Combined HERA DIS data and PDF fits

New Trends in HERA Physics, Ringberg'08

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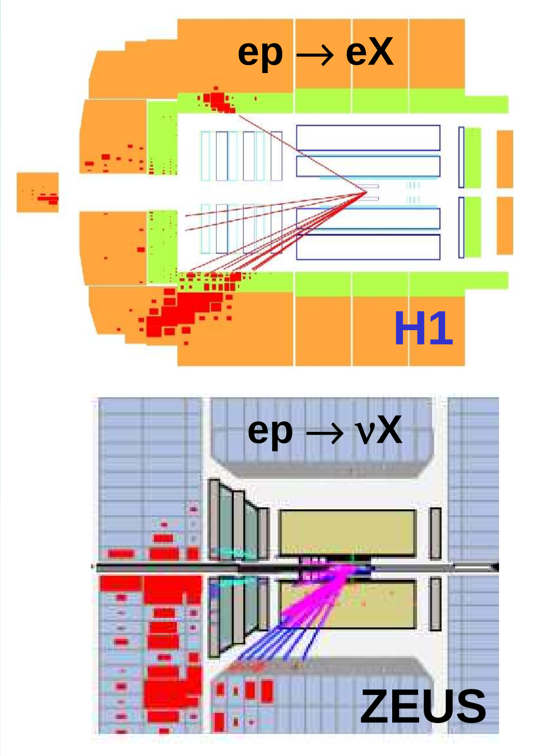
on behalf of the **HERA Structure Functions Working Group**

Outline

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

Motivation

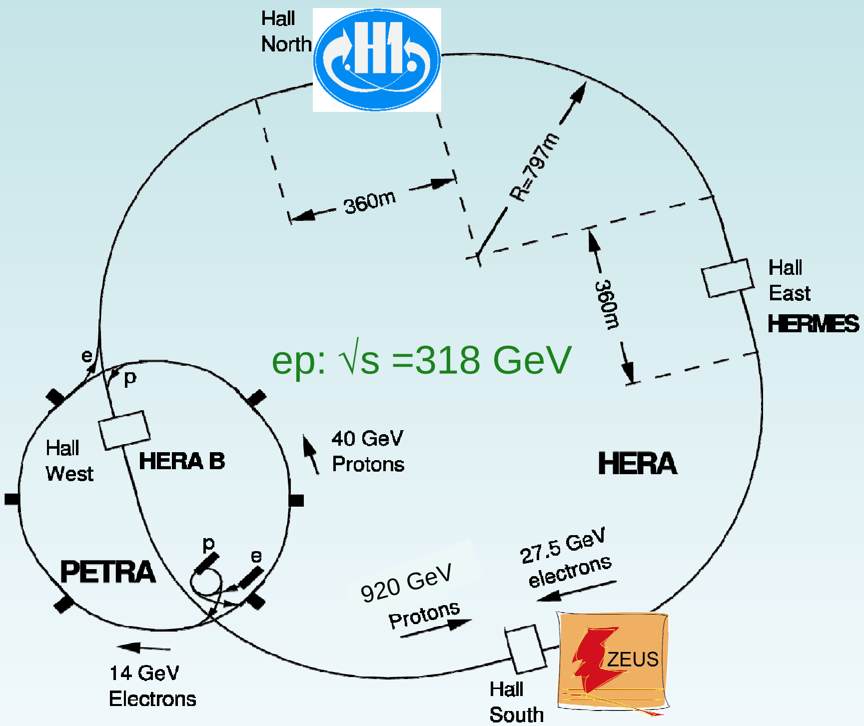
- HERA collider has provided a **wealth** of $e^{\pm}p$ data (from 94-07)
- measurements of Deep Inelastic Scattering (DIS), made by **H1** and **ZEUS**, **crucial** for constraining **quark** and **gluon** densities in the **proton**
- analysis of HERA-I data now (almost) complete and best precision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

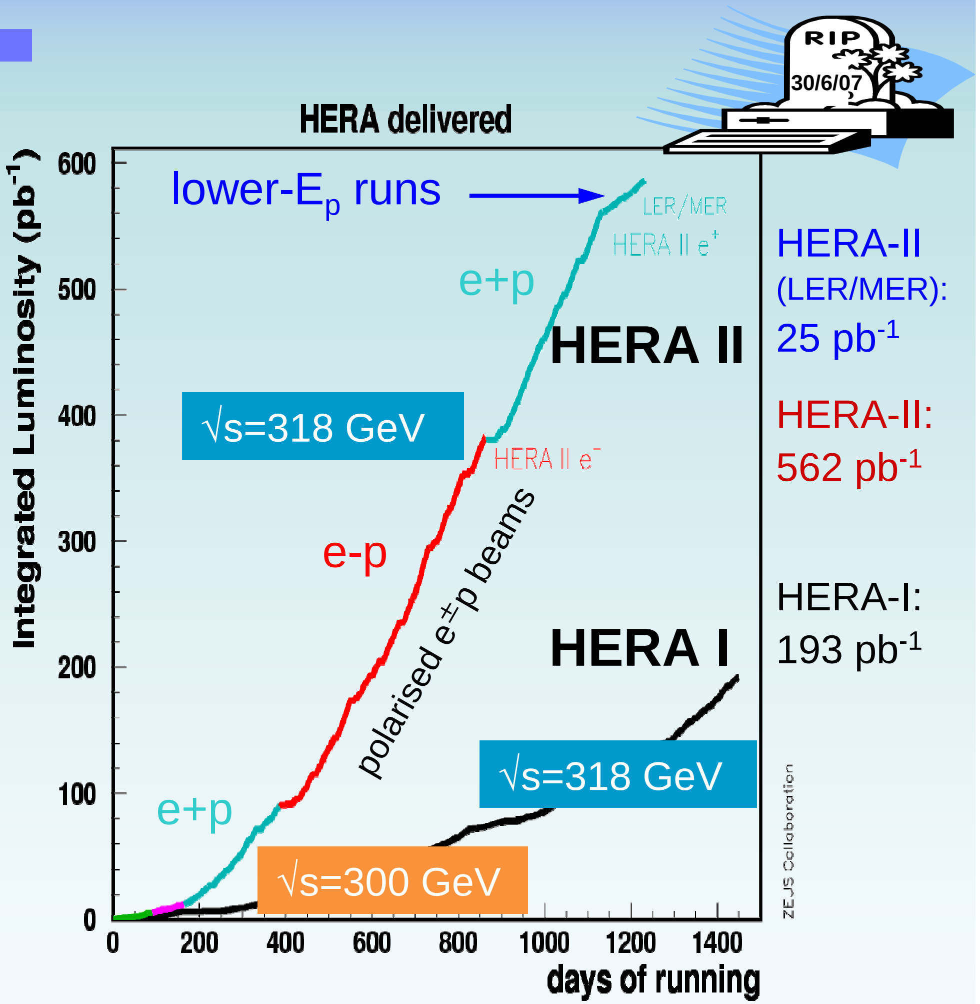


NOW: want to **maximise** impact of HERA by **combining** H1 and ZEUS data → obtain best precision cross sections → leading to most precise extractions of the proton parton density functions (PDFs)

HERA collider

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





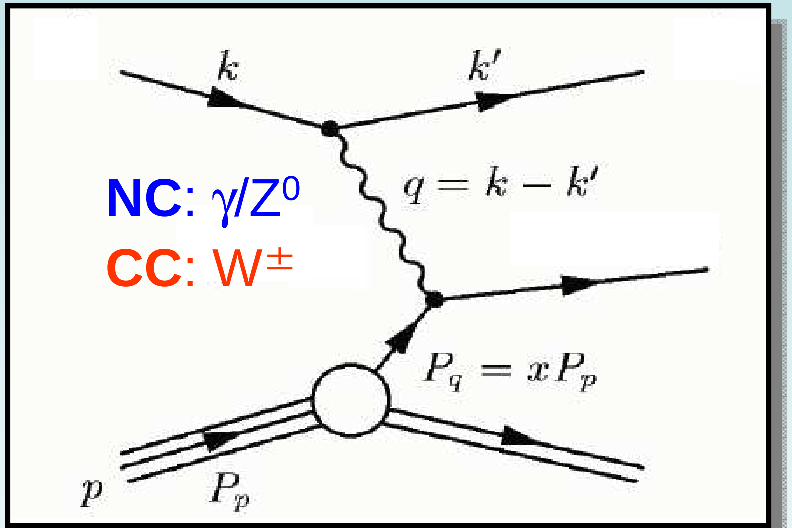
HERA ep data collected per exp.:

	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→eX; Charged Current (**CC**): ep→νX



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:

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

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

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

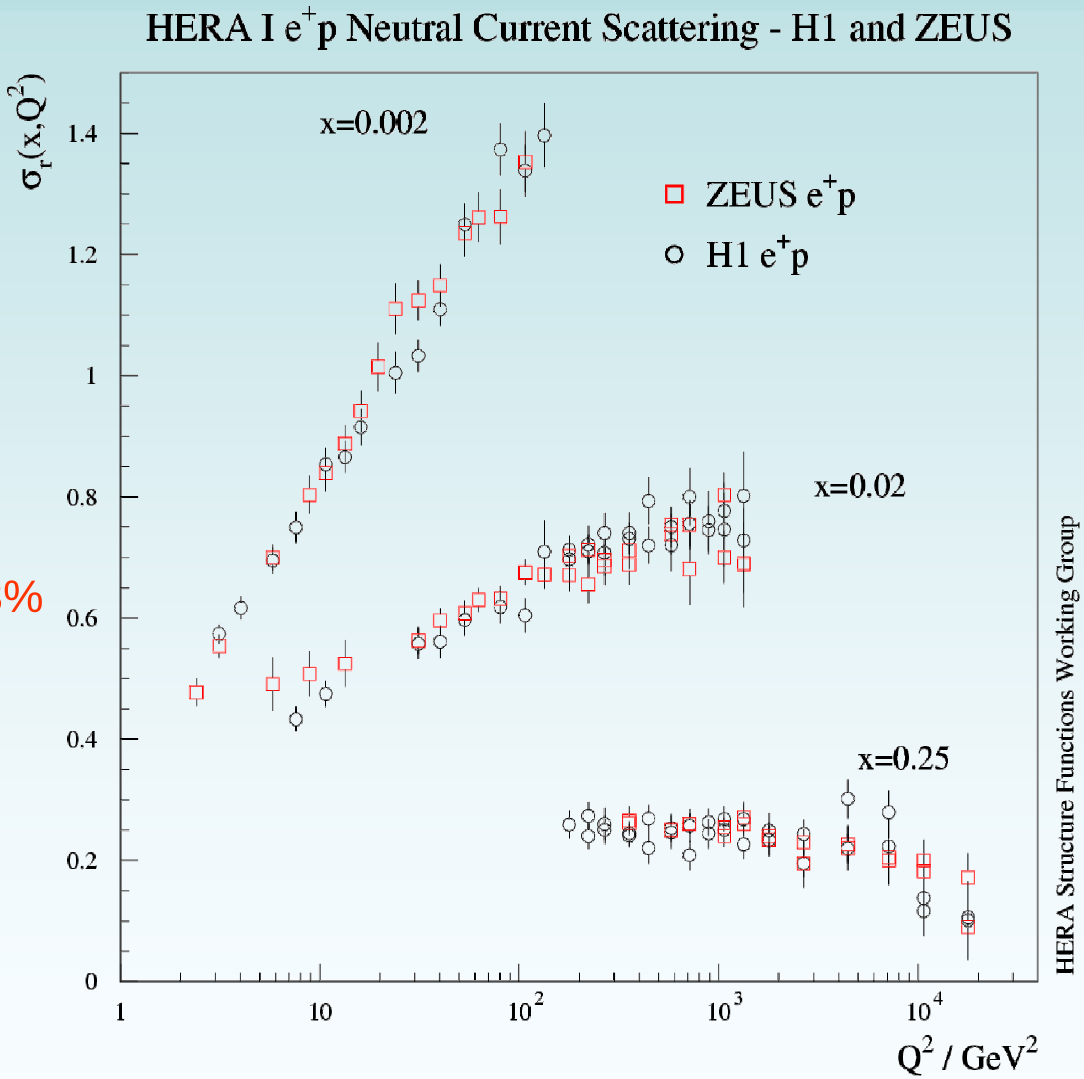
EXAMPLE data set for averaging: **e^+p NC DIS** from **H1** and **ZEUS**

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,Q^2)

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

- essentially: **H1** binning in **x**; **ZEUS** binning in $\mathbf{Q^2}$
- 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 ➔

X² definition

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

X² 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:** $\sigma_i \to \sigma_i\,(M^{i,true}/M^i)$
3. repeat step 1.

→ **convergence** is usually after two iterations

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

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

Uncertainties

treatment/prescription:

- 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 **same** **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

summary of sources:

- 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

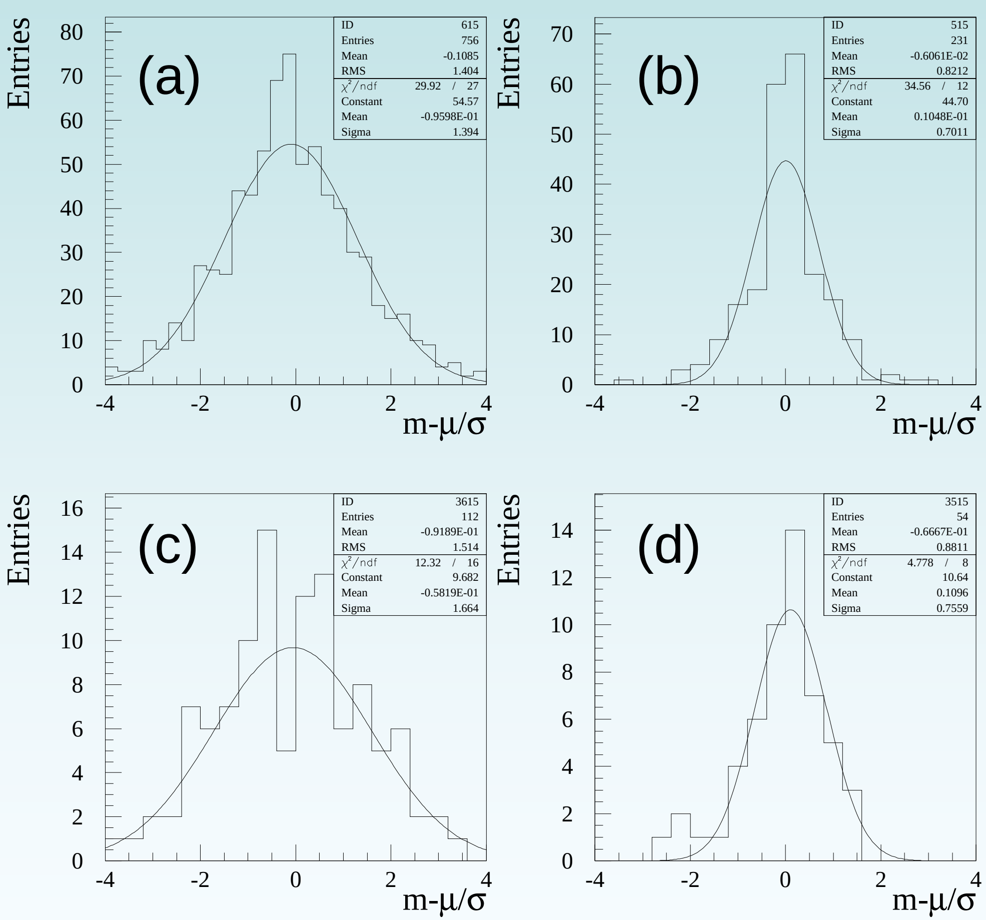
  - subtraction of **photoproduction** background: 1-2% at large y

these uncertainties are added to the averaged data points

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

Fit quality

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



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

resulting **good quality** of fit:

X^2/dof=510/599

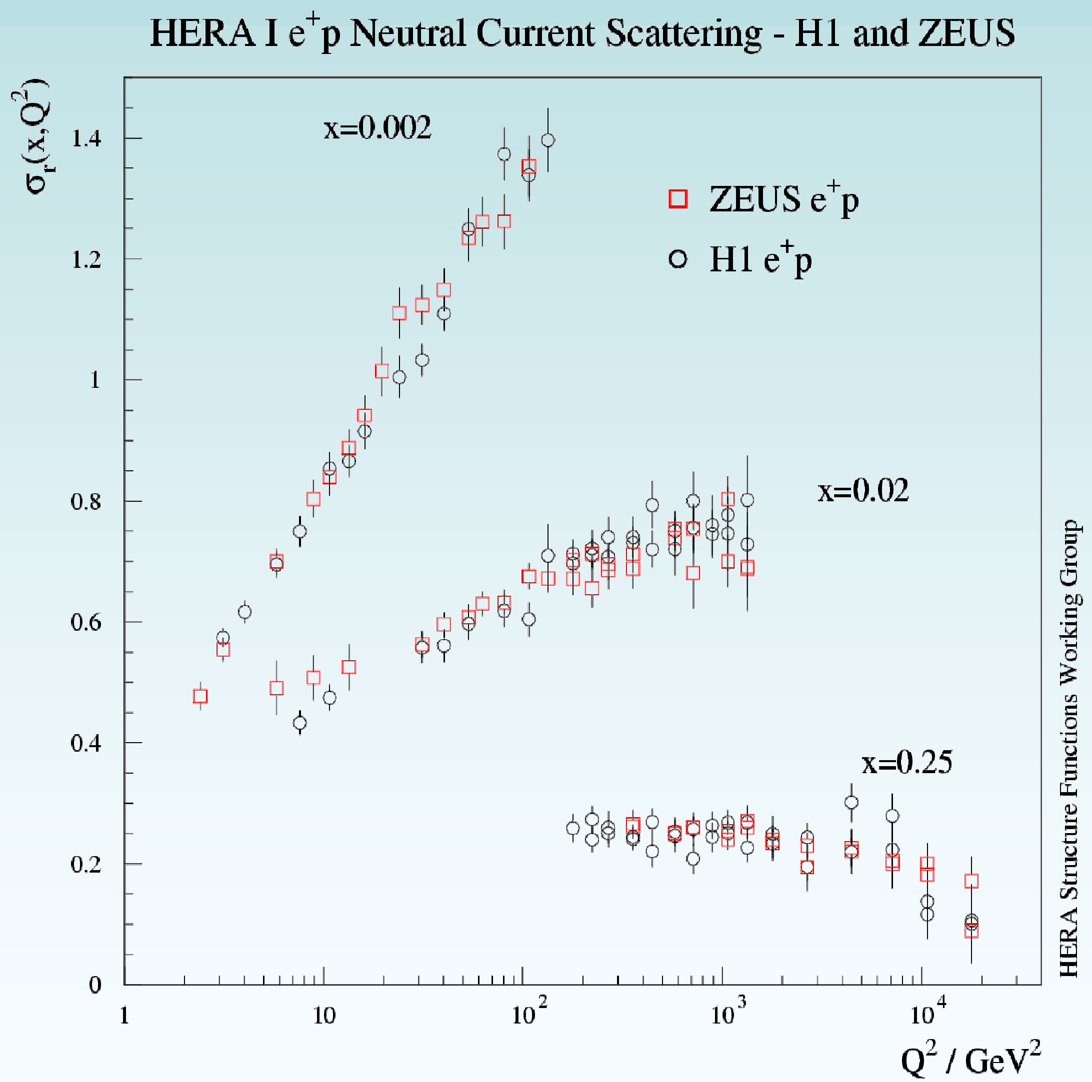
	pulls	
	mean	sigma
(a) NC e+p	-0.09	1.4
(b) NC e-p	0.01	0.7
(c) CC e+p	-0.05	1.7
(d) CC e-p	0.1	0.8

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

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

Results (i): NC e^+p

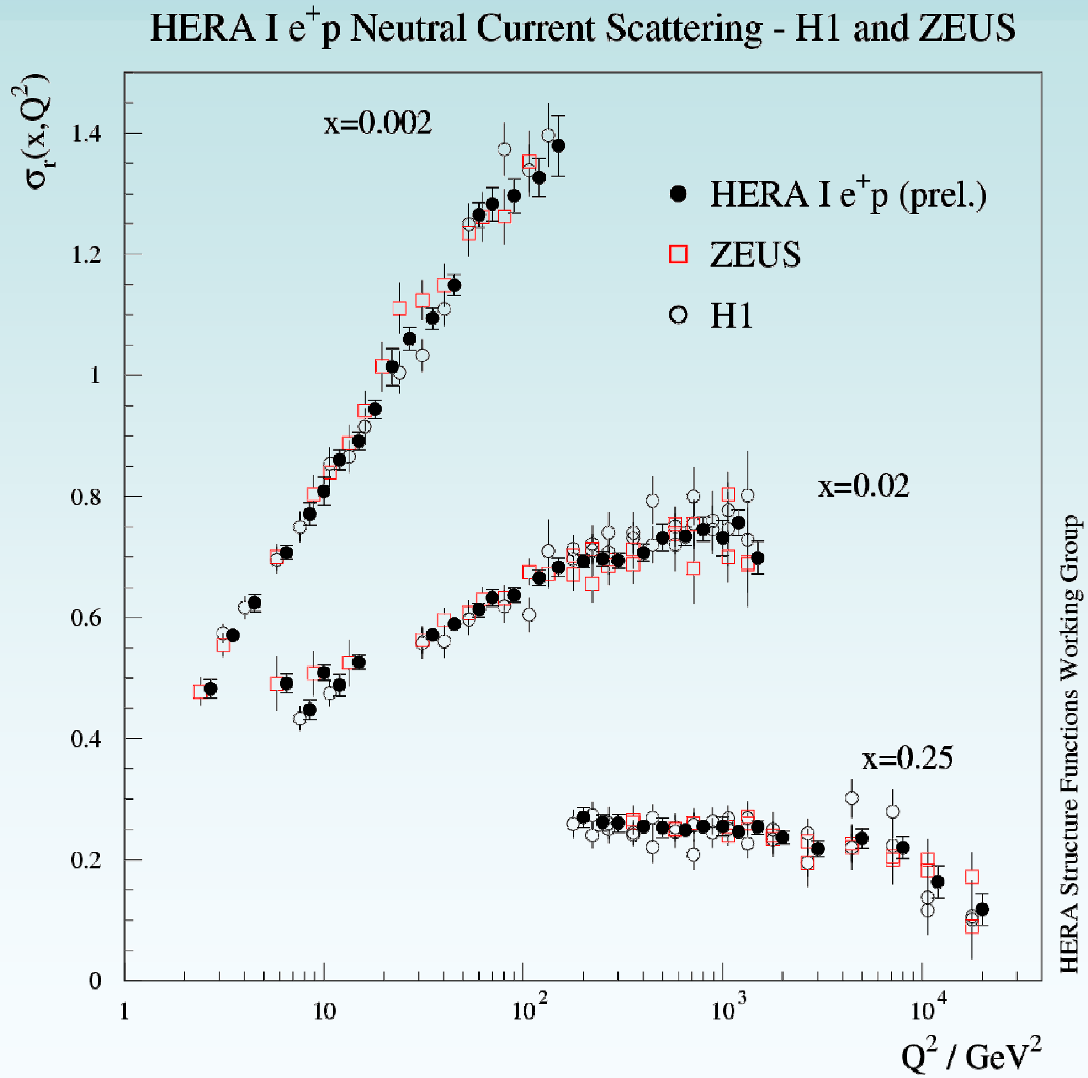
<u>REMINDER:</u> individual measurements from **H1** and **ZEUS** [zoom in on three example x values]



Results (i): NC e^+p

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

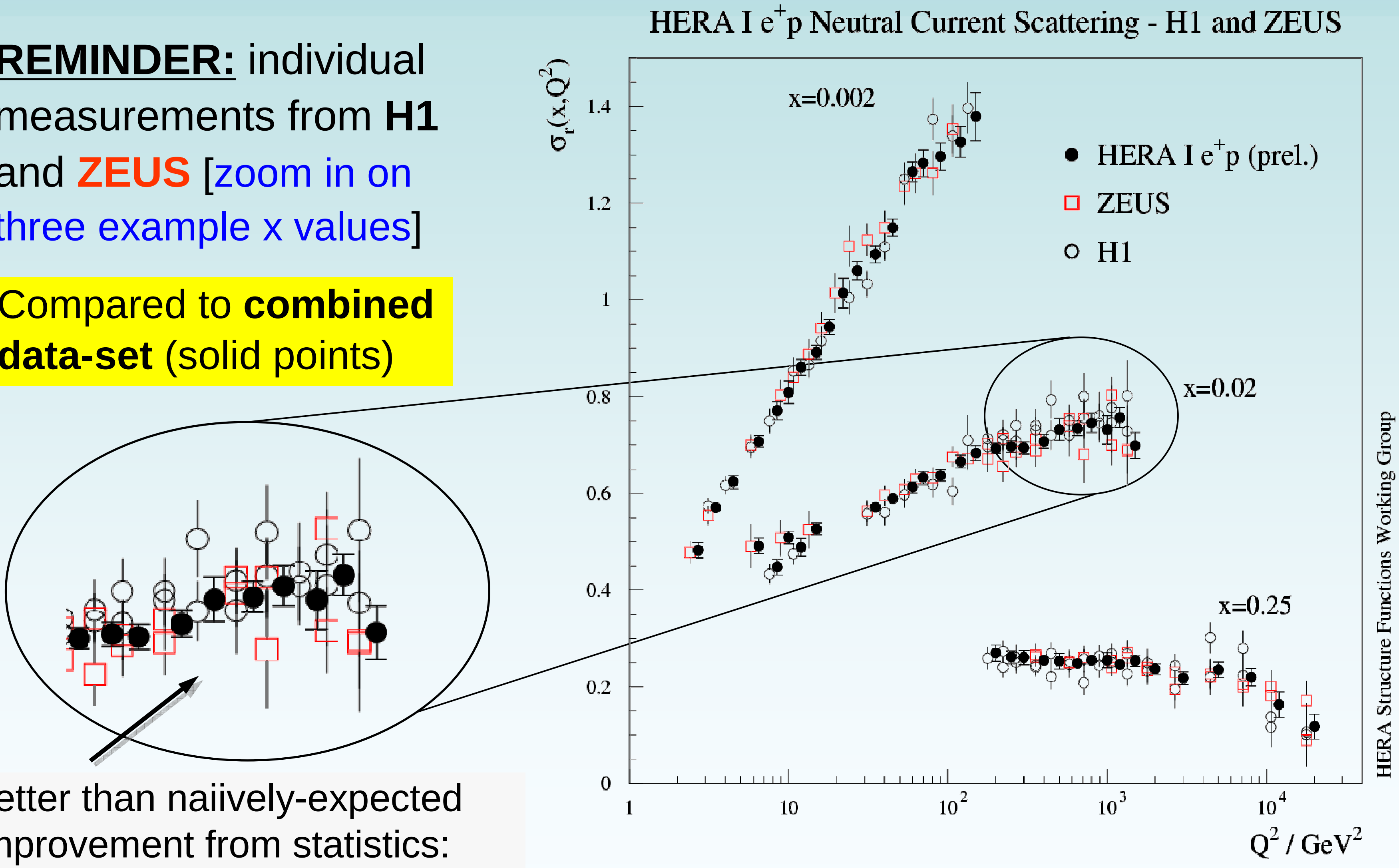
Compared to **combined data-set** (solid points)



Results (i): NC e⁺p

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

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

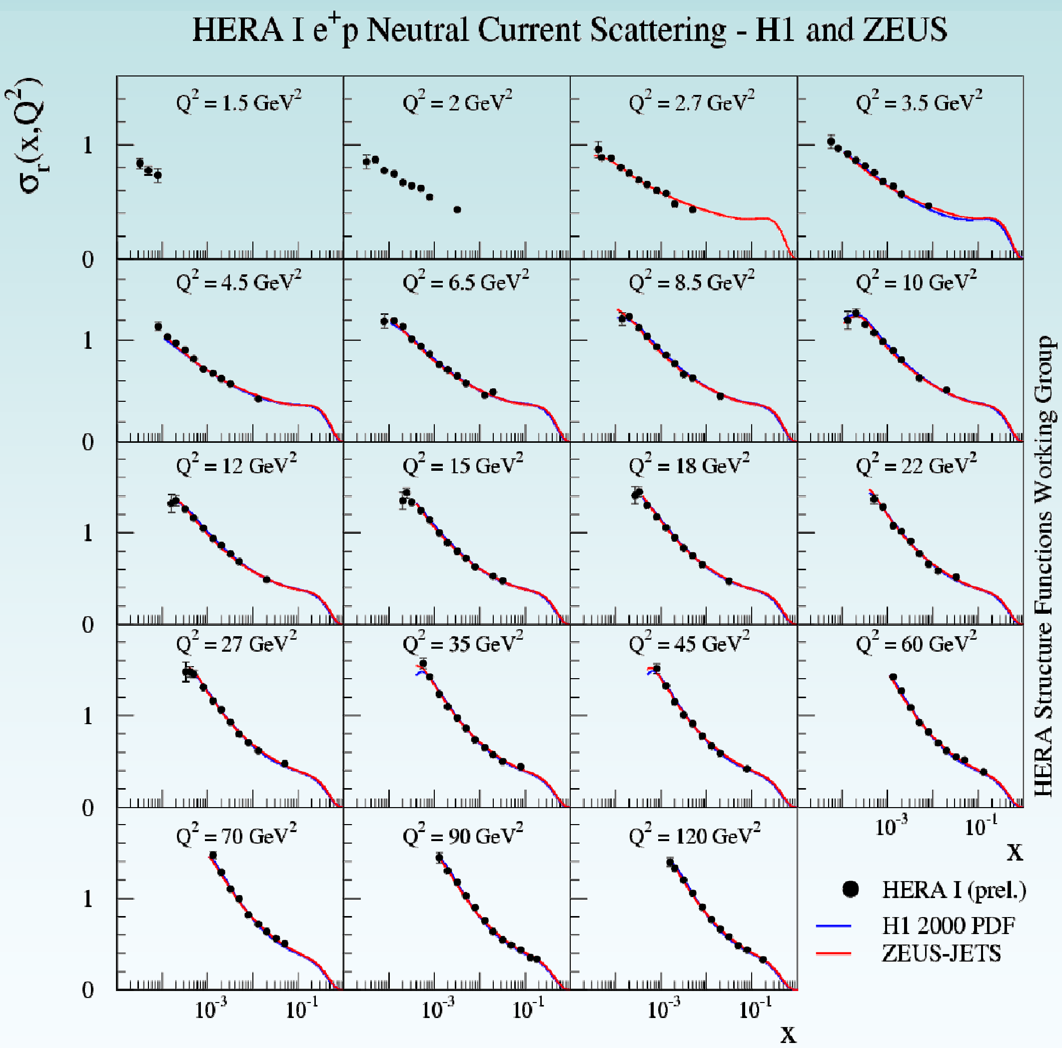


better than naiively-expected improvement from statistics: **"cross-calibration"**

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**

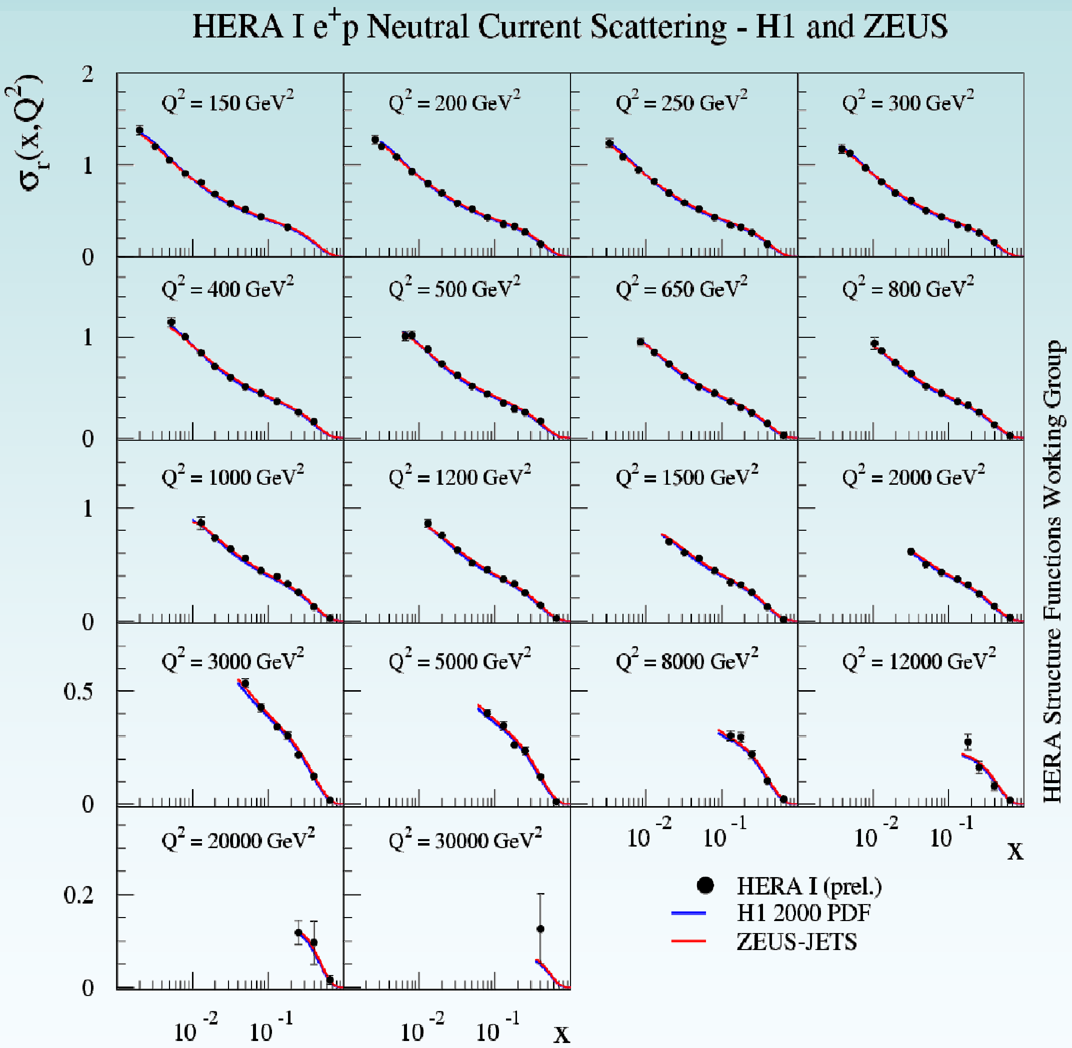


Results (iii): NC e^+p

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]

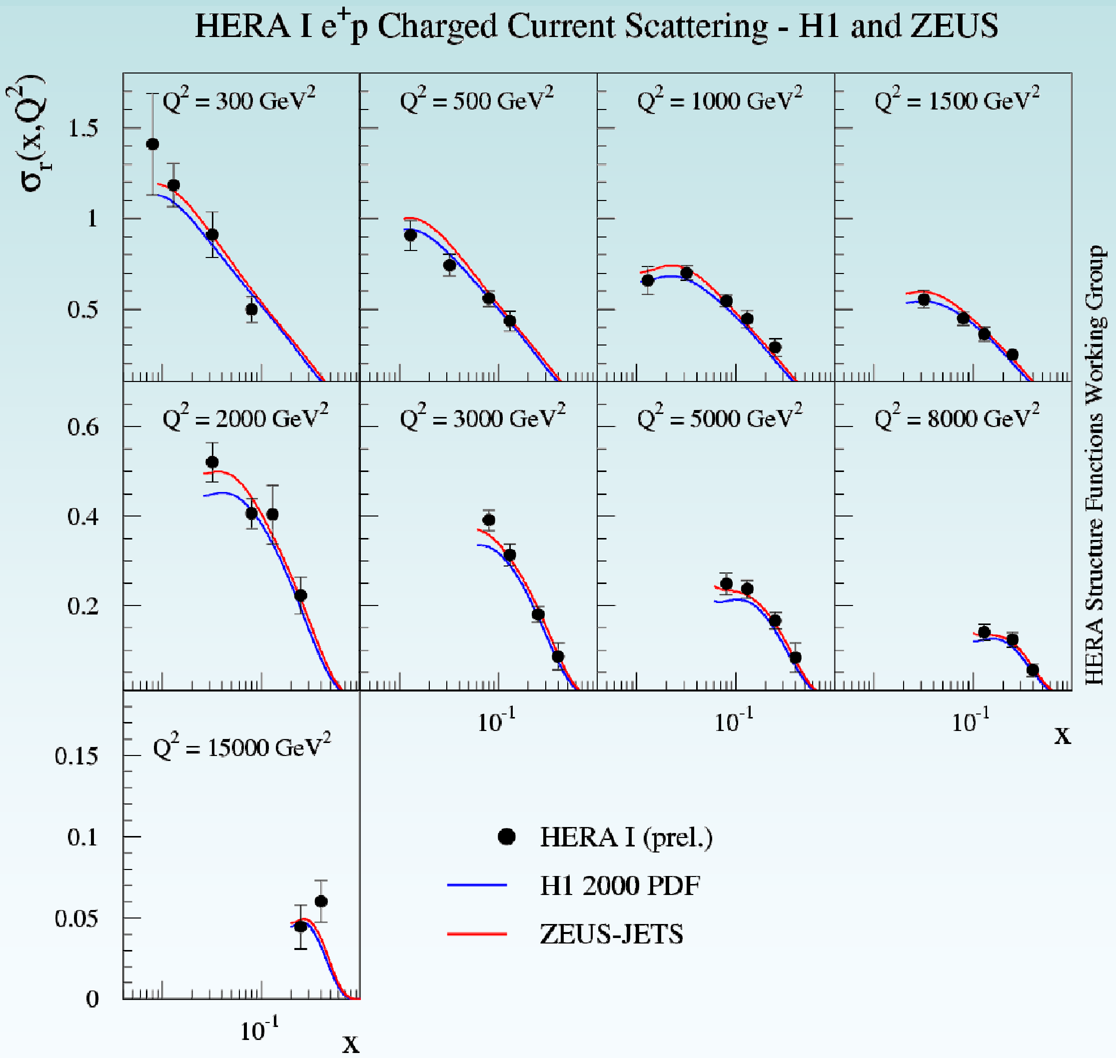


Results (iv): CC e^+p

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

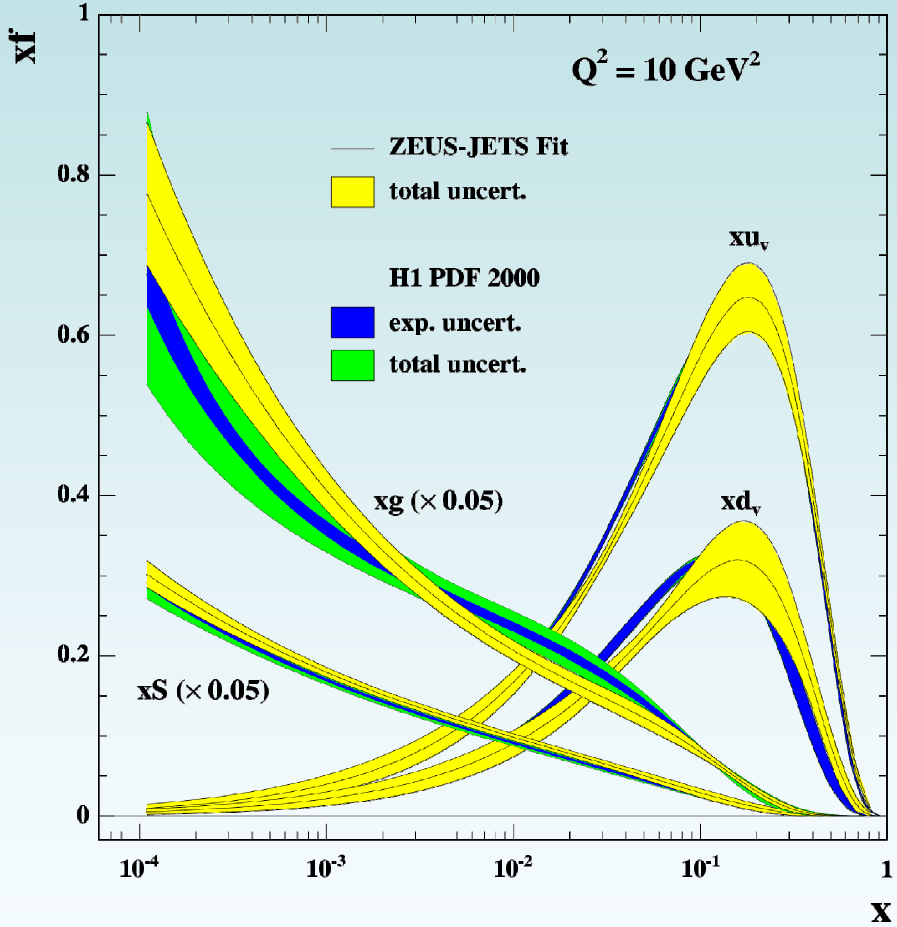
HERA NLO QCD fit

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 χ^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: $\bar{s}=f_s\bar{D}$, $\bar{c}=f_c\bar{U}$, $A(\bar{U})=(1-f_s)/(1-f_c)A(\bar{D})$; with f_s=0.33, f_c=0.15

(consistent with dynamical generation)

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

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

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

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

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

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

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

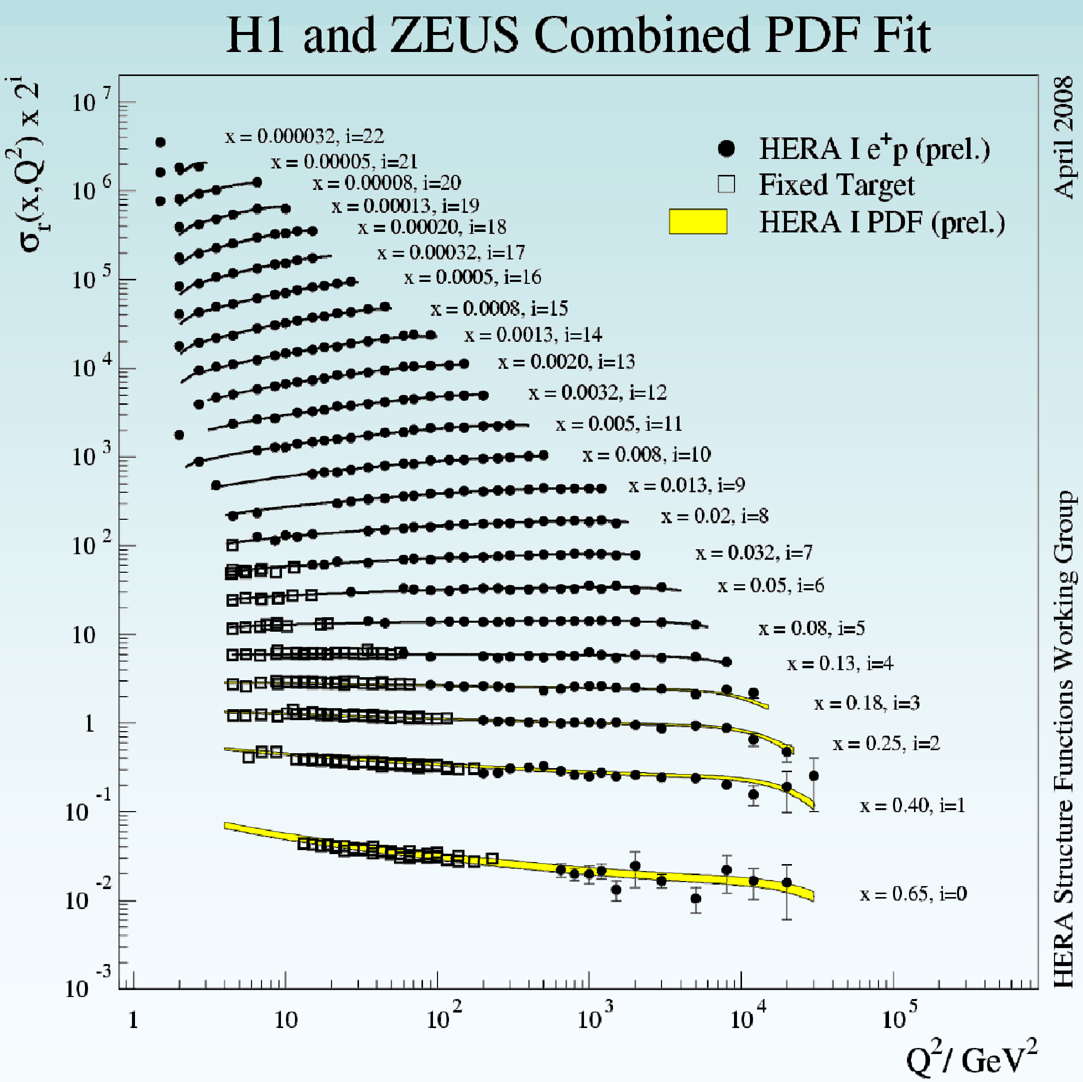
Results (i): NC e^+p comparison

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]



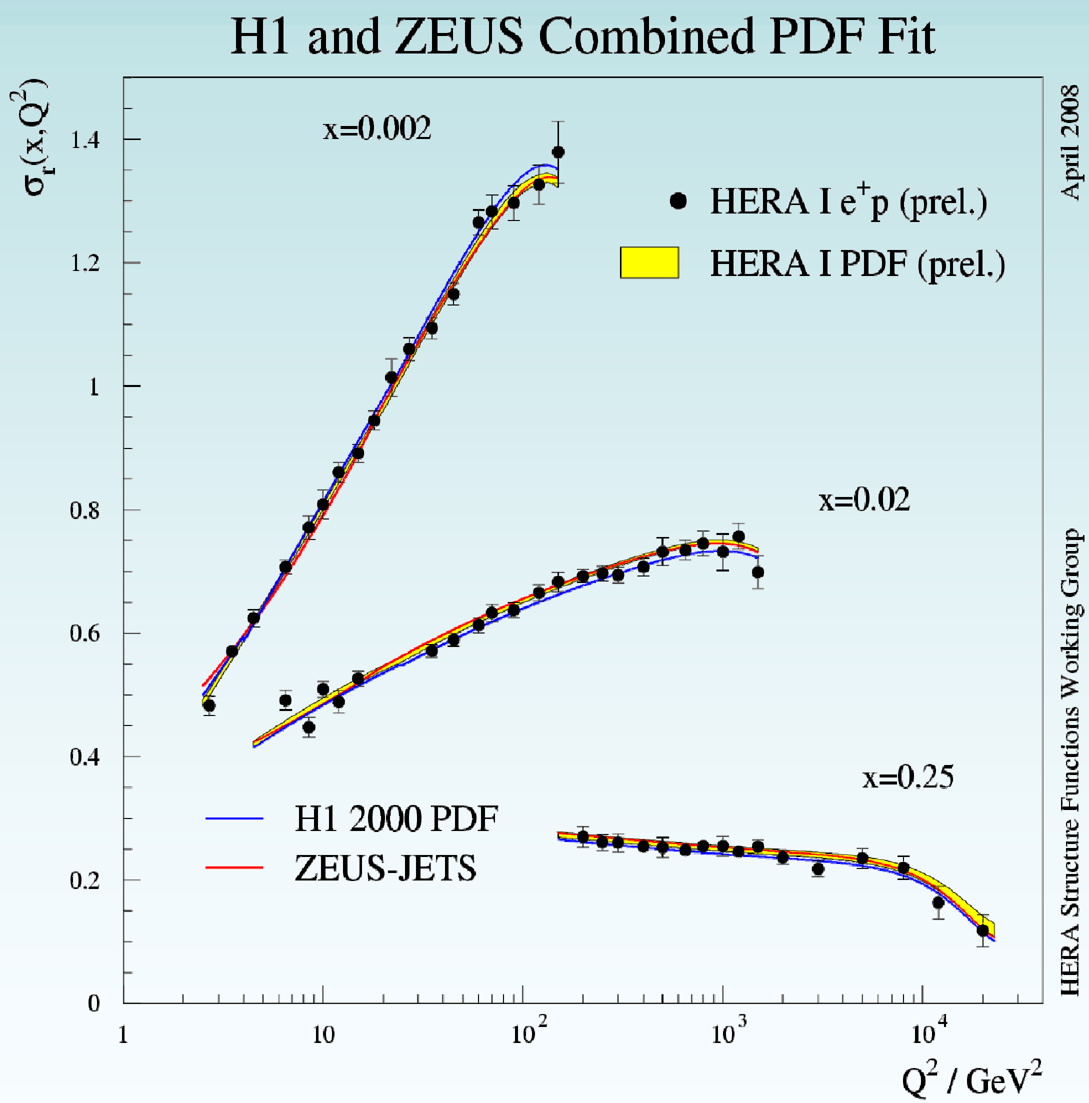
Results (ii): NC e^+p comparison

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**



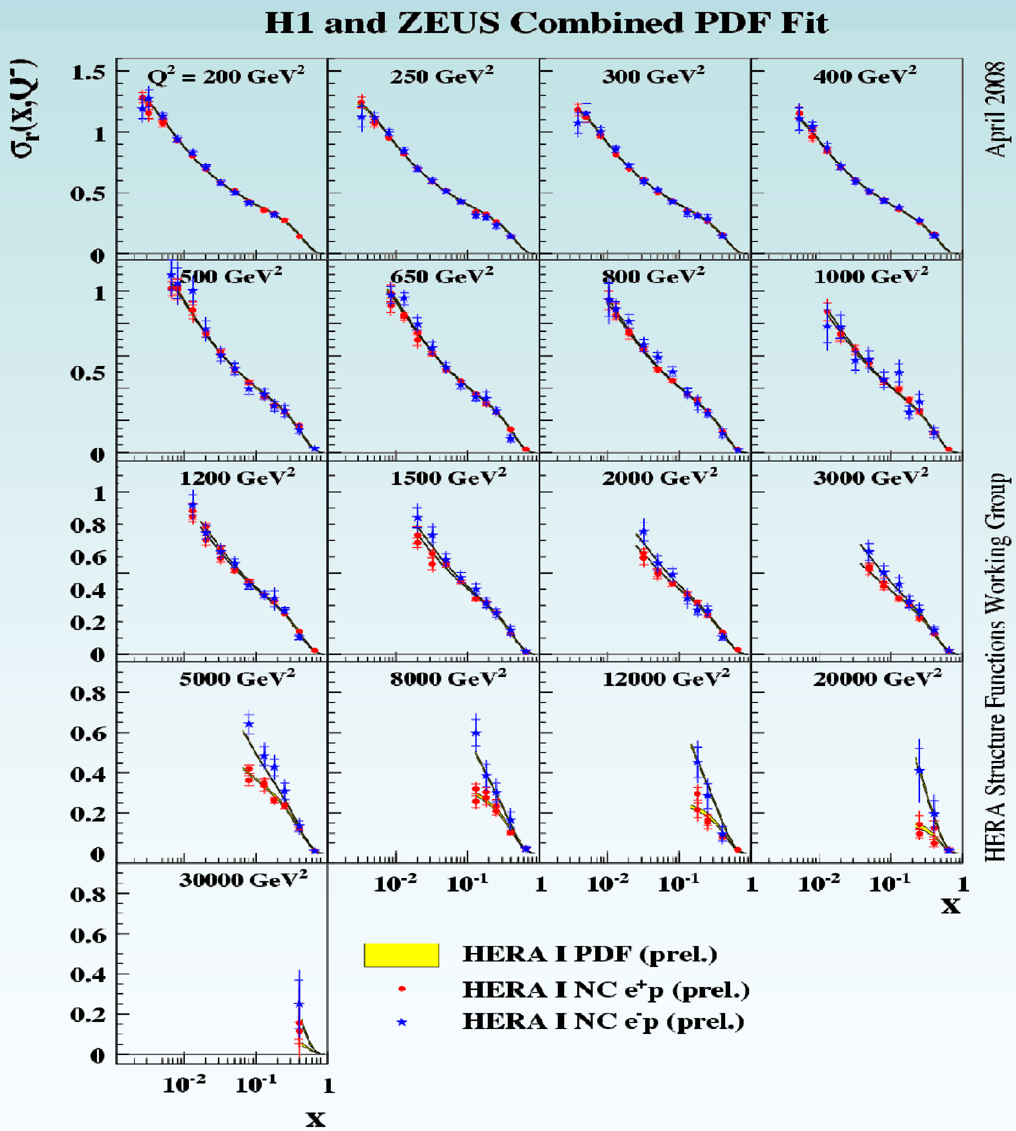
Results (iii): NC $e^{\pm}p$

NC $e^{\pm}p$ [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

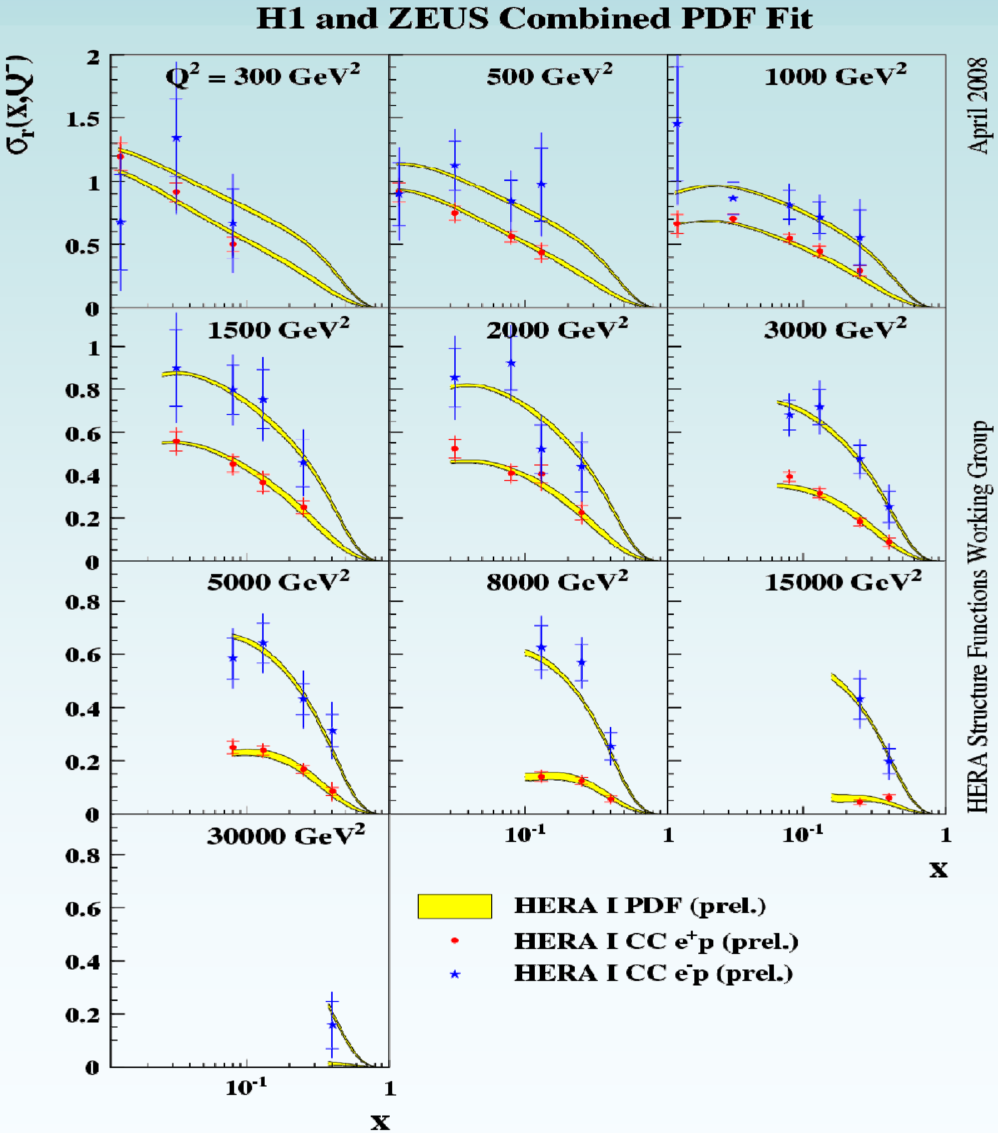
Charged Current e$^{\pm}$p

"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

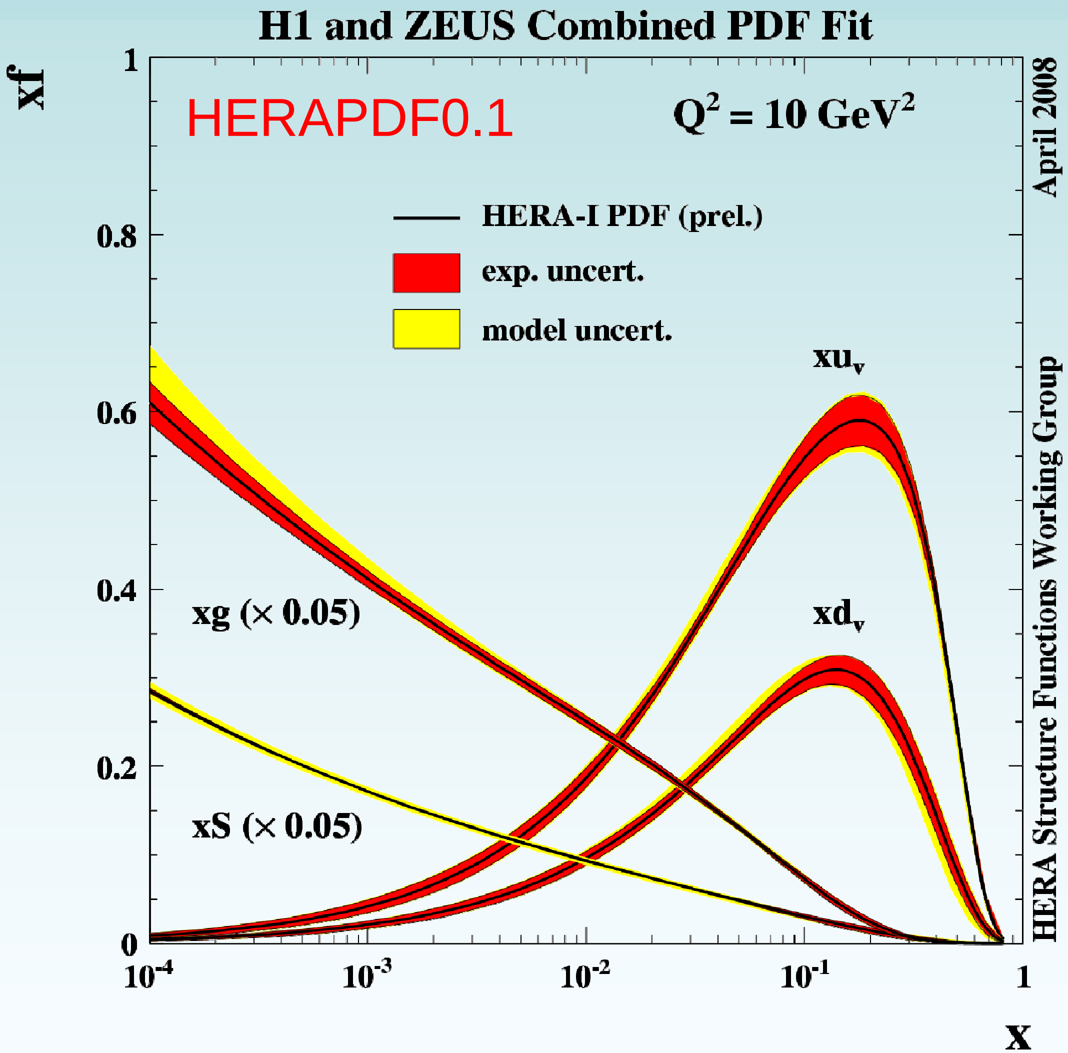
[avoids **nuclear corrections** from fixed target data]



HERA PDF

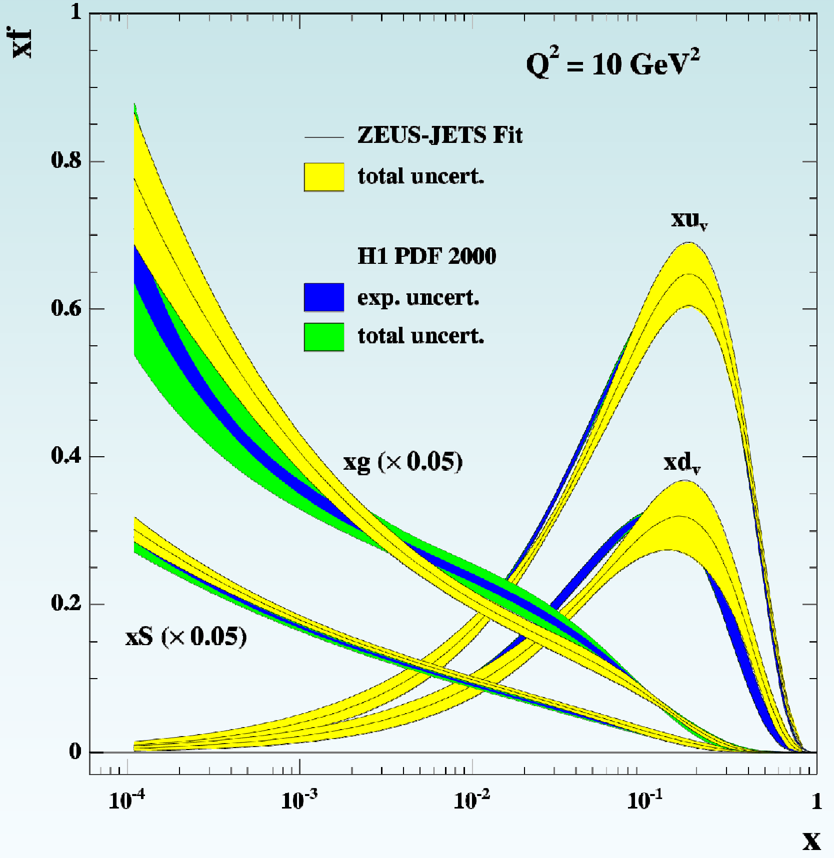
"HERAPDF0.1":
total **experimental uncertainty** band and **model uncertainties**

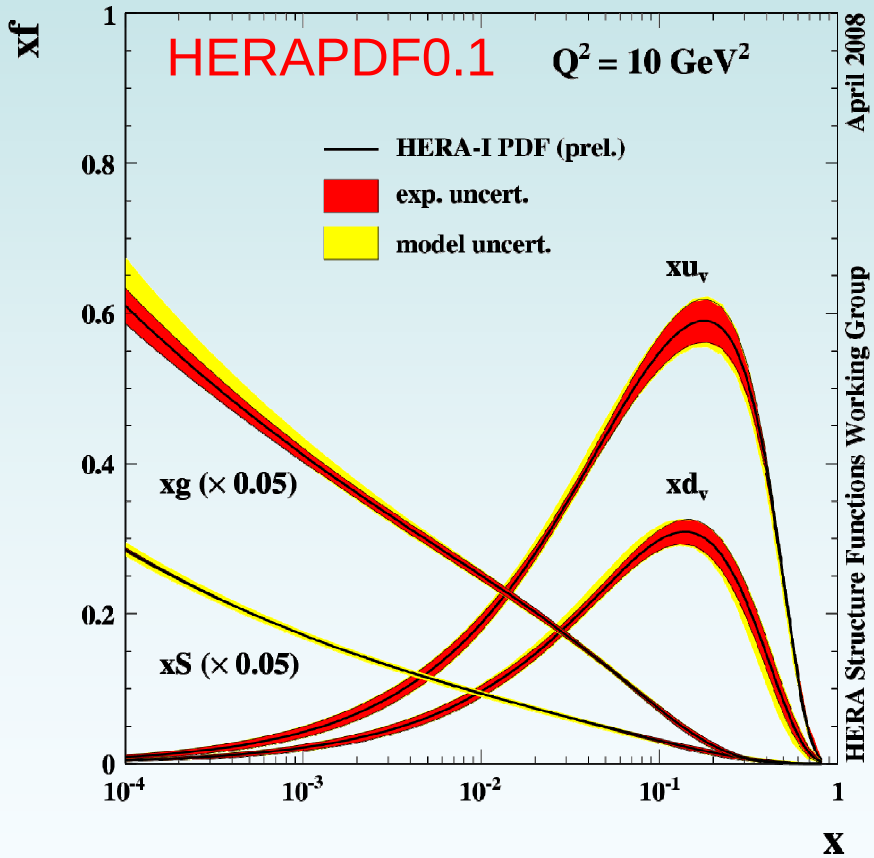
Note: **xg(x)** and **xS(x)** scaled down by ×20



cf. previous fits to HERA data

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



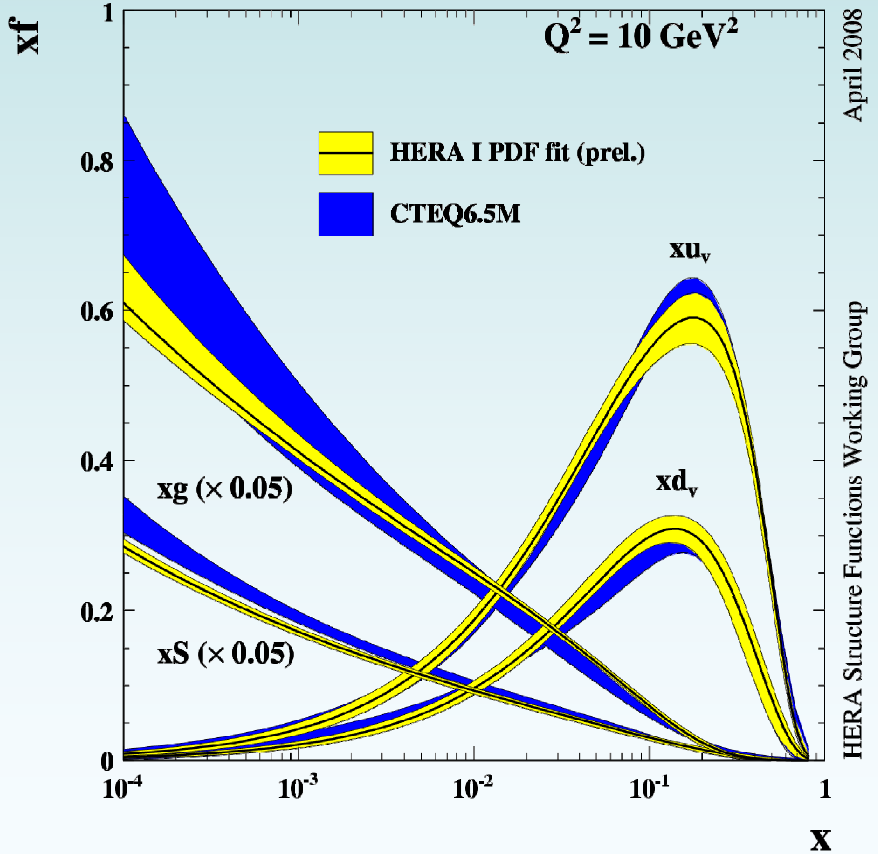


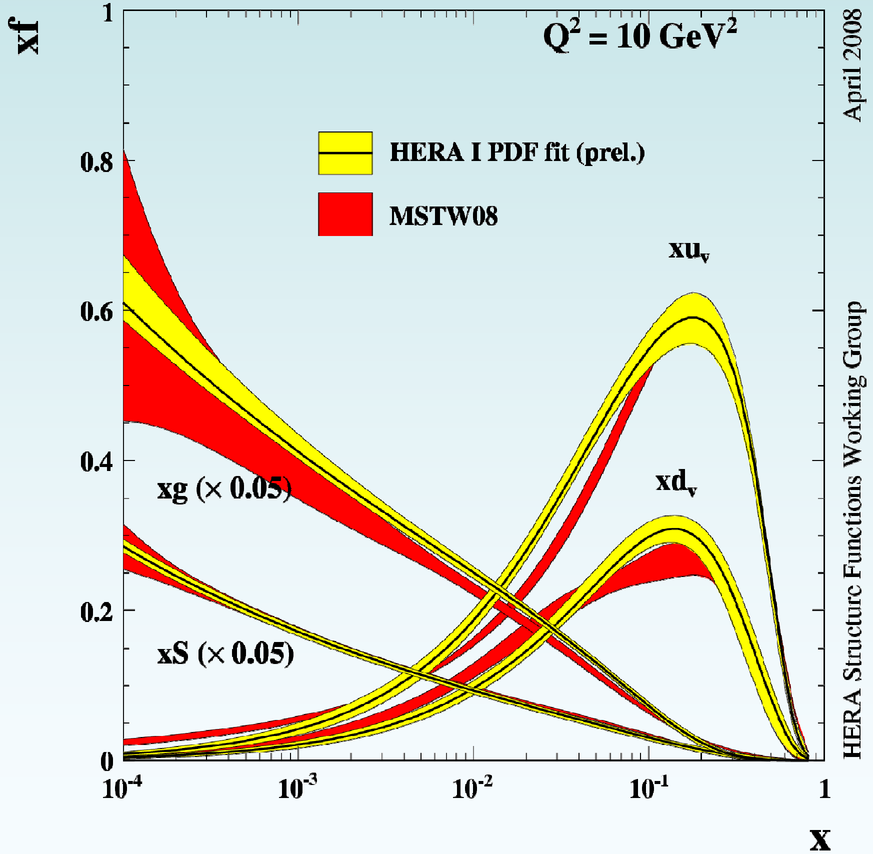
improvement in precision is **impressive**: originates from **data combination**

HERA PDF vs. Global fits

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

Caution:
Different ΔX^2's … also:
- global fits: 90% CL
- HERA fit: 68% CL





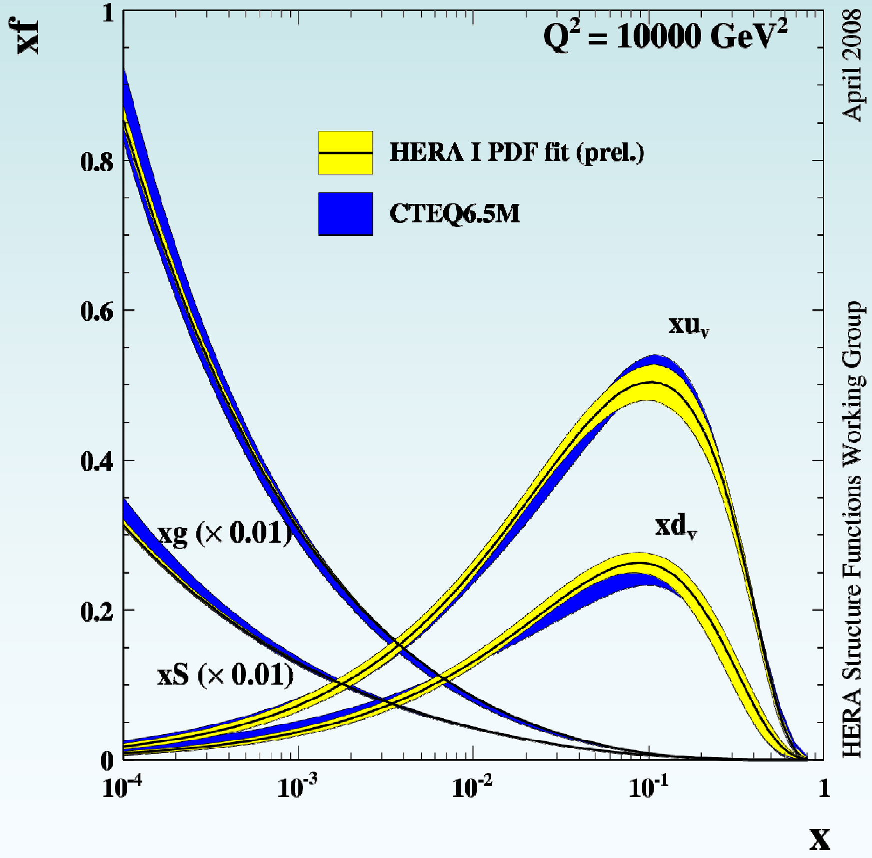
[note that MSTW08 is not yet published:- this is a **pre-release**]

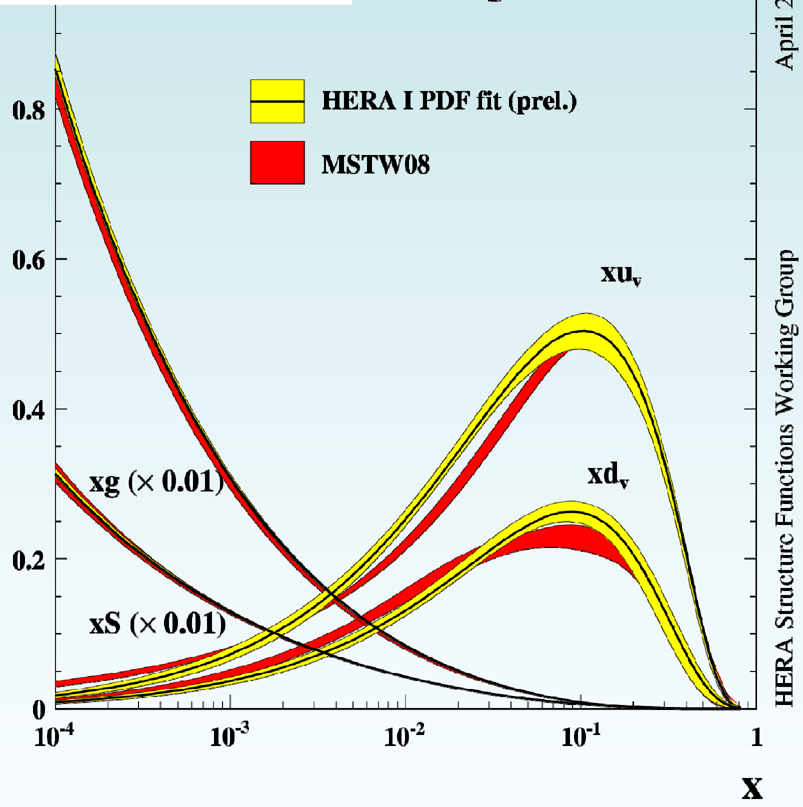
HERA PDF vs. Global fits

Caution:
Different ΔX^2's … also:
- global fits: 90% CL
- HERA fit: 68% CL

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

"LHC domain"

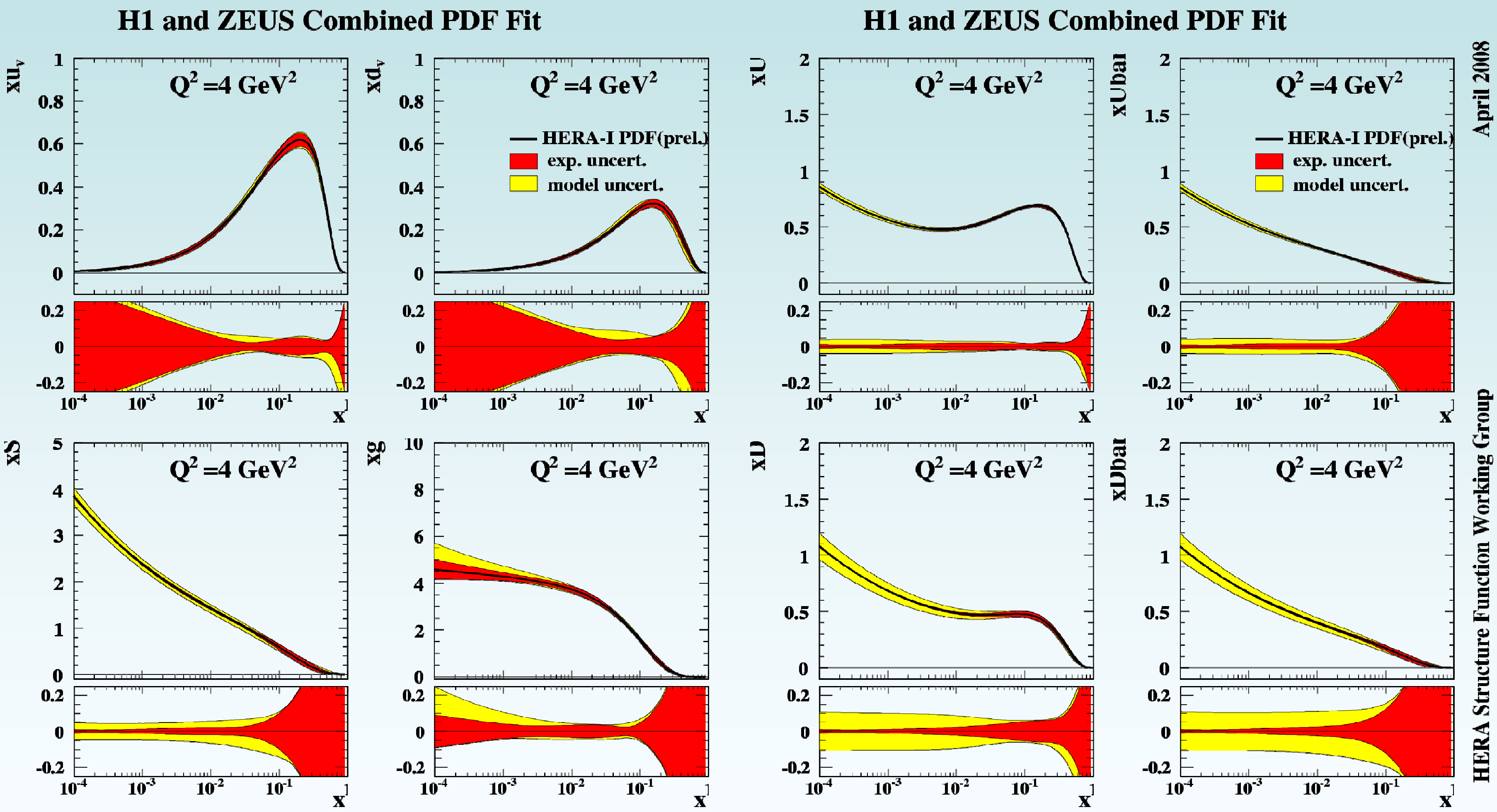




[note that MSTW08 is not yet published:- this is a **pre-release**]

HERA PDF: in more detail

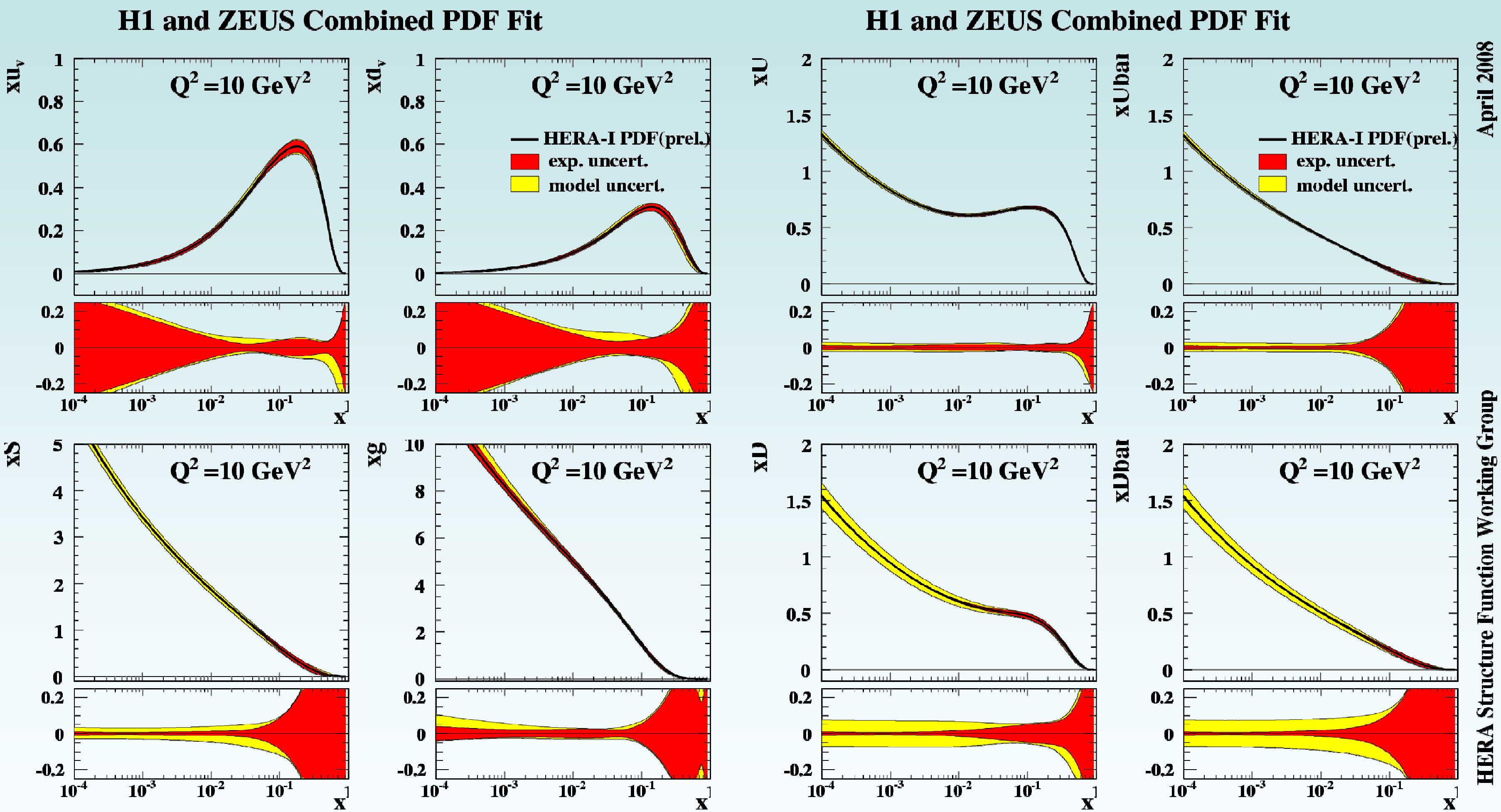
PDFs at starting scale, Q_0^2=4 GeV^2



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

HERA PDF: in more detail

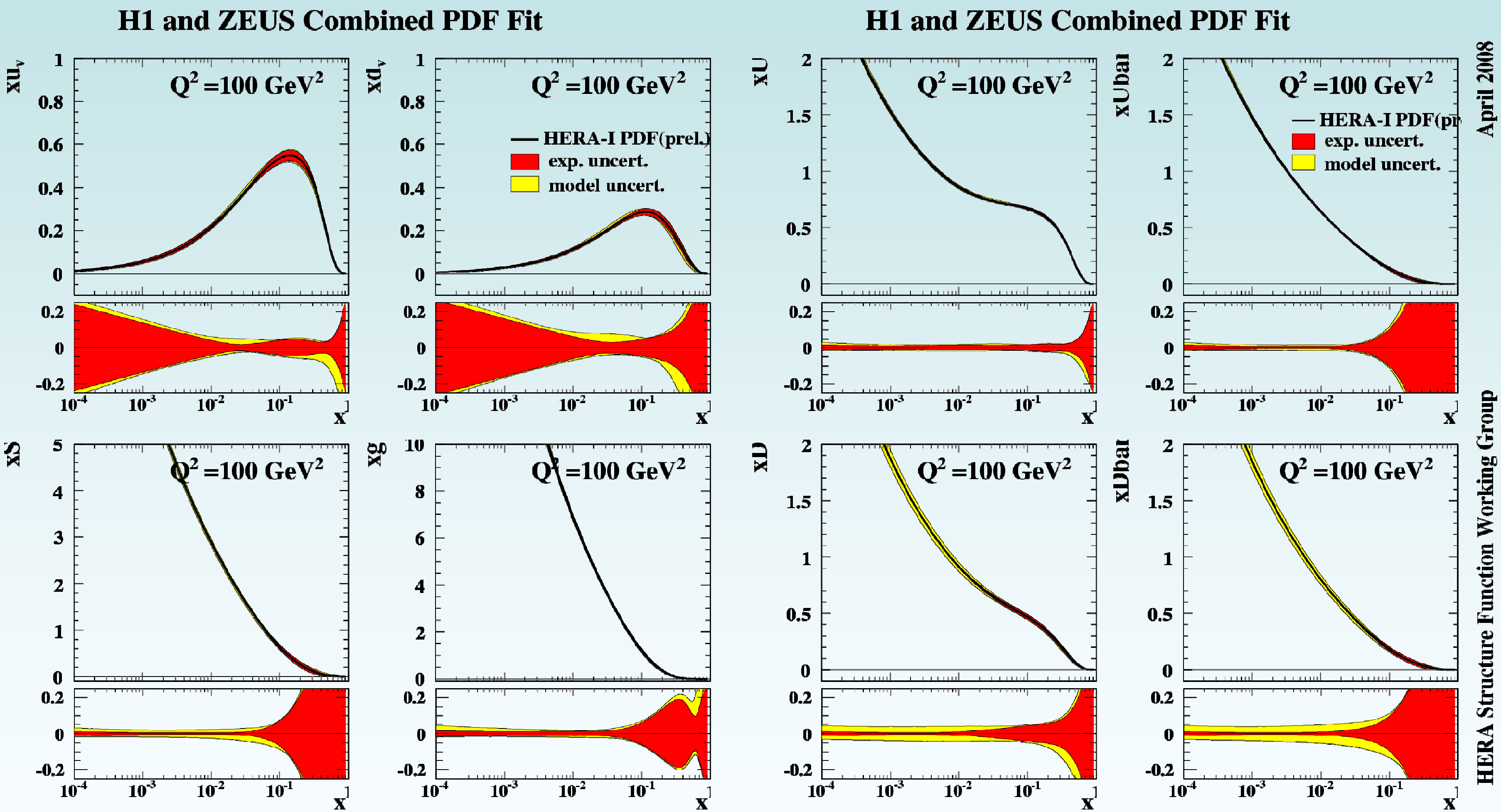
PDFs at Q^2=10 GeV^2



PDF uncertainties decrease as Q^2 increases

HERA PDF: in more detail

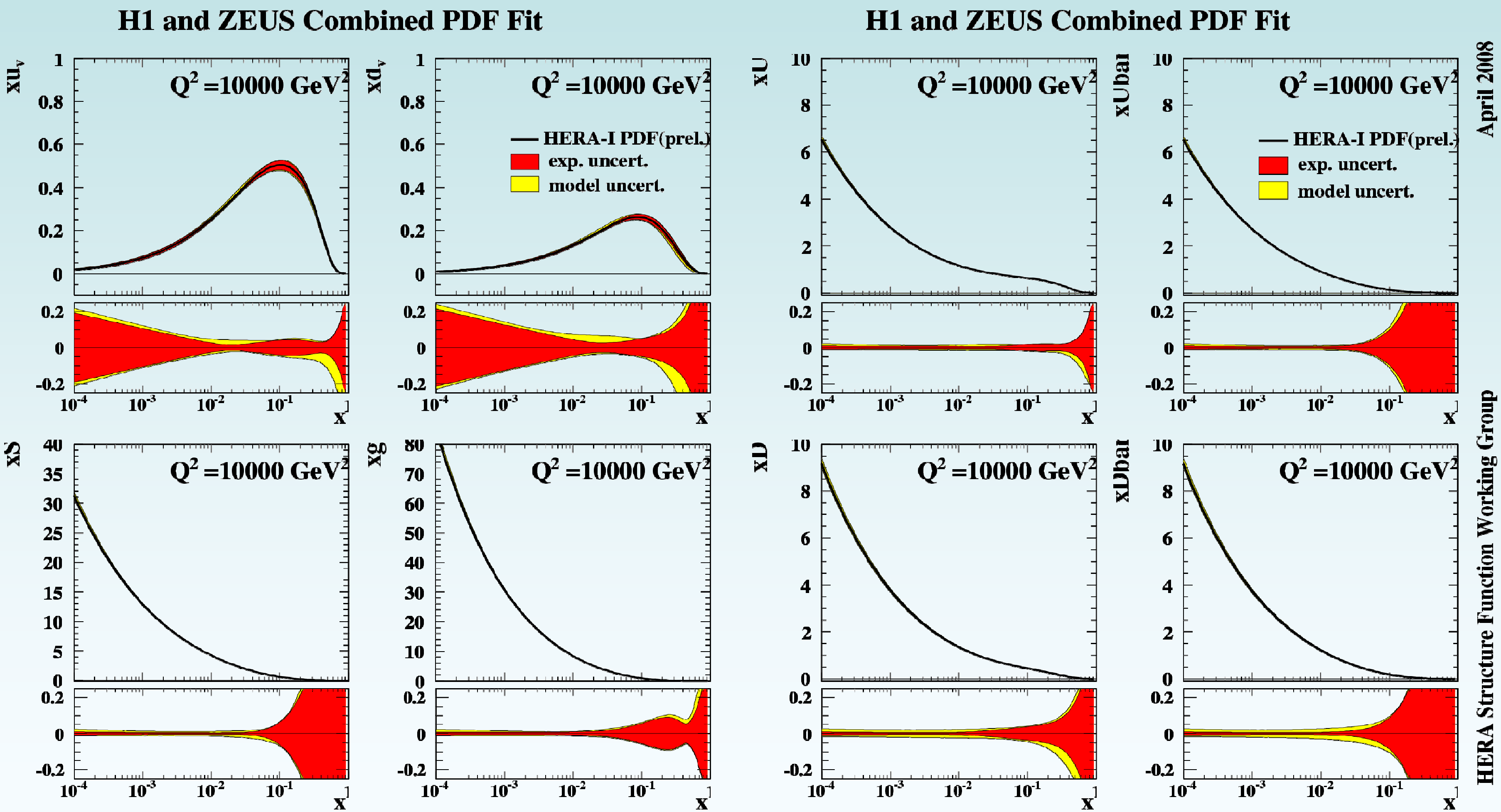
PDFs at Q^2=100 GeV^2



PDF uncertainties decrease as Q^2 increases

HERA PDF: in more detail

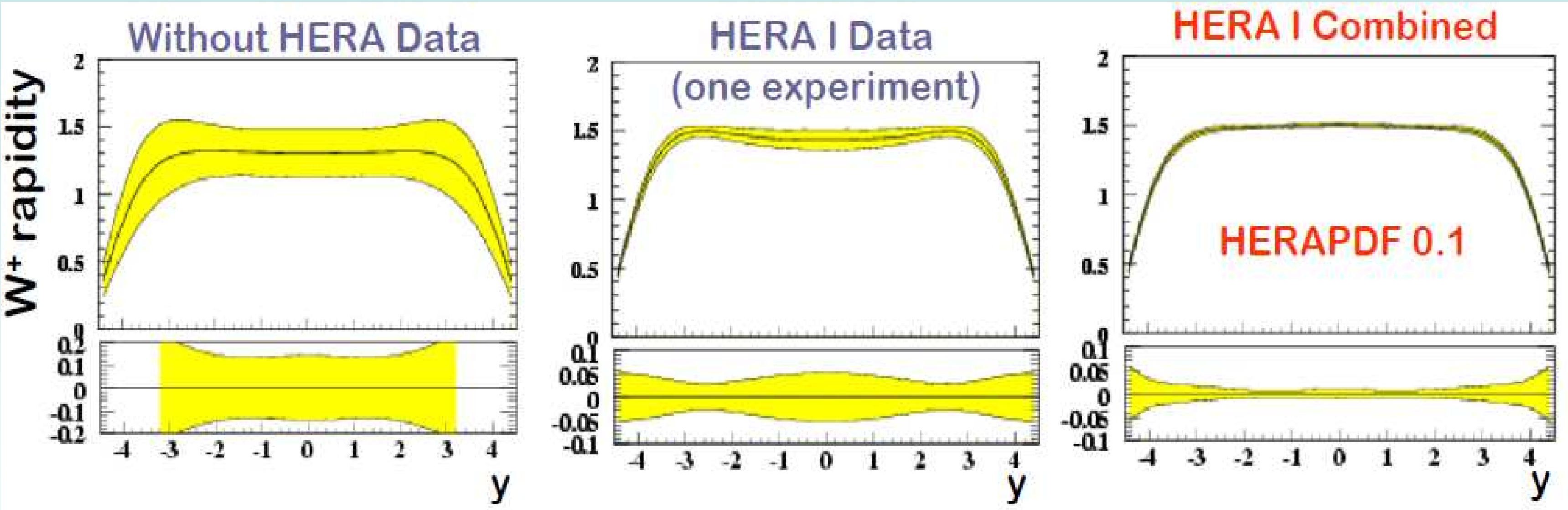
PDFs at Q^2=10000 GeV^2



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

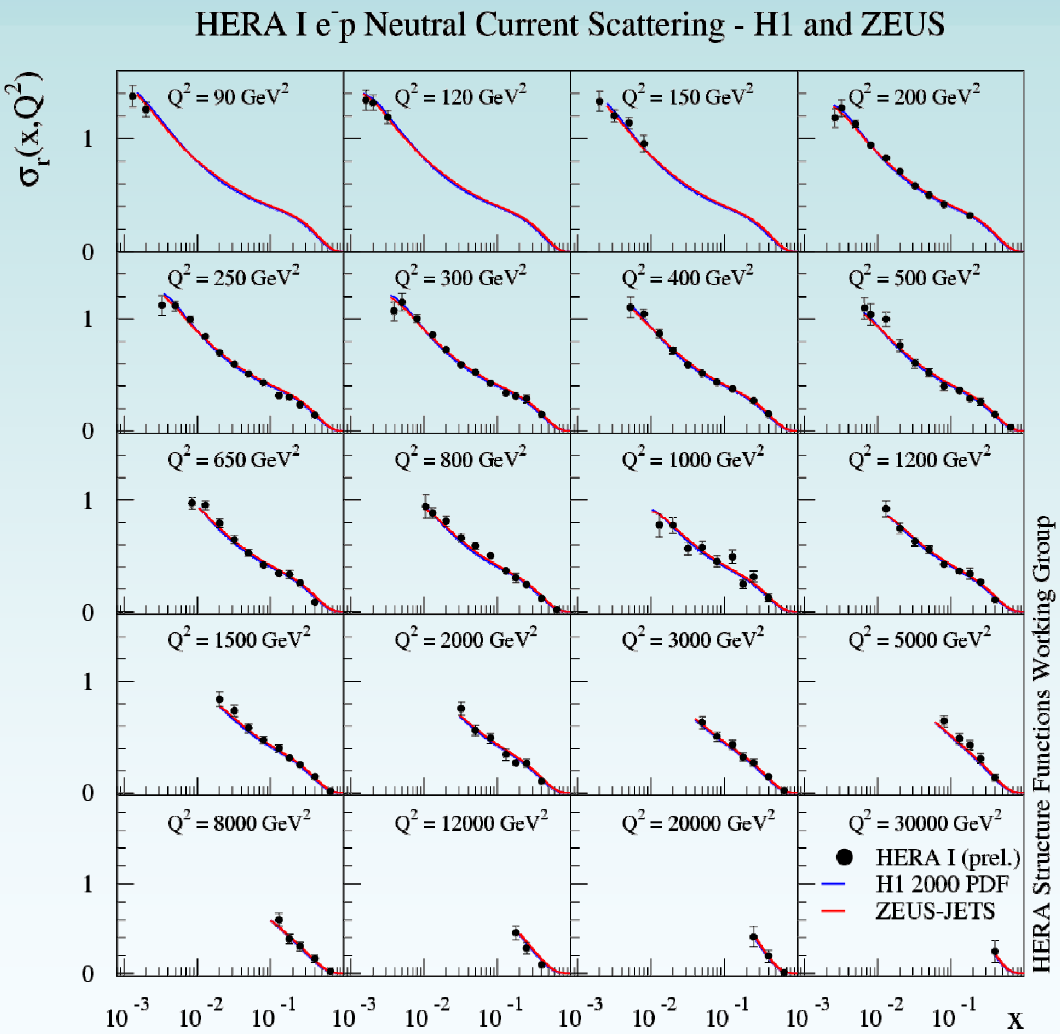
still to come:- use of all **HERA-II** data in both combination and fits

Extras

Results (extra): NC e⁻p

NC e⁻p [at high Q^2]:

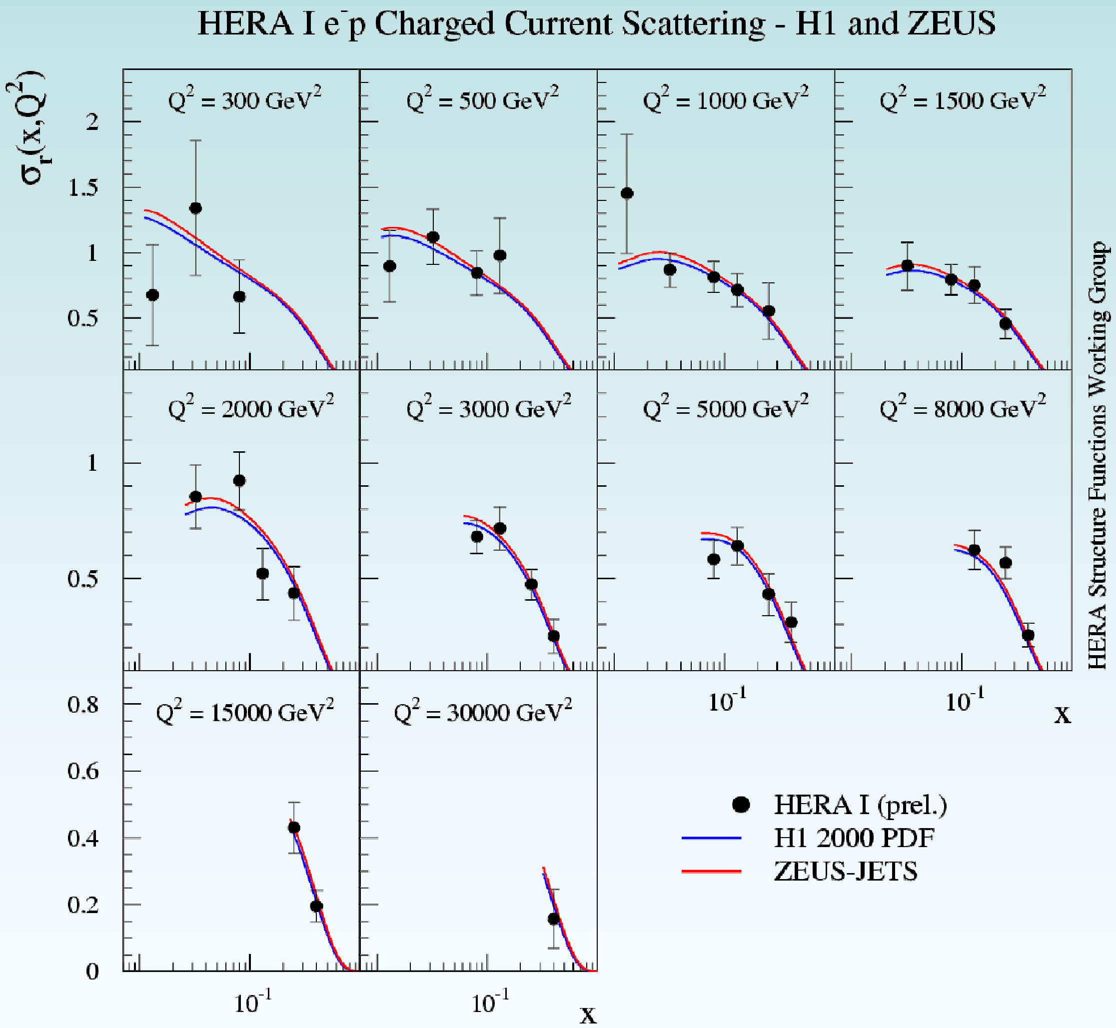
combined data compared to published **H1** and **ZEUS PDF fits** to (their own) data from HERA I



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**

<u>Offset Method</u> (in a nutshell)

1. perform fit <u>without</u> 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.

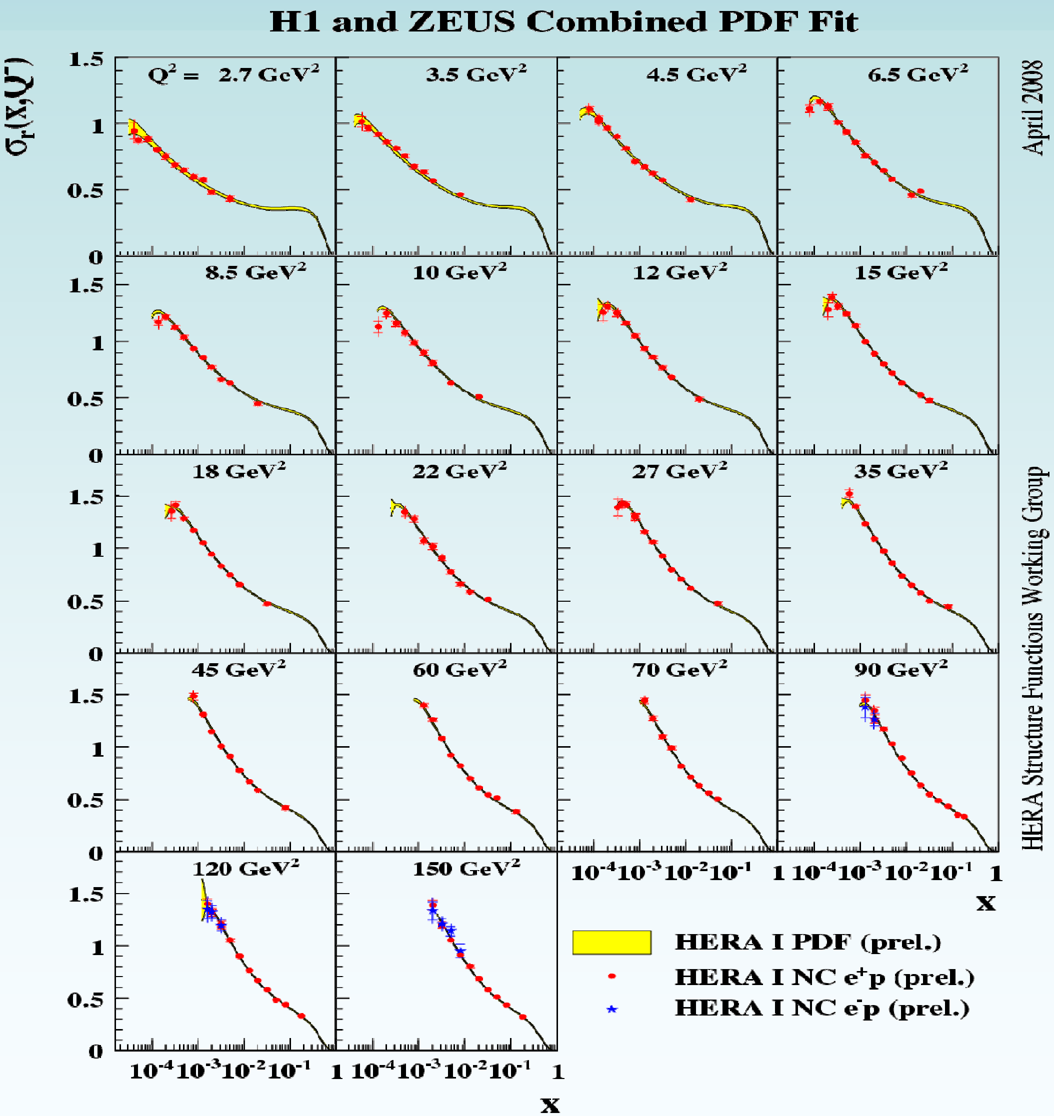
Note: clever ways to do this in practice [Pascaud and Zomer LAL-95-05, Botje hep-ph-0110123]

Results (extra): NC $e^{\pm}p$

NC $e^{\pm}p$ [at low Q^2]

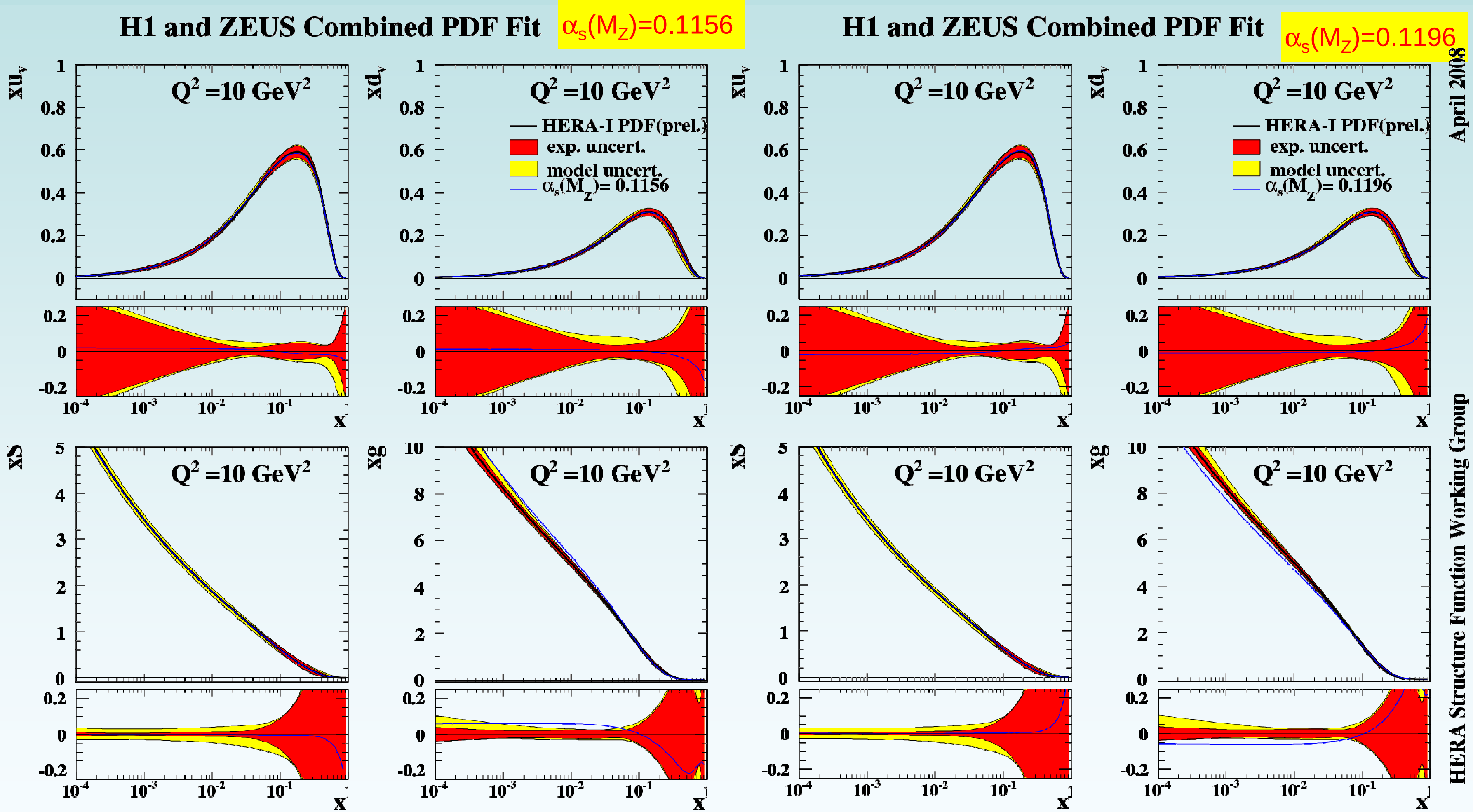
"HERAPDF0.1": fit quality to the **combined HERA-I data** for **NC e^+p and e^-p at high Q^2**

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



Model cross-checks

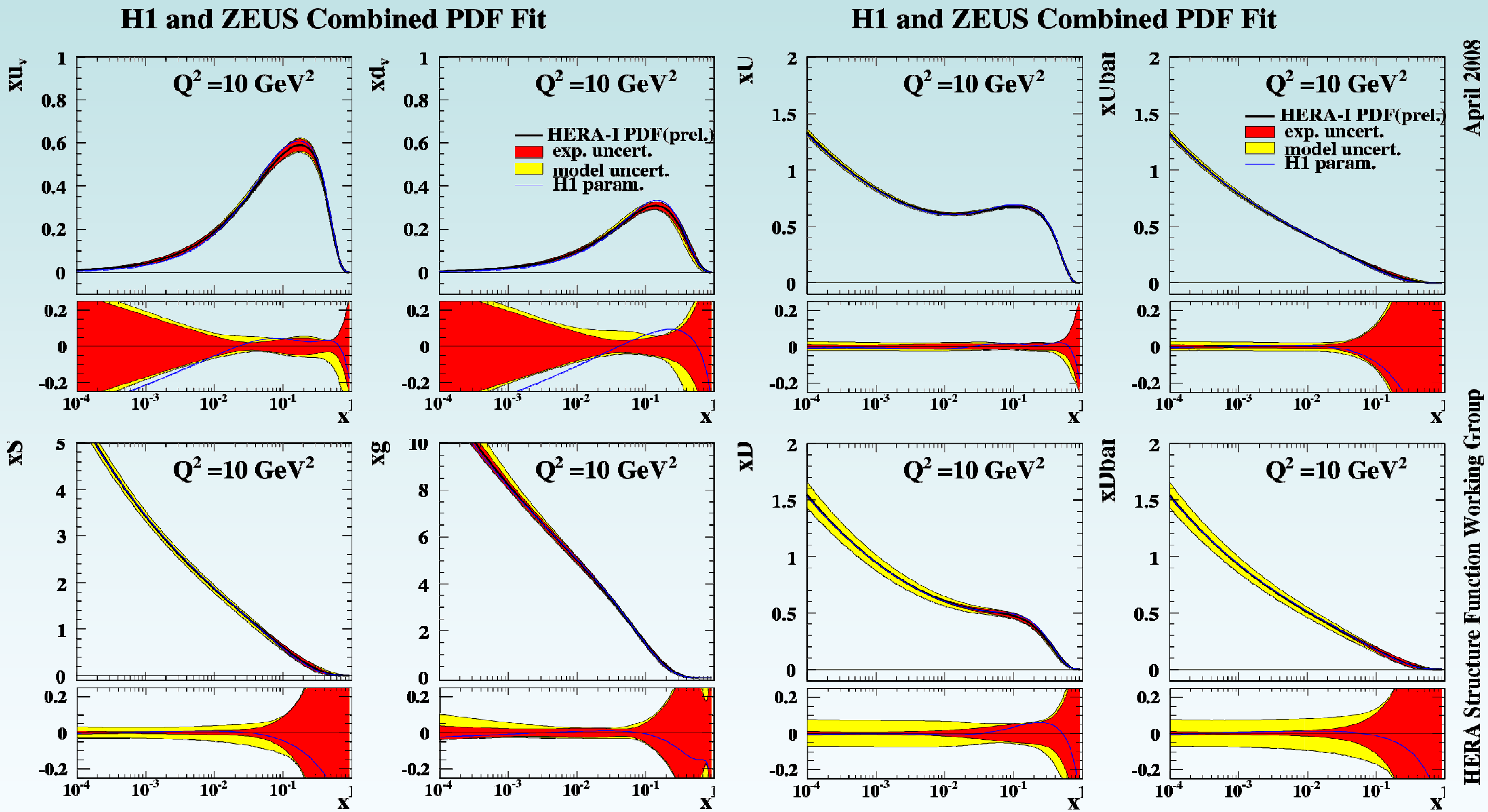
α_s-variation cf. nominal: $\alpha_s(M_Z)$=0.1176



variations outside gluon uncertainty bands (even including model uncertainty)

Model cross-checks

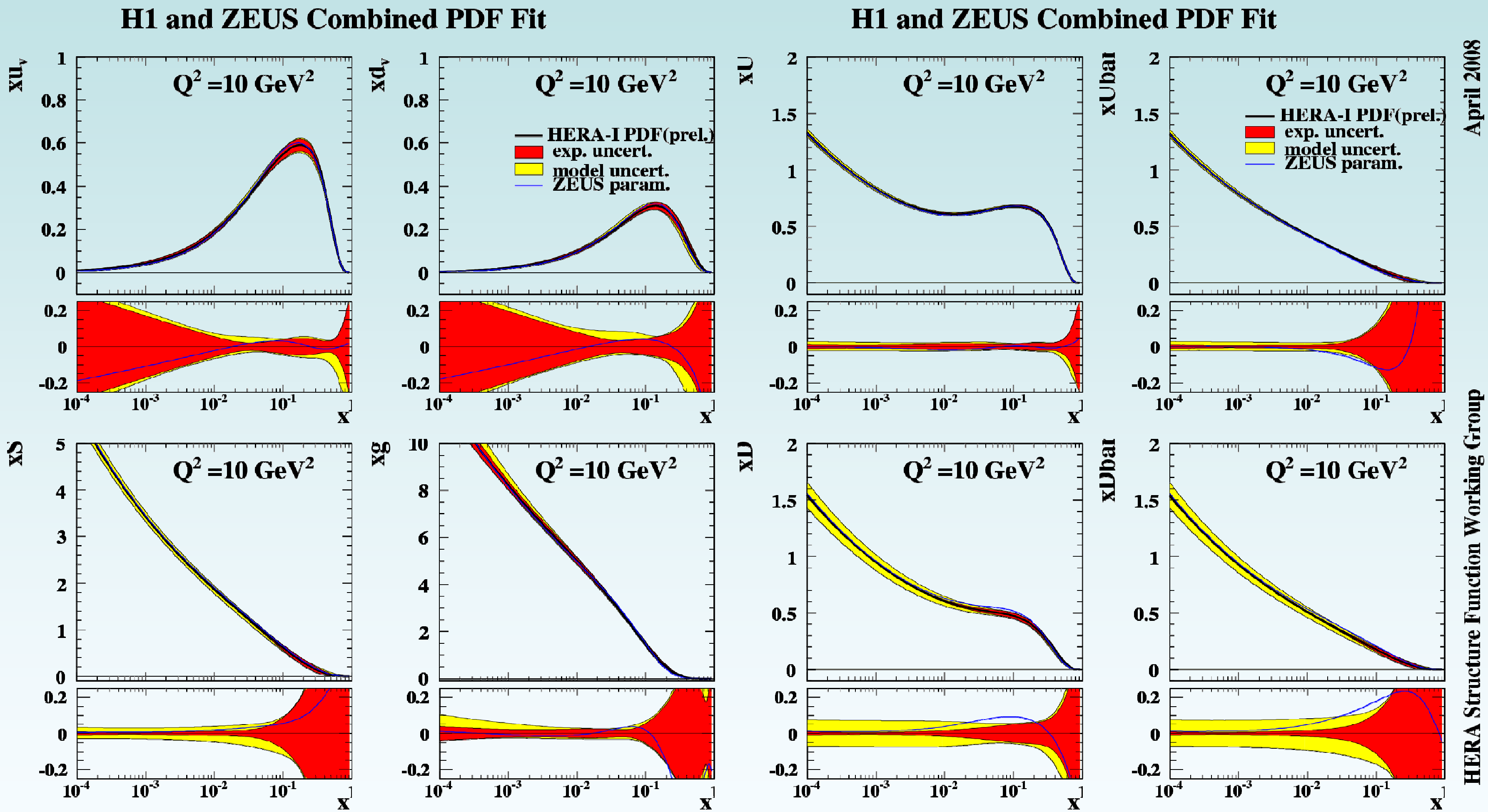
H1-style parameterisation



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)

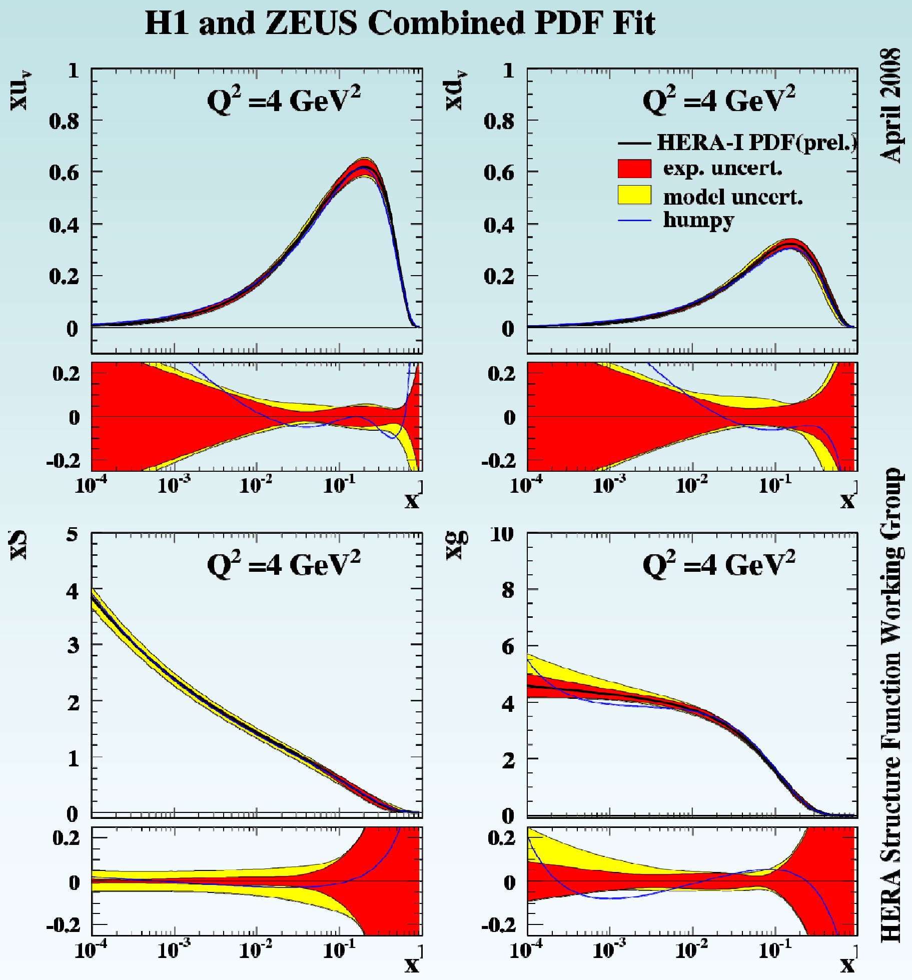
“straight” vs. “humpy” gluon

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

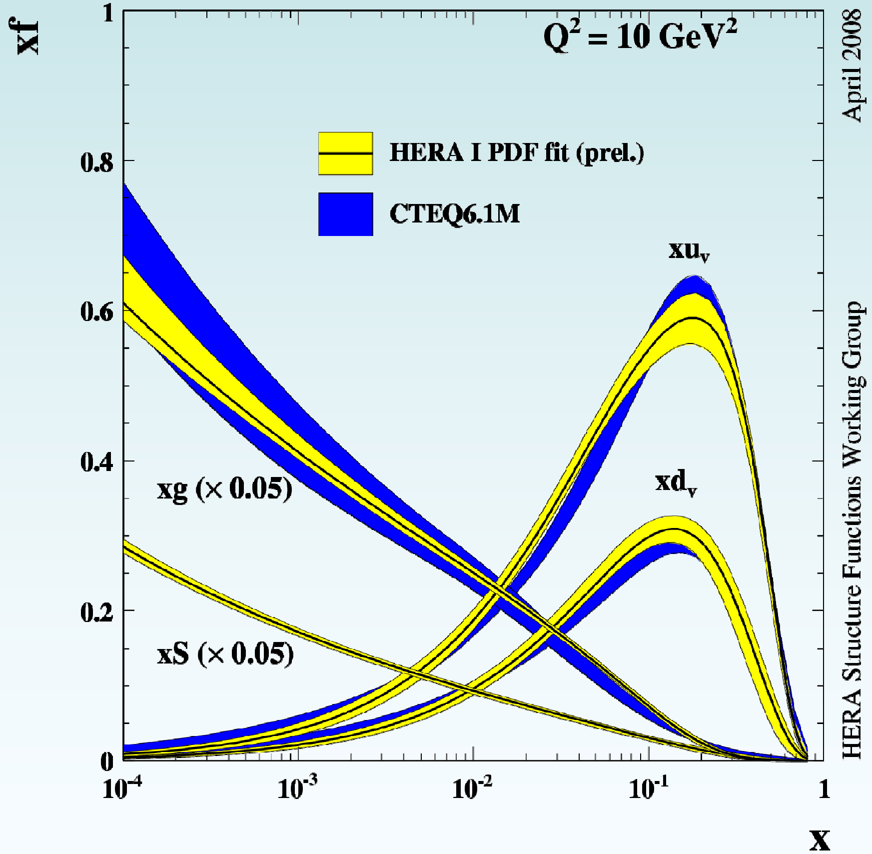
HERA combined data set:-
“straight” gluon solution favoured by about 10 X^2 points
[but “humpy” gluon still acceptable!]
Opposite: **“straight”** and **“humpy”** solutions are compared → results are very **consistent**

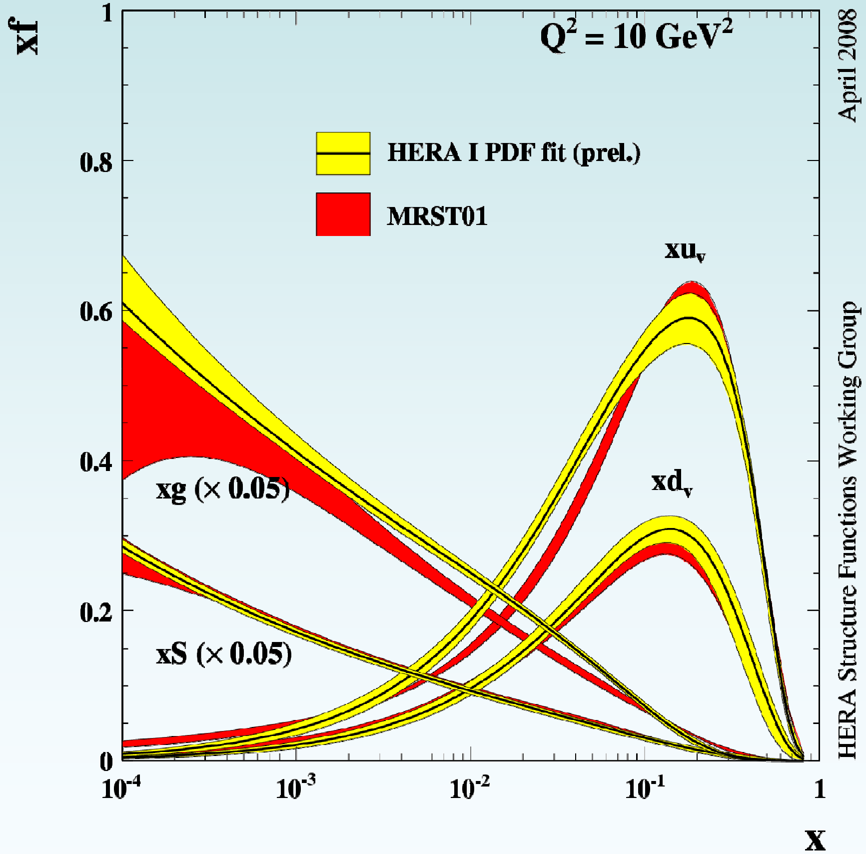


HERA PDF vs. Global fits

Caution:
Different ΔX^2's … also:
- global fits: 90% CL
- HERA fit: 68% CL

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

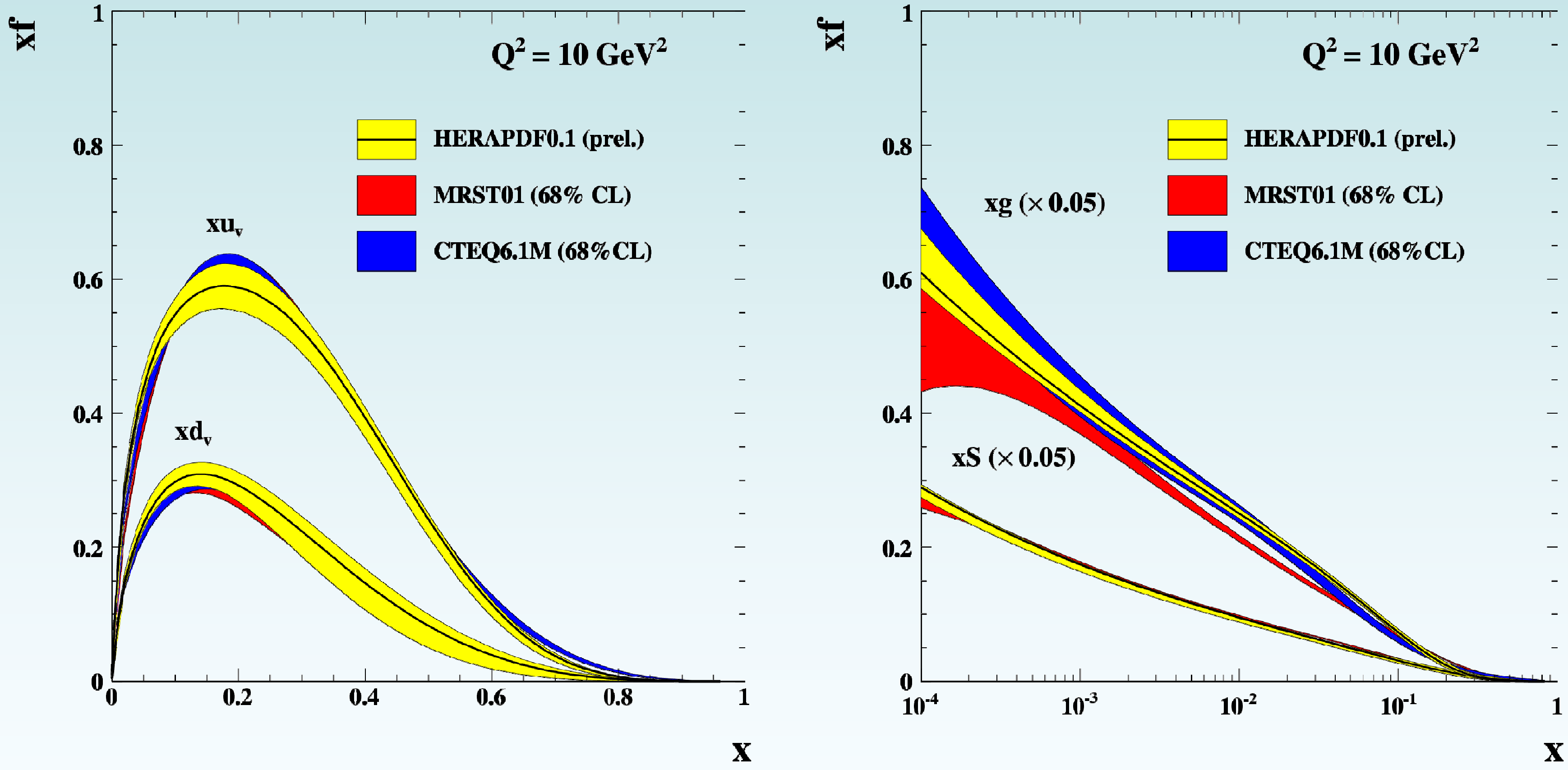




HERA PDF vs. Global fits

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

68% CL

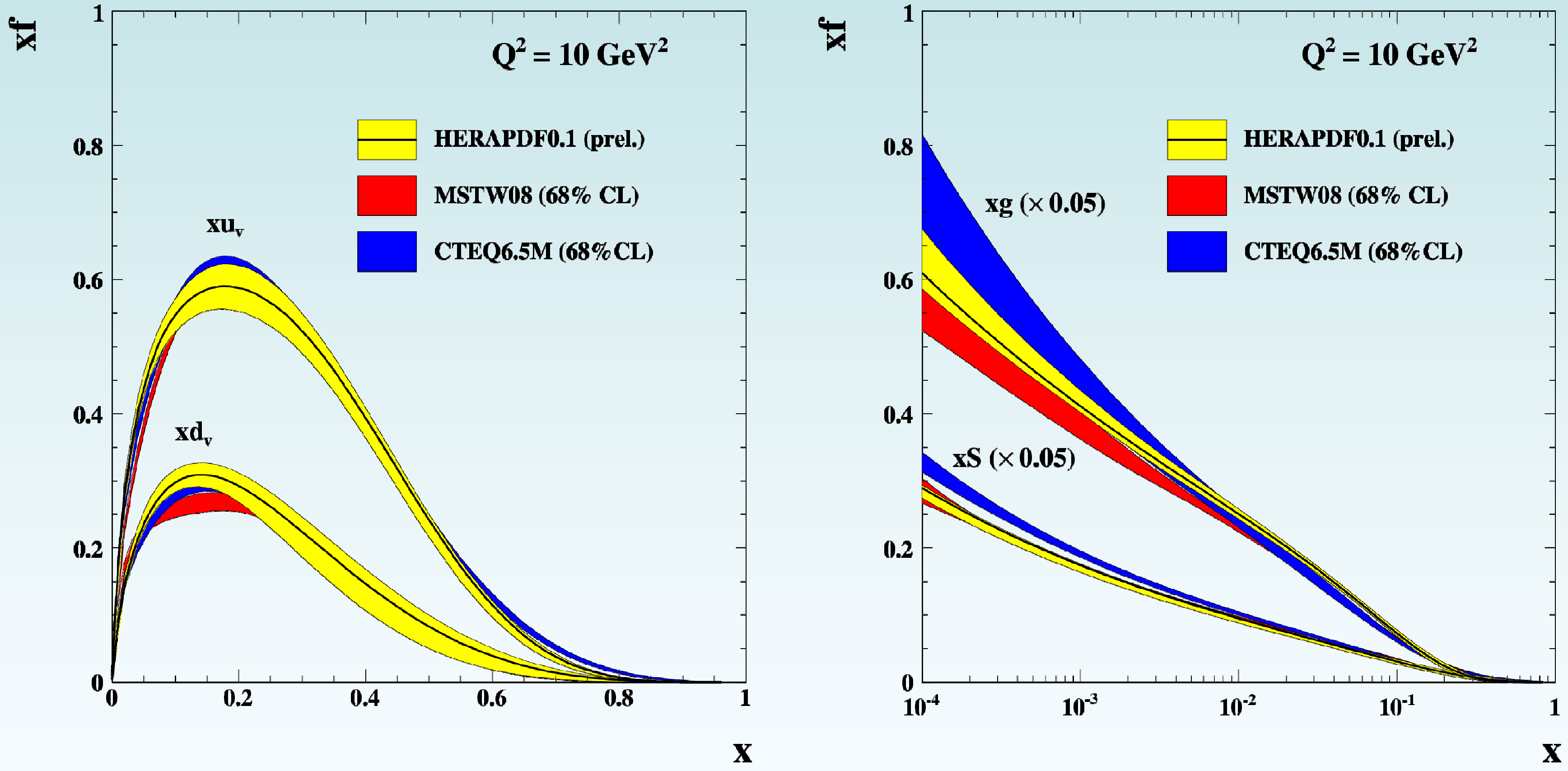


global fits scaled by 1.64485 [NB. HERA PDF includes exp. <u>and</u> model uncertainties]

HERA PDF vs. Global fits

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

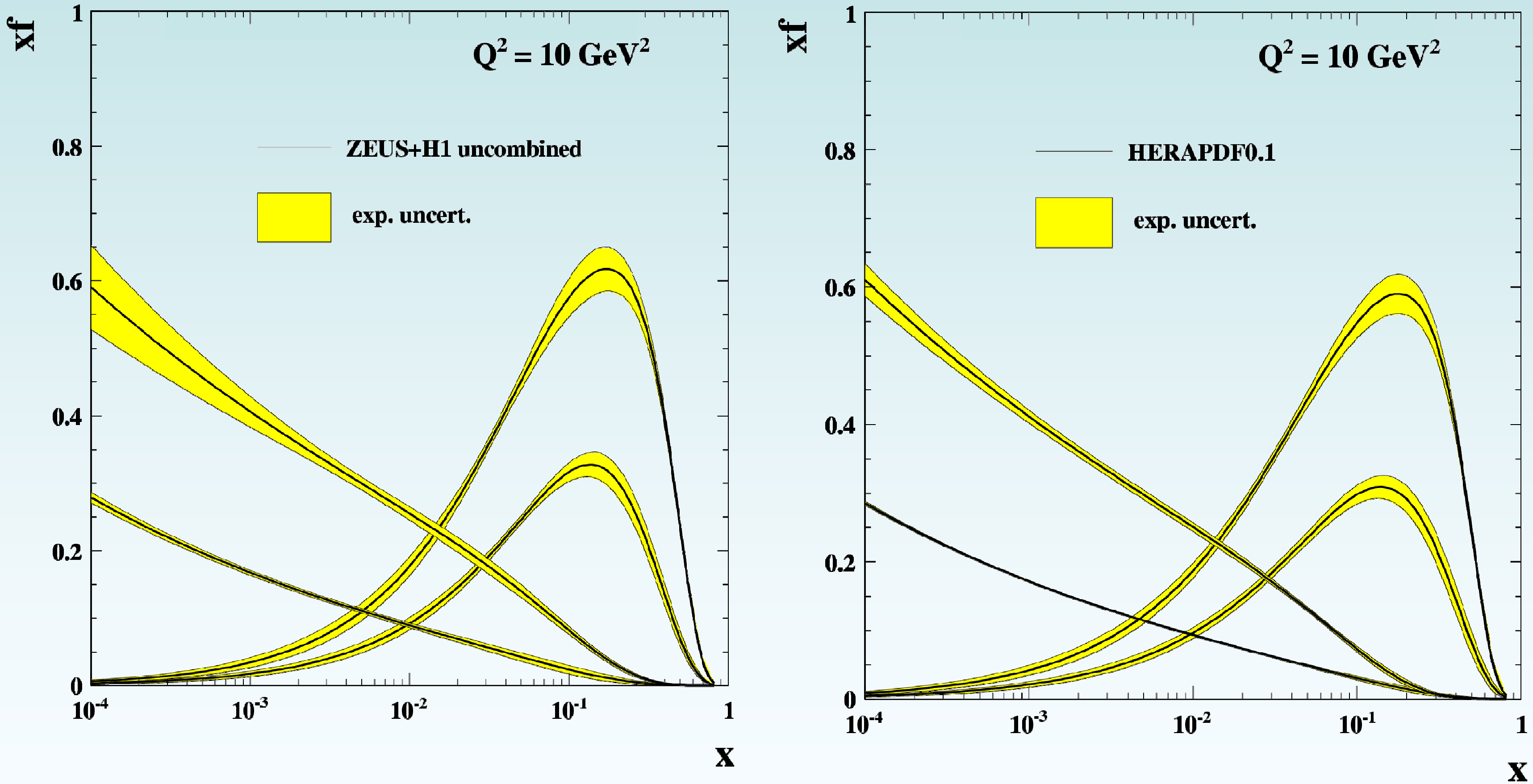
68% CL



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

HERA PDF: checks

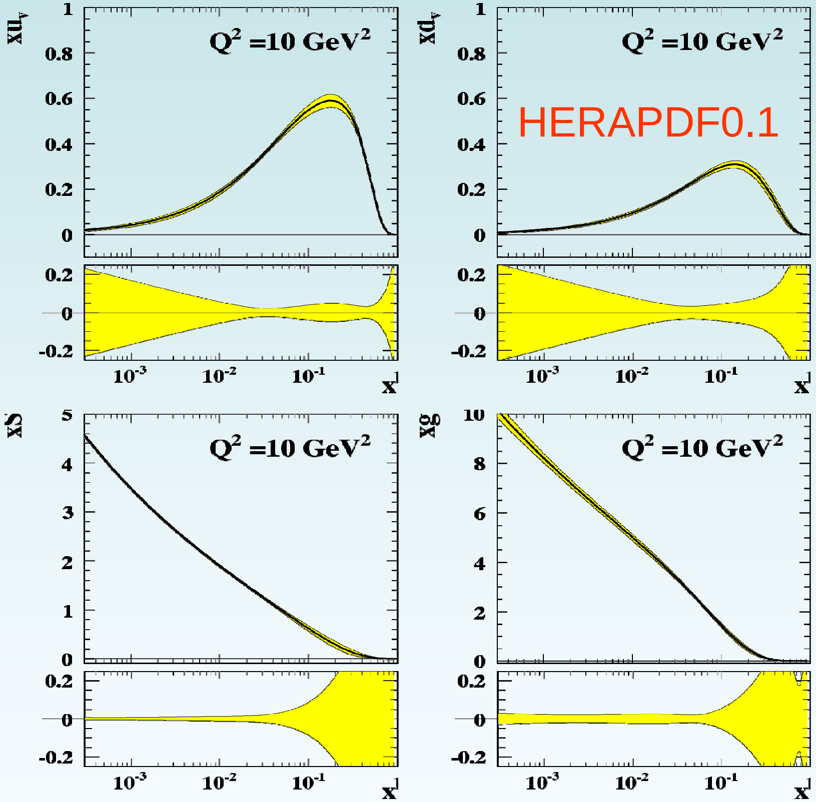
Comparison with fit to H1+ZEUS (uncombined)

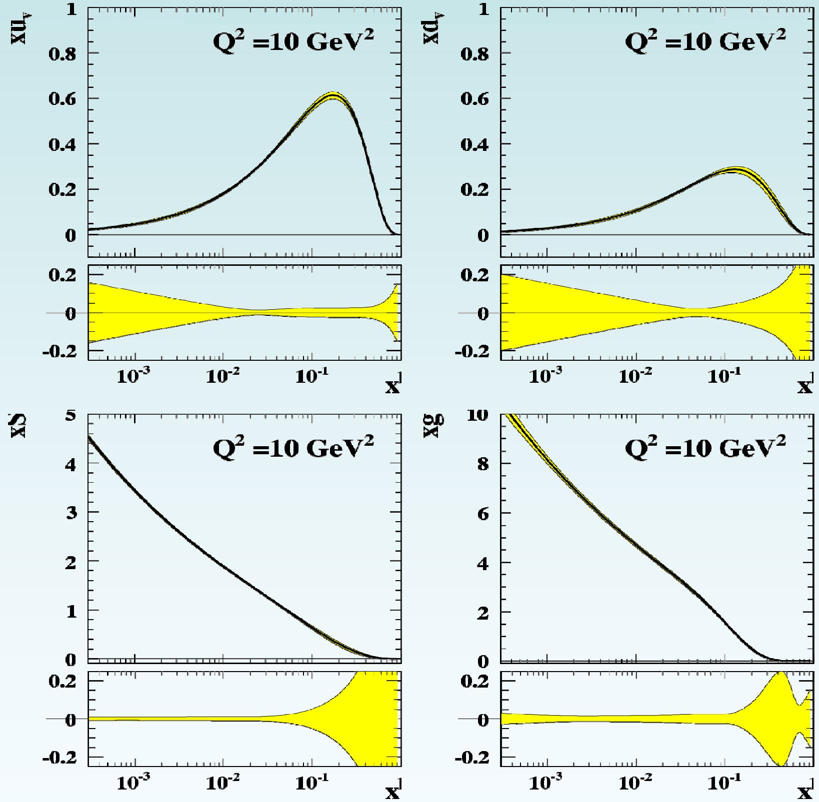


Same parameterisation and assumptions in both fits

HERA PDF: checks

Comparison of uncertainties for different treatments



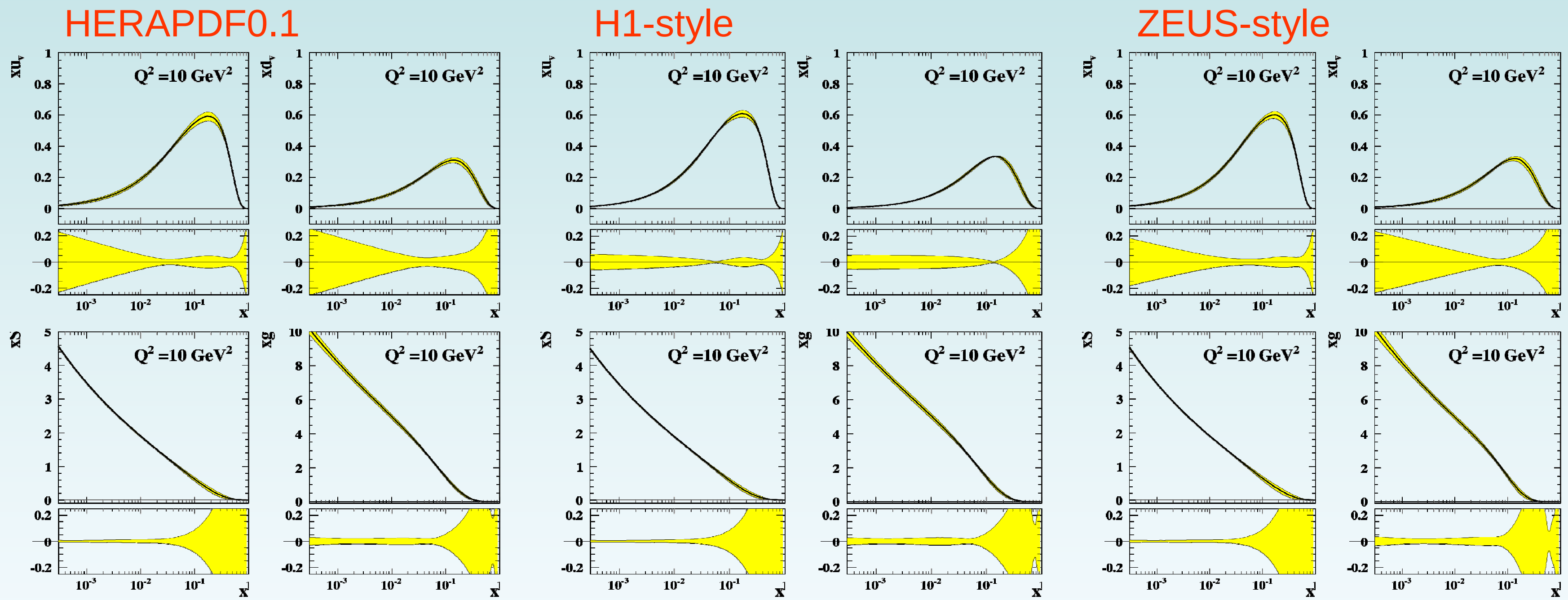


43 data systematics in quadrature ↑
+ offset 4 procedural uncertainties

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