PDF Fits to the Combined HERA I data

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On behalf of the H1 and ZEUS Collaborations

HERA Structure Function Working Group

Outline:

- Objectives
- Data Sets used for the fits
- NLO QCD fit analysis details
- Results and comparisons
- Summary

Objectives

- Main goal is to know the structure of the proton with the highest possible precision

- The purpose of combining the H1 and ZEUS data is to produce more consistent and precise cross section measurements
  - HERA I data combination presented by Enrico Tassi

- New combined precise HERA I data can be used as the sole input in a QCD analysis to extract HERA PDF set
  - New HERA PDF to complete the HERA I inclusive data
  - First release labeled HERAPDF0.1 (DIS 2008)
  - New data and QCD fit conditions → **HERAPDF0.2**

Data sets used for QCD fits

➔E.Tassi's talk

- Published HERA-I inclusive NC and CC DIS data (1994-2000)
  - Ep = 820 ($\sqrt{s}$=301) and 920 ($\sqrt{s}$=319) GeV, L = 240 pb^{-1}

- CC e-p data: H1 98, ZEUS 98
- CC e+p data: H1 94-97, H1 99-00, ZEUS 94-97, ZEUS 99-00
- NC e-p data: H1 98, ZEUS 98
- NC e+p data: ZEUS 96-97, H1 99-00 "highQ2", ZEUS 99-00

  - ZEUS-BPC/BPT, SVX95 ($0.045 \leq Q^2 \leq 17$ GeV^2)
  - H1 95-00 "low Q^2" ($0.5 \leq Q^2 \leq 12$ GeV^2)
  - H1 96-00 "medium Q^2" ($12 \leq Q^2 \leq 150$ GeV^2)

➔ A.Petrukhin & J.Kretzschmar' talks

    - 1% precision for the combined data in the 10-100 GeV^2 region

New data since HERAPDF0.1

QCD Analysis Framework

- Calculations in Heavy Flavour scheme (Thorne-Roberts Variable Flavour Number Scheme)
  - An improved theoretical treatment of heavy quarks that takes the quark masses into account
- NLO predictions using DGLAP evolution equations
  - QCDNUM17.02 (M. Botje): quicker, more accurate at high-x and can do NNLO fits
- Starting scale $Q_0^2 < M_c^2 \rightarrow Q_0^2 = 1.9$ GeV^2
  - Implies new starting sea fractions

- Differences between HERAPDF0.1 (DIS 2008) and HERAPDF0.2:

	HERAPDF0.1	HERAPDF0.2
Scheme	ZM-VFNS	TR-VFNS
Evolution	QCDNUM16.12	QCDNUM17.02
Order	NLO	NLO
Q_0^2	4 GeV^2	1.9 GeV^2
$f_s = s/D$	0.33	0.31
$f_c = c/U$	0.15	0.00
Renorm. and Fact. scales	Q^2	Q^2
Q^2_{min}	3.5 GeV^2	3.5 GeV^2
$\alpha_S(M_Z)$	0.1176	0.1176
M_c	1.4 GeV	1.4 GeV
M_b	4.75 GeV	4.75 GeV

- Fit for PDFs: $\mathrm{gluon}, u_{val}, d_{val}, \overline{U} = \bar{u} + \bar{c}, \overline{D} = \bar{d} + \bar{s} + \bar{b}$

HERA PDF parametrisation

- A generic functional form has been considered:

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

  - 6 parameters are fixed by the model assumptions
  - The optimum number of parameters are chosen by saturation of the χ^2 (i.e. only parameters that significantly contribute to χ^2 are let to vary)
- This results in 10 free parameters for the central fit (χ^2/dof=576/592)
  - All PDFs ≥ 0
  - Valence not too low compared to sea distribution at high x
  - Fit is stable with respect to the error treatment (correlations)

PDF	A	B	C	D	E
xg	sum rule	FIT	FIT	-	-
xu_{val}	sum rule	FIT	FIT	FIT for HERAPDF0.1	FIT
xd_{val}	sum rule	$=B_{u_{val}}$	FIT	-	-
$x\bar{U}$	$\lim_{x\to 0}\bar{U}/\bar{D}\to 1$	FIT	FIT	-	-
$x\bar{D}$	FIT	$=B_{\bar{U}}$	FIT	-	-

- Remark:
  - For HERAPDF0.1 the optimal parametrisation consisted of 11 free parameters
    - Include Du_{val}

PDF Uncertainties

The following sources of uncertainties have been considered:

- Experimental uncertainties
- Model uncertainties
- PDF parametrisation uncertainty
- Variation of the strong coupling
  - $\alpha_S(M_Z) = 0.1176 \pm 0.0020$ (according to PDG)

Experimental Uncertainties

- Uncorrelated uncertainties: ➔E.Tassi's talk
  - Statistical errors
  - Poin-to-point uncorrelated uncertainties:
    - e.g statistical errors due to MC simulations
    - Are added in quadrature to the statistical errors

- Correlated uncertainties:
  - Point-to-point correlated uncertainties
    - e.g. electromagnetic and hadronic energy scale calibration
    - Often common for CC and NC for a given experiment and run period

- Overall normalisation uncertainty:
  - Correlated for all data points for a given experiment and run period

- Correlations between H1 and ZEUS:
  - H1 and ZEUS use similar analyses methods
  - largest from photo-production MC and hadronic energy scales

There are 110 systematic errors which are combined in quadrature with the statistical errors and 3 sources of errors from the averaging procedure are offset.

- Small effects observed when errors are treated as correlated

Model Uncertainties

The following variations are considered as model uncertainties:

- Variation of the heavy quark thresholds:
  - Mc = 1.4 GeV ➔ 1.35 - 1.50 GeV
    - varied with Q^2_0 (1.77 - 2.19) GeV^2
  - Mb = 4.75 GeV ➔ 4.30 - 5.00 GeV

- Variation of the sea fractions:
  - f_s = s/D = 0.31 ➔ 0.23 - 0.38
  - f_c = c/U = 0.00 ➔ specified by TR-VFNS

- Variation of the starting scale of evolution of PDFs:
  - Q^2_0= 1.9 GeV^2 ➔ 1.5 - 2.5 GeV^2:
    - for Q^2_0= 2.5 GeV^2 vary f_s=0.32 and Mc=1.6 GeV because $Q^2_0 < Mc^2$
    - for Q^2_0= 1.5 GeV^2 vary f_s=0.29

- Variation of the minimum Q^2 cut on data:
  - Q^2_{min}= 3.5 GeV^2 ➔ 2.5 - 5.0 GeV^2

PDF parametrization uncertainty

PDFs are parametrised using the following general functional form:

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

- The optimization procedure leads to the choice of PDF parametrisation with 10 parameter with χ^2 /dof = 576/592
  - Similar optimization procedure used for H12009 PDF

  ➔J. Kretzschmar's talk

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$\bar{U}$	$\lim_{x\to 0} \bar{U}/\bar{D} \to 1$	FIT	FIT	-	-
x$\bar{D}$	FIT	$=B_{\bar{U}}$	FIT	-	-

Current strategy to determine PDF parametrisation uncertainty is to test alternative parametrisations with similar or better χ^2 which have been discarded due to additional optimisation requirements:

- Reasonable shape for valence and sea distributions at high-x
- All PDFs >0
- Stability in error treatment (correlated vs uncorrelated)

- Envelope of all these fits is formed and used as PDF parametrisation error
  - 7 fits out of all possible 11 parameter fits obtained by adding one additional parameter to the central fit parametrisation choice were used for the envelope

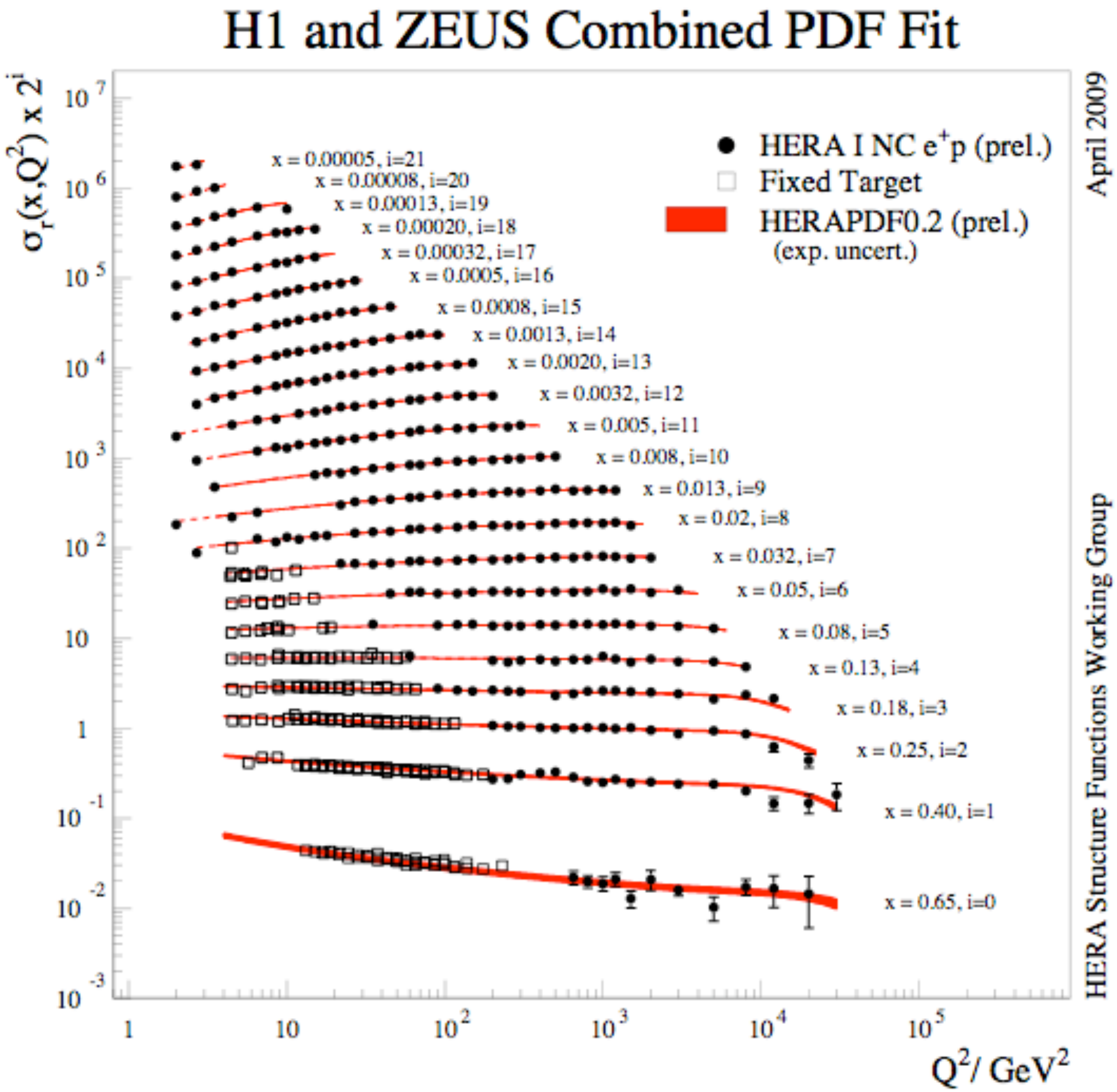
Note: the procedure addresses the high-x region

Fit Results

- $(\chi^2 /\mathrm{dof} = 576/592)$

- Plots show the extended kinematic range of the HERA data as compared to the fixed target measurements

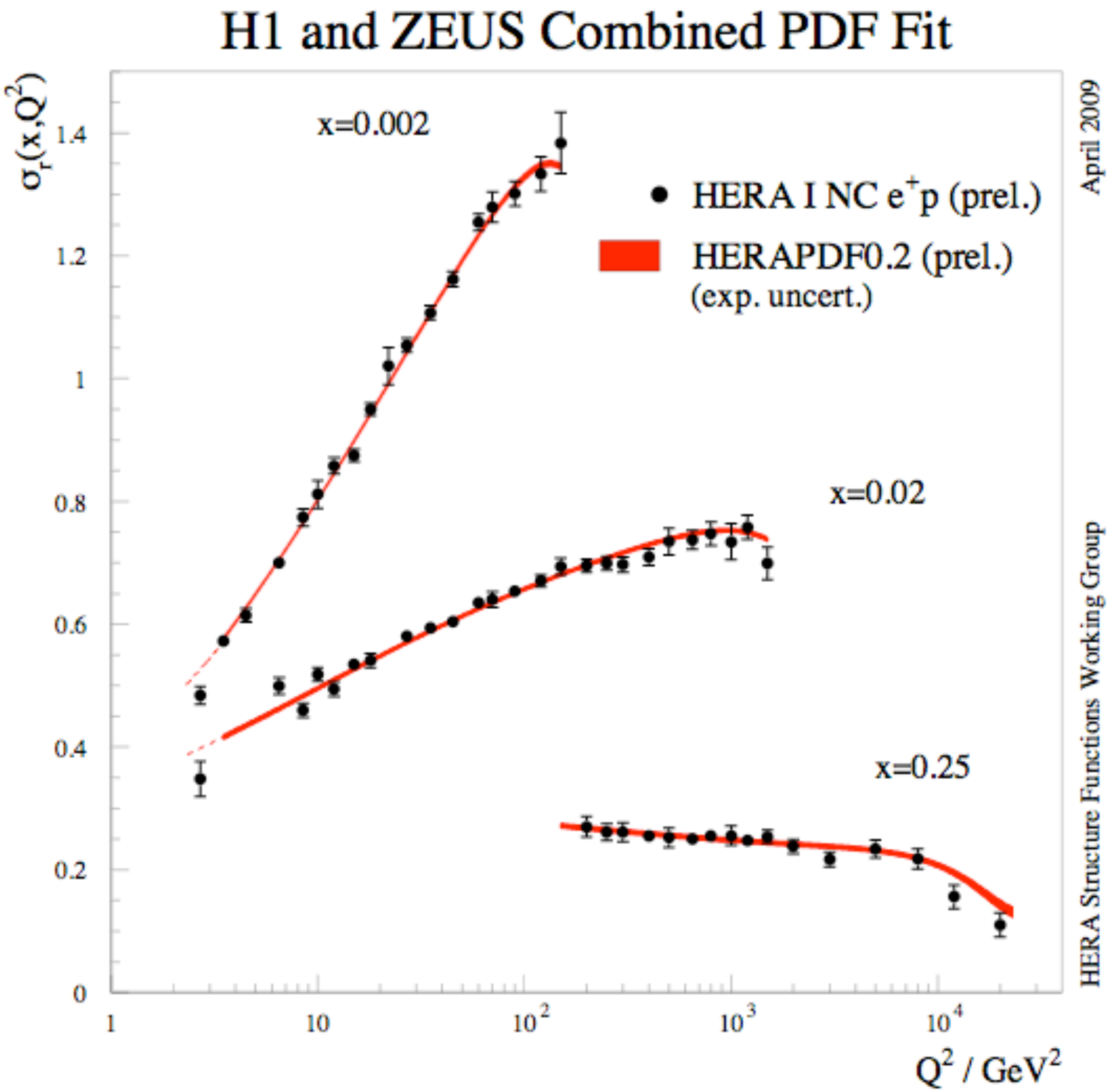
- Plots include experimental uncertainties on both data and fit



Fit Results

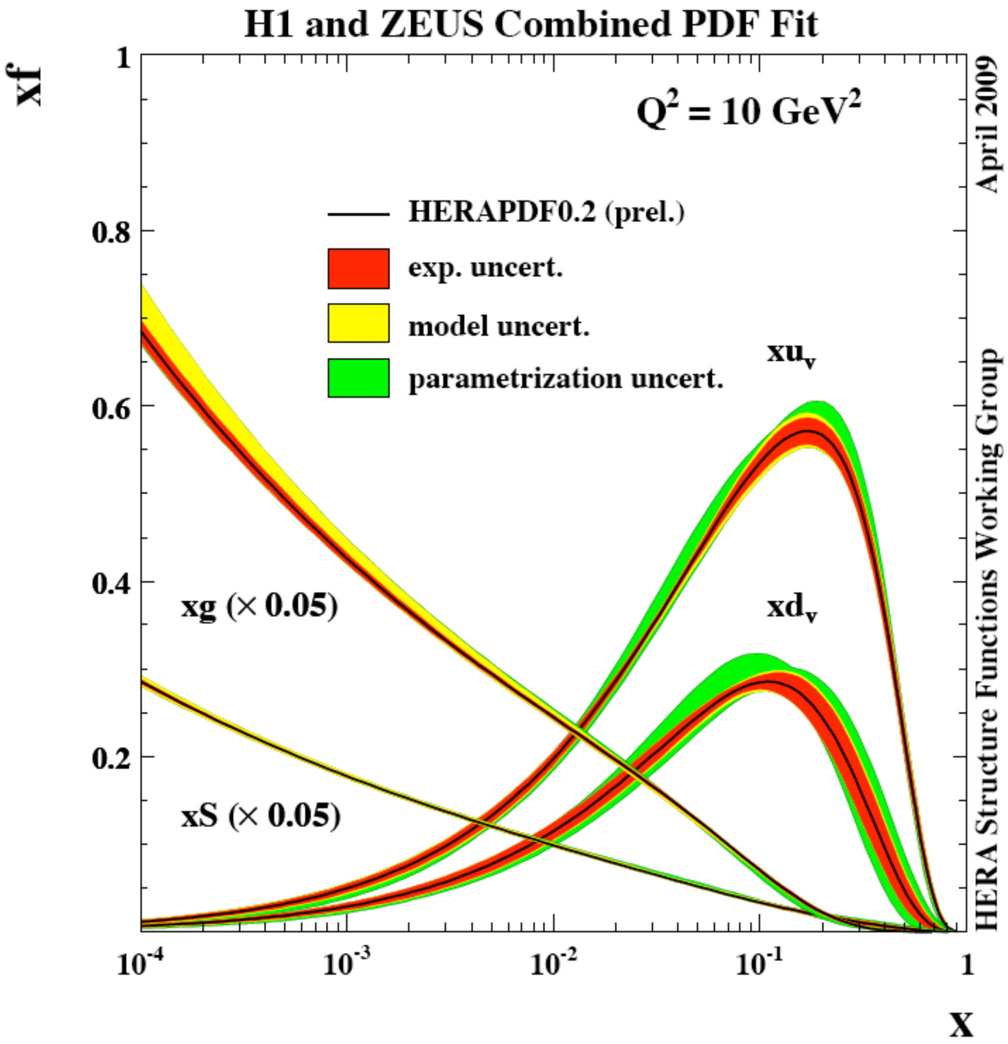
- Plots shown in more detail for 3 *x* bins:
  - Scaling violations

- Plots include experimental uncertainties on both data and fit



HERAPDF0.2

- Red: experimental uncertainties
- Yellow: model uncertainties
- Green: pdf parametrization uncertainties

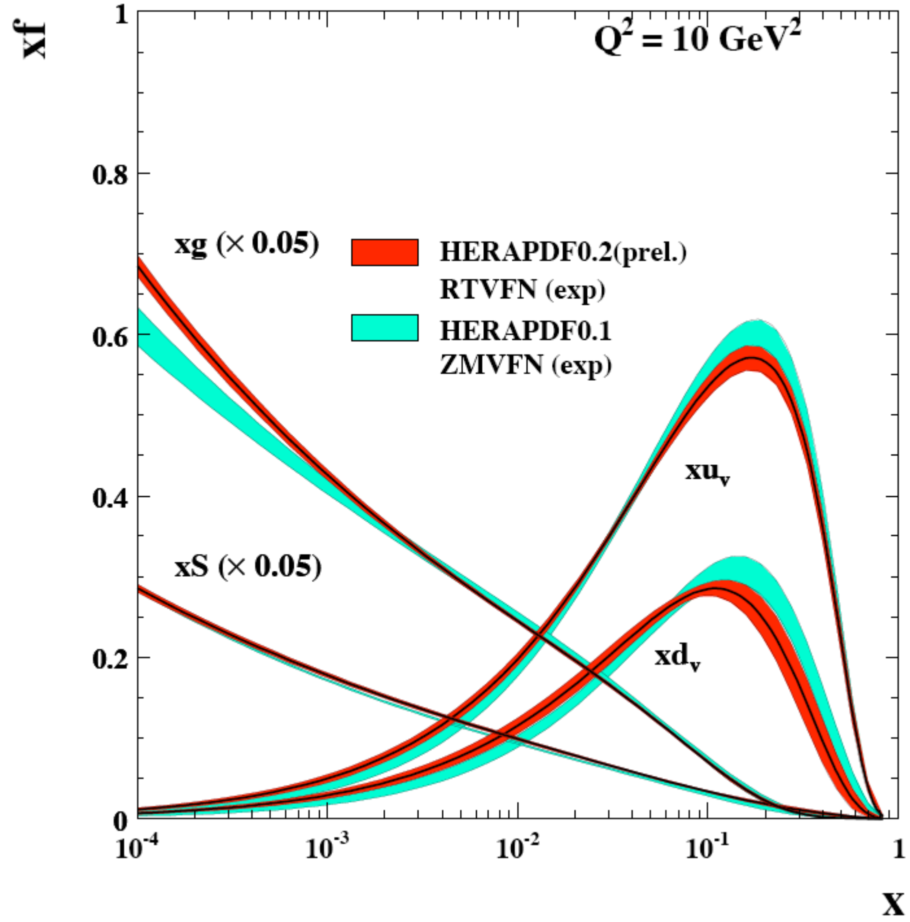


Observations:

- High-x and valence are mostly affected by the PDF parametrisation
  - The procedure to estimate PDF parametrisation uncertainty addresses the high-x region
  - Low-x region interesting to investigate

HERAPDF0.1 vs HERAPDF0.2

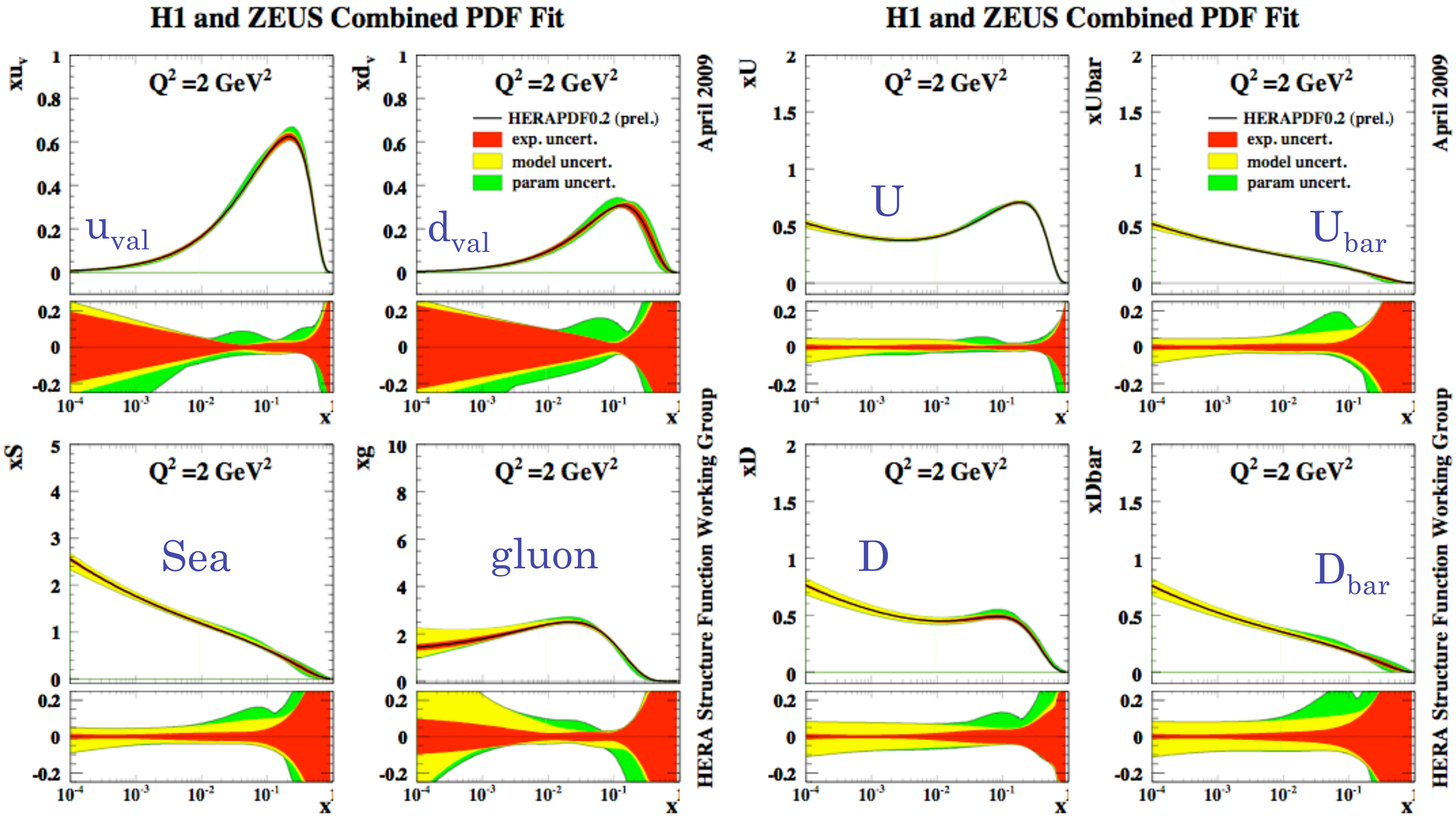
- For consistency, when comparing the HERA PDF sets only the experimental errors are used:
  - The model uncertainties of the two PDF sets are not identical
  - HERAPDF0.1 did not consider the uncertainty due to PDF parametrisation



- Observations:
  - Errors are smaller for HERAPDF0.2
  - d_{val} is softer
  - Gluon is steeper:
    - This is expected due to the heavy flavour treatment
      HERAPDF0.1 - massless quarks (ZM-VFNS)
      HERAPDF0.2 - massive quarks (TR-VFNS)

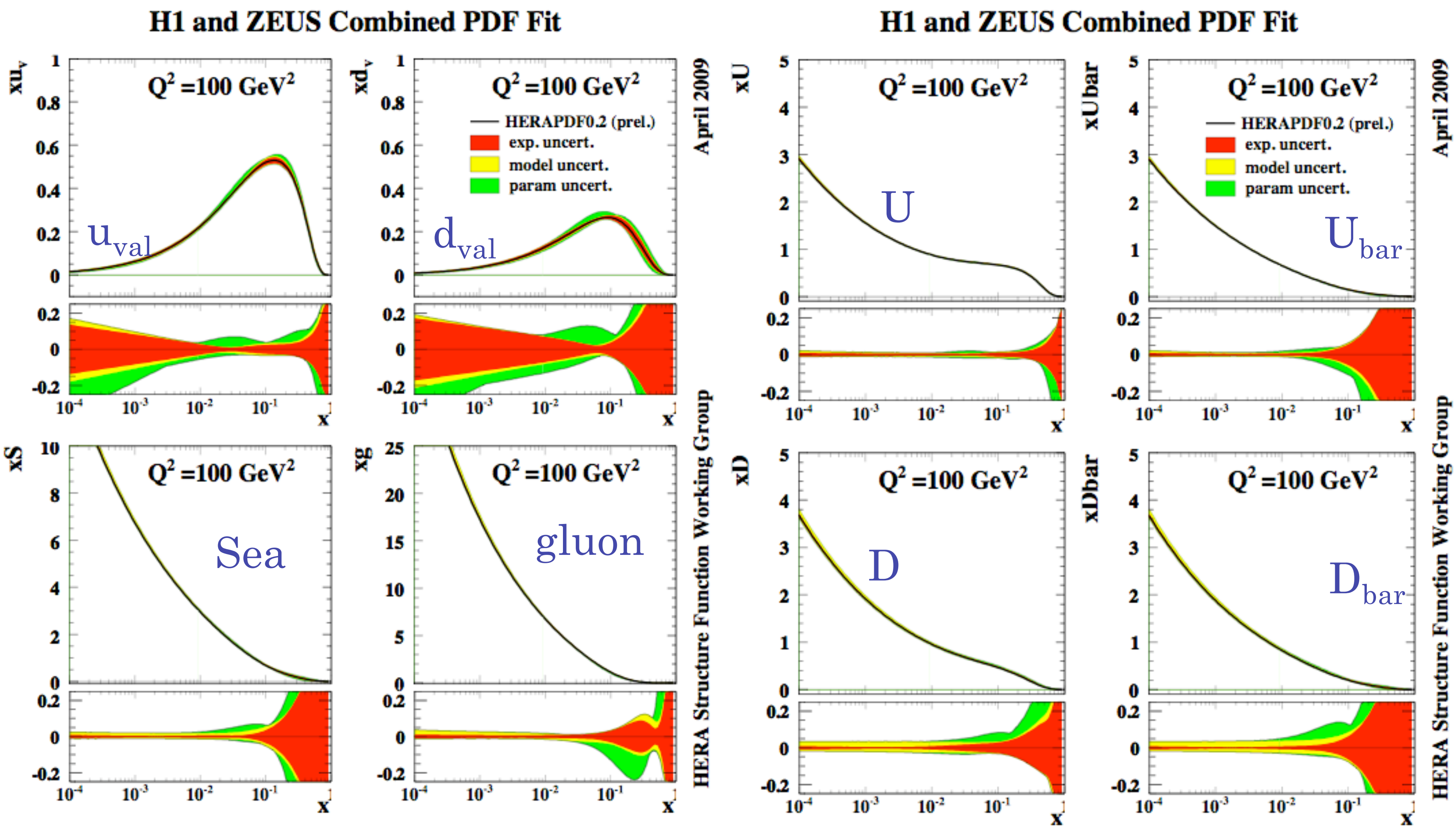
HERAPDF0.2 at Q^2=2 GeV^2

- At the starting scale gluon is valence like
- Q_0^2, Q^2_{min} dominate the model uncertainty of gluon and valence PDFs
- PDF parametrisation uncertainty dominates valence PDFs and high x region



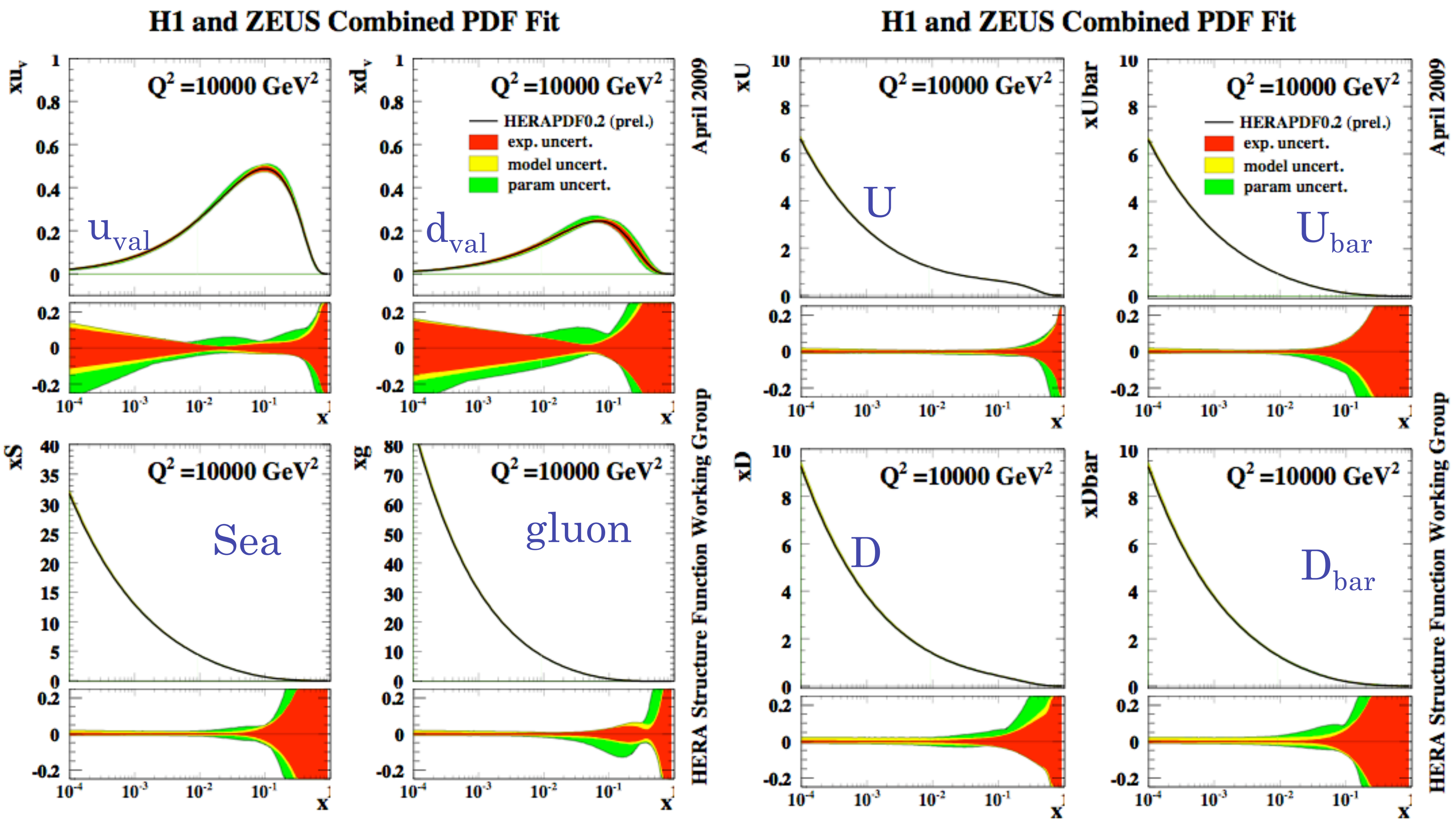
HERAPDF0.2 at Q^2=100 GeV^2

- Uncertainties are reduced for sea and gluon at higher scales
- PDF parametrisation uncertainty dominates valence PDFs and high x region

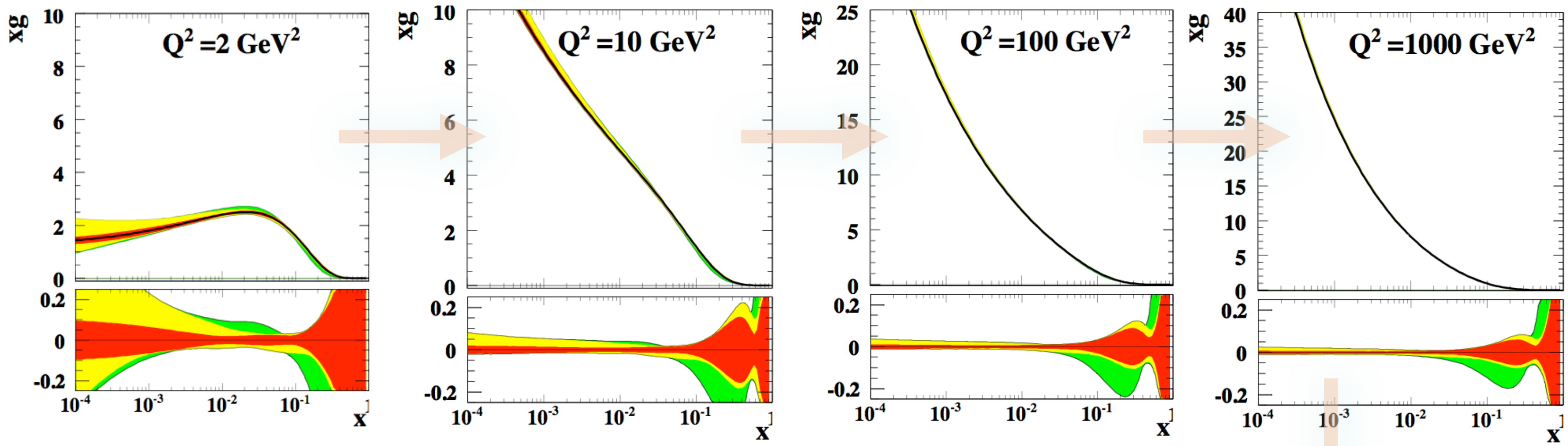


HERAPDF0.2 at Q^2=10000 GeV^2

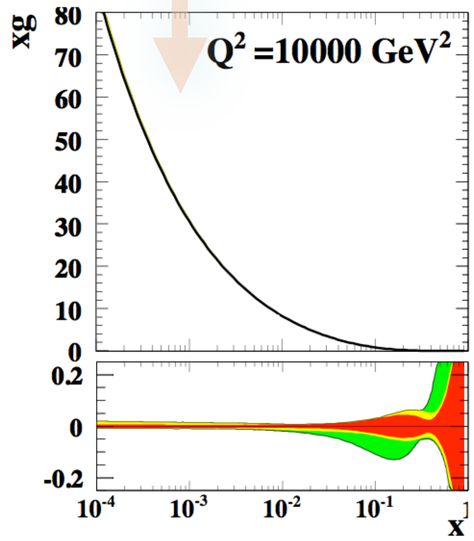
- PDF parametrisation uncertainty dominates valence PDFs and high x region
- Impressive precision at the scale relevant to LHC



Evolution of gluon with Q^2



- Near the starting scale gluon is valence like
  - The model uncertainties are large in low x region
    - Mostly due to Q_0^2 variations
  - The PDF param. uncertainty dominates high x

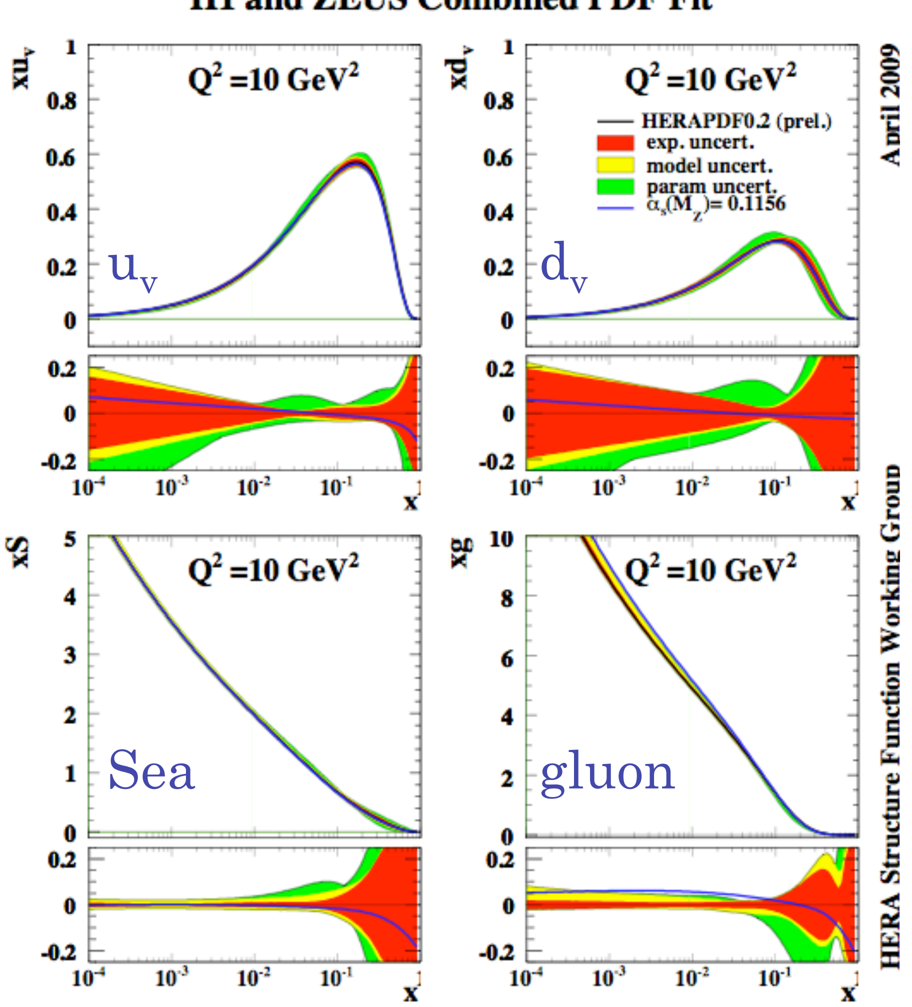


- Impressive precision at higher Q^2

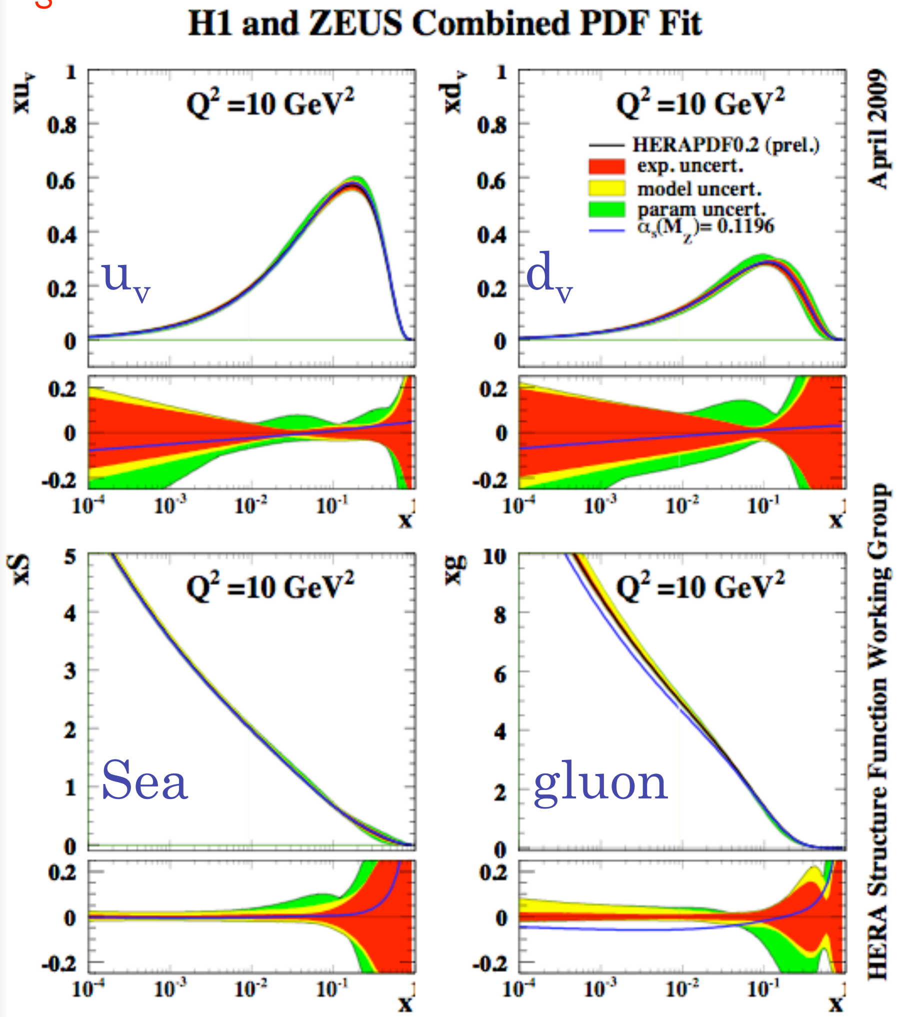
Variation of Strong Coupling

- Most pronounced in the gluon distribution (as expected)
    - Shown by the blue line

α_S=0.1156



α_S=0.1196



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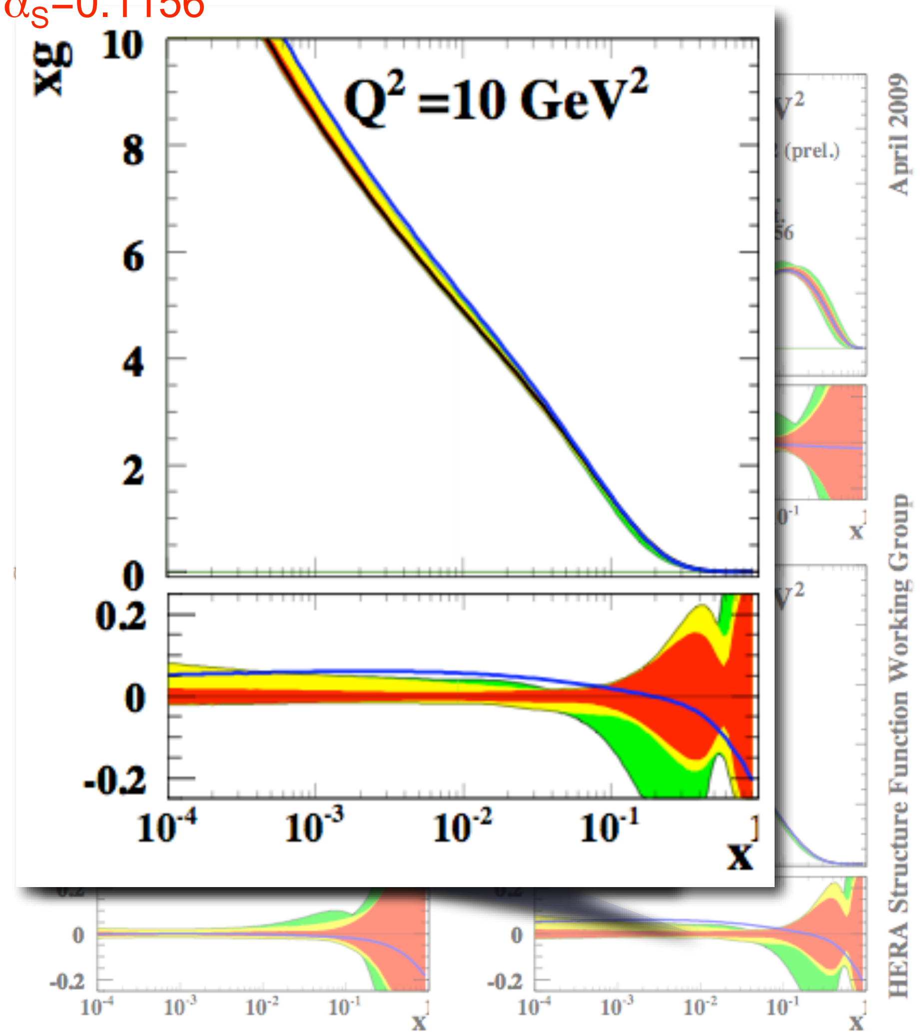

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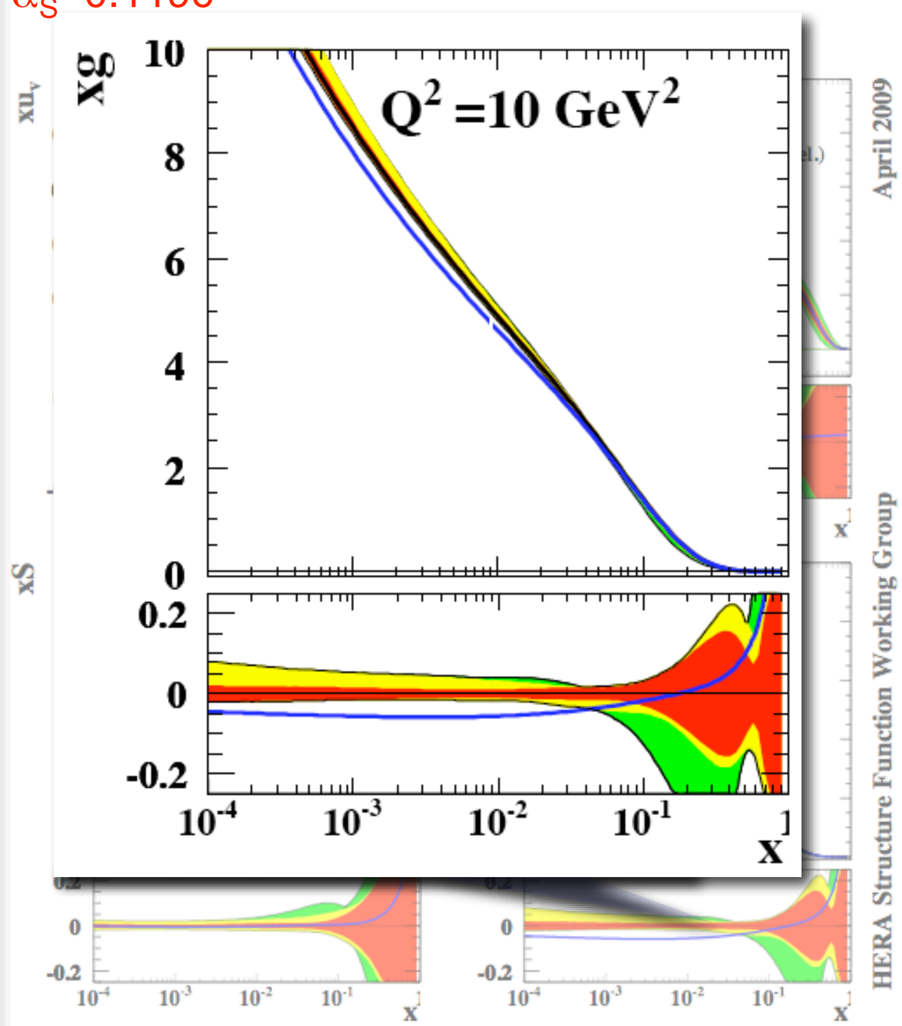
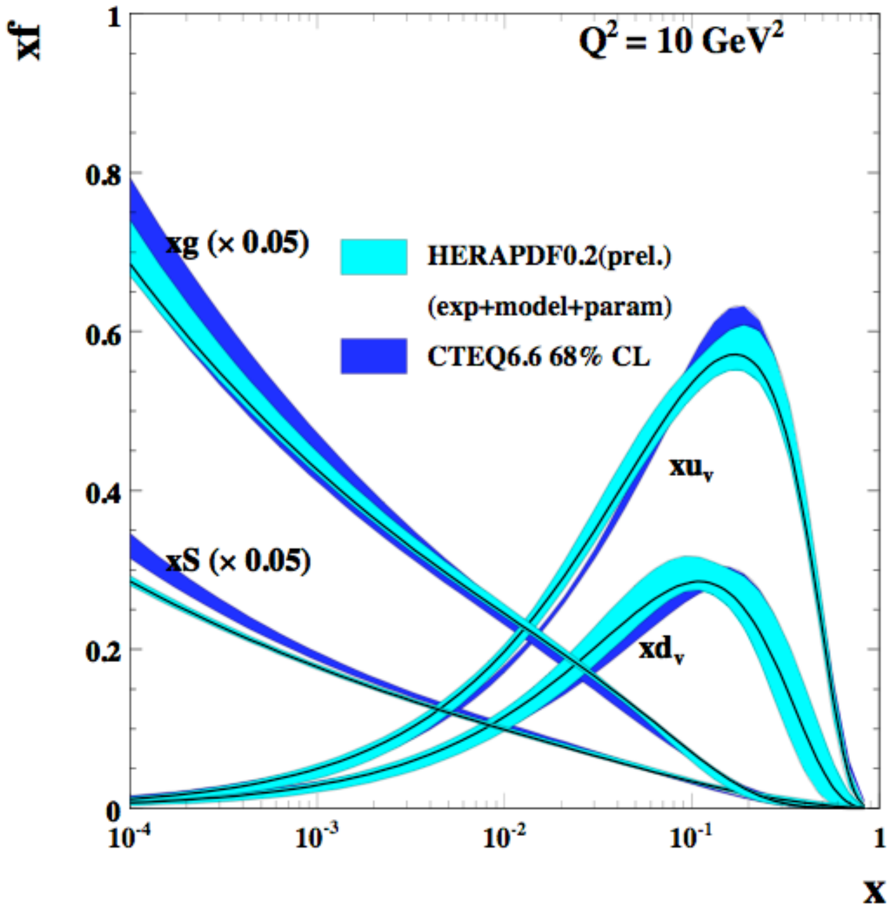


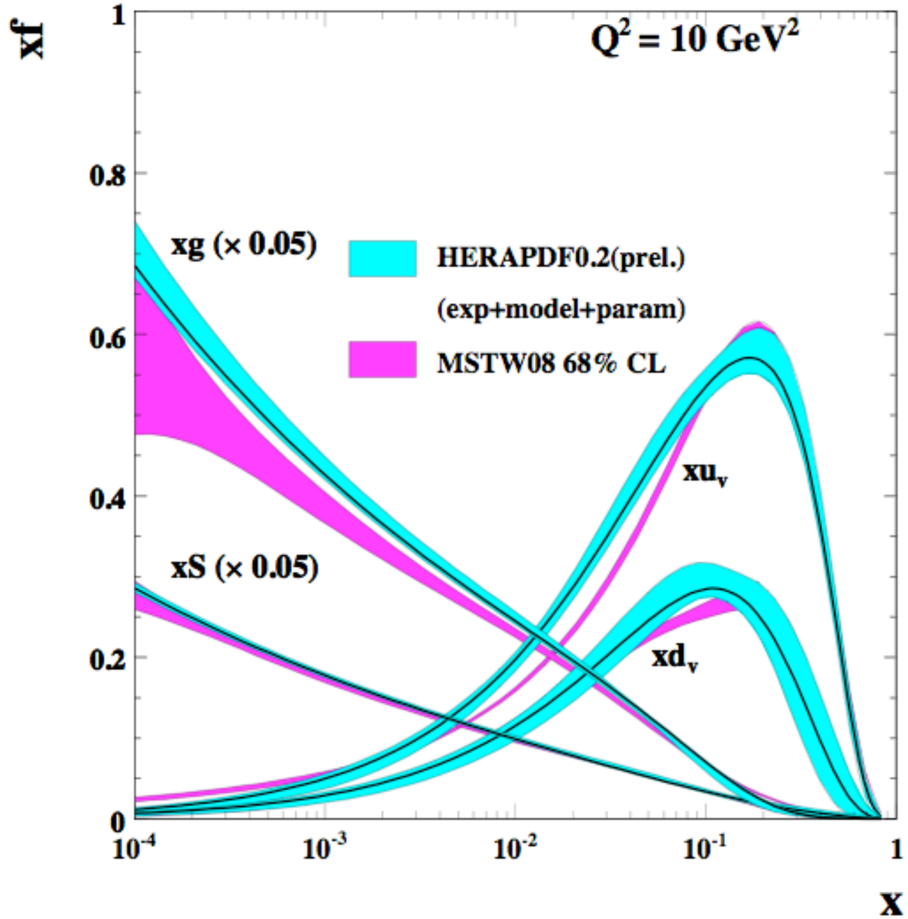
HERAPDF0.2 vs CTEQ/MSTW

- We compare HERAPDF0.2 to the global fits (at 68% CL)
  - The new combined HERA-I data provides a strong constraint on PDFs

CTEQ6.6



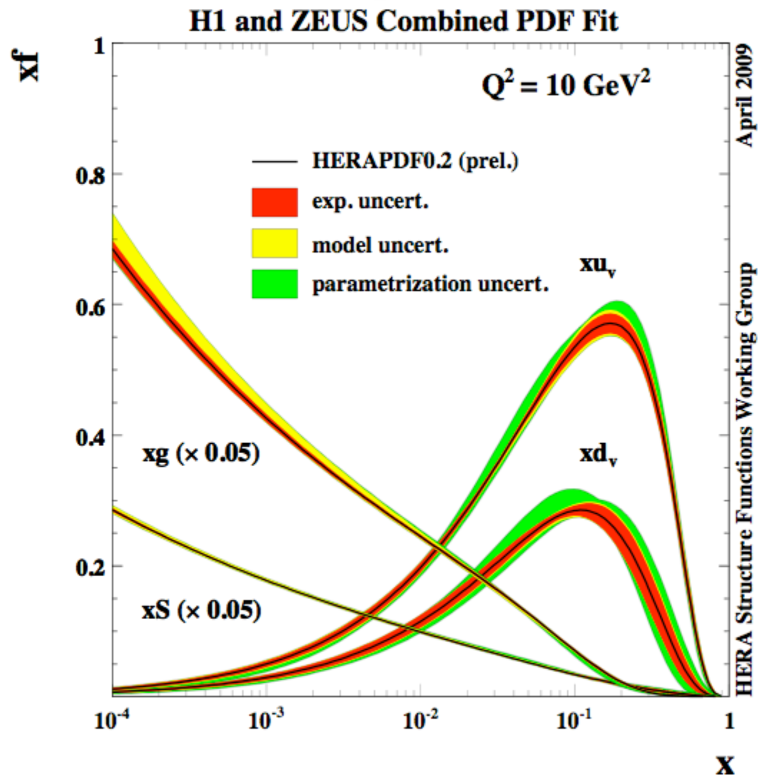
MSTW08

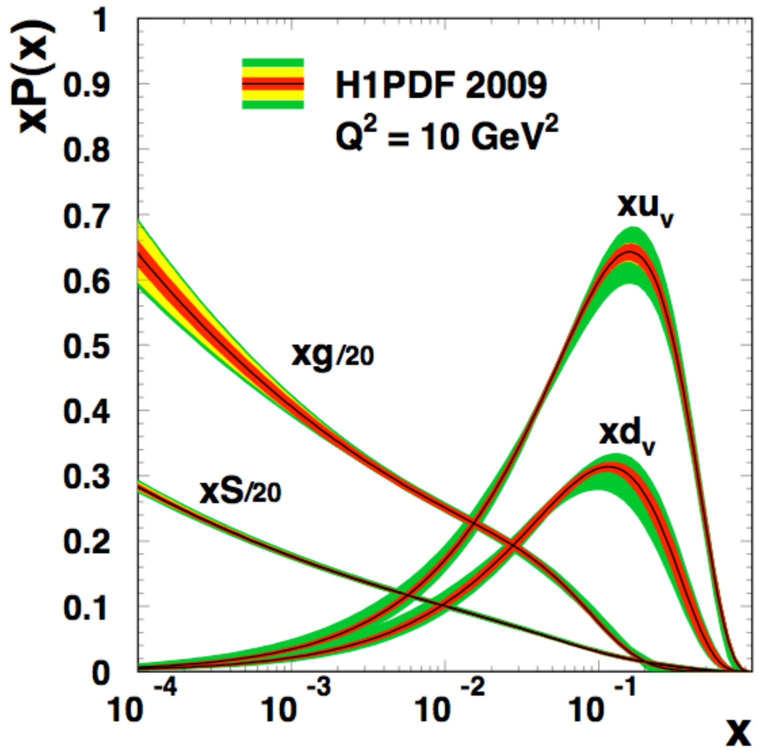


HERAPDF0.2 vs H12009 PDF

- We compare the HERAPDF0.2 produced from combined H1 and ZEUS data (HERA-I) with the H12009 PDFs produced using H1 data only (HERA-I)
  - Differences in the optimal choices for PDF parametrisation
    - H12009 PDFs uses additional parameter for gluon
    - HERAPDF0.2 uses additional parameter for u_{val}

    ➔J. Kretzschmar's talk
  - Model uncertainty due to Q_0^2 variation is symmetrised for H12009 PDFs
    - most visible in the gluon distribution





Summary

- New preliminary H1/ZEUS combined data is used to perform a new NLO QCD analysis resulting in HERAPDF0.2:
  - Improved theoretical treatment for heavy flavours (TR-VFNS)
  - Experimental errors are reduced compared to HERAPDF0.1
  - Model and PDF parametrisation uncertainties are considered
  - Impressive precision obtained at low x

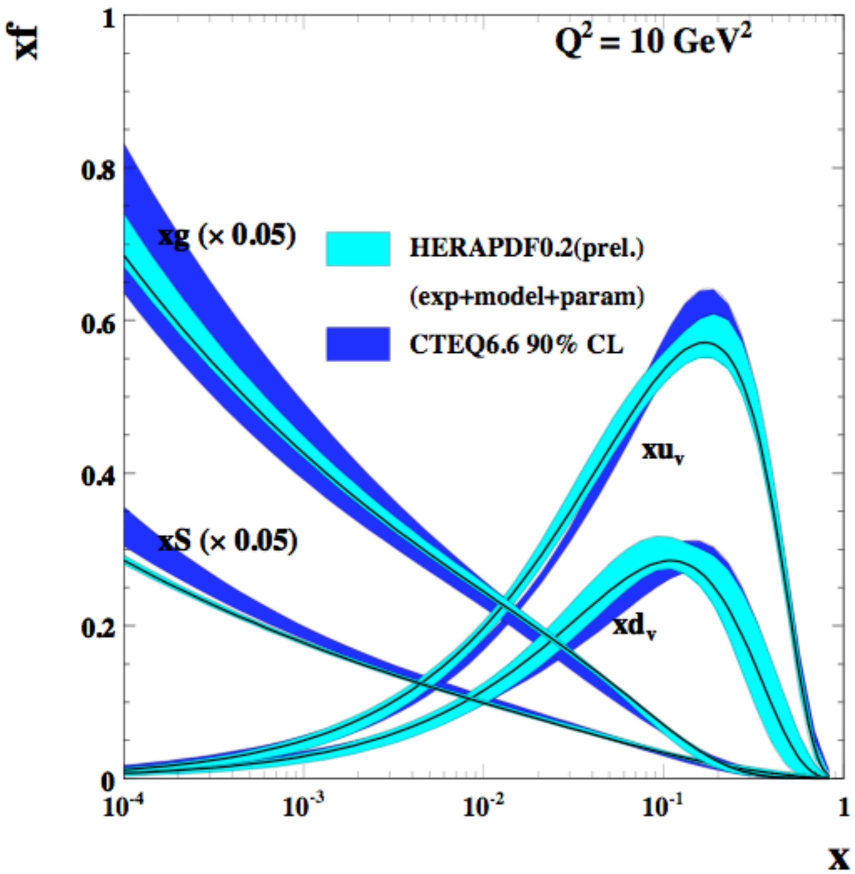
- HERA data is getting ready for precise predictions at the LHC

Backup

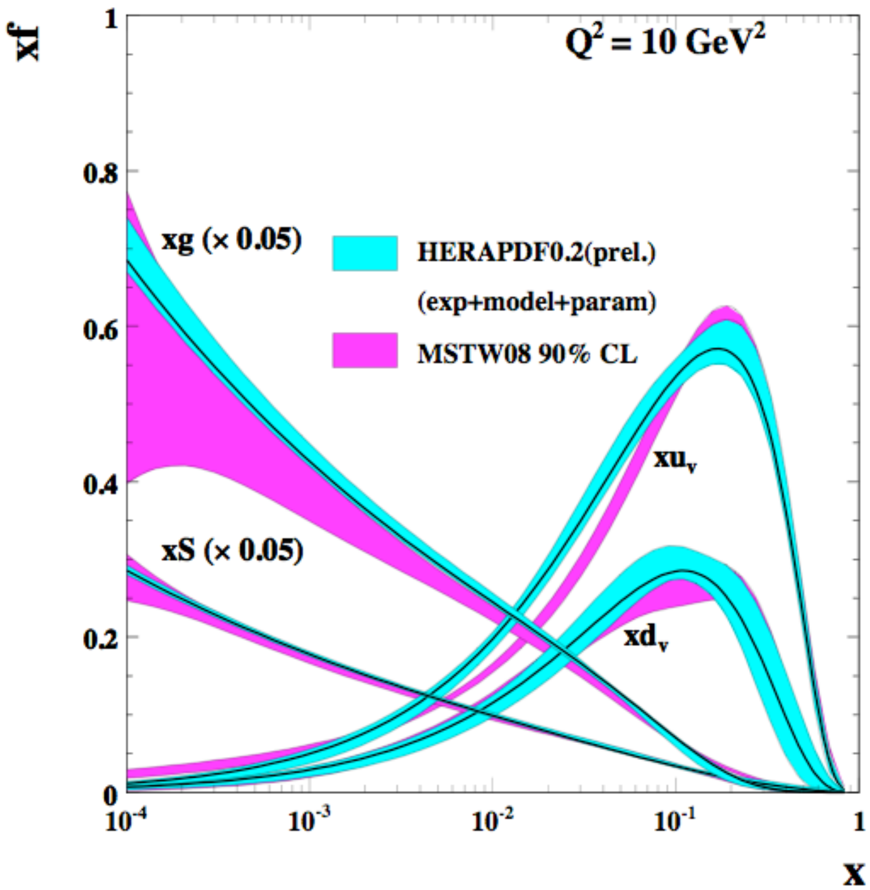
HERAPDF0.2 vs CTEQ/MSTW

- We compare HERAPDF0.2 to the global fits (at 90% CL)
  - The new combined HERA-I data provides a strong constraint on PDFs

CTEQ6.6



MSTW08



HERAPDF0.2 vs H12009 PDF

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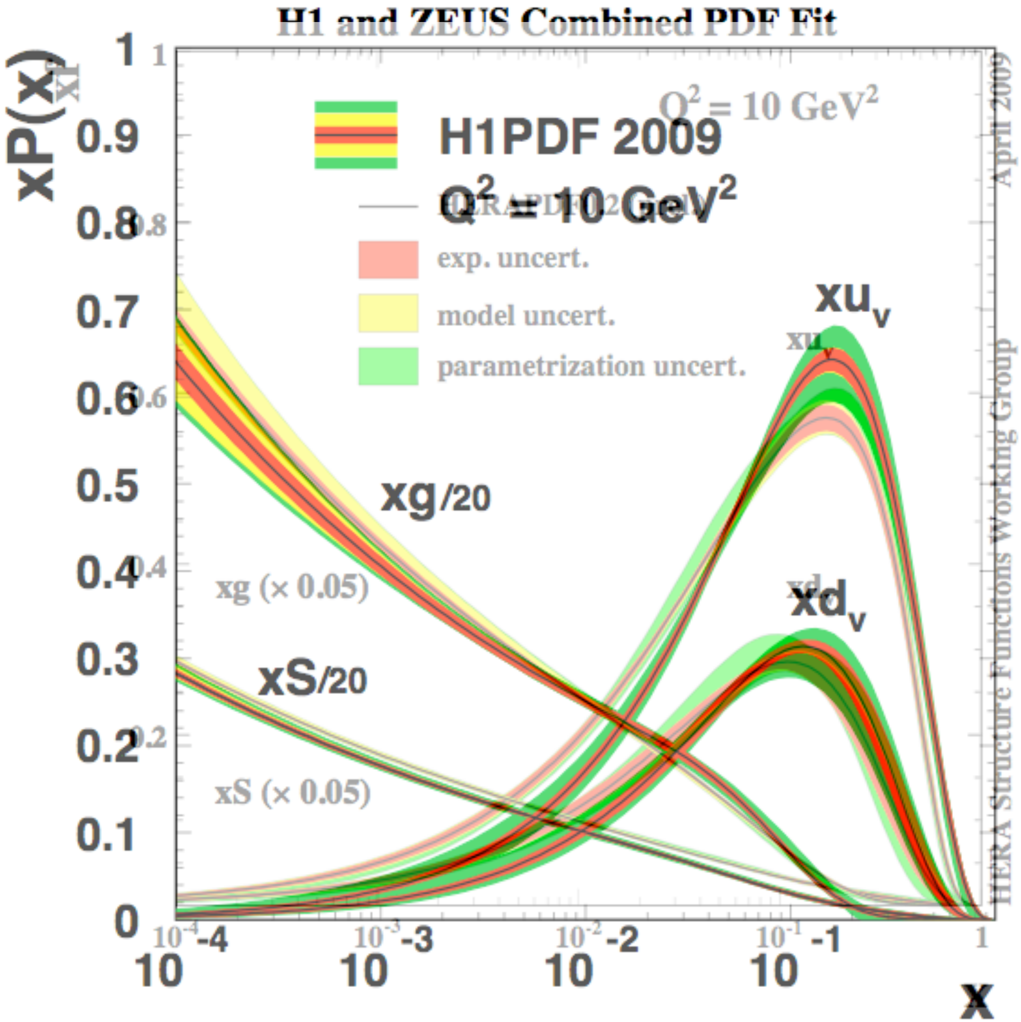

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