An Update of the MRST Parton Distributions

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Major update in people involved.

Dick Roberts completely retired from project.

Graeme Watt started as responsive RA on parton distributions from April 1st.

Major changes in theory.

Implementation of new heavy flavour VFNS (see talk), particularly at NNLO.

Inclusion of NNLO corrections to Drell-Yan data (still preliminary).

New data included.

NuTev data on $F_2^{\nu,\bar{\nu}}(x,Q^2)$ and $F_3^{\nu,\bar{\nu}}(x,Q^2)$ replacing CCFR.

New CDFII high-E_T jet data (compared, not fit).

Direct high-x data on $F_L(x,Q^2)$ (see talk).

Some important changes as NLO $\rightarrow$ NNLO.

Most important change compared to previous NNLO – new VFNS. $\rightarrow$ significant change in partons.

Obtain MRST(?) NNLO partons with uncertainties due to experimental errors for the first time.

Same procedure as before – 15 eigenvector sets of partons and $\Delta\chi^2 = 50$.

First time we have full NNLO with no major approximations. (Not aware anyone else has - heavy flavours a major issue.)

In general size of uncertainties similar to at NLO.

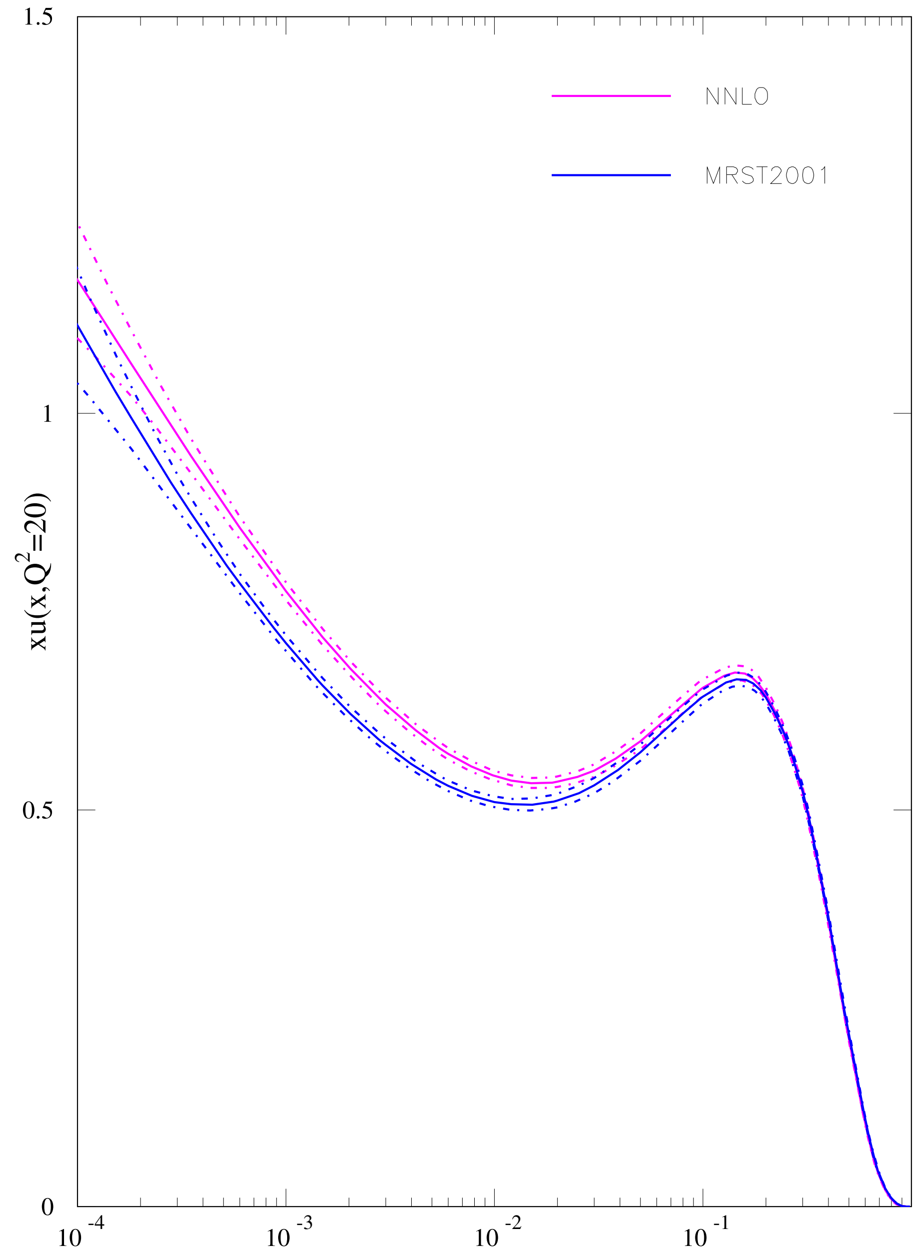
Constraint of partons comes mainly from , HERA neutral current, BCDMS, NMC, E866 Drell-Yan ratio, Tevatron jets, SLAC, E866 Drell-Yan, NuTeV, CDF W-asymmetry, $etc.$ in (very) rough order of degree of constraint.

More work to do to estimate theoretical uncertainty. Certainly important in some regions.

Changes in Partons

At small x effect of coefficient functions, particularly $C_{2,g}(x, Q^2)$, important.

Change from NLO to NNLO greater than uncertainty in each.

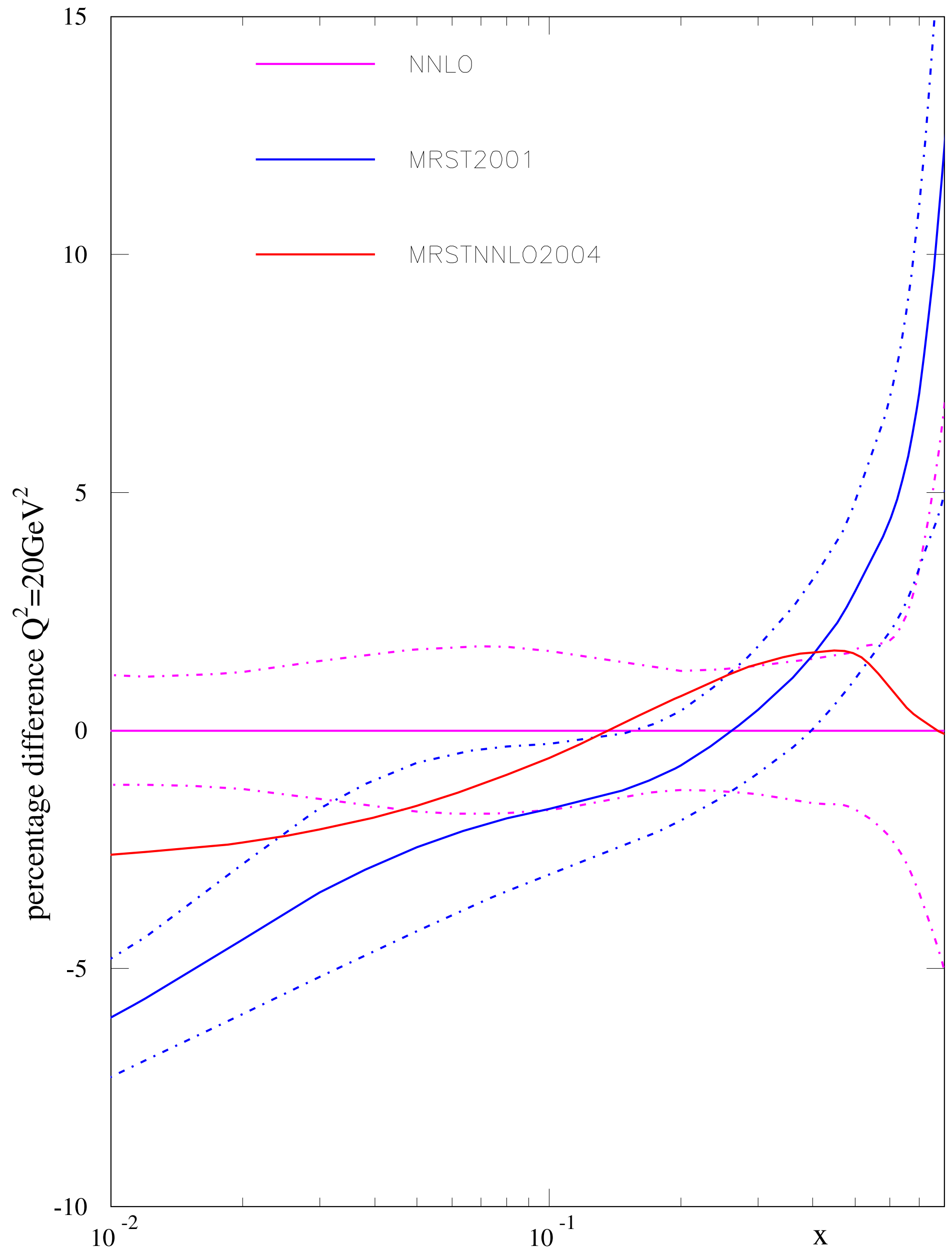


At large x coefficient functions important again,

$$C^2_{2,q}(x) \sim \left(\frac{\ln^3(1-x)}{1-x}\right)_+$$

Change from NLO to NNLO again larger than uncertainty in each.

No real change from MRST2004NNLO partons.



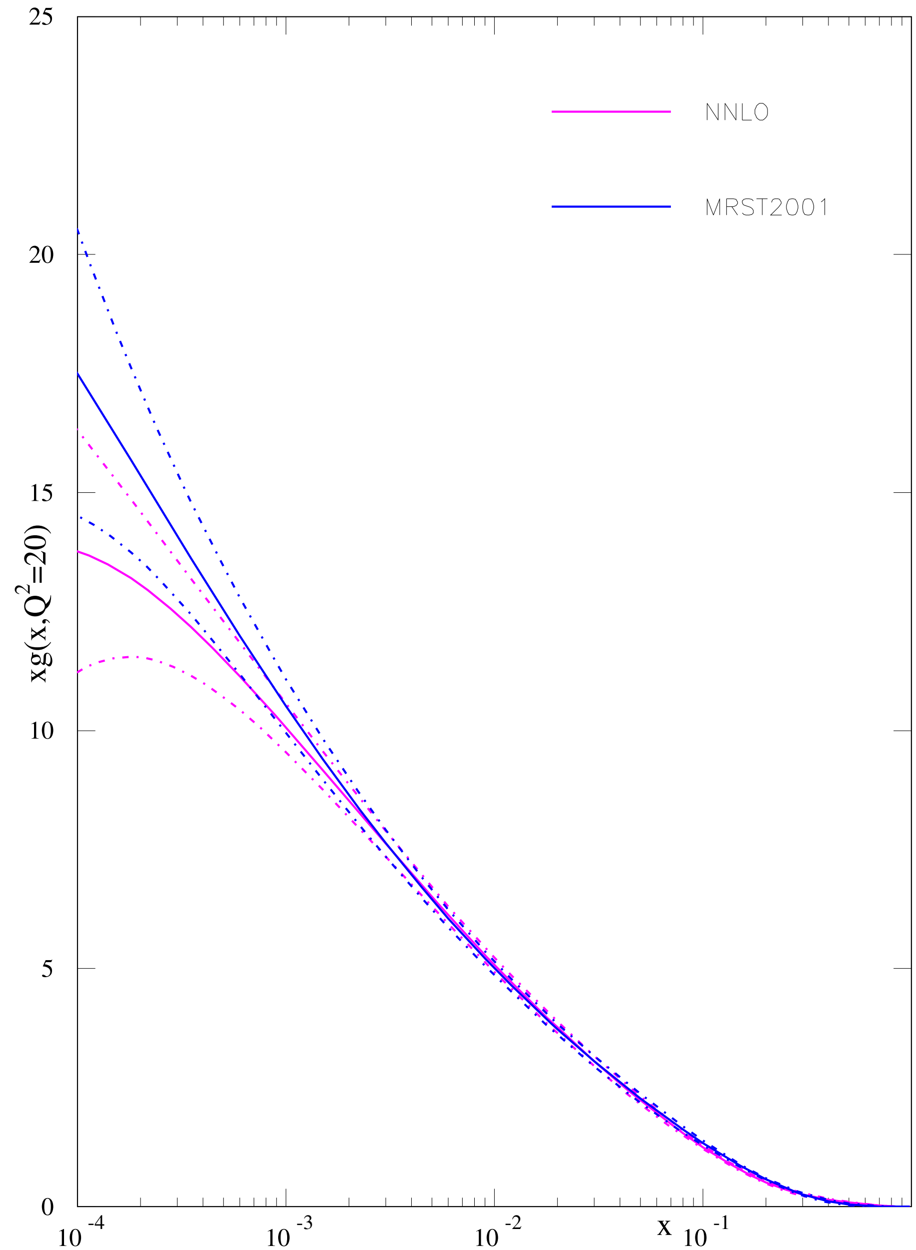
At small x effect of splitting functions particularly $P^2_{qg}(x,Q^2)$ important.

Positive $\ln(1/x)/x$ contribution at low x.

Affects gluon by fitting $dF_2(x,Q^2)/d\ln Q^2$.

Smaller at very low x.

NNLO coefficient functions very important for $F_L(x,Q^2)$. Details in F_L session.

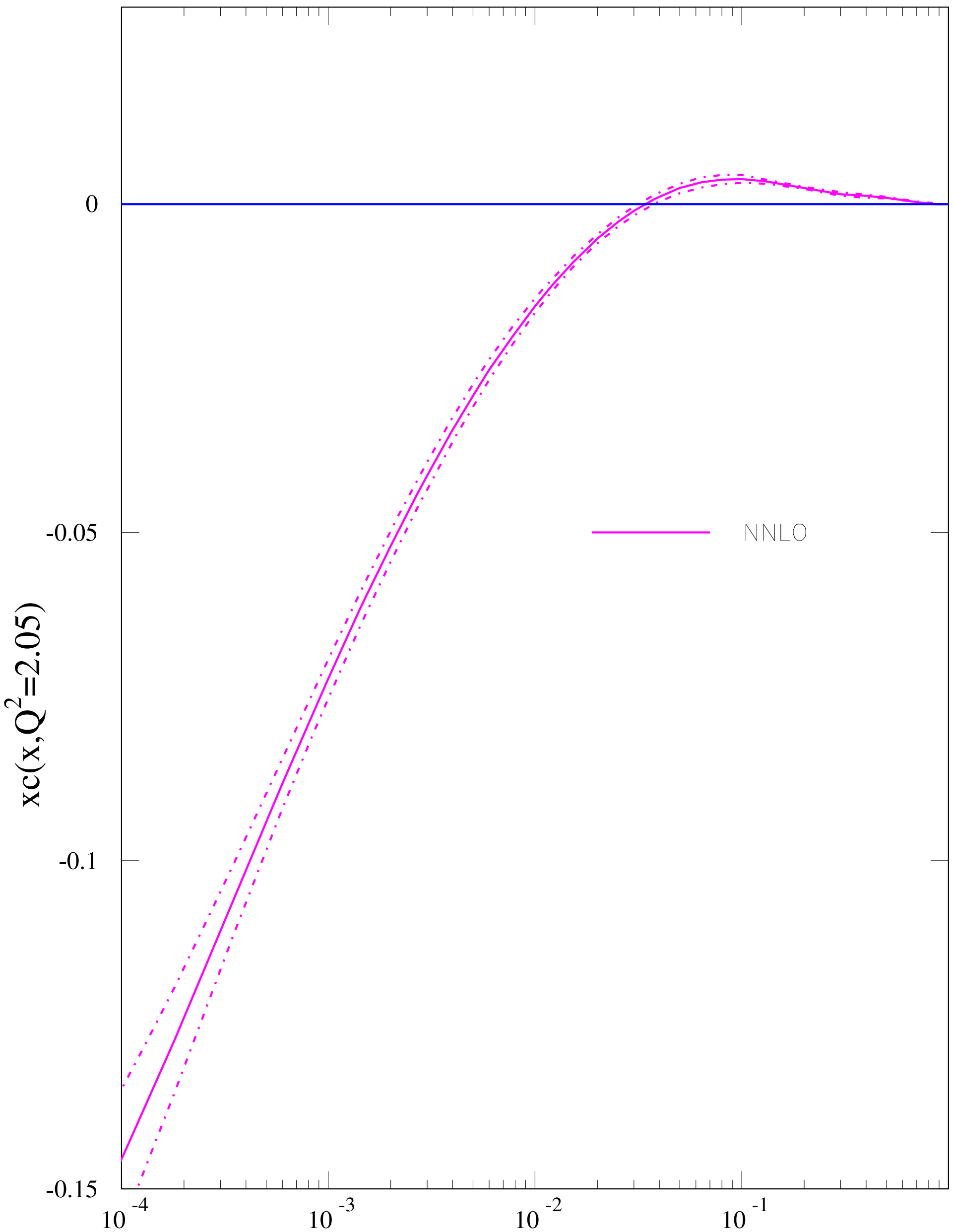


Heavy flavour no longer turns on from zero at $\mu^2 = m_c^2$

$$(c+\bar{c})(x, m_c^2) = A^2_{Hg}(m_c^2) \otimes g(m_c^2)$$

In practice turns on from negative value, (for general gluon).

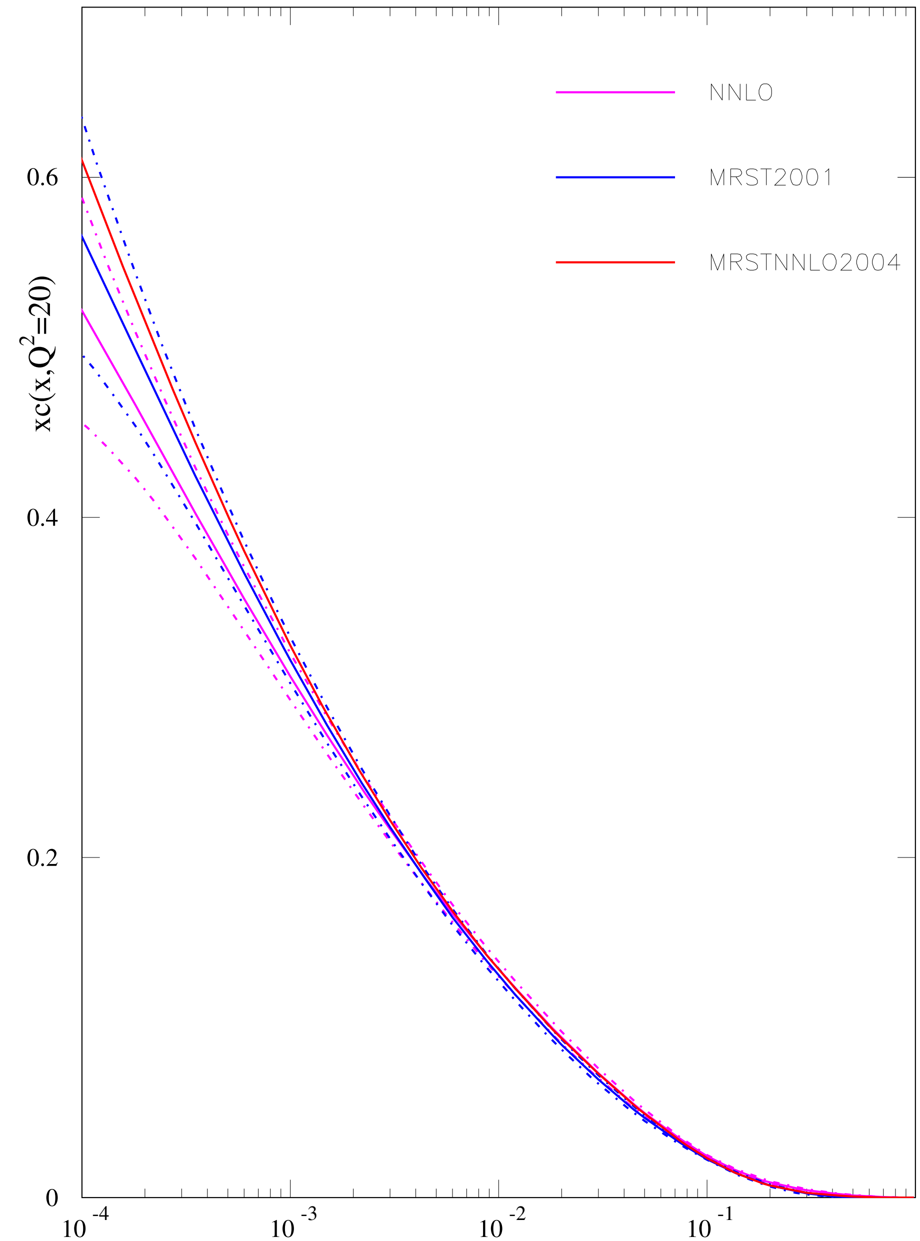
(Solved by small x resummation White?)



At small x increased evolution from NNLO splitting function allows charm to catch up a bit with NLO which starts from zero at m_c^2.

Always lags a little at higher Q^2

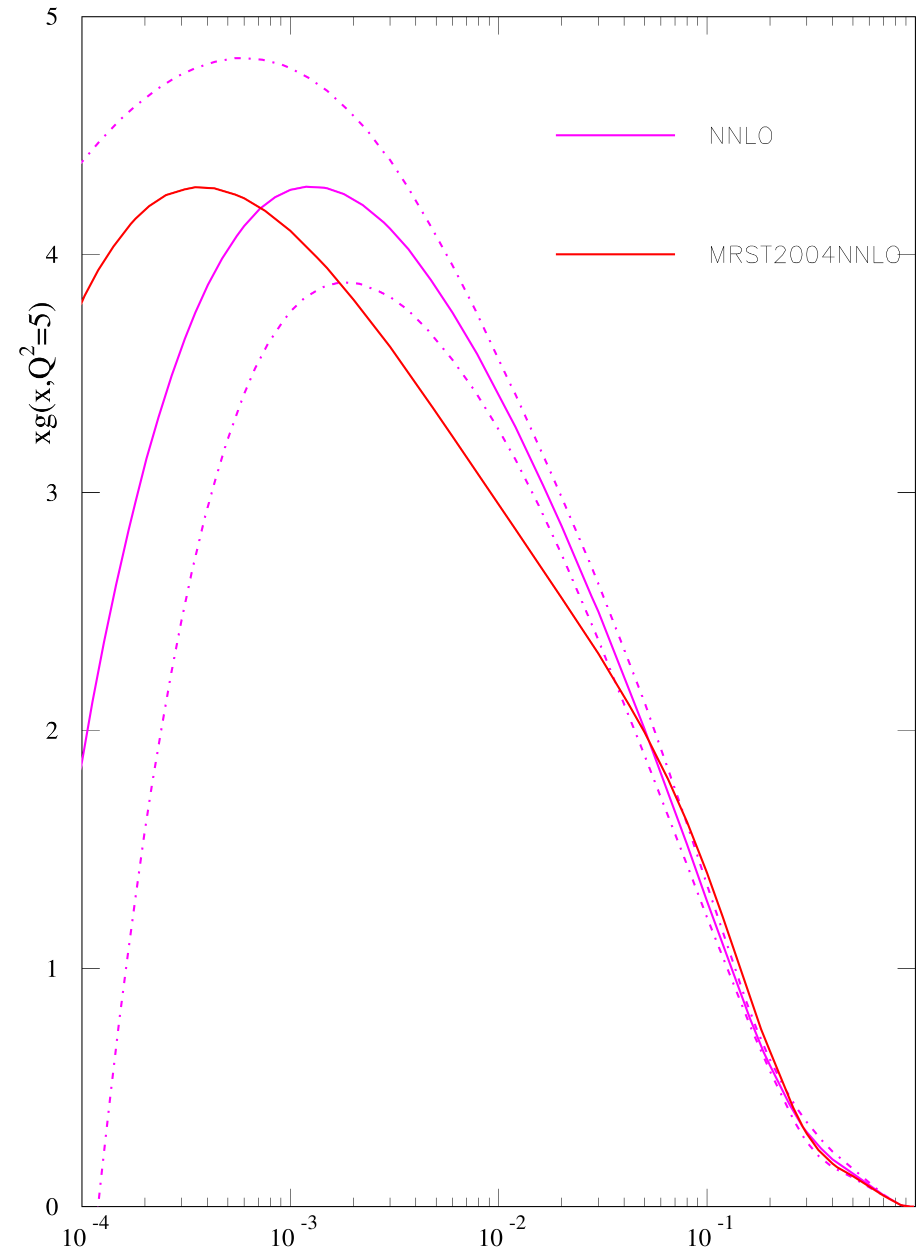
Significantly lags old approx MRST2004 distribution which turned on from zero.



Difference in charm procedure affects gluon compared to approx MRST2004 NNLO fit.

Change greater than uncertainty in some places. Correct heavy flavour treatment vital.

More on this in heavy flavour session.

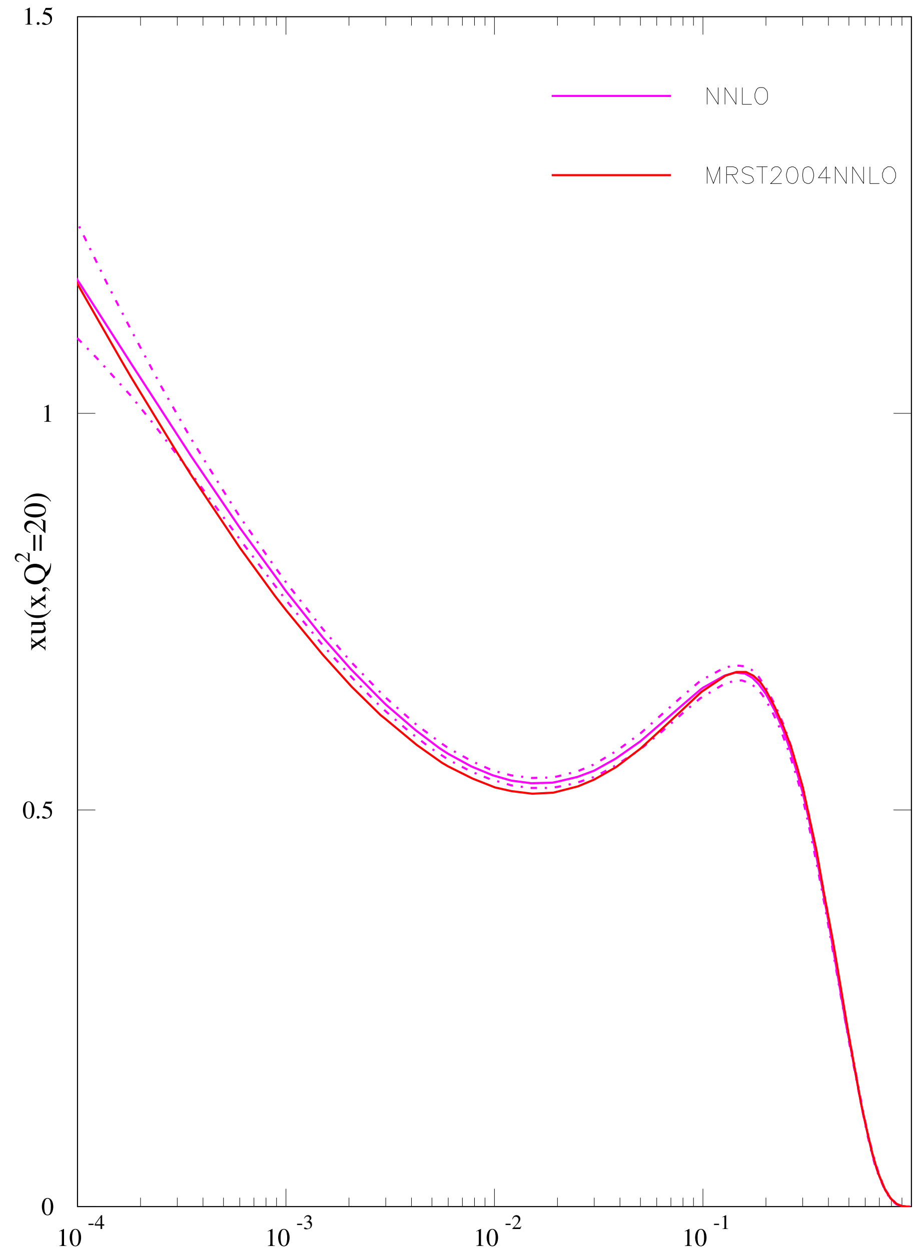


Not much change in light quarks due these to theoretical updates.

Minor change – bit bigger than MRST2004 at small x.

Slightly lower $s(x, Q^2)$ $\rightarrow$ more $u(x, Q^2)$.

Also slightly higher $\alpha_S(M_Z^2)$. Negative NNLO correction bigger $\rightarrow$ more $u(x, Q^2)$.

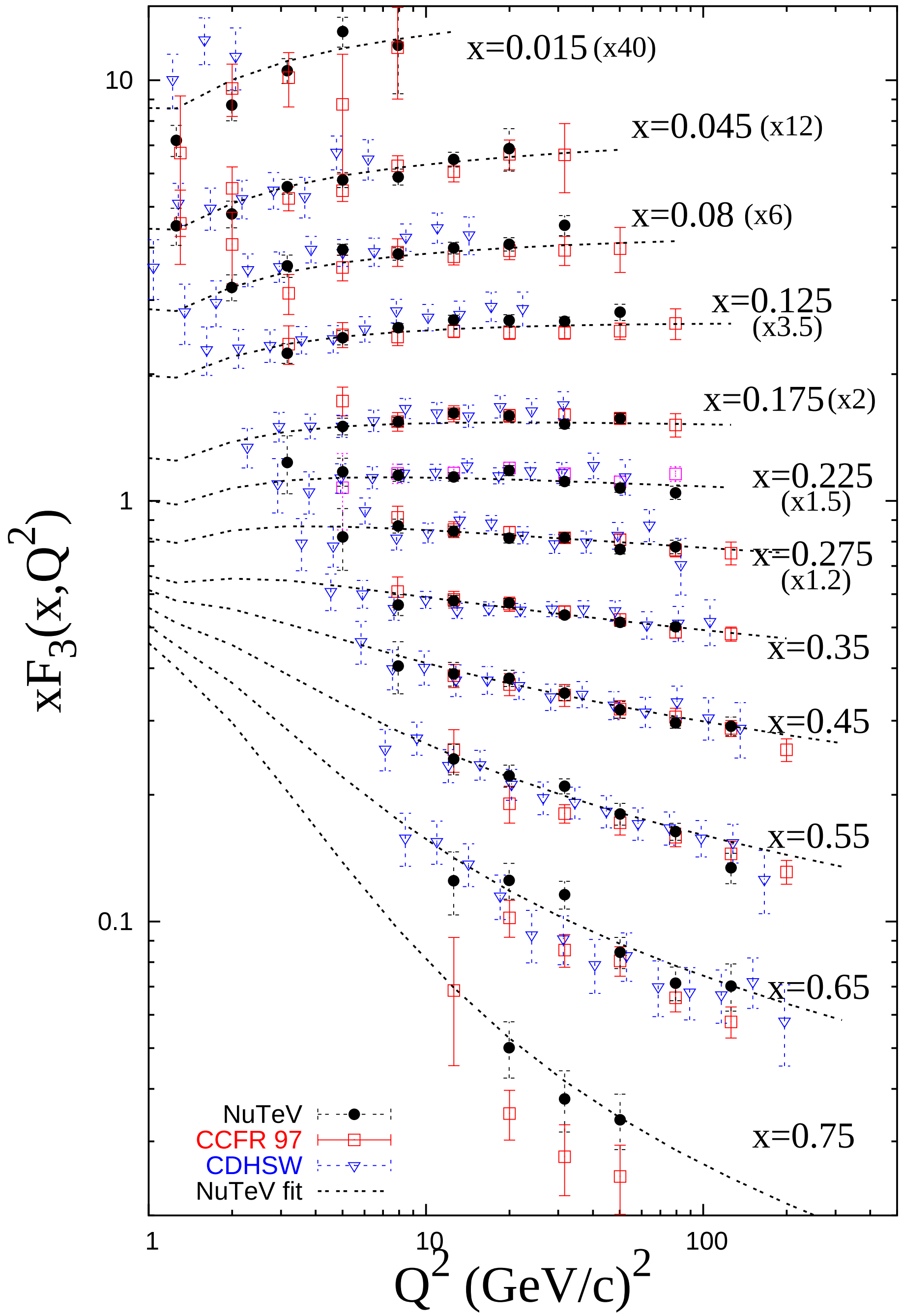


New Data

New NuTeV data not completely compatible with the older CCFR data.

Main source of discrepancy's calibration of magnetic field map of muon spectrometer $\longrightarrow$ muon energy scale.

However, previous parton distribution fits were perfectly compatible with CCFR data using EMC inspired Q^2 independent nuclear correction



Previously used correction applied to theoretical prediction.

$x < 0.0903 \quad R = 1.238 + 0.203 log_{10} x$

$x > 0.2340 \quad R = 0.783 - 0.385 log_{10} x$

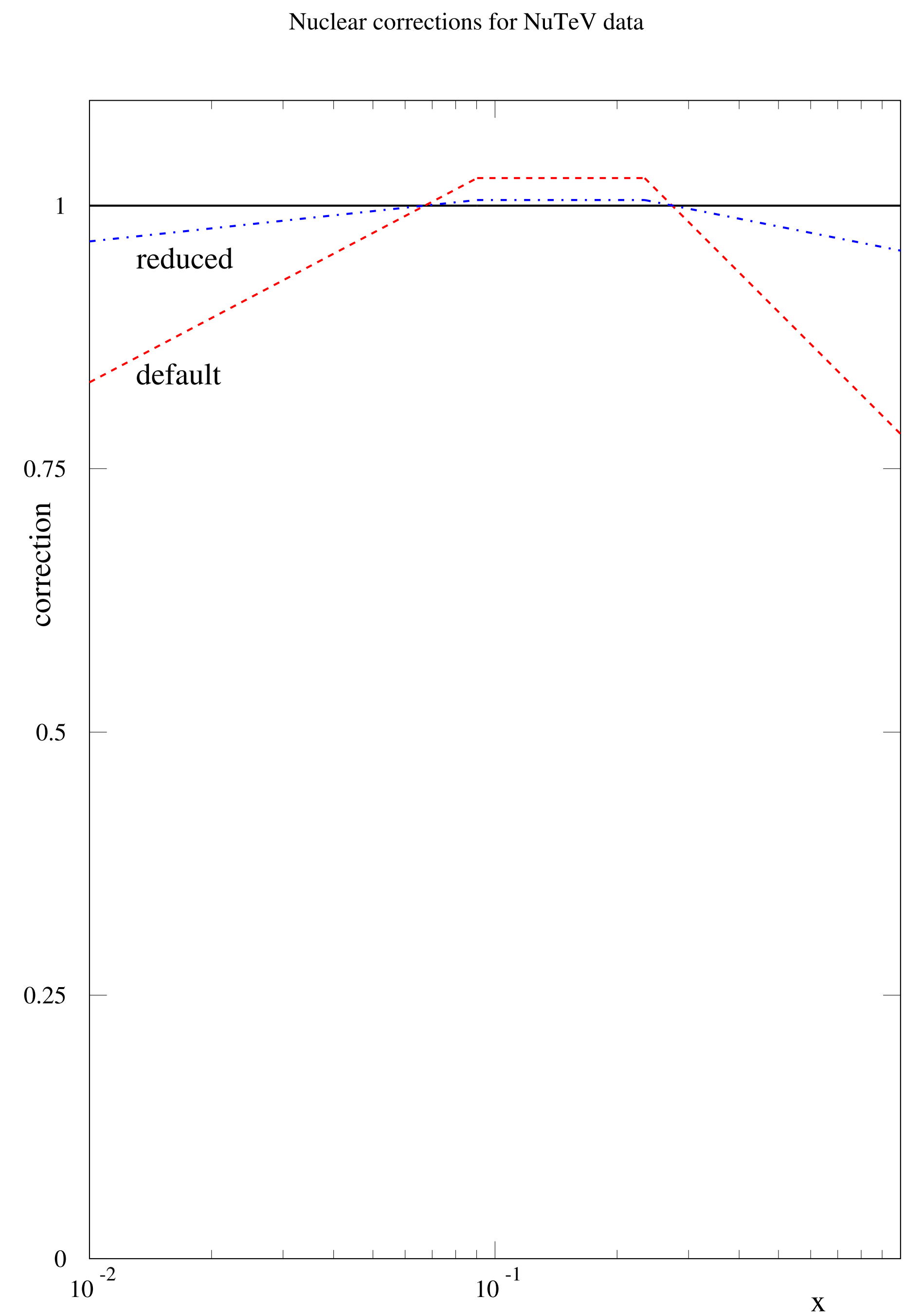
$0.234 > x > 0.0903 \quad R = 1.026$

Far too large for new NuTeV data. High-x completely determined by valence quarks for both $F_2^{\nu,\bar{\nu}}(x,Q^2)$ and $F_3^{\nu,\bar{\nu}}(x,Q^2)$.

These well known from fixed target $F_2^p(x,Q^2)$ and $F^d(x,Q^2)$.

Try form $R^{eff} = 1 + A * (R - 1)$.

Best fit $A = 0.2$.



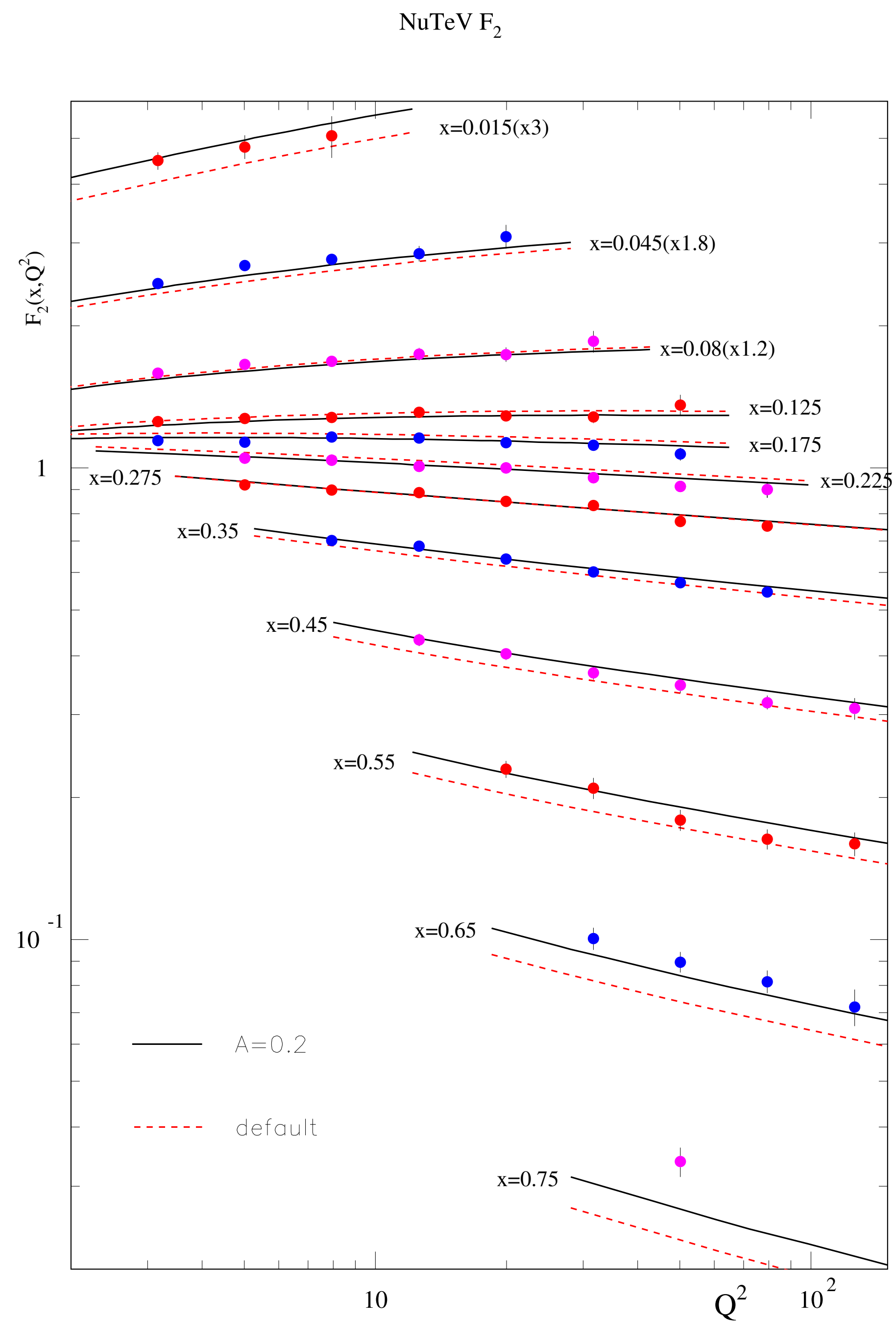
Previous nuclear correction clearly ruled out.

Obtained from EMC effect. Nuclear correction different for ν than for charged leptons.

More work needed here.

Partons in region of high correction already well-determined.

Important information in the region $x < 0.3$ - not too sensitive to corrections.

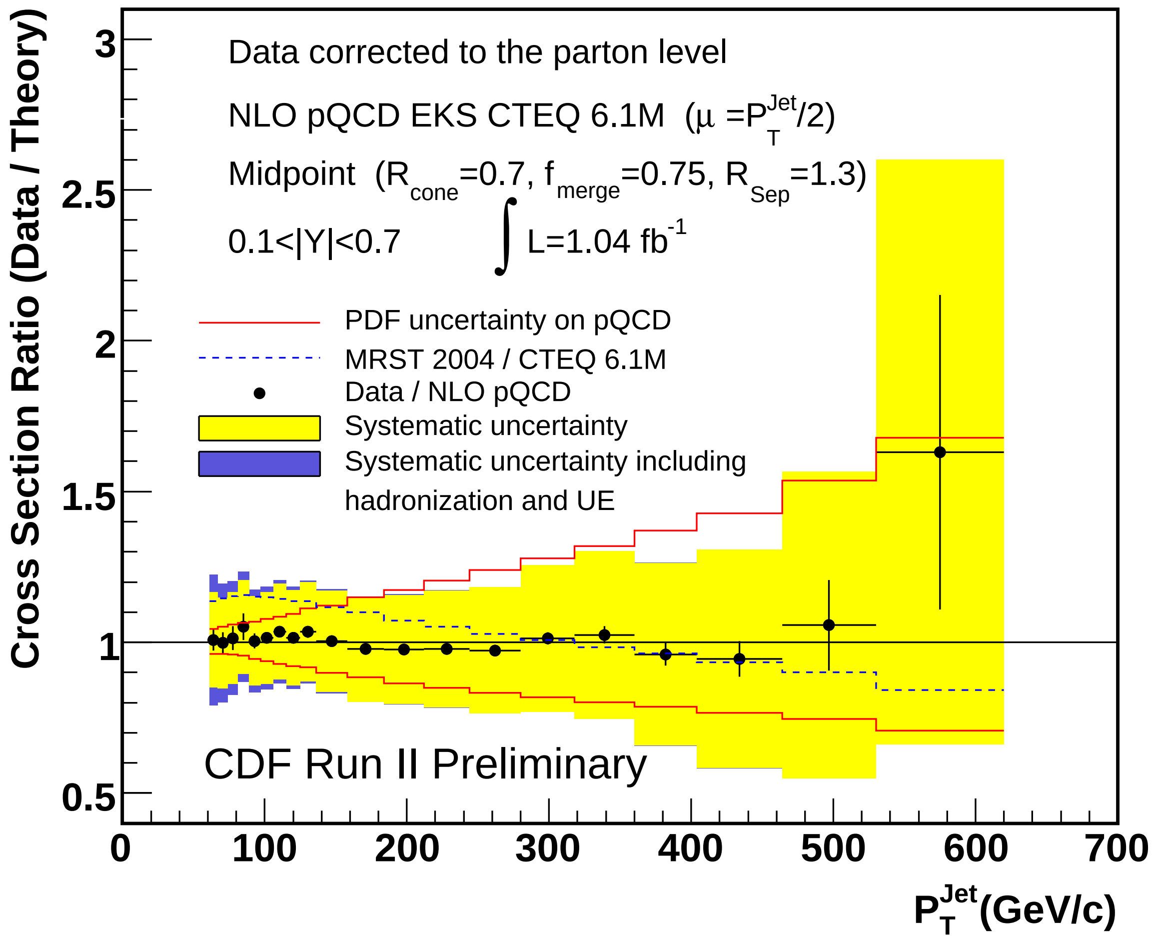


CDF II **jet data**.

Appears to be fit well by MRST partons.

Remember luminosity uncertainty of 6% and other normalization uncertainties – overshooting at low P_t allowed.

Shape – increasing with P_t a bit quicker than prediction. Also allowed for by systematic errors.

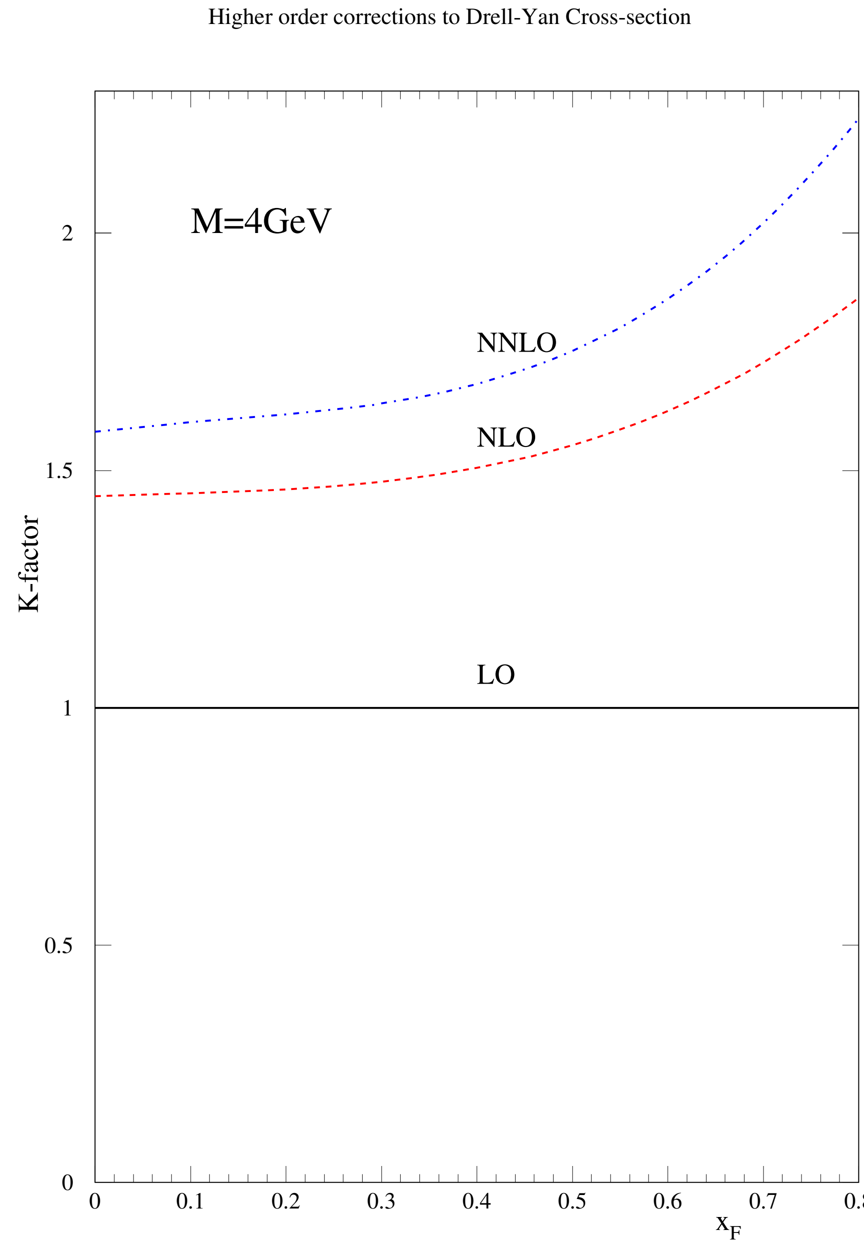


Drell-Yan corrections

The K-factors for Drell-Yan production at E866 – $\sqrt{s} = 38.8\text{GeV}$.

Enhancement at higher $x_F = x_1 - x_2$ due to logarithms. Similar to $\ln(1-x)$ enhancement in structure functions.

NLO corrections large, NNLO corrections significant – 10% or more.



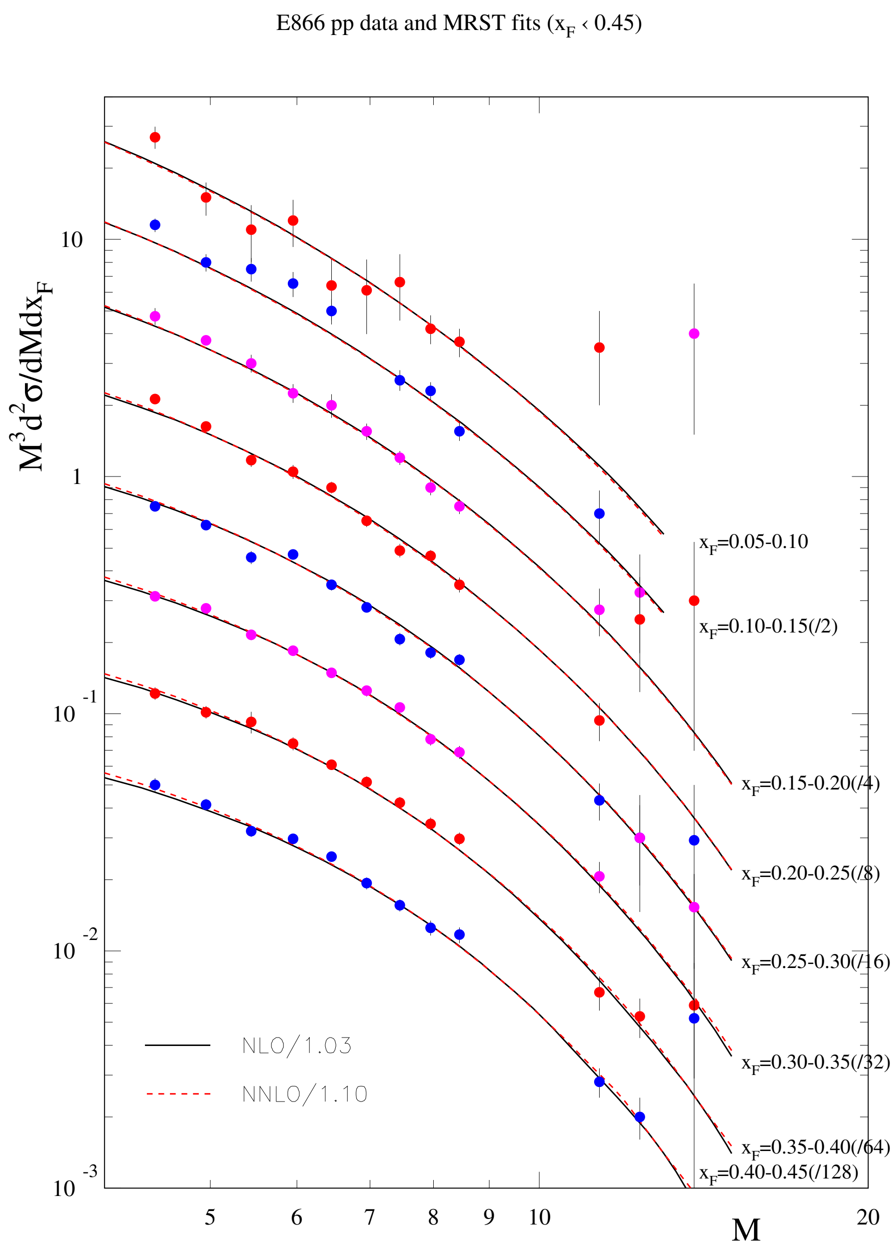
Quality of fit to E866 Drell-Yan production at E866 in proton-proton collisions.

$\chi^2 = 223/174$ at NLO.

$\chi^2 = 240/174$ at NNLO.

random scatter of points large – $\chi^2 \sim 220$ about best possible.

$\rightarrow$ fit good (despite previous claims).

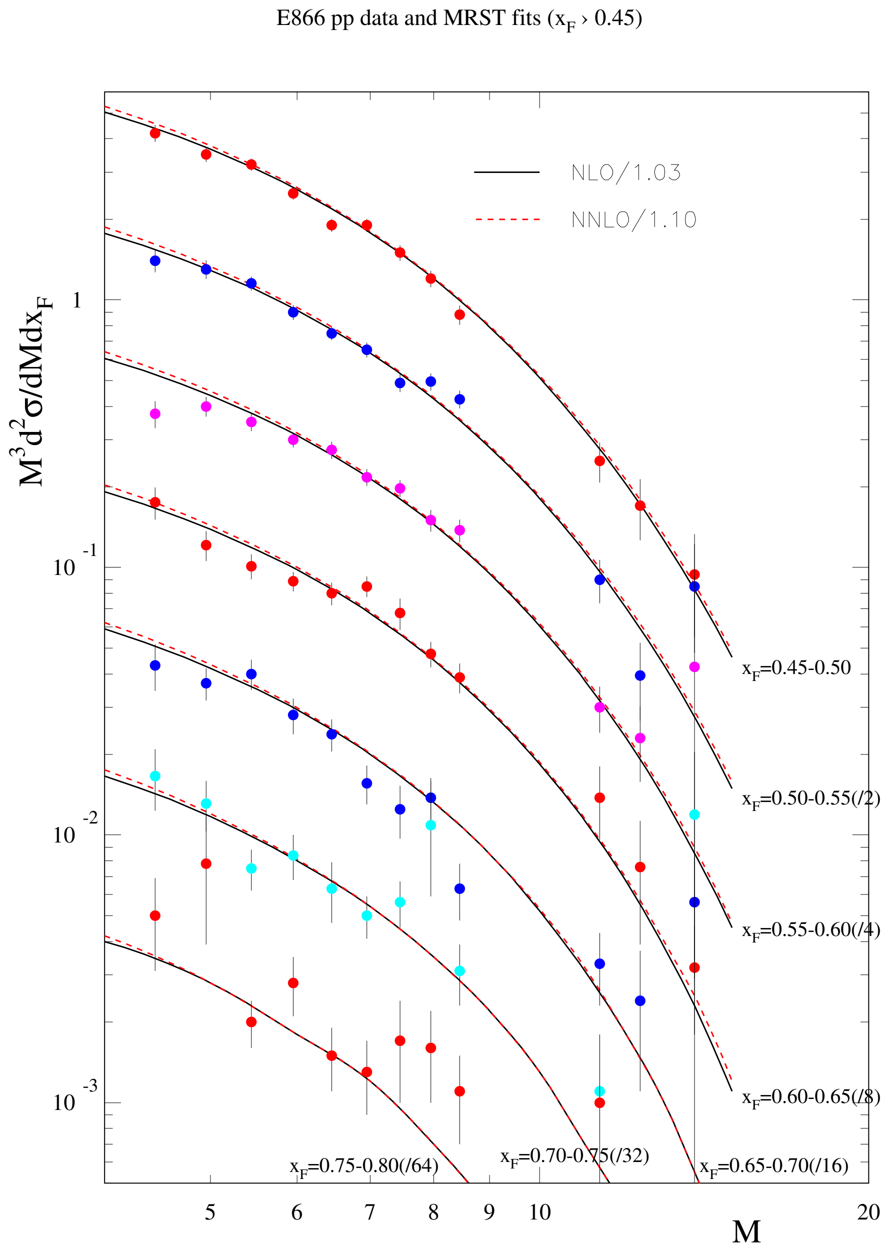


Consistent positive correction at NNLO requires data normalization equal 110%.

Best fit already 103% at NLO.

Sea for $x \leq 0.1$ and valence quarks already well-determined by structure function data.

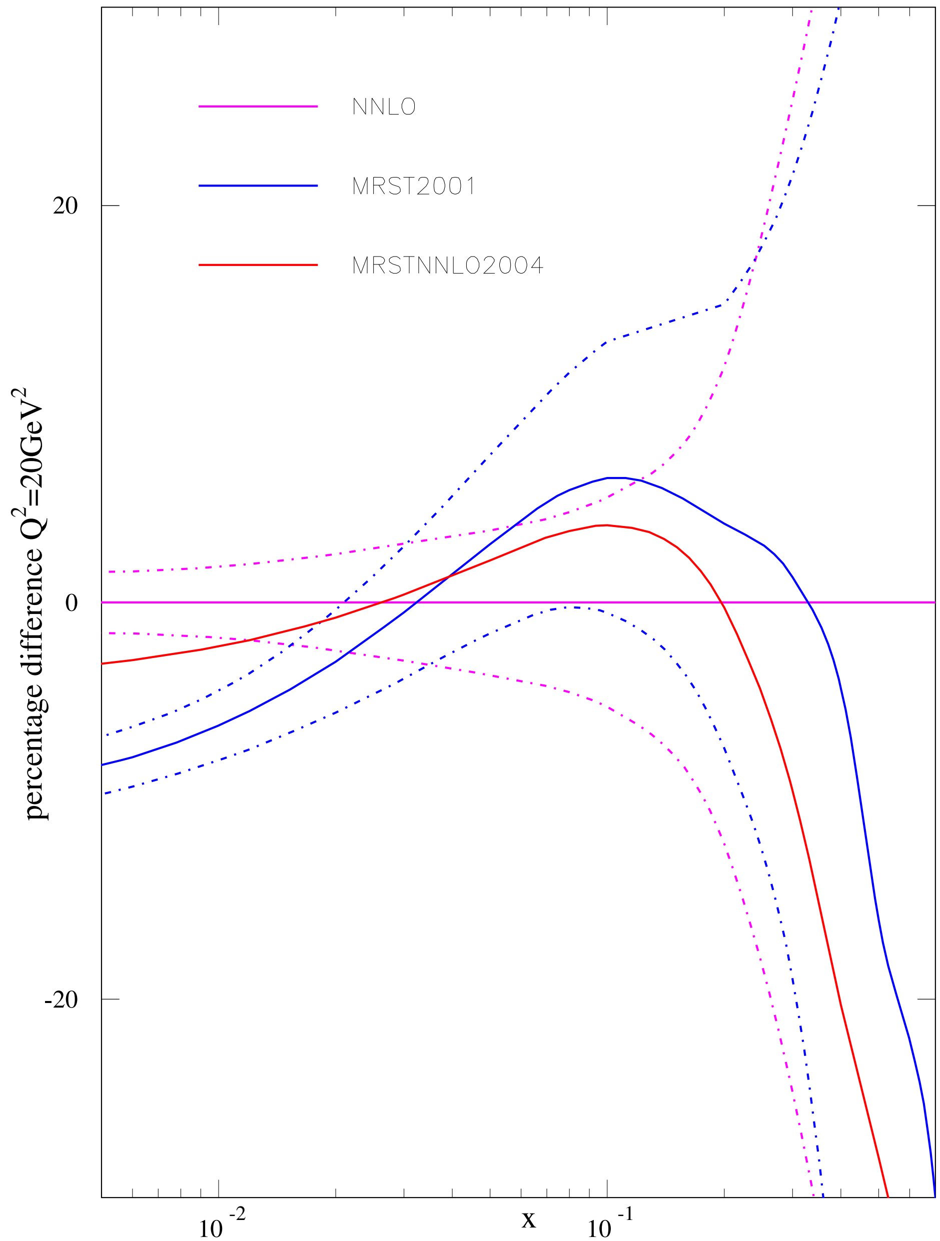
Normalization uncertainty 6.5% – change of 10% questionable?



Drell-Yan corrections affect sea quarks.

Even with increased normalization of data new NNLO partons smaller than MRST2004NNLO and NLO in region where constrained by data.

Must be bigger than these at smaller x as already seen.



Summary

Quality of full fit at NLO and at NNLO.

NNLO fairly consistently better than NLO.

Definite tendency for $\alpha_S(M_Z^2)$ to go up with all changes.

At NLO $\alpha_S(M_Z^2) = 0.121$.

At NNLO $\alpha_S(M_Z^2) = 0.119$.

Pull for high $\alpha_S(M_Z^2)$ at NLO from NMC data, SLAC data, Tevatron jets (indirectly) and $F_L(x, Q^2)$ data (against from BCDMS data).

Generally naturally improved by NNLO fit.

Some room for improvement.

Data set	No. of data pts	NLO	NNLO
H1 ep	425	446	444
ZEUS ep	356	279	265
BCDMS μp	167	202	192
BCDMS μd	155	211	205
NMC μp	126	129	128
NMC μd	126	101	96
SLAC ep	53	65	62
SLAC ed	54	60	55
E665 μp	53	61	67
E665 μd	53	52	64
NuTeV $F_2^{\nu N}$	64	71	65
NuTeV $F_3^{\nu N}$	64	67	63
NMC n/p	156	149	143
E866 DY	174	224	241
Tevatron Jets	113	125	118
H1 CC ep	28	29	29
ZEUS CC ep	30	36	35
E866 DYrat	15	9	15
CDF Wasymm	11	18	13
F_2^c	27	32	26
F_L	36	37	32
Total	2287	2406	2366

Comparisons

Compare with only other NNLO partons on market – Alekhin2002.

Nothing from CTEQ?

Much larger $\alpha_S(M_Z^2)$ in this fit than that of Alekhin ($\alpha_S(M_Z^2) = 0.119$ compared to 0.114).

Not much difference in high-x valence quarks, except than explained by difference in $\alpha_S(M_Z^2)$. Very well-constrained.

Differences in low-x sea quarks. Swamped by differences in flavour treatments – $\bar{u} - \bar{d}$ and $s(x, Q^2)$.

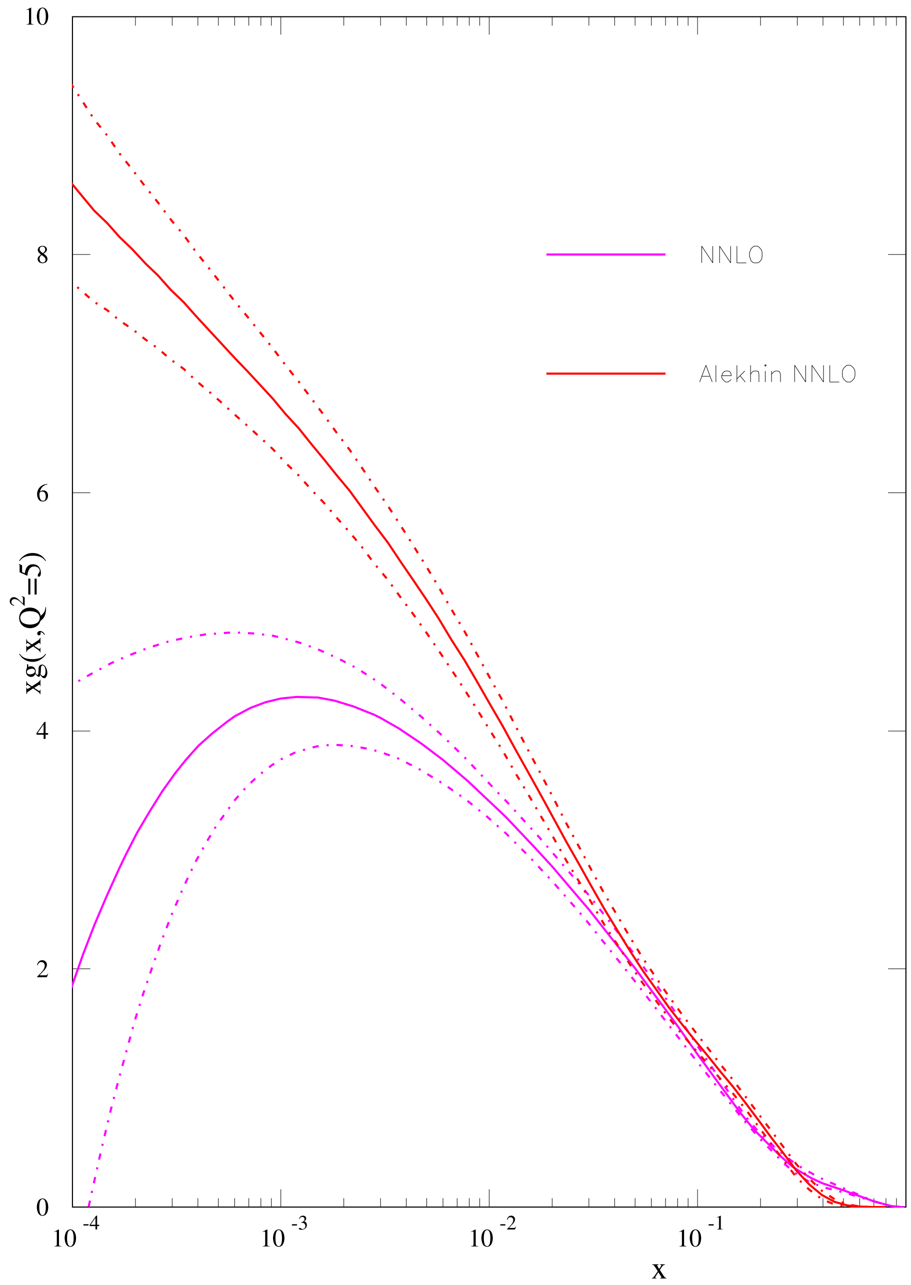
Main difference in gluon distribution.

Hugely different at small x.

Differences much bigger than uncertainties.

Differences in heavy flavour treatments
– already seen this is important.

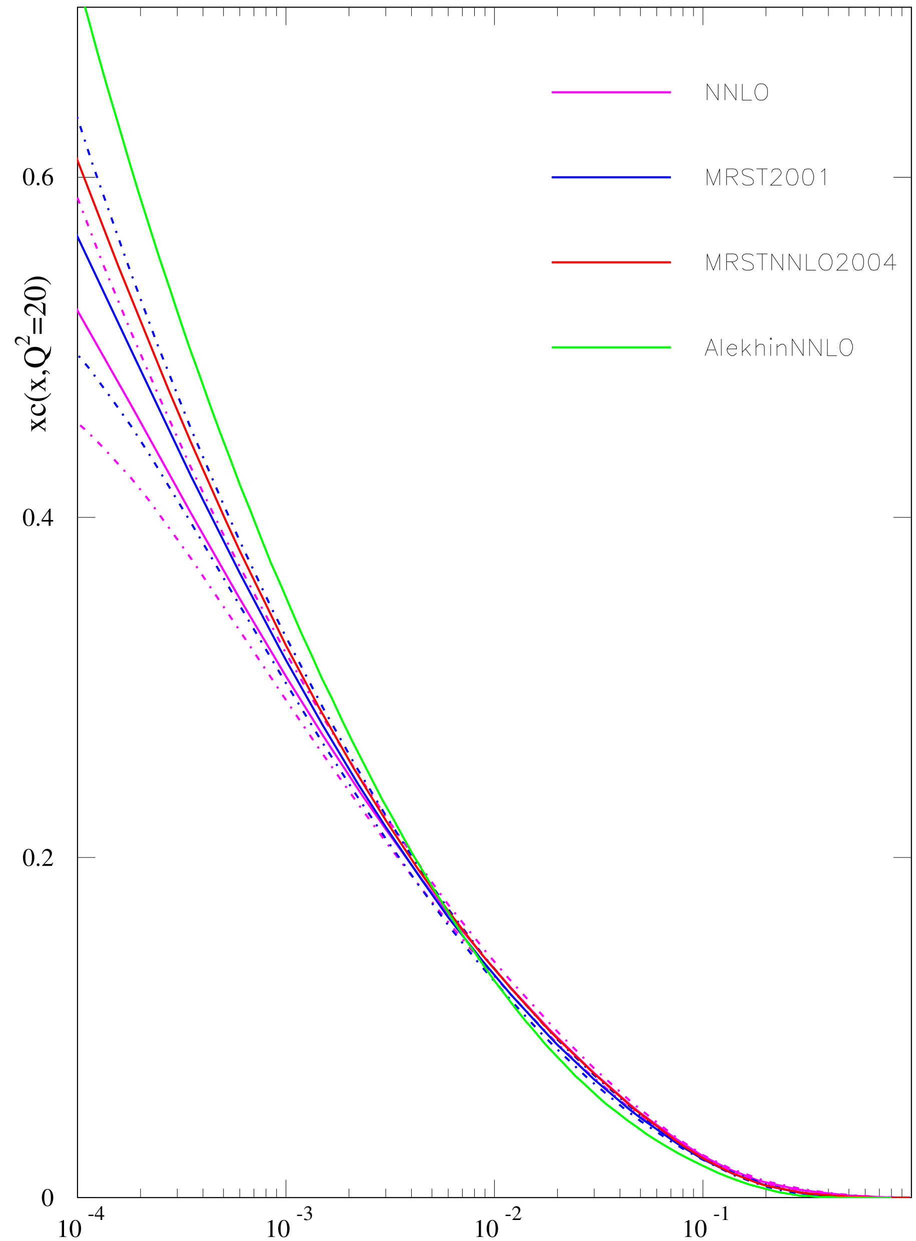
Differences in data fit and also in $\alpha_S(M_Z^2)$.



Difference in gluon feeds through to charm.

Alekhin2002 much bigger at small x.

Starts from zero as with MRST2004NNLO.

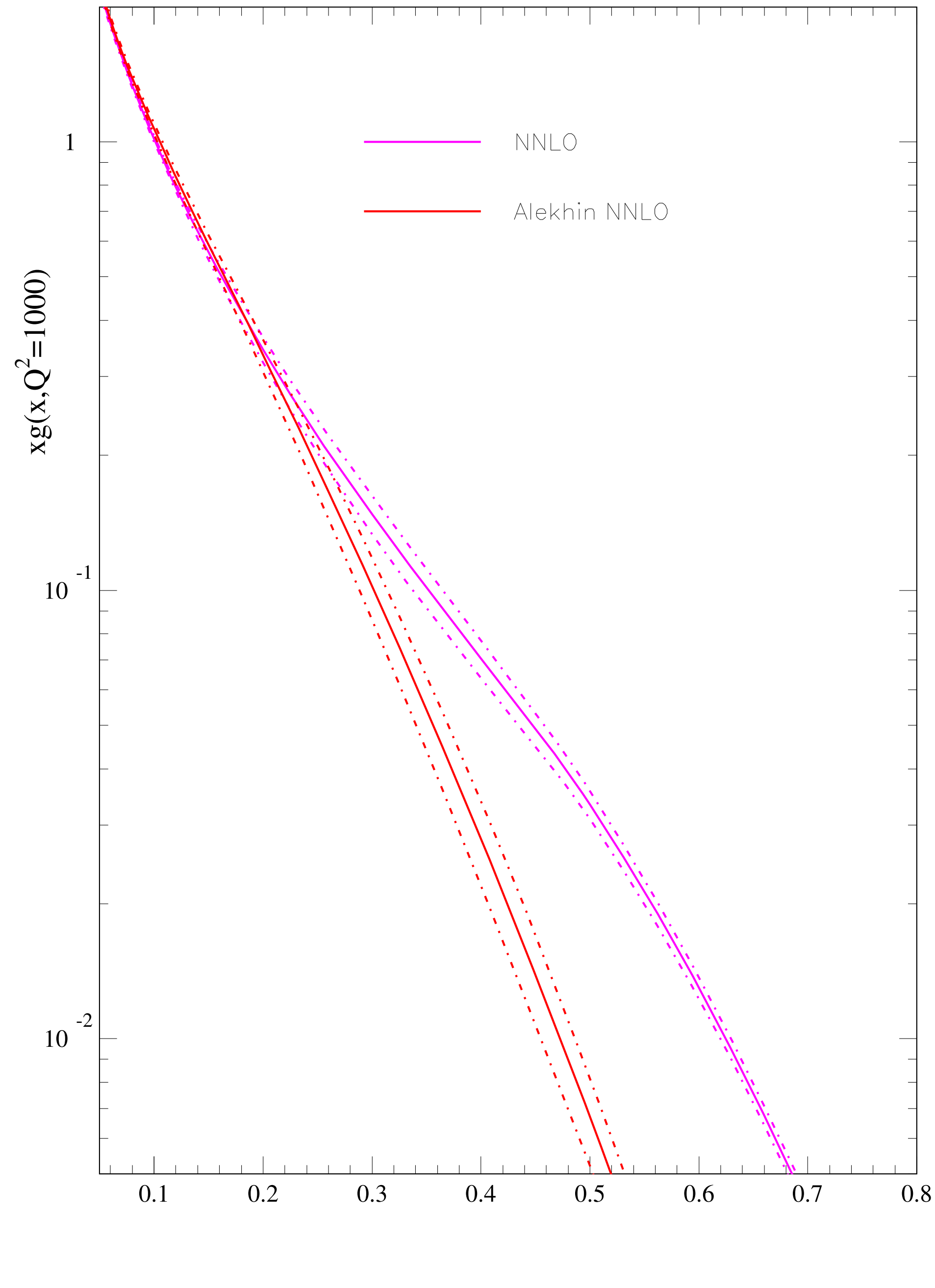


Big difference at high x and Q^2.

Determined by Tevatron jet data for MRST. Fit now excellent.

Divergence at $x = 0.25$ corresponds to $E_T \sim 225\mathrm{GeV}$.

In $\overline{MS}$ scheme gluon more important for jets at high x at NNLO because high-x quarks smaller.



Conclusions

Inclusion of new data. Correction required for NuTeV structure function data smaller than expected. At high x measure nuclear correction? New Tevatron jets ok. NNLO Drell-Yan corrections quite large. Fit data well but NLO better. In overall fit $\alpha_S(M_Z^2)$ creeping upwards.

NNLO essentially complete. Provisional update of partons. Main difference due to heavy flavour prescription. This is important.

Some new data to be included – HERA jets, more on Tevatron high-E_T jets. New heavy flavour? NuTeV di-muon data $\rightarrow s(x, Q^2) \neq \bar{s}(x, Q^2)$?

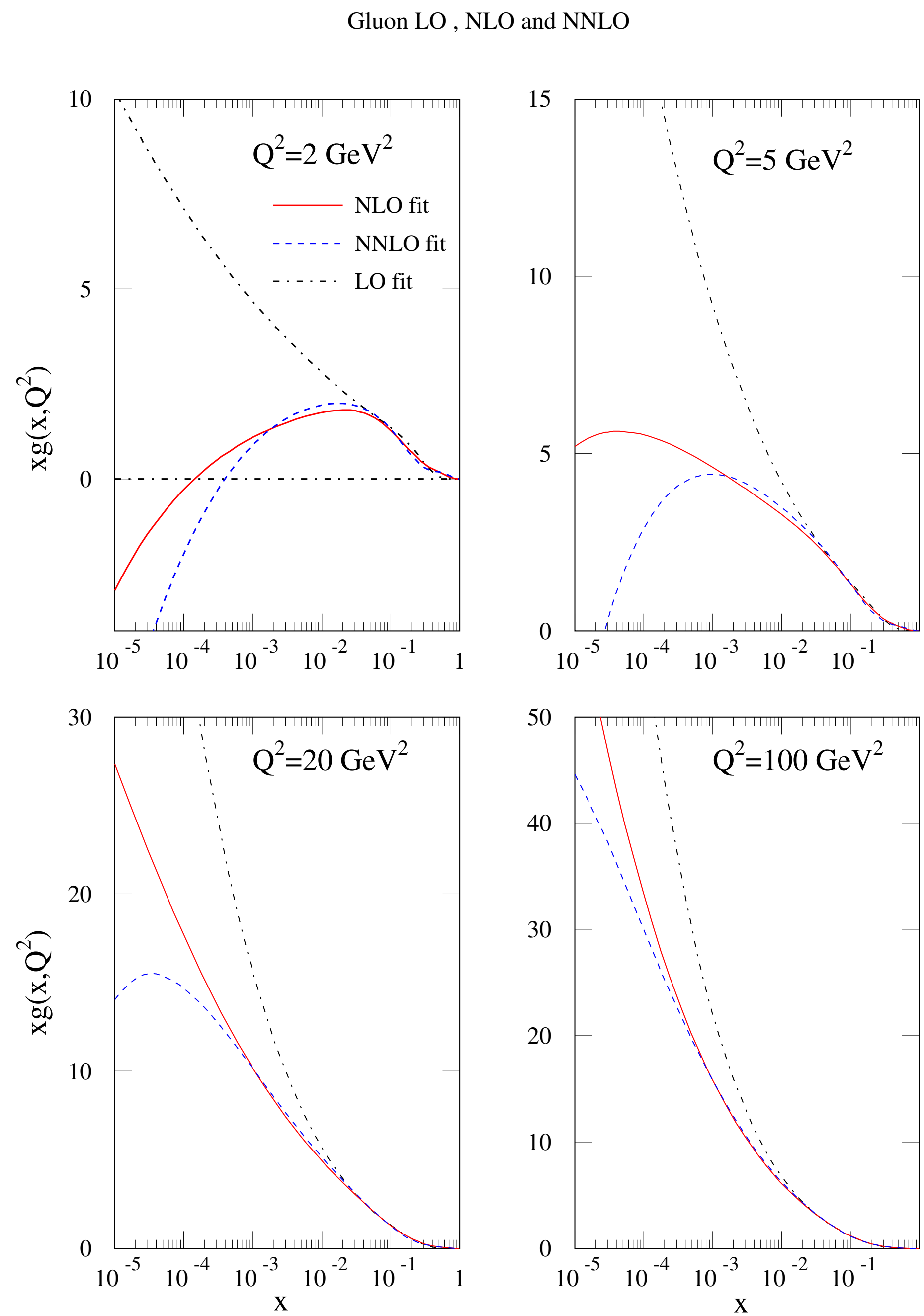
Also some theoretical fine-tuning and checking.

Will have full updated NLO and NNLO partons for LHC complete with uncertainties – experimental and theoretical.

The gluon extracted from the global fit at LO, NLO and NNLO.

Additional and positive small-x contributions in P_{qg} at each order lead to smaller small-x gluon at each order.

Note - this conclusion relied on correct application of flavour thresholds in a General Variable Flavour Number Scheme at NLO not present in earlier approximate NNLO MRST fits. Correct treatment of flavour particularly important at NNLO because discontinuities in unphysical quantities appear at this order.

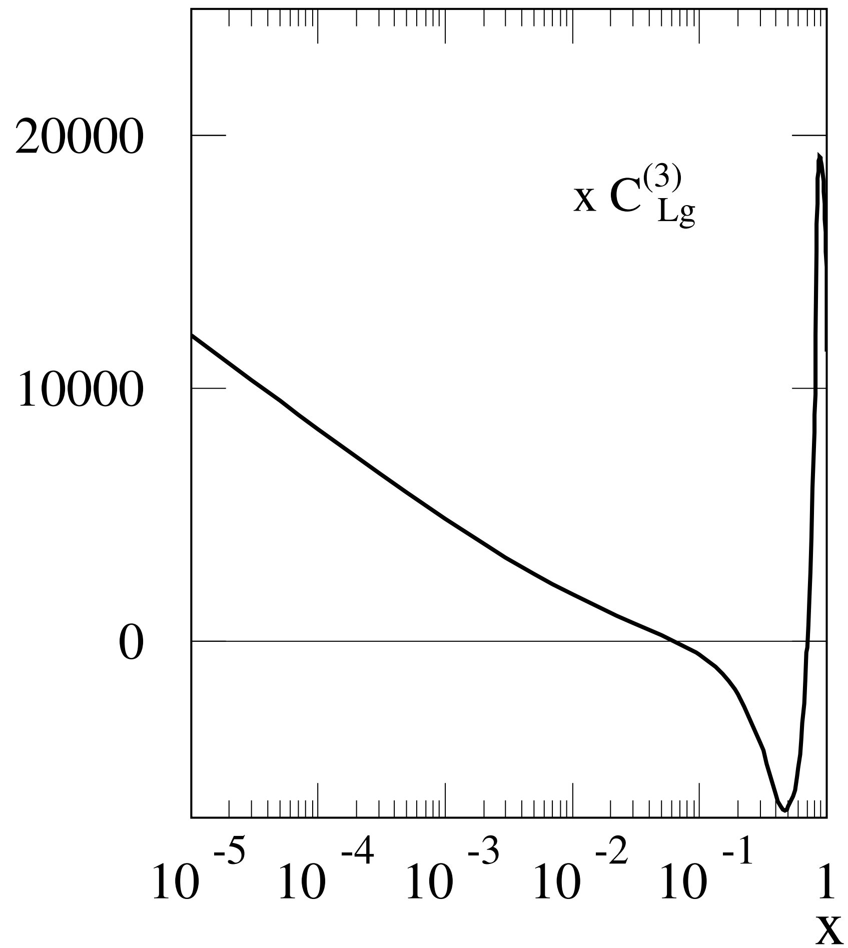


The NNLO $\mathcal{O}(\alpha_s^3)$ longitudinal coefficient function $C^3_{Lg}(x)$ given by

$$C^3_{Lg}(x) = n_f \left(\frac{\alpha_S}{4\pi}\right)^3 \left(\frac{409.5 \ln(1/x)}{x} - \frac{2044.7}{x} - \cdots\right.$$

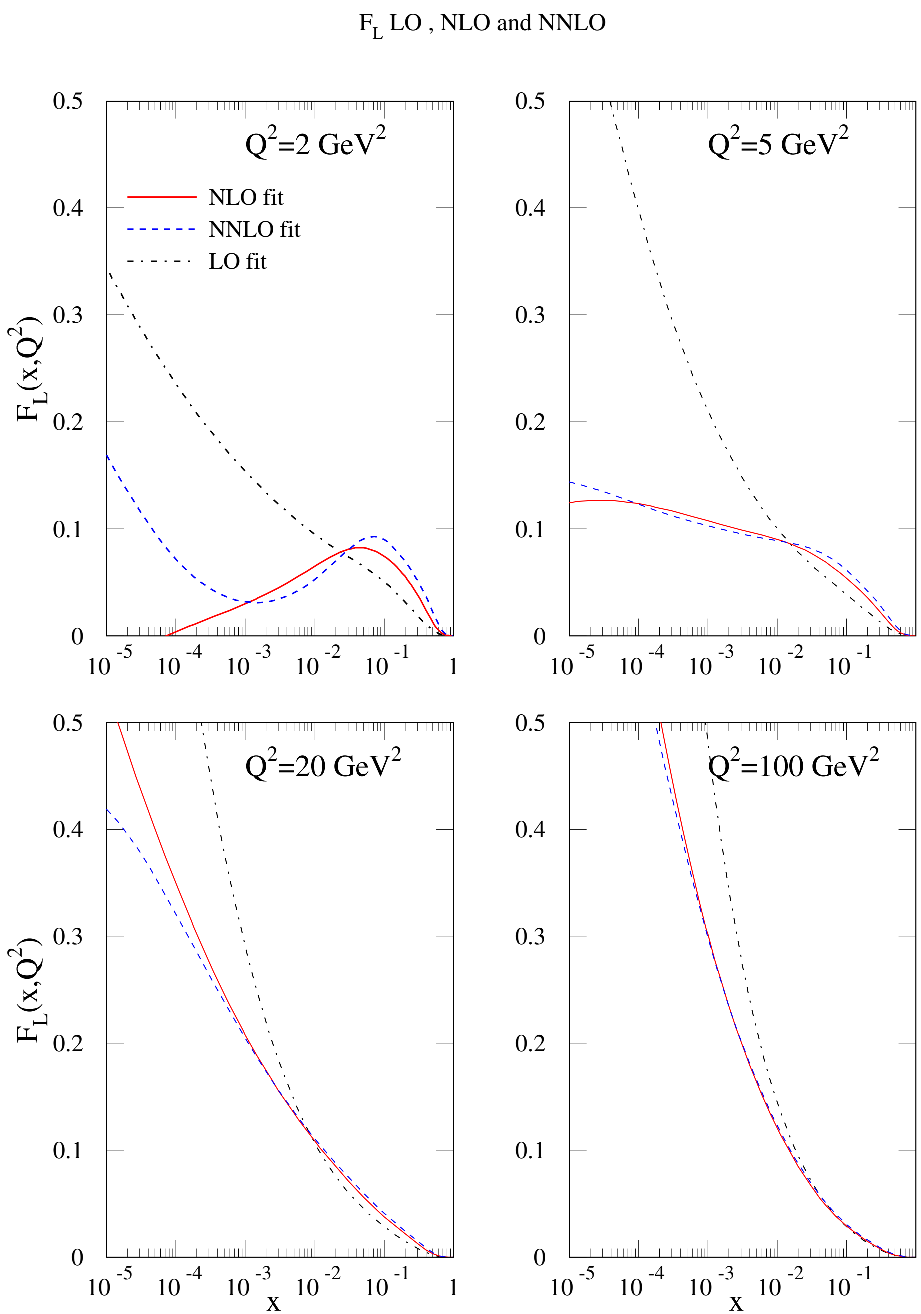
Clearly a significant positive contribution at small x.

Counters decrease in small-x gluon.



$F_L(x, Q^2)$ predicted from the global fit at LO, NLO and NNLO.

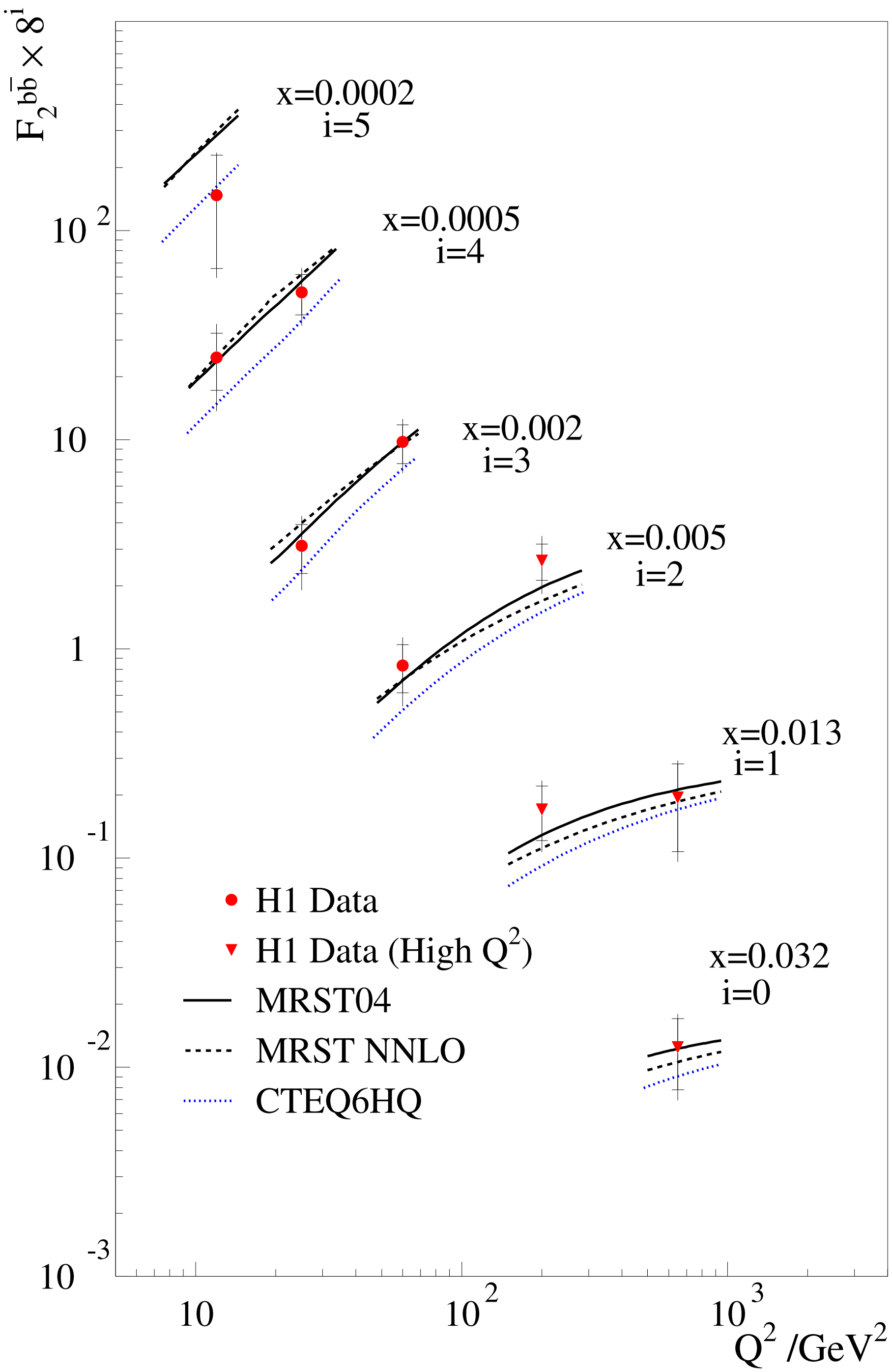
NNLO coefficient function more than compensates decrease in NNLO gluon.



This is the main difference in the NLO predictions from MRST and CTEQ in the comparison to H1 data on $F_2^b(x, Q^2)$.

$\mathcal{O}(\alpha_S^2)$ part is dominant at for $Q^2 \leq m_c^2$. "Frozen" part remains significant. Clearly improves match to data.

Choose TR approach.

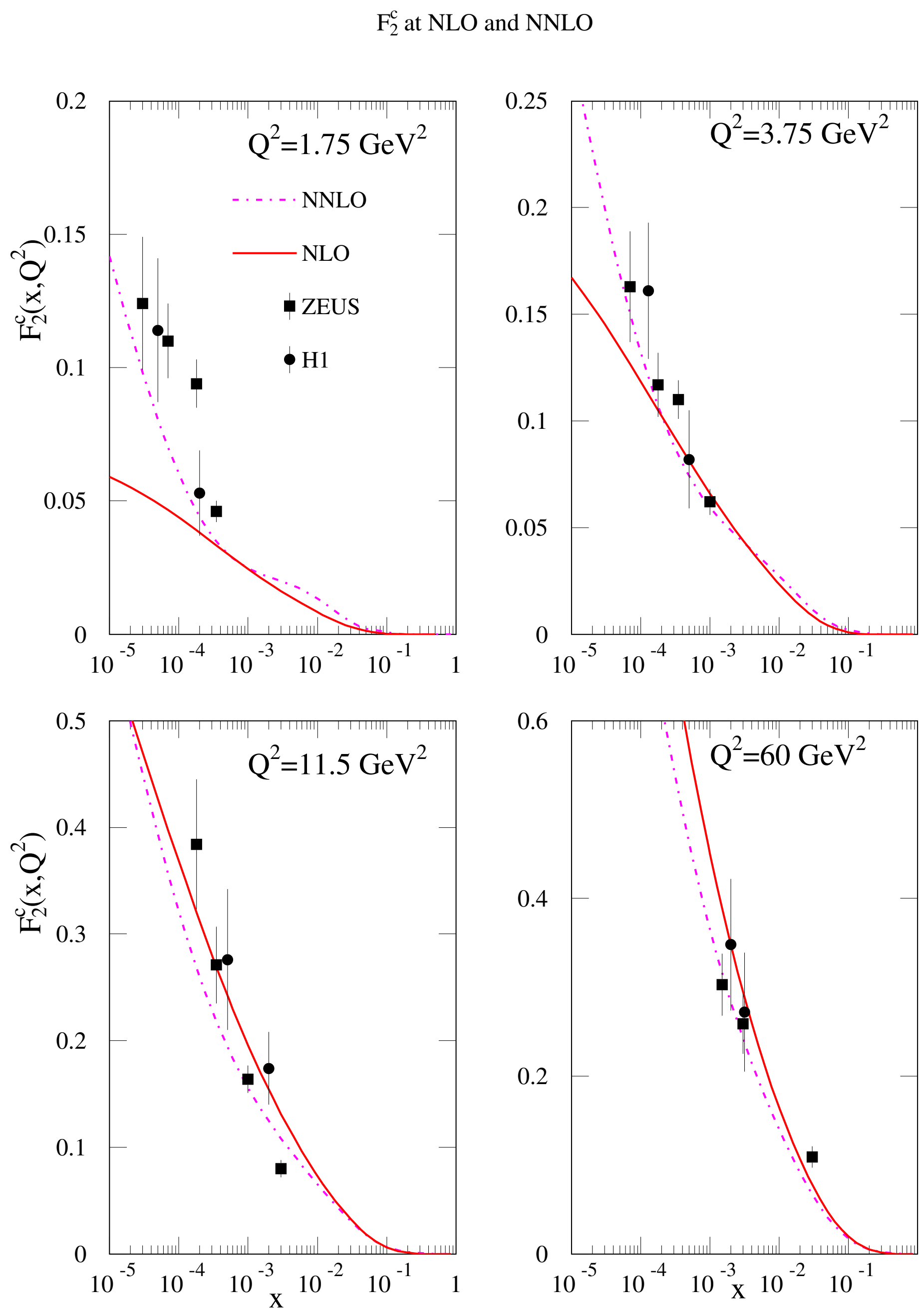


Can produce full NNLO predictions for charm with discontinuous partons, but continuous $F^H(x,Q^2)$.

Approximation in $\mathcal{O}(\alpha_S^3)$ heavy flavour coefficient functions for $Q^2 \leq m_H^2$ and frozen for $Q^2 > m_H^2$.

Results not very sensitive to choices in this, within sensible range.

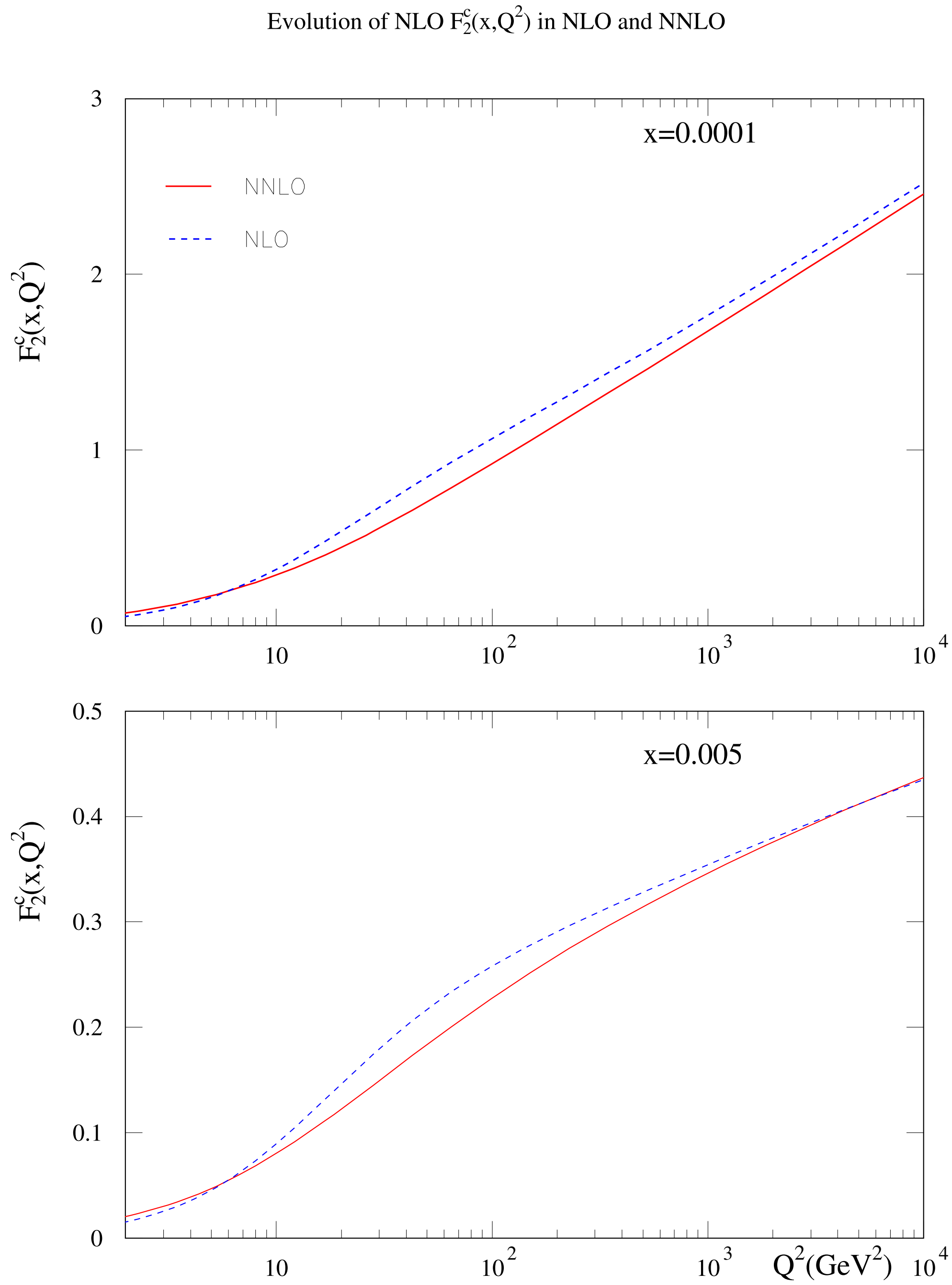
Clearly improves match to lowest Q^2 data, where NLO always too low.



NNLO $F_2^c(x,Q^2)$ starts from higher value at low Q^2.

At high Q^2 dominated by $(c+\bar{c})(x,Q^2)$. This has started evolving from negative value at $Q^2=m_c^2$. Remains lower than at NLO for similar evolution.

General trend – $F_2^c(x,Q^2)$ flatter in Q^2 at NNLO than at NLO. Important effect on gluon distribution going from one to other.



Exactly same consideration for $F_2^b(x, Q^2)$ comparing NNLO and NLO.