Update to the determination of PDFs with ATLAS data: ATLASepWZVjet20

PDF4LHC 2021

Gavin Pownall[1] on behalf of the ATLAS Collaboration
DESY

23.03.2021

[1]gavin.pownall@cern.ch

A quick overview

Aim: Consider a fit with minimal data (HERA + ATLAS) to **directly determine the constraints provided by ATLAS data.**

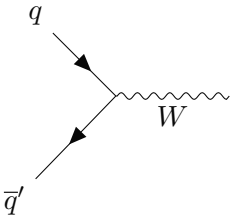
Data	epWZ16	epWZtop18	**epWZVjet20**
	HERA		
Inclusive combined	✓	✓	✓
	7 TeV pp		
Precision W, Z	✓	✓	✓
	8 TeV pp		
$t\bar{t}$ (l + jets, dilepton)		✓	
W + jets (link)			✓
Z + jets (link)			✓

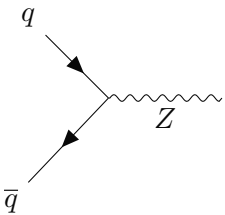
- ATLASepWZ16 published Eur.Phys.J.C 77 (2017) 367
- ATLASepWZtop18 PUB. note CDS: 2633819
- ATLASepWZVjet20 public arXiv:2101.05095

Previous analysis: ATLASepWZ16

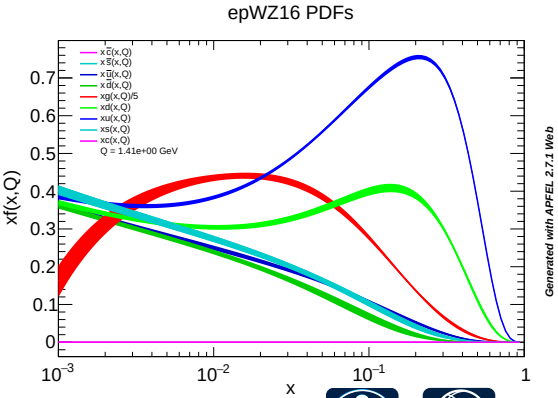
ATLASepWZ16

The ATLASepWZ16 PDF set uses the HERA baseline + inclusive W and Z production in 7 TeV collisions at ATLAS.





HERA inclusive data charge-sensitive but cannot differentiate $\bar{d}$ and $\bar{s}$...
Addition of W,Z cross section allows us to fit $\bar{s}$ independently from $\bar{d}$



Parameterisation

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

$$xu_v = A_{u_v} x^{B_{u_v}}(1-x)^{C_{u_v}}(1+E_{u_v}x^2)$$

$$xd_v = A_{d_v} x^{B_{d_v}}(1-x)^{C_{d_v}}$$

$$x\bar{u} = A_{\bar{u}} x^{B_{\bar{u}}}(1-x)^{C_{\bar{u}}}$$

$$x\bar{d} = A_{\bar{d}} x^{B_{\bar{d}}}(1-x)^{C_{\bar{d}}}$$

$$xg = A_g x^{B_g}(1-x)^{C_g}(1+D_g x) - A'_g x^{B'_g}(1-x)^{C'_g}$$

$$x\bar{s} = A_{\bar{s}} x^{B_{\bar{s}}}(1-x)^{C_{\bar{s}}} = xs$$

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

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

($\bar{u} = \bar{d}$ as $x \to 0$)

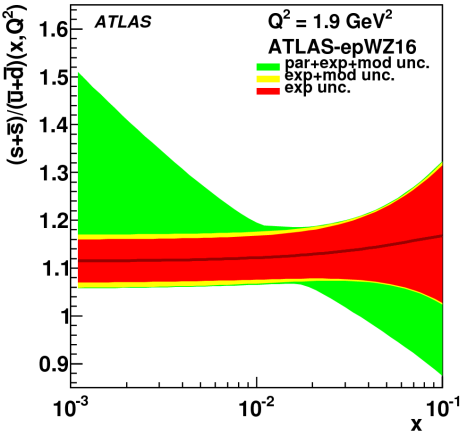
A_g (momentum sum rule)

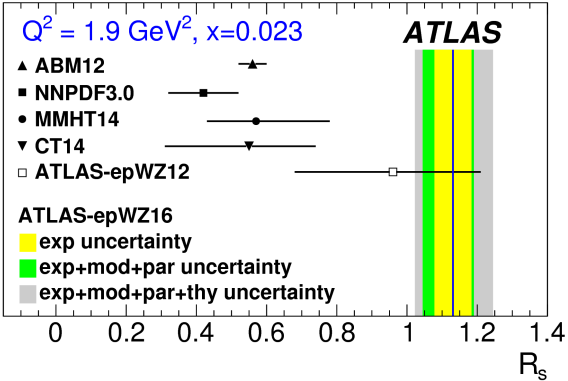
A_{u_v}, A_{d_v} (number sum rule)

$C'_g = 25 >> C_g$ suppresses at high x

D_g new parameter for V + jets fit

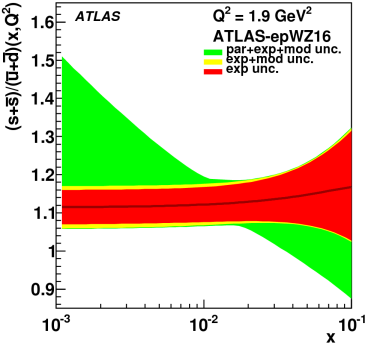
A Strange Result





$$@x \sim 0.02 : R_s = \frac{s+\bar{s}}{\bar{u}+\bar{d}} = \begin{cases} \sim 0.5 & \text{Global fits} \\ \sim 1 & \text{ATLAS} \end{cases}$$

Model and Parameterisation uncertainties



Variation	Total χ^2/n.d.f.
Nominal fit	1321 / 1102
Model variations	
$m_b = 4.25GeV$	1319 / 1102
$m_b = 4.75GeV$	1322 / 1102
$Q^2_{\rm min} = 5GeV^2$	1389 / 1149
$Q^2_{\rm min} = 10GeV^2$	1263 / 1062
$Q^2_0 = 1.6GeV^2$ and $m_c = 1.37GeV$	1322 / 1101
$Q^2_0 = 2.2GeV^2$ and $m_c = 1.49GeV$	1323 / 1101
Parameterization variations	
B_s	1319 / 1101
D_s	1321 / 1101
$D_{\bar{u}}$	1318 / 1101
D_d	1321 / 1101
D_{d_v}	1320 / 1101
D_{u_v}	1320 / 1101
D_g	1319 / 1101
F_{u_v}	1321 / 1101
F_{d_v}	1323 / 1101

Vary model/parameterisation, fit new PDFs, take difference as uncertainty.

- **Model uncs.**: Up/Down variations, summed in quadrature.
- **Param. uncs.**: Asymm envelope (largest variation counts)
- **Total unc** $=$ exp $\oplus$ model $\oplus$ param

Framework

All implemented in the xFitter package,
https://www.xfitter.org/
Cross-checked with Oxford fitting code.

- Q^2 evolution and predictions to NNLO in QCD
- ATLAS NLO theory fast-calculation using APPLGRID with K-factors correcting to NNLO in QCD
  - EW theory to NLO and NP corrections also using K-factors

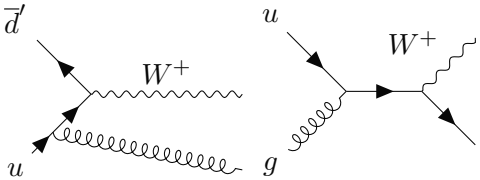
More details in document.

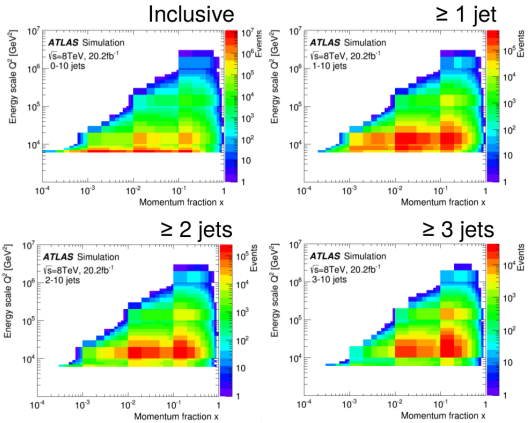
ATLASepWZVjet20

V + jets?

Aim: Add V + jets @ 8TeV to the previous fit for further constraints.

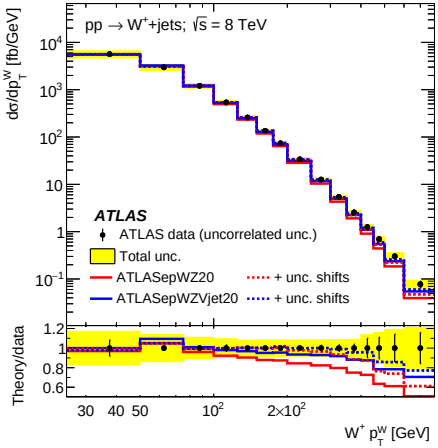
Including jet gives sensitivity to higher x and Q^2, while also providing sensitivity to gluon already at LO.

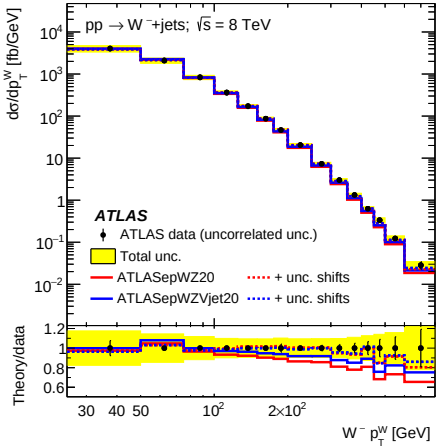




Plots: arXiv:1711.03296

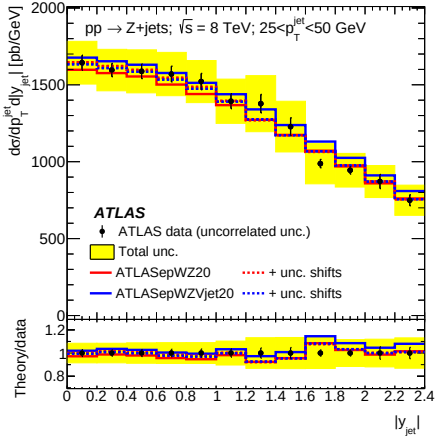
Data driving the change - W + jets

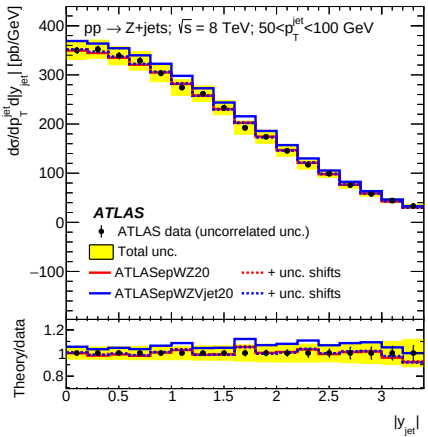




Spectrum used is p_T^W. Better fit to both W^+ and W^-, more extreme change in the former.

Data driving the change - Z + jets

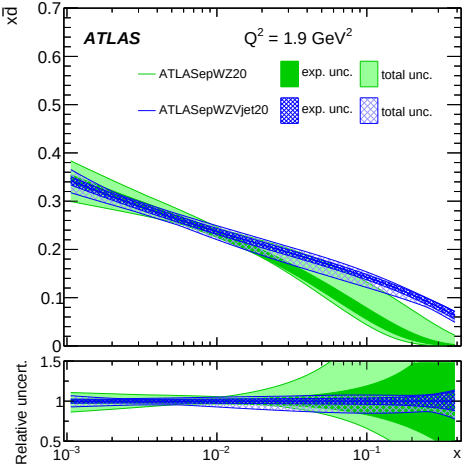


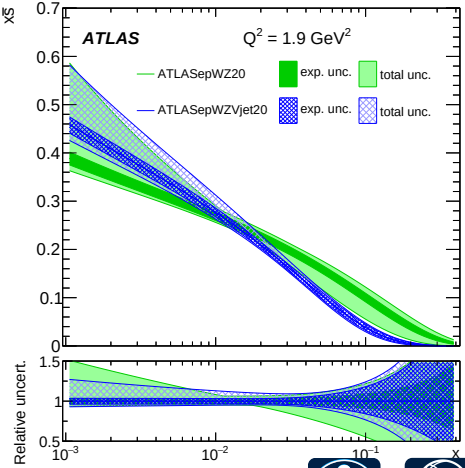


Change in normalisation of prediction.
Similar for other p_T bins (see backups).

ATLASepWZVjet20

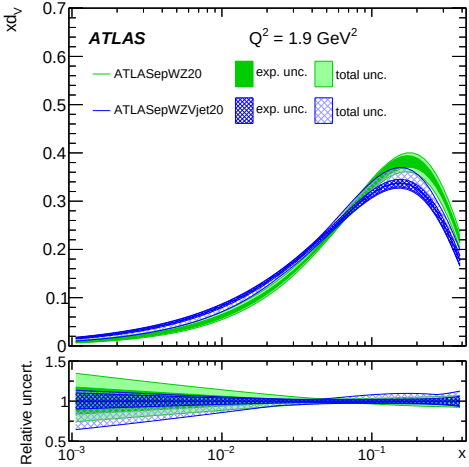
Uncertainty in down-type sea constrained in comparison to fit without V + jets.

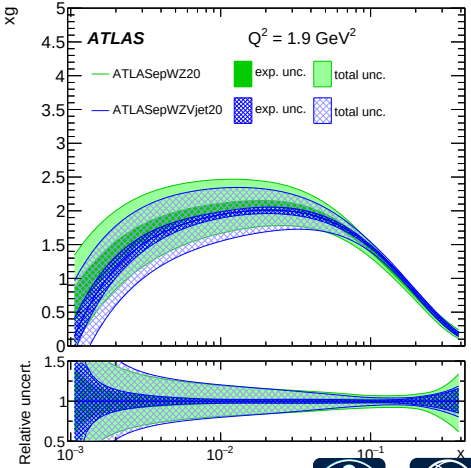




ATLASepWZVjet20

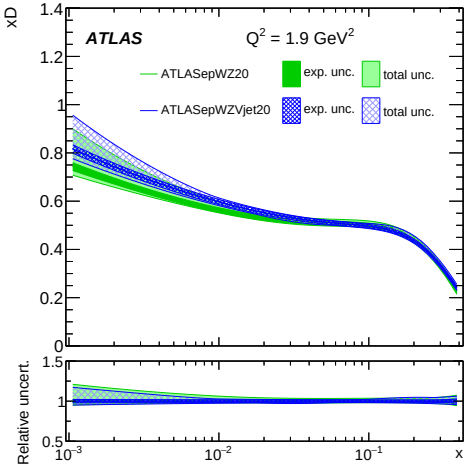
d_v and gluon exhibit similar uncertainties, with change in central position.

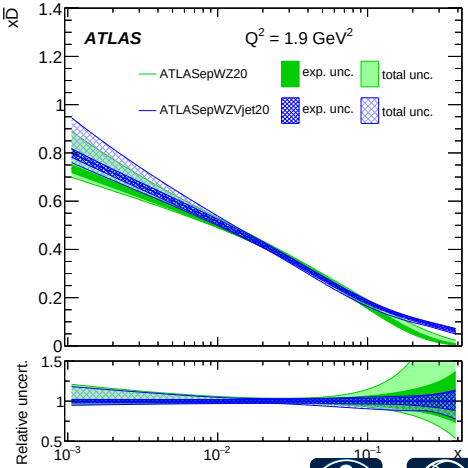




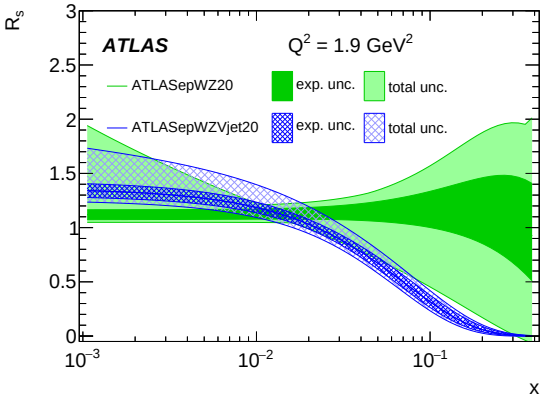
ATLASepWZVjet20

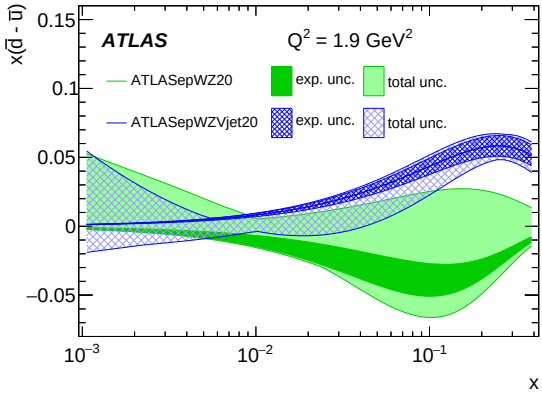
Changes are such that $D = d_v + \bar{d} + \bar{s}$ and $\bar{D} = \bar{d} + \bar{s}$ are maintained in mid-x.





New data provides constraining power at $x \gtrsim 0.02$.

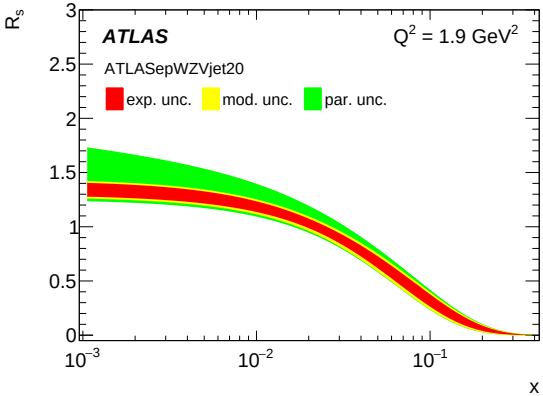


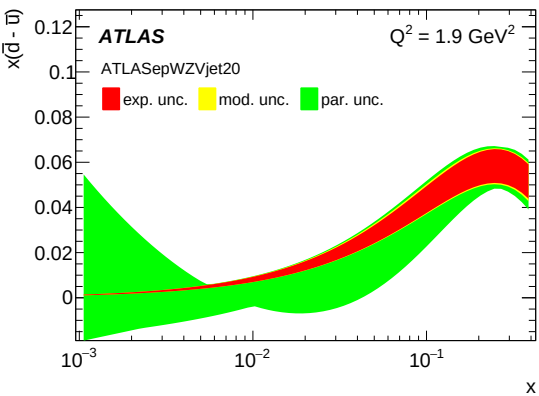


$R_s = (s + \bar{s})/(\bar{u} + \bar{d})$

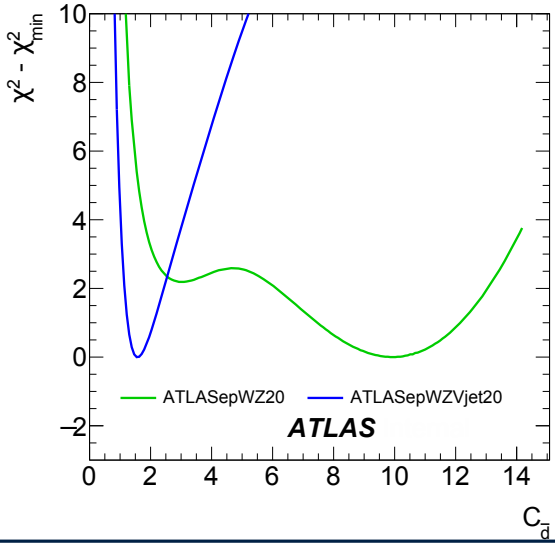
ATLASepWZVjet20

3-band uncertainties: experimental, model and parameterisation uncertainties.





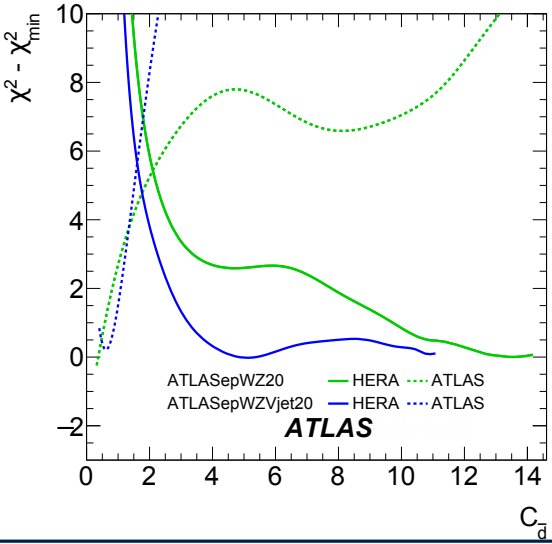
χ^2 scans



We present a scan of χ^2 along the $C_{\bar{d}}$ fit parameter, where $x\bar{d} \sim (1-x)^{C_{\bar{d}}}$.

- Double minimum observed in ATLASepWZ20
- V **+ jets breaks degeneracy**
- Highly constrained, favouring low $C_{\bar{d}}$ and therefore higher $\bar{d}$ at high x.

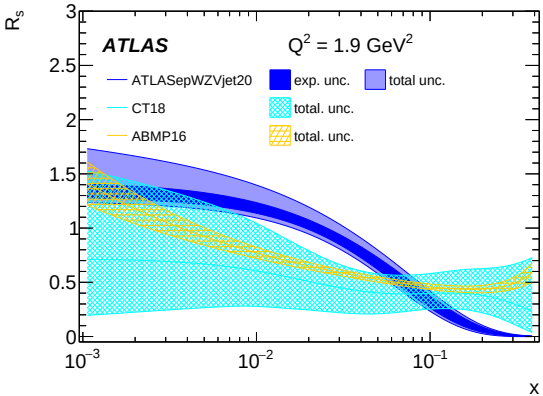
Partial χ^2 scans

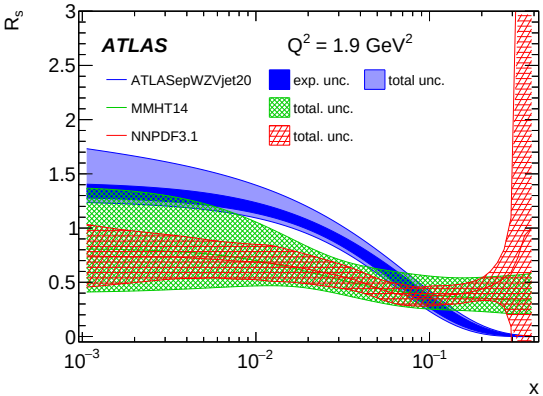


We present a scan of χ^2 along the $C_{\bar{d}}$ fit parameter, where $x\bar{d} \sim (1-x)^{C_{\bar{d}}}$.

- Both ATLAS datasets better described by fit at low $C_{\bar{d}}$.
- ie. 7 TeV W, Z better described by new fit position with falling R_s and $\bar{d} > \bar{u}$ at high x.

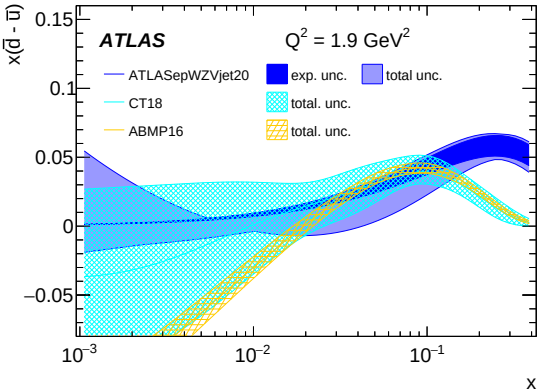
Comparisons to global PDF sets: strange ratio

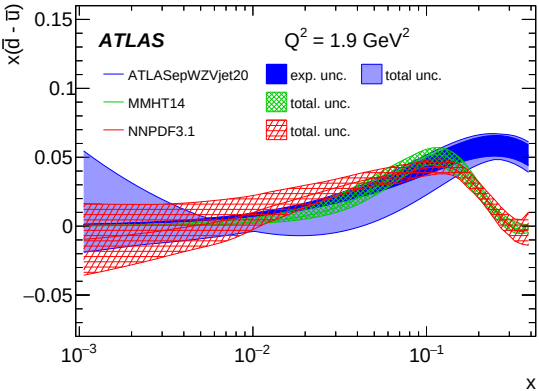




Falling R_s distribution gives good consistency at $x \approx 0.1$, but more suppressed higher.

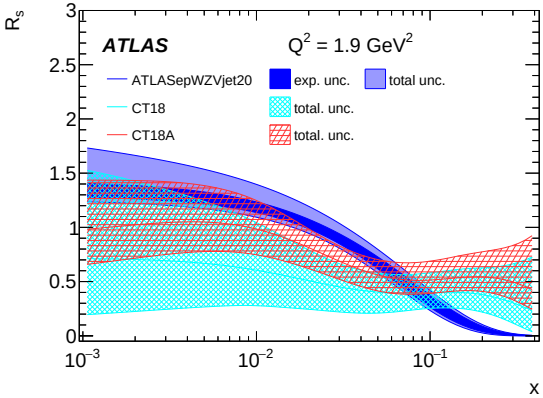
Comparisons to global PDF sets: $\bar{d} - \bar{u}$

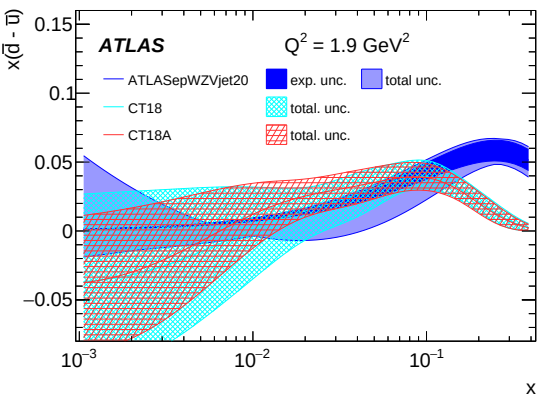




Much better consistency with global fits up to $x \approx 0.1$, tension thereafter.

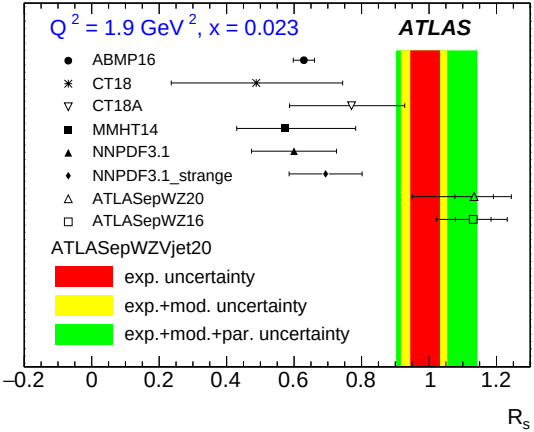
Comparisons to global PDF sets





CT18A = CT18 + ATLAS W, Z. Increased R_s distribution but only small effect on $\bar{d} - \bar{u}$.

To conclude...



- Presented the latest in the ATLAS PDF fits: **ATLASepWZVjet20**
- More constrained down-type sea at high x, falling R_s distribution, $\bar{d} > \bar{u}$.
- Better agreement with global PDFs at around $x = 0.1$, some tension higher.
- **Still much more potential, and much to come!**

Backups

Thanks for listening

χ^2 tables

Fit	ATLASepWZVjet20
Total χ^2/NDF	1460 / 1198
HERA partial χ^2/NDP	1132 / 1016
HERA correlated χ^2	50
HERA log penalty χ^2	−12
ATLAS W, Z partial χ^2/NDP	113 / 105
ATLAS W + jets partial χ^2/NDP	25 / 30
ATLAS Z + jets partial χ^2/NDP	82 / 63
ATLAS correlated χ^2	65
ATLAS log penalty χ^2	6

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

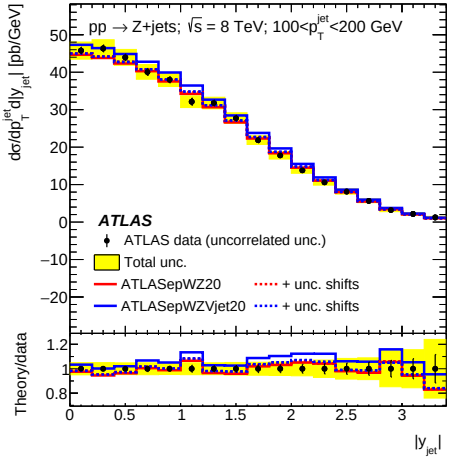
χ^2 table across different fits, split in to HERA and ATLAS datasets. Comparison to previous fits demonstrates consistency in data. New data exhibits reasonable goodness-of-fit.

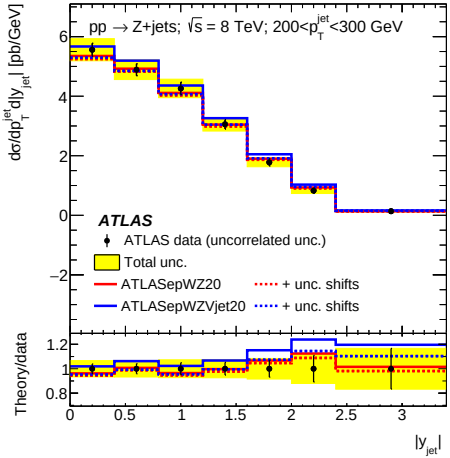
χ^2 tables

Nominal χ^2/NDF	1460 / 1198
Parameter variations	
$A_{\overline{u}} \neq A_{\overline{d}}$	1458 / 1197
$A_{\overline{u}} \neq A_{\overline{d}}$ & $B_{\overline{u}} \neq B_{\overline{d}}$	1454 / 1196
$B_{\overline{s}} \neq B_{\overline{d}}$	1459 / 1197
$B_{\overline{u}} \neq B_{\overline{d}}$	1459 / 1197
$D_{\overline{d}}$	1459 / 1197
D_{d_v}	1460 / 1197
$D_{\overline{s}}$	1460 / 1197
D_{u_v}	1457 / 1197
$E_{\overline{d}}$	1459 / 1197
$E_{\overline{s}}$	1460 / 1197
$E_{\overline{u}}$	1459 / 1197
F_{d_v}	1460 / 1197
$F_{\overline{s}}$	1460 / 1197
$F_{\overline{u}}$	1458 / 1197
F_{u_v}	1456 / 1197
Model variations	
$Q^2_{\rm min} = 12.5\ GeV^2$	1393 / 1149
$Q^2_{\rm min} = 7.5\ GeV^2$	1529 / 1238
$Q^2_0 = 2.2\ GeV^2$ and $m_c = 1.49\ GeV$	1465 / 1198
$Q^2_0 = 1.6\ GeV^2$ and $m_c = 1.37\ GeV$	1458 / 1198
$\alpha_{\rm S}(m_Z) = 0.120$	1463 / 1198
$\alpha_{\rm S}(m_Z) = 0.116$	1458 / 1198
$m_b = 4.75\ GeV$	1461 / 1198
$m_b = 4.25\ GeV$	1458 / 1198

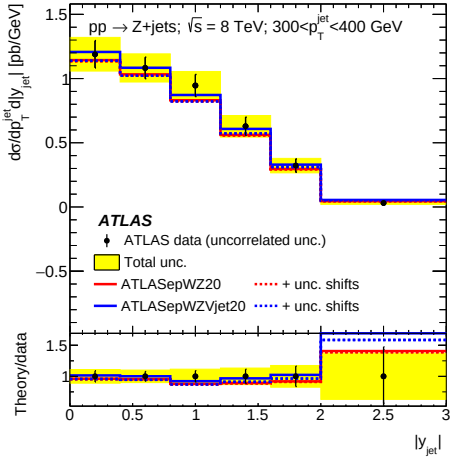
Largest decrease in χ^2 for a single parameter is four points – not significant enough to be included in central param.

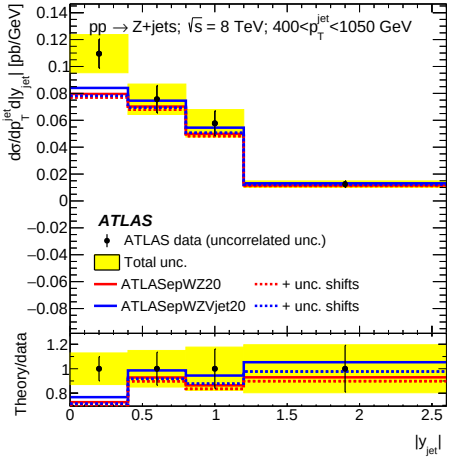
More Z + jets data plots



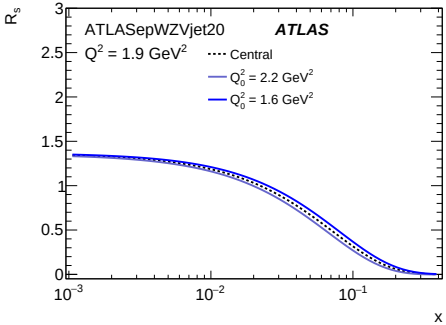


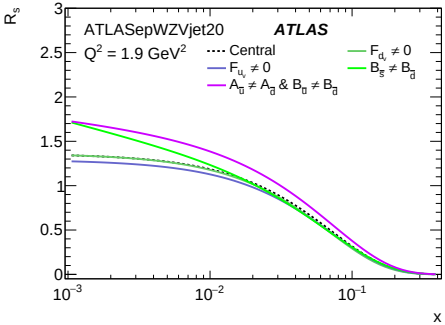
More Z + jets data plots pt. 2





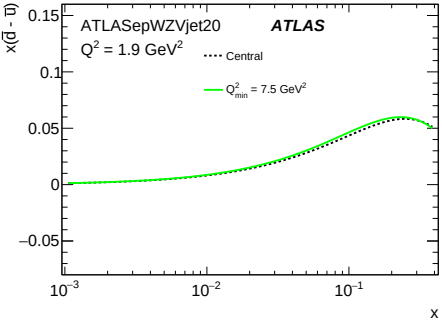
ATLASepWZVjet20

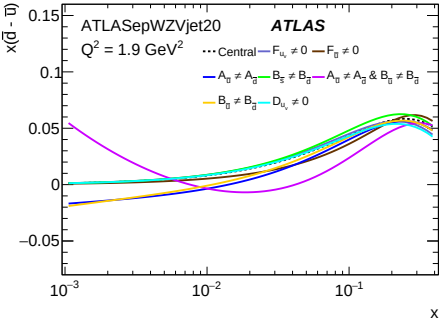




Plots depicting which variations give the most difference are available and in aux. material.

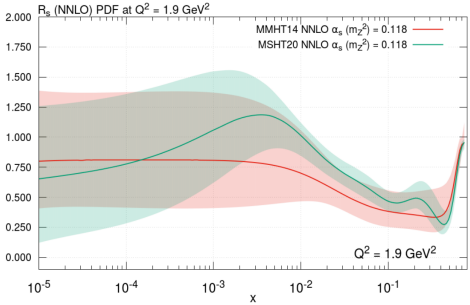
ATLASepWZVjet20

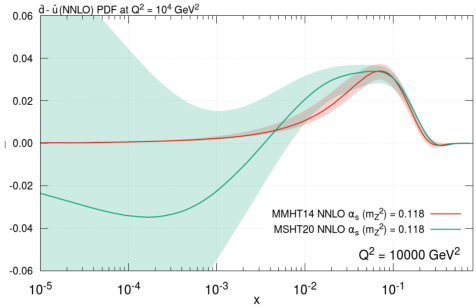




Plots depicting which variations give the most difference are available and in aux. material.

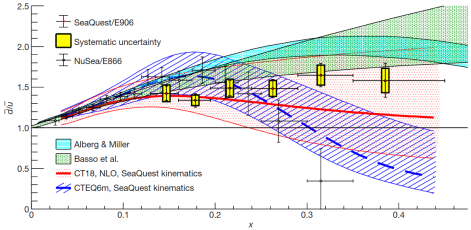
MSHT20





Comparison between MSHT20 and MMHT14 (arXiv:2012.04684)

New Seaquest results



Article.

New results give an increased $\bar{d}/\bar{u}$ distribution relative to previous results and global PDFs. Studies of ATLAS data ongoing.