Combined HERA DIS data and PDF fits

New Trends in HERA Physics, Ringberg'08

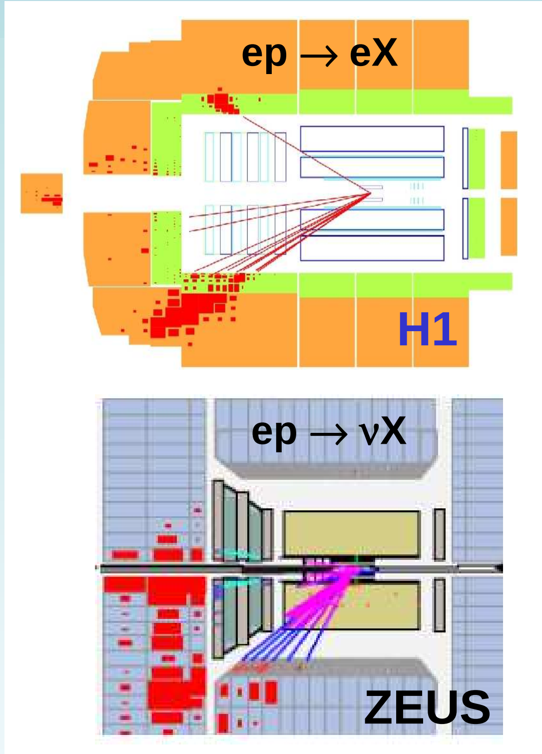
Claire Gwenlan (University of Oxford, STFC Fellow)
on behalf of the **HERA Structure Functions Working Group**

Outline

- Introduction
- Combined HERA DIS data
- NLO QCD fit to the data
- Summary

Motivation

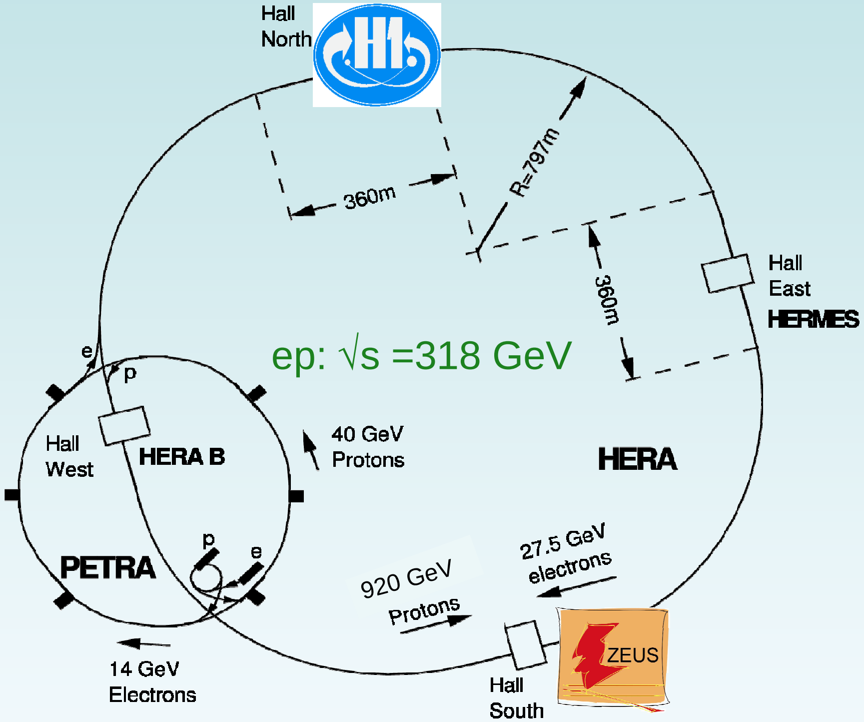
- HERA collider has provided a **wealth** of $e^{\pm}p$ data (from 94-07)
- measurements of Deep Inelastic Scattering (DIS), made by **H1** and **ZEUS**, **crucial** for constraining **quark** and **gluon** densities in the **proton**
- analysis of HERA-I data now (almost) complete and best precision HERA-II measurements coming soon …

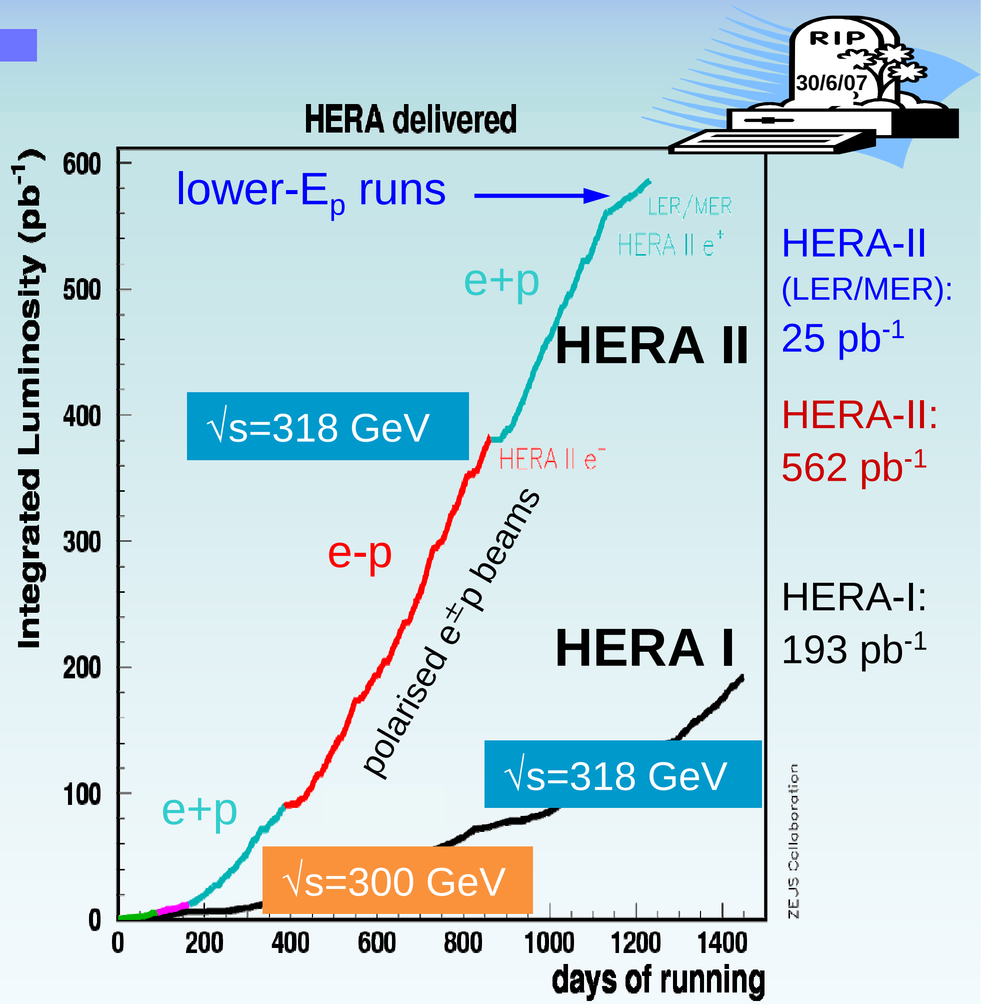


NOW: want to **maximise** impact of HERA by **combining** H1 and ZEUS data → obtain best precision cross sections → leading to most precise extractions of the proton parton density functions (PDFs)

HERA collider

HERA: world's **only** ep collider





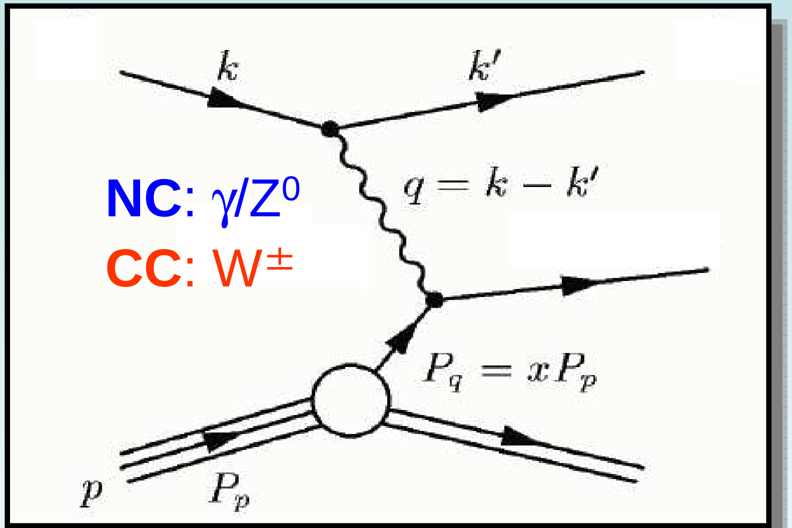
HERA ep data collected per exp.:

	e^+p	e^-p
HERA-I	~100 pb^{-1}	~20 pb^{-1}
HERA-II	~200 pb^{-1}	~200 pb^{-1}

HERA laid to rest summer'07

Deep Inelastic Scattering

Processes: Neutral Current (**NC**): $ep \rightarrow eX$; Charged Current (**CC**): $ep \rightarrow \nu X$



Kinematic Variables:

- 4-momentum transfer ("resolution"): $Q^2=-q^2=-(k-k')^2$
- Bjorken scaling variable: $x=Q^2/2p.q$
- inelasticity: $y=p.q/p.k$

related via s: $Q^2=sxy$

[where $\sqrt{s}$=COM energy: $s=(k+p)^2$]

NC: "reduced" cross section:

$$\tilde{\sigma}^{\pm} = \frac{d^2\sigma^{\pm}}{dxdQ^2}\frac{Q^4 x}{2\pi\alpha^2 Y_+} = \tilde{F}_2^{\pm} \mp \frac{Y_-}{Y_+} x\tilde{F}_3^{\pm} - \frac{y^2}{Y_+}\tilde{F}_L^{\pm}$$

valence and sea quarks
[gluon via scaling violations]

valence quarks

gluon

CC: similar decomposition, but **different** quark combinations accessed in e^+p or e^-p → **flavour sensitive**

Combined HERA DIS data

Idea:

AIM: combine **H1** and **ZEUS** inclusive NC and CC DIS data

specifically: "reduced" DIS cross sections; HERA I data only (so far!)

some details:

- combination method (developed by A. Glazov) uses an iterative X^2 minimisation → takes full account of correlated systematics
- different technologies of the **H1** and **ZEUS** detectors exploited to "**cross-calibrate**", and hence improve the systematic uncertainties
- **key assumption**: the two experiments are measuring the **same** cross section at the **same** kinematic point

Presented here: preliminary results, as submitted to Lepton-Photon '07

NC and CC data sets

1153 data points in total; $Q^2 > 1.5$ GeV^2

Based on published (as in summer'07) NC and CC data from HERA I:

input data: **published** HERA-I cross sections [total lumi.: ~240 pb^{-1}]

data set		x range		Q^2 range (GeV^2)		$\mathcal{L}$ pb^{-1}	comment
H1 NC min. bias	97	0.00008	0.02	1.5	12	1.8	e^+p $\sqrt{s} = 301$ GeV
H1 NC low Q^2	96 – 97	0.000161	0.20	12	150	17.9	e^+p $\sqrt{s} = 301$ GeV
H1 NC	94 – 97	0.0032	0.65	150	30 000	35.6	e^+p $\sqrt{s} = 301$ GeV
H1 CC	94 – 97	0.013	0.40	300	15 000	35.6	e^+p $\sqrt{s} = 301$ GeV
H1 NC	98 – 99	0.0032	0.65	150	30 000	16.4	e^-p $\sqrt{s} = 319$ GeV
H1 CC	98 – 99	0.013	0.40	300	15 000	16.4	e^-p $\sqrt{s} = 319$ GeV
H1 NC	99 – 00	0.00131	0.65	100	30 000	65.2	e^+p $\sqrt{s} = 319$ GeV
H1 CC	99 – 00	0.013	0.40	300	15 000	65.2	e^+p $\sqrt{s} = 319$ GeV
ZEUS NC	96 – 97	0.00006	0.65	2.7	30 000	30.0	e^+p $\sqrt{s} = 301$ GeV
ZEUS CC	94 – 97	0.015	0.42	280	17 000	47.7	e^+p $\sqrt{s} = 301$ GeV
ZEUS NC	98 – 99	0.005	0.65	200	30 000	15.9	e^-p $\sqrt{s} = 319$ GeV
ZEUS CC	98 – 99	0.015	0.42	280	30 000	16.4	e^-p $\sqrt{s} = 319$ GeV
ZEUS NC	99 – 00	0.005	0.65	200	30 000	63.2	e^+p $\sqrt{s} = 319$ GeV
ZEUS CC	99 – 00	0.008	0.42	280	17 000	60.9	e^+p $\sqrt{s} = 319$ GeV

NB: H1 minimum bias ($Q^2 < 12$ GeV^2) moved up by 3.4% after re-analysis of luminosity

NC e^+p example

$$\sigma_r^{e^\pm p \to e^\pm X} = F_2 - \frac{y^2}{Y_+} F_L \mp \frac{Y_-}{Y_+} xF_3$$

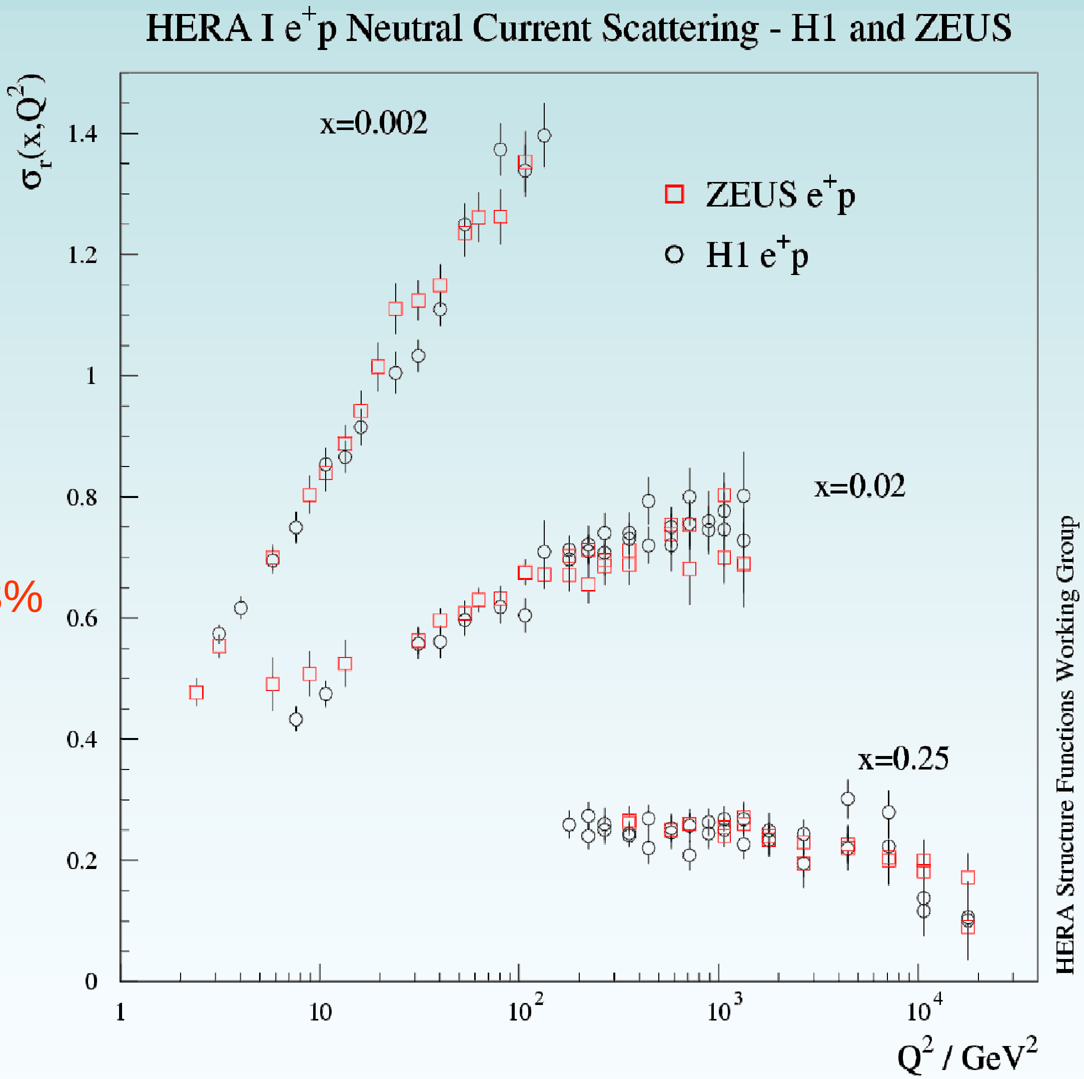
EXAMPLE data set for averaging: **e^+p NC DIS** from **H1** and **ZEUS**

precise measurements from **two** experiments:-

uncertainties:

- $Q^2 < 100$ GeV^2 : $\delta_{stat} < 1\%$, $\delta_{syst} < 3\%$
- $Q^2 > 1000$ GeV^2 : $\delta_{stat} > \delta_{syst}$

these data (plus others, as listed on previous slide) to be **combined** into **average** "HERA data set"



HERA combination method

Procedure (in a nutshell):

i. move all data points to **common** (x,Q^2) grid

ii. transform data to **common** proton beam energy

iii. calculate **average values** and **uncertainties**

iv. evaluate uncerts. due to **combination procedure**

further details on next slides ➔

Common (x,Q²)

move all data points to **common** (x,Q²) grid

- essentially: **H1** binning in **x**; **ZEUS** binning in **Q²**
- shift measured data by **simple interpolation** using H1PDF2k:

$$\sigma_{ep}^{meas}(x_{grid}, Q^2_{grid}) = \frac{\sigma_{ep}^{th}(x_{grid}, Q^2_{grid})}{\sigma_{ep}^{th}(x, Q^2)} \sigma_{ep}^{meas}(x, Q^2)$$

NB: sensitivity of interpolation to choice of PDF checked using ZEUS-Jets:
- NC **shift factors** agree to within a few permille;
- CC to <2% (i.e. much less than statistical uncertainties)

Beam energy correction

transform data to E_p = 920 GeV beam energy:

simple beam energy correction for CC data:

$$\sigma^{e^\pm p}_{CC\ 920}(x,Q^2) = \sigma^{e^\pm p}_{CC\ 820}(x,Q^2)\frac{\sigma^{th,e^\pm p}_{CC\ 920}(x,Q^2)}{\sigma^{th,e^\pm p}_{CC\ 820}(x,Q^2)}$$

additive beam energy correction performed for NC data:

$$\sigma^{e^\pm p}_{NC\ 920}(x,Q^2) = \sigma^{e^\pm p}_{NC\ 820}(x,Q^2) + \Delta\sigma^{e^\pm p}_{NC}(x,Q^2,y_{920},y_{820}).$$

$$\Delta\sigma e^\pm p_{NC}(x,Q^2,y_{920},y_{820}) = F_L(x,Q^2)\left[\frac{y^2_{820}}{Y^+_{820}} - \frac{y^2_{920}}{Y^+_{920}}\right] + xF_3(x,Q^2)\left[\pm\frac{Y^-_{820}}{Y^+_{820}} \mp \frac{Y^-_{920}}{Y^+_{920}}\right].$$

systematic uncertainty estimate: compare F_L=0 and F_L=F_L(H1PDF2k)
- up to 5% at large y → assigned as a correlated **"procedural"** systematic

Method

A. Glazov [DIS'05, HERA-LHC ws]

HERA averaging [uses Lagrange Multiplier (or "Hessian") method]:
model-independent* combination of H1 and ZEUS data, prior to QCD analysis, taking **full account** of correlated systematics

*only theoretical input to procedure:
H1 and **ZEUS** measure the **same** cross sections at the **same** x, Q^2, y
[i.e. we assume physics is the same, either side of the HERA ring!!!]

this gives a **strong constraint** → each experiment **calibrates** the other
→ works well since **systematic sources** rather **different** between experiments

method minimises the following probability (X^2) distribution ➔

X^2 definition

$\equiv$ **standard average** if $\Delta\alpha_j=0$

X^2 for single data set:

$$\chi^2_{\exp}(M^{i,true},\Delta\alpha_j) = \sum_i \frac{\left[M^{i,true} - \left(M^i + \sum_j \frac{\partial M^i}{\partial \alpha_j}\Delta\alpha_j\right)\right]^2}{\sigma_i^2} + \sum_j \frac{(\Delta\alpha_j)^2}{\sigma_{\alpha_j}^2}$$

- M^i : **measured** central values
- σ_i : **statistical** and **uncorrelated systematic** uncertainties of M
- σ_{α_j} : **correlated systematic** uncertainties
- $\frac{\partial M^i}{\partial \alpha_j}$: sensitivity of datum i to systematic uncertainty j
- $M^{i,true}$: fitted **combined** H1-ZEUS data [i.e. the "true" HERA values]
- $\Delta\alpha_j$: fitted shifts of **correlated uncertainties**

It's a **cross-calibration** of correlated systematics between different data sets

X^2 definition

X^2 for single data set:

$$\chi^2_{\exp}(M^{i,true}, \Delta\alpha_j) = \sum_i \frac{\left[M^{i,true} - \left(M^i + \sum_j \frac{\partial M^i}{\partial \alpha_j} \Delta\alpha_j \right) \right]^2}{\sigma_i^2} + \sum_j \frac{(\Delta\alpha_j)^2}{\sigma_{\alpha_j}^2}$$

CAVEAT:

- in principle, a nice simple X^2, which allows minimisation by **linear equations**
- **unbiased** for **"additive"** uncertainties (those independent of central value)
- BUT for **cross sections**, many uncertainties are **"multiplicative"** (ie. proportional to the central value)

→ **introduces bias towards smaller averages:** i.e. a smaller M^i will have a smaller relative uncertainty and hence give a smaller X^2

bias can be avoided by **modifying the definition** of the X^2 ➔

Revised X^2 definition

<u>**X^2** for single data set:</u>

$$\chi^2_{\exp}(M^{i,true},\Delta\alpha_j) = \sum_i \frac{\left[M^{i,true} - \left(M^i + \sum_j \frac{\partial M^i}{\partial \alpha_j} \frac{M^{i,true}}{M^i} \Delta\alpha_j\right)\right]^2}{\left(\sigma_i \frac{M^{i,true}}{M^i}\right)^2} + \sum_j \frac{(\Delta\alpha_j)^2}{\sigma^2_{\alpha_j}}$$

minimisation is now **non-linear** → use an **iterative procedure**:

1. minimise original X^2 to find an **initial approximation** $\{M^{i,true}\}$
2. translate **multiplicative** uncertainties to **additive:** $\sigma_i \rightarrow \sigma_i\,(M^{i,true}/M^i)$
3. repeat step 1.

→ **convergence** is usually after two iterations

$cov(M^{i,true},M^{j,true})$ gives the **error matrix** for the combined data

[NB. full X^2 is the **sum** over all X_{exp}^2]

Uncertainties

<u>treatment/prescription</u>:

- statistical and uncorrelated systematics combined in **quadrature** to give total point-to-point **uncorrelated uncertainty** (σ_i)
- treatment of **correlated** systematic uncertainties:
  - correlated **between** data sets of **<u>same</u> experiment**:
    - normalisation (clearly treat as **multiplicative**)
    - others (e.g. energy scale): **additive** or **multiplicative**? **Debatable!!!**

    extremes: treat all as “additive” and all as “multiplicative”

    → assign difference as additional correlated **“procedural”** uncert.
  - correlations **between** experiments? (next slide)

in total: **43** **sources** of correlated systematics from the data

Correlations between exps.?

consideration of correlations between H1 and ZEUS:

- correlations **between** experiments?

  - **similar methods** for MC simulations, calibration techniques, …

  → some correlations should exist

  identified twelve possible uncertainties of **common origin**:

  CHECK: take all pairs as **correlated** or **uncorrelated** in turn

  → calculate 2^{12}-1 alternative averages → determine **deviations from central value**

  → **mostly negligible**; largest differences arise from hadronic energy scale and photoproduction background

→ deviations from these two sources treated as **“procedural”** uncertainties

Procedural uncertainties

4 sources of uncertainty from the combination procedure

<u>summary of sources:</u>

- centre-of-mass energy correction
  - mostly at permille level, but up to 5% at largest y, Q^2~10 GeV^2

    [**note**: if only data with y < 0.35 transformed in centre-of-mass energy (as in most recent combinations), this uncertainty reduces to < 0.5%]
- **additive** versus **multiplicative** systematics
  - < 1% except at large x,Q^2
- correlations **between** experiments:

  - **hadronic energy scale**: 1% at low y

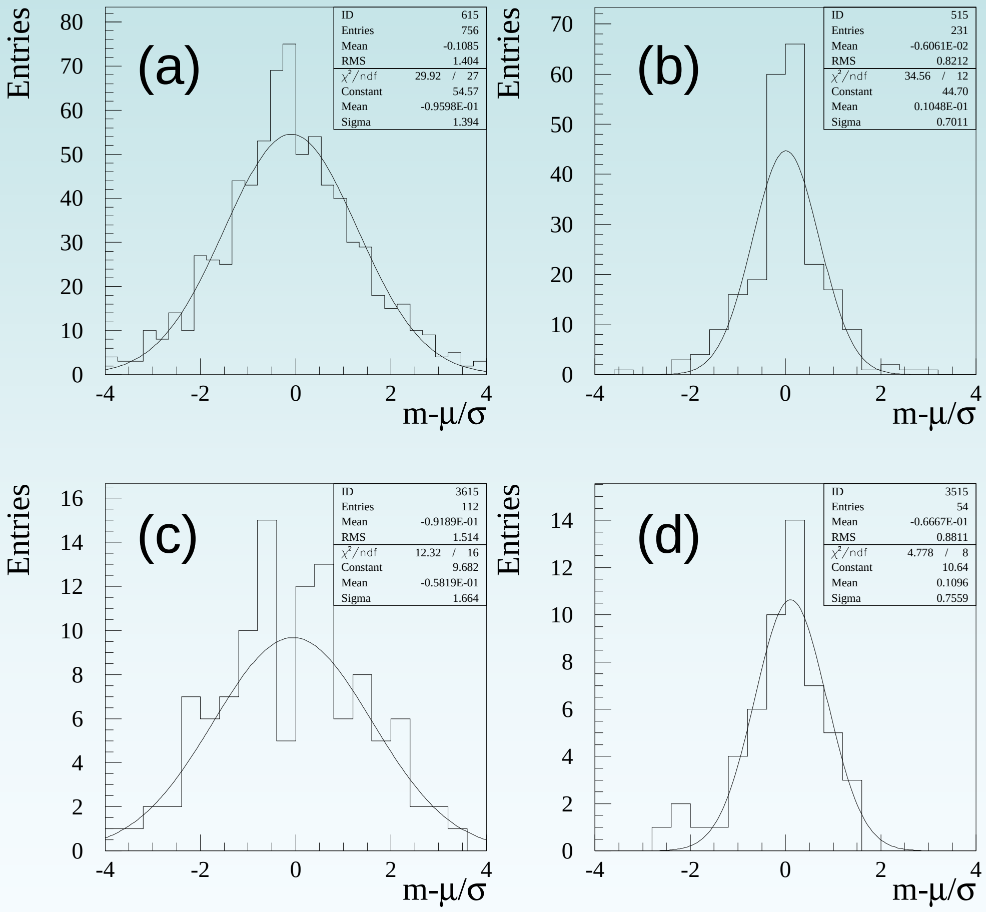
  - subtraction of **photoproduction** background: 1-2% at large y

these uncertainties are added to the averaged data points

[at **few permille level** across **most** of the **kinematic plane**, with few exceptions]

Fit quality

$(M\text{-}M^{true})/\sigma_i$



1153 **individual** NC and CC measurements from HERA I **averaged** to 554 **points**

resulting **good quality** of fit:

X^2/dof=510/599

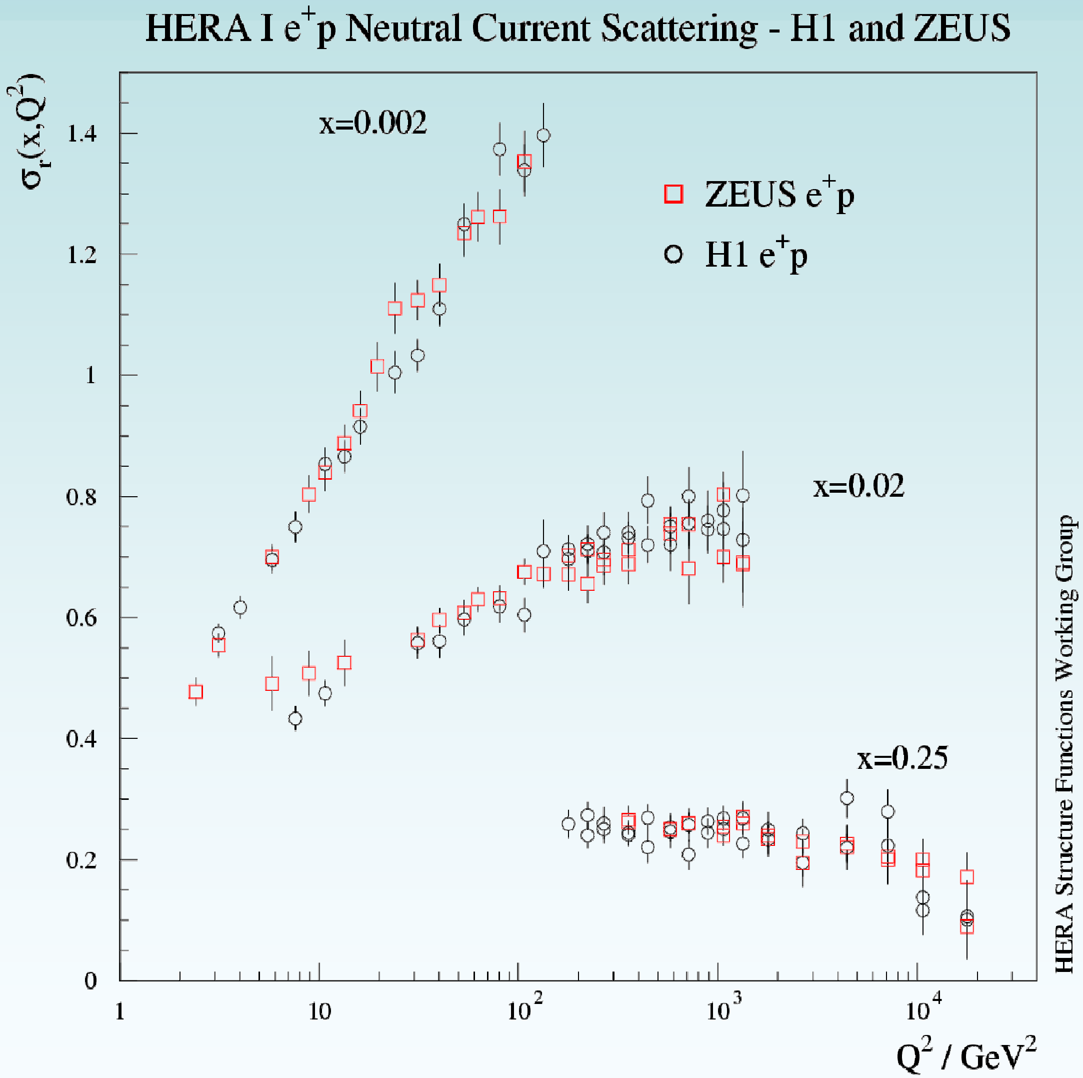
	pulls	
	mean	sigma
(a) NC e+p	-0.09	1.4
(b) NC e-p	0.01	0.7
(c) CC e+p	-0.05	1.7
(d) CC e-p	0.1	0.8

→ **no** significant **tensions** seen across kinematic plane

Note: 43 systematic uncertainties from data and 4 from combination procedure

Results (i): NC e^+p

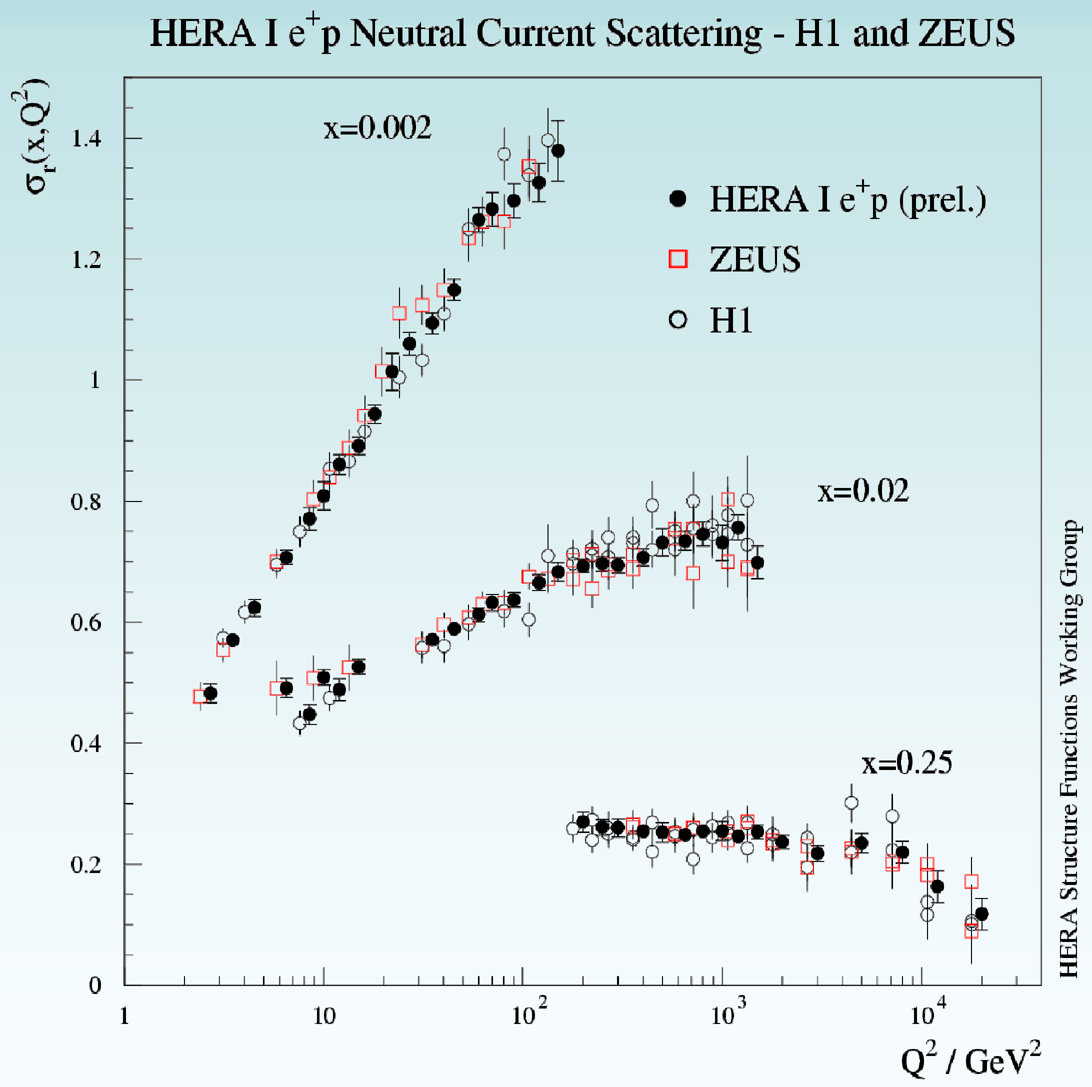
<u>REMINDER:</u> individual measurements from **H1** and **ZEUS** [zoom in on three example x values]



Results (i): NC e^+p

<u>REMINDER:</u> individual measurements from **H1** and **ZEUS** [zoom in on three example x values]

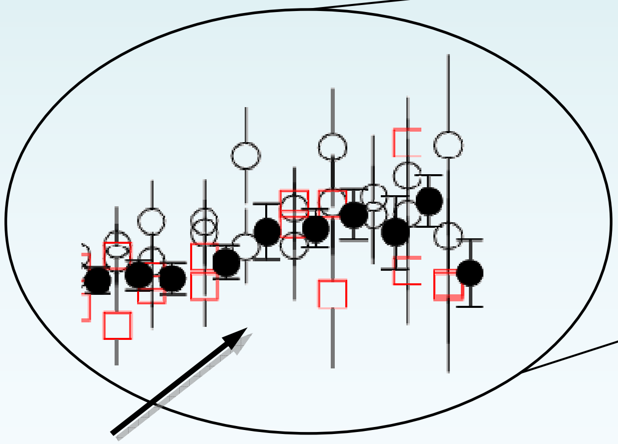
Compared to **combined data-set** (solid points)



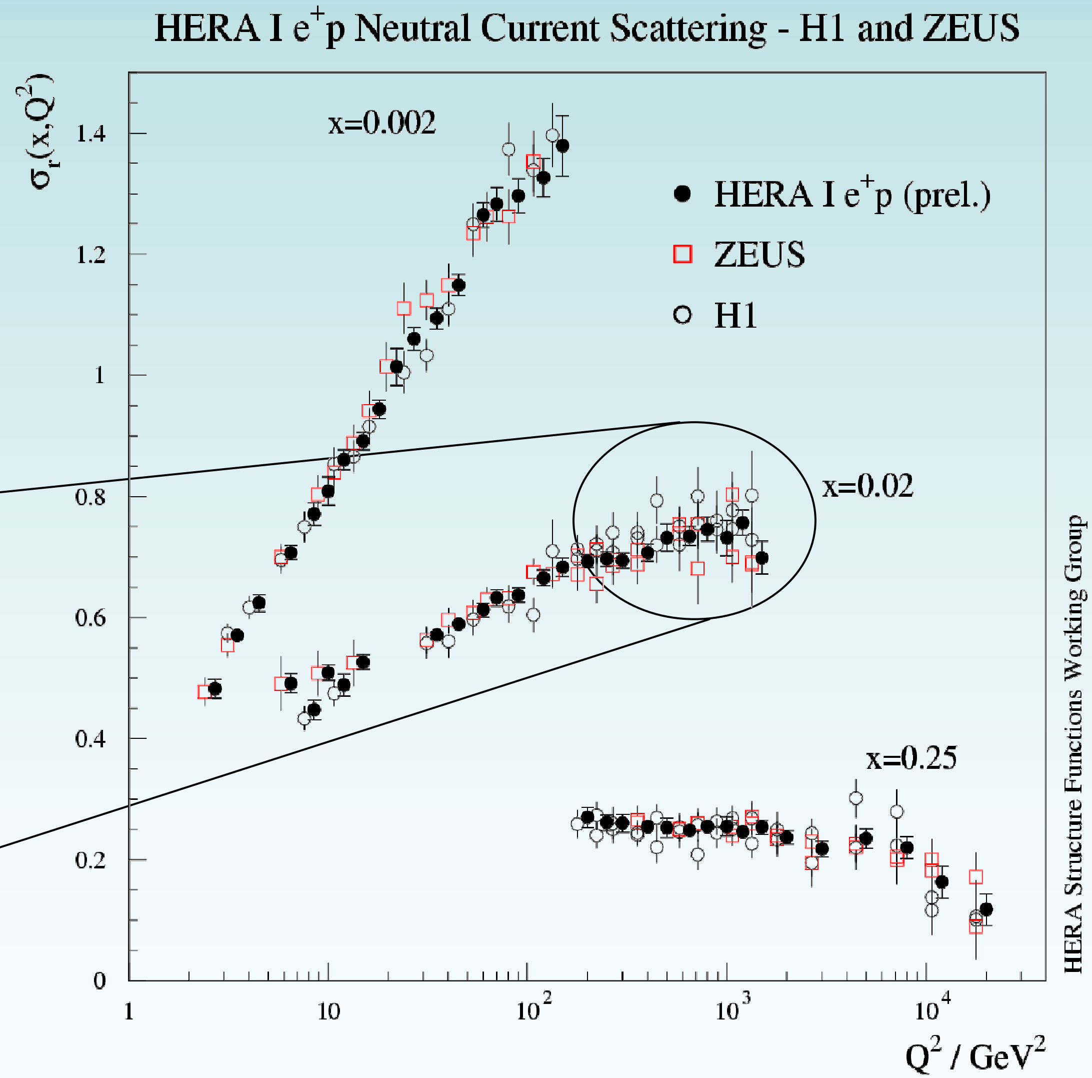
Results (i): NC e^+p

<u>REMINDER:</u> individual measurements from **H1** and **ZEUS** [zoom in on three example x values]

Compared to **combined data-set** (solid points)



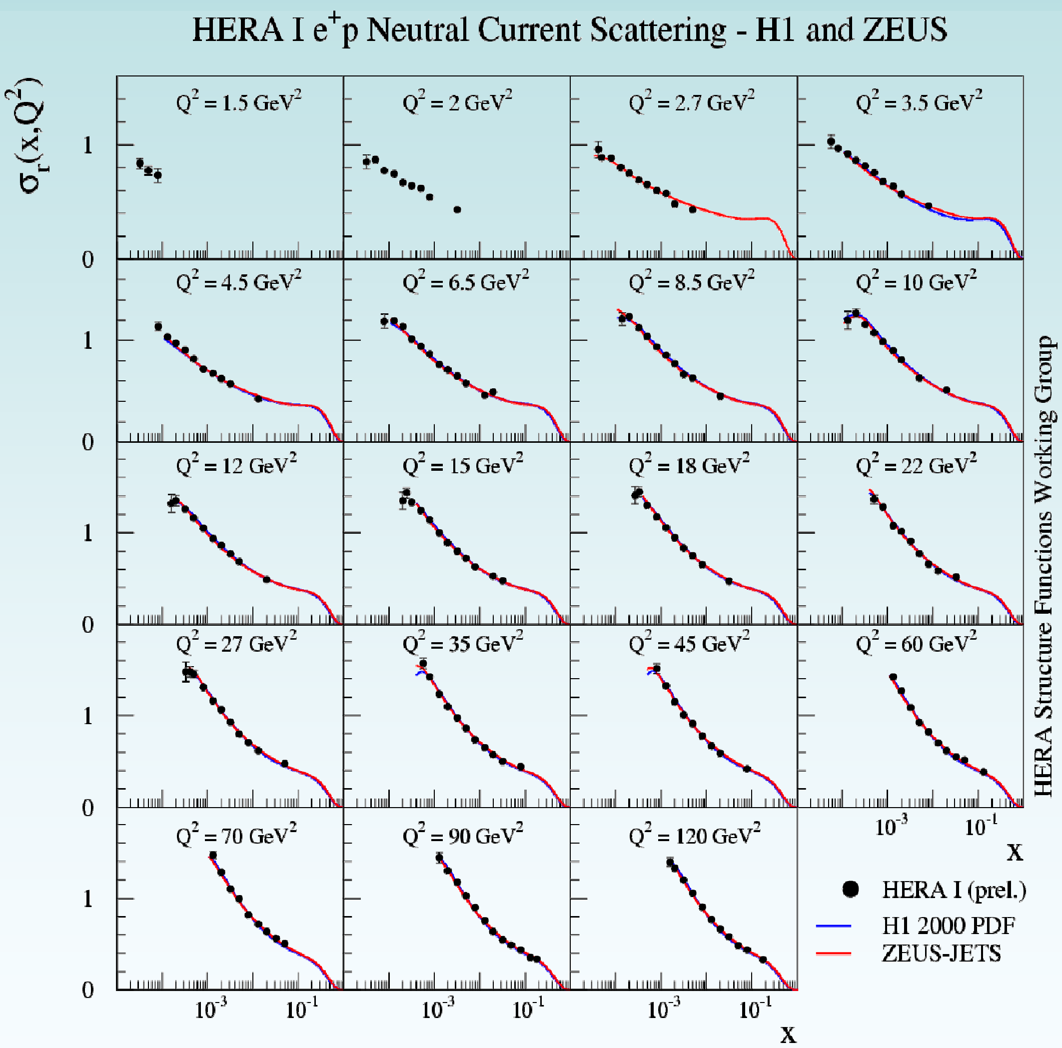
better than naiively-expected improvement from statistics: **"cross-calibration"**



Results (ii): NC e^+p

NC e^+p [at low Q^2]:

combined data compared to published **H1** and **ZEUS** **PDF fits** to (their own) data from **HERA I**

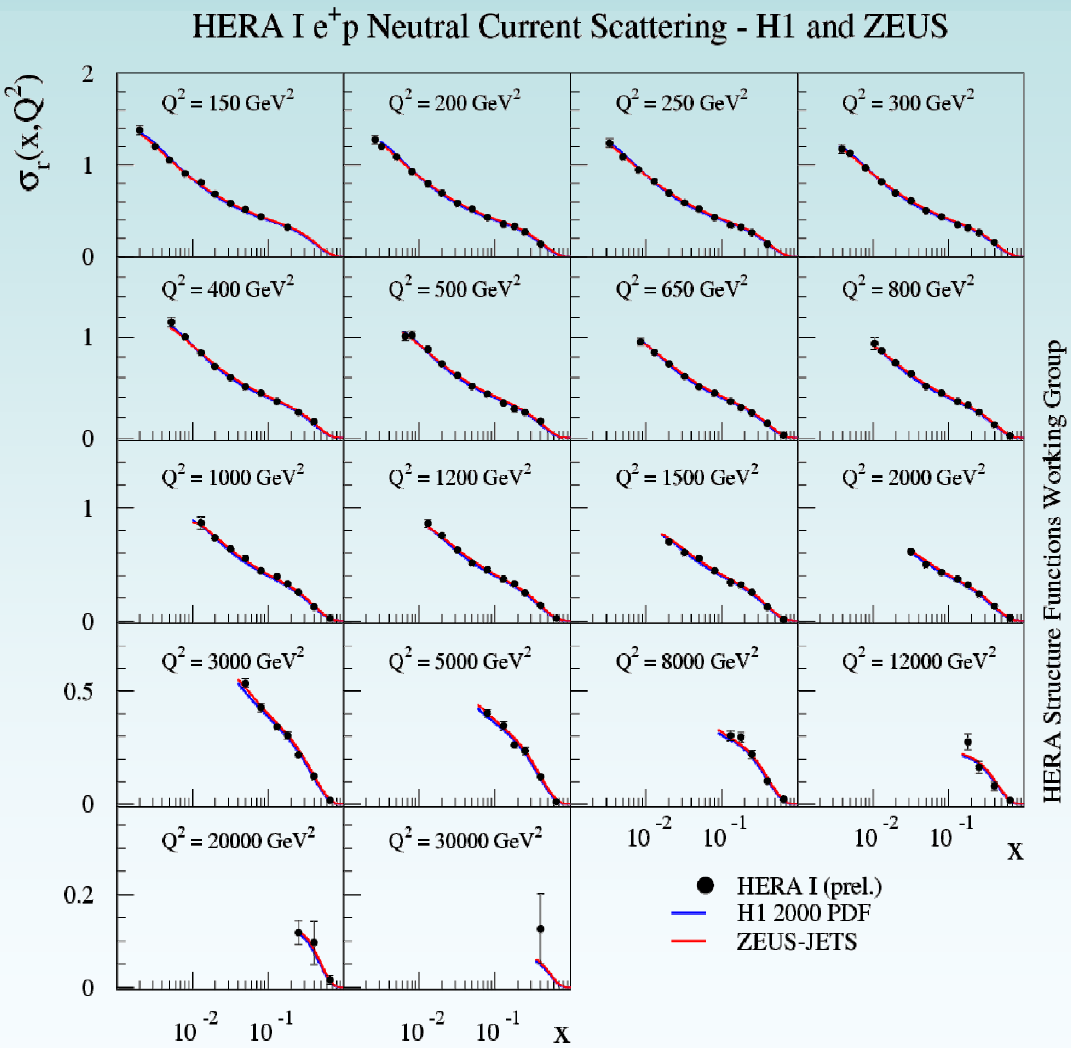


Results (iii): NC e^+p

NC e^+p [at high Q^2]:

combined data compared to published **H1** and **ZEUS** **PDF fits** to (their own) data from **HERA I**

[e-p equivalent in backups]

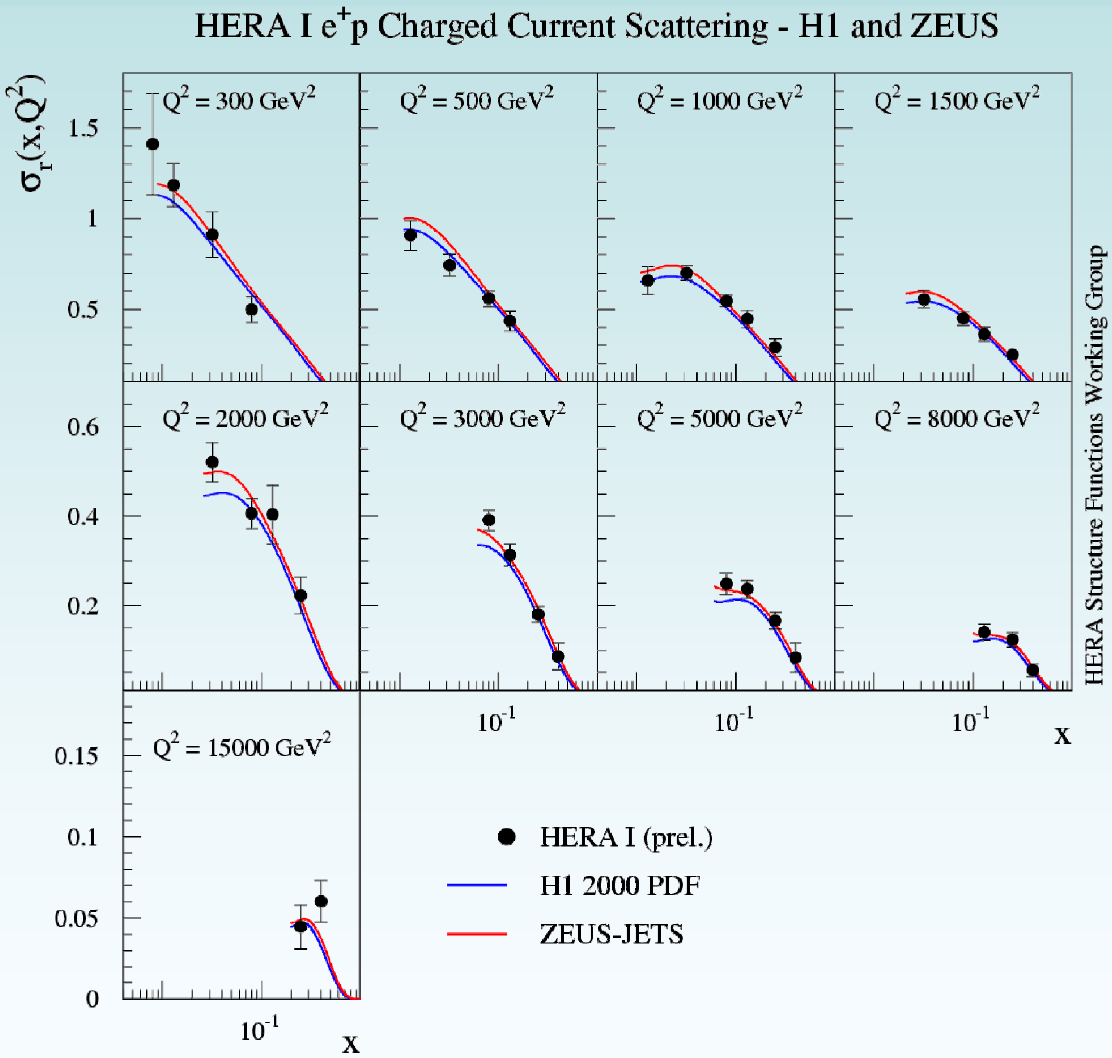


Results (iv): CC e^+p

CC e^+p:

combined data compared to published **H1** and **ZEUS** **PDF fits** to (their own) data from **HERA I**

[e-p equivalent in backups]



Results (cont.)

some final comments on the results

- all uncertainties **within** 1 sigma of original, published values
  [except normalisation of H1 low-Q^2 (96-97) → moved up by 1.6 sigma]
- almost all systematics improved. most significantly:
  - **H1** backward calorimeter energy scale:- factor of 3
  - **ZEUS** forward hadronic energy modelling:- factor of 4
- overall **precision improved**
  - $Q^2 < 12$ GeV^2: H1 and ZEUS separately ~2-3%; combined <2%
  - medium-Q^2: precision reaches 1.5%
  - high-Q^2: 10% level [statistics important here]

systematics now **smaller** than statistical uncerts. over most x,Q^2

QCD fit to the combined data

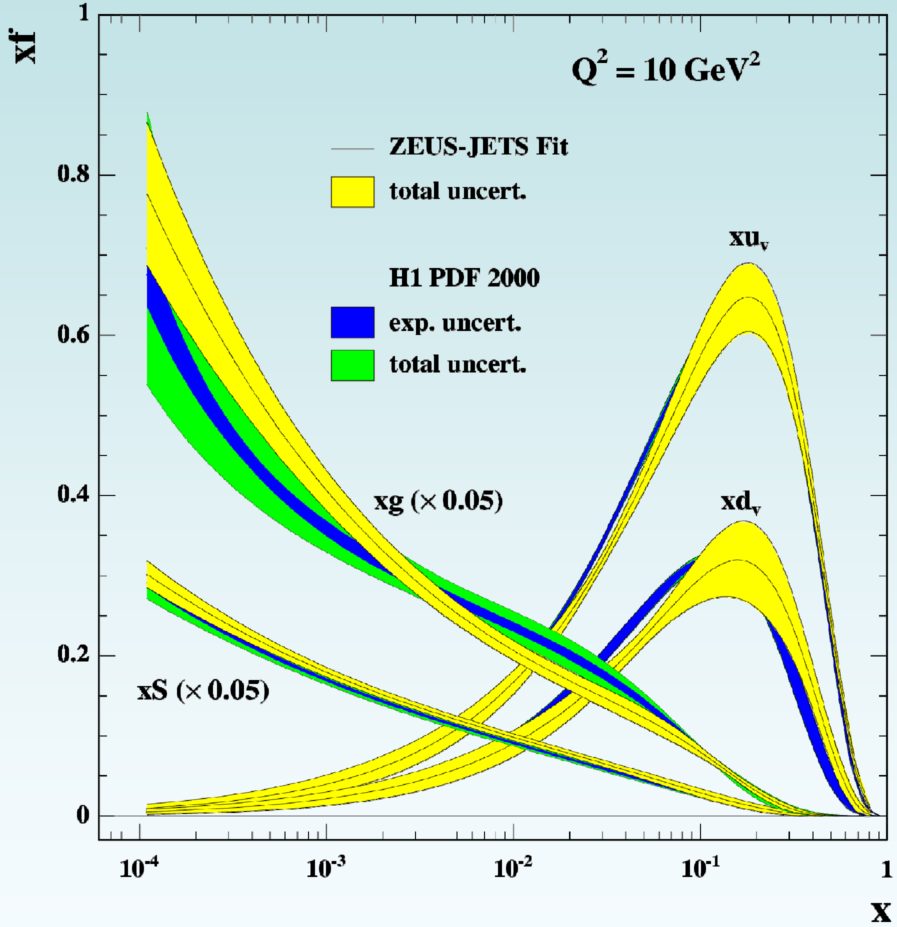
HERA NLO QCD fit

Previously: **H1** and **ZEUS** have performed **NLO QCD fits** to **their own** HERA-I data … ➔

NOW:
→ the **combined** HERA-I data have been used as **sole input** for a **new** **HERA NLO QCD fit** to extract the proton PDFs

AIM: **precision** extraction of PDFs using HERA data alone!!!

published HERA-I PDFs



Presented here: preliminary results, as submitted to ICHEP'08

HERA PDF parameterisation

Choose form of PDF parameterisation at Q_0^2 = 4 GeV^2

$$xf(x) = Ax^B(1-x)^C(1+Dx+Ex^2+Fx^3+\ldots)$$

normalisation

low-x behaviour

high-x behaviour

polynomial term

(terms added until no further X^2 advantage)

partons parameterised: gluon, u_v, d_v, $\bar{U} = \bar{u}+\bar{c}$, $\bar{D} = \bar{d}+\bar{s}+\bar{b}$

sea flavour break-up at Q_0: $s=f_s\bar{D}$, $c=f_c\bar{U}$, $A(\bar{U})=(1-f_s)/(1-f_c)A(\bar{D})$; with f_s=0.33, f_c=0.15

(consistent with dynamical generation)

	A	B	C	D	E
gluon	sum rule				
u_v	sum rule				
d_v	sum rule	$B(u_v)$			
$\bar{U}$	lim x->0 $\bar{u}/\bar{d}$->1				
$\bar{D}$		$B(\bar{U})$			

$xg(x)=Ax^B(1-x)^C$

$xu_v(x)=Ax^B(1-x)^C(1+DX+Ex^2)$

$xd_v(x)=Ax^B(1-x)^C$

$x\bar{U}(x)=Ax^B(1-x)^C$

$x\bar{D}(x)=Ax^B(1-x)^C$

parameter optimisation: start with **A,B,C** and add **D,E,F**… until no further X^2 advantage

→ 11 free parameters

HERA PDF parameterisation

some more notes:

- HERA PDF parameterisation inspired by **both** H1 and ZEUS
  - but less model dependence on B parameters than H1
  - no need for additional x(dbar-ubar) input, as in ZEUS
- H1 and ZEUS-style (**optimised**) parameterisations also looked at and used as model cross-checks (see backups)

"HERA" PDF parameterisation:
- results in **best** X^2 (although all three options are good)
- gives most **conservative** uncertainties

HERA PDF parameterisation: attempt at "best of both worlds"

More details

extra info on the fit:

- **NLO DGLAP framework** used to evolve PDFs in Q^2
- **heavy flavour** scheme: **Zero-Mass Variable-Flavour-Number**
  [for now; but work ongoing with General-Mass VFN schemes]
- renormalisation and factorisation scales: Q^2
- fit **573* combined** HERA-I NC and CC data points
- total of **11 free parameters** in the PDF fit (details on previous slide)

further fixed parameters:

- Q_0^2=4 GeV^2 **(starting scale)**
- Q_{min}^2 = 3.5 GeV^2 **(minimum Q^2 cut on fitted data)**
- m_c = 1.4 GeV **(charm mass);** m_b=4.75 GeV **(beauty mass)**
- $\alpha_s(M_Z)$ = 0.1176 [PDG2006 value] **(strong coupling)**

* from recent combination version where only points with y < 0.35 are transformed in E_p

Systematic error treatment

HERA **combination** procedure has already taken **full account** of correlated systematic uncertainties in the data:-

choice of treatment of uncertainties in HERA PDF fit:-

- combine 43 systematic uncertainties of the **data** with their statistical uncertainties, in **quadrature;**
- **OFFSET** the 4 systematic uncertainties arising from the **combination**

X^2/dof=477/(573-11)

[also **checked**:- treat all 47 systematics:

- in quadrature: **X^2=428/562**
- as correlated: **X^2=553/562**

all three methods **give similar** PDF central values and uncertainties]

self-consistency and **small systematics** of the **combined HERA data** allows the use of ΔX^2=1 to calculate the PDF parameter uncertainties

Model uncertainties

- several sources of model uncertainty considered:

(i) variations to be added to **total PDF uncertainty** (in quadrature):

	model variation	nominal	variations
m_c	charm mass (GeV)	1.4	**1.35, 1.5**
m_b	beauty mass (GeV)	4.75	**4.3, 5.0**
f_s	strange sea fraction at Q_0^2	0.33	**0.25, 0.40**
f_c	charm sea fraction at Q_0^2	0.15	**0.12, 0.18**
Q_0^2	starting scale (GeV^2)	4.0	**2.0, 6.0**
Q_{min}^2	cut on data included (GeV^2)	3.5	**2.5, 5.0**

[NB. **correlated variations**: i. for Q_0^2 variation, f_s and f_c also varied;
ii. for m_c variation, f_c also varied]

(ii) variations used as **model cross-checks** (shown in backups)**:**

	model variation	nominal	variations
$\alpha_s(M_Z)$	strong coupling	0.1176	**0.1156, 0.1196**
$xf(x)$	PDF parameterisation	“HERA”	**H1-, ZEUS-styles**

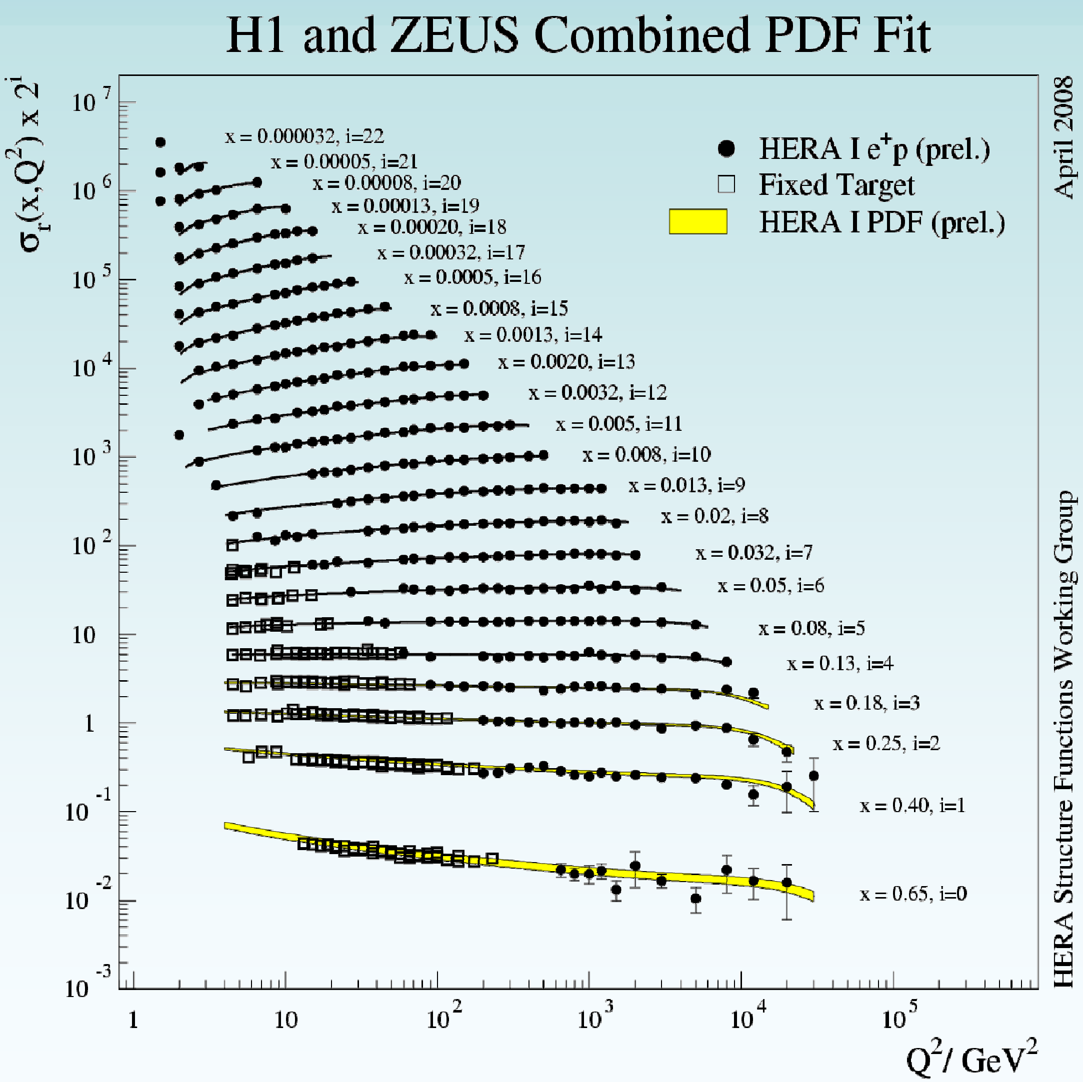
Results (i): NC e^+p comparison

Neutral Current e^+p

"HERAPDF0.1":
fit quality to the **combined HERA-I data** for **NC e^+p**

uncertainties on both **data** and **fit** included

beautifully **precise** data:-
very well described by **HERA-I PDF** [uncertainties can barely be resolved except at highest x,Q^2]



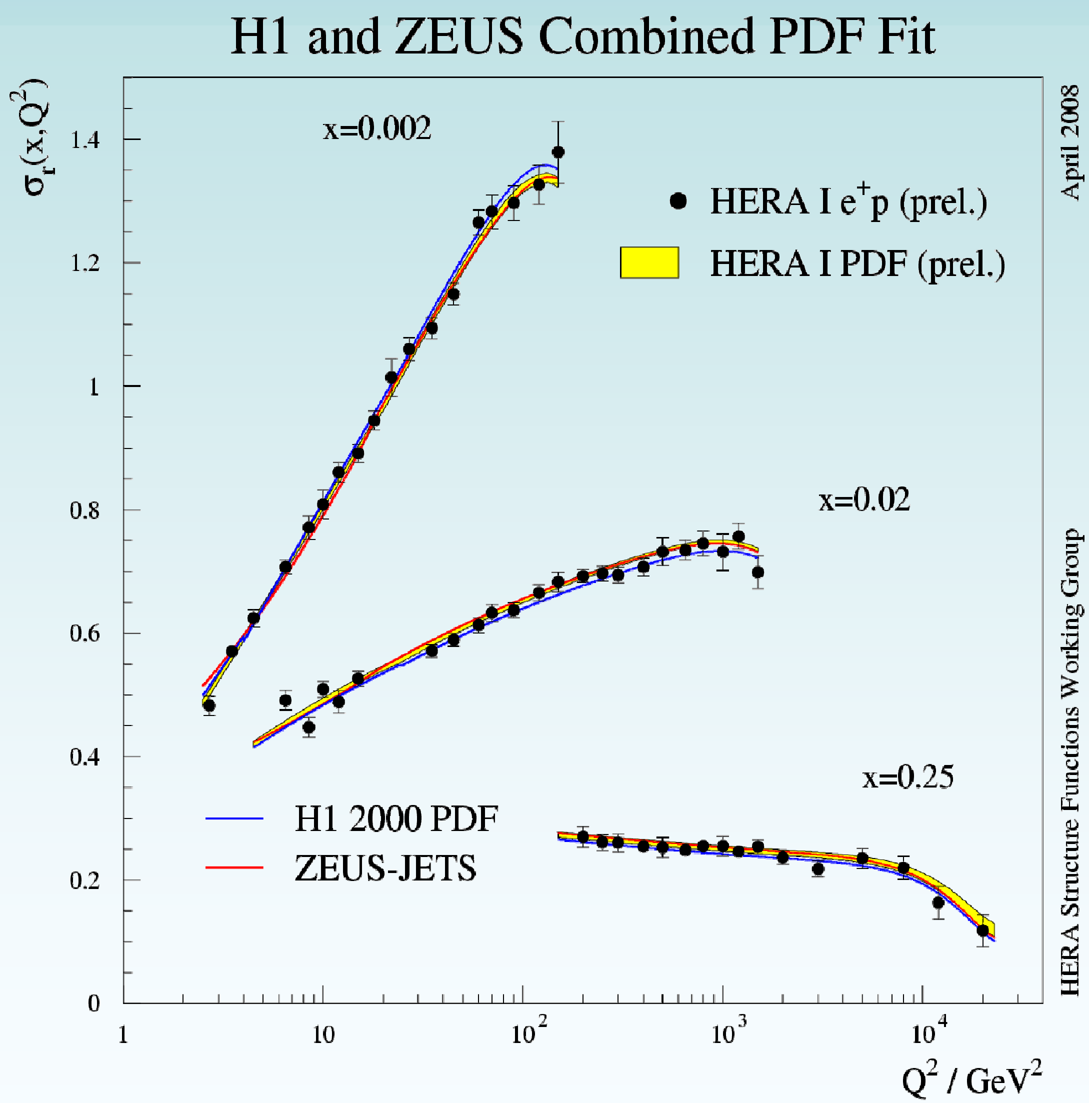
Results (ii): NC e^+p comparison

Neutral Current e^+p

in more detail:
zoom in on **three x-values** from plot on previous slide

"HERAPDF0.1" is compared to **previously published PDFs** from **H1** and **ZEUS**

scaling violations at low x clearly visible → **tight constraints on gluon**



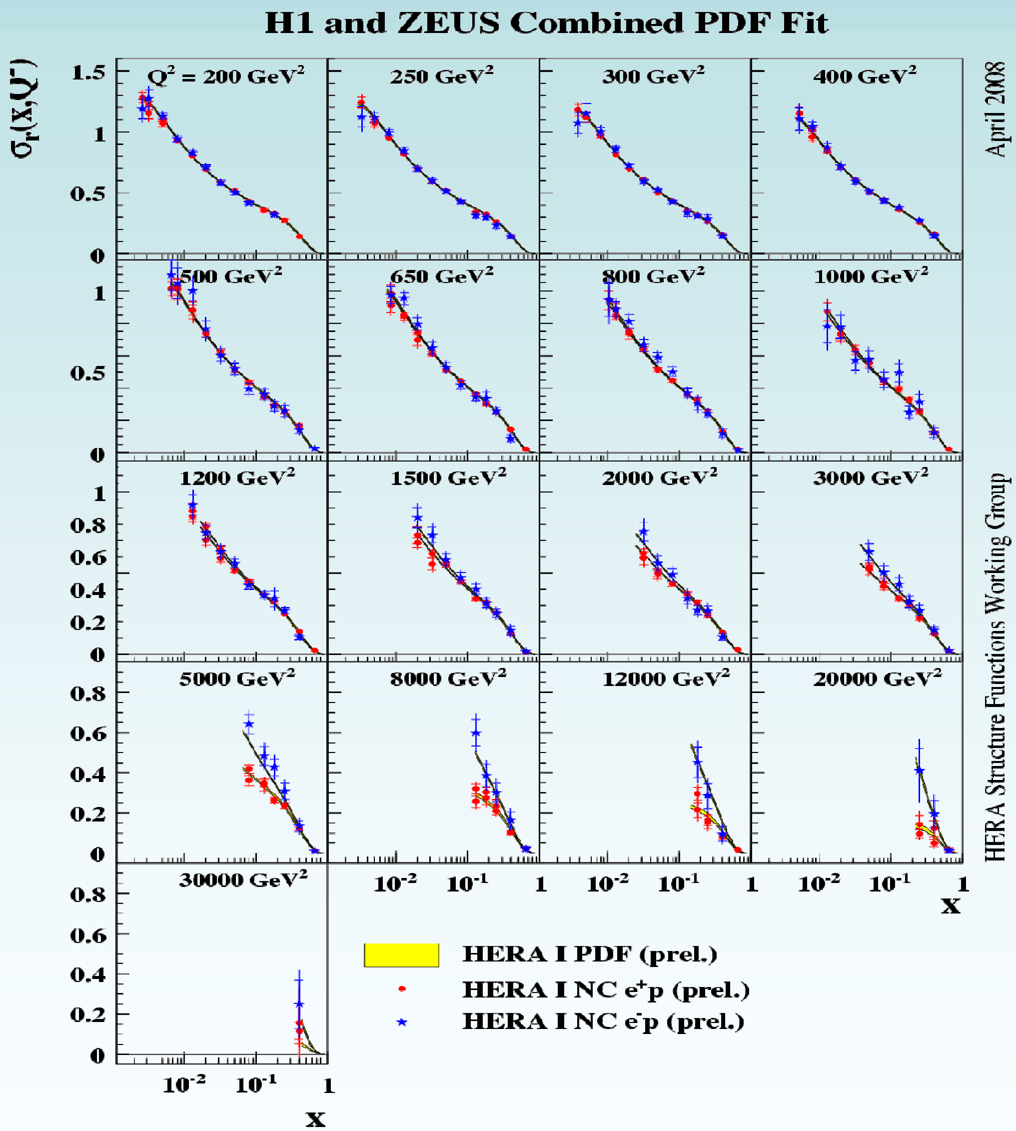
Results (iii): NC e±p

NC e±p [at high Q^2]

“HERAPDF0.1”:
fit quality to the **combined HERA-I data** for **NC e^+p and e^-p at high Q^2**

uncertainties on both **data** and **fit** included

difference between e^+p and e^-p NC at high Q^2 gives xF_3 → **direct sensitivity to valence quarks**



Results (iv): CC $e^{\pm}p$

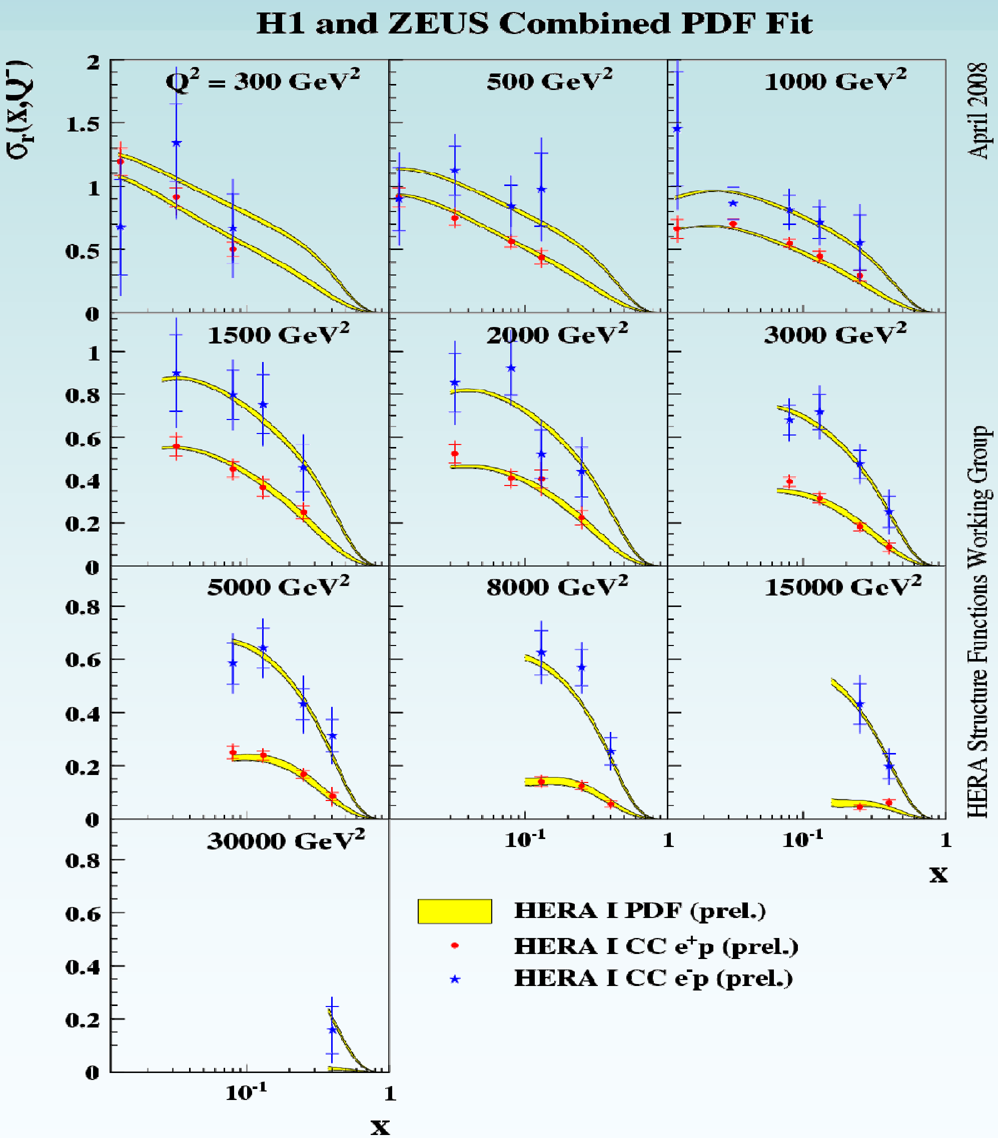
Charged Current $e^{\pm}p$

"HERAPDF0.1": fit quality to the **combined HERA-I data** for **CC $e^{+}p$ and $e^{-}p$ at high Q^2**

uncertainties on both **data** and **fit** included

difference between $e^{+}p$ and $e^{-}p$ CC **constrains flavour composition** of proton

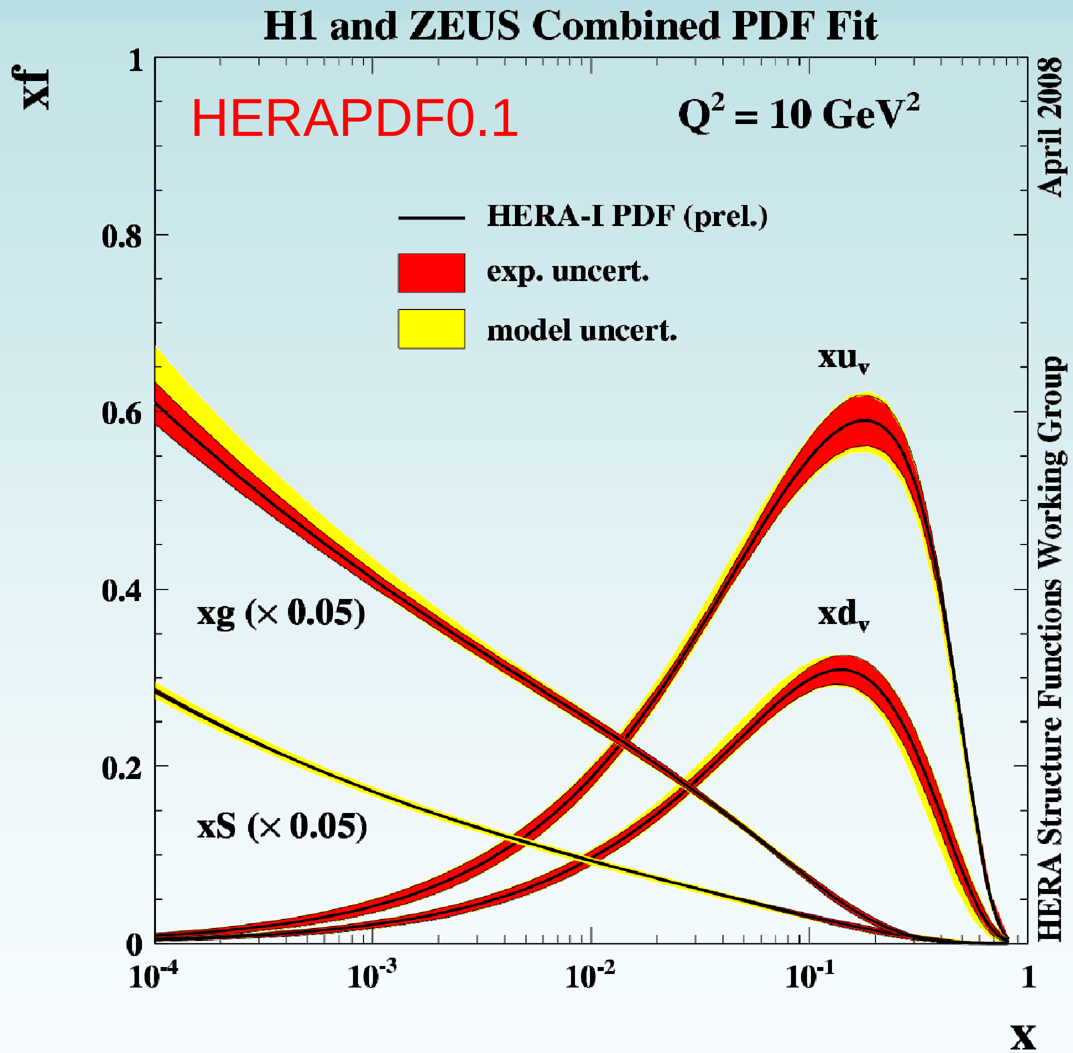
[avoids **nuclear corrections** from fixed target data]



HERA PDF

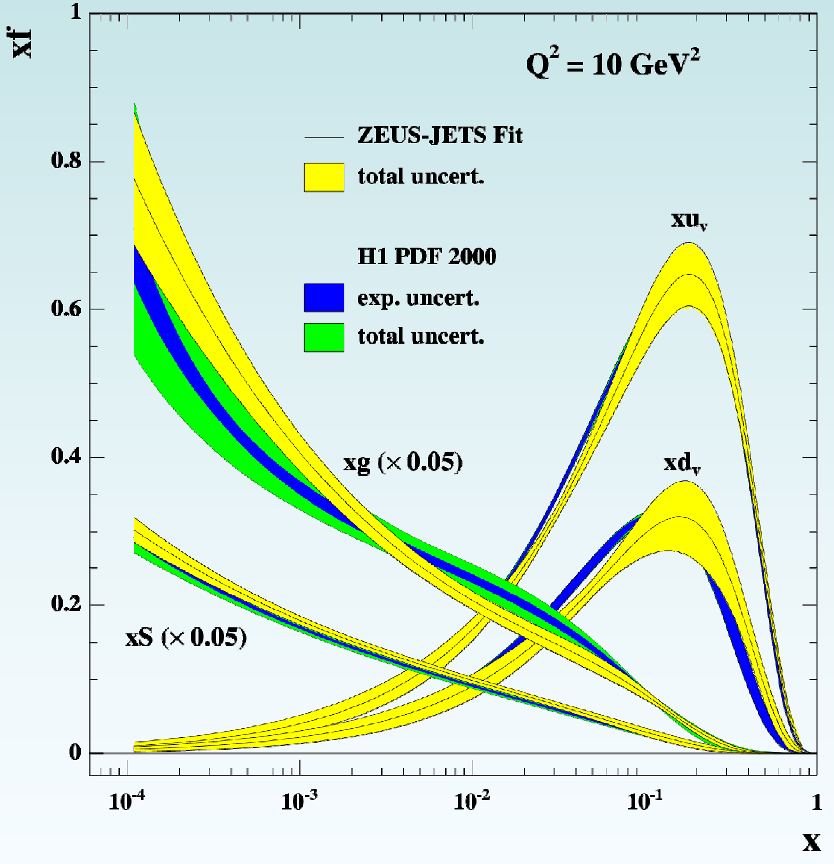
"HERAPDF0.1": total **experimental uncertainty** band and **model uncertainties**

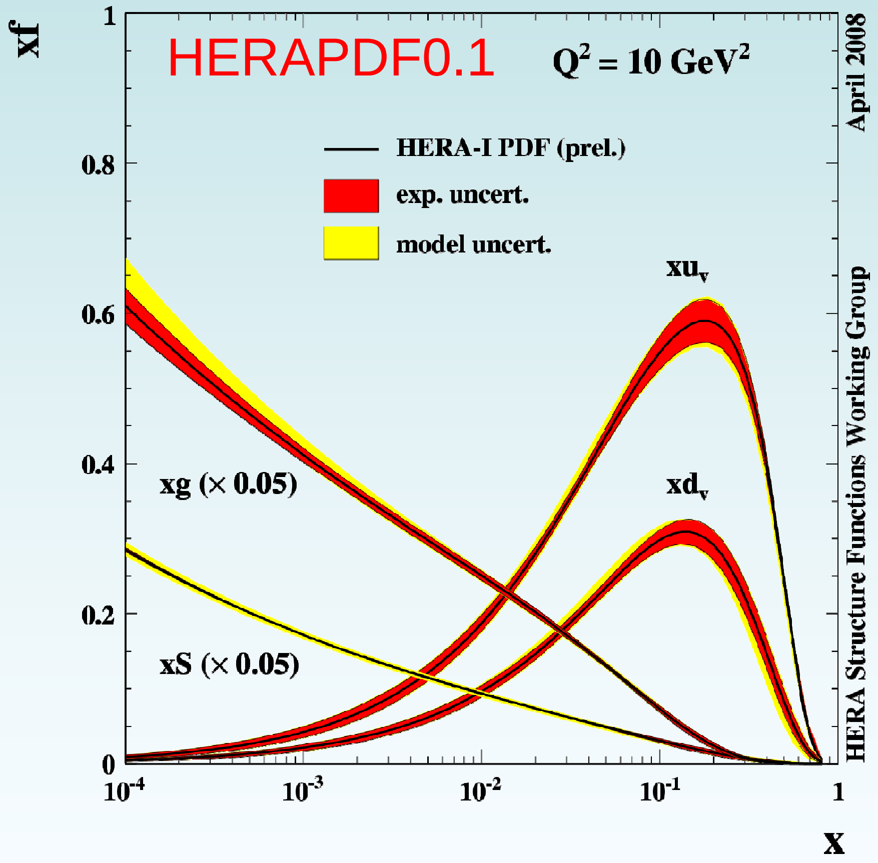
Note: **xg(x)** and **xS(x)** scaled down by ×20



cf. previous fits to HERA data

Comparison with **H1** and **ZEUS** published fits to their **own** HERA-I **data**



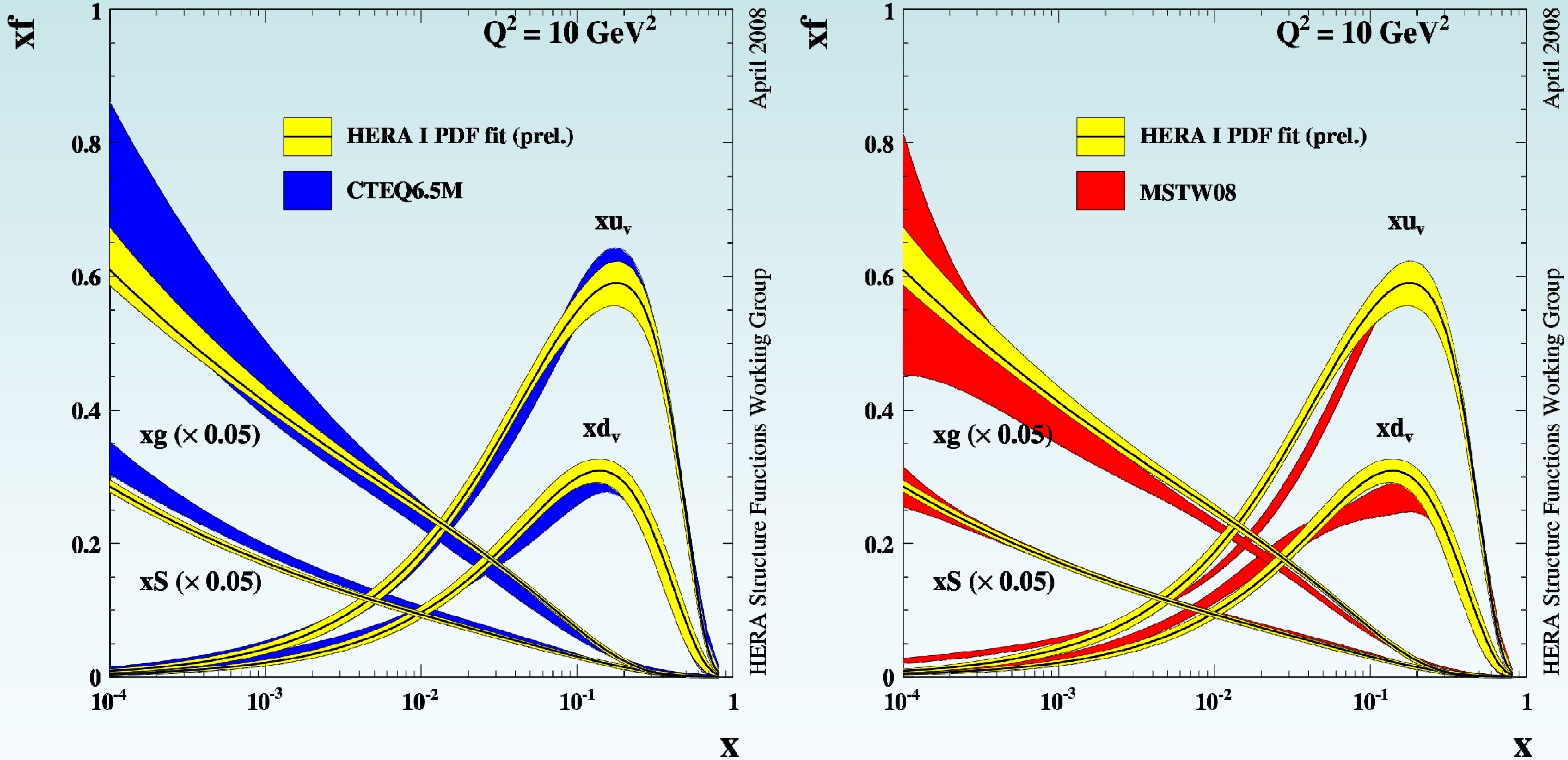


improvement in precision is **impressive**: originates from **data combination**

HERA PDF vs. Global fits

Comparison with recent **CTEQ** and **MSTW** PDFs

Caution:
Global fits: 90% CL
HERA fit: 68% CL



[note that MSTW08 is not yet published:- this is a **pre-release**]

HERA PDF vs. Global fits

Comparison with <u>recent</u> **CTEQ** and **MSTW** PDFs

Caution:
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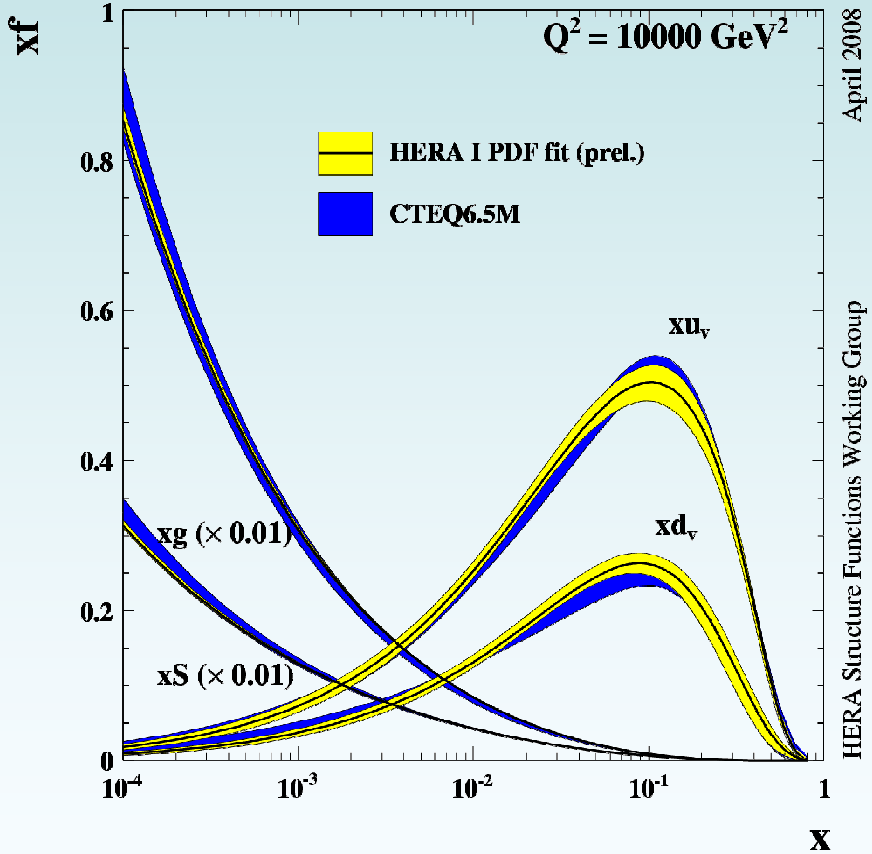
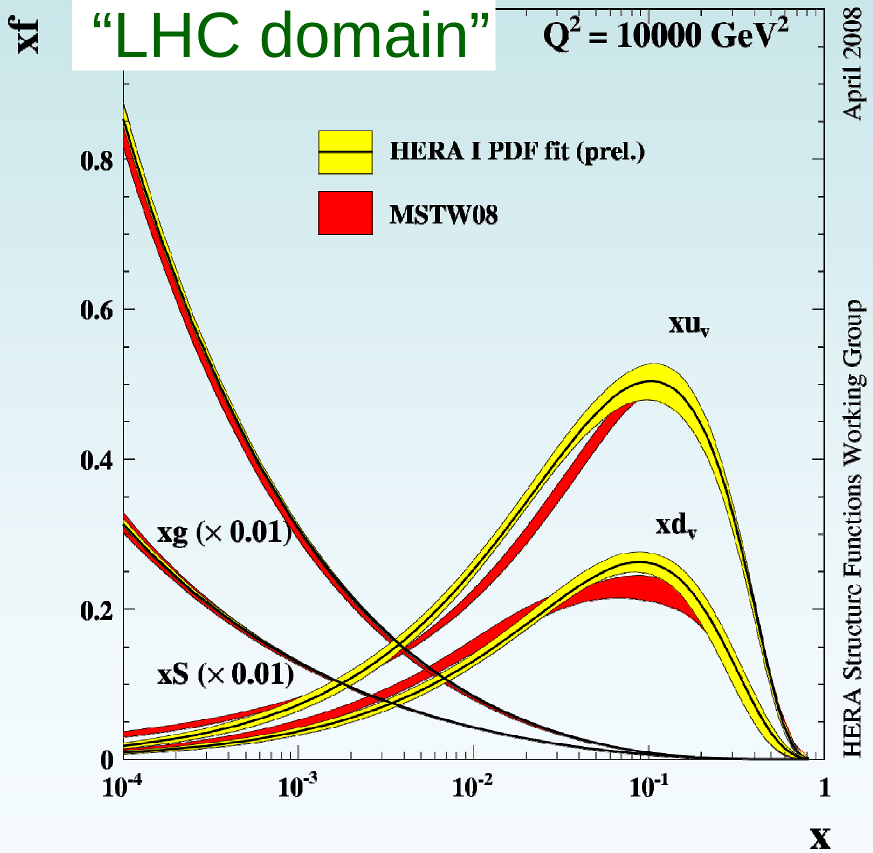


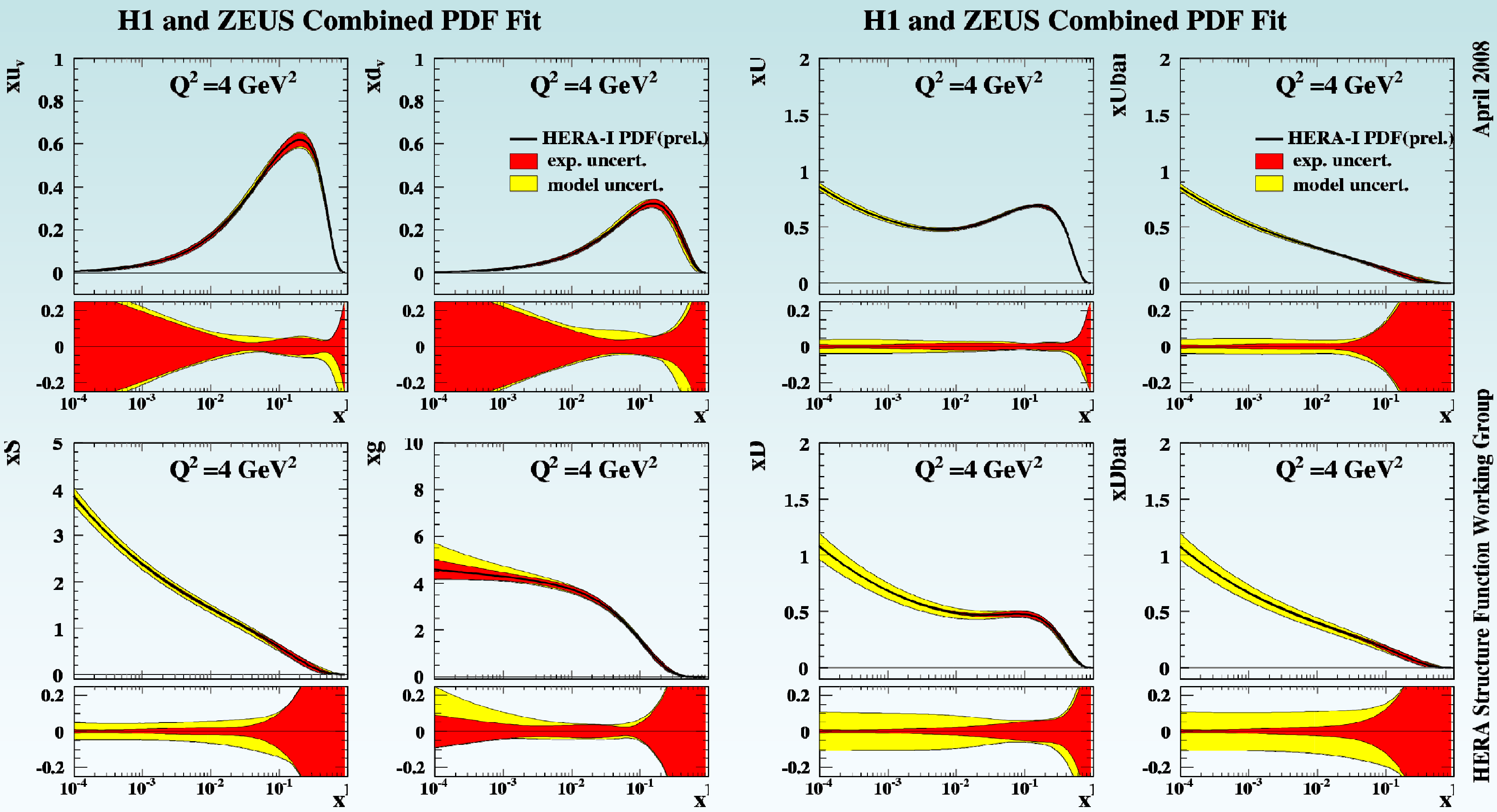
"LHC domain"



[note that MSTW08 is not yet published:- this is a **pre-release**]

HERA PDF: in more detail

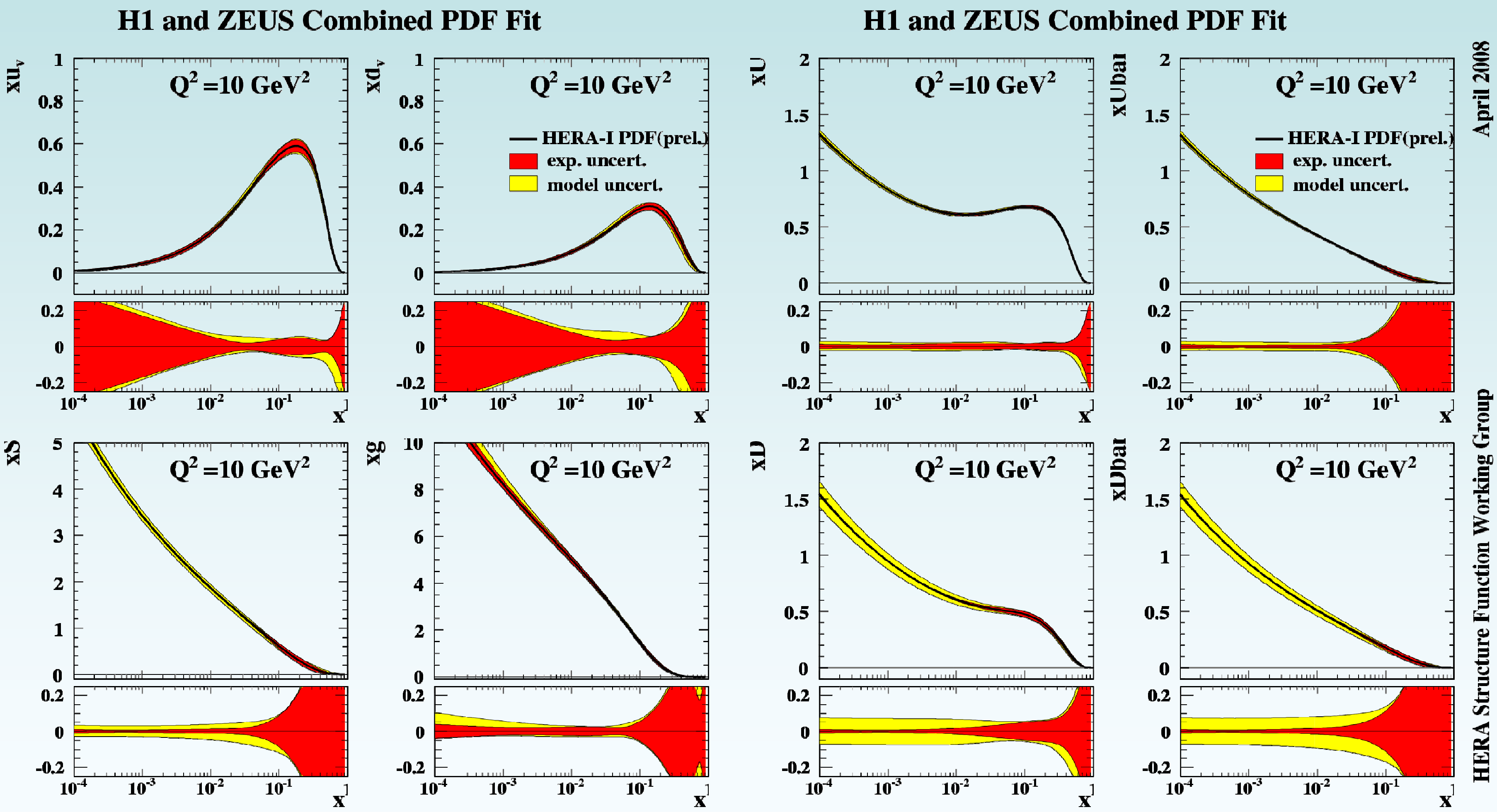
PDFs at starting scale, Q_0^2=4 GeV^2



f_s dominates model uncertainty on sea; Q_0^2 and Q_{min}^2 dominate xg and xq_v

HERA PDF: in more detail

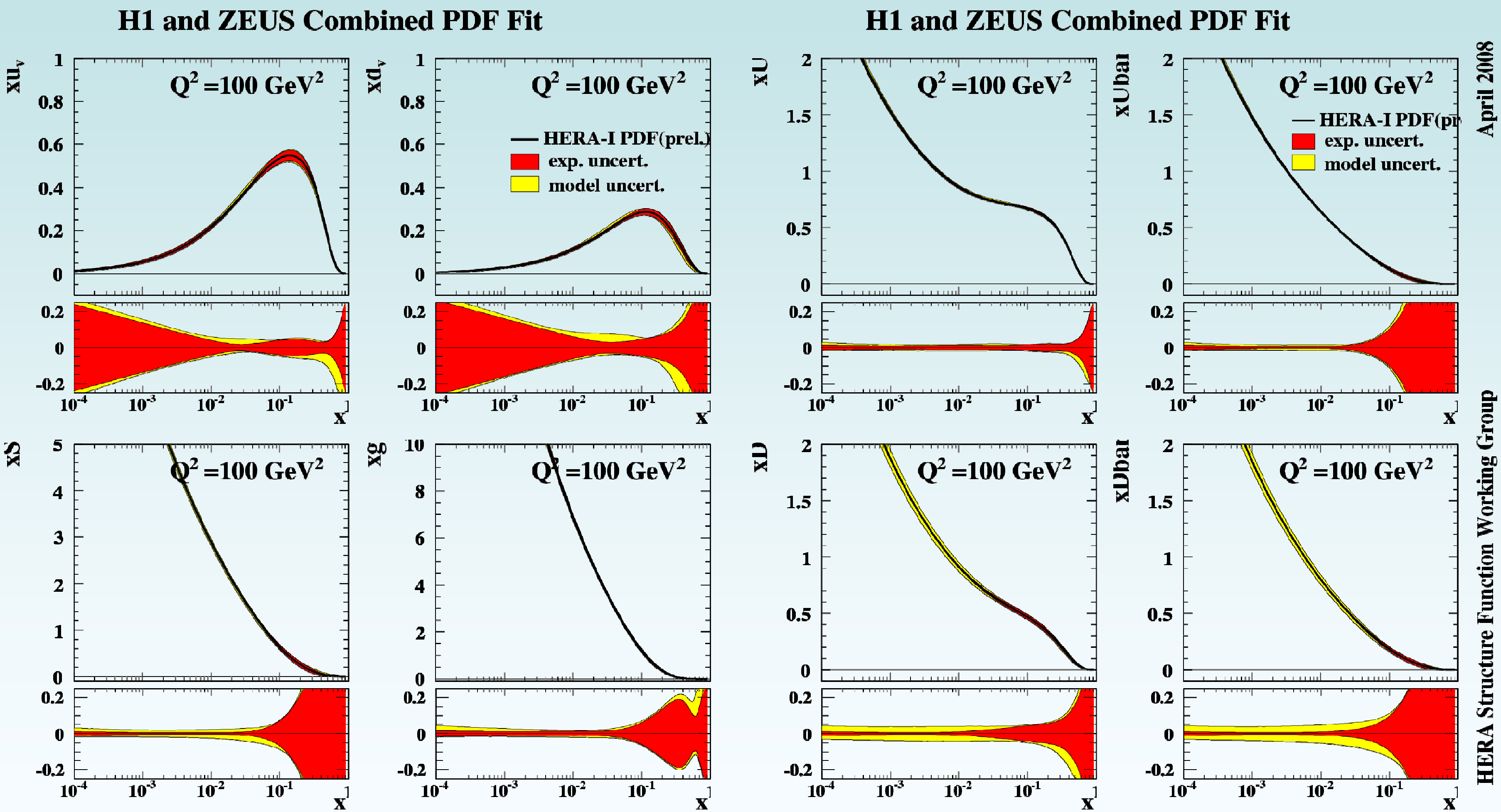
PDFs at Q^2=10 GeV^2



PDF uncertainties decrease as Q^2 increases

HERA PDF: in more detail

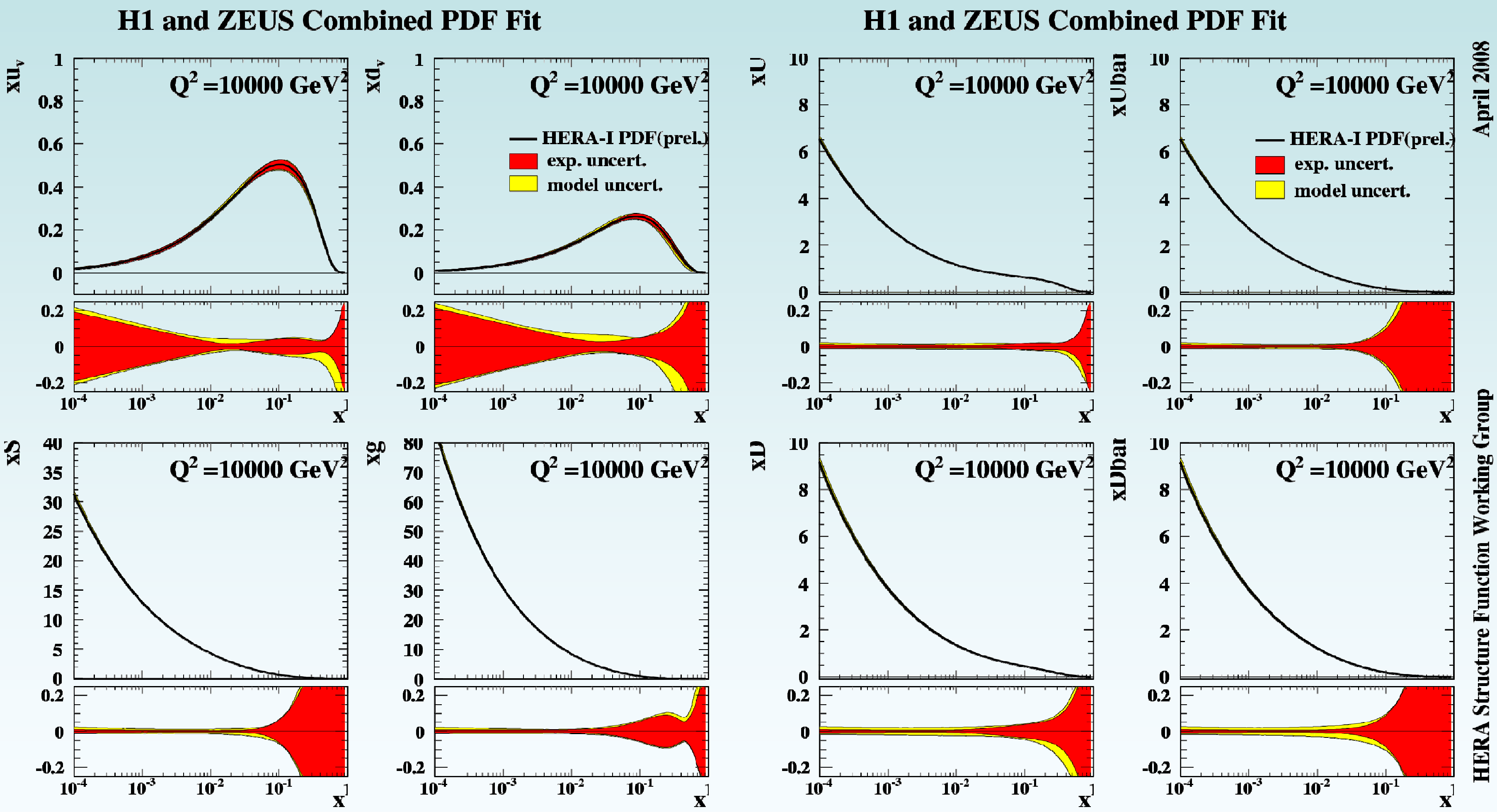
PDFs at Q^2=100 GeV^2



PDF uncertainties decrease as Q^2 increases

HERA PDF: in more detail

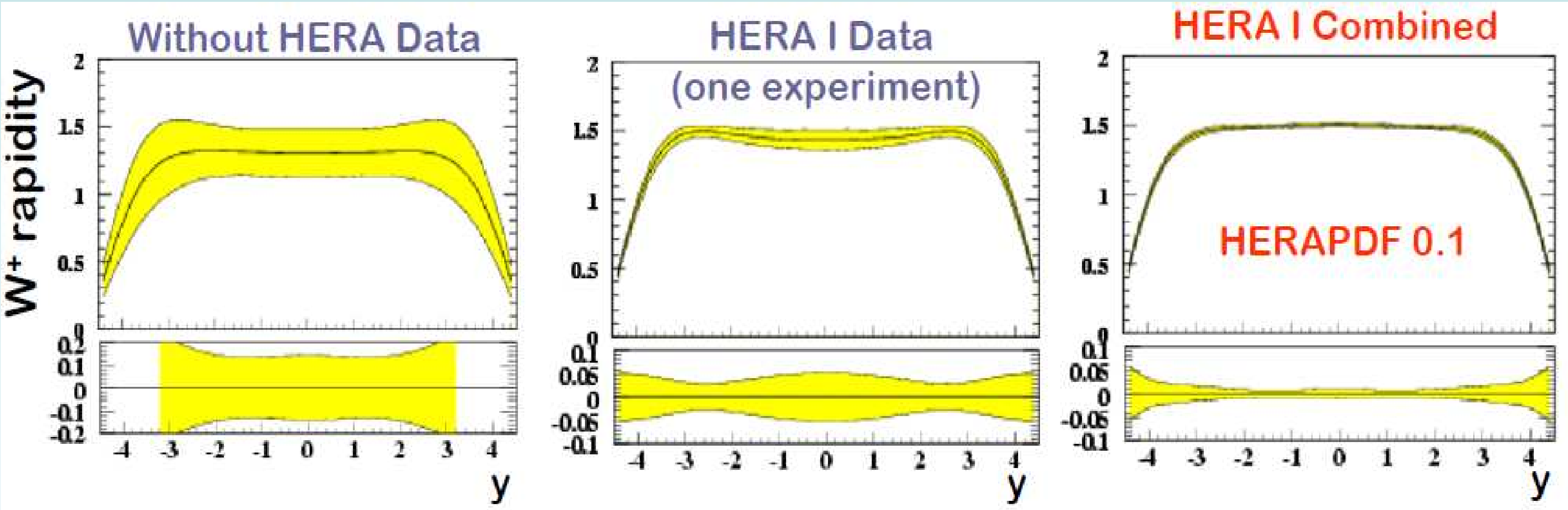
PDFs at Q^2=10000 GeV^2



scale relevant for LHC:- impressively small uncertainties

HERA PDF: impact

EXAMPLE: W^+ production at the LHC (study by A. Cooper-Sarkar)



- **HERA combined data** and **PDFs** will be crucial input for LHC predictions
  note, in these plots, uncertainty bands are from experimental sources only
  → step in **experimental precision** is striking

→ model uncertainties will become increasingly important …

[see also: A. Cooper-Sarkar and E. Perez - talk at the HERA-LHC ws, May'08]

LHAPDF?

HERAPDF0.1 very soon to be **released** in LHAPDFv5.6.0

will be available in both following forms:

- input parameters + evolution code (“.LHpdf”-style)
- PDF values on (x,Q^2) grid (“.Lhgrid”-style)

Note for users:

- to obtain experimental uncertainties, sum over N_{mem}=1-22
- to obtain experimental+model uncertainties, sum over N_{mem}=1-34

[for technical reasons, model uncerts. only available in “.Lhgrid”-style]

Summary

- **HERA** combination of inclusive NC and CC DIS data
  - robust, model-independent combination procedure developed

    - H1 and ZEUS experiments **cross-calibrate** each other

    → significantly **improved** systematics as well as statistics
  - hope to publish combined data within a few months

    [H1 has a couple of HERA I NC datasets still to be published]

- HERA **PDF fit** to combined data
  - NLO QCD fit to combined HERA-I data

    - uses ep data only → no need for nuclear corrections

    - results in a HERA PDF with impressive precision compared to previous HERA analyses and to global fits
  - very soon to be released in LHAPDF

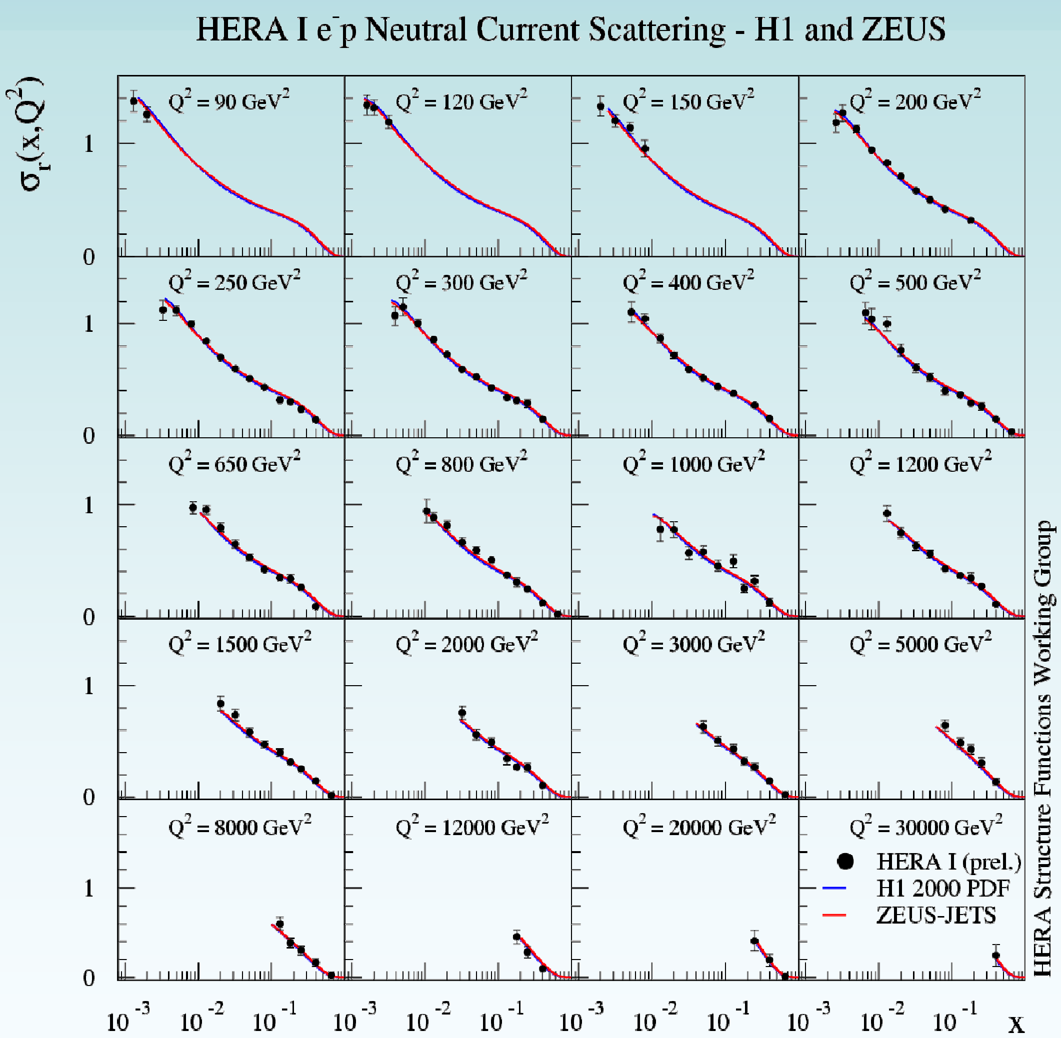
still to come:- use of all **HERA-II** data in both combination and fits

Extras

Results (extra): NC e^-p

NC e^-p [at high Q^2]:

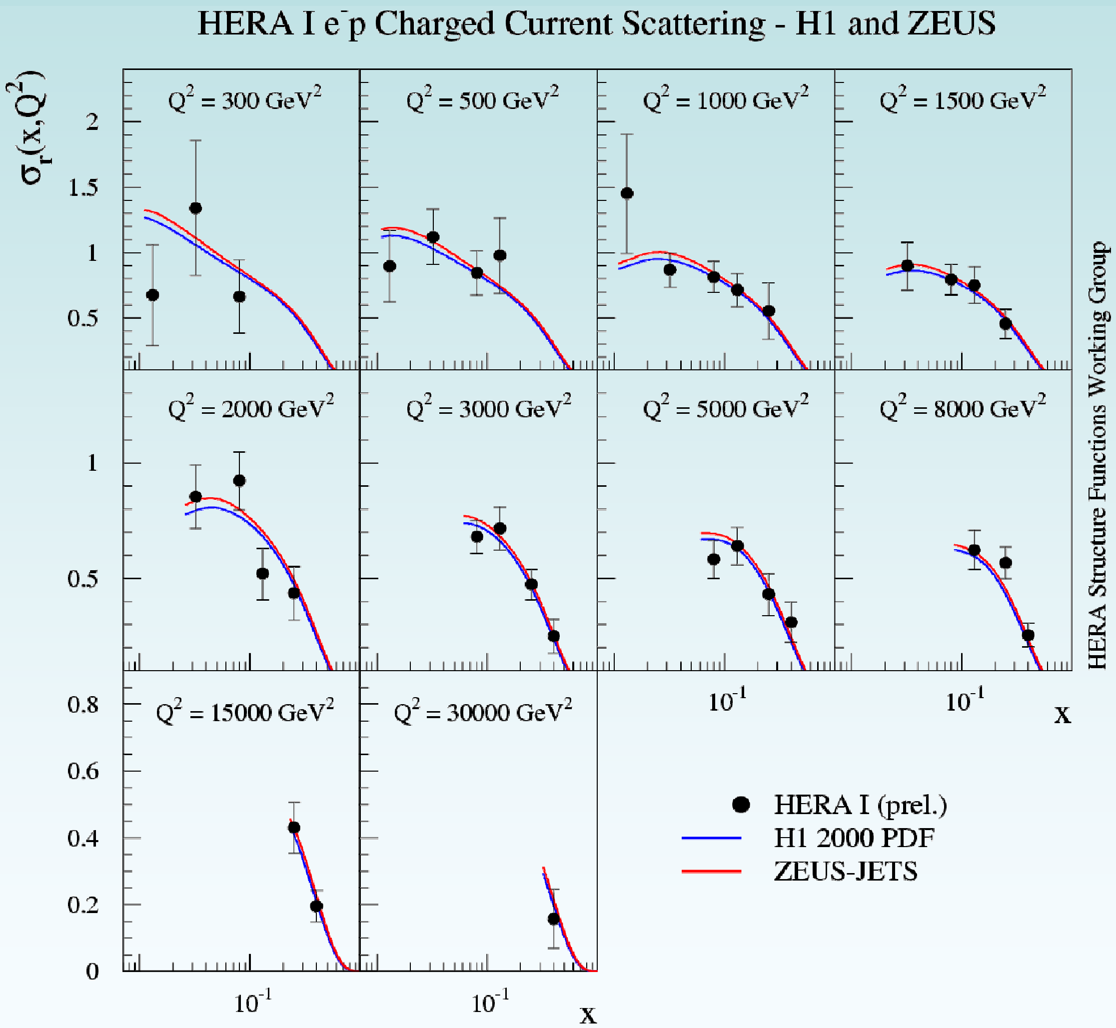
combined data compared to published **H1** and **ZEUS** **PDF fits** to (their own) data from HERA I



Results (extra): CC e⁻p

CC e⁻p:

combined data compared to published **H1** and **ZEUS** **PDF fits** to (their own) data from HERA I



Alternative parameterisations (i)

$xf(x) = Ax^{B}(1-x)^{C}(1+Dx+Ex^{2}+Fx^{3}+\ldots)$

"H1-style"-parameterisation [as used in H1PDF2k]:

partons parameterised: gluon, $U=u+c$, $D=d+s+b$, $\bar{U} = \bar{u}+\bar{c}$, $\bar{D} = \bar{d}+\bar{s}+\bar{b}$

sea flavour break-up at Q_0: $s=f_s\bar{D}$, $c=f_c\bar{U}$, $A(\bar{U})=(1-f_s)/(1-f_c)A(\bar{D})$; with $f_s=0.33$, $f_c=0.15$

	A	B	C	D	E	F
gluon	sum rule					
U	lim x->0 $\bar{u}/\bar{d}$->1			sum rule		
D		=B(U)		sum rule		
$\bar{U}$	=A(U)	=B(U)				
$\bar{D}$	=A(D)	=B(U)				

Alternative parameterisations (ii)

$xf(x) = Ax^B(1-x)^C(1+Dx+Ex^2+Fx^3+\ldots)$

"ZEUS-style"-parameterisation [as used in ZEUS-Jets]:

partons parameterised: gluon, u_v, d_v, sea=$u_{sea}+\bar{u}+d_{sea}+\bar{d}+s+\bar{s}+c+\bar{c}$

sea flavour break-up at Q_0: $s=(\bar{u}+\bar{d})/4$, charm dynamically generated, $\bar{d}-\bar{u}$ fixed to E866 data

	A	B	C	D	E
gluon	sum rule				0.
u_v	sum rule				
d_v	sum rule	$=B(u_v)$			0.
sea				0.	0.
$\bar{u}-\bar{d}$	parameters from ZEUS-S global fit (2002)			0.	0.

Offset method

HERA PDF fit: 4 correlated procedural uncertainties, arising from the data combination method, are treated with the **Offset method**

Offset Method (in a nutshell)

1. perform fit without correlated uncertainties for central fit
2. shift measurements to upper limit of one of its systematic uncertainties
3. redo fit, record differences of parameters from those of step 1
4. go back to 2, shift measurement to lower limit
5. go back to 2, repeat 2-4 for next source of systematic (and so on …)
6. add all deviations from central fit in quadrature (positive and negative deviations separately)

Does **not** assume uncertainties are Gaussian distributed. Also tends to give more conservative uncertainty estimates than other methods.

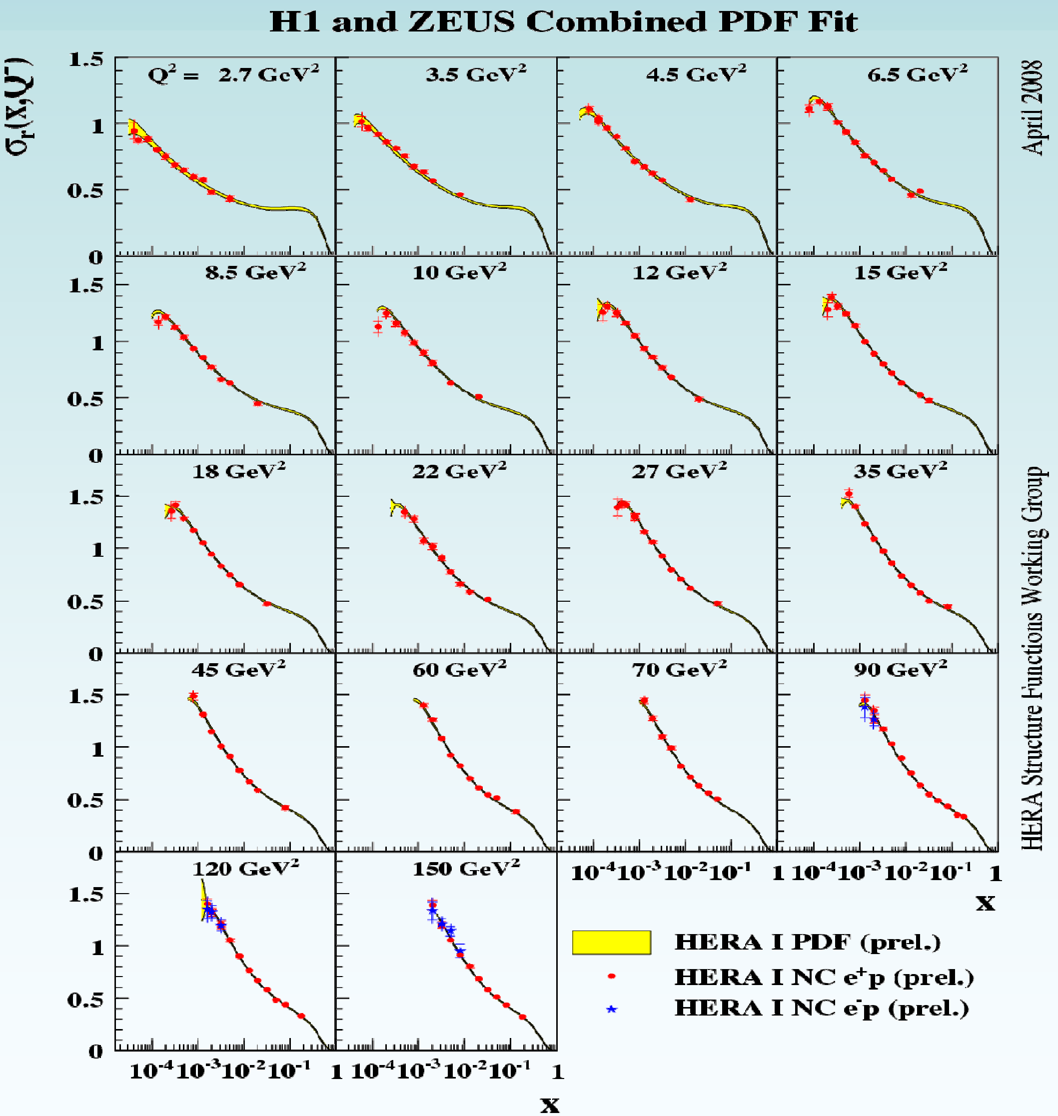
Note: clever ways to do this in practice [Pascaud and Zomer LAL-95-05, Botje hep-ph-0110123]

Results (extra): NC e±p

NC e±p [at low Q^2]

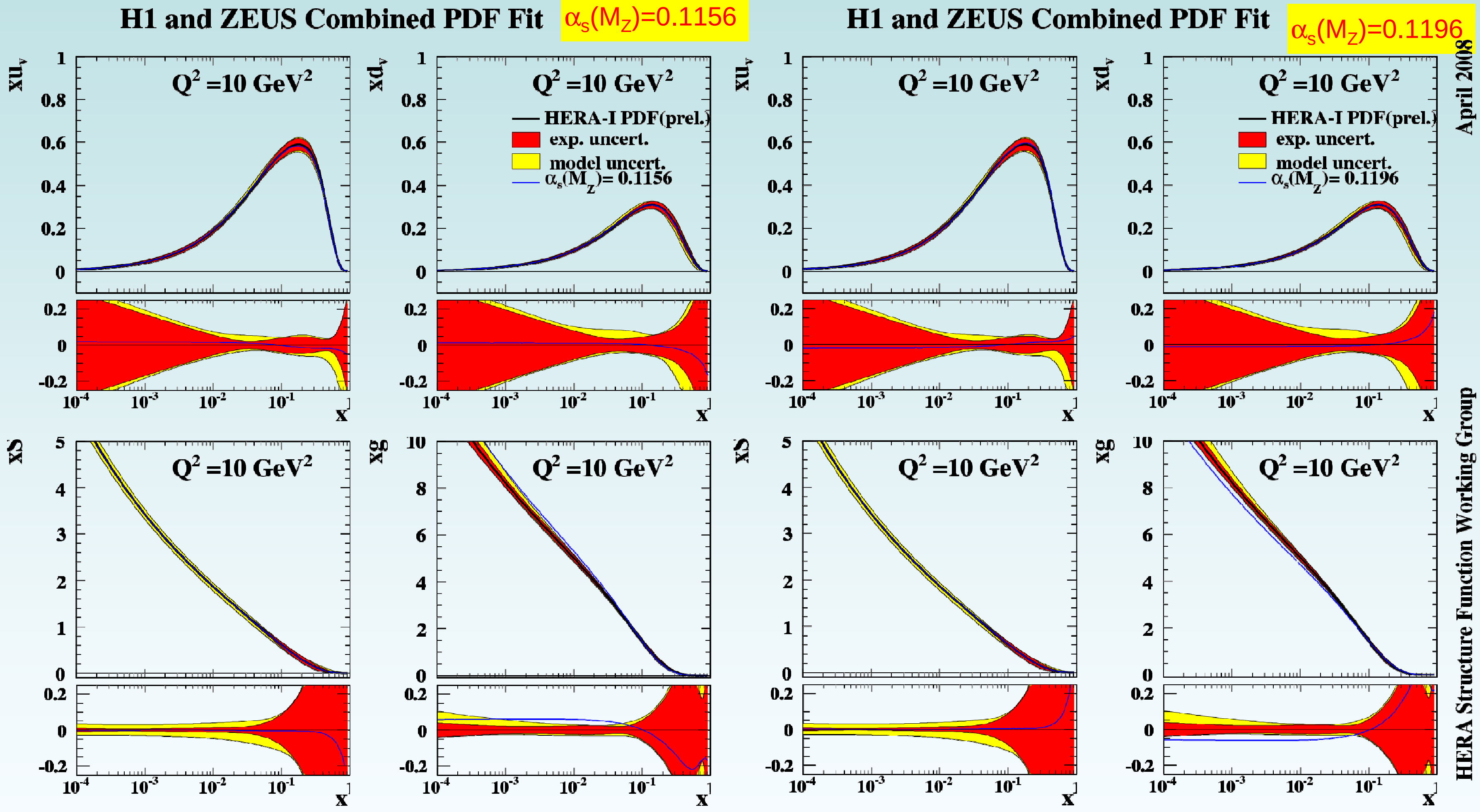
"HERAPDF0.1":
fit quality to the **combined HERA-I data** for **NC e^+p and e^-p at high Q^2**

uncertainties on both **data** and **fit** included



Model cross-checks

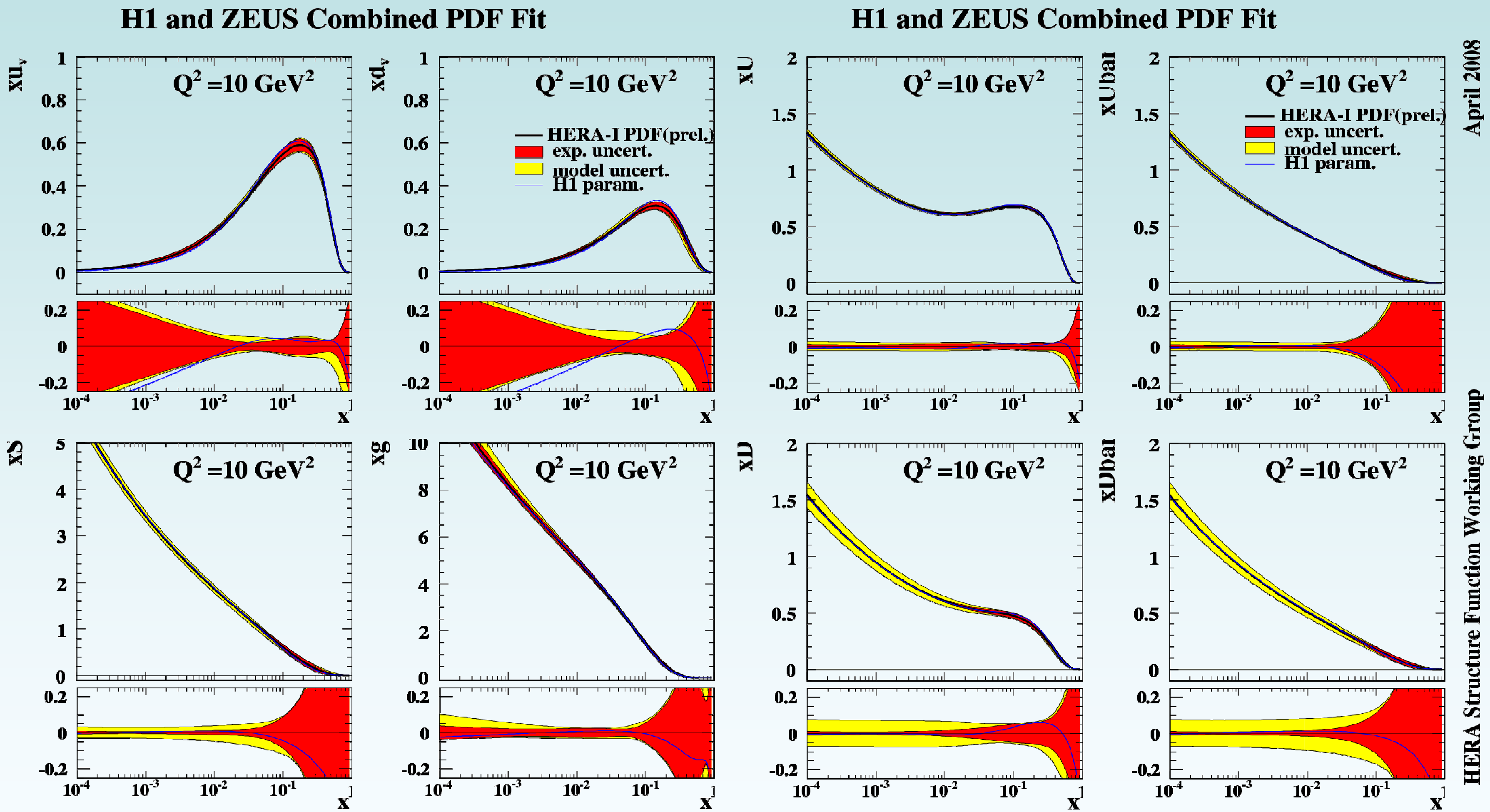
α_s-variation cf. nominal: $\alpha_s(M_Z)$=0.1176



variations outside gluon uncertainty bands (even including model uncertainty)

Model cross-checks

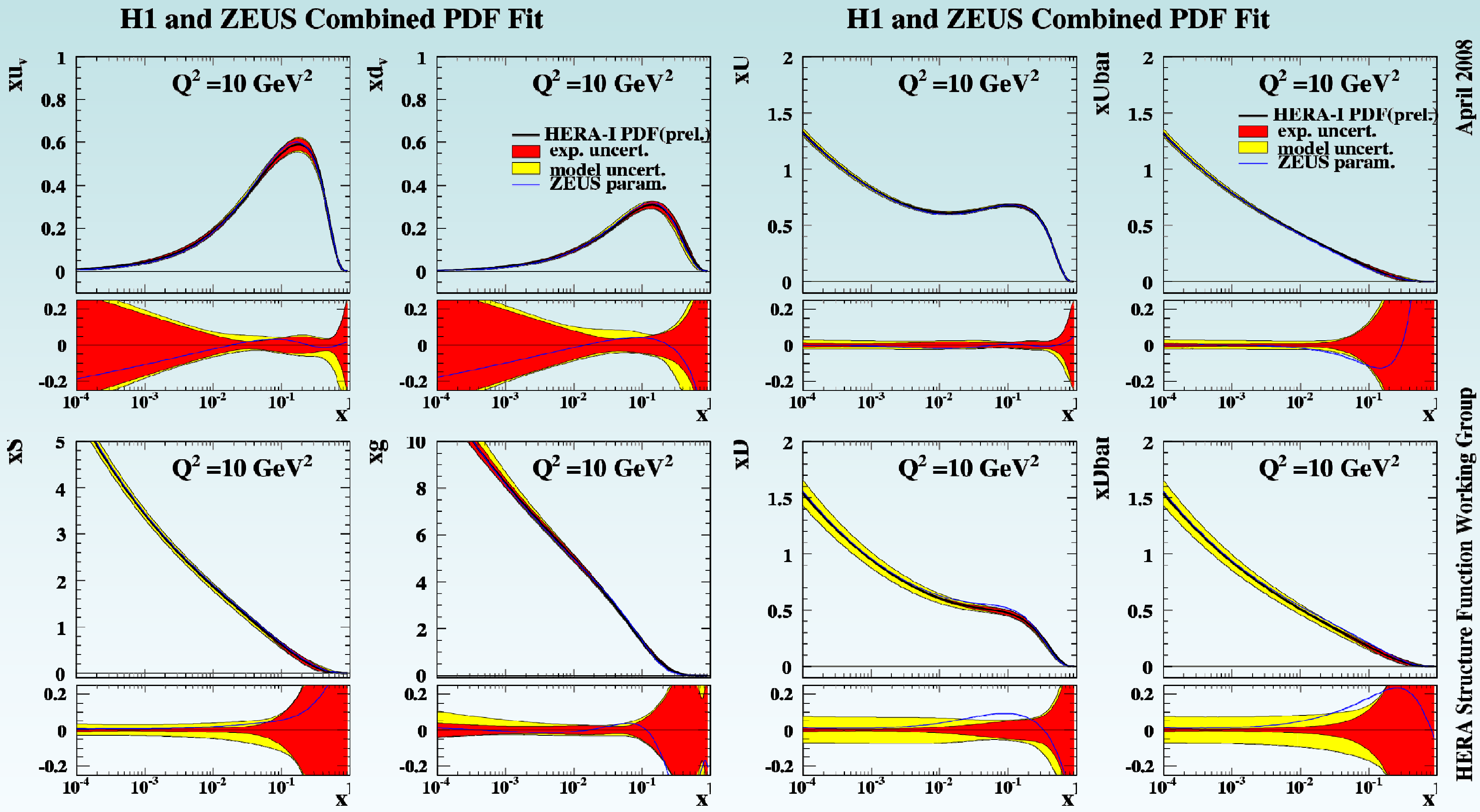
H1-style parameterisation



HERA-I PDF compared to central value of H1-style param. (optimised)

Model cross-checks

ZEUS-style parameterisation



HERA-I PDF compared to central value of ZEUS-style param. (optimised)

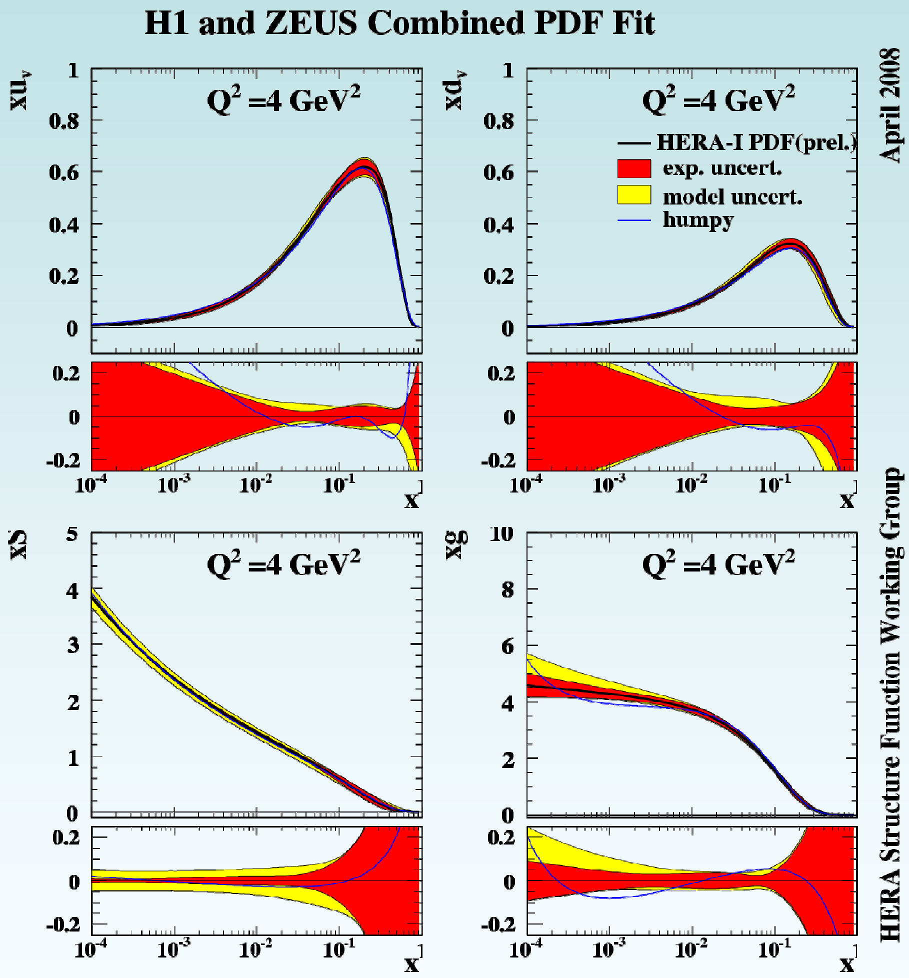
“straight” vs. “humpy” gluon

Resolution of an old discrepancy:

issue: H1 fits always produced a “humpy” shaped gluon, ZEUS did not

explanation: if a non-zero D-parameter used for the gluon, two minima are found (for any of the parameterisations): **“straight”** and **“humpy”** solutions

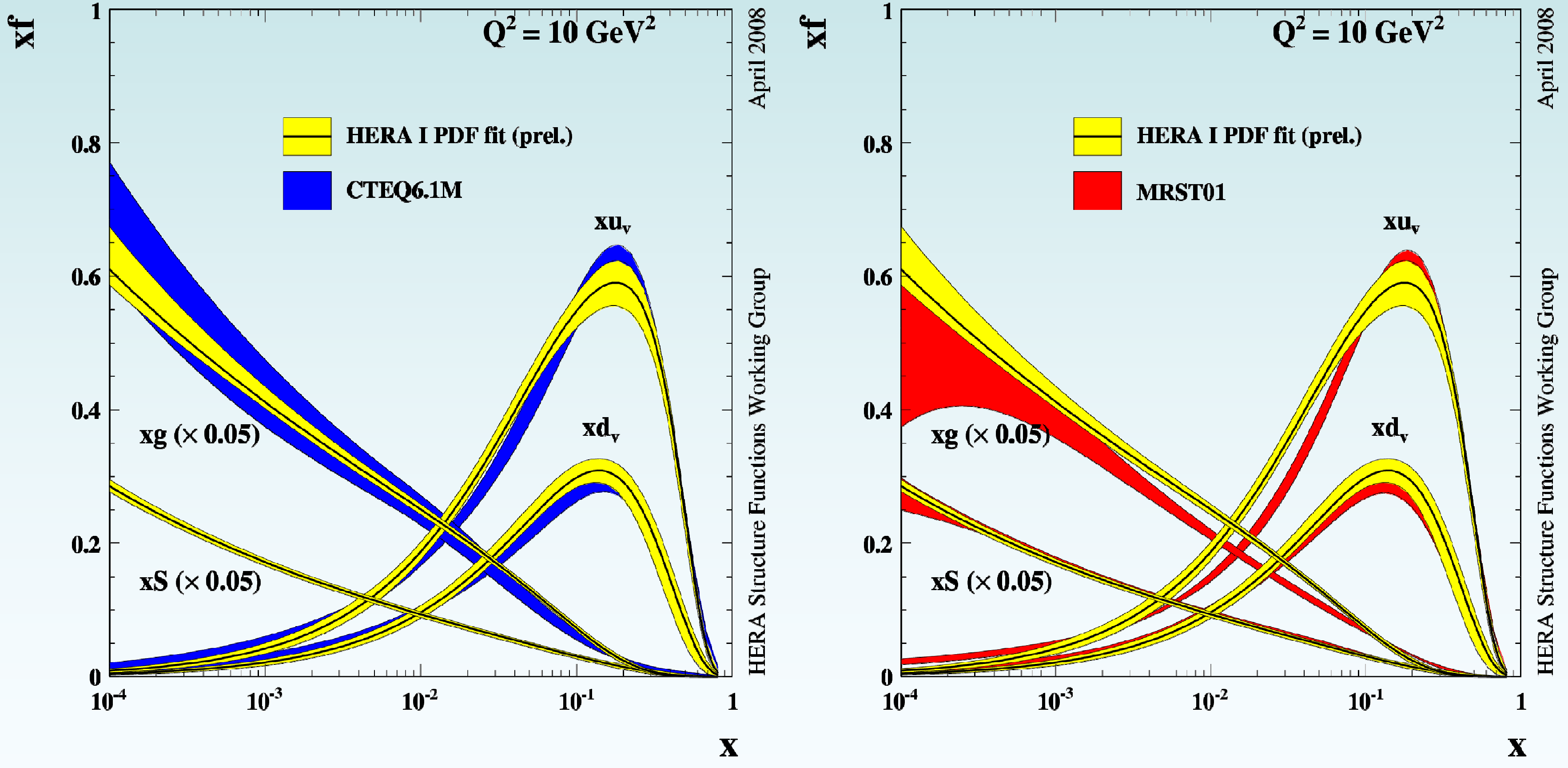
HERA combined data set:-
“straight” gluon solution favoured by about 10 X^2 points
[but “humpy” gluon still acceptable!]
Opposite: **“straight”** and **“humpy”** solutions are compared → results are very **consistent**



HERA PDF vs. Global fits

Comparison with <u>older</u> **CTEQ** and **MSTW** PDFs

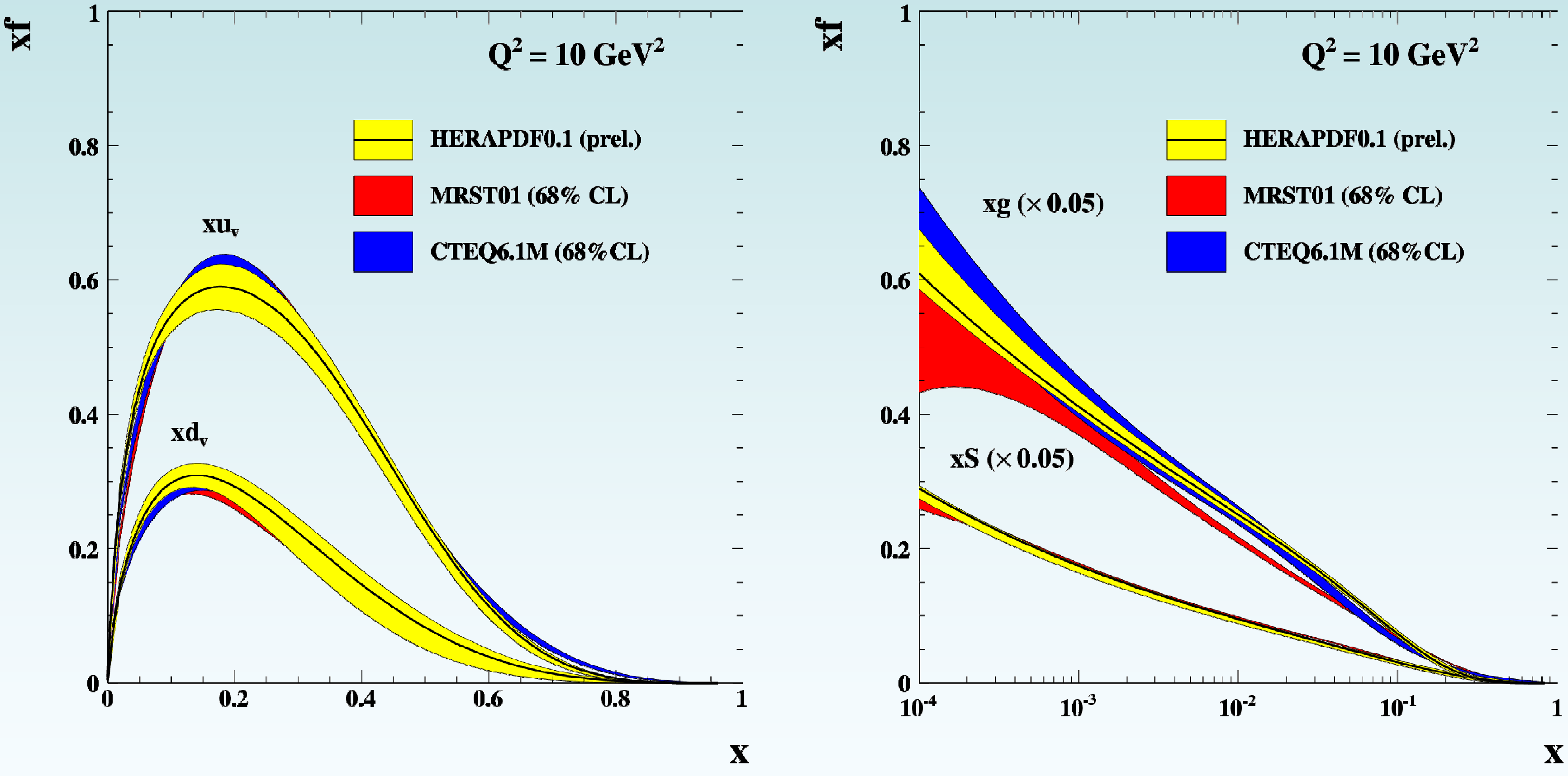
Caution:
Global fits: 90% CL
HERA fit: 68% CL



HERA PDF vs. Global fits

Comparison with <u>older</u> **CTEQ** and **MSTW** PDFs

68% CL

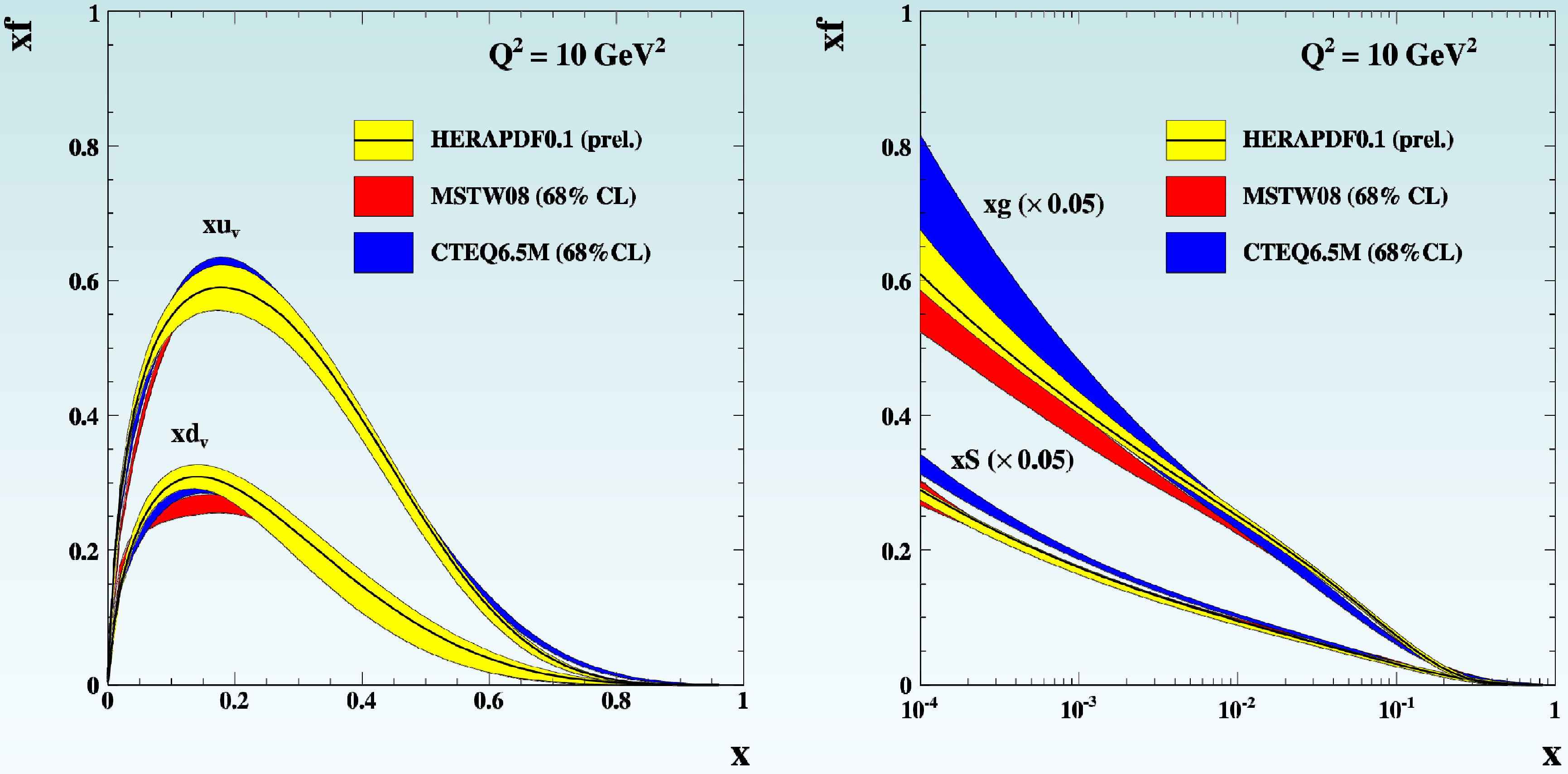


global fits scaled by 1.64485 [NB. HERA PDF includes exp. <u>and</u> model uncertainties]

HERA PDF vs. Global fits

Comparison with recent **CTEQ** and **MSTW** PDFs

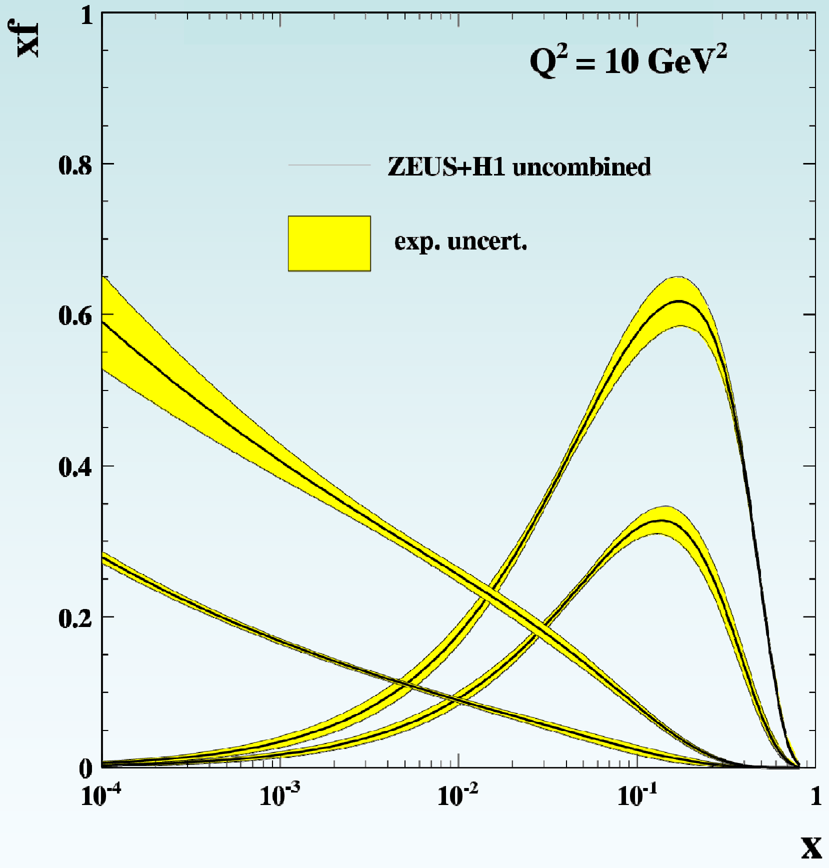
68% CL

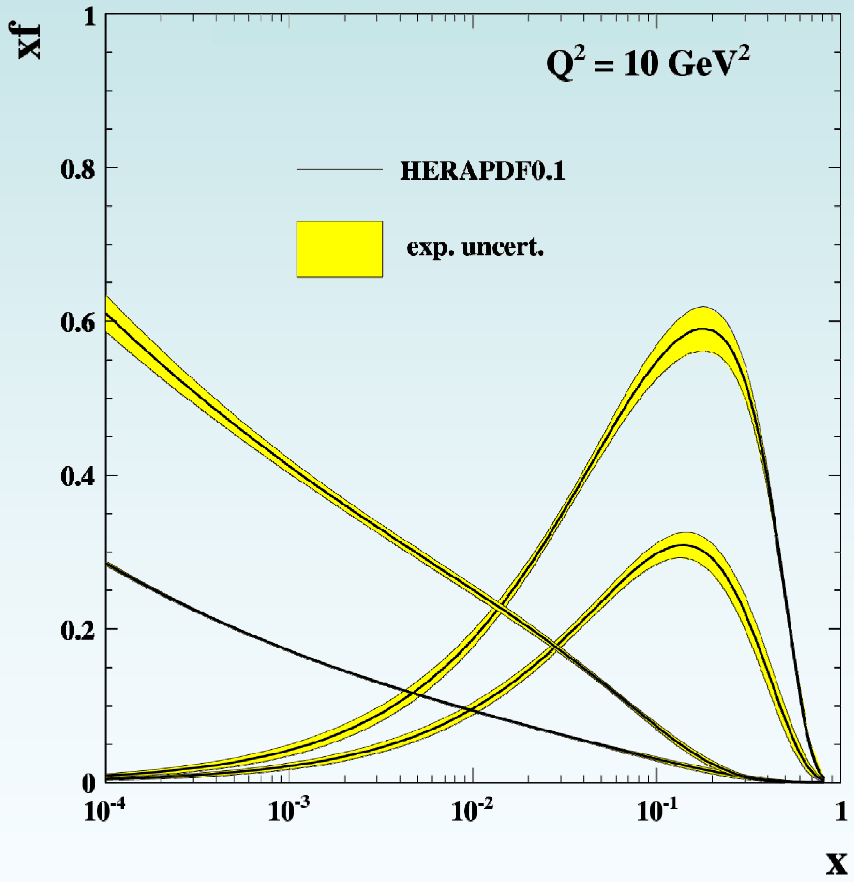


global fits scaled by 1.64485 [NB. HERA PDF includes exp. and model uncertainties]

HERA PDF: checks

Comparison with fit to H1+ZEUS (uncombined)

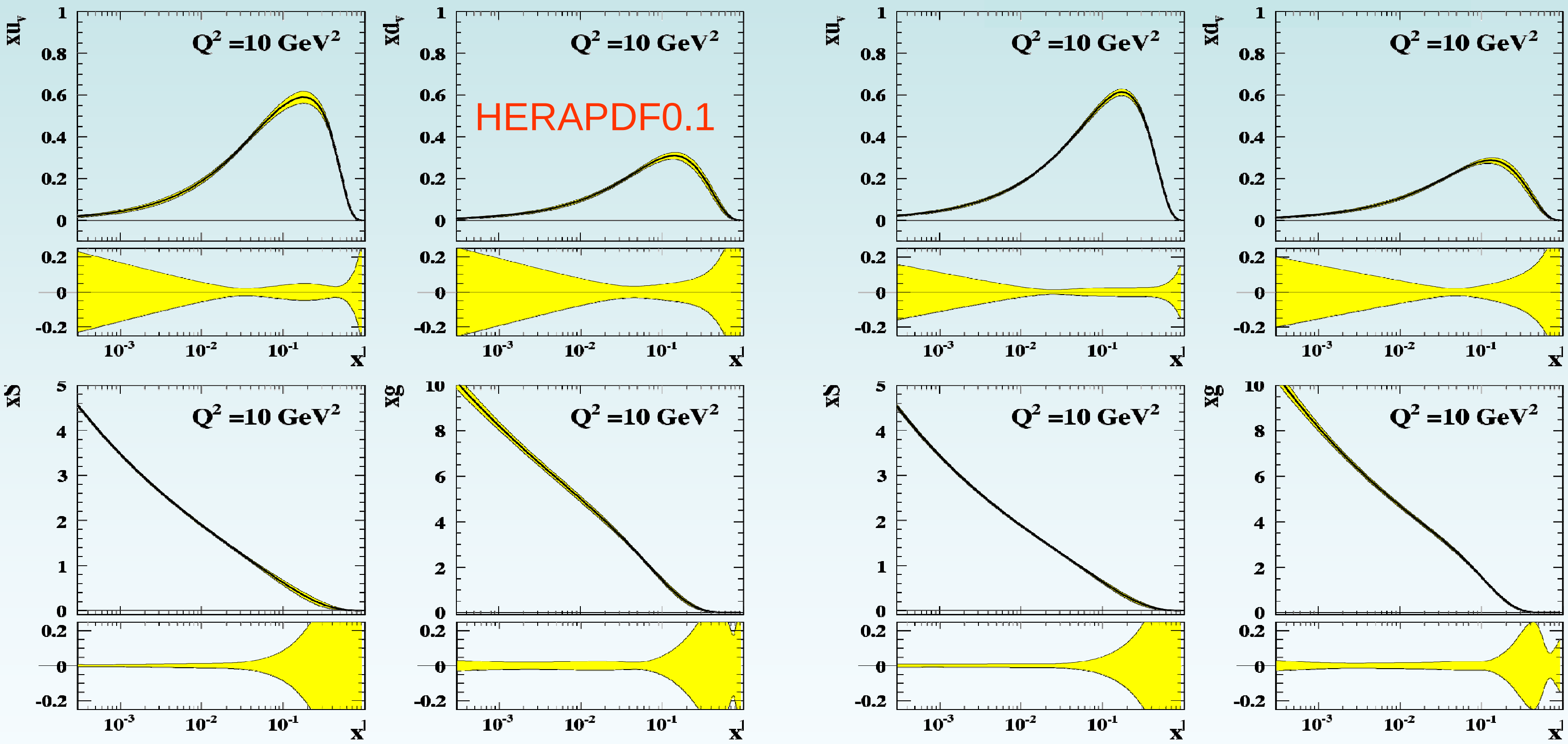




Same parameterisation and assumptions in both fits

HERA PDF: checks

Comparison of uncertainties for different treatments

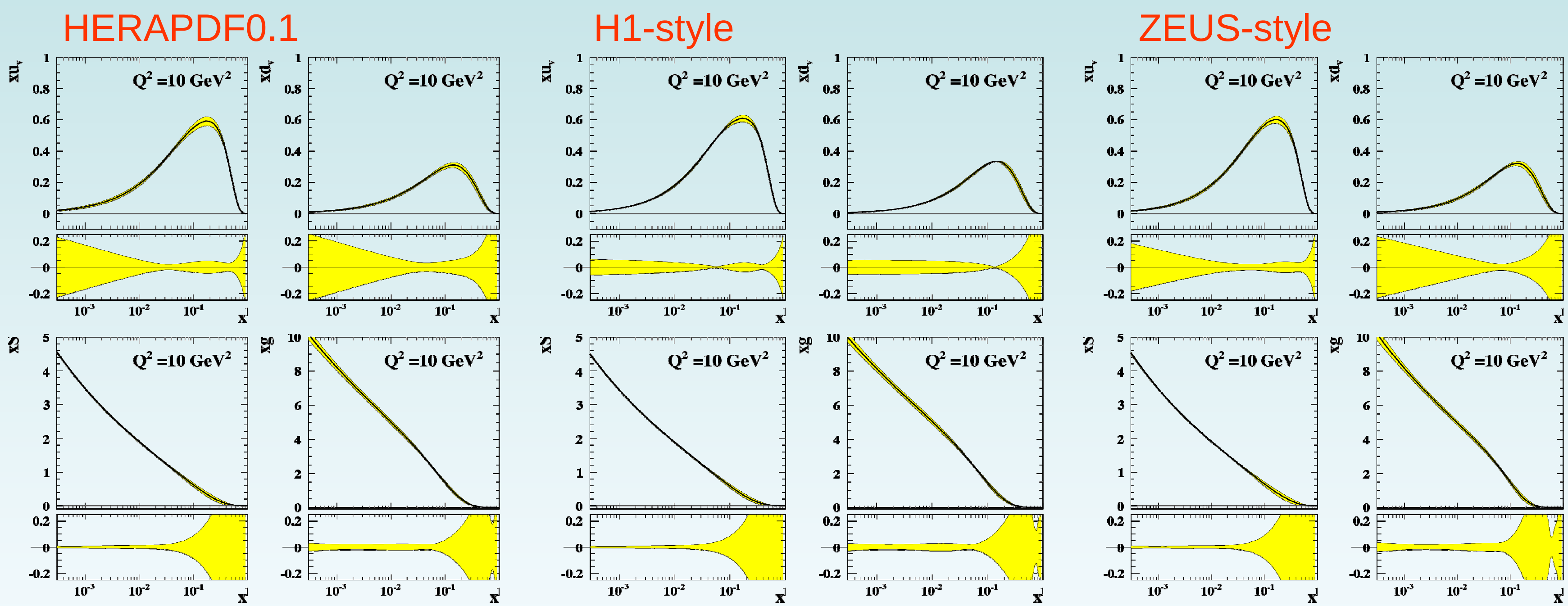


43 data systematics in quadrature ↑
+ offset 4 procedural uncertainties

↑ treat all 47 systs. as correlated

HERA PDF: checks

Comparison of uncertainties with different parameterisations



PDF uncertainties (experimental only) from different parameterisations: HERAPDF0.1 (left), H1-style (centre), ZEUS-style (right)

HERA and PDFs: a rough guide

NC DIS: $\tilde{\sigma}^{\pm} = \frac{d^2\sigma^{\pm}}{dx\,dQ^2}\frac{Q^4 x}{2\pi\alpha^2 Y_+} = \tilde{F}_2^{\pm} \mp \frac{Y_-}{Y_+} x\tilde{F}_3^{\pm} - \frac{y^2}{Y_+}\tilde{F}_L^{\pm}$