HERAPDF Fits including Low Energy Data

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Outline:

- Introduction
- Data Sets and QCD settings
- Results and Comparisons
- Summary

Introduction

- Preliminary HERA Combined Low Energy data available.
  [J.Grebenyuk's presentation]

- New accurate measurement in $Q^2>2.5$ GeV^2 range, sensitive to structure function F_L:
  - Study impact of these data on PDFs;
  - Test sensitivity on different heavy flavour treatments;
  - Compare fit results and measured structure function F_L.

Data Sets and QCD Fit settings

- Data Sets:
  - HERA I combined data (same as used for HERAPDF1.0 [JHEP01 (2010) 109])
    - NC e-, CC e-, CC e^+ (Q^2>100 GeV^2) [presented by S. Habib]
    - NC e^+ (Q^2>0.045 GeV^2)
  - Combined Low Energy Data Set of Ep=460, 575 GeV with Q^2>2.5 GeV^2 [presented by J. Grebenyuk]
- QCD Fit settings: same settings as for HERAPDF1.0
  - Fitted PDFs param at starting scale:

$$
\begin{aligned}
xg(x) &= A_g x^{B_g}(1-x)^{C_g}, \\
xu_v(x) &= A_{u_v} x^{B_{u_v}}(1-x)^{C_{u_v}}\left(1+E_{u_v}x^2\right), \\
xd_v(x) &= A_{d_v} x^{B_{d_v}}(1-x)^{C_{d_v}}, \\
x\bar{U}(x) &= A_{\bar{U}} x^{B_{\bar{U}}}(1-x)^{C_{\bar{U}}}, \\
x\bar{D}(x) &= A_{\bar{D}} x^{B_{\bar{D}}}(1-x)^{C_{\bar{D}}}.
\end{aligned}
$$

  - Other settings:

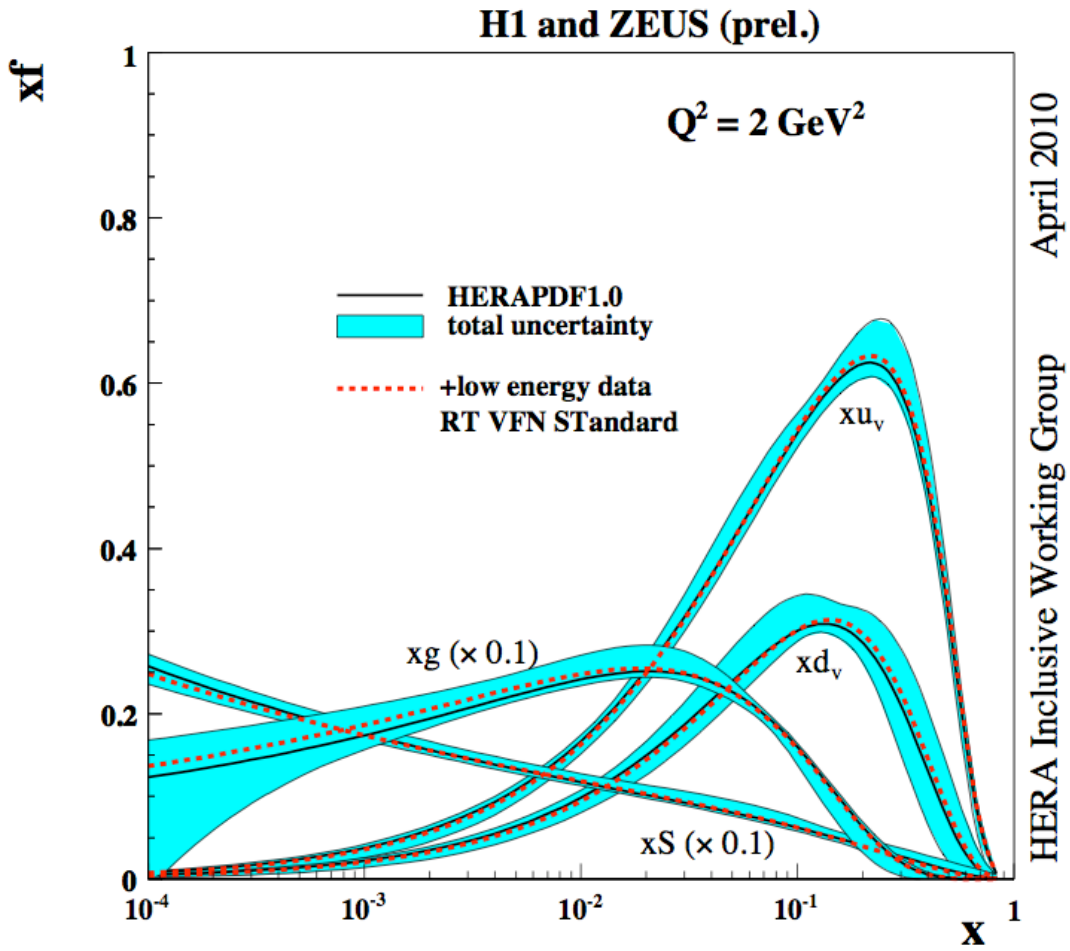
f_s	0.31
m_c [GeV]	1.4
m_b [GeV]	4.75
Q^2_{min} [GeV^2]	3.5
Q^2_0 [GeV^2]	1.9

  - NLO DGLAP evolution equations, RT-VFNS

New Fit vs HERAPDF1.0

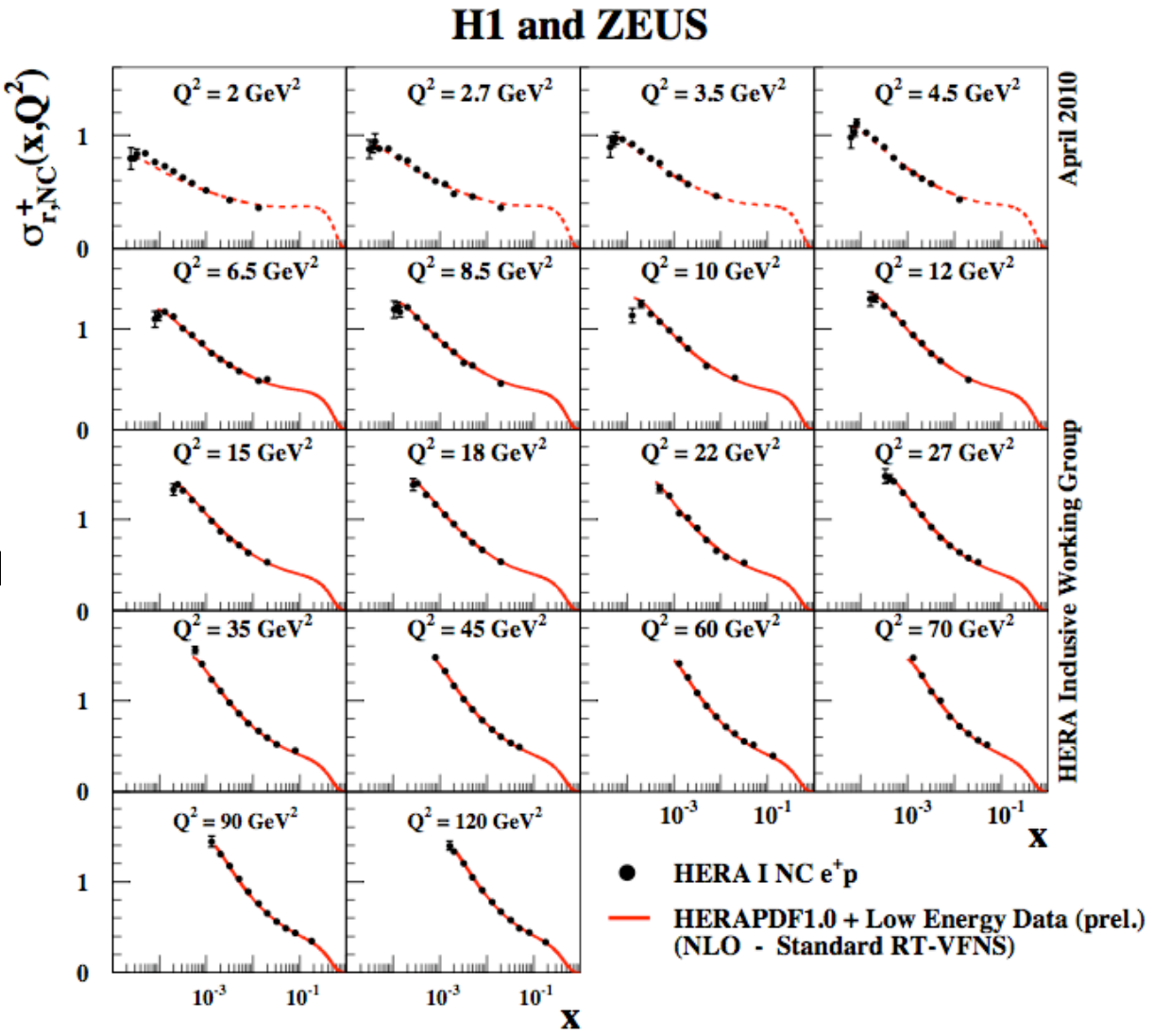
- PDFs from the new fit agree very well with HERAPDF1.0
- But, inclusion of the new data fits slightly worse:

	HERAPDF1.0	+LER
Total χ^2/dof	574/582	818/806



Comparison with Data

- Line is produced using standard HERAPDF1.0 settings fit to HERA I + LER data ($Q^2 \geq 3.5$ cut):
  - Turn over is observed for 920 GeV NC e^+p data at low x and Q^2 (high y $\rightarrow$ F_L sensitivity) which is not reproduced by the fit.
- Checks:
  - Parametrisation
  - Kinematic Dependence
  - Theory Models



Parametrisation and Model checks

Perform variation of parameterization, and model assumptions as for HERAPDF1.0:

[S. Habib's presentation]

- Parametrisation variations:
  - The 10 parameter fit for HERA-I fit still produces the best central fit parametrisation, other variations, including negative gluon terms bring no significant changes in χ^2.

- Model checks:
  - Variation of mc, mb bring little change in χ^2 or parameters.
  - Raising Q^2 cut has a significant change on χ^2 and PDF parameters.

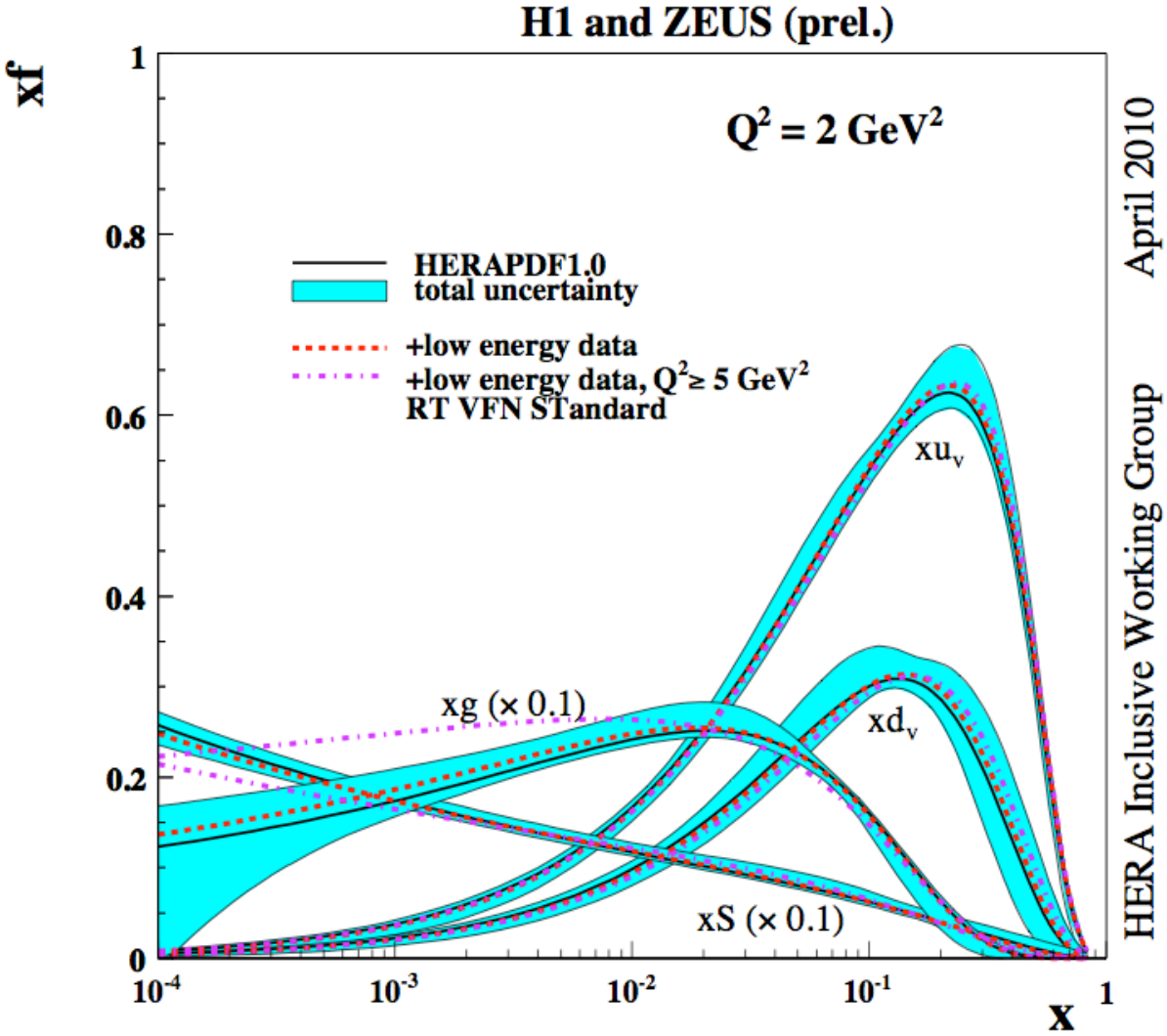
Kinematic Cut Dependence

- The Q^2 >5 GeV^2 cut brings large improvement in χ^2
  - 818/806 → 698/771

  however it returns different PDFs shape.
  - for the HERAPDF1.0, Q^2 cut variation is included in the model uncertainty, but it had smaller effect (in the same direction).

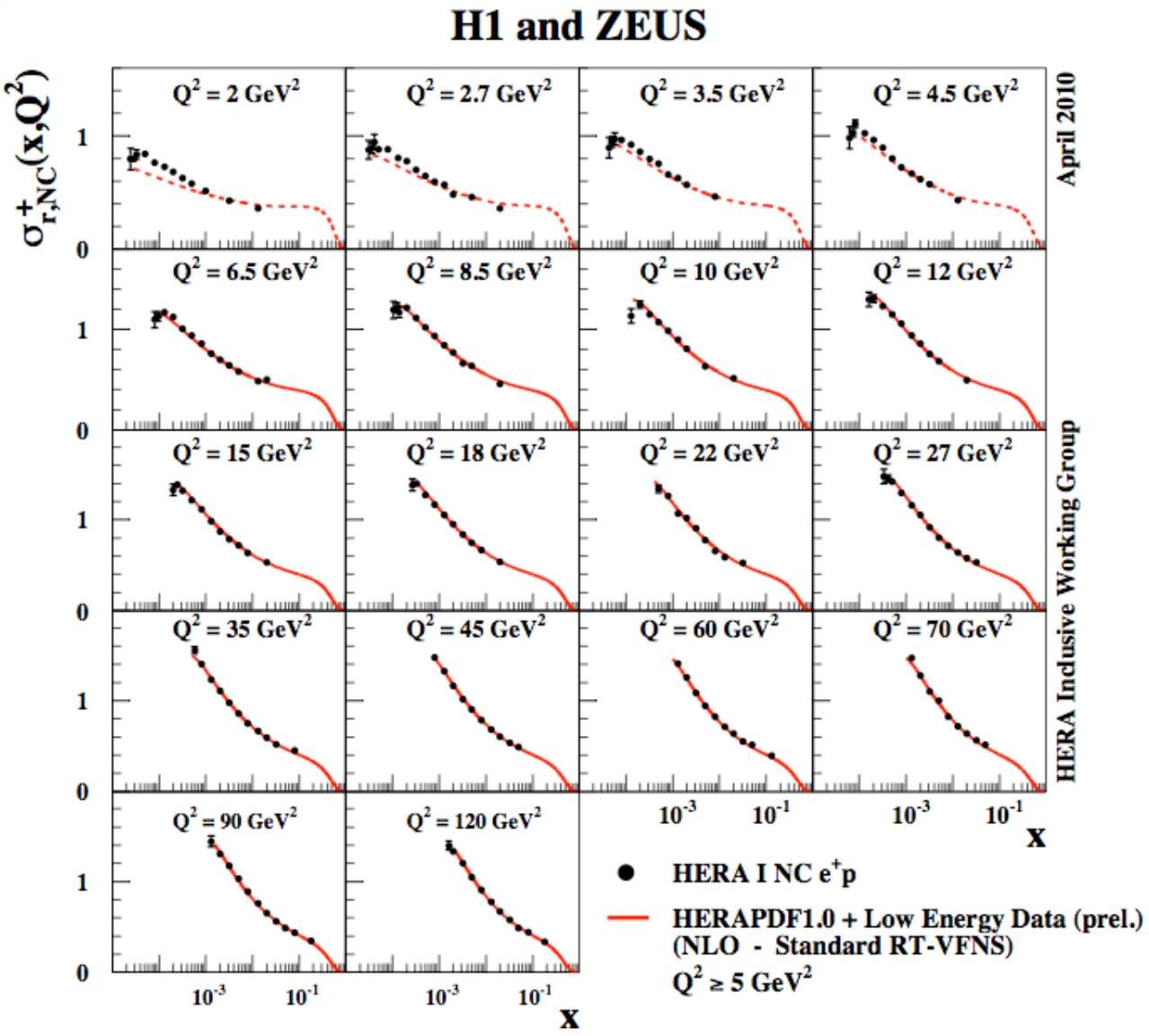
- Compare Red I (before cut) with Magenta (after cut):
  - Gluon is visibly enhanced for $Q^2 \geq 5$ GeV^2 cut

- How does it fit data?



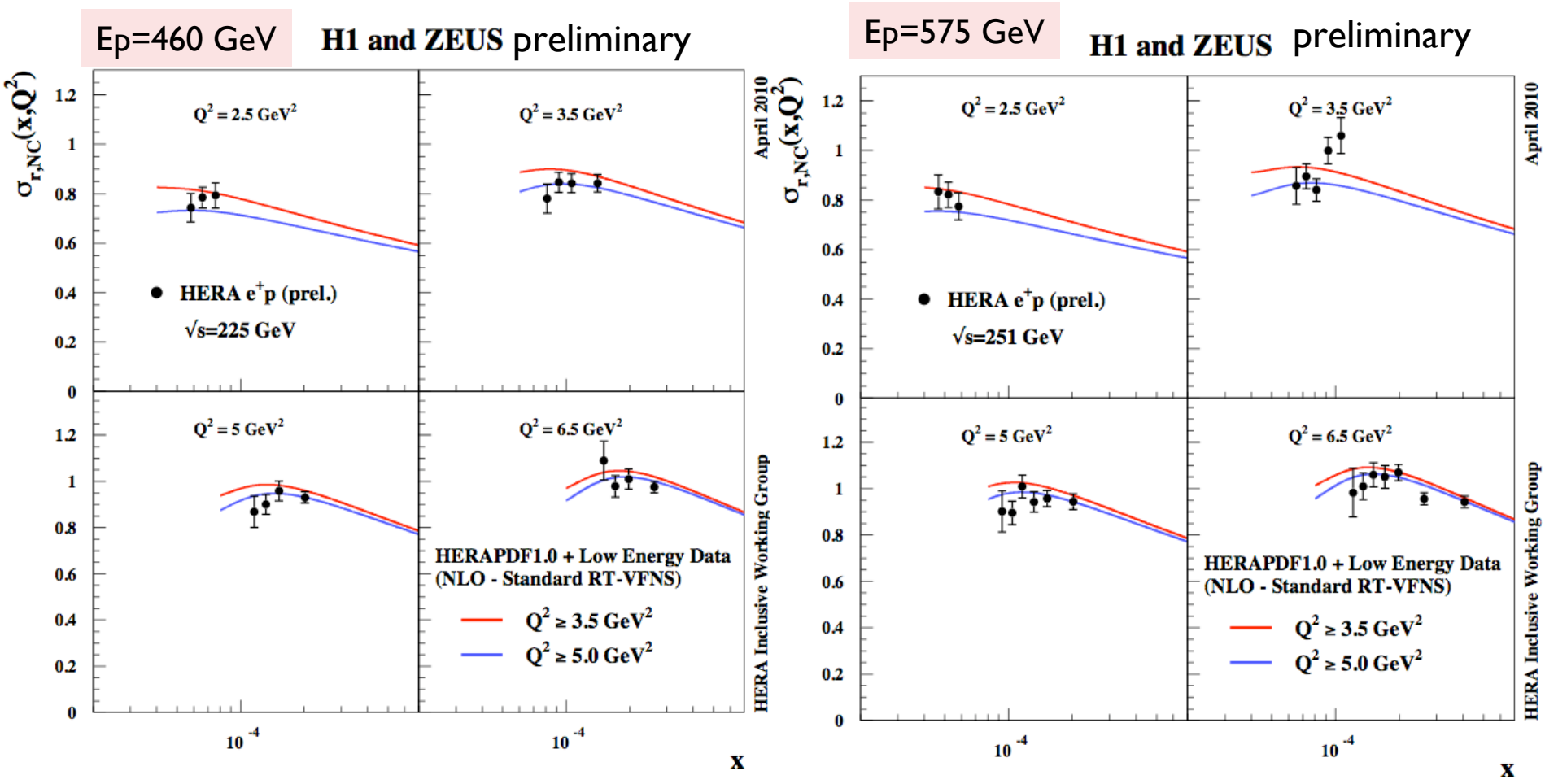
Comparison with Data, Fit with Q^2 cut

- Line is fit using standard HERAPDF1.0 settings to HERA I + Low Energy Data Runs (with $Q^2 \geq 5$ GeV^2):
  - Bad description in the region where data does not enter fit, apart from lowest x points at low Q^2 which correspond to high y → large influence of FL



Comparison with Low Energy data

- Note: $Q^2>5$ GeV^2 cut does not include first 2 bins in the fit.
  - The Q^2 cut case (blue) fits better 460 GeV data which are all located at y>0.35.



Various HF treatments

- Low Q^2 region is sensitive to the treatment of the charm quark production.

- Compare various schemes taking into account heavy quark production:
  - VFNS RT (standard [MSTW08] and optimal [R. Thorne's presentation])
  - VFNS ACOT (full [Phys.Rev.D50,1994] and χ [Phys.Rev.D62,2000])

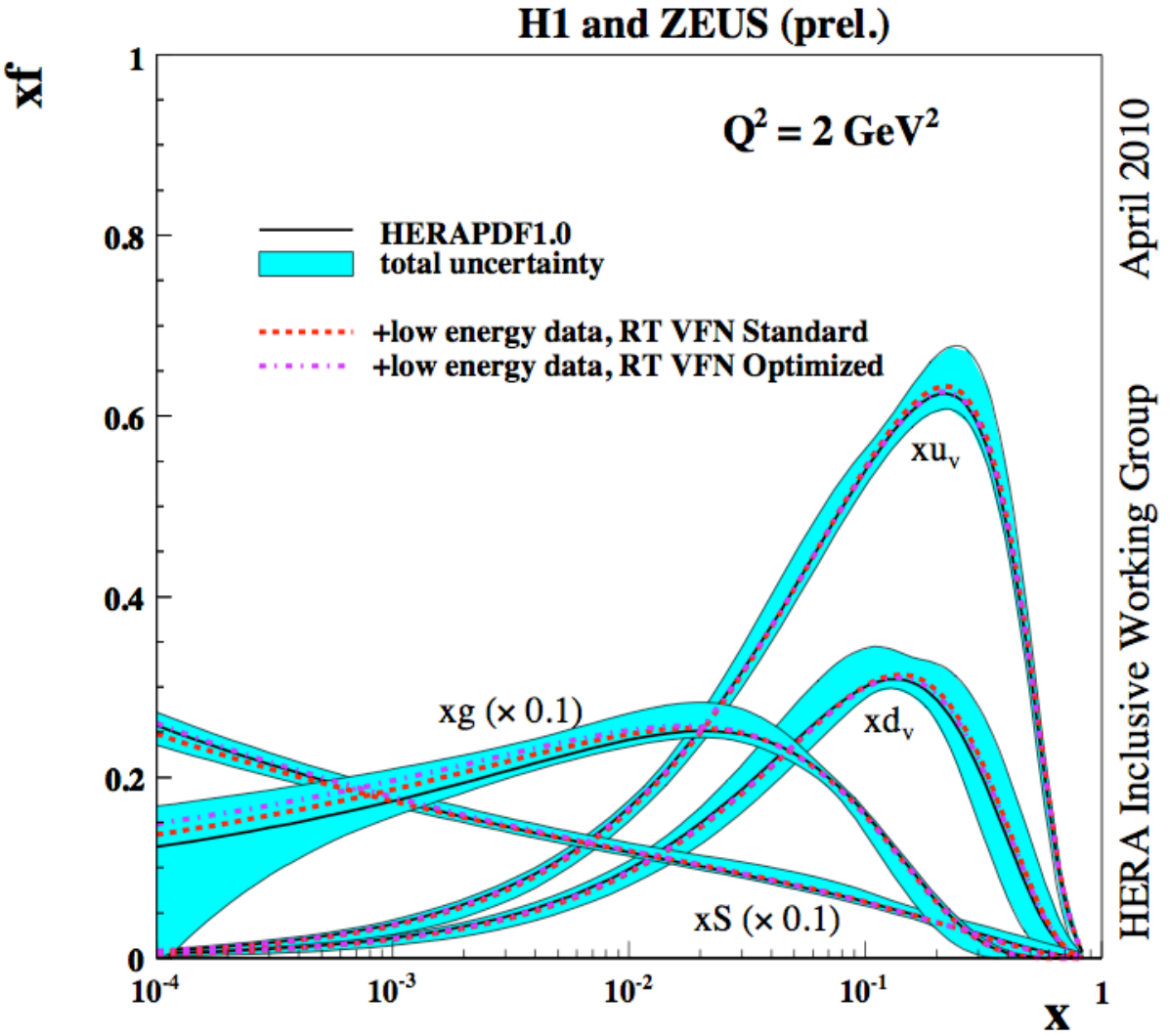
  - FFNS (from QCDNUM17v06 [M. Botje])

- We observe significant differences among these schemes → next slides.

RT schemes compared to HERAPDF1.0

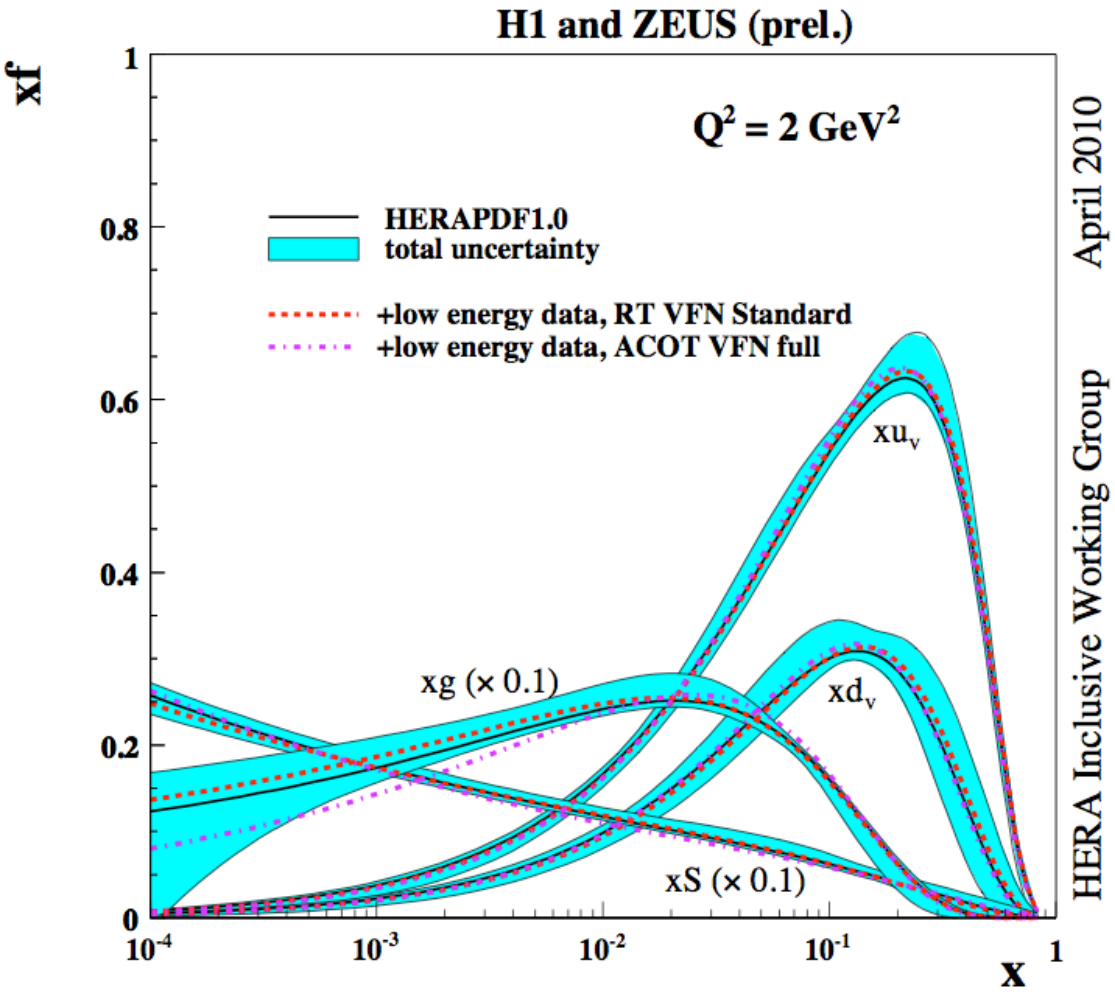
- Little improvement is observed in χ^2 (7 units) and in PDF shapes from the Standard to Optimal RT VFN scheme.

- The variations are within HERAPDF1.0 errors.



ACOT (Full) scheme compared to HERAPDF1.0

- Compare fits to HERA I data including Low Energy Data using the ACOT (full) scheme to the RT standard scheme (VFNS):
  - 30 Units improvement in χ^2
  - Large differences in the gluon at the starting scale
    - Differences are reduced with higher Q^2



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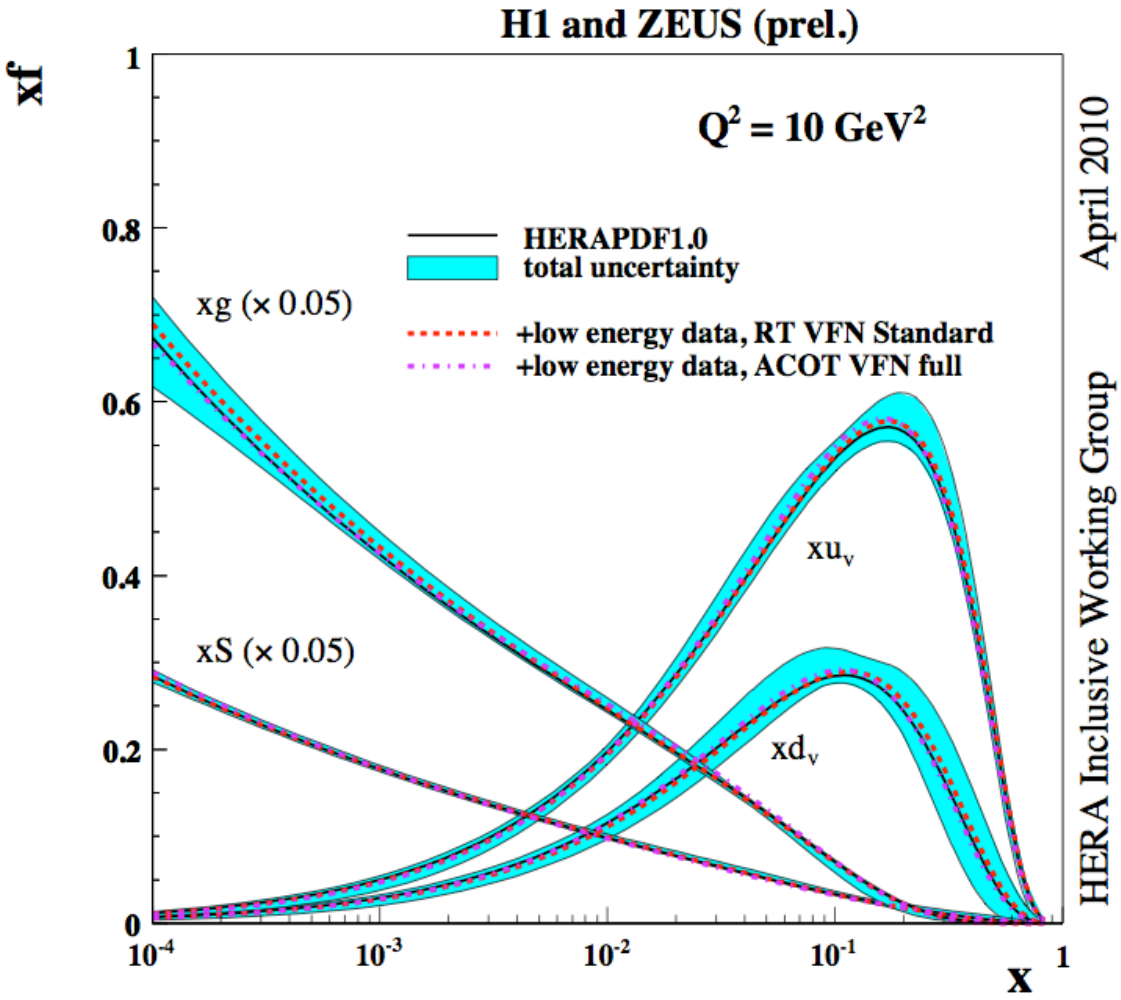
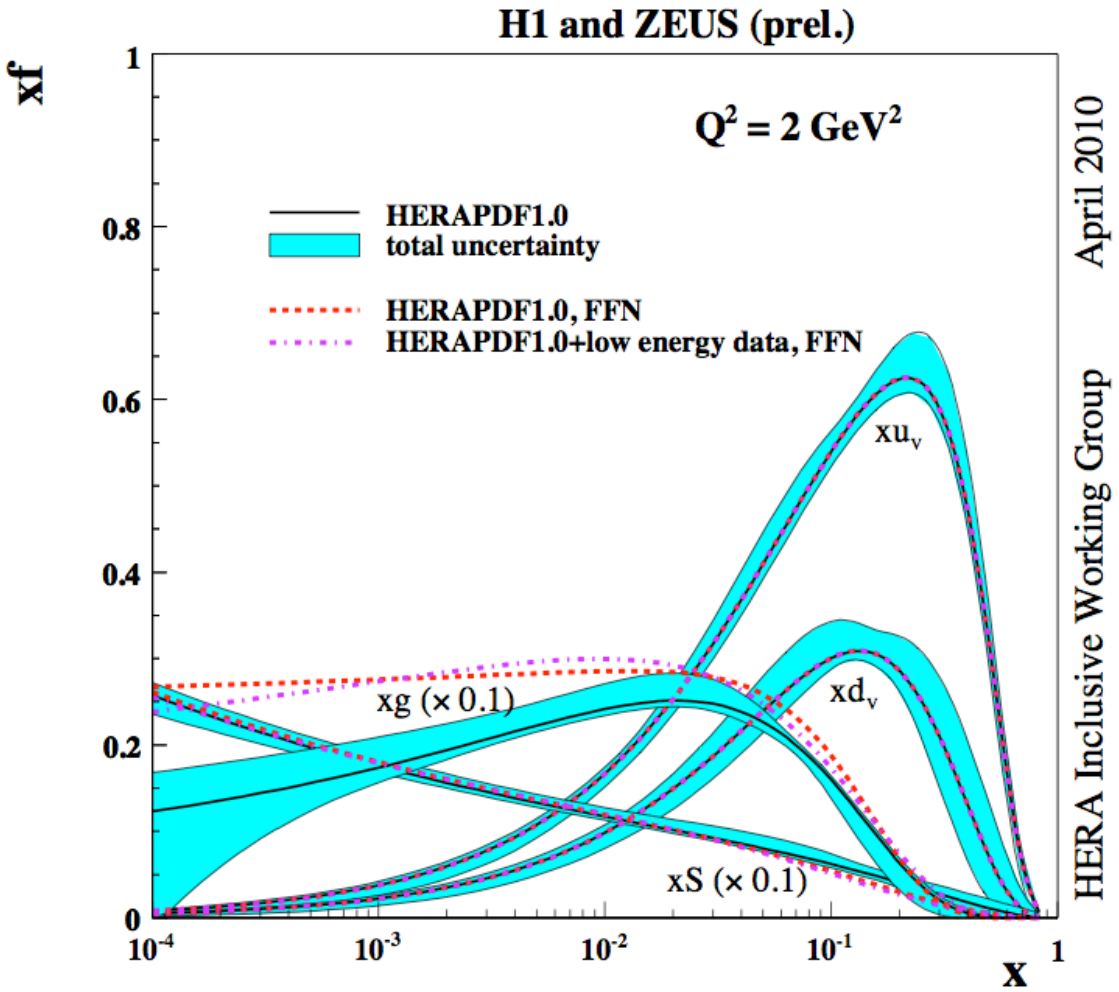


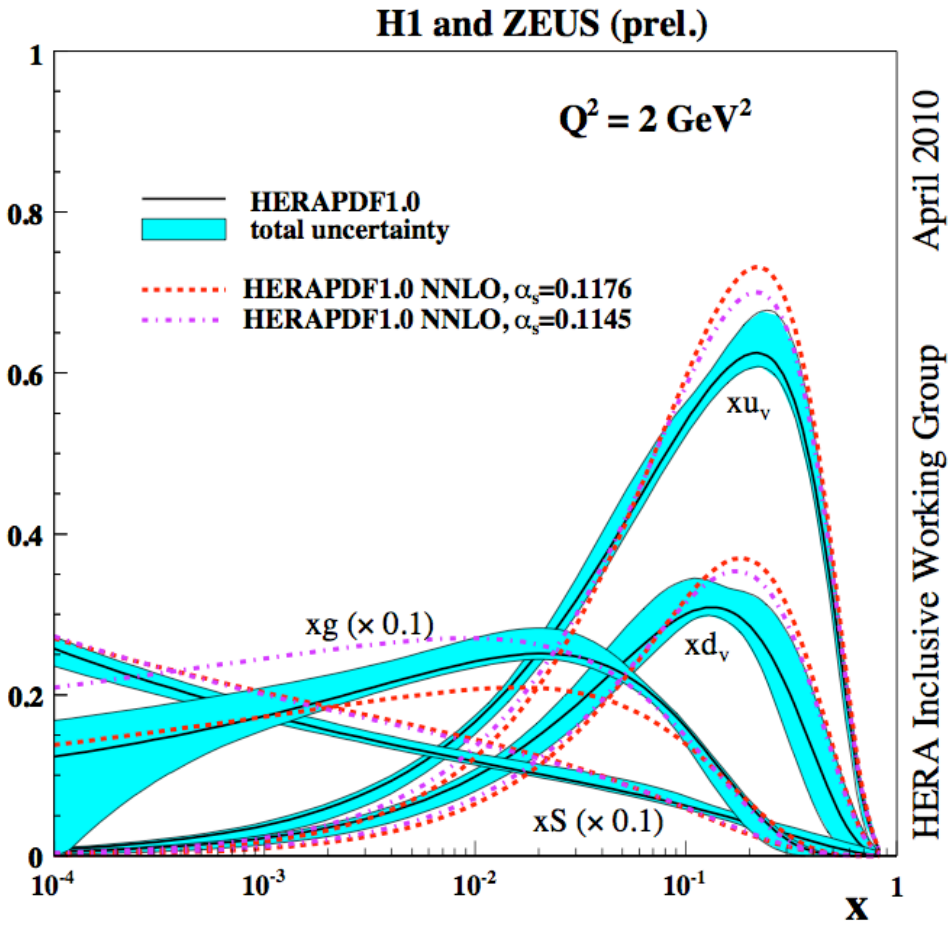
FFNS fits to Low Energy Data

- FFNS (nf=3) results in a similar improvement in χ^2 compared to RT (VFNS) as observed for ACOT (VFNS) scheme.
  - However, xF_3 and CC predictions are not available within FFNS scheme, hence we freeze the valence parameters and do not fit for CC data
- No much difference is observed between FFNS scheme fits with or without low energy data
- HERAPDF1.0 (VFNS) is shown as an illustration → not be compared (different objects)



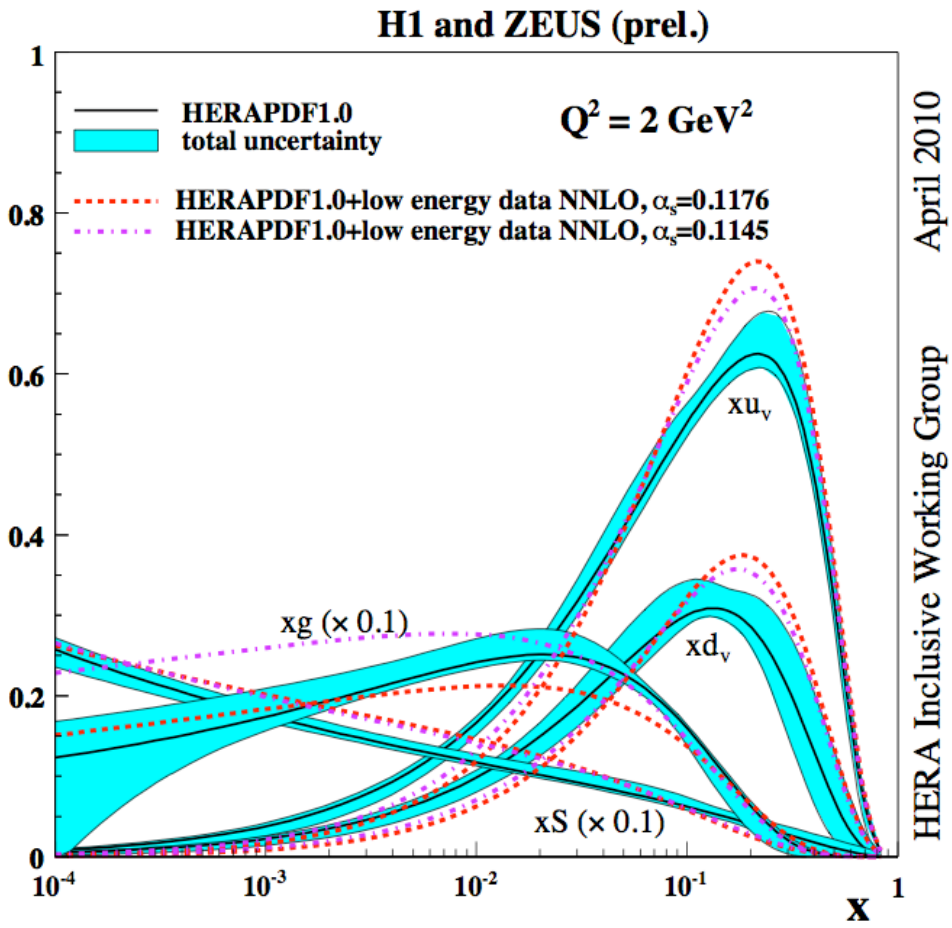
HERAPDF fits at NNLO

- Performed first fits of HERAPDF1.0 at NNLO (RT-VFNS):
  - Value of α_S(Mz) might need to be adjusted for NNLO fits:
    - Fitting α_S at NLO:
      - α_S(Mz) =0.1166±0.0044(exp) [close to world average 0.117
      - χ2/dof=574/582
    - Fitting α_S at NNLO:
      - α_S(Mz) =0.1145±0.0042(exp)
      - χ2/dof=623/582
- Using the same settings as for HERAPDF1.0 NNLO fit does not improve fit results.



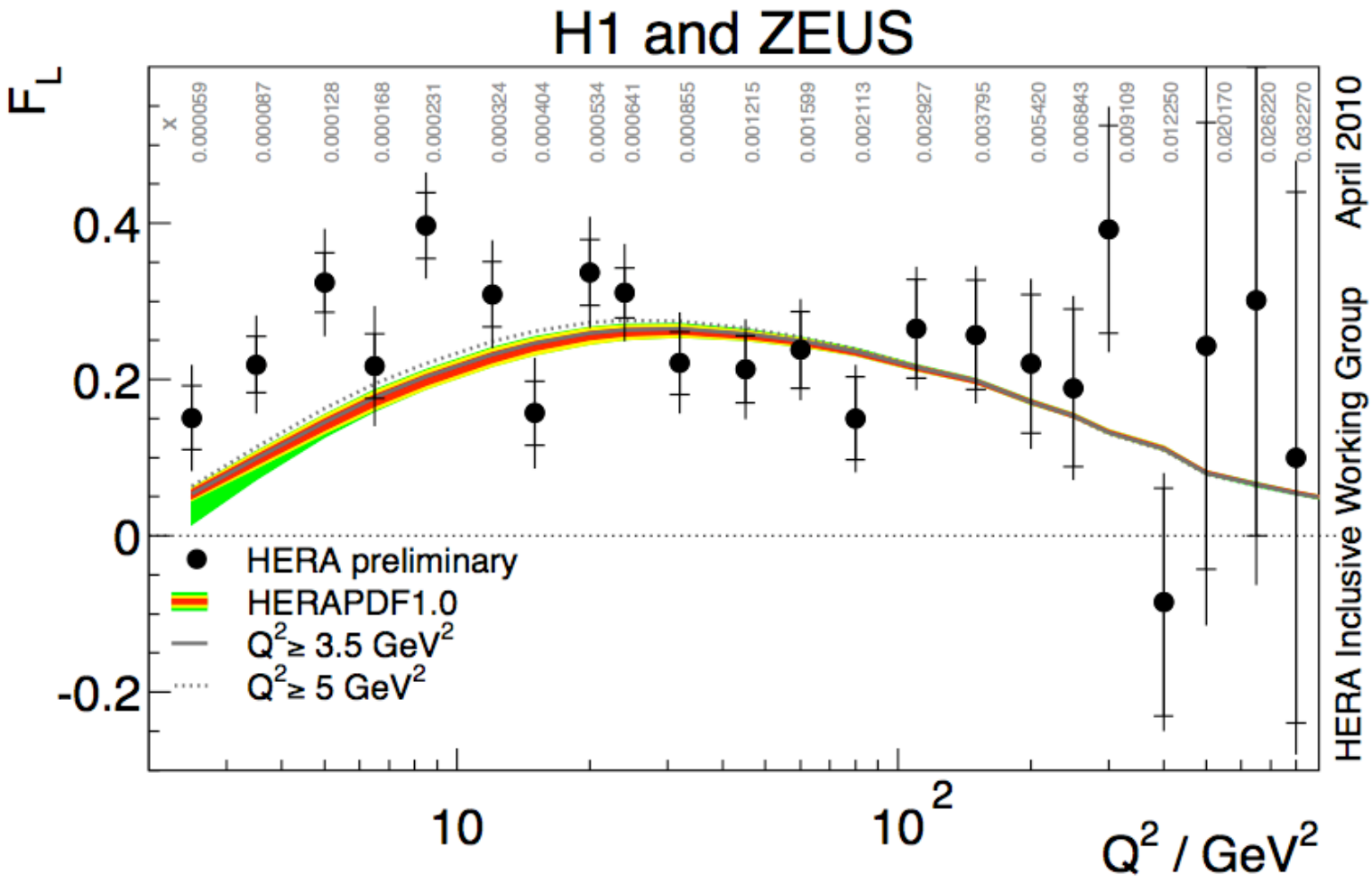
NNLO fits including Low Energy Data

- No significant change in PDFs is observed when including Low Energy Data.
- No improvement in fit quality is observed when Low Energy Data is included (χ^2 gets worse)



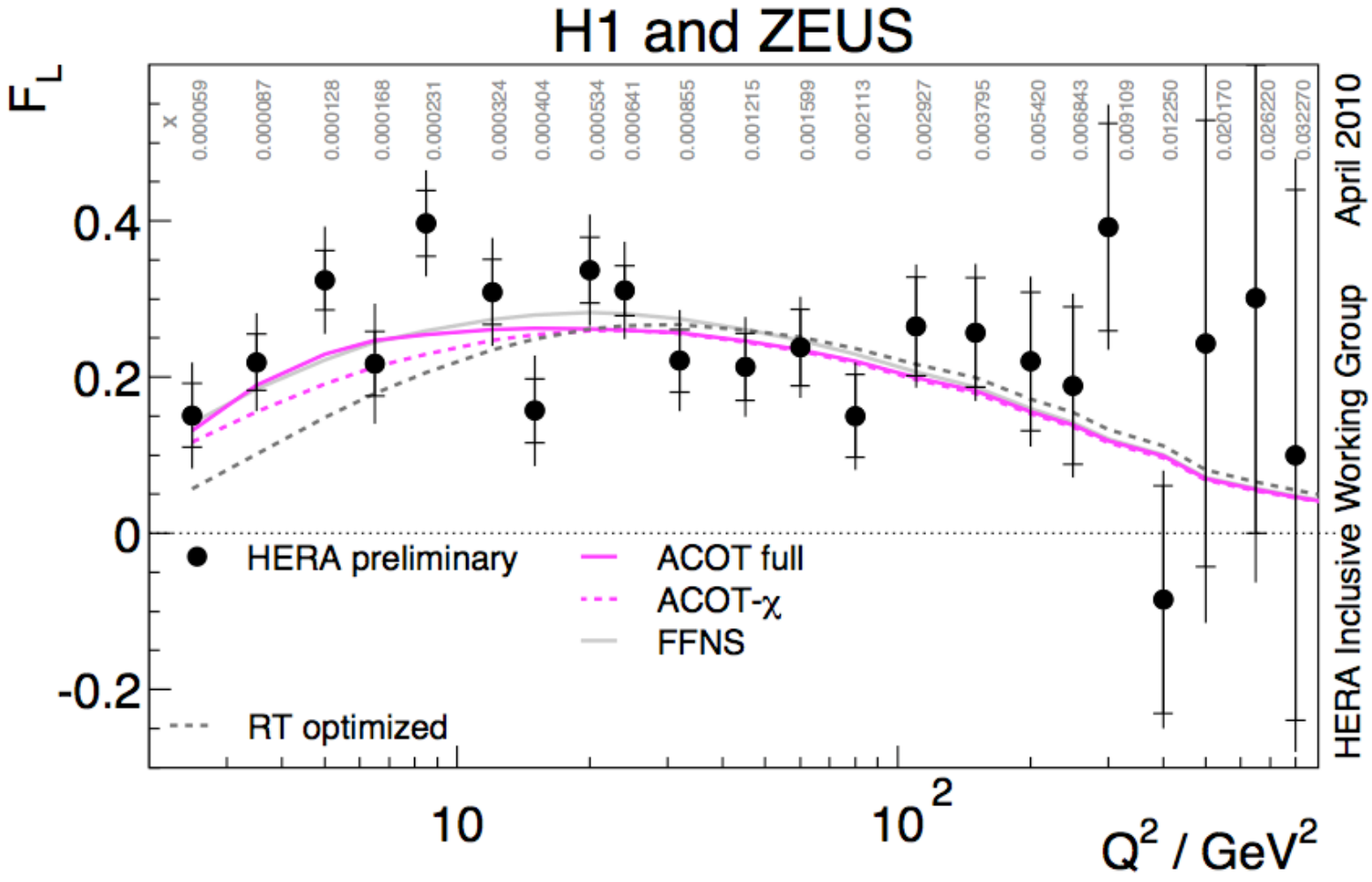
HERA F_L data vs F_L predictions: Q^2 cut

- Q^2 cut does not bring improvement in F_L prediction.



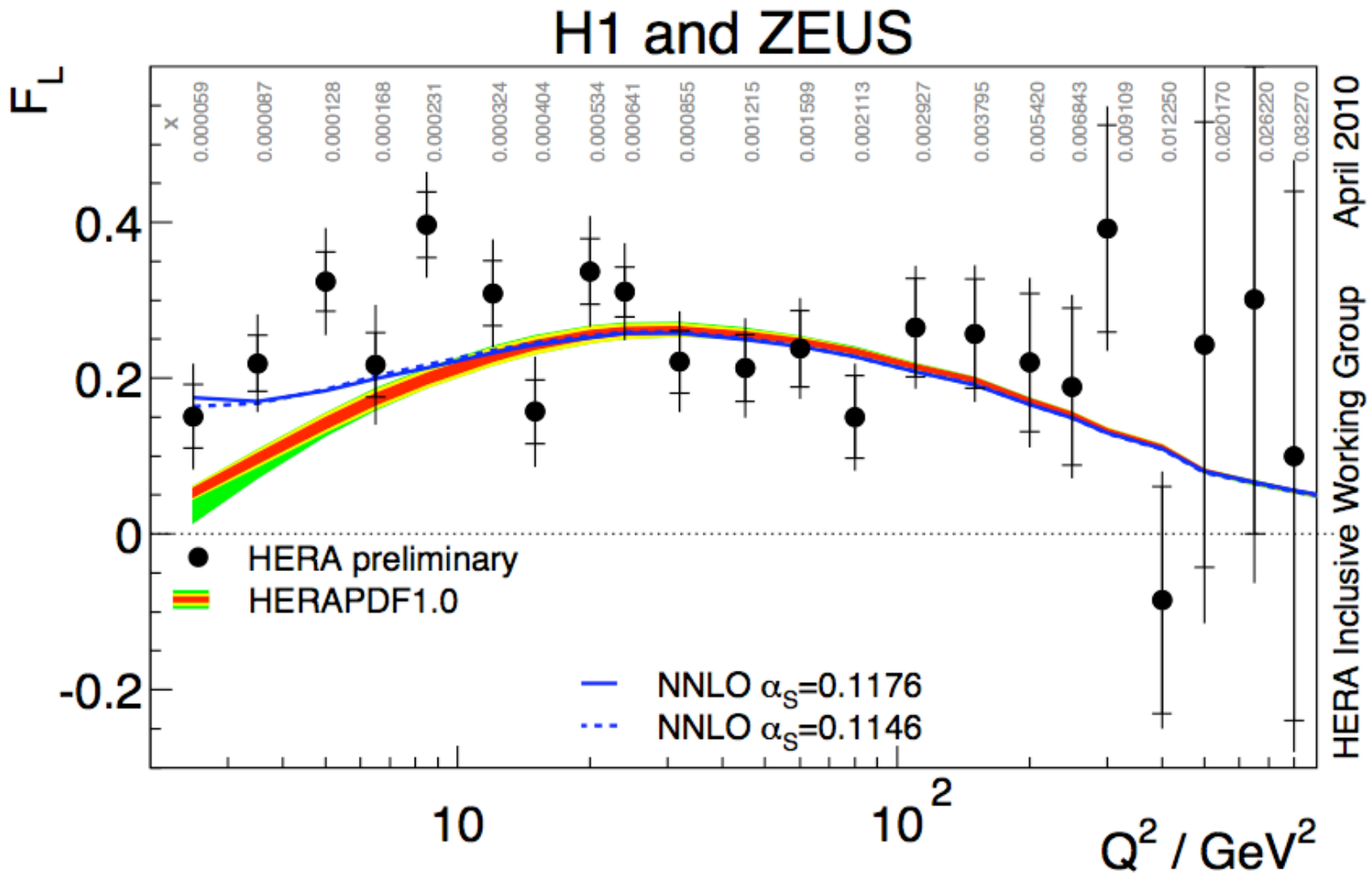
HERA F_L data vs F_L predictions: HF models

- For various HF treatments: best ACOT (full) and FFNS.



HERA F_L data vs F_L predictions: NNLO

NNLO prediction for $\alpha_S(Mz)=0.1176$ and 0.1145.



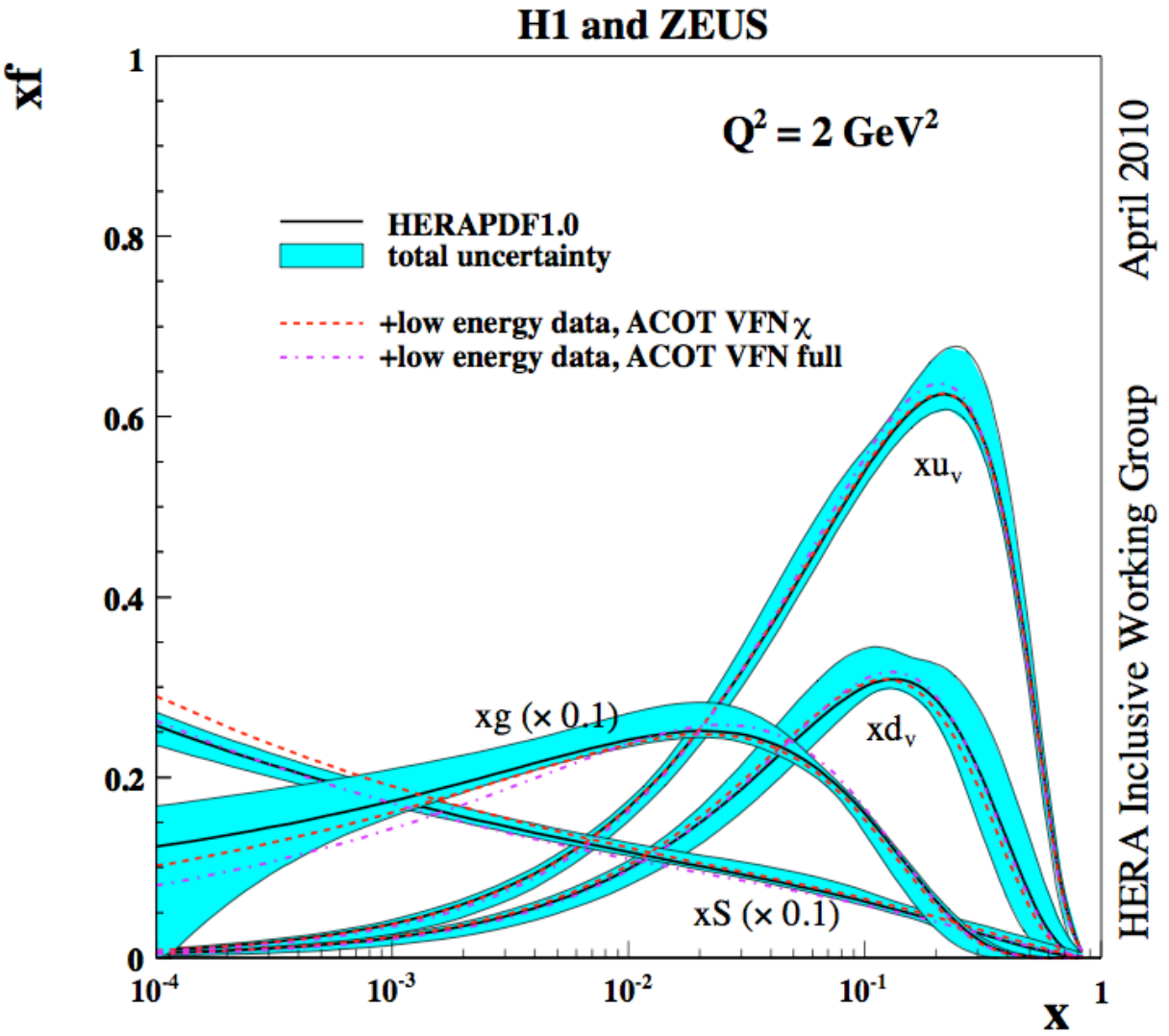
Summary

- New preliminary low energy runs data was included in the HERAPDF QCD fits which agrees with HERAPDF1.0, but does not fit as well as it could low Q^2 region:
  - Observe large sensititivity to Q^2 cut:
    - gives better χ^2, but it returns a significantly different PDF shape.
  - Inclusion of the new data brings sensitivity to HF model treatments:
    - RT: Variations of RT VFNS bring very small effect
    - ACOT (VFNS) and FFNS: decrease considerably χ^2 (compared to standard RT)
      - Different HF treatment in the fit yield interestingly different Fl prediction!
- First HERAPDF fits at NNLO (RT-VFNS) were presented:
  - Under HERAPDF1.0 settings, NNLO fit does not improve
  - NNLO fits including the low energy runs also don't bring improvement w/rt NLO
    - However, FL prediction does have an interestingly different shape!
- Low Q2 region remains very interesting for further QCD tests!

Compare ACOT schemes to HERAPDF1.0

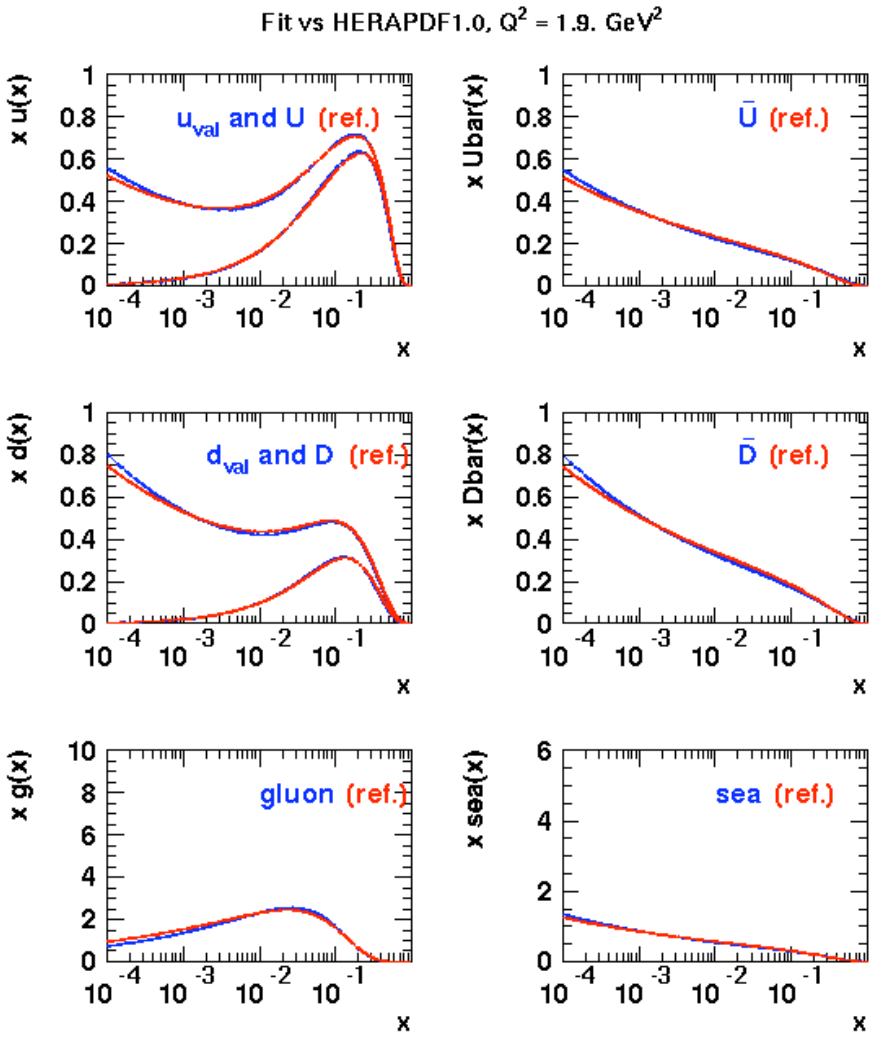
ACOT full fit results in a 5 units improvement in χ^2 compared to ACOTχ

- ACOT full:
  - Slightly less steeper gluon and sea is not changed much
  - Better fit of the high energy data
- ACOTχ :
  - A steeper gluon and sea
  - Better fit of the low energy data



Reminder on HF checks on HERA data alone

- RT: chi2/dof = 574/582 ACOT: chi2/dof=562/582



- RT heavy flavour scheme was cross checked against ACOT scheme for HERAPDF1.0
  - We did not observe much difference in the PDF distributions
  - ACOT line is shown in the HERAPDF1.0 paper

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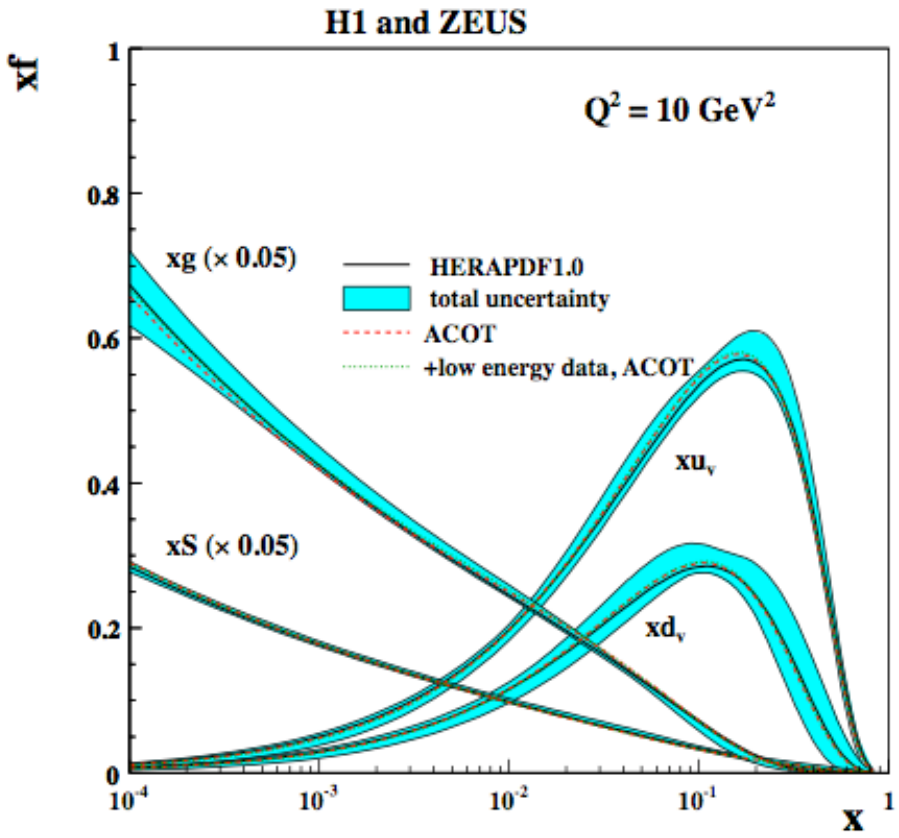

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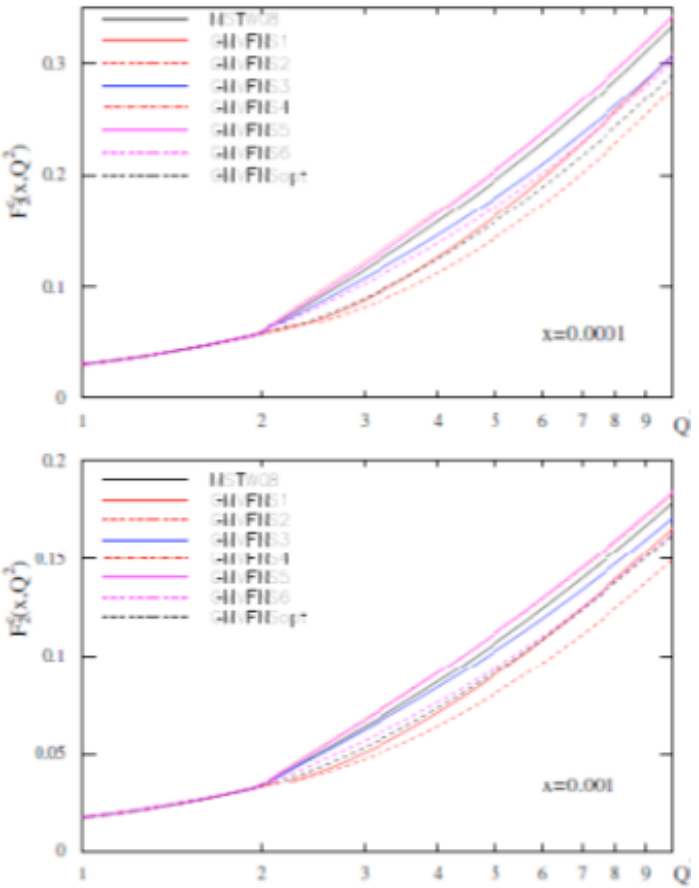
RT Standard vs Optimal

The published HERAPDF1.0 fits were done with the STANDARD RT-VFN formalism – as used by MSTW08

However, Thorne has subsequently shown alternative versions of the VFN scheme with somewhat different threshold behaviours. We have also tried the version which has a smoother threshold behaviour- which I will call OPTIMIZED RT-VFN- shown as GMVFNSopt These schemes are all equally valid.

In both cases Q^2 is the renormalisation and factorisation scale for light and heavy quarks as appropriate to these schemes



Various GM VFNS as considered by Thorne PDF4LHC meeting Oct23rd 2009

ACOT schemes

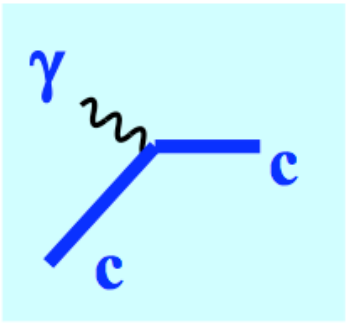
- [Fred Olness]

Effect of Kinematic Mass Re-Scaling

ACOT (Aivazis, Collins, Olness, Tung) A general framework for including the heavy quark components.
Phys.Rev.D50:3102-3118,1994.

S-ACOT (Simplified-ACOT) ACOT with the initial-state heavy quark masses set to zero.
Phys.Rev.D62:096007,2000.

ACOT-χ & S-ACOT-χ: As above with a generalized slow-rescaling
Phys.Rev.D62:096007,2000.



$$\chi = x\left[1 + \frac{(\mathbf{n}m_c)^2}{Q^2}\right]$$