Update of MRST Parton Distributions

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We (A.D. Martin, R.G. Roberts, W.J. Stirling and R.S.T.) perform a global fit to all available structure function and related data in order to obtain best possible determination of NLO parton distributions, and **also** to determine the success of NLO QCD in describing the data which are fit. Hence, include all data within the feasible range of applicability.

Data used

H1 $F_2^{e^+p}(x,Q^2)$ 1996-97 moderate Q^2 and 1996-97 high Q^2, and $F_2^{e^-p}(x,Q^2)$ 1998-99 high Q^2 New.

ZEUS $F_2^{e^+p}(x,Q^2)$ 1996-97 New.

BCDMS $F_2^{\mu p}(x,Q^2)$

NMC $F_2^{\mu p}(x,Q^2), F_2^{\mu d}(x,Q^2), (F_2^{\mu n}(x,Q^2)/F_2^{\mu p}(x,Q^2))$

SLAC $F_2^{\mu p}(x,Q^2)$

E665 $F_2^{\mu p}(x,Q^2), F_2^{\mu d}(x,Q^2)$

CCFR $F_2^{\nu(\bar{\nu})p}(x,Q^2), F_3^{\nu(\bar{\nu})p}(x,Q^2)$ New (in principle)

ZEUS $F_{2,c}^{e^+p}(x,Q^2)$ 1996-97 New.

E605 $pN \rightarrow \mu\bar{\mu} + X$ (E772 and New E866 not fit but consistent)

E866 Drell-Yan asymmetry $\bar{u}, \bar{d}$ New

CDF W-asymmetry u/d ratio at high x

CDF Inclusive jet data New (semi-implicit)

D0 Inclusive jet data New (semi-implicit)

CCFR Dimuon data (New NuTev) constrains strange sea

Fit currently performed by minimizing χ^2 to all data adding statistical and systematic errors in quadrature (other than jet data) - treatment of errors to improve. Start evolution at $Q_0^2 = 1\mathrm{GeV}^2$.

Cut data at $Q^2 = 2\mathrm{GeV}^2$ (HERA at $Q^2 = 1.5\mathrm{GeV}^2$) and at $W^2 = 10\mathrm{GeV}^2$ to avoid higher twist.

$\bar{u} \neq \bar{d}$ and is constrained by E866 Drell-Yan asymmetry.

$s = \bar{s}$ is constrained by CCFR (NuTev) Dimuon data. Implies $s = 0.5(\bar{u} + \bar{d})/2$ at Q_0^2

Use Thorne-Roberts VFNS. Improves global fit compared to ZM-VFNS and FFNS. Important for charged current data.

High x gluon. Previously used prompt photon data with $g\uparrow$, g and $g\downarrow$ corresponding to no intrinsic k_T, moderate k_T and max k_T. Both uncertainty in stability of theory and in consistency of experiments. Now use constraint of reasonable fit to jet data.

$\rightarrow$ $g(x, Q^2)$ somewhere between previous $g\uparrow$ and g (slightly nearer $g\uparrow$). $xg(x, Q_0^2) \sim (1-x)^{5.6}$.

Much below g fit to jet data deteriorates.

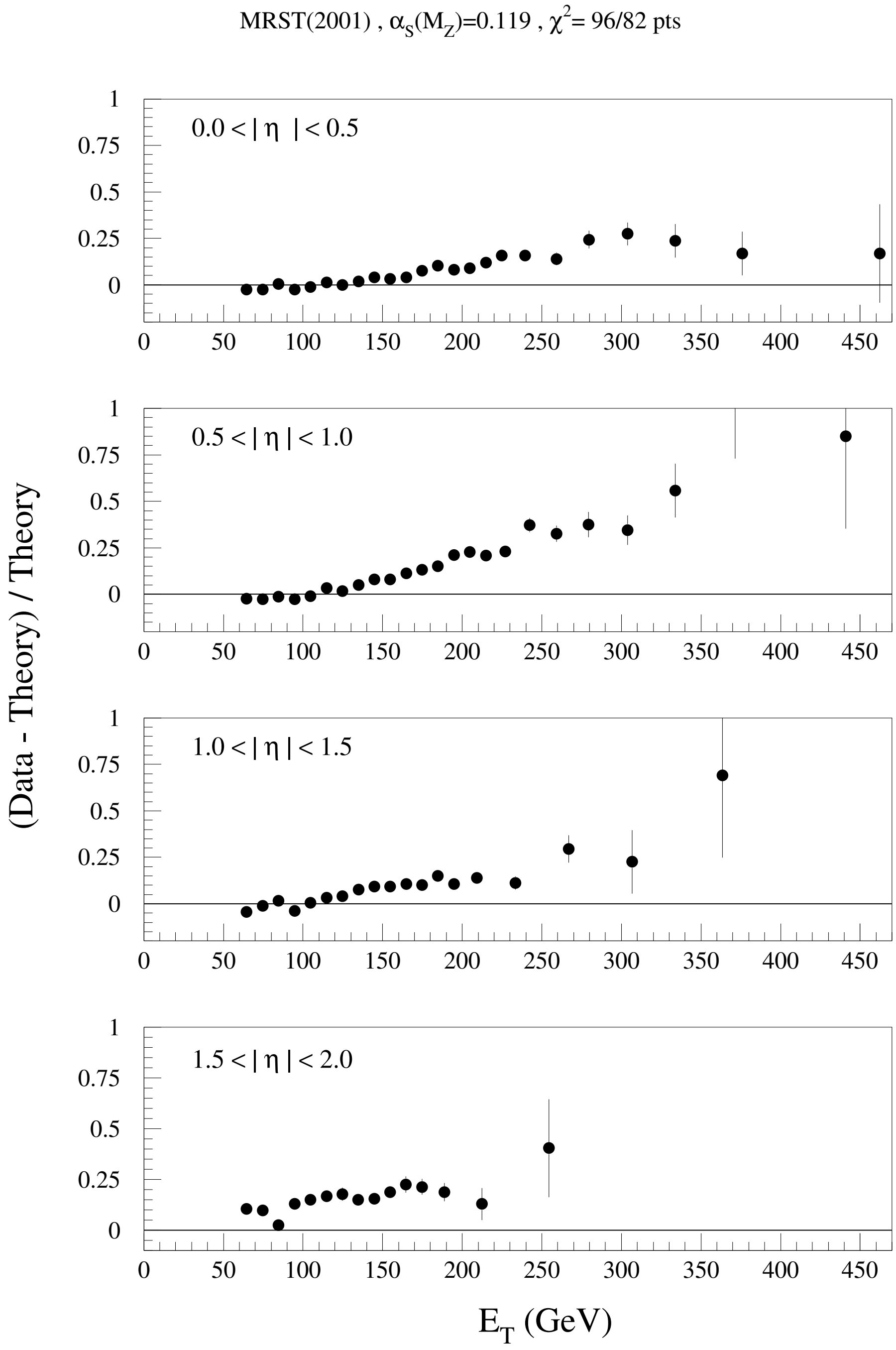
Much above $g\uparrow$ fit to rest of data deteriorates (other data prefer $g(x, Q^2) < g$ due to sum rule constraint).

Uncertainty of $\sim 20\%$ in $g(x, Q^2)$ for $x \sim 0.4$ $Q^2 \sim 20\mathrm{GeV}^2$.

Good fit to jet data. Normalization about correct.

Jet data prefer $\alpha_S(M_Z^2) = 0.117$. Compromise between this and other data.

Fit to new D0 jet data



New HERA data with larger coverage and much smaller errors have far more significant weight in fit.

low x low Q^2 data require gluon to be negative!

$$xg(x,Q_0^2) = A(1-x)^\eta(1+\epsilon x^{0.5}+\gamma x)x^\delta - A_-(1-x)^{\eta_-}x^{-\delta_-}$$

$\eta_- \sim 10$, $\delta_- \sim 0.2$.

HERA + other structure function data prefer the value $\alpha_S(M_Z^2) = 0.1205$. Compromise between this and jet data and world average (and for reasonable fit to BCDMS) use $\alpha_S(M_Z^2) = 0.119$.

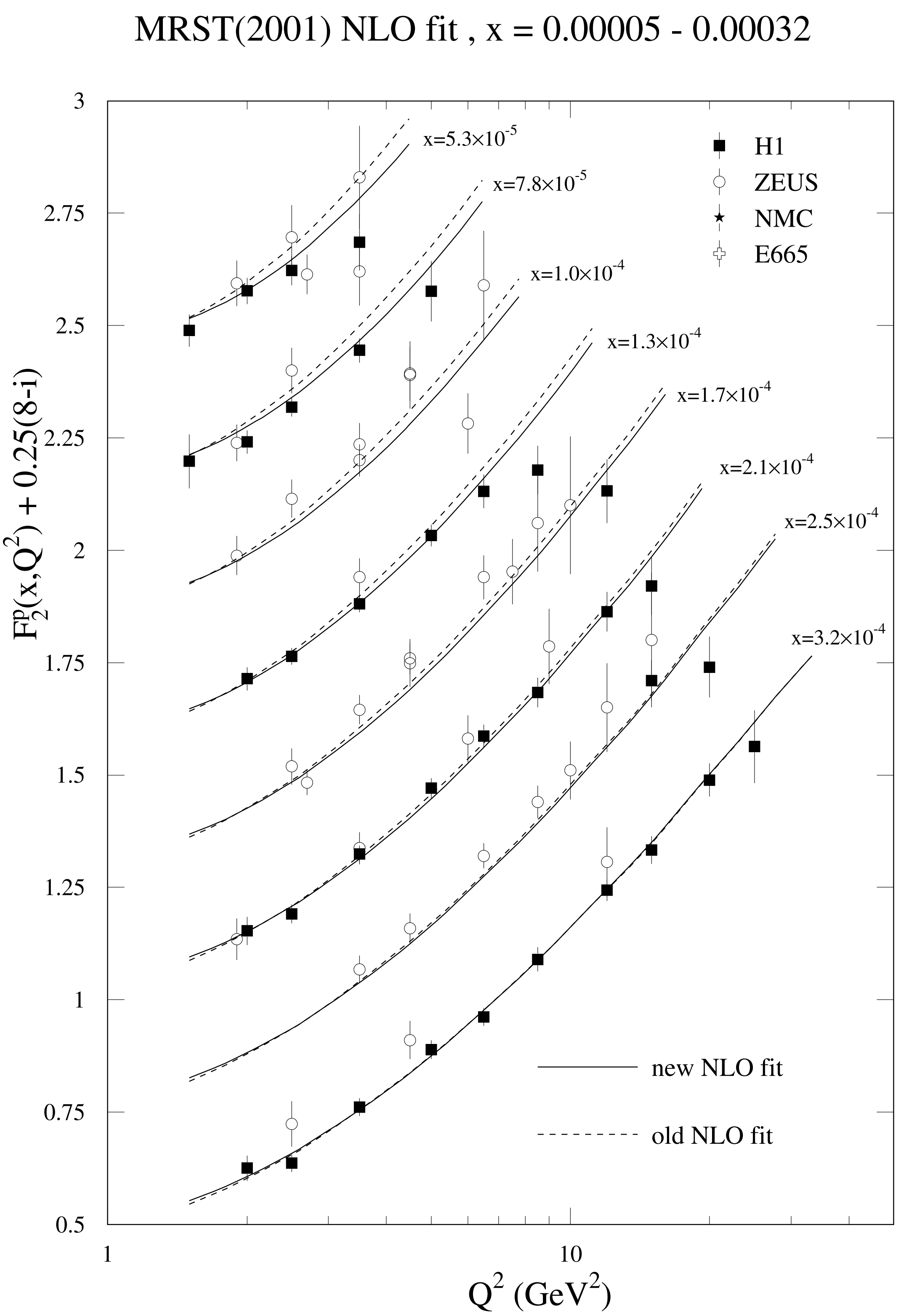
Good fit to HERA data (slight problem at highest Q^2 at moderate x, i.e. in $dF_2/d\ln Q^2$.)

$F_L(x,Q^2)$ dangerously small at smallest x, Q^2

Total $\chi^2/N = 1698/1540$. Reasonable (note confidence level really 0.003% - **not** due to inconsistency between data sets).

All data sets other than SLAC acceptable fits. (Cure by resummation of large $\ln(1-x)$ terms)

Comparison of MRST(2001) and MRST(1999)



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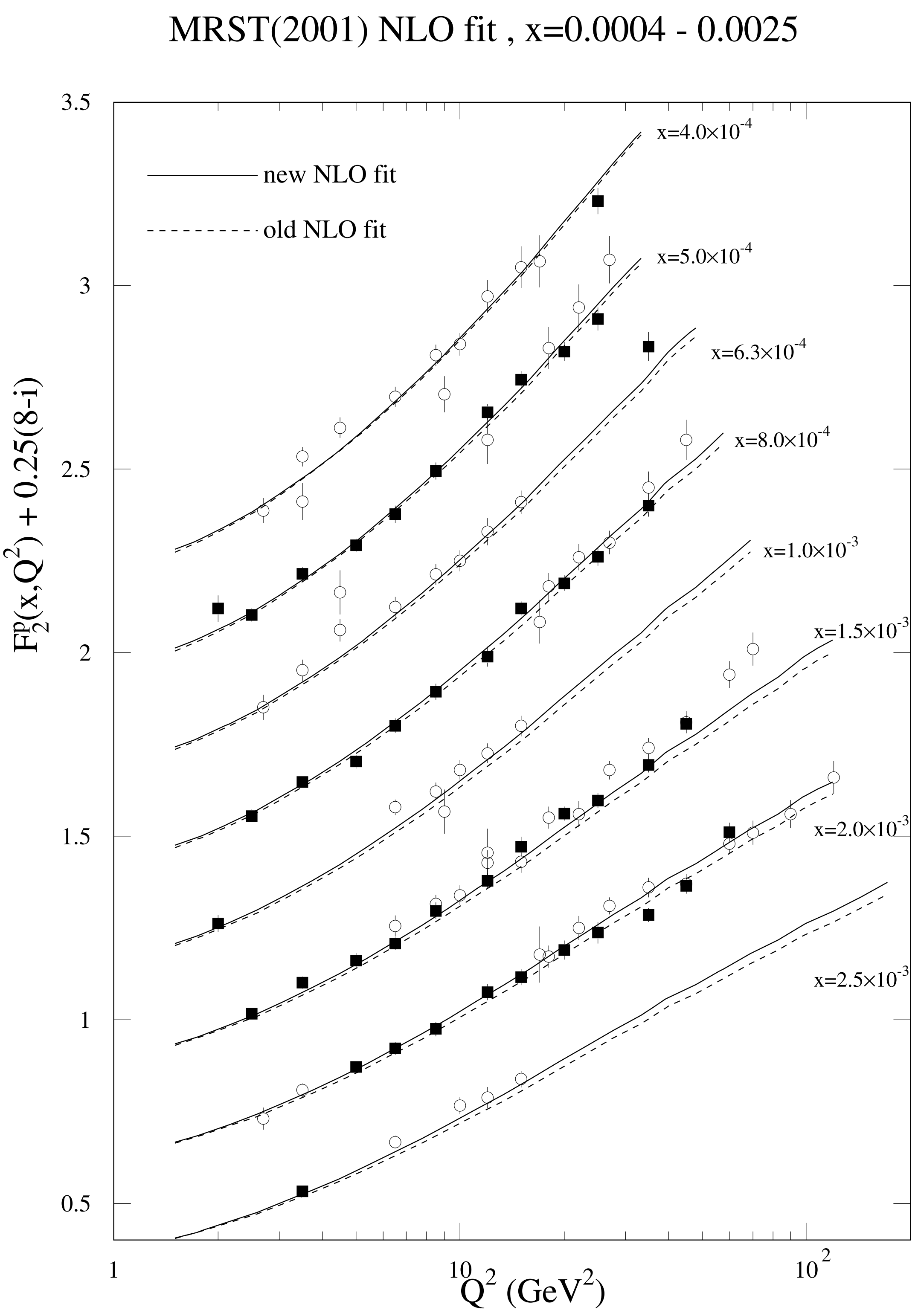

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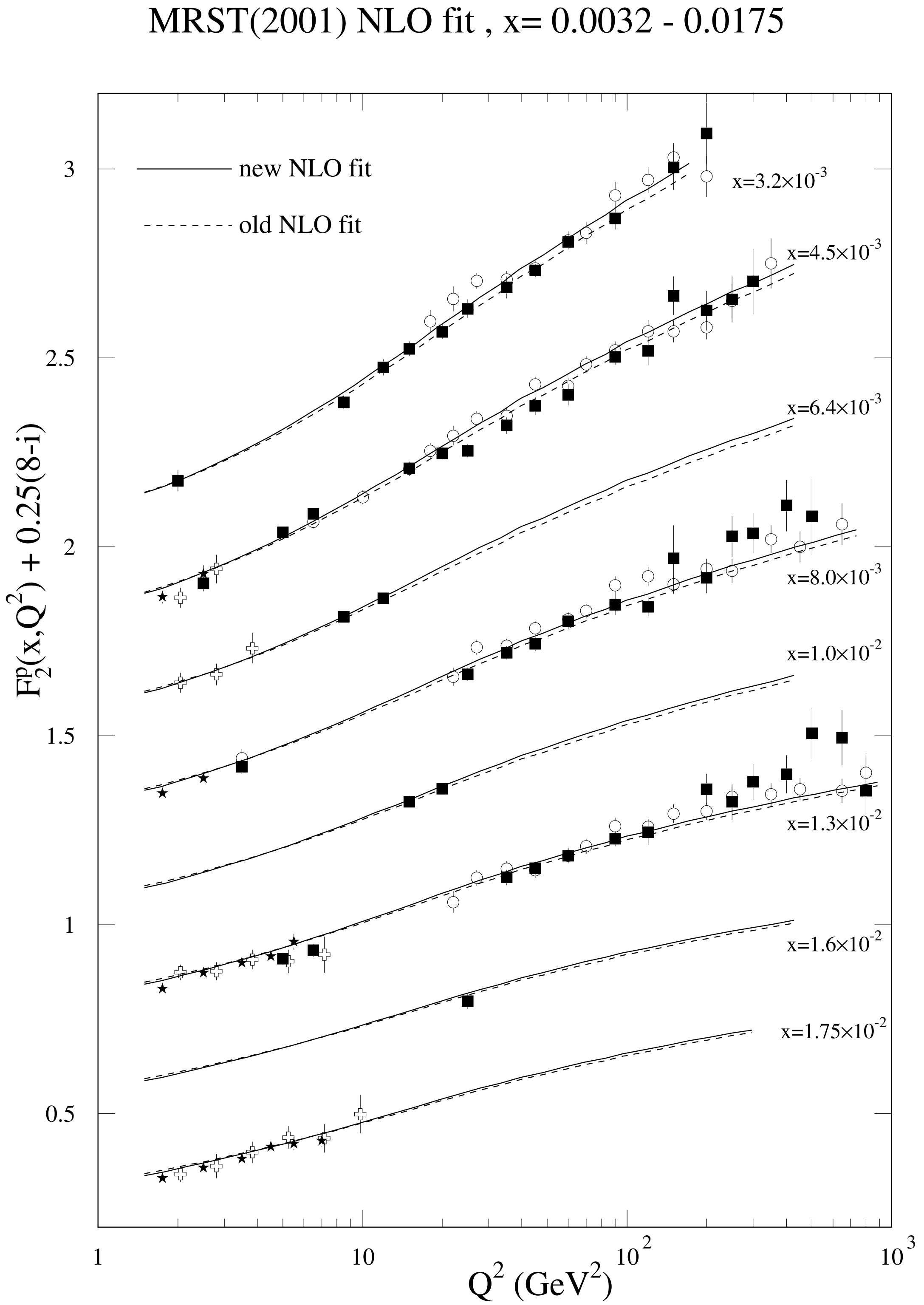

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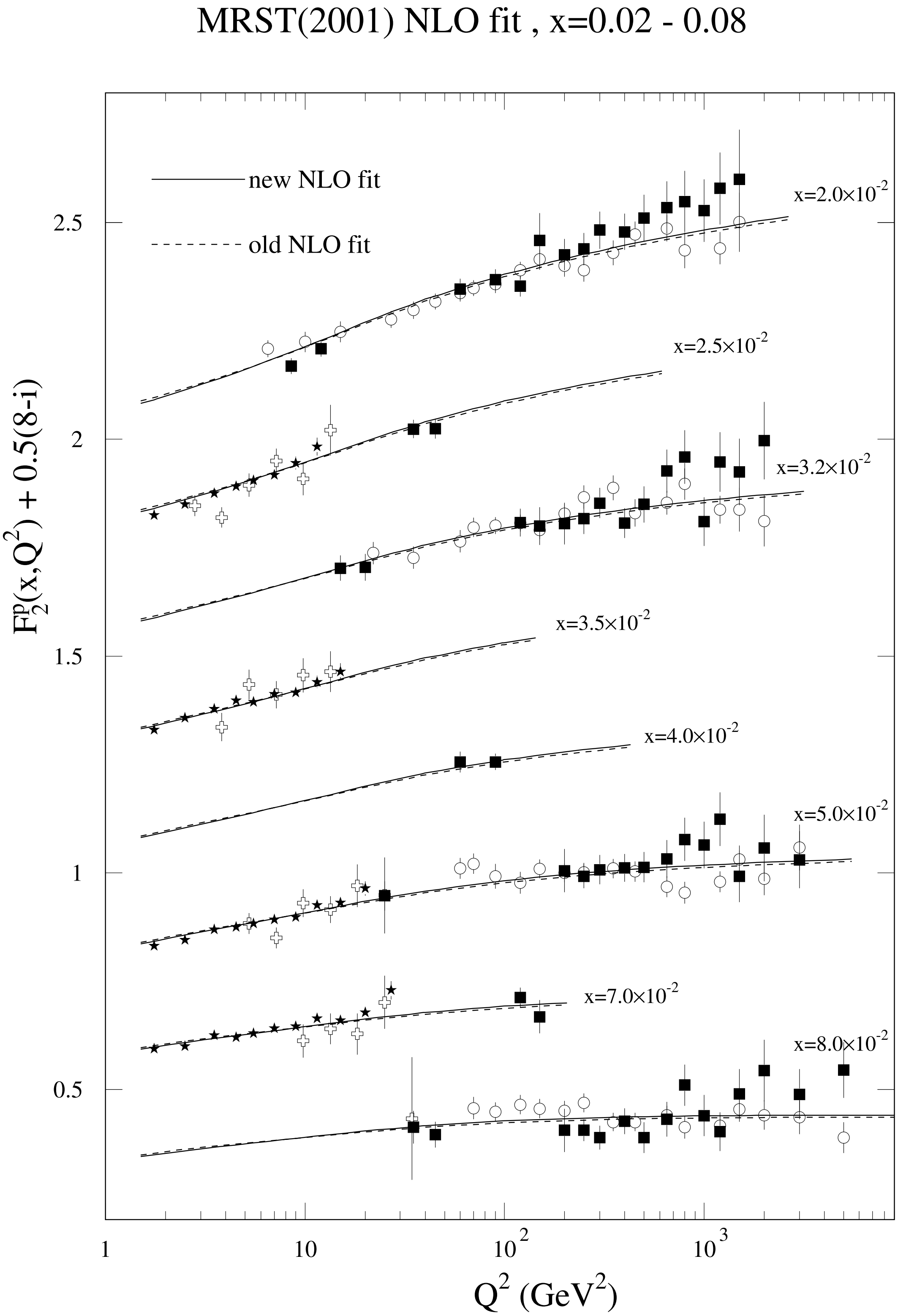


Issues to address for improvements/error estimates.

Theoretical issues

- massive quarks (VFNS for charm and bottom) - solved
- higher orders (NNLO)
- small x $(\alpha_s^n \ln^{n-1}(1/x))$
- large x $(\alpha_s^n \ln^{2n-1}(1-x))$
- low Q^2 (higher twist)

Also need to consider effect of assumptions made during fit

Constraint on large x gluon, form of strange sea, heavy flavour prescription, assumption of no isospin violation, strong coupling, cuts made on data ...

Currently most active work on -

Errors on partons (parton related quantities) due to experimental errors.

We continue along original lines by concentrating on errors on given physical quantities rather than unphysical partons. Different variables sensitive both to different data and to different theoretical uncertainties.

Consider W cross-section at Tevatron and LHC (possible luminosity monitor).

Tevatron - probes quarks (antiquarks) for $0.5 > x > 0.005$.

LHC - probes quarks (antiquarks) for $0.5 > x > 0.00007$.

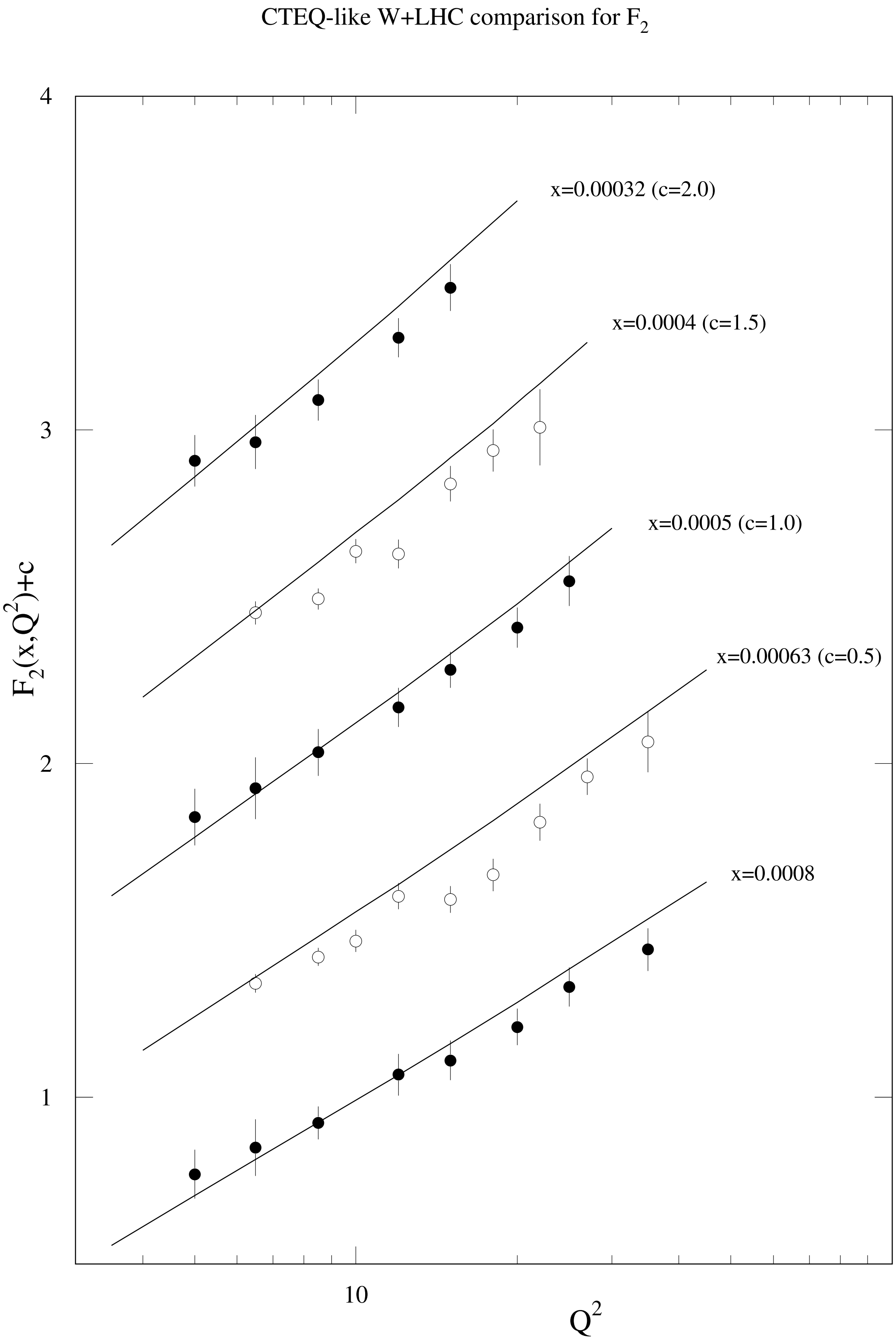
Values obtained from best fit

$$\sigma_W(\text{Tev}) = 22.3nb \qquad \sigma_W(LHC) = 192nb$$

As CTEQ consider fits required to raise/lower resulting σ_W by given amount.

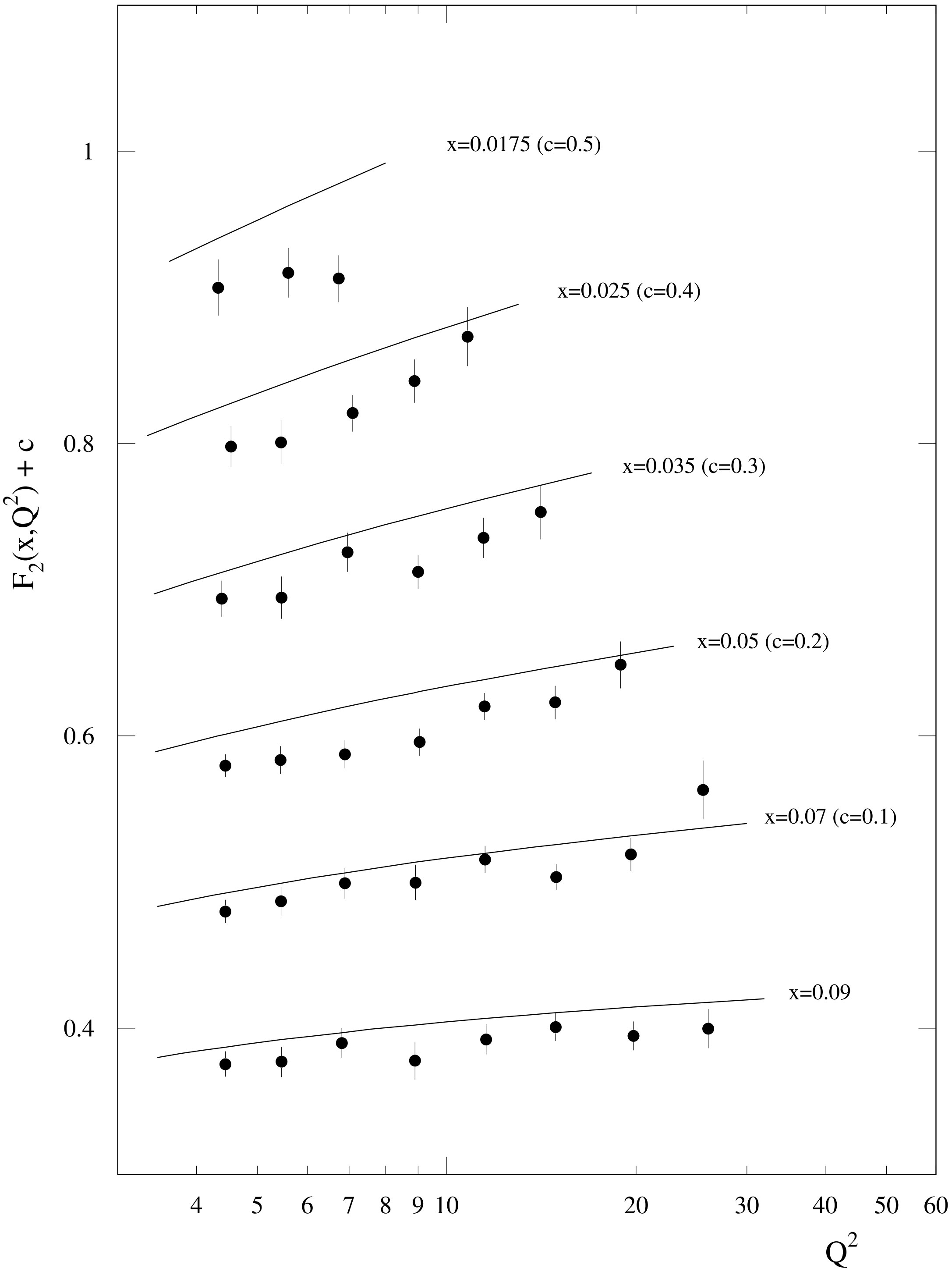
Different philosophy - repeat CTEQ method with same data (much now superseded) which has $\Delta\chi^2 \approx 180 \rightarrow \Delta\sigma_W(\text{Tev}) = 5\%$, $\Delta\sigma_W(LHC) = 8\%$. Big discrepancy in some regions of parameter space.

Worst region for increase in $\sigma_W(LHC)$



Worst region for increase in $\sigma_W(\mathrm{Tev})$

CTEQ-like W+Tev comparison for F_2



Conclude - even with old data uncertainty smaller than claim.

With most up-to-date data restriction is more severe. Impose rough criterion that for all data well fit by central best fit no data set has worse than 1% confidence level.

Limit often has fit to other data becoming poor though total $\Delta\chi^2$ varies.

Max LHC W cross-section up by 2% when H1 fit fails. $\Delta\chi^2 = 80$.

Min LHC W cross-section down by 2% when ZEUS fit fails. $\Delta\chi^2 = 70$.

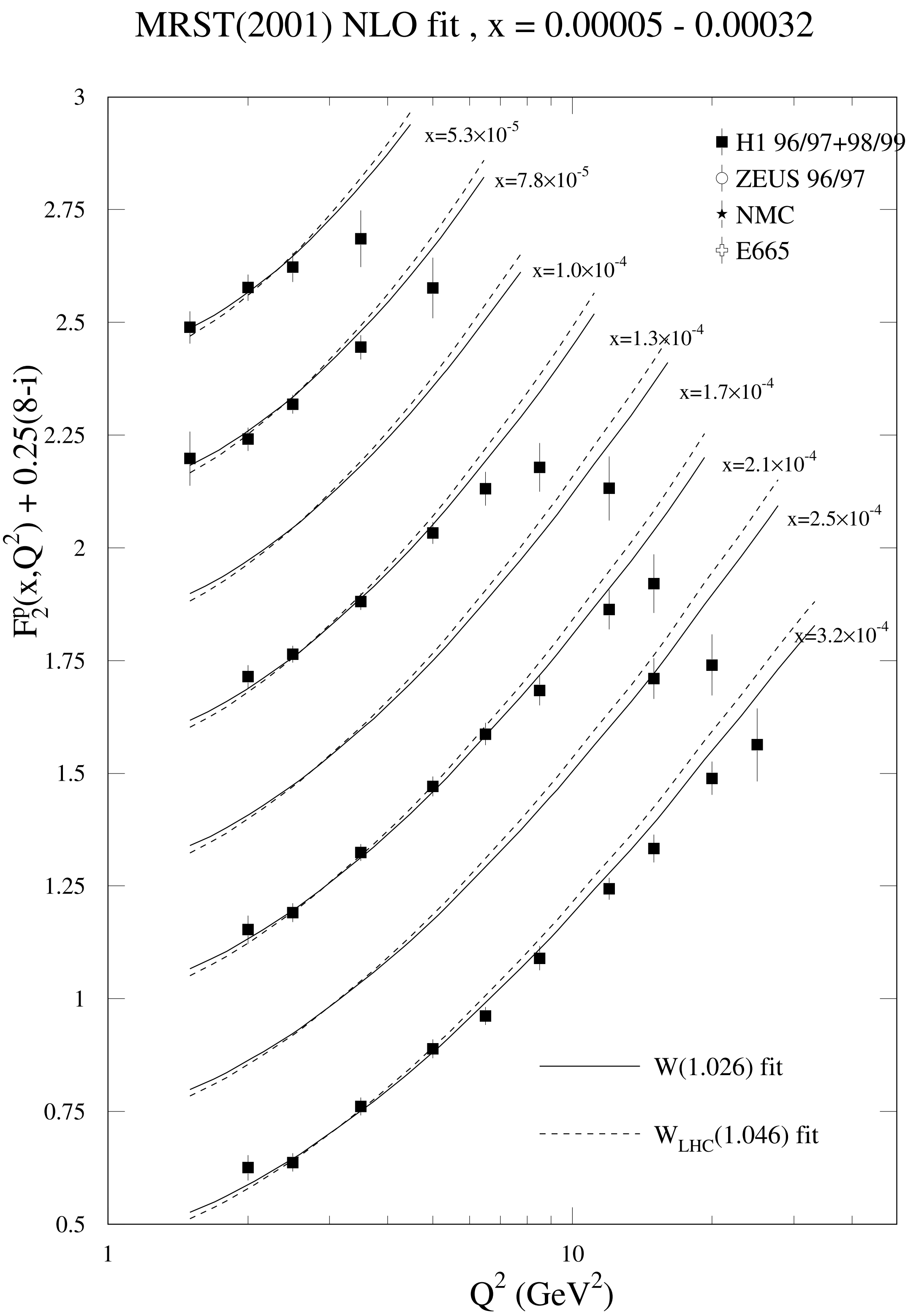
Max Tev W cross-section up by 2% when NMC proton fit fails. $\Delta\chi^2 = 160$. NMC d and CCFR F_3 also bad.

Min Tev W cross-section down by 2.5% when NMC n/p fit fails. $\Delta\chi^2 = 80$. CCFR F_3 also bad. SLAC improves.

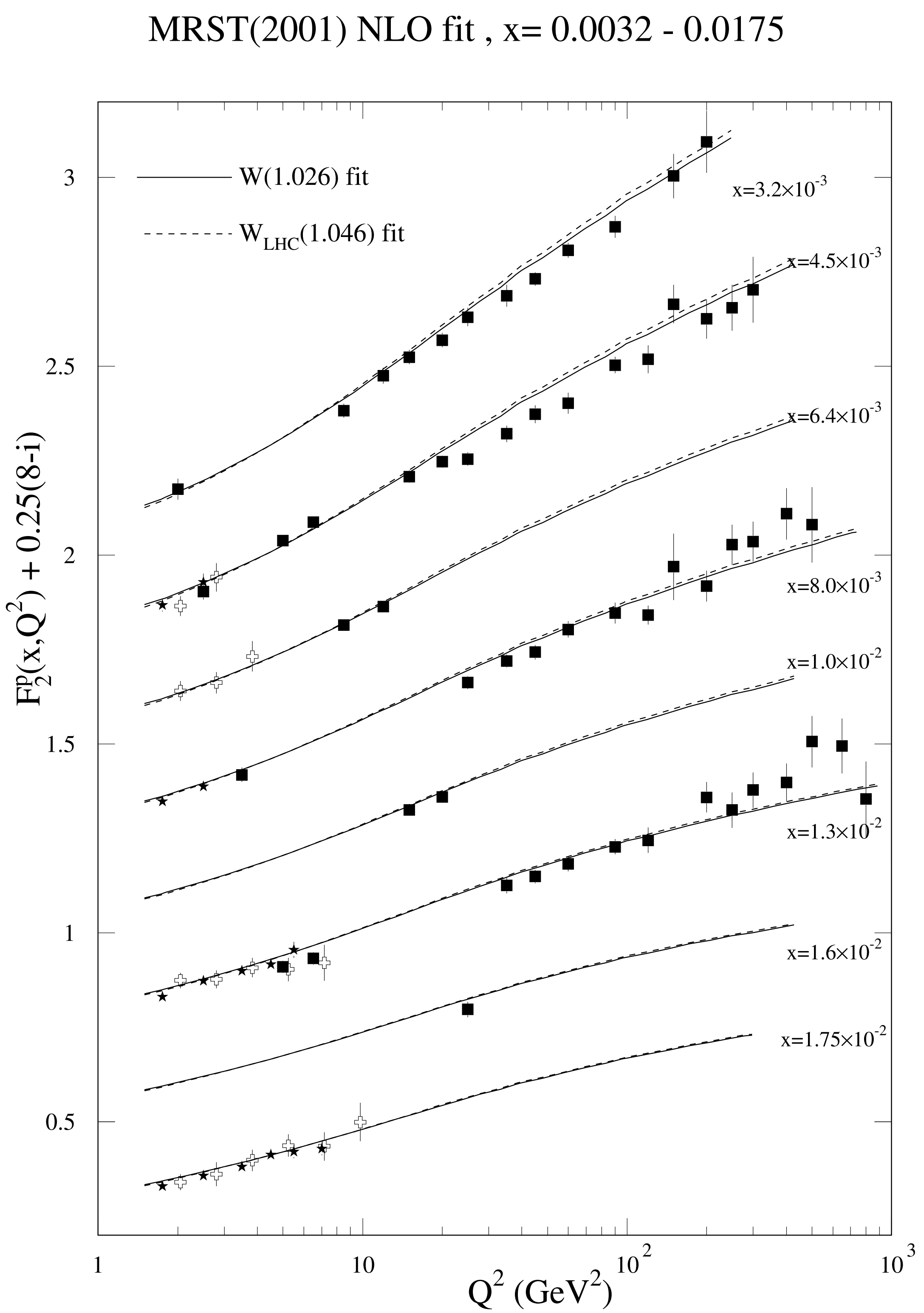
New data - much more restrictive indeed.

$\Delta\sigma_{exp}(LHC) \approx \pm 2\%$ $\qquad$ $\Delta\sigma_{exp}(\mathrm{Tev}) \approx \pm 2\%$

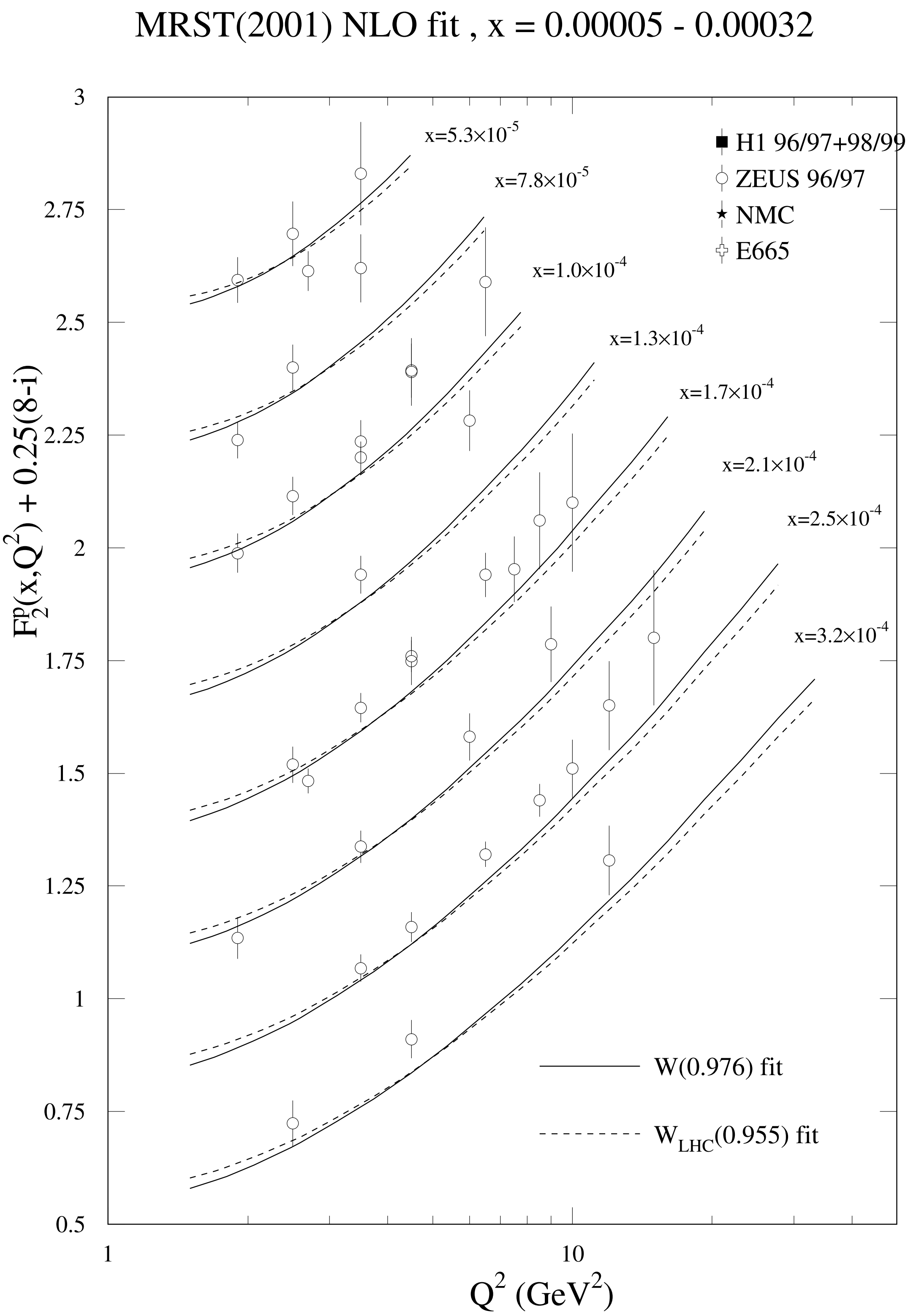
Failure in fit for increase in $\sigma_W(LHC)$



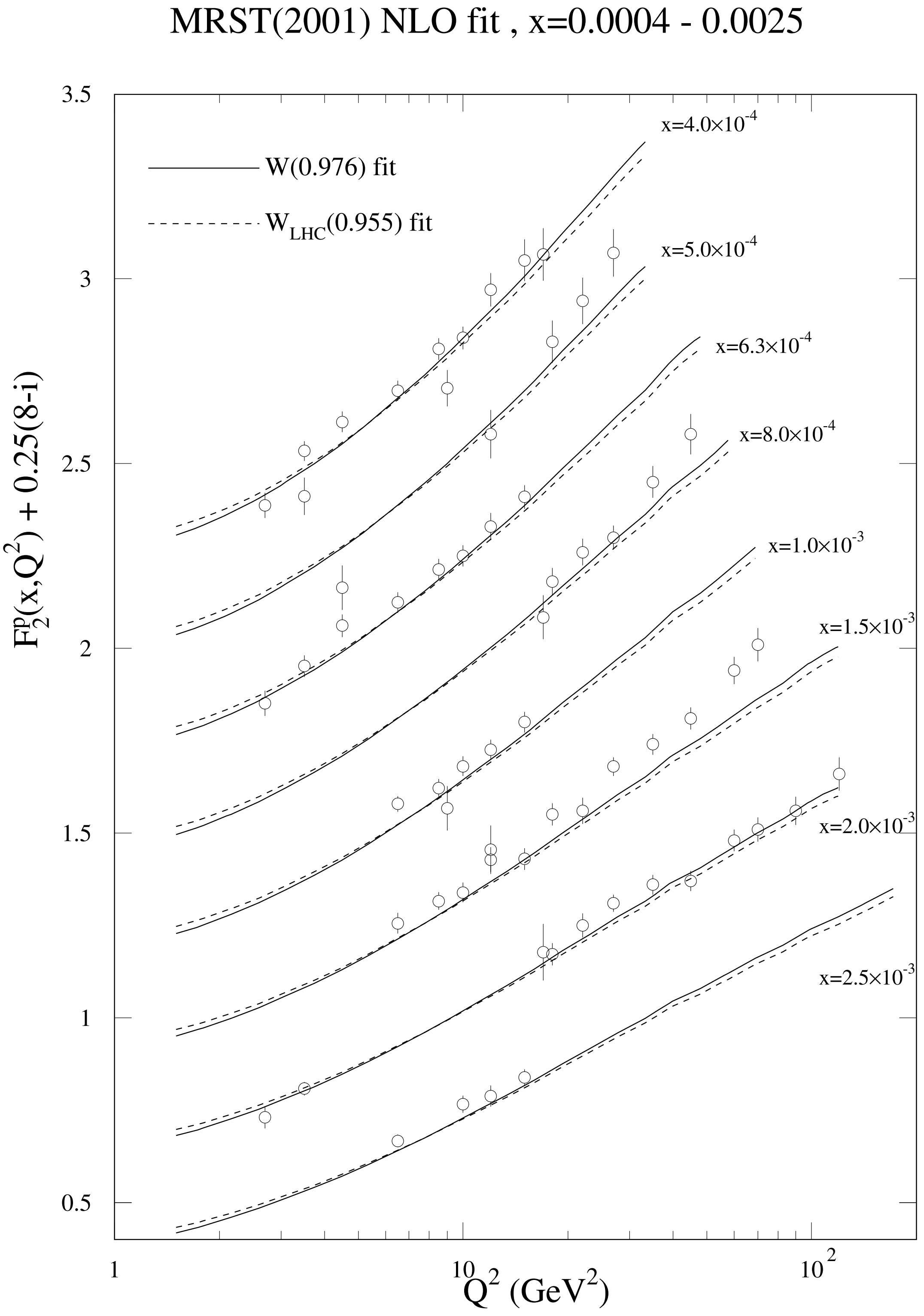
Failure in fit for increase in $\sigma_W(LHC)$



Failure in fit for decrease in $\sigma_W(LHC)$

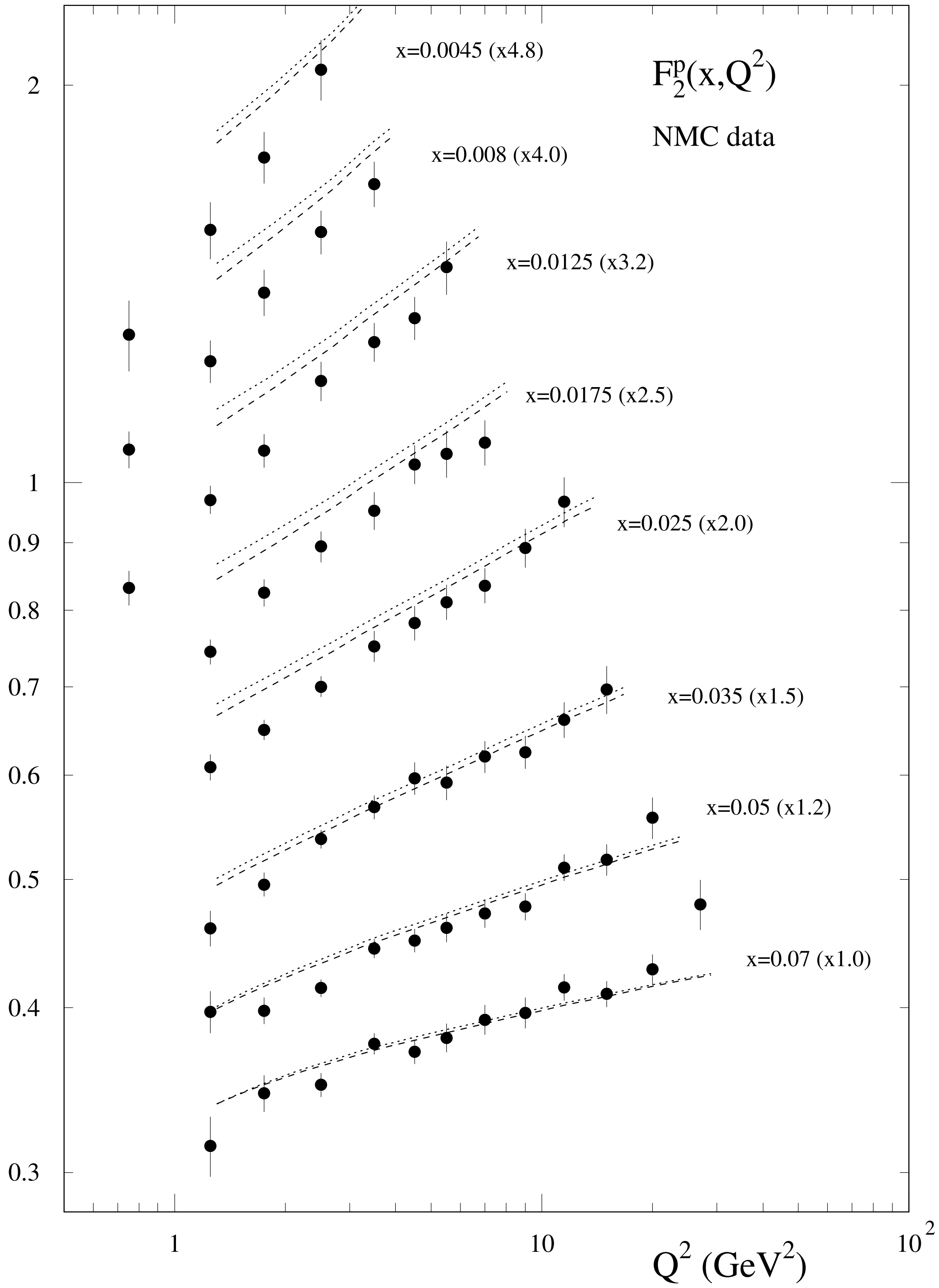


Failure in fit for decrease in $\sigma_W(LHC)$

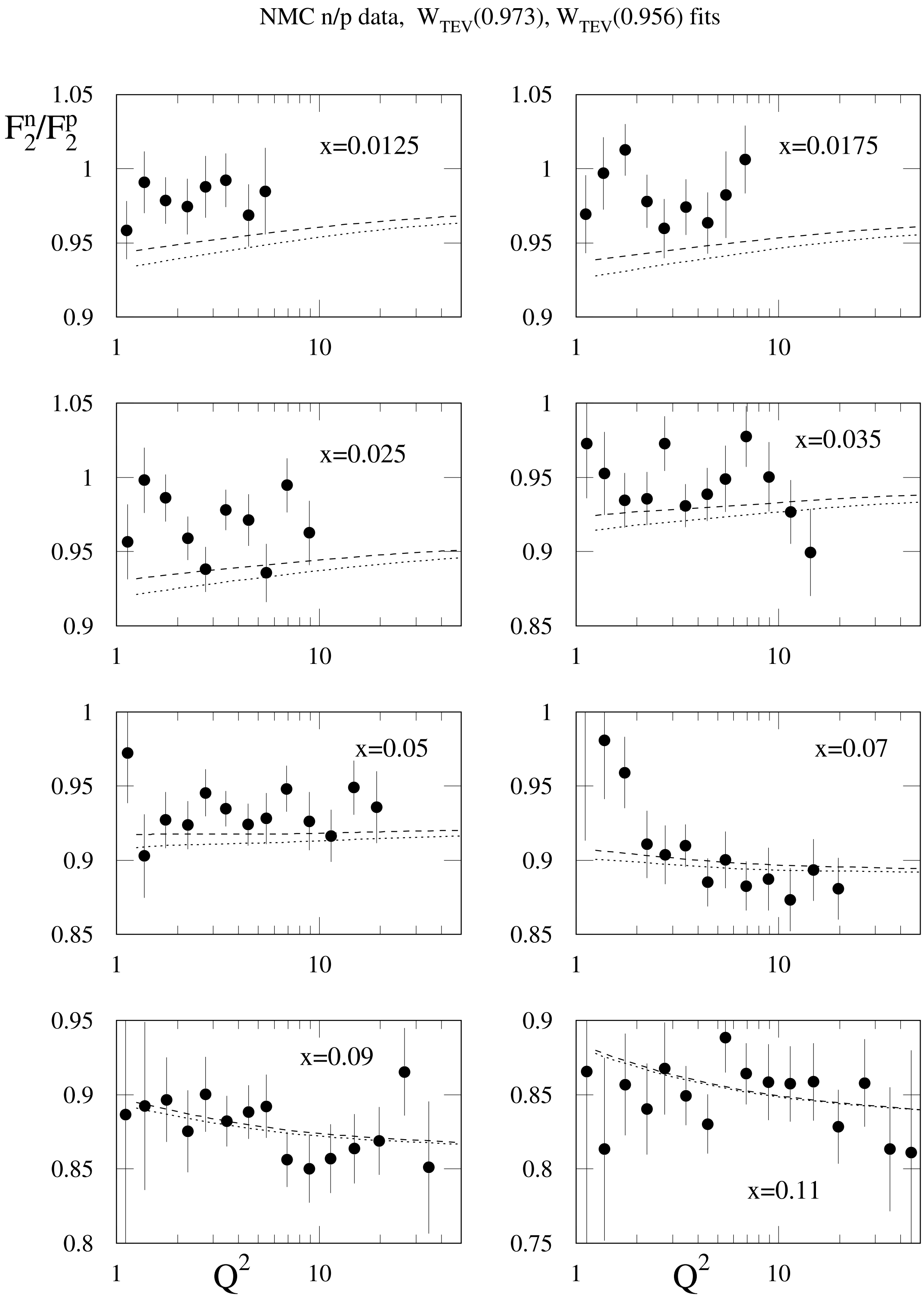


Failure in fit for increase in $\sigma_W(\mathrm{Tev})$

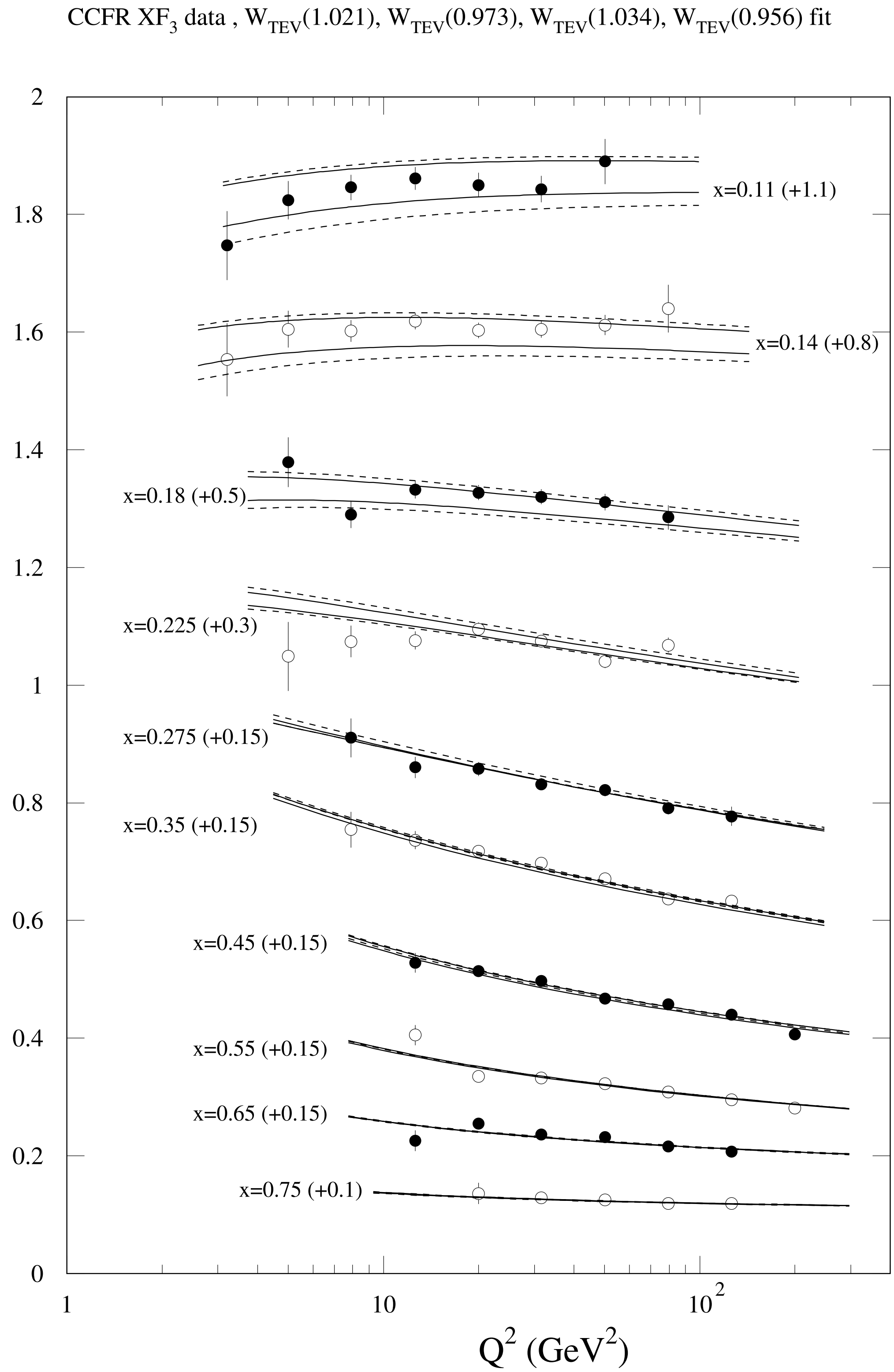
NMC F_2^p data, $W_{TEV}(1.021)$, $W_{TEV}(1.034)$ fits



Failure in fit for decrease in $\sigma_W(\mathrm{Tev})$



Deterioration in fit for increase and decrease in $\sigma_W(\mathrm{Tev})$



Therefore uncertainty due to experimental errors rather small. Can repeat for other observables:

Higgs production sensitive to small x gluon rather than small x quarks,

HERA charged current data sensitive to very high x quarks ....

Uncertainty from this source likely to be largest for quantity sensitive to highish x gluon (most other quantities very well constrained by data within theoretical/assumptions context) e.g. inclusive jets at LHC.

Also need to consider theoretical errors. Note renormalization/factorization scale variation is **not** reliable in general.

For example, at large x

$$C_{2,q}^{1,NS}(x,\mu^2) \sim \alpha_S(\mu^2)\frac{ln(1-x)}{(1-x)_+}$$

$$C_{2,q}^{n,NS}(x,\mu^2) \sim \alpha_S^n(\mu^2)\frac{ln^{2n-1}(1-x)}{(1-x)_+}$$

The scale variation of $C_{2,q}^{1,NS}(x,\mu^2)$ does not give an indication of these higher power $\ln(1-x)$ terms.

Similarly at small x

$$P_{qg}^1 \sim \alpha_S(\mu^2) \qquad\qquad P_{qg}^2 \sim \frac{\alpha_s(\mu^2)}{x}$$

$$P_{qg}^n \sim \frac{\alpha_S^n(\mu^2)\ln^{n-2}(1/x)}{x}$$

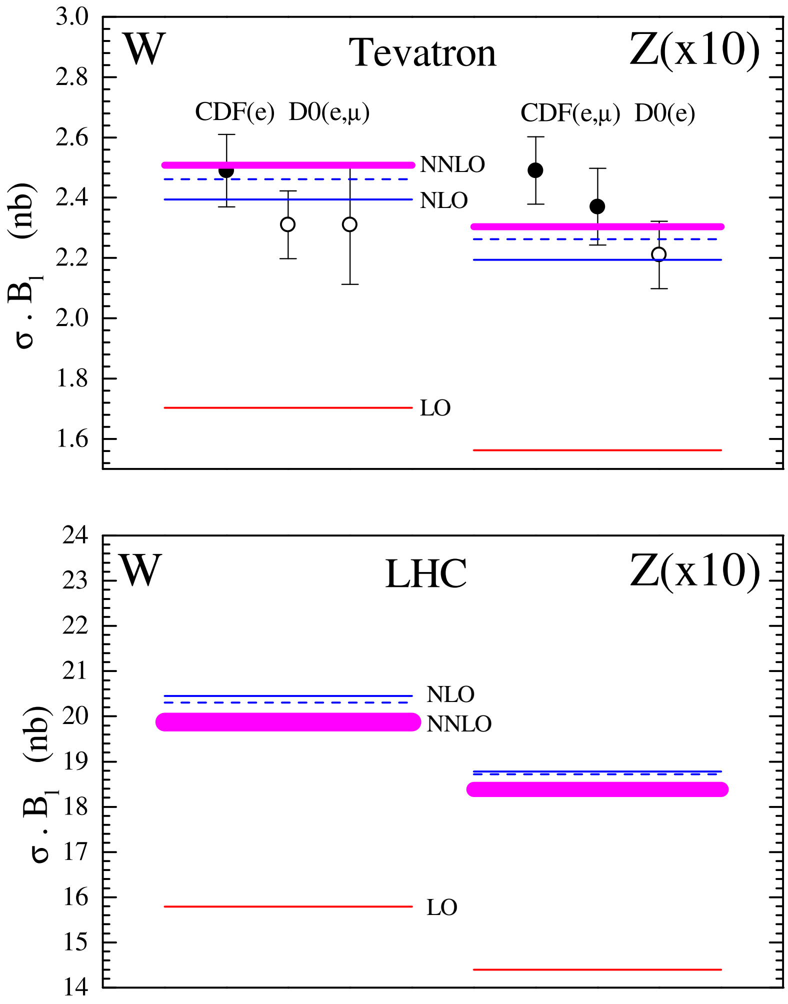
and scale variations of P_{qg}^1, P_{qg}^2 never give an indication of these terms.

In order to investigate true theoretical error must consider some way of performing correct large x and small x resummations (former easier), and/or use what we already know about NNLO.

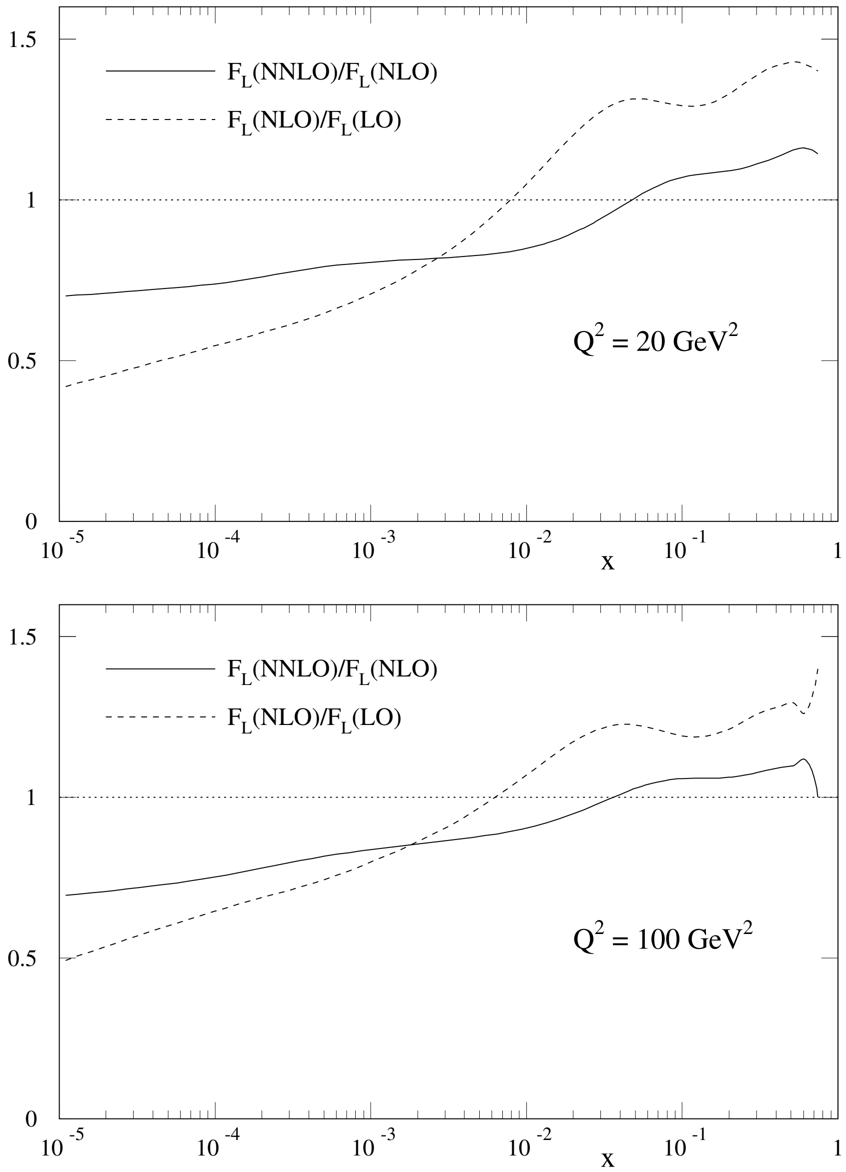
Coefficients functions known at NNLO

Singular limits $x \to 1$, $x \to 0$ known for NNLO splitting functions as well as limited moments (Larin, Nogueira, van Ritenberg Vermaseren, Retey). Approximate NNLO splitting functions devised by van Neerven and Vogt.

Used in global fit by MRST. Improve quality of fit. Implies reasonable stability for (quark-dominated) W and Z cross-sections. (Possible danger from unsatisfactory $dF_2/d\ln Q^2$)



More danger in gluon dominated quantities - gluon not directly constrained by data. Possible/probable poor convergence order by order for $F_L(x,Q^2)$ at small x.



Note K-factor for Higgs production at LHC ~ 1.6 Spira, Djouadi, Graudenz and Zerwas.

Conclusions

Perform global fit to all up-to-date data over wide range of parameter space. Fit fairly good - some slight worries:

low W^2 - $\alpha_S^n \ln^{2n-1}(1-x)$, higher twist,

$dF_2/d\ln Q^2$ - $\alpha_S^n \ln^{n-1}(1/x)$.

High x gluon constrained (to 20%) by new jet data. Upper part of previous range.

Look at uncertainty on W (and Z) cross-sections due to errors on data alone. Can be applied in same manner to other quantities.

$$\Delta\sigma_{exp}(LHC) \approx \pm 2\% \qquad \Delta\sigma_{exp}(\mathrm{Tev}) \approx \pm 2\%$$

Uncertainty from this source rather small. Even for quark dominated processes uncertainty from input assumptions e.g. $\alpha_S(M_Z^2)$, cuts on data, varying experimental normalization to limits ..., and from higher orders/resummation comparable and potentially larger.

For some processes theory probably the dominant source of uncertainty at present.