Diffractive production of $c\bar{c}$

Marta Łuszczak

Institut of Physics

University of Rzeszow

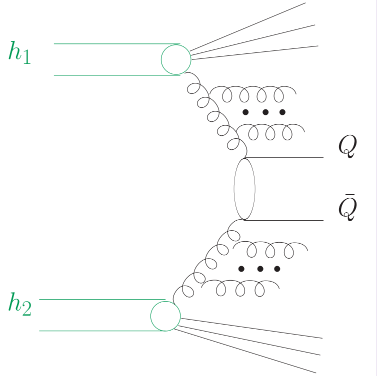
December 15-21, 2011
Qui Nhon, Vietnam

Plan of the talk

- Introduction
- Parton distributions
- Results
  - k_t-factorization
  - gluon distributions at small-x region
  - γg and $g\gamma$ subprocesses
  - $\gamma\gamma$ subprocesses
  - single and central diffraction
  - production of two $c\bar{c}$ pairs in double-parton scattering
- Conclusions

Production of heavy quarks

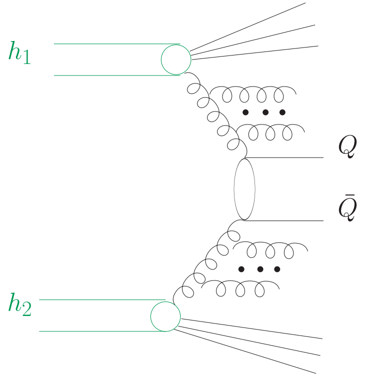
$h_1 + h_2 \rightarrow Q + \bar{Q} + X$:



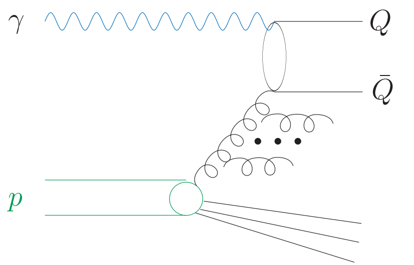
$\gamma + p \rightarrow Q + \bar{Q} + X$:

Production of heavy quarks

$h_1 + h_2 \rightarrow Q + \bar{Q} + X$:

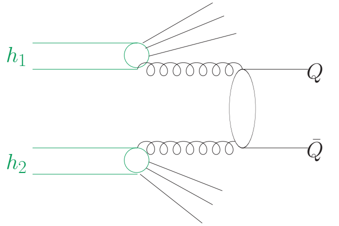


$\gamma + p \rightarrow Q + \bar{Q} + X$:

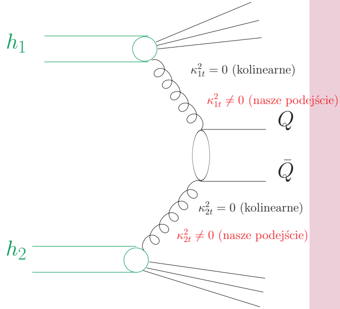


Dominant mechanism

LO collinear approach



k_t-factorization



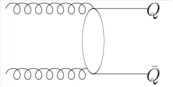
Formalism of collinear - factorization

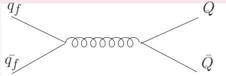
$$\frac{d\sigma}{dy_1 dy_2 d^2 p_t} = \frac{1}{16\pi^2 \hat{s}^2} \sum_{i,j} x_1 p_i(x_1, \mu^2)\, x_2 p_j(x_2, \mu^2)\, \overline{|\mathcal{M}_{ij}|^2}$$

$p_{1t} = p_{2t} = p_t$

$$x_1 = \frac{m_t}{\sqrt{s}} \left(\exp(y_1) + \exp(y_2)\right),$$

$$x_2 = \frac{m_t}{\sqrt{s}} \left(\exp(-y_1) + \exp(-y_2)\right)$$





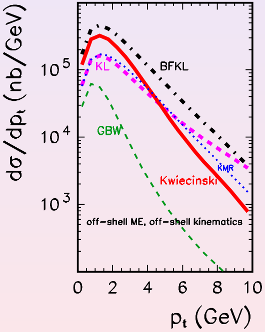
Formalism of k_t-factorization

$$\frac{d\sigma}{dy_1 dy_2 d^2p_{1,t} d^2p_{2,t}} = \sum_{i,j} \int \frac{d^2\kappa_{1,t}}{\pi} \frac{d^2\kappa_{2,t}}{\pi} \frac{1}{16\pi^2 (x_1 x_2 s)^2} \overline{|\mathcal{M}_{ij}|^2}$$
$$\delta^2\left(\vec{\kappa}_{1,t} + \vec{\kappa}_{2,t} - \vec{p}_{1,t} - \vec{p}_{2,t}\right) f_i(x_1, \kappa_{1,t}^2)\ f_j(x_2, \kappa_{2,t}^2)$$

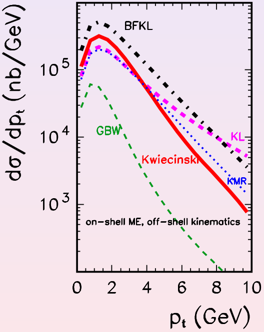
$$m_t = \sqrt{{p_t}^2 + m^2}$$

$$x_1 = \frac{m_{1,t}}{\sqrt{s}} \exp(y_1) + \frac{m_{2,t}}{\sqrt{s}} \exp(y_2),$$
$$x_2 = \frac{m_{1,t}}{\sqrt{s}} \exp(-y_1) + \frac{m_{2,t}}{\sqrt{s}} \exp(-y_2).$$

$gg \longrightarrow c\bar{c}$ (k_t-factorization)

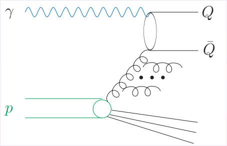


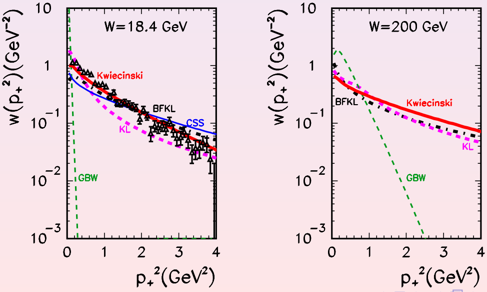
off-shell



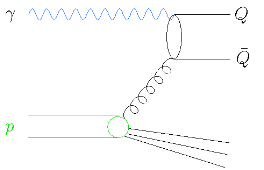
on-shell

$\gamma p \longrightarrow c\bar{c}$ (k_t-factorization)





How important are photon initiated processes in hadronic collisions?



Then photon is a parton of proton.

Martin-Roberts-Stirling-Thorne 2004 include photons.

MRSTQ parton distributions

The factorization of the QED-induced collinear divergences leads to QED-corrected evolution equations for the parton distributions of the proton.

$$\frac{\partial q_i(x,\mu^2)}{\partial \log \mu^2} = \frac{\alpha_S}{2\pi}\int_x^1 \frac{dy}{y}\Big\{P_{qq}(y)\, q_i(\frac{x}{y},\mu^2) + P_{qg}(y)\, g(\frac{x}{y},\mu^2)\Big\} + \frac{\alpha}{2\pi}\int_x^1 \frac{dy}{y}\Big\{\tilde{P}_{qq}(y)\, e_i^2 q_i(\frac{x}{y},\mu^2) + P_{q\gamma}(y)\, e_i^2 \gamma(\frac{x}{y},\mu^2)\Big\}$$

$$\frac{\partial g(x,\mu^2)}{\partial \log \mu^2} = \frac{\alpha_S}{2\pi}\int_x^1 \frac{dy}{y}\Big\{P_{gq}(y)\, \sum_j q_j(\frac{x}{y},\mu^2) + P_{gg}(y)\, g(\frac{x}{y},\mu^2)\Big\}$$

$$\frac{\partial \gamma(x,\mu^2)}{\partial \log \mu^2} = \frac{\alpha}{2\pi}\int_x^1 \frac{dy}{y}\Big\{P_{\gamma q}(y)\, \sum_j e_j^2\, q_j(\frac{x}{y},\mu^2) + P_{\gamma\gamma}(y)\, \gamma(\frac{x}{y},\mu^2)\Big\}$$

MRSTQ parton distributions

In addition to usual P_{qq}, P_{gq}, P_{qg}, P_{gg} spliting functions new spliting functions apper.

$$\tilde{P}_{qq} = C_F^{-1} P_{qq},$$

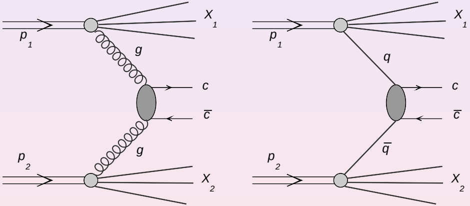
$$\mathrm{P}_{\gamma q} = C_F^{-1} P_{gq},$$
$$\mathrm{P}_{q\gamma} = T_R^{-1} P_{qg},$$
$$\mathrm{P}_{\gamma\gamma} = -\tfrac{2}{3} \textstyle\sum_i e_i^2 \, \delta(1-y)$$

momentum is conserved:

$$\int_0^1 dx \, x \left\{ \sum_i q_i(x,\mu^2) + g(x,\mu^2) + \gamma(x,\mu^2) \right\} = 1$$

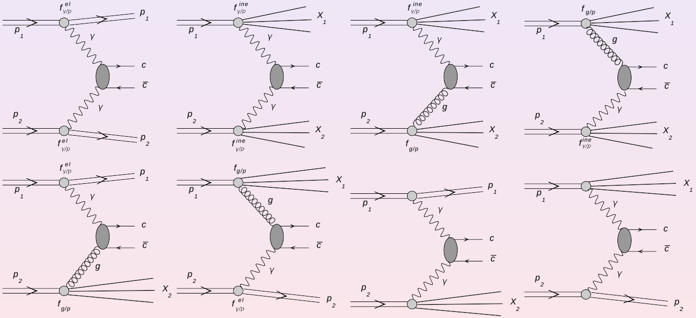
Standard diagrams

- Standard diagrams

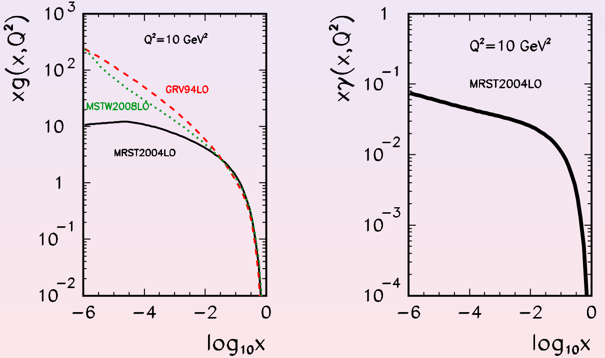


Photon included diagrams

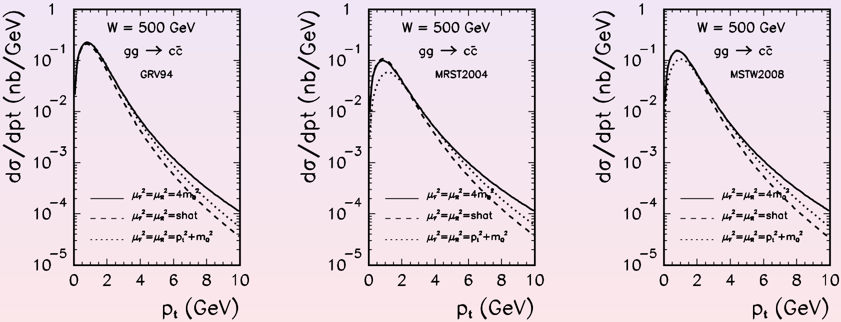
- Photon included diagrams



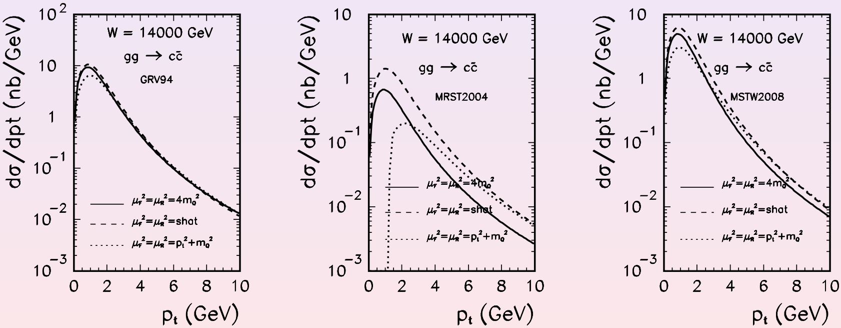
Collinear LO gluon and photon distributions



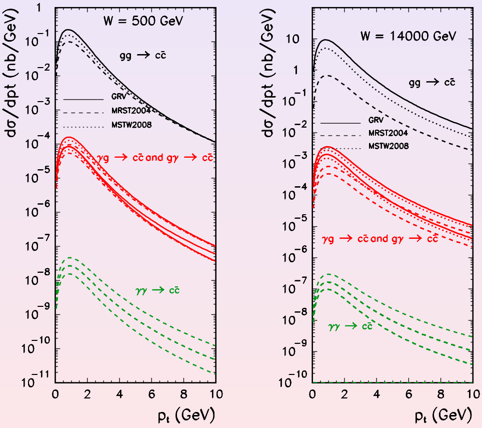
Distribution in quark/antiquark transverse momentum at $\sqrt{s} = 500$ GeV



Distribution in quark/antiquark transverse momentum at $\sqrt{s} = 14$ TeV

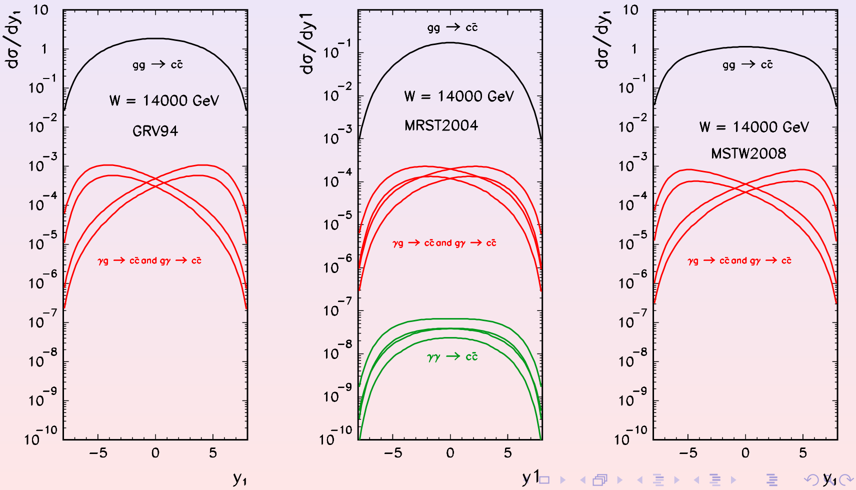


Distribution in the transverse momentum

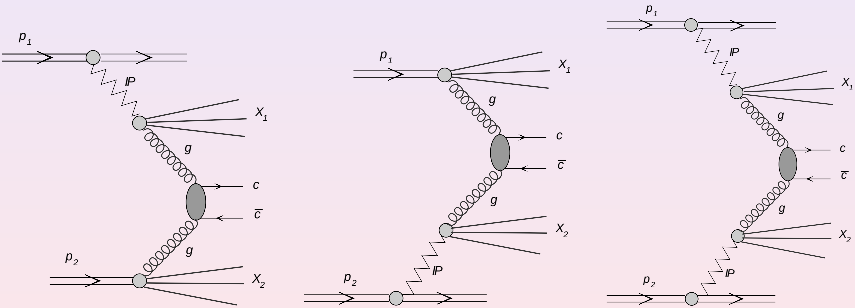


Luszczak, Maciula, Szczurek, Phys. Rev. **D84** (2011) 4018

Distribution in the rapidity



Single and central diffraction



Luszczak, Maciula, Szczurek, Phys. Rev. **D84** (2011) 4018

Formalism

In this approach one assumes that the Pomeron has a well defined partonic structure, and that the hard process takes place in a Pomeron–proton or proton–Pomeron (single diffraction) or Pomeron–Pomeron (central diffraction) processes.

$$\frac{d\sigma_{SD}}{dy_1 dy_2 dp_t^2} = K \frac{\left|M\right|^2}{16\pi^2 \hat{s}^2} \left[\left(x_1 q_f^D(x_1,\mu^2)\, x_2 \bar{q}_f(x_2,\mu^2) \right) + \left(x_1 \bar{q}_f^D(x_1,\mu^2)\, x_2 q_f(x_2,\mu^2) \right) \right],$$

$$\frac{d\sigma_{CD}}{dy_1 dy_2 dp_t^2} = K \frac{\left|M\right|^2}{16\pi^2 \hat{s}^2} \left[\left(x_1 q_f^D(x_1,\mu^2)\, x_2 \bar{q}_f^D(x_2,\mu^2) \right) + \left(x_1 \bar{q}_f^D(x_1,\mu^2)\, x_2 q_f^D(x_2,\mu^2) \right) \right]$$

Formalism

The 'diffractive' quark distribution of flavour f can be obtained by a convolution of the flux of Pomerons $f_{\mathbf{P}}(x_{\mathbf{P}})$ and the parton distribution in the Pomeron $q_{f/\mathbf{P}}(\beta, \mu^2)$:

$$q_f^D(x,\mu^2) = \int dx_{\mathbf{P}}\, d\beta\, \delta(x - x_{\mathbf{P}}\beta) q_{f/\mathbf{P}}(\beta,\mu^2)\, f_{\mathbf{P}}(x_{\mathbf{P}}) = \int_x^1 \frac{dx_{\mathbf{P}}}{x_{\mathbf{P}}}\, f_{\mathbf{P}}(x_{\mathbf{P}}) q_{f/\mathbf{P}}(\frac{x}{x_{\mathbf{P}}},\mu^2)\,.$$

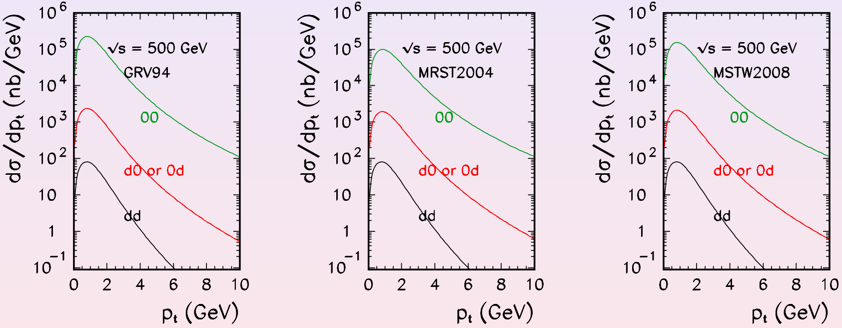
The flux of Pomerons $f_{\mathbf{P}}(x_{\mathbf{P}})$:

$$f_{\mathbf{P}}(x_{\mathbf{P}}) = \int_{t_{min}}^{t_{max}} dt\, f(x_{\mathbf{P}}, t)\,,$$

with t_{min}, t_{max} being kinematic boundaries.

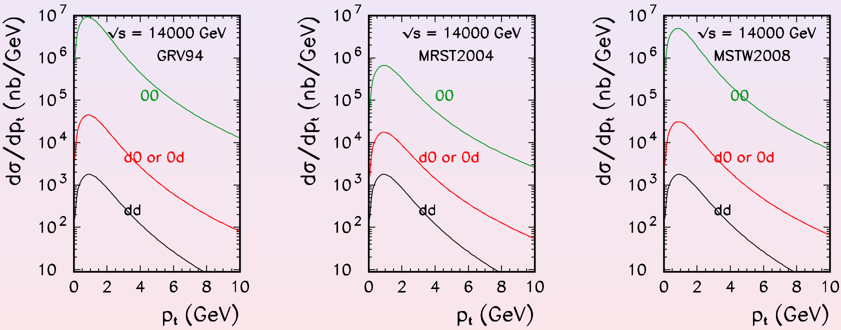
Both pomeron flux factors $f_{\mathbf{P}}(x_{\mathbf{P}}, t)$ as well as quark/antiquark distributions in the pomeron were taken from the H1 collaboration analysis of diffractive structure function at HERA.

Results



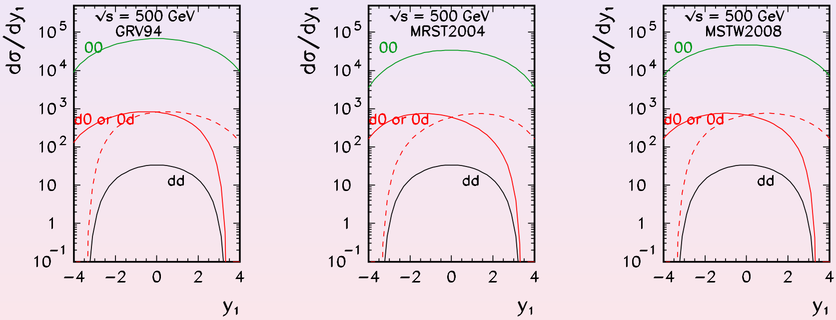
Absorption has been included

Results

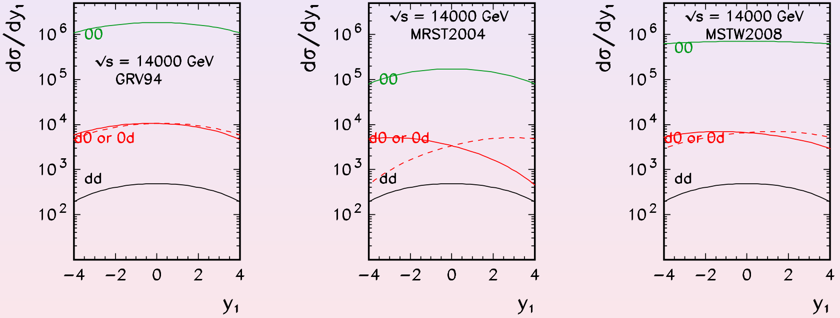


√s = 14000 GeV
GRV94
00
d0 or 0d
dd
dσ/dp_t (nb/GeV)
p_t (GeV)
√s = 14000 GeV
MRST2004
00
d0 or 0d
dd
dσ/dp_t (nb/GeV)
p_t (GeV)
√s = 14000 GeV
MSTW2008
00
d0 or 0d
dd
dσ/dp_t (nb/GeV)
p_t (GeV)

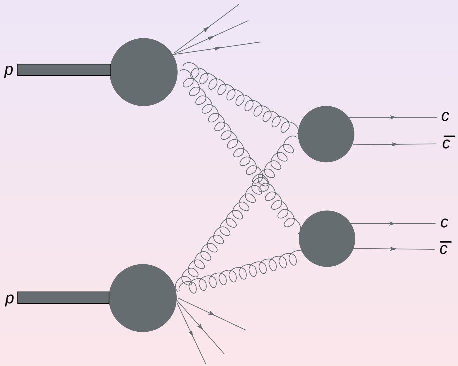
Results



Results


dσ/dy₁
√s = 14000 GeV
GRV94
00
d0 or 0d
dd
y₁
√s = 14000 GeV
MRST2004
00
d0 or 0d
dd
y₁
√s = 14000 GeV
MSTW2008
00
d0 or 0d
dd
y₁

Production of two $c\bar{c}$ pairs in double-parton scattering



Luszczak, Maciula, Szczurek, arXiv:1111.3255

Formalism

$$\sigma^{DPS}(pp \to c\bar{c}c\bar{c}X) = \frac{1}{2\sigma_{eff}} \sigma^{SPS}(pp \to c\bar{c}X_1) \cdot \sigma^{SPS}(pp \to c\bar{c}X_2).$$

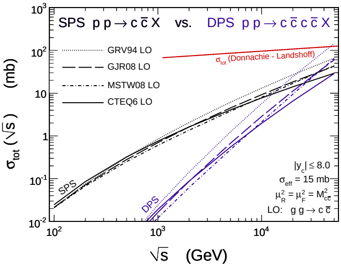
The simple formula can be generalized to include differential distributions

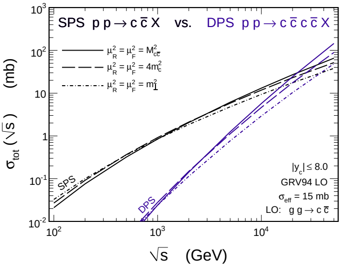
$$\frac{d\sigma}{dy_1 dy_2 d^2p_{1t} dy_3 dy_4 d^2p_{2t}} = \frac{1}{2\sigma_{eff}} \cdot \frac{d\sigma}{dy_1 dy_2 d^2p_{1t}} \cdot \frac{d\sigma}{dy_3 dy_4 d^2p_{2t}}.$$

$$d\sigma^{DPS} = \frac{1}{2\sigma_{eff}} F_{gg}(x_1, x_2, \mu_1^2, \mu_2^2) F_{gg}(x_1' x_2', \mu_1^2, \mu_2^2)$$

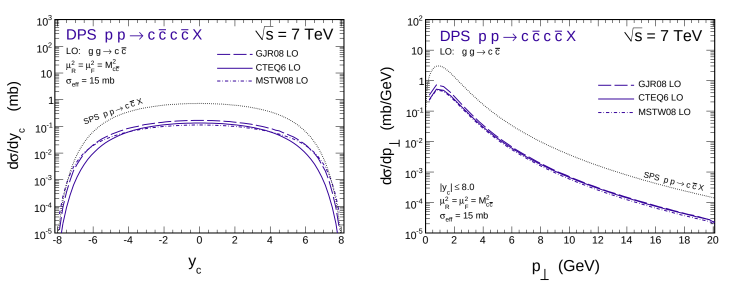
$$d\sigma_{gg \to c\bar{c}}(x_1, x_1', \mu_1^2) d\sigma_{gg \to c\bar{c}}(x_2, x_2', \mu_2^2) \; dx_1 dx_2 dx_1' dx_2' .$$

Results

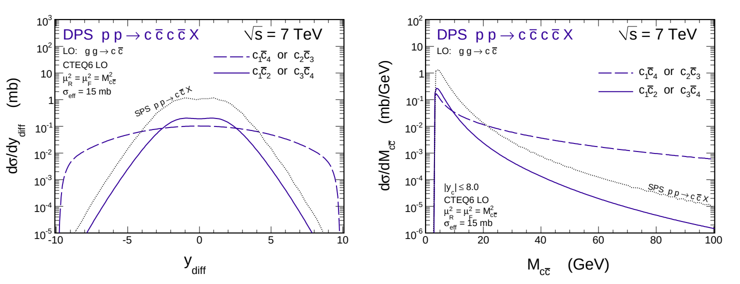

SPS p p → c c̄ X vs. DPS p p → c c̄ c c̄ X
GRV94 LO
GJR08 LO
MSTW08 LO
CTEQ6 LO
σ_tot (Donnachie - Landshoff)
|y_c| ≤ 8.0
σ_eff = 15 mb
μ²_R = μ²_F = M²_cc̄
LO: g g → c c̄
SPS
DPS
σ_tot (√s) (mb)
√s (GeV)


SPS p p → c c̄ X vs. DPS p p → c c̄ c c̄ X
μ²_R = μ²_F = M²_cc̄
μ²_R = μ²_F = 4m²_c
μ²_R = μ²_F = m²_⊥
|y_c| ≤ 8.0
GRV94 LO
σ_eff = 15 mb
LO: g g → c c̄
SPS
DPS
σ_tot (√s) (mb)
√s (GeV)

Results


DPS p p → c c̄ c c̄ X
√s = 7 TeV
LO: g g → c c̄
μ²_R = μ²_F = M²_cc̄
σ_eff = 15 mb
GJR08 LO
CTEQ6 LO
MSTW08 LO
SPS p p → c c̄ X
dσ/dy_c (mb)
y_c
|y_c| ≤ 8.0
dσ/dp_⊥ (mb/GeV)
p_⊥ (GeV)

Results


DPS p p → c c̄ c c̄ X
√s = 7 TeV
LO: g g → c c̄
CTEQ6 LO
σeff = 15 mb
c1c̄4 or c2c̄3
c1c̄2 or c3c̄4
SPS p p → c c̄ X
dσ/dy_diff (mb)
y_diff
dσ/dM_cc̄ (mb/GeV)
M_cc̄ (GeV)
|y_c| ≤ 8.0

Conclusions

- Huge sensitivity to gluon distribution and scales for W=14000 GeV.
- We have calculated cross section for many new photon included processes. They are small but there are many of them.
- The cross sections for single and central diffraction have been calculated.The SD_{cs} smaller by 2 orders of magnitude than the dominant gg term.
- We predict large cross section for two $c\bar{c}$ pair production in double-parton scattering.