HERAPDF fits update

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PDF4LHC July 4th 2010

We have more combined H1 + ZEUS data:

The low energy run data which was used to measure FL has been combined

The F2(charm) data has been combined

AND

STOP PRESS anouncement: HERA-II inclusive cross-section combination to go preliminary at ICHEP2010

This talk

•HERA-I plus low energy run data - from DIS10 and beyond

•NNLO fits – to be made publically available

•HERA-I plus F2(charm) data- from DIS10

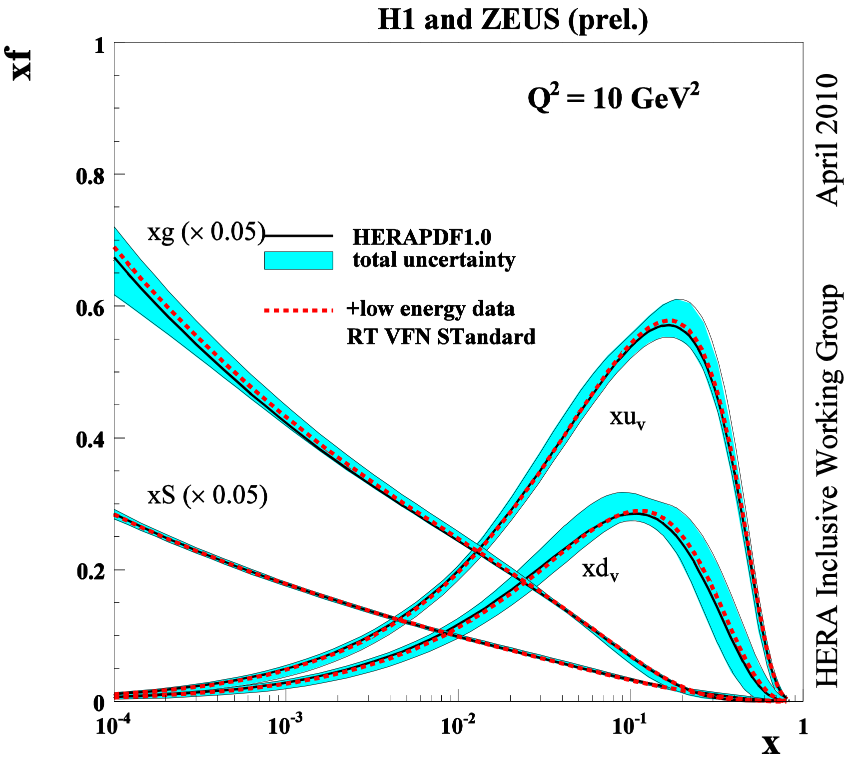
•HERA-1 plus F2(charm) plus low energy run data- post DIS10

Add combined data from runs at lower energies to the HERA-1 fit using the standard formalism

No significant difference at first sight

AND no great improvement in experimental PDF uncertainties either…

In fact model dependent PDF uncertainties may even have increased…

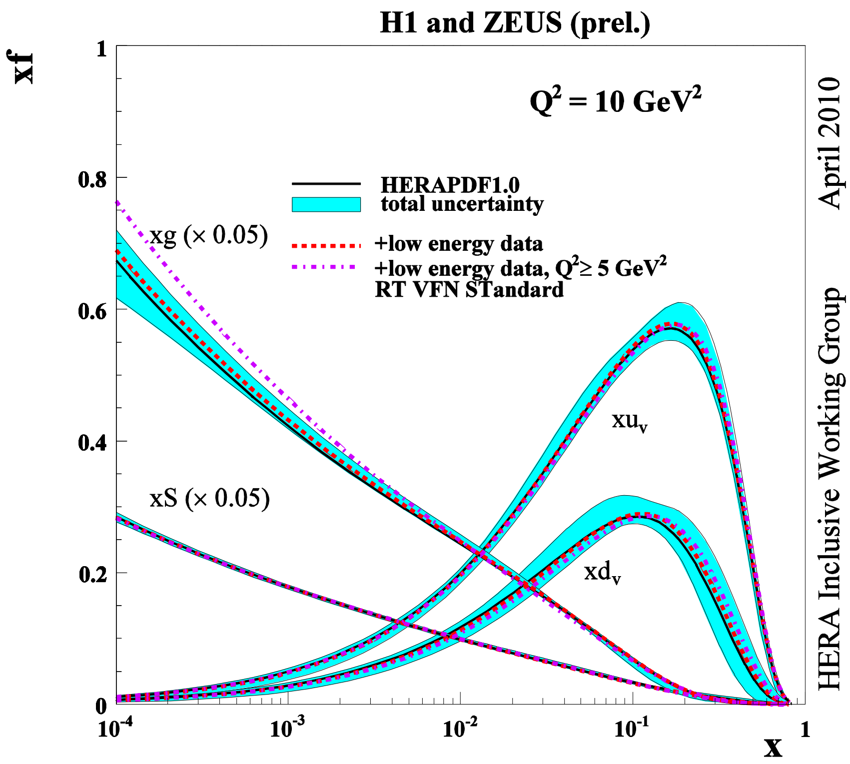


STANDARD VFN	
χ2 574.4/582	
X/N CCEP =	0.87 34
X/N CCEM =	0.58 34
X/N NCEP=	1.10 379
X/N NCEM=	0.74 145

Standard VFN	
χ2 818.5/806	
X/N CCEP =	0.86 34
X/N CCEM =	0.58 34
X/N NCEP=	1.13 379
X/N NCEM=	0.74 145
X/N NCEP 460/575	
	= 1.04 224

Perform all the usual model and parametrisation changes:

One change makes a significant difference- raising Q^2 minimum to 5 GeV^2



And it also improves the χ2 for NCe+p

for both the low energy run data and the older HERA-I data

But it's the low energy data which pull the central values outside the error band

Standard VFN

χ2 818.5/806

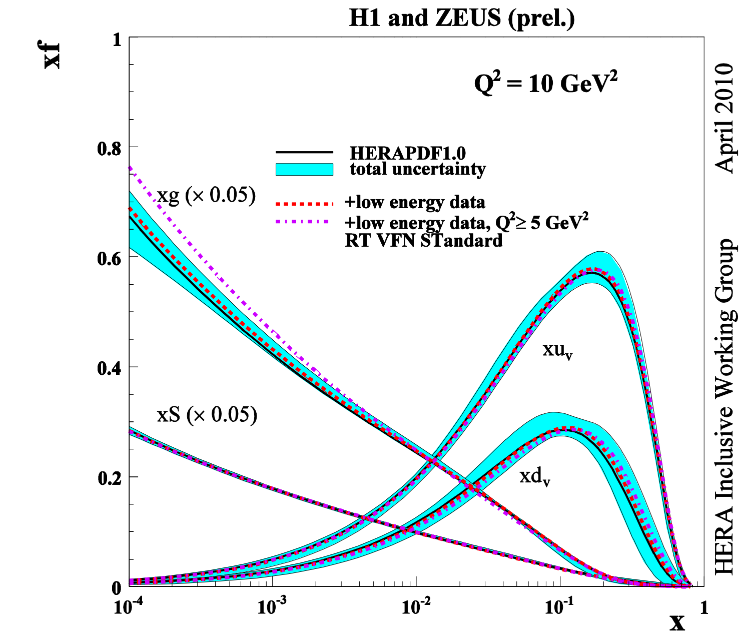
X/N CCEP =	0.86 34
X/N CCEM =	0.58 34
X/N NCEP=	1.13 379
X/N NCEM=	0.74 145
X/N NCEP 460/575 =	1.04 224

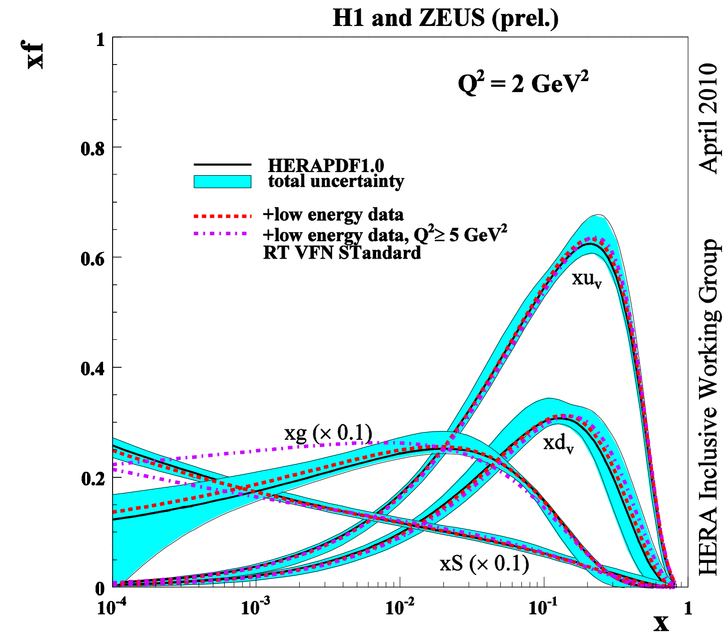
Standard VFN

$Q^2 > 5$

X2/ndf 698.3/771

X/N CCEP =	0.85 34
X/N CCEM =	0.58 34
X/N NCEP=	1.03 353
X/N NCEM=	0.75 145
X/N NCEP 460/575 =	0.82 215


H1 and ZEUS (prel.)
xf
$Q^2 = 10$ GeV^2
HERAPDF1.0
total uncertainty
+low energy data
+low energy data, $Q^2 \geq 5$ GeV^2
RT VFN STandard
xg (× 0.05)
xS (× 0.05)
xu_v
xd_v
x
April 2010
HERA Inclusive Working Group


H1 and ZEUS (prel.)
xf
$Q^2 = 2$ GeV^2
HERAPDF1.0
total uncertainty
+low energy data
+low energy data, $Q^2 \geq 5$ GeV^2
RT VFN STandard
xu_v
xd_v
xg (× 0.1)
xS (× 0.1)
x
April 2010
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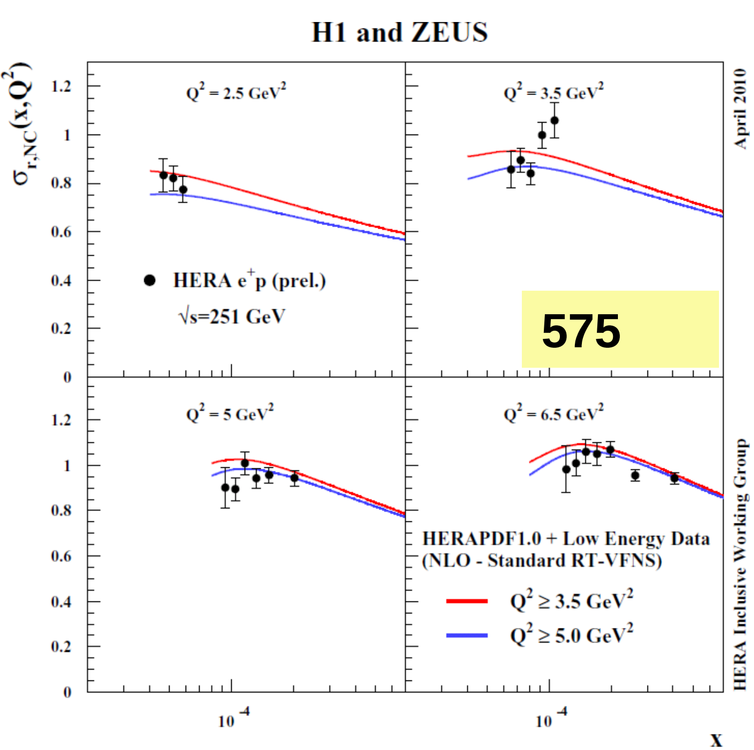
H1 and ZEUS
$\sigma_{r,NC}(x,Q^2)$
$Q^2 = 2.5$ GeV^2
$Q^2 = 3.5$ GeV^2
$Q^2 = 5$ GeV^2
$Q^2 = 6.5$ GeV^2
HERA e^+p (prel.)
$\sqrt{s}$=251 GeV
575
HERAPDF1.0 + Low Energy Data
(NLO - Standard RT-VFNS)
$Q^2 \geq 3.5$ GeV^2
$Q^2 \geq 5.0$ GeV^2
x
April 2010
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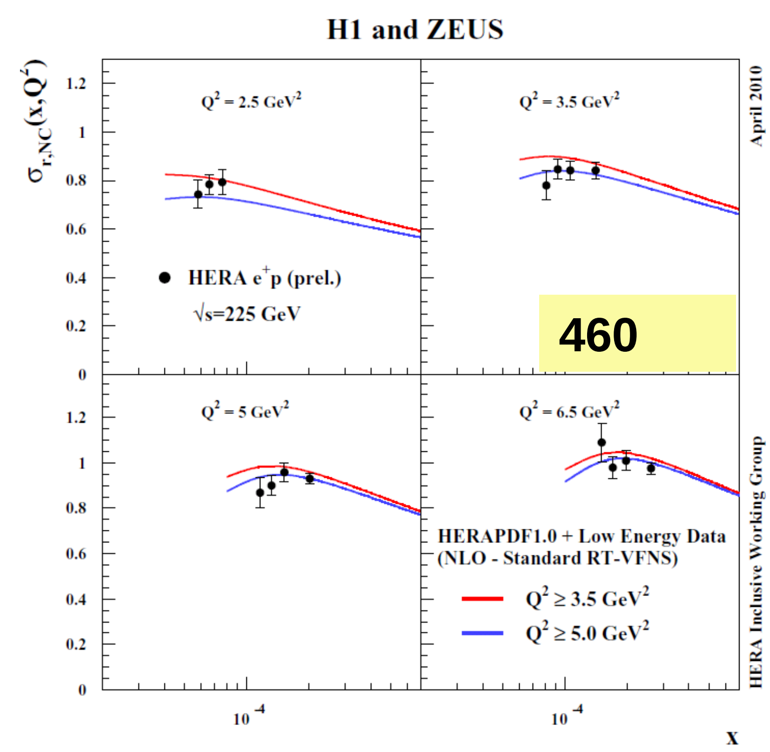

H1 and ZEUS
$\sigma_{r,NC}(x,Q^2)$
$Q^2 = 2.5$ GeV^2
$Q^2 = 3.5$ GeV^2
$Q^2 = 5$ GeV^2
$Q^2 = 6.5$ GeV^2
HERA e^+p (prel.)
$\sqrt{s}$=225 GeV
460
HERAPDF1.0 + Low Energy Data
(NLO - Standard RT-VFNS)
$Q^2 \geq 3.5$ GeV^2
$Q^2 \geq 5.0$ GeV^2
x
April 2010
HERA Inclusive Working Group

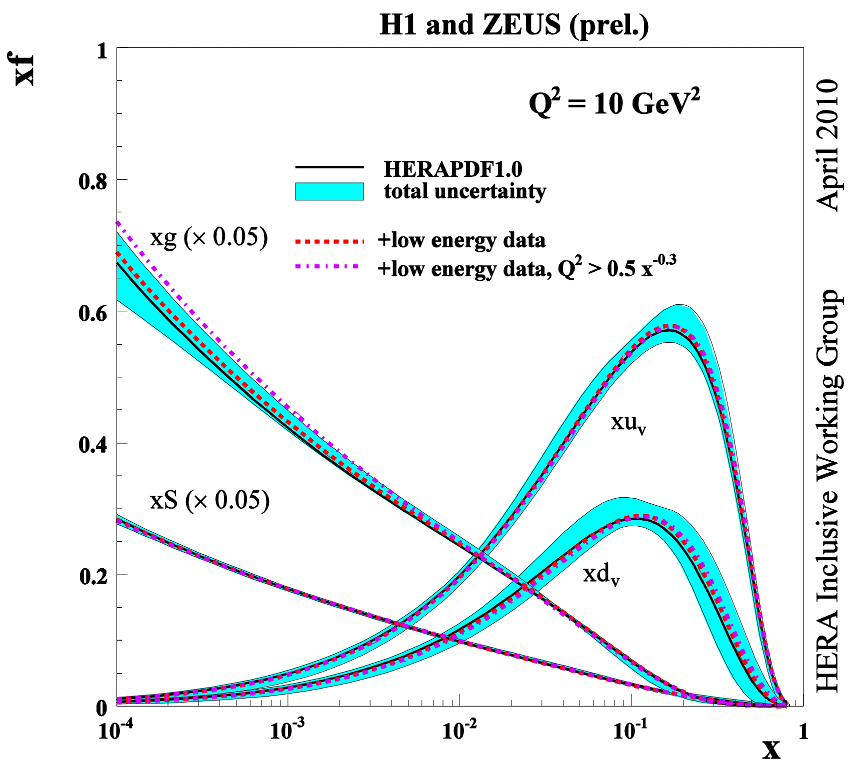
Since kinematically low Q^2 is also at low-x we tried an x cut $x > 5\ 10^{-4}$, which had a similar effect

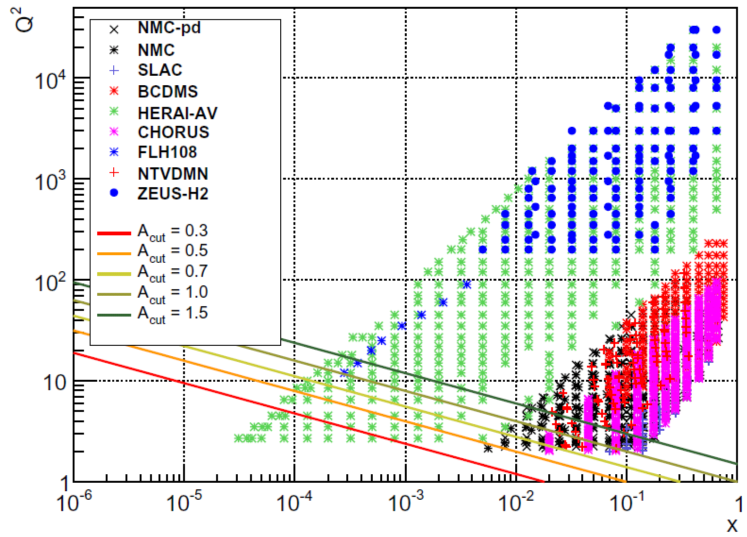
POST DIS10

Standard VFN
$Q2 > 0.5\ x^{-0.3}$
X2/ndf 683.4/760
X/N CCEP = 0.85 34
X/N CCEM = 0.58 34
X/N NCEP= 0.99 358
X/N NCEM= 0.75 145
X/N NCEP 460/575 = 0.86 199

And if we make a combined Q^2/x cut

$Q^2 > A\ x^{-0.3}$ (saturation inspired cut of Caola et al)





This suggests that there is something not ideally fitted by NLO DGLAP at small x/Q^2

Now investigate the effect of changes to the formalism

First of all charm treatment- there are different choices of heavy quark scheme

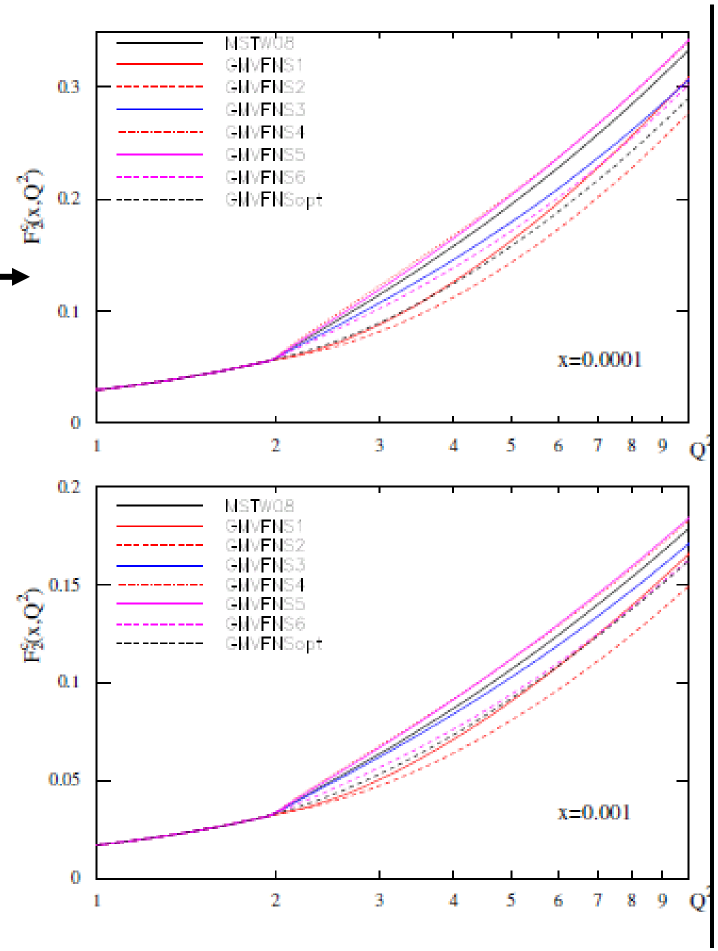
Look at OPTIMAL RT-VFN which has a smoother threshold behaviour

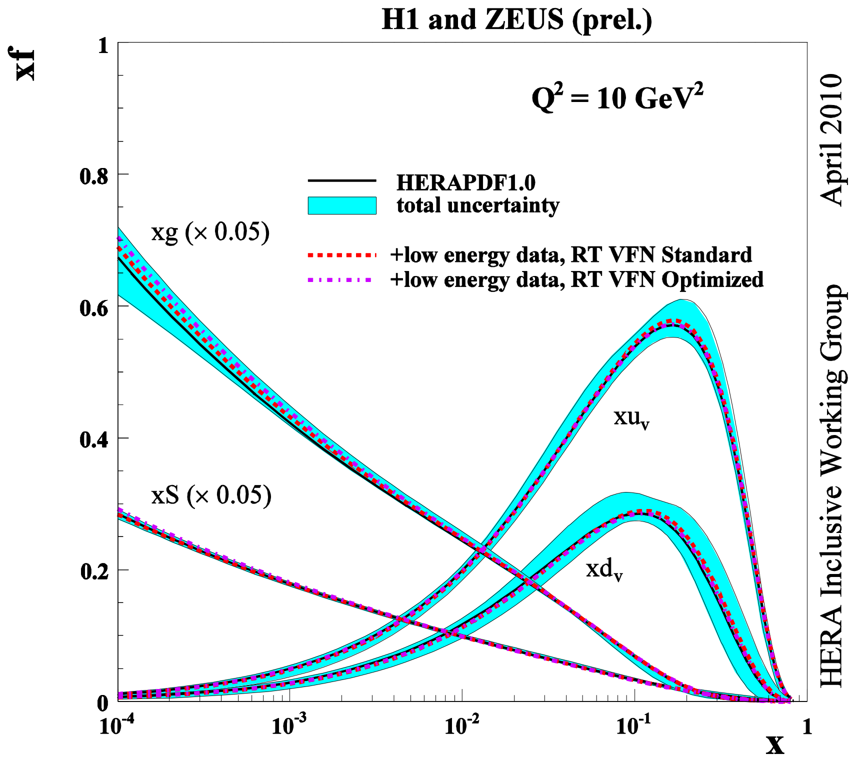
Also look at ACOT-VFN AND FFN fits

The OPTIMAL result is very close to the standard result

The ACOT- VFN gives a better χ2 for both ACOT-χ and full ACOT

The FFN also gives a better χ2 --- it seems to give a better fit to the low energy data by changing the gluon while leaving the sea more or less alone..
…but treat it with caution- no CC data- frozen parameters etc





Standard VFN

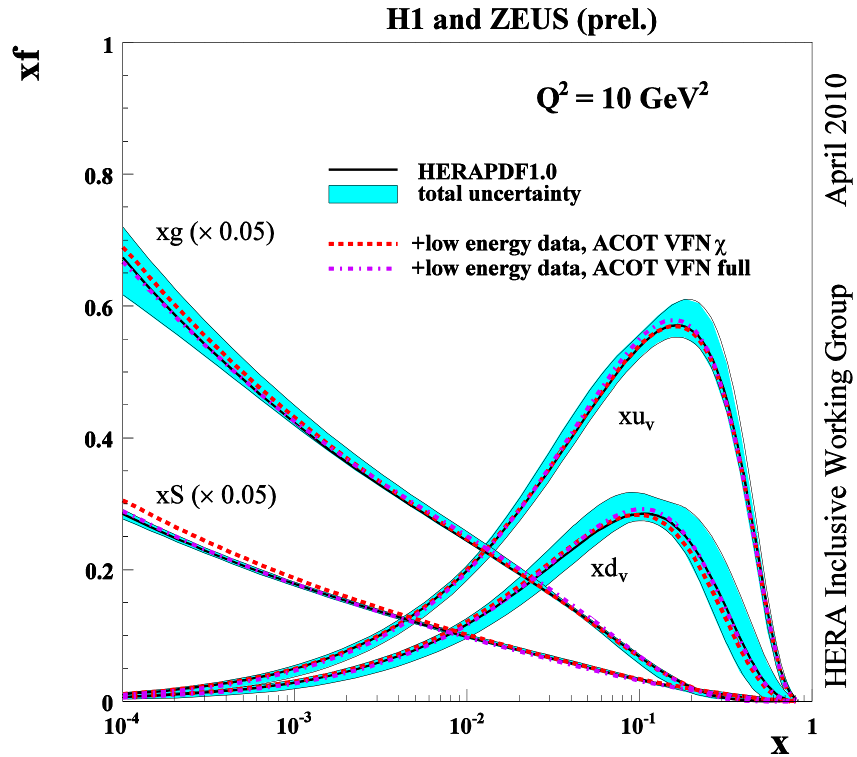
χ2 818.5/806

X/N CCEP =	0.86 34
X/N CCEM =	0.58 34
X/N NCEP=	1.13 379
X/N NCEM=	0.74 145
X/N NCEP 460/575 =	1.04 224

Optimal VFN

χ2 811.6/806

X/N CCEP =	0.86 34
X/N CCEM =	0.59 34
X/N NCEP=	1.13 379
X/N NCEM=	0.74 145
X/N NCEP 460/575 =	1.01 224



ACOT VFN

χ2 788.6/806

X/N CCEP = 0.89 34

X/N CCEM = 0.59 34

X/N NCEP= 1.09 379

X/N NCEM= 0.74 145

X/N NCEP 460/575 = 0.98 224

ACOT-χ VFN

χ2 793.2/806

X/N CCEP = 0.88 34

X/N CCEM = 0.58 34

X/N NCEP= 1.13 379

X/N NCEM= 0.75 145

X/N NCEP 460/575 = 0.92 224

Now TRY Fixed Flavour Number fits

These are needed because HVQDIS which is used to extract F_2 (charm) from D* production uses FFN

However we CANNOT fit Charged Current data – no readily usable FFN NLO coefficient functions are available for F_2 or xF_3 and although the scale is high for HERA CC data one cannot just use Zero Mass VFN for CC- the problem is that there is no charm PDF and so the process $W+c \rightarrow s$ is missing and no coefficient function is making up for this!

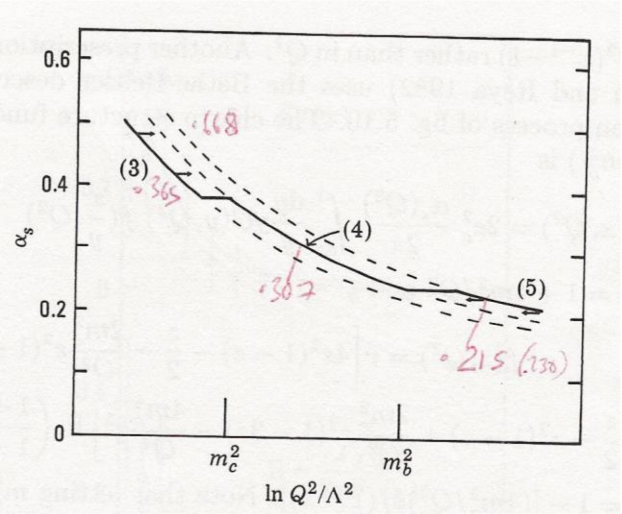
Thus we leave Charged Current data out: 633 data points down to 565
(Could also restrict $Q^2 < 3000$ GeV^2 because not resumming $\ln(Q^2/mc^2)$-but this makes little difference)

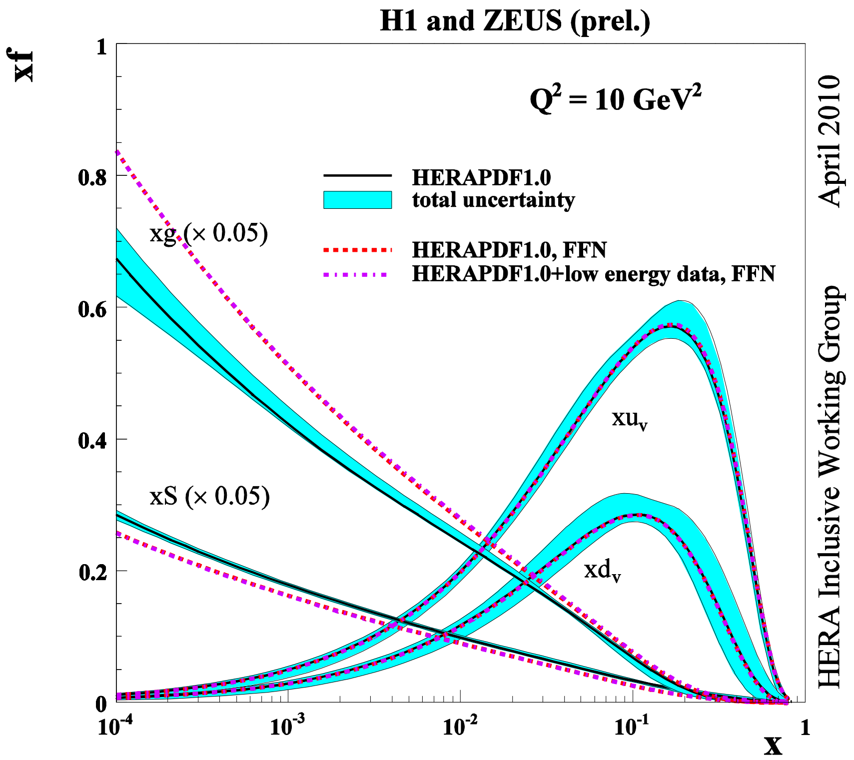
Fit σ NC e+ (379), NC e-(145) and F2c (41)

Hence FIX valence parameters- but try extra Sea/gluon parameters -no significant difference

USE heavy quark factorisation scale $Q^2+4m_c^2$
(but using Q^2 makes little difference)

USE 3-flavour $\alpha_S(Q^2)$ so $\alpha_S(M_z^2)$ must be set low (0.105) so that it is not too high at low energy





FFN
χ2 724.7/738
X/N CCEP =
X/N CCEM =
X/N NCEP= 1.08 379
X/N NCEM= 0.76 145
X/N NCEP 460/575
= 0.92 224

The FFN gluon is expected to be very different from the VFN one

BUT all of these schemes show a similar effect when low-x/Q^2 cuts are applied – the gluon becomes significantly steeper after the cut

IF low Q^2 is not well fit perhaps we need more evolution at low Q^2--- so investigate fits at NNLO

BUT first consider that $\alpha_S(M_Z)$=0.1176 is probably not ideal for NNLO

NNLO fits to HERA-I data give:

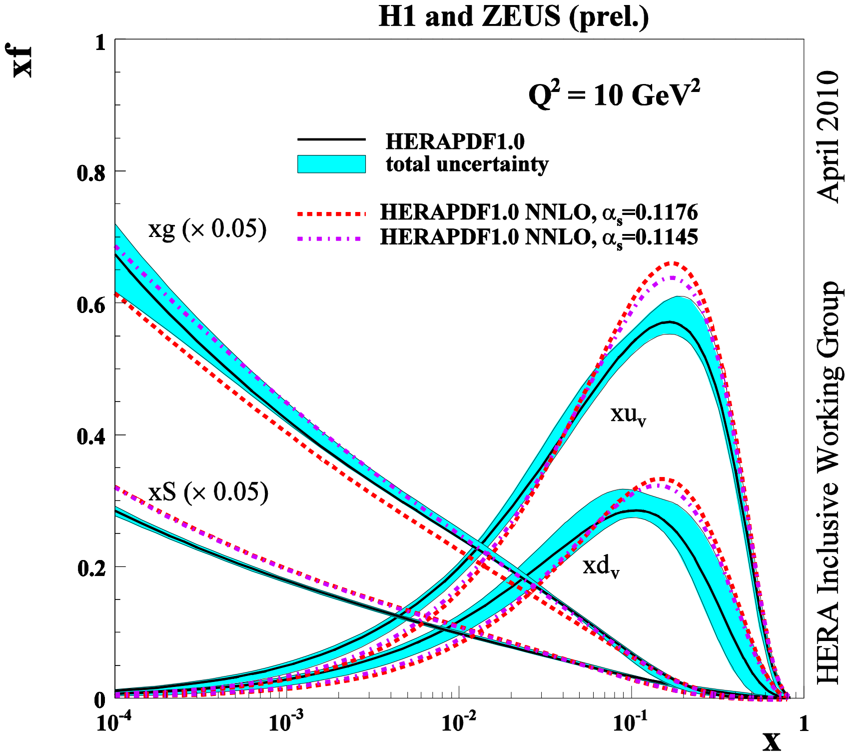
First fit $\alpha_S(M_Z)$ for NLO → 0.1166 0.0044(exp) χ2= 574.8 /592

Then fit $\alpha_S(M_Z)$ at NNLO→0.1145 0.0042(exp) χ2= 623.5 /592

The errors are large (we hope to improve with jets +HERA-2)-

For NLO the preference of the data is compatible with what we usually use.

For NNLO it is not incompatible but it is somewhat further away so I have considered NNLO at $\alpha_S(M_Z)$ =0.1176 and at 0.1145



NNLO just HERA-I

$\alpha_S(M_Z)$=0.1176

X2/ndf 638.3/592

X/N CCEP =	**1.07 34**
X/N CCEM =	**0.57 34**
X/N NCEP=	**1.25 379**
X/N NCEM=	**0.74 145**

NNLO

$\alpha_S(M_Z)$=0.1145

X2/ndf 623.74/592

X/N CCEP =	**0.98 34**
X/N CCEM =	**0.57 34**
X/N NCEP=	**1.22 379**
X/N NCEM=	**0.75 145**

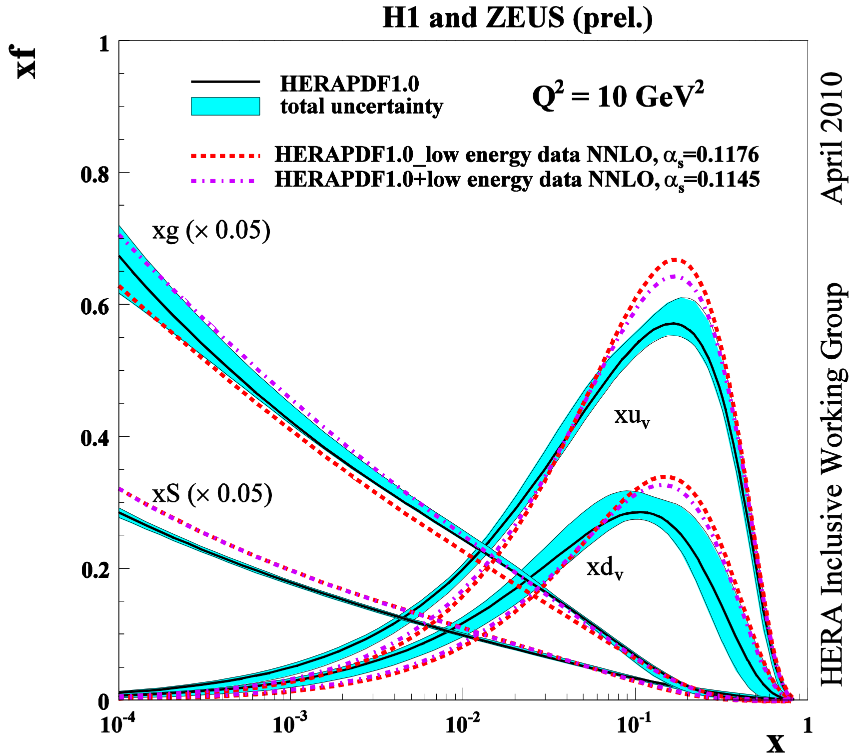
NOTE that NNLO PDFs are supposed to look different from NLO: gluon evolution is slower, whereas sea evolution is faster.

These NNLO PDFs are now available from the H1/ZEUS combination web-site

Now add low energy data

NNLO- +low-E data

X2/ndf 873.7/806	
X/N CCEP =	1.04 34
X/N CCEM =	0.57 34
X/N NCEP=	1.24 379
X/N NCEM=	0.75 145
X/N NCEP 460/575	
	= 1.07 224



Given that χ2 for the NCEP data are NOT better at NNLO than they were at NLO our 'problem' with the low Q2/low-x data is not solved by the move to NNLO

We could pursue this into making cuts at NNLO as well (and I have done so- see extras) ..

But let us summarise for now

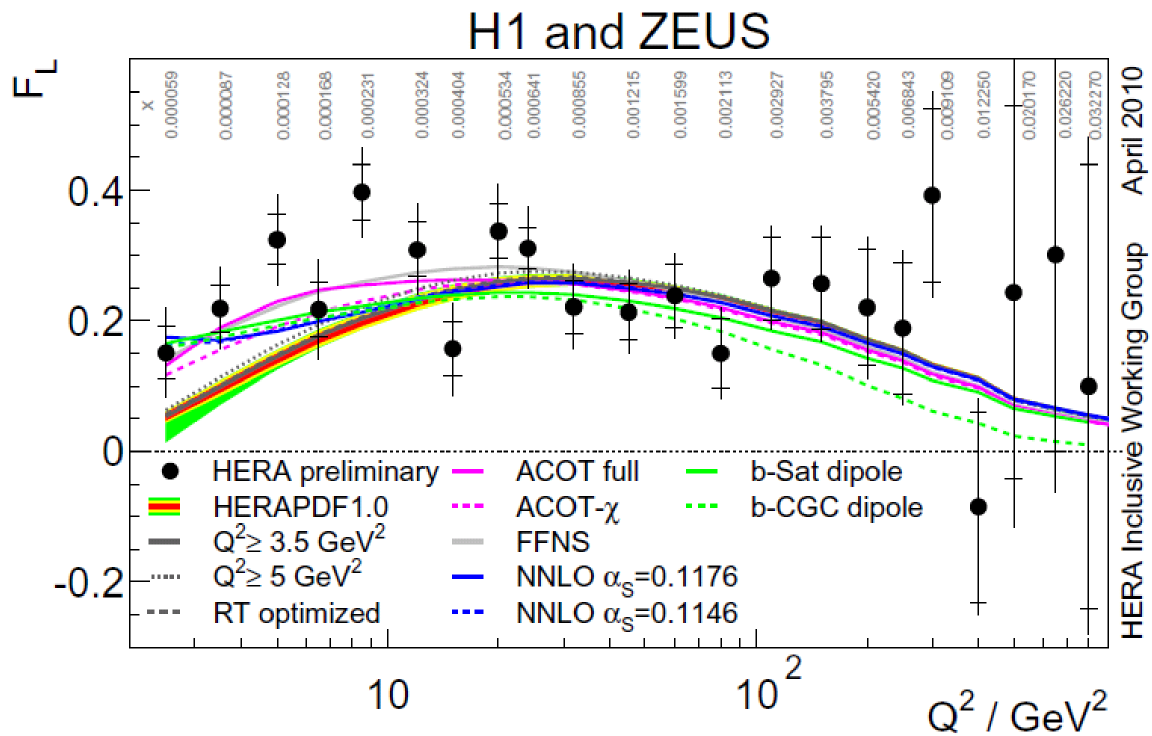
Low Energy data brings a new feature:

It is not fit as well as it could be at low Q^2/x

The problem is at: $x < 5\ 10^{-4}$, $Q^2 < 5$; $Q^2 < 0.5x^{-0.3}$

Imposing Q^2/x cuts changes the shape of the low-x gluon —

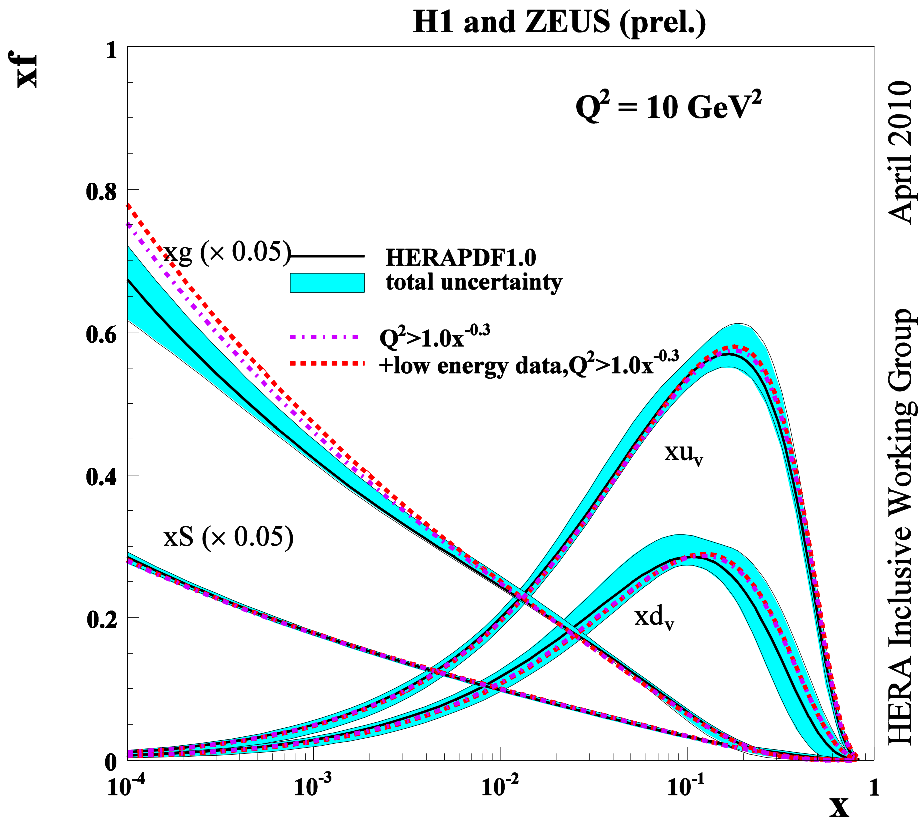
BUT NOTE it is NOT a very high y effect and these cuts do NOT have a big effect on the description of the FL-averaged plot- the changes of scheme to ACOT, FFN or NNLO matter more for this



The real question is: if low energy data has brought something new –that doesn't seem to follow DGLAP very well either at NLO or at NNLO- and that is also present (though not as strongly**) in the 920 data- how hard do we have to cut to go beyond this suspect region? We want to ensure that the 920 and lower energy data are giving the same results**

The saturation inspired cut achieves this goal for A=1.0

The HERA-1 data and HERA-1+ low-energy data fits now look similar



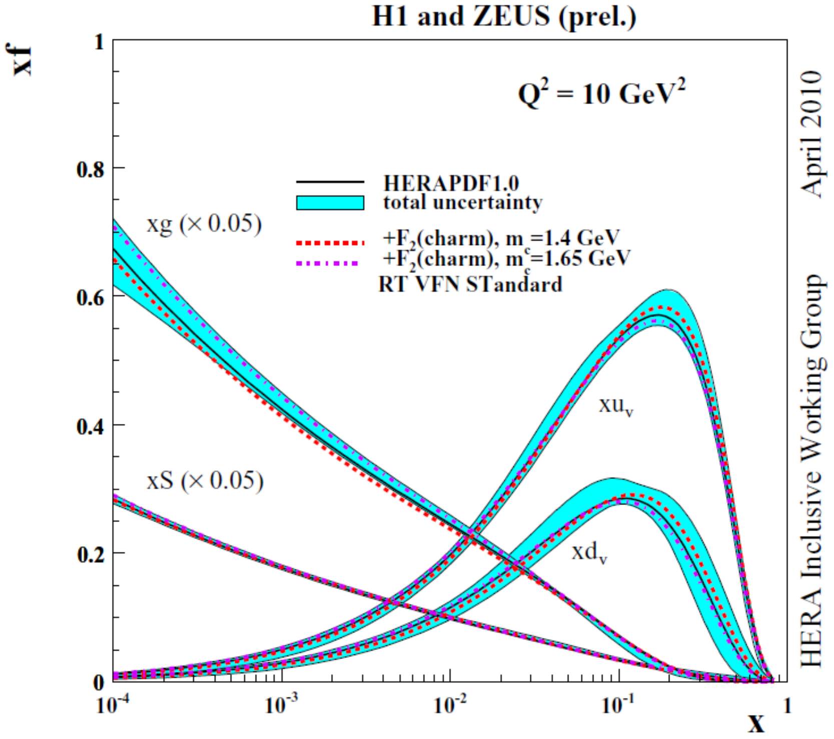
This implies that the 'true' gluon could be a little bit steeper than the HERAPDF1.0 gluon

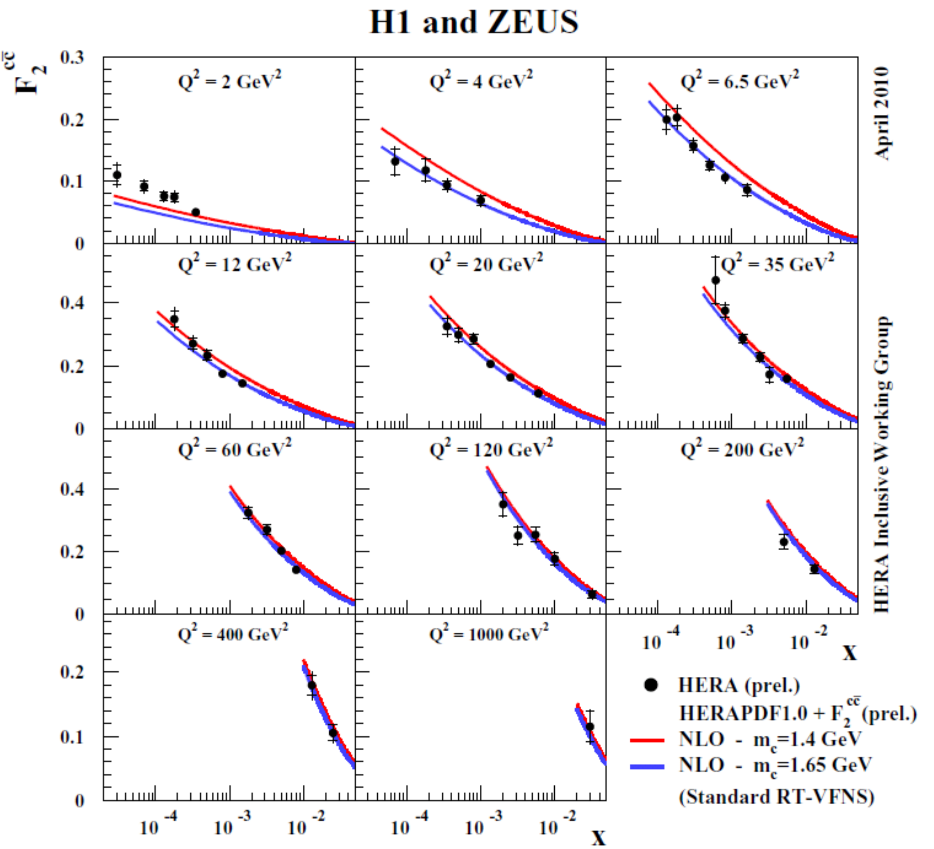
NOTE: this effect only starts to become important for $x < 10^{-3}$ so W/Z cross-sections at the LHC are only marginally affected- 1-1.5% up at 7 TeV ~1.5-2% at 14 TeV

Add combined F2(charm) data to the HERA-1 fit using the standard formalism

No significant difference at first sight

AND no great improvement in experimental PDF uncertainties either….but model dependent uncertainties due to the choice of charm mass could decrease since the charm data are sensitive to charm mass

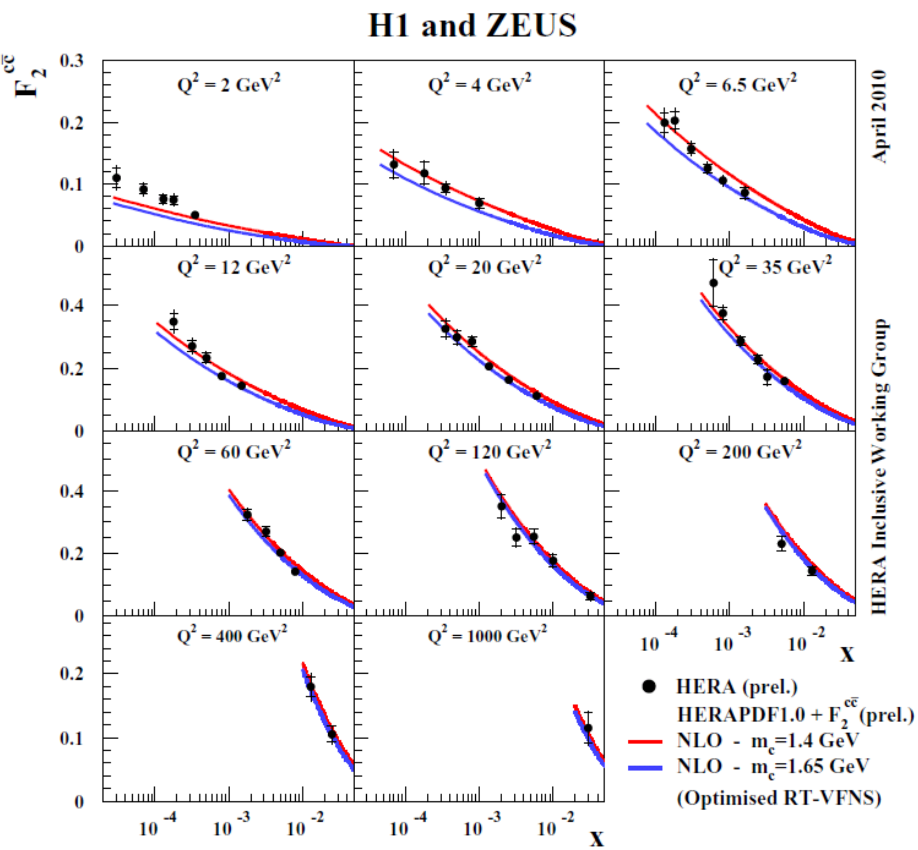


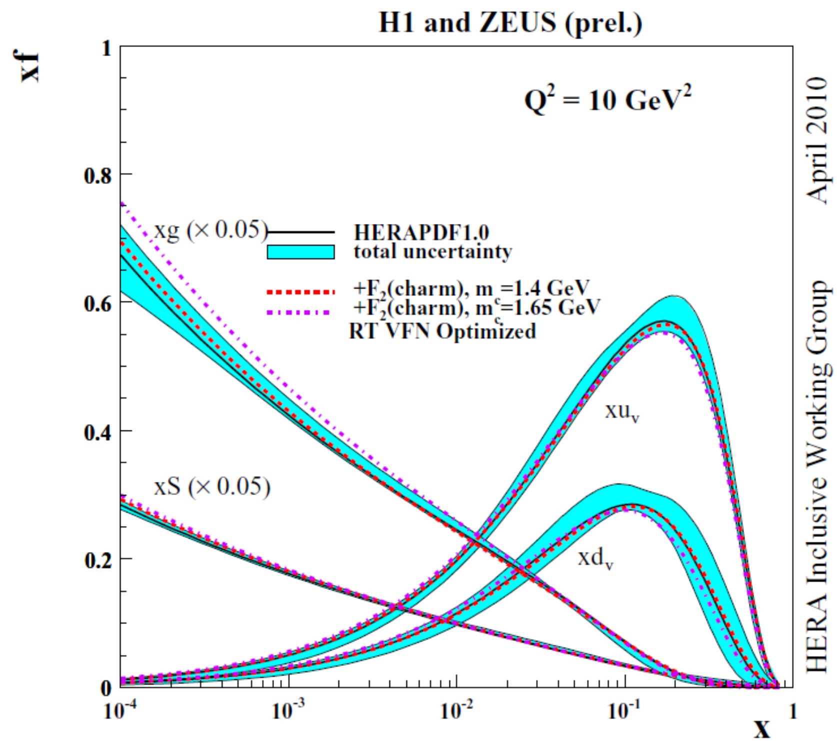


Investigate two choices of charm mass- mc=1.4GeV (standard choice) and mc=1.65GeV (pole mass).

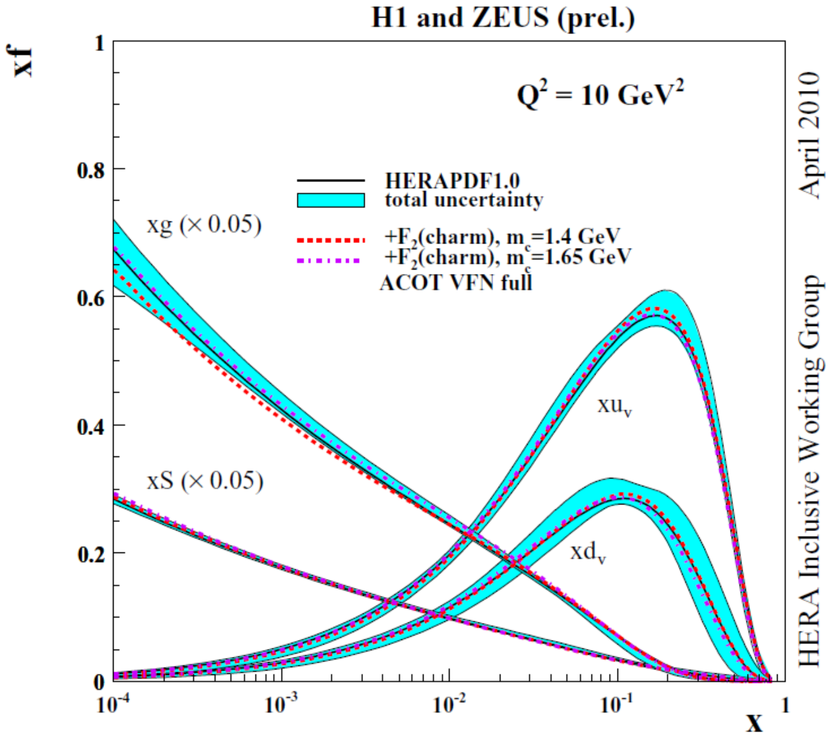
For the standard RT-VFN scheme the data prefer mc=1.65 to mc=1.4 GeV

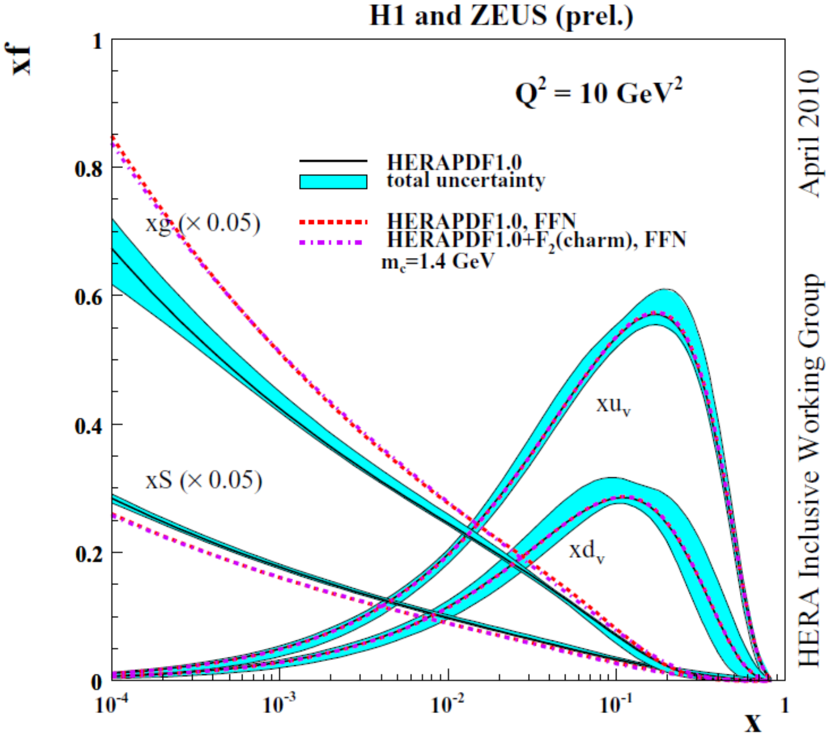
However this standard NLO heavy quark scheme is not unique: in fact Thorne has come up with an optimized scheme which has a smoother threshold behaviour





For the optimized RT-VFN scheme the data prefer mc=1.4 to mc=1.65 GeV



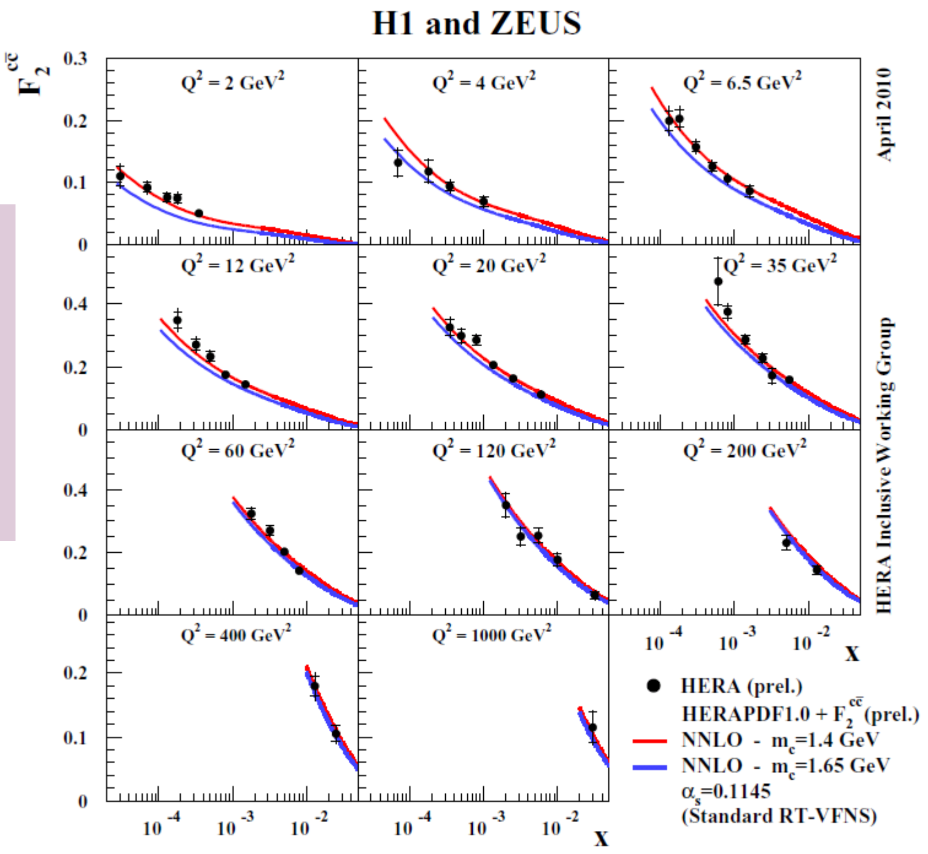


And there is also the ACOT scheme for which the data prefer mc=1.65 GeV

And the FFN fits- for which the data prefer mc=1.4 GeV

And the NNLO fits where the data prefer mc=1.4 GeV

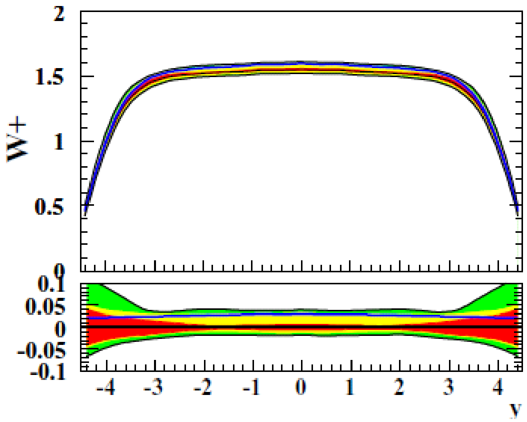
(and there is rather a nice description of the lower Q2 data which are not included in the fit)

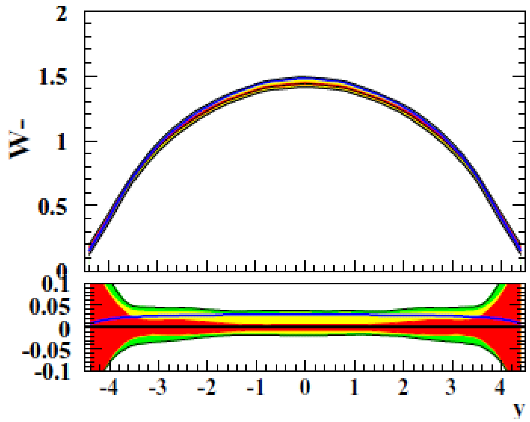


So there is substantial theoretical uncertainty- and we are pursuing these studies (ICHEP?) - Why does it matter?

There is an important consequence of the choice of the charm mass –it affects the W and Z cross-sections at the LHC: mc = 1.4 →1.65 gives ~3% increase in σ(W,Z)

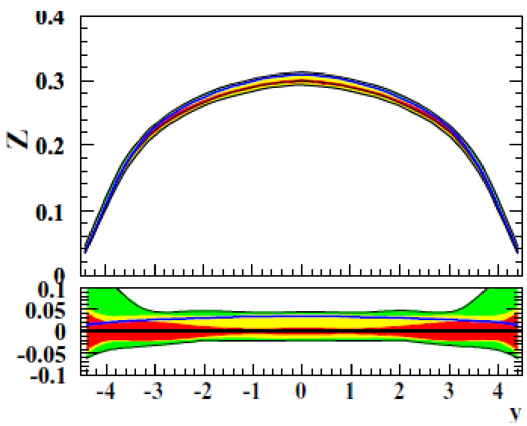
W and Z rapidity distributions





Predictions from HERAPDF1.0 for W+ W- and Z rapidity distributions at the LHC 14 TeV (m_c=1.4GeV)

The blue line shows the shift for m_c=1.65 GeV



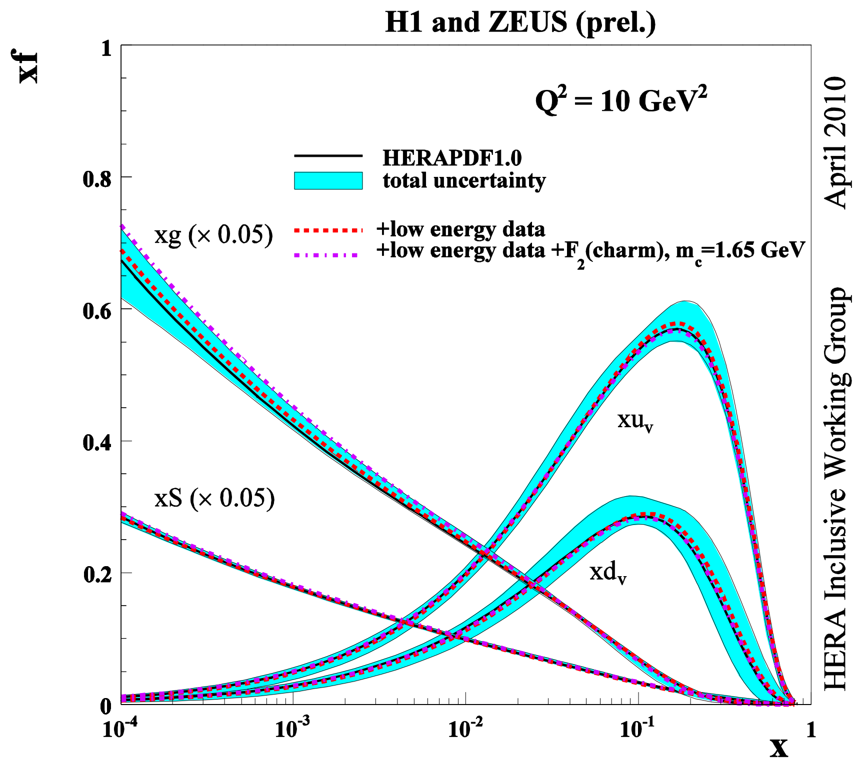
	$\sigma(W^{+}).B_{W\to l\nu}$ (nb)	$\sigma(W^{-}).B_{W\to l\nu}$ (nb)	$\sigma(Z).B_{Z\to ll}$ (nb)
m_c=1.4 GeV			
	12.44 0.01	9.28±0.05	2.076±0.014
	+0.31 -0.08	+0.25 -0.07	+0.059 -0.015
	+0.23 -0.06	+0.21 -0.04	+0.045 -0.009
m_c=1.65 GeV			
	12.76	9.52	2.13

There was some concern raised at DIS about the effect including of low-energy data and F2c data simultaneously. We have checked this and we conclude:

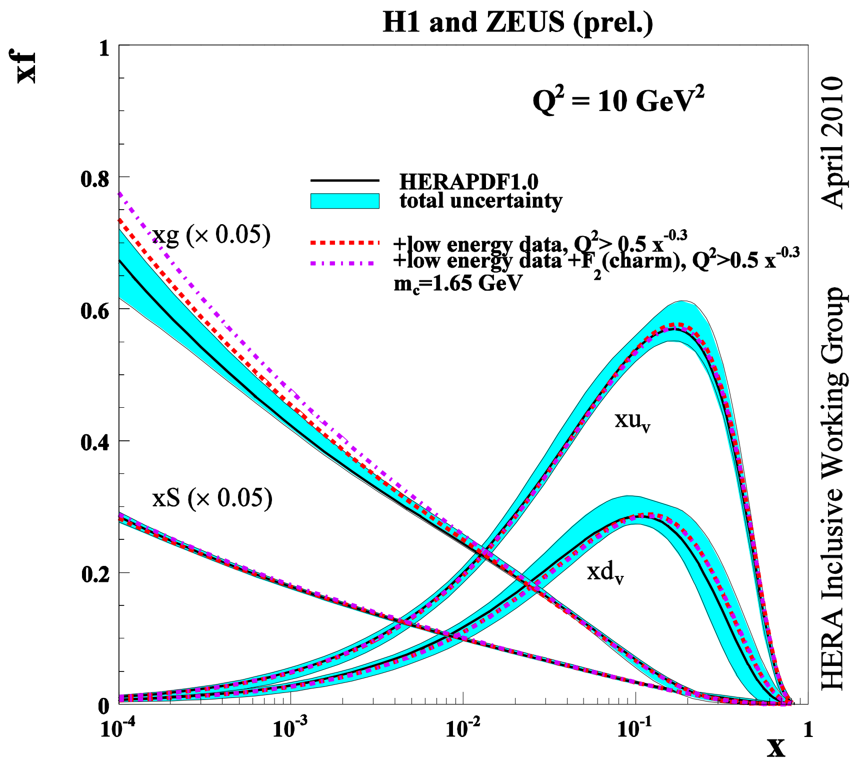
- **Sensitivity of the F2charm fits to heavy quark scheme and heavy quark mass are not altered by simultaneous inclusion of low energy data**
- **Sensitivity of a fit including low-energy data to the low-x/Q^2 region are not altered by inclusion of the charm data- BUT the charm mass should be chosen to give a good fit to charm- a bad fit to charm CAN distort the rest of the fit**

Just one illustration of this…

Add charm data to low energy data fits



Standard fits



Fits under a $Q^2 > 0.5\ x^{-0.3}$ cut

The charm data do not alter our conclusions about the cut.

Ask the question the other way: do the low energy data alter our conclusions on charm sensitivity to mc?

NO mc=1.65 is still preferred for this Standard RTVFN Fit ..etc

Summary

Low energy data seem to indicate some tension at low x /Q^2

– have we gone beyond the comfort zone of NLO and NNLO DGLAP

– is the true gluon a bit steeper at low x?

Charm data is sensitive to heavy quark-scheme and charm mass and can thus help to reduce model dependence

So far this scheme /mass dependence is not systematically accounted for in the PDF community

extras

Now consider x and Q2 cuts on NNLO fits at alphas=0.1145 with low-E data

NNLO- $Q2 > 0.5x^{-0.3}$	NNLO $x > 5\ 10^{-4}$	NNLO $Q2 > 5$
X2/ndf 723.9/760	X2/ndf 600.0/686	X2/ndf 762.4/771
X/N CCEP = 0.95 34	X/N CCEP = 0.86 34	X/N CCEP = 0.93 34
X/N CCEM = 0.57 34	X/N CCEM = 0.58 34	X/N CCEM = 0.56 34
X/N NCEP= 1.06 358	X/N NCEP= 0.95 322	X/N NCEP= 1.10 353
X/N NCEM= 0.75 145	X/N NCEM= 0.76 145	X/N NCEM= 0.76 145
X/N NCEP 460/575 = 0.92 199	X/N NCEP 460/575 = 0.83 161	X/N NCEP 460/575 = 0.85 215
Buv 0.780 ± 0.021	Buv 0.669 ± 0.034	Buv 0.763 ± 0.038
Cuv 4.65 ± 0.16	Cuv 4.69 ± 0.14	Cuv 4.71 ± 0.15
Euv 7.27 ± 1.49	Euv 10.43 ± 1.94	Euv 8.36 ± 1.81
Cdv 3.79 ± 0.25	Cdv 3.84 ± 0.41	Cdv 3.72 ± 0.28
ADbar 0.243 ± 0.005	ADbar 0.177 ± 0.004	ADbar 0.262 ± 0.005
BDbar -0.121 ± 0.004	BDbar -0.170 ± 0.011	BDbar -0.104 ± 0.009
CUbar 6.83 ± 0.42	CUbar 3.31 ± 0.72	CUbar 6.83 ± 0.96
CDbar 4.18 ± 0.59	CDbar 3.38 ± 0.98	CDbar 4.18 ± 0.92
Bg 0.072 ± 0.017	Bg 0.078 ± 0.033	Bg 0.023 ± 0.024
Cg 8.61 ± 0.39	Cg 7.90 ± 0.72	Cg 8.21 ± 0.64

Generally the cuts have a similar effect on the as at NLO. The q2 and $q2 > 0.5x^{-0.3}$ cuts improve chisq and change shape to enhances the gluon and flatten the sea as for NLO – the x cut also enhances the low-x sea

Now try fitting the F_2(charm) data

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.

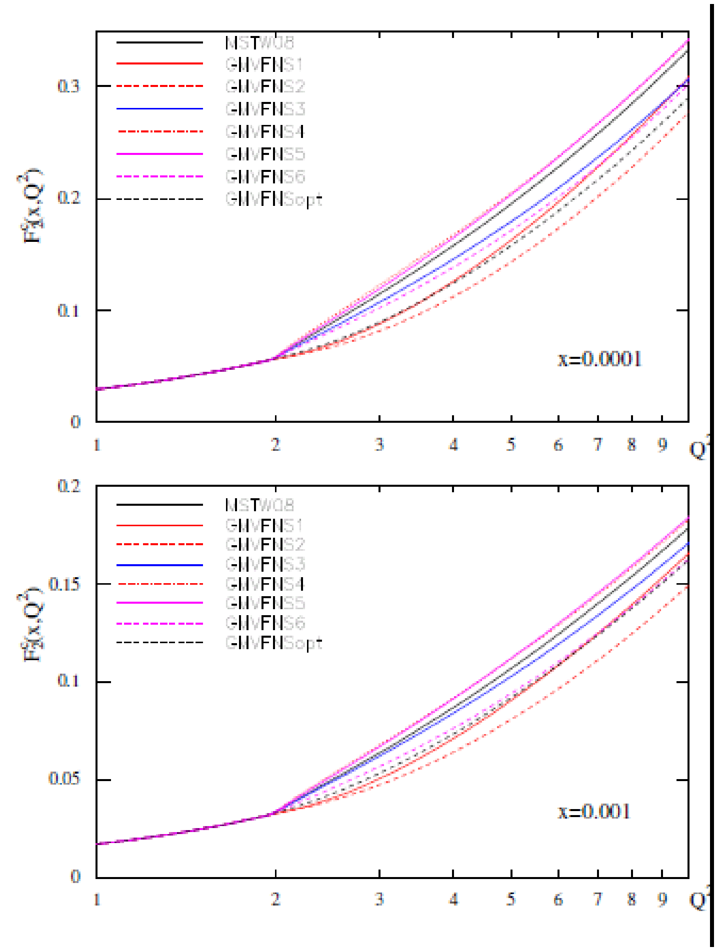
In both cases Q^2 is the renormalisation and factorisation scale for light and heavy quarks as appropriate to these schemes

We use the usual cuts on data $Q^2 > 3.5$ GeV^2, so 41 F_2^c data points are fitted

The formalism is the same as for HERAPDF1.0 unless otherwise stated

We compare two values of charm mass

m_c=1.4 GeV and m_c=1.65 GeV



Various GM VFNS as considered by Thorne PDF4LHC meeting Oct23rd 2009

Now TRY Fixed Flavour Number fits

These are needed because HVQDIS which is used to extract F_2 (charm) from D* production uses FFN

However we CANNOT fit Charged Current data – no readily usable FFN NLO coefficient functions are available for F_2 or xF_3 and although the scale is high for HERA CC data one cannot just use Zero Mass VFN for CC- the problem is that there is no charm PDF and so the process W+c →s is missing and no coefficient function is making up for this!

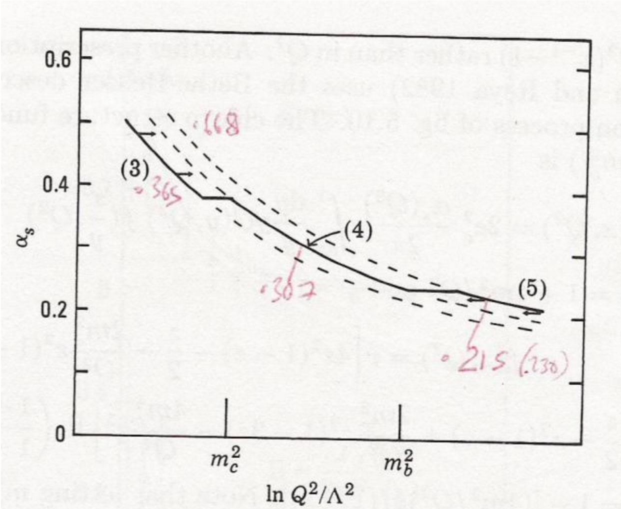
Thus we leave Charged Current data out: 633 data points down to 565
(Could also restrict $Q^2 < 3000$ GeV^2 because not resumming $\ln(Q^2/m_c^2)$-but this makes little difference)

Fit σ NC e+ (379), NC e-(145) and F2c (41)

Hence FIX valence parameters- but try extra Sea/gluon parameters -no significant difference

USE heavy quark factorisation scale $Q^2+4m_c^2$
(but using Q^2 makes little difference)

USE 3-flavour $\alpha_S(Q^2)$ so $\alpha_S(M_z^2)$ must be set low (0.105) so that it is not too high at low energy



scheme	RT Std $m_c=1.4$	RT Std $m_c=1.65$	RT Opt $m_c=1.4$	RT Opt $m_c=1.65$	ACOT $m_c=1.4$	ACOT $m_c=1.65$	#points
$\chi 2$	730.7	627.5	644.6	695.4	653.9	605.7	633
$F_2^{(charm)}$ Sub $\chi 2$	134.5	43.5	64.8	100.1	89.5	41.4	41

scheme	FFN $m_c=1.4$	FFN $m_c=1.65$	#points	FFN $m_c=1.4$ no F_2^c	#points
$\chi 2$	**567.0**	**852.0**	565	512.9	524
$F_2^{(charm)}$	51.7	248.9	41		0