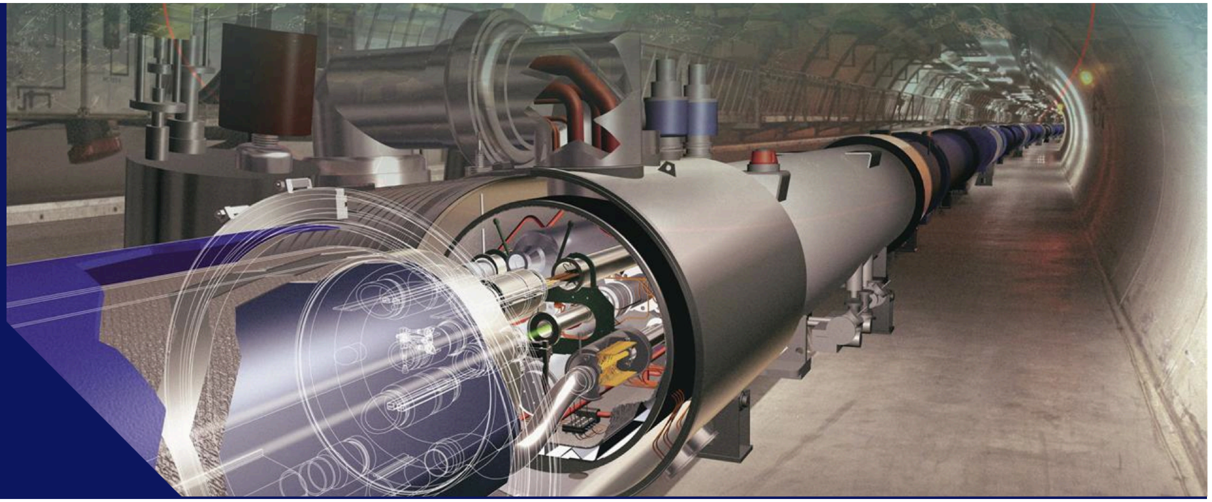
QCD@LHC 2019
Buffalo, New York
15 – 19 July 2019



Determination of proton parton distribution functions using ATLAS data

Claire Gwenlan, Oxford

on behalf of the ATLAS collaboration

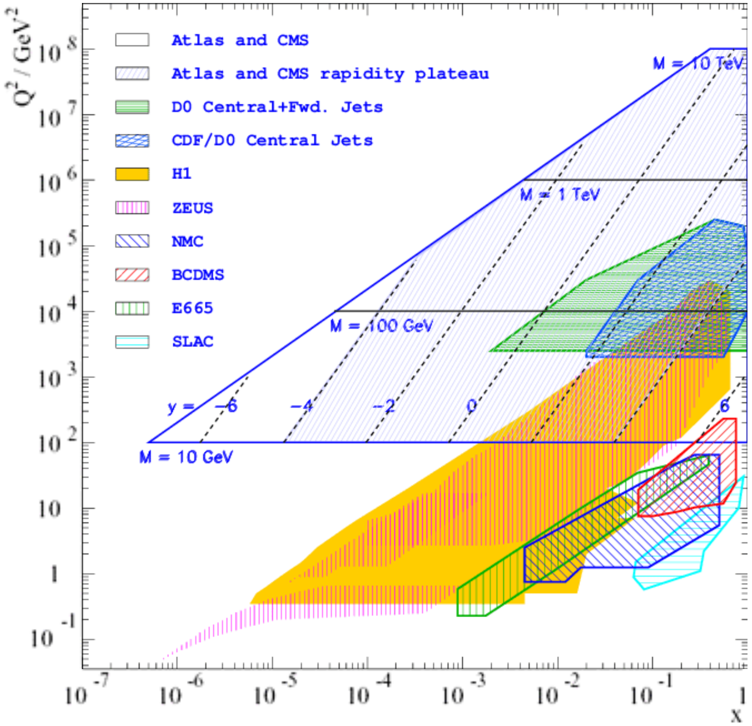
LHC and proton pdfs

the LHC has unprecedented kinematic coverage

wealth of SM measurements from ATLAS,
sensitive to proton structure (pdfs)

this talk, pdf constraints from ATLAS:

- W,Z inclusive (a reminder of ATLASepWZ16)
- **W+Jets** (ATL-PHYS-PUB-2019-016)
- **top quark pairs** (ATL-PHYS-PUB-2018-017)



FACTORISATION THEOREM:

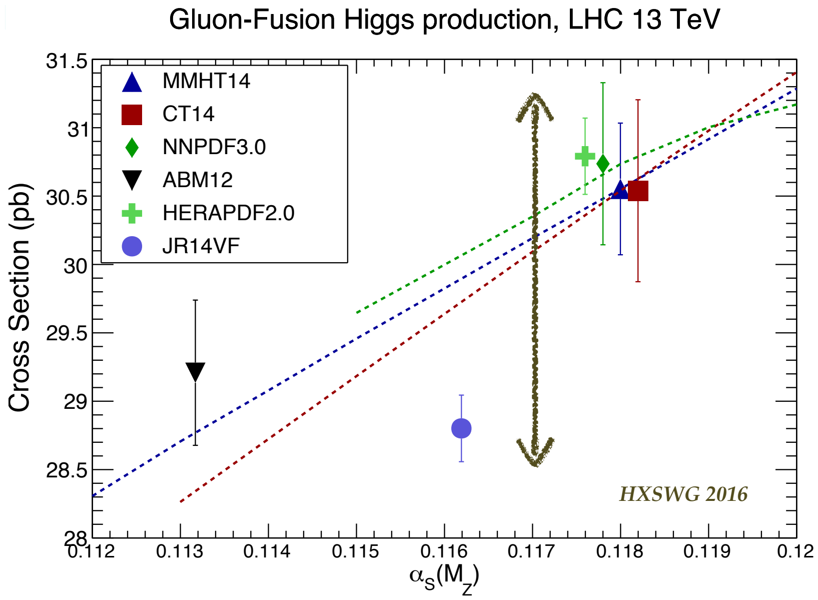
$$d\sigma_X = \sum_{i,j} \int dx_1 \int dx_2 \boxed{f_i(x_1,\mu_F^2) f_j(x_2,\mu_F^2)} \times \boxed{\hat{\sigma}_{ij\to X}(x_1,x_2,\mu_R^2)}$$

pdfs

hard subprocess
(calculable in pQCD)

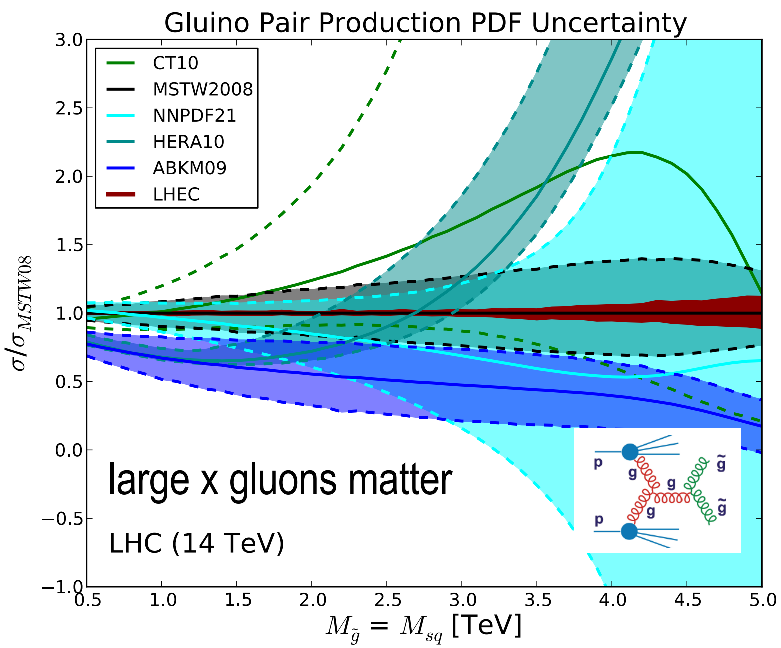
(extraction of precision **pdfs** requires both precise data, and precise theory calculations)

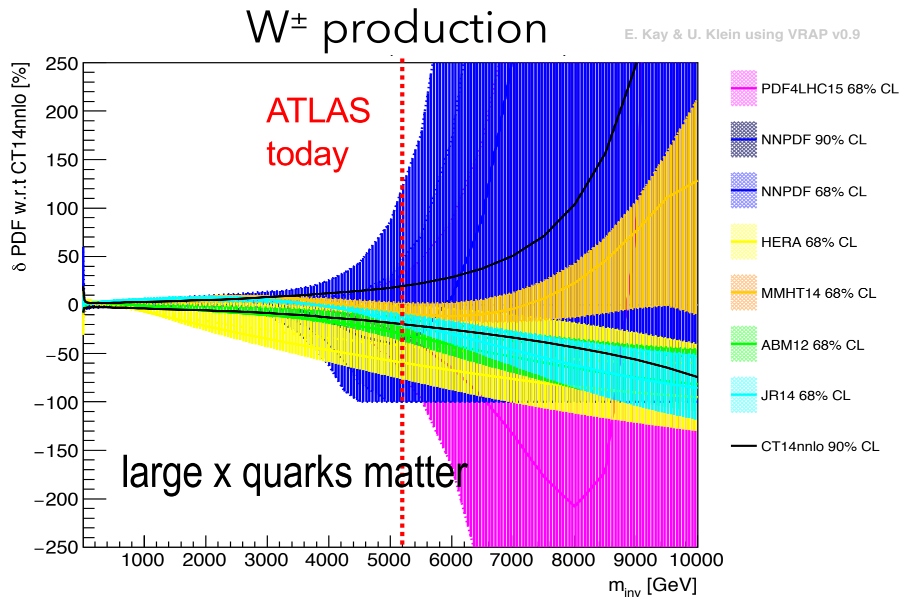
proton pdfs – why do they matter?



ATLAS, EPJ C78 (2018) 110

Channel	$m_{W^+} - m_{W^-}$ [MeV]	Stat. Unc.	Muon Unc.	Elec. Unc.	Recoil Unc.	Bckg. Unc.	QCD Unc.	EW Unc.	PDF Unc.	Total Unc.
$W \to e\nu$	−29.7	17.5	0.0	4.9	0.9	5.4	0.5	0.0	24.1	30.7
$W \to \mu\nu$	−28.6	16.3	11.7	0.0	1.1	5.0	0.4	0.0	26.0	33.2
Combined	−29.2	12.8	3.3	4.1	1.0	4.5	0.4	0.0	23.9	28.0





Mw

Higgs

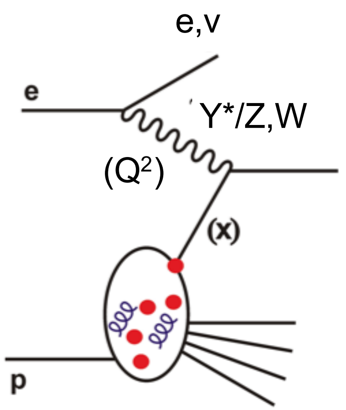
BSM

…

crucial for **SM** and **BSM** physics at hadron colliders

(**other questions:** validity of factorisation in pp, intrinsic charm/beauty in proton, small x dynamics, …)

pdf information from HERA



o Kinematic variables:

$Q^2 = -q^2 = -(k - k')^2$ Virtuality of the exchanged boson

$x = \frac{Q^2}{2p \cdot q}$ Bjorken scaling parameter

$y = \frac{p \cdot q}{p \cdot k}$ Inelasticity parameter

$s = (k + p)^2 = \frac{Q^2}{xy}$ Invariant c.o.m.

Neutral Current:

LO expressions

$$\frac{d^2\sigma^{\pm}_{NC}}{dx dQ^2} = \frac{2\alpha\pi^2}{xQ^4}\left(Y_+ F_2 \mp Y_- xF_3 - y^2 F_L\right)$$

$F_2 \sim \sum_i e_i^2 (xq_i + x\bar{q}_i)$ $\quad xF_3 \sim \sum_i (xq_i - x\bar{q}_i)$ $\quad F_L \sim \alpha_s \times g$

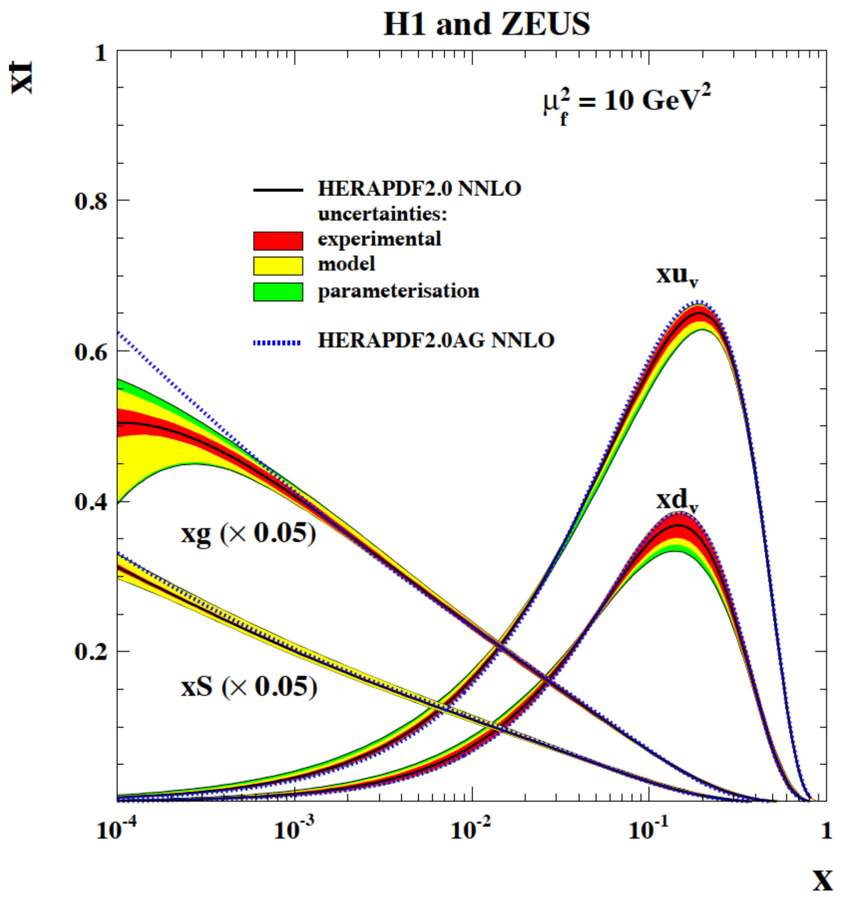
quarks pdfs — valence quarks — gluon via $\mathcal{O}(\alpha s)$

Charged Current:

$$\frac{d^2\sigma^{-}_{CC}}{dx dQ^2} = \frac{G_F^2}{2\pi}\frac{M_W^2}{M_W^2 + Q^2}\left(u + c + (1 - y^2)(\bar{d} + \bar{s})\right)$$

$$\frac{d^2\sigma^{+}_{CC}}{dx dQ^2} = \frac{G_F^2}{2\pi}\frac{M_W^2}{M_W^2 + Q^2}\left(\bar{u} + \bar{c} + (1 - y^2)(d + s)\right)$$

flavour decomposition

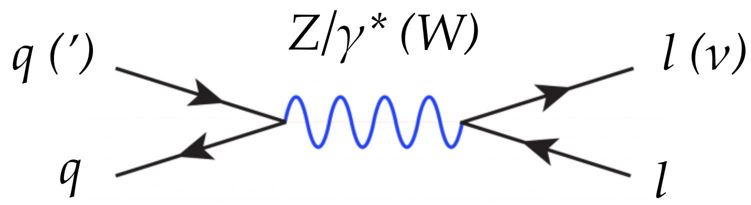


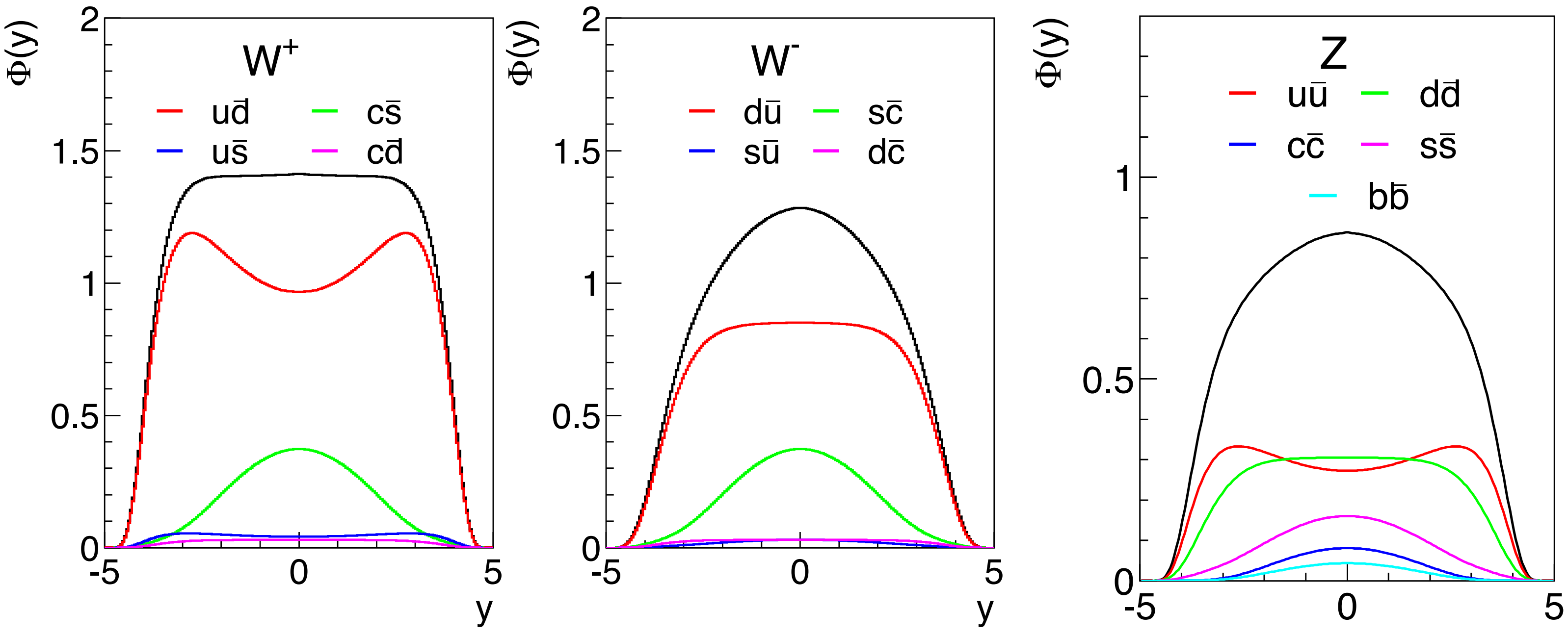
HERA is the single most important dataset in any pdf fit; used as baseline

NB, HERA inclusive NC,CC data do not measure **d**, **s** (or u, c) independently, but only their sum

ATLAS inclusive W, Z

- sensitivity to light quarks (u, d, s)
- different quark combinations contribute to each process; **flavour separation**





plots by S. Glazov, V. Radescu

experimentally very precise; state-of-the-art theory available (NNLO QCD + NLO EW)

(accurate modelling of contribution from second-generation quarks essential for precision physics)

a strange story

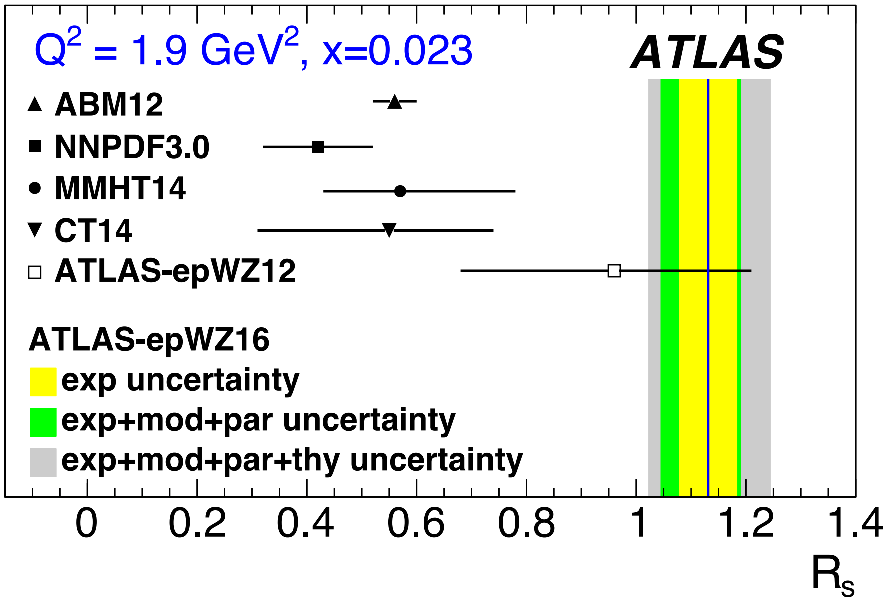
NNLO QCD analysis (following HERAPDF ansatz; xFitter framework) EPJ C77 (2017) 367

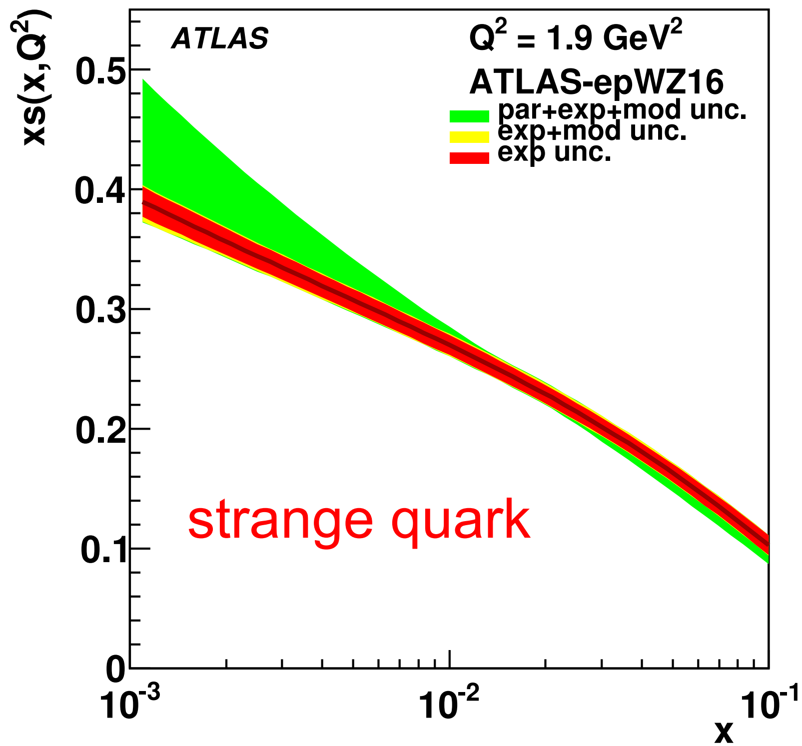
HERA I+II plus ATLAS (4.6 pb^{-1}) W$^{\pm}$ |η_l|, Z |y_{ll}|
(3 m$_{ll}$ central, 2 m$_{ll}$ forward)

NLO (MCFM interfaced to APPLGRID) plus k-factors, NNLO QCD (DYNNLO) + NLO EW (MCSANC)

→ ATLASepWZ16 pdf (available on LHAPDF)

$$R_s(x,Q^2) = \frac{s(x,Q^2)+\bar{s}(x,Q^2)}{\bar{u}(x,Q^2)+\bar{d}(x,Q^2)} \begin{cases} \approx 0.5 \text{ (from neutrino)} \\ \approx 1.0 \text{ (from ATLAS W,Z)} \end{cases}$$





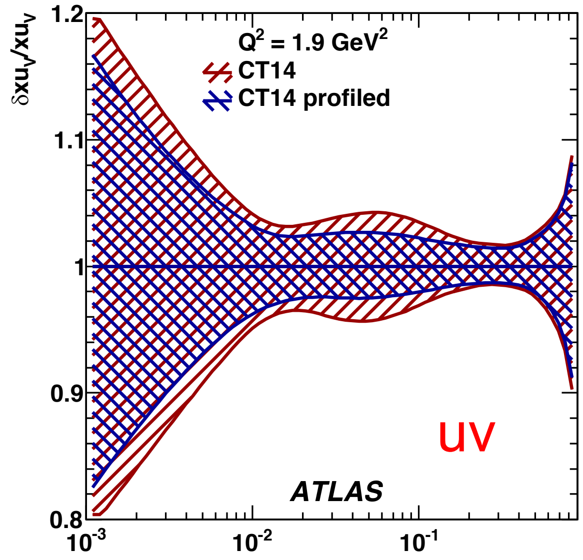
consistent with previous ATLAS results

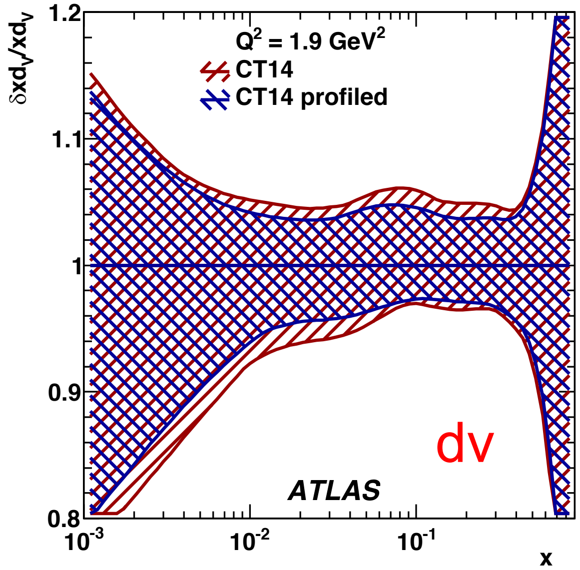
PRL 109 (2012) 012001 (W,Z inclusive, 36 pb^{-1})

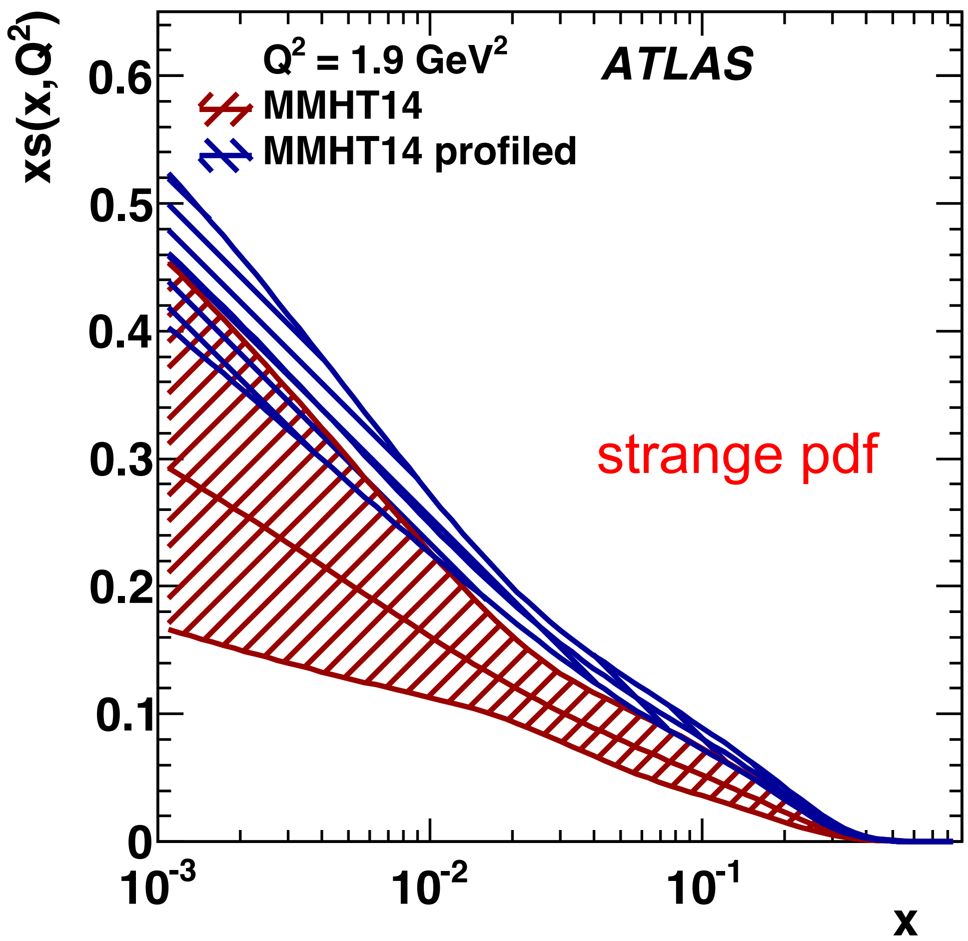
JHEP05 (2014) 068 (W+c analysis)

impact on modern global pdfs

EPJ C77 (2017) 367







- profiling exercise to study impact of ATLAS inclusive W,Z (4.6 pb^{-1}) differential cross sections on global pdf fits

improved valence; enhanced strange, consistent with ATLAS QCD fit

new ATLAS QCD fits

Regge theory inspired

f(1)=0

$$xf(x) = Ax^B(1-x)^C(1+Dx+Ex^2)e^{Fx}$$

(extra negative term for gluon $-A'_g x^{B'_g}(1-x)^{C'_g}$)

NNLO QCD pdfs using xFitter; theory calculations for LHC measurements interfaced to APPLGRID or fastNLO

constraints from: sum rules;

ubar=dbar as x→0; s=sbar;

Cg'=25; D,E,F only if χ^2 favours

xuv, xdv, xubar, xdbar, xsbar, xg

16 parameter central fit

Model: mc,b; start scale; Q^2 cut off

Parameter: extra D,E,F; relaxed assumptions

new ATLAS QCD fits

Regge theory inspired

f(1)=0

$$xf(x) = Ax^B(1-x)^C(1+Dx+Ex^2)e^{Fx}$$

(extra negative term for gluon $-A'_g x^{B'_g}(1-x)^{C'_g}$)

constraints from: sum rules;

ubar=dbar as x→0; s=sbar;

Cg'=25; D,E,F only if **Χ**² favours

xuv, xdv, xubar, xdbar, xsbar, xg

16 parameter central fit

Model: mc,b; start scale; Q² cut off

Parameter: extra D,E,F; relaxed assumptions

NNLO QCD pdfs using xFitter; theory calculations for LHC measurements interfaced to APPLGRID or fastNLO

start point: **ATLASepWZ16**, with following changes or improvements:

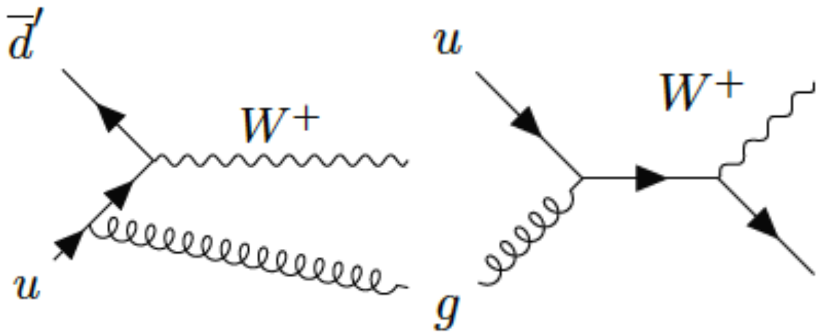
1. **Q² cut off: 7.5 ⟶ 10 GeV² ;** avoid small x resummation effects (arXiv:1506.06042, 1710.05935)
2. $x\bar{u} = A_{\bar{u}} x^{B_{\bar{u}}}(1-x)^{C_{\bar{u}}}(1+\boldsymbol{D_{\bar{u}}x})$ **; 1 extra free parameter**; plus more parameter variations as part of systematics
3. **W+Jets fits**: e and μ channels used **uncombined** for W,Z inclusive; more simply relates original sources of systematic uncertainty to aid full correlation with corresponding sources from W+Jets

not a general recommendation!

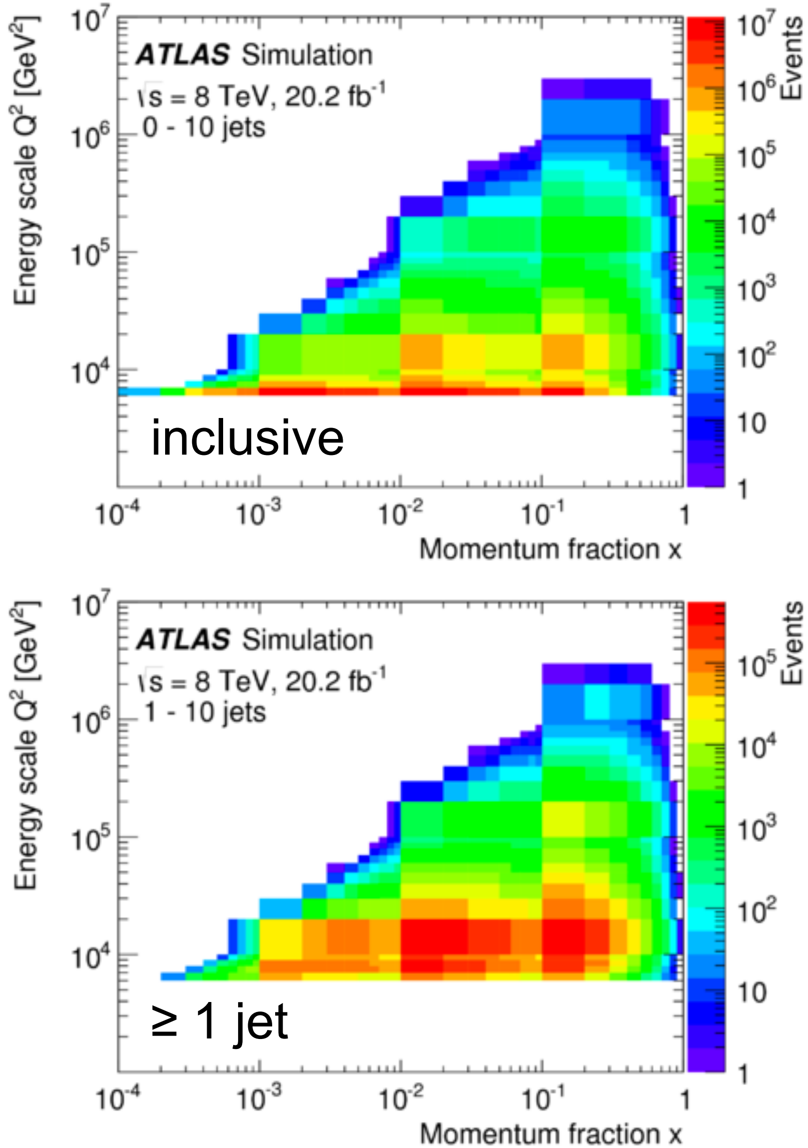
importance of W+Jets

jet requirement increases sensitivity at higher x and Q^2 cf. inclusive

gluon contributes already at lowest order



[JHEP 05 (2018) 077](#)



ATLAS NNLO QCD analysis:

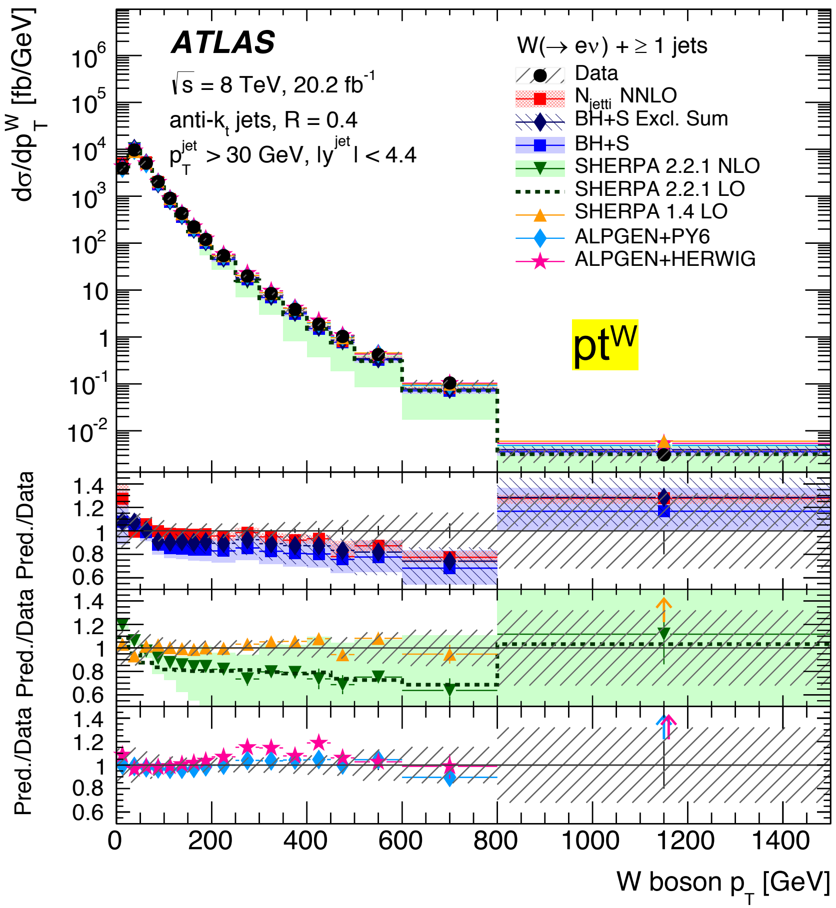
HERA I+II + ATLAS W,Z + **ATLAS W+Jet differential cross sections @ 8TeV**

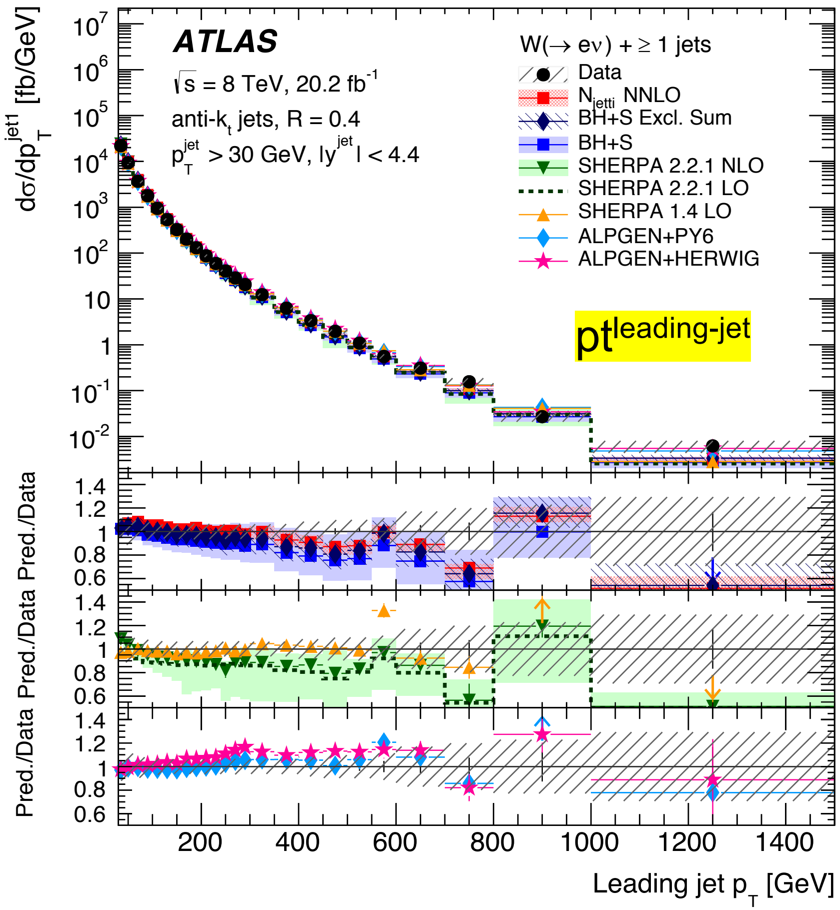
NLO (MCFM interfaced to APPLGRID) plus k-factors from NJETTI

ATLASepWZWjet19: ATL-PHYS-PUB-2019-016

ATLAS W+Jet cross sections @ 8 TeV

JHEP 05 (2018) 077

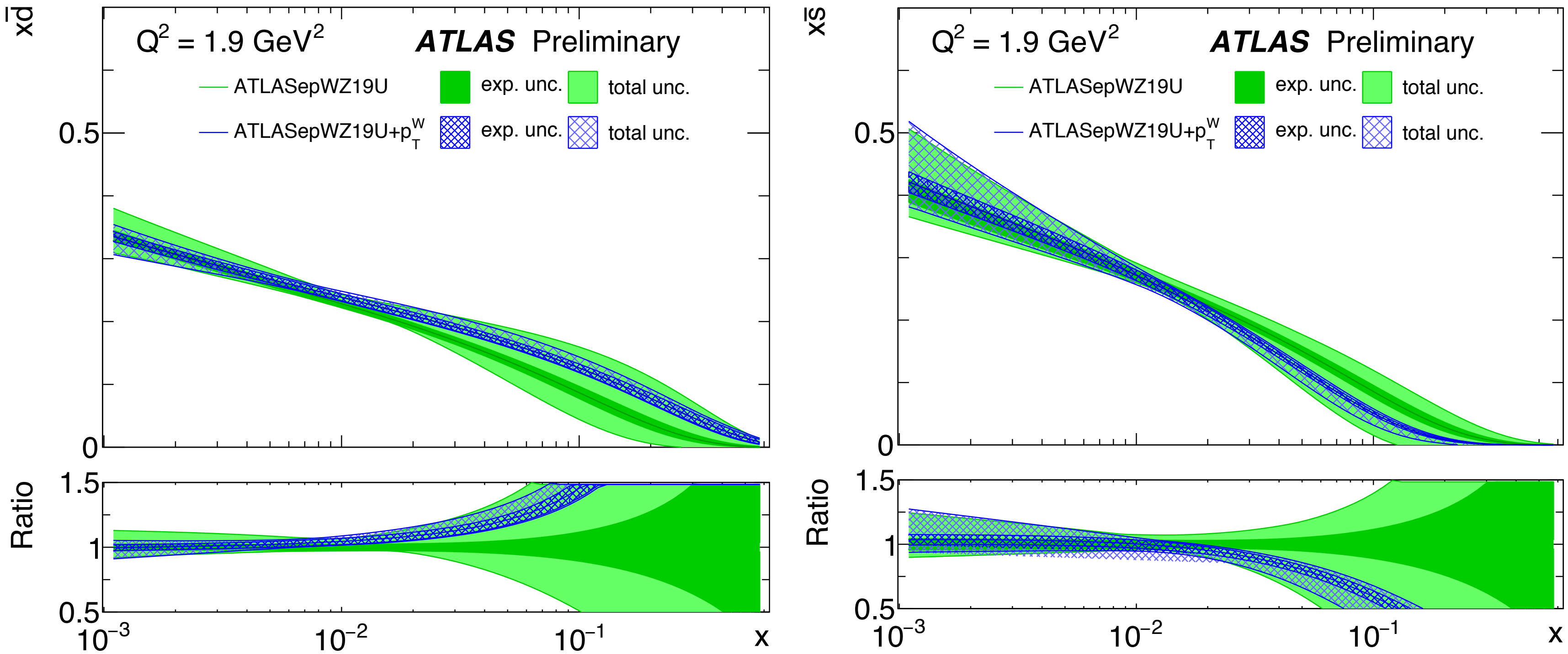




W→ev channel; multiple distributions available (**pt^W**, $pt^{leading\text{-}jet}$ used in the current fits)

statistical correlations between different spectra not available ⇝ fit only single distributions

ATLAS pdf fits with W+Jets

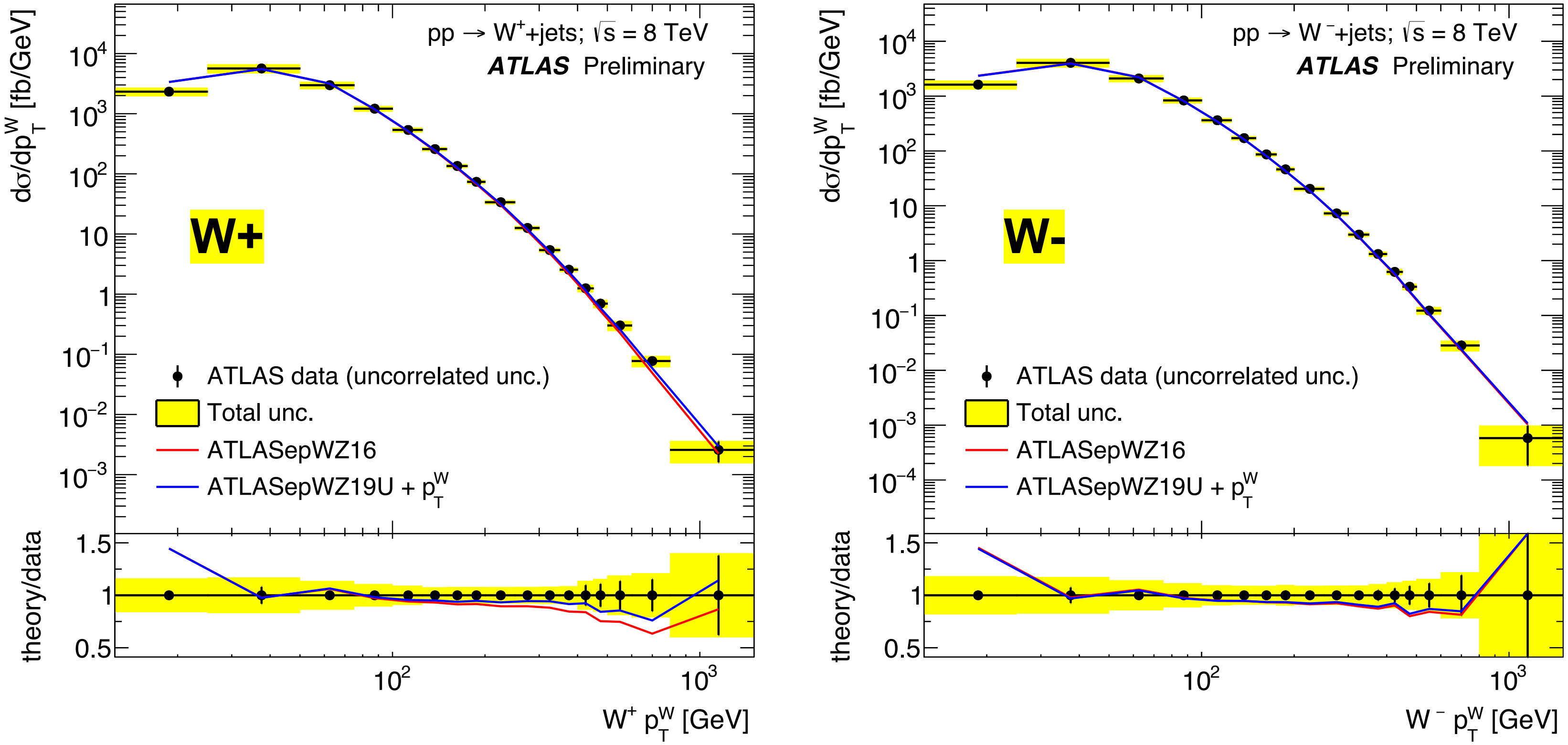


main impact on d and s sea quark distributions; other pdfs not significantly affected

- changes compensate each other (sum of dbar+sbar tightly constrained by HERA)
- total uncertainty constrained

† **U** in legend indicates use of uncombined e and μ channels cf. **C** for combined (comparisons in extras)

comparison of fits with W+Jet data



high pt^W ⇔ high x

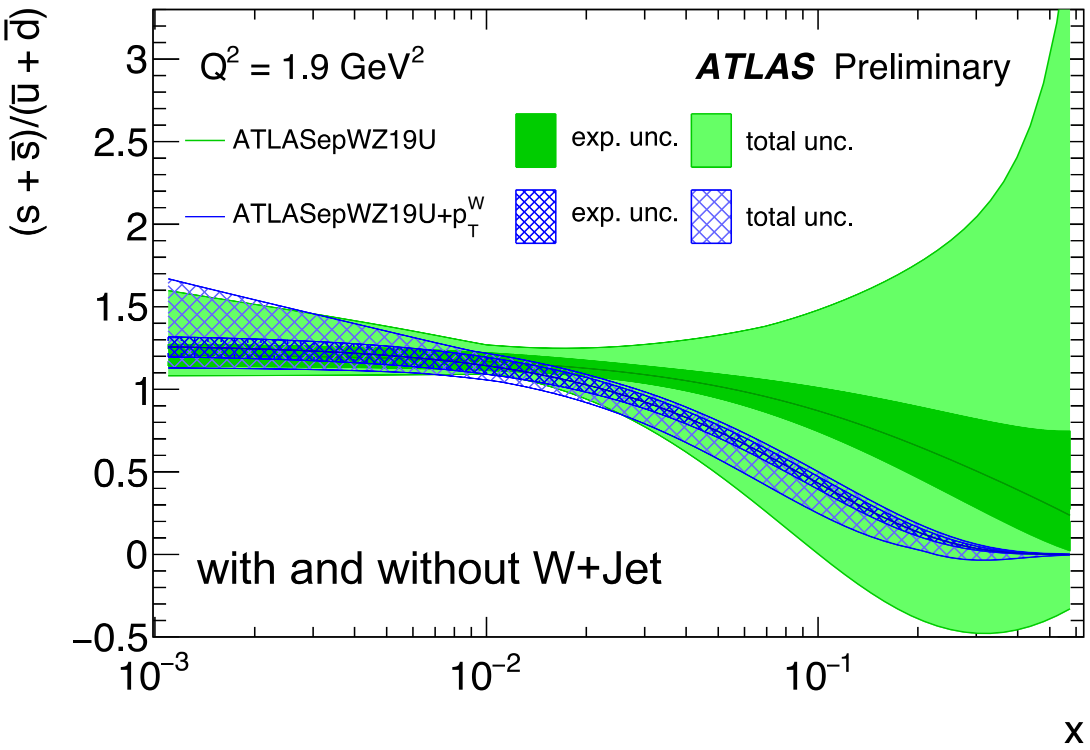
large change in W+ spectrum, not so much in W-

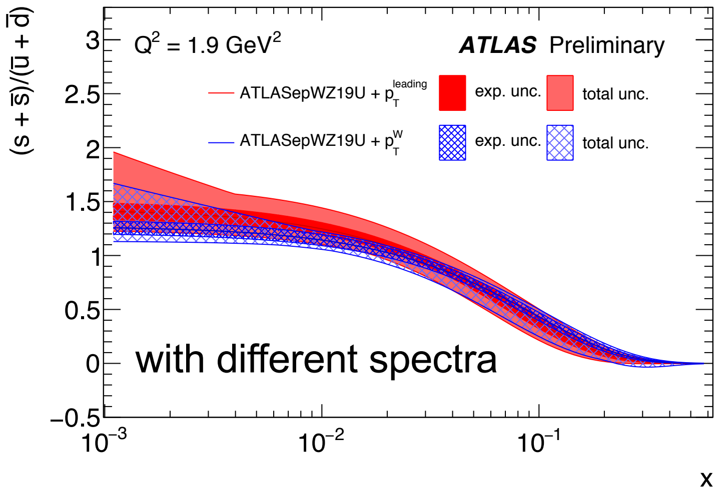
W+ from uv-dbar or uv-sbar combination

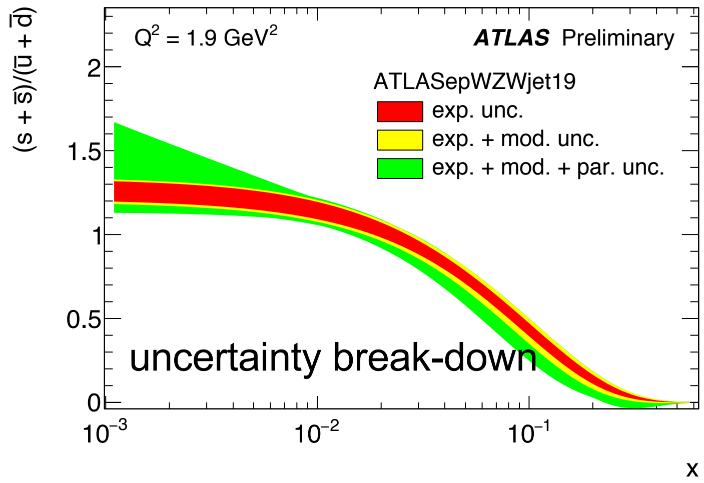
$\sigma \sim (0.97\bar{d} + 0.23\bar{s})^2$ with dbar+sbar well constrained from HERA

⇒ higher cross section from reduced sbar and higher dbar

more on the strange density



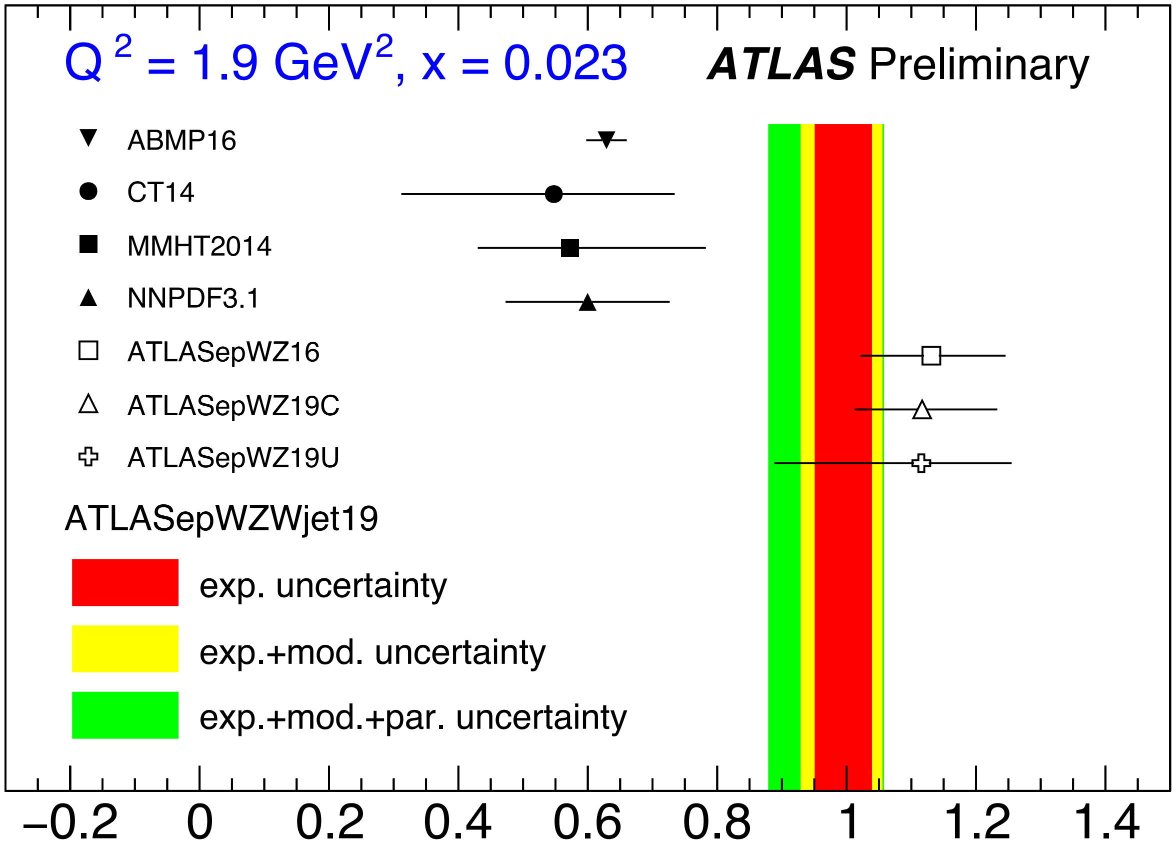




still consistent with enhanced strange at low x, as per previous ATLAS results

consistent picture from use of different spectra

more on the strange density

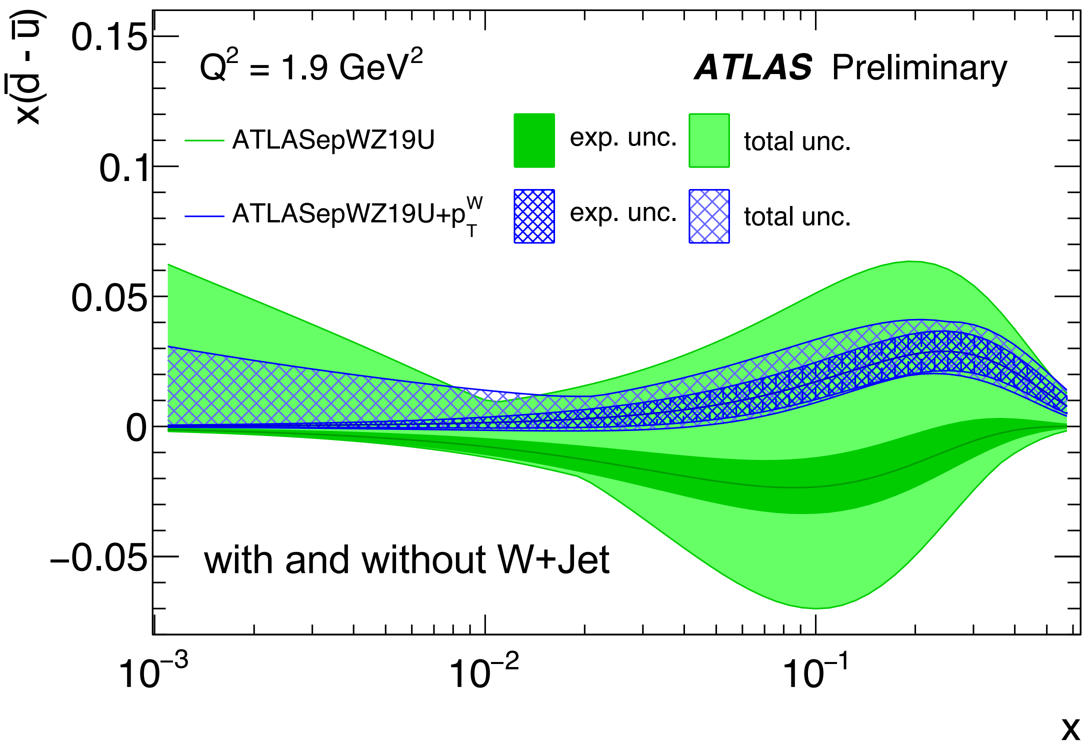


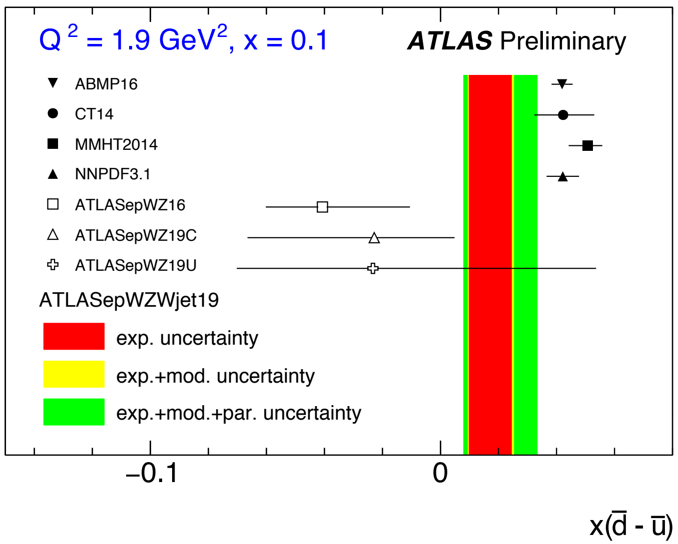
$$R_s = \frac{s + \bar{s}}{\bar{u} + \bar{d}}$$

consistent with previous ATLAS fits

slightly higher than current global pdfs

dbar – ubar





dbar – ubar now positive

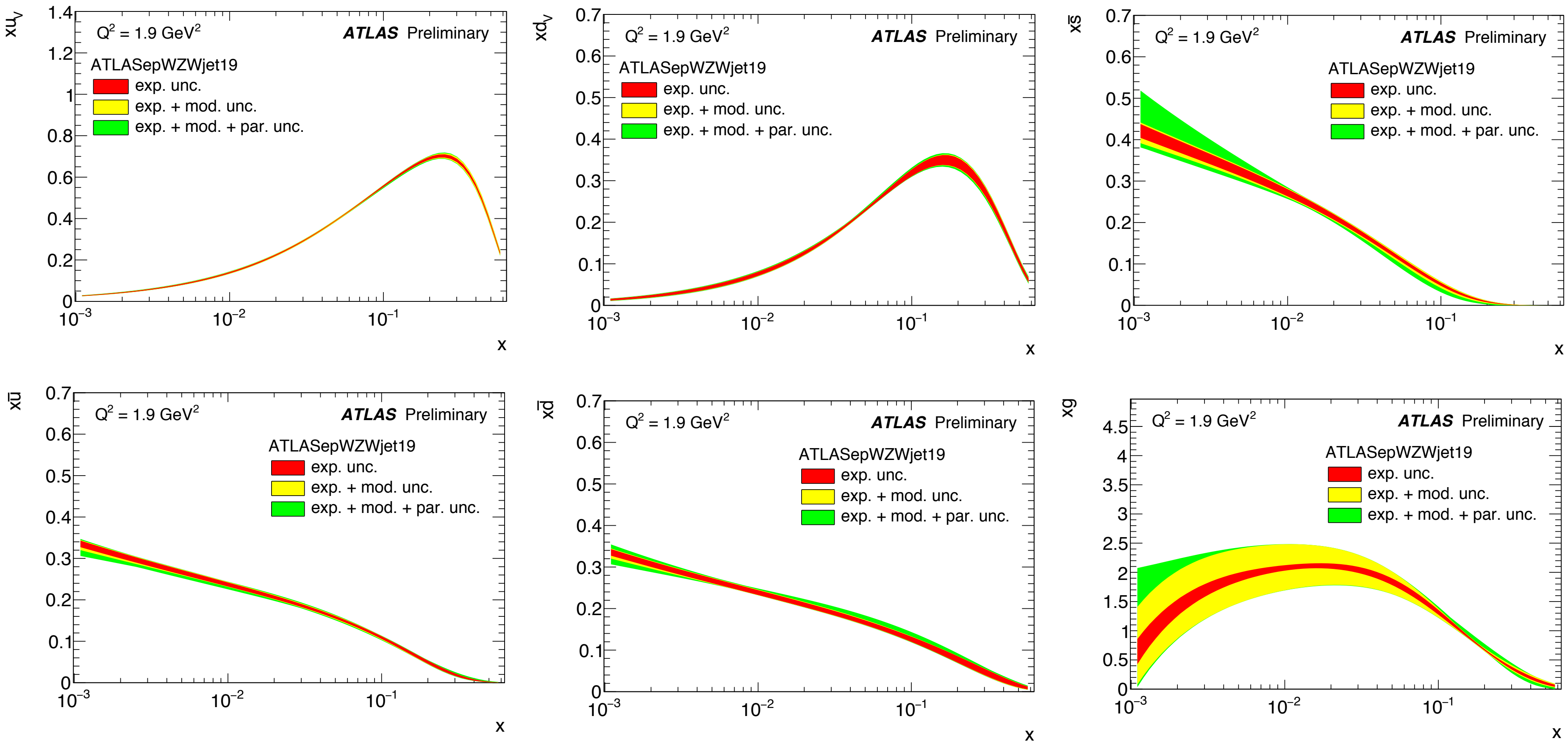
both experimental and additional uncertainties constrained

consistent with previous ATLAS fits

and more in line with global fits

while still retaining enhanced strange at low x

summary of ATLAS pdfs with W+Jets



ATLASepWZWjet19 pdf: HERA I+II + ATLAS W,Z + ATLAS W+Jet (ptW)

pdf set publicly available, at: [ATL-PHYS-PUB-2019-016]()

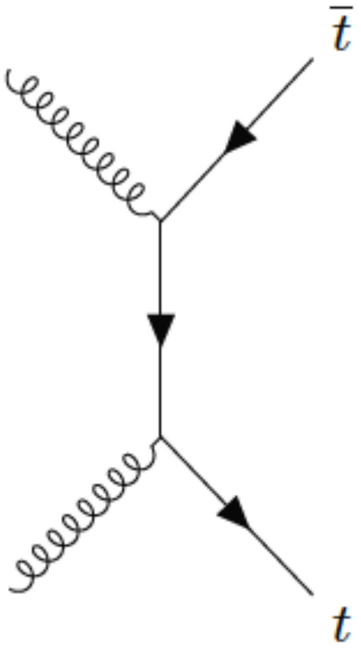
ATLAS fits to ttbar differential cross sections

ATLAS NNLO QCD analysis: ATL-PHYS-PUB-2018-017

HERA I+II + ATLAS W,Z +

ATLAS ttbar differential cross sections in lepton+jet (lj) and di-lepton (ll) final states @ 8TeV

ttbar: directly sensitive to gluon pdf



lj: multiple spectra considered **simultaneously**, taking into account statistical+syst. correlations

(**statistial correlations for lj**, within and between spectra, **made available in HEPDATA** (1404878); in addition to systematic correlations for all lj+ll spectra)

NNLO QCD calc.: PRL 116 (2016), 082003; JHEP04 (2017) 071

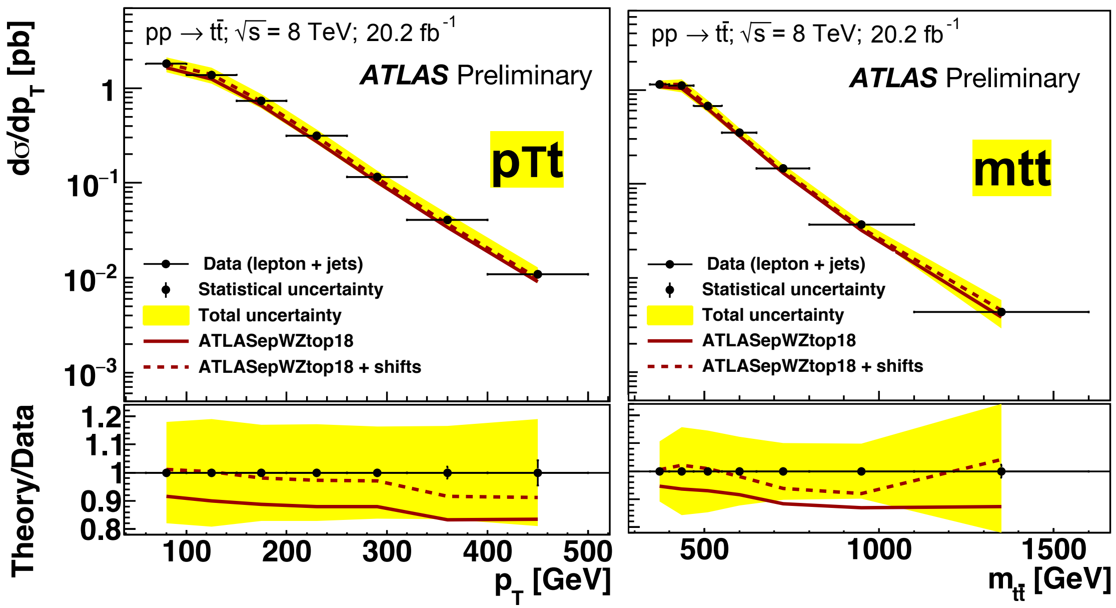
lj: NNLO QCD interfaced to fastNLO (arXiv:1704.08551)

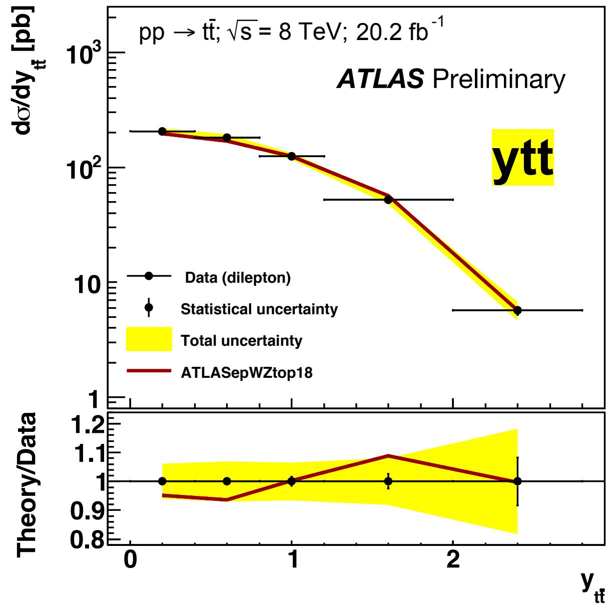
ll: NLO (MCFM interfaced to APPLGRID), plus k-factors from JHEP04 (2017) 071

ATLAS ttbar differential cross sections @ 8TeV

lj spectra: mtt, ytt, pTt, yt

ll spectra: mtt, ytt



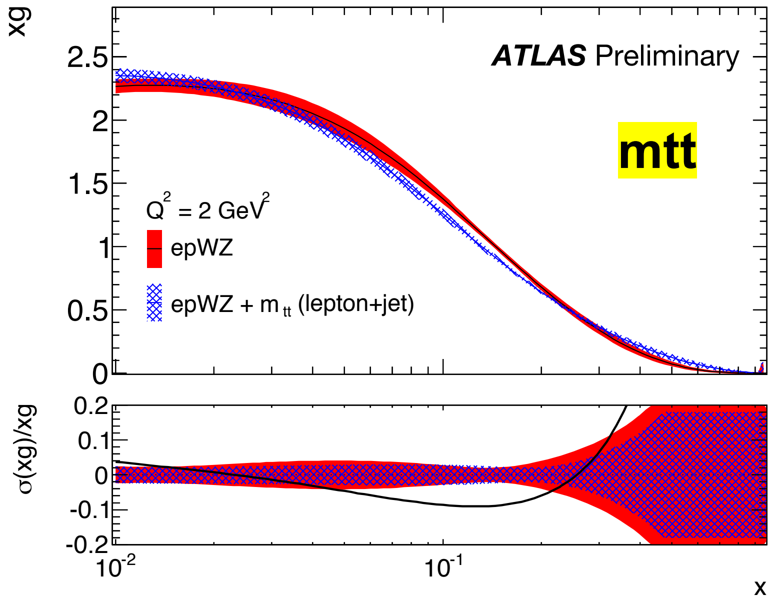


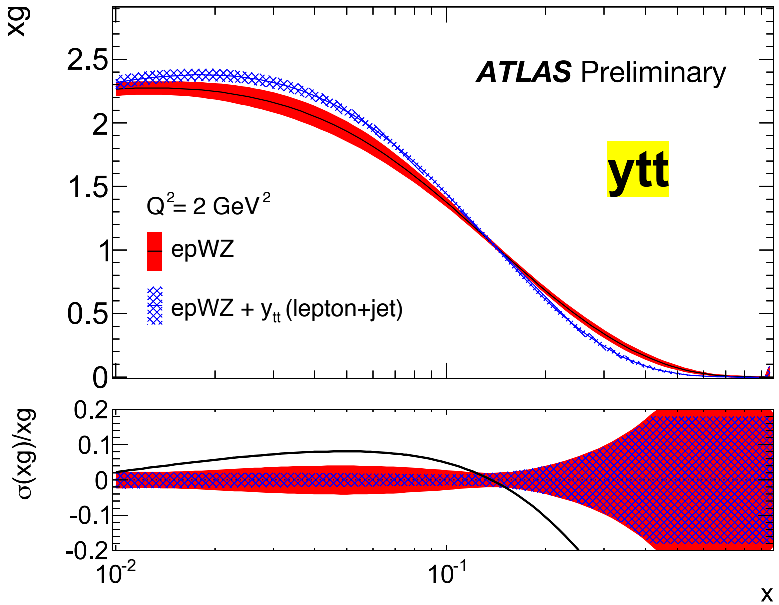
ATLAS ttbar cross sections in lepton+jet (lj) and di-lepton (ll) final states

ATLAS measurements: EPJ C76 (2016) 538 (lj) and Phys Rev D94 (2016) 092003 (ll)

multiple studies, fitting spectra individually and in combination

ATLAS fits with individual ttbar spectra





mtt, pTt prefer harder gluon

ytt, yt prefer softer gluon; **BUT poor X^2** for **lj**

more flexible parameterisation not found to help

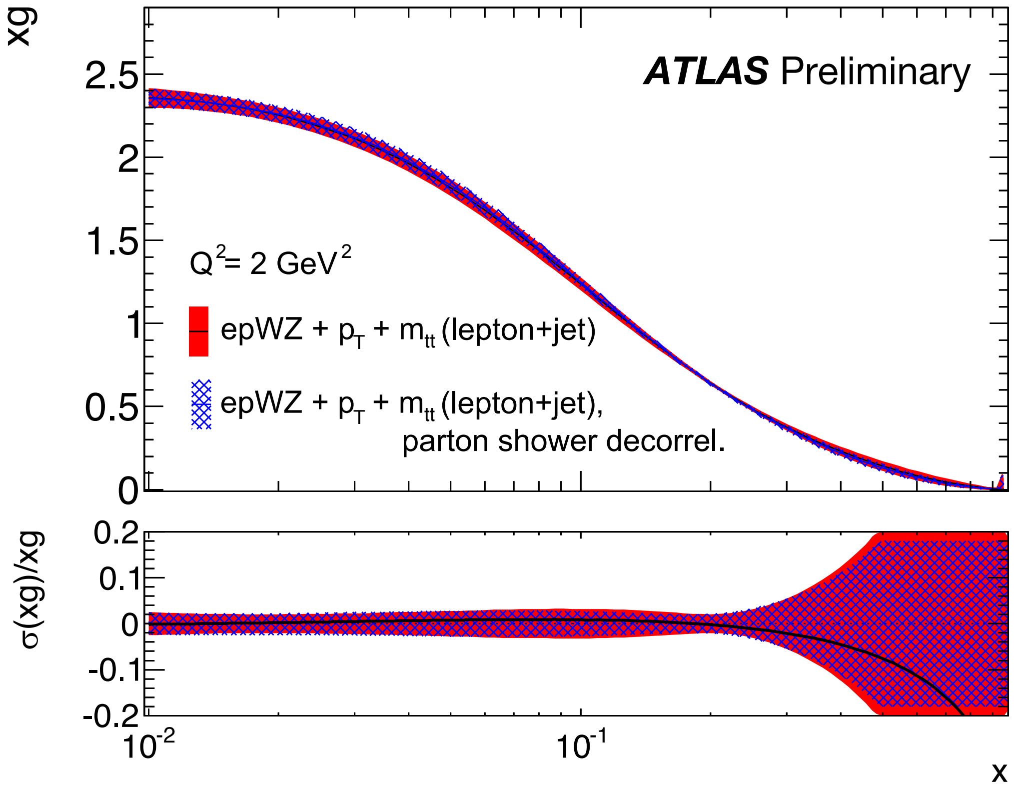
lj	mtt	pTt	ytt	yt
partial X^2/NDP	3.4/7	7.9/8	19.7/5	18.3/5

ll	mtt	ytt
partial X^2/NDP	2.6/6	4.5/5

(**ll: mtt** vs **ytt** yield same trends in gluon shape as **lj**, but can both be well fitted)

impact of including bin-to-bin statistical correlations is small (included here throughout)

simultaneous fits to more than one lj spectrum



X^2 poor for lj mtt+pTt;
though good fits for each spectrum individually, and with compatible trends for gluon pdf

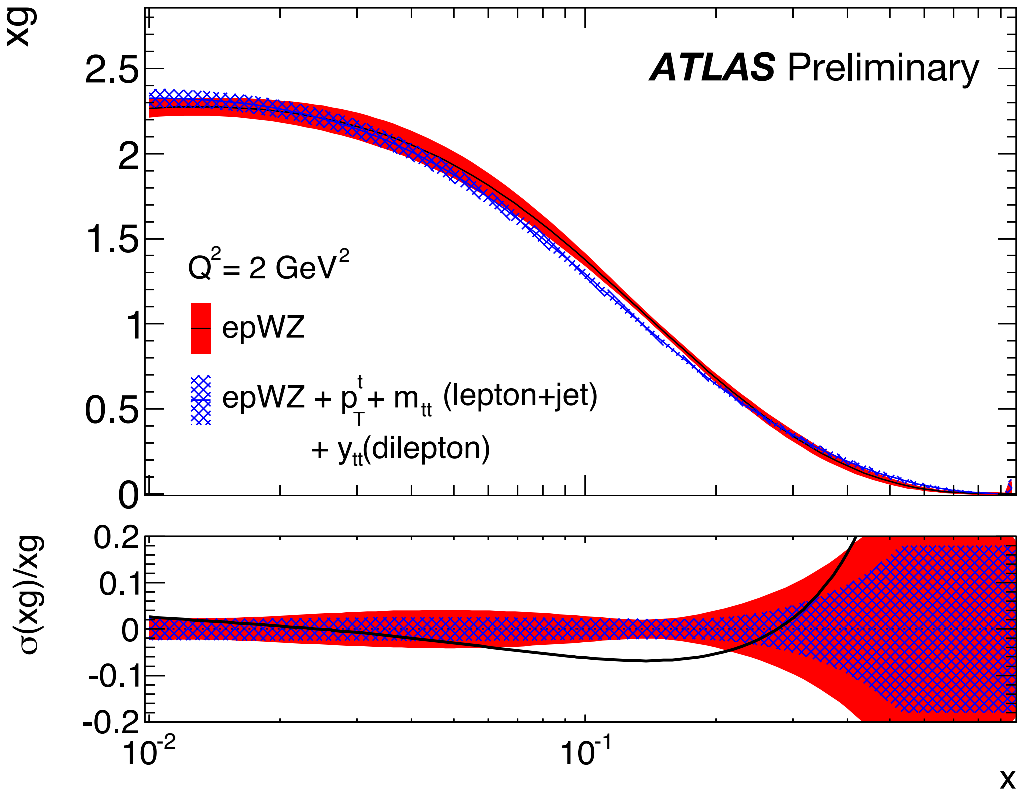
fit quality sensitive to treatment of two-point systematics (those evaluated from difference between two MCs),
especially parton shower model

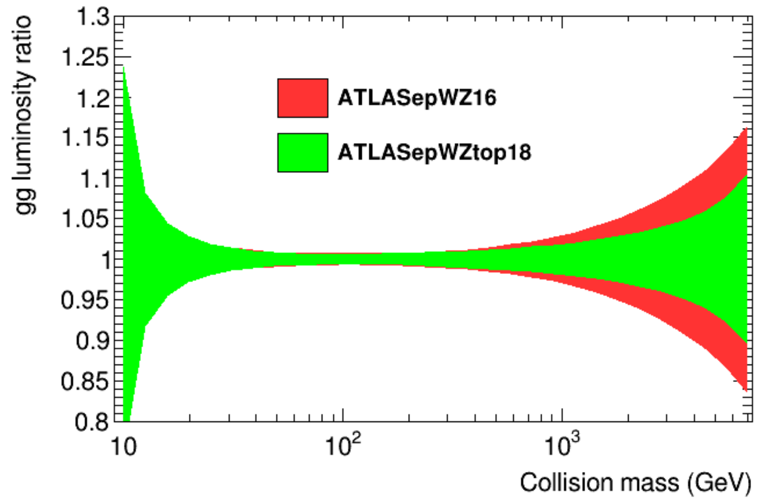
impact on fit quality only; NO significant impact on extracted pdfs

lj pTt+mtt	full syst. corrs.	two-point decorr.	PS only decorr.
partial X^2/NDP	45.0/15	11.5/15	14.1/15

(X^2 poor for any fits with **lj ytt** or **yt**; cannot be resolved by decorrelating two-point systematics)

ATLAS fits to ttbar lj and ll spectra





final choice of ttbar spectra:

mtt+pTt (lj) + ytt (ll)

impact on fit is a **harder gluon** with significant **additional constraint at high x**

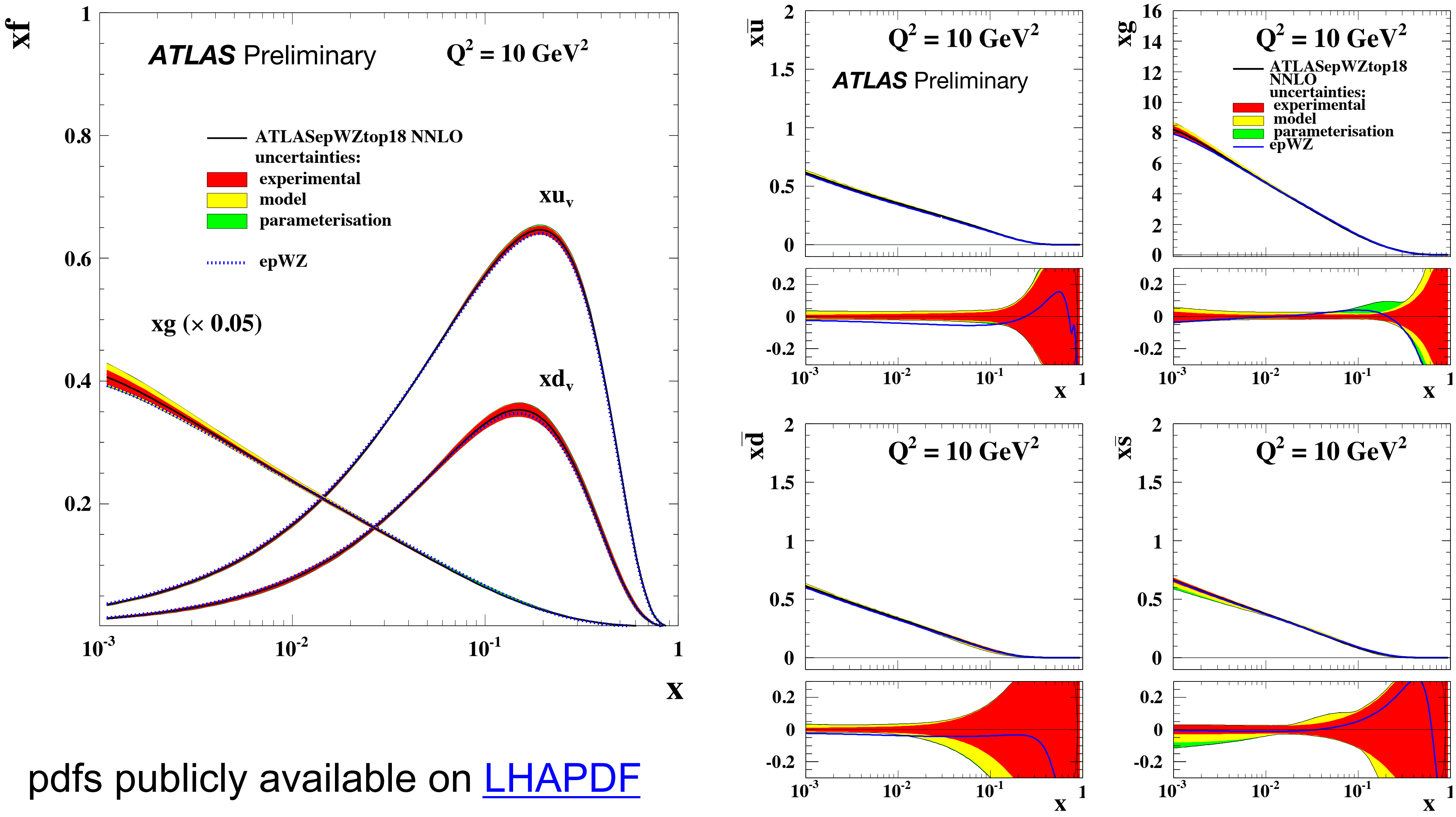
ATLAS ttbar	lj pTt+mtt	ll ytt
partial χ^2/NDP	16.0/15	5.4/5

(PS decorrelated between **lj** spectra)

NO tension with HERA and ATLAS inclusive W,Z

summary of ATLAS pdfs with ttbar

ATLASepWZtop18 pdf: HERA I+II + ATLAS W,Z + ATLAS ttbar (mtt + pTt (lj) + ytt (ll))



pdfs publicly available on LHAPDF

summary

ATLAS has extensive and growing portfolio of **pdf-sensitive** measurements

only a tiny subset presented here;

others include LM/HM DY; W+c; QCD jets; many more top measurements; Z+Jets; direct **γ**; … including measurements at **different CM energies**, and **ratio measurements** with partially cancelling systematics, which can provide **significant pdf constraints**

pdfs presented in this talk provide new constraints for x $\gtrsim$ 0.05

ATLASepWZWjet19 pdfs, supports unsuppressed strange at small x ~ 0.02, consistent with previous ATLAS results; dbar-ubar positive, consistent with results from neutrino scattering experiments

ATLASepWZtop18 pdfs, additional constraints on gluon at large x

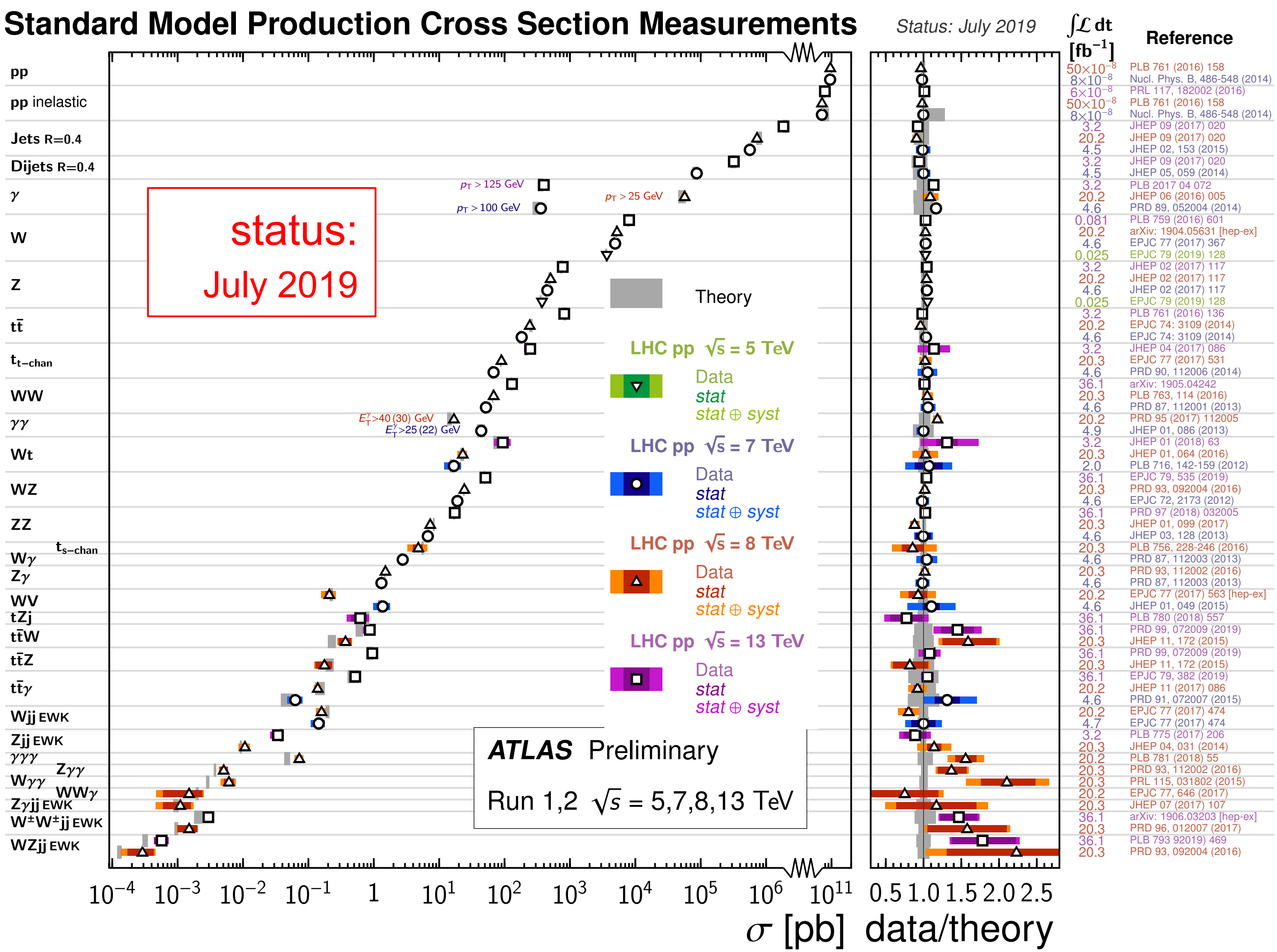
lj+ll channels; multiple spectra included, with full statistical correlations provided (lj);

still much to come from ATLAS from both Run 1 and Run 2 SM analyses

extras

ATLAS SM measurements

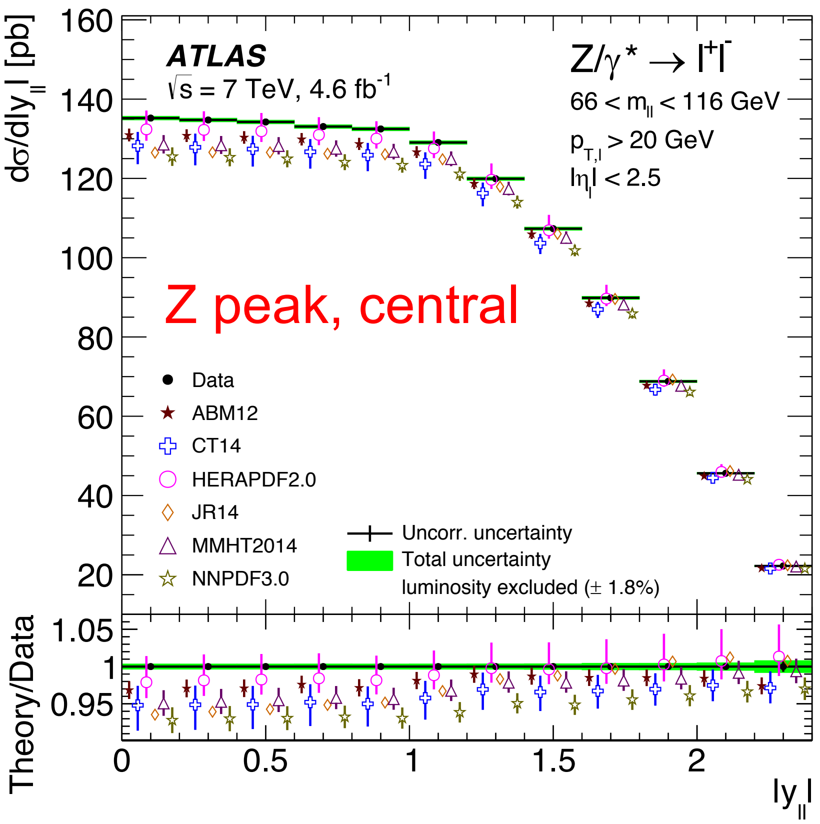
… providing insight into pQCD, **proton structure (pdfs)**, non-pert. effects, and other SM parameters

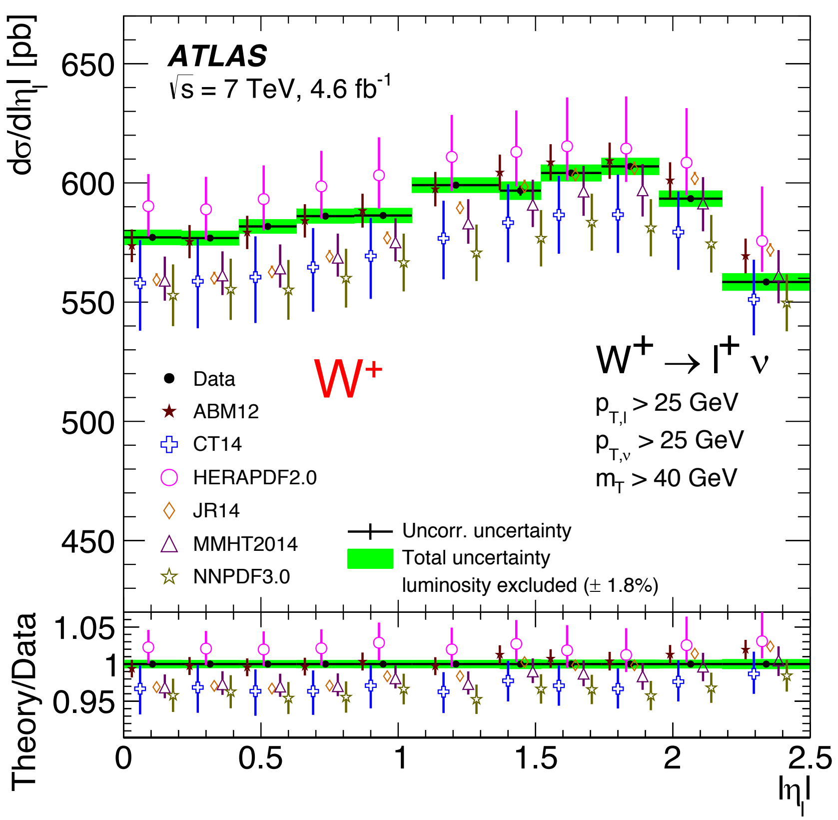


extraordinary agreement between **measurements** and **SM predictions**

ultimate precision W,Z differential cross sections

ATLAS incl. W,Z differential cross sections: W± |ηl|, Z |yll| (3 mll central, 2 mll forward)



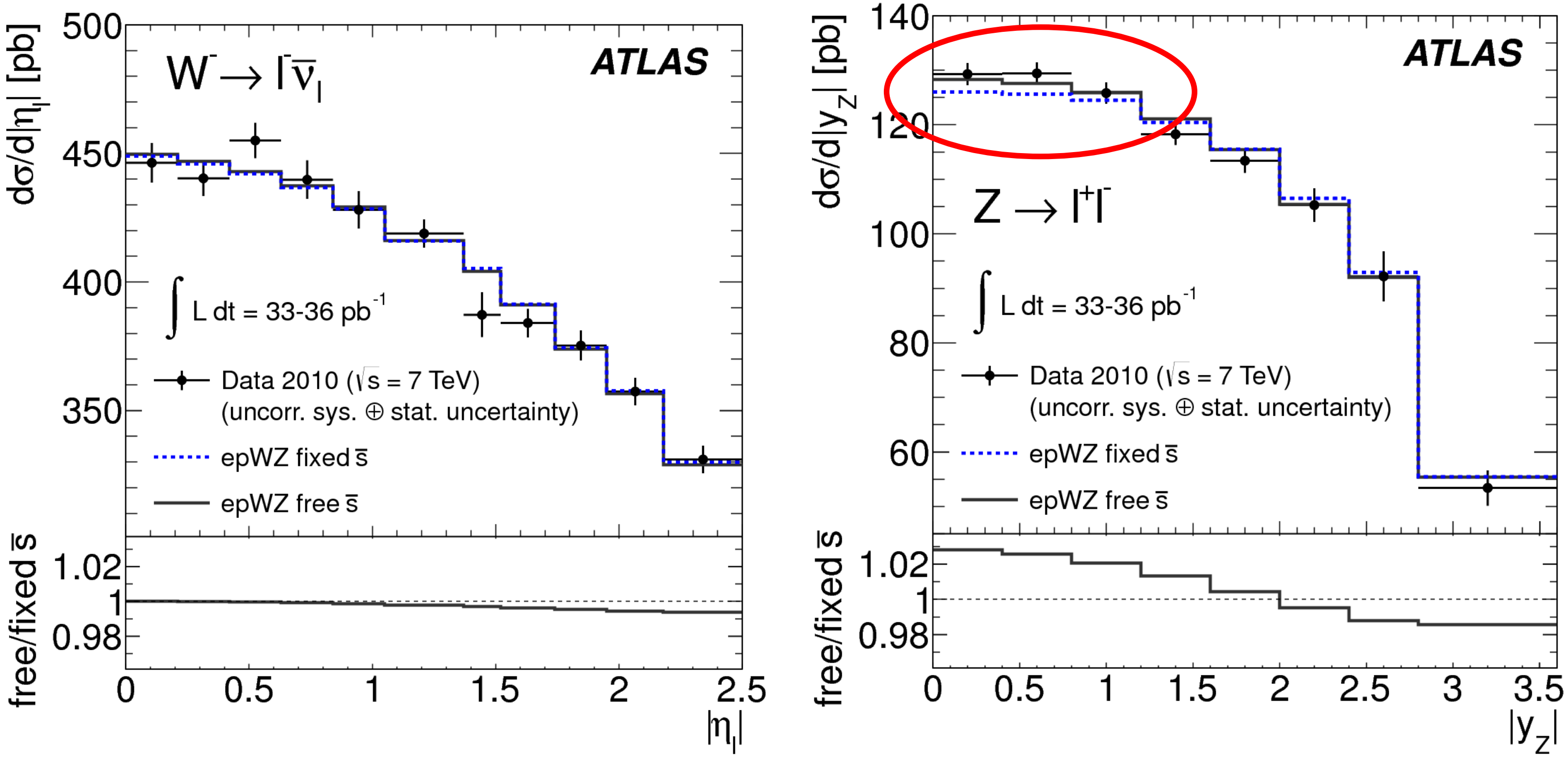


EPJ C77 (2017) 367

4.6 fb^{-1}; extraordinary total experimental precision (**< 1% uncertainty)**

light quark pdf constraints; enhanced from provision of both W,Z with full syst. correlations

ATLAS inclusive W, Z

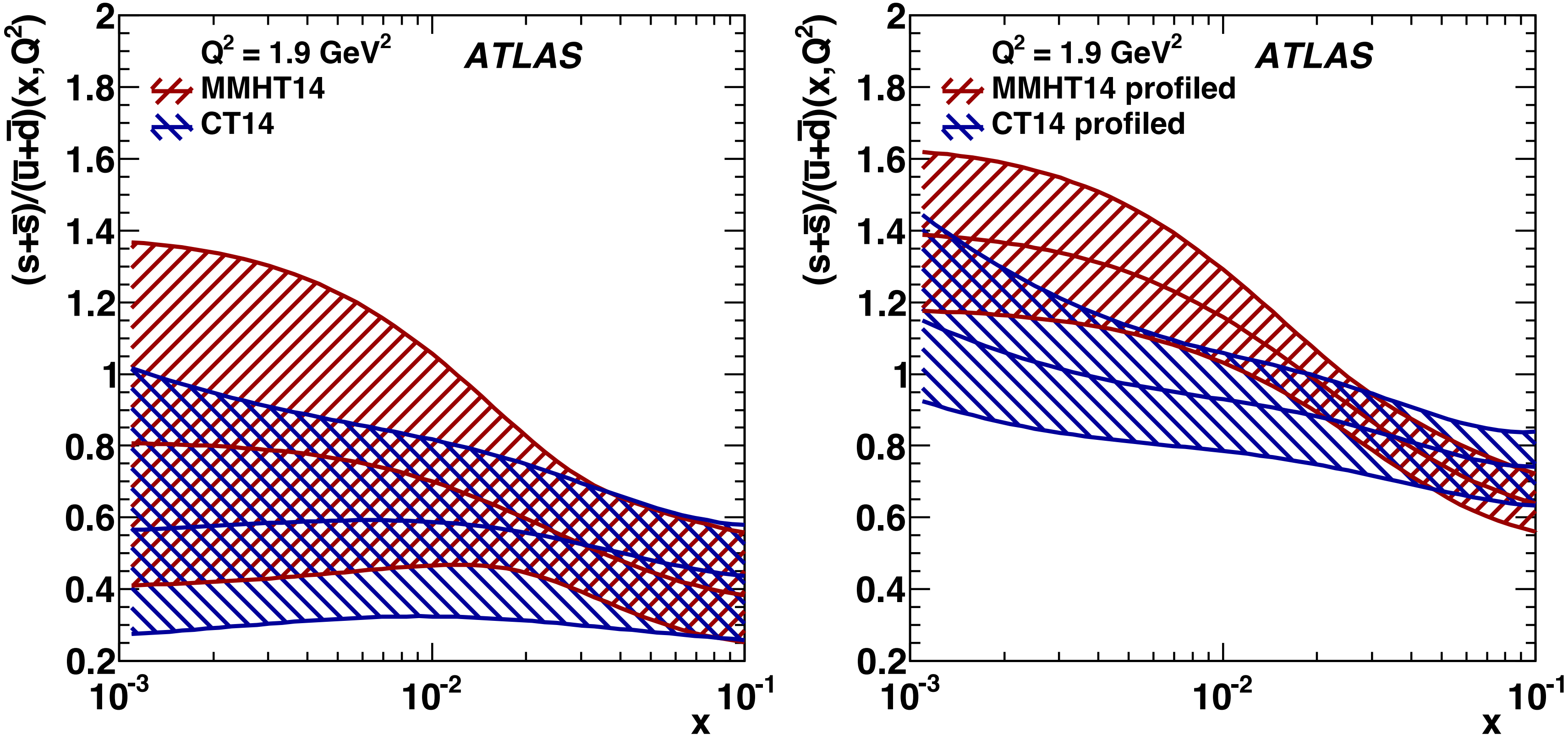


- impact of unsuppressed strange on W,Z inclusive cross sections

Phys Rev Lett 109 (2012) 012001

impact on modern global pdfs

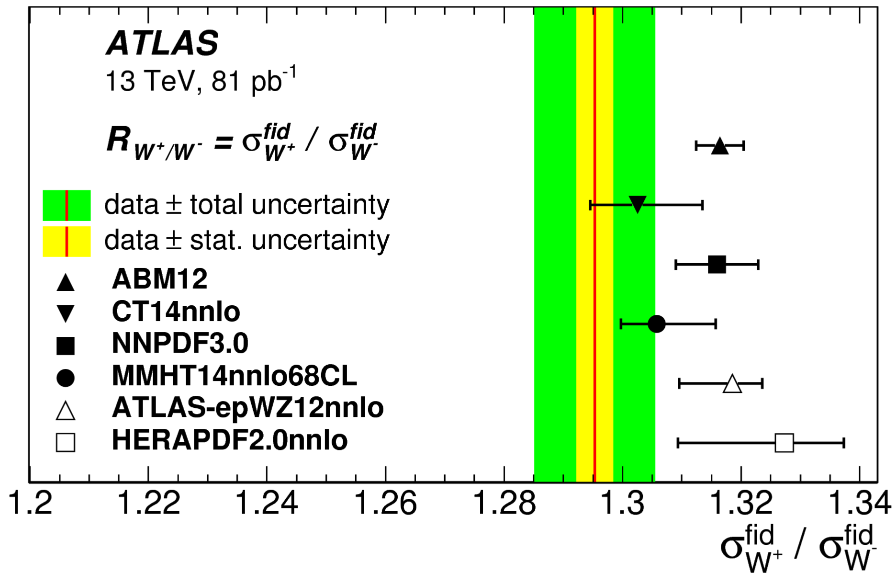
EPJ C77 (2017) 367

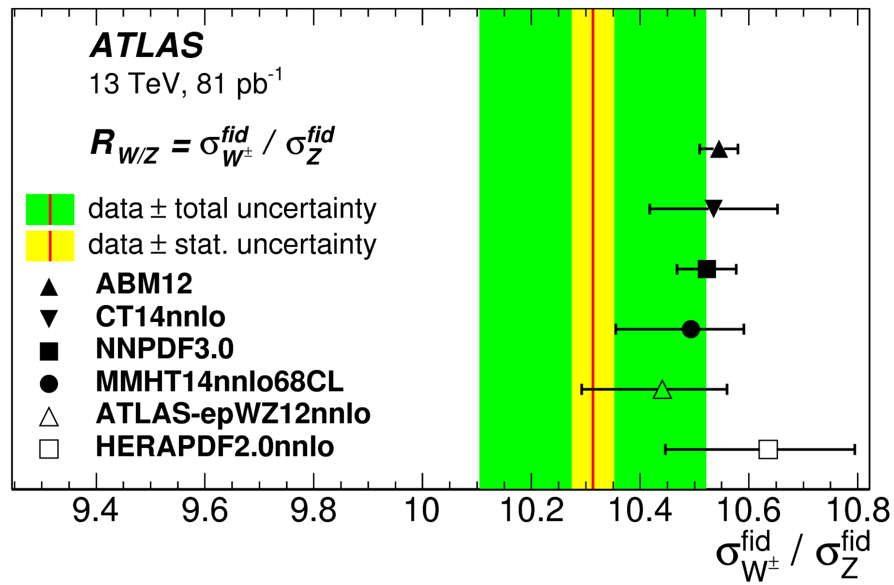


- profiling exercise to study impact of ATLAS W, Z (4.6 pb^{-1}) differential cross sections on proton pdfs from global fitters

ATLAS W and Z cross section ratios @ 13 TeV

PLB 759 (2016) 601





W+/W–:

sensitive to valence quarks at low x

W/Z:

constrains strange quark density

cross section ratio measurements: partial cancellation of systematics

sensitivity to pdf differences; W/Z ratio consistent with enhanced strange

ATLAS QCD fit technical details

$$
\begin{aligned}
xu_v(x) &= A_{u_v} x^{B_{u_v}} (1-x)^{C_{u_v}} (1 + E_{u_v} x^2)\,, \\
xd_v(x) &= A_{d_v} x^{B_{d_v}} (1-x)^{C_{d_v}}\,, \\
x\bar{u}(x) &= A_{\bar{u}} x^{B_{\bar{u}}} (1-x)^{C_{\bar{u}}}\,, \quad (1 + \boldsymbol{D_{\bar{u}} x}) \\
x\bar{d}(x) &= A_{\bar{d}} x^{B_{\bar{d}}} (1-x)^{C_{\bar{d}}}\,, \\
xg(x) &= A_g x^{B_g} (1-x)^{C_g} - A'_g x^{B'_g} (1-x)^{C'_g}\,, \\
x\bar{s}(x) &= A_{\bar{s}} x^{B_{\bar{s}}} (1-x)^{C_{\bar{s}}}\,,
\end{aligned}
$$

NNLO QCD fit;
xFitter framework;
QCDNUM for DGLAP evolution;
RT-VFN for HQs;
start scale: $Q_0^2 = 1.9\,\mathrm{GeV}^2$
$m_c = 1.43$ GeV, $m_b = 4.5$ GeV
$\alpha_s(M_Z) = 0.118$

with constraints:

16 free parameters

$A_{\bar{u}} = A_{\bar{d}}$

$B_{\bar{s}} = B_{\bar{d}} = B_{\bar{u}}$

ensuring ubar=dbar as x→0:

A_g (momentum sum) A_{u_v} A_{d_v} (number sum)

ATLASepWZWjet19 additional uncertainties

$$
\begin{aligned}
xd_v(x) &= A_{u_v} x^{B_{u_v}} (1-x)^{C_{u_v}} (1 + D_{d_v} x + E_{d_v} x^2) \exp F_{d_v} x \\
xu_v(x) &= A_{d_v} x^{B_{d_v}} (1-x)^{C_{d_v}} (1 + D_{u_v} x + E_{u_v} x^2) \exp F_{d_v} x \\
x\bar{d}(x) &= A_{\bar{d}} x^{B_{\bar{d}}} (1-x)^{C_{\bar{d}}} (1 + D_{\bar{d}} x + E_{\bar{d}} x^2) \\
x\bar{u}(x) &= A_{\bar{u}} x^{B_{\bar{u}}} (1-x)^{C_{\bar{u}}} (1 + D_{\bar{u}} x + E_{\bar{u}} x^2) \\
x\bar{s}(x) &= A_{\bar{s}} x^{B_{\bar{s}}} (1-x)^{C_{\bar{s}}} (1 + D_{\bar{s}} x + E_{\bar{s}} x^2) \\
xg(x) &= A_g x^{B_g} (1-x)^{C_g} (1 + D_g x + E_g x^2) + A'_g x^{B'_g} (1-x)^{C'_g}
\end{aligned}
$$

- greyed out parameters used as part of parameterization uncertainty systematics; plus other assumptions relaxed
- model variations: mc, mb, Q^2_0, Q^2_{min}, $\alpha_s(M_Z)$

parameterisation variations

Change in parameterisation	p_{T}^{W}	$p_{\mathrm{T}}^{\mathrm{leading}}$
Nominal χ^2/NDF	1354 / 1138	1365 / 1150
$A_g' = 0$	1409 / 1140	1428 / 1152
$A_{\bar{u}} \neq A_{\bar{d}}$	1352 / 1137	1363 / 1149
$B_{\bar{u}} \neq B_{\bar{d}}$	1352 / 1137	1362 / 1149
$B_{\bar{s}} \neq B_{\bar{d}}$	1353 / 1137	1363 / 1149
$D_{\bar{u}} = 0$	1357 / 1139	1373 / 1151
$D_{\bar{d}}$	1354 / 1137	1364 / 1149
$D_{\bar{s}}$	1353 / 1137	1359 / 1149
D_{u_v}	1354 / 1137	1365 / 1149
D_{d_v}	1354 / 1137	1364 / 1149
D_g	1353 / 1137	- / 1149
$E_{\bar{u}}$	1354 / 1137	1363 / 1149
$E_{\bar{d}}$	1354 / 1137	1365 / 1149
$E_{\bar{s}}$	1354 / 1137	1362 / 1149
E_g	1352 / 1137	1365 / 1149
F_{u_v}	1351 / 1137	1363 / 1149
F_{d_v}	1354 / 1137	1365 / 1149

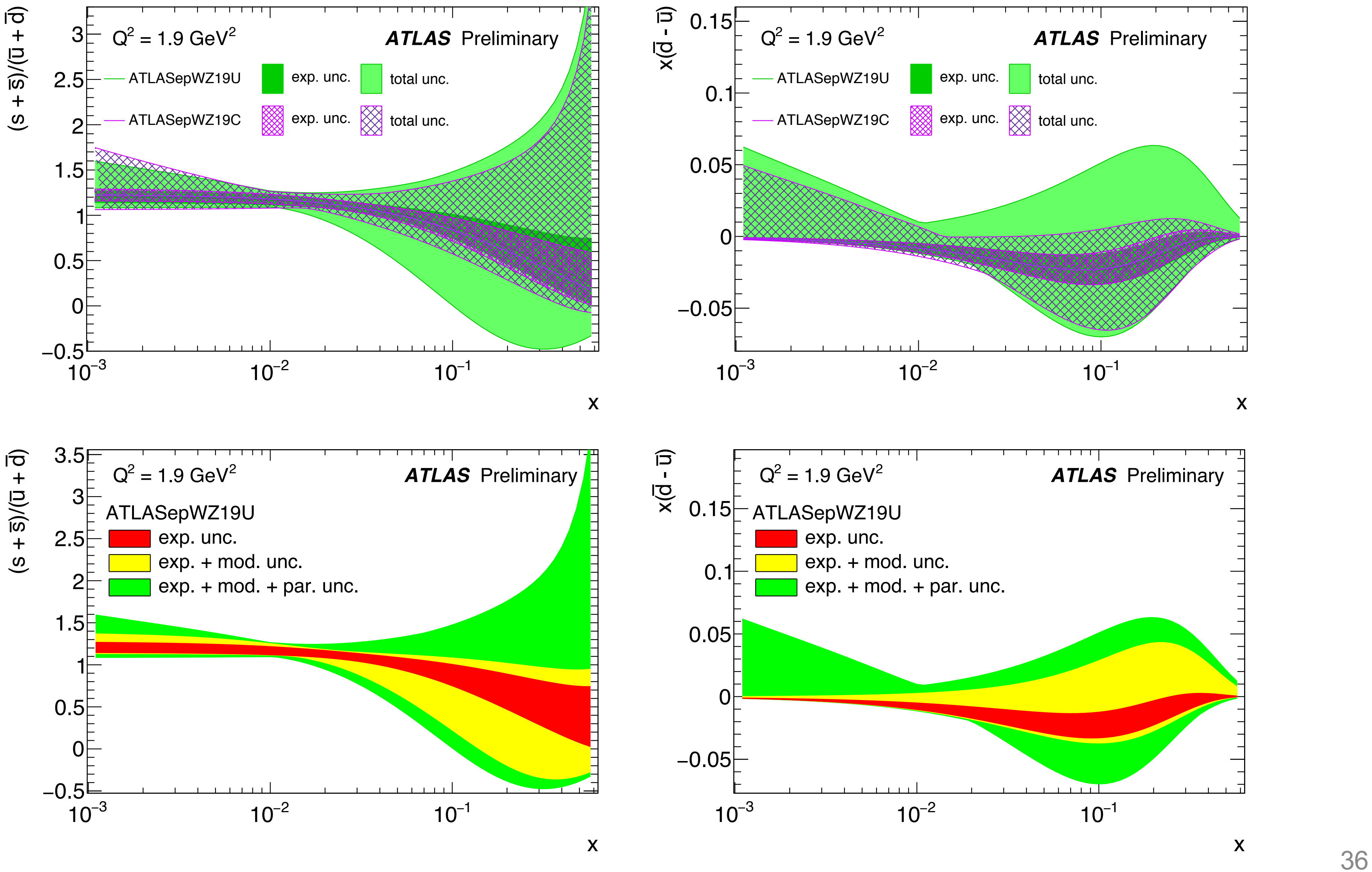
model variations

Change in model assumption	p_T^W	p_T^{leading}
Nominal χ^2/NDF	1354 / 1140	1365 / 1152
m_b = 4.25GeV	1352 / 1140	1364 / 1152
m_b = 4.75GeV	1356 / 1140	1367 / 1152
Q^2_{min} = 7.5GeV^2	1413 / 1180	1426 / 1192
Q^2_{min} = 12.5GeV^2	1283 / 1091	1296 / 1103
Q^2_0 = 1.6GeV^2 and m_c = 1.37GeV	1359 / 1140	1369 / 1152
Q^2_0 = 2.0GeV^2 and m_c = 1.49GeV	1353 / 1140	1366 / 1152
$\alpha_s(m_Z)$ = 0.116	1352 / 1140	1366 / 1152
$\alpha_s(m_Z)$ = 0.120	1357 / 1140	1366 / 1152

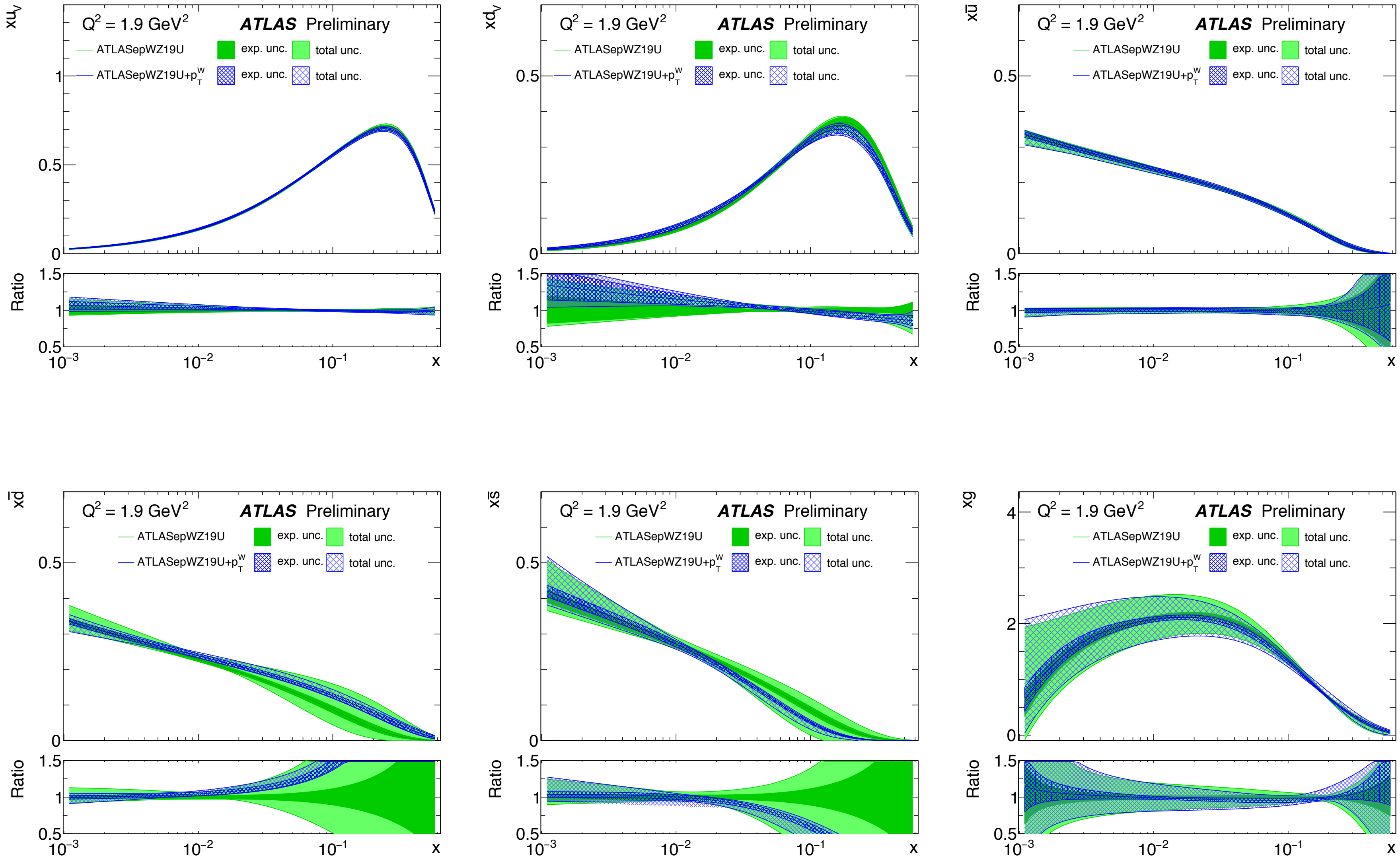
ATLASepWZWjet19 fit quality

Fit	ATLASepWZ19U	ATLASepWZ19U + p_{T}^{W}	ATLASepWZ19U + $p_{\mathrm{T}}^{\mathrm{leading}}$
Total χ^2/NDF	1310 / 1104	1354 / 1138	1365 / 1150
HERA partial χ^2/NDF	1123 / 1016	1132 / 1016	1141 / 1016
HERA correlated χ^2	48	49	50
HERA log penalty χ^2	-18	-22	-25
ATLAS W, Z partial χ^2/NDF	117 / 104	116 / 104	109 / 104
ATLAS W + jets partial χ^2/NDF	-	18 / 34	43 / 46
ATLAS correlated χ^2	40	62	47

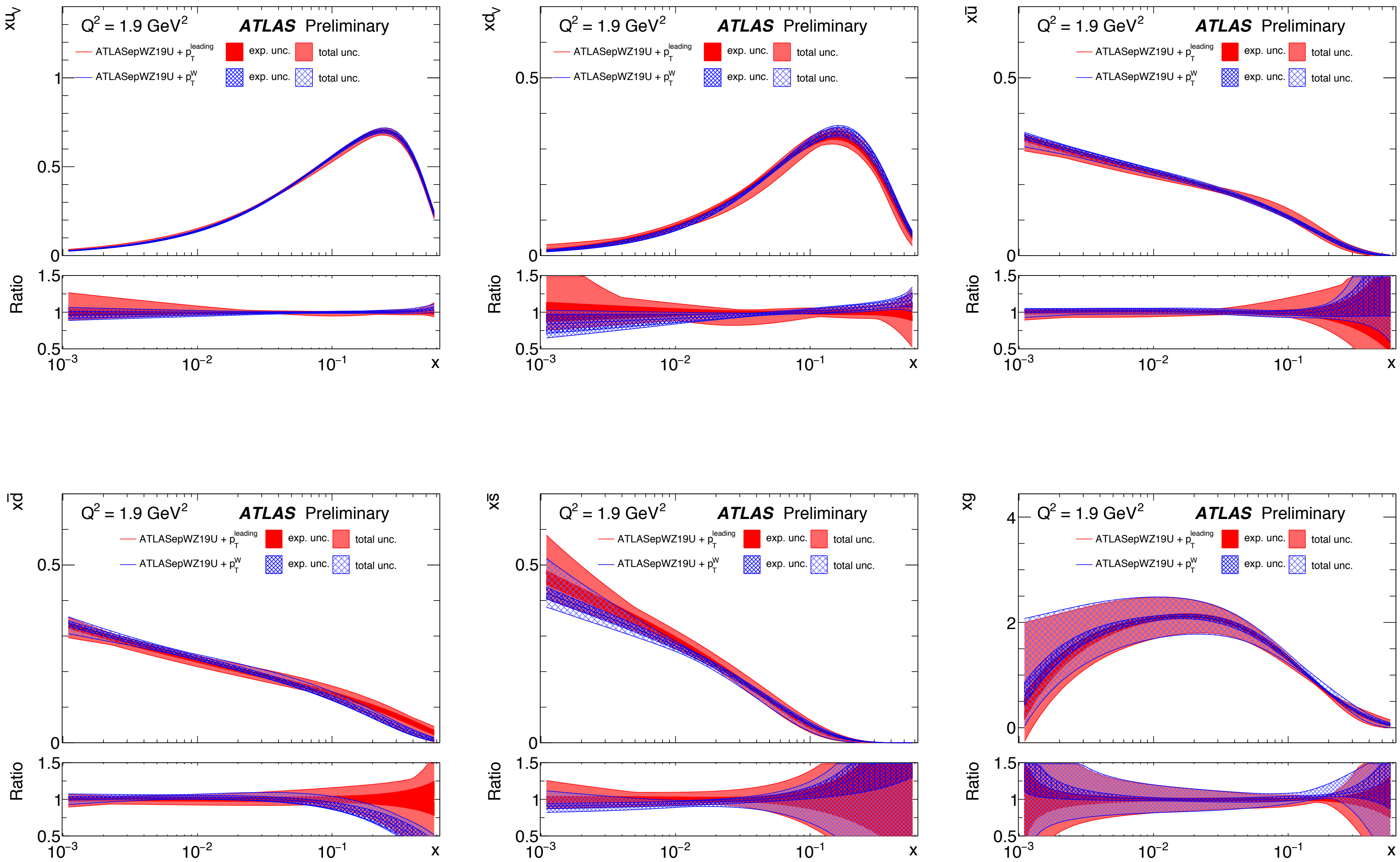
ATLASepWZ19 combined and uncombined fits



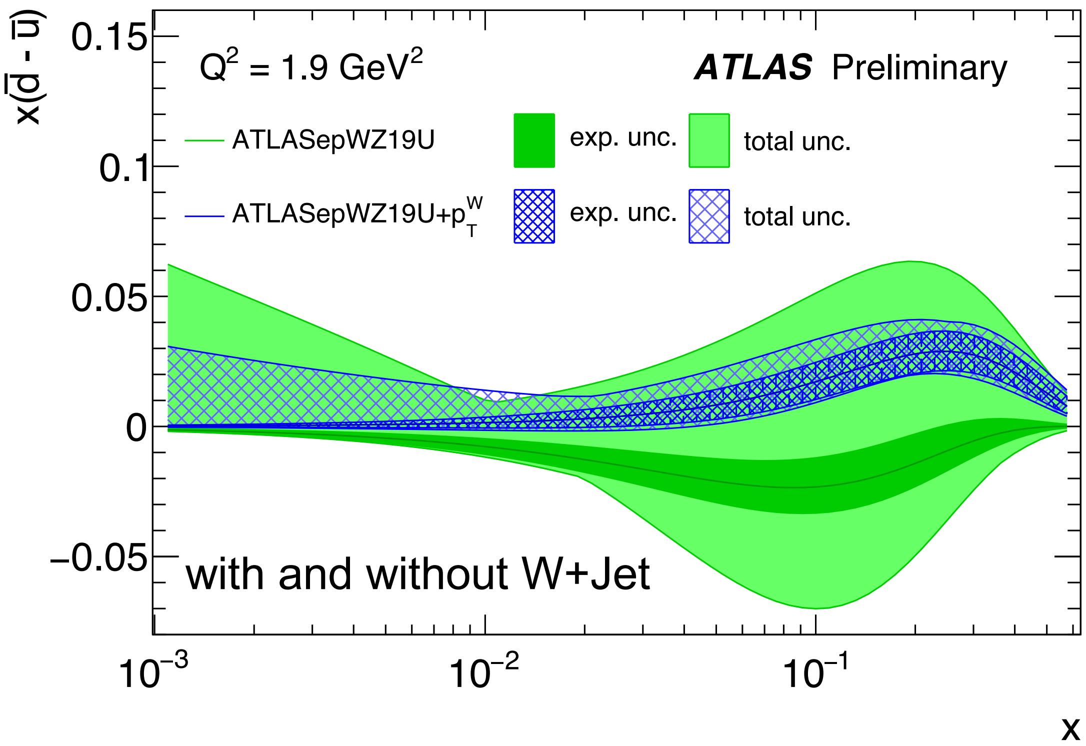
ATLAS fits with W+Jet cross sections

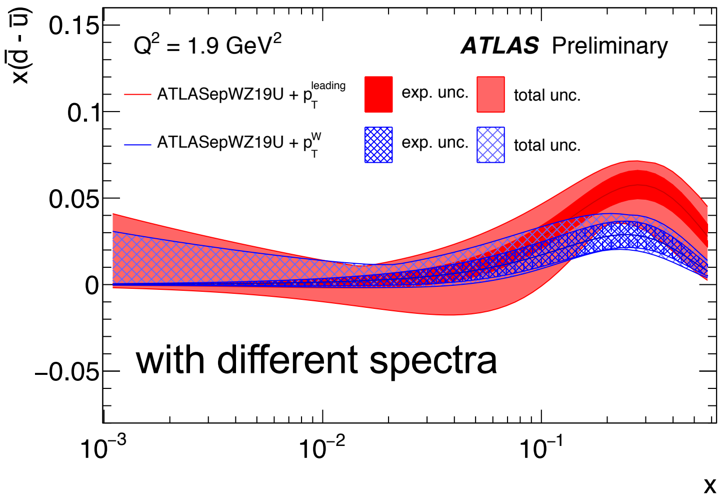


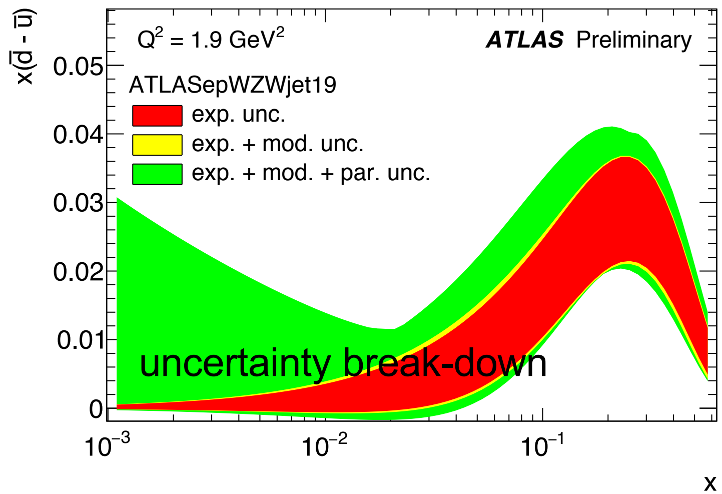
ATLAS fits with W+Jet cross sections



dbar – ubar



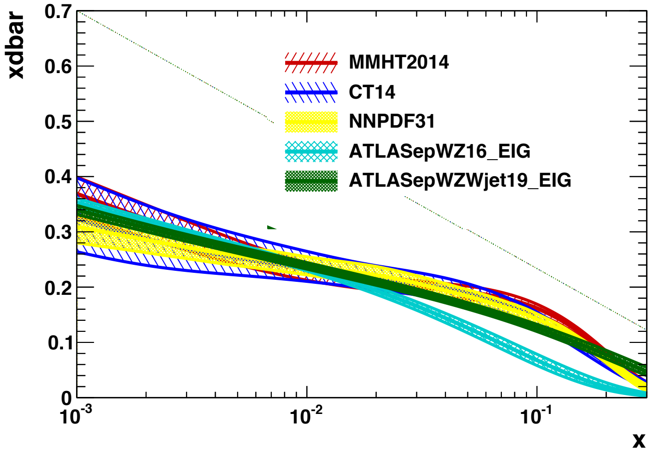


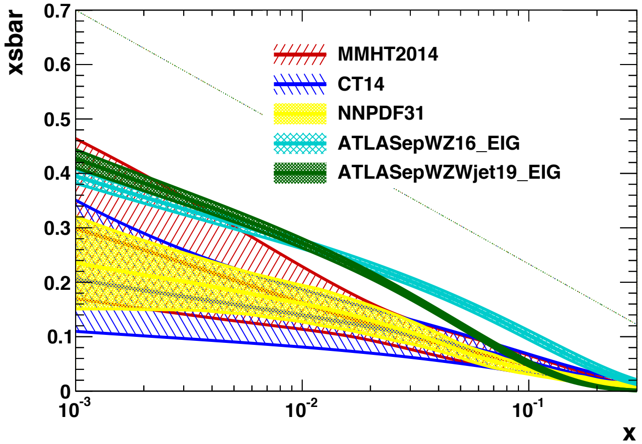


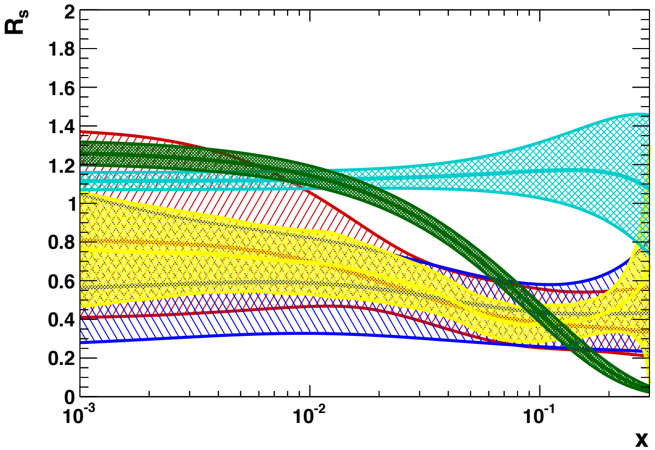
dbar – ubar now positive

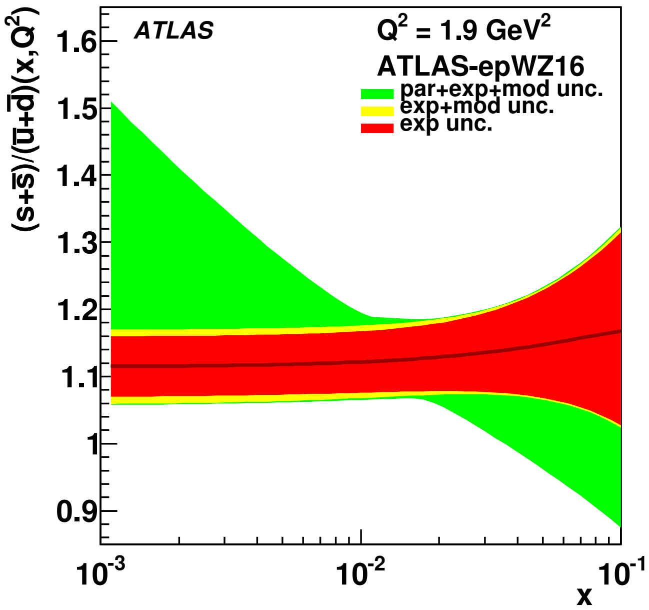
constraints are in both experimental and additional uncertainties

comparisons with global pdfs









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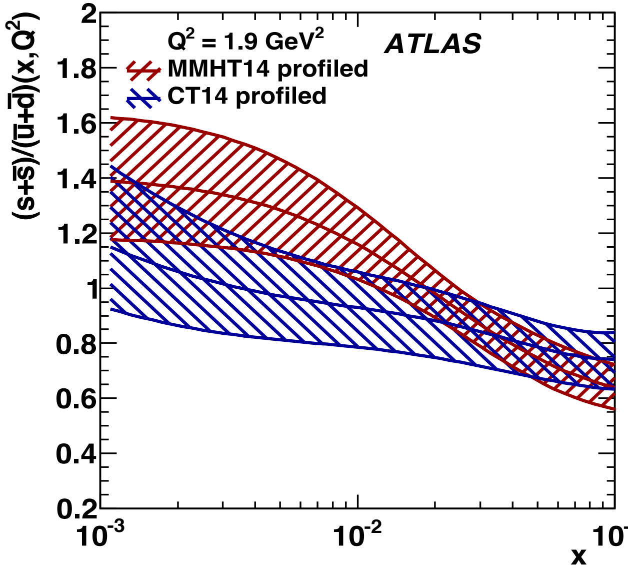
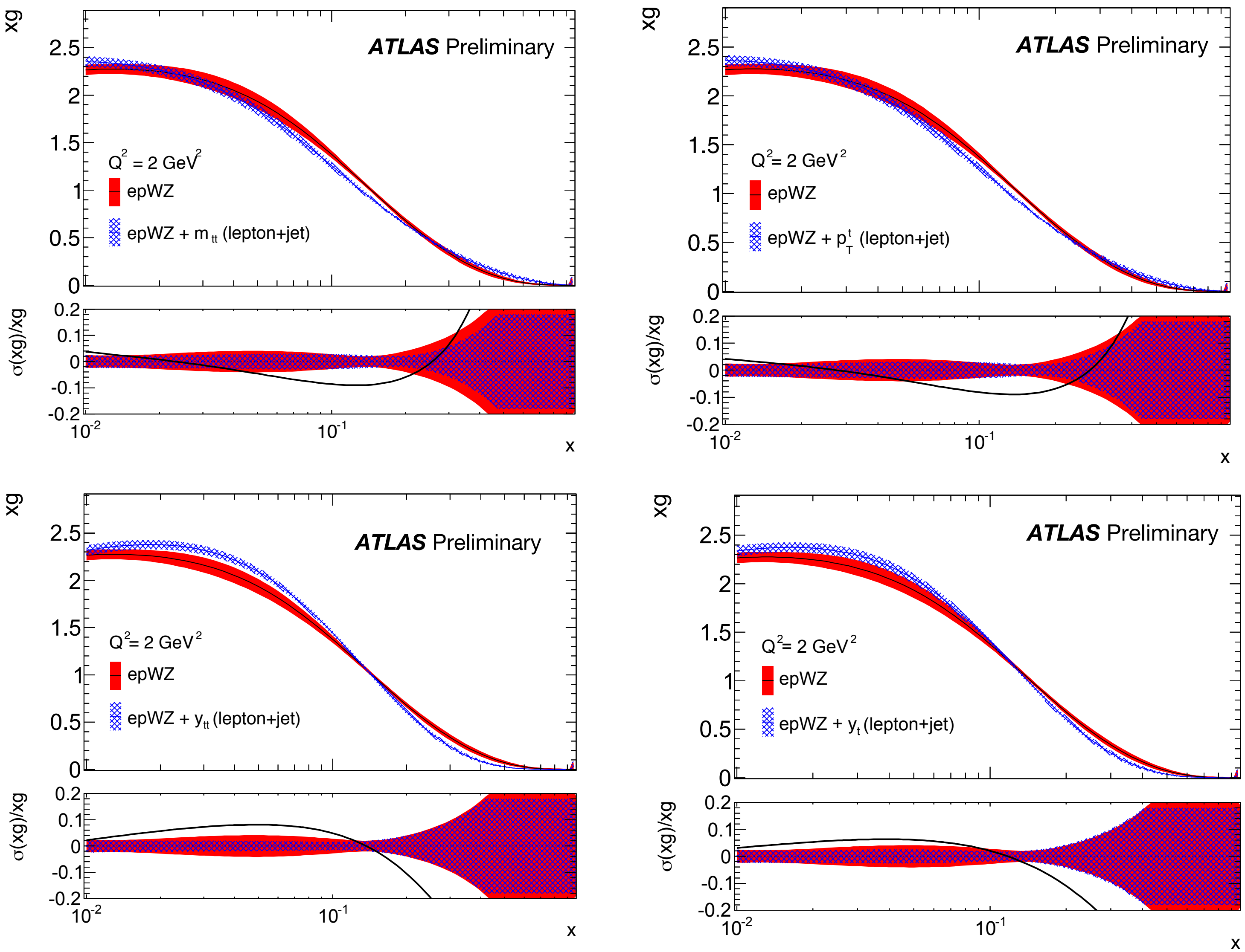
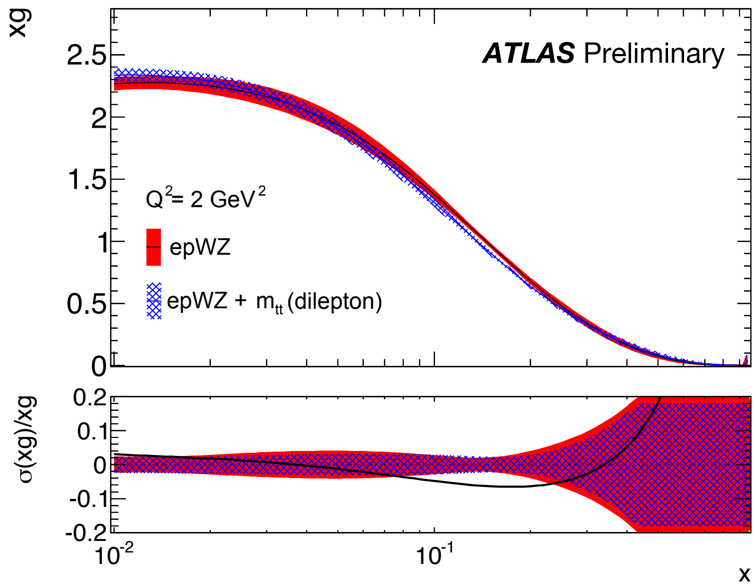
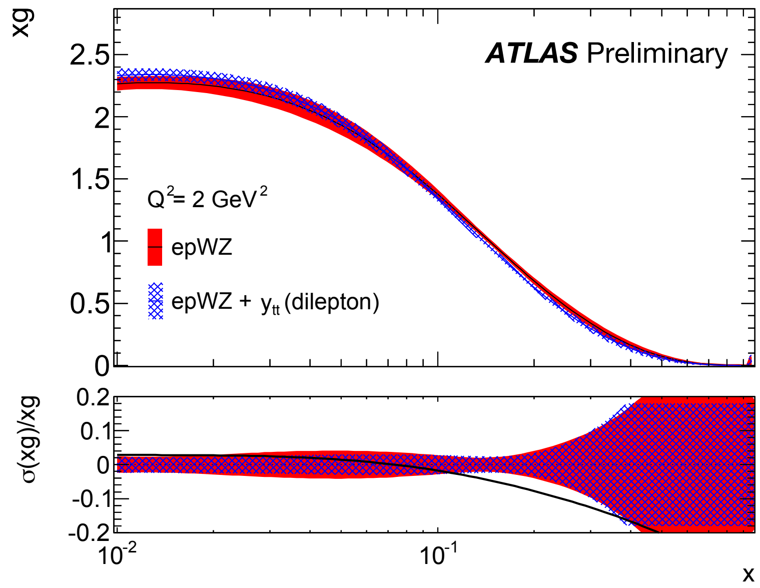


ATLAS fits with individual ttbar spectra (lj)



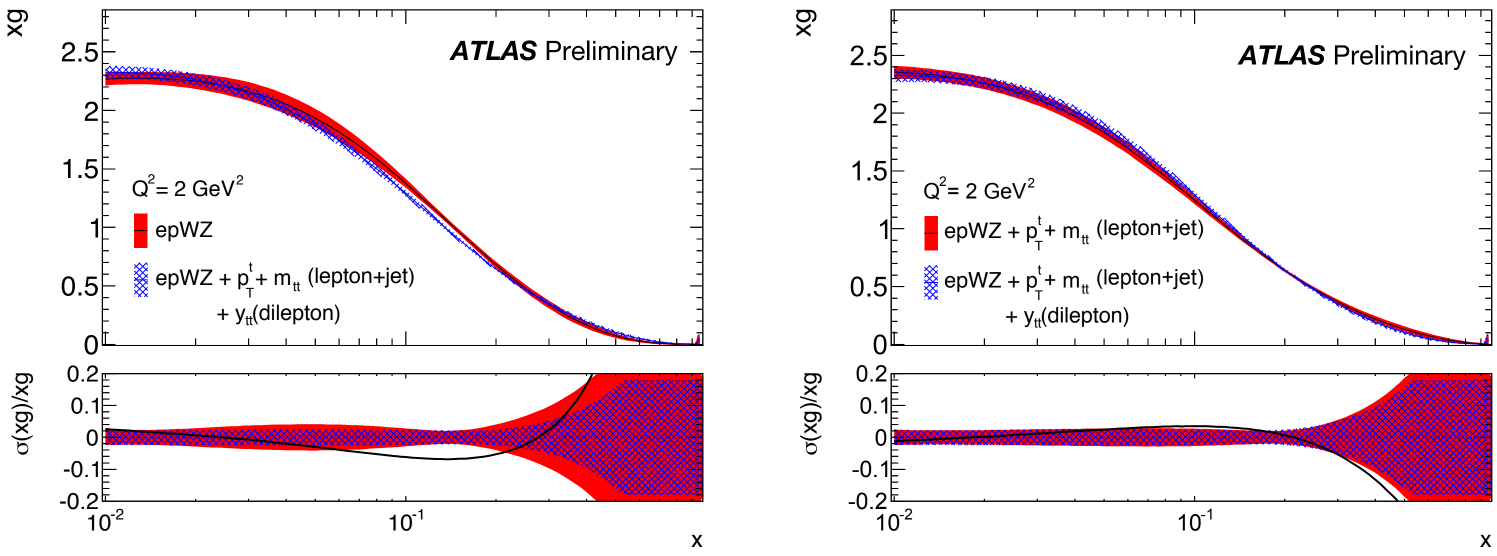
ATLAS fits with individual ttbar spectra (II)



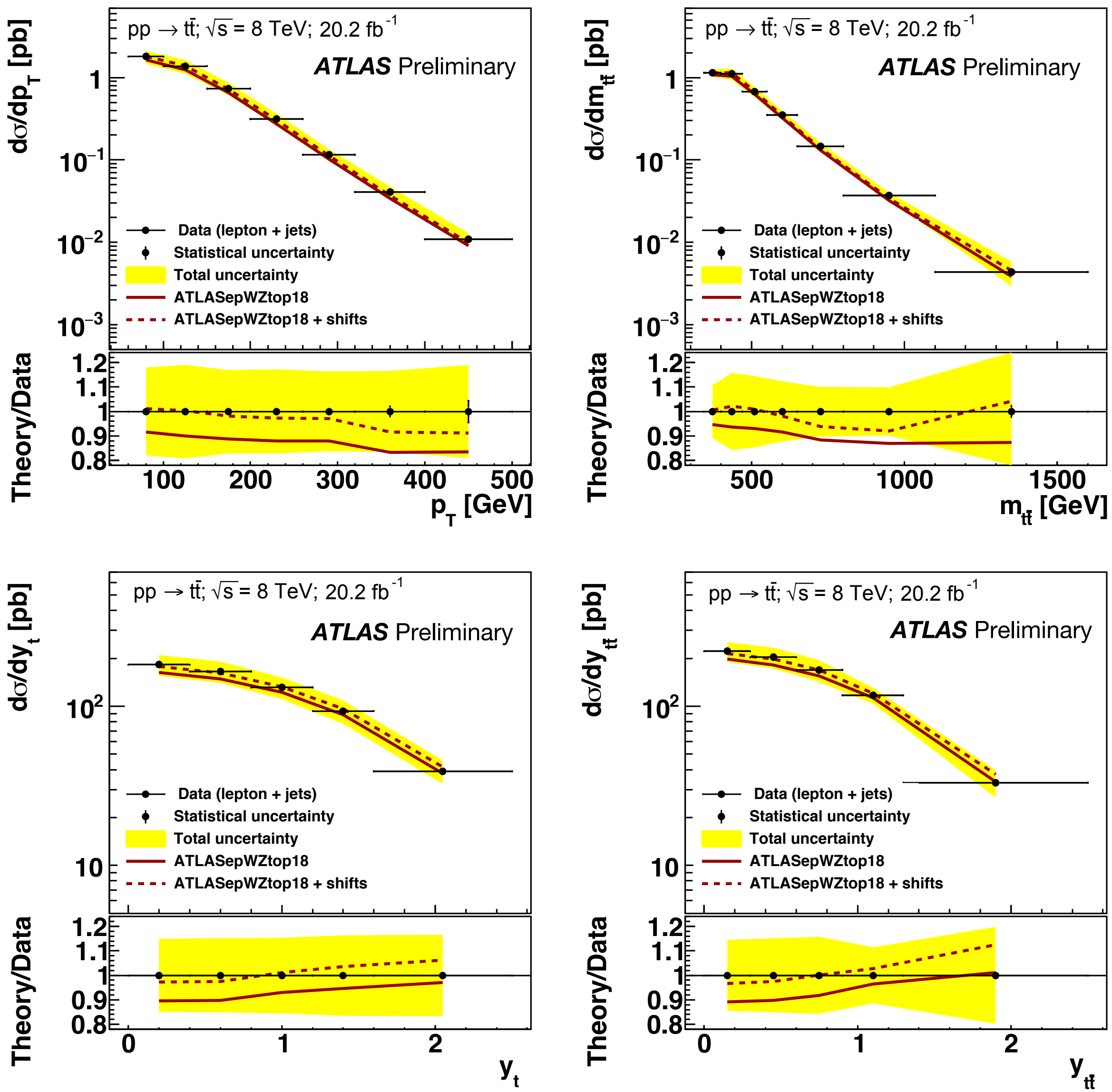


ATLAS fits with lj+ll spectra

		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



ATLAS ttbar differential cross sections (lj)



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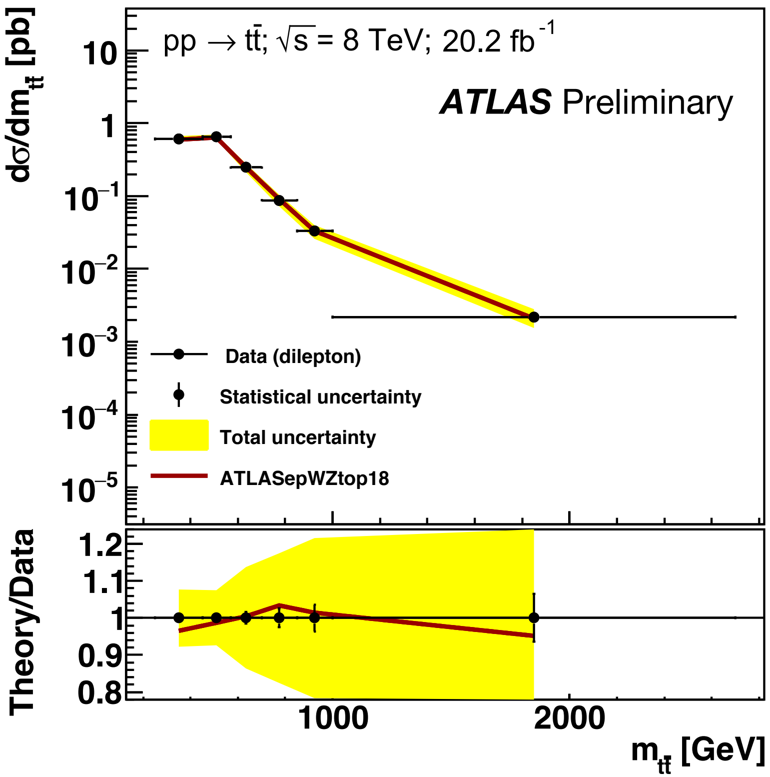
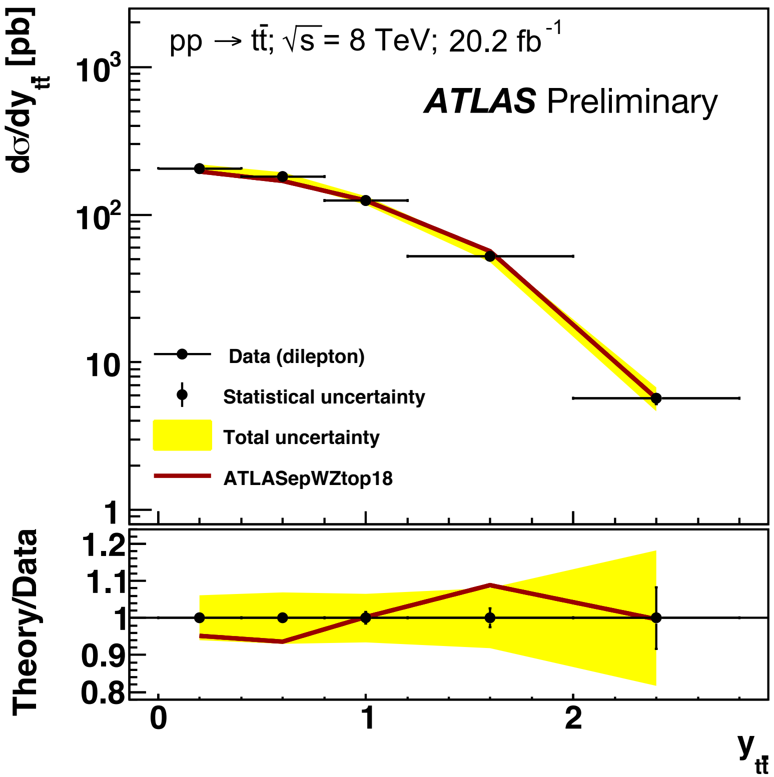
ATLAS ttbar differential cross sections (II)





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ATLAS fits to ttbar differential cross sections

		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

		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

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

fitted values of nuisance parameters for fits to HERA+ATLAS W,Z + separate ttbar lj spectra

Determination of Statistical Correlation

The determination of statistical correlations within each spectrum and between different spectra of the lepton+jets $t\bar{t}$ data are evaluated using the Bootstrap Method

- Based on the extraction of N Bootstrap samples from the data sample
- Each sample is made by associating a Poissonian weight to each event in data
- The spectra from each Bootstrap sample is subject to the same full analysis chain used for the nominal results
- Since the weights are generated on an event-by-event basis, the replicated spectra are synchronised, thus allowing the determination of statistical correlations among different spectra

The statistical correlations are evaluated bin-by-bin as in:

$$C_{ij}^{AB} = \frac{\frac{1}{N} \cdot \sum_{k=1}^{N} (\mathcal{R}_i^{A,k} - \mu_i^A)(\mathcal{R}_i^{B,k} - \mu_j^B)}{\sigma_i^A \cdot \sigma_j^B} \tag{3}$$

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 and $\mathcal{R}_i^{A,k}$ is the content of the i-th bin of the k-th replica for spectrum A

X2

with statistical correlations:

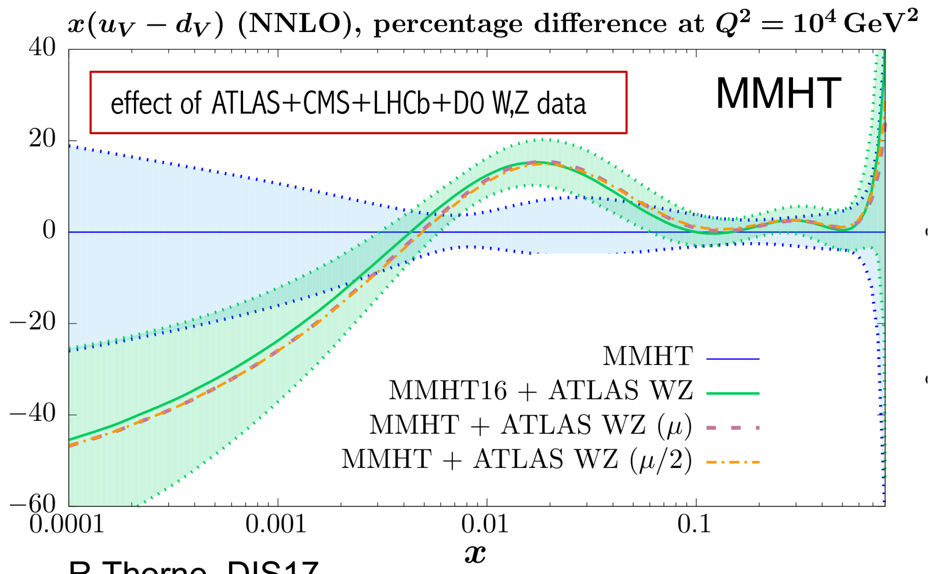
$$\chi^2 = \sum_{ik}\left(D_i - T_i(1-\sum_i \gamma_{ij}b_j)\right) C^{-1}_{\text{stat},ik}(D_i, D_k)\left(D_k - T_k(1-\sum_j \gamma_{kj}b_j)\right)$$
$$+ \sum_j b_j^2 \quad + \sum_i \log\frac{\delta^2_{i,\text{uncor}}T_i^2 + \delta^2_{i,\text{stat}}D_iT_i}{\delta^2_{i,\text{uncor}}D_i^2 + \delta^2_{i,\text{stat}}D_i^2}$$

without statistical correlations reduces to:

$$\chi^2 = \sum_i \frac{[D_i - T_i(1-\sum_j \gamma_{ij}b_j)]^2}{\delta^2_{i,\text{uncor}}T_i^2 + \delta^2_{i,\text{stat}}D_iT_i} + \sum_j b_j^2 + \sum_i \log\frac{\delta^2_{i,\text{uncor}}T_i^2 + \delta^2_{i,\text{stat}}D_iT_i}{\delta^2_{i,\text{uncor}}D_i^2 + \delta^2_{i,\text{stat}}D_i^2}$$

where D_i represent the measured data, T_i the corresponding theoretical prediction, $\delta_{i,\text{uncor}}$ and $\delta_{i,\text{stat}}$ are the uncorrelated systematic and the statistical uncertainties on D_i, and correlated systematics, described by γ_{ij}, are accounted for using the nuisance parameters b_j. Summations over i and k run over all data points and summation over j runs over all sources of correlated systematics. For each data set, the first term gives a partial χ^2 and the second term gives a *correlated* χ^2. The third term is a bias correction term, referred to as the *log penalty*, corresponding to a non-constant value of the covariance matrix, used as standard in HERA and ATLAS PDF fits

impact of LHC data on modern global pdf fits



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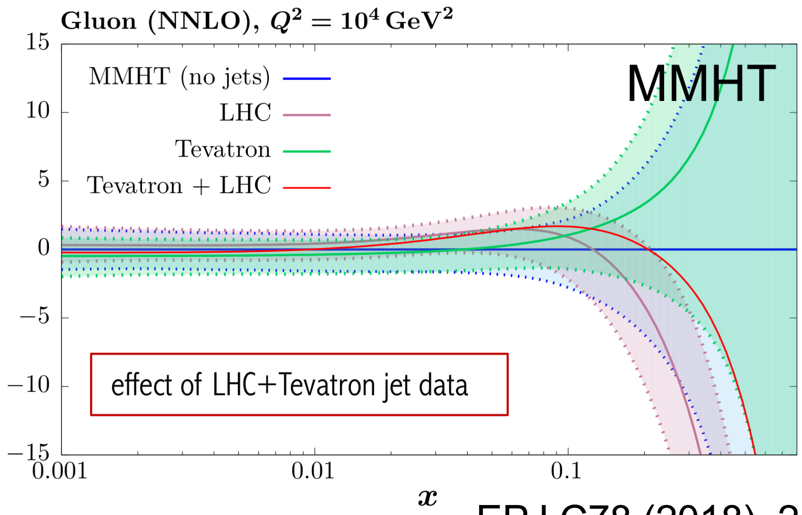

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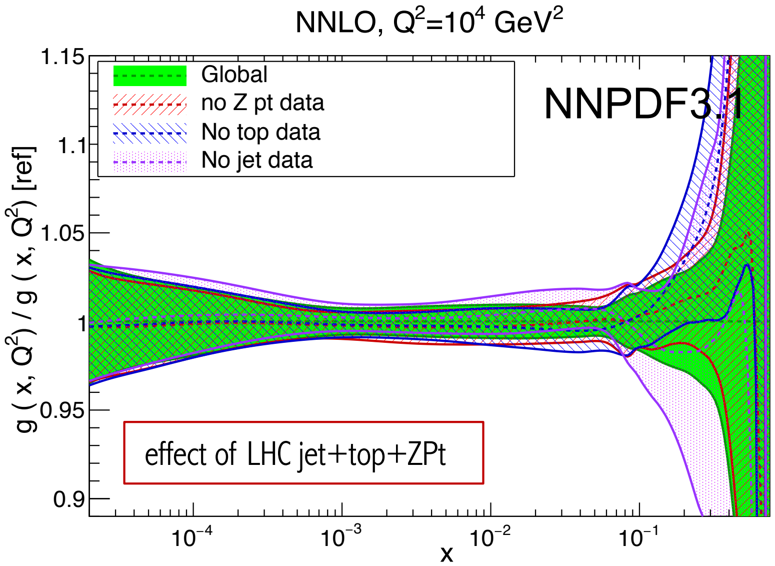
global pdf fitters actively including LHC data from **ATLAS**, CMS and LHCb

measurements shown in this talk are yet to be included

much more still to come…



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