

Evidence for breakdown of the DGLAP description in diffractive DIS at HERA

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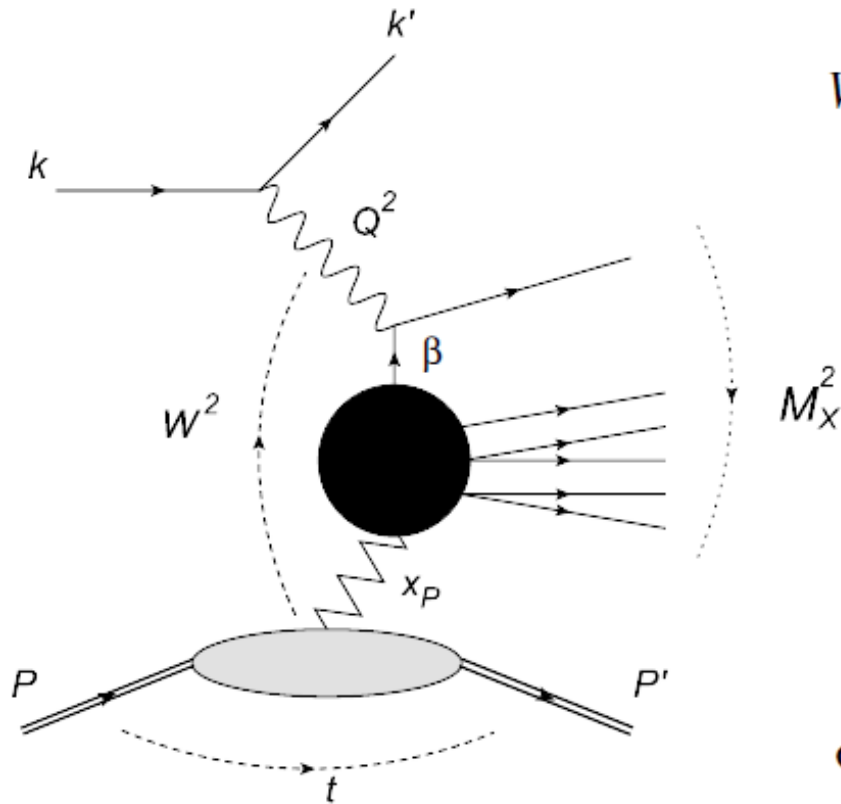
DIS, Bonn 2012

Outline

- DGLAP description of DDIS (at HERA)
- DGLAP breakdown
- Estimation of higher twists: saturation model
- Higher twists and the data
- Conclusions

Work in progress: Leszek Motyka, MS, Wojtek Slominski

Diffractive DIS: process and variables



$$W^2 = (P + q)^2 \quad x_{\mathbb{P}} = \frac{Q^2 + M_X^2}{Q^2 + W^2} \quad x = \beta x_{\mathbb{P}}$$

$$\beta = \frac{Q^2}{Q^2 + M_X^2} \quad t = (P' - P)^2$$

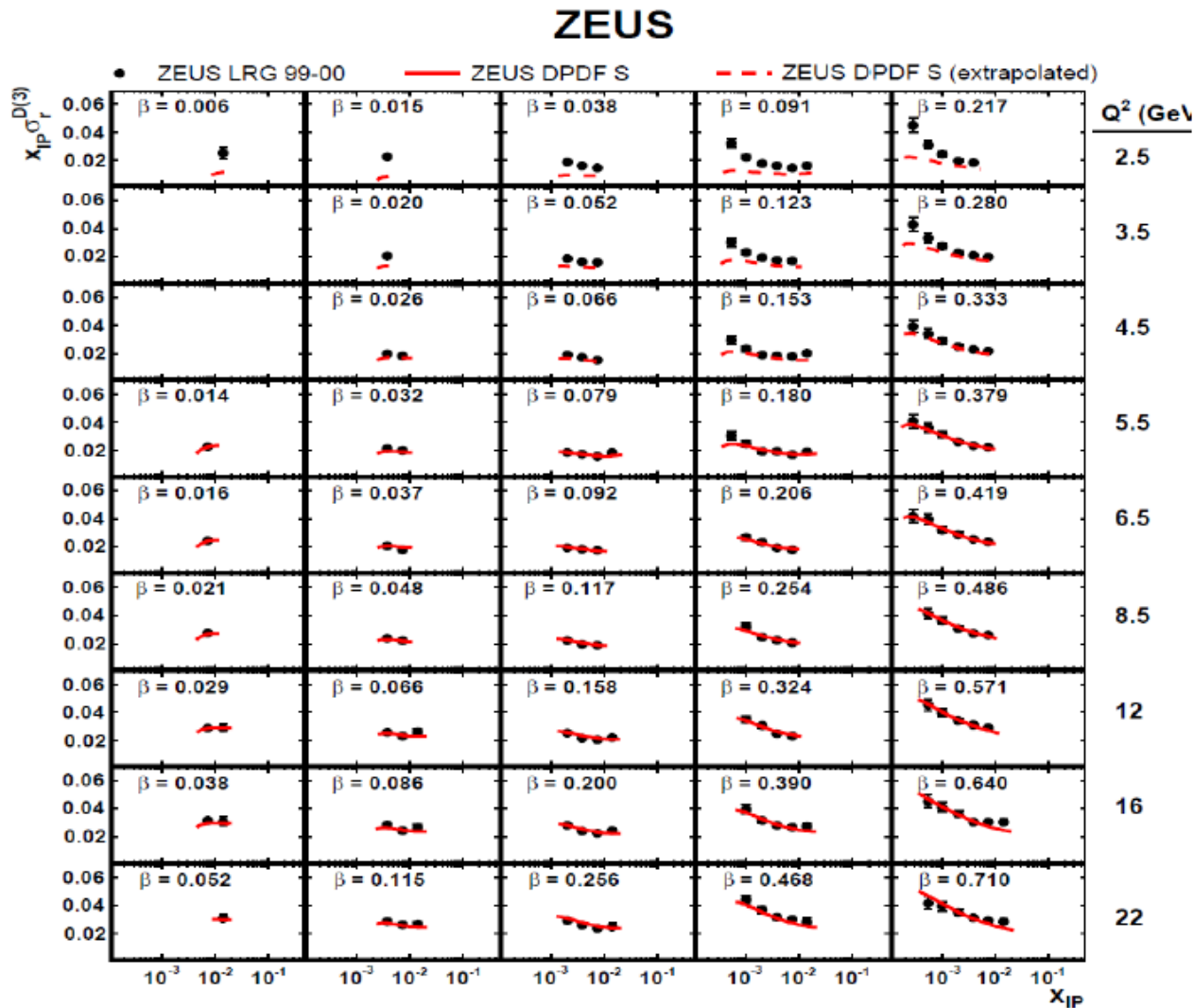
Domain of interest:

$$W \gg M_X^2 > Q^2 \gg |t|$$

$$\sigma_r(\beta, Q^2, x_{\mathbb{P}}) = F_2^{D(3)} - \frac{y^2}{1 + (1 - y)^2} F_L^{D(3)}$$

$$\frac{d\sigma^{ep \rightarrow eXp}}{d\beta dQ^2 dx_{\mathbb{P}}} = \frac{2\pi\alpha^2}{\beta Q^4} [1 + (1 - y)^2] \sigma_r(\beta, Q^2, x_{\mathbb{P}})$$

DGLAP fit to DDIS data (ZEUS, 2009)

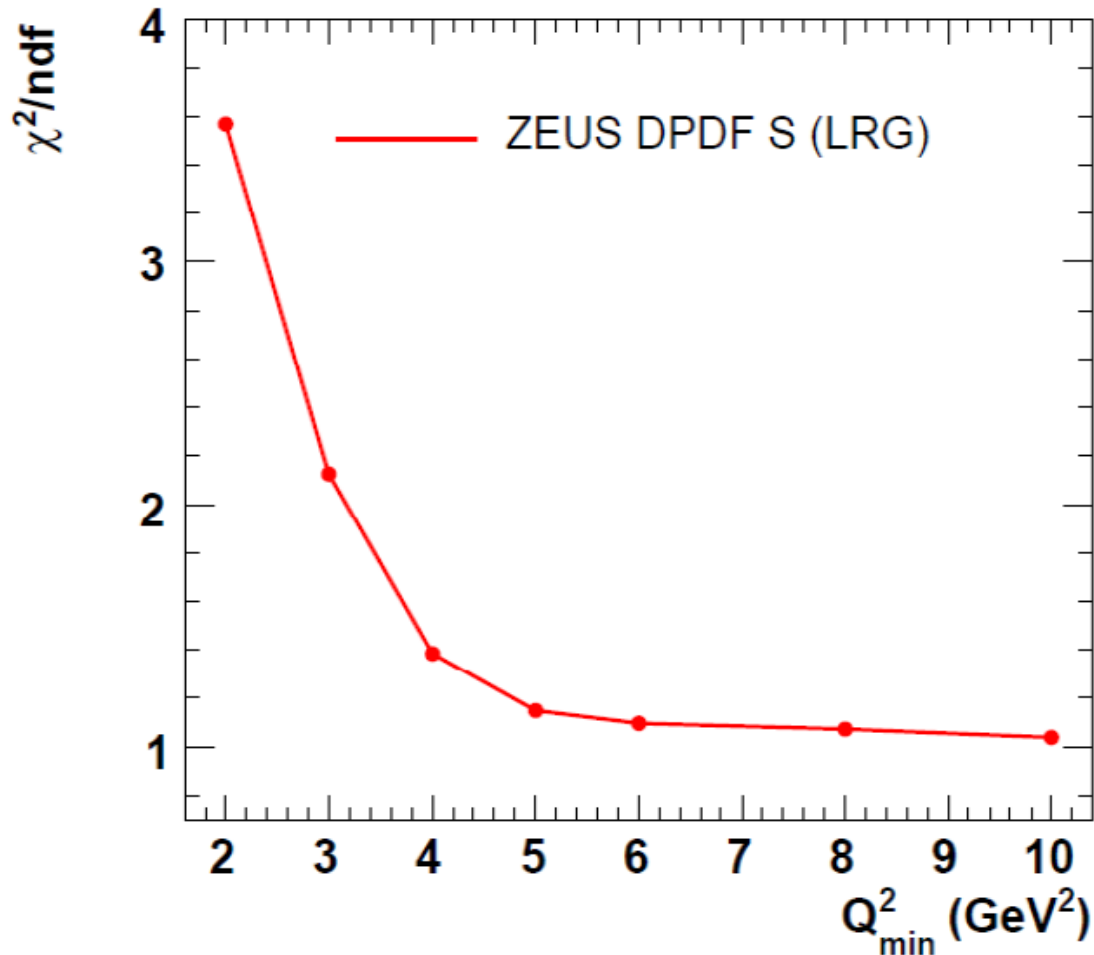


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- LRG ZEUS data
- $2.0 < Q^2 < 305$ GeV²
- DGLAP (NLO) fit (LRG + LPS)
- 265 d.o.f

DGLAP breakdown: "critical scale"

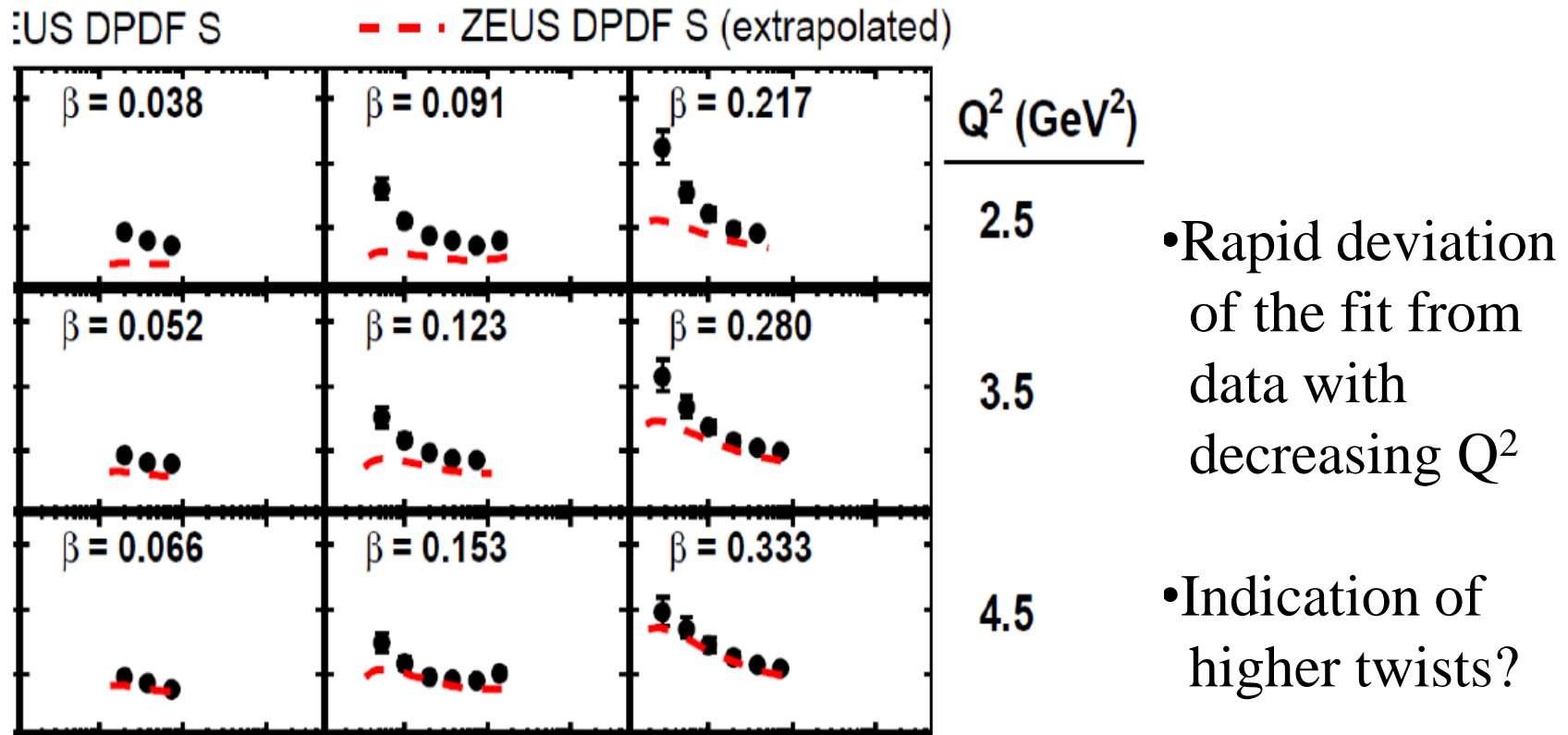
ZEUS



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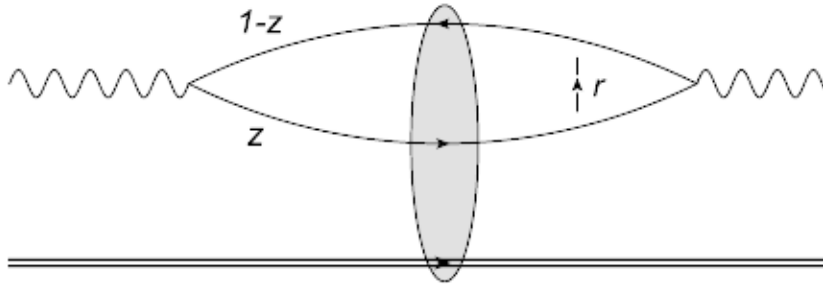
- DGLAP fits below 5 GeV² fails
- Strong DGLAP breaking effects below 3 GeV²

DGLAP breakdown: closer look



Problematic region: low x_p , low Q^2

Beyond DGLAP: dipole picture



Cross-section:

$$\sigma \sim \int d^2 r dz |\Psi(z, Q^2 r^2)|^2 \sigma_d(x, r^2)$$

GBW parametrization

$$\sigma_d(x, r^2) = \sigma_0 \left[1 - \exp\left(-\frac{r^2}{4R^2(x)}\right) \right]$$

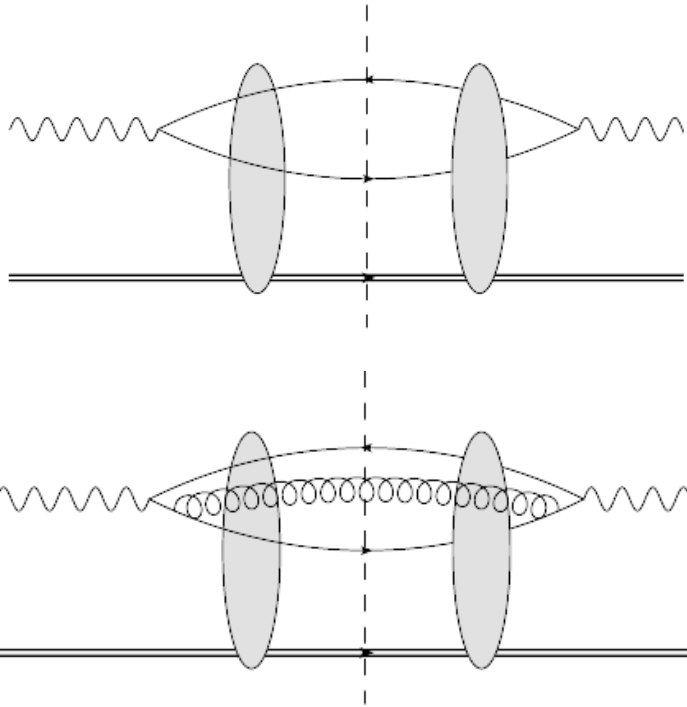
$$R(x) = \frac{1}{Q_0} \left(\frac{x}{x_0} \right)^{\lambda/2}$$

N.N. Nikolaev and B.G. Zakharov, Z. Phys. **C49** (1991) 607, **C53** (1992) 331

K. Golec-Biernat and M. Wusthoff, Phys. Rev. **D59** (1999) 014017, **D60** (1999) 114023

Inclusive scattering: large energy factorization+ eikonal
colour dipole scattering

Diffraction: quark – antiquark and quark – antiquark – gluon



$$\sigma^{diff} \sim \int d^2r dz |\Psi(z, Q^2 r^2)|^2 \sigma_d^2(x, r^2)$$

- An exponential t-dependence of the amplitude
- Strongly suppressed at small β

$$\sigma_{2d} \sim \alpha_s \int d^2r_{02} K(r_{01}, r_{02}) [N_{02} + N_{12} - N_{01} - N_{02}N_{12}]^2$$

- Subleading in the α_s constant, but enhanced at small β – due to the dipole size
- Effectively 2 dipoles at large N_c limit

M.L. Good and W.D. Walker, Phys. Rev. **120** (1960) 1857

A. Bialas and R. Peschanski, Phys. Lett. **B378** (1996) 302

S. Munier and A. Shoshi, Phys. Rev. **D69** (2004) 074022

Tuning the model

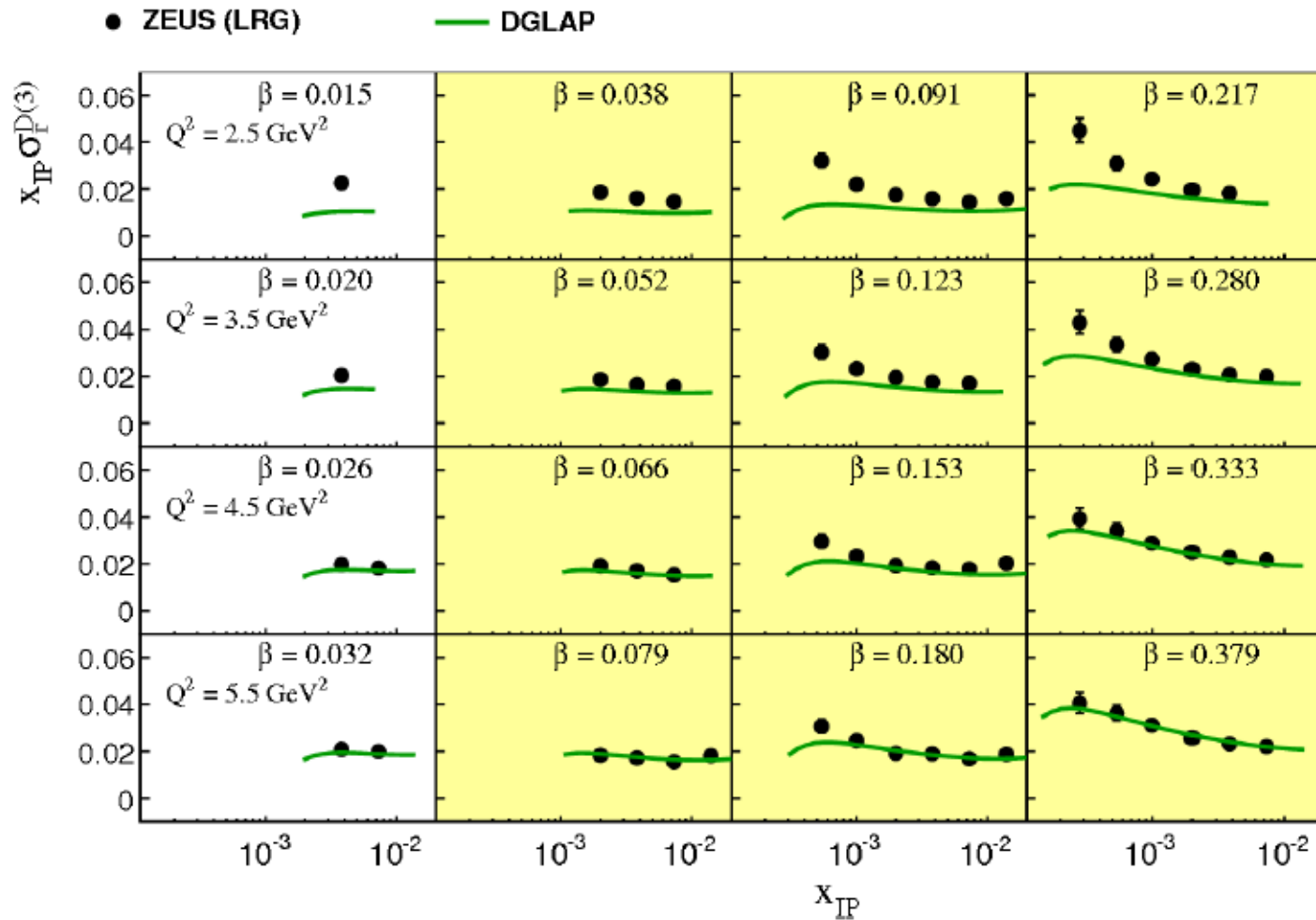
- The dipole cross-section fixed by the GBW fit to inclusive data (massless quarks, no charm)
- Phase space improvement following GBW calculation:

$$F_2^{D(3)}(\beta, Q^2, x_{\mathbb{P}}) = F_2^{D(3),LL(1/\beta)}(Q^2, x_{\mathbb{P}}) \frac{F_2^{GBW}(\beta, Q^2, x_{\mathbb{P}})}{F_2^{GBW}(\beta = 0, Q^2, x_{\mathbb{P}})}$$

C. Marquet, Phys. Rev. **D76** (2007) 094017

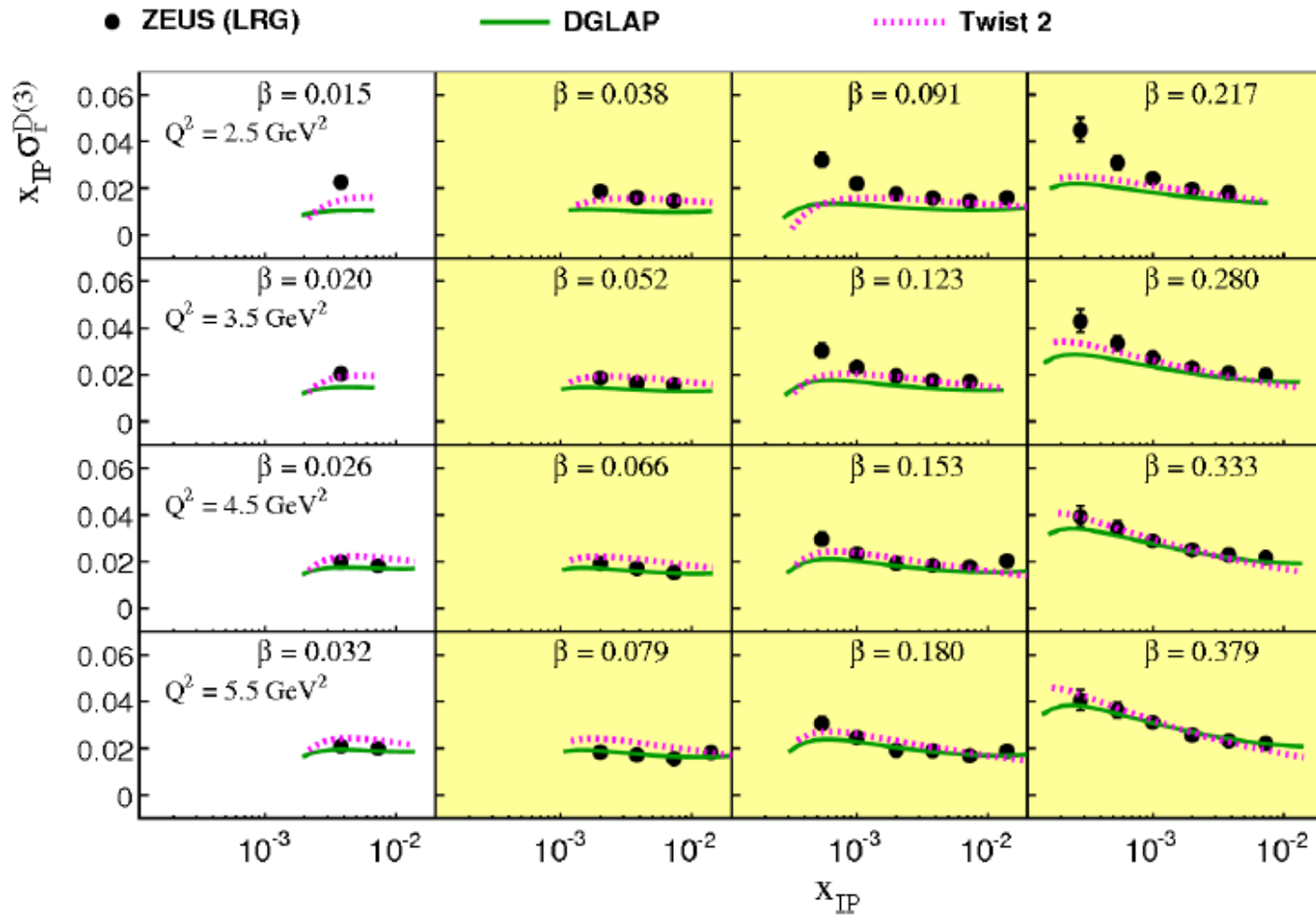
- In the gluonic term, "x₀" parameter is rescaled by a factor of 2 (in inclusive DIS case "x₀" relates to Bjorken x for DDIS to pomeron x_p)

Data vs DGLAP: crucial bins of low Q^2



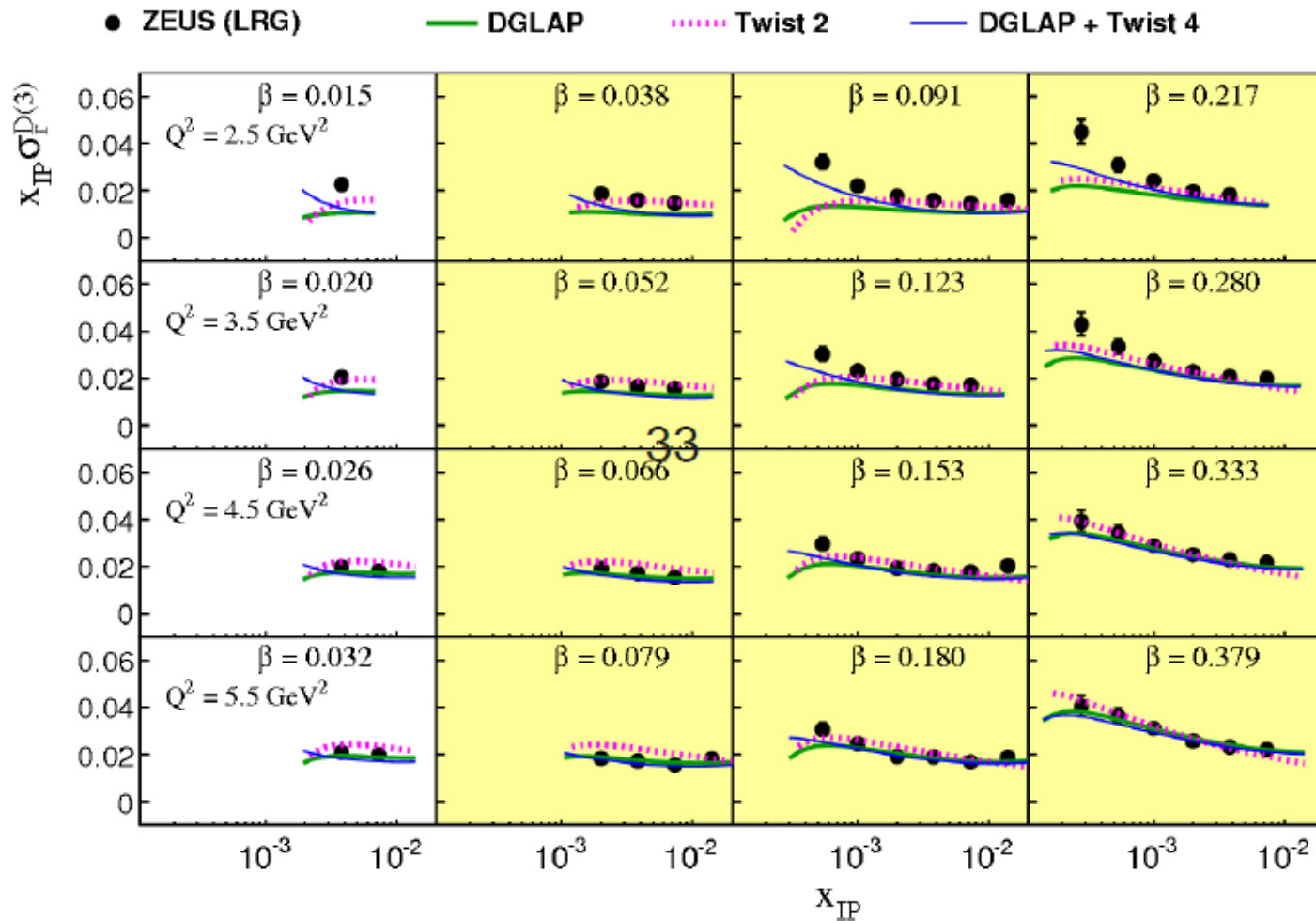
Low β region expected contributions from 2 gluons emissions from the dipol

Data vs DGLAP and twist-2 from GBW



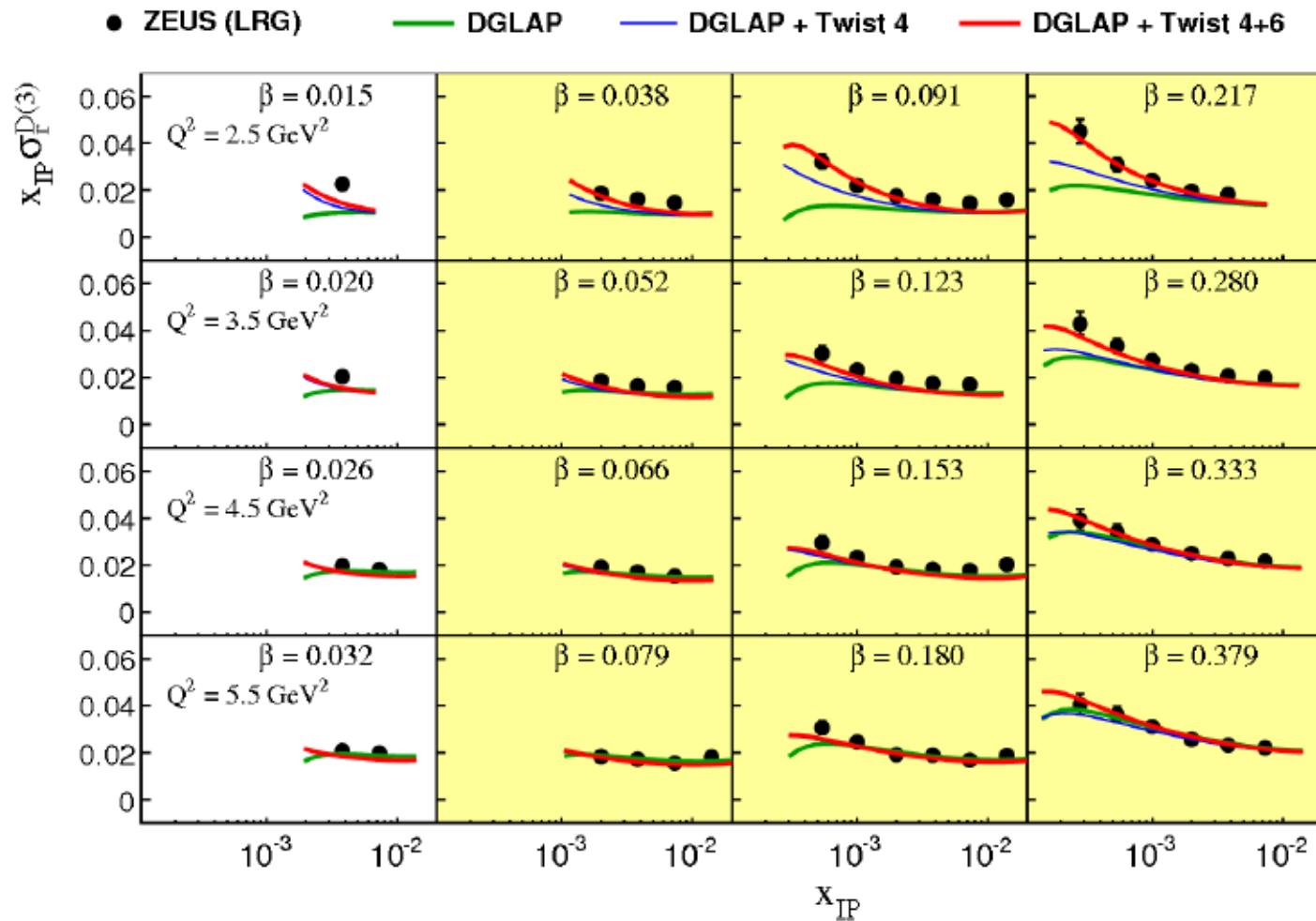
Satisfactory consistence of twist-2 GBW and NLO DGLAP fit

Data vs DGLAP + twist-4 from GBW



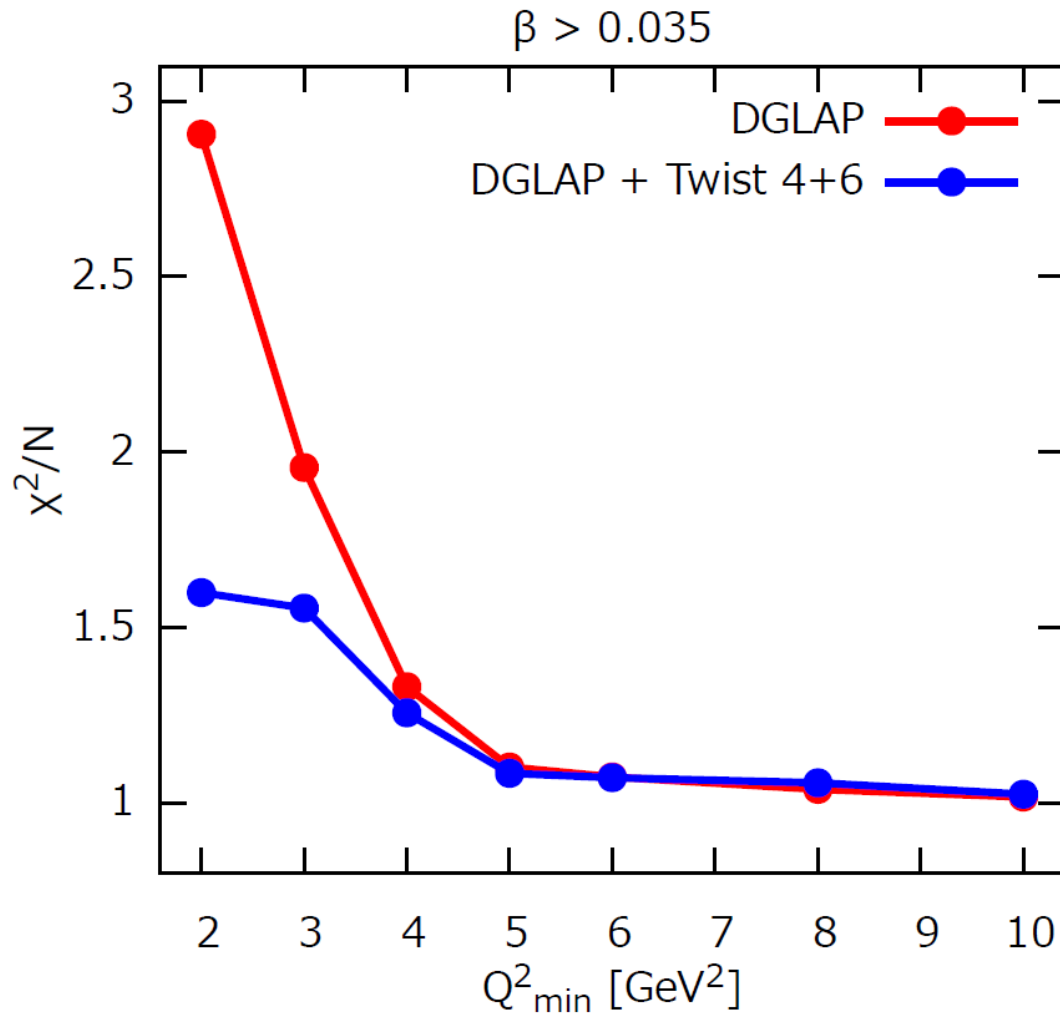
- Correct sign of twist-4 but too weak effect
- Emergence of twist-4 contribution correlated with data deviations from DGLAP fit

Data vs DGLAP + twist-4 + twist-6



- Good description of data
- Dependence on Q^2 difficult to explain without higher twists

Data vs DGLAP + twist-4 + twist-6

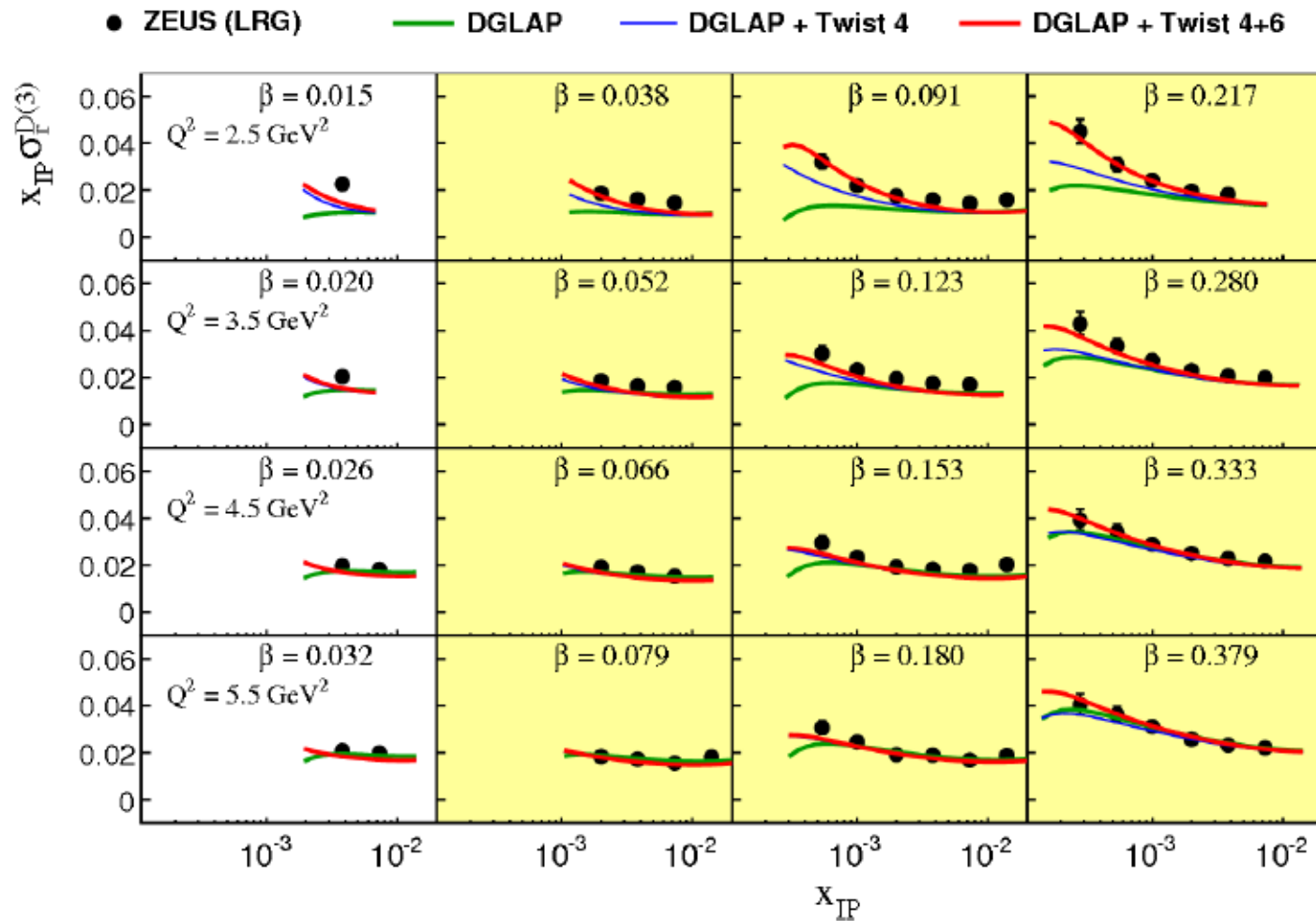


- Improvement in the description of data

- Red: DGLAP fit

- Blue: DGLAP (fit) + twists

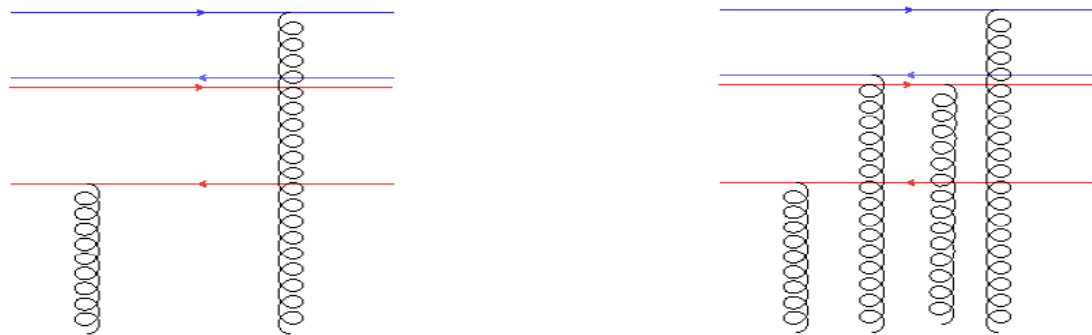
Data vs DGLAP + twist-4 + twist-6



•Warning: inclusion of all twists below DGLAP and twist-4

Constraints on higher twists

- Very weak constraints from experimental inclusive DIS data
J. Bartels, K. Golec-Biernat and L. Motyka, Phys. Rev. **D81** (2010) 054017
- BFKL bootstrap (LL): only one (reggeized) gluon couples to one fundamental (quark) line \longrightarrow eikonal multi-gluon coupling is unrealistic \longrightarrow cut off some higher twists is reasonable
- Example: GBW couples 2 gluons at the amplitude level: twist-2 and twist-4 in the diffractive cross-section



Conclusions

- HERA data are consistent with discovery of the strong (up to 100%) positive higher twists effect in DDIS at, and below Q^2 of order 5 GeV^2
- The main evidence: significant, systematic deviation of DDIS data from DGLAP fits at small x and Q^2
- The saturation model predicts correctly the DGLAP breakdown line (x, Q^2) due to the emergence of higher twists
- The saturation model provides a good description of data when the twist series is cut-off at twist-6
- Experimental and theoretical exploration of higher twists may be now possible

Diffraction: quark – antiquark contribution

$$x_{\mathbb{P}} F_{L,T}^{D(3)}(\beta, Q^2, x_{\mathbb{P}}) = \frac{Q^4}{4\pi^2 \alpha \beta} \left(\frac{d\sigma_{L,T}^{\gamma^* p}}{dM_x^2} \right)$$

$$\frac{d\sigma_{L,T}^{q\bar{q}}}{dM_x^2} = \frac{1}{16\pi b_D} \sum_f \int \frac{d^2 p}{(2\pi)^2} \int_0^1 dz \delta \left(\frac{p^2}{z\bar{z}} - M_x^2 \right) \sum_{spin} \left| \int d^2 r e^{i\vec{p}\cdot\vec{r}} \Psi_{h\bar{h},\lambda}^f(Q, z, \vec{r}) \sigma(r) \right|^2$$

$$\sum_{spin} \Psi_{h\bar{h},\lambda}^f(Q, z, \vec{r}) \Psi_{h\bar{h},\lambda}^{f*}(Q, z, \vec{r}') = \frac{N_c \alpha e_f^2}{2\pi^2} \begin{cases} 4Q^2 (z\bar{z})^2 K_0(\varepsilon r) K_0(\varepsilon r') & (L) \\ \varepsilon^2 (z^2 + (1-z)^2) \frac{\vec{r}\cdot\vec{r}'}{rr'} K_1(\varepsilon r) K_1(\varepsilon r') & (T) \end{cases} \quad \varepsilon = \sqrt{z\bar{z}} Q$$

$$\frac{d\sigma_{L,T}^{q\bar{q}}}{dM_x^2} = \frac{N_c \alpha}{8\pi^2 b_D} \frac{\sigma_0^2}{Q^2} \sum_f e_f^2 \int_0^\infty d\rho d\rho' \rho K_{0,1}(\rho) J_{0,1}(w\rho) \rho' K_{0,1}(\rho') J_{0,1}(w\rho')$$

$$\left[h_{L,T} \left(\frac{\rho^2}{Q^2 R^2} \right) + h_{L,T} \left(\frac{\rho'^2}{Q^2 R^2} \right) - h_{L,T} \left(\frac{\rho^2 + \rho'^2}{Q^2 R^2} \right) \right]$$

$$h_L(v) = \frac{1}{8} \left[\frac{4}{3} - \sqrt{\pi} G_{1,2}^{2,0} \left(v \left| \begin{matrix} \frac{5}{2} \\ 0, 2 \end{matrix} \right. \right) \right] \quad h_T(v) = \frac{1}{8} \left[\frac{4}{3} - \sqrt{\pi} G_{1,2}^{2,0} \left(v \left| \begin{matrix} \frac{3}{2} \\ 0, 1 \end{matrix} \right. \right) + \frac{\sqrt{\pi}}{2} G_{1,2}^{2,0} \left(v \left| \begin{matrix} \frac{5}{2} \\ 0, 2 \end{matrix} \right. \right) \right]$$

Diffraction: quark – antiquark – gluon contribution

$$\frac{d\sigma_{L,T}^{q\bar{q}g}}{dM_x^2} = \frac{1}{16\pi b_D} \frac{N_c \alpha_s}{2\pi^2} \frac{\sigma_0^2}{M_x^2} \sum_f \int d^2 r_{01} \int_0^1 dz \sum_{spin} |\Psi_{h\bar{h},\lambda}^f(Q, z, r_{01})|^2 \sigma_{2d}(r_{01})$$

$$\sigma_{2d}(r_{01}) = \int d^2 r_{02} K(01|2) [N_{02} + N_{12} - N_{02}N_{12} - N_{01}]^2$$

$$K(01|2) = \frac{r_{01}^2}{r_{02}^2 r_{12}^2}$$

$$\frac{d\sigma_{L,T}^{q\bar{q}g}}{dM_x^2} = \frac{1}{16\pi b_D} \frac{N_c \alpha_s}{2\pi^2} \frac{\sigma_0^2}{M_x^2} \sum_f \int \frac{ds}{2\pi i} \left(\frac{4Q_0^2}{Q^2} \right)^{-s} \tilde{H}_{L,T}^f(-s) \tilde{\sigma}_{2d}(s)$$

$$\tilde{\sigma}_{2d}(s) = I_1 - I_2$$

$$I_1 = \frac{(Q_0^2)^s}{\pi} \int d^2 r_{01} (r_{01}^2)^{s-1} \int d^2 r_{02} K(01|2) \left[(N_{02} + N_{12} - N_{02}N_{12})^2 - N_{01}^2 \right]$$

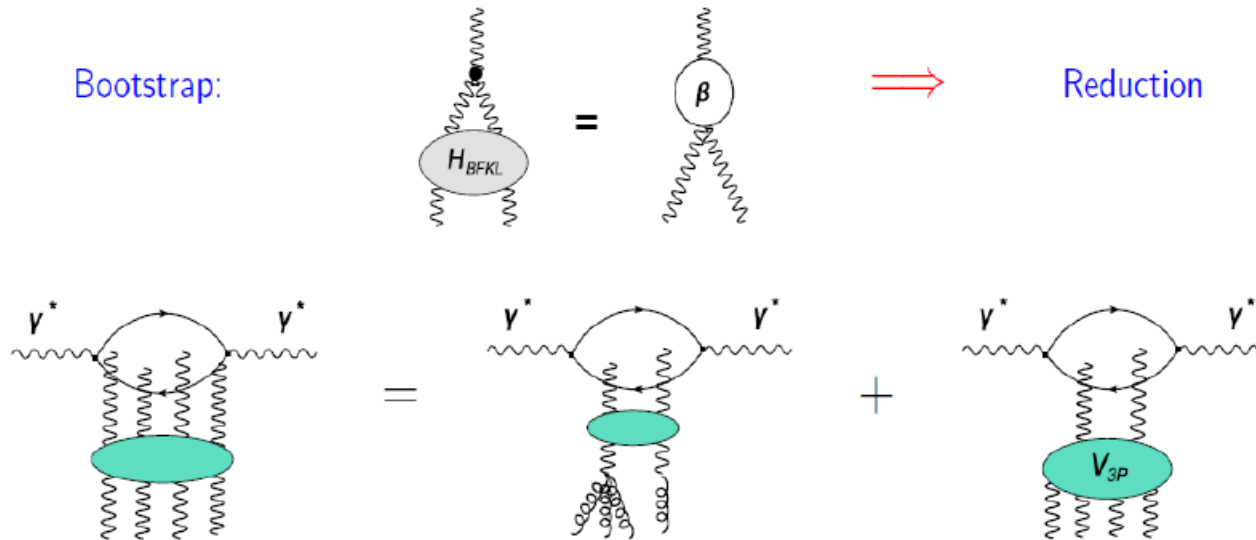
$$I_2 = \frac{(Q_0^2)^s}{\pi} \int d^2 r_{01} (r_{01}^2)^{s-1} \int d^2 r_{02} K(01|2) 2N_{01} [N_{02} + N_{12} - N_{02}N_{12} - N_{01}]$$

$$I_1 = \pi (Q_0 R)^{2s} 2^{1+s} (2^{1+s} - 1) \Gamma(s) [H_s - {}_3F_2(1, 1, 1-s; 2, 2; -1)s]$$

$$H_s = \sum_{k=1}^s \frac{1}{k}$$

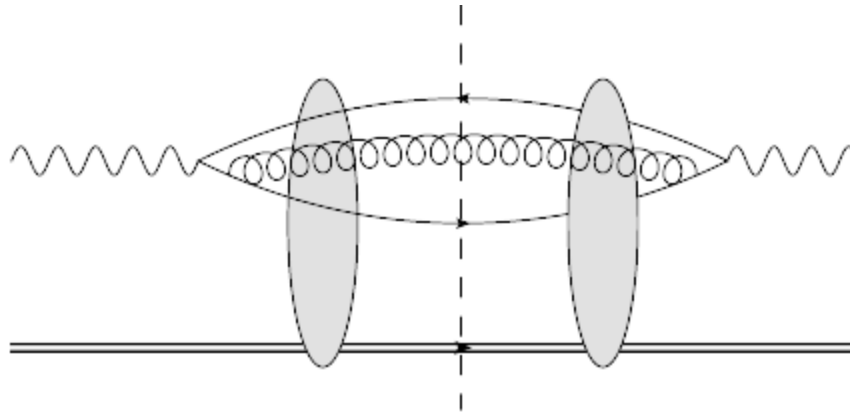
$$I_2 = \pi (Q_0 R)^{2s} 2^{1+2s} \Gamma(s) \left\{ 1 - 2^{1-s} + 3^{-s} + \frac{2^{-s}s}{1+s} \left[1 - {}_2F_1 \left(1+s, 1+s; 2+s; -\frac{1}{2} \right) \right] \right\}$$

BFKL bootstrap equation



- BFKL bootstrap (LL) \rightarrow only one (reggeized) gluon couples to one fundamental (quark) line
- Common double logarithmic limit of BFKL and DGLAP evolutions \rightarrow eikonal multi-gluon coupling is unrealistic \rightarrow cut off of some higher twists

Diffraction: quark – antiquark – gluon



- Effectively 2 dipoles at large N_c limit
- Subleading in the α_s constant, but enhanced at small β – due to the dipole size

$$\sigma_{2d} \sim \alpha_s \int d^2 r_{02} K(r_{01}, r_{02}) [N_{02} + N_{12} - N_{01} - N_{02}N_{12}]^2$$

M.L. Good and W.D. Walker, Phys. Rev. **120** (1960) 1857

A. Bialas and R. Peschanski, Phys. Lett. **B378** (1996) 302

S. Munier and A. Shoshi, Phys. Rev. **D69** (2004) 074022

$$\frac{d}{p} \approx 0.003 \cdot p$$