New developments in the statistical approach of parton distributions

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C. Bourrely, F. Buccella, J.S.

- A Statistical Approach for Polarized Parton Distributions
  Euro. Phys. J. C23, 487 (2002)
- Recent Tests for the Statistical Parton Distributions
  Modern Phys. Letters A18, 771 (2003)
- The Statistical Parton Distributions: status and prospects
  Euro. Phys. J. C41, 327 (2005)
- The extension to the transverse momentum of the statistical parton distributions
  Modern Phys. Letters A21, 143 (2006)
- Stangeness asymmetry of the nucleon in the statistical parton model
  Phys. Letters B648, 39 (2007)
- New tests and predictions from the statistical parton distributions

  (in preparation)

Outline

- Basic procedure to construct the statistical polarized parton distributions
- Essential features from the Deep Inelastic Scattering data
- First predictions tested against new data
  DIS and hadronic processes
- Very recent tests from DIS
  COMPASS, H1
- Conclusions and future

Basic procedure

Use a simple description of the PDF, at input scale Q_0^2, proportional to $[\exp[(x - X_{0p})/\bar{x}] \pm 1]^{-1}$, *plus* sign for quarks and antiquarks, corresponds to a Fermi-Dirac distribution and *minus* sign for gluons, corresponds to a Bose-Einstein distribution. X_{0p} is a constant which plays the role of the *thermodynamical potential* of the parton *p* and $\bar{x}$ is the *universal temperature*, which is the same for all partons.

We recall that from the chiral structure of QCD, we have two important properties, allowing to relate quark and antiquark distributions and to restrict the gluon distribution:

- The potential of a quark q^h of helicity *h* is opposite to the potential of the corresponding antiquark $\bar{q}^{-h}$ of helicity *-h*

$$X_{0q}^{h} = -X_{0\bar{q}}^{-h} \ .$$

- The potential of the gluon G is zero

$$X_{0G} = 0 \ .$$

The polarized PDF at $Q_0^2 = 4\mathbf{GeV}^2$

For light quarks $q = u, d$ of helicity $h = \pm$, we take

$$xq^{(h)}(x, Q_0^2) = \frac{AX_{0q}^h x^b}{\exp[(x - X_{0q}^h)/\bar{x}] + 1} + \frac{\tilde{A}x^{\tilde{b}}}{\exp(x/\bar{x}) + 1},$$

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consequently for antiquarks of helicity $h = \mp$

$$x\bar{q}^{(-h)}(x, Q_0^2) = \frac{\bar{A}(X_{0q}^h)^{-1}x^{2b}}{\exp[(x + X_{0q}^h)/\bar{x}] + 1} + \frac{\tilde{A}x^{\tilde{b}}}{\exp(x/\bar{x}) + 1}.$$

Note: $q = q^+ + q^-$ and $\Delta q = q^+ - q^-$ (idem for $\bar{q}$)

Strange quarks

For the strange quarks and antiquarks, s and $\bar{s}$, given our poor knowledge on both unpolarized and polarized distributions, we take

$$xs(x,Q_0^2) = x\bar{s}(x,Q_0^2) = \frac{1}{4}[x\bar{u}(x,Q_0^2) + x\bar{d}(x,Q_0^2)] \ ,$$

and

$$x\Delta s(x,Q_0^2) = x\Delta\bar{s}(x,Q_0^2) = \frac{1}{3}[x\Delta\bar{d}(x,Q_0^2) - x\Delta\bar{u}(x,Q_0^2)]$$

This is the original version, which was improved recently (see BBS, Phys. Lett. B648, 39 (2007))

Gluons

We use a Bose-Einstein expression given by

$$xG(x, Q_0^2) = \frac{A_G x^{b_G}}{\exp(x/\bar{x}) - 1} \ ,$$

with a vanishing potential and the same temperature $\bar{x}$. We also need to specify the polarized gluon distribution and we take the particular choice $x\Delta G(x, Q_0^2) = 0$. (Note that $b_G = \tilde{b} + 1$)

Essential features from the DIS data

From well established features of u and d extracted from DIS data, we anticipate some simple relations between the potentials:

- $u(x)$ dominates over $d(x)$, therefore we should have $X^+_{0u} + X^-_{0u} > X^+_{0d} + X^-_{0d}$
- $\Delta u(x) > 0$, therefore $X^+_{0u} > X^-_{0u}$
- $\Delta d(x) < 0$, therefore $X^-_{0d} > X^+_{0d}$.

So we expect X^+_{0u} to be the largest potential and X^+_{0d} the smallest one. In fact, we have the following ordering (see below)

$$X^+_{0u} > X^-_{0d} \sim X^-_{0u} > X^+_{0d} \, .$$

This ordering has important consequences for $\bar{u}$ and $\bar{d}$, namely

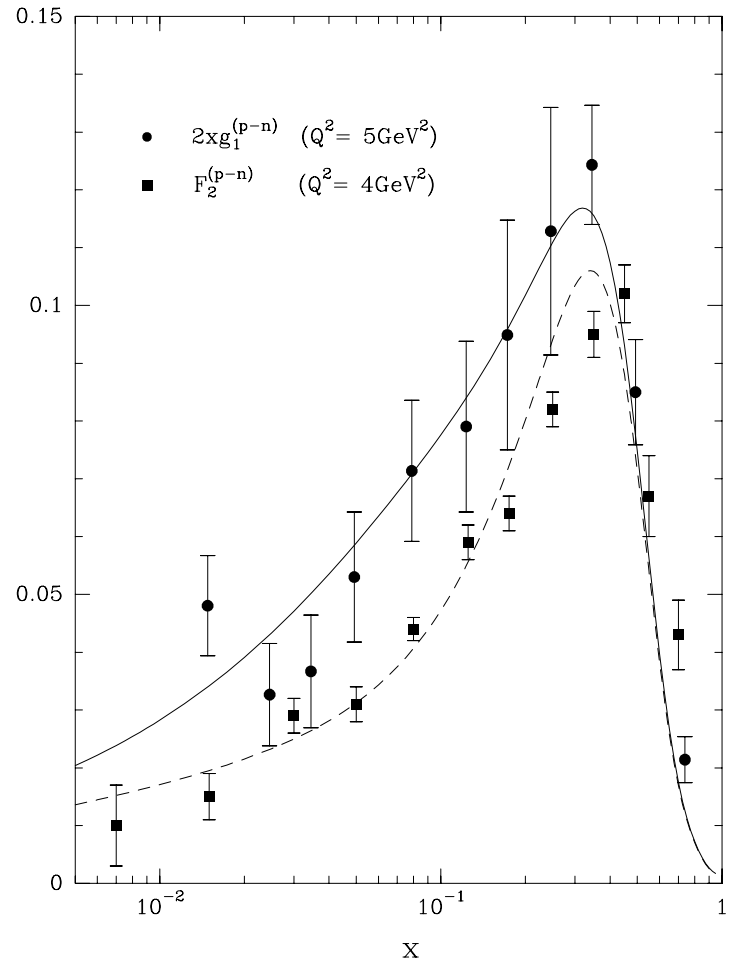
- $\bar{d}(x) > \bar{u}(x)$, flavor symmetry breaking expected from Pauli exclusion principle. This was already confirmed by the violation of the Gottfried sum rule (NMC).
- $\Delta\bar{u}(x) > 0$ and $\Delta\bar{d}(x) < 0$, which remain to be checked and this will be done at RHIC-BNL from $W^{\pm}$ production.

- Note that since $u^-(x) \sim d^-(x)$, it follows that $\bar{u}^+(x) \sim \bar{d}^+(x)$, so we have

$$\Delta\bar{u}(x) - \Delta\bar{d}(x) \sim \bar{d}(x) - \bar{u}(x) \ ,$$

i.e. the flavor symmetry breaking is almost the same for unpolarized and polarized distributions ($\bar{u}$ and $\bar{d}$ polarizations contribute to about 10% to the Bjorken sum rule).

An interesting observation (Will come back to this)



Only eight free parameters

By performing a NLO QCD evolution of these PDF in 2002, we were able to obtain a good description of a large set of very precise data on $F_2^p(x,Q^2), F_2^n(x,Q^2), xF_3^{\nu N}(x,Q^2)$ and $g_1^{p,d,n}(x,Q^2)$, in correspondance with eight free parameters: the four potentials
$X_{0u}^+ = 0.46128,\ X_{0u}^- = 0.29766,$
$X_{0d}^- = 0.30174,\ X_{0d}^+ = 0.22775,$ and

$$\bar{x} = 0.09907,\ b = 0.40962,\ \tilde{b} = -0.25347,\ \tilde{A} = 0.08318.$$

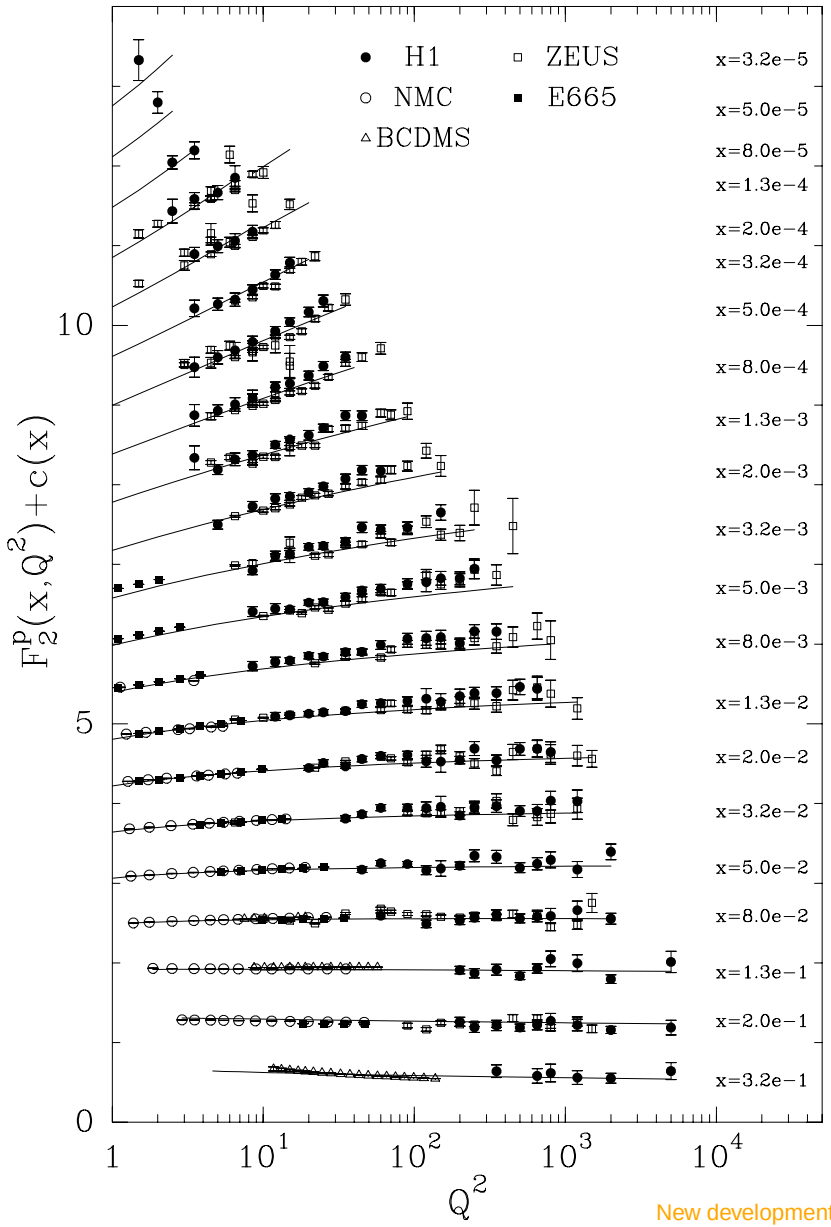
We also have three additional parameters, which are fixed by two normalization conditions

$$u - \bar{u} = 2, \quad d - \bar{d} = 1 \ ,$$

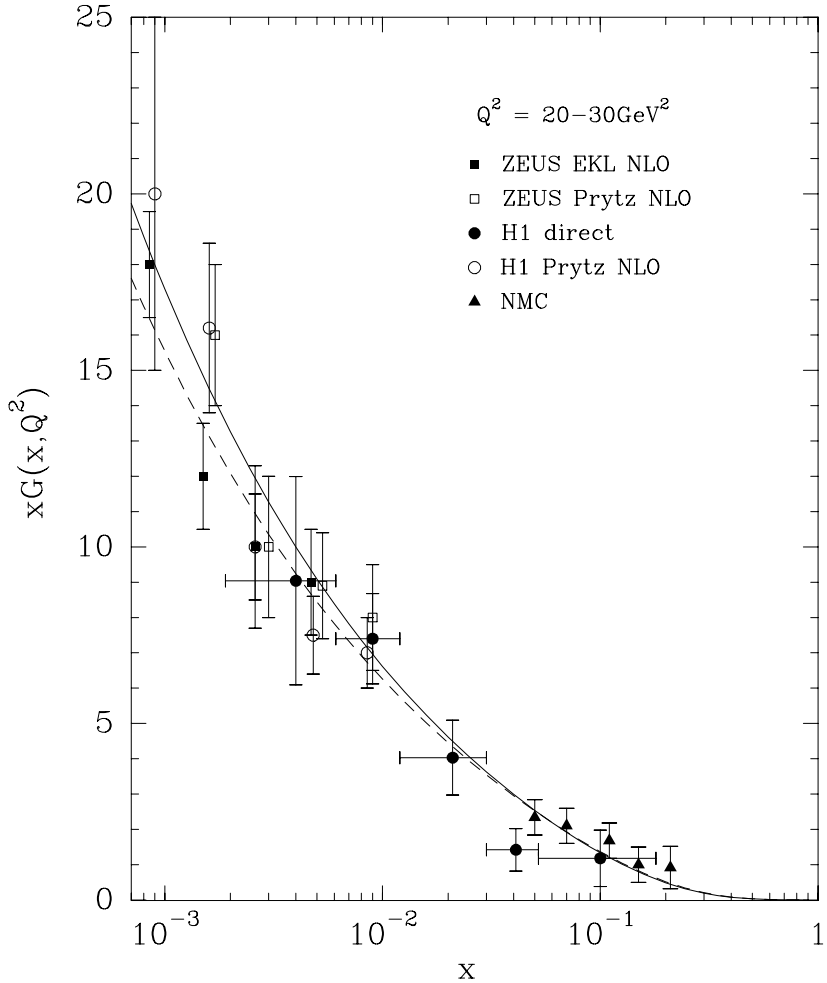
and the momentum sum rule.

$$A = 1.74938, \ \bar{A} = 1.90801, \ A_G = 14.27535 \, .$$

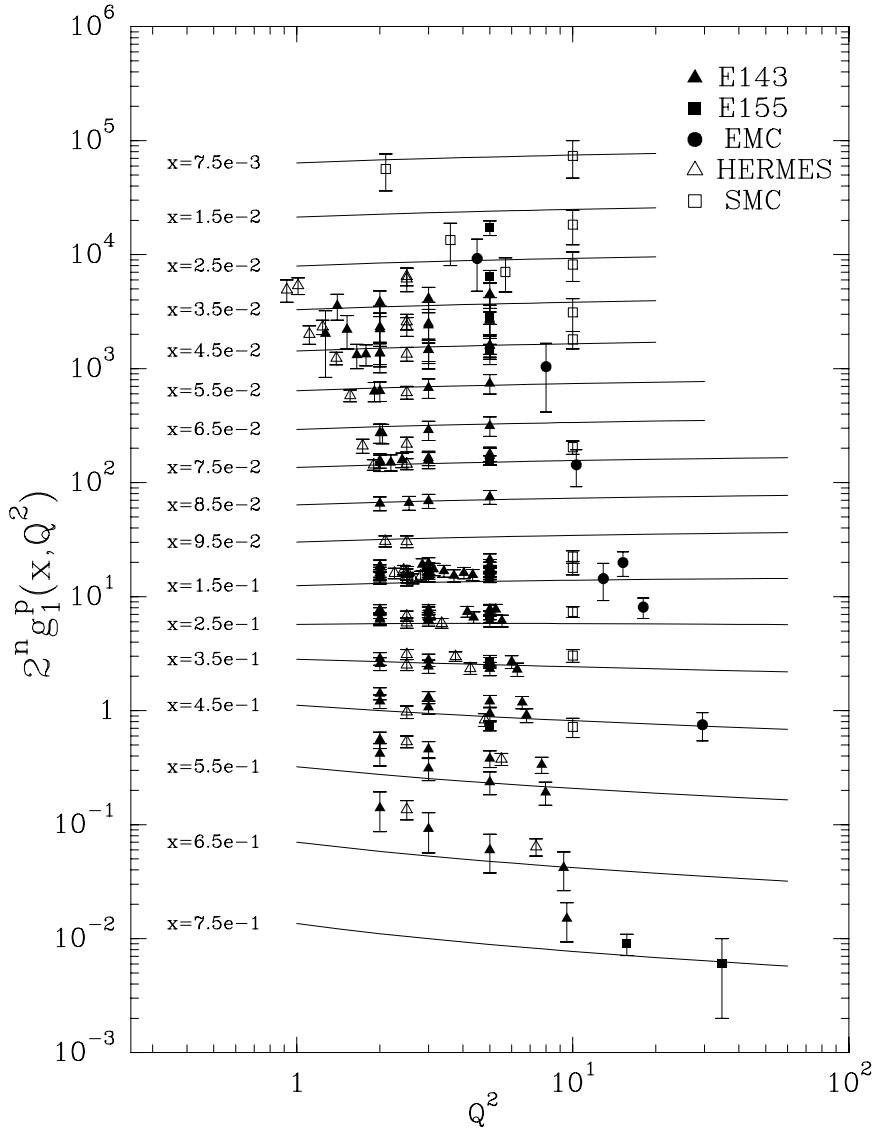
Ealier results



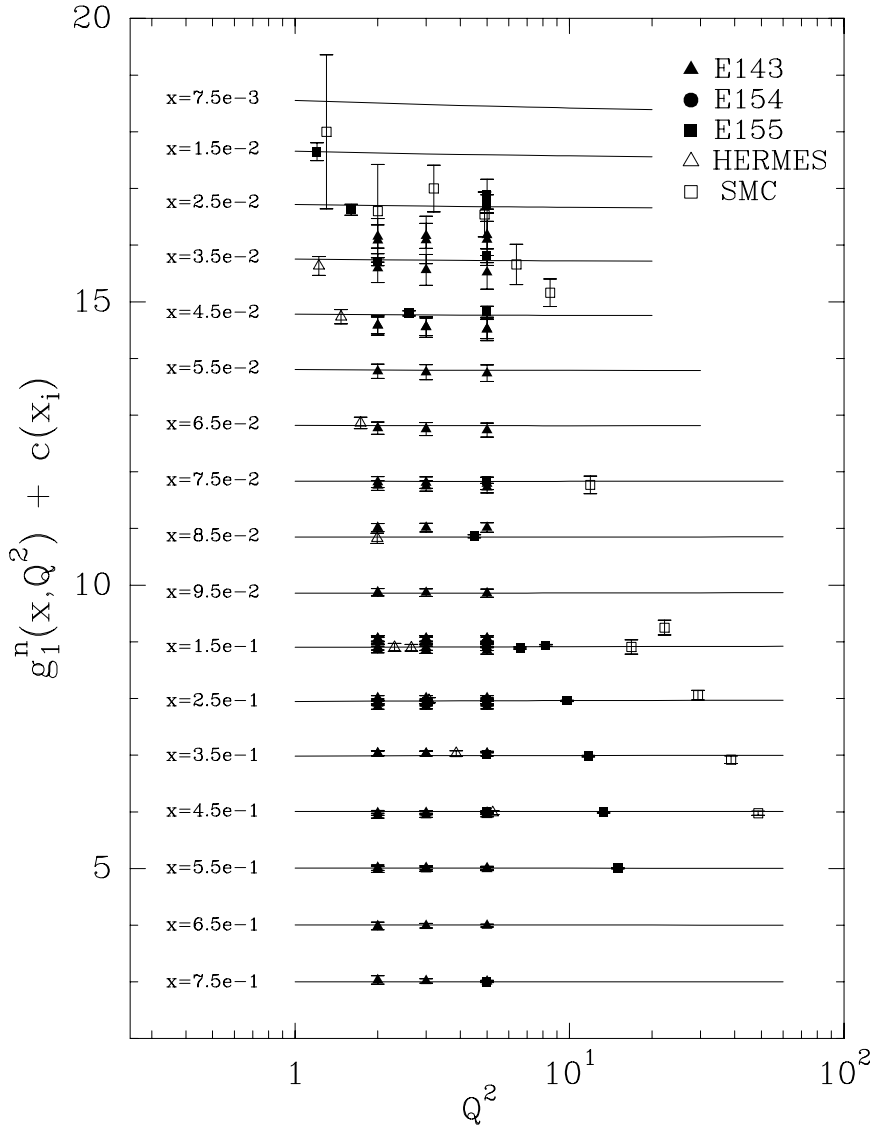
Ealier results (Will come back to this)



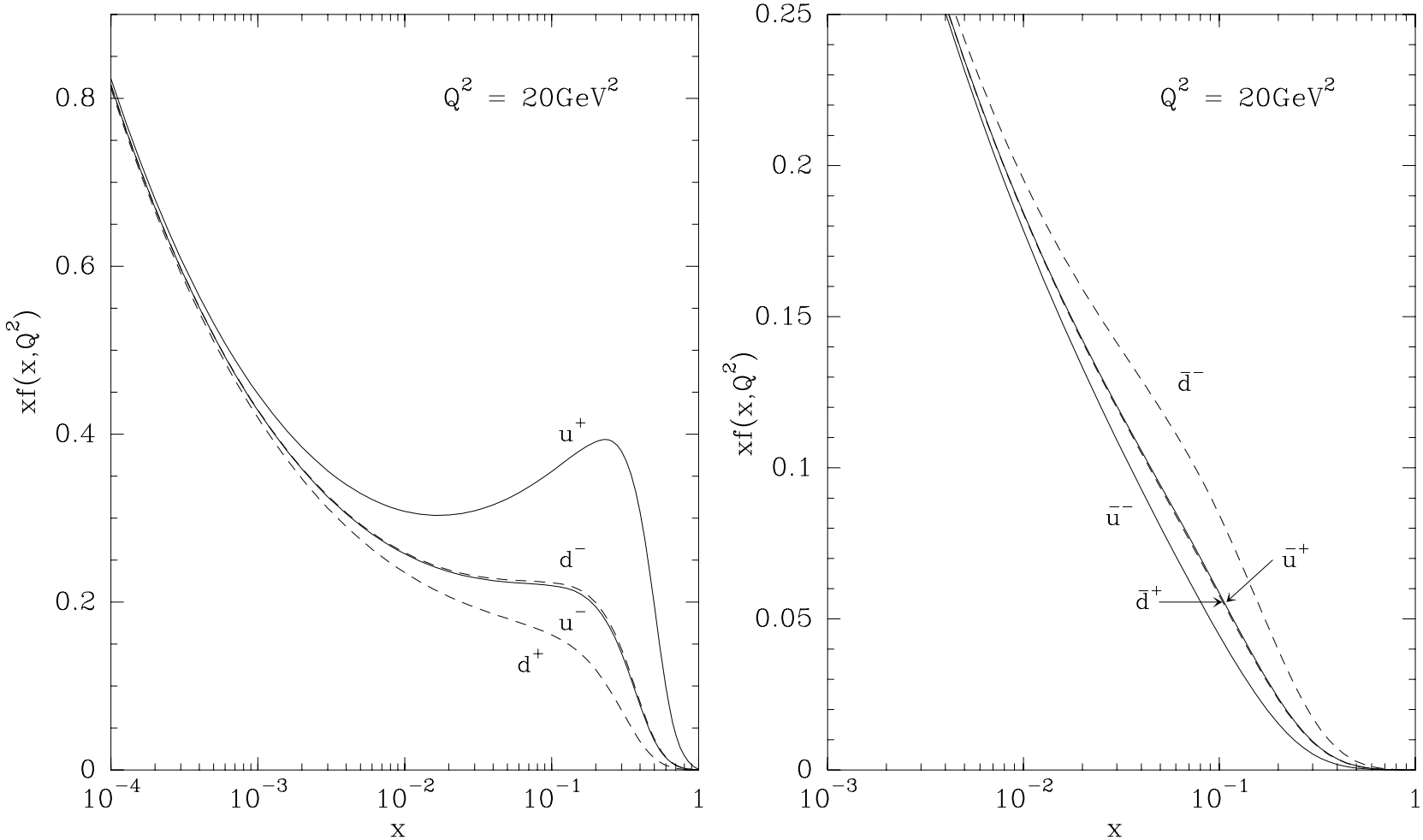
Ealier results



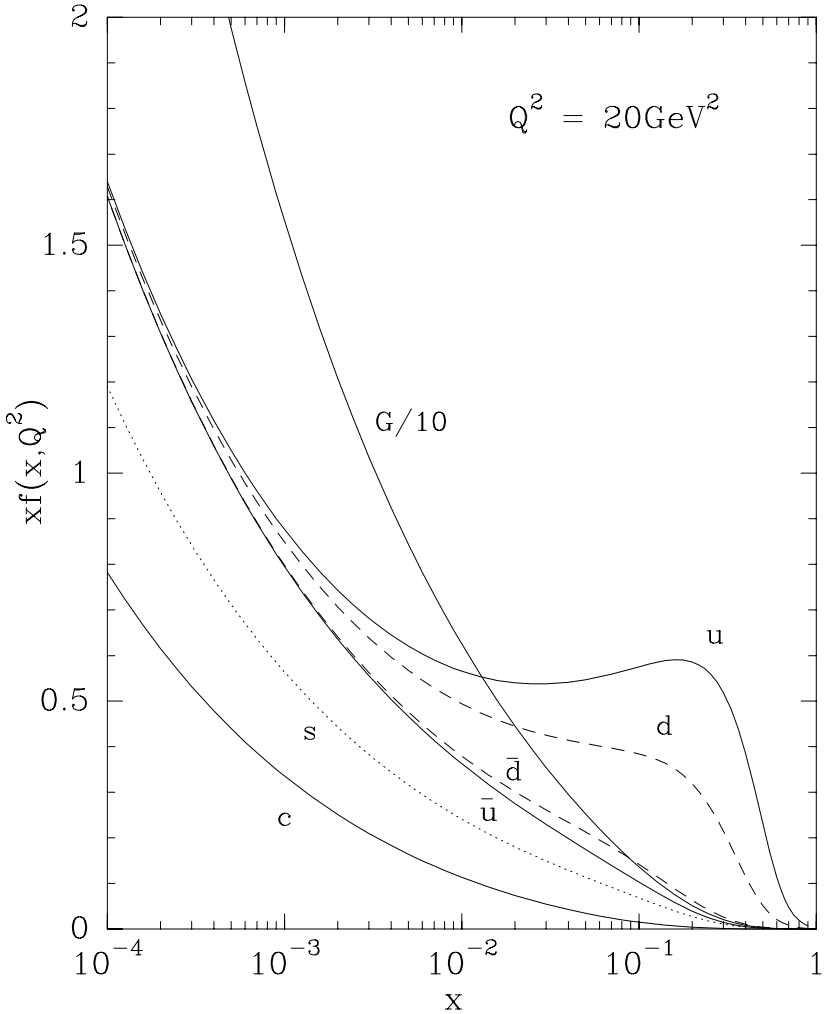
Ealier results

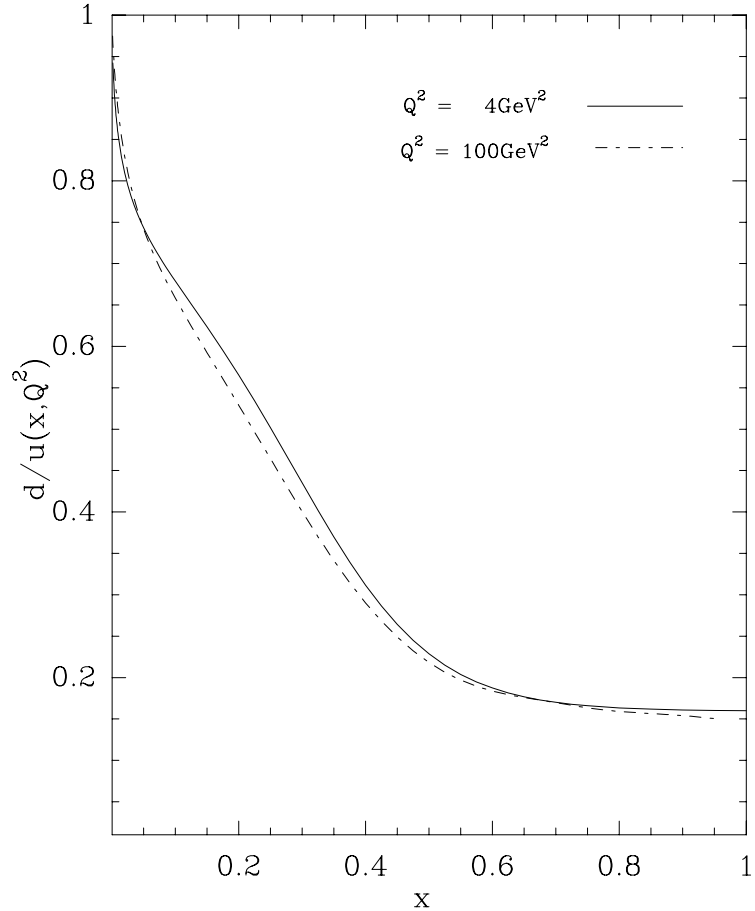


Pol. Light quarks distri. (vs. x)



PDF (vs. x) and d/u ratio: 3 regions

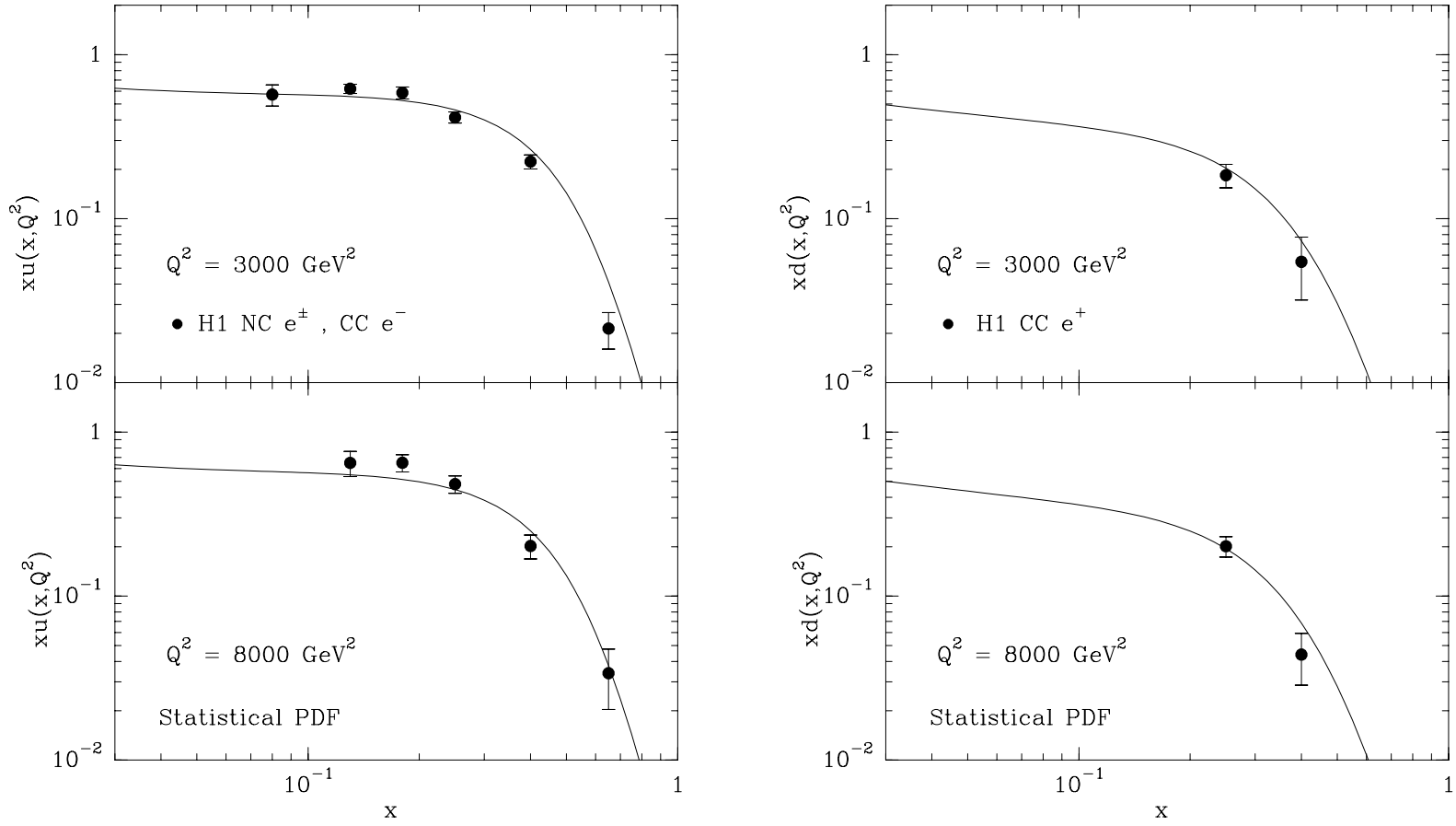




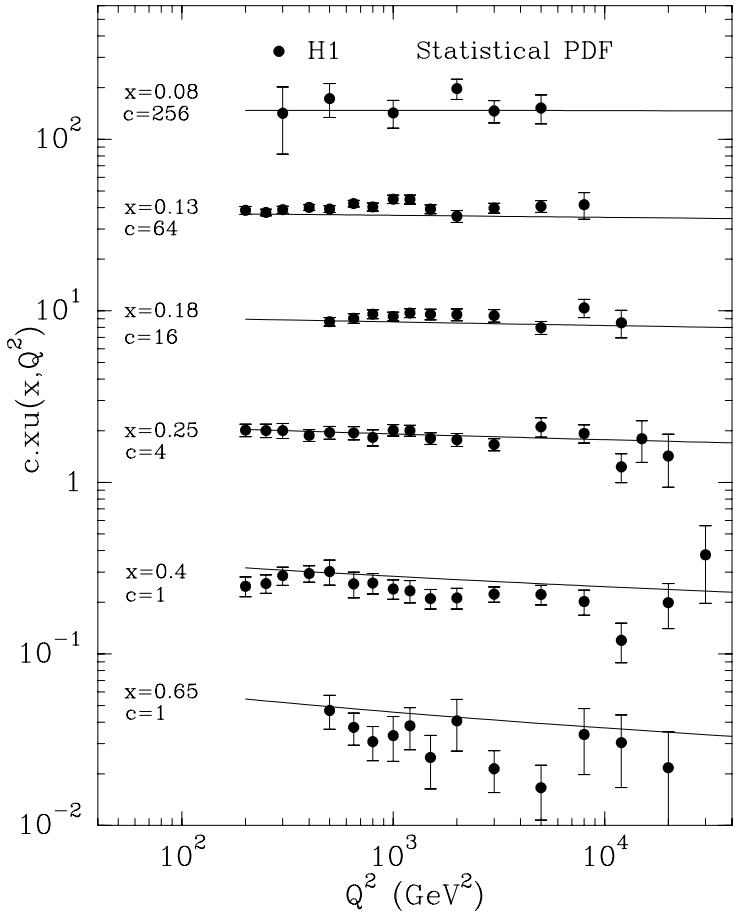
First predictions tested against data

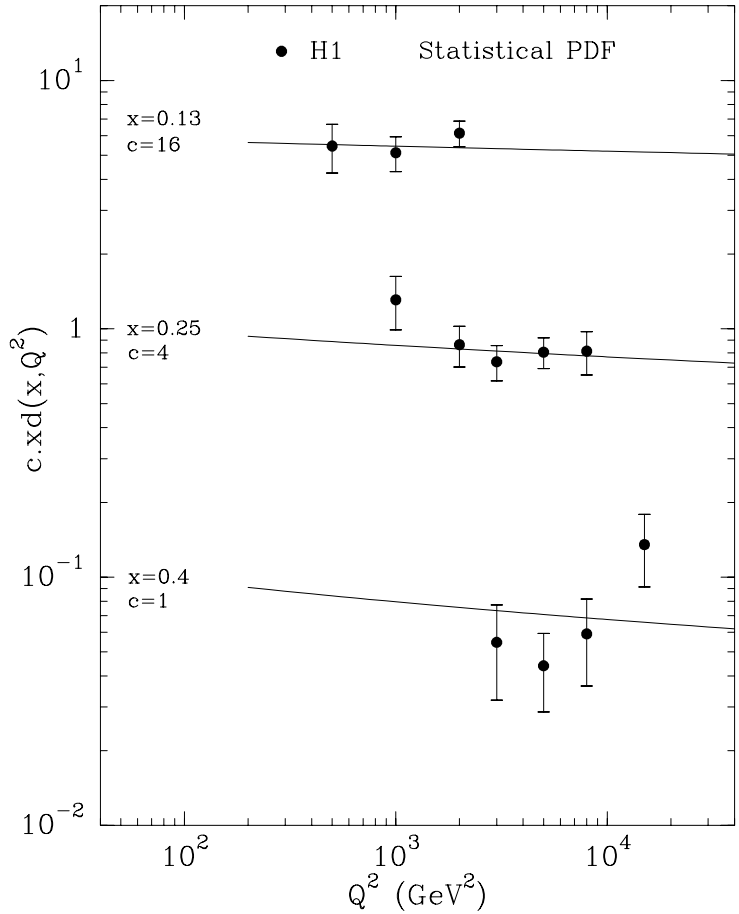
- Deep Inelastic Scattering
- Hadronic Collisions

Light quarks distributions (vs. x)

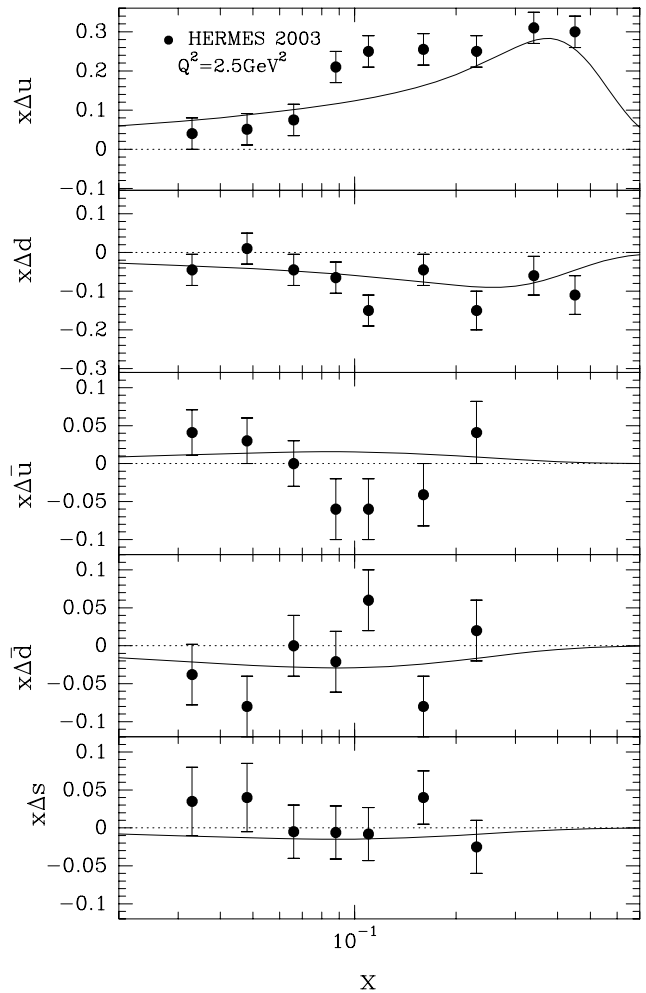


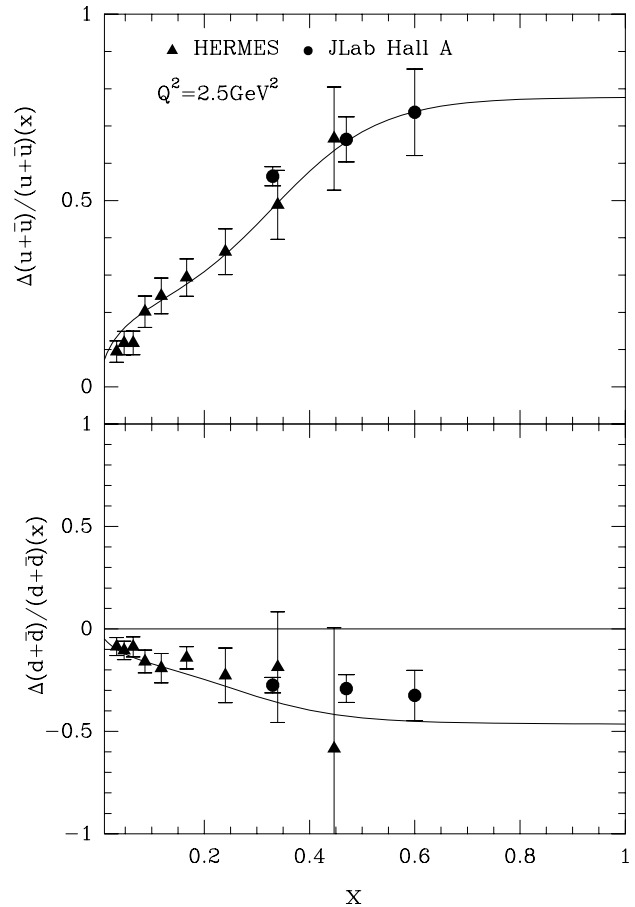
Light quarks distribu. (vs. Q^2)



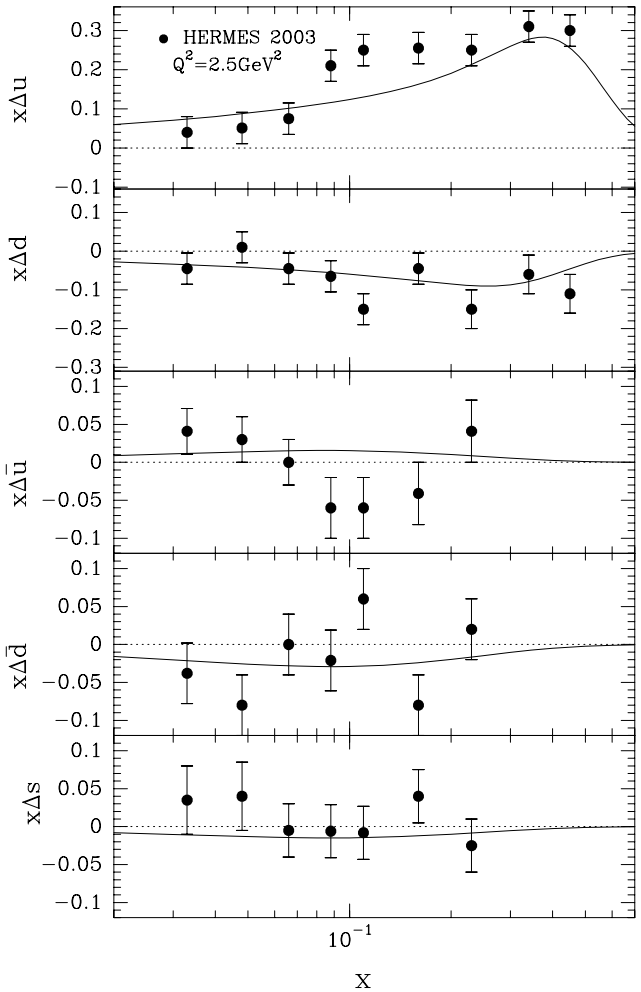


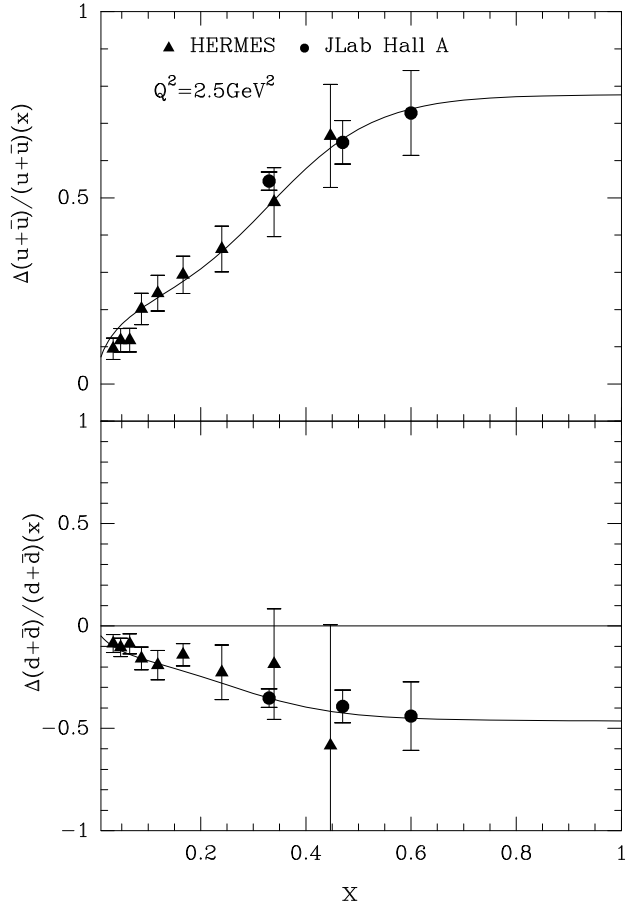
Polarized quarks distributions



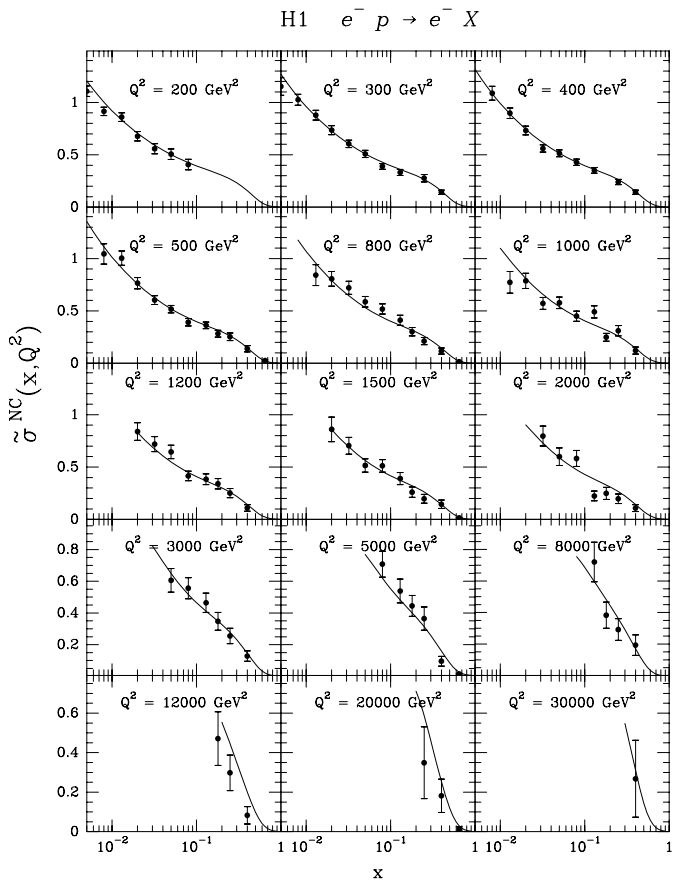


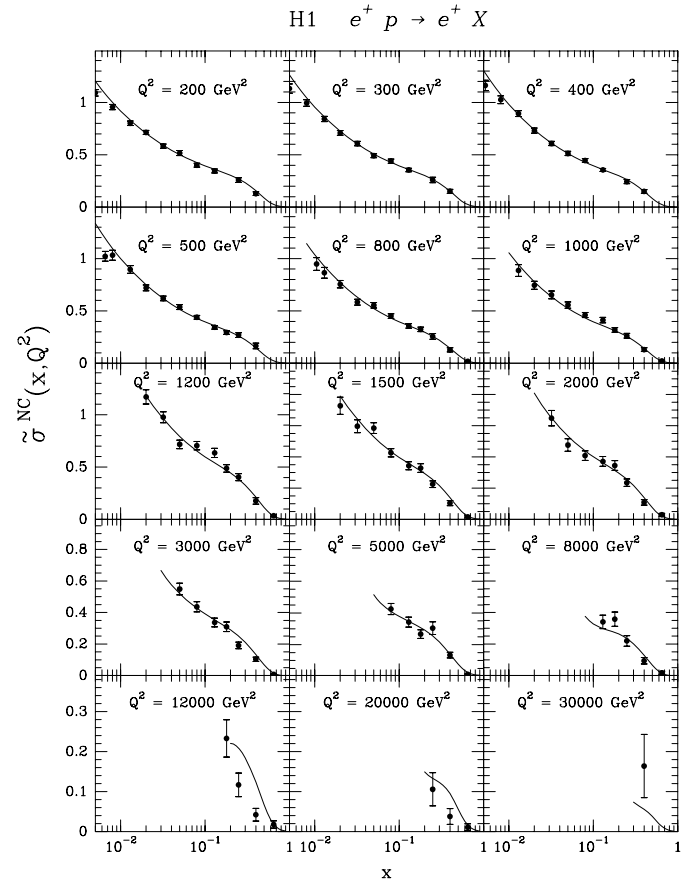
but final data move down!!!



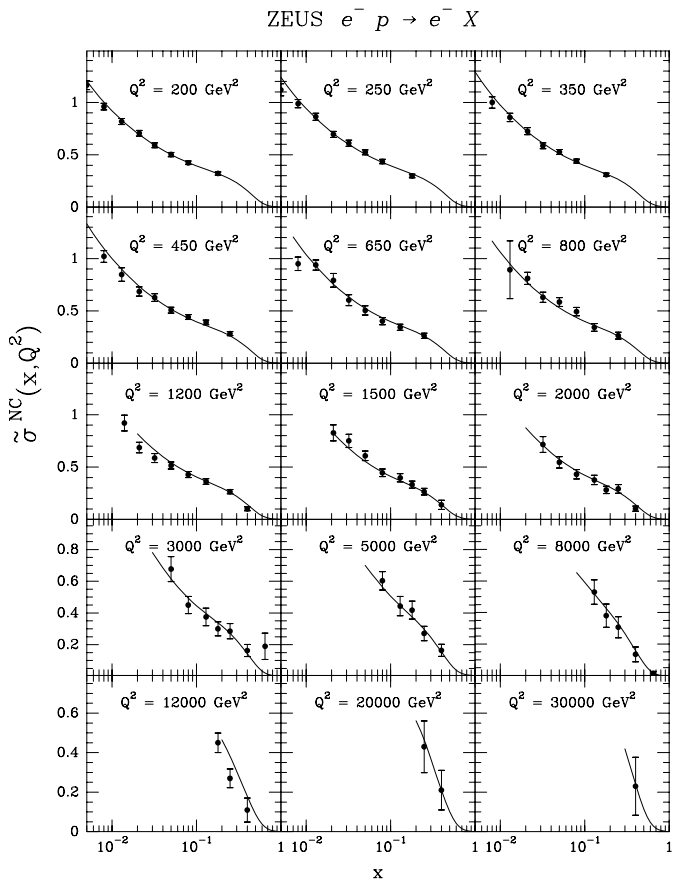


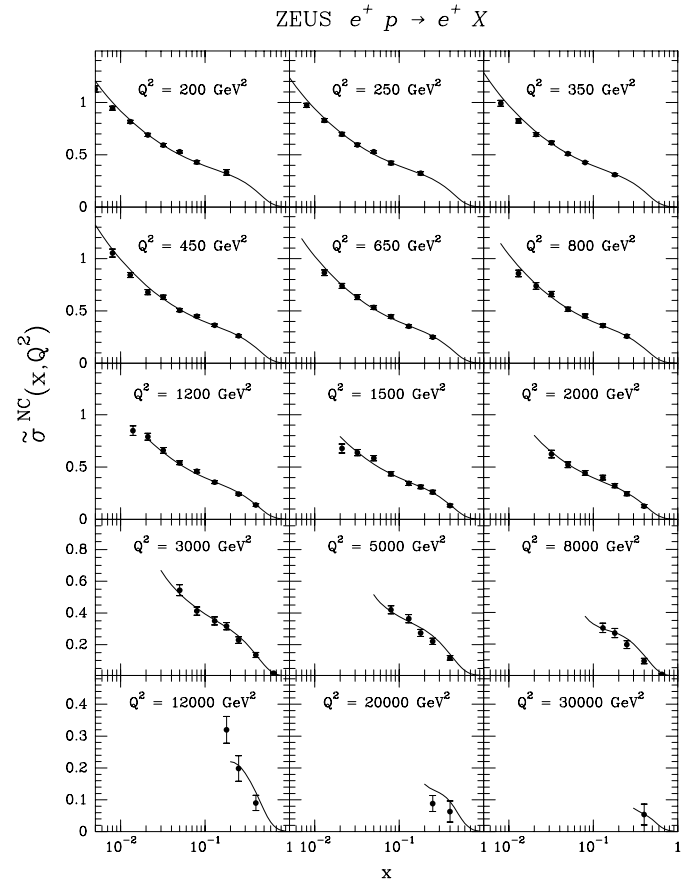
Neutral current in $e^{\pm}p$ collisions (H1)



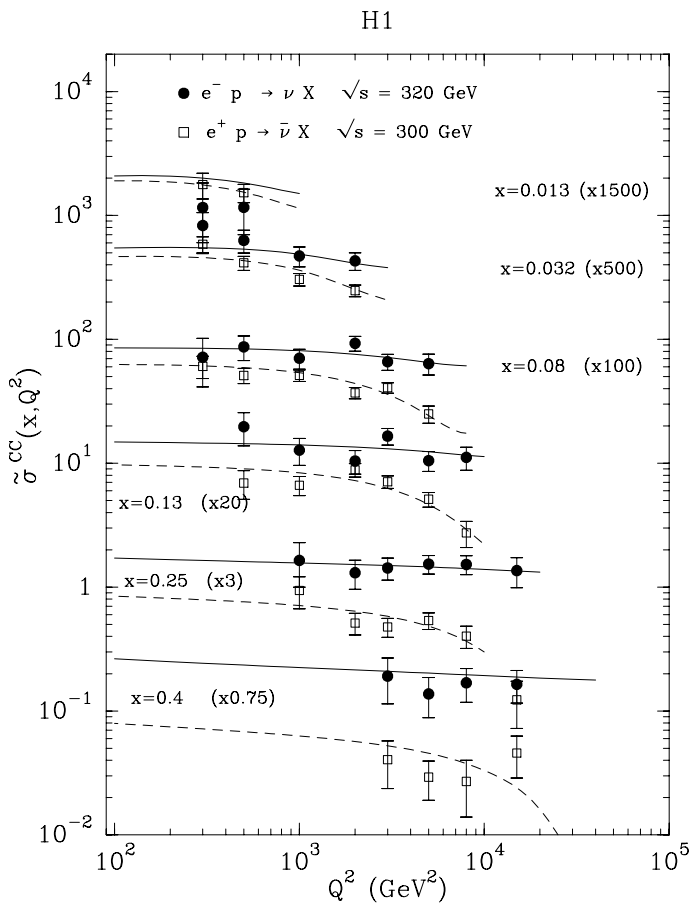


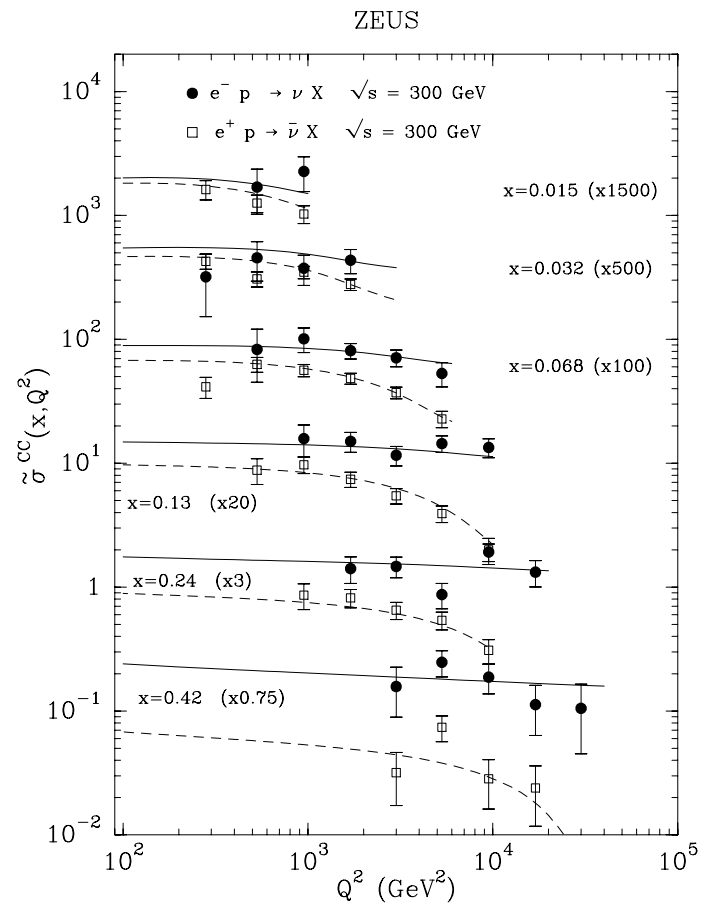
Neut. current in $e^{\pm}p$ collisions(ZEUS)



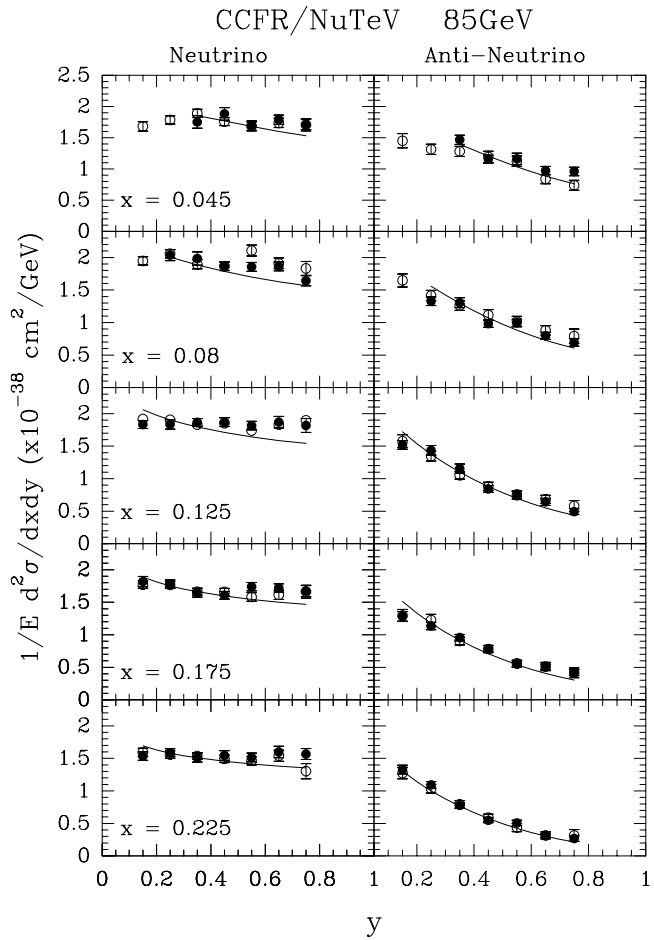


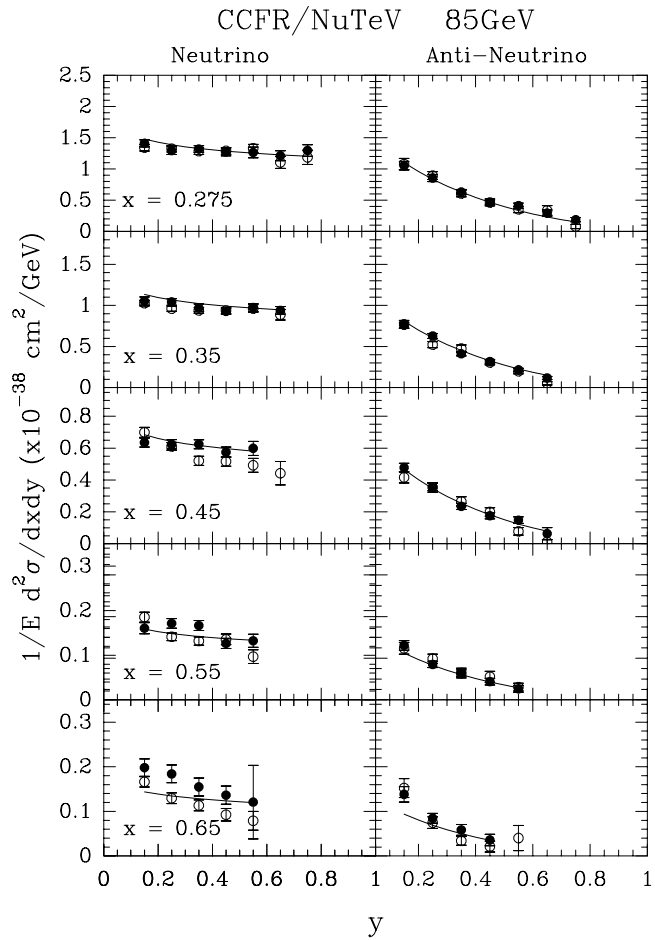
Charged current in $e^{\pm}p$ collisions



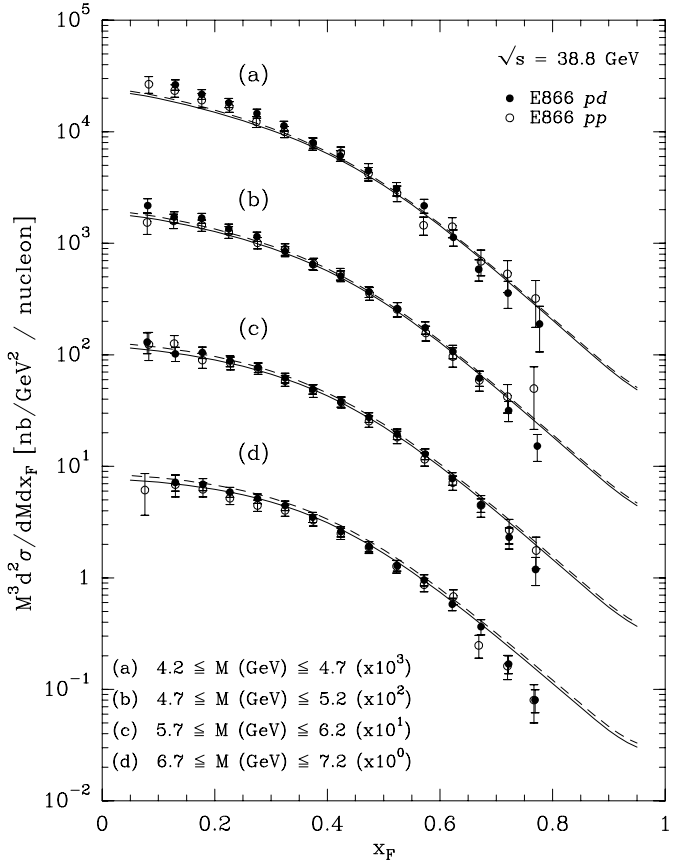


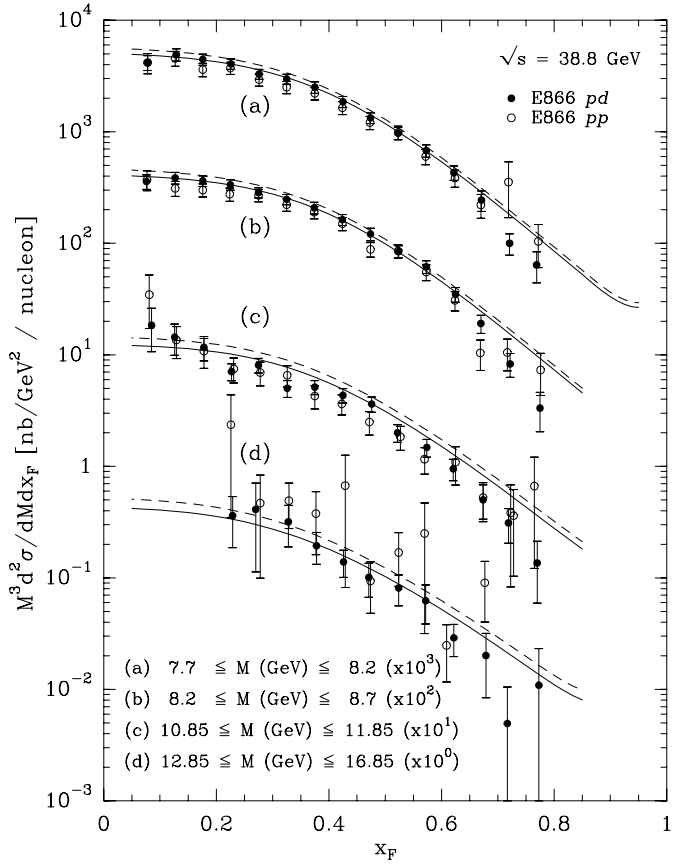
Charged current neutrino c. sections





Drell-Yan processes





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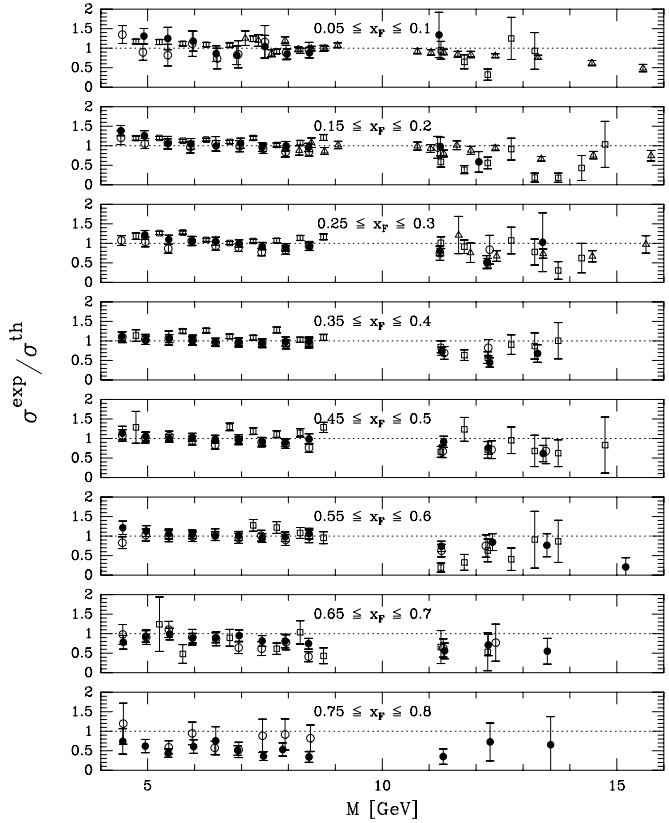
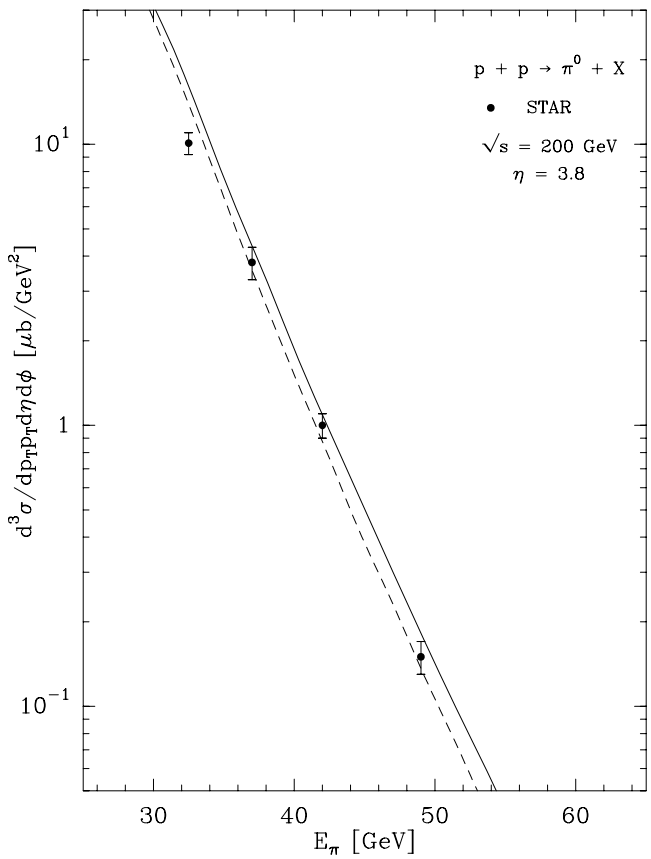
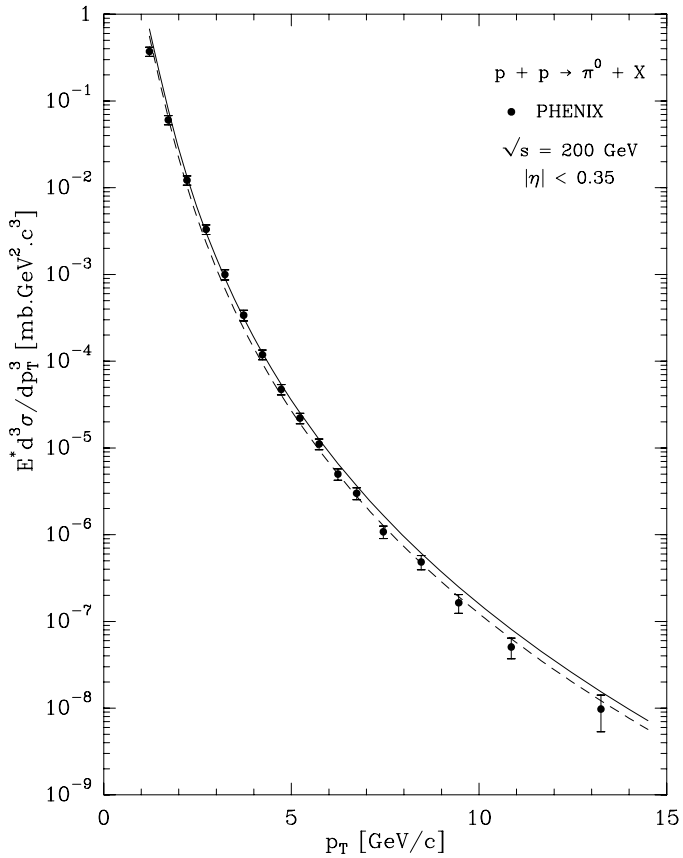
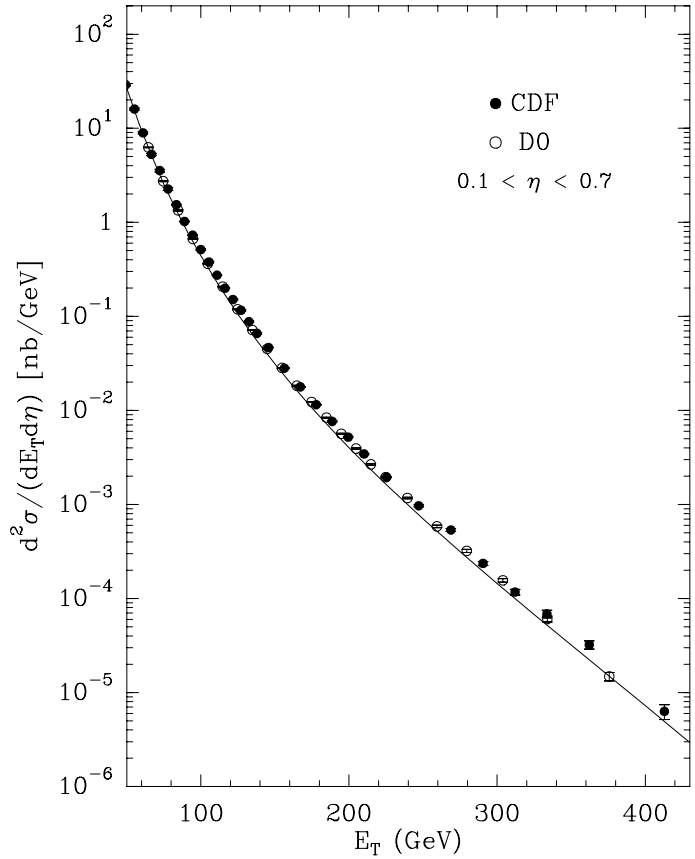


Inclusive π^0 production in pp collisions

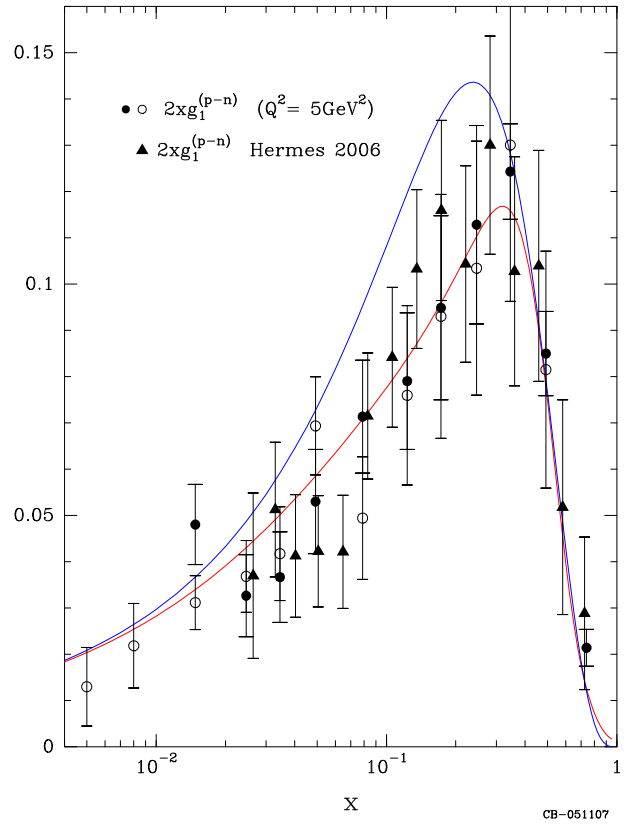




Single-jet production in $\bar{p}p$ collisions

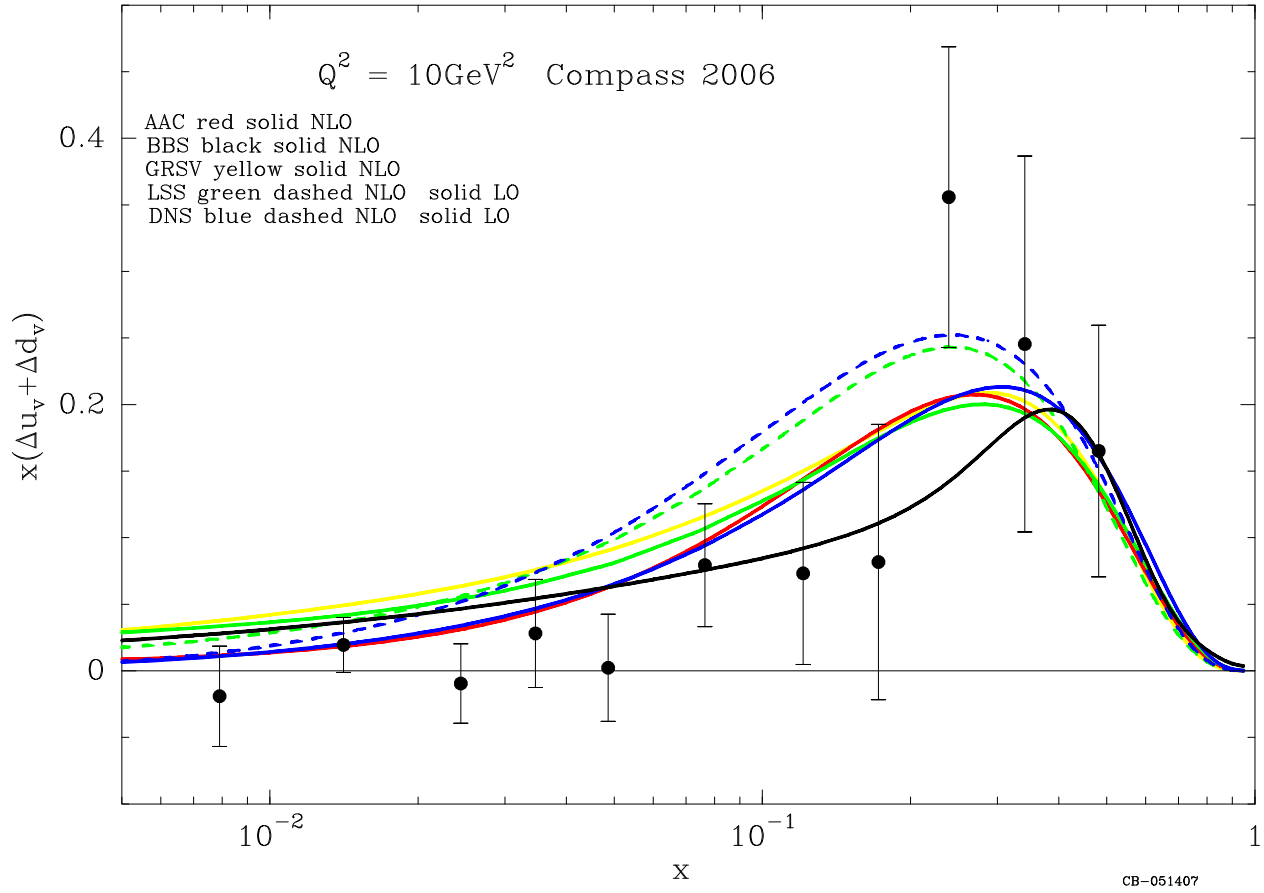


Very recent tests from DIS (COMPASS)



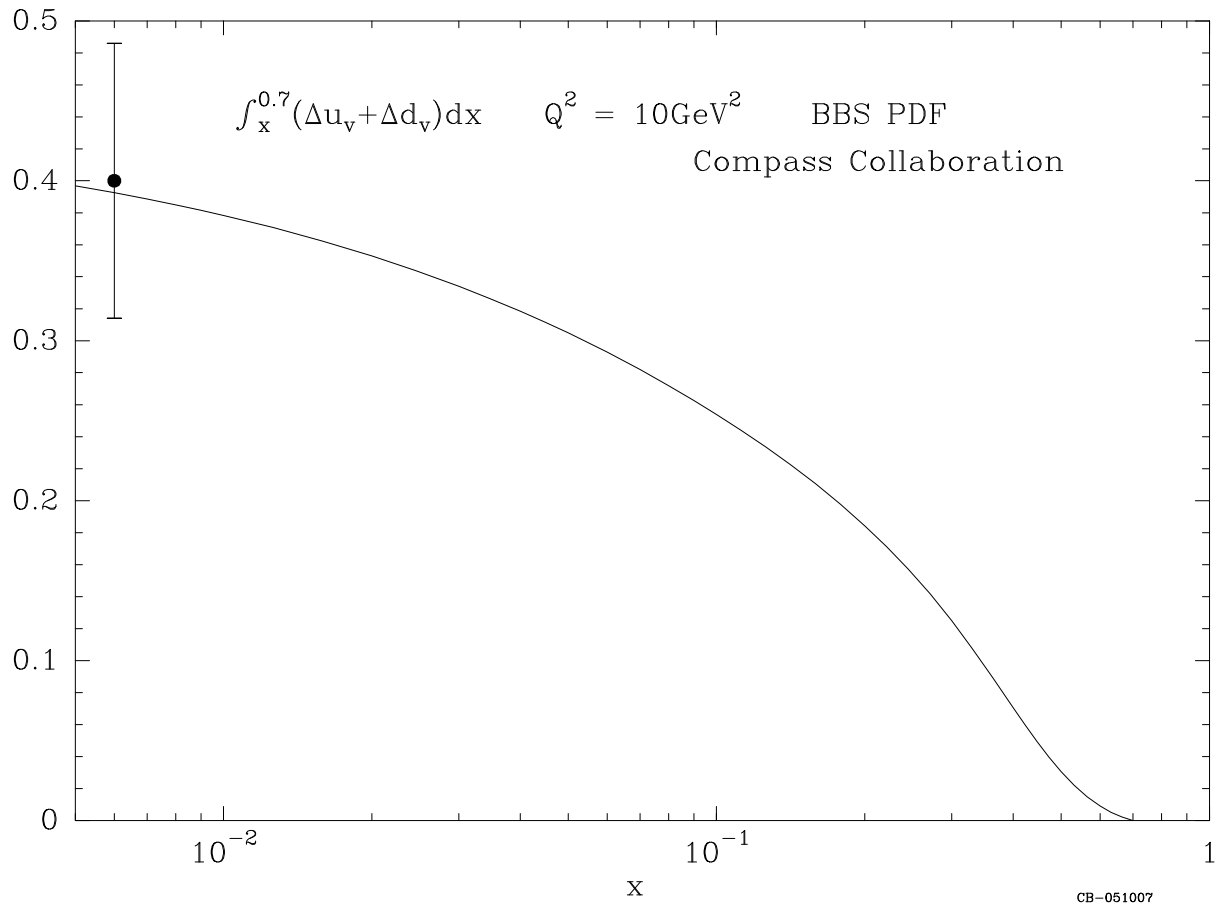
Non-Singlet part of $g_1^p - g_1^n$: red BBS $\Delta\bar{u} > 0$, $\Delta\bar{d} < 0$ and blue AAC $\Delta\bar{u} = \Delta\bar{d}$

Very recent tests from DIS (COMPASS)



Comparison of various parametrizations with the data

Very recent tests from DIS (COMPASS)

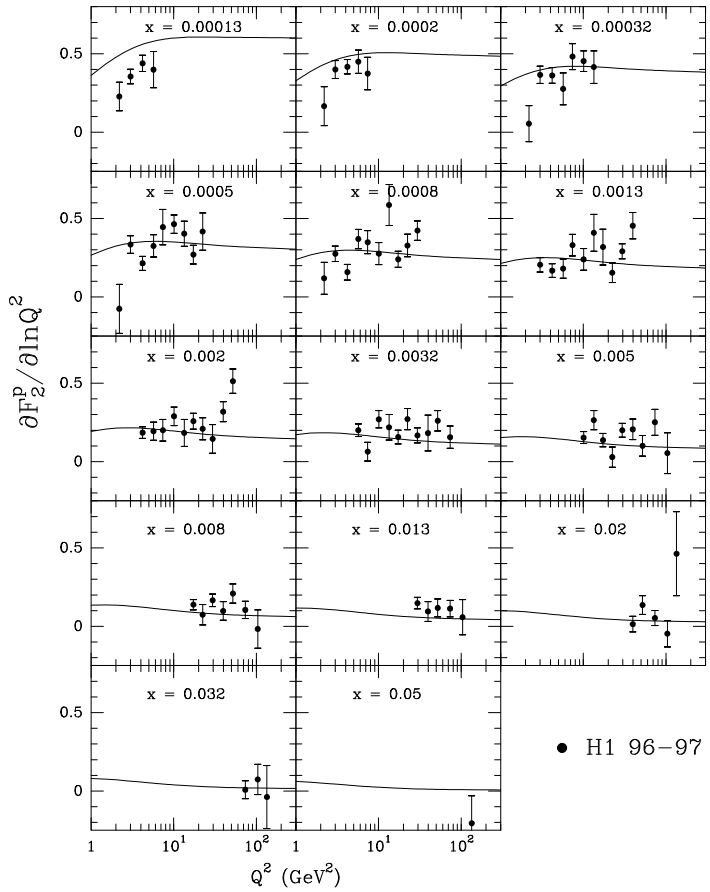


A flavor symmetric $\Delta\bar{q}$ leads to a much higher value ~ 0.6

Accurate determination of $G(x)$ at HERA

Two ways to determine the gluon distribution: measure F_L or $dF_2/dlnQ^2$

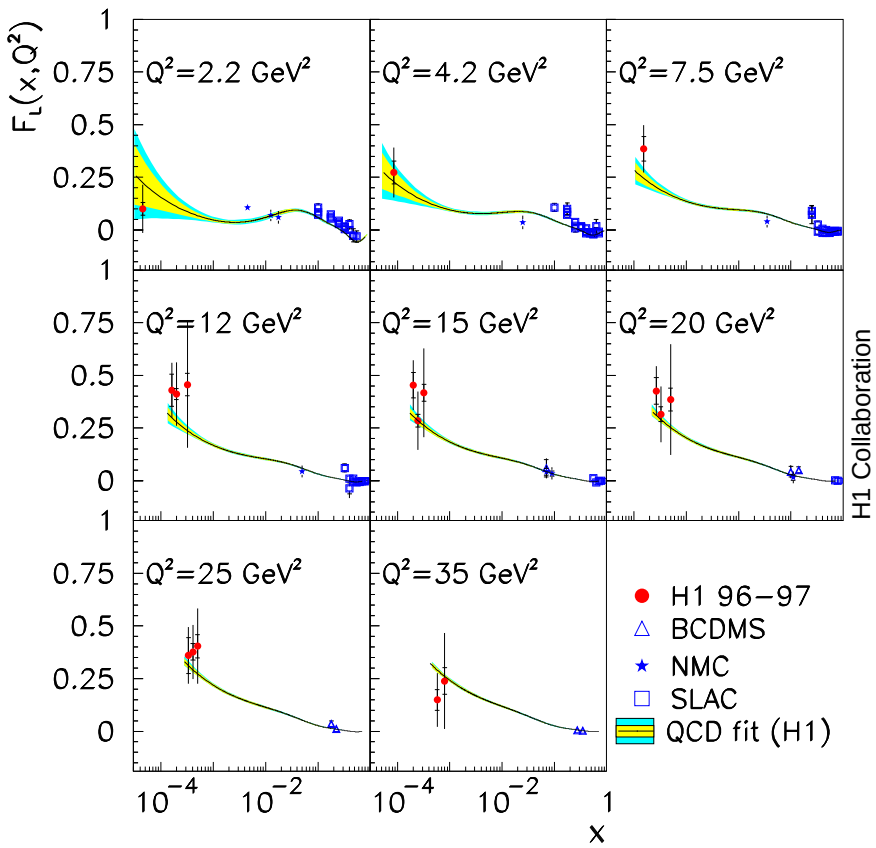
At LO $dF_2/dlnQ^2 \sim \alpha_s G(2x) + ...$

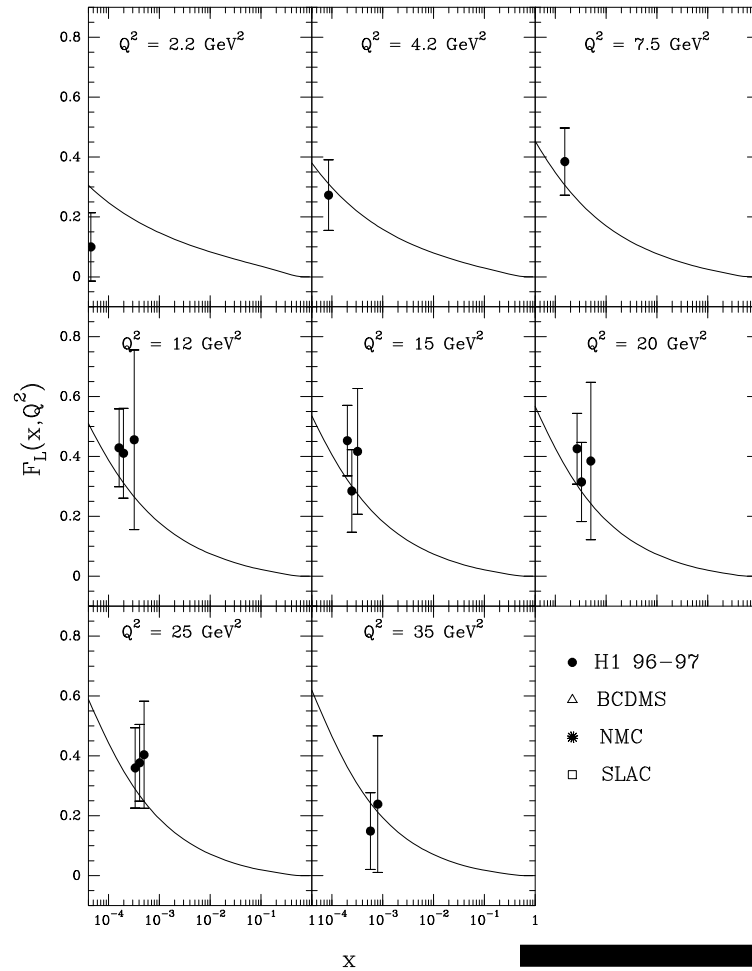


Accurate determination of $G(x)$ at HERA

Two ways to determine the gluon distribution: measure F_L or $dF_2/dlnQ^2$

F_L is the last measurement at HERA





Conclusions and Future

- A new set of PDF is constructed in the framework of a statistical approach of the nucleon
- All unpolarized and polarized distributions depend upon eight free parameters
- New tests against experimental (unpolarized and polarized) data are very satisfactory
- Special features need to be confirmed