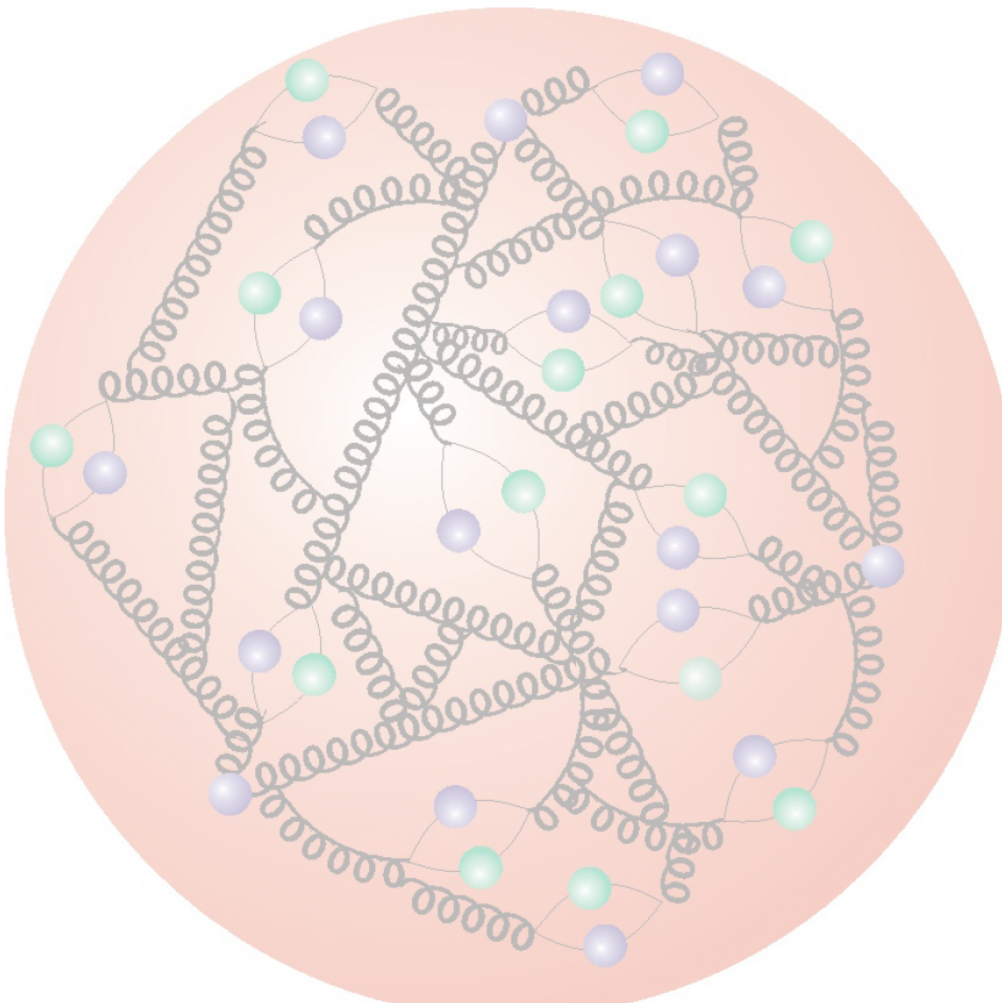
New DIS & Collider Results



- Introduction
- HERA-II Updates
- H1 NC/CC $e^{\pm}p$
- ZEUS NC $e^{+}p$
- HERAPDF Plans
- LHC Constraints

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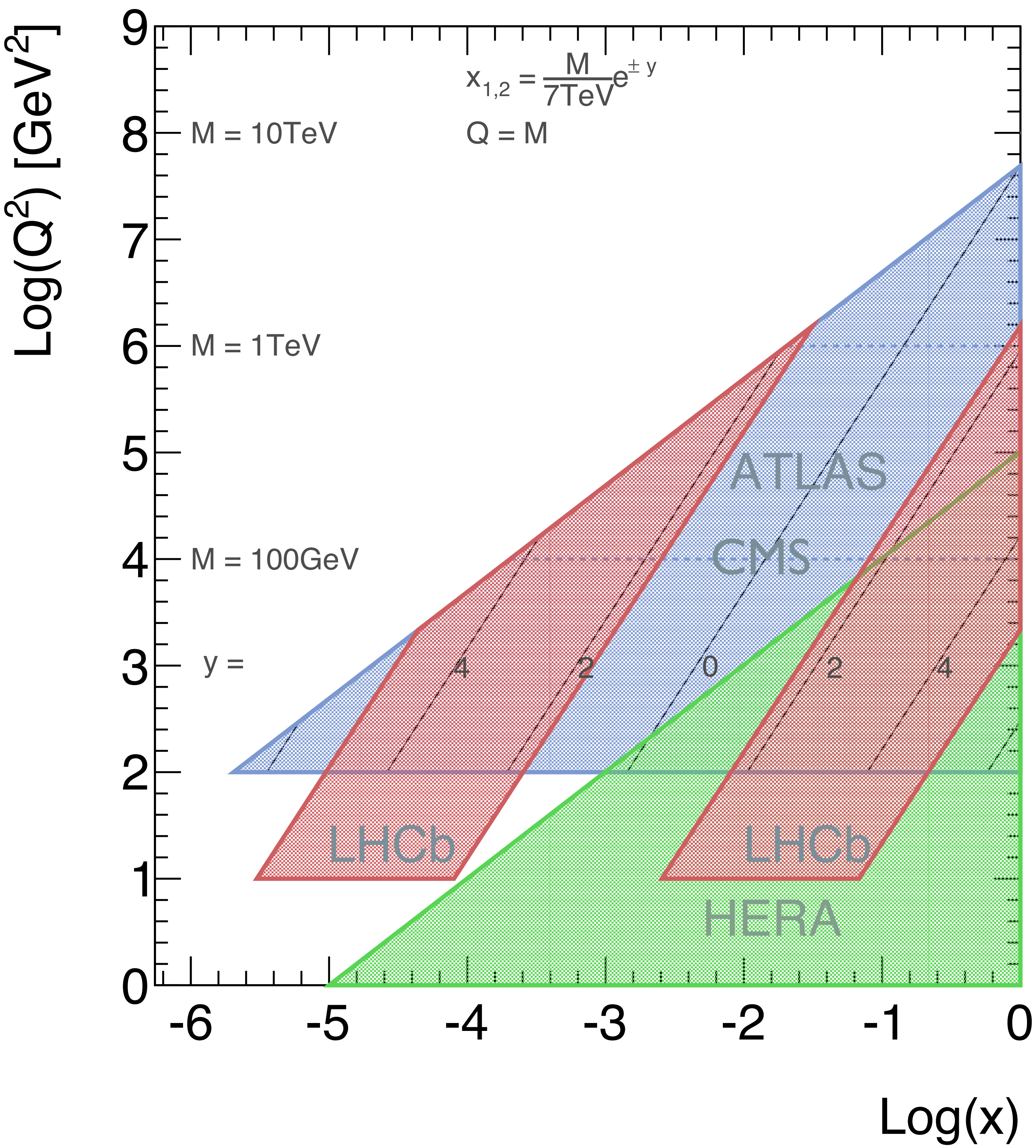
International Workshop on Neutrino-Nucleus Interactions

Rio de Janeiro – 23rd Oct. 2012

The New Kinematic Plane



Final H1 & ZEUS structure function data published

New LHC data being rapidly published

Searches for high mass states require precision knowledge at high x

For central production $x=x_1=x_2$

$M=x^2\sqrt{s}$

→ M > 1 TeV probes x>0.1

DGLAP evolution allows predictions to be made

High x predictions rely on

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

Low x region important for high energy cosmic rays

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 $Q^2 \sim M_Z^2$

$$\tilde{F}_L \propto \alpha_s \cdot xg(x,Q^2)$$ Only sensitive at low Q^2 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:

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

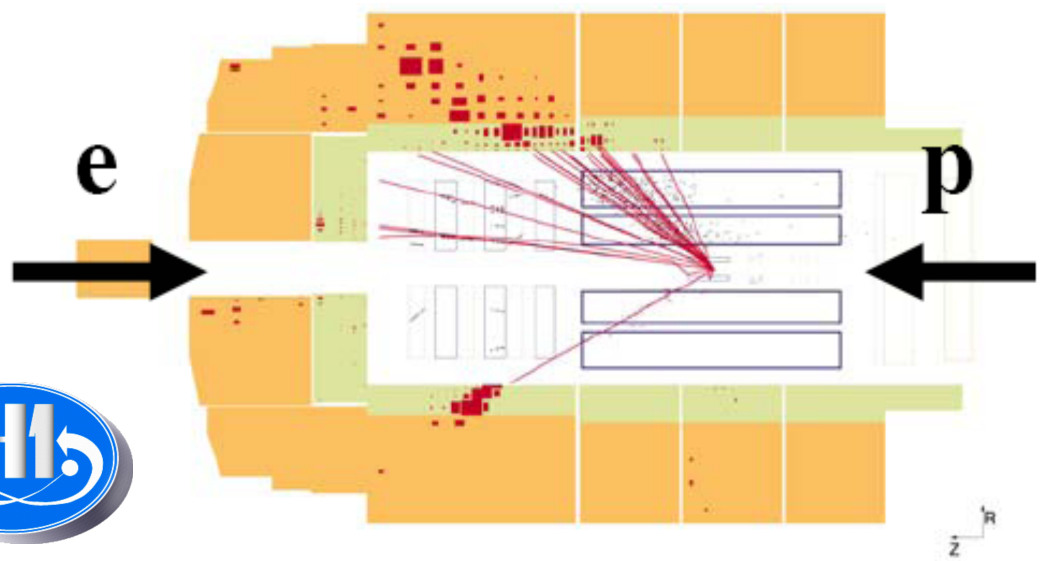
$$\tilde{\sigma}^{\pm}_{NC} \sim \tilde{F}_2 \mp \frac{Y_-}{Y_+} x\tilde{F}_3$$

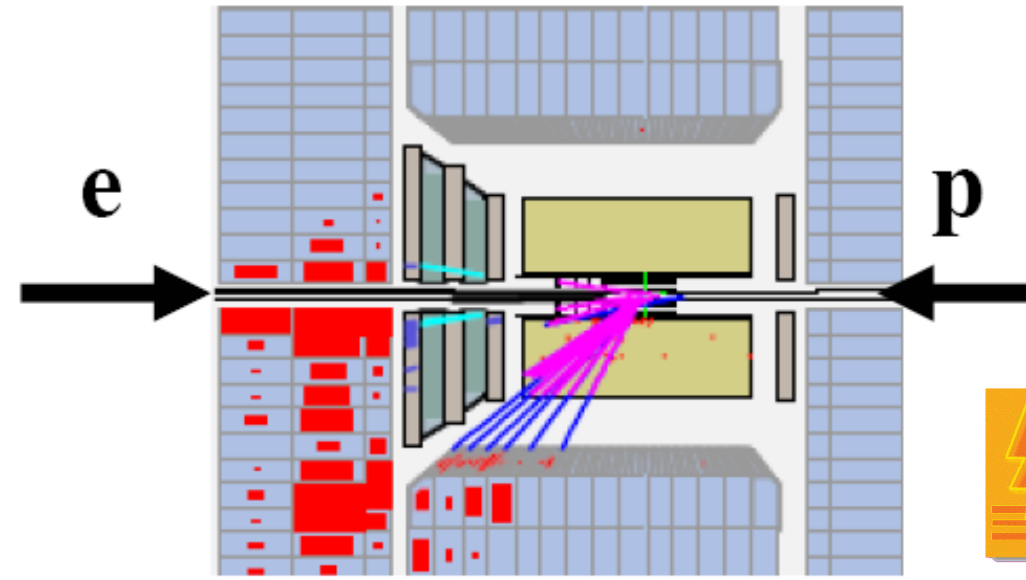
The CC reduced cross section defined as:

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

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

H1 and ZEUS





Neutral current event selection:

High P_T isolated scattered lepton
Suppress huge photo-production background by imposing longitudinal energy-momentum conservation

Kinematics may be reconstructed in many ways: energy/angle of hadrons & scattered lepton provides excellent tools for sys cross checks

Removal of scattered lepton provides a high stats "pseudo-charged current sample"
Excellent tool to cross check CC analysis

Final selection: $\sim 10^5$ events per sample at high Q^2
$\sim 10^7$ events for $10 < Q^2 < 100$ GeV^2

Charged current event selection:

Large missing transverse momentum (neutrino)

Suppress huge photo-production background

Topological finders to remove cosmic muons

Kinematics reconstructed from hadrons

Final selection: $\sim 10^3$ events per sample

HERA Operation

<u>HERA-I operation 1993-2000</u>

Ee = 27.6 GeV

Ep = 820 / 920 GeV

$\int\mathcal{L}$ ~ 110 pb^{-1} per experiment

<u>HERA-II operation 2003-2007</u>

Ee = 27.6 GeV

Ep = 920 GeV

$\int\mathcal{L}$ ~ 330 pb^{-1} per experiment

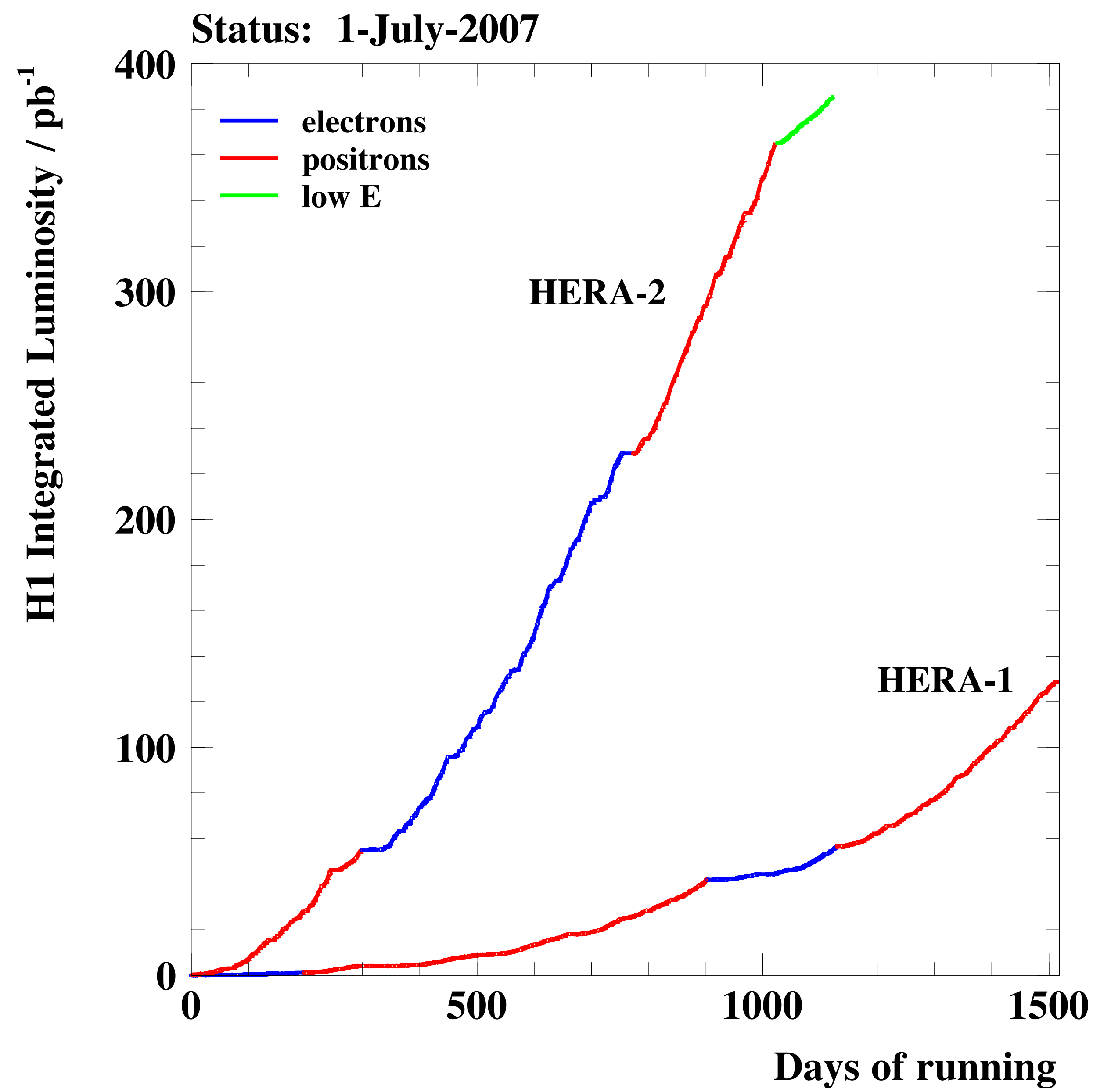
Longitudinally polarised leptons

<u>Low Energy Run 2007</u>

Ee = 27.6 GeV

Ep = 575 & 460 GeV

Dedicated F_L measurement



breakdown of HERA-II data samples

	R	L
e^-p	$\mathcal{L} = 47.3\,\mathrm{pb}^{-1}$ $P_e = (+36.0 \pm 1.0)\%$	$\mathcal{L} = 104.4\,\mathrm{pb}^{-1}$ $P_e = (-25.8 \pm 0.7)\%$
e^+p	$\mathcal{L} = 101.3\,\mathrm{pb}^{-1}$ $P_e = (+32.5 \pm 0.7)\%$	$\mathcal{L} = 80.7\,\mathrm{pb}^{-1}$ $P_e = (-37.0 \pm 0.7)\%$

HERA Structure Function Data

Up till now HERA-II datasets only partially published

ZEUS CC e^-p	175 pb^{-1}	EPJ C 61 (2009) 223-235
ZEUS CC e^+p	132 pb^{-1}	EPJ C 70 (2010) 945-963
ZEUS NC e^-p	170 pb^{-1}	EPJ C 62 (2009) 625-658
ZEUS NC e^+p	135 pb^{-1}	ZEUS-prel-11-003
H1 CC e^-p	149 pb^{-1}	H1prelim-09-043
H1 CC e^+p	180 pb^{-1}	H1prelim-09-043
H1 NC e^-p	149 pb^{-1}	H1prelim-09-042
H1 NC e^+p	180 pb^{-1}	H1prelim-09-042

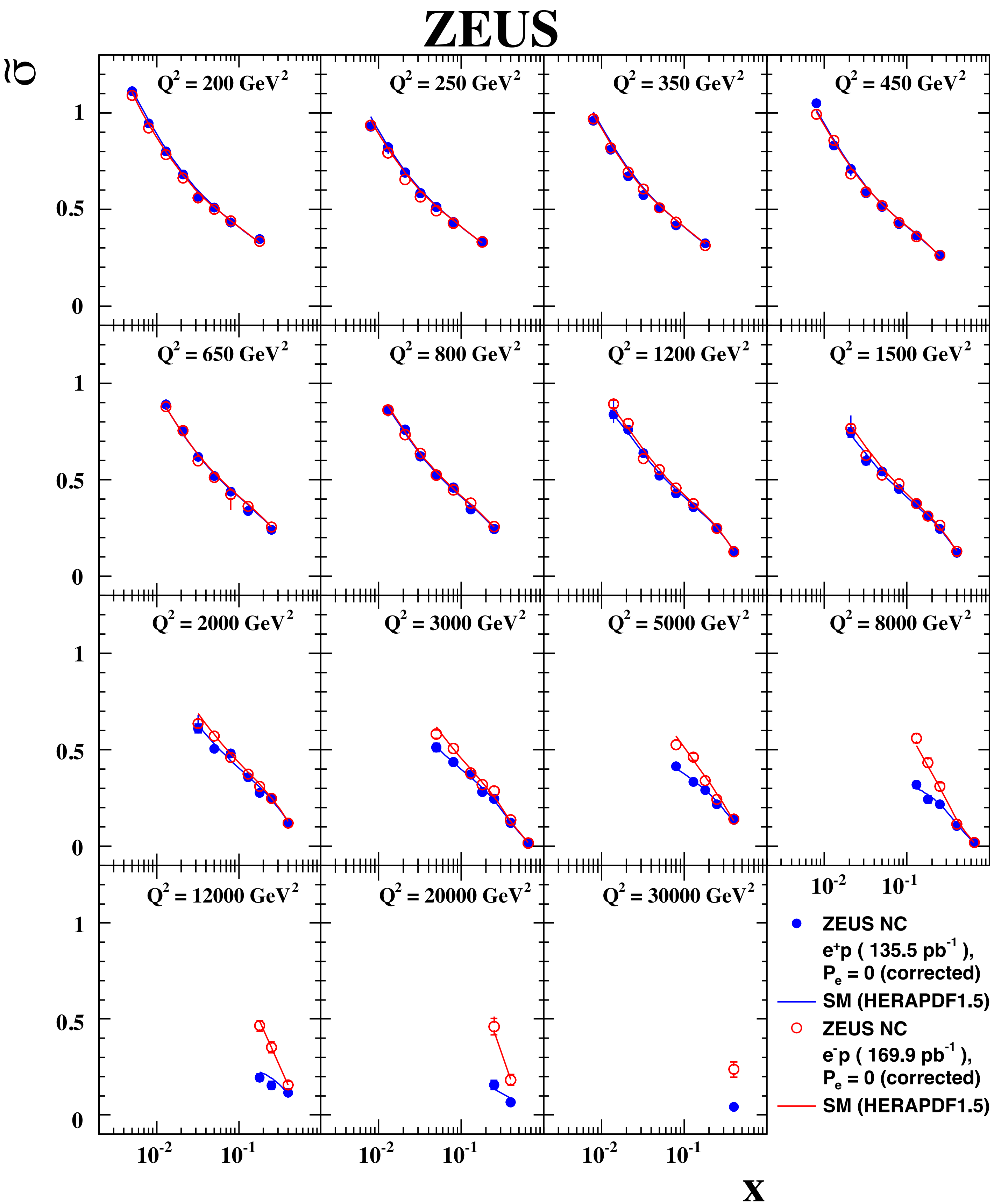
HERA-II datasets
Combined in HERAPDF1.5
(except ZEUS NC e^+p)

ZEUS CC e^-p	175 pb^{-1}	EPJ C 61 (2009) 223-235
ZEUS CC e^+p	132 pb^{-1}	EPJ C 70 (2010) 945-963
ZEUS NC e^-p	170 pb^{-1}	EPJ C 62 (2009) 625-658
ZEUS NC e^+p	135 pb^{-1}	**arXiv:1208.6138**
H1 CC e^-p	149 pb^{-1}	**arXiv:1206.7007**
H1 CC e^+p	180 pb^{-1}	
H1 NC e^-p	149 pb^{-1}	
H1 NC e^+p	180 pb^{-1}	

Complete the analyses of HERA high Q^2 inclusive structure function data

New published data increase $\int\mathcal{L}$ by
~ factor 3 for e^+p
~ factor 10 for e^-p
much improved systematic uncertainties

High Q^2 NC Cross Sections



Z^0 contribution enhances as Q^2 increases

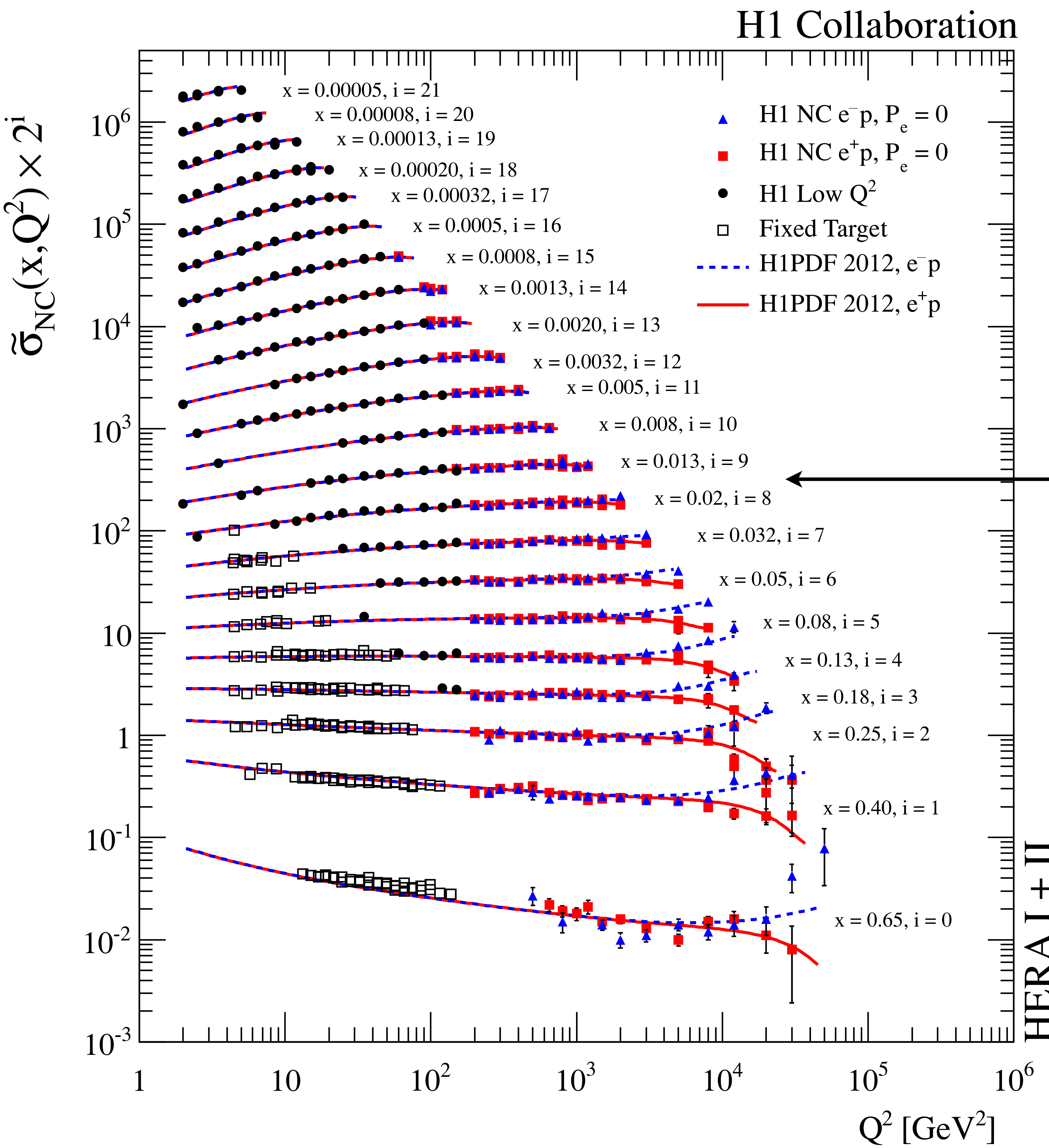
Final measurement of ZEUS NC e^+p data

Shown here for P=0

Polarised measurements also available

Compared to published NC e^-p data

High Q^2 NC Cross Sections



H1 precision 1.5% for $Q^2 < 500$ GeV²
⇒ factor 2 reduction in error wrt HERA-I

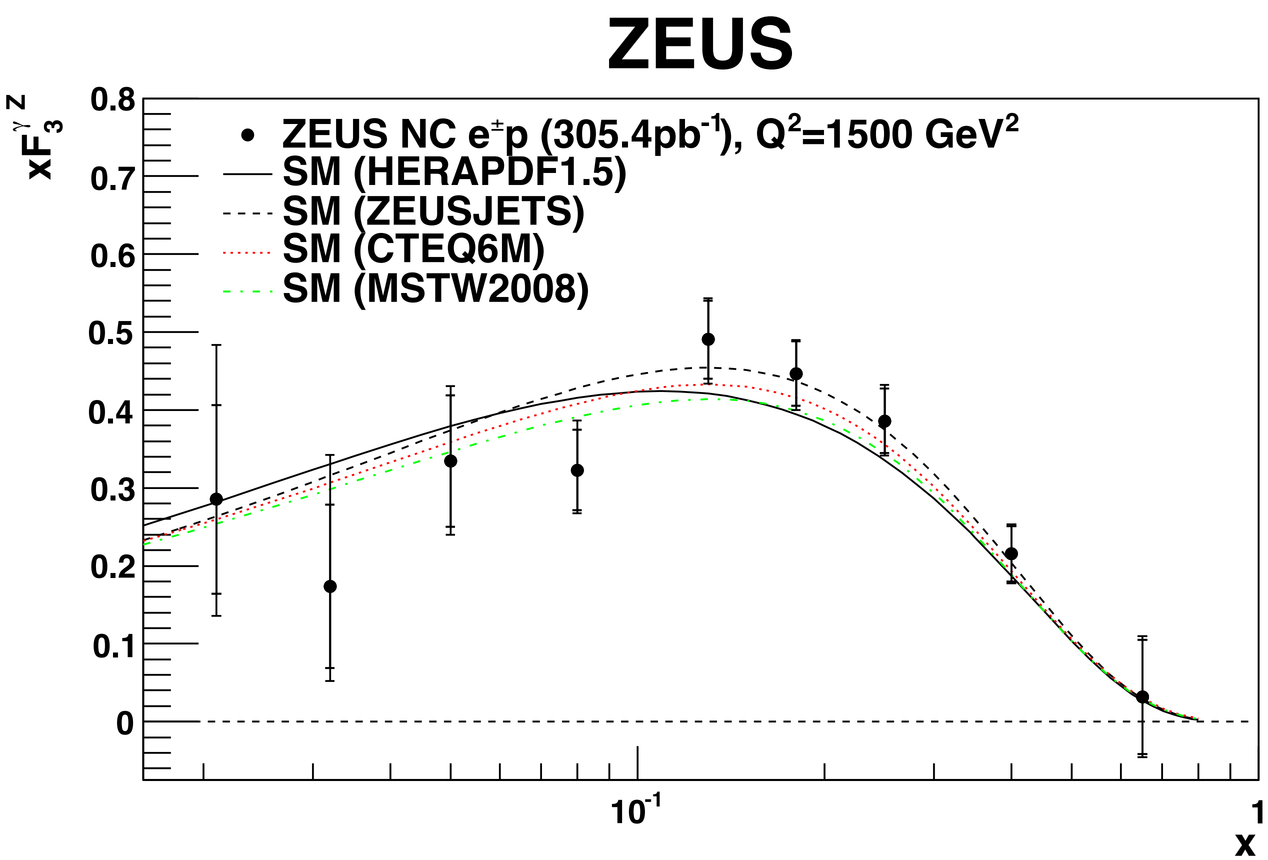
Statistics limited at higher Q^2 and high x

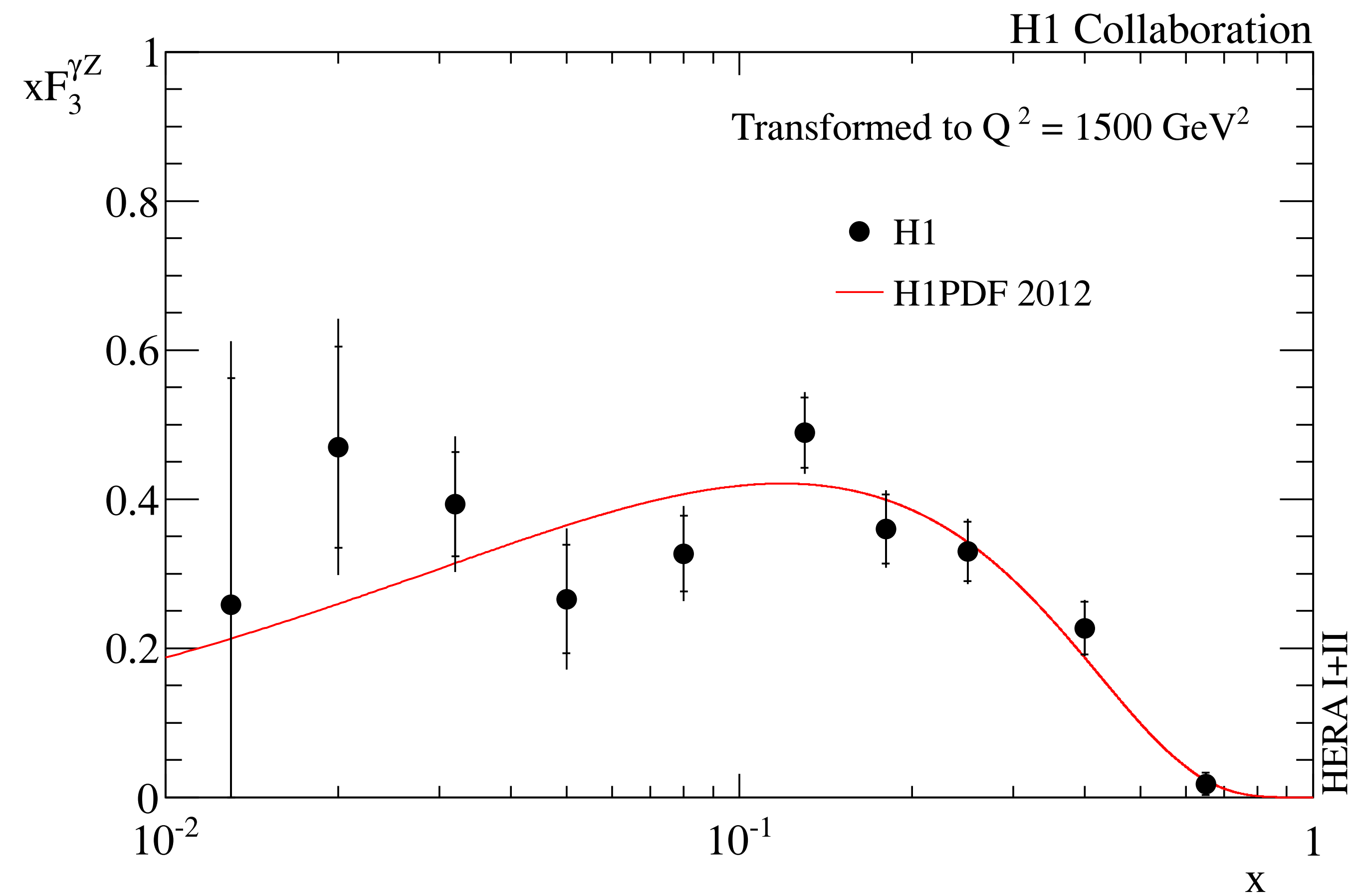
Extended reach at high x compared to H1 preliminary data

This x region is the 'sweet spot'
High precision with long Q^2 lever arm
x-range relevant for Higgs production

Combination of high Q^2 data
HERA-I and HERA-II

Larger HERA-II luminosity
→ improved precision at high x / Q^2





At high Q^2 xF_3 arises due to Z^0 effects
enhanced e^- cross section wrt e^+
Difference is xF_3
Sensitive to valence PDFs

$$x\tilde{F}_3 = \frac{Y_+}{2Y_-}(\tilde{\sigma}^-_{NC} - \tilde{\sigma}^+_{NC}) \approx a_e \chi_Z x F_3^{\gamma Z}$$

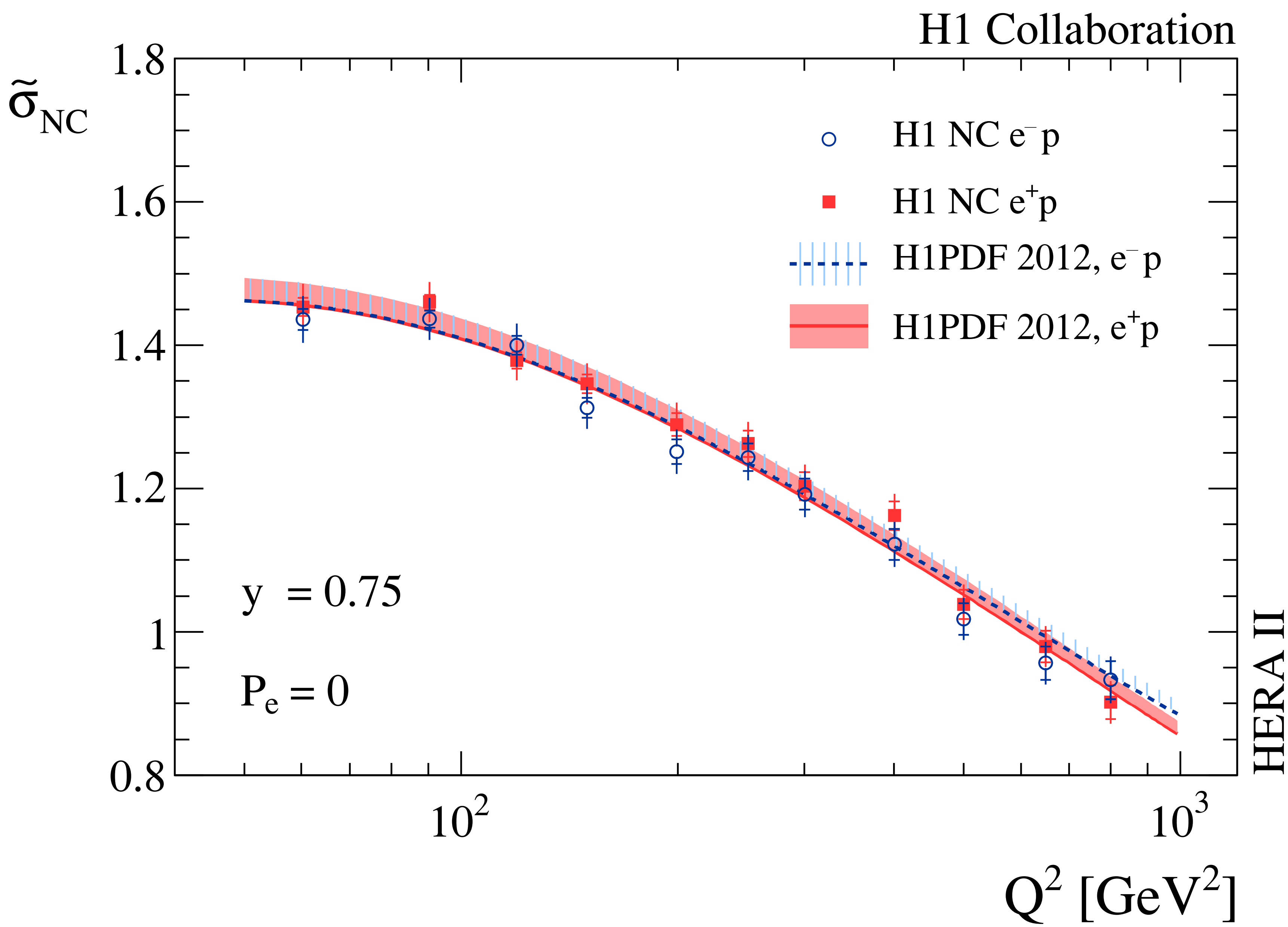
$$x\tilde{F}_3 \propto \sum (xq_i - x\bar{q}_i)$$

H1 measure integral of $xF_3^{\gamma Z}$ - validate sumrule:

$$\int_{0.016}^{0.725} \mathrm{d}x \; F_3^{\gamma Z}(x, Q^2 = 1\,500\,\mathrm{GeV}^2) = 1.22 \pm 0.09(\mathrm{stat}) \pm 0.07(\mathrm{syst})$$

NLO integral predicted to be $5/3 + \mathcal{O}(\alpha_S/\pi) = 1.16$

NC Cross Sections at High y



Measurement extension to high y at high Q^2

Sensitive to F_L and xg

Difficult measurement:
- low scattered electron energy $E_e' > 5$ GeV
- large photo-production background

Total uncertainty reduced by factor 2:
HERA-I ~4%
HERA-II ~2%

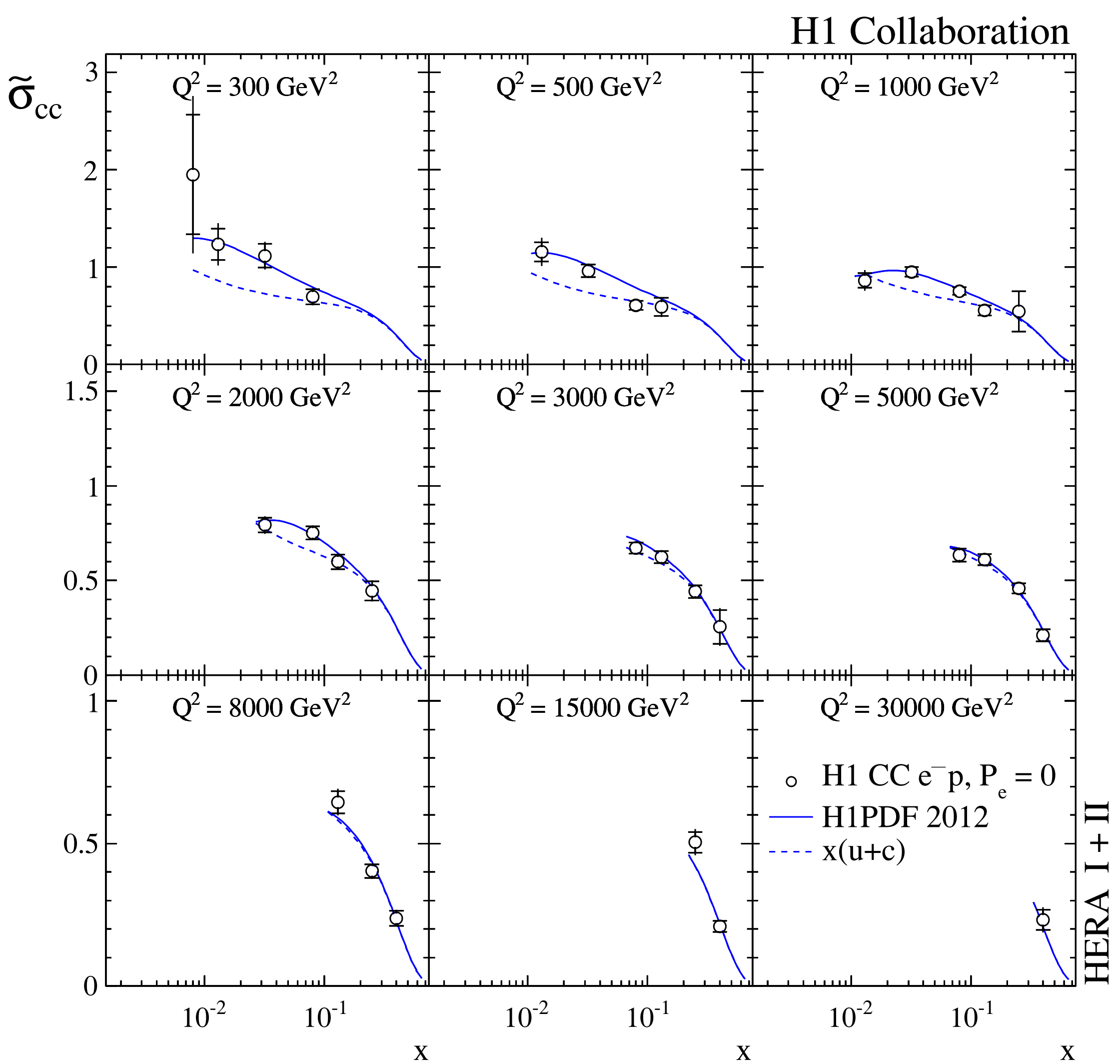
High Q^2 CC Cross Sections

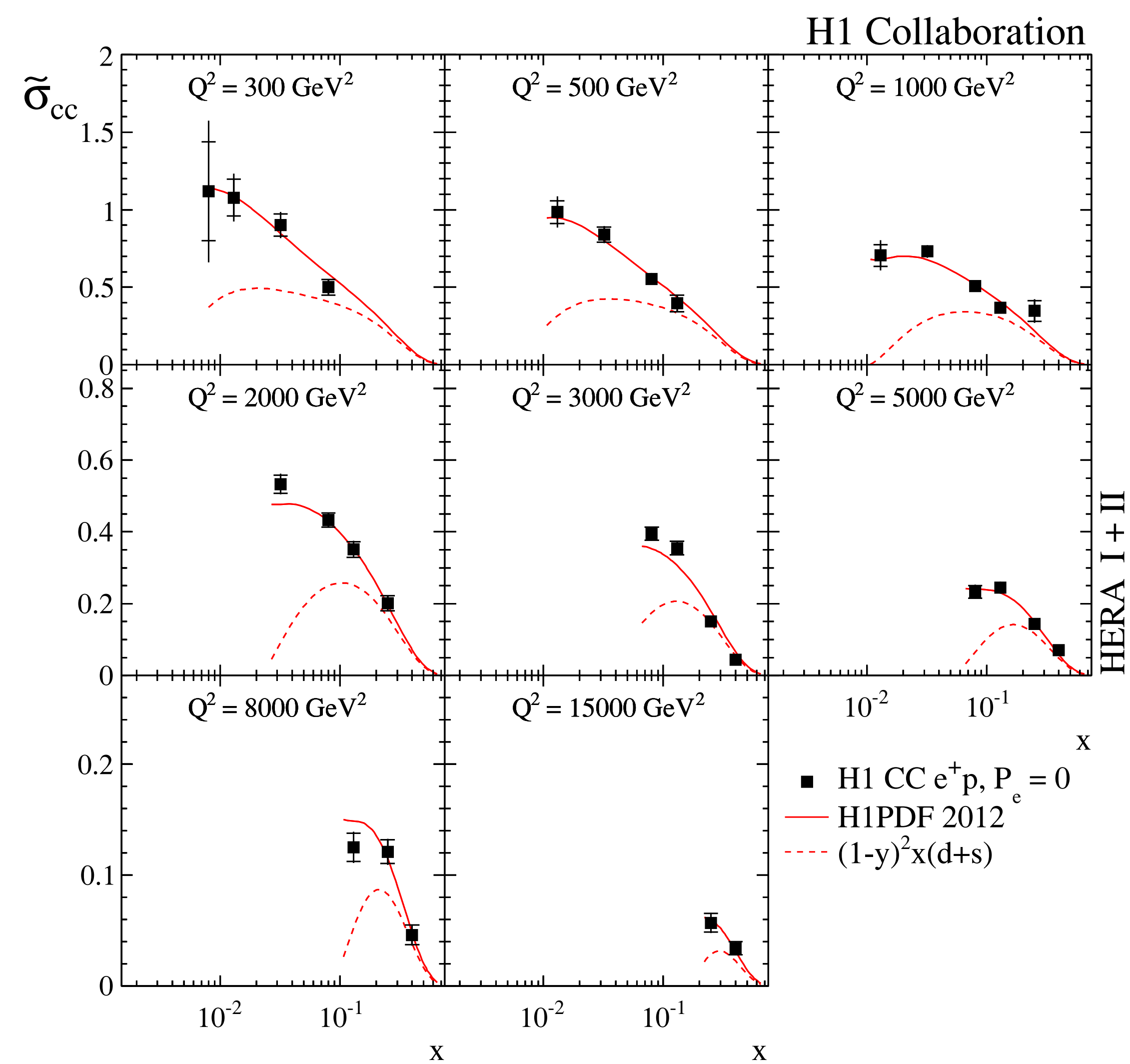
Electron scattering

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

Positron scattering

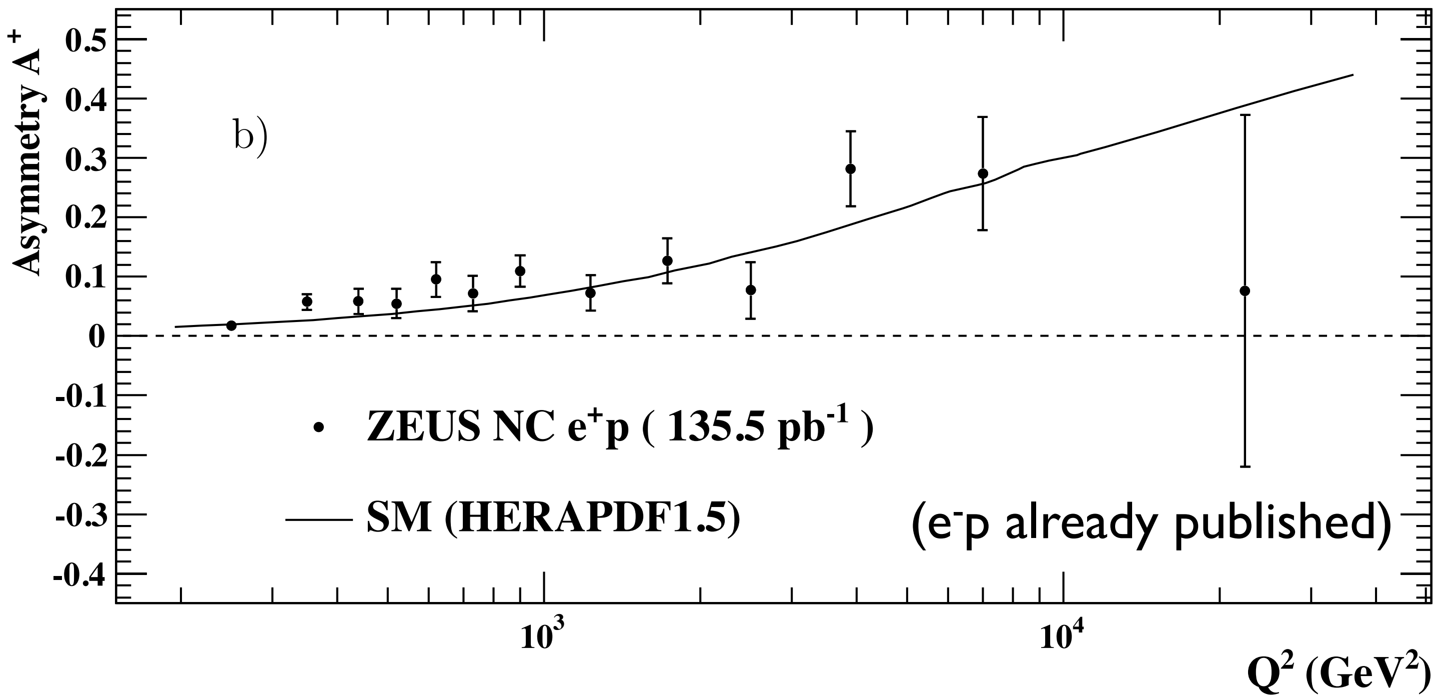
$$\frac{d^2\sigma^+_{CC}}{dxdQ^2} = \frac{G_F^2}{2\pi}\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2\left[(\bar{u}+\bar{c})+(1-y)^2(d+s)\right]$$





H1 combination of high Q^2 CC data (HERA-I+II)
Improvement of total uncertainty
Dominated by statistical errors
Provide important flavour decomposition information

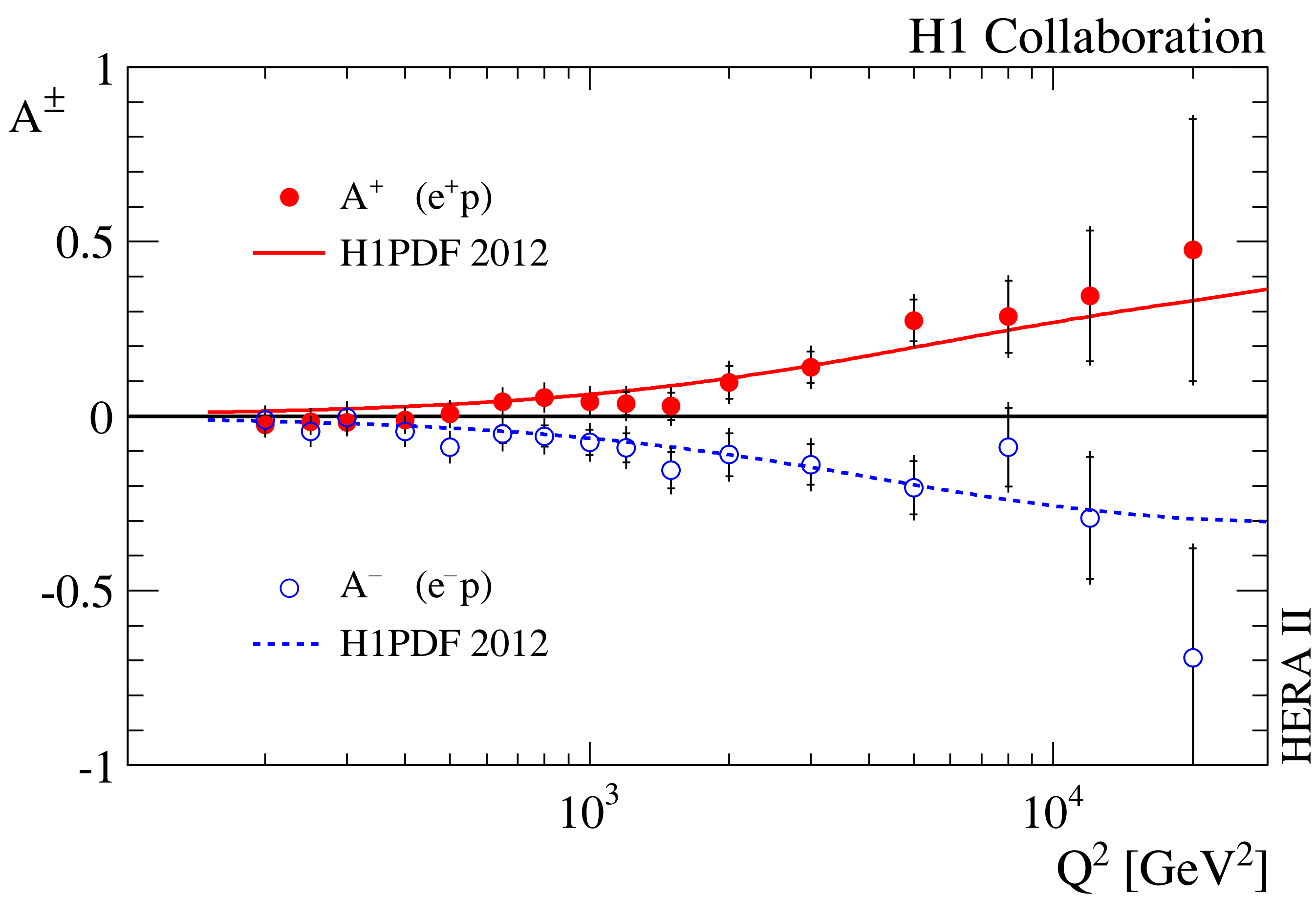
CC e+ data provide strong d_v constraint at high x
Precision limited by statistics: typically 5-10%
HERA-I precision of 10-15% for e+p
Large gain to come after combination with ZEUS



NC polarisation asymmetry:

$$A^{\pm} = \frac{2}{P_L^{\pm} - P_R^{\pm}} \cdot \frac{\sigma^{\pm}(P_L^{\pm}) - \sigma^{\pm}(P_R^{\pm})}{\sigma^{\pm}(P_L^{\pm}) + \sigma^{\pm}(P_R^{\pm})}$$

At large x $A^{\pm} \propto \pm\kappa \frac{1 + d_v/u_v}{4 + d_v/u_v}$

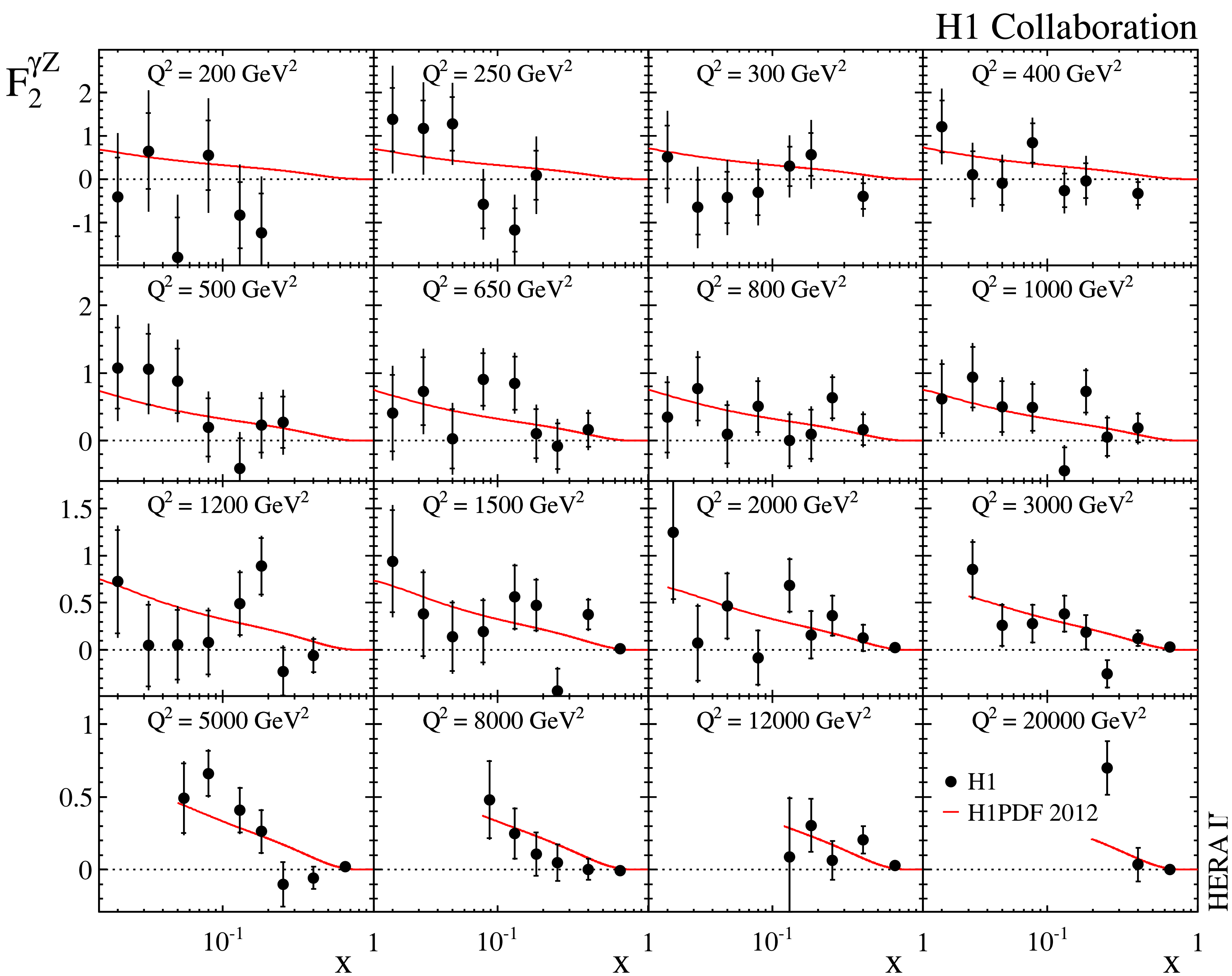


$F_2^{\gamma Z}$

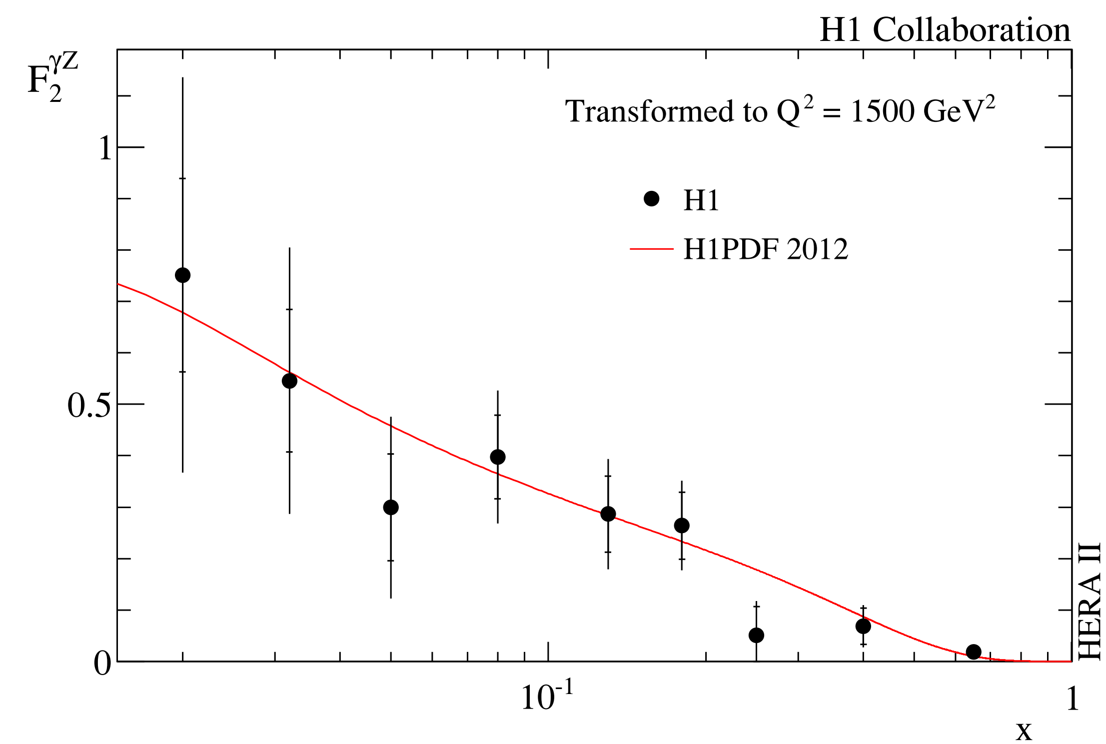
Measuring the difference in NC polarised cross sections gives access to new structure functions:

$$\frac{\sigma^{\pm}(P_L^{\pm}) - \sigma^{\pm}(P_R^{\pm})}{P_L^{\pm} - P_R^{\pm}} = \frac{\kappa Q^2}{Q^2 + M_Z^2}\left[\mp a_e F_2^{\gamma Z} + \frac{Y_-}{Y_+} v_e x F_3^{\gamma Z} - \frac{Y_-}{Y_+}\frac{\kappa Q^2}{Q^2 + M_Z^2}(v_e^2 + a_e^2) x F_3^Z\right]$$

xF_3 terms eliminated by subtracted e^-p from e^+p



Due to different couplings $F_2^{\gamma Z}$ has different sensitivity to U-type and D-type compared to F_2



New PDF fit performed: can be thought of as a ‘stepping-stone’ towards HERAPDF2.0

$$
\begin{aligned}
xg(x) &= A_g x^{B_g}(1-x)^{C_g} - A'_g x^{B'_g}(1-x)^{25}\,, \\
xu_v(x) &= A_{u_v} x^{B_{u_v}}(1-x)^{C_{u_v}}\left(1+E_{u_v}x^2\right)\,, \\
xd_v(x) &= A_{d_v} x^{B_{d_v}}(1-x)^{C_{d_v}}\,, \\
x\overline{U}(x) &= A_{\overline{U}} x^{B_{\overline{U}}}(1-x)^{C_{\overline{U}}}\,, \\
x\overline{D}(x) &= A_{\overline{D}} x^{B_{\overline{D}}}(1-x)^{C_{\overline{D}}}\,.
\end{aligned}
$$

Parameter	Central Value	Lower Limit	Upper Limit
f_s	0.31	0.23	0.38
m_c (GeV)	1.4	1.35 (for $Q_0^2 = 1.8$ GeV)	1.65
m_b (GeV)	4.75	4.3	5.0
$Q^2_{\rm min}$ (GeV^2)	3.5	2.5	5.0
Q_0^2 (GeV^2)	1.9	1.5 ($f_s = 0.29$)	2.5 ($m_c = 1.6$, $f_s = 0.34$)

13 parameter fit: additional flexibility given to u_v and d_v compared to H1PDF2009 / HERAPDF1.0

Apply momentum/counting sum rules:

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

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

Parameter constraints:
$B_{Ubar} = B_{Dbar}$
sea = 2 x (Ubar +Dbar)
Ubar = Dbar at x=0
f_s = sbar/Dbar

Q_0^2 = 1.9 GeV^2 (below m_c)
Q^2 > 3.5 GeV^2
2 x 10^{-4} < x < 0.65
Fits performed using RT-VFNS

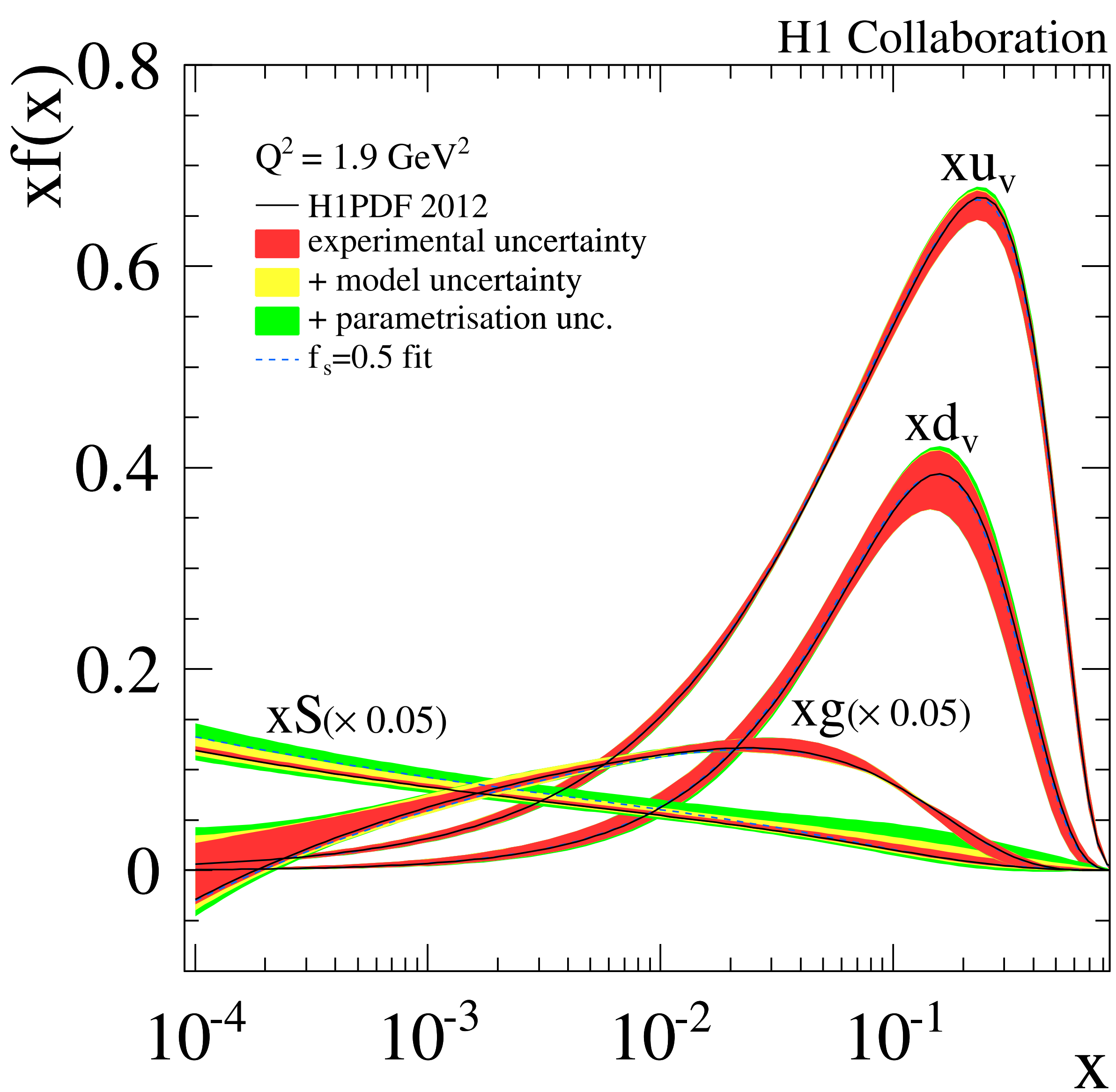
Experimental uncertainties produced using RMS spread of 400 replica fits
Parameterisation uncertainty determined from envelope of 14 parameter fit & Q_0^2 variations
Error band is applied to central value fit ⇒ asymmetric errors since mean of replicas ≠ central fit

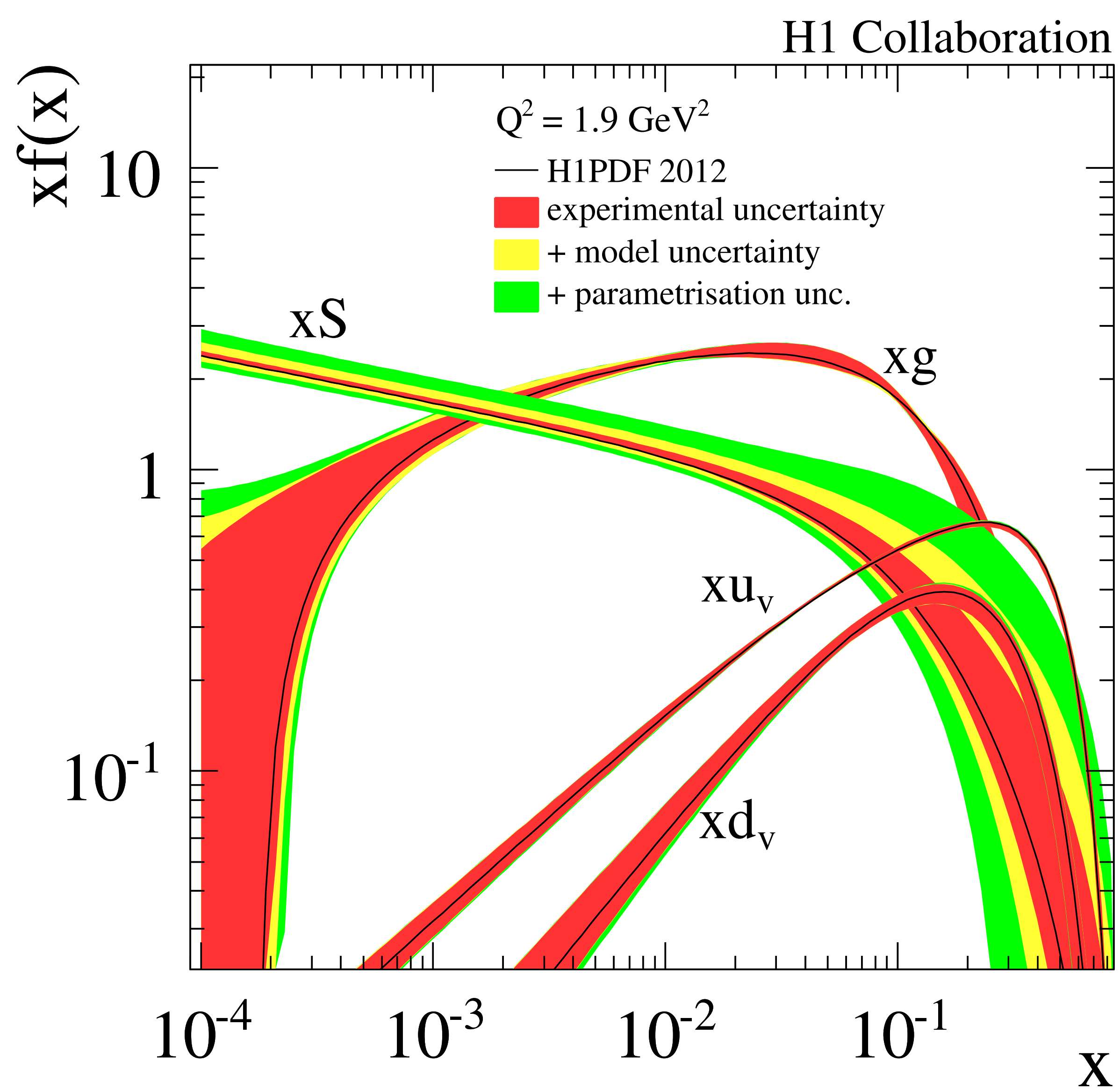
$$\chi^2 = \sum_i \frac{\left[\mu_i - m_i\left(1-\sum_j \gamma^i_j b_j\right)\right]^2}{\delta^2_{i,\rm unc} m_i^2 + \delta^2_{i,\rm stat}\mu_i m_i\left(1-\sum_j \gamma^i_j b_j\right)} + \sum_j b_j^2 + \sum_i \ln\frac{\delta^2_{i,\rm unc} m_i^2 + \delta^2_{i,\rm stat}\mu_i m_i}{\delta^2_{i,\rm unc}\mu_i^2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

μ_i measurement i
m_i theory i
b_j correlated sys source j
γ^i_j correlated error i,j

Errors prop to measured values - avoid stat fluctuations by scaling errors by expectation m_i
Modified χ^2 definition includes *ln* term to account for likelihood transition to χ^2 after error scaling

H1PDF 2012

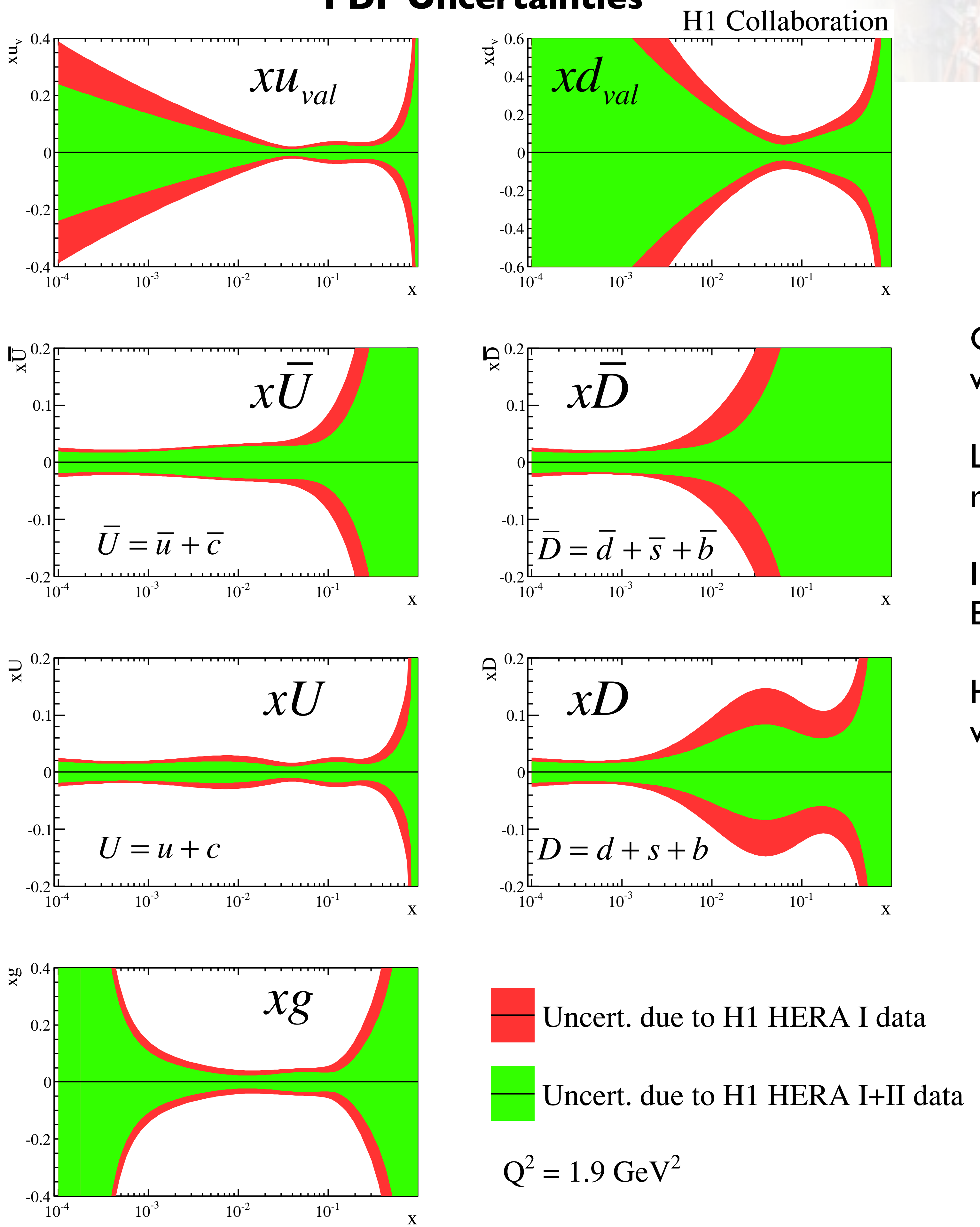




χ^2/ndf = 1570/1461 = 1.07

Fit with unsuppressed strange sea (f_s=0.5) is well within error bands

PDF Uncertainties



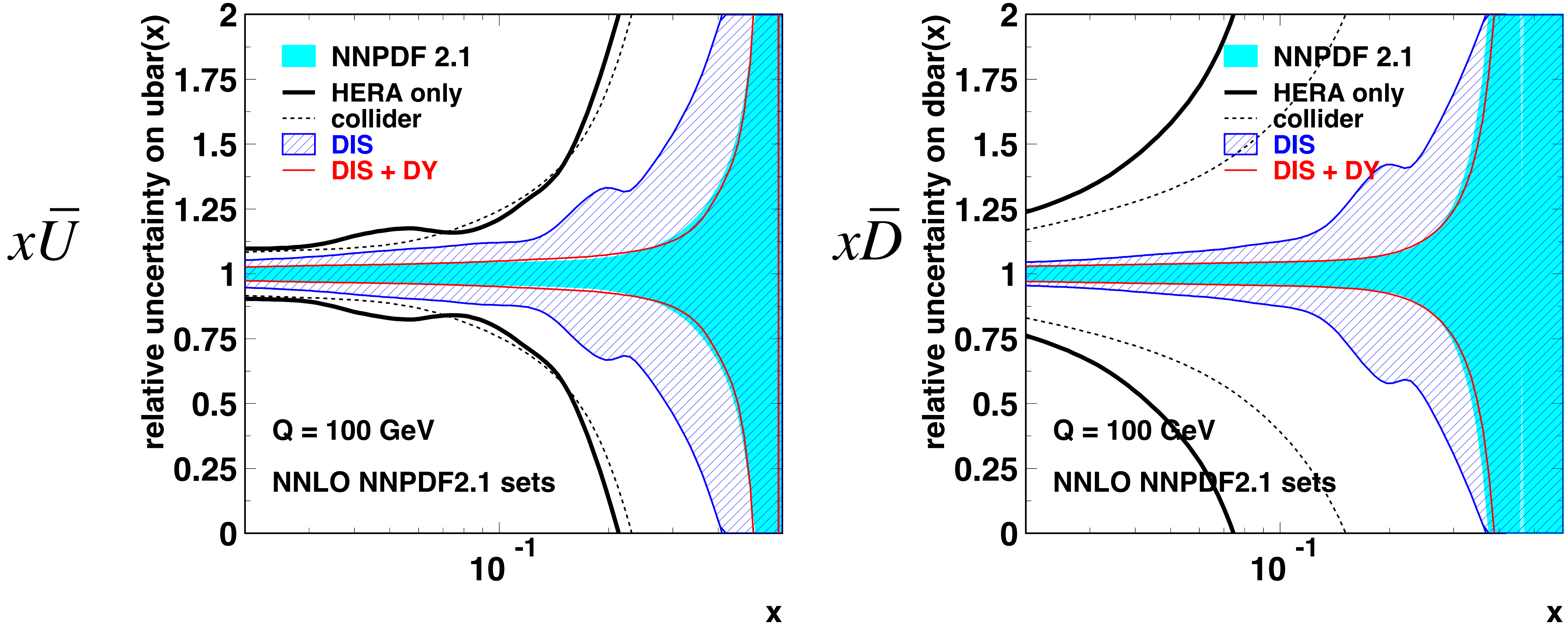
Comparison of PDF uncertainties from H1 fits with and without new HERA-II data

Large improvement in xd_v and xD over wide x range - driven by more precise CC e^+p data

Improvement in xu_v from NC at high x.
Error reduction at low x arises from sum rules

High x gluon is also improved from scaling violations

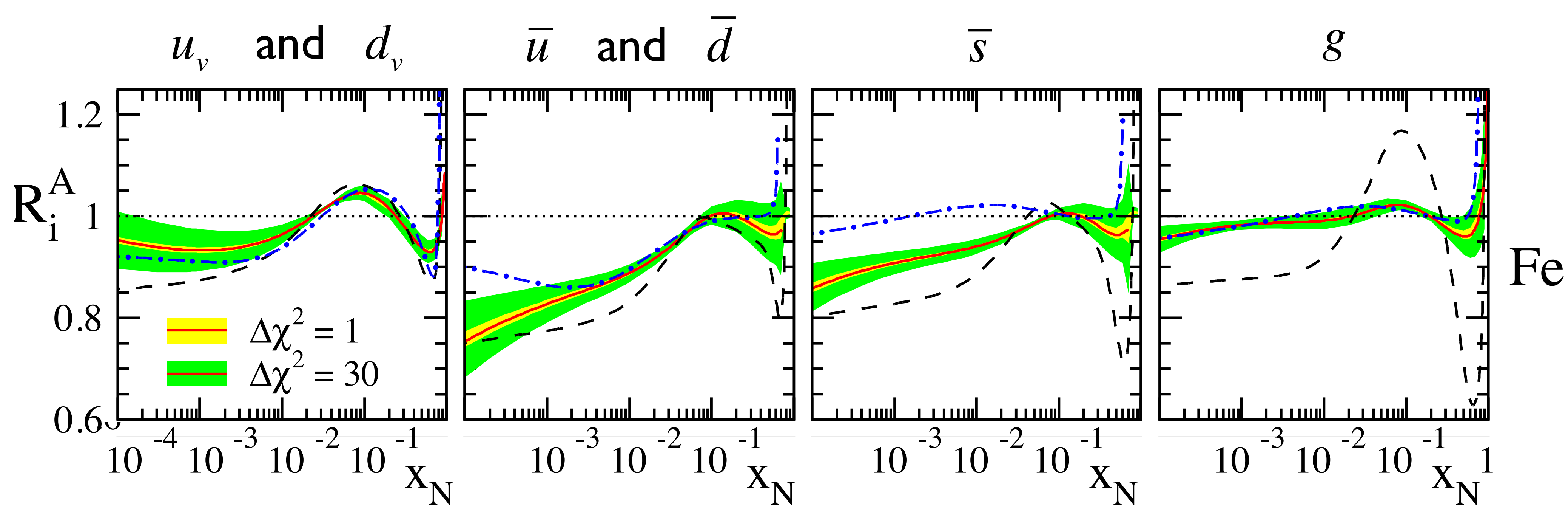
Fixed Target & Collider Data at High x



HERA-I data only

At high x strongest constraints on anti-quarks from deuterium Drell-Yan measurements
Also d quark constraints from deuterium DIS

Cross section ratio for Fe : proton target



HERAPDF philosophy: Fewer data sets → better control of experimental uncertainties
PDF experimental uncertainty defined by $\Delta\chi^2=1$ criterion
Compare to MSTW / CTEQ: effectively use $\Delta\chi^2=50$ to 100
Avoid complications of data using nuclear targets

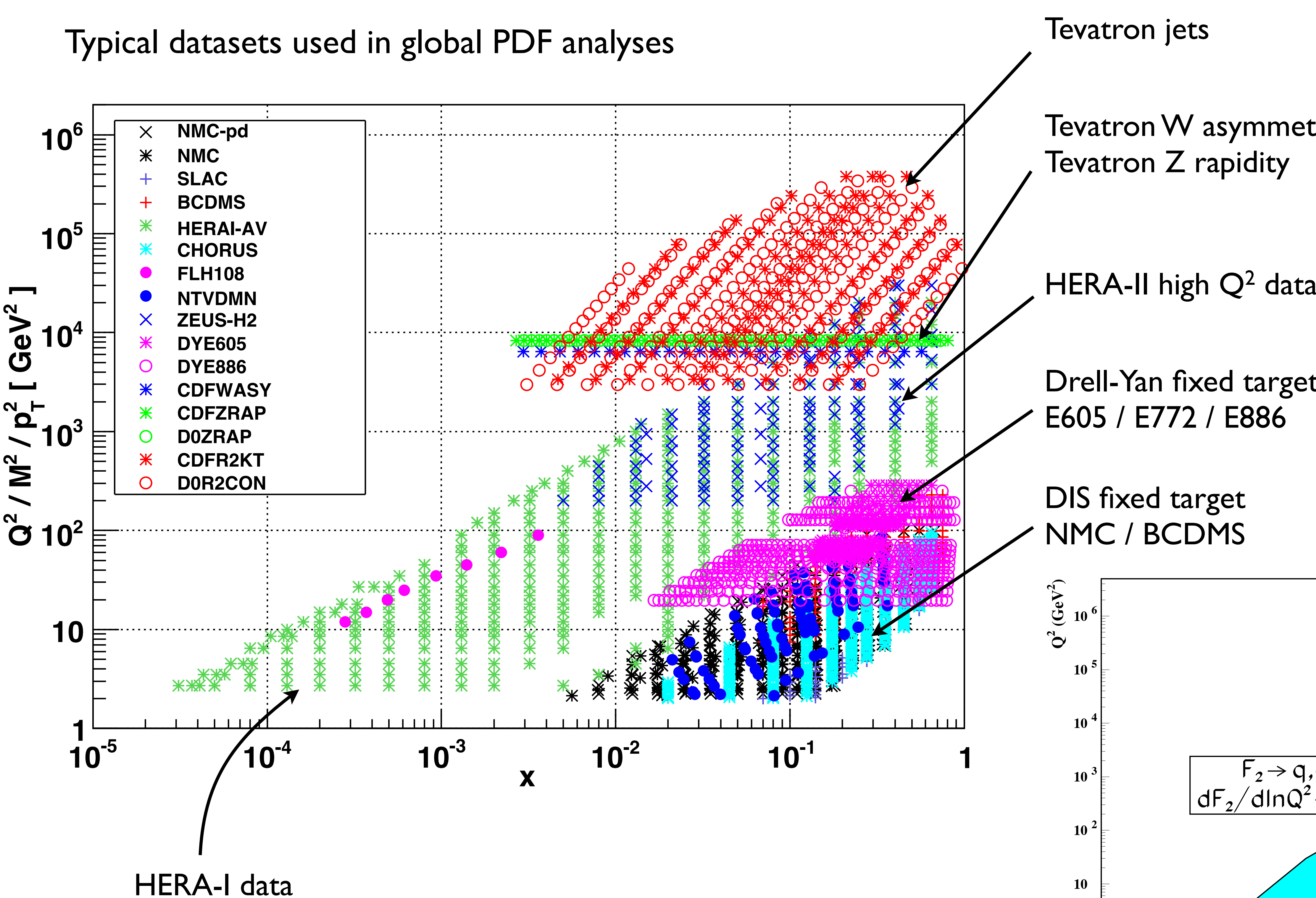
HERAPDF2.0
Include final:
HERA-I low/medium Q^2 precision F_2
HERA-II high Q^2 polarised NC/CC data
HERA-II low/medium $E_P=575/460$ GeV energy NC data
HERA-I+II F_2^{cc} combined data - almost ready
HERA-I+II multijet data - awaiting H1 publication

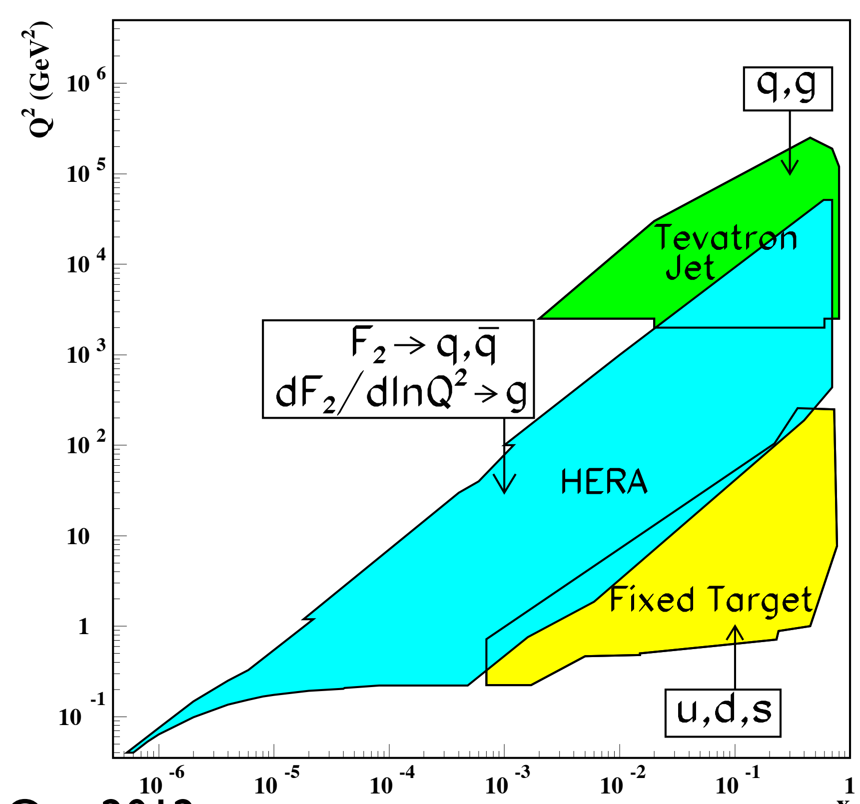
Expect several fits:
- NLO vs NNLO
- NLO will be: inclusive NC/CC data & inclusive + F_2^{cc} (+ jets?)
- Include fit to α_S
- MC method for experimental errors will be used

Timescale ~ spring 2013 (DIS workshop?)

Data Sets in Global PDF Analyses

Typical datasets used in global PDF analyses





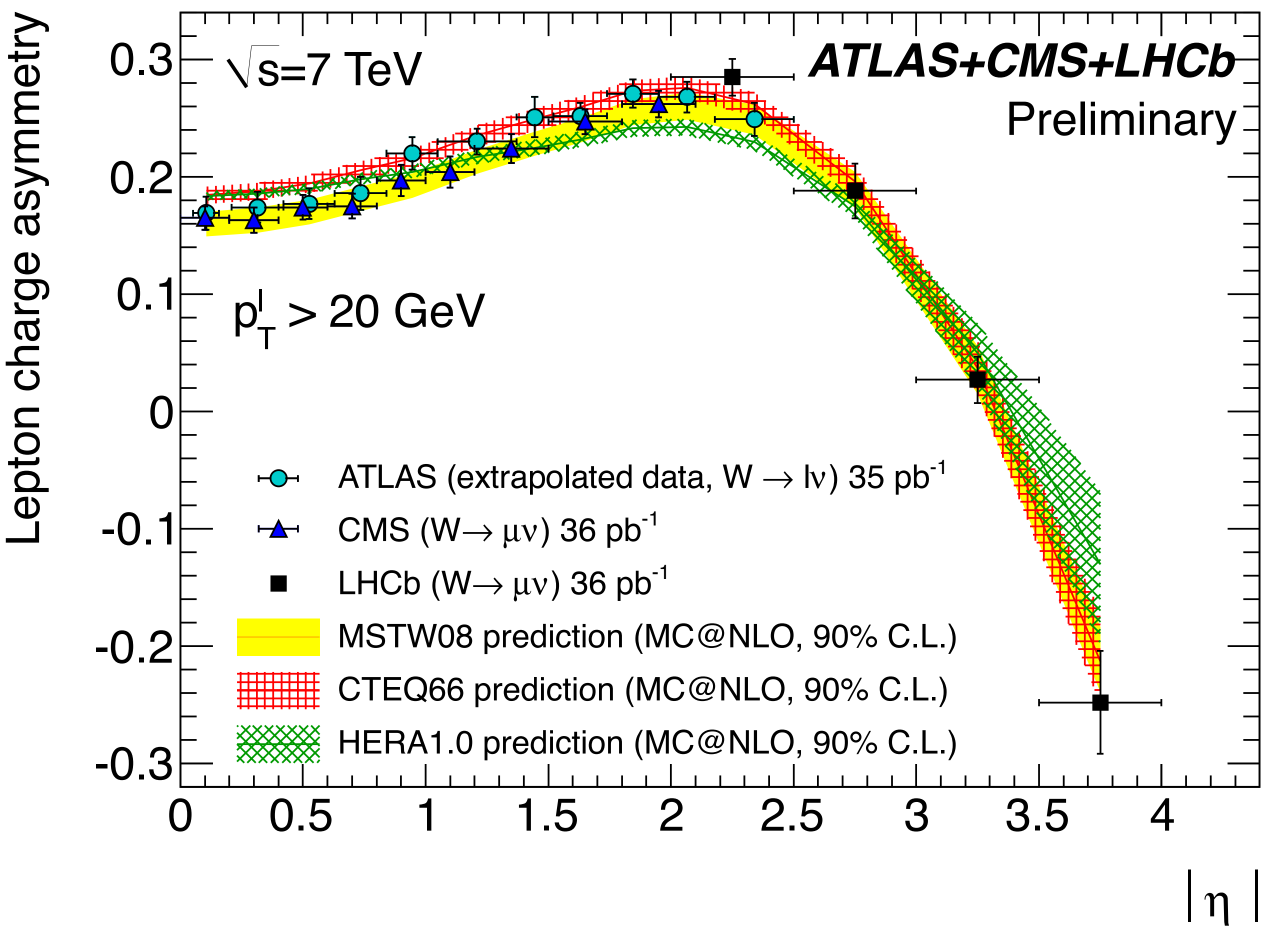
W± lepton charge asymmetry

$$A(\eta) = \frac{d\sigma/d\eta(W^+ \to l^+\nu) - d\sigma/d\eta(W^- \to l^-\bar{\nu})}{d\sigma/d\eta(W^+ \to l^+\nu) + d\sigma/d\eta(W^- \to l^-\bar{\nu})}$$

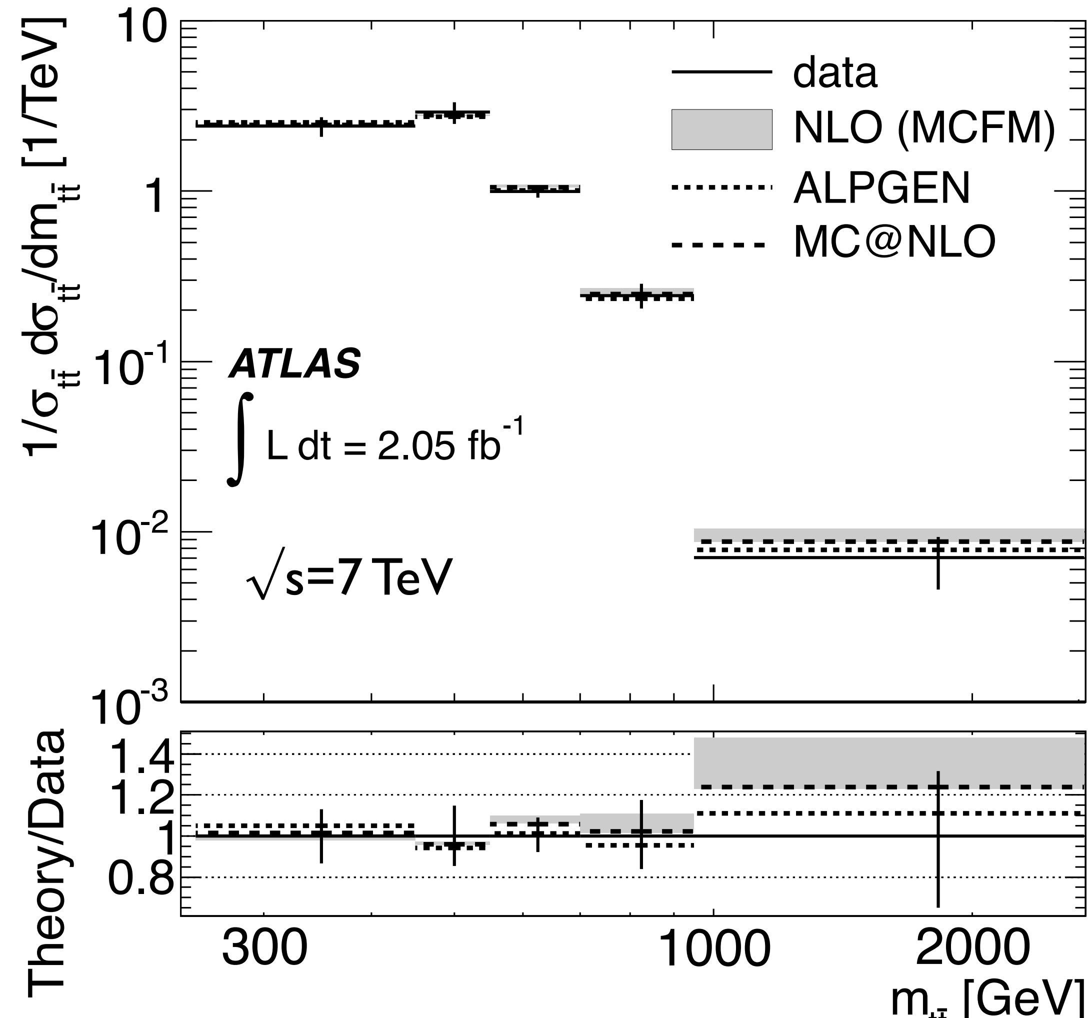
$$W^+ : u\bar{d} + c\bar{s}$$
$$W^- : d\bar{u} + s\bar{c}$$

probes flavour structure

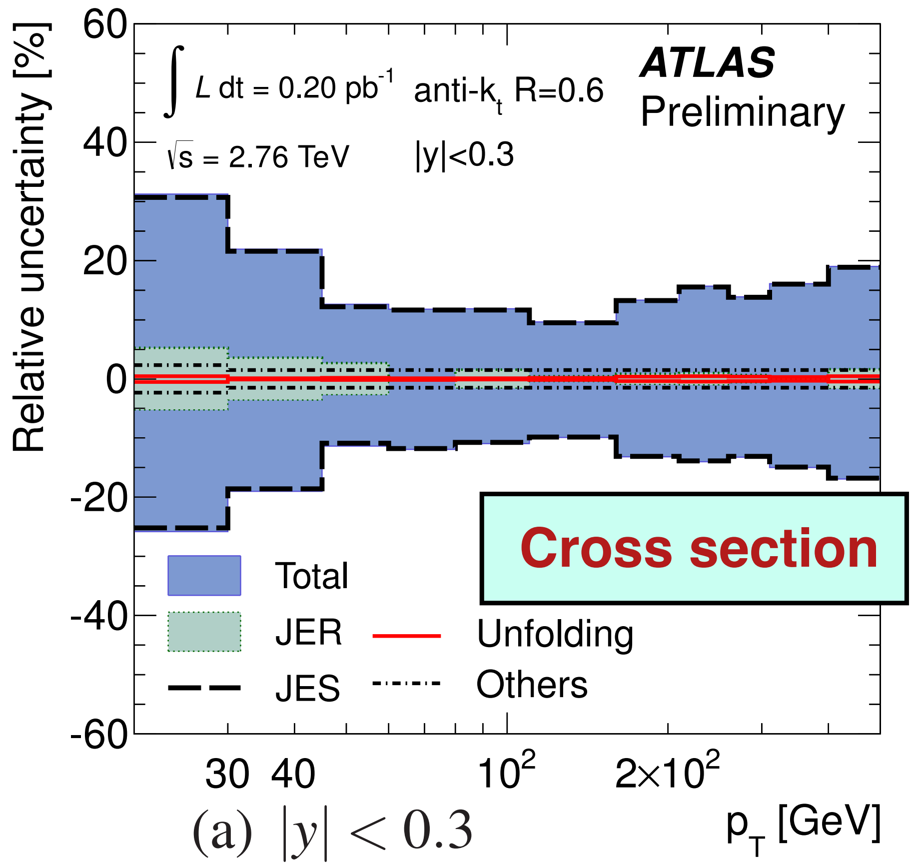
D0 measurements show tension with CDF
Alleviated with improved flexibility of PDF functions?
(Thorne, PDF4LHC Workshop, Sept 2012)



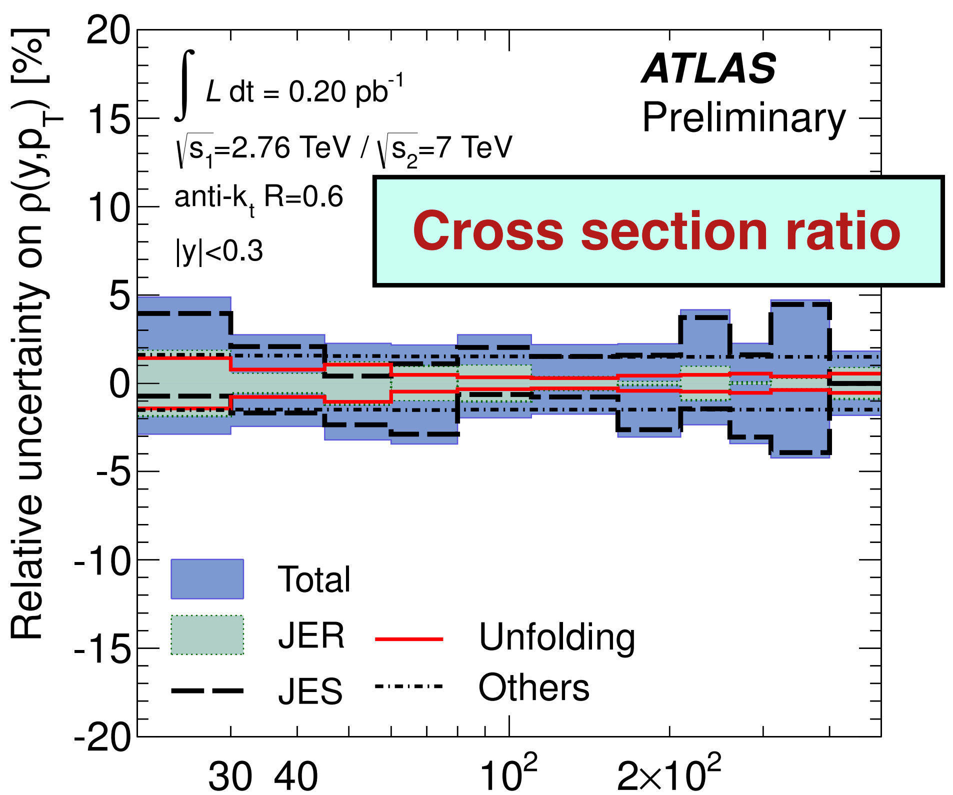
Top/anti-top differential cross section
At $\sqrt{s}$=14 TeV dominant contribution 90% is from gg
Constrains high x gluon



LHC Constraints



(a) $|y| < 0.3$



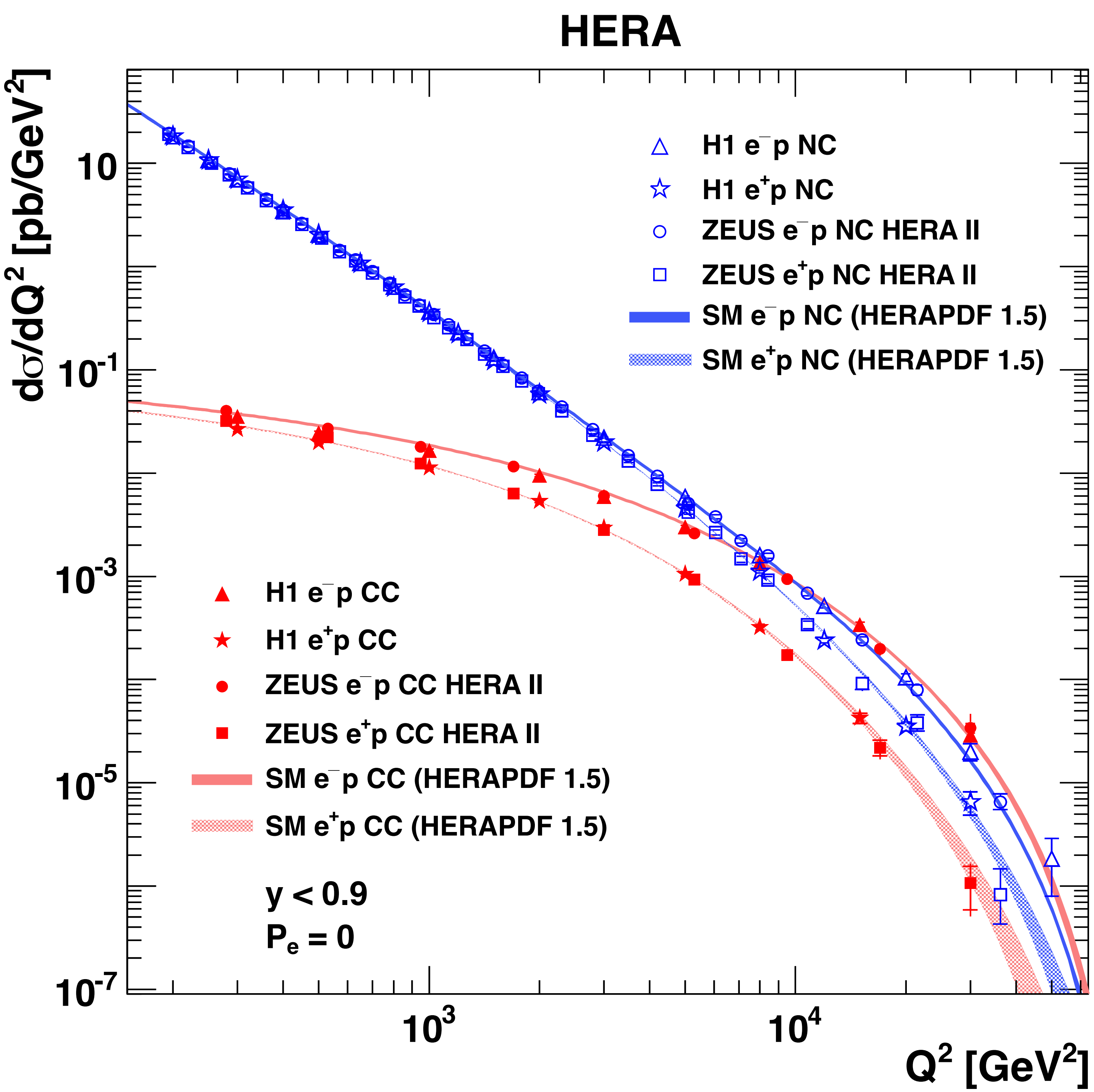
(d) $\rho(y, p_T), |y| < 0.3$

<u>LHC inclusive jets</u>

Can reach very high x ~ 0.9
Constrains qq and qg at high x
Large detector uncertainty from energy scale
Reduce error by taking cross section ratio at different $\sqrt{s}$
⇒ correlated systematic errors ~cancel
Atlas published data for $\sqrt{s}$=2.76 TeV and $\sqrt{s}$=7 TeV

<u>Other LHC constraints</u>

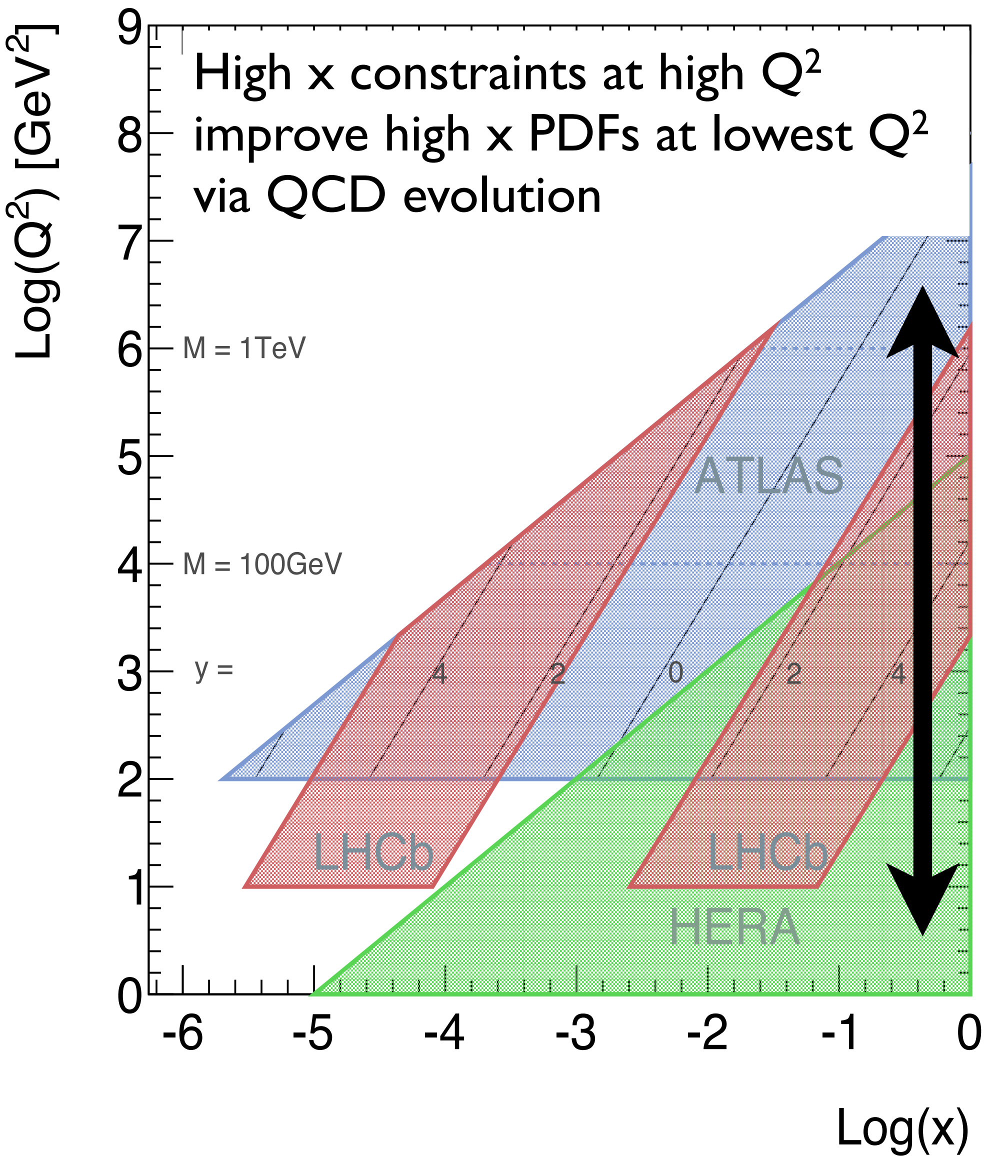
W^++c & W^-+c gives access to strange/anti-strange
High mass Drell-Yan → anti-quarks at high x
Prompt photon production $qg \rightarrow \gamma q$ constrains high x gluon
....

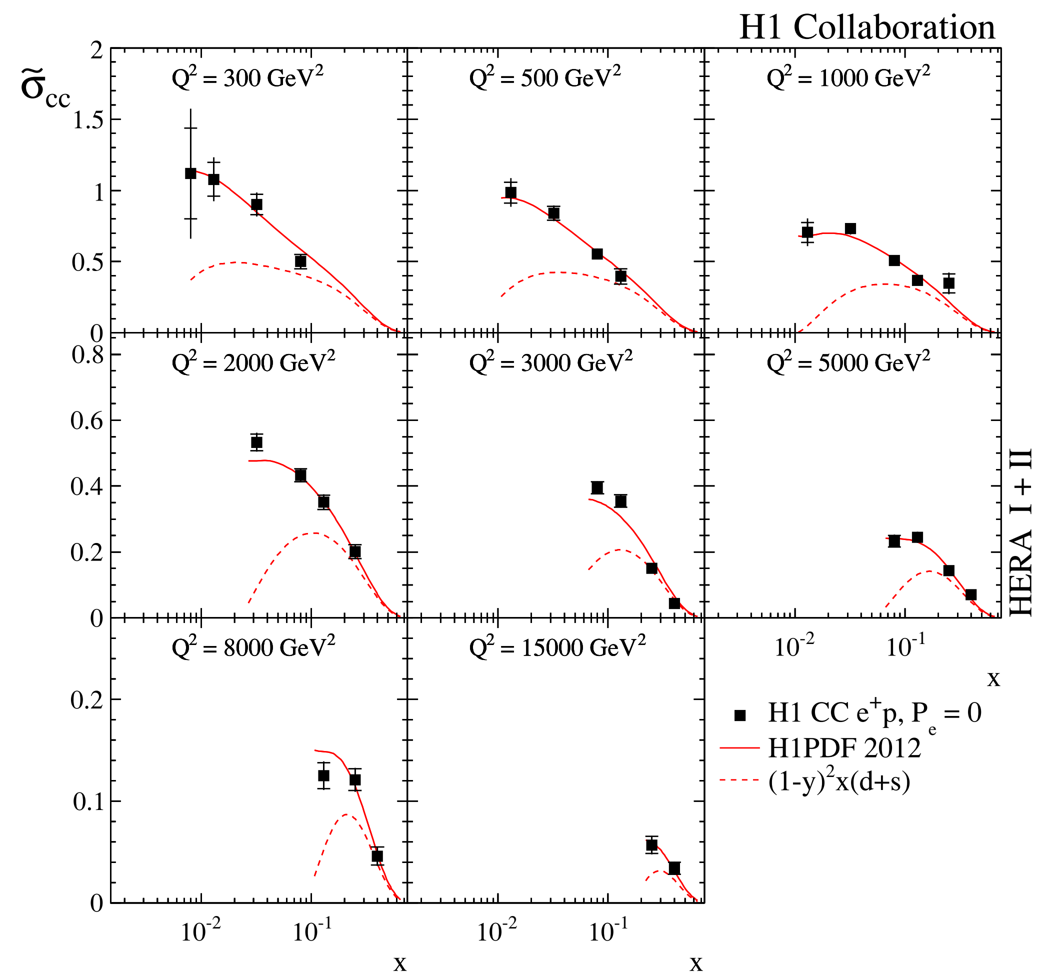


- H1 / ZEUS completed their final SF measurements
- New HERA-II data provide tighter constraints at high x / Q^2
- HERA data provide some of the most stringent constraints on PDFs
- Stress-test of QCD over 4 orders of mag. in Q^2
- DGLAP evolution works very well
- HERA data provide a self-consistent data set for complete flavour decomposition of the proton
- New combination of HERA data underway
- Combination ⇒ HERAPDF2.0 QCD fit
- Global PDF analyses now start to use LHC data

Backup Slides

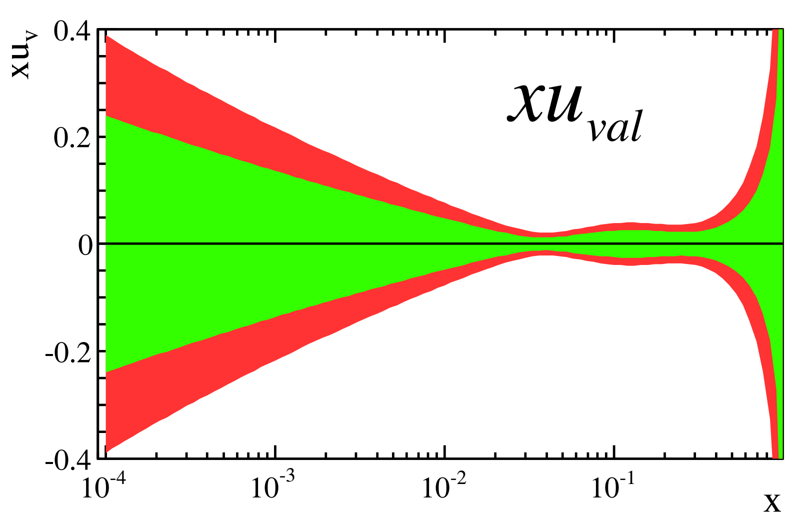
New High x Constraints from HERA DIS

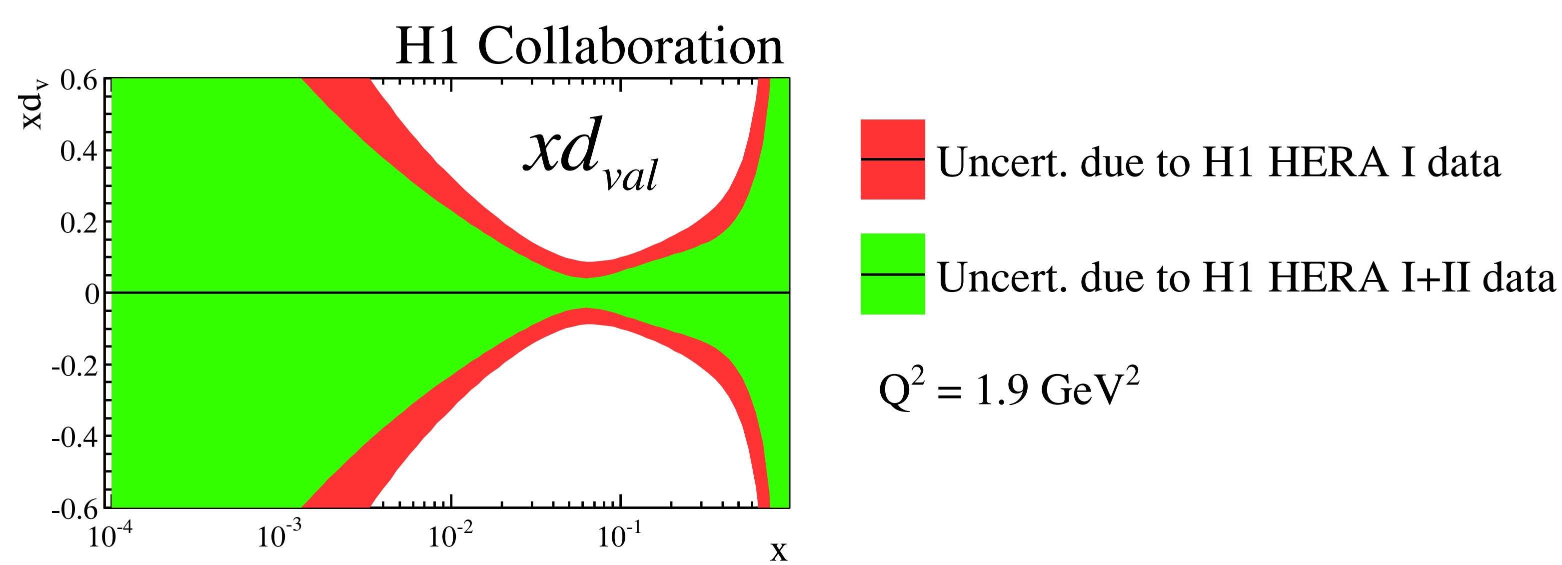




Final high x / high Q^2 NC and CC cross sections now published from H1 & ZEUS - legacy data sets

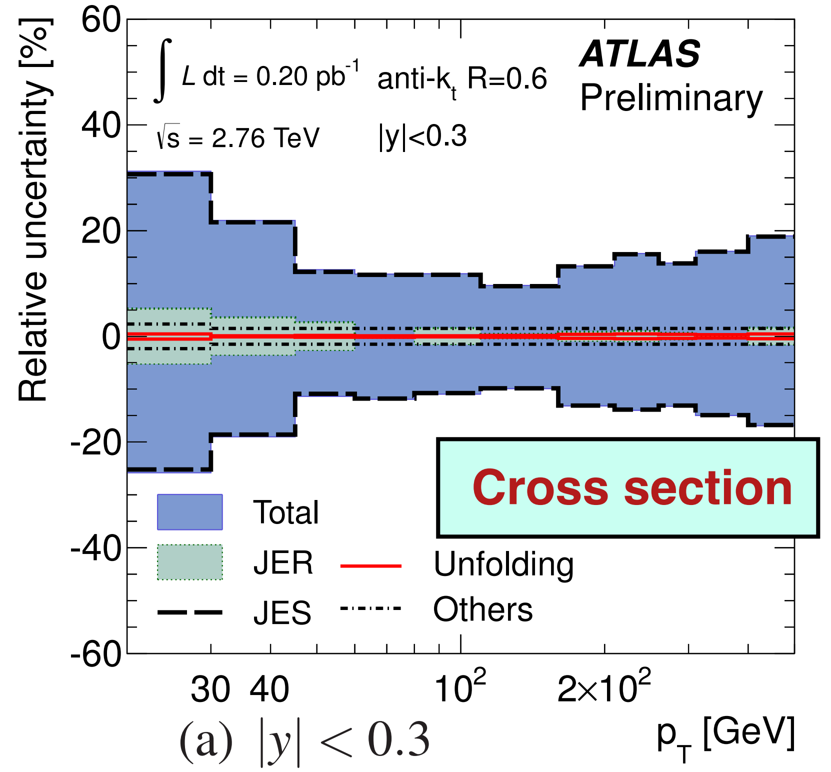
CC e^+p gives strong clean constraints on xd_v



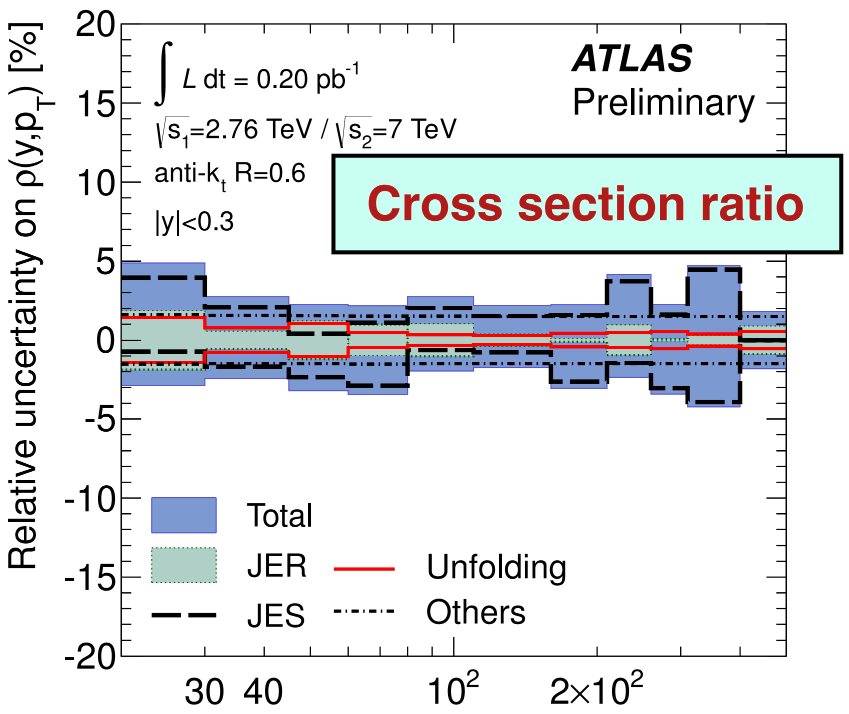


New High x Constraints From LHC

Inclusive jets at $\sqrt{s}$=2.76 TeV and $\sqrt{s}$=7 TeV
Constrain qg and gg PDFs



(a) $|y| < 0.3$

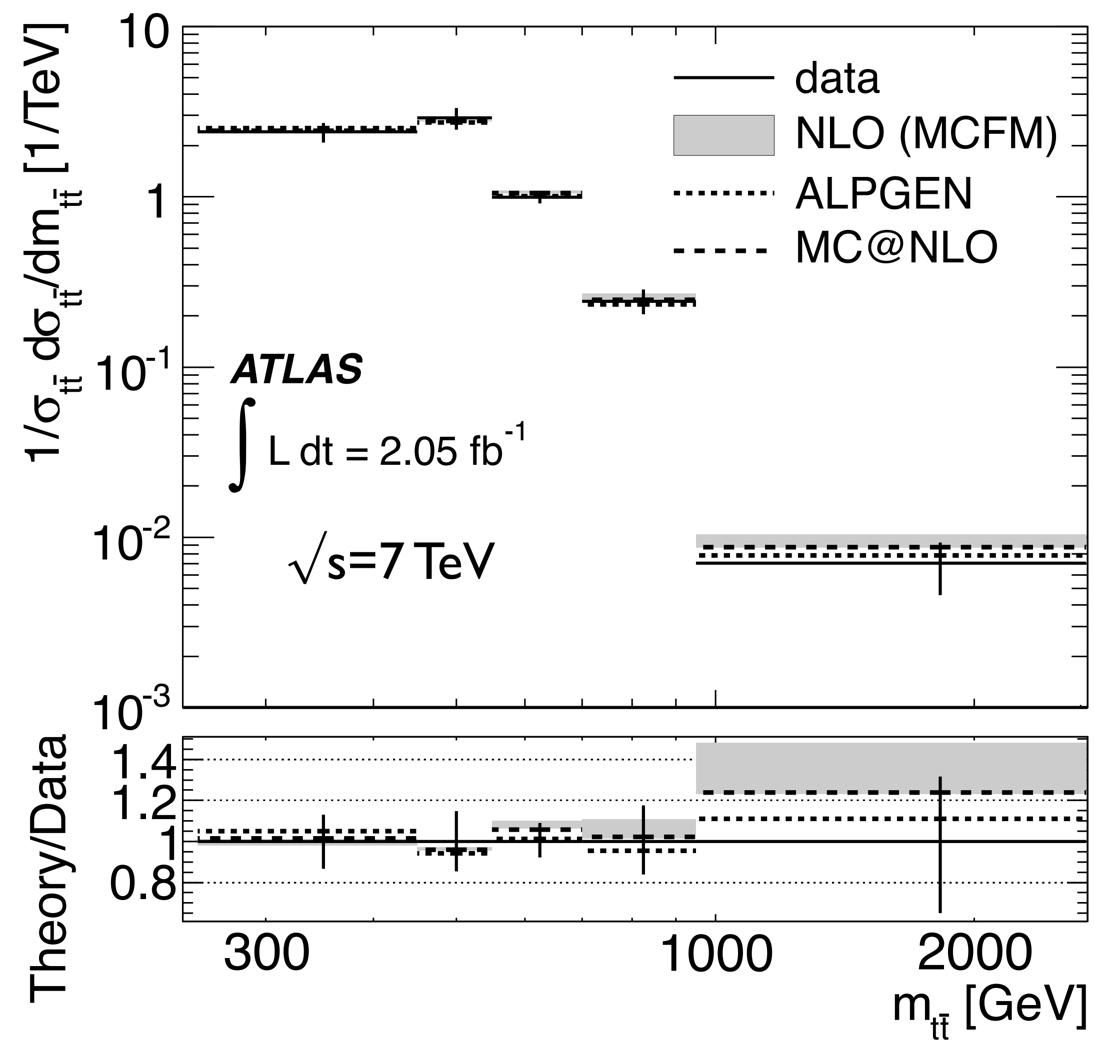


(d) $\rho(y, p_T), |y| < 0.3$

LHC data provide new high x constraints
Yet to be included in QCD fits to PDFs
← two examples ↓

Top/anti-top differential cross section

First measurement at $\sqrt{s}$=7 TeV
Large stat error - future $\sqrt{s}$=14 TeV will give better constraints

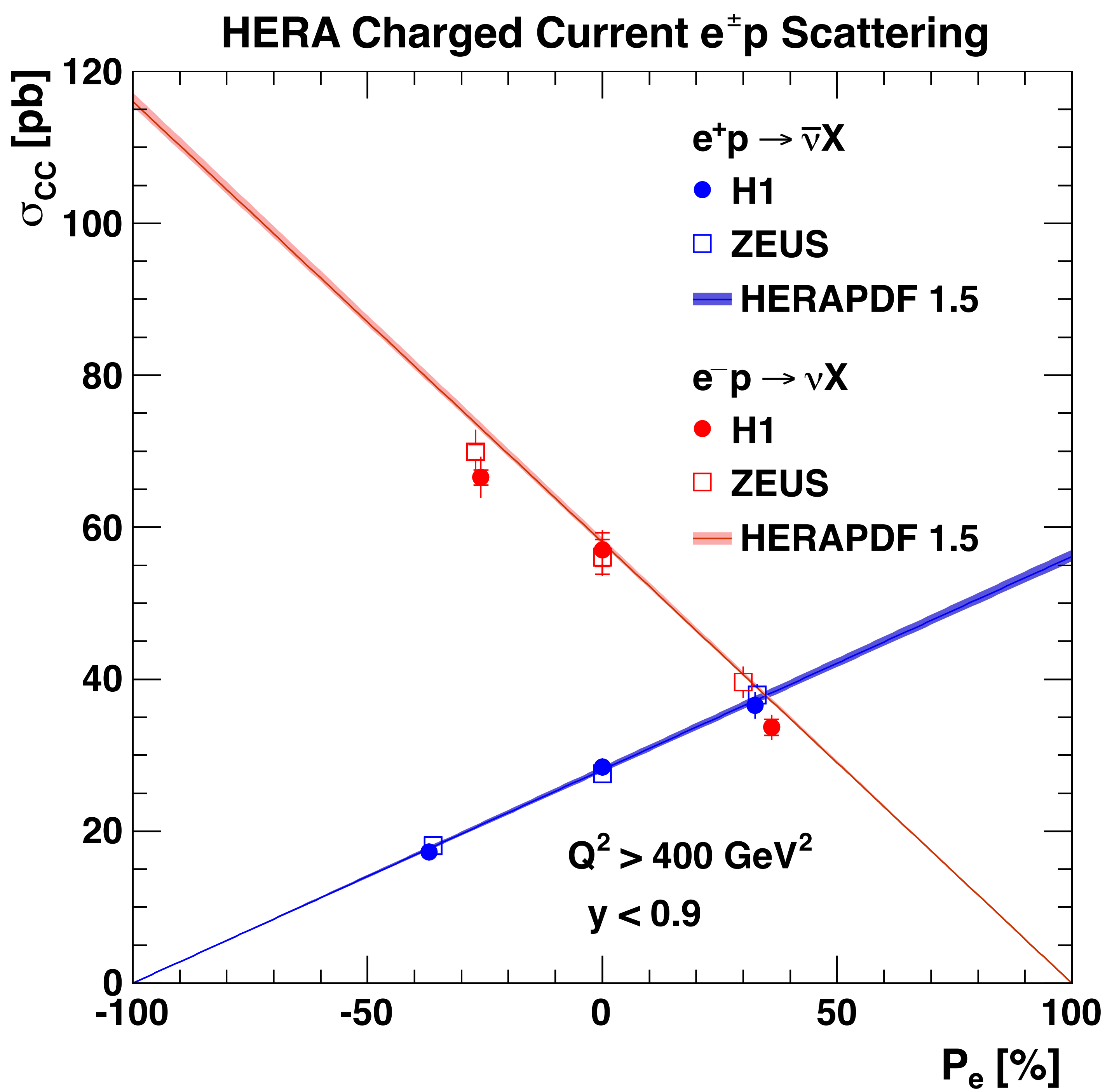


Summary of HERA-I datasets
Combined in HERAPDF1.0

Available since 2009

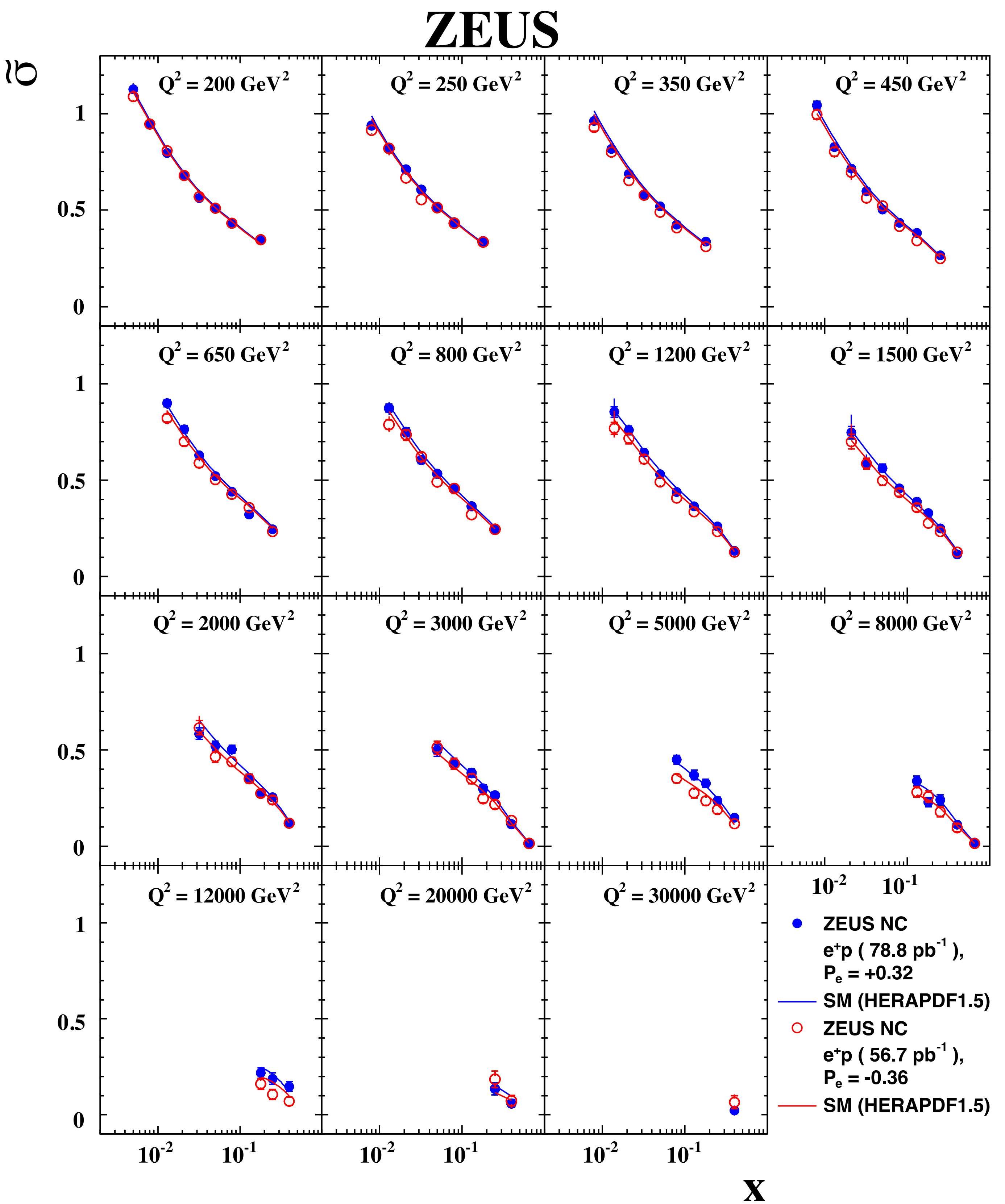
Data Set		x Range		Q^2 Range GeV^2		$\mathcal{L}$ pb^{-1}	e^+/e^-	$\sqrt{s}$ GeV
H1 svx-mb	95-00	5×10^{-6}	0.02	0.2	12	2.1	e^+p	301-319
H1 low Q^2	96-00	2×10^{-4}	0.1	12	150	22	e^+p	301-319
H1 NC	94-97	0.0032	0.65	150	30000	35.6	e^+p	301
H1 CC	94-97	0.013	0.40	300	15000	35.6	e^+p	301
H1 NC	98-99	0.0032	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



Polarisation dependence of CC cross section now final from H1 and ZEUS

Polarised NC Cross Sections



Polarised NC measurements completed for e^+p , e^-p , L-handed , R-handed scattering

Difference in L,R scattering visible at high Q^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

α_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

α_s = 0.1202 ± 0.0013 (exp) ± 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

New H1 data are combined with all previously published H1 inclusive cross section measurements

854 data points averaged to 413 measurements
χ^2/ndf = 412/441 = 0.93

Normalisation shifts for H1 data after averaging

Source	Shift in units of standard deviation	Shift in % of cross section
$\delta^{\mathcal{L}1}$ (BH Theory)	-0.39	-0.19
$\delta^{\mathcal{L}2}$ (e^+ 94-97)	-0.46	-0.66
$\delta^{\mathcal{L}3}$ (e^- 98-99)	-0.69	-1.20
$\delta^{\mathcal{L}4}$ (e^+ 99-00)	-0.07	-0.10
$\delta^{\mathcal{L}5}$ (QEDC)	0.81	1.70
$\delta^{\mathcal{L}6}, \delta^{\mathcal{L}7}$ (e^+L+R)	0.84	0.80
$\delta^{\mathcal{L}8}, \delta^{\mathcal{L}9}$ (e^-L+R)	0.84	0.89

Precision medium Q^2 HERA-I data ~unshifted

New high Q^2 HERA-II data shifted by ~1.7% (less than 1 std.dev)

H1 Systematic Error Source Correlation

Data set	$\delta^{\mathcal{L}}$		δ^{E}	δ^{θ}	δ^{h}	δ^{N}	δ^{B}	δ^{V}	δ^{S}	$\delta^{\rm pol}$
e^+ Combined low Q^2	$\delta^{\mathcal{L}1}$									
e^+ Combined low E_p	$\delta^{\mathcal{L}1}$									
e^+ NC 94-97	$\delta^{\mathcal{L}1}$	$\delta^{\mathcal{L}2}$	δ^{E1}	$\delta^{\theta 1}$	δ^{h1}	δ^{N1}	δ^{B1}	–	–	–
e^+ CC 94-97	$\delta^{\mathcal{L}1}$	$\delta^{\mathcal{L}2}$	–	–	δ^{h1}	δ^{N1}	δ^{B1}	δ^{V1}	–	–
e^- NC 98-99	$\delta^{\mathcal{L}1}$	$\delta^{\mathcal{L}3}$	δ^{E1}	$\delta^{\theta 2}$	δ^{h1}	δ^{N1}	δ^{B1}	–	–	–
e^- NC 98-99 *high* y	$\delta^{\mathcal{L}1}$	$\delta^{\mathcal{L}3}$	δ^{E1}	$\delta^{\theta 2}$	δ^{h1}	δ^{N1}	–	–	δ^{S1}	–
e^- CC 98-99	$\delta^{\mathcal{L}1}$	$\delta^{\mathcal{L}3}$	–	–	δ^{h1}	δ^{N1}	δ^{B1}	δ^{V2}	–	–
e^+ NC 99-00	$\delta^{\mathcal{L}1}$	$\delta^{\mathcal{L}4}$	δ^{E1}	$\delta^{\theta 2}$	δ^{h1}	δ^{N1}	δ^{B1}	–	δ^{S1}	–
e^+ CC 99-00	$\delta^{\mathcal{L}1}$	$\delta^{\mathcal{L}4}$	–	–	δ^{h1}	δ^{N1}	δ^{B1}	δ^{V2}	–	–
e^+ NC *high* y	$\delta^{\mathcal{L}5}$	$\delta^{\mathcal{L}6}, \delta^{\mathcal{L}7}$	δ^{E2}	$\delta^{\theta 3}$	δ^{h2}	δ^{N2}	–	–	δ^{S2}	–
e^- NC *high* y	$\delta^{\mathcal{L}5}$	$\delta^{\mathcal{L}8}, \delta^{\mathcal{L}9}$	δ^{E2}	$\delta^{\theta 3}$	δ^{h2}	δ^{N2}	–	–	δ^{S2}	–
e^+ NC L	$\delta^{\mathcal{L}5}$	$\delta^{\mathcal{L}6}$	δ^{E2}	$\delta^{\theta 3}$	δ^{h2}	δ^{N2}	δ^{B1}	–	–	δ^{P1}
e^+ CC L	$\delta^{\mathcal{L}5}$	$\delta^{\mathcal{L}6}$	–	–	δ^{h2}	δ^{N3}	δ^{B1}	δ^{V3}	–	δ^{P1}
e^+ NC R	$\delta^{\mathcal{L}5}$	$\delta^{\mathcal{L}7}$	δ^{E2}	$\delta^{\theta 3}$	δ^{h2}	δ^{N2}	δ^{B1}	–	–	δ^{P2}
e^+ CC R	$\delta^{\mathcal{L}5}$	$\delta^{\mathcal{L}7}$	–	–	δ^{h2}	δ^{N3}	δ^{B1}	δ^{V3}	–	δ^{P2}
e^- NC L	$\delta^{\mathcal{L}5}$	$\delta^{\mathcal{L}8}$	δ^{E2}	$\delta^{\theta 3}$	δ^{h2}	δ^{N2}	δ^{B1}	–	–	δ^{P3}
e^- CC L	$\delta^{\mathcal{L}5}$	$\delta^{\mathcal{L}8}$	–	–	δ^{h2}	δ^{N3}	δ^{B1}	δ^{V3}	–	δ^{P3}
e^- NC R	$\delta^{\mathcal{L}5}$	$\delta^{\mathcal{L}9}$	δ^{E2}	$\delta^{\theta 3}$	δ^{h2}	δ^{N2}	δ^{B1}	–	–	δ^{P4}
e^- CC R	$\delta^{\mathcal{L}5}$	$\delta^{\mathcal{L}9}$	–	–	δ^{h2}	δ^{N3}	δ^{B1}	δ^{V3}	–	δ^{P4}

correlation of H1 systematic error sources

$\delta^{\mathcal{L}1}$ → 0.5% BH theoretical error HERA-I

$\delta^{\mathcal{L}5}$ → 2.3% Compton lumi error HERA-II

$\delta^{\mathcal{L}\text{6-9}}$ → 1.5% Compton unc. error HERA-II

Data Period	Global Normalisation	Per Period Normalisation	Total Normalisation
e^+ Combined low Q^2	0.993	–	0.993
e^+ Combined low E_p	0.993	–	0.993
HERA I e^+ 94-97	0.993	0.999	0.992
HERA I e^- 98-99	0.993	1.003	0.996
HERA I e^+ 99-00	0.993	1.005	0.998
HERA II e^+ L	1.029	0.991	1.020
HERA II e^+ R	1.029	1.013	1.042
HERA II e^- L	1.029	1.010	1.039
HERA II e^- R	1.029	1.014	1.043

normalisations from H1PDF 2012

Low Q^2 data shifted by -0.7%
HERA-I high Q^2 by -0.3%
HERA-II high Q^2 by +2 to +4%

All shifts are <1.3 std.devs

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)

desy-09-158

HERAPDF1.5
Include additional NC and CC HERA-II data
Complete MSbar NLO and NNLO fit
NLO: standard parameterisation with10 parameters
HERAPDF1.5f
NNLO: extended fit with 14 parameters

H1-10-142 / ZEUS-prel-10-018

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

xg, xu_v, xd_v, $x\bar{U}$, $x\bar{D}$ → xg, $xU = xu + xc$, $xD = xd + xs$, $x\bar{U} = x\bar{u} + x\bar{c}$, $x\bar{D} = x\bar{d} + x\bar{s}$ →

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

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

Apply momentum/counting sum rules:

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

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

Parameter constraints:
$B_{uv} = B_{dv}$
$B_{Ubar} = B_{Dbar}$
sea = 2 x (Ubar +Dbar)
Ubar = Dbar at x=0

Q_0^2 = 1.9 GeV^2 (below m_c)
Q^2 > 3.5 GeV^2
$2 \times 10^{-4} < x < 0.65$
Fits performed using RT-VFNS

QCD Analysis

HERAPDF1.0 central values:

	A	B	C	E
xg	6.8	0.22	9.0	
xu_v	3.7	0.67	4.7	9.7
xd_v	2.2	0.67	4.3	
$x\bar{U}$	0.113	−0.165	2.6	
$x\bar{D}$	0.163	−0.165	2.4	

χ^2/ndf = 574/582

Experimental systematic sources of uncertainty allowed to float in fit
Include model assumptions into uncertainty:
f_s , m_c , m_b , Q^2_0, Q^2_{min}

Variation	Standard Value	Lower Limit	Upper Limit
f_s	0.31	0.23	0.38
m_c [GeV]	1.4	1.35$^{(a)}$	1.65
m_b [GeV]	4.75	4.3	5.0
Q^2_{min} [GeV^2]	3.5	2.5	5.0
Q^2_0 [GeV^2]	1.9	1.5$^{(b)}$	2.5$^{(c,d)}$

$^{(a)} Q_0^2 = 1.8$ $^{(c)} m_c = 1.6$
$^{(b)} f_s = 0.29$ $^{(d)} f_s = 0.34$

Excellent consistency of input data allow standard statistical error definition:
$\Delta\chi^2 = 1$

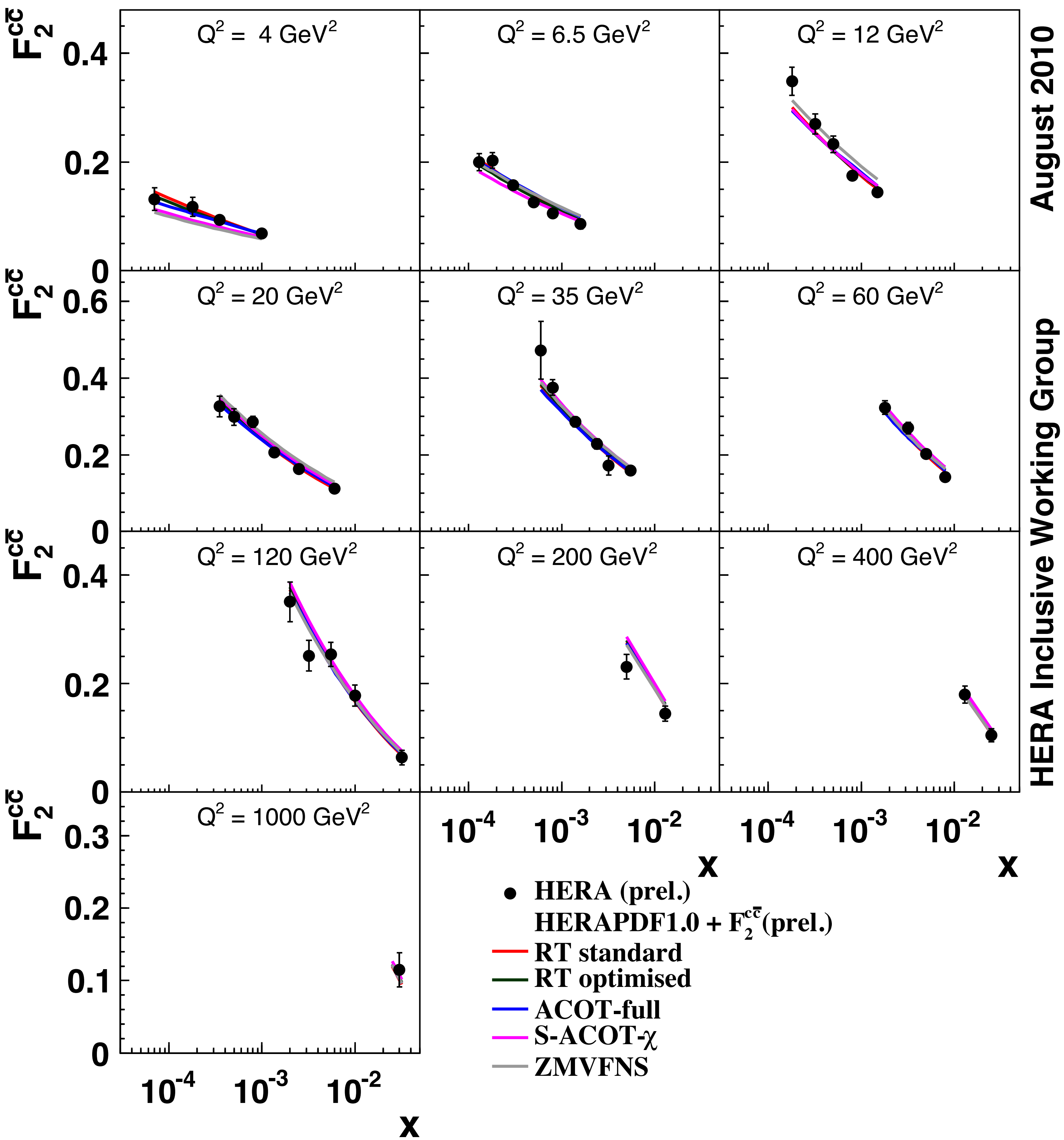
Exclusive jet data required for free α_s fit
See talk of Krzysztof Nowak

In 14 parameter fit:
release $B_{uv} = B_{dv}$ constraint
allow more flexible gluon

$$xg(x,Q_0^2) = A \cdot x^B \cdot (1-x)^C - A' \cdot x^{B'} \cdot (1-x)^{25}$$

allows for valence-like or negative gluon at Q_0^2

Charm Content of the Proton



The inclusive charm content of proton can be measured in several methods: D* decays , impact parameter significance... Combination yields ~5-10% precision

Data cover wide phase space region including charm threshold region

Theory predictions have small spread
⇒ use optimised m_c parameter

Spread of LHC Z/W production predictions is reduced ~4.5% → ~0.7%
when using optimal value of m_c