Higher twist effects in diffractive DIS at HERA

Mariusz Sadzikowski
Jagiellonian University, Cracow

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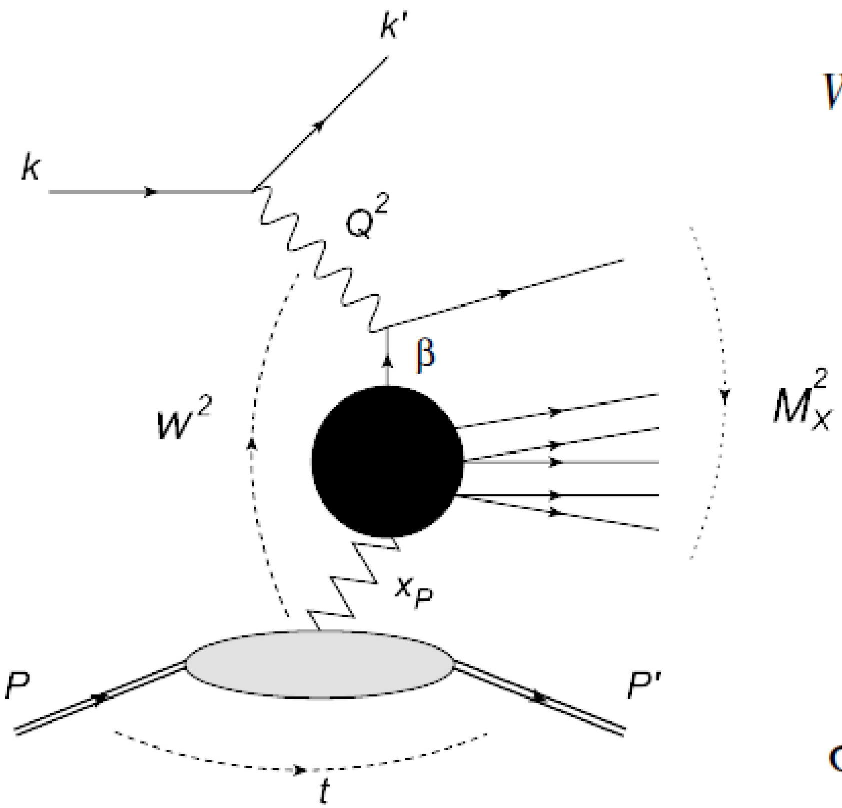
Outline

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

L. Motyka, MS, W. Slominski, Phys. Rev. **D86**, 111501(R), (2012)

Diffractive DIS: process and variables



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

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

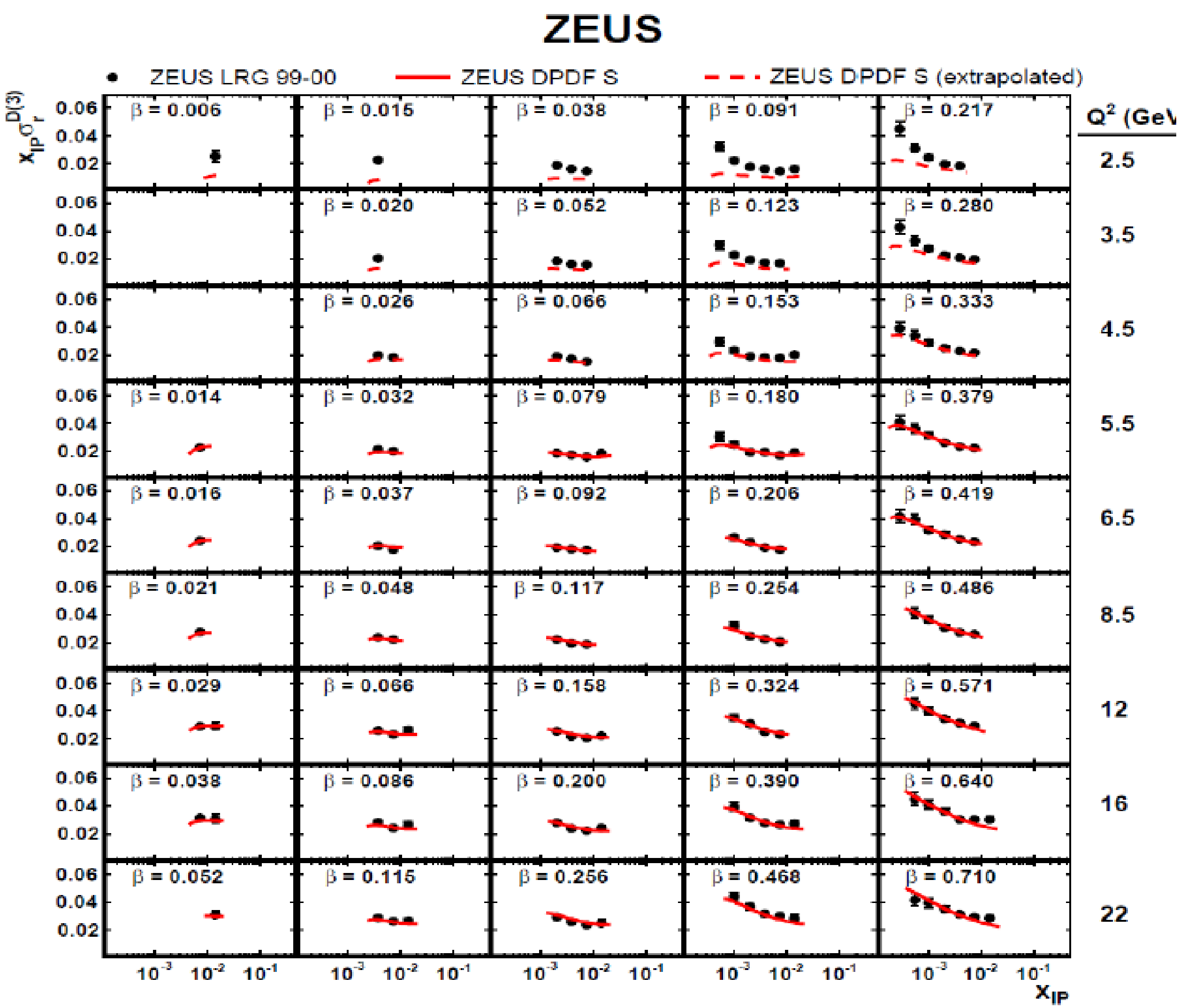
Domain of interest:

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

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

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

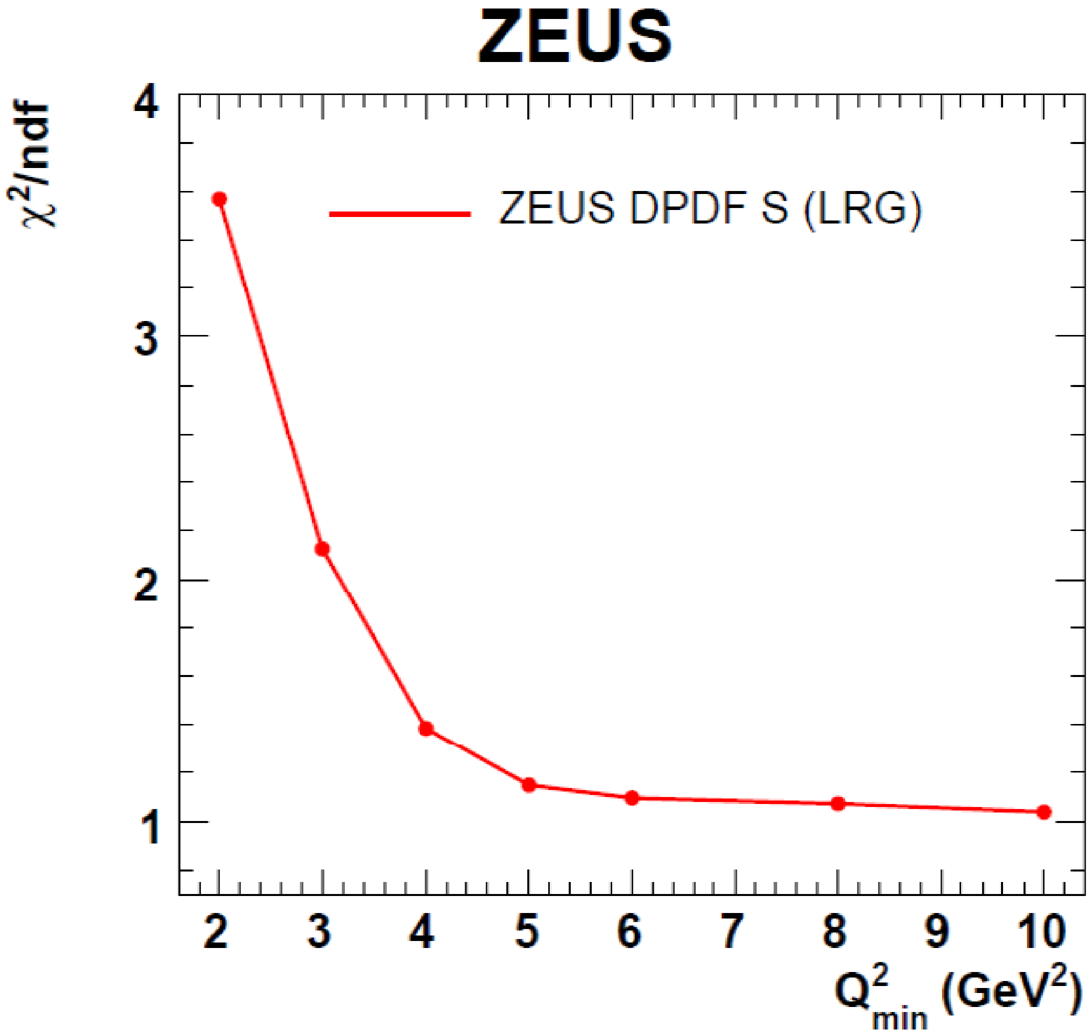
DGLAP fit to DDIS data (ZEUS, 2009)



Nucl. Phys. **B831** (2010) 1

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

DGLAP breakdown: ”critical scale”



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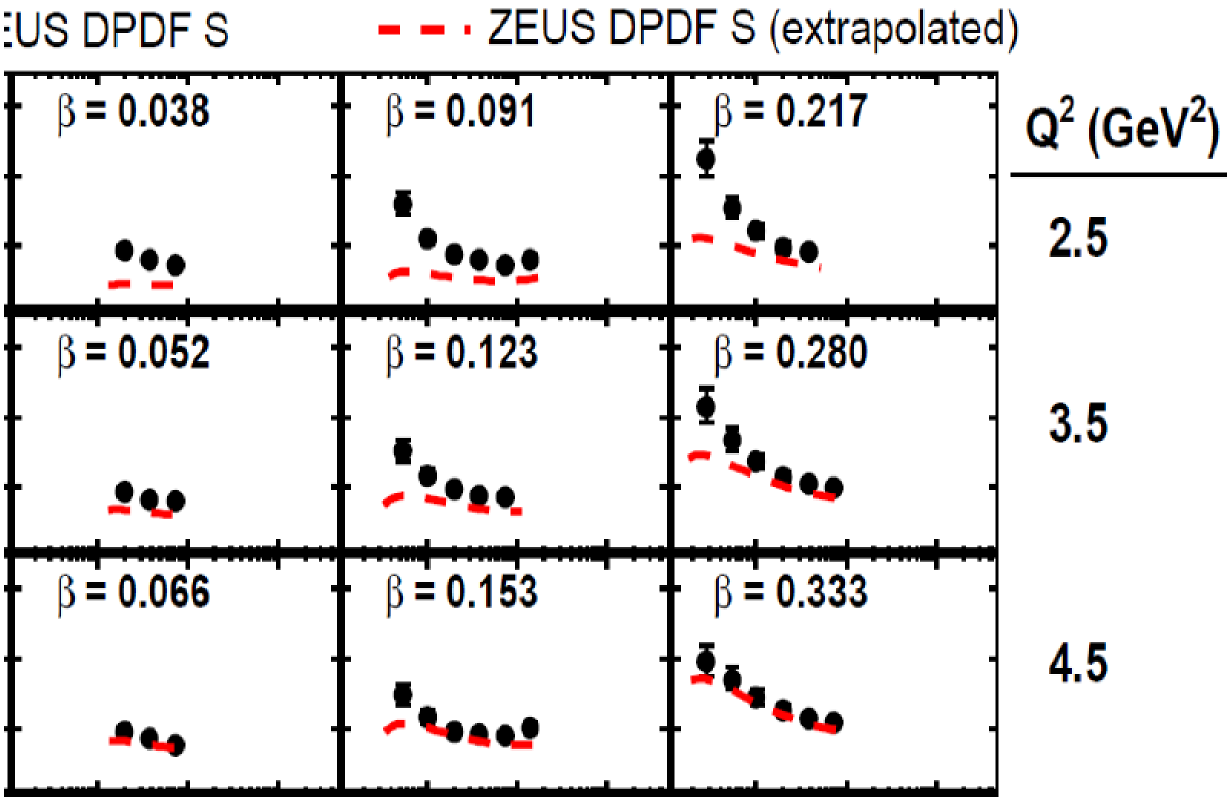
- DGLAP fits below 5 GeV^2 fails
- Strong DGLAP breaking effects below 3 GeV^2

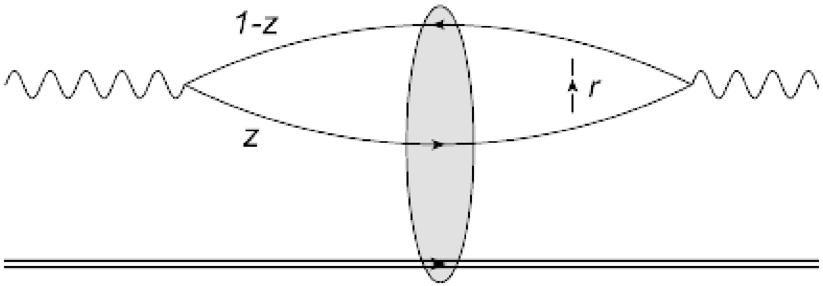
DGLAP breakdown: closer look



- Rapid deviation of the fit from data with decreasing Q^2
- Indication of higher twists?

Problematic region: low x_P, low Q^2

Beyond DGLAP: dipole picture



Cross-section:

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

GBW parametrization

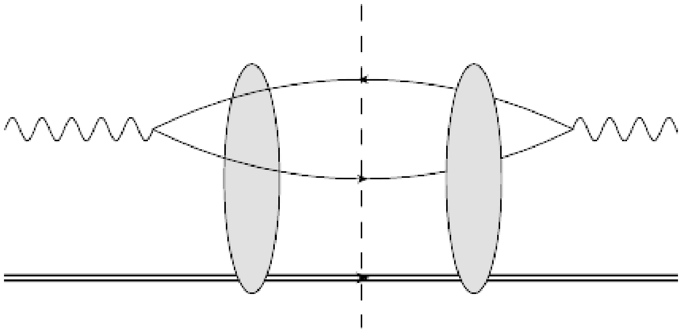
$$\sigma_d(x, r^2) = \sigma_0 \left[1 - \exp\left(-\frac{r^2}{4R^2(x)}\right)\right] \qquad R(x) = \frac{1}{Q_0}\left(\frac{x}{x_0}\right)^{\lambda/2}$$

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

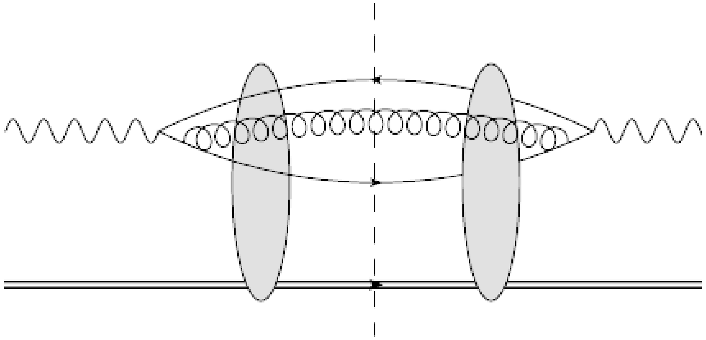
Inclusive scattering: large energy factorization+ eikonal colour dipole scattering

Diffraction: quark – antiquark and quark – antiquark – gluon



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

- 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)

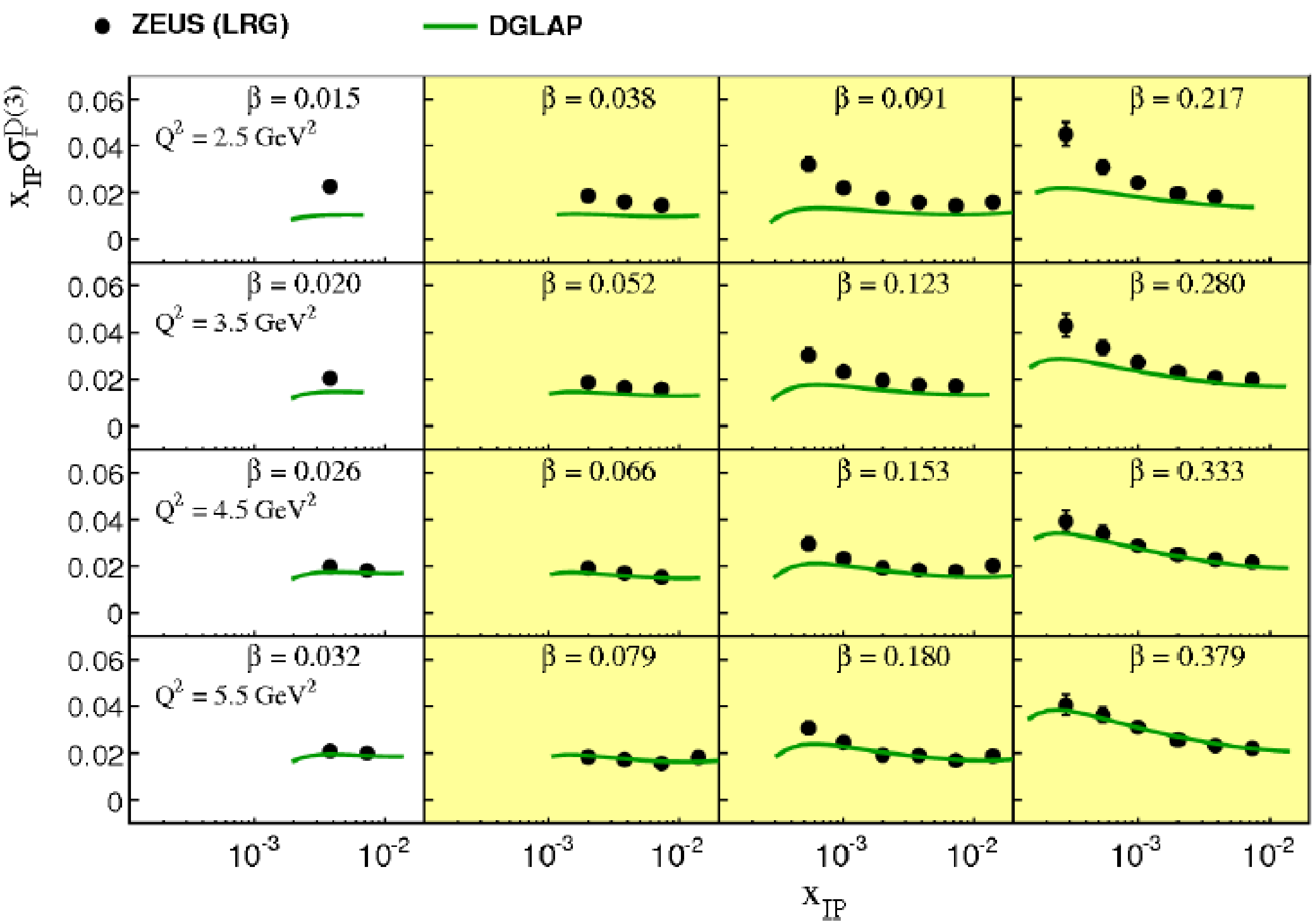
- Phase space improvement following GBW calculation:

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

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

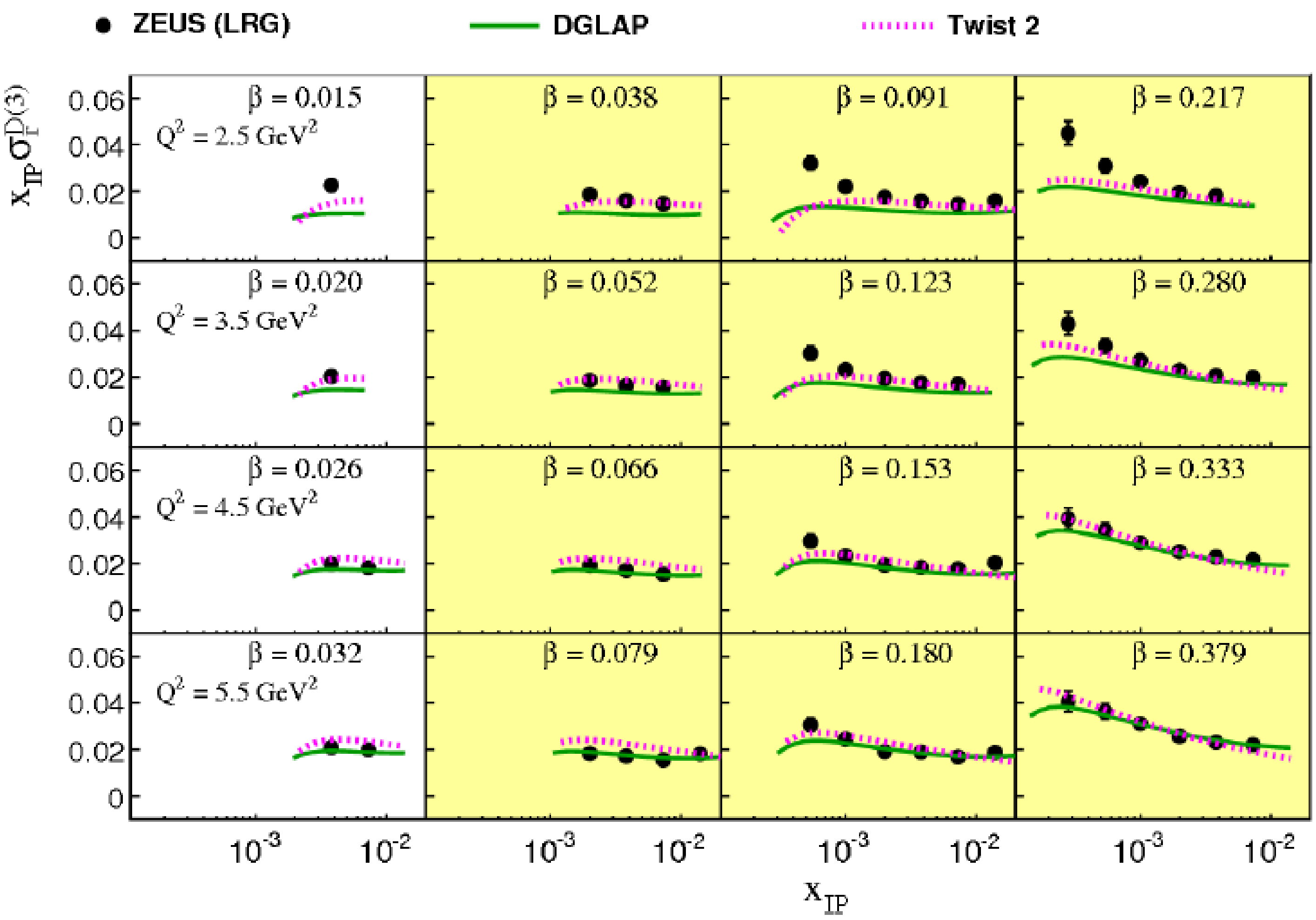
- In the gluonic term, ”x_0” parameter is rescaled by a factor of 2 (in inclusive DIS case ”x_0” relates to Bjorken x for DDIS to pomeron x_P)

Data vs DGLAP: crusial bins of low Q^2



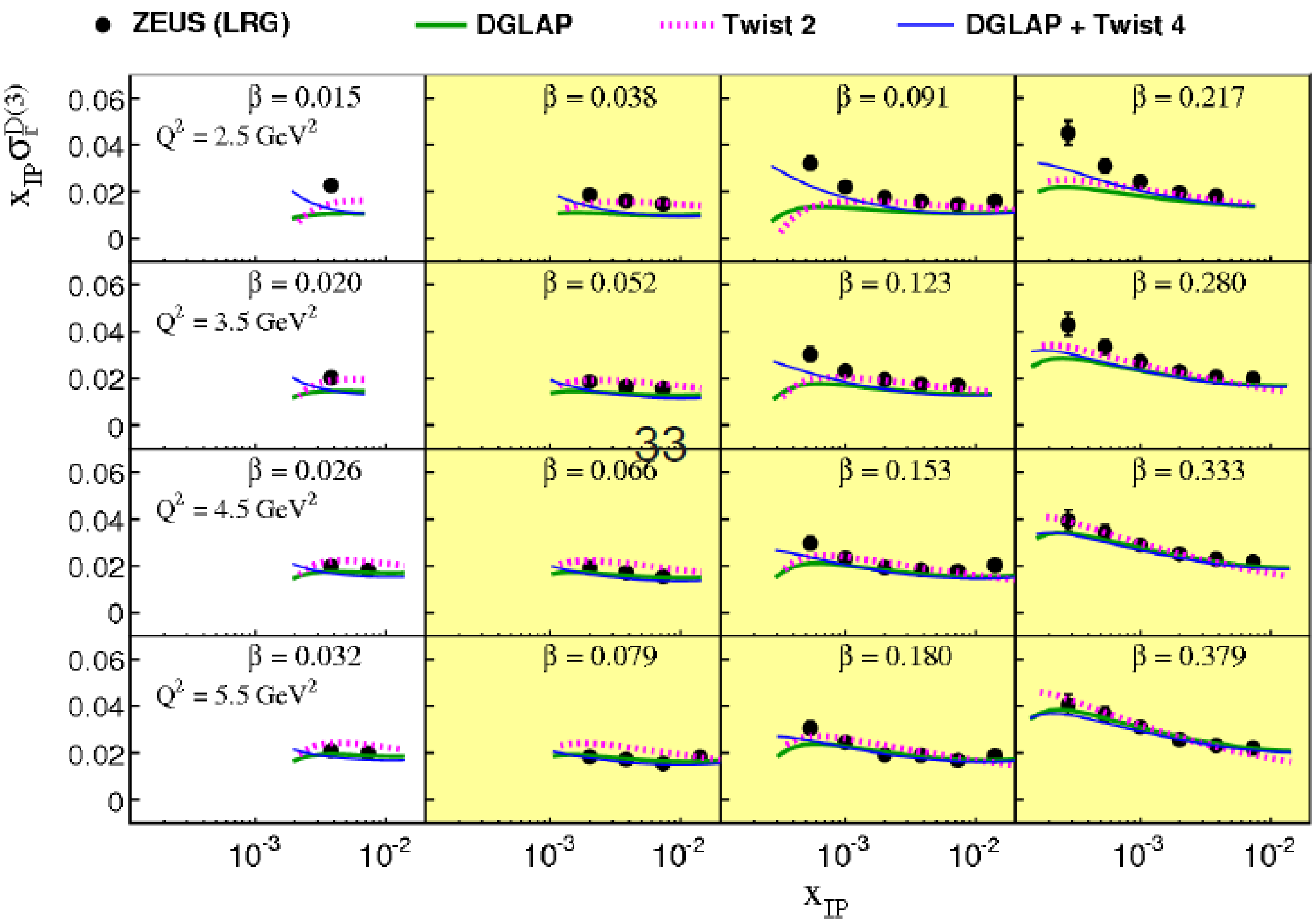
Low β region expected contributions from 2 gluons emissions from the dipol

Data vs DGLAP and twist-2 from GBW



Satisfactory consistence of twist-2 GBW and NLO DGLAP fit

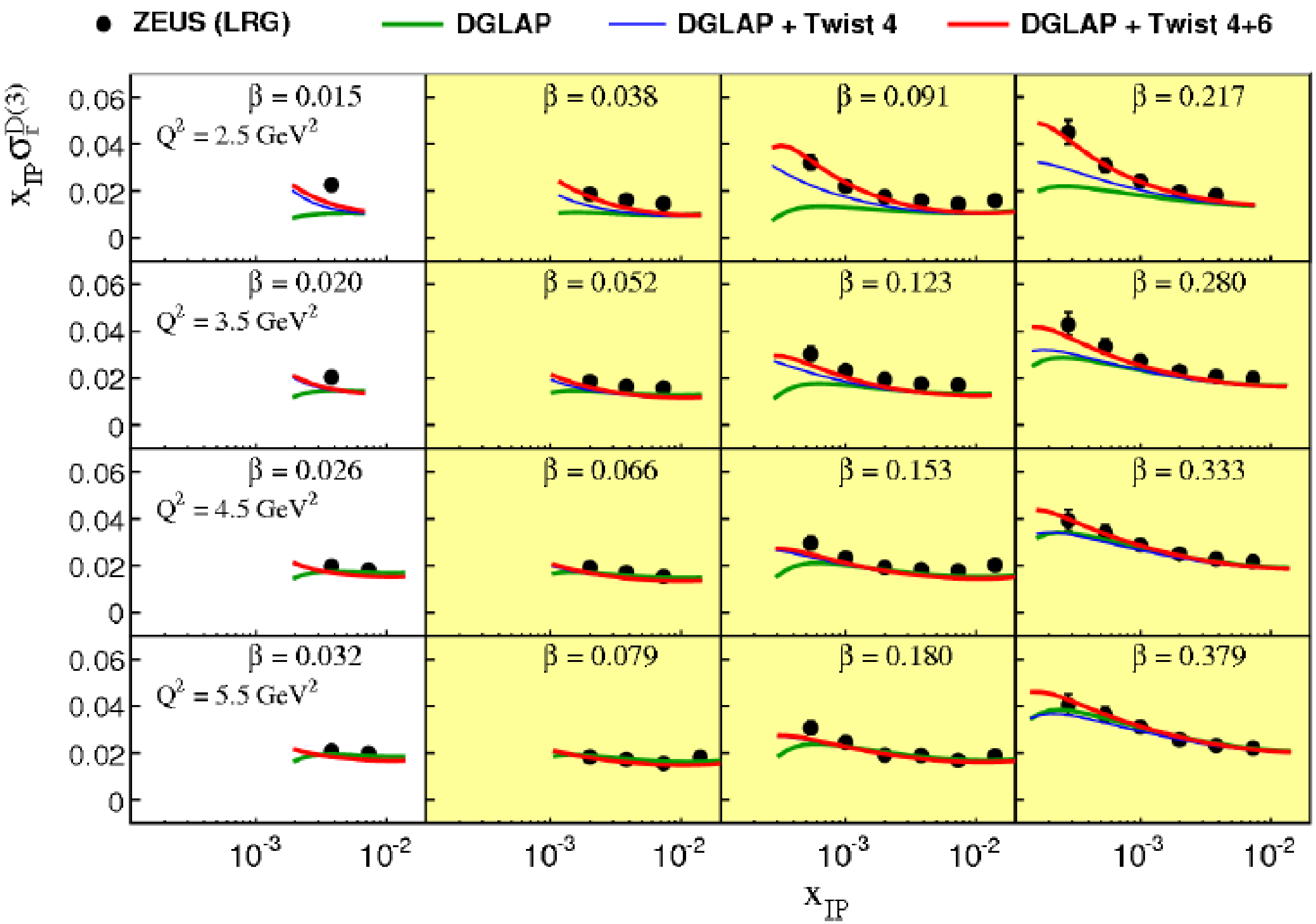
Data vs DGLAP + twist-4 from GBW



•Correct sign of twist-4 but too weak effect

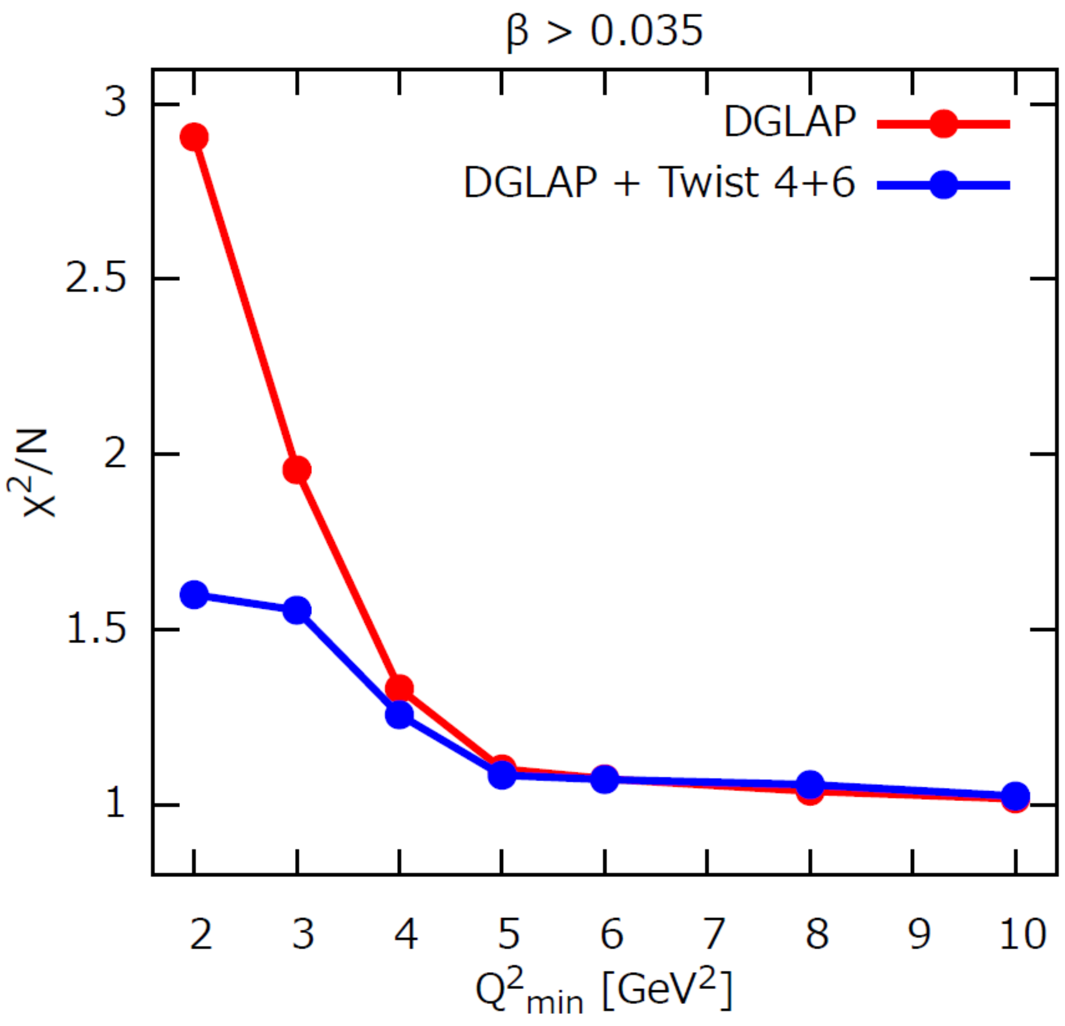
•Emergence of twist-4 contribution correlated with data deviations from DGLAP fit

Data vs DGLAP + twist-4 + twist-6



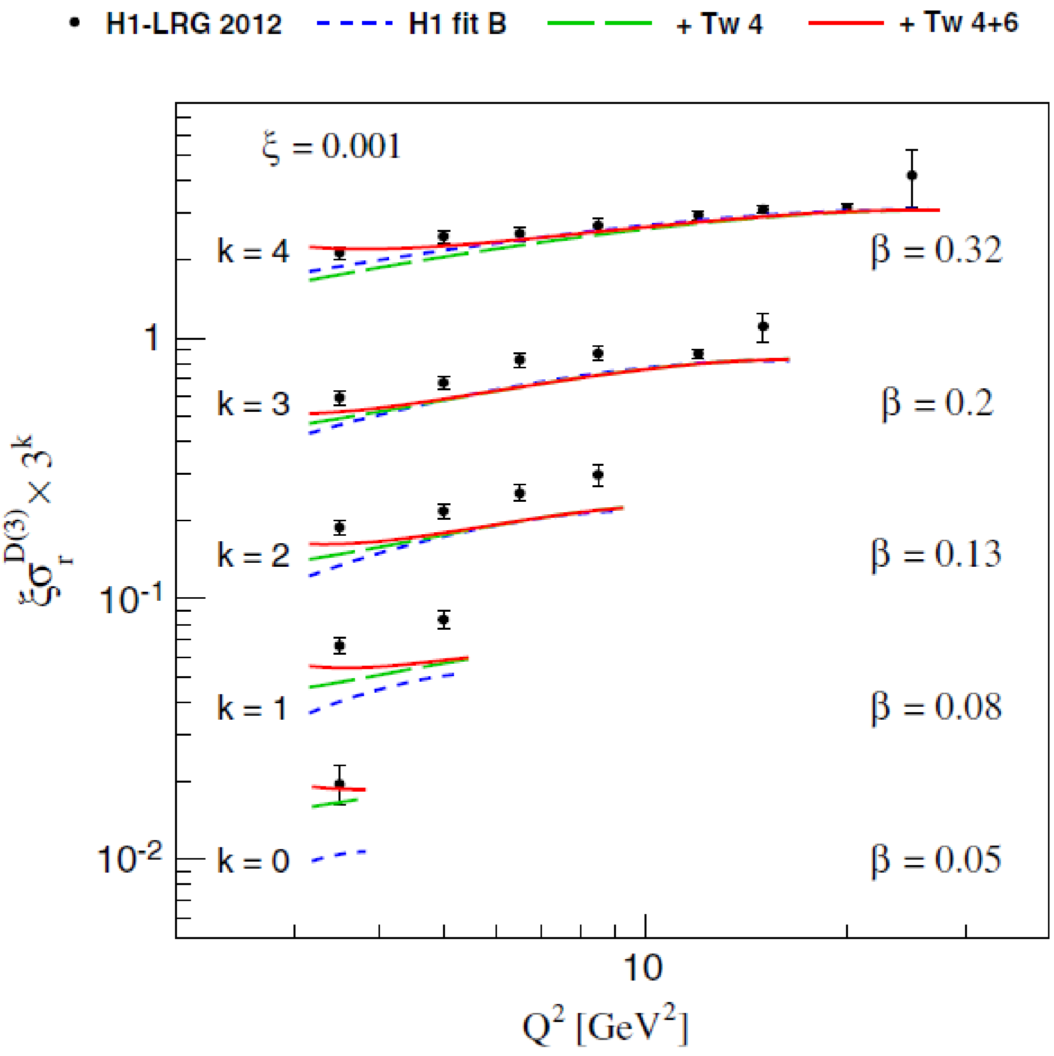
- Good description of data
- Dependence on Q^2 difficult to explain without higher twists

Data vs DGLAP + twist-4 + twist-6

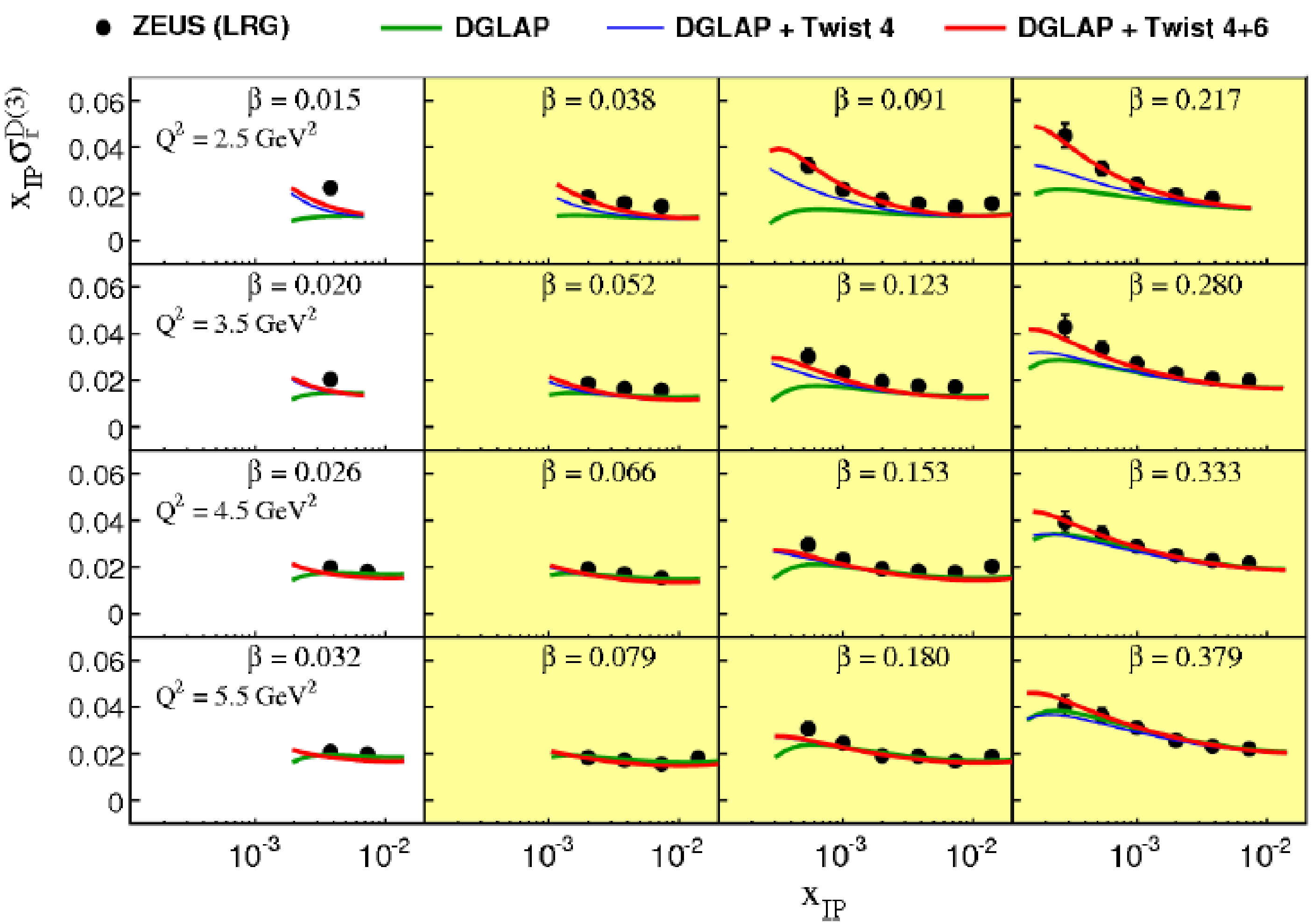


- Improvement in the description of data
- Red: DGLAP fit
- Blue: DGLAP (fit) + twists

H1 data vs.+ twist-4 + twist-6



Data vs DGLAP + twist-4 + twist-6



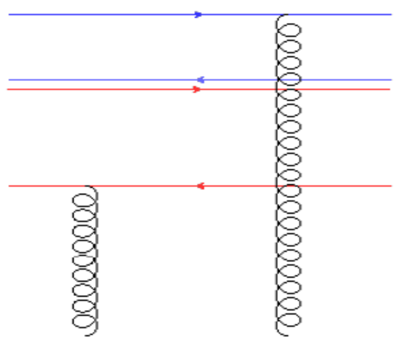
•Warning: inclusion of all twists below DGLAP and twist-4

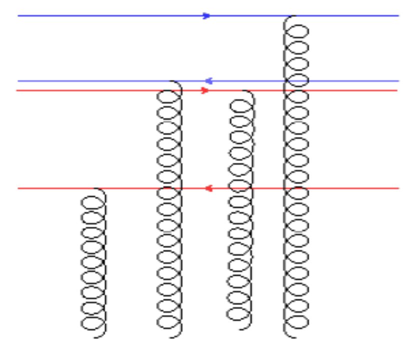
Constraints on higher twists

- 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 ⟶ eikonal multi-gluon coupling is unrealistic ⟶ 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

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

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

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

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

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

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

Diffraction: quark – antiquark – gluon contribution

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

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

$$\frac{d\sigma^{q\bar{q}g}_{L,T}}{dM_x^2} = \frac{1}{16\pi b_D}\frac{N_c\alpha_s}{2\pi^2}\frac{\sigma_0^2}{M_x^2}\sum_f \int \frac{ds}{2\pi i}\left(\frac{4Q_0^2}{Q^2}\right)^{-s}\tilde{H}^f_{L,T}(-s)\tilde{\sigma}_{2d}(s) \qquad \tilde{\sigma}_{2d}(s) = I_1 - I_2$$

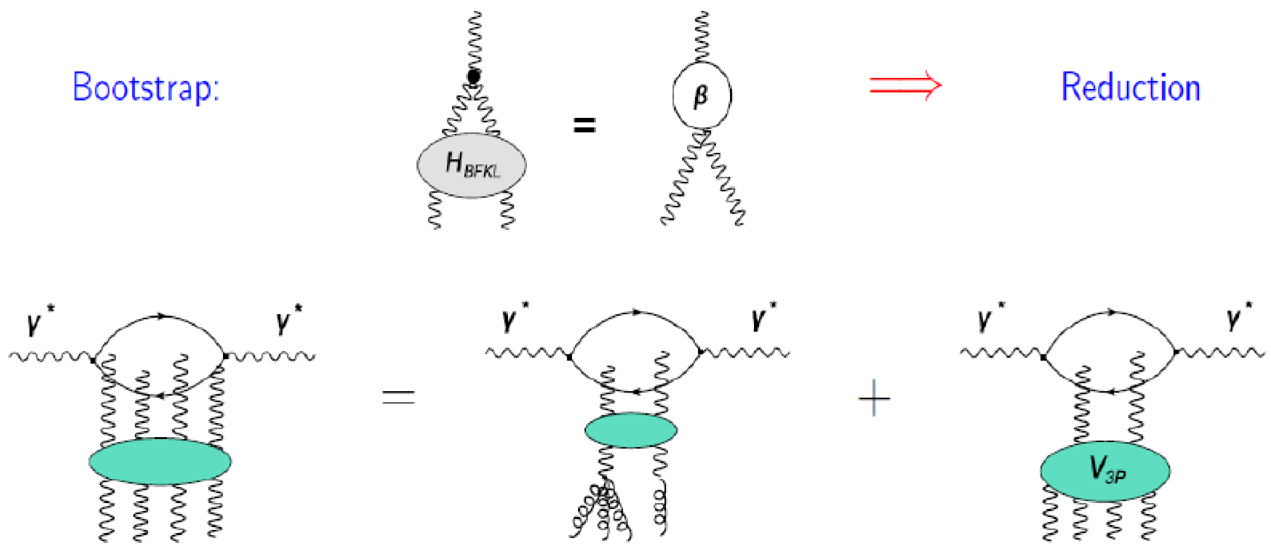
$$I_1 = \frac{(Q_0^2)^s}{\pi}\int d^2r_{01}(r_{01}^2)^{s-1}\int d^2r_{02}K(01|2)\left[(N_{02}+N_{12}-N_{02}N_{12})^2 - N_{01}^2\right]$$

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

$$I_1 = \pi(Q_0R)^{2s}2^{1+s}(2^{1+s}-1)\Gamma(s)\left[H_s - {}_3F_2(1,1,1-s;2,2;-1)s\right] \qquad H_s = \sum_{k=1}^{s}\frac{1}{k}$$

$$I_2 = \pi(Q_0R)^{2s}2^{1+2s}\Gamma(s)\left\{1-2^{1-s}+3^{-s}+\frac{2^{-s}s}{1+s}\left[1-{}_2F_1\left(1+s,1+s;2+s;-\frac{1}{2}\right)\right]\right\}$$

BFKL bootstrap equation



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