Precise dipole model analysis of diffractive DIS

Agnieszka Łuszczak

Institute of Nuclear Physics PAN, Cracow, Poland

in collaboration with Krzysztof Golec-Biernat

arXiv:0812.3090 [hep-ph]

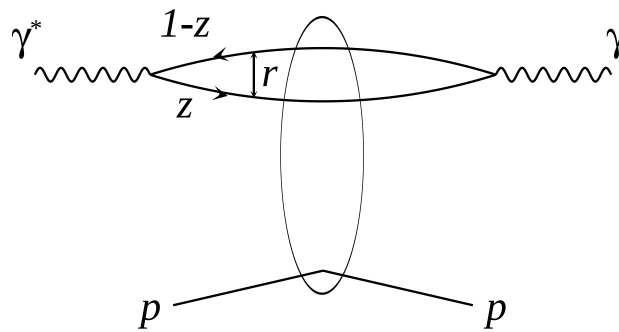
DIS 2009, Madrid, April 27, 2009

Outline

- Dipole model approach
- GBW and CGC parametrization
- Diffractive structure functions in dipole models
- Diffractive charm quark production
- Comparision with HERA data
- Summary

Dipole model of DIS

- Dipole picture of DIS at small x in the proton rest frame



r - dipole size

z - longitudinal momentum fraction of the quark/antiquark

- Factorization: dipole formation + dipole interaction

$$\sigma^{\gamma p} = \frac{4\pi^2\alpha_{em}}{Q^2} F_2 = \sum_f \int d^2r \int_0^1 dz \, |\Psi^\gamma(r, z, Q^2, m_f)|^2 \ \hat{\sigma}(r, x)$$

- Dipole-proton interaction $\hat{\sigma}(r, x)$ is parameterized.

GBW parametrization

(Golec-Biernat Wusthoff,99)

- GBW parametrization with heavy quarks $f = u, d, s, c$

$$\hat{\sigma}(r,x) = \sigma_0 \left(1 - \exp(-r^2/R_s^2)\right), \qquad R_s^2 = 4 \cdot (x/x_0)^{\lambda} \ \text{GeV}^2$$

- The dipole scattering amplitude in such a case reads

$$\hat{N}(\mathbf{r},\mathbf{b},x) = \theta(b_0 - b)\left(1 - \exp(-r^2/R_s^2)\right)$$

where

$$\hat{\sigma}(r,x) = 2\int d^2b\, \hat{N}(\mathbf{r},\mathbf{b},x)$$

- Parameters b_0, x_0 and λ from fits of scattering amplitude to F_2 data

$$\lambda = 0.288 \qquad x_0 = 4 \cdot 10^{-5} \qquad \sigma_0 = 2\pi b_0^2 = 29 \text{ mb}$$

CGC parametrization

(Iancu, Itakura, Munier, Soyez 04-07)

- The dipole scattering amplitude in this parametrization

$$\hat{N}(\mathbf{r}, \mathbf{b}, x) = S(\mathbf{b})\, N(\mathbf{r}, x)\,, \qquad S(\mathbf{b}) = \exp(-b^2/(2B_d))$$

- Dipole cross section is given by ($Q_s = 1/R_s$)

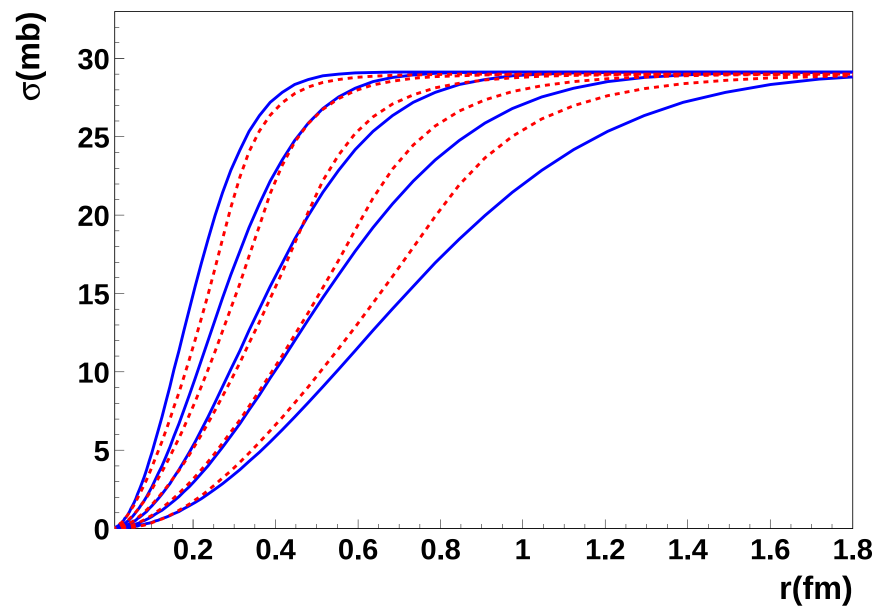
$$\hat{\sigma}(\mathbf{r}, x) = 4\pi B_d\, N(\mathbf{r}, x)\,.$$

$$N(\mathbf{r}, x) = \begin{cases} N_0 \left(\frac{rQ_s}{2}\right)^{2\gamma_s} \mathrm{e}^{\frac{2\ln^2(rQ_s/2)}{\kappa\lambda\ln(x)}} & \text{for} \quad rQ_s \le 2 \\ 1 - \mathrm{e}^{-4\alpha\ln^2(\beta r Q_s)} & \text{for} \quad rQ_s > 2 \end{cases}$$

- Parameters λ, x_0, σ_0, N_0 and B_d are equal to

$$\lambda = 0.22, \quad x_0 = 1.63 \cdot 10^{-5}, \quad N_0 = 0.7, \quad B_d = 6\ GeV^{-2}$$

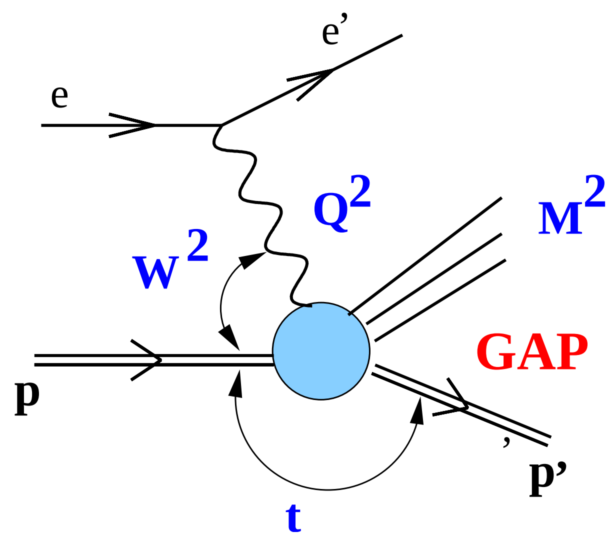
Comparison of GBW with CGC



- The same normalization.
- In GBW from a fit to F_2 data: $\sigma_0 = 29\ \mathrm{mb}$.
- In CGC from measured diffractive slope at HERA: $B_d = 6\ GeV^{-2}$

$$\sigma_0 = 4\pi B_d = 29\ \mathrm{mb}$$

DIS diffraction



- Kinematic variables

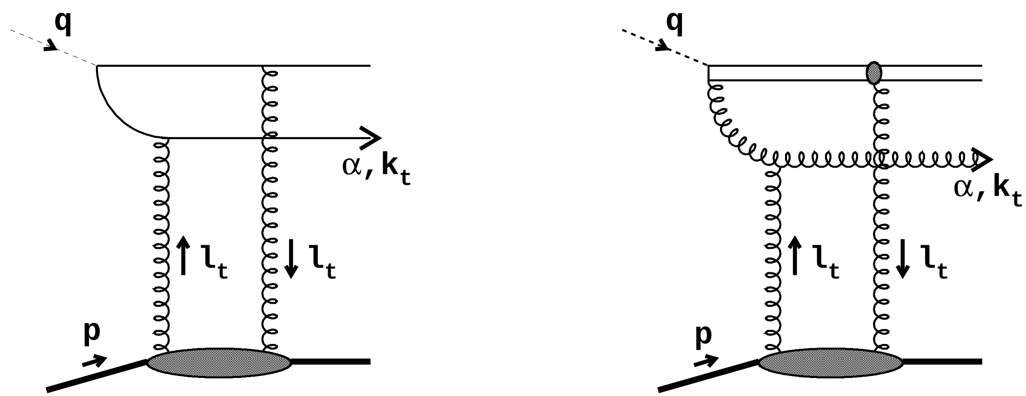
$$x_{I\!P} = \frac{M^2 + Q^2}{W^2 + Q^2}\,, \qquad \beta = \frac{Q^2}{Q^2 + M^2}$$

- Diffractive structure functions

$$F_2^D(x_{I\!P}, \beta, Q^2) \qquad F_L^D(x_{I\!P}, \beta, Q^2)$$

DIS diffraction in dipole models

- Successful description with two component diffractive state



- Diffractive production of state $q\bar{q}$ i $q\bar{q}g$ from photon T, L

- Diffractive structure functions are given by

$$F_2^D = F_T^{(q\bar{q})} + F_L^{(q\bar{q})} + F_T^{(q\bar{q}g)}$$
$$F_L^D = F_L^{(q\bar{q})}$$

Diffractive structure functions: $q\bar{q}$ component

- The $q\bar{q}$ components from T and L polarised photons are given by

$$x_{I\!P} F_T^{(q\bar{q})} = \frac{3Q^4}{64\pi^4 \beta B_d} \sum_f e_f^2 \int_{z_f}^{1/2} dz\, z(1-z) \times \left\{ \left[z^2 + (1-z)^2\right] Q_f^2\, \phi_1^2 + m_f^2\, \phi_0^2 \right\}$$

$$x_{I\!P} F_L^{(q\bar{q})} = \frac{3Q^6}{16\pi^4 \beta B_d} \sum_f e_f^2 \int_{z_f}^{1/2} dz\, z^3 (1-z)^3\, \phi_0^2$$

- The functions ϕ_i take the following form for $i = 0, 1$

$$\phi_i = \int_0^\infty dr\, r\, K_i(Q_f r)\, J_i(k_f r)\, \hat{\sigma}(r, x_{I\!P})$$

- In diffractive DIS substitution in $\hat{\sigma}(r, x_{I\!P})$

$$x = \frac{Q^2}{Q^2 + W^2} \qquad \rightarrow \qquad x_{I\!P} = \frac{Q^2 + M^2}{Q^2 + W^2}$$

Diffractive structure functions: $q\bar{q}g$ component

- The $q\bar{q}g$ component from transverse photons with massless quarks

$$x_{I\!P} F_T^{(q\bar{q}g)} = \frac{81\beta\alpha_s}{512\pi^5 B_d} \sum_f e_f^2 \int_\beta^1 \frac{dz}{(1-z)^3} \left[\left(1-\frac{\beta}{z}\right)^2 + \left(\frac{\beta}{z}\right)^2 \right]$$

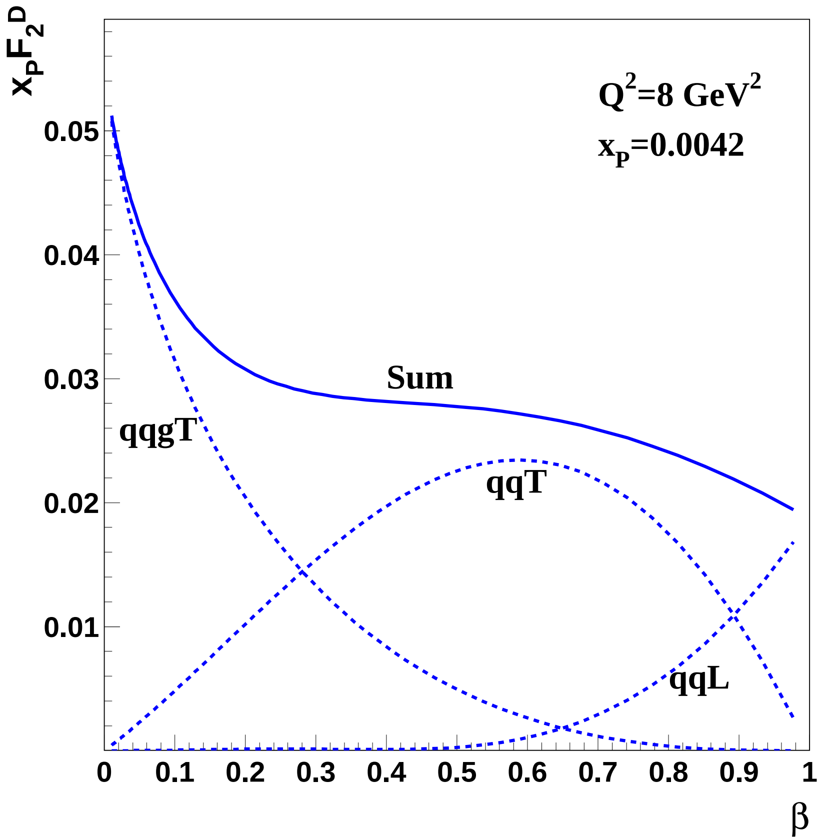
$$\times \int_0^{(1-z)Q^2} dk^2 \log\left(\frac{(1-z)Q^2}{k^2}\right) \phi_2^2(x_{I\!P}, z, k) \, ,$$

- Since $k_{Tq} \approx k_{T\bar{q}} \gg k_{Tg}$ we have a gluon dipole and the GBW dipole cross section is given by

$$\hat{\sigma} \equiv \hat{\sigma}_{gg} = \sigma_0 \left(1 - \mathrm{e}^{-(C_A/C_F) r^2 Q_s^2/4}\right)$$

- Color factor modyfication: $C_A/C_F = 9/4$ for $N_c = 3$

Summary of the three contributions to F_2^D



$$\beta = \frac{Q^2}{Q^2 + M^2}$$

- $q\bar{q}$ from transverse photons for $\beta \approx 1/2$
- $q\bar{q}$ from longitudinal photons for $\beta \approx 1$ (for small diffractive mass)
- $q\bar{q}g$ for $\beta \ll 1$ (for large diffractive mass)

Diffractive charm production: only $c\bar{c}$

- Standard dipole model formula with $m_c = 1.4\ \mathrm{GeV}$ and $e_c = 2/3$

$$x_{I\!P} F_T^{(c\bar{c})} = \frac{3Q^4 e_c^2}{64\pi^4 \beta B_d} \int_{z_c}^{1/2} dz\, z(1-z) \\ \times \quad \left\{ \left[z^2 + (1-z)^2 \right] Q_c^2\, \phi_1^2 \, + \, m_c^2\, \phi_0^2 \right\}$$

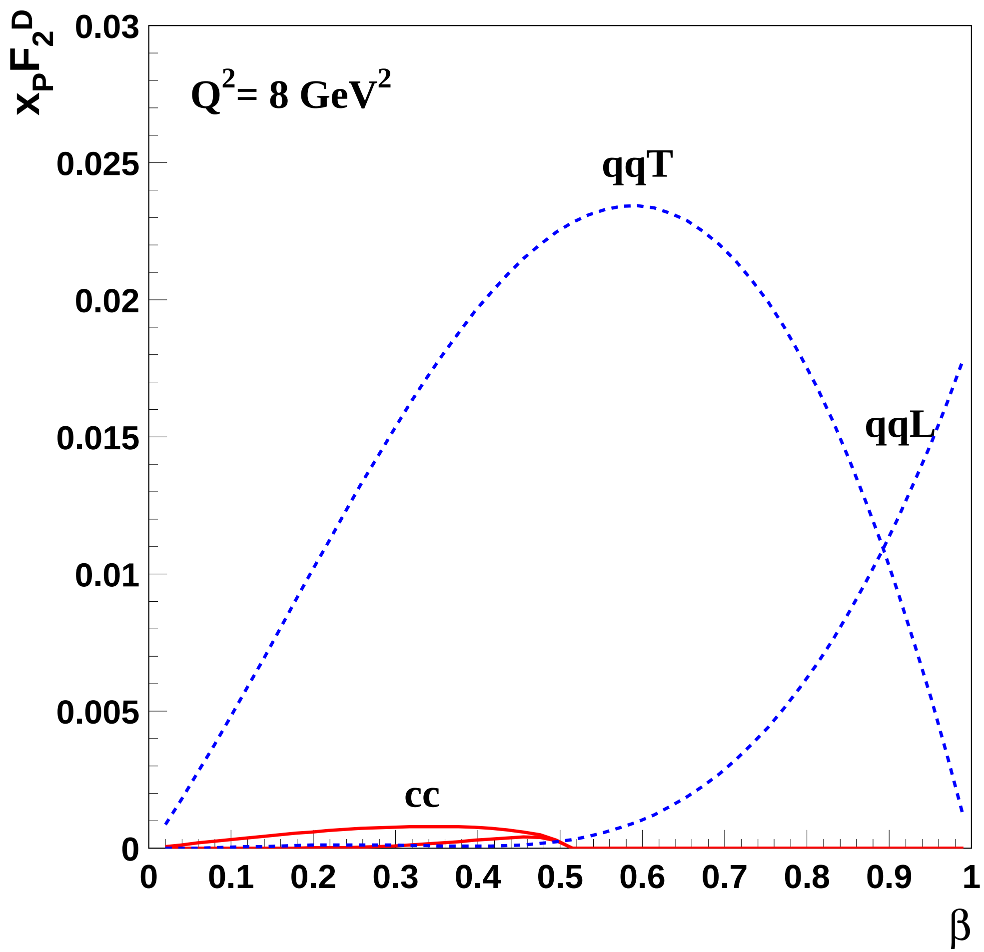
with $z_c = (1 - \sqrt{1 - 4m_c^2/M^2})/2$

- Minimal diffractive mass $M_{min}^2 = 4m_c^2$ gives maximal value of β

$$\beta_{max} = \frac{Q^2}{Q^2 + 4m_c^2} < 1$$

- Pure $c\bar{c}$ contributions is very small.

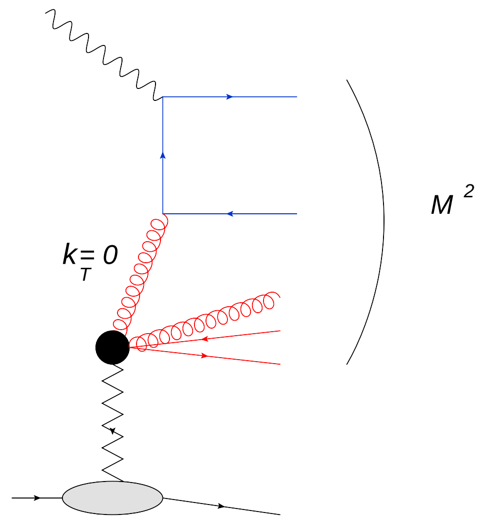
Exclusive $c\bar{c}$ contribution



- We use collinear factorisation formula for $c\bar{c}X$ diffractive production

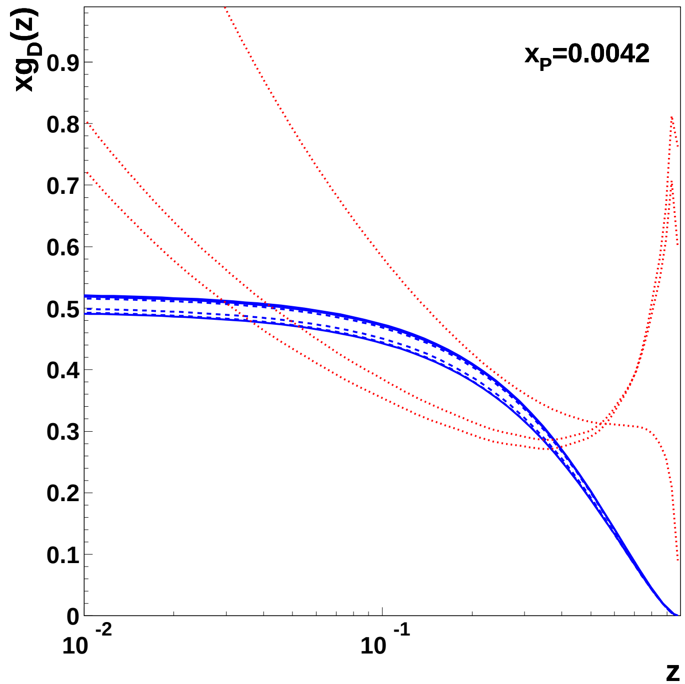
$$F_{2,L}^{D(c\bar{c}X)} = 2\beta\, e_c^2 \frac{\alpha_s(\mu_c^2)}{2\pi} \int_{a\beta}^{1} \frac{d\beta'}{\beta'} C_{2,L}\left(\frac{\beta}{\beta'}, \frac{m_c^2}{Q^2}\right) \; g^D(x_{I\!P}, \beta', \mu_c^2)$$

where $a = 1 + 4m_c^2/Q^2$ and the factorization scale $\mu_c^2 = 4m_c^2$.



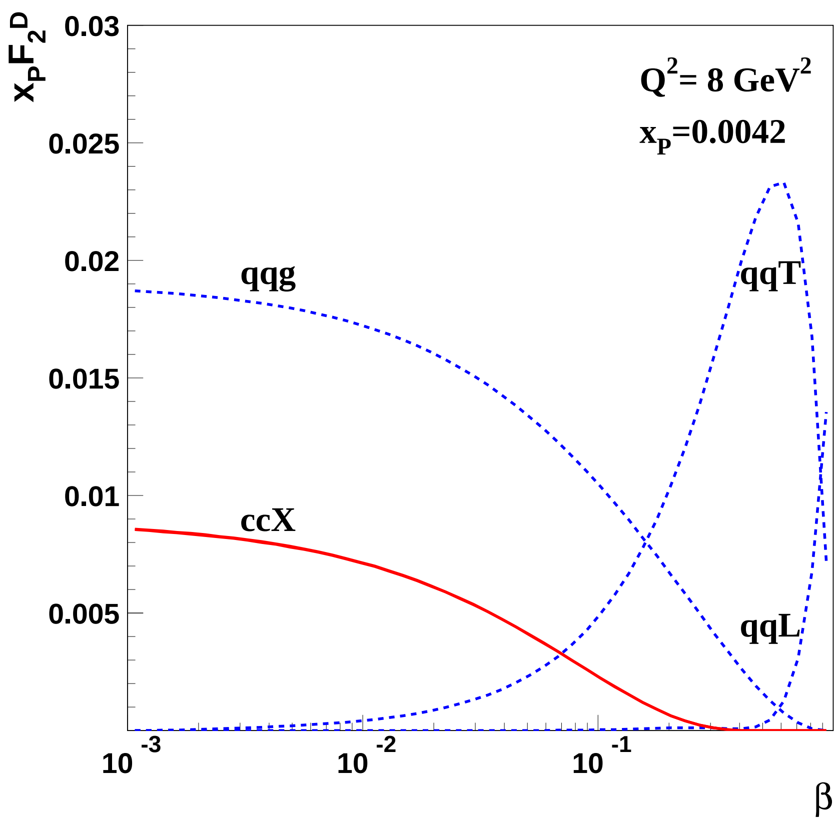
- The standard gluon distribution is replaced by the diffractive gluon distribution $g^D(x_{I\!P}, \beta', \mu_c^2)$.

Diffractive gluon distribution



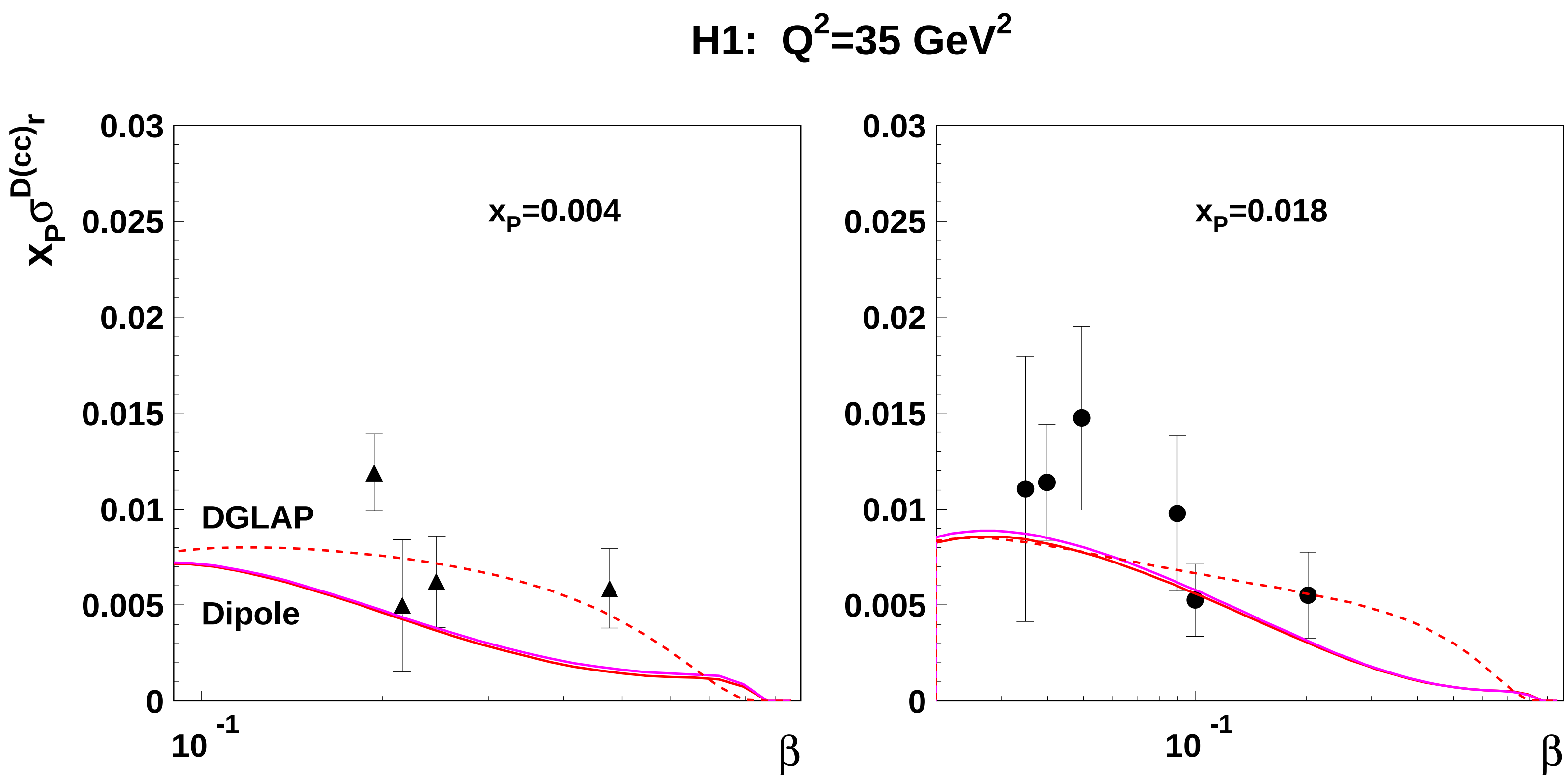
- Gluon from the $q\bar{q}g$ component of the dipole model (blue lines)
- Gluon from DGLAP fits to HERA diffractive data (red lines)

Diffractive charm production: $c\bar{c}X$



- $c\bar{c}X$ contributes up to 30% to F_2^D for large diffractive mass (small β).

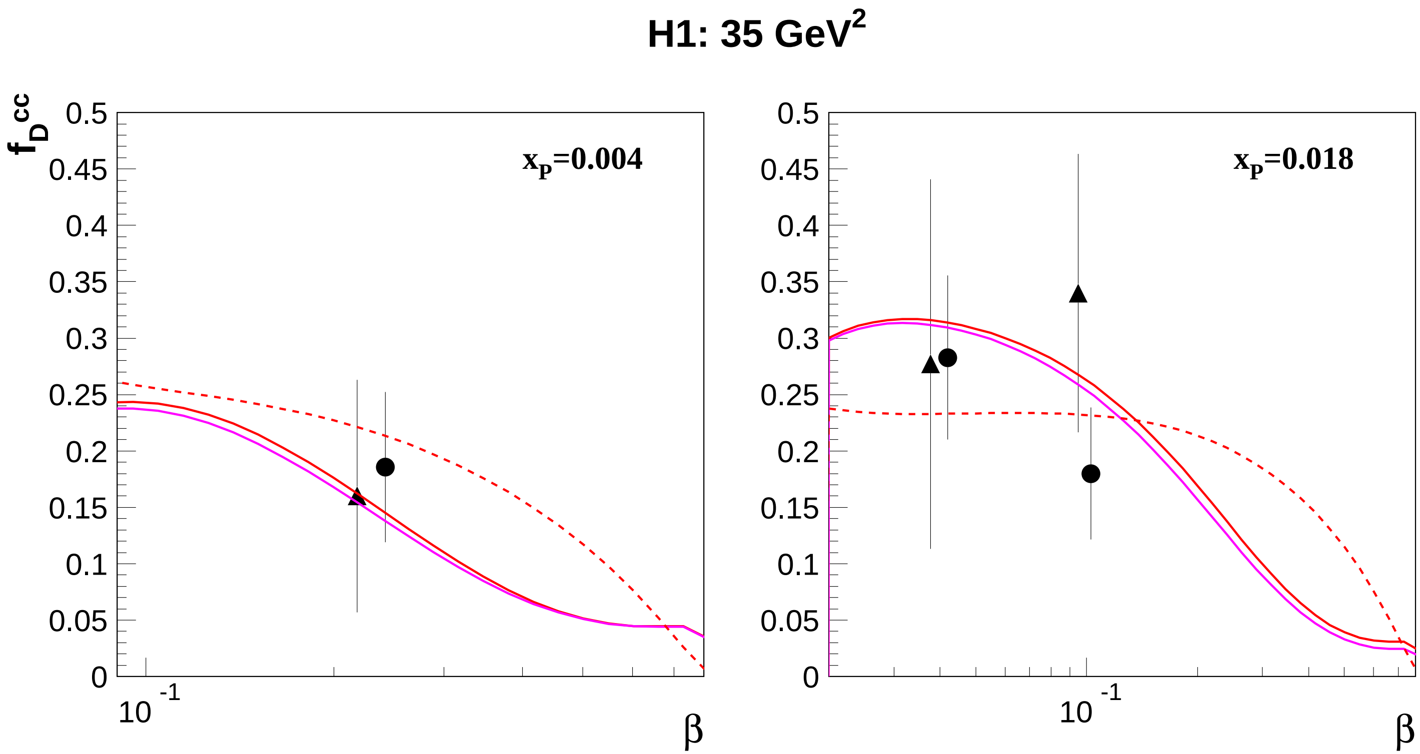
Comparison with HERA data



- Reduced cross section

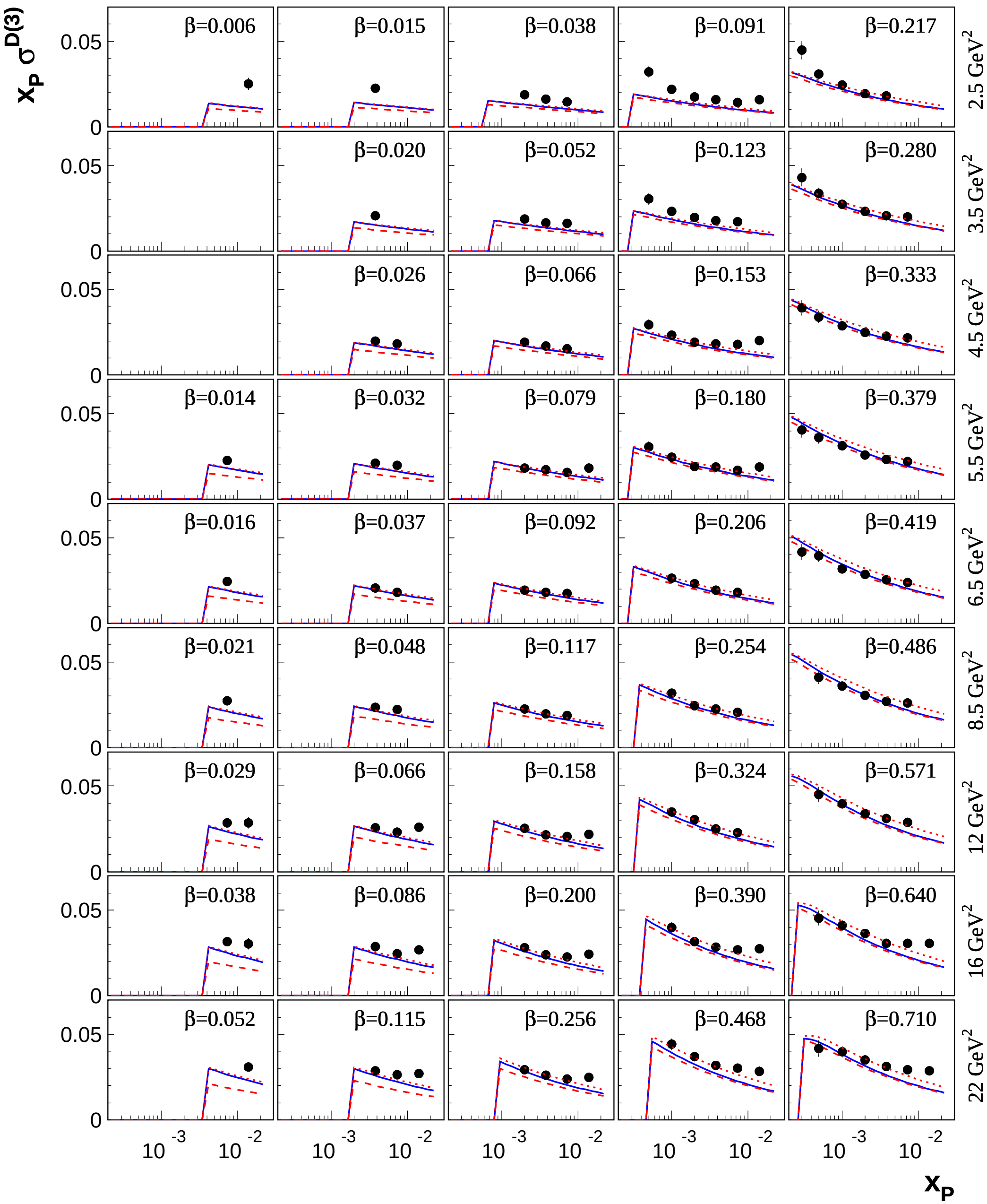
$$\sigma_r^{D(charm)} = F_2^{D(charm)} - \frac{y^2}{1+(1-y)^2} F_L^{D(charm)} .$$

Fractional charm contribution

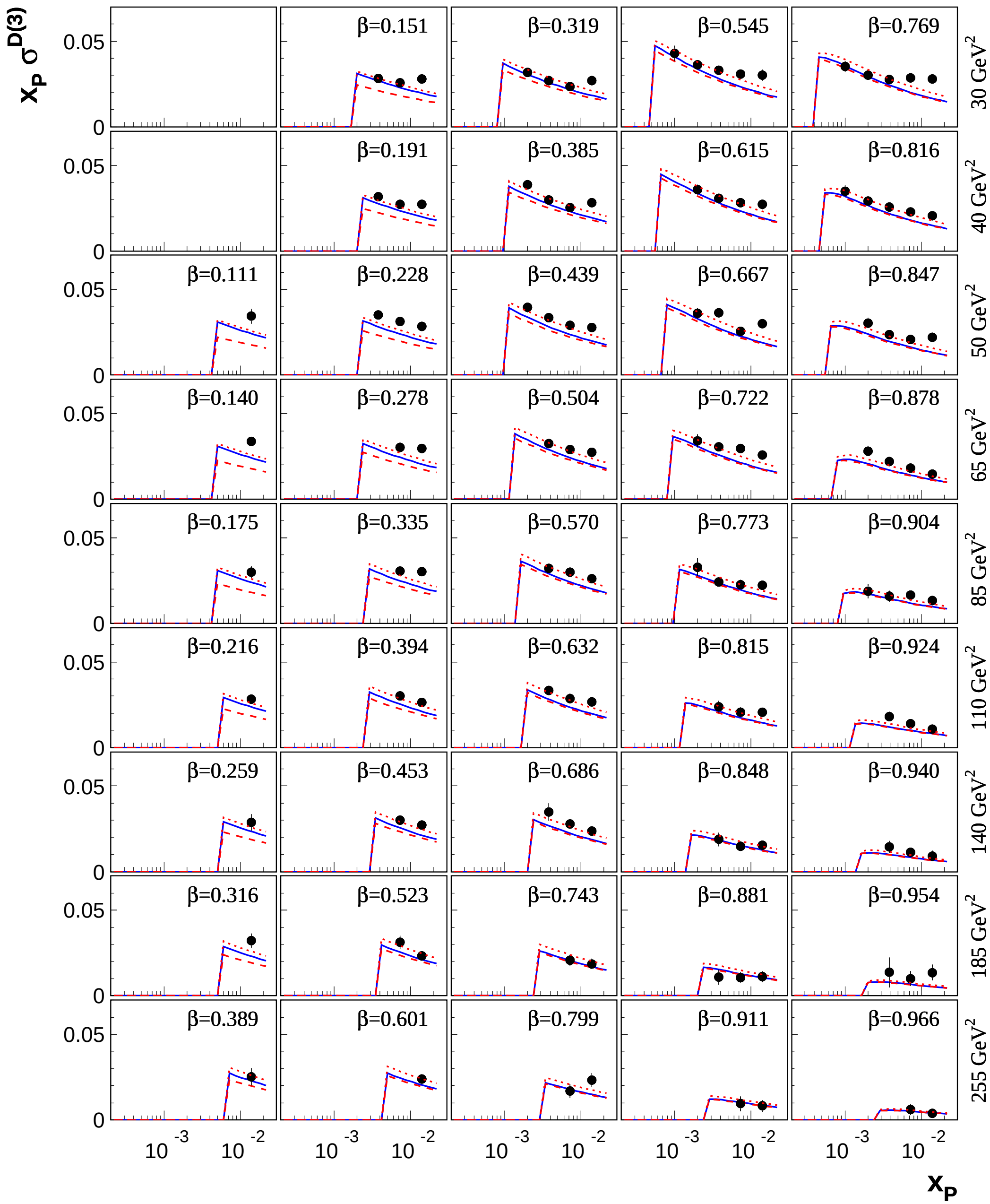


- Fractional contribution $f^{D(charm)} = \sigma_r^{D(charm)}/\sigma_r^D$ of the diffractive charm to total diffractive cross section.
- Up to $20 - 30\%$.

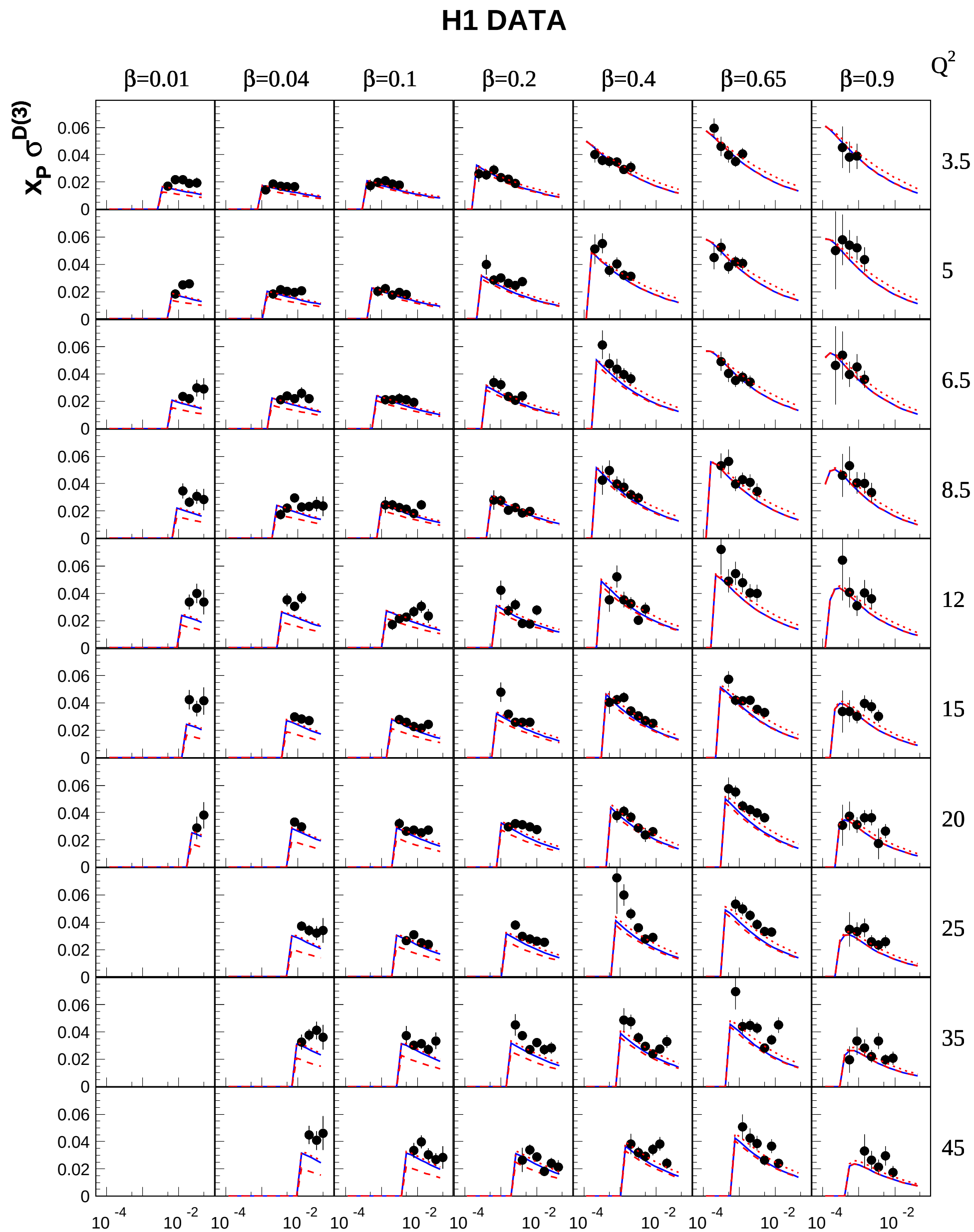
The comparison for $\sigma_r^D = F_2^D - \frac{y^2}{1+(1-y)^2} F_L^D$: ZEUS 2009



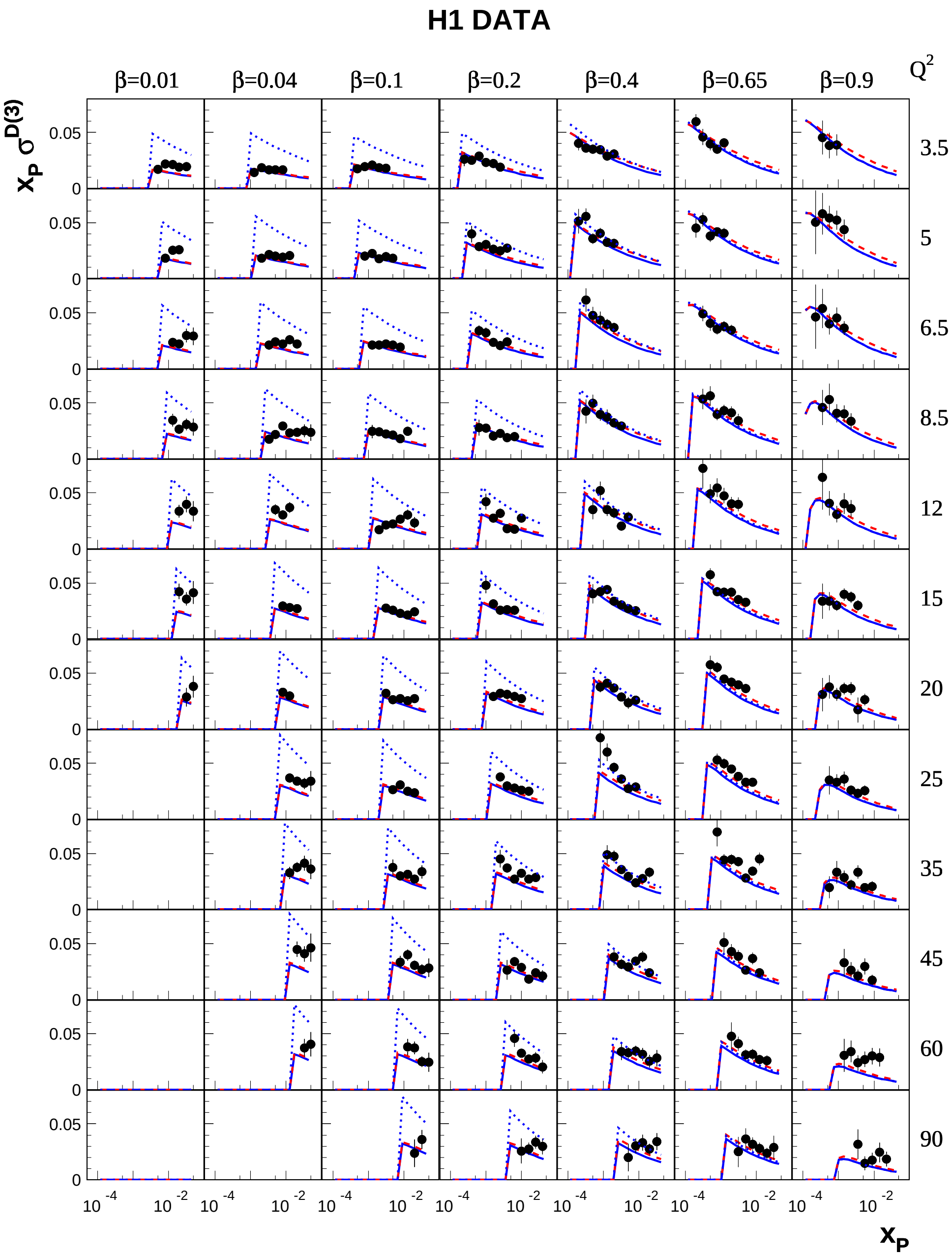
The comparison for $\sigma_r^D = F_2^D - \frac{y^2}{1+(1-y)^2} F_L^D$: ZEUS 2009



The comparison with $\sigma_r^D = F_2^D - \frac{y^2}{1+(1-y)^2} F_L^D$: H1

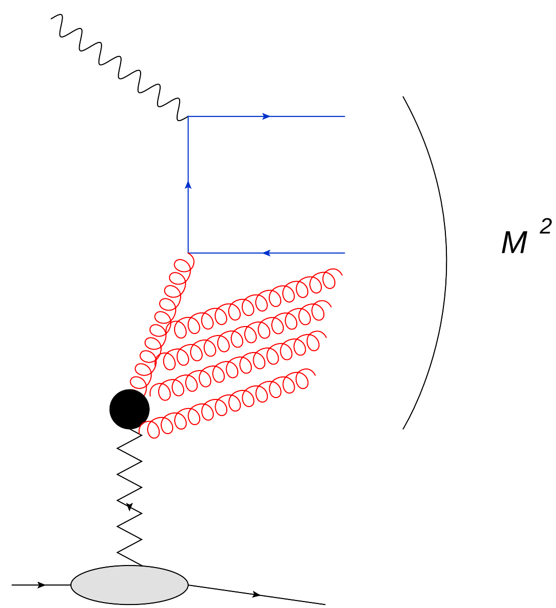


Gluon dipole versus quark dipole in $qq\bar{g}$ component for GBW



Conclusions

- Good overall agreement.
- Charm contribution is important, especially for small β (large diffractive mass)
- For small β curves below the data - more complicated diffractive state than $q\bar{q}g$ necessary.



- Using DGLAP evolution we add more gluons and quark pairs in the diffractive state.

From DGLAP analysis