Associated quarkonium production with LHCb

Jean-Philippe Lansberg

Mini-workshop on charmonium production at LHCb,
June 16, 2017, CERN

Part I

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

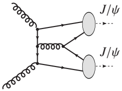
Part II

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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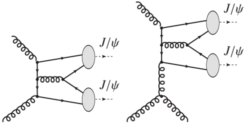

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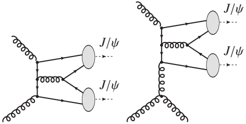

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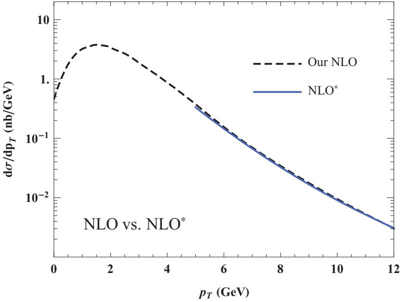
L.P. Sun *et al.* arXiv:1404.4042 [hep-ph]



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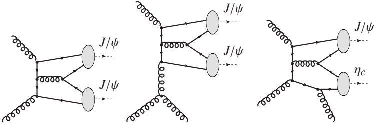

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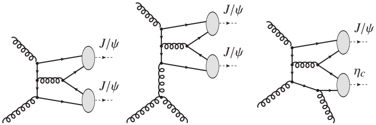

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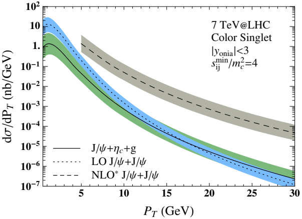

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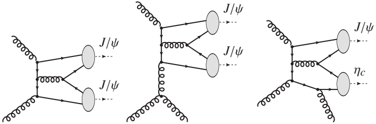

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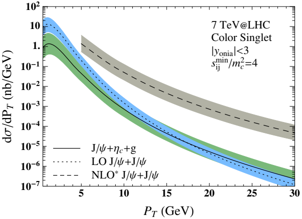

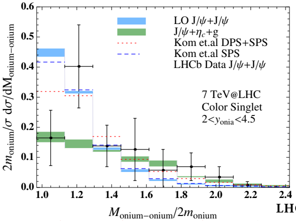

LHCb PLB 707 (2012) 52

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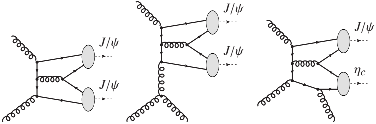

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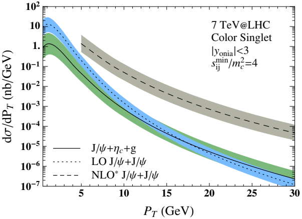

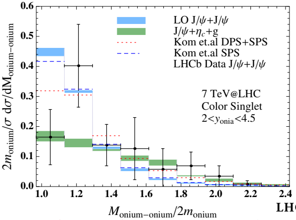

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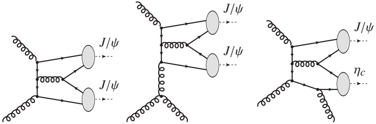

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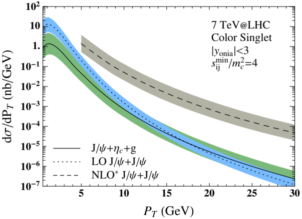

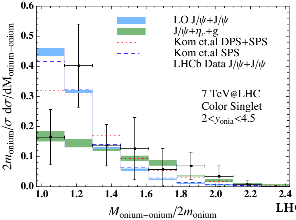

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Only CSM SPS at low P_T?

- $J/\psi + \eta_c$: look for η_c in the J/ψ sample ? Avoid trigger issues ?

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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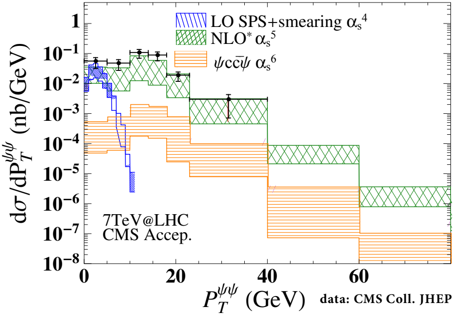

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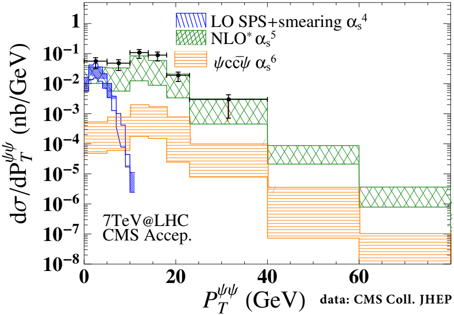

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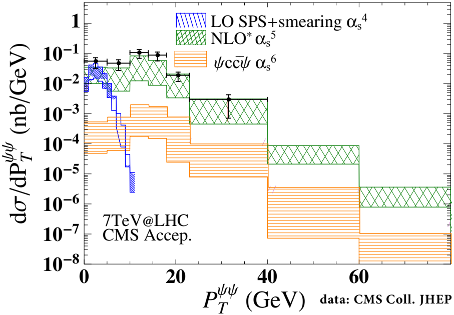

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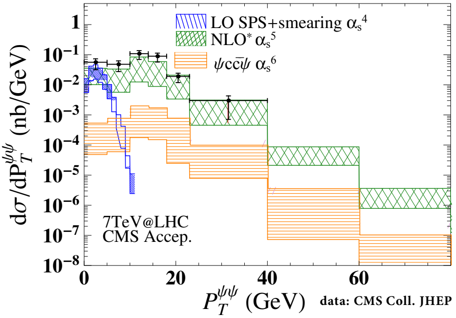

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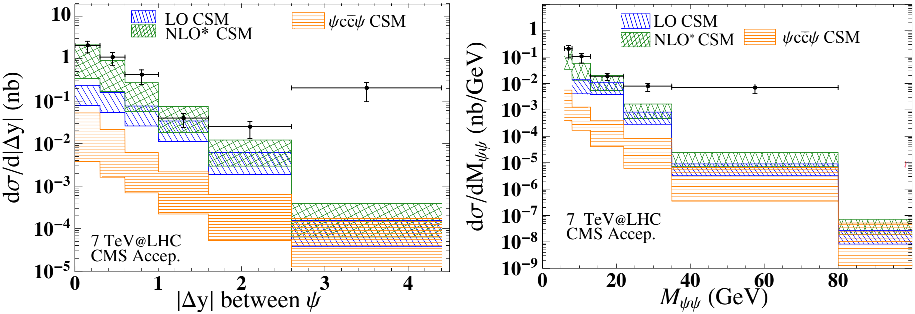
- We do not expect NNLO (α_s^6) contributions to matter where one currently has data

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

The so-called CMS puzzle



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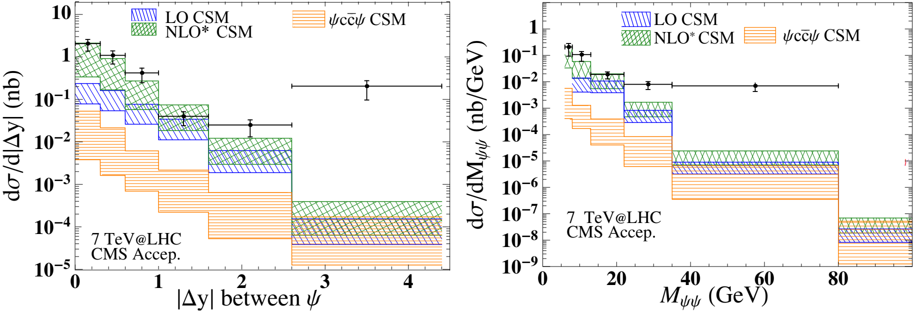

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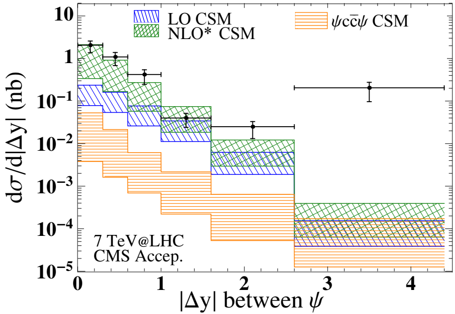

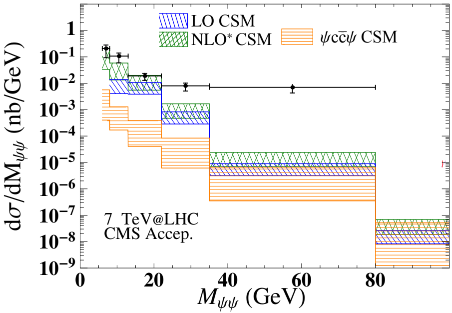

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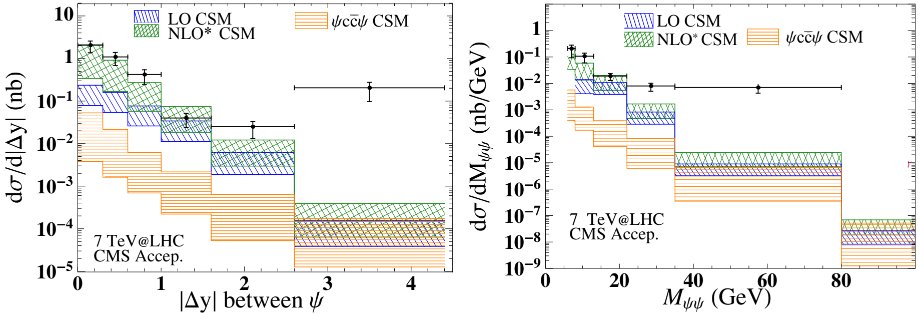

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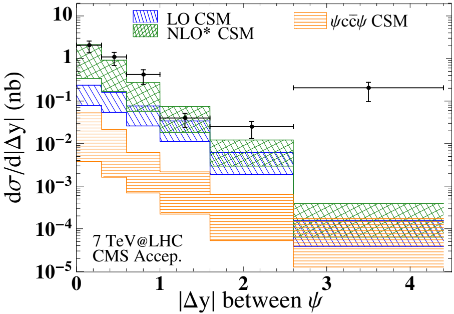

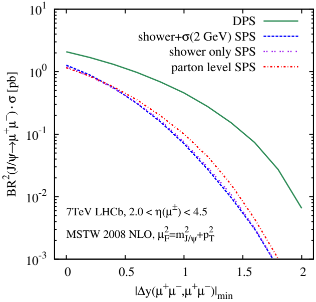

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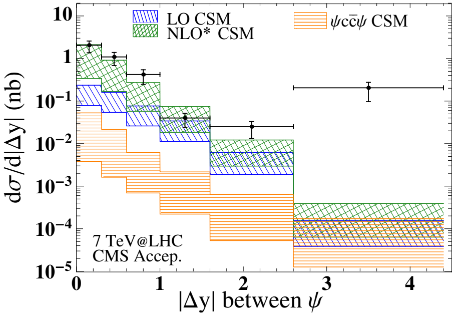

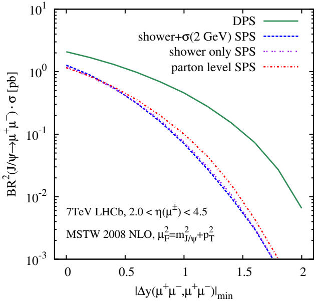

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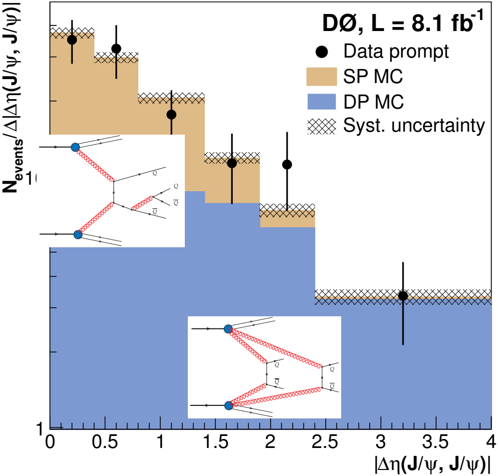
- He & Kniehl found at LO that CO ≫ CS at large Δy; yet still in disagreement with the data; NLO needed !

Z. He, B. Kniehl PRL 115, 022002 (2015)

On the importance of double parton scatterings at large Δy I

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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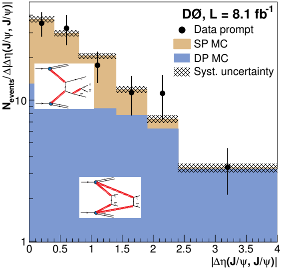

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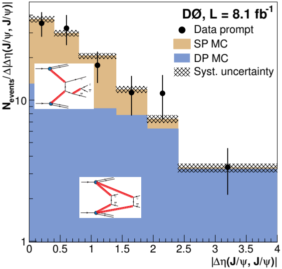

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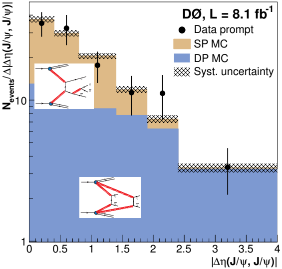

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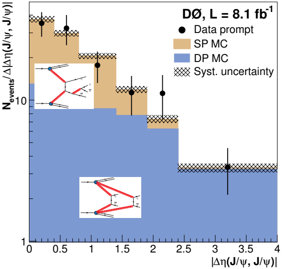

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- A question arises: using $\sigma^{\rm DPS} = \frac{1}{2}\frac{\sigma_\psi \sigma_\psi}{\sigma_{\rm eff}}$ and $\sigma_{\rm eff} = 4.8 \pm 2.5$ mb, can one account for the large Δy CMS data ?

On the importance of double parton scatterings at large Δy II

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

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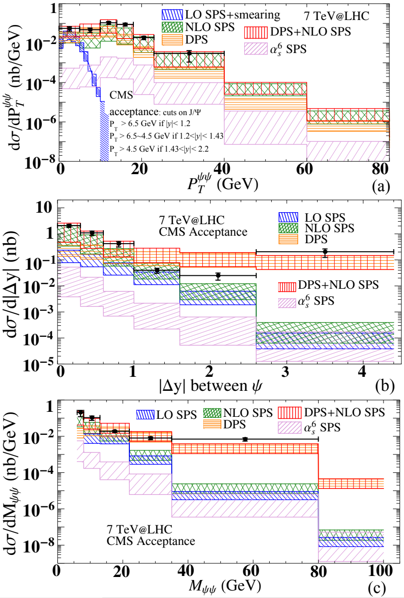

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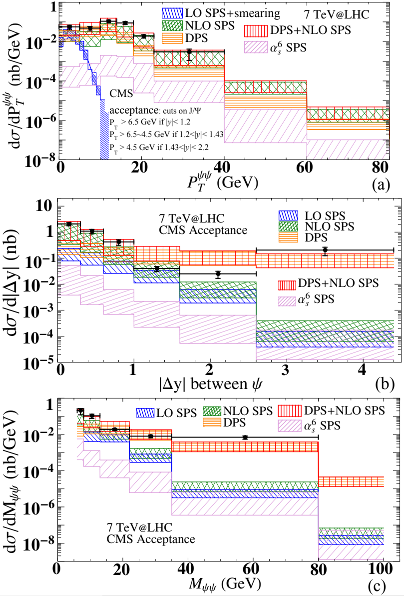

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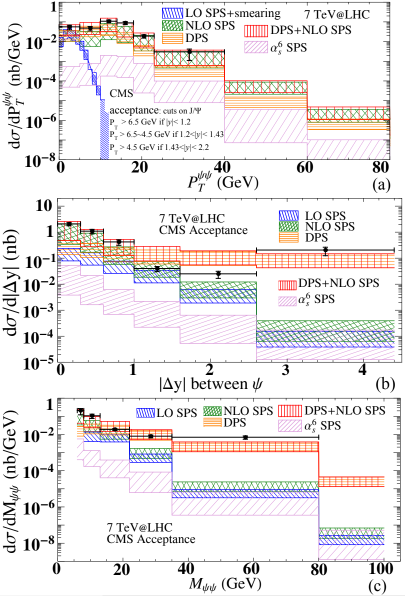

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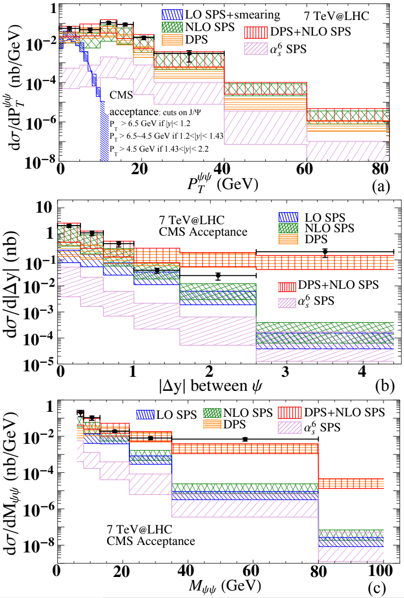

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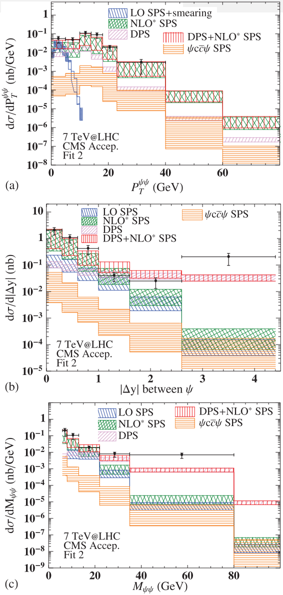

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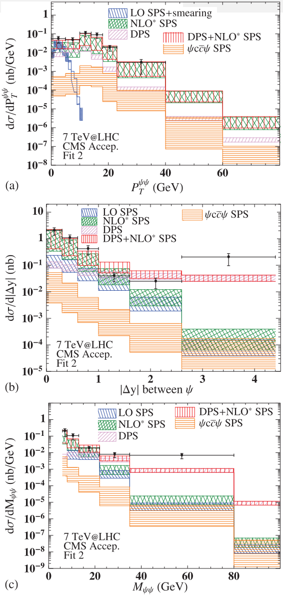

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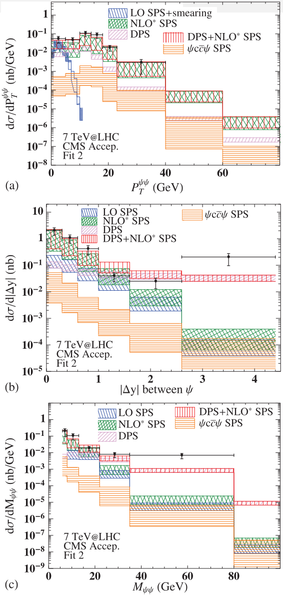

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Result of the fit of the DPS yield via σ_{eff} on the 18 CMS values.

	σ_{eff} [mb]	$\chi^2_{\text{d.o.f.}}$	d.o.f.
σ_ψ Fit 1 [25]	11 ± 2.9	1.9	16
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Only LO SPS	N/A	7.6	17
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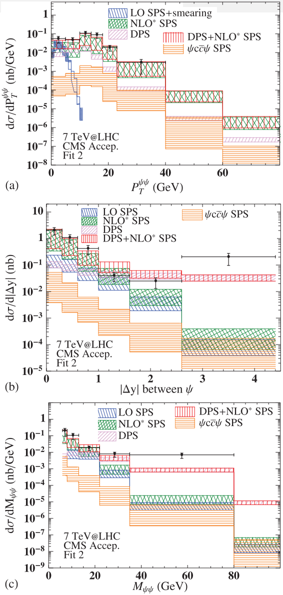

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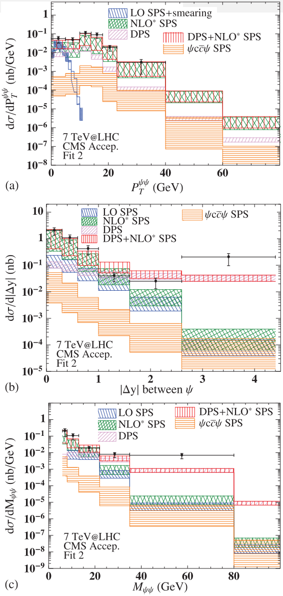

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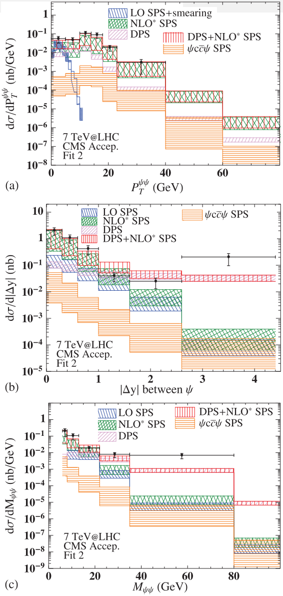
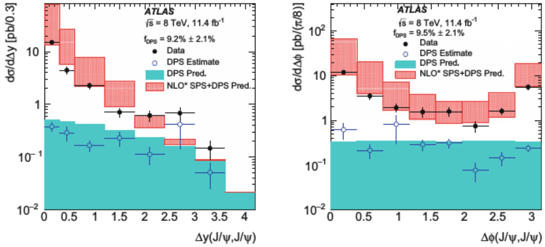
- Best agreement with Fit 3 confirming the consistency: $\sigma_{\text{eff}} = 4.8 \pm 2.5$ mb vs $\sigma_{\text{eff}} = 5.3 \pm 1.4$ mb



Comparison with ATLAS data

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



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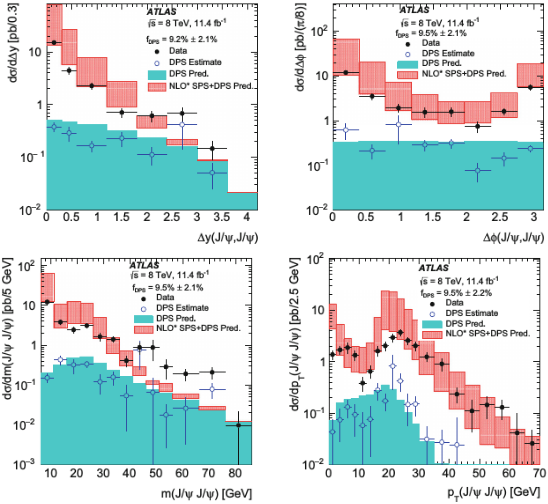

ATLAS extraction: $\sigma_{\text{eff}} = 6.3 \pm 1.6(stat) \pm 1.0(syst) \pm 0.1(BF) \pm 0.1(lumi)$ mb.

Harvesting new quarkonium data

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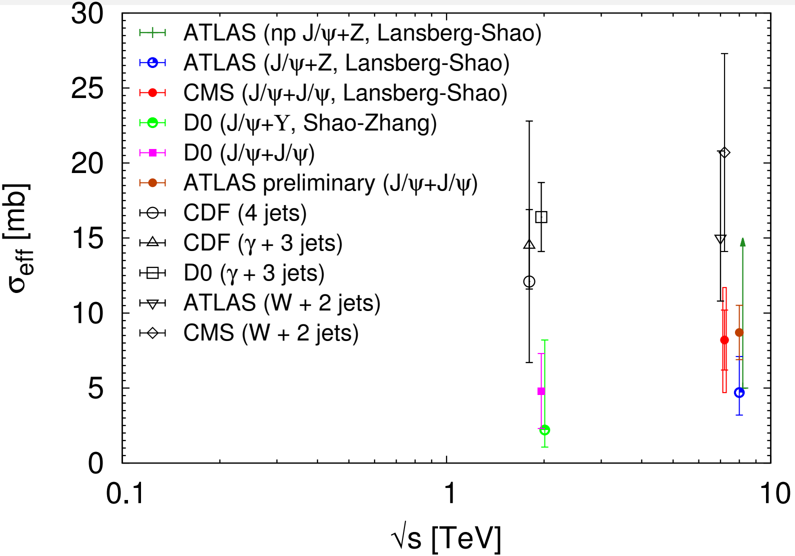

4 quarkonium extractions using theory ingredients !

Comparison with the new LHCb data at 13 TeV

LHCb JHEP06(2017)047

$\sigma(\psi\psi)$nb	no P_T cut	$P_T > 1$ GeV	$P_T > 3$ GeV
NLO* CS	$15.4 \pm 2.2^{+51}_{-12}$	$14.8 \pm 1.7^{+53}_{-12}$	$6.8 \pm 0.6^{+22}_{-5}$
NLO CS	$11.9^{+4.6}_{-3.2}$	—	—
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- REMINDER: it is not an option to "switch off"/ignore the NLO CS contribution [parameter free]
- Yet, room for DPS; however tension if $\sigma_{\text{eff}} \simeq 7$ mb
- Tension between LHCb and other di-J/ψ extractions [rapidity effect ?]

Predictions: excited states and more

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

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- Hence the importance of measuring $J/\psi + \psi'$ and $J/\psi + \chi_c$
- Back to the first slide, $J/\psi + \eta_c$ can also tell something about DPS and about $\sigma_{\rm eff}$

Part III

Charmonium + charm

Double charm: $J/\psi + D$

→ $J/\psi + D$ or J/ψ+lepton in the yield integrated over P_T

S. J. Brodsky and JPL, PRD 81 051502 (R), 2010

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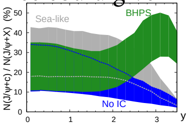

plot for RHIC kinematics

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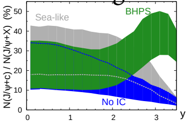

plot for RHIC kinematics

→ $J/\psi + D$ or J/ψ+lepton at large P_T (say, $P_T > 15$ GeV)

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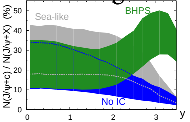

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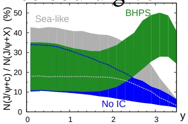

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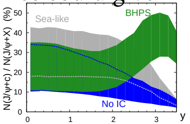

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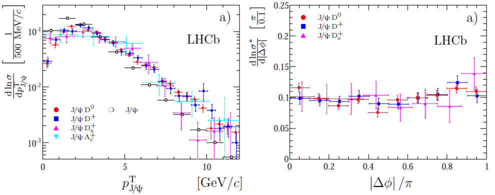

LHCb, JHEP 1206 (2012) 141

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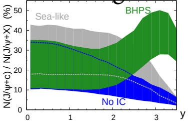

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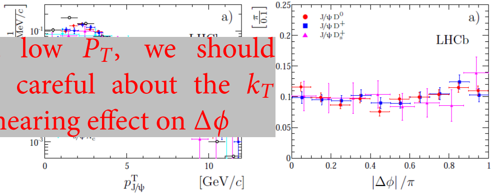

At low P_T, we should be careful about the k_T smearing effect on $\Delta\phi$

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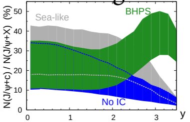

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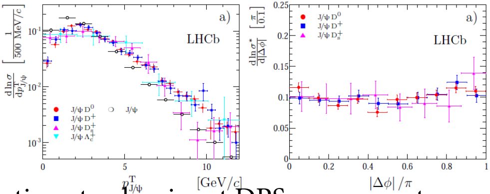

LHCb, JHEP 1206 (2012) 141

→ Yet, rates are hinting at a dominant DPS component [σ_{eff} above 10 mb ?]

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- $D + \chi_c$ necessary to complete the picture [confirm DPS dominance or ?]

Part IV

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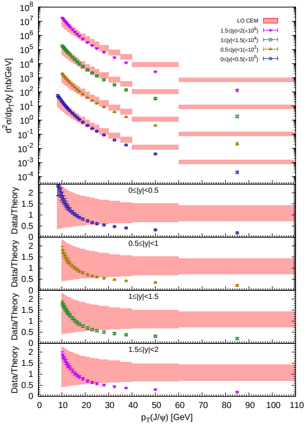
- Hint at a flavour dependence of σ_{eff} ?
- As outlooks, TMD-oriented studies using associated quarkonium production should now become possible for di-J/ψ, $\Upsilon + \gamma$, later for $\mathcal{Q} + \ell^+\ell^-$

W. den Dunnen, JPL, C. Pisano, M. Schlegel, PRL 112, 212001 (2014); JPL, C. Pisano, M. Schlegel, NPB 920 (2017) 192; JPL.

Part V

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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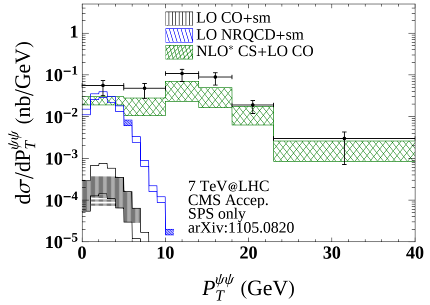

Single J/ψ LDME fit: M. Butenschoen, B. Kniehl arXiv:1105.0820, PRD 84 (2011) 0515

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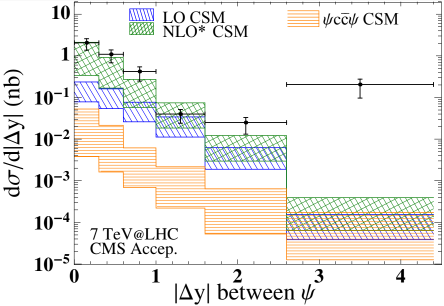

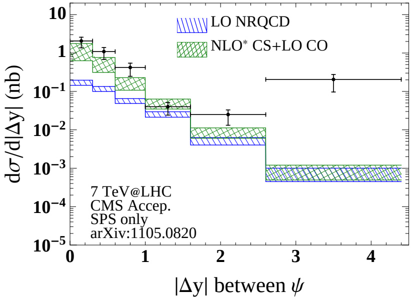

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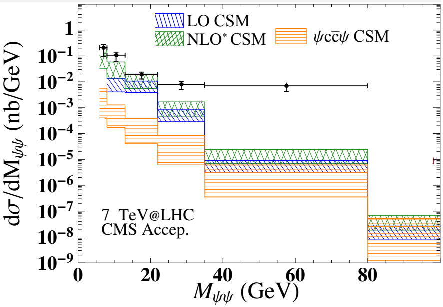

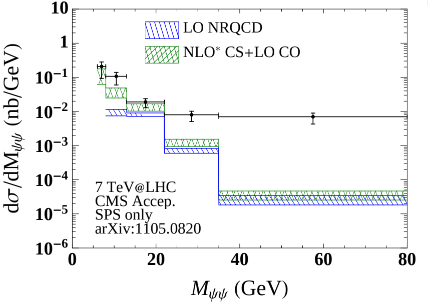

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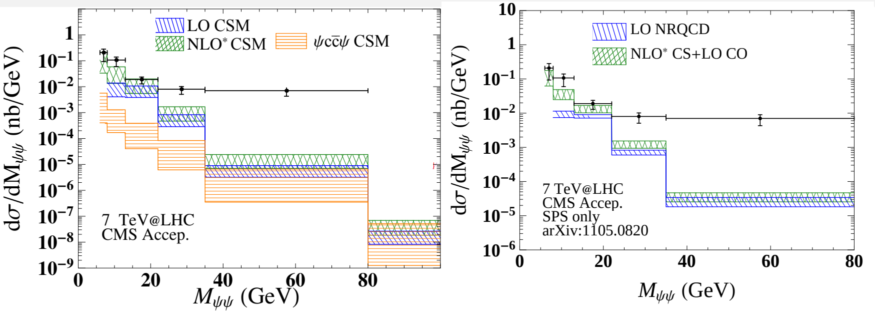

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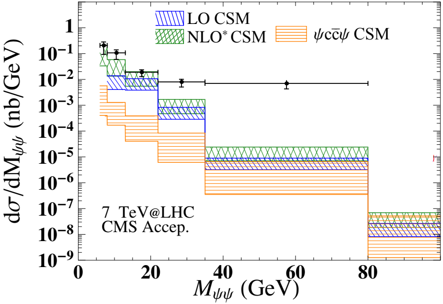

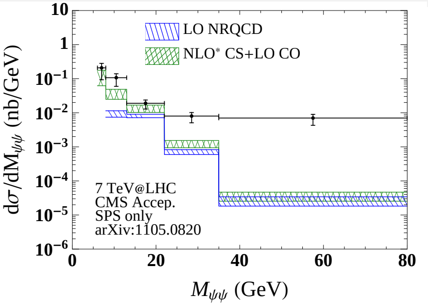

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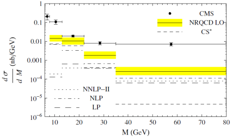

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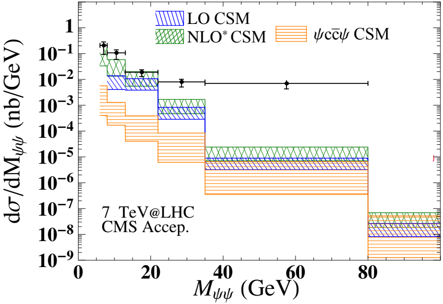

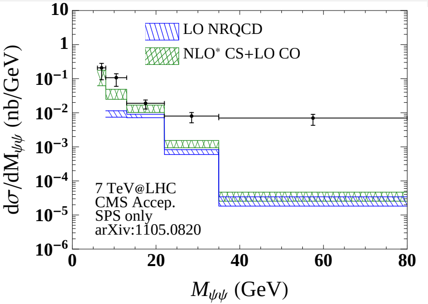

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- In terms of $\chi^2_{\rm d.o.f}$:

	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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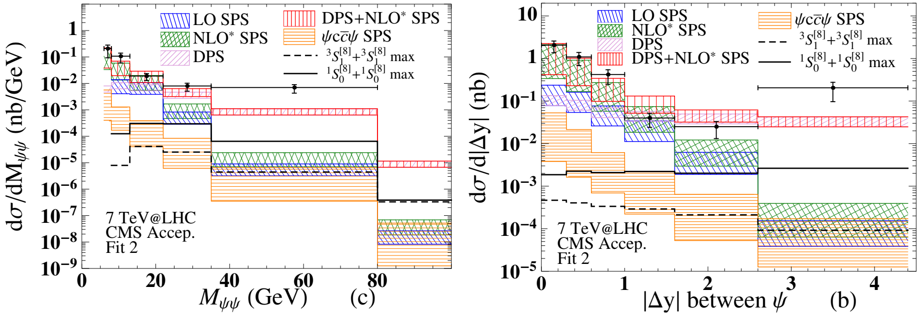

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JPL, H.-S.Shao PLB 751 (2015) 479

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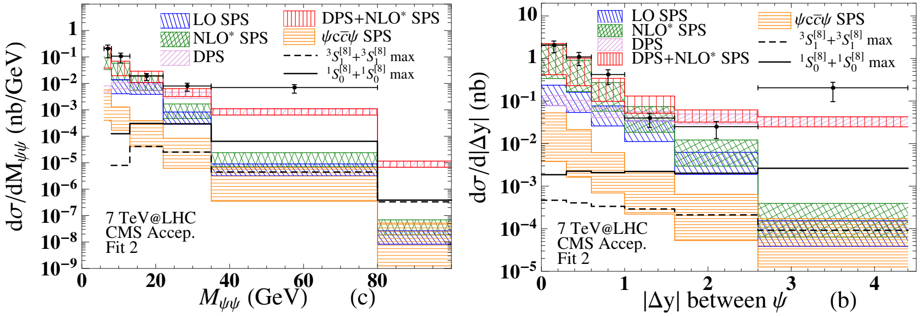

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H. Han *et al.*PRL 114 (2015) 092005

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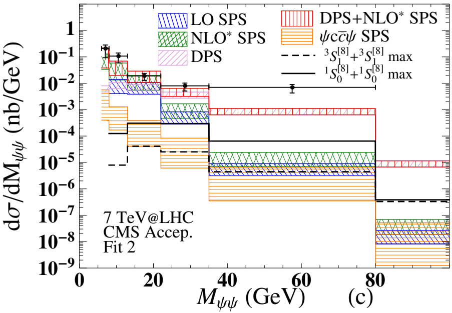

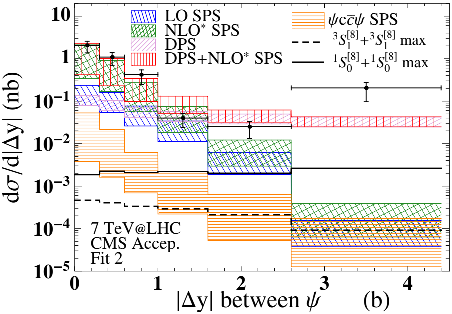

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  H. Han ***et al.*** **PRL 114 (2015) 092005**
- Ignoring all previous constraints and fitting (one channel at a time) the LDME on the CMS data one gets irrealistically large values:
  $\langle \mathcal{O}^{J/\psi}({}^3S_1^{[8]})\rangle = 0.42 \pm 0.12$ GeV^3 & $\langle \mathcal{O}^{J/\psi}({}^1S_0^{[8]})\rangle = 0.91 \pm 0.22$ GeV^3 !!!