Double-Parton-Scattering Theory Studies with Quarkonia

Jean-Philippe Lansberg
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Part I

Quick introduction to quarkonium production

Production Models: the current situation in one slide ...

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…not as clear now

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- All approaches have troubles in describing the polarisation and/or the η_c data
- This motivates the study of new observables

  which can be more discriminant for specific effects

Part II

New observables in quarkonium production

New observables: what for ?

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

Part III

Z+prompt J/ψ

Our re-analysis of Z+prompt J/ψ at NLO and with DPS

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- Significant tensions between the ATLAS measurement and the SPS NRQCD yields: normalisation, P_T and $\Delta\phi$ distributions

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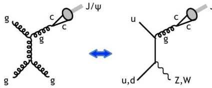

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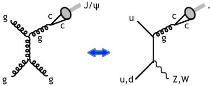
- we obtain (ATLAS quoted ratio converted to σ)



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ATLAS inclusive	1.6 ± 0.4	$0.10^{+0.03}_{-0.03}$	$0.19^{+0.05}_{-0.04}$	0.46

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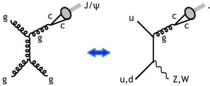

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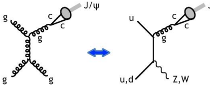

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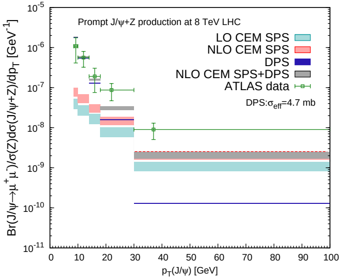

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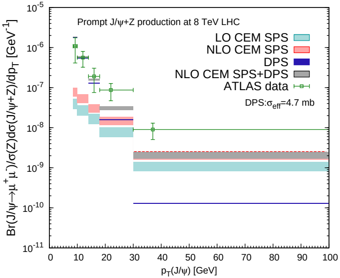

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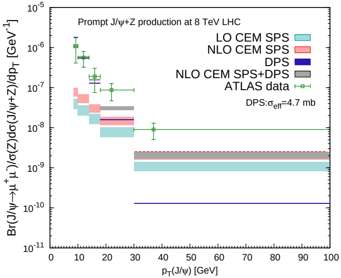

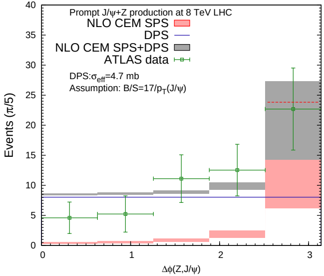

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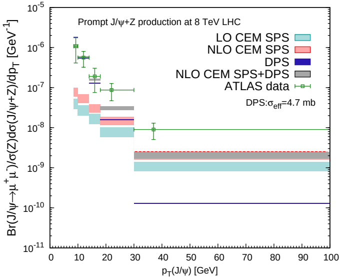

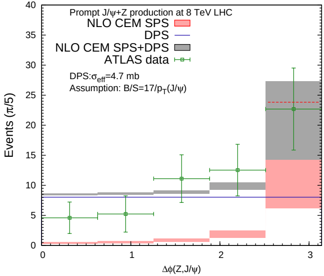

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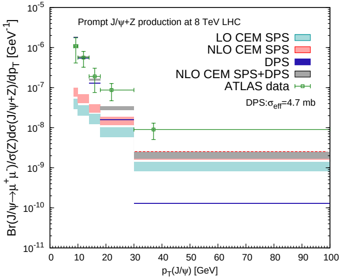

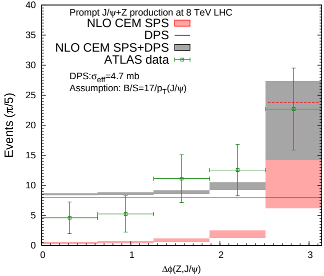

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- We are waiting for an ATLAS update to confirm our explanation

Part IV

Z+non-prompt J/ψ

Our analysis of Z+non-prompt J/ψ at NLO and with DPS

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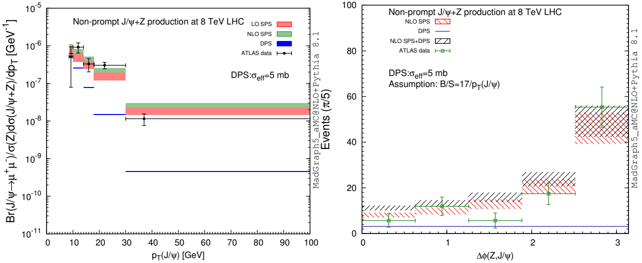
- This gives an original handle on $Z + b$ at lower P_T than b-jets
- Interesting check that nothing went wrong with the prompt analysis
- SPS predictions were absent at the time of the publication. We filled this gap using MadGraph5_aMC@NLO and Pythia 8.1.



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 $\sigma_{\rm eff}$ more than with a lower limit, 5.0 mb, at 68 % CL.

Part V

W+prompt J/ψ

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- DPS yield evaluated with $\sigma_{\rm eff} = 15$ mb is also too small
- Fitting $\sigma_{\rm eff}$ gives $6.1^{+3.3}_{-1.9}$ mb

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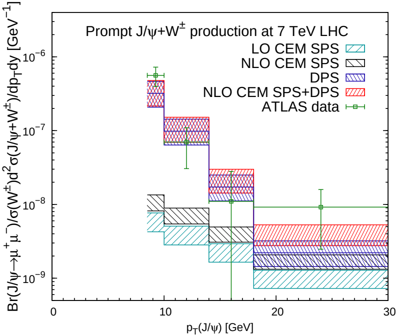
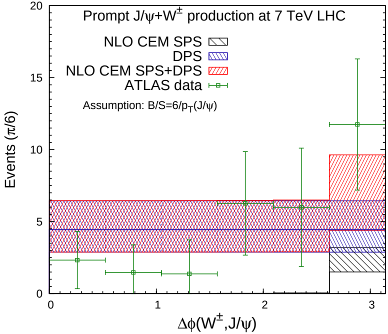
- Like for $Z + J/\psi$, DPS dominate at low P_T and SPS at large P_T in the ATLAS acceptance, [black histogram vs. the blue one]





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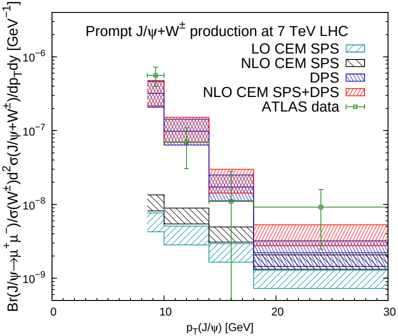

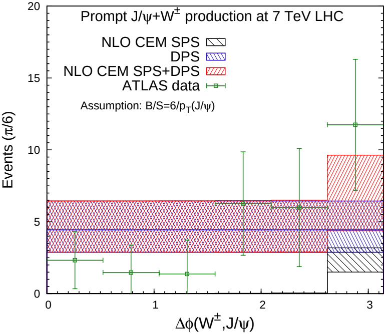

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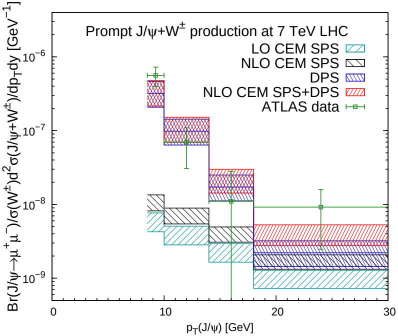

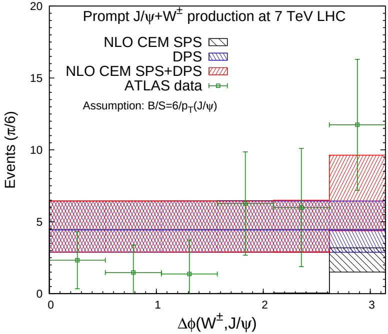

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- We are waiting for ATLAS data at 13 TeV

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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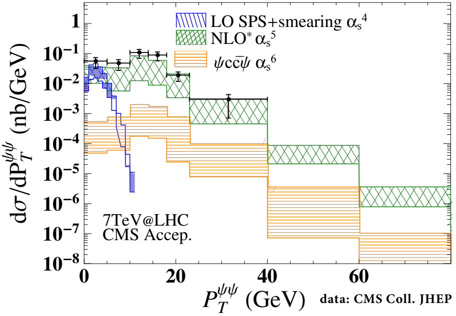

data: CMS Coll. JHEP 1409 (2014) 094

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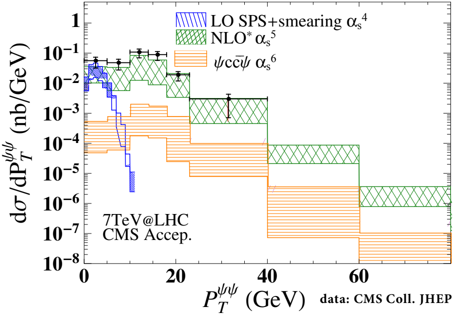

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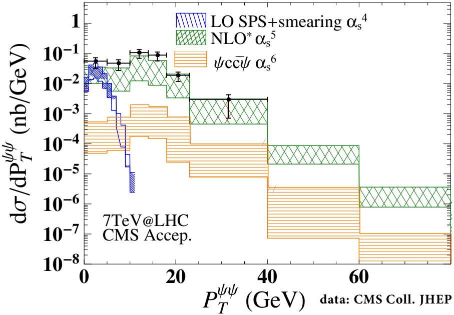

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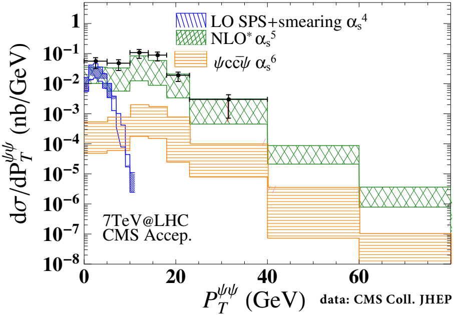

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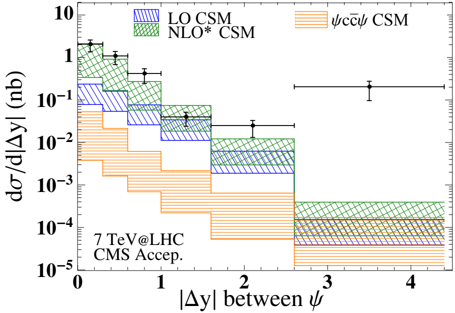
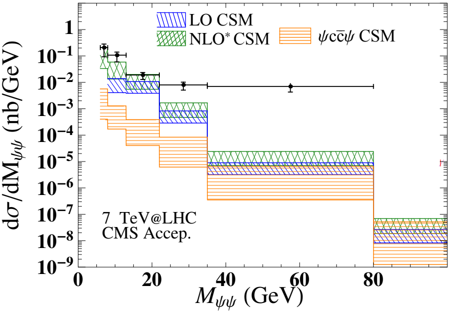
[the orange histogram shows one class of leading P_T α_s^6 contributions]

The so-called CMS puzzle





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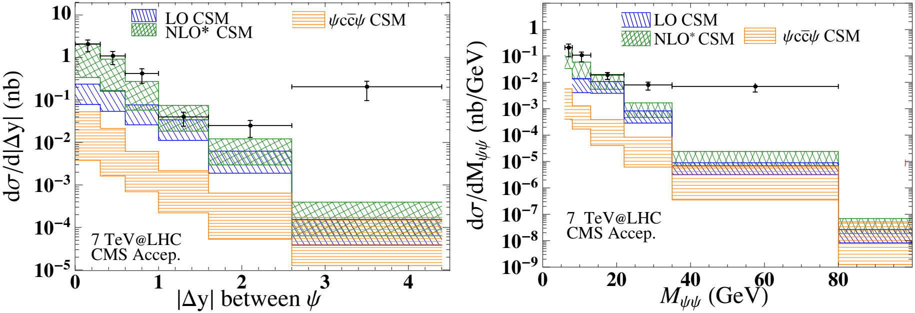

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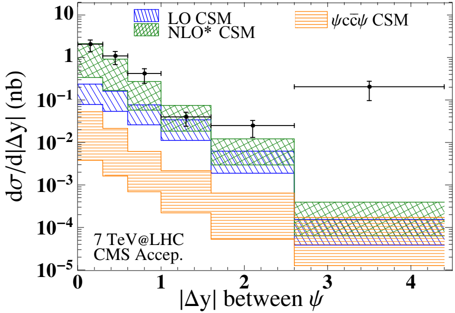

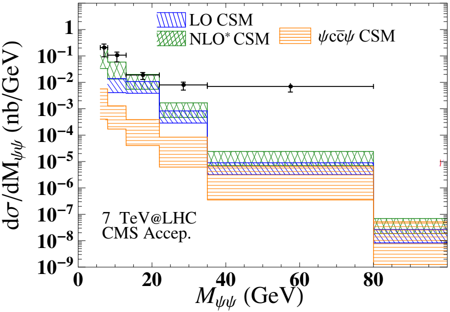

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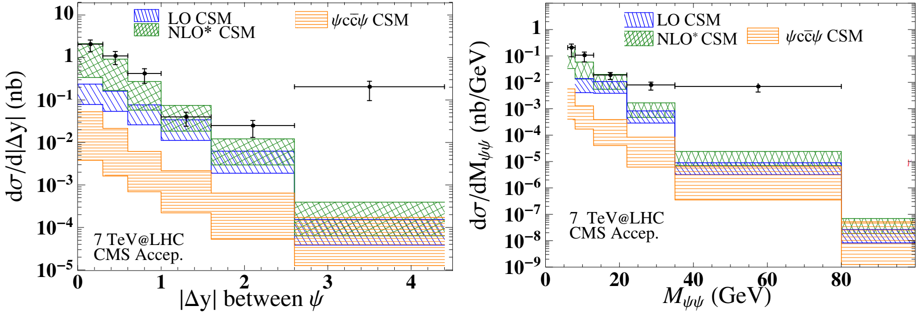

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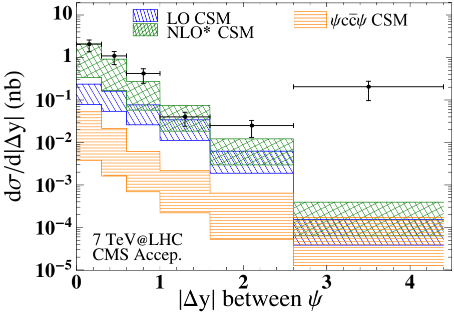

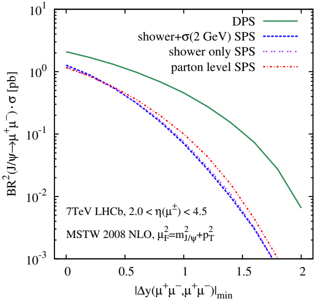

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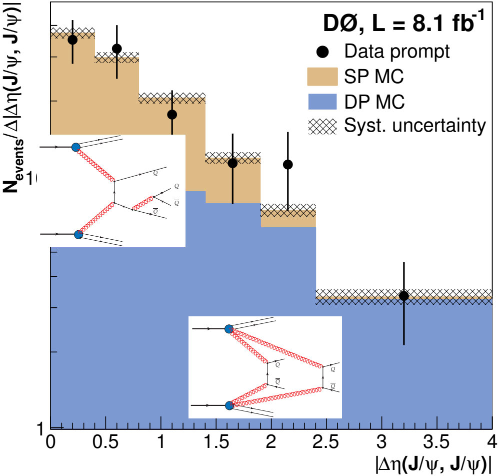
- Predictions for LHCb, DPS ≫ SPS at large Δy — **C.H. Kom, A. Kulesza, W.J. Stirling PRL 107 (2011) 082002**

On the importance of double parton scatterings at large Δy I

In fact, the argument of C.H. Kom, A. Kulesza, and W.J. Stirling was used by D0 to separate out DPS from SPS contributions



D0 Coll. PRD 90 (2014) 111101

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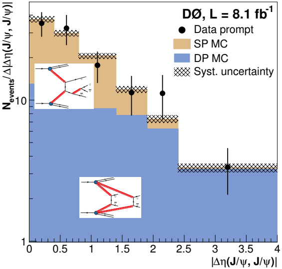

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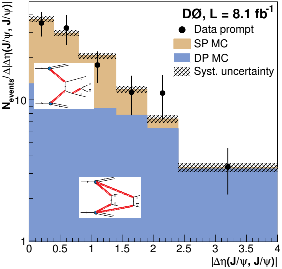

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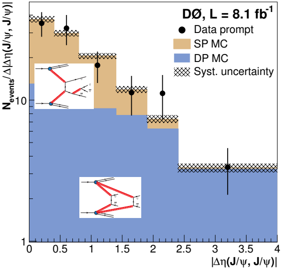

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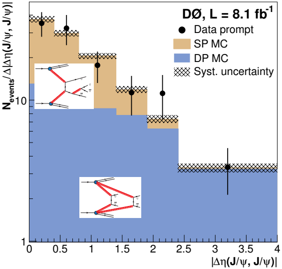

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- A question arises: using $\sigma^{\rm DPS} = \frac{1}{2}\frac{\sigma_\psi \sigma_\psi}{\sigma_{\rm eff}}$ and $\sigma_{\rm eff} = 4.8 \pm 2.5$ mb, can one account for the large Δy CMS data ?

On the importance of double parton scatterings at large Δy II

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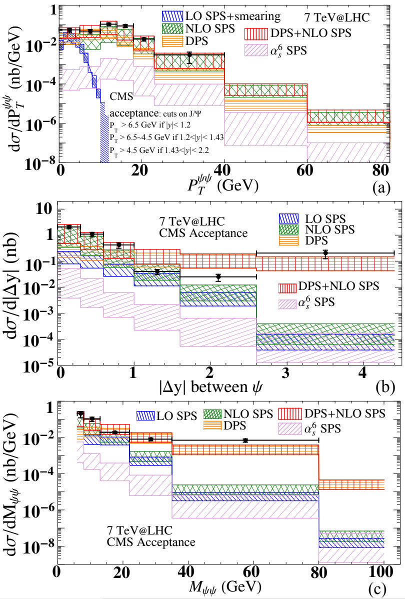

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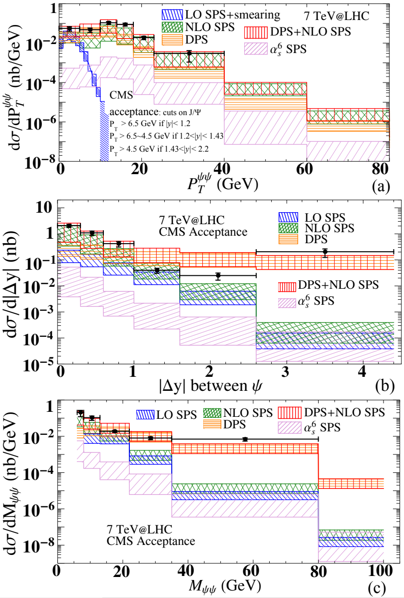

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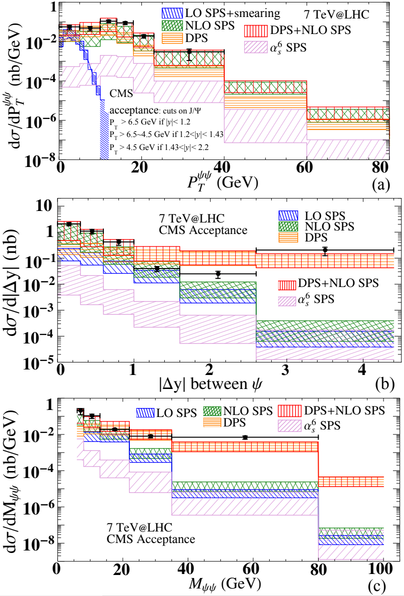

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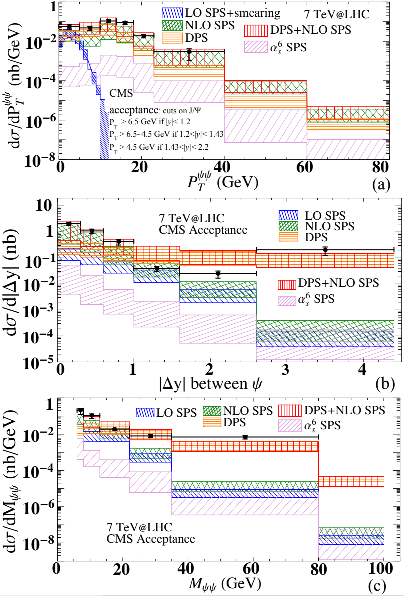
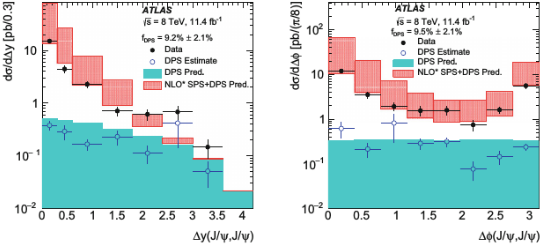
- Fit done prior the ATLAS analysis → good agreement !



Comparison with the recent ATLAS data

ATLAS Eur. Phys. J. C (2017) 77:76



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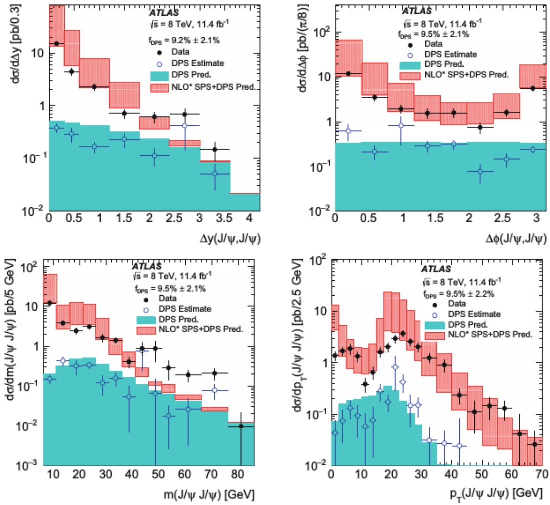

ATLAS extraction: $\sigma_{\rm eff} = 6.3 \pm 1.6(stat) \pm 1.0(syst) \pm 0.1(BF) \pm 0.1(lumi)$ mb

Predictions: excited states

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

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- Under SPS CSM dominance,
  - $F^{\psi'}_{\psi\psi}$ is slightly enhanced by symmetry factors,
  - $F^{\chi_c}_{\psi\psi}$, unlike single quarkonium production, is not enhanced and is found to be small

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  - $F^{\chi_c}_{\psi\psi}$, unlike single quarkonium production, is not enhanced and is found to be small
- Overall :

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

Harvesting quarkonium data: 4 extractions using theory

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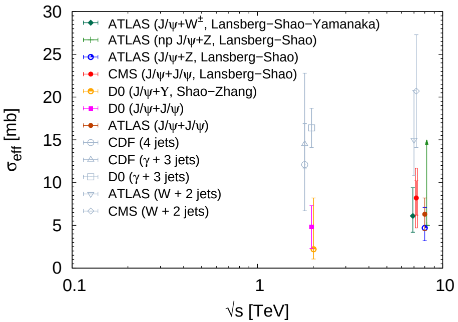

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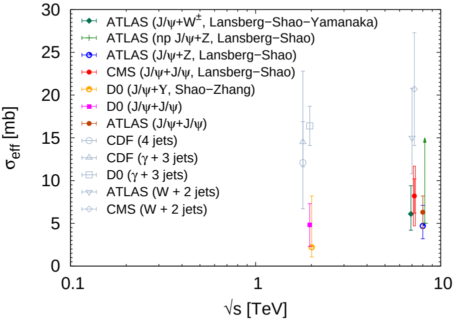

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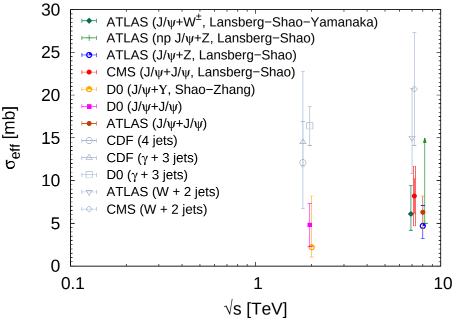

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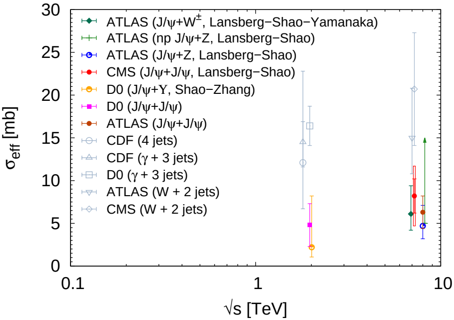

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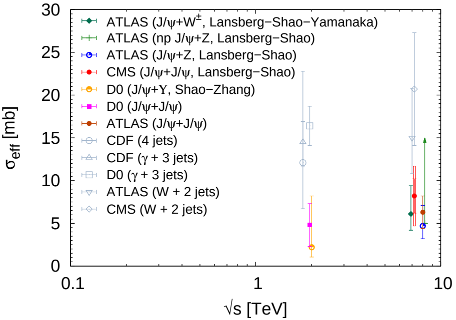

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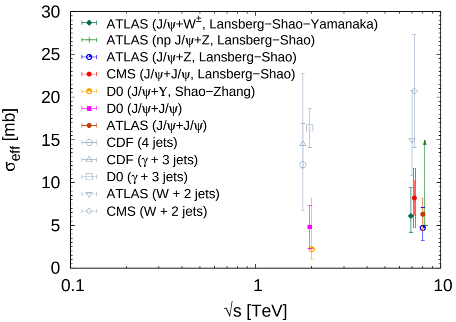

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CMS JHEP05(2017)013

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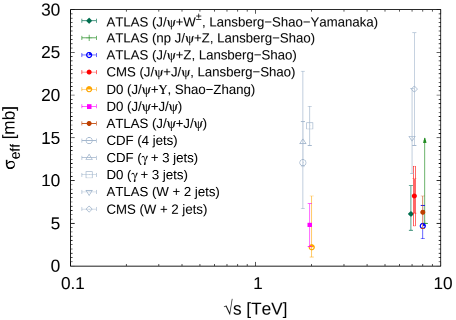

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CMS JHEP05(2017)013

- D0 $J/\psi + \Upsilon$ data clearly points at a very large DPS

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

Part VII

Conclusion

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- Still for di-J/ψ, this provide evidence for
  - (i) the dominance of α_s^4 (LO) CS SPS contributions for the total cross section,
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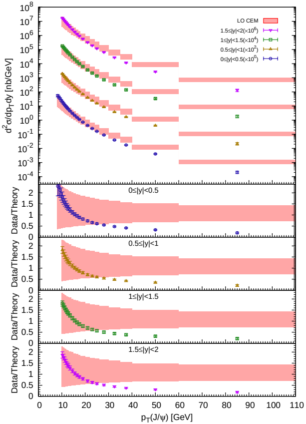
- Hint at a flavour dependence of σ_{eff} ?
- There could also kinematical dependences involved **See e.g. B. Blok M. Strikman EPJC 76 (2016) 694**

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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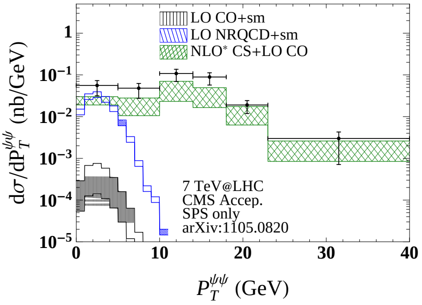

Single J/ψ LDME fit: M. Butenschoen, B. Kniehl arXiv:1105.0820, PRD 84 (2011) 0515

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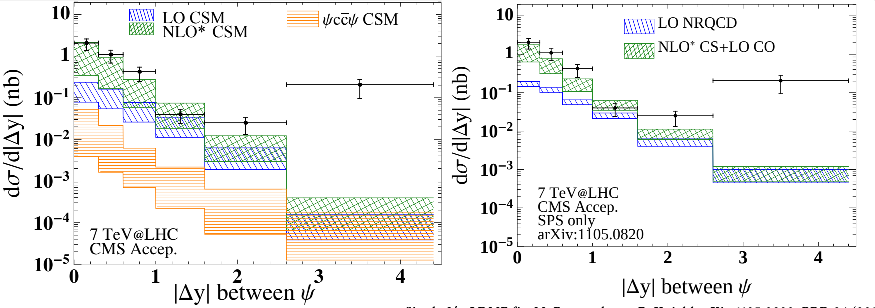

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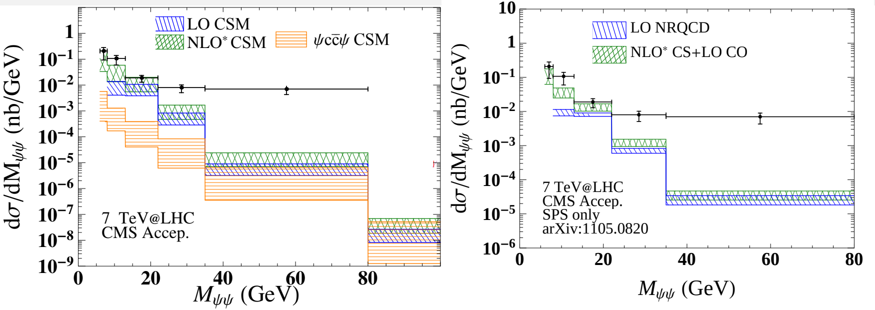

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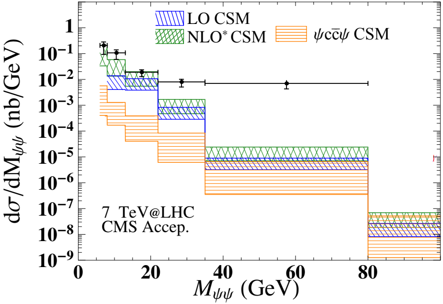

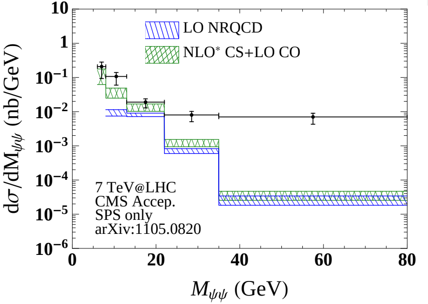

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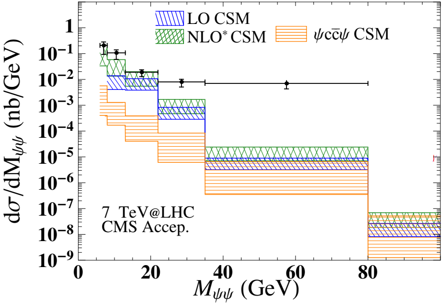

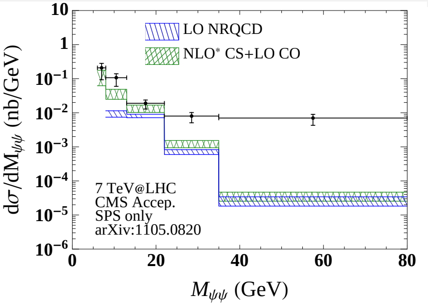

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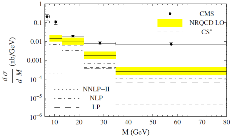

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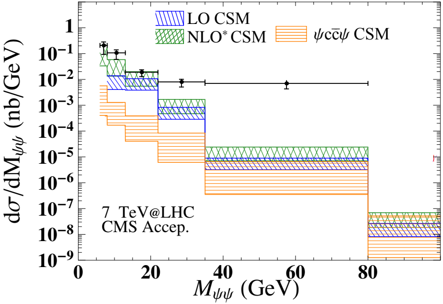

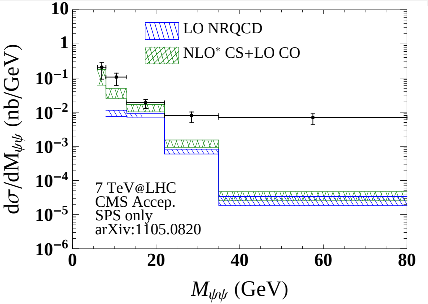

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- In terms of $\chi^2_{\rm d.o.f}$:

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

Another way to see this with 2 CO channels

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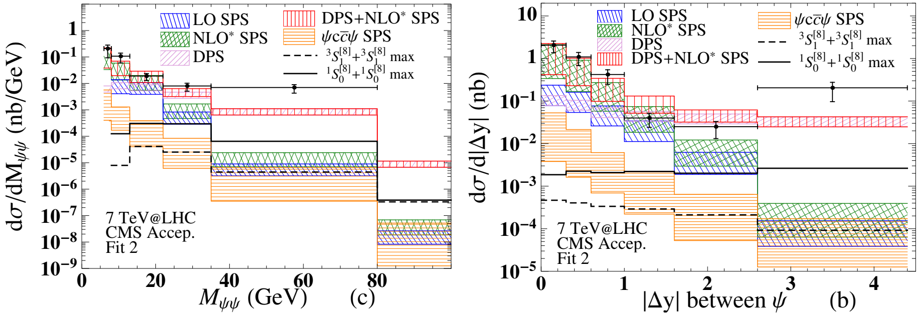

- Using for the upper bound: $\langle \mathcal{O}^{J/\psi}(^3S_1^{[8]})\rangle < 2.8 \times 10^{-3}$ GeV^3 & $\langle \mathcal{O}^{J/\psi}(^1S_0^{[8]})\rangle < 5.4 \times 10^{-2}$ GeV^3

  [see the solid and dashed black lines]

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

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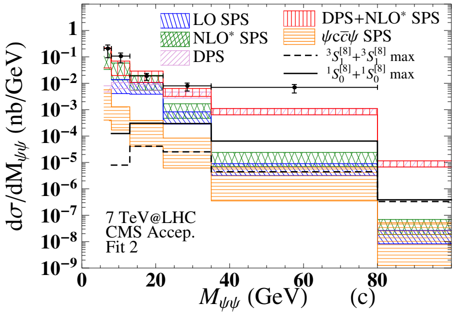

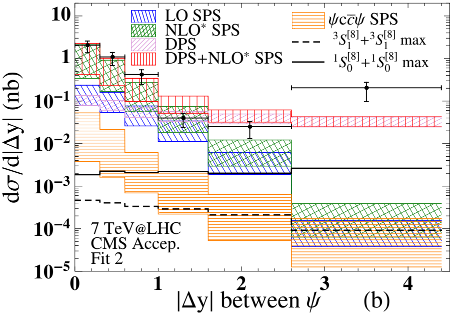

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- Nota: η_c data : $\langle^{J/\psi}({}^1S_0^{[8]})\rangle = \langle^{\eta_c}({}^3S_1^{[8]})\rangle < 1.46\times10^{-2}$ GeV^3

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

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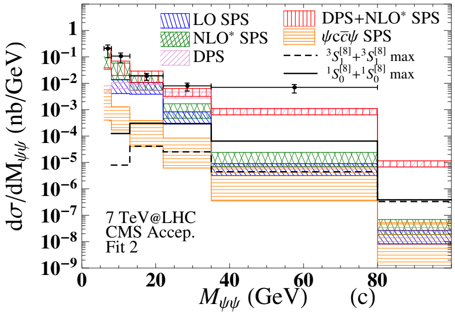

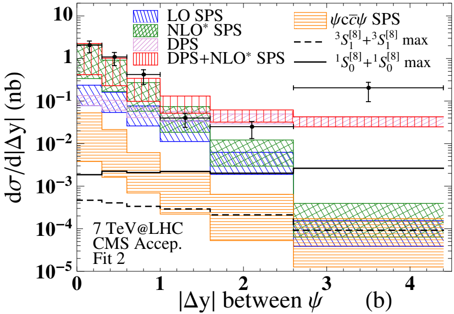

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H. Han *et al.*PRL 114 (2015) 092005

- Ignoring all previous constraints and fitting (one channel at a time) the LDME on the CMS data one gets irrealistically large values:
  $\langle \mathcal{O}^{J/\psi}(^3S_1^{[8]})\rangle = 0.42 \pm 0.12$ GeV^3 & $\langle \mathcal{O}^{J/\psi}(^1S_0^{[8]})\rangle = 0.91 \pm 0.22$ GeV^3 !!!