Correlations in J/ψ pair production as SPS versus DPS discriminators

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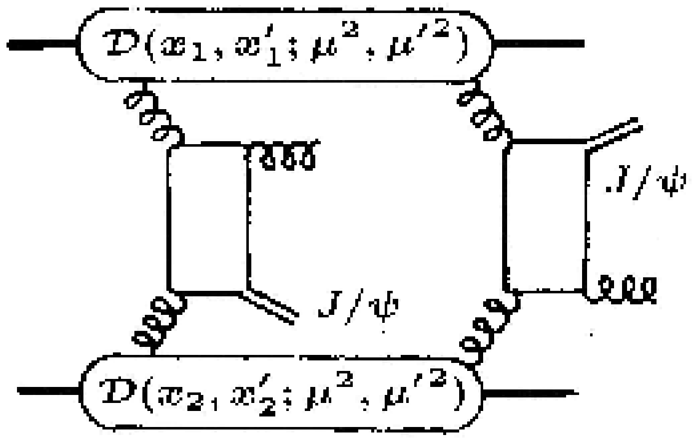
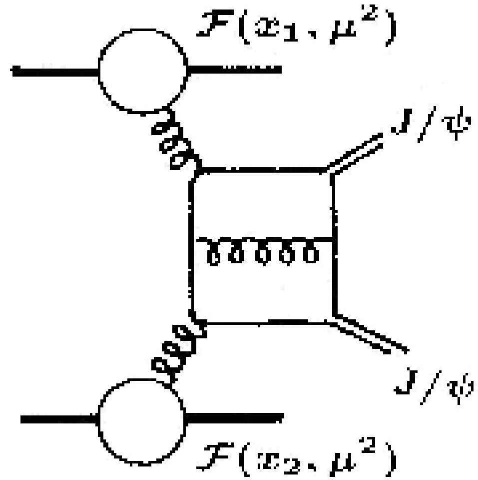
1. Motivation
2. Transverse momentum and azimuthal correlations
3. Rapidity correlations
4. Conclusions

MOTIVATION

Disentangling the single- and double-parton scattering





Encouraged by the recent LHCb, CMS and D0 measurents

R. Aaij *et al.* (LHCb Collab.,) Phys.Lett.B 707, 52 (2012)
V. Khachatryan *et al.* (CMS Collab.,) arXiv:1406.0484
V.M. Abazov *et al.* (D0 Collab.,) arXiv:1406.2380

The two mechanisms have comparable cross sections

A.V.Berezhnoy, A.K.Likhoded, A.V.Luchinsky, A.A.Novoselov, Phys. Rev. D 84, 094023 (2011)
C.-H.Kom, A.Kulesza, W.J.Stirling, Phys. Rev. Lett. 107, 082002 (2011)
S.P.Baranov, A.M.Snigirev, N.P.Zotov, Phys.Lett.B 705, 116 (2011)

DPS can be discriminated from SPS if the kinematics is different
$\Rightarrow$ we need a detailed understanding of the production properties with all of the possible contributions carefully taken into account

THEORETICAL FRAMEWORK

Subprocesses taken into consideration

on the SPS side:

Leading-Order direct production $\mathcal{O}(\alpha_s^4)$ $g + g \to J/\psi + J/\psi$

Onium-onium (pseudodiffractive) scattering $\mathcal{O}(\alpha_s^6)$
(can mimic the DPS kinematics)

- **one-gluon exchange** $g + g \to J/\psi + J/\psi + g + g$
- **two-gluon exchange** $g + g \to J/\psi + J/\psi$

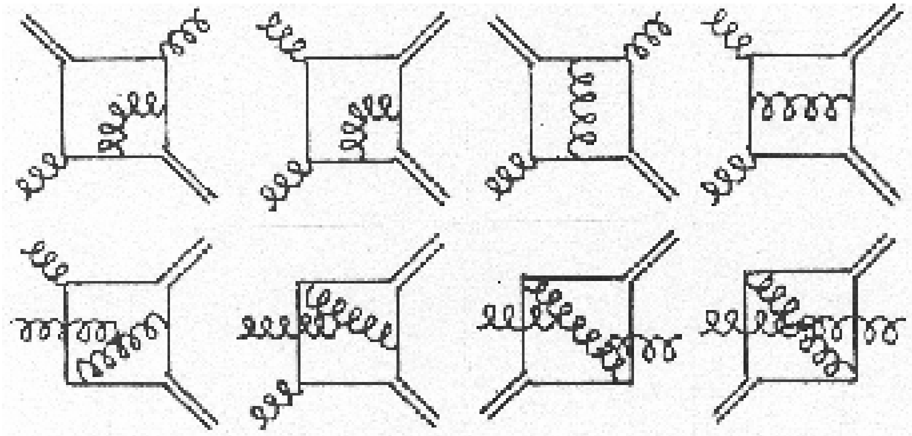
on the DPS side:

Inclisuve direct J/ψ production $g + g \to J/\psi + g$

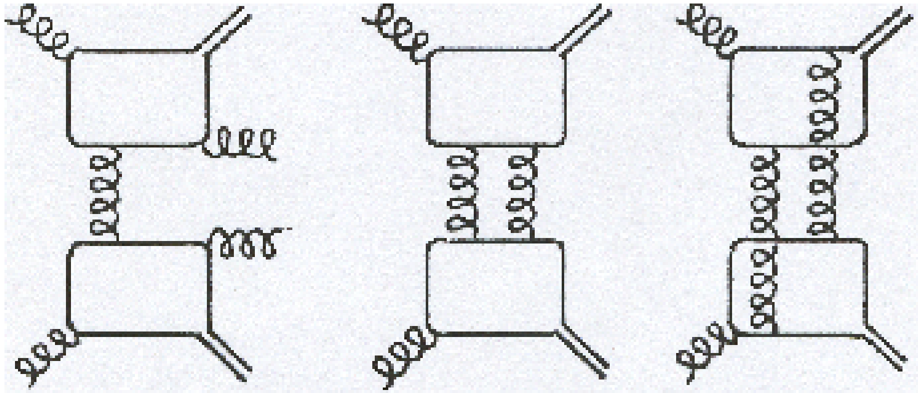
Inclisuve direct χ_c production $g + g \to \chi_c \to \psi + \gamma$

Straightforward calculations, all done in the k_t-factorization approach
S.P.Baranov,A.M.Snigirev,N.P.Zotov,A.Szczurek,W.Schäfer (Phys. Rev. D 87, 034035 (2013))

Examples of Feynman diagrams for SPS contributions



Direct gluon-gluon fusion
(Leading-Order)



Onium-onium scattering:
one-gluon exchange
two-gluon exchange

Double Parton interactions

Two independent interactions $\hat{\sigma}^A$ and $\hat{\sigma}^B$ at a time:

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

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

$$\Gamma_{ij}(x, x'; \mathbf{b_1}, \mathbf{b_2}; Q^2, Q'^2) = \mathcal{D}_{ij}(x, x'; Q^2, Q'^2) f(\mathbf{b_1}) f(\mathbf{b_2})$$

Factorization of parton distributions

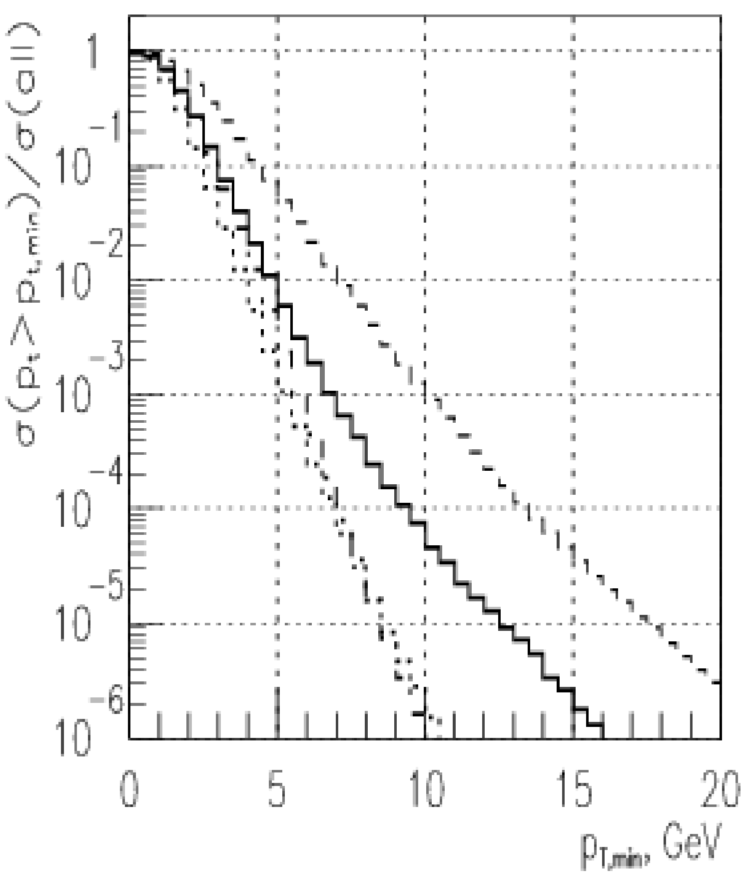
$$\mathcal{D}_{ij}(x, x'; Q^2, Q'^2) = \mathcal{F}_i(x, Q^2) \mathcal{F}_j(x', Q'^2)$$

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

NUMERICAL RESULTS

Transverse momentum correlations:

fraction of the cross section after imposing cuts $p_t(J/\psi) > p_{t,min}$



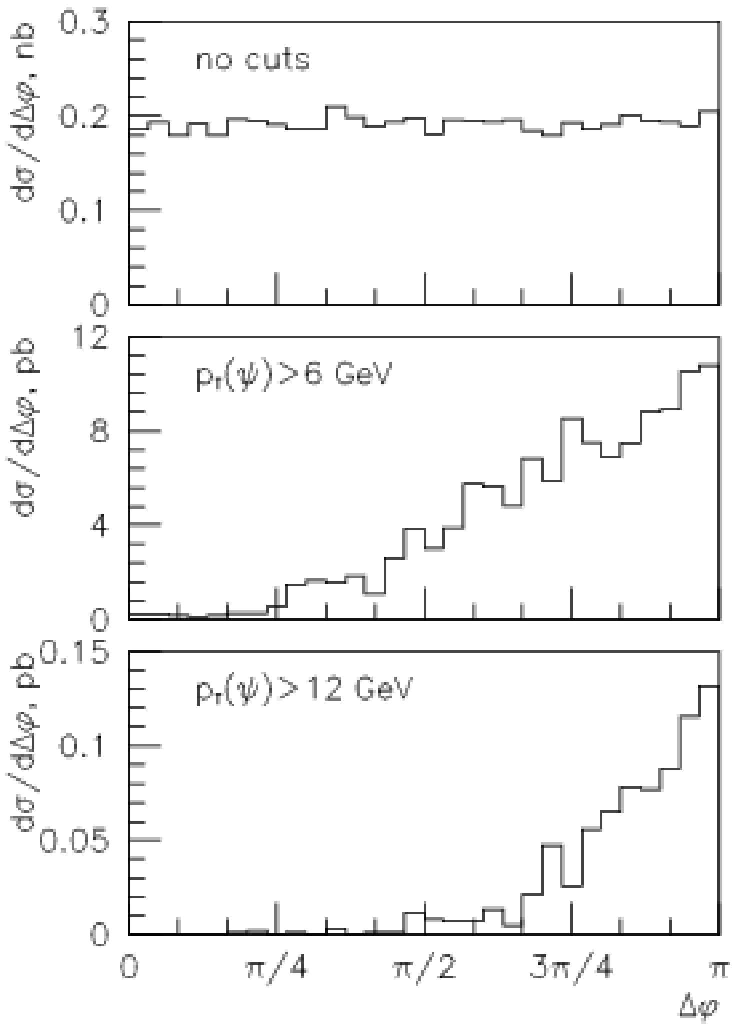
Dashed = cuts on only one J/ψ in the SPS production mode (equivalent to cuts on both J/ψ's if they were fully back-to-back)

Dotted = square of dashed line (idealistic independent mode)

Dash-dotted = cuts on both J/ψ's in the true DPS production mode

Solid line = cuts on both J/ψ's in the true SPS production mode

Azimuthal angle correlations in SPS, effect of cuts $p_t(J/\psi) > p_{t,min}$

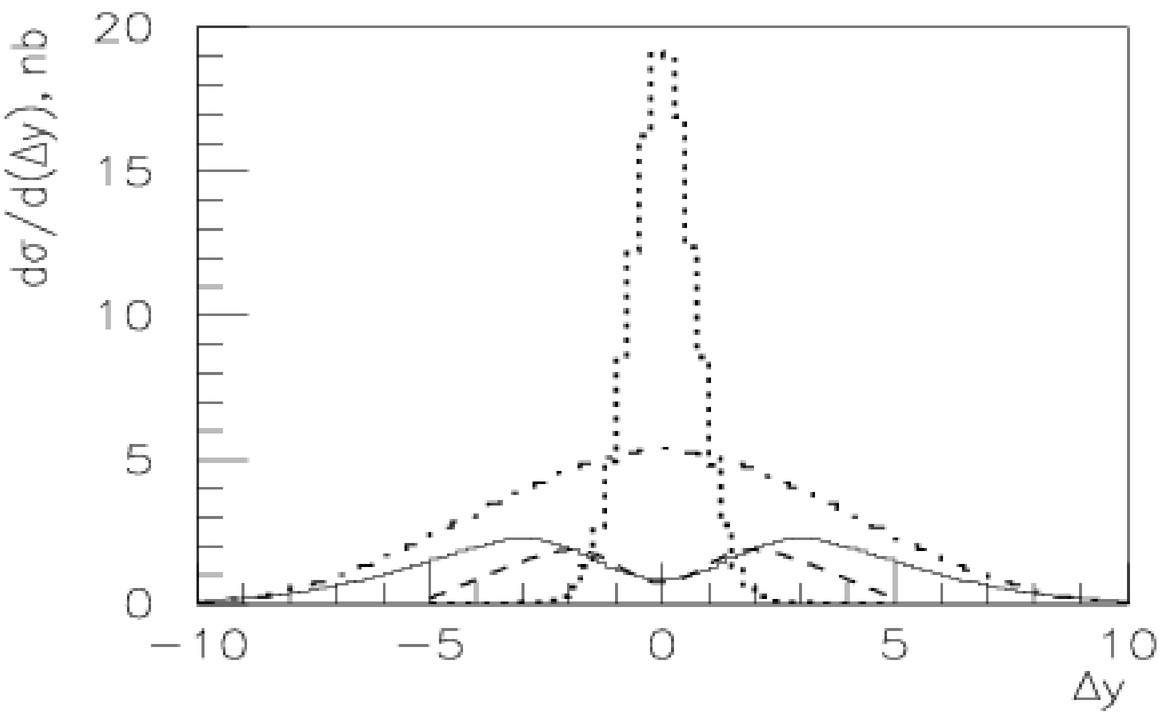


DPS is always flat in $\Delta\varphi$

SPS is very similar to DPS at $p_{t,min} < 4$ **Gev. At hihger** p_t **the SPS production becomes correlated, but the cross section falls dramatically.**

Difficult to detect experimentally

$J/\psi - J/\psi$ rapidity difference



Dotted line = direct LO gluon-gluon fusion (SPS mode)
Dash-dotted = Double Parton Scattering
Dashed line = one-gluon exchange (multiplied by 1000)
Solid line = two-gluon exchange (multiplied by 25)

A0 gluon densities

(In fact, the shapes are stable against variations in gluon densities)

Reasons for pseudo-diffractive processes to be small

– **Two extra powers of** α_s

– **Larger average invariant mass** $M(\psi\psi)$

– **Color: Direct** $g + g \to J/\psi + J/\psi$

$$|tr\{T^aT^cT^cT^b\}|^2 = |[(N_c^2 - 1)/(4N_c)]\delta^{ab}|^2 = [\tfrac{2}{3}\delta^{ab}]^2 = 32/9$$

compared to Pseudodiffractive one- and two-gluon exchange

$$[\tfrac{1}{4}d^{ace}\tfrac{1}{4}d^{bde}]^2 = \frac{(N_c^2-1)(N_c^2-4)^2}{256\ N_c^2} = \frac{1}{256}\frac{200}{9} \simeq 0.1$$

– **Specific properties of the one-gluon exchange amplitude (vanishes when any of the gluons becomes soft)**

CONCLUSIONS

A careful inspection of all possible contributions shows that:

– **Total SPS and DPS rates are comparable in size**

– **Transverse momentum and azimuthal correlations:**
SPS and DPS look similar at $p_t(J/\psi) < 4$ GeV,
they become different at larger $p_t(J/\psi)$
but the cross sections fall dramatically

– **Rapidity difference $\Delta y = y(\psi_1) - y(\psi_2)$:**
a very good discriminator;
SPS is concenrated within $|\Delta y| < 2$,
DPS spreads far beyond $|\Delta y| >> 2$

– **No contamination from onium-onium scattering**

– **CMS and D0 data favor the presence of DPS**