

Precision studies of the post-CT18 LHC Drell-Yan data in the CTEQ-TEA global analysis

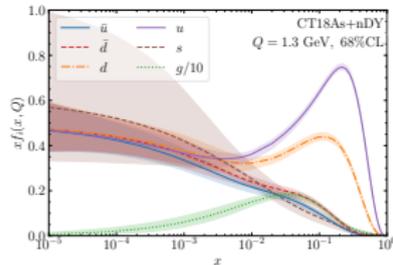


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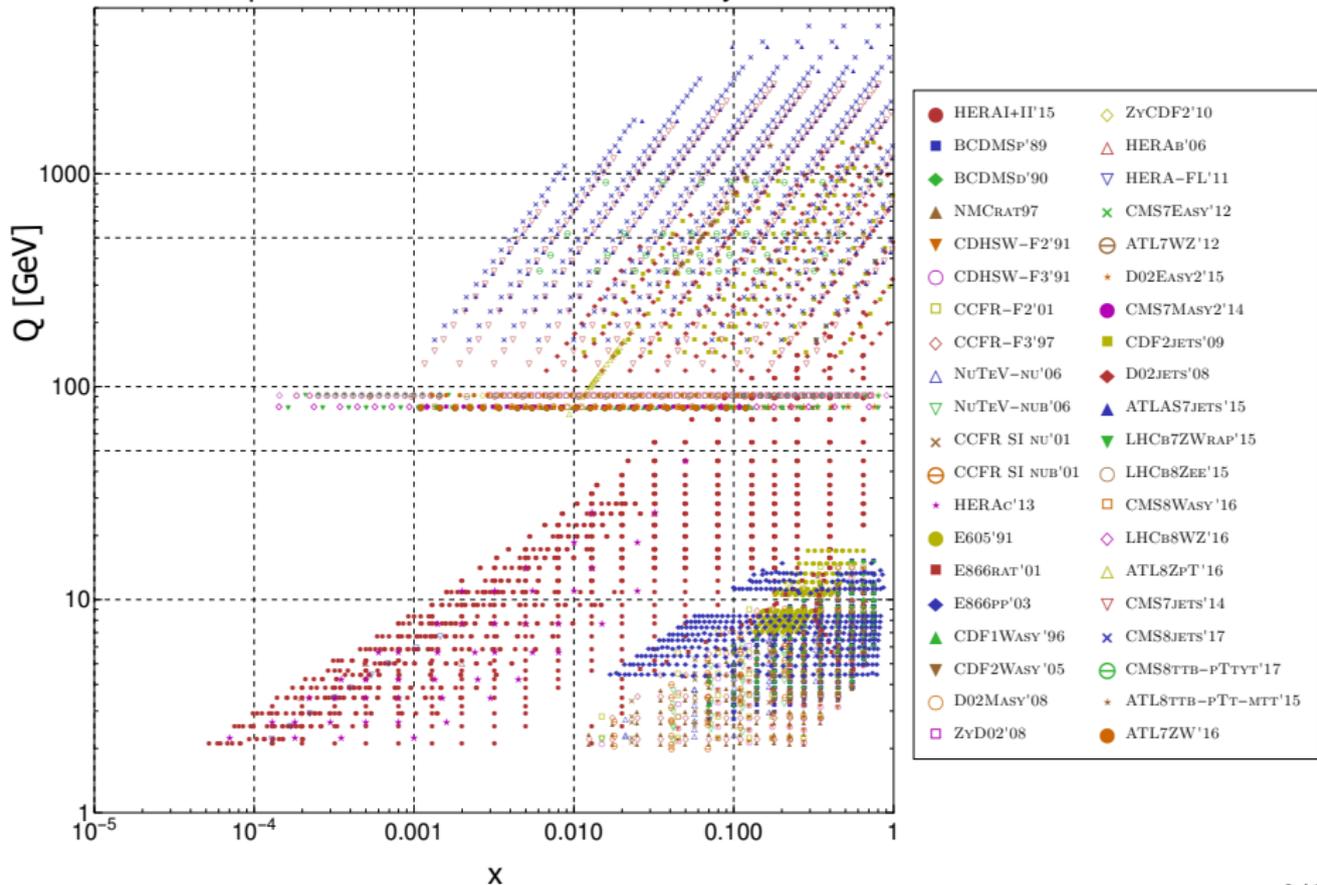
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In collaboration with
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T.-J. Hou (South China U.), C.-P. Yuan (MSU)



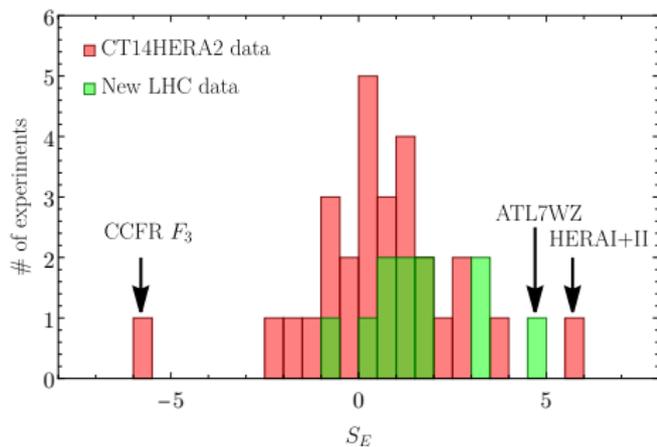
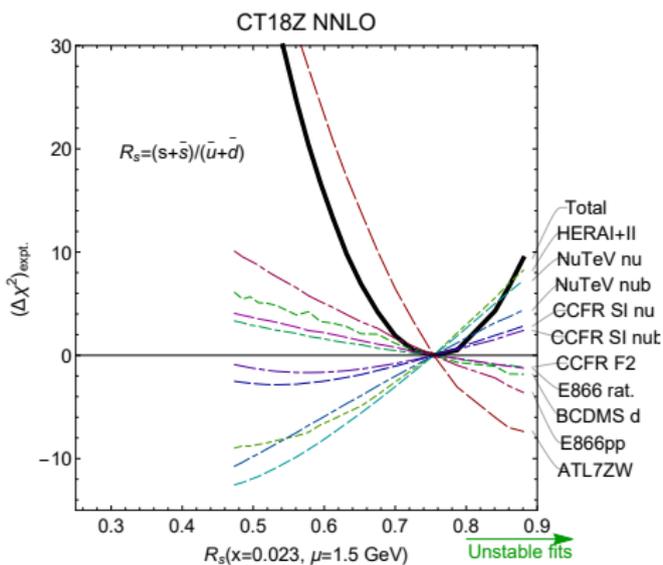
Global data included in the CT18 global analysis

Experimental data in CT18 PDF analysis



Lessons from the CT18 PDF family

- CT18 family PDFs include the LHC data up to the mid-2018.
- CT18A/Z PDFs include the in-tension data ATLAS 7 TeV W, Z , which enlarge strangeness PDF in the small and middle x region.
- CT18As incorporates more flexible strangeness PDF parameterization with $s \neq \bar{s}$, which relaxes this tension [See T.-J. Hou's talk].



$$S_E = \sqrt{\chi^2} - \sqrt{2N_E - 1}$$

Drell-Yan data in CT18(Z) global analyses

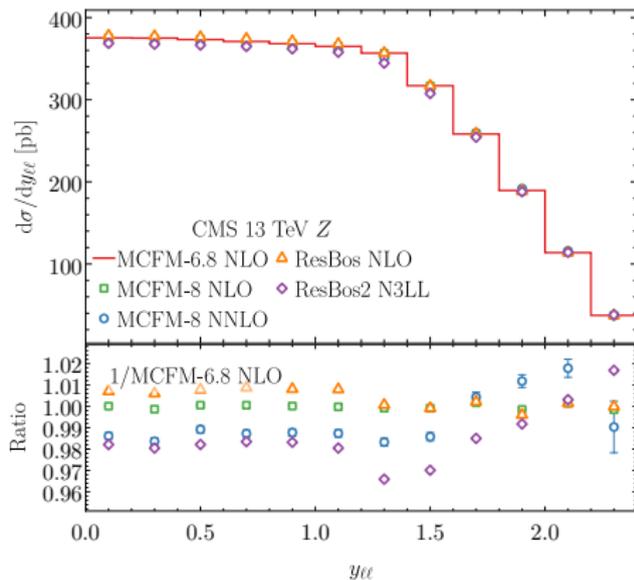
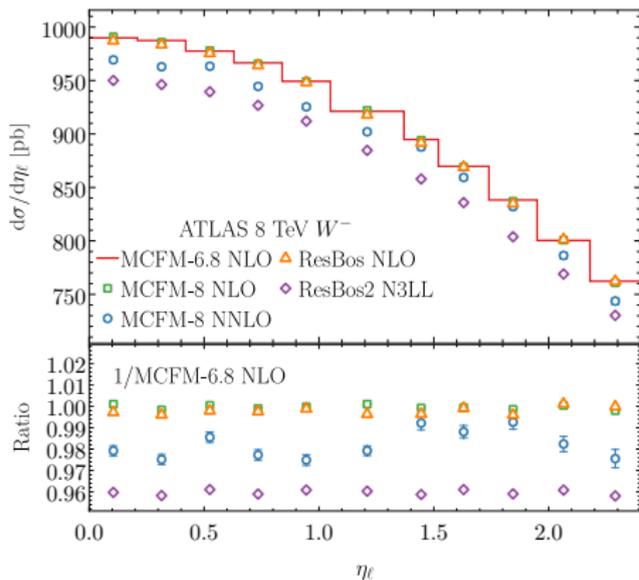
ID	Expt.	N_{pt}	χ^2	χ^2/N_{pt}	S_E
CT14HERA2 data					
201	E605DY	119	103.4(102.4)	0.9(0.9)	-1.0(-1.1)
203	E866 $\sigma_{pd}/(2\sigma_{pp})$	15	16.1(17.9)	1.1(1.2)	0.3(0.6)
204	E866 $Q^3 d^2\sigma_{pp}/(dQ dx_F)$	184	244(240)	1.3(1.3)	2.9(2.7)
225	CDF1Z $A(e)$	11	9.0(9.3)	0.8(0.8)	-0.3(-0.2)
227	CDF2W $A(e)$	11	13.5(13.4)	1.2(1.2)	0.6(0.6)
234	DØ2W $A(\mu)$	9	9.1(9.0)	1.0(1.0)	0.2(0.1)
260	DØ2Z $y_{\ell\ell}$	28	16.9(18.7)	0.6(0.7)	-1.7(-1.3)
261	CDF2Z $y_{\ell\ell}$	29	48.7(61.1)	1.7(2.1)	2.2(3.3)
266	CMS7W $A(\mu)$	11	7.9(12.2)	0.7(1.1)	-0.6(0.4)
267	CSM7W $A(e)$	11	4.6(5.5)	0.4(0.5)	-1.6(-1.3)
268	ATL7WZ ₍₂₀₁₂₎	41	44.4(50.6)	1.1(1.2)	0.4(1.1)
281	DØ2W $A(e)$	13	22.8(20.5)	1.8(1.6)	1.7(1.4)
New LHC data					
245	LHCb7WZ(μ)	33	53.8(39.9)	1.6(1.2)	2.2(0.9)
246	LHCb8Z(e)	17	17.7(18.0)	1.0(1.1)	0.2(0.3)
248	ATL7WZ ₍₂₀₁₆₎	34	287.3(88.7)	8.4(2.6)	13.7(4.8)
249	CMS8W $A(\mu)$	11	11.4(12.1)	1.0(1.1)	0.2(0.4)
250	LHCb8WZ(μ)	34	73.7(59.4)	2.1(1.7)	3.7(2.6)
253	ATL8ZpT	27	30.2(28.3)	1.1(1.0)	0.5(0.3)

New post-CT18 LHC Drell-Yan data

Boson	\sqrt{s}	Lumi	Observable	Ref.
ATLAS				
W, Z	2.76	4.0 pb ⁻¹	$\sigma^{\text{fid,tot}}$	1907.03567
W, Z	13	81.0 pb ⁻¹	σ^{fid}	1603.09222
W, Z	5.02	25.0 pb ⁻¹	$(\eta_\ell, y_{\ell\ell})$	1810.08424
Z	8	20.2 fb ⁻¹	$(m_{\ell\ell}, y_{\ell\ell})$	1710.05167
$W \rightarrow \mu\nu$	8	20.2 fb ⁻¹	η_μ	1904.05631
Z	13	36.1 fb ⁻¹	$p_T^{\ell\ell}$	1912.02844
CMS				
Z	13	2.8 fb ⁻¹	$m_{\ell\ell}$	1812.10529
Z	13	35.9 fb ⁻¹	(y, p_T, ϕ^*)	1909.04133
W	13	35.9 fb ⁻¹	$\sigma^{\text{fid}}, y_W, (\eta_\ell, p_T^\ell)$	2008.04174
LHCb				
$W \rightarrow e\nu$	8	2.0 fb ⁻¹	η_e	1608.01484
Z	13	294 pb ⁻¹	$\sigma^{\text{fid}}, (y, p_T, \phi^*)$	1607.06495
$Z \rightarrow \mu\mu$	13	5.1 fb ⁻¹	$\sigma^{\text{fid}}, (y, p_T, \phi^*)$	2112.07458

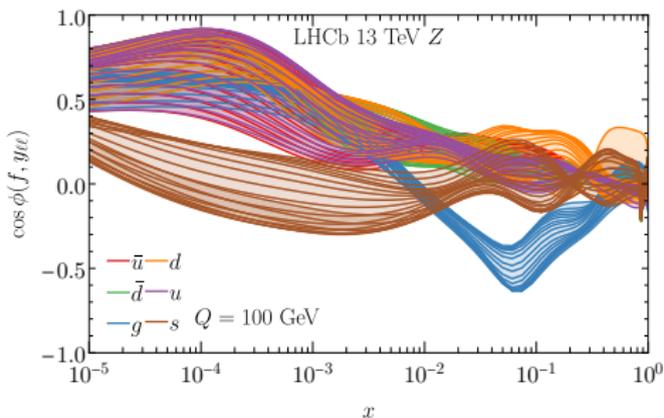
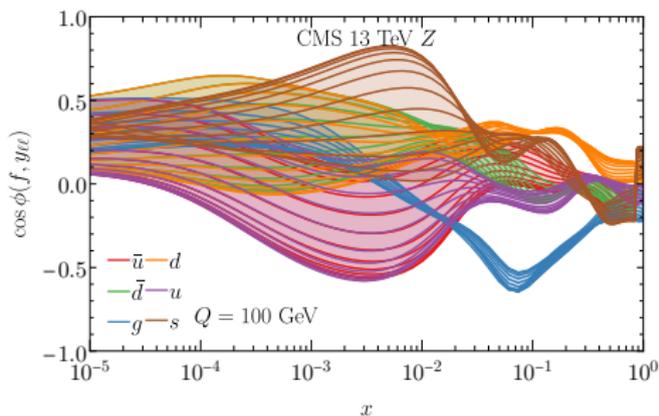
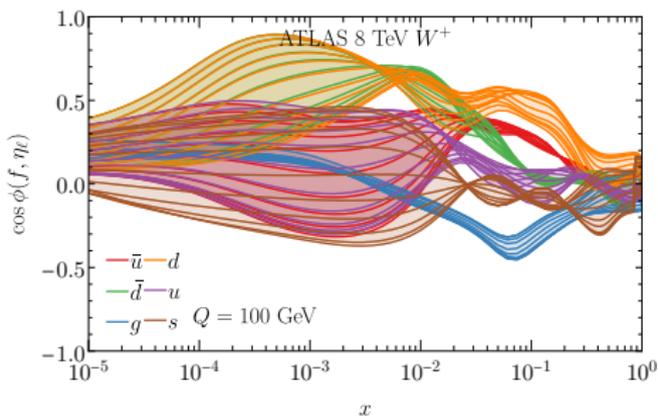
We mainly focus on (pseudo)rapidity distributions (~ 300 data points) in this work.

Theoretical calculations



- We have checked that the NLO fixed order calculation agrees well between MCFM and ResBos.
- ResBos (NNLO+N3LL) gives an overall shift as a result of the fiducial cuts.
- NNLO fixed-order calculations suffer a little from the Monte-Carlo uncertainty.

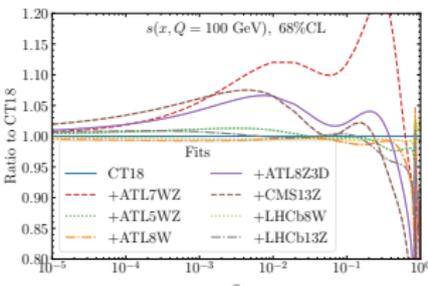
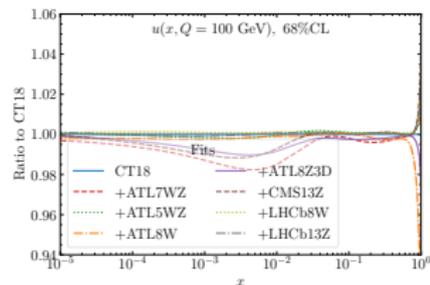
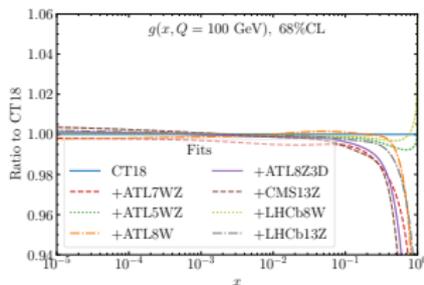
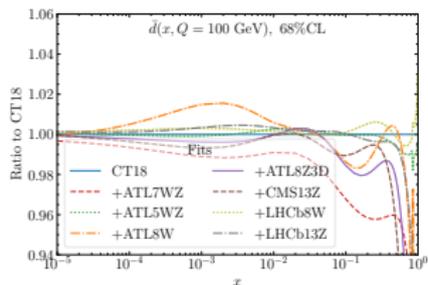
The correlation between data and PDFs



- Large correlations to d -quark and sea PDFs in the range $10^{-4} \lesssim x \lesssim 10^{-2}$.
- LHCb forward data probe much smaller x .
- Z data are sensitive to strangeness PDF.

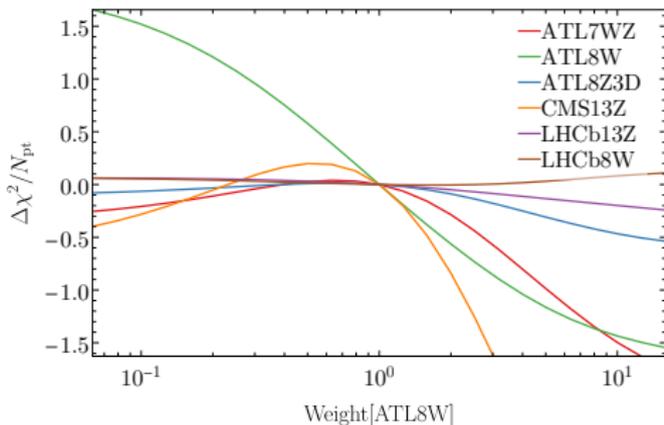
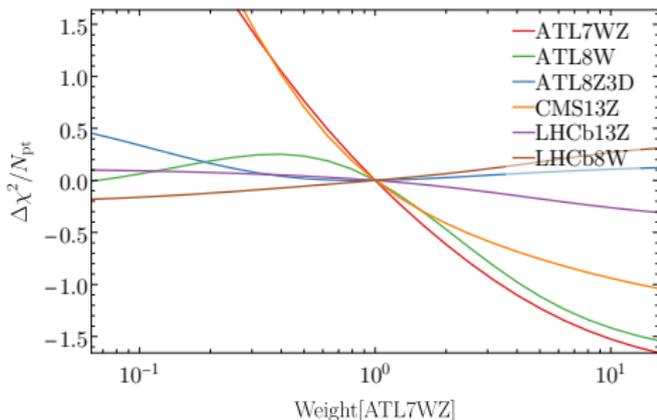
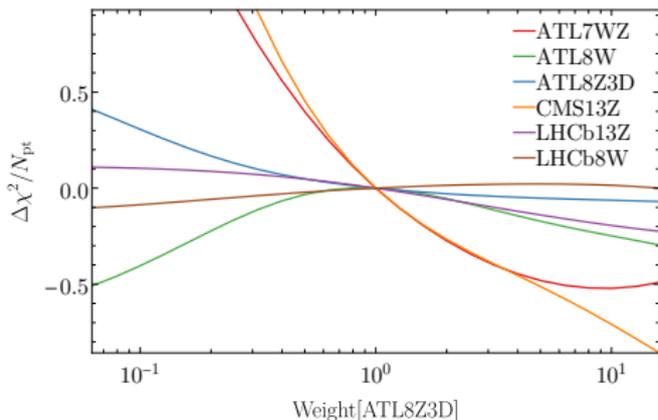
Impacts from ePump updating or individual fits

ID	Experiment	N_{pt}	χ^2/N_{pt}				
			Pre-fit [†]	ePump [†]	CT18	CT18A	CT18As
215	ATL5WZ	27	1.15	0.96	1.07	0.74	0.71
211	ATL8W	22	5.23	3.32	2.78	3.03	2.79
214	ATL8Z3D	188	1.95	1.18	1.16	1.13	1.14
212	CMS13Z	12	9.24	2.93	2.75	1.89	2.02
216	LHCb8W	(16)14	(3.48)1.52	(3.24)1.45	(2.81)1.33	(1.89)1.45	(3.00)1.52
	LHCb13ZII	18	0.89	0.88	0.99	0.92	—
213	LHCb 13Z	(18)16	(2.39)1.27	(2.33)1.17	(2.55)1.12	(2.49)1.12	(2.28)0.87



- ATL8Z3D and CMS13Z enhance strangeness.
- ATL8W pull $d(\bar{d})$ to the opposite direction from ATLAS 7 TeV W, Z around $x \sim 10^{-3}$.
- A big χ^2 for ATL8W and CMS13Z, reflecting tensions.
- More flexible parameterizations in CT18As can relax this tension.

Consistency between ATLAS 7 and 8 TeV data

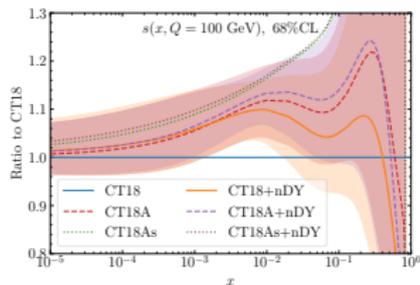
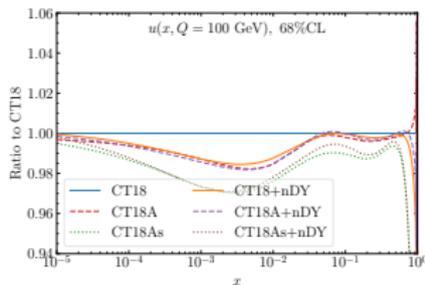
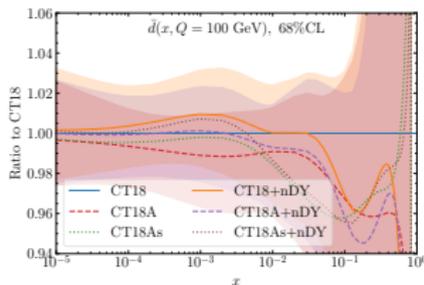


- ATL8Z3D and CMS13Z data are consistent with 7 TeV $W(Z)$ data.
- ATL8W data show a tension with ATL7WZ (cf. $d(\bar{d})$ PDF around $x \sim 10^{-3}$)

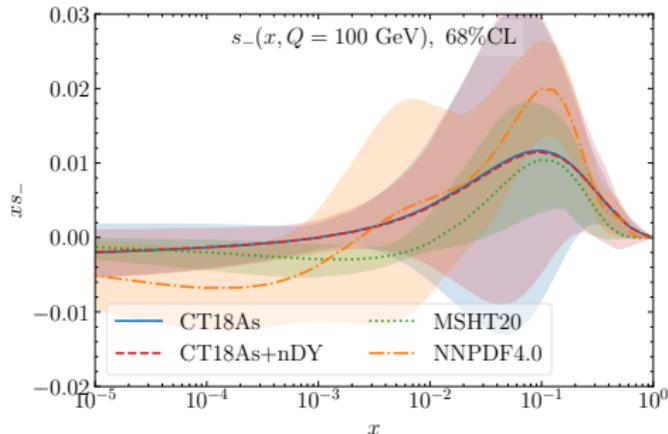
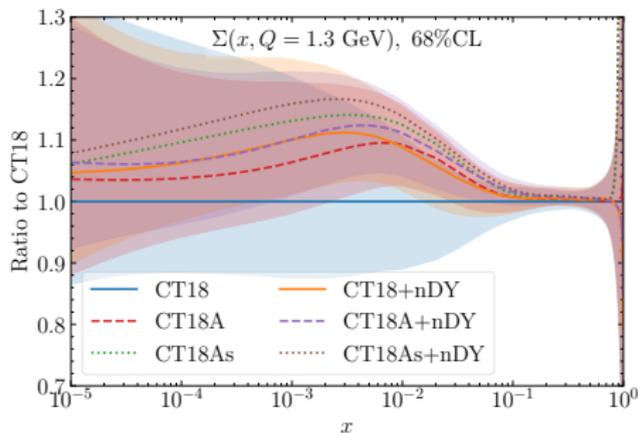
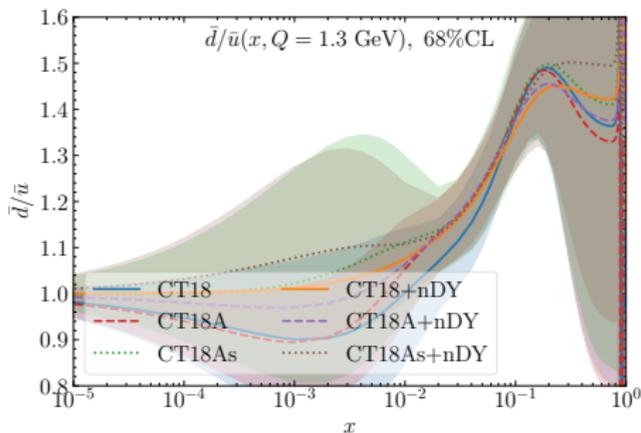
Simultaneous fits

ID	Experiment	N_{pt}	χ^2/N_{pt}					
			CT18	CT18A	CT18As	ATLASpdf21	MSHT20	NNPDF4.0
215	ATL5WZ	27	0.89	0.70	0.70	–	–	–
211	ATL8W	22	2.75	2.94	2.79	1.41	2.61	[3.50]
214	ATL8Z3D	188	1.14	1.13	1.17	1.13(184)	1.45(59)	1.22(60)
212	CMS13Z	12	2.45	2.02	1.73	–	–	–
216	LHCb8W	14	1.41	2.02	1.73	–	–	–
213	LHCb13Z	16	1.24	0.98	0.82	–	–	–
248	ATL7WZ	34	2.59	2.51	2.31	1.24(55)	1.91(61)	1.67(61)
Total 3994/3953/3959 points			1.20	1.20	1.19	–	–	–

- The global fitted results can be deduced from the individual fits.
- The tension between the ATL8W and ATL7WZ can be relaxed (but not completely resolved) with a more flexible strangeness parameterization.
- With CT18As, the impact on strangeness is minimal, but on $d(\bar{d})$ remains

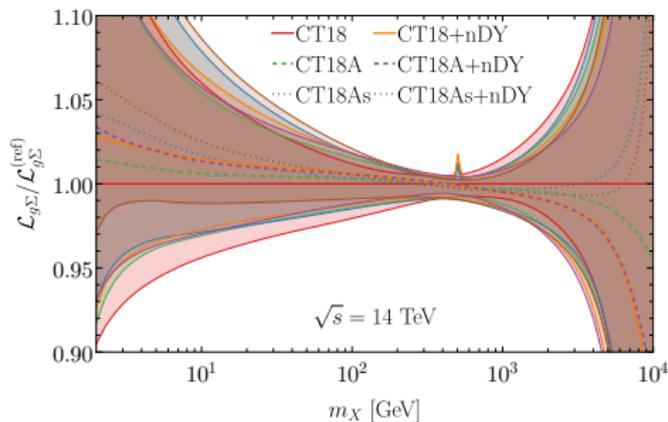
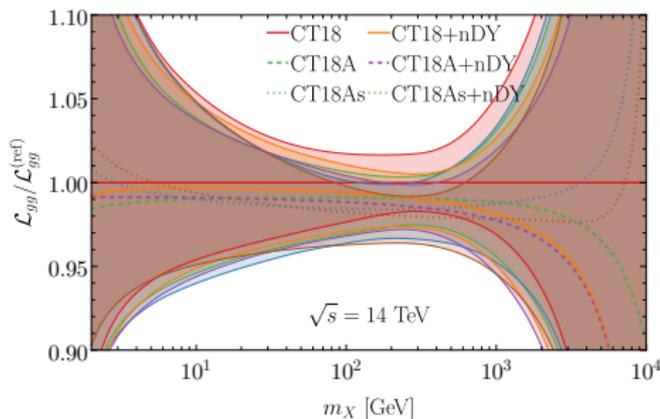
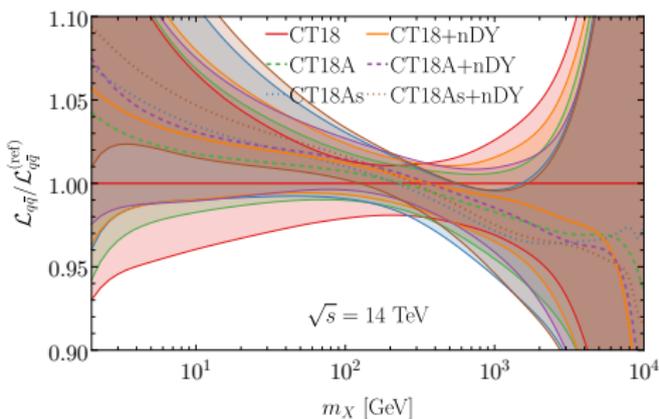


Flavor combinations



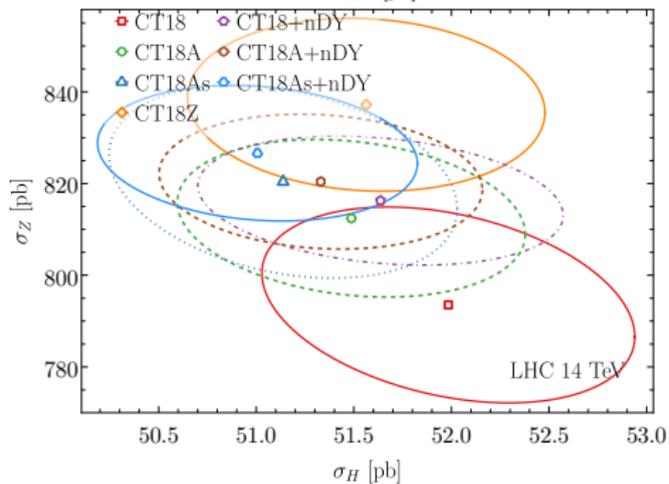
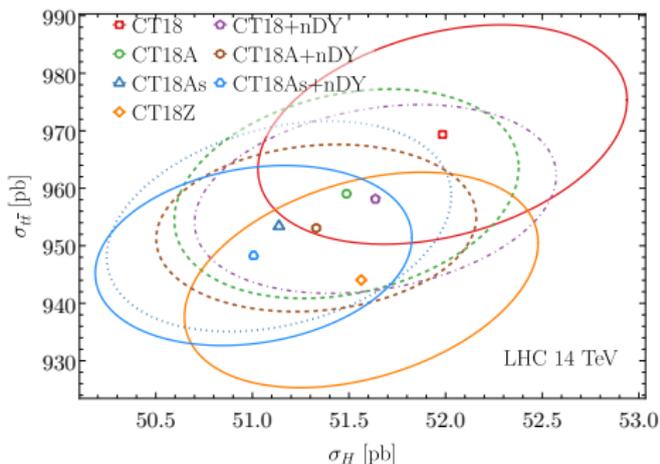
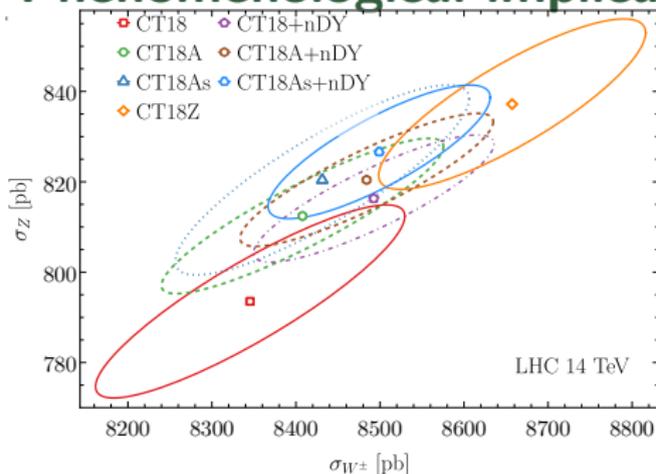
- The enhancement of \bar{d}/\bar{u} is mainly driven by the ATL8W data
- The flavor-singlet PDF gets enhanced, with error bands shrunk.
- A similar minimal change in the $s_- = s - \bar{s}$, larger than the MSHT20, but smaller than NNPDF4.0 at large x .

Parton Luminosities



- Similar to the ATL7WZ data, the new Drell-Yan data will increase (decrease) the quark-related luminosity at low (high) invariant mass, but reduce the pure gluon one.
- The error bands are reduced.
- The flexible strangeness parameterization in the CT18As can enlarge the variation of quark-related luminosity.

Phenomenological implications



- Both AT7LWZ and new DY data can increase the single boson production cross sections.
- The post-CT18 Drell-Yan data pull the CT18 predictions to the CT18Z direction.
- The error ellipses get smaller, reflecting the constraining power.

Summary and prospects

- Recall that we found tensions between the ATL7WZ precision data with other sets in CT18. For that, we release an alternative PDF set, CT18A.
- In this work, we have carefully examined the impact of new Drell-Yan data sets on the CT18 PDFs.
- We find that most of the new Drell-Yan data sets (especially ATL8Z3D, and CMS13Z) are consistent with the ATL7WZ, which enhances the strangeness, but to a smaller extent, than ATL7WZ.
- But we do find a tension from the ATL8W, and a minor one from LHCb8W, which pull the $d(\bar{d})$ PDFs to the opposite direction of ATL7WZ.
- With the accumulation of these new DY data sets, the PDF error bands are shrunk, reflecting the constraining power.
- The quark-related luminosities get enhanced at a low invariant mass, reflecting the impact on the flavor singlet PDFs.
- The post-CT18 LHC Drell-Yan data pull the CT18 luminosities and predictions to the CT18Z direction.