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# **Heavy flavor production in DGLAP improved saturation model**

**Sebastian Sapeta**

CERN, Geneva, Switzerland

and

Jagellonian University, Cracow, Poland

*in collaboration with Krzysztof Golec–Biernat*

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## EXPLANATION

DGLAP Improved Saturation Model

= Saturation model of Bartels, Golec and Kowalski (BGK)

## MOTIVATION

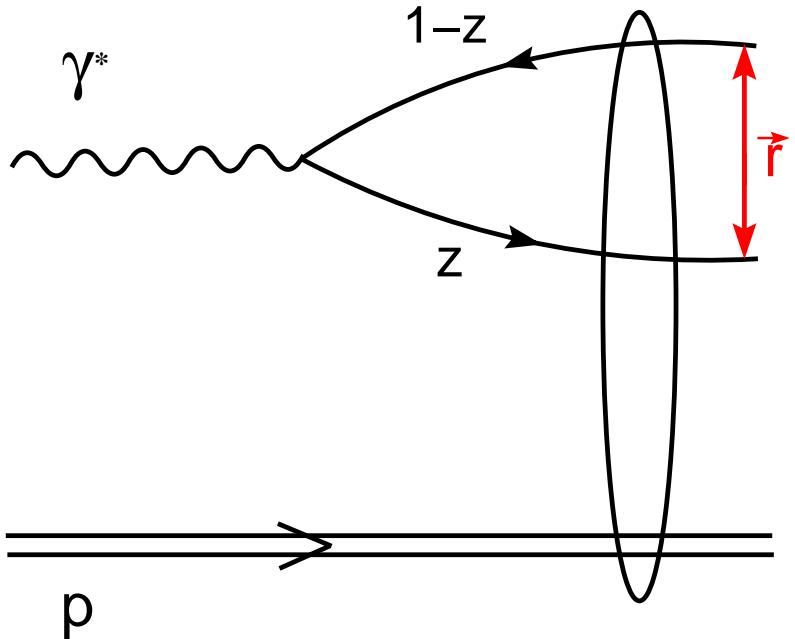
Consistent description of deep inelastic scattering at HERA in the limit of low  $x$  - heavy quarks cannot be neglected

## OUTLINE

1. DIS - introduction, dipole representation
2. Saturation Models
  - Golec–Biernat Wüsthoff Model (GBW)
  - Bartels–Golec–Kowalski Model (BGK)
3. BGK Model with Heavy Quarks (this results)
4. Summary

# DIS IN DIPOLE REPRESENTATION AT LOW x

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$$F_2 = \frac{Q^2}{4\pi^2 \alpha_{em}} \left( \sigma_T^{\gamma^* p} + \sigma_L^{\gamma^* p} \right)$$

$$\sigma_{T,L}^{\gamma^* p}(x, Q^2) = \sum_f \int d^2 \vec{r} \int_0^1 dz |\Psi_{T,L}^f(\vec{r}, z, Q^2)|^2 \hat{\sigma}(x, \vec{r})$$

f - active flavors

- |                                     |                                      |  |
|-------------------------------------|--------------------------------------|--|
| $ \Psi_{T,L}^f(\vec{r}, z, Q^2) ^2$ | -                                    | describes $\gamma^* \rightarrow q\bar{q}$ splitting , known from QED |
| $\hat{\sigma}(x, r)$                | -                                    | dipole-proton cross section, <b>preserves unitarity</b>              |
| small r:                            | $\hat{\sigma}(x, r) \sim r^2$        | - color transparency   |
| large r:                            | $\hat{\sigma}(x, r) \simeq \sigma_0$ | - saturation   |

# GOLEC–BIERNAT WÜSTHOFF SATURATION MODEL

$$\hat{\sigma}(x, r) = \sigma_0 \left\{ 1 - \exp \left( -\frac{r^2}{4R_0^2(x)} \right) \right\}$$

saturation scale

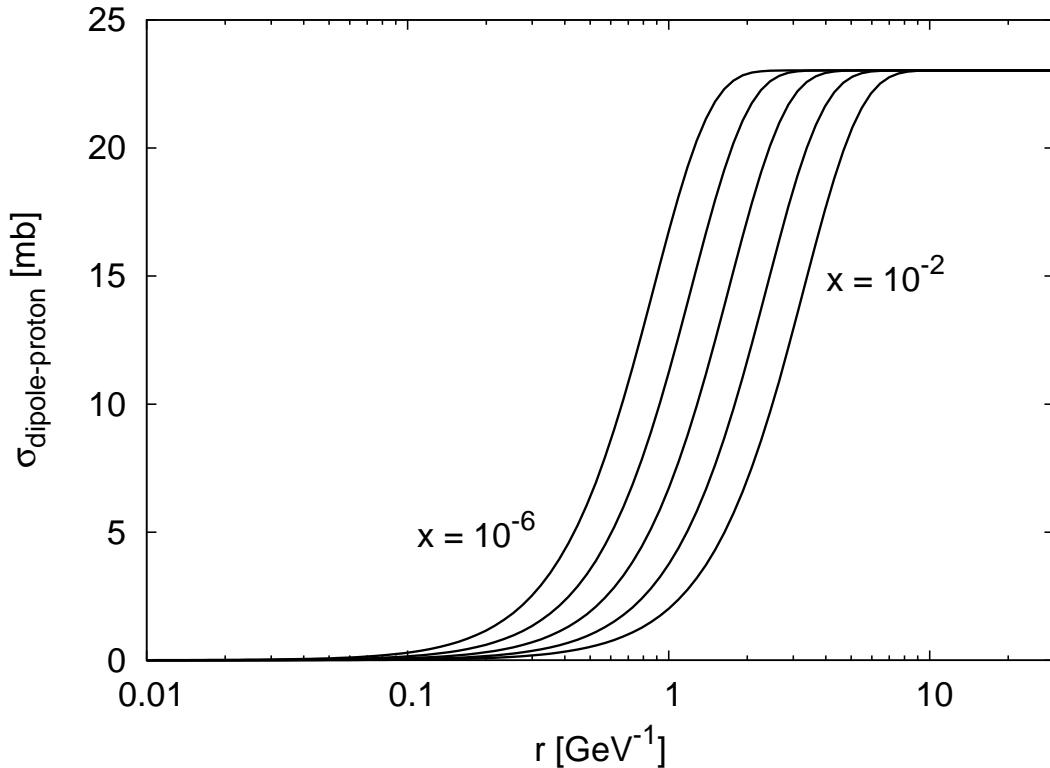
$$Q_s^2(x) = \frac{1}{R_0^2(x)} = \left( \frac{x_0}{x} \right)^\lambda$$

fit results to  $F_2$  old data

H1/ZEUS 94

FIT	$\chi^2/\text{ndf}$
light	1.18
light + c	1.50

at HERA:  $Q_s^2(x) \simeq 1 \text{ GeV}^2$



# SATURATION MODEL WITH DGLAP EVOLUTION

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Standard pQCD formula for the dipole cross section, valid at small  $r$

$$\hat{\sigma}(x, r) \simeq \frac{\pi^2}{3} \alpha_s(\mu^2) r^2 x g(x, \mu^2) \quad \text{with} \quad \mu^2 \propto \frac{1}{r^2}$$

Bartels Golec Kowalski model

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

with

$$\mu^2 = \frac{C}{r^2} + \mu_0^2$$

Gluon density  $x g(x, \mu^2)$  evolves with  $\mu^2$  according to DGLAP equations with the initial condition

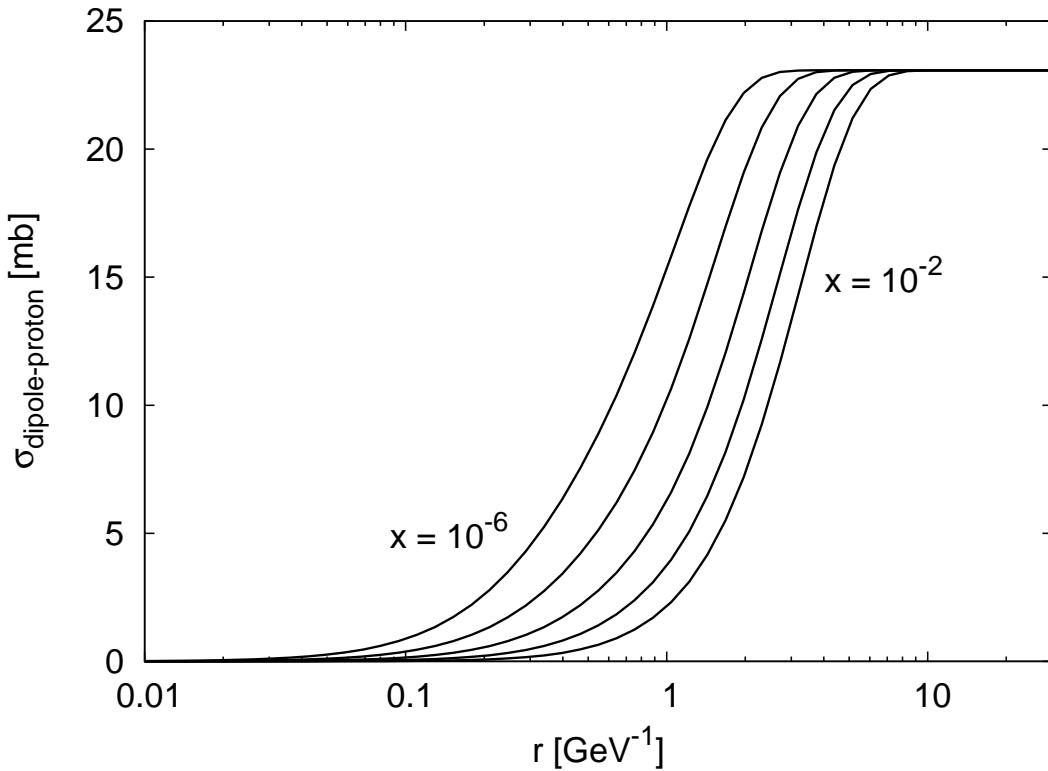
$$x g(x, Q_0^2) = A_g x^{-\lambda_g} (1-x)^{5.6} \quad \text{at} \quad Q_0^2 = 1 \text{ GeV}^2$$

# SATURATION MODEL WITH DGLAP EVOLUTION

fit results to  $F_2$  new data

H1/ZEUS 96-97

FIT	$\chi^2/\text{ndf}$
light	0.97–1.18
light + c + b	???



dipole cross section

- small  $r$ : improved by DGLAP evolution of gluon density
- large  $r$ : saturates identically with GBW model

## MOTIVATION FOR HEAVY QUARKS

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Universal form of the dipole cross section

$$F_2 = F_2^{\text{light}} + F_2^{c\bar{c}} + F_2^{b\bar{b}}$$

$$F_2 = \int |\Psi_{\text{light}}|^2 \hat{\sigma}_{\text{dipole}} + \int |\Psi_{\text{charm}}|^2 \hat{\sigma}_{\text{dipole}} + \int |\Psi_{\text{beauty}}|^2 \hat{\sigma}_{\text{dipole}}$$

HERA data

$F_2^{c\bar{c}}/F_2$  from 10% to 30%

$F_2^{b\bar{b}}/F_2$  up to 3%

Goal: to include heavy quarks in DGLAP improved saturation model and see its impact on saturation properties

# THE FIT TO DIS DATA

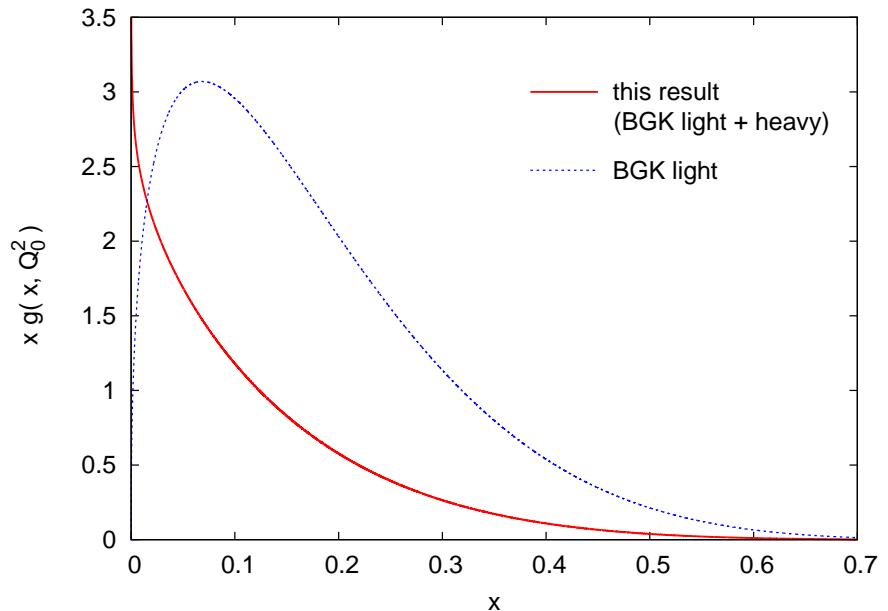
$$m_{\text{light}} = 0.0 \text{ MeV}$$

$$m_{\text{charm}} = 1.3 \text{ GeV}$$

$$m_{\text{beauty}} = 5.0 \text{ GeV}$$

	$\sigma_0$ [mb]	$A_g$	$\lambda_g$	$C$	$\mu_0^2$	$\chi^2/ndf$
light + c + b	22.7	1.23	0.080	0.35	1.60	1.16
light + c	22.4	1.35	0.079	0.38	1.73	1.06
light	22.8	13.71	- 0.41	11.10	0.52	0.97

- BGK model with heavy quarks gives very good fit
- parameters significantly different than in the case of light quarks only
- very small and positive  $\lambda_g$ , initial distribution is gluon-like



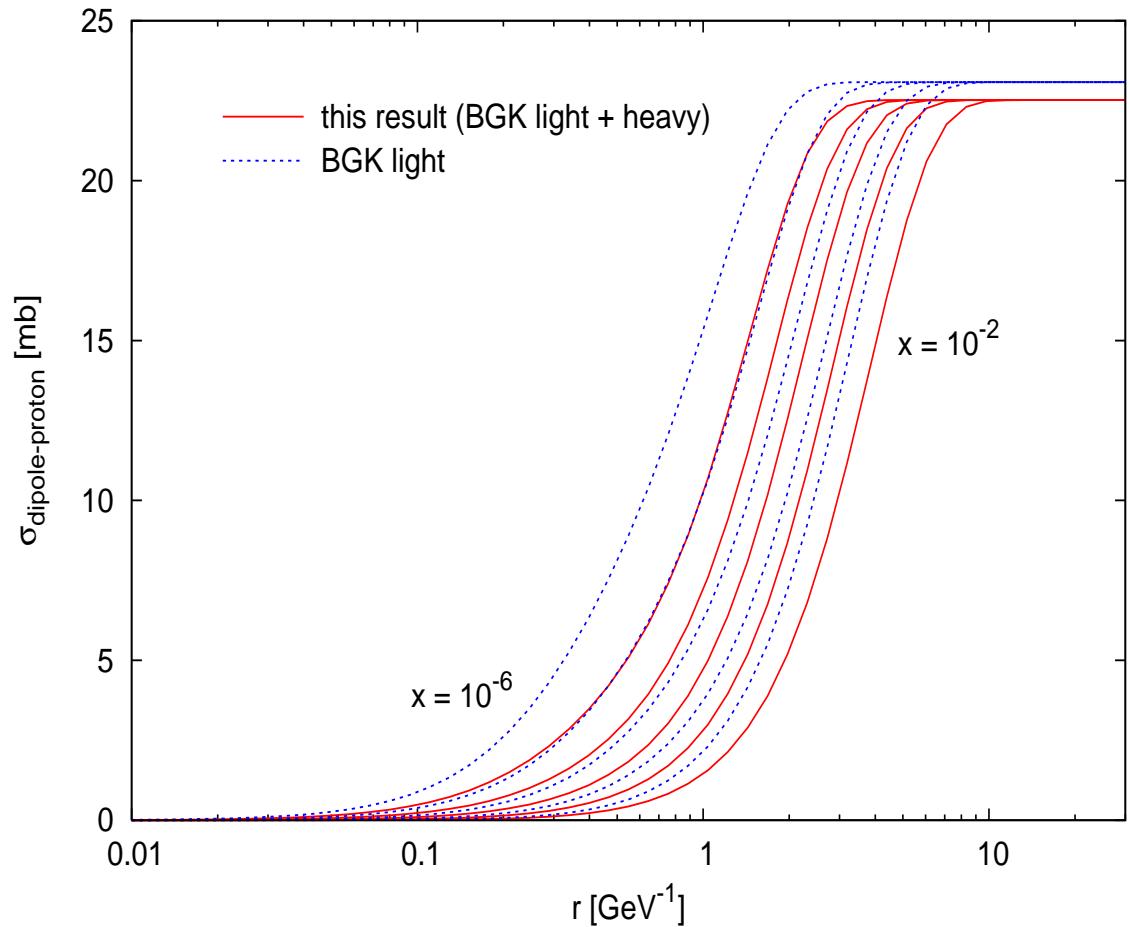
# DIPOLE CROSS SECTION

$$F_2 = F_2^{\text{light}} + F_2^{\text{c+b}}$$

$$F_2 = \int \sum \underbrace{|\Psi|^2}_{\text{suppressed at large } r} \hat{\sigma}$$

suppressed at large  $r$

In the model with heavy quarks the dipole cross section for a given dipole size saturates at higher energy (smaller  $x$ )



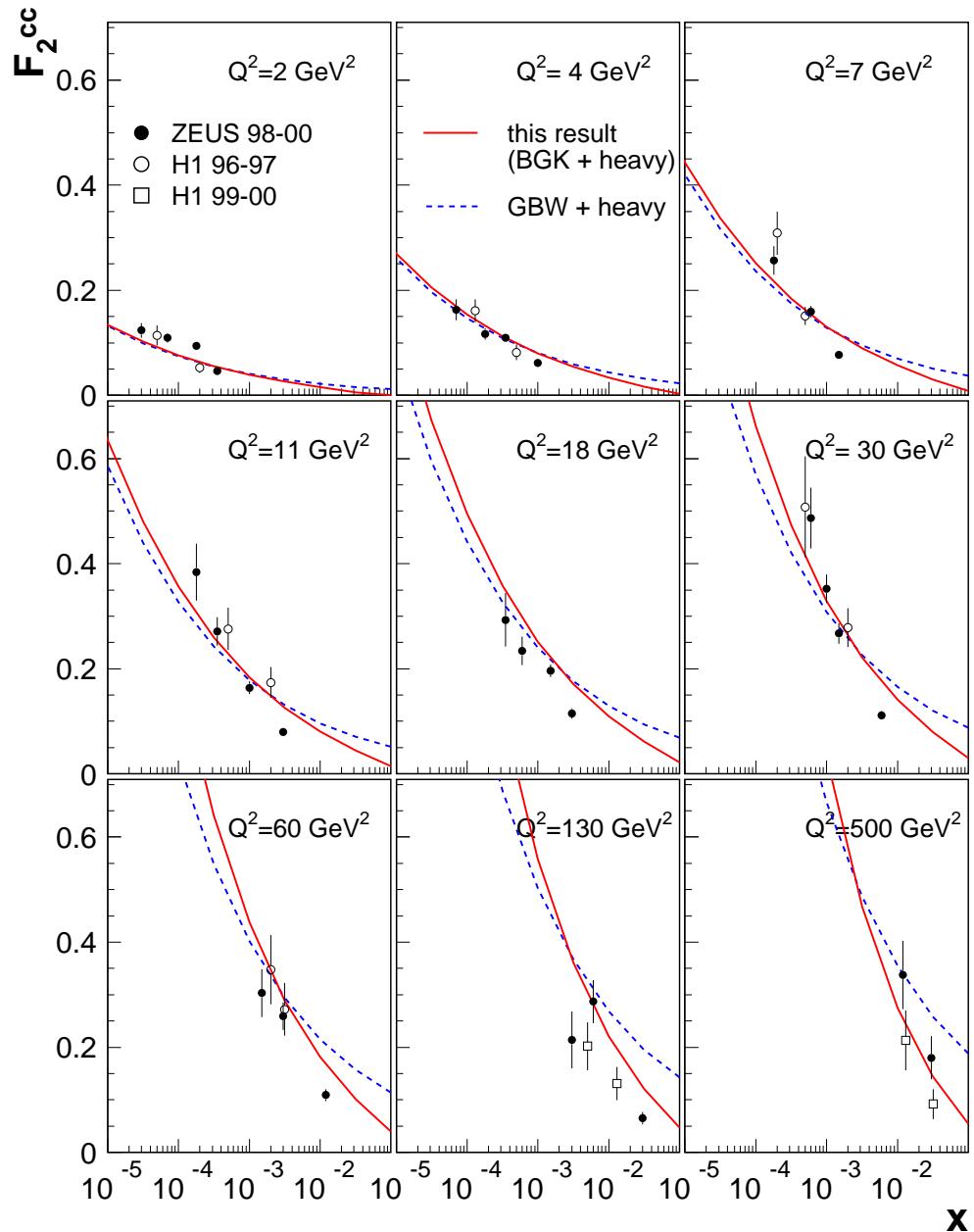
# CHARM STRUCTURE FUNCTION

Correct predictions for  $F_2^{c\bar{c}}$

- proper normalization
- DGLAP evolution improves the slope of  $F_2^{c\bar{c}}$  at large  $Q^2$

$$F_2 = F_2^{\text{light}} + F_2^{c\bar{c}} + F_2^{b\bar{b}}$$

$\uparrow$                      $\uparrow$   
fitted                  predicted



# BEAUTY STRUCTURE FUNCTION

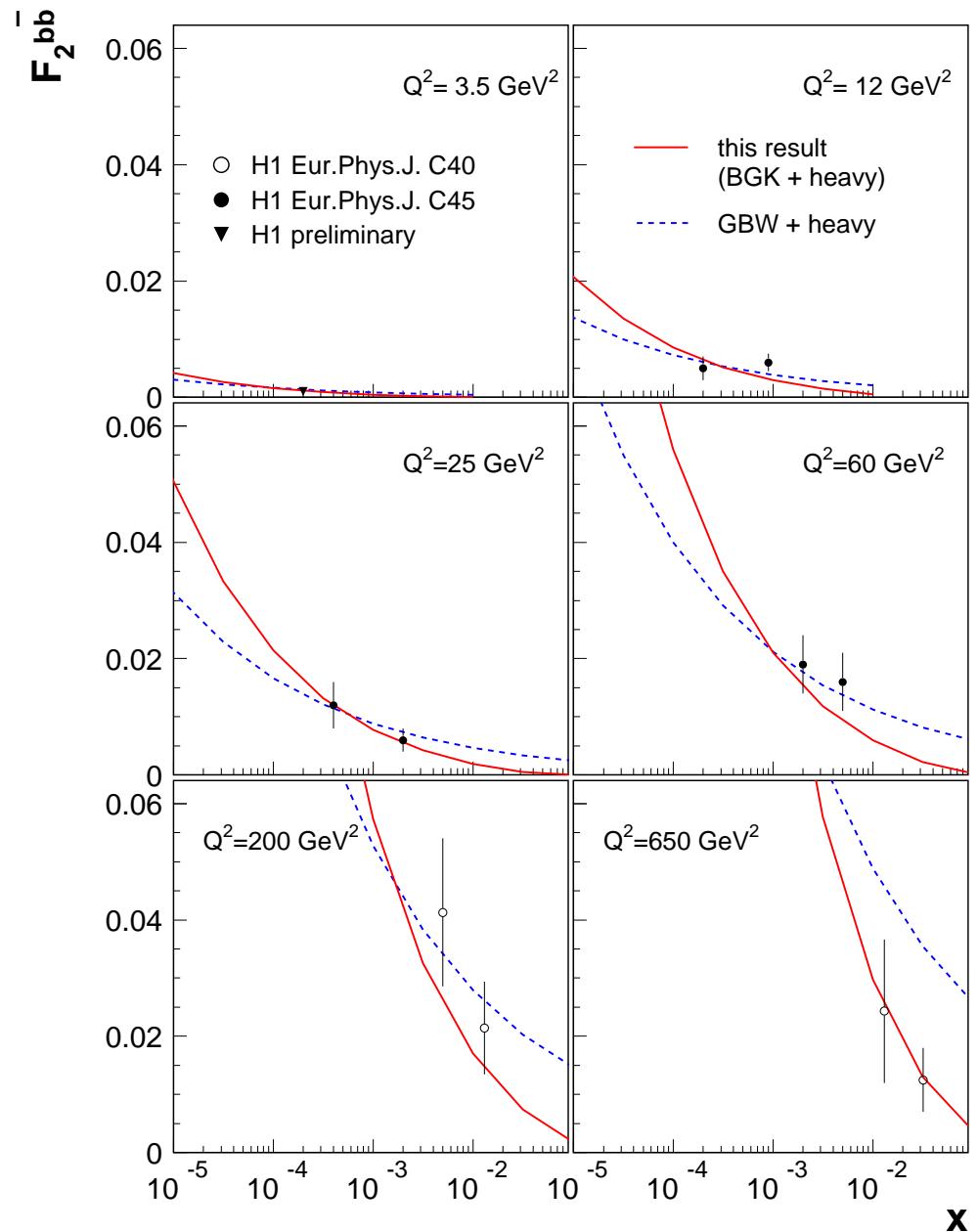
Correct predictions for  $F_2^{b\bar{b}}$

- proper normalization !
- DGLAP evolution improvement important at large  $Q^2$  !

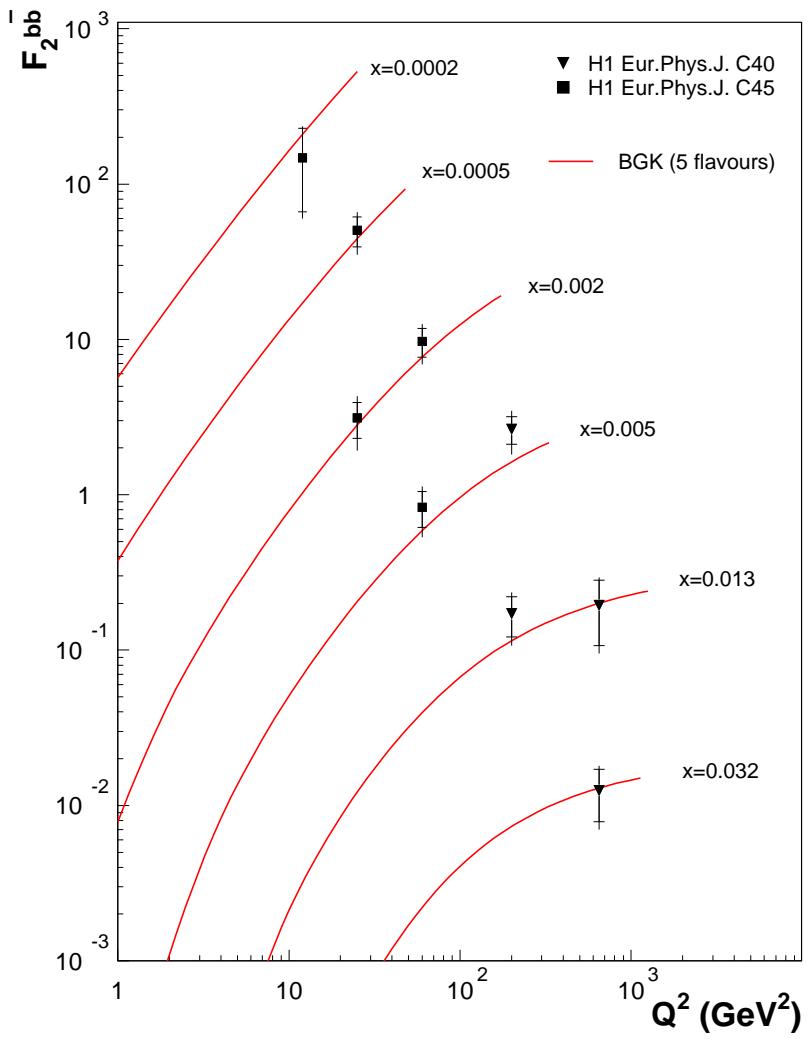
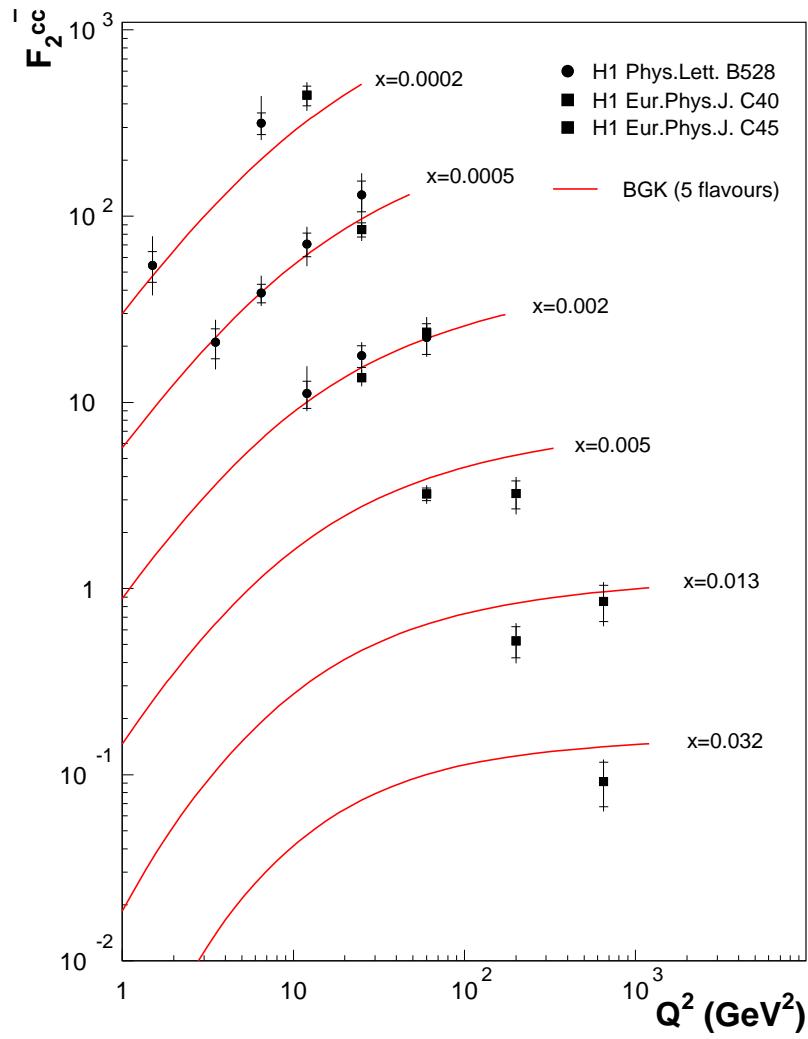
$$F_2 = F_2^{\text{light}} + F_2^{c\bar{c}} + F_2^{b\bar{b}}$$

↑   ↑

fitted   predicted

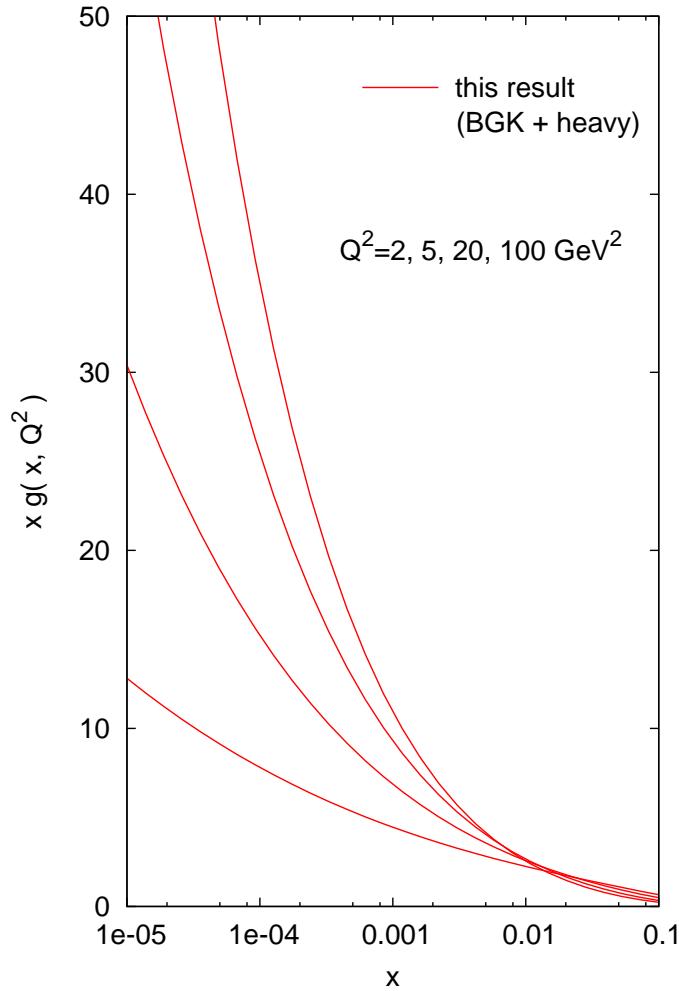


# CHARM AND BEAUTY STRUCTURE FUNCTIONS

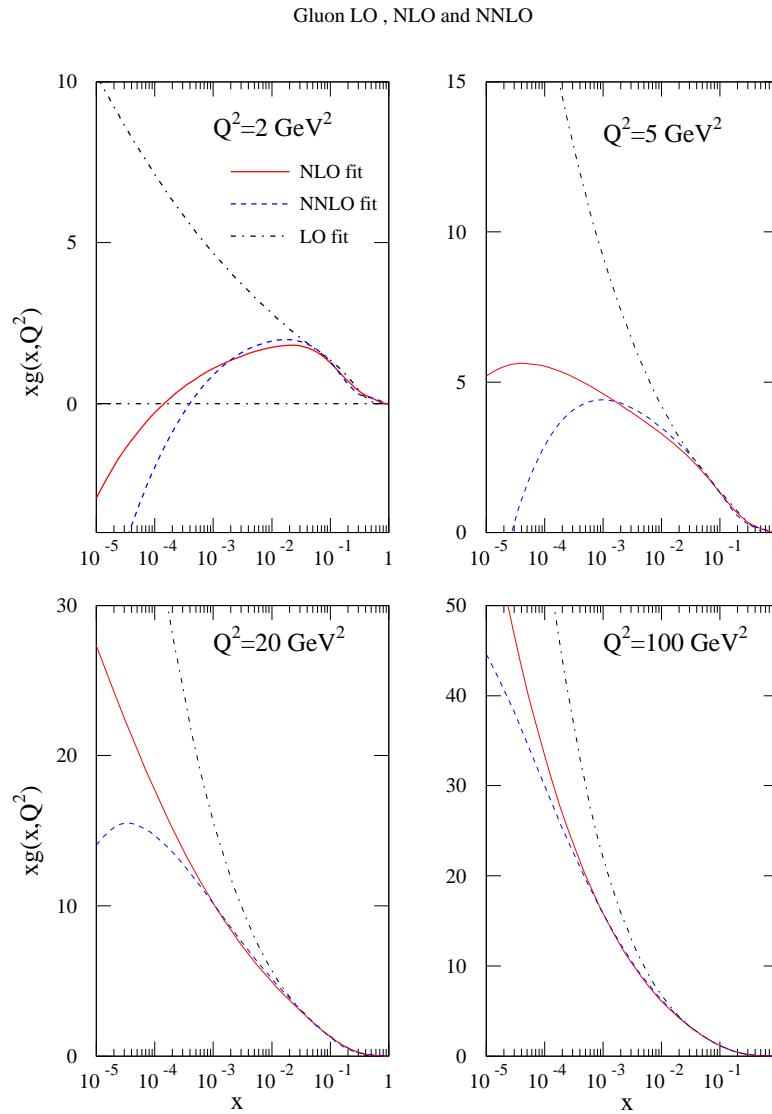


# GLUON DISTRIBUTION

Improved Saturation Model



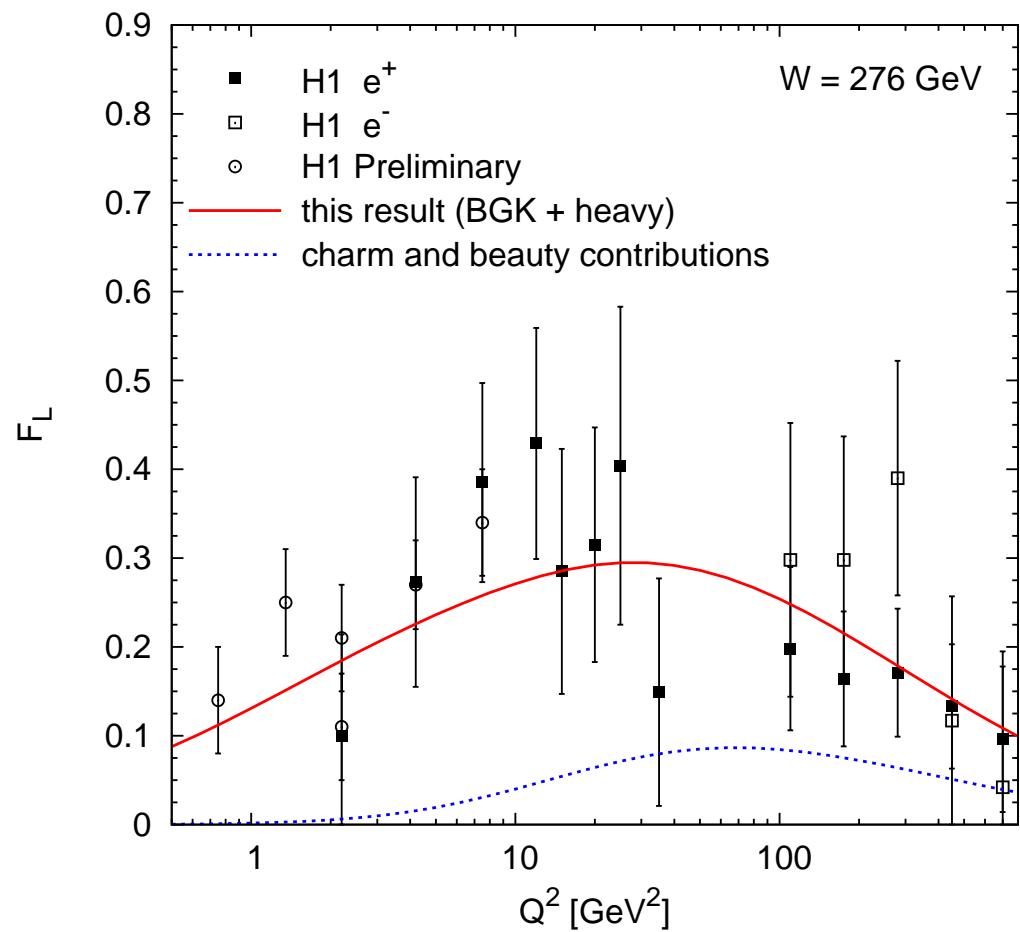
MRST at NNLO



# LONGITUDINAL STRUCTURE FUNCTION

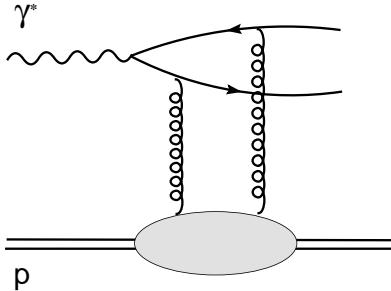
No direct measurements of  $F_L$  available at the moment

- rough agreement with H1 estimations
- ongoing measurements of H1/ZEUS
- comparison with the direct measurements will be particularly interesting

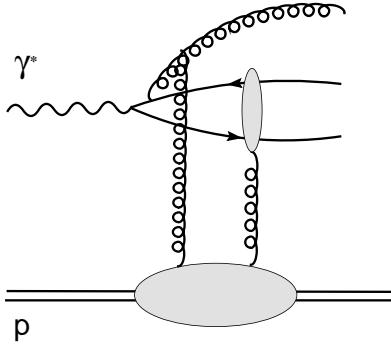


# DIFFRACTIVE STRUCTURE FUNCTION

$q\bar{q}$  dipole



$q\bar{q}g$  dipole

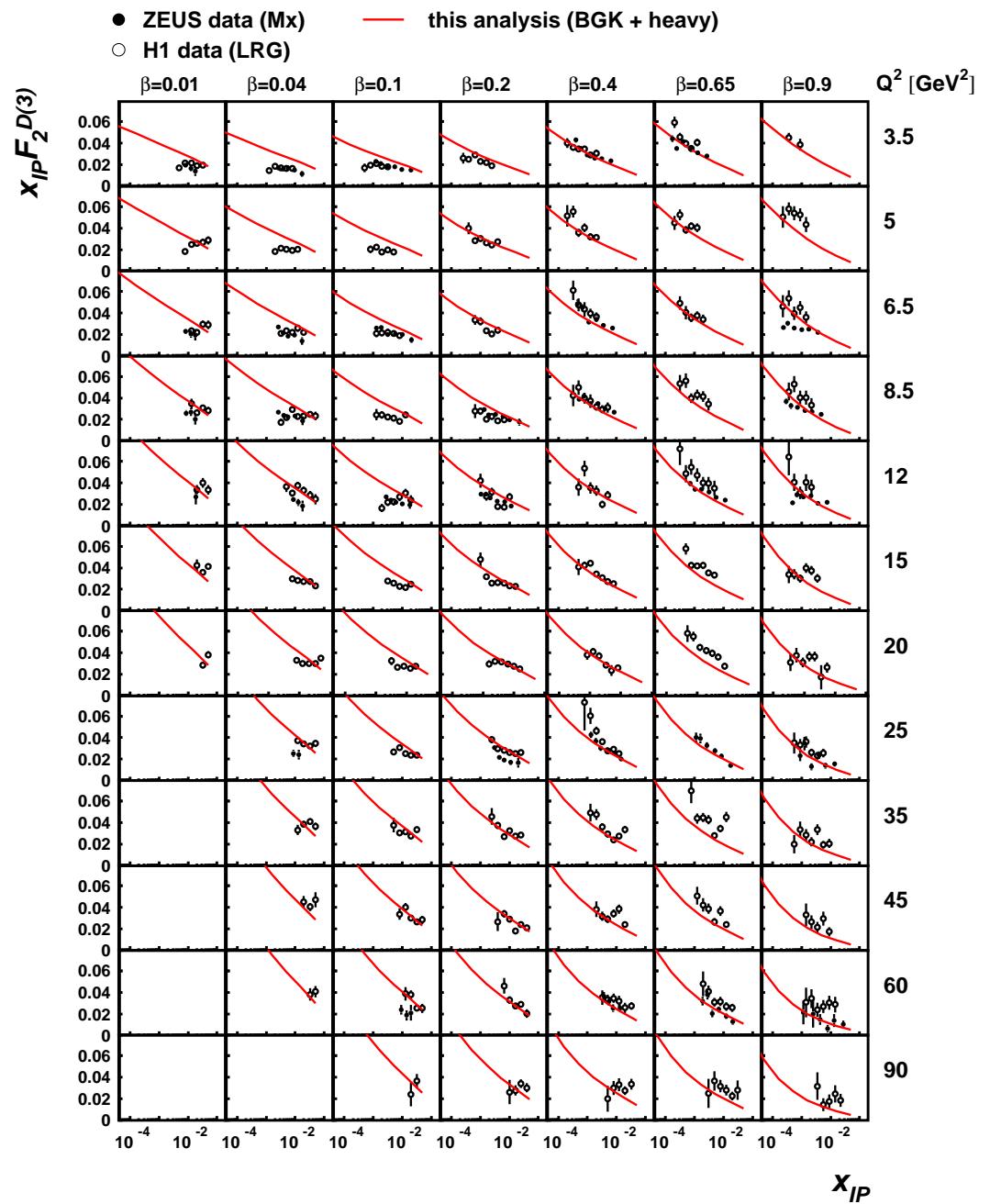


$$F_2^{D(3)} = F_{T,q\bar{q}} + F_{L,q\bar{q}} + F_{q\bar{q}g}$$

$$\text{diff. slope: } B_D = 6.0 \text{ GeV}^{-2}$$

ZEUS data  $\times 0.86$

predictions  $\times 1.23$



# CRITICAL LINE

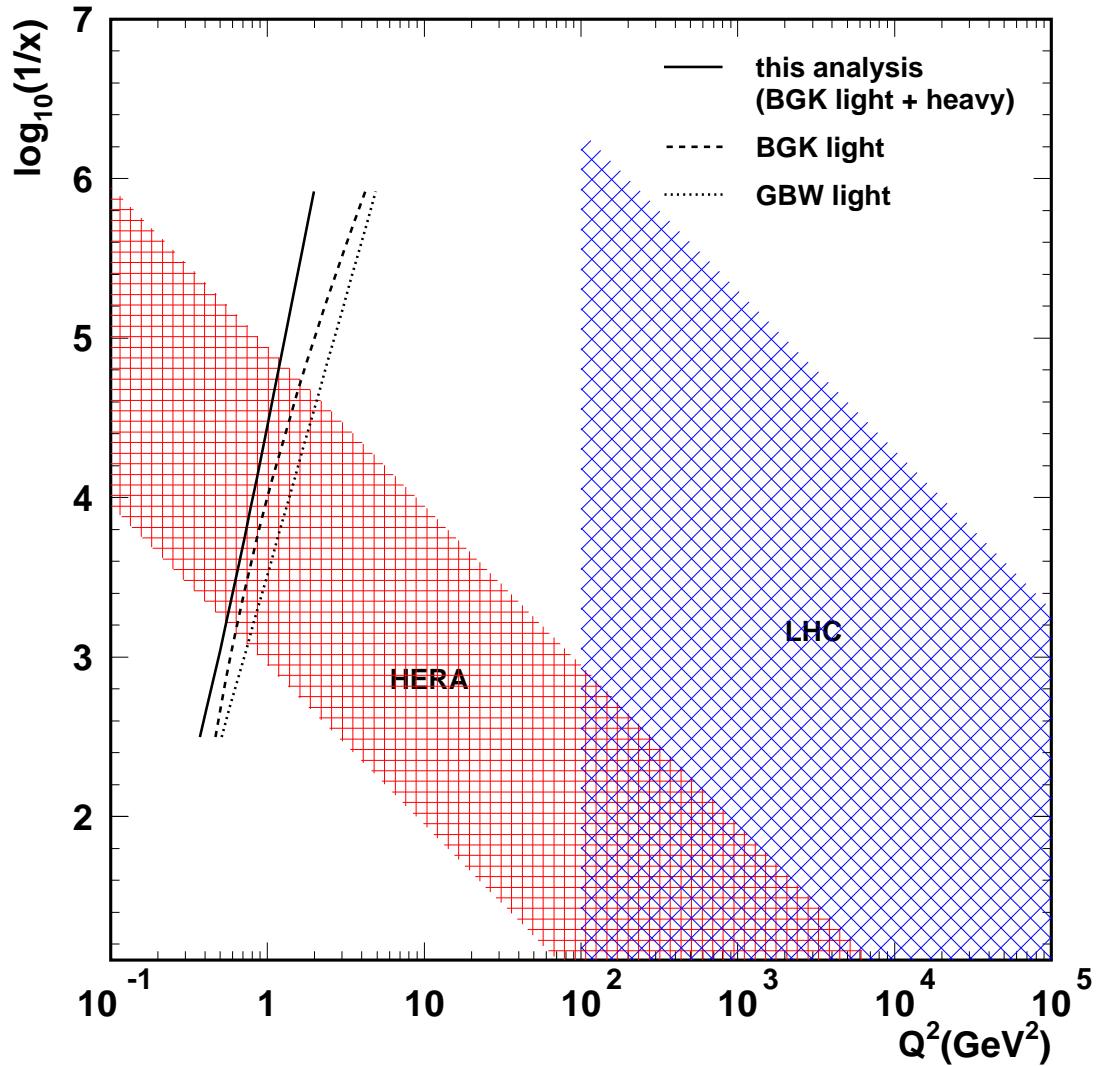
Characteristic dipole size

$$\bar{r} = 2/Q$$

at which

$$\hat{\sigma}(x, \bar{r}) \simeq \sigma_0$$

Shifting of the dipole cross section results in the **shift of the critical line towards smaller values of  $Q^2$**



## SUMMARY

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- Heavy quarks have to be taken into account in order to consistently describe deep inelastic scattering at HERA in the limit of low  $x$
- DGLAP improved saturation model with heavy quarks provides successful description of wide scope of observables for DIS at low  $x$ 
  - fit to inclusive  $F_2$  data,  $\chi^2/ndf = 1.06 - 1.16$
  - correct predictions for  $F_2^{c\bar{c}}$  and  $F_2^{b\bar{b}}$
  - predictions for  $F_L$
  - reasonable agreement for diffractive structure function  $F_2^{D(3)}$
- Adding heavy quarks results in the shift of the critical line towards smaller values of  $Q^2$