The low-Q deep-inelastic scattering data in the global fit of PDFs

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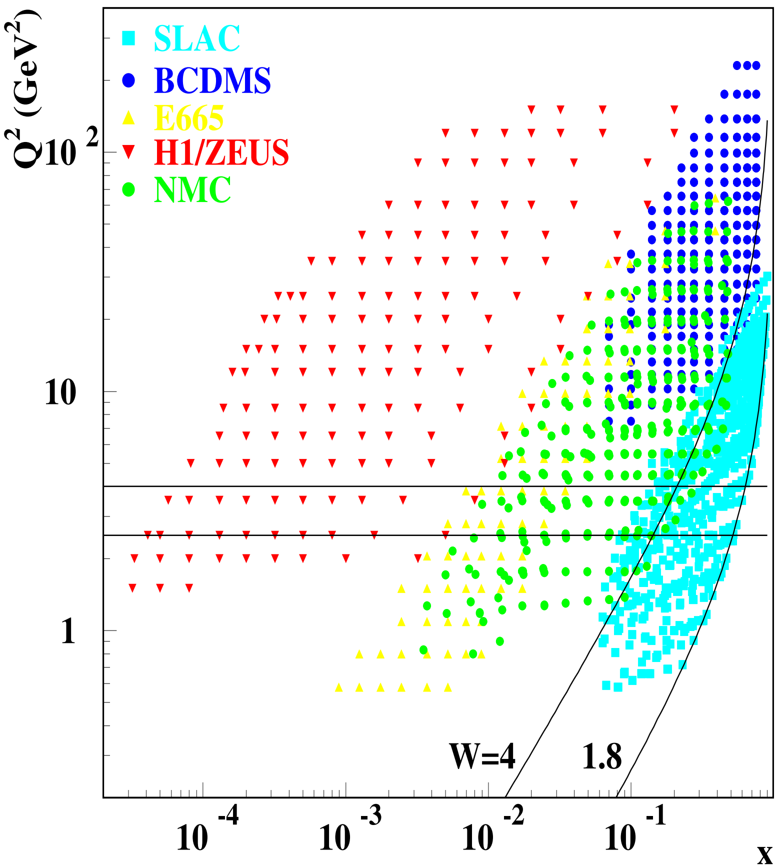
The low-Q DIS data are necessary at least for several reasons

- The DIS c.s. falls with the transferred momentum Q as $1/Q^4$ and the biggest part of experimental data is collected at low Q. The rate of QCD evolution of the DIS structure functions rises at small Q, therefore sensitivity to the strong coupling constant is biggest in this region

- The QCD factorization is valid only at asymptotically big values of Q; at small Q the power corrections (high twist terms) has to be taken into account. Nowadays only phenomenological study of the data can give constraint on the value of power corrections and define the region of validity for the parton model.

- We need clarification of the low-Q region for practical purposes (modeling low energy neutrino experiments and spin asymmetries analysis).

Kinematics of the inclusive DIS data



Regular practice it to cut the low-Q (low-W) data in order to avoid potentially dangerous regions, however in this case a lot of precise data is lost.

The data on the DIS *cross sections* with $Q^2 > 1$ GeV^2, $W > 1.8$ GeV are used in the fit and parameterized in the NNLO QCD with account of the target mass corrections and the dynamical high-twist terms

$$\overline{\sigma} = \left[1 - y - \frac{(M_p x y)^2}{Q^2}\right] F_2(x, Q^2) + \frac{y^2}{2} F_{\mathrm{T}}(x, Q^2)$$

$$F_{2,\mathrm{T}}(x, Q) = F_{2,\mathrm{T}}^{\mathrm{LT,TMC}}(x, Q) + \frac{H_{2,\mathrm{T}}^{(2)}(x)}{Q^2} + \frac{H_{2,\mathrm{T}}^{(4)}(x)}{Q^4} \qquad \text{(OPE)}$$

$$F_{2,\mathrm{T}}^{\mathrm{LT,TMC}}(x, Q) = F_{2,\mathrm{T}}^{\mathrm{LT}} \otimes \left[\mathbf{1} + \frac{M_N^2}{Q^2} C^{\mathrm{TMC}}\right] \qquad \text{(TMC)}$$

$$F_{2,\mathrm{T}}^{\mathrm{LT}} = \left[C_{2,\mathrm{T}}^{(0)} + \alpha_{\mathrm{s}} C_{2,\mathrm{T}}^{(1)} + \alpha_{\mathrm{s}}^2 C_{2,\mathrm{T}}^{(2)}\right] \otimes PDFs \qquad \text{(NNLO QCD)}$$

The fixed-target Drell-Yan (DY) data are included into the sample for better determination of the sea PDFs; the DY c.s. are also calculated with the NNLO QCD accuracy.

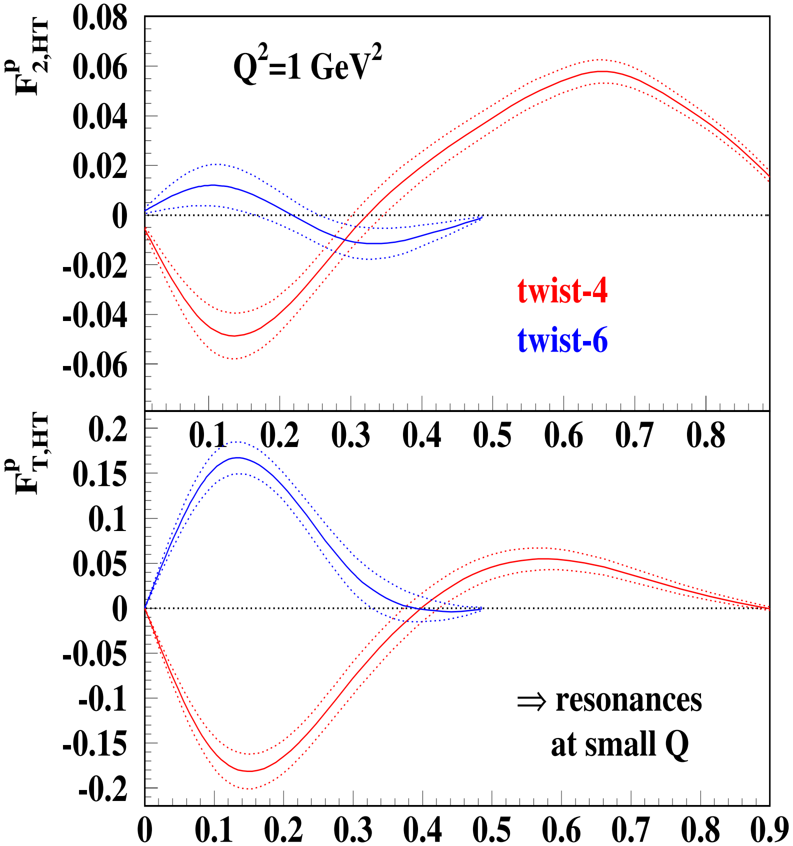
The leading-twist parton distributions are parameterized at $Q^2 = 9$ GeV^2 as

$$xp(x) = x^{\alpha}(1-x)^{\beta}x^{(ax+bx^2)}$$

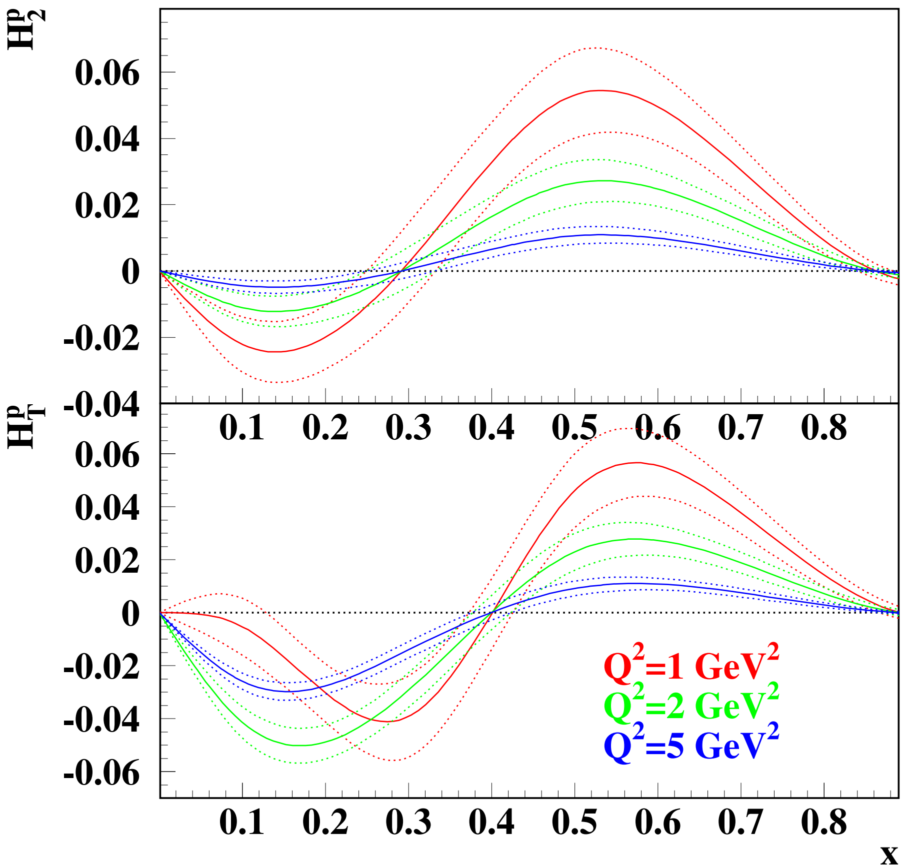
The dynamical twist-4,6 terms $H_{2,\mathrm{T}}^{(2,4)}(x)$ (*parton correlations*), are given by the cubic splines with the values at $x = 0.1, 0.3, 0.5, 0.7, 0.9$ fitted to the data.

- $H_{2,\mathrm{T}}^{(2,4)}(0) = 0$ *(no clear evidence for the saturation effects found at HERA)*
- $H_{2,\mathrm{T}}^{(4)} = 0$ at $x > 0.5$ *(no chance to constraint them out of the resonance region)*

High-twist terms in the fit with $Q^2 > 1$ GeV^2

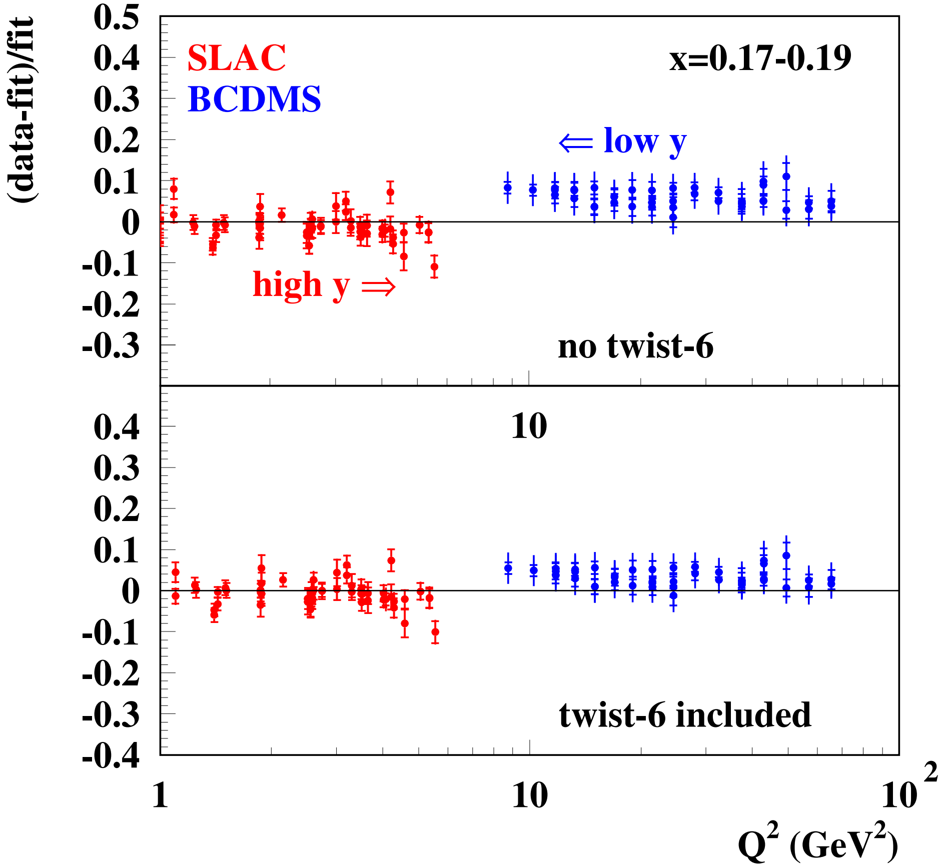


- The HT terms in F_2 demonstrate good convergence: $H_2^{(4)}$ is much smaller than $H_2^{(2)}$ and comparable to 0 within the errors.
- For $F_{\rm T}$ the picture is different: the magnitudes of the twist-4 and twist-6 terms are comparable and somehow compensate each other (*poor convergence of the OPE?*)



The total HT contribution to F_{T} demonstrates weak dependence on Q at $x < 0.3$.

Impact of the twist-6 terms on pulls of the fit



The twist-6 terms in F_{T} arise due to mismatch of the SLAC and BCDMS data at $Q^2 = 5 \div 10\ \mathrm{GeV}^2$ and *different* y.

(Whitlow 90)

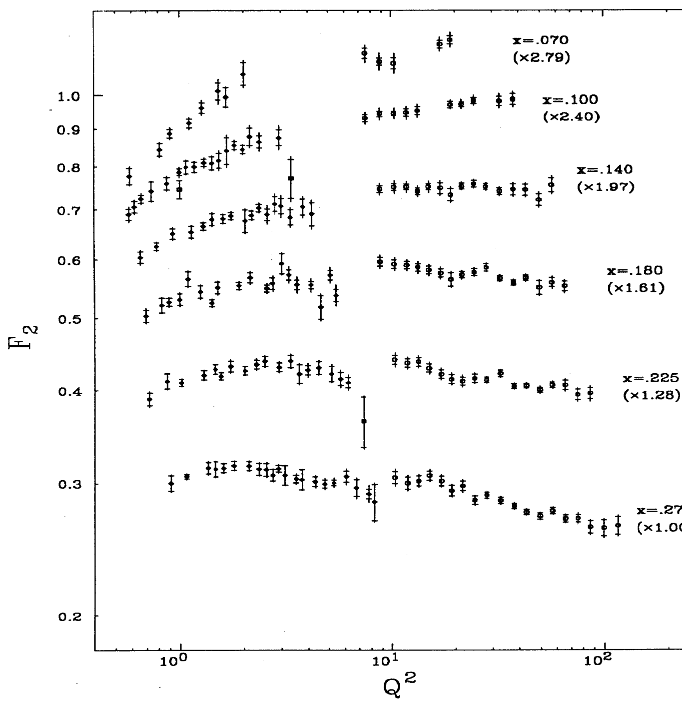


Figure 5.14. Shown is a comparison of the SLAC and BCDMS hydrogen F_2 results. A relative normalization of 1.000 is assumed. See also the caption to Figure 5.9. Figure continues on next page.

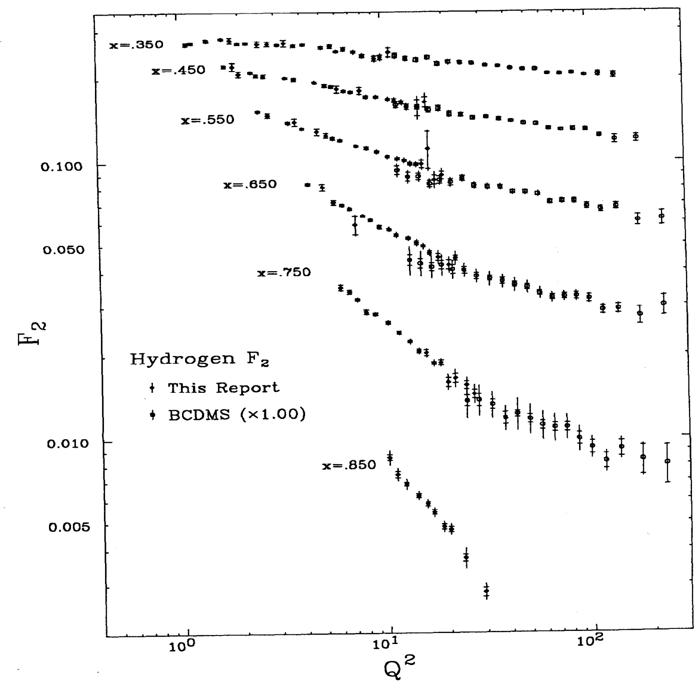
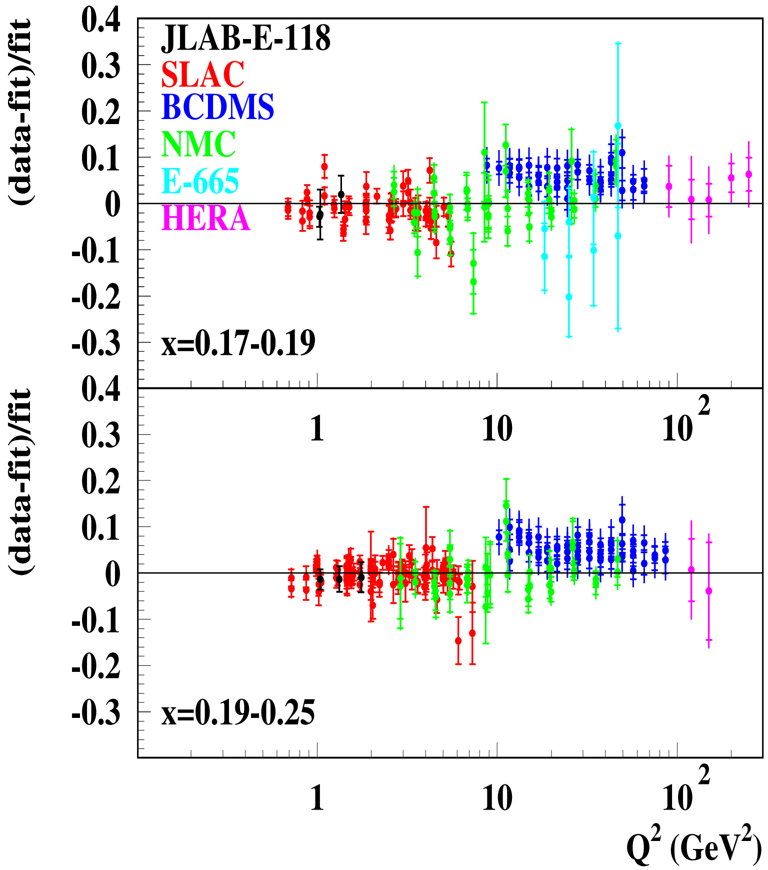
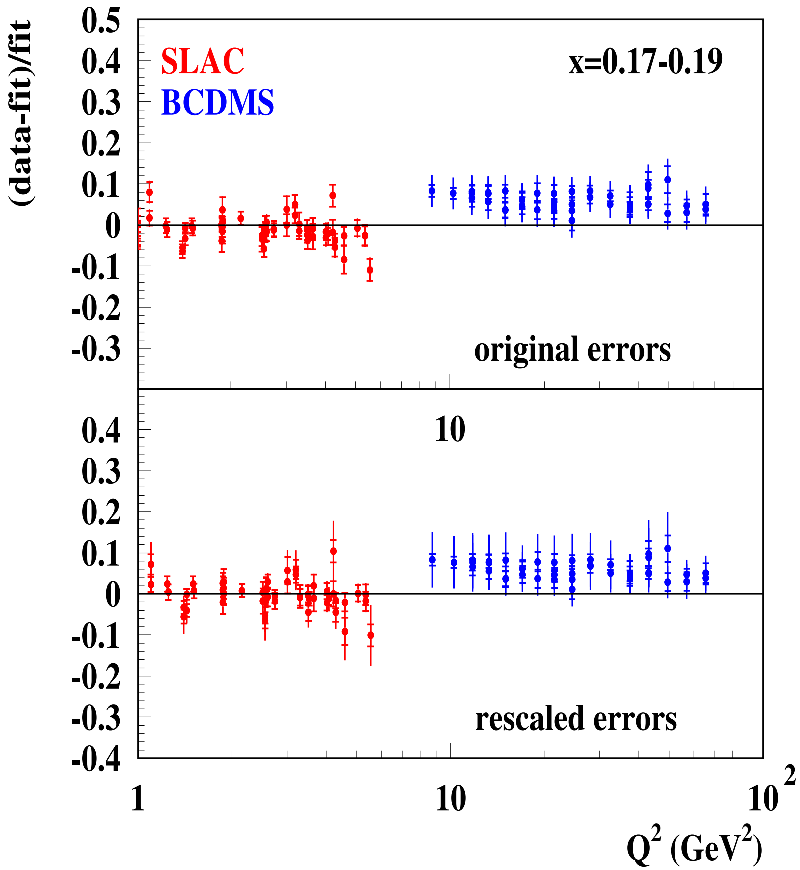


Figure 5.14/continued: Comparison of SLAC and BCDMS hydrogen F_2 results.

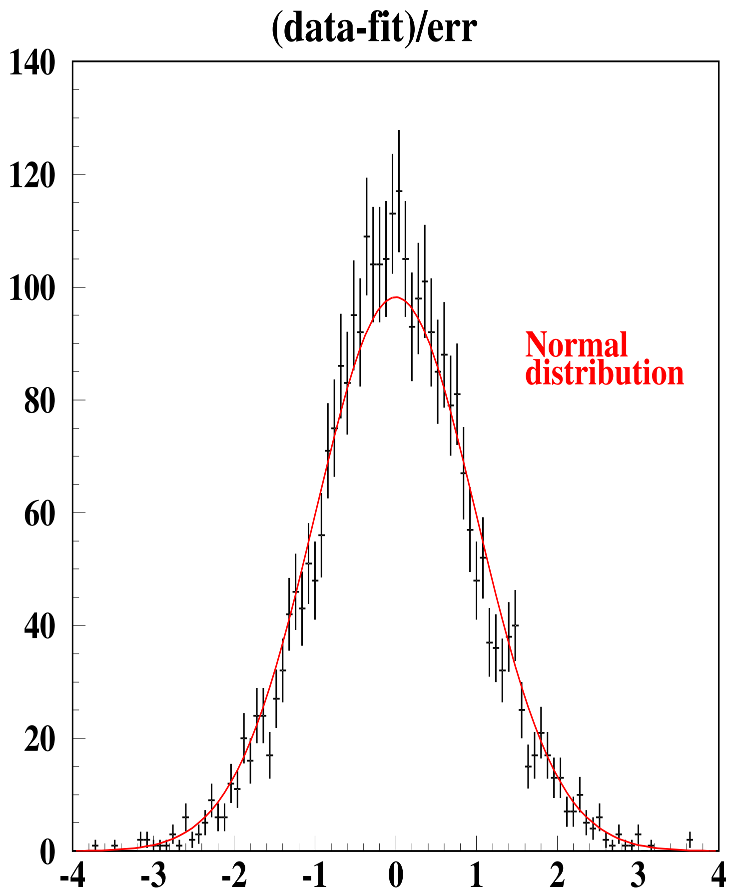


Attempts to find a phenomenological explanation of the SLAC-BCDMS discrepancy fail. Meanwhile the preliminary data by JLAB-E-118 are in agreement with low-Q part of the SLAC data.

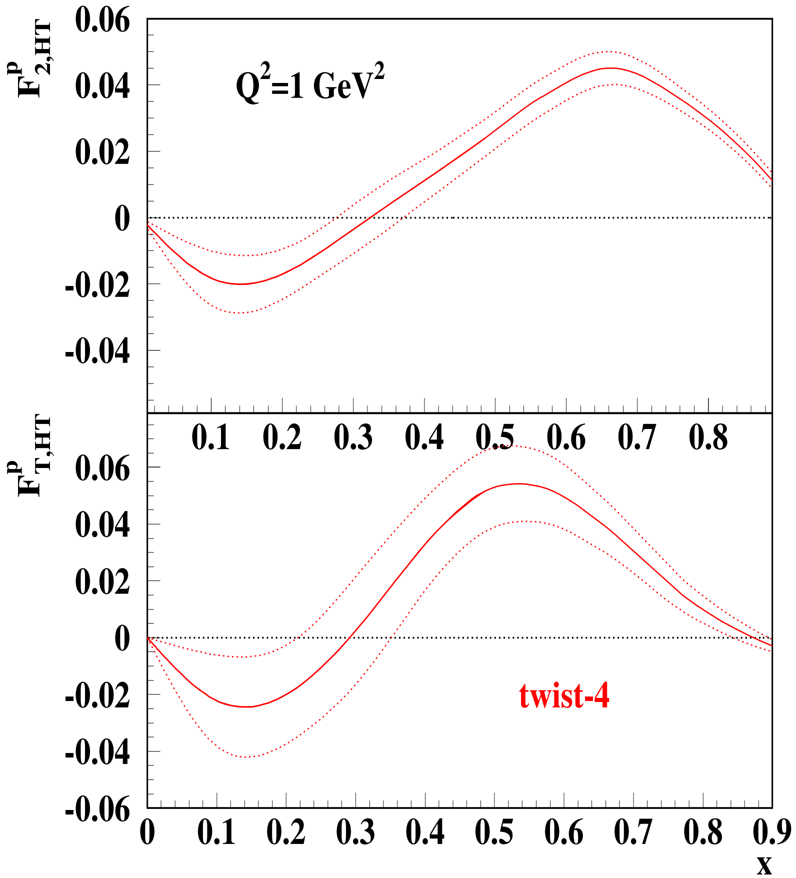
Rescaling of the errors



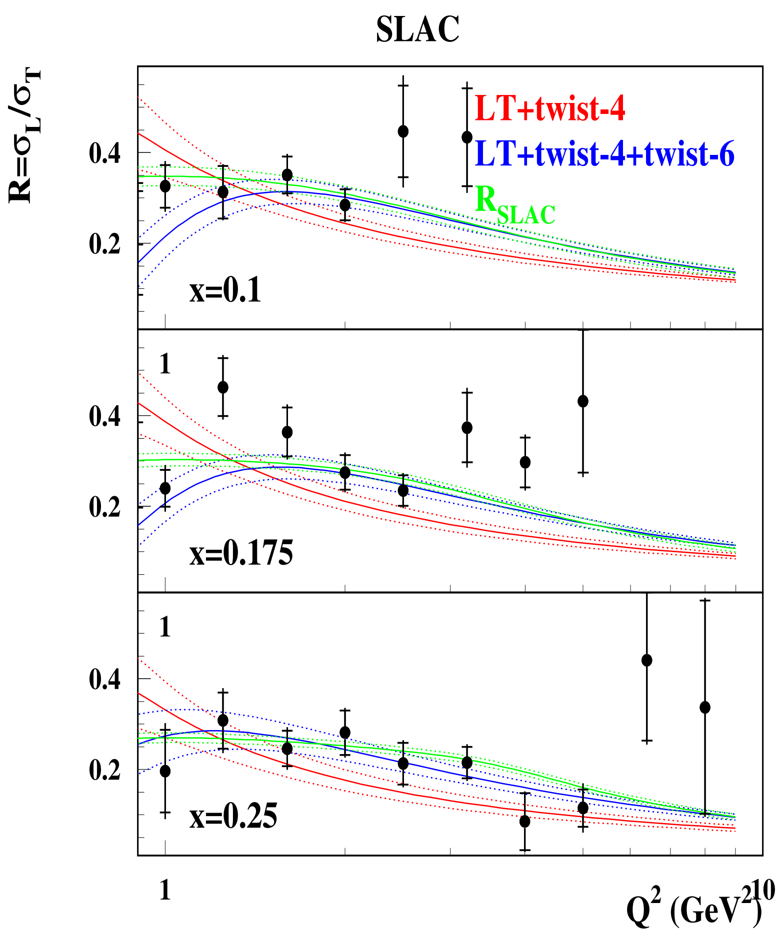
We expand the errors in the SLAC and BCDMS data in order to provide agreement between the data sets (the errors are rescaled if $abs(pull) > 1.5$). Despite such error estimation is very conservative ($\chi^2/NDP = 679/1275$ for SLAC and $429/605$ for BCDMS; the total $\chi^2/NDP = 2845/3076$), the impact of the rescaling is marginal.



In the final version of the fit the rescaling of the errors was less conservative: It was applied to all experiments with $\chi^2/NDP >$ 1 in order to get it equal to 1. With such rescaling we have χ^2/NDP =0.95 for NDP=3076 (1.25 without rescaling).



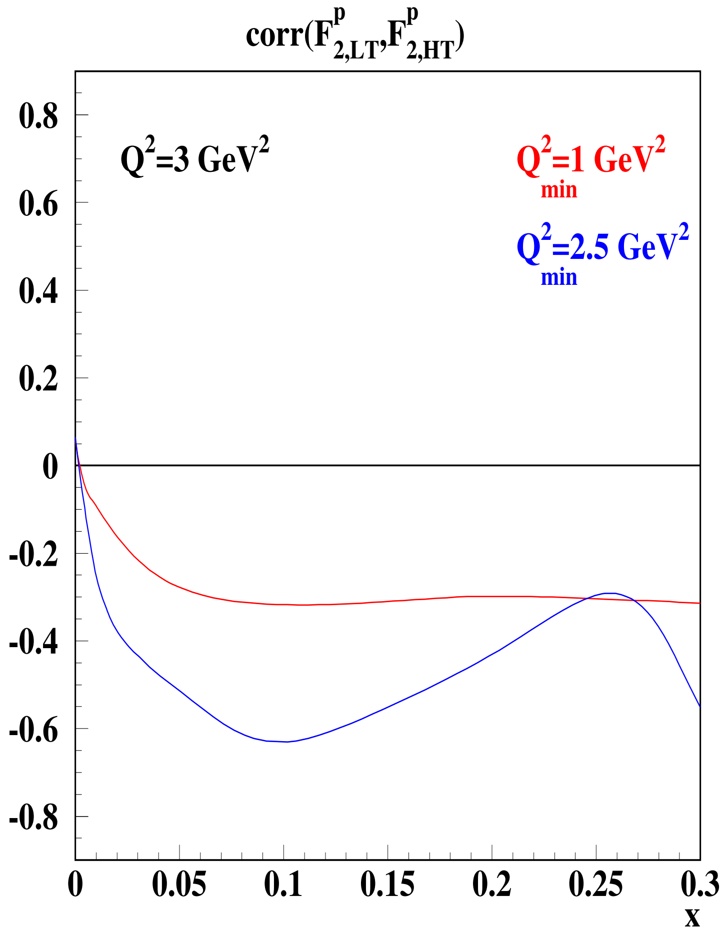
For the variant of fit with the twist-6 terms dropped the shapes and magnitudes of twist-4 terms in F_T and F_2 are comparable.



The excess in SLAC data on R at $x \sim 0.2$ with respect to the QCD predictions was considered as evidence of the big HT contribution to R (and F_L)

(Miramontes-... 89)

Meanwhile this excess is evidently connected with the SLAC/BCDMS discrepancy and can be hardly attributed to the HT contribution.

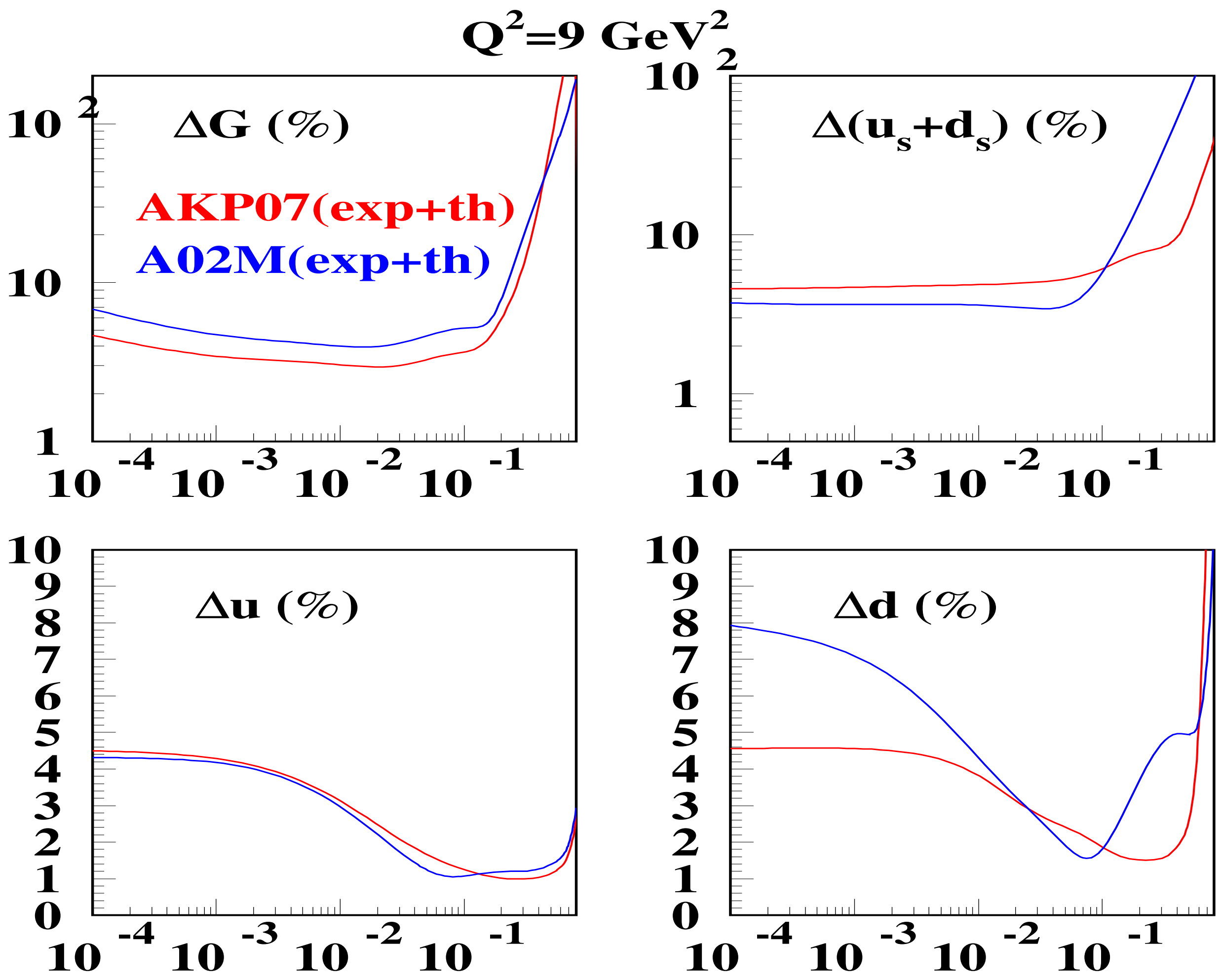


With the low-Q data included separation of the LT and HT terms is better. At smallest Q the HT terms give $\lesssim 10\%$ of the total structure functions *(convergence of the OPE expansion)*.

The value of α_s is stable with respect to cut on Q and in agreement to the non-singlet NNLO fit by Blümlein-Bottcher-Guffanti

	$\alpha_s(3\ \mathrm{GeV})$	$\alpha_s(M_Z)$
$Q^2 > 2.5\ \mathrm{GeV}^2$	0.2280(59)	0.1125(14)
$Q^2 > 1\ \mathrm{GeV}^2$	0.2291(34)	0.1128(11)
BBG		0.1134(18)

Progress in the PDFs uncertainties



Uncertainty in the extraction of the weak mixing angle (s_W) due to PDFs

$$R^- = \frac{\sigma^{\nu}_{\rm NC} - \sigma^{\bar\nu}_{\rm NC}}{\sigma^{\nu}_{\rm CC} - \sigma^{\bar\nu}_{\rm CC}} \approx \frac{1}{2} - s_W^2 + \delta R^-_{\rm tot}$$

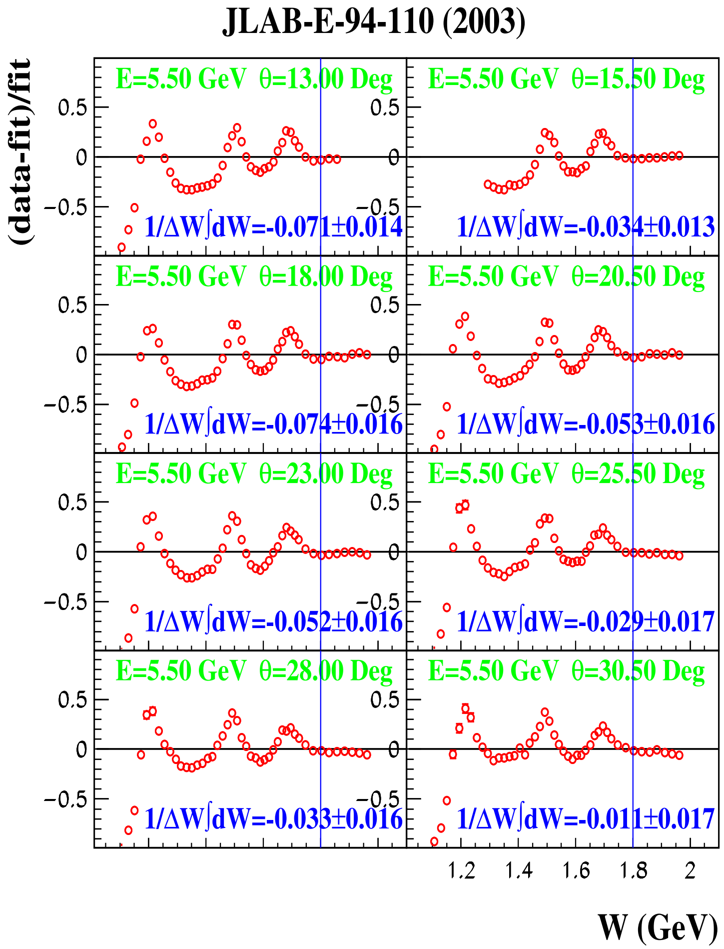
$$\delta R^-_{\rm tot} = \left(\frac{x_1^-}{x_0^-}\right)_A \left(1 - \frac{7}{3}s_W^2 + \mathcal{O}(\alpha_S)\right) \approx \frac{Z-N}{A}\left(\frac{x_1^-}{x_0^-}\right)_p \left(1 - \frac{7}{3}s_W^2\right)$$

$$x^-_{0,1} = \int {\rm d}x\, x(u_{\rm val} \pm d_{\rm val})$$

For the iron target magnitude of δR^- is about 10 times the error in the NuTeV measurement of R^-, hence the uncertainty in $(x_1^-/x_0^-)_p$ must be $\ll$ 10% ($\ll$ 0.04 by absolute value).

PDFs	$(x_1^-/x_0^-)_p$
CTEQ6(NLO)	0.42 ± 0.03
MRST01(NLO)	0.43 ± 0.02
A02M(NNLO)	0.43 ± 0.03
AKP07(NNLO)	$\mathbf{0.424 \pm 0.006}$

Extrapolation to the resonance region



The Bloom-Gilman duality is confirmed at the percent level; this also gives indirect indication that the twist-6 terms at large x are small.

Summary

- The existing DIS data at $x \gtrsim 0.001$ can be described within pQCD in the NNLO approximation down do $Q = 1$ GeV. Contribution of the twist-4 terms is less than 10% for this kinematics; the HT terms in $R = \sigma_{\mathrm{L}}/\sigma_{\mathrm{T}}$ are small.

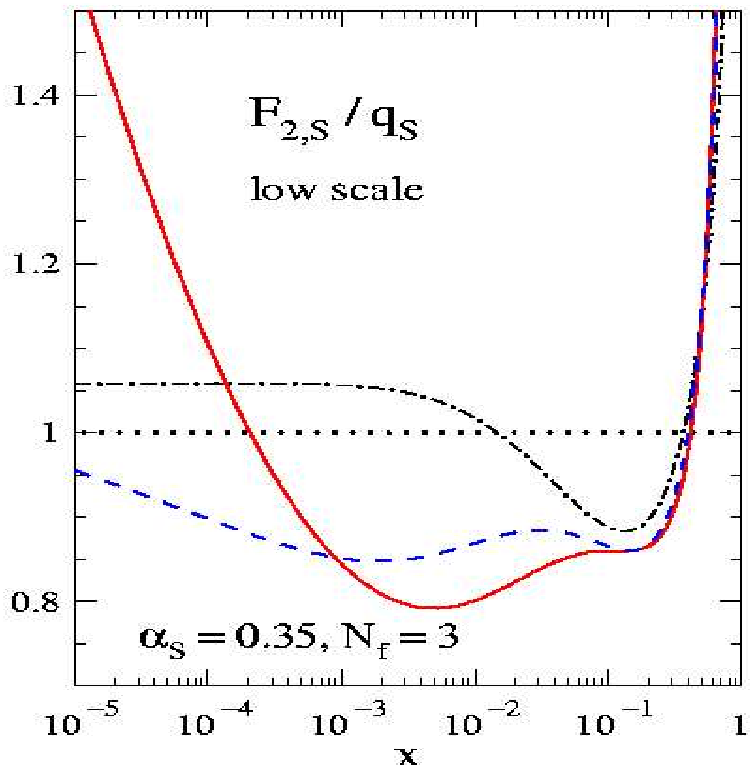
- Despite some disagreement between different experiments the low-Q part of the DIS sample provides valuable constraint on the valence d-quark distribution.

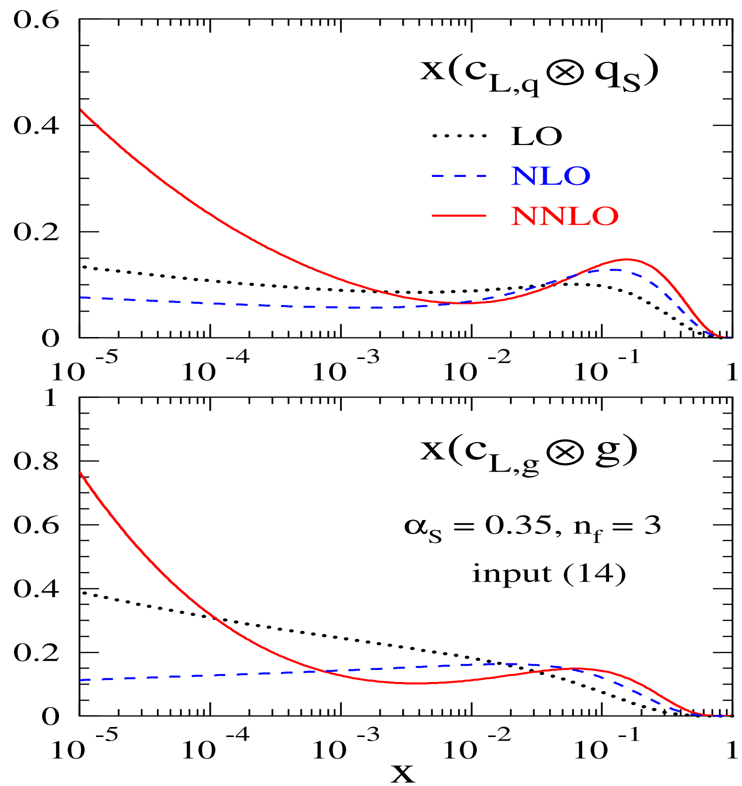
- Extrapolation of the fit into the resonance region demonstrates validity of the Bloom-Gilman duality; this allows to use this fit for estimation of the integral effects of the resonances in various practical applications.

BACKUP

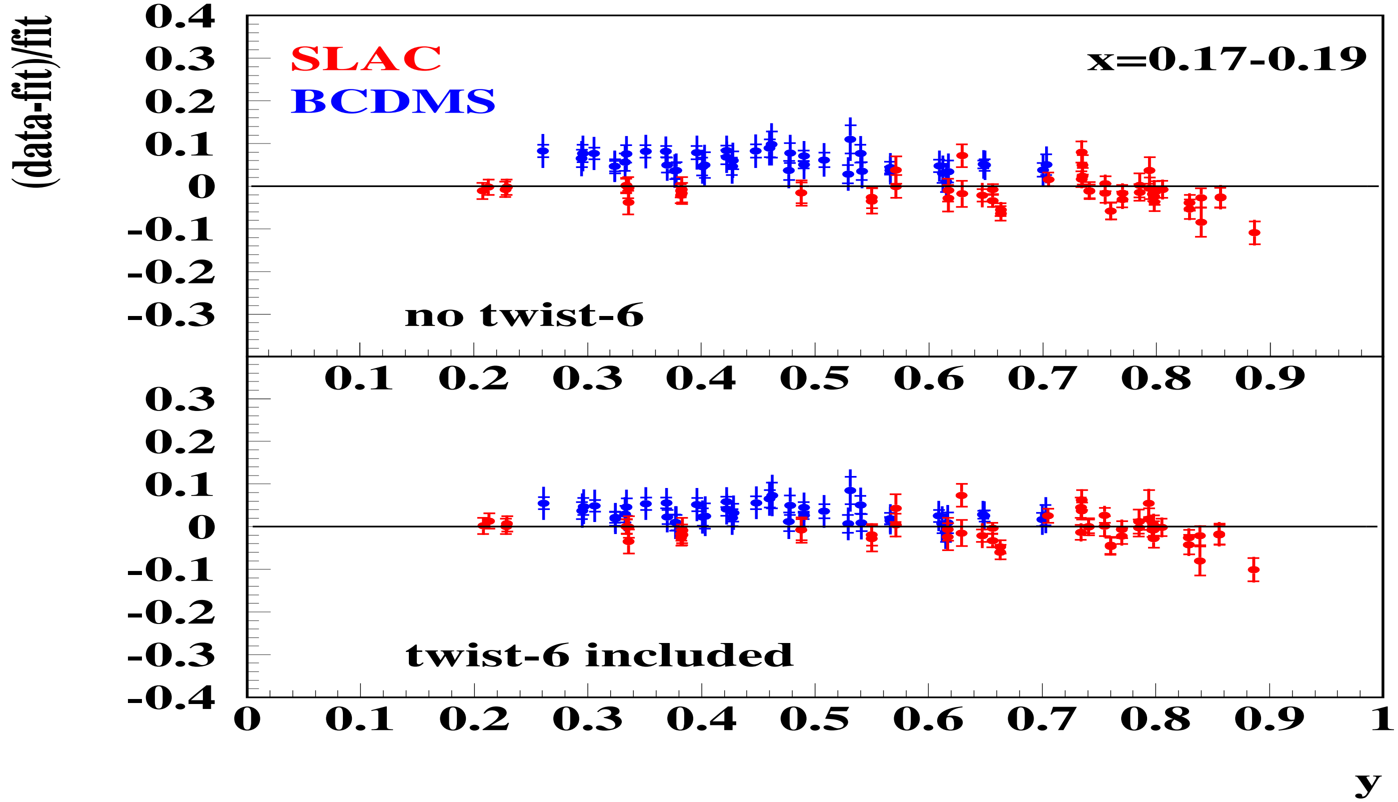
The $O(\alpha_s^3)$ corrections to the DIS coefficient functions

(Moch-Vermaseren-Vogt 04-05)



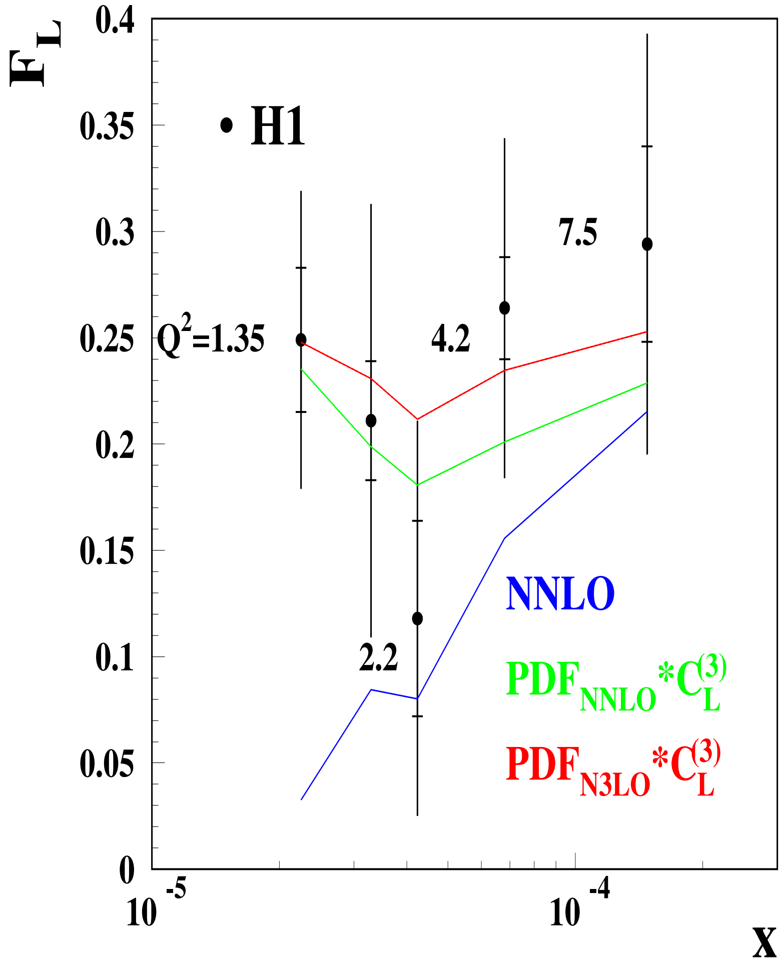


This correction doesn't change fitted twist-6 terms



The electro-weak corrections seems not to be responsible for the SLAC/BCDMS discrepancy too.

The HO QCD corrections and F_L at small x



The $O(\alpha_s^3)$ corrections by Moch-Vermaseren-Vogt clearly improve agreement to the data, however at the same time it raises the question about perturbative stability of the predictions (check the k_T re-summation results for $C_L^{(3,4,5)}$ by Catani-Hautmann).