Mécanismes élémentaires de production d'états quarkonium

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plusieurs échelles :

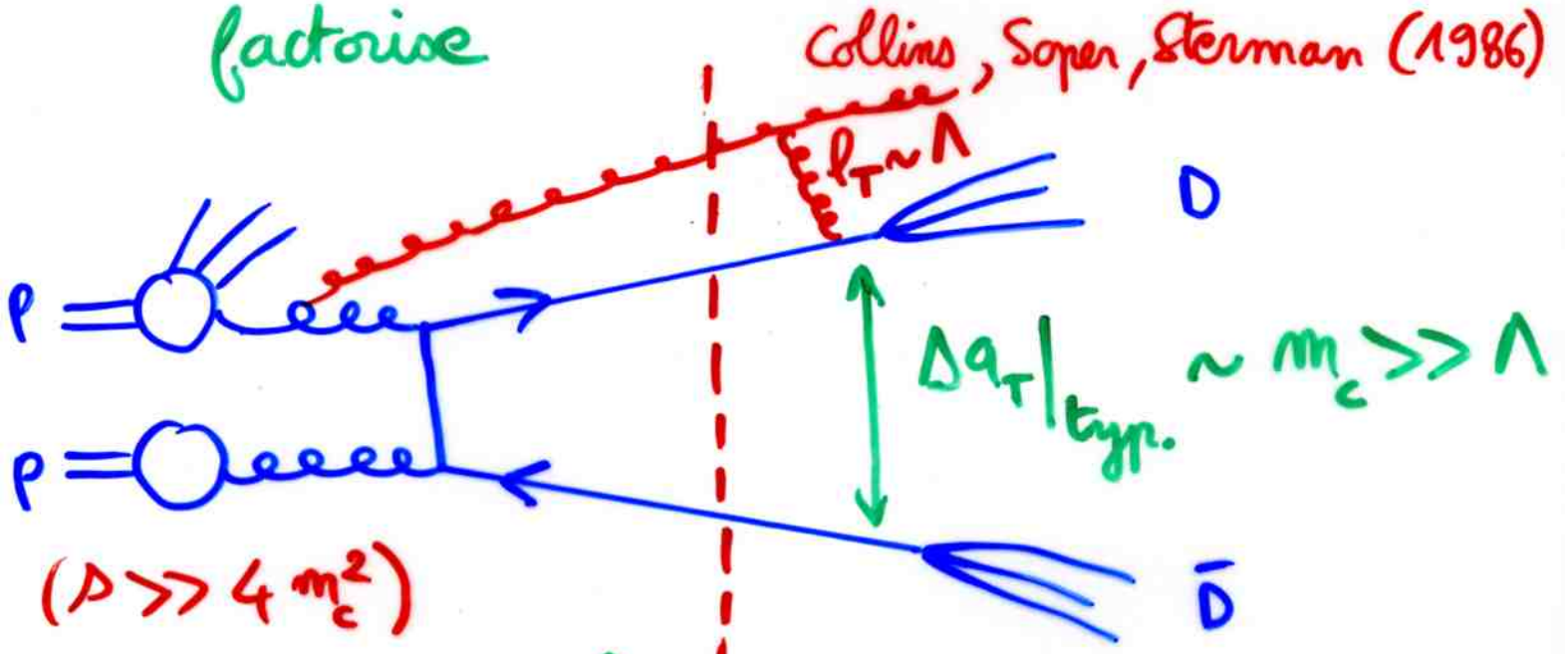
$$m_Q \; (= m_c, m_b) \gg \{\Lambda_{QCD}, \alpha_s^m m_Q\} \equiv \Lambda$$

$\Rightarrow$ approximation NR pour $\Psi = \{Q\bar{Q}\}$

($V_{Q\bar{Q}}(r) \sim -\frac{\kappa}{r} + k\,r$

$\rightarrow$ description des familles $\{c\bar{c}\}$, $\{b\bar{b}\}$)

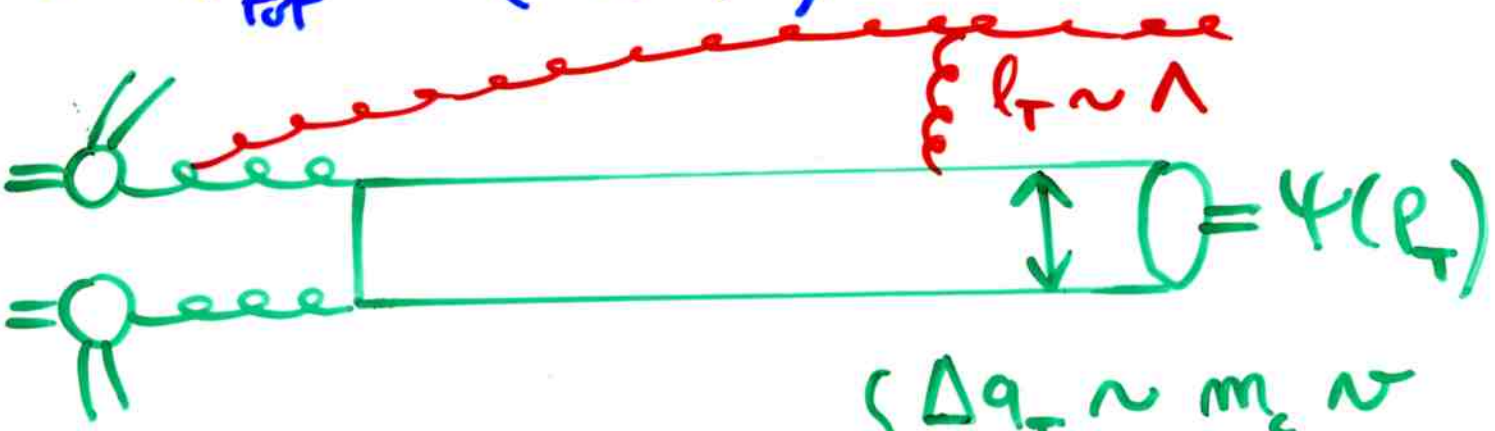
$\Rightarrow$ hadrol° de "charme ouvert" se factorise



$$\sigma_{tot}(D\bar{D}) \sim \hat{\sigma}(c\bar{c}) \otimes \underbrace{P(c\bar{c} \to D\bar{D})}_{\simeq 1}$$

Production d'état lié ?

- $\sigma_{tot}^{hadro}(J/\psi)$



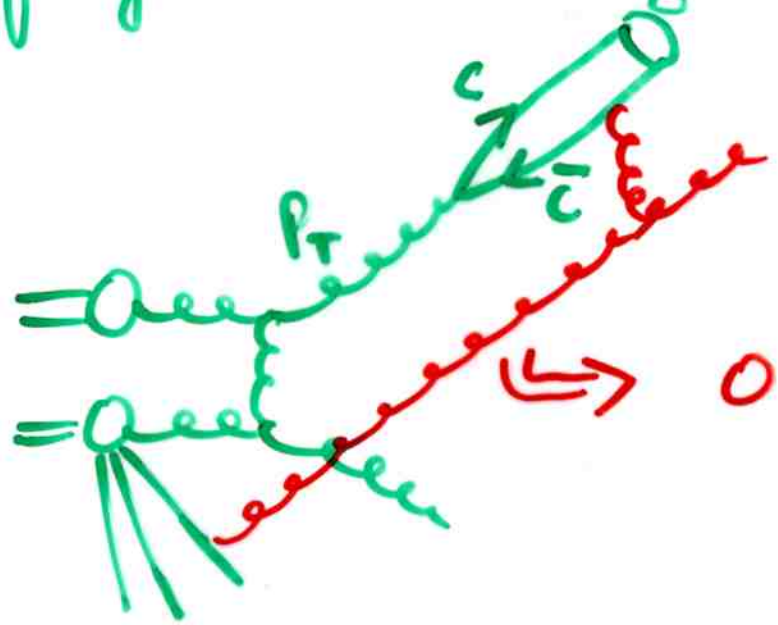
$\Delta q_T \sim m_c \sim$

$p_T \lesssim m_c$

pas de factorisation à $p_T \lesssim m_c$.

- $d\sigma^{hadro}/dp_T$ $(p_T >> m_c)$

fragmentation de gluon Braaten, Yuan (93)



$\forall$ modèle de P^0

$\hookrightarrow O(1/p_T^n)$

$$d\sigma(p_T) \sim d\hat{\sigma}(g(p_T/z)) \otimes D_{g\to\psi}(z) + O(m_c^2/p_T^2)$$

moins clair : " factorisation " :

$$D_{g\to\psi} \overset{?}{=} \sum_{[n]} d_{g\to c\bar{c}[n]} \underbrace{\langle \hat{O}^{\psi}_{[n]} \rangle}_{P(c\bar{c}[n]\to\psi)}$$

(COM)

- suggéré par Bodwin, Braaten, Lepage (1995)
- factorisation non démontrée complètement
  Bodwin hep-ph/0312173
  Nayak, Qiu, Sterman hep-ph/0501235
  ↳ factorisation peut-être invalide

- CEM, CSM, COM supposent la factorisation :

$$d\sigma(\psi) \sim d\hat{\sigma}(c\bar{c}) \otimes P(c\bar{c}\to\psi)$$

(à $p_T \lesssim m_c$ et $p_T \gg m_c$)

- différent par $P(c\bar{c}\to\psi)$

- vu le statut de la factorisation :
confrontation aux données = test de l'hyp. de fact

Color Evaporation Model (CEM)

Fritzsch, Halzen, Matsuda (1977)

$$\sigma_\psi = f_\psi \int_{2m_c}^{2m_D} dm_{c\bar{c}} \, \frac{d\sigma_{c\bar{c}}}{dm_{c\bar{c}}}$$

Postulat : ajustement de $\{ {}^{2S+1}L_J$, couleur$\}$ par émission de gluons mous.

- P° non polarisée

  $\Upsilon(2S+3S)$ transverse □

- $\frac{\sigma(H_1)}{\sigma(H_2)}$ universels

$\left(\frac{\chi_2}{J/\psi}\right)_{\gamma p \to \psi + X} < 0.3$; $\left(\frac{\chi_2}{J/\psi}\right)_{hN} = 1.8 \pm 0.4$

(NA14, 1989) (E705)

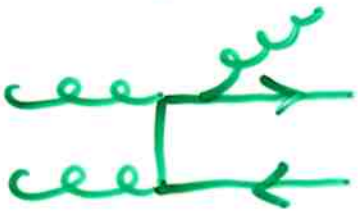
- $\sigma_\psi(A) = \sigma_{D\bar{D}}(A)$

$\sigma_{D\bar{D}} \propto A^1$ (E789) ; $\sigma_\psi(A) \propto A^{0.92}$ (E866)

Color Singlet Model (CSM)

Kühn, Chang, Baier & Rückl, ...
(1980's)

Traitement explicite des nbs quantiques :

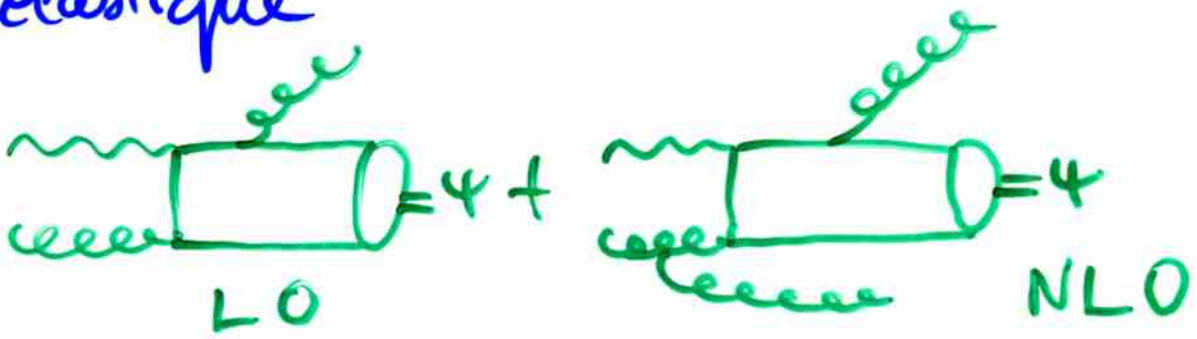
$\mathcal{M}(J/\psi) \sim$  $= J/\psi \propto R_\psi(0)$

$[^3S_1, 1]$

- CSM sous-estime σ^{ψ}_{hadro}
  - $p_T \lesssim m_c$ (cible fixe) ☐
  - $p_T \gg m_c$ (Tevatron) ☐
- CSM non complet théoriquement

CSM (NLO) consistant avec $\sigma^{\psi}_{\gamma p^0}$

γp^0 inélastique

CSM 

H1, ZEUS ☐

DIS

H1 comparé au CSM (LO) ☐

Kniehl, hep-ph/0210217

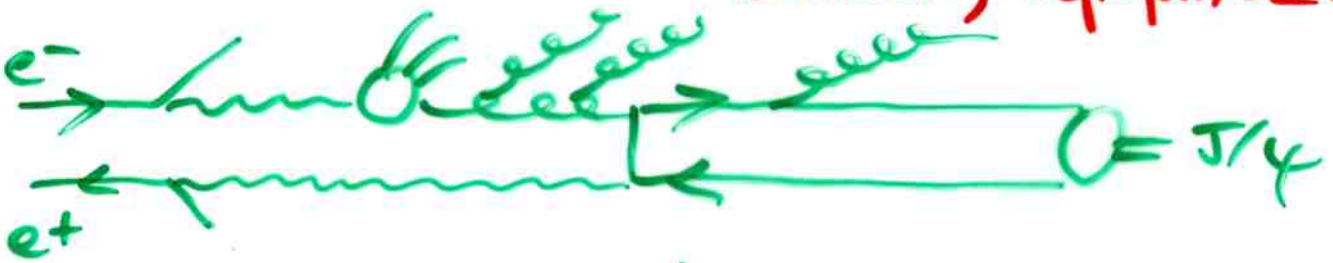
$\gamma\gamma$

DELPHI, $p_T \leq 3$ GeV hep-ex/0307049

$\frac{\sigma^{\psi}_{\gamma\gamma}}{CSM} \gtrsim 10$

Processus avec γ résolu dominent

(Klasen, hep-ph/0210144)



$\neq \gamma p^0$!

NRQCD

Caswell, Lepage (1986)

Bodwin, Braaten, Lepage (1995)

NRQCD = théorie effective issue de QCD avec quarks lourds

- décrit $p \sim m_Q v$

→ théorie complète des désintégrations de quarkonium

→ mécanismes "octet de couleur", contribuant aussi à la production :

$$\Gamma_\psi \overset{?}{=} \sum_n \Gamma_{Q\bar{Q}[n]} \langle \hat{O}^\psi_{[n]} \rangle$$

($[n]$ = singulet ou octet)

$\langle \hat{O}^\psi_{[n]} \rangle$ = $P(Q\bar{Q}[n] \to \psi + x)$ non perturbatif ;

"scaling" en v prédit par NRQCD

$\overset{?}{=}$ suggéré par BBL

$p_T \gg m_c$: $\overset{?}{=}$ $\Rightarrow$

$D_{g\to\psi}^{(z)} \overset{?}{=} \sum_{[n]} d_{g\to Q\bar{Q}[n]}^{(z)} \langle \hat{O}^{\psi}_{[n]} \rangle$

COM pour la production =
NRQCD + hyp. de factorisation

Succès :

- cadre théorique pour "anomalie du ψ'"
- $\gamma\gamma \to J/\psi + X$ (LEP2)

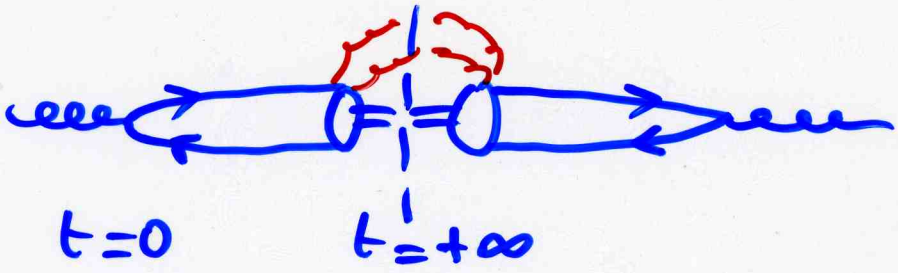
Difficultés :

- γp° à HERA
- Polarisation de J/ψ / ψ' à $p_T \gg m_c$ ☐

explication ?

- $\langle \hat{O}^{\psi}_{[n]} \rangle_{\text{SPIN-FLIP}}$ anormalement grand ?
  ... peut-être pas Bodwin, Lee, Sinclair hep-lat/0503032
- pb avec la factorisation ?
  ... peut-être Nayak, Qiu, Sterman

$\langle \hat{O}_8^4 \rangle \sim$

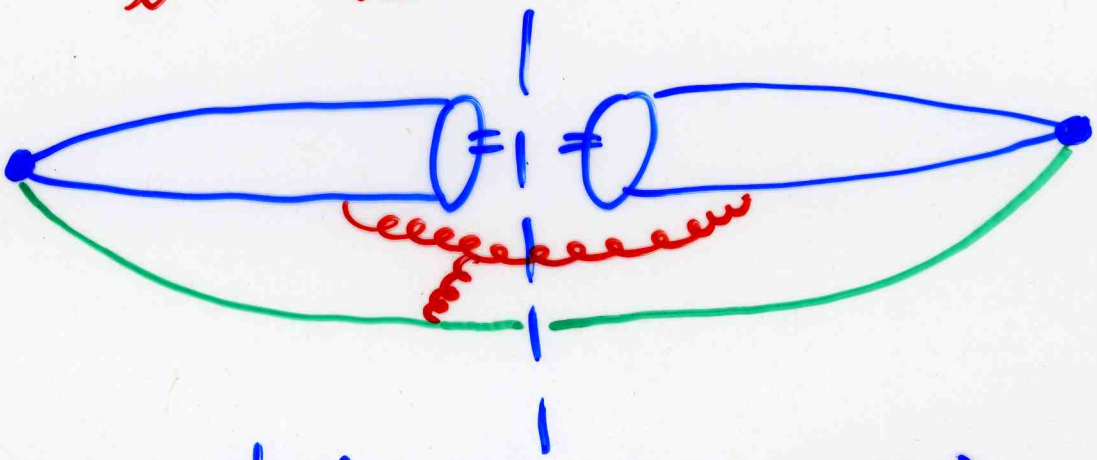


$$\sim \langle [\chi^+ K_a \psi(0)]\, a_\psi^+(\infty)\, a_\psi(\infty) [\psi^+ K'_a \chi(0)] \rangle$$

inv. de jauge $\Rightarrow$

$$\langle [\chi^+ K \psi(0)]_b \Phi(0,\infty)_{ba} a_\psi^+(\infty) a_\psi(\infty) \Phi(\infty,0)_{ac} [\psi^+ K'_c \chi(0)] \rangle$$

$\Rightarrow$

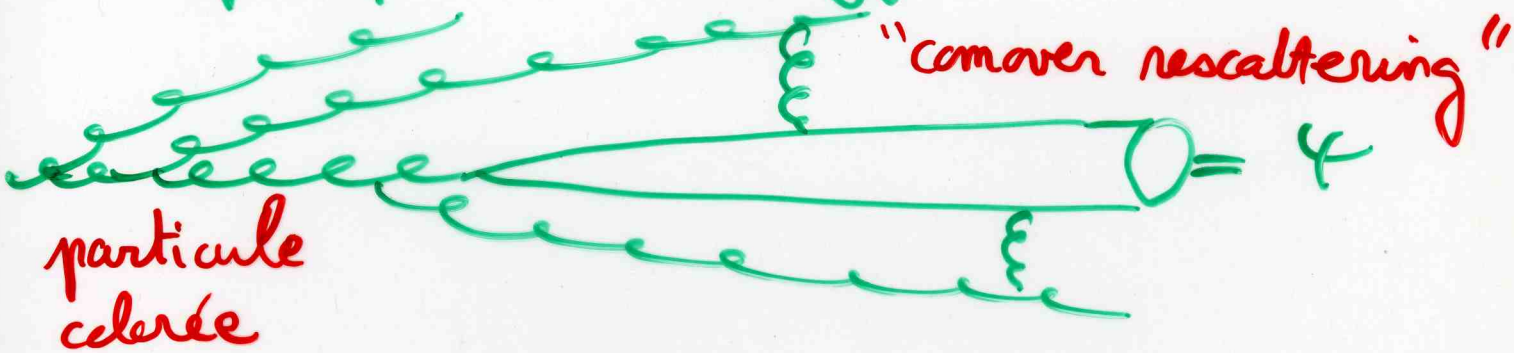


NNLO, contribue à $D(g \to \psi)$, contient div. IR modifiant $\langle \hat{O}_8^4 \rangle$

CONCLUSION

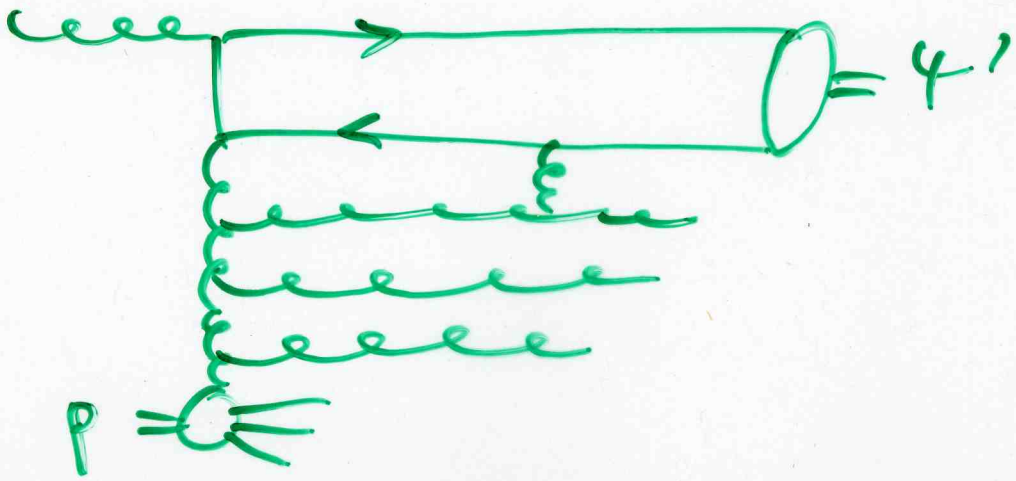
- CEM, CSM : pbs et non complets
- COM = NRQCD + hyp. de fact°
  → pb avec polarisation de ψ à $p_T \gg m_c$
  → fact° invalide ?
- Modèles sans factorisation.
  - Comover Enhancement Scenario
    P. Hoyer, S.P.
    hep-ph/9806424

analyse qualitative suggère :



- Khoze, Martin, Ryskin, Stirling
hep-ph/0410020

nouveau mécanisme :



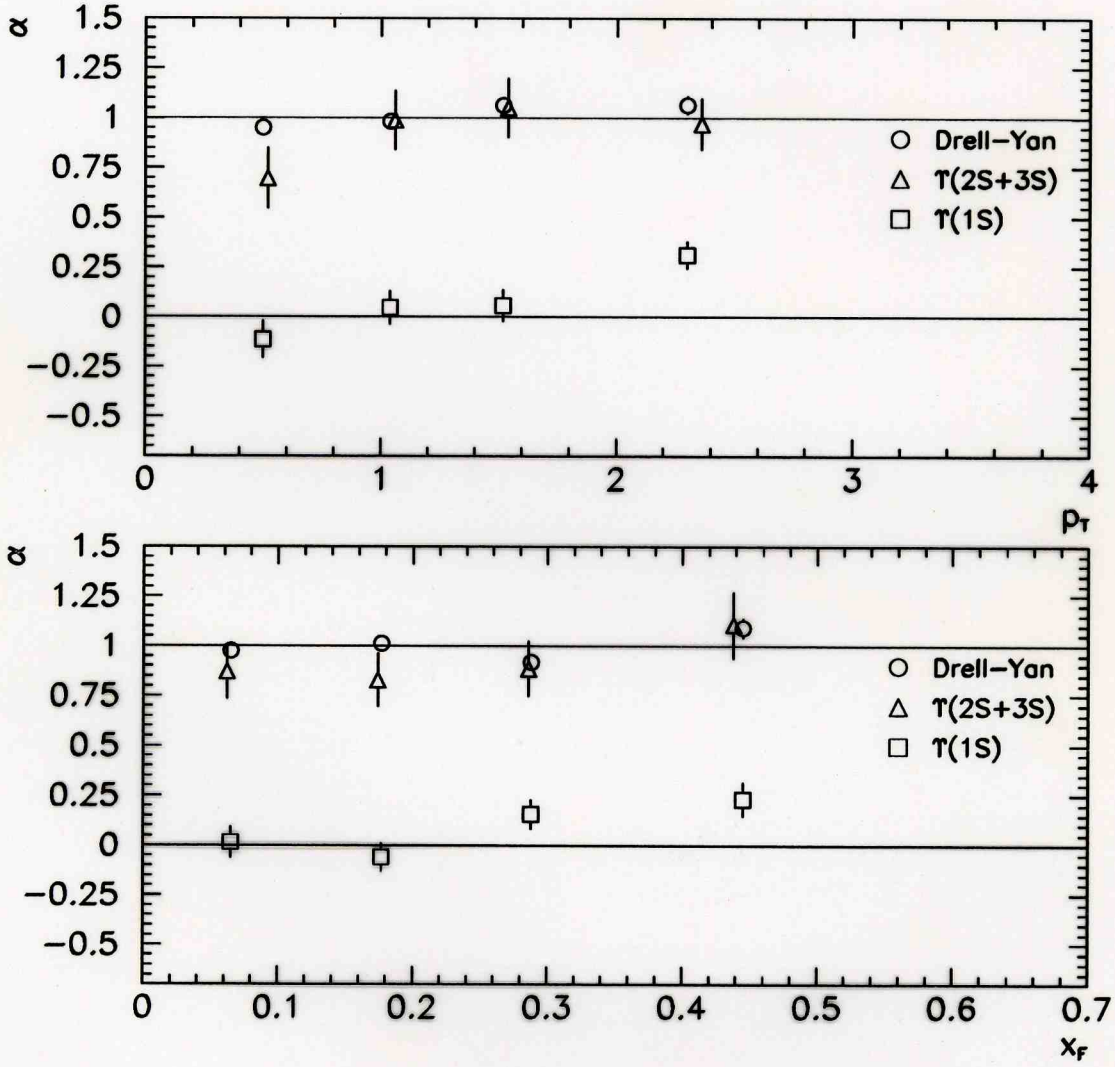
explique l'anomalie du ψ' dans le cadre du CSM !!

$\alpha_s \ll 1$ compensé par $n_{gluons} \gg 1$

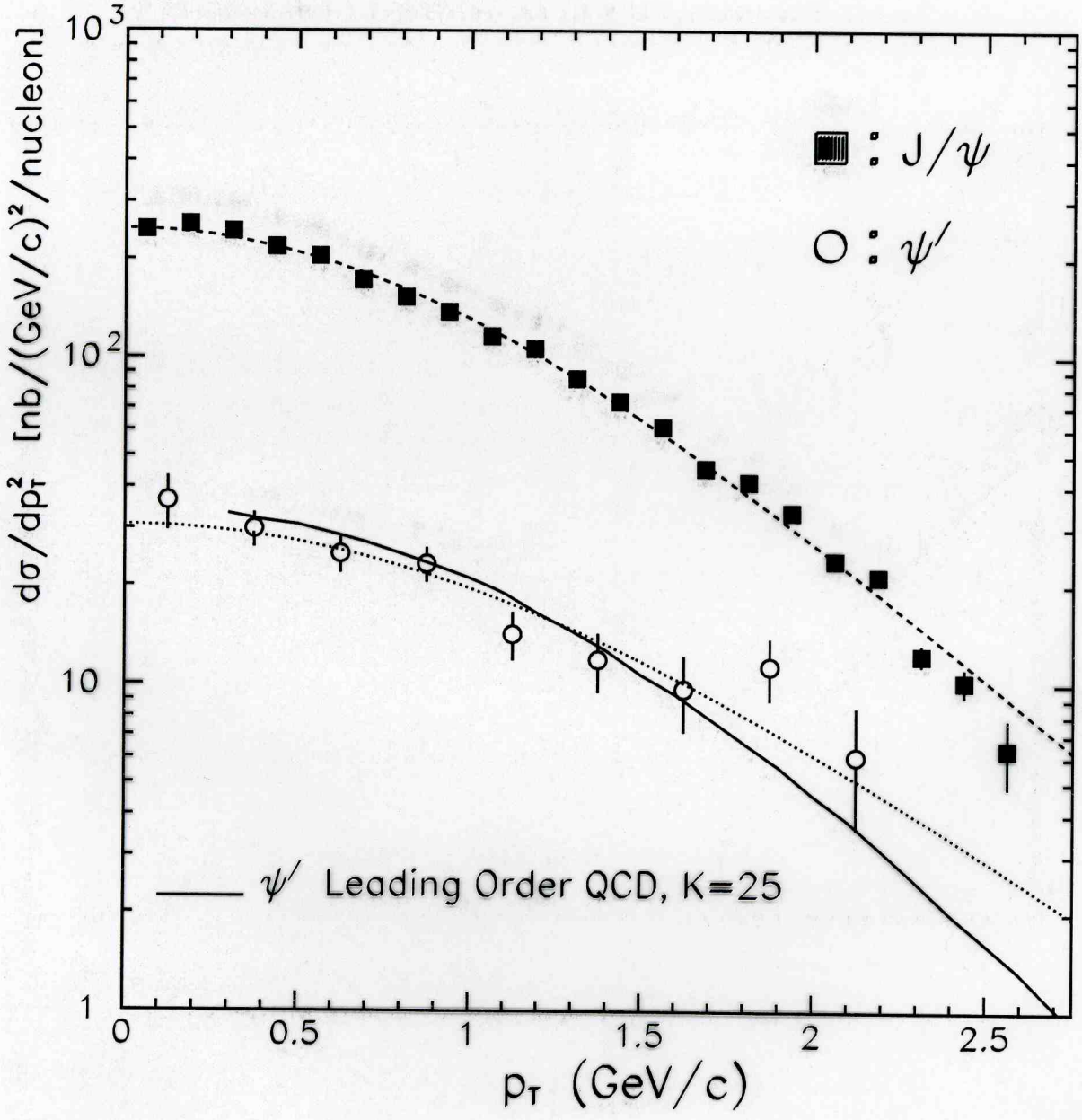
En l'absence d'effets nucléaires, la production de quarkonium n'est pas encore totalement comprise -

Brown et al., E866/NuSea Collab., hep-ex/0011030

$$\frac{d\sigma}{d\cos\theta_\mu} \propto 1 + \alpha \cos^2\theta_\mu$$

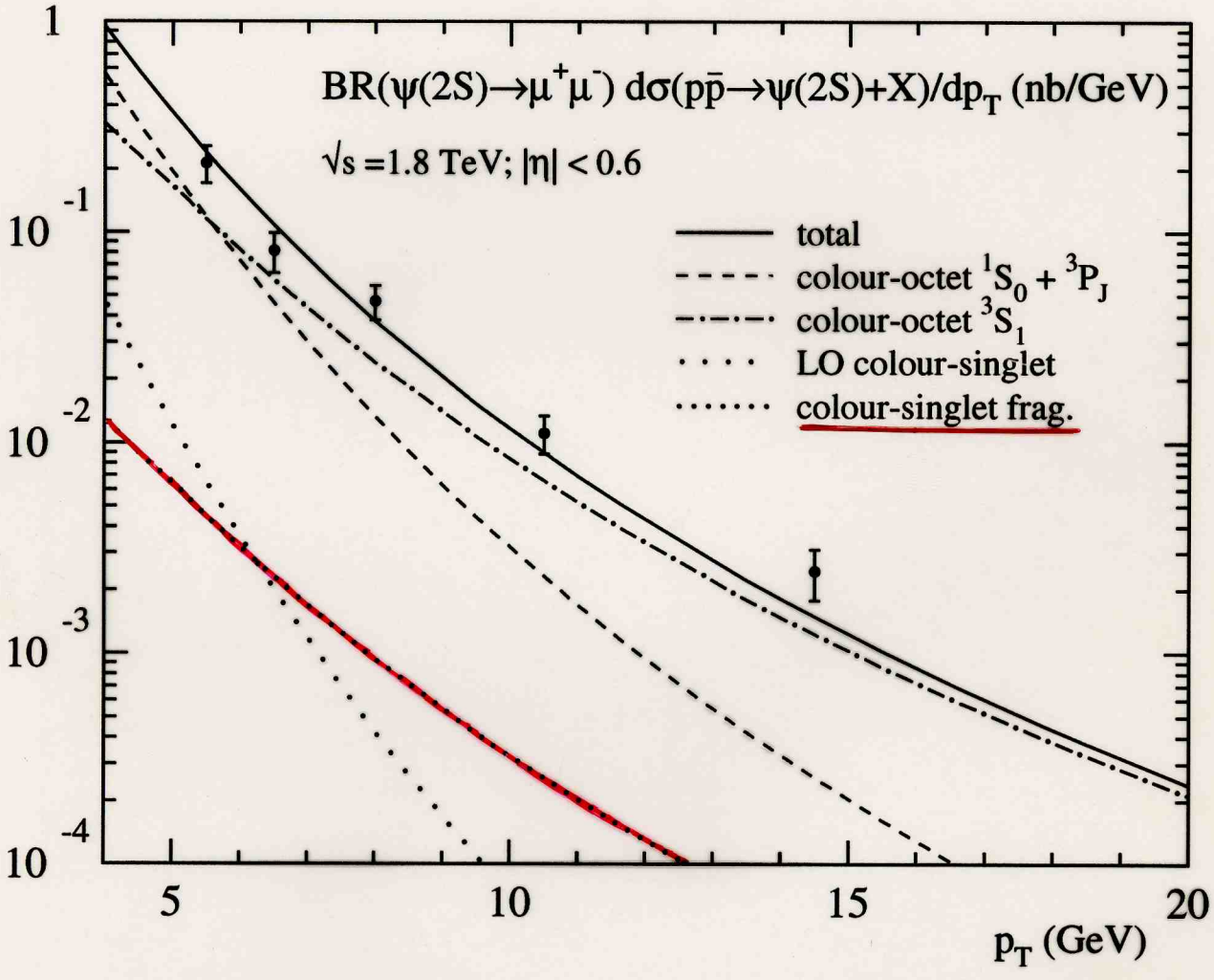


E789 Collab., hep-ex/9610003

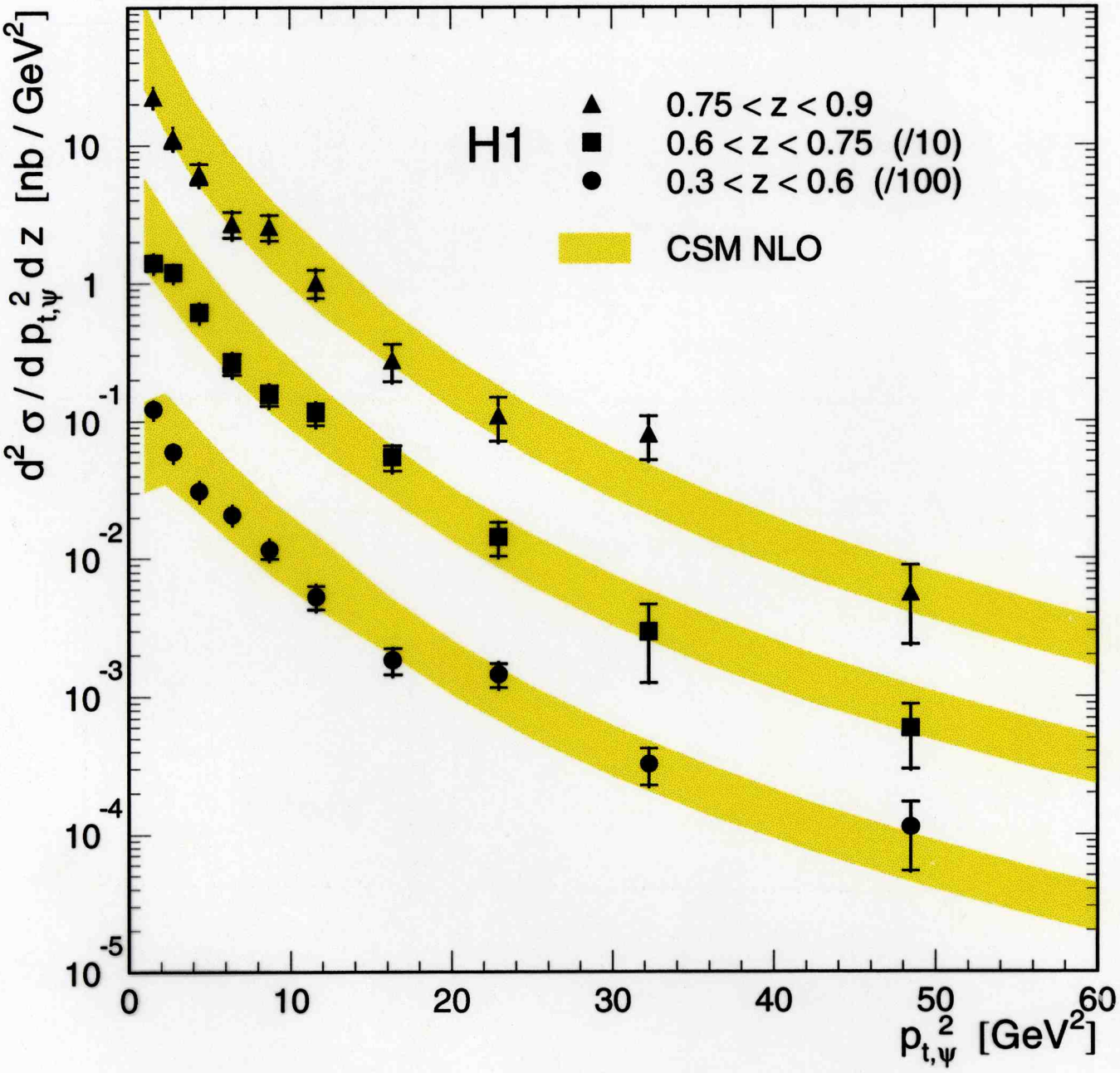


Michael Krämer, hep-ph/0106120

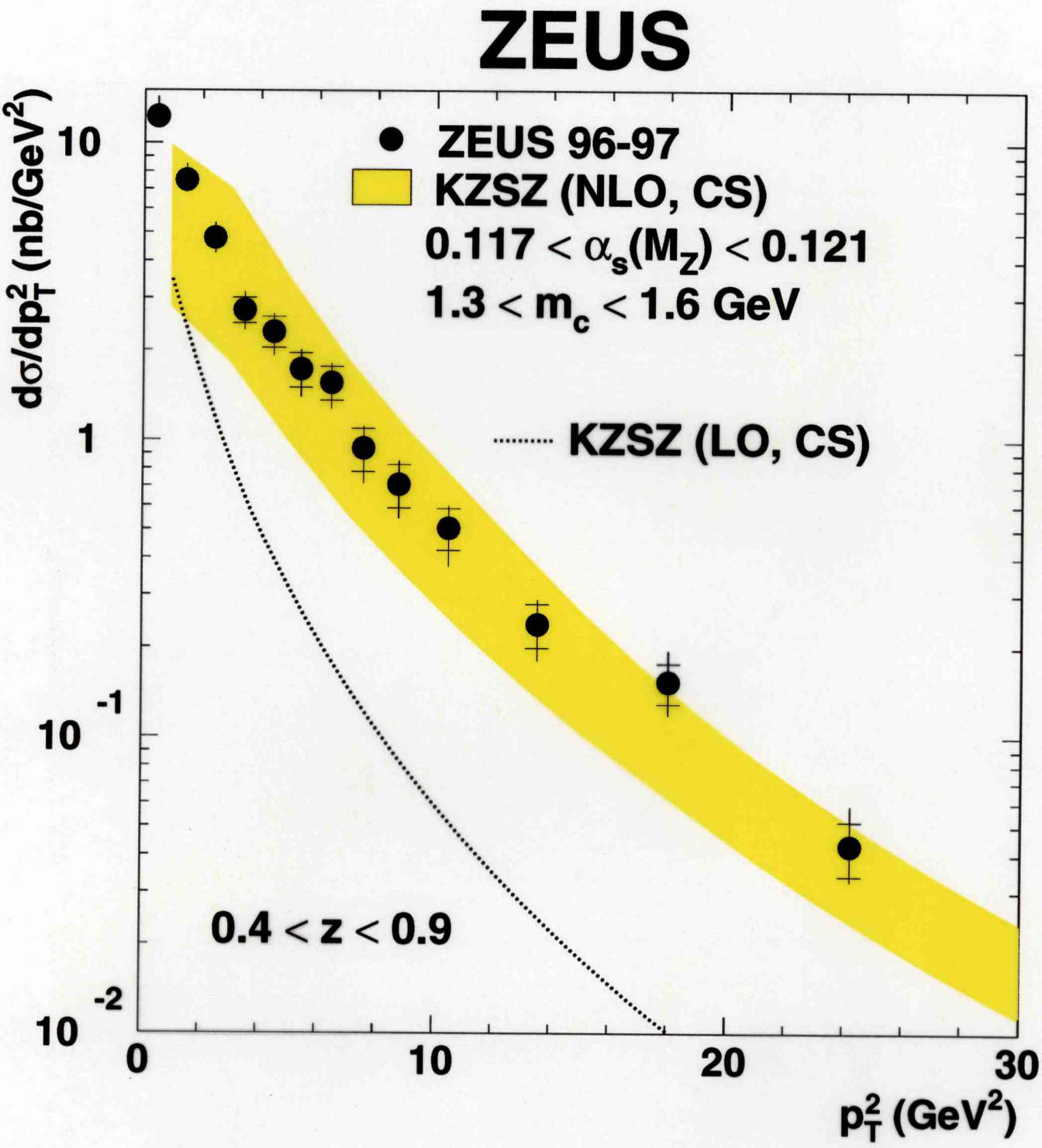
direct $\psi(2S)$ 'anomaly'



Inelastic J/ψ photoproduction

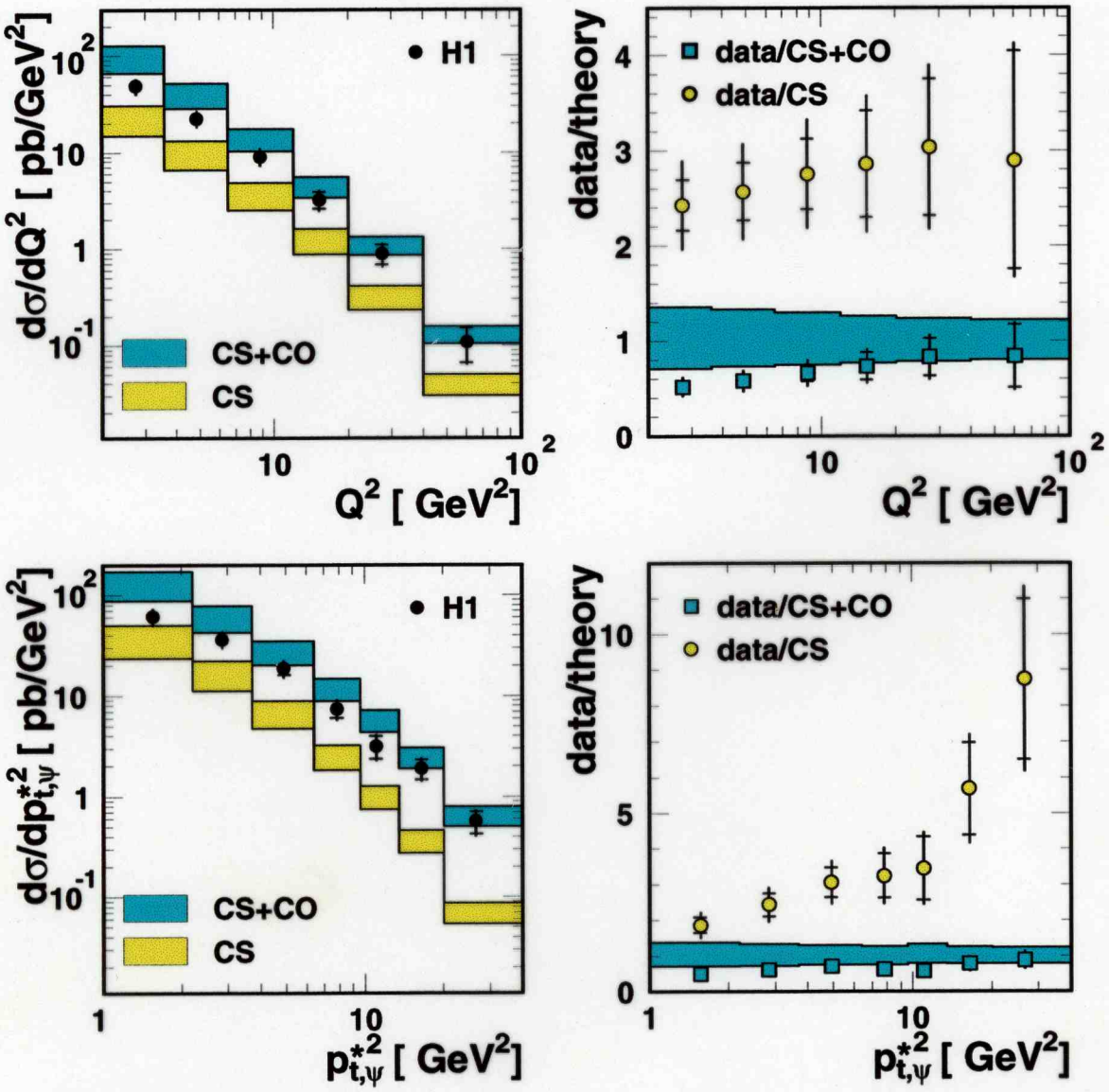


Inelastic J/ψ photoproduction



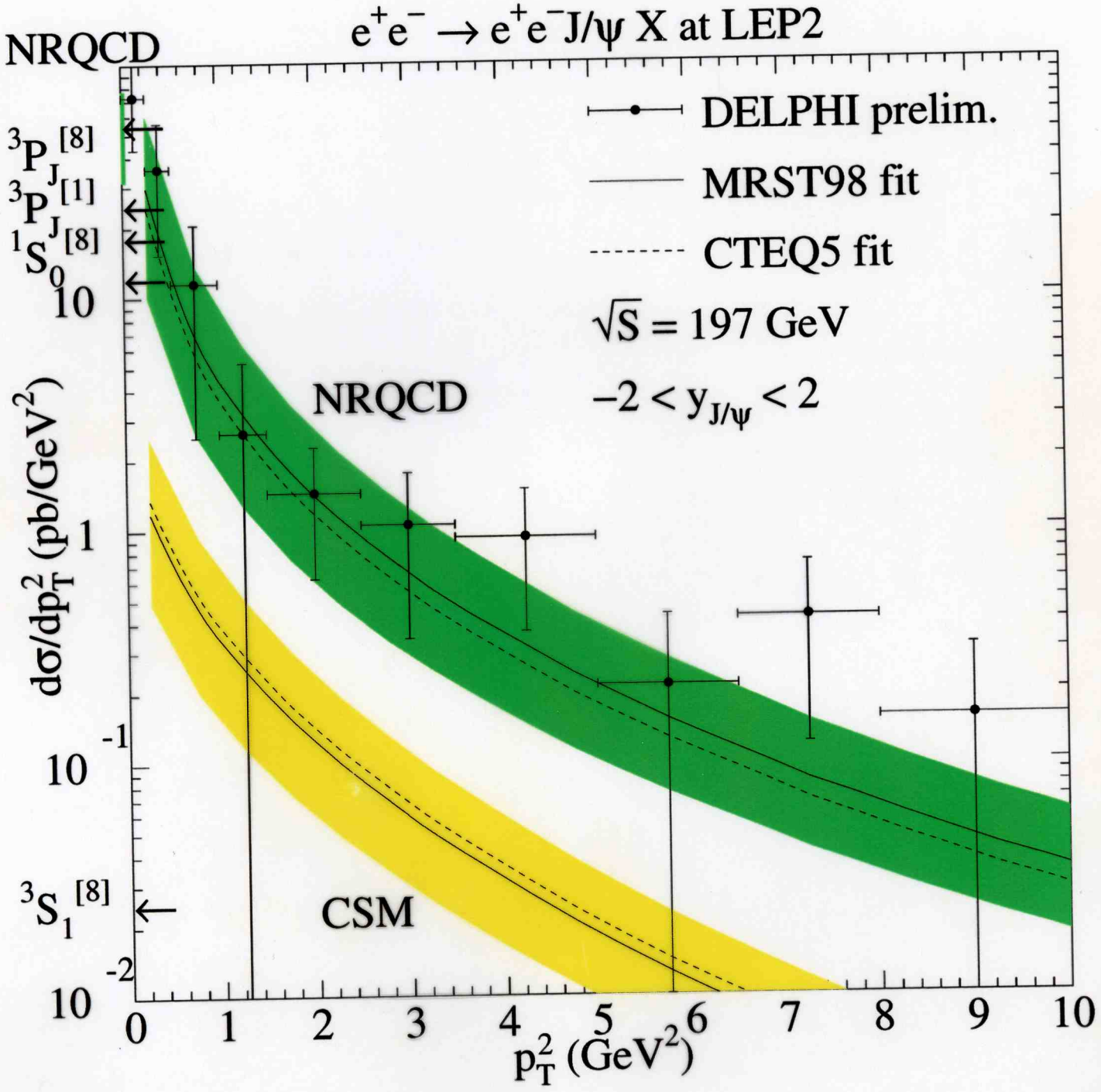
B. Kniehl, hep-ph/0210217

J/ψ production in DIS



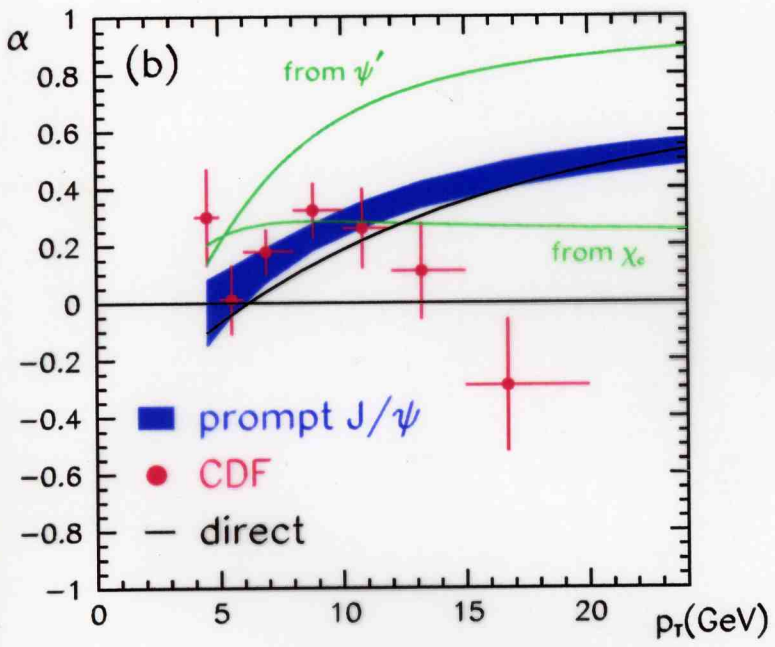
M. Klasen, hep-ph/0210144

J/ψ production in $\gamma\gamma$ collisions



Braaten, Kniehl, Lee, hep-ph/9911436

J/ψ and ψ' polarization at the Tevatron



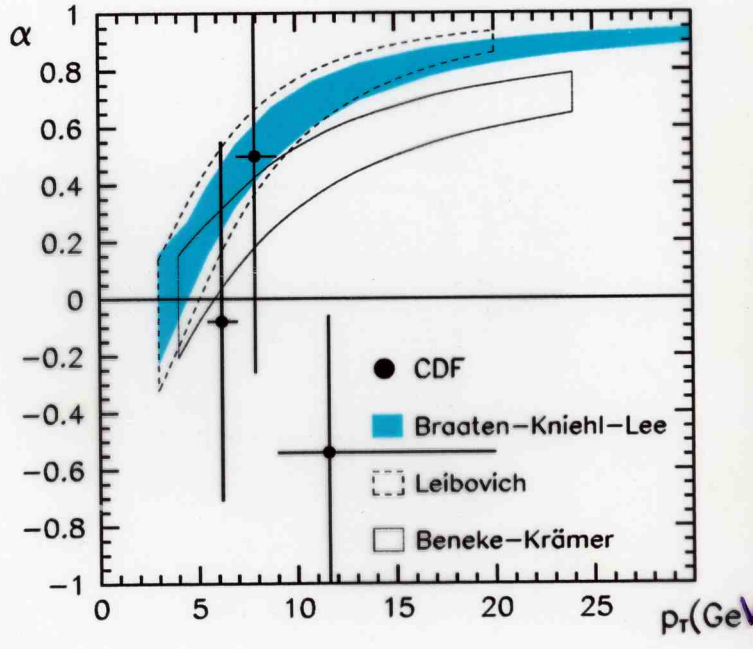


Figure 1: Left-hand side: J/ψ polarization at the Tevatron. The band is the total NRQCD-factorization prediction. The other curves give the contributions from feeddown from higher charmonium states. Right-hand side: ψ' polarization at the Tevatron. The bands give various NRQCD-factorization predictions. The data points are from the CDF measurement.