Modeling νN interactions with account of the QCD corrections up to $O(\alpha_s^3)$

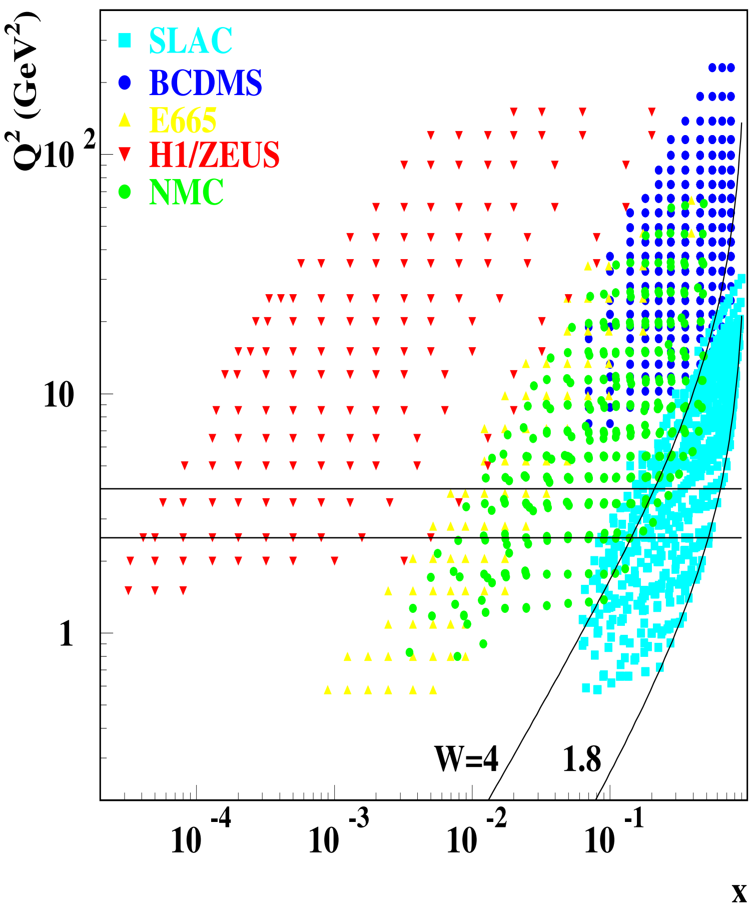
(S.Alekhin, IHEP, Protvino)

in collaboration with

S.Kulagin (INR, Moscow)

R.Petti (CERN & South Carolina U.)

Validation of the factorization at low Q



- For the NOMAD data $< Q^2 >\sim 5$ GeV^2, relatively low value
- The low-Q charged-leptons data are used to tune the PDFs and the high-twist terms
- The high-order QCD corrections, up to $O(\alpha_s^3)$, are taken into account

The HO QCD corrections in DIS

Splitting Functions (up to $O(\alpha_s^3)$):

(Moch-Vermasseren-Vogt 04)

Massless quarks coefficient functions (up to $O(\alpha_s^3)$)

(Zijlstra-van Neerven 91-92)

(Kazakov-Kotikov 92)

(Vermasseren-Moch-Vogt 05)

Heavy quarks coefficient functions (up to $O(\alpha_s^2)$):

(Laenen-Riemersam-Smith-van Neerven 92-93)

Non-QCD corrections

- The DIS structure functions are calculated using OPE

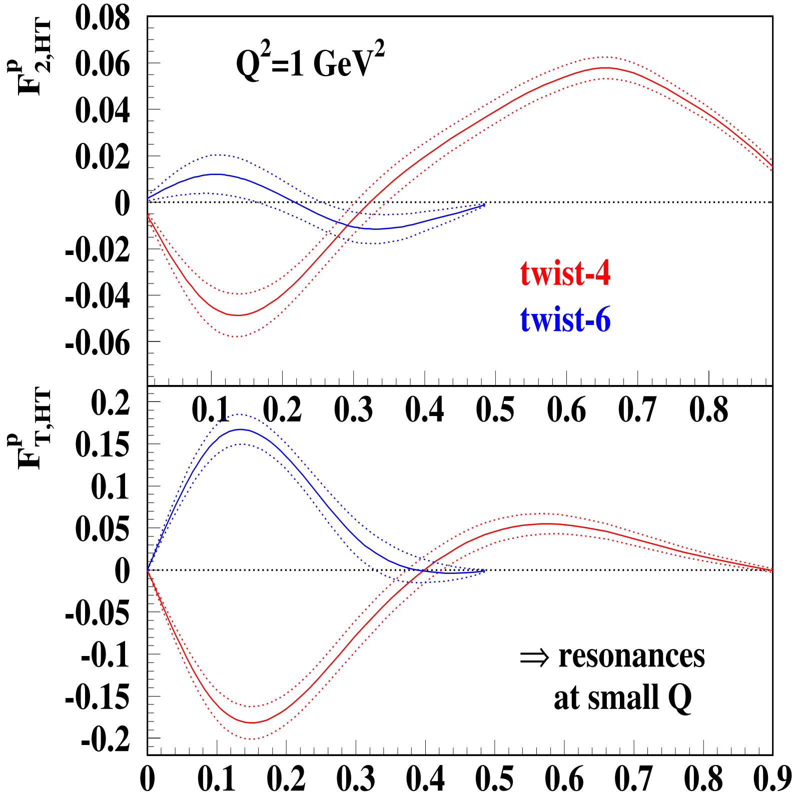
$$F_{2,\mathrm{T}}(x,Q) = F_{2,\mathrm{T}}^{\mathrm{LT}}(x,Q) + \frac{H_{2,\mathrm{T}}^{(2)}(x)}{Q^2} + \left(\frac{H_{2,\mathrm{T}}^{(4)}(x)}{Q^4}\right)$$

  The leading-twist terms (entirely dominant at $Q^2 \gtrsim 10$ GeV^2). The twist-4 terms (contributes at $Q^2 \lesssim 10$ GeV^2) and the twist-6 terms (might contribute at $Q^2 \lesssim 3$ GeV^2) – no QCD evolution.

- The target-mass correction by Georgi-Politzer

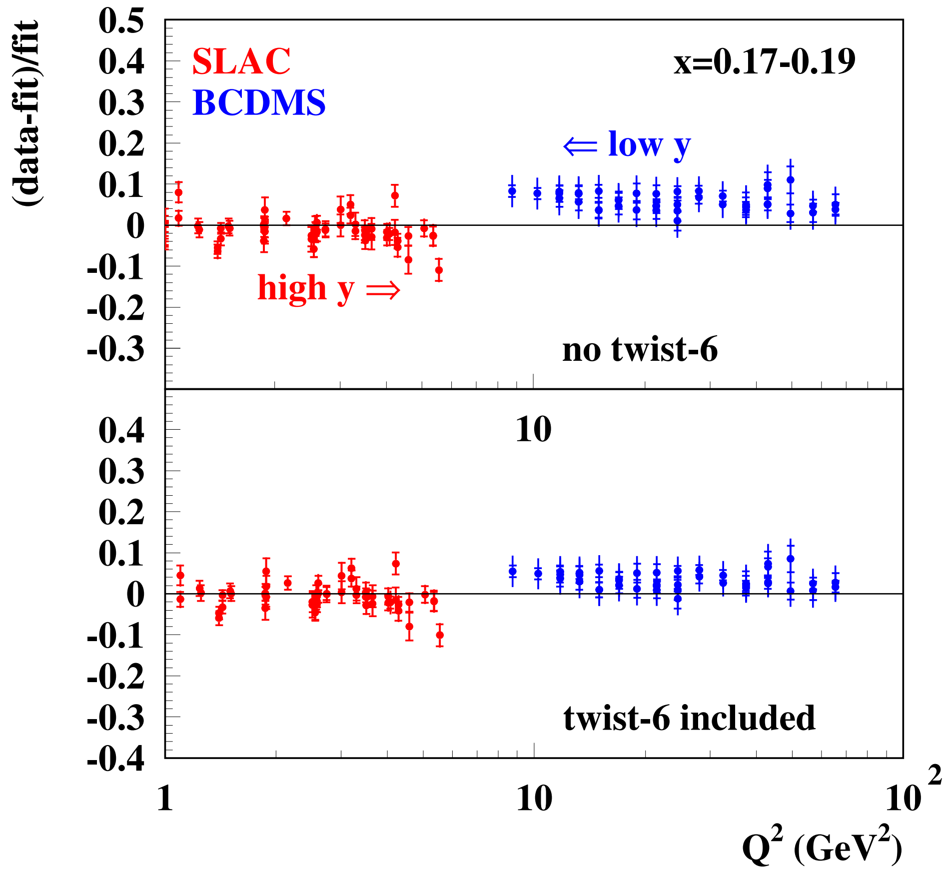
- The deuteron nuclear corrections by Kulagin-Petti

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



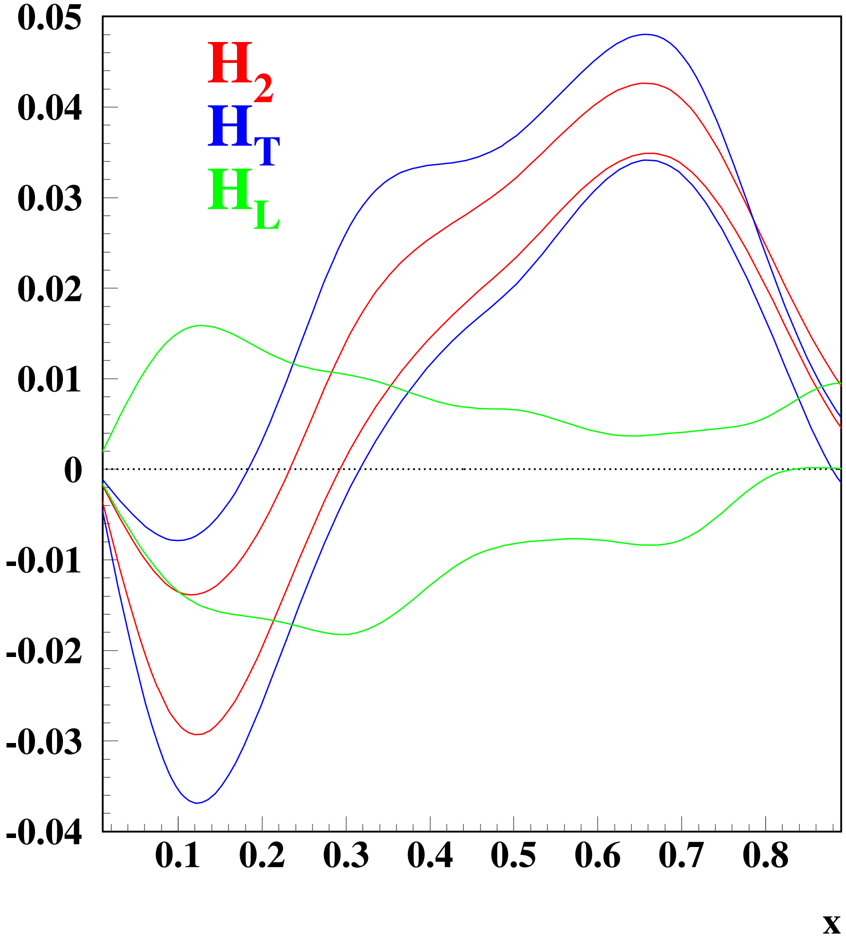
- The HT terms in F_2 demonstrate good convergence: $H_2^{(4)}$ is much smaller than $H_2^{(2)}$ and comparable to 0 within the errors.
- For F_{T} the picture is different: the magnitudes of the twist-4 and twist-6 terms are comparable and somehow compensate each other (*poor convergence of the OPE?*)

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

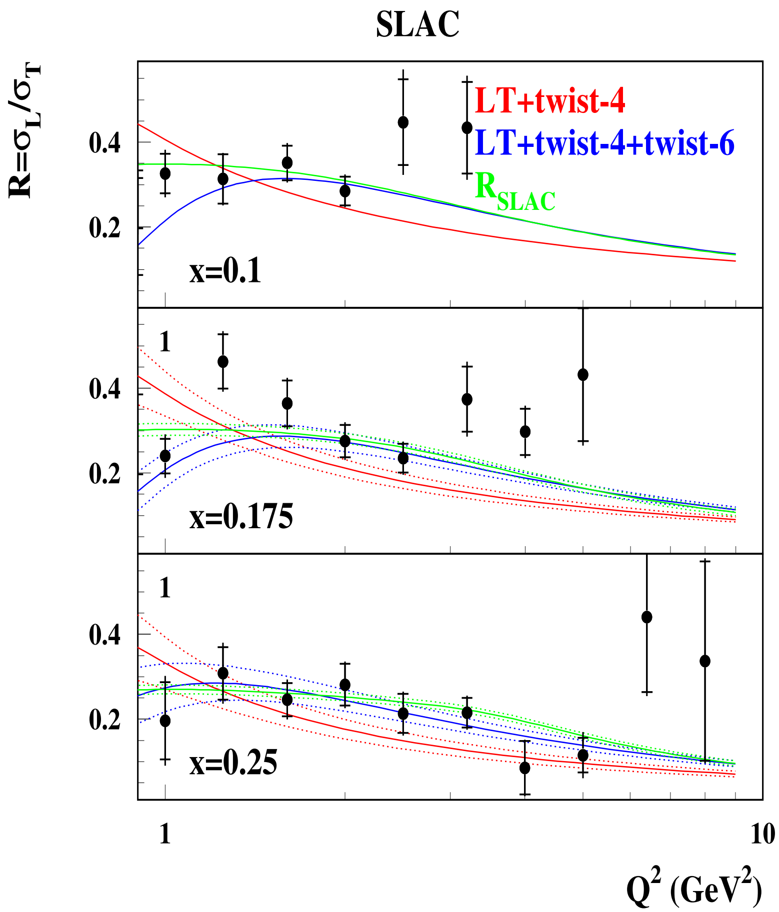


The twist-6 terms in F_{T} arise due to mismatch of the SLAC and BCDMS data at $Q^2 = 5 \div 10$ GeV^2 and *different* y. The corrections of $Q^2 > 1$ GeV^3 to the coefficient functions do not help to resolve this discrepancy; the EW corrections seems not to be responsible too. In the final version of the fit twist-6 terms are set to 0.

The HT terms of the final fit



The HT terms in F_2 and $F_{\rm T}$ averaged over proton and neutron are very similar within the errors; therefore the HT term in F_L is comparable to 0. The constraint $H_2^{lN} = H_{\rm T}^{lN}$ was further imposed everywhere.

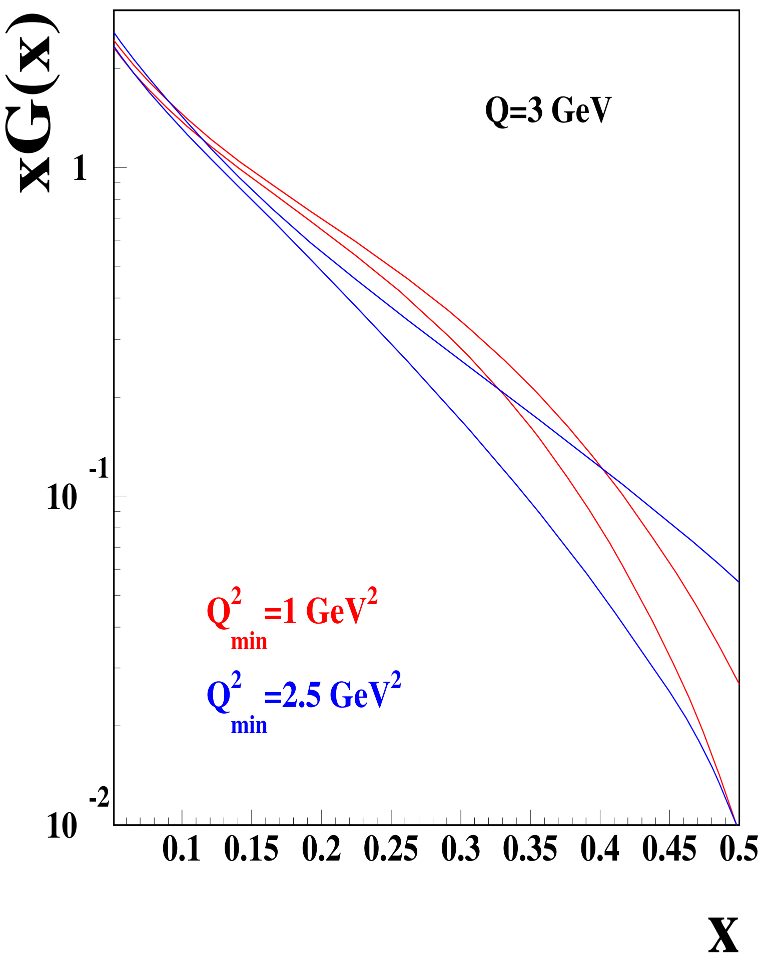


The excess in SLAC data on R at $x \sim 0.2$ with respect to the QCD predictions was considered as evidence of the big HT contribution to R (and F_{L})

(Miramontes-... 89)

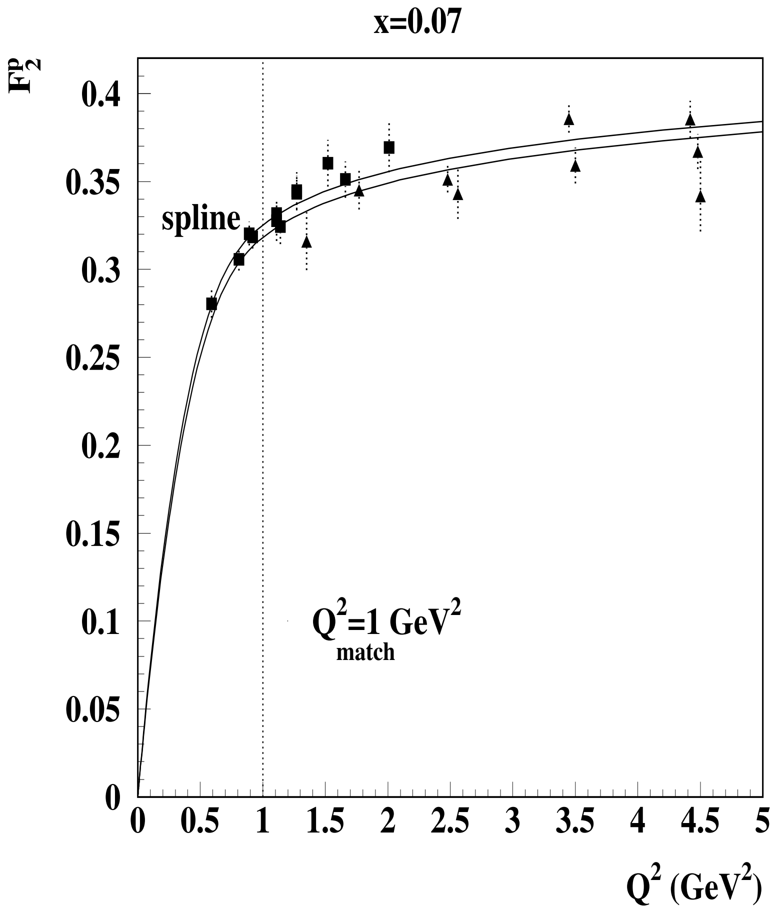
Meanwhile this excess is evidently connected with the SLAC/BCDMS discrepancy and can be hardly attributed to the HT contribution.

Gluons in the low-Q DIS fit



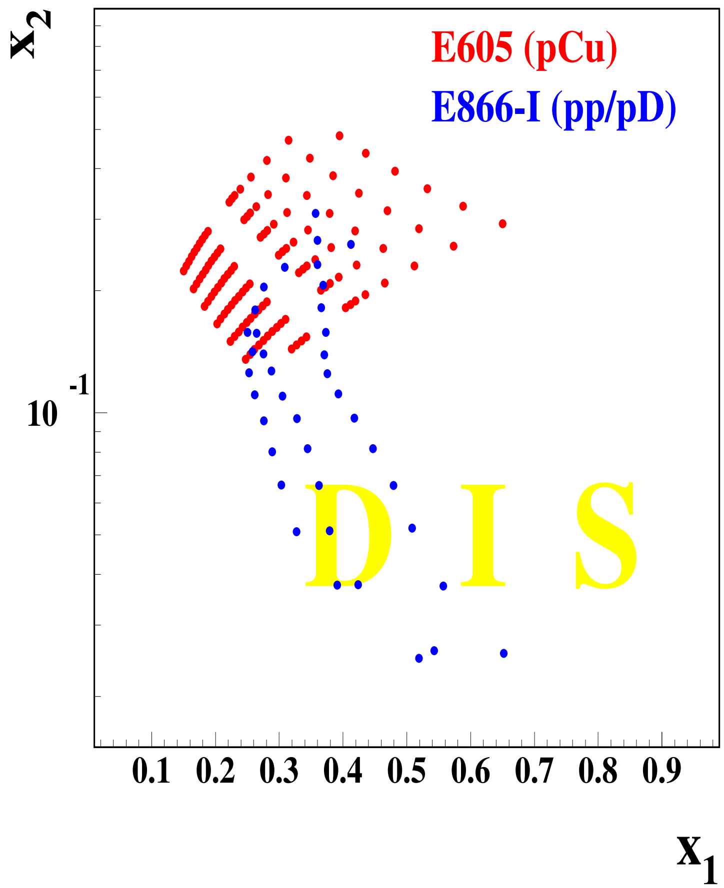
The change in G(x) due to the low-Q data is 2-3σ at $x \sim 0.2$; this is correlated with the change in the structure function R. Other PDFs are less affected by the low-Q data.

Extrapolation of the fit to $Q = 0$



- $F_2 \sim Q^2$, $F_L \sim Q^4$ at $Q \to 0$ from the vector current conservation
- cubic spline interpolation between $Q = 1$ GeV and $Q = 0$.

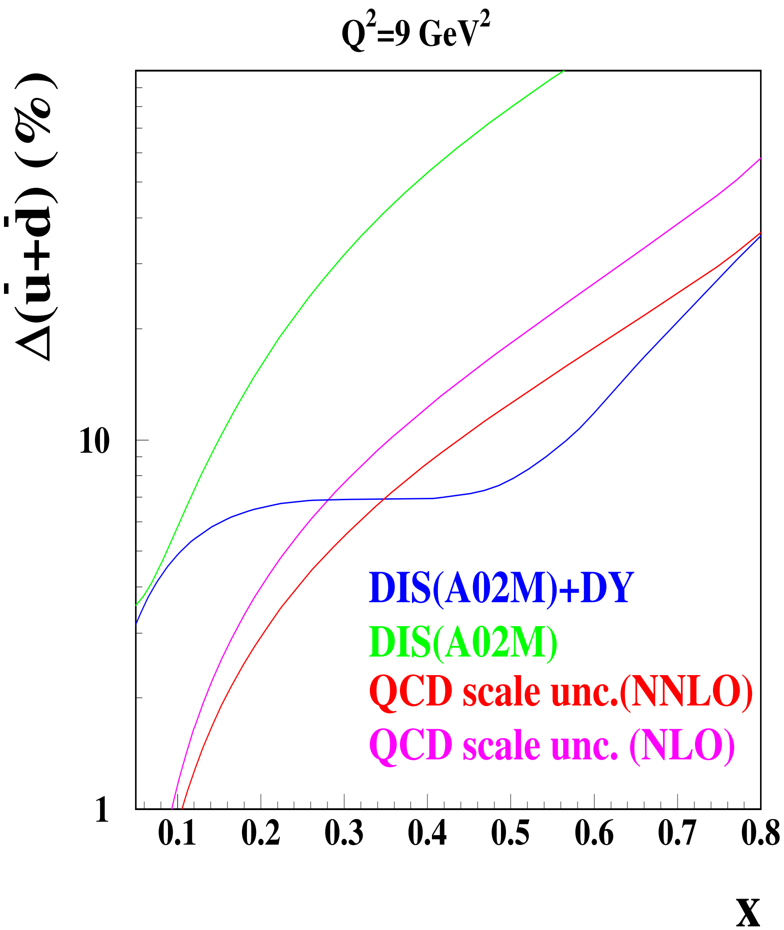
The Drell-Yan data kinematics



The Drell-Yan data are supplementary to the DIS ones.

Impact of the DY data on the sea distribution

(sa-Melnikov-Petriello 06)



- Experimental errors in the sea is < 20 % at $x \lesssim 0.7$.
- The errors in PDFs due to variation of the DY scales are comparable to the experimental ones (*the corrections of* $O(\alpha_s^2)$ *by Anastasiou-Dixon-Melnikov-Petriello are crucial at this point*).

Determination of the strange sea from the dimuon neutrino data (NuTeV and CCFR)

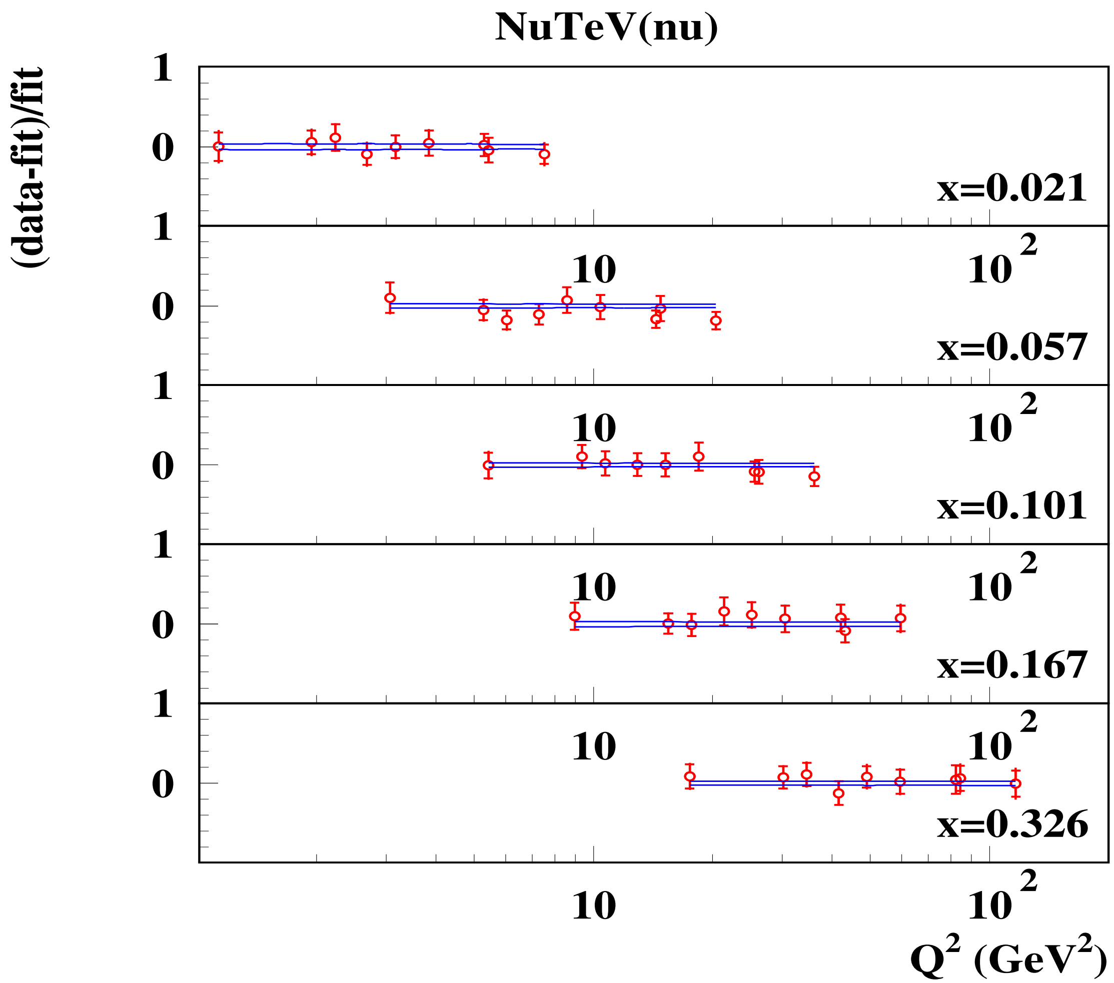
$$\nu_\mu + \mathrm{N} \longrightarrow \mu^- + c + \mathrm{X}$$
$$\hookrightarrow \mu^+ + X$$

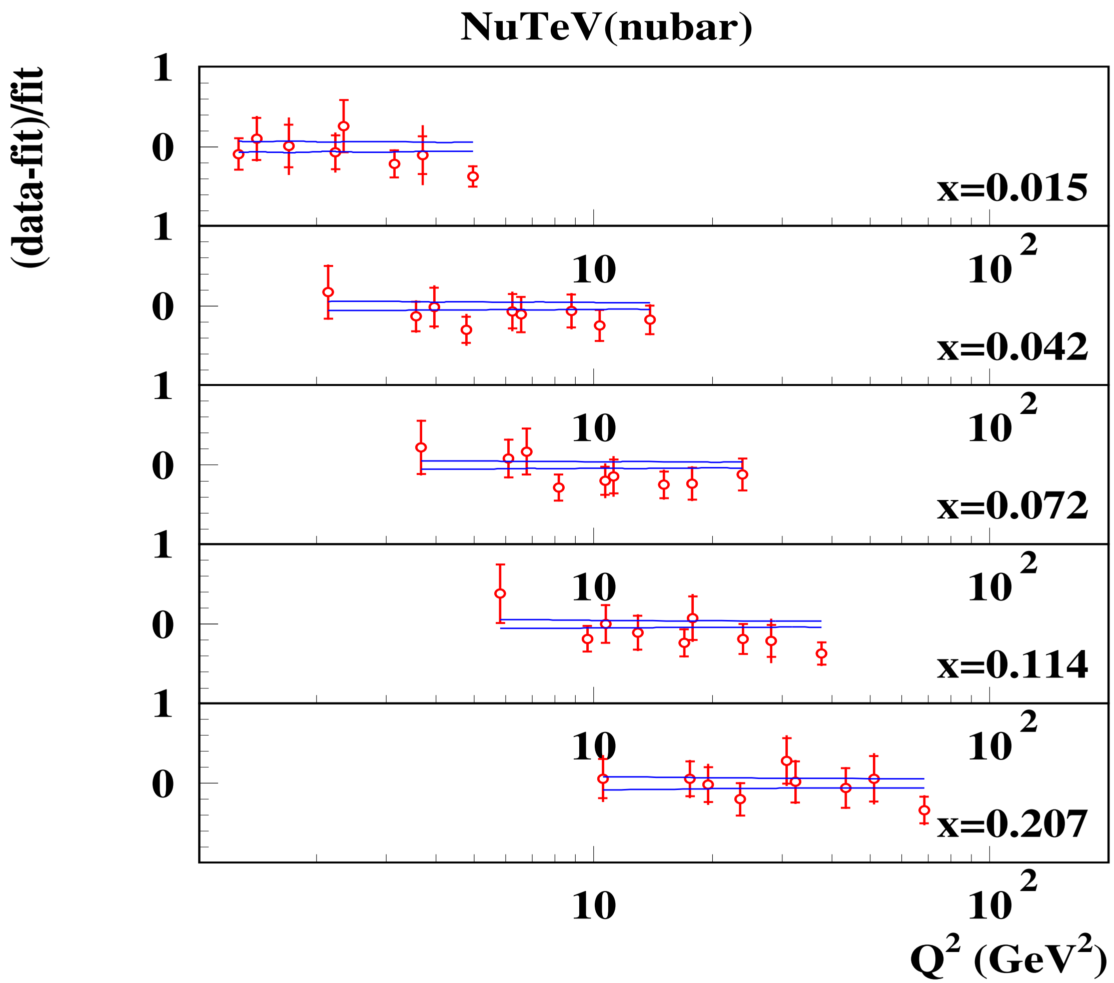
$$W^+ s \longrightarrow c \qquad O(\alpha_\mathrm{s}^0)$$

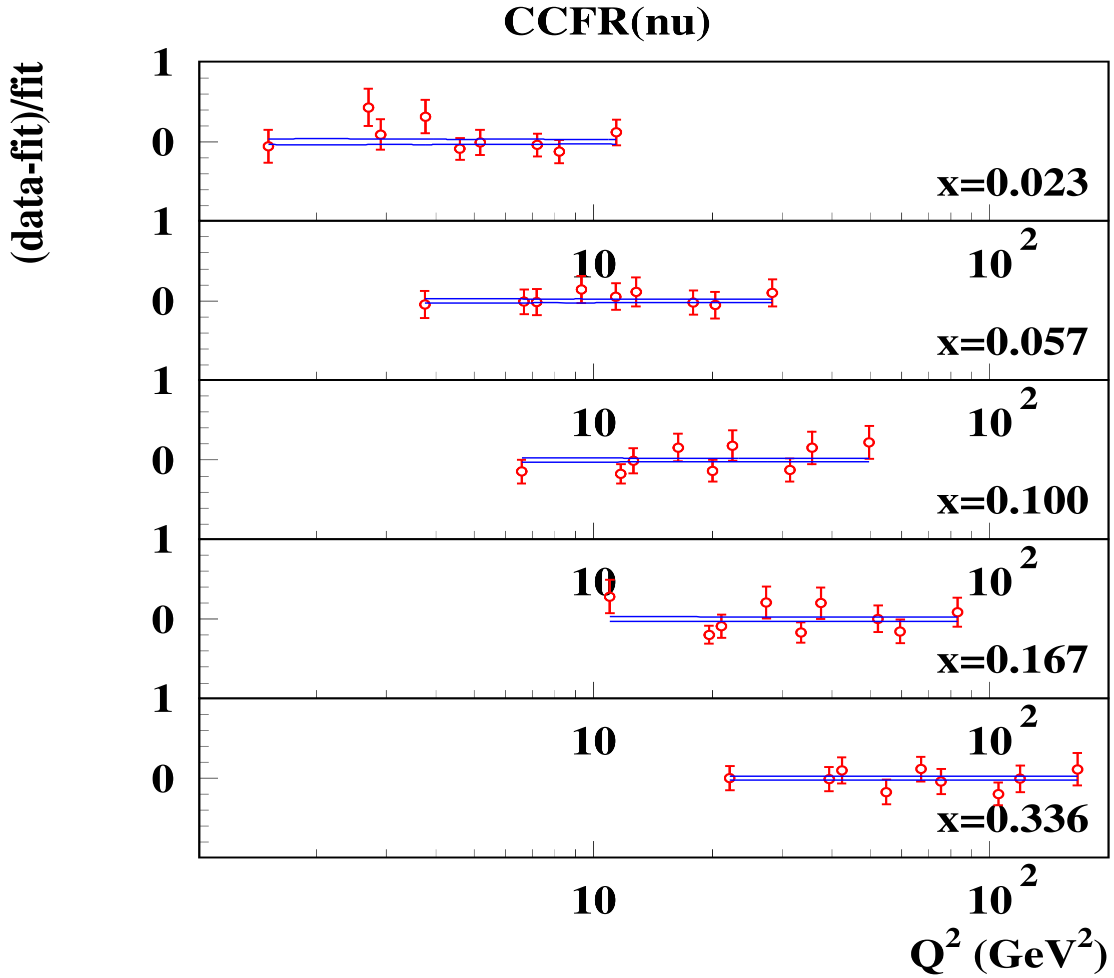
$$W^+ s \longrightarrow cg \qquad O(\alpha_\mathrm{s}^1)$$

$$W^+ g \longrightarrow c\overline{s} \qquad O(\alpha_\mathrm{s}^1)$$

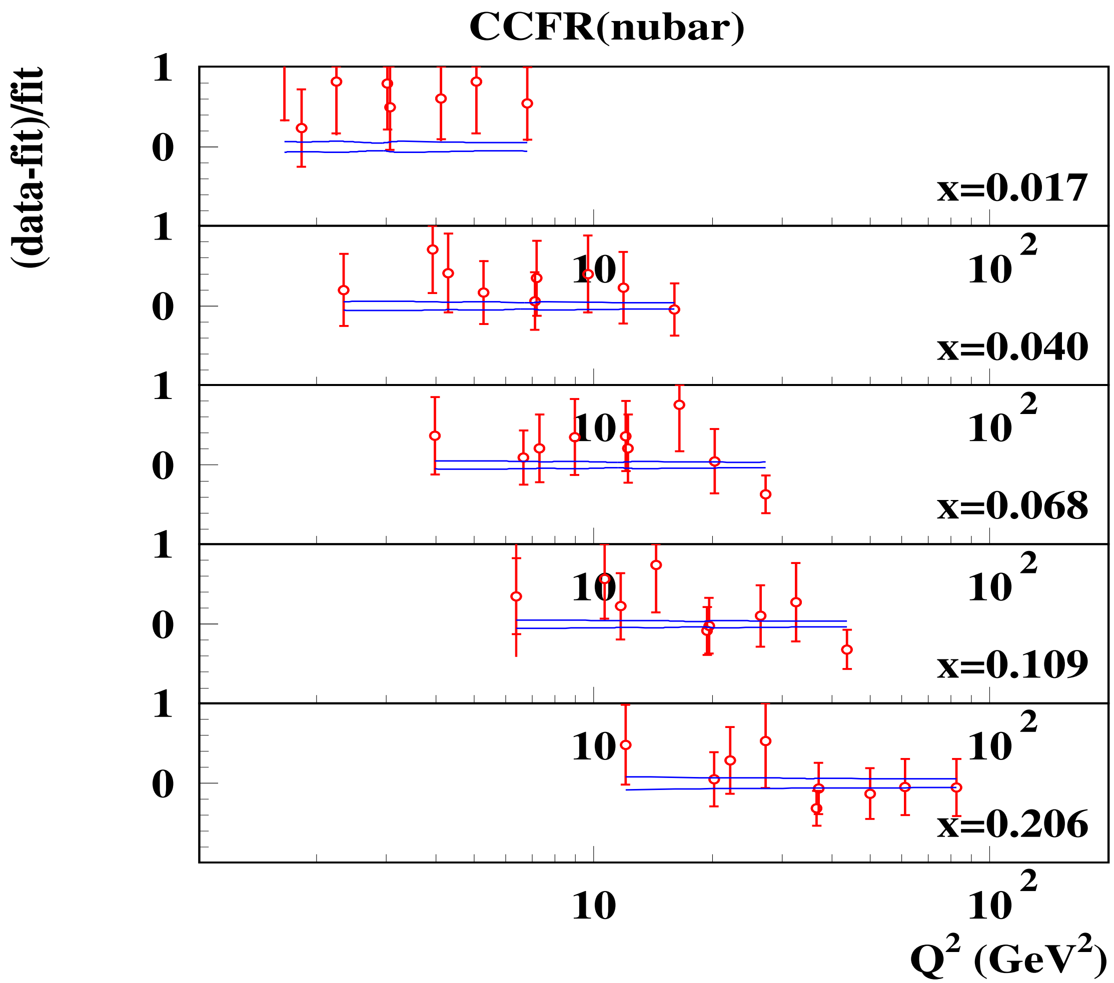
(Gottschalk 81)


NuTeV(nu)
(data-fit)/fit
1
0
1
x=0.021
10
10 2
x=0.057
x=0.101
x=0.167
x=0.326
Q2 (GeV2)

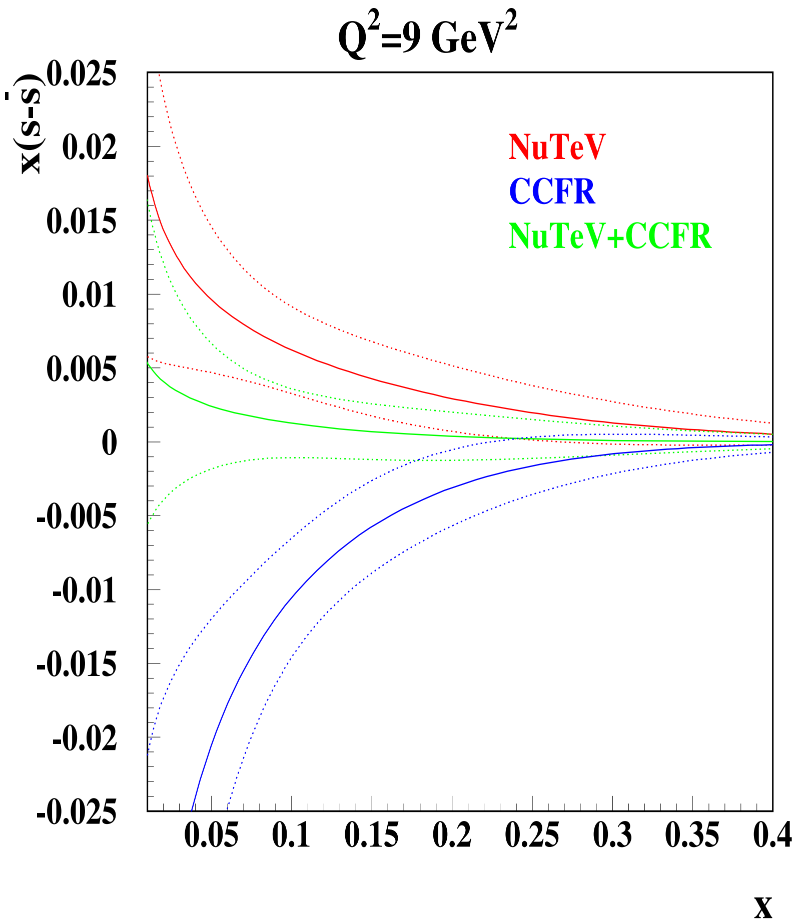

NuTeV(nubar)
(data-fit)/fit
1
0
1
x=0.015
10
10^2
x=0.042
x=0.072
x=0.114
x=0.207
Q^2 (GeV^2)



CCFR(nu)
(data-fit)/fit
1
0
x=0.023
x=0.057
x=0.100
x=0.167
x=0.336
10
10 2
Q2 (GeV2)

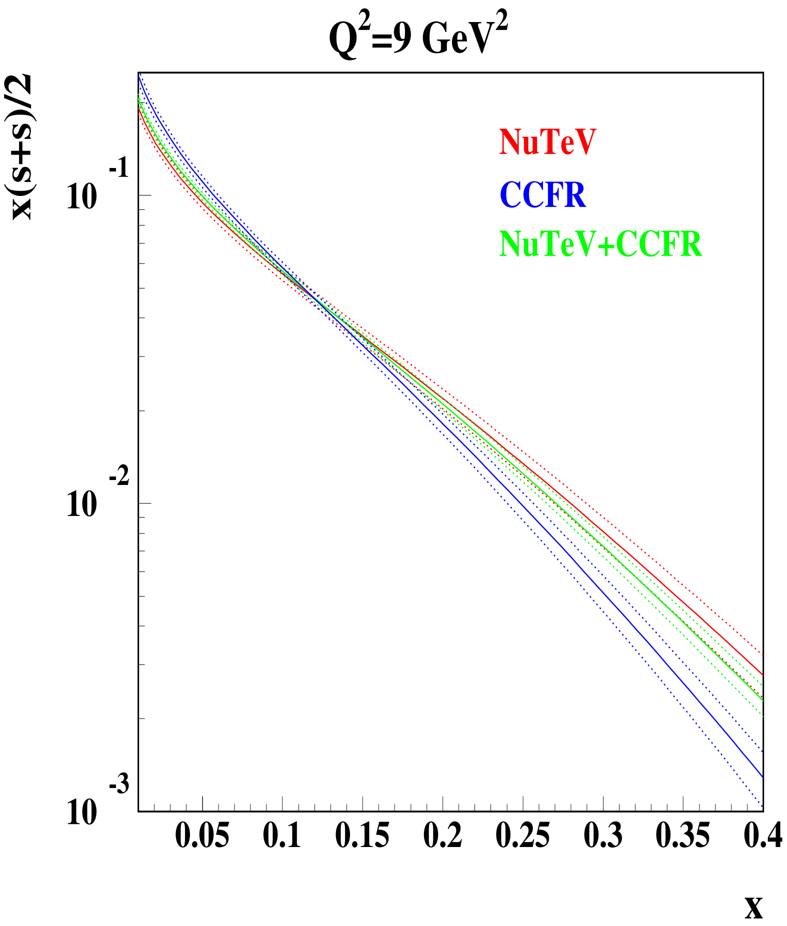

CCFR(nubar)
(data-fit)/fit
1
0
1
0
1
0
1
0
1
0
x=0.017
x=0.040
x=0.068
x=0.109
x=0.206
10
10^2
Q^2 (GeV^2)

Strange sea asymmetry



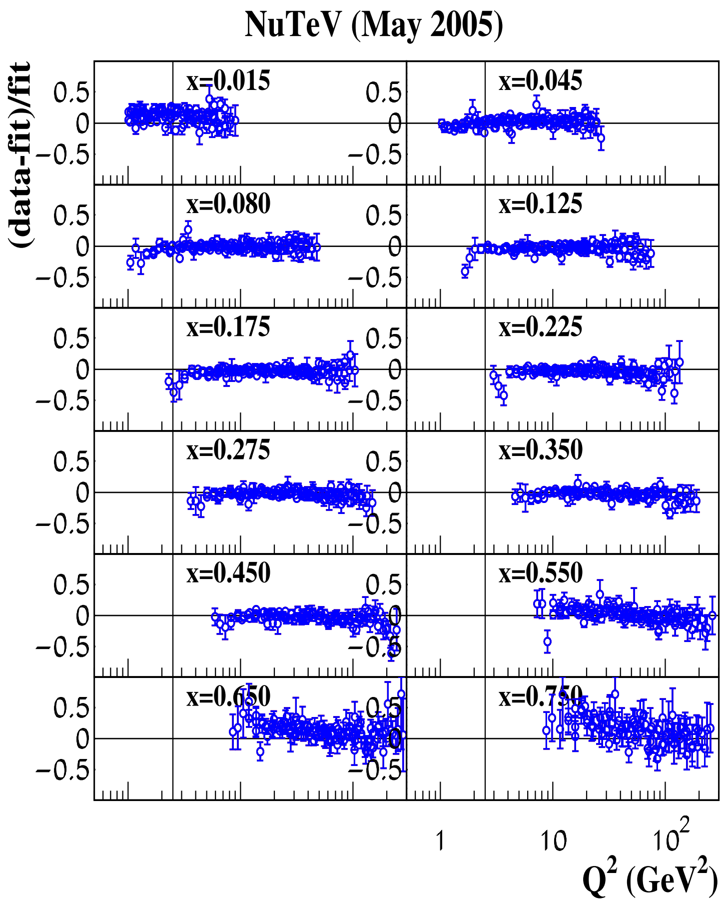
- The NuTeV and CCFR data prefer asymmetry of different sign; averaging of both gives zero
- The MRST fit gives positive value, close to the NuTeV result
- The value of asymmetry is not very sensitive to the QCD, EW, and nuclear correction

Total strange sea



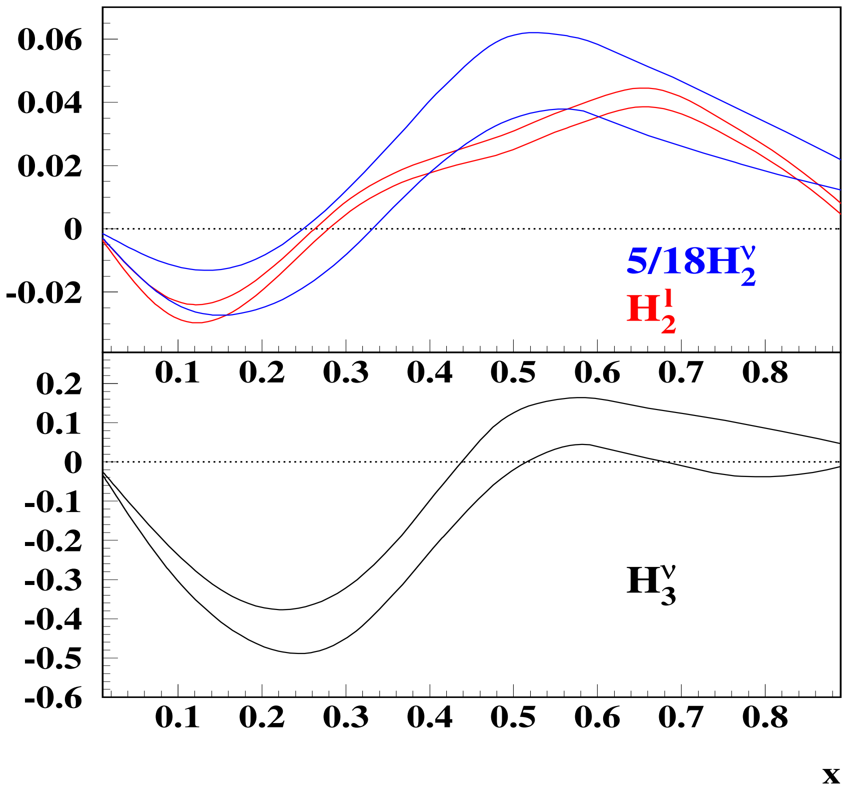
- The strange suppression factor value from the combined fit is 0.54 ± 0.02 at $Q^2 = 20\ \text{GeV}^2$
- The CCFR analysis of their own data gives this value about 0.4; due to enhanced d-quark distribution defined from the inclusive sample

Status of the inclusive NuTeV data



The NuTeV data at $x \sim 0.01$ go above the charged-leptons fit. This discrepancy cannot be removed due to account of the $O(\alpha_s^3)$ corrections to the C-odd coefficient functions by Moch-Rogal-Vogt; modification of the nuclear corrections did not help too. At large x the NuTeV data also go above the the charged-leptons fit.

The HT terms in νN structure functions from the global fit including the CHORUS data



- $H_2^{\nu N} = H_{\rm T}^{\nu N}$, motivated my the charged-leptons fit
- $H_2^{\nu N}$ is in remarkable agreement to H_2^{lN} rescaled with the quarks charge
- $\int H_3^{\nu N}(x)dx$ is -0.10 ± 0.03 GeV^2, in nice agreement to the early calculations by Braun-Kolesnichenko.

Uncertainty in the extraction of the Weinberg angle sine (s_W) due to PDFs

$$R^\nu = \frac{\sigma^\nu_{\rm NC}}{\sigma^\nu_{\rm CC}} \approx \frac{1}{2} - s_W^2 + \frac{5}{9}(1+r)s_W^4$$

$$r = \frac{\sigma^{\bar\nu}_{\rm CC}}{\sigma^\nu_{\rm CC}} \approx \frac{(U+D)/3 + \bar U + \bar D + 2\bar S}{U + D + 2S + (\bar U + \bar D)/3} = 0.4999(24)$$

The uncertainty in r would lead to the uncertainty in s_W^2 at the level of 0.00005, much better than expected experimental accuracy of the NOMAD analysis.

Summary

- The fit of the PDFs and HTs to the combined charged leptons DIS, fixed-target Drell-Yan, dimuon neutrino data by NuTeV and CCFR, and inclusive neutrino data by CHORUS demonstrates reasonable consistency of the data: $\chi^2/NDP = 5177/4338 = 1.2$; $\alpha_{\rm s}(M_{\rm Z}) = 0.1138(7)$.

- The charged leptons DIS data are well described down to $Q^2 = 1\ GeV^2$ with account of the QCD corrections up to $O(\alpha_{\rm s}^3)$ and down to $Q^2 \approx 0.5\ GeV^2$ using the spline interpolation combined with the current-conservation constraints.

- The HT terms extracted from the fit demonstrate remarkable universality: $H_2^{lN} \approx H_{\rm T}^{lN} \approx 5/18 H_{2,\rm T}^{\nu N}$.

- Accuracy of the PDFs obtained is quite sufficient for the precise extraction of the Weinberg angle from the NOMAD data.