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

Jian-Xiong Wang
Institute of High Energy, Chinese Academy of Science, Beijing

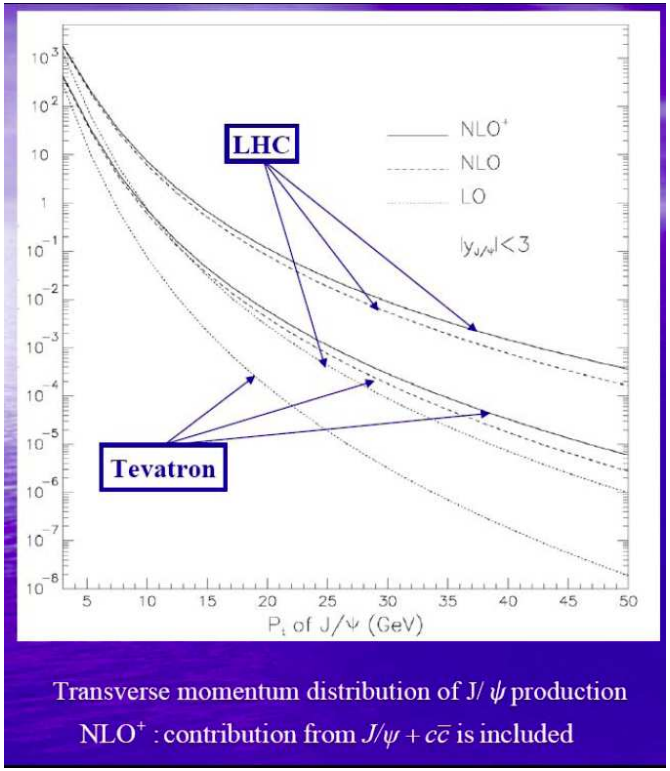
QWG2013, April 22-26, 2013, IHEP, Beijing

Based on our recent work: PRL110, 042002, 2013, ArXiv:1205.6682,
and paper for $\Upsilon(1S, 2S, 3S)$ in preparation,
by B. Gong, L. P. Wan, J. X. Wang and H. F. Zhang

Introduction

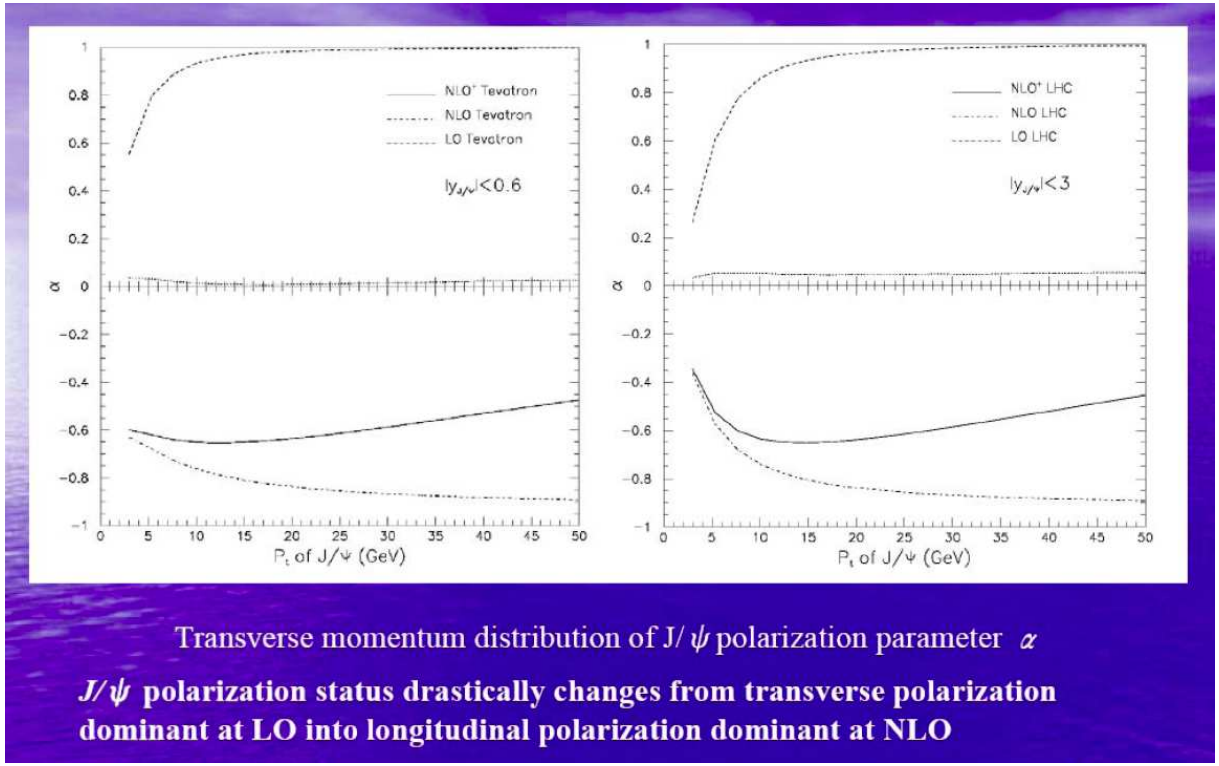
- Perturbative and non-perturbative QCD, hadronization, factorization
- Color-singlet and Color-octet mechanism was proposed based on NRQCD since b and c-quark is heavy.
- Clear signal to detect J/ψ.
- heavy quarkonium production is a good place to testify these theoretical framework.
- J/ψ photoproduction 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.

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

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)

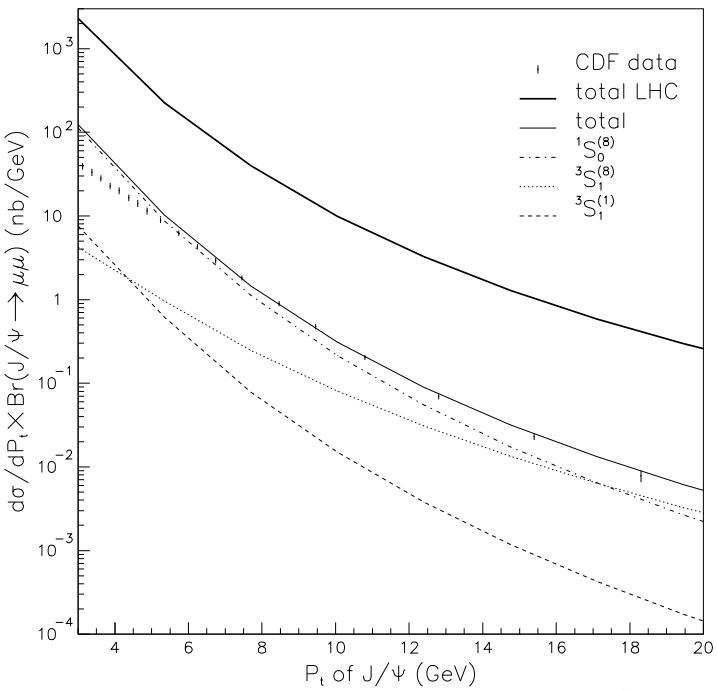
$$gg \to J/\psi\left[{}^1S_0^{(8)}, {}^3S_1^{(8)}\right]gg, \quad gg \to J/\psi\left[{}^1S_0^{(8)}, {}^3S_1^{(8)}\right]q\bar{q},$$

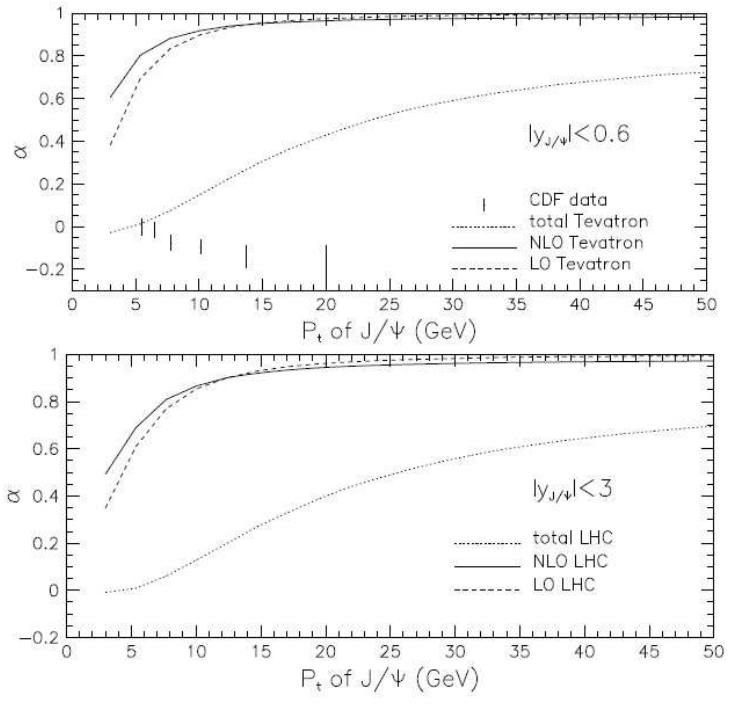
$$gq \to J/\psi\left[{}^1S_0^{(8)}, {}^3S_1^{(8)}\right]gq, \quad q\bar{q} \to J/\psi\left[{}^1S_0^{(8)}, {}^3S_1^{(8)}\right]gg,$$

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

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

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

Refer to K. T. Chao's talk and B. Kniehl's talk for
QCD Correction to prompt $J/\psi(^1S_0^8,\ ^3S_1^8,\ ^3P_J^8)$ production
PRL 106, 042002,2011, Yan-Qing Ma, Kai Wang, Kuang-Ta Chao
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
PRL 108, 172002,2012, Mathias Butenschoen, Bernd A. Kniehl

Our work is on: QCD Correction to prompt $J/\psi(^3S_1^1,\ ^1S_0^8,\ ^3S_1^8,\ ^3P_J^8)$ production and polarization

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

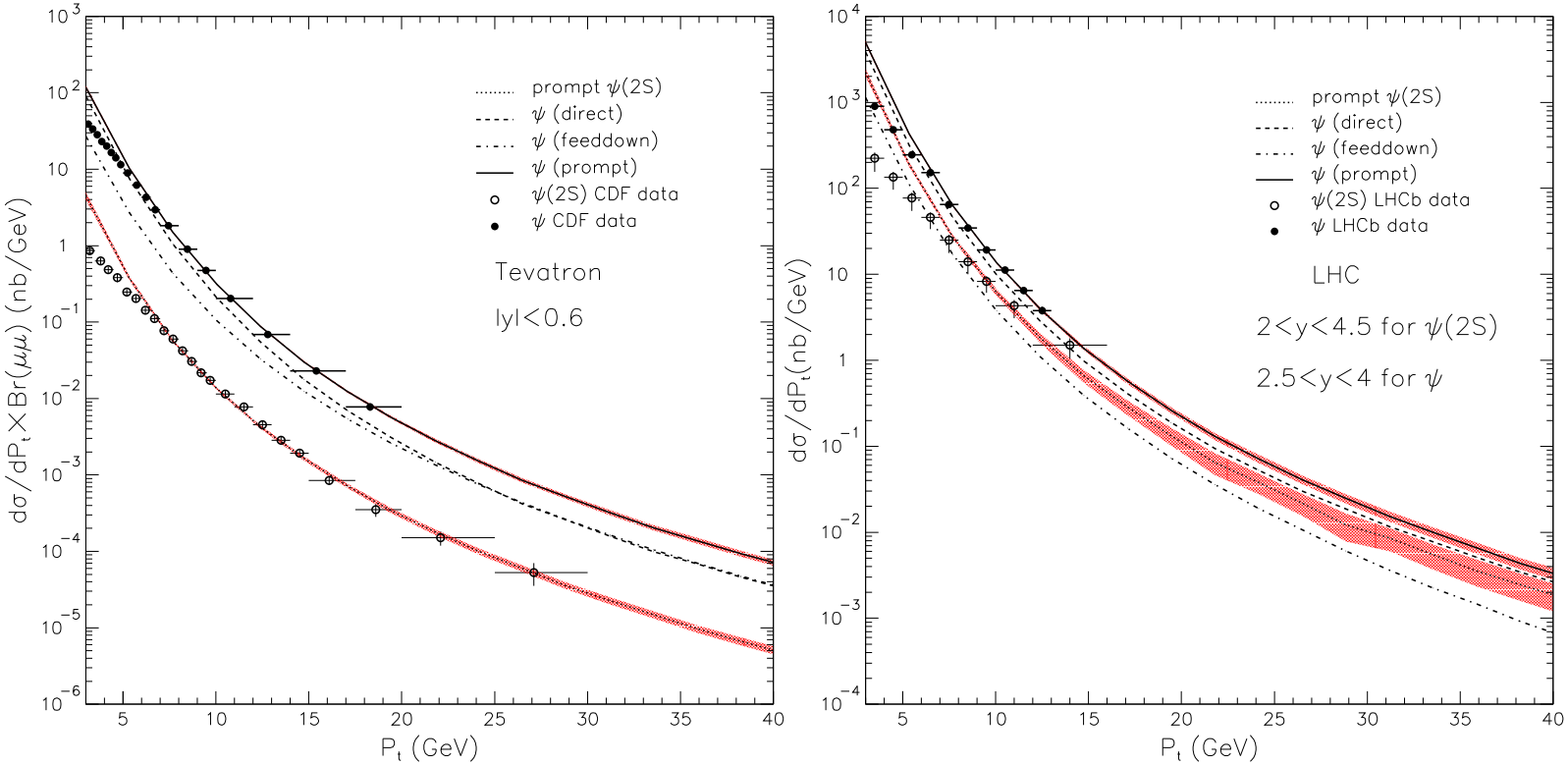


Figure: p_t distribution of prompt J/ψ and ψ' hadroproduction. The CDF and LHCb data are taken in the fitting.

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

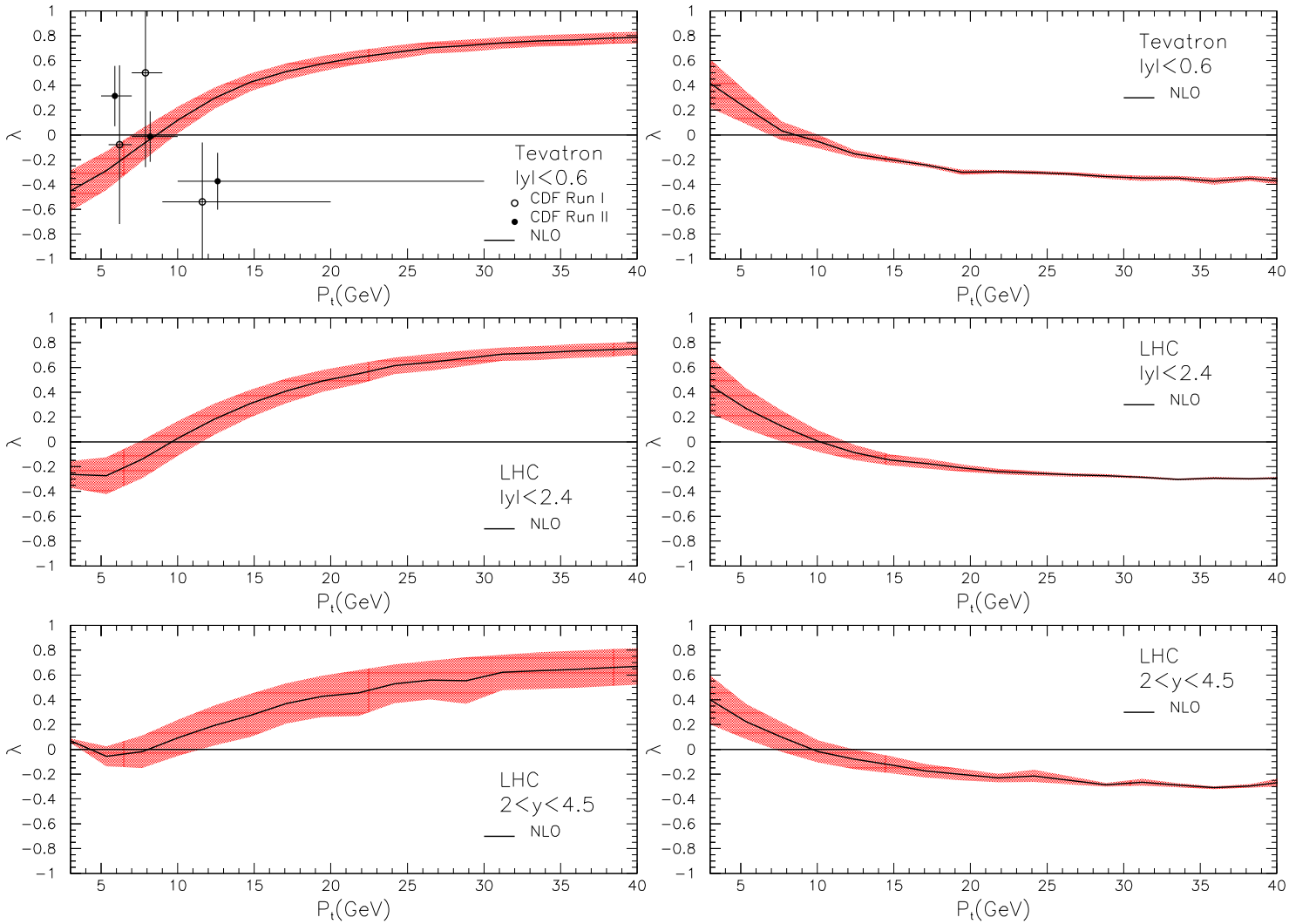


Figure: Polarization parameter λ of J/ψ' in helicity(left) and CS(right) frames.

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

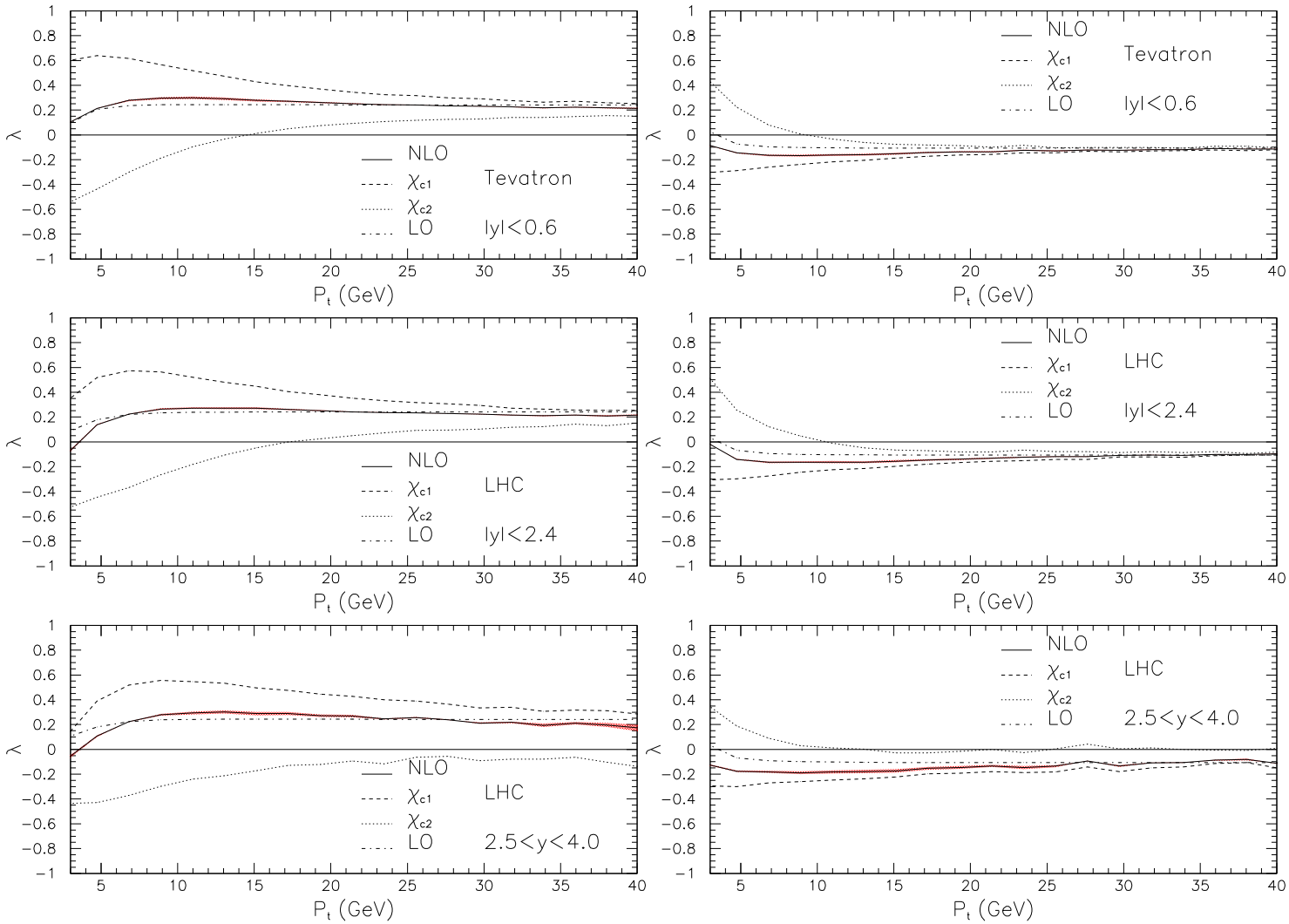


Figure: Polarization parameter λ of J/ψ in helicity(left) and CS(right) frames.

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

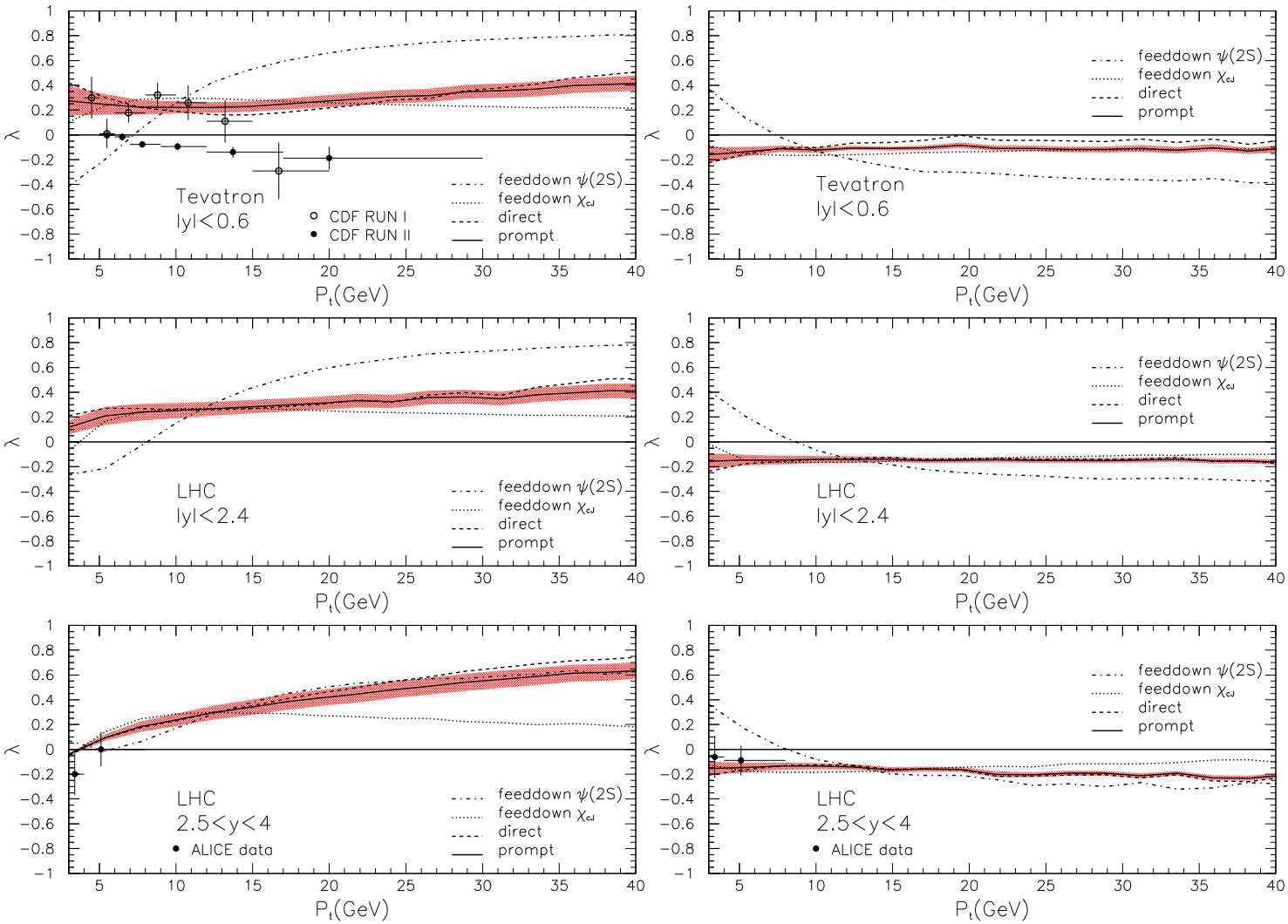
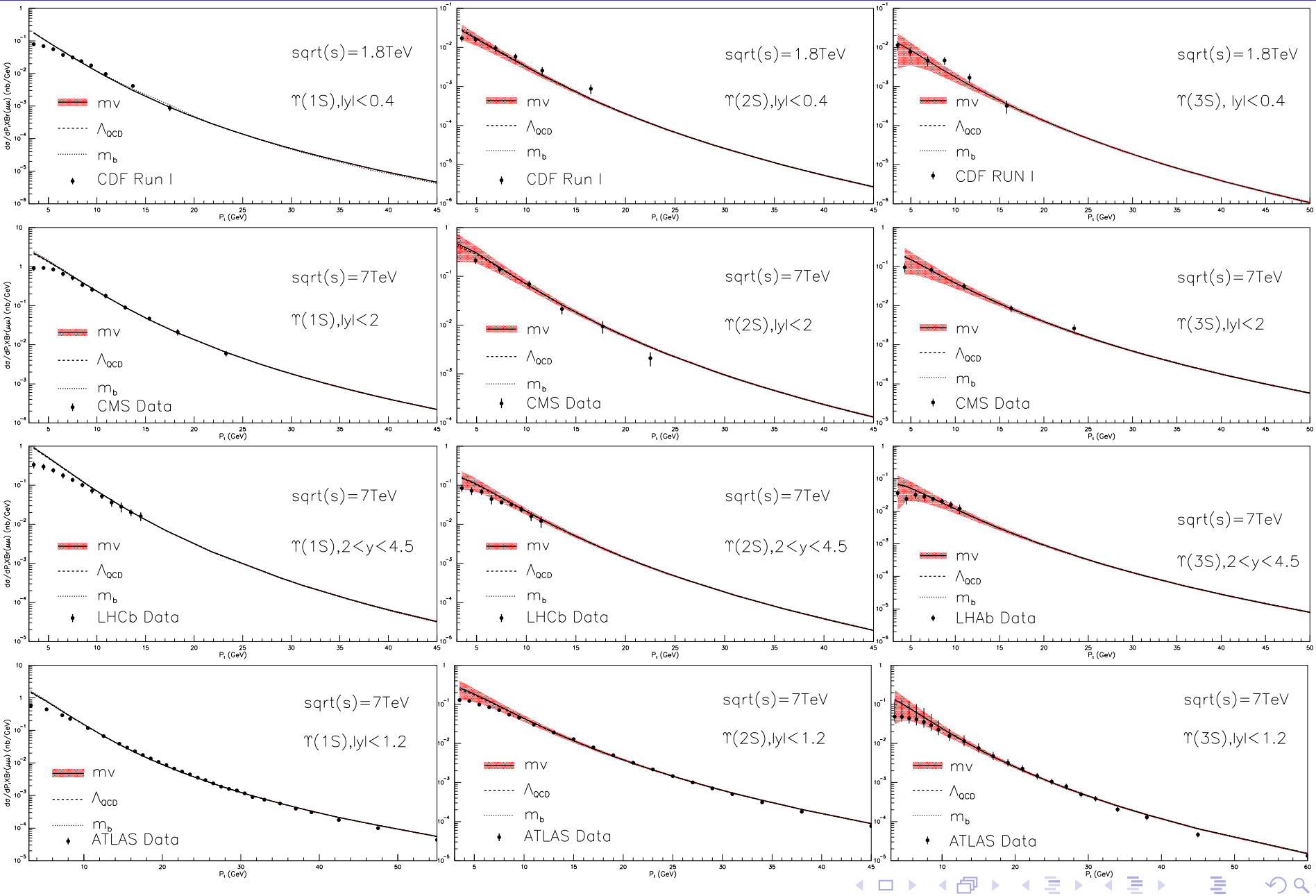


Figure: Polarization parameter λ of prompt J/ψ hadroproduction in helicity(left) and CS(right) frames.

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

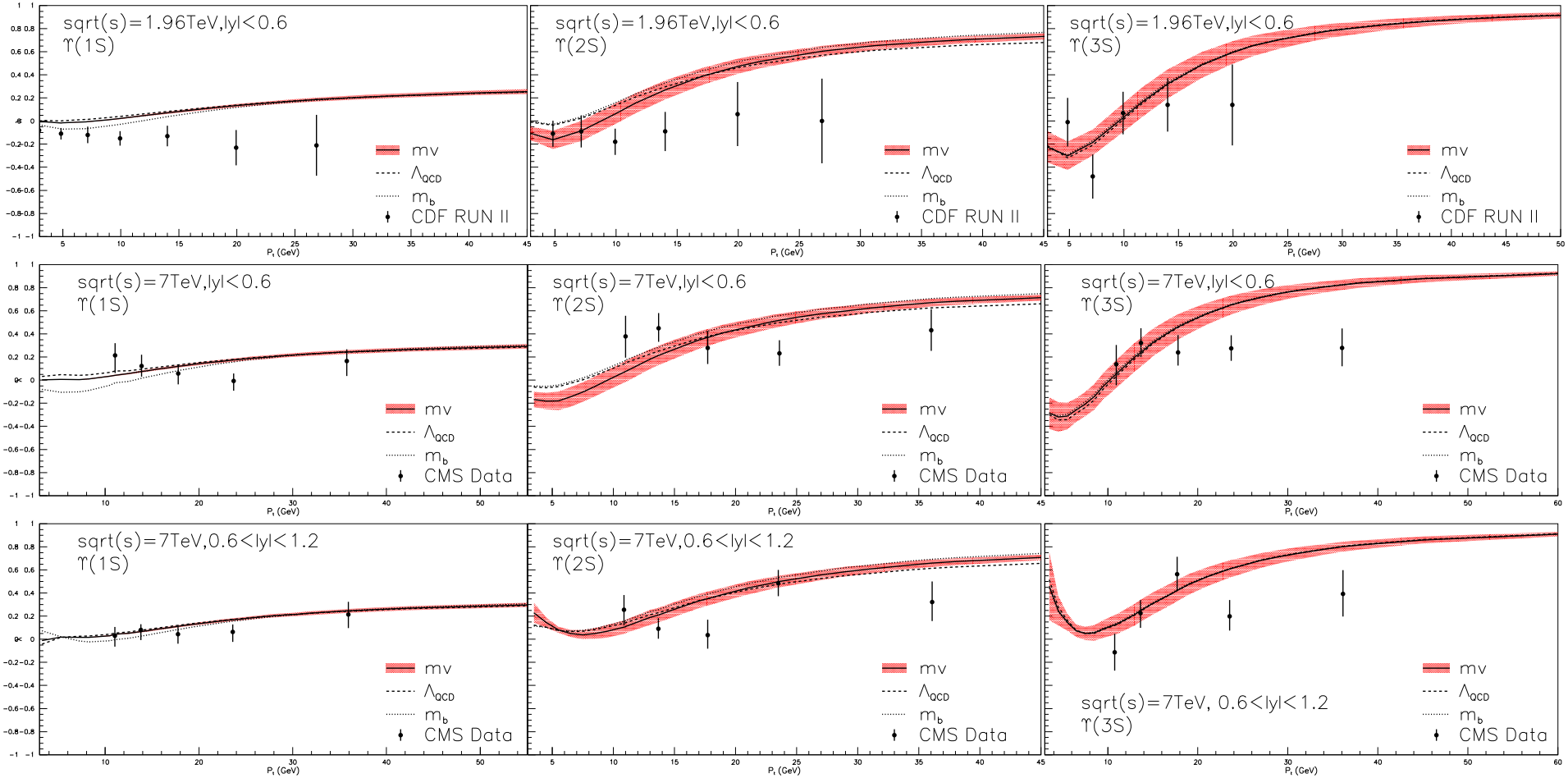
- recent measurement by the CMS collaboration at the LHC
- $m_b \sim 3m_c$ measn that both of the perturbative QCD expansion and nonrelativistic expansion are better than charonium case.
- logarithm term $ln(m_Q/p_t)$ plays important role later, i.e. $p_t = 20$ GeV for $J/\psi \sim p_t = 3x20$ GeV for Υ.
- Can we expect better desciption of experimental measurement on $\Upsilon(1S, 2S, 3S)$ by NLO NRQCD calculation?
- It is very interesting to the comparision between theoretical calculation and the experimental measurement!

QCD Correction to $\Upsilon(1S, 2S, 3S)$ production



Paper in preparation, by Bin Gong, Lu-Ping Wan, Jian-Xiong Wang and Hong-Fei Zhang

QCD Correction to $\Upsilon(1S, 2S, 3S)$ polarization



Paper in preparation, by Bin Gong, Lu-Ping Wan, Jian-Xiong Wang and Hong-Fei Zhang

Figure: Polarization parameter λ of prompt $\Upsilon(1S, 2S, 3S)$ hadroproduction in helicity frame

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, the transverse momentum distributions of $\Upsilon(1S, 2S, 3S)$ production represent the measurements very well, and the polarizations of $\Upsilon(1S, 2S, 3S)$ are in (good, not good, bad) agreement with recent CMS measurement, but in conflict with the CDF RUN II measurement.

Thank you!