New developments in the quantum statistical approach of the parton distributions

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Outline

- Basic procedure to construct the statistical polarized parton distributions
- Essential features from unpolarized and polarized Deep Inelastic Scattering data
- Predictions tested against new data : DIS, Semi-inclusive DIS and several hadronic processes
- Conclusions

Collaboration with Claude Bourrely and Franco Buccella

- A Statistical Approach for Polarized Parton Distributions
  Euro. Phys. J. C23, 487 (2002)
- Recent Tests for the Statistical Parton Distributions
  Mod. Phys. Letters A18, 771 (2003)
- The Statistical Parton Distributions: status and prospects
  Euro. Phys. J. C41,327 (2005)
- The extension to the transverse momemtum of the statistical parton distributions
  Mod. Phys. Letters A21, 143 (2006)
- Strangeness asymmetry of the nucleon in the statistical parton model
  Phys. Lett. B648, 39 (2007)
- How is helicity related to transversity for quarks and antiquarks inside the proton?
  (submitted for publication)
- New tests of the quantum statistical approach of the parton distributions
  (in preparation)

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.

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

- Potential of a quark q^h of helicity h is opposite to the potential of the corresponding antiquark $\bar{q}^{-h}$ of helicity -h, $X_{0q}^h = -X_{0\bar{q}}^{-h}$.

- Potential of the gluon G is zero, $X_{0G} = 0$.

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

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

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

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 $\bar{q}$).

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Note: $q = q^+ + q^-$ and $\Delta q = q^+ - q^-$ (idem for $\bar{q}$).
For strange quarks and antiquarks, s and $\bar{s}$, given our poor knowledge on both unpolarized and polarized distributions, we first took in 2002
$xs(x, Q_0^2) = x\bar{s}(x, Q_0^2) = \frac{1}{4}[x\bar{u}(x, Q_0^2) + x\bar{d}(x, Q_0^2)]$
and
$x\Delta s(x, Q_0^2) = x\Delta\bar{s}(x, Q_0^2) = \frac{1}{3}[x\Delta\bar{d}(x, Q_0^2) - x\Delta\bar{u}(x, Q_0^2)]$.
However given the strange quark asymmetry, this was improved in Phys. Lett. B648, 39 (2007).
For 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 $x\Delta G(x, Q_0^2) = 0$.

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 $X^-_{0d} > X^+_{0d}$.

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, from our fit we have obtained 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 $\Delta\bar{d}(x) < 0$, a prediction in agreement with polarized DIS (see below) and will be more precisely checked at RHIC-BNL from $W^{\pm}$ production.

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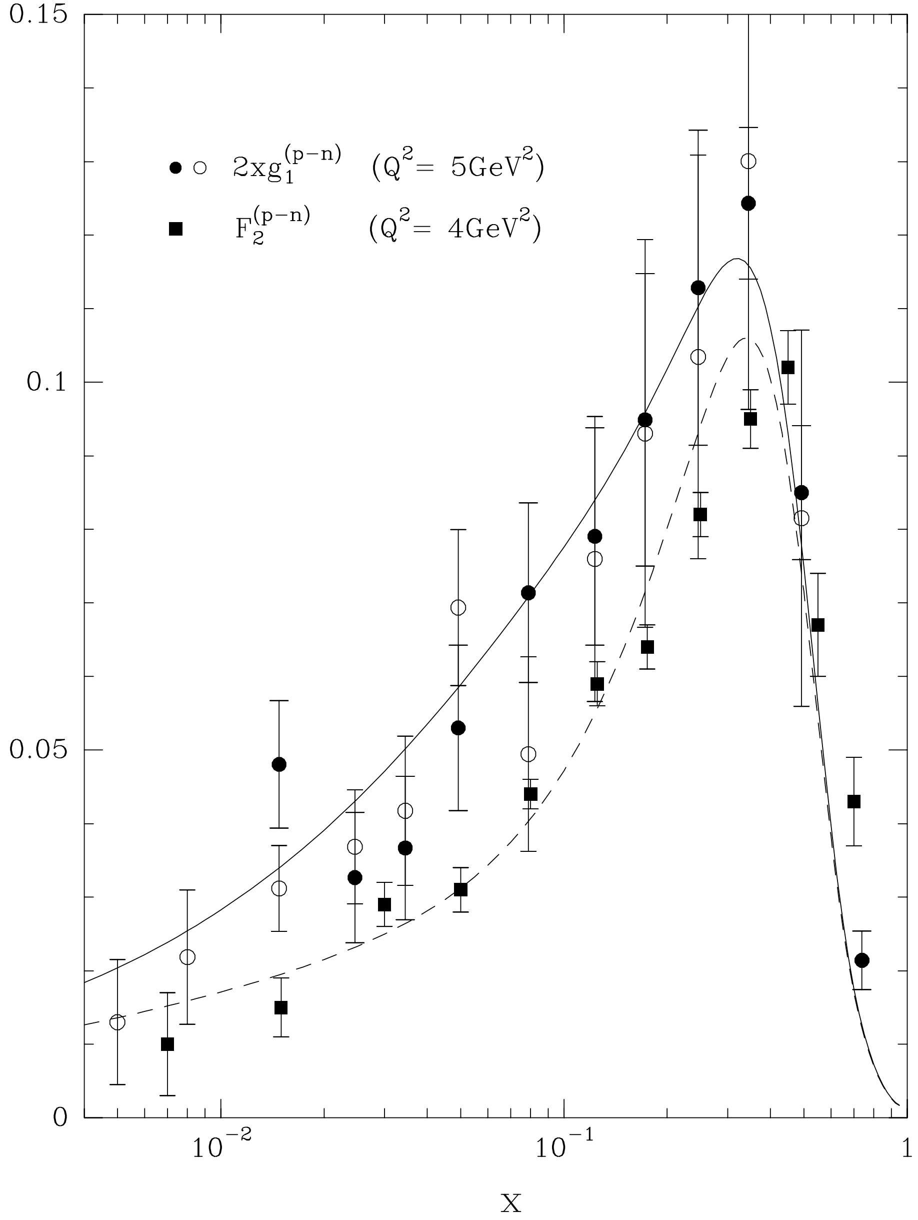
- Note that since $u^{-}(x) \sim d^{-}(x)$, it follows that $\bar{u}^{+}(x) \sim \bar{d}^{+}(x)$, (see next slide) so we have

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

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

An interesting observation



Nine free parameters

By performing a NLO QCD evolution of these PDF, 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 nine free parameters with some physical significance:

* the four potentials $X_{0u}^+,\ X_{0u}^-,\ X_{0d}^-,\ X_{0d}^+$,
* the universal temperature $\bar{x}$,
* and $b,\ \tilde{b},\ b_G,\ \tilde{A}$.

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* the universal temperature $\bar{x}$,

* and $b,\ \tilde{b},\ b_G,\ \tilde{A}$.

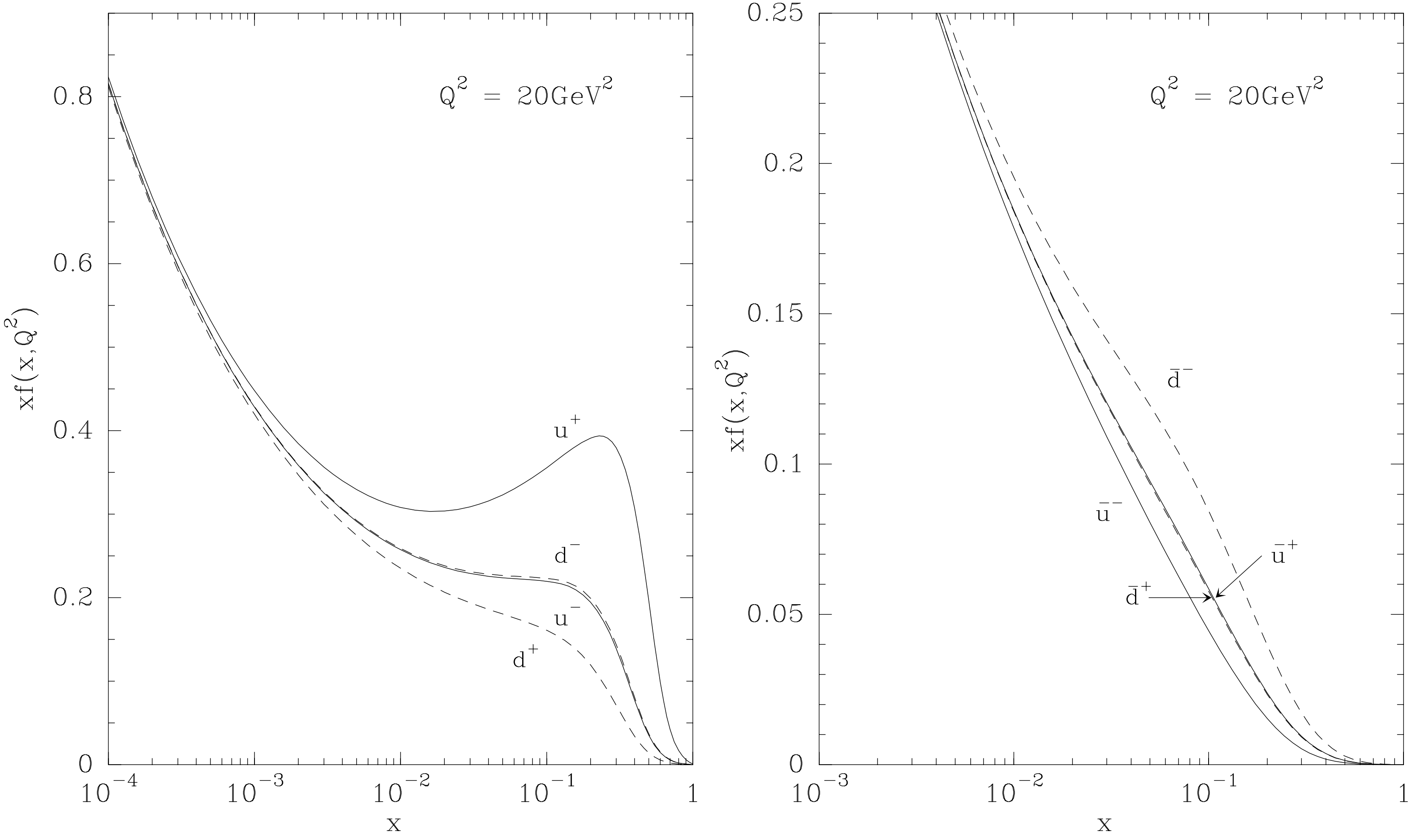
We also have three additional parameters, $A,\ \bar{A},\ A_G$, which are fixed by 3 normalization conditions .

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

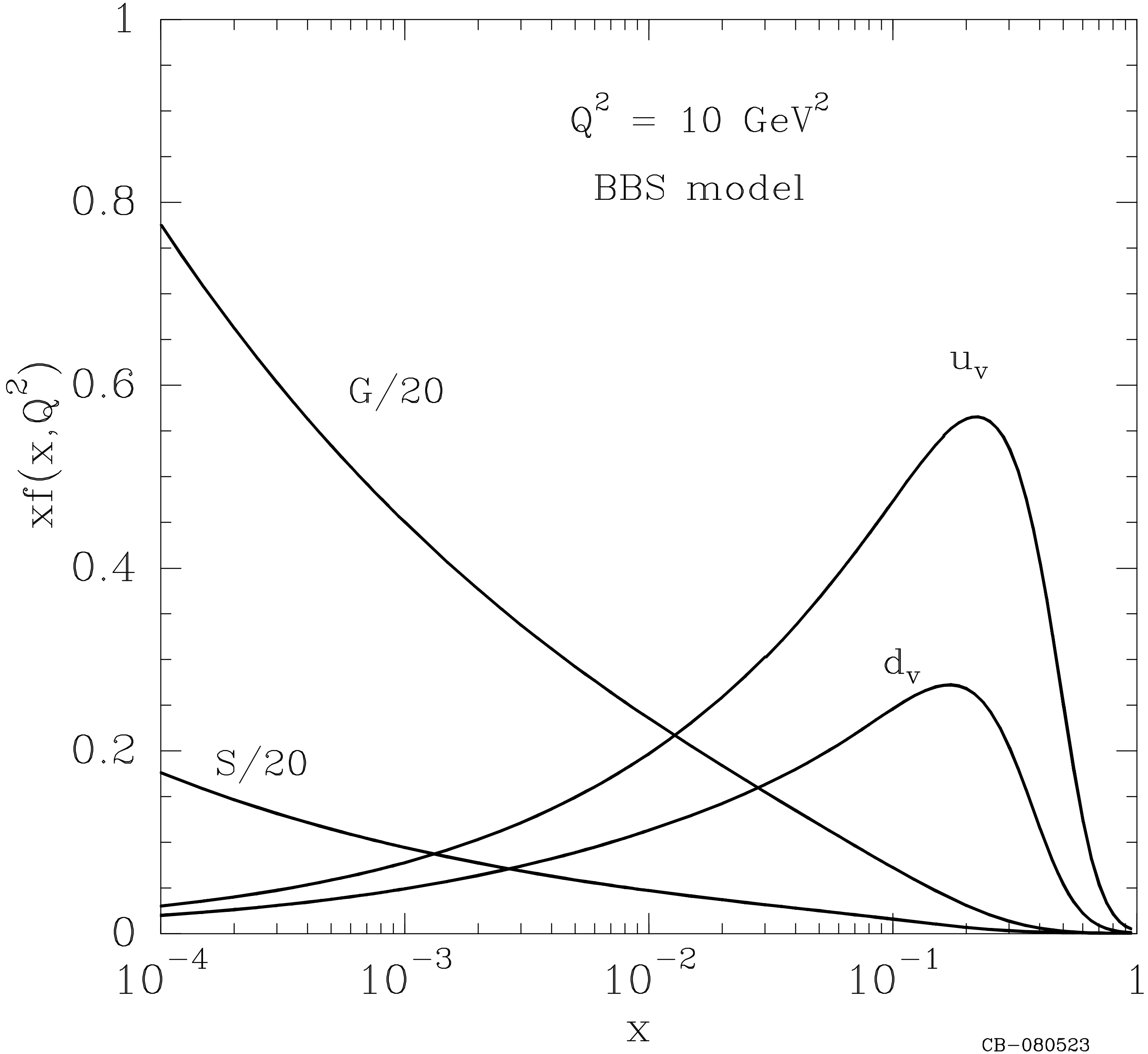
and the momentum sum rule.

Polarized light quarks distributions versus x

As we could anticipated u^+, is the largest one and is maximum near $x = 0.3$



A global view of the unpolarized parton distributions



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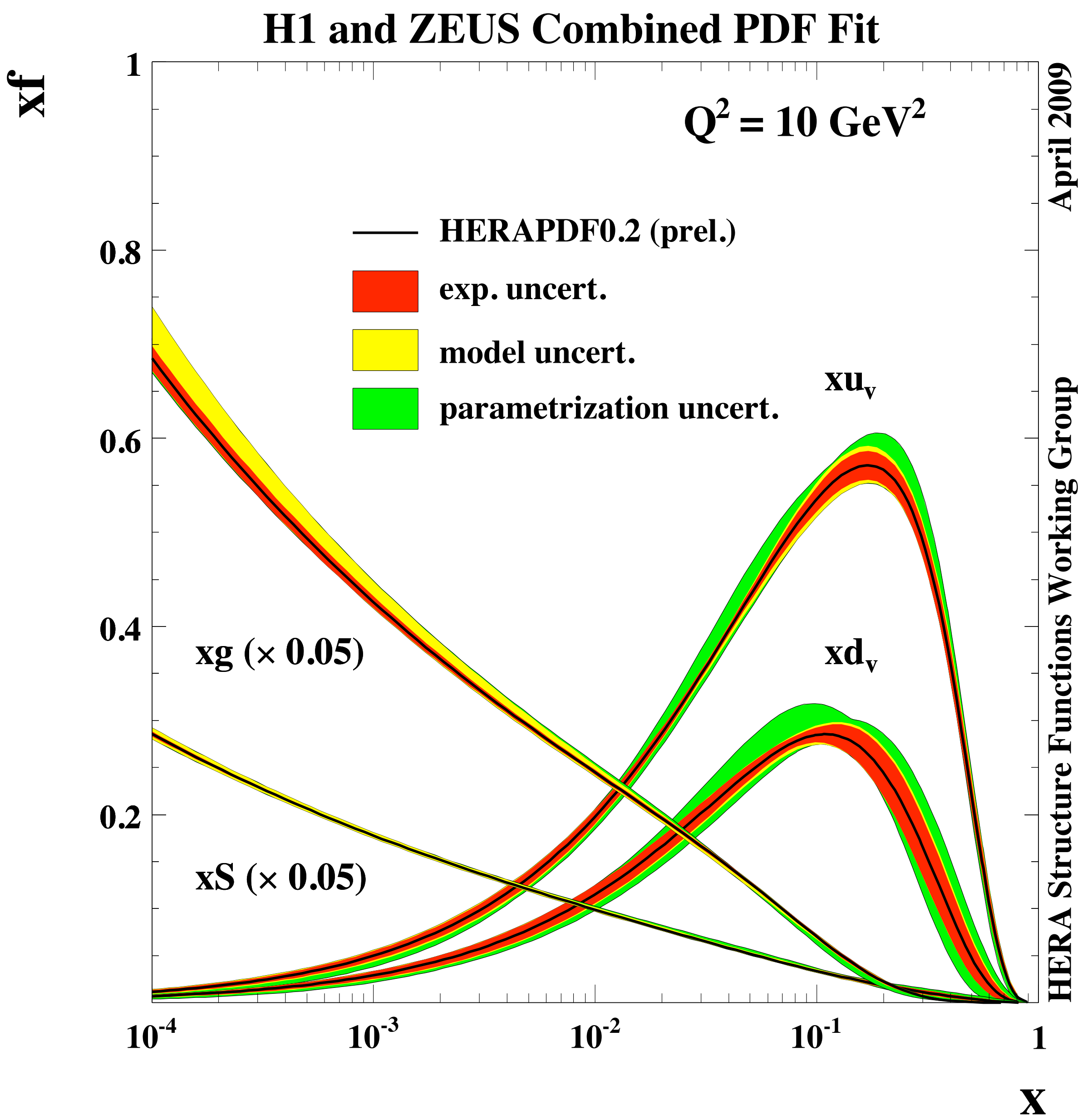
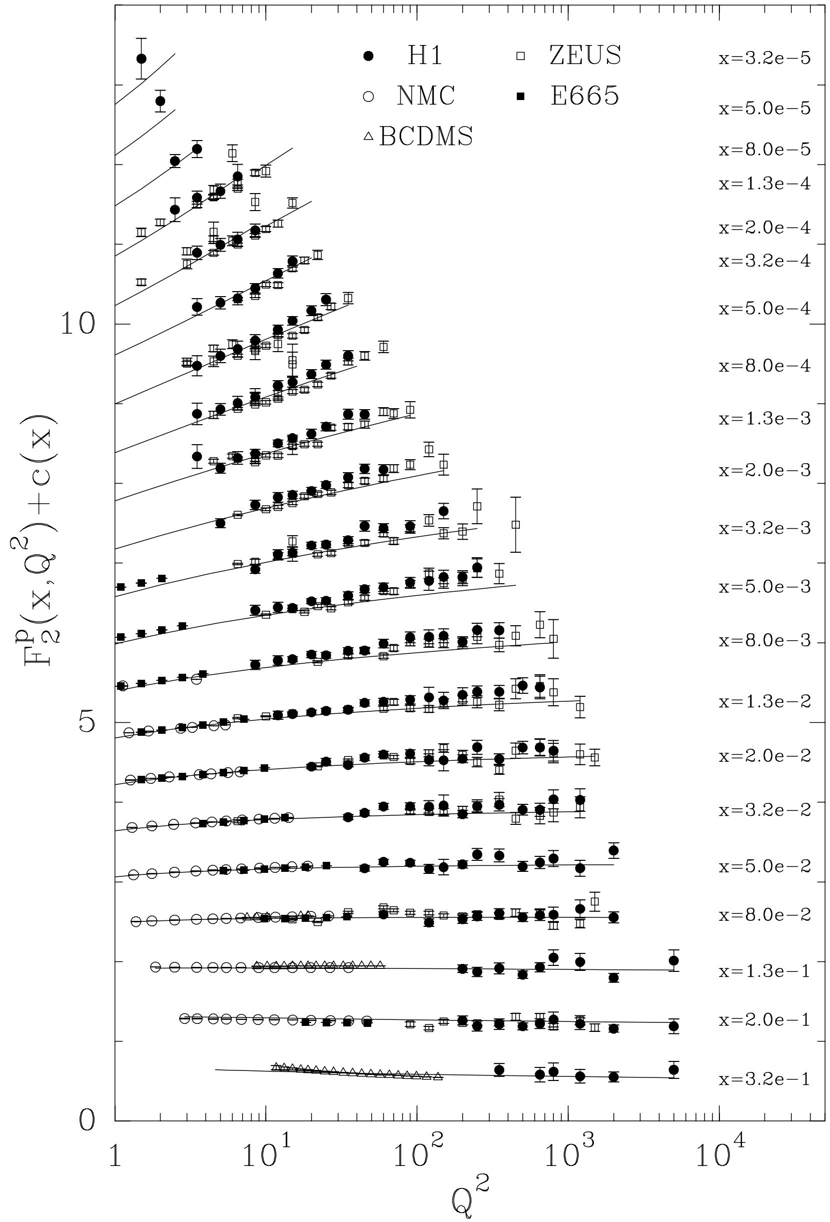
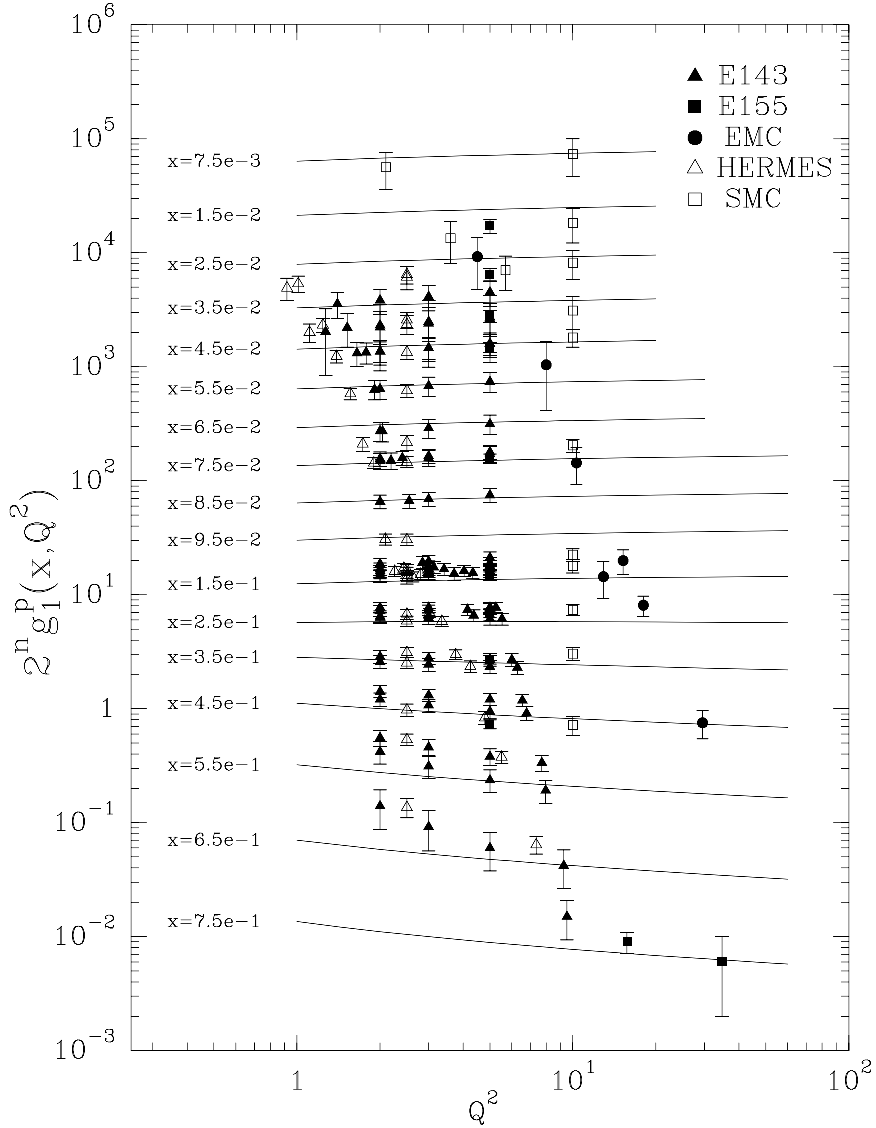


Ealier results on F_2^p and g_1^p

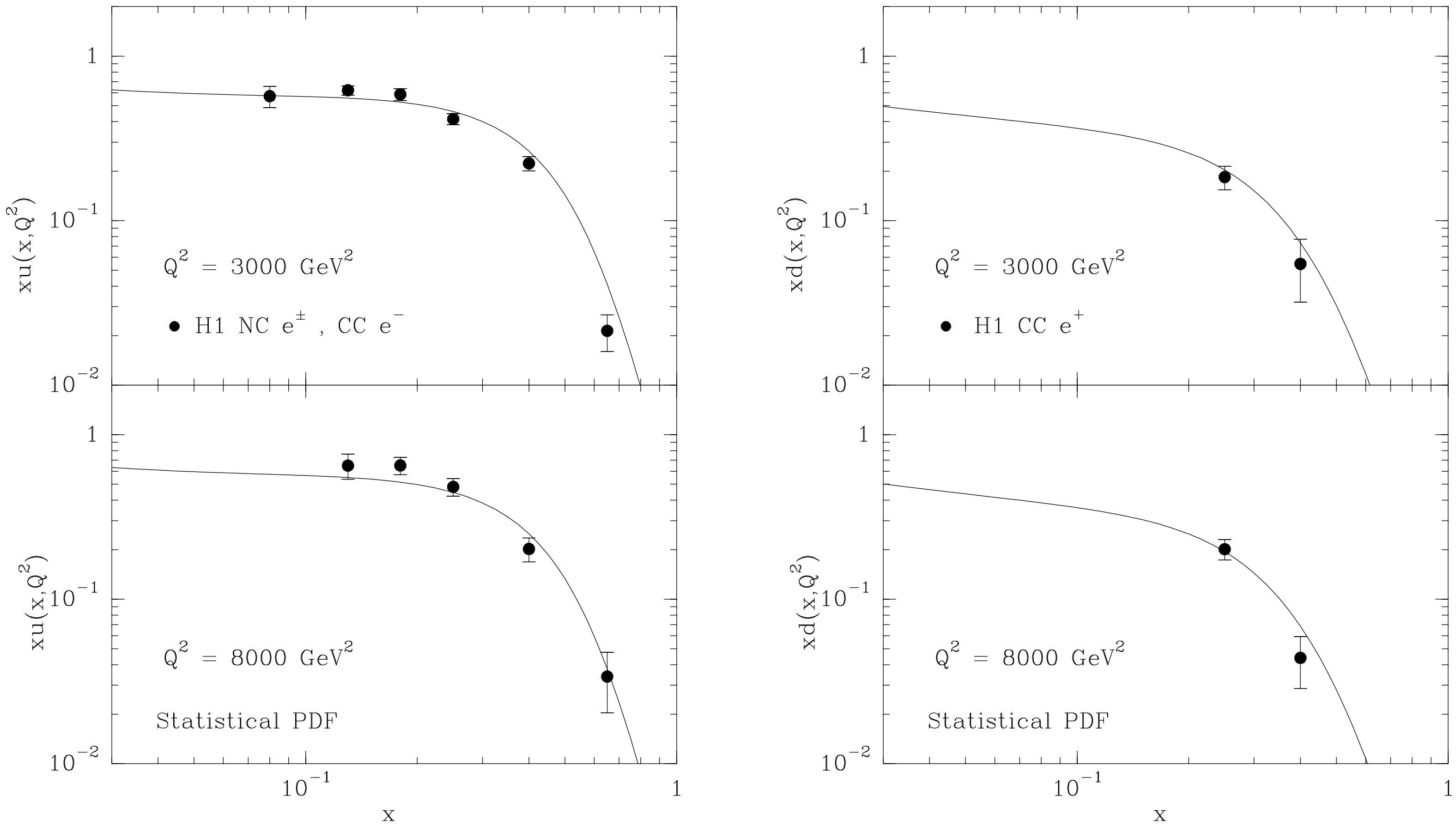




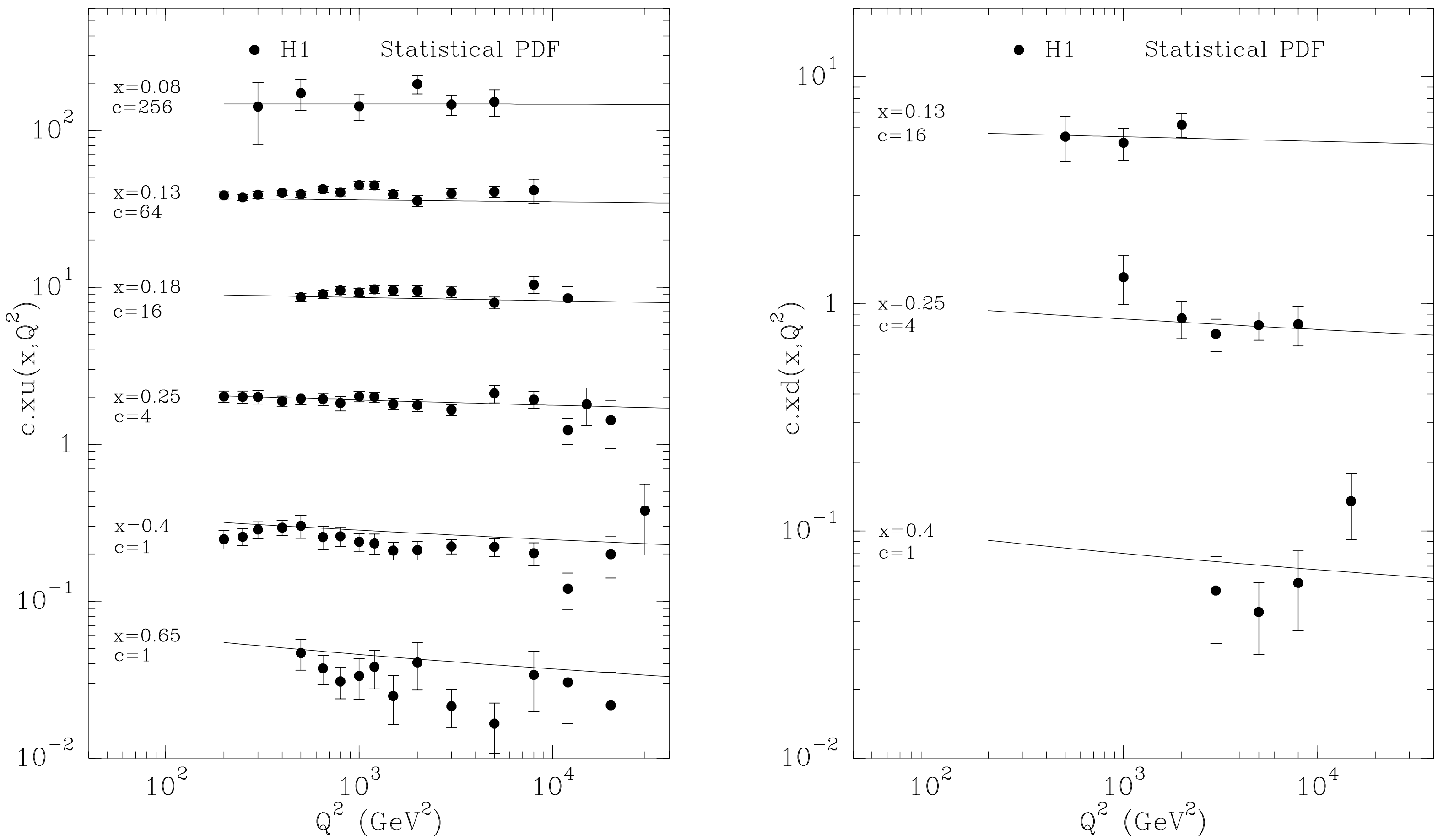
Predictions tested against some data 2002 - 2005

- Deep Inelastic Scattering
- Hadronic Collisions

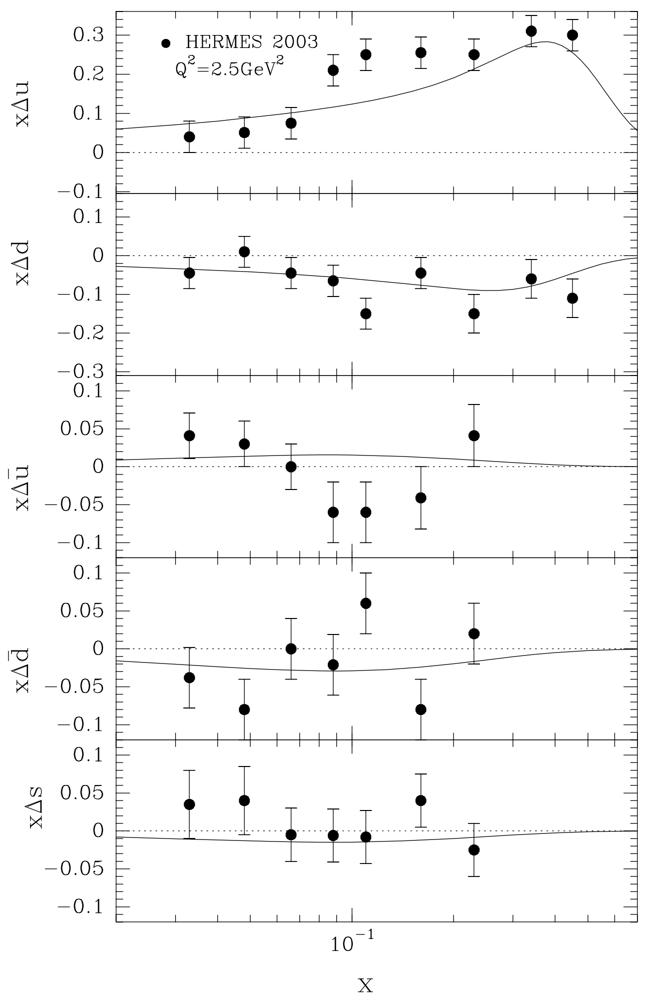
Light quarks distributions versus x from HERA

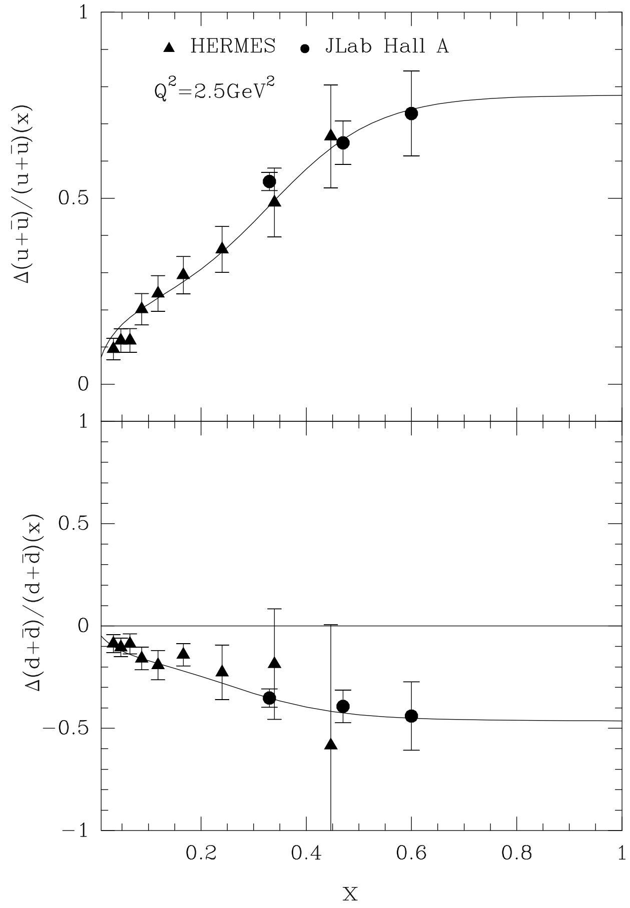


Light quarks distributions versus Q^2 from HERA

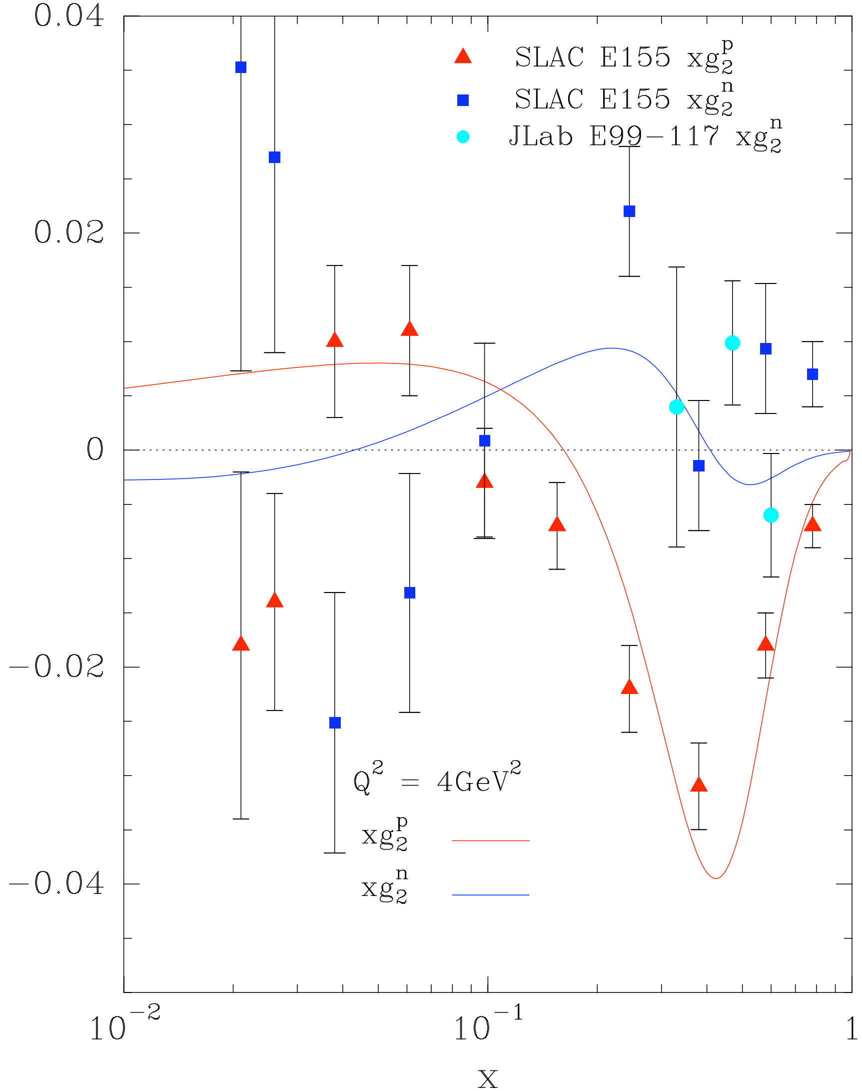


Polarized quarks distributions vs x at DESY and JLab



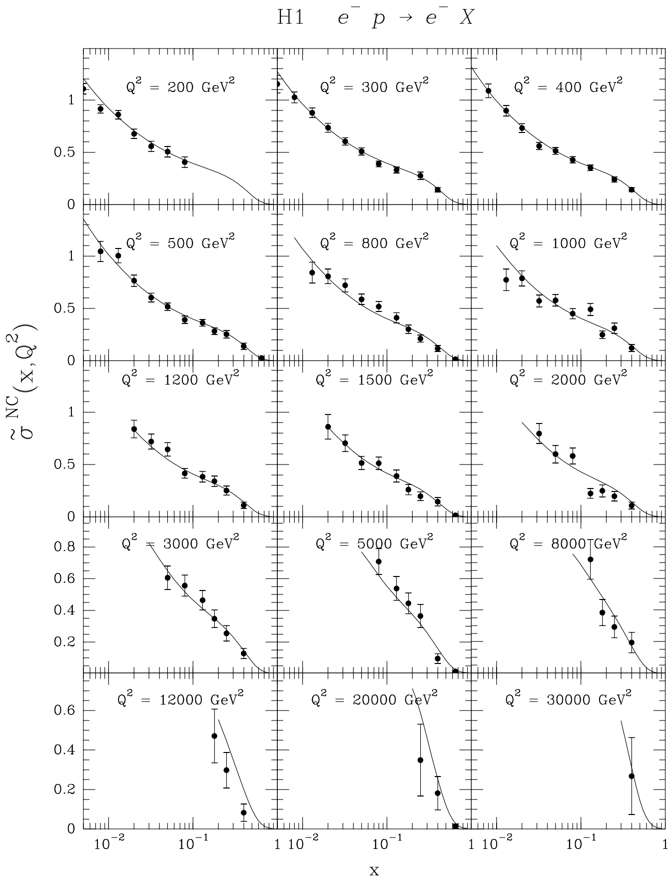


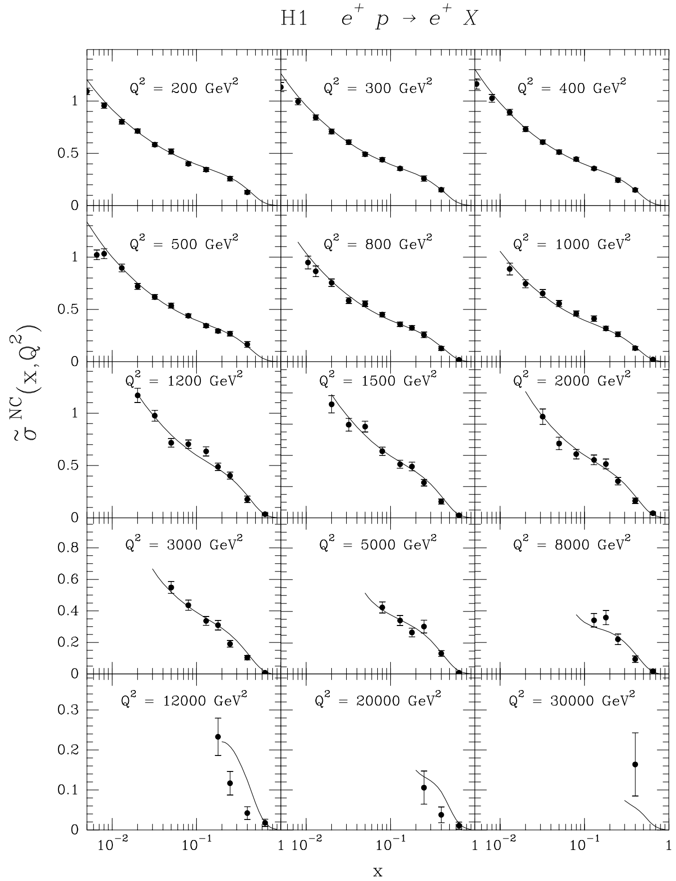
The $g_2^{p,n}$ structure functions versus x



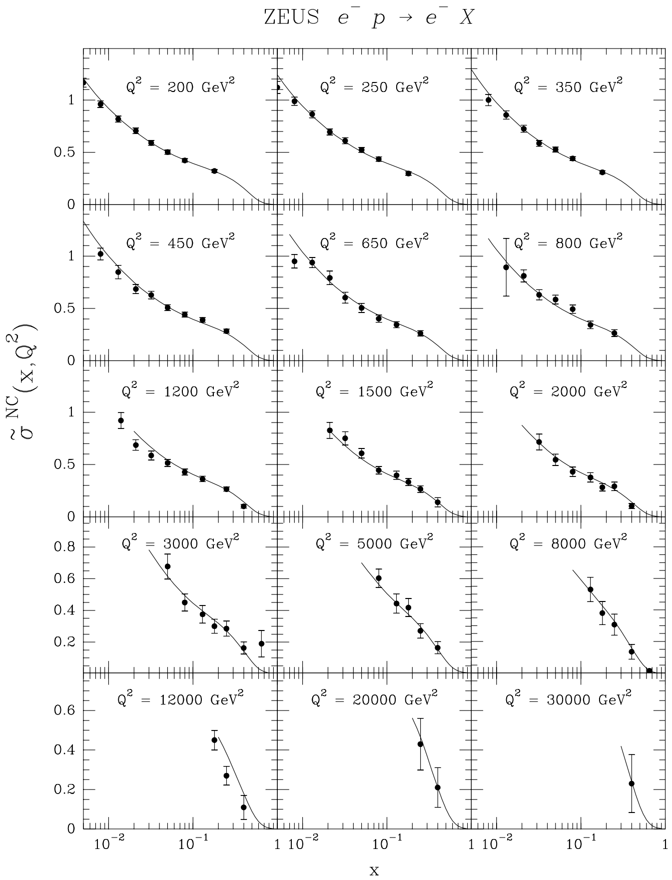
Predictions at leading twist assuming Wandzura-Wilczek sum rule

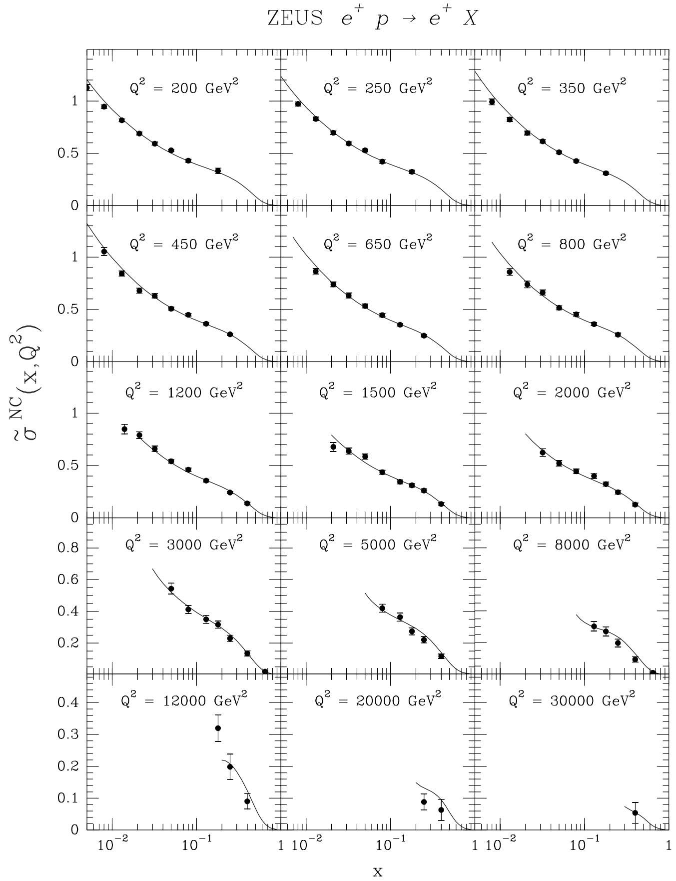
Neutral current in unpolarized $e^{\pm}p$ collisions (H1)



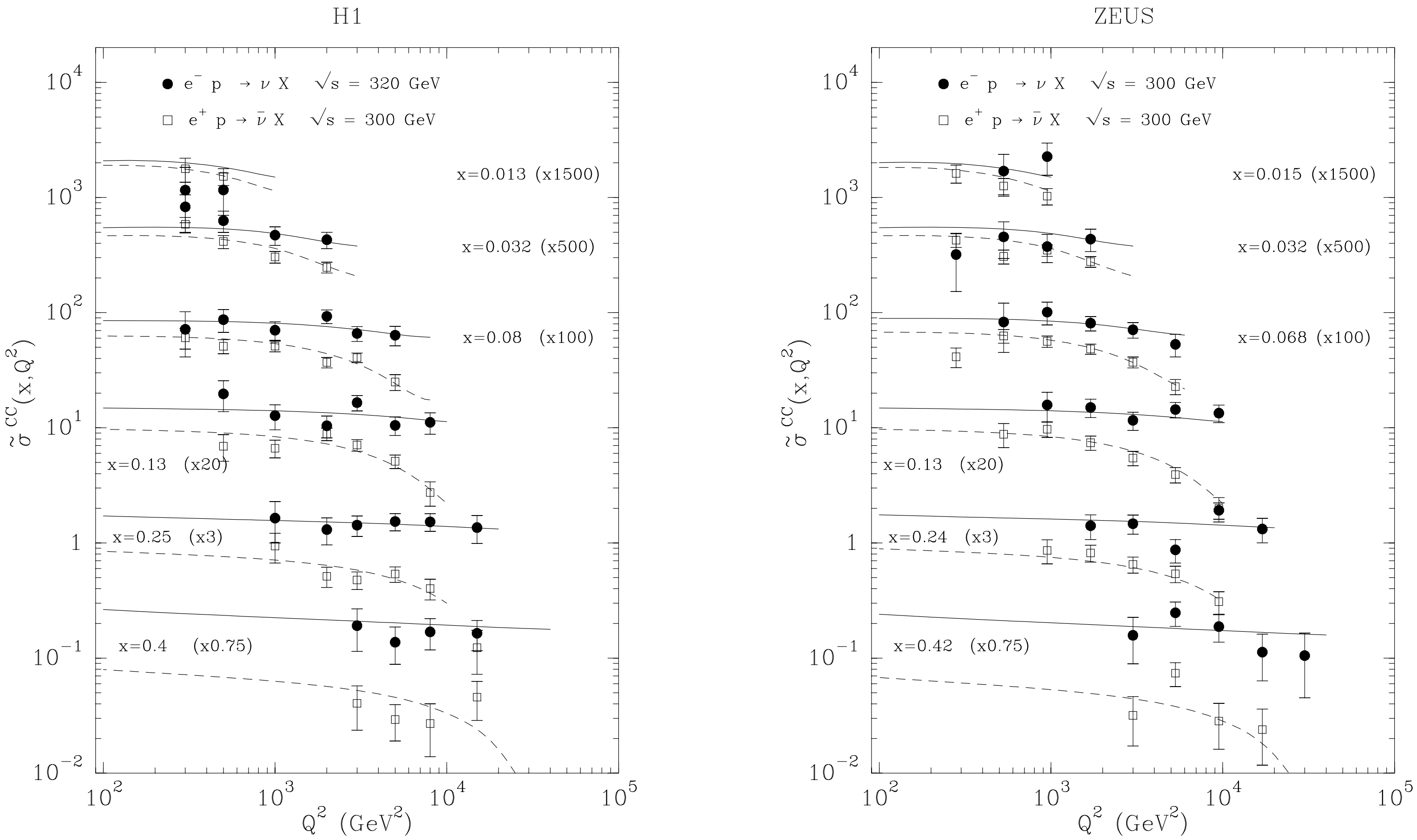


Neutral current in unpolarized $e^{\pm}p$ collisions (ZEUS)

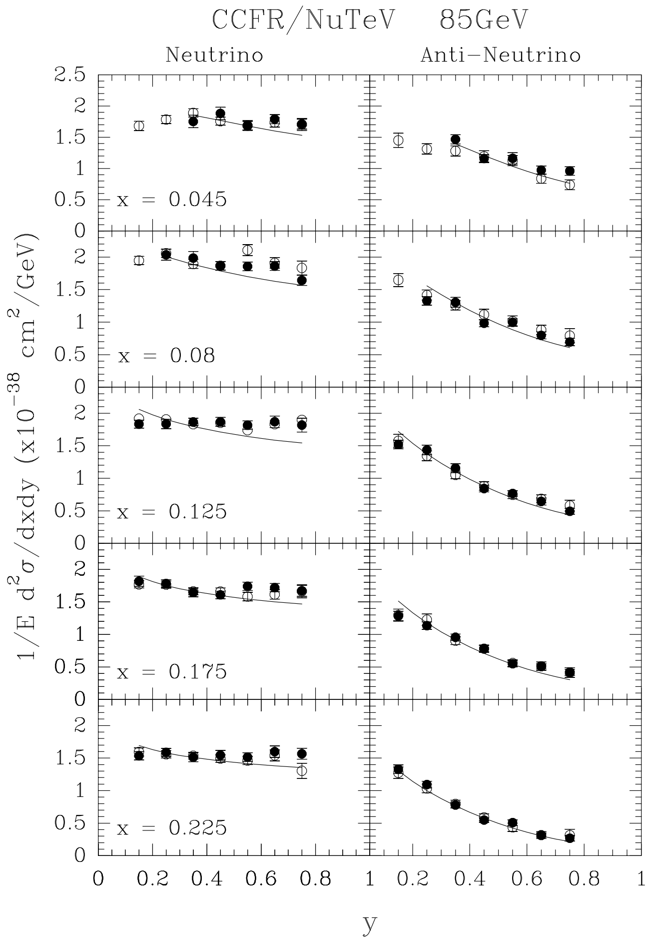


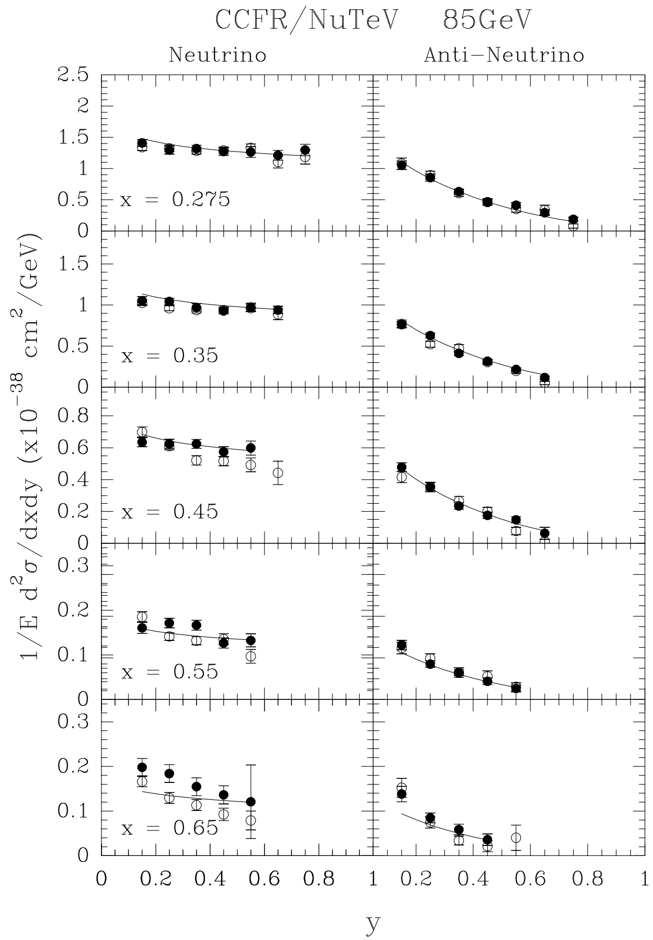


Charged current in $e^{\pm}p$ collisions at HERA

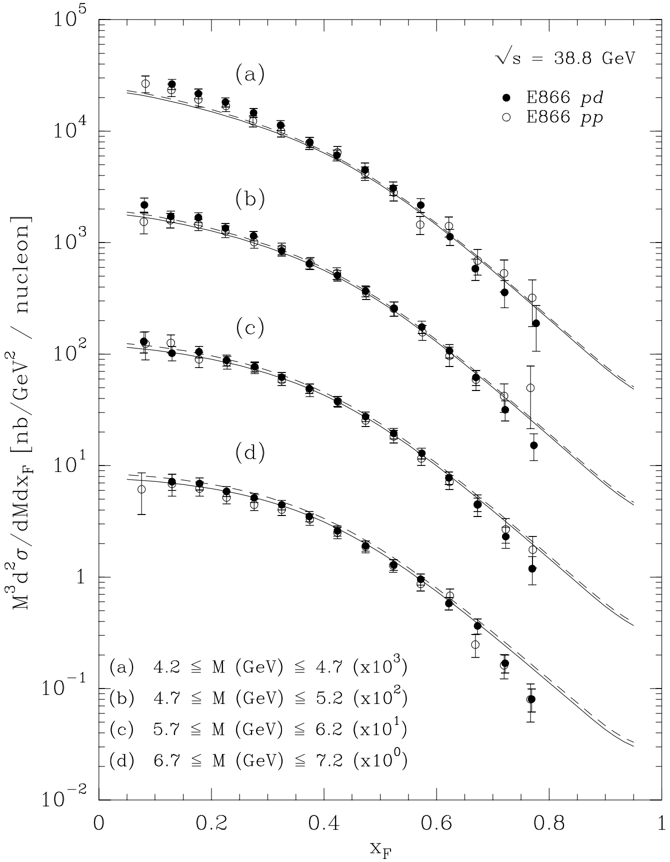


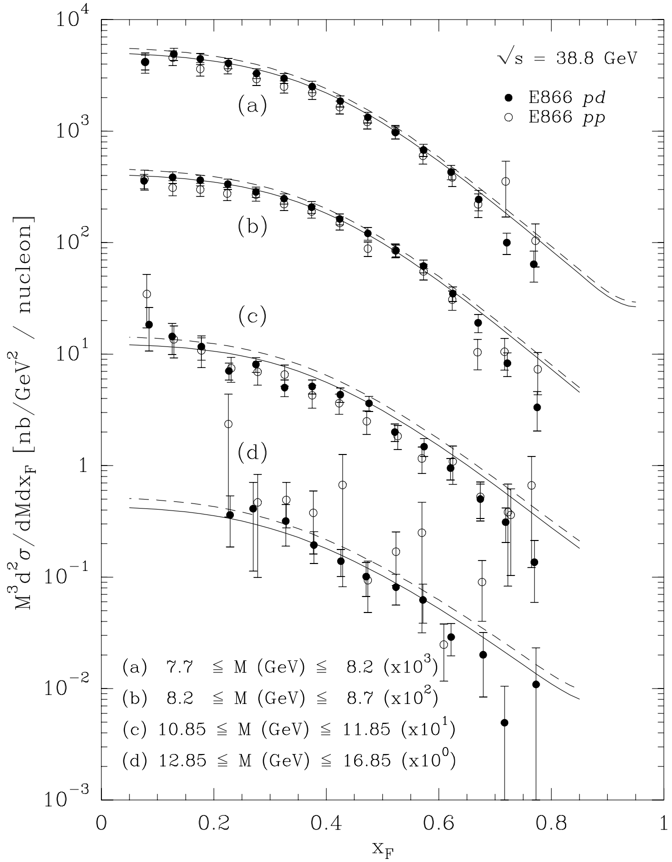
Charged current neutrino cross sections at FNAL





Drell-Yan processes at FNAL





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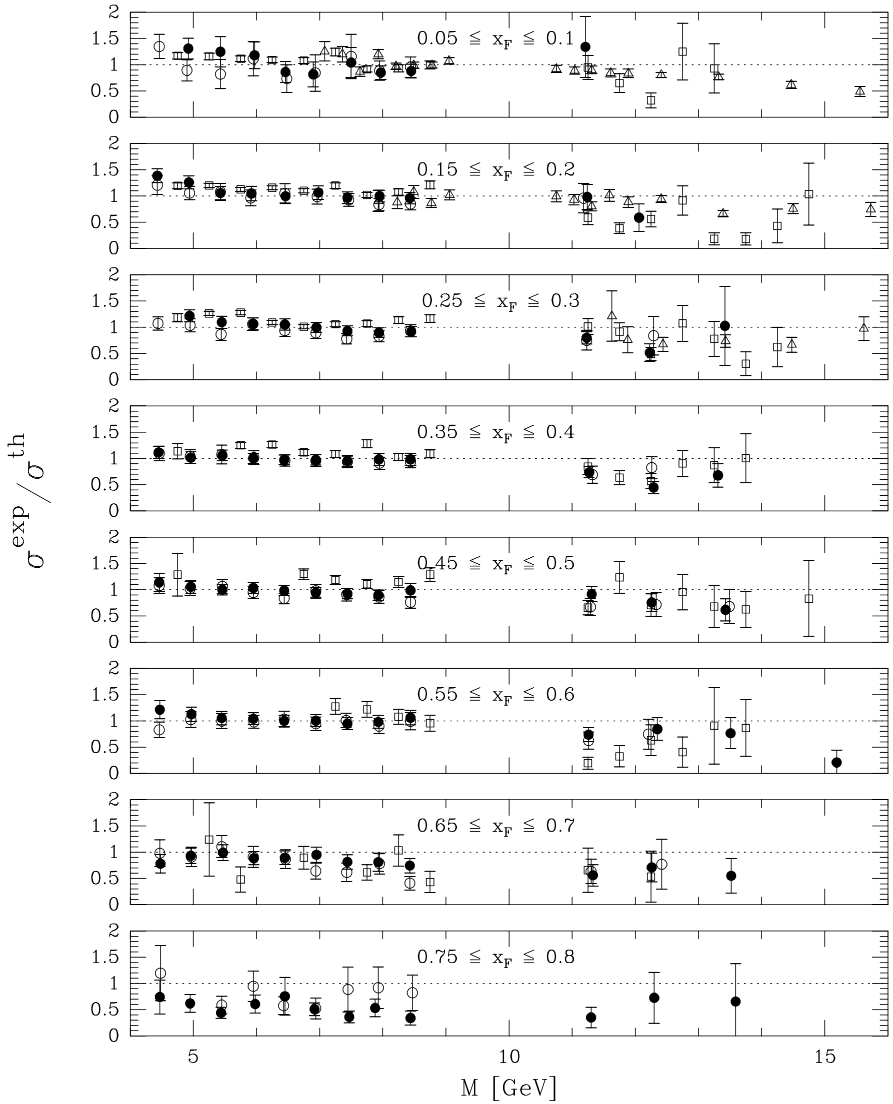
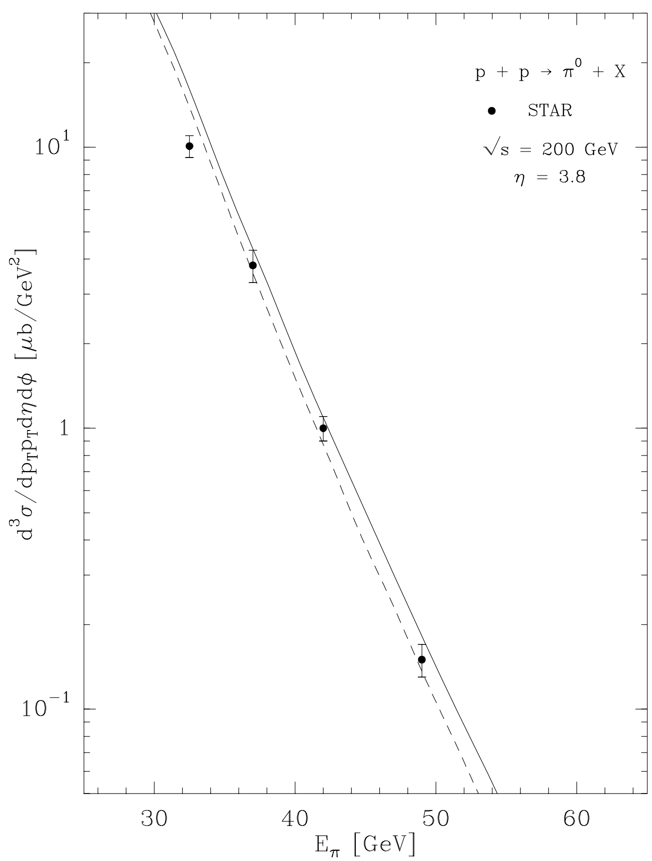
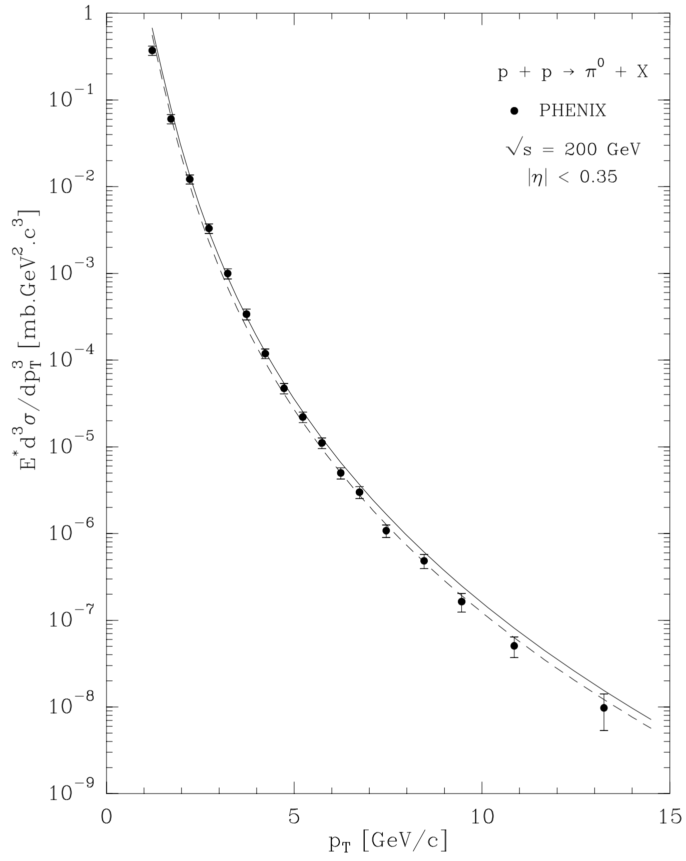


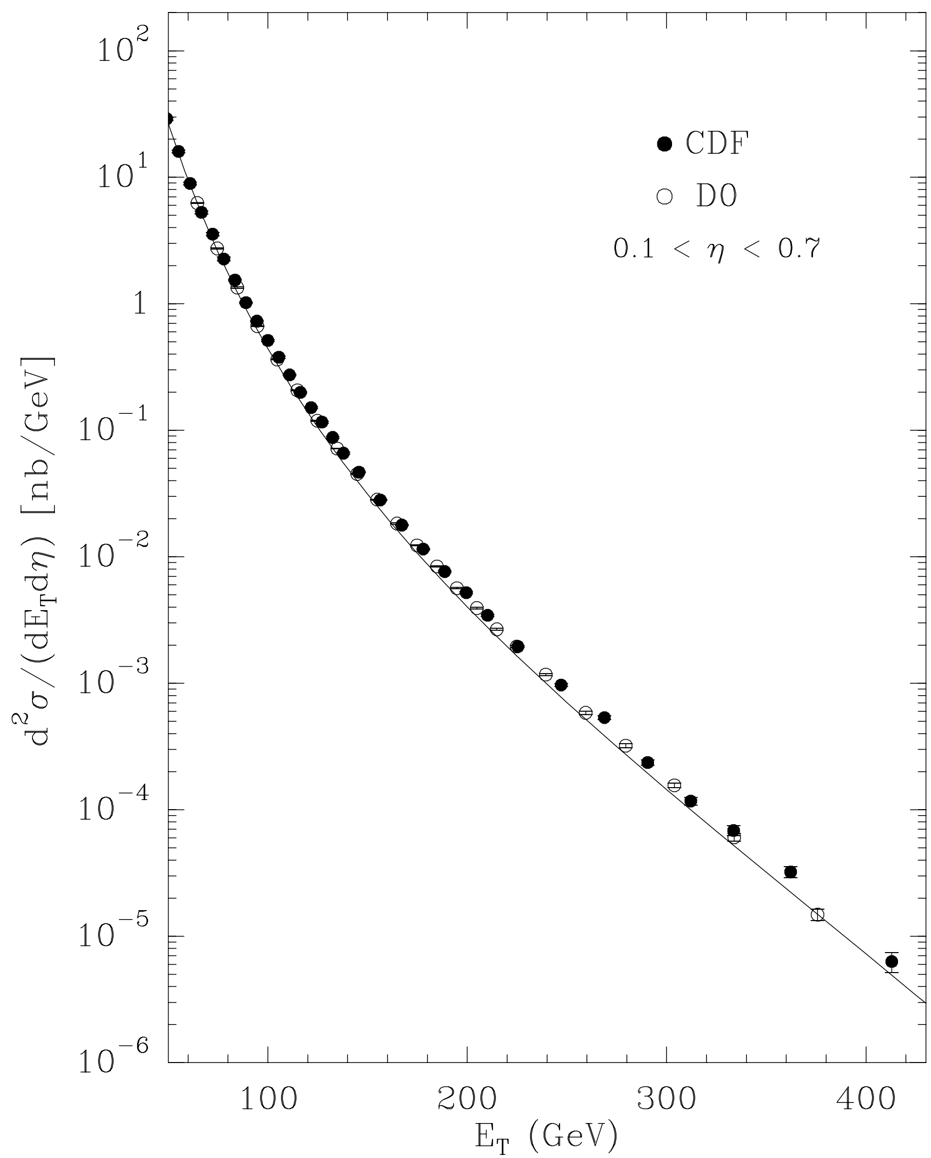
Inclusive π^0 production in pp collisions at RHIC





Mid-rapidity and central region

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



Predictions tested against some very recent data

- Unpolarized Deep Inelastic Scattering
  - Gluon

    * Can be extracted from scaling violations of F_2, i.e. derivatives w.r.t Q^2 and x

    * The structure function F_L is a direct sensitivity to the gluon: $F_L = 0$ in quark-parton model, but $F_L \neq 0$ in NLO pQCD
  - Strange quark and antiquark

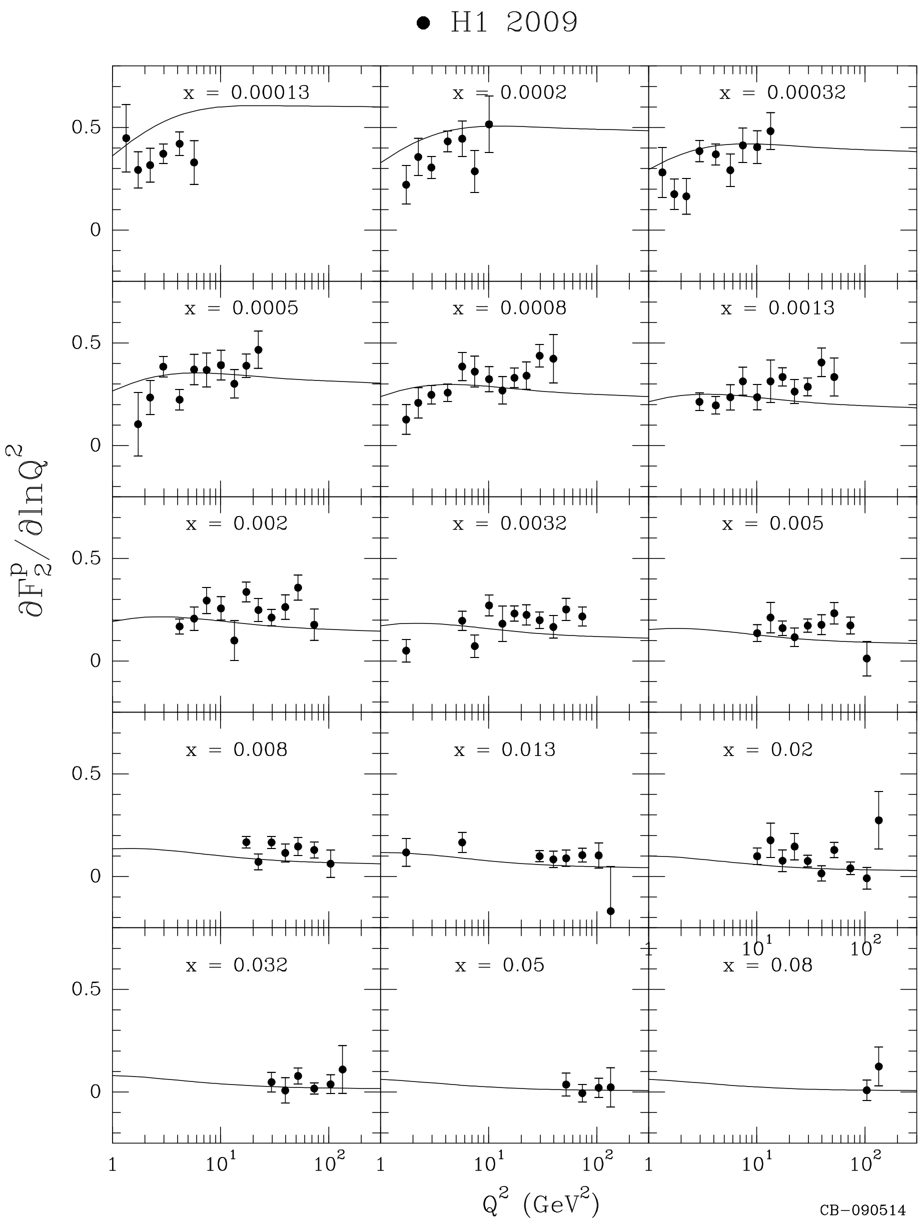
    First determined from NuTeV and tested against Semi-inclusive DIS from Hermes
  - Valence light quarks

    From $\gamma - Z$ interference in neutral current $e^{\pm}p$ collisions
- Polarized Deep Inelastic Scattering

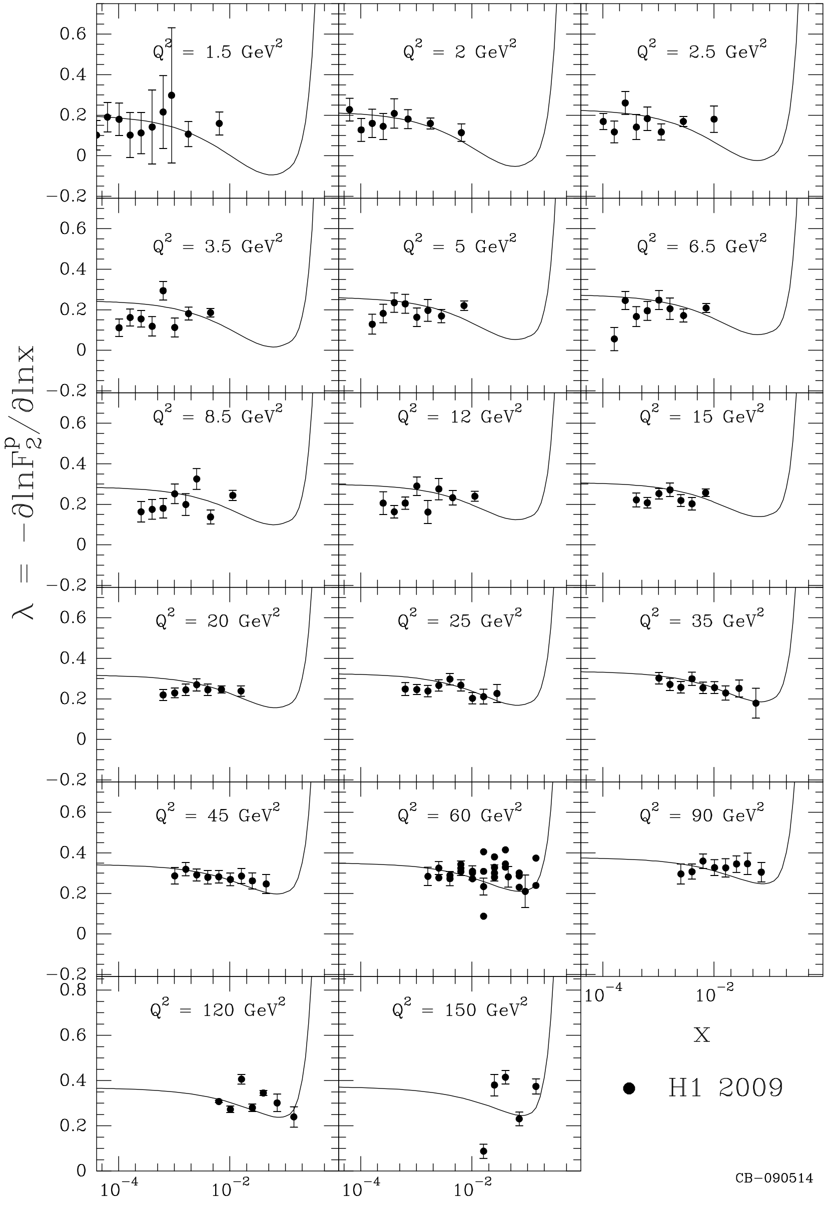
  * Polarized valence light quarks from Semi-inclusive DIS on Deuterium

  * Non-symmetric polarized sea quarks

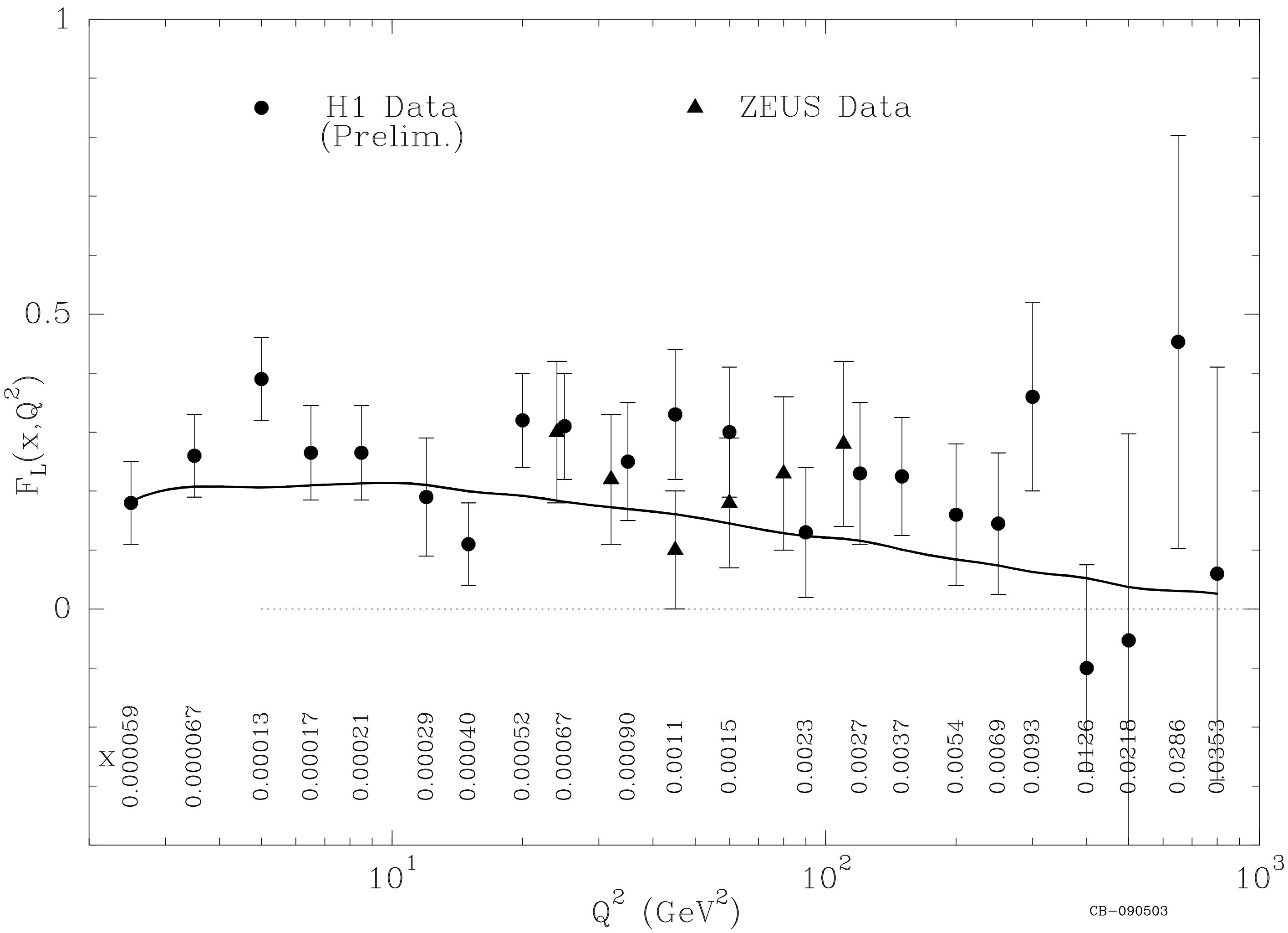
The derivative of F_2^p with respect to lnQ^2



The derivative of lnF_2^p with respect to lnx



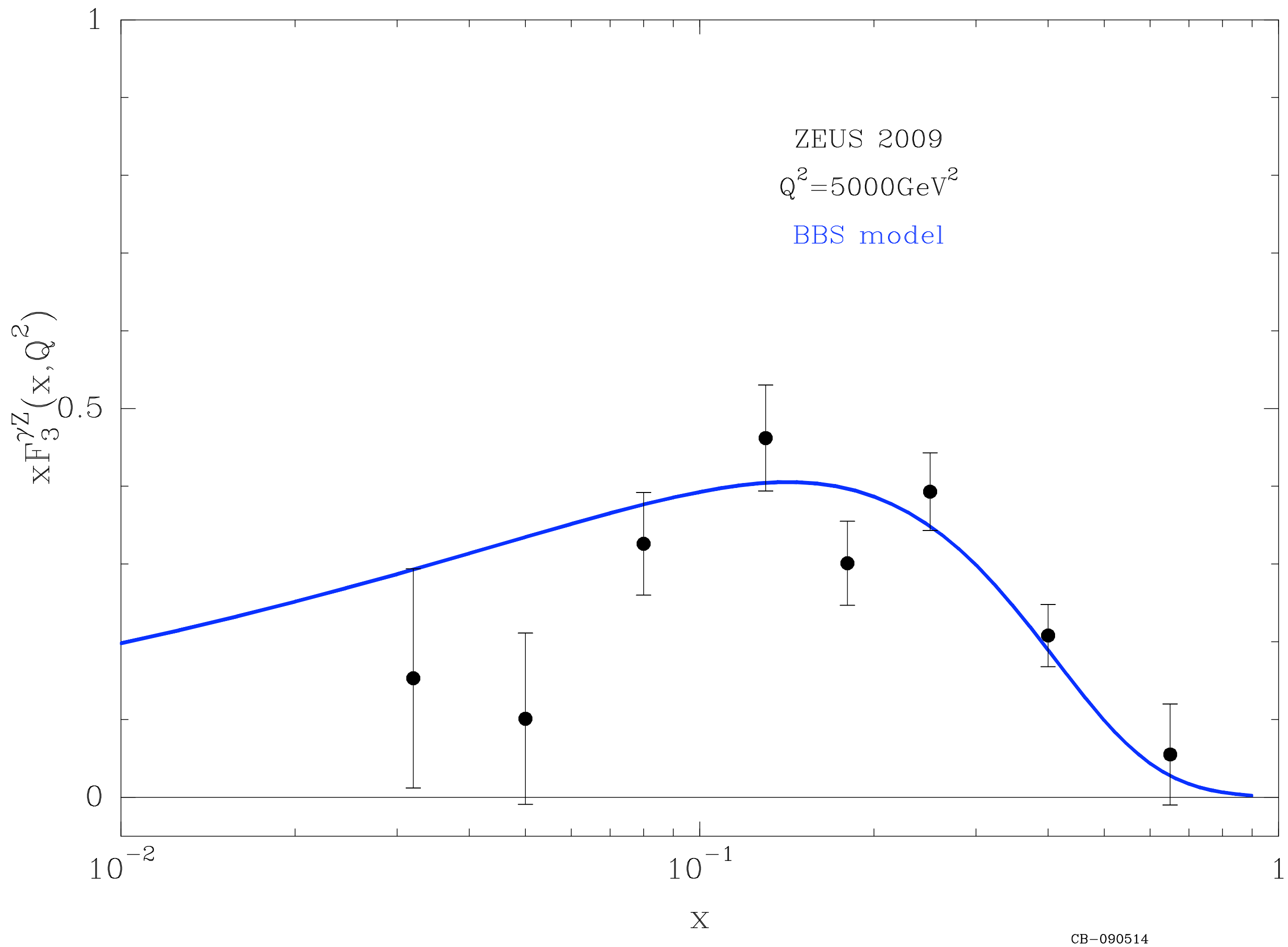
The longitudinal structure function F_L



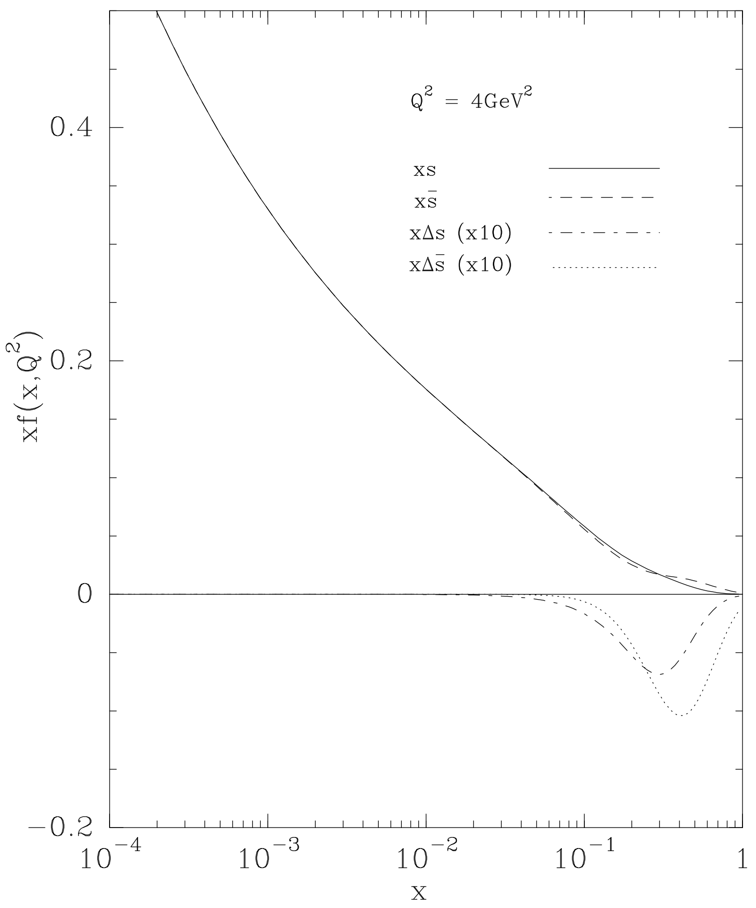
The structure function $F_3^{\gamma Z}$

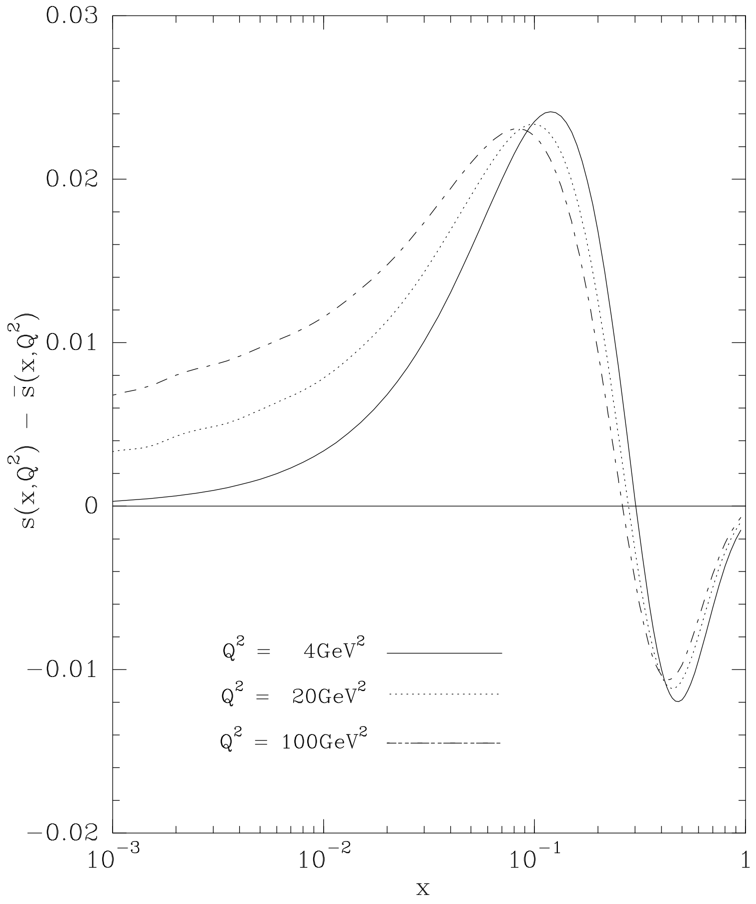
Interference term which can be isolated in neural current $e^{\pm}p$ collisions at high Q^2

We have to a good approximation $xF_3^{\gamma Z} = \frac{x}{3}(2u_v + d_v)$



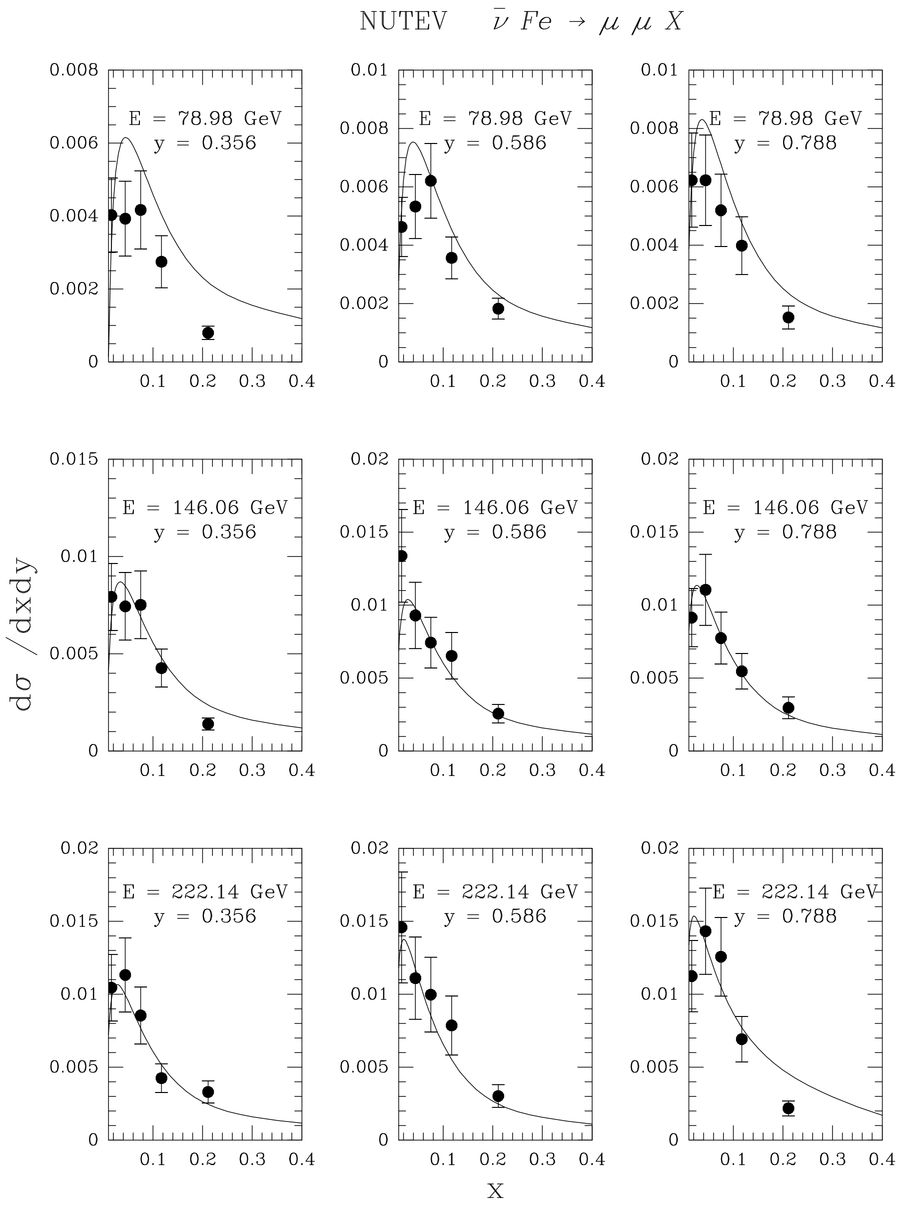
The strange quark and antiquark distributions



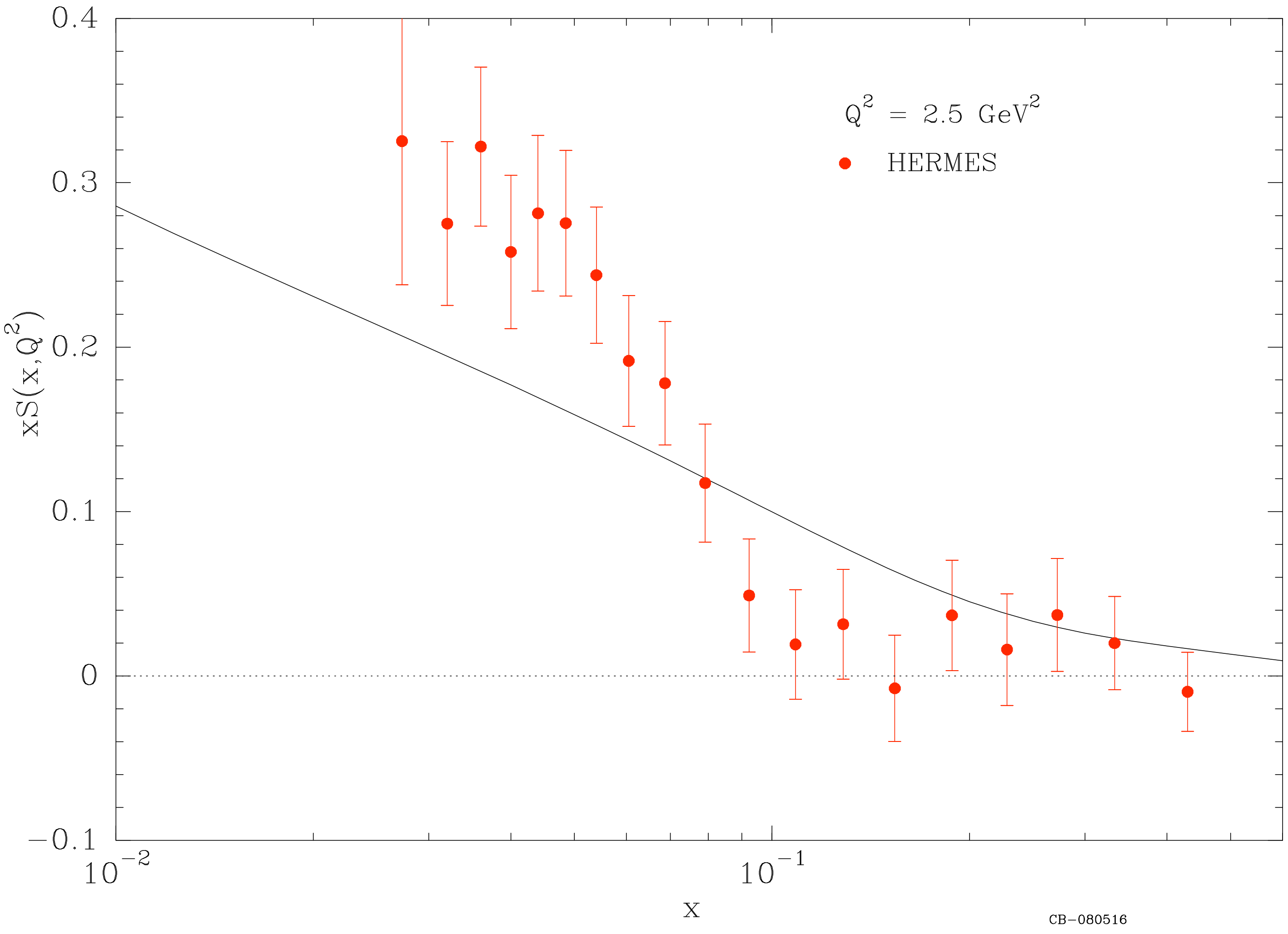


This requires four new parameters $X_{0s}^{\pm}, b_s, \tilde{A}_s$ to fit the CCFR and NuTeV neutrino data for dimuon production

The antineutrino NuTeV data

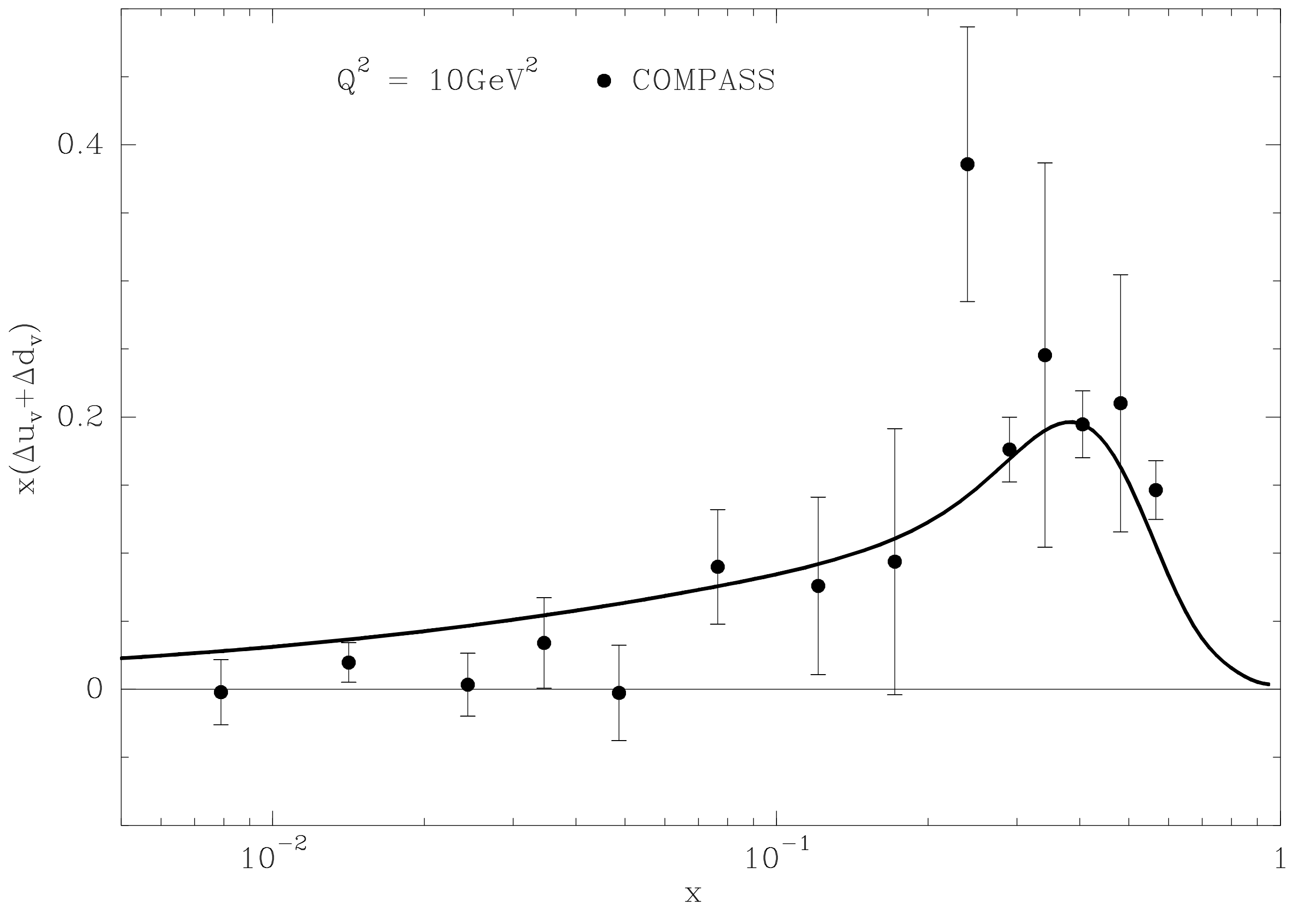


The $xS(x) = xs(x) + x\bar{s}(x)$ distribution from Hermes



The valence quark helicity distributions versus x

From semi-inclusive DIS $\mu p \to \mu h^{\pm} X$ can determine the valence quark helicity distributions
Combined with g_1^d it leads to $\Delta\bar{u} + \Delta\bar{d} = 0.0 \pm 0.04.03$, *i.e.* non-symmetric polarized sea



Conclusions

- A new set of PDF is constructed in the framework of a statistical approach of the nucleon
- All unpolarized and polarized distributions depend upon nine free parameters, with some physical meaning.
- New tests against experimental (unpolarized and polarized) data on DIS, Semi-inclusive DIS and hadronic processes are very satisfactory
- Special features and good predictive power

Not discussed here:

* The extension to the k_T dependence of the parton distributions
* A simple model for quark transversity distributions