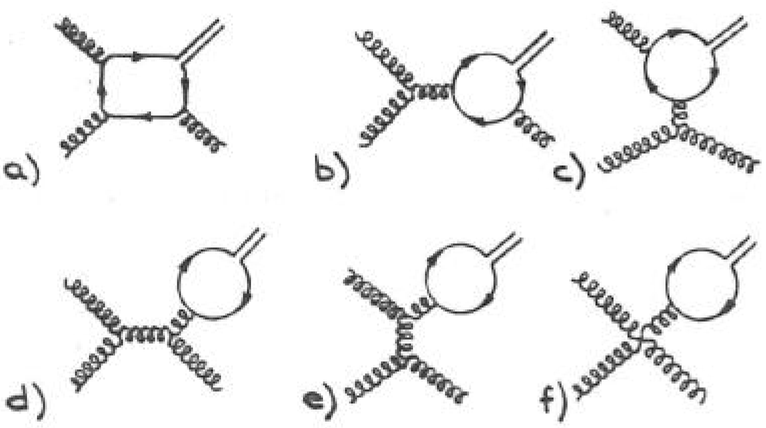
S. Baranov

HIGHLIGHTS FROM THE k_T-FACTORIZATION APPROACH ON THE J/ψ POLARIZATION PUZZLE



a) b) c) d) e) f)

PRODUCTION MECHANISMS

COLOUR-SINGLET (a)

- perturbative creation of a $c\bar{c}$ pair with J/ψ quantum numbers
- bound state formation is determined by $|\Psi(0)|^2 \sim v^3$

COLOUR-OCTET (a - f)

- perturbative creation of a $c\bar{c}$ pair in octet state
- subsequent emission of nonperturbative gluons

$^3P_J(8) \to {}^3S_1(1) \quad \sim v^5,$

$^3S_1(8) \to {}^3S_1(1) \quad \sim v^7,$ dominant at high p_T

$^1S_0(8) \to {}^3S_1(1) \quad \sim v^7.$

EXTENSION TO SEMIHARD APPROACH

- introduction of noncollinear (= unintegrated) gluon distribution functions $\mathcal{F}(x, k_T, \mu^2)$
- modification of spin density matrix

$\epsilon^\mu \epsilon^{\nu *} \sim k_T^\mu k_T^\nu / |k_T|^2$

(appearance of longitudinal components)

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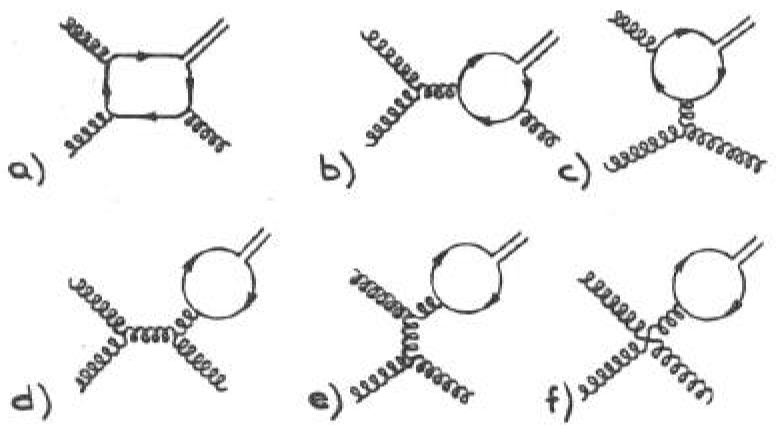

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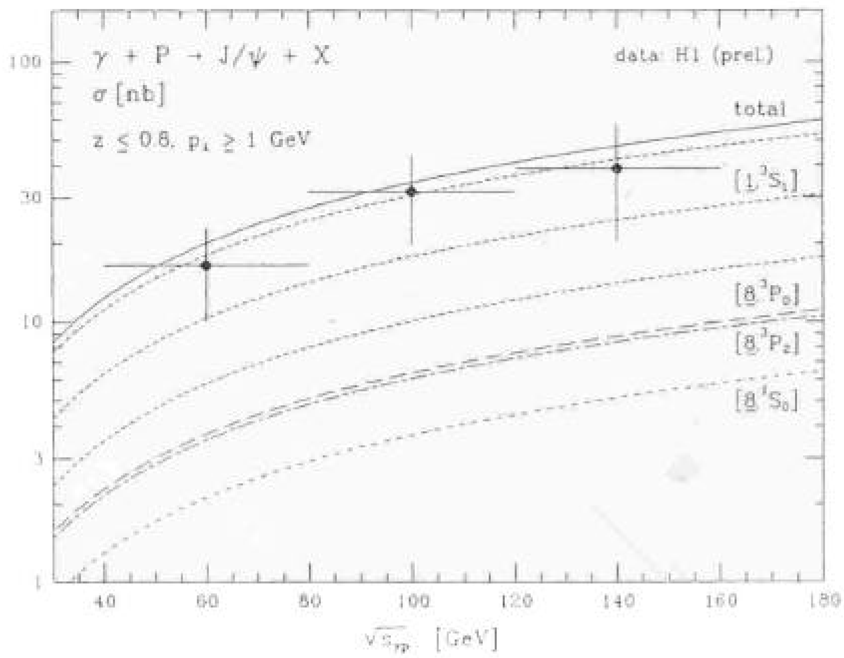
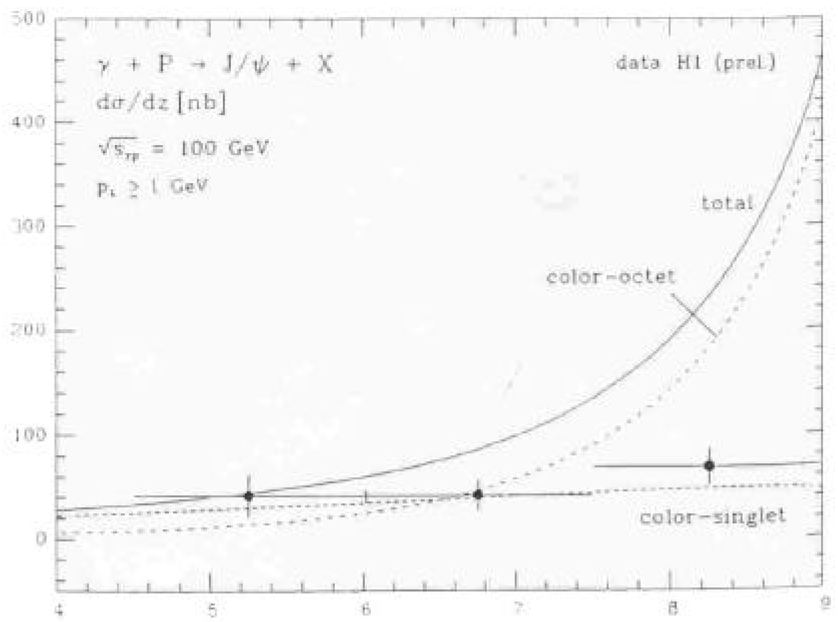
J/ψ PHOTOPRODUCTION AT HERA

(conventional parton model)

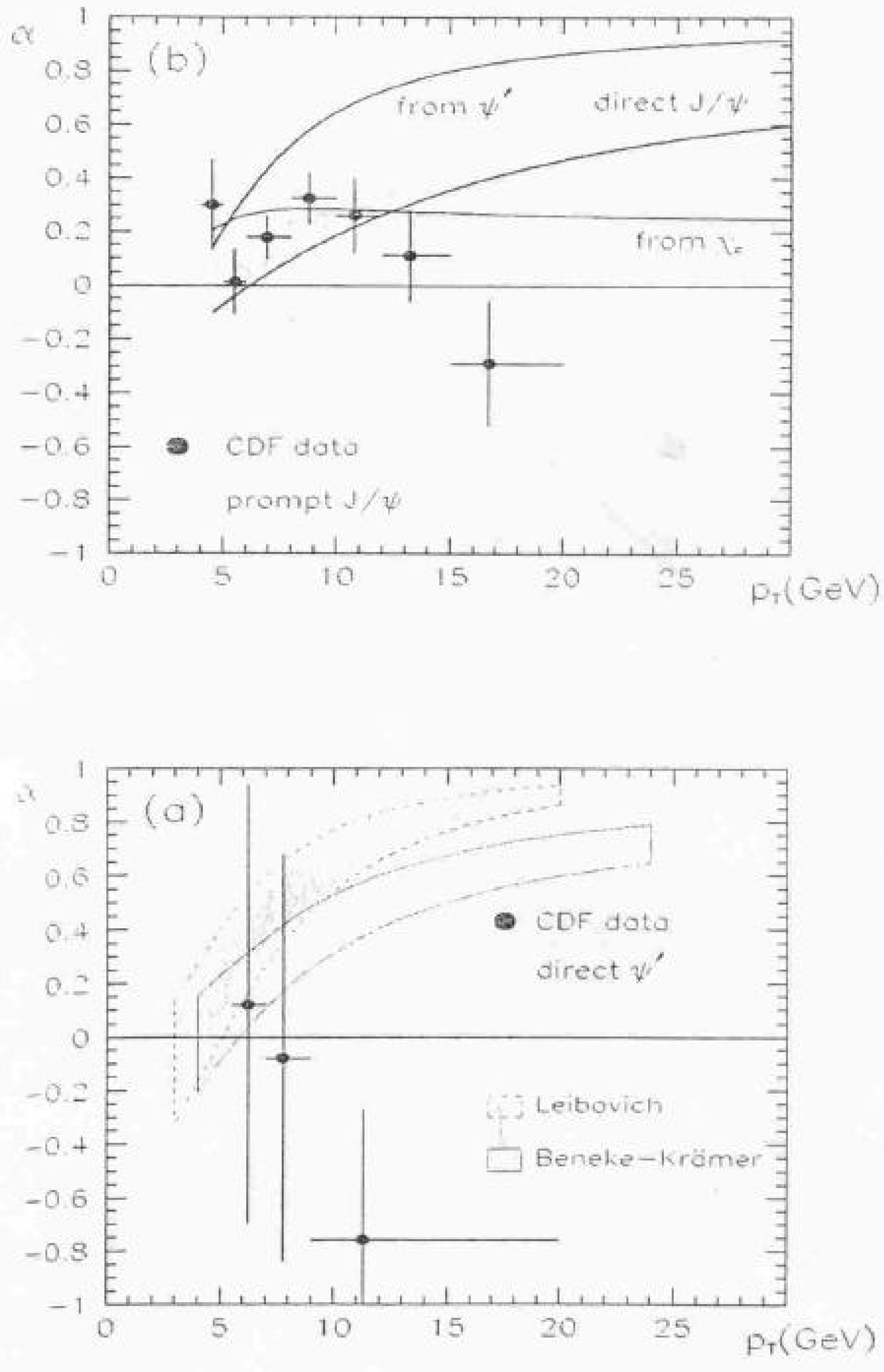




$z = E_\psi / E_\gamma$

J/ψ AND ψ′ SPIN ALIGNEMENT AT TEVATRON

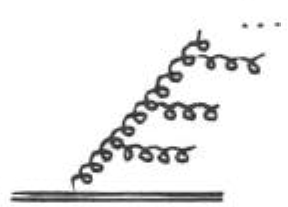
(conventional parton model)



WHAT IS k_T-FACTORIZATION

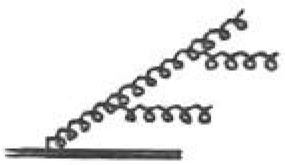
Essential point # 1: GLUON OFF-SHELLNESS

QED	QCD
Collinear approximation Weizsäcker-Williams $F_\gamma(y) = \frac{\alpha}{2\pi y}[1+(1-y)^2]\ln\frac{s}{4m^2}$	Conventional Parton Model Gluon density $G(x,\mu^2)$
Equivalent Photon Approx. $F_\gamma(y,Q^2) = \frac{\alpha}{2\pi y}\cdot\frac{1}{Q^2}[1+(1-y)^2]$ $Q^2 \simeq k_\perp^2/(1-y)$	Non-collinear or Unintegrated Gluon density $\mathcal{F}(x,k_\perp^2,\mu^2)$ $\int_0^{\mu^2}\mathcal{F}(x,k_\perp^2,\mu^2)\,dk_\perp^2 = G(x,\mu^2)$
Polarization properties are determined by the Lepton tensor $L^{\mu\nu} \simeq p_e^\mu p_e^\nu$ use $k_\gamma = y\cdot p_e + k_\perp$ then gauge shift $\epsilon \to \epsilon - k/y$	Virtual gluon spin density matrix $\Rightarrow \epsilon^\mu \epsilon^{*\nu} \simeq k_\perp^\mu k_\perp^\nu / x$
EPA is easily calculable within perturbation theory (one photon exchange is usually enough)	Some complicated equation to describe parton cascade



Essential point #2:

RESUMMATION OF "LARGE LOGARITHMS"



an elementary emission gives $1/x \cdot 1/q^2$
x = Longitudinal momentum fraction
q^2 = virtuality

Integration over the phase space yields $\ln(1/x)\ \ln(q^2)$

$\Rightarrow$ The effective small parameter in perturbation expansion is $\alpha_s \times$ Large Logs

Technically, summation of ladder diagrams is formulated in terms of integro-differential equations

DGLAP collects the terms $[\alpha_s \cdot \ln(q^2/\Lambda^2)]^n$, $n \to \infty$

BFKL collects the terms $[\alpha_s \cdot \ln(1/x)]^n$, $n \to \infty$

The evolution leads to decreasing x and increasing $k_\perp$ (random walk in the $k_\perp$ plane)

small x $\longleftrightarrow$ Large $k_\perp$

TERMINOLOGY

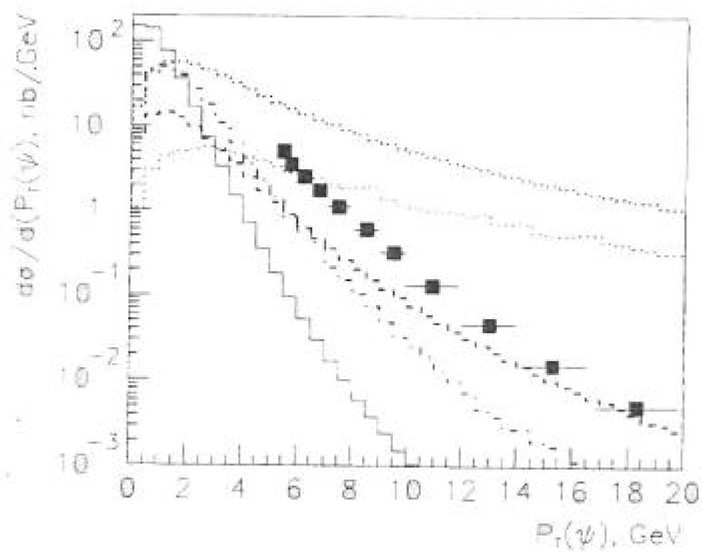
Different names to call the same phenomenon:

"$k_\perp$-factorization"

"Small-x physics"

"Semi-hard approach"

VARIOUS APPROACHES TO J/ψ HADROPRODUCTION AT TEVATRON, $p\bar{p}$ ($\sqrt{s}$ = 1.8 TeV)



———— Colour-singlet, Collinear

- - - - - - Colour-octet $^3S_1(8)$, Collinear

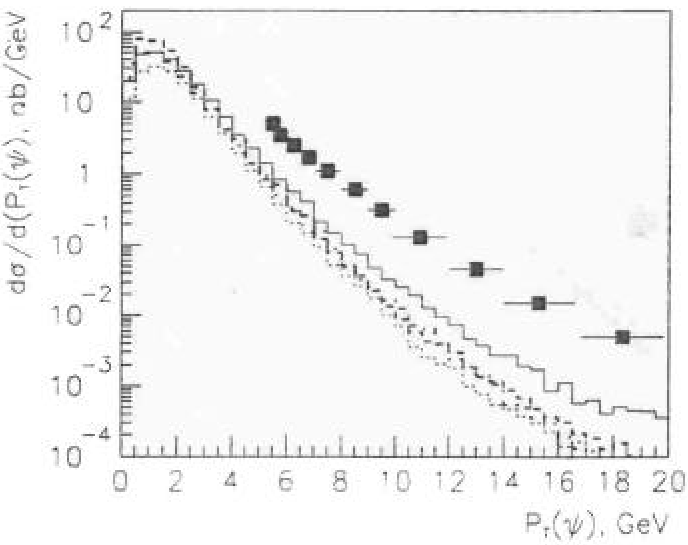
-·-·-·- Colour-singlet, k_T-factorization

·········· Colour-octet $^3S_1(8)$, k_T-factorization
upper curve: $2 \to 1$ subprocess
lower curve: $2 \to 2$ subprocess, $q_R^2 = m_\psi^2$

Blümlein's gluon distribution functions

CDF data

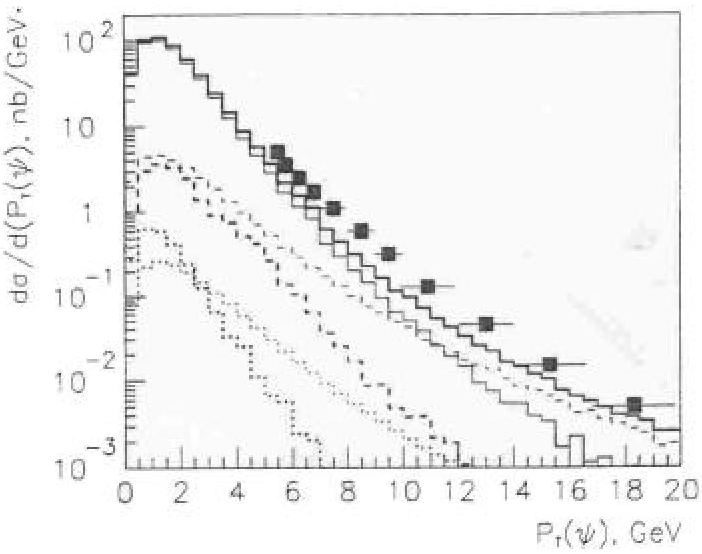
EFFECT OF THE UNINTEGRATED GLUON DISTRIBUTIONS ON THE SHAPE OF THE $p_T(J/\psi)$ SPECTRUM



Color singlet contributions

————	Blümlein
- - - - - - -	KMS
-·-·-·-·-	CCFM (Jung)
··············	DGLAP
■	CDF data

AN OVERALL FIT OF THE J/ψ HADROPRODUCTION WITHIN THE k_T-FACTORIZATION APPROACH



——— $g+g \to J/\psi + g$ $\quad |R(0)|^2 = 8\cdot 10^{-1}\,GeV^3$

- - - - - $g+g \to {}^3P_J[8] + g$ $\quad |R'(0)|^2 = 1.4\cdot 10^{-3}\,GeV^5$

- - - - - $g+g \to {}^3P_J[8]$

········ $g+g \to {}^1S_0[8] + g$ $\quad |R(0)|^2 = 1.6\cdot 10^{-3}\,GeV^3$

········ $g+g \to {}^1S_0[8]$

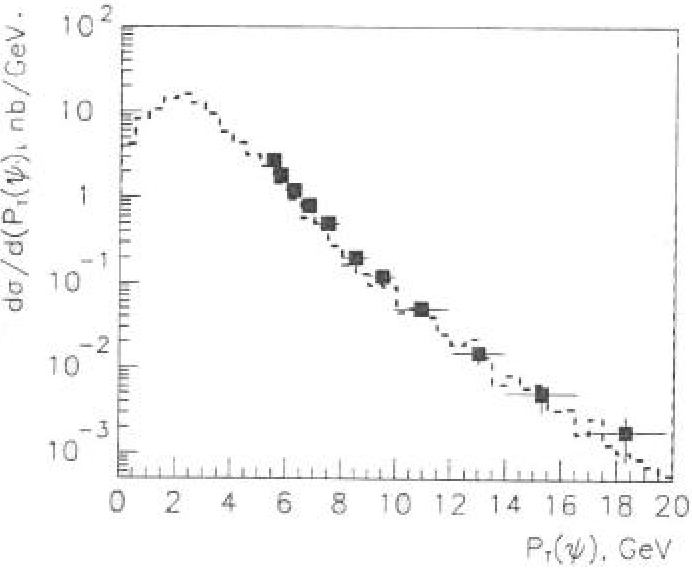
——— all summed together

Blümlein's gluon distribution functions,

$q_R^2 = 1\,GeV^2$

CDF data

AN OVERALL FIT OF THE χ_c HADROPRODUCTION WITHIN THE k_T-FACTORIZATION APPROACH



------- $g + g \to \chi_c$ (colour singlet only)

$\quad\quad\quad\quad\quad\quad \hookrightarrow J/\psi + \gamma$

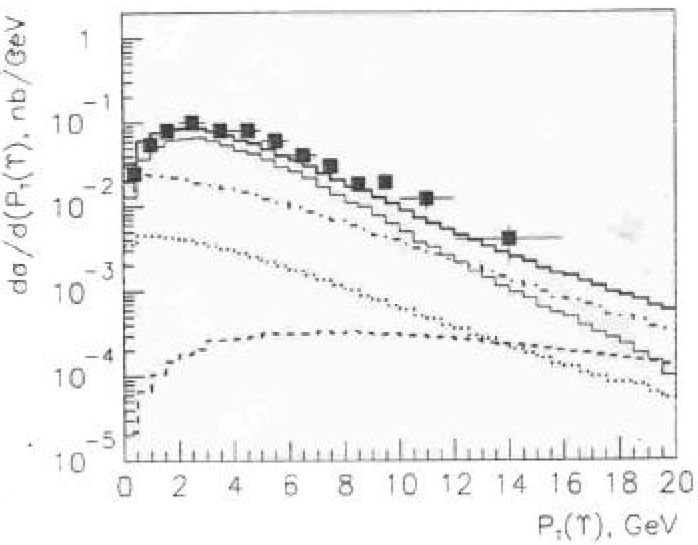
Blümlein's gluon distribution function

$|R'(0)|^2 = 0.07 \text{ GeV}^5$

CDF data

AN OVERALL FIT OF THE Υ HADROPRODUCTION

WITHIN THE k_T- FACTORIZATION APPROACH



————	$g+g \to \Upsilon + g$	$\lvert R(0)\rvert^2 = 6\ \mathrm{GeV}^3$
-·-·-·-·-	$g+g \to {}^3P_J[8]$	$\lvert R'(0)\rvert^2 = 0.5\ \mathrm{GeV}^5$
··········	$g+g \to {}^1S_0[8]$	$\lvert R(0)\rvert^2 = 1\cdot 10^{-1}\ \mathrm{GeV}^3$
-------	$g+g \to {}^3S_1[8]$	$\lvert R(0)\rvert^2 = 6\cdot 10^{-3}\ \mathrm{GeV}^3$
━━━━	all summed together	

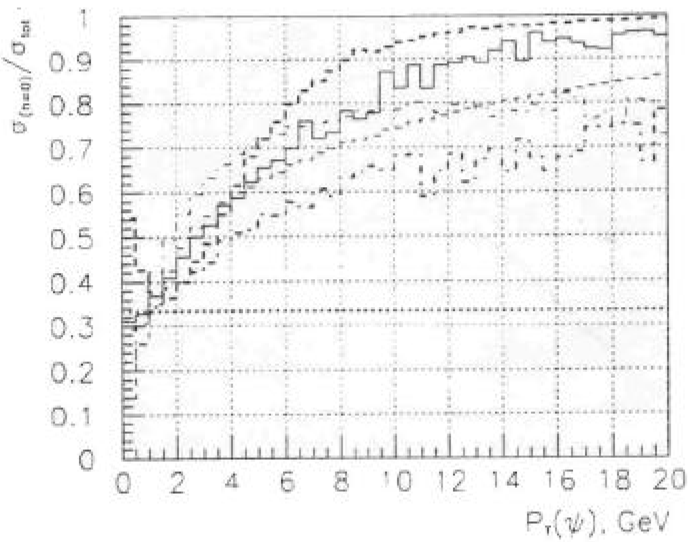
Blümlein's gluon distribution functions,

$q_R^2 = 10\ \mathrm{GeV}^2$

■ CDF data

S. Baranov

FRACTION OF LONGITUDINALLY POLARISED MESONS IN DIFFERENT PARTONIC SUBPROCESSES



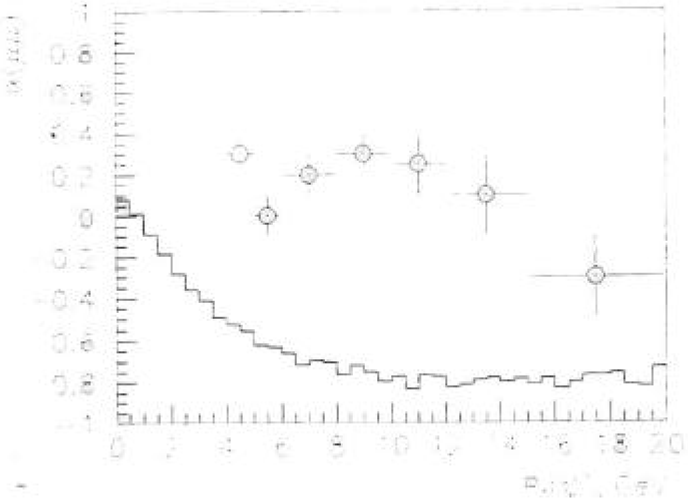
———— (solid)	$g+g \to J/\psi + g$
- - - - - - - -	$g+g \to {}^3S_1[8]$
- - - - - - - (bold dashed)	$g+g \to {}^3S_1[8]+g$
-·-·-·-·-	$g+g \to {}^3P_J[8]$
-··-··-··-	$g+g \to {}^3P_J[8]+g$
··············	$g+g \to {}^1S_0[8]$, $g+g \to {}^1S_0[8]+g$

J/ψ AND ψ′ SPIN ALIGNEMENT AT TEVATRON CONDITIONS

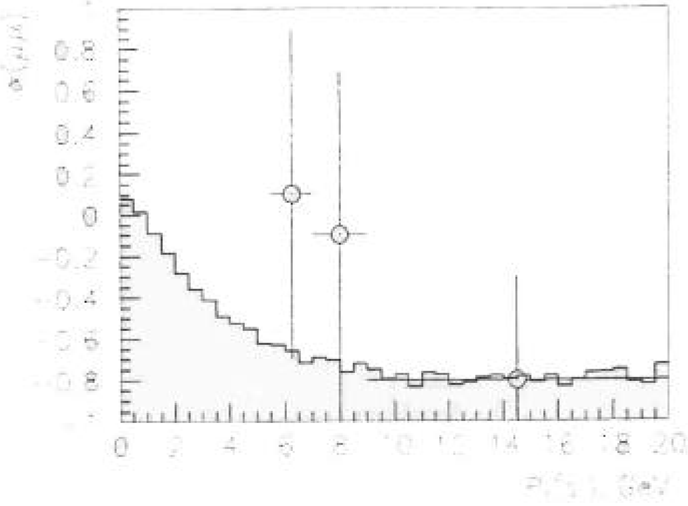
——— theoretical predictions (k_T-factorization)

experimental data (CDF)

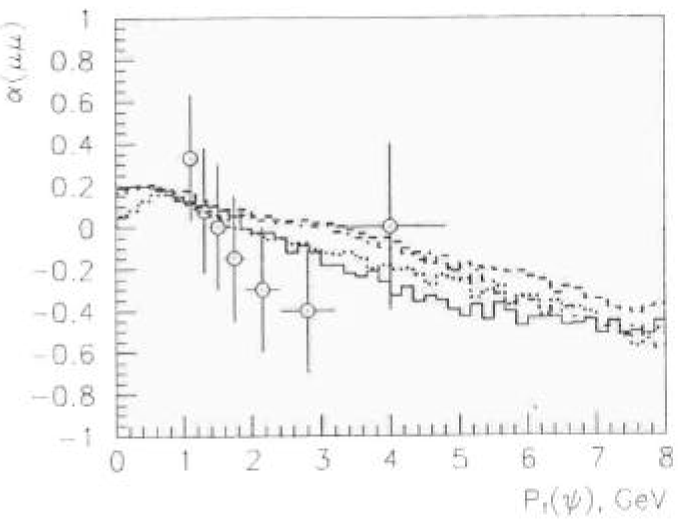
J/ψ



ψ′



J/ψ' SPIN ALIGNEMENT AT HERA
(photoproduction, ZEUS)



DATA: ⊕ ZEUS (preliminary)

MODELS= different gluon densities

——— BFKL (Blümlein)

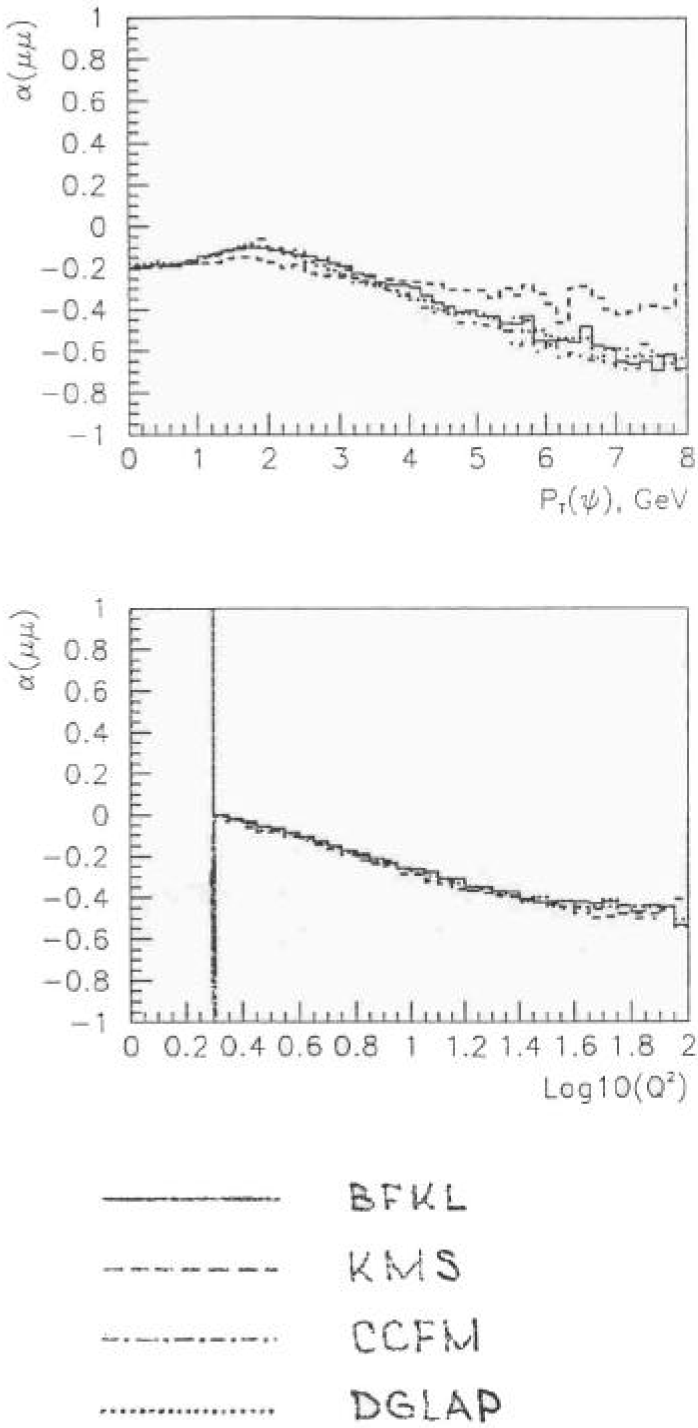
- - - - - KMS

-·-·-·- CCFM (Jung)

·········· DGLAP

J/ψ SPIN ALIGNEMENT AT HERA

(DIS, H1)



CONCLUSIONS

STATE OF THE ART

yet not precise quantitative; the theory is rather qualitative, with some elements of crude phenomenology

Large uncertainties connected with:
- perturbative matrix elements ($2 \to 2$ subprocesses)
- non-perturbative colour-octet transitions
- gluon distribution functions

Complex interplay of their effects on the particle production properties
makes it impossible to fix the relevant parameters by a comparison with experiment

Inclusion of NLO strains many problems, e.g. infrared instability, double counting, etc.

Collinear approximation has fewer internal difficulties, but seems to be less efficient in describing the data

POSITIVE ACHIEVEMENTS

Qualitative agreement in the p_T (J/ψ, χ_c, Υ) spectra; a self-consistent description of both pp and ep

Qualitative agreement with spin alignement data
- the only explanation known at present !

THE CRUCIAL ROLE OF SPIN OBSERVABLES

Allow to clearly distinguish between the on-shell and off-shell gluon dynamics (in favour of the latter)