

# PDF comparisons

PDF4LHC Nov 23<sup>rd</sup> 2022  
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In the Snowmass report 2203.13923 various comparisons of modern PDF sets at NNLO were made

PDFs

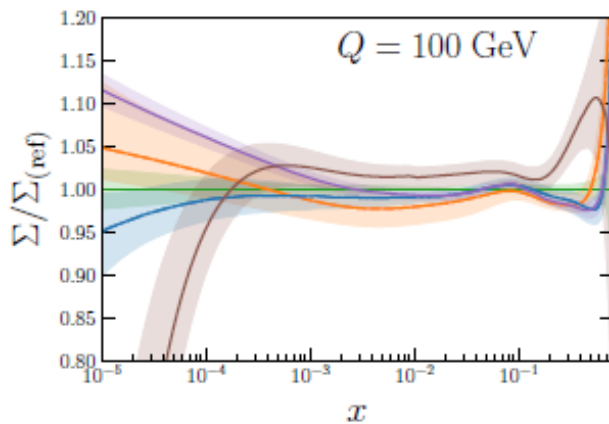
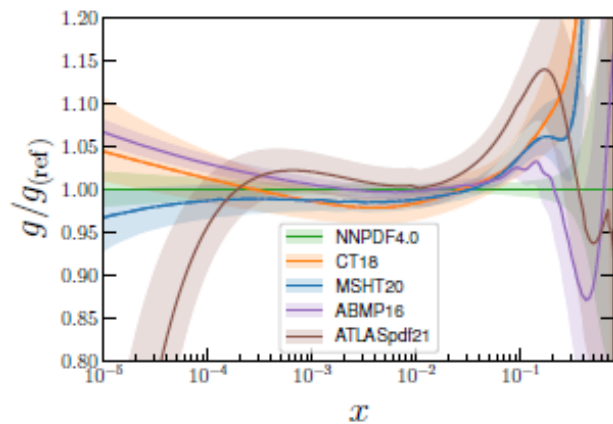
PDF uncertainties

F2,FL

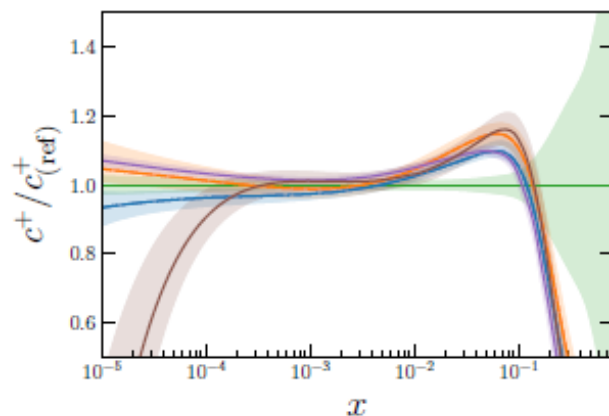
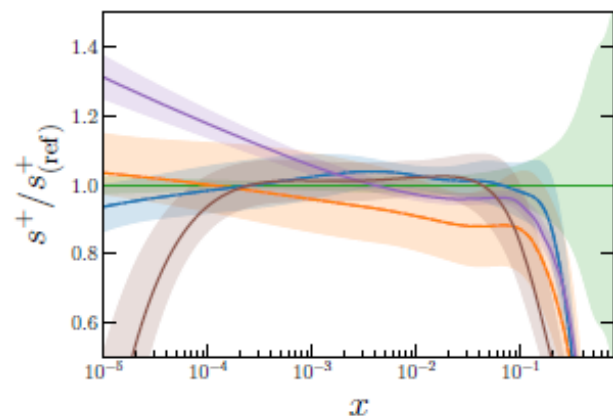
Luminosities for the LHC

Plus Keping Xie has updated these to add in even more modern variants including 'beyond NNLO'

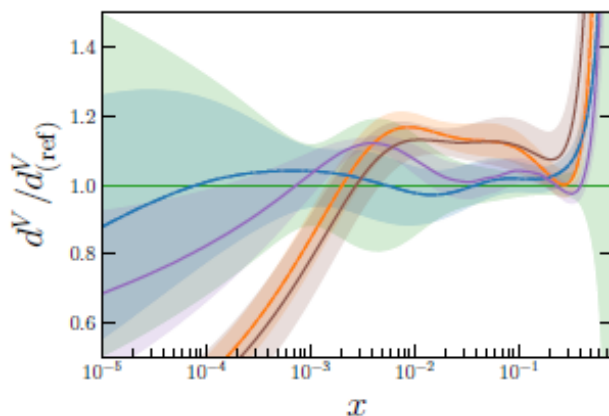
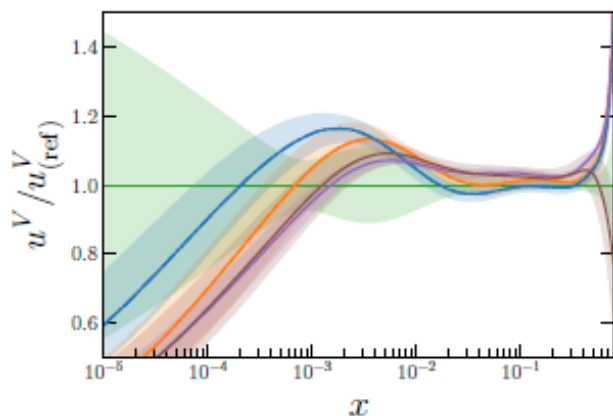
So as an introduction to the uncertainties section let us look at these  
And ask questions as to where the differences come from



In ratio to NNPDF4.0  
We are not so surprised  
by differences at high- $x$ ,  
though they can be  
outside uncertainties

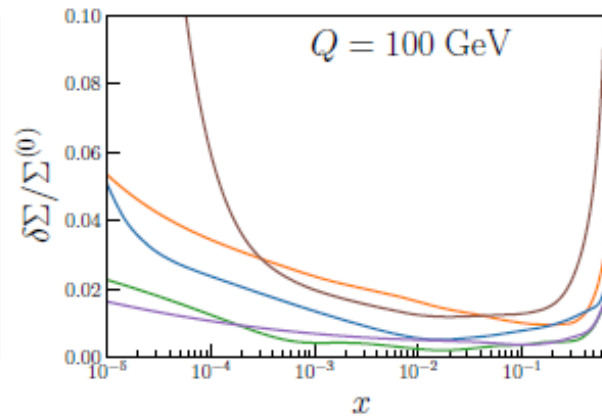
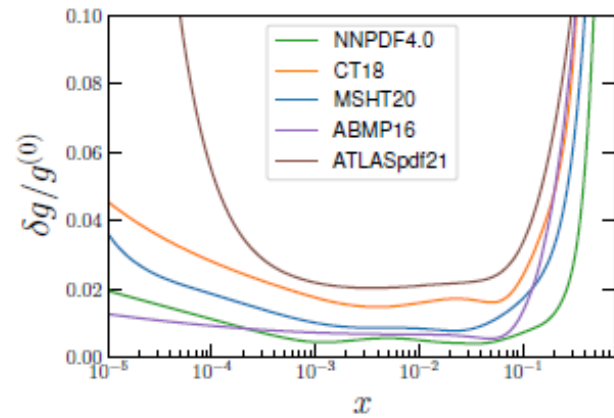


NNPDF has intrinsic  
charm. But also less  
strange suppression



Differences in low- $x$   
valence are also  
unsurprising, when little is  
known on valence at very  
low- $x$   
**BUT I mostly want to talk  
about the low- $x$  gluon**

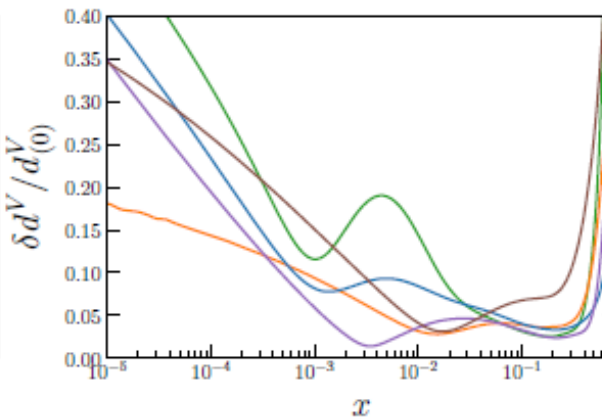
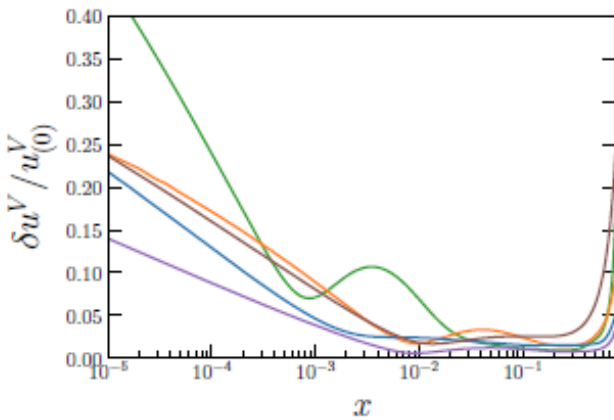
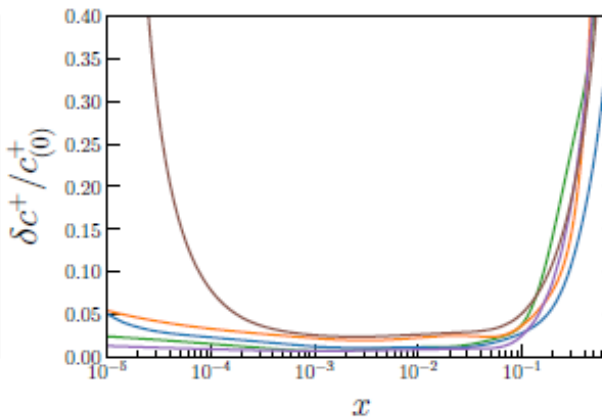
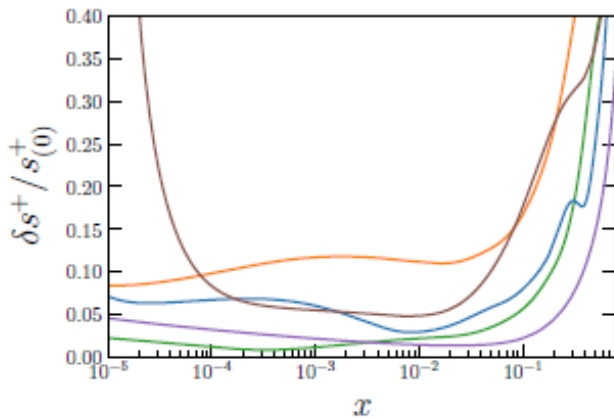
And note these plots do go to VERY low- $x$  for  $Q=100$ , central  
LHC probes only down to  $x \sim 10^{-3}$



Before that let us look at uncertainties

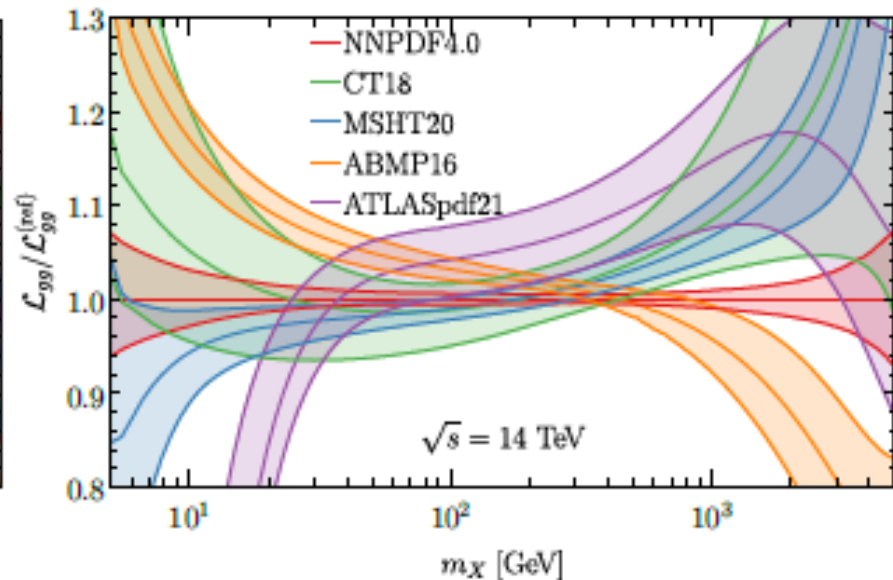
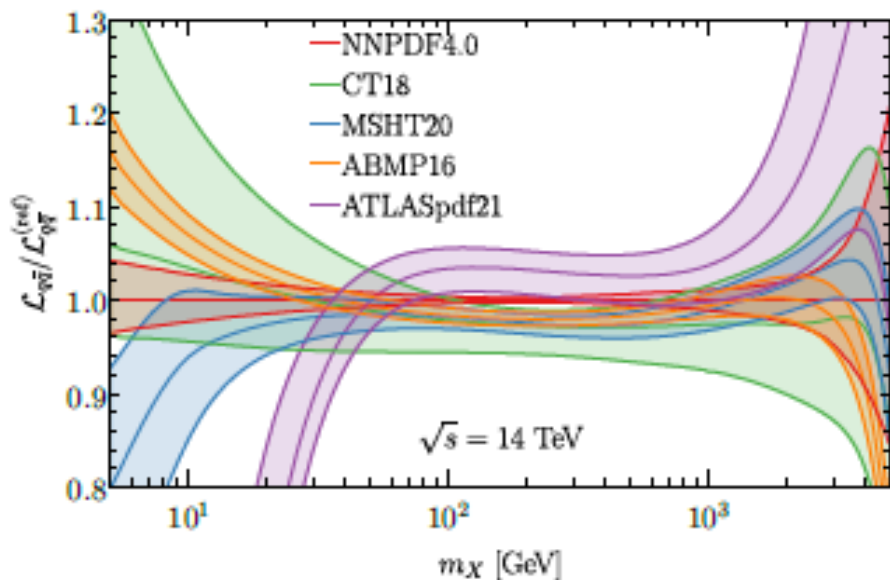
NOTE ABMP16 is relatively small in regions where similar amounts of data are used because  $\Delta\chi^2=1$  is used rather than a higher tolerance

ATLASpdf21 is larger at low and small x because less data are used



CT18 is often the larger of CT, MSHT because of a larger tolerance than MSHT

NNPDF4.0 has generally very small uncertainties--- new procedure, positivity etc..we will discuss



Now let us see the consequences of differences at low- $x$  for LHC luminosities:

q-qbar left, g-g right in ratio to NNPDF

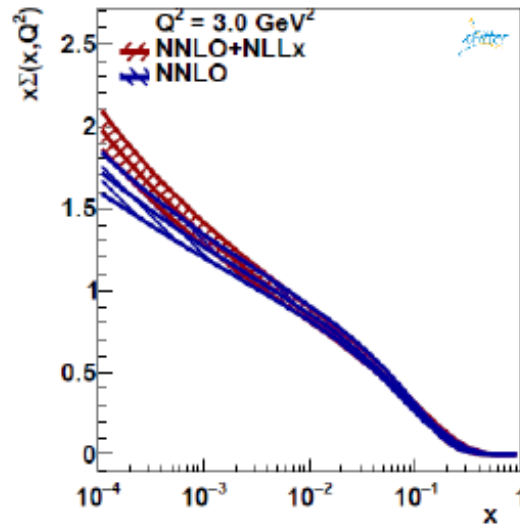
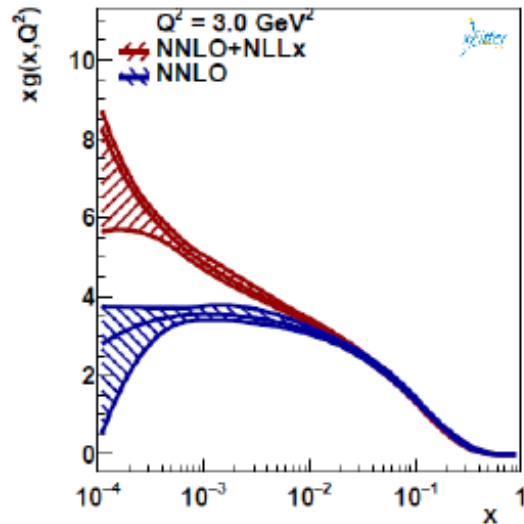
We don't often worry about  $m_X < 30$  GeV at the LHC

But if we did.. We need to worry about the low- $x$  theory

- i) The HERA data at  $Q^2 < 10 \text{ GeV}^2$  ( $x < \sim 10^{-4}$ ) were cut precisely to avoid this problematic region— (the HERA data are still the main data which probe this region) but it turns out that this is almost exactly the wrong thing to do at NNLO— a better approximation to 'the truth' would be got by fitting down to lower  $Q^2$  and putting up with the larger  $\chi^2$ — as is done by MSHT (who have a similar gluon parametrisation), CT, NNPDF

What do I mean by 'the truth'— well I mean what one might get at higher order or with BFKL  $\ln(1/x)$  resummation

There has long been an issue that at low-x one should probably be resumming  $\ln(1/x)$  terms as well as  $\ln(Q^2)$  terms –this is BFKL resummation and is beyond DGLAP  
 This has been done by NNPDF- NNPDF3.1sx 1710.05935  
 And on the HERAPDF using xFitter 1802.00064 (using HELL, Bonvini 1805.08785)



What does it do?

It turns blue into red— **dramatic change on the low-x gluon**

Gets a better  $\chi^2$  for the low-x,  $Q^2$  HERA data by  $\sim 70$  units

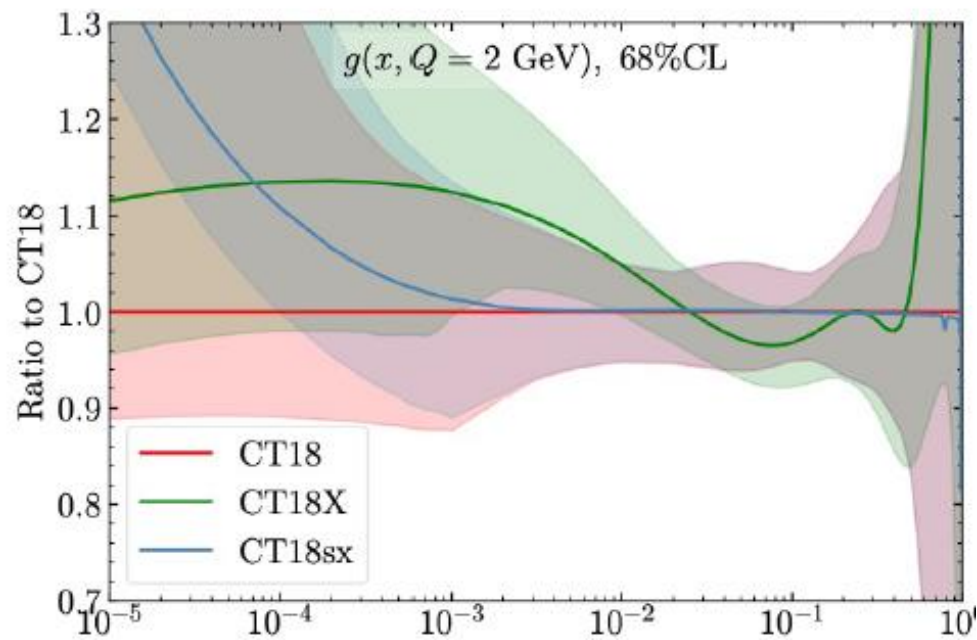
**CT have now also done this in CT18sx**

But there is another thing one needs to consider— **high density effects** when the gluon gets large such that gluons may recombine, as well as split, and this may lead to gluon saturation. CT have modelled this with an x dependent scale for DIS in CT18X  
 Not  $Q^2$  BUT

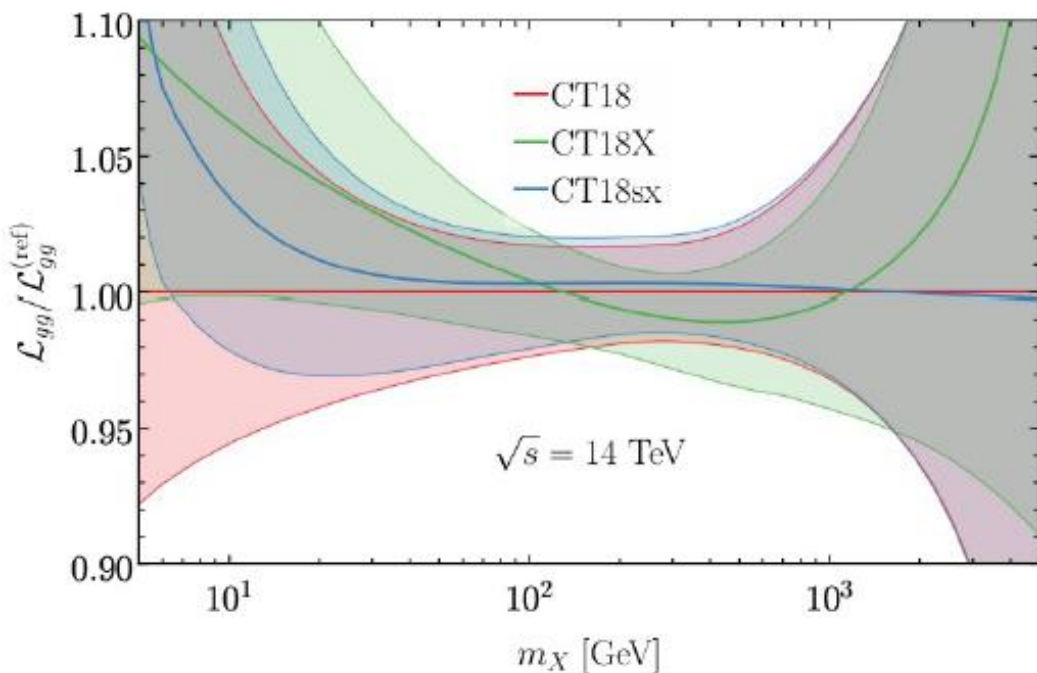
$$\mu_{DIS,X}^2 = 0.8^2 \left( Q^2 + \frac{0.3 \text{ GeV}^2}{x^{0.3}} \right)$$

This also enhances the low-x gluon---

And it gives a similar decrease in  $\chi^2$  for the low-x,  $Q^2$  HERA data by  $\sim 70$  units



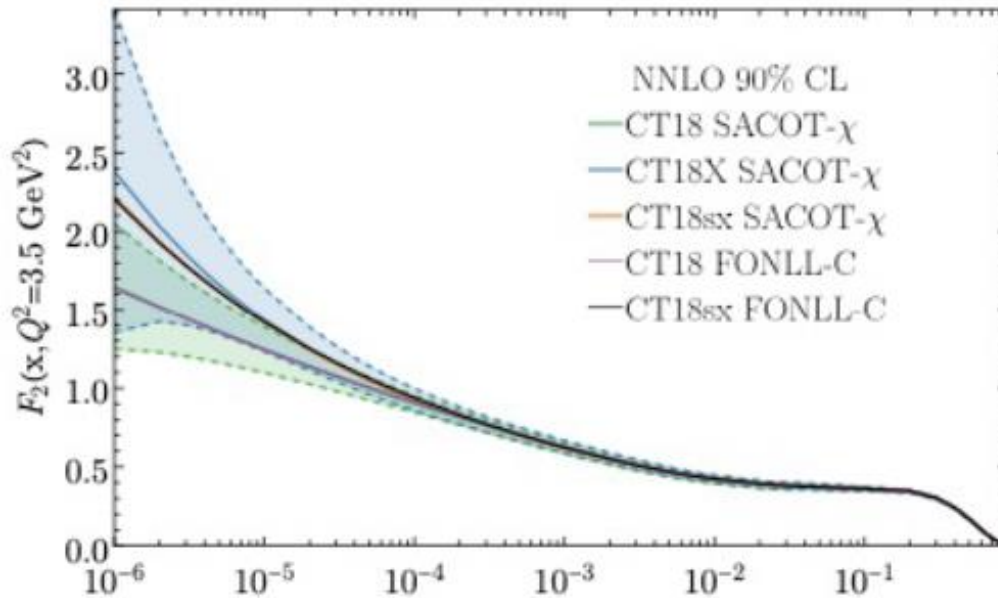
Compare gluon shapes at low scale



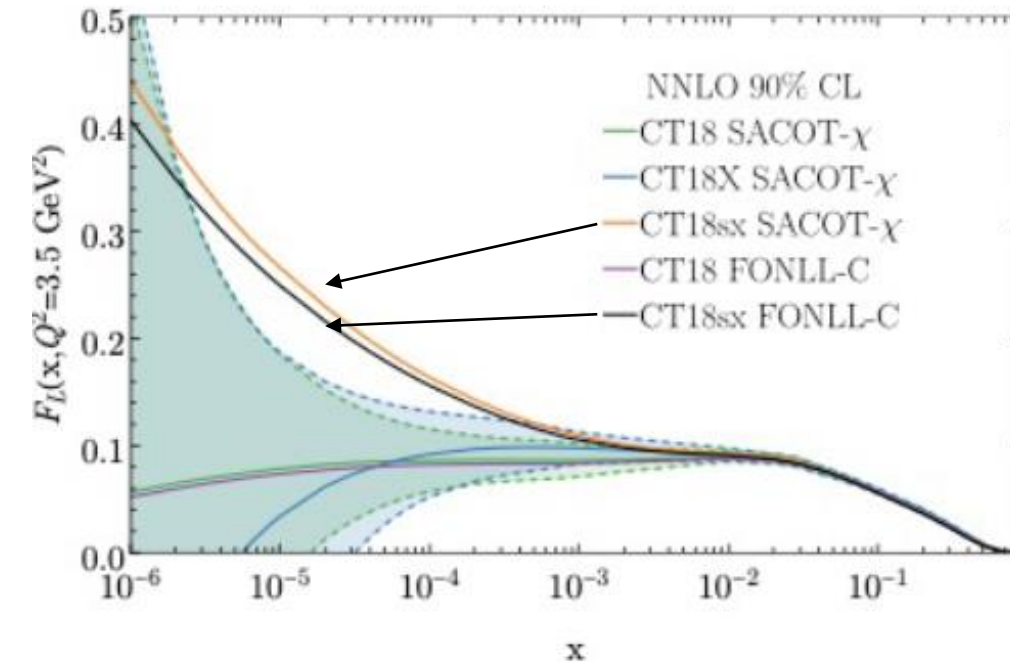
And then compare gluon-gluon luminosities for the LHC

Hard to distinguish within uncertainties BUT..





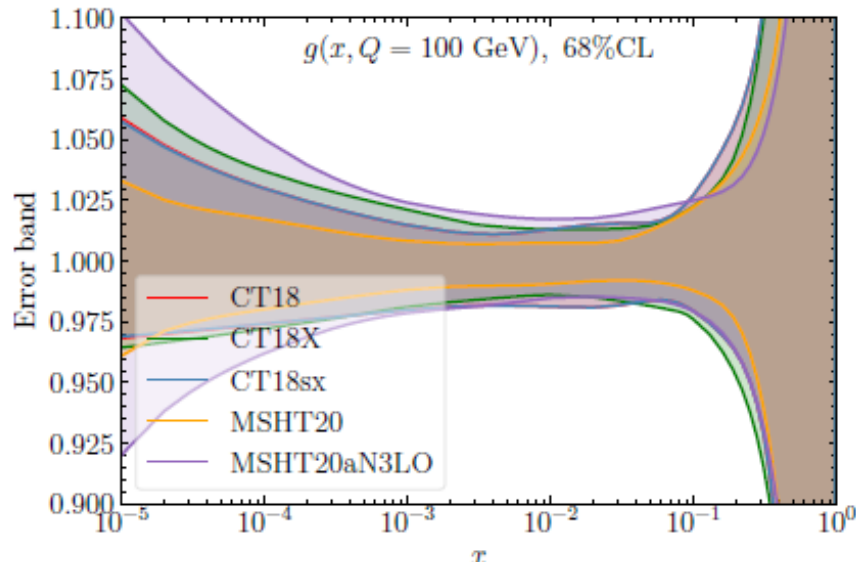
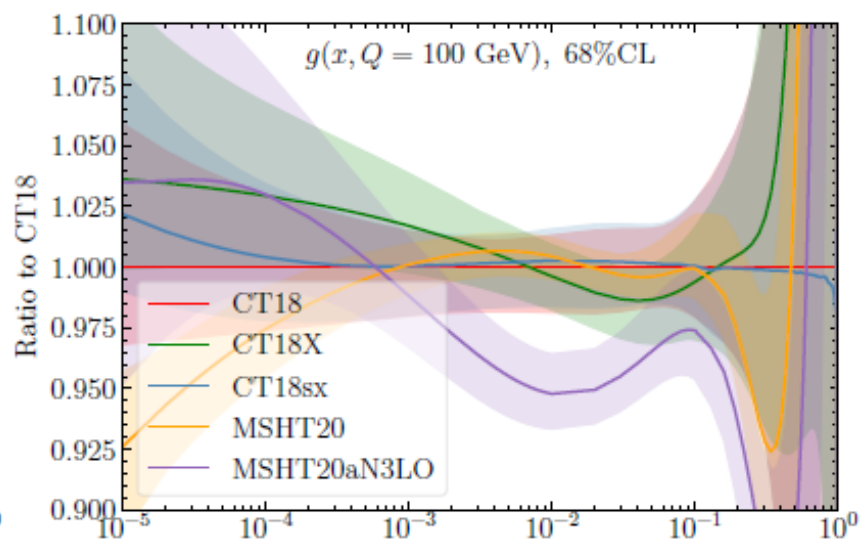
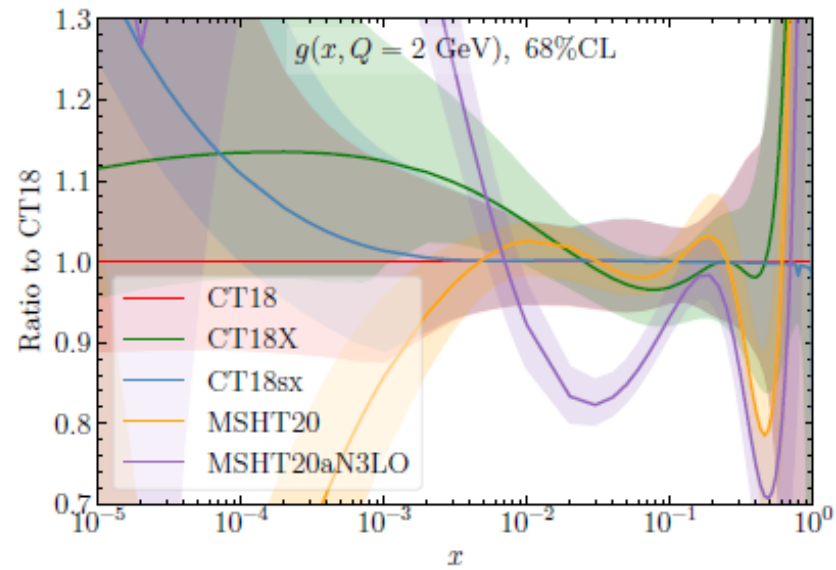
DIS structure function FL at low Q  
Can maybe tell difference between  
CT18/CT18X and CT18sx



Returning to the LHC there has been a parallel development --- N3LO  
Well at least approximately

This has an astounding effect on the low-x gluon at low scales

Which persists to LHC scales

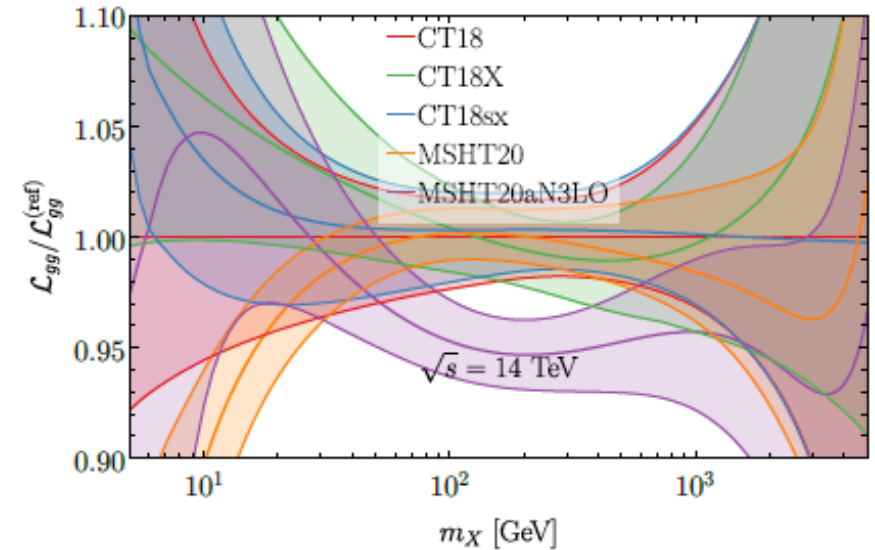
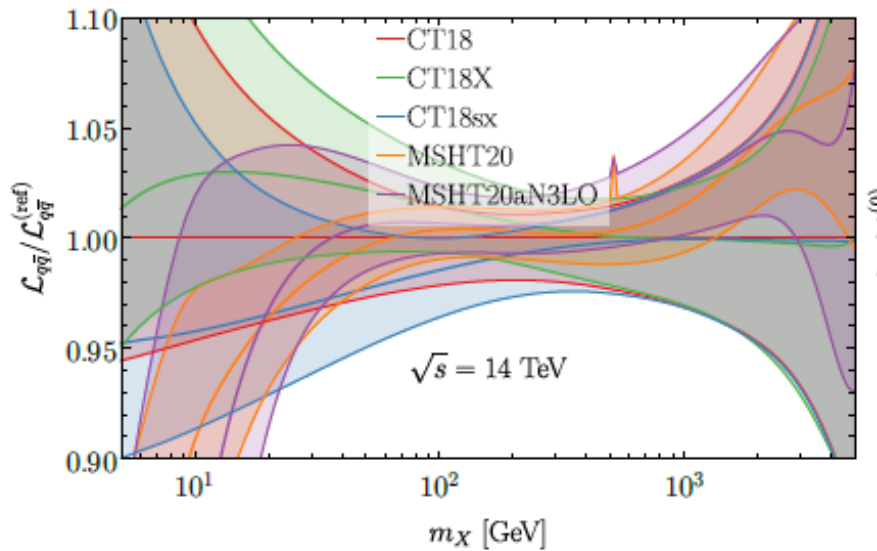


Contrast the MSHT20 NNLO<sup>x</sup>  
With the MSHT20aN3LO  
But also note it is much stronger than the changes of CT18 to either CT18sx or CT18X– although there are similarities in a rise of the low-x gluon

And note in passing that the uncertainties are larger because there is an attempt to include uncertainty from yet higher orders



How about LHC parton-parton luminosities in these newer variants?



q-qbar left and g-g right, in ratio to CT18

Note especially the ‘knock-on’ effect of the rise in gluon luminosity at low scale for N3LO to a decrease of  $\sim 5\%$  at the Higgs scale...

Clearly we are going to have to consider low-x both

- If we go forward to FPF
- And if we go to higher energy—when the kinematic region moves to lower-x

But ALSO – we need to worry about the consequences at the Higgs scale