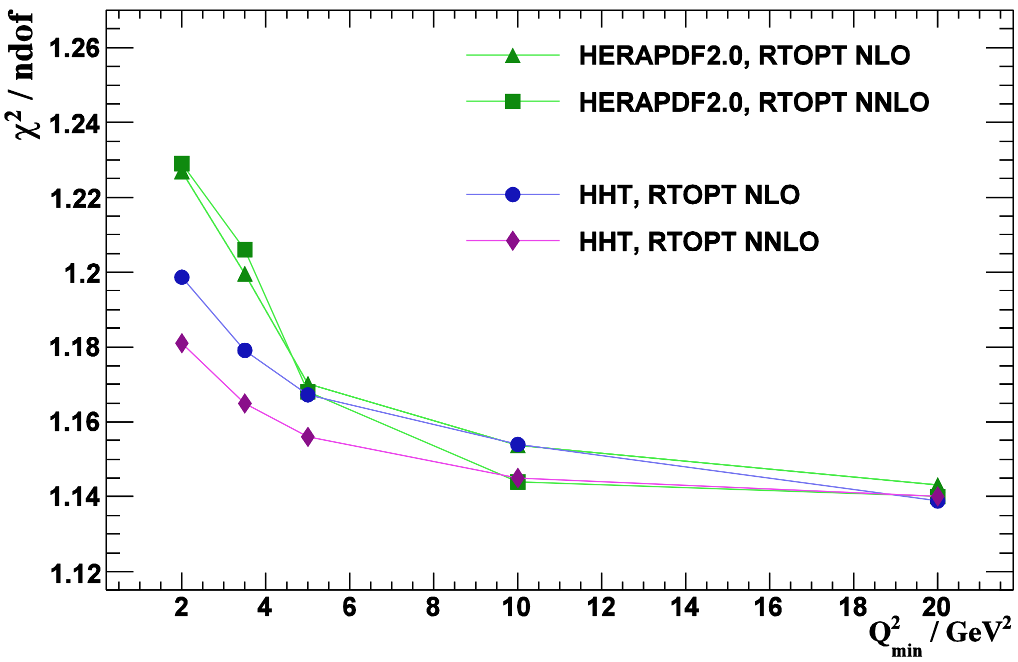
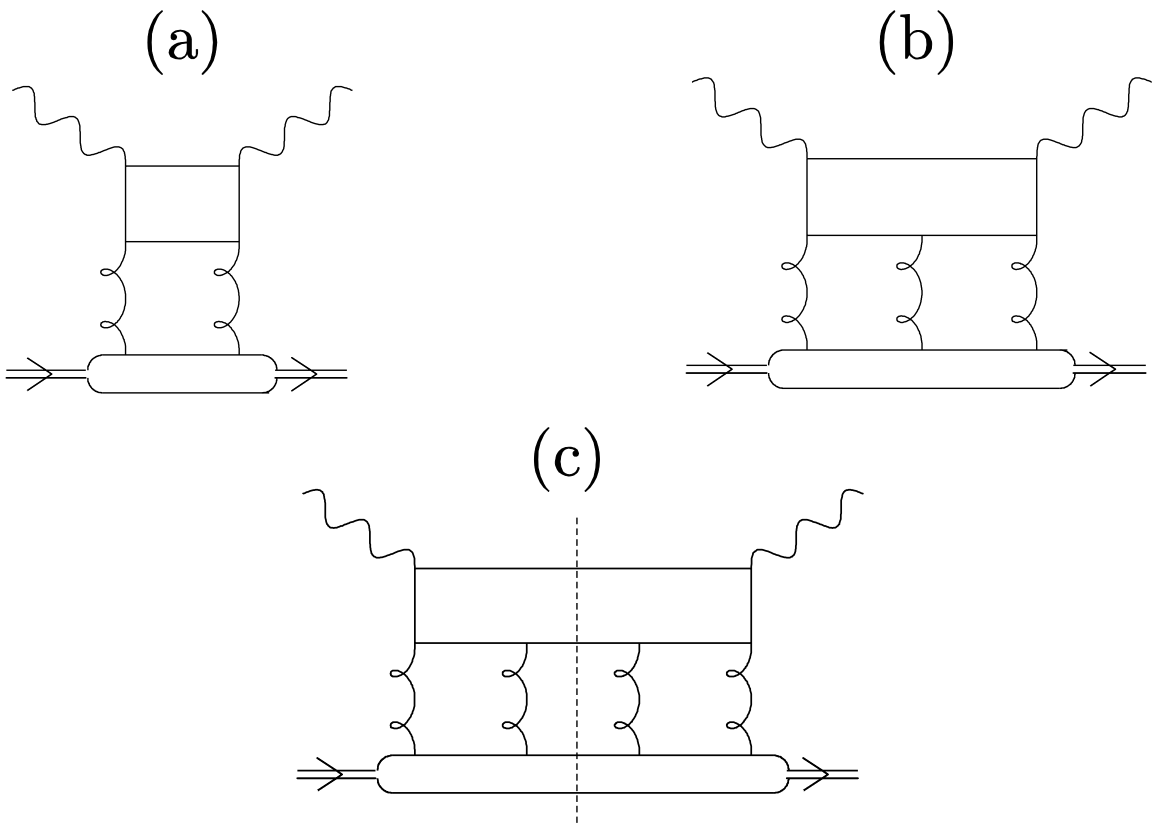
HERA data at low Q^2

We all remember that the $\chi 2$/ndof is somewhat worse at low Q^2



One way to improve this is to add higher twist terms -HHT

BUT NOTE- these are not the high-x, low Q2 terms we usually associate with the terminology ‘higher twist’



They are higher twist terms which act a low-x
Their origin COULD be to do with the recombination of gluon ladders.
Bartels, Golec-Biernat, Kowalski suggest that such higher twist terms would cancel between σ_L and σ_T in F2, but remain strong in FL

Try the simplest of possible modification to the structure functions F_2 and F_L

$$F_{2,L} = F_{2,L}\,(1 + A_{2,L}^{HT}/Q^2)$$

We find that such a modification of F_L is favoured, whereas for F_2 it is not.

At NNLO the χ2/ndof = 1363/1131 for HERAPDF2.0
If A_2^{HT} is added this becomes 1357/1130 and $A_2^{HT} = 0.12 \pm 0.07$ GeV^2
If A_L^{HT} is added this becomes 1316/1130 and $A_L^{HT} = 5.5 \pm 0.6$ GeV^2
If both A_L^{HT} and A_2^{HT} are added the result is consistent with just adding A_L^{HT}

So now concentrating on just F_L, we call these fits HHT

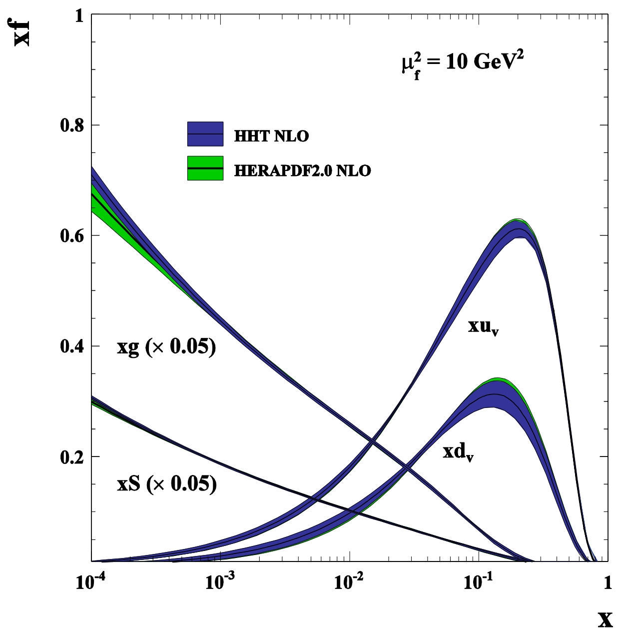
Fit at	with $Q^2_{min} = 3.5$ GeV^2	HERAPDF2.0	HHT	A_L^{HT}
NNLO	χ^2/ndof	1363/1145	1316/1145	5.5±0.6
	Partial χ^2/ndof for NC e^+p: $Q^2 \geq Q^2_{min}$	451/377	422/377	
	χ^2/ndp for NC e^+p: $2.0 \leq Q^2 < Q^2_{min}$	41/25	32/25	
NLO	χ^2/ndof	1356/1145	1329/1145	4.2±0.7
	Partial χ^2/ndof for NC e^+p: $Q^2 \geq Q^2_{min}$	447/377	431/377	
	χ^2/ndp for NC e^+p: $2.0 \leq Q^2 < Q^2_{min}$	46/25	46/25	

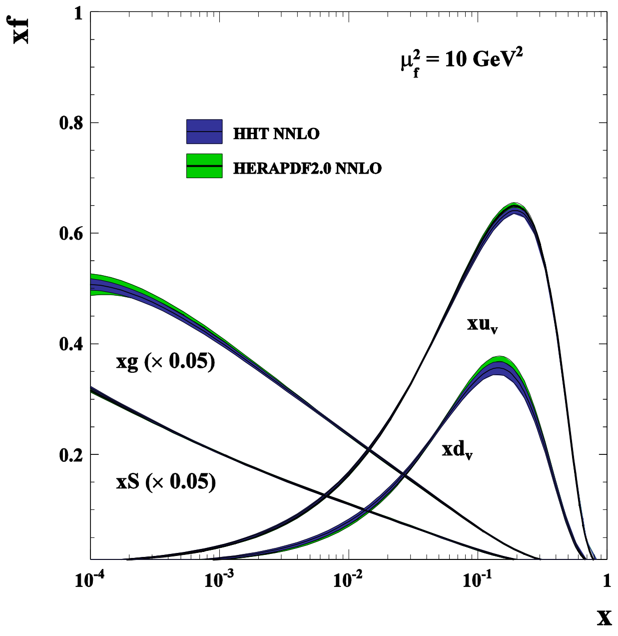
Δχ2 =-47

Δχ2 =-28

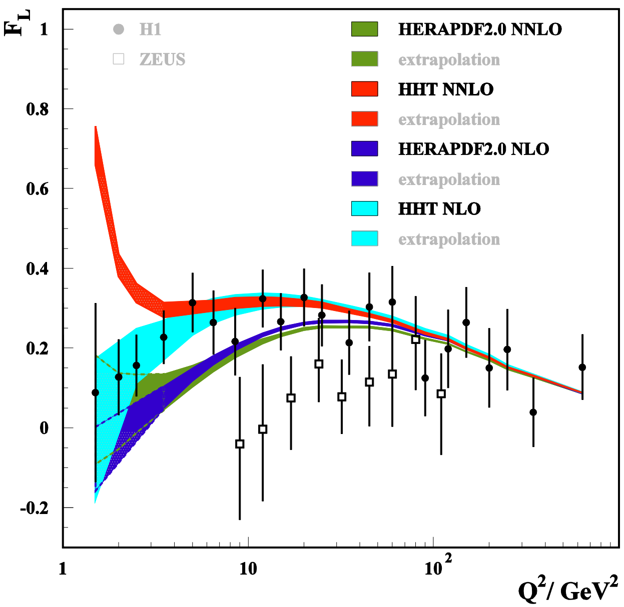
After HT is added the NNLO fit is better than the NLO fit
A substantial part of the improvement comes from the NCe^+p 920 data
This persists even below Q^2_{min}

Note the HHT PDFs themselves barely change from HERAPDF2.0 – the higher twist modification does not affect high-scale LHC physics





The HHT fits tend to increase the value of F_L for both NLO and NNLO



Here's how F_L looks for both HERAPDF2.0 and our HHT analysis

You might think that -since F_L is related to the gluon - an easier way to obtained larger F_L would be to drop the negative term in the gluon PDF parametrisation.

So we did- we call this the AG parametrisation

This makes almost no difference for the NLO fits However it is strongly disfavoured for the NNLO fits. At NNLO the fit wants a negative term in the gluon parametrization AND a higher twist term in F_L.

For HERAPDF2.0 AG the χ2/ndof = 1389/1131 cf 1363/1130 for the standard fit
For HHT AG the χ2/ndof = 1350/1130 cf 1316/1130 for the standard fit

These two contributions clearly affect the fit in different ways

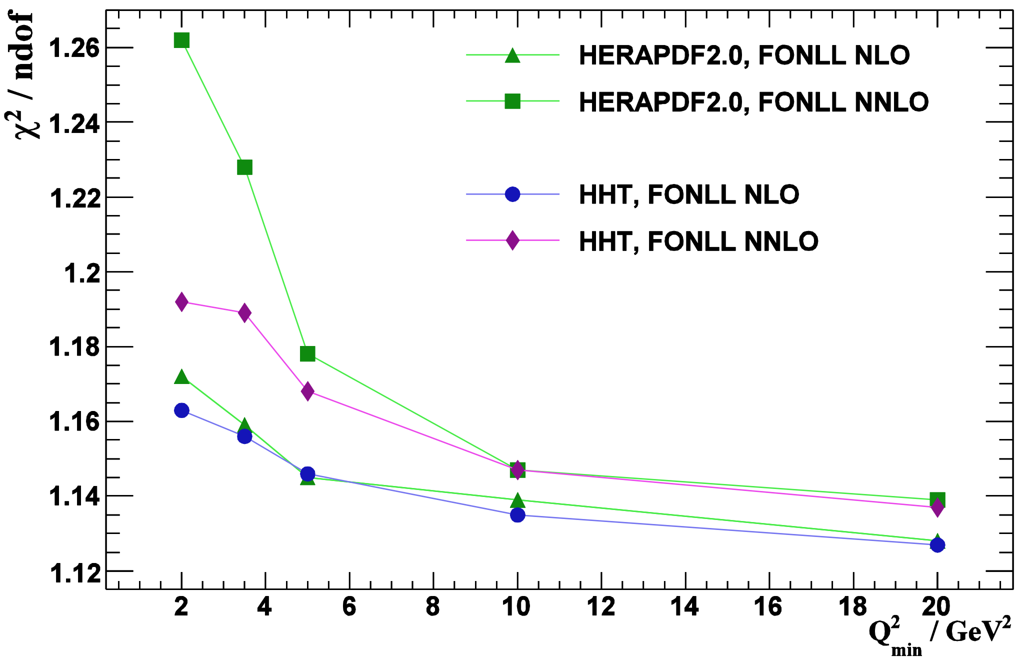
Another consideration is that we know that the rate of decrease χ2/ndof with increasing Q^2_{min} differs with the heavy flavour scheme used AND with the order in α_S to which F_L is evaluated

So let's take a look at FONLL

For FONLL at NNLO a higher twist term in FL brings a substantial decrease in the χ2/ndof with a similar value of $A_L^{HT}=6.0 \pm 0.7$ GeV^2 to that for the RTOPT scheme.

For FONLL at NLO a higher twist term in FL brings almost no decrease in χ2/ndof .

This is probably related to the order in α_S to which F_L is evaluated



For FONLL/RTOPT at NNLO, F_L is evaluated to $O(\alpha_S^2)$/ $O(\alpha_S^3)$

For FONLL/RTOPT at NLO, F_L is evaluated to $O(\alpha_S)$/ $O(\alpha_S^2)$

The value of F_L at $O(\alpha_S)$ is relatively large in any scheme and thus there is little need for higher twist.

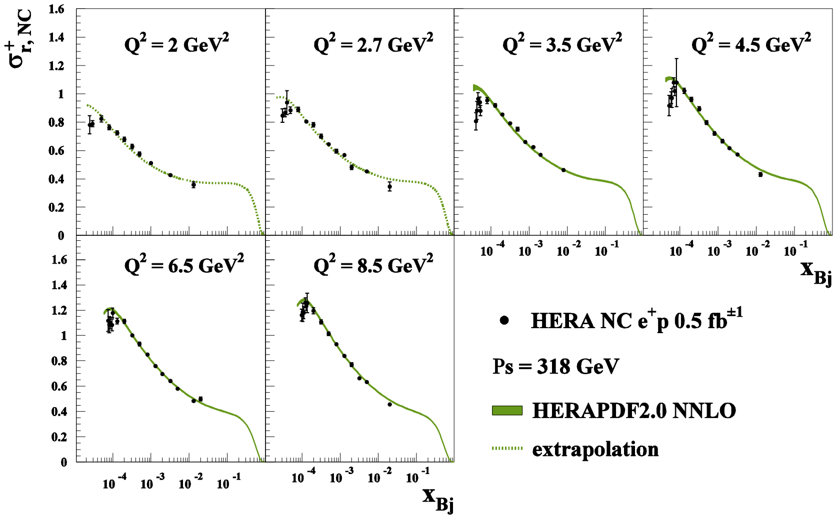
However as soon as F_L is evaluated to $O(\alpha_S^2)$ or higher the need for higher twist appears

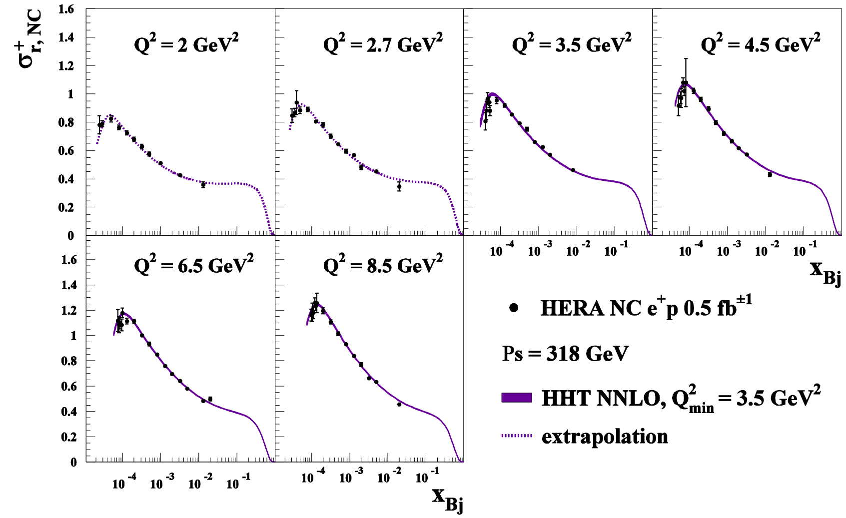
So now let's look at why the HHT fits do so well

It is because they describe the turn over at low x, Q2 much better

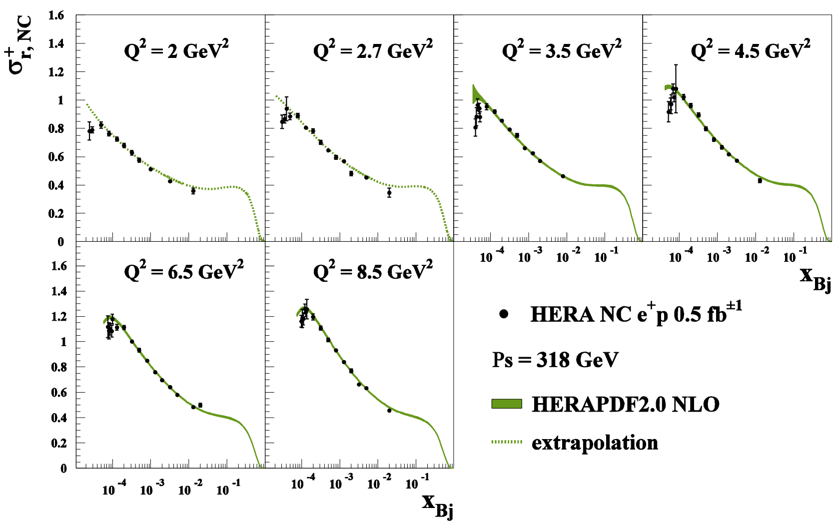
$$\sigma_{red} = F_2 - y^2/Y_+ F_L$$

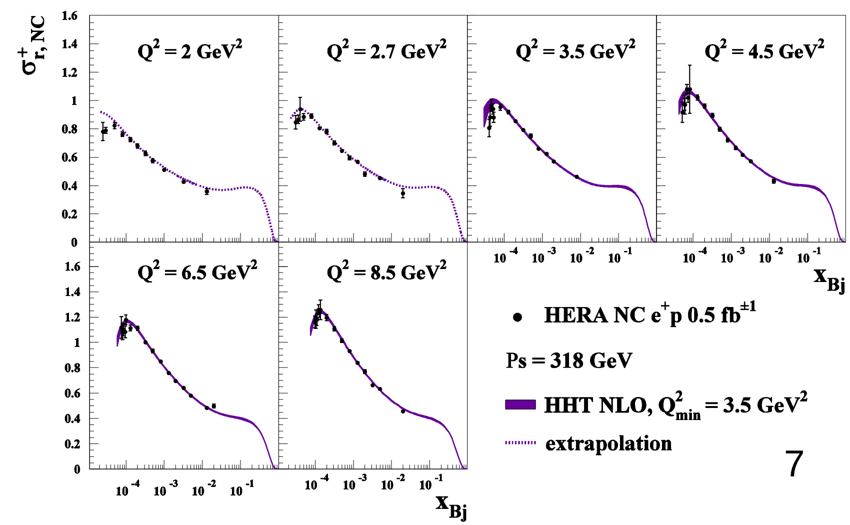
The data clearly wants a larger F_L and this is what the higher twist term provides





|You can also see that NNLO does better than NLO

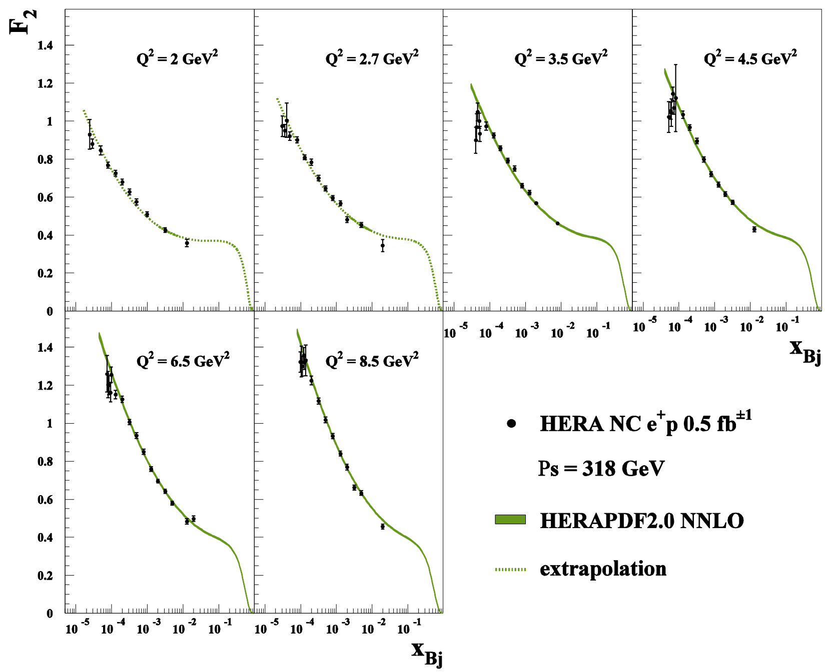


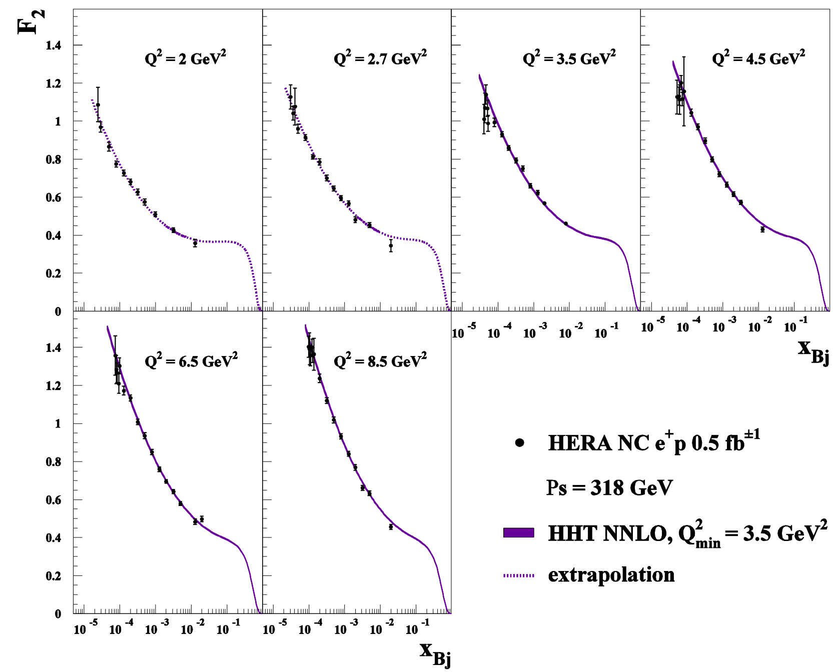


It is also interesting to look at F_2, where the data points are extracted as

$$F_2^{extracted} = F_2^{predicted} \frac{\sigma_r^{measured}}{\sigma_r^{predicted}}.$$

Since F_2 is the dominant part of the reduced cross section this is a reasonable procedure





This essentially means that we get F_2 by correcting σ_{red} with our predicted F_L

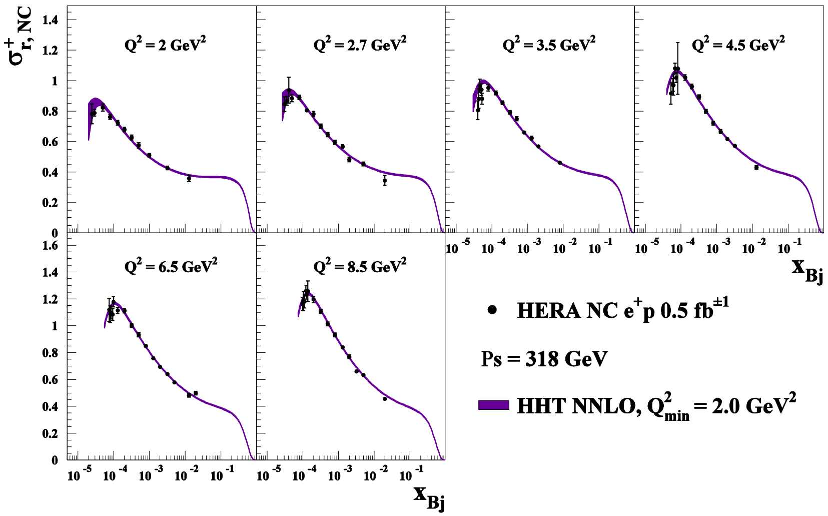
$$F_2 = \sigma_{red} + y^2/Y_+ F_L$$

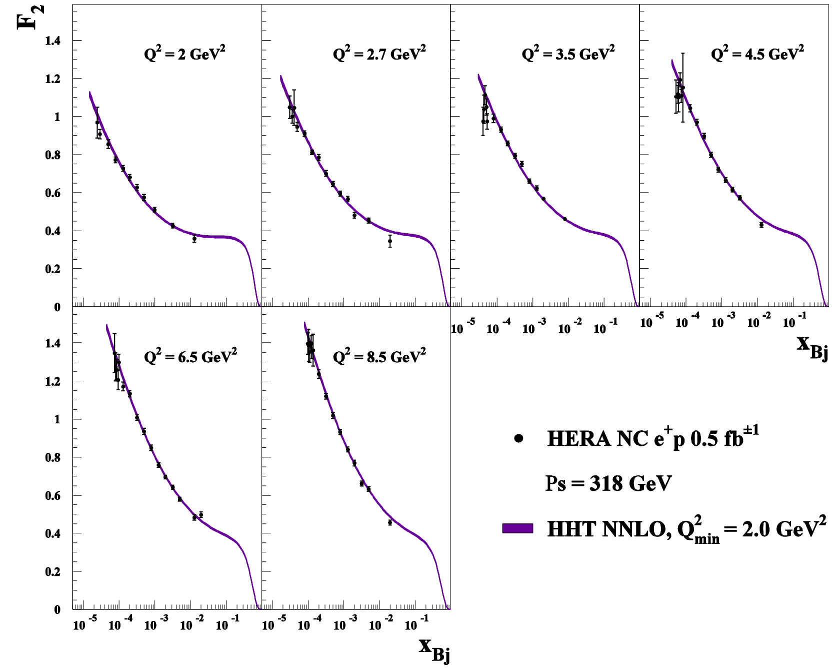
If our predicted F_L is too small the F_2 will also be too small and this is what we see in HERAPDF2.0 F_2 at low x,Q^2. The extracted F_2 takes a turn over!

This is not the pQCD F_2 predictions say.

If we use the HHT predictions for F_L then the F_2 extracted is much closer to the F_2 predictions– and these F_2 predictions are very similar for HERAPDF2.0 and HHT because they depend ONLY on the very similar PDFs.

(The picture is similar but not quite so good for NLO- see back-up)

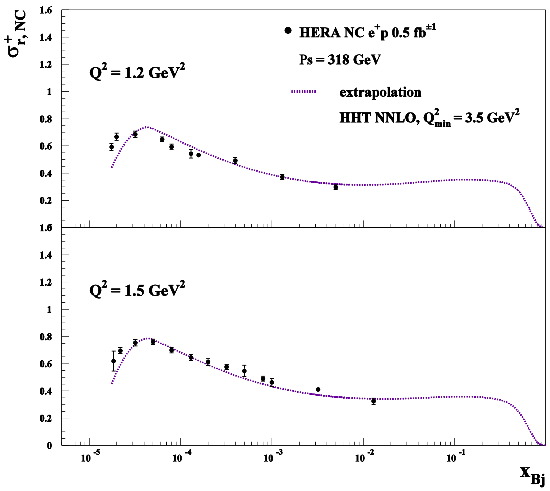




Looking at the extrapolations of our fits below Q^2_{min} =3.5 GeV^2 made us bold enough to extend the fit down to Q^2_{min}=2.0 GeV^2

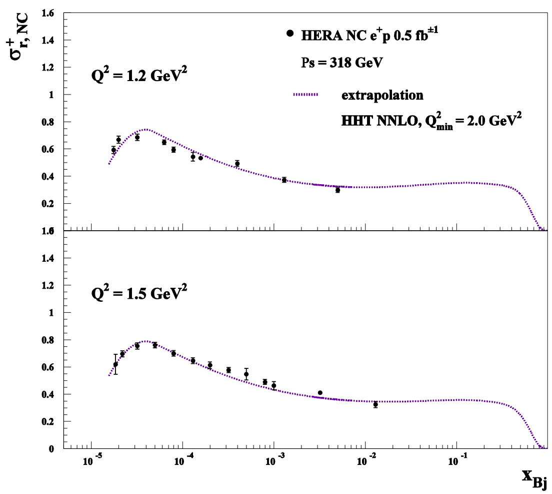
Fit at	with Q^2_{min} = 2.0 GeV^2	HERAPDF2.0	HHT	A_L^{HT}
NNLO	χ^2/ndof	1437/1185	1381/1188	5.2±0.7
	Partial χ^2/ndof for NC e^+p: $Q^2 \geq Q^2_{min}$	486/402	457/402	
	Partial χ^2/ndof NC e^+p: $Q^2_{min} \leq Q^2 < 3.5$ GeV^2	31/25	26/25	
NLO	χ^2/ndp	1433/1185	1398/1188	4.0±0.6
	Partial χ^2/ndof for NC e^+p: $Q^2 \geq Q^2_{min}$	487/402	466/402	
	Partial χ^2/ndof NC e^+p: $Q^2_{min} \leq Q^2 < 3.5$ GeV^2	40/25	31/25	

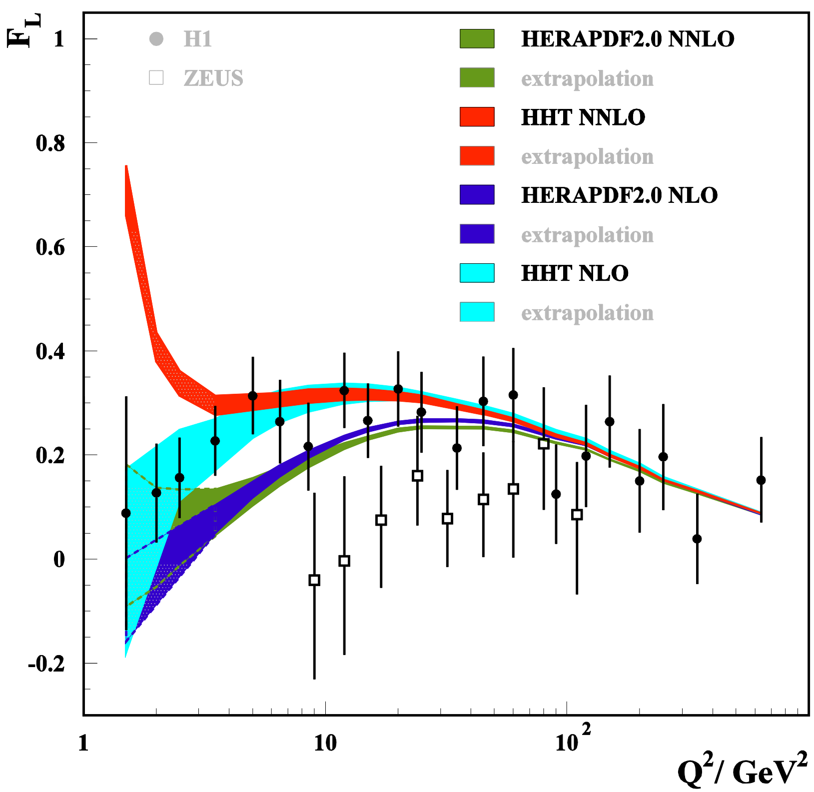
Where not much changes for the NNLO fit, and the NLO fit improves a little
See back-up



So we got even bolder and looked at lower Q^2- by backward evolution

But beware…is this actually reasonable? What does FL itself look like?





NNLO HHT F_L prediction is becoming untamed at low Q^2– this approach cannot be pushed too far.
This comes from NNLO coefficient functions and the $1/Q^2$ term just makes it worse

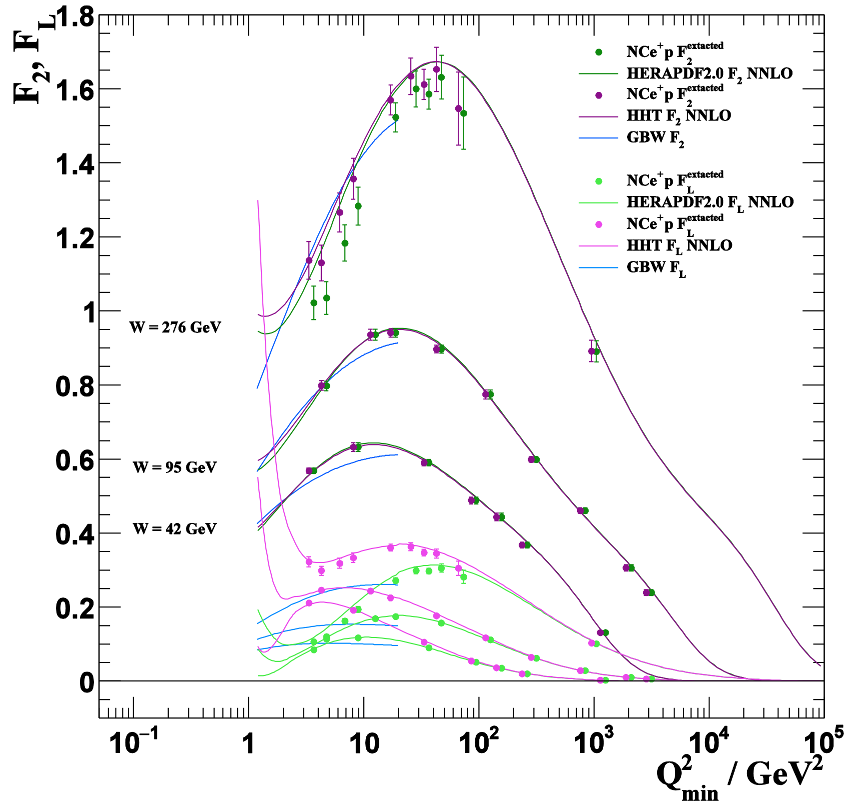
Another interesting way to look at this is by looking at plots of F_2 and F_L at fixed W as a function of Q^2 (This is the Golec-Biernat Wusthoff dipole model way of looking at it)

First look at the top three curves for F2

Compare the HHT F_2 extracted points to the F_2 predictions – the description is good.
Then compare the HERAPDF2.0 F2 extracted points to the F2 predictions the description is not so good.

This is essentially what we saw in the F2 curves on slide 8 but it emphasizes that the discrepancy comes at low x. Only the top curve W=276GeV involves data at really low x

$x = Q^2/(W^2+Q^2)$



Now look at the bottom three curves for F_L
The predictions for HHT go crazy at very low Q^2.
In fact this upturn happens in HERAPDF as well- and it is starting to happen in F_2. It is a feature of the low-x coefficient functions

Here the extracted F_L points are got from

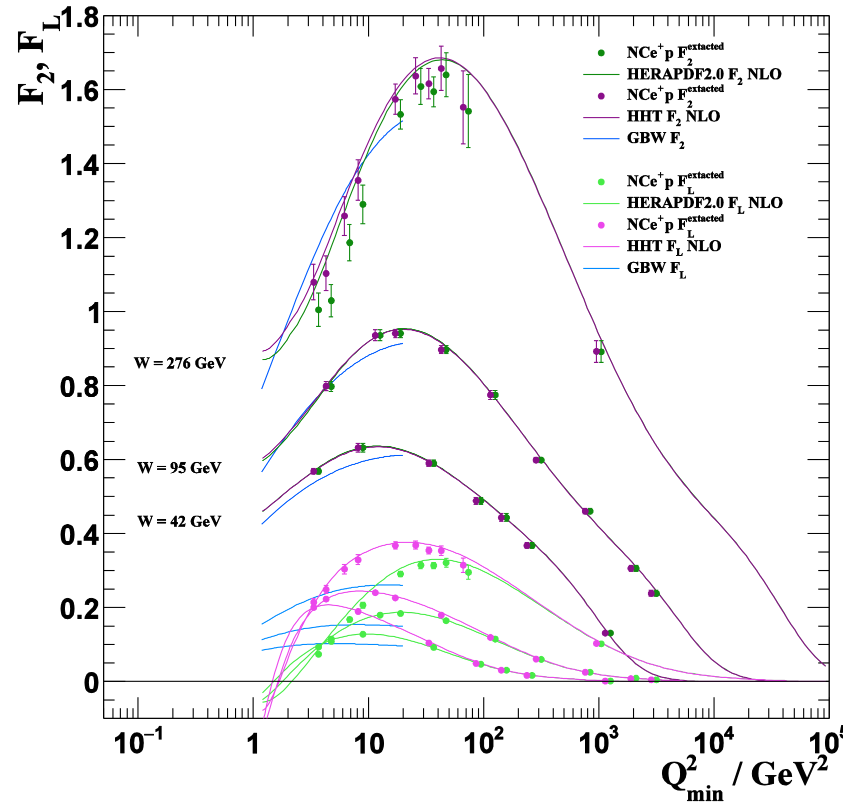
$$F_L^{extracted} = F_L^{predicted} \frac{\sigma_r^{measured}}{\sigma_r^{predicted}} .$$

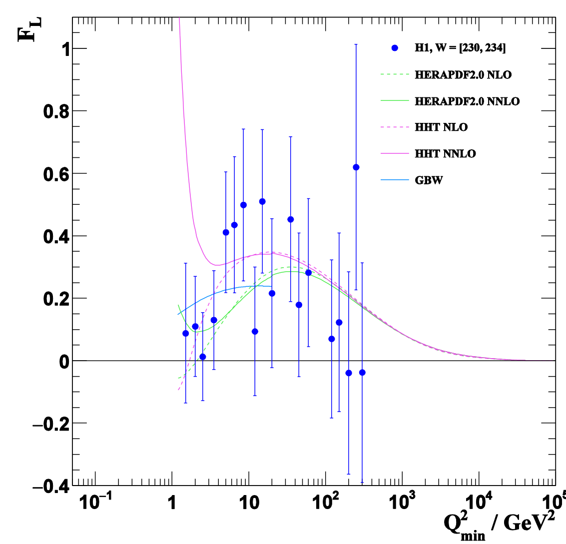
Since F_L is not the dominant part of the reduced cross section these cannot be considered as measurements and they simply follow the predictions

It is not just the NNLO F_L which is becoming unacceptable at low Q^2, the NLO predictions also have problems. They are becoming negative. This is not allowed for a structure function (as opposed to a PDF)

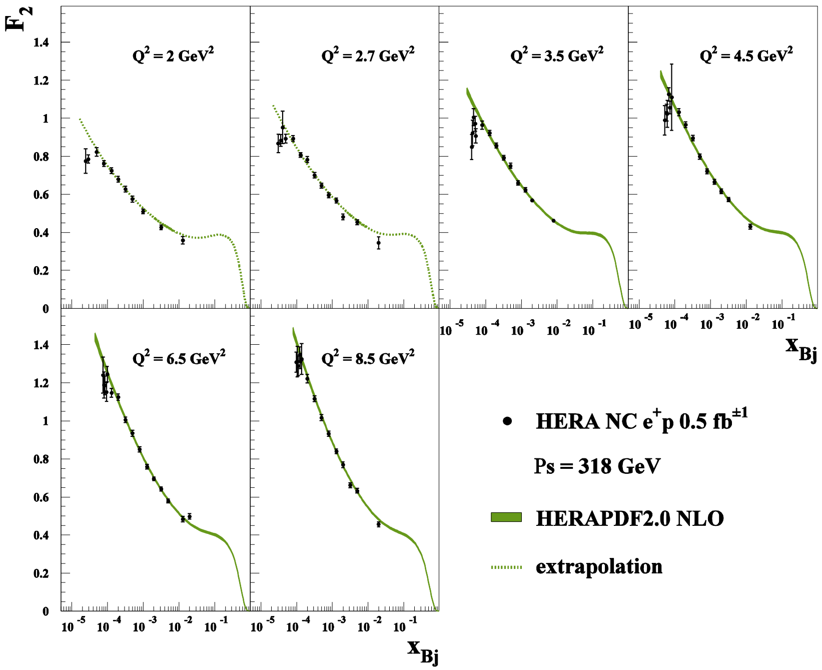
The GBW predictions at both NNLO and NLO are also compared to the extracted data points in these figures. They are broadly compatible with the HHT predictions for F_2 for $Q^2 < 10$ GeV^2

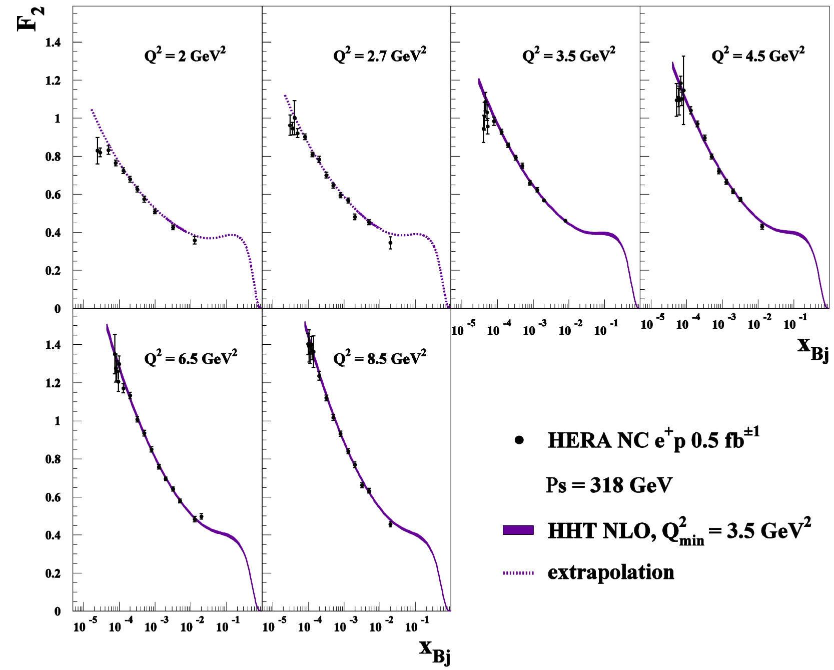
Finally we look at the FL predictions for HERAPDF2.0 and HHT at NNLO as compared to the H1 direct measurements at W= 232 GeV.
The data are able to exclude the extreme behaviour of the HHT prediction for $Q^2 < 3.5$ GeV^2



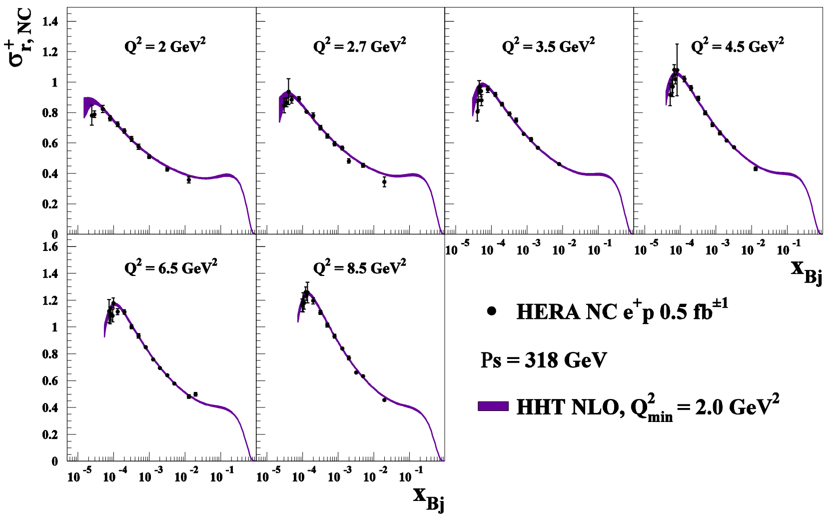


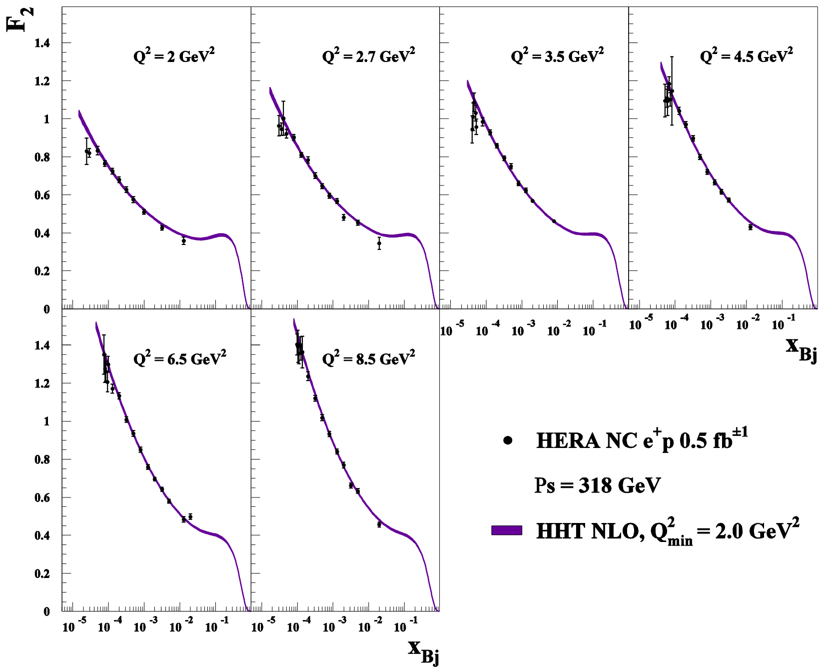
Back-up





And at NLO –the F2 down to Q2min=3.5





And at NLO down to Q2min=2.0