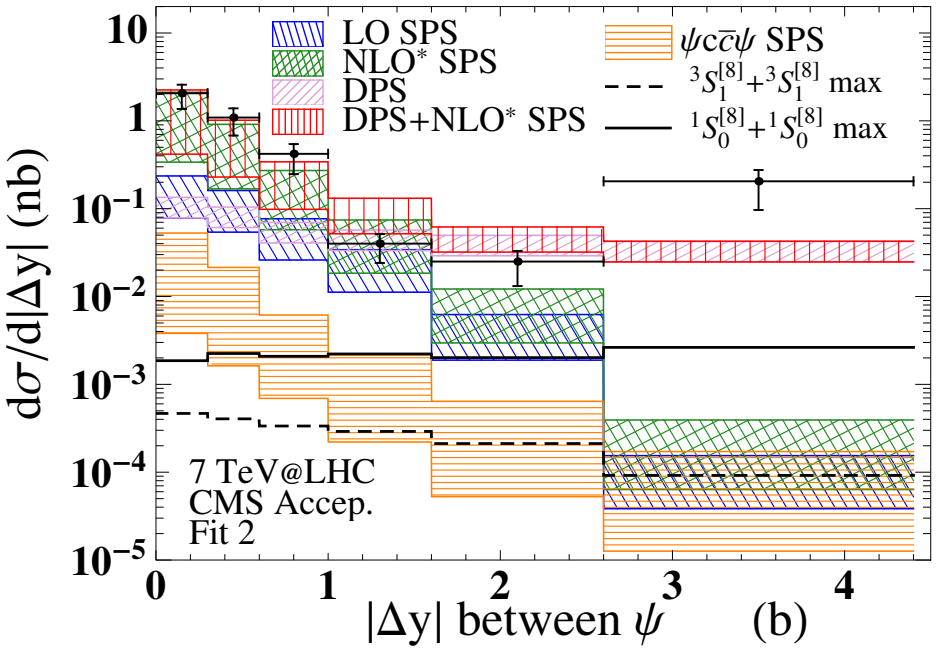
  [see the solid and dashed black lines]

JPL, H.-S.Shao PLB 751 (2015) 479

Another way to see this with 2 CO channels





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  JPL, H.-S.Shao PLB 751 (2015) 479
- Nota: η_c data : $\langle^{J/\psi}(^1S_0^{[8]})\rangle = \langle^{\eta_c}(^3S_1^{[8]})\rangle < 1.46\times10^{-2}$ GeV^3

H. Han *et al.*PRL 114 (2015) 092005

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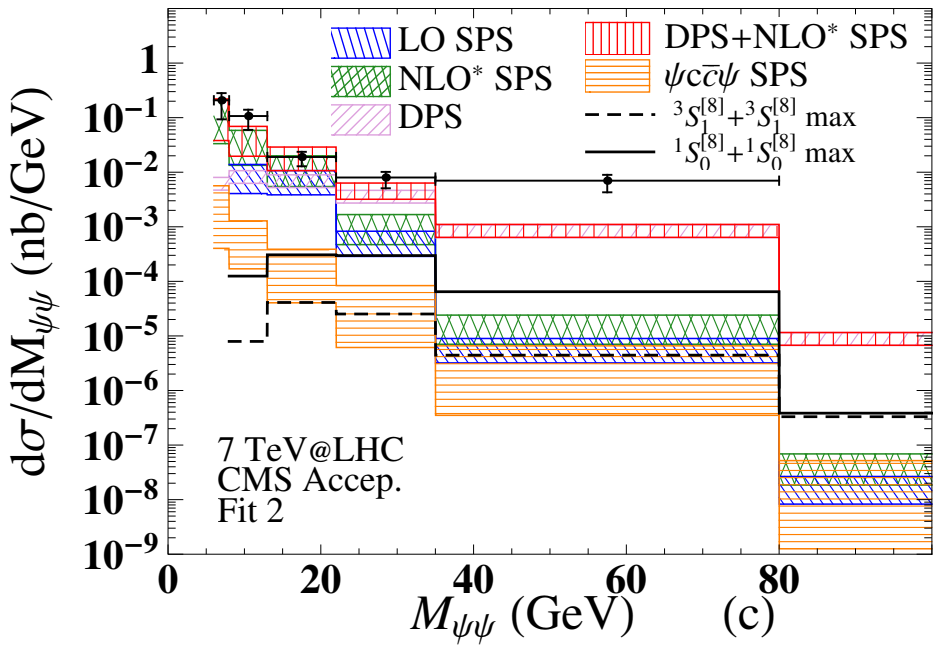

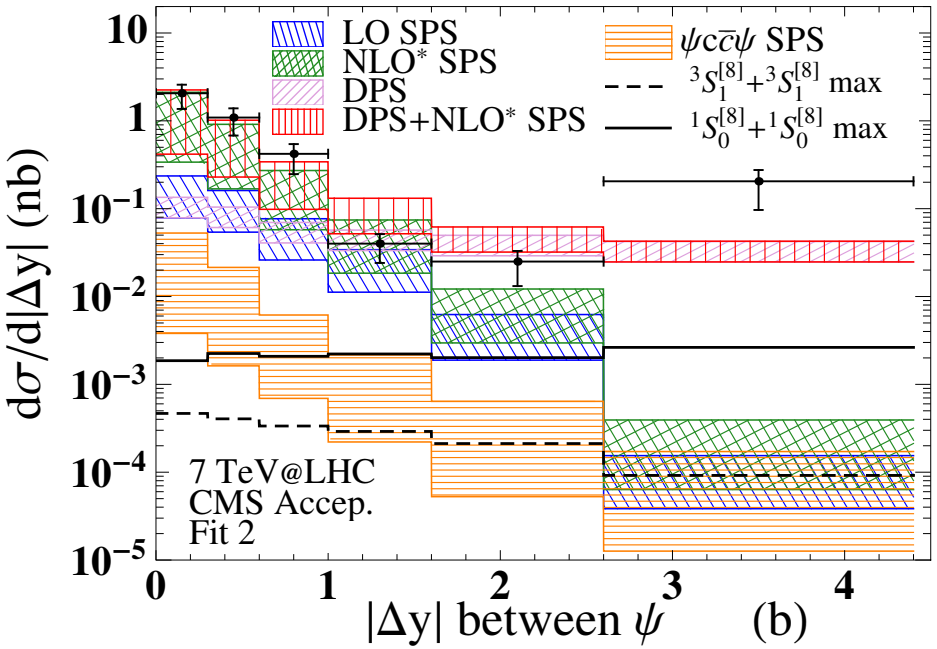

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- Ignoring all previous constraints and fitting (one channel at a time) the LDME on the CMS data one gets irrealistically large values:
  $\langle \mathcal{O}^{J/\psi}(^3S_1^{[8]})\rangle = 0.42\pm0.12$ GeV^3 & $\langle \mathcal{O}^{J/\psi}(^1S_0^{[8]})\rangle = 0.91\pm0.22$ GeV^3 !!!