News from ATLAS

A M Cooper Sarkar on behalf of the ATLAS collaboration

PDF4LHC Dec 2018

- Fits to t-tbar differential cross sections

Full correlation information between spectra available
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2018-017/

- Some reflections on the strangeness issue – as reported in the Nov 13th meeting of the EWWG----in the second file

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. Results for normalised spectra are in back-up

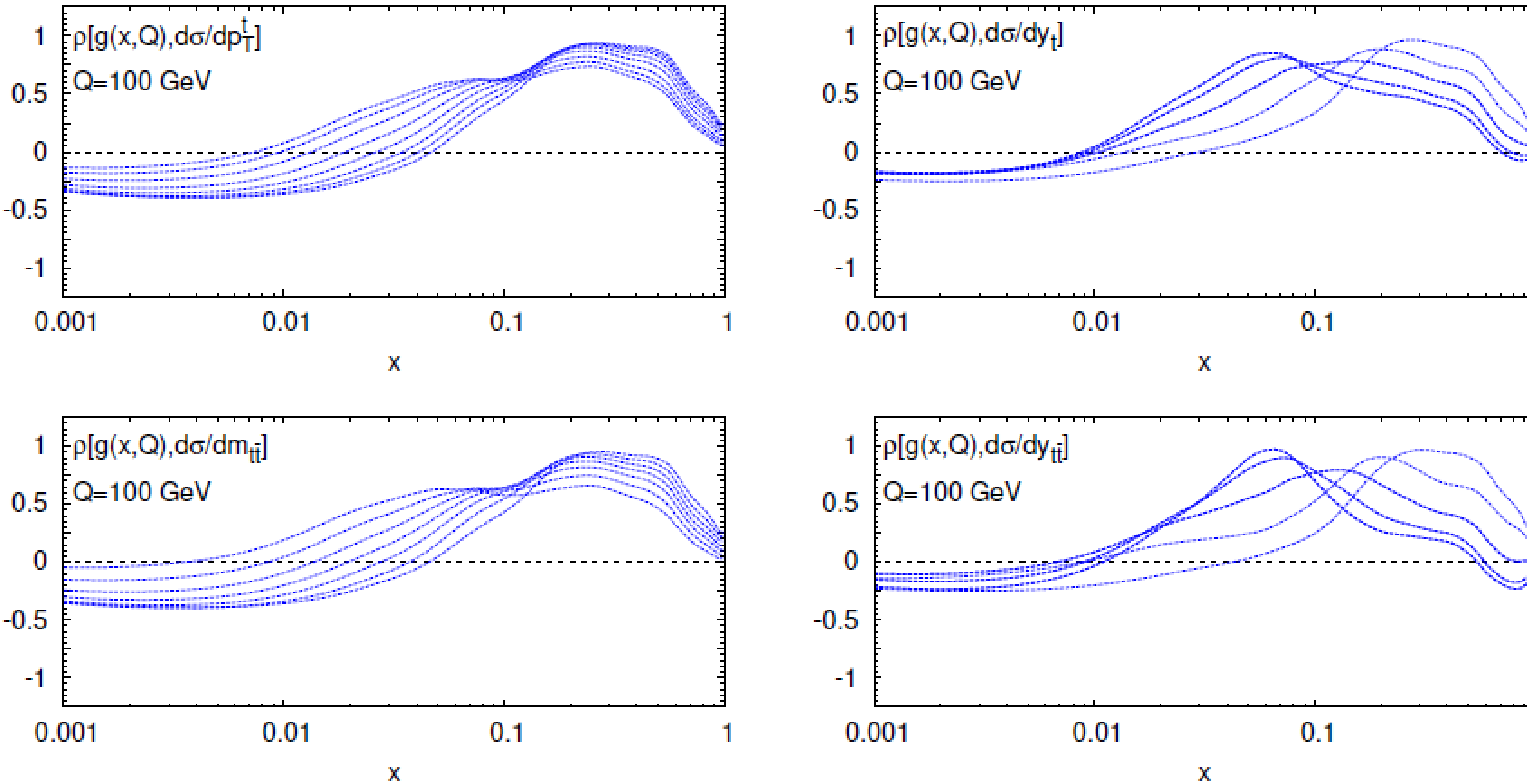
- The top data are used in addition to the HERA I+II combined data, and the ATLAS W,Z 7 TeV data – so the fits **ATLASopWZtop18** are an extension to **ATLASepWZ16**
- Note the top data and W,Z data are complementary – top affects the gluon, whereas W,Z affects the quarks.
- Conclusions on top are similar 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 between the top 8 TeV lepton+jets and dilepton data are also small—except fro 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

Here correlation coefficients for each bin of each spectrum with the gluon PDF are plotted as a function of x (from arXIV:1611.08609)



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	0.193066	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	-0.00928392	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	0.0839061	0.179544	0.180693	0.151204	0.137084	0.0904961	-0.0151066	0.111899	0.20052	0.306824	0.192282	0.0875043	0.0213644
5	-0.123318	-0.166392	-0.16322	0.189977	1	0.146452	-0.112662	-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	-0.00928392	-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	-0.0166362	-0.0131954	0.0130482	0.158587	0.205627
1	0.193066	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	0.163073	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	0.0839061	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	0.0358952
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	0.00998306	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	0.0939908	0.0489947	0.00816948
5	0.0801098	0.114189	0.115662	0.0904961	0.0579249	0.0343439	0.0245572	0.00892468	-0.0606758	-0.0404607	0.0579035	0.255948	0.379725	0.00998306	-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	0.163073	0.132723	0.0878424	0.0457679	0.134049	0.158414	0.132604	0.128643	0.117539	1	0.52067	-0.254831	-0.249306	-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	-0.0660809	-0.010135
3	0.1566	0.252227	0.357748	0.20052	0.114799	-0.0102559	-0.0266078	-0.0166362	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	-0.249306	-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	0.0130482	0.144966	0.147774	0.12442	0.120789	0.0949771	0.183829	0.176059	0.13443	0.0939908	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	-0.0660809	-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	0.0358952	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
Tables 167,168,169,170,172,173,174,176,177,179
https://www.hepdata.net/record/84154
Tables 29,31,27,23 for the distributions themselves

Form of the χ2 for correlated systematic/statistical errors

Use a form of χ2 which accounts for correlated systematics using nuisance parameters b_j for each source of systematic j for ATLAS

$$\chi^2_{\exp}(m,b) = \sum_i \frac{\left[m^i - \sum_\alpha \gamma^i_\alpha \mu^i b_\alpha - \mu^i\right]^2}{\left(\delta_{i,\mathrm{stat}}\,\mu^i\right)^2 + \left(\delta_{i,\mathrm{uncor}}\,\mu^i\right)^2} + \sum_\alpha b_\alpha^2 .$$

Where μ^i is the measurement for point i, m^i is the prediction, γ^i_α is the fractional systematic error on point i from source α and δ's are statistical and uncorrelated systematic errrors

In the case of correlated (off-diagonal) statistical uncertainties, the χ^2 function reads

$$\chi^2_{\exp}(m,b) = \sum_{ij}\left(m^i - \sum_\alpha \Gamma^i_\alpha(m^i)\, b_\alpha - \mu^i\right) C^{-1}_{\mathrm{stat}\ ij}(m^i,m^j) \left(m^j - \sum_\alpha \Gamma^j_\alpha(m^j)\, b_\alpha - \mu^j\right) + \sum_\alpha b_\alpha^2 .$$

$\Gamma^i_\alpha(m^i) = \gamma^i_\alpha \mu^i$ for additive $\Gamma^i_\alpha(m^i) = \gamma^i_\alpha m^i.$ for multiplicative

Predictions for HERA DIS and ATLAS W,Z and Top

The formalism to relate PDFs to the DIS cross sections is text book stuff we only have to define the input PDFs and standard programmes do the rest

- QCDNUM for DGLAP evolution at NNLO
- DIS matrix-elements also from QCDNUM with RTVFN heavy quark scheme
- W,Z matrix elements at NLO from MCFM using Applgrid for input to PDF fit
- Augmented with NNLO/NLO k-factors from DYNNLO cross-checked with FEWZ for ATLAS, arXIV:1612.03016
- NLO-EW and photon induced corrections also applied

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

As usual in PDF fitting a parametrisation is assumed at a low scale Q^2_0

$$xq_i(x) = A_i x^{B_i}(1-x)^{C_i} P_i(x), \quad \text{where } P_i(x) = (1 + D_i x + E_i x^2)e^{F_i x}.$$

Where $xq_i(x)$ are the quark distributions $(xu_v,\ xd_v)$ and $(x\bar{u},\ x\bar{d},\ x\bar{s})$.

The gluon distribution has an extra term $xg(x) = A_g x^{B_g}(1-x)^{C_g} - A'_g x^{B'_g}(1-x)^{C'_g}$
Which allows larger uncertainties at small-x.
The valence and gluon normalisations are set by the number and momentum sum-rules
A few other constraints are applied to the low-x sea-such that ubar=dbar at very low-x,
But the strange normalisation is free --as for the ATLASepWZ16 fit.

The fit begins assuming $P_i(x)=1$ and parameters D,E,F are added to each distribution until there is no further improvement in χ2---saturation of the χ2.
Some extra parameters can nevertheless change the shape of the PDFs and these are included as part of the parametrisation uncertainty.
Assumptions on the low-x sea are also varied as part of parametrisation uncertainty

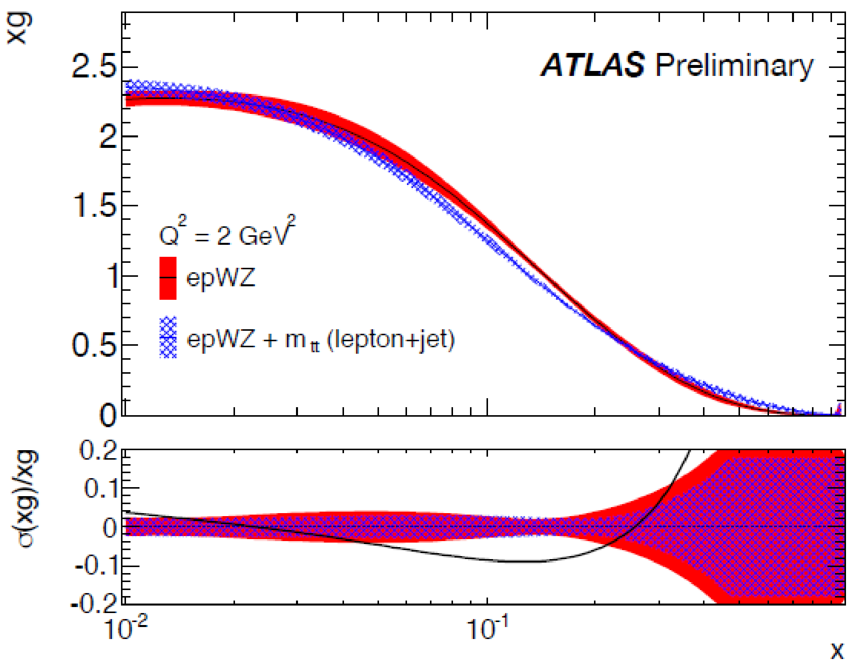
PDF fits must also assume values for the starting scale Q^2_0=1.9GeV^2, the minimum Q^2=10GeV^2 of input data, the charm and beauty masses m_c=1.43, m_b=4.5 GeV and the strong coupling $\alpha_S(M_Z)$=0.118
All of the input values are varied as part of the model uncertainty

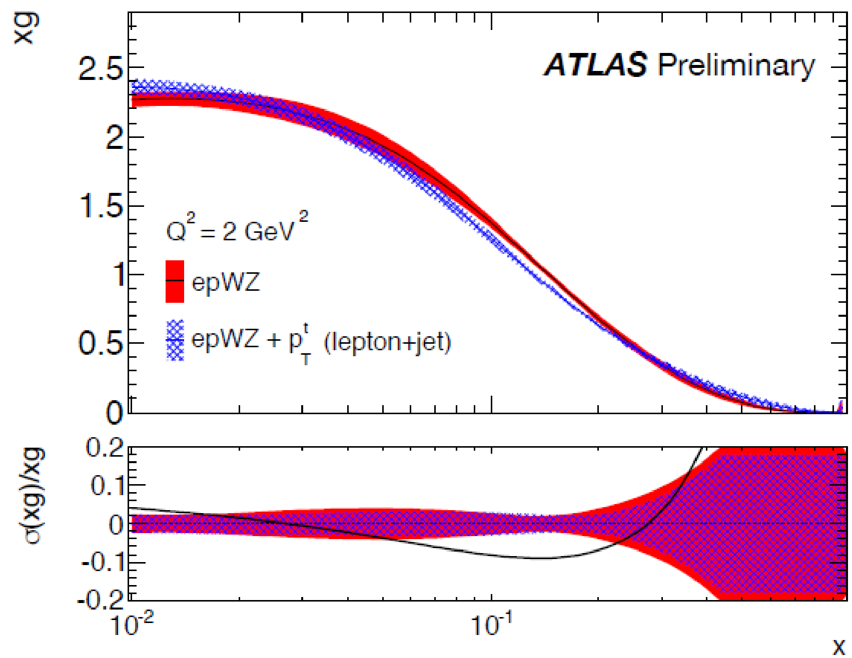
First **consider one spectrum at a time INCLUDING statistical correlations bin-to-bin**

		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
Partial χ^2/NDP	HERA	1153 / 1016	1151 / 1016	1149 / 1016	1146 / 1016
Partial χ^2/NDP	ATLAS $W, Z/\gamma^*$	82.0 / 55	82.1 / 55	86.4 / 55	85.0 / 55
Partial χ^2/NDP	ATLAS $t\bar{t}$	3.4 / 7	7.9 / 8	19.7 / 5	18.3 / 5

χ2 for p_T^t and m_{ttbar} are good

The χ2 for the HERA and ATLAS W,Z are similar to when they are fitted without top—there is no tension





Both p_T^t and m_{ttbar} spectra harden the gluon in comparison to just ATLAS epWZ (HERA +ATLAS WZ2011)

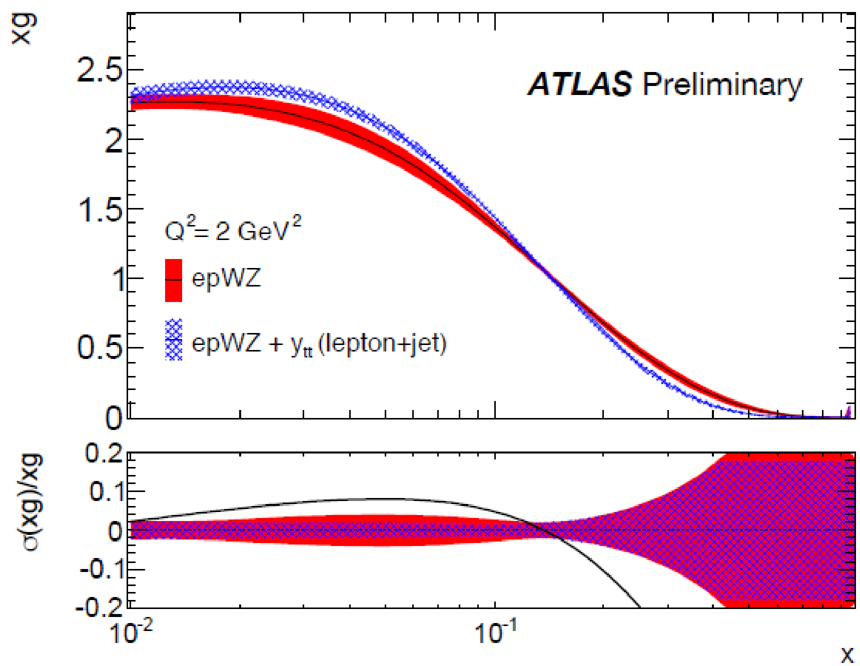
Now **consider one spectrum at a time INCLUDING statistical correlations bin to bin**

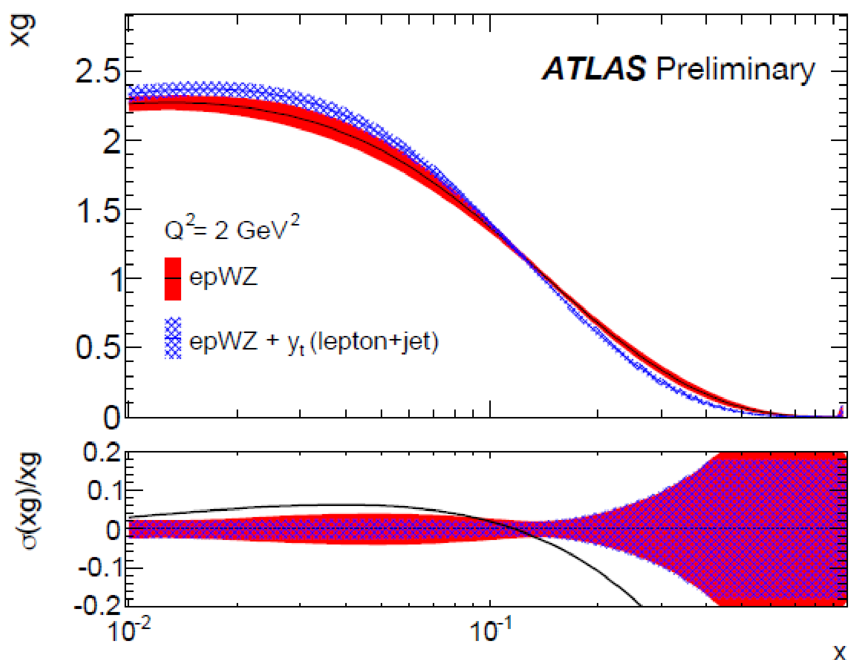
		lepton+jets spectrum			
		$m_{t\bar{t}}$	p_T^t	$y_{t\bar{t}}$	y_t
Total χ^2/NDF		1238.4 / 1062	1239.4 / 1063	1257.5 / 1060	1246.5 / 1060
Partial χ^2/NDP	HERA	1153 / 1016	1151 / 1016	1149 / 1016	1146 / 1016
Partial χ^2/NDP	ATLAS $W, Z/\gamma^*$	82.0 / 55	82.1 / 55	86.4 / 55	85.0 / 55
Partial χ^2/NDP	ATLAS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

χ2 for y_t and y_{ttbar} are not good.

The χ2 for the HERA and ATLAS W,Z are similar to when they are fitted without top—there is no tension.

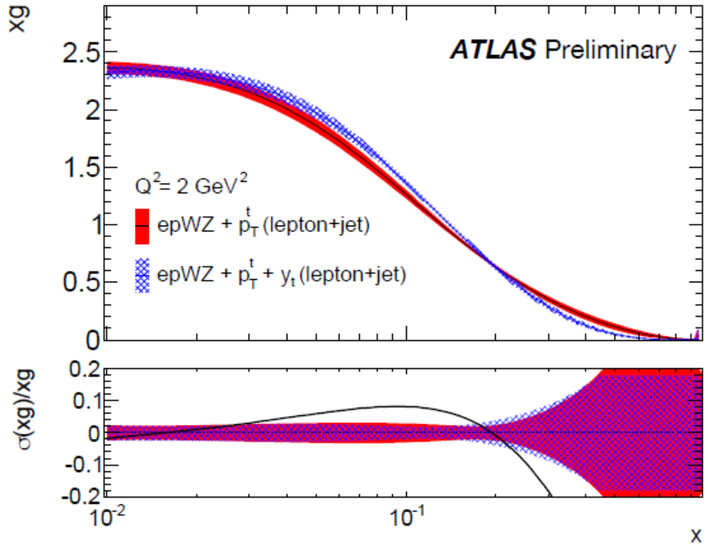
The χ2 for these rapidity spectra does not improve much even if the high-x gluon parametrisation is extended with D, E and F terms



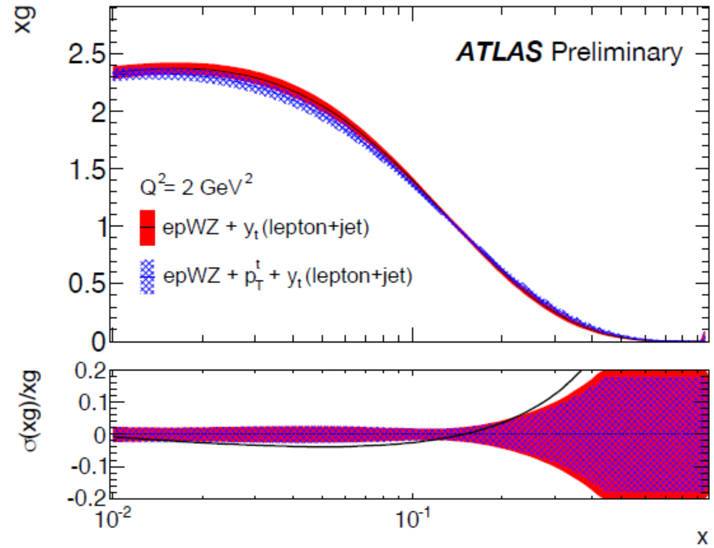


Both y_t and y_{ttbar} spectra soften the gluon

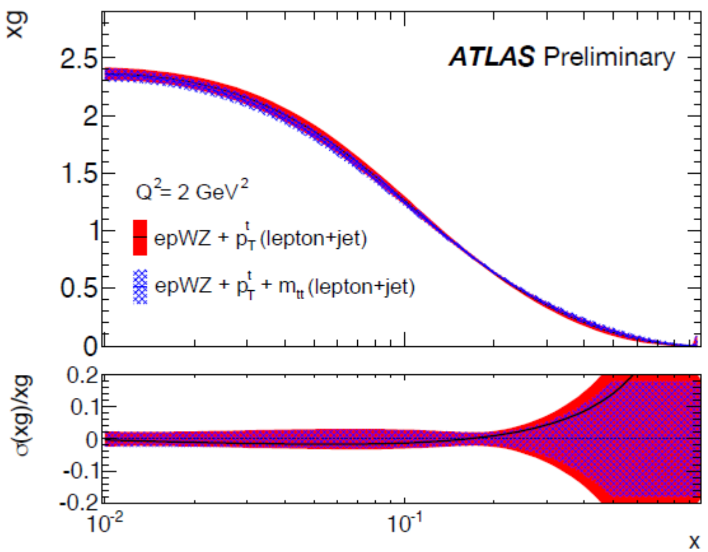
Now try the spectra two by two accounting for BOTH statistical and systematic correlations between the spectra



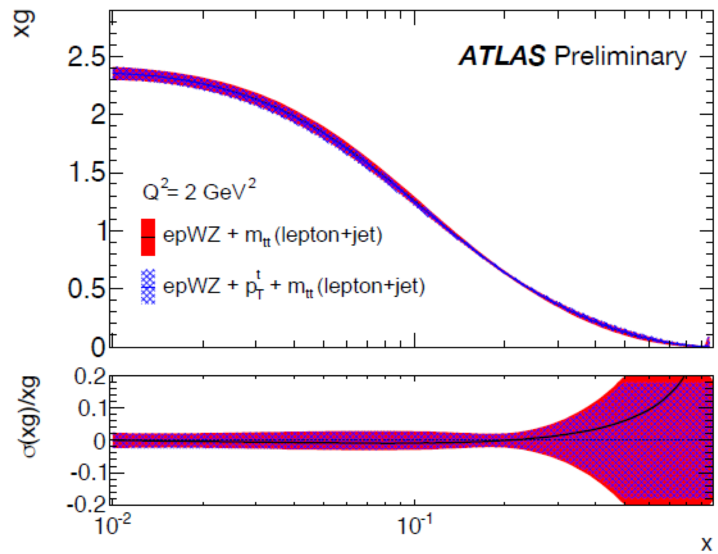
y_t has a stronger pull than p_T^t



Compare fits first adding one spectrum and then two



m_{ttbar} has a stronger pull than p_T^t



NOW try fitting 2 spectra at a time: (p_T^t and y_t) and (p_T^t and m_{ttbar})

------------------------**look at the χ2 for these fits**

		lepton+jets 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
Partial χ^2/NDP	HERA	1148 / 1016	1147 / 1016	1162 / 1016	1162 / 1016
Partial χ^2/NDP	ATLAS $W, Z/\gamma^*$	82.7 / 55	83.5 / 55	83.2 / 55	83.1 / 55
Partial χ^2/NDP	ATLAS $t\bar{t}$	33 / 13	30 / 13	45 / 15	42 / 15

This Table shows fits to (p_T^t and y_t) and (p_T^t 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 p_T^t + y_t χ2 is only a bit larger than the added sum of the p_T^t and y_t separate fit χ2 = 26.2, so the main problem here is the poor fit to y_t
whereas the p_T^t +m_{ttbar} χ2 is much larger than the sum of the p_T^t and m_{ttbar} 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 systematic uncertainties are the sys isr/fsr (~8%) and the sys-ps_model (~5%) and the hard scattering model (~4%). These are '2-point systematics'.

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 m_{ttbar} 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 p_T^t and m_{ttbar} together is -0.32 ± 0.10, which suits neither spectrum.

Let's investigate decorrelating these sources of systematic uncertainty between the 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 (with the isr/fsr uncertainty a close second)

		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

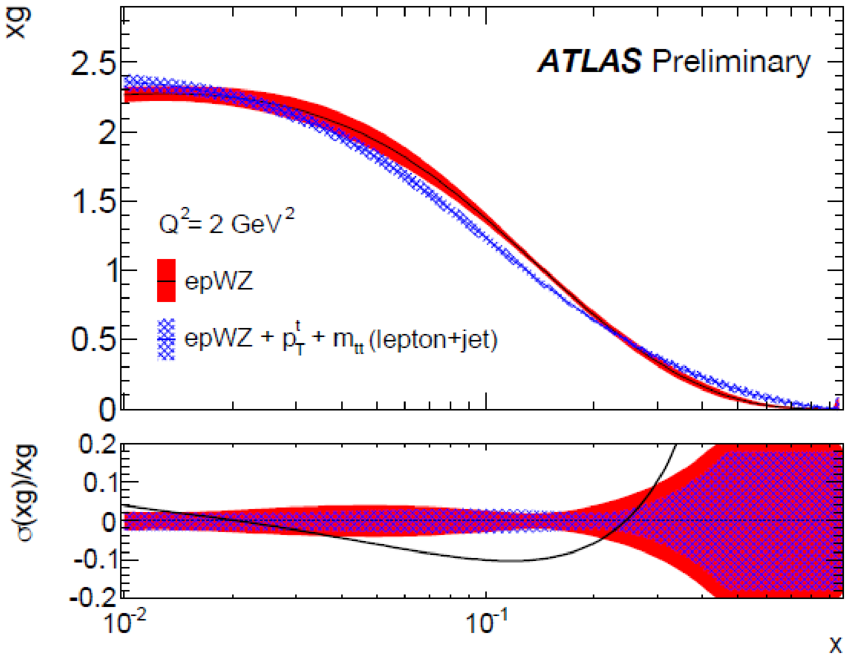
The effect of decorrelation is marginal for the p_T^t and y_t spectra, as expected since the shifts induced by these spectra are similar when they are fitted separately. The resultant χ2 is closer to the sum of the χ of the separate fits (26.2) but is not changed much

The effect of decorrelation is dramatic for the p_T^t and m_{ttbar} spectra, now that the shifts are allowed to be different. (The separate nuisance parameters are -0.47 for pt and +0.10 for mtt). The resultant χ2 is close to the sum of the χ2 of the separate fits (11.3)

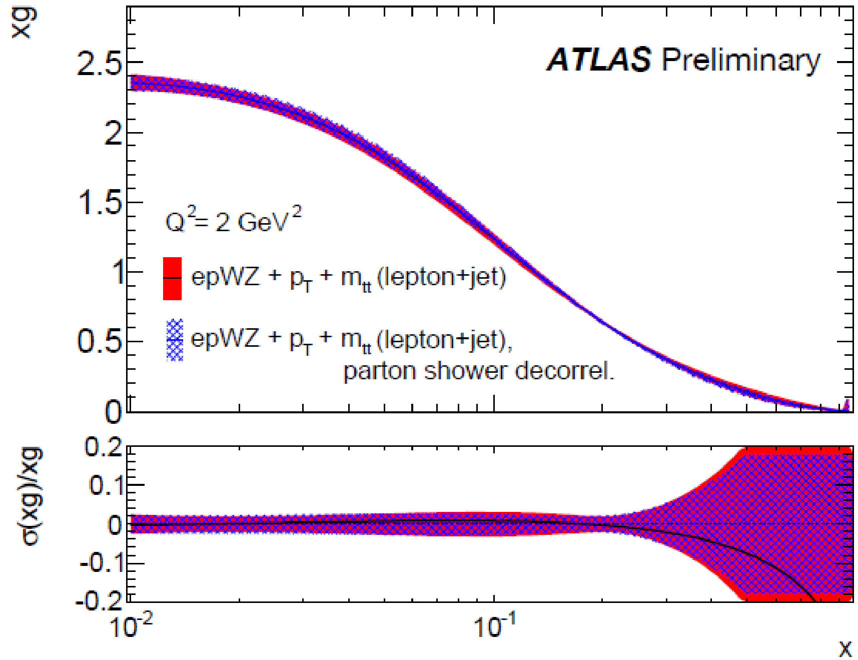
The resultant shape of the gluon barely changes when these systematics are decorrelated- the main effect is the improvement in χ2

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

Now look at t-tbar data in the dilepton channel

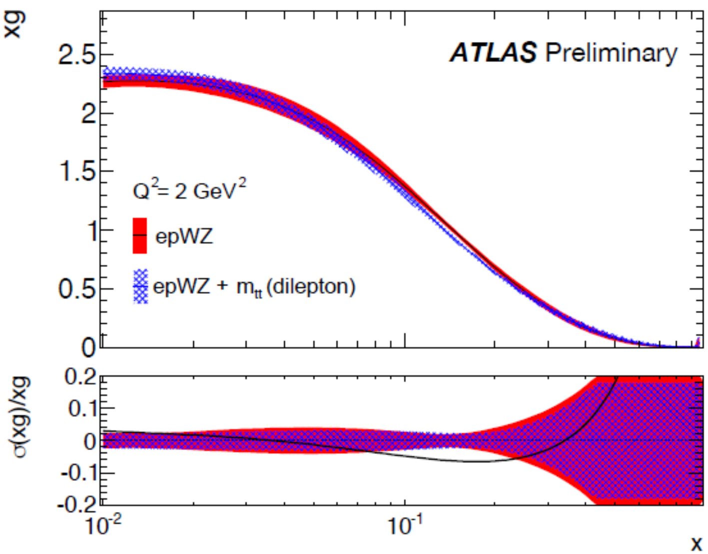
Dilepton 8 TeV data from HEPDATA for 1607.07281

In this publication dileptons are used to reconstruct top variables, the decay lepton variables themselves are not used. (NO NNLO predictions)

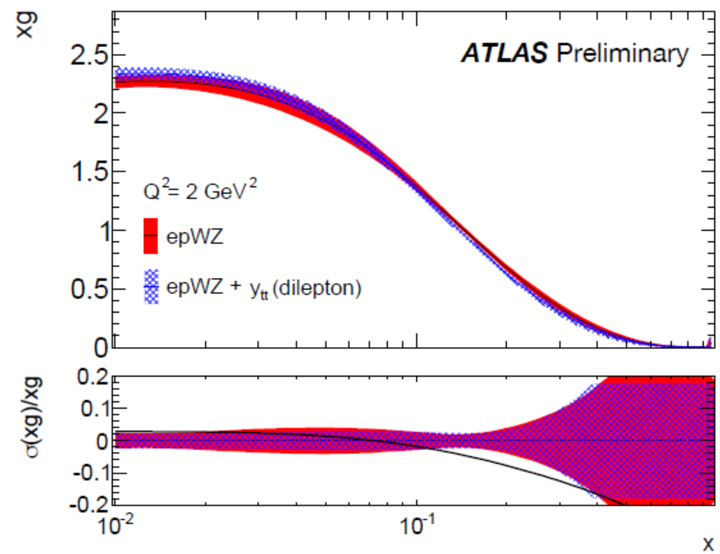
There are the y_{ttbar}, m_{ttbar} spectra for the dilepton mode

There are TOTAL covariance matrices for these data within each spectrum but not between them so you can only fit ONE at a time.

Use 8 TeV data because there are no NNLO predictions for the 7 TeV



Just as for the lepton plus jets channel the m_{ttbar} spectrum somewhat hardens the gluon, whereas the y_{ttbar} spectrum softens it– in both cases marginally

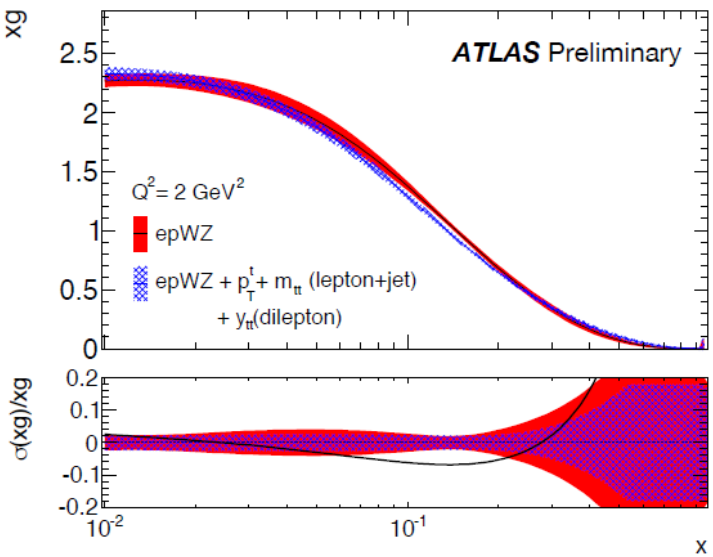


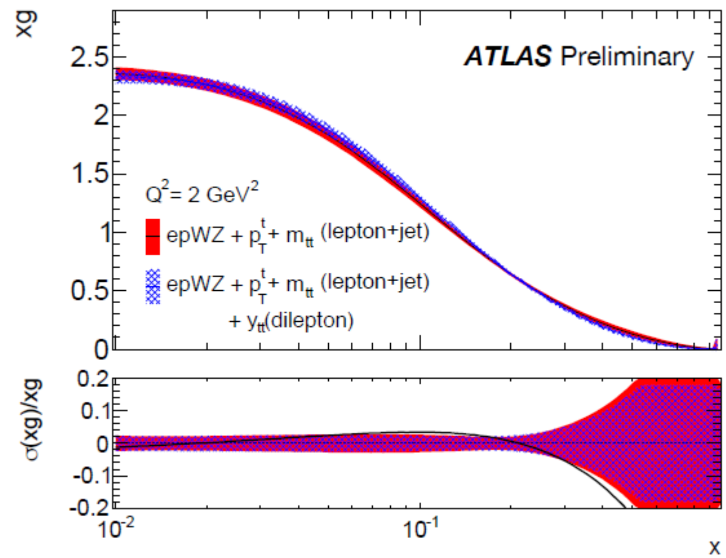
		dilepton spectrum	
		m_{tt}	y_{tt}
Total χ^2/NDF		1233.8 / 1061	1233.8 / 1060
Partial χ^2/NDP	HERA	1152 / 1016	1147 / 1016
Partial χ^2/NDP	ATLAS $W, Z/\gamma^*$	79.3 / 55	82.8 / 55
Partial χ^2/NDP	ATLAS $t\bar{t}$	2.6 / 6	4.5 / 5

And in both cases the fits have good χ2. NOTE this is NOT because they have larger errors than the lepton+jets, the total level of accuracy is comparable between di-lepton and lepton+jets

Make some choices.

- Take p_T^t and m_{ttbar} from lepton+jets with parton shower uncertainty decorrelated
- Do not take y_t and y_{ttbar} from lepton+jets because of poor χ2
- Instead take y_{ttbar} from dilepton data – this also softens gluon and has good χ2





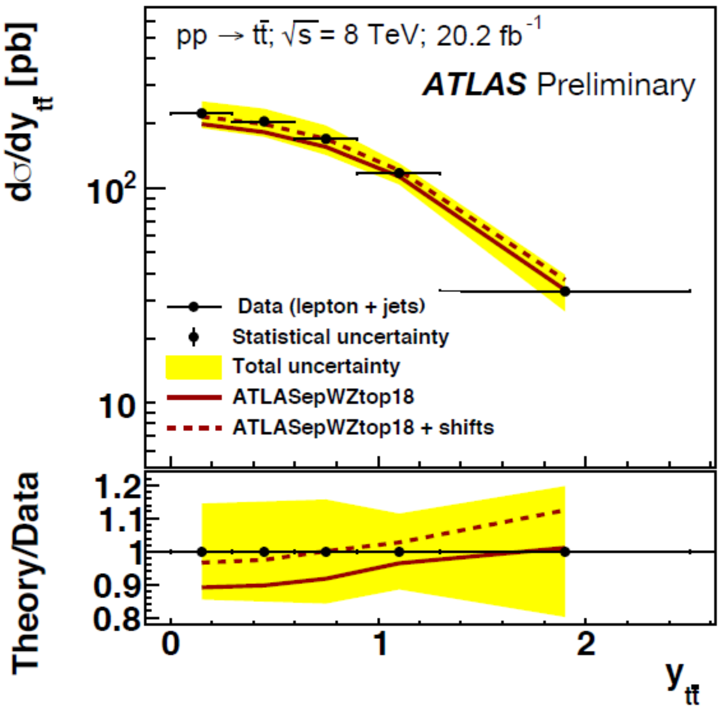
Compare this fit

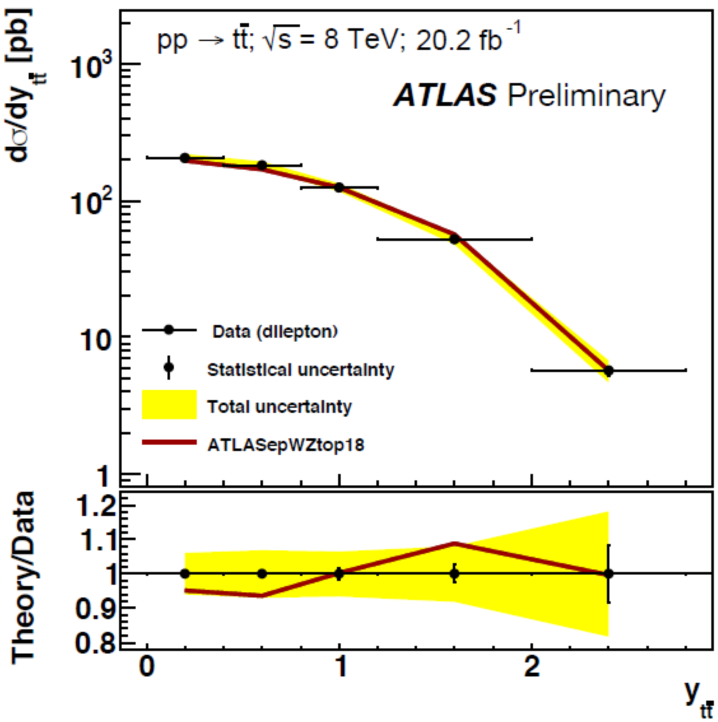
- To HERA +ATLAS W,Z alone –harder gluon, smaller uncertainties
- To HERA+ATLASW,Z + top p_T^t and m_{ttbar} from lepton+jets, shows y_{ttbar} from dilepton has some softening effect, and some marginal further reduction in uncertainty

		lepton+jets p_T^t, m_{tt} and dilepton y_{tt} spectra
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 y_{ttbar} from lepton+jets and dilepton channels to the predictions of this fit
(NOTE y_{ttbar} from lepton+jets was not included in the fit)

There is a trend of the y_{ttbar} lepton+jets data that is hard to fit despite comparable level of total uncertainties
BUT for the dilepton channel statistical (uncorrelated) uncertainties are a larger contribution to the total
--- correlated systematic uncertainties matter





Other data fit comparisons in back-up

However so far we have only considered uncertainties on the fit coming from input experimental data.

There are also uncertainties from model and parametrisation assumptions.

$(1.37 < m_c < 1.49\,\mathrm{GeV}$ and $4.25 < m_b < 4.75\,\mathrm{GeV})$

Additionally we consider variation of mass top 172.3 < m_t < 175 GeV. Changing the top mass has very little effect on the PDFs although the χ2 is sensitive to it—preferring the default value

$$(7.5 < Q^2_{min} < 12.5\,\mathrm{GeV}^2),\ (1.6 < Q^2_0 < 2.2\,\mathrm{GeV}^2).$$

(0.116 < $\alpha_S(M_Z)$ < 0.120) – these variations affect the shape of the gluon and are supplied as alternative PDFs rather than folded into the uncertainty –as is conventional for PDFsets, which are compared at fixed $\alpha_S(M_Z)$ values.

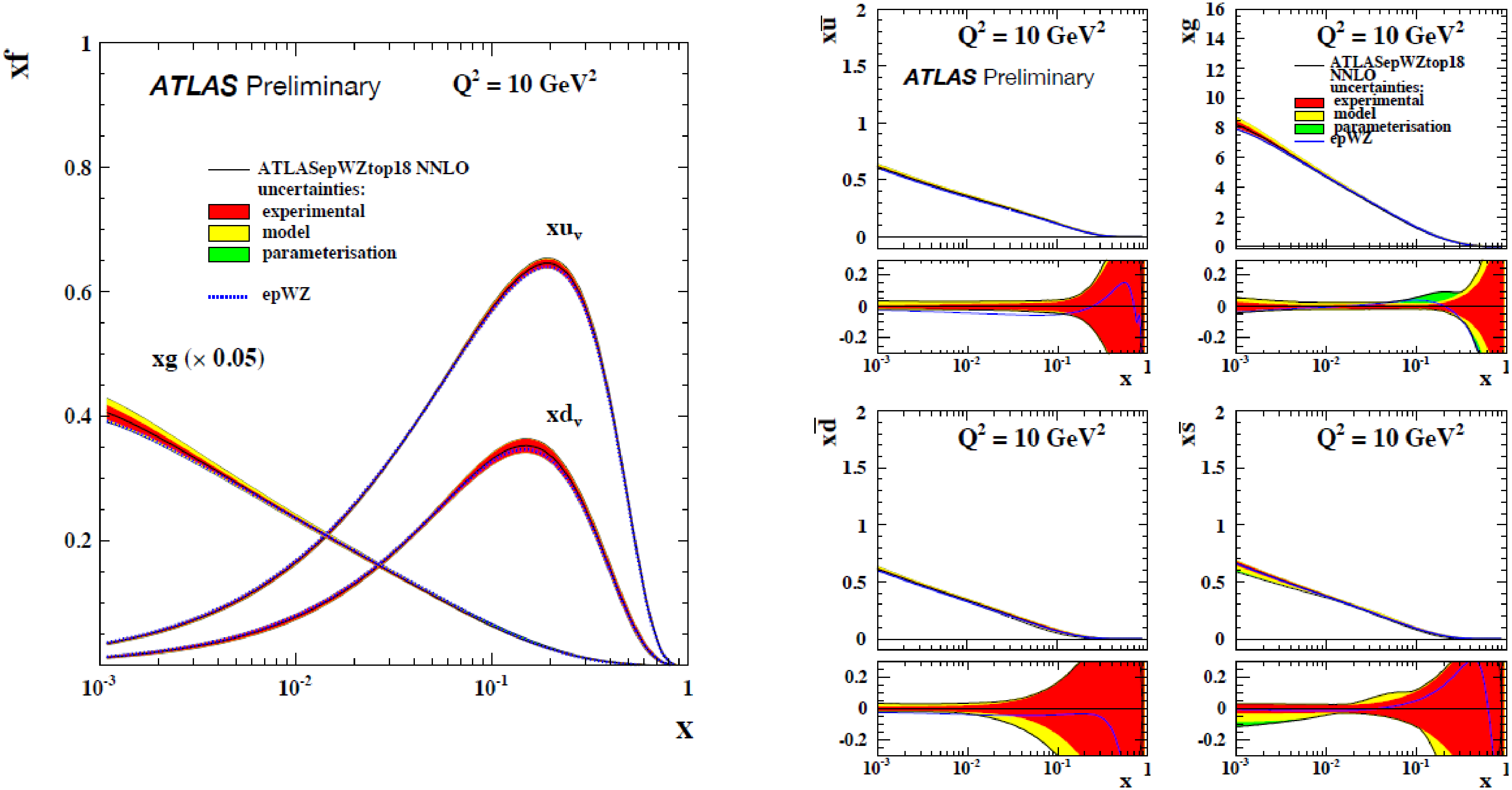
The parametrisation uncertainty is the envelope of results obtained with extra parameters. Either extra D,E, F parameters in the polynomial $P_i(x)$, or relaxation of the low-x sea constraints.

The only significant parametrisation variations are

i) freeing the low-x strange sea slope B_s and

ii) adding extra terms to the main term of the gluon PDF $(1+D_g x)$

Add model and parametrisation uncertainties: ATLASepWZtop18 PDFs



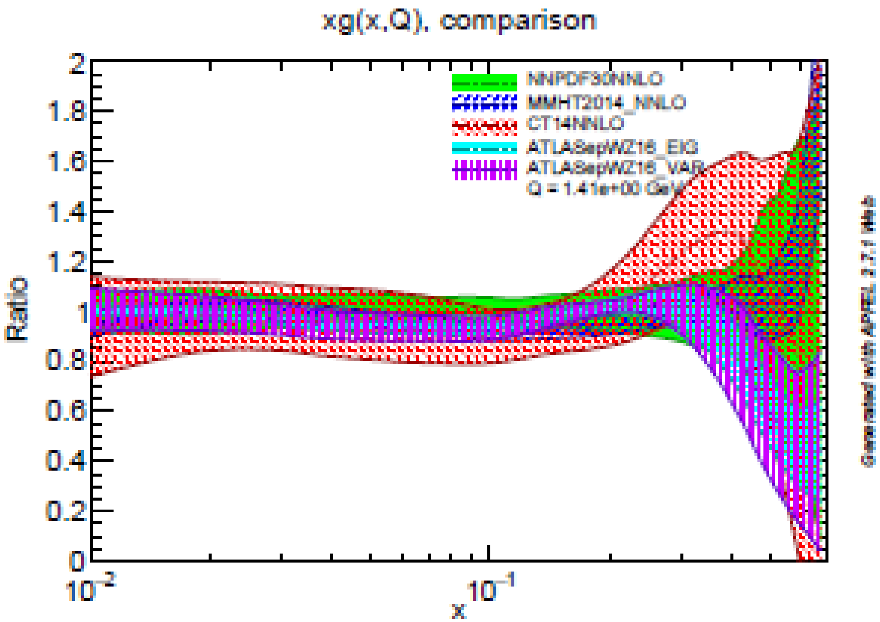
Valence and sea are not much affected by the model and parametrisation uncertainties

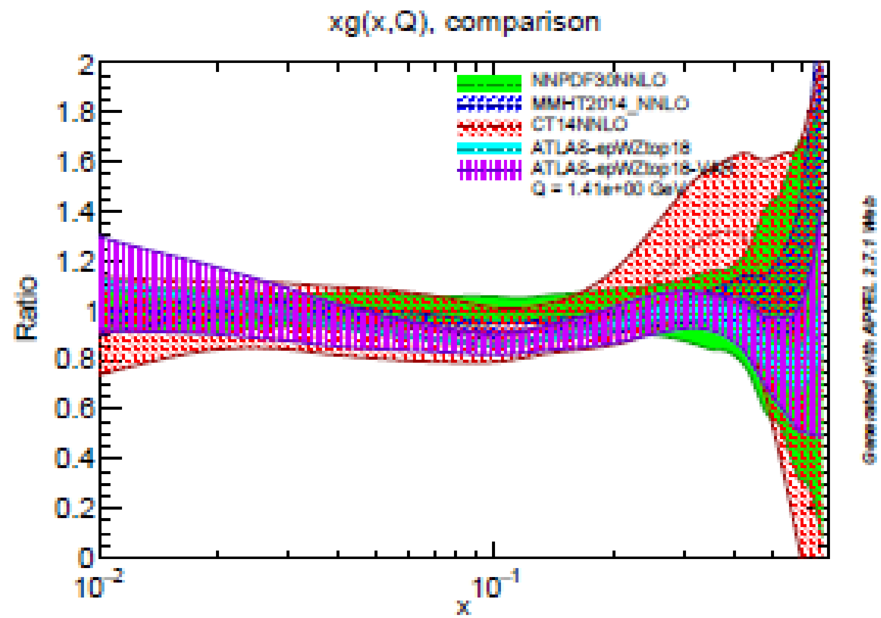
Gluon is affected at high-x

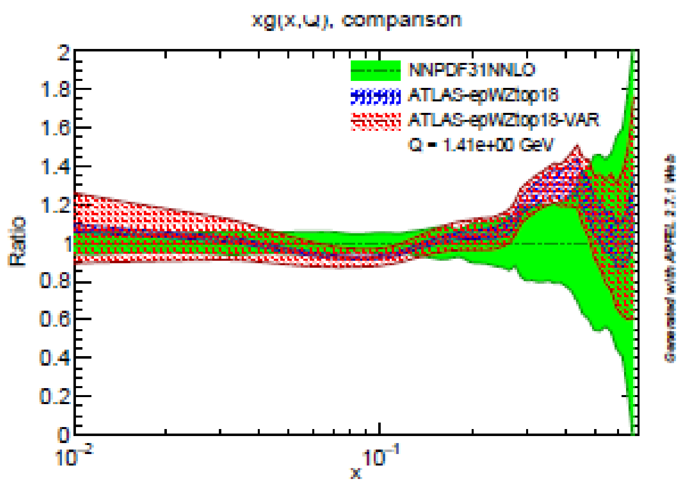
The fractional uncertainties show the effect of model and parametrisation uncertainty more clearly ---for gluon and sea

Comparison epWZ shows hardening of the gluon

FINALLY compare the new fit with HERA, ATLAS WZ2011, ATLAS top2012-- **called ATLASepWZtop18- to global PDFs**
This is easy because it is now on LHAPDF and we can use APFEL







The **harder gluon of ATLASepWZtop18** -as compared to ATLASepWZ16 -**is in better agreement with MMHT14, CT14, NNPDF3.0**
And also OKAY with NNPDF3.1

Recently the statistical correlation matrices between the spectra have been evaluated

	1	2	3	4	5	6	7	8
1	1	0.523003	-0.0865203	-0.230593	-0.123318	-0.0355471	-0.0183453	-0.00742052
2	0.523003	1	0.258974	-0.232733	-0.166392	-0.0568362	-0.0232129	-0.00928392
3	-0.0865203	0.258974	1	0.211745	-0.16322	-0.0930239	-0.0348095	-0.015387
4	-0.230593	-0.232733	0.211745	1	0.189977	-0.128108	-0.057691	-0.0144478
5	-0.123318	-0.166392	-0.16322	0.189977	1	0.146452	-0.112662	-0.028564
6	-0.0355471	-0.0568362	-0.0930239	-0.128108	0.146452	1	0.104131	-0.0939535
7	-0.0183453	-0.0232129	-0.0348095	-0.057691	-0.112662	0.104131	1	0.0584419
8	-0.00742052	-0.00928392	-0.015387	-0.0144478	-0.028564	-0.0939535	0.0584419	1
1	0.193366	0.258845	0.252667	0.174912	0.138193	0.0936114	0.0583097	0.0351814
2	0.199054	0.259962	0.256505	0.186568	0.144556	0.089112	0.0677387	0.044628
3	0.165572	0.215854	0.204611	0.143437	0.113236	0.0721004	0.0534449	0.0329678
4	0.119437	0.157379	0.153019	0.121854	0.0888044	0.0567852	0.028248	0.0154428
5	0.092386	0.11636	0.112391	0.0838061	0.0533645	0.0347566	0.0197736	0.0038406
1	0.191687	0.257006	0.245568	0.179544	0.137564	0.0933875	0.0582822	0.0365307
2	0.211977	0.265854	0.26638	0.180693	0.147322	0.0967962	0.065875	0.0394551
3	0.170986	0.221259	0.217244	0.151204	0.115839	0.0795374	0.0532866	0.0347108
4	0.141897	0.190785	0.176239	0.137084	0.10241	0.0556884	0.0378831	0.0206278
5	0.0801098	0.114189	0.115662	0.0904961	0.0579249	0.0343439	0.0245572	0.00892468
1	0.313266	0.367823	0.206166	-0.0151066	-0.047342	-0.0254326	-0.0164502	0.000869021
2	0.358684	0.46559	0.296708	0.111899	-0.0350948	-0.0447006	-0.0264189	-0.00799165
3	0.1566	0.252227	0.357748	0.30052	0.114799	-0.0102559	-0.0266078	-0.0166962
4	0.0379843	0.0946659	0.205561	0.306824	0.280595	0.101504	0.00383807	-0.0131964
5	-0.00850053	0.0174152	0.0849696	0.192282	0.292134	0.262709	0.112064	0.0139482
6	-0.0167743	-0.0106161	0.0238164	0.0875043	0.178125	0.226378	0.272357	0.158587
7	-0.00412765	-0.00640371	-0.00260146	0.0213644	0.0566404	0.0986235	0.163028	0.205627

	1	2	3	4	5
1	0.193366	0.199054	0.165572	0.119437	0.092386
2	0.258845	0.259962	0.215854	0.157379	0.11636
3	0.252667	0.256505	0.204611	0.153019	0.112391
4	0.174912	0.186568	0.143437	0.121854	0.0838061
5	0.138193	0.144556	0.113236	0.0888044	0.0533645
6	0.0936114	0.089112	0.0721004	0.0567852	0.0347566
7	0.0583097	0.0677387	0.0534449	0.028248	0.0197736
8	0.0351814	0.044628	0.0329678	0.0154428	0.0038406
1	1	-0.0196275	-0.209871	-0.138556	-0.058594
2	-0.0196275	1	0.0361891	-0.139761	-0.090291
3	-0.209871	0.0361891	1	0.055808	-0.116518
4	-0.138556	-0.139761	0.055808	1	0.0230257
5	-0.058594	-0.090291	-0.116518	0.0230257	1
1	0.489861	0.247887	0.0309966	-0.0363669	-0.0239123
2	0.299719	0.3457	0.170229	0.0317	-0.0160335
3	0.0681119	0.236424	0.273071	0.158325	0.0398061
4	-0.046792	0.0775306	0.257601	0.296765	0.185696
5	-0.0606758	-0.0404607	0.0579035	0.255948	0.379725
1	0.171685	0.169373	0.132723	0.0878424	0.0457679
2	0.262747	0.273609	0.21484	0.130365	0.0820693
3	0.237413	0.248759	0.193211	0.141035	0.0974089
4	0.19099	0.201697	0.156733	0.130769	0.10323
5	0.144966	0.147774	0.12442	0.120789	0.0949771
6	0.0966219	0.0990592	0.102127	0.0846287	0.0793067
7	0.0493263	0.0480445	0.0485058	0.0346981	0.0358962

	1	2	3	4	5
1	0.191687	0.211977	0.170986	0.141897	0.0801098
2	0.257006	0.265854	0.221259	0.190785	0.114189
3	0.245568	0.26638	0.217244	0.176239	0.115662
4	0.179544	0.180693	0.151204	0.137084	0.0904961
5	0.137564	0.147322	0.115839	0.10241	0.0579249
6	0.0933875	0.0967962	0.0795374	0.0556884	0.0343439
7	0.0582822	0.065875	0.0532866	0.0378831	0.0245572
8	0.0365307	0.0394551	0.0347108	0.0206278	0.00892468
1	0.489861	0.299719	0.0681119	-0.046792	-0.0606758
2	0.247887	0.3457	0.236424	0.0775306	-0.0404607
3	0.0309966	0.170229	0.273071	0.257601	0.0579035
4	-0.0363669	0.0317	0.158325	0.296765	0.255948
5	-0.0239123	-0.0160335	0.0398061	0.185696	0.379725
1	1	-0.0274769	-0.263436	-0.0870922	0.00996306
2	-0.0274769	1	0.17176	-0.195766	-0.0497008
3	-0.263436	0.17176	1	0.111911	-0.180419
4	-0.0870922	-0.195766	0.111911	1	-0.0338399
5	0.00996306	-0.0497008	-0.180419	-0.0338399	1
1	0.134049	0.158414	0.132604	0.128643	0.117539
2	0.225154	0.257381	0.217563	0.204679	0.146678
3	0.221049	0.246893	0.209858	0.185544	0.099773
4	0.203422	0.20935	0.173215	0.142059	0.069673
5	0.183829	0.176059	0.13443	0.0939908	0.0272868
6	0.144336	0.136116	0.100188	0.0489947	0.00203619
7	0.0816254	0.0727846	0.0396299	0.00816948	-0.00530476

	1	2	3	4	5	6	7
1	0.313266	0.358684	0.1566	0.0379843	-0.00850053	-0.0167743	-0.00412765
2	0.367823	0.46559	0.252227	0.0946659	0.0174152	-0.0106161	-0.00640371
3	0.206166	0.296708	0.357748	0.205561	0.0849696	0.0238164	-0.00260146
4	-0.0151066	0.111899	0.30052	0.306824	0.192282	0.0875043	0.0213644
5	-0.047342	-0.0350948	0.114799	0.280595	0.292134	0.178125	0.0566404
6	-0.0254326	-0.0447006	-0.0102559	0.101504	0.262709	0.226378	0.0986235
7	-0.0164502	-0.0264189	-0.0266078	0.00383807	0.112064	0.272357	0.163028
8	0.000869021	-0.00799165	-0.0166962	-0.0131964	0.0139482	0.158587	0.205627
1	0.171685	0.262747	0.237413	0.19099	0.144966	0.0966219	0.0493263
2	0.169373	0.273609	0.248759	0.201697	0.147774	0.0990592	0.0480445
3	0.132723	0.21484	0.193211	0.156733	0.12442	0.102127	0.0485058
4	0.0878424	0.130365	0.141035	0.130769	0.120789	0.0846287	0.0346981
5	0.0457679	0.0820693	0.0974089	0.10323	0.0949771	0.0793067	0.0358962
1	0.134049	0.225154	0.221049	0.203422	0.183829	0.144336	0.0816254
2	0.158414	0.257381	0.246893	0.20935	0.176059	0.136116	0.0727846
3	0.132604	0.217563	0.209858	0.173215	0.13443	0.100188	0.0396299
4	0.128643	0.204679	0.185544	0.142059	0.0939908	0.0489947	0.00816948
5	0.117539	0.146678	0.099773	0.069673	0.0272868	0.00203619	-0.00530476
1	1	0.52067	-0.254831	-0.249305	-0.10418	-0.0214541	0.000815721
2	0.52067	1	0.298679	-0.250712	-0.221548	-0.0669809	-0.010135
3	-0.254831	0.298679	1	0.409987	-0.163016	-0.142808	-0.0315226
4	-0.249305	-0.250712	0.409987	1	0.334172	-0.169248	-0.0742702
5	-0.10418	-0.221548	-0.163016	0.334172	1	0.184151	-0.122152
6	-0.0214541	-0.0669809	-0.142808	-0.169248	0.184151	1	0.145869
7	0.000815721	-0.010135	-0.0315226	-0.0742702	-0.122152	0.145869	1

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 $m_{t\bar{t}}$.

The determination of statistical correlations within each spectrum and among different spectra are evaluated using the Bootstrap Method [22]. The method is based on the extraction of $\mathcal{N}$ Bootstrap samples from the data sample. The $i-th$ sample is made by associating a Poissonian weight to each event in data. From each Bootstrap sample the spectra are replicated following the very same procedure used for the nominal results. Since the weights are generated on an event-by-event basis, the replicated spectra are synchronized, thus allowing the determination of statistical correlations among different spectra.

The statistical correlations are evaluated bin-by-bin following the master formula:

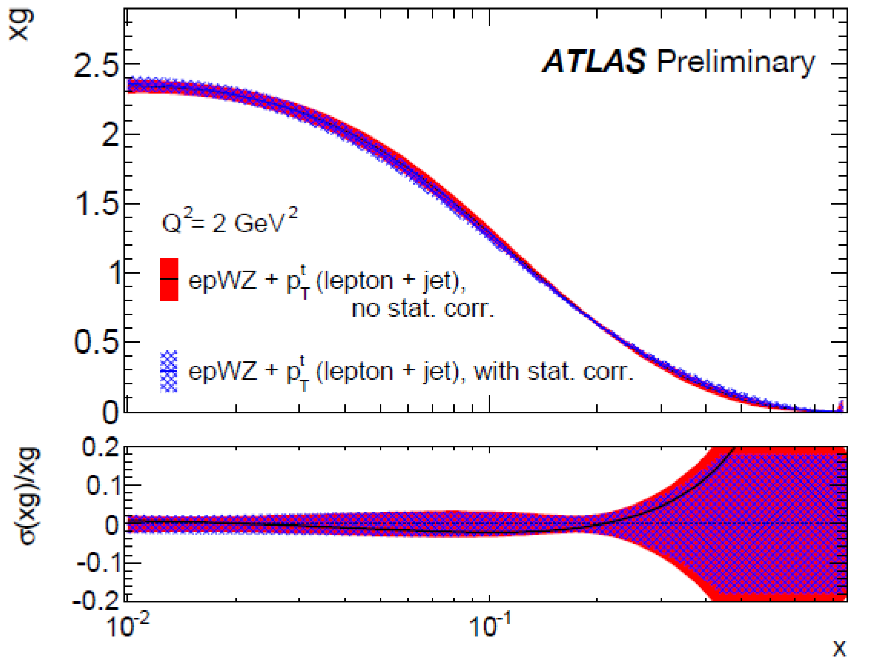
$$C_{ij}^{AB} = \frac{\frac{1}{\mathcal{N}} \cdot \sum_{k=1}^{\mathcal{N}} (\mathcal{R}_i^{A,k} - \mu_i^A)(\mathcal{R}_j^{B,k} - \mu_j^B)}{\sigma_i^A \cdot \sigma_j^B}$$

where C_{ij}^{AB} is the element (i,j) of the statistical correlation matrix among spectra A and B, μ_i^A and σ_i^A are the mean and the standard deviation between the replicas in the i-th bin of spectrum A, respectively, and $\mathcal{R}_i^{A,k}$ is the content of the i-th bin of the k-th replica for spectrum A. The number of replicas has been set to $\mathcal{N}$ =100k.

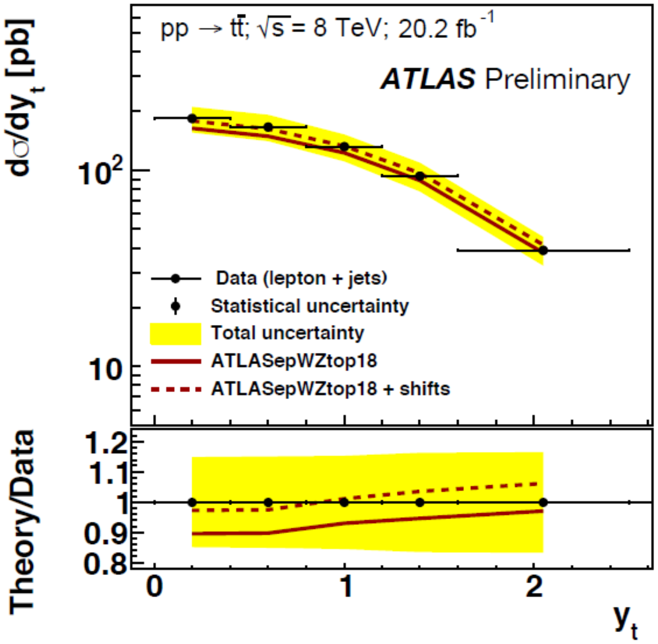
First consider the effect of the bin to bin statistical correlations

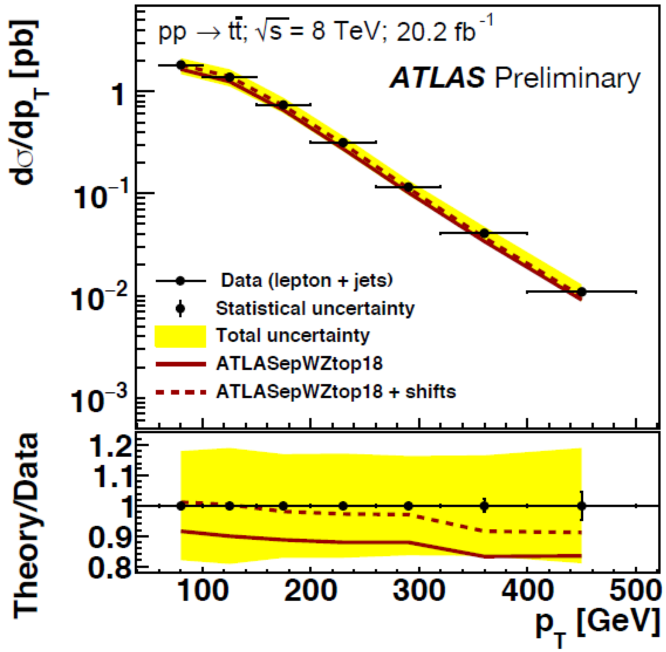
Compare a fit to the p_T^t spectrum with and without statistical correlations

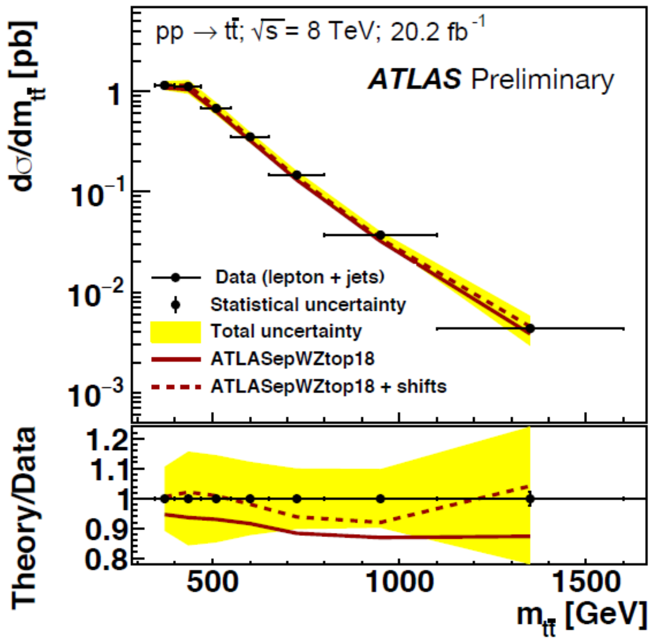
Small but significant difference

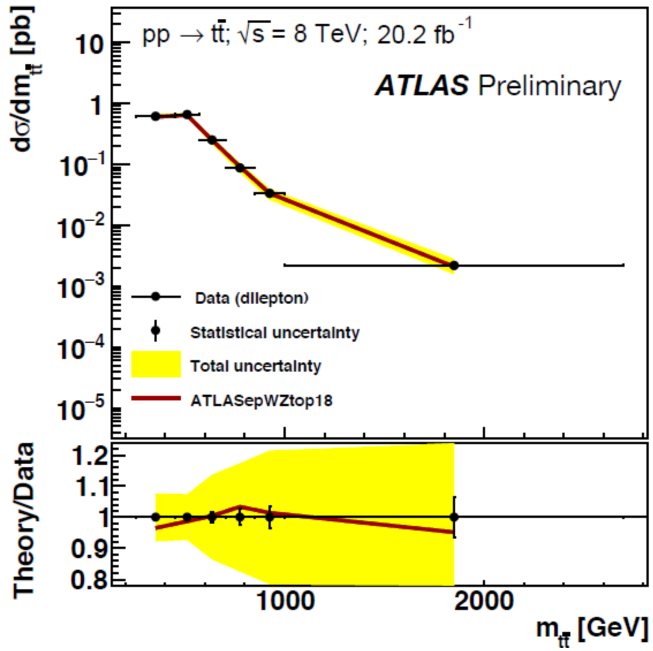


Using the statistical correlations gives a somewhat harder gluon and a larger decrease in the uncertainty of the gluon at high-x









This one is not in the fit but is well described

Fitting normalised spectra

When fitting spectra separately these give similar result to fitting the absolute—and are somewhat less constraining

But the situation wrt correlations could be different -in fact in this case it is the hard scattering model which is the most significant systematic. We consider decorrelation of this systematic.

There is a different Table of statistical correlations for the normalised spectra AND when fitting we remove one data point per spectrum (in practice the last one which is least well determined) to allow for the common normalisation.

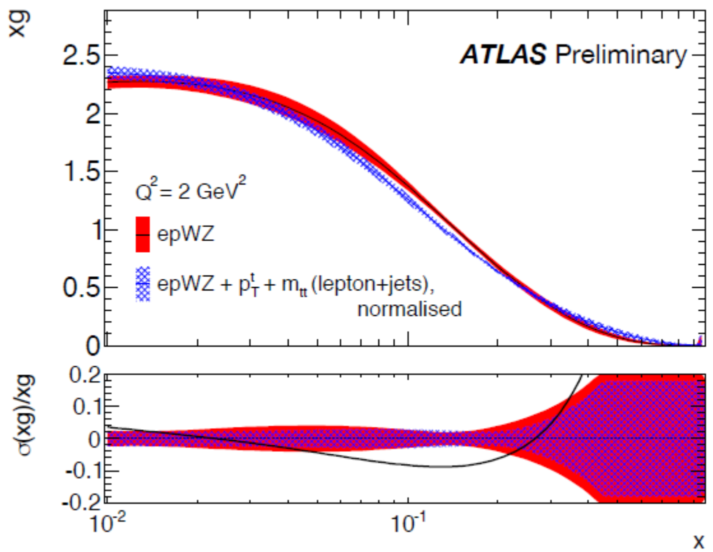
Despite the differing pattern of systematics the results are similar to those found when fitting absolute spectra.

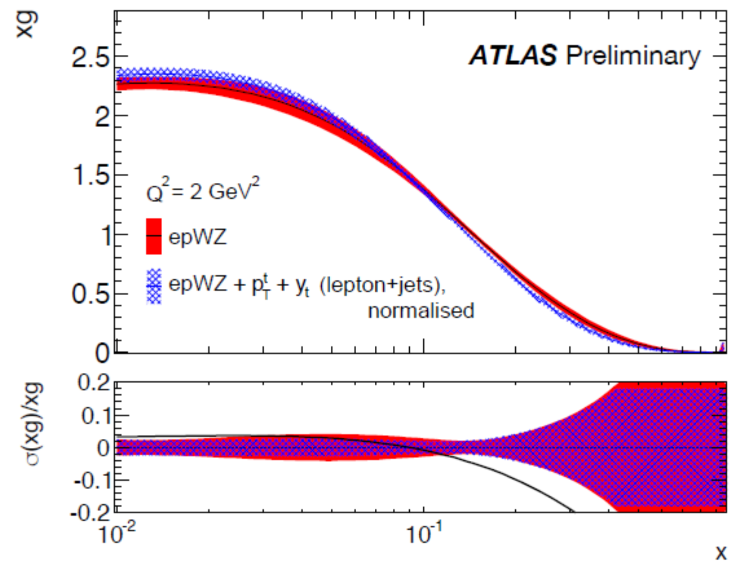
Fits to yt+pt are poor and soften the gluon

Fits to mtt+pt are poor, if all systematics are fully correlated, and harden the gluon

Fits to mtt+pt are good, if the hard scattering systematic is decorrelated between the spectra, and harden the gluon, with a similar shape to that of the correlated case.

		normalised lepton+jets spectra			
		p_T^t and y_t correlated hard-scattering systematics	p_T^t and y_t decorrelated hard-scattering systematics	p_T^t and m_{tt} correlated hard-scattering systematics	p_T^t and m_{tt} decorrelated hard-scattering systematics
Total χ^2/NDF		1262 / 1066	1260 / 1066	1259 / 1068	1247 / 1068
Partial χ^2/NDP	HERA	1147 / 1016	1146 / 1016	1154 / 1016	1152 / 1016
Partial χ^2/NDP	ATLAS $W, Z/\gamma^*$	83.3 / 55	83.2 / 55	82.0 / 55	81.9 / 55
Partial χ^2/NDP	ATLAS $t\bar{t}$	31.2 / 11	30.5 / 11	23.5 / 13	13.1 / 13





The results with decorrelation of the hard scattering systematic between spectra