Quarkonia as a tool to measure Double Parton Scatterings, gluon TMDs and (n)PDFs

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[Work done in collaboration with

M.G. Echevarria, T. Kasemets, C. Pisano, F. Scarpa, M. Schlegel, H.S. Shao, A. Signori]

Part I

Quick introduction

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- Yet, quarkonium hadroproduction remains a very sensitive probe of the gluon content of the proton

Part II

Quarkonia as probes of the glue

New: an automated code to evaluate the impact of nuclear PDF on hard probes

JPL, H.S. Shao Eur.Phys.J. C77 (2017) 1

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- Conversely, one can test this hypothesis by comparing our curves with data
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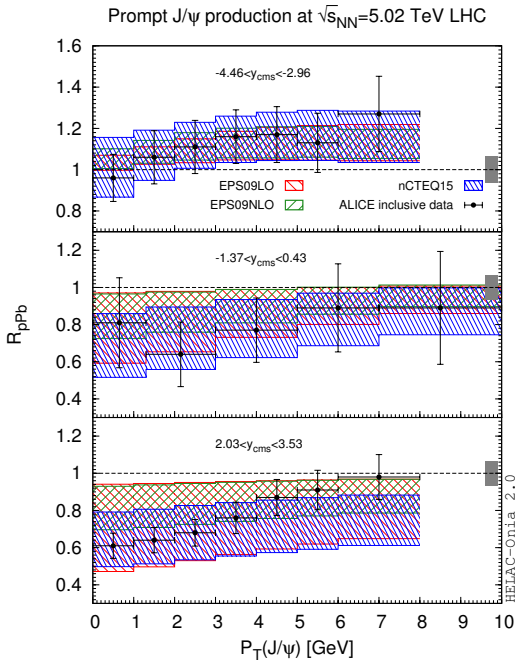
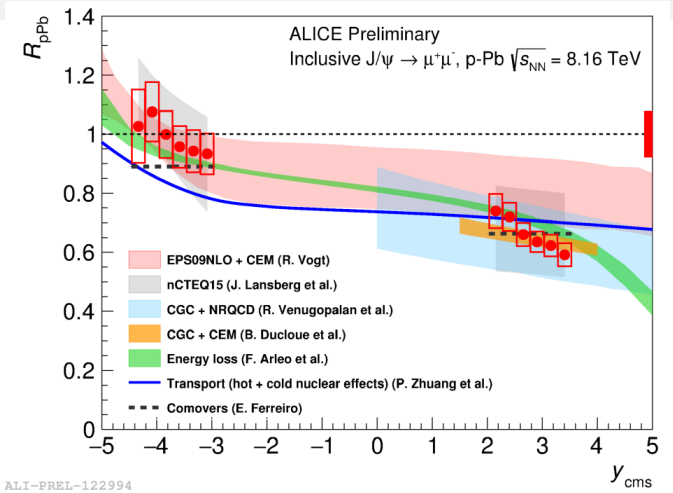
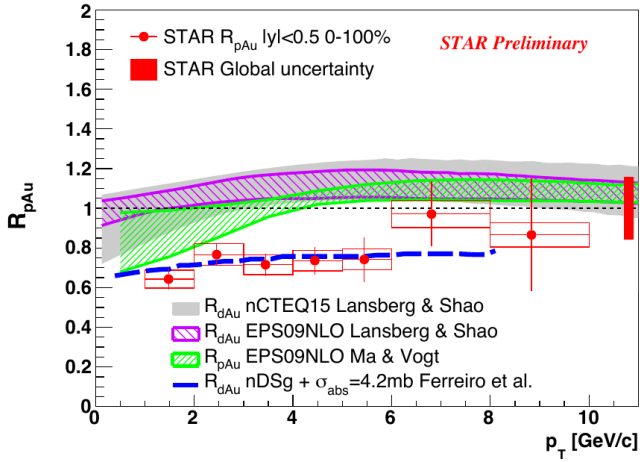
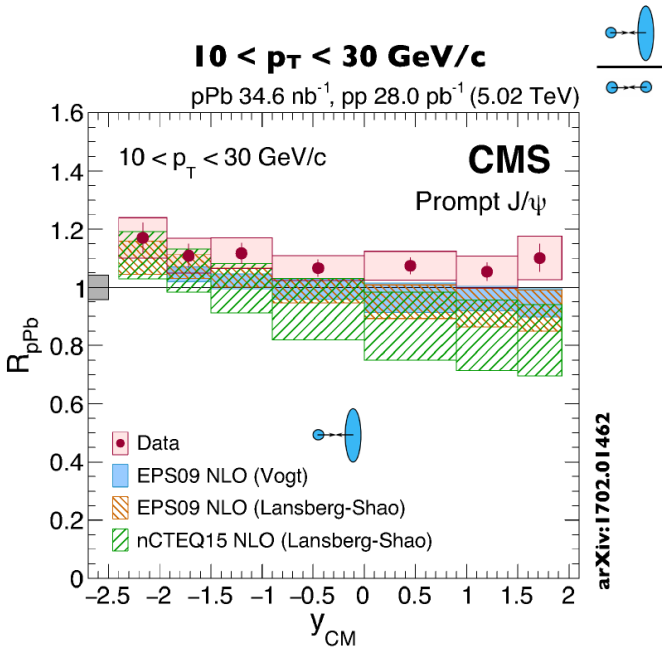
- Last but not least: the automation of the evaluation allows one to study different nPDF sets AND the scale uncertainties: better control of the theory uncertainties

Some comparisons [top left by us; 3 other shown at QM2017]









STAR: T.Todoroki; ALICE: M. Tarhini (ALICE-PUBLIC-2017-001); CMS: J. M. Blanco

Part III

New observables in quarkonium production

New observables: what for ?

Observables	Experiments	CSM	CEM	NRQCD	Interest
J/ψ+J/ψ	LHCb, CMS, ATLAS, D0 (+NA3)	NLO, NNLO*	LO ?	LO	Prod. Mechanism (CS dominant) + DPS
J/ψ+D	LHCb	LO	LO ?	LO	Prod. Mechanism (c to J/psi fragmentation) + DPS
J/ψ+ϒ	D0	(N)LO	LO ?	LO	Prod. Mechanism (CO dominant) + DPS
J/ψ+hadron	STAR	LO	--	LO	B feed-down; Singlet vs Octet radiation
J/ψ+Z	ATLAS	NLO	NLO	Partial NLO	Prod. Mechanism + DPS
J/ψ+W	ATLAS	LO	LO ?	Partial NLO	Prod. Mechanism (CO dominant) + DPS
J/ψ vs mult.	ALICE,CMS (+UA1)	--	--	--	
J/ψ+b	-- (LHCb, D0, CMS ?)	--	--	LO	Prod. Mechanism (CO dominant) + DPS
ϒ+D	LHCb	LO	LO ?	LO	DPS
ϒ+γ	--	NLO, NNLO*	LO ?	LO	Prod. Mechanism (CO LDME mix) + gluon TMD/PDF
ϒ vs mult.	CMS	--	--	--	
ϒ+Z	--	NLO	LO ?	LO	Prod. Mechanism + DPS
ϒ+ϒ	CMS	NLO ?	LO ?	LO ?	Prod. Mechanism (CS dominant ?) + DPS

Part IV

Z+prompt J/ψ

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	exp	LO CEM SPS	NLO CEM SPS	DPS ($\sigma_{\text{eff}} \simeq 15$ mb)
ATLAS inclusive	$63 \pm 13 \pm 5 \pm 10$	$4.1^{+1.3}_{-1.0}$	$7.6^{+2.0}_{-1.6}$	17
ATLAS fiducial	$36.8 \pm 6.7 \pm 2.5$	$2.2^{+0.7}_{-0.6}$	$4.2^{+1.1}_{-0.9}$	7
CMS fiducial	–	$3.9^{+1.3}_{-0.9}$	$7.5^{+2.0}_{-1.6}$	16

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- This naturally points at a smaller σ_{eff} (as other onium related data), but the $\Delta\phi$ distribution shows a peak at $\Delta\phi \simeq \pi \rightarrow$ SPS dominance ???

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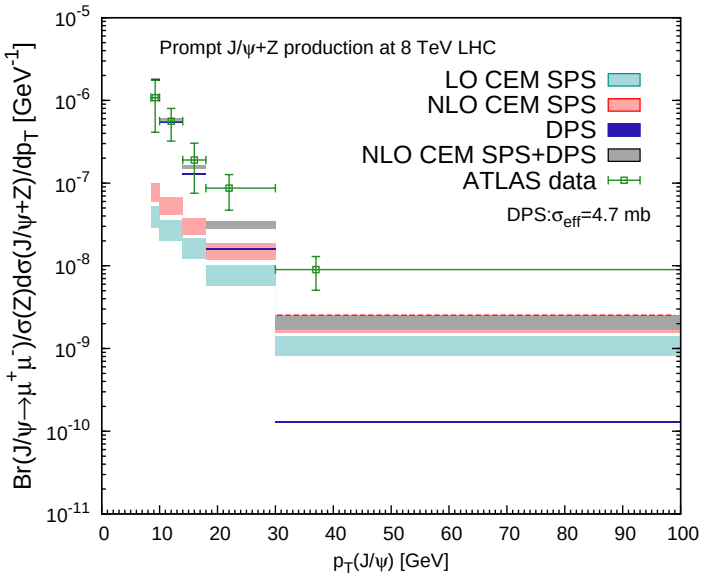

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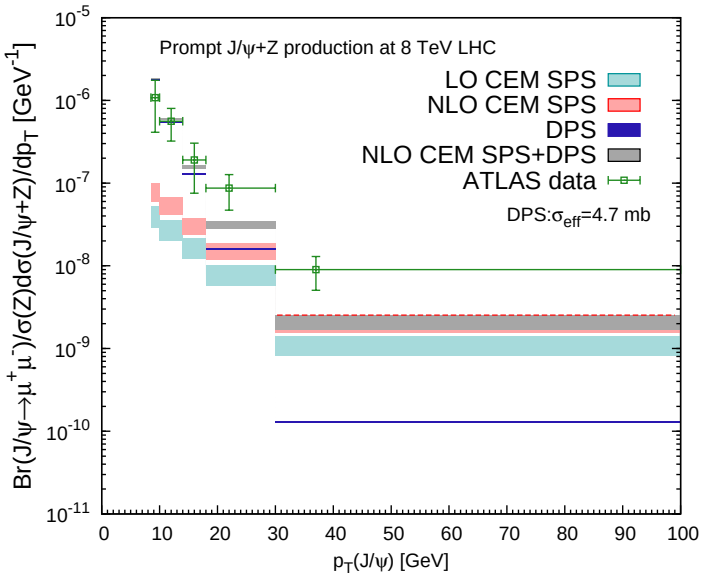

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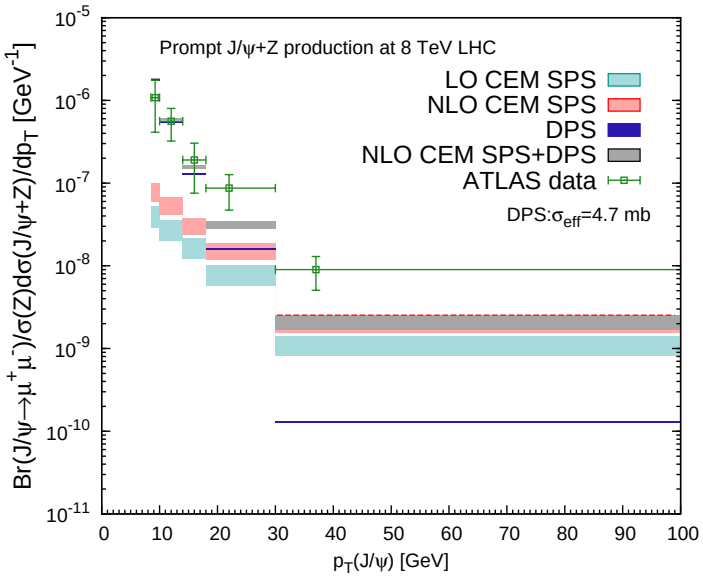

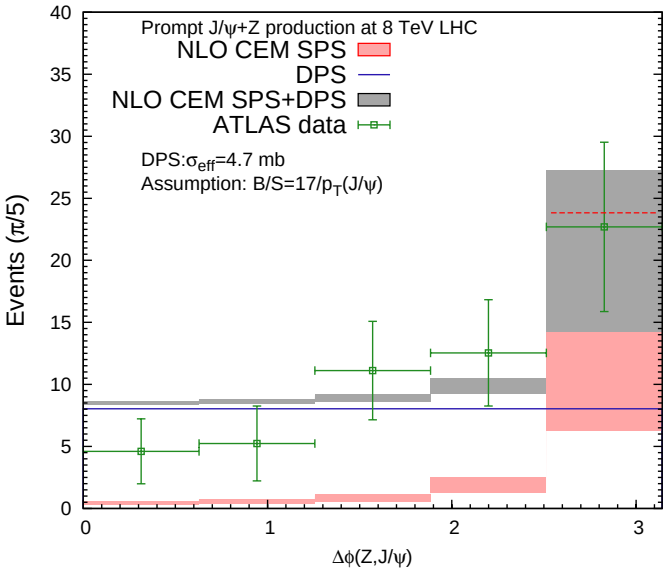

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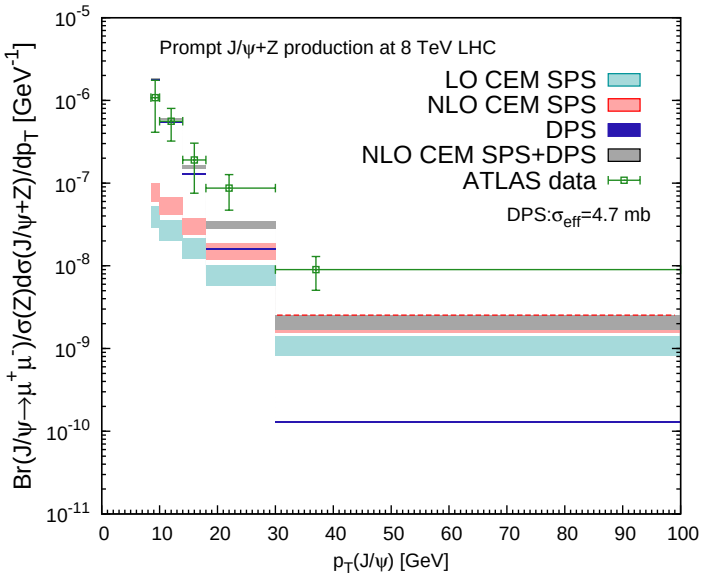

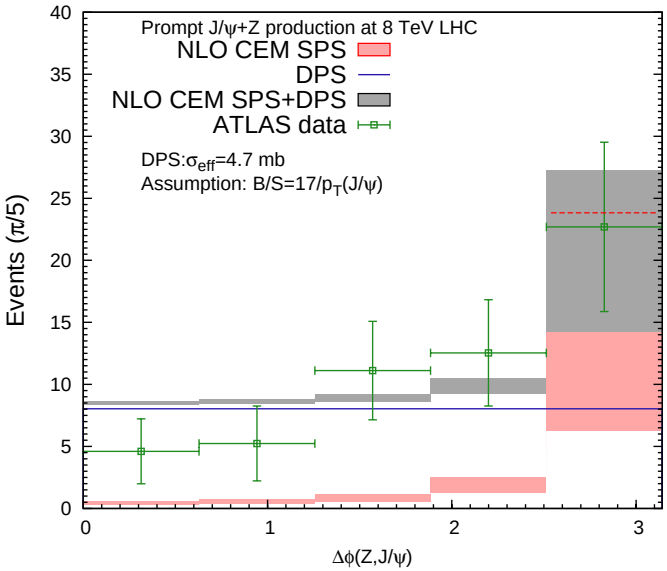

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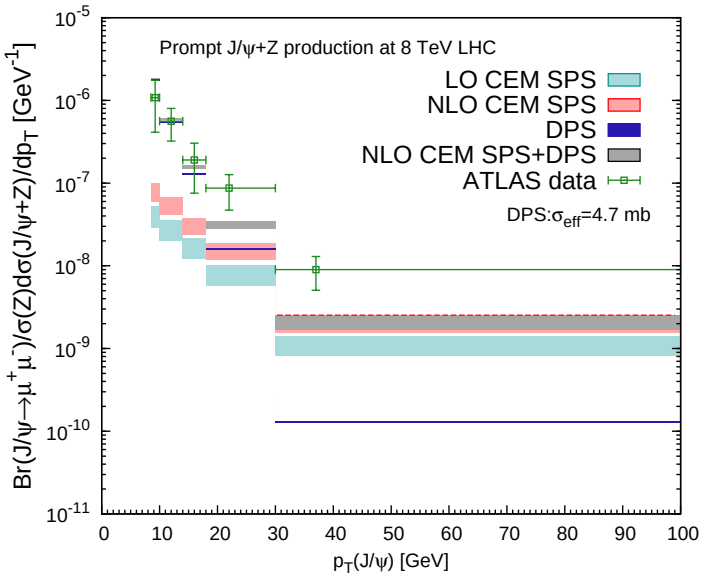

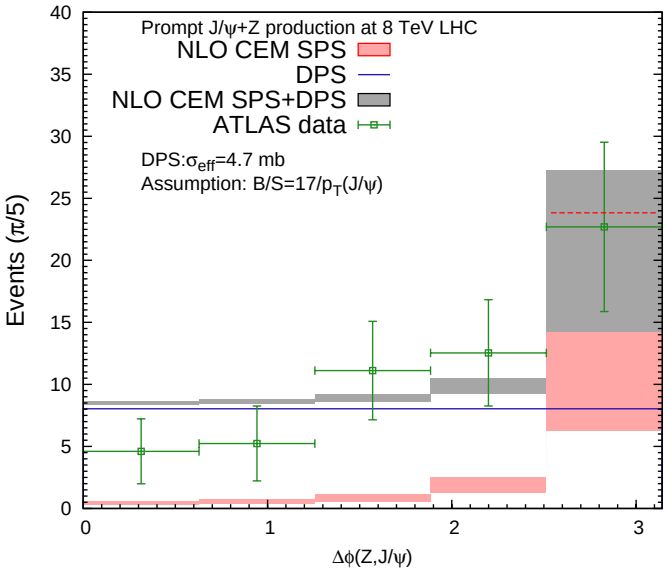

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- We are waiting for an ATLAS update to confirm our explanation

Part V

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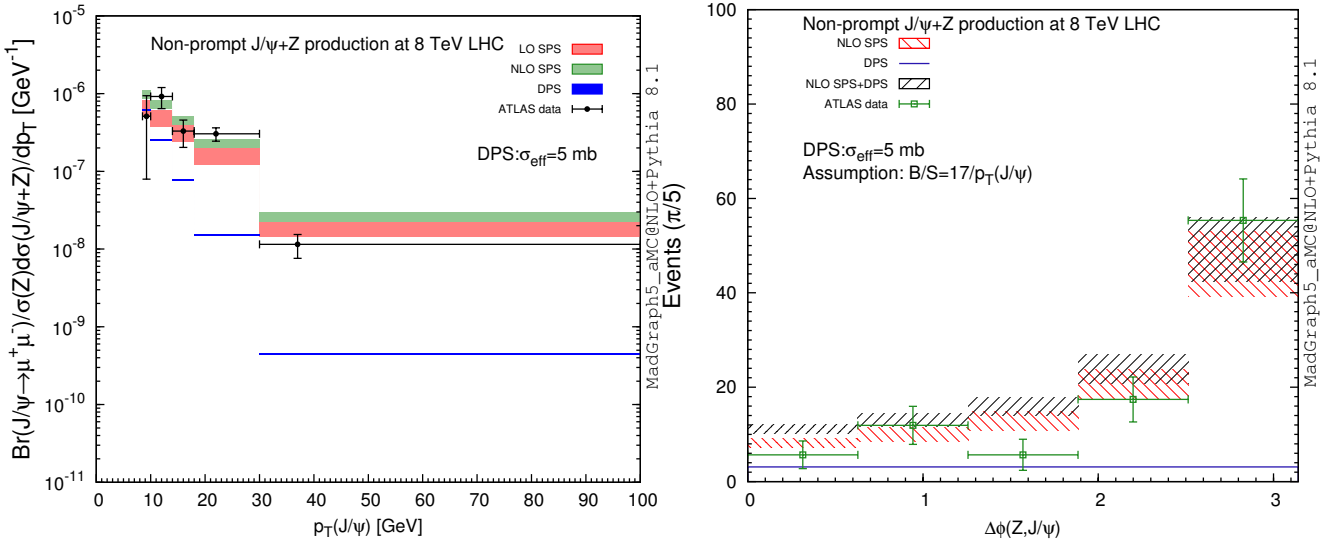
- Interesting check that nothing went wrong with the prompt analysis
- SPS predictions were absent at the time of the publication. We filled this gap using MadGraph5_aMC@NLO and Pythia 8.1.



Differential cross section/distributions for non-prompt $J/\psi + Z$ production: p_T distribution of J/ψ (left) and azimuthal angle distribution (right)

- Good agreement. Owing to the data uncertainties at low P_T, we cannot constrain σ_{eff} more than with a lower limit, 5.0 mb, at 68 % CL.

Part VI

Quarkonium-pair production

On the importance of QCD corrections : P_T enhanced topologies

JPL, H.-S.Shao PRL 111, 122001 (2013); PLB 751 (2015) 479

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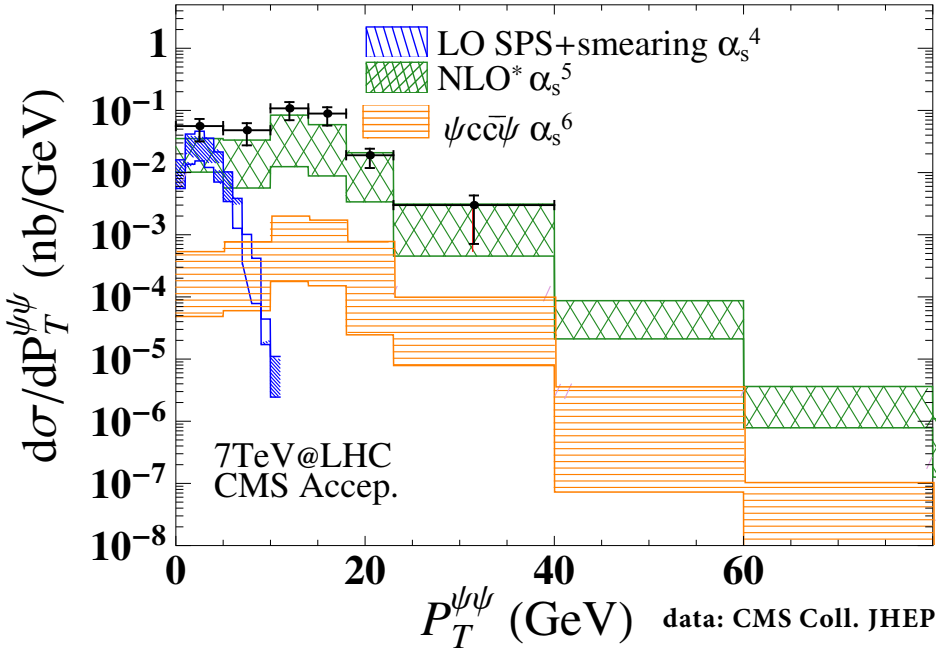

data: CMS Coll. JHEP 1409 (2014) 094

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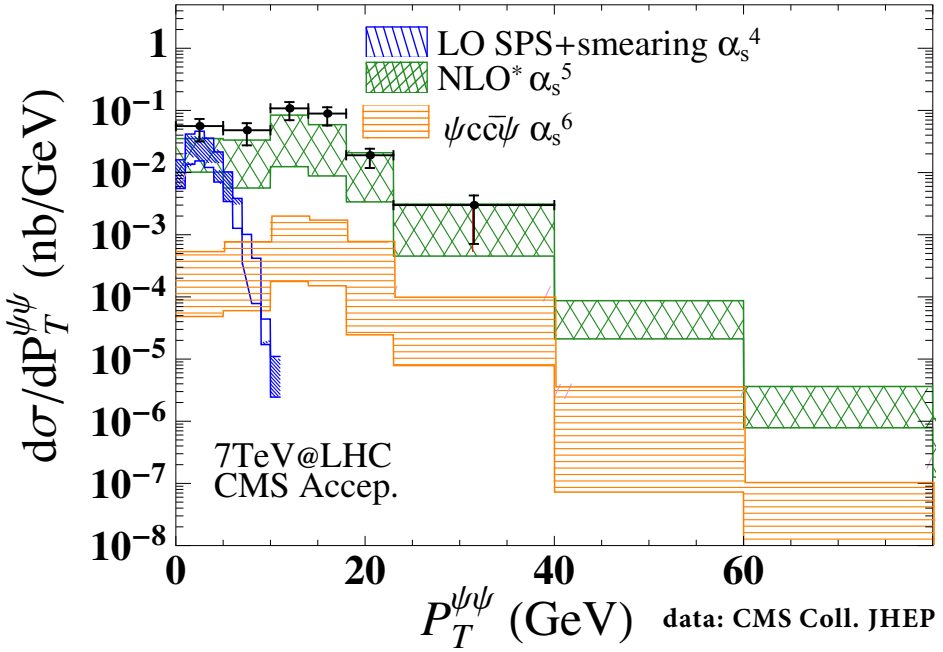

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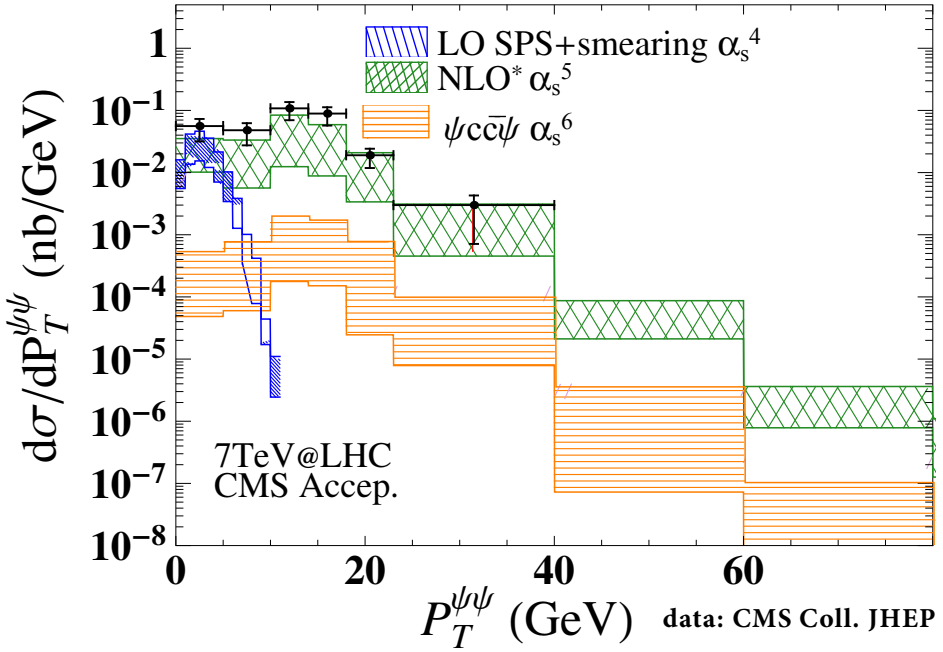

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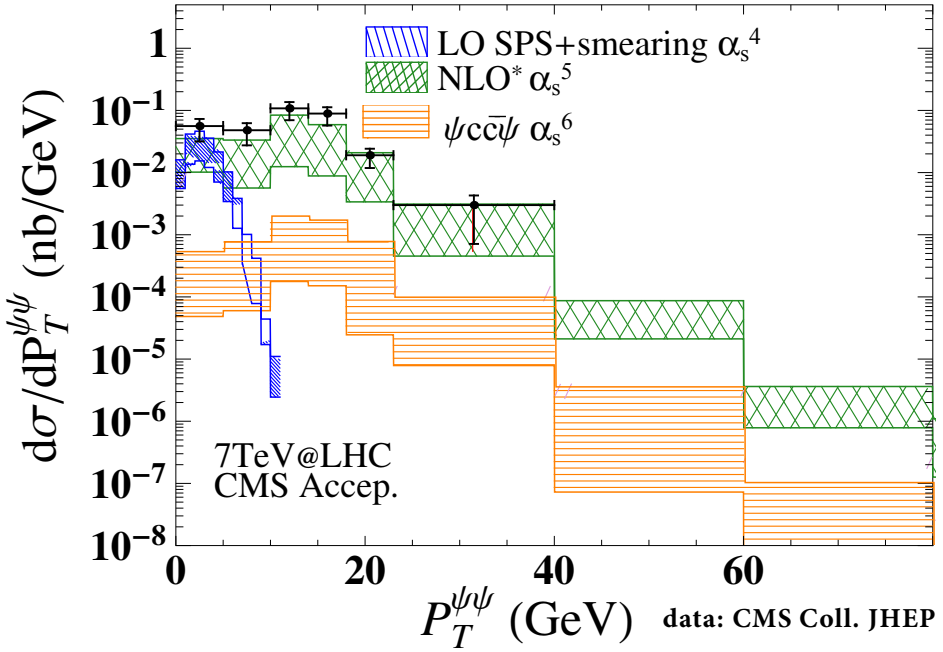

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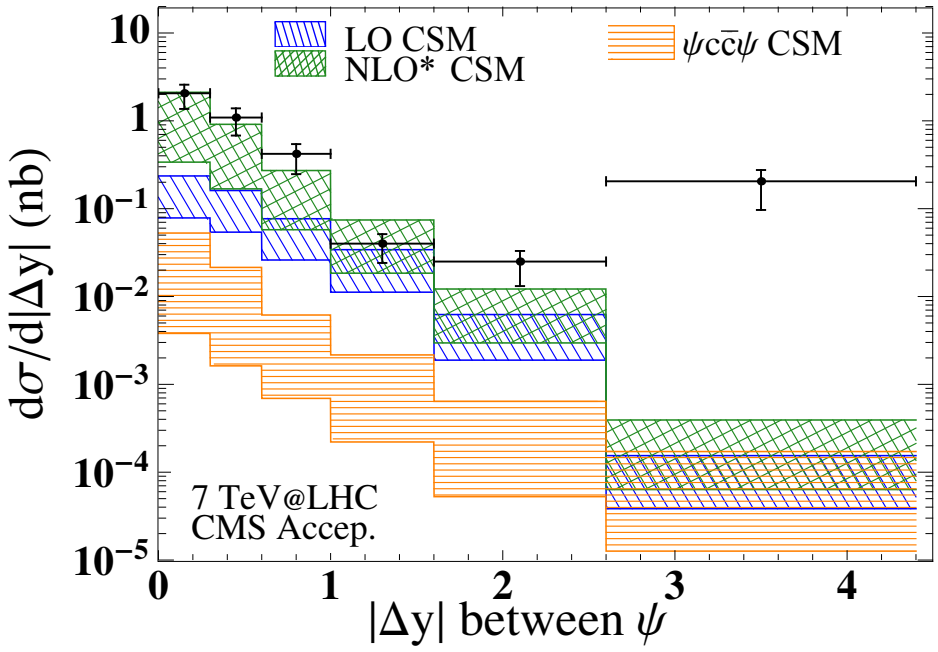
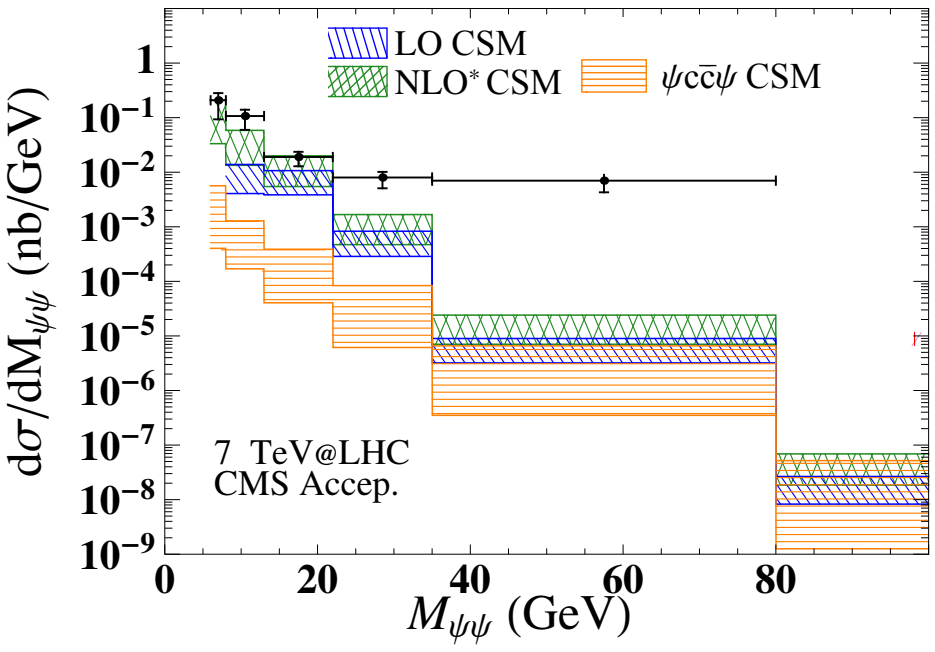
[the orange histogram shows one class of leading P_T α_s^6 contributions]

The so-called CMS puzzle





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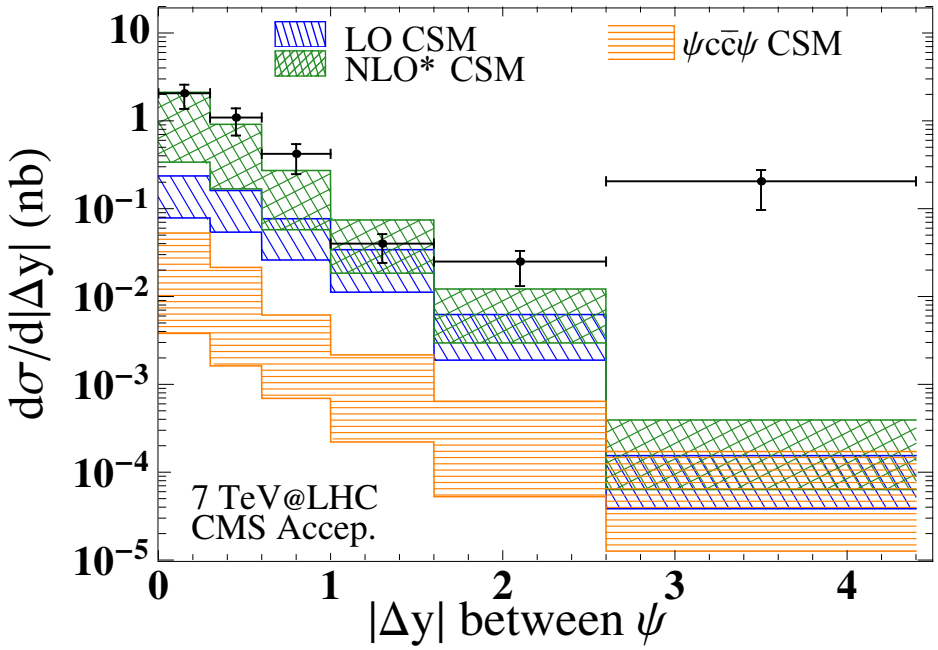

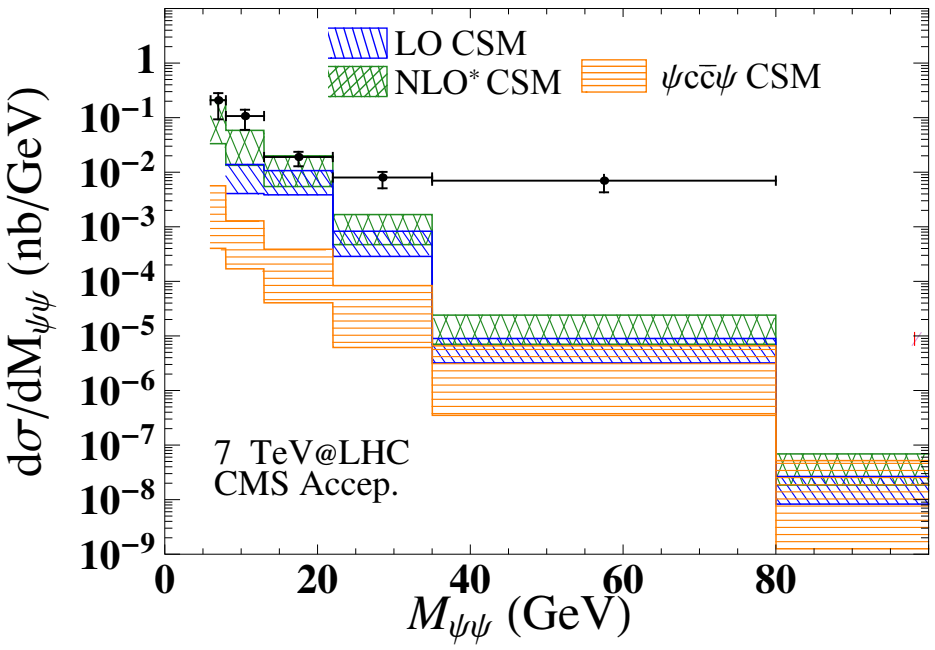

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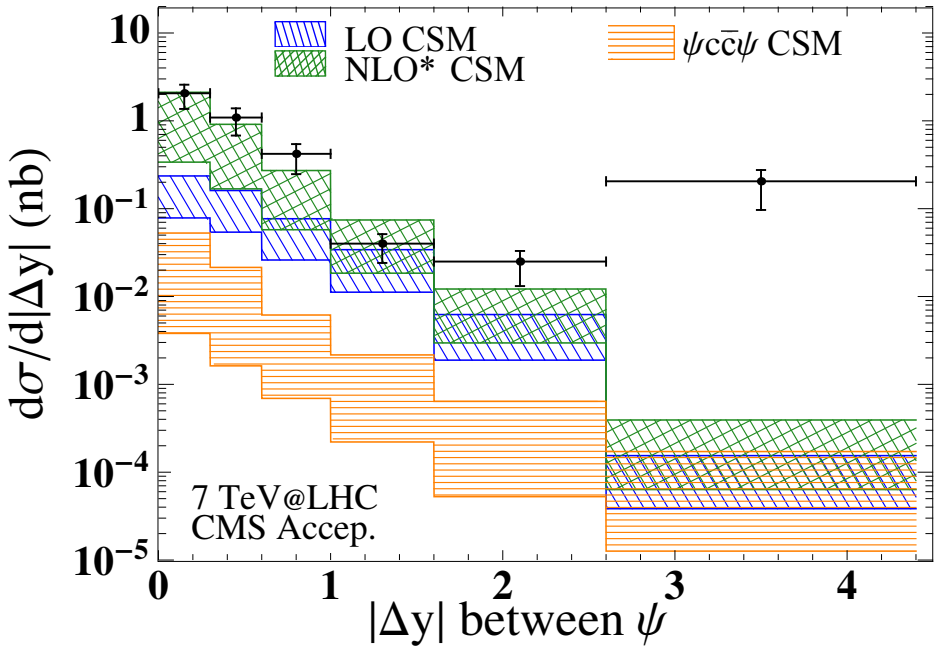

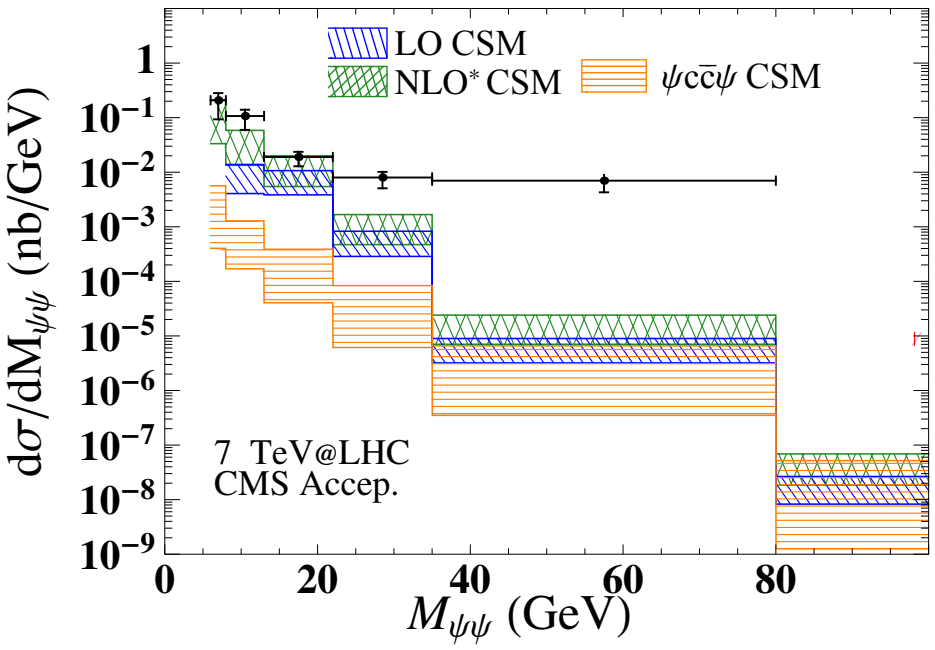

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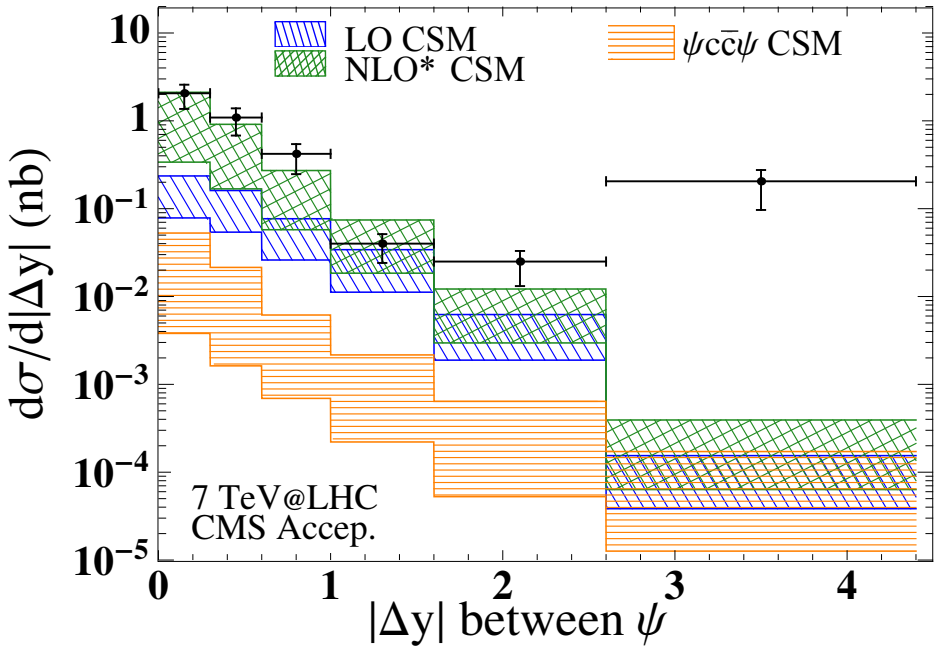

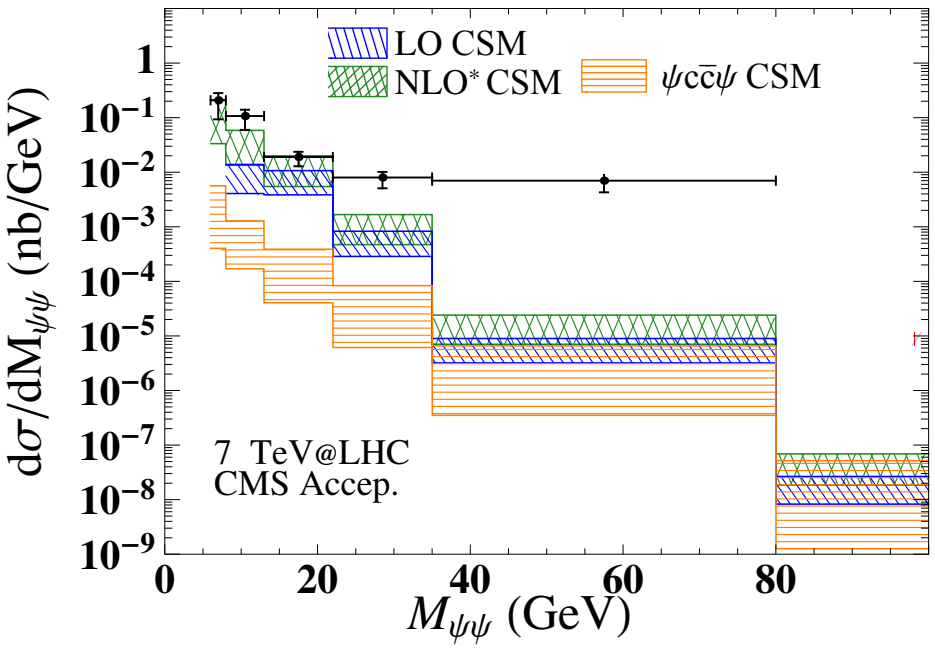

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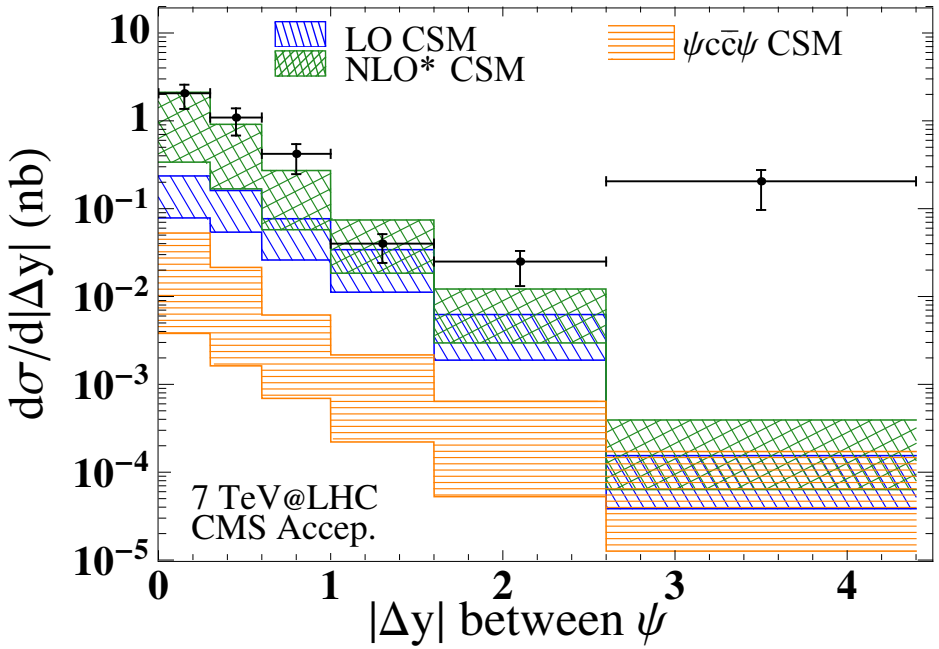

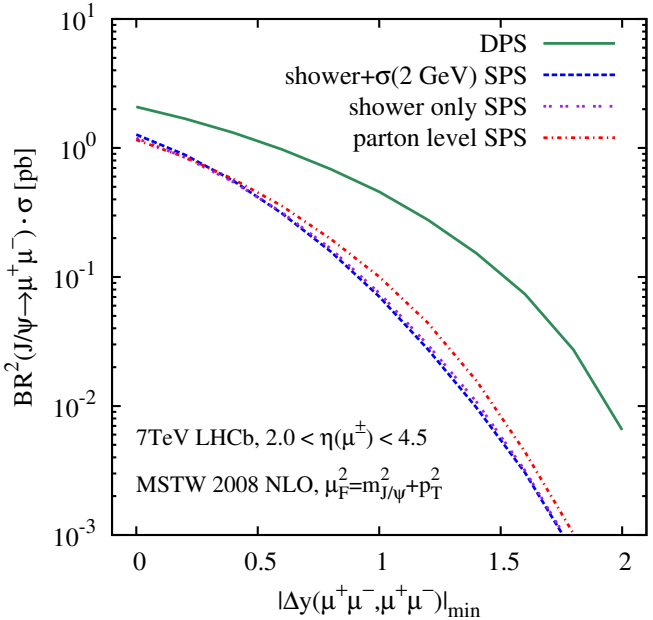

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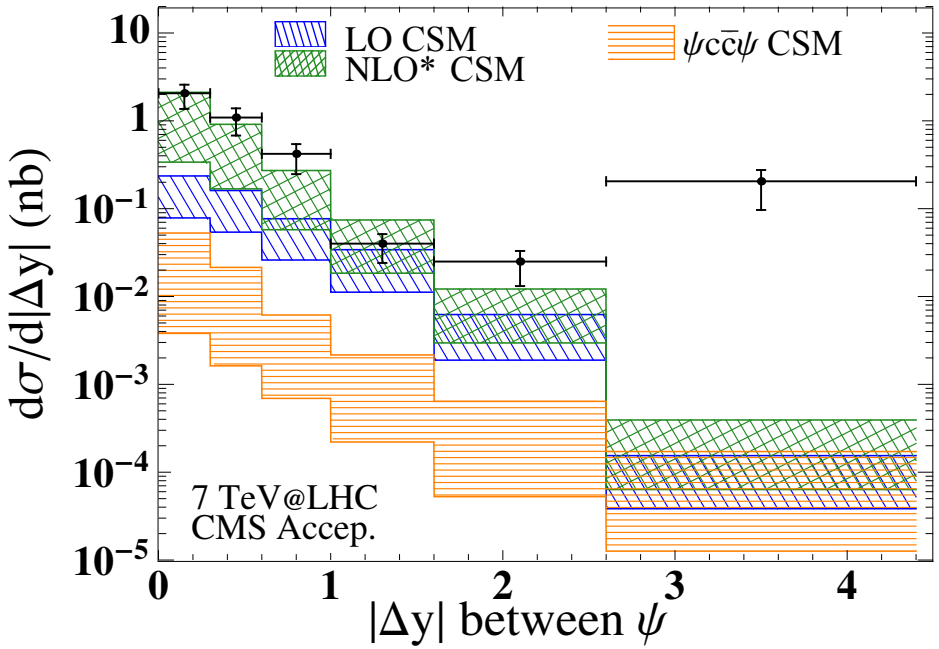

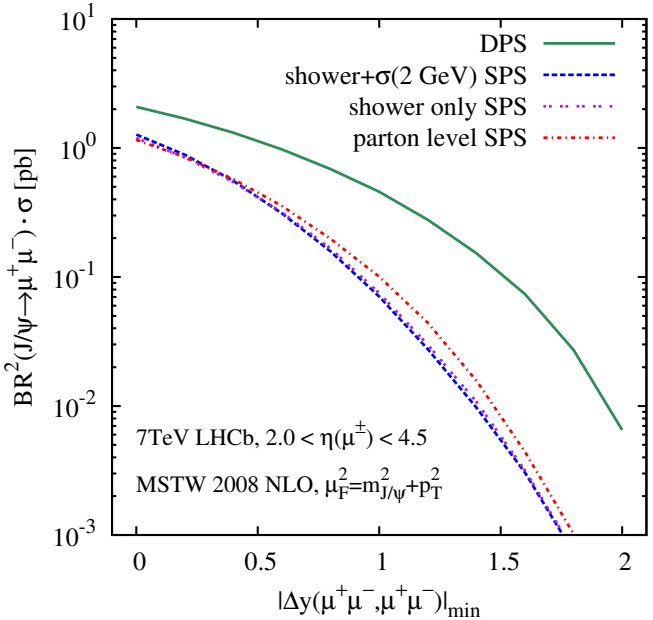

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- He & Kniehl found at LO that CO ≫ CS at large Δy; yet still in disagreement with the data; NLO needed ! — Z. He, B. Kniehl PRL 115, 022002 (2015)

On the importance of double parton scatterings at large Δy I

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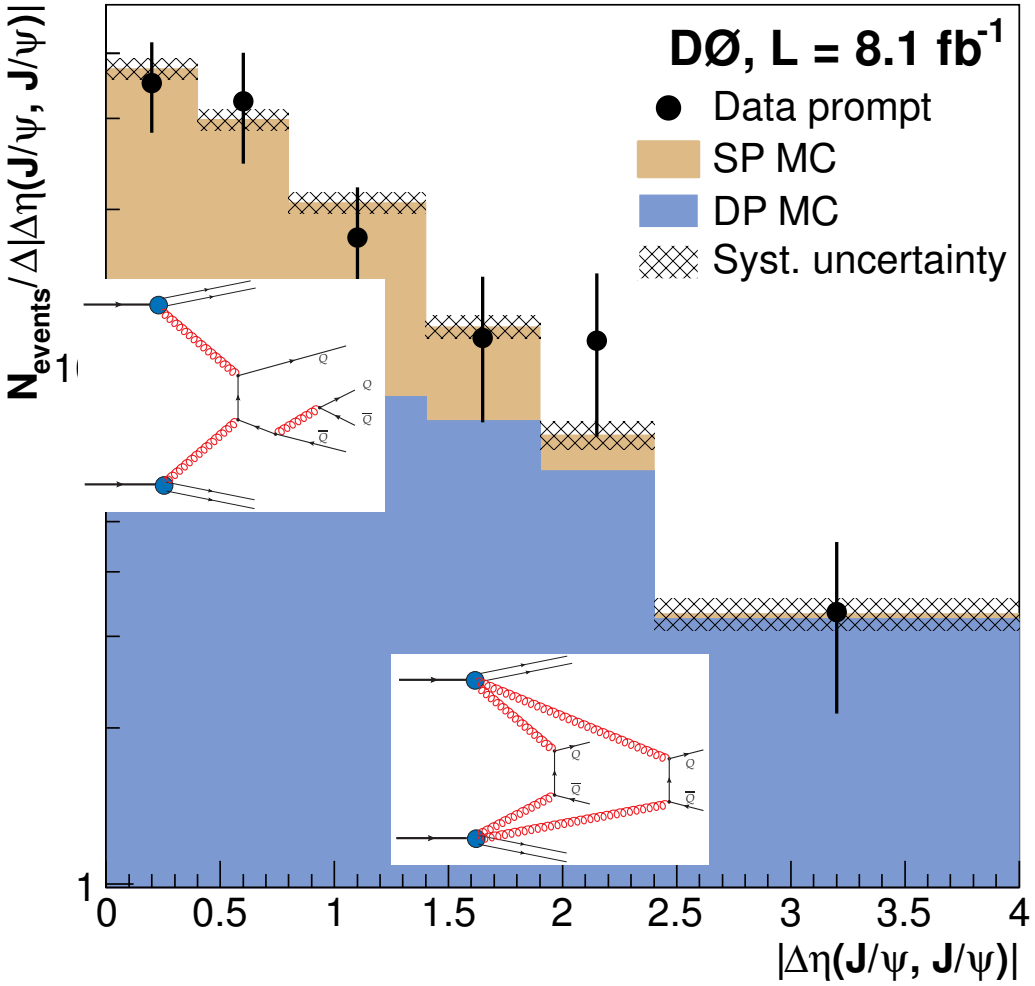

D0 Coll. PRD 90 (2014) 111101

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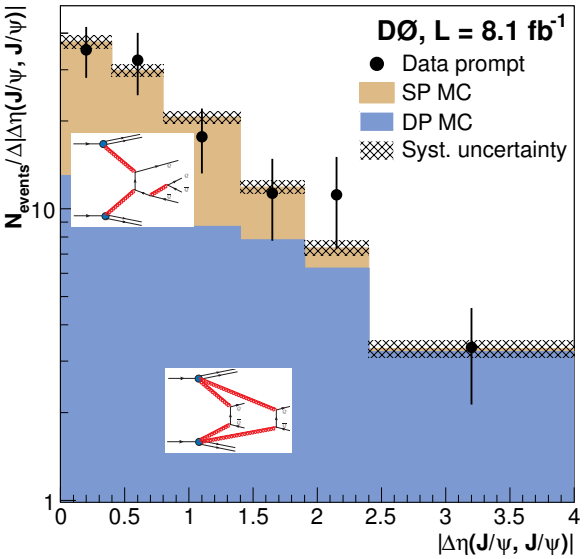

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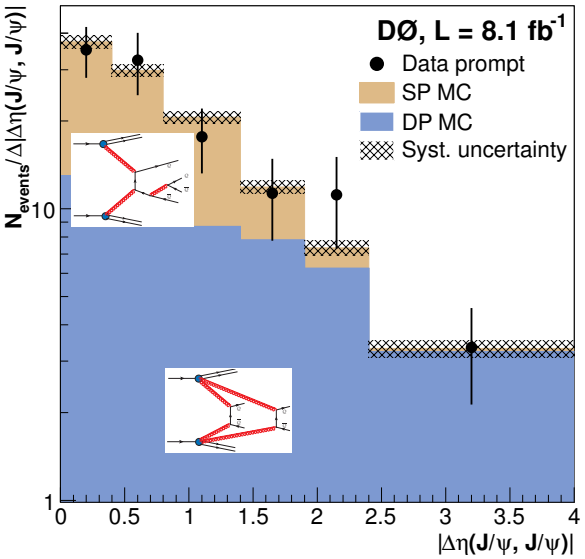

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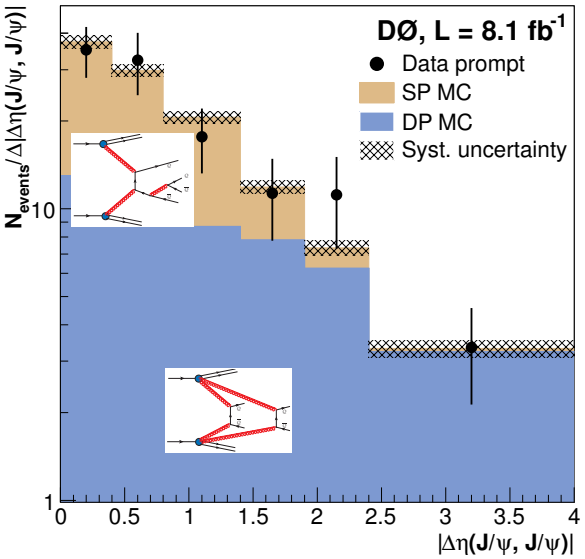

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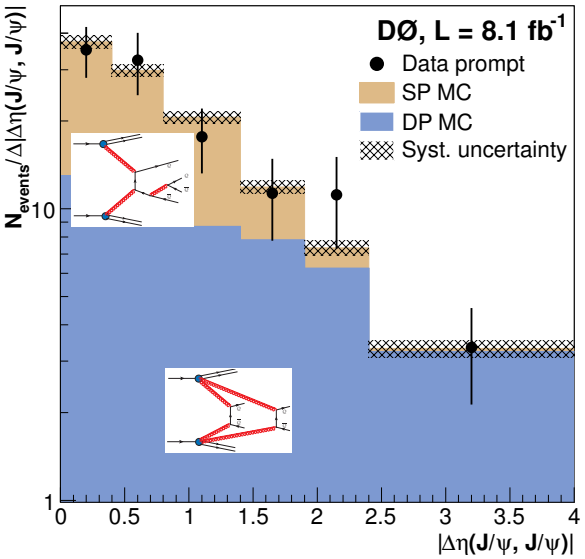

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- A question arises: using $\sigma^{\rm DPS} = \frac{1}{2}\frac{\sigma_\psi \sigma_\psi}{\sigma_{\rm eff}}$ and $\sigma_{\rm eff}$ = 4.8 ± 2.5 mb, can one account for the large Δy CMS data ?

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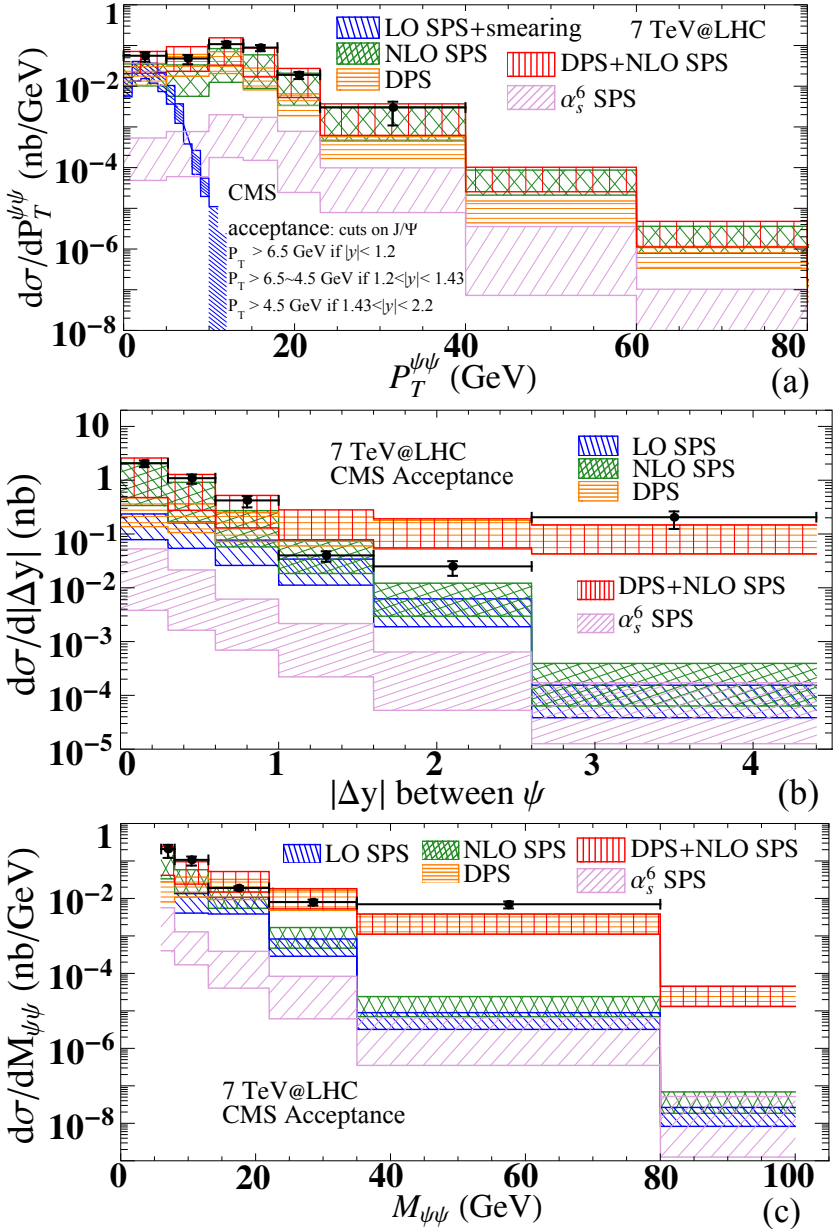

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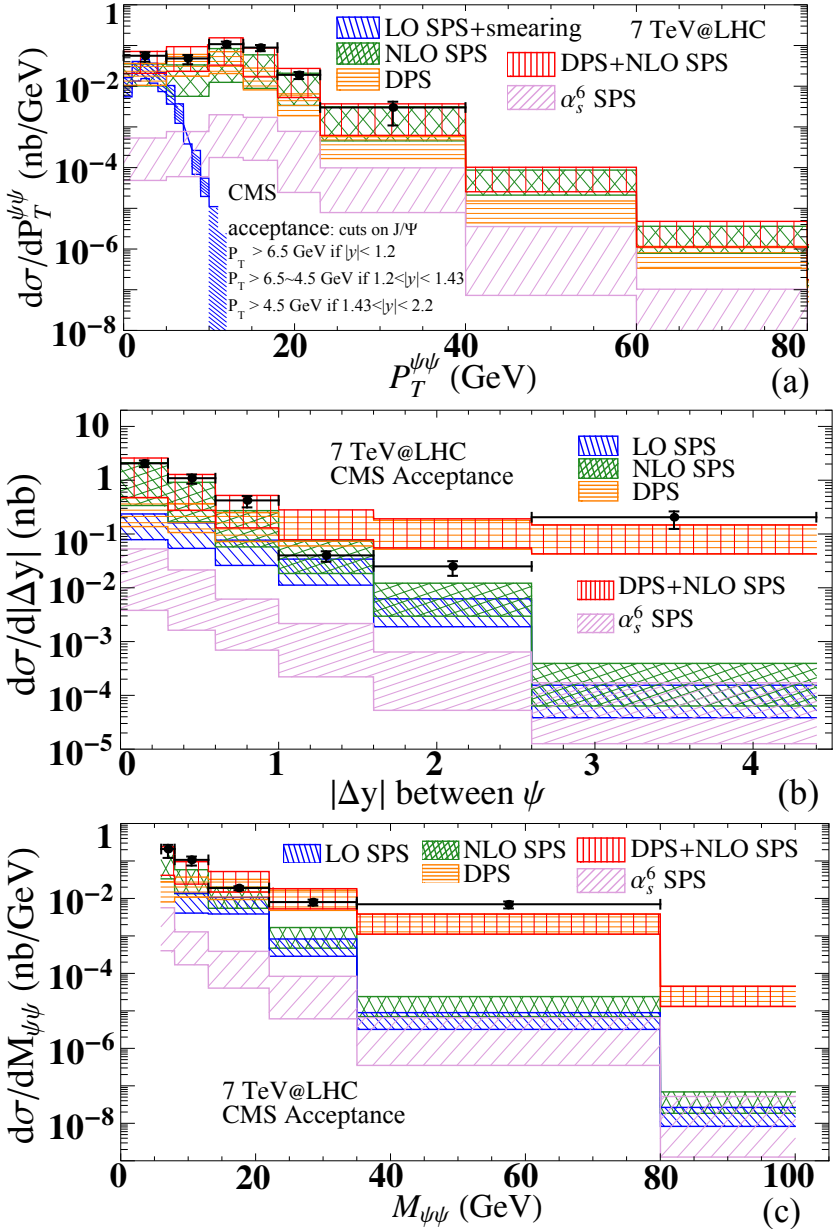

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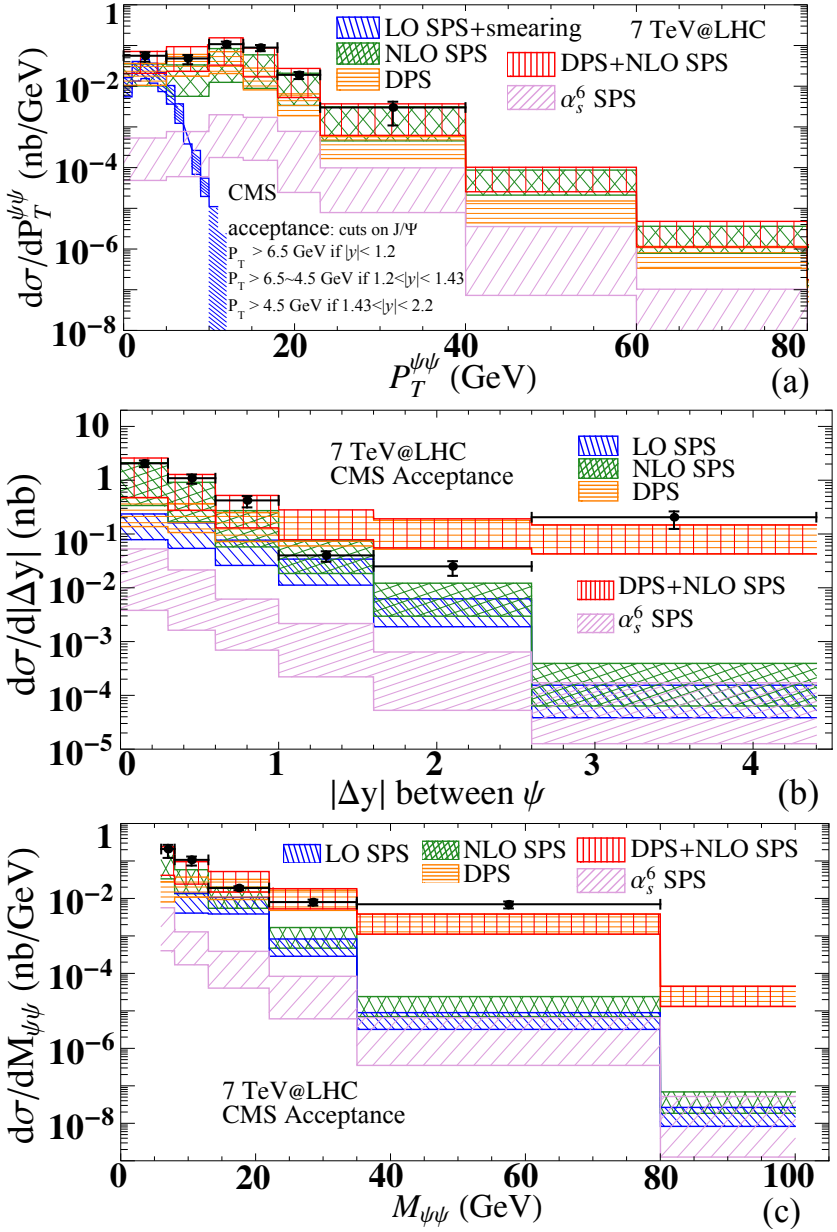

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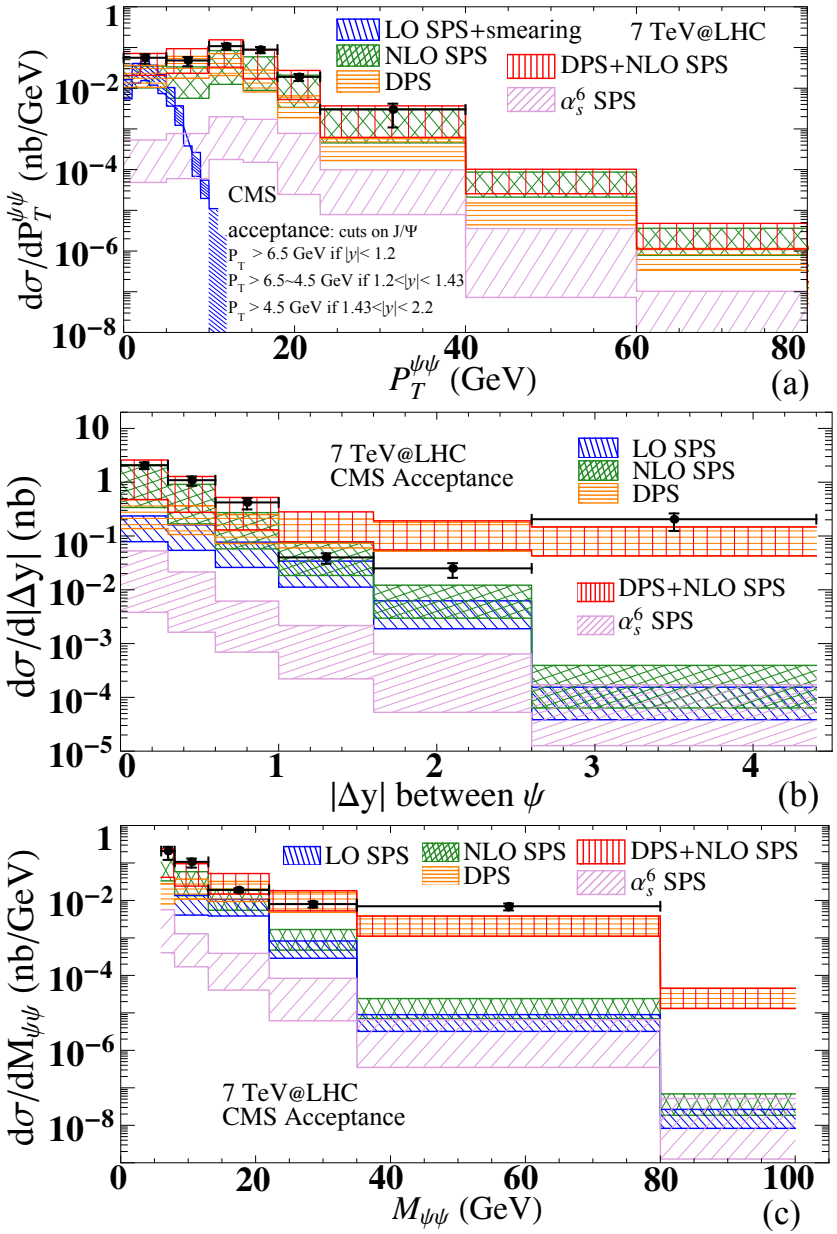
- Fit done prior the ATLAS analysis → good agreement !



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

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$$F^{\chi_c}_{\psi\psi} = F^{\chi_c}_{\psi} \times \left(F^{\chi_c}_{\psi} + 2F^{\rm direct}_{\psi} + 2F^{\psi'}_{\psi}\right), F^{\psi'}_{\psi\psi} = F^{\psi'}_{\psi} \times \left(F^{\psi'}_{\psi} + 2F^{\rm direct}_{\psi} + 2F^{\chi_c}_{\psi}\right), F^{\rm direct}_{\psi\psi} = \left(F^{\rm direct}_{\psi}\right)^2$$

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- Under DPS dominance (e.g. large Δy), $\sigma^{\rm DPS}_{ab} = \frac{m}{2}\frac{\sigma_a\sigma_b}{\sigma_{\rm eff}}$ (m: symmetry factor)

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- Under SPS CSM dominance,
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Predictions: excited states

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

- Even though we find it a natural, accounting for DPS introduces another parameter
- How to check that one is not playing with a further d.o.f. on the theory side?
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- Overall :

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

Harvesting new quarkonium data

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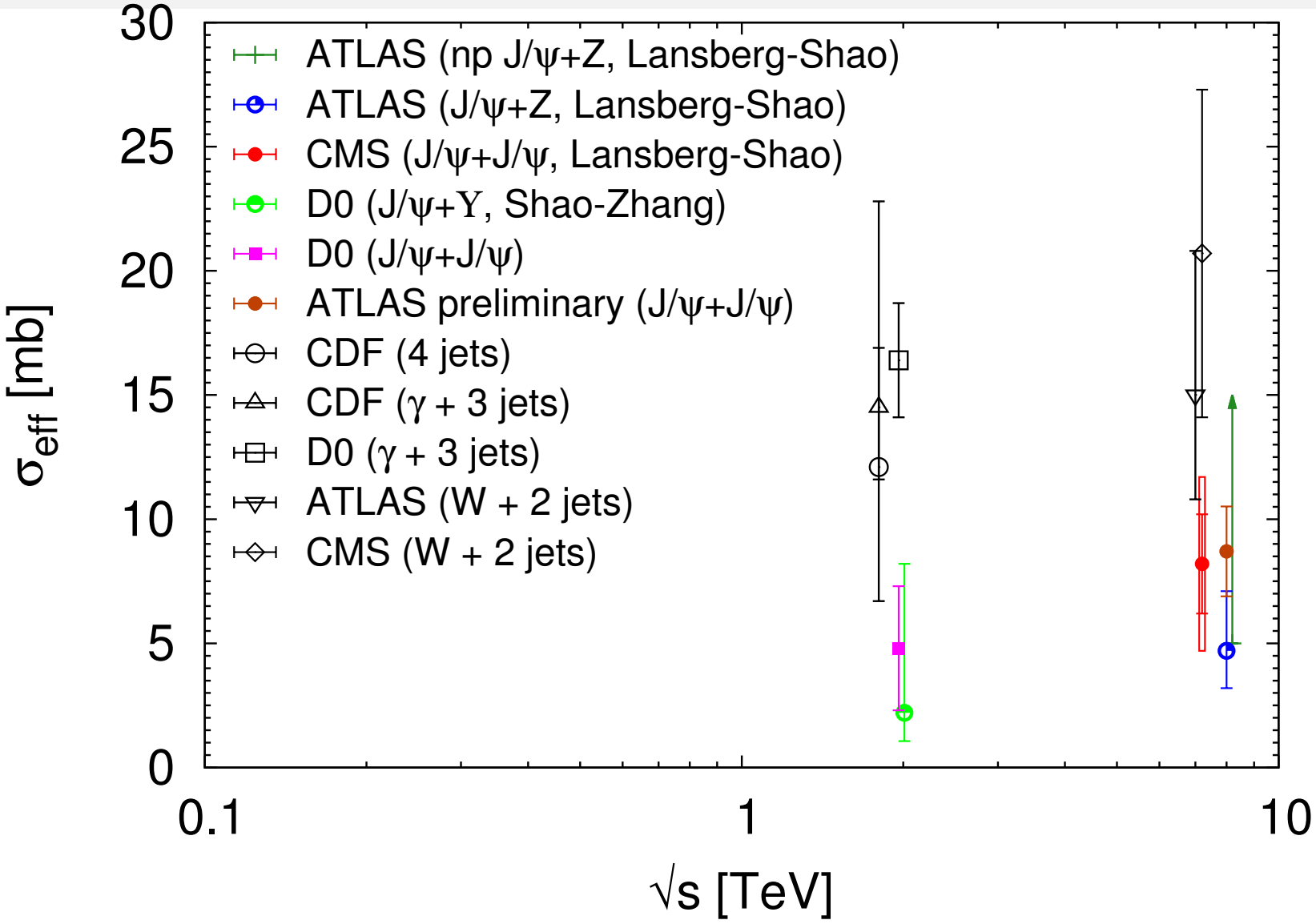

4 quarkonium extractions using theory ingredients !

Part VII

Conclusion

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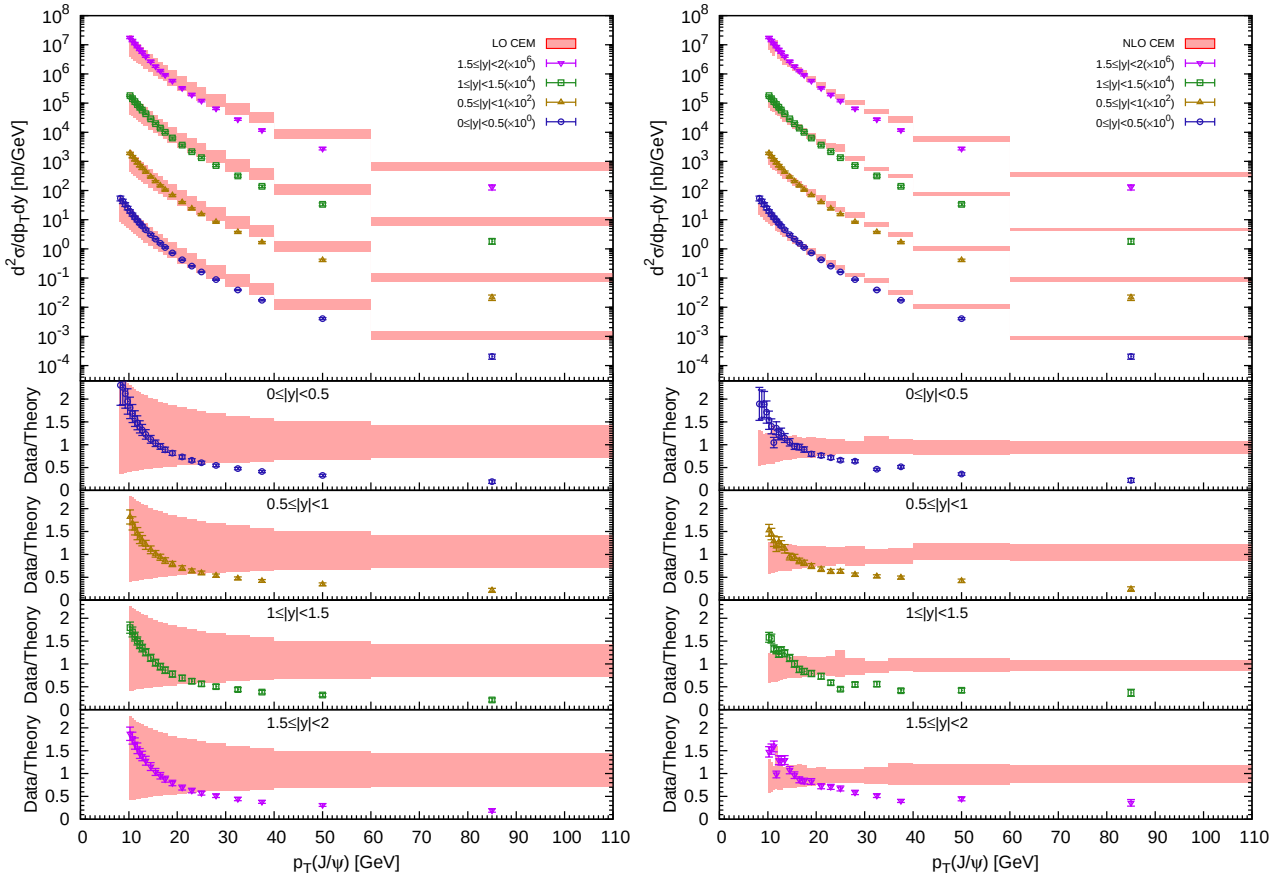
- Hint at a flavour dependence of $\sigma_{\rm eff}$?
- As outlooks, TMD-oriented studies using associated quarkonium production should now become possible for $\Upsilon + \gamma$, later for $\mathcal{Q} + \ell^+\ell^-$

  W. den Dunnen, JPL, C. Pisano, M. Schlegel, PRL 112, 212001 (2014); JPL, C. Pisano, M. Schlegel, 1702.00305 [hep-ph]

Part VIII

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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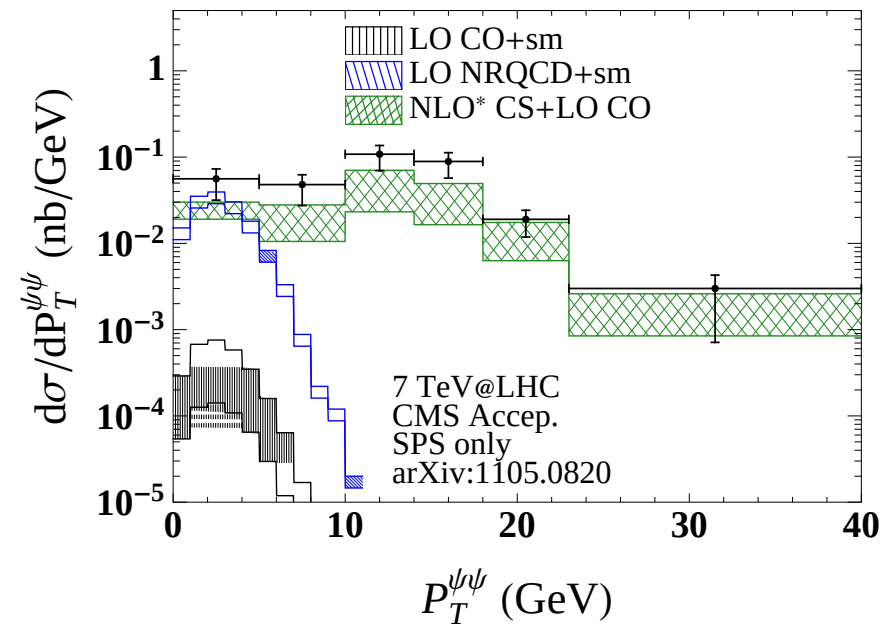

Single J/ψ LDME fit: M. Butenschoen, B. Kniehl arXiv:1105.0820, PRD 84 (2011) 0515

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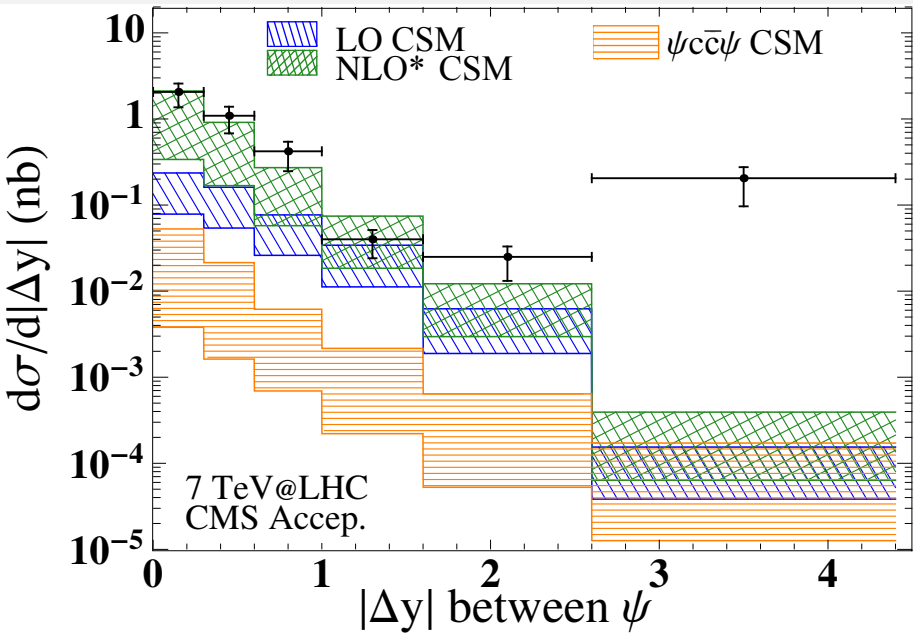

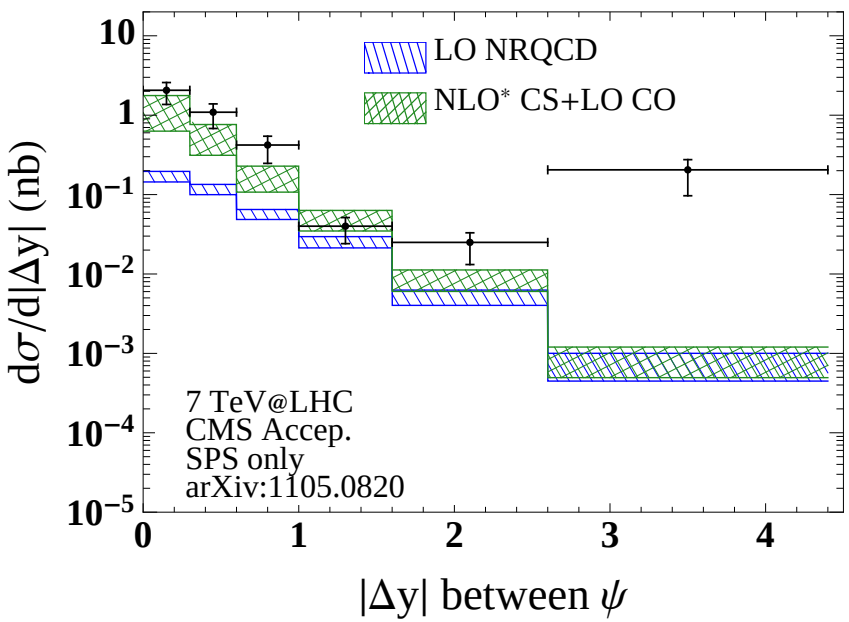

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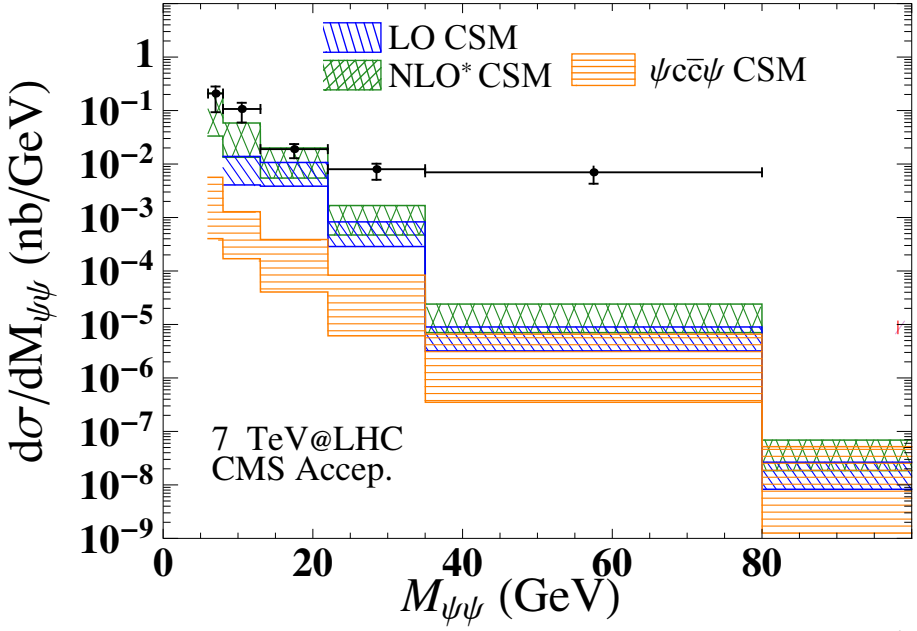

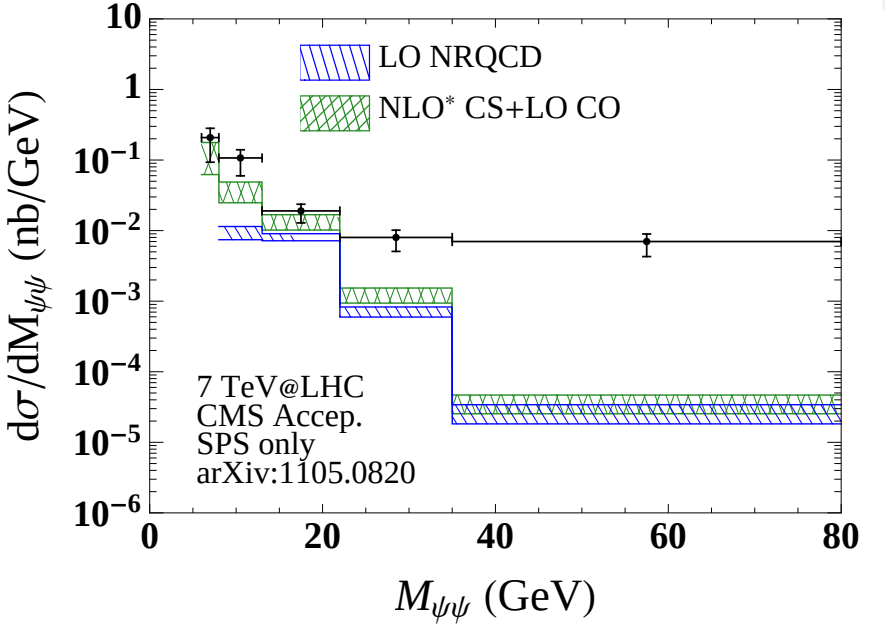

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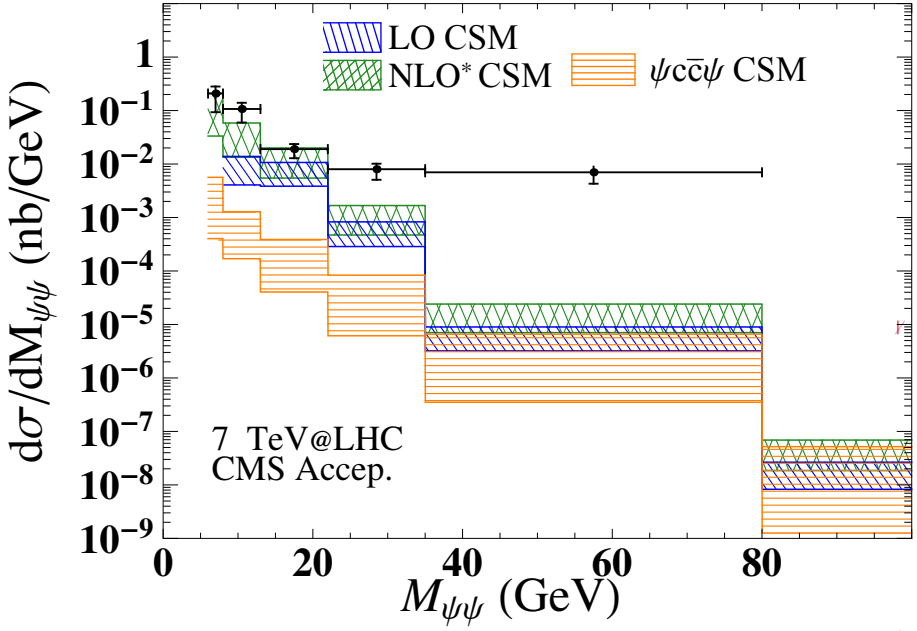

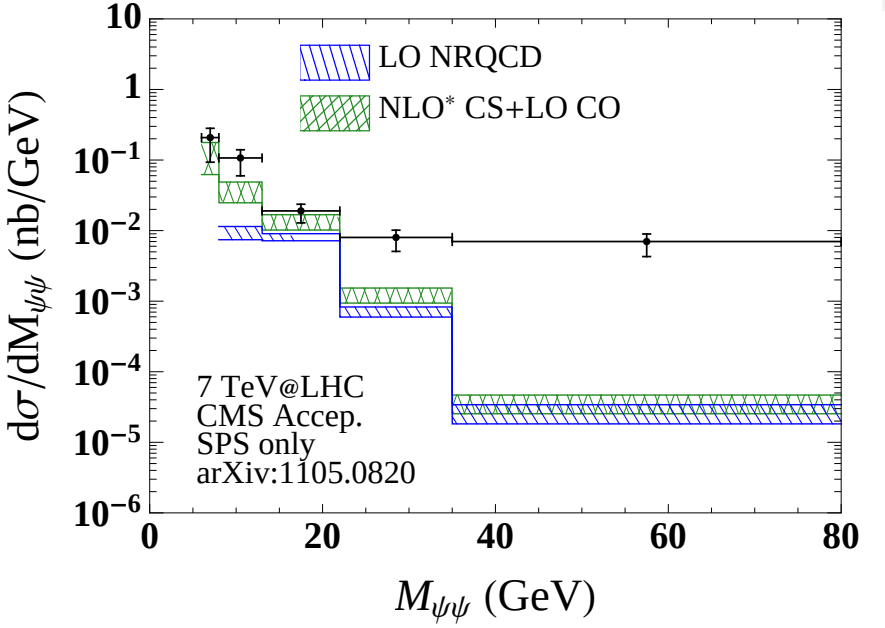

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PRL 110 (2013) 042002 ; JHEP 1505 (2015) 103; PRL 113 (2014) 022001

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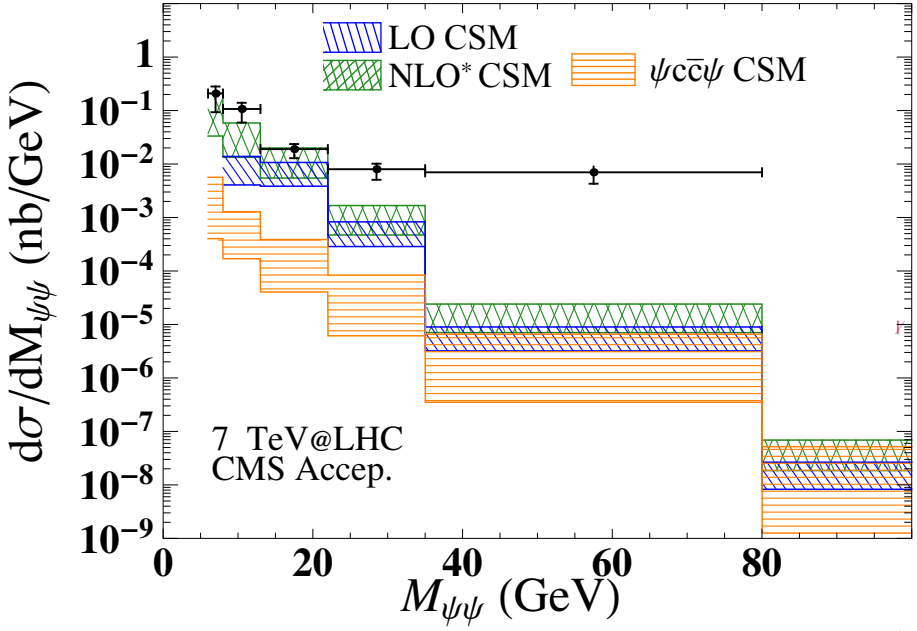

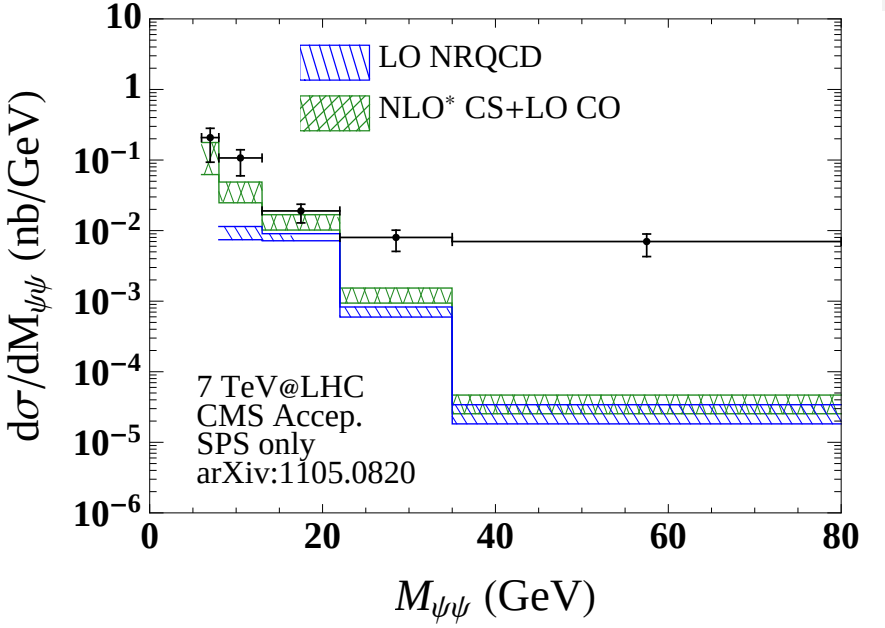

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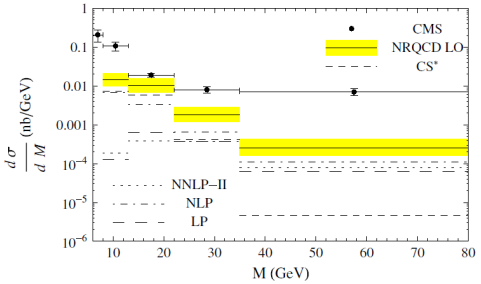

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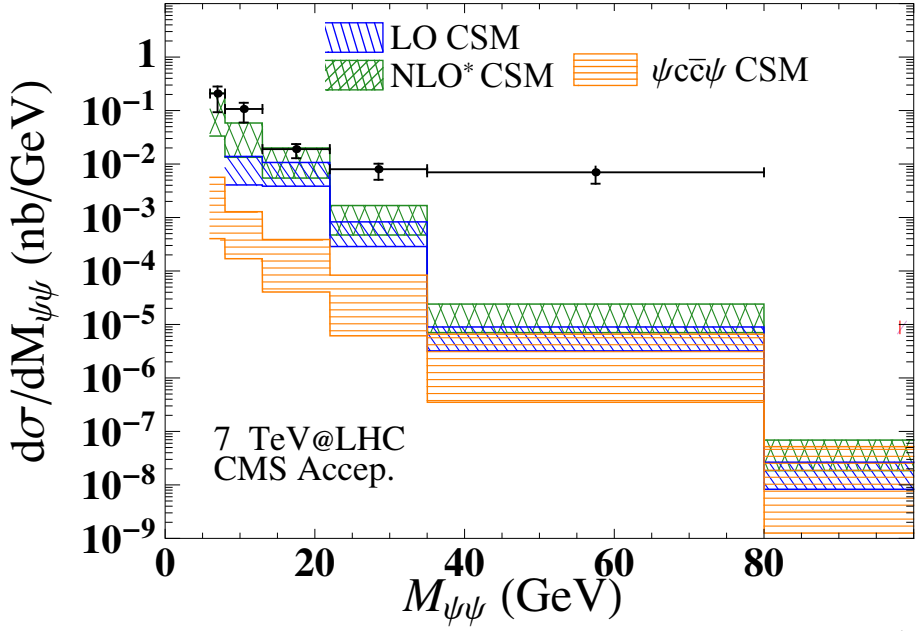

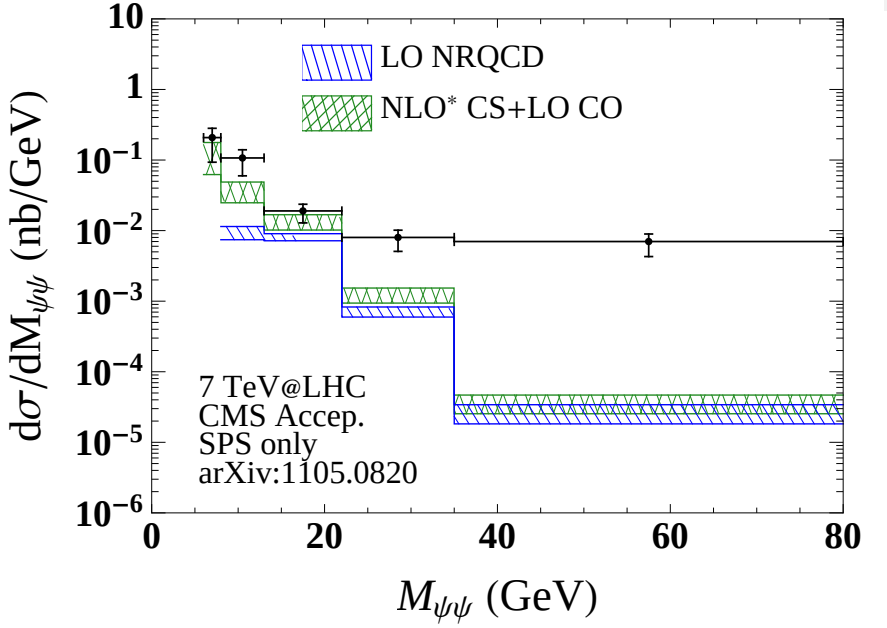

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- In terms of $\chi^2_{\mathrm{d.o.f}}$:

	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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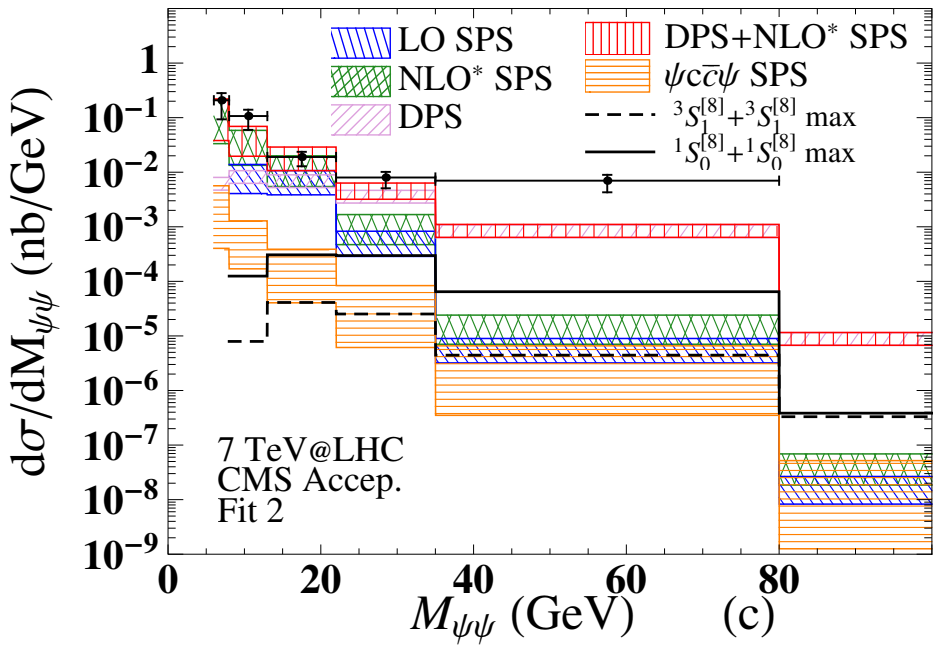

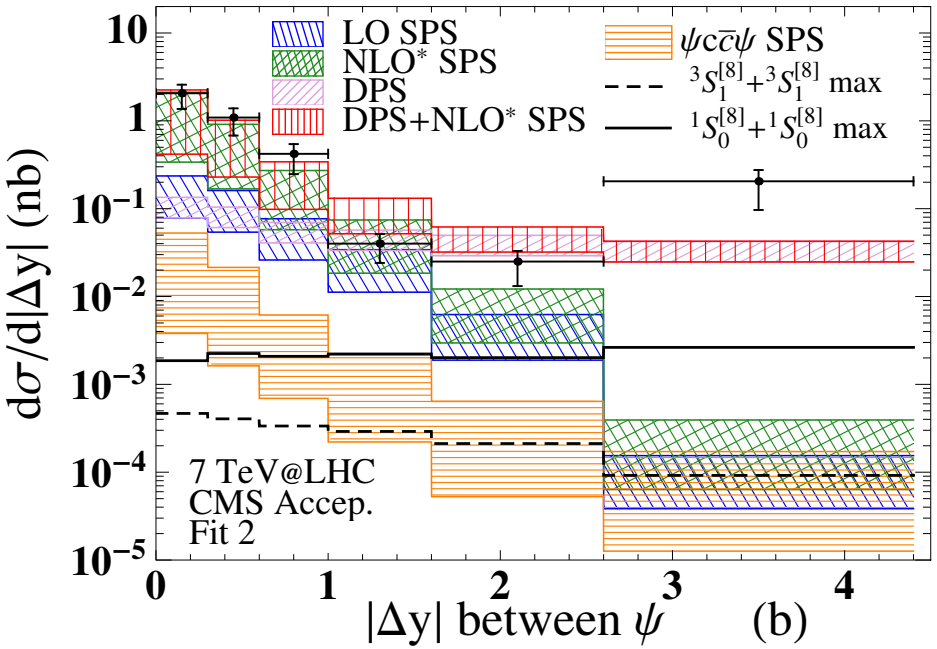

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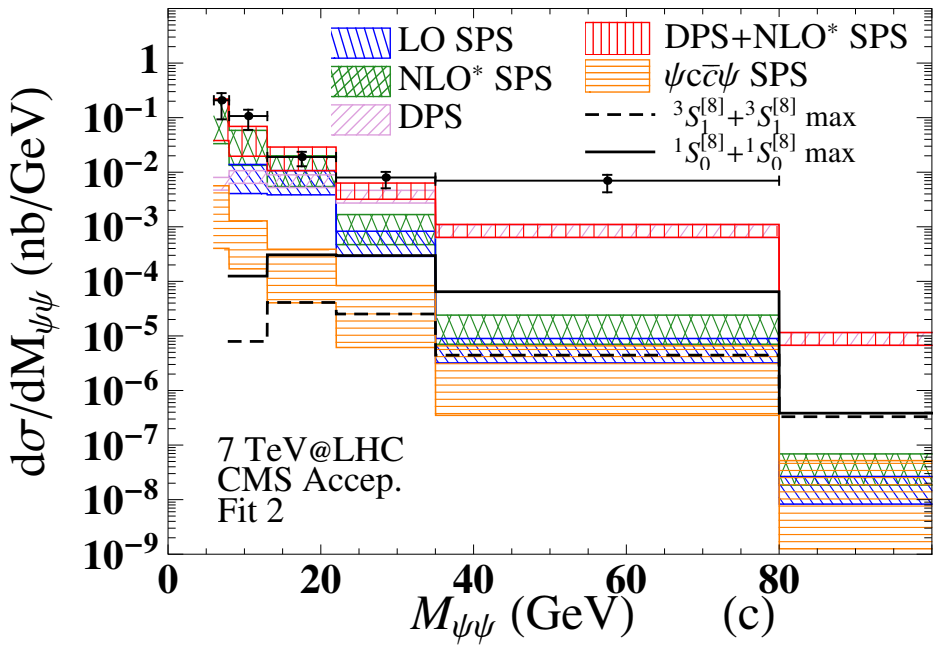
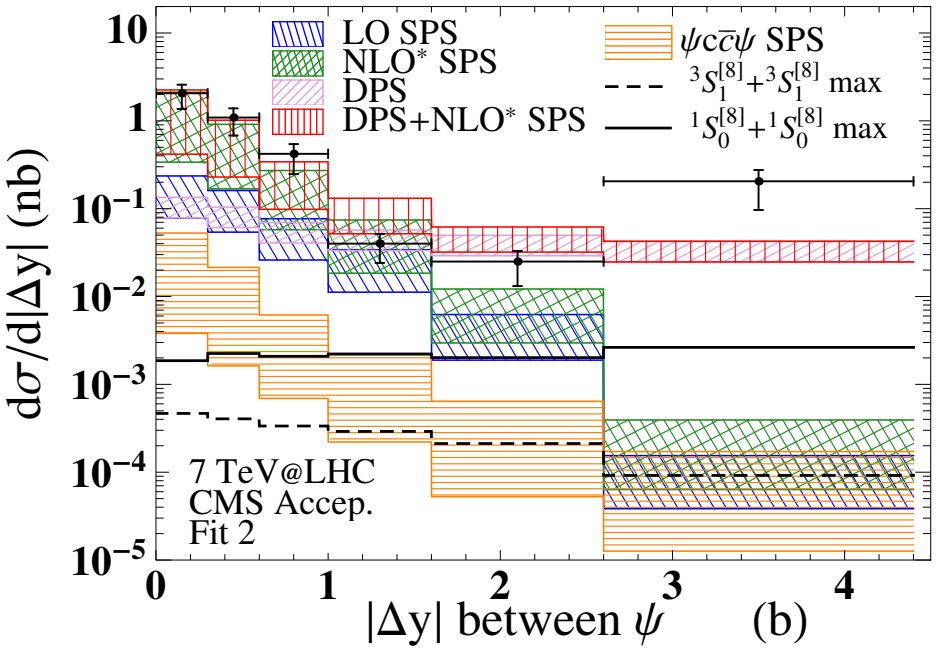
  [see the solid and dashed black lines]

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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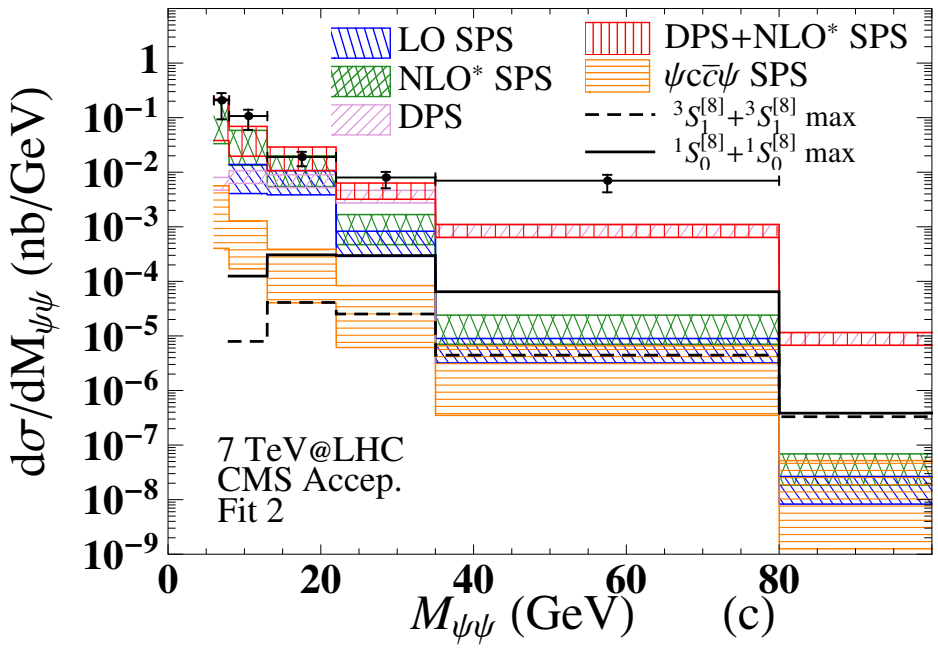

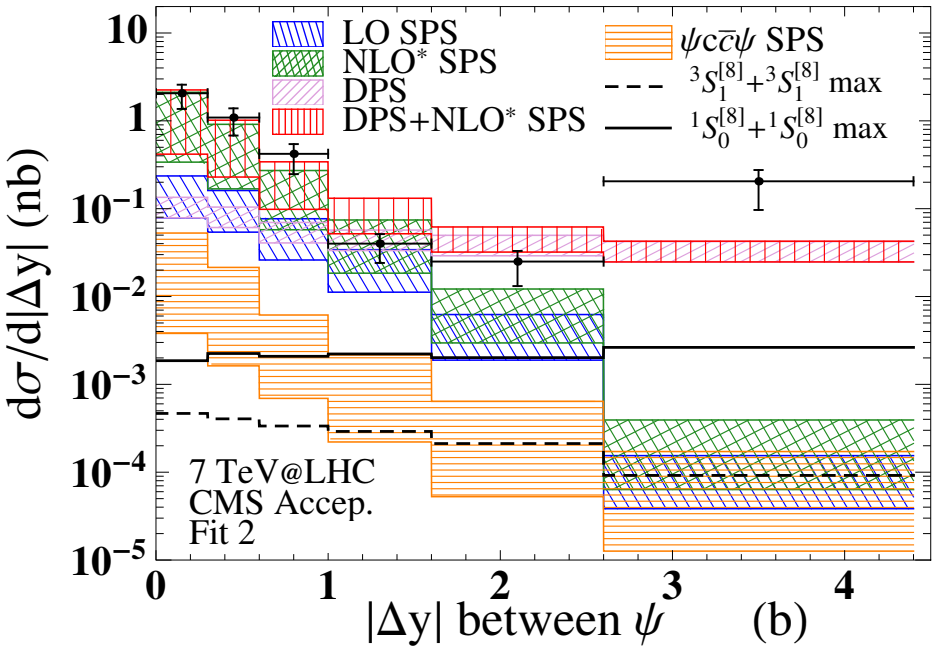

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  H. Han *et al.*PRL 114 (2015) 092005
- Ignoring all previous constraints and fitting (one channel at a time) the LDME on the CMS data one gets irrealistically large values:
  $\langle \mathcal{O}^{J/\psi}(^3S_1^{[8]})\rangle = 0.42\pm0.12$ GeV^3 & $\langle \mathcal{O}^{J/\psi}(^1S_0^{[8]})\rangle = 0.91\pm0.22$ GeV^3 !!!