Double J/ψ production in the k_t-factorization

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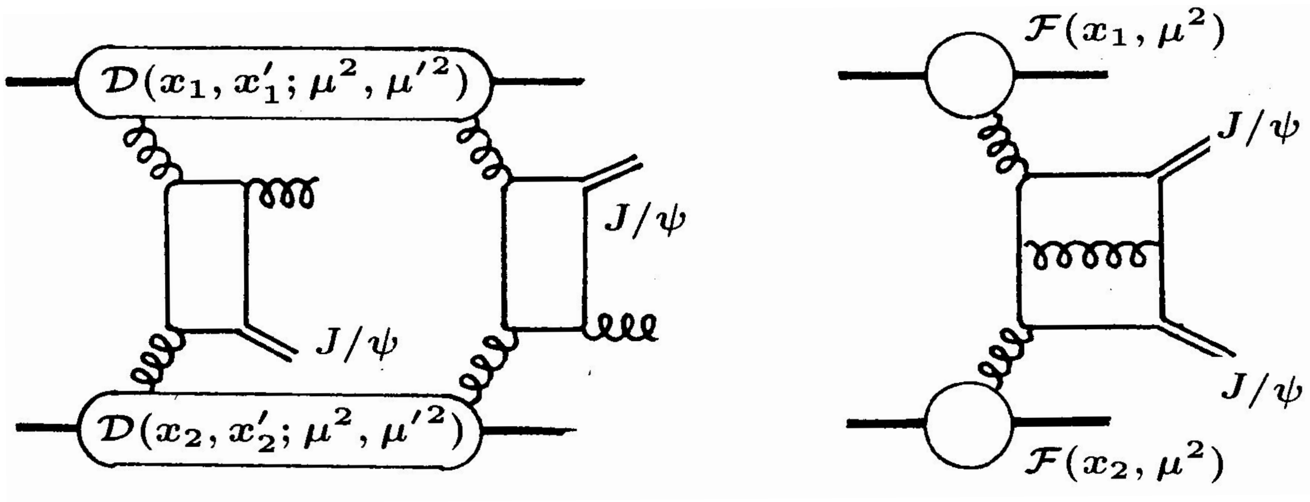
INTRODUCTION

The production of J/ψ pairs is interesting:
– on its own, as a QCD test
– as a possible indicator of double parton scattering (DPS)



The two mechanisms have comparable cross sections;
DPS can be discriminated from SPS if the kinematics is different

THEORETICAL FRAMEWORK

Color-Singlet Gluon-Gluon Fusion

Perturbative production of a heavy quark pair within QCD;

Gluon spin density matrix: $\epsilon_g^\mu \epsilon_g^{*\nu} = k_T^\mu k_T^\nu / |k_T|^2$

Spin projection operators to guarantee the proper quantum numbers:

for Spin-triplet states $\mathcal{P}(^3S_1) = \not\epsilon_V(\not p_Q + m_Q)/(2m_Q)$

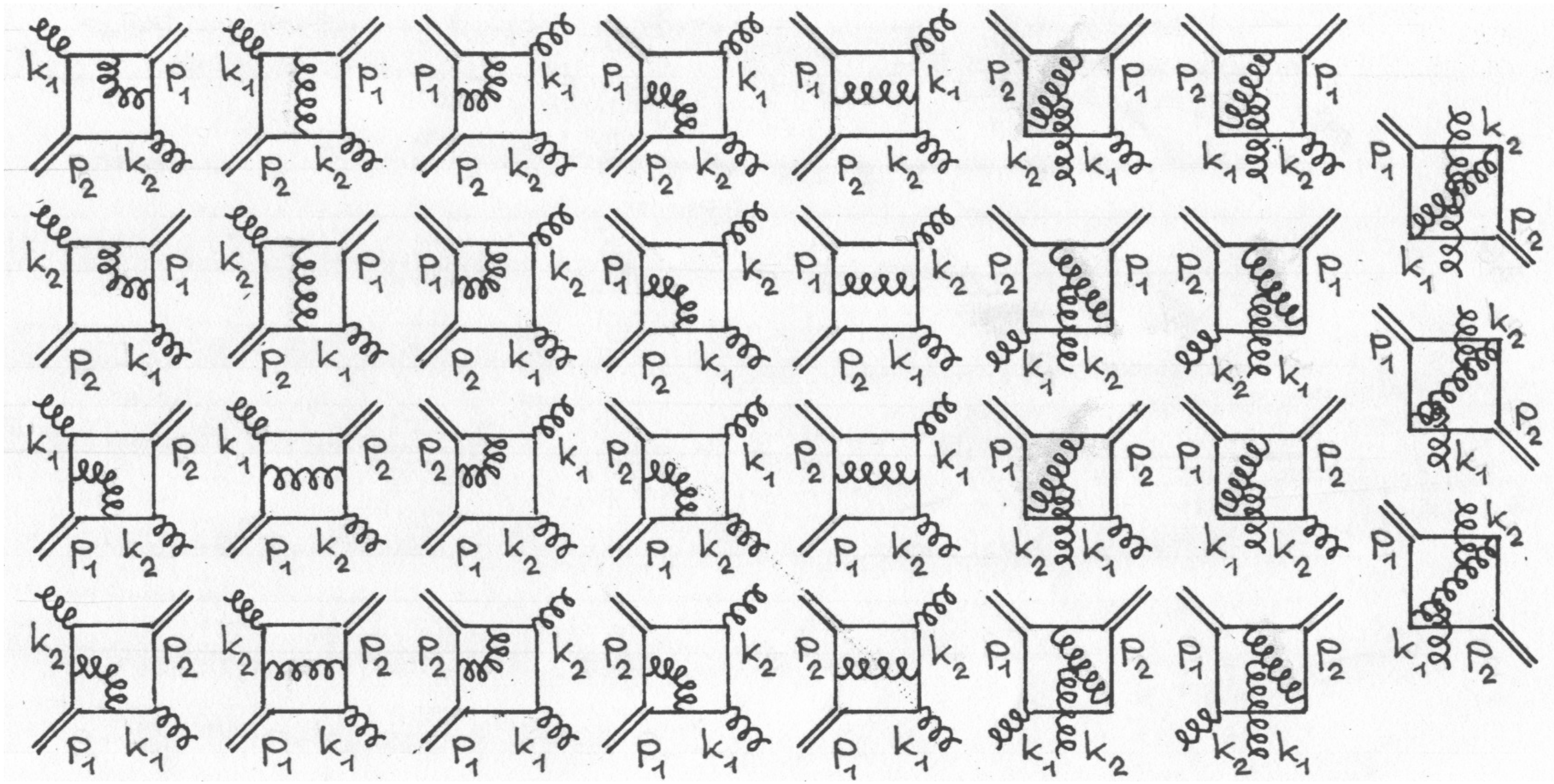
Probability to form a bound state is determined by the wave function:

for S-wave states $|R_\psi(0)|^2$ is known from leptonic decay widths

J/ψ spin density matrix (including the decay $J/\psi \to \mu^+\mu^-$):

$$\epsilon_\psi^\mu \epsilon_\psi^{*\nu} = 3(l_1^\mu l_2^\nu + l_2^\mu l_1^\nu - m_\psi^2 g^{\mu\nu}/2)/m_\psi^2$$

Feynman diagrams



$\boldsymbol{k_1}$, $\boldsymbol{k_2}$, **the incoming gluon momenta**
$\boldsymbol{p_1}$, $\boldsymbol{p_2}$, **the produced** $\boldsymbol{J/\psi}$ **momenta**

NUMERICAL RESULTS

What do we expect:

Changes in the p_T spectra:

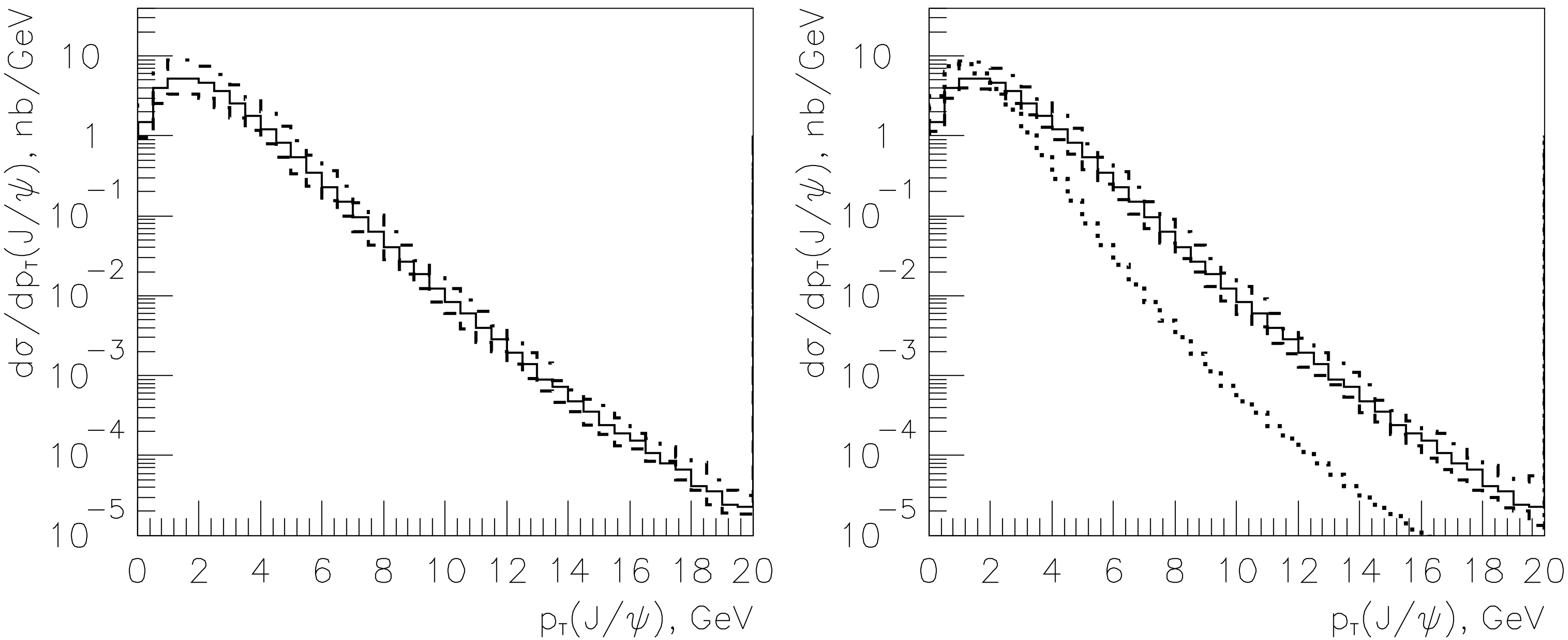
Hard subprocess matrix element $|\mathcal{M}(gg \to J/\psi J/\psi)|^2 \propto 1/p_T^8$

Transverse momentum generated in the evolution cascade results in the k_t-dependent gluon densities $\mathcal{F}(x, k_t^2, \mu^2) \propto 1/k_t^4$

Changes in the kinematics:
In particular, destroyed azimuthal correlations (see to what extent it is true)

Changes in the polarization properties
as a result of gluon off-shellness

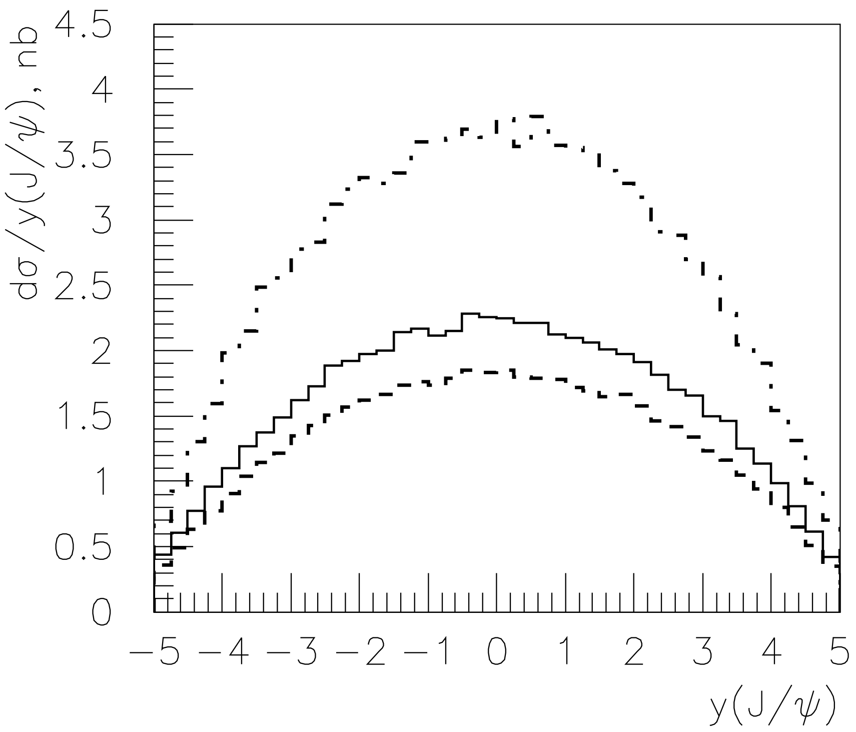
J/ψ transverse momentum distributions

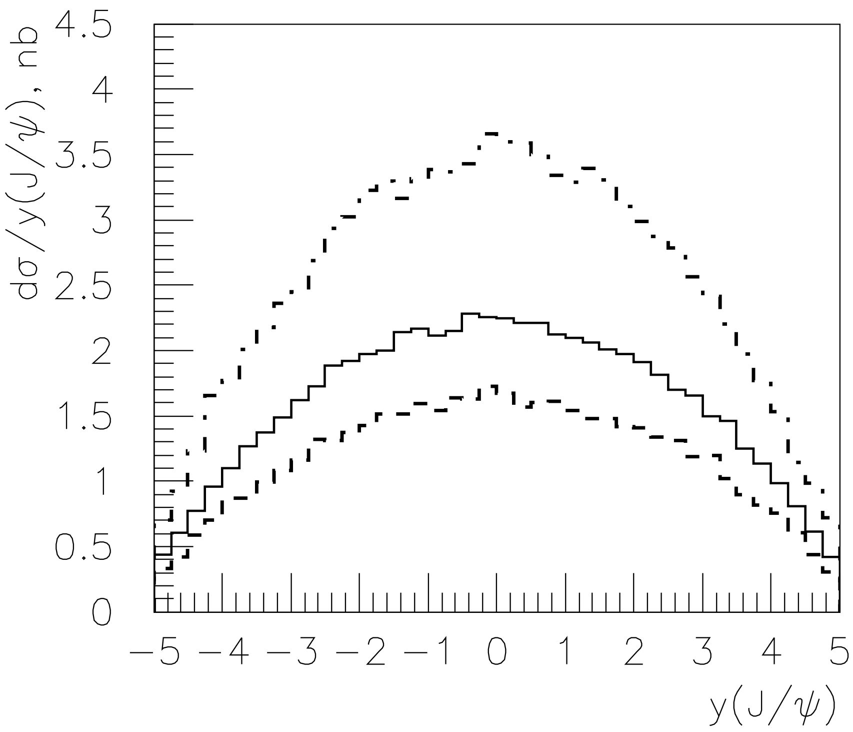


Renormalization scale
$\mu_R^2 = \hat{s}/2; \quad \underline{\hat{s}/4}; \quad \hat{s}/8$

$\mathcal{F}(x, k_t^2, \mu_F^2) = A+, \ \underline{A0}, \ A-$
dotted line = collinear GRV

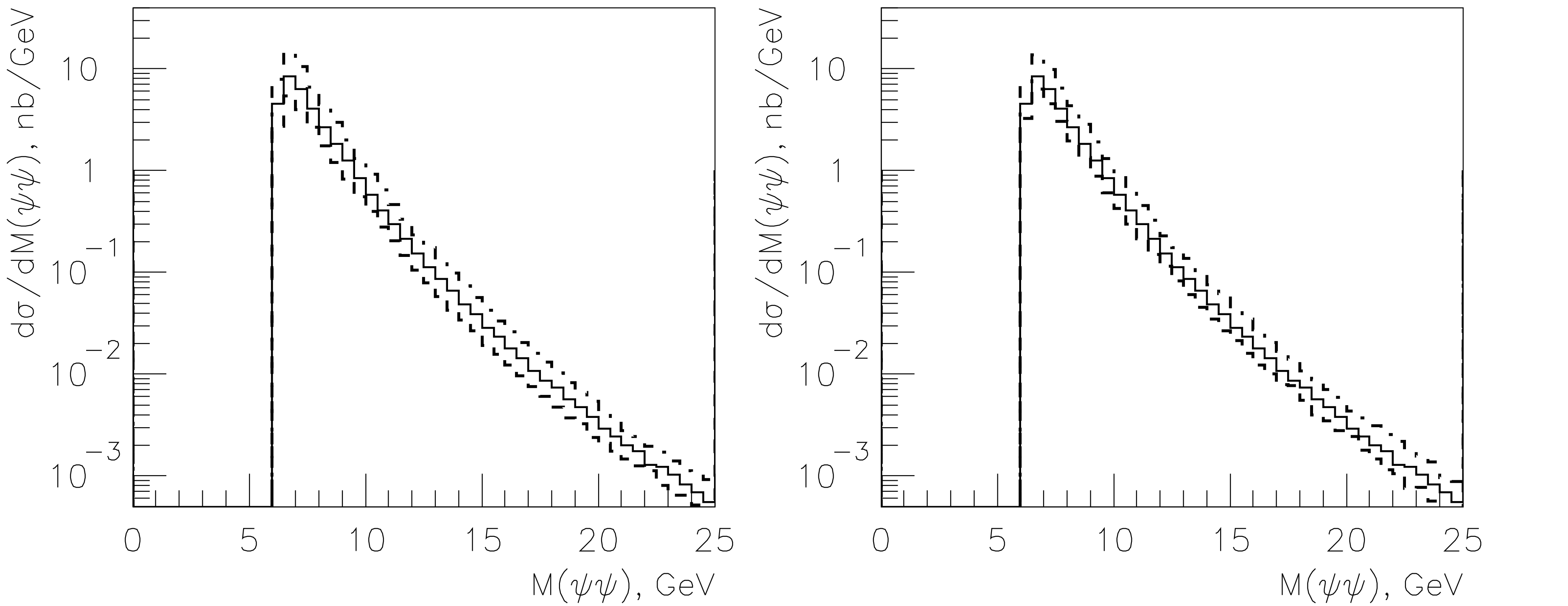
J/ψ rapidity distributions





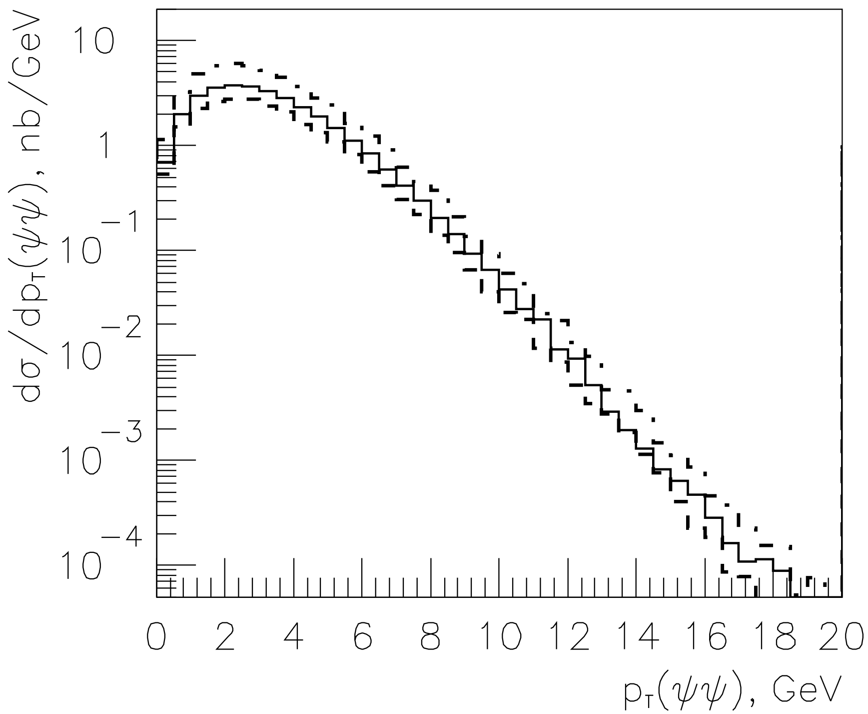
$\mu_R^2 = \hat{s}/2; \quad \underline{\hat{s}/4}; \quad \hat{s}/8$ $\qquad$ $\mathcal{F}(x, k_t^2, \mu_F^2) = A+, \ \underline{A0}, \ A-$

$J/\psi\ J/\psi$ invariant mass distributions



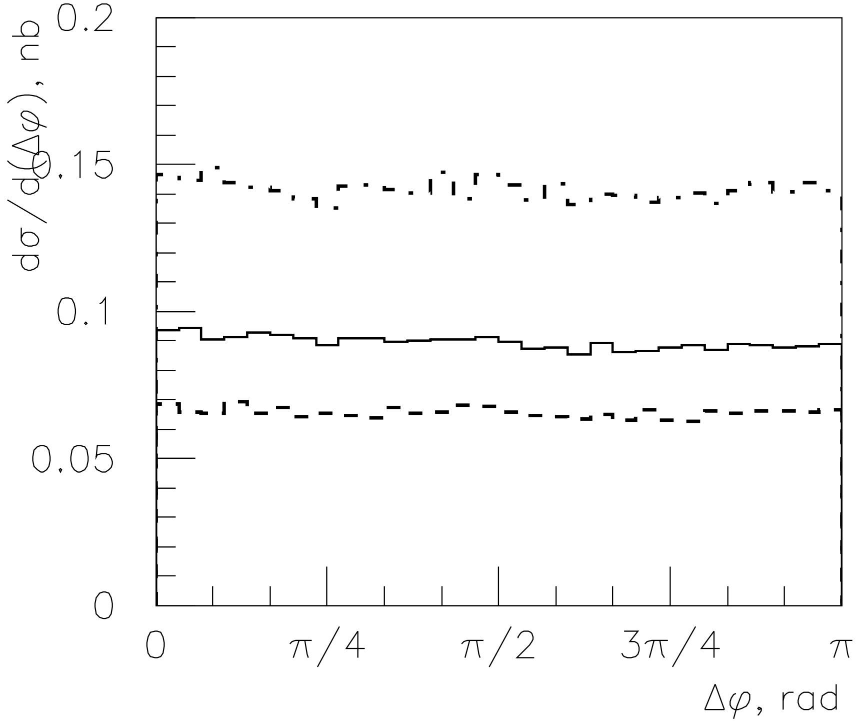
$\mu_R^2 = \hat{s}/2;\quad \underline{\hat{s}/4};\quad \hat{s}/8$ $\qquad$ $\mathcal{F}(x, k_t^2, \mu_F^2) = A+,\ \underline{A0},\ A-$

J/ψ pair transverse momentum



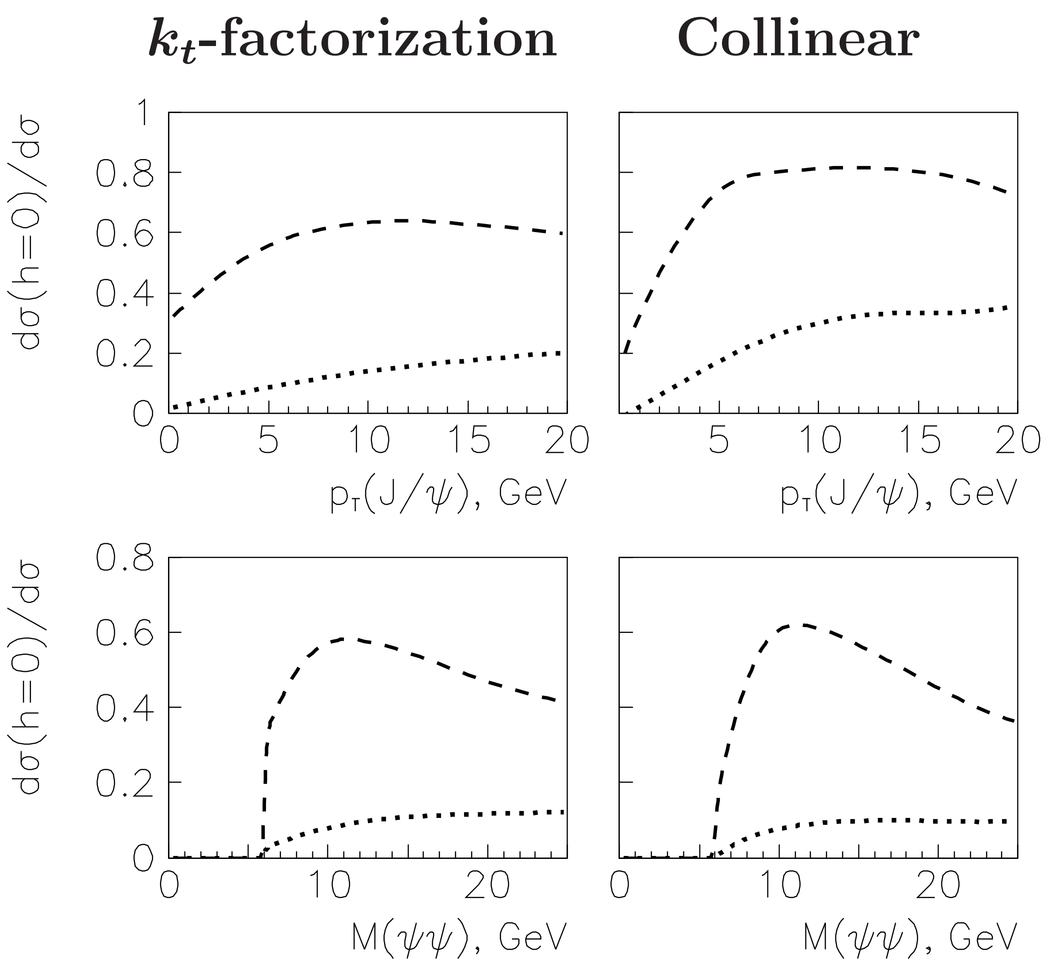
$$\mathcal{F}(x, k_t^2, \mu_F^2) = A+,\ \underline{A0},\ A-$$

Azimuthal correlations



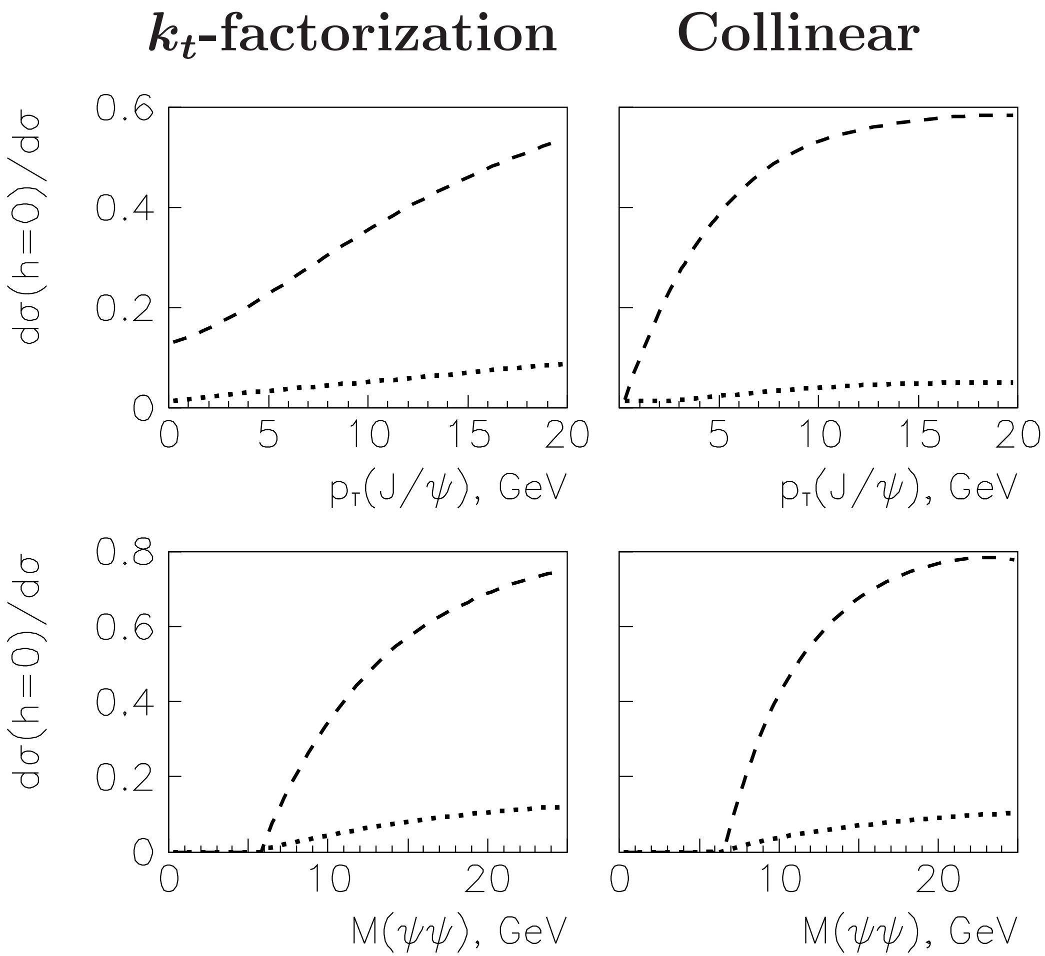
$$\mathcal{F}(x, k_t^2, \mu_F^2) = A+,\ \underline{A0},\ A-$$

J/ψ spin alignement in the Helicity frame



Dashed, at least one J/ψ has longitudinal polarization;
Dotted, both J/ψ have longitudinal polarization.

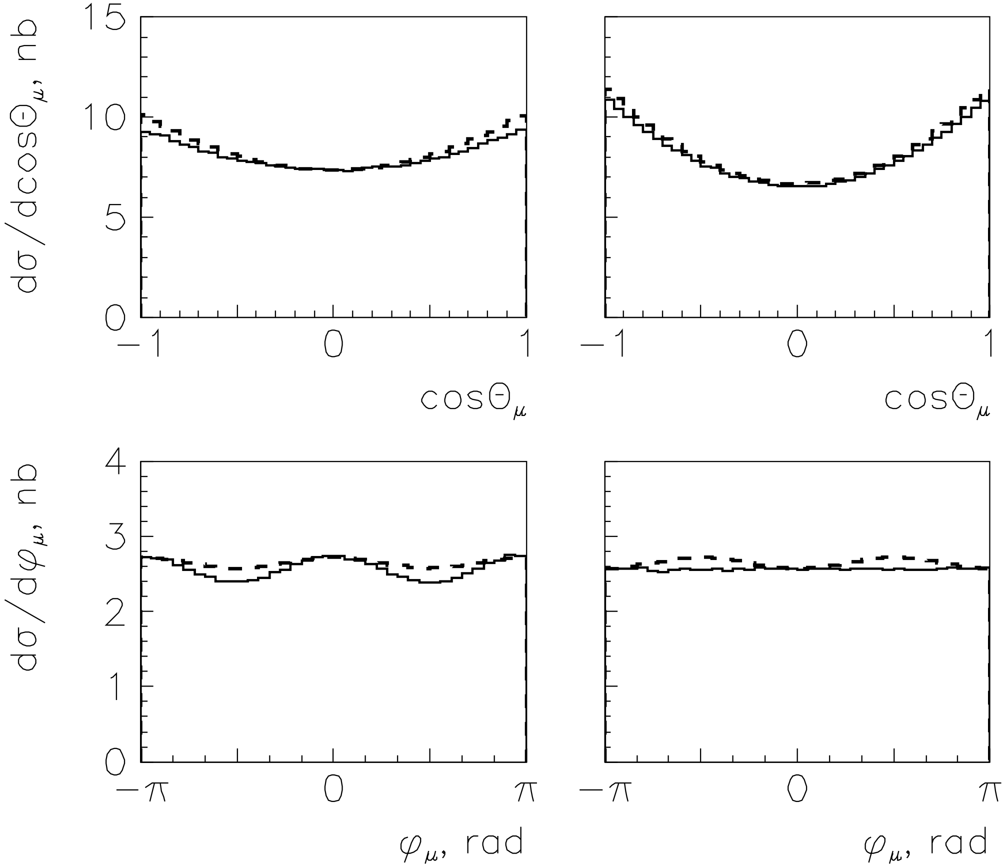
J/ψ spin alignement in the Collins-Soper frame



Dashed, at least one J/ψ has longitudinal polarization;
Dotted, both J/ψ have longitudinal polarization.

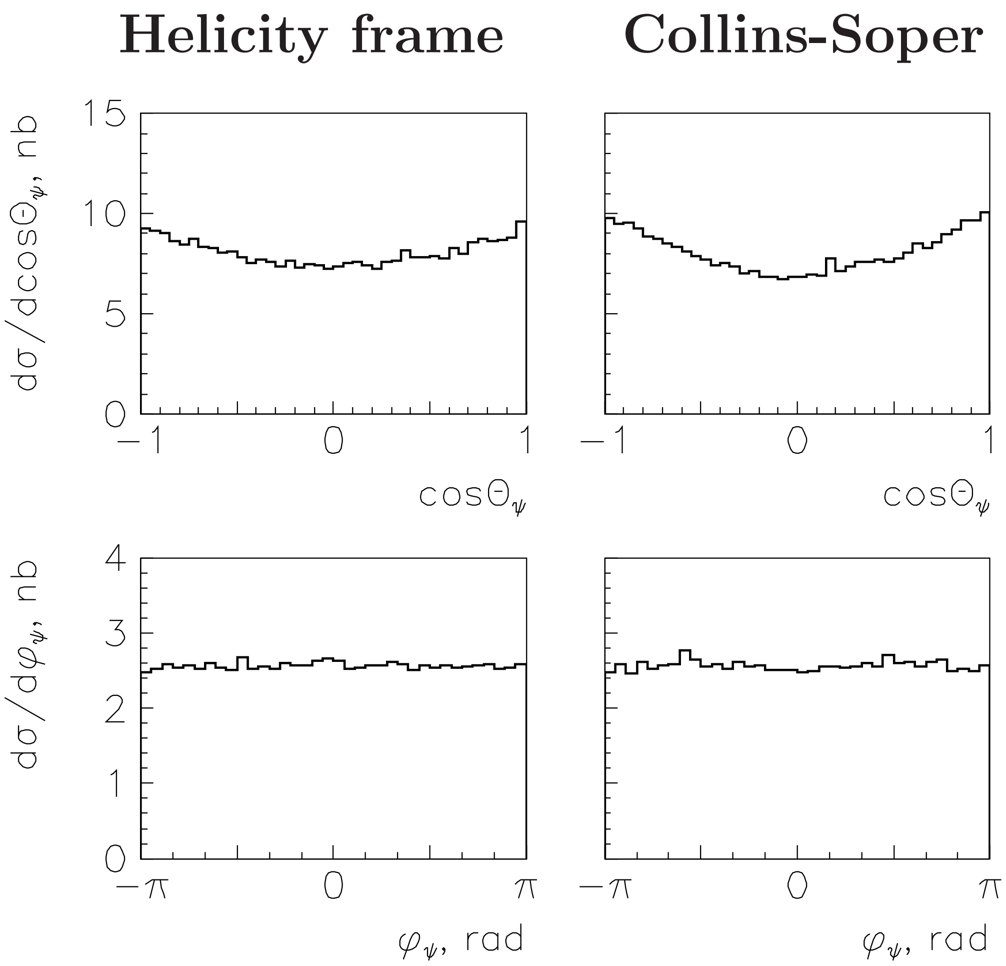
Decay muon angular distributions

Helicity frame **Collins-Soper**



Solid, k_t-factorization approach;
Dashed, collinear parton model

J/ψ meson angular distributions (pair rest frame)



k_t-factorization approach only

CONCLUSIONS

The absolute production cross section
ranges from 10 nb to 27 nb,
depending on the choice of the gluon densities and the scale μ_R

Transverse momentum distributions
are very different from those seen in the collinear case

Azimuthal correlations
show no evidence of the original back-to-back J/ψ configuration
(bad for detecting double parton scattering)

Polarization properties
are more or less similar to those seen in the collinear case

DOUBLE PARTON INTERACTIONS

Two independent interactions at a time

$$\sigma^{\rm AB}_{\rm DPS} = \frac{1}{2}\sum_{i,j,k,l}\int \Gamma_{ij}(x_1, x_1'; {\rm b}_1, {\rm b}_2; Q^2, Q'^2)\hat\sigma^A_{ik}(x_1, x_2, Q^2)$$
$$\times\Gamma_{kl}(x_2, x_2'; {\rm b}_1-{\rm b}, {\rm b}_2-{\rm b}; Q^2, Q'^2)\hat\sigma^B_{jl}(x_1', x_2', Q'^2)$$
$$\times dx_1\, dx_2\, dx_1'\, dx_2'\, d^2b_1\, d^2b_2\, d^2b$$

with b_i being the impact parameters and Q^2 the probing scales

N. Paver, D. Treleani, Nuovo Cimento A 70, 215 (1982)

Further assumptions:
Decoupling of longitudinal and transversal variables

$$\Gamma_{ij}(x, x'; {\rm b}_1, {\rm b}_2; Q^2, Q'^2) = \mathcal{D}_{ij}(x, x'; Q^2, Q'^2) f({\rm b}_1) f({\rm b}_2)$$

Factorization of parton distributions

$$\mathcal{D}_{ij}(x, x'; Q^2, Q'^2) = \mathcal{F}_i(x, Q^2)\mathcal{F}_j(x', Q'^2)$$

Result in $\sigma^{\rm AB}_{\rm DPS} = \frac{1}{2}\frac{\sigma^A_{\rm SPS}\sigma^B_{\rm SPS}}{\sigma_{\rm eff}}$ **with** $\sigma_{\rm eff} = 14.5\ mb$

Comparisons with LHCb at $\sqrt{s} = 7$ Tev

The only restriction is $2 < y^{J/\psi} < 4.5$
Acceptance is corrected for $p_t(\mu) > 650$ MeV

With $|\mathcal{R}_\psi(0)|^2$=0.8 GeV^3, $|\mathcal{R}'_\chi(0)|^2$=0.075 GeV^5, $\alpha_s(\hat{s}/4)$,
and A0 gluon densities we obtain

$$\left.\begin{array}{l} \sigma_{\rm SPS}^{\rm direct}(J/\psi) = 7.1\ \mu{\rm b} \\ \sigma_{\rm SPS}(\chi_1) = 1.5\ \mu{\rm b} \\ \sigma_{\rm SPS}(\chi_2) = 5.1\ \mu{\rm b} \end{array}\right\} \sigma_{\rm SPS}^{\rm prompt}(J/\psi) = 8.7\ \mu{\rm b}\ [\text{LHCb result} \simeq 10\ \mu{\rm b}]$$

$$\left.\begin{array}{l} \sigma_{\rm DPS}(J/\psi + J/\psi) = 2\ {\rm nb} \\ \sigma_{\rm SPS}(J/\psi + J/\psi) = 4\ {\rm nb} \end{array}\right\} \quad [\text{LHCb result} = 5.6 \pm 1.1 \pm 1.2\ {\rm nb}]$$

$\sigma_{\rm DPS}$ is hardly identifiable over the theoretical uncertainty in $\sigma_{\rm SPS}$

OTHER INTERESTING PROCESSES

$\chi_c + \chi_c$

Suppressed by the P-state wave functions by two orders of magnitude

$\sigma_{\rm DPS} \simeq 0.1$ **nb (for J/ψ J/ψ final state)**

Experimental disadvantage: low-energy photons

$J/\psi + \chi_c$

Not possible at the Leading Order due to charge parity conservation

$\sigma_{\rm DPS} \simeq 1$ **nb (for J/ψ J/ψ final state)**

Experimental disadvantage: low-energy photons

$J/\psi + \Upsilon$

Not possible at the Leading Order (no Feynman diagrams)

$\sigma_{\rm DPS} \simeq 70$ **pb**

To be continued...