Fits with the dipole model of DIS

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Legacy

- Seminal work of H1 and Zeus collaborations on inclusive DIS

  ZEUS, H1 collaboration, F. D. Aaron et al., *JHEP* **01** (2010) 109
  ZEUS, H1 collaboration, H. Abramowicz et al., *Eur. Phys. J.* **C75** (2015) 580

- Inspiring recent effort

  I. Abt, A. M. Cooper-Sarkar, B. Foster, V. Myronenko, K. Wichmann and M. Wing, *Phys. Rev.* **D96** (2017) 014001, (*ACFMW*^{2})

- My past work with distinguished collaborators

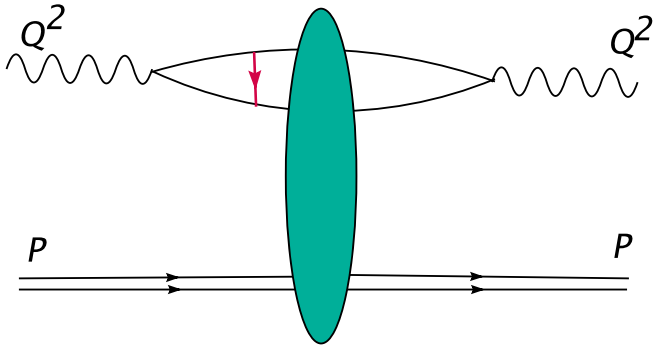
  [1.] K. Golec-Biernat and M. Wusthoff, *Phys. Rev.* **D59** (1998) 014017, (GBW)
  [2.] K. Golec-Biernat and M. Wusthoff, *Phys. Rev.* **D60** (1999) 114023
  [3.] A. M Staśto, K. Golec-Biernat and J. Kwieciński, *Phys. Rev. Lett.* **86** (2001) 596
  [4.] J. Bartels, K. J. Golec-Biernat and H. Kowalski, *Phys. Rev.* **D66** (2002) 014001
  [5.] K. Golec-Biernat and S. Sapeta, *Phys. Rev.* **D74** (2006) 054032, (GS)

Motivation - some history

- Describe transition of F_2 at HERA to small Q^2 region $\rightarrow$ Caldwell plot
- Small x domain since $x = Q^2/W^2 \ll 1$ $\rightarrow$ BFKL equation
- Parton saturation in dense gluon system at small x $\rightarrow$ GLR, MQ, CGC
- Saturation scale Q_s as an intrinsic scale of dense systems

Idea of the model

- Dipole picture of DIS at small x



- Structure functions $F_{T,L} \sim Q^2 \sigma^{\gamma p}_{T,L}$

$$\sigma^{\gamma p}_{T,L} = \sum_q \int_0^1 dz \int d^2 r \, |\Psi^{\gamma}_{T,L}(z, r, Q^2, m_q)|^2 \, \sigma_{dip}(x, r)$$

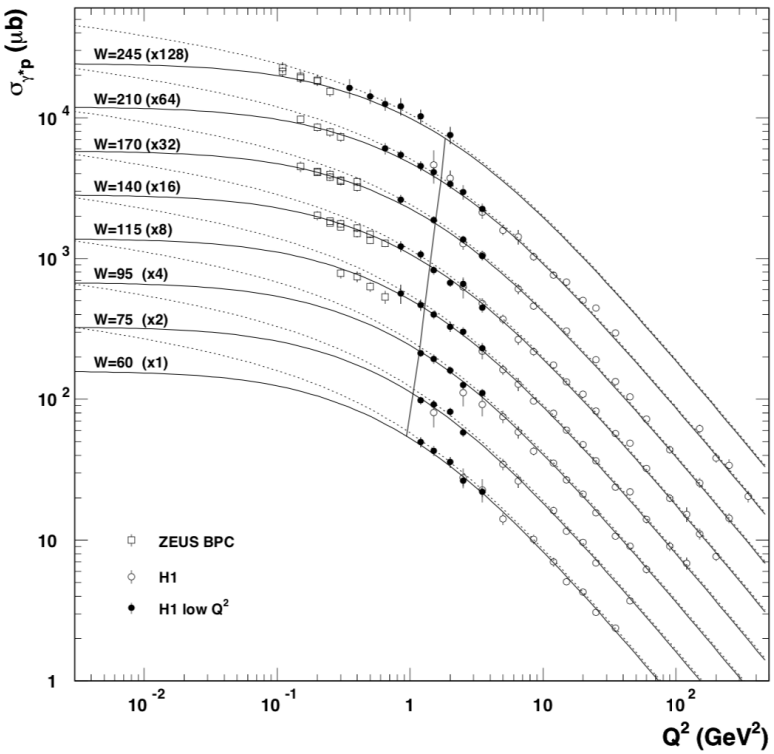
- Dipole cross section parameterization with saturation scale Q_s^2 (in GeV^2)

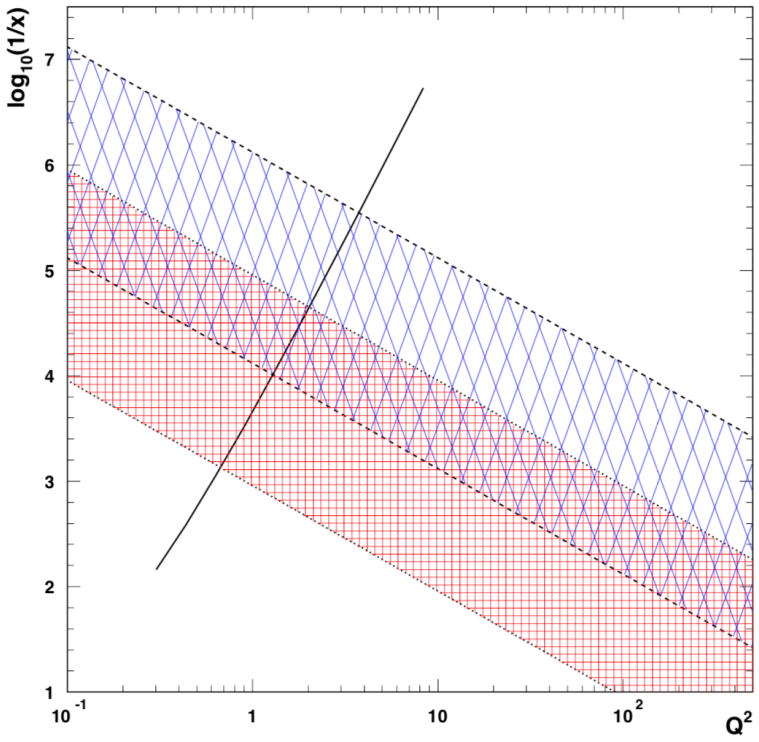
$$\sigma_{dip}(x, r) = \sigma_0 \left\{ 1 - \exp(-r^2 Q_s^2(x)/4) \right\} \qquad Q_s^2(x) = \left(\frac{x}{x_0} \right)^{\lambda}$$

- 3 parameter fit to DIS data with $x \leq 10^{-2}$

Transition to small Q^2 and saturation line

(GB and Wuesthoff, 1998)





- Saturation line: $Q_s^2(x) = Q^2$ in the perturbative region $Q_s > 1\,\mathrm{GeV}$

New fits with GBW model

- Fit to F_2 ($ACFMW^2$) with $x \leq 10^{-2}$ and $Q^2 \leq 10\,\mathrm{GeV}^2$ (222 exp. points)

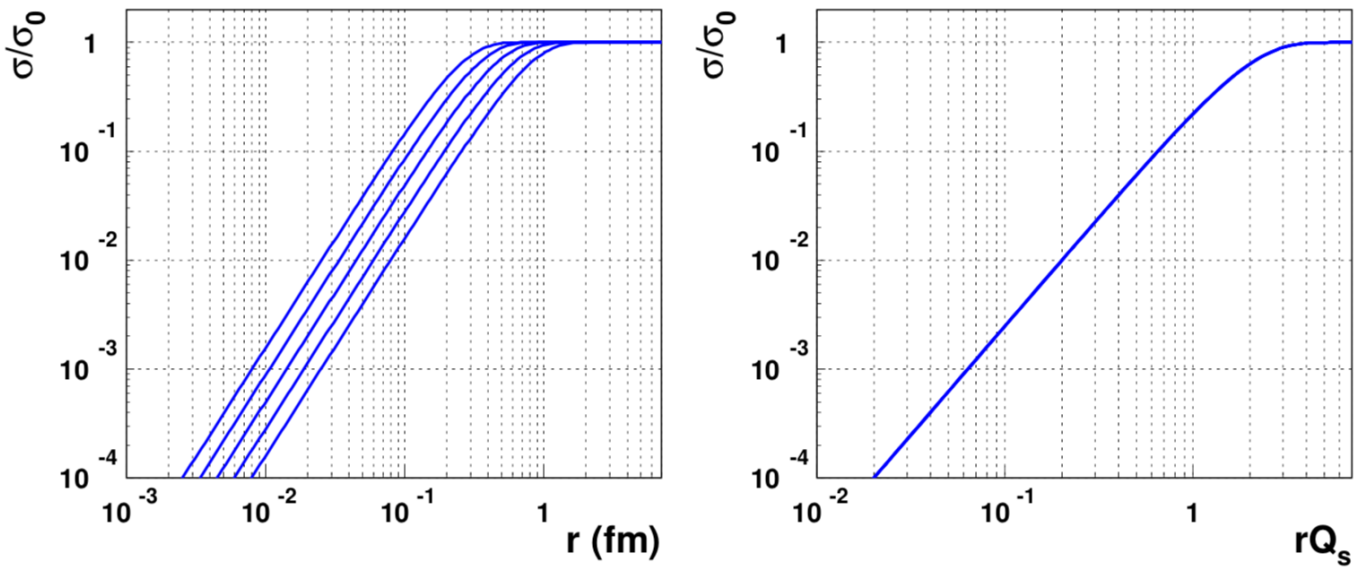
Fit	m_l	m_c	m_b	σ_0/mb	λ	$x_0/10^{-4}$	χ^2/N_{df}
GBW	0.14	–	–	23.02	0.288	3.04	2.86
GBW	0.14	1.4	–	29.12	0.277	0.41	3.78
0	0.14	–	–	23.6	0.270	2.24	1.83
1	0.14	1.4	–	27.3	0.248	0.42	1.60
2	0.14	1.4	4.6	27.4 ± 0.4	0.248 ± 0.002	0.40 ± 0.04	1.61

- Fits with heavy quarks work better now! Why $Q^2_{max} = 10\,\mathrm{GeV}^2$?

Q^2_{max}	N_{exp}	σ_0/mb	λ	$x_0/10^{-4}$	χ^2/N_{df}
5	181	28.2	0.237	0.31	1.64
10	222	27.4	0.248	0.40	1.61
20	264	26.6	0.259	0.53	1.65
50	318	25.2	0.281	0.80	2.43

Dipole cross section

- Dipole cross section $\sigma_{dip}(x, r)$ from Fit 2 for $x = 10^{-6}, \ldots, 10^{-2}$

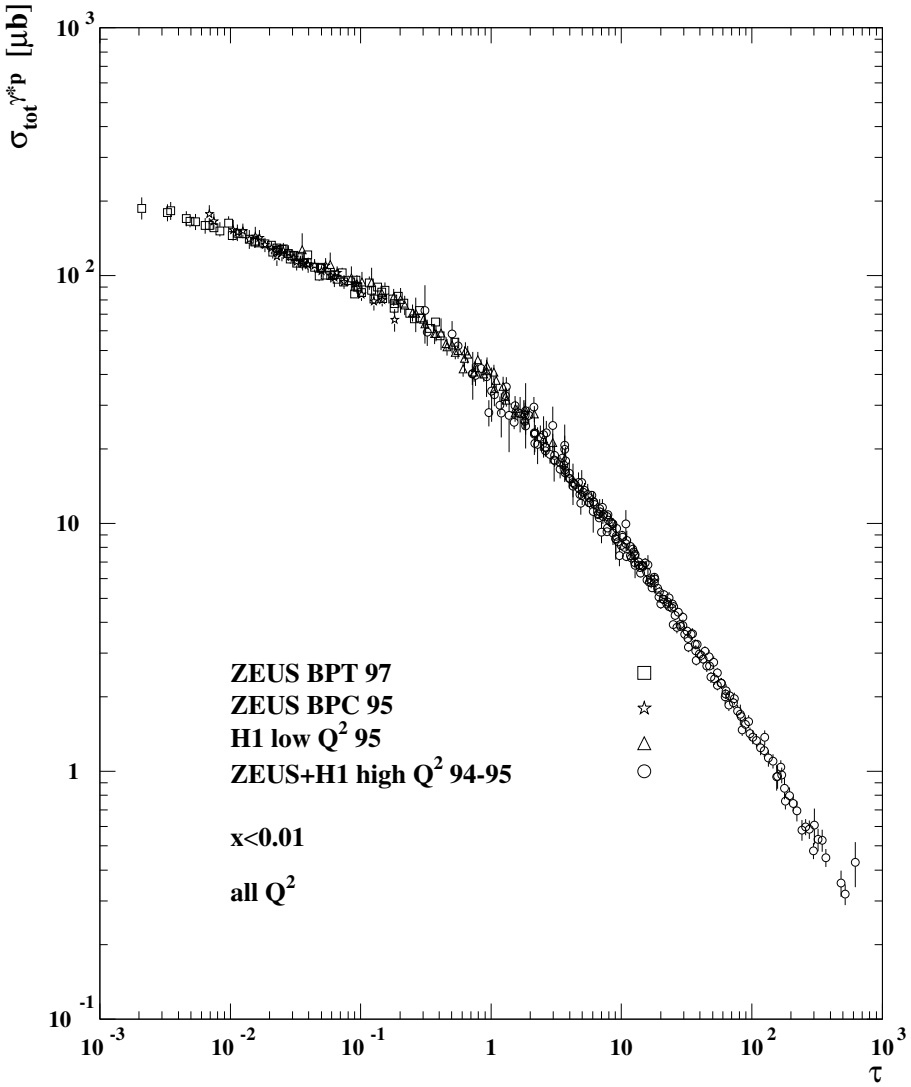


- Geometric scaling for massless quarks:

$$\sigma_{dip}(rQ_s(x)) \;\rightarrow\; \sigma^{\gamma p}\left(\frac{Q^2}{Q_s^2(x)}\right)$$

Geometric scaling

(Staśto, GB, Kwieciński, 2001)



DGLAP modification of GBW model

- We want to include higher Q^2 points (with $x \leq 10^{-2}$).
- For dipole $r \to 0$ perturbative QCD result

$$\sigma_{dip} \approx \frac{\pi^2 r^2}{N_c} \alpha_s(\mu^2)\, xg(x,\mu^2) \qquad \mu^2 = \frac{C}{r^2}$$

- Our proposal (Bartels, GB, Kowalski, Sapeta, 2002, 2006, 2017)

$$\sigma_{dip} = \sigma_0 \left\{ 1 - \exp\left(-\frac{\pi^2 r^2 \alpha_s(\mu^2)\, xg(x,\mu^2)}{3\,\sigma_0} \right) \right\} \qquad \mu^2 = \frac{\mu_0^2}{1 - \exp(-\mu_0^2\, r^2/C)}$$

- For $r \to 0$ pQCD result and for $r \to \infty$ GBW model

$$\sigma_{dip} = \sigma_0 \left\{ 1 - \exp(-r^2 Q_s^2(x)/4) \right\} \qquad Q_s^2(x) = \frac{4\pi^2}{3\sigma_0} \alpha_s(\mu_0^2)\, xg(x,\mu_0^2)$$

- Gluon distribution at the scale μ_0^2 gives saturation scale!

Fits with DGLAP improved model

- 5 parameter fit: σ_0, μ_0^2, C, and in the initial gluon for DGLAP evolution

$$xg(x, Q_0 = 1\,\mathrm{GeV}) = A_g\, x^{-\lambda_g}(1-x)^{5.6}$$

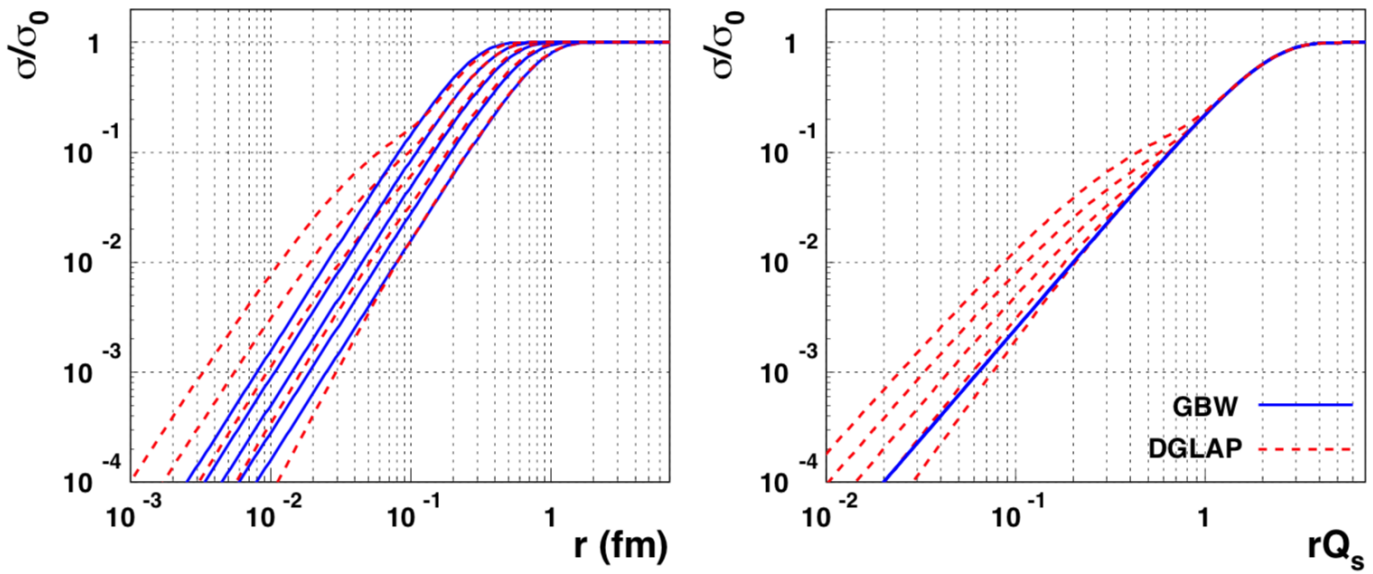
- 387 experimental points with $x \leq 10^{-2}$ and $Q^2 \leq 650\,\mathrm{GeV}^2$

Fit	m_b	σ_0/mb	A_g	λ_g	C	μ_0^2/GeV^2	χ^2/N_{df}
GS	–	22.4	1.35	0.08	0.38	1.73	2.02
GS	4.6	22.7	1.23	0.08	0.35	1.60	2.43
1	–	22.6	1.18	0.11	0.29	1.85	1.40
2	4.6	22.9	1.07	0.11	0.27	1.74	1.51

GS=(GB and Sapeta, 2006)

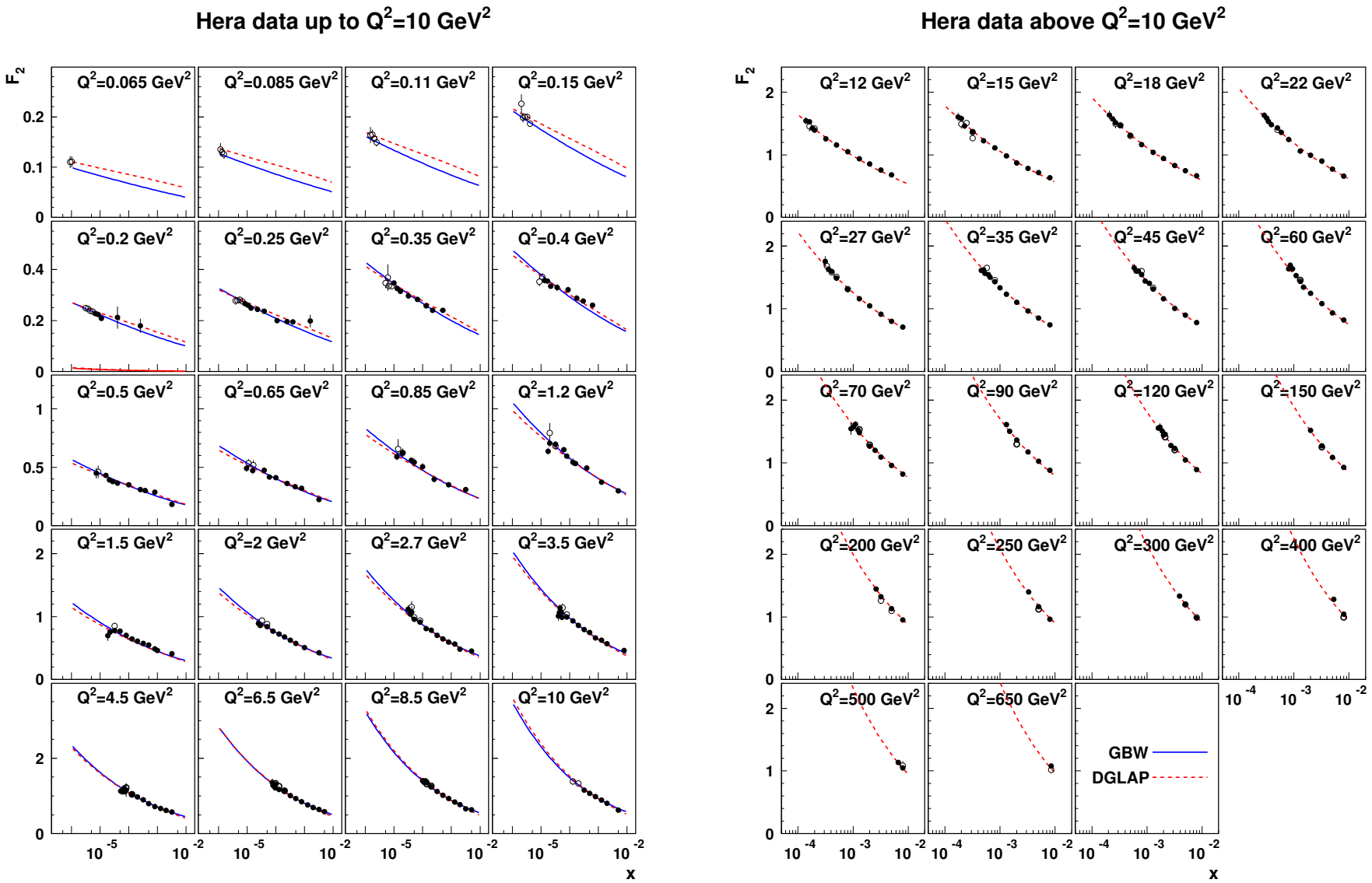
Dipole cross section comparison

- GBW versus DGLAP dipole cross sections for $x = 10^{-6}, \ldots, 10^{-2}$

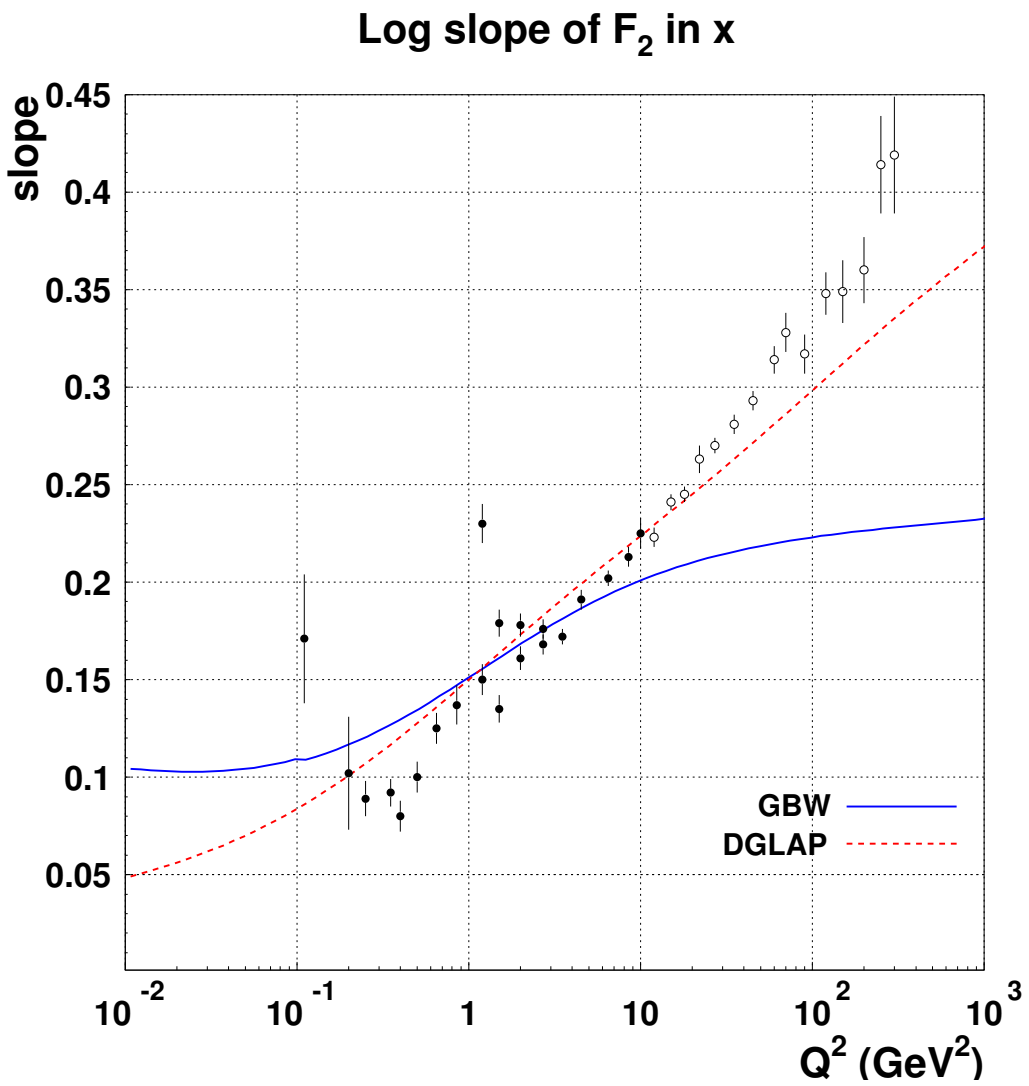


- Geometric scaling for $rQ_s > 1$

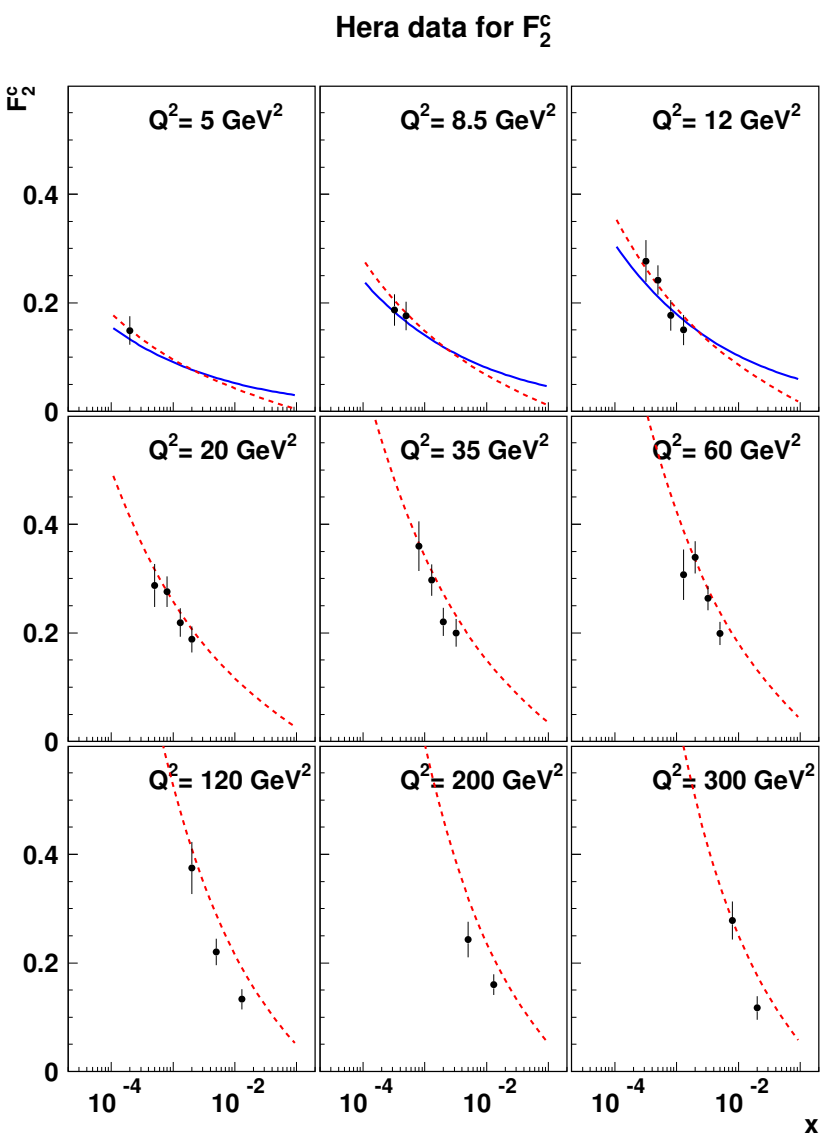
Data comparison - F_2 from fits

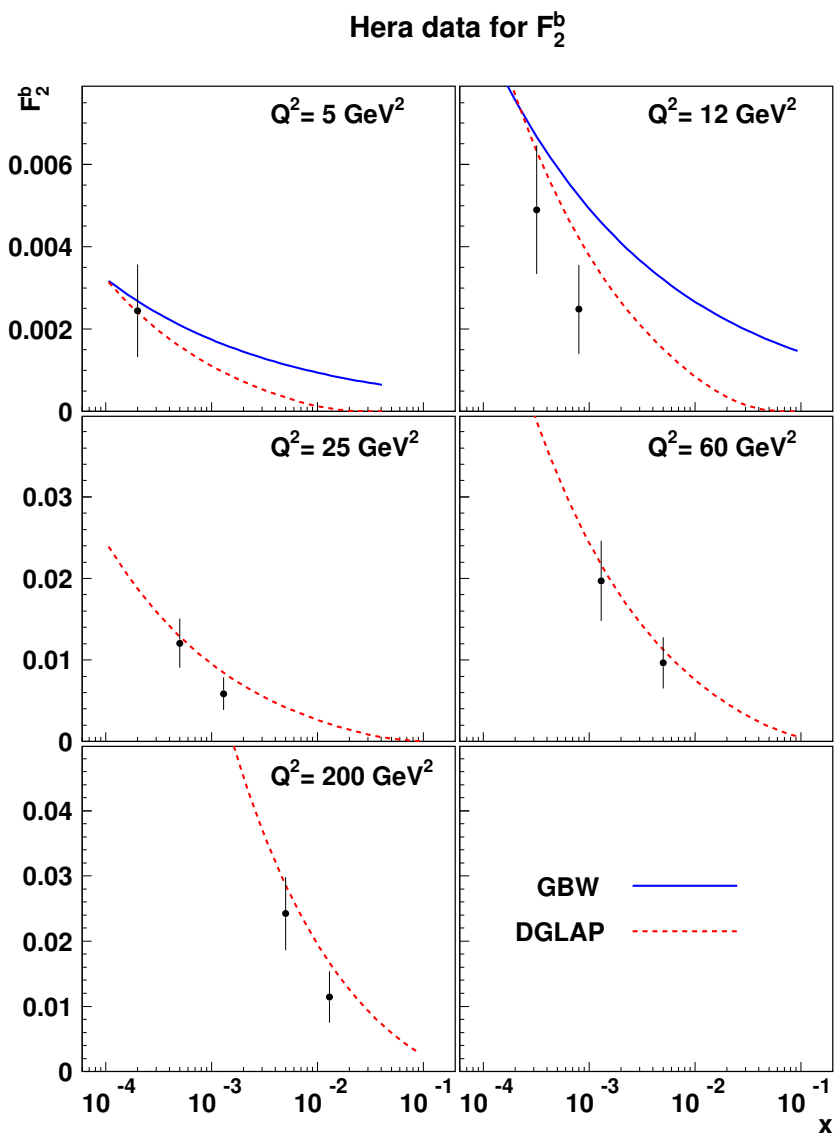


Logarithmic slopes - $F_2 \sim x^{-\lambda(Q)}$

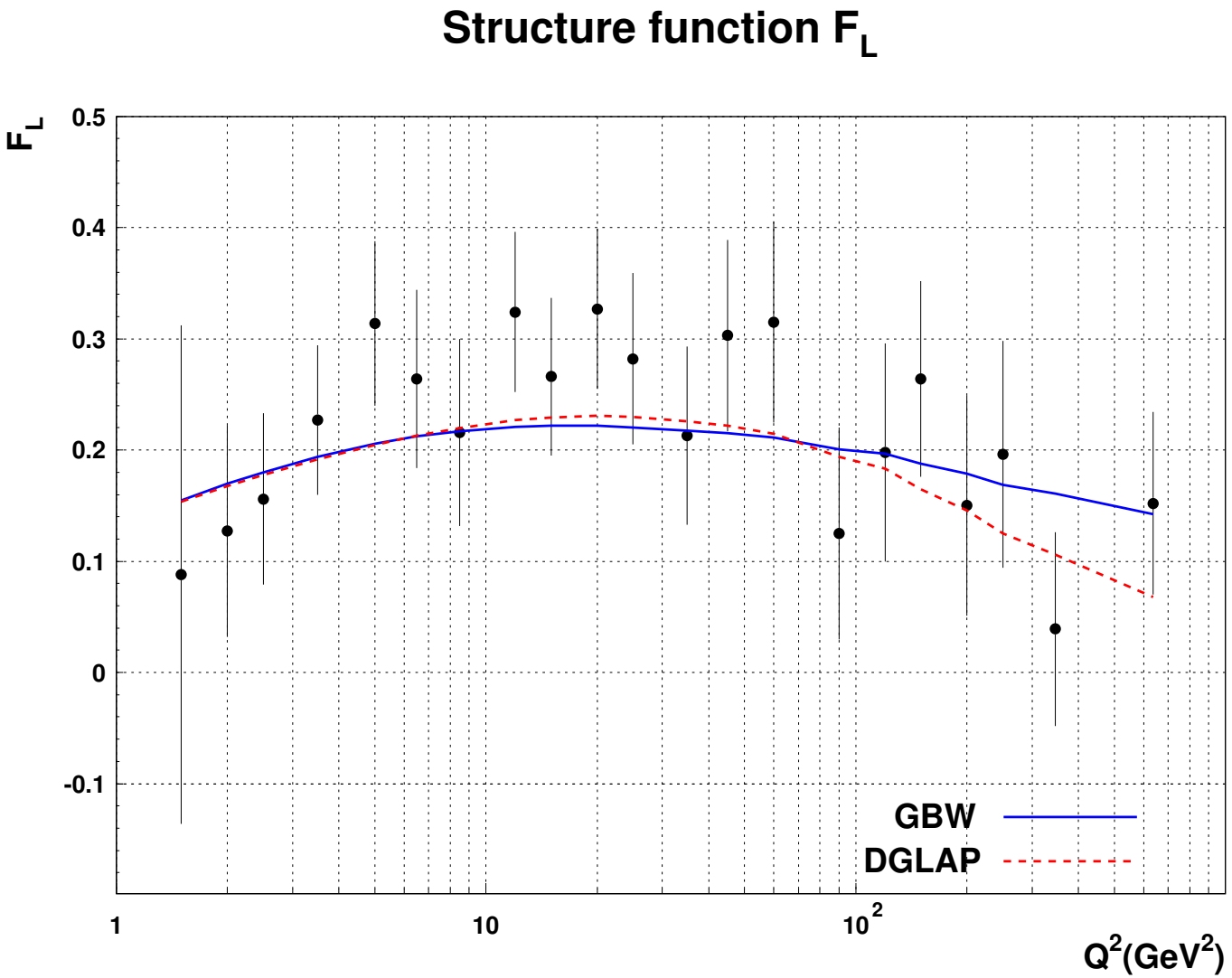


Data comparison - $F_2^{c,b}$ as the prediction

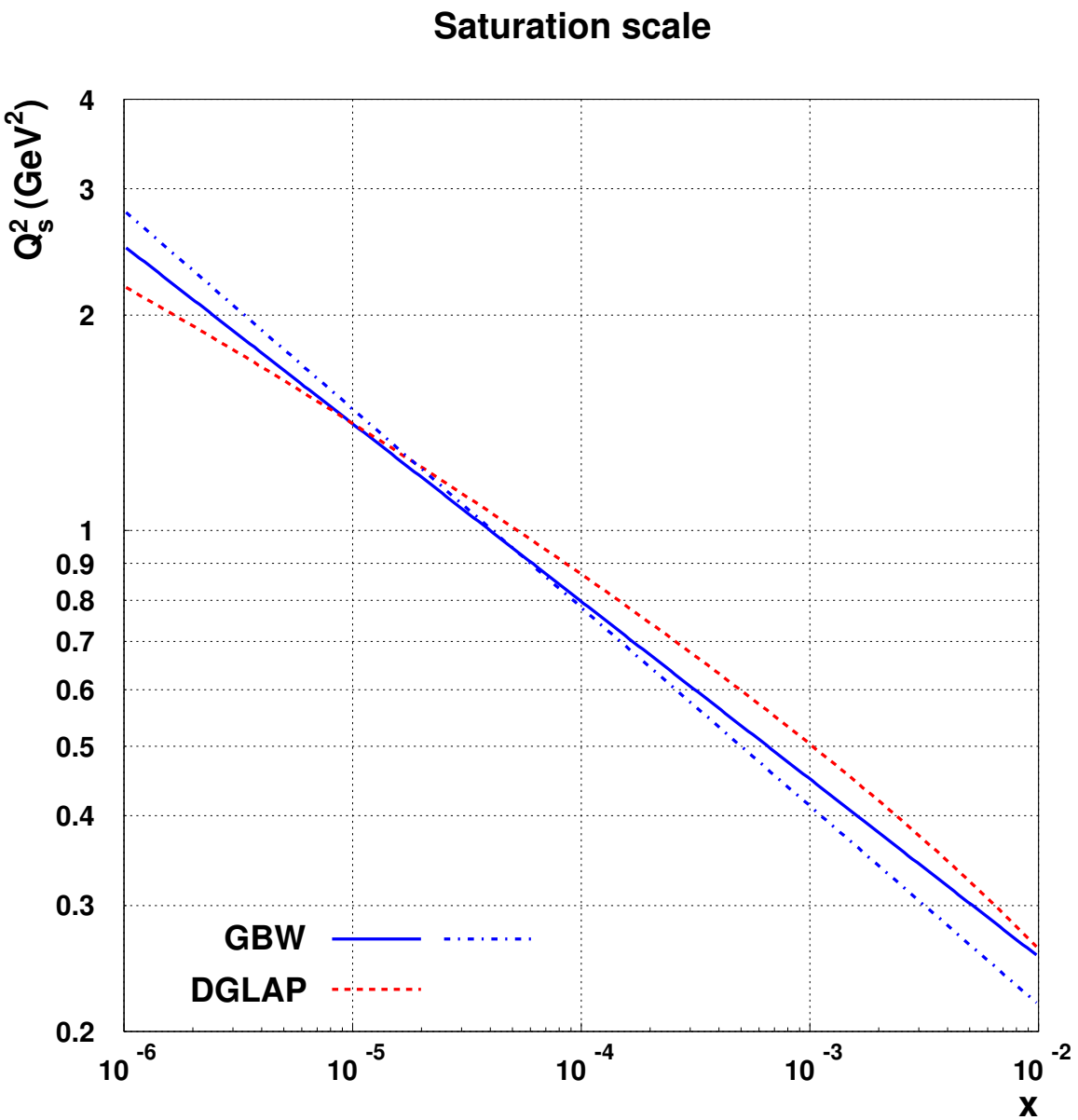




Data comparison - F_L as the prediction



Saturation scale $Q_s^2(x)$



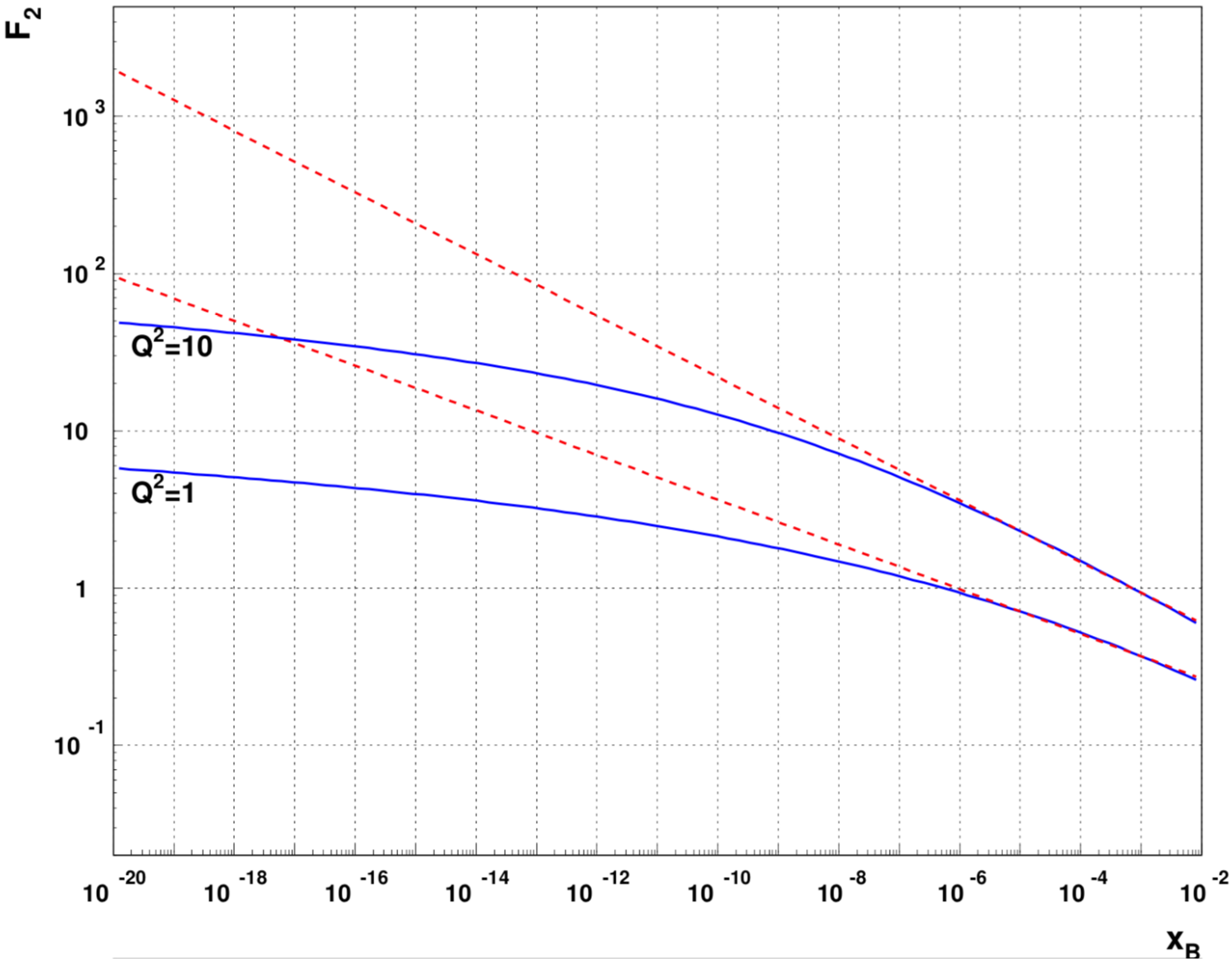
Summary

- After 20 years the GBW model with parton saturation ideas is still alive!
- DGLAP improved model provides robust picture of DIS at small x
- Huge theoretical work done in these years on parton saturation
  - Color Glass Condensate - L. McLerran, R. Venugopalan,.....
  - QCD color dipoles - A.H. Mueller, Yu. Kovchegov,...
  - QCD shock waves - I. Balitsky,...
  - NLO high energy QCD corrections - L.N. Lipatov, V. Fadin,....

Lev Nikolaevich Lipatov 1940-2017

Backup

Saturation of F_2



Saturation of F_L