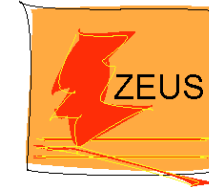




HERAPDF Fits including Low Energy Data



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on behalf of the HI and ZEUS Collaboration

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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 $Q^2 > 2.5 \text{ GeV}^2$ 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+ ($Q^2 > 100 \text{ GeV}^2$) [presented by S. Habib]
 - ▽ NC e+ ($Q^2 > 0.045 \text{ GeV}^2$)
 - Combined Low Energy Data Set of $E_p = 460, 575 \text{ GeV}$ with $Q^2 > 2.5 \text{ GeV}^2$ [presented by J. Grebenyuk]
- **QCD Fit settings:** same settings as for HERAPDF1.0
 - Fitted PDFs param at starting scale:
 - Other settings:

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

f_s	0.31
m_c [GeV]	1.4
m_b [GeV]	4.75
Q_{min}^2 [GeV ²]	3.5
Q_0^2 [GeV ²]	1.9

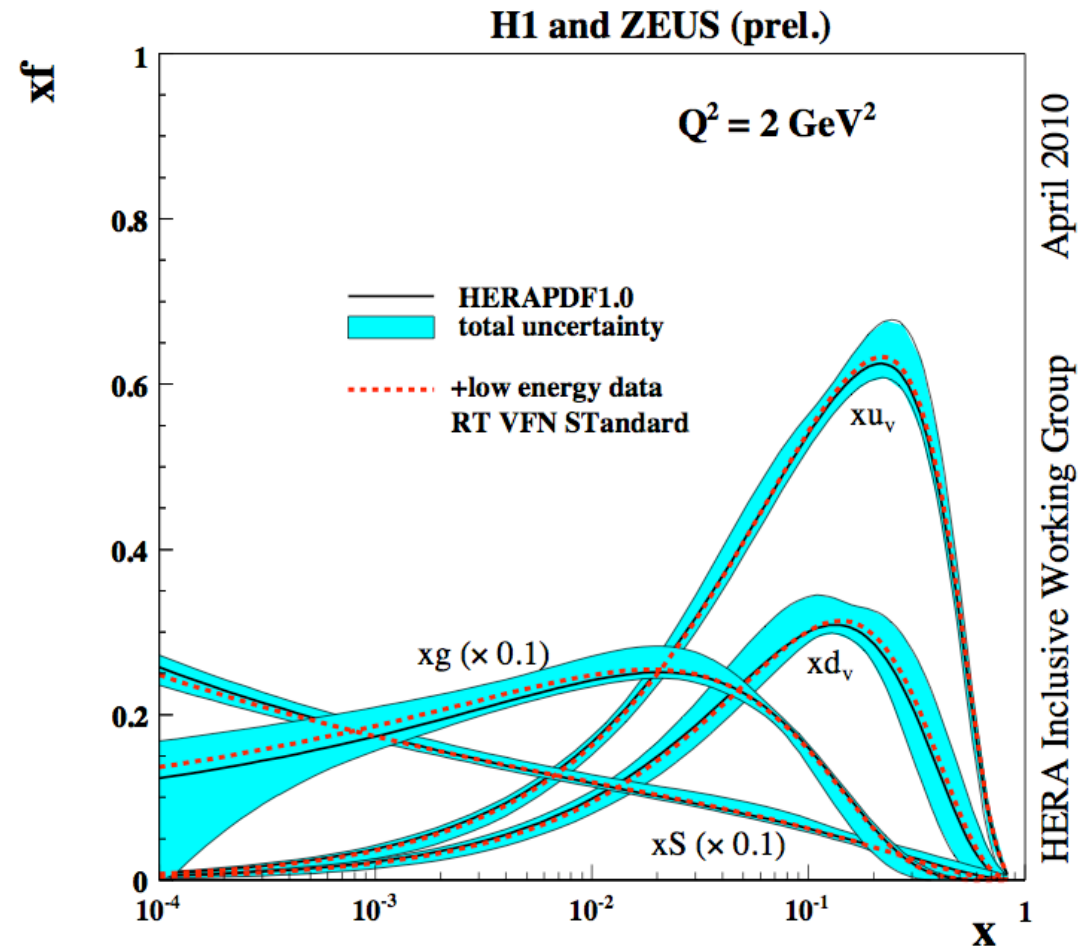
- NLO DGLAP evolution equations, RT-VFNS



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





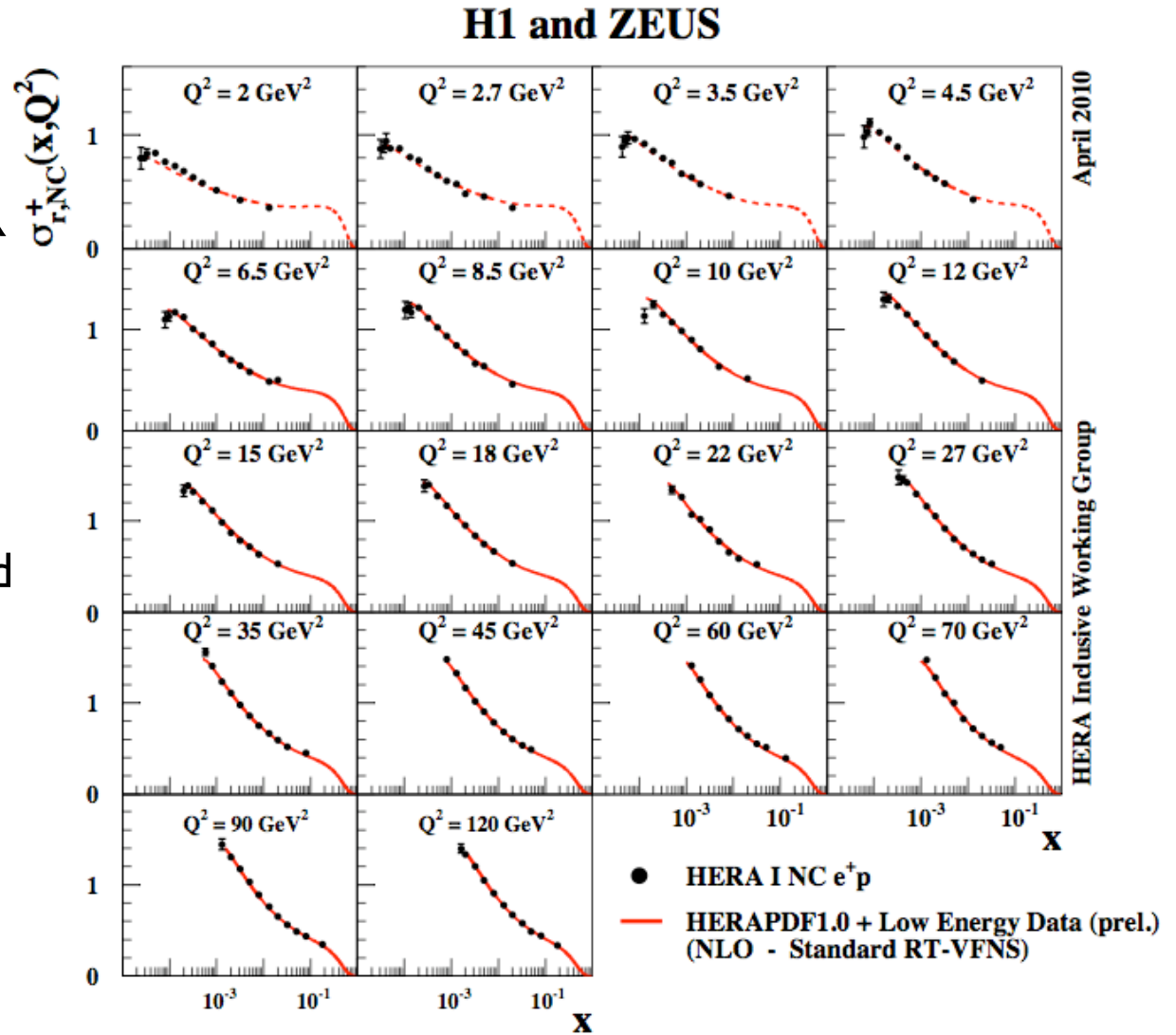
Comparison with Data

- 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

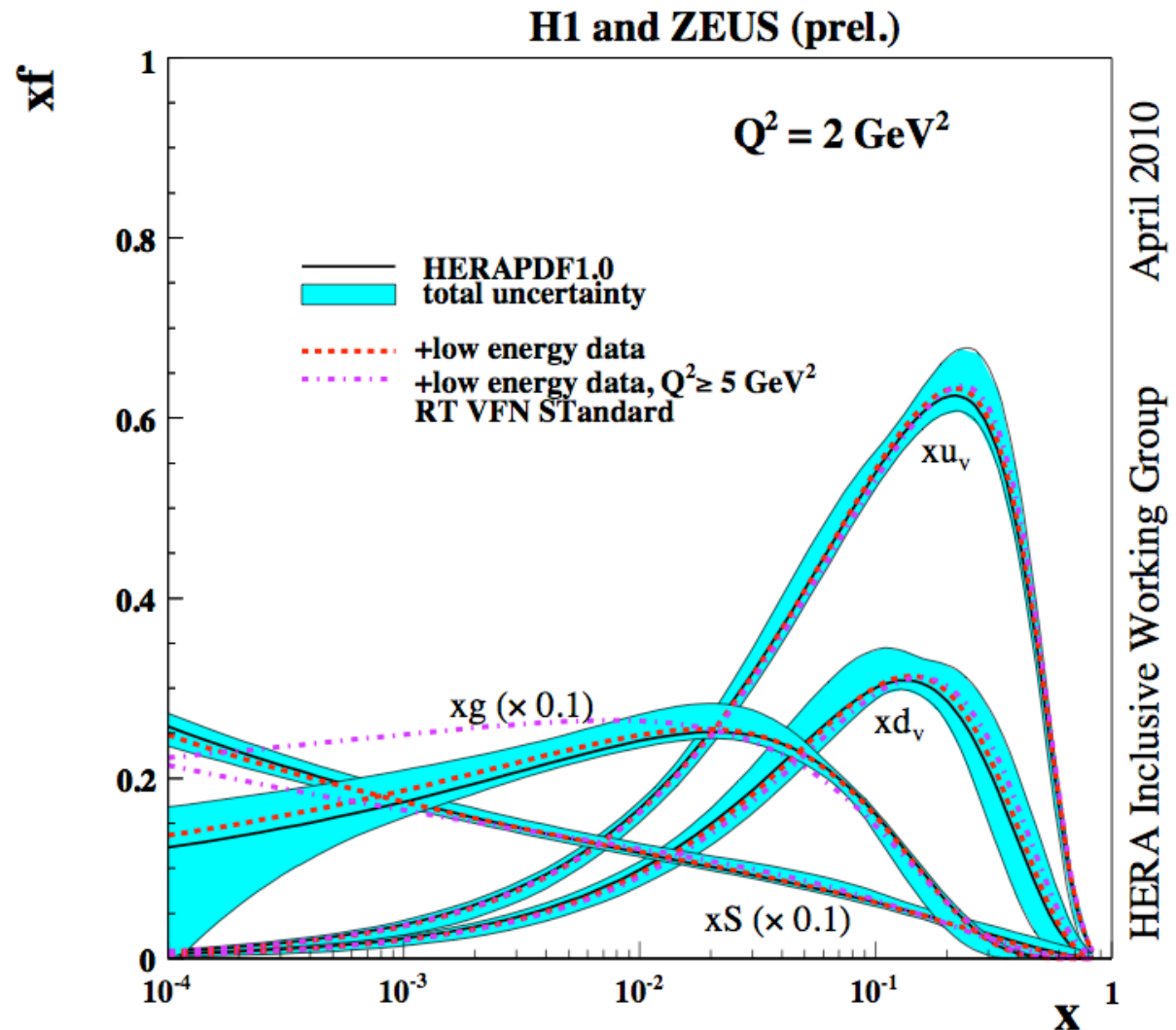
Perform variation of parameterization, and model assumptions as for HERAPDF1.0:
[S. Habib's presentation]

- **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 m_c , m_b 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

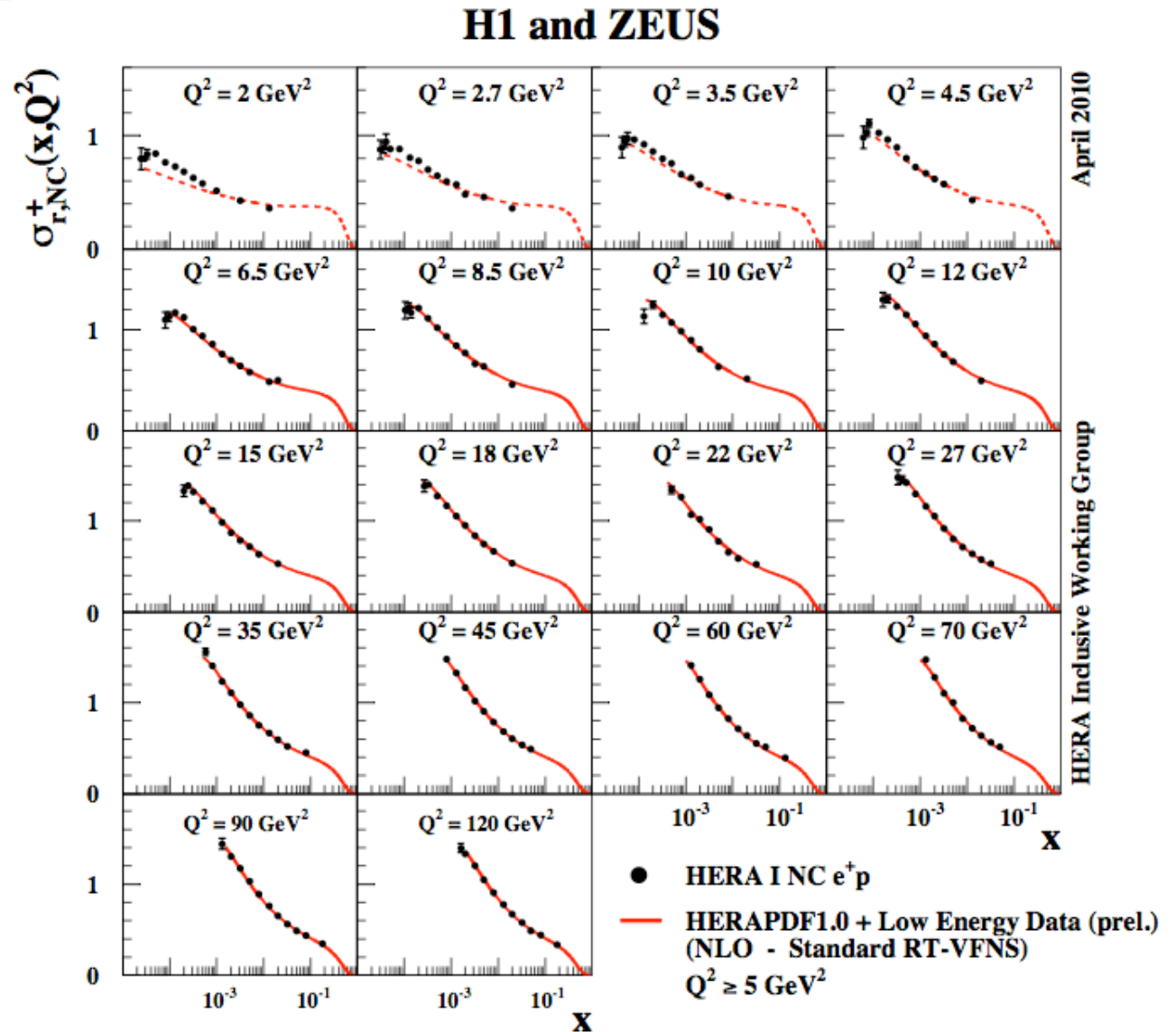
- The $Q^2 > 5 \text{ GeV}^2$ cut brings large improvement in χ^2
 - 818/806 \rightarrow 698/771
- however it returns different PDFs shape.
 - for the HERAPDF1.0, Q^2 cut variation is included in the model uncertainty, but it had smaller effect (in the same direction).
- Compare Red I (before cut) with Magenta (after cut):
 - Gluon is visibly enhanced for $Q^2 \geq 5 \text{ GeV}^2$ cut
- How does it fit data?





Comparison with Data, Fit with Q^2 cut

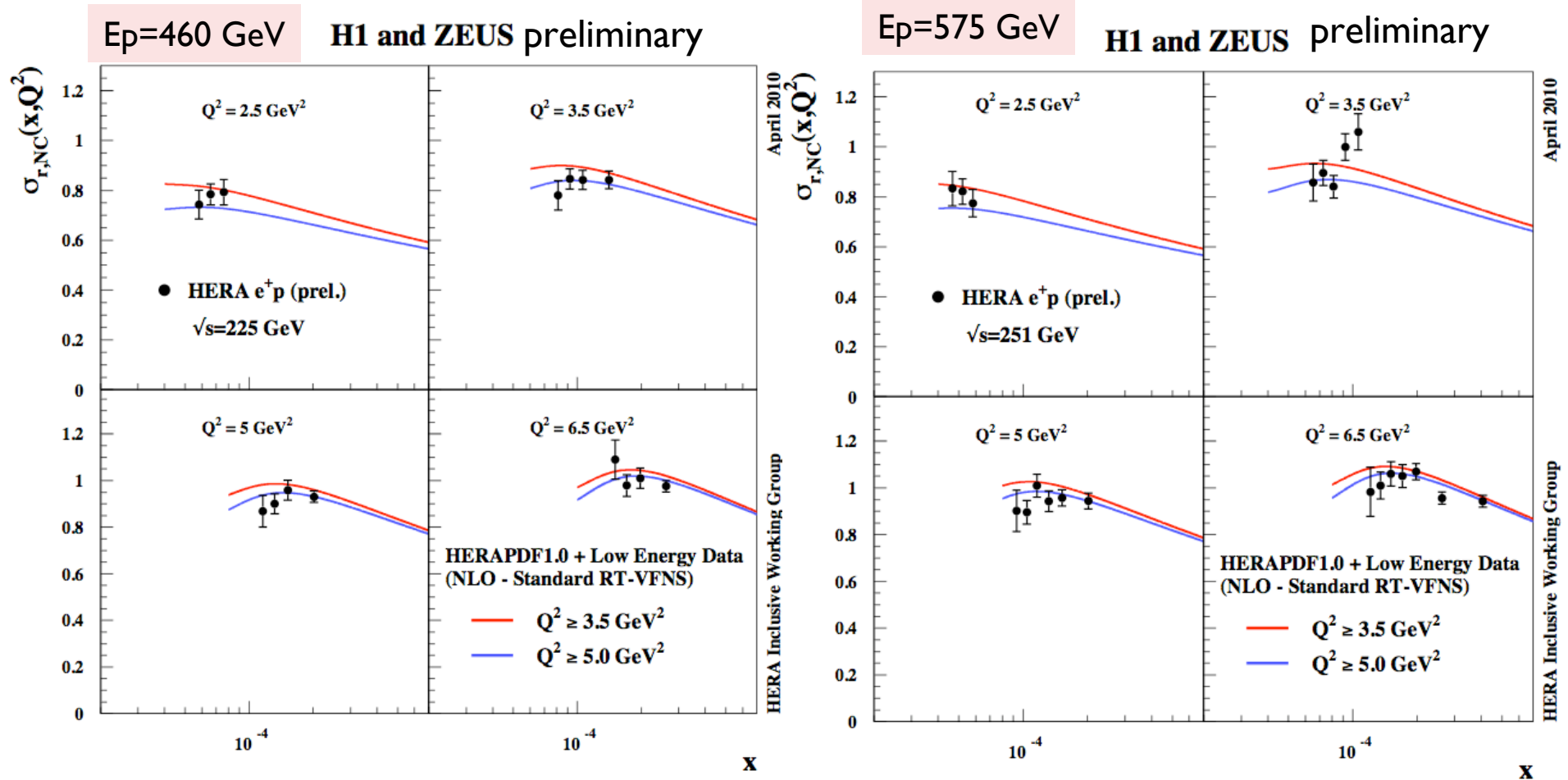
- Line is fit using standard HERAPDF1.0 settings to HERA I + Low Energy Data Runs (with $Q^2 \geq 5 \text{ GeV}^2$):
 - Bad description in the region where data does not enter fit, apart from lowest x points at low Q^2 which correspond to high $y \rightarrow$ large influence of FL





Comparison with Low Energy data

- Note: $Q^2 > 5 \text{ GeV}^2$ 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 $y > 0.35$.





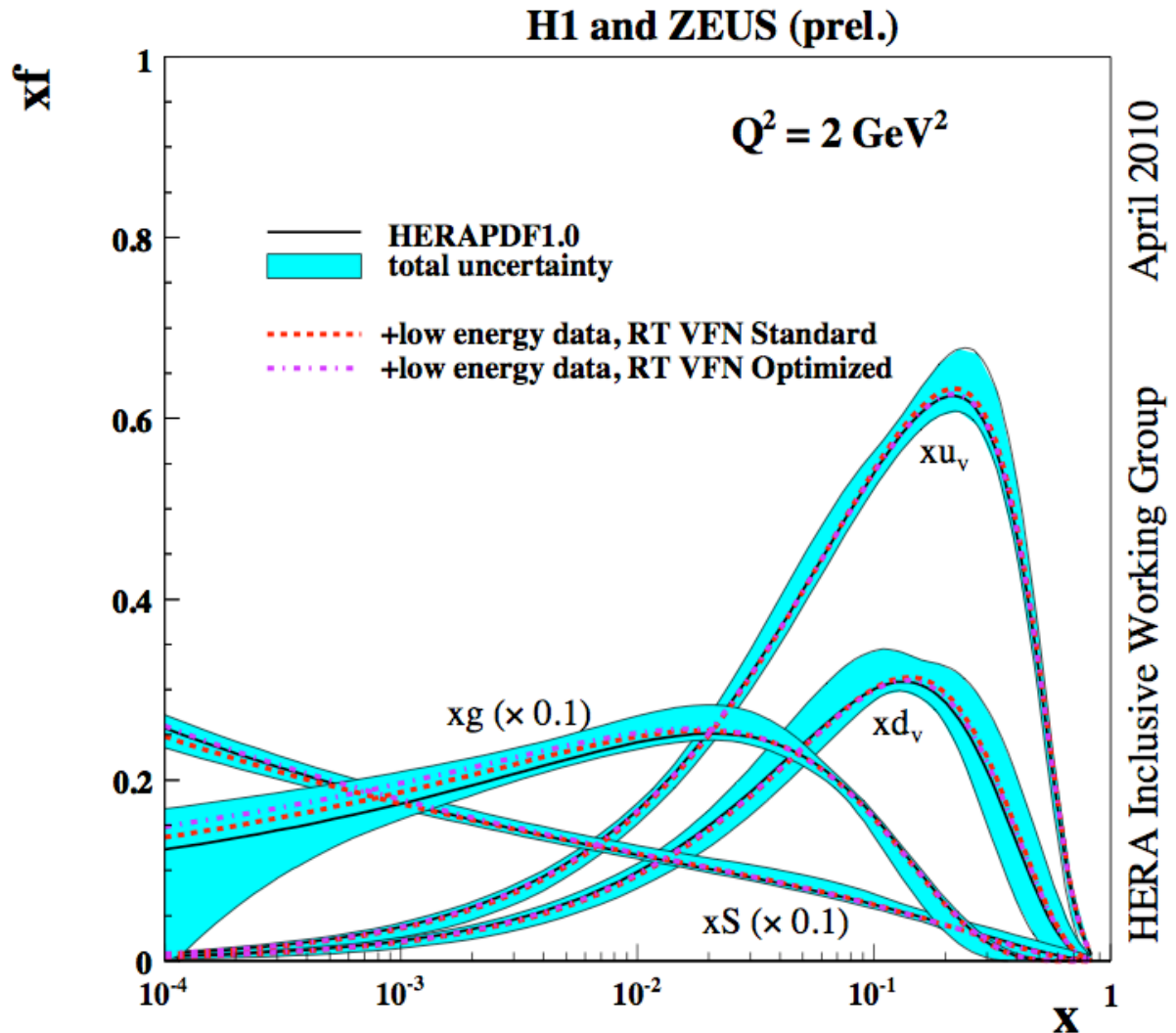
Various HF treatments

- 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 \rightarrow 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.



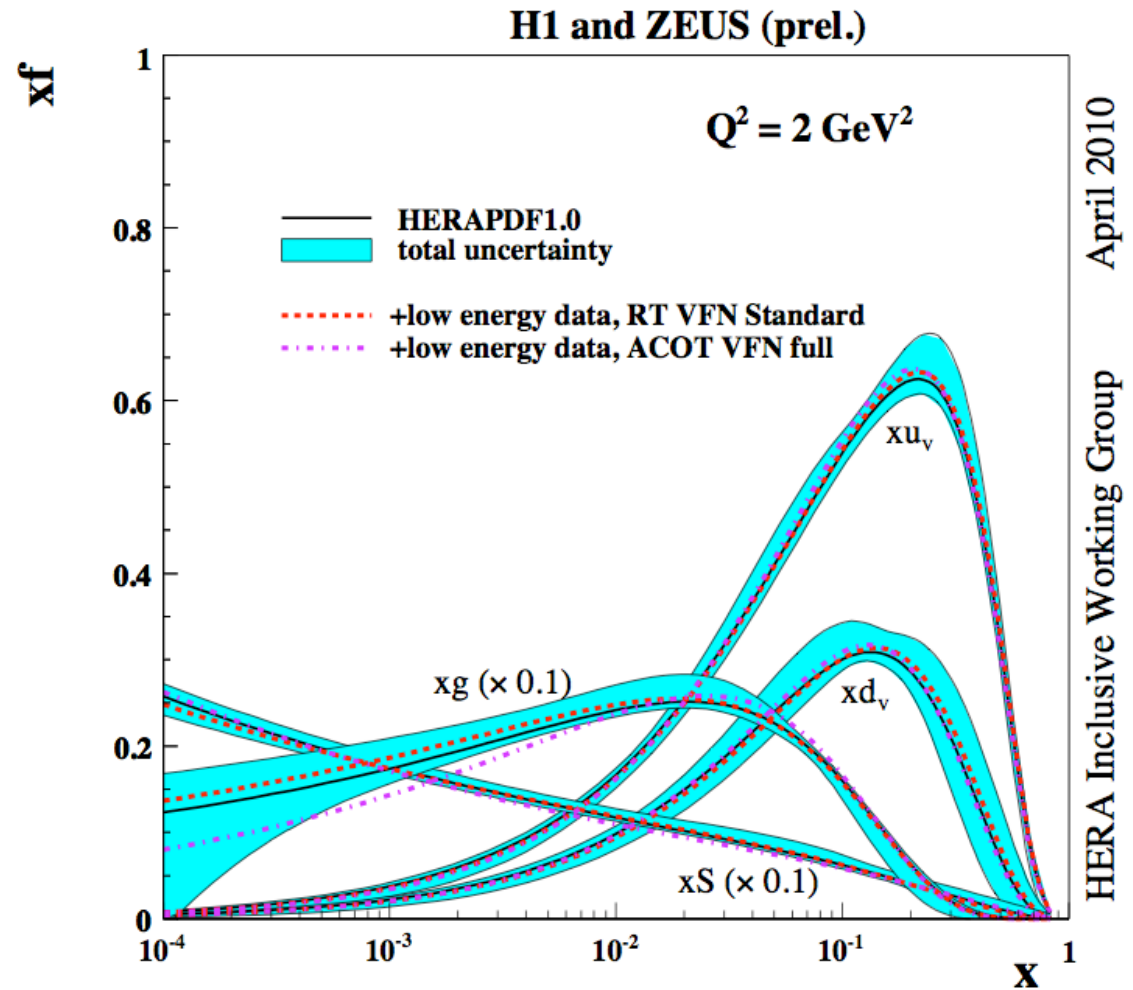


ACOT (Full) scheme compared to HERAPDF1.0

- 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



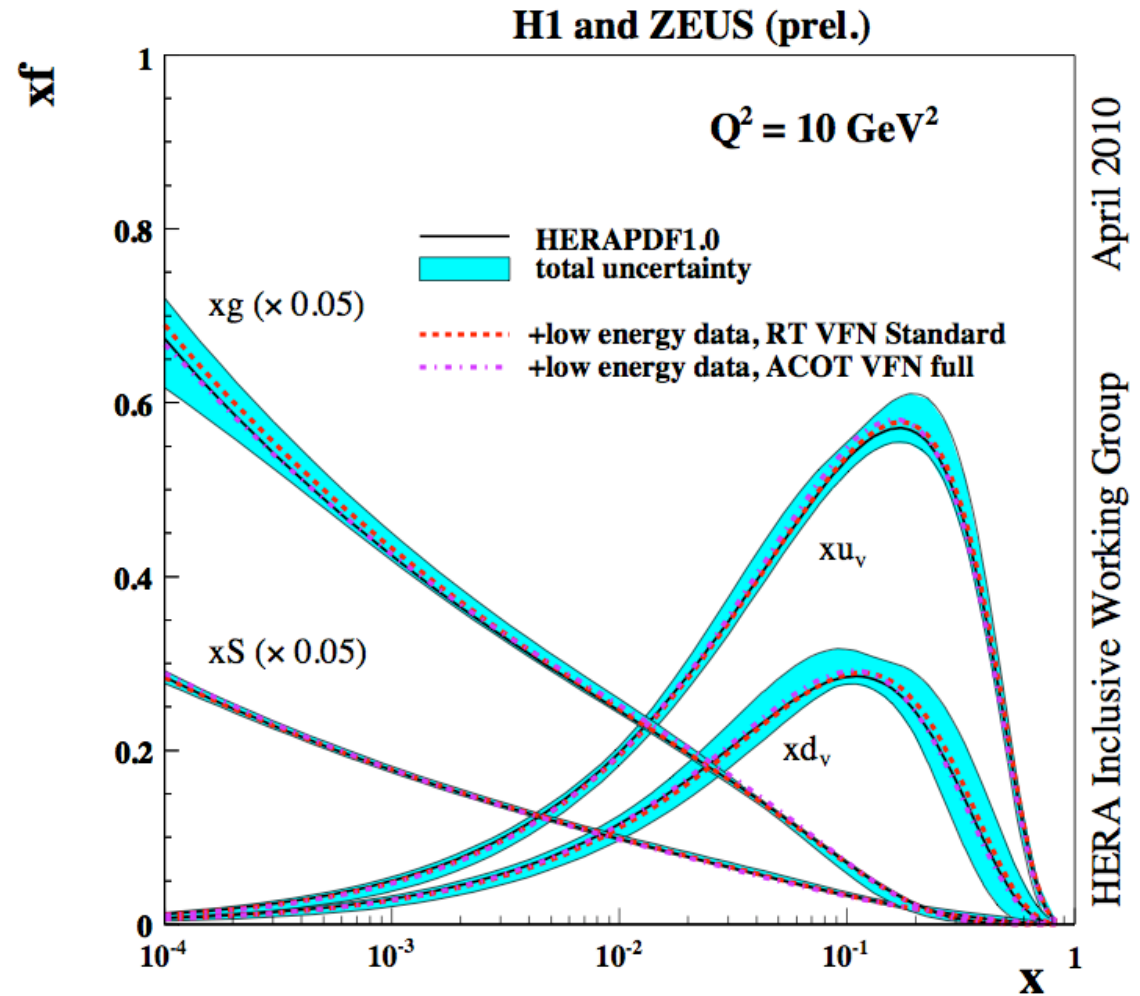


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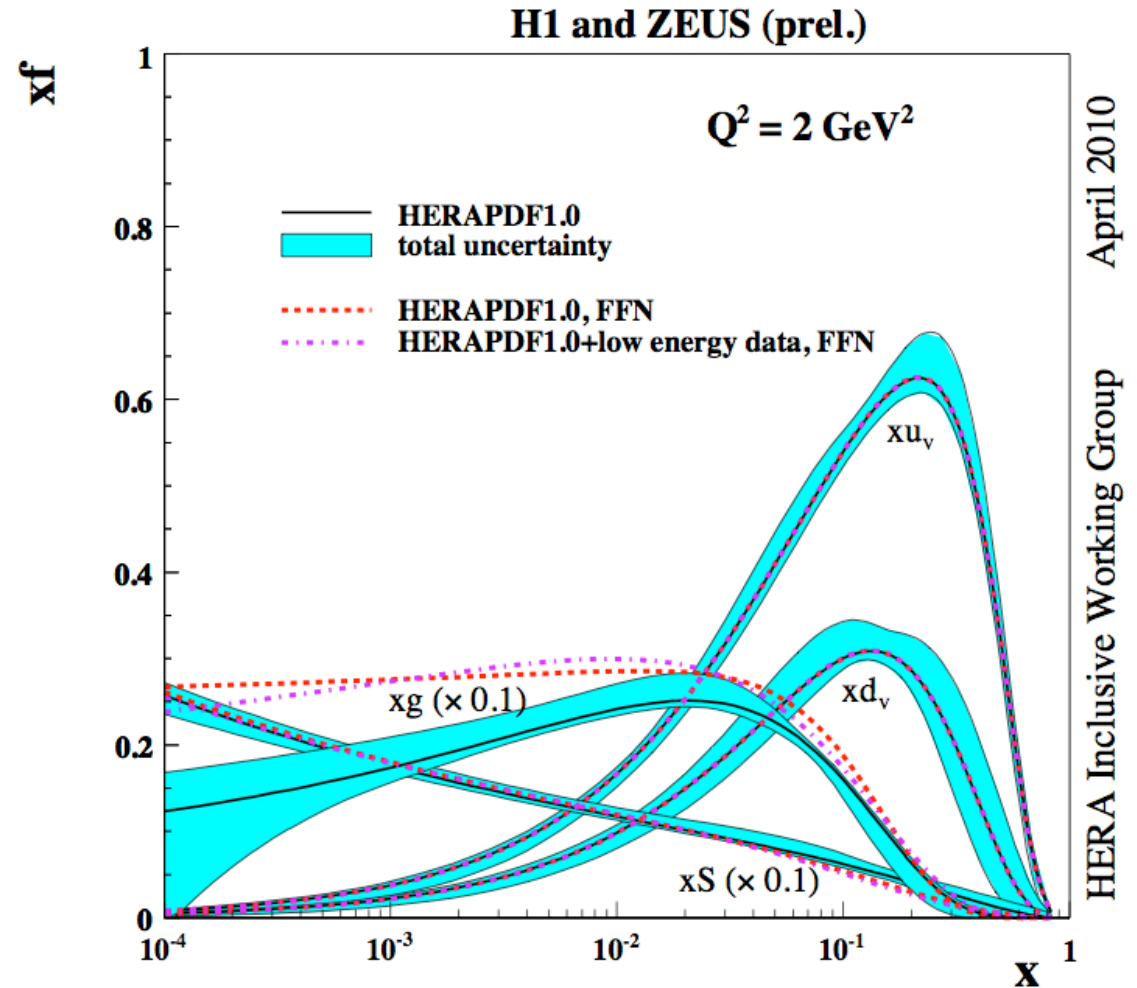
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FFNS fits to Low Energy Data

- FFNS ($n_f=3$) 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 \rightarrow not be compared (different objects)





HERAPDF fits at NNLO

- Performed first fits of HERAPDF1.0 at NNLO (RT-VFNS):

- Value of $\alpha_s(M_Z)$ might need to be adjusted for NNLO fits:

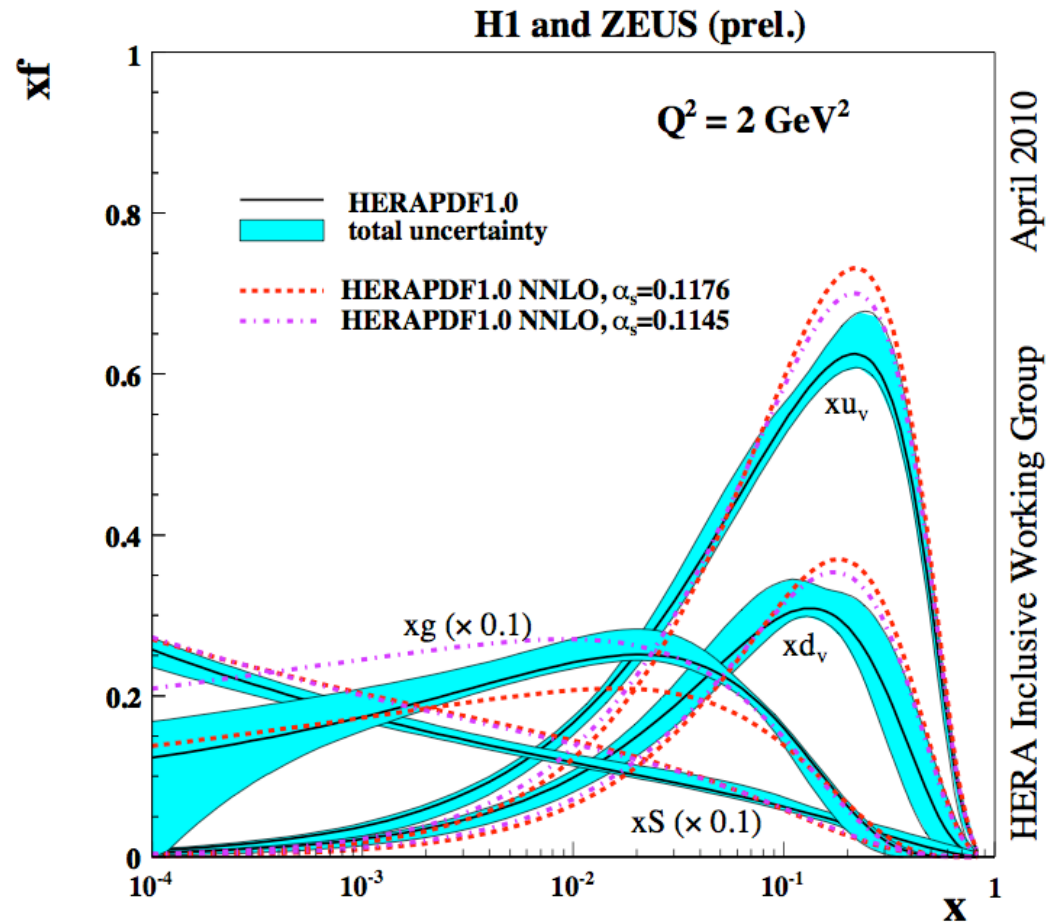
- ▾ Fitting α_s at NLO:

- $\alpha_s(M_Z) = 0.1166 \pm 0.0044(\text{exp})$
[close to world average 0.117]
- $\chi^2/\text{dof} = 574/582$

- ▾ Fitting α_s at NNLO:

- $\alpha_s(M_Z) = 0.1145 \pm 0.0042(\text{exp})$
- $\chi^2/\text{dof} = 623/582$

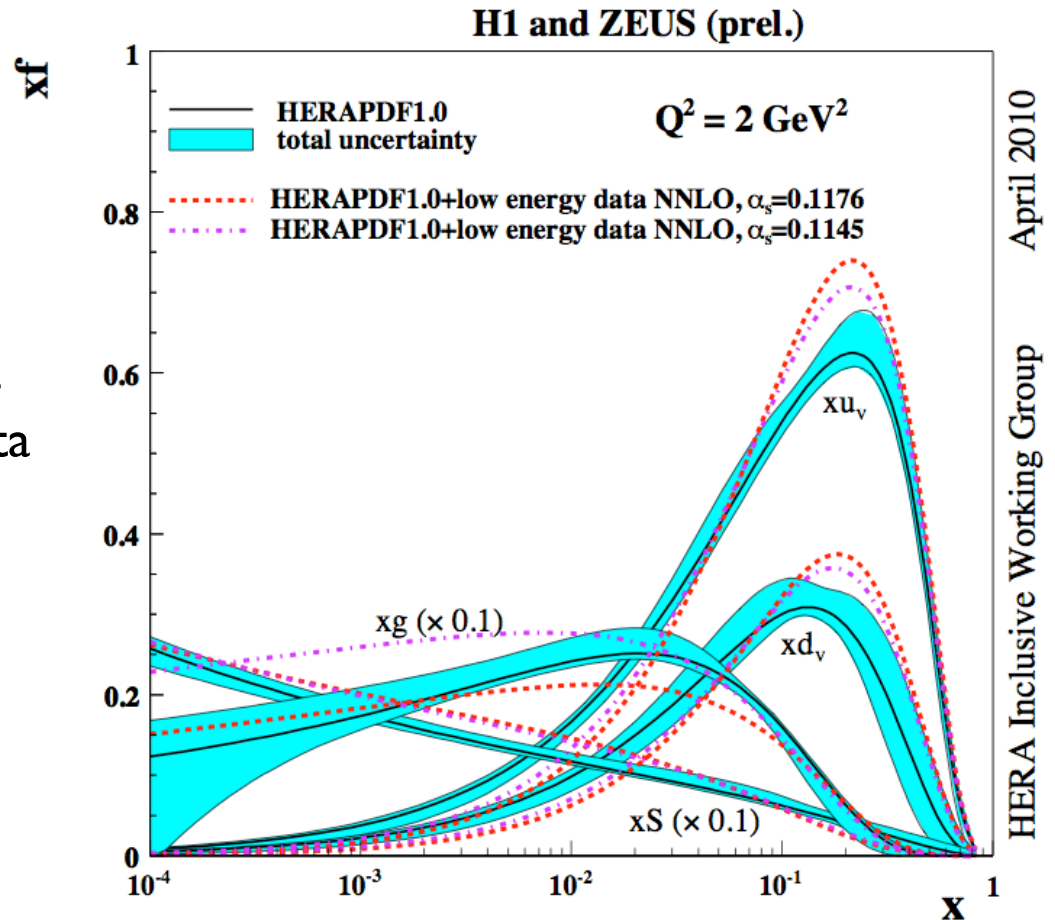
- Using the same settings as for HERAPDF1.0 NNLO fit does not improve fit results.





NNLO fits including Low Energy Data

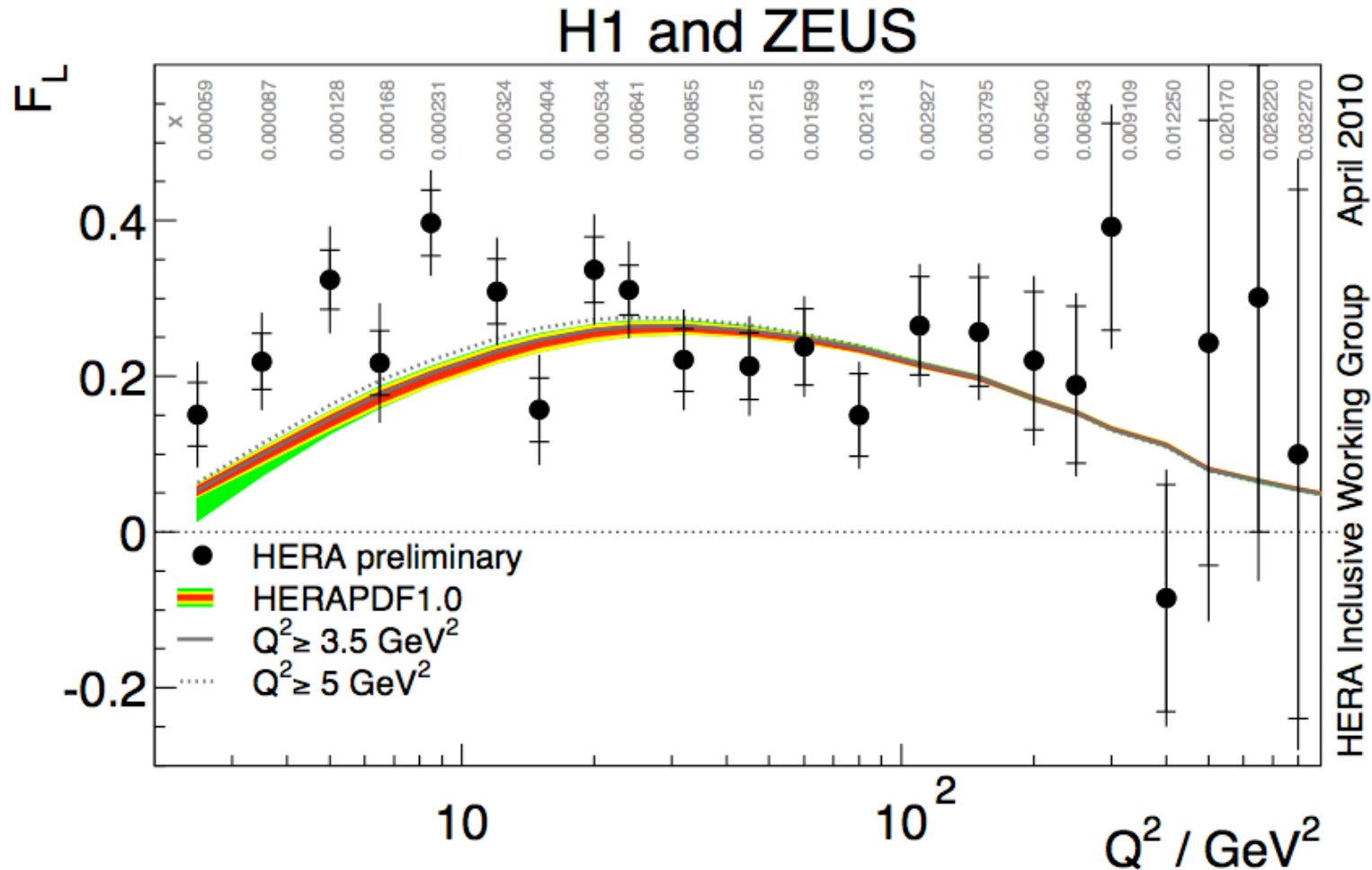
- No significant change in PDFs is observed when including Low Energy Data.
- No improvement in fit quality is observed when Low Energy Data is included (χ^2 gets worse)





HERA F_L data vs F_L predictions: Q^2 cut

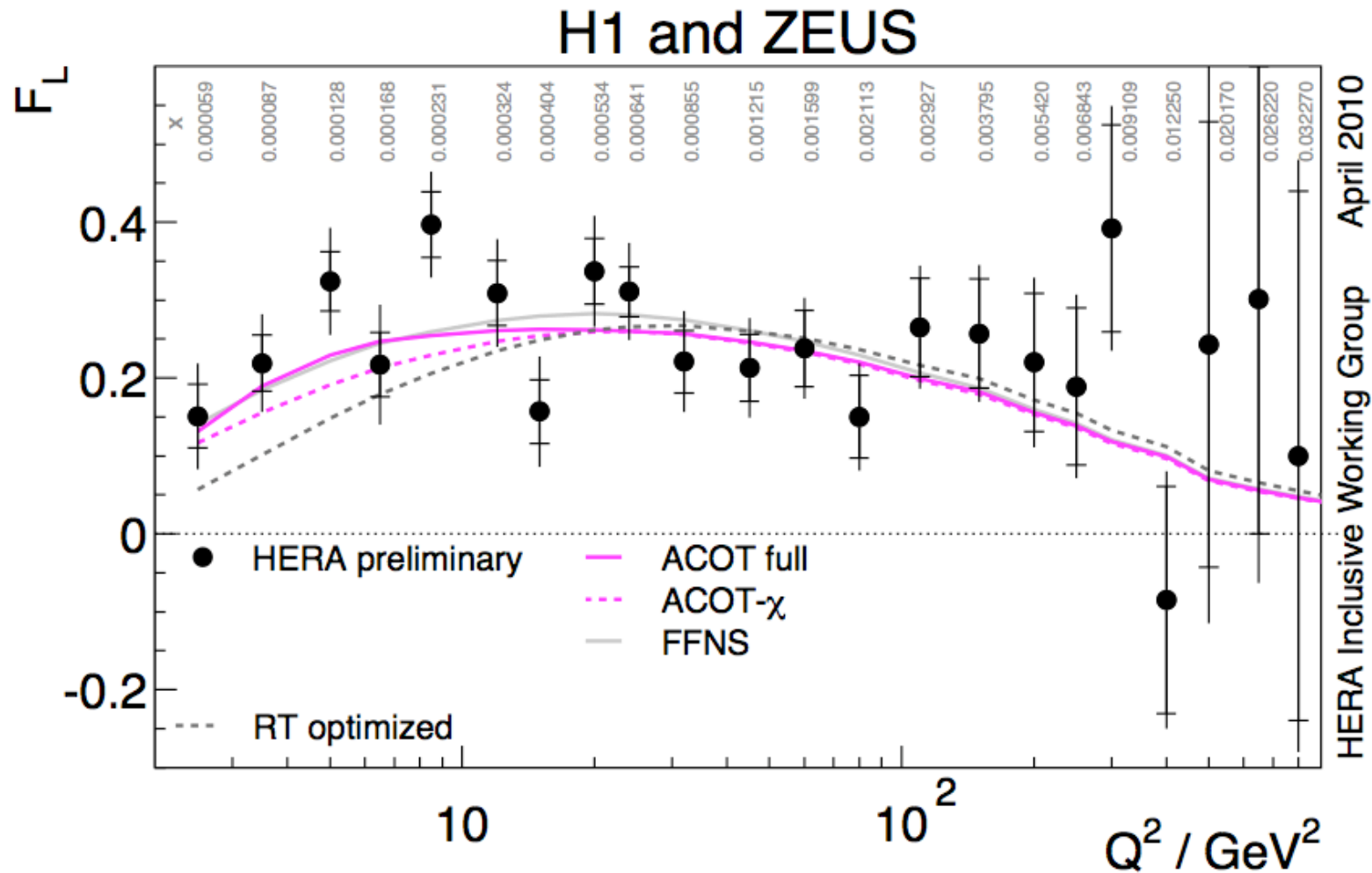
- Q^2 cut does not bring improvement in F_L prediction.





HERA F_L data vs F_L predictions: HF models

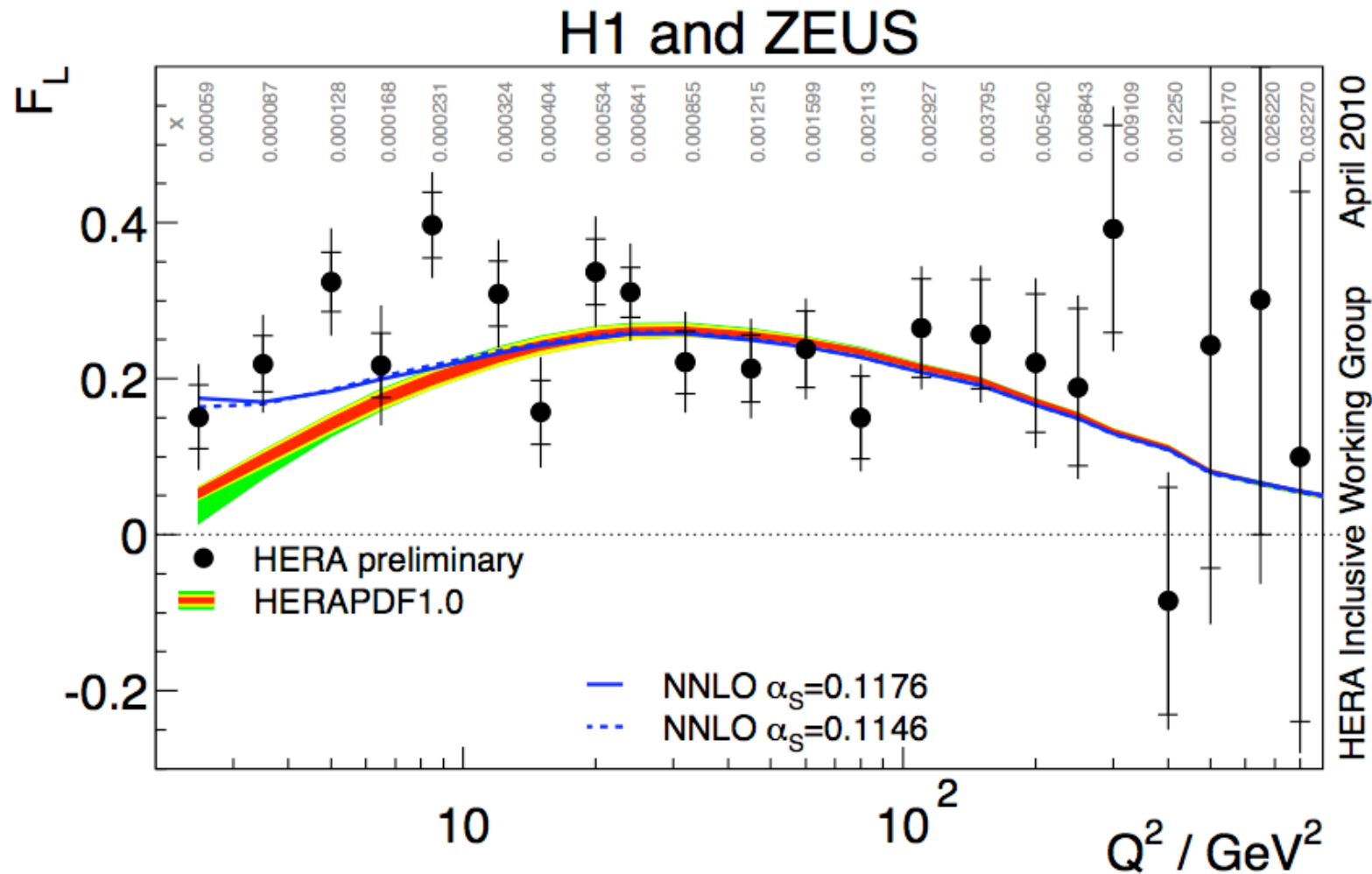
- For various HF treatments: best ACOT (full) and FFNS.





HERA F_L data vs F_L predictions: NNLO

NNLO prediction for $\alpha_s(M_Z)=0.1176$ and 0.1145 .





Summary

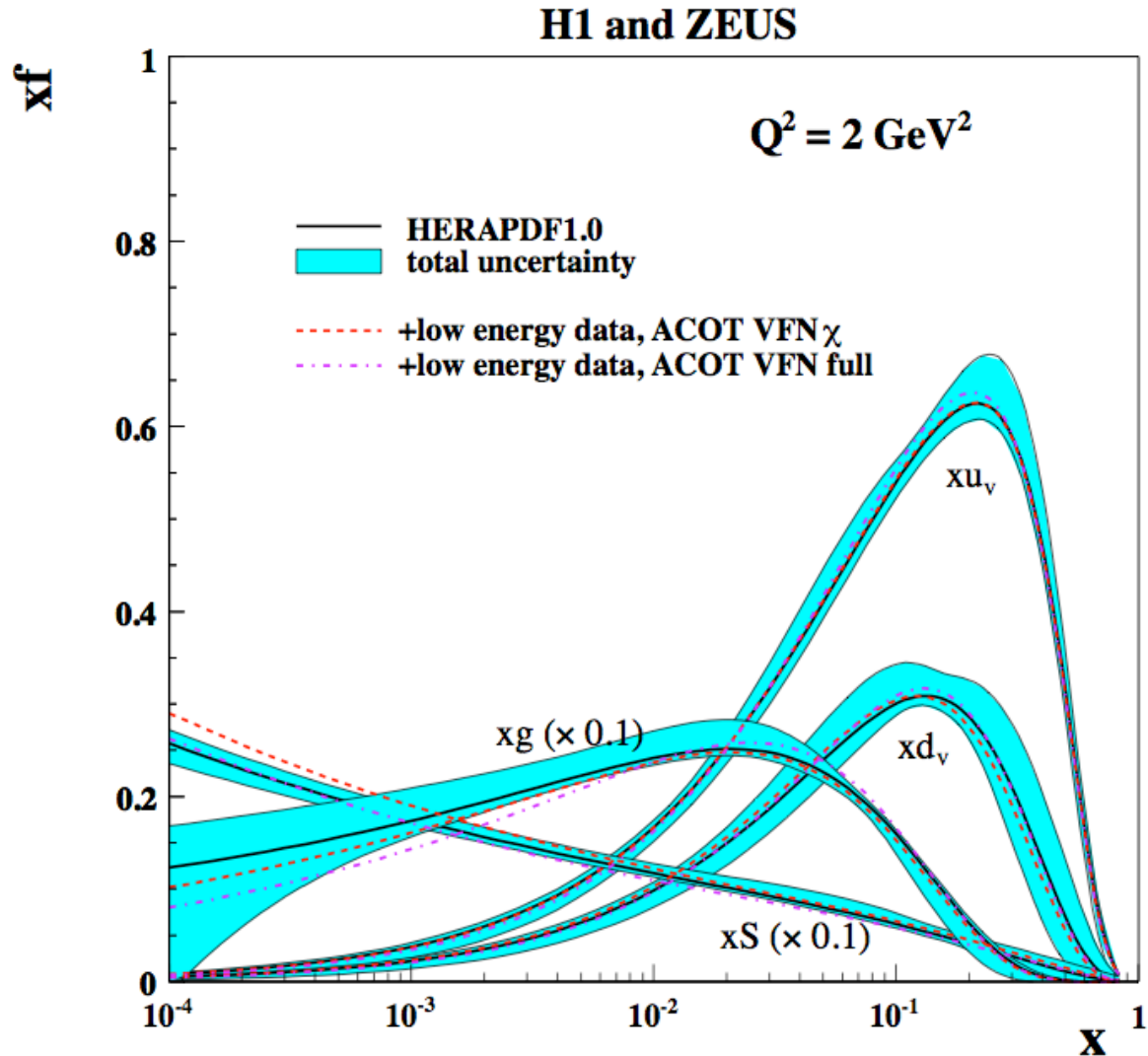
- New preliminary low energy runs data was included in the HERAPDF QCD fits which agrees with HERAPDF1.0, but does not fit as well as it could low Q^2 region:
 - Observe large sensitivity to Q^2 cut:
 - gives better χ^2 , but it returns a significantly different PDF shape.
 - Inclusion of the new data 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 FI 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 Q^2 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 ACOT χ

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



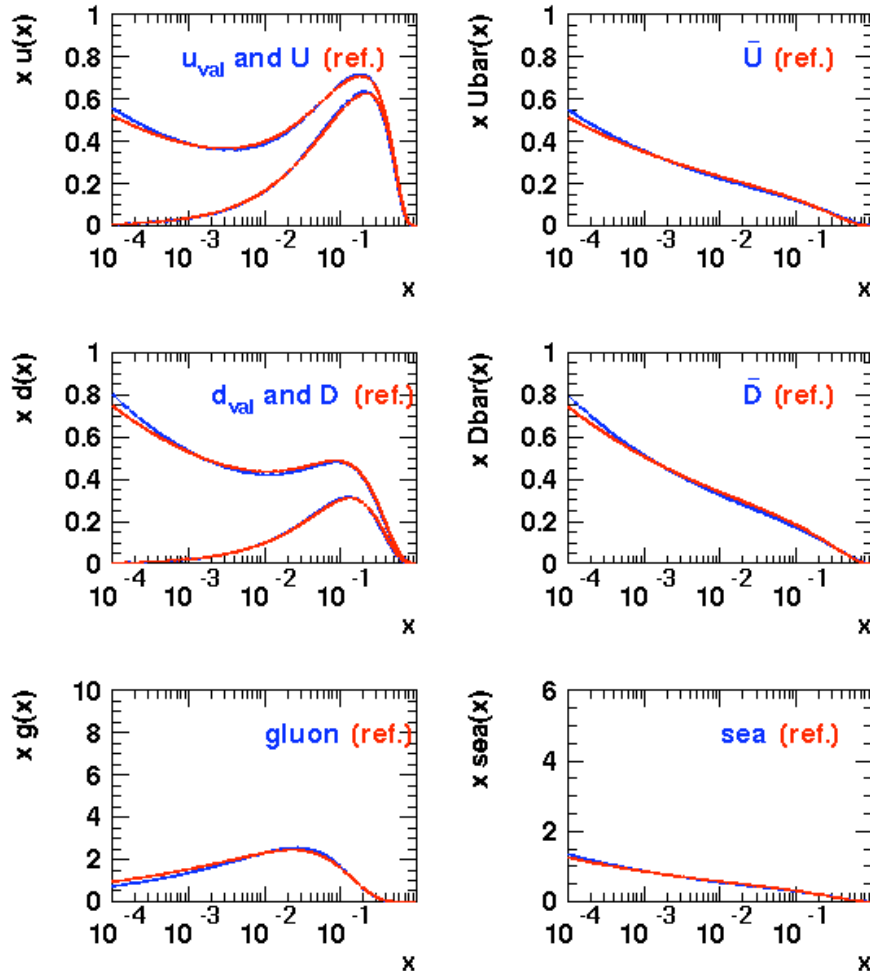


Reminder on HF checks on HERA data alone

• RT: $\chi^2/\text{dof} = 574/582$

ACOT: $\chi^2/\text{dof}=562/582$

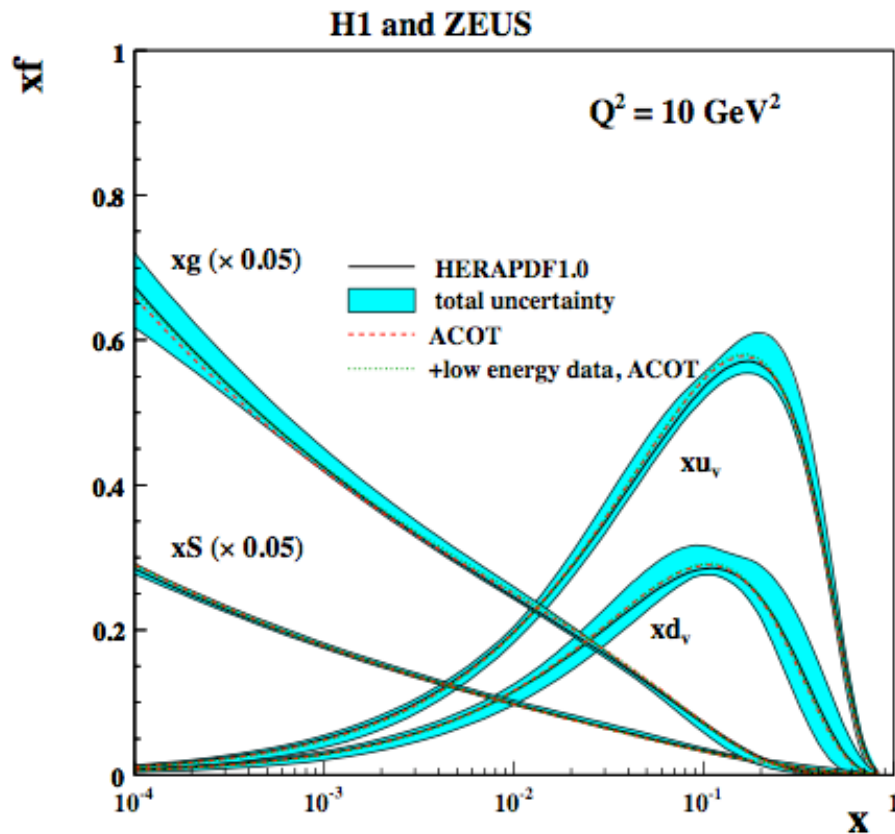
Fit vs HERAPDF1.0, $Q^2 = 1.9. \text{ GeV}^2$



- 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



Reminder on HF checks on HERA data alone



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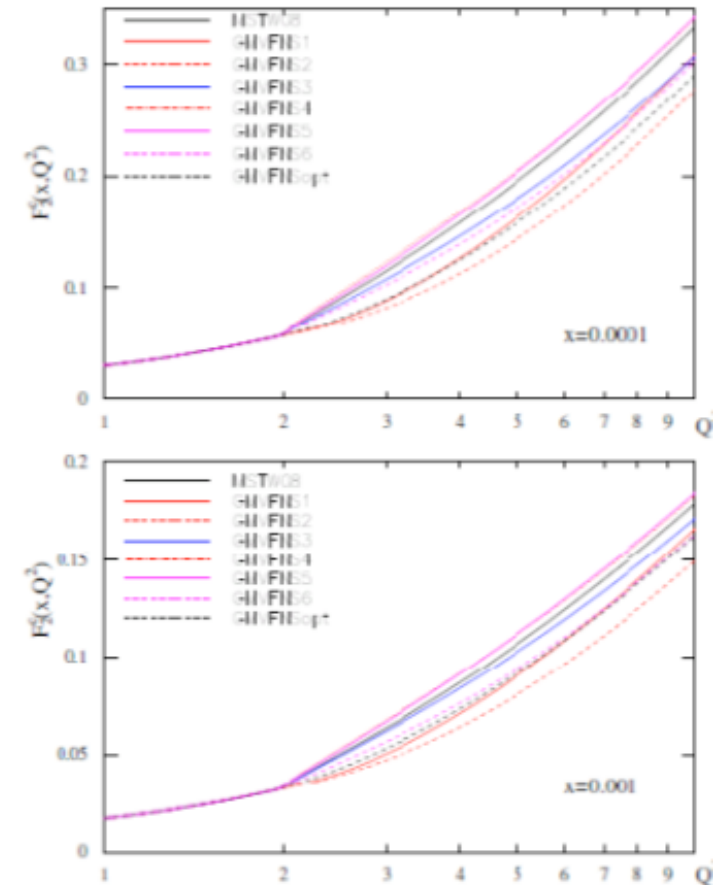


RT Standard vs Optimal

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.

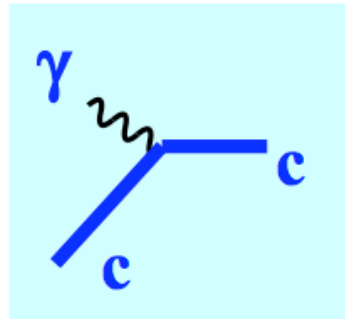
Phys.Rev.D50:3102-3118,1994.

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.



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

