Critical tests of unintegrated gluon distribution: $F_2^{c,b}$ and F_L

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1. Introduction

The SF $F_L(x, Q^2)$ is directly connected to gluon in proton. It is not equal zero in pQCD only.
However pQCD leads to controversal results still.
In the LO approximation F_L takes about 10-20% of the F_2.
The NLO QCD corrections are large and can be negative at small x and low Q^2.
The NNLO corrections for F_L restore positivity of F_L at low x (even with a negative gluon).
But as it was shown recently:

- **The F_L exp. data at HERA seem to be inconsistent with some of the NLO theor. prediction (in particular the MRST) at small x**
- **The BFKL effects significantly improve the description of the low x data when compared to a standard NLO $\bar{M}S$-scheme global fit**
- **NNLO global fits become better taking into account higher order terms involving powers of $\ln(1/x)$**

R.S. Thorne, hep-ph/0511351;
C.D. White, R.S. Thorne, PR D74 (2006) 014002,
PR D75 (2007) 034005.

$\Rightarrow$ We need **resummation procedure**.

It is known the BFKL effects are taken into account from the very beginning in the k_T **factorization** approach

S. Catani, M. Ciafaloni, F. Hautman, Nucl. Phys. B366 (1991) 135;
J.C. Collins, R.K. Ellis, Nucl. Phys. B360 (1991) 3;
E. Levin, M. Ryskin, Yu. Shabelski, A. Shuvaev, Sov. J. Nucl. Phys. 53 (1991) 657.

Applications of k_T-factorization are shown:

Bo Andersson et al. (Small x Collaboration), Eur. Phys. J. C25 (2002) 77,
J. Andersen et al. (Small x Collaboration), Eur. Phys. J. C25 (2002) 77, C35 (2004) 67.

The k_T-factorization approach is based on BFKL

L.N. Lipatov, Sov. J. Nucl. Phys. 23 (1976) 338;
E.A. Kuraev, L.N. Lipatov and V.S. Fadin, Sov. Phys. JETP 44 (1976) 443, 45 (1977) 199;
Ya.Ya. Balitzki and L.N. Lipatov, Sov. J. Nucl. Phys. 28 (1978) 822;
L.N. Lipatov, Sov. Phys. JETP 63 (1986) 904.

or CCFM

M. Ciafaloni, Nucl. Phys. B296 (1988) 49;
S. Catani, F. Fiorani, G. Marchesini, Nucl. Phys. B336 (1990) 18;
G. Marchesini, Nucl. Phys. B445 (1995) 49

gluon evolution equations which sum up the large logarithmic terms proportional to $\ln(1/x)$ or $\ln(1/(1-x))$ in the LLA.

In the framework of k_T-factorization approach the study of the longitudinal SF F_L began ten years ago

Catani and F. Hautmann, Nucl. Phys. B427 (1994) 475,
S. Catani, hep-ph/9608310,

where the small x asymptotics of F_L has been evaluated using the BFKL results for the Mellin transform of the unintegrated gluon distribution and the longitudinal Wilson coefficient functions have been calculated analytically for the full perturbative series at asymptotically small x values.
Since we want to analyze SF data in a broader range at small x we use a more phenomenological approach in our analyses of F_2 and F_L data:

B.Badelek, J.Kwiecinski and A. Stasto,
Z. Phys. C74 (1997) 297.
A.V. Kotikov, A.V. Lipatov and N.Z.
Eur. Phys. J. C26 (2002) 51.

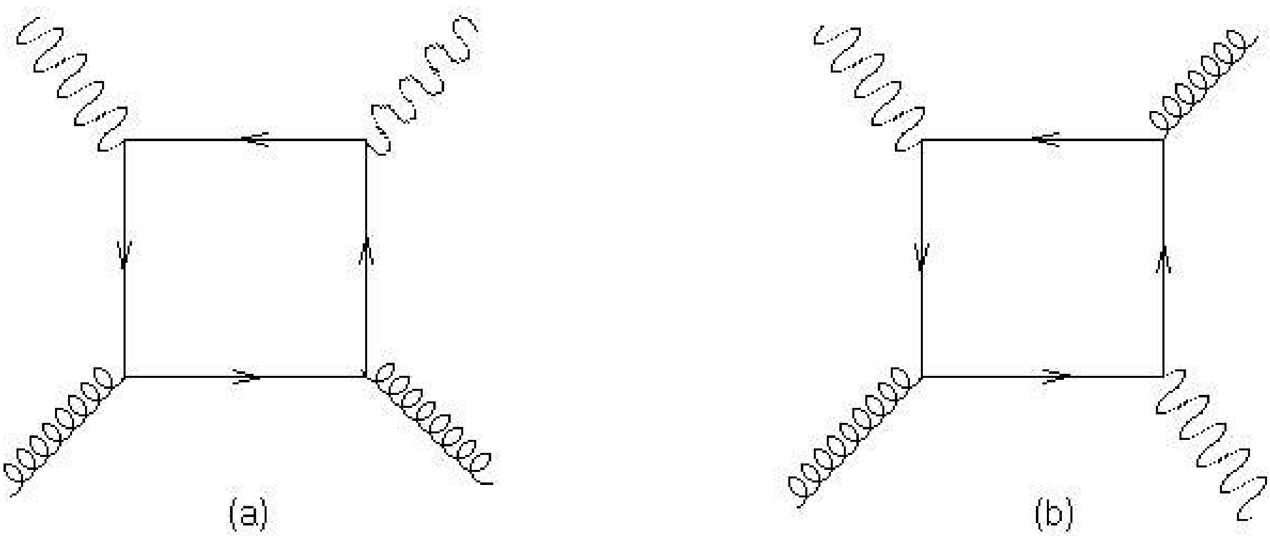
Using the k_T-factorization approach for the description of different SF at small x we hope to obtain additional information (or restrictions), in particular, about one of the main ingradient of k_T-factorization approach - the unintegrated gluon distribution (UGD).

2. SF in the k_T-factorization approach

In the k_T-factorization the SF $F_{2,L}(x, Q^2)$ are driven at small x primarily by gluons and are related in the following way to the unintegrated distribution $\Phi_g(x, k_T^2)$:

$$F_{2,L}(x, Q^2) = \int_x^1 \frac{dz}{z} \int^{Q^2} dk_T^2 \sum_{i=u,d,s,c} e_i^2 \cdot \hat{C}^g_{2,L}(x/z, Q^2, m_i^2, k_T^2) \; \Phi_g(z, k_T^2),$$

The functions $\hat{C}^g_{2,L}(x, Q^2, m_i^2, k_T^2)$ can be regarded as SF of the off-shell gluons with virtuality k_T^2 (hereafter we call them *hard structure functions*). They are described by the sum of the quark box (and crossed box) diagram contribution to the photon-gluon interaction.



It is instructive to note that these diagrams are similar to those of the photon-photon scaterring prosess. The corresponding QED contributions have been calculated many years ago:

V.N. Baier, V.S. Fadin, V.A. Khose, Sov. J. JETP 23 (1966) 104;
V.G. Zima, Sov. J. Nucl. Phys. 16 (1973) 580;
V.M. Budnev, I.F. Ginsburg, G.V. Meledin, V.G. Serbo, Phys. Report 15 (1975) 181.

To apply Eq. for SF at low Q^2 we change the low Q^2 asymptotics of the QCD coupling constant within hard structure functions. We apply the so called "freezing" procedure which can be done in the hard or the soft way.

In the hard case the strong coupling constant itself is modified: it is taken to be constant at all Q^2 values less then some Q_0^2, i.e. $\alpha_s(Q^2) = \alpha_s(Q_0^2)$, if $Q^2 \leq Q_0^2$.

In the soft case the subject of the modification is the argument of the strong coupling constant: it is shifted $Q^2 \to Q^2 + M^2$. Then $\alpha_s = \alpha_s(Q^2 + M^2)$.

For massless quarks $M = m_\rho$, for massive quarks with mass $m_Q, M = 2m_Q$.

We have used the soft version of freezing procedure.

To calculate the SF $F_2^{c,b}$ and $F_L(x, Q^2)$ we used:

- **The hard SF $\hat{C}^g_{2,L}(x, Q^2, m^2, k_T^2)$ from**

  A.V. Kotikov, A.V. Lipatov and N.Z.

  Eur. Phys. J. C26 (2002) 51, C27 (2003) 219.

  To note that at $Q^2 \to 0$ there is full agreement of our results with the formulae for the photoproduction of heavy quarks from the paper

  S. Catani, M. Ciafaloni and F. Hautmann

  Proc. of the Workshop on Physics at HERA, Hamburg, 1991, **v.2, p.690.**

- **Two unintegrated gluon distributions $\mathcal{A}(x, \mathbf{k}_T^2, \mu^2)$ obtained in our previous paper**

  H.Jung, A.V. Kotikov, A.V. Lipatov and N.Z.

  ICHEP'07, Moscow, **hep-ph/0611093.**

Unintegrated gluon distributions

The unintegrated gluon distribution is determined by a convolution of the non-perturbative starting distribution $\mathcal{A}_0(x)$ and CCFM evolution denoted by $\bar{\mathcal{A}}(x, \mathbf{k}_T^2, \mu^2)$:

$$x\mathcal{A}(x, \mathbf{k}_T^2, \mu^2) = \int dz \mathcal{A}_0(z) \frac{x}{z} \bar{\mathcal{A}}(\frac{x}{z}, \mathbf{k}_T^2, \mu^2),$$

where

$$x\mathcal{A}_0(x) = N x^{-B_g} (1-x)^{C_g} (1 - D_g x). \qquad (1)$$

The parameters N, B_g, C_g, D_g of $\mathcal{A}_0$ are determined in the fits to F_2 and F_2^c independently.

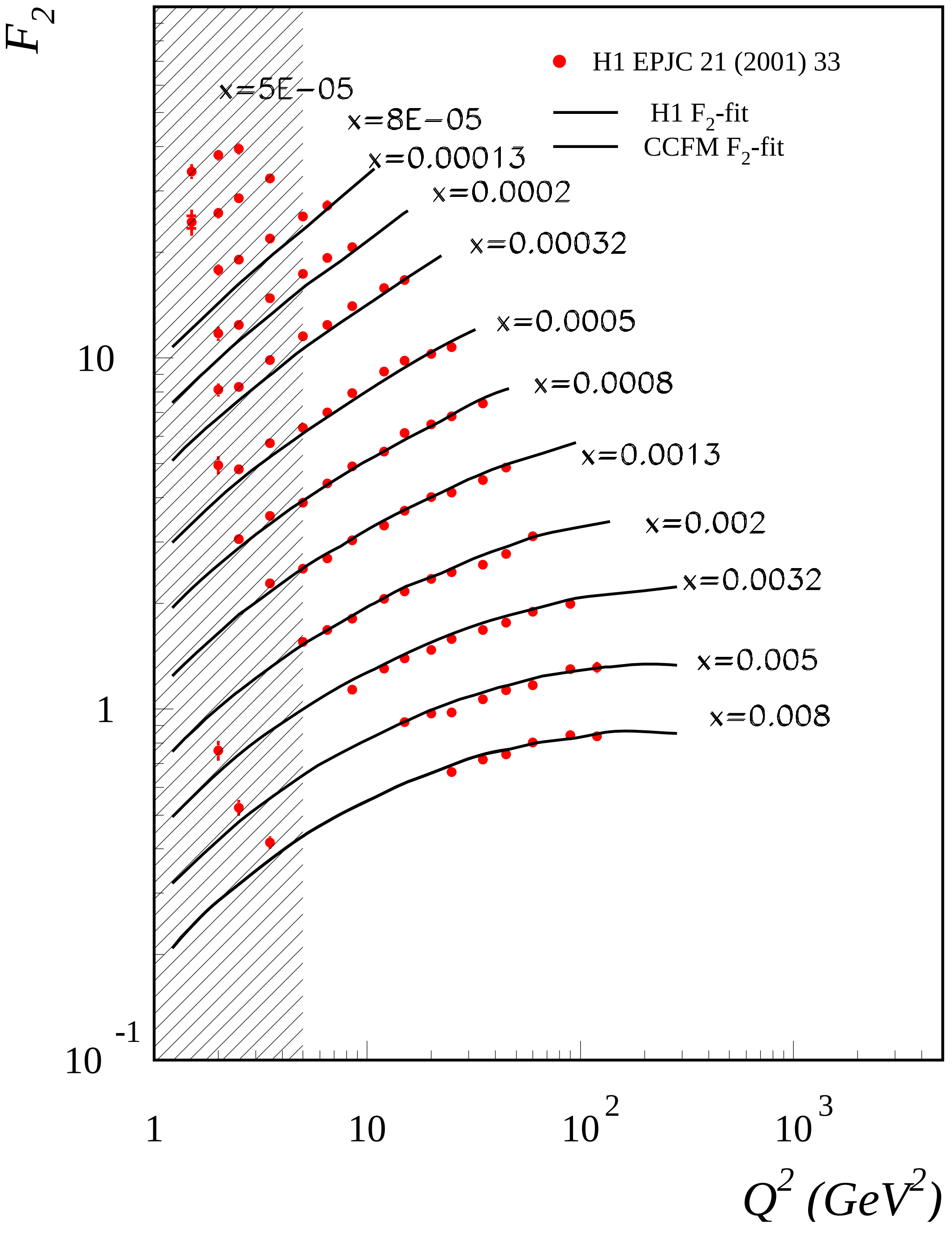
The measurement of $F_2(x, Q^2)$

H1 Collab., A. Adloff et al.

Eur. Phys. J. **C21** (2001) 33

was used in the range $x < 0.005$ **and** $Q^2 > 5$ $\mathbf{GeV}^2$ **to determine "first" UGD.**
The parameters of $\bar{\mathcal{A}}_0$ **were investigated separetely. The starting distribution** $\bar{\mathcal{A}}_0$ **was paremetrized at** $\bar{q}_0 = 1.2$ **GeV.**
The running coupling $\alpha_s(\mu)$ **was used in the 1-loop approximation in the region** $\mu > \bar{q}_0$**, and was kept fixed at** $\alpha(\bar{q}_0)$ **at** $\mu < \bar{q}_0$**.**
A acceptable fit to the neasured F_2 **values was obtained with** $\chi^2/ndf = 118.8/61 = 1.83$ **(compare to** $\chi^2/ndf \sim 1.5$ **in the collinear approach at NLO).**
The dependence on the choice of Λ_{QCD} **was investigated also. A clear preference for** $\Lambda_{QCD}^{(4)} \sim 130$ **MeV was observed.**

Here the measurement is compared to the fit of the SF $F_2(x, Q^2)$:



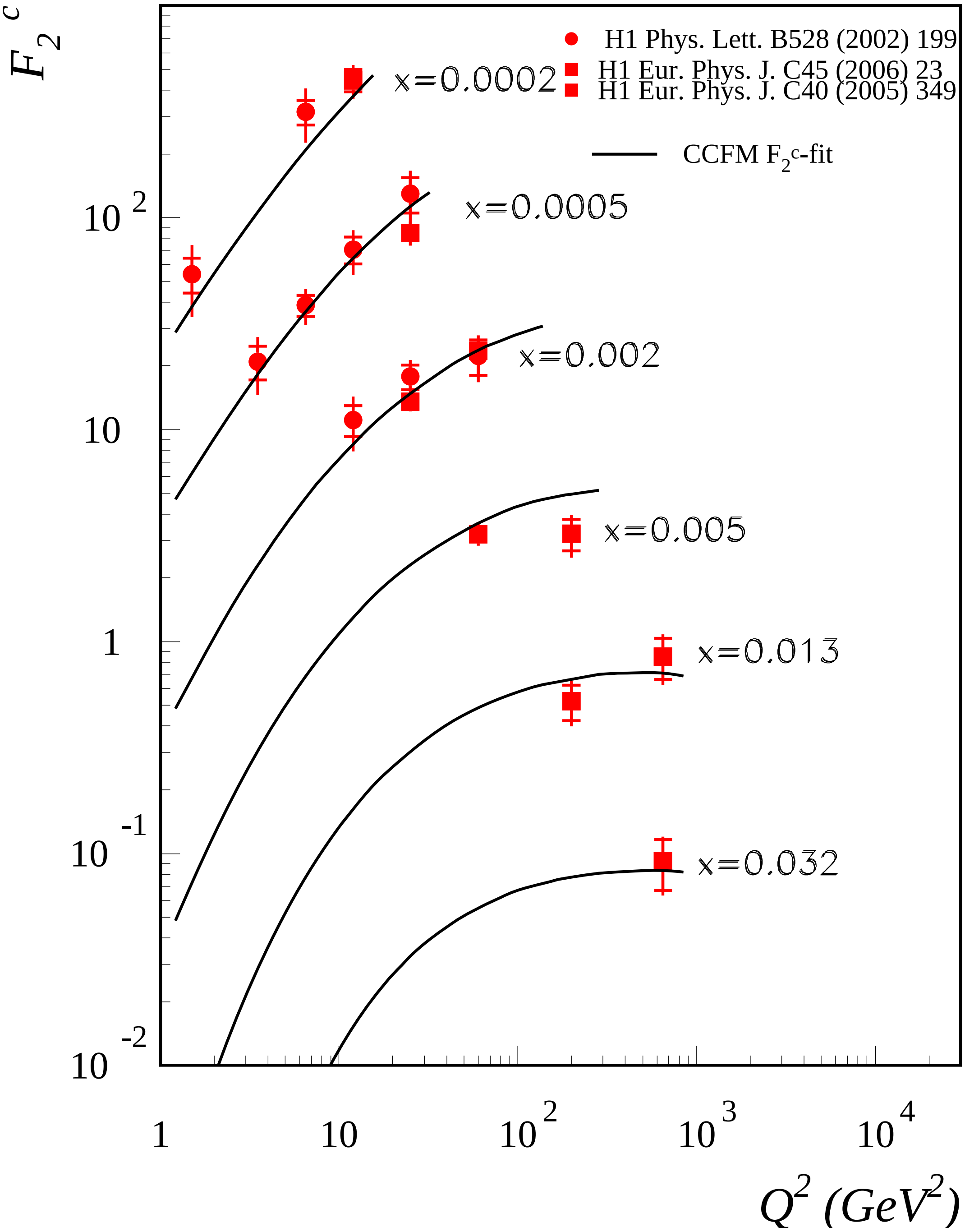
The SF $F_2(x, Q^2)$ as function of Q^2 for different values of x. The shaded area shows the region which is not used in the fit.

The SF F_2^c is directly sensitive to the gluon density.
The measurements of

H1 Collab., A. Adloff et al.
Phys. Lett. B528 (2002) 199,
A. Aktas et al., Eur.Phys. J. C40 (2005) 349,
Eur.Phys. J. C45 (2006) 23,

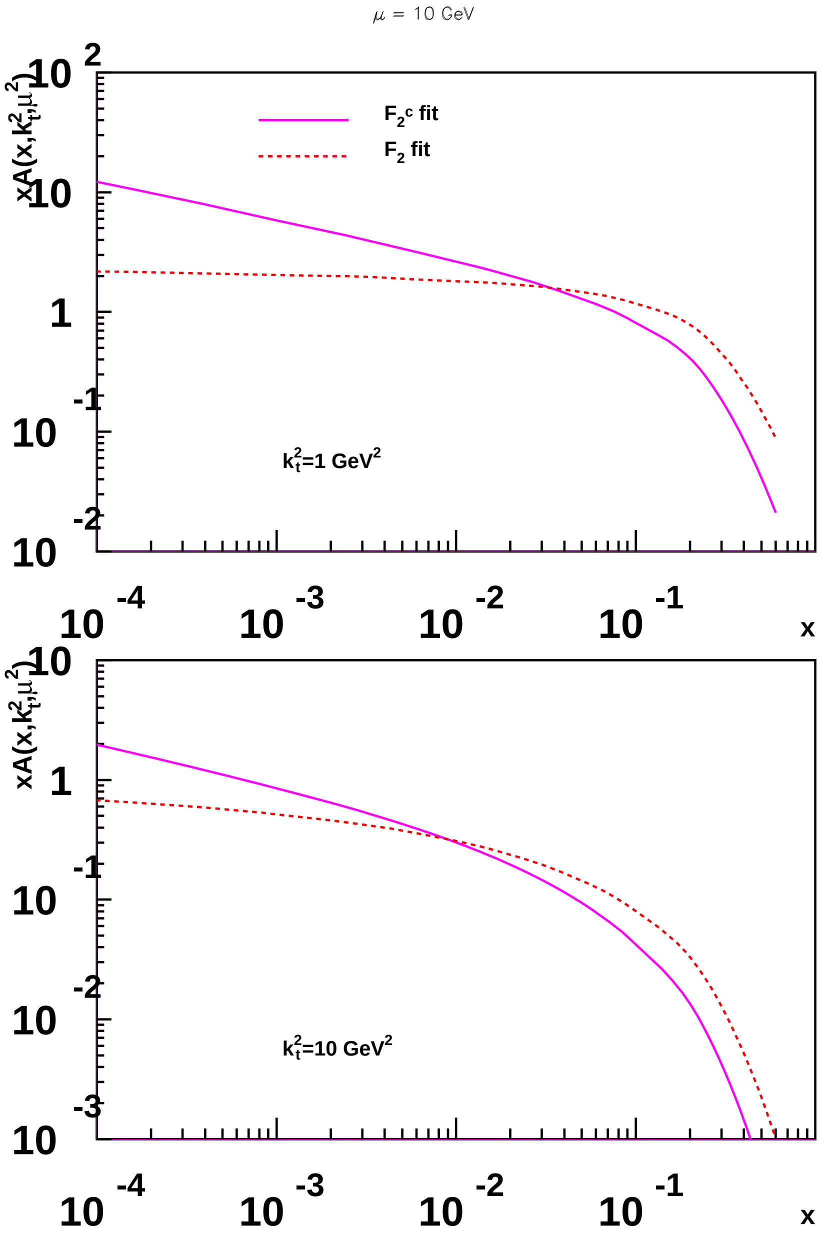
were used to determine the UGD in the range $Q^2 \geq 1.5$ GeV^2.
A acceptable fit to the measured F_2^c values was obtained with $\chi^2/ndf = 18.8/20 = 0.94$ using statistical and systematic uncertainties.

Here the measurement is compared to the prediction of the SF $F_2^c(x, Q^2)$ as obtained from the fit:



The SF $F_2^c(x, Q^2)$ as function of of Q^2 for different values of x.

$\Rightarrow$ **We have obtained two unintegrated gluon densities:**

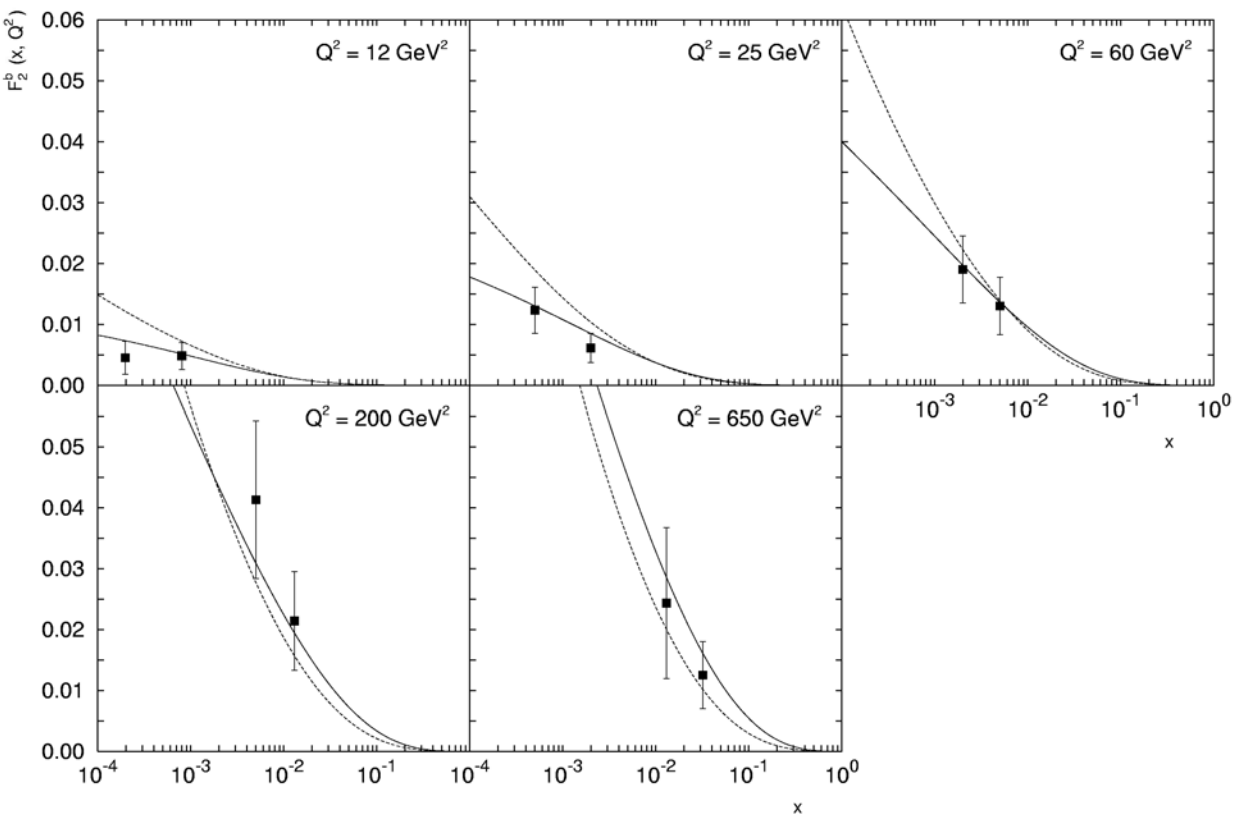


The small x behaviour of these UGD is very different. See also

H. Jung, talk in HFS working group.

Numerical results

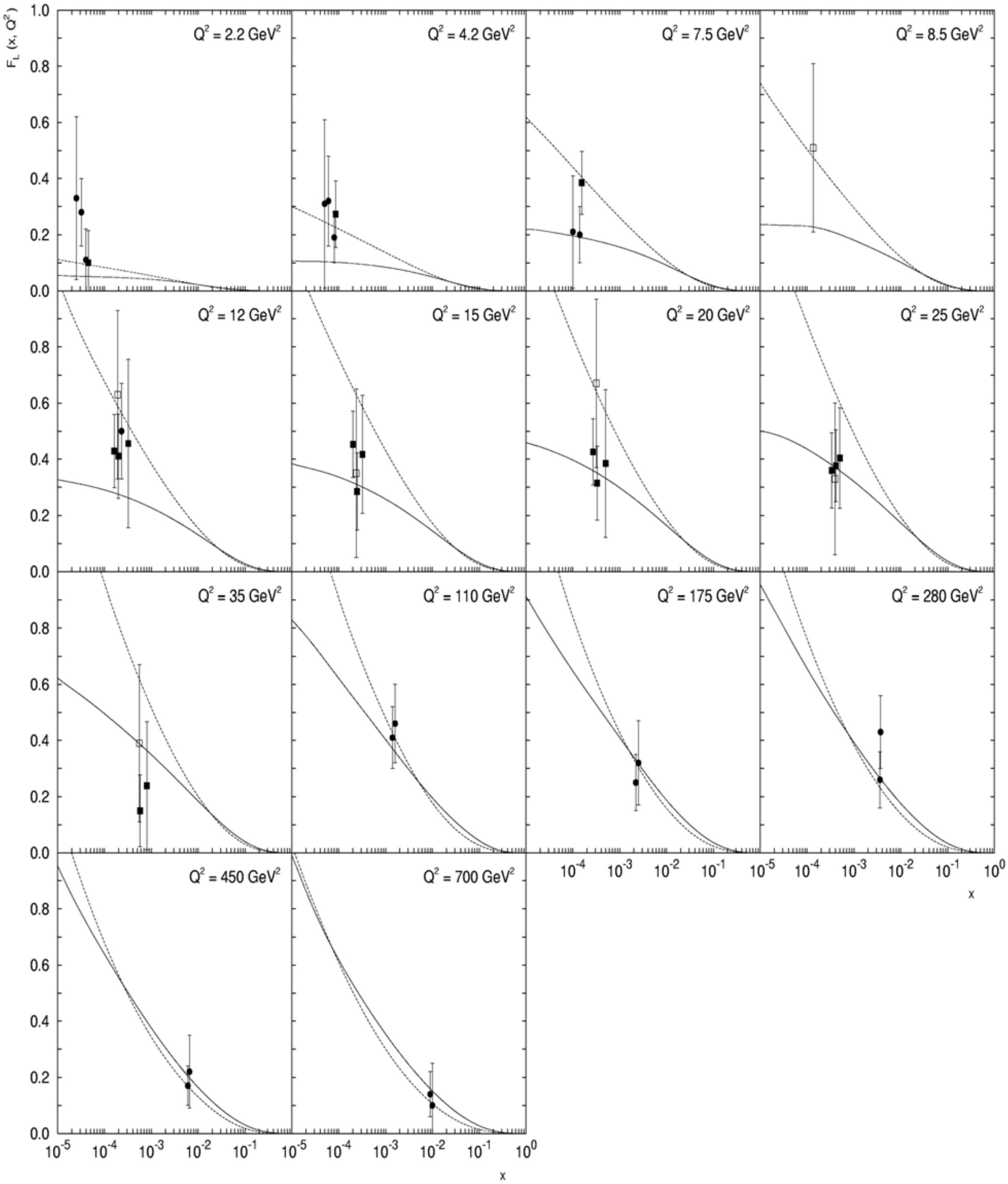
To calculate the SF $F_2^b(x, Q^2)$ and $F_L(x, Q^2)$ we took $m_c = 1.4$ GeV and $m_b = 4.75$ GeV and used the $m^2 = 0$ limit of the above formulae to evaluate the corresponding light quark contributions to the SF.



The SF F_2^b as a function of x at fixed Q^2 compared to the H1 data:

H1 Collab., A. Aktas et al. EPJ **C40** *(2005) 349,* **C45** *(2006) 23.*

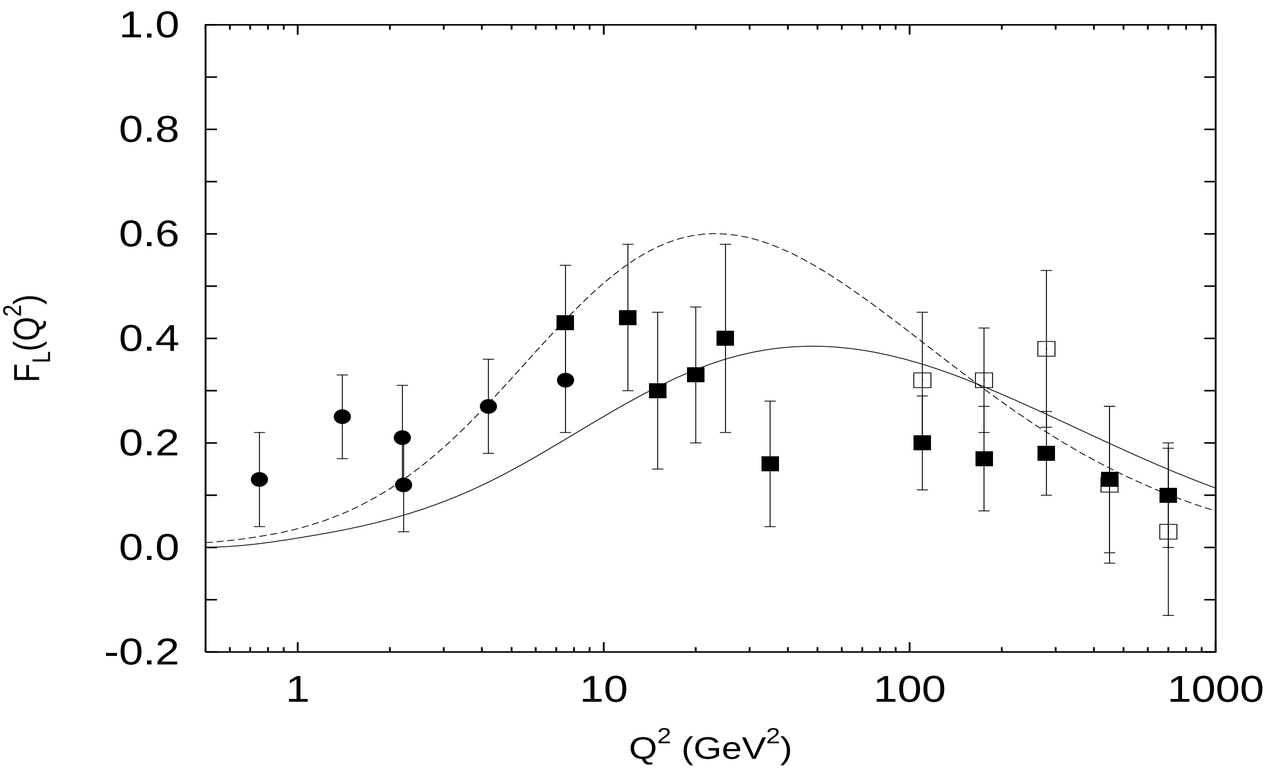
The solid and dashed lines are from CCFM-evolved UGD obtained from the fits to $F_2(x, Q^2)$ and $F_2^c(x, Q^2)$.



The SF F_L as a function of x at fixed Q^2 compared to the H1 data. The solid and dashed lines are from CCFM-evolved UGD obtained from the fits to $F_2(x, Q^2)$ and $F_2^c(x, Q^2)$.

The H1 exp. data points are from

H1 Collab., S. Aid et al.
Phys. Lett. B393 (1997) 452,
A. Adloff et al., Eur.Phys. J. C21 (2001) 33,
N. Gogitidze, J. Phys. G 28 (2002) 751.



The Q^2 *dependence of SF* F_L *(at* $W = 276\ GeV$*) compared to the H1 data. The solid and dashed lines are from CCFM-evolved UGD obtained from the fits to* $F_2(x, Q^2)$ *and* $F_2^c(x, Q^2)$.

The H1 exp. data points are from

E.M. Lobodzinska

in *Proc. of the DIS 2003, Gatchina, Russia,* **p. 93.**

Conclusions

- **The k_T- factorization approach with the CCFM-evolved UGD obtained from the fits to the $F_2(x, Q^2)$ and $F_2^c(x, Q^2)$ data reproduces the H1 data for SF $F_2^b(x, Q^2)$, $F_L(x, Q^2)$ and F_L at fixed W.**
- **The new exp. data for $F_L(x, Q^2)$ and at fixed W are very important for the UGD.**
- **We need more precise experimental data for the SF $F_2^c(x, Q^2)$ and $F_2^b(x, Q^2)$ also.**