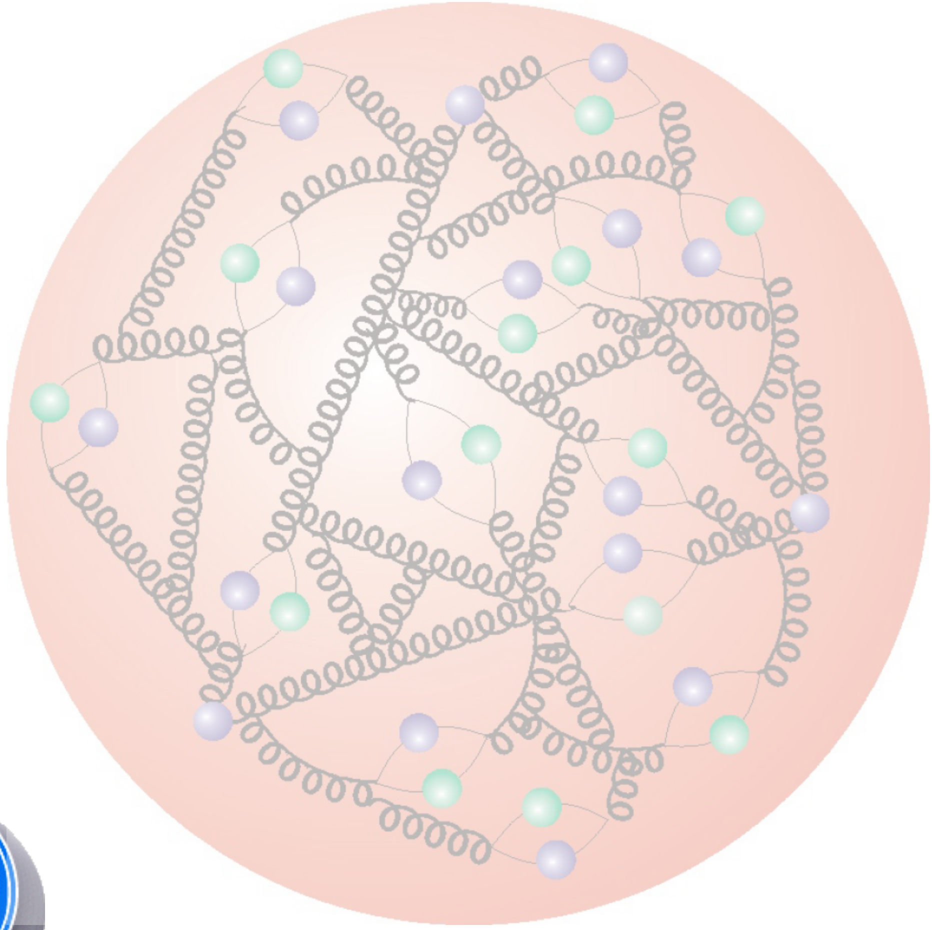
Inclusive DIS at HERA & PDF Fits



- Introduction
- HERA-II Data Sets
- Combination Procedure
- Combined Data Precision
- HERAPDF 2.0

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25th-29th August 2014

Structure Functions

$$\frac{d\sigma^{\pm}_{NC}}{dxdQ^2} = \frac{2\pi\alpha^2}{x}\left[\frac{1}{Q^2}\right]^2\left[Y_+\tilde{F}_2 \mp Y_- x\tilde{F}_3 - y^2\tilde{F}_L\right]$$

$$\frac{d\sigma^{\pm}_{CC}}{dxdQ^2} = \frac{G_F^2}{4\,\pi\,x}\left[\frac{M_W^2}{M_W^2+Q^2}\right]^2\left[Y_+\,\tilde{W}_2^{\pm} \mp Y_-\,x\tilde{W}_3^{\pm} - y^2\tilde{W}_L^{\pm}\right]$$

$$Y_{\pm} = 1 \pm (1-y)^2$$

$$\tilde{F}_2 \propto \sum(xq_i + x\bar{q}_i)$$

Dominant contribution

$$x\tilde{F}_3 \propto \sum(xq_i - x\bar{q}_i)$$

Only sensitive at high Q² ~ M_Z^2

$$\tilde{F}_L \propto \alpha_s \cdot xg(x,Q^2)$$

Only sensitive at low Q² and high y

similarly for pure weak CC analogues:

$W_2^{\pm}$, $xW_3^{\pm}$ and $W_L^{\pm}$

The NC reduced cross section defined as:

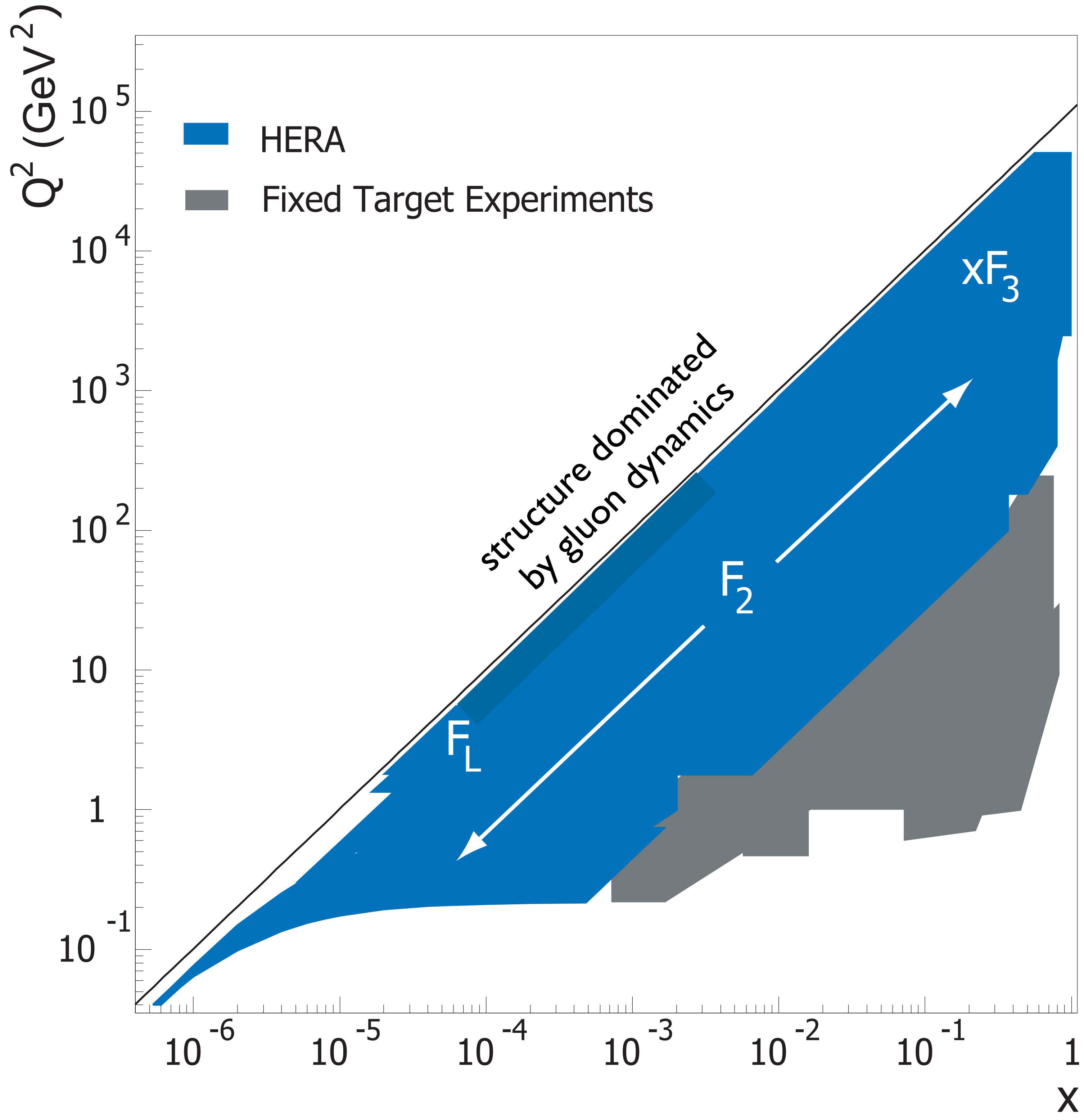
$$\tilde{\sigma}^{\pm}_{NC} = \frac{Q^2x}{2\alpha\pi^2}\frac{1}{Y_+}\frac{d^2\sigma^{\pm}}{dxdQ^2}$$

$$\tilde{\sigma}^{\pm}_{NC} \sim \tilde{F}_2 \mp \frac{Y_-}{Y_+}x\tilde{F}_3$$

The CC reduced cross section defined as:

$$\sigma^{\pm}_{CC} = \frac{2\pi x}{G_F^2}\left[\frac{M_W^2+Q^2}{M_W^2}\right]^2\frac{d\sigma^{\pm}_{CC}}{dxdQ^2}$$

$$\frac{d\sigma^{\pm}_{CC}}{dxdQ^2} = \frac{1}{2}\left[Y_+\,W_2^{\pm} \mp Y_-\,xW_3^{\pm} - y^2W_L^{\pm}\right]$$



HERA data cover wide region of x,Q^2

NC Measurements

F_2 dominates most of Q^2 reach

xF_3 contributes in EW regime

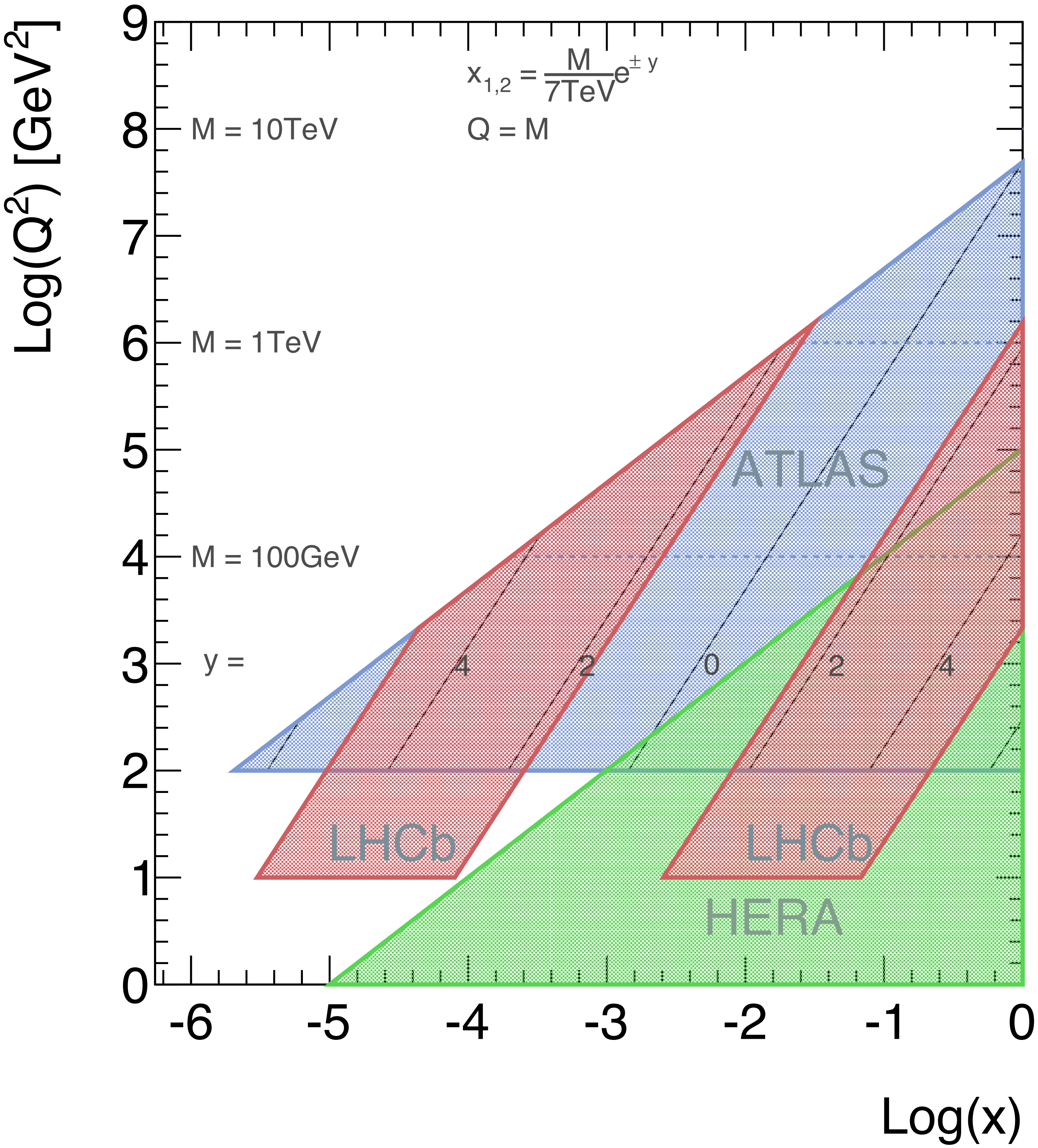
F_L contributes only at highest y

CC Measurements

W_2 and xW_3 contribute equally

W_L only at high y

Where Are We Going?



LHC: largest mass states at large x

For central production $x=x_1=x_2$

$M=x\sqrt{s}$

i.e. M > 1 TeV probes x>0.1

Searches for high mass states require precision knowledge at high x

Z′ / quantum gravity / susy searches...

DGLAP evolution allows predictions to be made

High x predictions rely on

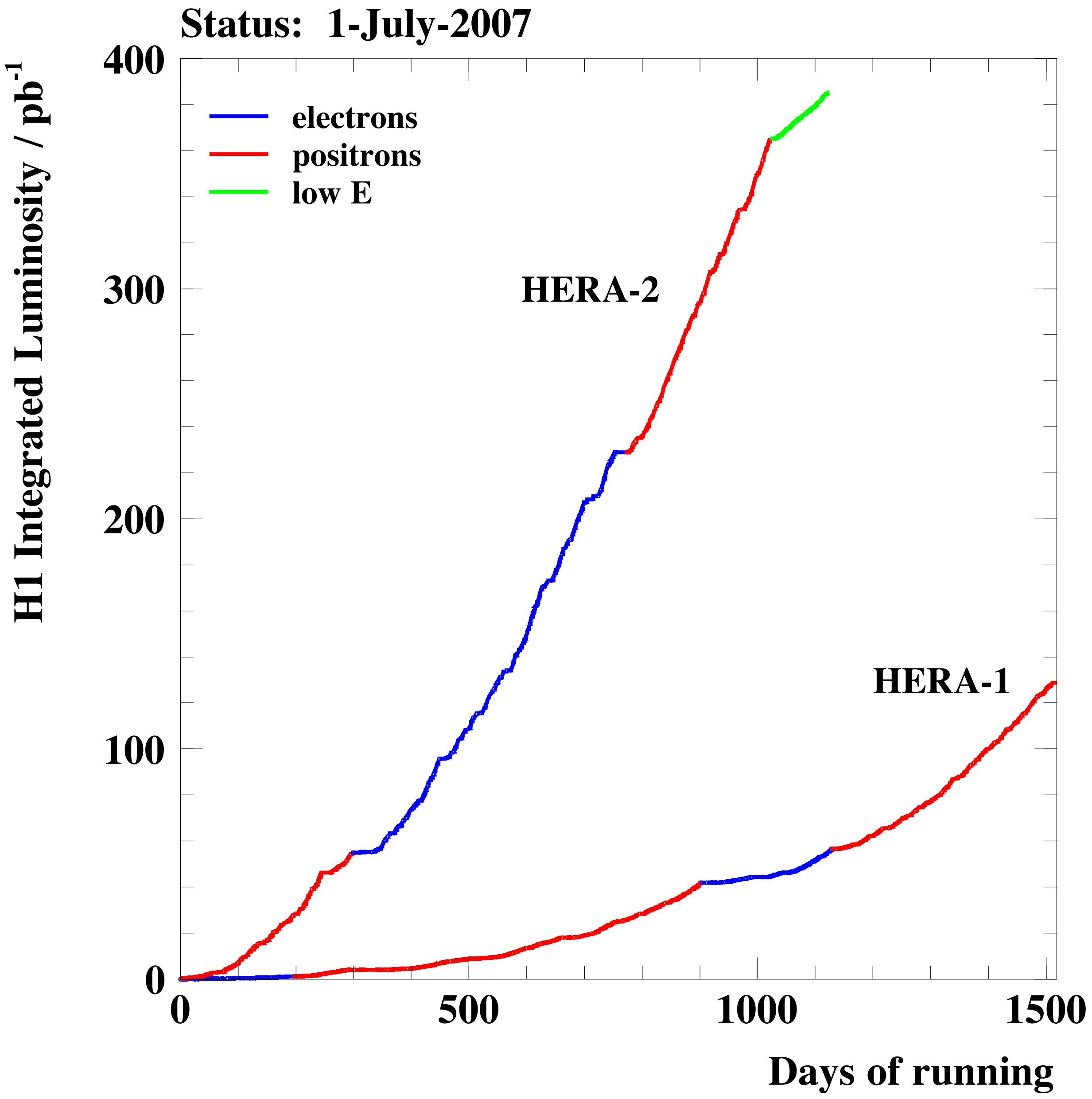
- data (DIS / fixed target)
- sum rules
- behaviour of PDFs as $x \to 1$

HERA Operation

<u>HERA-I operation 1993-2000</u>
Ee = 27.6 GeV
Ep = 820 / 920 GeV
$\int\mathcal{L} \sim 110$ pb^{-1} per experiment

<u>HERA-II operation 2003-2007</u>
Ee = 27.6 GeV
Ep = 920 GeV
$\int\mathcal{L} \sim 330$ pb^{-1} per experiment
Longitudinally polarised leptons

<u>Low Energy Run 2007</u>
Ee = 27.6 GeV
Ep = 575 & 460 GeV
Dedicated F_L measurement



HERA Structure Function Data

Summary of HERA-I datasets
Combined in HERAPDF1.0

Available since 2009

Data Set		x Range		Q^2 Range GeV^2		$\mathcal{L}$ pb^{-1}	e^+/e^-	$\sqrt{s}$ GeV
H1 svx-mb	95-00	5×10^{-6}	0.02	0.2	12	2.1	e^+p	301-319
H1 low Q^2	96-00	2×10^{-4}	0.1	12	150	22	e^+p	301-319
H1 NC	94-97	0.0032	0.65	150	30000	35.6	e^+p	301
H1 CC	94-97	0.013	0.40	300	15000	35.6	e^+p	301
H1 NC	98-99	0.0032	0.65	150	30000	16.4	e^-p	319
H1 CC	98-99	0.013	0.40	300	15000	16.4	e^-p	319
H1 NC HY	98-99	0.0013	0.01	100	800	16.4	e^-p	319
H1 NC	99-00	0.0013	0.65	100	30000	65.2	e^+p	319
H1 CC	99-00	0.013	0.40	300	15000	65.2	e^+p	319
ZEUS BPC	95	2×10^{-6}	6×10^{-5}	0.11	0.65	1.65	e^+p	301
ZEUS BPT	97	6×10^{-7}	0.001	0.045	0.65	3.9	e^+p	301
ZEUS SVX	95	1.2×10^{-5}	0.0019	0.6	17	0.2	e^+p	301
ZEUS NC	96-97	6×10^{-5}	0.65	2.7	30000	30.0	e^+p	301
ZEUS CC	94-97	0.015	0.42	280	17000	47.7	e^+p	301
ZEUS NC	98-99	0.005	0.65	200	30000	15.9	e^-p	319
ZEUS CC	98-99	0.015	0.42	280	30000	16.4	e^-p	319
ZEUS NC	99-00	0.005	0.65	200	30000	63.2	e^+p	319
ZEUS CC	99-00	0.008	0.42	280	17000	60.9	e^+p	319

High Q^2 NC and CC data limited to
100 pb^{-1} e^+p
16 pb^{-1} e^-p

HERA Structure Function Data

Data Set		x Grid		Q^2/GeV^2 Grid		$\mathcal{L}$	e^+/e^-	$\sqrt{s}$	x,Q^2 from	Ref.
		from	to	from	to	pb^{-1}		GeV	equations	
HERA I E_p = 820 GeV and E_p = 920 GeV data sets										
H1 svx-mb	95-00	0.000005	0.02	0.2	12	2.1	e^+p	301, 319	11,15,16	[2]
H1 low Q^2	96-00	0.0002	0.1	12	150	22	e^+p	301, 319	11,15,16	[3]
H1 NC	94-97	0.0032	0.65	150	30000	35.6	e^+p	301	17	[4]
H1 CC	94-97	0.013	0.40	300	15000	35.6	e^+p	301	12	[4]
H1 NC	98-99	0.0032	0.65	150	30000	16.4	e^-p	319	17	[5]
H1 CC	98-99	0.013	0.40	300	15000	16.4	e^-p	319	12	[5]
H1 NC HY	98-99	0.0013	0.01	100	800	16.4	e^-p	319	11	[6]
H1 NC	99-00	0.0013	0.65	100	30000	65.2	e^+p	319	17	[6]
H1 CC	99-00	0.013	0.40	300	15000	65.2	e^+p	319	12	[6]
ZEUS BPC	95	0.000002	0.00006	0.11	0.65	1.65	e^+p	300	11	[10]
ZEUS BPT	97	0.0000006	0.001	0.045	0.65	3.9	e^+p	300	11, 17	[11]
ZEUS SVX	95	0.000012	0.0019	0.6	17	0.2	e^+p	300	11	[12]
ZEUS NC	96-97	0.00006	0.65	2.7	30000	30.0	e^+p	300	19	[13]
ZEUS CC	94-97	0.015	0.42	280	17000	47.7	e^+p	300	12	[14]
ZEUS NC	98-99	0.005	0.65	200	30000	15.9	e^-p	318	18	[15]
ZEUS CC	98-99	0.015	0.42	280	30000	16.4	e^-p	318	12	[16]
ZEUS NC	99-00	0.005	0.65	200	30000	63.2	e^+p	318	18	[17]
ZEUS CC	99-00	0.008	0.42	280	17000	60.9	e^+p	318	12	[18]
HERA II E_p = 920 GeV data sets										
H1 NC	03-07	0.0008	0.65	60	30000	182	e^+p	319	11, 17	[7][1]
H1 CC	03-07	0.008	0.40	300	15000	182	e^+p	319	12	[7][1]
H1 NC	03-07	0.0008	0.65	60	50000	151.7	e^-p	319	11, 17	[7][1]
H1 CC	03-07	0.008	0.40	300	30000	151.7	e^-p	319	12	[7][1]
H1 NC med Q^2 $^{*y.5}$	03-07	0.0000986	0.005	8.5	90	97.6	e^+p	319	11	[9]
H1 NC low Q^2 $^{*y.5}$	03-07	0.000029	0.00032	2.5	12	5.9	e^+p	319	11	[9]
ZEUS NC	06-07	0.005	0.65	200	30000	135.5	e^+p	318	11,12,18	[21]
ZEUS CC	06-07	0.0078	0.42	280	30000	132	e^+p	318	12	[22]
ZEUS NC	05-06	0.005	0.65	200	30000	169.9	e^-p	318	18	[19]
ZEUS CC	04-06	0.015	0.65	280	30000	175	e^-p	318	12	[20]
ZEUS NC nominal ^{*y}	06-07	0.000092	0.008343	7	110	44.5	e^+p	318	11	[23]
ZEUS NC satellite ^{*y}	06-07	0.000071	0.008343	5	110	44.5	e^+p	318	11	[23]
HERA II E_p = 575 GeV data sets										
H1 NC high Q^2	07	0.00065	0.65	35	800	5.4	e^+p	252	11, 17	[8]
H1 NC low Q^2	07	0.0000279	0.0148	1.5	90	5.9	e^+p	252	11	[9]
ZEUS NC nominal	07	0.000147	0.013349	7	110	7.1	e^+p	251	11	[23]
ZEUS NC satellite	07	0.000125	0.013349	5	110	7.1	e^+p	251	11	[23]
HERA II E_p = 460 GeV data sets										
H1 NC high Q^2	07	0.00081	0.65	35	800	11.8	e^+p	225	11, 17	[8]
H1 NC low Q^2	07	0.0000348	0.0148	1.5	90	12.2	e^+p	225	11	[9]
ZEUS NC nominal	07	0.000184	0.016686	7	110	13.9	e^+p	225	11	[23]
ZEUS NC satellite	07	0.000143	0.016686	5	110	13.9	e^+p	225	11	[23]

H1 & ZEUS have now published all datasets

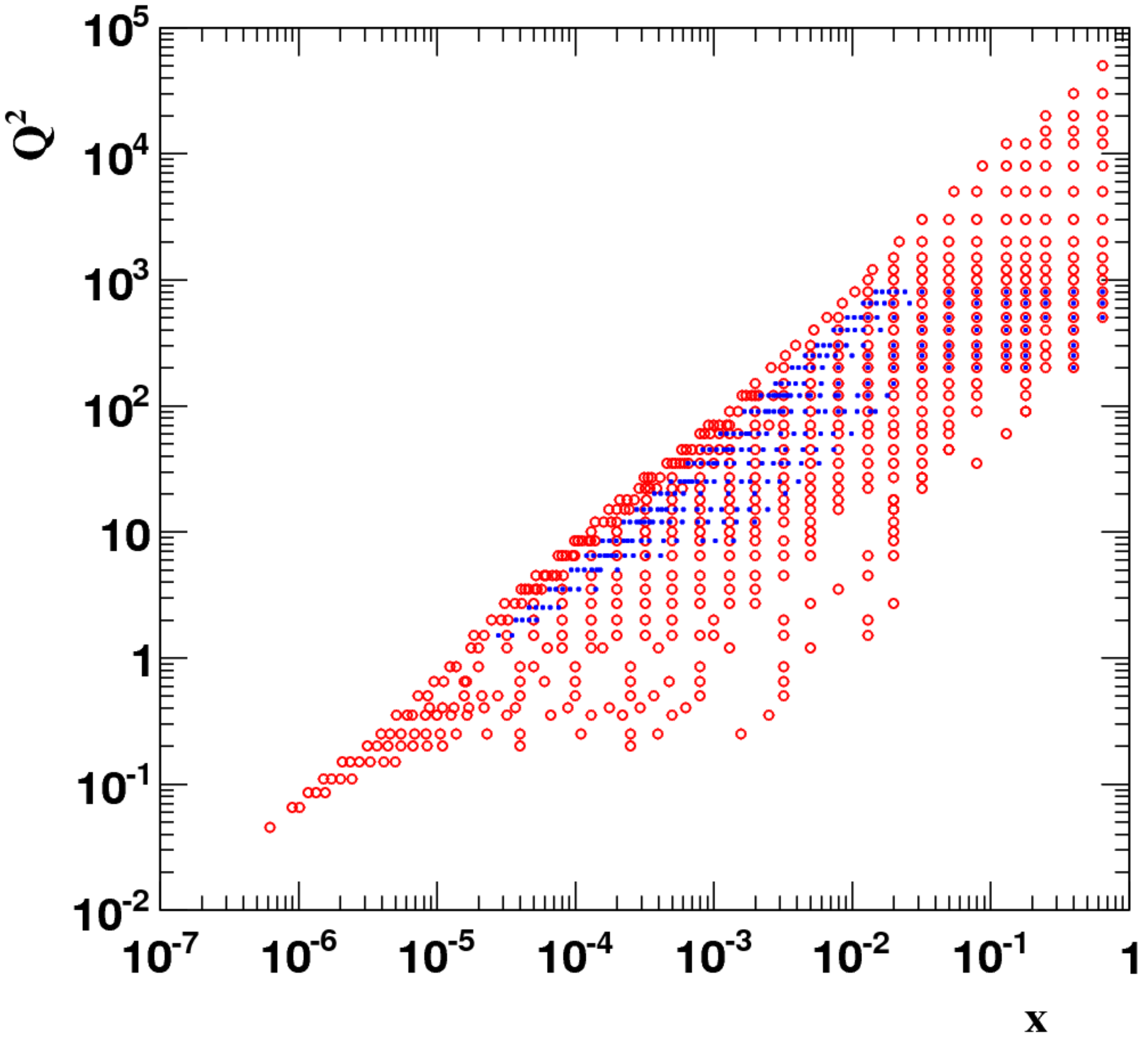
- HERA-II measurements at high $\int\mathcal{L}$
- reduced $\sqrt{s}$ data

41 data sets to be combined:
  - NC & CC cross sections
  - e^+p and e^-p scattering
  - 4 different $\sqrt{s}$ values

2927 data points in total

In some cases 6 measurements combined

H1 & ZEUS Data Combination



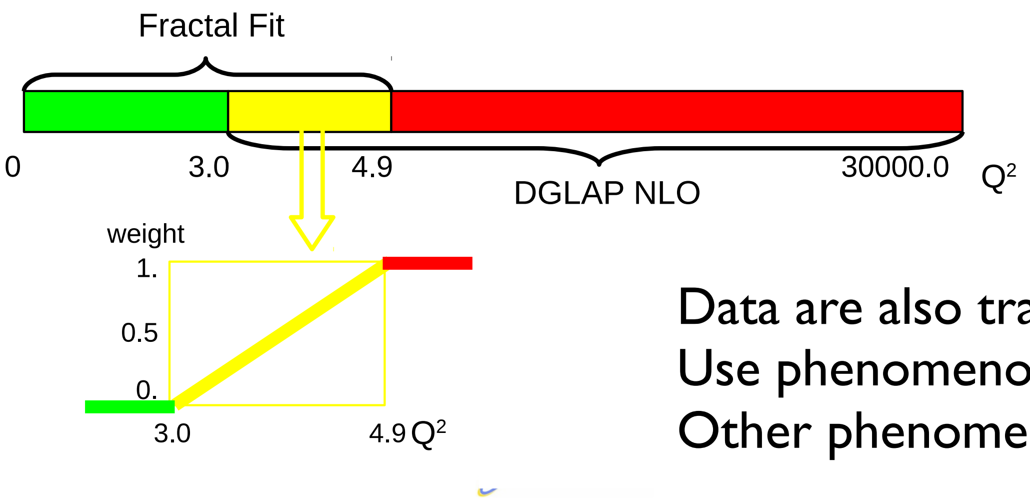
Data are combined onto a common x,Q^2 grid
Two grids used:

- inclusive measurements $\sqrt{s}$=301 & 319 GeV
- fine x grid for $\sqrt{s}$=575 & 460 GeV

2927 data points → 1307 combined measurements

Data are translated to nearest x,Q^2 grid point
Iterative process using NLO QCD fit to data
Use uncombined data in first iteration
Then combined data in later iterations
No changes after 3 iterations

$$\sigma(x_{grid}, Q^2_{grid}) = \frac{\sigma_{model}(x_{grid}, Q^2_{grid})}{\sigma_{model}(x_{meas}, Q^2_{meas})} \cdot \sigma_{meas}(x_{meas}, Q^2_{meas})$$



Data are also translated outside of region of DGLAP fit validity Q^2 < 3.0 GeV^2
Use phenomenological "fractal" model and interpolate to DGLAP region
Other phenomenological fits tested → negligible differences

H1 & ZEUS Data Combination

i data points
j systematic error sources

Correlated uncertainties treated multiplicative: size proportional to central averaged value
True for normalisation uncertainties
Perhaps not true for other uncertainties

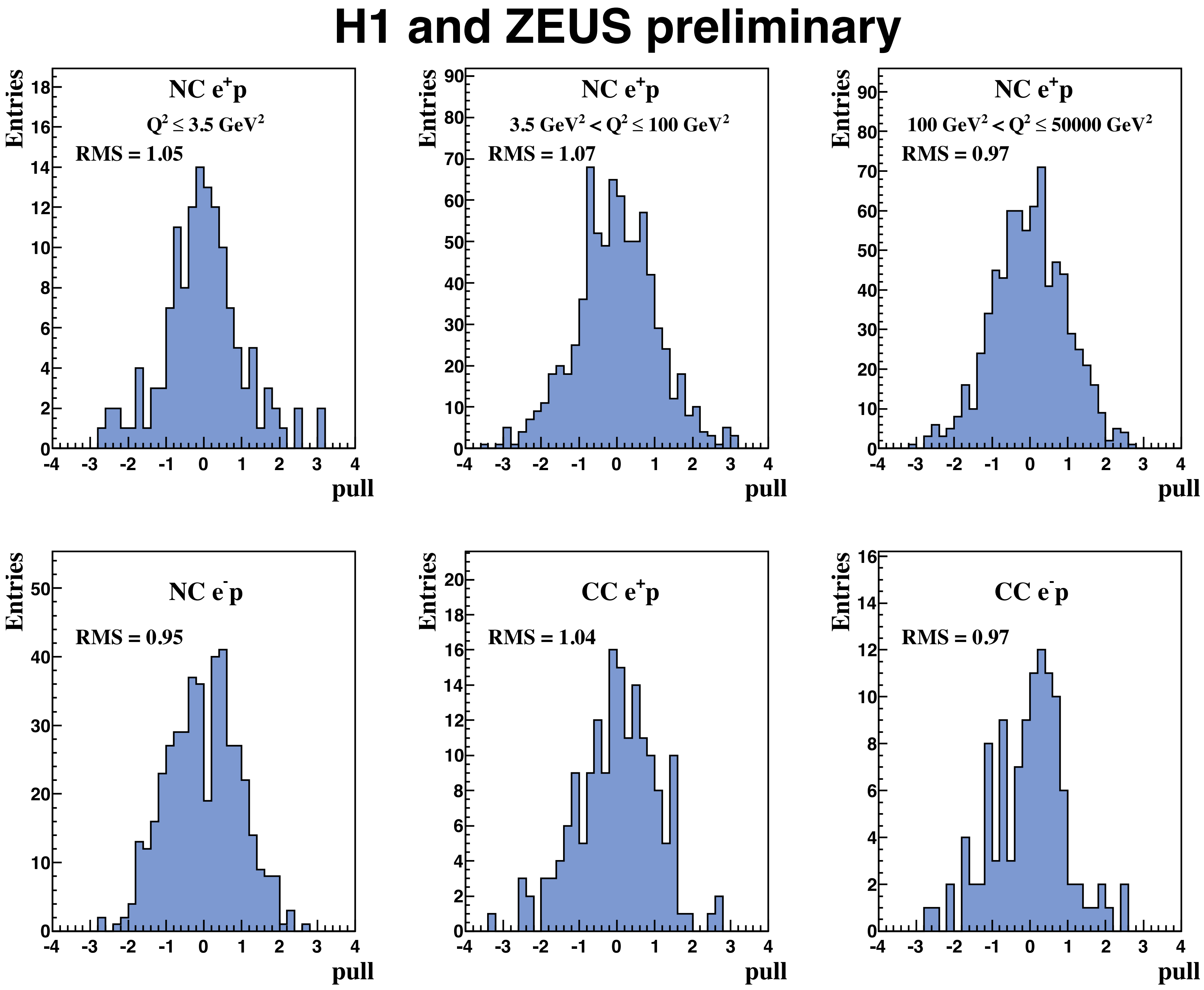
$$\chi^2_{tot}(\mathbf{m},\mathbf{b}) = \sum_i \frac{[\mu^i - m^i(1-\sum_j \gamma^i_j b_j)]^2}{\delta^2_{i,stat}\mu^i m^i(1-\sum_j \gamma^i_j b_j) + (\delta_{i,unc} m^i)^2} + \sum_j b_j^2$$

μ^i = measurement
m^i = averaged value
$\gamma^i{}_j$ = correlated relative (%) sys uncertainty on point i from error source j
b_j = systematic error source strength
  nuisance parameter left free in fit but constrained
  no extra degrees of freedom due to additional constraint

For HERAPDF2.0 number of correlated error sources j = 162
These include:
  b/g uncertainty
  luminosity uncertainty
  EM calibration scale
  had calibration scale
  etc….
Are correlated point-to-point within a single measurement
Reported in detail in individual publications from experiments
May also be correlated across measurements
May also be correlated between H1 & ZEUS (e.g. had scale & photoproduction b/g)

Extra procedural uncertainty included:
difference between using
additive vs multiplicative
correlated uncertainties (except normalisation)
⇒ extra ~0.5% uncertainty

H1 & ZEUS Data Combination



Overall χ^2/ndf = 1685 / 1620 = 1.04

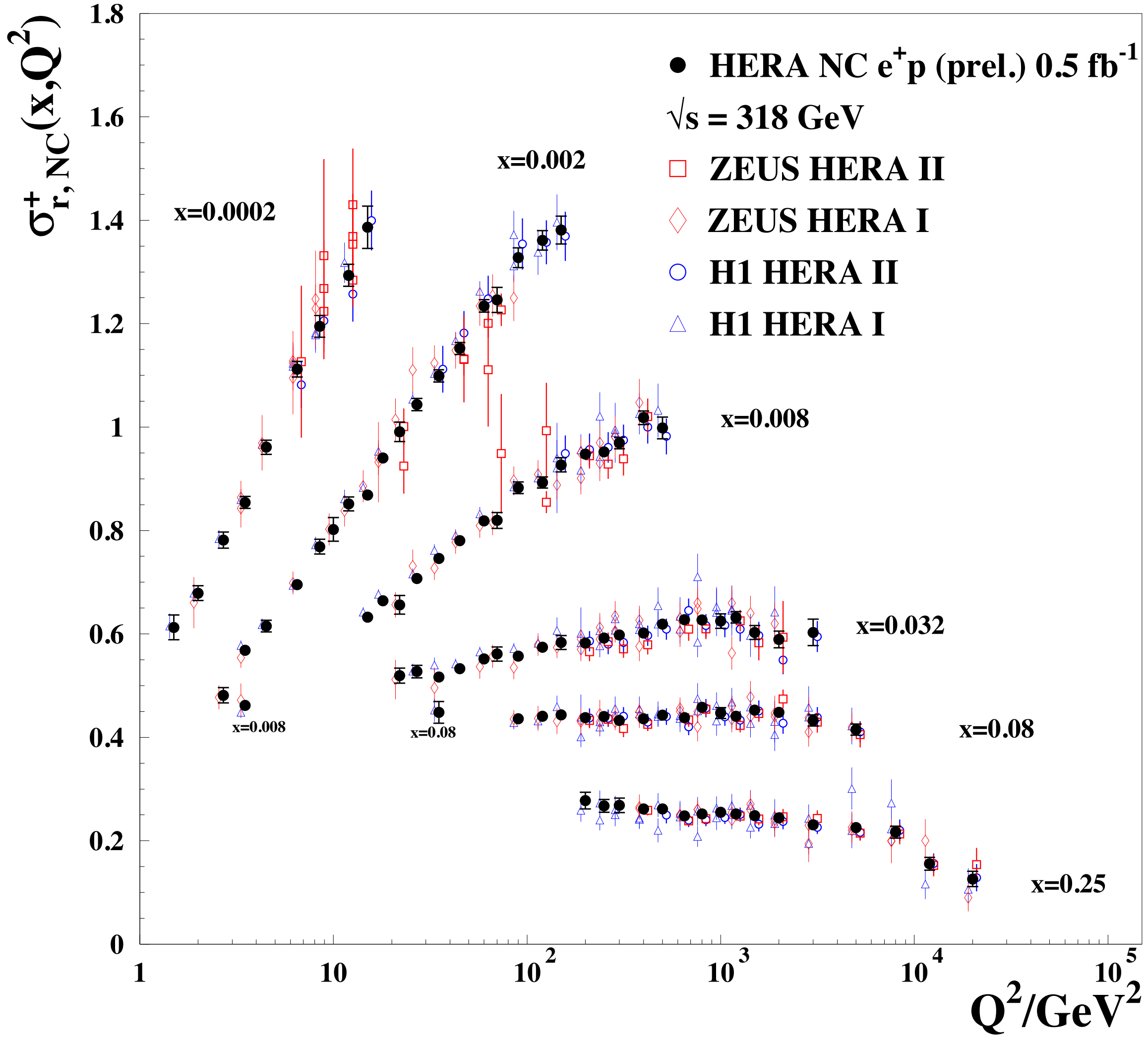
Pulls defined for each measurement difference between measured & average values after applying sys shifts b_j in units of uncorrelated uncertainty

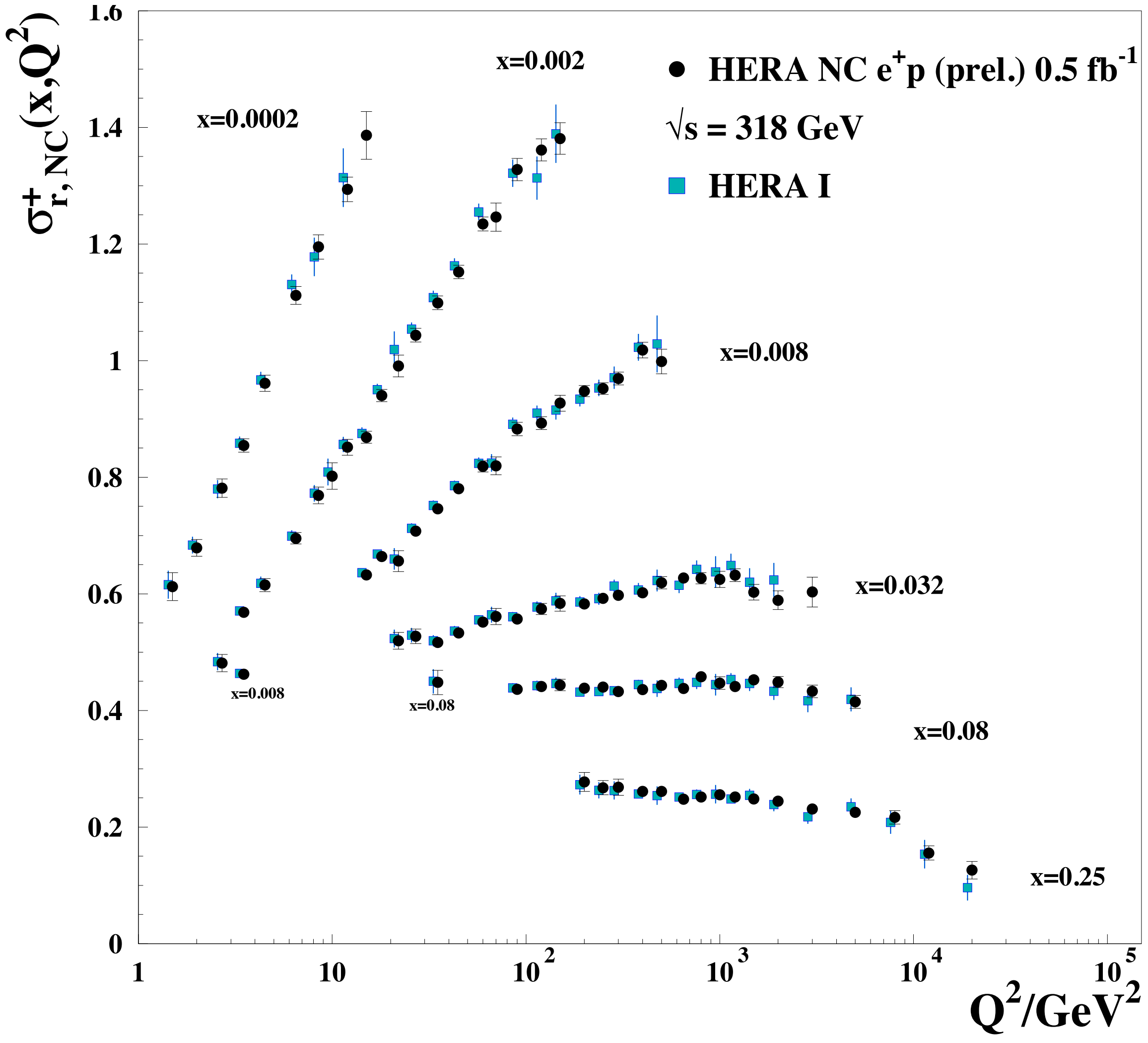
Pulls of the data points should be distributed as a unit Gaussian

Each measurement channel shows pull centred on zero & unit width

H1 & ZEUS Data Combination

NC e^+p inclusive cross sections





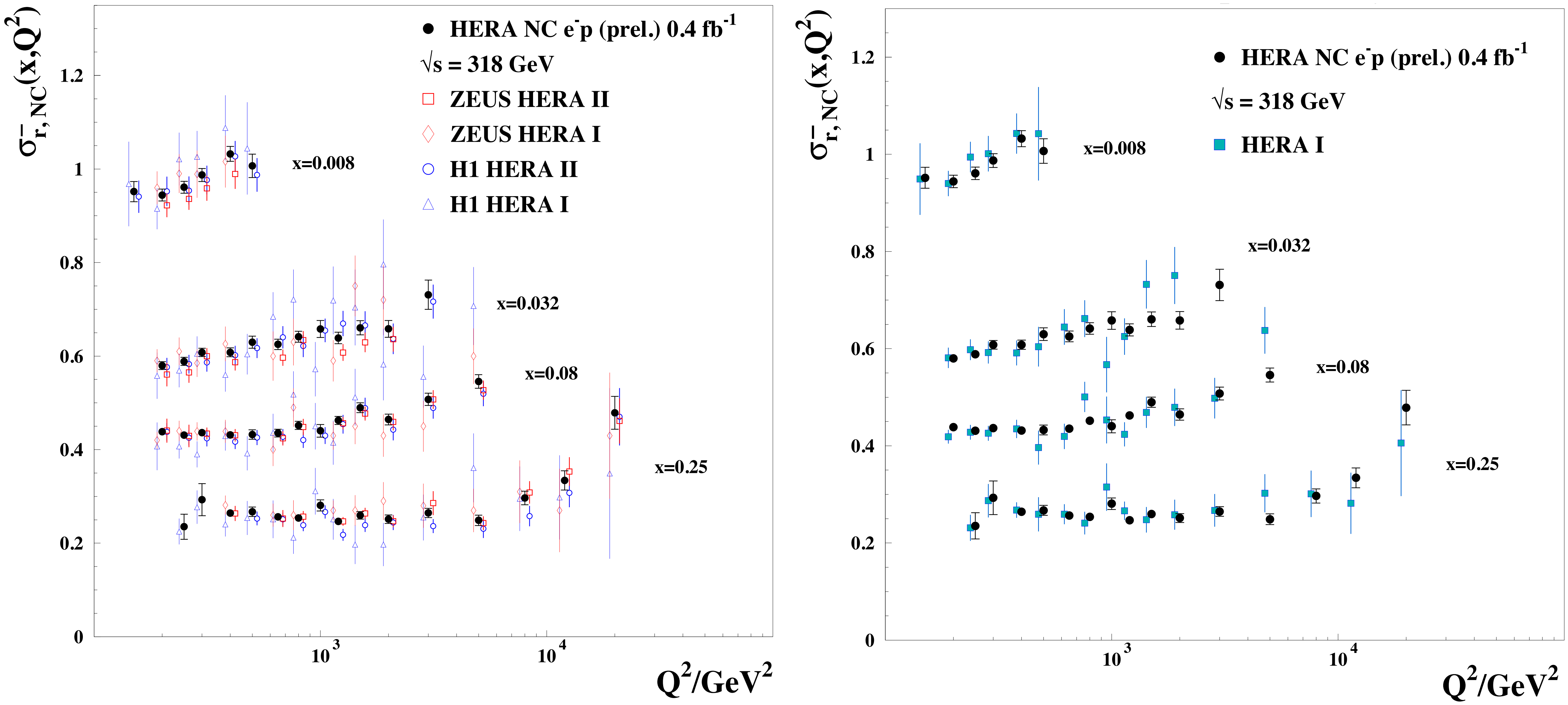
Significant improvement in NC uncertainties for $Q^2 > 100$ GeV^2 for $\sqrt{s}$=318 GeV

Compared to HERA I combination: factor 3 increase in statistical precision

- stat error < 0.9% for Q^2 up to 400 GeV^2
- total error < 1.3% for Q^2 up to 400 GeV^2

H1 & ZEUS Data Combination

NC e⁻p inclusive cross sections



Significant improvement in NC uncertainties for $Q^2 > 100$ GeV^2 for $\sqrt{s}=318$ GeV

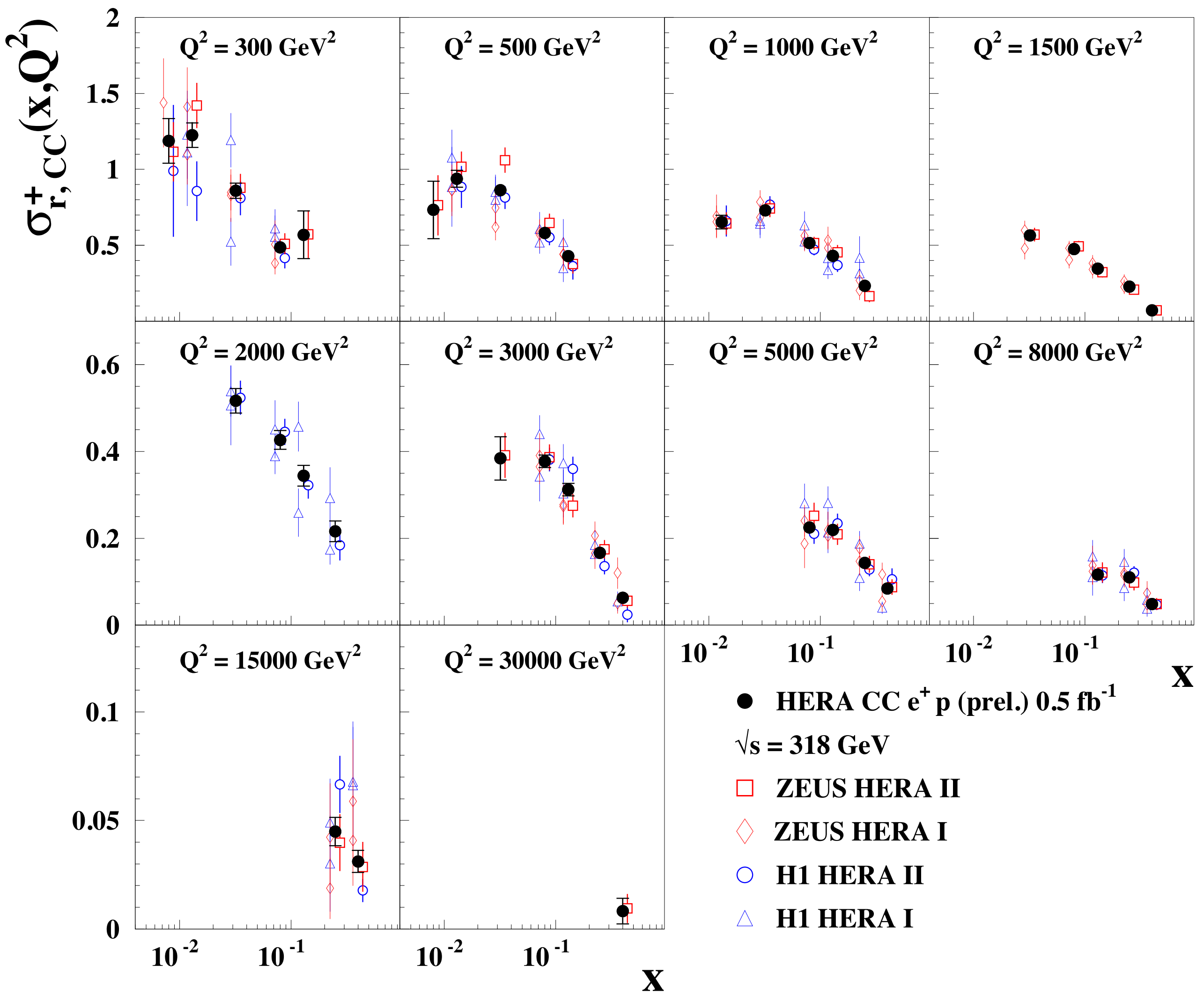
Compared to HERA I combination: factor 10 increase in statistical precision

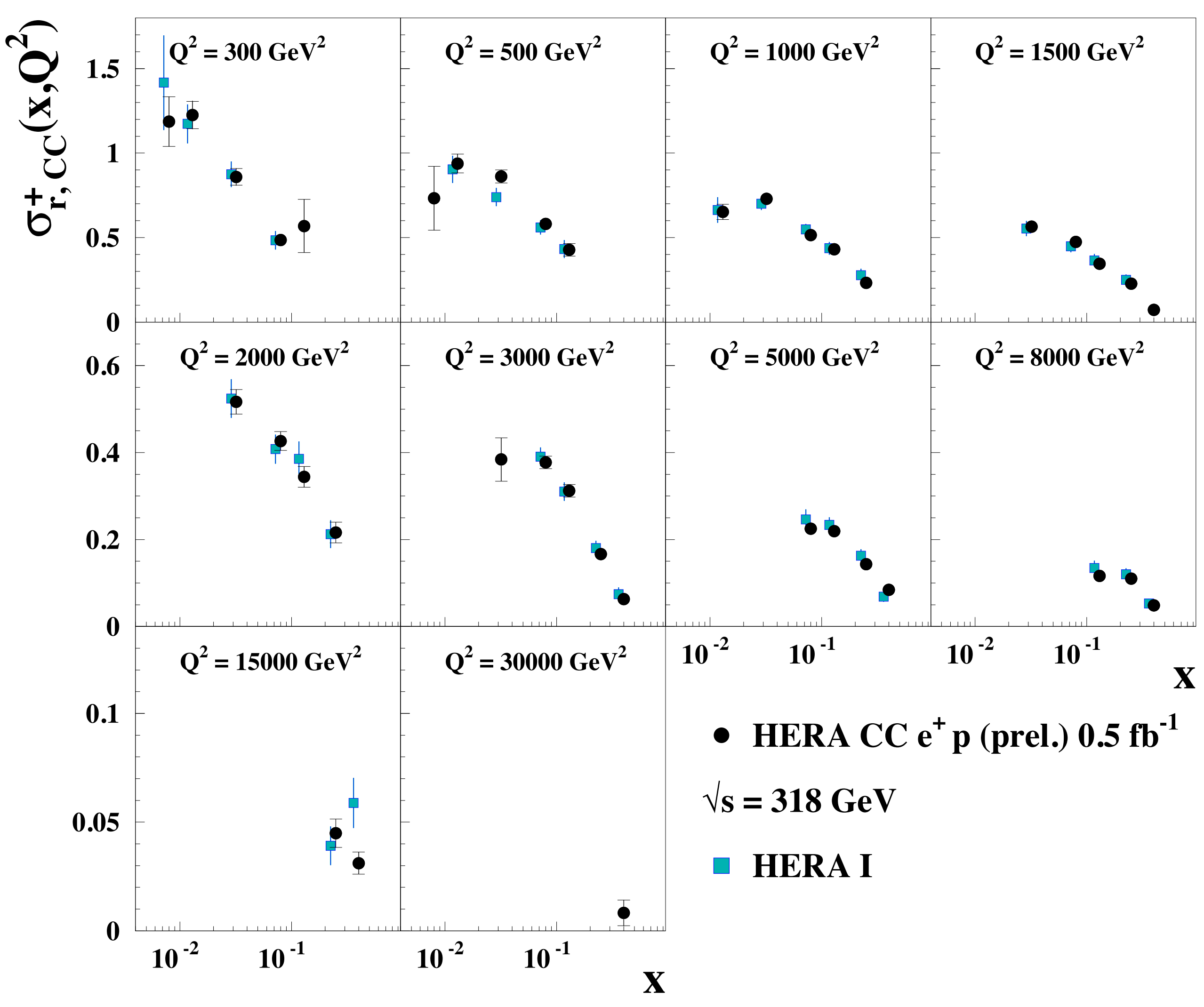
stat error < 0.9% for Q^2 up to 400 GeV^2

total error < 1.6% for Q^2 up to 400 GeV^2

H1 & ZEUS Data Combination

CC $e^{+}p$ inclusive cross sections





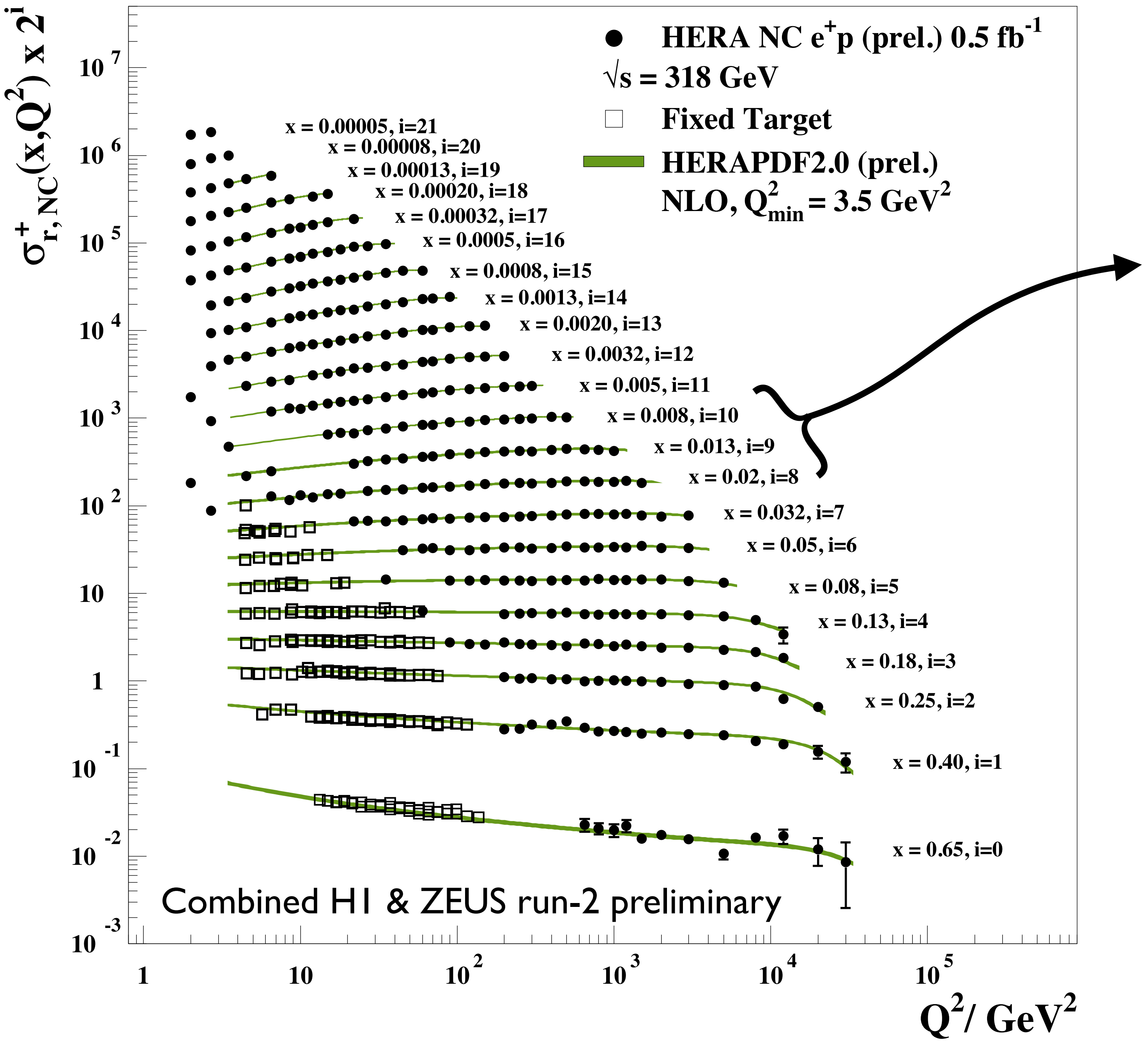
At high x the CC $e^{+}p$ cross sections provide direct clean access to the *xd* density

Compared to HERA I combination: factor 3 increase in statistical precision

HERAPDF1.0 combination total error ~10-20%
HERAPDF2.0 combination total error ~5-10%
up to x ~ 0.25

Dominated by statistical precision

H1 & ZEUS Data Combination



x ~ 10^{-2} is a sweet-spot
high precision with long Q^2 lever arm
relevant for LHC Higgs production

Precision:
1.2% $Q^2 < 60\ GeV^2$
1.3% $Q^2 < 400\ GeV^2$
2% $Q^2 < 1200\ GeV^2$

Compendium for HERAPDF

HERAPDF1.0

Combine NC and CC HERA-I data from H1 & ZEUS

Complete MSbar NLO fit

NLO: standard parameterisation with10 parameters

$\alpha_s = 0.1176$ (fixed in fit)

HERAPDF1.5

Include additional NC and CC HERA-II data

Complete MSbar NLO and NNLO fit

NLO: standard parameterisation with 10 parameters

HERAPDF1.5f

NNLO: extended fit with 14 parameters

HERAPDF1.6

Include additional NC inclusive jet data $5 < Q^2 < 15000$

Complete MSbar NLO fit

NLO: standard parameterisation with 14 parameters

$\alpha_s = 0.1202 \pm 0.0013$ (exp) $\pm$ 0.004 (scales) free in fit

HERAPDF1.7

Include 41 additional F_2^{cc} data $4 < Q^2 < 1000$

Include 224 combined cross section points E_p=575/460 GeV

Complete MSbar NLO fit

NLO: standard parameterisation with 14 parameters

HERAPDF 2.0

HERAPDF2.0

Include final:

HERA-I low/medium Q^2 precision F_2

HERA-II high Q^2 NC/CC data

HERA-II low/medium energy NC data

NLO & NNLO fits

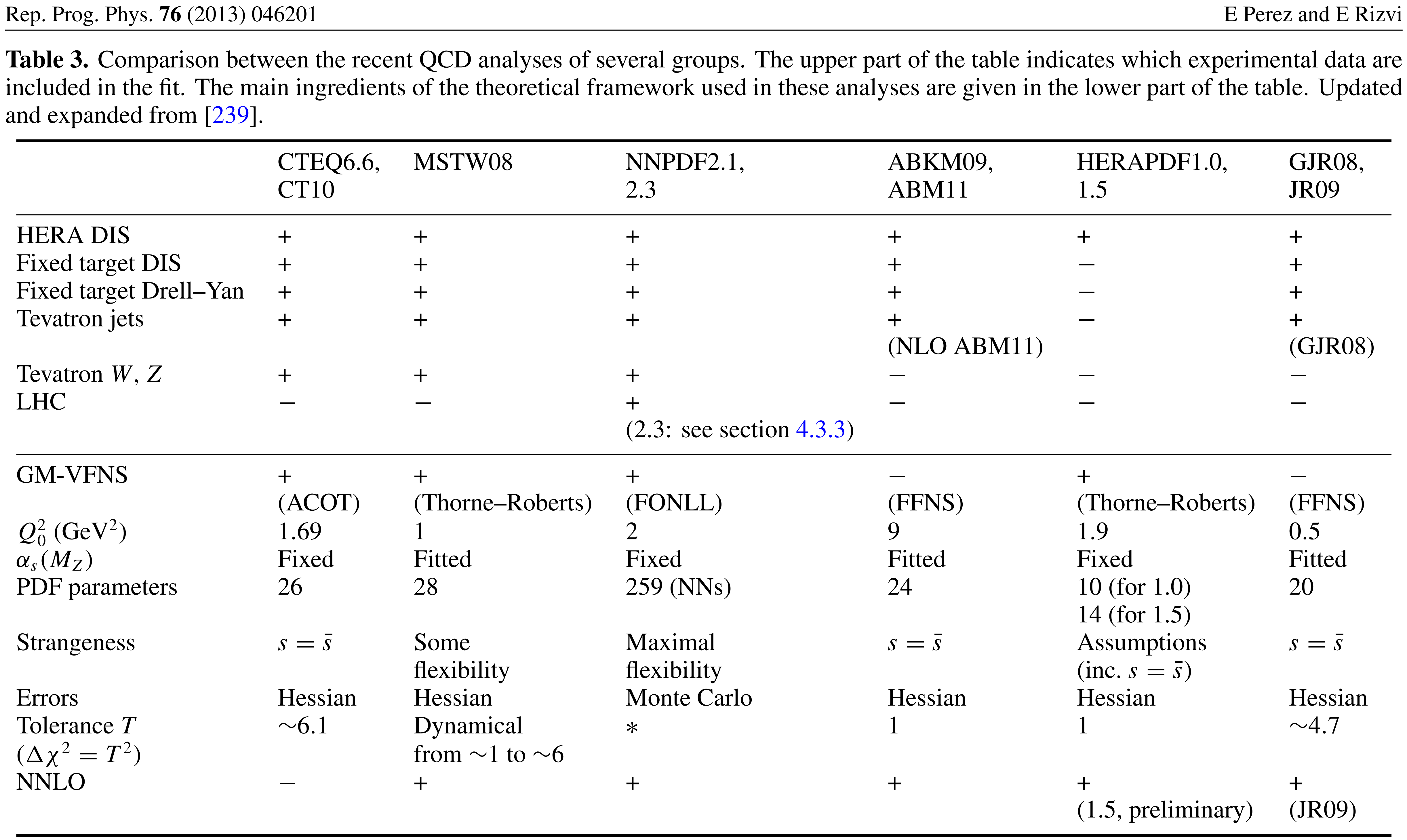
Final structure function measurements from H1 / ZEUS now published

Combination of the data is underway

New combination will include:

- HERA-I published data
- HERA-II published data
- low/medium energy E_p=575/460 GeV run data

QCD Analyses



Rep. Prog. Phys. **76** (2013) 046201 E Perez and E Rizvi

Table 3. Comparison between the recent QCD analyses of several groups. The upper part of the table indicates which experimental data are included in the fit. The main ingredients of the theoretical framework used in these analyses are given in the lower part of the table. Updated and expanded from [239].

	CTEQ6.6, CT10	MSTW08	NNPDF2.1, 2.3	ABKM09, ABM11	HERAPDF1.0, 1.5	GJR08, JR09
HERA DIS	+	+	+	+	+	+
Fixed target DIS	+	+	+	+	−	+
Fixed target Drell–Yan	+	+	+	+	−	+
Tevatron jets	+	+	+	+ (NLO ABM11)	−	+ (GJR08)
Tevatron W, Z	+	+	+	−	−	−
LHC	−	−	+ (2.3: see section 4.3.3)	−	−	−
GM-VFNS	+ (ACOT)	+ (Thorne–Roberts)	+ (FONLL)	− (FFNS)	+ (Thorne–Roberts)	− (FFNS)
Q_0^2 (GeV^2)	1.69	1	2	9	1.9	0.5
$\alpha_s(M_Z)$	Fixed	Fitted	Fixed	Fitted	Fixed	Fitted
PDF parameters	26	28	259 (NNs)	24	10 (for 1.0) 14 (for 1.5)	20
Strangeness	$s = \bar{s}$	Some flexibility	Maximal flexibility	$s = \bar{s}$	Assumptions (inc. $s = \bar{s}$)	$s = \bar{s}$
Errors	Hessian	Hessian	Monte Carlo	Hessian	Hessian	Hessian
Tolerance T ($\Delta\chi^2 = T^2$)	∼6.1	Dynamical from ∼1 to ∼6	$*$	1	1	∼4.7
NNLO	−	+	+	+	+ (1.5, preliminary)	+ (JR09)

HERAPDF 2.0

HERAPDF1.0 & 1.5
Combine NC and CC HERA-I data from H1 & ZEUS
Complete MSbar NLO fit
NLO: standard parameterisation with10 parameters
NNLO HERAPDF 1.5 with 14p

HERAPDF2.0
Include additional NC and CC HERA-II combined data
Complete MSbar NLO and NNLO fit
NLO & NNLO fits require15 parameters

H1-14-042 / ZEUS-prel-14-007

$$xf(x,Q_0^2) = A \cdot x^B \cdot (1-x)^C \cdot (1 + Dx + Ex^2)$$

$$\begin{array}{ll} xg & xg \\ xu_v & xU = xu + xc \\ xd_v & xD = xd + xs \\ x\bar{U} & x\bar{U} = x\bar{u} + x\bar{c} \\ x\bar{D} & x\bar{D} = x\bar{d} + x\bar{s} \end{array} \longrightarrow$$

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

HERAPDF1.0 & NLO HERAPDF1.5

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

HERAPDF2.0

$x\bar{s} = f_s x\bar{D}$ strange sea is a fixed fraction f_s of $\bar{D}$ at Q_0^2

Apply momentum/counting sum rules:

$$\int_0^1 dx \cdot (xu_v + xd_v + x\bar{U} + x\bar{D} + xg) = 1$$

$$\int_0^1 dx \cdot u_v = 2 \qquad \int_0^1 dx \cdot d_v = 1$$

$B_{\bar{U}} = B_{\bar{D}}$

$Sea = 2(\bar{U} + \bar{D})$

$A_{\bar{U}} = A_{\bar{D}}(1 - f_s)$

ensures $x\bar{u} \to x\bar{d}$ as $x \to 0$

$B_{u_v} = B_{d_v}$ constraint removed since HERAPDF1.5

$Q_0^2 = 1.9$

$Q^2_{\min} = 3.5$ or $10\ GeV^2$

$\alpha_s(M_z^2) = 0.118$

$2 \cdot 10^{-4} \leq x \leq 0.65$

HERAPDF 2.0

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

⬜ fixed or constrained by sum-rules

🟦 parameters set equal but free

NC structure functions

$$F_2 = \frac{4}{9}\left(xU + x\bar{U}\right) + \frac{1}{9}\left(xD + x\bar{D}\right)$$

$$xF_3 \sim xu_v + xd_v$$

CC structure functions

$$W_2^- = x(U + \overline{D})\,, \qquad W_2^+ = x(\overline{U} + D)$$

$$xW_3^- = x(U - \overline{D})\,, \qquad xW_3^+ = x(D - \overline{U})$$

Additional parameters:
heavy quark masses M_c and M_b are optimised
f_s = 0.4 ⇒ compromise value between unsuppressed (f_s = 0.5) and 'default' strange sea from dimuon data

$$\chi^2_{tot}(\mathbf{m},\mathbf{b}) = \sum_i \frac{[\mu^i - m^i(1-\sum_j \gamma^i_j b_j)]^2}{\delta^2_{i,stat}\mu^i m^i(1-\sum_j \gamma^i_j b_j) + (\delta_{i,unc}m^i)^2} + \sum_j b_j^2 + \sum_i \ln\frac{\delta^2_{i,unc}m_i^2 + \delta^2_{i,stat}\mu^i m^i}{\delta^2_{i,unc}\mu_i^2 + \delta^2_{i,stat}\mu_i^2}$$

modified χ^2 definition includes ln term to account for likelihood transition to χ^2 after error scaling

HERAPDF 2.0 Uncertainties

Uncertainties of three types considered
- experimental
- model
- parametrisation

Experimental sources:

Hessian method used

Better control of systematics and correlations

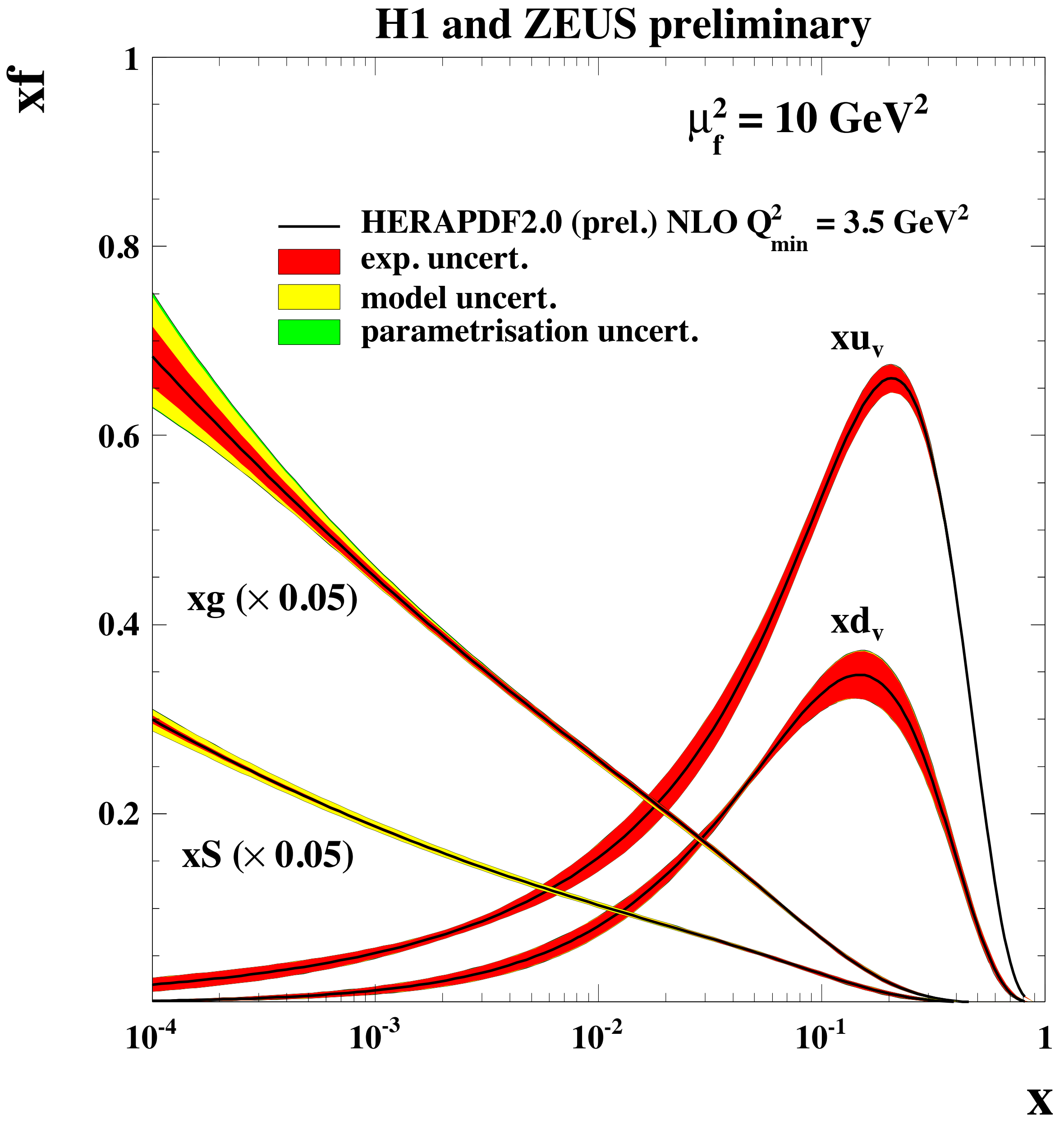
Use traditional error definition $\Delta\chi^2 = 1$ to define error bands

Model Uncertainties:

We consider variations of all assumed input parameters in the fit

Deviations from central value fit quadratically summed

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 Uncertainty:

Take envelope of variations which include

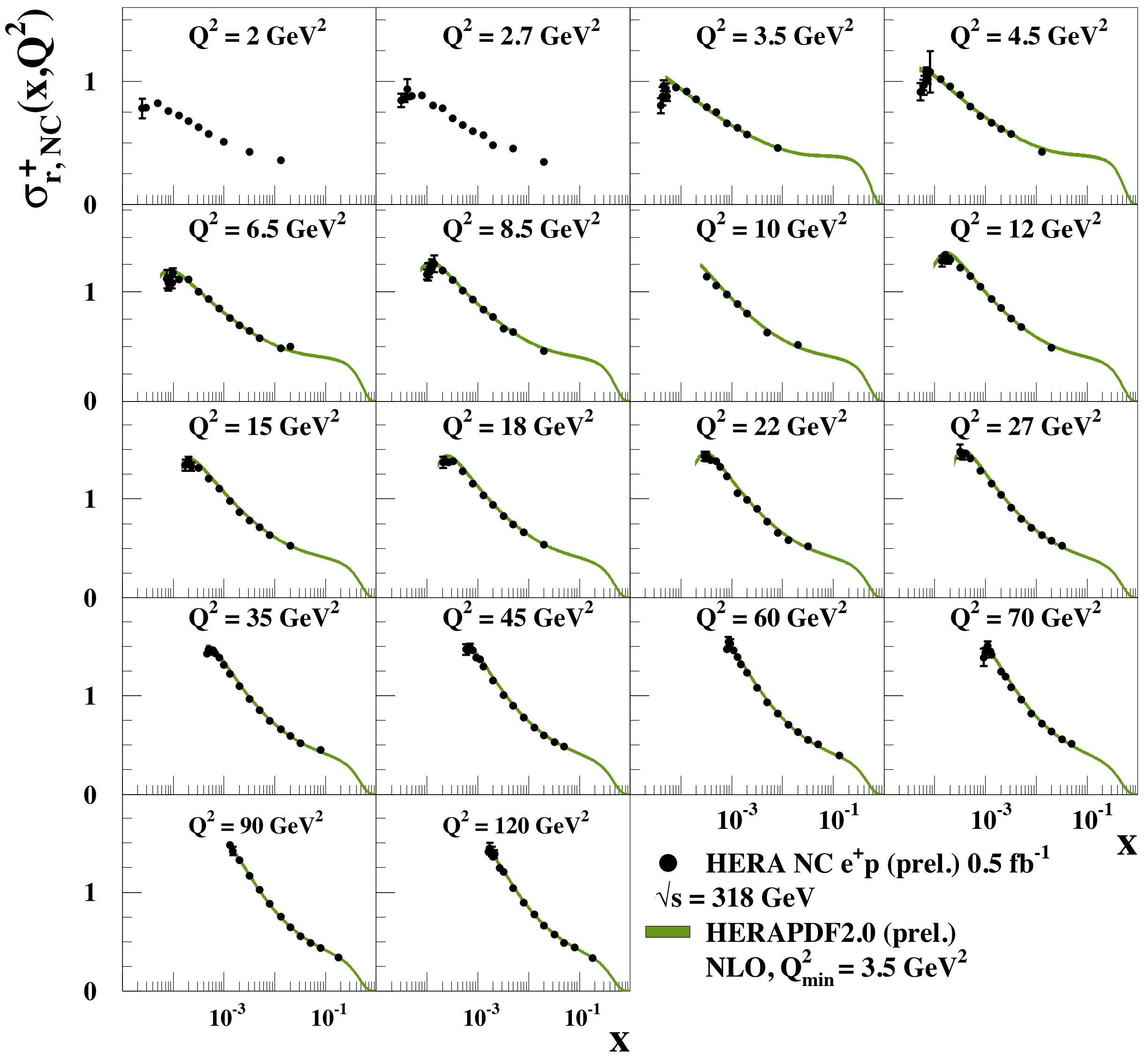
variation of the arbitrary starting scale Q_0^2

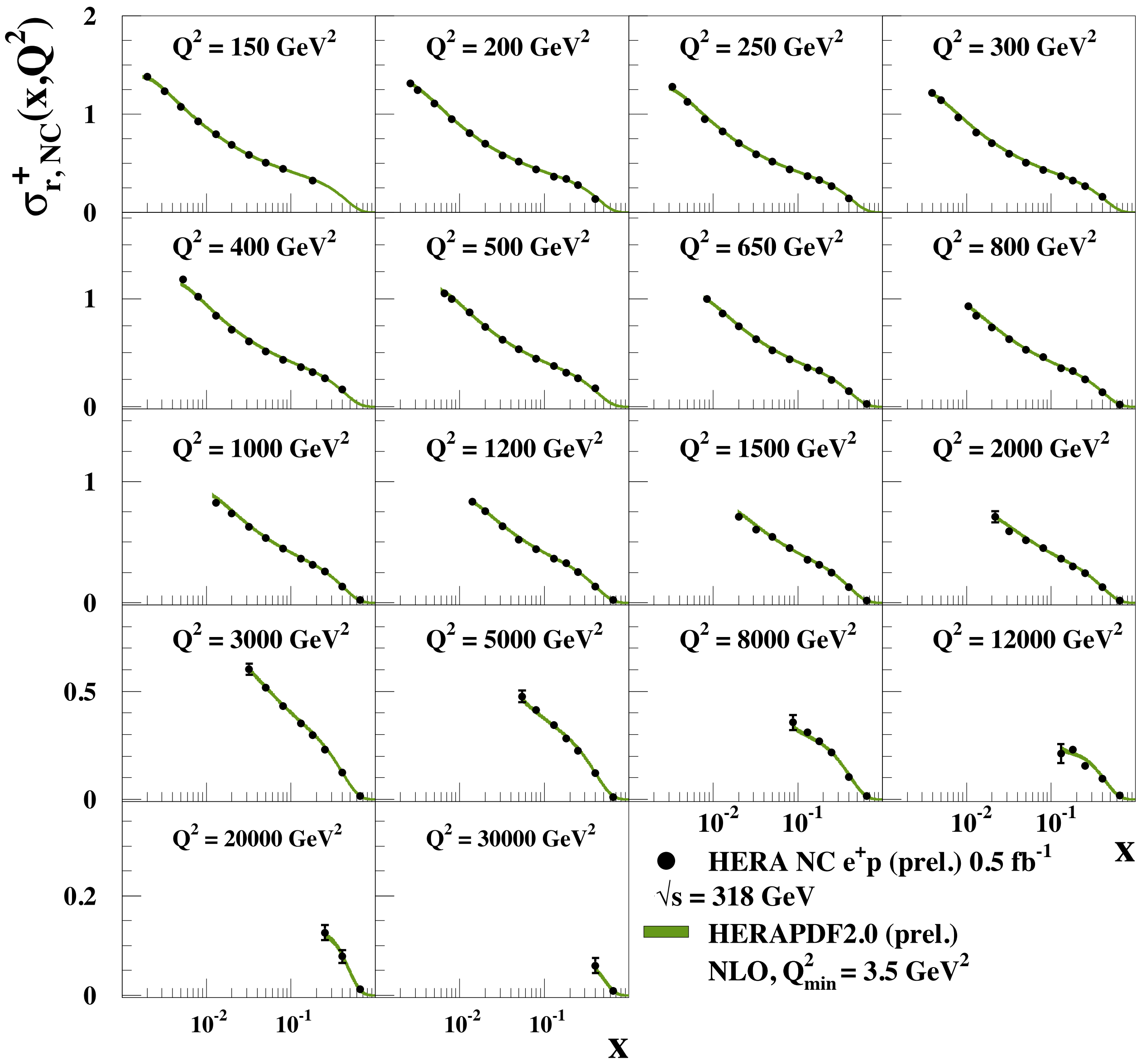
all additional 16p fits with non-zero D or E parameters

Only significant effect is from Q_0^2 variation

HERAPDF 2.0

NC e^+p reduced cross section

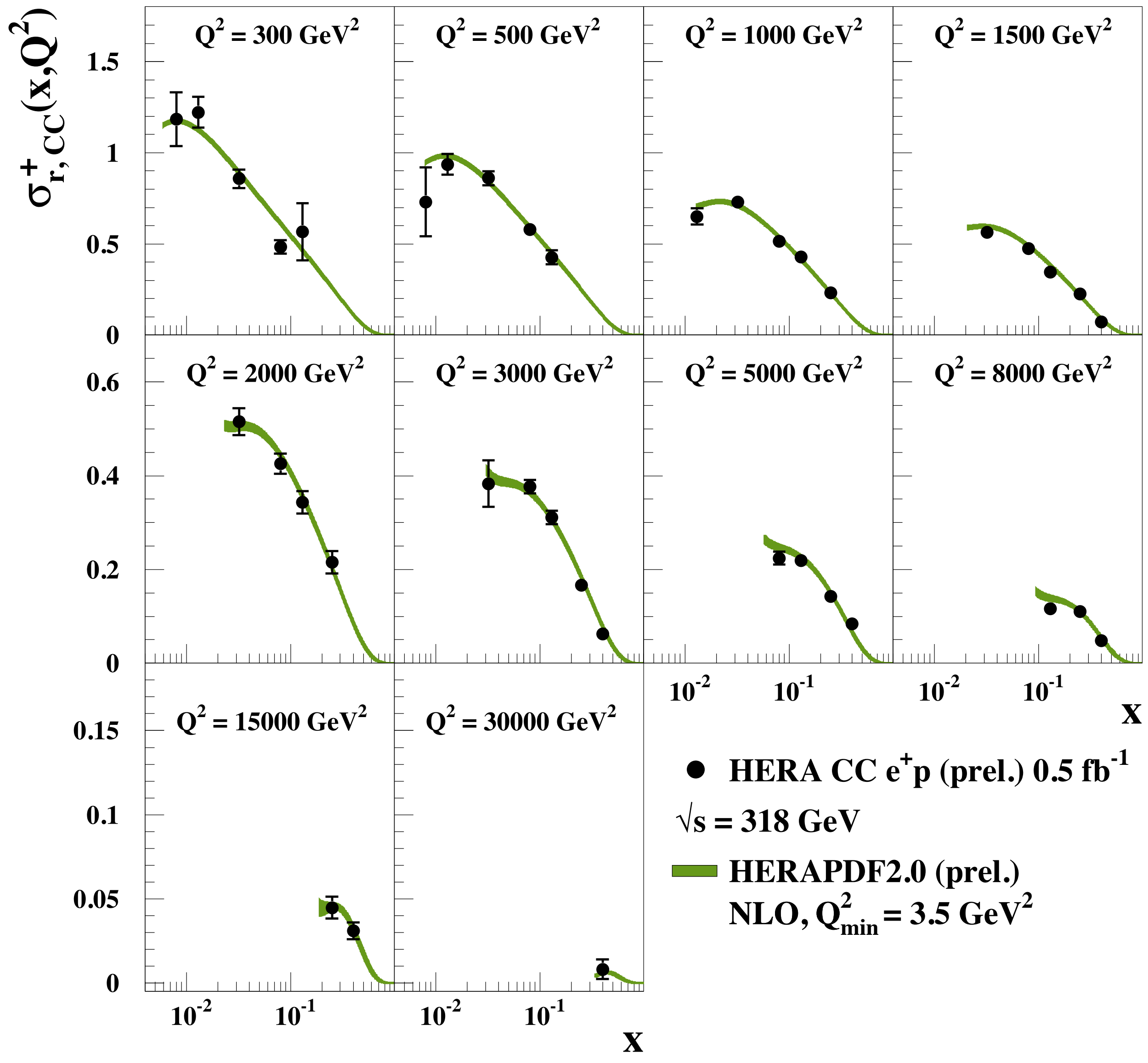

$3.5 \leq Q^2 \leq 120$ GeV^2


$150 \leq Q^2 \leq 30000$ GeV^2

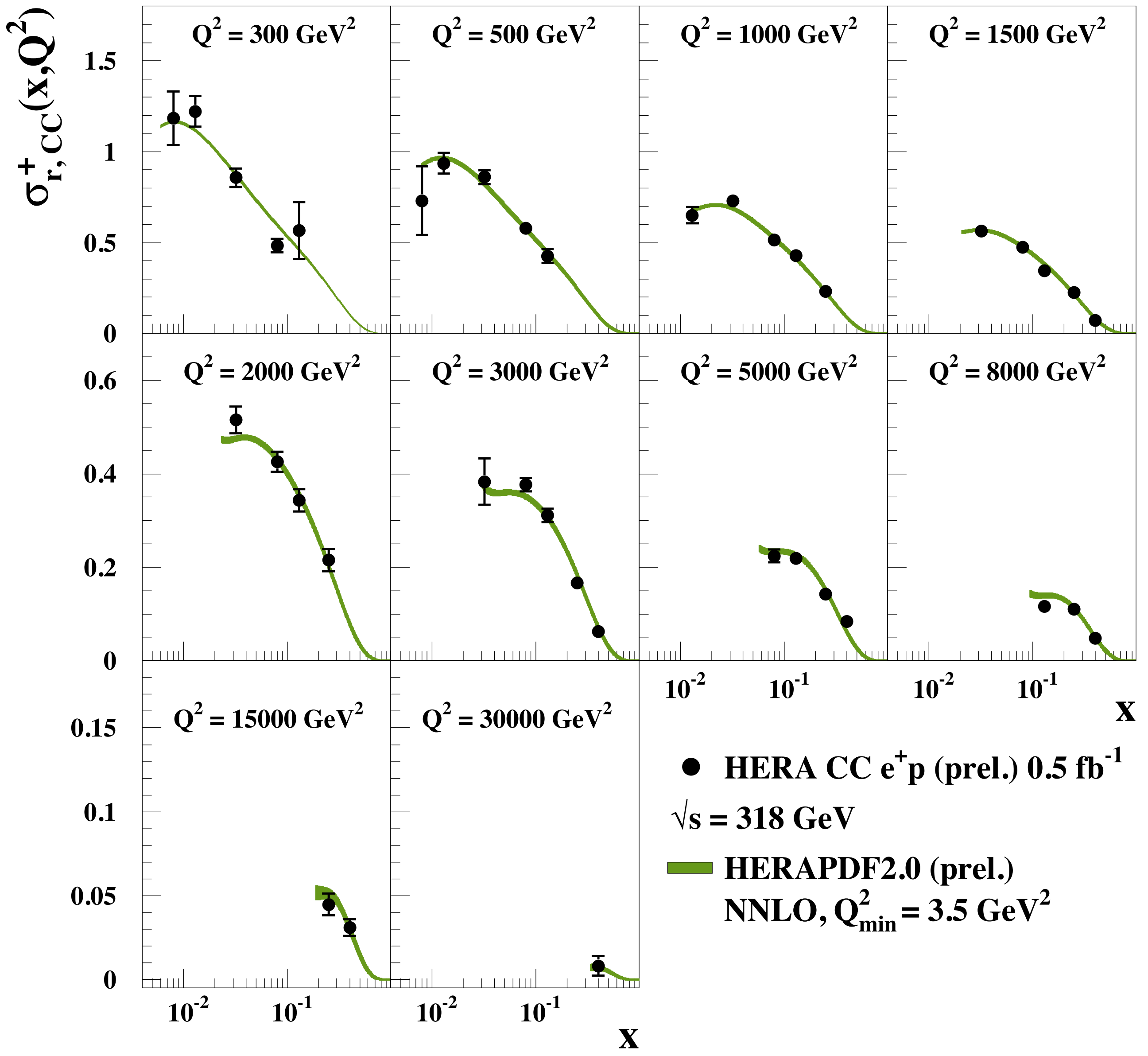
Good description of the data over ~full Q^2 range
Shown here for NLO
Similar for NNLO

CC e^+p reduced cross section

$300 \leq Q^2 \leq 30000$ GeV^2

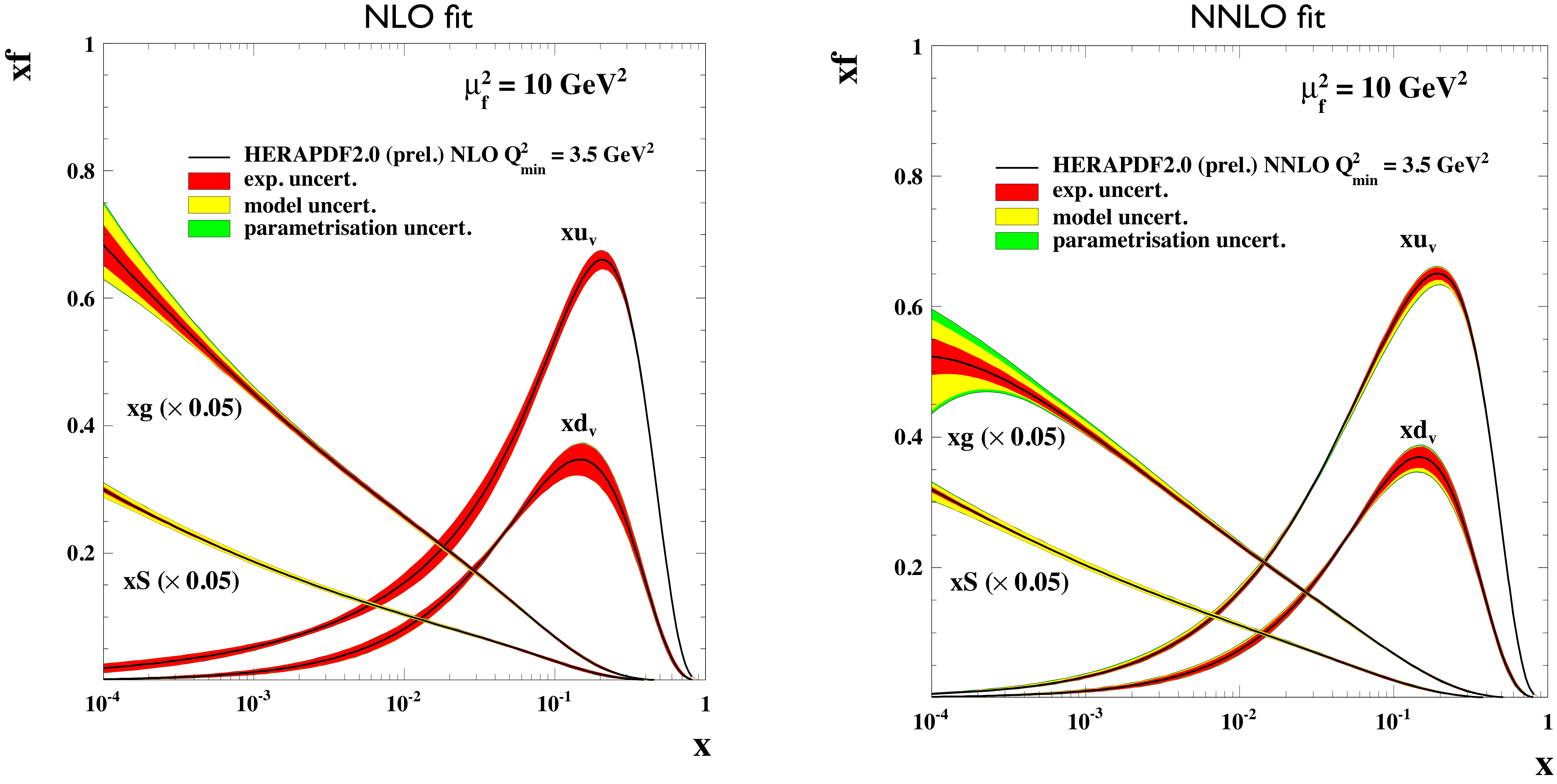


$150 \leq Q^2 \leq 30000$ GeV^2



Good description of the CC data over full Q^2 range
Shown here for NLO & NNLO
Similar for e^-p data

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

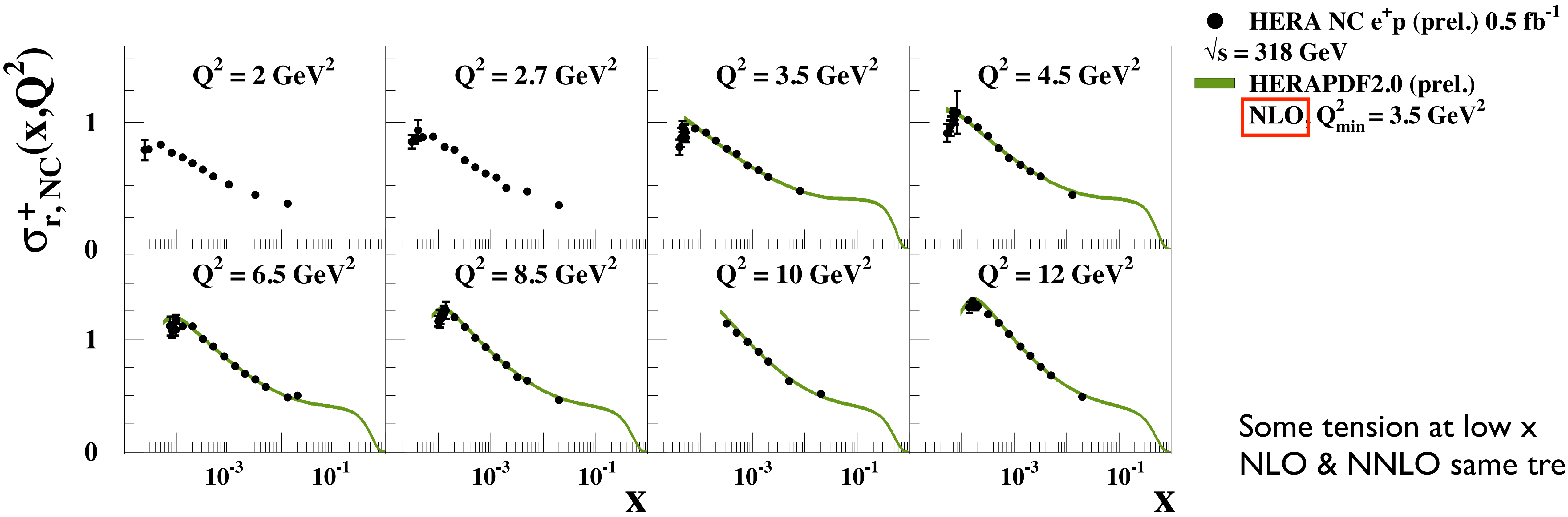


χ^2/ndf = 1385/1130

χ^2/ndf = 1414/1130

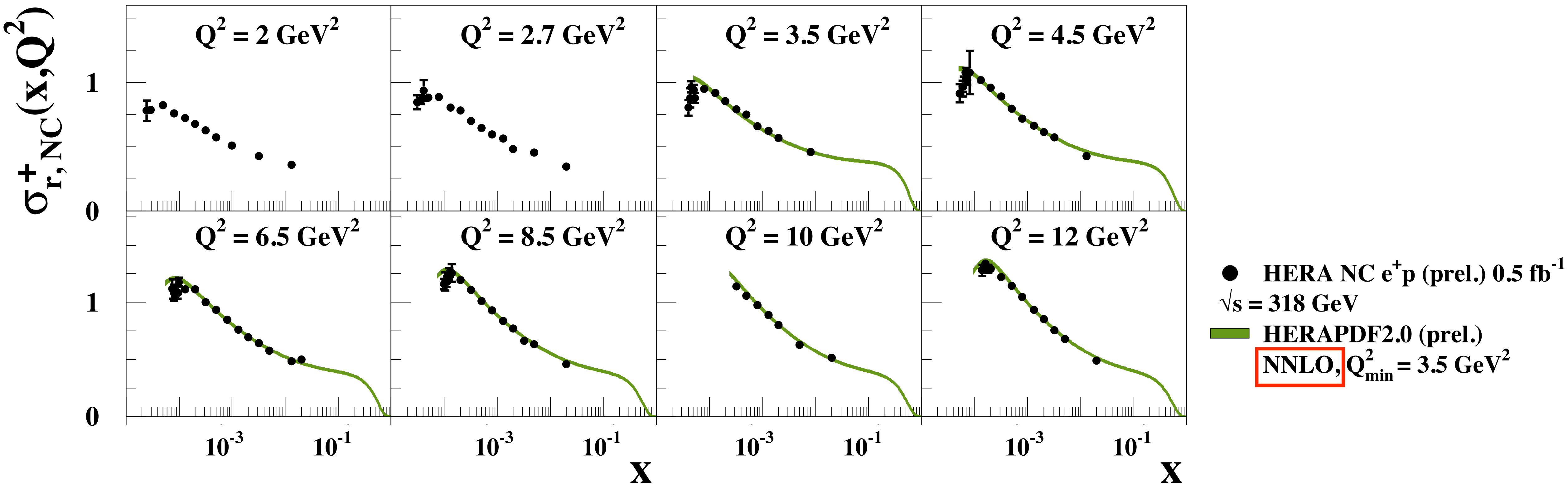
NLO & NNLO fits similar
Largest differences in xg and xS at low x

HERAPDF 2.0: LOW X / Q^2

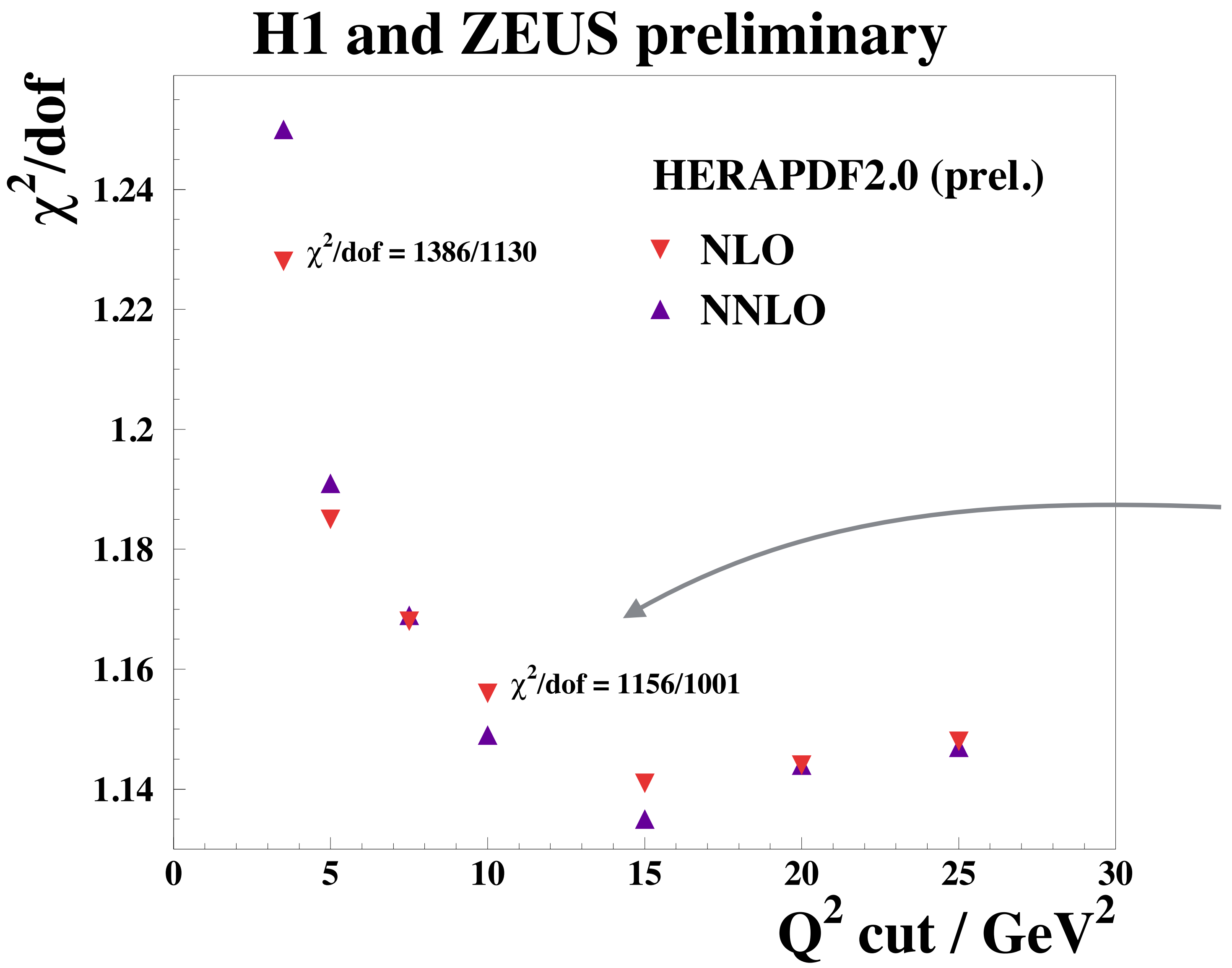


Some tension at low x

NLO & NNLO same trends



HERAPDF 2.0: LOW x / Q^2



Adjust minimum Q^2 cut on data entering fit
Already included in uncertainty
Look at larger range and effect on χ^2/ndf

For Q^2_{min} = 3.5 GeV^2
χ^2/ndf = 1385 / 1130 at NLO
χ^2/ndf = 1414 / 1130 at NNLO

For Q^2_{min} = 10 GeV^2
χ^2/ndf = 1156 / 1001 at NLO
χ^2/ndf = 1150 / 1001 at NNLO

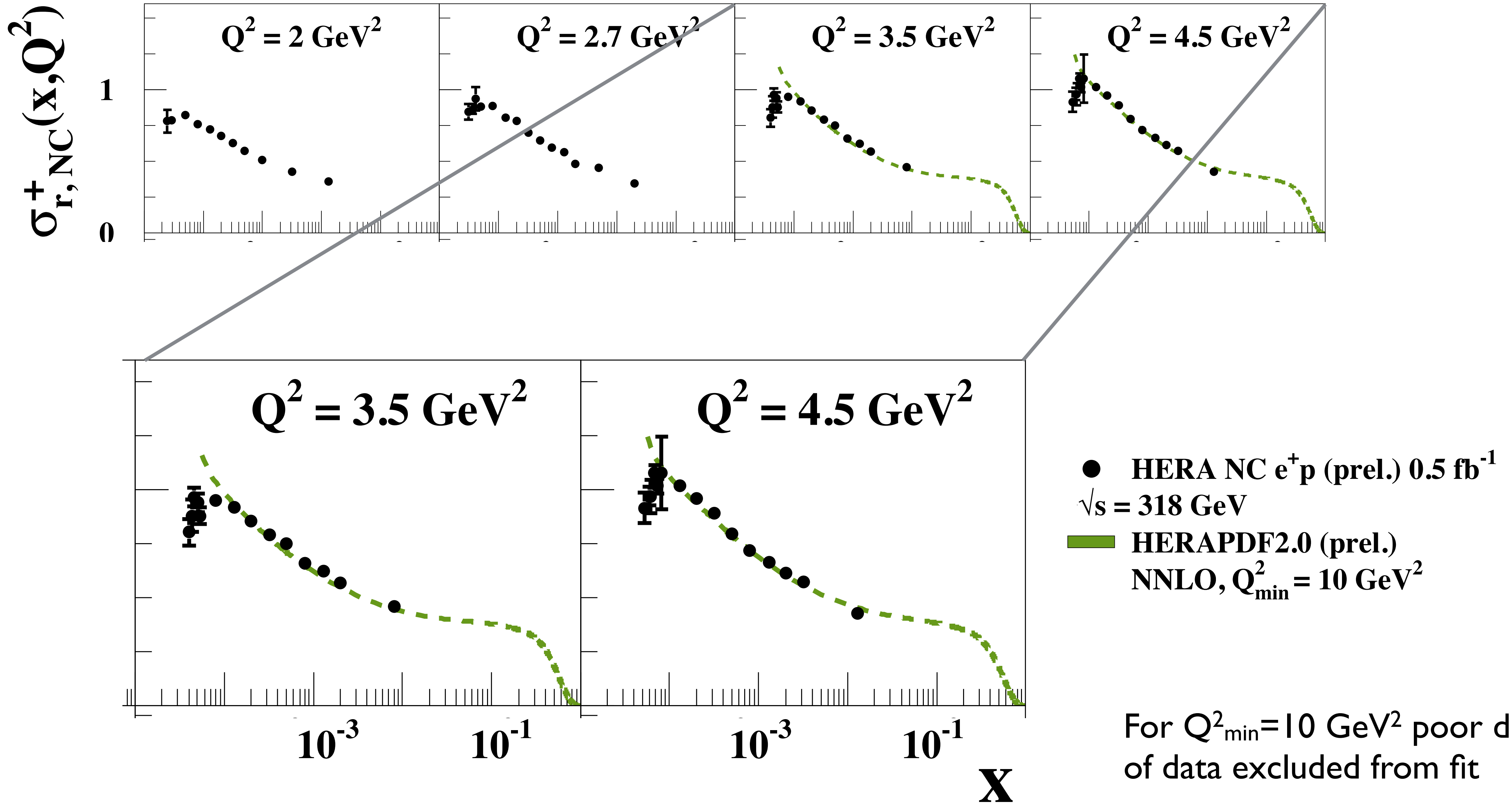
χ^2 appears to saturate for Q^2_{min} = 10 GeV^2

Similar behaviour observed for HERA-I combination
Not so clear due to lower high Q^2 precision

For HERA-I Q^2_{min} = 3.5 GeV^2
χ^2/ndf = 637 / 656 at NLO

Alternative χ^2 definitions show same behaviour
Alternative cuts in x, y, Q^2_{max} have much smaller effect

HERAPDF 2.0: LOW x / Q^2



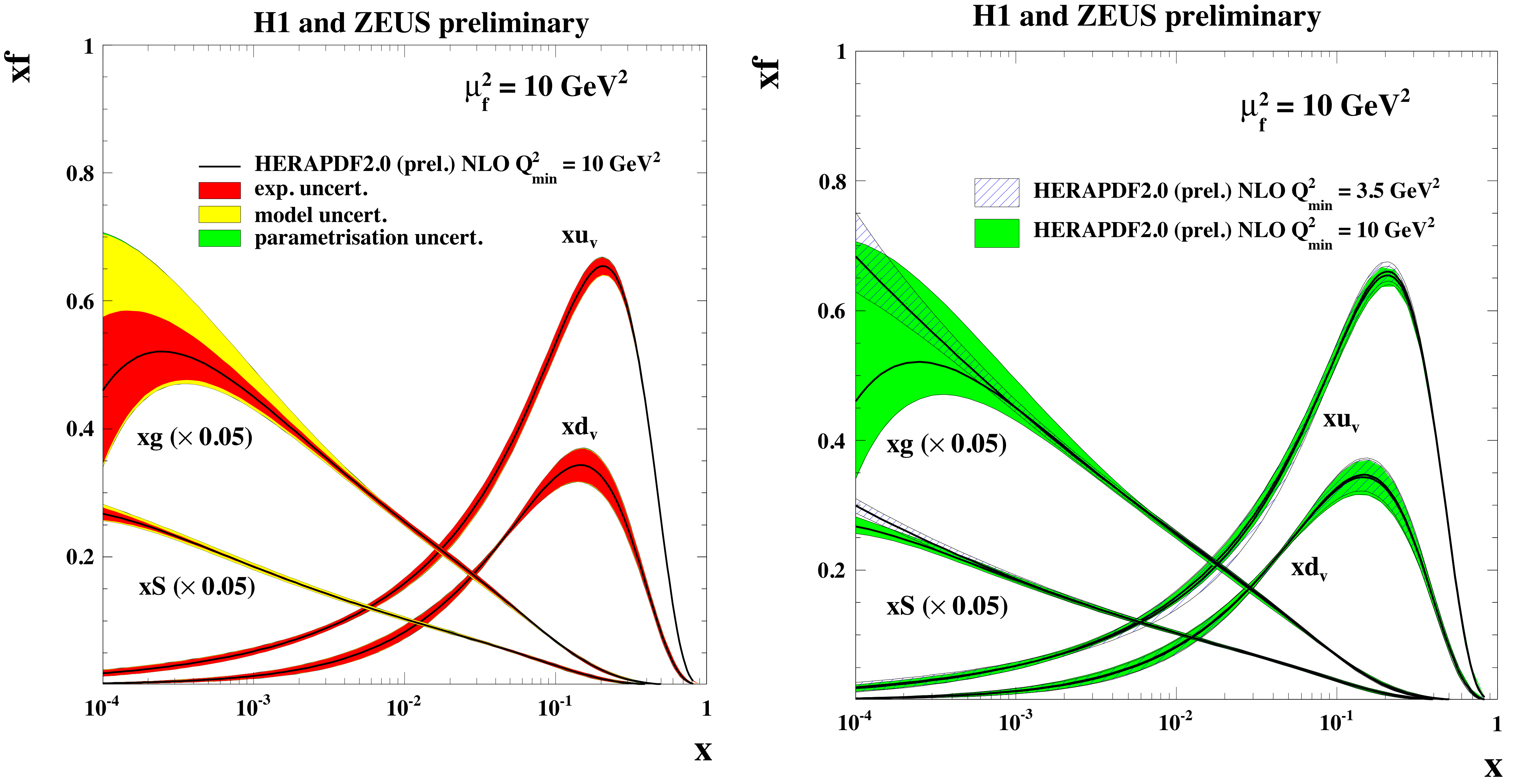
For Q^2_{min}=10 GeV^2 poor description of data excluded from fit

Extrapolated fit systematically higher than data at low x / low Q^2

Similar for NLO fit

HERAPDF 2.0: LOW x / Q^2

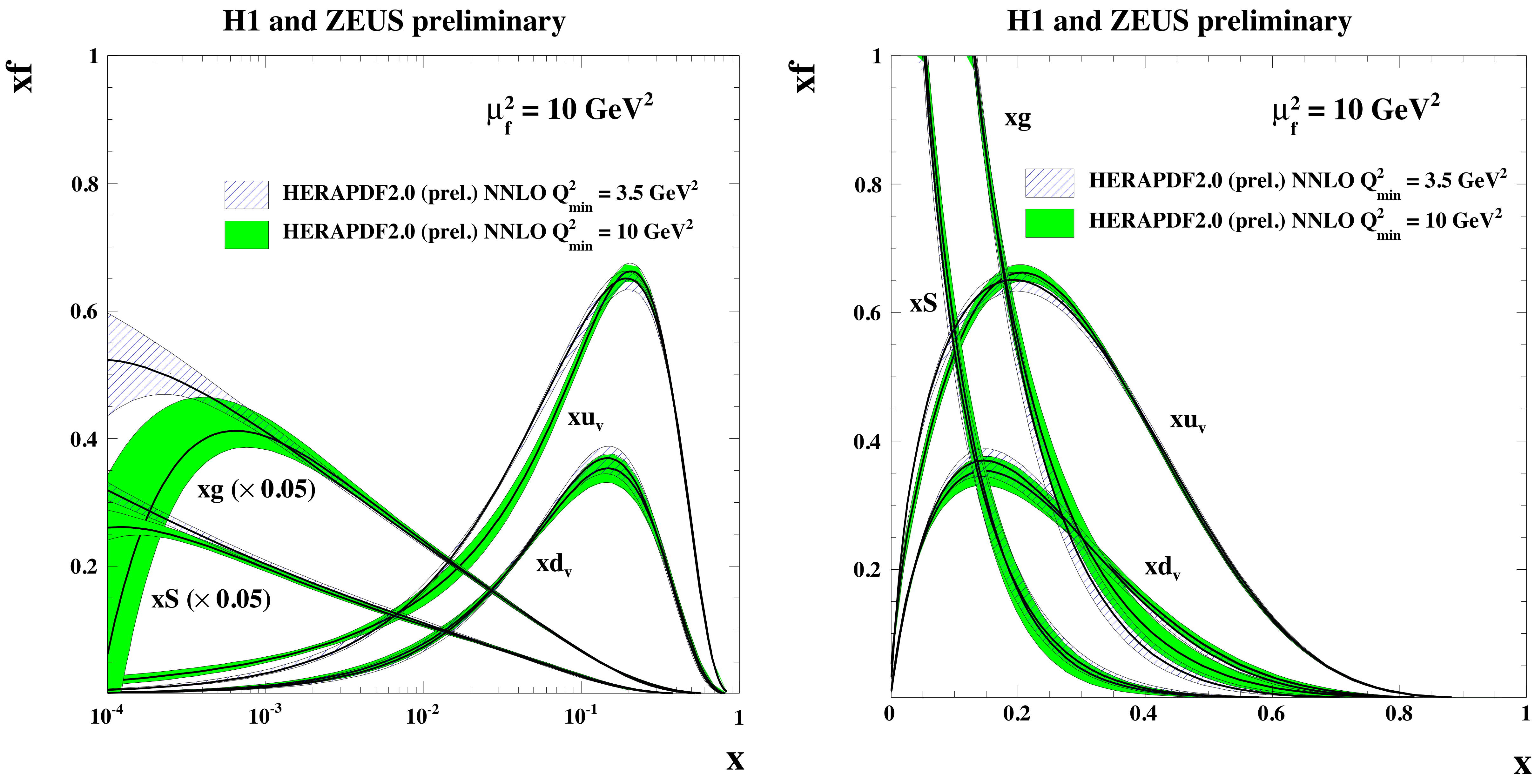
Compare PDFs at NLO with Q^2_{min}=3.5 and 10 GeV^2



PDF central values in good agreement for x>10^{-3}
Higher Q^2_{min} cut increase low x gluon uncertainty as expected
Large model uncertainty arising from Q^2_{min} cut variation

HERAPDF 2.0: LOW x / Q^2

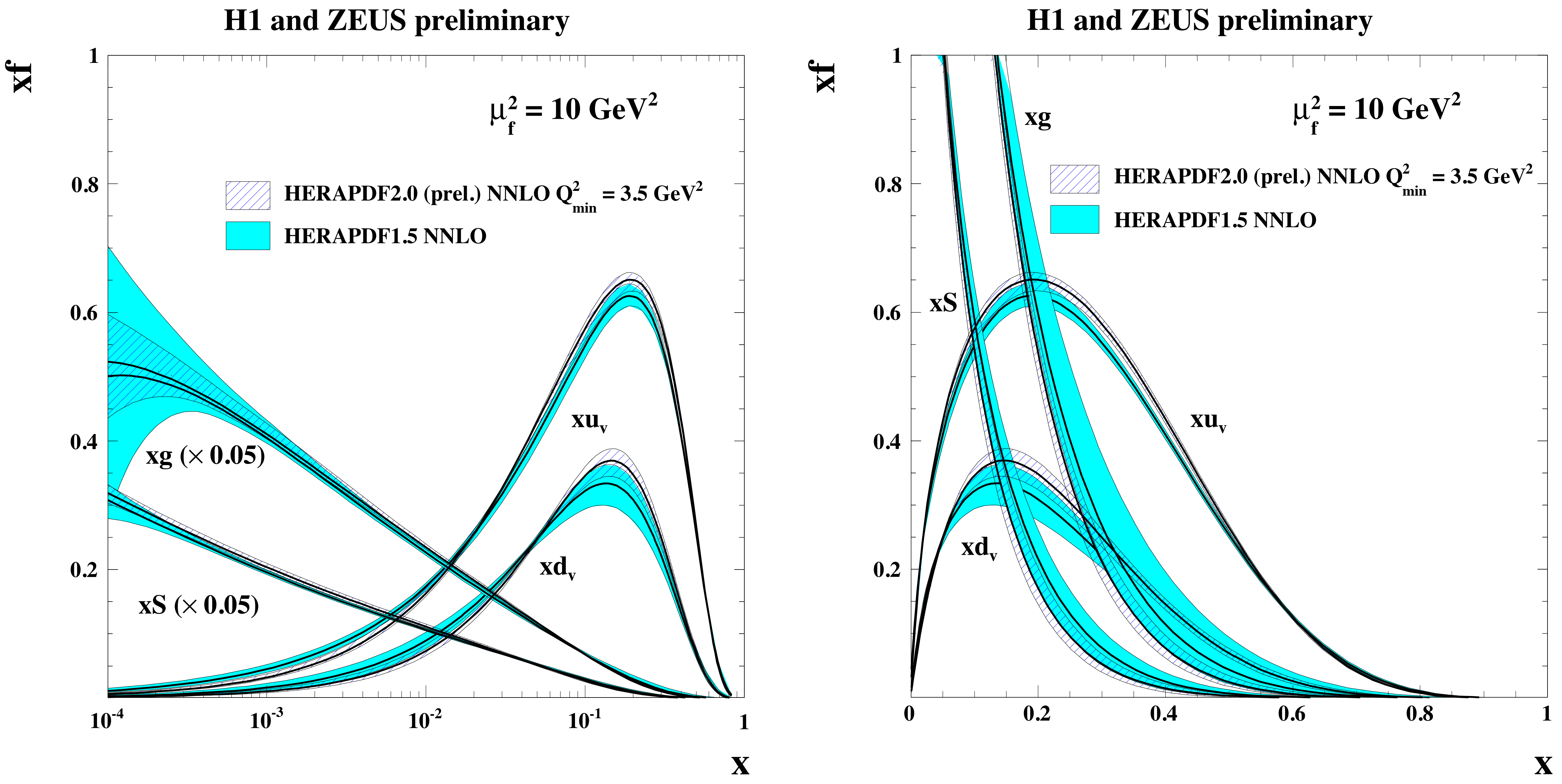
Compare PDFs at NNLO with Q^2_{min}=3.5 and 10 GeV^2



Similar story at NNLO:
PDF central values in good agreement for $x > 10^{-3}$
Higher Q^2_{min} cut increase low x gluon uncertainty as expected
Large model uncertainty arising from Q^2_{min} cut variation

HERAPDF 1.5 vs 2.0

Compare HERAPDF1.5 and HERAPDF2.0 at NNLO



At high x gluon and sea uncertainties reduced
gluon & sea distributions become softer in HERAPDF2.0
Uncertainties on valence distributions are reduced

HERA Legacy

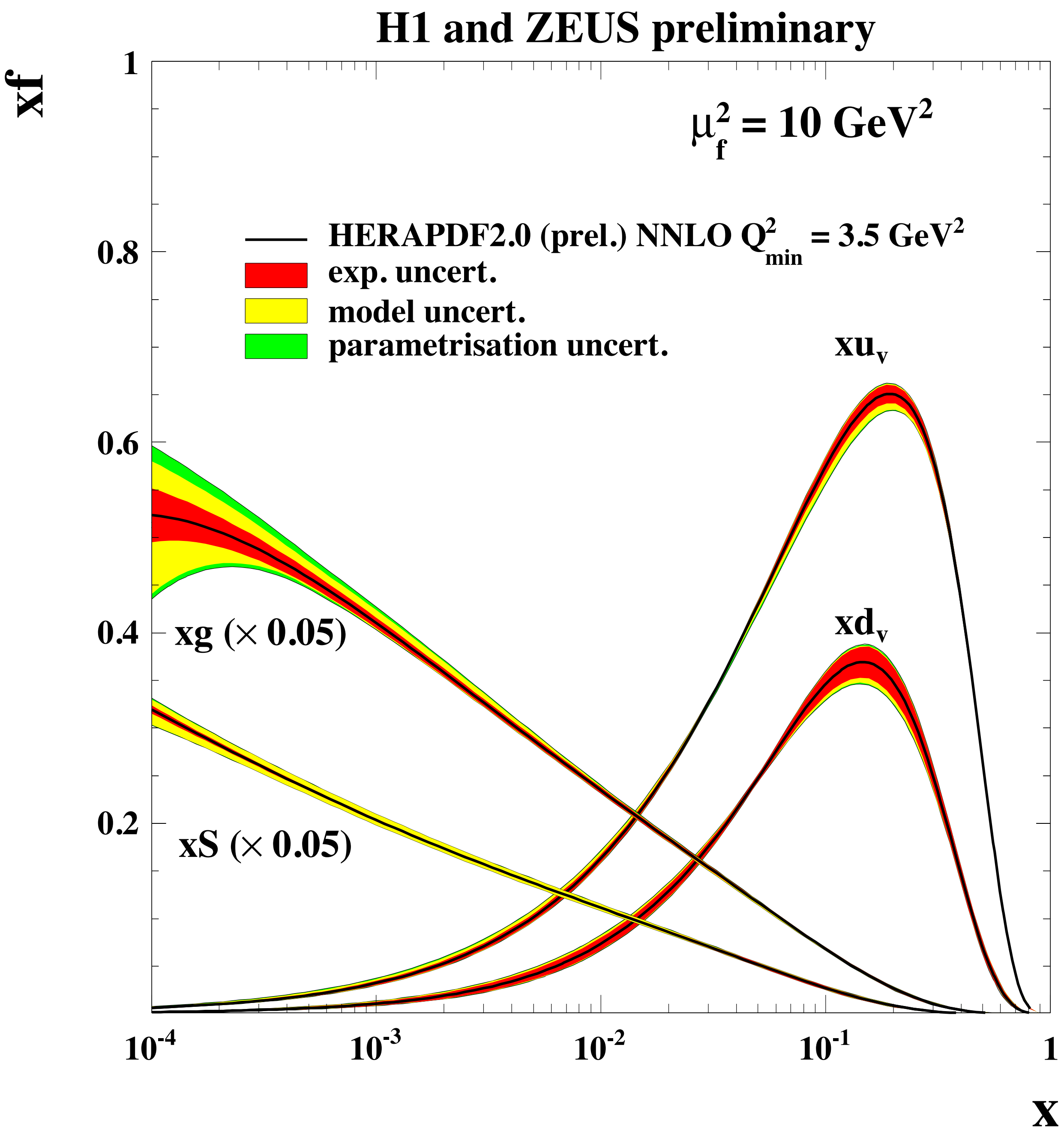
HERA data provided detailed insight into parton dynamics

Helped experimentally establish NNLO pQCD

Underpins all LHC measurements

Precise determination of PDFs (specially gluon)
⇒ accurate predictions of LHC Higgs production

Plan:
publish the combined inclusive data & HERAPDF2.0



Backup

H1 & ZEUS Data Combination