H1 and ZEUS combined Cross Section Analysis

.

A new Level of Precision

On behalf of H1 and ZEUS Collaborations

Outline

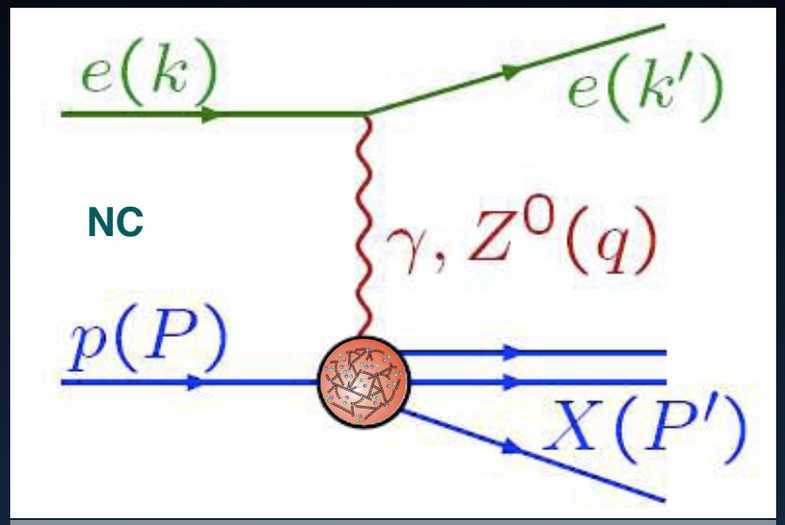
- DIS @ HERA – kinematics

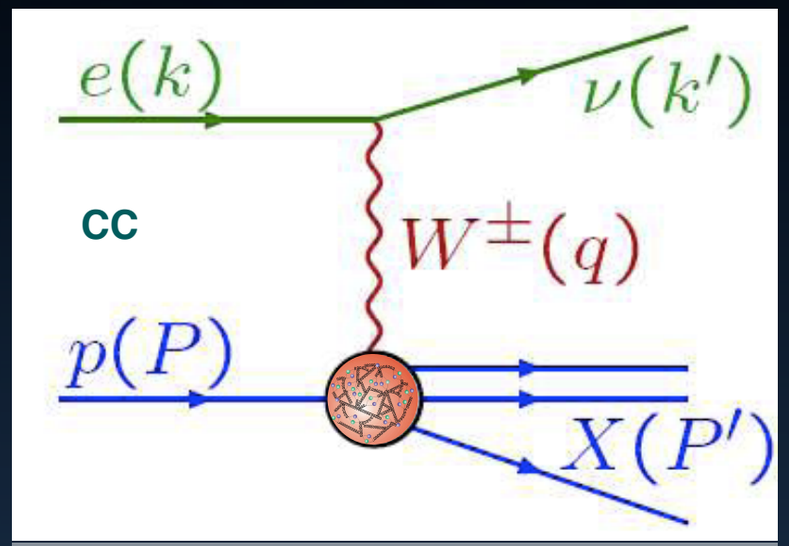
- Definitions – DIS cross sections
- Event based kinematics

- H1 & ZEUS combination of data sets
- Combined fit – HERAPDF0.1

- Conclusions

DIS Kinematics





- Kinematics of lepton · proton scattering
  - $S = (k + P)^2$ – CMS energy
  - $Q^2 = -q^2 = -(k - k')^2$ – Virtuality/resolution
  - $x = \frac{Q^2}{2P \cdot q}$ – Bj-scaling variable, momentum fraction of proton carried by parton
  - $y = \frac{q \cdot P}{k \cdot P} = \frac{Q^2}{S \cdot x}$ – Inelasticity, relative energy transfer

Cross Sections

- DIS cross section with generalized structure functions:

$$\frac{\mathrm{d}^2\sigma^{NC}_{e^\pm p}}{\mathrm{d}x\mathrm{d}Q^2} = \kappa\left(\mathbf{F_2} - \frac{y^2}{Y_+}\mathbf{F_L} \pm \frac{Y_-}{Y_+}x\mathbf{F_3}\right), \quad Y_\pm = 1 \pm (1-y)^2$$

$\mathbf{F_L}$ sizeable/sensitive at high y only

- Using the kinematical factor $\kappa = \frac{2\pi\alpha^2}{xQ^4}Y_+$

the reduced cross section σ_r is derived

$$\sigma_r = \frac{1}{\kappa}\cdot\frac{\mathrm{d}^2\sigma_{e^\pm p}}{\mathrm{d}x\mathrm{d}Q^2}$$

- For low Q^2 $\mathbf{F_2}$ and $\mathbf{F_L}$ can be related to cross sections

$$\mathbf{F_2} = \frac{Q^2}{4\pi^2\alpha}(1-x)\cdot(\sigma_L+\sigma_T) \qquad \mathbf{F_L} = \frac{Q^2}{4\pi^2\alpha}(1-x)\cdot\sigma_L$$

of transversely σ_T and longitudinally σ_L polarised photons.

- $\mathbf{F_L} = 0$ (spin 1/2 partons – Callan–Gross) at leading order and proportional to gluon at higher orders – see talk by E.Lobodzinska
- In low Q^2 region, contribution of Z^0 boson exchange negligible ($x\mathbf{F_3}$).

Parton Distributions

- Leading order relations:

$$
\begin{aligned}
F_2 &= x\sum e_q^2\left(q\left(x\right)+\overline{q}\left(x\right)\right)\\
\sigma_{e^+p}^{CC} &\sim x\left(\overline{u}+\overline{c}\right)+x\left(1-y\right)^2\left(d+s\right)\\
\sigma_{e^-p}^{CC} &\sim x\left(u+c\right)+x\left(1-y\right)^2\left(\overline{d}+\overline{s}\right)
\end{aligned}
$$

- DIS NC and CC data allow to unfold individual quark flavors.
  The gluon is determined from scaling violations and/or from jet cross sections.

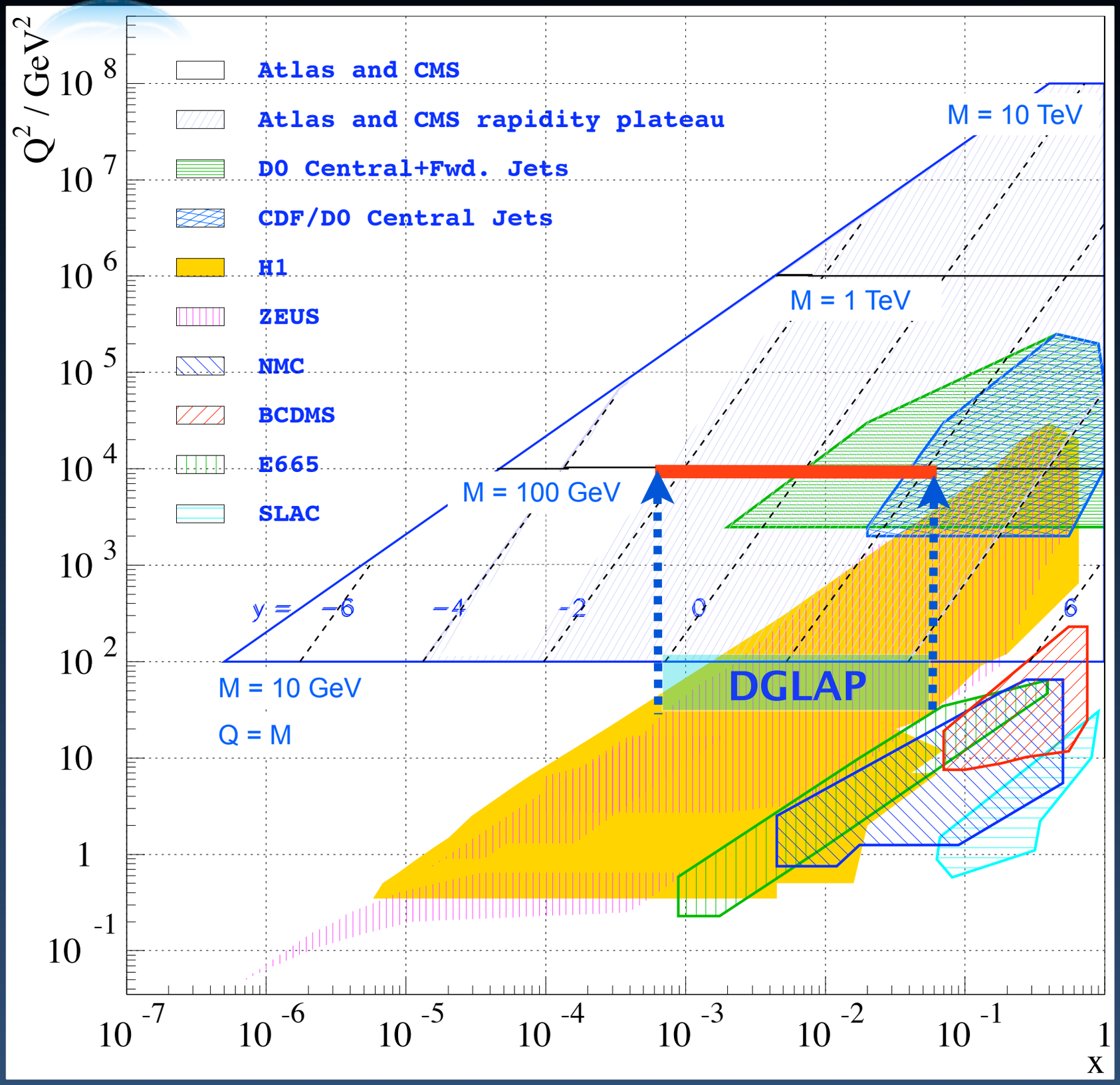
↪

- Allows the measurement of PDF's and is important for $\mathrm{W}^{\pm}, Z^0$ cross section predictions at LHC.
  HERA data allow to measure

$$
\begin{aligned}
xU &= x\left(u+c\right), \quad xD = x\left(d+s\right),\\
x\overline{U} &= x\left(\overline{u}+\overline{c}\right), \quad x\overline{D} = x\left(\overline{d}+\overline{s}\right)
\end{aligned}
$$

  and xg in a single experiment.

Evolution - HERA to LHC



- DGLAP evolution (appropriate?) of PDF / cross sections from HERA into LHC region
- figure comprises kinematical accessible regions @
  - fixed target experiments
  - TEVATRON
  - HERA
  - LHC

- Artist view of the evolution:

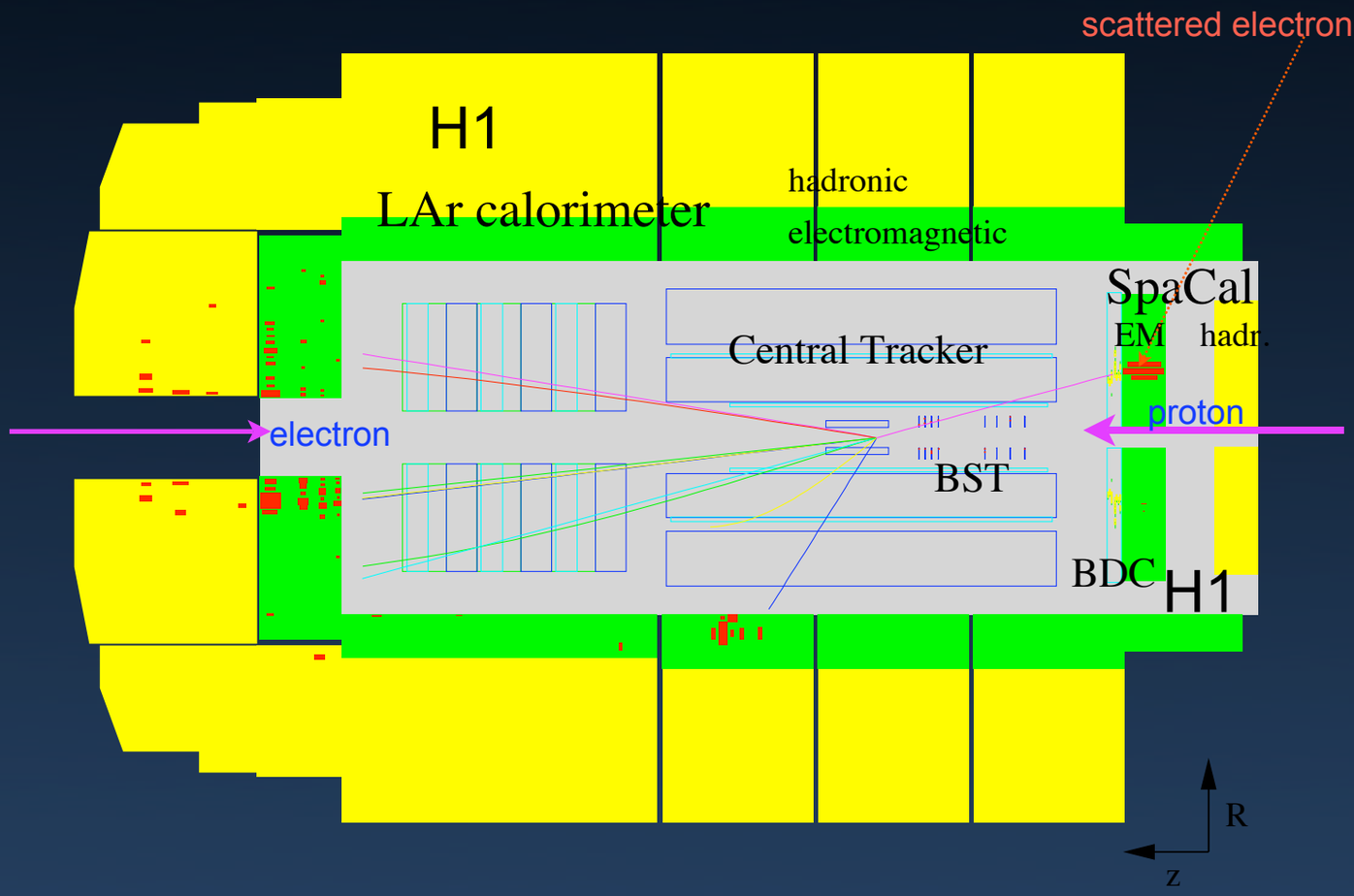
  HERA kinematical area

  ↓

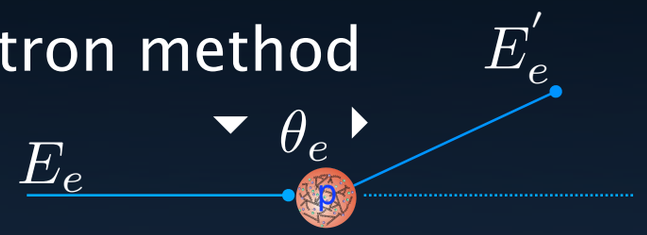
  LHC central rapidity

courtesy of eA, MK

Event based Kinematics



- Using electron method



- Virtuality:
  $Q^2 = 2E_e E'_e \left(1 + \cos\theta_e\right)$
- Inelasticity:
  $y = 1 - \frac{E'_e \left(1 - \cos\theta_e\right)}{2E_e} \equiv \frac{2E_e - \Sigma_e}{2E_e}$
- Bjorken x:
  $x = \frac{Q^2}{(Sy)}$
- besides electron method – hadron based measures
  - over-determined system of variables (e + HFS)

The definitions of event variables for reconstruction are very similar for ZEUS

Experiment Systematics

- Both Experiments:
  Systematic effects controlled
  - detector calibration
  - trigger efficiency
  - photo production background
  - initial state radiation – radiative correction

Combination of Data Sets to Achieve Optimum Accuracy

HERA-1: Averaged H1 and ZEUS Data Sets

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	$\sqrt{s} = 301GeV$
H1 NC low Q^2	96 - 97	0.000161	0.20	12	150	17.9	e^+p	$\sqrt{s} = 301GeV$
H1 NC	94 - 97	0.0032	0.65	150	30000	35.6	e^+p	$\sqrt{s} = 301GeV$
H1 CC	94 - 97	0.013	0.40	300	15000	35.6	e^+p	$\sqrt{s} = 301GeV$
H1 NC	98 - 99	0.0032	0.65	150	30000	16.4	e^-p	$\sqrt{s} = 319GeV$
H1 CC	98 - 99	0.013	0.40	300	15000	16.4	e^-p	$\sqrt{s} = 319GeV$
H1 NC	99 - 00	0.00131	0.65	100	30000	65.2	e^+p	$\sqrt{s} = 319GeV$
H1 CC	99 - 00	0.013	0.40	300	15000	65.2	e^+p	$\sqrt{s} = 319GeV$
ZEUS NC	96 - 97	0.00006	0.65	2.7	30000	30.0	e^+p	$\sqrt{s} = 301GeV$
ZEUS CC	94 - 97	0.015	0.42	280	17000	47.7	e^+p	$\sqrt{s} = 301GeV$
ZEUS NC	98 - 99	0.005	0.65	200	30000	15.9	e^-p	$\sqrt{s} = 319GeV$
ZEUS CC	98 - 99	0.015	0.42	280	30000	16.4	e^-p	$\sqrt{s} = 319GeV$
ZEUS NC	99 - 00	0.005	0.65	200	30000	63.2	e^+p	$\sqrt{s} = 319GeV$
ZEUS CC	99 - 00	0.008	0.42	280	17000	60.9	e^+p	$\sqrt{s} = 319GeV$

- Data sets HERA–I published

Method of Combination

- Move all data points to a common $x \leftrightarrow Q^2$ grid
  - Grid: basically H1–x binning and ZEUS–Q^2 binning
    interpolation formula

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

  - "swimming in" of data sets – optimising the error functions

- Calculate the average values and the errors
- Evaluate the uncertainties related to the combination method – consistency checks between the experiments

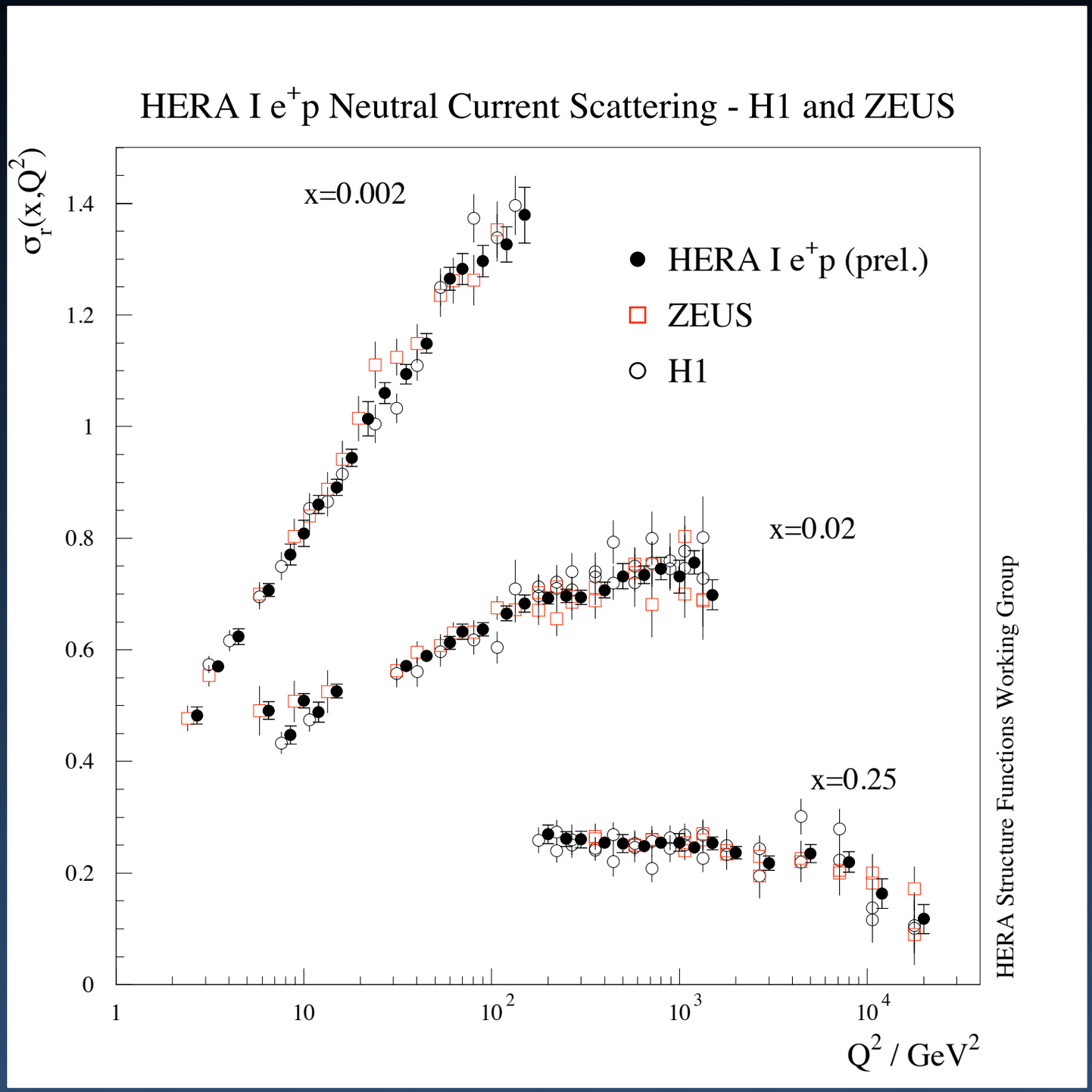
Averaging Method

- A **model independent combination**, prior to performing QCD analysis which includes full error correlations (A. Glazov – DIS 05)

- The **key assumption**:
  H1 and ZEUS experiments measure the same cross sections at the same kinematical points

- It is a cross calibration between different data sets
  - the (un)correlated errors have been identified and taken into account

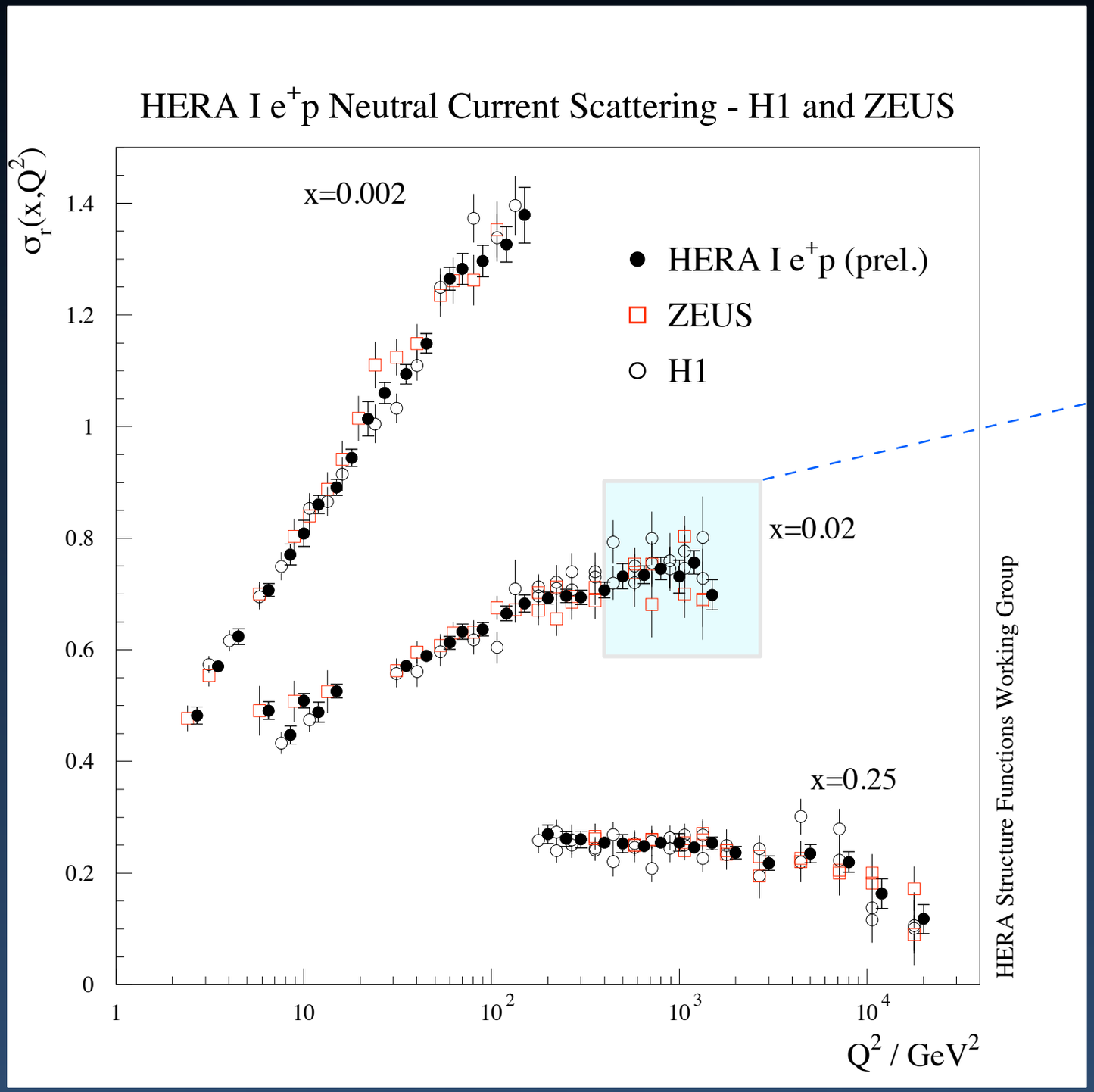
HERA-I Neutral Current e^+p

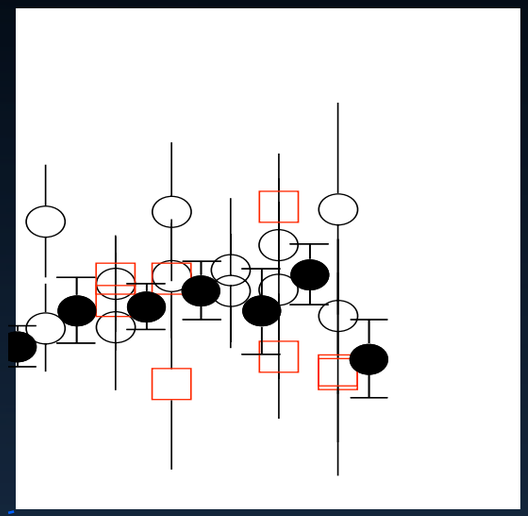


- fig.: three x-values only
- Combined H1-ZEUS ≡ HERA-I dataset characterised by:

- reduction of systematics at low Q^2 and reduction of statistical errors at high Q^2

HERA-I Neutral Current e^+p

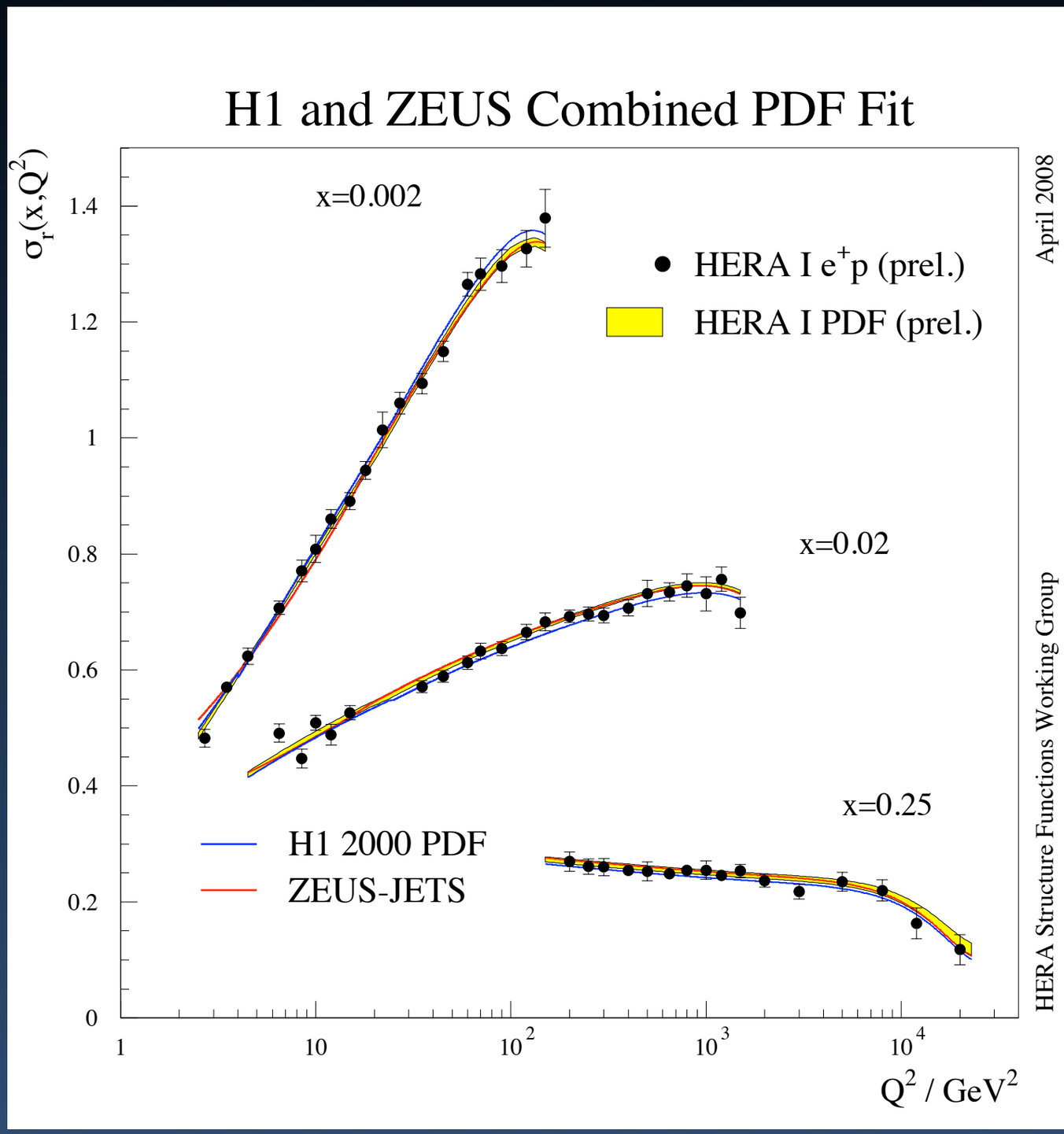




- fig.: three x-values only
- Combined H1-ZEUS ≡ HERA-I dataset characterised by:

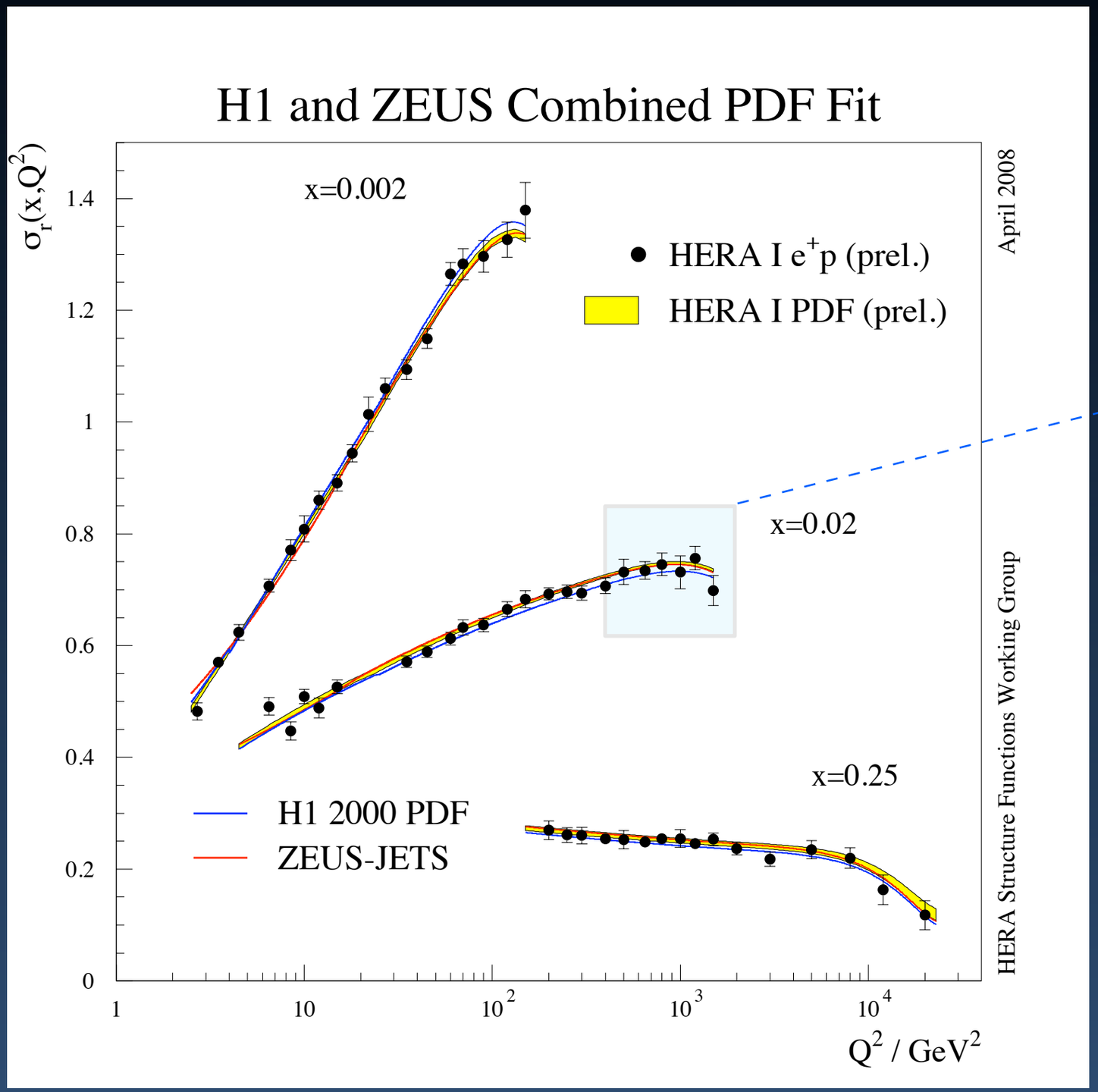
- reduction of systematics at low Q^2 and reduction of statistical errors at high Q^2

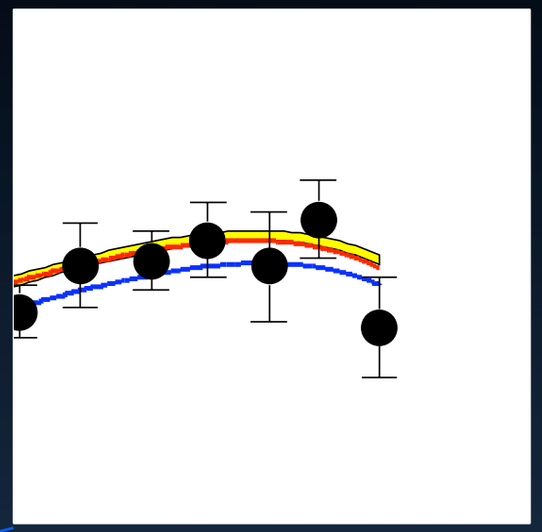
High Precision Fit HERA-I Neutral Current e^+p



- Fit of combined H1–ZEUS ≡ HERA-I Datasets
- High precision HERAPDF0.1 compared to **old** H1 2000 ZEUS-JETS fits
- Total uncertainties on the PDF fit predictions included

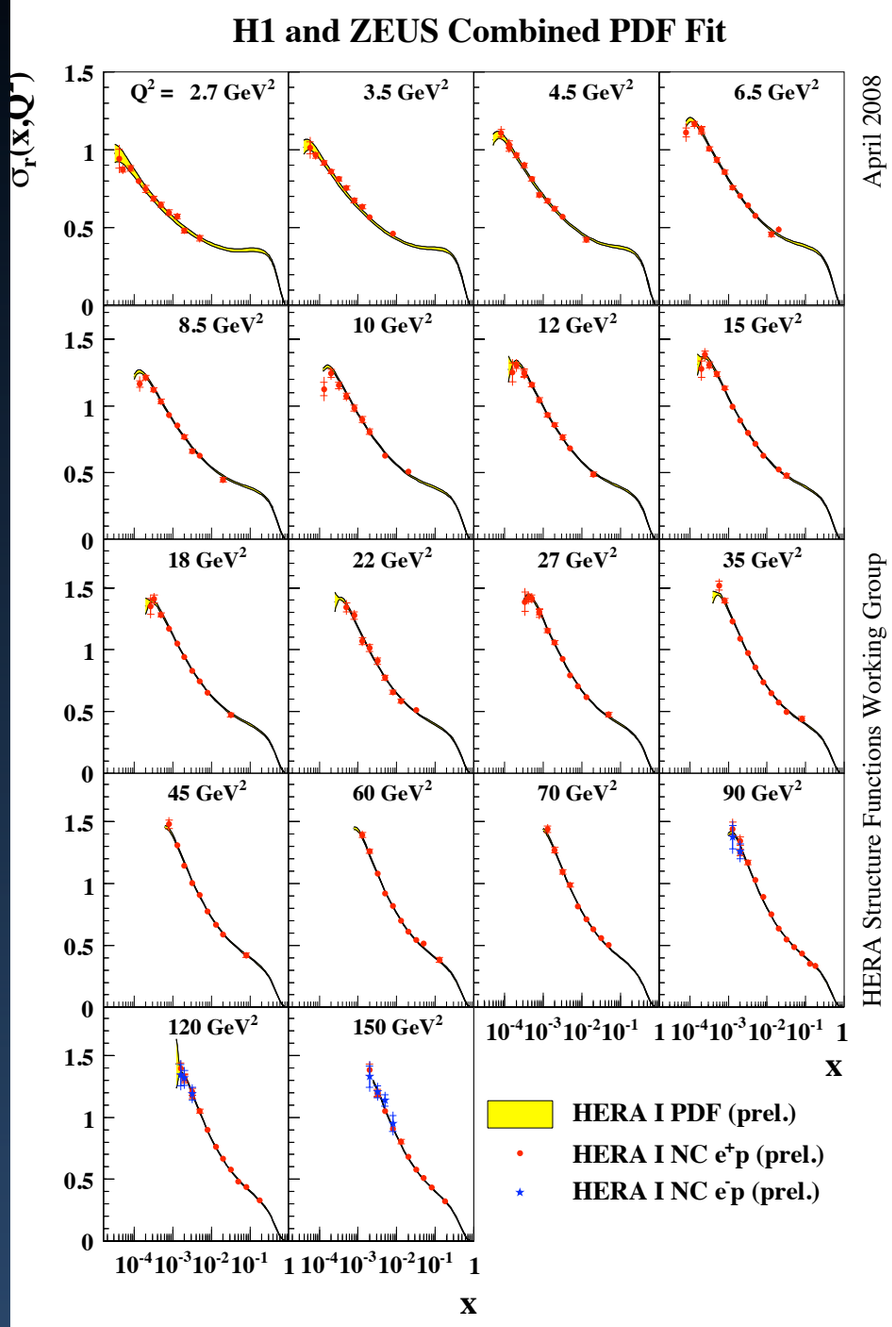
High Precision Fit HERA-I Neutral Current e^+p

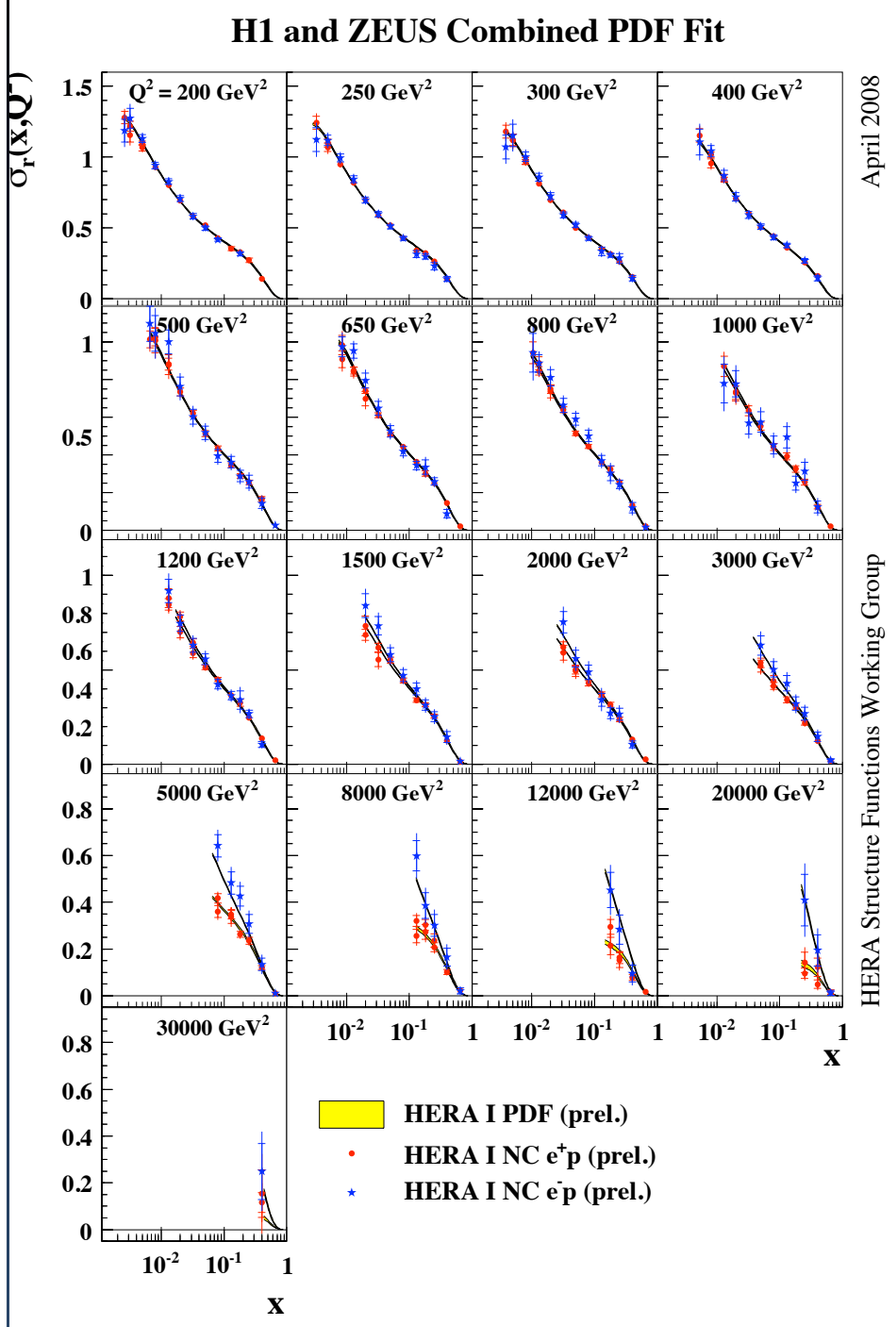




- Fit of combined H1–ZEUS ≡ HERA–I Datasets
- High precision HERAPDF0.1 compared to **old** H1 2000 ZEUS–JETS fits
- Total uncertainties on the PDF fit predictions included

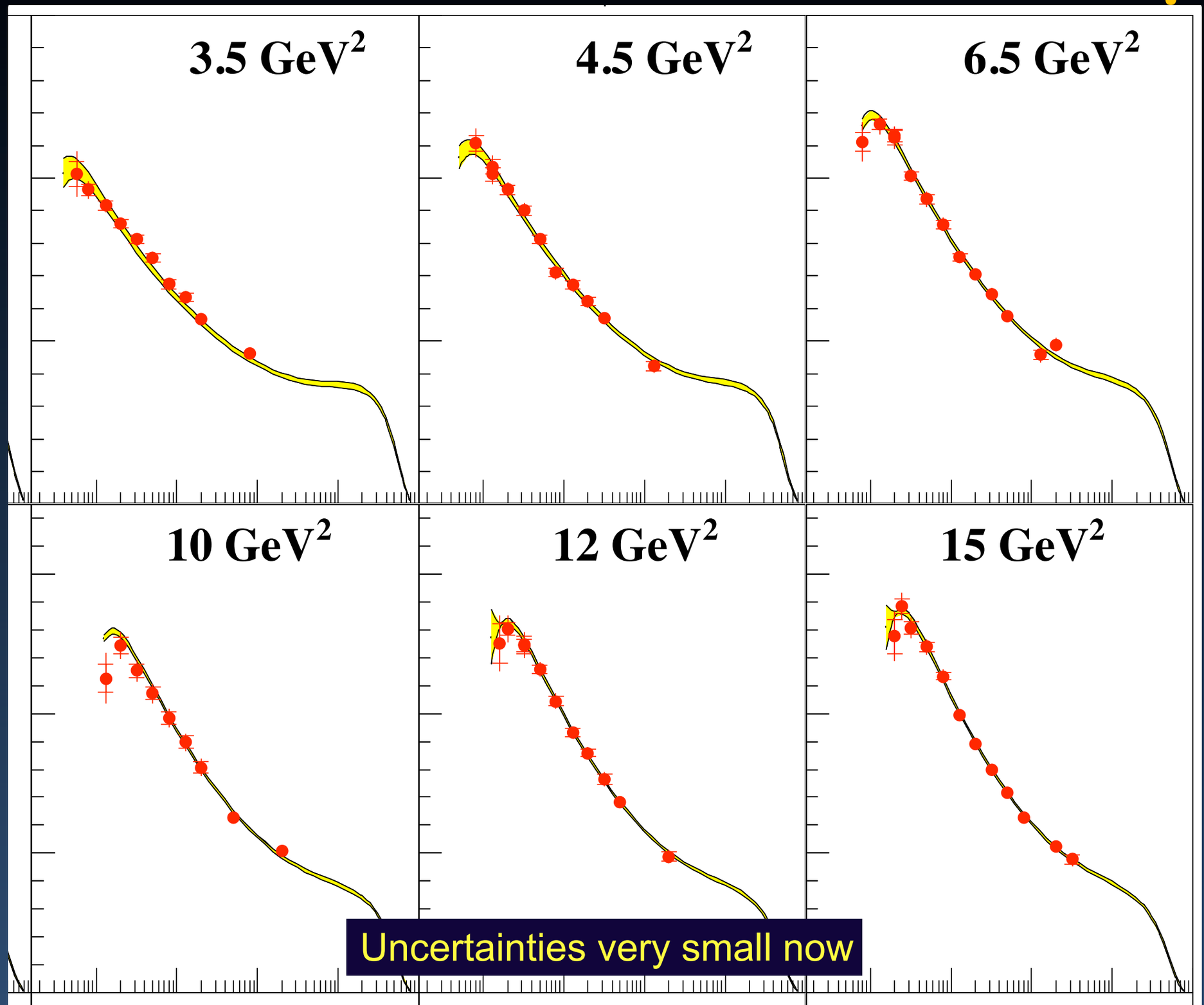
HERA-I Neutral Current $e^{\mp}p$





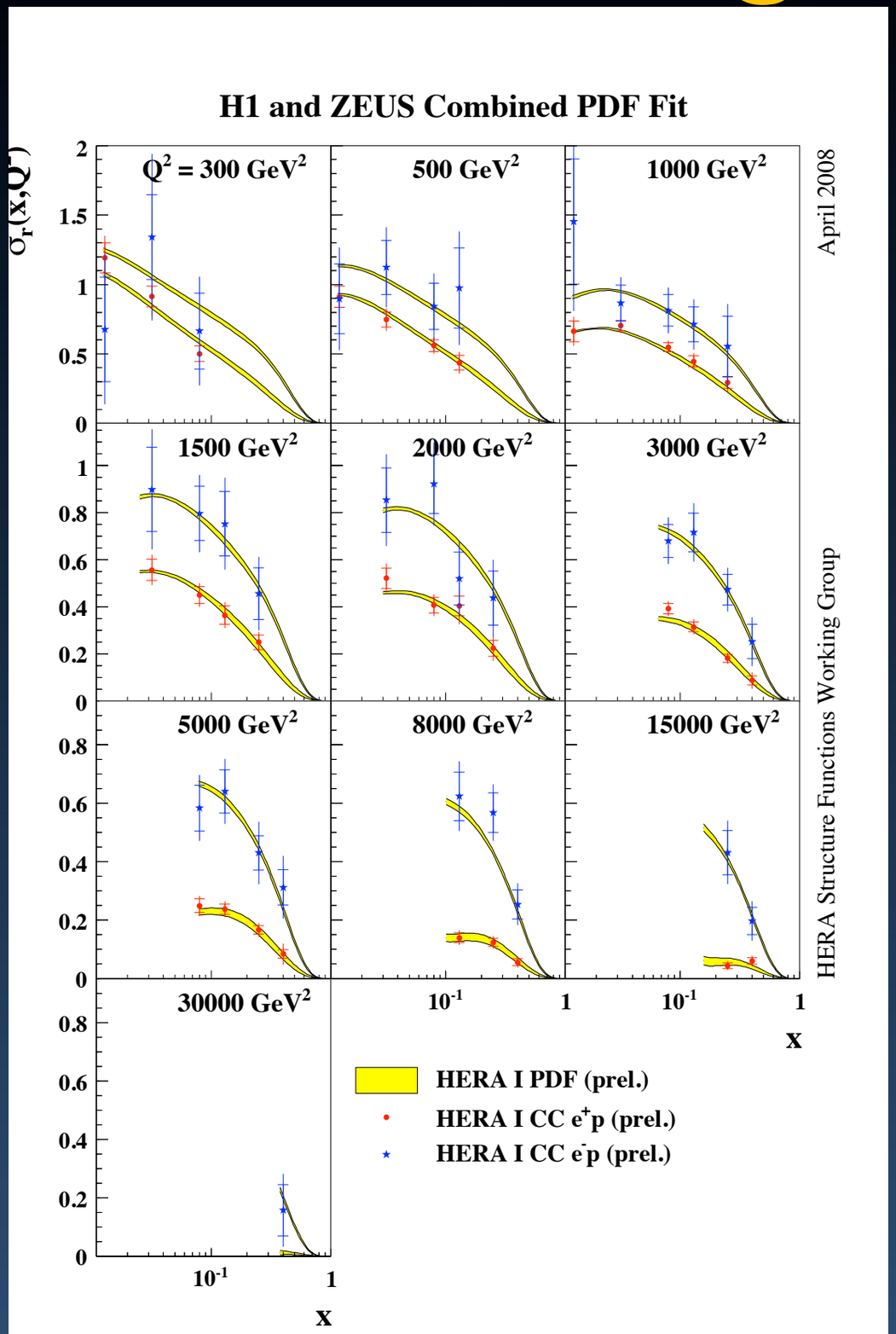
New HERA-I PDF fit predictions vs. HERA Combined Data for NC $e^{+/-}p$ at low (left) and high (right) Q^2.
Total uncertainties on the PDF fit predictions are included

HERA-I Neutral Current $e^{\mp}p$



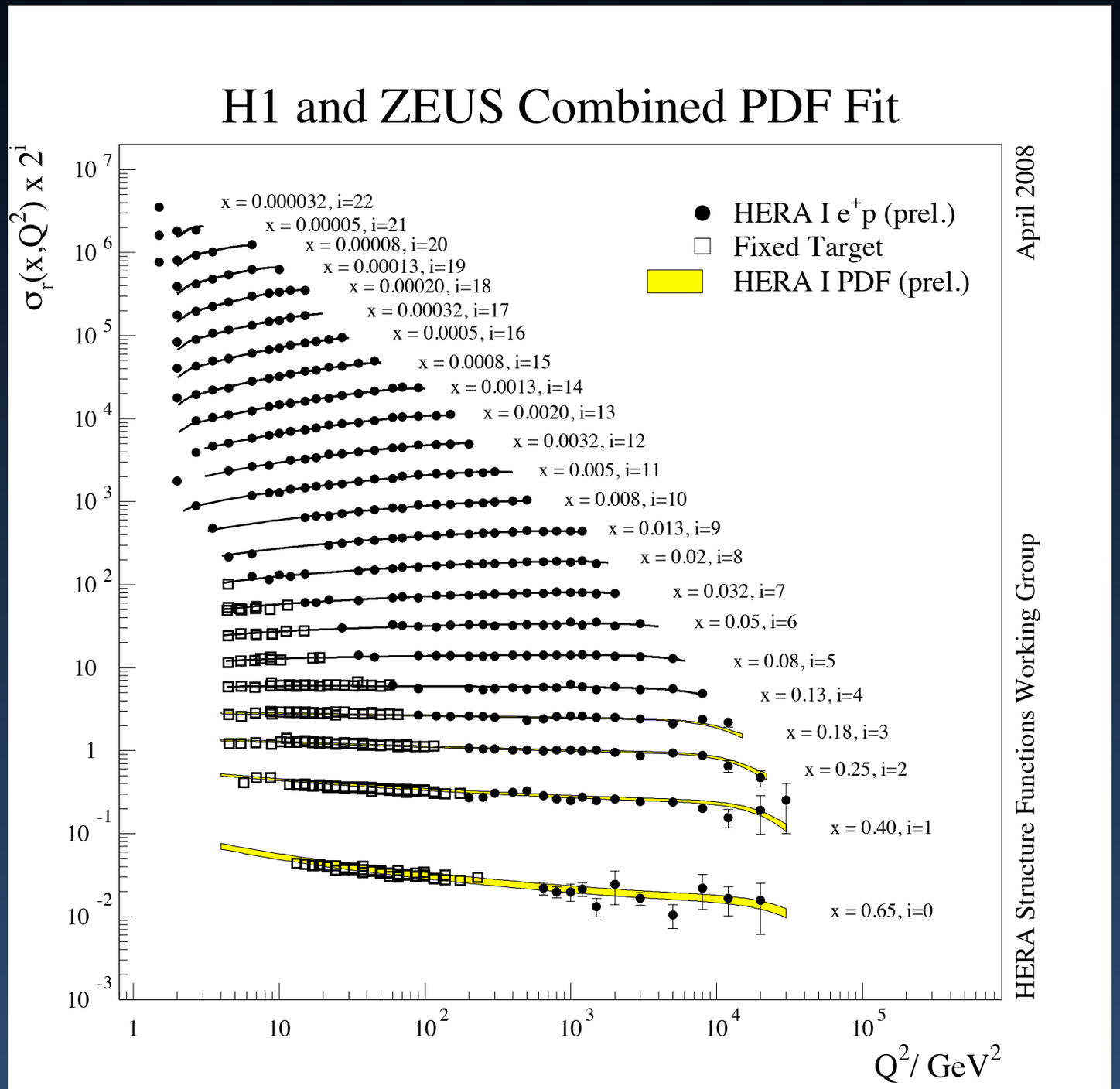
Total uncertainties on the PDF fit predictions are included

HERA-I Charged Current $e^{\mp}p$



- New HERA–I PDF fit predictions vs. HERA combined data for
  - NC $e^{+/-}p$
    Q^2: 300 GeV^2 – 30000 GeV^2
- Total uncertainties on the PDF fit predictions are included

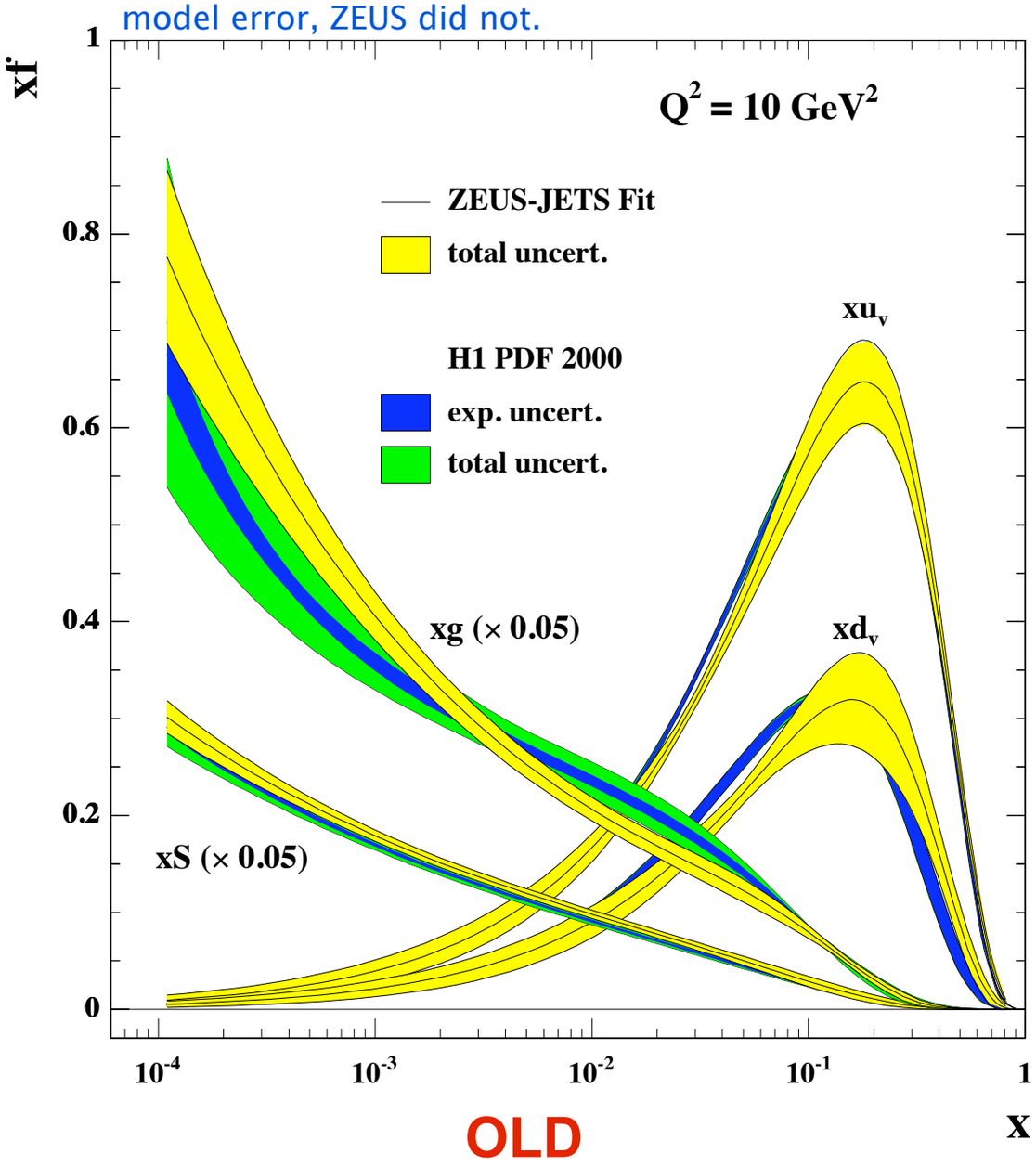
HERA-I Neutral Current e^+p



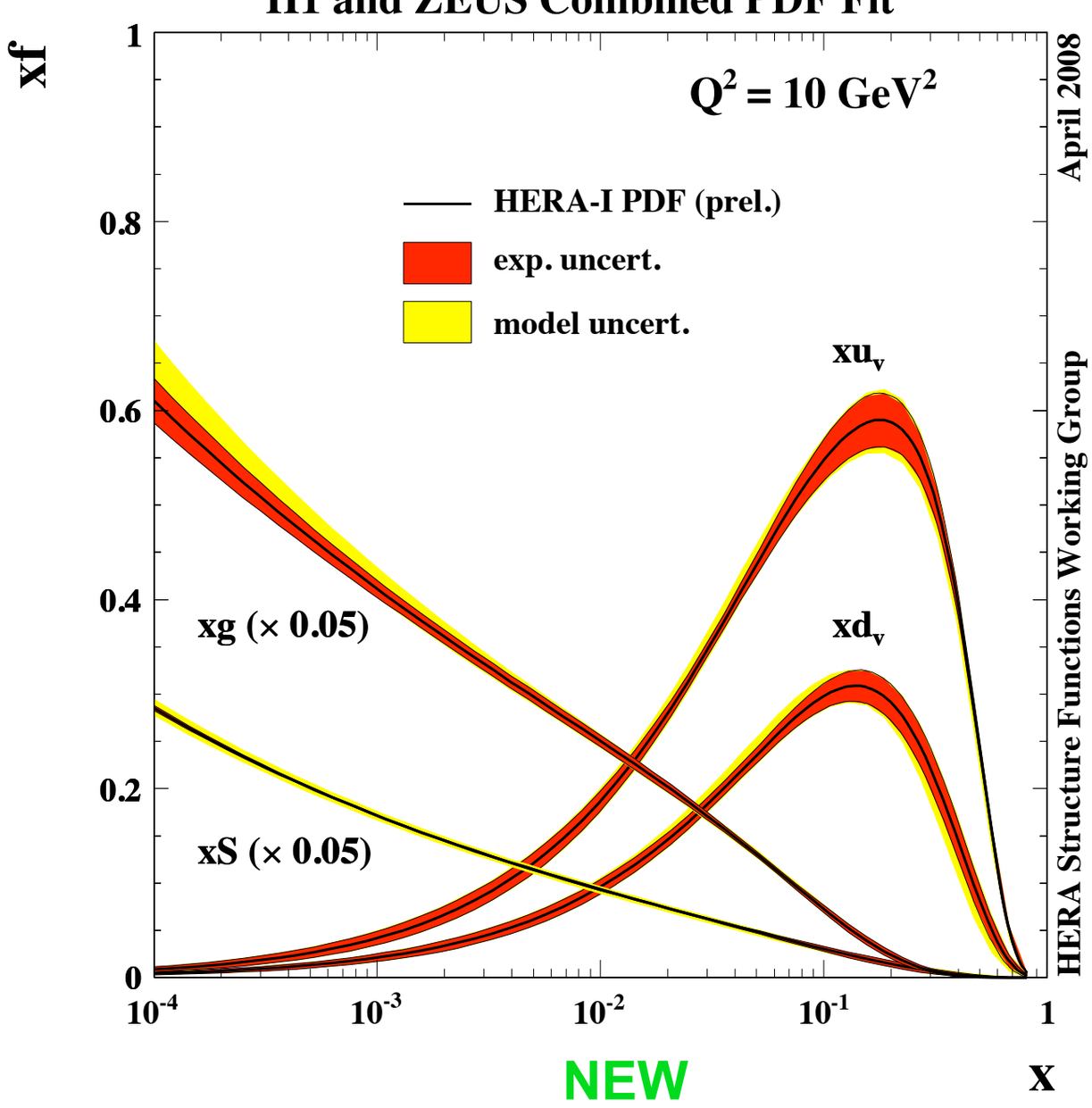
- New Fit – Total uncertainties on the PDF fit predictions included
- Proton scan with high precision
- NLO fit (DGLAP) – good description of data
- Systematic uncertainties are now smaller than statistical uncertainties across the x, Q^2 plane.

Accurate Determination of HERA-I PDF's

Note in published PDFs H1 did include α_S variation in model error, ZEUS did not.



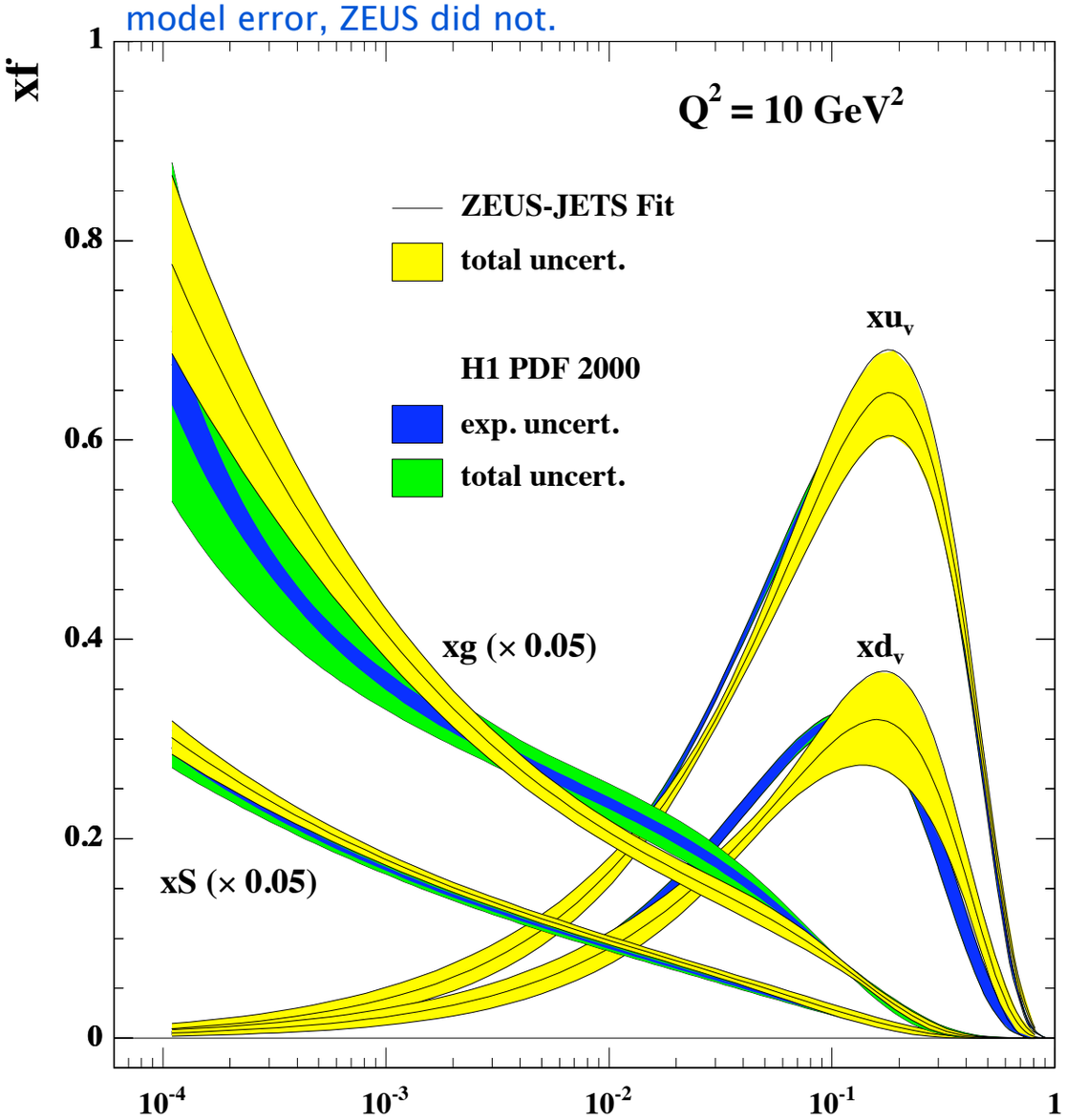
OLD



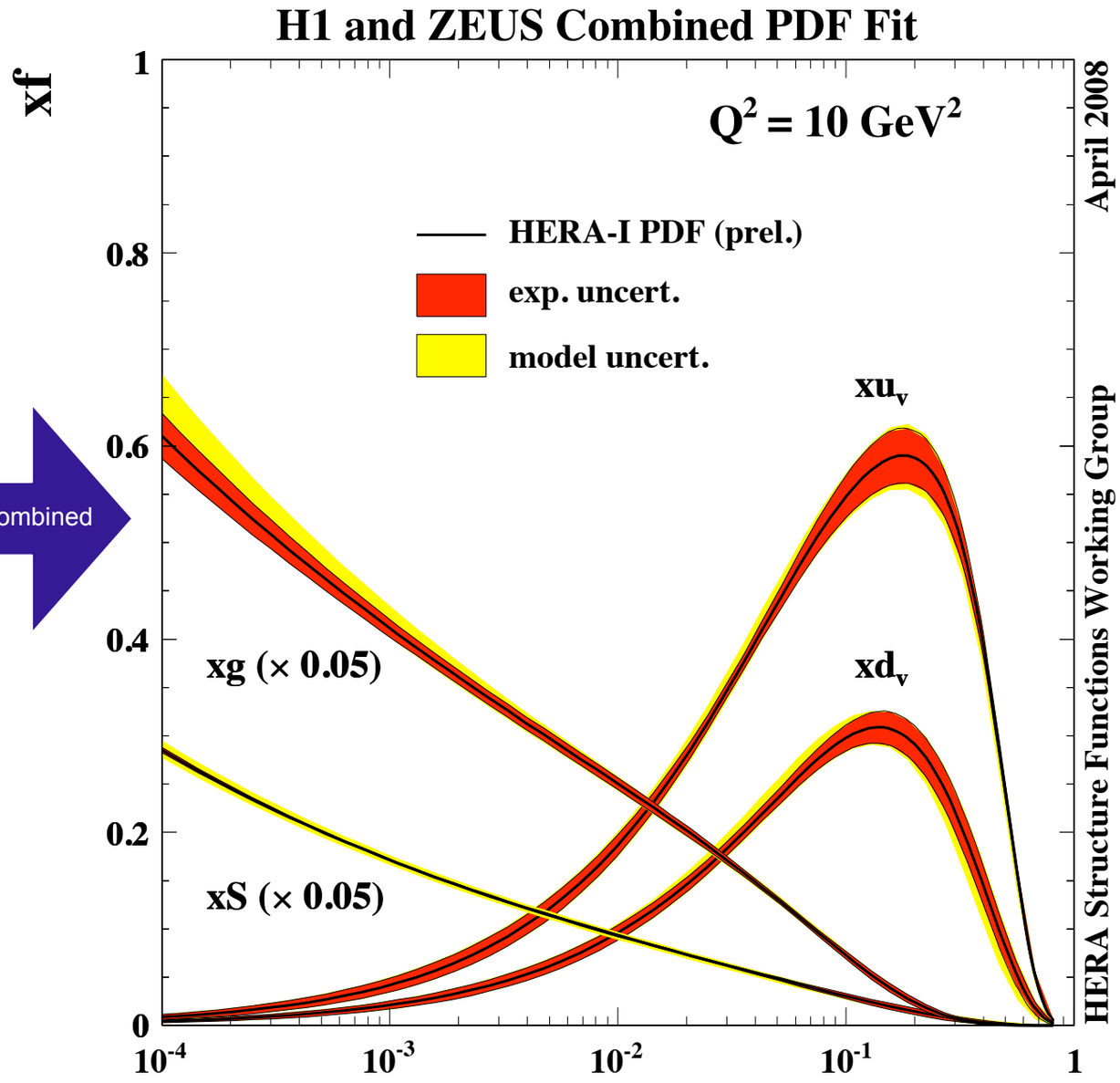
NEW

Accurate Determination of HERA-I PDF's

Note in published PDFs H1 did include α_S variation in model error, ZEUS did not.



data combined



OLD Impressive improvement in our knowledge of the low-x gluon **NEW**

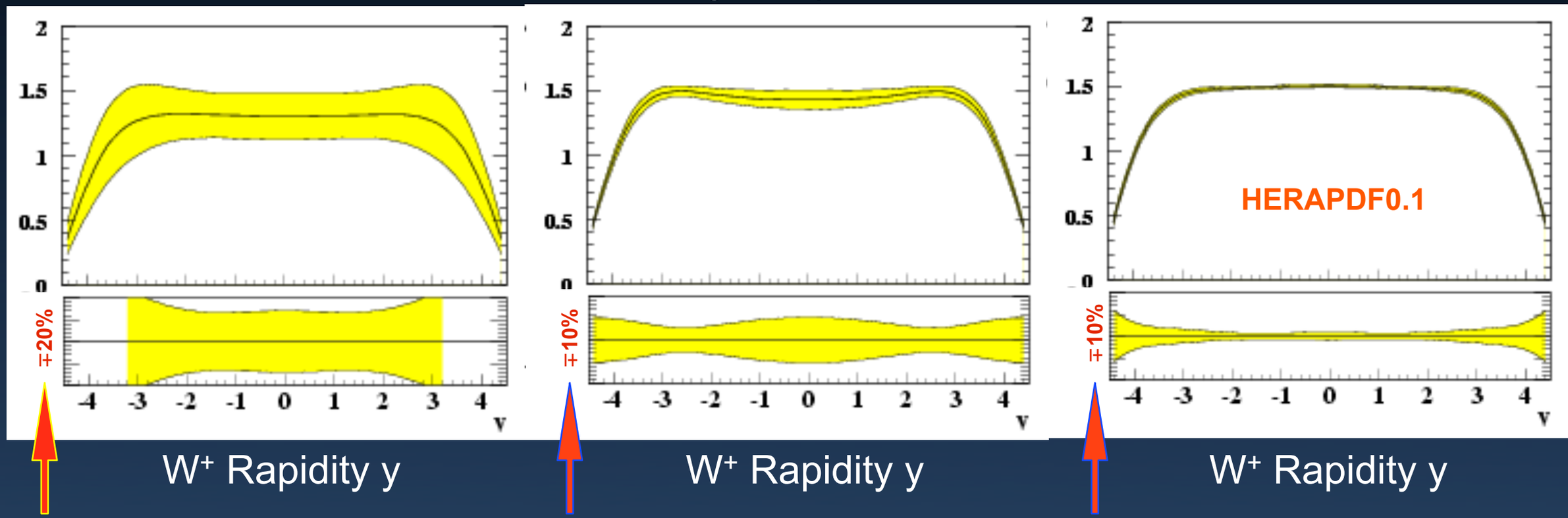
- New level of certainty – publication expected soon
- HERAPDF0.1 available for predictions soon – will be in LHAPDF

Predictions for W/Z Boson Production at LHC

Without HERA Data Constrains

HERA-I Data single Experiment

HERA-I Data H1-ZEUS Combined



Note different scale of uncertainty

Only the fit uncertainty shown here, no model variations

Summary

- The combination of data sets of ZEUS and H1 inclusive cross-sections is very successful and convincing
  - greatly improved precision compared to the measurements of either experiment separately
  - effort directed to publication
  - many new results expected (whole data of HERA-II)

- HERA $e^{\mp}p$ experiments provide unique information on proton structure over wide range of x

- This is not only interesting by itself but also provides an important precision input for physics at the LHC

Stay Tuned!