Dipole model analysis of highest precision HERA data, including very low Q^2's

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Introduction

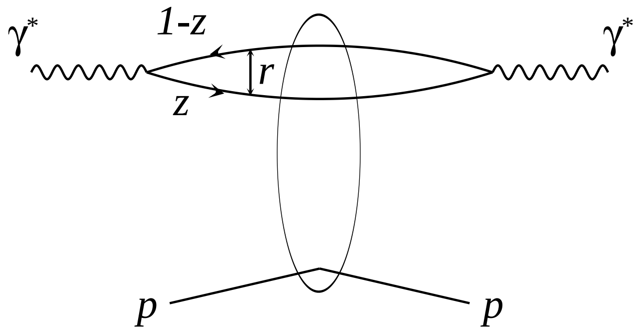
- Motivation: We analyse, within a dipole model, the final, inclusive HERA DIS cross section data in the low x region, using fully correlated errors.
- We show, that these highest precision data are very well described within the dipole model framework starting from very low Q^2 values of 0.3 GeV^2 to the highest values of $Q^2 = 250$ GeV^2.
- We discuss the saturation question and the properties of the gluon density obtained in this way.
- The analysis was done in the xFitter framework.

Outline

- Dipole model approach.
- GBW and BGK parametrization of dipole cross section.
- Results of the fits from BGK dipole model.
- Gluon density.
- 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

$$\hat{\sigma}(r, x) = \sigma_0 \left(1 - \exp\{-\hat{r}^2\}\right) \qquad\qquad \hat{r} = r/R_s(x)$$

Dipole cross section

- BGK (Bartels-Golec-Kowalski) parametrization

$$\hat{\sigma}(r,x) = \sigma_0 \left\{1 - \exp\left[-\pi^2 r^2 \alpha_s(\mu^2) xg(x,\mu^2)/(3\sigma_0)\right]\right\}$$

- $\mu^2 = C/r^2 + \mu_0^2$ is the scale of the gluon density
- μ_0^2 is a starting scale of the QCD evolution. $\mu_0^2 = Q_0^2$
- gluon density is evolved according to the LO or NLO DGLAP eq.
- soft gluon:

$$xg(x,\mu_0^2) = A_g\, x^{\lambda_g}\, (1-x)^{C_g}$$

- soft + hard gluon:

$$xg(x,\mu_0^2) = A_g\, x^{\lambda_g}\, (1-x)^{C_g} (1 + D_g x + E_g x^2)$$

Results of the Fits

- Dipole model BGK fit with fix valence quarks and without

Q^2_{min} [GeV^2]	$\sigma_0[mb]$	A_g	λ_g	C_g	N_{df}	χ^2	χ^2/N_{df}
3.5	87.0± 8.9	2.32± 0.009	-0.056± 0.11	8.21± 0.80	534	551.05	1.03
8.5	72.36± 7.4	2.766± 0.009	-0.042± 0.123	6.543± 0.632	448	452.48	1.01

Table 1: BGK fit with fixed valence quarks for σ_r for H1ZEUS-NC data in the range $Q^2 \geq 3.5$ or 8.5 GeV^2 and $x \leq 0.01$. NLO fit. *Soft gluon.* $m_{uds} = 0.14, m_c = 1.3$ GeV. $Q_0^2 = 1.9$ GeV^2.

1.2 BGK NLO fit without valence quarks for σ_r for HERA1+2-NCep-460, HERA1+2-NCep-575, HERA1+2-NCep-820, HERA1+2-NCep-920 and HERA1+2-NCem in the range $Q^2 \geq 3.5$ GeV^2 and $Q^2 \geq 8.5$ and $x \leq 0.01$. *Soft gluon.*

No	Q^2	HF Scheme	σ_0	A_g	λ_g	Cg	$cBGK$	Np	χ^2	χ^2/Np
1	$Q^2 \geq 3.5$	RT OPT	85.111	2.075	-0.093	4.989	4.0	568	592.46	1.04
2	$Q^2 \geq 8.5$	RT OPT	123.31	1.997	-0.0975	4.655	4.0	482	479.37	0.99

Results of the Fits

- Dipole model BGK fit with fitted valence quarks

1.3 BGK NLO fit with fitted valence quarks for σ_r for HERA1+2-NCep-460, HERA1+2-NCep-575, HERA1+2-NCep-820, HERA1+2-NCep-920 and HERA1+2-NCem in the range $Q^2 \geq 3.5$ GeV^2 and $Q^2 \geq 8.5$ and $x \leq 0.01$. *Soft gluon.*

No	Q^2	HF Scheme	σ_0	A_g	λ_g	Cg	$cBGK$	Np	χ^2	χ^2/Np
1	$Q^2 \geq 3.5$	RT OPT	85.111	1.921	-0.103	4.674	4.0	557	575.30	1.03
2	$Q^2 \geq 8.5$	RT OPT	93.581	1.665	-0.124	6.066	4.0	473	476.71	1.01

- HERAPDF fit with fitted valence quarks

1.4 HERAPDF NLO fit with fitted valence quarks for σ_r for HERA1+2-NCep-460, HERA1+2-NCep-575 HERA1+2-NCep-820, HERA1+2-NCep-920, HERA1+2-NCem, HERA1+2-CCep and HERA1+2-CCem data in the range $Q^2 \geq 3.5$ and $Q^2 \geq 8.5$ and $x \leq 1.0$.

No	Q^2	HF Scheme	Np	χ^2	χ^2/Np
1	$Q^2 \geq 3.5$	RT	1131	1356.70	1.20
2	$Q^2 \geq 8.5$	RT	456	470.88	1.15

Results of the Fits

HERAPDF fit with fix valence quarks, soft gluon

HERAPDF NLO fit with fix valence quarks for σ_r for HERA1+2-NCep-460, HERA1+2-NCep-575 HERA1+2-NCep-820, HERA1+2-NCep-920, HERA1+2-NCem data in the range $Q^2 \geq 3.5$ and $x \leq 0.01$.

No	Q^2	HF Scheme	Np	χ^2	χ^2/Np
1	$Q^2 \geq 3.5$	RT	534	572.69	1.07

HERAPDF fit with fix valence quarks, soft + hard gluon

HERAPDF NLO fit with fix valence quarks for σ_r for HERA1+2-NCep-460, HERA1+2-NCep-575 HERA1+2-NCep-820, HERA1+2-NCep-920, HERA1+2-NCem data in the range $Q^2 \geq 3.5$ and $x \leq 0.01$.

No	Q^2	HF Scheme	Np	χ^2	χ^2/Np
1	$Q^2 \geq 3.5$	RT	532	564.80	1.06

Results of the Fits

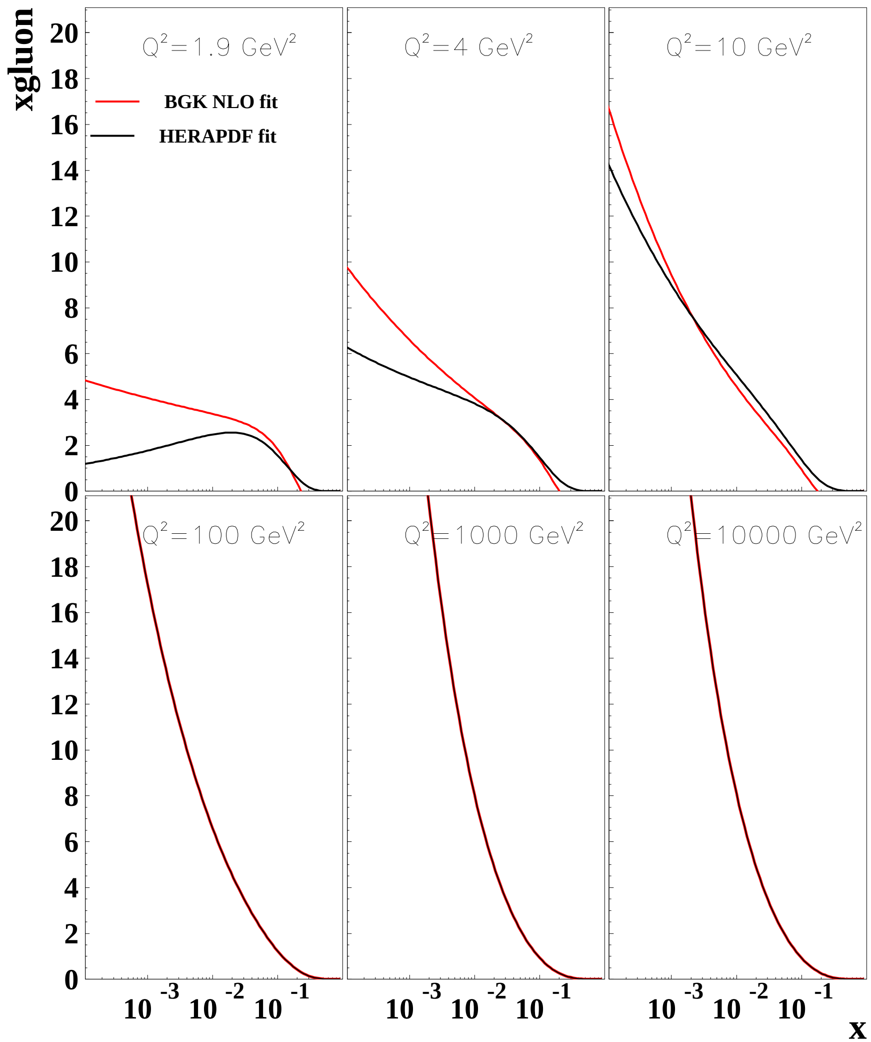
- $m_{u,d,s} = 140\ MeV$, $m_c = 1.3\ GeV$
- $\hat{\sigma}(r,x) = \sigma_0 \left\{1 - \exp\left[-\pi^2 r^2 \alpha_s(\mu^2) x g(x,\mu^2)/(3\sigma_0)\right]\right\}$ with saturation

Q^2_{min} [GeV^2]	$\sigma_0[mb]$	A_g	λ_g	Cg	Dg	Eg	N_{df}	χ^2	χ^2/N_{df}
3.5	77,6$\pm$ 18,6	2.6166$\pm$ 0.158	-0.0636$\pm$ 0.0087	37.114$\pm$ 5.057	3.0597 $\pm$ 6.510	1406.4$\pm$ 552.65	532	534.17	1.00
8.5	63.5 $\pm$ 18.5	2.112$\pm$ 0.101	-0.0541$\pm$ 0.0065	21.341$\pm$ 4.062	1.098 $\pm$ 5.764	867.23$\pm$ 423.67	448	439.04	0.98

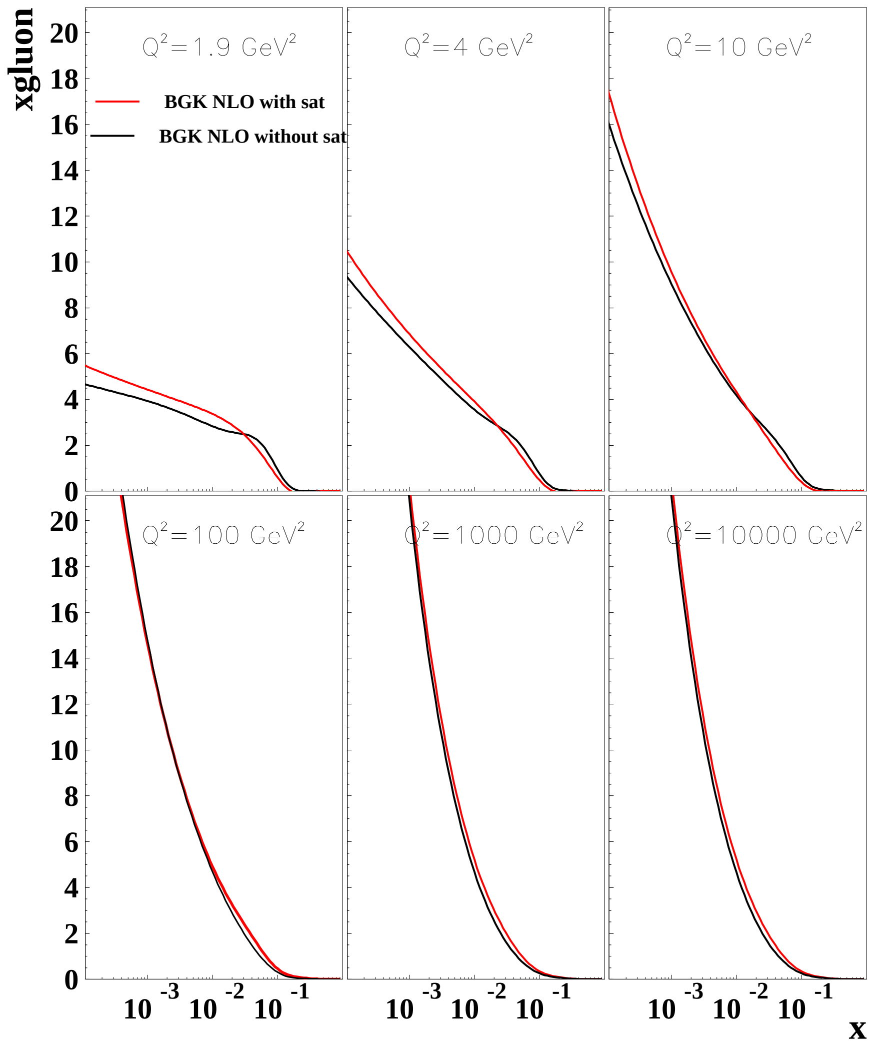
- $\hat{\sigma}(r,x) = \sigma_0 \left[\pi^2 r^2 \alpha_s(\mu^2) x g(x,\mu^2)/(3\sigma_0)\right]$ without saturation

Q^2_{min} [GeV^2]	A_g	λ_g	Cg	Dg	Eg	Ndf	χ^2	χ^2/Np
3.5	2.3313$\pm$ 0.100	-0.0936$\pm$ 0.0056	14.762$\pm$ 11.546	9.802 $\pm$ 14.668	-99.503$\pm$ 74.830	533	556.17	1.04

Gluon density

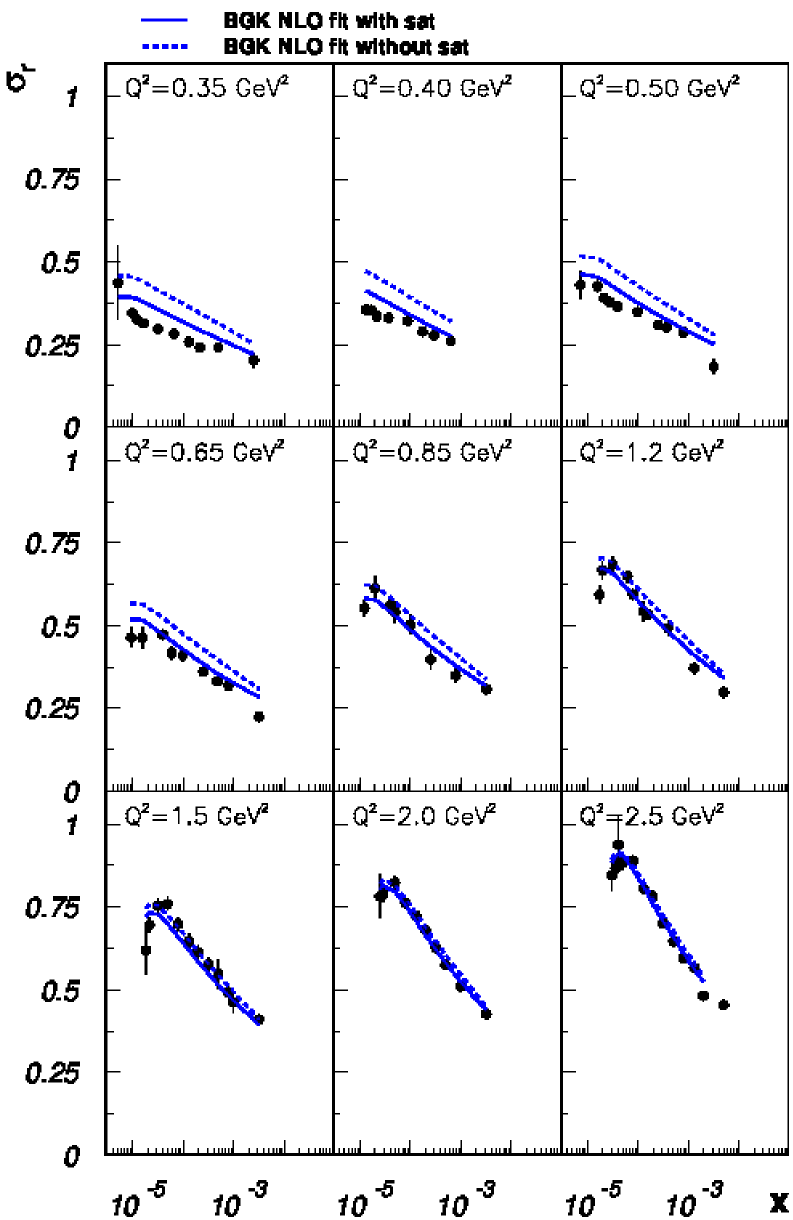


Gluon density

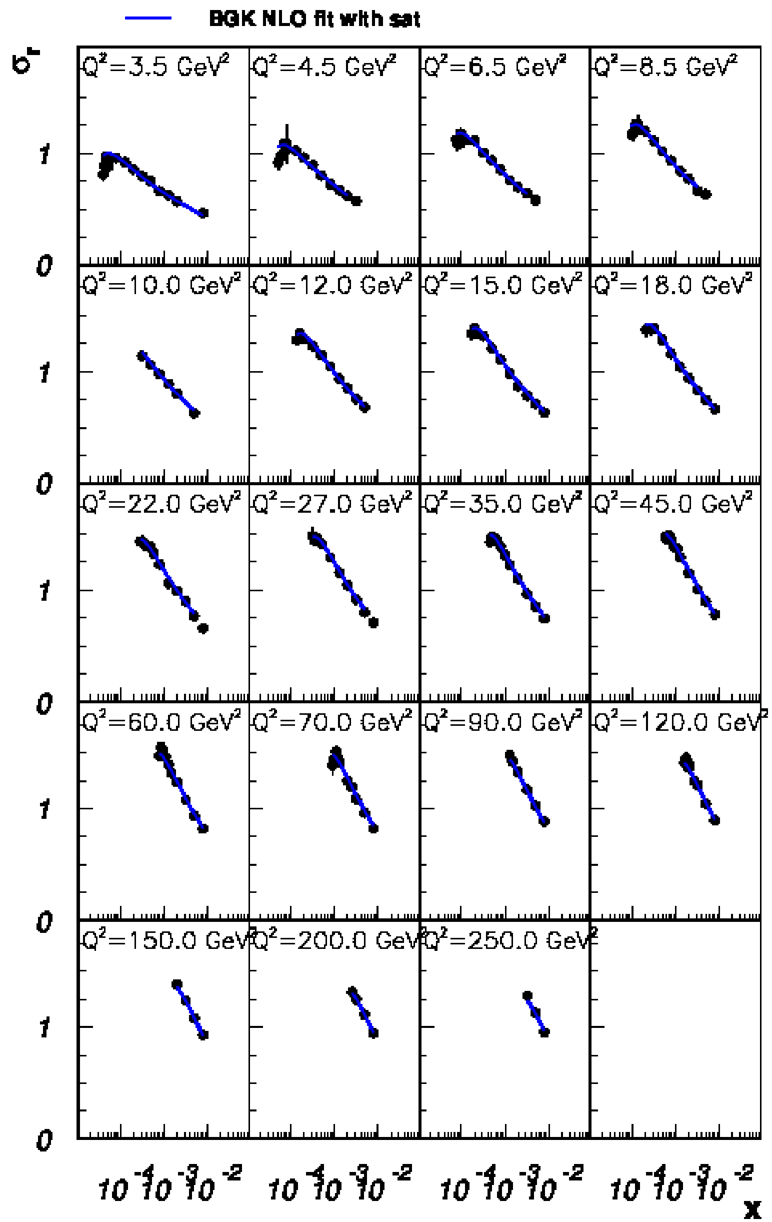


- The differences are disappearing at larger Q^2.

Comparision with HERAI+II data



Comparision with HERAI+II data



Summary

- BGK dipole fits (with saturation) describe the final, high precision HERA data with $x < 0.01$, very well: $\chi^2/Np \to 1$.
- Little sensitivity to valence quarks contribution observed.
- Gluon density from the dipole models is higher than the PDFs gluon at low Q^2.
- The extrapolation to the very low Q^2 region shows a sizable overshoot. This indicates that at very low Q^2 saturation effects of the eikonal aproximation are too small.
- The fit in the whole Q^2 region, $0.3 < Q^2 < 250$ GeV^2 is only slightly better than in the extrapolated case. The systematic overshoot of the fits over data remains.
- The χ^2/N_{df} in the region: $0.3 < Q^2 < 250$ GeV^2 is sizably higher than in the fits in the region $3.5 < Q^2 < 250$ GeV^2, $\chi^2/N_{df} = 1.21$, with the saturation ansatz and $\chi^2/N_{df} = 1.52$ without the saturation ansatz.
- In the lower $Q^2 < 3.5$ GeV^2 range the saturated ansatz of the gluon density seems to be prefered.

Dipole scattering amplitude with GBW parametrization

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

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

- 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 $\hat{N}$ to F_2 data

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