Cross section and polarization of prompt J/ψ in proton-proton collisions at RHIC

PHYSICAL REVIEW D81, 014020 (2010)
arXiv:0911.2113 [hep-ph]

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International Workshop on Heavy Quarkonium 2010
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Outline

Polarization of J/ψ at the Fermilab Tevatron

Polarization of J/ψ at RHIC

Summary

Polarization of prompt J/ψ at the Tevatron

J/ψ production channels

channels	$^3S_1^{(1)}$	$^3S_1^{(8)}$	$^1S_0^{(8)}$	$^3P_J^{(8)}$
velocity scaling	1	v^4	v^3	v^4
$d\sigma/dp_T$	$\propto \alpha_s^3 p_T^{-8}$	$\propto \alpha_s^3 p_T^{-4}$	$\propto \alpha_s^3 p_T^{-6}$	
matrix elements	fit to EM decay	fit to cross section at large pT	fit to cross section	

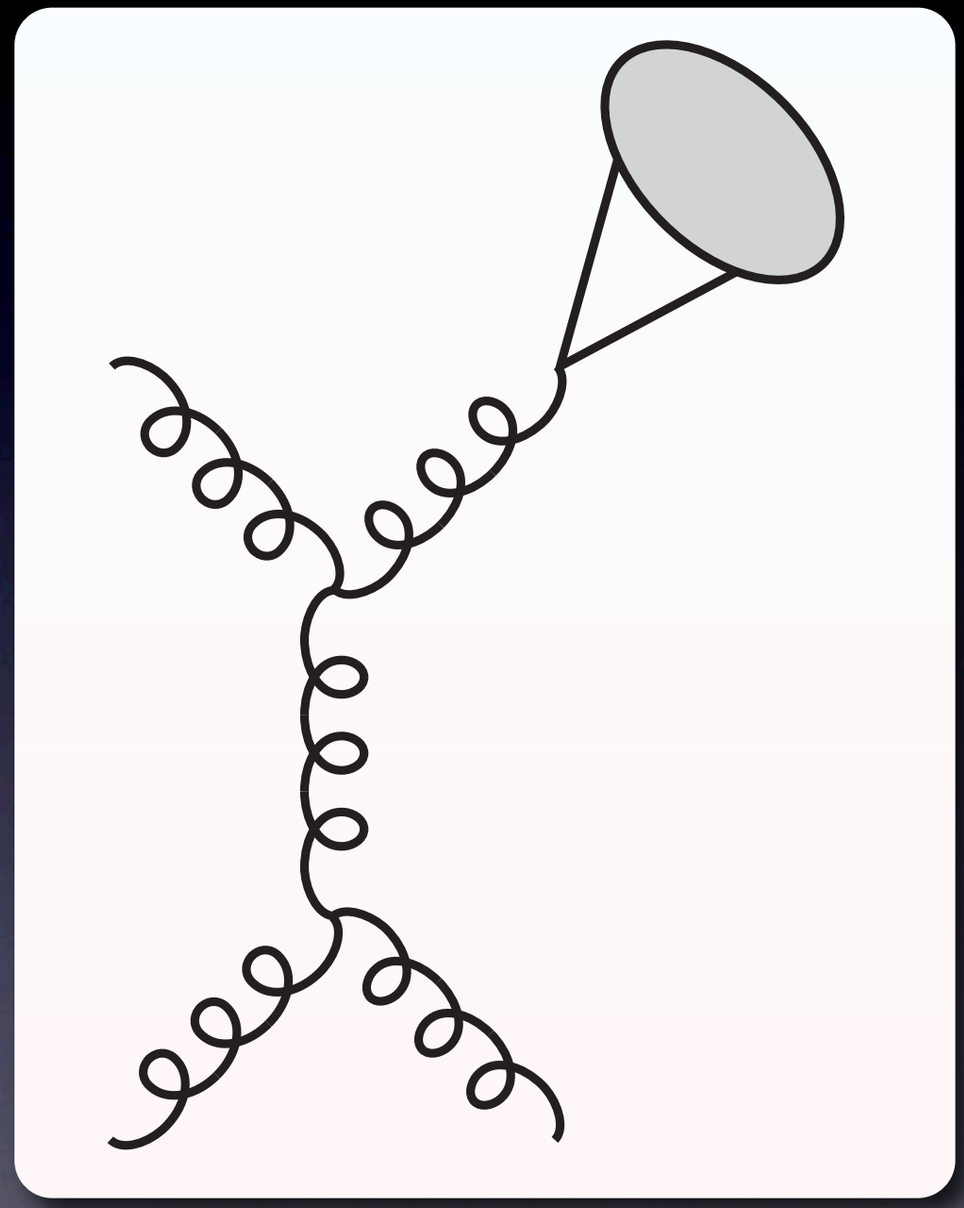
- Color-singlet (CS) gluon fusion disagrees in size and shape.
- CS gluon fragmentation describes shape only.

Braaten and Yuan, PRL71, 1673 (1993)

- Color-octet (CO) gluon fragmentation describes size and shape by fitting $^3S_1^{(8)}$ matrix element (ME) to large-p_T data.

Braaten and Fleming, PRL74, 3327 (1995)

- At large p_T, color-octet gluon fragmentation dominates.
- At large p_T, the gluon is nearly on mass shell, and, so, is transversely polarized.
- Heavy-quark spin symmetry makes the polarization of J/ψ in $g^* \to c\bar{c}[^3S_1^{(8)}] \to J/\psi + X$ transverse.
- Independent test of color-octet gluon fragmentation.



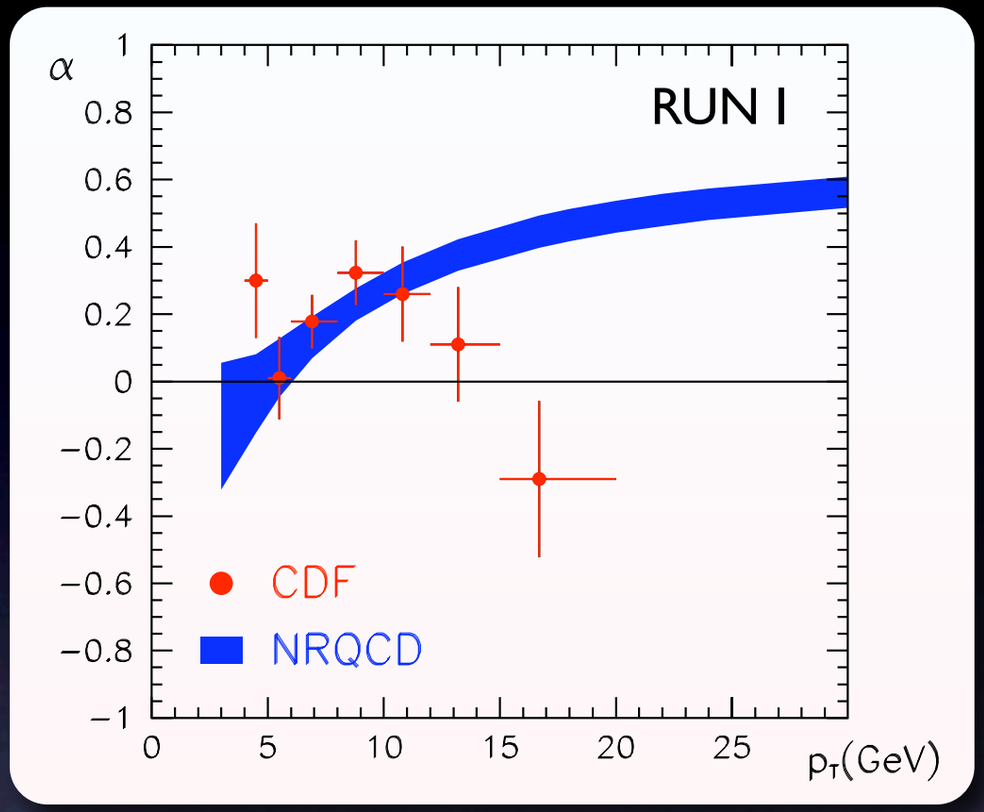
Polarization parameter α

- The polarization of J/ψ can be measured from the angular distribution of the dilepton produced from the leptonic decay of J/ψ.
- $\frac{d\sigma}{d\cos\theta} \propto 1 + \alpha\cos^2\theta$

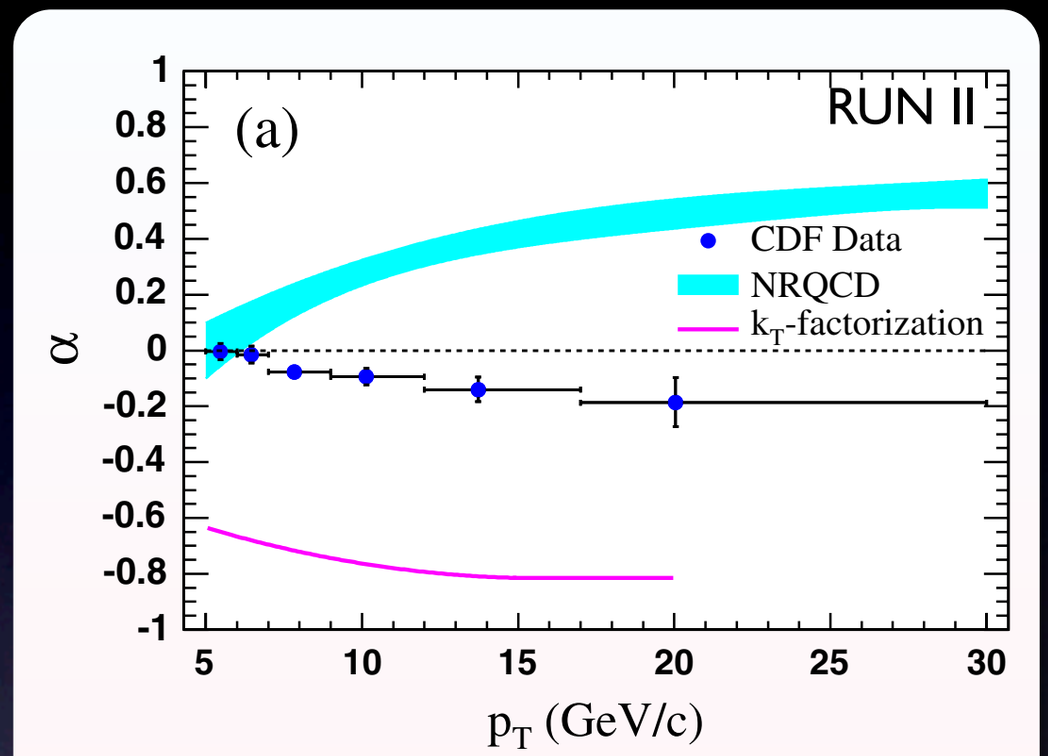
$\alpha = +1$ is completely transverse
$\alpha = 0$ is unpolarized
$\alpha = -1$ is completely longitudinal

$$\alpha = \frac{\sigma_T - 2\sigma_L}{\sigma_T + 2\sigma_L} = \frac{\sigma - 3\sigma_L}{\sigma + \sigma_L}$$

Polarization of prompt J/ψ at the Tevatron



CDF, PRL85, 2886 (2000)

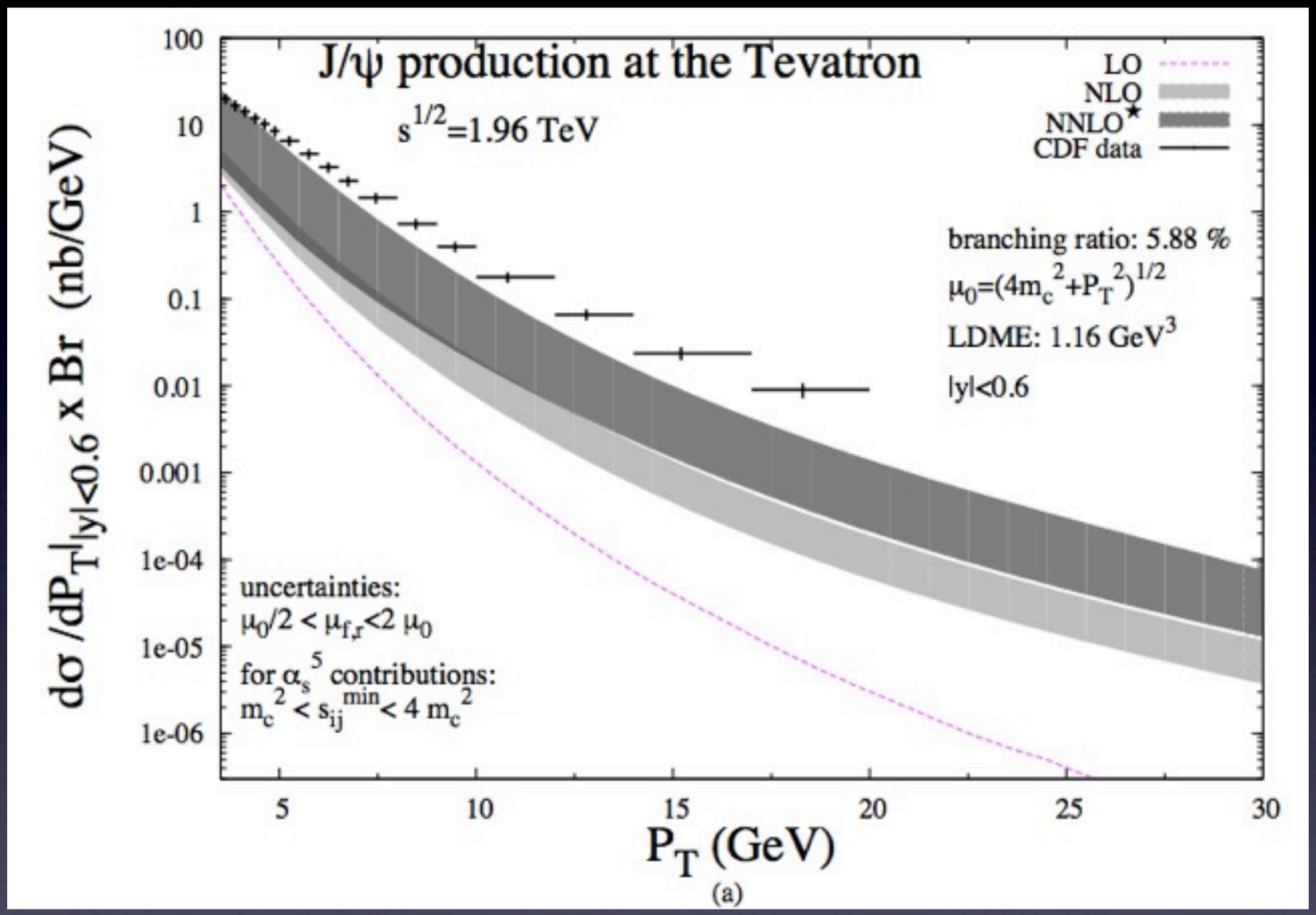


CDF, PRL99, 132001 (2007)

Braaten, Kniehl, and Lee, PRD62, 094005 (2000);
Kniehl and Lee, PRD62, 114027 (2000)

- NRQCD predicts transverse J/ψ at large p_T
- RUN I : Disagreed only at the highest p_T bin
- RUN II : Disagrees with both RUN I and NRQCD
- Problem still open

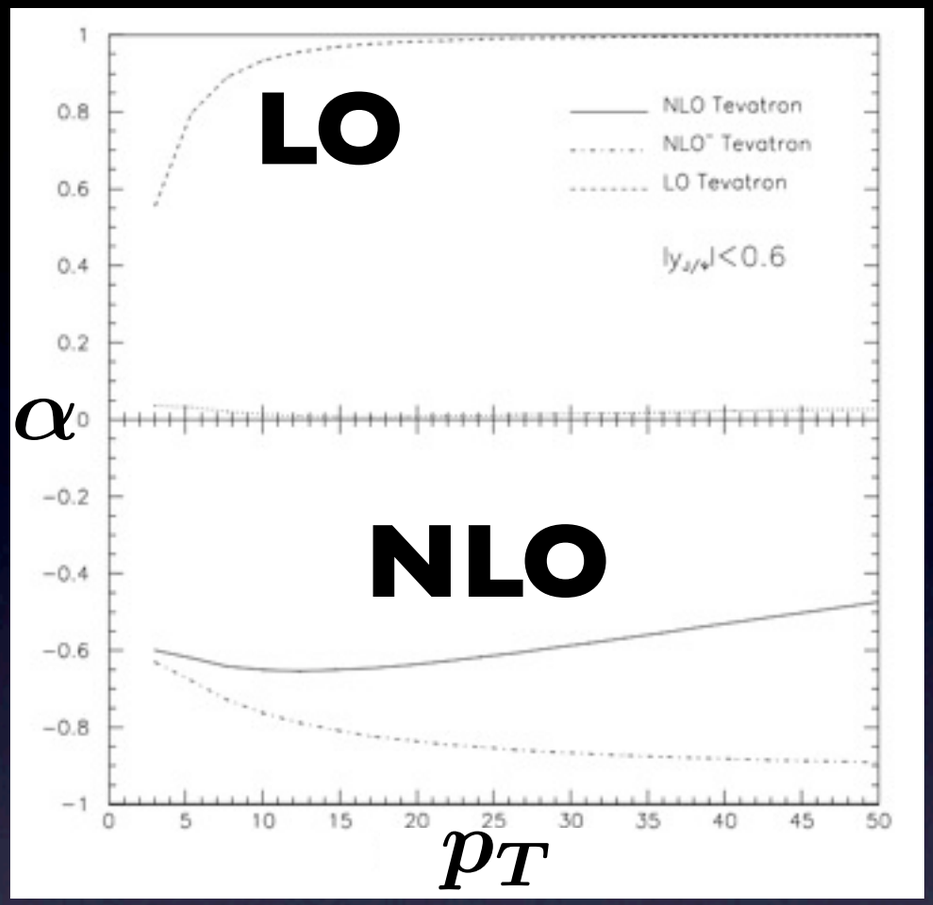
Radiative corrections to CS Model



- CS with NLO and partial N^2LO still underestimates the data

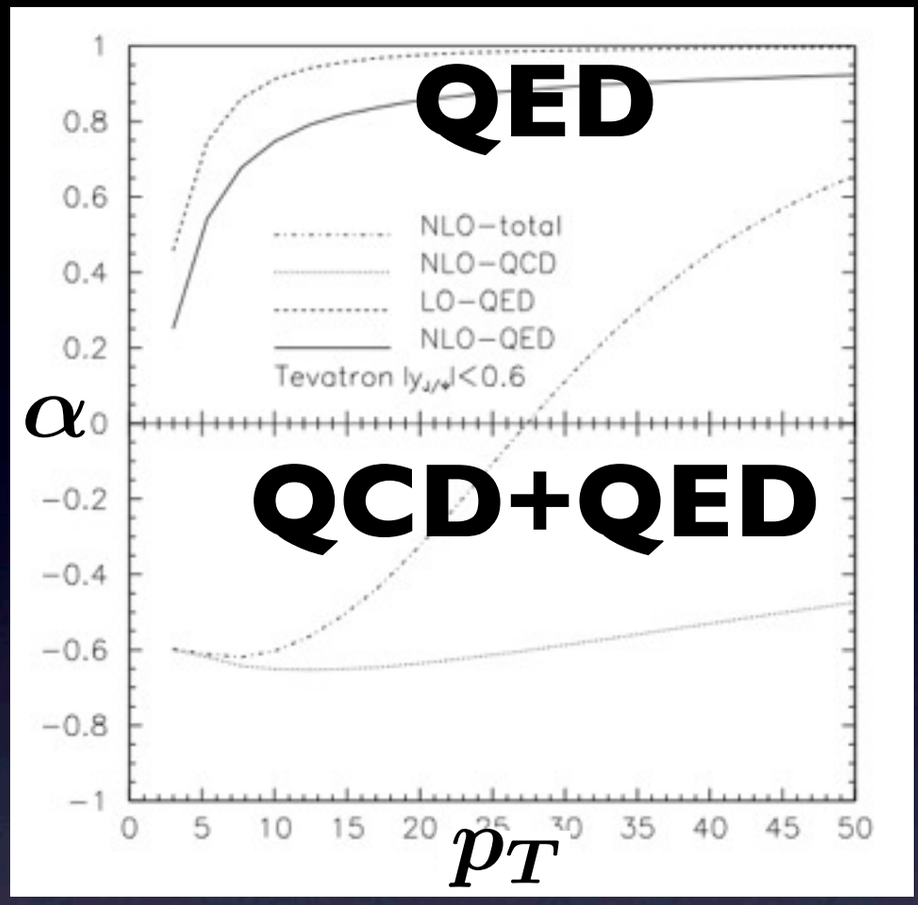
P. Artoisenet, Proc. Sci., CONFINEMENT8 (2008) 098

Radiative corrections to CS Model



Gong and Wang, PRL100, 232001 (2008);
Gong and Wang, PRD78,074011 (2008)

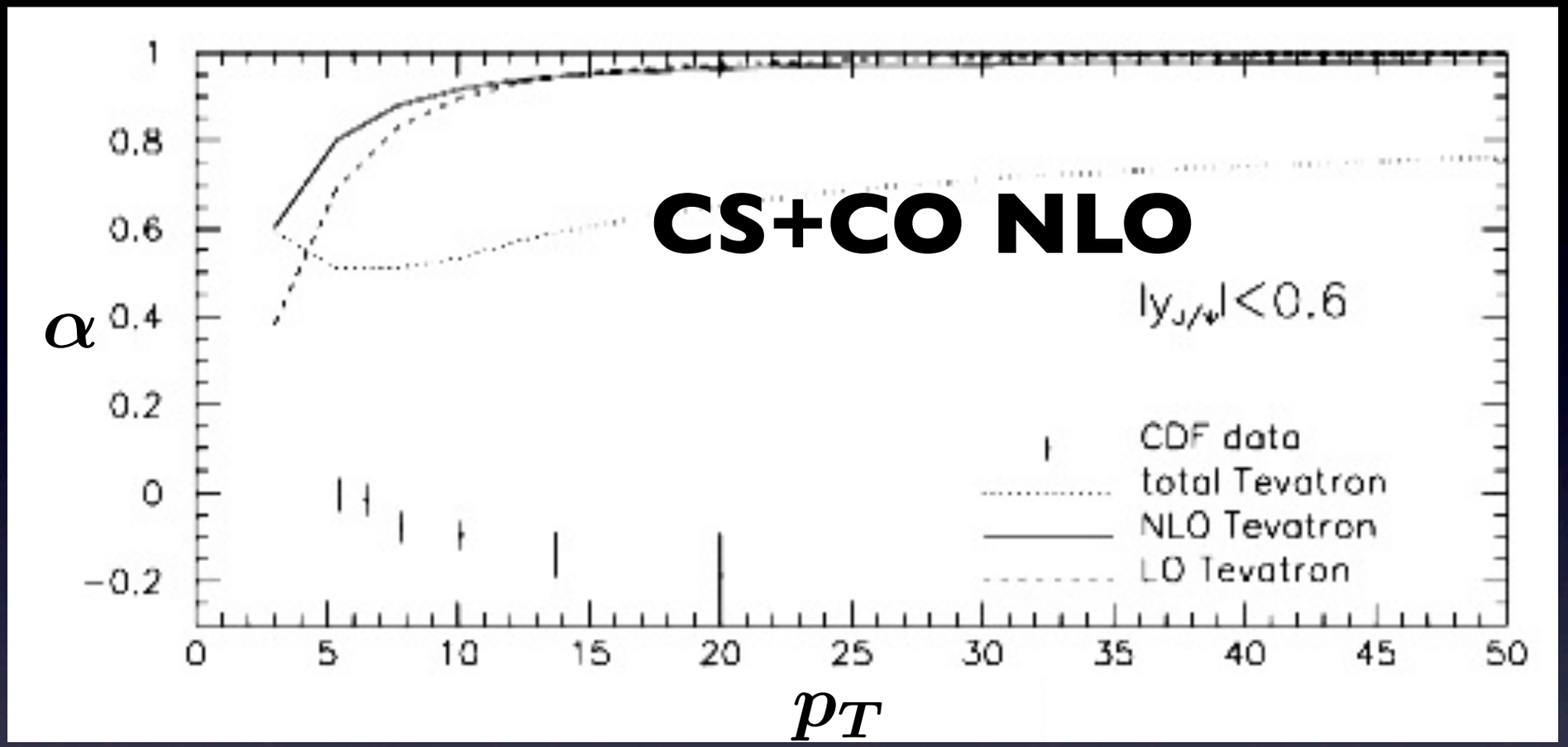
- LO : strong transverse polarization
- NLO : longitudinal over the whole p_T



He, Li, and Wang, arXiv:0904.1477
See Zhi-Guo He's talk yesterday

- Photon fragmentation (QED) : transverse polarization

Radiative corrections to CO

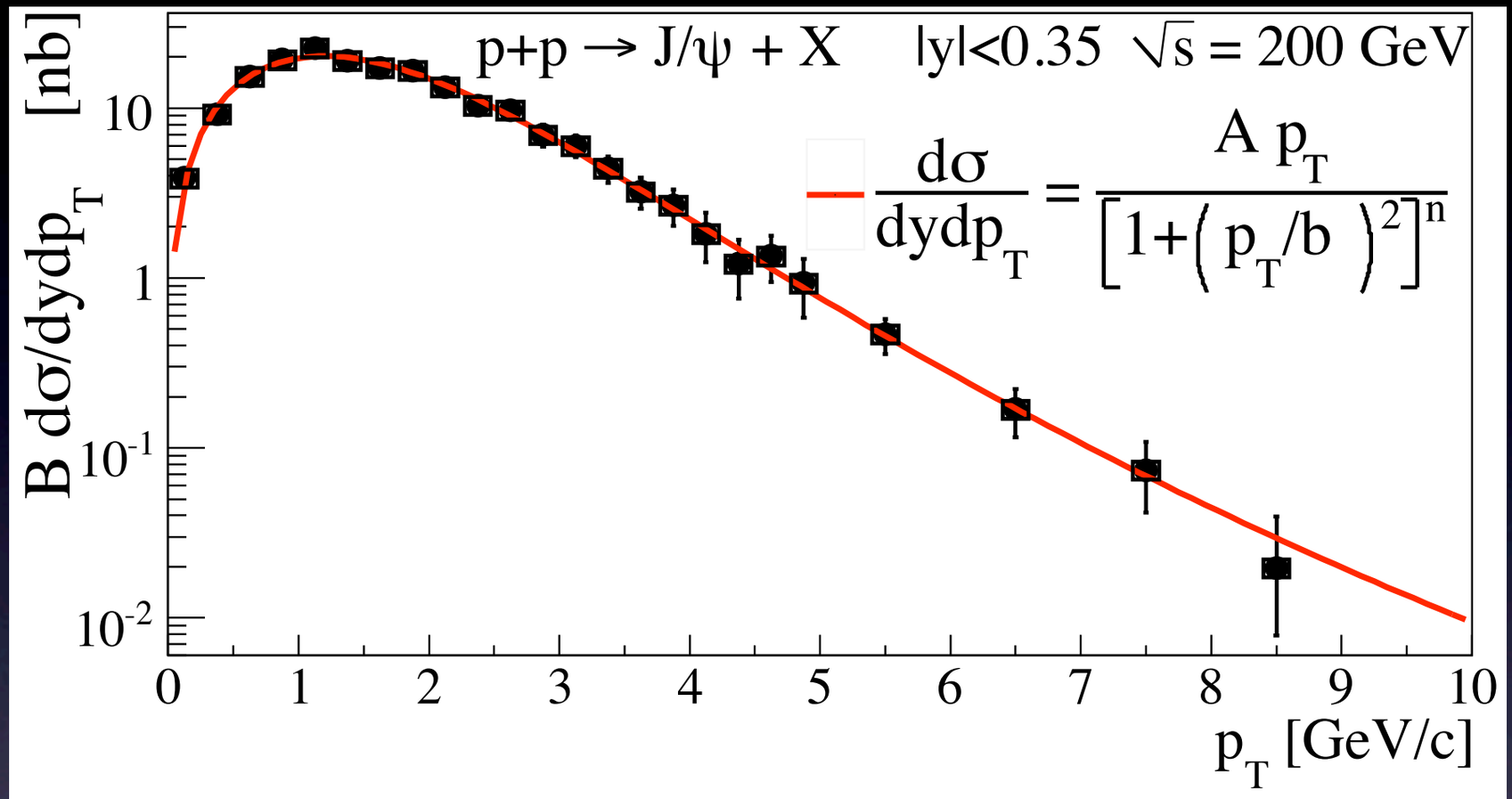


Gong, Li, and Wang, PLB673, 197(2009)

- After including CO contributions at NLO, J/ψ becomes transverse again, which disagrees with CDF RUN II data

Polarization of prompt J/ψ at RHIC

p_T distribution of inclusive J/ψ at RHIC



PHENIX, 2009
(arXiv:0912.2082)

See Todd Kempel's talk this morning

- Polarization parameter α was also measured
- NRQCD prediction is necessary
- To make a fair comparison with Tevatron data, we provide with a prediction consistent with Tevatron experiment

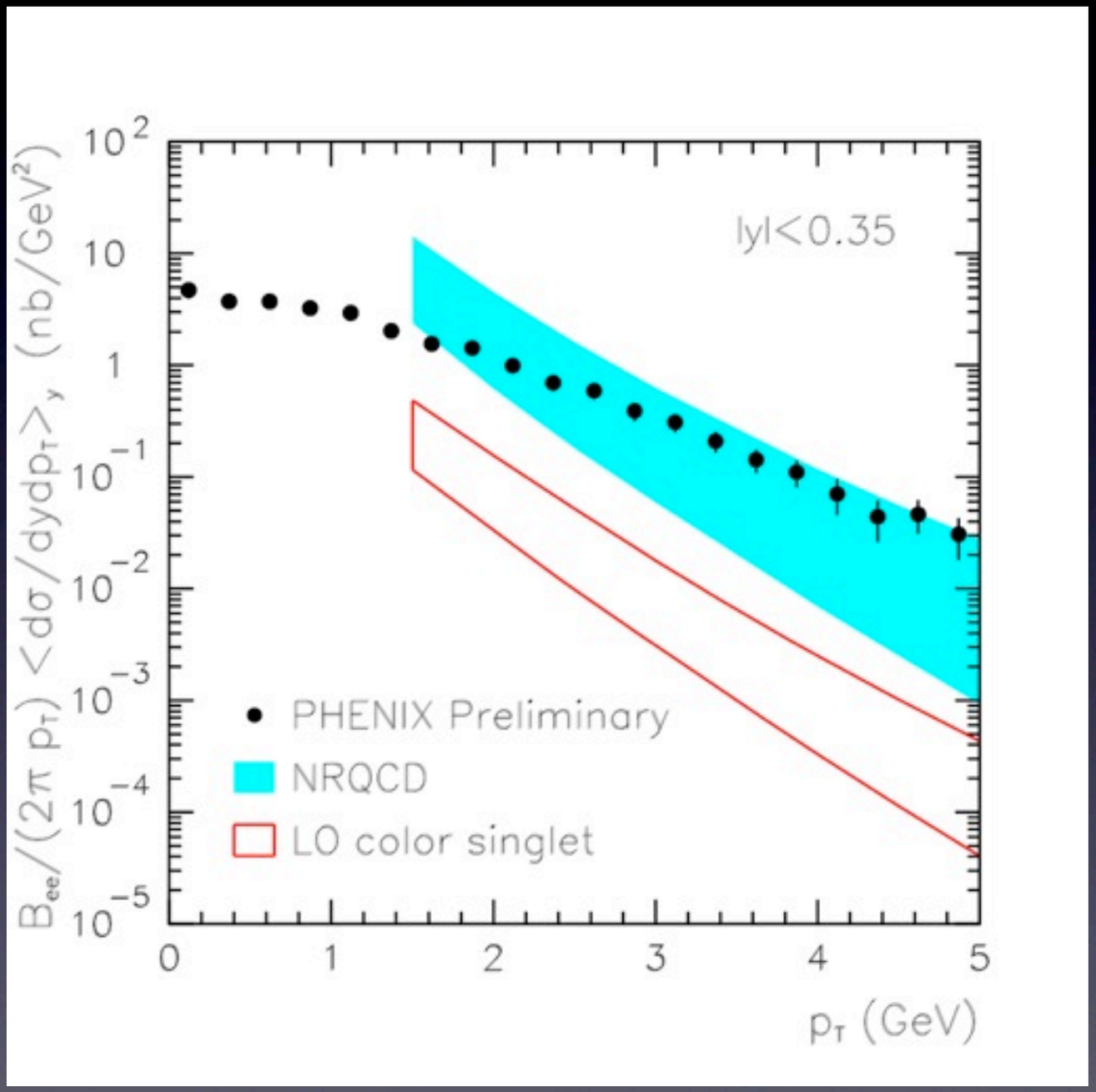
Strategy of calculation

- the same strategy employed in Tevatron case
- parton process : LO, $ij \rightarrow c\bar{c} + k$ with $i, j = g, q, \bar{q}$
- PDF : MRST98LO and CTEQ5L
- Same ME used in Tevatron case

- J/ψ from B decay only ~4%
  - inclusive cross section essentially same as the prompt one

Oda, J.Phys.G35, 104134 (2008) (PHENIX Collaboration)

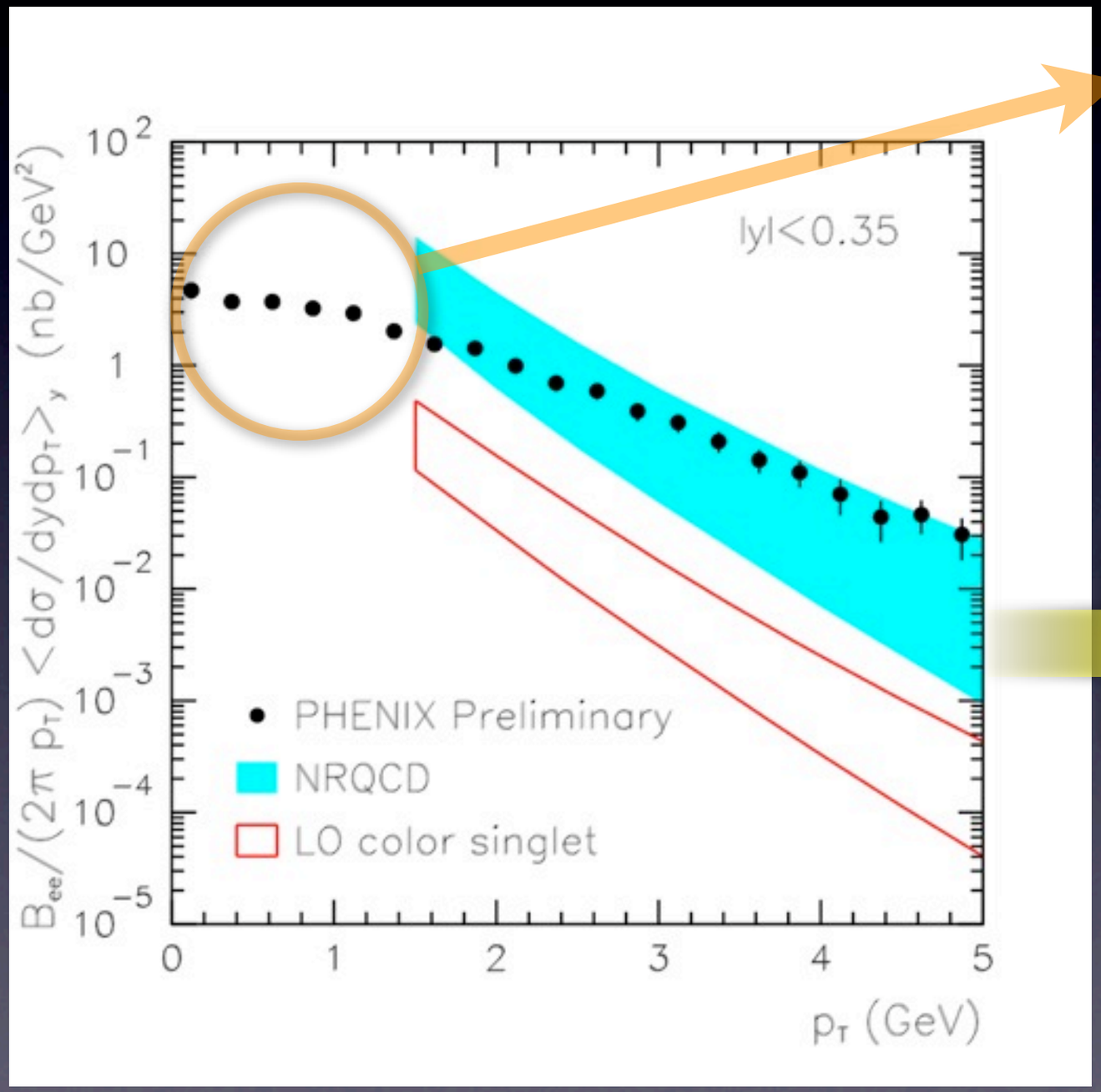
p_T distribution of prompt J/ψ at RHIC



- NRQCD agrees with data.
- Errors mainly from scale dependence.
- LO CS severely underestimates.
- Cross section consistent with Cooper, Liu, and Nayak [PRL93, 171801 (2004)]

Chung, Yu, Kim, and Lee, PRD81, 014020 (2010)

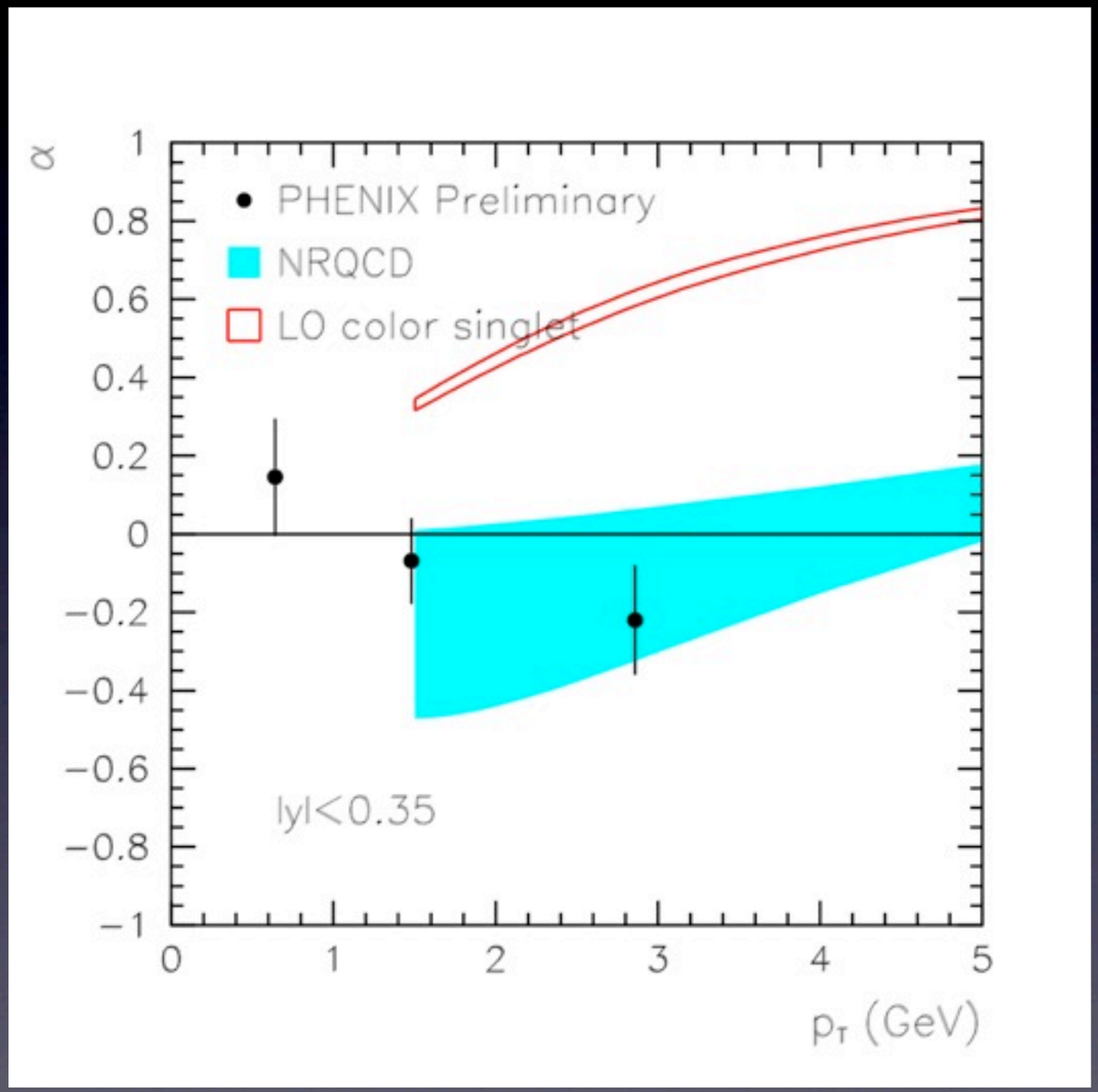
p_T distribution of prompt J/ψ at RHIC



- For lower p_T, order-α_s^2 $2 \rightarrow 1$ processes, its NLO contribution, and soft-gluon emissions must be taken into account.

For higher p_T, fragmentation evolution using DGLAP equation must be considered.

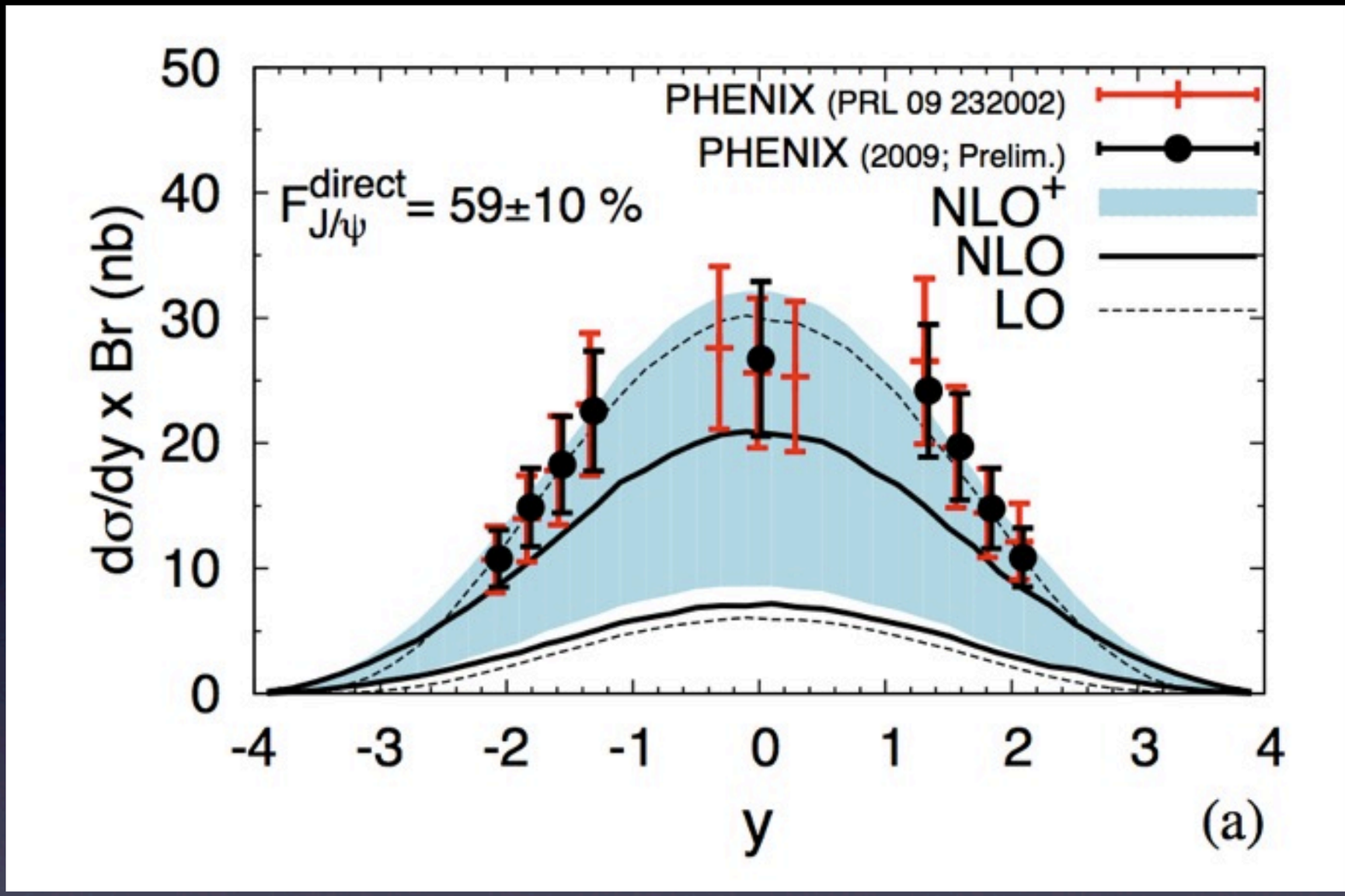
Polarization of prompt J/ψ at RHIC



- NRQCD agrees with data.
- LO CS does not.
- Dominant source of errors : Large uncertainties in ${}^1S_0^{(8)}$ and ${}^3P_J^{(8)}$ ME

Chung, Yu, Kim, and Lee, PRD81, 014020 (2010)

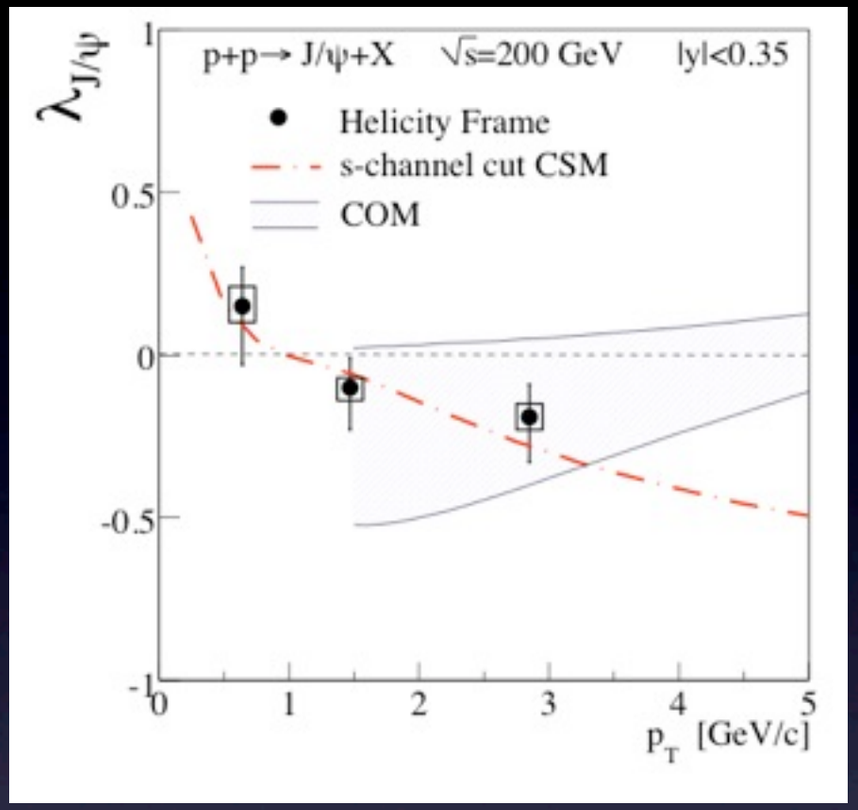
Rapidity distribution of J/ψ at RHIC



Brodsky and Lansberg, PRD81, 051502 (2010)

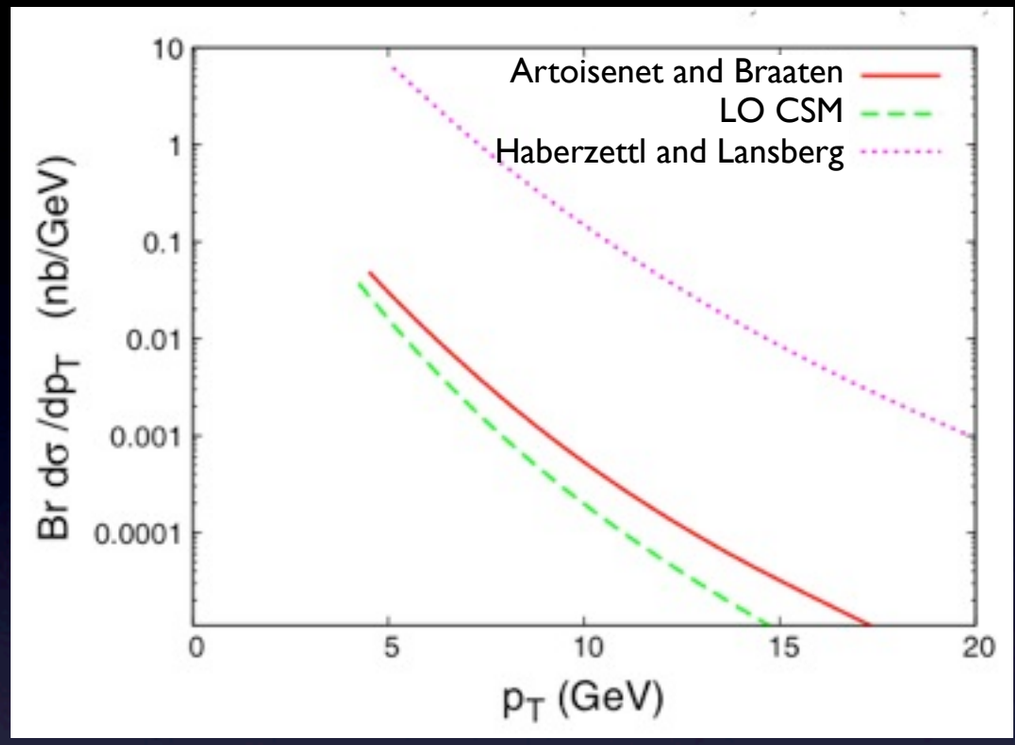
- CSM agrees in rapidity distribution of cross section
- Integrated over p_T - cannot be compared with our results

S-channel cut CSM predictions



PHENIX, 2009 (arXiv:0912.2082)
Haberzettl and Lansberg,
PRL100, 032006 (2009)

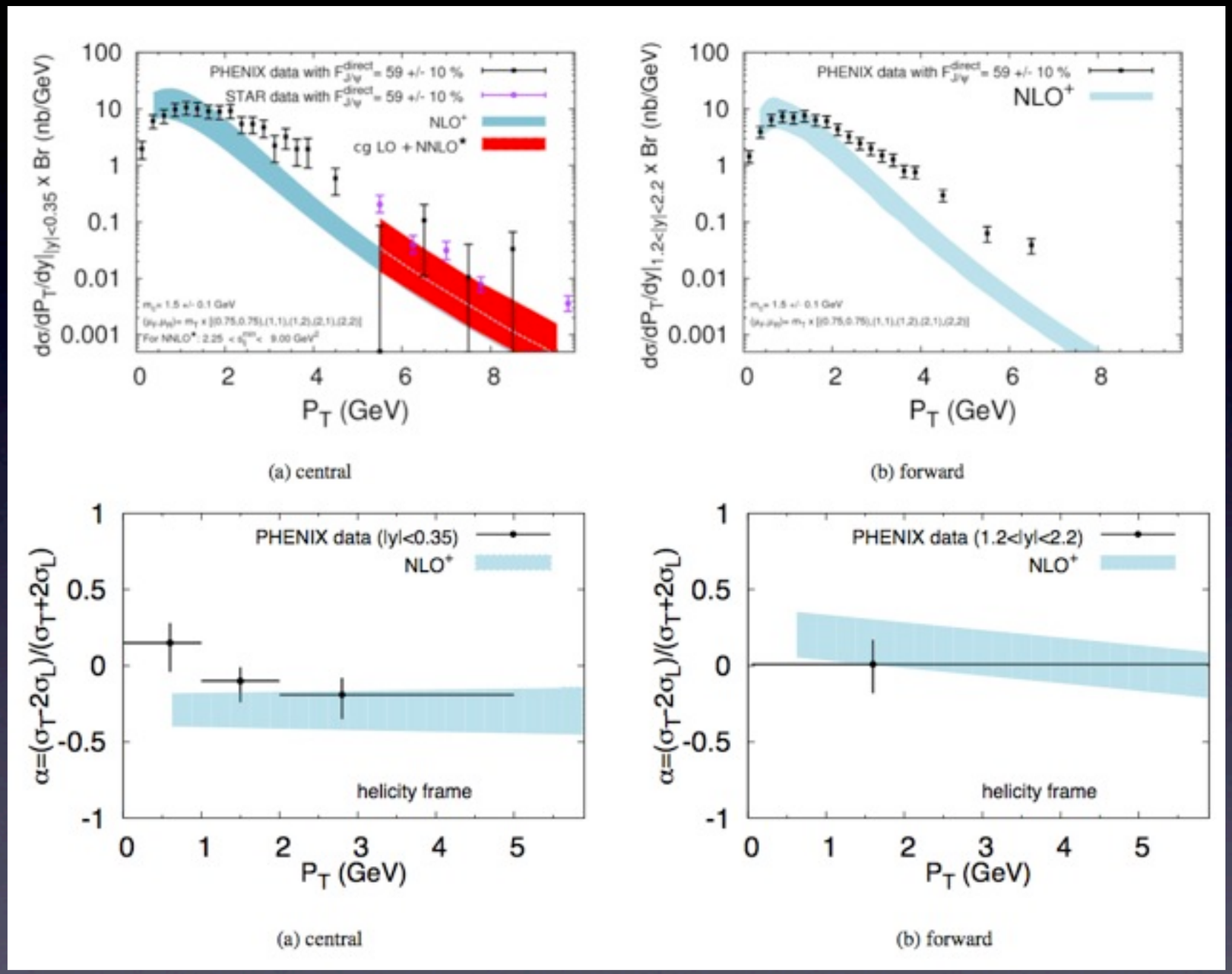
- s-channel cut CSM agrees with polarization data.



Artoisenet and Braaten,
PRD80, 034018 (2009)

- s-channel cut contribution is a part of NNLO correction to CSM
- cross section overestimated by more than 2 orders of magnitude.

Radiative corrections to CSM



- Very recently, Lansberg computed the NLO and dominant NNLO contributions as well as the cg fusion contribution to the CSM.
- The NLO CSM prediction for the polarization agrees with data.

Lansberg, 2010 (arXiv:1003.4319)

Summary

- Both NRQCD and CSM predictions for polarization of J/ψ at the Tevatron disagree with data.
- NRQCD prediction agrees with PHENIX data for both cross section and polarization of J/ψ.
- FIRST NRQCD prediction of J/ψ polarization at RHIC.
- CO is still very important at NLO accuracies.
- Independent analysis by DØ is eagerly waited.

Supplementary

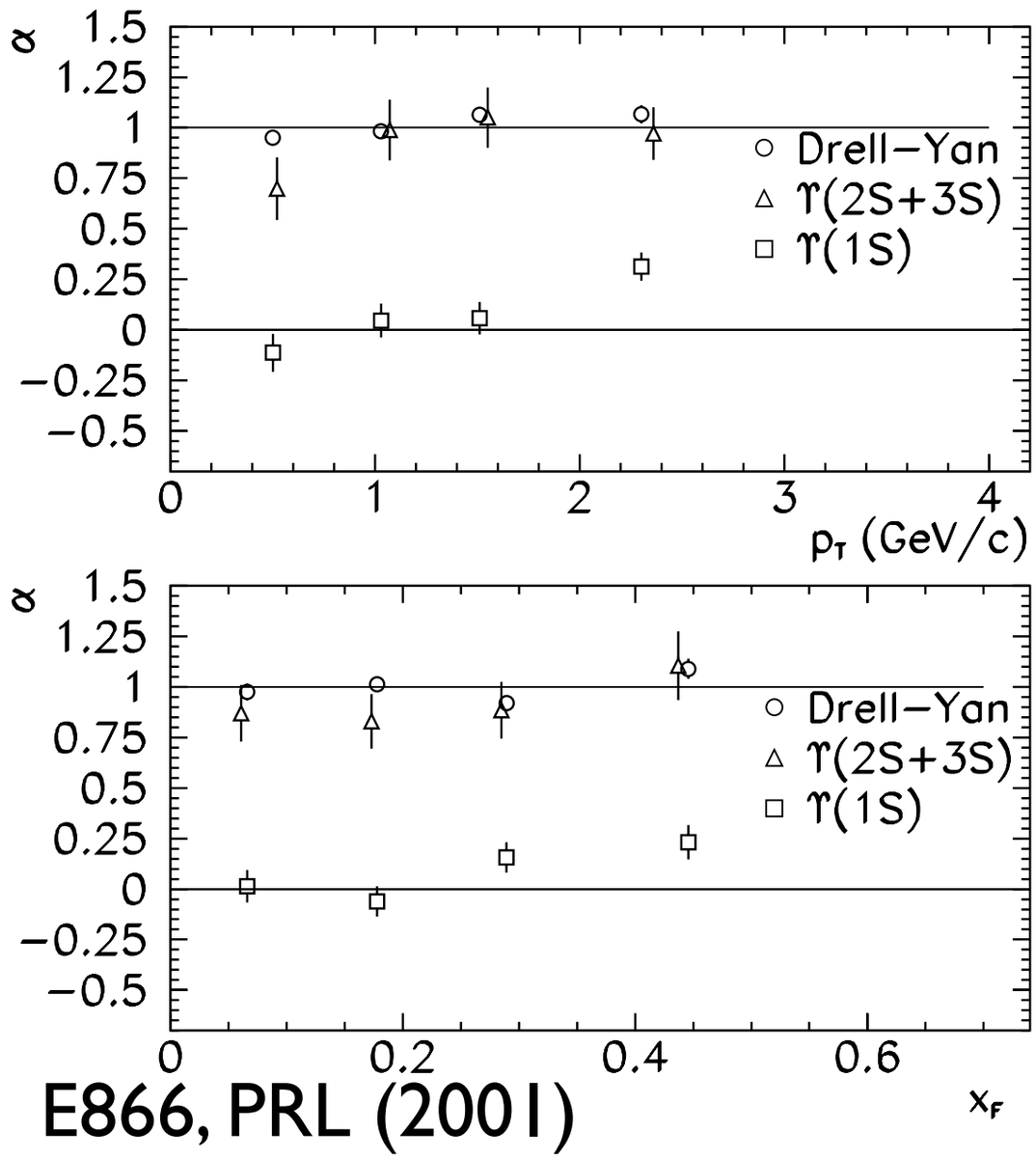
E866 Measurement of Υ Polarization in p-Cu

$\Upsilon(1S)$: UNPOLARIZED

$\Upsilon(2+3S)$: TRANSVERSELY POL $(\sim 100\%)$

a) α versus p_T (E866)
Drell-Yan ($m_{\mu^+\mu^-} = 8.1 - 8.45, 11.1 - 15.0$ GeV)
Υ(1S)($8.8 < m_{\mu^+\mu^-} < 10.0$ GeV)
Υ(2S+3S)($10.0 < m_{\mu^+\mu^-} < 11.1$ GeV)
$0.28 < \alpha^{\text{LO Theory}}_{\Upsilon(1S)} < 0.31$: Tkabladze, PLB462 (99)

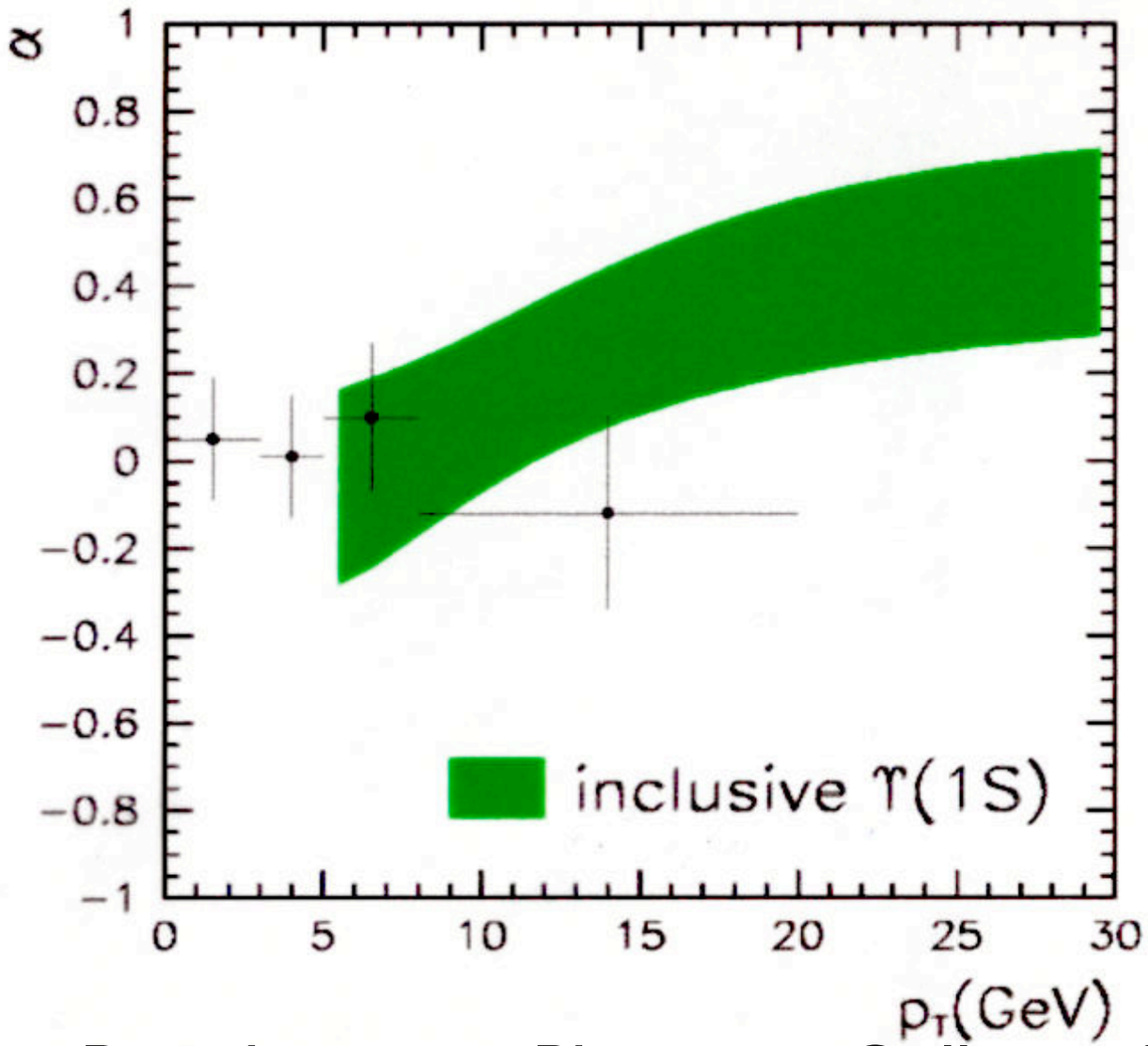
b) α versus x_F (E866)
The errors shown are statistical, there is an additional systematic error not shown of 0.02 in α for Drell-Yan polarizations and 0.06 in α for onium polarizations.



E866, PRL (2001)

- No fragmentation dominance
- Feeddown dilutes polarization
- Color-evaporation model disagrees with data

Polarization of Upsilon at the Tevatron : RUN I (CDF)



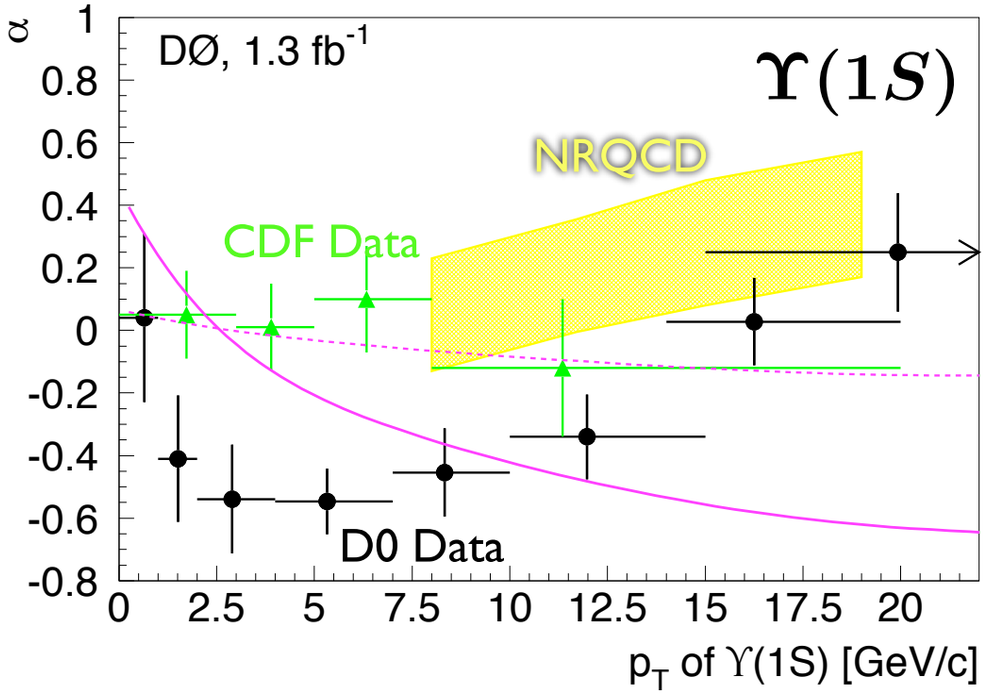
Run I:
PRL 88 (2002)161802

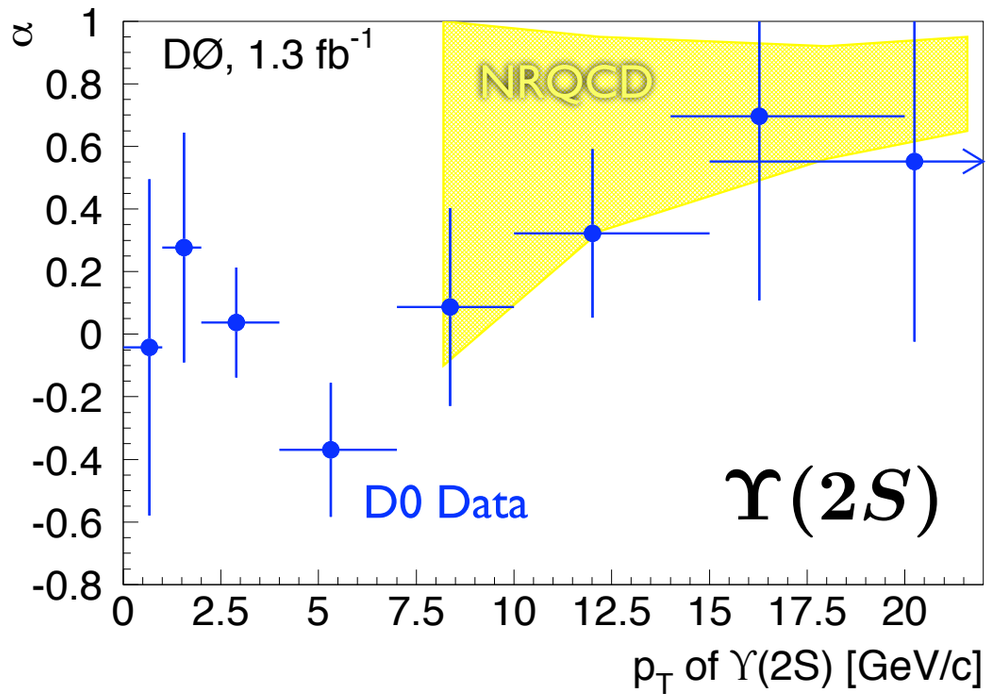
- similar to $c\bar{c}$ → as yet inconclusive
- Insufficient data with $p_T > 20$ GeV/c

- Prediction less dramatic as J/ψ : no fragmentation dominance
- Large errors from uncertainties in NRQCD matrix elements

Vaia Papadimitriou, Physics in Collision 2003
Braaten, Lee, PRD (2001)

Polarization of Upsilon at the Tevatron : RUN II (D0)



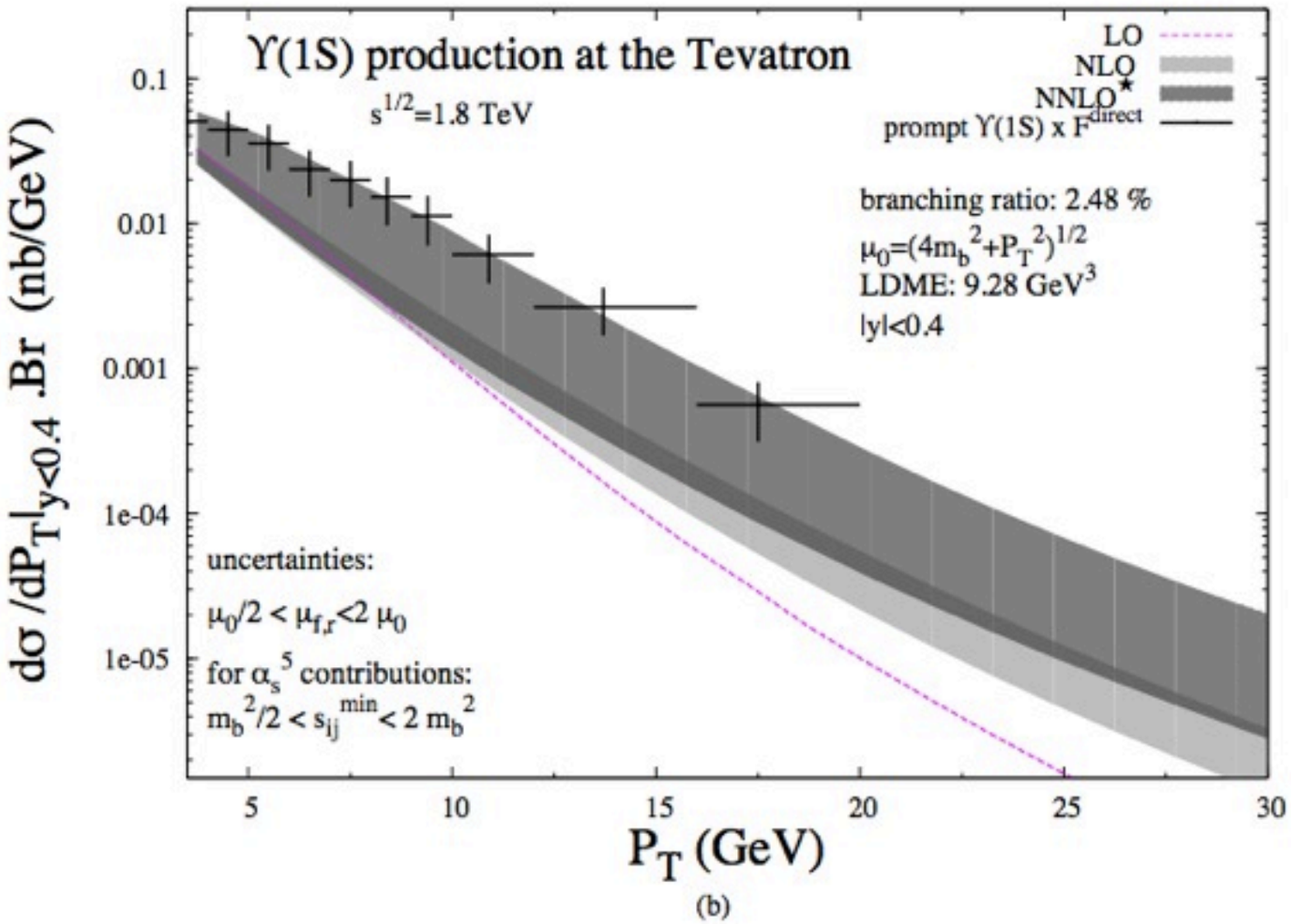


D0, arXiv:0804.2799
Braaten, Lee, PRD (2001)

- Strong longitudinal polarization at low p_T.
- As p_T increases, α increases, but not up to the NRQCD Predictions.

- α increases as p_T increases.
- Low p_T prediction not available.
- $\Upsilon(2S)$ is more transverse (less feeddown) : consistent with NRQCD
- D0 data disagree with CDF

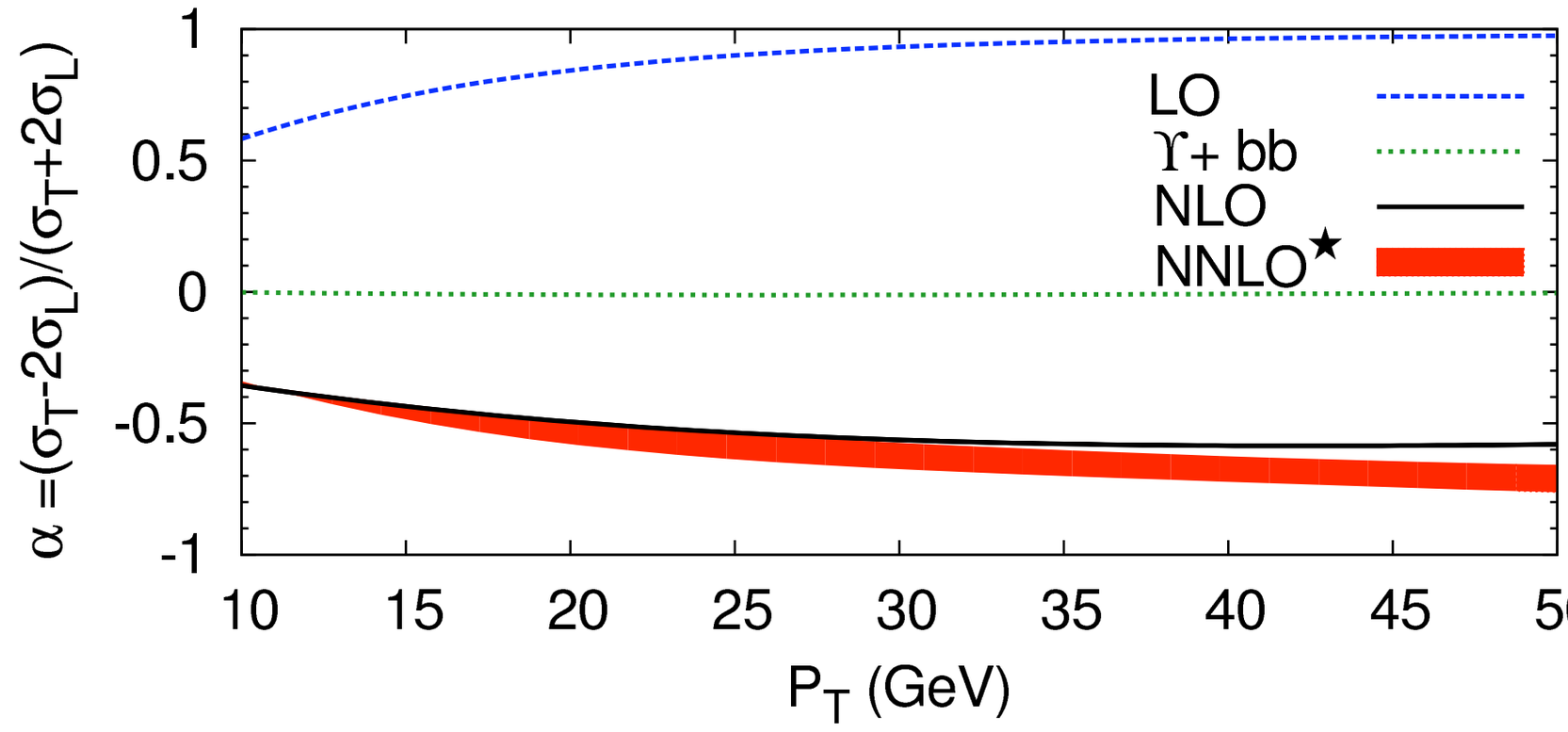
Radiative corrections to CSM : Upsilon production



- There is almost no room for color-octet production.
- Consistent with the fact that color-octet production is suppressed as v^4.

P. Artoisenet, Proc. Sci., CONFINEMENT8 (2008) 098

Radiative corrections to CSM : Upsilon production



Artoisenet, Campbell, Lansberg, Maltoni, Tramontano (2008)

- Color-singlet polarization changes from transverse to longitudinal by inclusion of NLO corrections.

Large rapidity region

- Cross section and polarization at large rapidity (1.0<|y|<1.2) have also been announced.

	cross section (nb/GeV^2)	Polarization
PHENIX	1.06±0.16	0.02±0.16
NRQCD	2.24±1.82	0.15±0.10
LO CSM	0.08±0.05	0.19±0.03
s-channel cut	agree	over-estimated

$p_T = 1.6$ GeV