Polarization for Prompt J/ψ and $\psi(2s)$ production at the Tevatron and LHC

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Rencontres de Moriond
March 9-16, 2013, La Thuile
Based on our recent work: PRL110, 042002, 2013, ArXiv:1205.6682,
B. Gong, L. P. Wan, J. X. Wang and H. F. Zhang

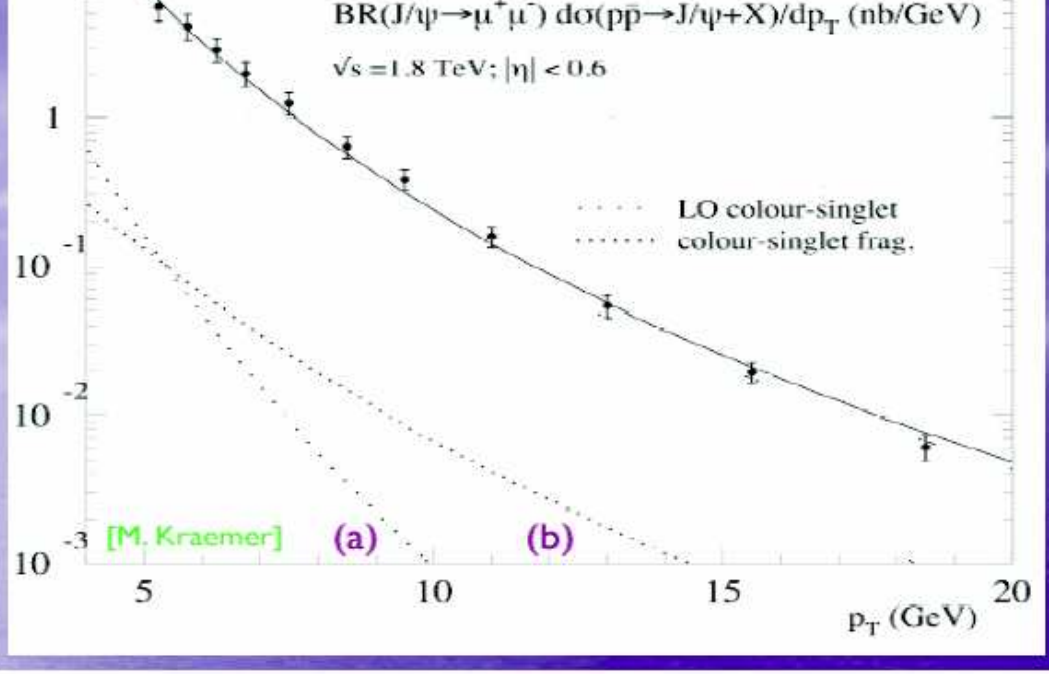
1. Introduction

2. J/ψ production at the Tevatron and LHC
   - QCD Correction to color-singlet J/ψ production
   - QCD Correction to color-octet J/ψ production

3. Summary

Introduction

- Perturbative and non-perturbative QCD, hadronization, factorization
- Color-singlet and Color-octet mechanism was proposed based on NRQCD since b and c-quark is heavy.
- Clear signal to detect J/ψ.
- heavy quarkonium production is a good place to testify these theoretical framework.
- J/ψ photoproduction at HERA
- J/ψ production at the B factories
- J/ψ production and polarization at the Tevatron
- J/ψ production at the LHC
- LO theoretical predication were given before more than 15 years
- NLO theoretical predications were given within last 5 years.
- It seems that the QCD NLO calculations can adequately describe the experimental data.
- But there are still many difficulties.



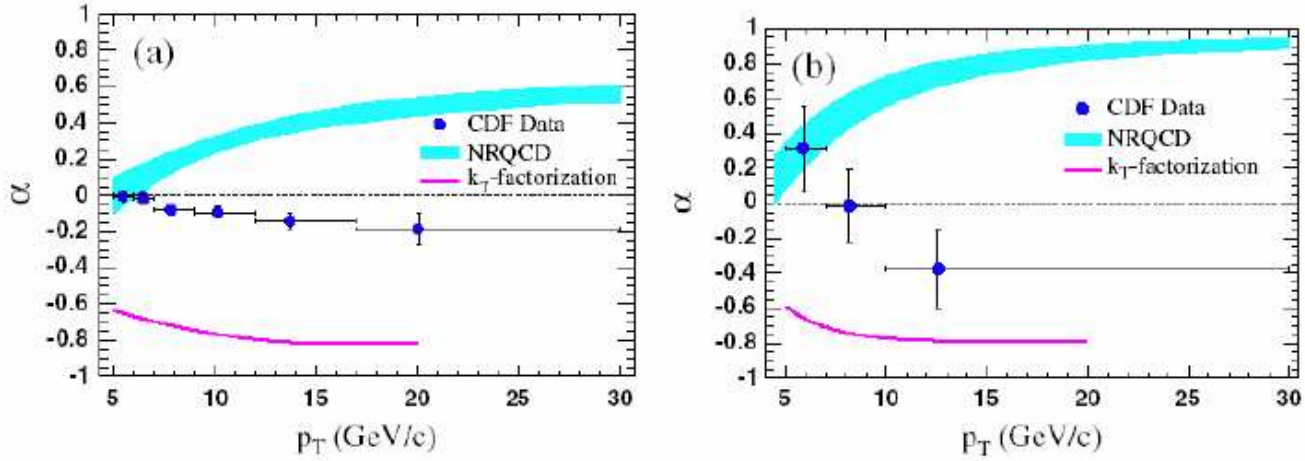


FIG. 4 (color online). Prompt polarizations as functions of p_T: (a) J/ψ and (b) $\psi(2S)$. The band (line) is the prediction from NRQCD [4] (the k_T-factorization model [9]).

The cross section of h hadroproduction is

$$\sigma[pp \to hx] = \sum \int \mathrm{d}x_1 \mathrm{d}x_2 G_p^i G_p^j \hat{\sigma}[ij \to (c\bar{c})_n x] \langle \mathcal{O}_n^h \rangle, \tag{1}$$

where p is either a proton or anti-proton, the indices i, j run over all the partonic species and n represents the $c\bar{c}$ intermediate states $({}^3S_1 1, {}^3S_1 8, {}^1S_0 8, {}^3P_J 8)$ for J/ψ and ψ', and $({}^3P_J 1, {}^3S_1 8)$ for χ_{cJ}.

- double expansions in α_s and the heavy-quark velocity v.
- predication can be sysmatically improved with these two perturbative expansions.
- limited number of universal long-distance matrix elements to be extracted from experiment.

Introduction

In last five years, there were a few very important progresses in the next-to-leading Order (NLO) QCD correction calculation:

- QCD Correction to color-singlet J/ψ production
- QCD Correction to color-singlet J/ψ polarization
- QCD Correction to color-octet $J/\psi(^1S_0^8,\ ^3S_1^8)$ production and polariozation
- QCD Correction to color-octet $J/\psi(^1S_0^8,\ ^3S_1^8, ^3P_J^8)$ production
- QCD Correction to color-octet $J/\psi(^1S_0^8,\ ^3S_1^8, ^3P_J^8)$ polarization
- QCD Correction to $\chi_{cJ}(^3S_1^8, ^3P_J^1)$ production

Before our work, there are:

p_t distributioin of J/ψ yield for prompt J/ψ hadroproduction at QCD NLO

p_t distributioin of J/ψ polarization for direct J/ψ hadroproduction at QCD NLO

feeddown of χ_{cJ} about $20-30\%$ to prompt J/ψ production and very improtant.

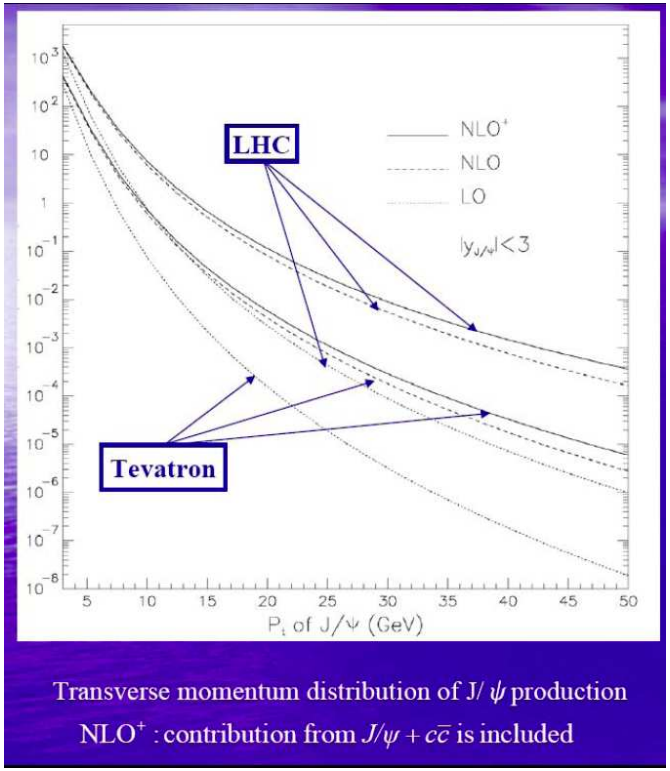
prompt: included the J/ψ feeddown from excited charmonium state than direct production

We need:

p_t distributioin of J/ψ polarization for prompt J/ψ hadroproduction at QCD NLO

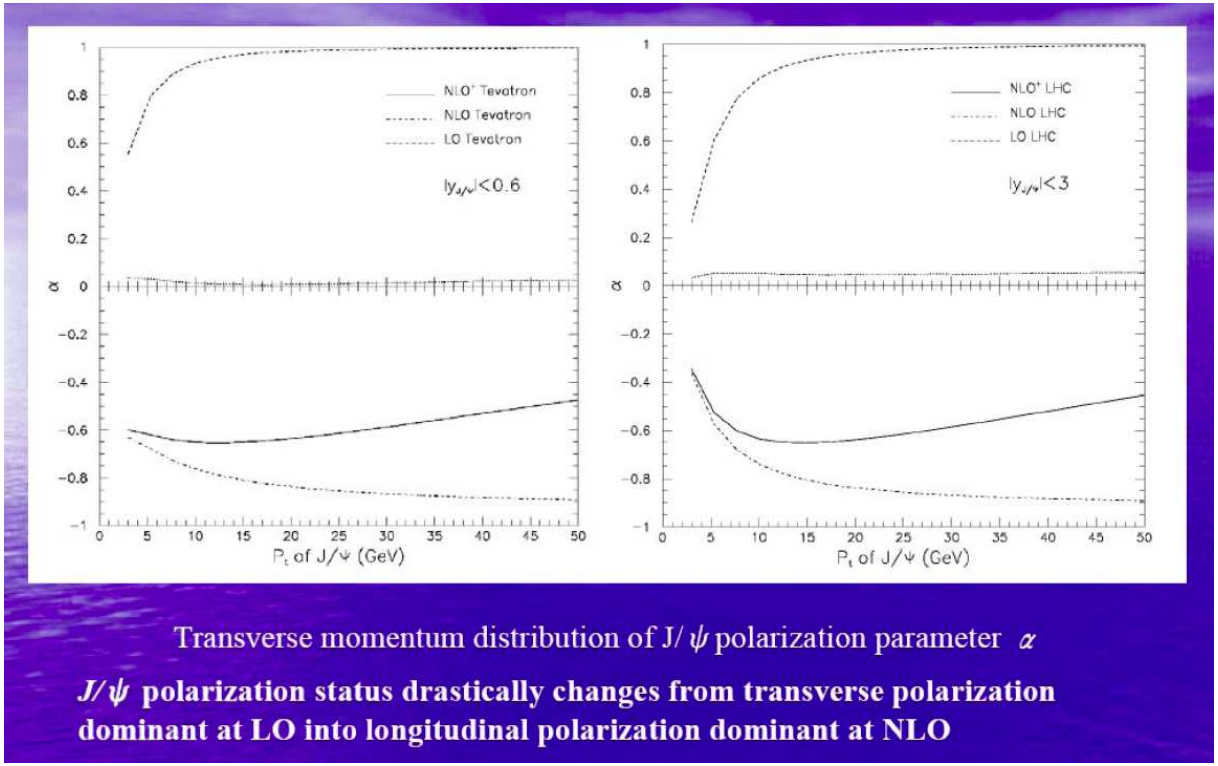
We have finished this work and presented in a recent paper ArXiv:1205.6682,
Bin Gong, Lu-Ping Wan, Jian-Xiong Wang and Hong-Fei Zhang

QCD Correction to color-singlet J/ψ production



Transverse momentum distribution of J/ ψ production

NLO$^+$: contribution from $J/\psi + c\bar{c}$ is included



Transverse momentum distribution of J/ ψ polarization parameter α

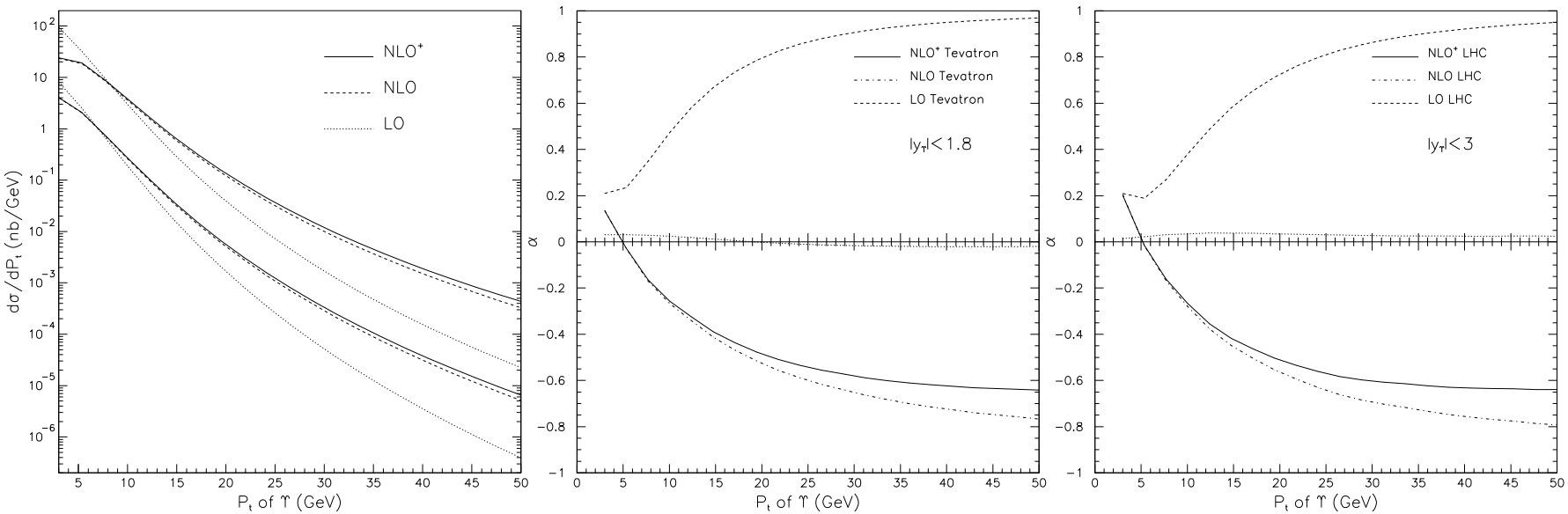
J/ψ polarization status drastically changes from transverse polarization dominant at LO into longitudinal polarization dominant at NLO

P_t distribution of J/ψ production at QCD NLO was calculated in PRL98,252002 (2007), J. Campbell, F. Maltoni F. Tramontano

Some technique problems must be solved to calculate J/ψ polarization

P_t distribution of J/ψ polarization at QCD NLO was calculated in PRL100,232001 (2008), B. Gong and J. X. Wang

QCD Correction to color-singlet Υ production

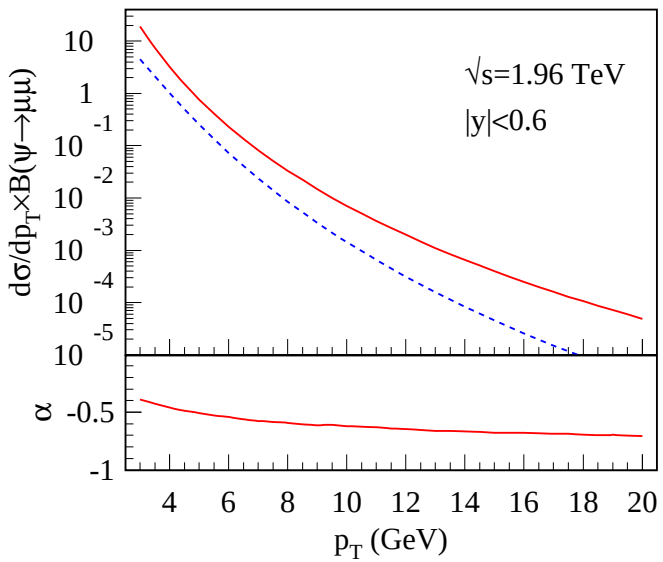


Υ polarization drastically changes from transverse polarization dominant at LO into longitudinal polarization dominant at NLO

P_t distribution of Υ polarization at QCD NLO was calculated with detail in PRD78 074011 (2008), B. Gong and J. X. Wang

Partly NNLO calculation for Υ production calculated by PRL101, 152001(2008), P. Artoisenet, John M. Campbell, J.P. Lansberg, F. Maltoni, F. Tramontano

The main point is to extended the fragmentation factorization
from: one-parton fragment into hadron
to: two-parton fragment into hadron
There will be more fragmentation function needed in this scheme.



PRL 108 (2012) 102002, Zhong-Bo Kang, Jian-Wei Qiu and George Sterman

NLO QCD corrections to J/ψ production via S-wave color octet states

3 tree processes at LO

At NLO

$$g(p_1) + g(p_2) \to J/\psi\left[{}^1S_0^{(8)}, {}^3S_1^{(8)}\right](p_3) + g(p_4), \quad (267, 413)$$

$$g(p_1) + q(p_2) \to J/\psi\left[{}^1S_0^{(8)}, {}^3S_1^{(8)}\right](p_3) + q(p_4), \quad (49, 111)$$

$$q(p_1) + \bar{q}(p_2) \to J/\psi\left[{}^1S_0^{(8)}, {}^3S_1^{(8)}\right](p_3) + g(p_4). \quad (49, 111)$$

Real Correction (8 processes at NLO)

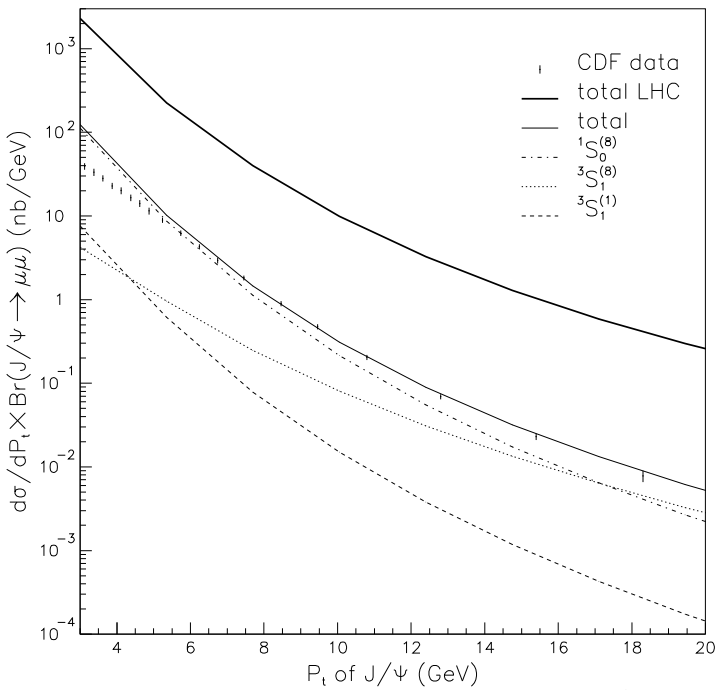
$$gg \to J/\psi\left[{}^1S_0^{(8)}, {}^3S_1^{(8)}\right]gg, \quad gg \to J/\psi\left[{}^1S_0^{(8)}, {}^3S_1^{(8)}\right]q\bar{q},$$

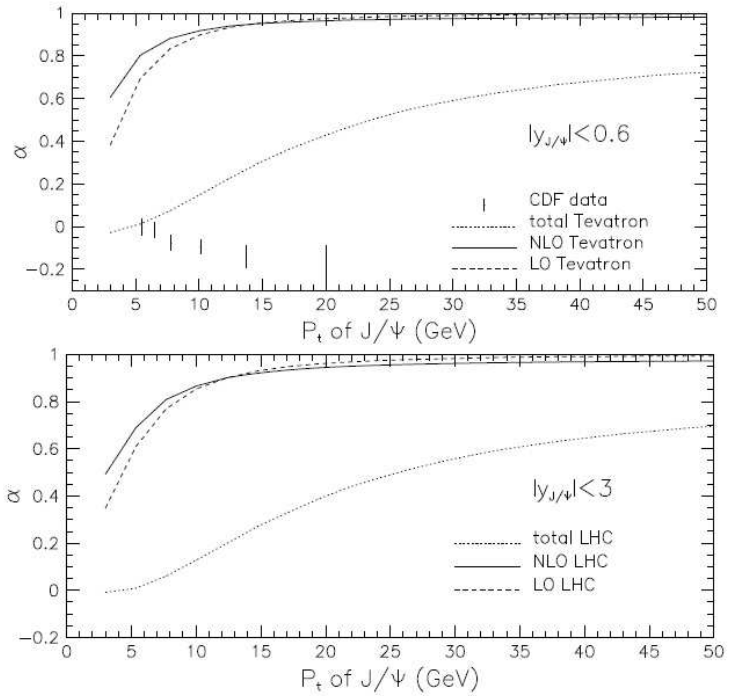
$$gq \to J/\psi\left[{}^1S_0^{(8)}, {}^3S_1^{(8)}\right]gq, \quad q\bar{q} \to J/\psi\left[{}^1S_0^{(8)}, {}^3S_1^{(8)}\right]gg,$$

$$q\bar{q} \to J/\psi\left[{}^1S_0^{(8)}, {}^3S_1^{(8)}\right]q\bar{q}, \quad q\bar{q} \to J/\psi\left[{}^1S_0^{(8)}, {}^3S_1^{(8)}\right]q'\bar{q}',$$

$$qq \to J/\psi\left[{}^1S_0^{(8)}, {}^3S_1^{(8)}\right]qq, \quad qq' \to J/\psi\left[{}^1S_0^{(8)}, {}^3S_1^{(8)}\right]qq',$$

QCD Correction to $J/\psi(^3S_1^1,\ ^1S_0^8,\ ^3S_1^8)$ production and polarization without $^3P_J^8$ contribution

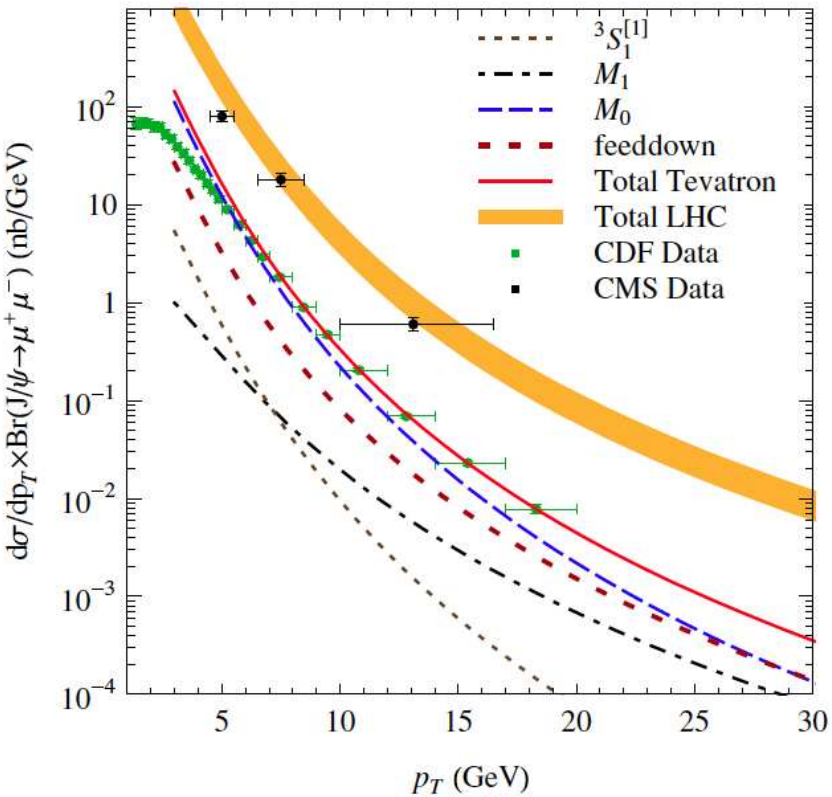


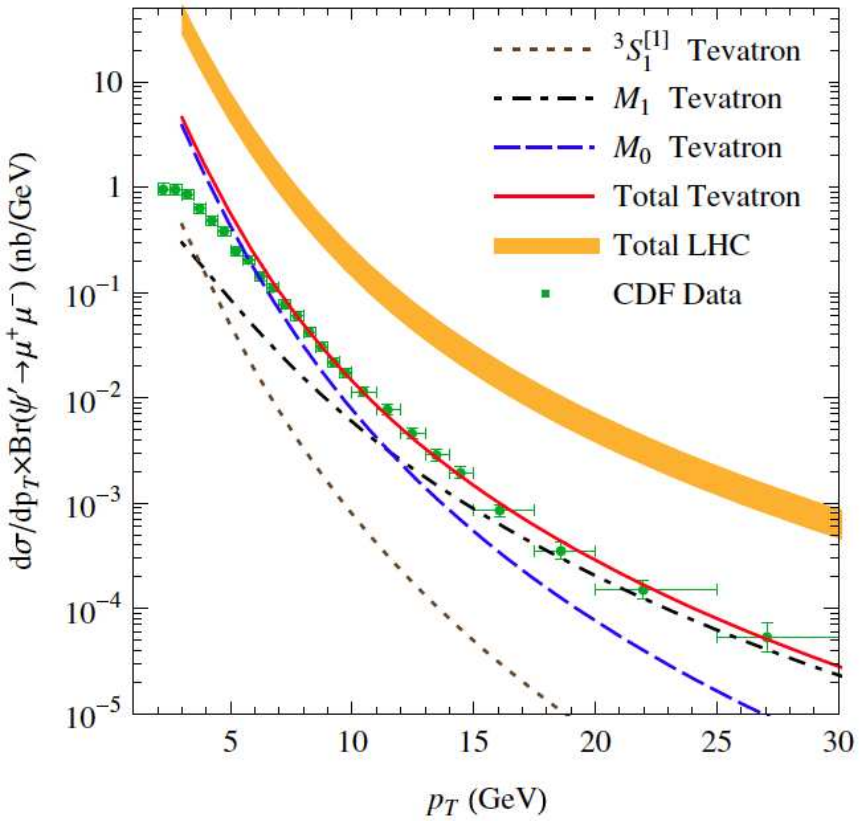


To fit the Tevatron P_t distribution give more $\langle \mathcal{O}_8^{\psi}(^1S_0)\rangle = 0.075\ \mathrm{GeV}^3$ and less $\langle \mathcal{O}_8^{\psi}(^3S_1)\rangle = 0.0021\ \mathrm{GeV}^3$ than they are at LO fitting The experimental data with $p_t < 6$ GeV have to abandon

PLB673:197,2009, Erratum-ibid.693:612,2010 , B. Gong X. Q. Li and J. X. Wang

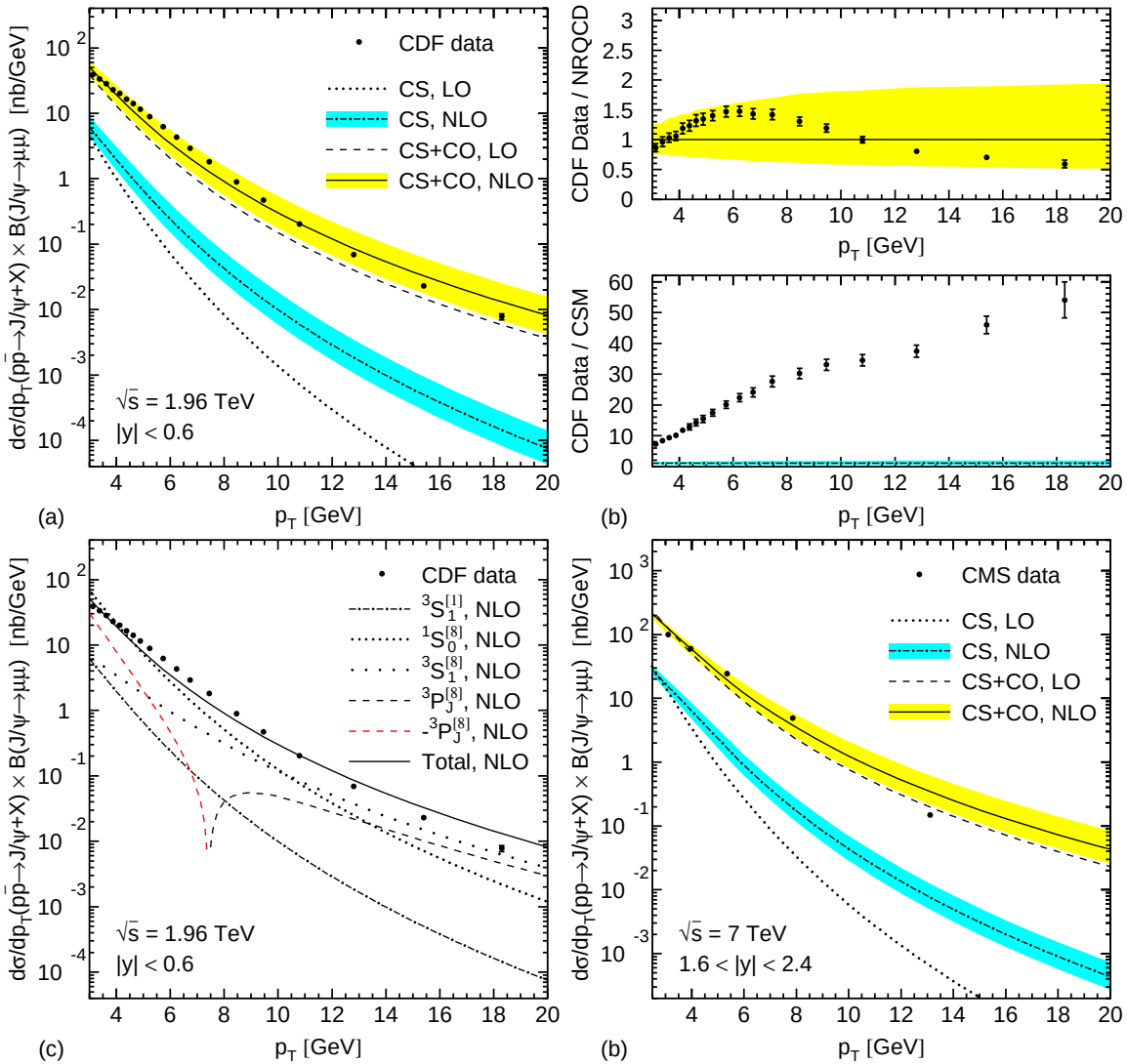
QCD Correction to prompt $J/\psi(^3S_1^1, ^1S_0^8, \ ^3S_1^8, \ ^3P_J^8)$ production without calculation of polarization





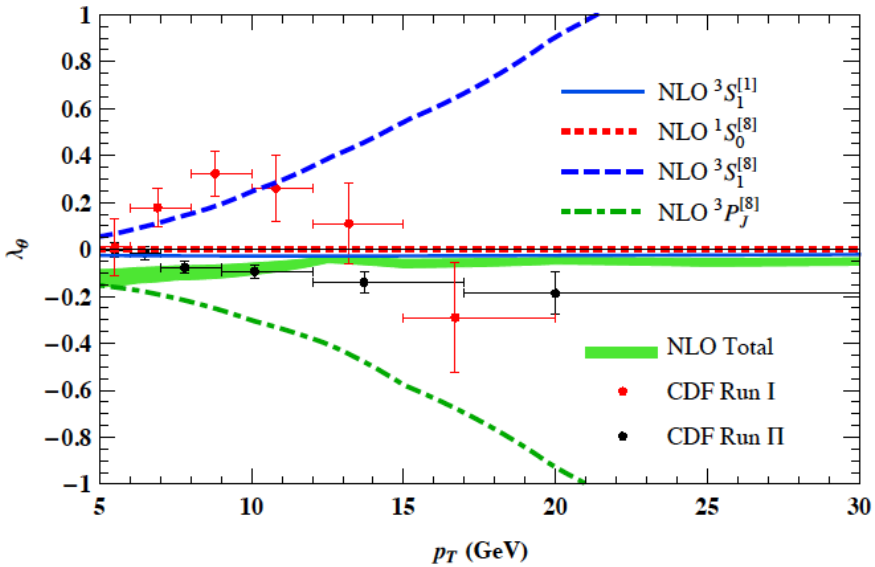
PRL 106, 042002,2011, Yan-Qing Ma, Kai Wang, Kuang-Ta Chao

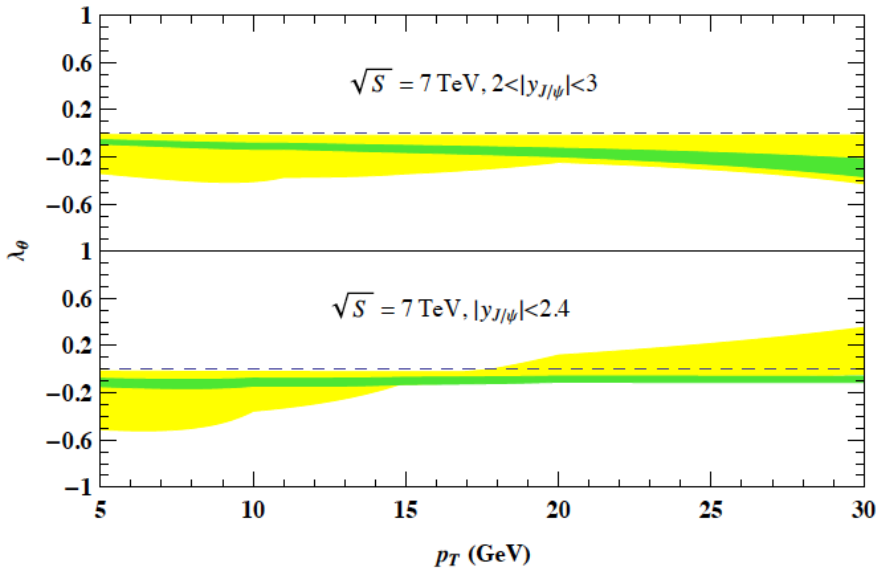
QCD Correction to $J/\psi(^3S_1^1,\ ^1S_0^8,\ ^3S_1^8,\ ^3P_J^8)$ production without calculation of polarization



PRL 106, 022003,2011, Mathias Butenschoen, Bernd A. Kniehl

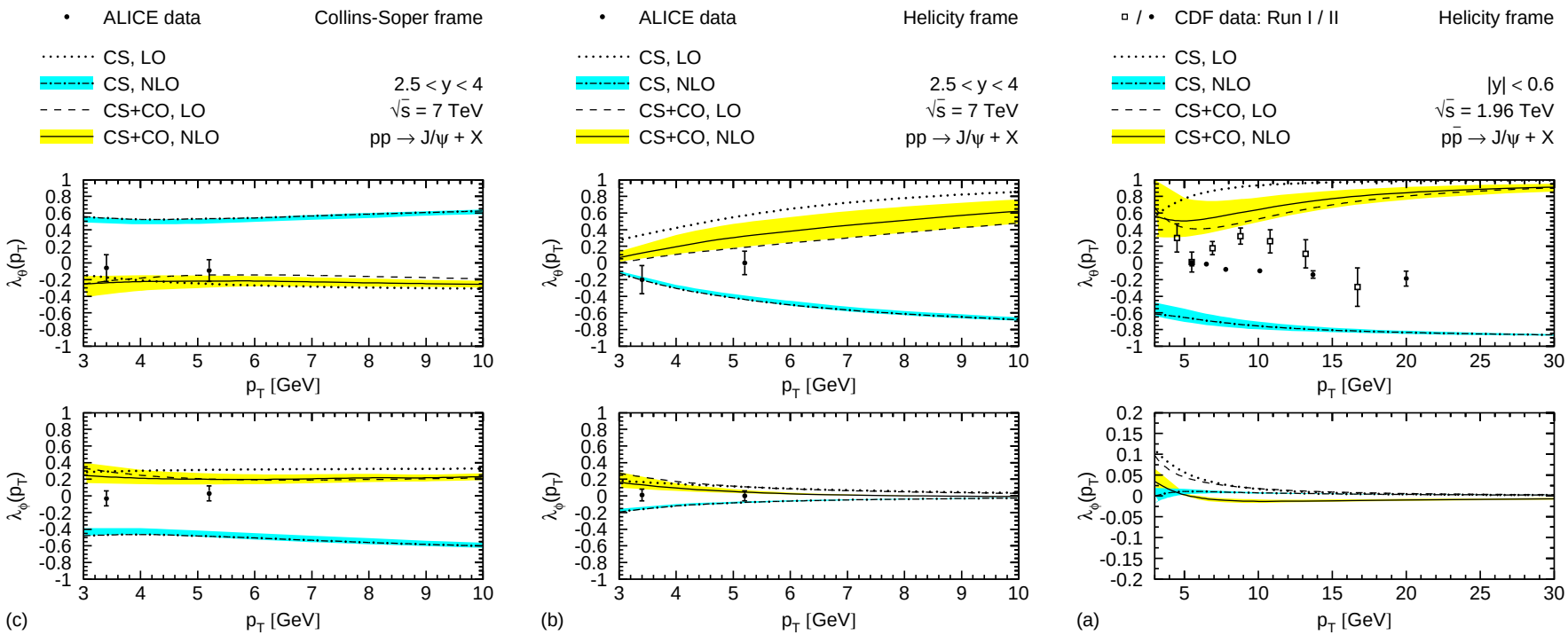
QCD Correction to polarization of $J/\psi(^1S_0^8,\ ^3S_1^8,\ ^3P_J^8)$ direct production





PRL 108, 248004,2012 Kuang-Ta Chao, Yan-Qing Ma, Hua-Sheng Shao, Kai Wang, Yu-Jie Zhang

QCD Correction to polarization of $J/\psi(^3S_1^1,\ ^1S_0^8,\ ^3S_1^8,\ ^3P_J^8)$ direct production



PRL 108, 172002,2012, Mathias Butenschoen, Bernd A. Kniehl

QCD Correction to prompt $J/\psi(^3S_1^1,\ ^1S_0^8,\ ^3S_1^8,\ ^3P_J^8)$ production

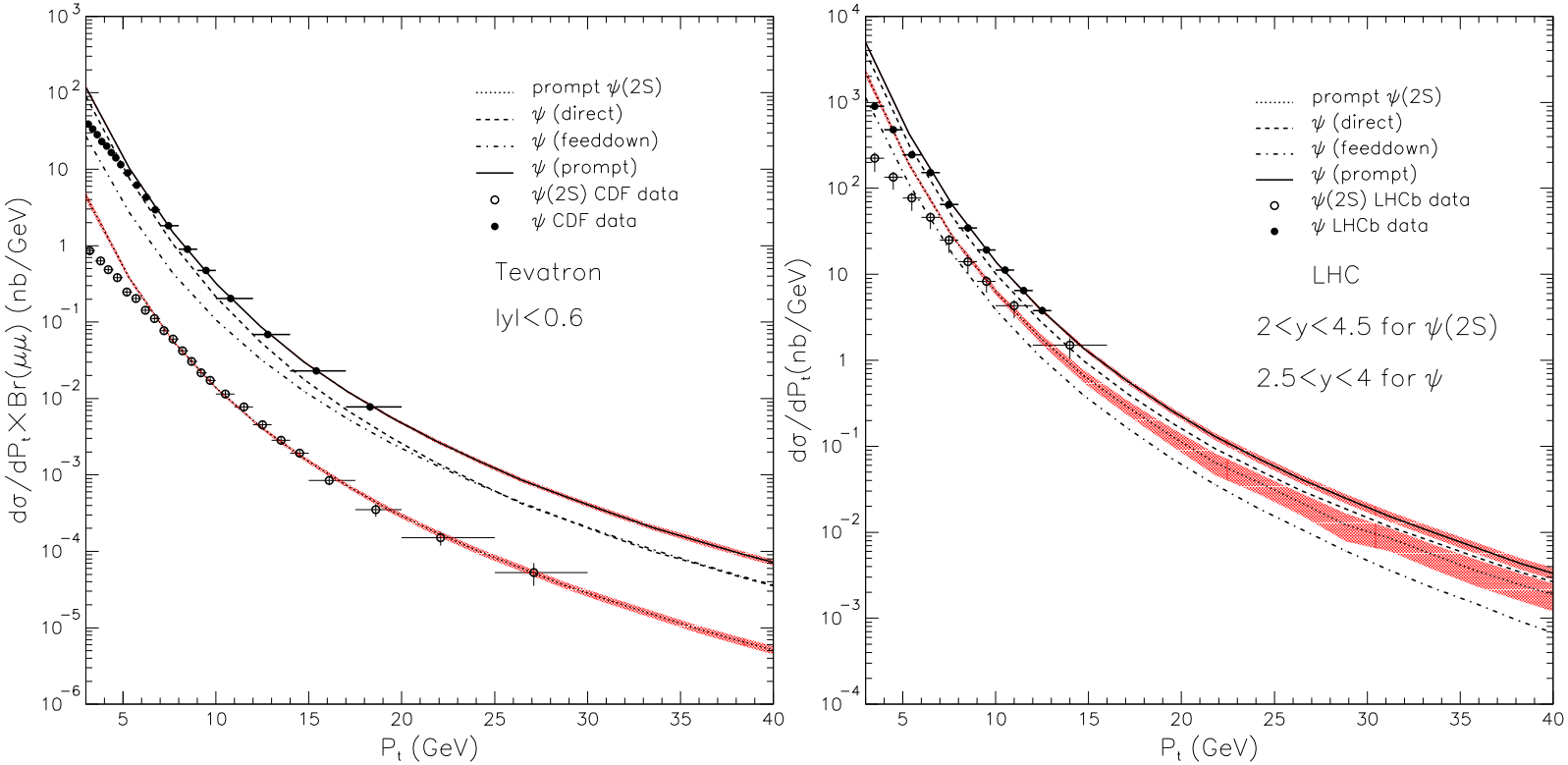


Figure: p_t distribution of prompt J/ψ and ψ' hadroproduction. The CDF and LHCb data are taken in the fitting.

PRL110, 042002, 2013, ArXiv:1205.6682, Bin Gong, Lu-Ping Wan, Jian-Xiong Wang and Hong-Fei Zhang

QCD Correction to $\psi'(^3S_1^1,\ ^1S_0^8,\ ^3S_1^8,\ ^3P_J^8)$ polarization

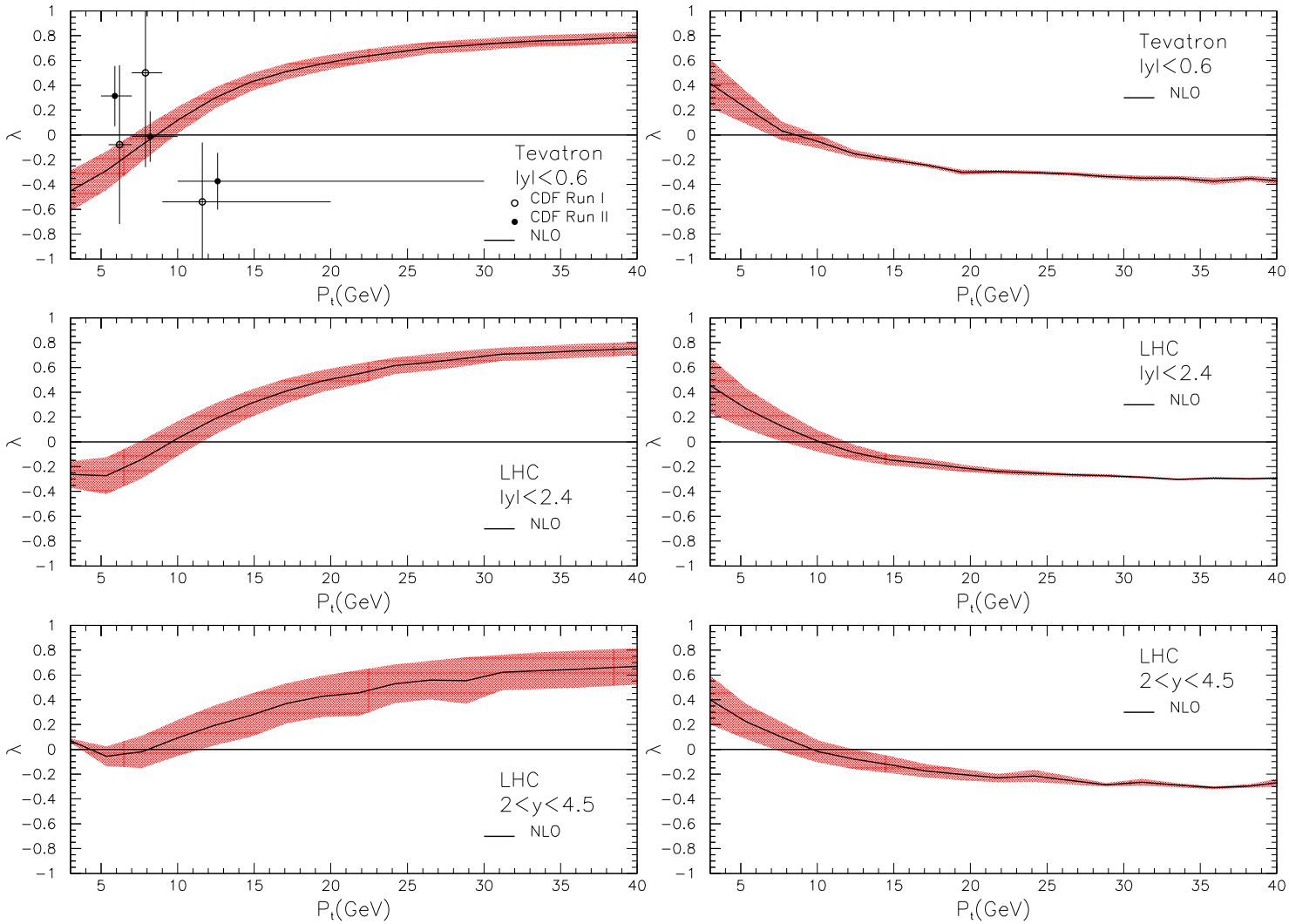


Figure: Polarization parameter λ of J/ψ' in helicity(left) and CS(right) frames.

PRL110, 042002, 2013, ArXiv:1205.6682, Bin Gong, Lu-Ping Wan, Jian-Xiong Wang and Hong-Fei Zhang

QCD Correction to $\chi_{cJ}(^3P_J^1,\ ^3S_1^8) \to J/\psi$ polarization

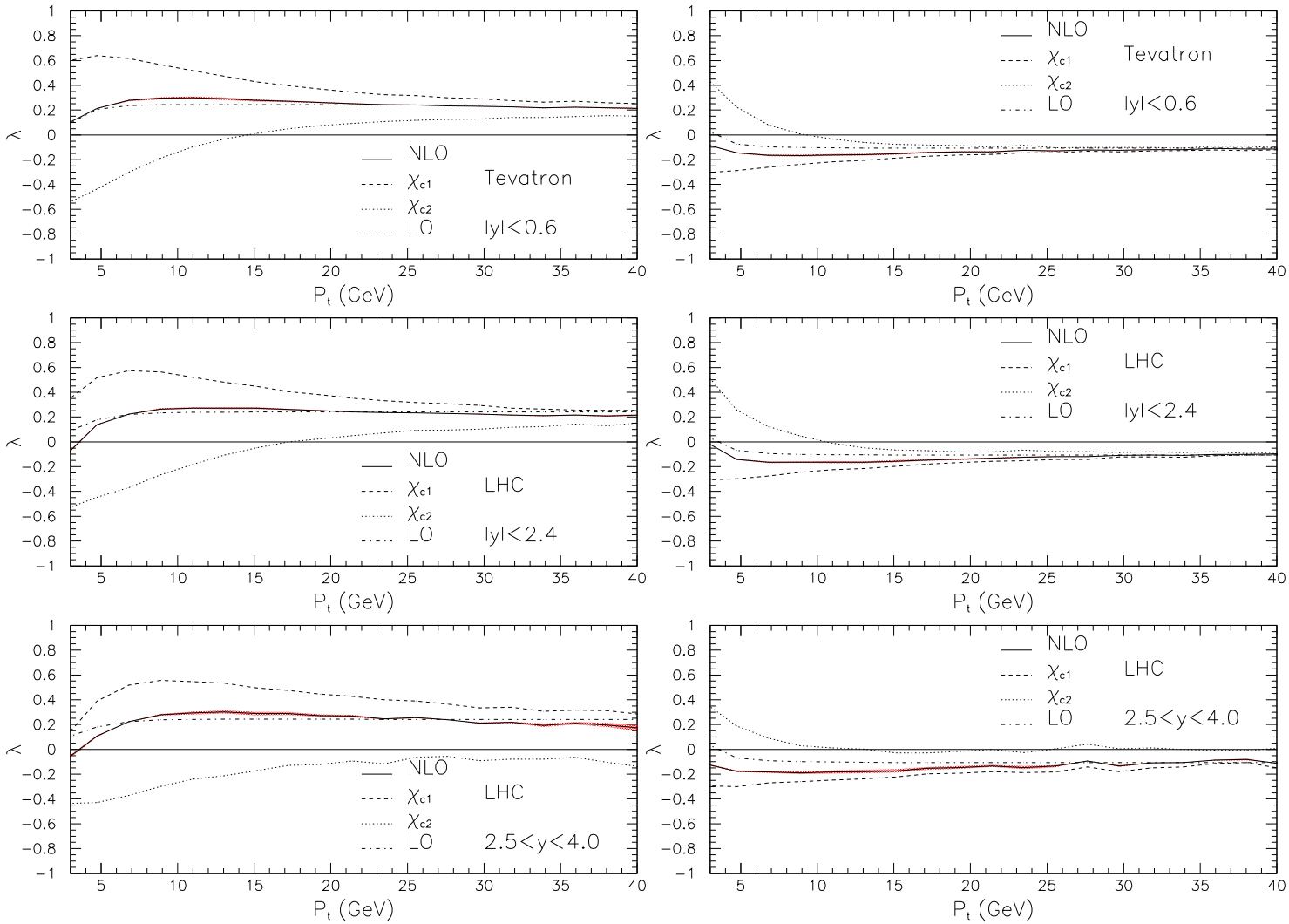


Figure: Polarization parameter λ of J/ψ in helicity(left) and CS(right) frames.

PRL1100420022013), ArXiv:1205.6682, Bin Gong, Lu-Ping Wan, Jian-Xiong Wang and Hong-Fei Zhang

QCD Correction to prompt $J/\psi(^3S_1^1,\ ^1S_0^8,\ ^3S_1^8,\ ^3P_J^8)$ polarization

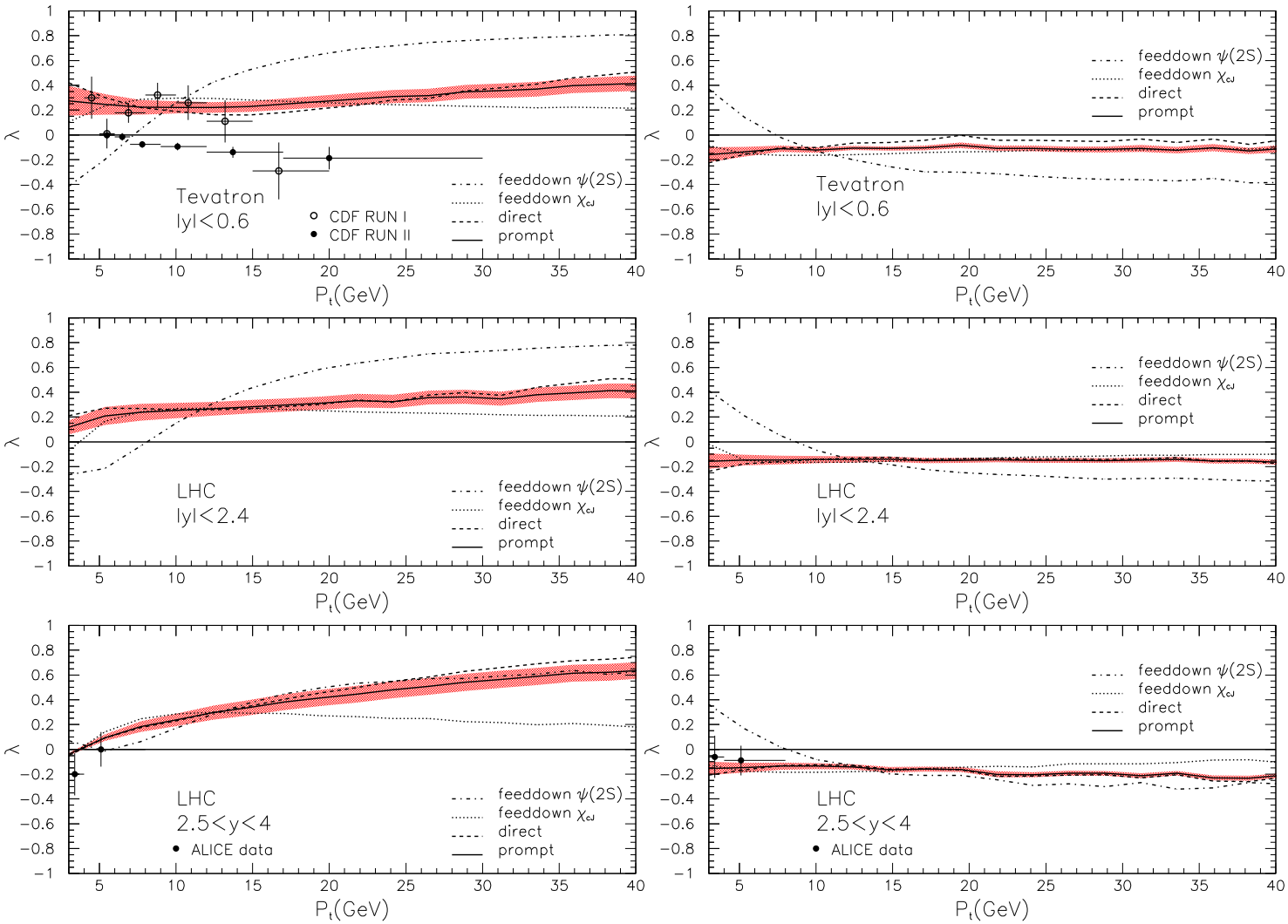
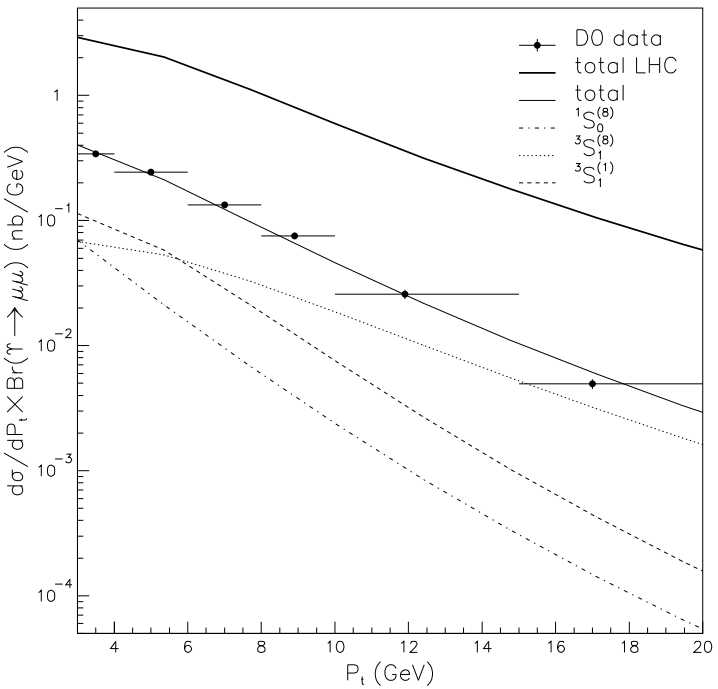
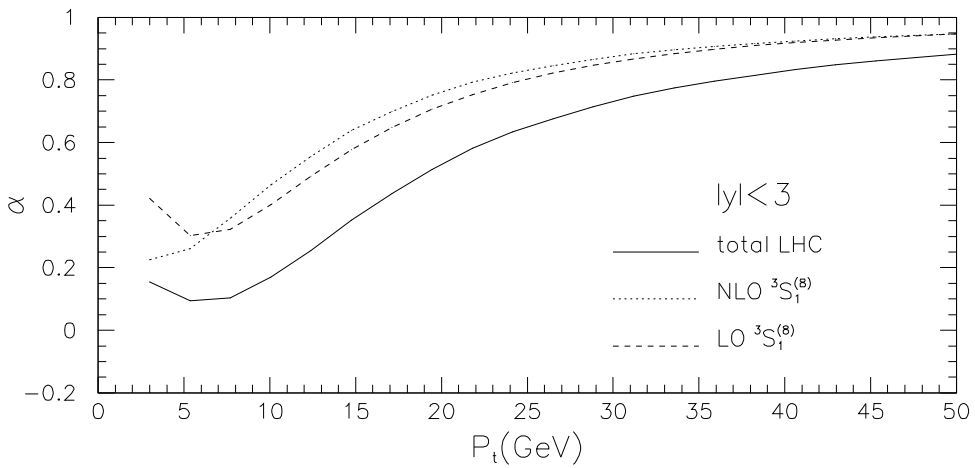


Figure: Polarization parameter λ of prompt J/ψ hadroproduction in helicity(left) and CS(right) frames.

PRL110, 042002, 2013, ArXiv:1205.6682, Bin Gong, Lu-Ping Wan, Jian-Xiong Wang and Hong-Fei Zhang

QCD Correction to color-octet $\Upsilon(^3S_1^1,\ ^1S_0^8,\ ^3S_1^8)$ production without $^3P_J^8$ contribution





PRD 83:114021,2011, B. Gong, J. X. Wang and H. F. Zhang

Summary

- For B-factories: NRQCD at NLO of α_s and v can well described J/ψ production data.
- The prediction on the polarization of prompt J/ψ hadroproduction is archived at QCD NLO, but polarization puzzle is still unclear.
- The more precision experimental measurements at LHC are needed to clarify the situation.
- More theoretical Progresses are needed on relativistic coorection, ... to solve the polarization pzzle.
- For Υ, ...

Thank you!