Dipole model + valence quarks analysis of data within the HERAFitter framework

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Introduction

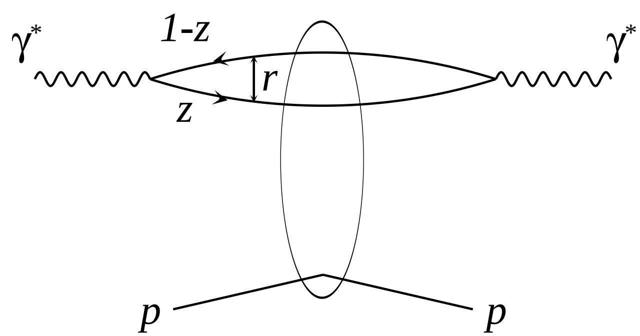
- Motivation: Investigation of the gluon density with dipole model, as an alternative to the PDF approach. Prefered choice : BGK dipole model, which has very similar physics interpretation as PDFs, i.e. DGLAP evolution in the kt factorization scheme (in contrast to the collinear factorization for PDFs).
- The precise knowledge of the gluon density is mandatory to fully exploit the LHC physics potential - because gluon density determines the Higgs production rate.
- The analysis was done in the HERAFitter - an open source QCD fit framework and ready platform to analyse new data and their impact.

Outline

- Dipole model approach.
- GBW and BGK parametrization of dipole cross section.
- Results of the fits for BGK dipole model with valence quarks.
- 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

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

- 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

- GBW (Golec-Biernat Wüsthoff) parametrization

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

- BGK (Bartels-Golec-Kowalski) parametrization

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

- R_s^2 is replacing by a gluon density with explicit DGLAP evolution
- $\mu^2 = C/r^2 + \mu_0^2$ is the scale of the gluon density
- gluon density is evolved according to the (LO) DGLAP equation

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

Results of the Fits

- Dipole model BGK fit without valence quarks

TABLE 1. Dipole model BGK fit without valence quarks for σ_r for H1ZEUS-NC-(e+p) and H1ZEUS-NC-(e-p) data in the range $Q^2 \geq 3.5$ and $Q^2 \geq 8.5$ and $x \leq 0.01$.

No	Q^2	σ_0	A_g	λ_g	C_{BGK}	μ_0^2	Np	χ^2	χ^2/Np
1	$Q^2 \geq 3.5$	40.43	1.596	-0.249	1.529	0.401	197	214.46	1.10
2	$Q^2 \geq 8.5$	32.48	1.691	-0.256	1.463	0.155	156	125.10	0.80

- The fits with the BGK dipole model alone show a very good agreement with data. the χ^2 values are similar to the χ^2 values of the standard PDFs fits.

Results of the Fits

- HERAPDF fit with valence quarks

TABLE 2. HERAPDF fit with valence quarks for σ_r for H1ZEUS-NC-(e+p), H1ZEUS-NC-(e-p) data in the range $Q^2 \geq 3.5$ and $Q^2 \geq 8.5$ and $x \leq 0.01$. χ^2 is calculated in the region $x \leq 0.01$.

No	Q^2	HF Scheme	Np	χ^2	χ^2/Np
1	$Q^2 \geq 3.5$	RT	197	220.64	1.12
2	$Q^2 \geq 3.5$	ACOT Full	197	206.85	1.05
3	$Q^2 \geq 8.5$	RT	156	131.04	0.84
4	$Q^2 \geq 8.5$	ACOT Full	156	131.04	0.84

- The χ^2 values of the standard PDFs fits are similar to the χ^2 values of the BGK dipole model.

Results of the Fits

- Dipole model BGK fit with valence quarks

TABLE 3. Dipole model BGK fit with valence quarks for σ_r for H1ZEUS-NC-(e+p) and H1ZEUS-NC-(e-p) data [5] in the range $Q^2 \geq 3.5$ and $Q^2 \geq 8.5$ and $x \leq 0.01$. The calculation was done in ACOT Full HF Scheme.

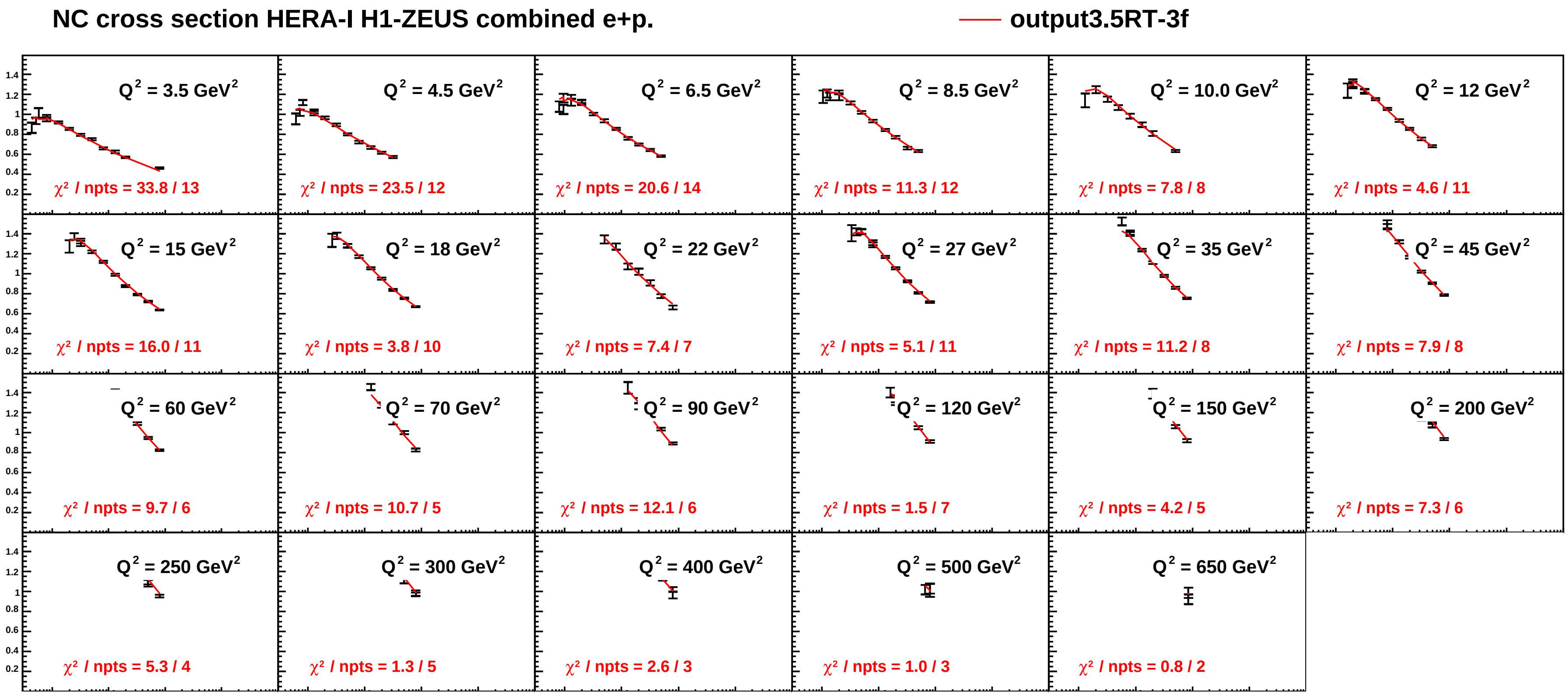
No	Q^2		σ_0	A_g	λ_g	C_g	C_{BGK}	μ_0^2	Np	χ^2/Np
1	$Q^2 \geq 3.5$	LO	66.6	4.0	-0.039	18.6	4.0	5.3	196	0.930
2	$Q^2 \geq 8.5$	LO	63.6	4.2	-0.036	19.8	4.0	5.1	157	0.790
3	$Q^2 \geq 3.5$	NLO	79.4	3.2	-0.021	13.7	4.0	6.7	196	0.927
4	$Q^2 \geq 8.5$	NLO	67.5	1.9	-0.14	15.9	4.0	3.8	157	0.781

- The four fits of the BGK dipole model with valence quarks in the LO and NLO approach are shown. We have five fitted parameters : σ_0, A_g, λ_g, C_g, μ_0^2. The fit results are again very good.
- The quality of the fits of the BGK dipole model with valence quarks matches the quality of HERAPDF fits in the low x region.

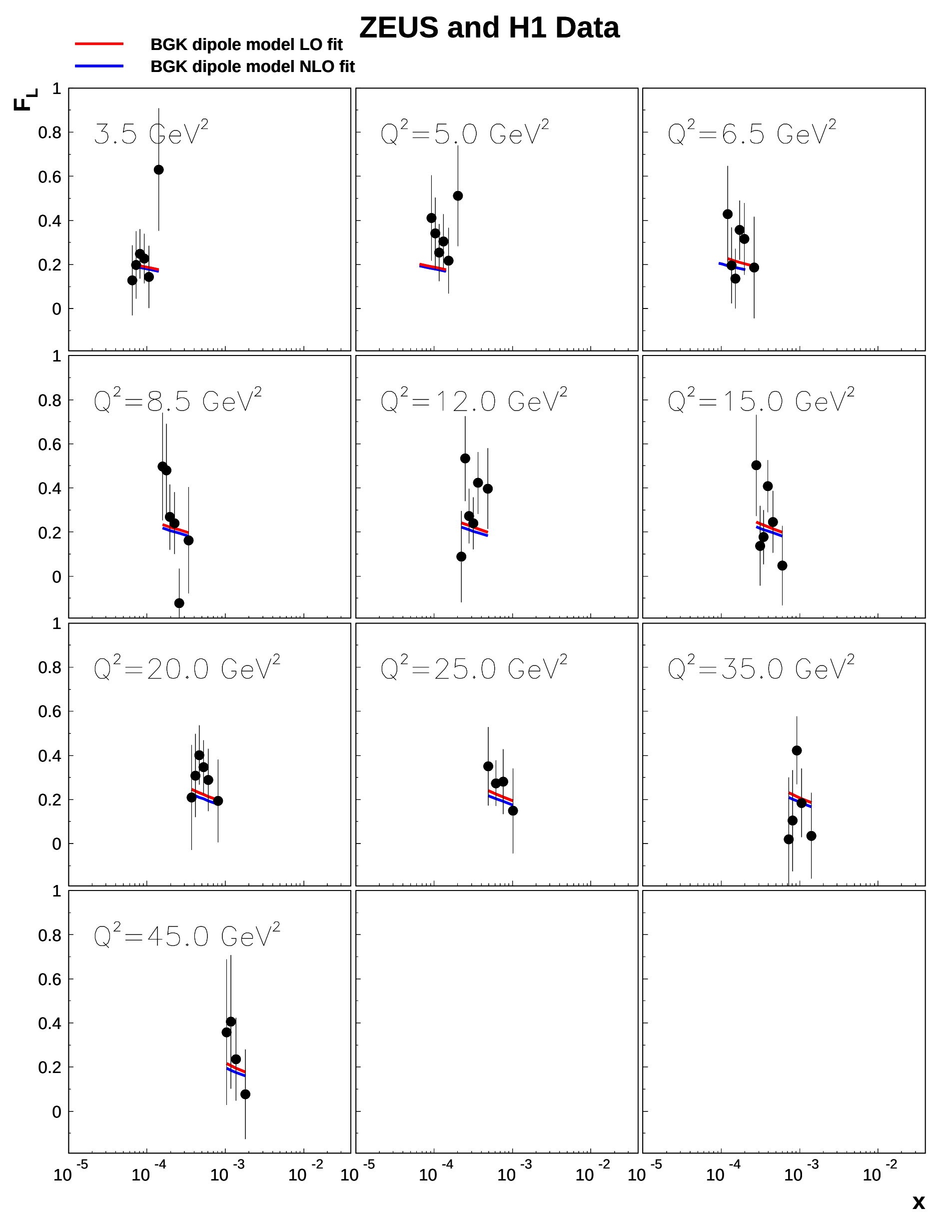
BGK fits with valence quarks from different sets of PDFs

- *CTEQ66* valence quarks:
  1) $Q2 > 3.5$, $\chi^2/Np = 0.92$
  2) $Q2 > 8.5$, $\chi^2/Np = 0.78$
- *HERAPDF15NLO* valence quarks:
  1) $Q2 > 3.5$, $\chi^2/Np = 0.93$
  2) $Q2 > 8.5$, $\chi^2/Np = 0.79$
- *MSTW2008nlo68* valence quarks:
  1) $Q2 > 3.5$, $\chi^2/Np = 0.91$
  2) $Q2 > 8.5$, $\chi^2/Np = 0.78$

Comparison with HERA data



Prediction for FL function from BGK dipole model



Summary

- It is possible to describe the HERA data very well using solely the dipole model gluon density with added valence quarks from the usual PDFs.
- The quality of the fits from the BGK dipole model with valence quarks and without valence quarks are very good.
- This could show a way to improve the PDFs fits because the gluon density within dipole model is less sensitive to the higher order corrections than in the collinear factorization scheme, which is usually used.

Dipole scattering amplitude with GBW parametrization

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

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

- 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

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