HERAPDF2.0(prel.)

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PDF4LHC MAY 16th 2014

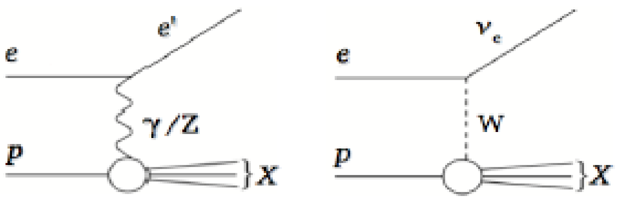
HERAPDF2.0(prel.) fitted to new FINAL combined inclusive cross sections from HERA NCe+p, NCe-p, CCe+p, CCe-p proton beam energies, 920, 820,575, 460 GeV

HERAPDF2.0 NLO and NNLO fits performed for both Q^2 >3.5 GeV^2 and Q^2 > 10 GeV^2

Compared to HERAPDF1.0 NLO and HERAPDF1.5NNLO, some noteworthy differences.

DIS is the best tool to probe proton structure

NC : $e\,p \to e'\,X$ CC : $e\,p \to \nu_e\,X$



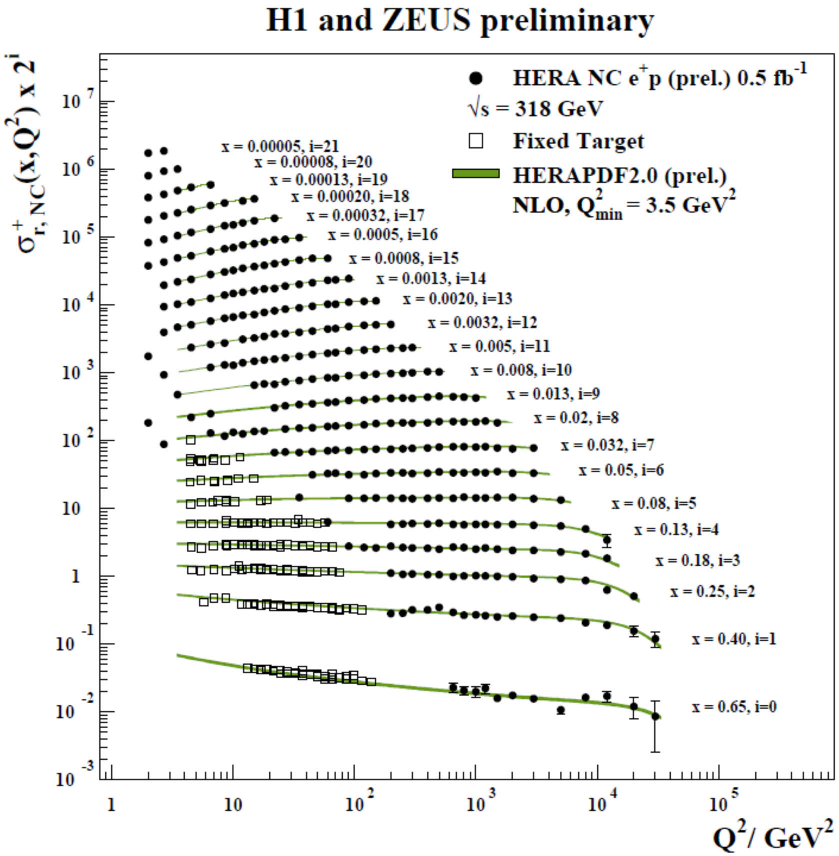
- Kinematic variables:

$Q^2 = -q^2 = -(k-k')^2$ Virtuality of the exchanged boson

$x = \frac{Q^2}{2p \cdot q}$ Bjorken scaling parameter

$y = \frac{p \cdot q}{p \cdot k}$ Inelasticity parameter

$s = (k+p)^2 = \frac{Q^2}{xy}$ Invariant c.o.m.



Neutral current:

$$\frac{d^2\sigma^{\pm}_{NC}}{dx\,dQ^2} = \frac{2\alpha\pi^2}{xQ^4}\left(Y_+ F_2 \mp Y_- xF_3 - y^2 F_L\right)$$

$F_2 \propto \sum_i e_i^2 (xq_i + x\bar{q}_i)$ quark distributions gluon from scaling violation

$xF_3 \propto \sum_i (xq_i - x\bar{q}_i)$ valence quarks

$F_L \propto \alpha_s \times g$ gluon at NLO

Charged current:

LO expressions

$$\frac{d^2\sigma^{-}_{CC}}{dx\,dQ^2} = \frac{G_F^2}{2\pi}\frac{M_W^2}{M_W^2+Q^2}\left(u+c+(1-y^2)(\bar{d}+\bar{s})\right)$$

$$\frac{d^2\sigma^{-}_{CC}}{dx\,dQ^2} = \frac{G_F^2}{2\pi}\frac{M_W^2}{M_W^2+Q^2}\left(\bar{u}+\bar{c}+(1-y^2)(d+s)\right)$$

flavour decomposition

Gluon from the scaling violations: DGLAP equations tell us how the partons evolve

$$\frac{dq(x,Q^2)}{d\ln Q^2} = \frac{\alpha_s}{2\pi}\int_x^1 \frac{dy}{y}\left[P_{qq}\left(\frac{x}{y}\right)q(y,Q^2) + P_{qg}\left(\frac{x}{y}\right)g(y,Q^2)\right]$$

$$\frac{dg(x,Q^2)}{d\ln Q^2} = \frac{\alpha_s}{2\pi}\int_x^1 \frac{dy}{y}\left[P_{gq}\left(\frac{x}{y}\right)q(y,Q^2) + P_{gg}\left(\frac{x}{y}\right)g(y,Q^2)\right]$$

HERAPDF approach uses only HERA data

Some of the debates about the best way of estimating PDF uncertainties concern the use of many different data sets with varying levels of consistency.

The combination of the HERA data yields a very accurate and consistent data set for 4 different processes: e+p and e-p Neutral and Charged Current reactions.

The use of the single consistent data set allows the usage of the conventional $\chi 2$ tolerance $\Delta\chi 2 = 1$ when setting 68%CL experimental errors

NOTE the use of a pure proton target means d-valence is extracted without need for heavy target/deuterium corrections or strong iso-spin assumptions these are the only PDFs for which this is true

Furthermore, the kinematic coverage at low-x ensures that these are the most crucial data when extrapolating predictions from W, Z and Higgs cross-sections to the LHC

HERAPDF evaluates model uncertainties and parametrisation uncertainties in addition to experimental uncertainties

- PDFs are parametrised at the starting scale Q_0^2=1.9 GeV^2 as follows:

$$
\begin{aligned}
xg(x) &= A_g x^{B_g}(1-x)^{C_g} - A'_g x^{B'_g}(1-x)^{C'_g}, \\
xu_v(x) &= A_{u_v} x^{B_{u_v}}(1-x)^{C_{u_v}}\left(1 + D_{u_v}x + E_{u_v}x^2\right), \\
xd_v(x) &= A_{d_v} x^{B_{d_v}}(1-x)^{C_{d_v}}, \\
x\bar{U}(x) &= A_{\bar{U}} x^{B_{\bar{U}}}(1-x)^{C_{\bar{U}}}\left(1 + D_{\bar{U}}x\right), \\
x\bar{D}(x) &= A_{\bar{D}} x^{B_{\bar{D}}}(1-x)^{C_{\bar{D}}}.
\end{aligned}
$$

QCD Sum rules constrain
Normalisation parameters: A_g, A_{u_v}, A_{d_v}
And the condition that:

$$x\bar{u} \rightarrow x\bar{d} \text{ as } x \rightarrow 0.$$

relate $A_{\bar{U}}$ to $A_{\bar{D}}$, and with $x\bar{s} = f_s x\bar{D}$

  - **Due to increased precision of data, more flexibility in functional form is allowed → 15 free parameters**
- PDFs are evolved via evolution equations (DGLAP) to NLO and NNLO (alphas(MZ)=0.118)[QCDNUM]
- Thorne-Roberts GM-VFNS for heavy quark coefficient functions – as used in MSTW
- Chi2 definition used in the minimisation [MINUIT] accounts for correlated uncertainties:

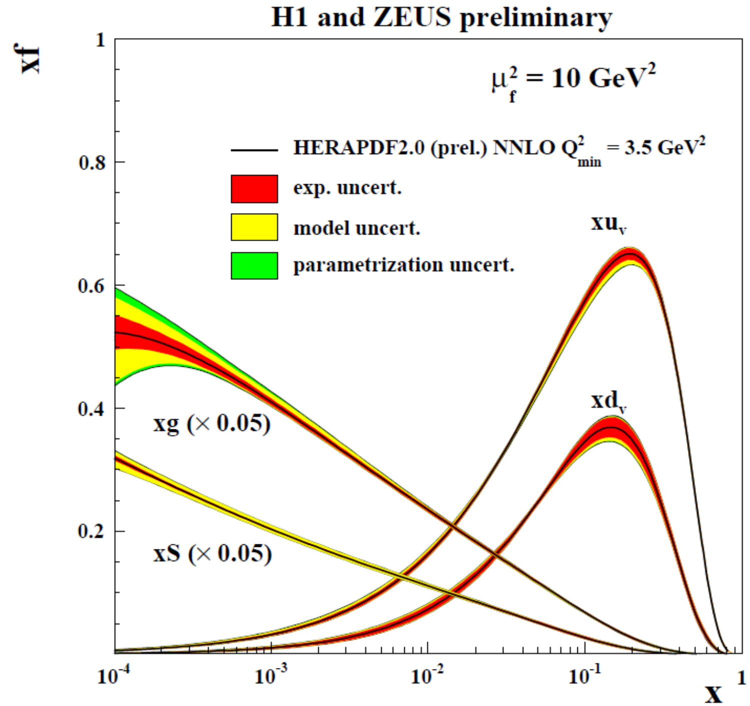
$$\chi^2 = \sum_i \frac{\left[\mu_i - m_i\left(1 - \sum_j \gamma^i_j b_j\right)\right]^2}{\delta^2_{i,\mathrm{unc}} m_i^2 + \delta^2_{i,\mathrm{stat}}\mu_i m_i\left(1 - \sum_j \gamma^i_j b_j\right)} + \sum_j b_j^2 + \sum_i \ln \frac{\delta^2_{i,\mathrm{unc}} m_i^2 + \delta^2_{i,\mathrm{stat}}\mu_i m_i}{\delta^2_{i,\mathrm{unc}} \mu_i^2 + \delta^2_{i,\mathrm{stat}}\mu_i^2}$$

m_i is the theoretical prediction
μ_i is the measured cross section

$\delta_{i,\mathrm{stat}}$, $\delta_{i,\mathrm{unc}}$ statistical and uncorrelated systematic uncertainty
γ^i_j correlated systematic uncertainties
b_j shifts

Sources of HERAPDF uncertainties

- **Experimental:**
  - Hessian method is used to evaluate experimental uncertainties
  - Consistent data sets → use $\Delta\chi^2=1$



- **Model:**
  - Following variations have been considered

Variation	Standard Value	Lower Limit	Upper Limit
f_s	0.4	0.3	0.5
M_c^{opt}(NLO) [GeV]	1.47	1.41	1.53
M_c^{opt} (NNLO) [GeV]	1.44	1.38	1.50
M_b [GeV]	4.75	4.5	5.0
Q^2_{min} [GeV^2]	10.0	7.5	12.5
Q^2_{min} [GeV^2]	3.5	2.5	5.0
Q^2_0 [GeV^2]	1.9	1.6	2.2

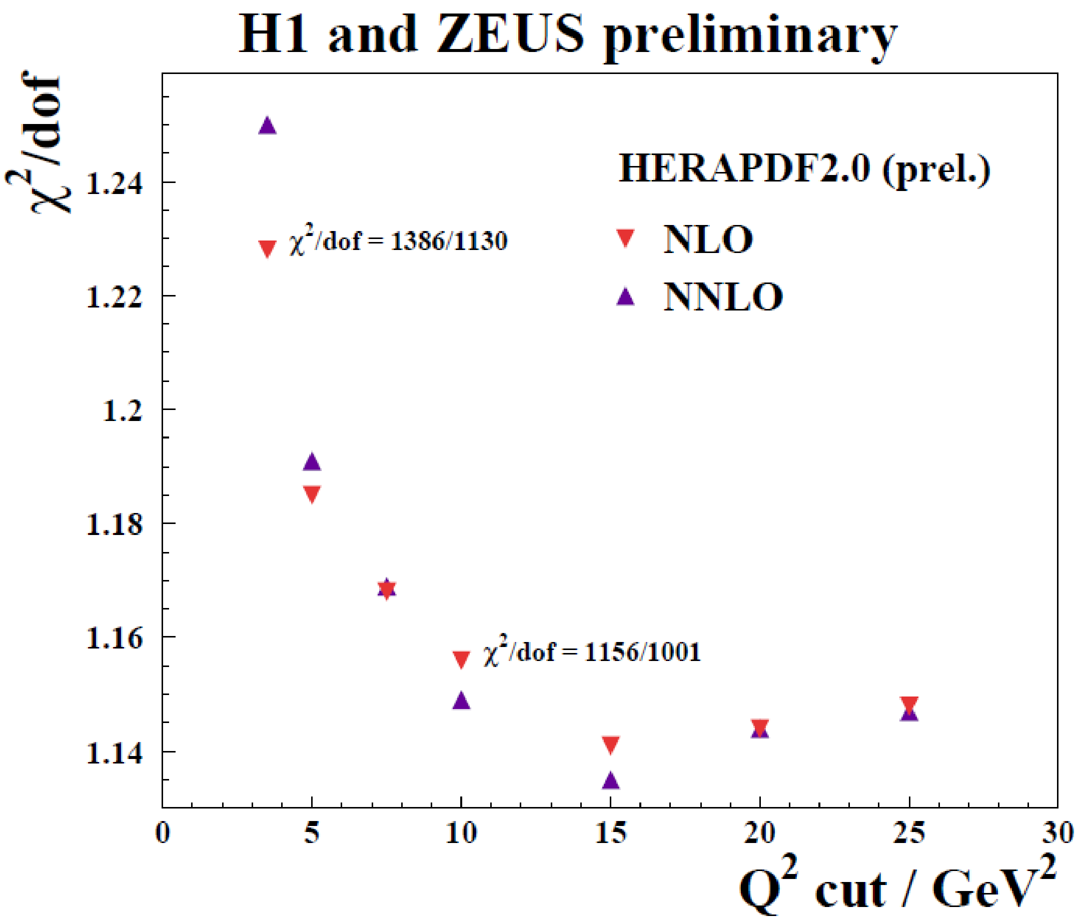
- **Parametrisation:**
  - An envelope is formed from PDF fits using variants of parametrisation form
    - Scanning of 16 parameter space with D or E as extra parameters of $(1 + Dx + Ex^2)$
    - Q_0^2 variation → dominant parametrisation uncertainty

Values of Mc and its uncertainties from scanning χ2 for fits including HERA charm combination data

Value of fs from considering ATLAS result AND ν di-muon results

Reconsider the Q2 cut on the data

Traditionally Q2>3.5 GeV2



For Q^2_{min} = 3.5 GeV^2

Chi2/dof (NLO) = 1386/1130

Chi2/dof(NNLO)= 1414/1130

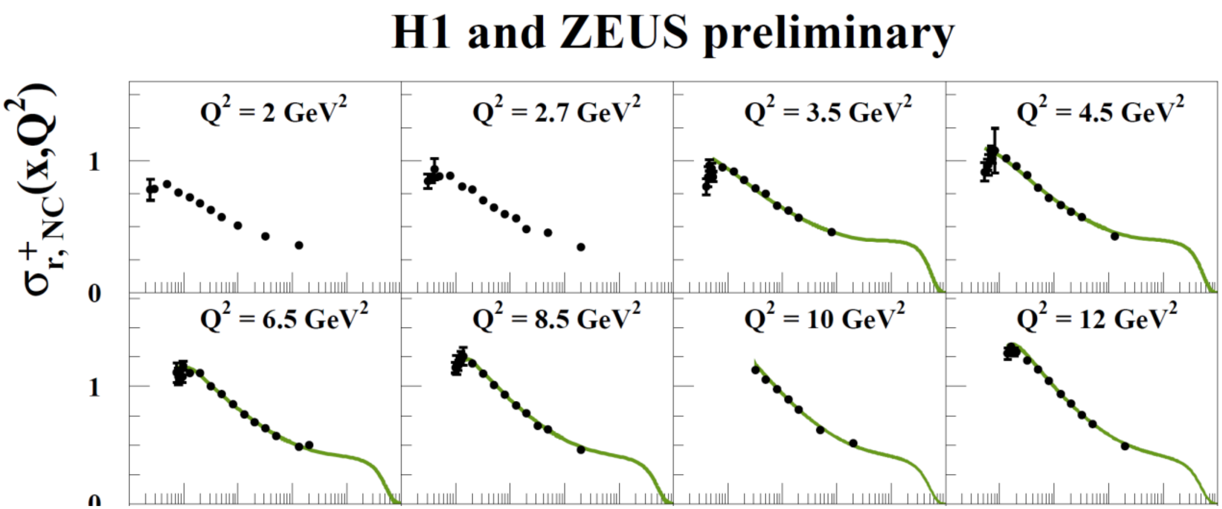
For Q^2_{min} = 10 GeV^2

Chi2/dof (NLO) = 1156/1001

Chi2/dof(NNLO)= 1150/1001

Fits for two Q^2 cuts will be presented: Q^2 > 3.5 and Q^2 >10 GeV^2

Note that HERA kinematics is such that cutting out low Q^2 also cuts the lowest x values



NLO
Q^2>3.5 GeV^2

For Q^2_{min}= 3.5 GeV^2

Chi2/dof (NLO) = 1386/1130

Chi2/dof(NNLO)= 1414/1130

For Q^2_{min}= 10 GeV^2

Chi2/dof (NLO) = 1156/1001

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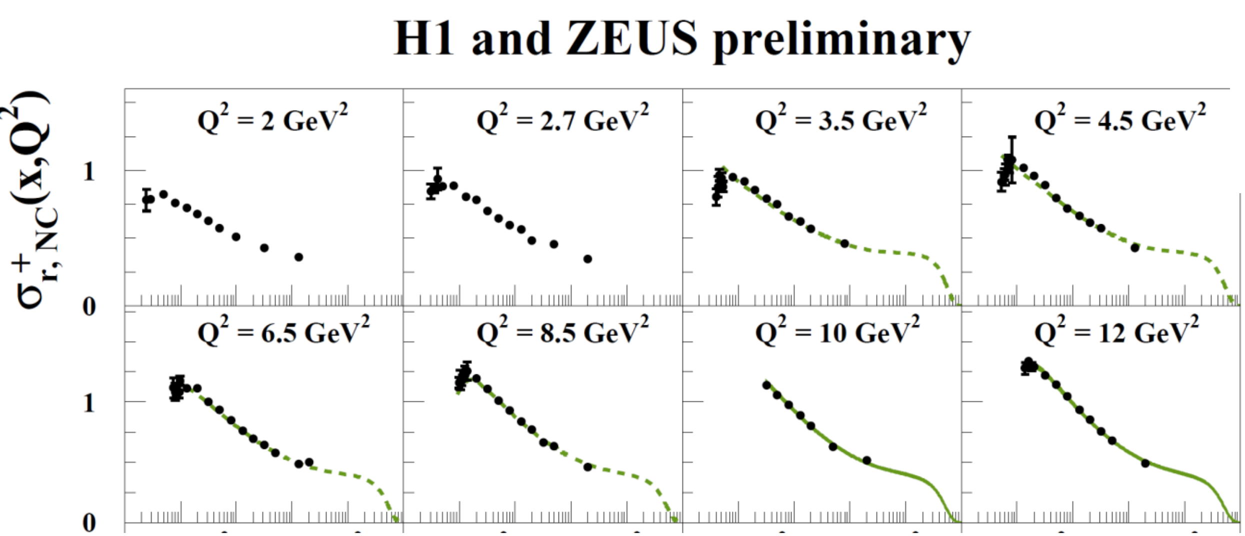
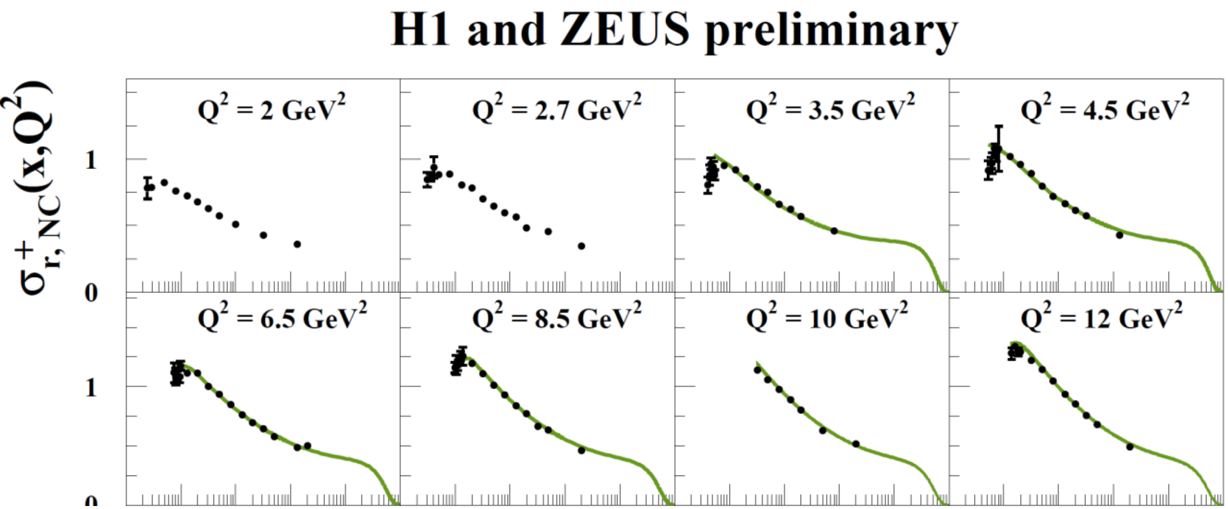


NLO
Q^2>10 GeV^2

These are the comparisons of the fit to the NCe+p data at low Q^2
The fit with Q^2>10 misses the lower Q2 data in a systematic matter – worse at low-x and low Q2--- (not just at high-y)



NNLO
Q^2>3.5 GeV^2

For Q^2_{min}= 3.5 GeV^2

Chi2/dof (NLO) = 1386/1130

Chi2/dof(NNLO)= 1414/1130

For Q^2_{min}= 10 GeV^2

Chi2/dof (NLO) = 1156/1001

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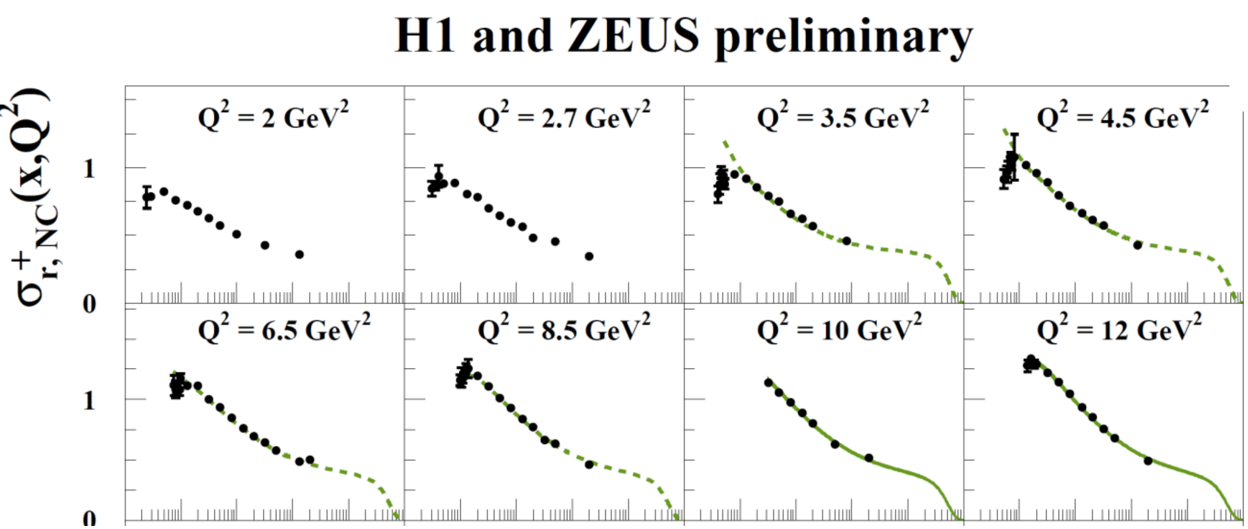
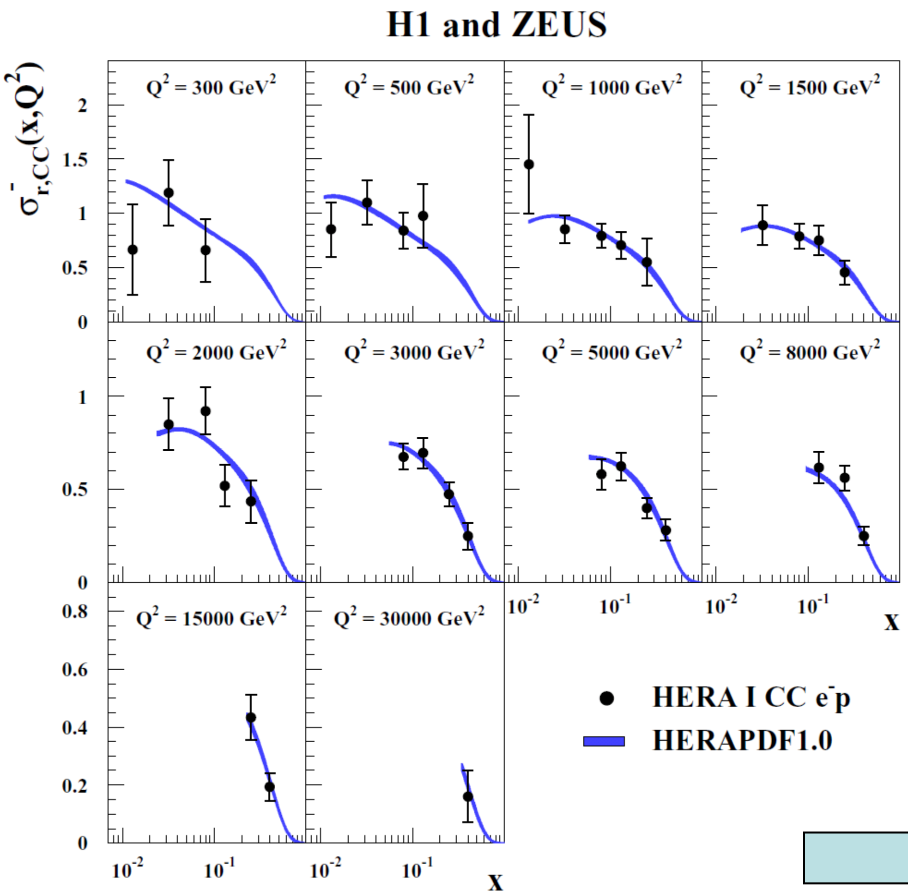
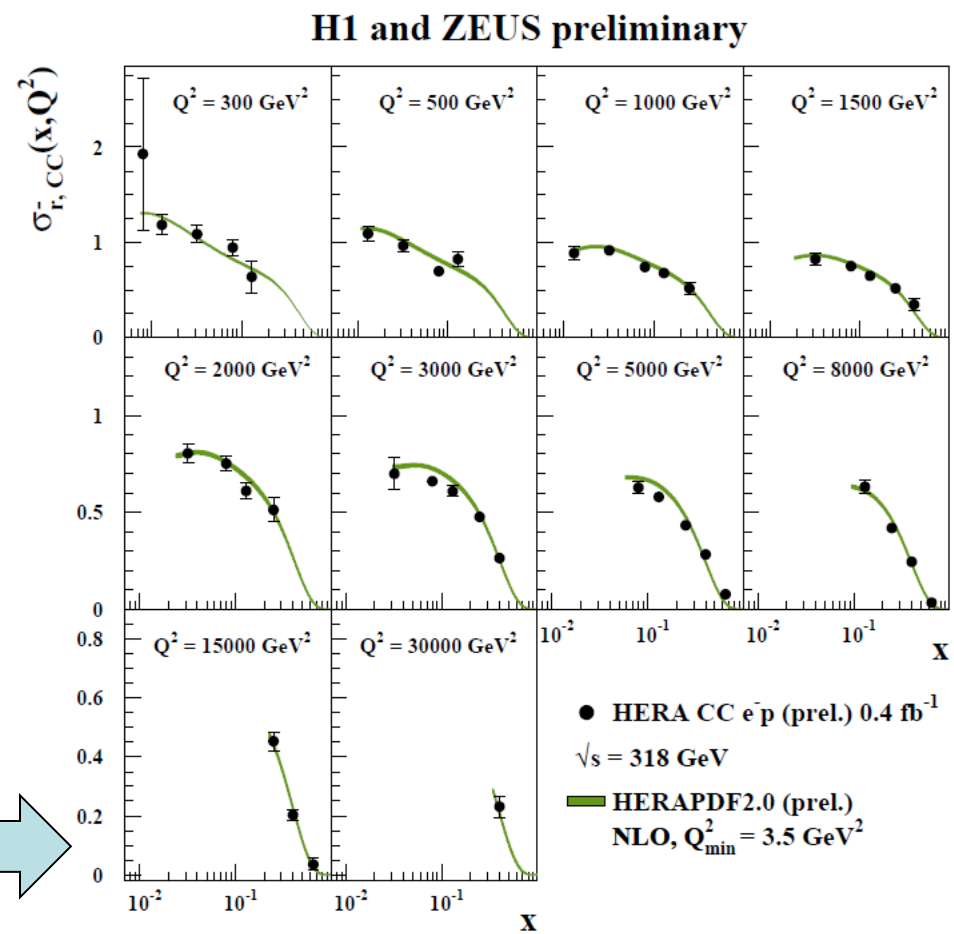


NNLO
Q^2>10 GeV^2

Going to higher orders does not improve the fit at low-Q2, low-x

So let's take a look at the fits starting with NLO Q2>3.5
Comparison to data

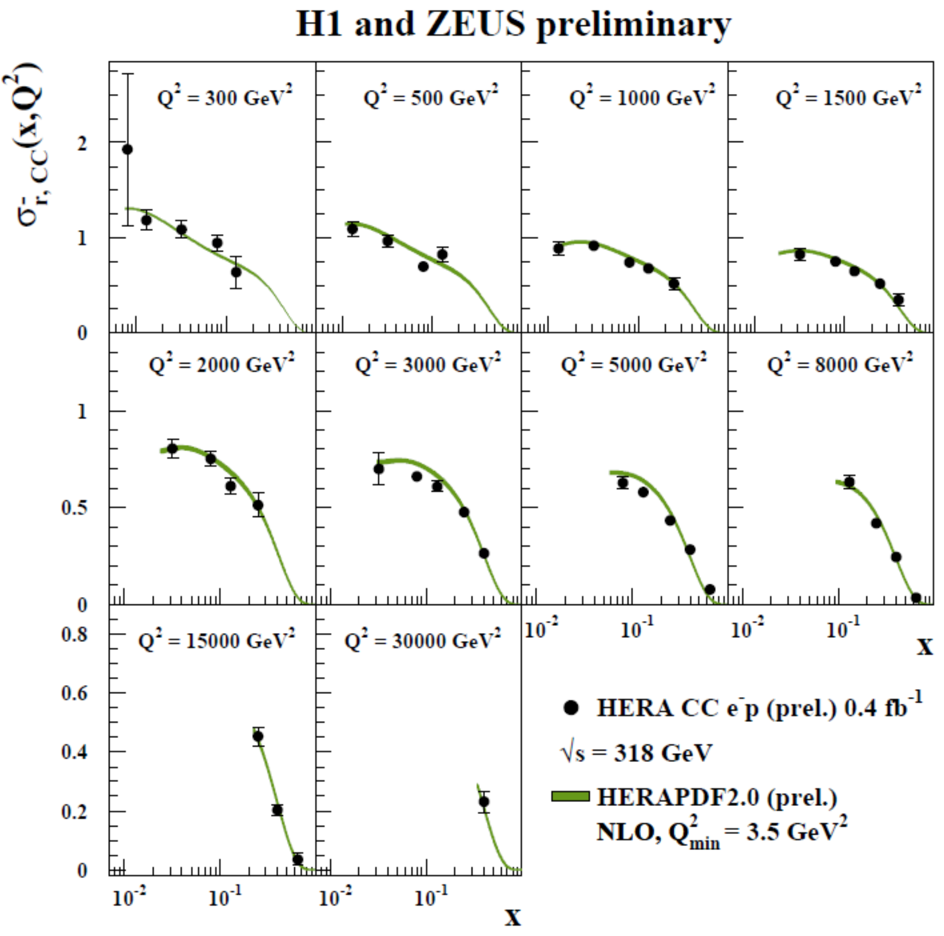


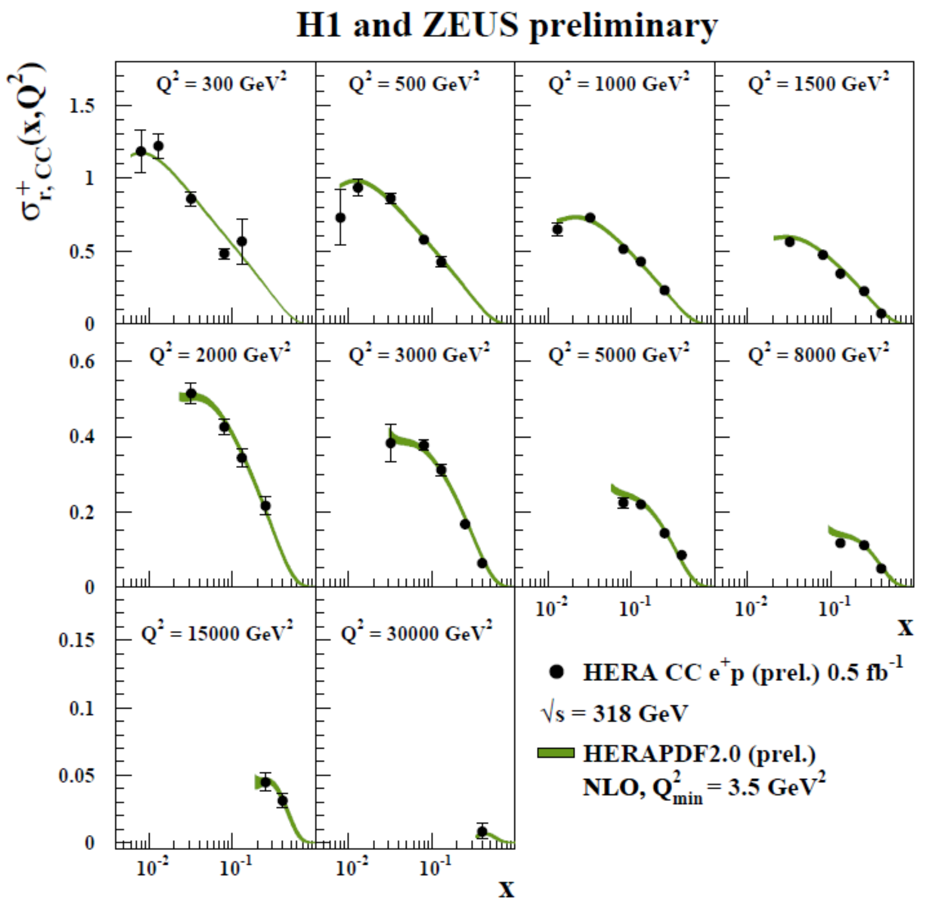


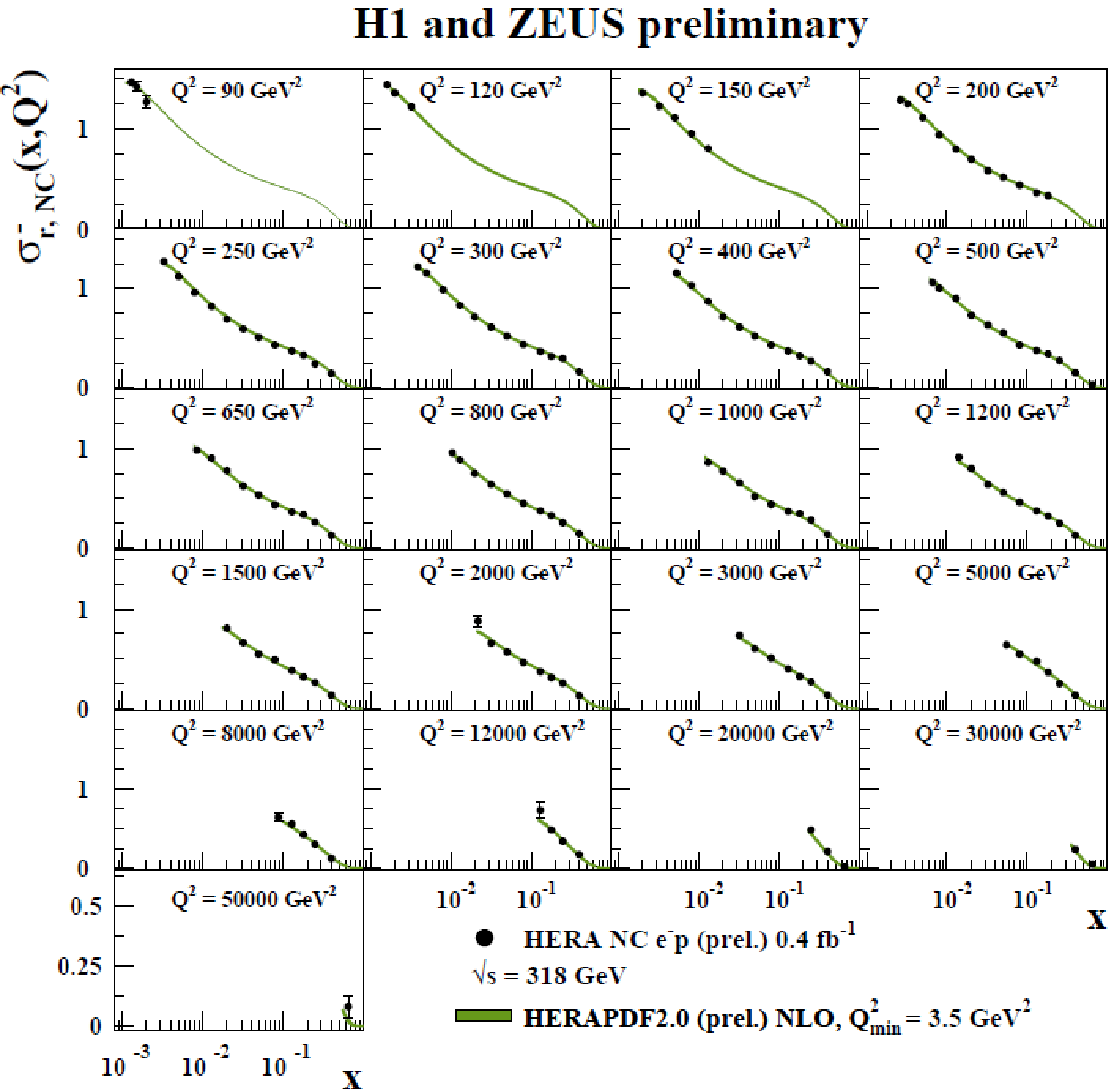
Improvement since HERAPDF1.0

Data vs fit comparison NLO Q2> 3.5

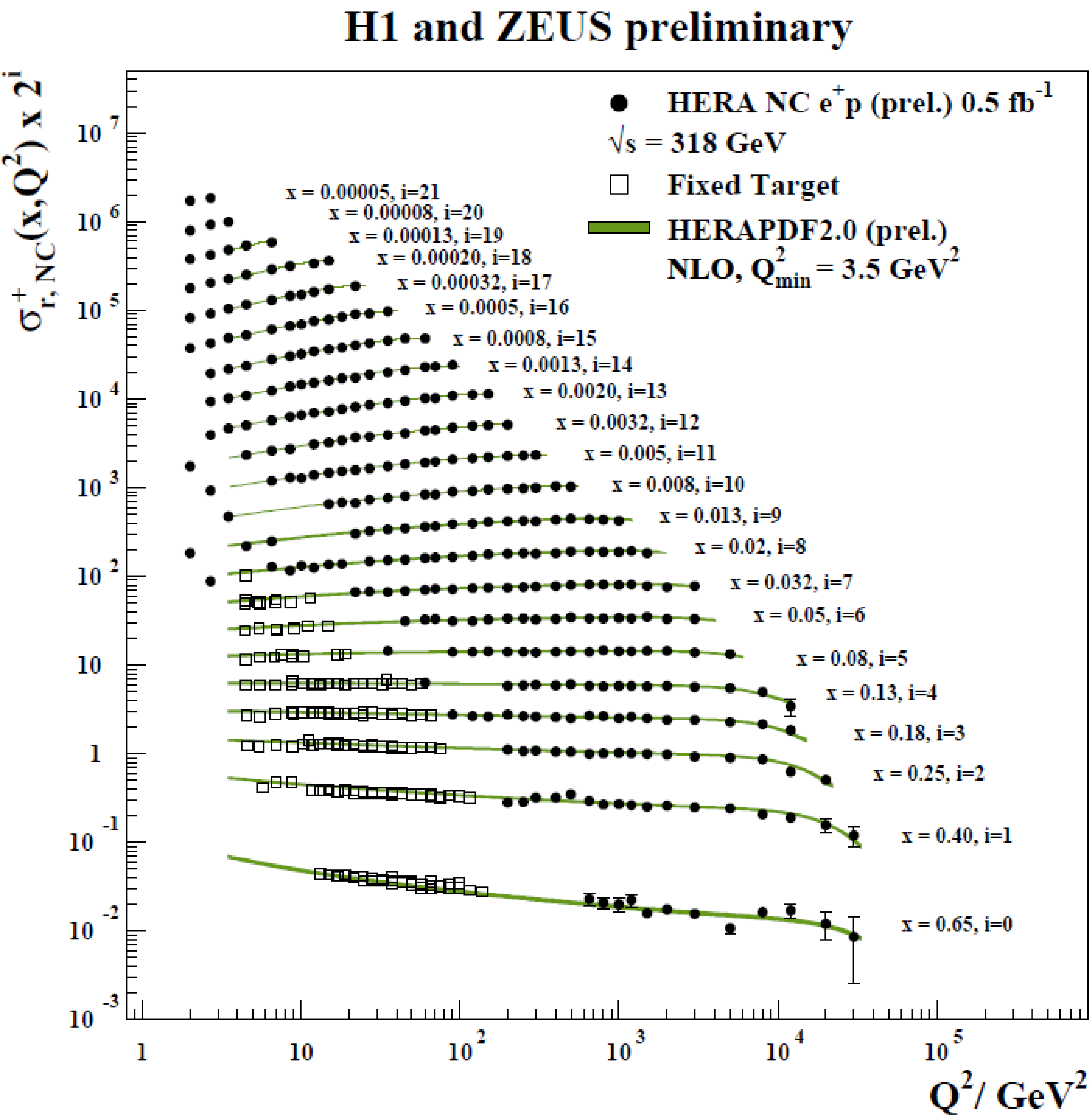
NLO
Q^2>3.5 GeV^2







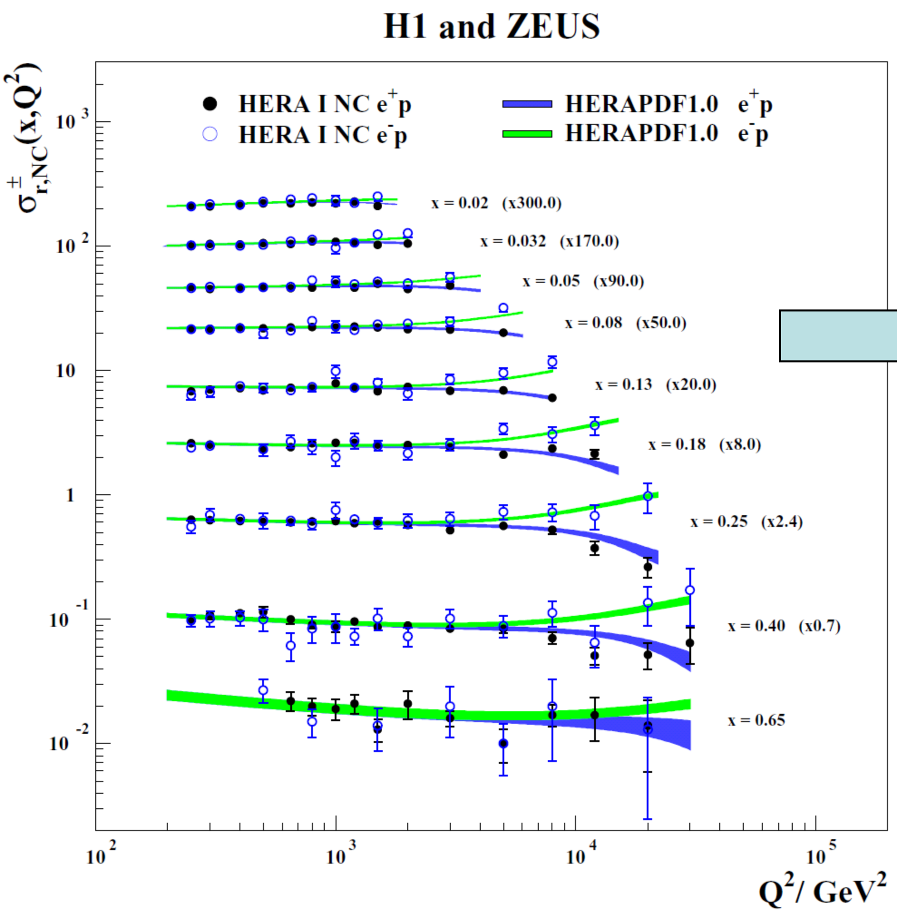
NLO
Q^2>3.5 GeV^2

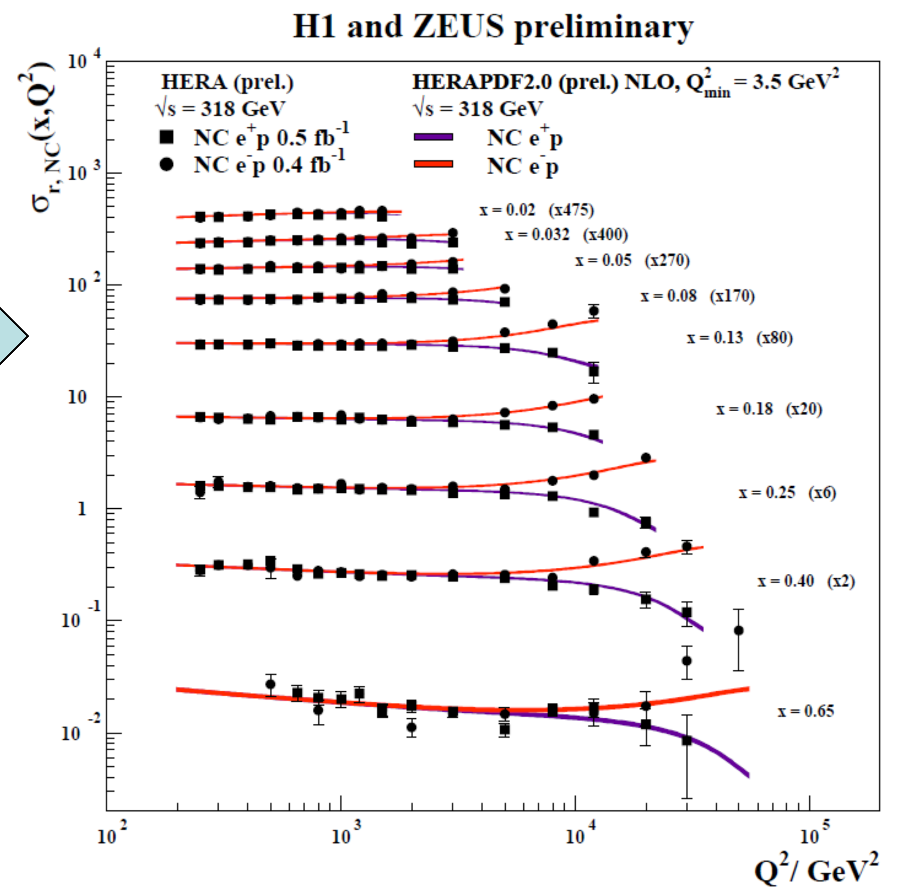


NLO
Q^2>3.5 GeV^2

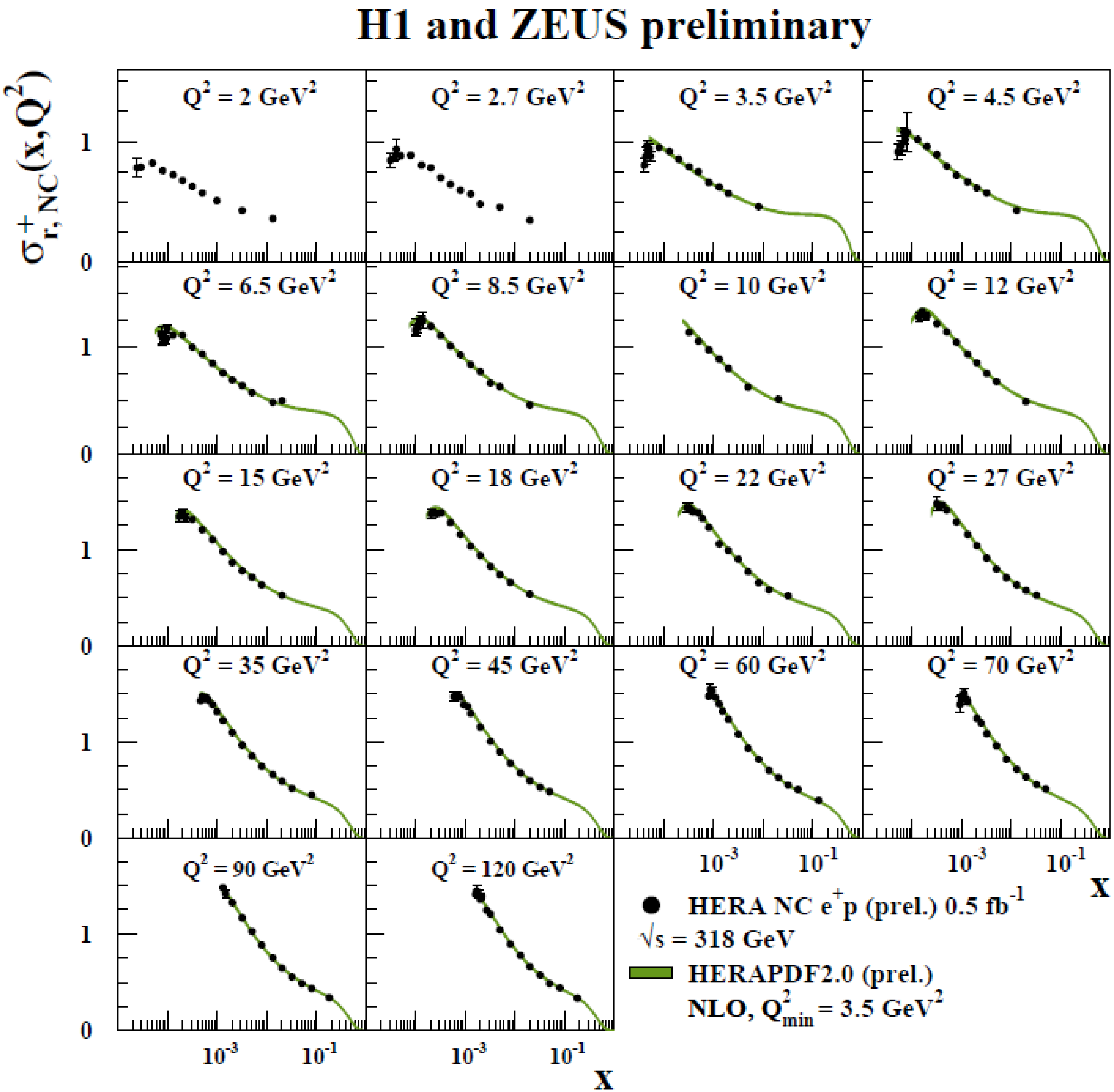
NLO

$Q^2 > 3.5\ GeV^2$

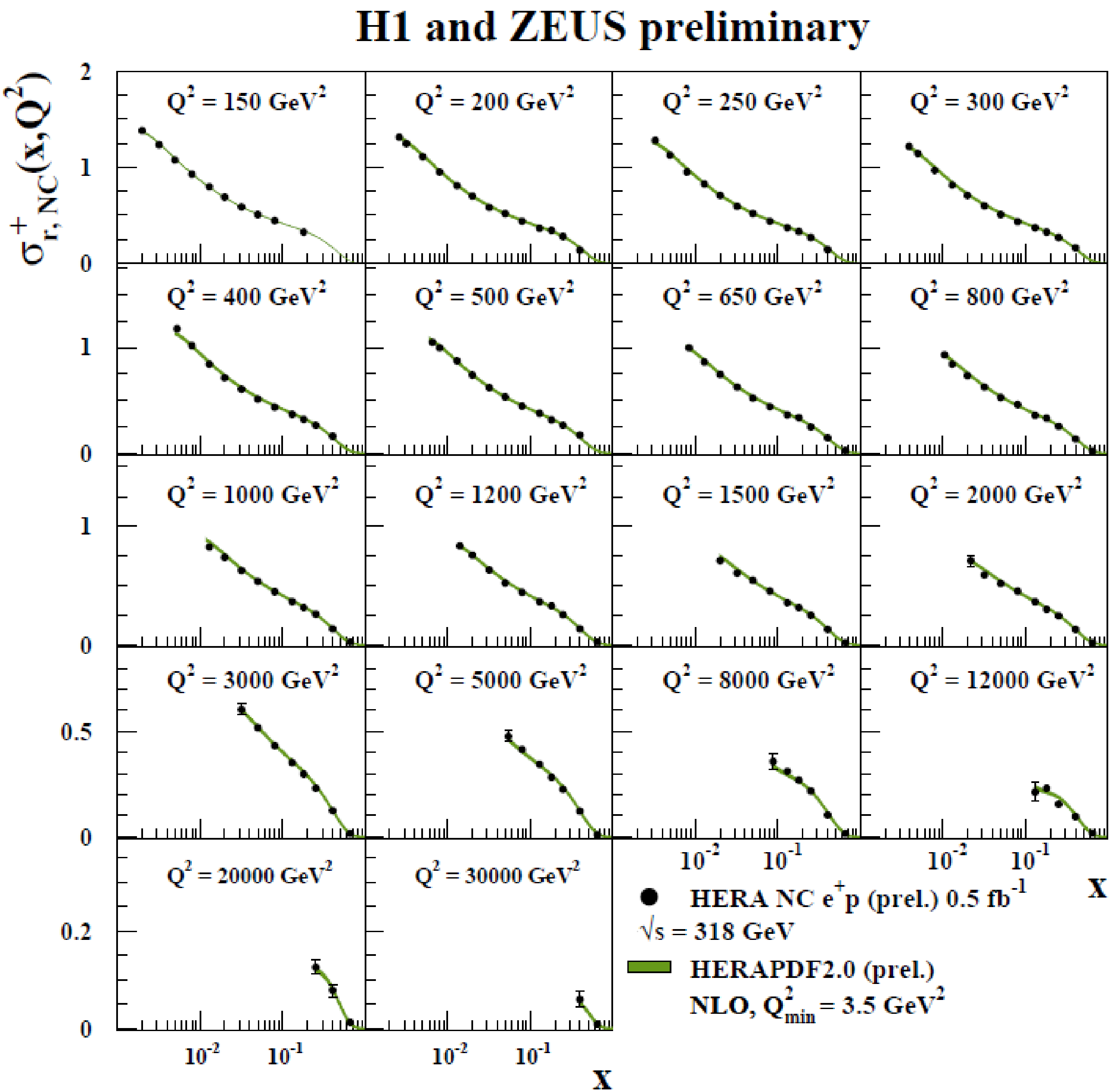




Improvement since HERAPDF1.0

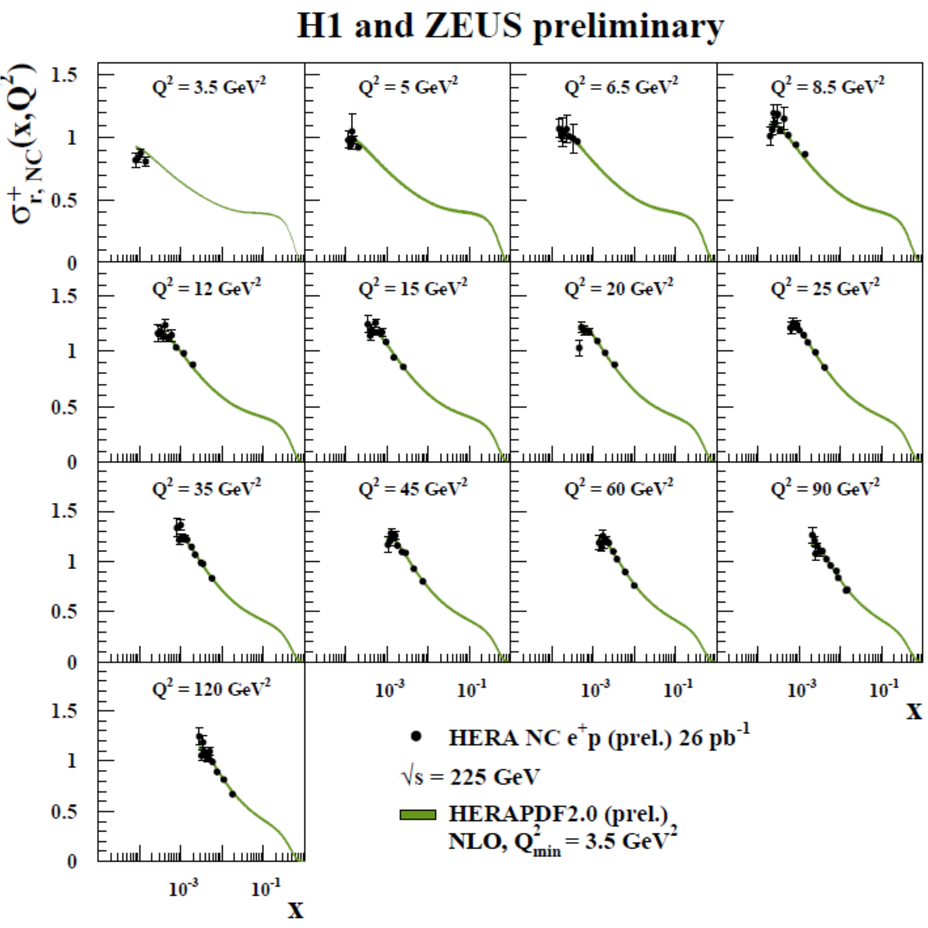


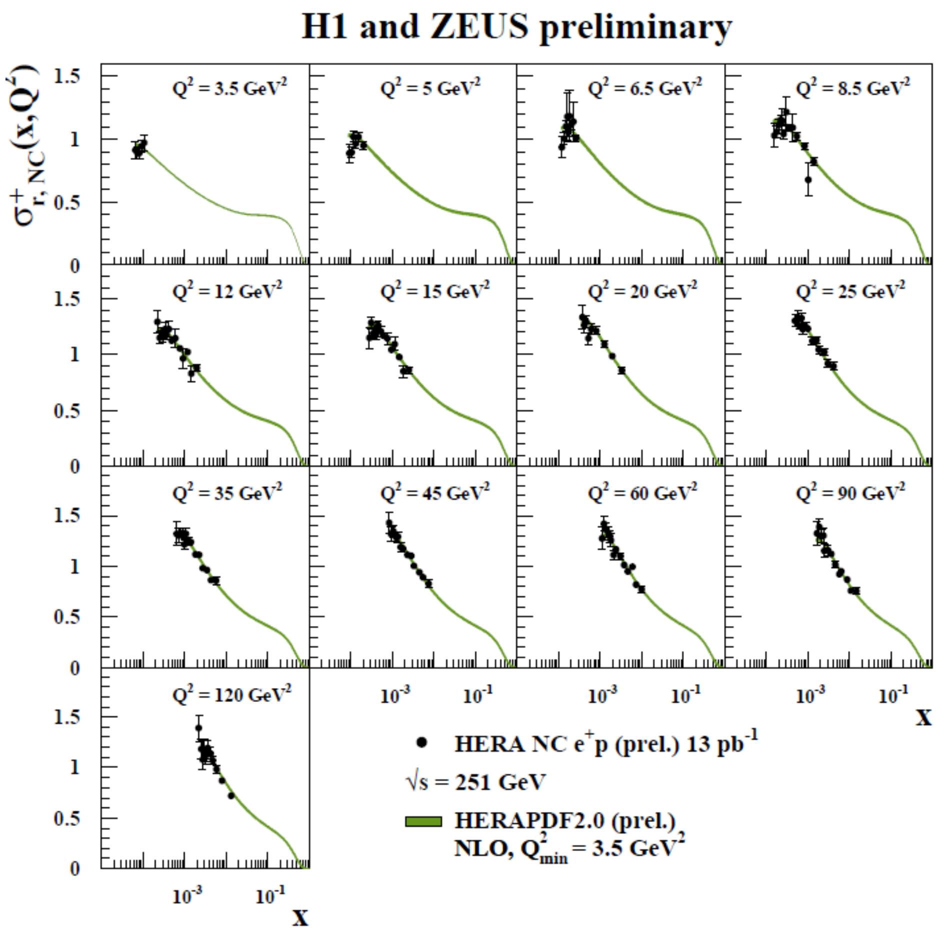
NLO
$Q^2 > 3.5$ GeV^2



NLO
Q^2>3.5 GeV^2

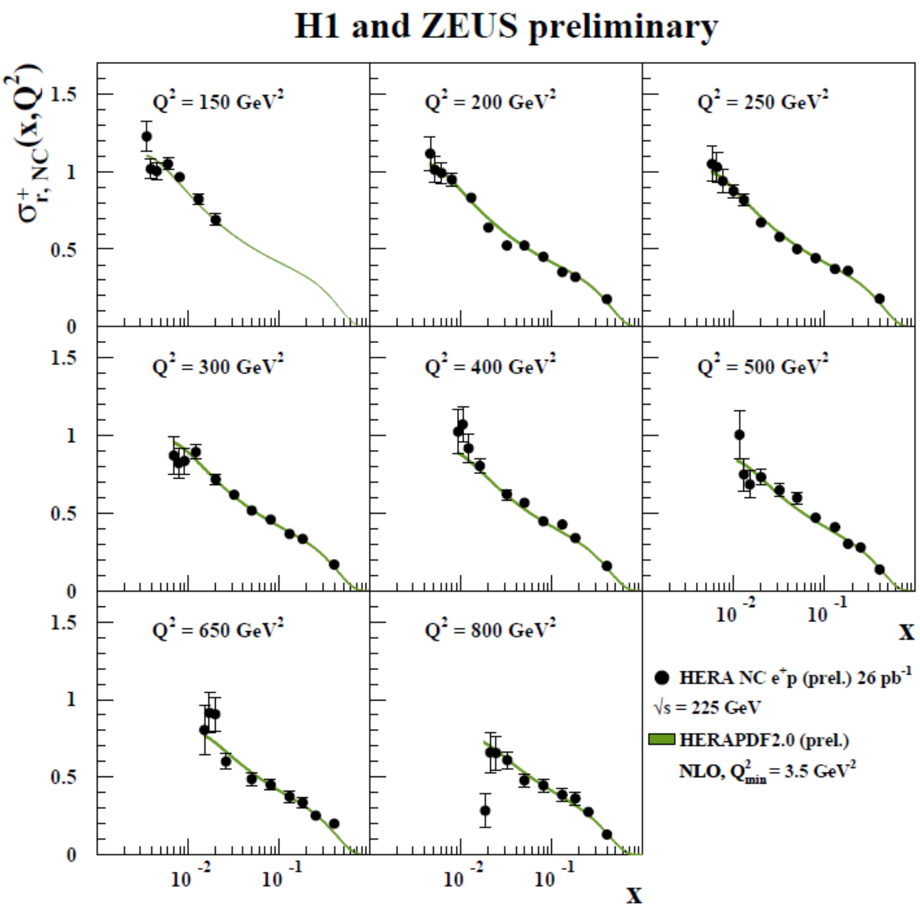
NLO
$Q^2 > 3.5\ GeV^2$

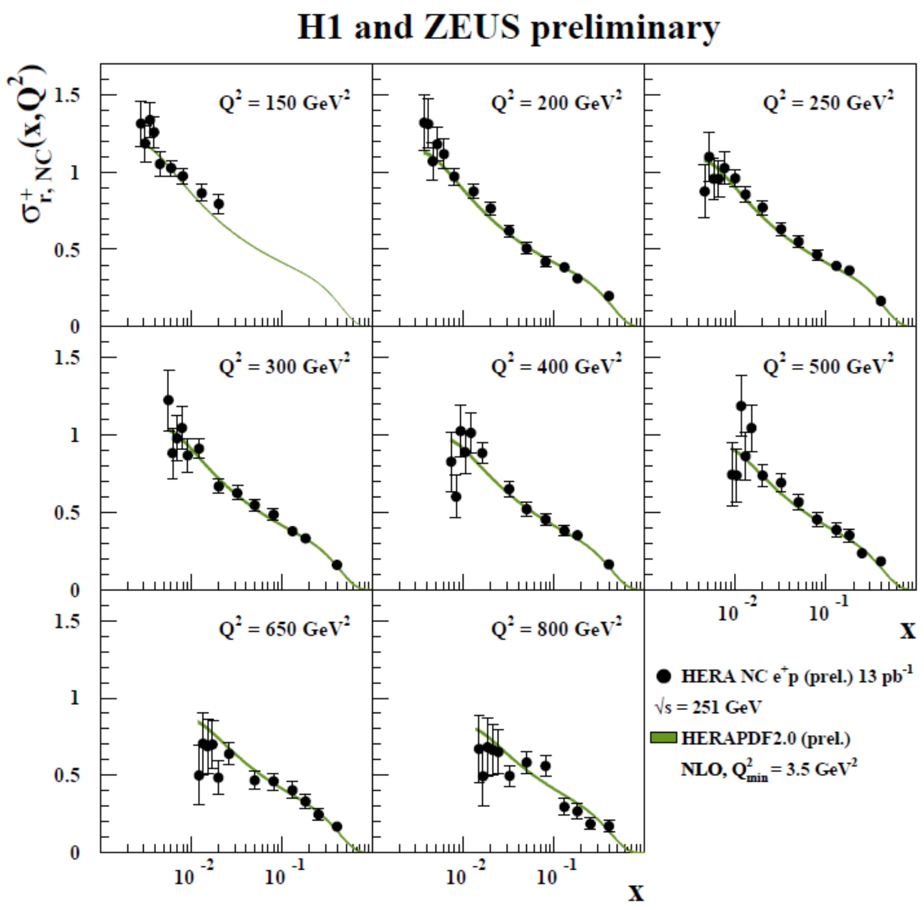




New since HERAPDF1.0

NLO
Q^2>3.5 GeV^2

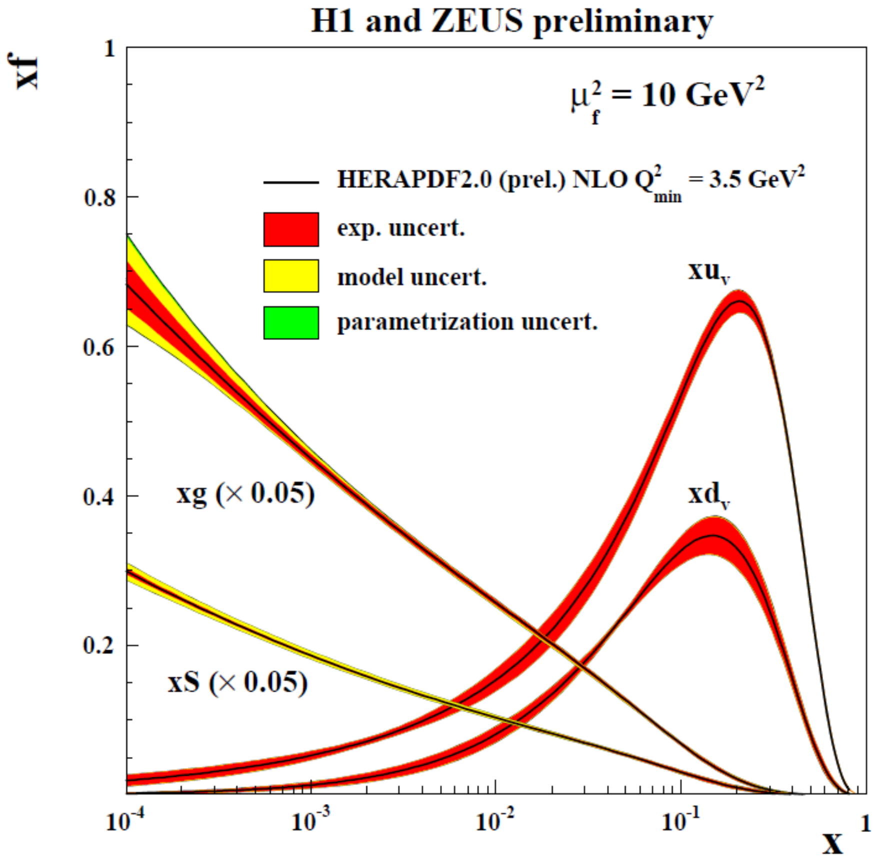


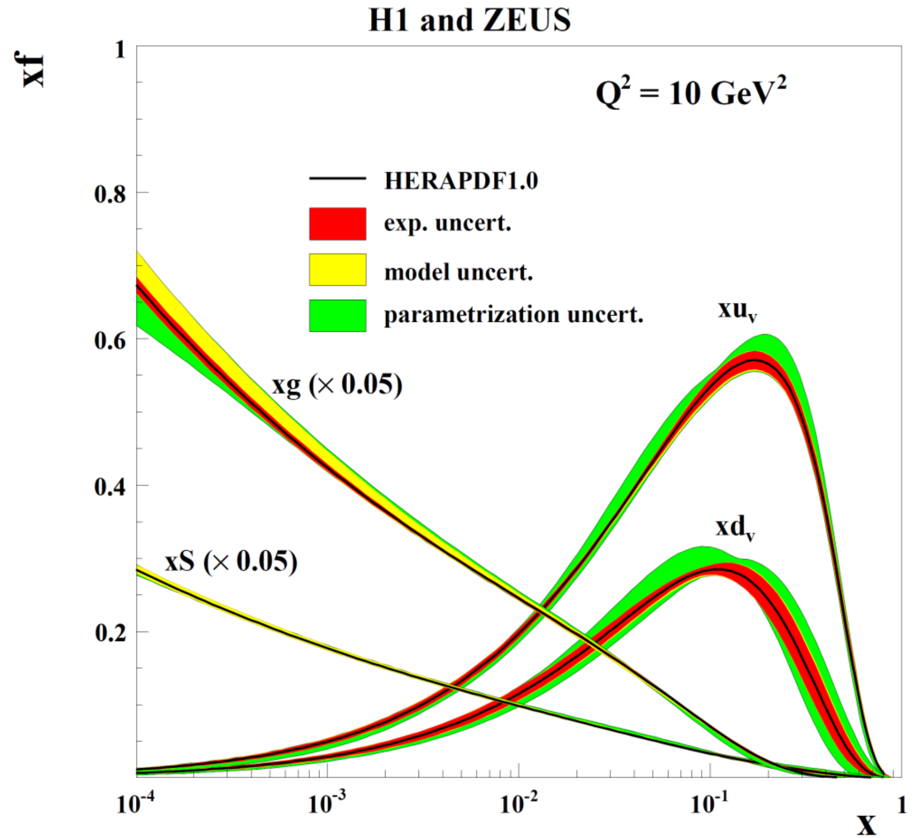


New since HERAPDF1.0

Now let's take a look at the PDFs

NLO
$Q^2 > 3.5\ \mathrm{GeV}^2$

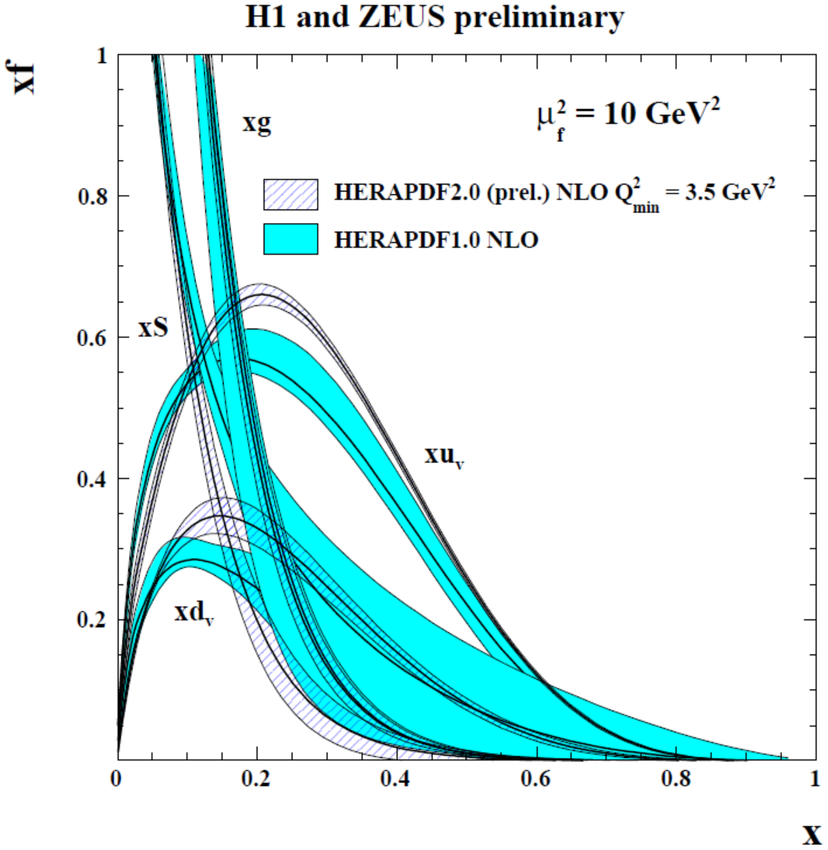


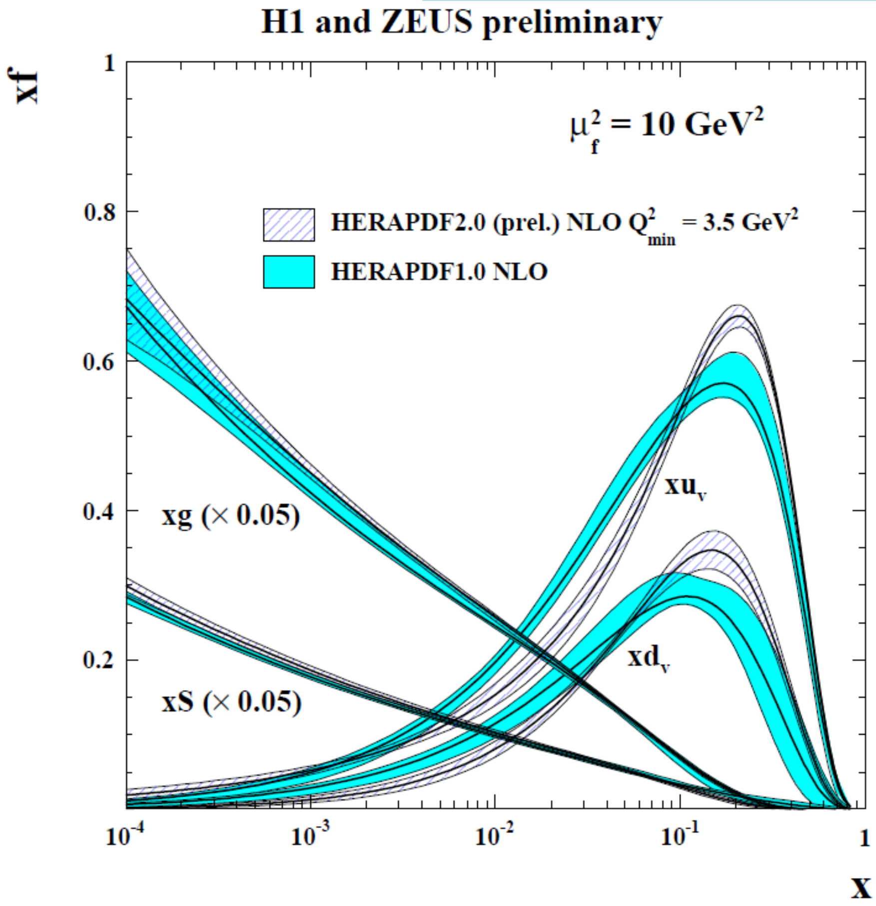


Compare to HERAPDF 1.0– more in experimental less in param because of 15parameters not 10parameters.
Note that the extra parameters in the 10p+parametrisation variation are exactly those which now come into 15p.

Now make the same comparison by overlaying

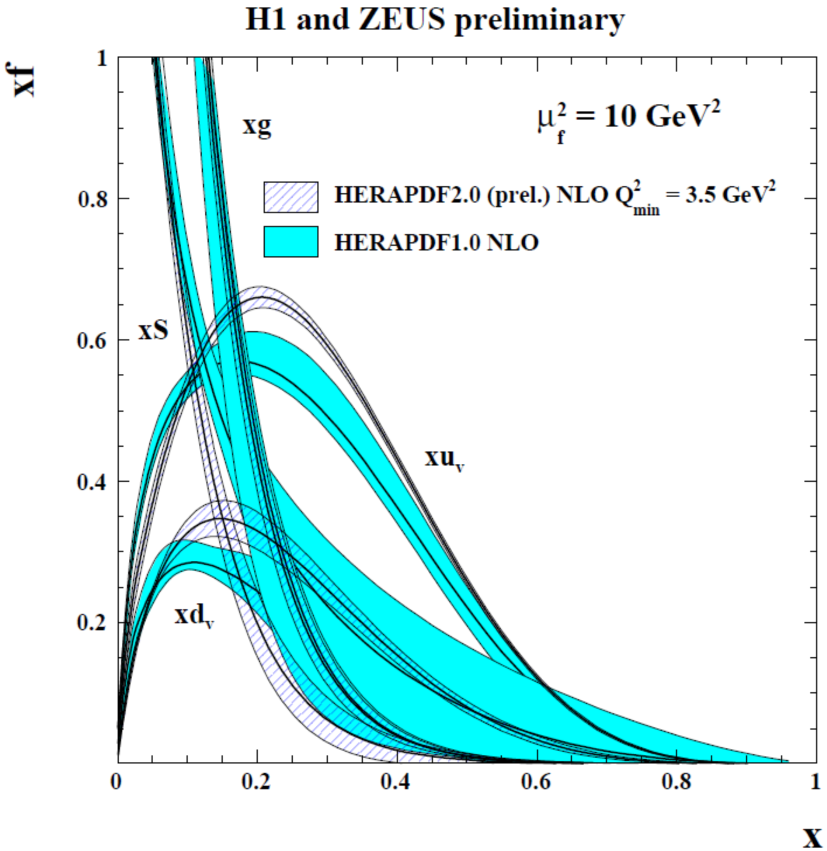
NLO
$Q^2>3.5$ GeV^2

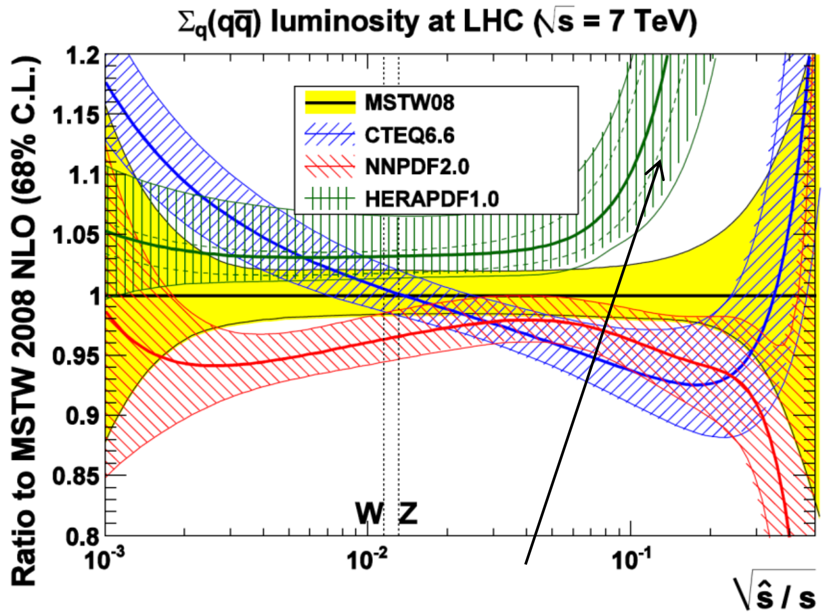




These figures have all the model/param variations included in the blue bands

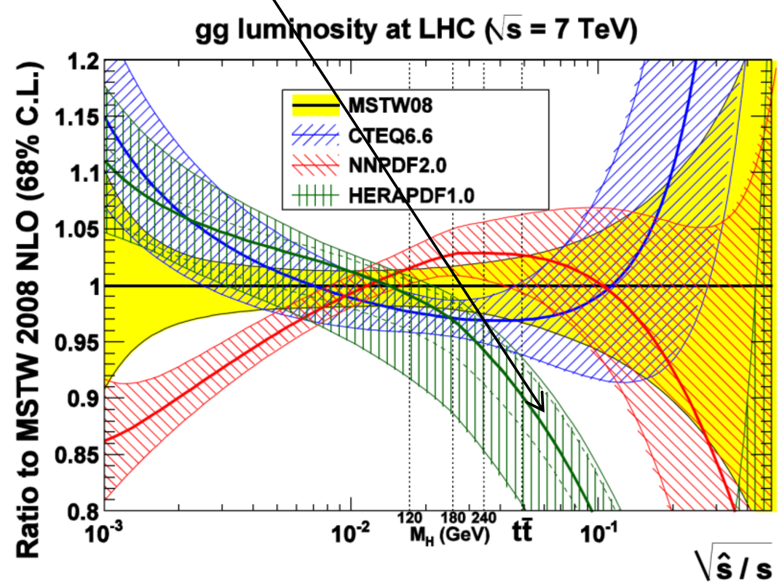
- HERAPDF1.0 had a rather hard high-x sea, harder than the gluon (within large uncertainties).This is no longer the case and uncertainties are reduced
- The valence shapes are also somewhat different- new high-x data in the fit



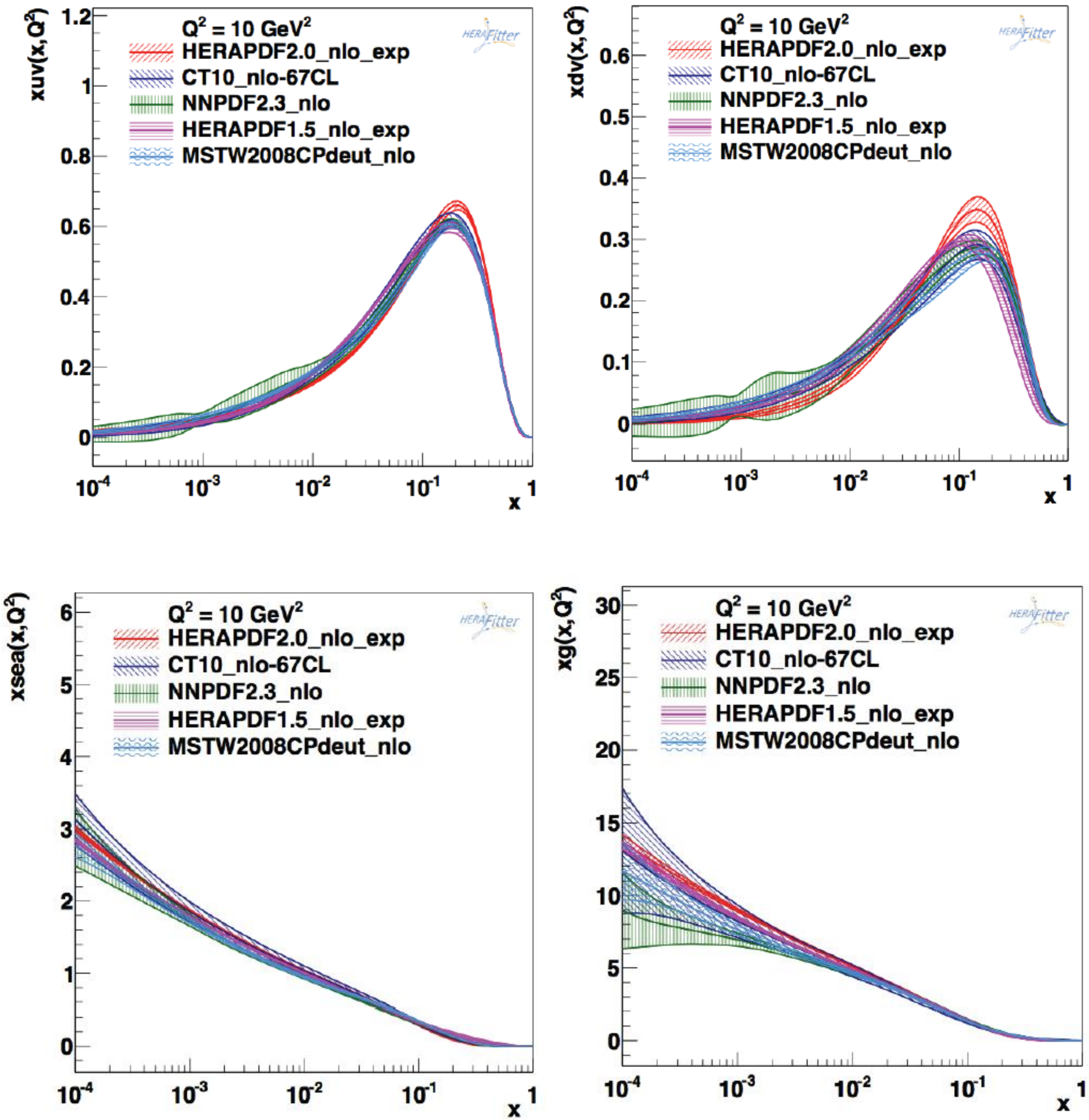


So the q-qbar luminosity at high-x comes down

And the g-g luminosity a high-x goes up

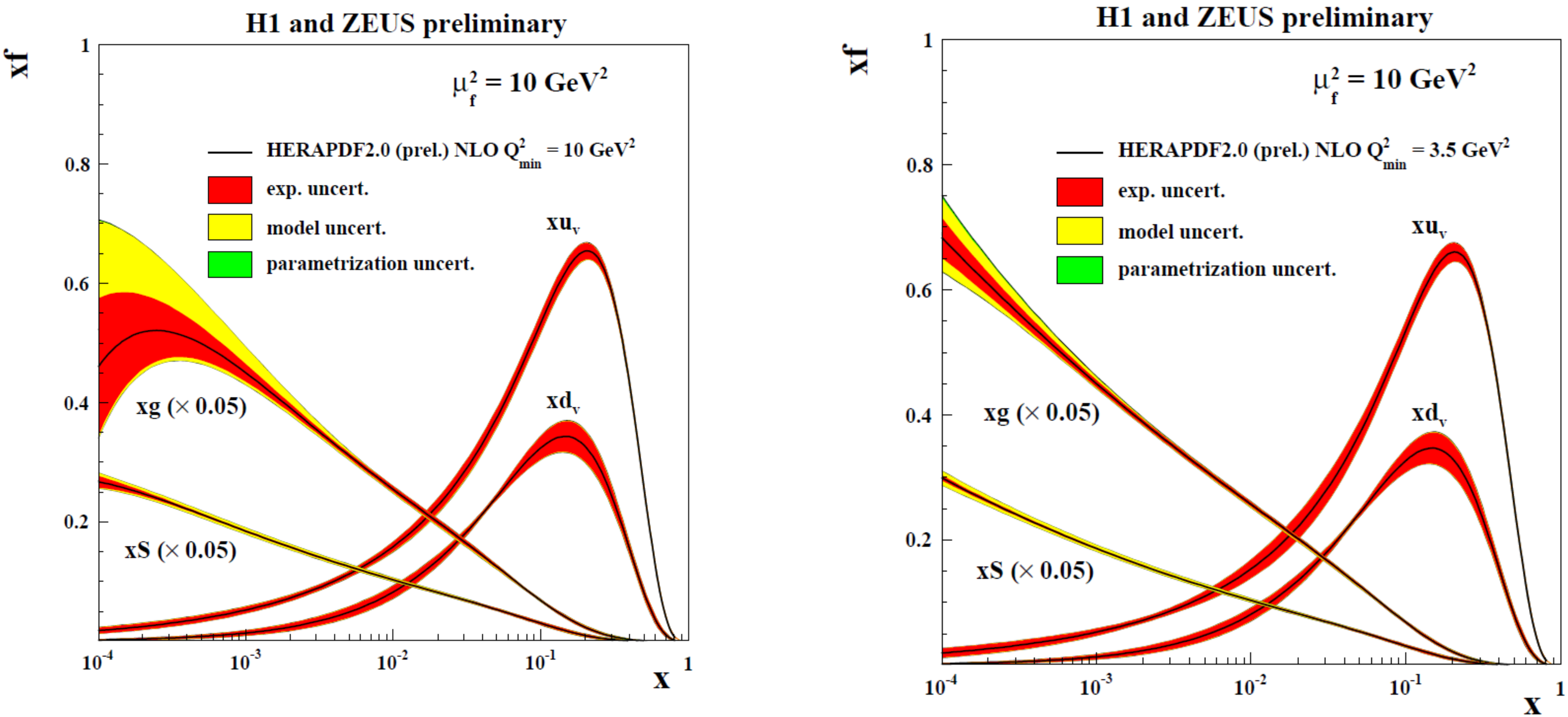


The Sea is a lot softer at high-x
Whereas the gluon is harder



xuv(x,Q²)
xdv(x,Q²)
xsea(x,Q²)
xg(x,Q²)
Q² = 10 GeV²
HERAPDF2.0_nlo_exp
CT10_nlo-67CL
NNPDF2.3_nlo
HERAPDF1.5_nlo_exp
MSTW2008CPdeut_nlo
HERAFitter
x

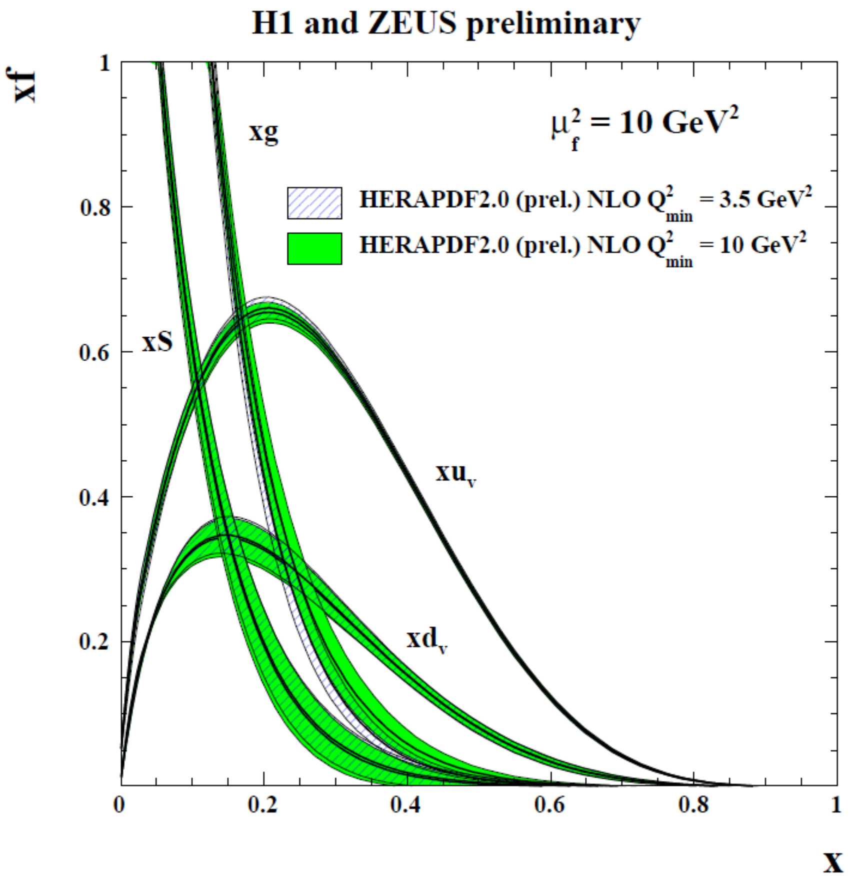
NLO
Q^2>10 GeV^2

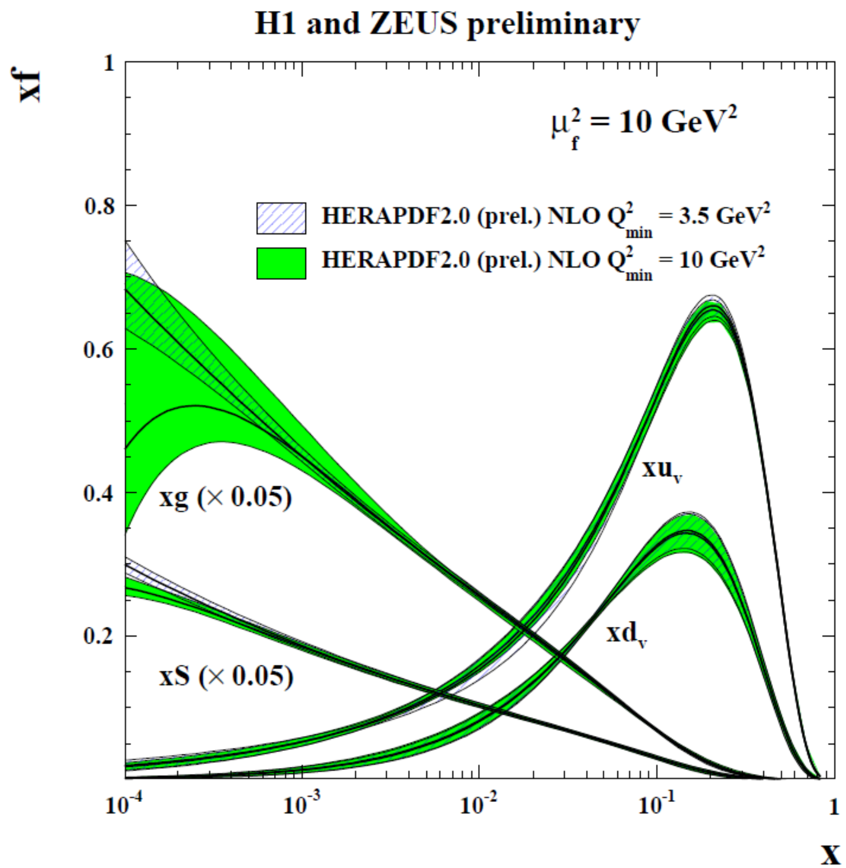


Compare to Q^2>3.5 results -----Q^2>10 cut increases uncertainty of low-x gluon– obviously

NLO
$Q^2 > 10 GeV^2$

We could also compare the $Q^2 > 10$ and $Q^2 > 3.5$ fits overlaid on each other.



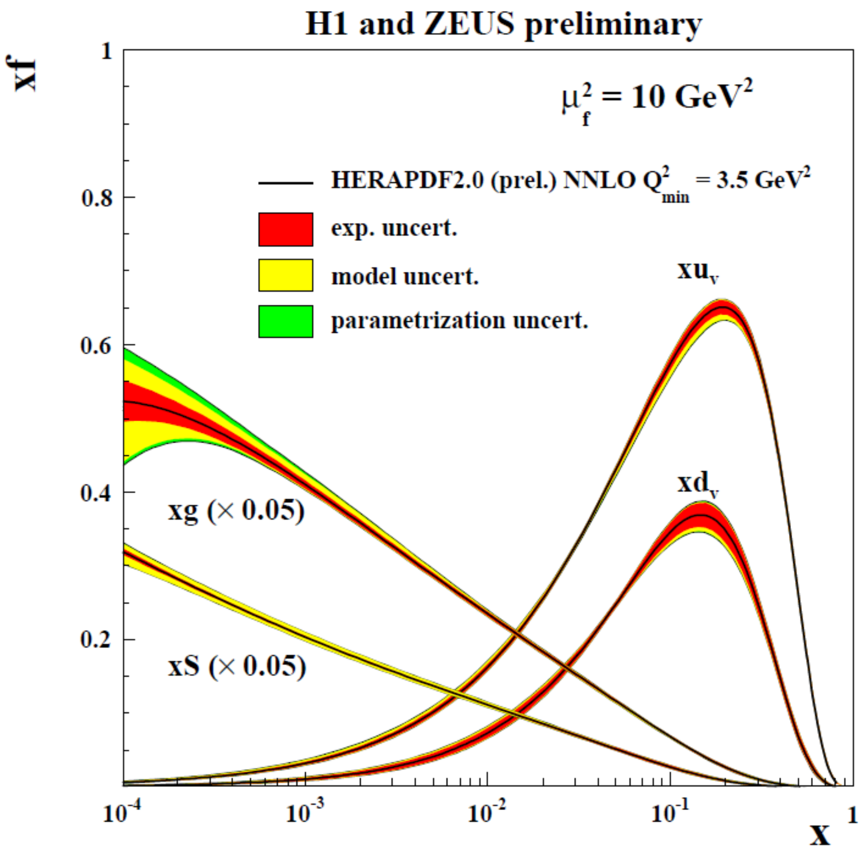


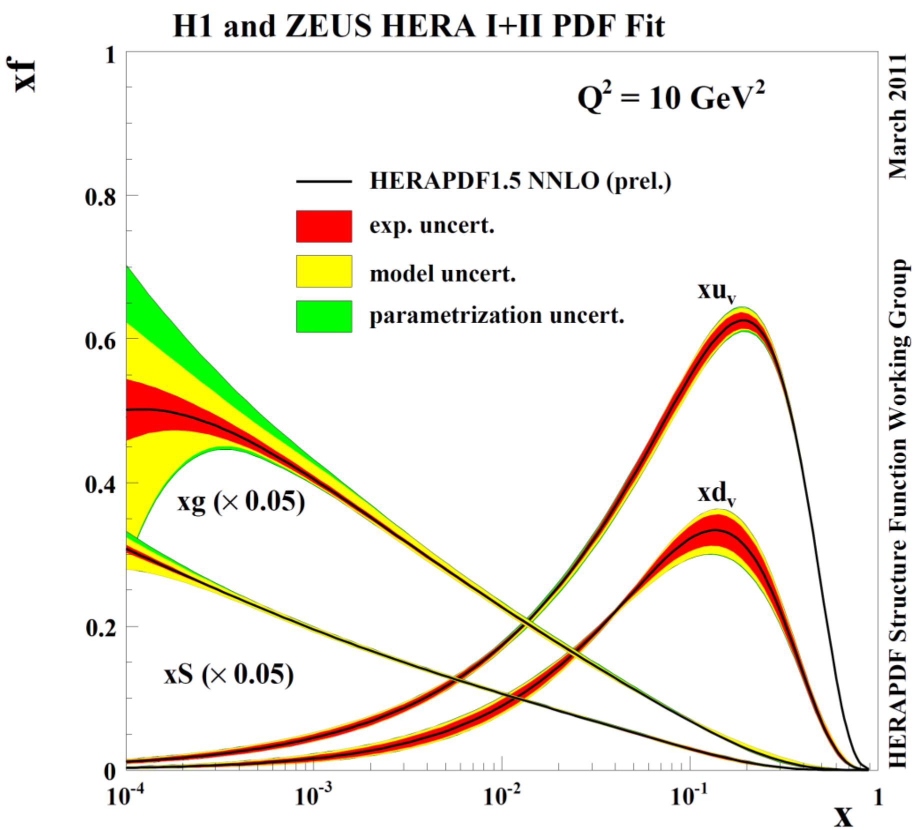
As well as greater uncertainty at low-x for Sea and glue there is also some small shift of gluon and sea shape at low-x
At large x gluon and sea and valence are all similar

NNLO

NNLO
Q^2>3.5 GeV^2

Compare to HERAPDF1.5 NNLO- very compatible, smaller uncertainties

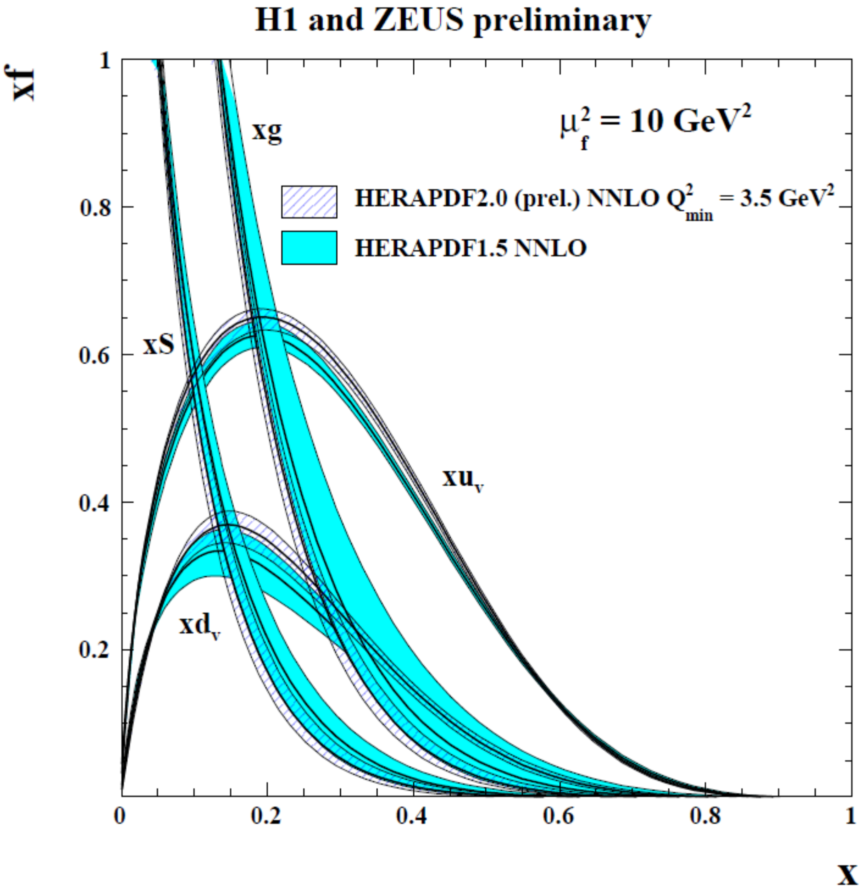


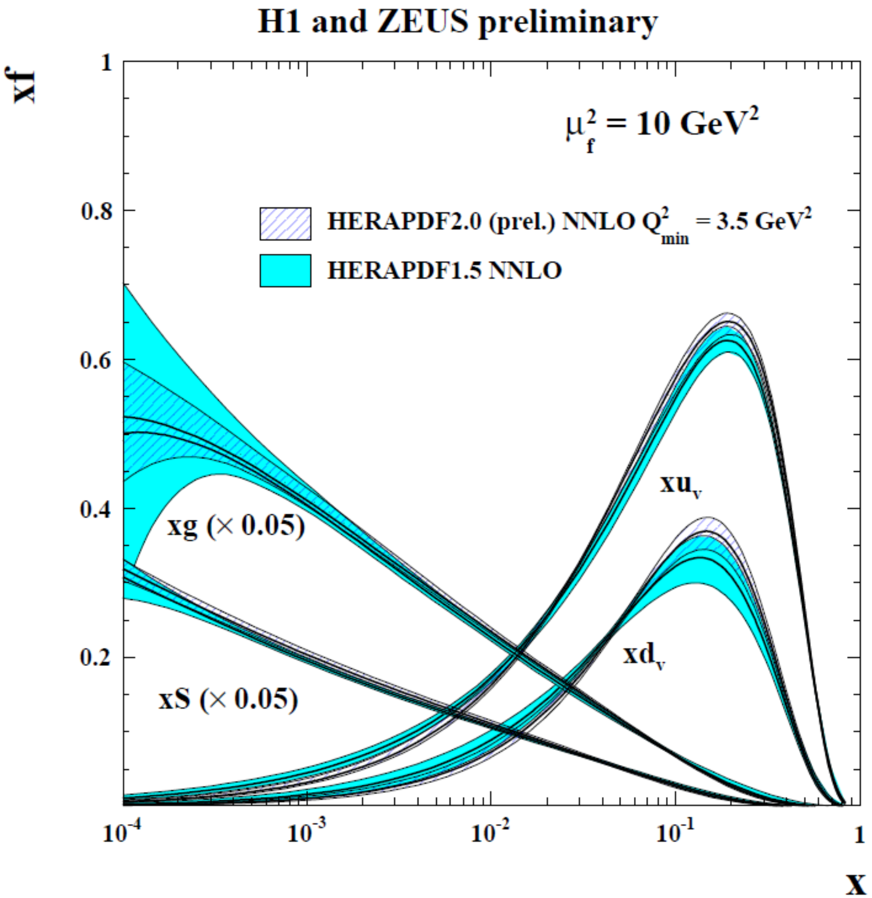


The model dependence on the gluon (yellow) is mostly the Q2cut – similar but not quite as extreme as before.

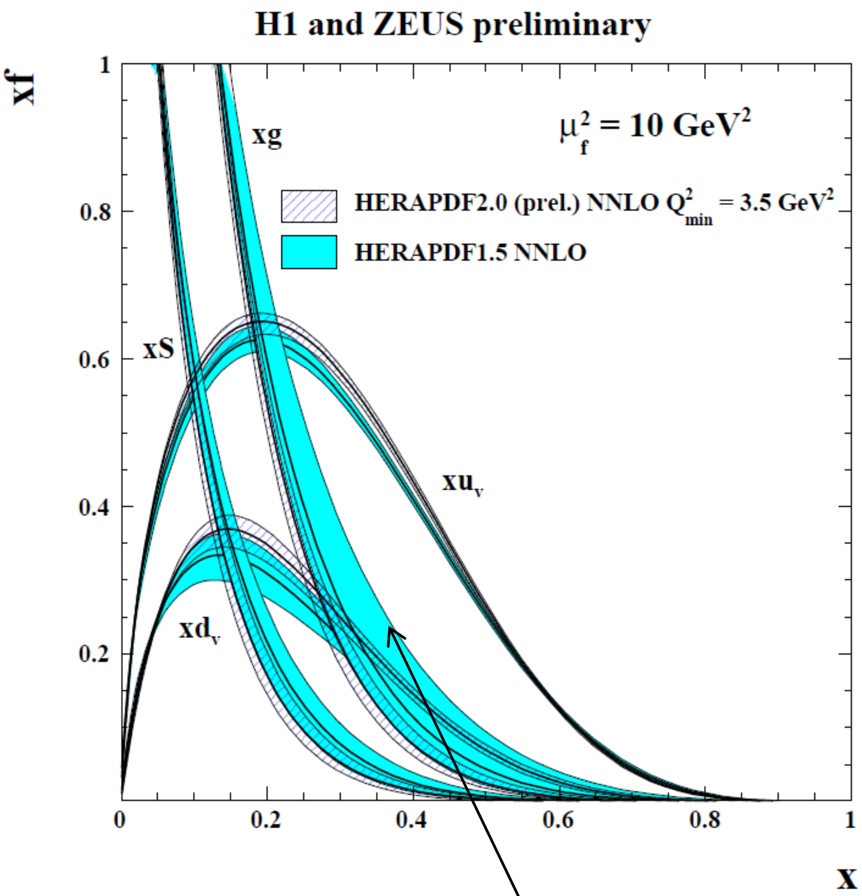
Now make the same comparison by overlaying

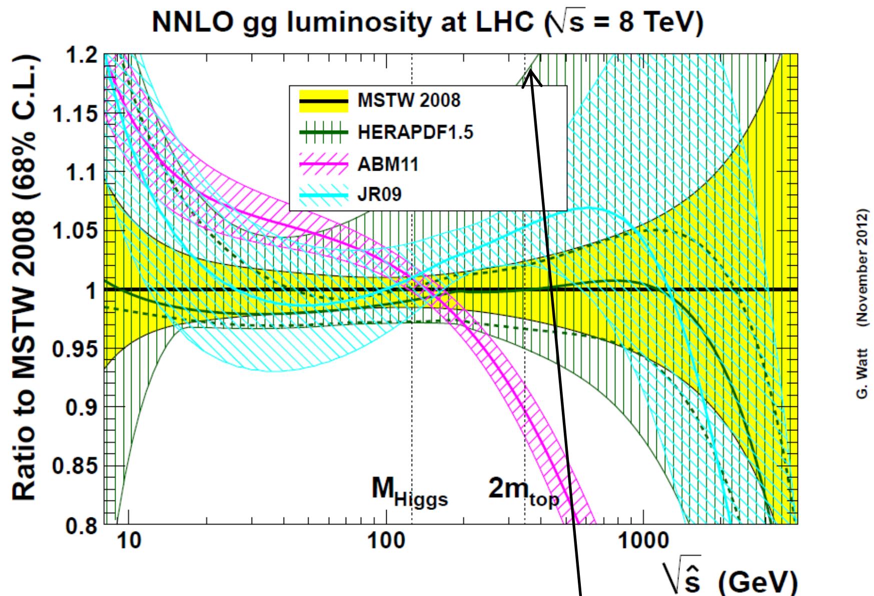
NNLO
Q^2>3.5 GeV^2





Reduction in gluon uncertainty both at low-x and high-x.
A lot of this reduction is because the effect of the Q2 cuts is not as dramatic now that we have more data.
(NOTE: HERAPDF2.0 has smaller uncertainty on the high-x g-g luminosity and hence on top predictions!)

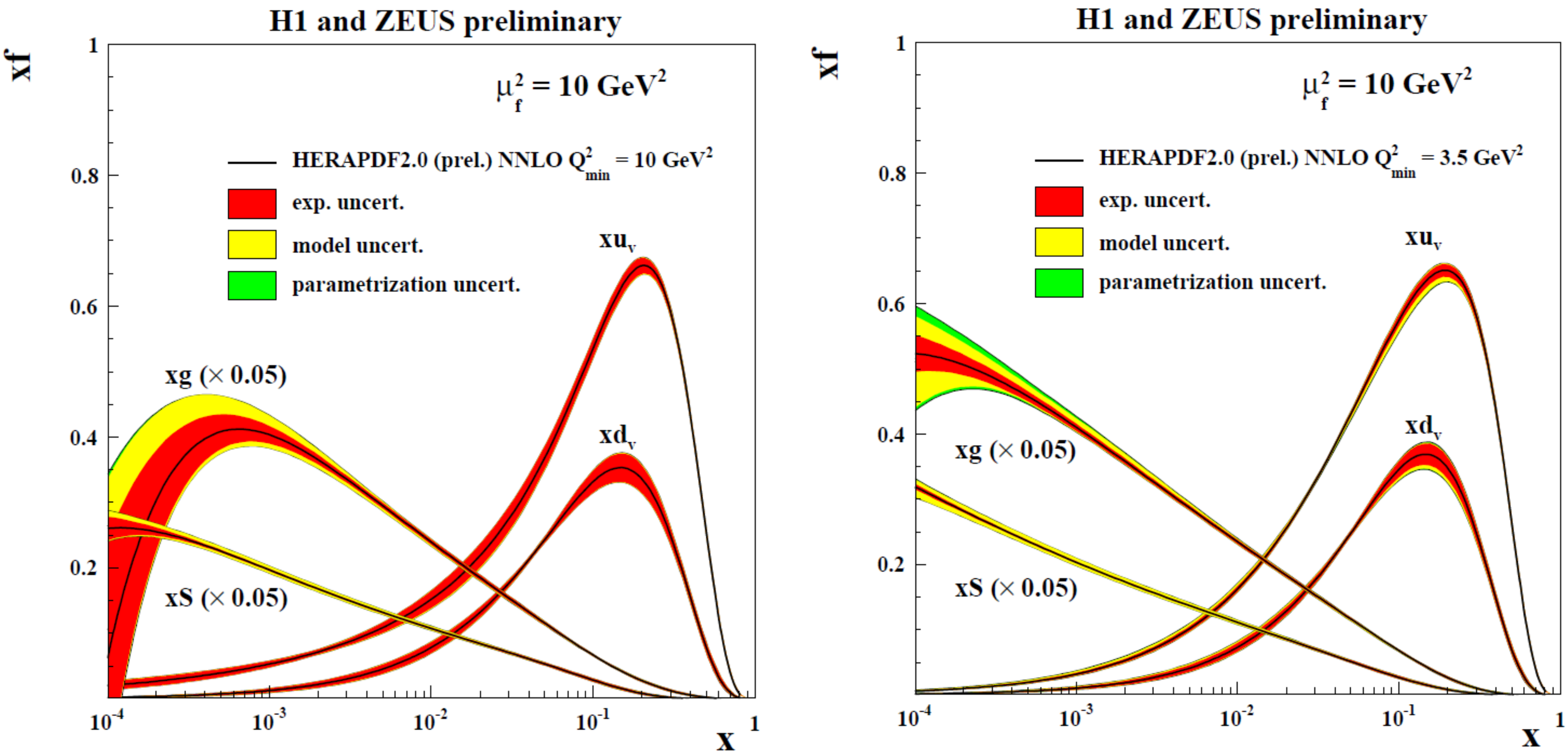




This uncertainty on the gluon decreases

So this uncertainty on the g–g luminosity will also decrease

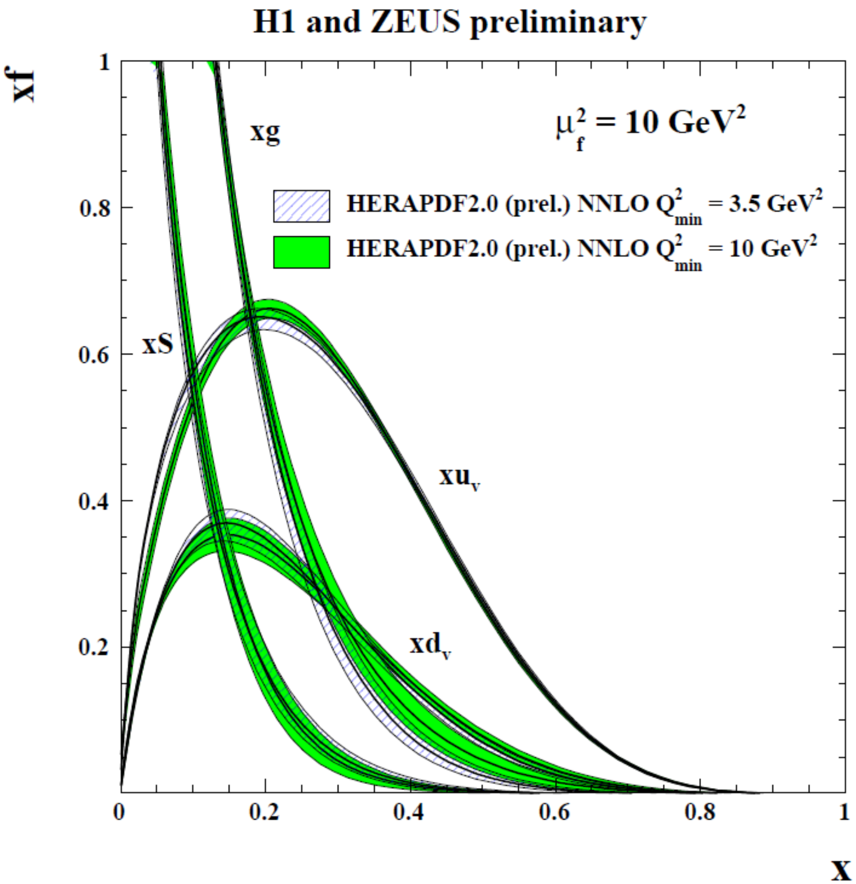
NNLO
$Q^2>10\ GeV^2$

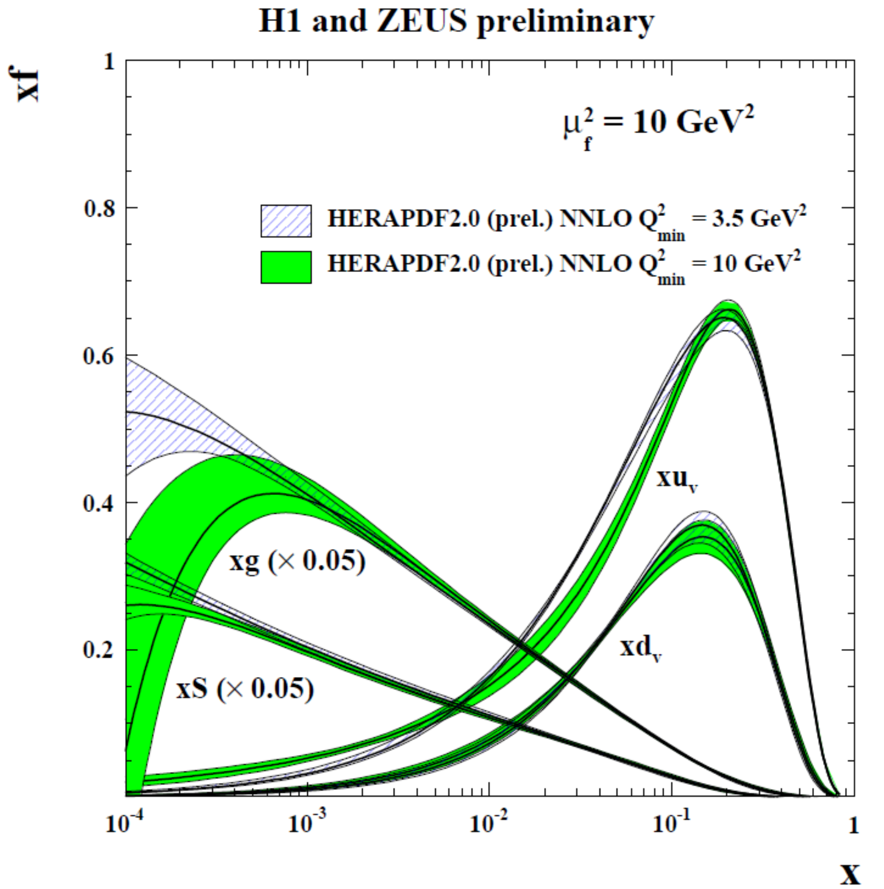


Compare to $Q^2>3.5$ results -----$Q^2>10$ cut increases uncertainty of low-x gluon– obviously –BUT
there is not just an increase of uncertainty at low-x as there was at NLO,
there is also a systematic shape difference, both in low-x sea and gluon

NNLO
Q^2>10 GeV^2

We could also compare the Q^2>10 and Q^2>3.5 fits overlaid on each other.





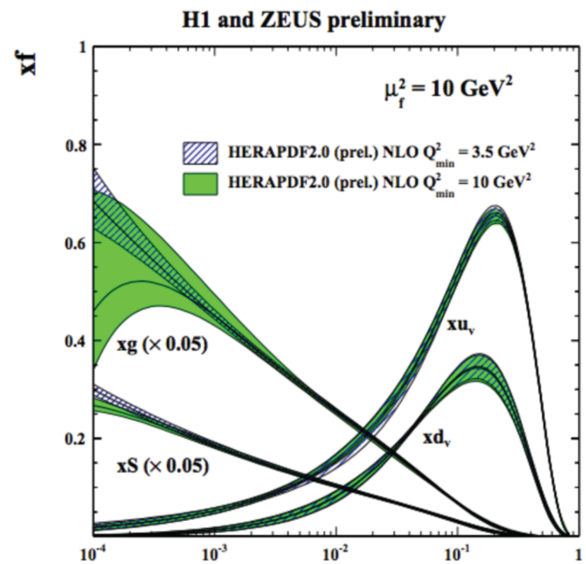
Fits are VERY compatible at high-x ---like in NLO case
BUT the difference in shape for low-x Sea and gluon– has now become pronounced

Summary

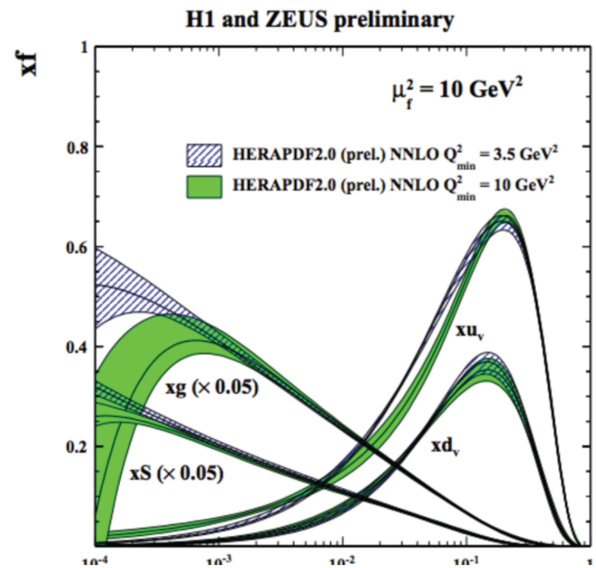
- HERA provides a clean determination of the proton's PDFs based solely on ep collider data
- New preliminary combined HERA I+II+low energy measurements improves precision of PDFs

- Q^2 dependence of fit observed and two sets, Q^2>3.5 GeV^2 and Q^2>10 GeV , provided

HERAPDF2.0(prel) at NLO and NNLO with full uncertainties



NLO



NNLO