Evidence for the higher twists effects in diffractive DIS at HERA

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Schedule

• DGLAP description of DDIS (at HERA)

• DGLAP breakdown

• Inclusion of multiple scattering: saturation models

• Higher twists and the data

• Conclusions

Work in progress: Leszek Motyka, MS, Wojtek Slominski
Diffractive DIS: process and variables

\[ W^2 = (P + q)^2 \]
\[ x_P = \frac{Q^2 + M_{X}^2}{Q^2 + W^2} \]
\[ x = \beta x_P \]

\[ \beta = \frac{Q^2}{Q^2 + M_{X}^2} \]
\[ t = (P' - P)^2 \]

Domain of interest:

\[ W \gg M_{X}^2 > Q^2 \gg |t| \]

\[ \sigma_r(\beta, Q^2, x_P) = F_2^{D(3)} - \frac{y^2}{1 + (1 - y)^2} F_L^{D(3)} \]

\[ \frac{d\sigma^{ep\rightarrow eXp}}{d\beta dQ^2 dx_P} = \frac{2\pi\alpha^2}{\beta Q^4} \left[ 1 + (1 - y)^2 \right] \sigma_r(\beta, Q^2, x_P) \]
DGLAP fit to DDIS data (ZEUS, 2009)

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

DGLAP breakdown: ”critical scale”

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

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DGLAP breakdown: closer look

Problematic region: low $x_p$, low $Q^2$

- Rapid deviation of the fit from data with decreasing $Q^2$
- Indication of multiple exchanges?
Beyond DGLAP: GBW saturation model

\[ \sigma \sim \int d^2r \, dz \, |\Psi(z, Q^2 r^2)|^2 \sigma_d(x, r^2) \quad \sigma(x, r^2) = \sigma_0 \left[ 1 - \exp(-Q_0^2 r^2 x^{-\lambda}) \right] \]


Inclusive scattering: large energy factorization + eikonal colour dipole scattering
Diffraction: quark - antiquark

- Colour singlet exchange on the amplitude level
- An exponential $t$-dependence of the amplitude
- Strongly suppressed at small $\beta$
Diffraction: quark – antiquark – gluon

- Effectively 2 dipoles at large $N_c$ limit
- Subleading in the $\alpha_s$ constant, but enhanced at small $\beta$ – due to the dipole size

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

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

\[ F_2^{D(3)}(\beta, Q^2, x_P) = F_2^{D(3),LL(1/\beta)}(Q^2, x_P) \frac{F_2^{GBW}(\beta, Q^2, x_P)}{F_2^{GBW}(\beta = 0, Q^2, x_P)} \]


• 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: crucial bins of low $Q^2$

Low $\beta$ 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

- Good description of data, but...
- Warning: inclusion of all twists below DGLAP and twist-4
Constraints on higher twists

• Very weak constraints from experimental inclusive DIS data

• BFKL bootstrap (LL): only one (reggeized) gluon couples to one fundamental (quark) line → eikonal multi-gluon coupling is unrealistic → cut off some higher twists

• 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

\[ x_p F_{L,T}^{D(3)}(\beta, Q^2, x_p) = \frac{Q^4}{4\pi^2 \alpha \bar{\alpha}} \left( \frac{d\sigma_{L,T}^{q\bar{q}}}{dM_x^2} \right) \]

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

\[ \sum_{\text{spin}} \psi_{h\bar{h},\lambda}^f(Q, z, \bar{r}) \psi_{h\bar{h},\lambda}^{f*}(Q, z, \bar{r}') = \frac{N_c \alpha e_f^2}{2\pi^2} \left\{ \begin{array}{ll}
4Q^2(z\bar{z})^2 K_0(\varepsilon r)K_0(\varepsilon r') & (L) \\
\varepsilon^2(z^2 + (1-z)^2)\frac{1}{r'}K_1(\varepsilon r)K_1(\varepsilon r') & (T) 
\end{array} \right. \]

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

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

\[ h_L(v) = \frac{1}{8} \left[ \frac{4}{3} - \sqrt{\pi} G_{1,2}^{2,0} \left( v \mid \frac{5}{2}, 0, 2 \right) \right] \]

\[ h_T(v) = \frac{1}{8} \left[ \frac{4}{3} - \sqrt{\pi} G_{1,2}^{2,0} \left( v \mid \frac{3}{2}, 0, 1 \right) + \frac{\sqrt{\pi}}{2} G_{1,2}^{2,0} \left( v \mid \frac{5}{2}, 0, 2 \right) \right] \]
Diffraction: quark – antiquark – gluon contribution

\[
\frac{d\sigma_{qg}^{qg}}{dM_x^2} = \frac{1}{16\pi b_D} \frac{N_c\alpha_s}{2\pi^2} \sigma_0^2 \sum_f \int d^2r_{01}N_{qg}^2(r_{01}) \sum_{spin} \int_0^1 dz \left| \psi_f^{h\bar{h},\lambda}(Q, z, r_{01}) \right|^2
\]

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

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

\[
\frac{d\sigma_{qg}^{qg}}{dM_x^2} = \frac{1}{16\pi b_D} \frac{N_c\alpha_s}{2\pi^2} \sigma_0^2 \sum_f \int \frac{ds}{2\pi i} \left( \frac{4Q_0^2}{Q^2} \right)^{-s} \tilde{H}_{L,T}^f(-s) \tilde{N}_{qg}^2(s)
\]

\[
\tilde{N}_{qg}^2(s) = I_1 - I_2
\]

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

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

\[
H_s = \sum_{k=1}^{s} \frac{1}{k}
\]

\[
I_1 = \pi(Q_0R)^{2s}2^{1+s}(2^{1+s} - 1)\Gamma(s) [H_s - 3F_2(1, 1, 1 - s; 2, 2; -1)s]
\]

\[
I_2 = \pi(Q_0R)^{2s}2^{1+2s}\Gamma(s) \left\{ 1 - 2^{1-s} + 3^{-s} + \frac{2^{-s}s}{1+s} \left[ 1 - 2F_1 \left( 1 + s, 1 + s; 2 + s; -\frac{1}{2} \right) \right] \right\}
\]
BFKL bootstrap equation

Bootstrap: \[ H_{\text{BFKL}} \stackrel{\beta}{=} \quad \Rightarrow \quad \text{Reduction} \]

- BFKL bootstrap (LL) → only one (reggeized) gluon couples to one fundamental (quark) line
- Common double logarithmic limit of BFKL and DGLAP evolutions → eikonal multi-gluon coupling is unrealistic → cut off of some higher twists
\[ \frac{d}{p} \approx 0.003 \cdot p \]