HERAPDF Fits including Low Energy and Charm Data

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on behalf of the H1 and ZEUS Collaborations

Low X 2010, Kavala

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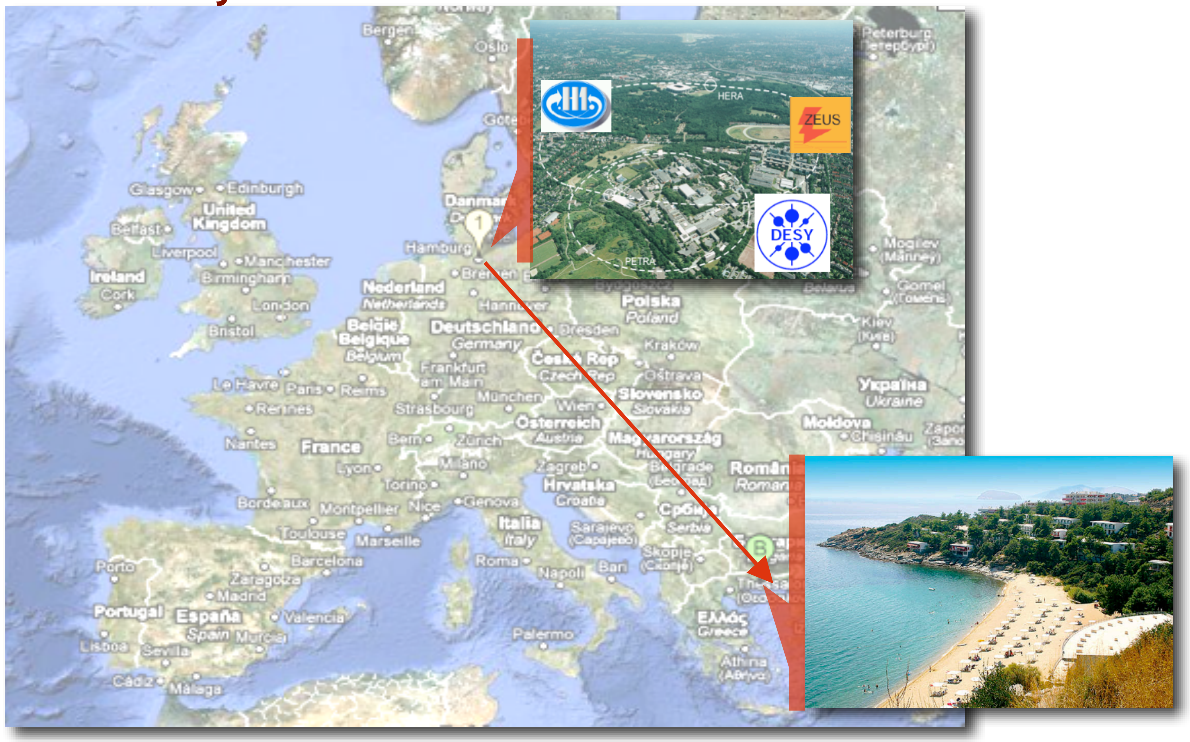
Outline:

- Introduction
- QCD fits including:
  - Low Energy Data
  - Charm Data
- Results and Comparisons
- Summary



Extensions to HERAPDF1.0

- New preliminary data are available and can be included in the HERA fits in addition to the data used for HERAPDF1.0:
  - HERA Combined Low Energy [H. Kowalski's presentation]
    - Accurate measurement in $Q^2 \geq 2.5$ GeV^2 range, sensitive to structure function F_L:
      - Study impact of those data on PDFs and investigate the low Q^2 region;
      - Test sensitivity to different heavy flavour treatments;
      - Compare fit results and measured structure function F_L.
  - HERA Combined F_2 Charm [V. Libov's presentation]
    - Charm data are sensitive to the charm mass and the heavy quark scheme:
      - Study impact of those data on PDFs and investigate charm mass dependence;
      - Test sensitivity to different heavy flavour treatments.
- HERA NNLO fits to HERA I data with and without Low Energy and Charm data.

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) [J. Sztuk'presentation]
    - NC e^+ (Q^2>0.045 GeV^2)

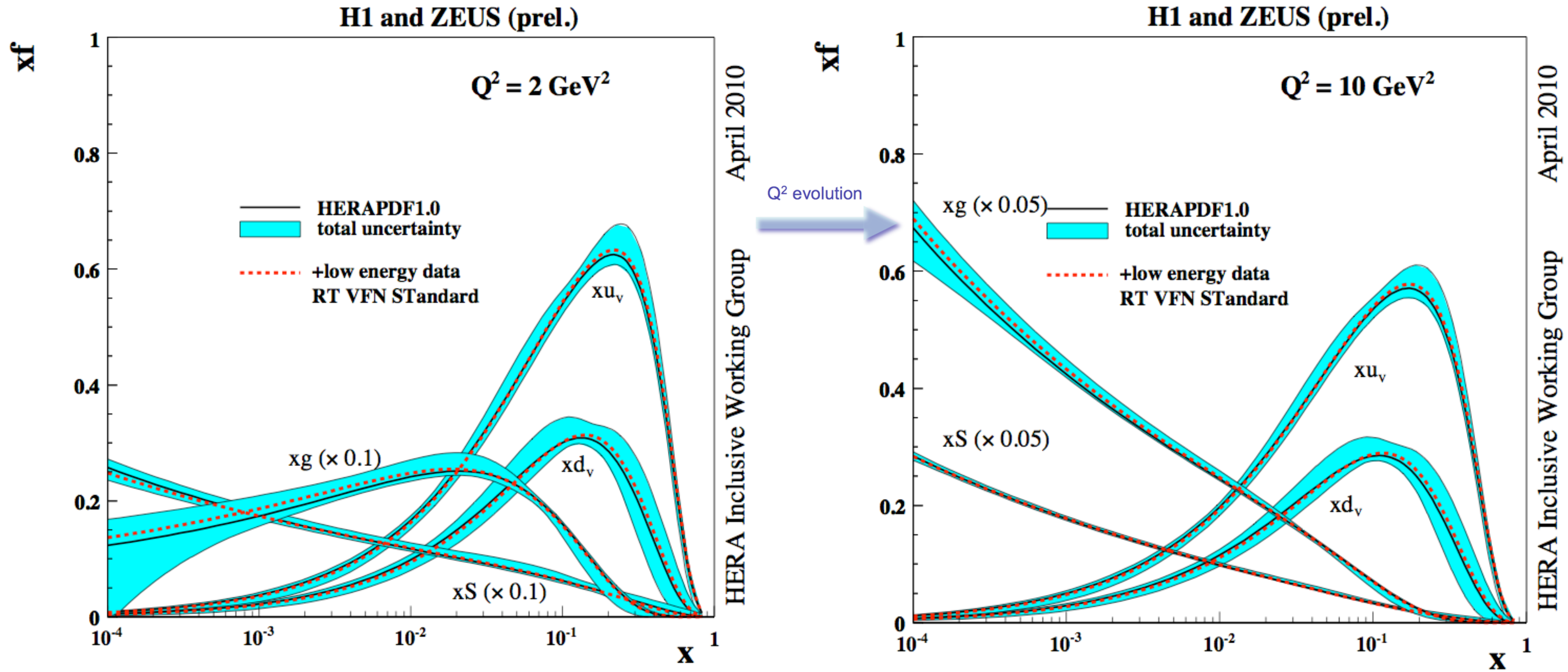
    } 592 points
  - Combined HERA Low Energy Data Set of Ep=460, 575 GeV with Q^2>2.5 GeV^2
    [H. Kowalski's presentation] ➔ 224 points
  - Combined HERA F_2 Charm data with Q^2>1.5 GeV^2
    [V. Libov's presentation] ➔ 41 points

- QCD Fit settings: same settings as for HERAPDF1.0 [J. Sztuk'presentation]

f_s	0.31	
m_c [GeV]	1.4	→ (1.4 - 1.65)
m_b [GeV]	4.75	
Q^2_{min} [GeV^2]	3.5	→ cut variation
Q^2_0 [GeV^2]	1.9	

  - NLO (and NNLO) DGLAP evolution equations, RT-VFNS (as for MSTW08)
    - Other schemes were investigated as well: RT (optimal), ACOT (full and χ), FFNS

HERAPDF including Low Energy data

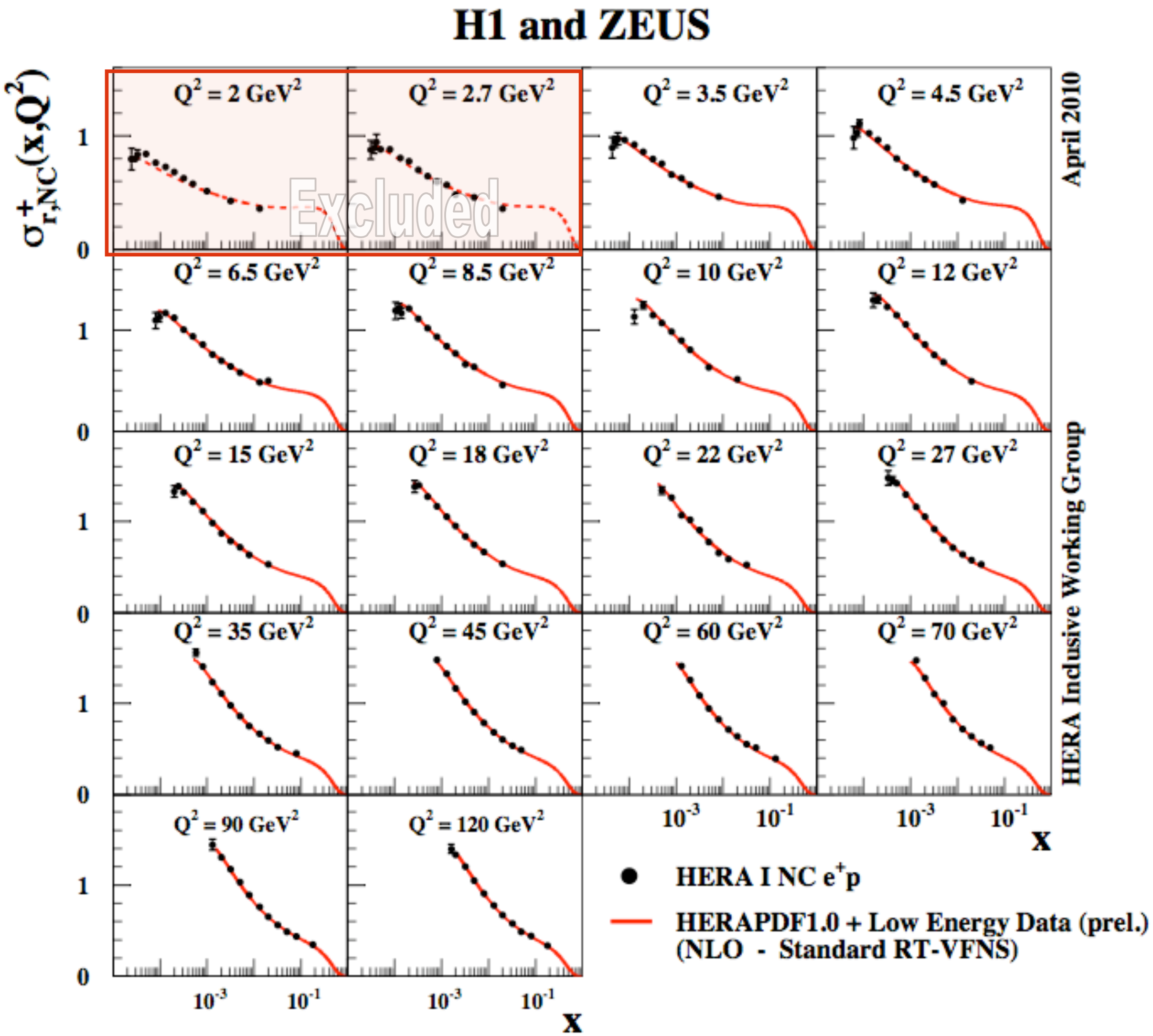


- PDFs from the new fit agree very well with HERAPDF1.0
- But, inclusion of the new data gives slightly worse fit:

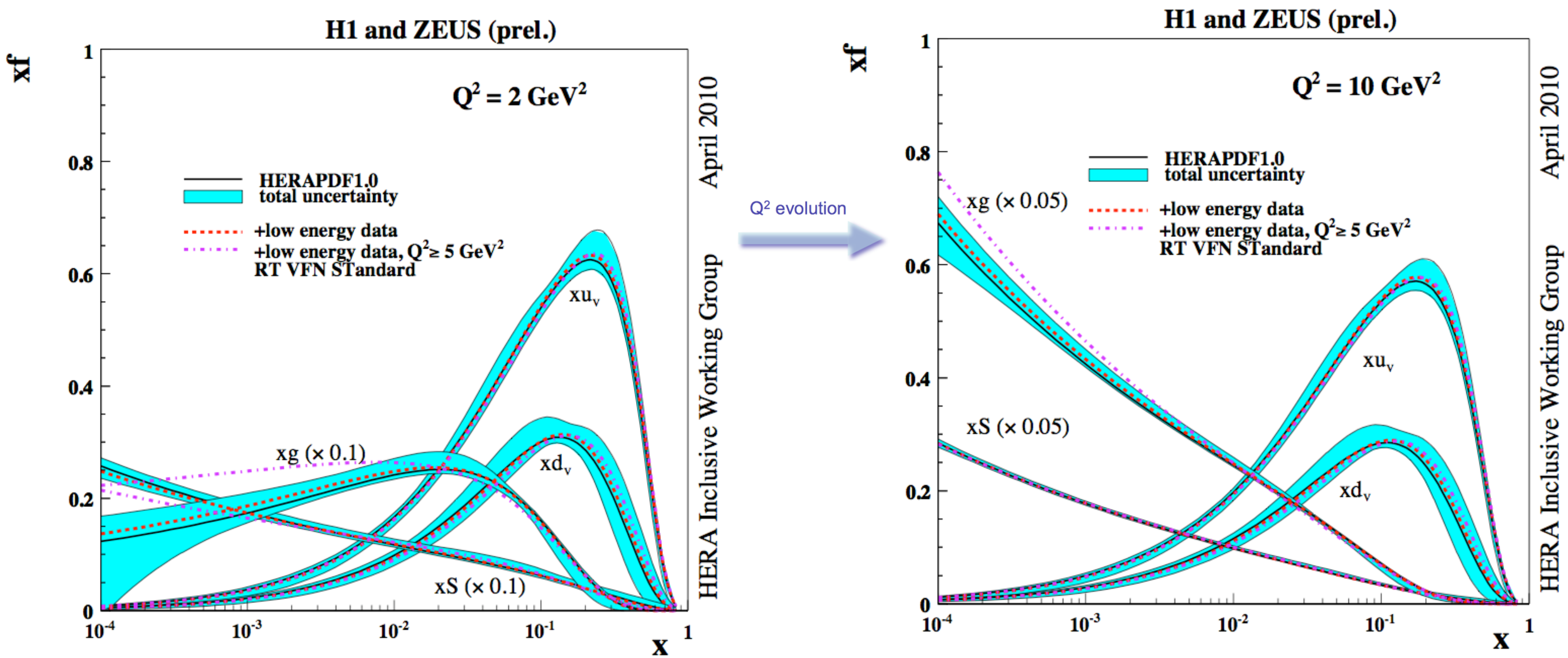
Data sets	HERAPDF1.0	+ Low Energy data
Total χ^2/dof	574/582	818/806

Comparison with Data

- Line is produced fitting HERA I and Low Energy data ($Q^2 \geq 3.5$ GeV^2 cut) using standard HERAPDF1.0 settings fit;
  - Turn over is observed for 920 GeV NC e^+p data at low x and Q^2 (high y → F_L sensitivity) which is not reproduced by the fit.
- Investigate the low x and Q^2 region.



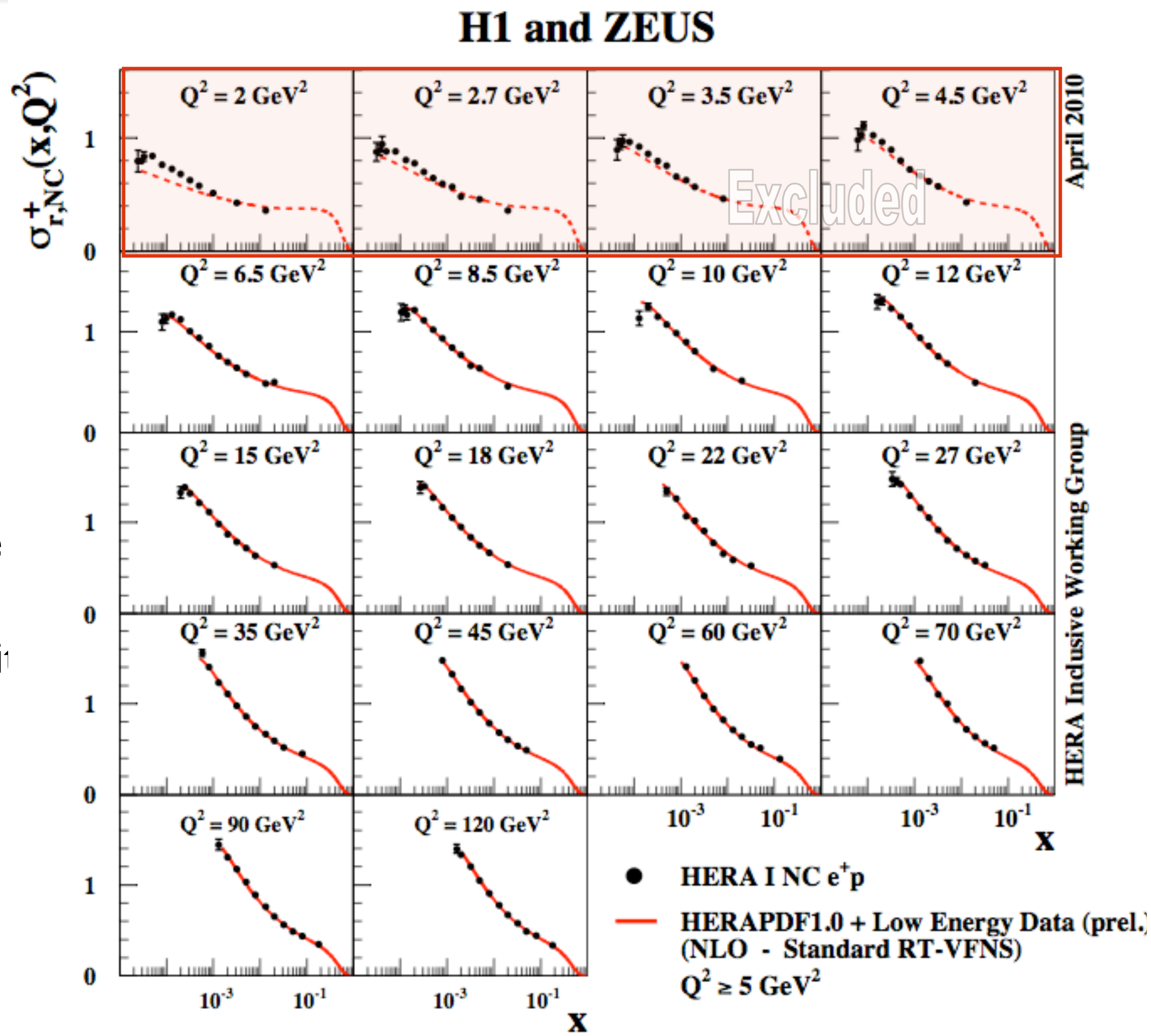
Study Q^2 Cut Dependence



- The $Q^2 \geq 5$ GeV^2 cut brings large improvement in χ^2 [818/806 → 698/771] and it yields different shapes for gluon and sea PDFs.
  - 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 (before Q^2 cut) with Magenta (after Q^2 cut):
  - Gluon is visibly enhanced for $Q^2 \geq 5$ GeV^2 cut.

Comparison with Data, Fit with Q^2 cut

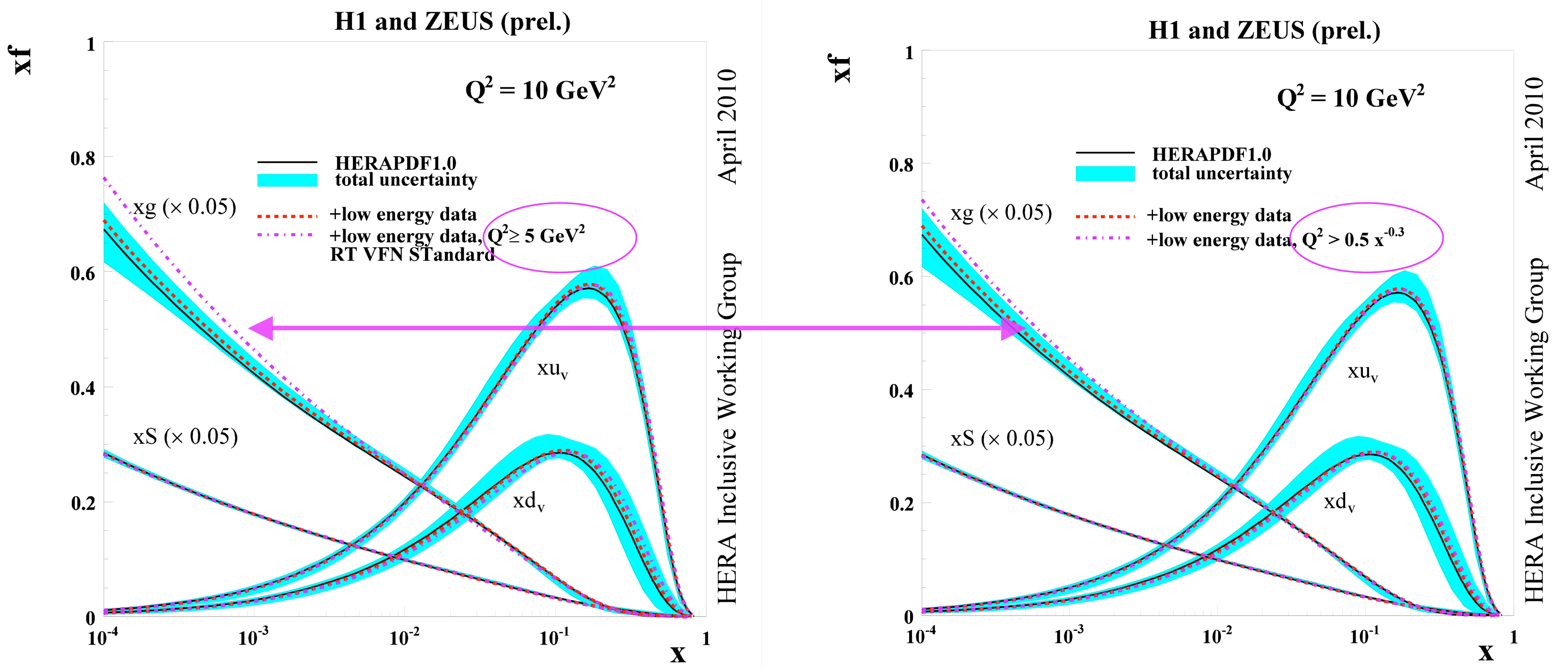
- Line is produced fitting HERA I and Low Energy data (with $Q^2 \geq 5$ GeV^2) using standard HERAPDF1.0 settings
  - Bad description in the region where data do NOT enter into the fi



Further Kinematic Cut Tests

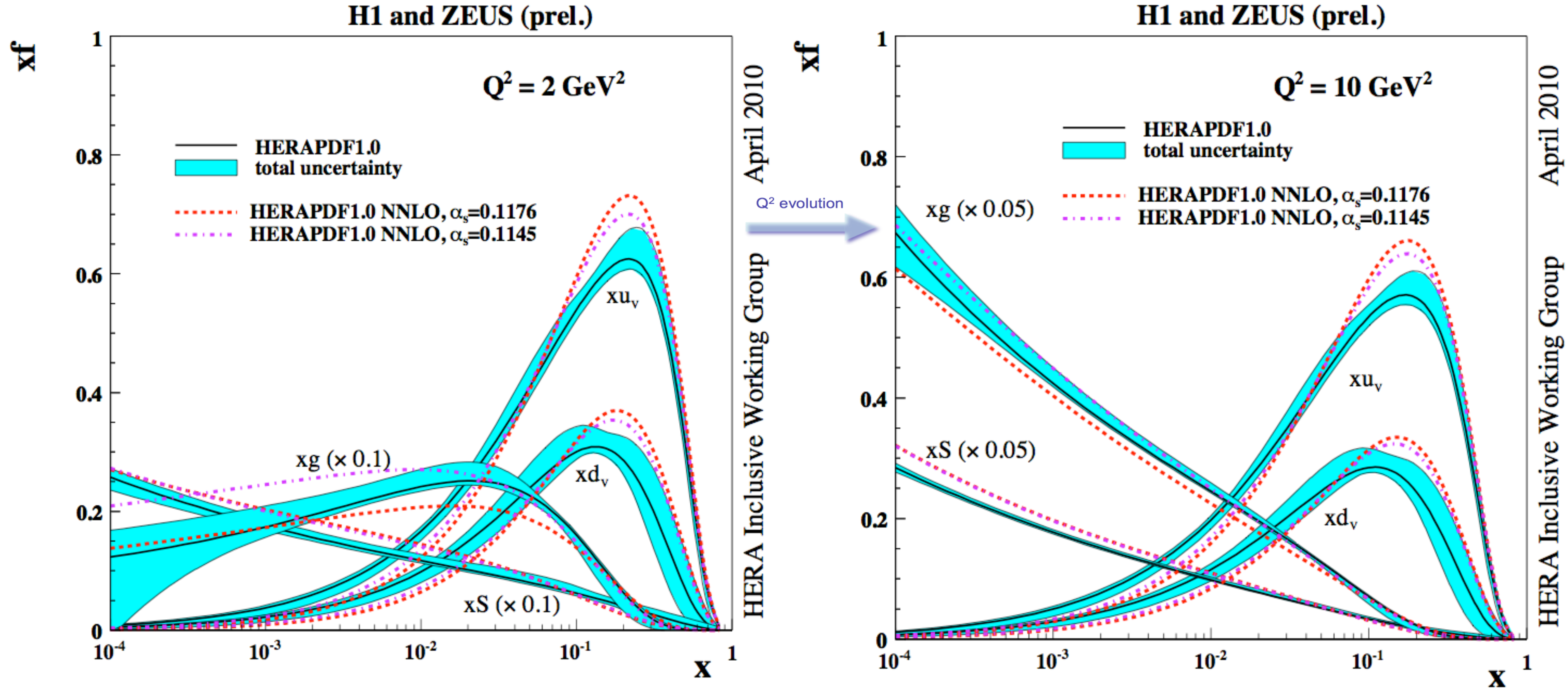
- Inspired by Fabrizio Caola's presentation at DIS2010 Workshop
[http://indico.cern.ch/contributionDisplay.py?contribId=189&confId=86184]:
  - Use a different cut criterion: $Q^2 > Q_S(x)^2 = Ax^{-\lambda}$ with λ=0.3 and varying A

Cut	Q^2>0.5$x^{-0.3}$	X>5 $\cdot 10^{-4}$	Q^2>5	No cut
All χ^2/dof	683.4/760	598.2/686	698.3/771	818/806
Low Energy data χ^2/npts	0.86 (199)	0.79 (161)	0.82 (215)	1.04 (224)



HERAPDF fits at NNLO

- Fits performed to HERA I data (as used for HERAPDF1.0) at NNLO using RT-VFNS:
  - $\alpha_S(Mz)$ at NLO = 0.1176 and $\alpha_S(Mz)$ at NNLO = 0.1145

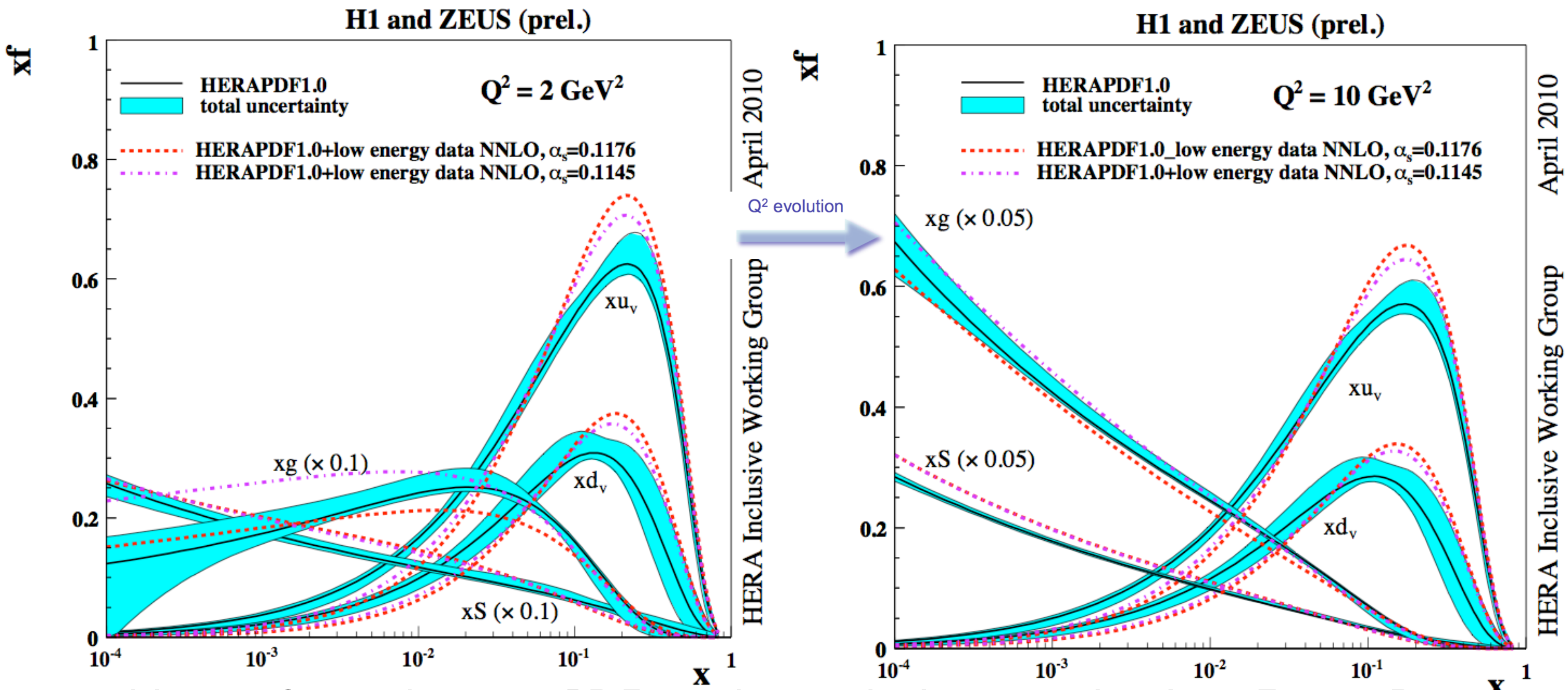


- Using the same settings as for HERAPDF1.0 NNLO fit does not improve fit results.

scheme	NNLO	NNLO	NLO
All χ^2/dof	623.7/582	638.3/582	574.4/582

NNLO HERAPDF fits including Low Energy Data

$\alpha_s(Mz)$ at NLO = 0.1176 and $\alpha_s(Mz)$ at NNLO = 0.1145



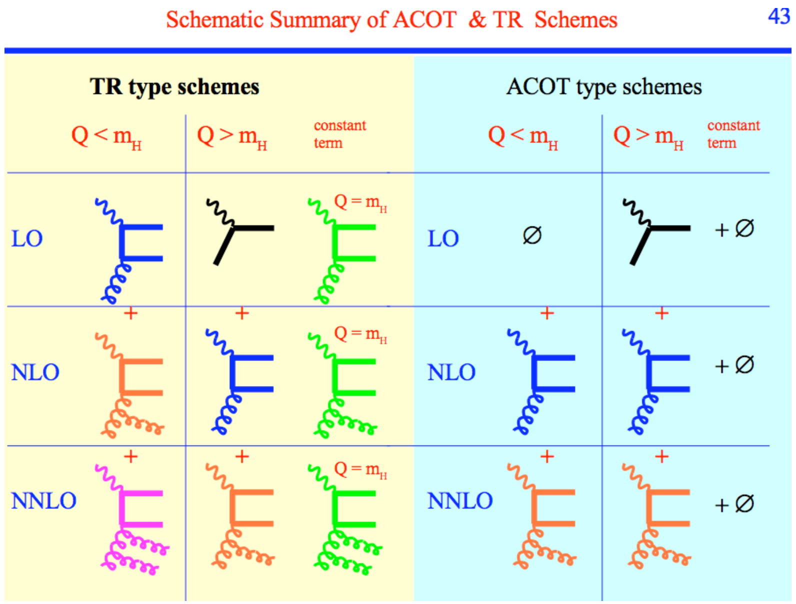
- No significant change in PDFs is observed when including Low Energy Data.

scheme	NNLO	NNLO	NLO
All χ^2/dof	911.5/806	893.2/806	818/806

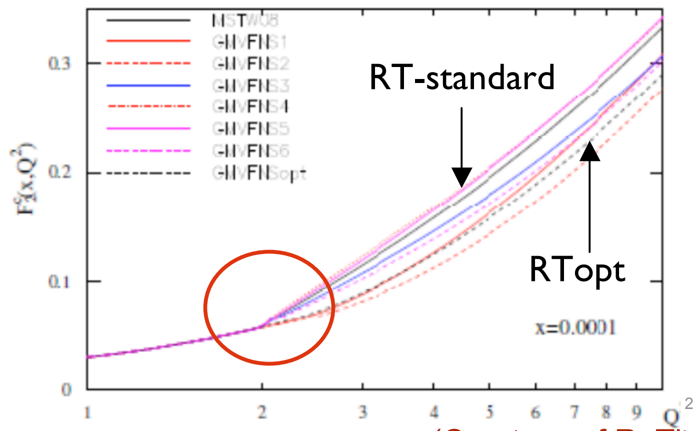
Various Heavy Flavour treatments at NLO

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

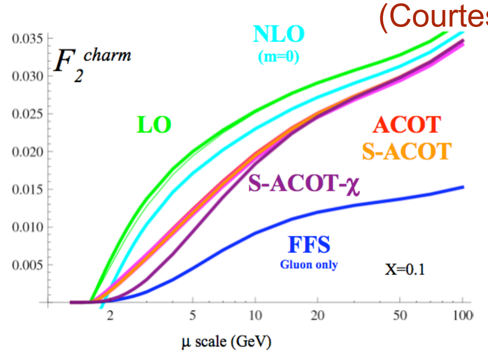
- Compare various schemes taking into account heavy quark production:
  - VFNS RT (standard [MSTW08] and optimal [R. Thorne's presentation])
  - VFNS ACOT (full [Phys.Rev.D50,1994] and χ [Phys.Rev.D62,2000])



(Courtesy of F. Olness)



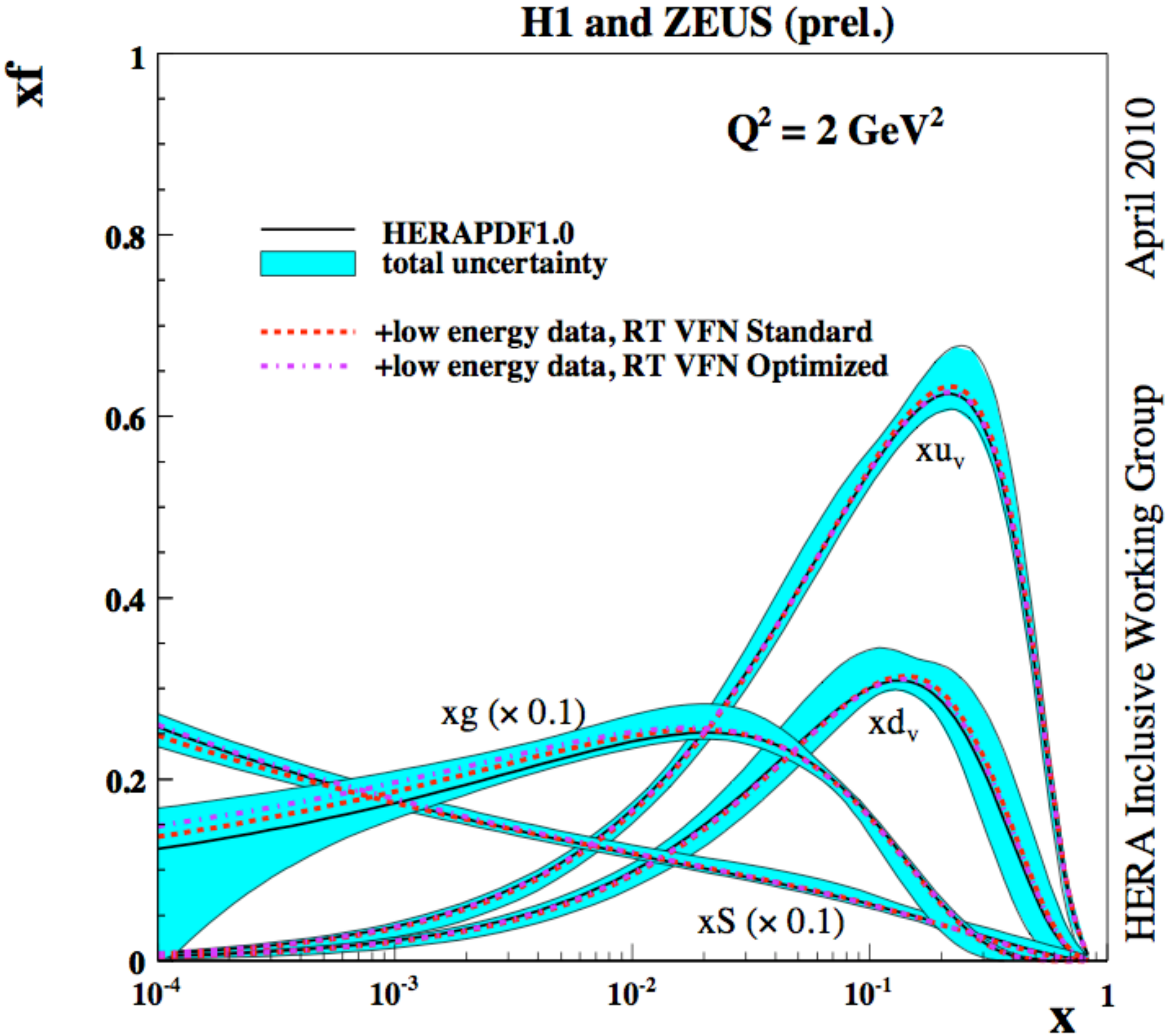
(Courtesy of R. Thorne)



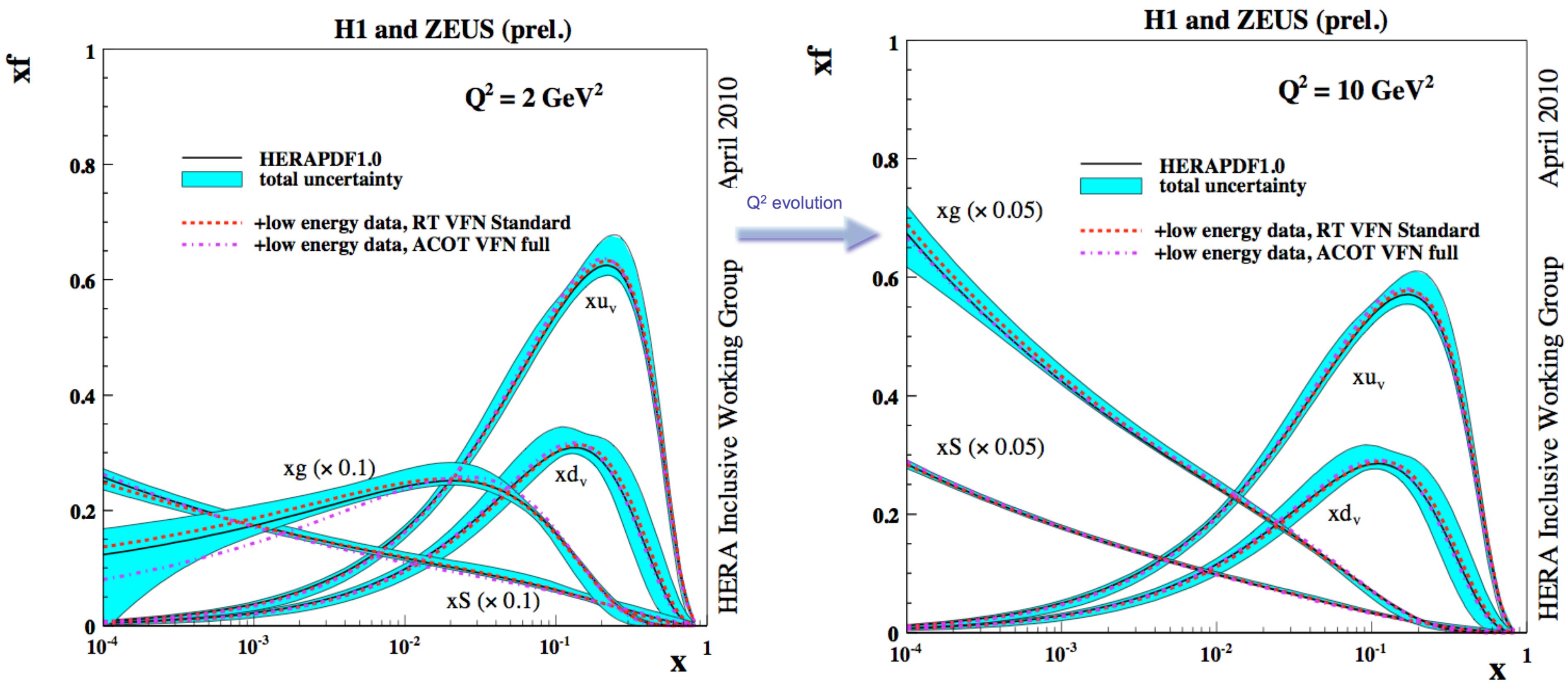
  - FFNS (from QCDNUM17v06 [M. Botje])
- We observe significant differences among these schemes → next slides.

RT schemes compared to HERAPDF1.0

- HERAPDF1.0 (blue) is compared to HERA NLO fits which include the low energy data using Standard and Optimal RT.
  - 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

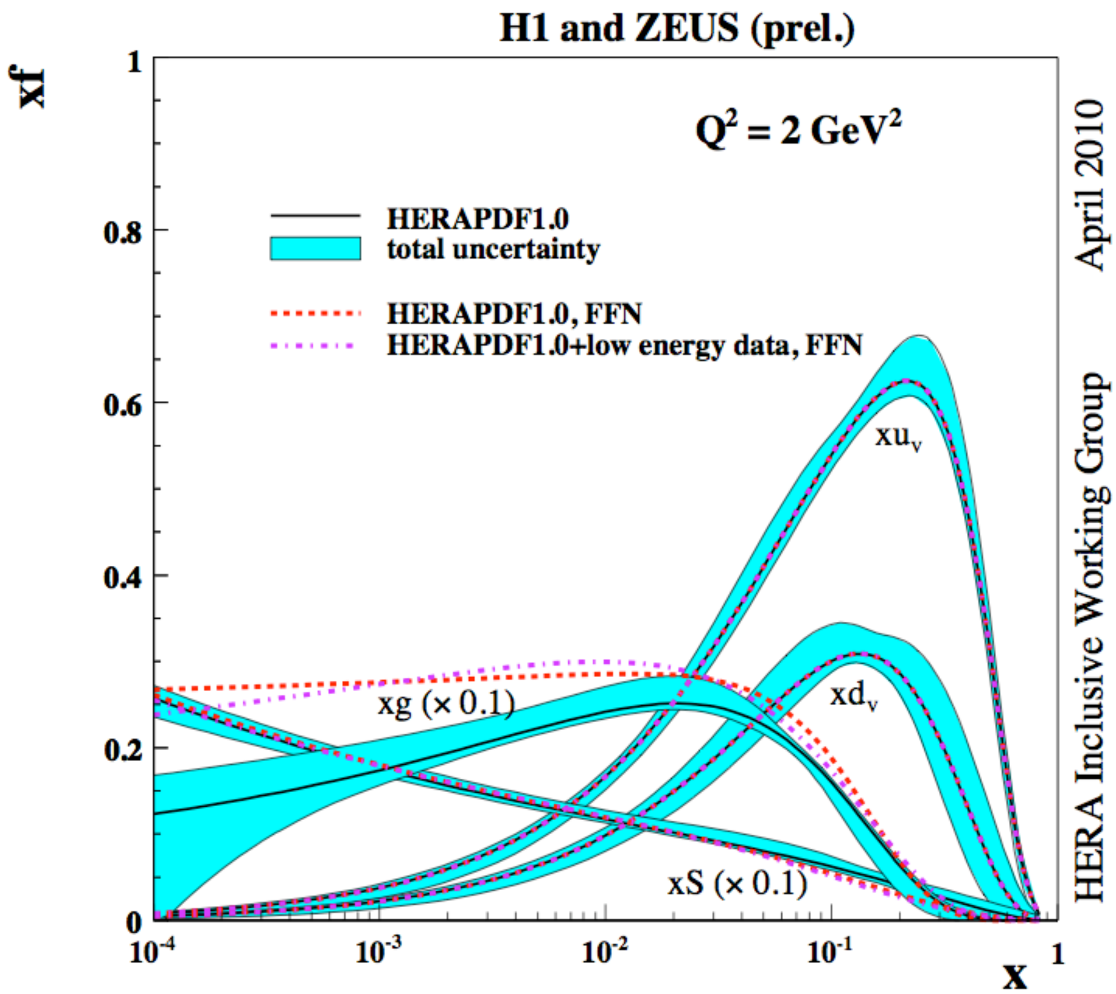


Compare fits to combined HERA I data including Low Energy Data using the ACOT (full) scheme to the RT standard scheme (VFNS):

- 30 Units improvement in χ^2 when using ACOT scheme!
- Large differences in the gluon at the starting scale, which are reduced with higher Q^2

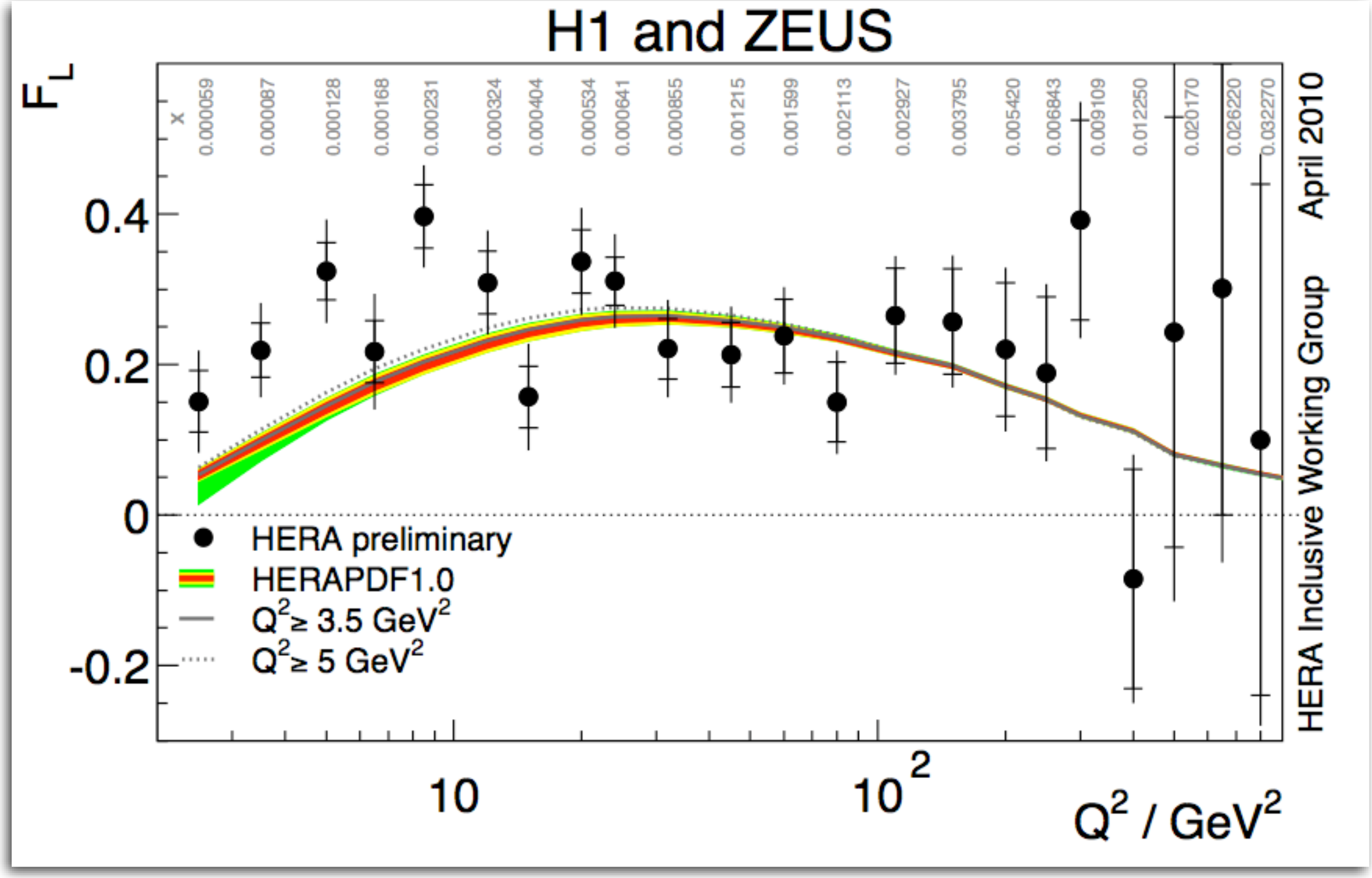
FFNS fits including Low Energy Data

- FFNS (nf=3) results in a similar improvement in χ^2 as observed for ACOT (VFNS) scheme in contrast to RT (VFNS).
  - xF_3 and CC predictions are not available within FFNS scheme, hence we freeze the valence parameters and do not fit for CC data.
- Not much difference is observed between FFNS scheme fits with or without low energy data.
- HERAPDF1.0 (VFNS) is shown as an illustration.



HERA F_L data vs F_L predictions

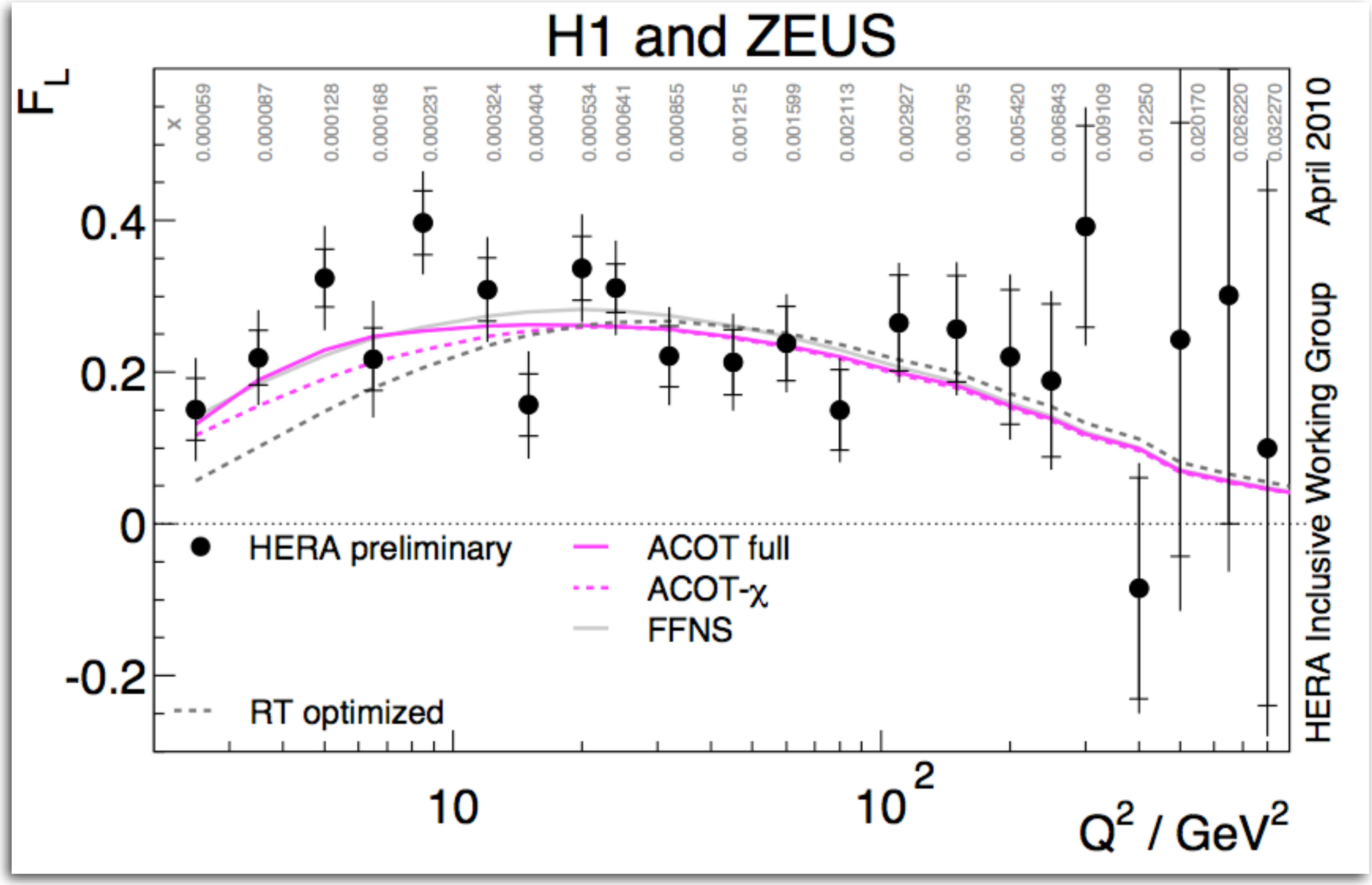
The lines are F_L predictions using combined HERA I and low energy data.



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

HERA F_L data vs F_L predictions

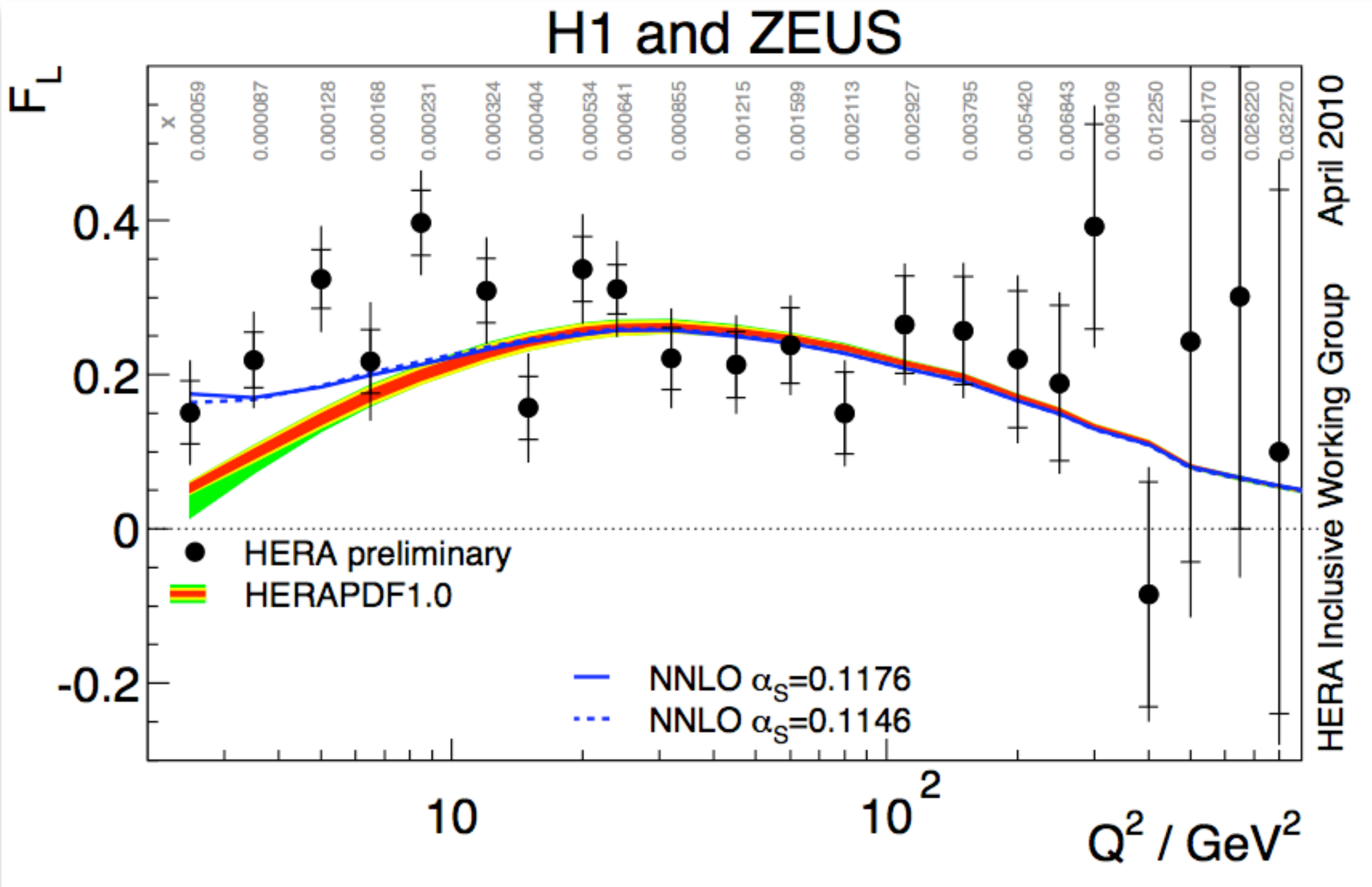
The lines are F_L predictions using combined HERA I and low energy data.



Various Heavy Flavour schemes: best ACOT(full) and FFNS

HERA F_L data vs F_L predictions

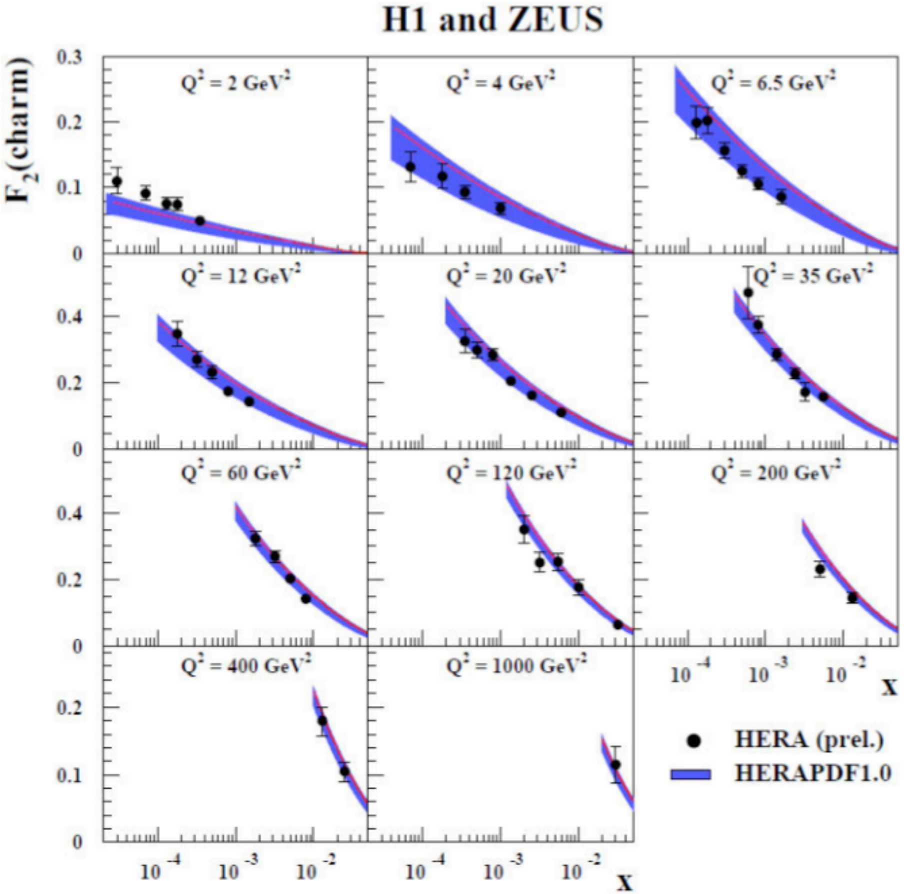
The lines are F_L predictions using combined HERA I and low energy data.



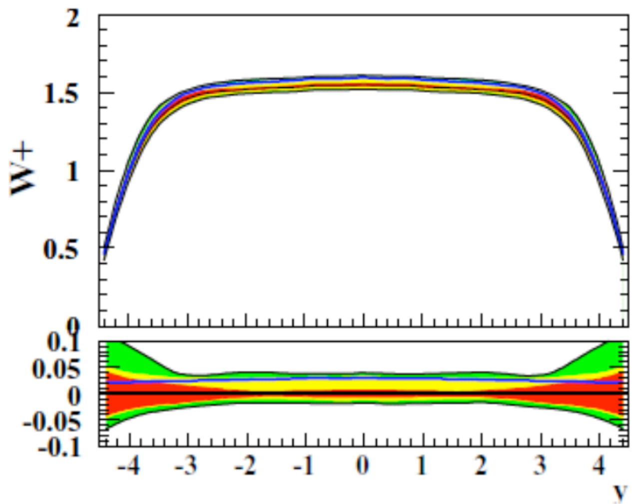
NNLO (RT) prediction yields interesting behaviour at low Q^2

PDF fit sensitivity to Charm mass

- Unlike inclusive data, fits to charm data are sensitive to the choice of the m_c:
  - PDF fits are usually done with m_c=1.4 GeV, but the pole mass is m_c=1.65 GeV.
    - In the published HERAPDF1.0 fit the charm mass varies between m_c=1.35 GeV (top of error band) and m_c=1.65 GeV (bottom of error band)

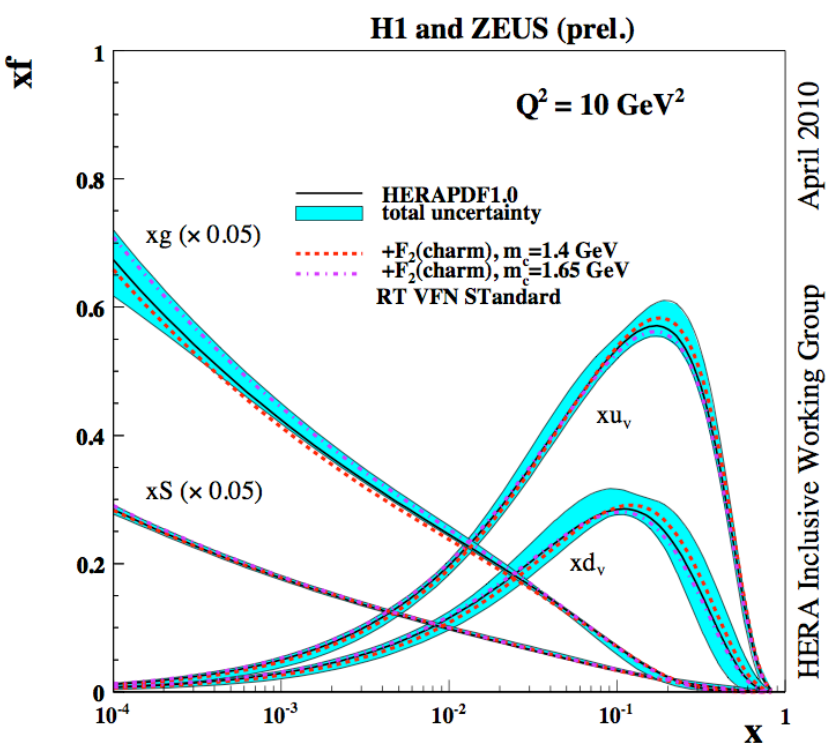


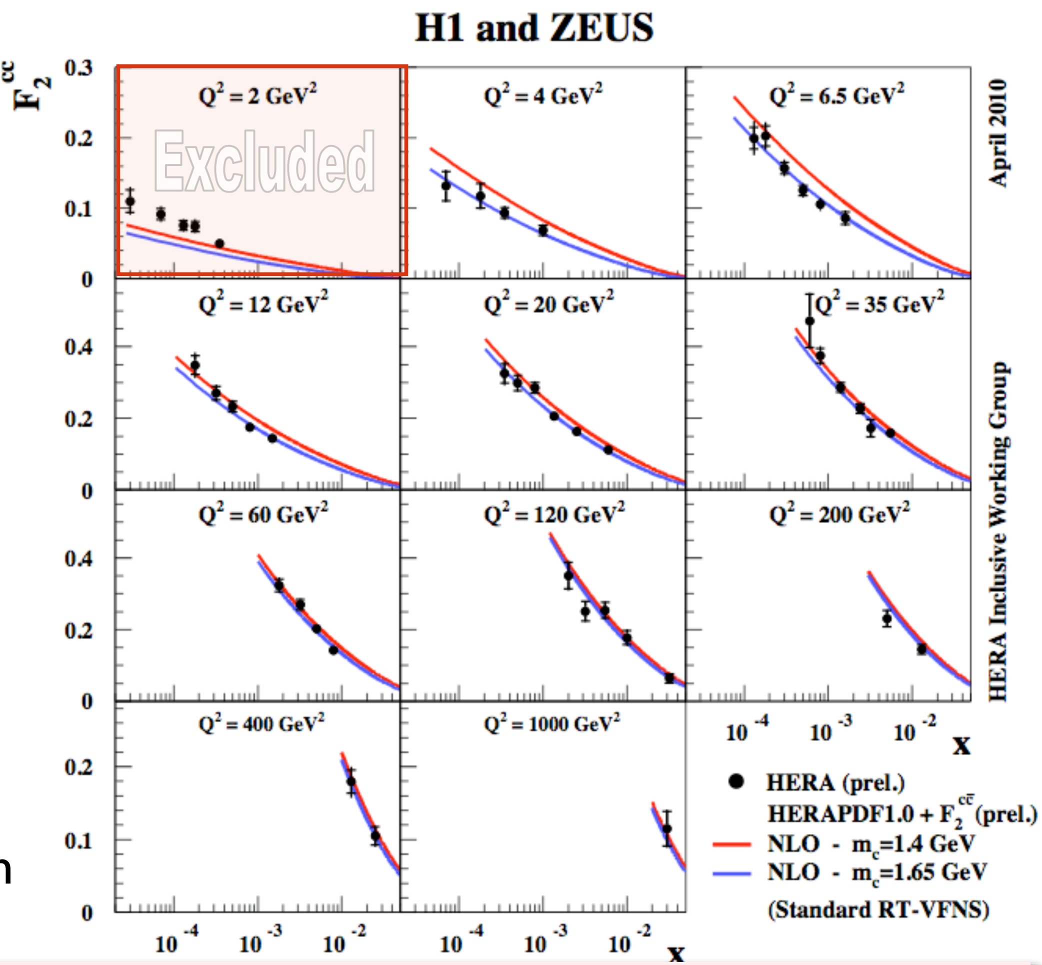
W and Z rapidity distributions



The choice of the charm mass has significant effect on the W/Z cross section predictions at the LHC, raising it by ~3% (blue line)

HERAPDF fits with Charm data: RT standard

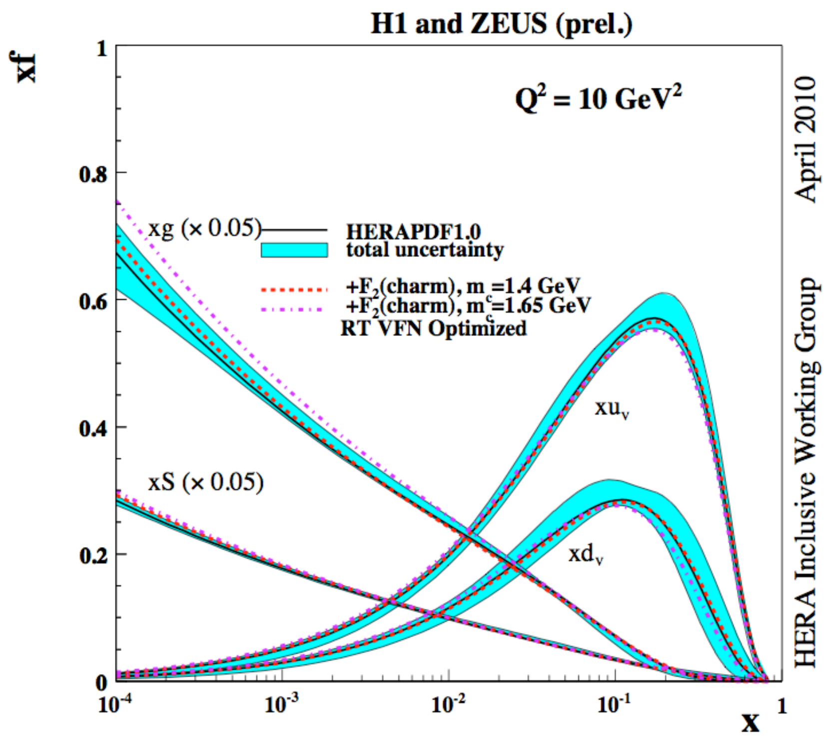


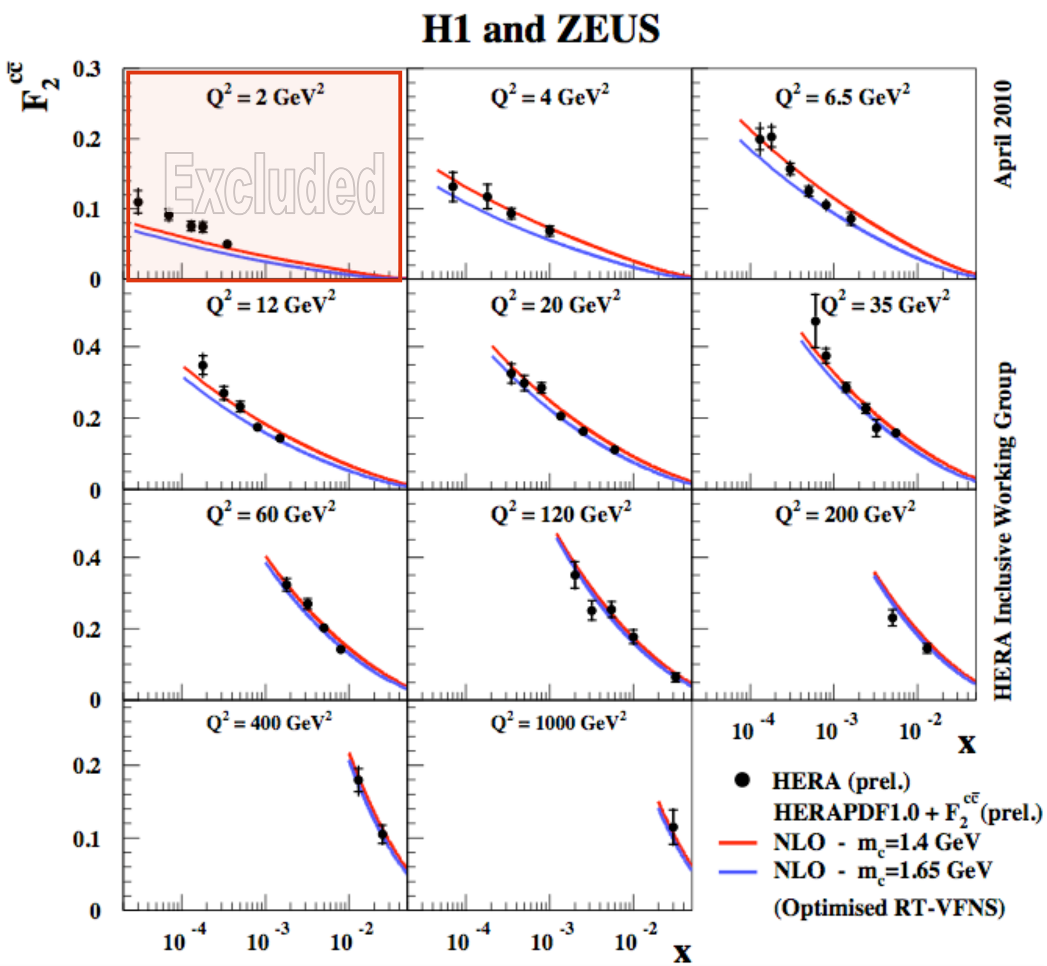


- Higher charm mass results in a suppressed F_2^c, but enhanced gluon at low-x

- When using RT VFN standard scheme, data prefer fit with m_c=1.65 GeV
  - For mc=1.65 GeV: Total: χ^2/ndf=627.5/633
  - For mc=1.40 GeV: Total: χ^2/ndf=730.7/633

HERAPDF fits with Charm data: RT optimised

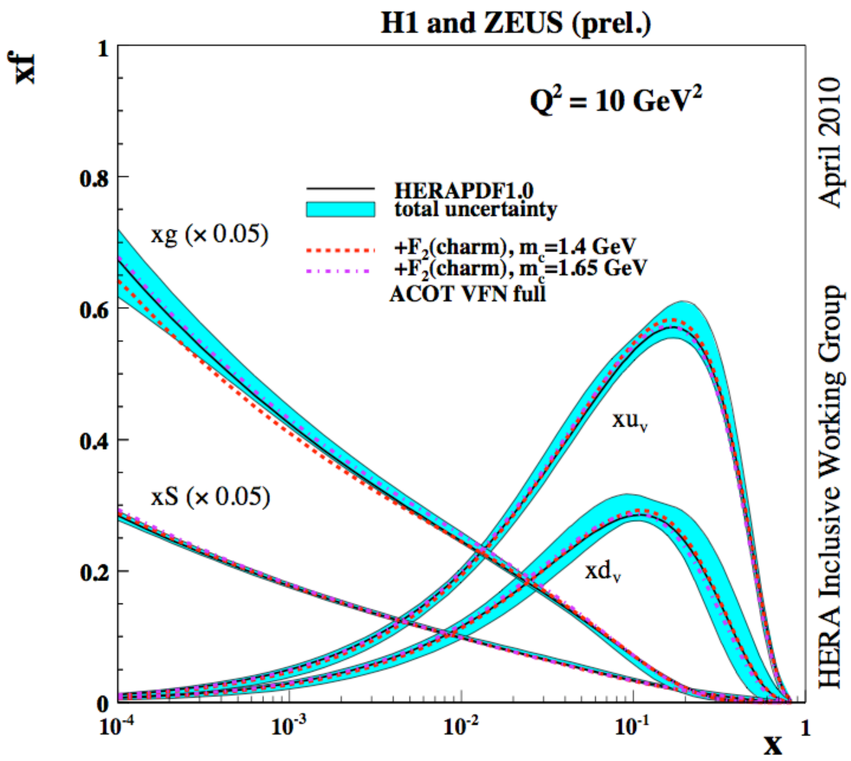


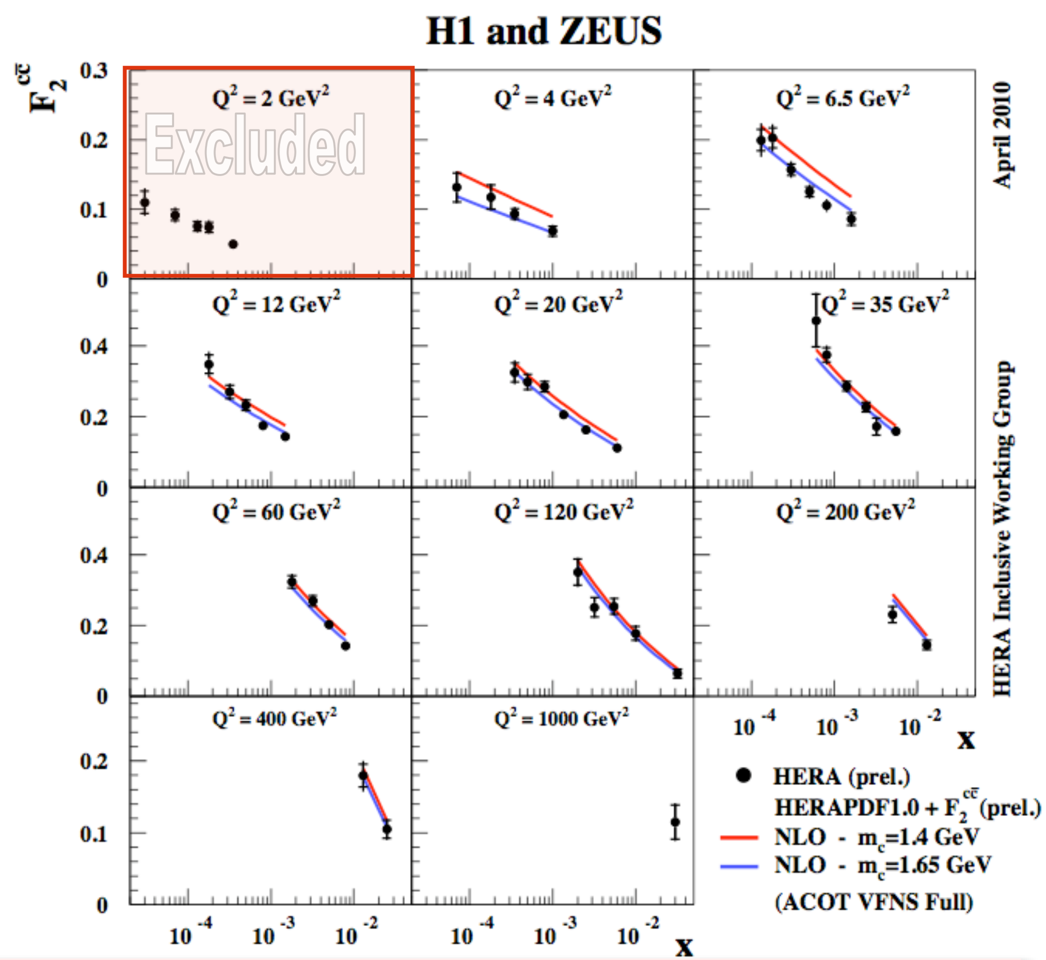


- Higher charm mass results in a suppressed F_2^c, but enhanced gluon at low-x

- When using RT optimal scheme, data prefer fit with m_c=1.4 GeV
  - For mc=1.65 GeV: Total: χ^2/ndf=695.4/633
  - For mc=1.40 GeV: Total: χ^2/ndf=644.6/633

HERAPDF fits with Charm data: ACOT



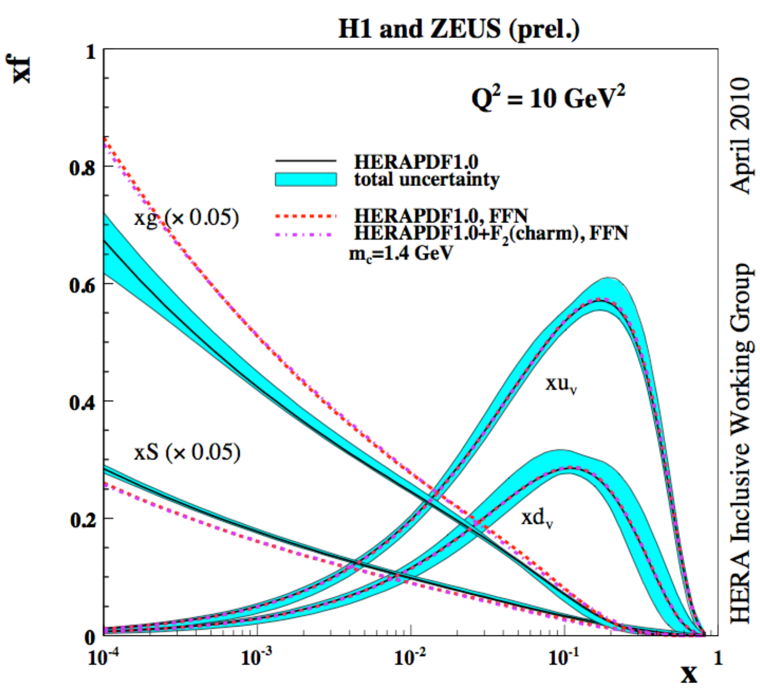


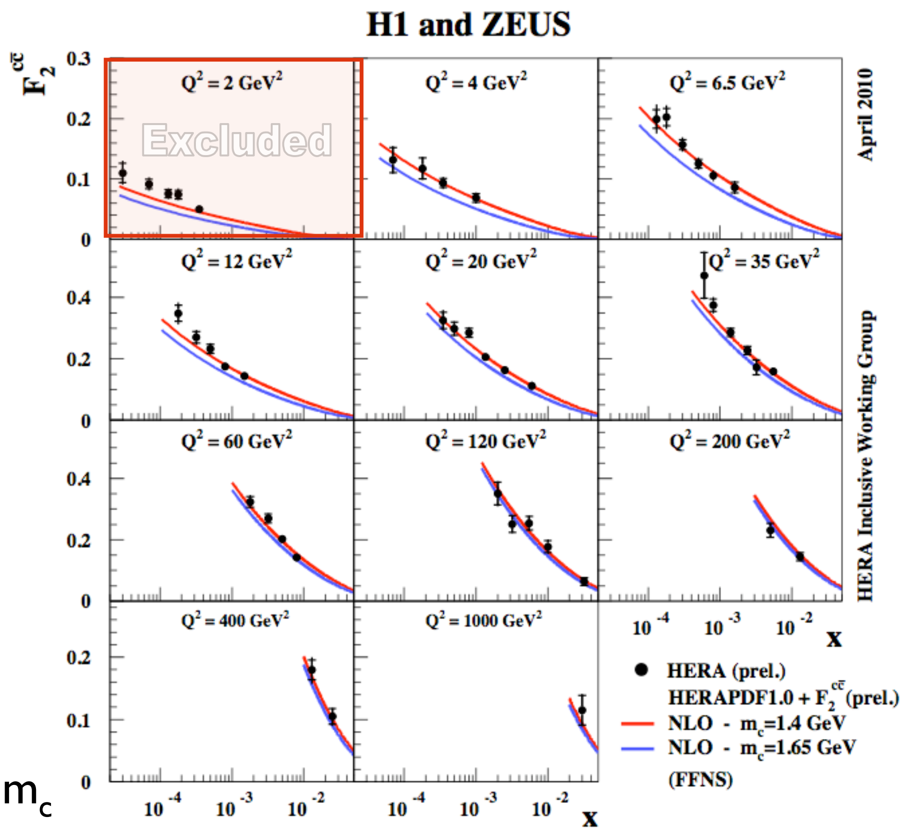
- ACOT gluon shape is suppressed compared to standard RT VFNS used for HERAPDF1.0

- When using ACOT full scheme, data prefer fit with m_c=1.65 GeV
  - For mc=1.65 GeV: Total: χ^2/ndf=605.7/633
  - For mc=1.40 GeV: Total: χ^2/ndf=653.9/633

HERAPDF fits with Charm data: FFNS

- Use heavy quark factorisation scale Q^2+4mc^2 (small difference to Q^2 scale)
- FFNS for nf=3, hence use α_S for 3 flavours - with $\alpha_S(M_Z^2) = 0.105$



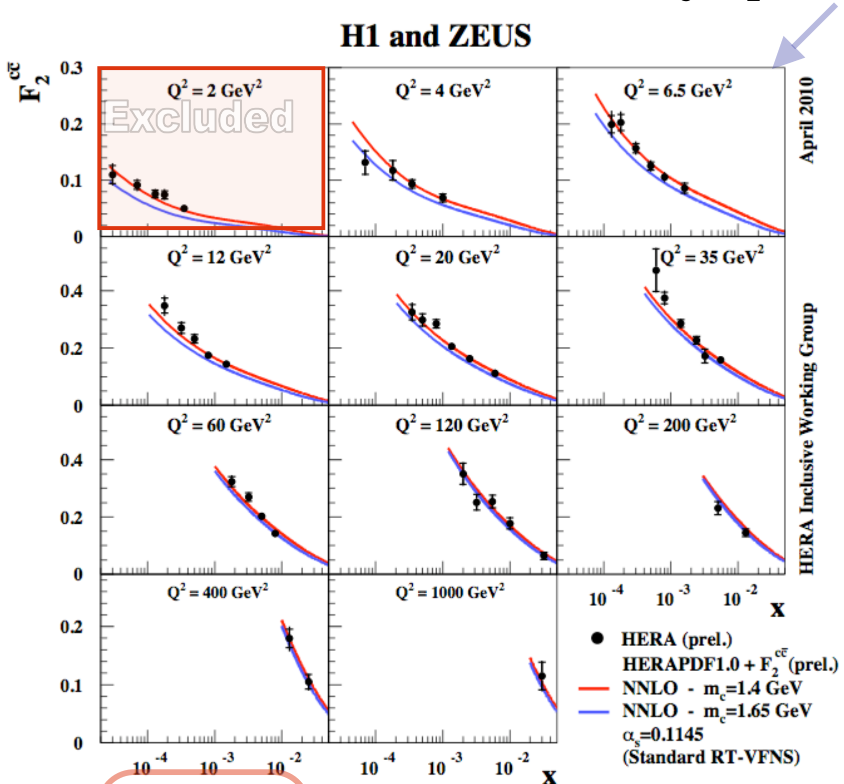


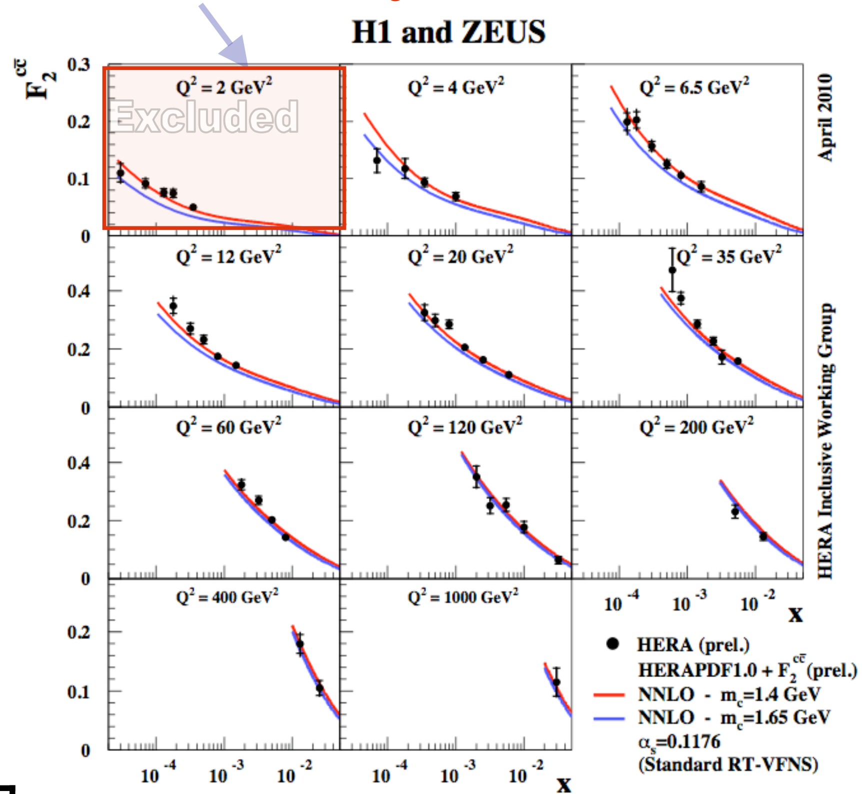
- F_2^c in FFNS is relatively suppressed, hence does not need a larger value for m_c to suppress the F_2 charm predictions.

- When using FFNS scheme, data prefer fit with m_c=1.4 GeV
  - For mc=1.65 GeV: Total: χ^2/npts=852.0/565
  - For mc=1.40 GeV: Total: χ^2/npts=567.0/565

HERAPDF fits with Charm data: NNLO fits

- NNLO fits to charm data are performed using the Standard RT VFNS
- Variations of schemes are considerably reduced at NNLO
  - Performed NNLO fits for $\alpha_S(M_Z)$=0.1145 and 0.1176 and m_c=1.4 and 1.65 GeV



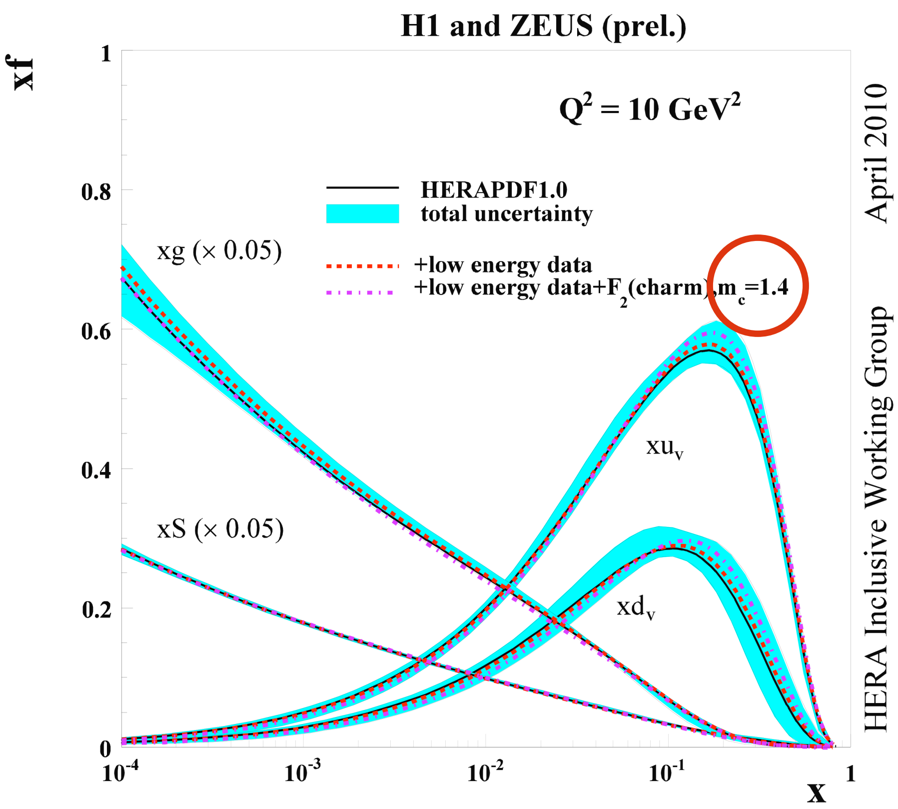


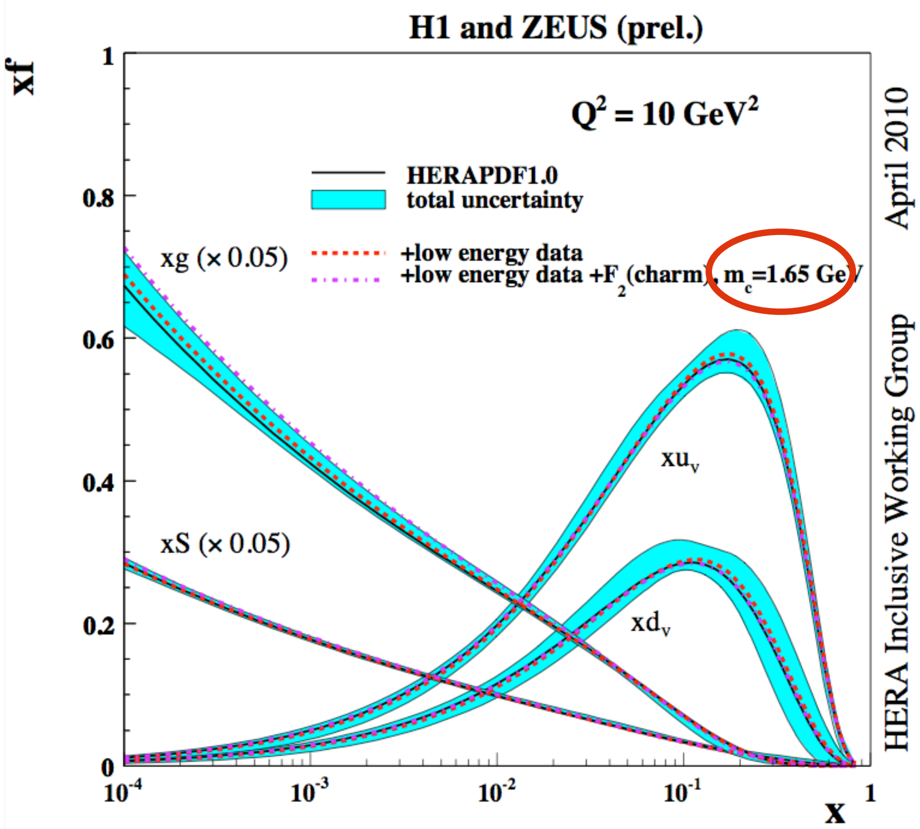
NNLO	α_S=0.1145, m_c=1.4	α_S=0.1145, m_c=1.65	α_S=0.1176, m_c=1.4	α_S=0.1176, m_c=1.65
χ^2/ndf	681/633	832/633	703/633	862/633

→ NNLO fit with $\alpha_S(M_Z)$=0.1145 And m_c=1.4 is preferred.

Fits including Low Energy and Charm data

- When including both Low Energy and Charm data in the HERA fits, conclusions about sensitivity to heavy quark schemes and charm mass are not altered.
- Conclusions about sensitivity to the kinematic cut dependence are not altered when including both data in the fit as long as the optimal choice for m_c is made.





Summary

- New preliminary low energy data have been included in the HERAPDF QCD fits
- New fits are in general in agreement with HERAPDF1.0 fits, but do not provide a good fit of the low Q^2 region:
  - Observe large sensititivity to kinematic cut at low Q^2 and low x
  - Inclusion of the new data brings sensitivity to Heavy Flavour model treatments:
    - ACOT (VFNS) and FFNS: decrease χ^2 considerably (compared to standard RT)
    - Different Heavy Flavour treatment in the fit yield interestingly different F_L prediction!
- With HERAPDF1.0 settings HERAPDF fits at NNLO (RT-VFNS) were presented:
  - NNLO fit does not improve when using HERAPDF1.0 settings
  - NNLO fits including the low energy data also don't bring improvement w/rt NLO
- New preliminary charm data have been included in the HERAPDF fits:
  - Fits of charm data are sensitive to the charm mass and the heavy quark scheme
- Simultaneous fits including low energy and charm data do not alter the conclusions from above.

- Low Q2 region remains very interesting for further QCD tests!

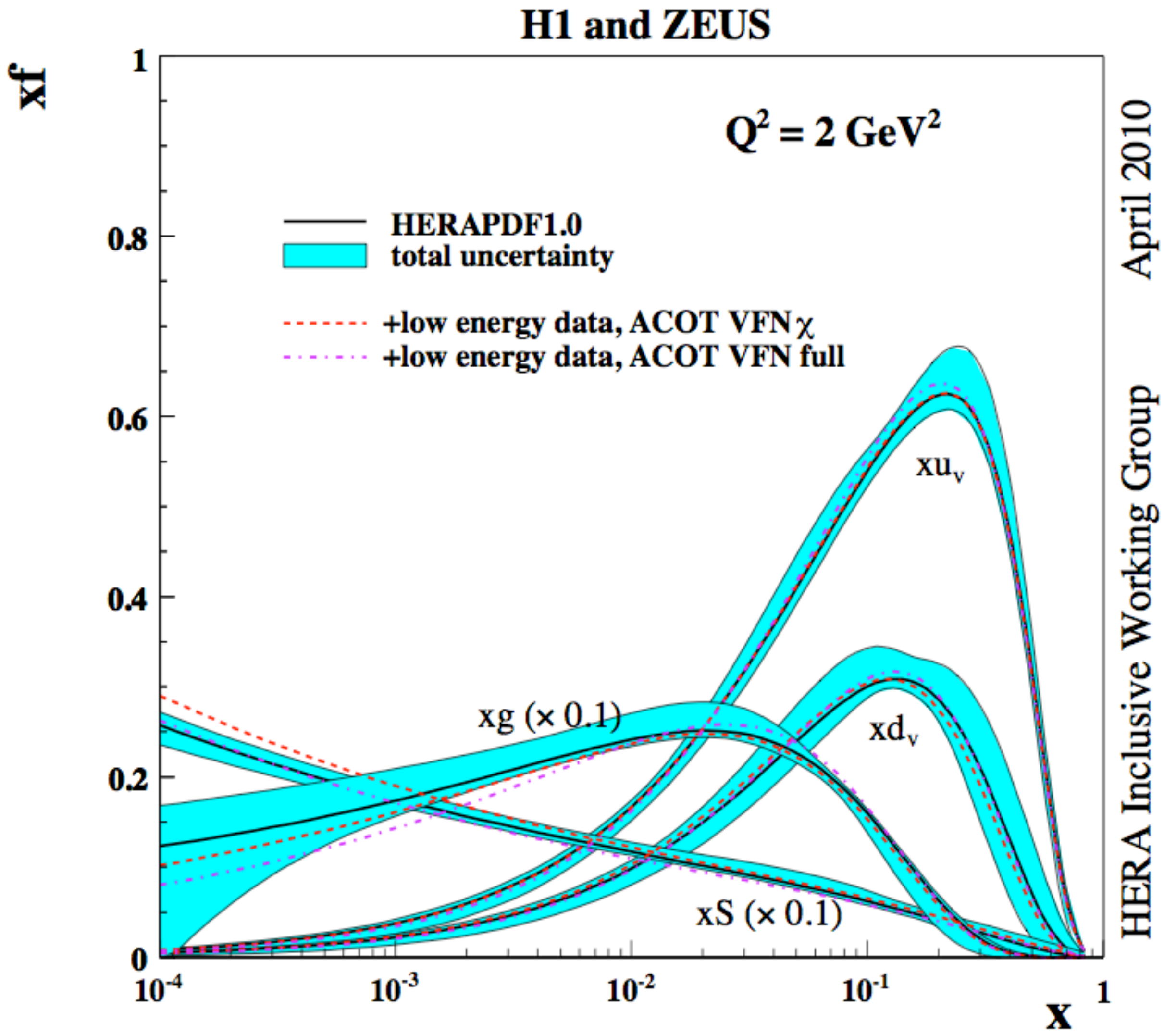
H1-ZEUS combined results

https://www.desy.de/h1zeus/combined_results/index.php

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



Parametrisation and Model checks

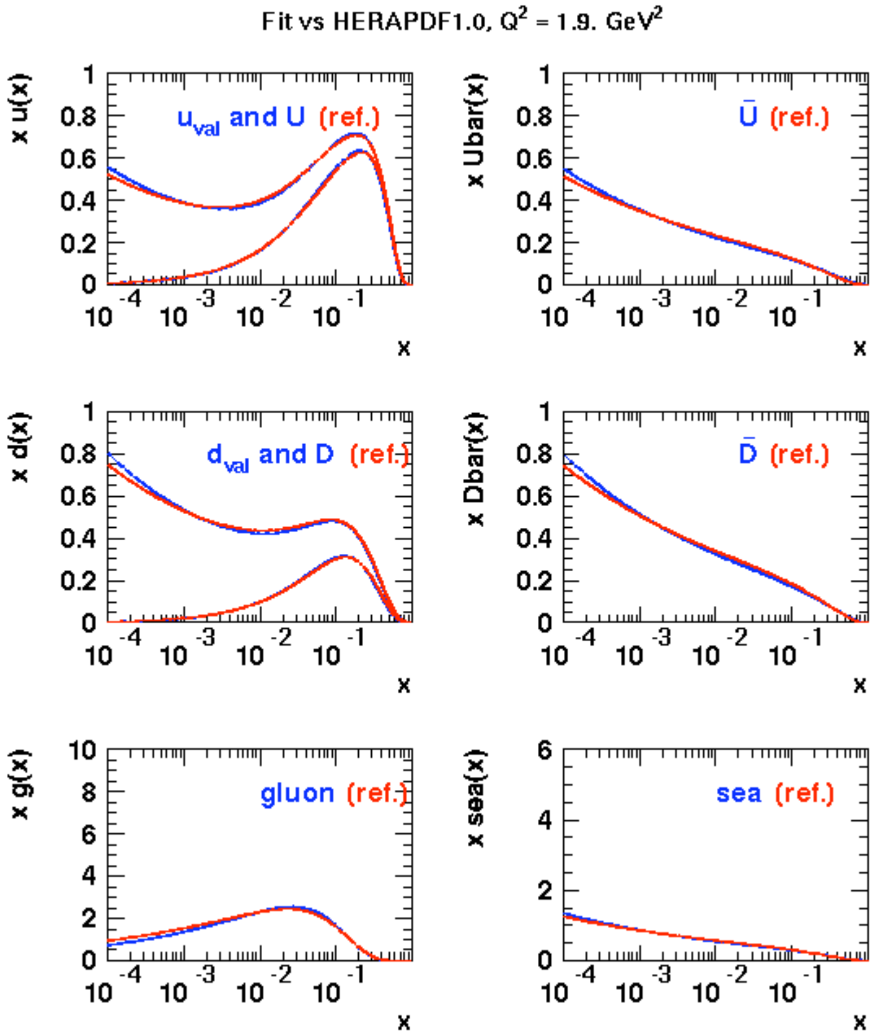
Parameterisation variations and model assumptions were performed similarly to HERAPDF1.0 [J. Sztuk's presentation]

- 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.

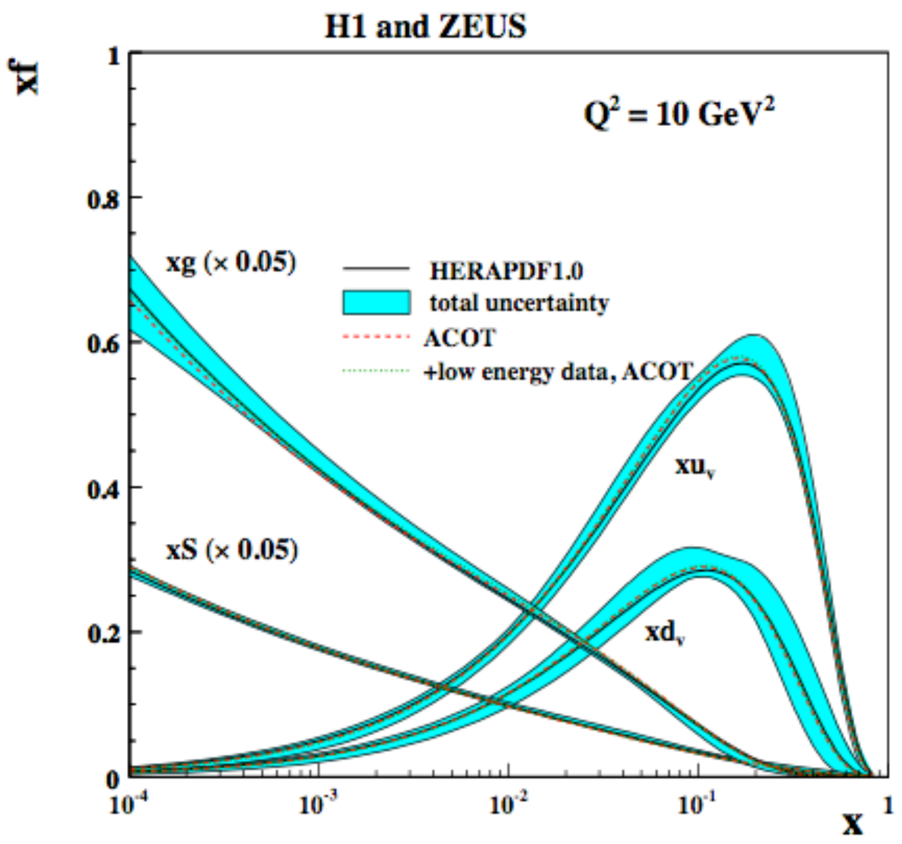
Reminder on HF checks on HERA data alone

- 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

Reminder on HF checks on HERA data alone

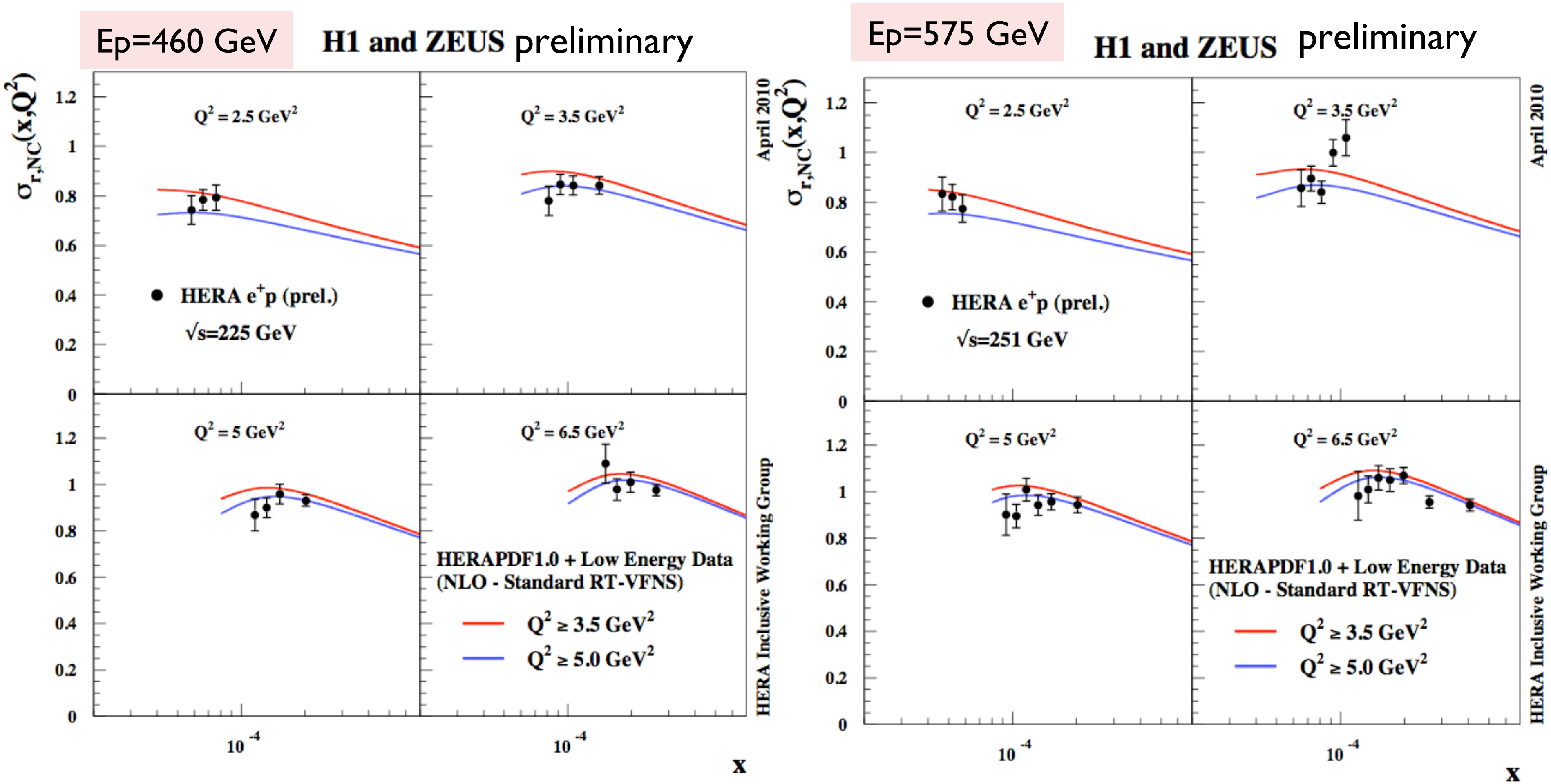


- RT: chi2/dof = 574/582
- ACOT: chi2/dof=562/582

- 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

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 $y>0.35$.



ACOT schemes

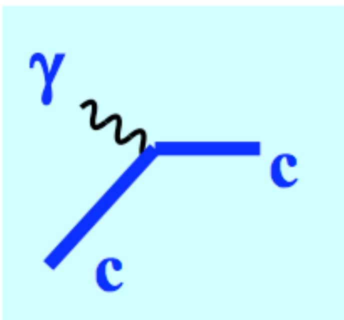
- [Fred Olness]

Effect of Kinematic Mass Re-Scaling

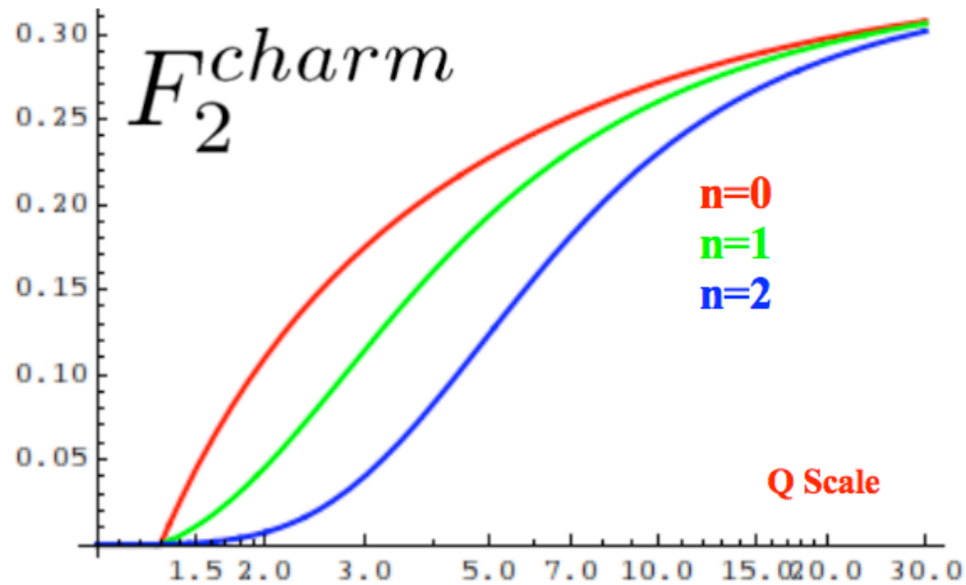
ACOT (Aivazis, Collins, Olness, Tung) A general framework for including the heavy quark components.
Phys.Rev.D50:3102-3118,1994.

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.



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



Optimal cut?

- Is there a cut which can bring the high energy data alone and extension of the high energy data to low energy data into agreement?

Cut	$Q^2 > 1.0\ x^{-0.3}$	$Q^2 > 1.0\ x^{-0.3}$	$X > 5 \cdot 10^{-4}$	No cut
All $\chi 2$/dof	683.4/760	683.4/750	598.2/686	818.5/806
NCe+ $\chi 2$/dof	0.95 (330)	0.97 (330)	0.97 (322)	1.13 (379)
LER $\chi 2$/dof	N/A	0.82 (181)	0.79 (161)	1.04 (224)

- The saturation based cut looks optimal for A=1.0:
  - The high energy data and high energy + low energy data results look similar
  - This cut is no more dramatic than the low x cut.

→ Very interesting initial studies and more explorations are needed!

Saturation inspired cut