Quarkonium production at the LHC and beyond: theory vs data

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IPN Orsay – Paris-Sud U.

Heavy Ion Meeting,
May 4, 2012
SPhN-IRFU-CEA, Saclay

Part I

Introduction

Basic pQCD approach: the Colour Singlet Model (CSM)

Common wisdom on the quarkonium-production puzzle before 2007

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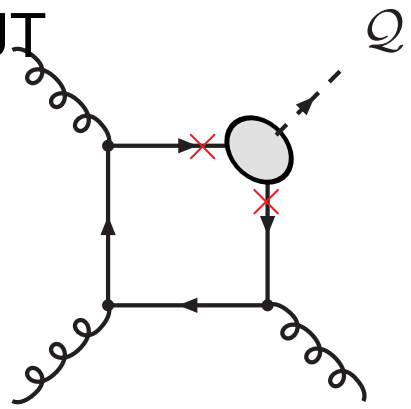
➥ Perturbative creation of 2 quarks Q and $\bar{Q}$ BUT



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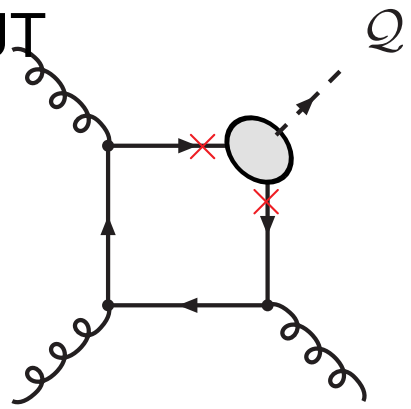

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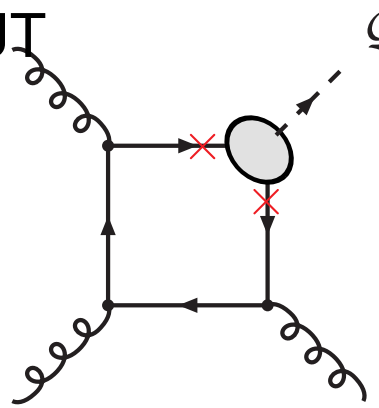

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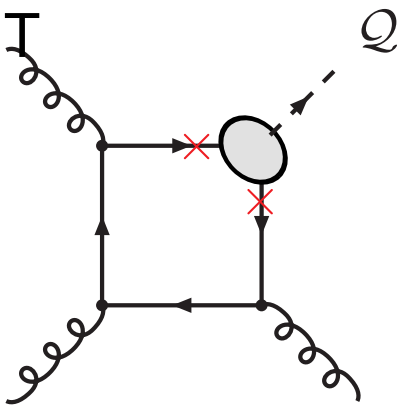

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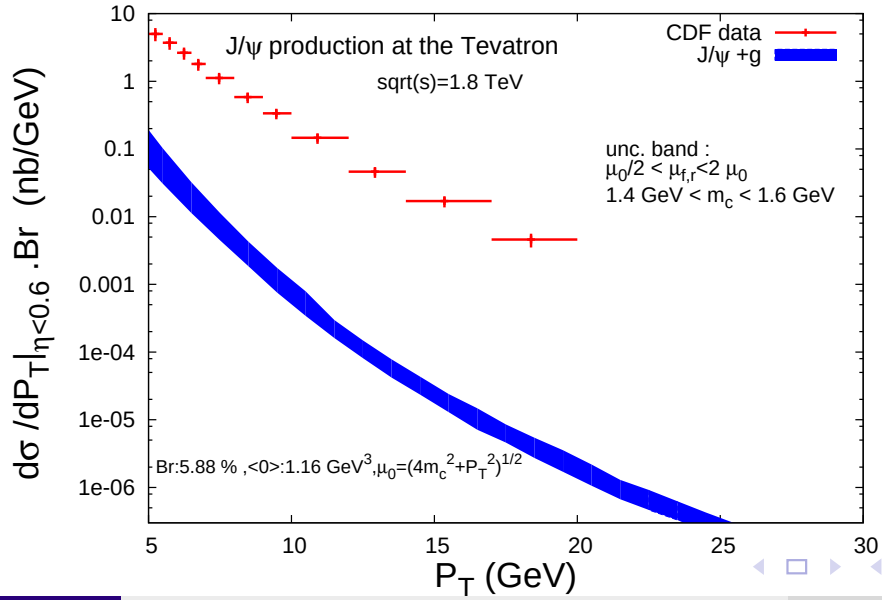

CDF, PRL 79:572 & 578,1997

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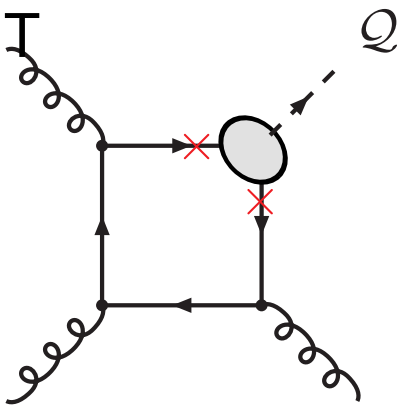

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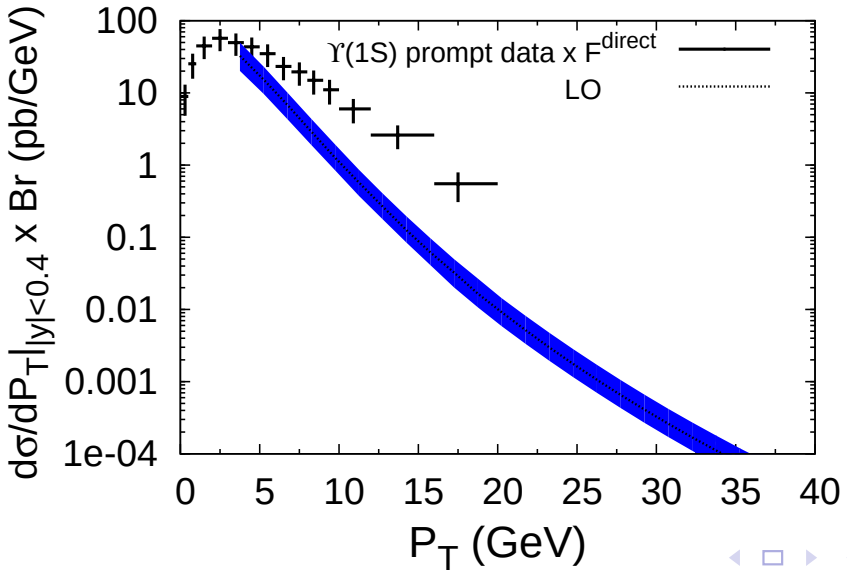

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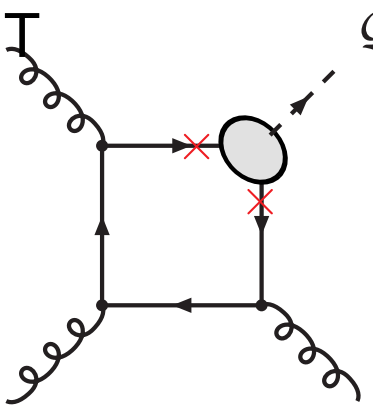

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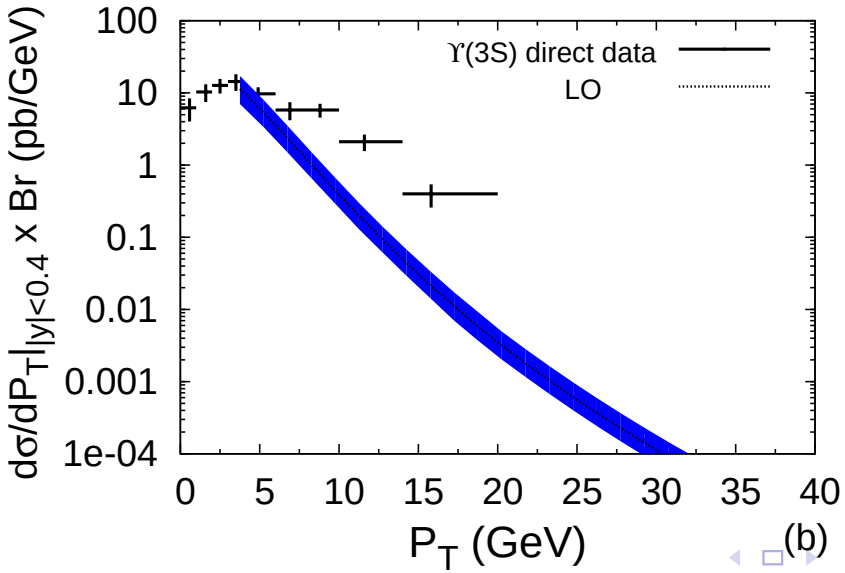

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CSM predictions account for the P_T-integrated yield

S. J. Brodsky and JPL, PRD 81 051502 (R), 2010; JPL, PoS(ICHEP 2010), 206 (2010)

→ The yield vs. $\sqrt{s}$ (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

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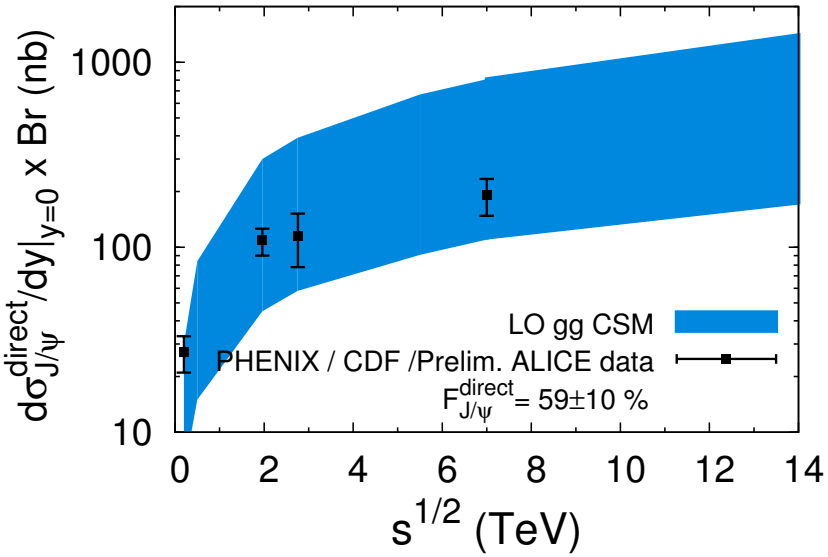

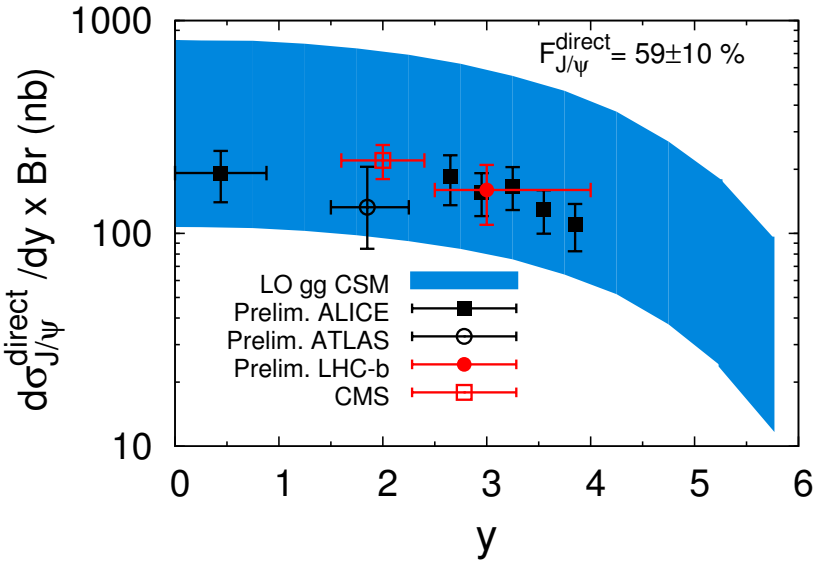

Part II

Recent progresses: QCD corrections

Describing the mid- and high-P_T's: QCD corrections

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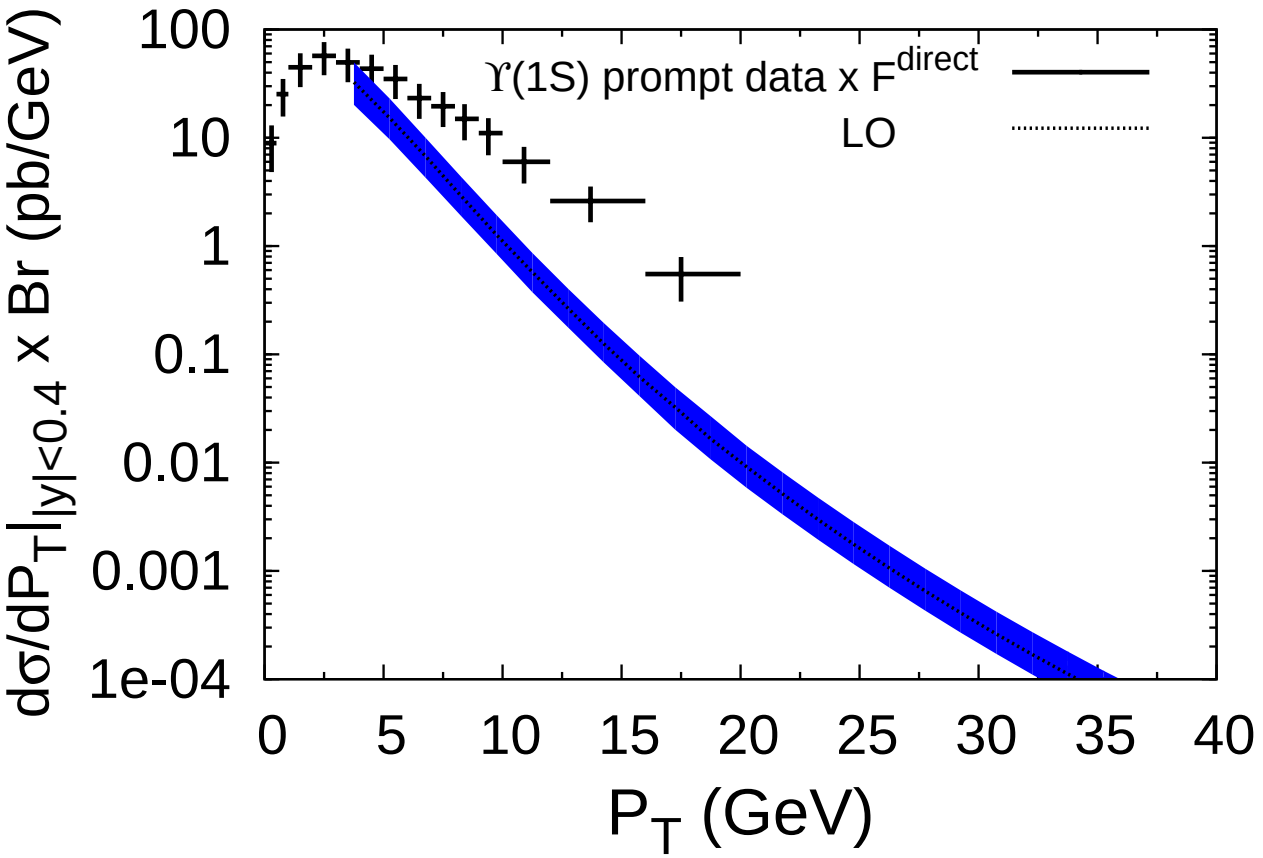

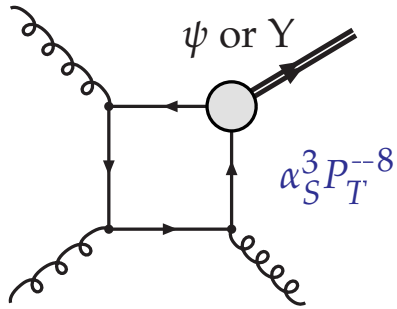

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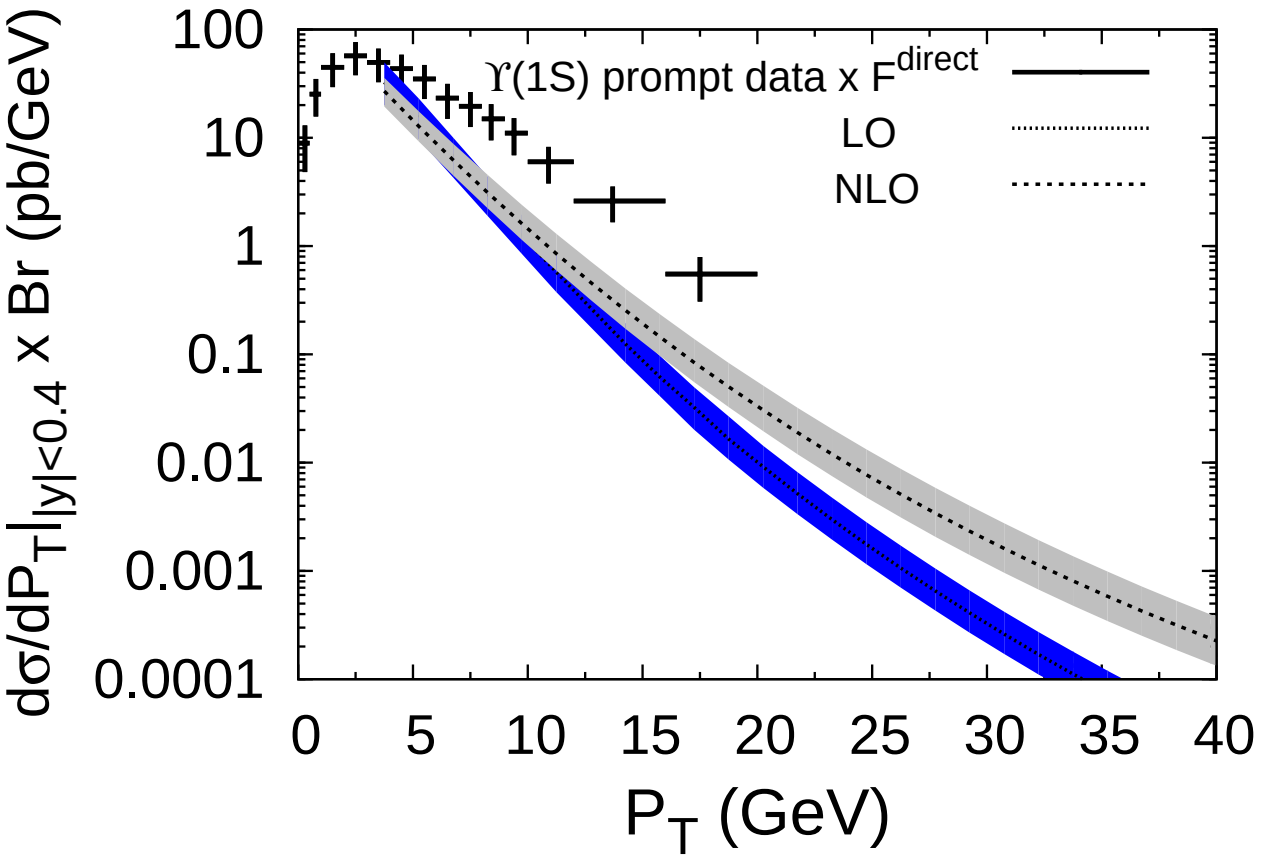

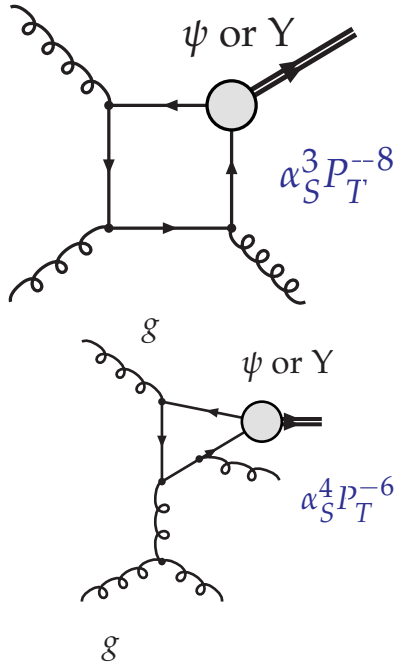

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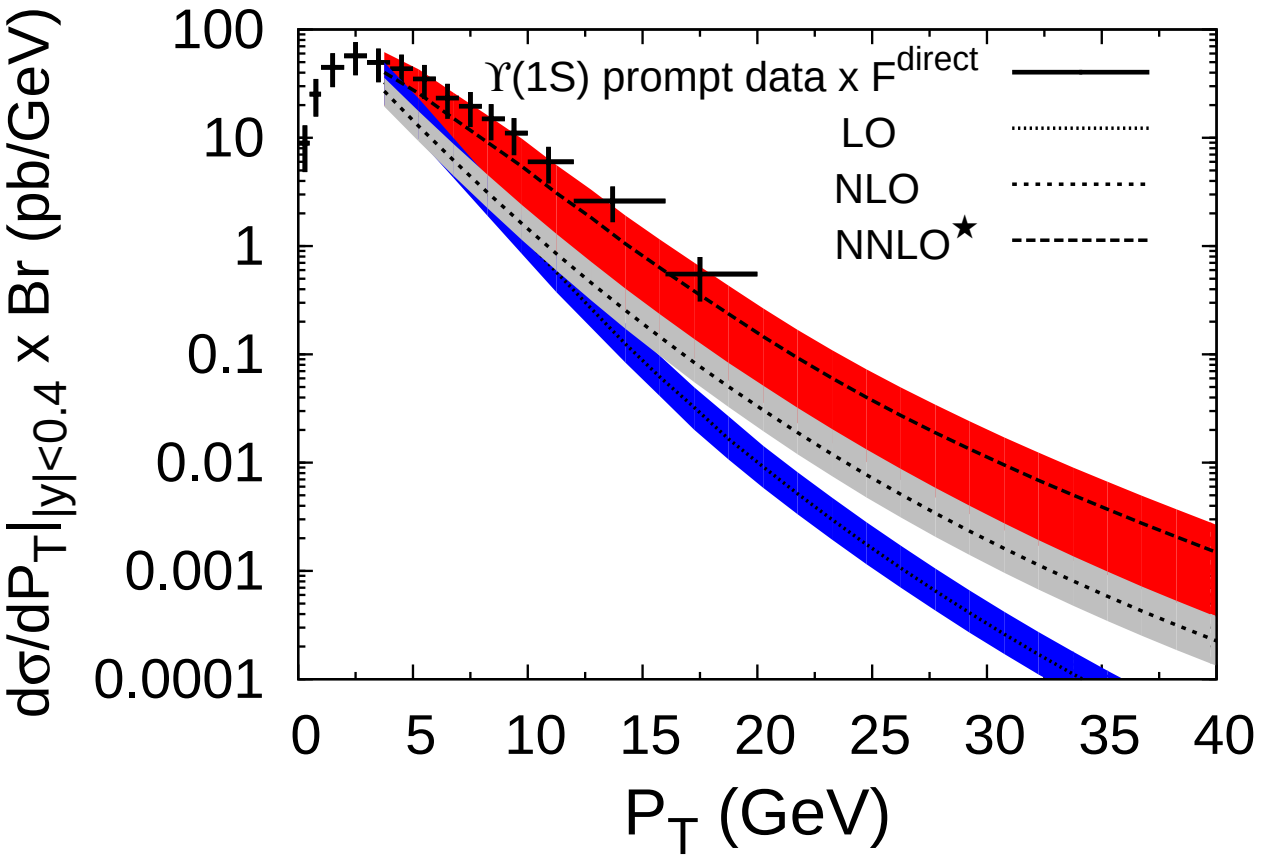

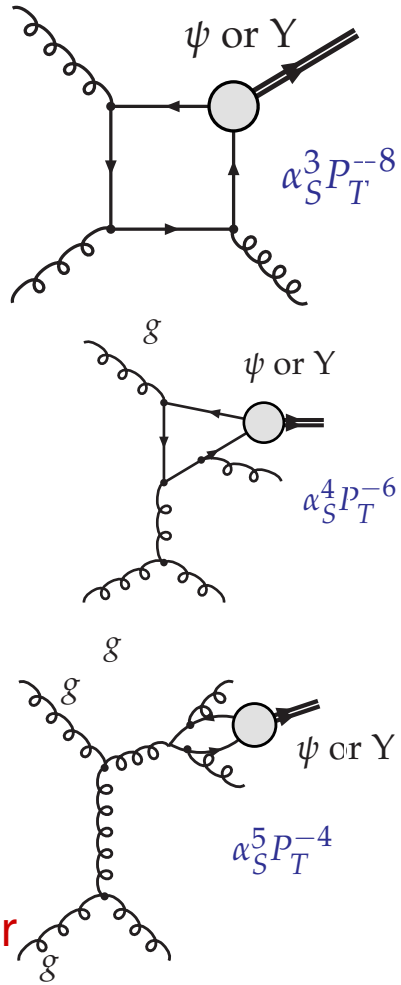

Yet, the impact of double t-channel gluon exchange at α_S^5 is not clear

(NNLO* is not a complete NNLO)

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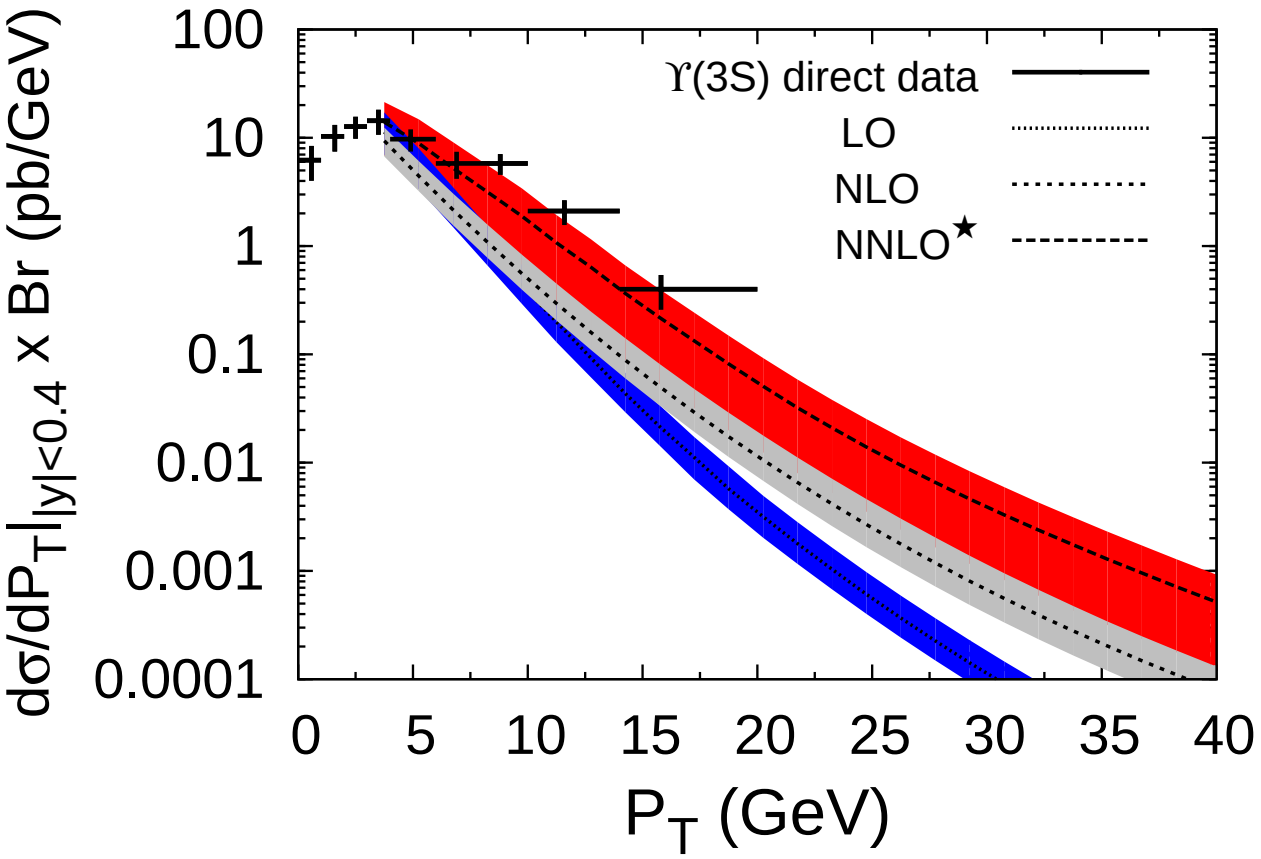

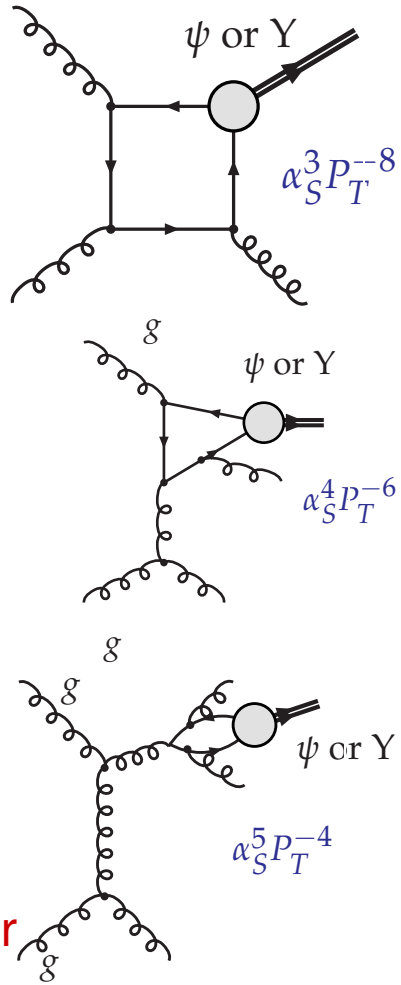

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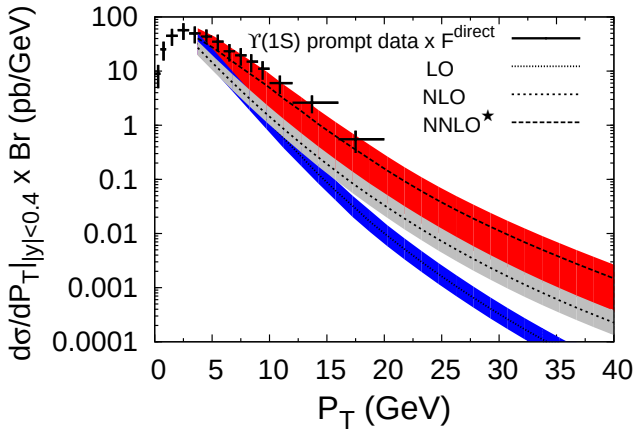

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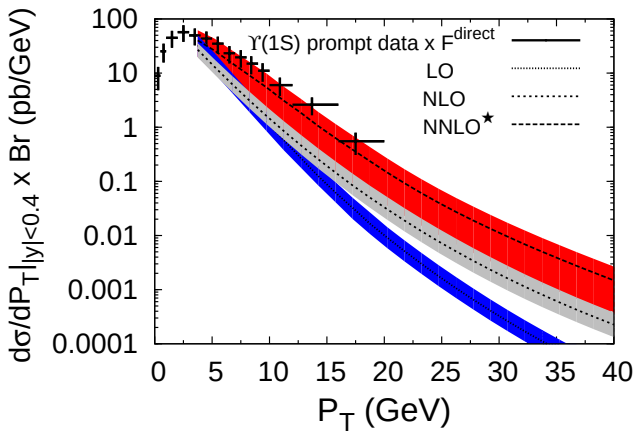

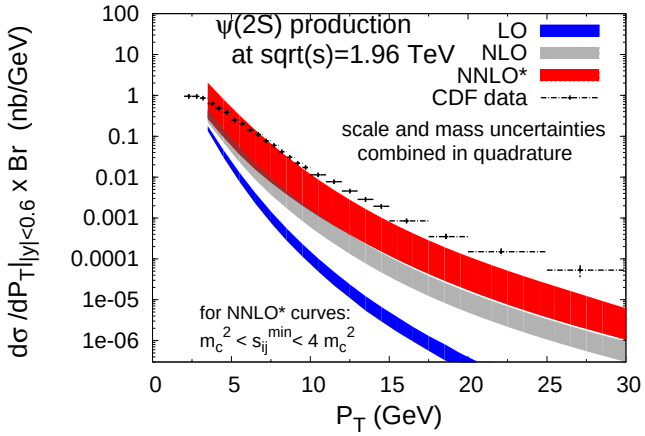

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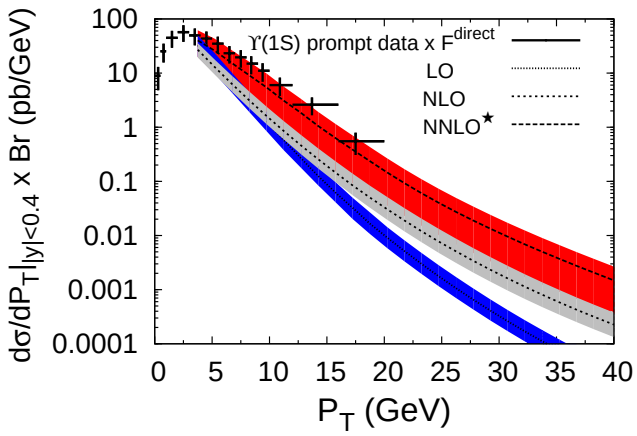

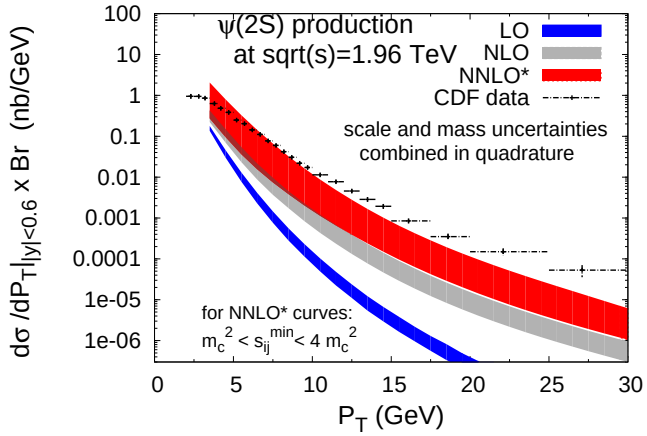

The NNLO* is not a complete NNLO $\rightarrow$ possibility of uncanceled logs !

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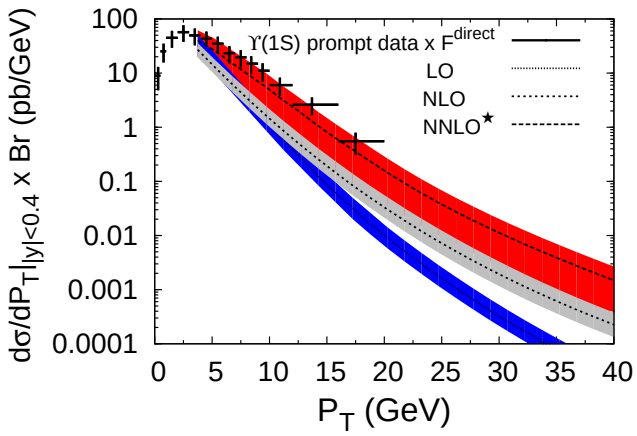

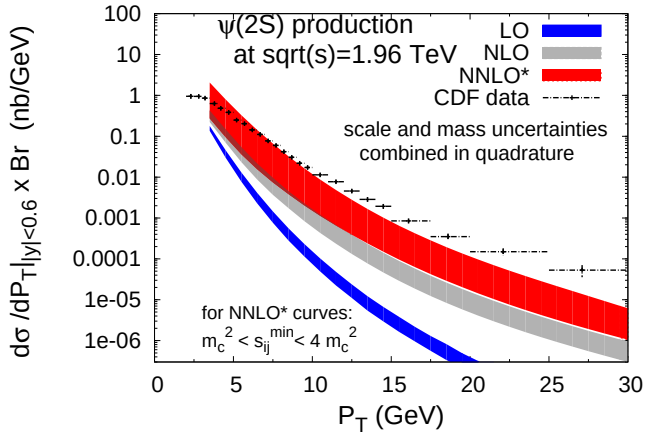

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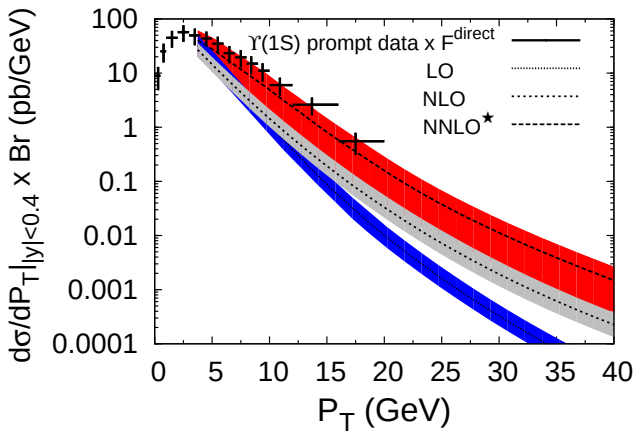

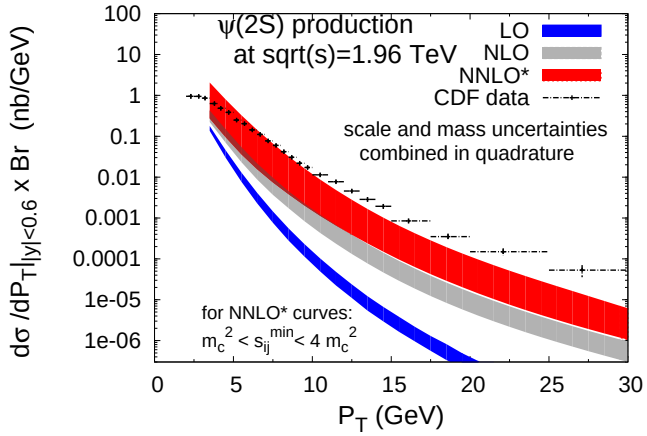

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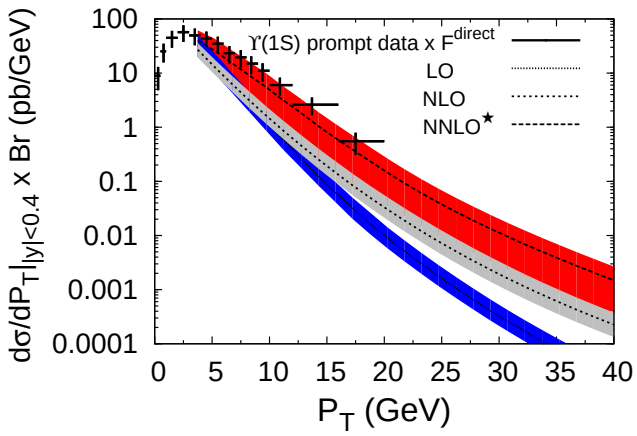

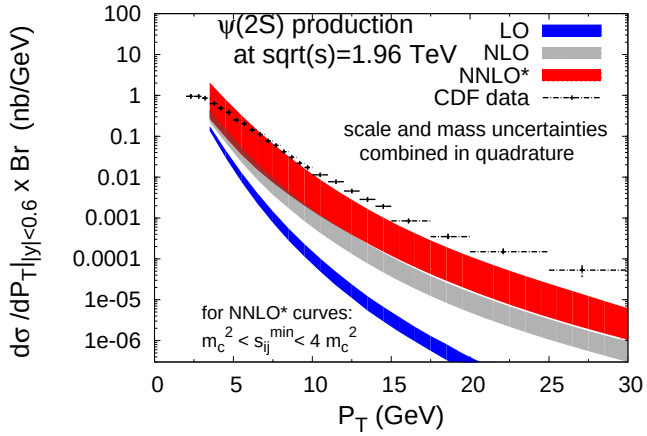

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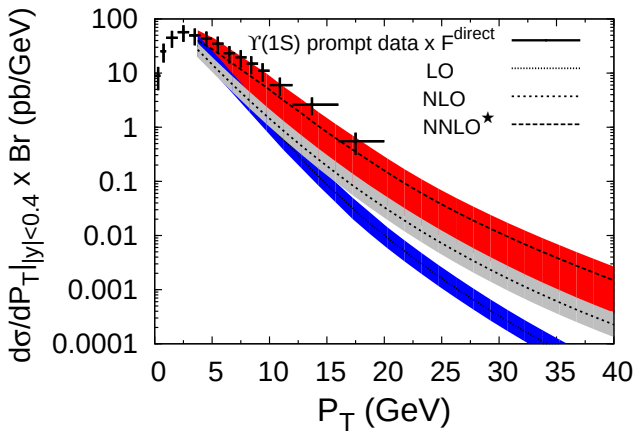

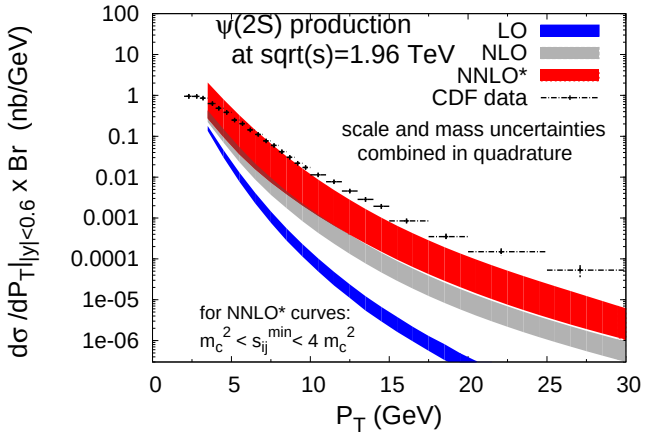

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e^+e^- constraints on ${}^1S_0^{[8]}$ & ${}^3P_J^{[8]}$

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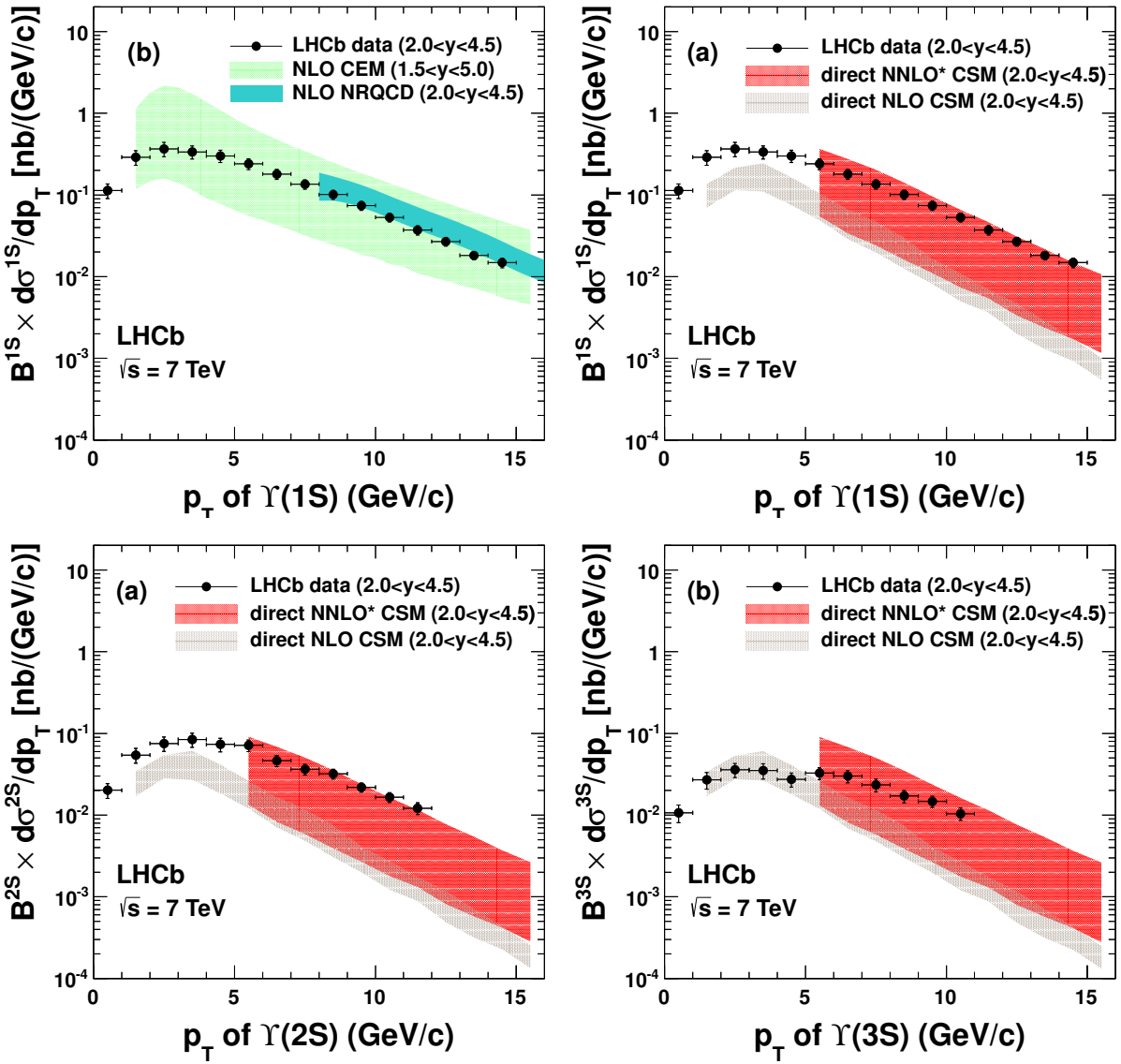
k_T fact. $\leftrightarrow$ NNLO Collinear fact. ?

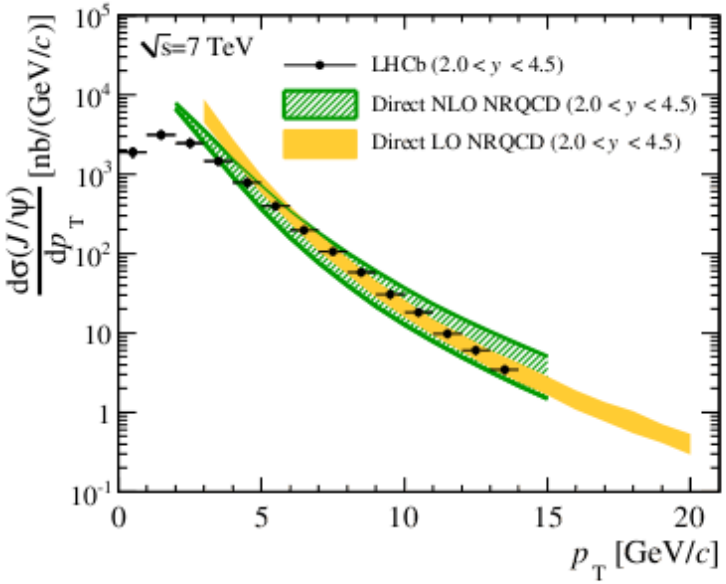
Models vs. LHCb data for the Υ

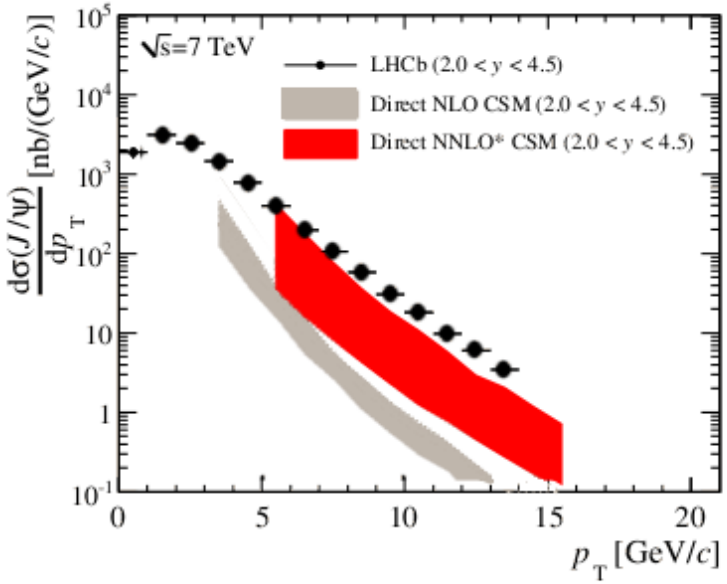
P.Artoisenet, J.Campbell, JPL, F.Maltoni, F. Tramontano, Phys. Rev. Lett. 101, 152001 (2008)
K.Wang,..., K.T. Chao arXiv:1202.6012
LHCb, arXiv:1202.6579

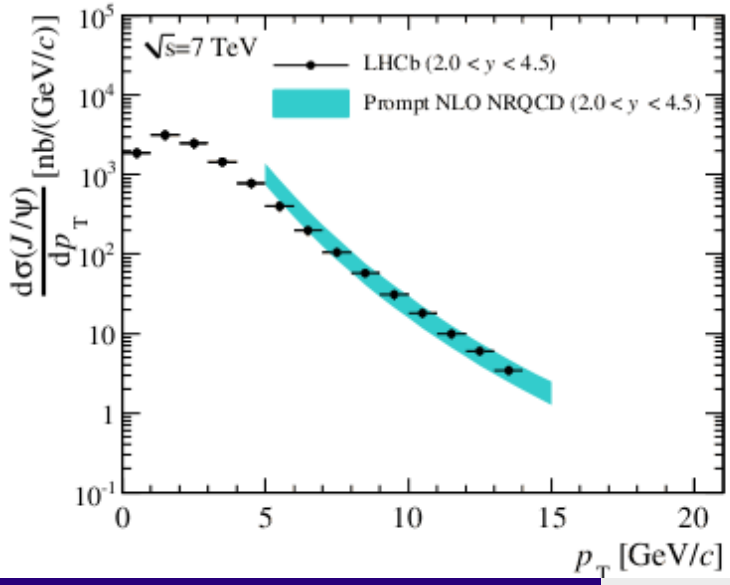


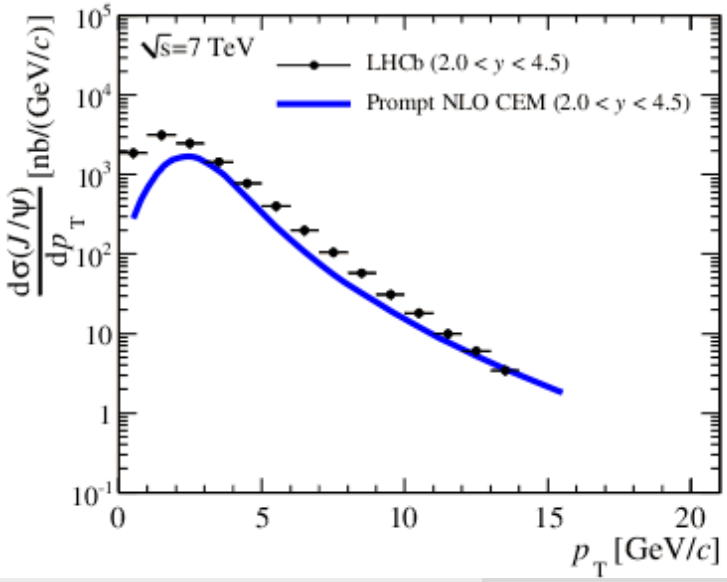
Gray and red CSM bands:
only for direct. 50 % for $1S$, and 60 % for $2S$

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









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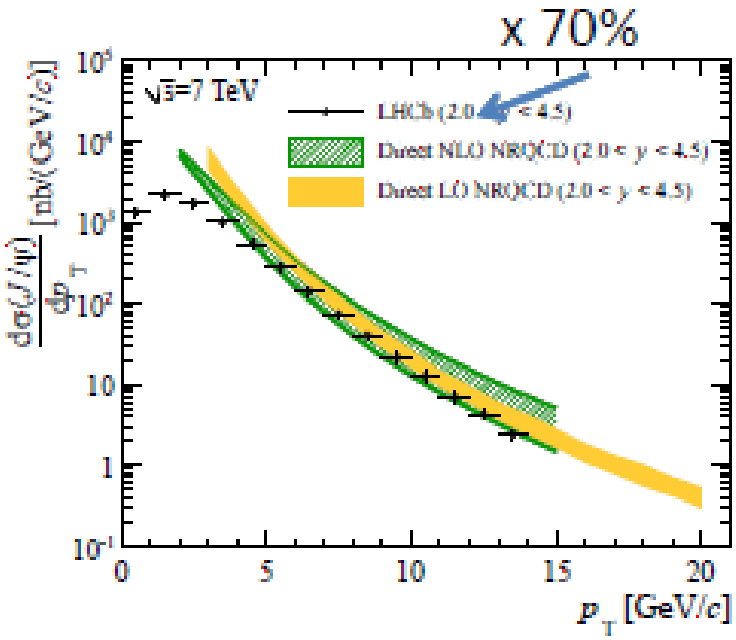
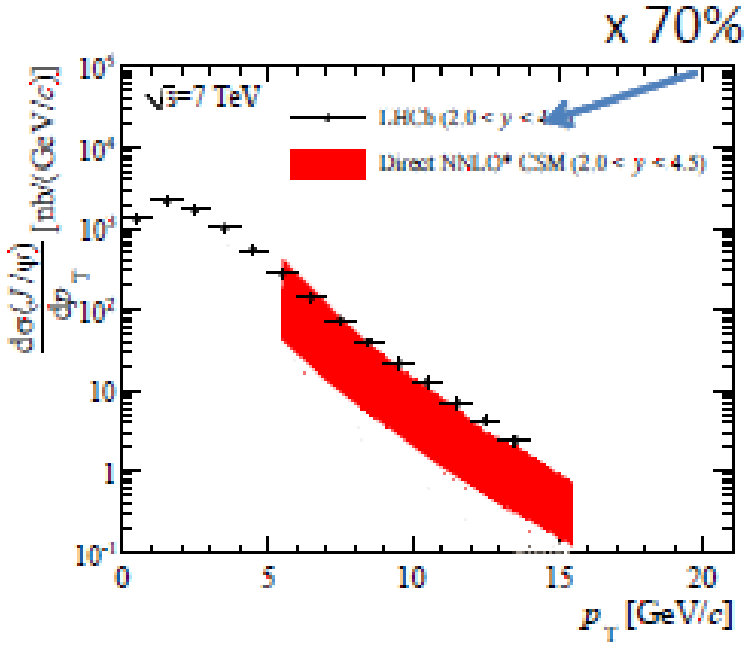
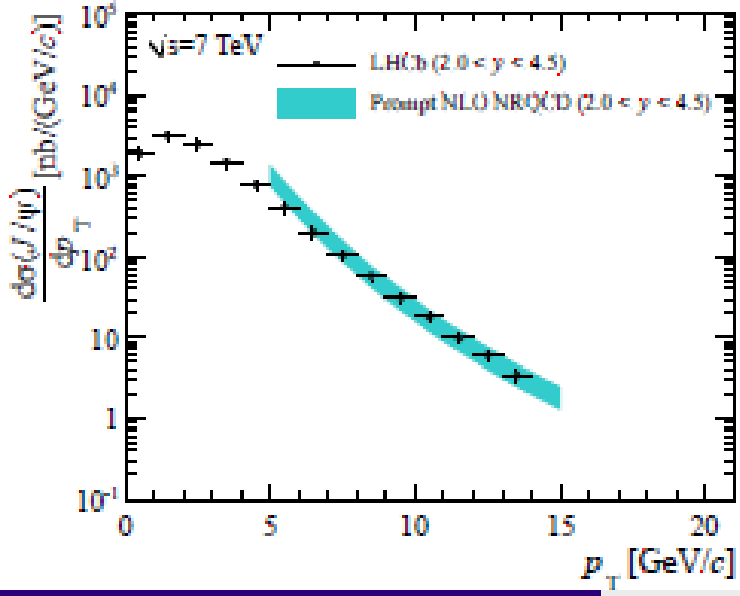
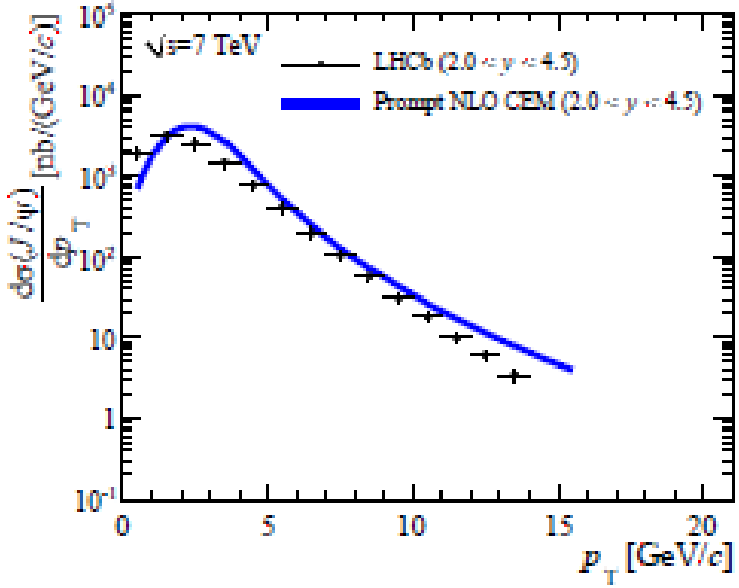
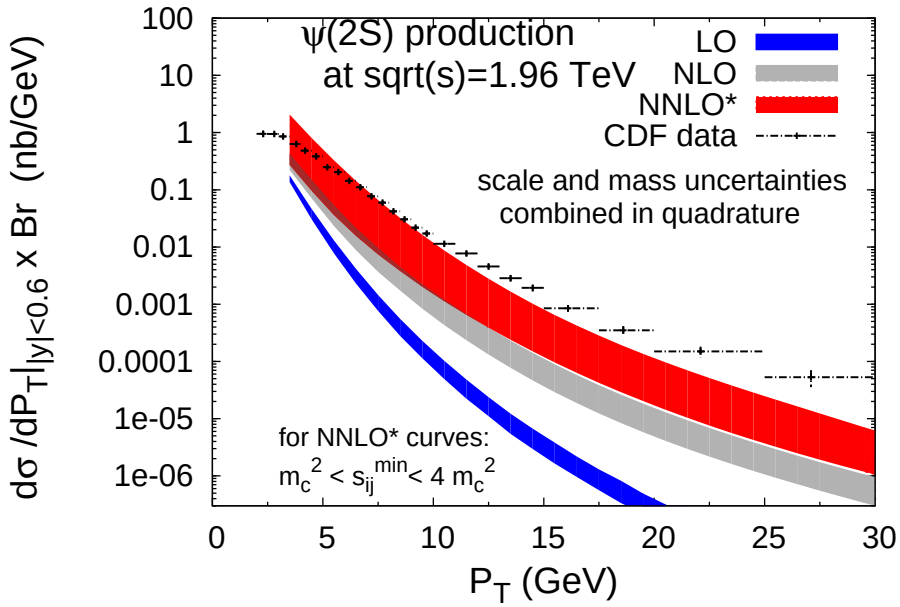


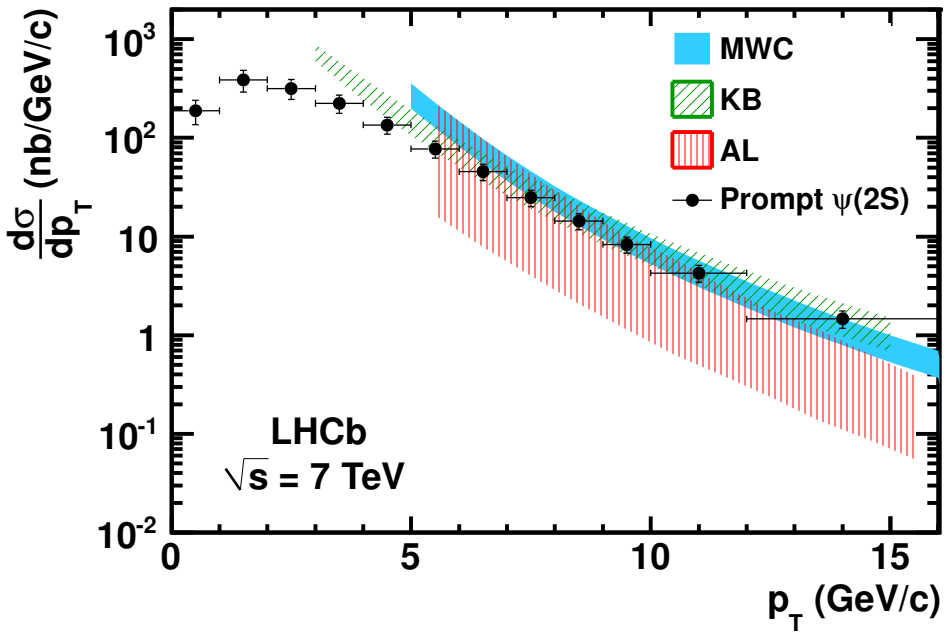






Models vs. LHCb data for the $\psi(2S)$





LHCb, arxiv:1204.1258

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IF one ignores the CSM: upper bound on CO

Y. Zhang,...,K.T. Chao, PRD81:034015,2010.

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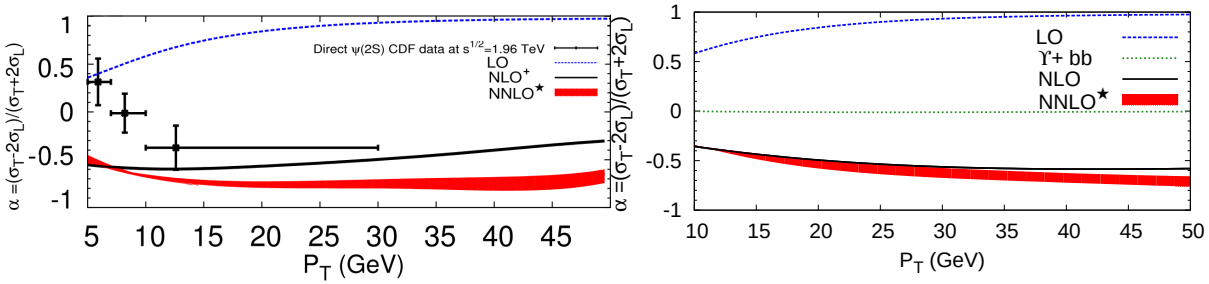

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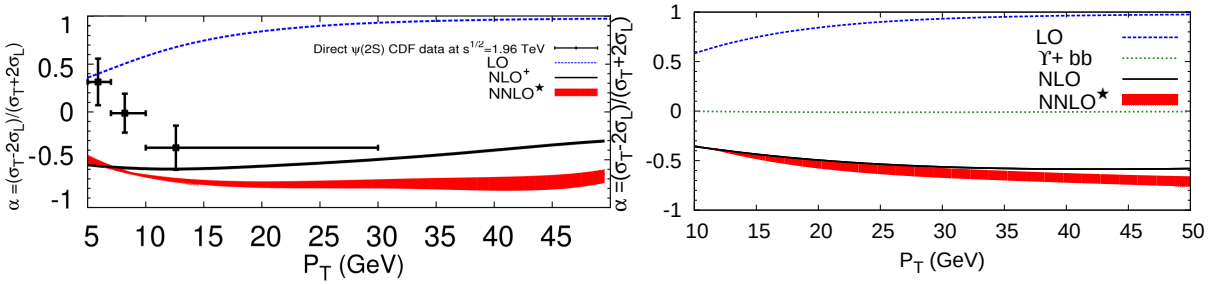

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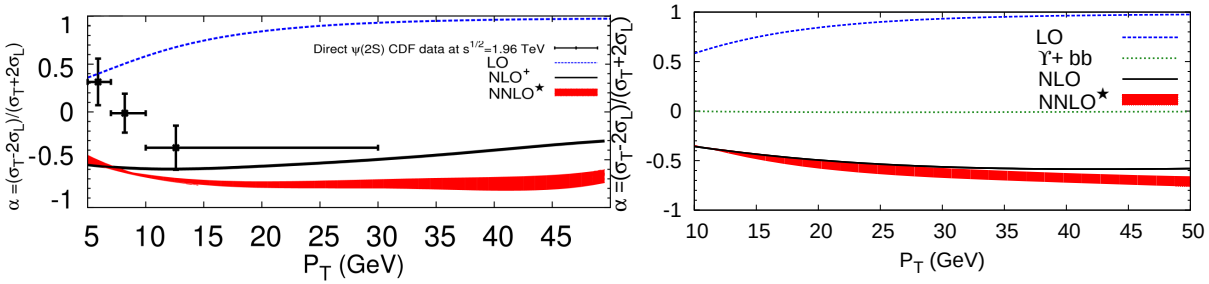

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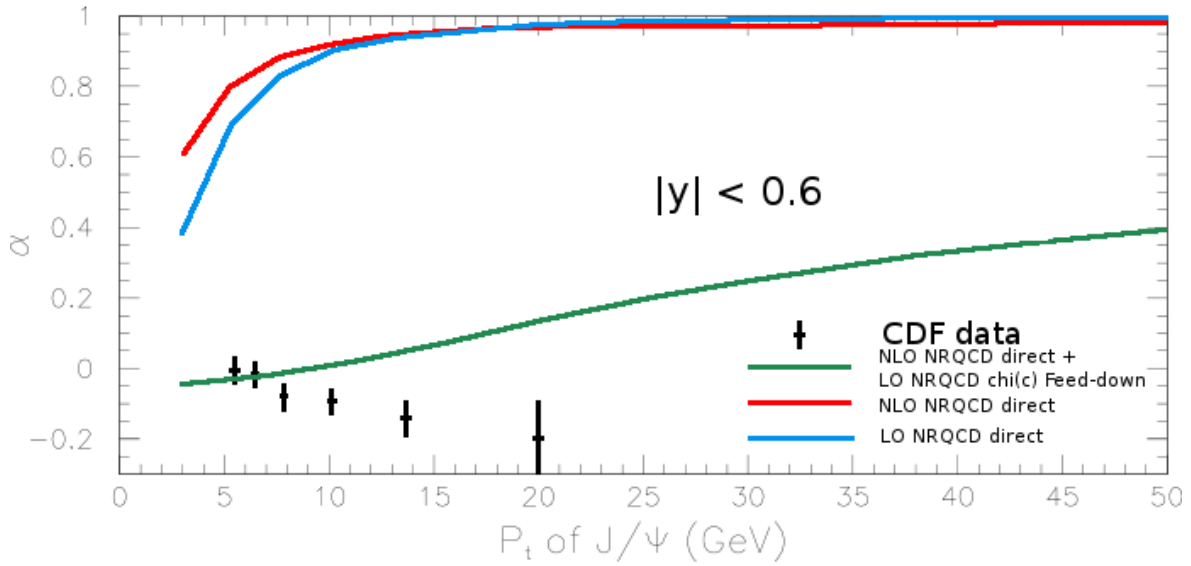

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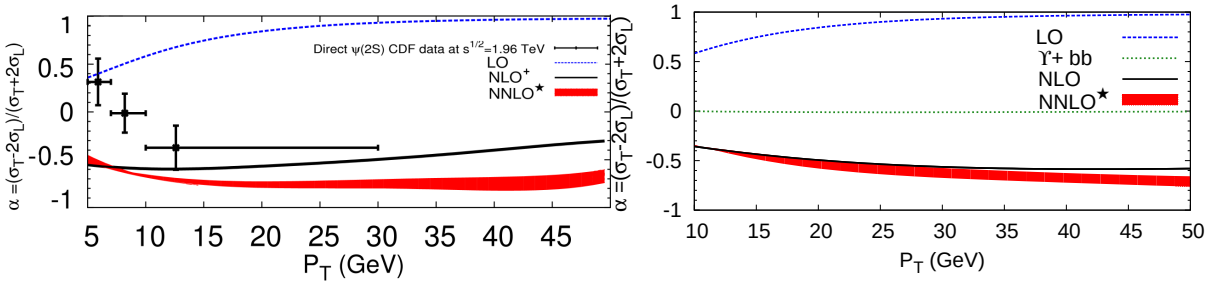

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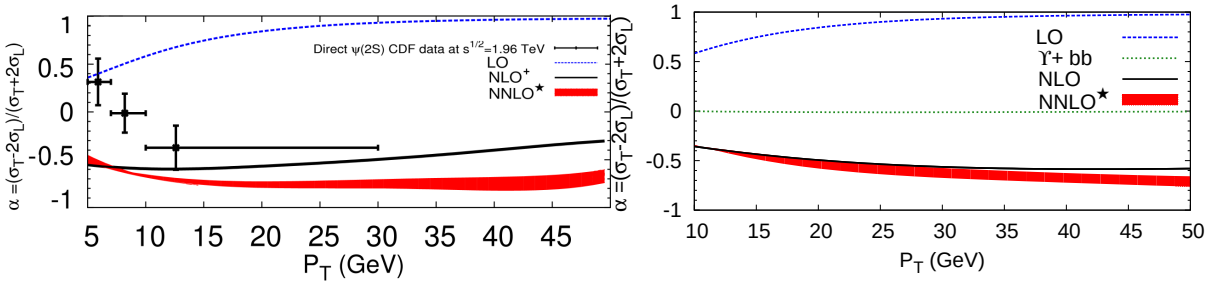

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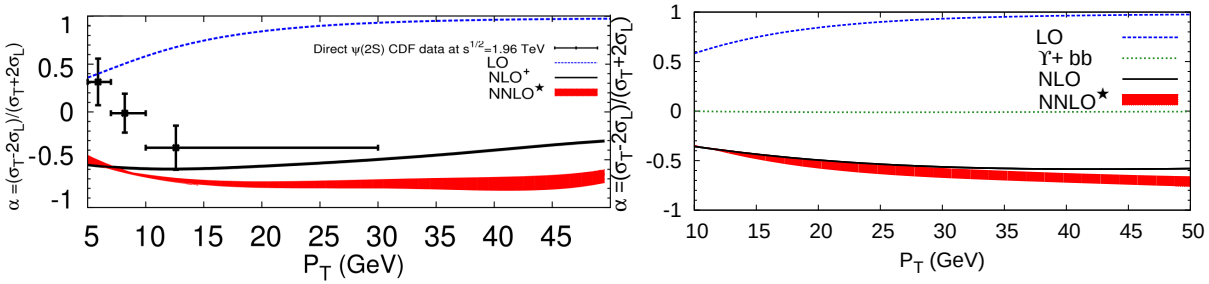

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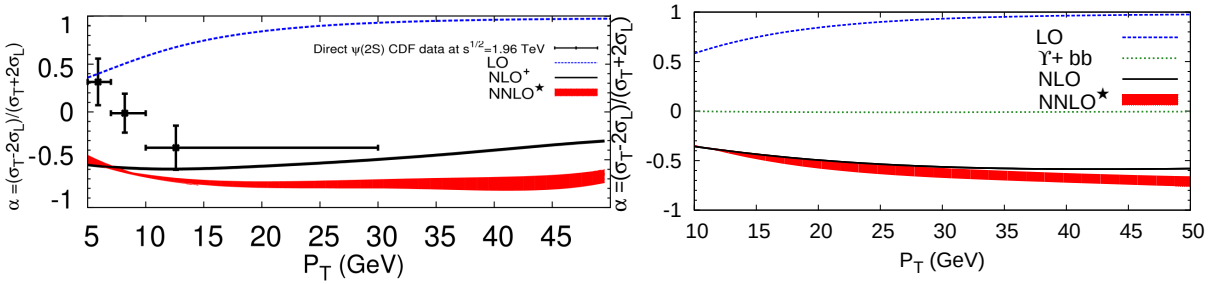

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JPL J. Phys. G 38 (2011) 124110

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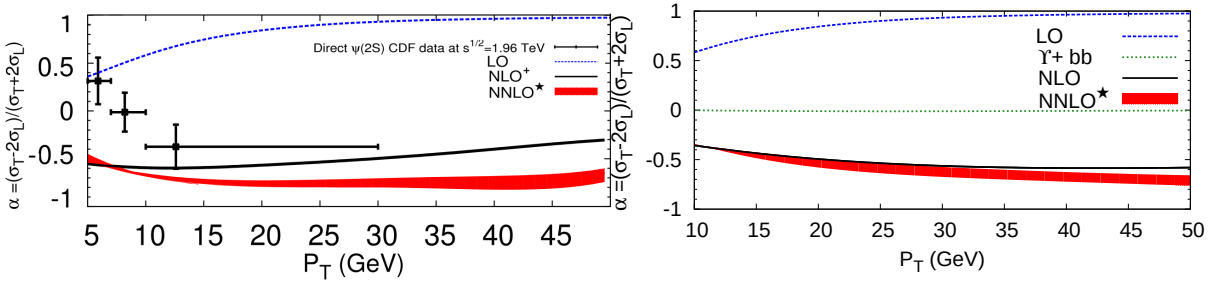

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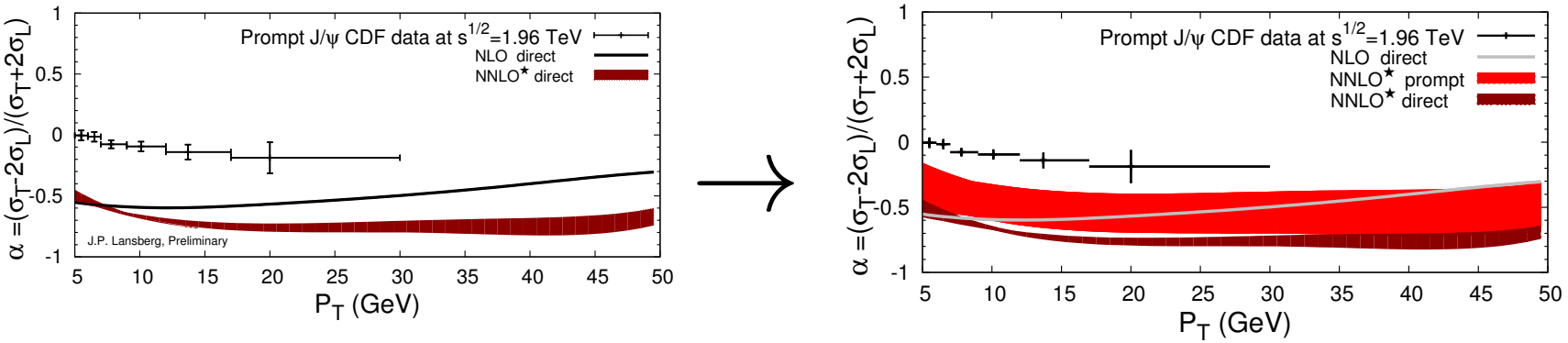

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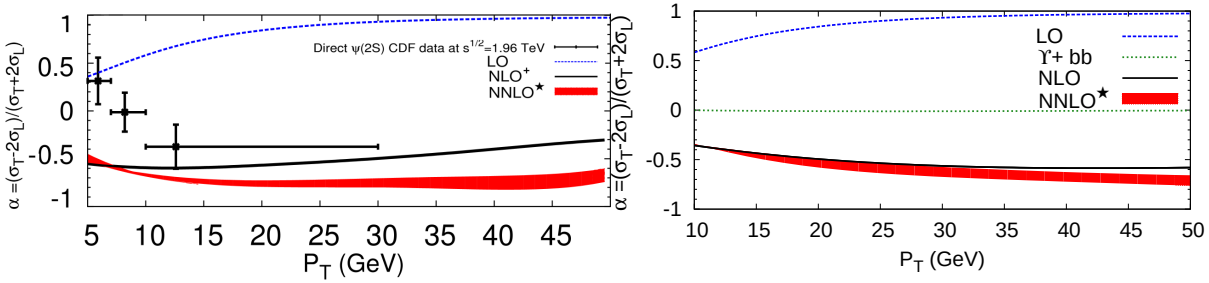

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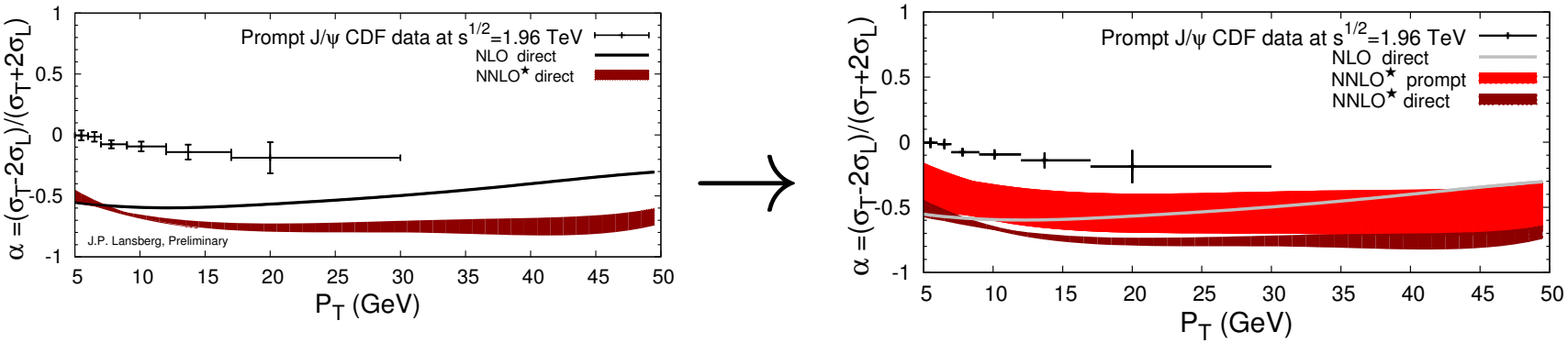

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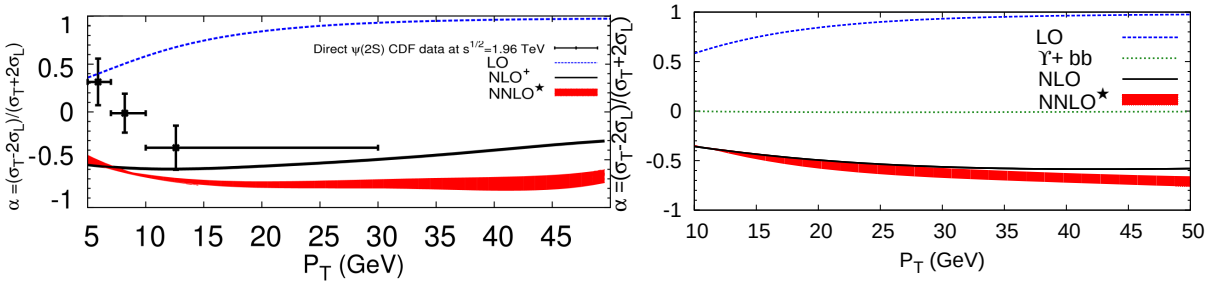

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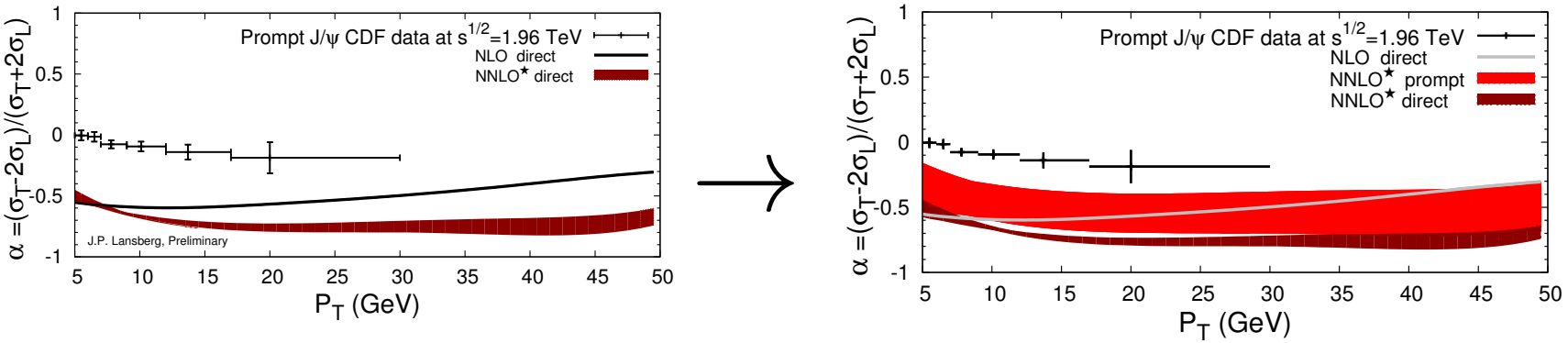

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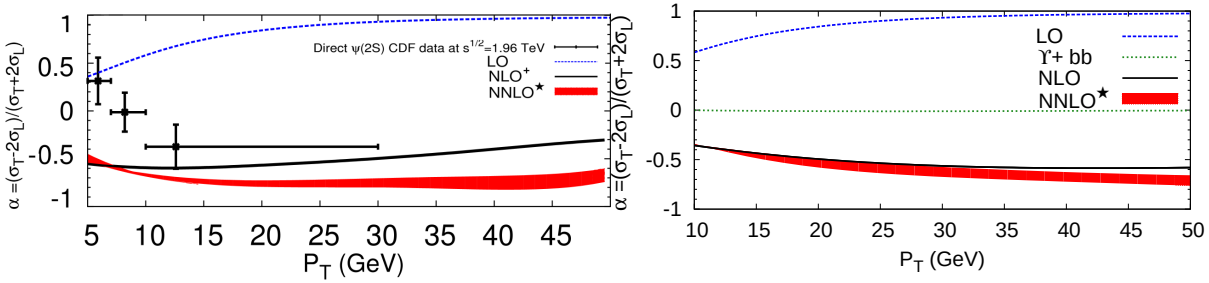

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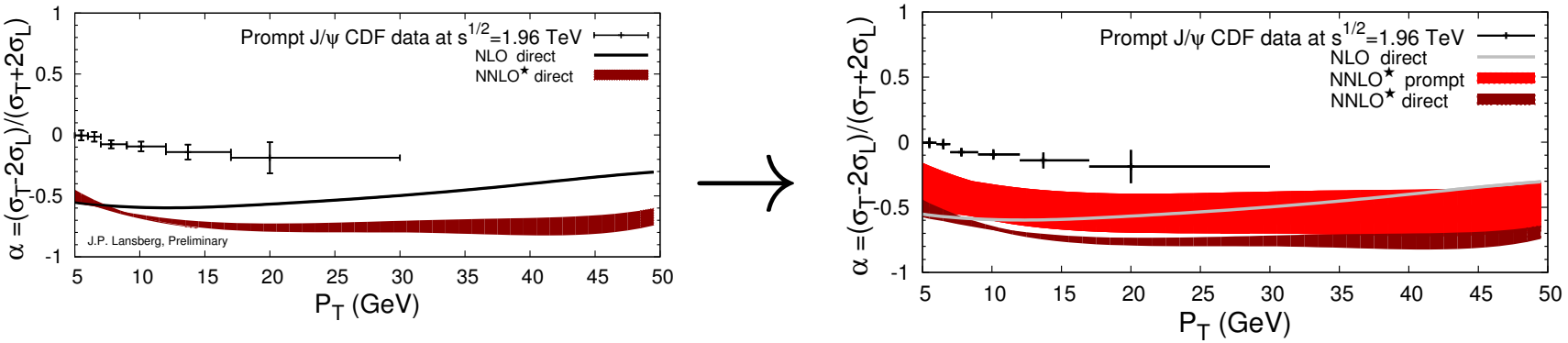

Polarisation is maybe not so discrimant

Part III

what we expect from the LHC:

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what we expect from the LHC: new measurements

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→ $J/\psi+$ hadron azimuthal correlations **STAR Collab., Phys.Rev.C80:041902 (R),2009.**

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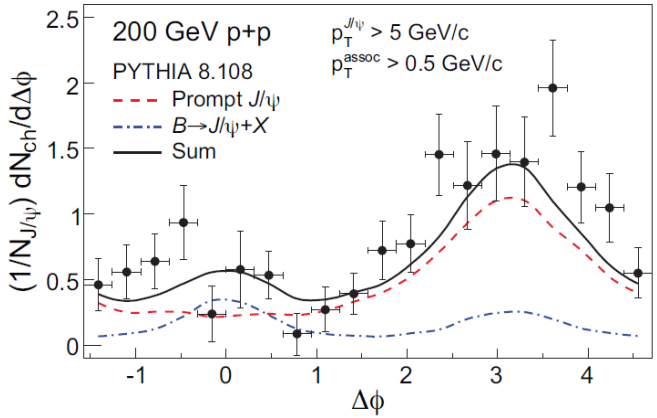

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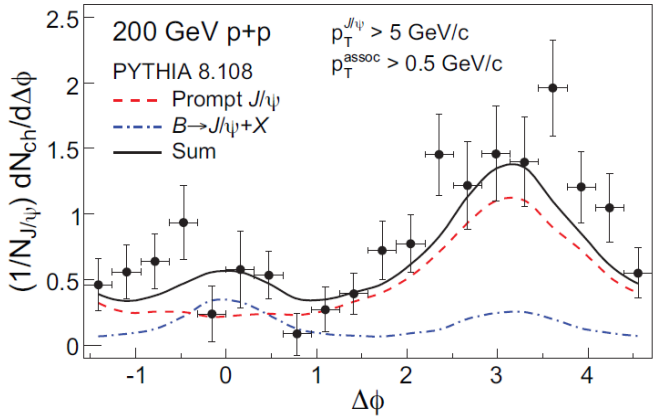

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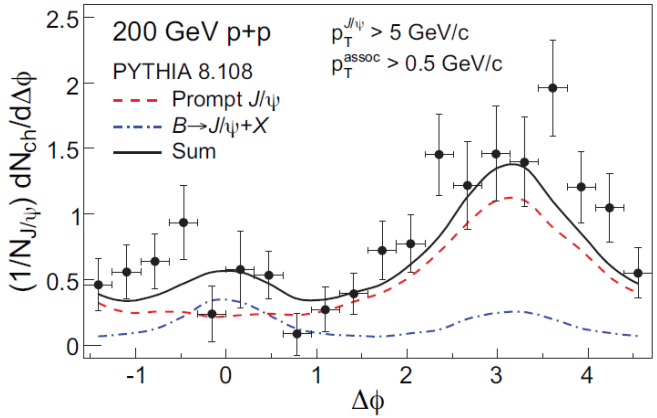

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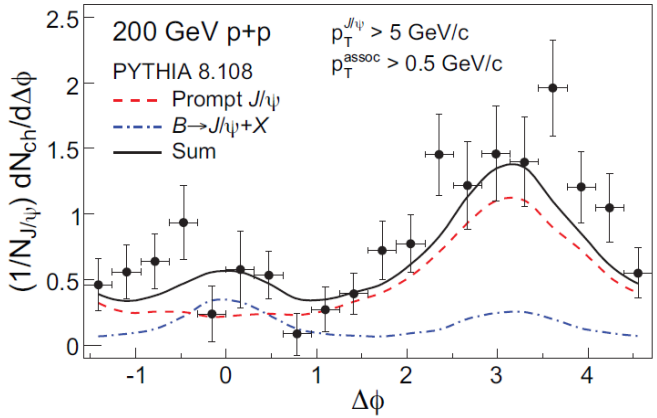

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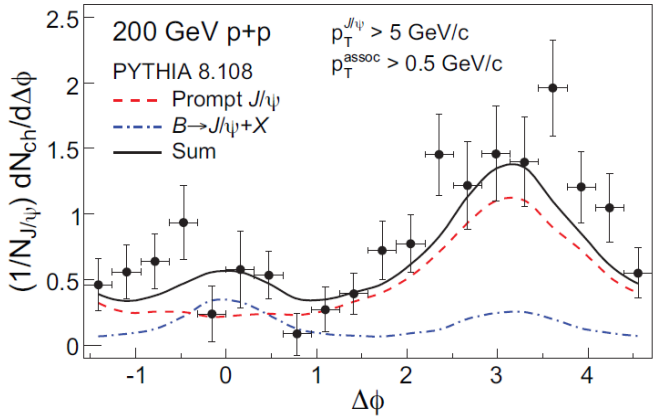

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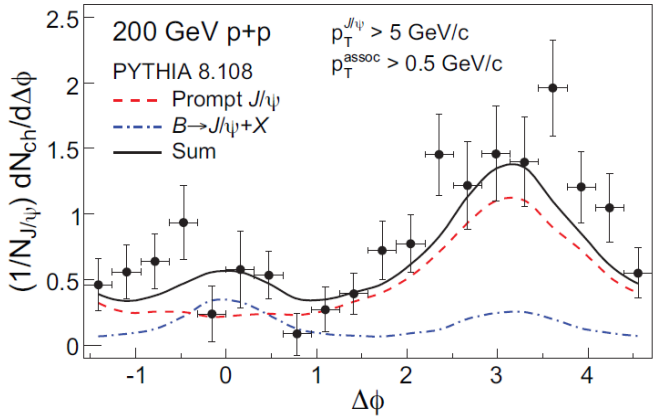

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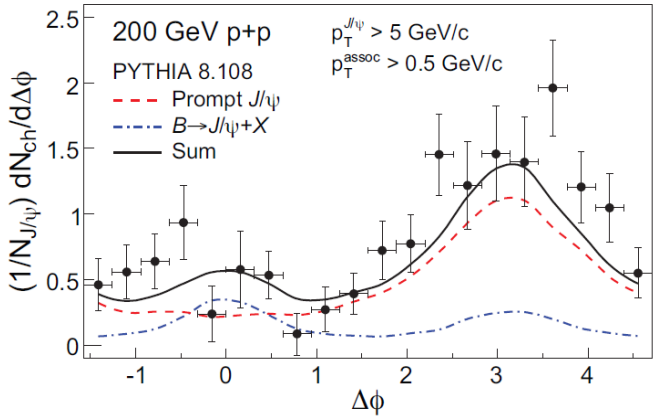

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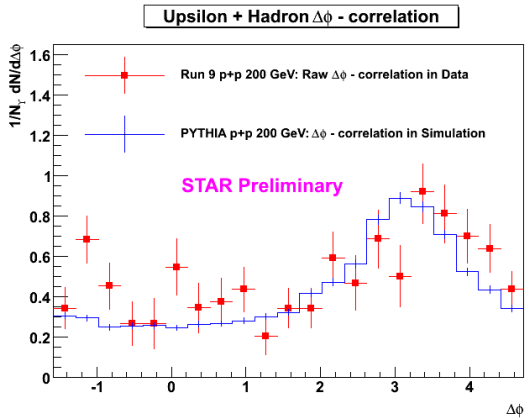
→ Υ + hadron azimuthal correlations **Talk by M. Cervantes (STAR) at WWND 2011**



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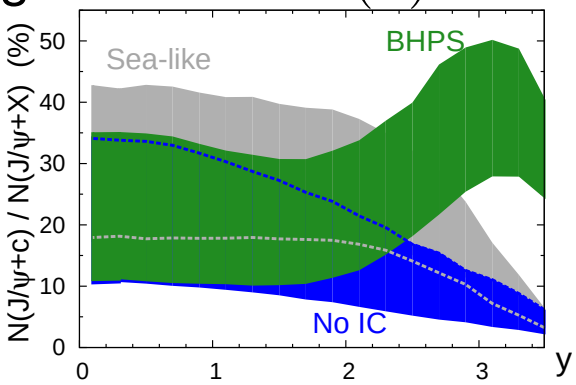

plot for RHIC kinematics

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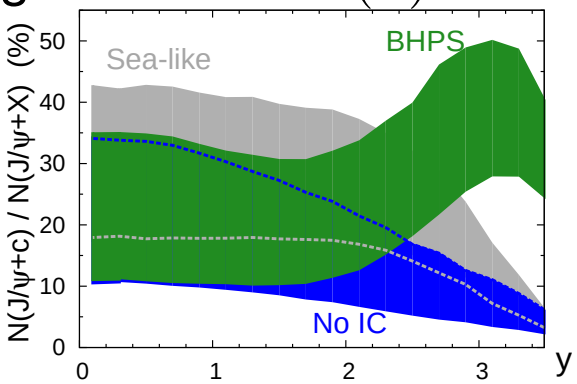
S. J. Brodsky and JPL, PRD 81 051502 (R), 2010



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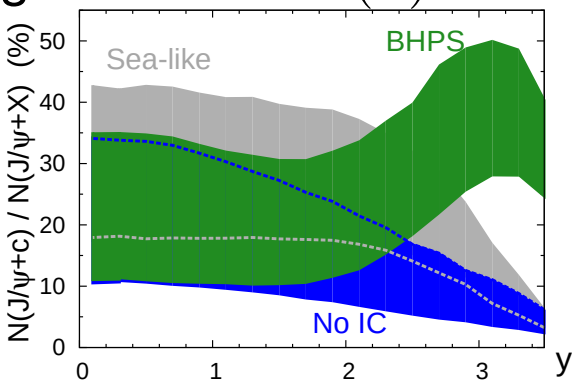

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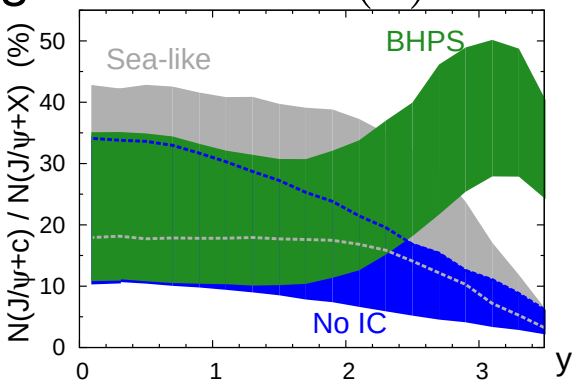

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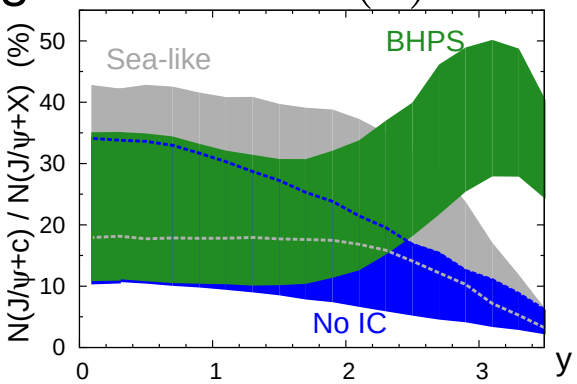

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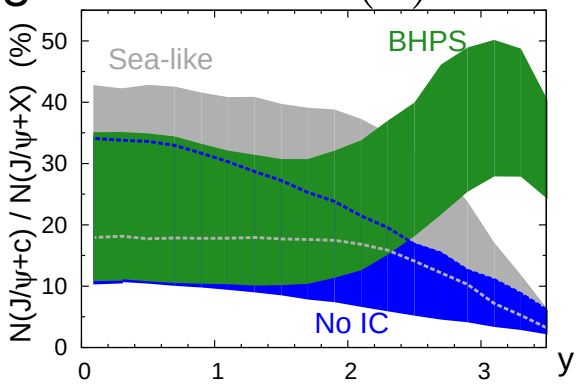

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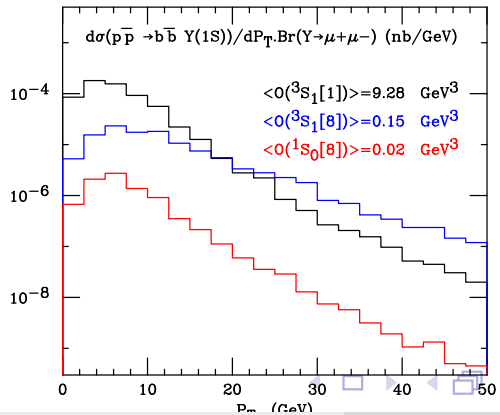

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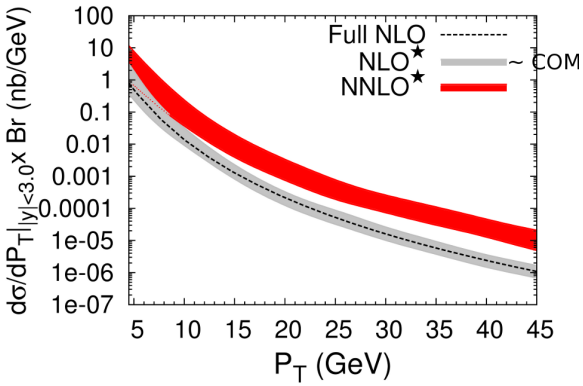

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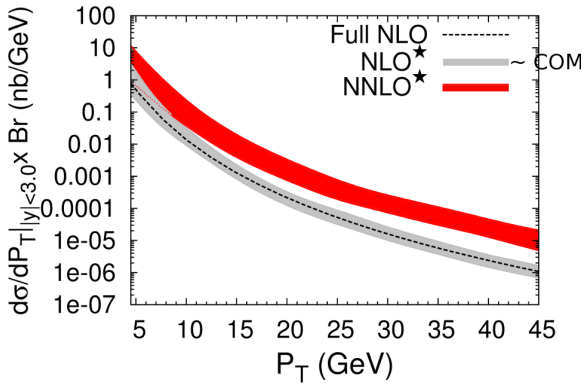

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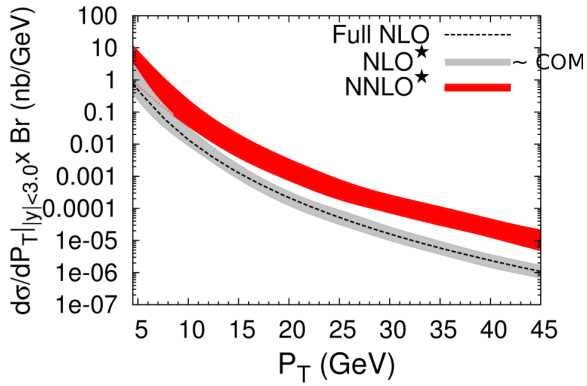

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- Possible: see $(c, b) - jet + \gamma$ studies by D0 up to $P_T^\gamma \simeq 150$ GeV !

D0, PRL102 (2009) 192002.

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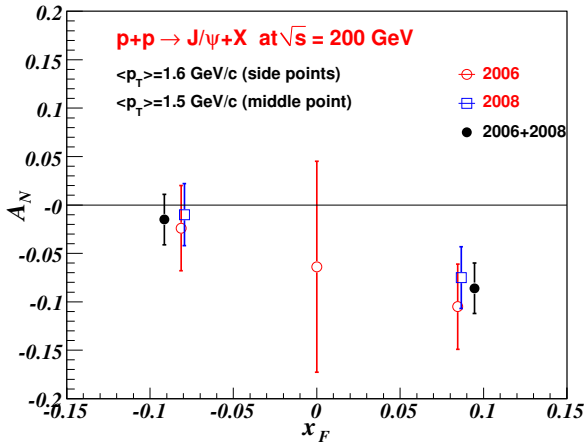

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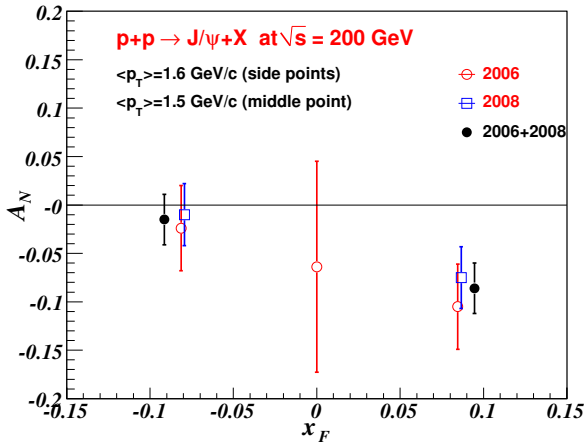

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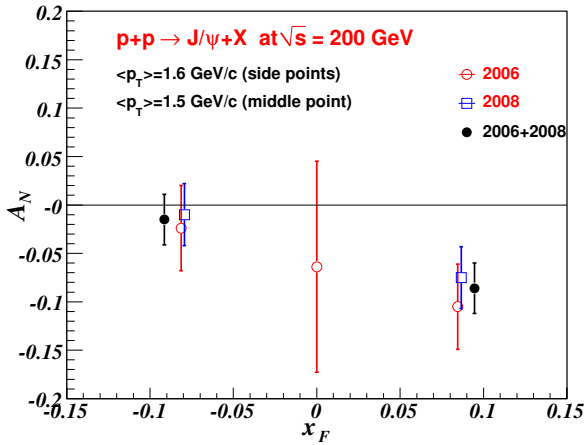


PHENIX, PRD 82, 112008 (2010)

- At $x_F > 0$, the gluon from the $\vec{p}$ has a larger x_B
- It knows more about the proton spin than at low x_B

Part IV

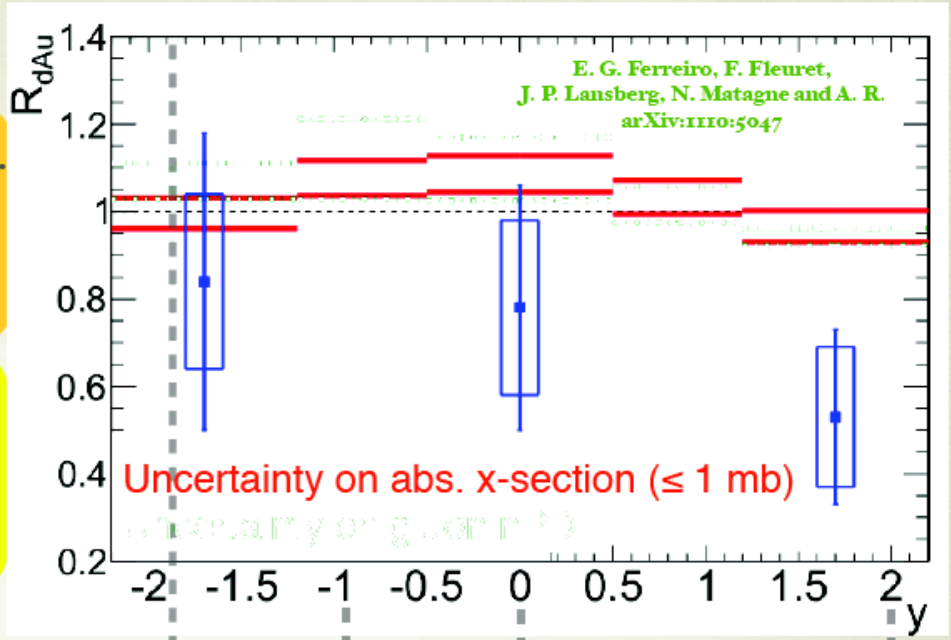
new measurement at the LHC: Υ in pA

Υ in dAu @ RHIC : abs. **effective** x-section

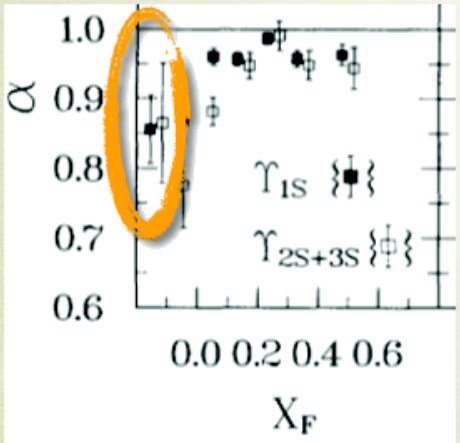
σ_{abs} should be small :

- at bkwd-y, $t_f < r_{Au}$, fully formed Υ. But no diff. exp. seen between Υ(1S) and Υ(2S+3S) σ_{abs}.
- at $y>0$, $t_f > r_{Au}$, same small-size pre-resonance for all Υ states

$$\sigma_\Upsilon \sim 0.1\,\sigma_{J/\psi}\ ?$$



E772 collaboration, PRL 66 (1991) 2285.



increasing t_f in the Au rest frame

r_{Au} $2.r_{Au}$ $7.r_{Au}$ $52.r_{Au}$

propagating in Au :

fully formed Υ

pre-resonant state $\sigma_\Upsilon \sim \left(\frac{m_c}{m_b}\right)^2 \sigma_{J/\psi}$

$x_F = 0$ $x_F \simeq 0.28$

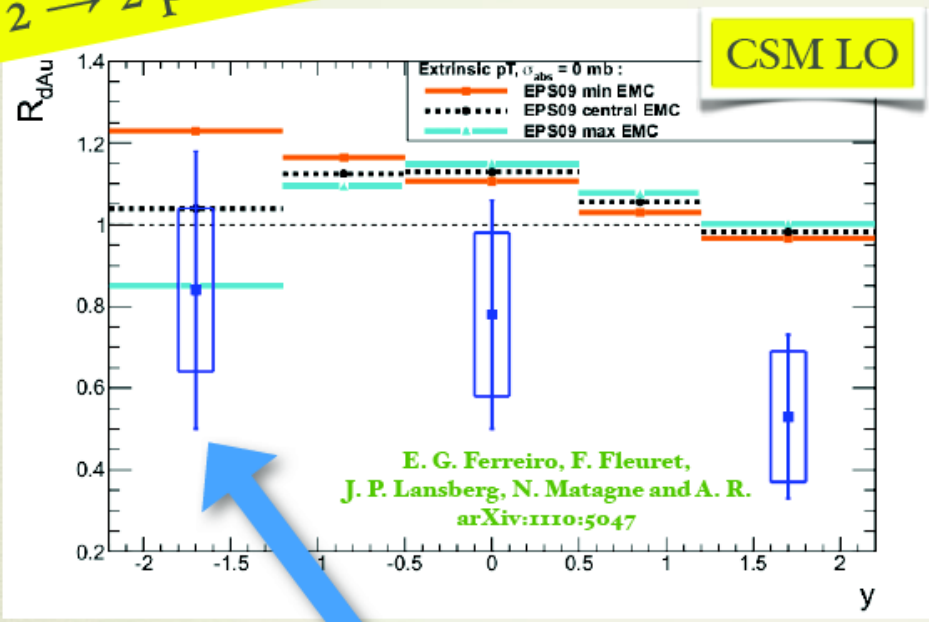
Υ in dAu @ RHIC : gluon EMC effect

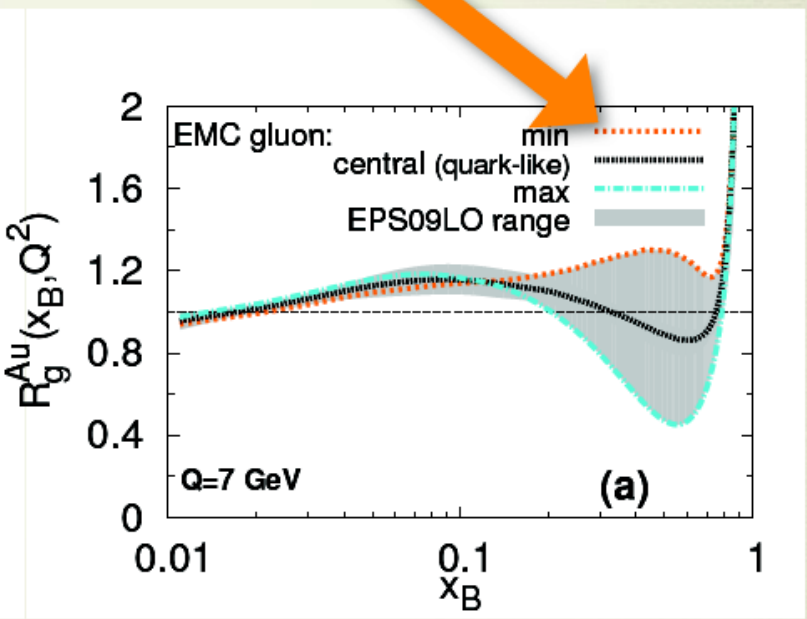
Let us focus in the EMC region and pick the EPS09 sets that are the limiting cases in this region :

$2 \to 2$ process

min. disfavoured

CSM LO





EMC effect stronger for g than for q ?

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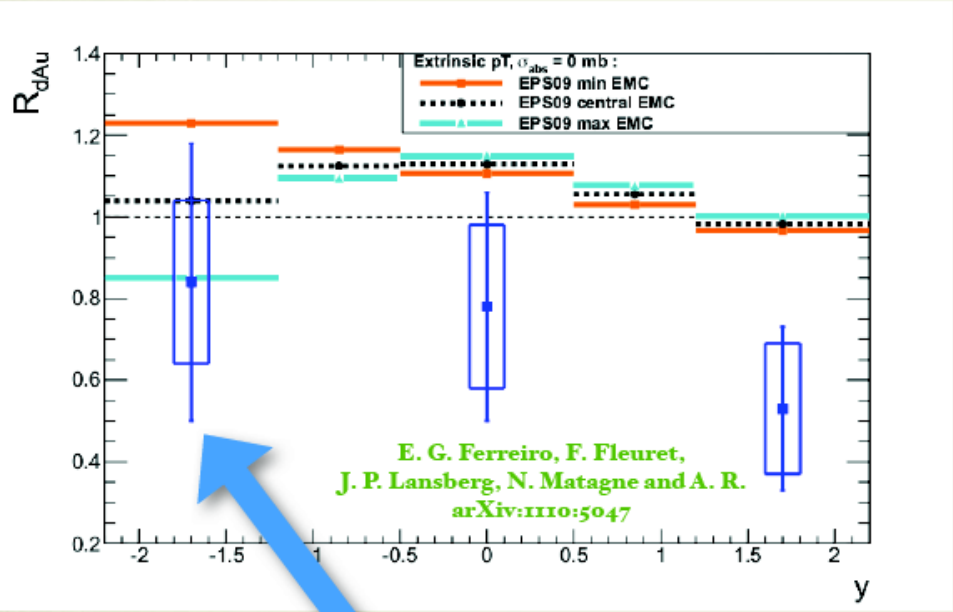

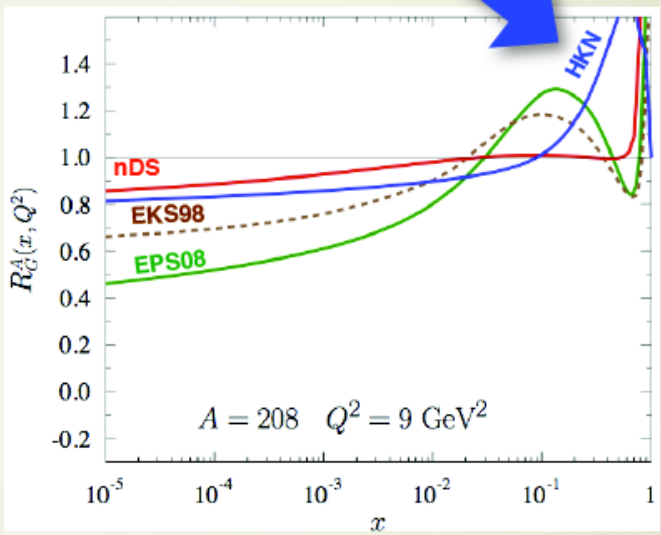

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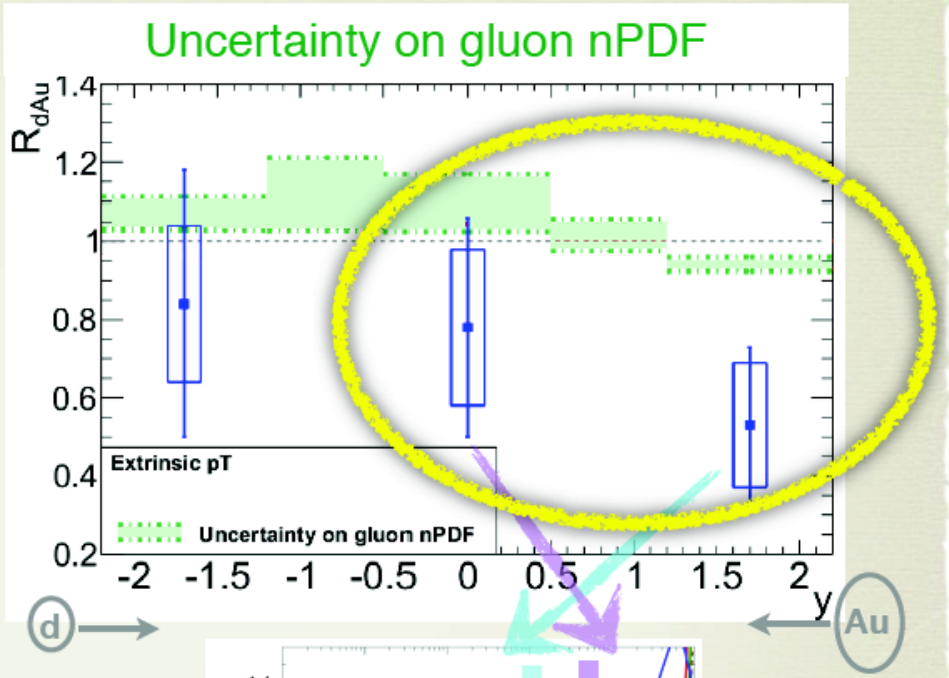
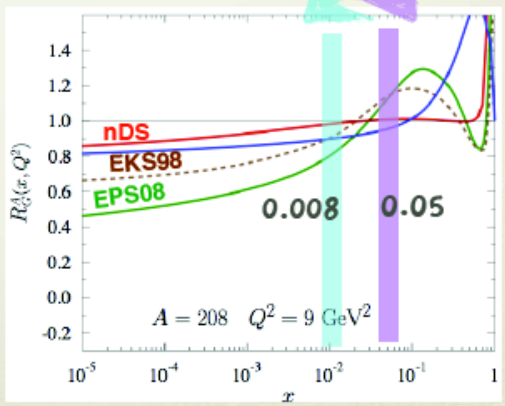
Υ in dAu @ RHIC : shadowing

E. G. Ferreiro, F. Fleuret, J. P. Lansberg, N. Matagne and A. R.
arXiv:1110:5047

Typical gluon nPDF parametrisations induce a **flat rapidity dependence** w.r.t. data





$\langle x_2 \rangle$

shadowing not strong enough
absence of antishadowing ?

Data:
STAR Preliminary, Nucl. Phys. A855 (2011) 440,
PRD 82 (2010) 012004.
PHENIX Preliminary, PoS DIS2010 (2010) 077.

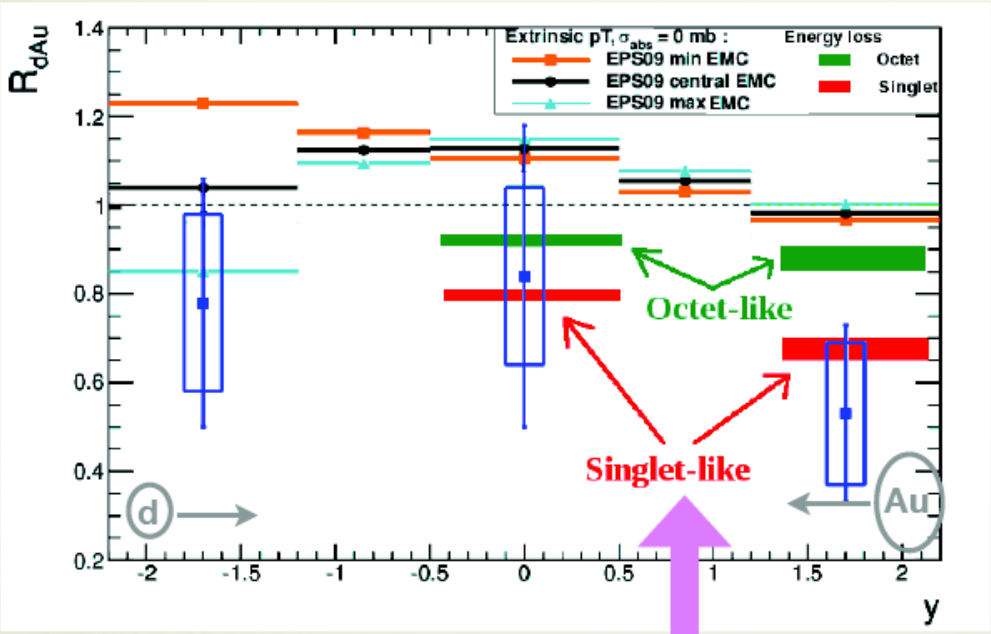
Υ in dAu @ RHIC : energy loss

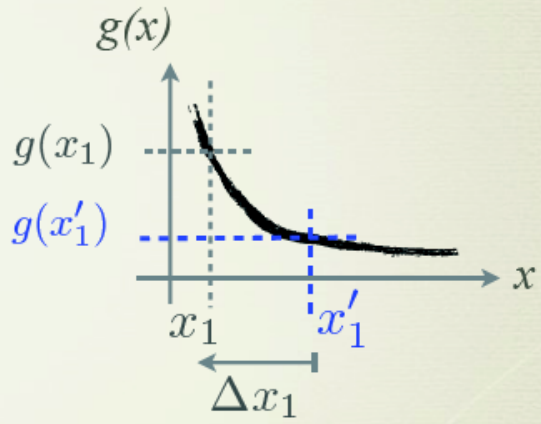
$$t_f^{\text{gluon}} \gg r_{Au} \qquad \Delta E/E = \Delta x_1/x_1 \simeq N_c \alpha_s \sqrt{\Delta \langle p_T^2 \rangle / M_T}$$

[F. Arleo, S. Peigné, T. Sami, PRD 83 (2011) 114036]

radiation off the incoming parton and outgoing colored object is coherent (small scattering angle in the rest frame of the nucleus)

E. G. Ferreiro, F. Fleuret, J. P. Lansberg, N. Matagne and A. R. arXiv:1110:5047





$$R_{\text{loss}}(x_1, Q^2) = \frac{g(x_1', Q^2)}{g(x_1, Q^2)}$$

different E loss for CSM vs COM, **singlet** favoured by the data

J/ψ in dAu @ RHIC : energy loss

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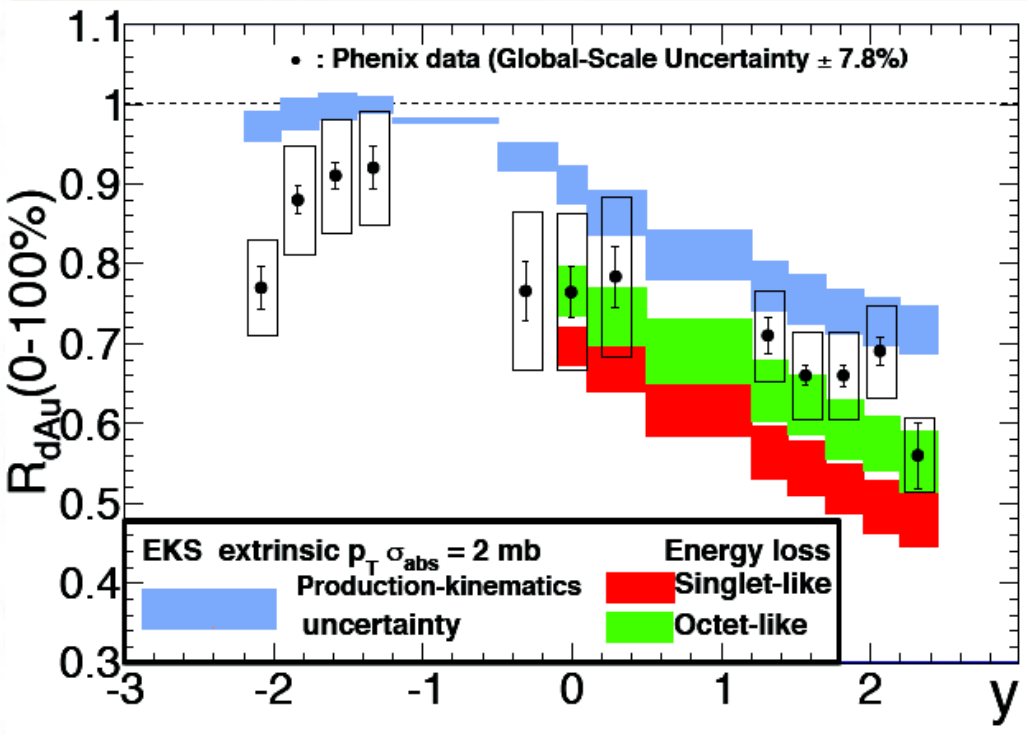

Data:
PHENIX Collaboration, PRL 107 (2011) 142301.

J/ψ picture less clear w.r.t. ϒ :

- rather large uncertainty from the prod. model
- large uncertainty on σ_{abs} (here only one value was chosen)
- one may choose σ_{abs} =0 mb

Difficult to draw conclusions about the colour state of the produced $c\bar{c}$ pair.

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- Agrees with the strong reduction of CO contributions at low/mid P_T
  expected from e^+e^- analyses
- LO CSM fails as far as $d\sigma/dP_T$ is concerned
- Higher-QCD corrections open leading P_T channel: they are needed !
  $2 \to 3$, $2 \to 4$ channels
- **Drawback**: large theoretical uncertainties...
  Dominant contributions are known only at Born order (ex: $gg \to J/\psi ggg$)
- (N)NLO corrections alter the polarization : transverse $\to$ longitudinal
- CO fits of xsection disagree in their prediction of polarisation
- Need for **new observables**, need for NLO evaluations
  at the LHC or elsewhere !

Part V

Backup

Analogy with the P_T spectrum for the Z^0 boson