

Color singlet contribution and the quarkonium production puzzle

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**Brookhaven Summer Program, Quarkonium Production in
Elementary and Heavy Ion Collisions**

June 9, 2011

Brookhaven National Laboratory, USA

Outline

Introduction

- 1 Basic pQCD approach: Colour Singlet Model → Puzzle

Solution to the puzzle ... which puzzle ?

- 2 The CSM predictions and the total yield

Recent progresses: QCD corrections

- 3 Describing the mid- and high- P_T 's: QCD corrections
- 4 Colour Octet Dominance is challenged at low/mid P_T in pp
- 5 QCD corrections and feed-down do matter for the polarisation
- 6 ψ production at very large P_T

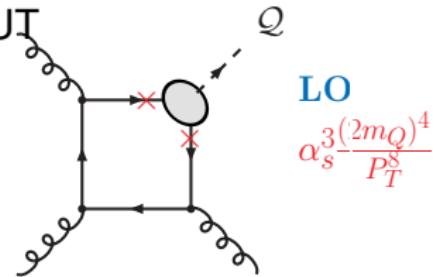
Part I

Introduction

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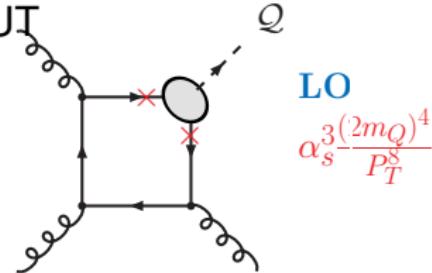


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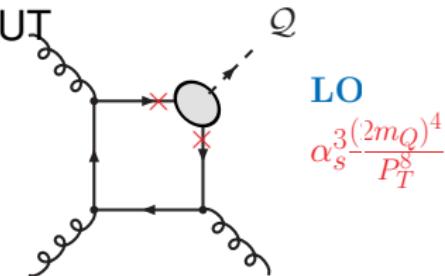
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- ⇒ in a colour singlet state
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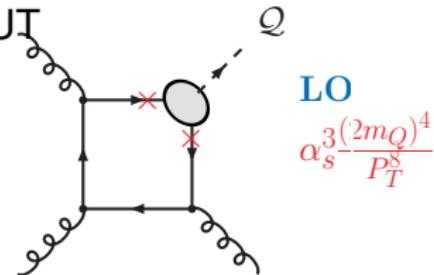


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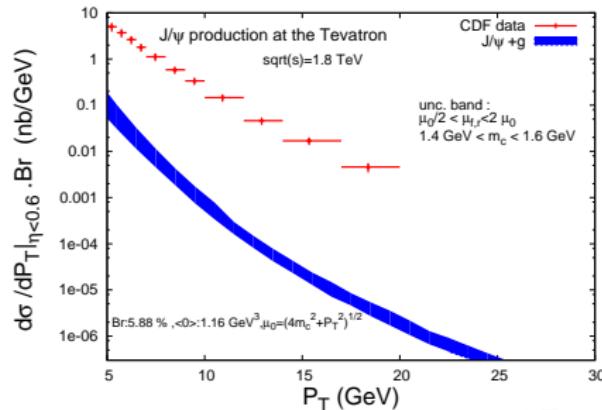
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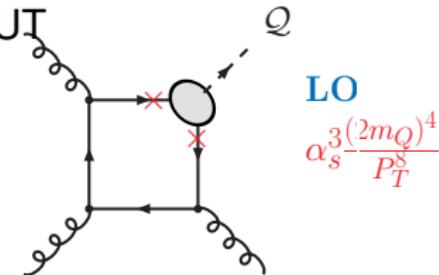
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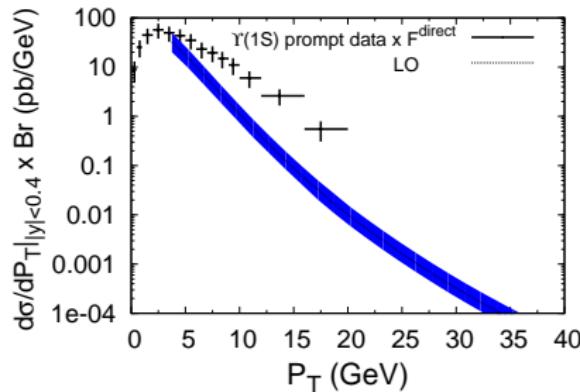
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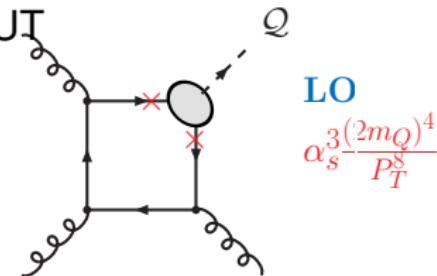
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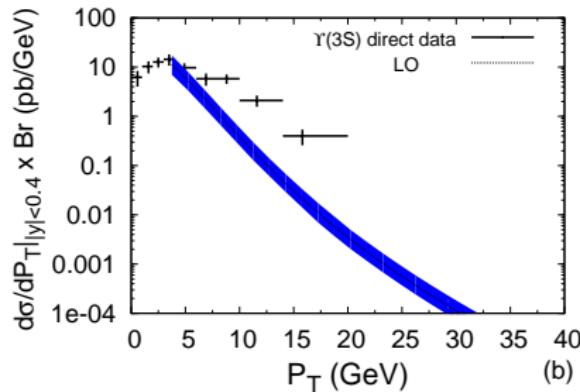
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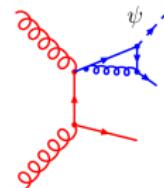
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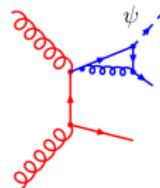
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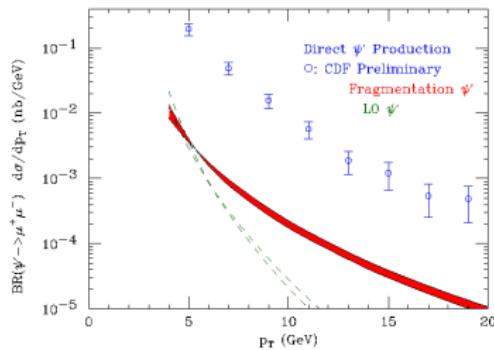


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- Different p_T behaviour: P_T^{-4} vs. P_T^{-8} .
- Illustration for the ψ'

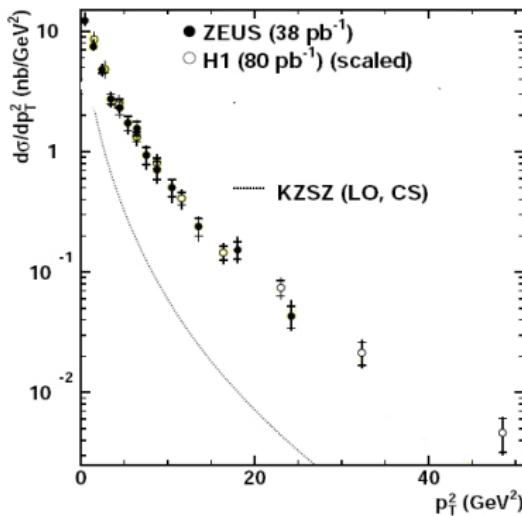
- ✗ Off by factor 30-100 for J/ψ and ψ'
- ✗ Off by factor 10 for Y's



J/ψ photoproduction at HERA

M.Kramer Nucl.Phys.B459:3 1996
H1,EPJC 25, 2,2002; ZEUS, EPJC 27, 173, 2003

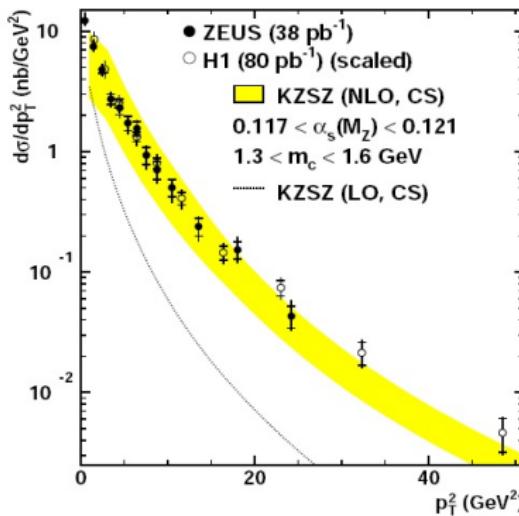
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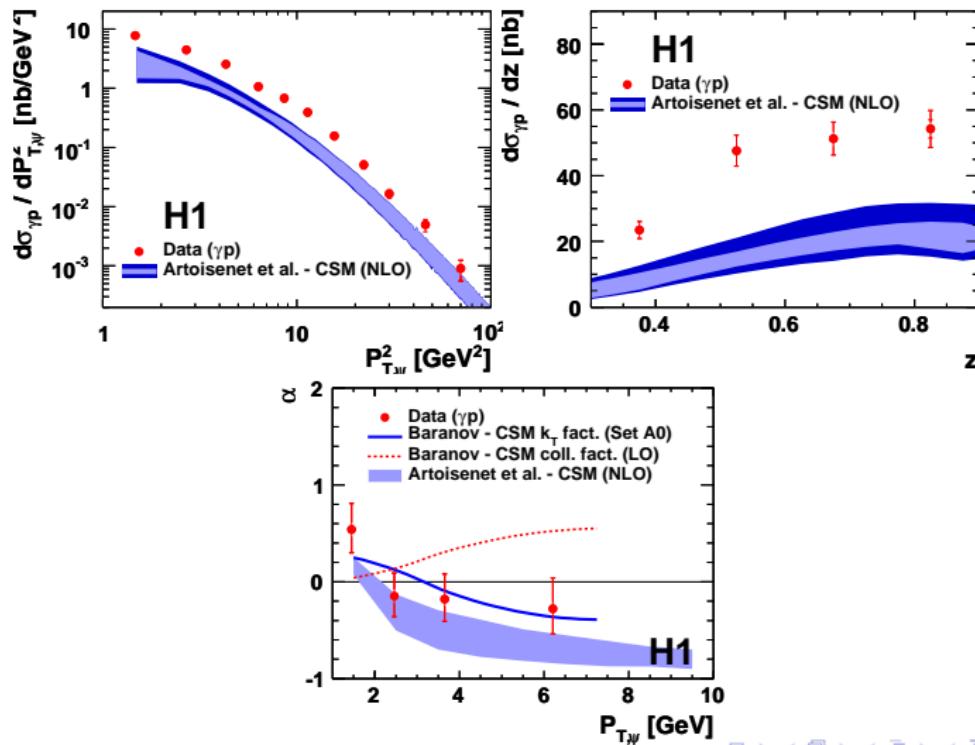


BUT NLO CSM is in better agreement with the data !

see however Phys. Rev. Lett. 102, 142001 (2009) and Phys. Rev. D80:034020, 2009

J/ψ photoproduction at HERA

P. Artoisenet et al. Phys. Rev. Lett. 102, 142001 (2009)
e.g. H1, arXiv:1002.0234



Part II

Solution to the puzzle ...
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The CSM predictions for the total yield & $\frac{d\sigma}{dy}$?

As we have seen:

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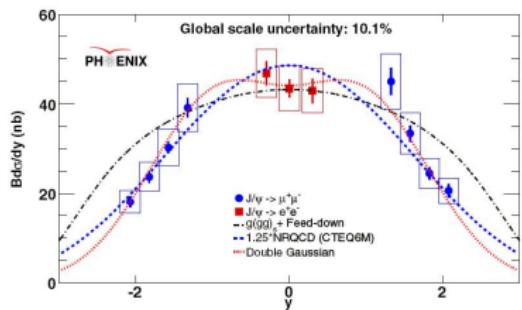
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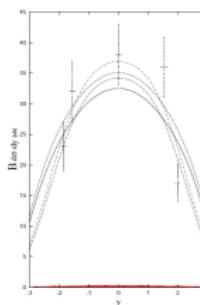
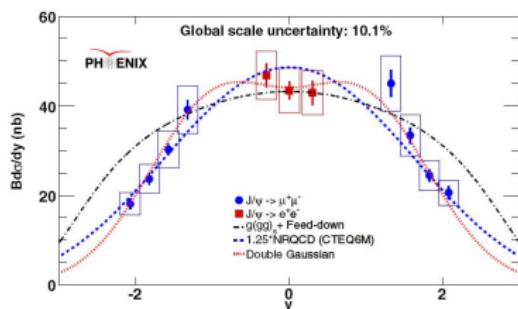


No CSM curve, why ?

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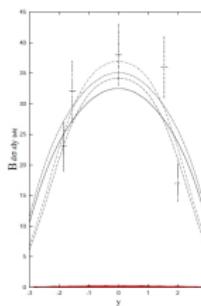
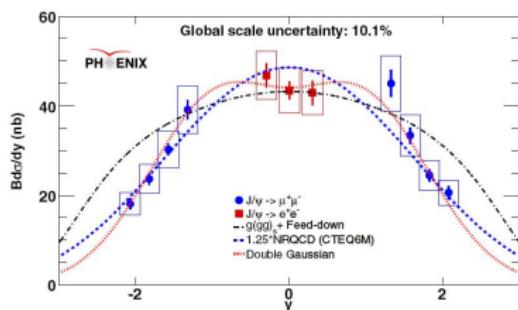


PHENIX, PRL98 232002,2007/ CSM: Cooper *et al.*, PRL 93:171801,2004

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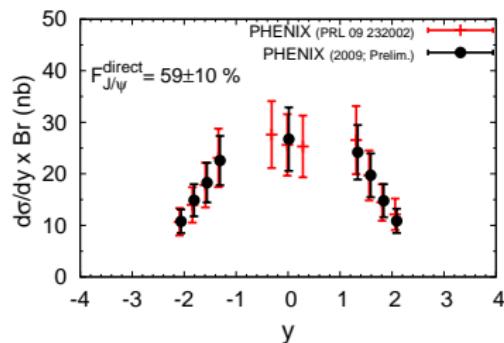
section in the singlet and octet channel. In the color singlet channel, the J/ψ production cross section at α_s^2 order is given by:

$$\sigma_1^{pp \rightarrow J/\psi}(s) = \sigma_1^{pp \rightarrow \chi_0}(s) BR_{\chi_0} + \sigma_1^{pp \rightarrow \chi_2}(s) BR_{\chi_2}. \quad (9)$$

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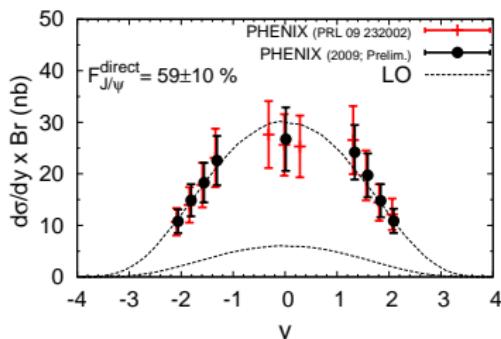
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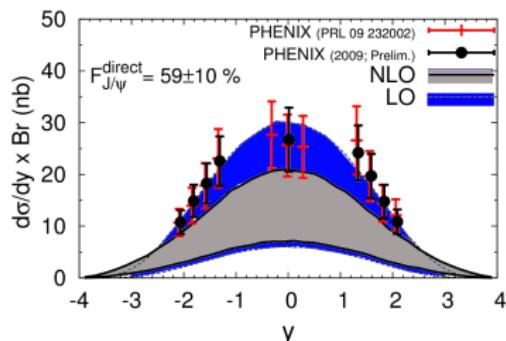


LO: $gg \rightarrow J/\psi g$ (see slide 5, nothing new !)

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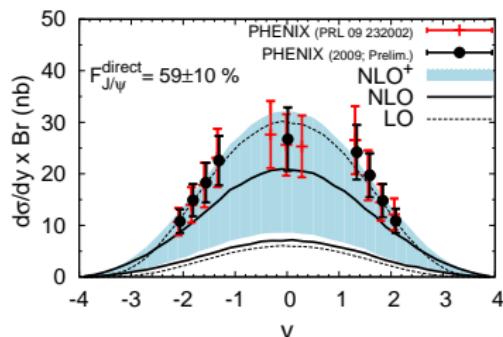
NLO: $gg \rightarrow J/\psi$, $gg gq \rightarrow J/\psi gq$, ...

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

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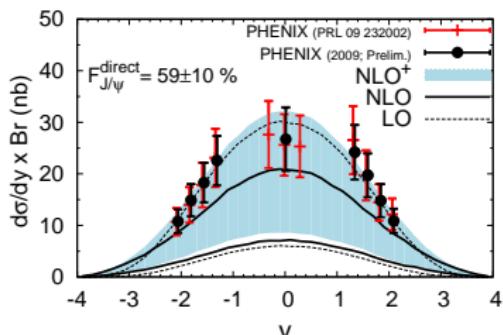


NLO⁺: adding one **new contribution** at LO $cg \rightarrow J/\psi c$

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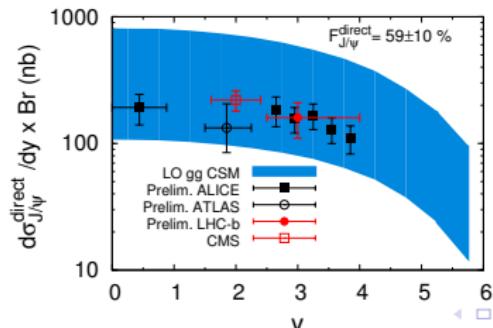
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→ LHC ($\sqrt{s} = 7$ TeV)

JPL, PoS(ICHEP 2010), 206 (2010)



the CSM predictions account for the yield

→ The yield vs. \sqrt{s}

JPL, PoS(ICHEP 2010), 206 (2010)

(here only LO curves)

- Unfortunately, very large th. uncertainties: masses, scales (μ_R , μ_F), gluon PDFs at low x and Q^2 , ...
- Good agreement with RHIC, Tevatron and LHC data
(multiplied by a constant F^{direct})

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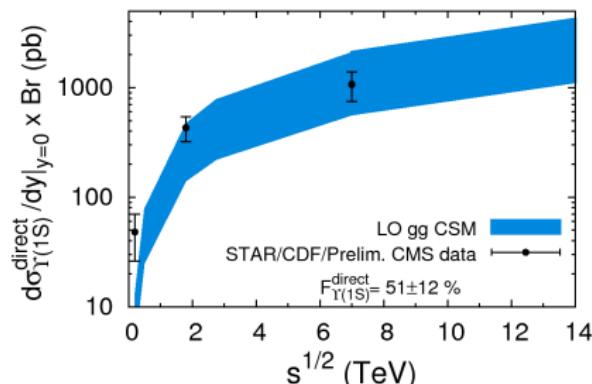
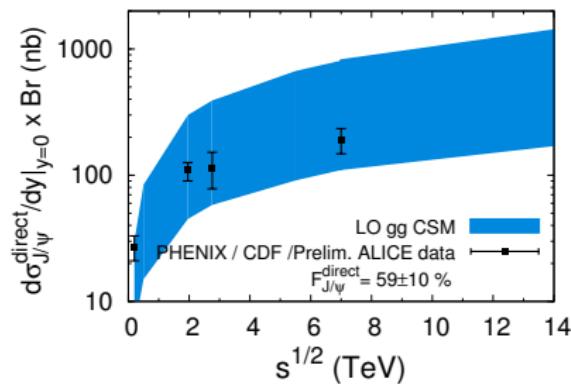
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Part III

Recent progresses: QCD corrections

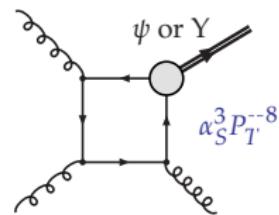
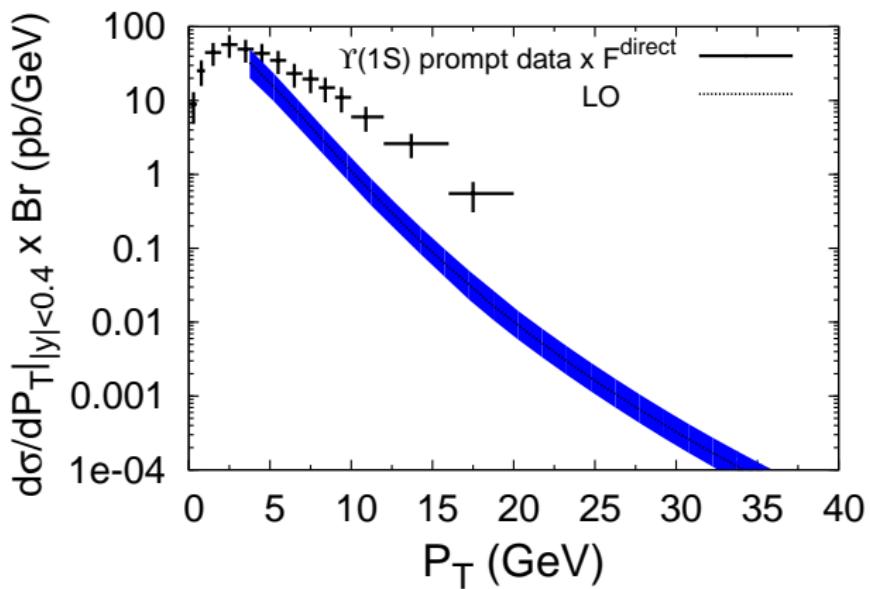
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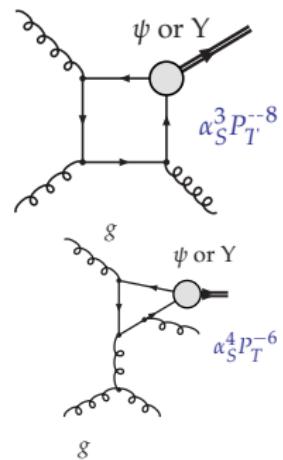
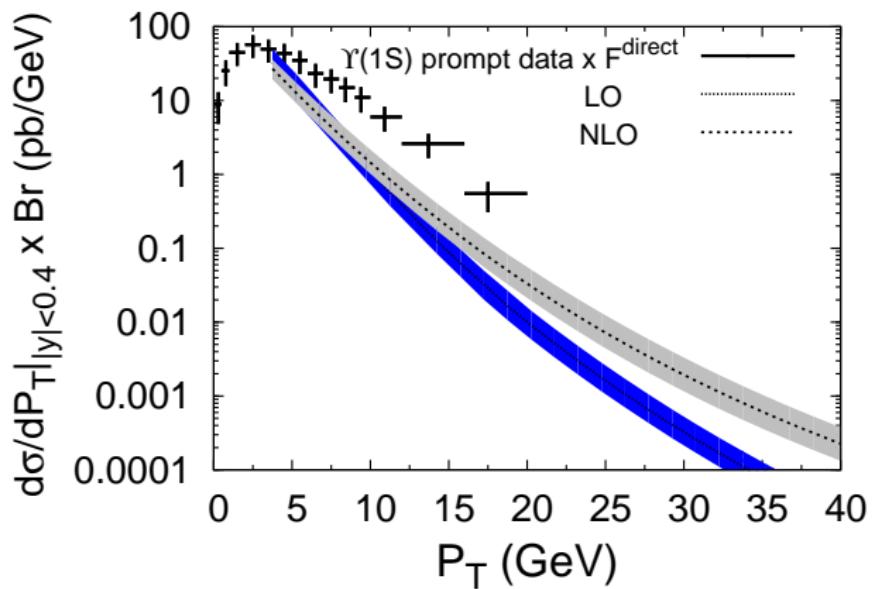


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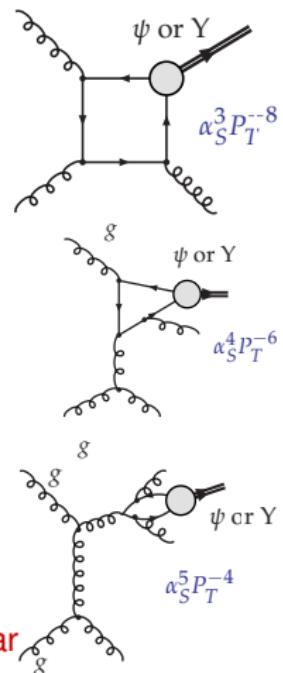
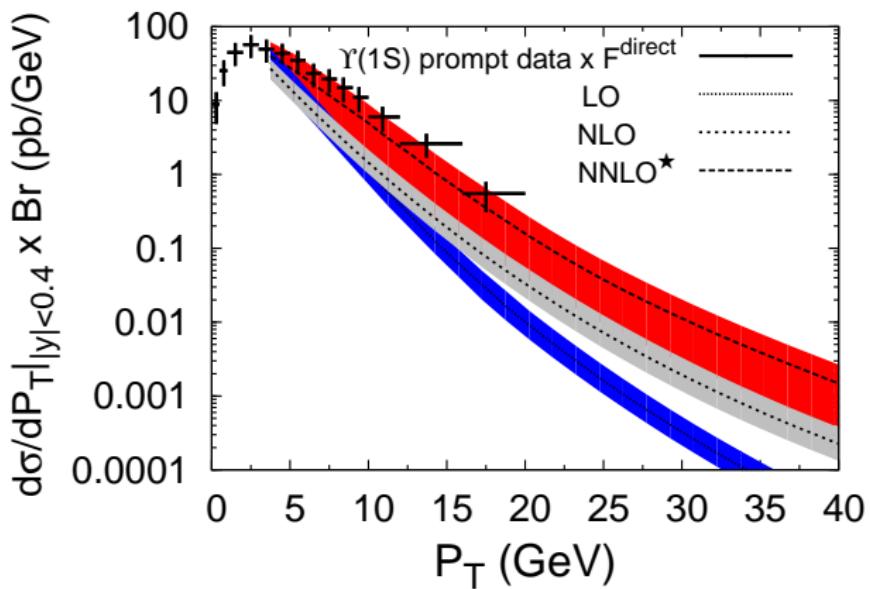


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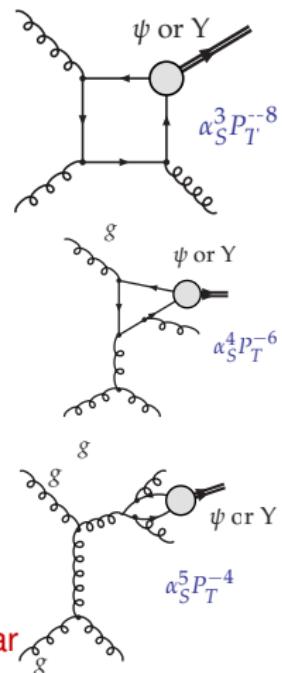
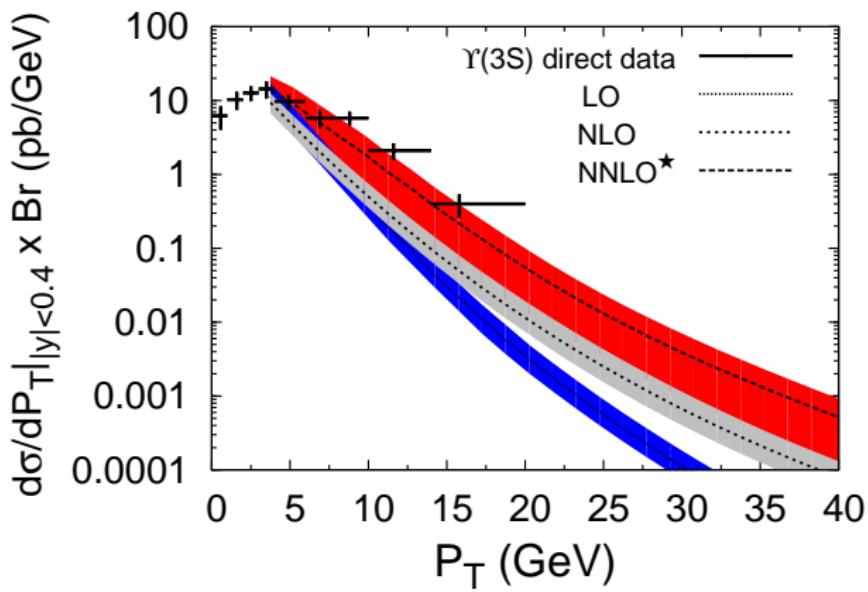
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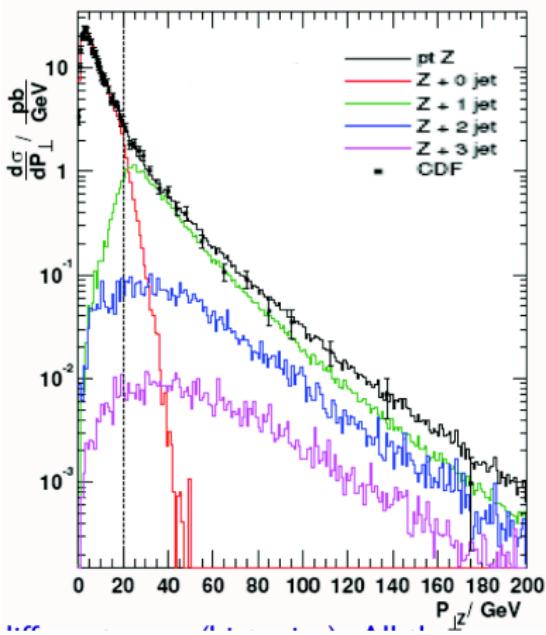
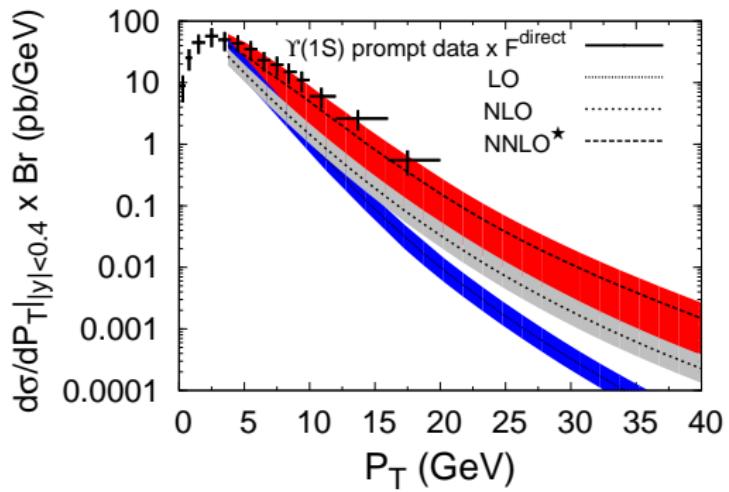
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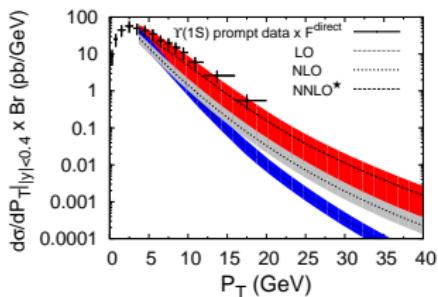


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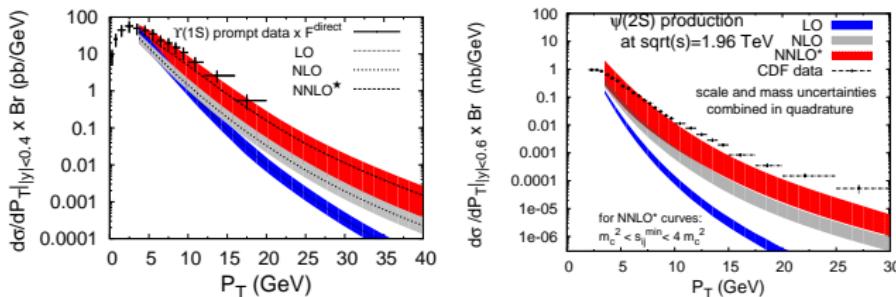
Analogy with the P_T spectrum for the Z^0 boson



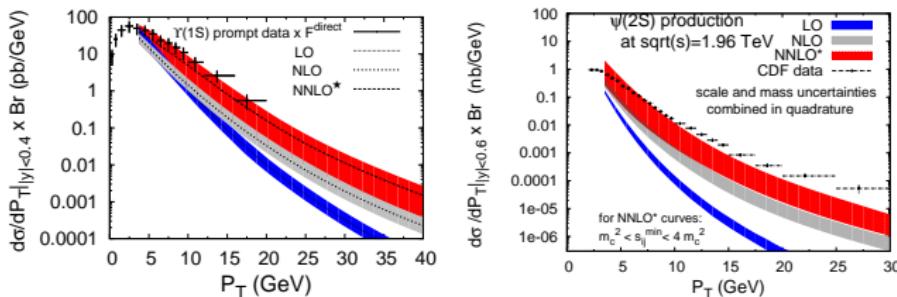
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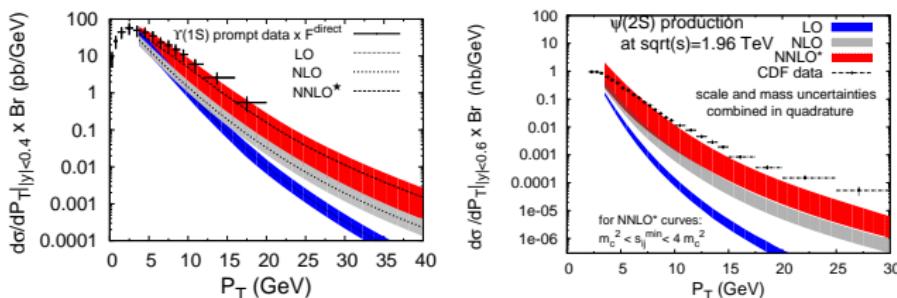


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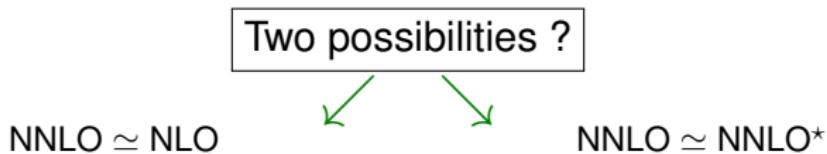


The NNLO* is not a complete NNLO → possibility of uncanceled logs !

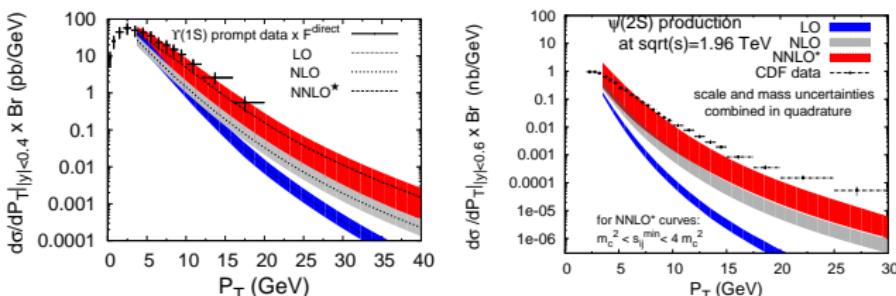
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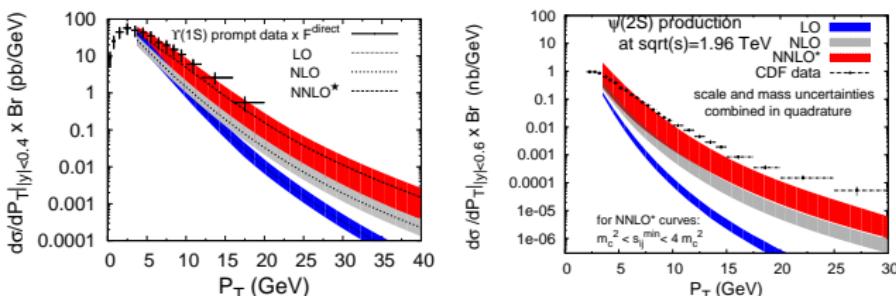


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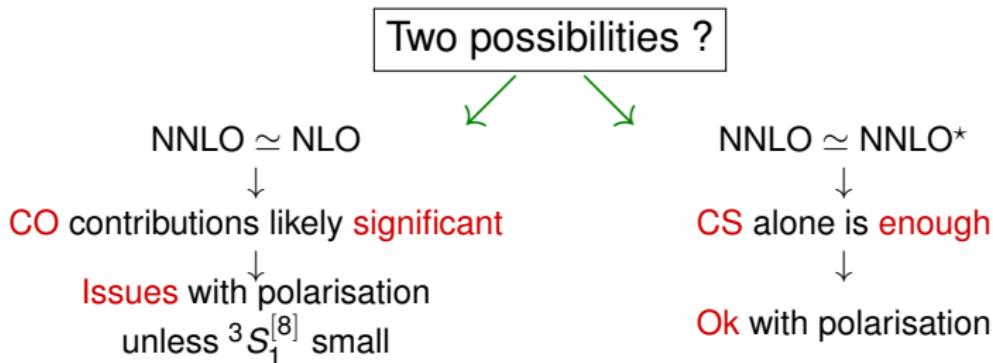
Two possibilities ?



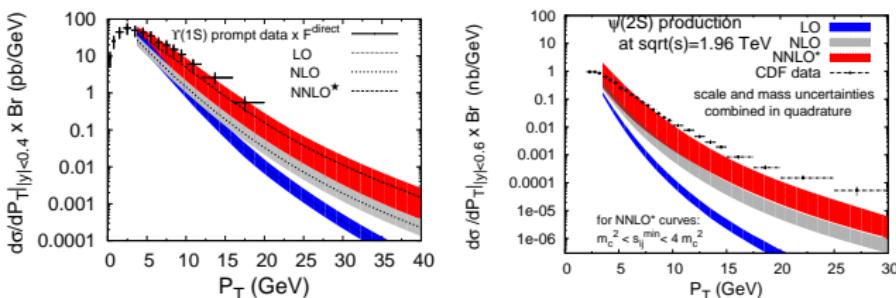
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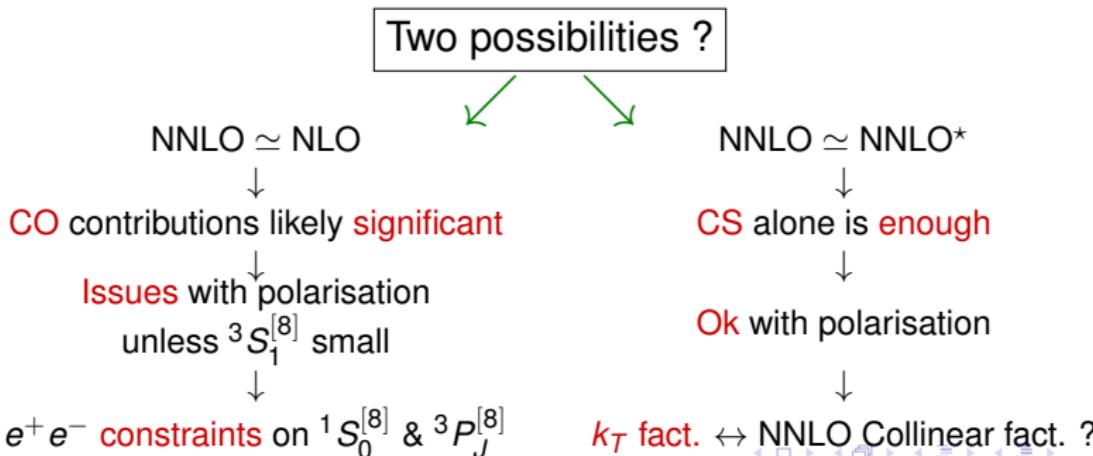
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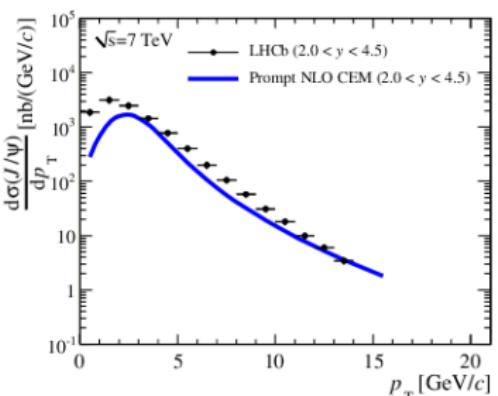
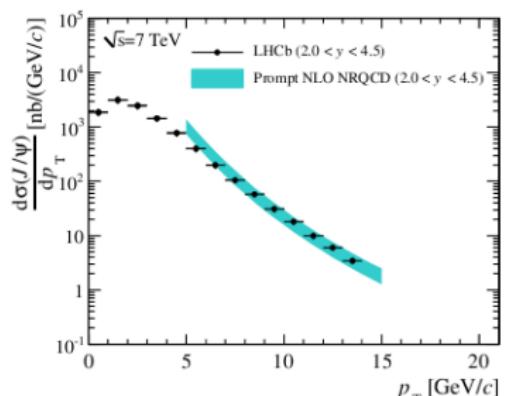
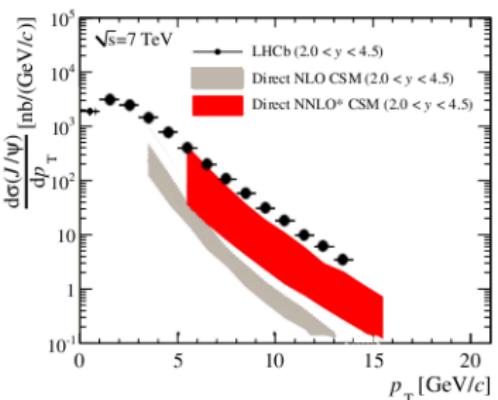
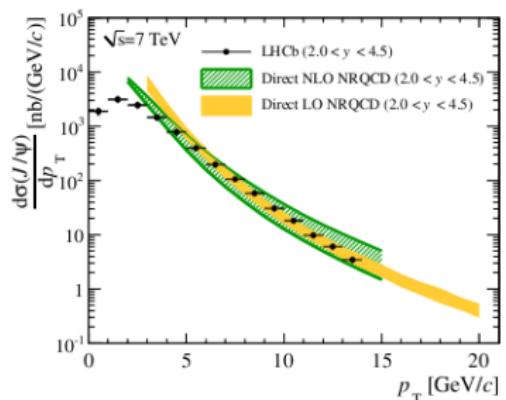
Impact of QCD corrections to CSM at mid and high P_T



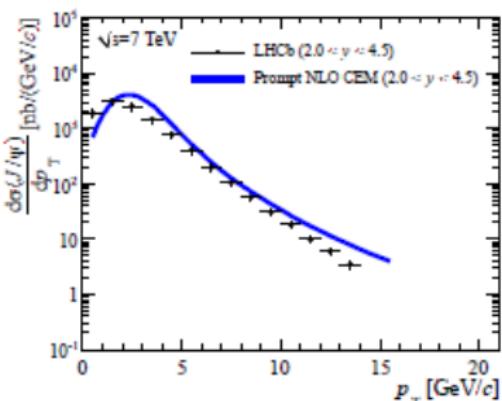
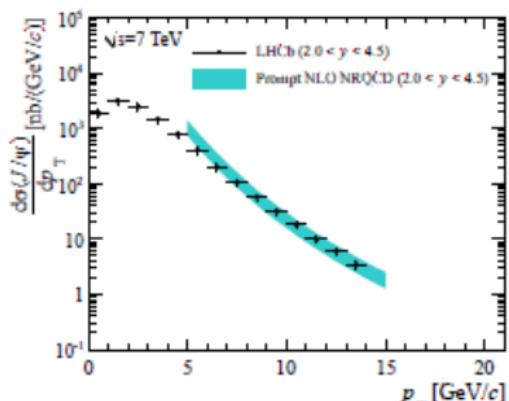
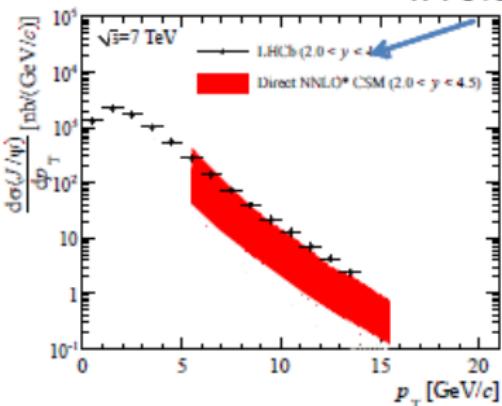
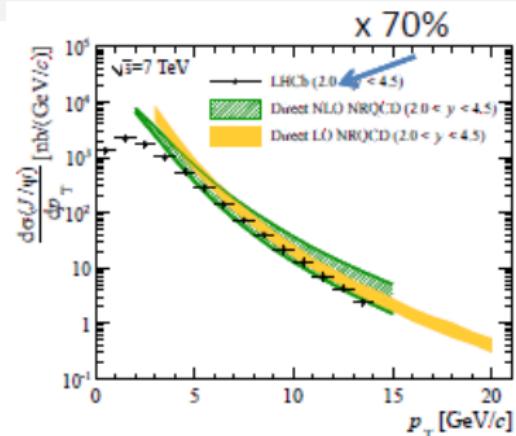
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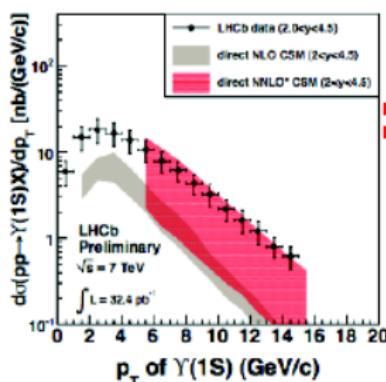
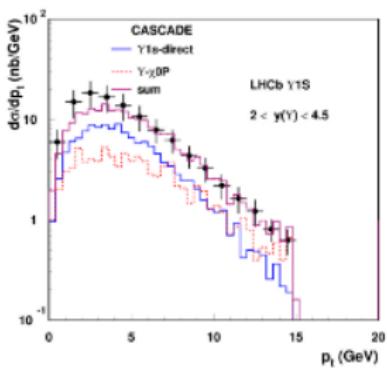
Models vs. LHCb data for the J/ψ (Courtesy of J.He & P. Robbe)



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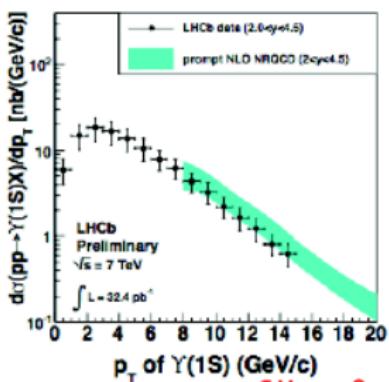
Models vs. LHCb data for the Υ (borrowed from G. Manca, April'11)



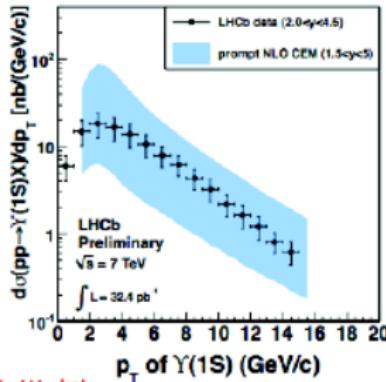
J.-P. Lansberg, Eur. Phys. J. C 61 (2009) 693

P. Artoisenet et al., PRL 101, 152001, 2008

Y. Q. Ma, K. Wang and
K. T. Chao, Phys. Rev. Lett. 106 (2011) 042002.



A. D. Frawley, T. Ullrich and R. Vogt, Phys. Rep. 462 (2008) 125.

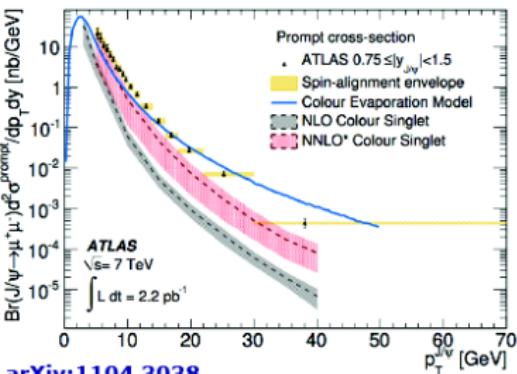
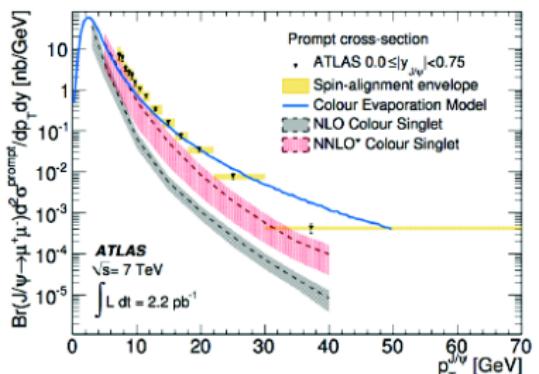


19.4.2011

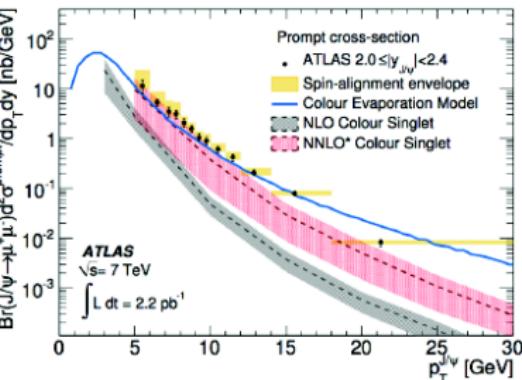
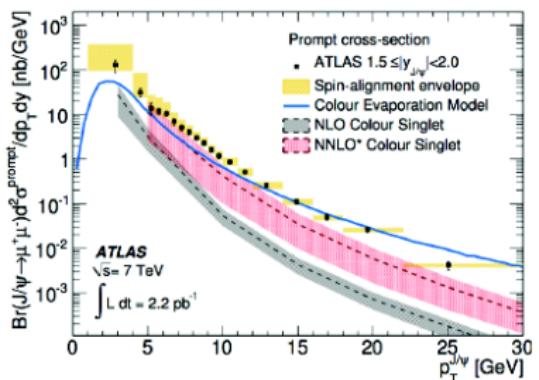
G. Manca, Quarkonia Workshop

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Models vs. ATLAS data for the J/ψ (borrowed from D. Price, April'11)



arXiv:1104.3038



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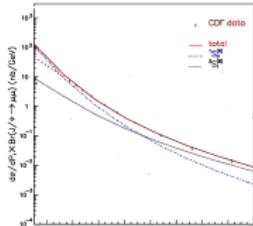
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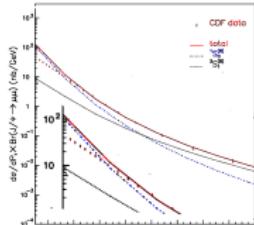
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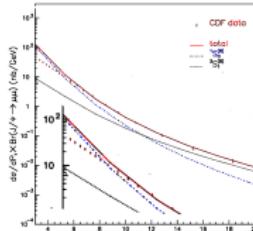
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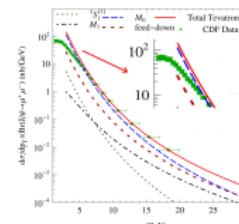
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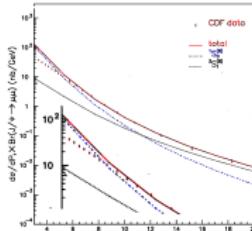
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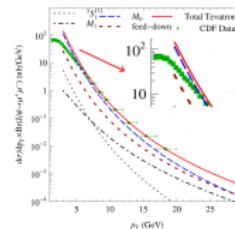
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- ISR resummations would smear the divergence at $P_T \rightarrow 0$ out

Would this further enhance the CO yield at low P_T ?

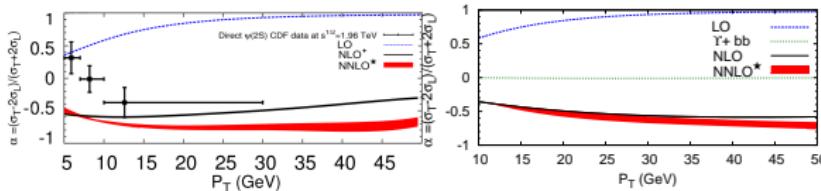
QCD corrections, feed-down and polarisation

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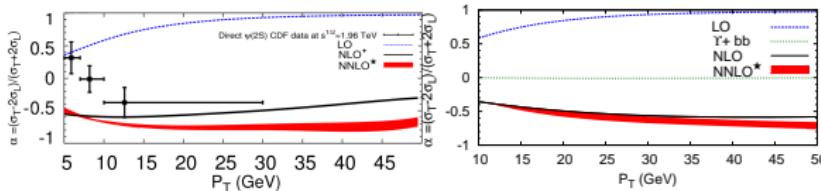
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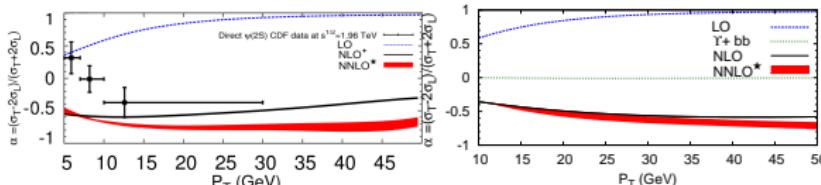


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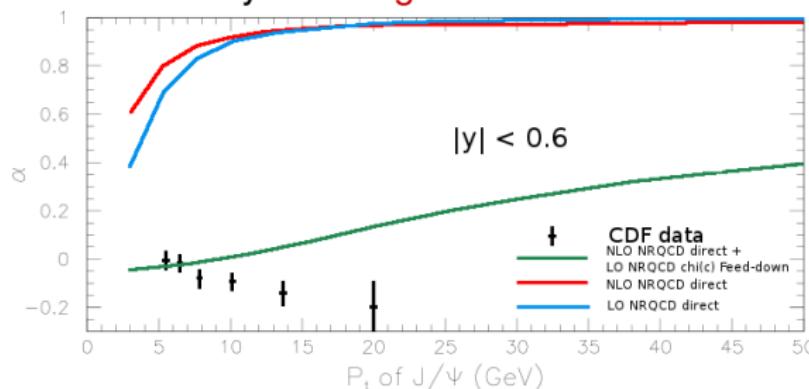
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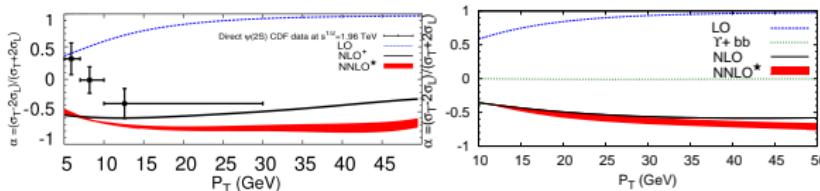
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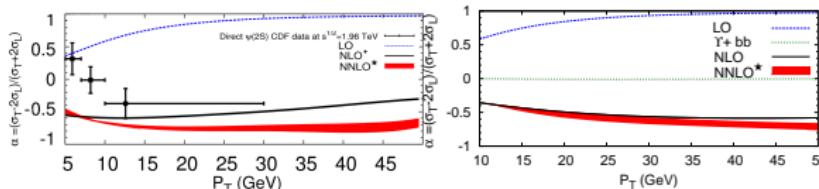


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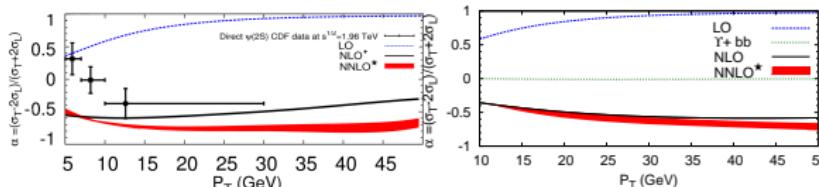
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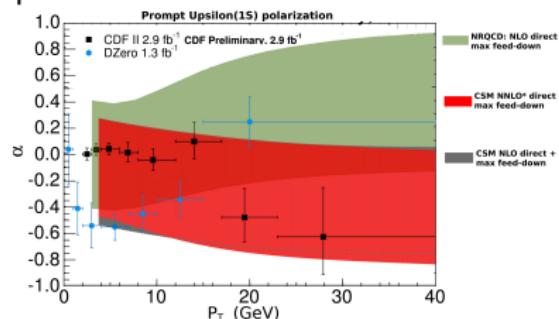
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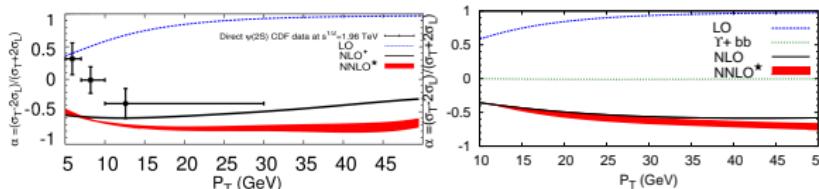
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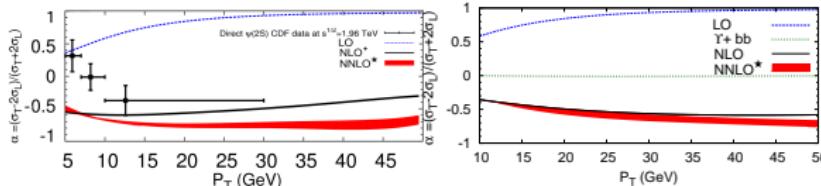
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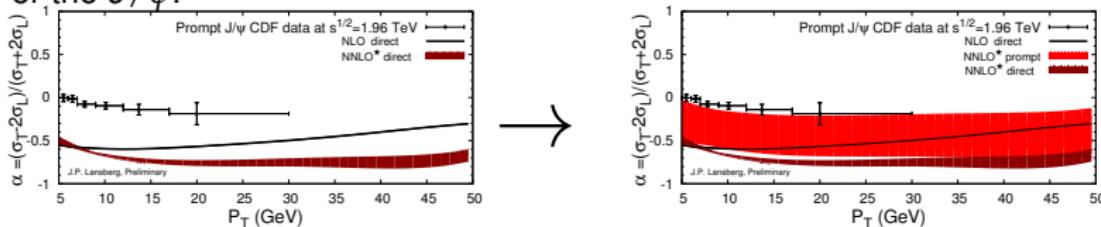
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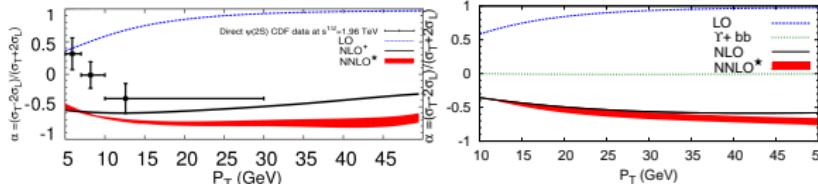
- $\alpha_{tot} = F_{dir.}\alpha_{dir.} + (1 - F_{dir.})\alpha_{FD}$ $\xrightarrow{if \alpha_{FD} \approx 0} F_{direct}\alpha_{direct}$ (unless $|\alpha_{FD}| = 1$, $|\alpha_{tot}| < |\alpha_{direct}|$)
- If $\chi_c \rightarrow ^3S_1\gamma$ is E1: $\alpha_{from \chi_c}^{max} = +1.00$ and $\alpha_{from \chi_c}^{min} = -0.45$
- For the J/ψ :



QCD corrections, feed-down and polarisation

P.Artoisenet, J.Campbell, JPL, F.Maltoni, F.Tramontano, Phys. Rev. Lett. 101,152001,2008
 B. Gong, J.X Wang, Phys. Rev. Lett. 100,232001,2008.
 JPL, EPJC 61,693,2009. JPL, PLB695:149-156,2011.

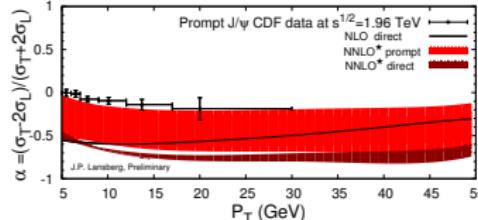
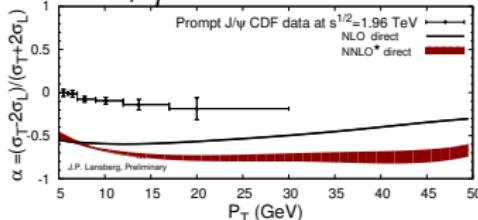
→ Complete modification of the CSM polarisation at NLO (also at NNLO*)



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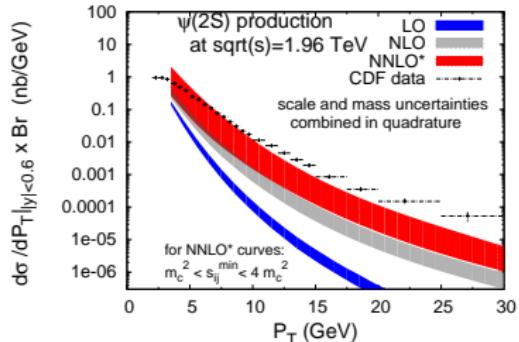
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The CSM does describe the data

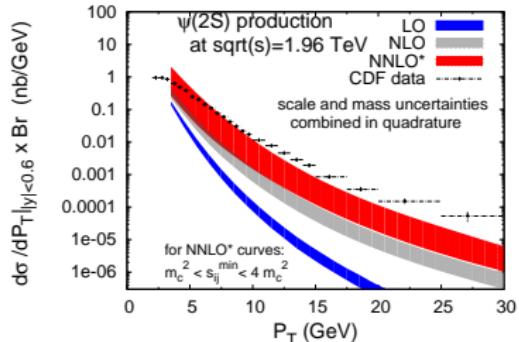
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Gap at large P_T ?

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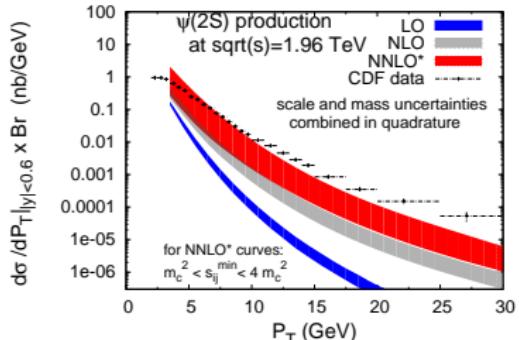
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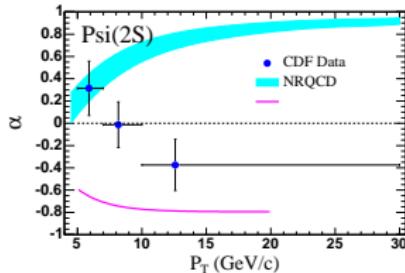
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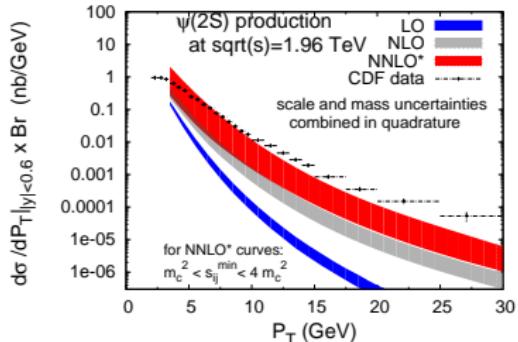


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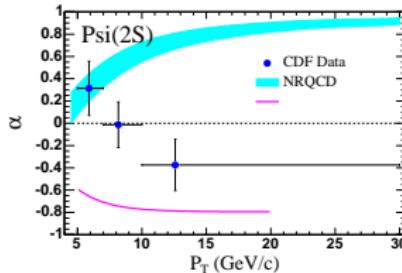


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- Let's wait for the LHC data for prompt $\psi(2S)$ or direct J/ψ

Part IV

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- (N)NLO corrections alter the polarization : transverse → longitudinal
Yet, most polarisation data are prompt
- Need for new observables
at the LHC or elsewhere !