Proton Structure Functions and HERA QCD Fit

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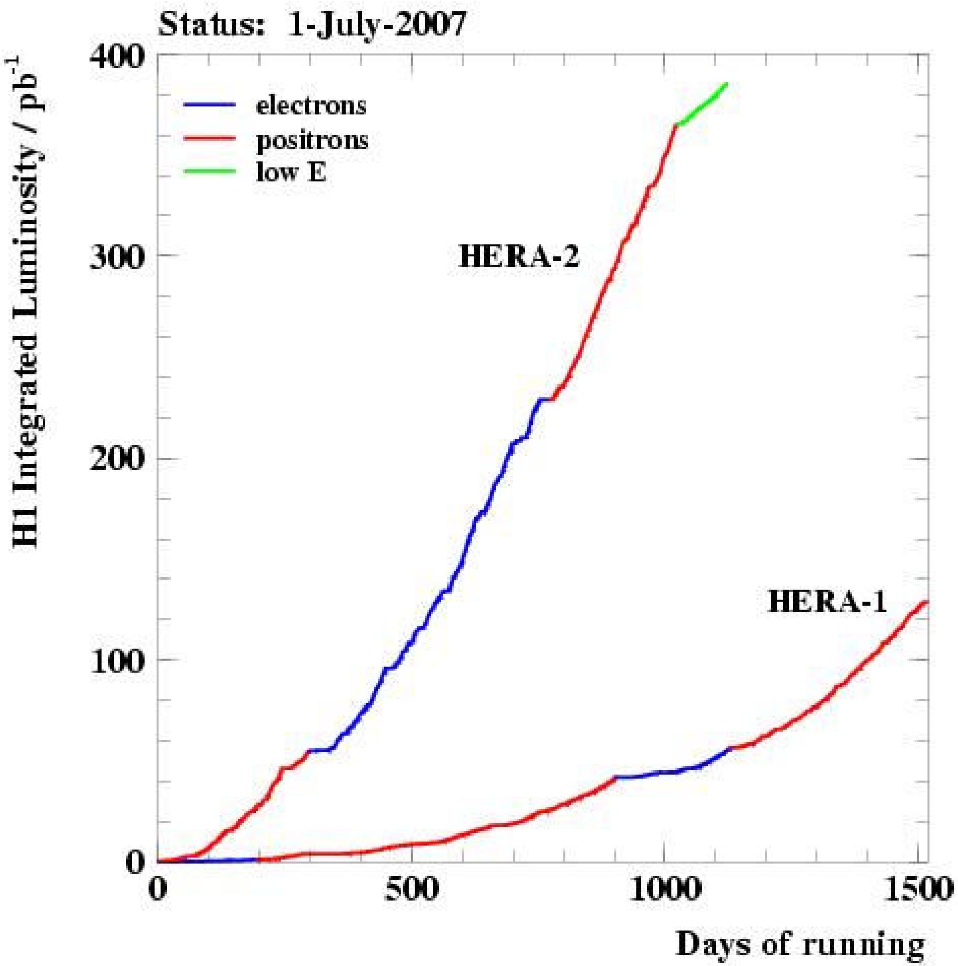
for the H1 and ZEUS Collaborations

- HERA+Experiments
- F_2
- Charged Current+xF_3
- HERA QCD Fit

Low x, Ischia 9th-12th September 2009

HERA



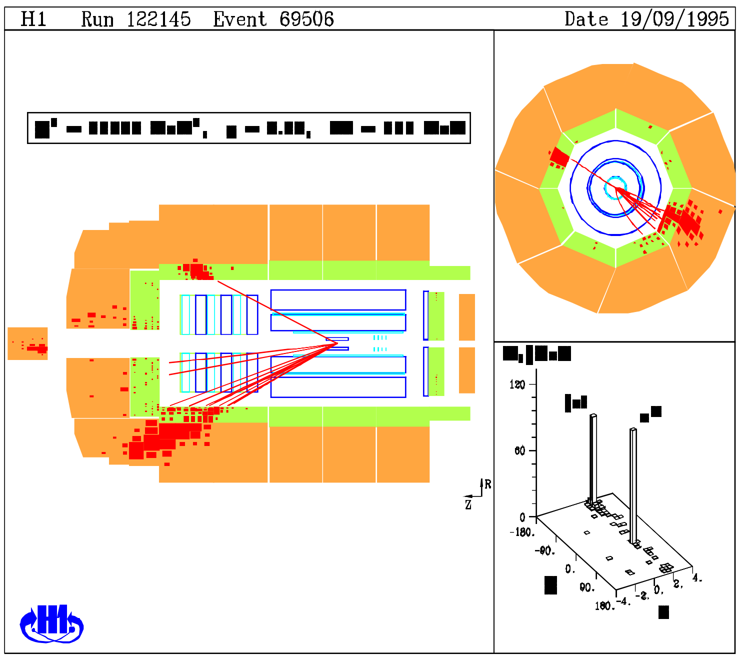
- In total ~500pb^{-1} of high energy data collected in e^-p and e^+p modes
- CMS Energy $\sqrt{s}$=320 GeV
- Luminosity upgrade in 2001, detectors upgraded
- Low energy run for F_L in 2007

DIS events as seen in H1+ZEUS

Two Types of reaction possible
Neutral Current (NC) and Charged Current (CC)

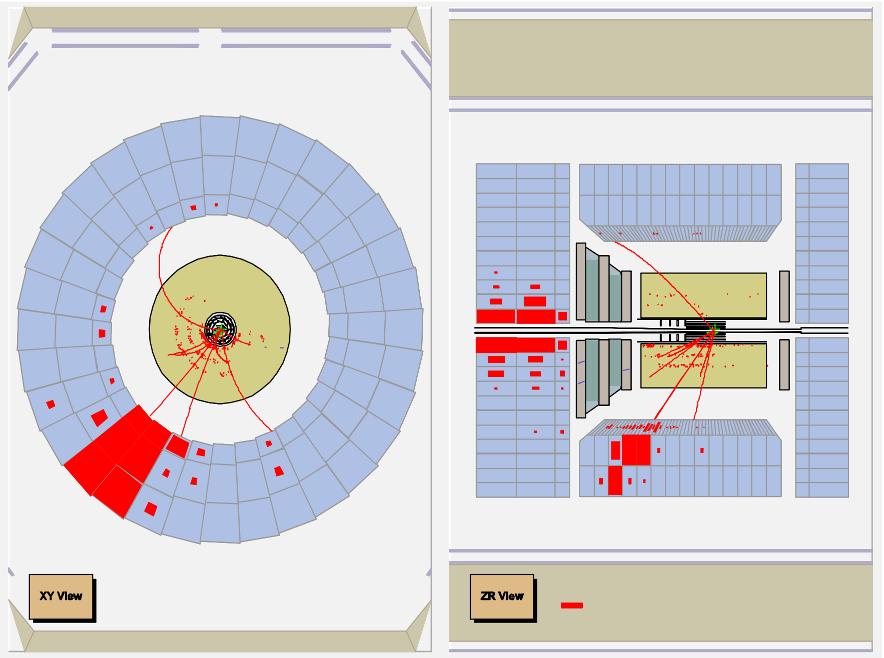
$$ep \rightarrow eX$$

γ^*, Z exchange

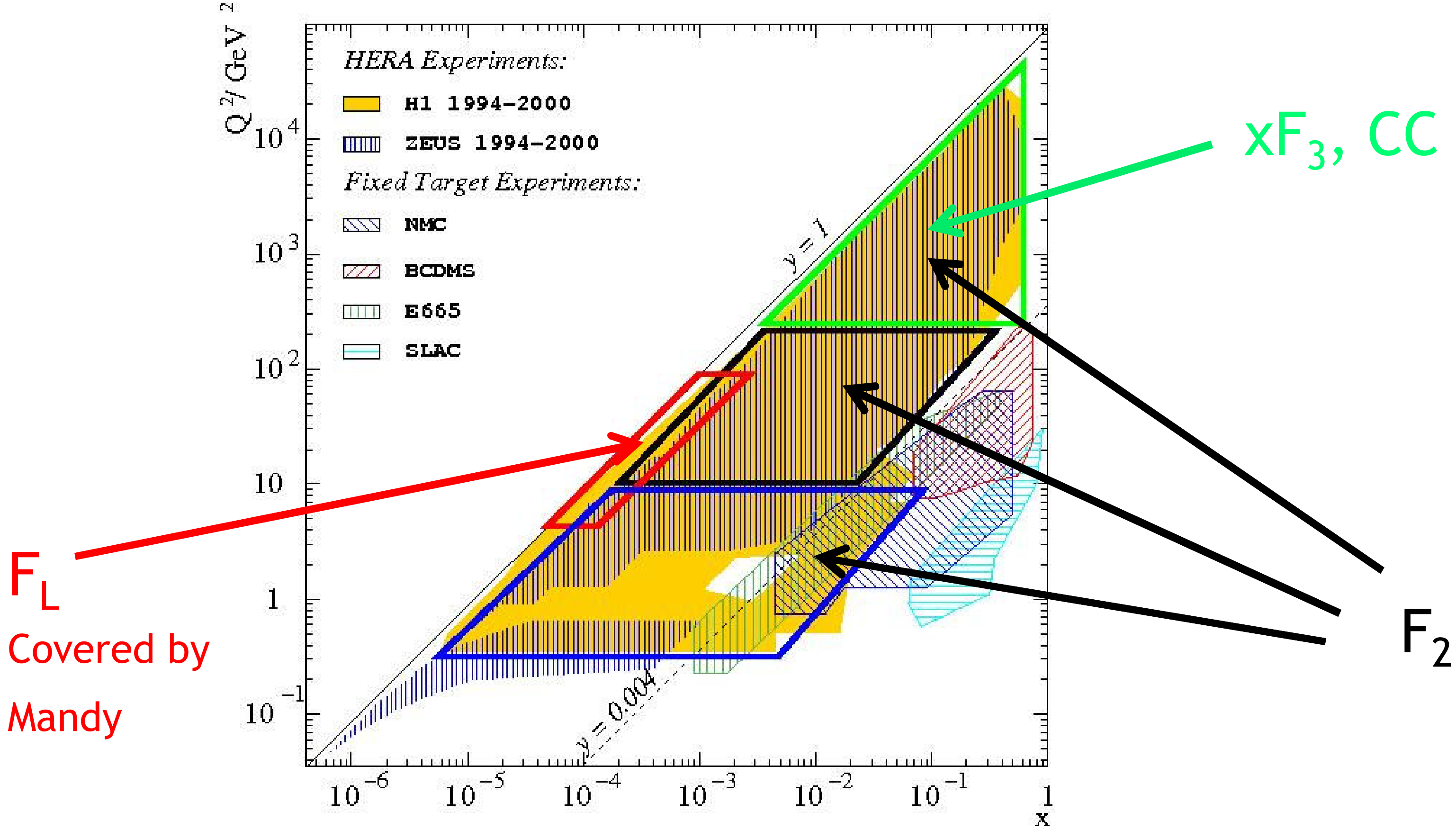


$$ep \rightarrow \nu X$$

W exchange



The kinematic plane



- Q^2 is square of momentum transfer of γ^*, Z, W
- x is fraction of proton’s momentum carried by struck quark
- y is inelasticity parameter $Q^2 = sxy$

Deep inelastic scattering

NC: Sensitive to all quarks, valence quarks and gluon

$$\frac{\mathrm{d}^2\sigma^{\pm}_{NC}}{\mathrm{d}x\mathrm{d}Q^2} = \frac{2\alpha\pi^2}{xQ^4}\left[Y_+\tilde{F}_2 \mp Y_- x\tilde{F}_3 - y^2\tilde{F}_L\right] \qquad Y_\pm = \tfrac{1}{2}(1 \pm (1 - y^2))$$

$$\tilde{F}_2 \propto \sum_i e_i^2 (xq_i + x\bar{q}_i)$$

All quarks at LO. Gluon from scaling violations.

$$x\tilde{F}_3 \propto \sum_i xq_i - x\bar{q}_i$$

Valence quarks

$$\tilde{F}_L \propto \alpha_s xg$$

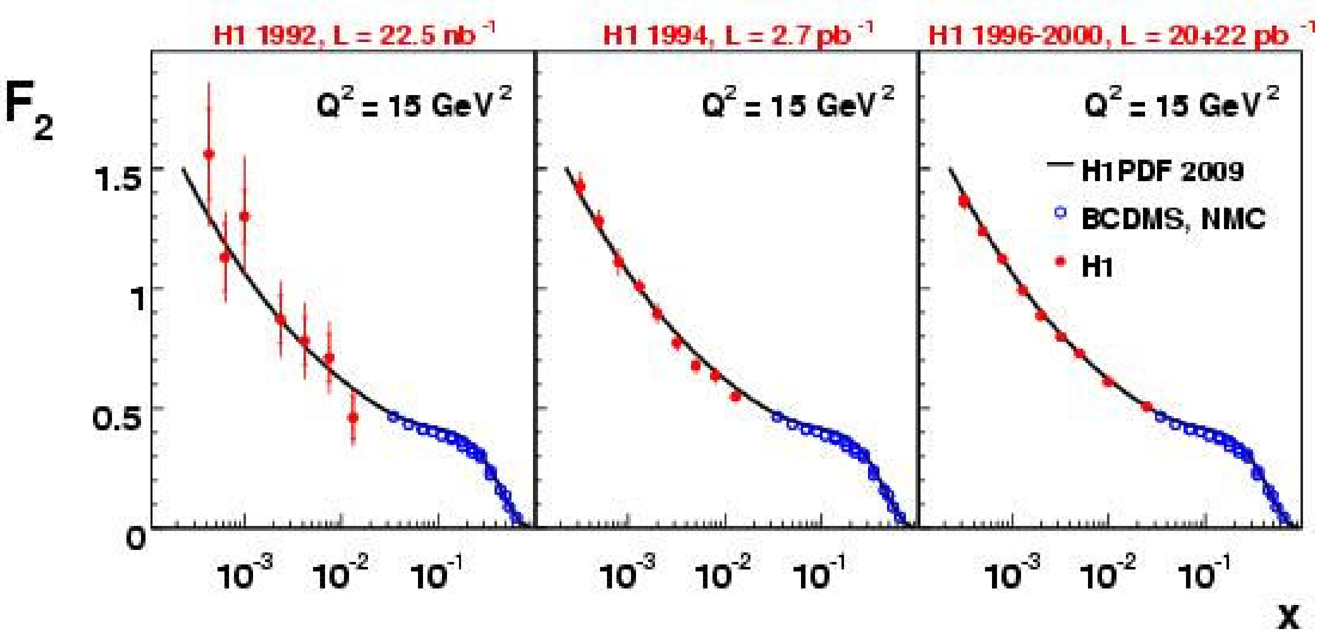
Gluon at NLO

Use ‘reduced cross section’ to remove kinematic dependence:

$$\sigma_r = \frac{xQ^2}{2\alpha\pi^2 Y_+}\frac{\mathrm{d}^2\sigma^{\pm}_{NC}}{\mathrm{d}x\mathrm{d}Q^2} \approx \tilde{F}_2$$

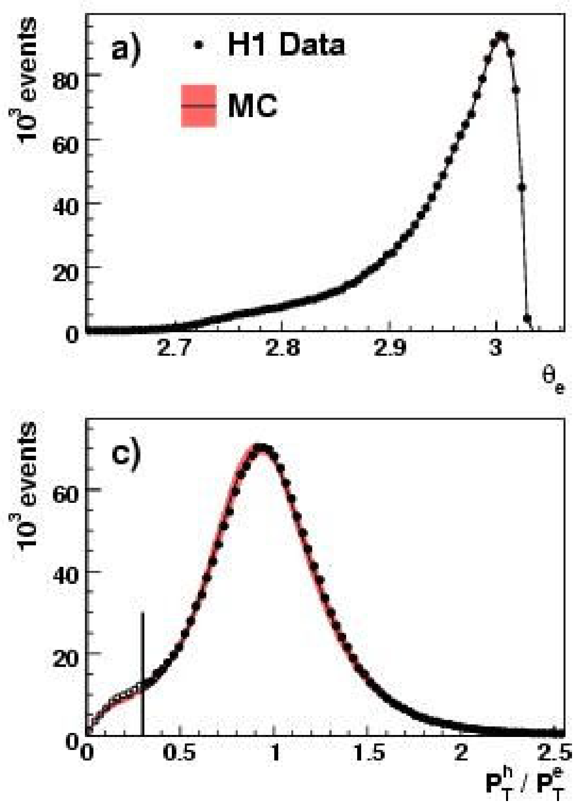
F_2 at medium Q^2

Majority of DIS data is sensitive to F_2.
Most accurately measured structure function.
New measurement from H1 of HERA I data gives best precision so far achieved **arXiv:0904.3513** + **arXiv:0904.0929**



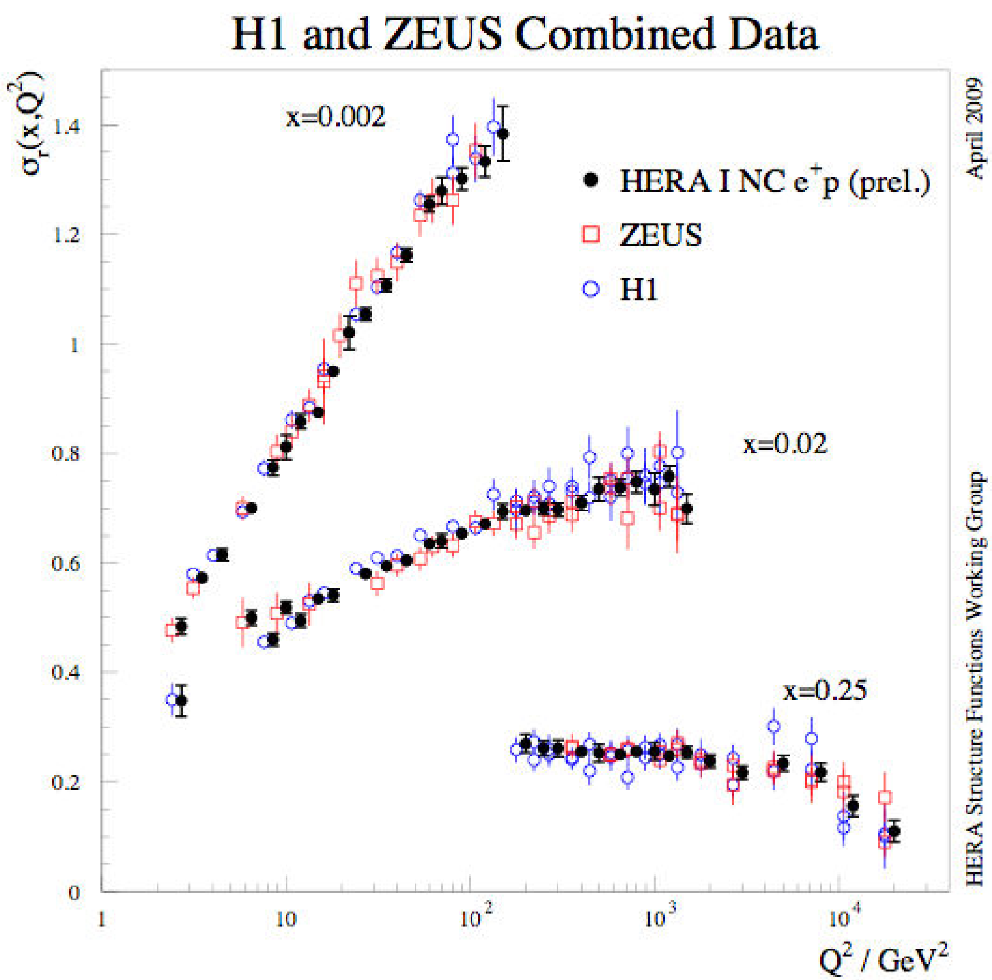
Accuracies improved to 1.3%-2%

Technical control plots



Accuracy achieved by careful calibration of scattered electron and hadronic final state, using over-constraint of kinemtics

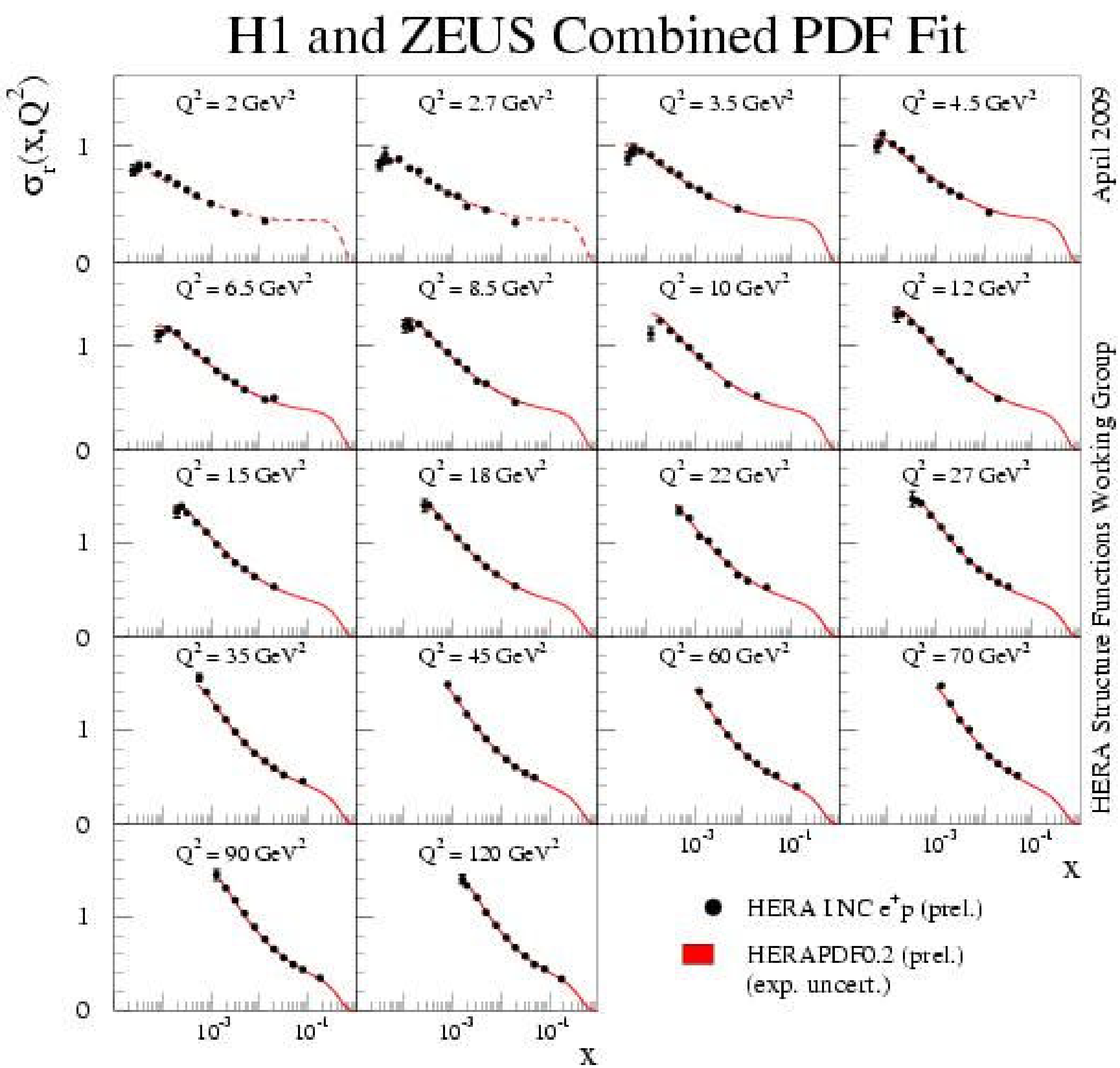
Combination of H1+ZEUS



Can improve accuracy further by combining all H1+ZEUS data, using method of arXiv:0904.0929

Different systematic errors of the two experiments help cross calibrate and reduce the errors further

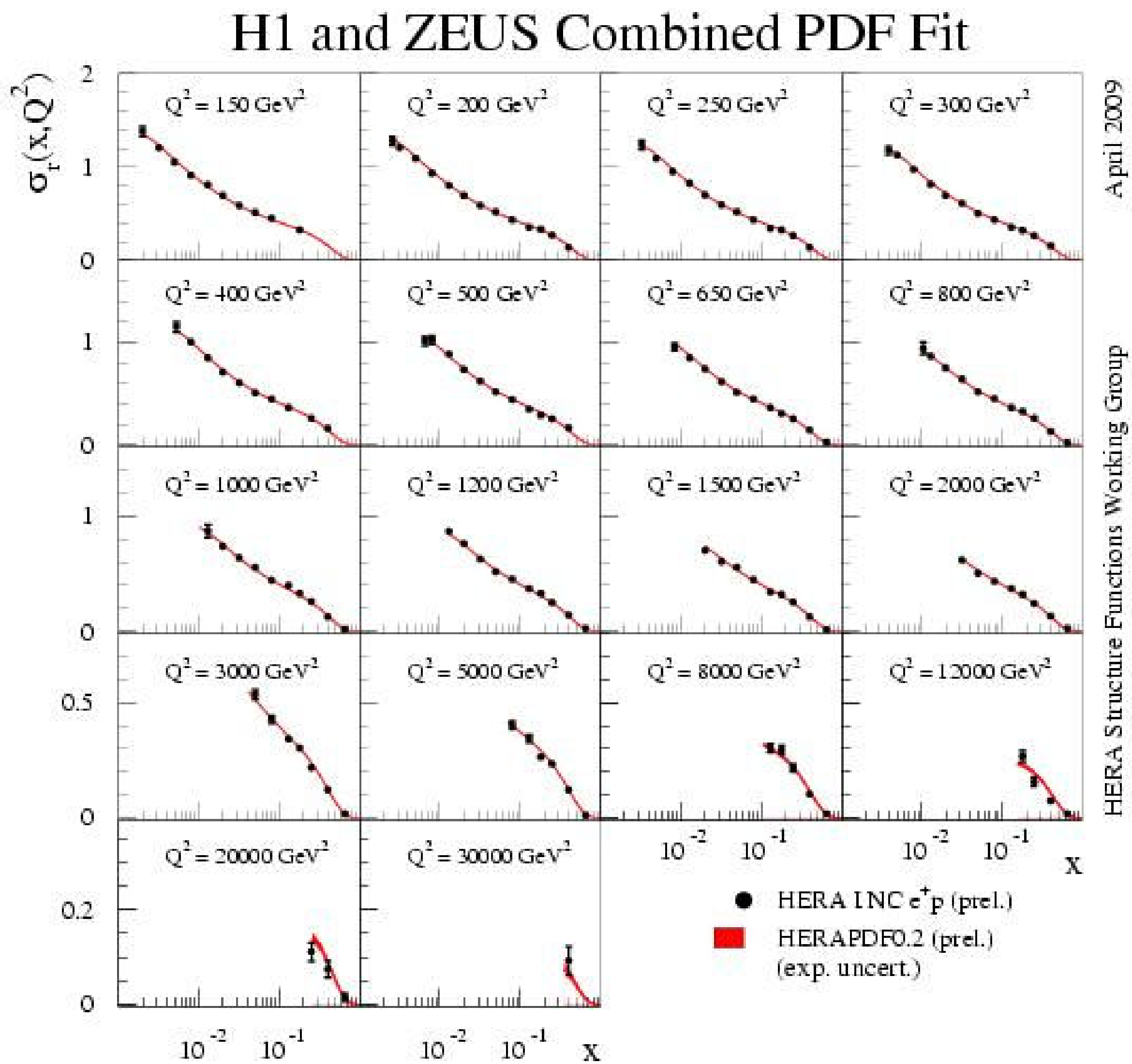
F_2 at medium Q^2



Combination give 1% precision in this region

F_2 shows a steep rise towards low x. Well described by QCD fit (see later).

F_2 at high Q^2



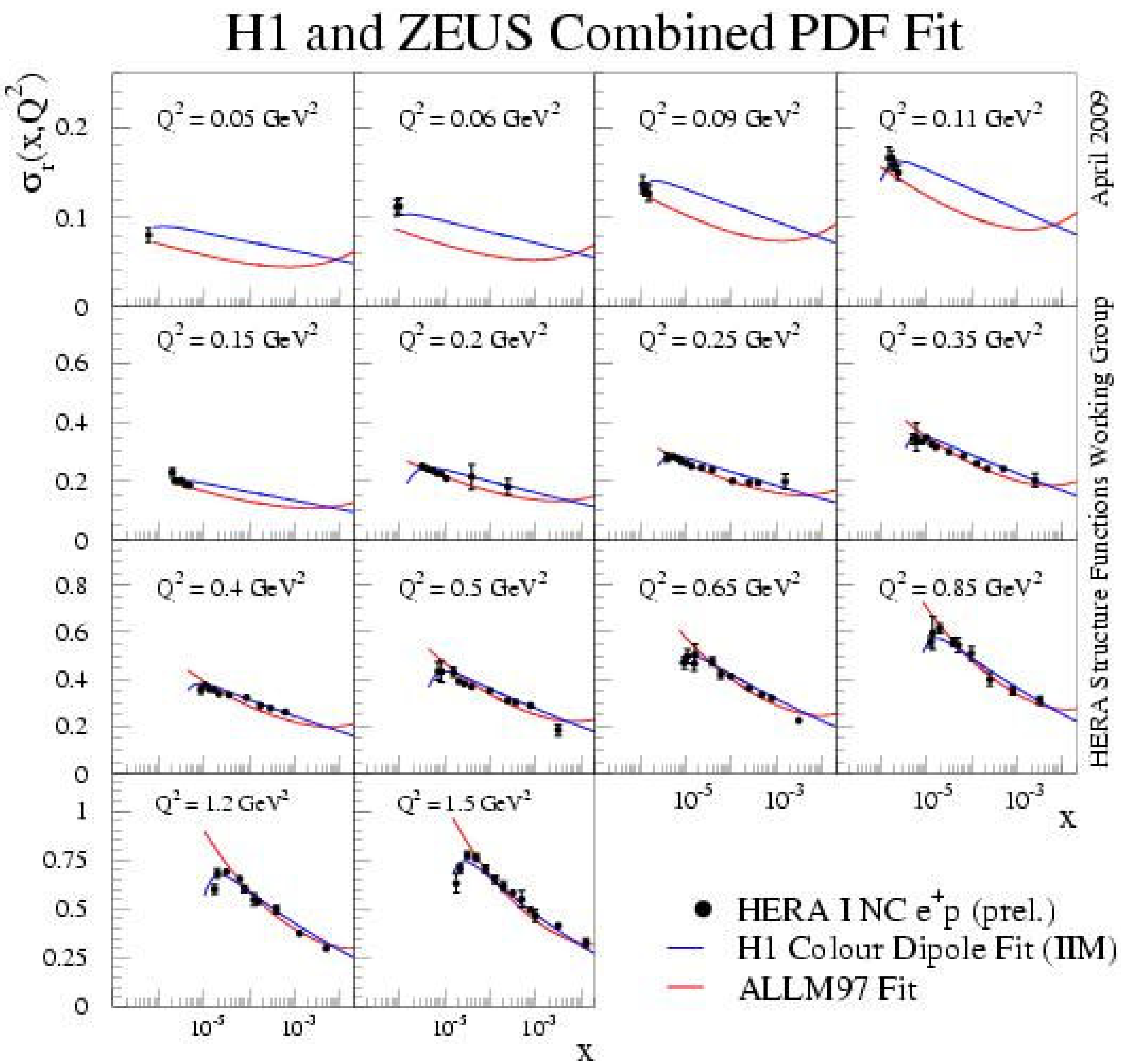
Data shown in the high Q^2 region.

Measurements up to 30000 GeV^2.

Rise of F_2 persists up to the highest Q^2.

Data well described by QCD fit from Q^2=3.5 to 30000 GeV^2.

F_2 at low Q^2

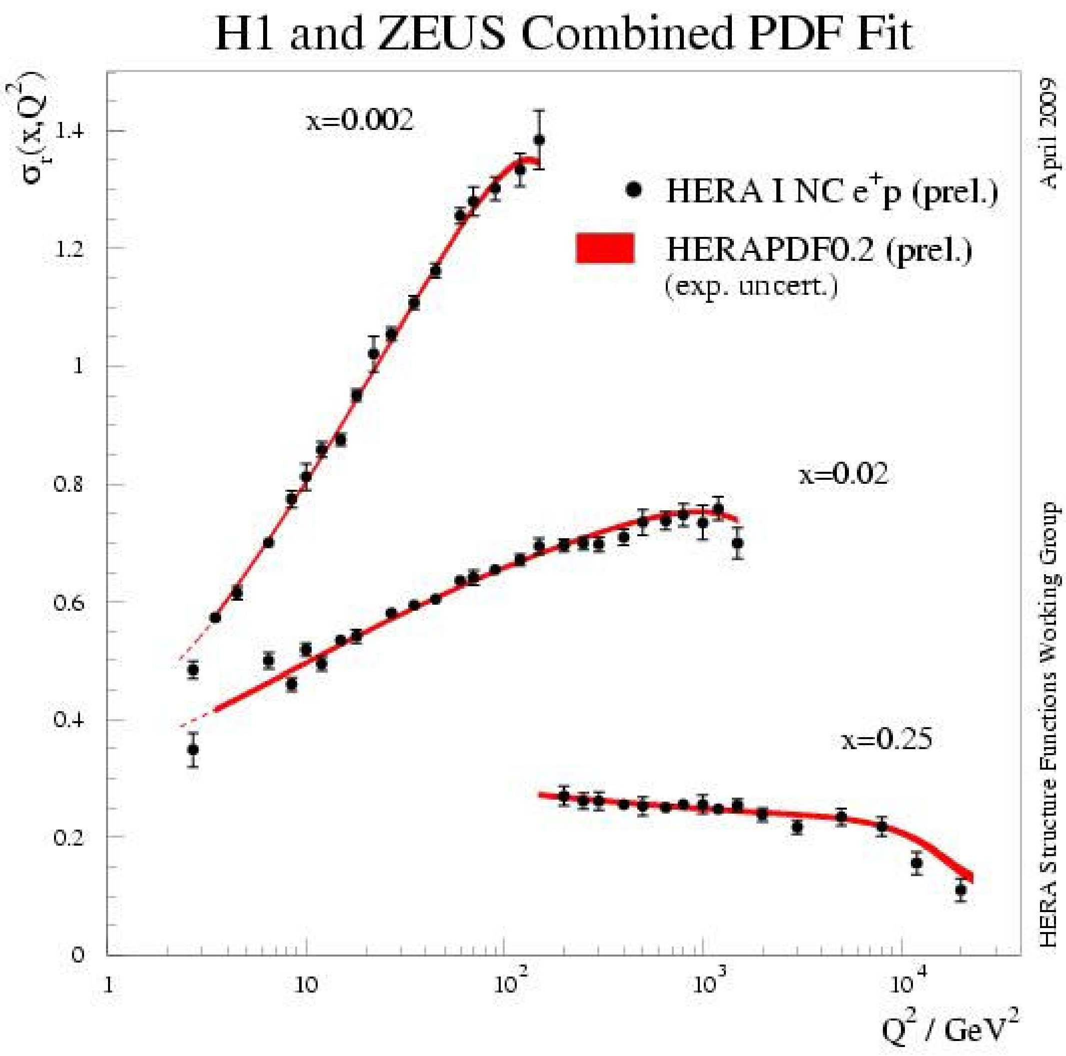


Data shown in the low Q^2 region.

pQCD not expected to work in the very low Q^2 region.

QCD inspired models do a reasonable job at describing data

F2 as a function of Q^2



Plot data vs Q^2

Data show strong scaling violations at low x

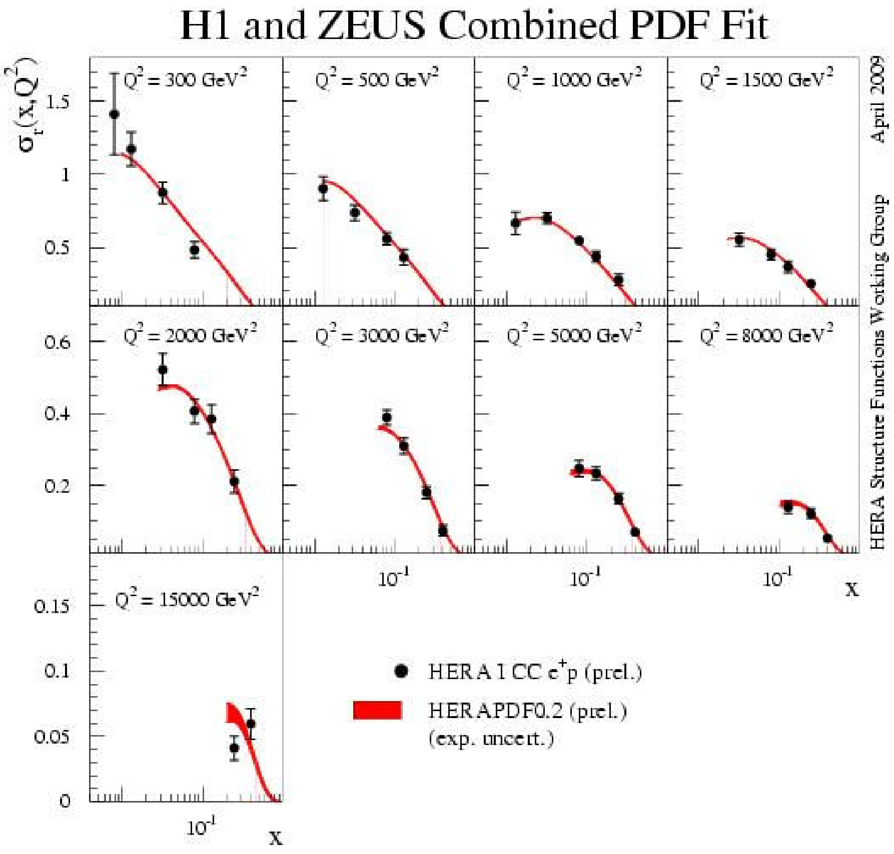
These are used to constrain the gluon:

$$\left(\frac{\partial F_2(x,Q^2)}{\partial Q^2}\right)_x \propto \alpha_s x g(x,Q^2)$$

Charge Current data

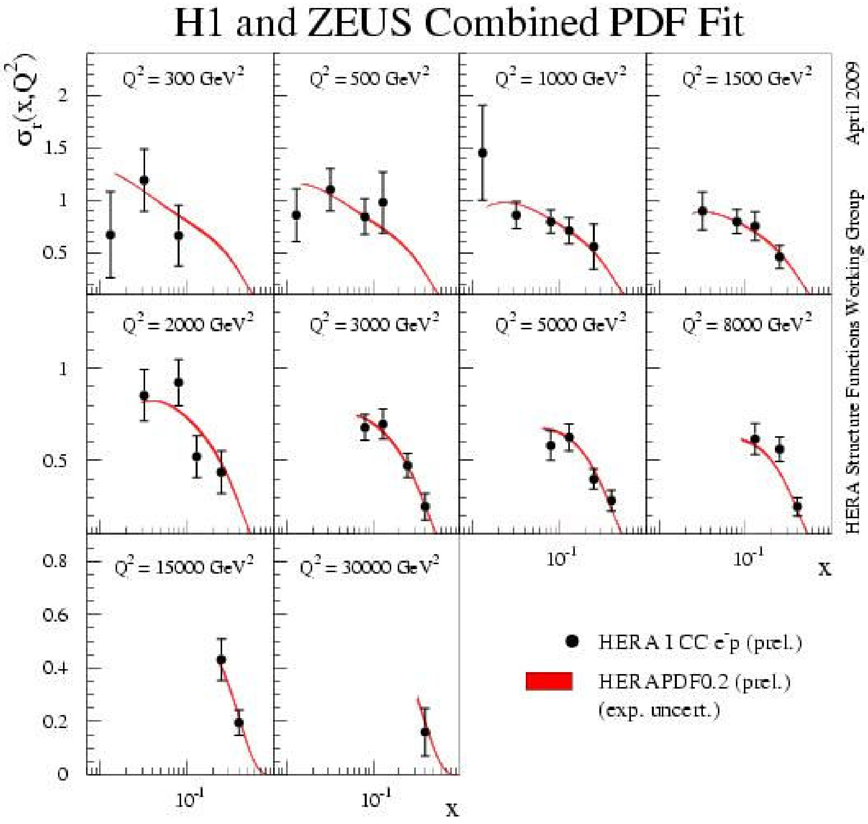
e⁺p

$$\sigma_r \propto \left[\bar{u} + \bar{c} + (1-y)^2 (d + s)\right]$$



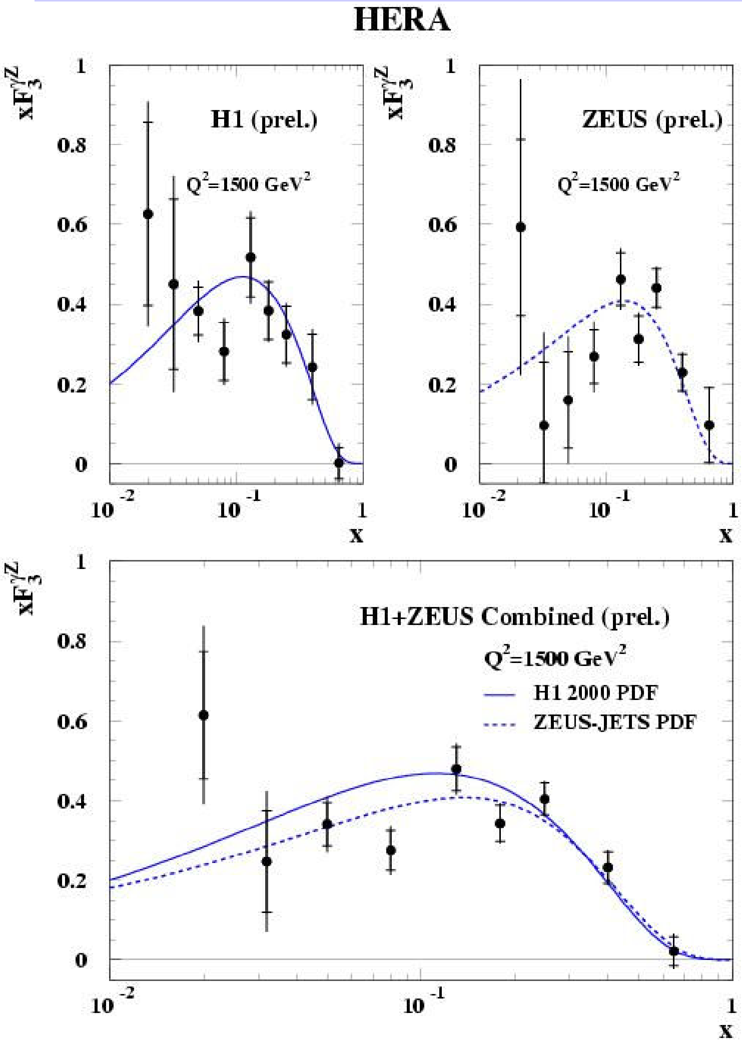
e⁻p

$$\sigma_r \propto \left[u + c + (1-y)^2 (\bar{d} + \bar{s})\right]$$



CC e⁺p is sensitive to d density, which is not constrained well by NC

xF_3



- xF_3 is extracted from the difference between the e+p and e$^-$p NC cross-sections
- It is sensitive only to the valence quarks
- Measured by H1+ZEUS and combined to make most precise measurement at low x
- Sensitive to differences between fits
- Not used directly in the fit but indirectly via e+p and e-p cross sections

New HERA QCD Fit

- Fit uses combined H1+ZEUS NC, CC data only. No fixed target data.
- HERA jet data is not used in present fit, but has previously shown to improve g density

- Fit perform at NLO
- Parameterize parton distribution functions at starting scale and evolve with Q^2.

- Calculations now use the Thorne-Roberts Variable Flavour Number Scheme: an improved theoretical treatment of heavy quarks that takes the quark masses into account

	HERAPDF0.2
Scheme	TR-VFNS
Evolution	QCDNUM17.02
Order	NLO
Q_0^2	1.9 GeV^2
$f_s = s/D$	0.31
$f_c = c/U$	0.00
Renorm. and Fact. scales	Q^2
Q^2_{min}	3.5 GeV^2
$\alpha_S(M_Z)$	0.1176
M_c	1.4 GeV
M_b	4.75 GeV

- Starting scale $Q^2_0 < M_c^2$ so $Q^2_0 = 1.9$ GeV^2
 Fix *s* density (no good constraints from HERA data)

Parametrisation form of the PDFs:
$xf(x,Q_0^2) = Ax^B(1-x)^C(1+Dx+Ex^2)$
10 free parameters

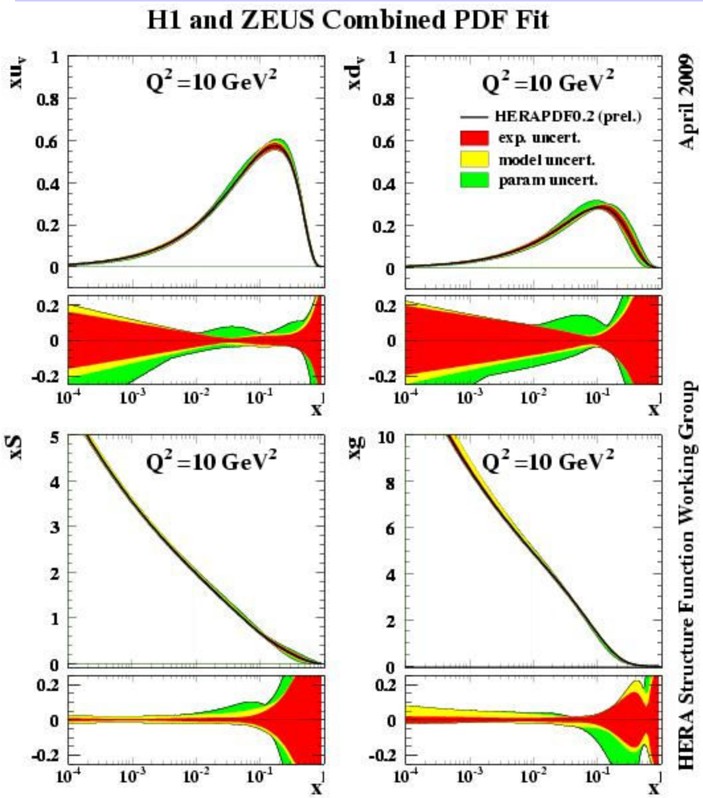
PDF	A	B	C	D	E
xg	sum rule	FIT	FIT	-	-
xu_{val}	sum rule	FIT	FIT	-	FIT
xd_{val}	sum rule	$=B_{u_{val}}$	FIT	-	-
$x\overline{U}$	$\lim_{x\to 0}\overline{u}/\overline{d} \to 1$	FIT	FIT	-	-
$x\overline{D}$	FIT	$=B_{\overline{U}}$	FIT	-	-

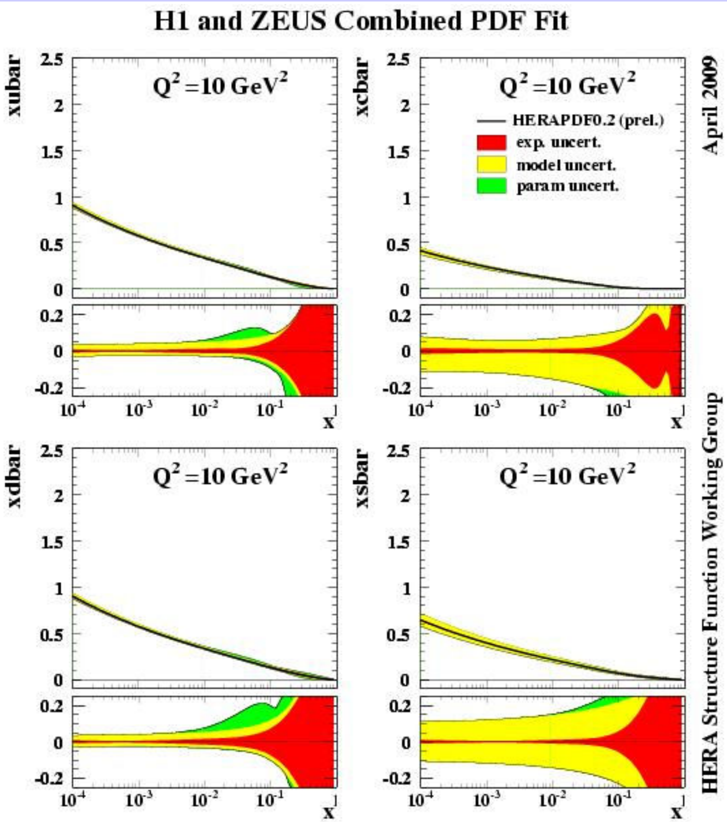
QCD Fit Uncertainties

- Experimental uncertainty:
  Take into account experimental errors including, correlations bin to bin and between experiments/datasets
  Use $\Delta\chi^2=1$
- Model uncertainty includes theoretical errors:
  - M_c 1.35 → 1.5 GeV, M_b 4.3 → 5.0 GeV
  - strangeness s/D 0.23 → 0.38
  - Q^2_0 1.5 → 2.9 GeV^2
  - Minimum Q^2 cut on data 2.5 → 5.0 GeV^2
  - $\alpha_S(Mz)=0.1176 \pm 0.0020$ [PDG]
- Parameterisation uncertainty:
  Vary parameterisation of PDFs at starting scale by adding in extra parameters in the fit

Good fit obtained with χ^2/dof=576/592

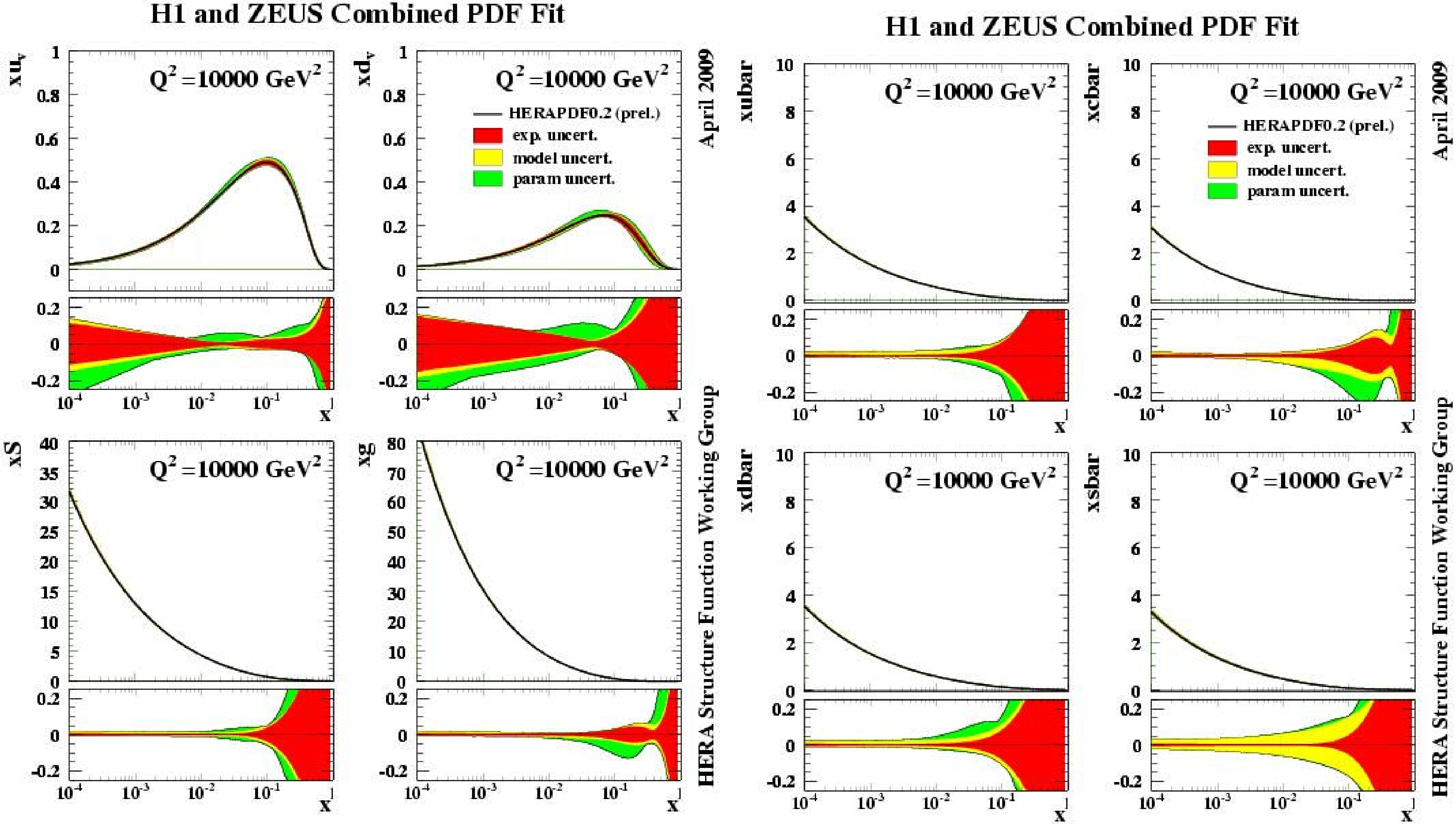
HERA QCD fit Q^2=10 GeV^2





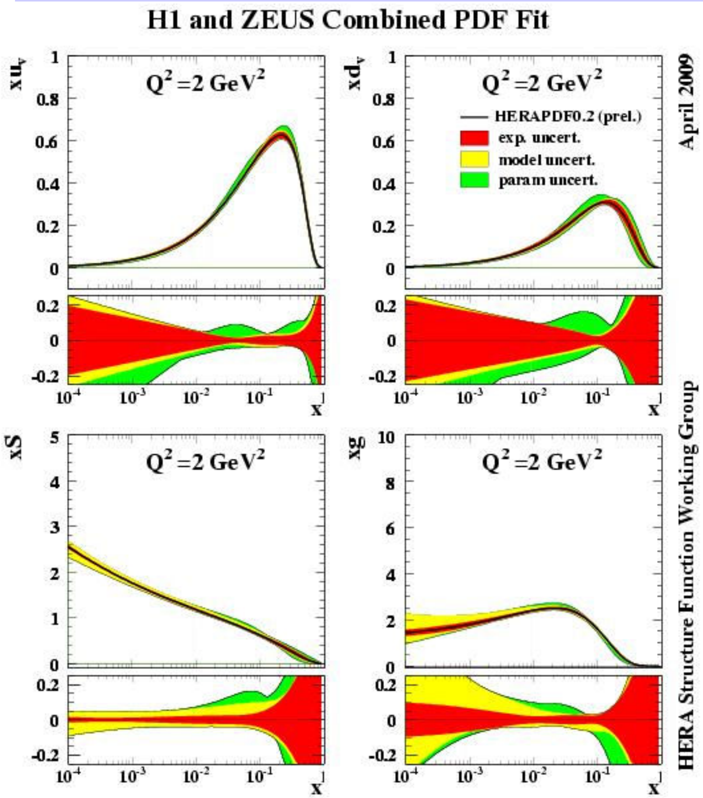
- Impressive precision for sea and gluon at low x
- Reasonable precision for valence at high x
- Gluon error relatively large at high x
- Model uncertainty large for charm at Q^2=10 GeV^2
- Strange not constrained by HERA data

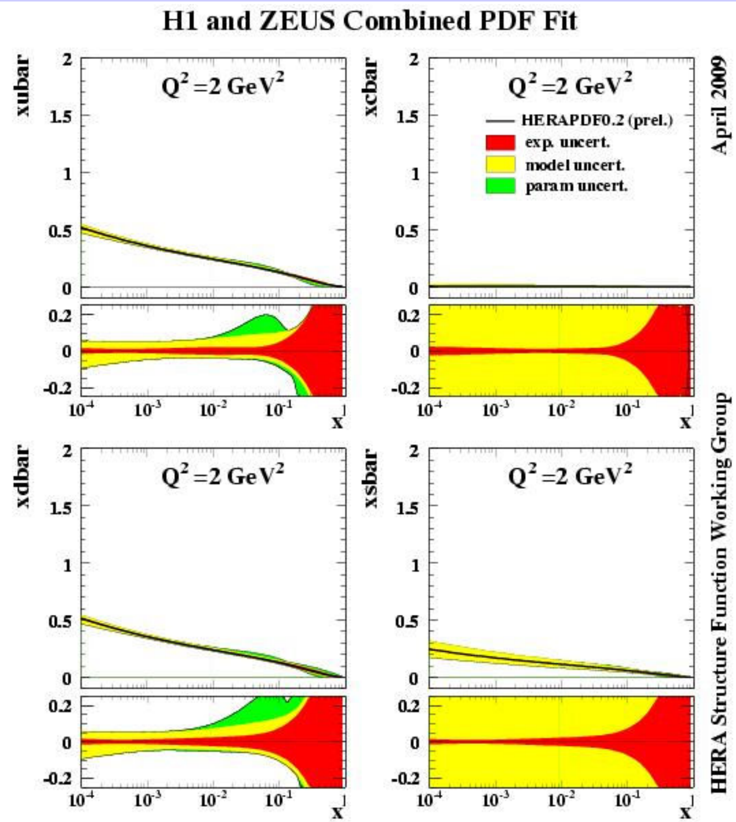
HERA QCD fit at high Q^2



- QCD evolution generally means a reduction of theory errors
- Impressive errors on PDFs at LHC energies
- Enables precision predictions for LHC cross sections

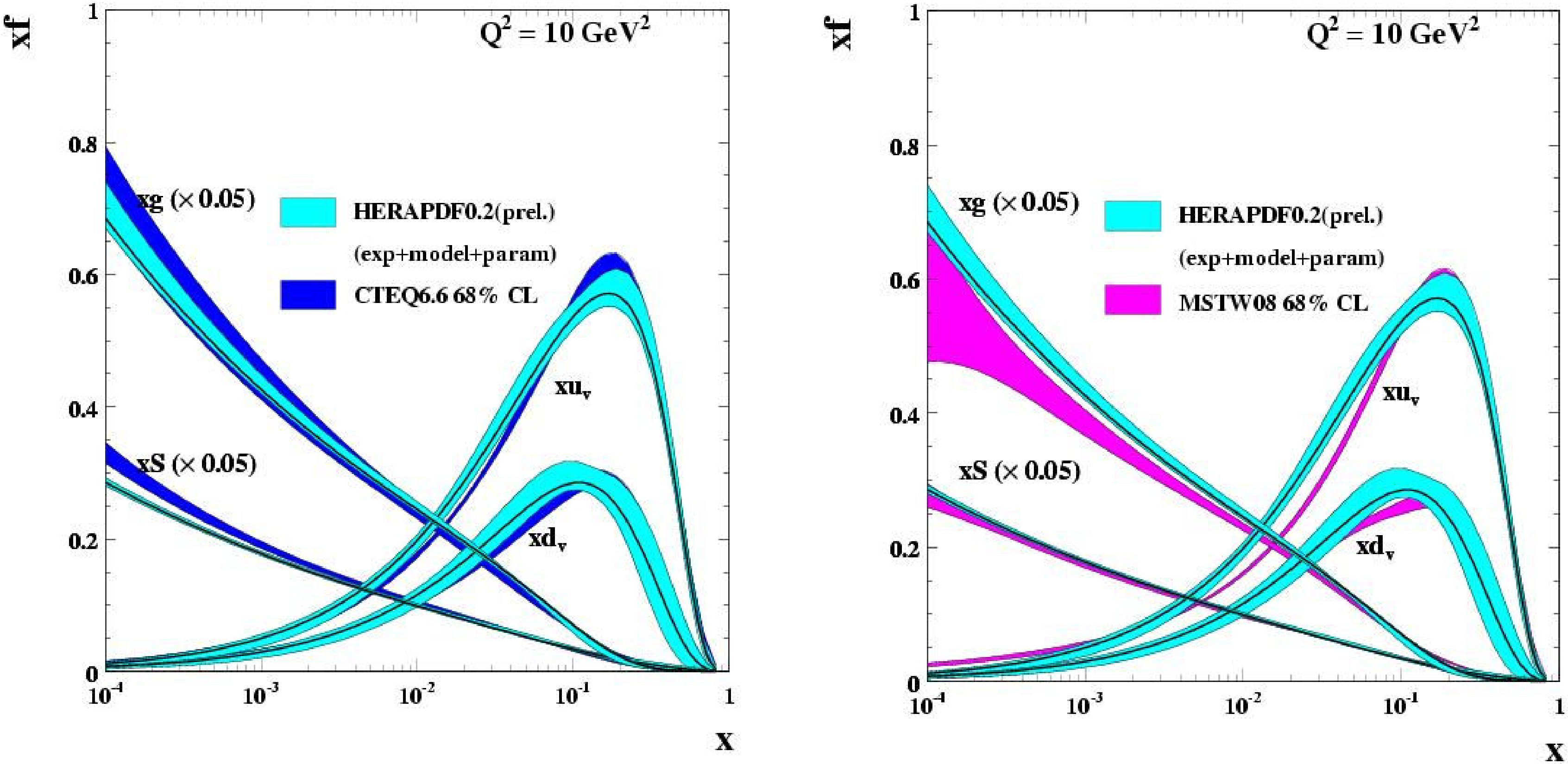
HERA QCD fit Q^2=2 GeV^2





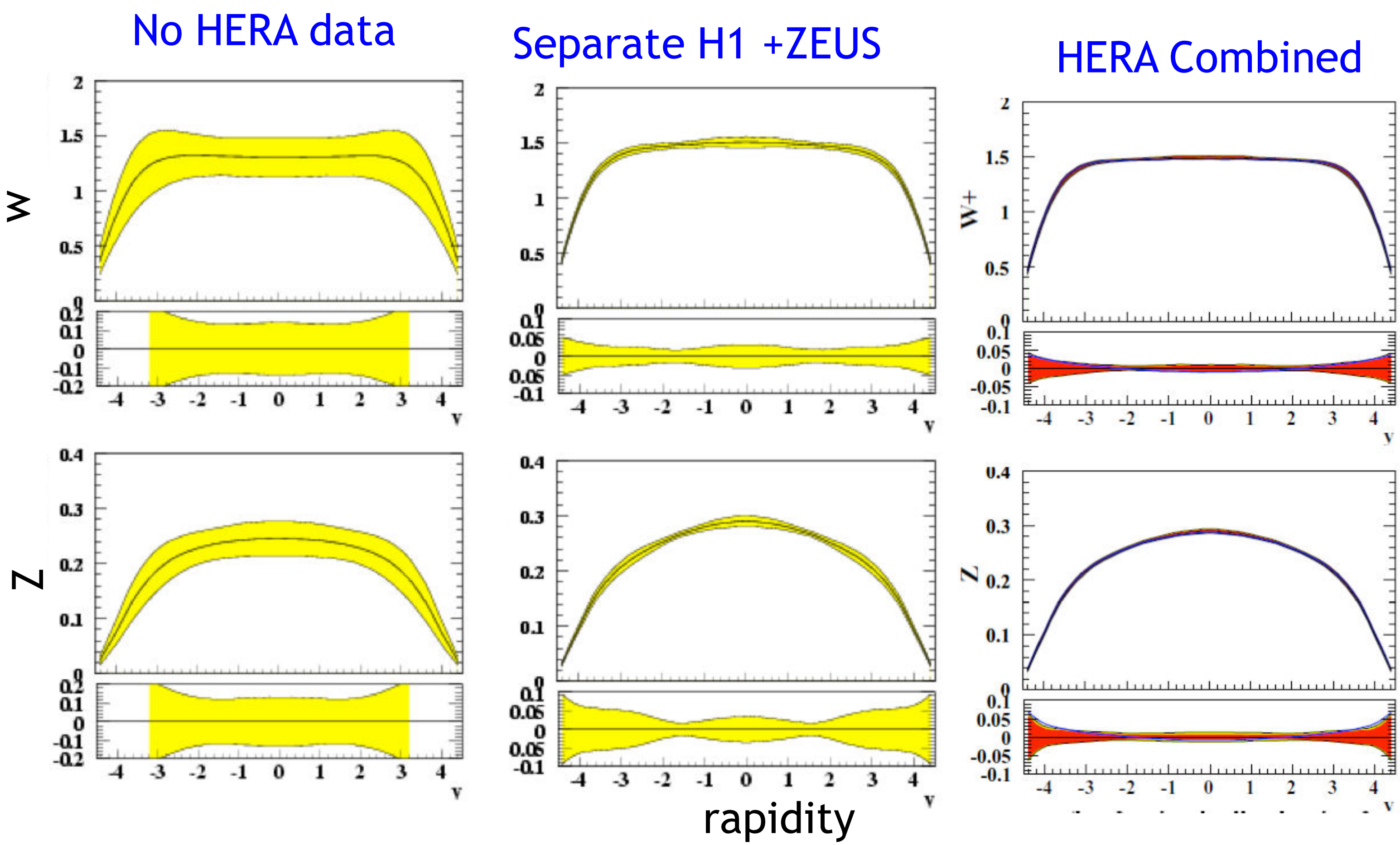
- Partons well behaved at Q^2=2 GeV^2
- Model uncertainty large for gluon at low x

Comparison with global fits



Still some differences to investigate, but HERA fit in agreement with either CTEQ or MSTW in all regions. Smaller overall error for gluon and sea at low x due to new HERA combined data.

Impact of HERA data on LHC



Only experimental errors shown
Great improvement by combining data!

Summary

•HERA has produced a wealth of inclusive NC/CC cross section measurements

• Measurement precision is now at low as 1%

• Accuracy improved by combining H1+ZEUS

• Data described by NLO QCD down to Q^2=2.0 GeV^2

• QCD fits to data provide the most precise PDFs yet obtained, crucial to understand LHC physics