ATLAS PDF analyses,
Past, present and future

AM Cooper-Sarkar for the PDF forum
SM meeting Sep 5th 2018, QMUL

PAST

- Inclusive W,Z 7 TeV- valence, strangeness

PRESENT

- T-tbar 8 TeV-- gluon
- W+jets 8 TeV---flavour separation in the sea
- Direct Photon 8 TeV--gluon

NEAR FUTURE

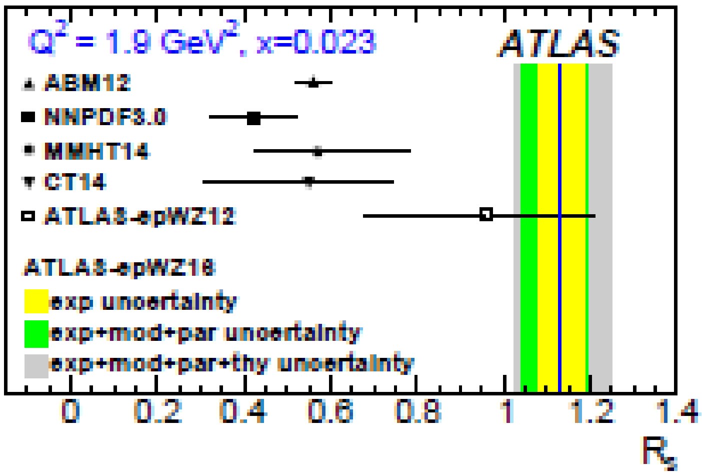
- Z+jets 8 TeV—flavour separation and gluon?
- Z3D, W+/W- 8 TeV--- flavour separation/valence
- W+D/D* 8 TeV, W+c 13 TeV--strangeness
- Inclusive jets 8,13 TeV-------gluon

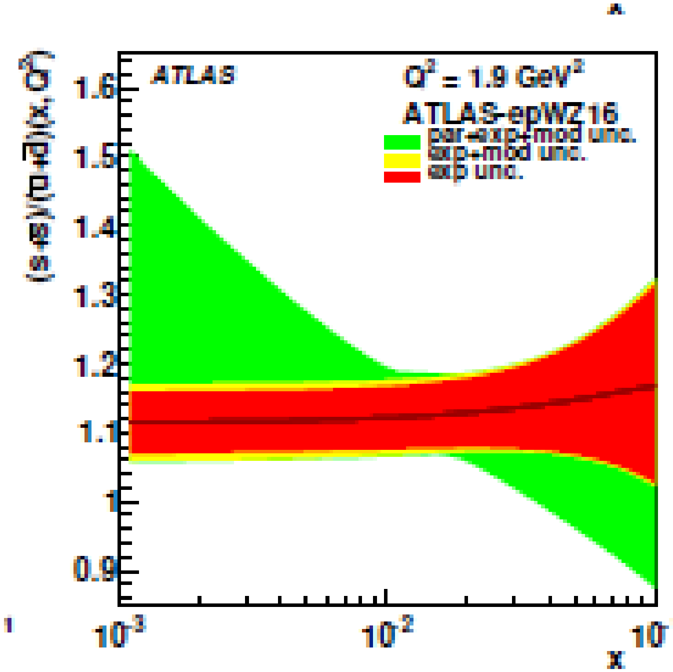
FURTHER FUTURE

- 13 TeV many channels
- HL-LHC

We have seen that the ATLAS inclusive W,Z 2011 precision data arXIV:1612.03016

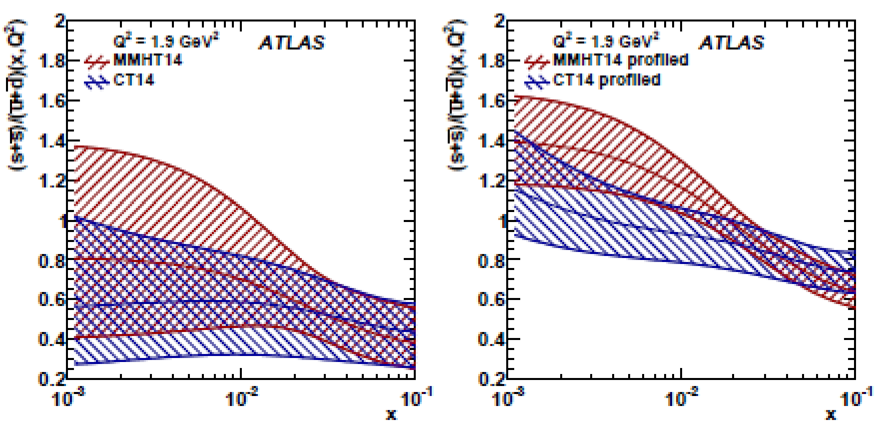
Imply unsuppressed strangeness

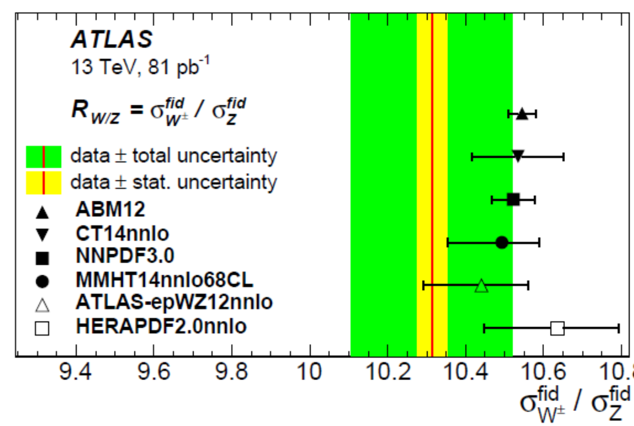




We consider strangeness in ratio to the light quark PDFs as a function of x Not just at a single x,Q2 point

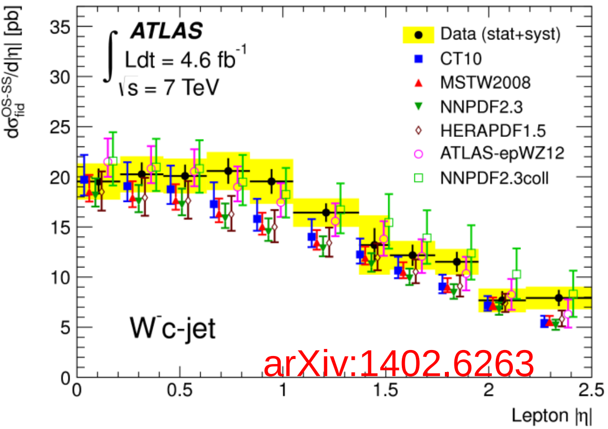
Profiling other PDFsets tells the same story- more strangeness at low-x



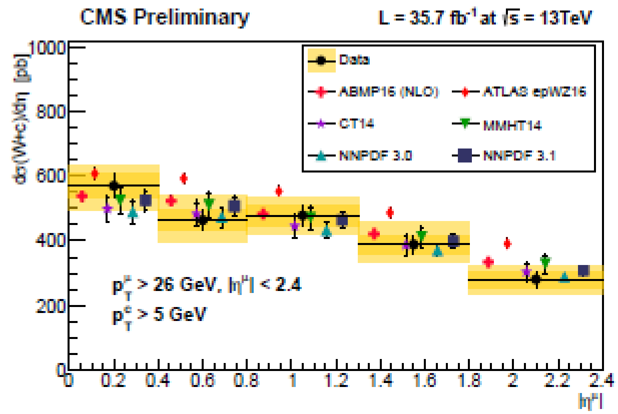


We also see it in 13Tev supressed W/Z ratio

But do we see it in W+c production?—ATLAS does, CMS does NOT



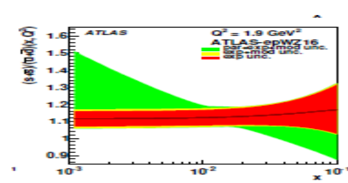
Older ATLAS data
NEW CMS data

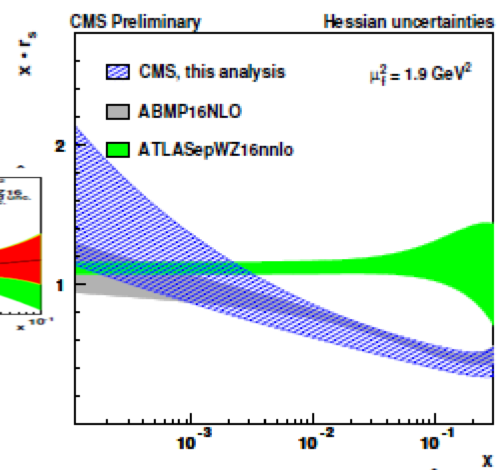


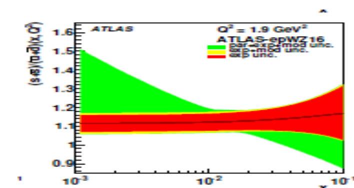
ATLAS data agrees with PDFs which have unsuppressed strangeness
CMS – now at 13 TeV--data has a smaller cross section and less strangeness CMS-PAS-SMP-17-014

BUT

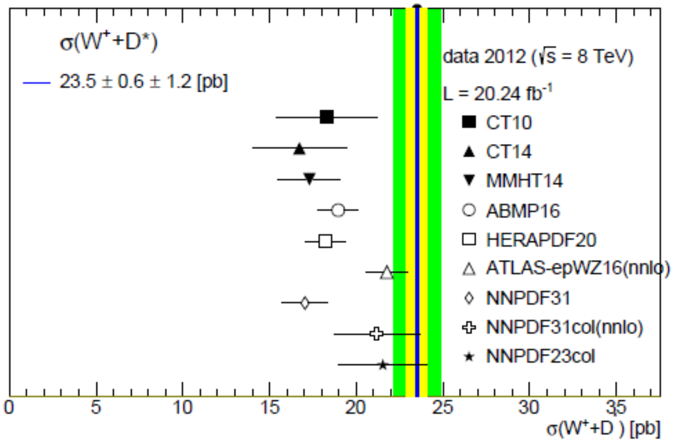
1) If the full error band of the ATLAS inclusive analysis is laid on the CMS plot the discrepancy is not so eye-catching
2) CMS still implies larger strangeness than the conventional 0.5 suppression at low –x, x< 0.005



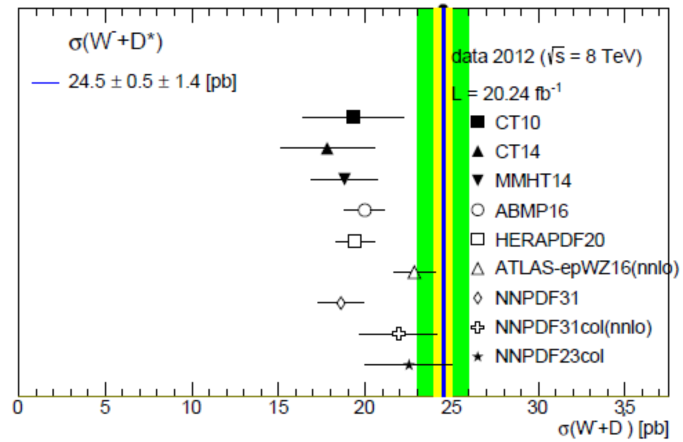




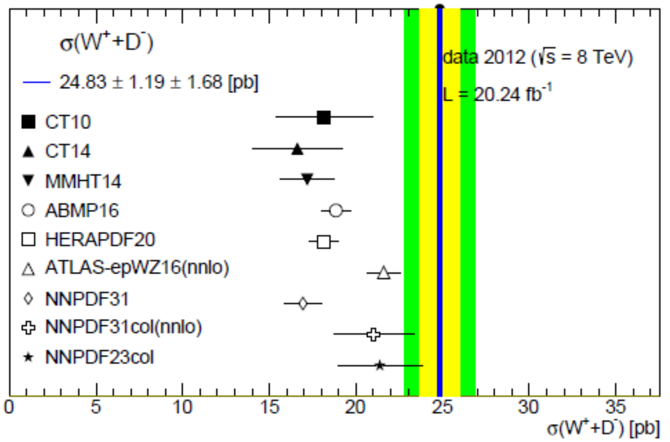
However NEW ATLAS W+D/D* data is now in EB review (and Z+D/D*)



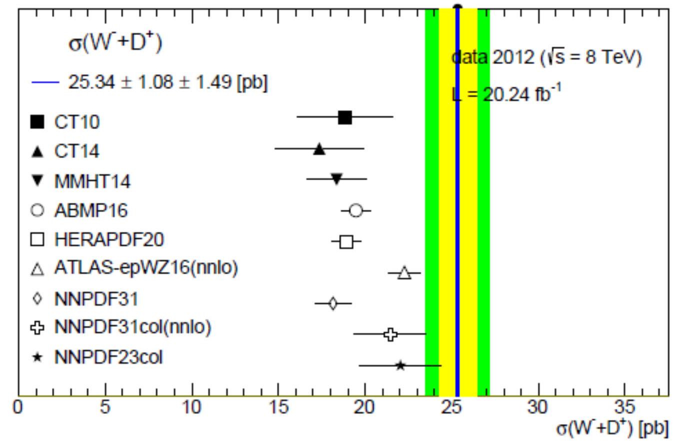
(a) $\sigma^{OS-SS}_{fid}(W^+D^{*-})$



(b) $\sigma^{OS-SS}_{fid}(W^-D^{*+})$

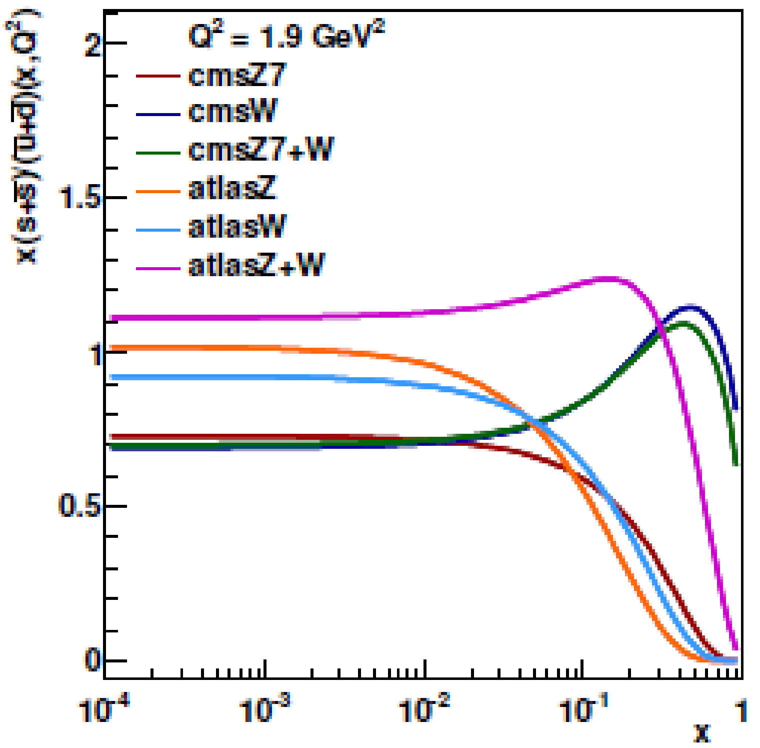


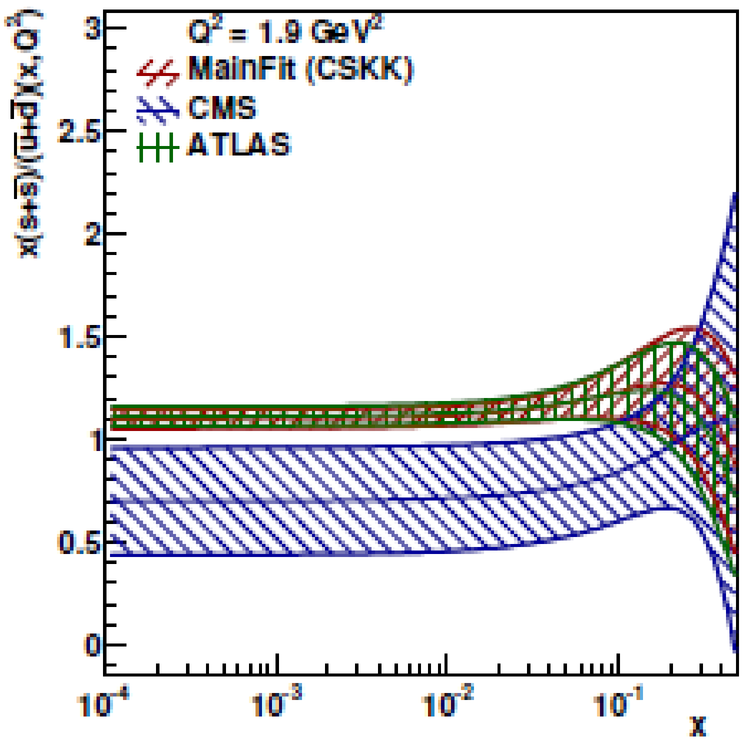
(c) $\sigma^{OS-SS}_{fid}(W^+D^-)$



(d) $\sigma^{OS-SS}_{fid}(W^-D^+)$

And W+c-jet data at 13 TeV are also coming





arXIV:1803.00968 considers inclusive W and Z data sets from ATLAS and CMS separately and together.

In the left hand figure inclusive W, Z data from ATLAS and CMS are fitted separately and W+Z together and the strangeness ratio is extracted as a function of x.

The correlations of ATLAS 7 TeV W and Z data make a big difference (there are none for CMS)

In the right hand figure inclusive W + Z data are fitted for AT LAS and CMS separately and together- when fitted together the accuracy of the ATLAS data dominated the fit. There is NO significant tension with CMS inclusive data

Fits to t-tbar differential distributions now public

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2018-017/

https://www.hepdata.net/record/84154

Lepton+jets 8 TeV data from arXIV:1511.04716, di lepton data: arXiv:1607.07281

Top data exists as normalised and absolute spectra .
Absolute also carries information on the total t-tbar cross-sections which is useful to constrain PDF fits.

- The top data are used in addition to the HERA I+II combined data, and the ATLAS W,Z 7 TeV data – so the fits **ATLASopWZtop18** are an extension to **ATLASepWZ16**
- Note the top data and W,Z data are complementary – top affects the gluon, whereas W,Z affects the quarks.
- Conclusions on top are similar if W,Z is removed

Correlations between the top 8 TeV data and the W,Z 7 TeV data are small—this was considered in the t-tbar/Z paper arXIV:1612.03636

Correlations betwee the top 8 TeV lepton+jets and dilepton data are also small—except for the common luminosity

The most constraining top distributions are p_T^t , y_t y_{ttbar}, m_{ttbar} and they mostly constrain the high-x gluon

But until VERY recently no more than one spectrum could be fitted at once

Because the statistical correlations between the spectra were missing

Recently the statistical correlation matrices between the spectra have been evaluated

1	1	0.523003	-0.0865203	-0.230593	-0.123318	-0.0355471	-0.0183453	-0.00742052	0.193366	0.199054	0.165572	0.119437	0.092385	0.191687	0.211977	0.170986	0.141897	0.0801098	0.313266	0.358684	0.1566	0.0379843	-0.00850053	-0.0167743	-0.00412765
2	0.523003	1	0.258974	-0.232733	-0.166392	-0.0568362	-0.0232129	-0.00928292	0.258845	0.259962	0.215854	0.157379	0.11635	0.257006	0.263854	0.221259	0.190785	0.114189	0.367823	0.46559	0.252227	0.0946659	0.0174152	-0.0106161	-0.00640371
3	-0.0865203	0.258974	1	0.211745	-0.16322	-0.0930239	-0.0348096	-0.015387	0.252667	0.256505	0.204611	0.153019	0.112391	0.245568	0.26638	0.217244	0.176239	0.115662	0.206166	0.396708	0.357748	0.205561	0.0849696	0.0238164	-0.00260146
4	-0.230593	-0.232733	0.211745	1	0.189977	-0.128108	-0.057691	-0.0144478	0.174912	0.186568	0.143437	0.121854	0.0838061	0.179544	0.180693	0.151204	0.137084	0.0904951	-0.0151066	0.111899	0.30052	0.306824	0.192282	0.0875043	0.0213644
5	-0.123318	-0.166392	-0.16322	0.189977	1	0.146452	-0.11266	0.028564	0.138193	0.144556	0.113236	0.0888044	0.0533645	0.137564	0.147322	0.115839	0.10241	0.0579249	-0.047342	-0.0350948	0.114799	0.280595	0.292134	0.178125	0.0566404
6	-0.0355471	-0.0568362	-0.0930239	-0.128108	0.146452	1	0.104131	-0.0939535	0.0936114	0.089112	0.0721004	0.0567852	0.0347566	0.0933875	0.0957962	0.0795374	0.0556884	0.0343439	-0.0254326	-0.0447006	-0.0102559	0.101504	0.262709	0.226378	0.0986235
7	-0.0183453	-0.0232129	-0.0348096	-0.057691	-0.112662	0.104131	1	0.0584419	0.0583097	0.0677387	0.0534449	0.028248	0.0197735	0.0582822	0.065875	0.0532866	0.0378831	0.0245572	-0.0164502	-0.0264189	-0.0266078	0.00383807	0.112064	0.272357	0.163028
8	-0.00742052	-0.00928292	-0.015387	-0.0144478	-0.028564	-0.0939535	0.0584419	1	0.0351814	0.044628	0.0329678	0.0154428	0.0038405	0.0365307	0.0394551	0.0347108	0.0206278	0.00892468	0.000869021	-0.00799165	-0.0166962	-0.0131954	0.0129482	0.158587	0.205627
1	0.193366	0.258845	0.252667	0.174912	0.138193	0.0936114	0.0583097	0.0351814	1	-0.0196275	-0.209871	-0.138556	-0.058594	0.489861	0.299719	0.0681119	-0.046792	-0.0606758	0.171685	0.262747	0.237413	0.19099	0.144966	0.0966219	0.0493263
2	0.199054	0.259962	0.256505	0.186568	0.144556	0.089112	0.0677387	0.044628	-0.0196275	1	0.0361891	-0.139761	-0.090291	0.247887	0.3457	0.236424	0.0775936	-0.0404607	0.169373	0.273609	0.248759	0.201697	0.147774	0.0990592	0.0480445
3	0.165572	0.215854	0.204611	0.143437	0.113236	0.0721004	0.0534449	0.0329678	-0.209871	0.0361891	1	0.055808	-0.116518	0.0399966	0.170229	0.273071	0.257601	0.0579035	0.132723	0.21484	0.193211	0.156733	0.12442	0.102127	0.0485058
4	0.119437	0.157379	0.153019	0.121854	0.0888044	0.0567852	0.028248	0.0154428	-0.138556	-0.139761	0.055808	1	0.0230257	-0.0363669	0.0317	0.158325	0.296765	0.255948	0.0878424	0.139365	0.141035	0.130769	0.120789	0.0846287	0.0346981
5	0.092385	0.11635	0.112391	0.0838061	0.0533645	0.0347566	0.0197735	0.0038405	-0.058594	-0.090291	-0.116518	0.0230257	1	-0.0239123	-0.0160335	0.0398061	0.185696	0.379725	0.0457679	0.0820693	0.0974089	0.10323	0.0949771	0.0793067	0.0358962
1	0.191687	0.257006	0.245568	0.179544	0.137564	0.0933875	0.0582822	0.0365307	0.489861	0.247887	0.0399966	-0.0363669	-0.0239123	1	-0.0274769	-0.263436	-0.0870922	0.00998396	0.134049	0.225154	0.221049	0.203422	0.183829	0.144336	0.0816254
2	0.211977	0.263854	0.26638	0.180693	0.147322	0.0957962	0.065875	0.0394551	0.299719	0.3457	0.170229	0.0317	-0.0160335	-0.0274769	1	0.17176	-0.195766	-0.0497008	0.158414	0.257381	0.246893	0.20935	0.176059	0.136116	0.0727846
3	0.170986	0.221259	0.217244	0.151204	0.115839	0.0795374	0.0532866	0.0347108	0.0681119	0.236424	0.273071	0.158325	0.0398061	-0.263436	0.17176	1	0.111911	-0.180419	0.132604	0.217563	0.209858	0.173215	0.13443	0.100188	0.0396299
4	0.141897	0.190785	0.176239	0.137084	0.10241	0.0556884	0.0378831	0.0206278	-0.046792	0.0775936	0.257601	0.296765	0.185696	-0.0870922	-0.195766	0.111911	1	-0.0338399	0.128643	0.204679	0.185544	0.142059	0.0930908	0.0489947	0.00816948
5	0.0801098	0.114189	0.115662	0.0904951	0.0579249	0.0343439	0.0245572	0.00892468	-0.0606758	-0.0404607	0.0579035	0.255948	0.379725	0.00998396	-0.0497008	-0.180419	-0.0338399	1	0.117539	0.146678	0.099773	0.069673	0.0272868	0.00203619	-0.00530476
1	0.313266	0.367823	0.206166	-0.0151066	-0.047342	-0.0254326	-0.0164502	0.000869021	0.171685	0.169373	0.132723	0.0878424	0.0457679	0.134049	0.158414	0.132604	0.128643	0.117539	1	0.52067	-0.254831	-0.249305	-0.10418	-0.0214541	0.000815721
2	0.358684	0.46559	0.396708	0.111899	-0.0350948	-0.0447006	-0.0264189	-0.00799165	0.262747	0.273609	0.21484	0.139365	0.0820693	0.225154	0.257381	0.217563	0.204679	0.146678	0.52067	1	0.298679	-0.250712	-0.221548	-0.0669809	-0.010135
3	0.1566	0.252227	0.357748	0.30052	0.114799	-0.0102559	-0.0266078	-0.0166962	0.237413	0.248759	0.193211	0.141035	0.0974089	0.221049	0.246893	0.209858	0.185544	0.099773	-0.254831	0.298679	1	0.409987	-0.163016	-0.142808	-0.0315226
4	0.0379843	0.0946659	0.205561	0.306824	0.280595	0.101504	0.00383807	-0.0131954	0.19099	0.201697	0.156733	0.130769	0.10323	0.203422	0.20935	0.173215	0.142059	0.069673	-0.249305	-0.250712	0.409987	1	0.334172	-0.169248	-0.0742702
5	-0.00850053	0.0174152	0.0849696	0.192282	0.292134	0.262709	0.112064	0.0129482	0.144966	0.147774	0.12442	0.120789	0.0949771	0.183829	0.176059	0.13443	0.0930908	0.0272868	-0.10418	-0.221548	-0.163016	0.334172	1	0.184151	-0.122152
6	-0.0167743	-0.0106161	0.0238164	0.0875043	0.178125	0.226378	0.272357	0.158587	0.0966219	0.0990592	0.102127	0.0846287	0.0793067	0.144336	0.136116	0.100188	0.0489947	0.00203619	-0.0214541	-0.0669809	-0.142808	-0.169248	0.184151	1	0.145869
7	-0.00412765	-0.00640371	-0.00260146	0.0213644	0.0566404	0.0986235	0.163028	0.205627	0.0493263	0.0480445	0.0485058	0.0346981	0.0358962	0.0816254	0.0727846	0.0396299	0.00816948	-0.00530476	0.000815721	-0.010135	-0.0315226	-0.0742702	-0.122152	0.145869	1
	1	2	3	4	5	6	7	8	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	6	7

Table 1: Statistical correlation matrix between the absolute differential cross-sections. All variables are included to show the correlations between different bins of different variables. From left to right and top to bottom the rows and columns are labeled by bin number for each variable and the variables are ordered: p_T^t, $|y_t|$, $|y_{t\bar{t}}|$, and $m_{t\bar{t}}$.

This information is added to the HEPDATA entry for the lepton+jets spectra

Predictions for top

Mitov et al issued fast grids at NNLO: arXiv:1704.08551 to facilitate PDF fitting using FastNLO. These can be used for the lepton+jets channel

For the dilepton channel MCFM NLO Applgrids are used with NNLO/NLO k-factors from arXiV:1611.08609

Mitov et all also issued Electroweak corrections arXIV: 1705.04105 these are included as k-factors

The predictions for y_t y_{ttbar}, m_{ttbar} are made for renormalisation and factorisation scale $H_T/4$, where

$$H_T = \sqrt{m_t^2 + (p_T^t)^2} + \sqrt{m_t^2 + (p_T^{tbar})^2}$$

Whereas the predictions for p_T^t use the scale $m_T/2$ where $m_T = \sqrt{m_t^2 + p_T^2}$

And m_t= 173.3 GeV.

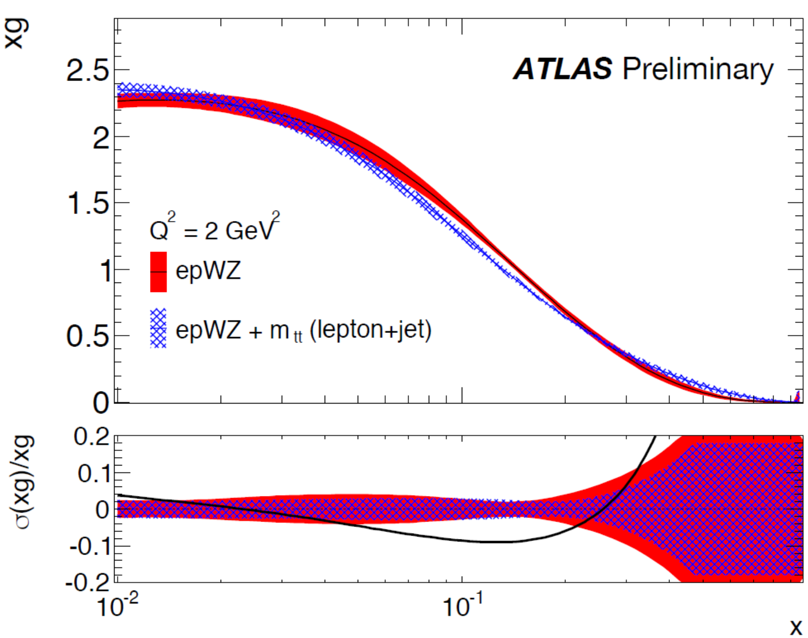
These scale choices are taken from Czakon, Heymes, Mitov, arXIV:1606.03350

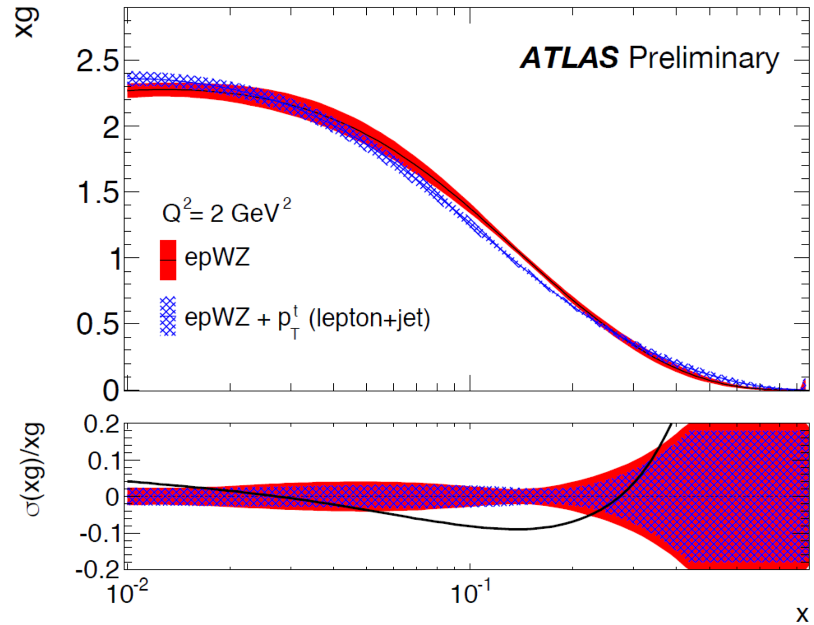
Now **consider one spectrum at a time INCLUDING statistical correlations bin to bin**

top lepton+jets spectrum	m_{tt}	p_T^t	y_{tt}	y_t
total χ^2/NDF	1238.4/1062	1239.4/1063	1257.5/1060	1246.5/1060
HERA partial χ^2/NDP	1153/1016	1151/1016	1149/1016	1146/1016
ATLAS W,Z partial χ^2/NDP	82.0/55	82.1/55	86.4/55	85.0/55
ATLAS top χ^2/NDP	3.4/7	7.9/8	19.7/5	18.3/5

χ2 for p_T^t and m_{ttbar} are good

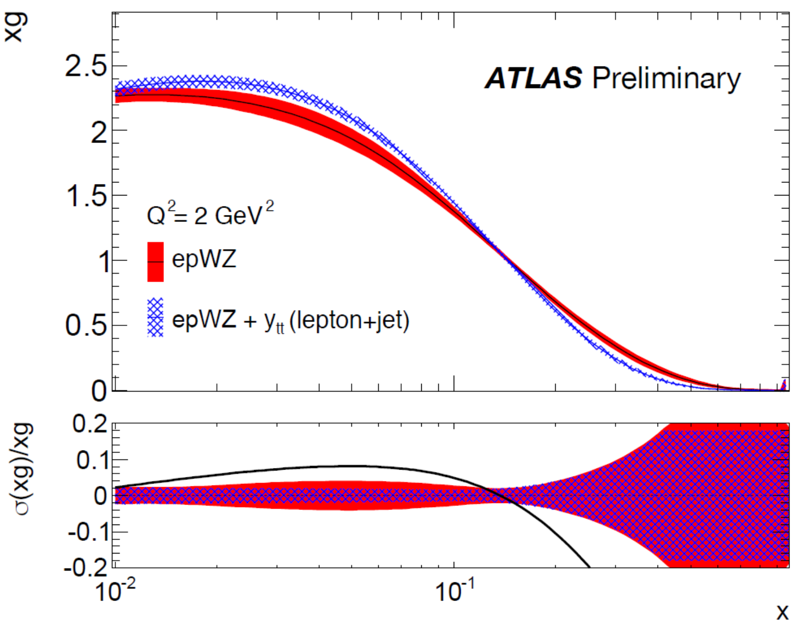
χ2 for y_t and y_{ttbar} are not good

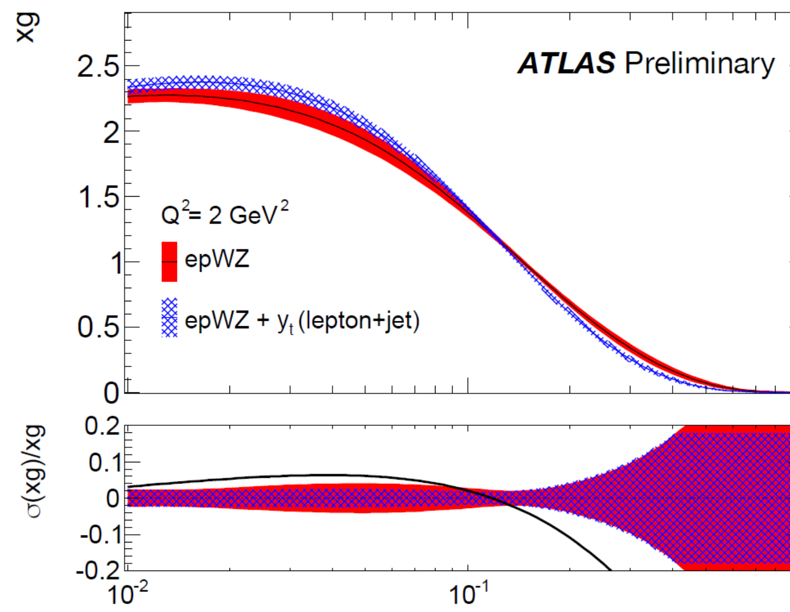




Both p_T^t and m_{ttbar} spectra harden the gluon

Both y_t and y_{ttbar} spectra soften the gluon





NOW try fitting 2 spectra at a time: (pt and yt) and (pt and mtt)
------------------------look at the χ2 for these fits

	top spectra			
	p_T^t and y_t with statistical correlations	p_T^t and y_t without statistical correlations	p_T^t and m_{tt} with statistical correlations	p_T^t and m_{tt} without statistical correlations
total χ^2/NDF	1264 / 1068	1260 / 1068	1290 / 1070	1287 / 1070
HERA partial χ^2/NDP	1148 / 1016	1147 / 1016	1162 / 1016	1162 / 1016
ATLAS W,Z partial χ^2/NDP	82.7 / 55	83.5 / 55	83.2 / 55	83.1 / 55
ATLAS top χ^2/NDP	33 / 13	30 / 13	45 / 15	42 / 15

This Table shows fits to (pt and yt) and (pt and mtt) simultaneously.
In all cases the correlated systematics between the spectra are included.
The correlated statistical uncertainties are used by default but are also switched off to assess their impact. This makes it clear that the statistical correlations are NOT the source of the bad χ2

None of these top χ2 is satisfactory BUT the pt+yt χ2 is only a bit larger than the added sum of the pt and yt separate fit χ2 = 26.2, so the main problem here is the poor fit to yt
whereas the pt+mtt χ2 is much larger than the sum of the pt and mtt separate χ2 = 11.3- This is surprising since the fits to the individual spectra are good

Since the source of the poor χ2 is not the statistical correlations look at the systematic correlations. Should they ALL be correlated between the spectra?

Three particularly LARGE systematics are the sys isr/fsr (~8%) and the sys-ps_model (~5%) and the hard scattering model (~4%)

Table 3: Fitted values of the nuisance parameters (b_k)for the named systematic uncertainty sources (k) of $t\bar{t}$ data, as defined in Eqn. 2, for the fits to HERA and ATLAS W, Z data plus the four $t\bar{t}$ spectra separately

Systematic uncertainty source	lepton+jets spectrum			
	p_T^t	y_t	y_{tt}	m_{tt}
Hard scattering model	+0.74± 0.31	+0.48± 0.22	+0.92± 0.37	-0.43± 0.20
Parton shower model	-1.32± 0.43	-0.79± 0.26	-0.51± 0.17	+0.39±0.13
ISR/FSR model	-0.47± 0.18	-0.87±0.30	-1.27± 0.38	+0.33± 0.10

$$\chi^2 = \sum_{ij}\left(m^i - \sum_k \gamma_k^i b_k - \mu^i\right) C^{-1}_{\text{stat}\ ij}\left(m^j - \sum_k \gamma_k^j b_k - \mu^j\right) + \sum_k b_k^2$$

The treatment of correlated systematics as nuisance parameters means that they can introduce correlated shifts in the predictions. Examining the shifts due to these 3 sources shows that the mtt spectrum induces an opposite shift to the other three spectra, when the spectra are fitted separately. When fitting together the shifts are forced to be the same ---if 100% correlation is assumed between the spectra. E.g. the common nuisance parameter for the Parton Shower uncertainty when fitting pt and mtt together is -0.32 ± 0.10, which suits neither spectrum.

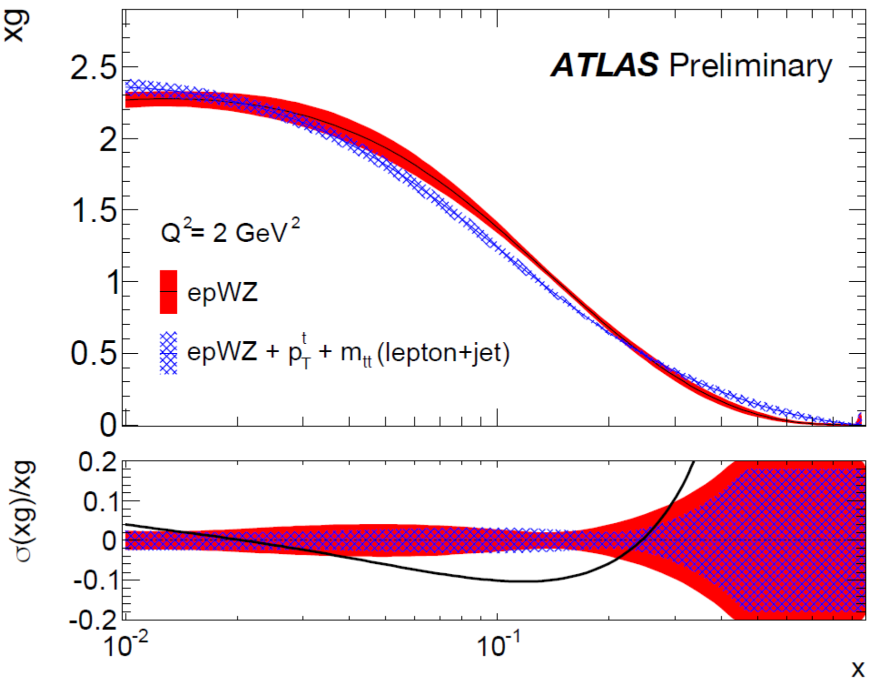
Let's investigate decorrelating between spectra, while preserving bin-to-bin correlations within the spectra.
First decorrelate all 3 sources simultaneously and then decorrelate one at a time.
This shows us that it is the decorrelation of the parton shower systematic which is the most significant.

		lepton+jets spectra		
		p_T^t and y_t decorrelate 2-point uncertainties	p_T^t and m_{tt} decorrelate 2-point uncertainties	p_T^t and m_{tt} decorrelate parton-shower model uncertainty
Total χ^2/NDF		1259 / 1068	1247 / 1070	1248 / 1070
Partial χ^2/NDP	HERA	1147 / 1016	1154 / 1016	1153 / 1016
Partial χ^2/NDP	ATLAS $W, Z/\gamma^*$	83.9 / 55	81.9 / 55	81.6 / 55
Partial χ^2/NDP	ATLAS $t\bar{t}$	27.8 / 13	11.5 / 15	14.1 / 15

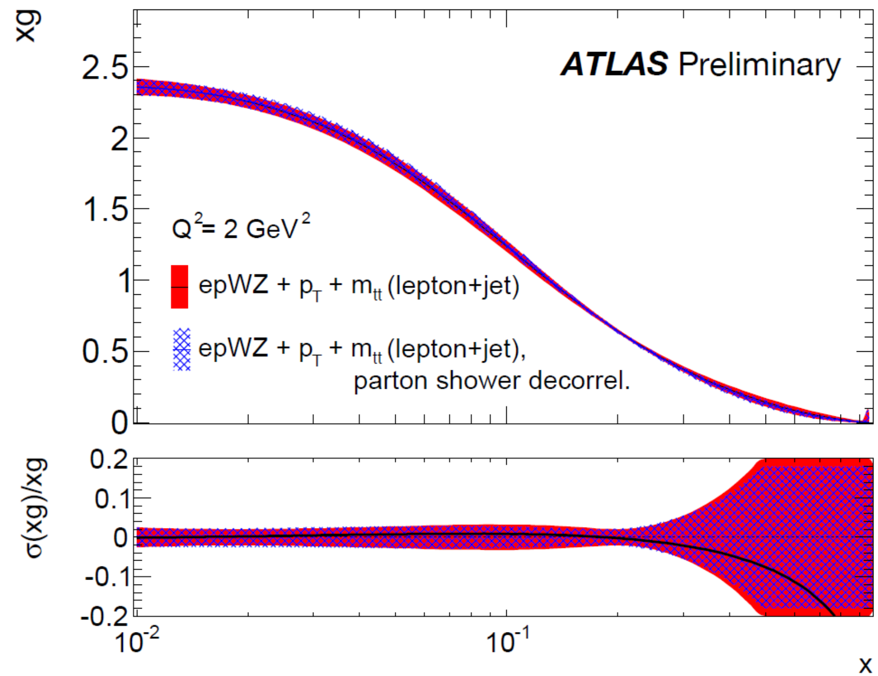
The effect of decorrelation is marginal for the pt and yt spectra, as expected since the shifts induced by these spectra are similar when they are fitted separately. The resultant χ2 is closer to the sum of the χ of the separate fits (26.2) but is not changed much
The effect of decorrelation is dramatic for the pt and mtt spectra, now that the shifts are allowed to be different. (The separate nuisance parameters are -0.47 ± 0.15 for pt and +0.10 ± 0.03 for mtt). The resultant χ2 is close to the sum of the χ2 of the separate fits (11.3)
The resultant shape of the gluon barely changes when these systematics are decorrelated- the main effect is the improvement in χ2

The resultant shape of the gluon barely changes when these systematics are decorrelated- the main effect is the improvement in χ2

All uncertainties fully correlated



Compare parton shower uncertainty correlated/decorrelated



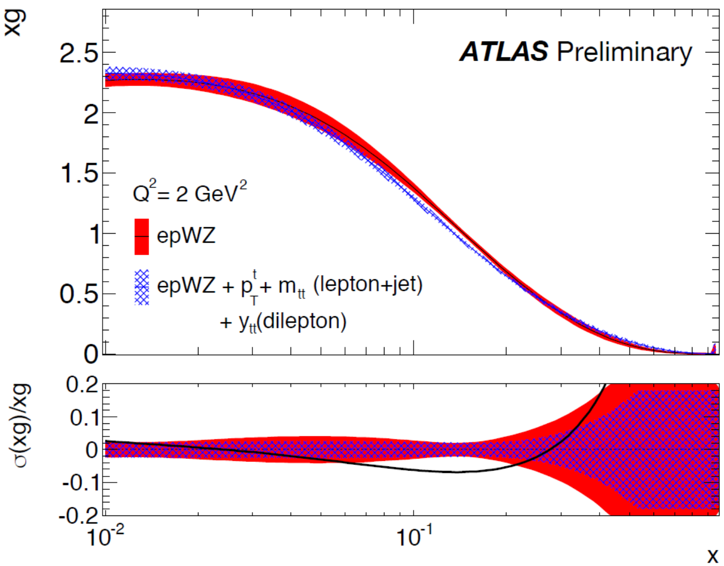
100% correlation has a marginally stronger pull on the gluon and a marginally smaller uncertainty

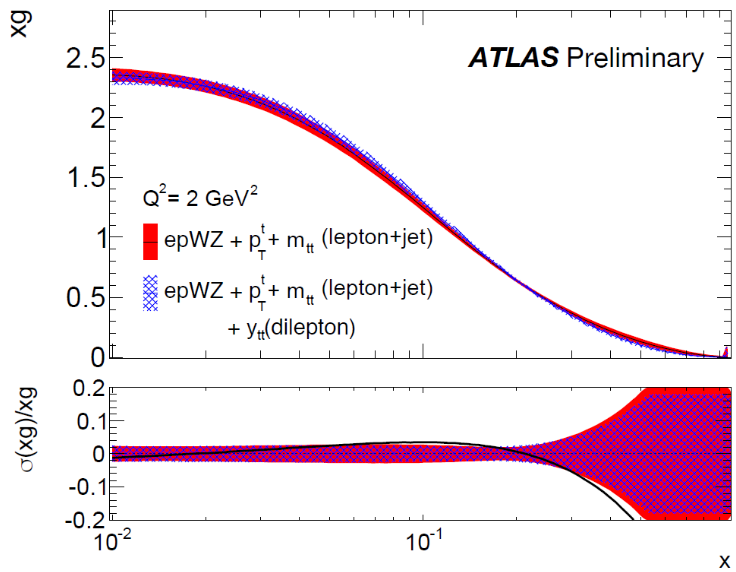
Make some choices.

Take pt and mtt from lepton+jets with parton shower uncertainty decorrelated

Do not take yt and ytt because of poor χ2

Instead take ytt from dilepton data – this also softens gluon and has good χ2



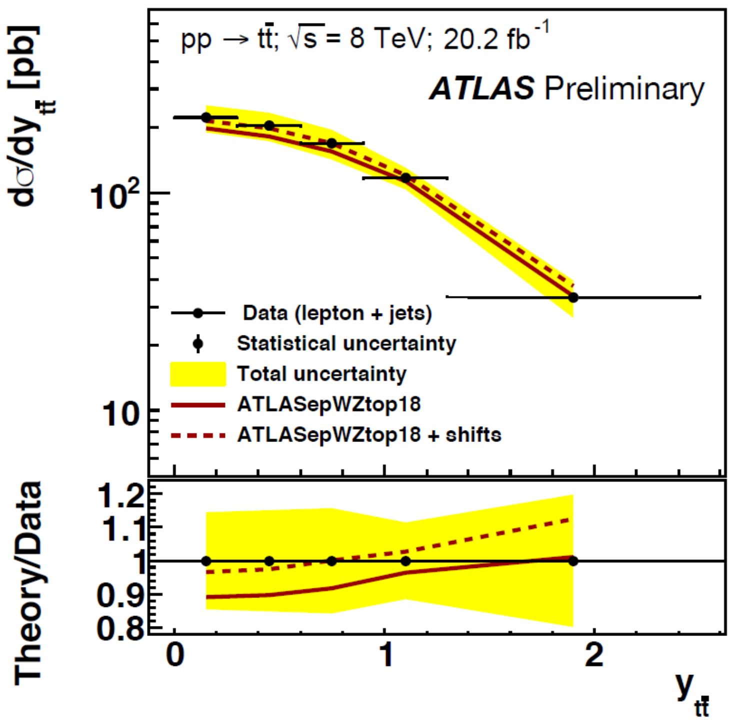


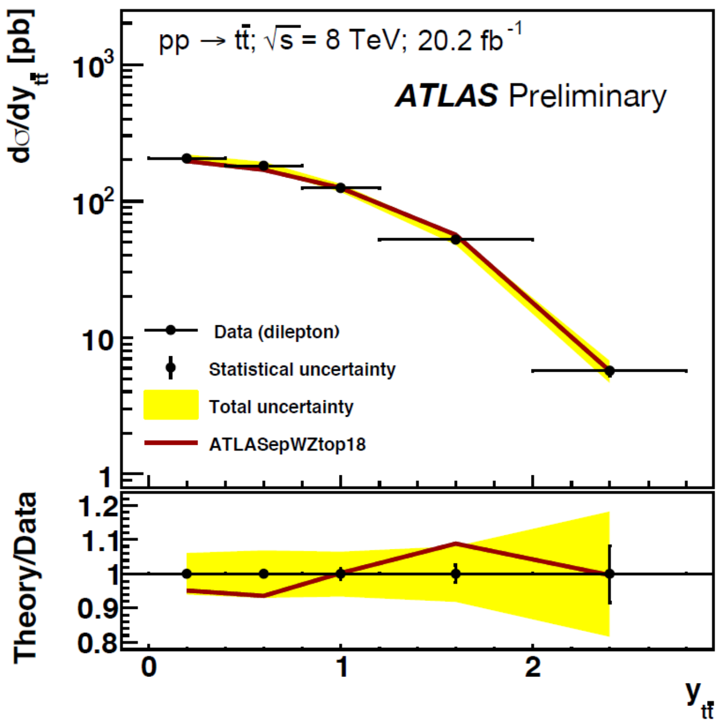
Compare this fit to top mtt +pt from lepton+jets and ytt from dileptons

- To HERA +ATLAS W,Z alone –harder gluon, smaller uncertainties
- To HERA+ATLASW,Z + top mtt+pt from lepton+jets, shows ytt from dilepton has some softening effect, and some marginal further reduction in uncertainties

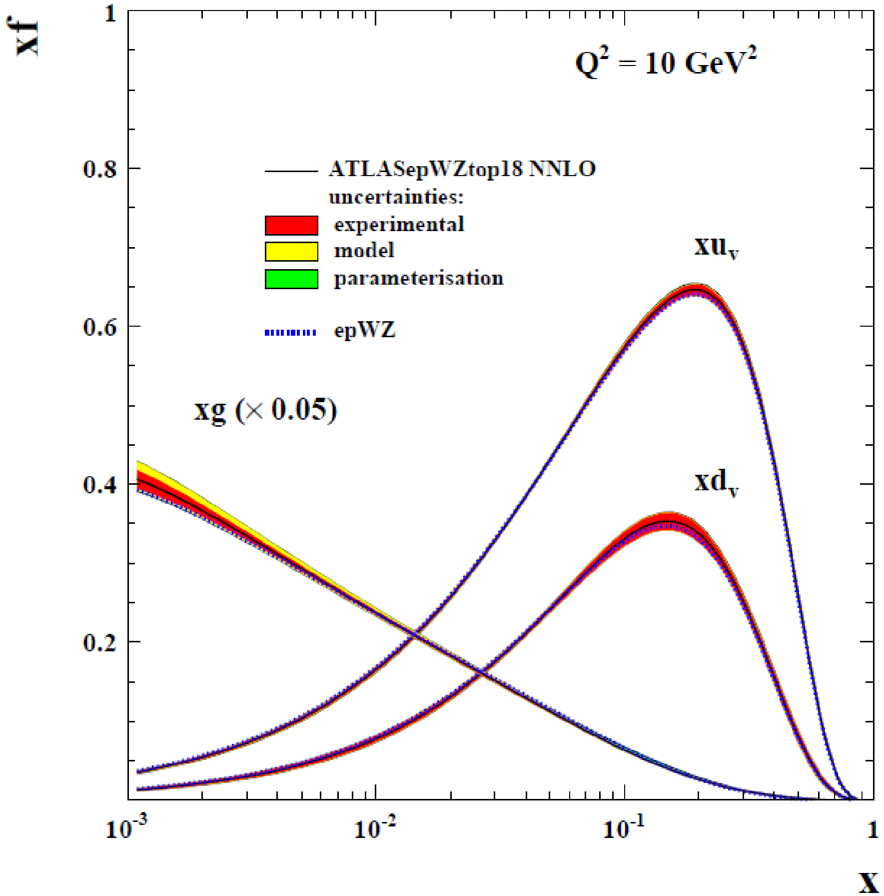
total χ^2/NDF		1253.8 / 1061
Partial χ^2/NDP	HERA	1149 / 1016
Partial χ^2/NDP	ATLAS $W, Z/\gamma^*$	78.9 / 55
Partial χ^2/NDP	ATLAS lepton+jets p_T^t, m_{tt}	16.0 / 15
Partial χ^2/NDP	ATLAS dilepton y_{tt}	5.4 / 5

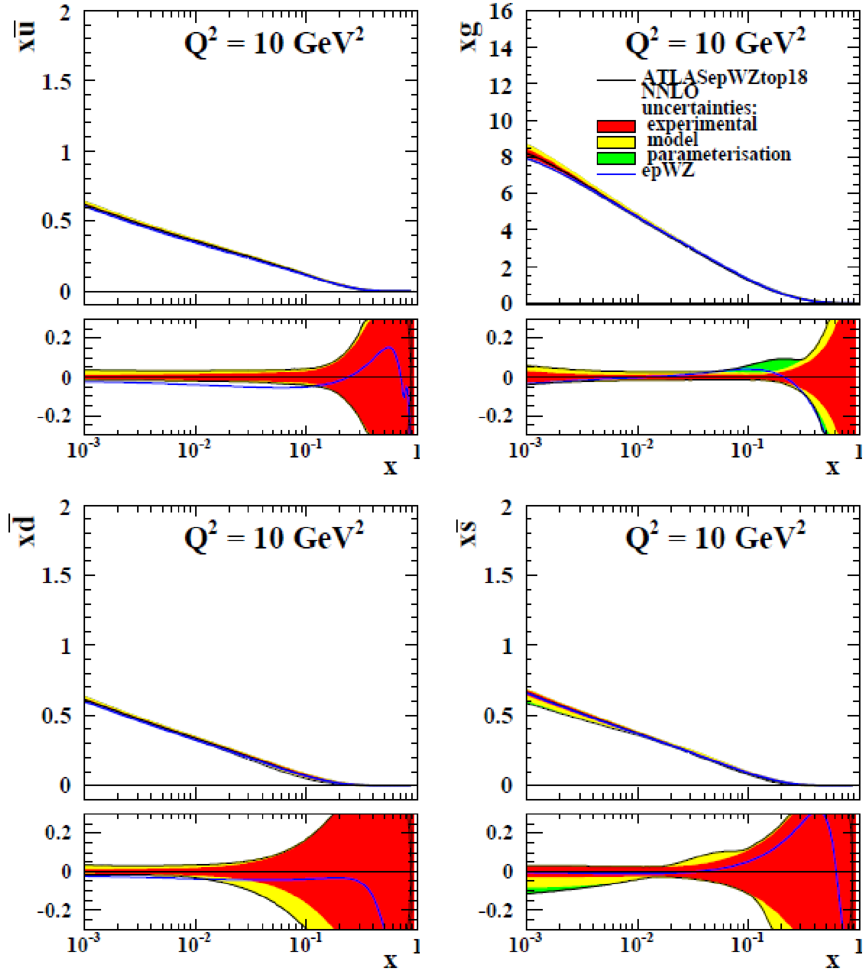
Compare ytt from lepton+jets and dilepton data.
There is a trend of the ytt data that is hard to fit despite comparable level of total uncertainties--- correlations matter





Add model and parametrisation uncertainties: ATLASepWZtop18 PDFs

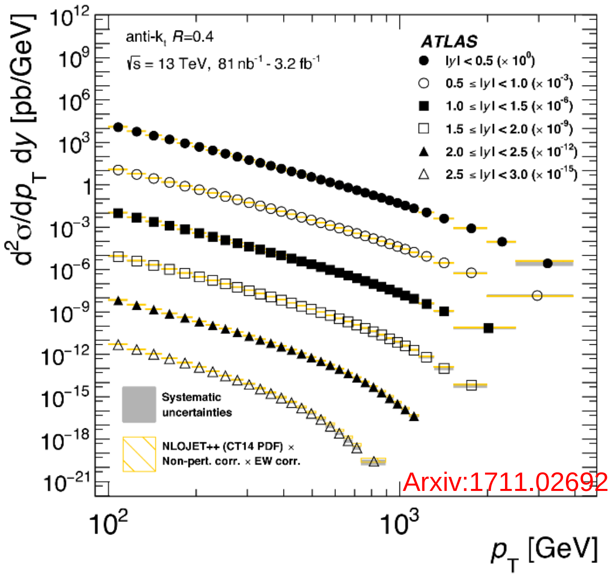


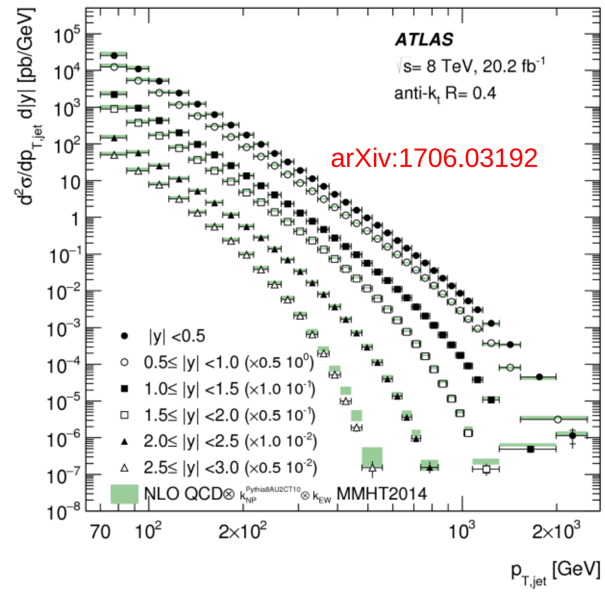


Valence and sea are not much affected by the model and parametrisation
Gluon is affected at high-x

The fractional uncertainties show the effect of model and parametrisation uncertainty more clearly ---for gluon and sea
Comparison epWZ shows hardening of the gluon

ATLAS jet production data at 8 and 13 TeV





State of the art prediction becomes NNLO- BUT many studies still at NLO. Applfast grids are being created for NNLO

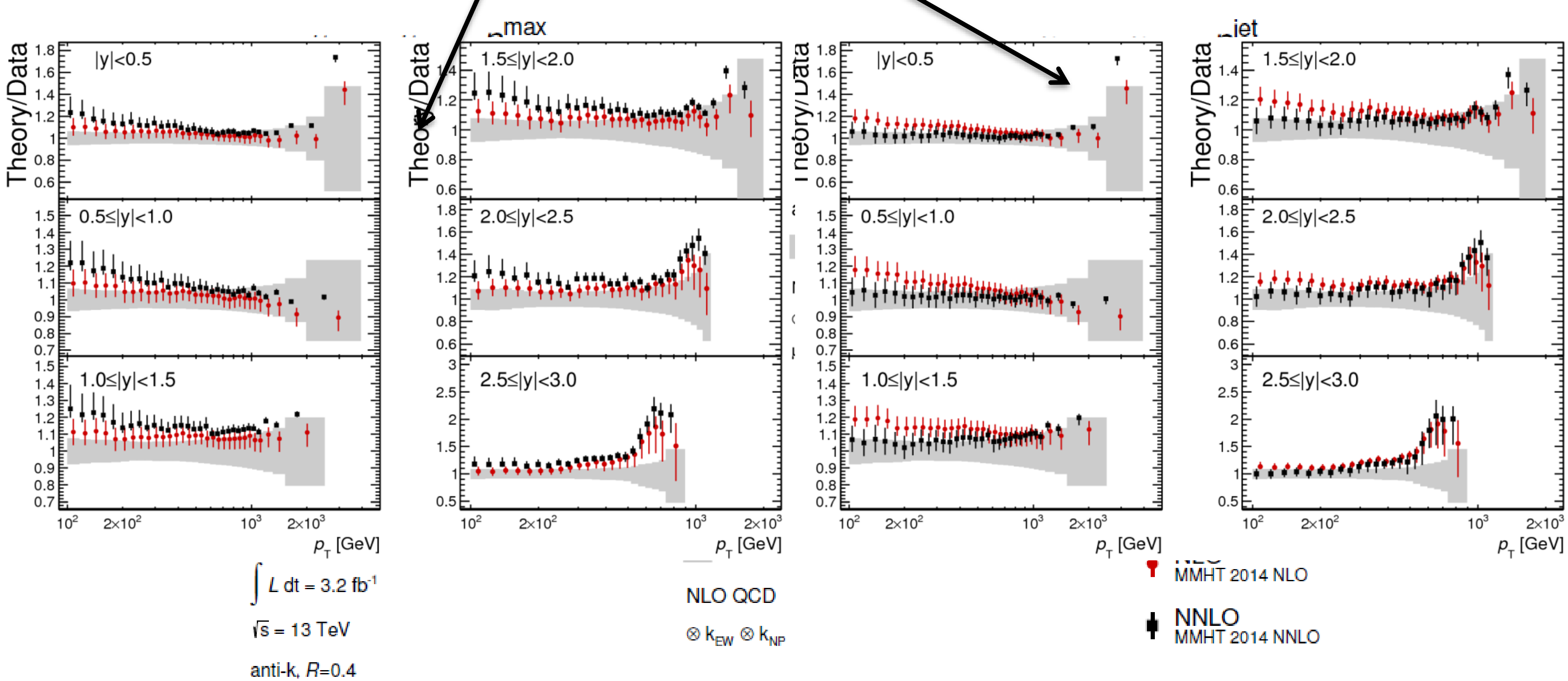
Large χ2 when fitting different rapidity bins simultaneously for all inclusive jet samples at NLO. This has been found both by ATLAS and by global fitters
Much work on considering realistic de-correlations for 2-point systematics and on alternative scale variations choices and one still obtains χ2/ndp ~ 260/159- (and decorrelating theory systematics is just as important as decorrelating experimental systematics) see arXIV:1706.03192

BUT NNLO can describe the data better?....

There is progress on the NNLO corrections- scale choice matters.
P_T^{jet} as the scale choice and larger cone size R=0.6, gives the most compatible results

NLO/Data vs NNLO/Data

- NNLO ($\mu = p_T^{jet}$) describes the data within uncertainties
  - except at $|y| > 2$ and high-p_T
- NNLO ($\mu = p_T^{max}$) overestimates the measured cross-section



Now it seems that Glover et al argue for the choice of p_T^{jet} or rather $2p_T^{jet}$
arXIV:1807.06057

W+jets fits are also active and working towards a PUB-NOTE

- W + jet production at 8TeV
  - W_{p_t}
  - Leading jet p_T
  - Scalar transverse energy sum (H_T)
- NNLO fits provided through APPLGRID + K-factors:

$$K_f = \frac{\sigma_{\text{NNLO QCD}}(N_{\text{jetti}})}{\sigma_{\text{NLO QCD}}(\text{APPLGRID})}$$

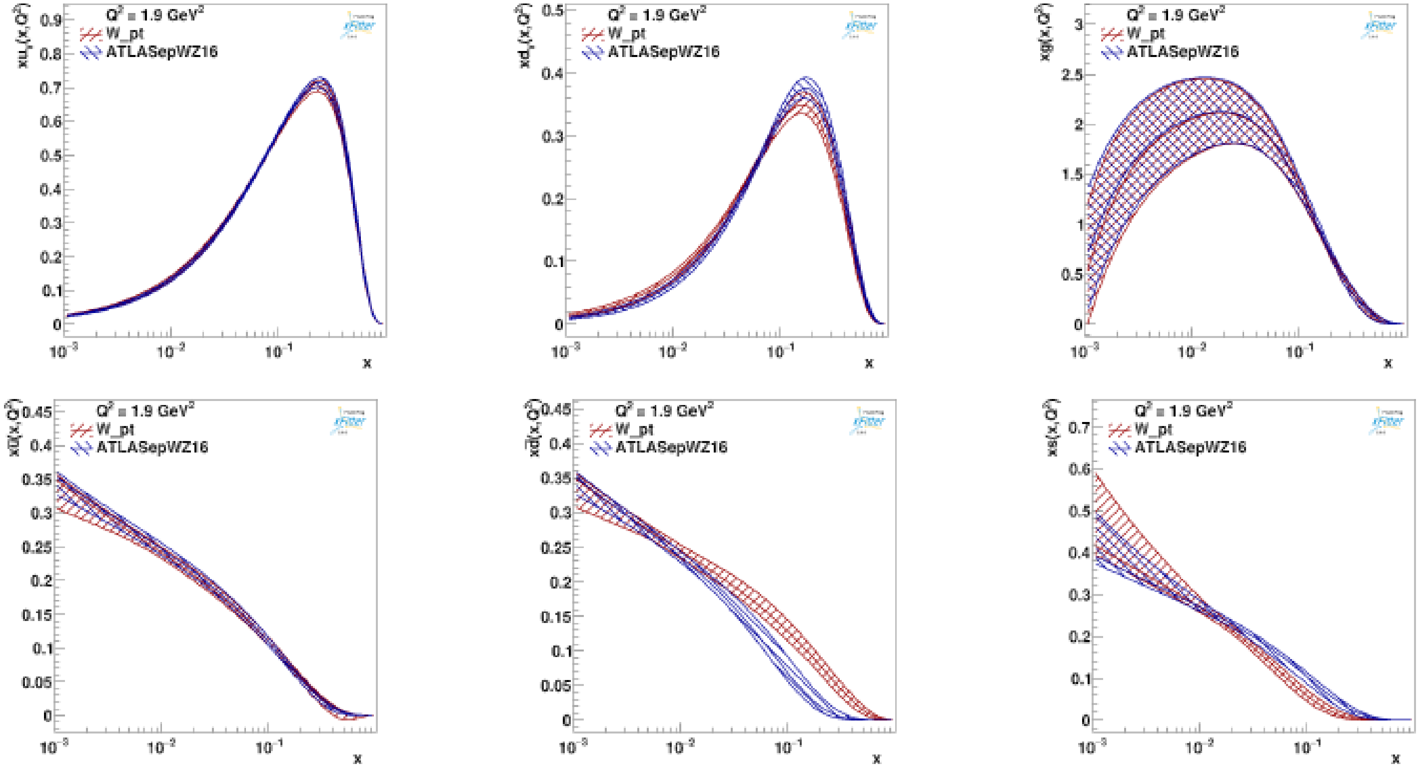
- Data published: arXiv:1711.03296

These data are added to HERA and ATLAS 7TeV inclusive W,Z as usual
Work is ongoing to assess correlations to the W,Z data

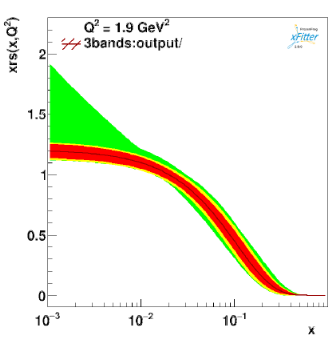
- Two-point systematic from difference between generators (for unfolding process) causing some problems in W_{p_T} distribution - this was fully decorrelated for all spectra.
- Resulting PDFs had marginal differences.

Spectrum/Ndof	ATLAS params		Fitted params		ATLAS (uncor syst)		Fitted (uncor syst)	
	W^+	W^-	W^+	W^-	W^+	W^-	W^+	W^-
$W_{p_T}/17$	130	82	85	50	19	12	8.8	9.7
$H_T/21$	104	35	54	29	54	19	28	16
jet $p_T/23$	86	46	51	32	42	18	27	15

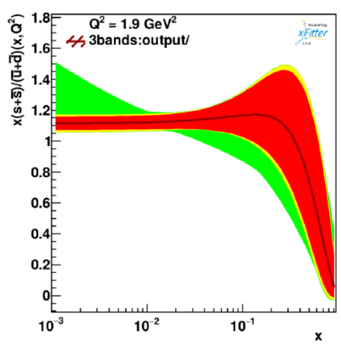
Only one spectrum can be fitted at a time because statistical correlations are not available. Wpt is chosen but the others give similar results



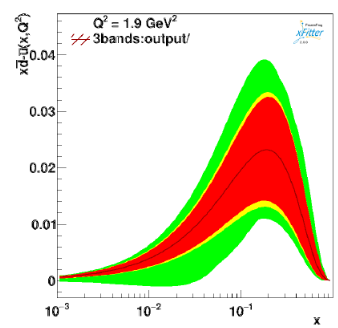
The differences from ATLASepWZ16 come in the flavour structure of the sea



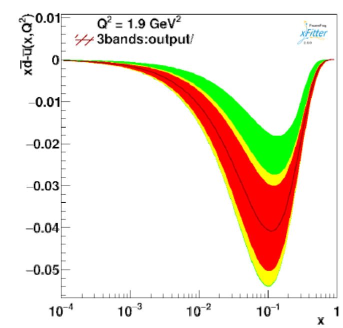
(a) W_{p_T} r_s distribution



(b) ATLASepWZ16



(a) W_{p_T} $\bar{d} - \bar{u}$ distribution

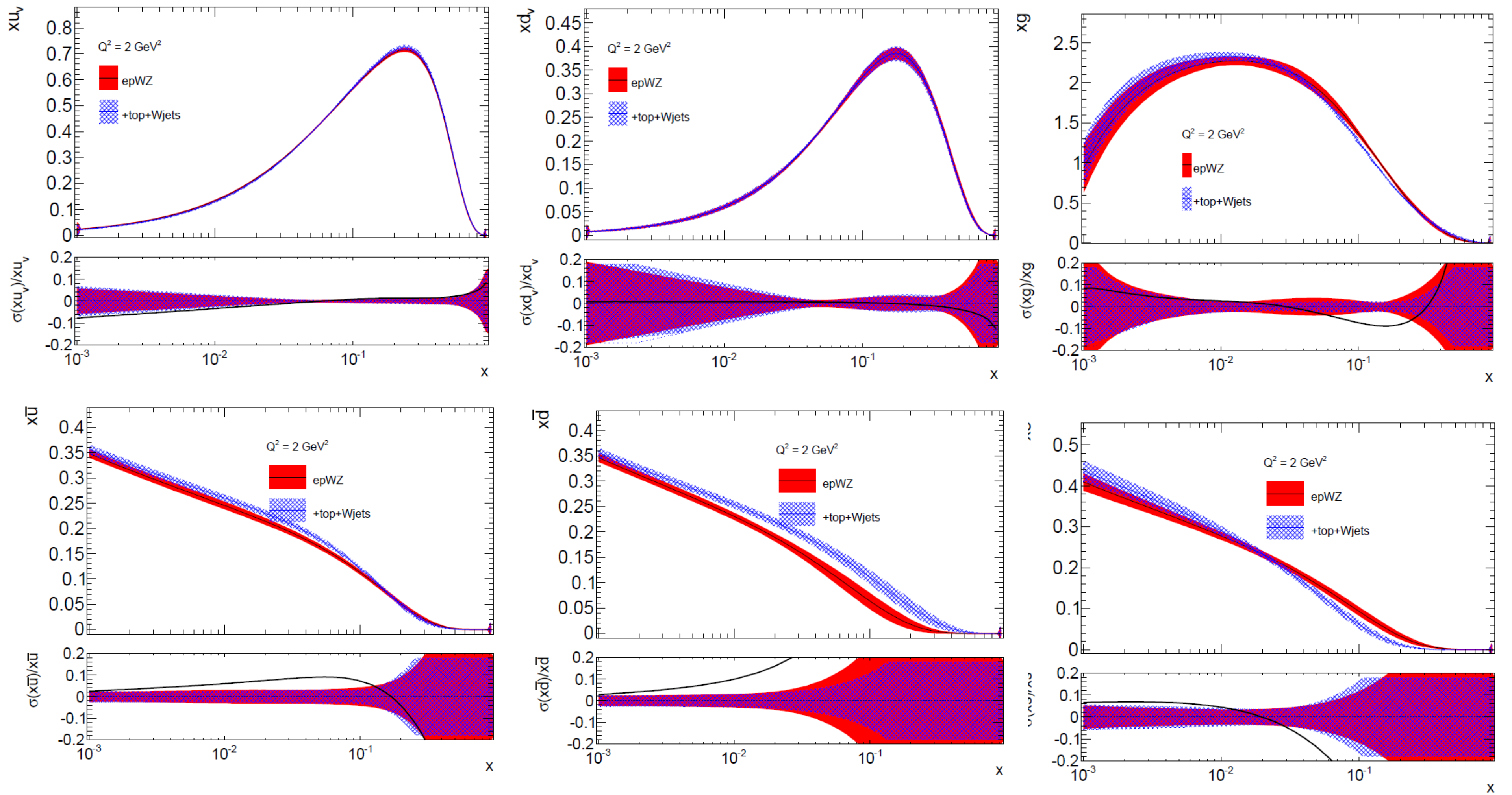


(b) ATLASepWZ16

Strangeness more suppressed at high-x

dbar-ubar positive at high-x

How about using 8 TeV W+jets AND t-tbar data? (and HERA and W,Z 7 TeV as usual)



The behaviour of the gluon is completely dominated by the top
The behaviour of the sea is dominated by the W+jets
--the best of both worlds, BUT correlations (apart from luminosity) of the data sets must be considered

Have also implemented 8 TeV direct photon data in the fit arXIv: 1605.03495

- Using NLO Applgrids from NNPDF
- NNLO QCD k-factors from Campbell, Ellis Williams
- Resummed electroweak corrections from Becher, Garcia I Tormo, but these are only really reliable at high E_t^γ, so use $E_t^\gamma > 65$ GeV
- Isolation algorithms to reduce fragmentation component from Frixione—these are as close as an analytic form can come to the experimental requirements

- The data is differential in η^γ and E_T^γ with 4 rapidity regions

  region 1: $0 < |\eta^\gamma| < 0.6$,
  region 2: $0.6 \leq |\eta^\gamma| < 1.37$,
  region 3: $1.56 \leq |\eta^\gamma| < 1.81$,
  region 4: $1.81 \leq |\eta^\gamma| < 2.37$.

- And covering a maximum range $25 < E_T^\gamma < 1500$ GeV
- We exclude the first few bins in E_T^γ as the LL EW resummation is only valid for above $E_T^\gamma \gtrsim m_Z$

There are some sources of uncertainty amongst the 30 systematics (listed as 60 +/- entries) which are not correlated bin-to-bin. Following the labels used in HEPDATA, those which are _not_ correlated are listed below:

- sysPhotonID
- sysPhotonIsolation
- sysBackgroundID
- sysBackgroundIsolation
- sysEnergyResolution

However, whether we correlate or do not correlate these sources of uncertainty is not such a big effect. It matters more whether or not we include the highest rapidity bin

Using all 4 bins
5 systematic decorrelated

NDP	χ2
63	181.1

Using first 3 bins
5 systematic decorrelated

NDP	χ2
46	86.2

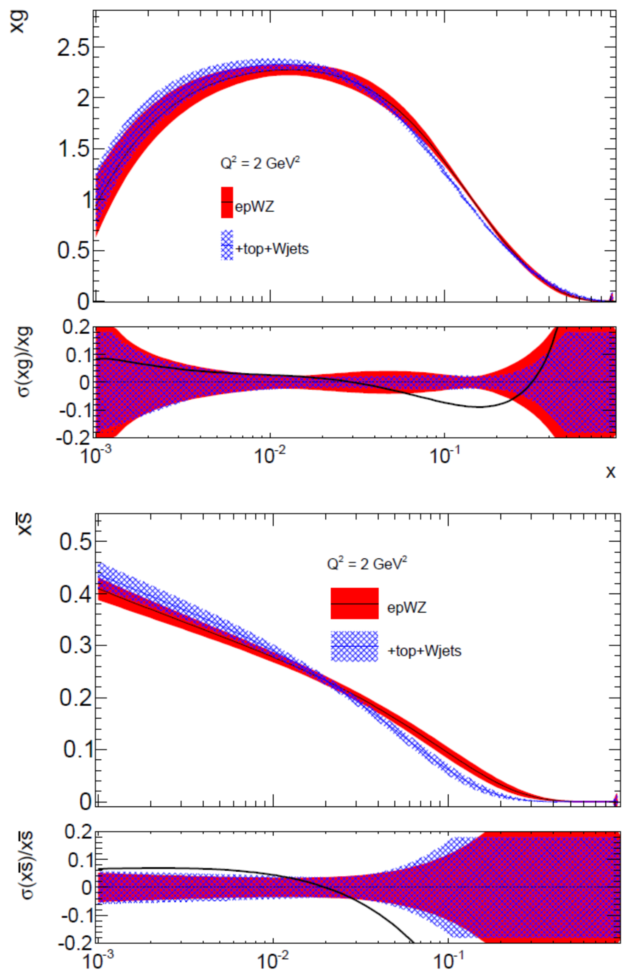
Using first 3 bins
All systematics correlated

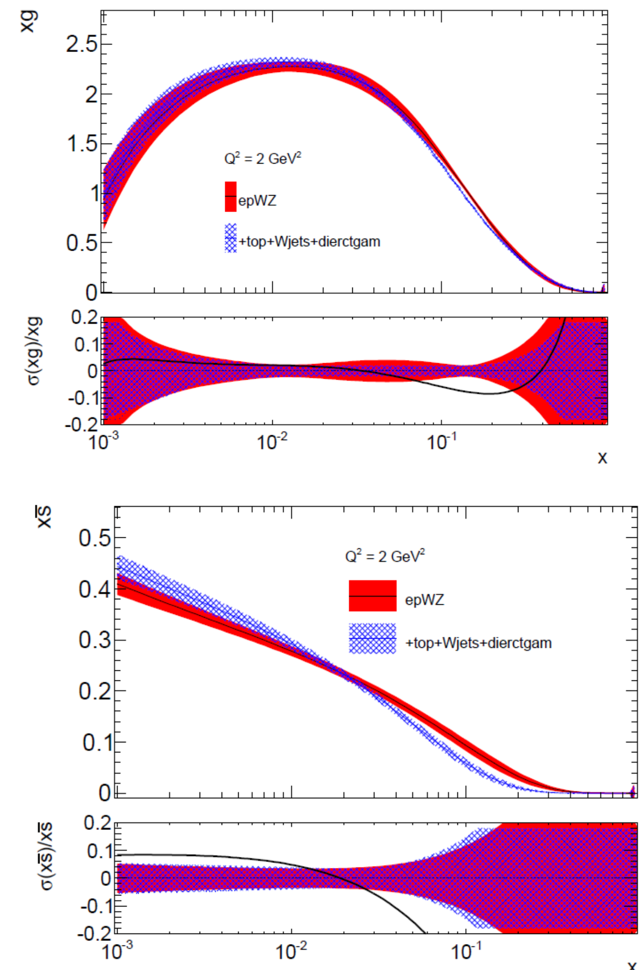
NDP	χ2
46	91.2

Effect of direct photon data on the fit is mild— Marginal softening of the high-x gluon

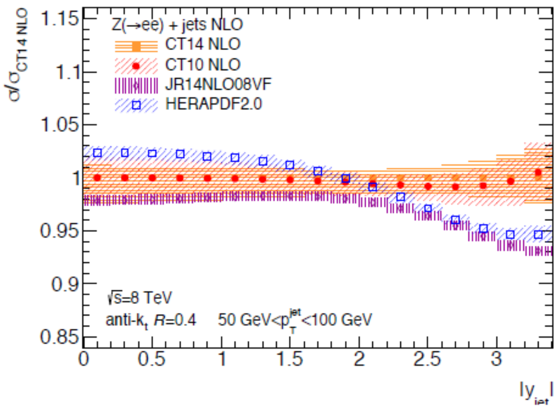
No further effects on the sea flavour sector

Once more correlations between these 8 TeV data sets remain to be assessed

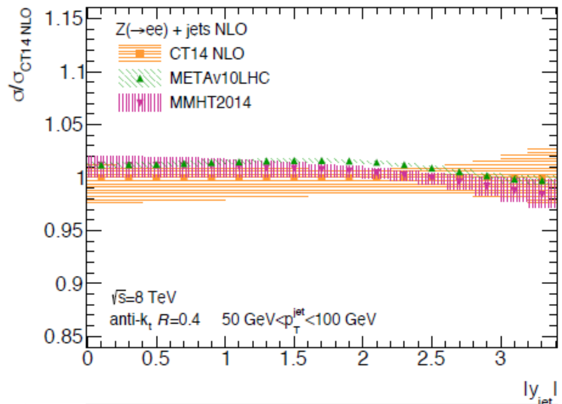


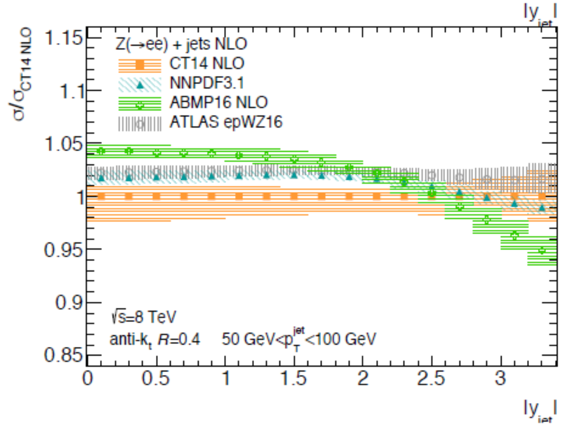


Moving further to the future-----Z+jets 8 TeV in SM review



- NLO predictions are obtained with different PDFs. Only PDF uncertainties are shown.
- The study shows up to 10% difference in Z+jets cross-sections calculated with different PDFs. This shows the PDF sensitivity of the measurement.





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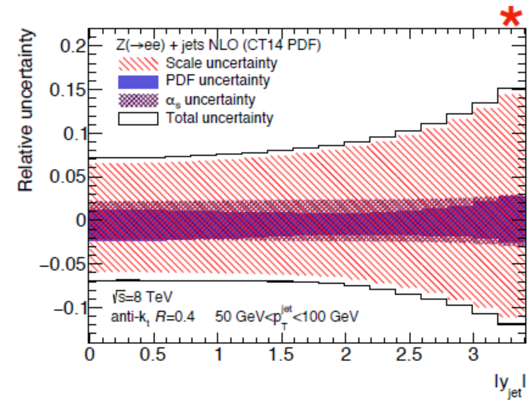
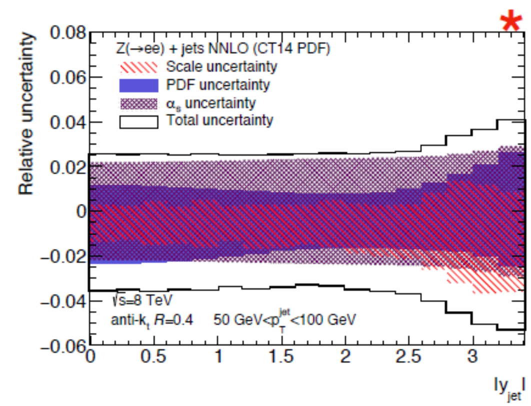
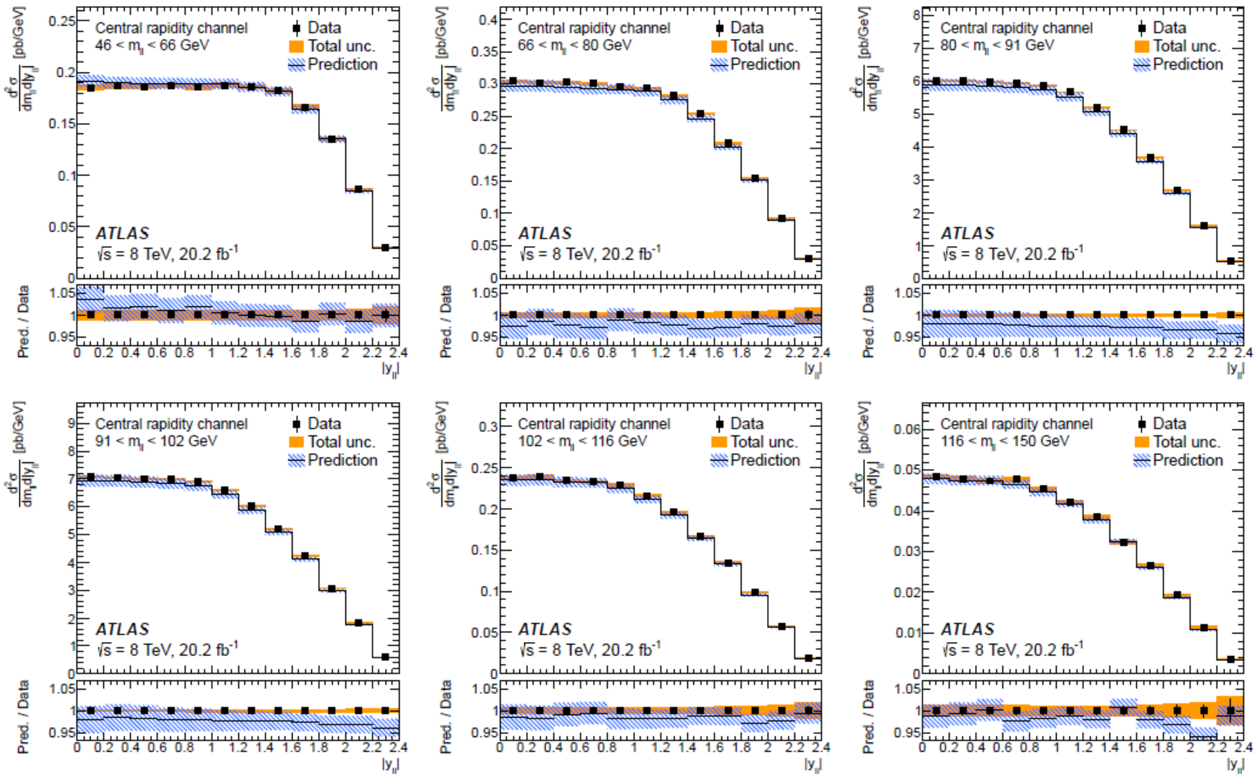




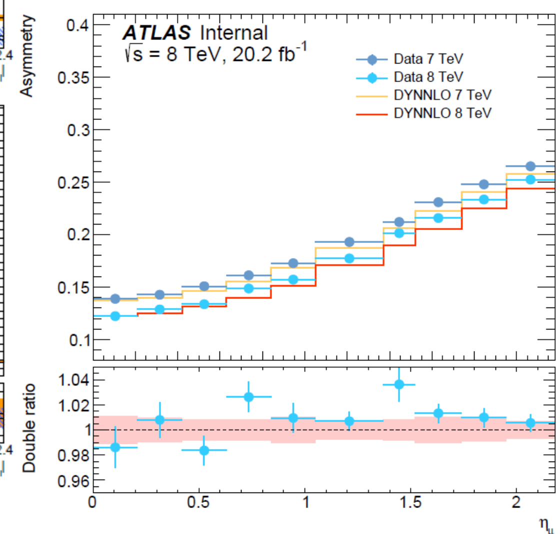
Result has PDF sensitivity—under investigation

We would like to consider Z+jets together with W+jets accounting for correlations between them

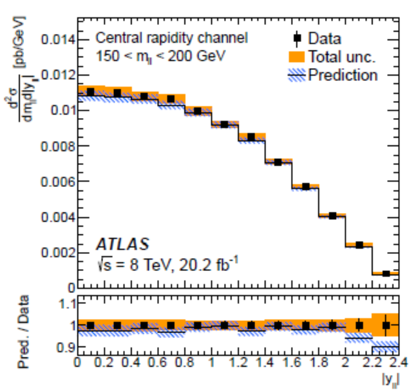
There is the 8 TeV ‘Z3D’ arxiv:1710.05167- for PDFS this could be fitted as ‘Z2D’, the rapidity spectra in mass bins



There is also W+/W- from muons at 8 TeV https://cds.cern.ch/record/2242512



We don’t have the predictions in usable form yet



Ideally these should be fitted together with accounting for correlations.

SUMMARY

PAST

- Inclusive W,Z 7 TeV- valence, strangeness

PRESENT

- T-tbar 8 TeV-- gluon
- W+jets 8 TeV---flavour separation in the sea
- Direct Photon 8 TeV--gluon

NEAR FUTURE

- Z+jets 8 TeV—flavour separation and gluon?
- Z3D, W+/W- 8 TeV--- flavour separation/valence
- W+D/D* 8 TeV, W+c 13 TeV--strangeness
- Inclusive jets 8,13 TeV-------gluon
- 13 TeV t-tbar spectra

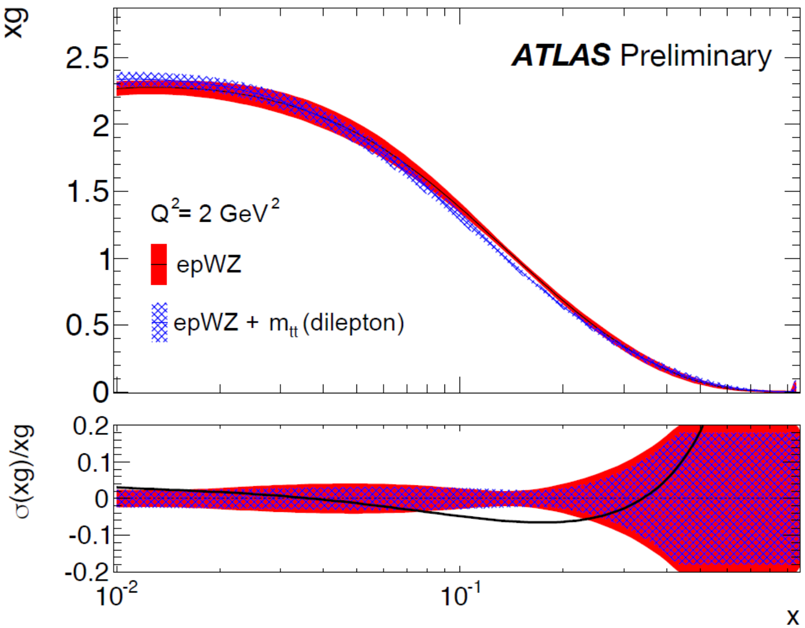
FURTHER FUTURE

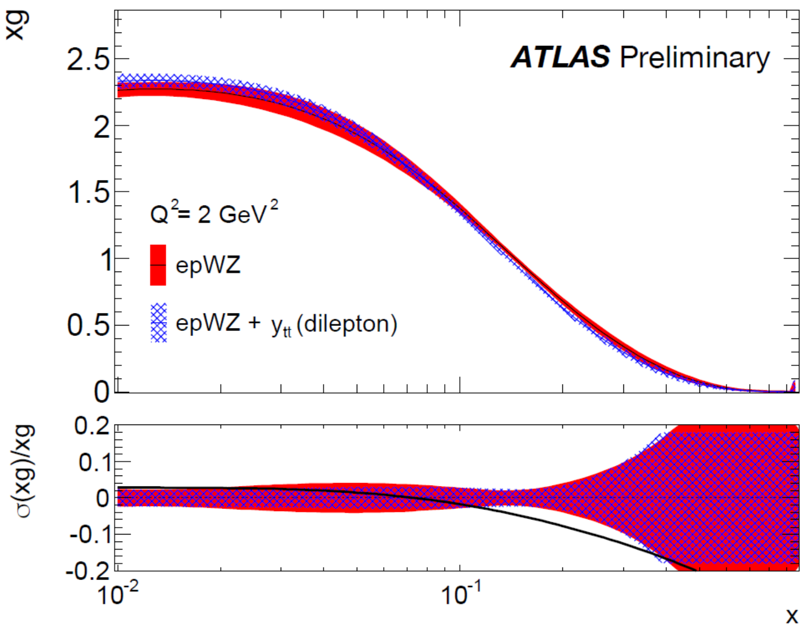
- 13 TeV many channels- --low mass Drell-Yan may need low-x resummation
- HL-LHC… projections look very promising!

The main message is that we need to be aware/take account of correlations between data sets as well as within them

Back-up

Now look at t-tbar dilepton data

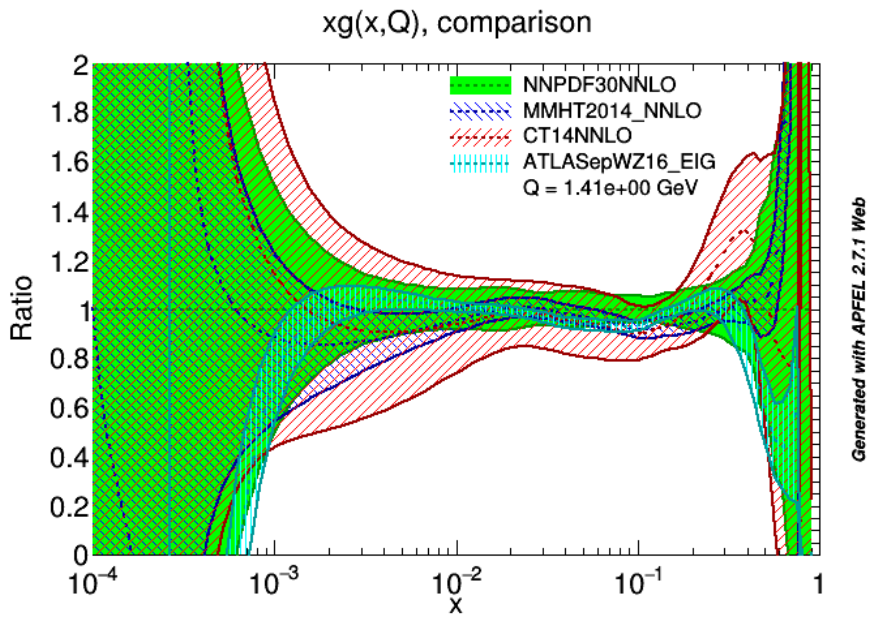




		dilepton spectrum	
		m_{tt}	y_{tt}
Total χ^2/NDF		1233.8 / 1061	1233.8 / 1060
Partial χ^2/NDP	HERA	1152 / 1016	1147 / 1016
Partial χ^2/NDP	ATLAS $W, Z/\gamma^*$	79.3 / 55	82.8 / 55
Partial χ^2/NDP	ATLAS $t\bar{t}$	2.6 / 6	4.5 / 5

As for the lepton+jets channel the mtt spectrum somewhat hardens the gluon, whereas the pt spectrum softens it– in both cases marginally. And in both cases the fits have good χ2.

Comparison to global PDFs



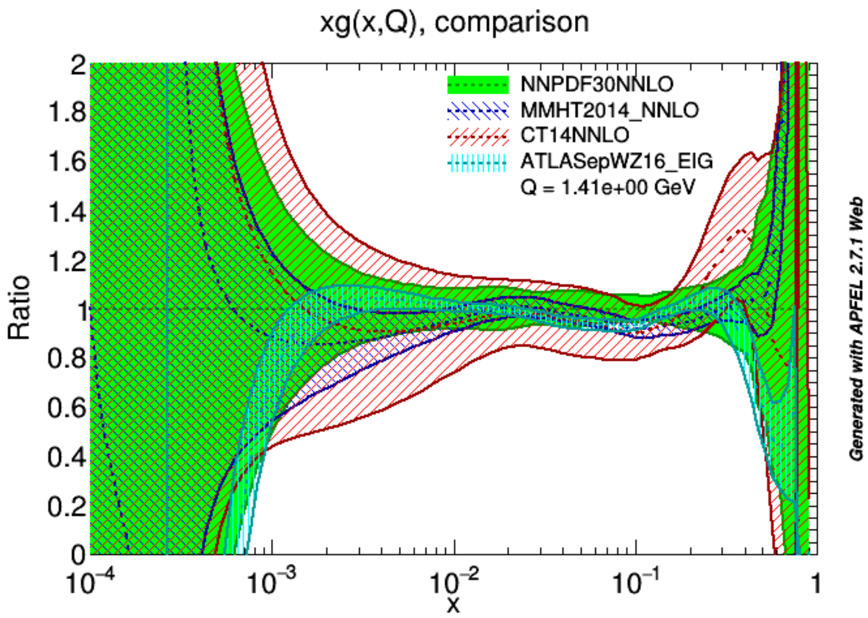
NOTE ATLASepWZ16 gluon is a little softer at high-x than CT14 or MMHT2014 or NNPDF30

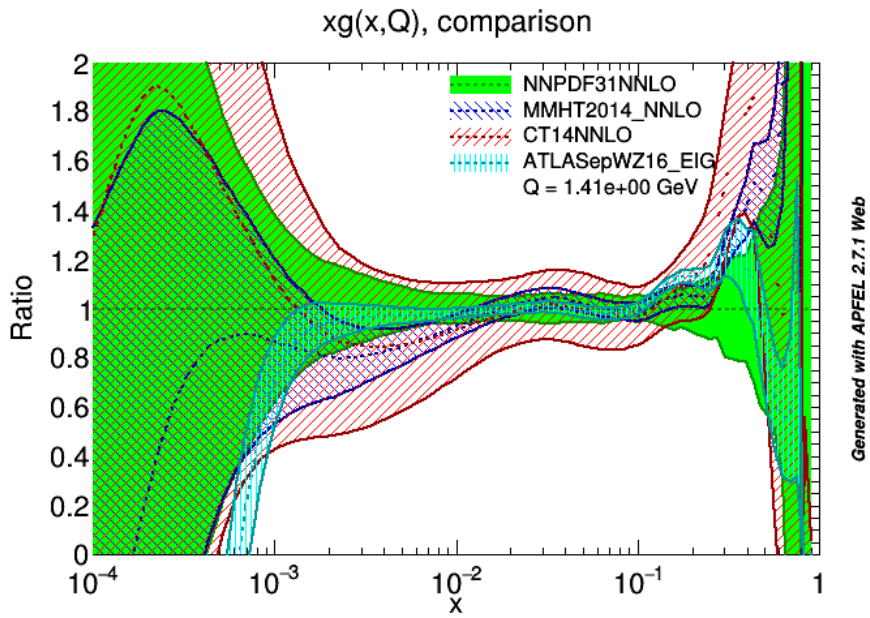
(Note these PDFs have no top distributions, but they have jets)

.

Thus a hardening of the ATLASepWZ16 gluon brings it into better agreement with the global PDFs

Comparison to global PDFs





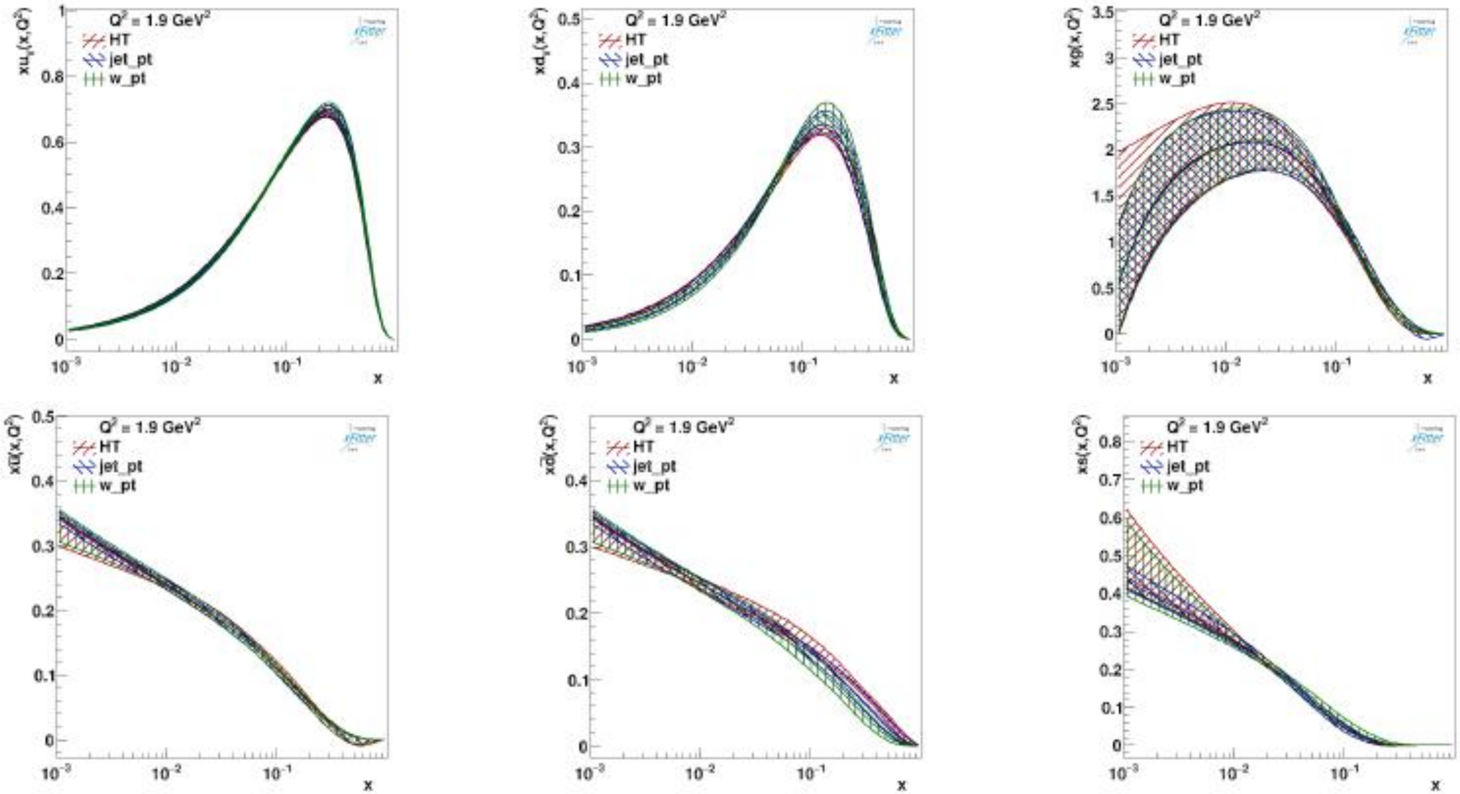
NOTE ATLASepWZ16 gluon is a little softer at high-x than CT14 or MMHT2014 or NNPDF30 which have no top data

.

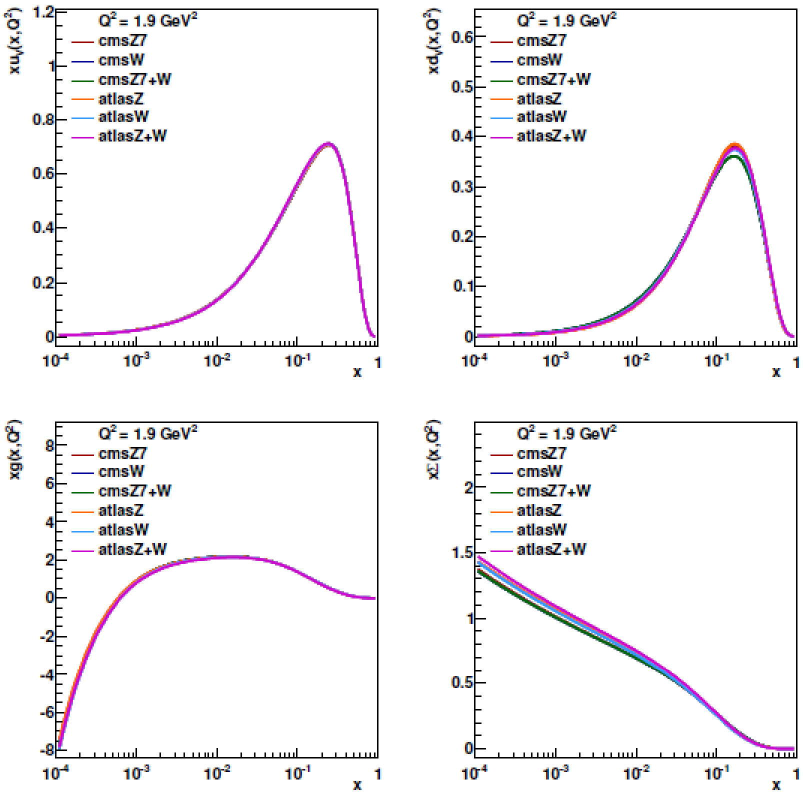
Thus a hardening of the ATLASepWZ16 gluon brings it into better agreement with the global PDFs

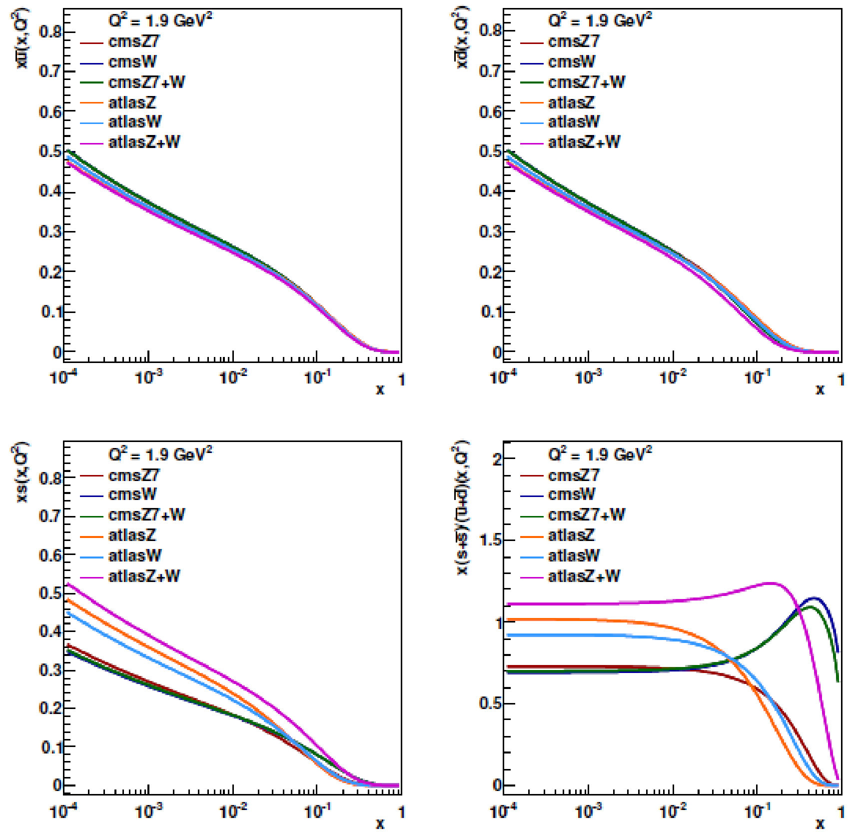
NOTE it is more compatible with NNPDF3.1-- which is already softer than NNPDF3.0 (because of top data)– but still a little softer at high-x

Results for all three (W_pt, HT, jet_pt) of the spectra available for W+jets compared



All of these include model/parameterisation errors, calculated in the same way as in the ATLASepWZ16 set



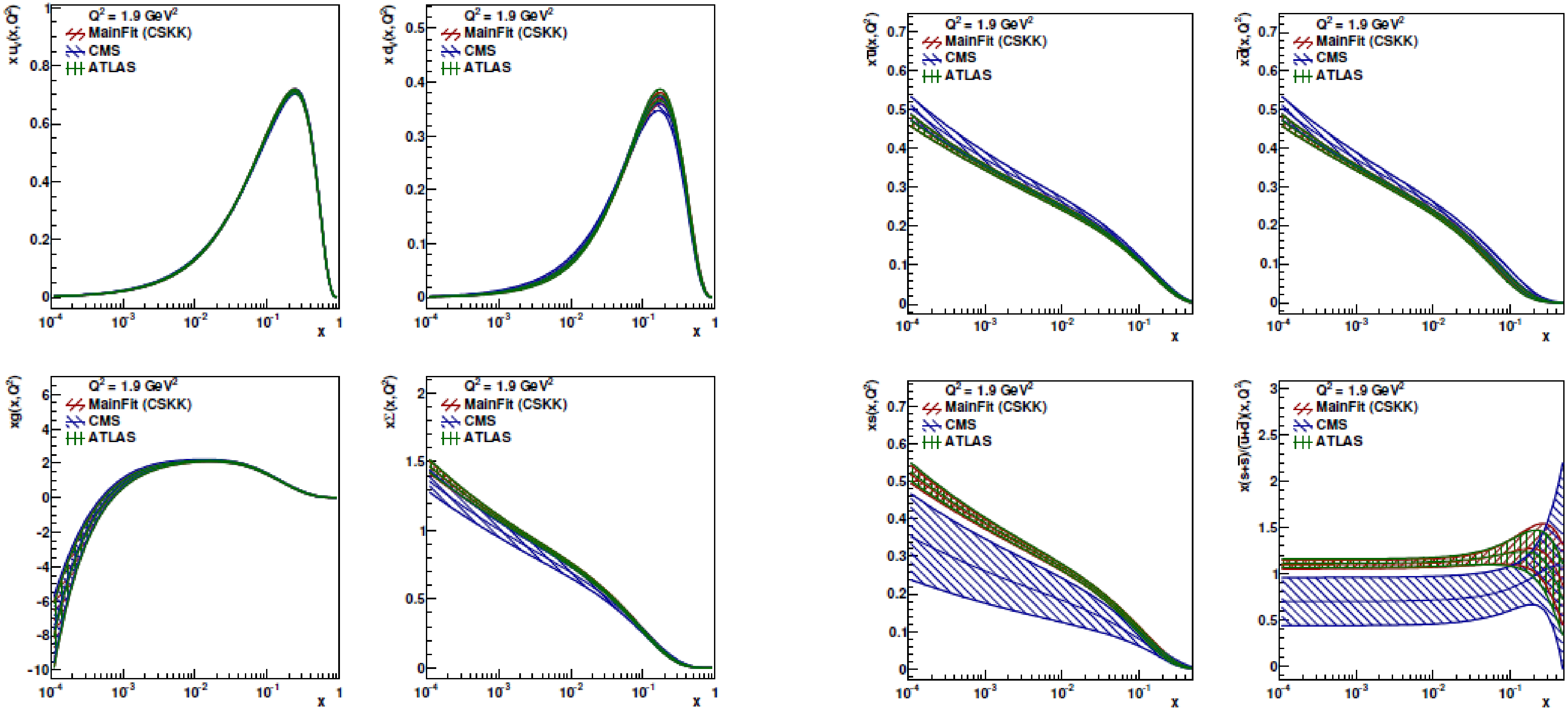


Consider W and Z data sets from each experiment separately

Very similar valence, gluon and total sea PDFs Different flavour break up to strangeness **BUT none are as suppressed as Rs = 0.5**

	CMS Z7	CMS W7,8	CMS Z7 + W7,8
Total χ^2/NDF	1218/1965	1225/1074	1236/1098
Data set			
HERA χ^2/NDP	1156/1056	1157/1056	1157/1056
CMS 7 TeV central Z χ^2/NDP	11/24		11/24
CMS 7 TeV W-asym. χ^2/NDP		13/11	13/11
CMS 8 TeV W^+, W^- χ^2/NDP		4/22	4/22

	ATLAS Z	ATLAS W	ATLAS W,Z
Total χ^2/NDF	1233/1062	1245/1063	1276/1084
Data set			
HERA χ^2/NDP	1155/1056	1160/1056	1164/1056
ATLAS W^+ χ^2/NDP		12/11	12/11
ATLAS W^- χ^2/NDP		8/11	9/11
ATLAS Z central CC χ^2/NDP	14/12		15/12
ATLAS Z central CF χ^2/NDP	9/9		8/9



	CMS Z7 + W7,8
Total χ^2/NDF	1236/1098
Data set	
HERA χ^2/NDP	1157/1056
CMS 7 TeV central Z χ^2/NDP	11/24
CMS 7 TeV W-asym. χ^2/NDP	13/11
CMS 8 TeV W^+, W^- χ^2/NDP	4/22

	ATLAS W,Z
Total χ^2/NDF	1276/1084
Data set	
HERA χ^2/NDP	1164/1056
ATLAS W^+ χ^2/NDP	12/11
ATLAS W^- χ^2/NDP	9/11
ATLAS Z central CC χ^2/NDP	15/12
ATLAS Z central CF χ^2/NDP	8/9

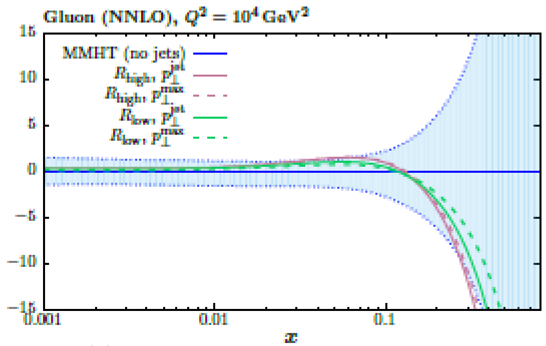
	ATLAS and CMS W and Z
Total χ^2/NDF	1308/1141 = 1.15
Data set	
HERA χ^2/NDP	1163/1056
ATLAS W^+ χ^2/NDP	13/11
ATLAS W^- χ^2/NDP	9/11
ATLAS central CC Z χ^2/NDP	16/12
ATLAS central CF Z χ^2/NDP	7/9
CMS 7 TeV central Z χ^2/NDP	12/24
CMS 7 TeV W-asym. χ^2/NDP	14/11
CMS 8 TeV W^+, W^- χ^2/NDP	5/22

Then consider CMS W+Z and ATLAS W+Z and compare to ALL: **no tension, disagreement in strangeness is only at 1.5σ level.** ATLAS is more accurate and thus dominates the fit to both together

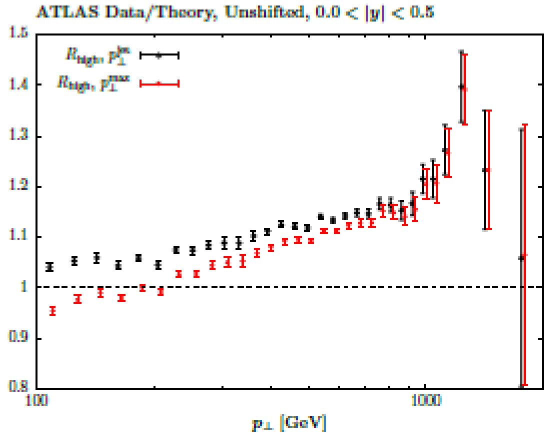
It seems that fits do not care so much about scale– the jet radius matters more

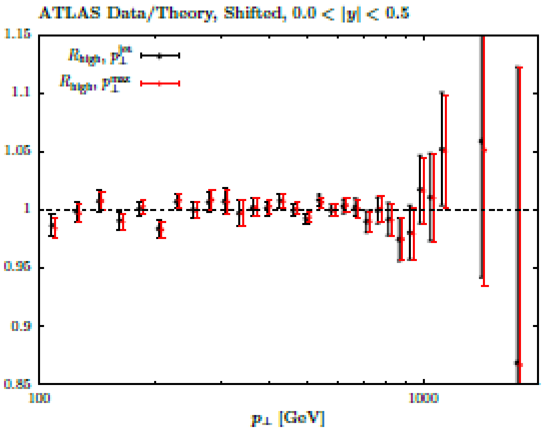
	$R_{\rm low},\ p_\perp^{\rm jet}$	$R_{\rm low},\ p_\perp^{\rm max}$	$R_{\rm high},\ p_\perp^{\rm jet}$	$R_{\rm high},\ p_\perp^{\rm max}$
ATLAS (NLO)	213.8	190.5	171.5	161.2
ATLAS (NNLO)	172.3	199.3	149.8	152.5
CMS (NLO)	190.3	185.3	195.6	193.3
CMS (NNLO)	177.8	187.0	182.3	185.4

Table 3: The χ^2 for the combined fit to the ATLAS ($N_{\rm pts} = 140$) and CMS ($N_{\rm pts} = 158$) 7 TeV jet data. The values for the ATLAS and CMS contributions are given, for different choices of jet radius and scale, at NLO and NNLO.



All fits result in a somewhat softer high-x gluon





PDFs currently insensitive to choice of scale and jet radius at NNLO.

Different shifts of data relative to theory required.