Accessing double parton scatterings with associated-quarkonium production

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Picture taken by A. Lardeux at ''Quarkonia as Tools'', Aussois, Jan. 2019

Part I

Introduction

Approaches to (Inclusive) Quarkonium Production

See JPL, arXiv:1903.09185 [hep-ph] for a recent review.

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  3. Colour Octet Mechanism (encapsulated in NRQCD): higher Fock states of the mesons taken into account; $Q\bar{Q}$ can be produced in octet states with different quantum # as the meson; bleaching with semi-soft gluons ?

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…not as clear now

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- However, as we will now see, these offer new ways to study DPS

Part II

New observables in quarkonium production

Associated-quarkonium production

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See section 3 of JPL, arXiv:1903.09185 [hep-ph]

Observables	Experiments	CSM	CEM	NRQCD	Interest
J/ψ+J/ψ	LHCb, CMS, ATLAS, D0 (+NA3)	NLO, NNLO*	LO ?	LO	Prod. Mechanism (CS dominant) + DPS + gluon TMD
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	NLO	NLO (?)	Prod. Mechanism (CO dominant) + DPS
J/ψ vs mult.	ALICE,CMS (+UA1)	--	--	--	Initial vs Final state effects ?
J/ψ in jet.	LHCb, CMS	LO	--	LO	Prod. Mechanism (?)
J/ψ(ϒ) + jet	--	--	--		Prod. Mechanism (QCD corrections)
Isolated J/ψ(ϒ)	--	--	--	--	Prod. Mechanism (CS dominant ?)
J/ψ+b	--	--	--	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 + gluon TMD

On the importance of QCD corrections to $J/\psi + J/\psi$ production

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- At Born (LO) order, the $P_T^{\psi\psi}$ spectrum is $\delta(P_T^{\psi\psi})$: $2 \to 2$ topologies

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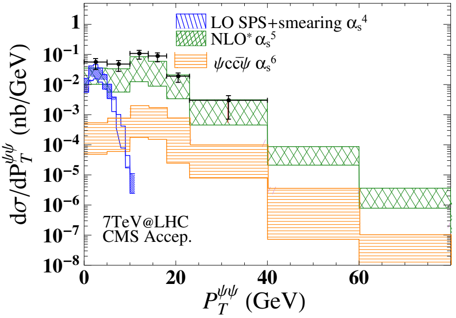

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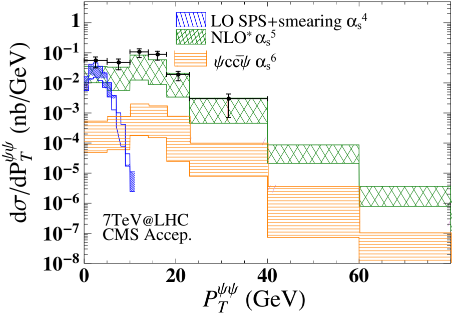

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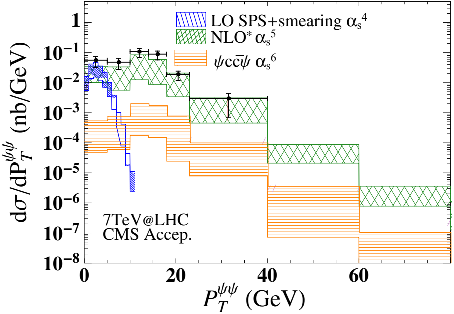

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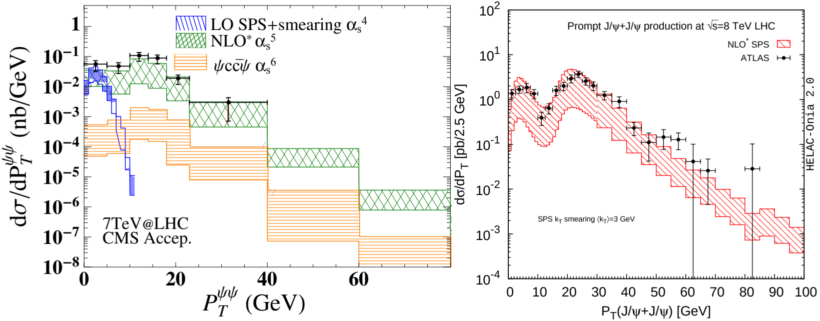

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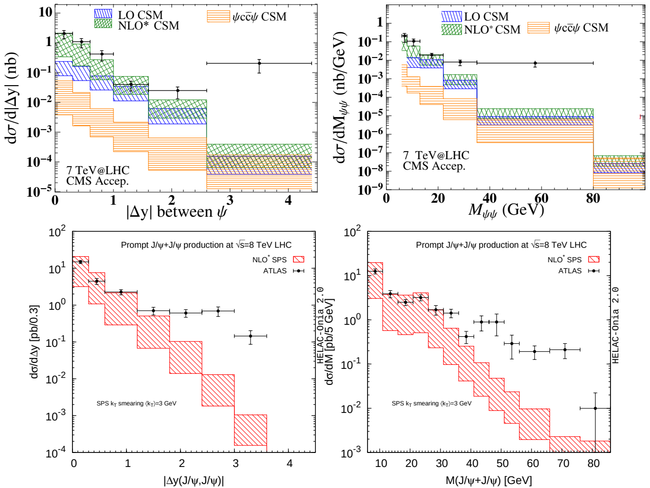

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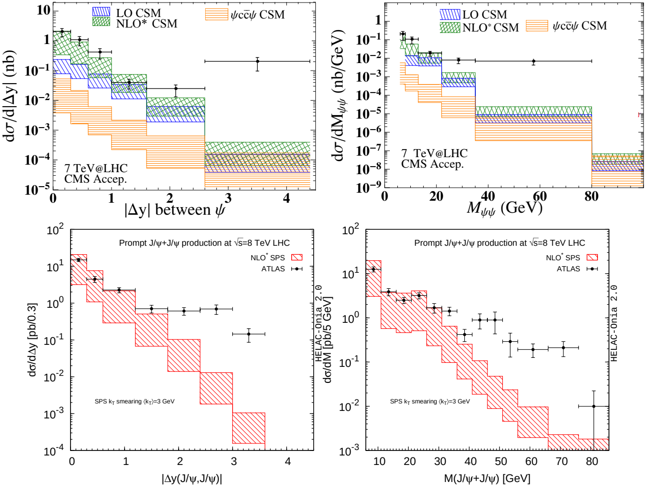

The most natural solution for this excess is the independent production of two J/ψ

→ double parton scattering

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NB: Agreement not perfect with the ATLAS data **[See P. Iengo's talk yesterday in WG5]**

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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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- Overall :

	(CSM) SPS	Low P_T DPS	High P_T DPS
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- Based on up-to-date feed-down values (J/ψ is 80% direct at low P_T) JPL, 1903.09185

Predictions: excited states and more

JPL, H.-S.Shao PLB 751 (2015) 479; JPL 1903.09185

- 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?
- DPS vs SPS dominance are characterised by different feed-down patterns
- We define $F^{\chi_c}_{\psi\psi}$ ($F^{\psi'}_{\psi\psi}$) as the fraction of events containing at least one χ_c (ψ')
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JPL, H.S. Shao, JHEP 1610 (2016) 153

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

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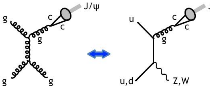

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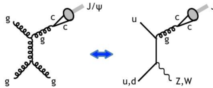

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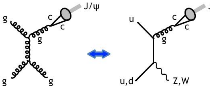

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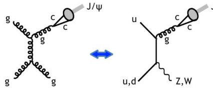

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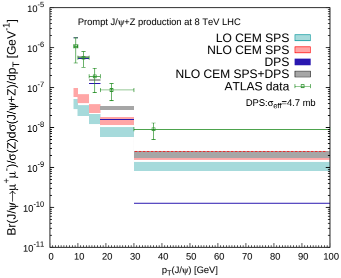

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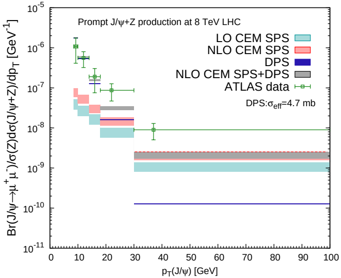

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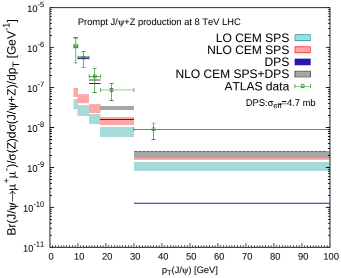

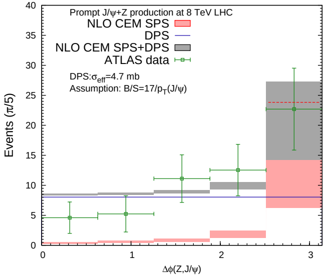

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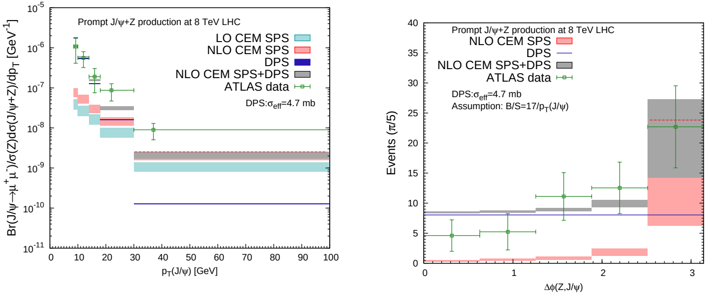

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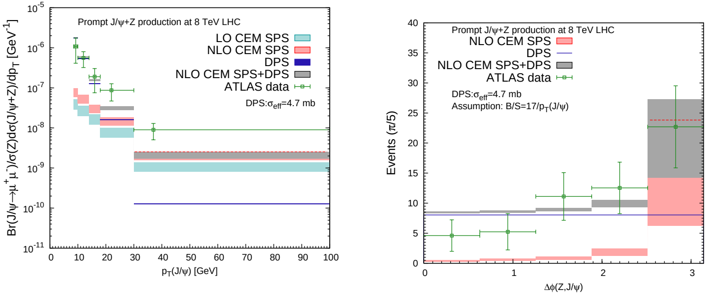

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- We are waiting for an ATLAS update to confirm our explanation

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

JPL, H.S. Shao, Nucl.Phys. B916 (2017) 132

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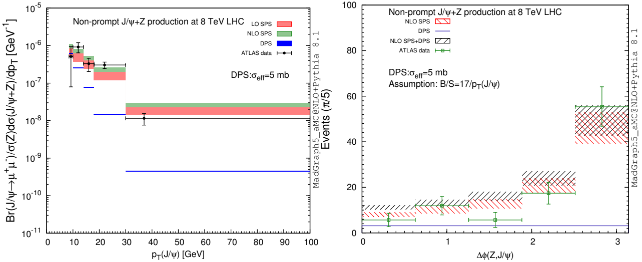

Differential cross section/distributions for non-prompt $J/\psi + Z$ production: p_T distribution of J/ψ (left) and azimuthal angle distribution (right)

- 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.

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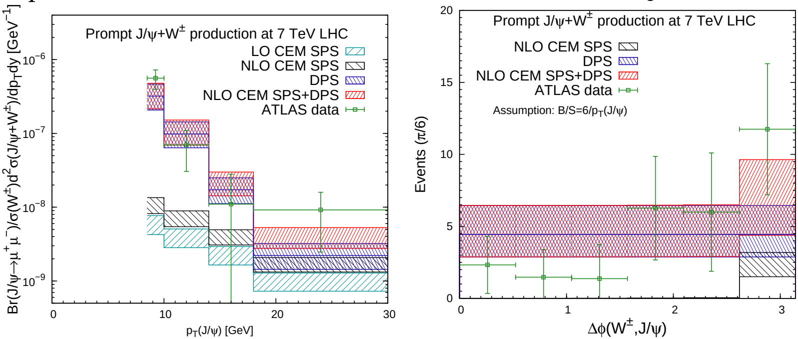

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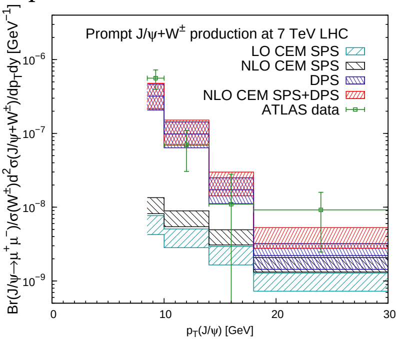

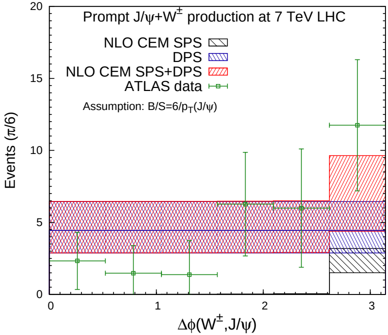

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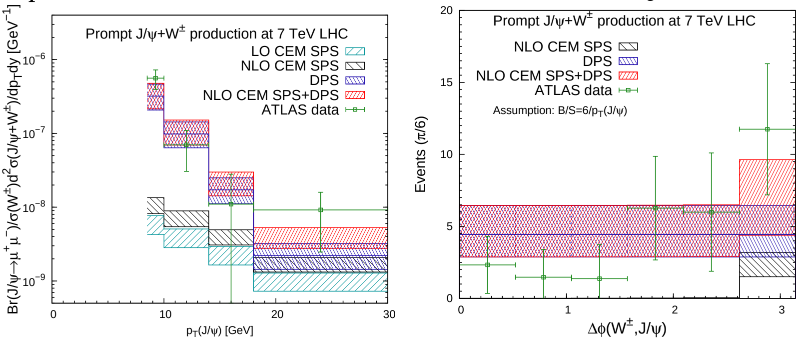

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$\Upsilon + \Upsilon$

CMS JHEP05(2017)013

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R. Li *et al.* PRD 80 (2009) 014020; P. Ko *et al.*JHEP 1101 (2011) 070; A.V Berezhnoy *et al.*PRD 87 (2013) 054023; JPL *et al.*to appear

[Mass uncertainty not accounted for, but likely large; CO below % level]

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Harvesting quarkonium data: 5 extractions using theory

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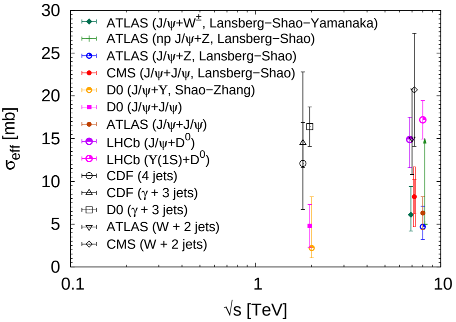

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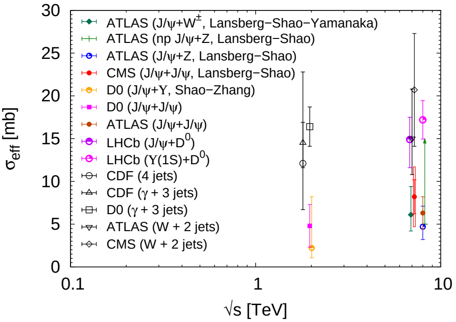

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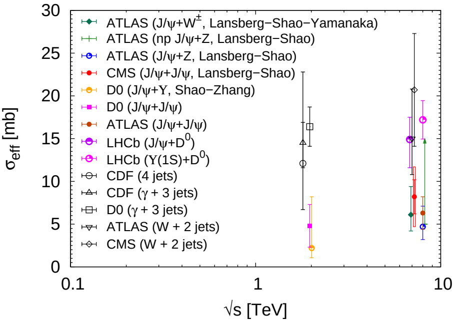

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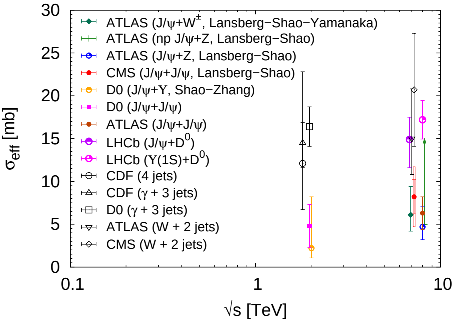

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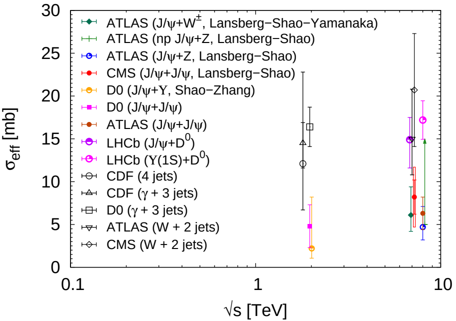

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D0 PRL 116 (2016) 082002 + H.S. Shao - Y. J. Zhang PRL 117 (2016) 062001

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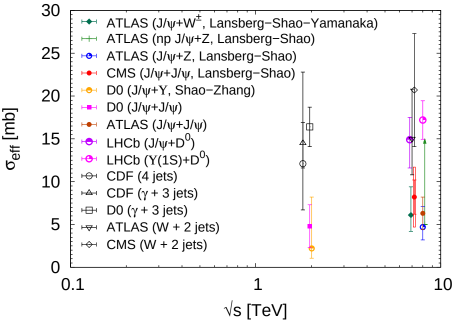

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- Except for both LHCb extractions, all the quarkonium-based extraction point at very small $\sigma_{\rm eff}$ values: dependence on the flavour, the rapidity or the scale(s) ?

Part III

Conclusion

Summary

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- Beside the production-mechanism debate, quarkonia already allow us to probe the parton correlation through DPS studies
- They also start to tell us new information on the gluon Transverse Momentum Distribution distributions

See talks by C. Pisano and F. Scarpa yesterday, F. Murgia and P. Taels on Tuesday and M.A. Ozcelik today

NLOAccess [in2p3.fr/nloaccess]

GENERAL DESCRIPTION

Objectives:

NLOAccess will give access to automated tools generating scientific codes allowing anyone to evaluate observables -such as production rates or kinematical properties – of scatterings involving hadrons. The automation and the versatility of these tools are such that these scatterings need not to be pre-coded. In other terms, it is possible that a random user may request for the first time the generation of a code to compute characteristics of a reaction which nobody thought of before. NLOAccess will allow the user to test the code and then to download to run it on its own computer. It essentially gives access to a dynamical library

Show more

This project has been included in the STRONG2020 submission for EU funding.

To search type and hit enter

HELAC-Onia Web [in2p3.fr/nloaccess/HO]

HELAC-Onia Web   Request Registration   References   Contact us   Login

Automated perturbative NLO calculation with HELAC-Onia Web

Welcome to HELAC-Onia Web!

HELAC-Onia ia an automatic matrix element generator for the calculation of the heavy quarkonium helicity amplitudes in the framework of NRQCD factorization.
The program is able to calculate helicity amplitudes of multi P-wave quarkonium states production at hadron colliders and electron-positron colliders by including new P-wave off-shell currents. Besides the high efficiencies in computation of multi-leg processes within the Standard Model, HELAC-Onia is also sufficiently numerical stable in dealing with P-wave quarkonia and P-wave color-octet intermediate states.

Already registered to the portal? Please login.

Do you not have an account? Make a registration request.

Part IV

Backup

CEM vs. CSM vs. COM in a little more details

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1. COLOUR EVAPORATION MODEL
   - any $Q\bar{Q}$ state contributes to a specific quarkonium state
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3. **Colour Octet Mechanism**
   - one non-perturbative parameter per Fock State
   - expansion in v^2; series can be truncated
   - the phenomenology partly depends on this
   - HQSS relates some non-perturbative parameters to each others and to a specific quarkonium polarisation

QCD corrections to the COM – NRQCD

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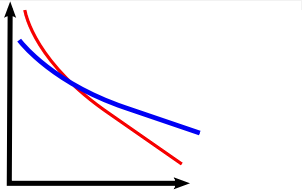
- At LO, P_T spectrum driven by the combination of 2 CO components : ${}^3S_1^{[8]}$ vs. ${}^1S_0^{[8]}$ & ${}^3P_J^{[8]}$



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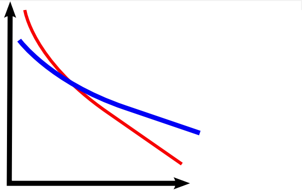

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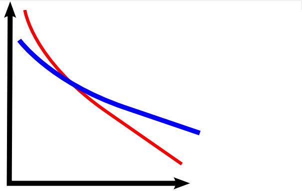

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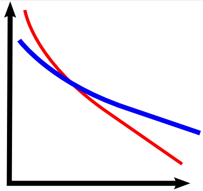

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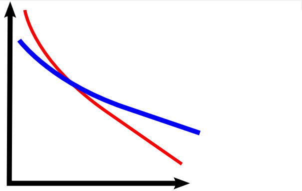

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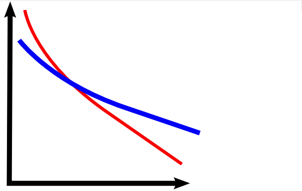

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- Polarisation: ${}^1S_0^{[8]}$: unpolarised; ${}^3S_1^{[8]}$ & ${}^3P_J^{[8]}$: transverse

QCD corrections to the CEM P_T dependence

JPL, H.S. Shao JHEP 1610 (2016) 153

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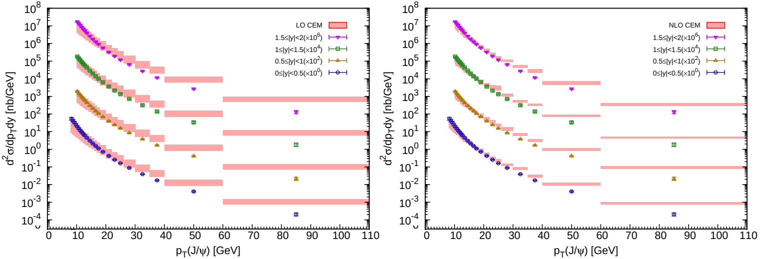
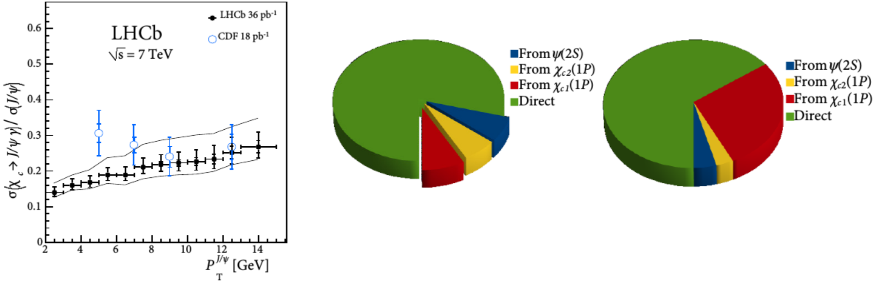


Feed downs from the excited states

JPL, arXiv:1903.09185 [hep-ph]



(a) (b) Low P_T J/ψ (c) High P_T J/ψ

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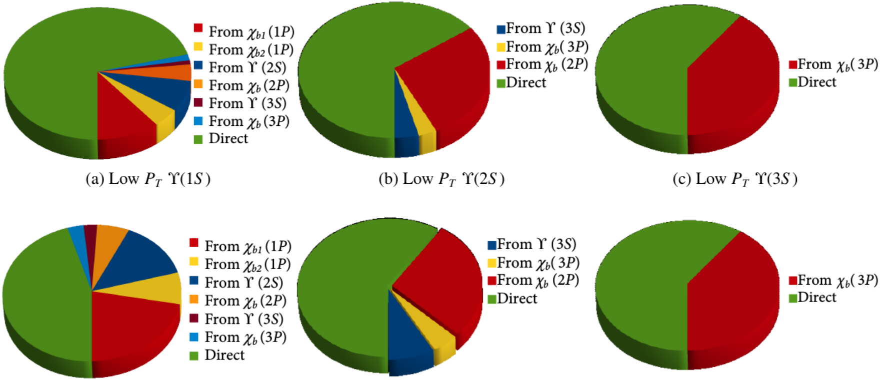

(a) Low P_T $\Upsilon(1S)$ (b) Low P_T $\Upsilon(2S)$ (c) Low P_T $\Upsilon(3S)$

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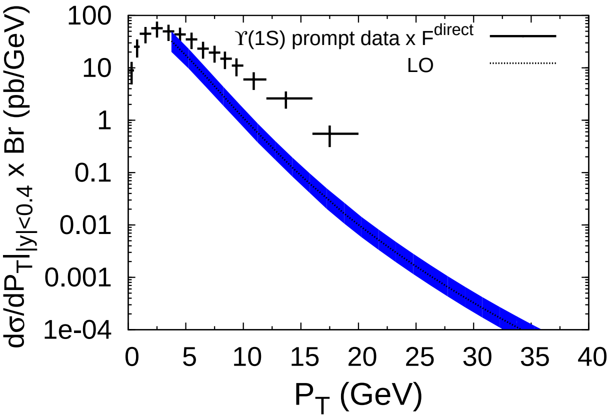

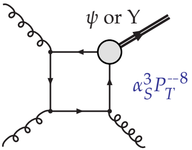

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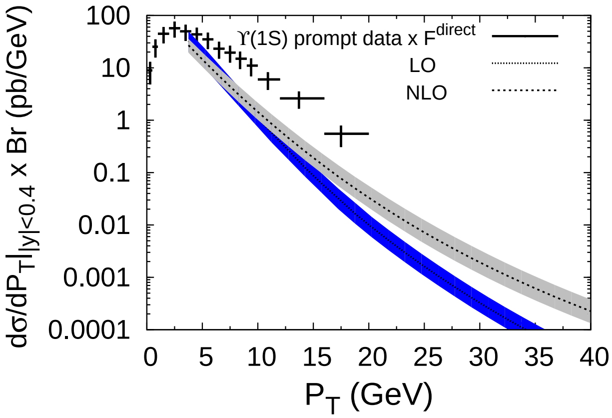

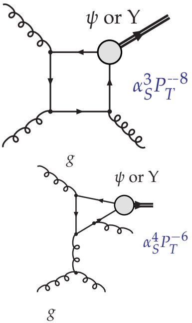

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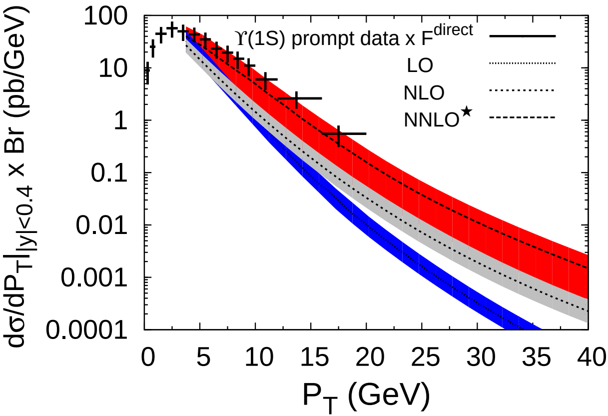

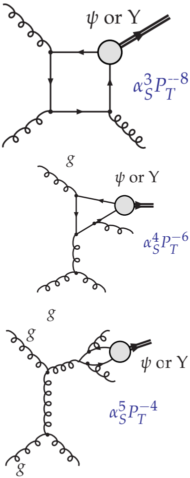

Attention: the NNLO⋆ is not a complete NNLO
See a recent study by H.S. Shao **JHEP 1901 (2019) 112**

QCD corrections to the CSM for Υ at colliders

J.Campbell, F. Maltoni, F. Tramontano, Phys.Rev.Lett. 98:252002,2007
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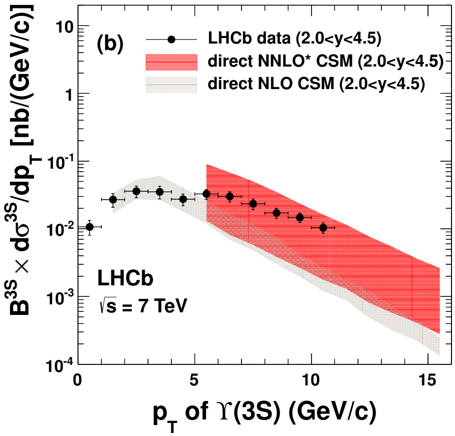

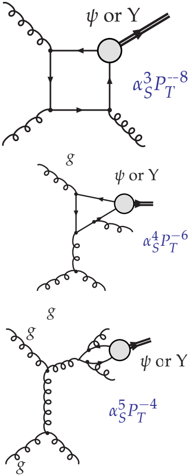

$\Upsilon(3S)$: 60 % direct; $\Upsilon(2S)$:60-70 % direct; $\Upsilon(1S)$: 50-70 % direct

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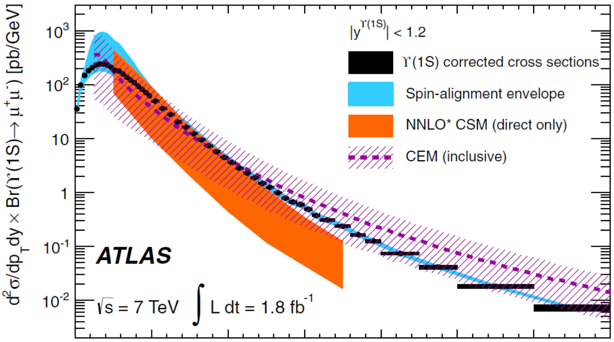
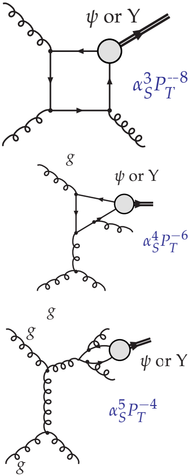
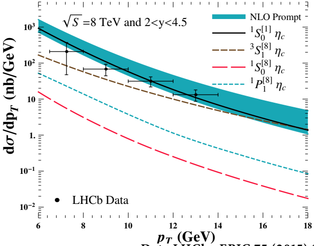




CSM theory curve extrapolated to prompt: × 2

The last piece in the puzzle: the η_c



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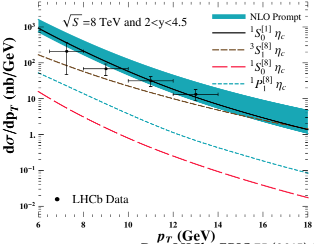

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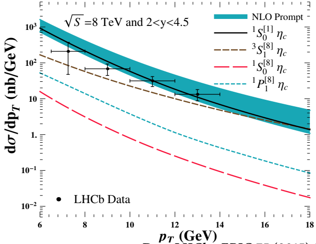

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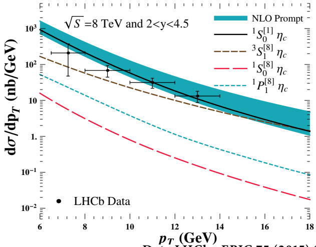

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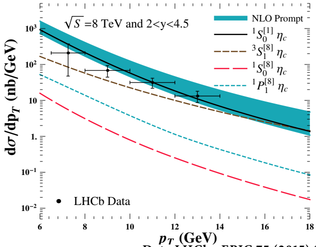

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- Nobody foresaw the impact of measuring η_c yields: 3 PRL published right after the LCHb data

came out **(Hamburg) M. Butenschoen** *et al.* **PRL 114 (2015) 092004; (PKU) H. Han** *et al.* **114 (2015) 092005; (IHEP) H.F. Zhang** *et al.* **114 (2015) 092006**

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JPL, H.S. Shao, H.F. Zhang, PLB 786 (2018) 342

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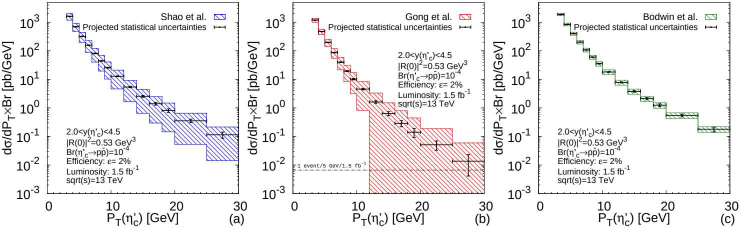

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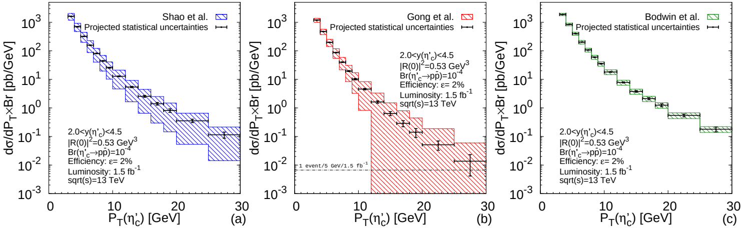

→ Belle-II data on the inclusive $\psi(2S)$ production will also be crucial

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- etc ...

Why is it important to know how low-P_T quarkonia are produced

Also because, some very high P_T quarkonia which we study can be as rare as a few millionth of the produced quarkonia

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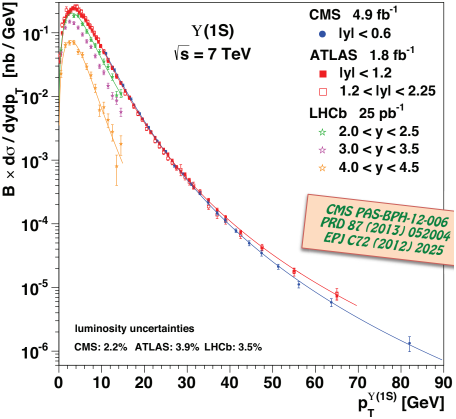

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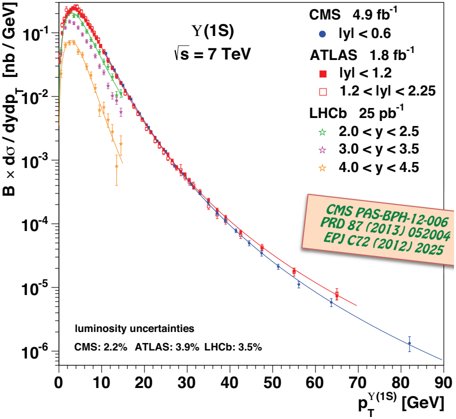

Most probably the production of a Υ with P_T = 90 GeV, even also 20 GeV, has very few things to do with the bulk of Υ

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	$15.4 \pm 2.2^{+51}_{-12}$	$14.8 \pm 1.7^{+53}_{-12}$	$6.8 \pm 0.6^{+22}_{-5}$
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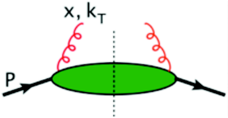
- Yet, room for DPS; however tension if $\sigma_{\text{eff}} \simeq 7$ mb
- Tension between LHCb and other di-J/ψ extractions [rapidity effect ?]

Gluon TMDs in unpolarised protons



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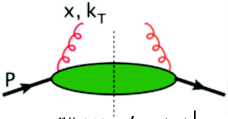

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$$\Phi_g^{\mu\nu}(x,\boldsymbol{k}_T,\zeta,\mu) \equiv \int \frac{\mathrm{d}(\xi\cdot P)\,\mathrm{d}^2\xi_T}{(xP\cdot n)^2(2\pi)^3}\, e^{i(xP+k_T)\cdot\xi}\langle P|F^{n\nu}(0)\mathcal{U}_{[0,\xi]}F^{n\mu}(\xi)\mathcal{U}'_{[\xi,0]}|P\rangle\Big|_{\xi\cdot P'=0}$$

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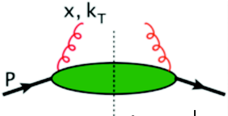

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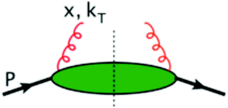

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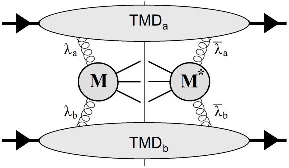
- f_1^g: TMD distribution of unpolarised gluons
- $h_1^{\perp g}$: TMD distribution of linearly polarised gluons

[Helicity-flip distribution]

gg fusion in arbitrary unpolarised process [colourless final state]

$d\sigma^{gg} \propto$



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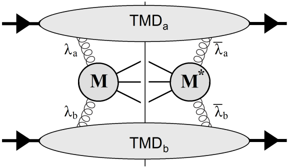

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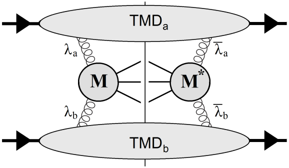
$\Rightarrow$ double helicity flip, azimuthally independent



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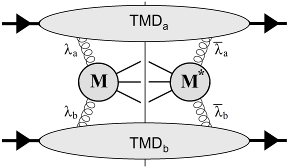

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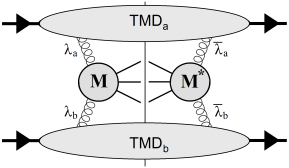
$\Rightarrow$ double helicity flip, $\cos(4\phi)$-modulation



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None are measured so far ...

$J/\psi + J/\psi$ at low $P_T^{\psi\psi}$

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- J/ψ:relatively easy to detect. Already studied by LHCb, CMS, ATLAS & D0

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J.P.L., H.S. Shao NPB 900 (2015) 273

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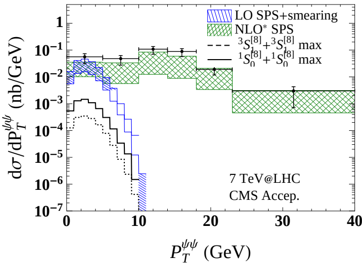

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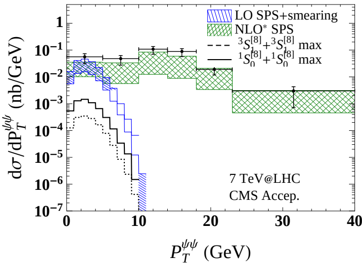

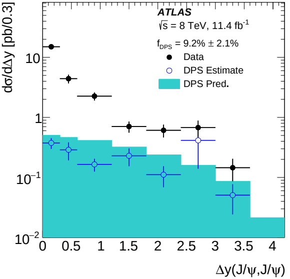

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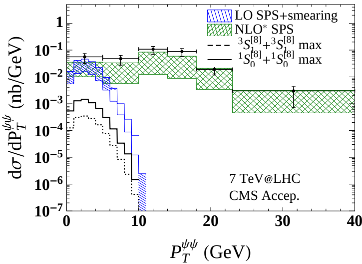

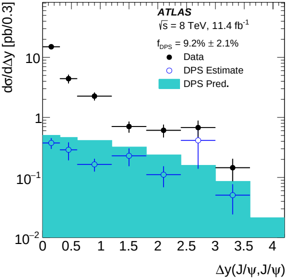

- DPS in LHCb data [kinematical distributions well controlled : independent scatterings]

What's special about double vector onium production ?

JPL, C. Pisano, F. Scarpa, M. Schlegel, PLB 784 (2018) 217

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$F_4 = F_1$ at large $M_{\mathcal{Q}\mathcal{Q}}$

$\Rightarrow$ di-J/ψ (or di-Υ) maximise the observability of $\cos 4\phi$ modulations in a kinematical region where data are already taken !

TMD modelling : f_1^g and the relevance of the LHCb data

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  where $g(x)$ is the usual collinear PDF
- First experimental determination [with a pure colorless final state] of $\langle k_T^2 \rangle$
  by fitting $\mathcal{C}[f_1^g f_1^g]$ over the normalised LHCb $d\sigma/dP_{\psi\psi_T}$ spectrum at 13 TeV from which we have subtracted the DPS yield determined by LHCb

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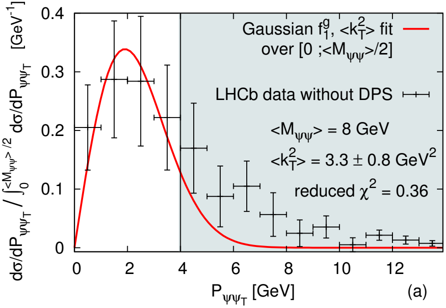

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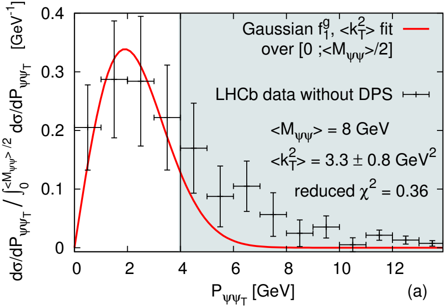

- Integration over $\phi \Rightarrow \cos(n\phi)$-terms cancel out
- $F_2 \ll F_1 \Rightarrow$ only $\mathcal{C}[f_1^g f_1^g]$ contributes to the cross-section
- No evolution so far: $\langle k_T^2\rangle \sim 3$ GeV^2 accounts both for non-perturbative and perturbative broadenings at a scale close to $M_{\psi\psi} \sim 8$ GeV
- Disentangling such (non-)perturbative effects requires data at different scales

Expected azimuthal asymmetries

JPL, C. Pisano, F. Scarpa, M. Schlegel, PLB 784 (2018) 217

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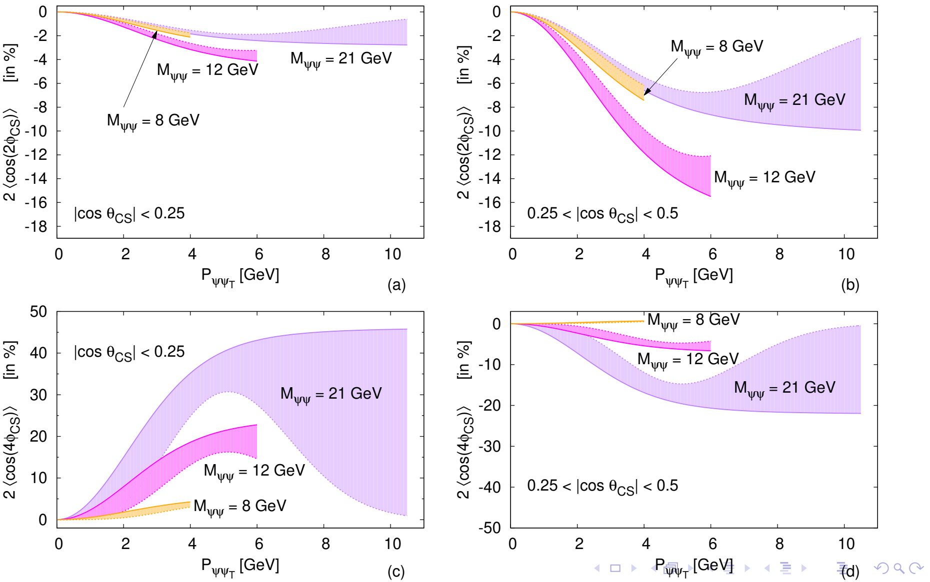

Basic pQCD approach: the Colour Singlet Model (CSM)

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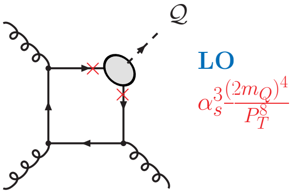

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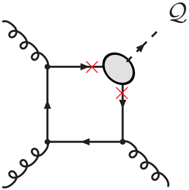

LO

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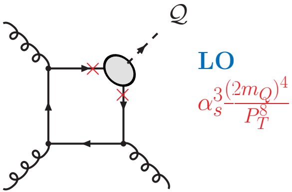

- Non-perturbative binding of quarks → Schrödinger wave function

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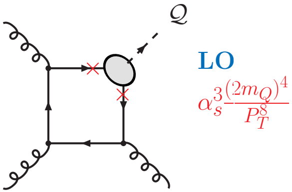

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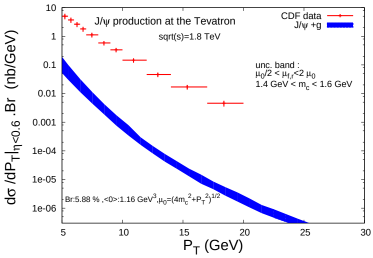

CDF, PRL 79:572 & 578,1997

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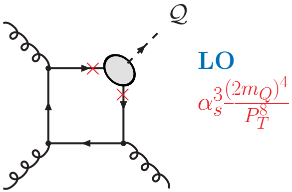

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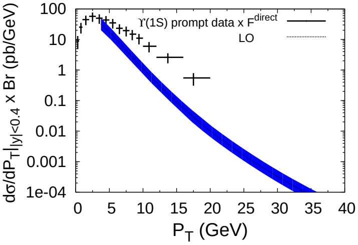

CDF, PRL 88:161802,2002

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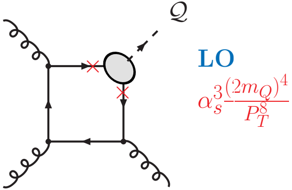

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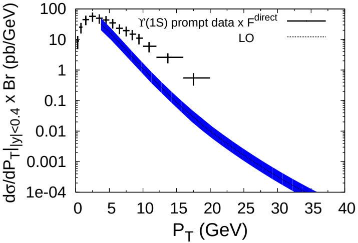

- Large QCD corrections from new topologies reduce the gap with data at mid and large P_T

P.Artoisenet, J.Campbell, JPL, F.Maltoni, F. Tramontano, PRL 101, 152001 (2008

The LO CSM accounts for the P_T-integrated yield

S. J. Brodsky and JPL, PRD 81 051502 (R), 2010; JPL, PoS(ICHEP 2010), 206 (2010); NPA 910-911 (2013) 470

→ The yield vs. $\sqrt{s}$, y

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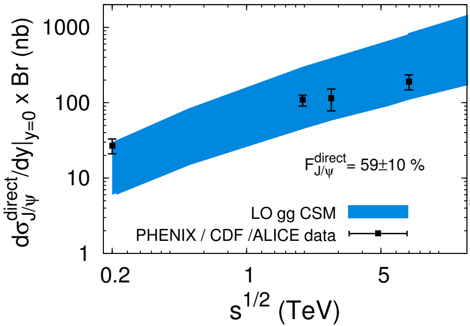

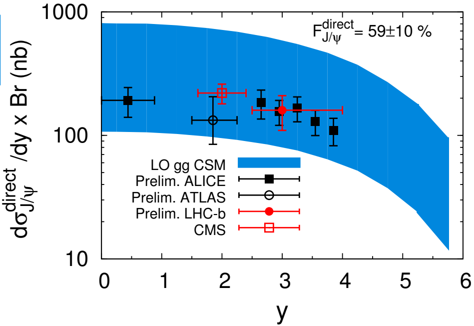

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S. J. Brodsky and JPL, PRD 81 051502 (R), 2010; JPL, PoS(ICHEP 2010), 206 (2010); NPA 910-911 (2013) 470

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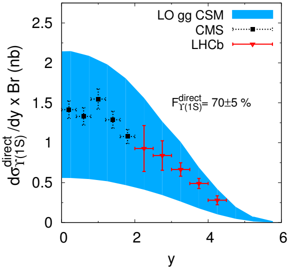
- Good agreement with RHIC, Tevatron and LHC data [LHC J/ψ points to be updated, sorry] (multiplied by a constant F^{direct}, considered to be constant)



CMS PRD 83 (2011) 112004; LHCb EPJC 72 (2012) 2025

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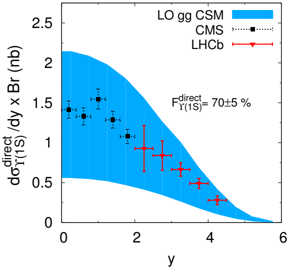

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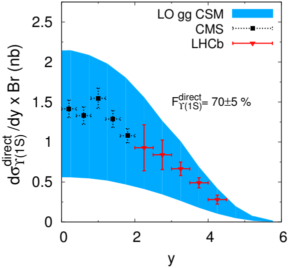

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- Earlier claims that CSM contribution to $d\sigma/dy$ was small were based on the incorrect assumption that χ_c feed-down was dominant

NLO CSM at RHIC

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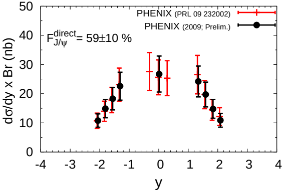
→ J/ψ



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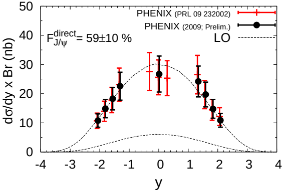

LO: $gg \to J/\psi g$

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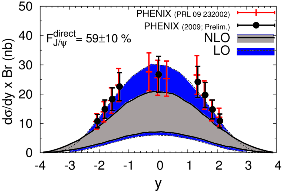

NLO: $gg \to J/\psi gg$, $gq \to J/\psi gq$, ...

using the matrix elements from J.Campbell, F. Maltoni, F. Tramontano, PRL 98:252002,2007

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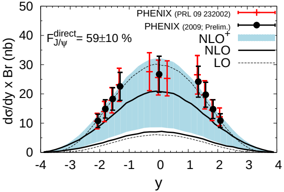

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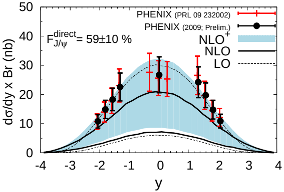
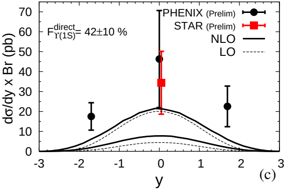


NLO$^+$: possible new contribution at LO $cg \to J/\psi c$

→ Υ^*



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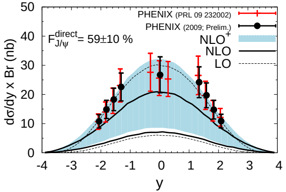

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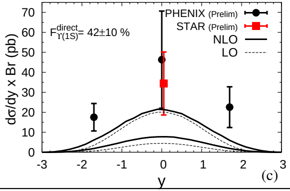

A priori, good convergence NLO w.r.t. LO

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NLO NRQCD up to RHIC

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- At α_S^3, one has in addition real emissions (including **one CS process**)

$$g + g \rightarrow Q\bar{Q}[^1S_0^{[8]}, {}^3S_1^{[8]}, {}^3P_{J=0,2}^{[8]}] + g,\ g + q(\bar{q}) \rightarrow Q\bar{Q}[^1S_8^{[0]}, {}^3S_1^{[8]}, {}^3P_{J=0,2}^{[8]}] + q(\bar{q})$$

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- Done with NRQCD LDMEs fitted **at LO** on P_T spectra from CDF ($\simeq$ 2 TeV)

Table 1
Reference NRQCD matrix elements for charmonium production. The color-singlet matrix elements are taken from the potential model calculation of [14, 15]. The color-octet matrix elements have been extracted from the CDF data [16] in Ref. [17]

H	$\langle \mathcal{O}_1^H \rangle$	$\langle \mathcal{O}_8^H[^3S_1] \rangle$	$\langle \mathcal{O}_8^H[^1S_0^{(8)}] \rangle = \langle \mathcal{O}_8[^3P_0^{(8)}] \rangle / m_c^2$
J/ψ	1.16 GeV^3	1.19×10^{-2} GeV^3	1.0×10^{-2} GeV^3
$\psi(2S)$	0.76 GeV^3	0.50×10^{-2} GeV^3	0.42×10^{-2} GeV^3
χ_{c0}	0.11 GeV	0.31×10^{-2} GeV^3	–

NLO NRQCD up to RHIC II

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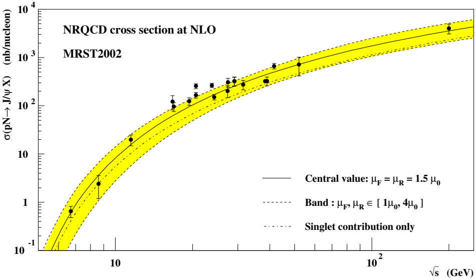

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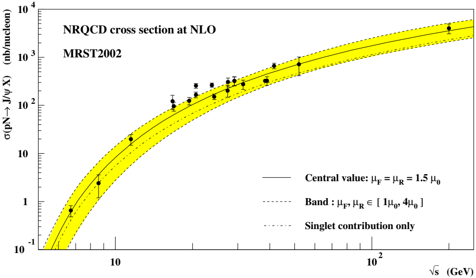

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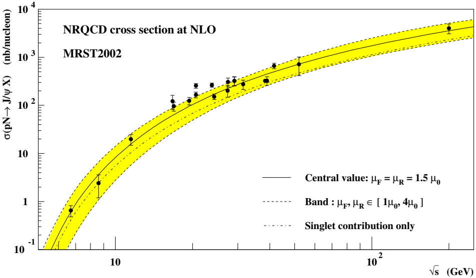

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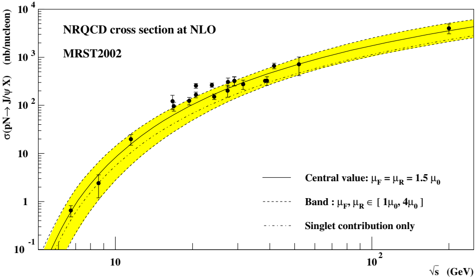

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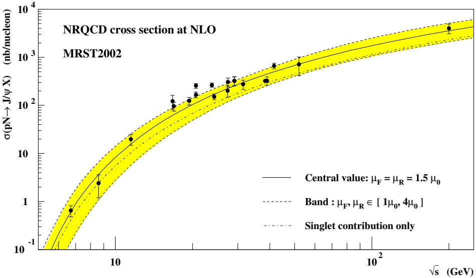

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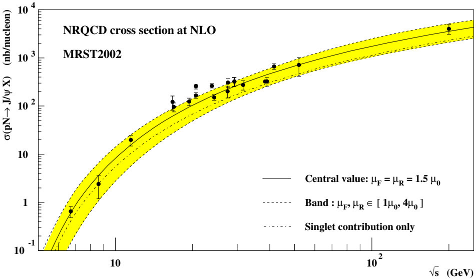

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- Never updated with LDMEs fitted at NLO

What we did[Y. Feng, JPL, J.X. Wang, EPJC (2015)75:313]

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  - LHC data
- constant feed-down (FD) fractions
  - $F^{\rm direct}_{J/\psi} = 60 \pm 10\%$
  - $F^{\rm direct}_{\Upsilon(1S)} = 66 \pm 10\%$
  - $F^{\rm direct}_{\Upsilon(1S+2S+3S)} = 60 \pm 10\%$
  - Uncertainty on $F^{\rm direct}$ combined in quadrature with that of data

Arguable but accounts for a possible energy dependence of the FD fraction

What we did II

We used LDMEs fitted at NLO/one loop on the P_T spectra

- J/ψ

Ref.	$\langle \mathcal{O}_{J/\psi}(^3P_0^{[8]}) \rangle$ (in GeV^5)	$\langle \mathcal{O}_{J/\psi}(^1S_0^{[8]}) \rangle$ (in GeV^3)	$\langle \mathcal{O}_{J/\psi}(^3S_1^{[8]}) \rangle$ (in GeV^3)
Y.-Q. Ma,*et al.* PRL 106 (2011) 042002.	-2.0×10^{-3}	7.8×10^{-2}	0
	2.1×10^{-2}	3.5×10^{-2}	5.8×10^{-3}
	4.1×10^{-2}	0	1.1×10^{-2}
B. Gong,*et al.* PRL 110 (2013) 042002	-2.2×10^{-2}	9.7×10^{-2}	-4.6×10^{-3}
M.Butenschoen, B.Kniehl. PRD (2011) 051501	-9.1×10^{-2}	3.0×10^{-2}	1.7×10^{-3}

- ψ'

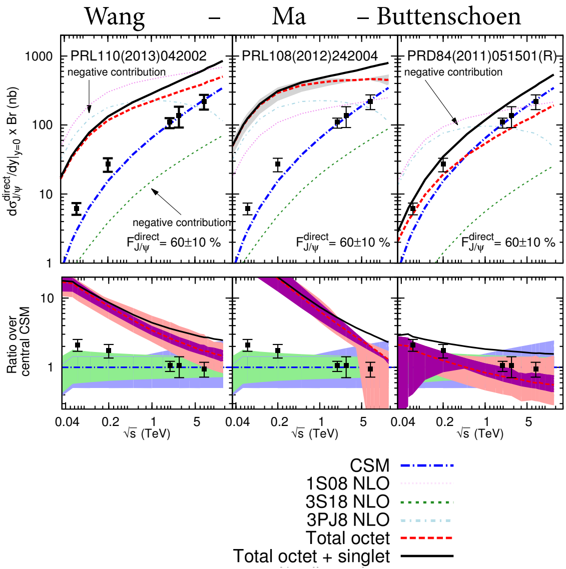
Ref.	$\langle \mathcal{O}_{\psi(2S)}(^3P_0^{[8]}) \rangle$ (in GeV^5)	$\langle \mathcal{O}_{\psi(2S)}(^1S_0^{[8]}) \rangle$ (in GeV^3)	$\langle \mathcal{O}_{\psi(2S)}(^3S_1^{[8]}) \rangle$ (in GeV^3)
B. Gong,*et al.* PRL 110 (2013) 042002	9.5×10^{-3}	-1.2×10^{-4}	3.4×10^{-3}
Y.-Q. Ma,*et al.* PRL 106 (2011) 042002	-4.8×10^{-3}	2.9×10^{-2}	0
	7.9×10^{-3}	5.6×10^{-3}	3.2×10^{-3}
	1.1×10^{-2}	0	3.9×10^{-3}

- $\Upsilon(1S)$

Ref.	$\langle \mathcal{O}_{\Upsilon(1S)}(^3P_0^{[8]}) \rangle$ (in GeV^5)	$\langle \mathcal{O}_{\Upsilon(1S)}(^1S_0^{[8]}) \rangle$ (in GeV^3)	$\langle \mathcal{O}_{\Upsilon(1S)}(^3S_1^{[8]}) \rangle$ (in GeV^3)
B. Gong, *et al.* PRL 112 (2014) 3, 032001.	-10.36×10^{-2}	11.15×10^{-2}	-4.1×10^{-2}

[We have also added the fit of G.T. Bodwin, *et al.*, PRL 113, 022001 (2014) even though it is based on a fragmentation function approach]

Results for the J/ψ



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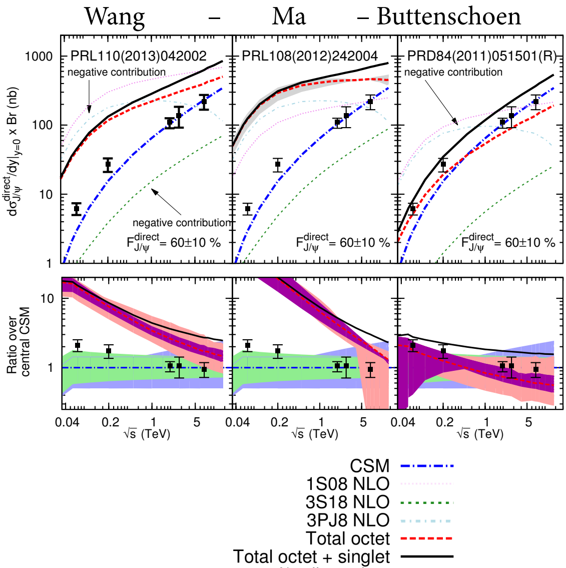
- First 2 fits: 10 times above the data around 200 GeV – as Maltoni *et al.*



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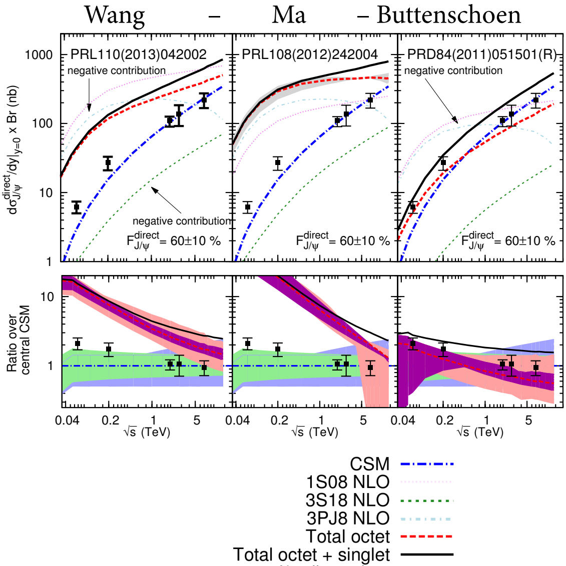

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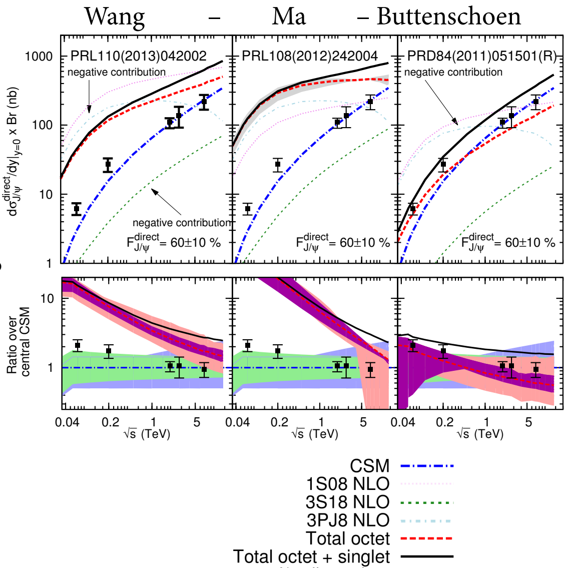

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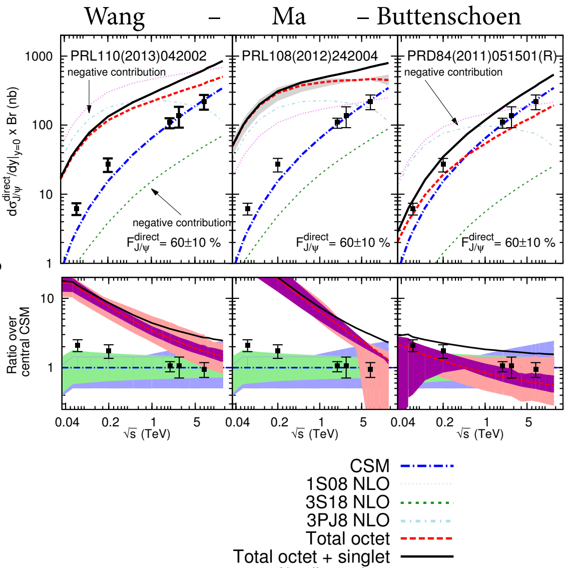

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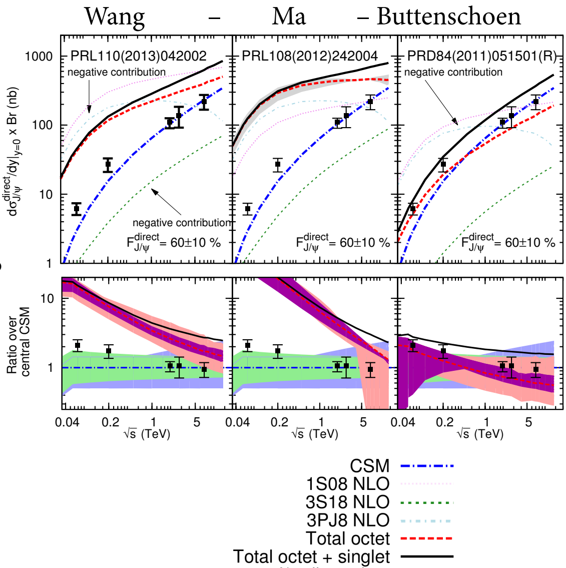

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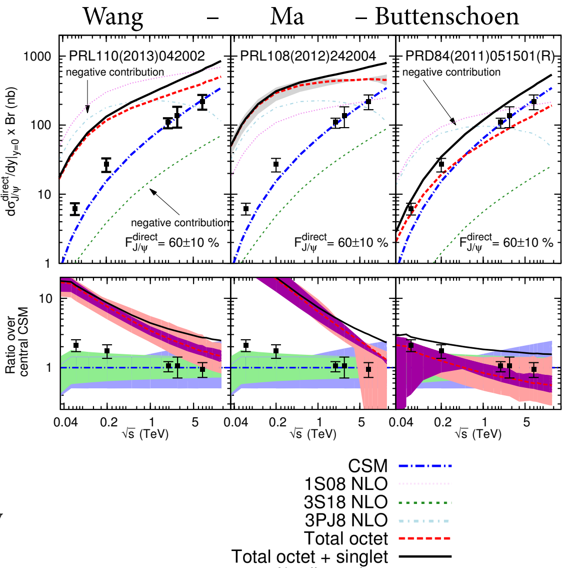
- Not a surprise since the CSM alone accounts well for the data; adding any contribution creates a "surplus"



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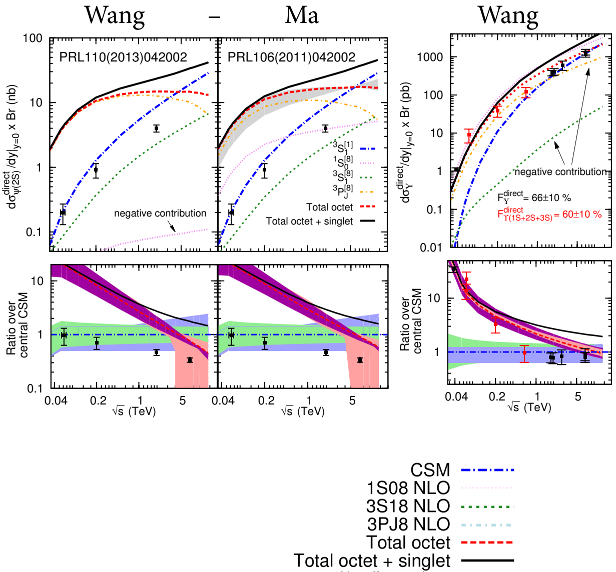

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For $\psi(2S)$

- Worse than for J/ψ
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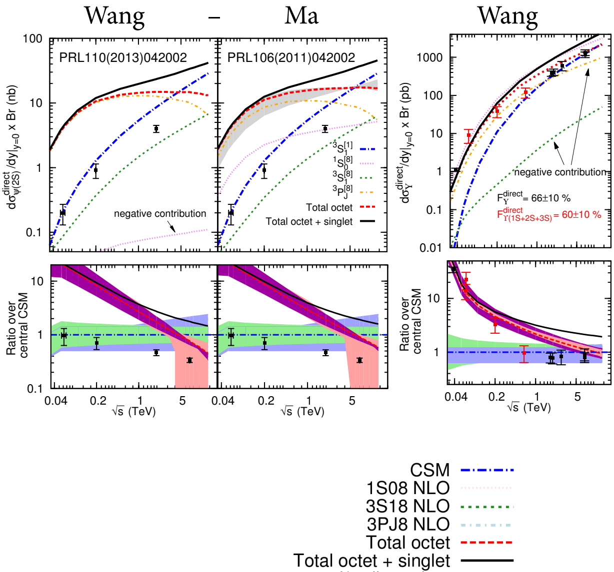

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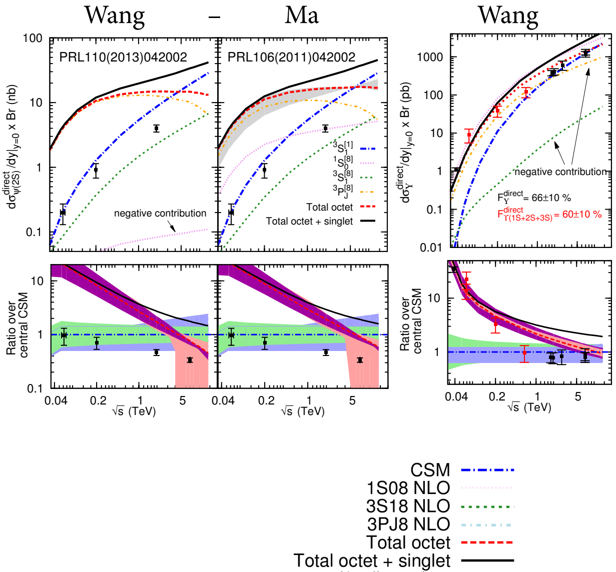
For $\Upsilon(1S)$

- Reasonnable trend for Υ
- CSM is doing a perfect job in the TeV range – note that the RHIC points moved down
- On the other hand, CO needed at low $\sqrt{s}$? High x gluon pdf underestimated ?



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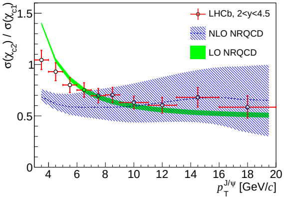

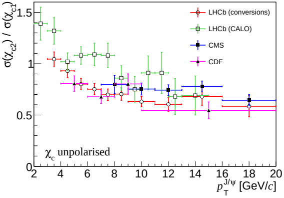

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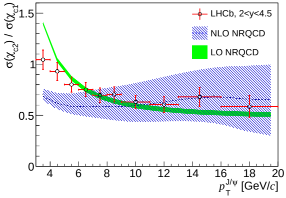

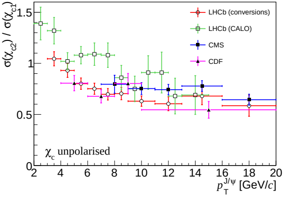

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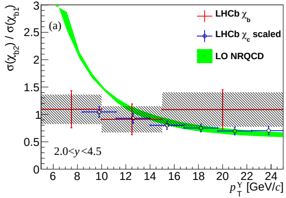

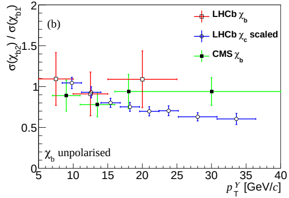

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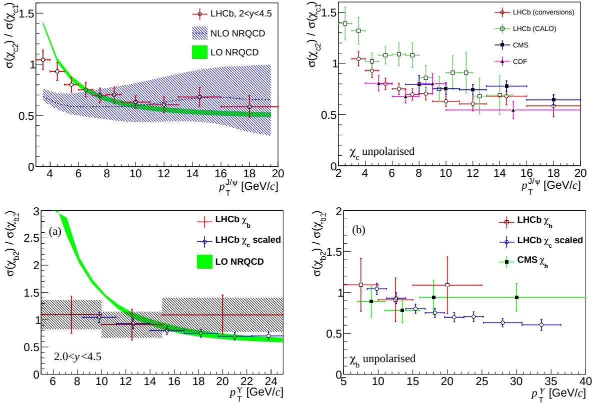

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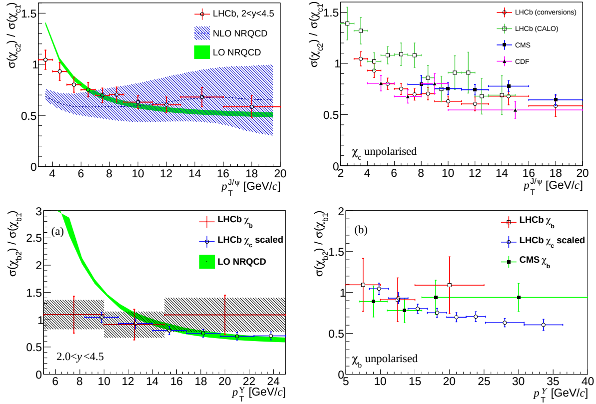

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- The nature (quantum #) of the produced final state seems still relevant !

Basics of the Colour Evaporation Model

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H. Fritzsch, PLB 67 (1977) 217; F. Halzen, PLB 69 (1977) 105

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- It can easily be check by MCFM at NLO for instance `http://mcfm.fnal.gov/`

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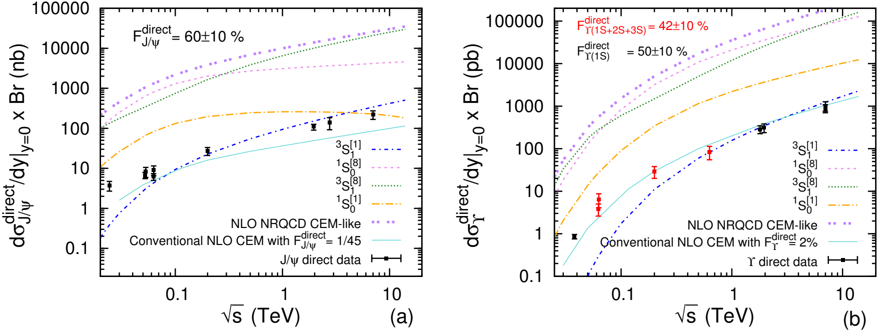
- If, as it should be in NRQCD, $\langle \mathcal{O}_{^3S_1}(^3S_1^{[1]}) \rangle$ is the usual CS LDME, *i.e.* $\frac{2N_C}{4\pi}\,(2J+1)\,|R(0)|^2$, everything is fixed

CEM results



$d\sigma^{direct}_{J/\psi}/dy|_{y=0}$ x Br (nb)
$F^{direct}_{J/\psi}$ = 60±10 %
$^3S_1^{[1]}$
$^1S_0^{[8]}$
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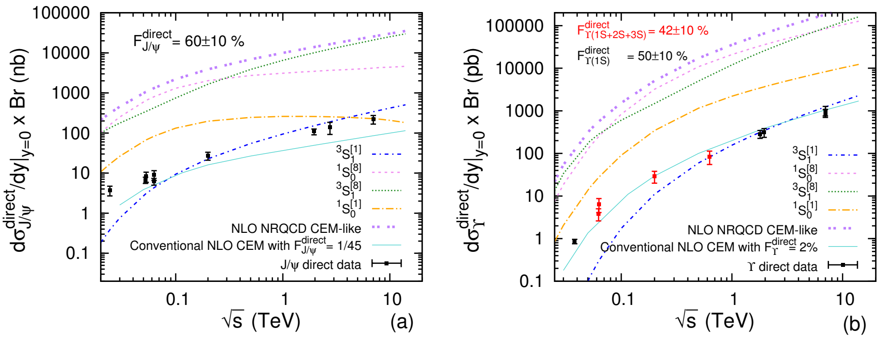
$^1S_0^{[1]}$
NLO NRQCD CEM-like
Conventional NLO CEM with $F^{direct}_{J/\psi}$ = 1/45
J/ψ direct data
$\sqrt{s}$ (TeV)
(a)
$d\sigma^{direct}_{\Upsilon}/dy|_{y=0}$ x Br (pb)
$F^{direct}_{\Upsilon(1S+2S+3S)}$ = 42±10 %
$F^{direct}_{\Upsilon(1S)}$ = 50±10 %
NLO NRQCD CEM-like
Conventional NLO CEM with F^{direct}_{Υ} = 2%
ϒ direct data
$\sqrt{s}$ (TeV)
(b)

CEM results



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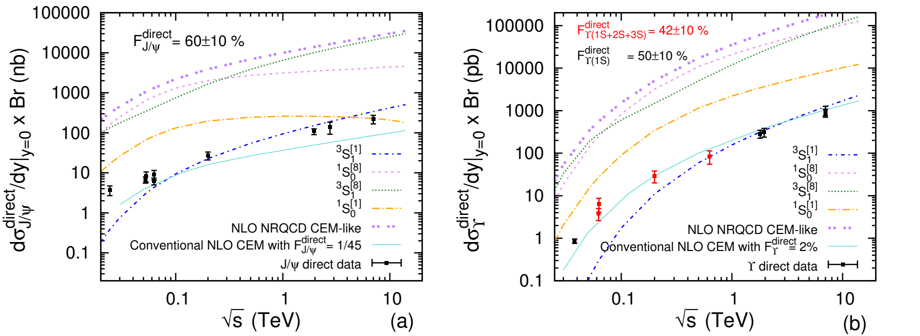

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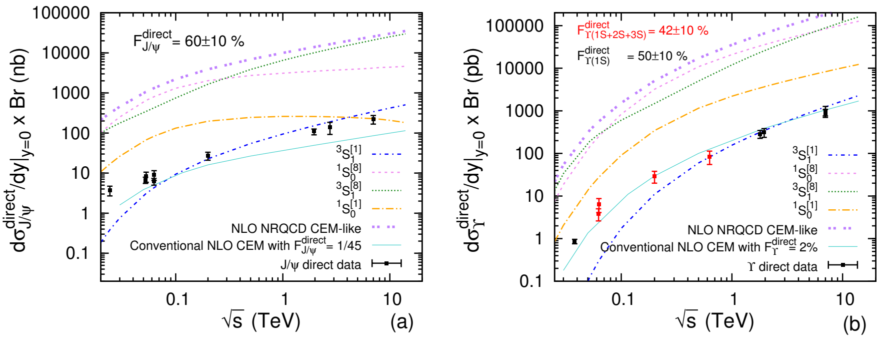

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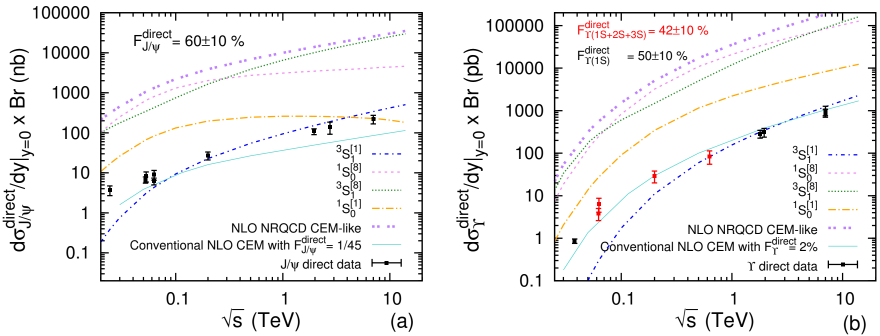

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  - Weird energy behaviour
- Conventional CEM does a pretty good job
  - No th. uncertainty shown
  - "Natural" value of $F^{direct}_{J/\psi}$ is ok