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

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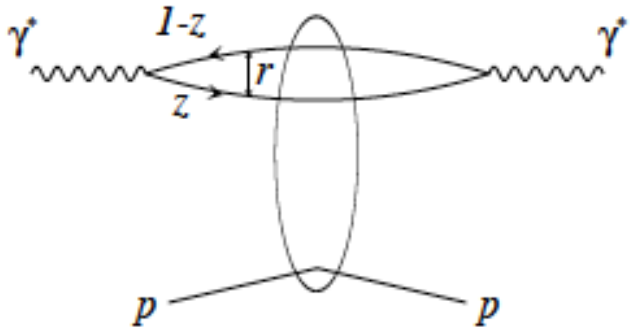
Introduction

- 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 **Q^2 values** of **3.5** 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.

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

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

- Dipole-proton interaction

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

Dipole cross section

- BGK (Bartels-Golec-Kowalski) parametrization

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

- $\mu^2 = C/r^2 + \mu_0^2$ 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

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

No	Q^2_{min} [GeV^2]	HF Scheme	Np	χ^2	χ^2/Np	
1	3.5	FONLL-B	534	539,3	1.01	**Soft**
2	3.5	FONLL-B	532	537,3	1.01	**Soft+Hard**

Results of the Fits

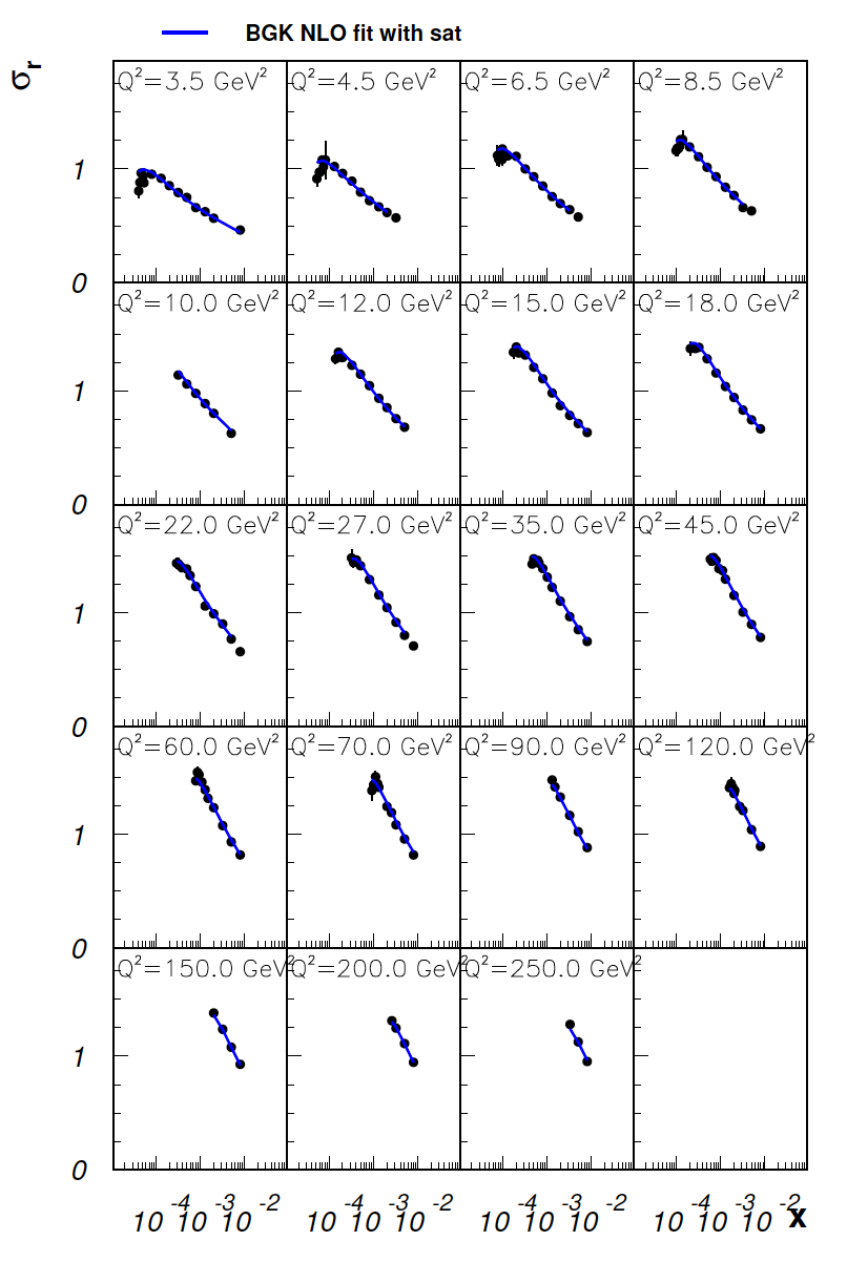
- $m_{u,d,s} = 140\ MeV,\ m_c = 1.3\ GeV$
- $\hat{\sigma}(r,x) = \sigma_0 \left\{1 - \exp\left[-\pi^2 r^2 \alpha_s(\mu^2) x g(x,\mu^2)/(3\sigma_0)\right]\right\}$ with saturation

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± 18,6	2.6166± 0.158	-0.0636± 0.0087	37.114± 5.057	3.0597 ± 6.510	1406.4± 552.65	532	534.17	1.00
8.5	63.5 ± 18.5	2.112± 0.101	-0.0541± 0.0065	21.341± 4.062	1.098 ± 5.764	867.23± 423.67	448	439.04	0.98

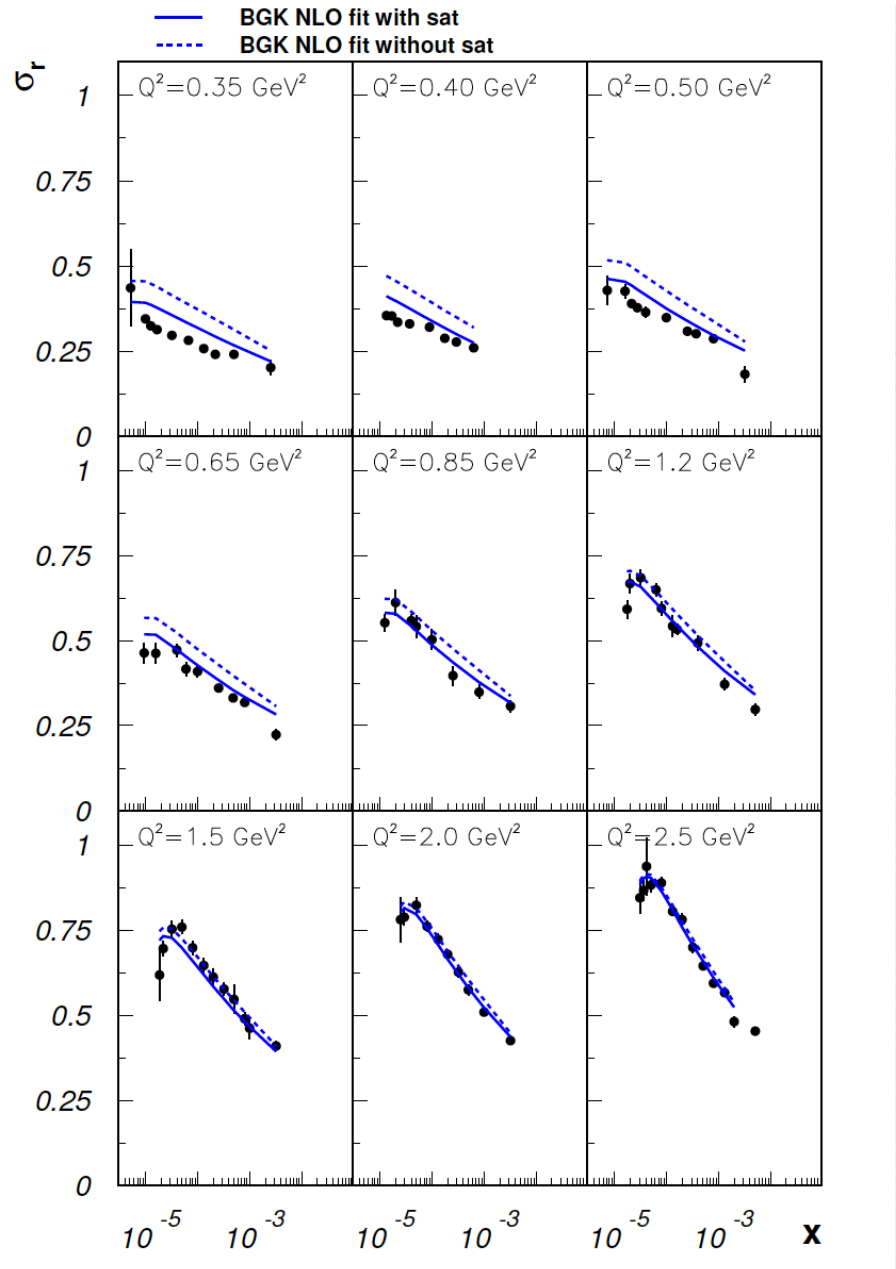
- $\hat{\sigma}(r,x) = \sigma_0 \left[\pi^2 r^2 \alpha_s(\mu^2) x g(x,\mu^2)/(3\sigma_0)\right]$ without saturation

Q^2_{min} [GeV^2]	Q^2_0 [GeV^2]	A_g	λ_g	C_g	D_g	E_g	Ndf	χ^2	χ^2/Np
3.5	1.9	2.33± 0.10	-0.094± 0.006	14.8± 11.5	9.80 ± 14.7	-99.5± 74.830	533	556.17	1.04
3.5	1.1	3.80± 0.22	0.10± 0.01	32.5± 1.6	-25.2 ± 3.49	1868 ± 252	533	539.2	1.01

Comparision with HERAI+II data



Comparision with HERAI+II data



extrapolated fits

Fits to data including the lower $Q^2 > 0.35$ GeV^2 region

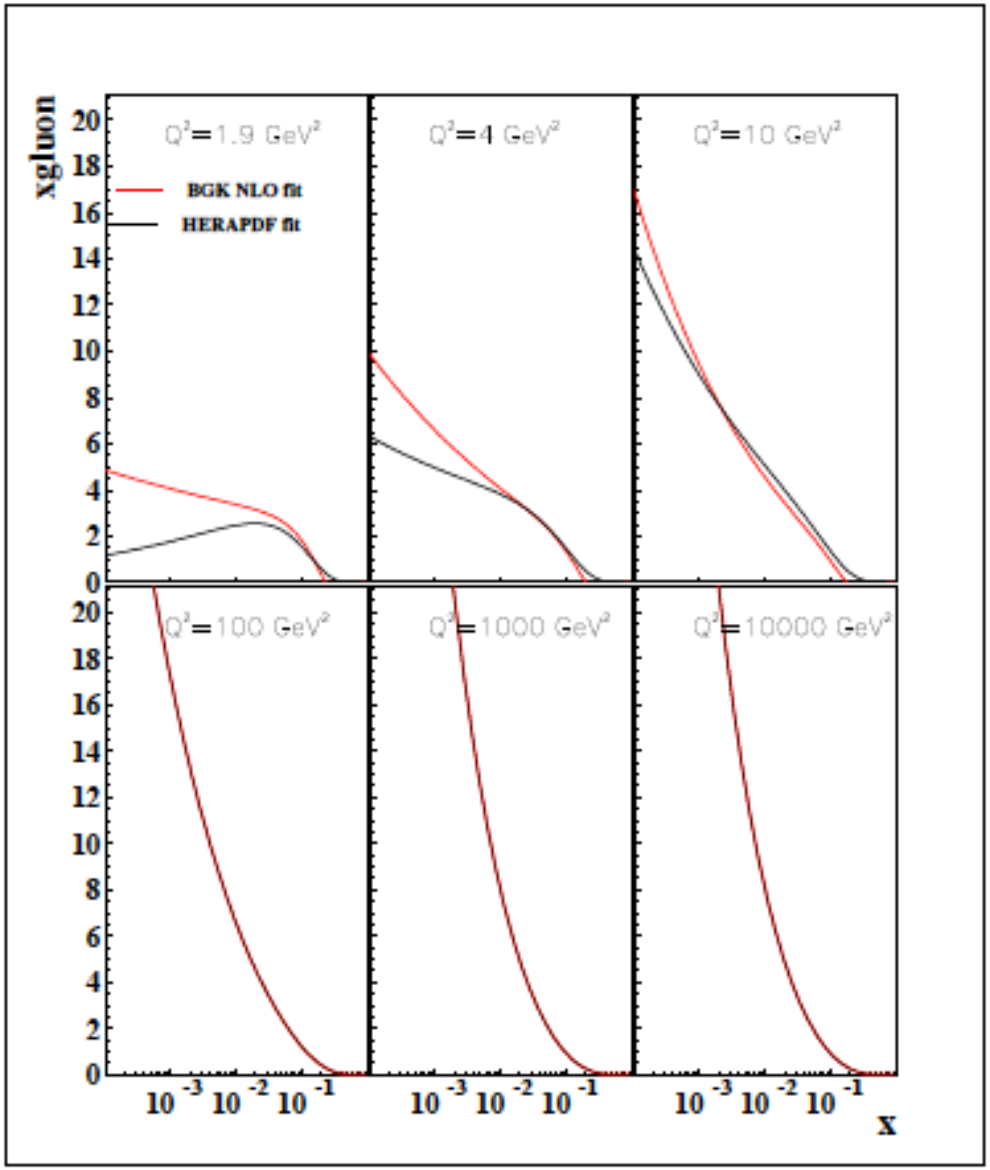
with saturation

Q_0^2 [GeV^2]	σ_0 [mb]	A_g	λ_g	C_g	D_g	E_g	N_{df}	χ^2	χ^2/N_{df}
1.9	38.2 ± 4.1	2.80 ± 0.14	-0.063 ± 0.006	46.3± 4.58	12.1 ± 6.00	1970.4 ± 566.0	653	790.4	1.21
1.1	196,1 ± 105	6.24 ± 0.53	0.098 ± 0.012	52.3 ± 6.5	-22.0 ± 10.64	2145.0 ± 835.7	653	894.1	1.37

without saturation

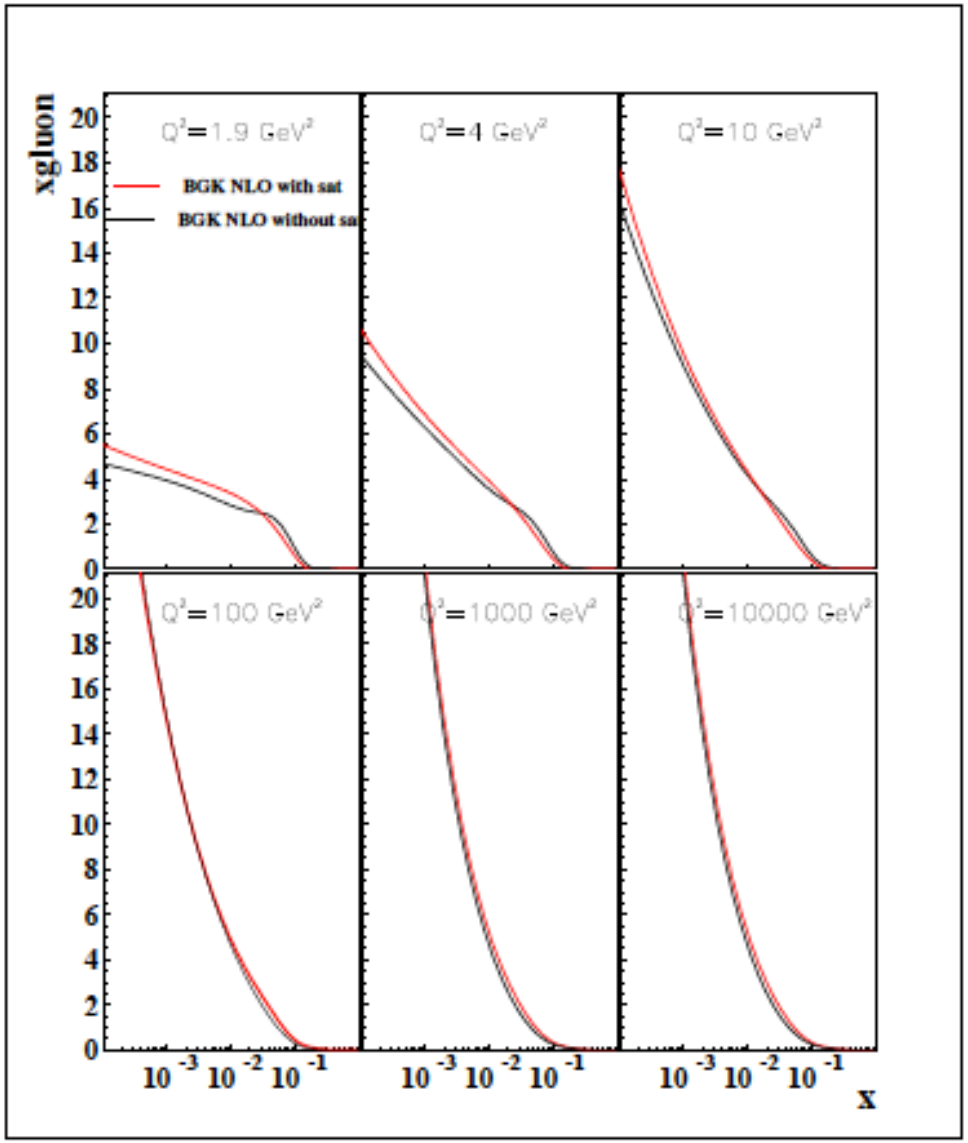
Q_0^2 [GeV^2]	A_g	λ_g	C_g	D_g	E_g	N_{df}	χ^2	χ^2/N_{df}
1.9	3.05 ± 0.092	-0.022 ± 0.004	40.3 ± 1.067	-32.3 ± 3.02	3158.3 ± 219.3	654	1024.3	1.56
1.1	5.62 ± 0.13	0.158 ± 0.001	43.320 ± 0.15	-55.011 ± 8.62	3791.6± 187.7	654	999.98	1.53

Gluon density



Gluon density

saturated gluon density is higher than the non-saturated



- The differences are disappearing at larger Q^2.

Summary

The dipole BGK fits with the DGLAP QCD evolution, describe the highest precision HERA data, in the low x region and for $3.5 < Q^2 < 250$ GeV^2 very well.

For $Q^2 > 3.5$ GeV^2 no significant differences between the saturated and non-saturated fits were observed

The fits to data including the lower $Q^2 > 0.35$ GeV^2 region show that the saturated gluon density is preferred.

In the old saturation investigation were the first set of HERA data was used, the fits with and without saturation had the same quality, even when the low Q^2 region was included in the fit. The present result showing that the fit with saturation has a sizably better quality than that without saturation is new and is due to the substantially improved quality of HERA data.

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