Υ production at NLO and beyond

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IPN Orsay – Paris-Sud U. –CNRS/IN2P3

Workshop on Charmonium production and decays : new results and perspectives
LAL Orsay
March 6-8, 2013

Part I

(Single) Υ production in *pp*

Reminder: QCD corrections for Υ at the Tevatron

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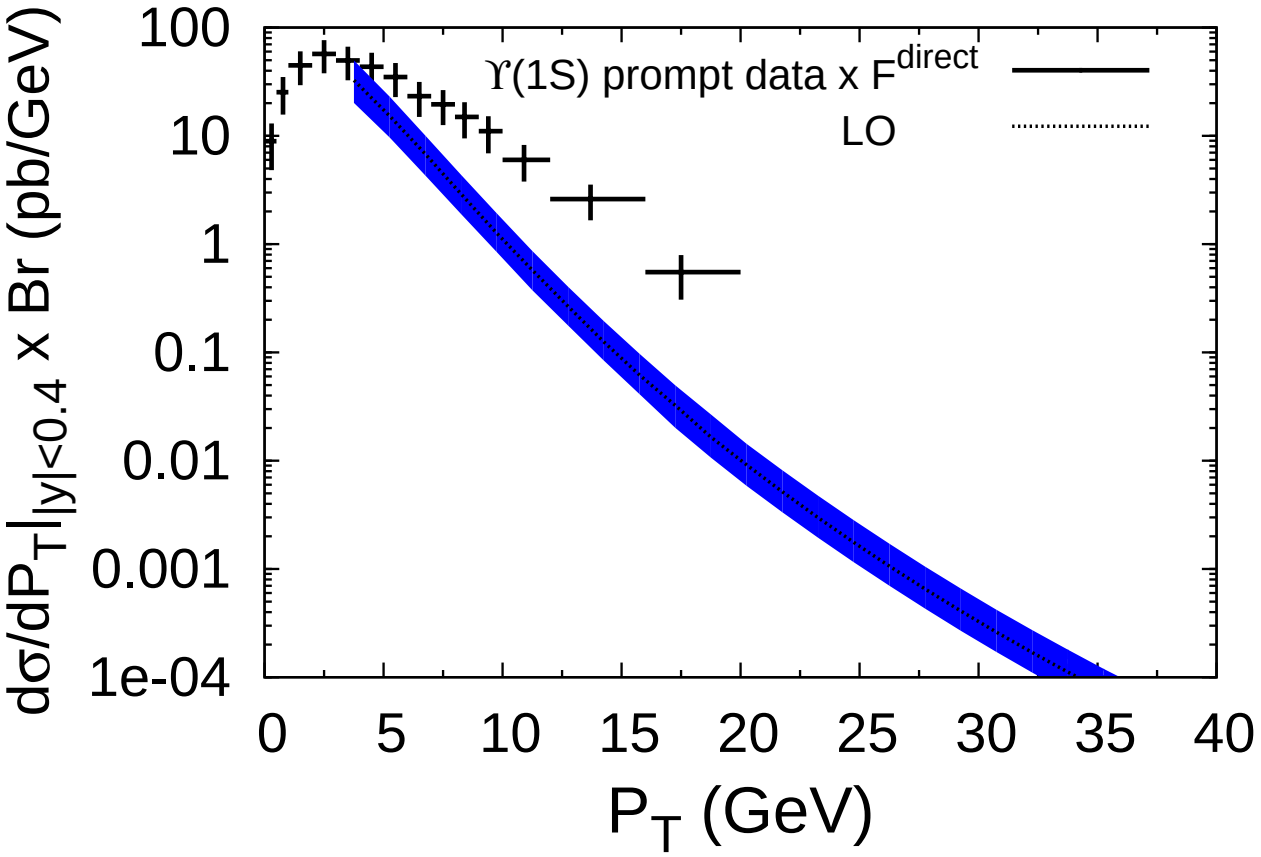
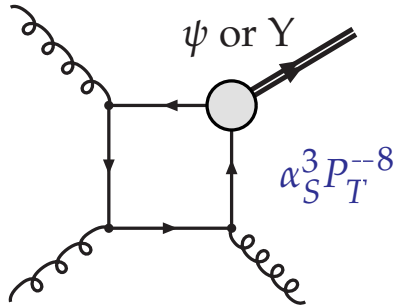
CDF PRL 88 (2002) 161802; LHCb EPJC 72 (2012) 2025





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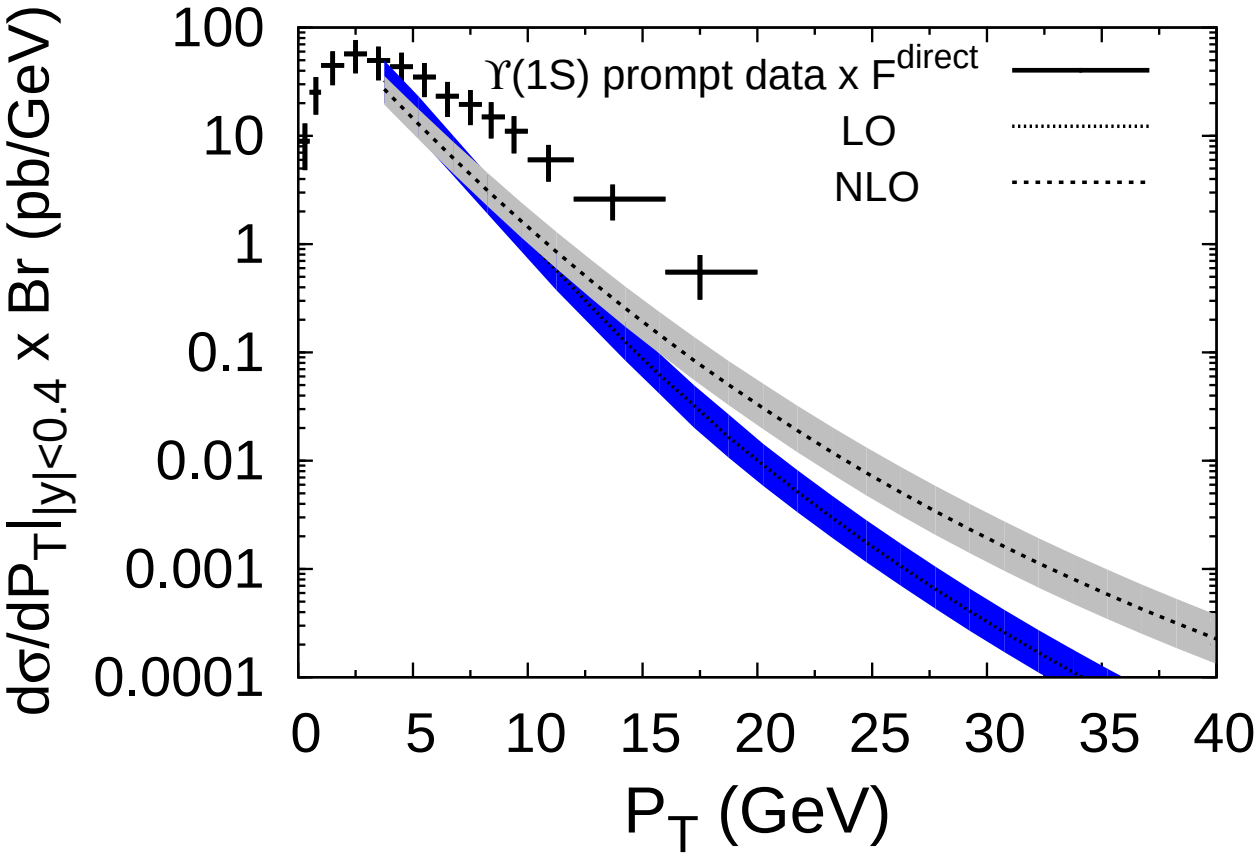

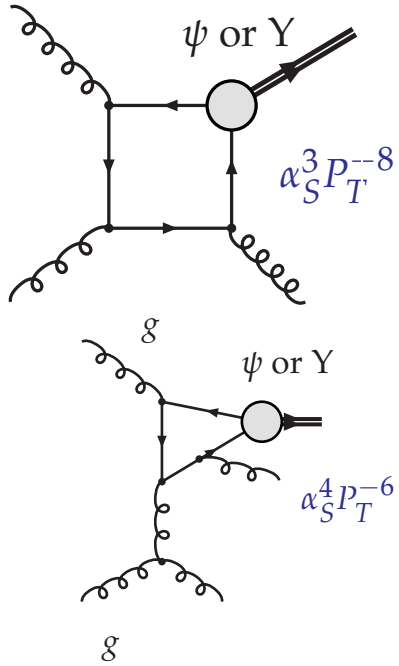

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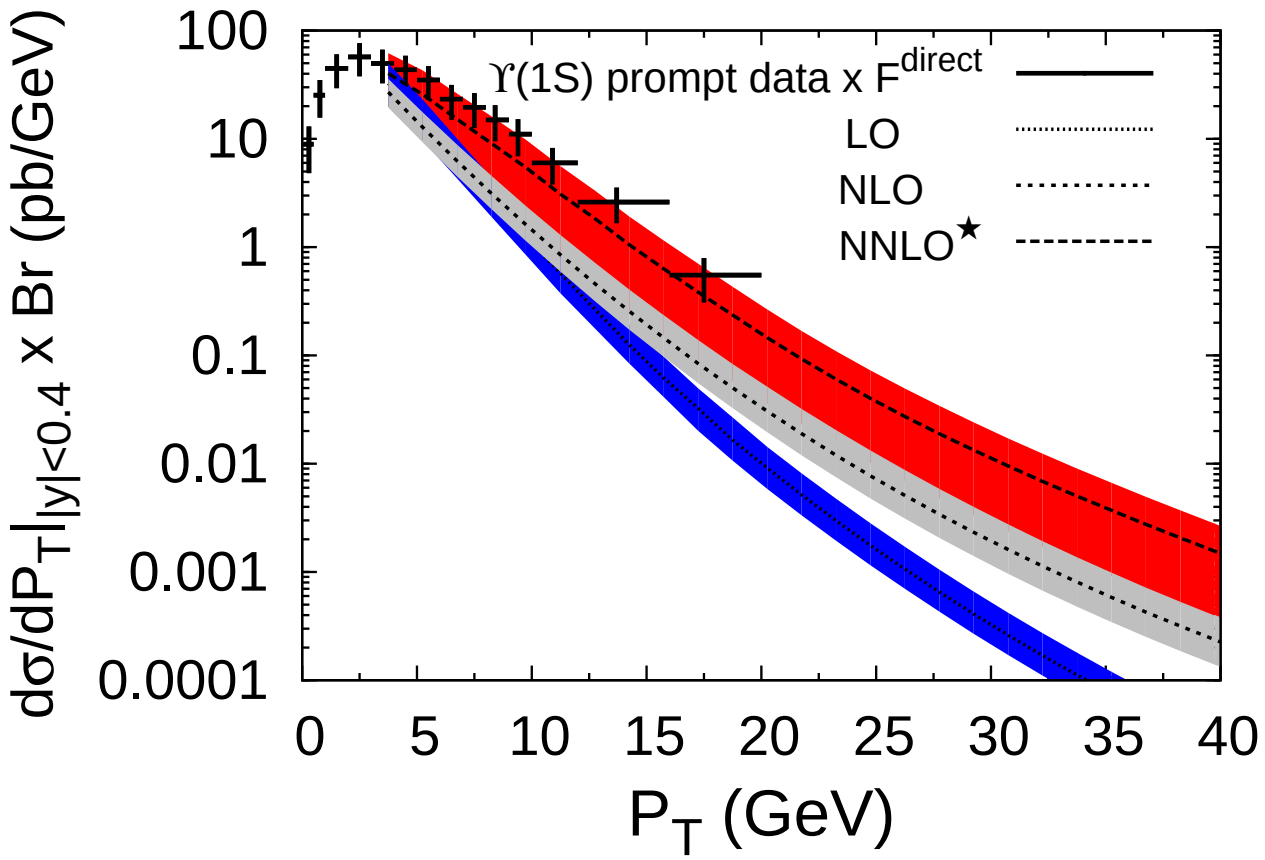

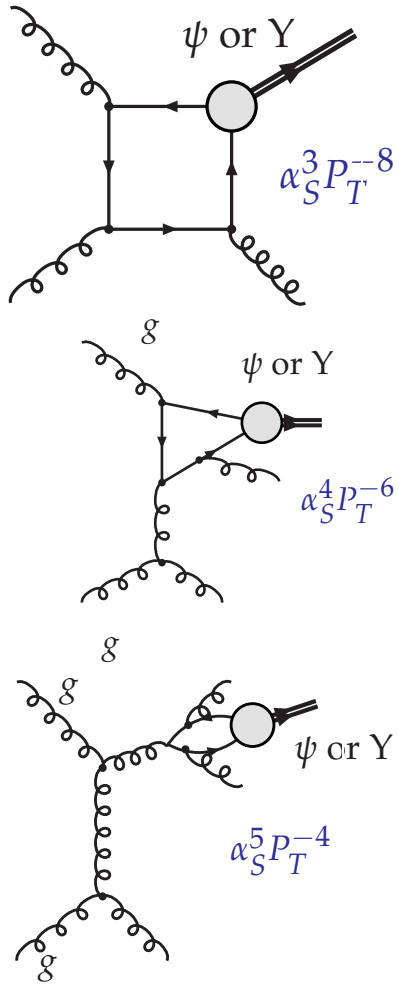

+ double t-channel gluon exchange at α_S^5

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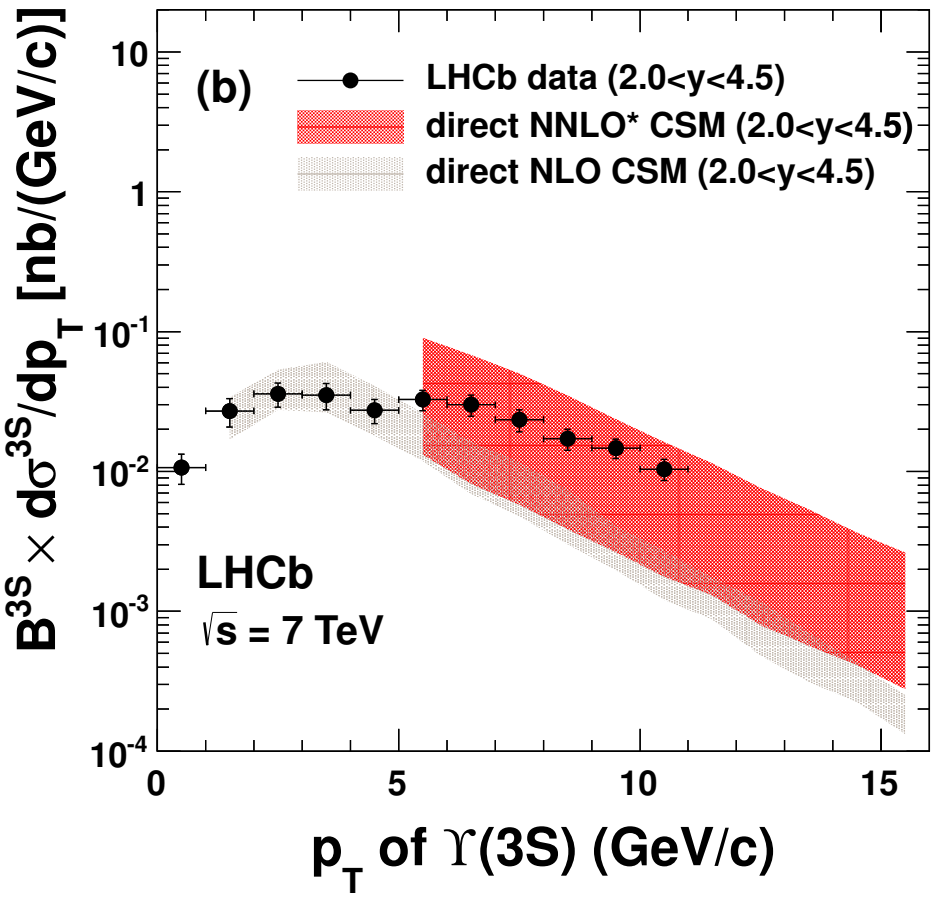

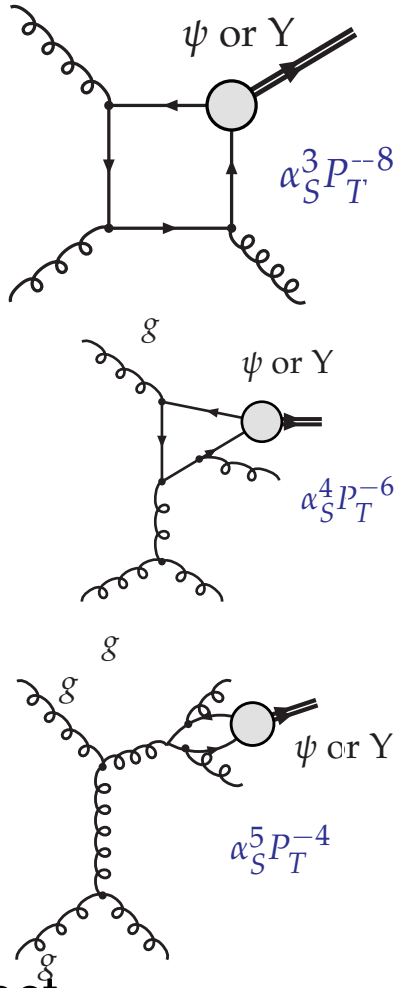

$\Upsilon(3S)$: 100 % direct; $\Upsilon(2S)$:60-70 % direct; $\Upsilon(1S)$: 50 % direct

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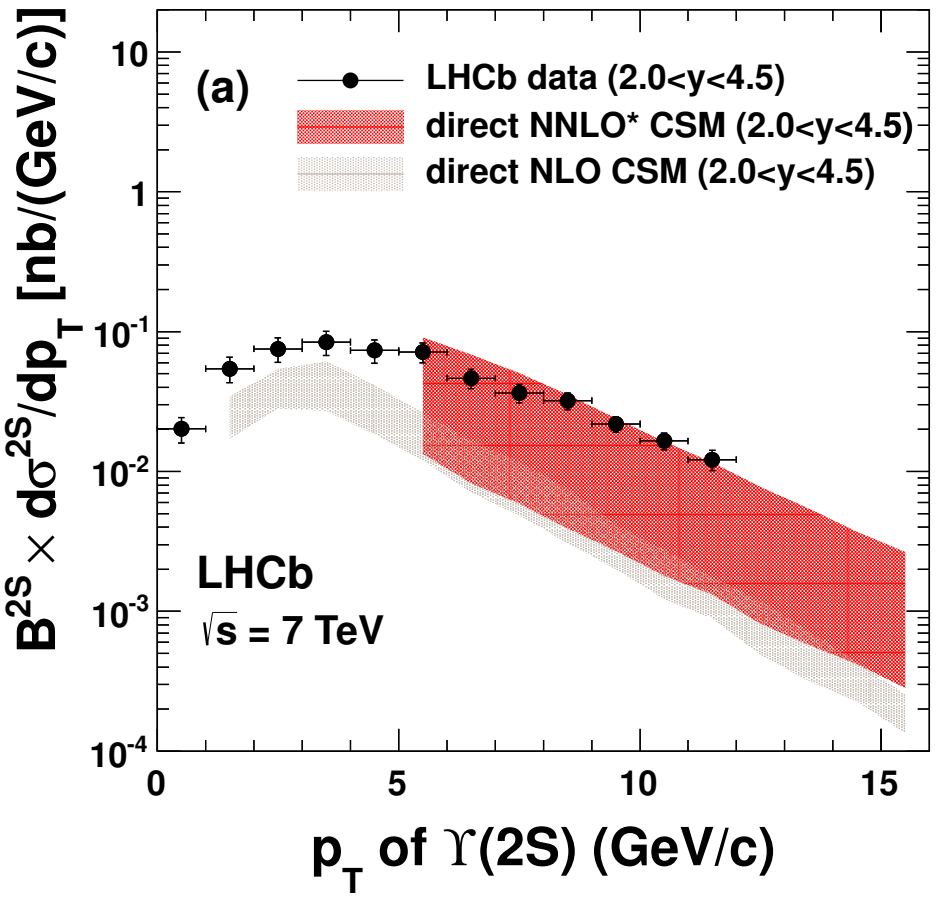

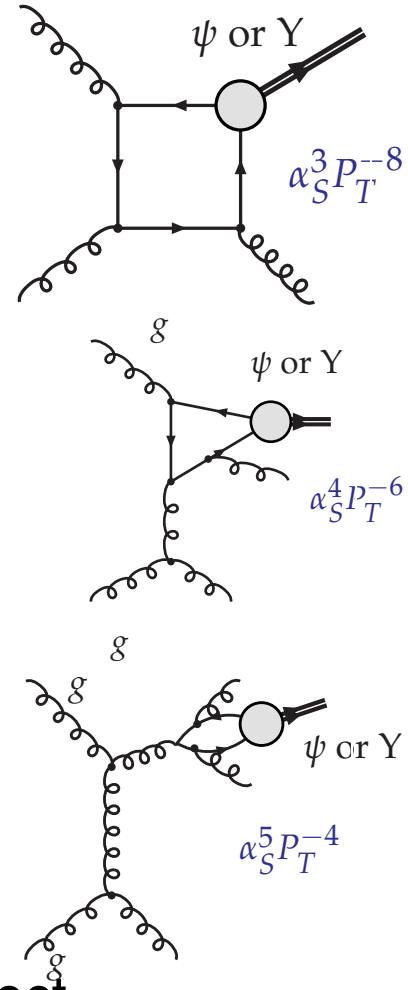

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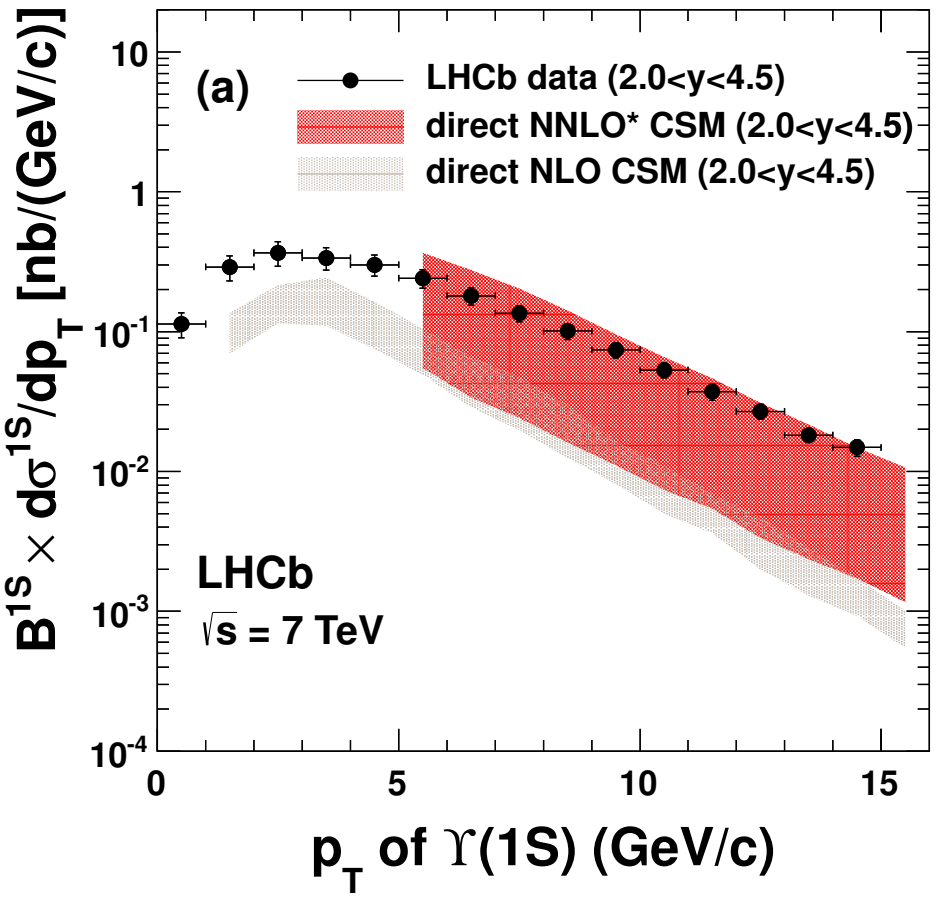

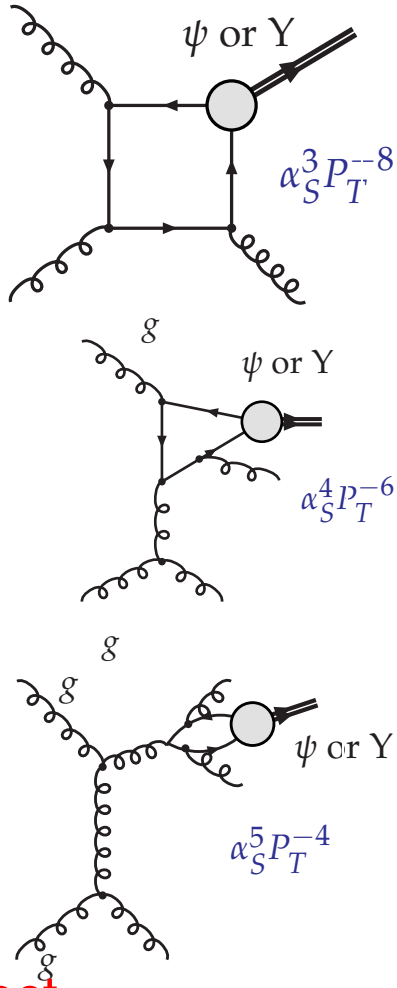

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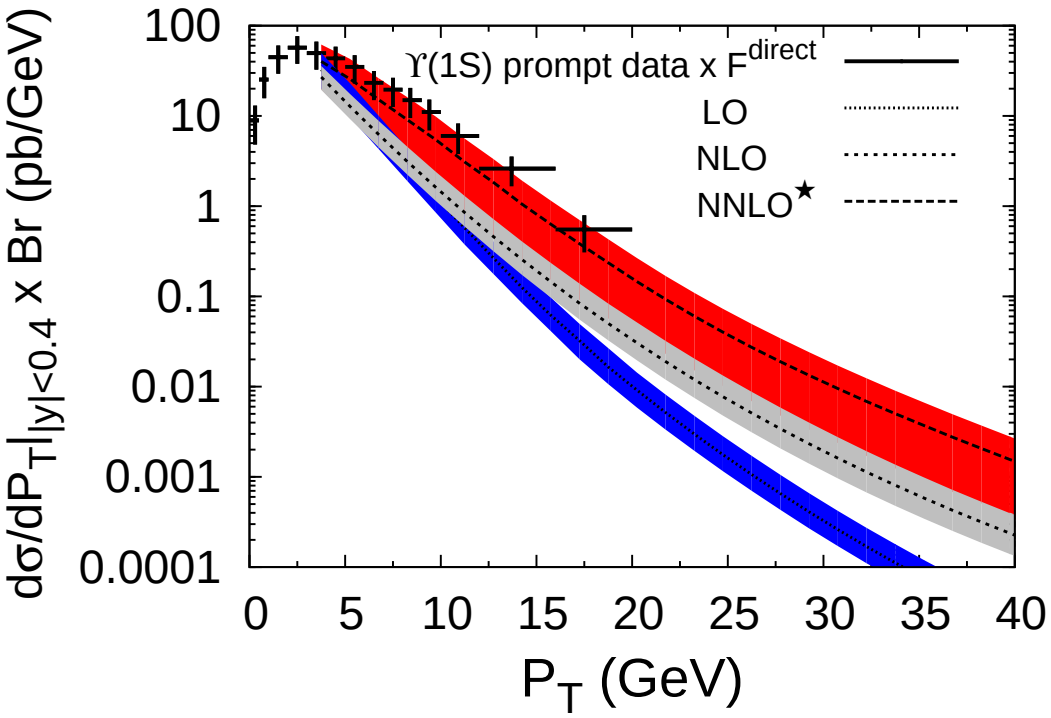
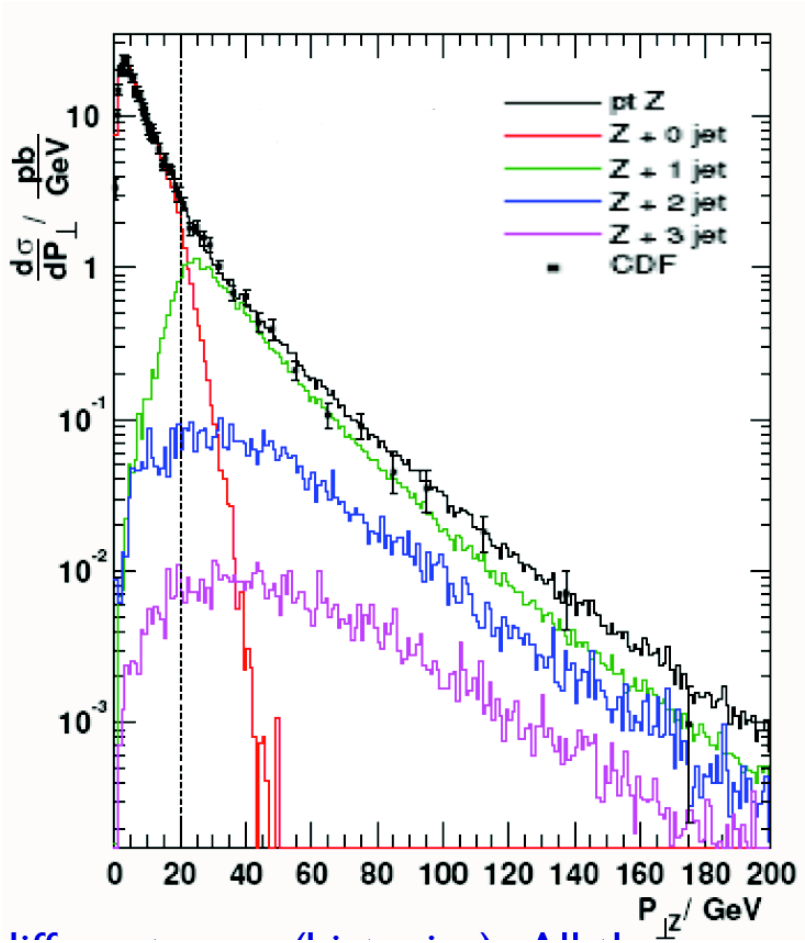
Analogy with the P_T spectrum for the Z^0 boson





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); NPA (2012), 10.1016/j.nuclphysa.2012.12.051

→ The yield vs. $\sqrt{s}$ (here only LO curves[1])

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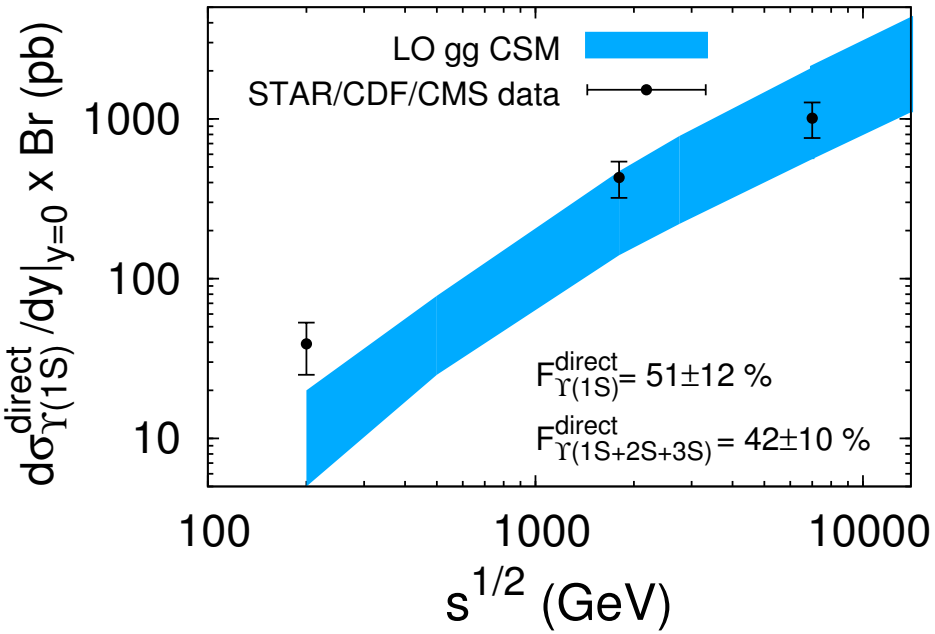

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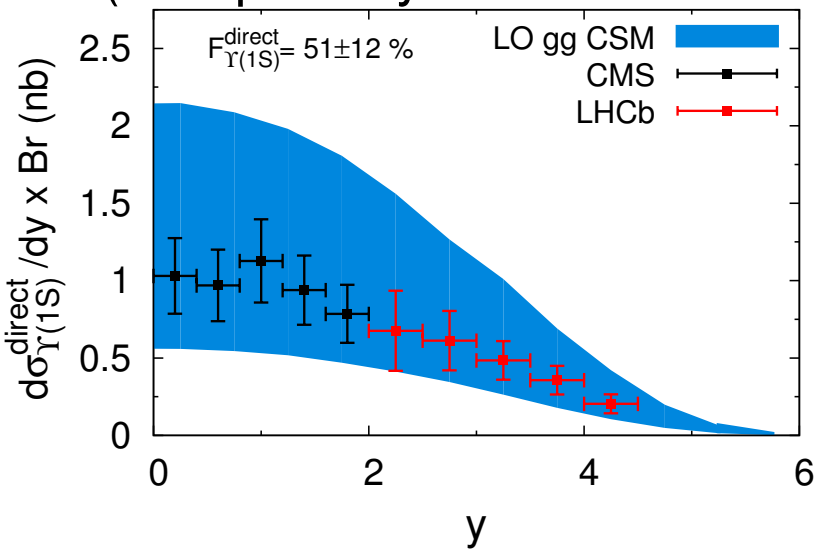

STAR PRD 82 (2010) 012004 ; CDF PRL 88 (2002) 161802; CMS PRD 83 (2011) 112004; LHCb EPJC 72 (2012) 2025

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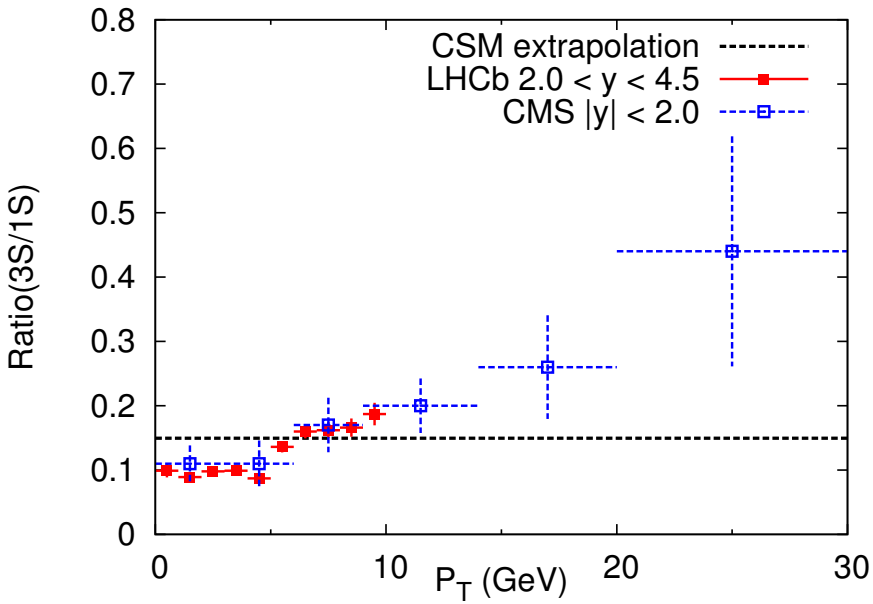
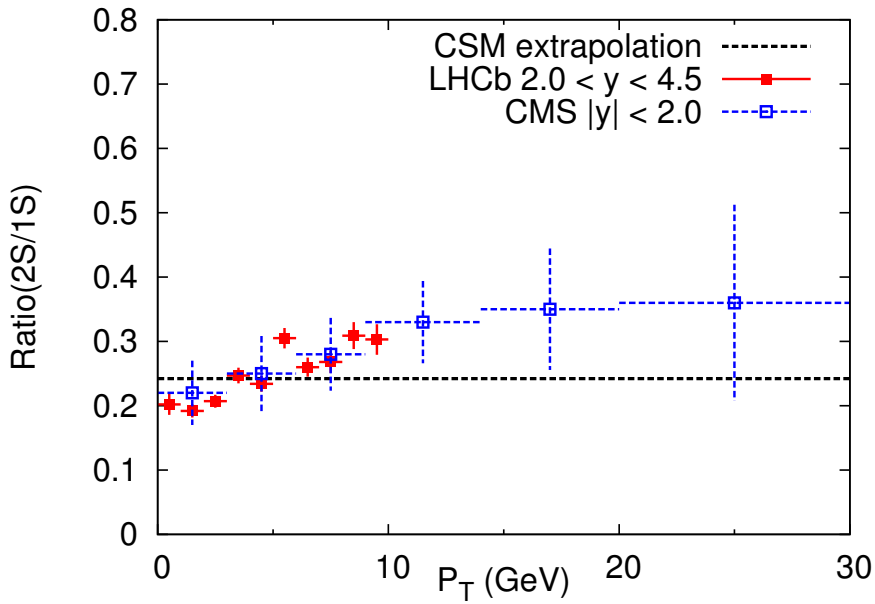
- NEW: the $3S$ yield likely not 100% direct

CMS, PRD 83, 112004 (2011)

cf. $\chi_b(3P)$ observation by ATLAS PRL, 108, 152001 (2012)

Cross section ratio II





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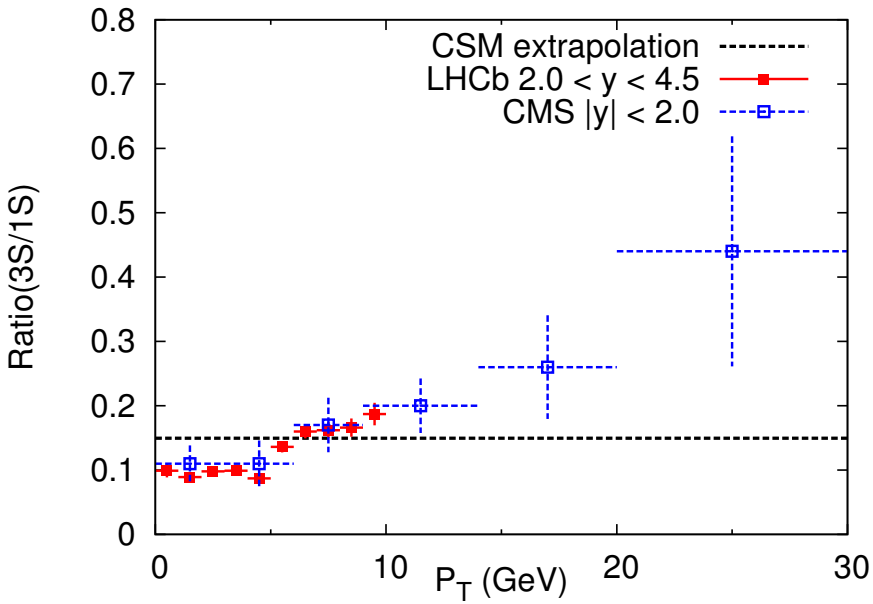

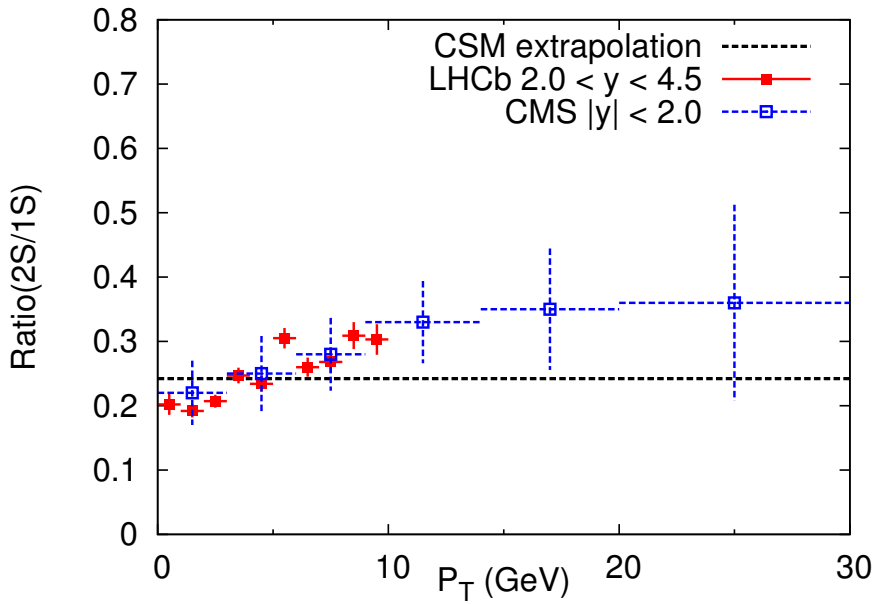

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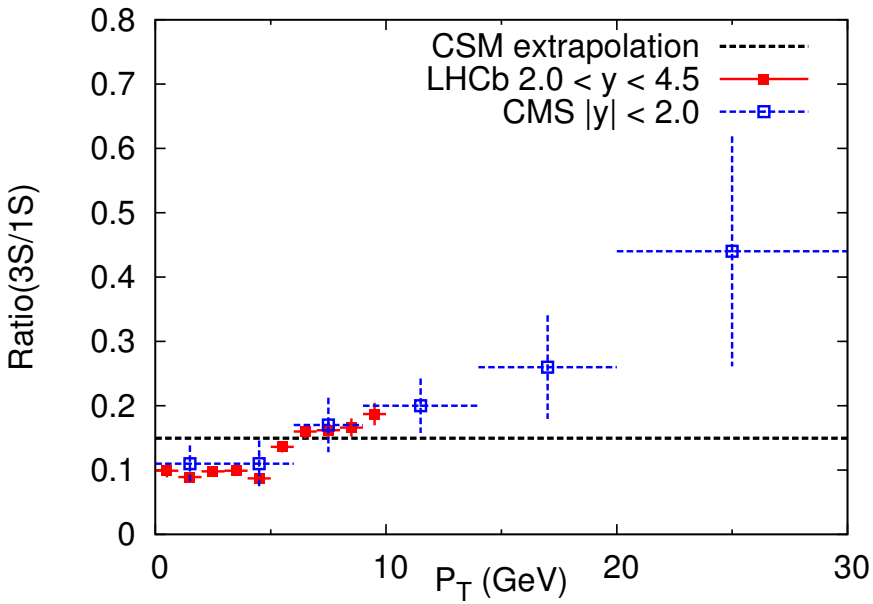

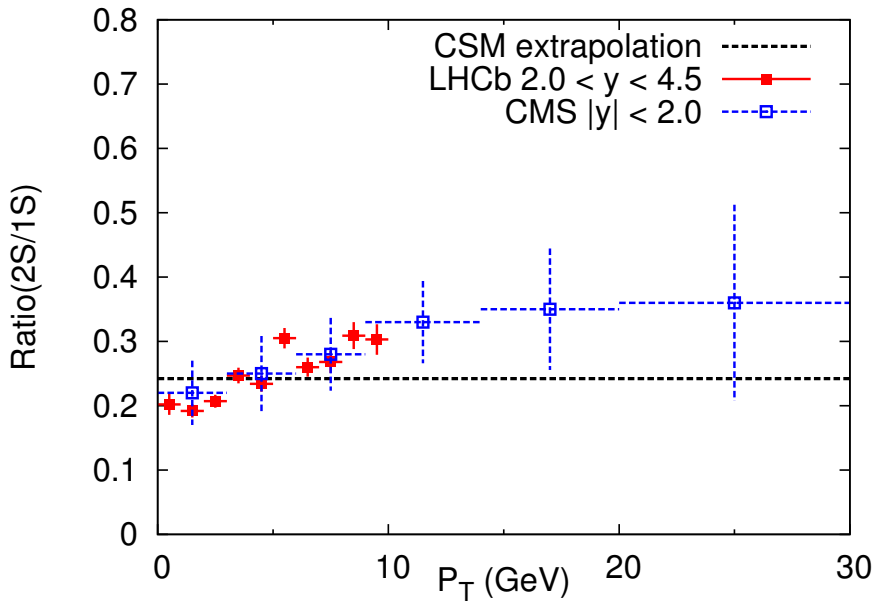

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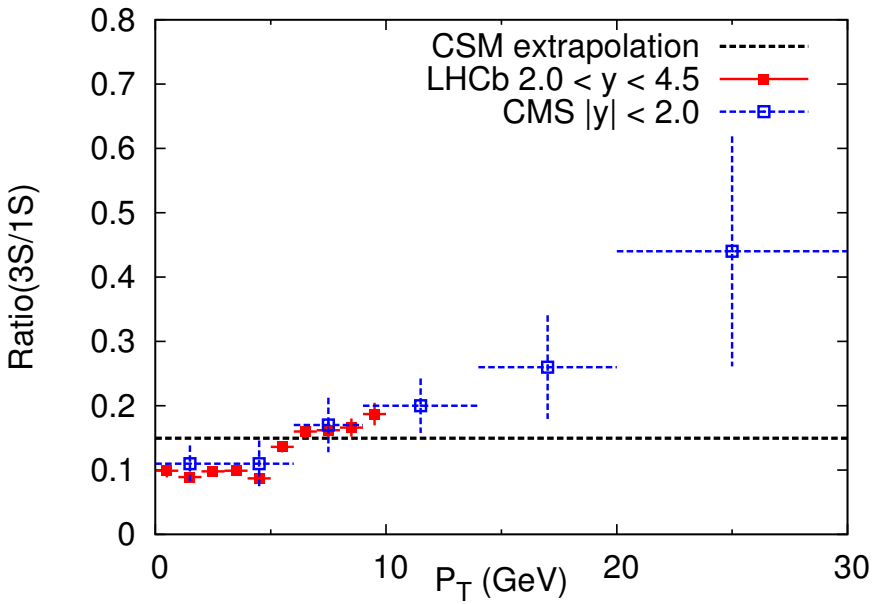

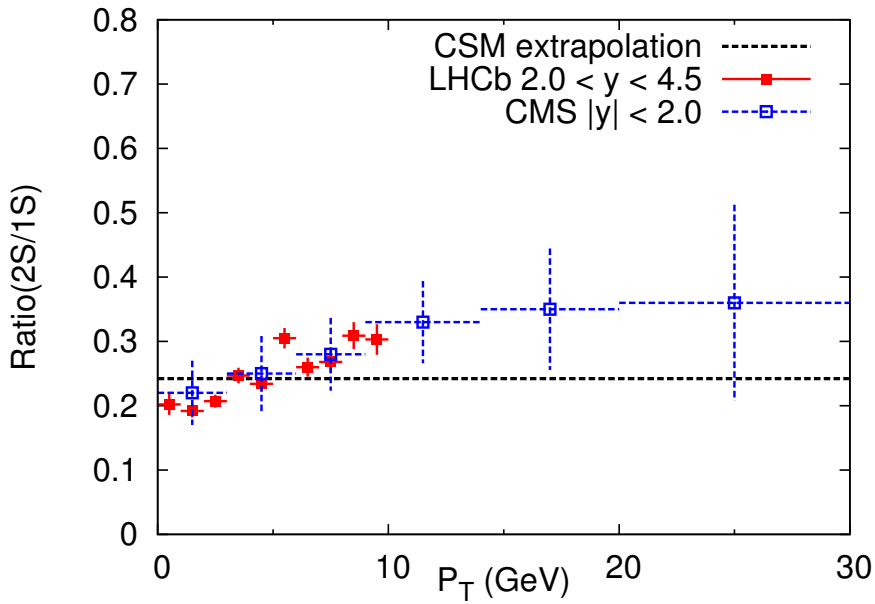

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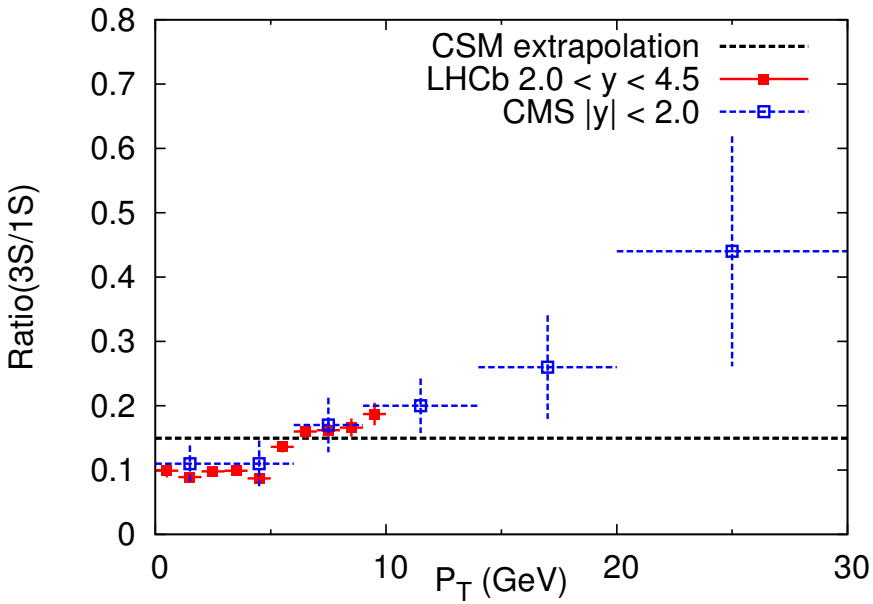

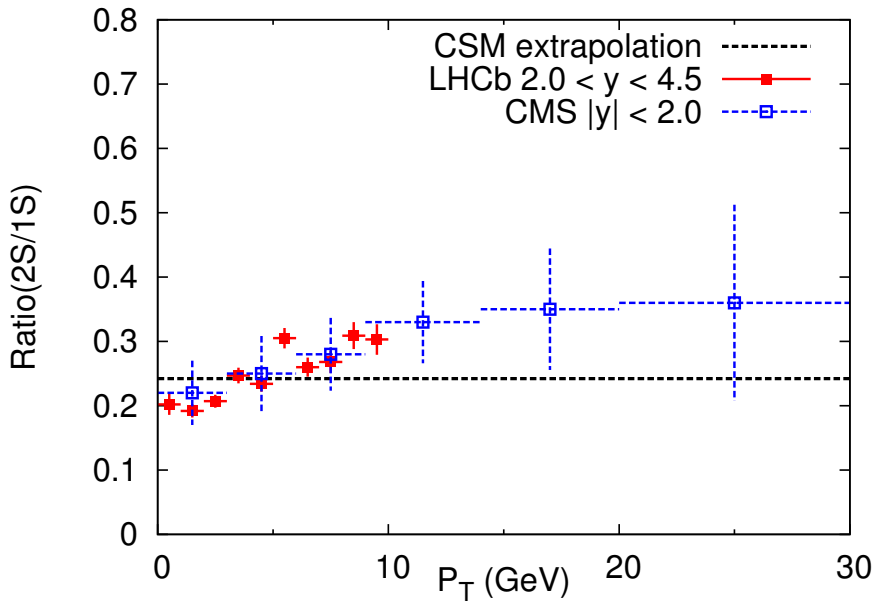

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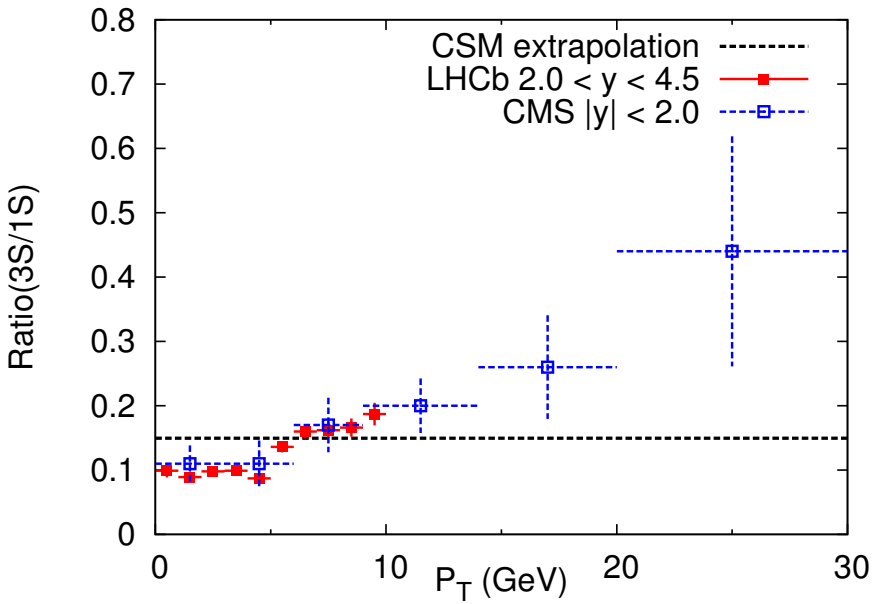

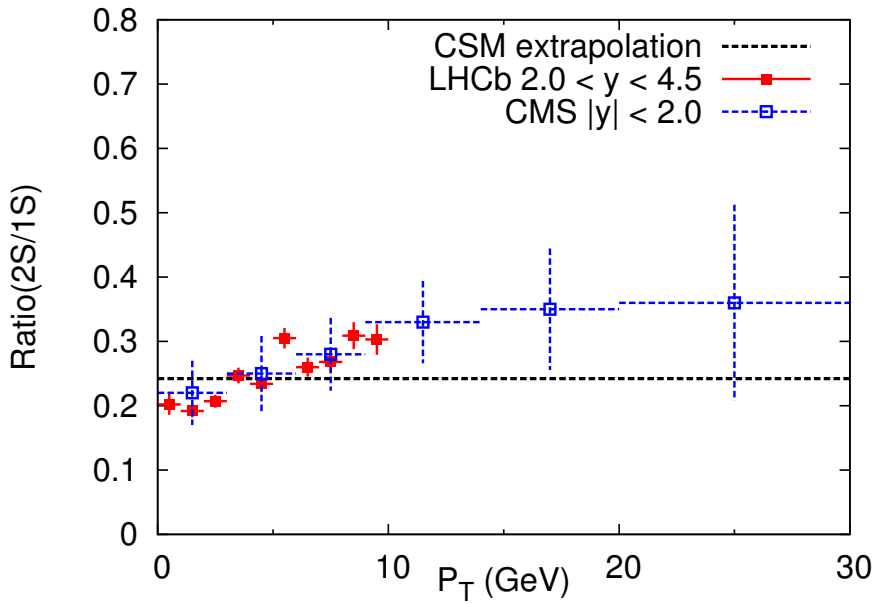

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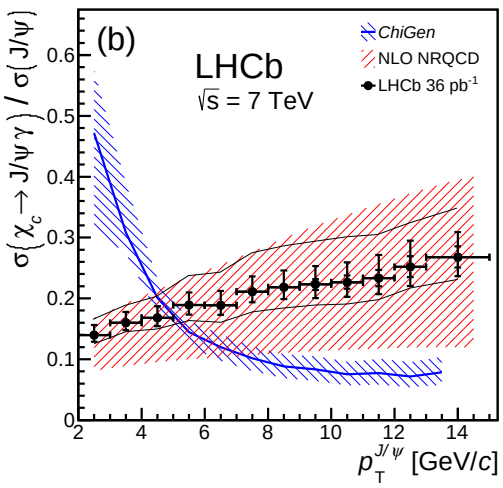
  - harmful if n changes, esp. true at low P_T where $\frac{d\sigma}{dP_T}$ can be flat

Impact of *P*-waves



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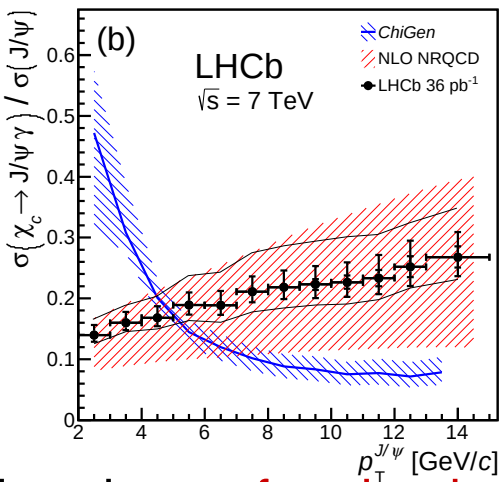

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- LHCb: first indication that the χ_c fraction increases

Note: NLO NRQCD does not necessarily mean "Colour Octet dominance". At NLO, the Colour-Singlet and Colour-Octet transition yields depend –for the *P* waves– on the unphysical scale $\Lambda_{\rm NRQCD}$ and the NRQCD subtraction scheme

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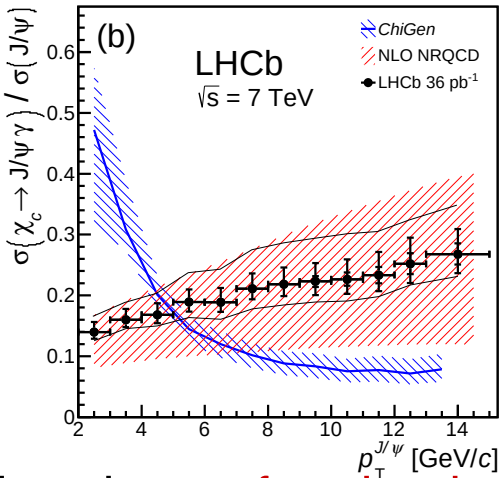

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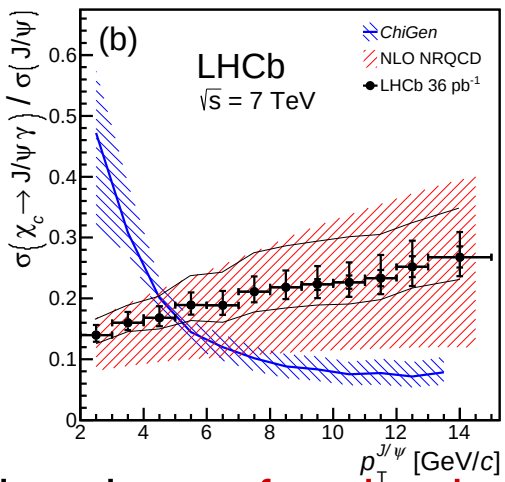
- About 40 % of $\Upsilon(1S)$ are from χ_b at the Tevatron **CDF, PRL 84, 2094 (2000).**

Impact of *P*-waves



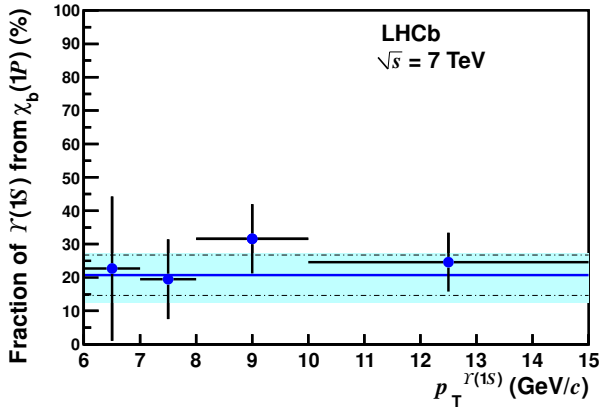
ChiGen: L. A. Harland-Lang and W. J. Stirling, `http://projects.hepforge.org/superchic/chigen.html`

NLO NRQCD: Y.-Q. Ma, K. Wang, K.-T. Chao, Phys. Rev. D83 (2011) 111503 (R)
The most important and overlooked theory paper on quarkonium physics in 2010 !
LHCb, Phys.Lett. B718 (2012) 431-440

- LHCb: first indication that the χ_c fraction increases

Note: NLO NRQCD does not necessarily mean "Colour Octet dominance". At NLO, the Colour-Singlet and Colour-Octet transition yields depend –for the *P* waves– on the unphysical scale $\Lambda_{\rm NRQCD}$ and the NRQCD subtraction scheme

- About 40 % of $\Upsilon(1S)$ are from χ_b at the Tevatron **CDF, PRL 84, 2094 (2000).**
- At the LHC:



A priori: no P_T dependence. However, the plot scales are different

LHCb JHEP 1211 (2012) 031

QCD corrections, feed-down and polarisation

B. Gong, J.X Wang, Phys. Rev. Lett. 100,232001,2008. P.Artoisenet, J.Campbell,JPL, F.Maltoni, F. Tramontano, Phys. Rev. Lett. 101,152001,2008
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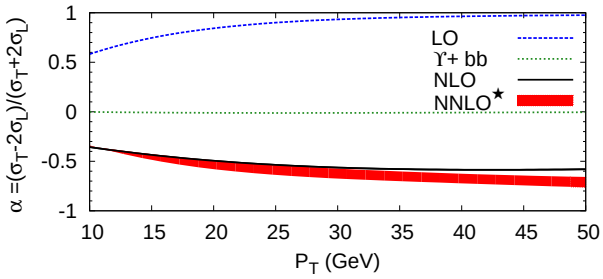

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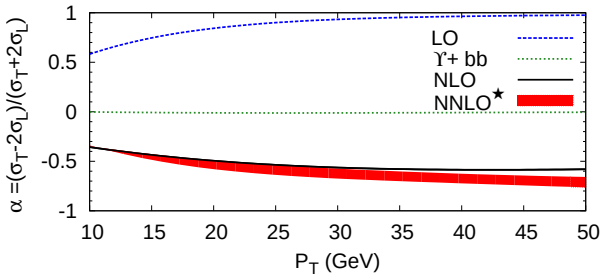

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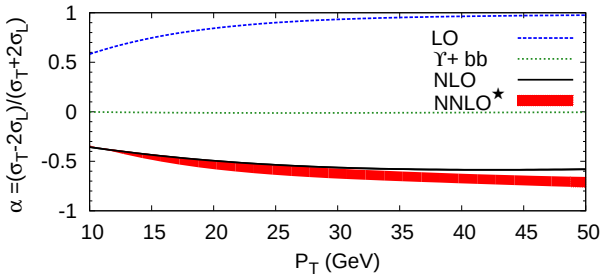

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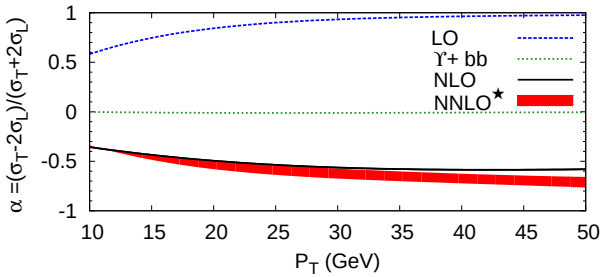

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JPL J. Phys. G 38 (2011) 124110

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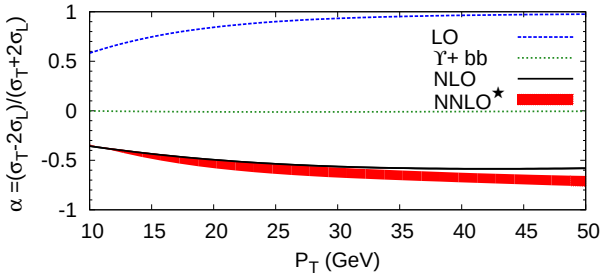

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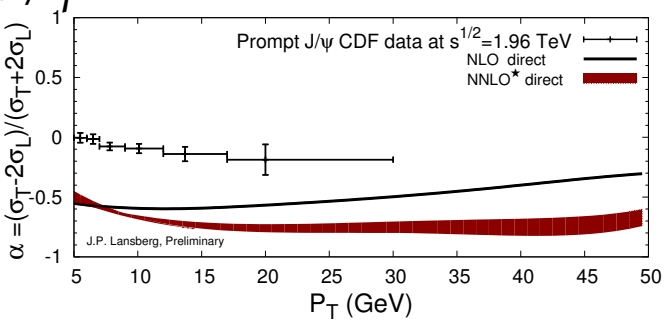

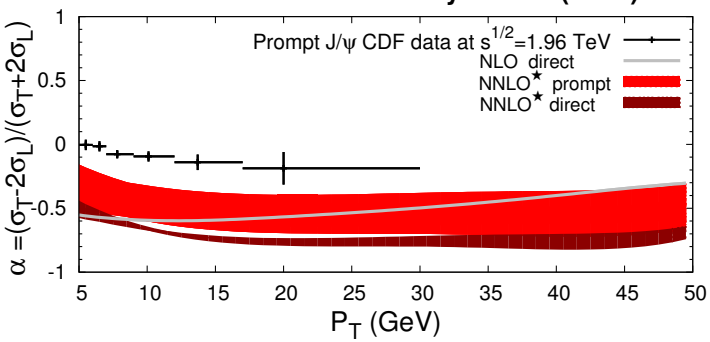

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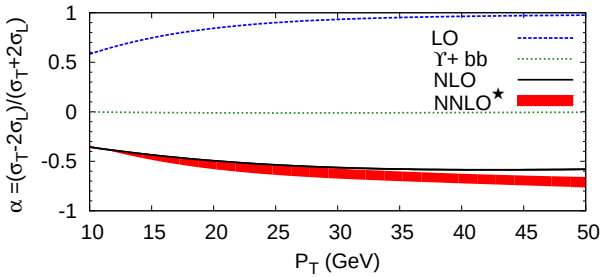

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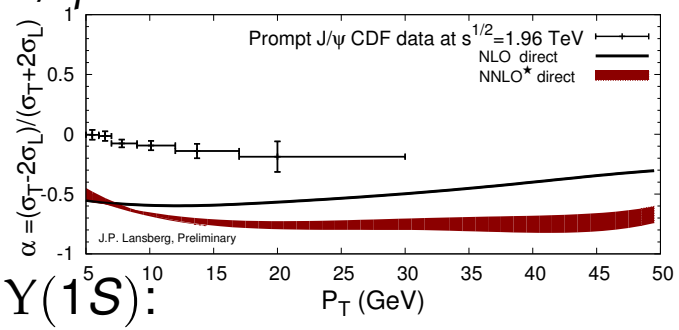
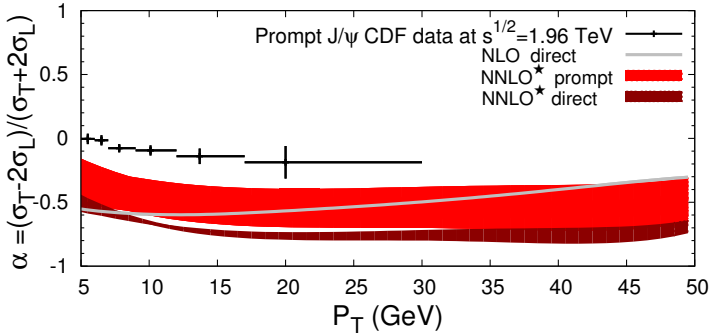
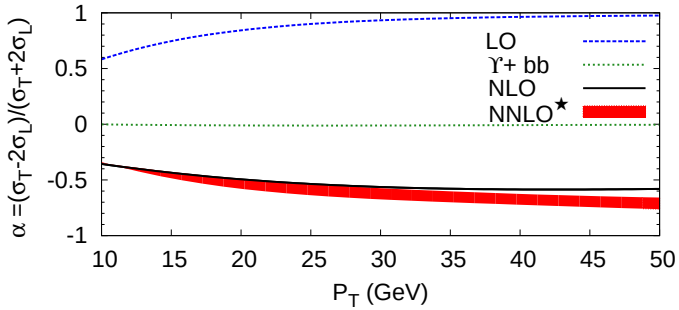
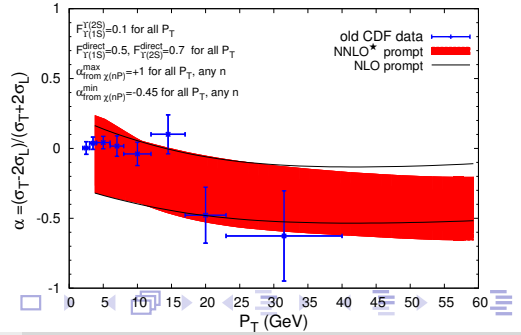




- For the $\Upsilon(1S)$:





Part II

Associated Υ production

Associated production: J/ψ vs. Υ

- A number of associated-production channels proposed for J/ψ
  - $J/\psi + J/\psi$
  - $J/\psi + \gamma$
  - $J/\psi + c$ or $J/\psi + D$ or $J/\psi + \textit{lepton}$
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  - $J/\psi + Z$
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- Less studies for Υ
  - rates are usually lower
  - $J/\psi + c$ and $J/\psi + J/\psi$, sometimes motivated by intrinsic charm

    Intrinsic bottom expected to be 10 times smaller

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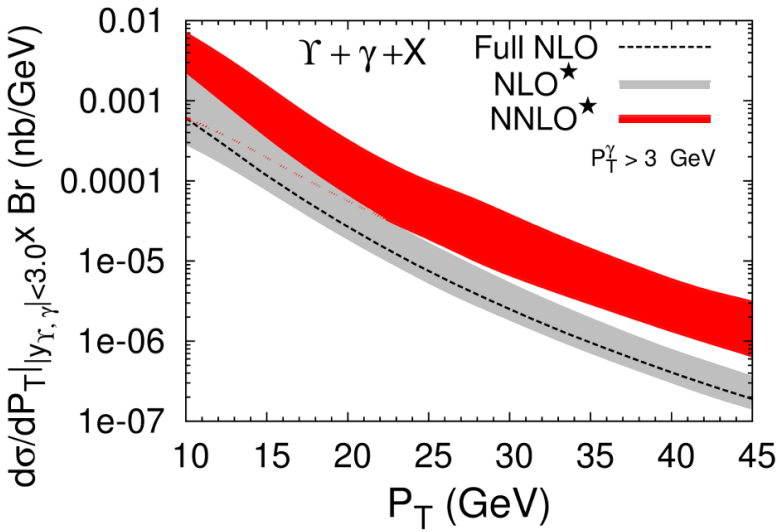

JPL, PLB 679,340,2009.

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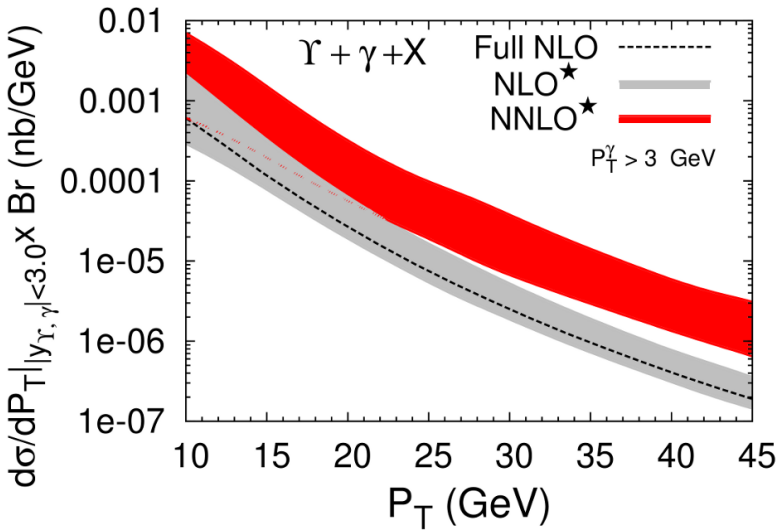

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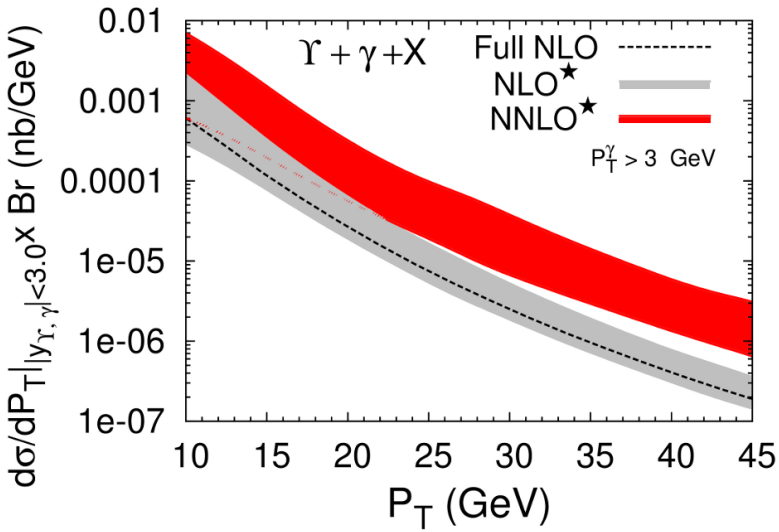

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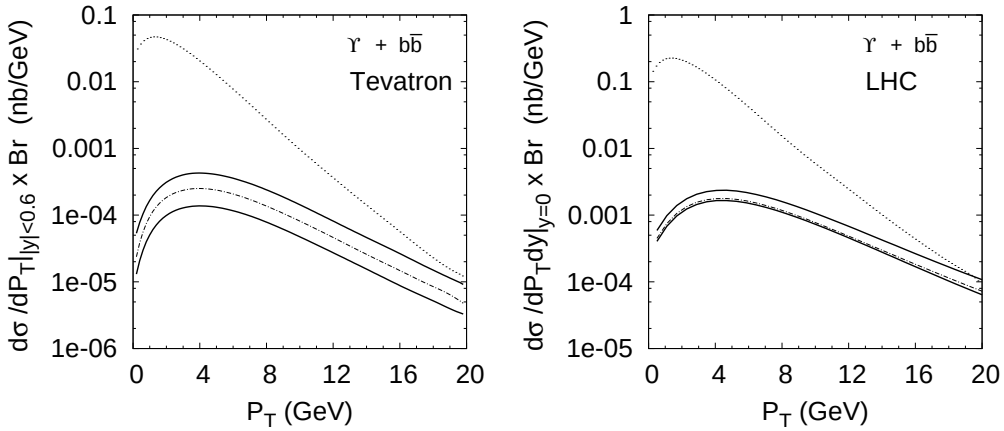
- Possible: see $(c, b) - jet + \gamma$ studies by D0 up to $P_T^\gamma \simeq 150$ GeV !

D0, PRL102 (2009) 192002.

$\Upsilon + b$-tagged jet



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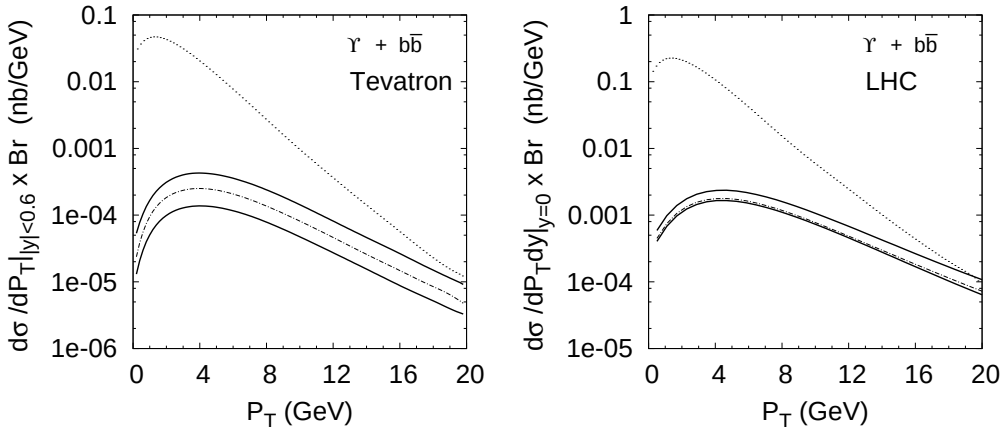

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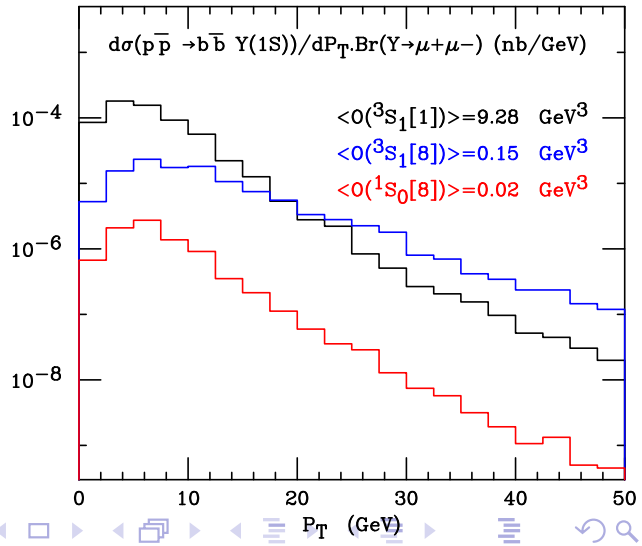

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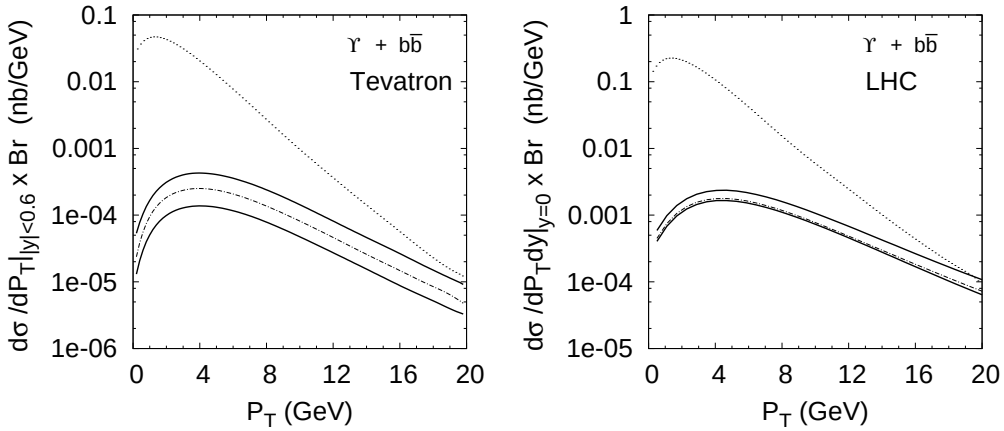

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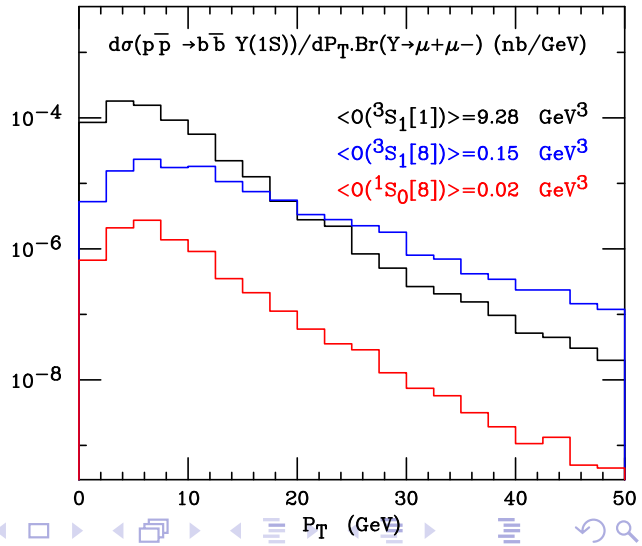
- $\Upsilon + b$: CSM vs. COM channels
- Different topologies:
  - CSM: 1 b away, 1 b near(er)
  - COM: 2 b's away (from a recoiling gluon)



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CDF Collaboration,PRL. 90 (2003) 221803

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- $J/\psi + Z$ and $J/\psi + W$ recently computed at NLO in α_s

L.Gang *et al.* PRD83,014001,2011; JHEP02(2011)071

- $J/\psi|\Upsilon + Z$ at NLO in α_s + Polarisation **B.Gong *et al.* arXiv:1210.2430 [hep-ph] to appear in JHEP**

$\Upsilon + Z$ cross sections

B. Gong, J.P. Lansberg, C. Lorcé, J.X. Wang, arXiv:1210.2430 [hep-ph] to appear in JHEP

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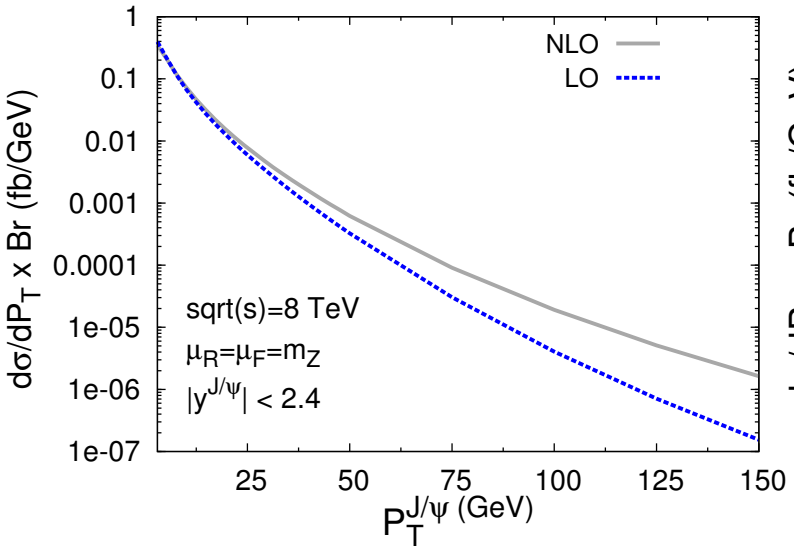

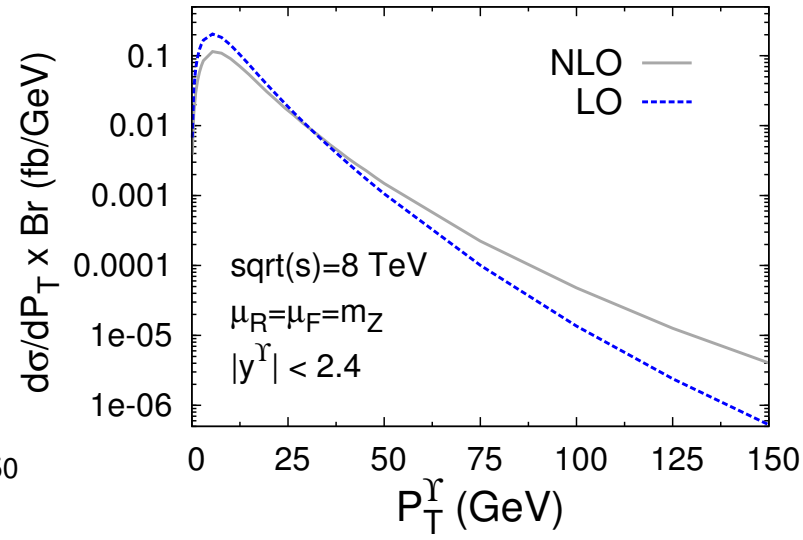

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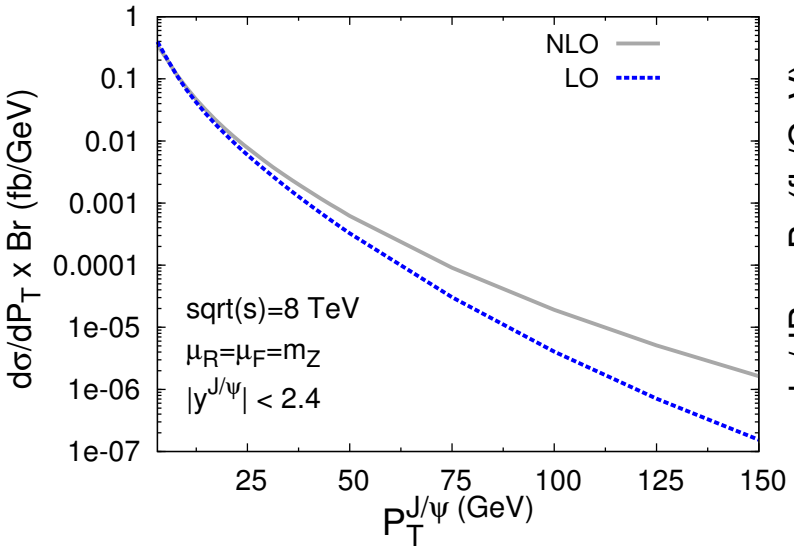

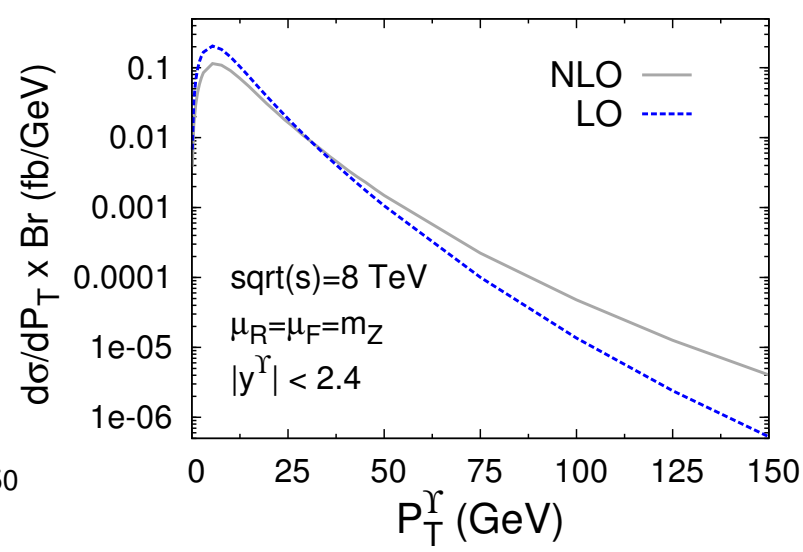

- Mass effects ($m_c \leftrightarrow m_b$ less relevant because of m_Z)
- $|R(0)|^2$ is 10 times larger for Υ than for J/ψ
- Branching "only" 2.5 times smaller

$\Upsilon + Z$:Υ polarisation

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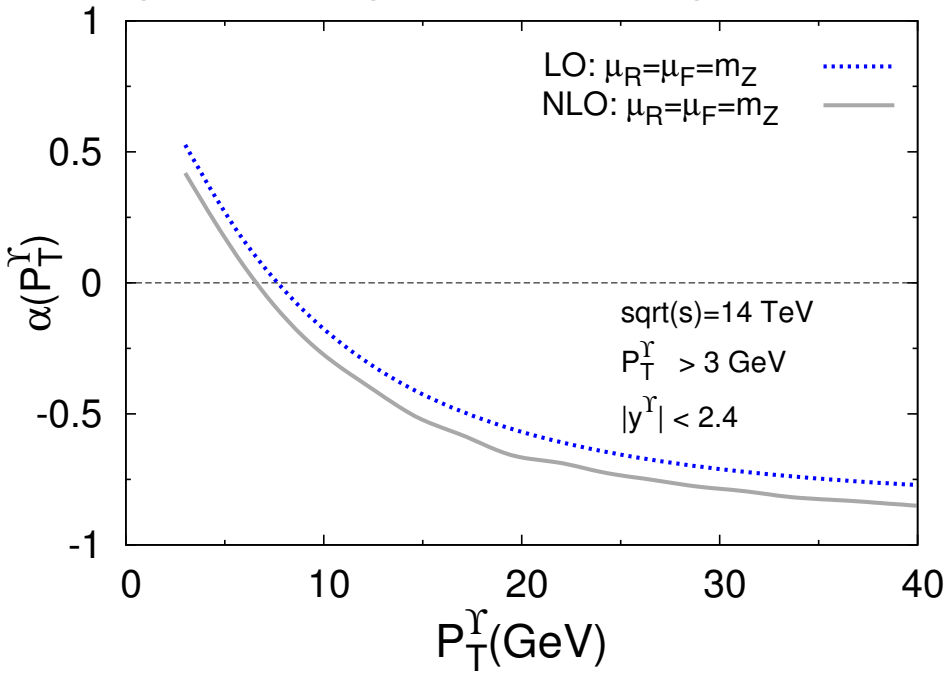

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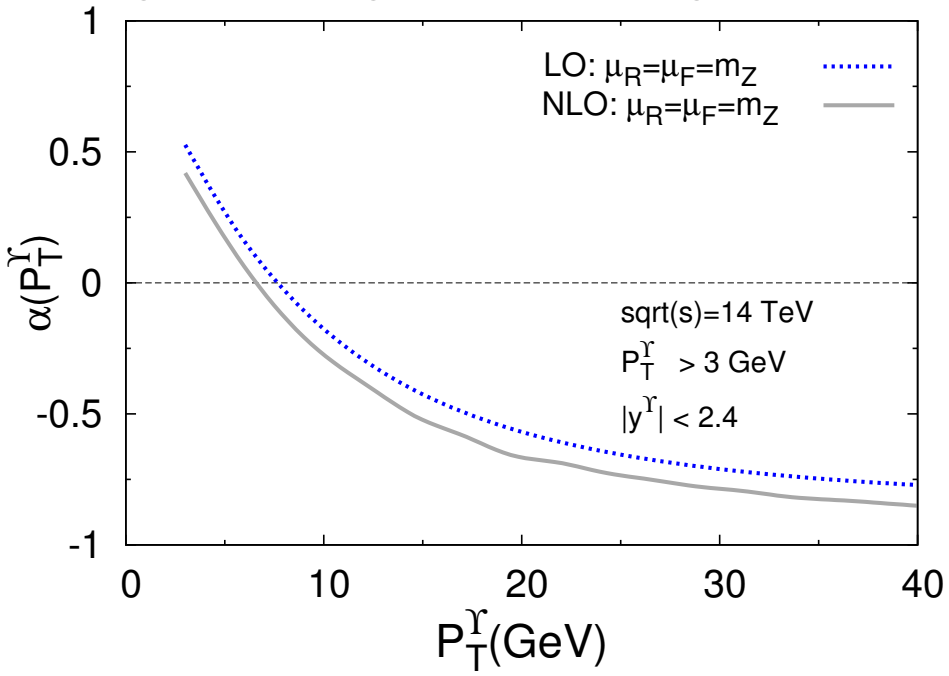

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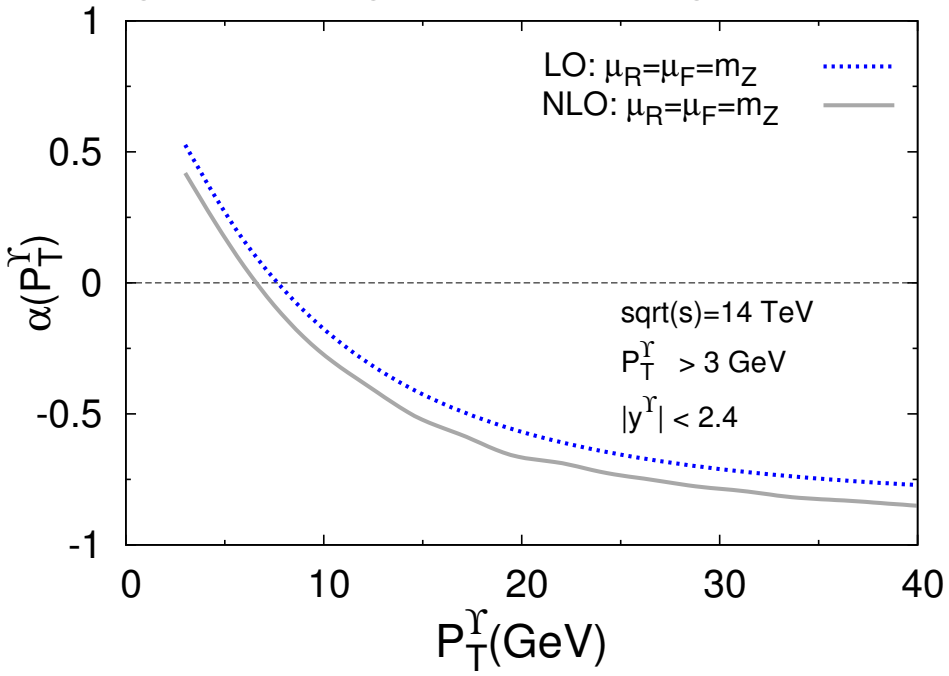

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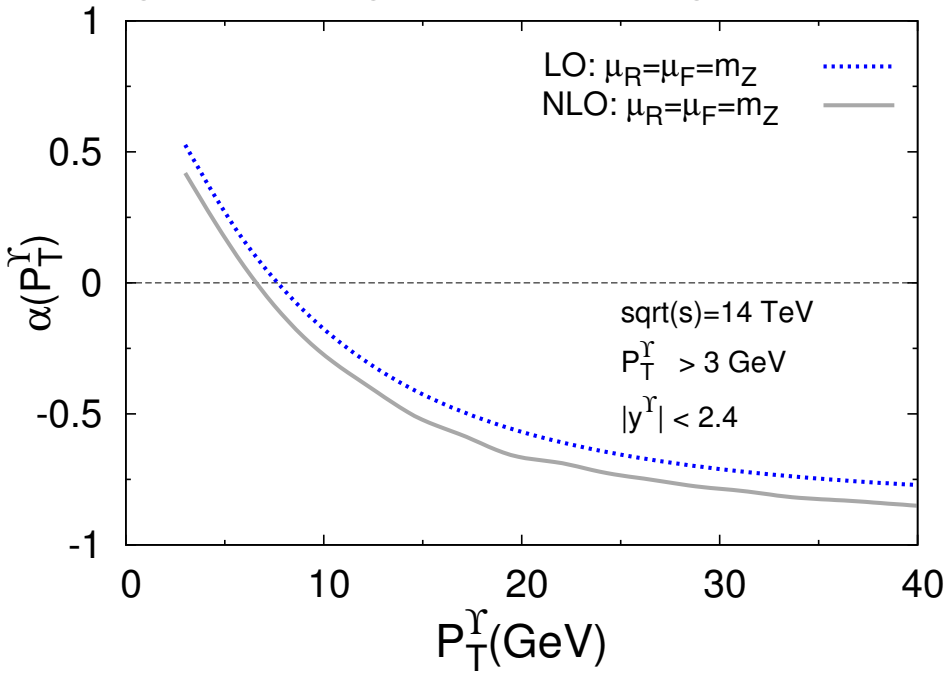

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- unlike the inclusive case
- not clear why: need for further investigation
- CSM predictions seem robust both for the yield and the polarisation

Part III

Υ in $p(d)A$ at RHIC and the LHC

Absorption: Υ vs. J/ψ

E.G. Ferreiro *et al.* **arXiv:1110.5047 v4 [hep-ph]**

σ_{abs}^{Υ} should be small $\rightarrow$ nuclear PDF should play the major role

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At the LHC, the $b\bar{b}$ pair propagating in the nuclear matter (the Pb nucleus) is nearly always in a pre-resonnant (small) state

nPDF uncertainty on Υ production in *d*Au collisions at RHIC

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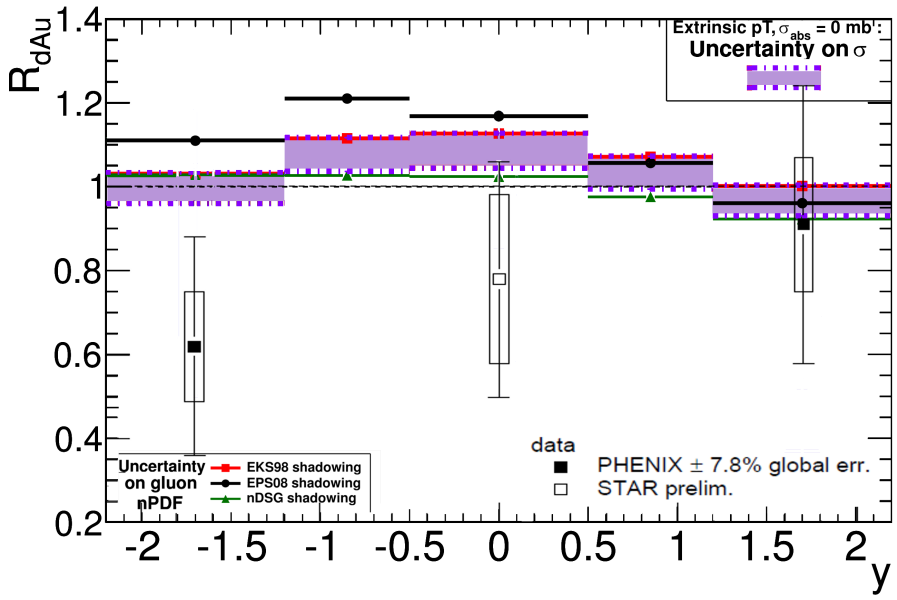

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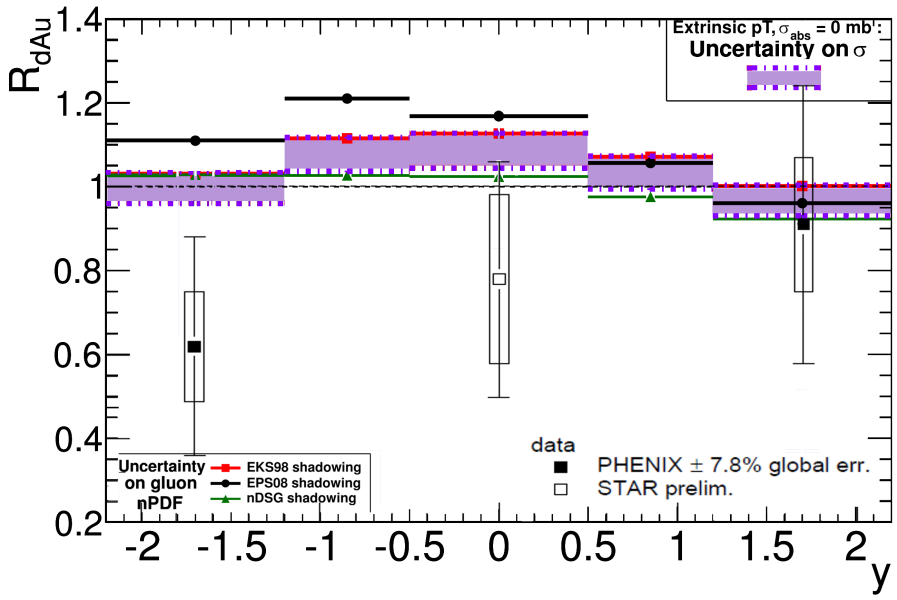

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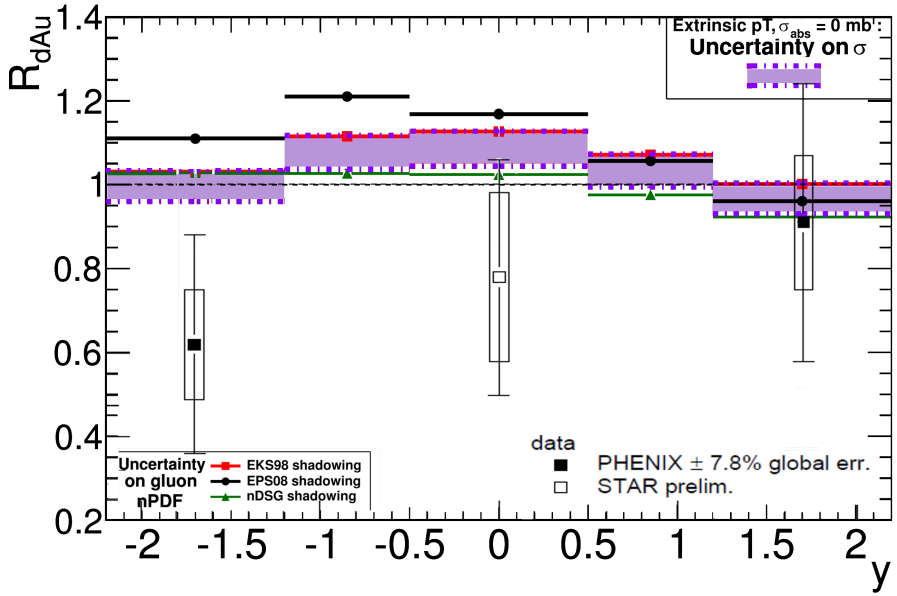

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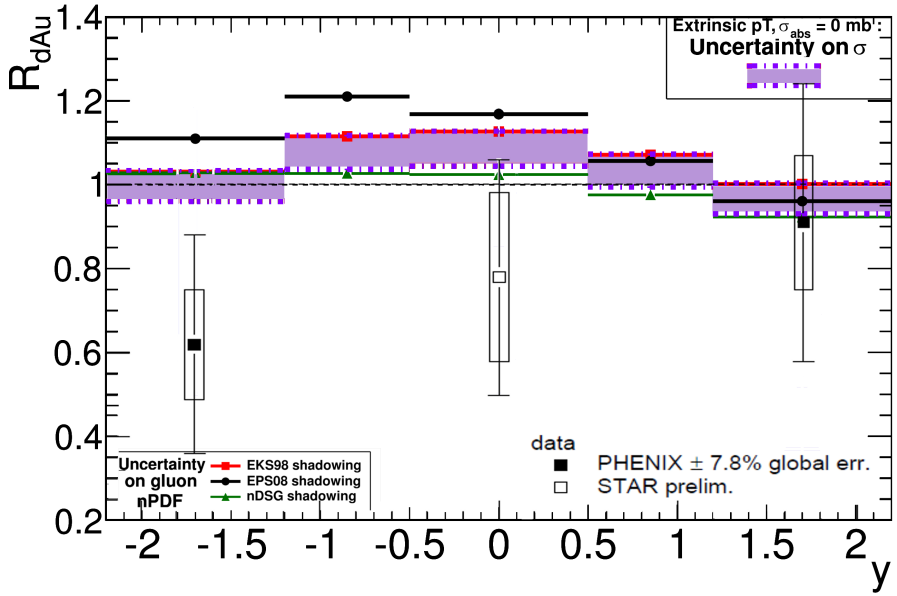

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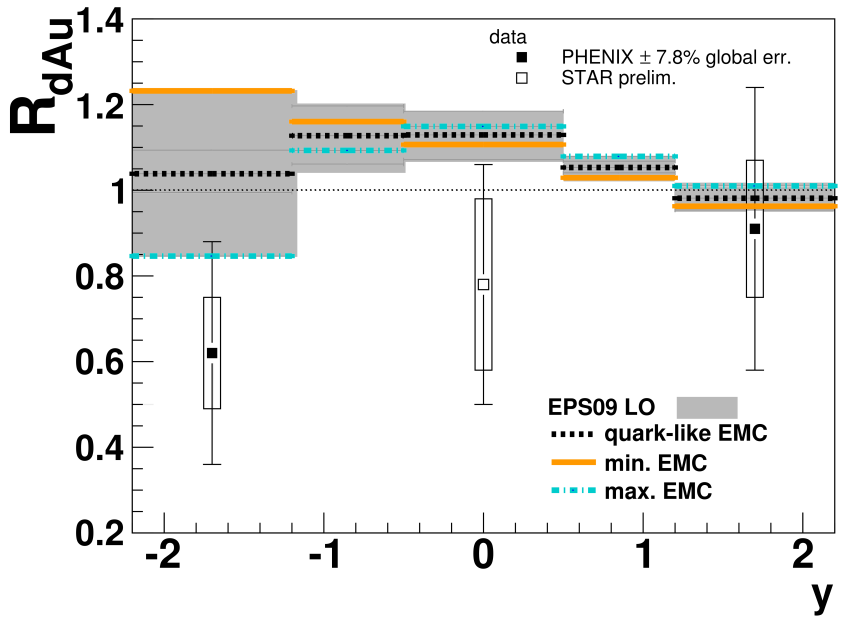

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- But, uncertainties in the EMC region are in fact large ...

Idea of a measurement for LHCb

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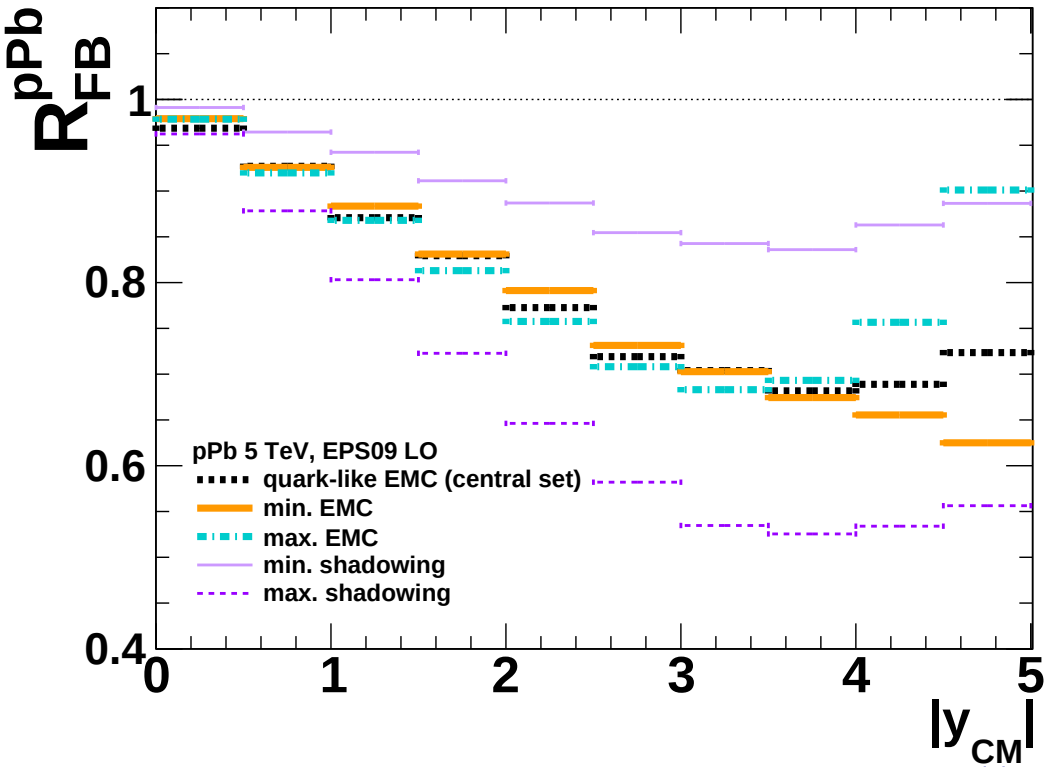

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- Suggestion for the pPb data: forward-backward ratio
  [pp reference irrelevant]