Low-Q DIS and $\nu(\bar{\nu})$ charm production data in the global fit of PDFs

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OUTLINE

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- *Motivations*
- *Kinematics and phenomenological parameterizations*

II *Results from charged lepton scattering*

- *Data sets and uncertainties*
- *Relevance of low-Q Deep Inelastic Scattering (DIS) data*
- *Interplay between Leading and Higher Twists*
- *Uncertainties on Parton Distribution Functions (PDF)*

III *Application to neutrino (antineutrino) scattering*

- *Implications for the Paschos-Wolfenstein relation*
- *Determination of strange sea distributions and asymmetry*
- *Impact of neutrino (antineutrino) data on global fits*

MOTIVATIONS

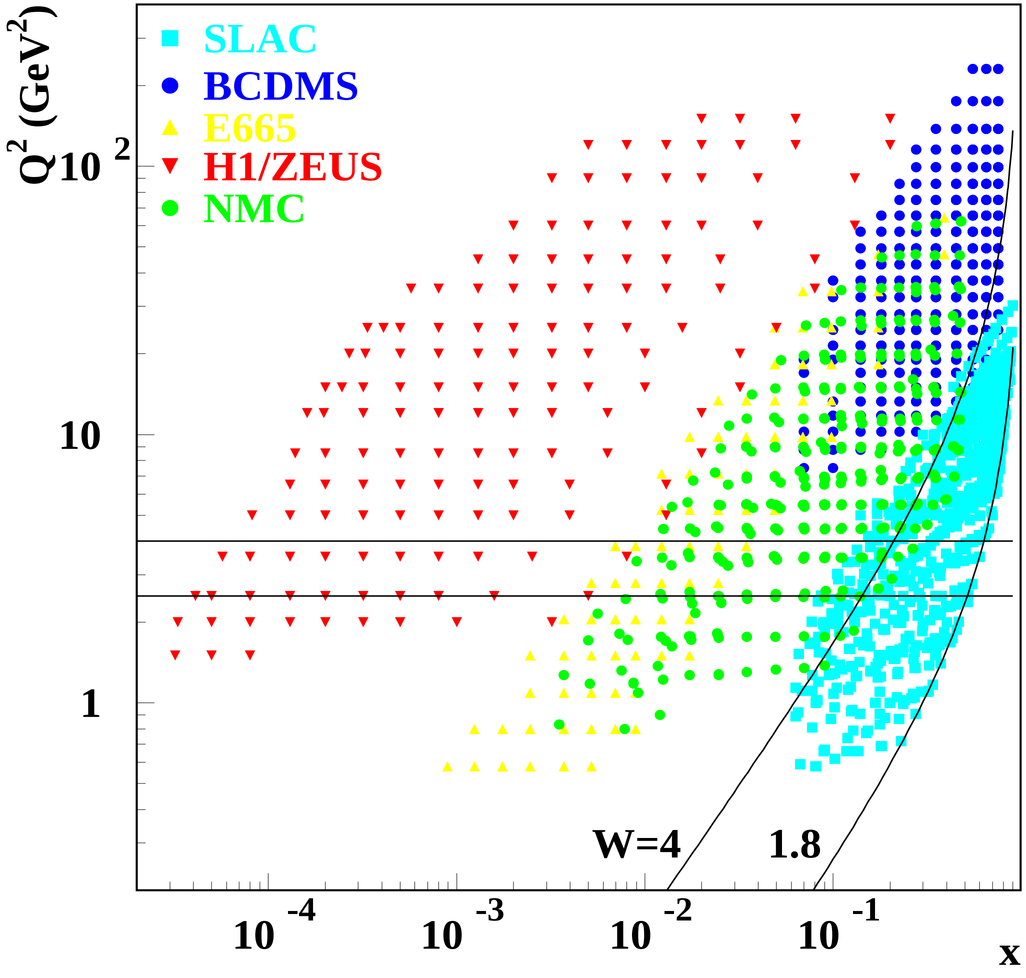
- *The charged lepton DIS cross-section falls with the transfered momentum Q as $1/Q^4$ and the biggest part of experimental data is collected at low Q values.*

- *The rate of QCD evolution of the DIS structure functions rises at small Q, therefore the sensitivity to the strong coupling constant is higher in this region.*

- *The QCD is valid only at asymptotically big values of Q and at small Q the power corrections (High Twists terms) have to be taken into account. Due to their nonperturbative nature, only phenomenological studies of existing data can constrain power corrections and therefore define the region of validity of perturbative QCD.*

- *A clarification of the low-Q region is crucial for modeling low energy $\nu(\bar{\nu})$ interactions.*

KINEMATICS OF INCLUSIVE DIS DATA



- *Regular practice followed is to cut the low-Q (low-W) data to avoid potentially dangerous regions, however is such case a lot of precise data is lost*
- *Extend the kinematic region used for global fits to* $\boxed{Q^2 > 1.0\ GeV^2}$ *and* $W > 1.8$ *GeV and study impact of low Q data*
- *Compare results with the previous default fit with* $Q^2 > 2.5\ GeV^2$

STRUCTURE FUNCTION PHENOMENOLOGY

- *Structure functions are parameterized in the NNLO QCD approximation by taking into account of the Target Mass Corrections (TMC) following Georgi-Politzer prescription and the dynamical High Twist (HT) terms:*

  $$F_{2,T}(x,Q^2) = F_{2,T}^{\mathrm{LT,TMC}}(x,Q^2) + \frac{H_{2,T}^{\tau 4}}{Q^2} + \frac{H_{2,T}^{\tau 6}}{Q^4} \qquad (OPE)$$

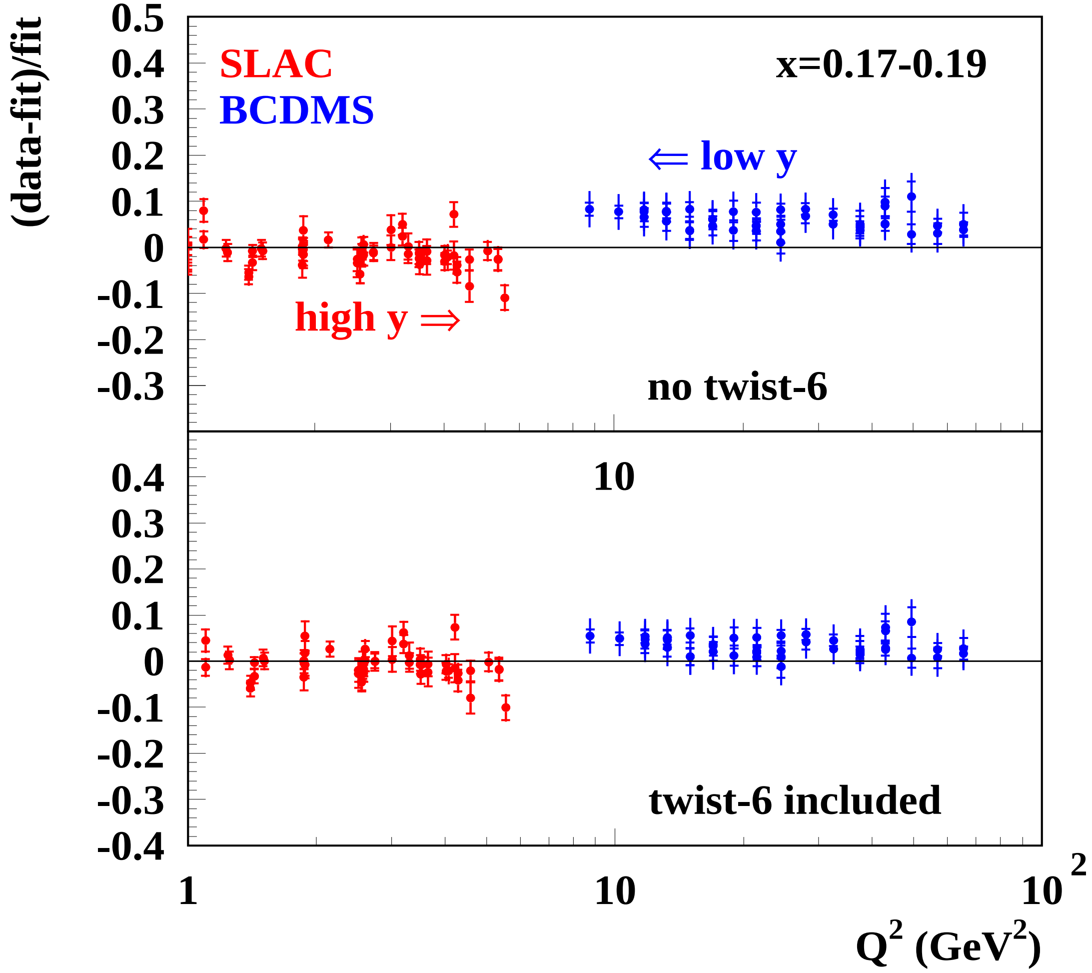
  The fixed-target Drell-Yan (DY) data are included into the sample for better determination of the sea PDFs. The DY cross-sections are also calculated at NNLO.

- *The Leading Twist (LT) parton distributions are parameterized at $Q_0^2 = 9$ GeV^2 as:*

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

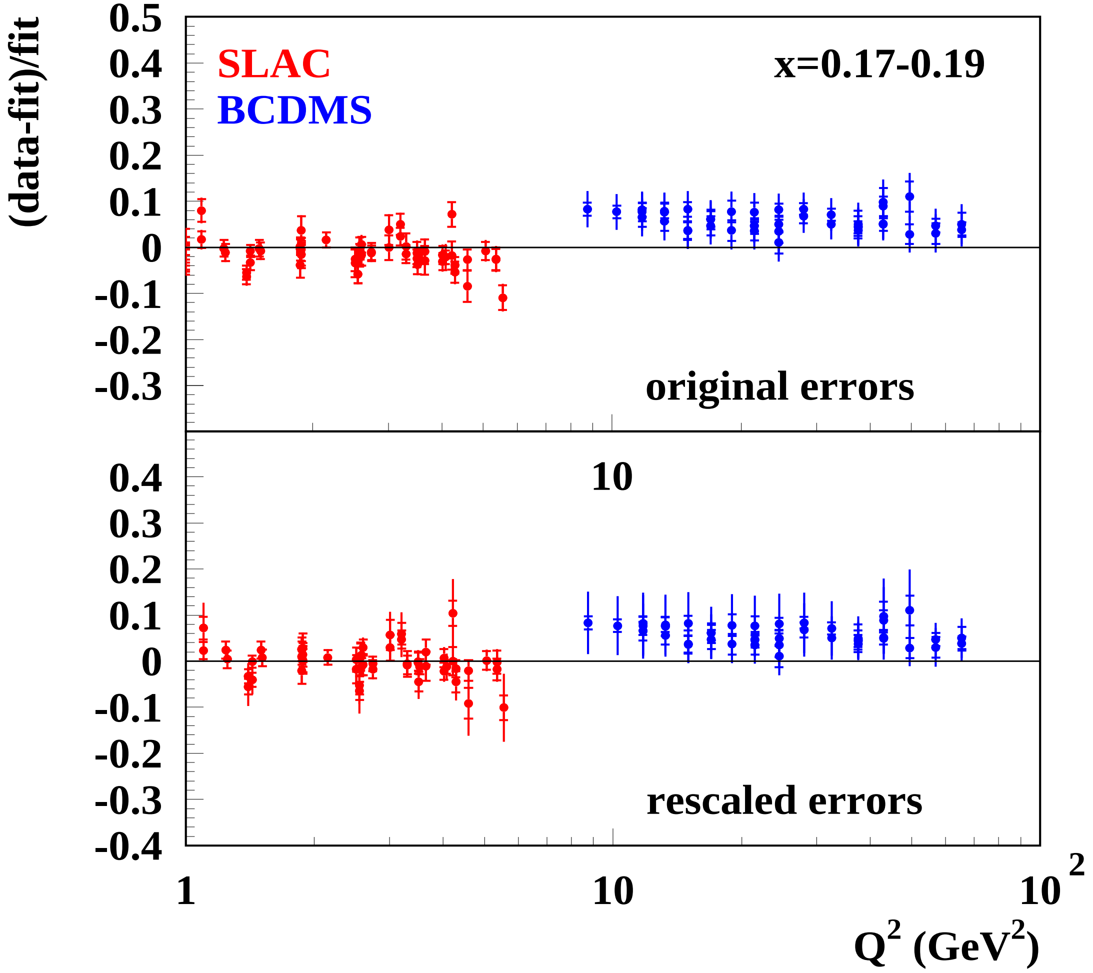
- *The dynamical Twist-4,6 terms ($H_{2,T}^{\tau 4,\tau 6}$) describing multi-parton correlations are parameterized as cubic splines with the values at $x = 0.1, 0.3, 0.5, 0.7, 0.9$ fitted from data. Few constraints are imposed:*
  - $H_{2,T}^{\tau 4,\tau 6}(0) = 0$ *since no clear evidence for saturation effects is found at HERA;*
  - $H_{2,T}^{\tau 6} = 0$ at $x > 0.5$ *due to the impossibility to extract them out of the resonance region.*

IMPACT OF DATA DISCREPANCIES



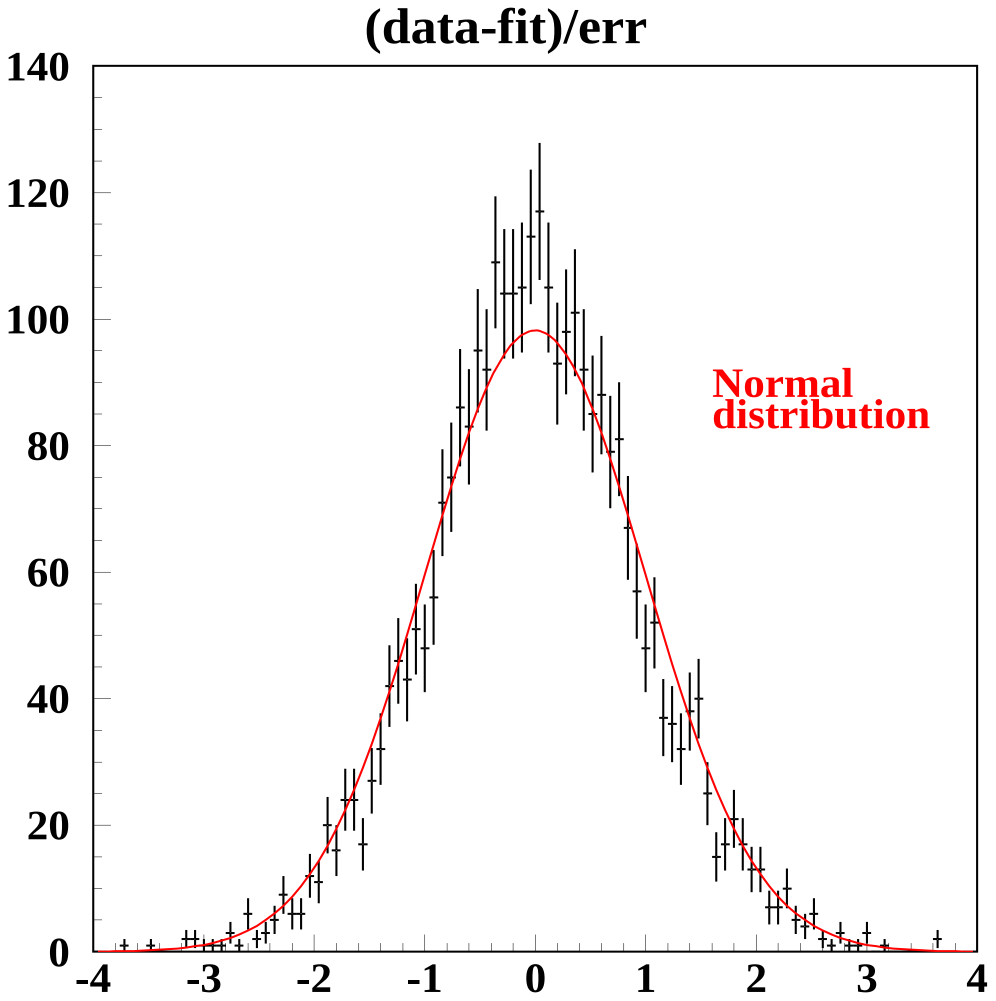
- A mismatch between SLAC and BCDMS data at $Q^2 = 5 \div 10$ GeV^2 but different y produces artificial Twist-6 terms in the global fit including low-Q data
- The behaviour of the fake Twist-6 terms contradicts the OPE convergence and distorts the F_T structure function (see our talk in the previous session)
- The final global fits are therefore performed by imposing $H^{\tau 6} \equiv 0$ in the whole x range

RESCALING EXPERIMENTAL UNCERTAINTIES



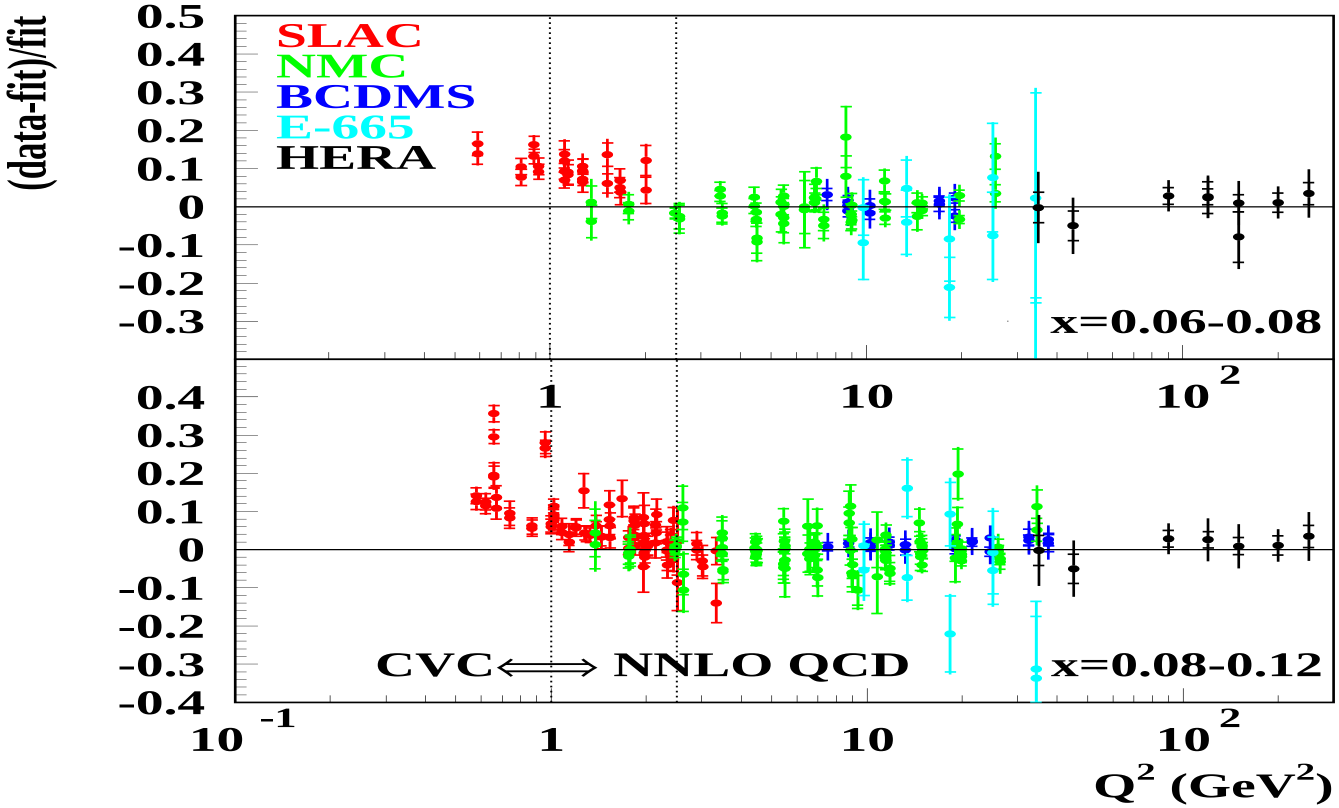
- *Increase the experimental uncertainties in SLAC and BCDMS data in order to achieve consistency between data sets. Rescaling of errors if* $| pull | > 1.5$.

- *Despite the estimation of the uncertainty is very conservative* ($\chi^2/DOF = 679/1275$ *for SLAC and* $429/605$ *for BCDMS) the impact of such rescaling is found to be marginal*



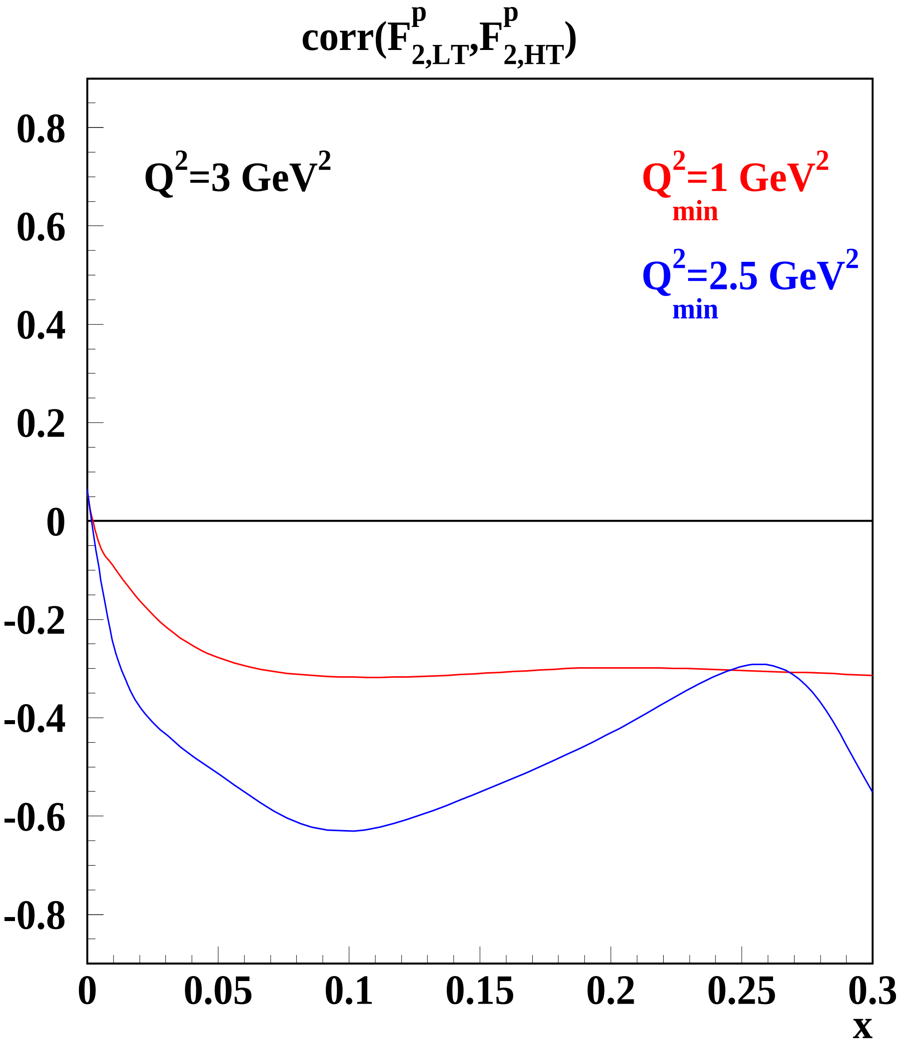
- The error rescaling was applied to all data sets with $\chi^2/DOF > 1$ in order to bring it equal to unity
- After the rescaling of experimental uncertainties we obtain $\chi^2/DOF = 2934/3067$ for the complete data set

RELEVANCE OF LOW Q DATA



- *The extrapolation of the fit with $Q^2 > 2.5$ GeV^2 does not describe data at lower Q^2*
- *The region $1.0 < Q^2 < 2.5$ GeV^2 contains crucial information to determine High Twists*

INTERPLAY BETWEEN LT AND HT



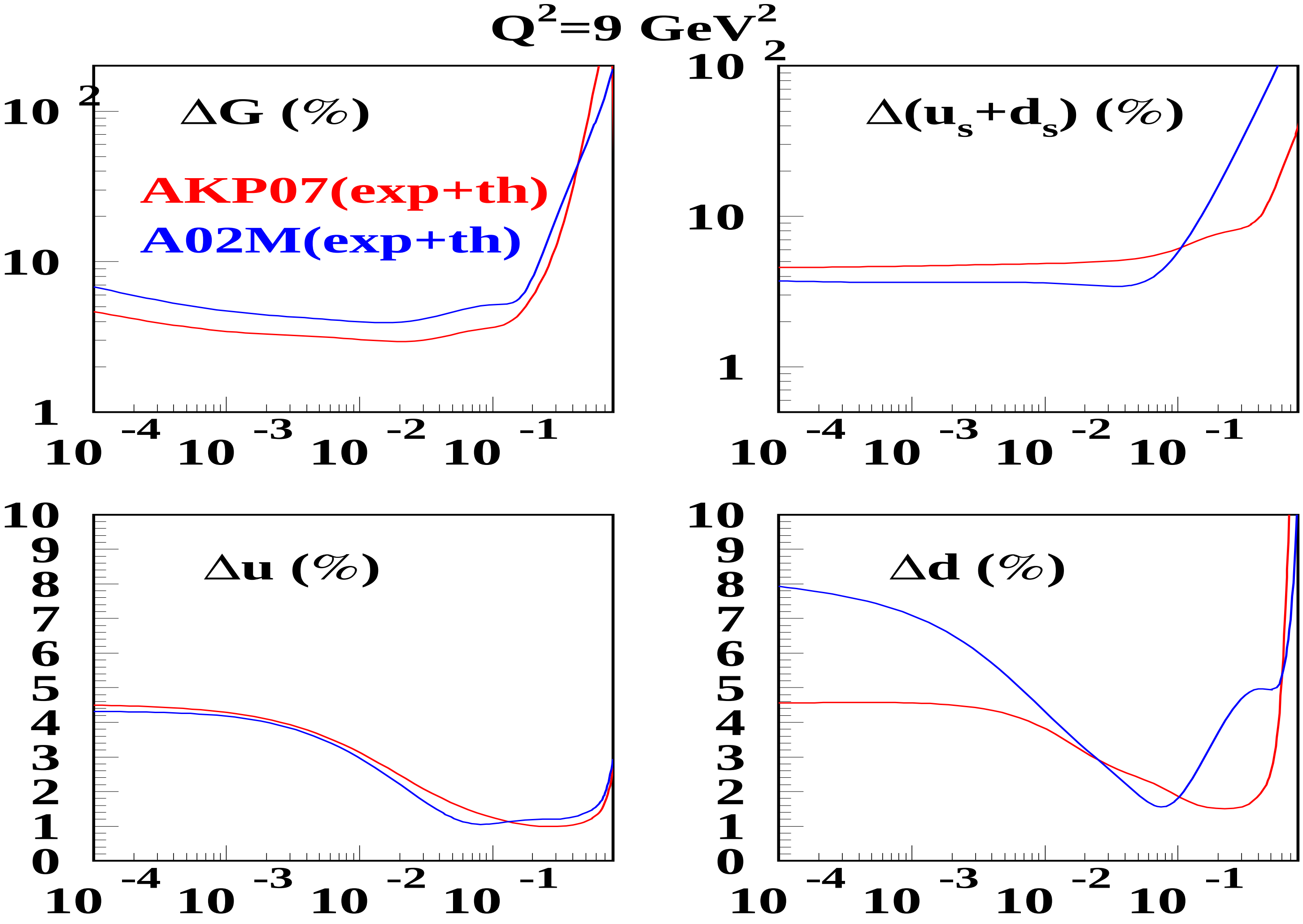
- *Improved separation of the Leading and Higher twists with the low-Q data included in the global fit (final without twist-6)*

  $\Longrightarrow$ *Largest correlation with gluons.*

- *The value of α_s is stable with respect to the Q^2 lower cut and it is in agreement with the non-singlet NNLO determination by Blumlein-Bottcher-Guffanti:*

Analysis	$\alpha_s(M_Z)$
$Q^2 > 1.0$ GeV^2	0.1128 ± 0.0011
$Q^2 > 2.5$ GeV^2	0.1125 ± 0.0014
BBG	0.1134 ± 0.0018
$Q^2 > 1.0$ GeV^2 **with twist-6**	0.1093 ± 0.0011

UNCERTAINTIES ON PARTON DISTRIBURIONS



IMPLICATIONS FOR PASCHOS-WOLFENSTEIN RELATION

- *The Paschos-Wolfenstein relation can be used to determine experimentally the weak mixing angle from Neutral Current (NC) and Charged Current (CC) interactions:*

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

where $s_W^2 = \sin^2\theta_W$ *with* θ_W *weak mixing angle*

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

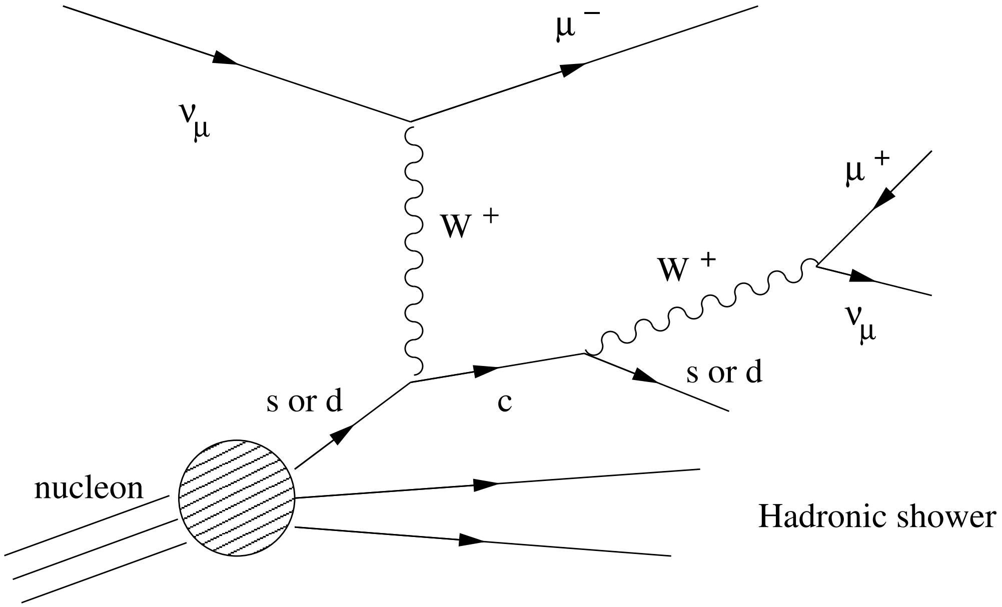
with $x^-_{0,1} = \int x(u_{\rm val} \pm d_{\rm val})dx$

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

PDF set	Order	$(x_1^-/x_0^-)_p$
CTEQ6	NLO	$0,42 \pm 0.03$
MRST01	NLO	0.43 ± 0.02
A02M	NNLO	0.43 ± 0.03
AKP07	**NNLO**	$\mathbf{0.424 \pm 0.006}$

$\Longrightarrow$ *Improvement by a factor of five in the x_1^-/x_0^- overall uncertainty*

DETERMINATION OF STRANGE SEA



Available dimuon statistics:

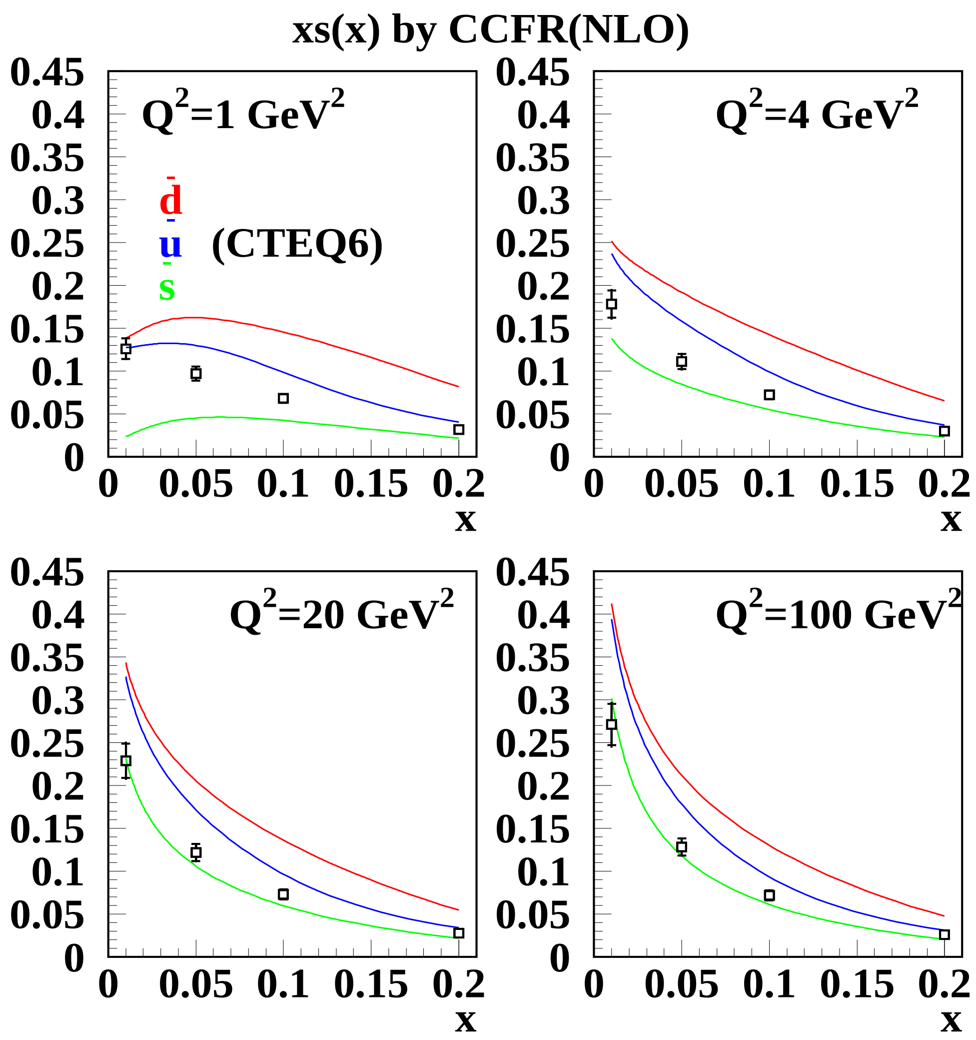
Type	*NuTeV*	*CCFR*	*Total*
ν	*5012*	*5030*	**10042**
$\bar{\nu}$	*1458*	*1060*	**2518**

- *Charm production in ν N DIS is a direct probe of the strange content of the nucleon:*

$$\frac{d\sigma_{\mu^\pm\mu^\mp}}{dxdy} = \int d\Gamma d\Omega \frac{d\sigma_{\mu^\mp c}}{dxdyd\Gamma} \times D_c(\Gamma) \times \Delta_c(\Omega) \, |_{E_{\mu^\pm}>5\ GeV}$$

where $D_c(\Gamma)$ is the charm fragmentation function and $\Delta_c(\Omega)$ the decay distribution.

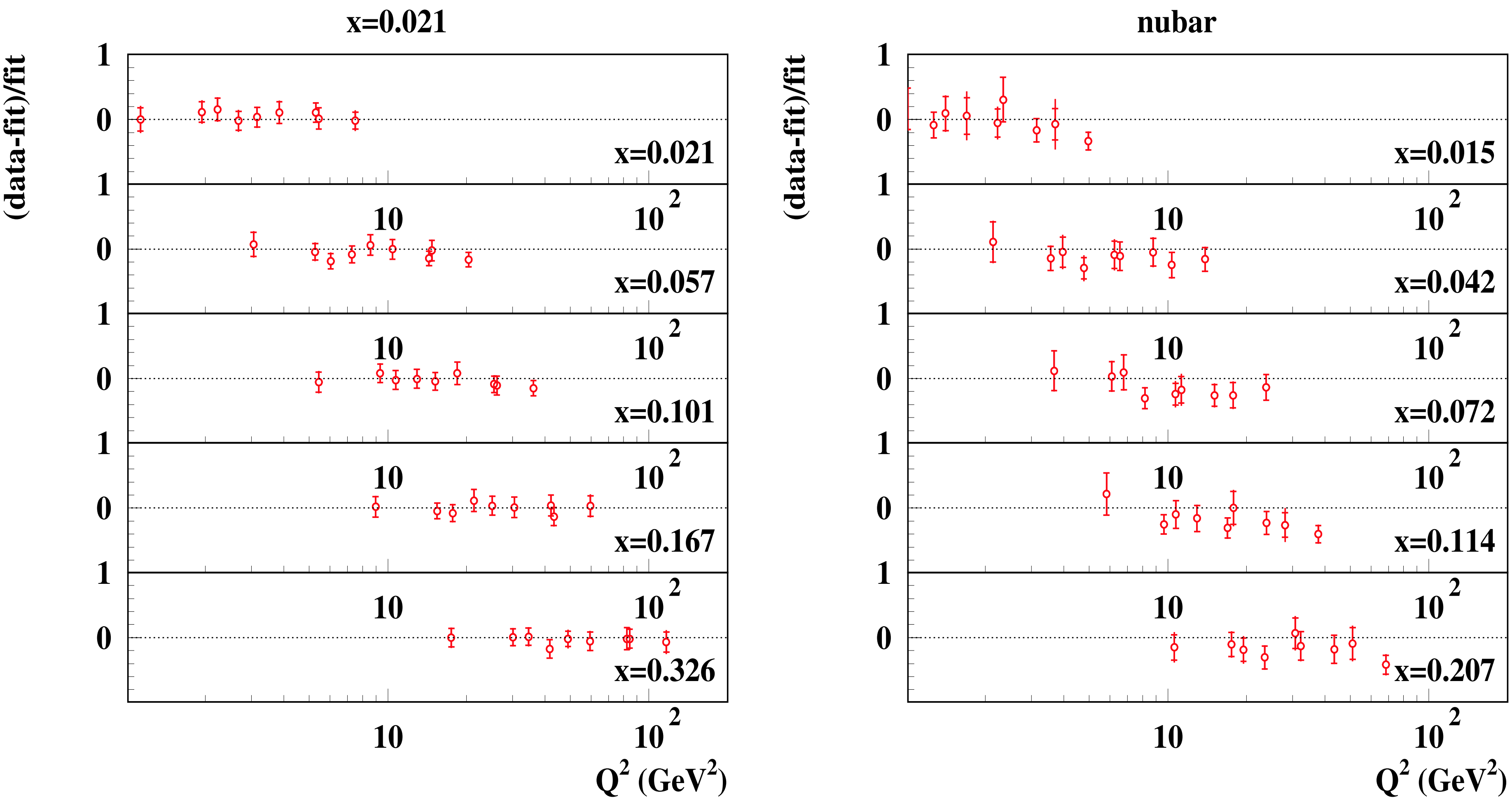
- *Add dimuon $\nu(\bar{\nu})$ cross-section data from NuTeV and CCFR to global fit of charged lepton DIS and Drell-Yan data. Use NLO acceptance corrections for fragmentation ($E_{\mu^\pm} > 5\ GeV$) kindly provided by D. Mason.*



- *As a first step try to use a fixed parameterization of $s(x)$ from CCFR determination in Z.Phys.C 65 (1995) 189.*

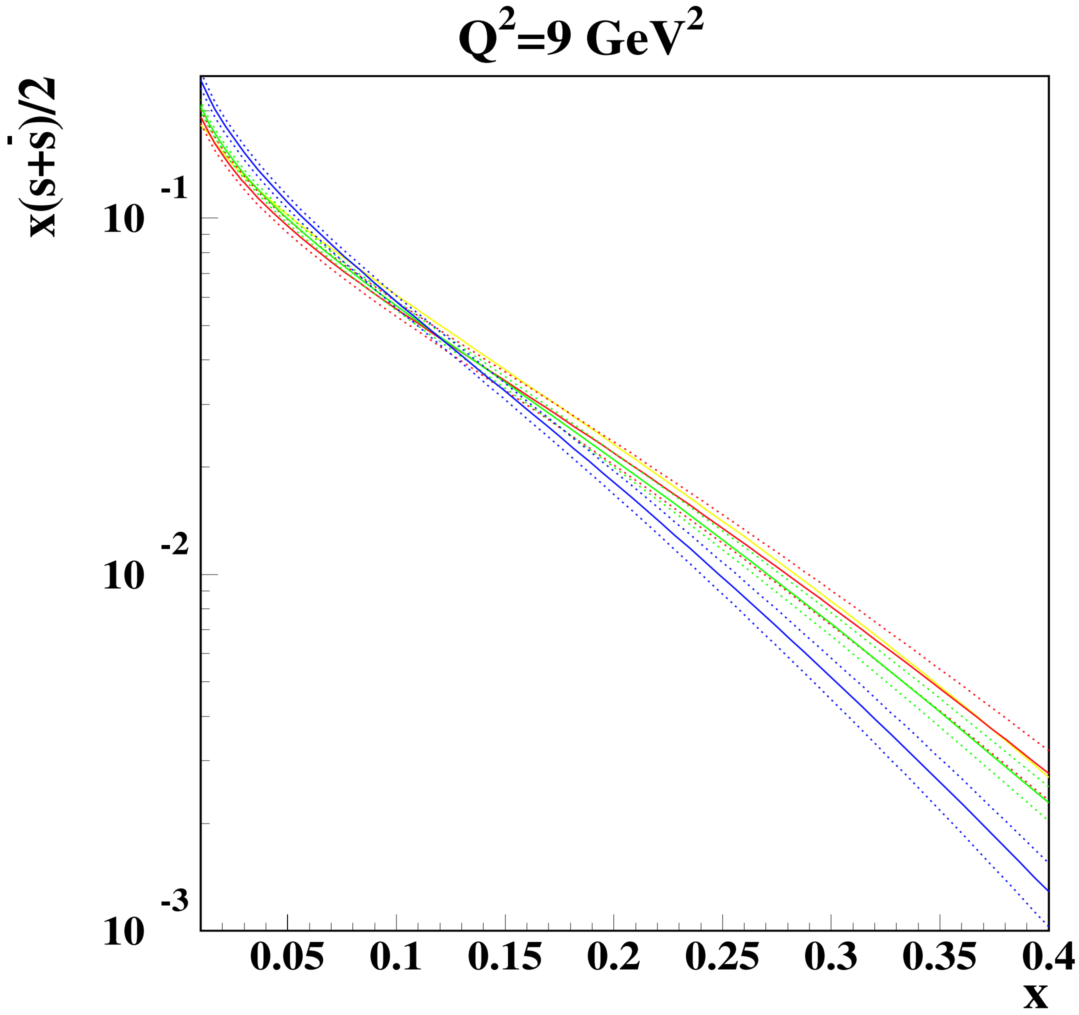
- *Problems to describe the complete set of CCFR points with QCD Q^2 evolution. If $s(x)$ parameterized from high Q^2, discrepancies at the lower Q^2 values and even negative values obtained in the extrapolation to low x and Q^2.*

- *Choose an intermediate Q^2 value and compare with direct extraction from the fit to dimuon cross-section data.*



- *Calculation of the charm cross-section in global fits performed at NLO in the fixed flavour scheme ($N_f = 3$). The mass of charm quark is initially set $m_c = 1.5$ GeV (*hep-ph/0109084*) and later determined from the fit itself.*

- *Semileptonic branching ratio fixed at $B_c = 0.10 \pm 0.01$ from previous determinations.*



- *Compare independent determinations of $s(\bar{s})$ from NuTeV and CCFR data:*

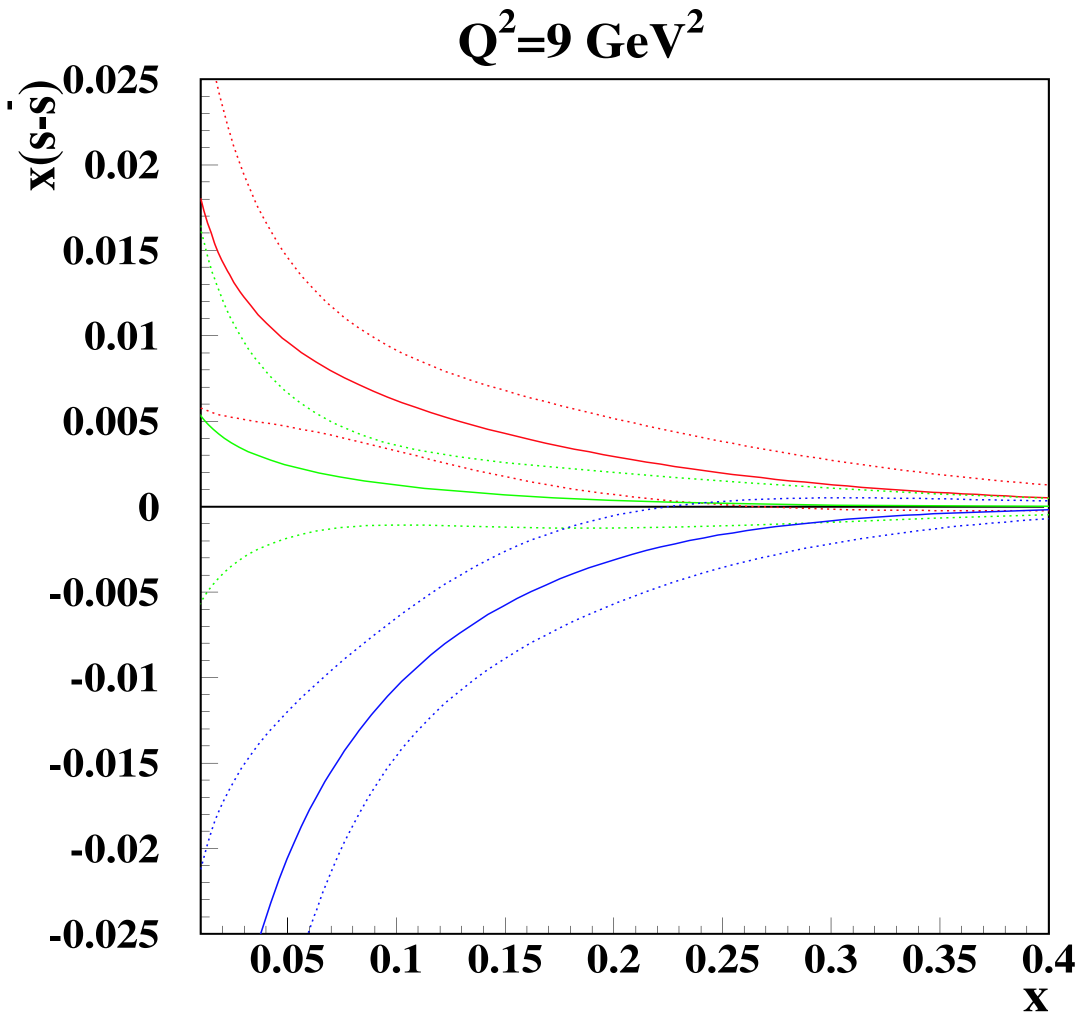
$$xs(x) = Ax^{\alpha}(1-x)^{\beta}$$

where A, α and β can be different for $s(x)$ and $\bar{s}(x)$ distributions

- *Results from NuTeV cross-section data (red) are very close to the parameterization previously defined from CCFR $s(x)$ extraction (yellow).*

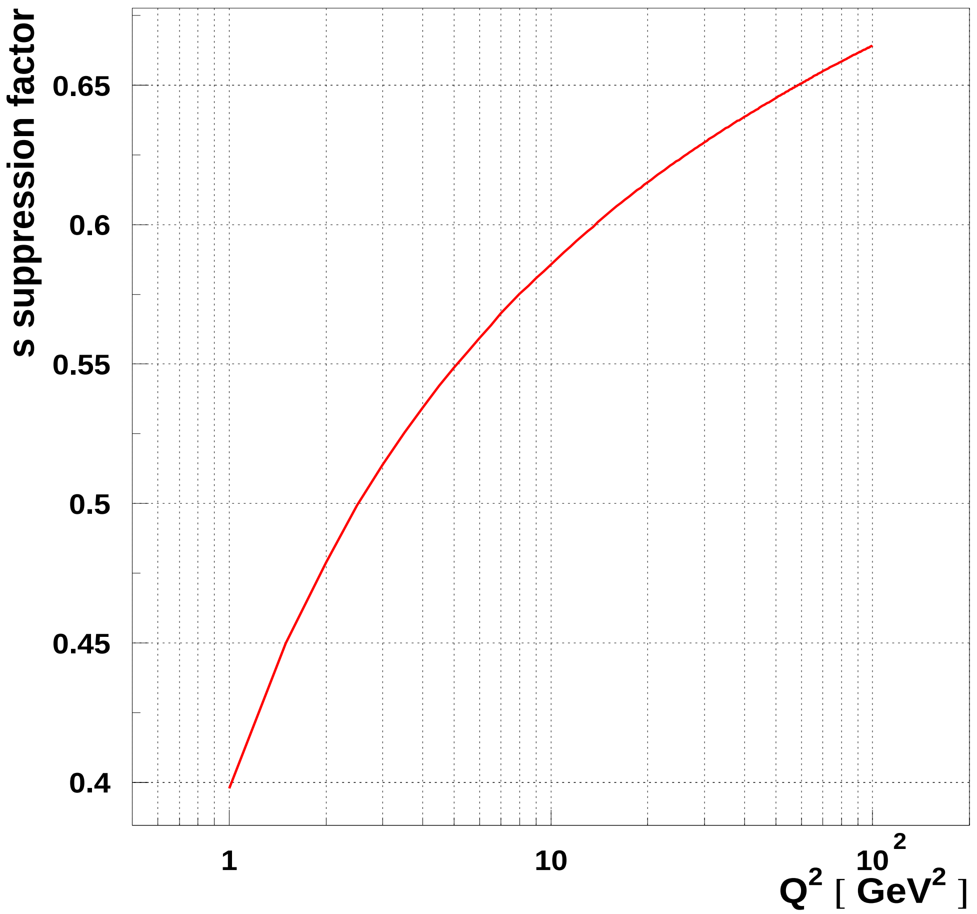
- *Results from CCFR data (blue) are somewhat higher at small x values, although the worse precision does not change dramatically the combined results (green).*

STRANGE SEA ASYMMETRY



- *Independent parameters are used for* $s(x)$ *and* $\bar{s}(x)$*, thus allowing the possibility of strange sea asymmetry*
- *Initially do not impose constraints on* $\int_0^1 x(s-\bar{s})dx$ *to check unbiased results.*
- *The curve extracted from NuTeV data (red) is consistent with what reported by the NuTeV analysis (D. Mason).*
- *The fit to CCFR data (blue) gives opposite sign for the asymmetry, so that the combined result (green) is consistent with zero in the whole* x *range.*

STRANGE SEA SUPPRESSION



- *Calculate the overall strange sea suppression factor η as:*

$$\eta = \frac{\int_0^1 \left[xs(x) + x\bar{s}(x)\right] dx}{\int_0^1 \left[x\bar{u}(x) + x\bar{d}(x)\right] dx}$$

- *The value of η is strongly Q^2 dependent.*
- *Our results from the global fit provide $\eta = 0.61$ at $Q^2 = 20$ GeV^2, which is substantially higher than typical numbers obtained by CCFR/NuTeV (0.42).*
- *It must be noted η is deeply connected to the specific parameterization of parton densities used*

IMPACT OF $\boldsymbol{\nu(\bar{\nu})}$ DIS ON GLOBAL FITS

- *Charm dimuon production in $\nu(\bar{\nu})$ DIS provides a direct probe of the strange sea quark distributions:*
  - *Charged lepton DIS and Drell-Yan data have marginal sensitivity to $s(x)$ and $\bar{s}(x)$*
  - *The NuTeV and CCFR data allow the determination of both $s(x)$ and the asymmetry $s(x) - \bar{s}(x)$*
  - *A new measurement is expected from the NOMAD experiment with a statistics of about 13,000 charm dimuons after background subtraction.*

- *The inclusive $\nu(\bar{\nu})$ A differential cross-section allows the extraction of the dynamical High Twist contribution to xF_3 (twist-4 $H_3^{\tau 4}$):*
  - *External constraints on $H_2^{\tau 4}$ and $H_T^{\tau 4}$ from charged lepton DIS*
  - *Simultaneous determination of $H_3^{\tau 4}$ $H_2^{\tau 4}$ and $H_T^{\tau 4}$ by global fit.*

- *Large potential of $\nu(\bar{\nu})$ A differential cross-sections on the determination of the Leading Twist, due to the precise sea/valence and flavour separation. However, discrepancies among existing data sets do not allow to fully exploit it at present.*

SUMMARY

- *The low-Q region of DIS data down to $Q^2 = 1.0$ GeV^2 plays an important role:*
  - *Improved separation of Leading from Higher Twists*
  - *Crucial information to model low-Q cross-sections*
  - *Reduced uncertainties on α_s and d/u separation*

- *The dynamical Twist-4 terms contribute to structure functions at $Q^2 < 10$ GeV^2 and affect uncertainties on the Leading Twist, in particular for α_s and gluons*

- *Charm dimuon data from $\nu(\bar{\nu})$ DIS provide valuable constraints on strange sea:*
  - *Some differences found between NuTeV and CCFR data samples*
  - *Combined analysis of NuTeV and CCFR data within global fits indicates a strange sea asymmetry $s(s) - \bar{s}(x)$ consistent with zero within errors in the whole x range*
  - *Overall strange sea suppression factor $\eta = 0.61$ obtained at $Q^2 = 20$ GeV^2*

- *The new set of PDFs from the extended low-Q fit is now ready and will be released soon together with the corresponding High Twist parameterizations.*