Recent developments in the CTEQ-TEA global analysis

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CTEQ-TEA group

- CTEQ – Tung et al. (TEA)
  in memory of Prof. Wu-Ki Tung, who established CTEQ Collaboration in early 90's.
- Current members:
  Sayipjamal Dulat, Tie-Jiun Hou, Ibrahim Sitiwaldi (Xinjiang U.)
  Jun Gao (Shanghai Jiaotong U.)
  Marco Guzzi (Kennesaw State U.)
  Pavel Nadolsky, Timothy Hobbs, Keping Xie, Boting Wang (Southern Methodist U.)
  Joey Huston, Jon Pumplin, Carl Schmidt, Dan Stump, Jan Winter, C.-P. Yuan (Michigan State U.)

CT18 in a nutshell

- Start with CT14-HERAII (HERAII combined data released after publication of CT14)
- PDFSense (arXiv:1803.02777) to determine quantitatively which data will have impact on global PDF fit
- ePump (arXiv:1806.07950) on quickly exploring the impact of data prior to global fit within the Hessian approximation
- Examine a wide range of PDF parameterizations
- Use as much relevant LHC data as possible using applgrid/fastNLO interfaces to data sets, with NNLO/NLO K-factors, or fastNNLO tables in the case of top pair production
- Implement a parallelization of the global PDF fitting to allow for faster turn-around time
- Lagrange Multiplier studies to examine constraints of specific data sets on PDF distributions, and (in some cases) the tensions (useful information; will spend some time on this)

How sensitive is an experiment to a PDF?
Can we know it before doing the global fit?

PDFsense predicts that the CMS jet data will have the largest impact

PDFSense estimates…

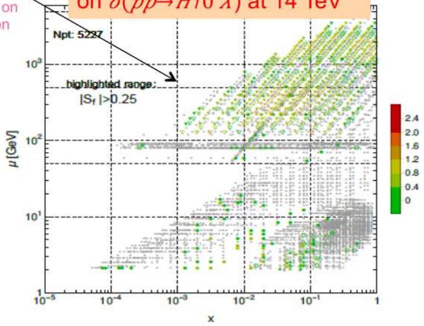
- ranking of strength of sensitivities of experimental data sets to PDF flavors without (re-)doing the full global fit
- impact on global fit requires both correlation and sensitivity

for example, HERAII, CMS jets provide information on gluon and on Higgs σ

No.	Exp. ID	N_{pt}	$\sum_f \lvert S_f \rvert$	$\sum_f \langle \lvert S_f \rvert \rangle / N_f$	$\lvert S_{\bar u} \rvert$	$\langle \lvert S_{\bar u} \rvert \rangle$	$\lvert S_{\bar d} \rvert$	$\langle \lvert S_{\bar d} \rvert \rangle$	$\lvert S_g \rvert$	$\langle \lvert S_g \rvert \rangle$	$\lvert S_u \rvert$	$\langle \lvert S_u \rvert \rangle$	$\lvert S_d \rvert$	$\langle \lvert S_d \rvert \rangle$	$\lvert S_s \rvert$	$\langle \lvert S_s \rvert \rangle$
					Rankings											
1	160	1120.	620.	0.0922	A	3	B		A	3	A	3	B		C	
2	545	288	397.	0.234	B	3	B	3	A	1	C		C	3	B	3
3	542	280	359.	0.217	B	3	B	3	A	1	C		C		B	3
4	201	238	225.	0.158	B	2	B	2			C	3				
5	111	86	218.	0.423	C	1	C	1		3	B	1	C	2		
6	204	368	206.	0.0942	B	3	C	3	C		C	3				
7	101	337	184.	0.0909	C				C		B	3	C			
8	104	123	169.	0.229			C	2			C	2	B	2		
9	102	250	141.	0.0938			C		C	3	C	3	C	3		
10	109	96	115.	0.199	C	2	C	2		3	C	2	C	3		
11	538	222	109.	0.0834					C	3						
12	110	69	89.3	0.216		3		3	C	2		3		2		3
13	250	84	82.9	0.165		3	C	3		3		3	C	2		
14	108	85	82.4	0.161		3		3		3		3	C	3		
15	544	236	79.8	0.0573					C	3						
16	268	82	79.3	0.161		3		3				3		3		3
17	249	66	78.3	0.198		3		2				3		2		3
18	252	94	68.5	0.121		3		3				3				3
19	203	30	66.6	0.37	C	1	C	1				3		2		
20	245	66	60.3	0.152		3		3		3		3		3		
21	124	38	58.9	0.258		3		3				3		3	C	1

…kinematical distributions of sensitivities to the PDFs in the $\{x,\mu\}$ plane

Sensitivity to the PDF error on $\sigma(pp \to H^0 X)$ at 14 TeV



2018-03-05

P. Nadolsky, xFitter workshop, Krakow

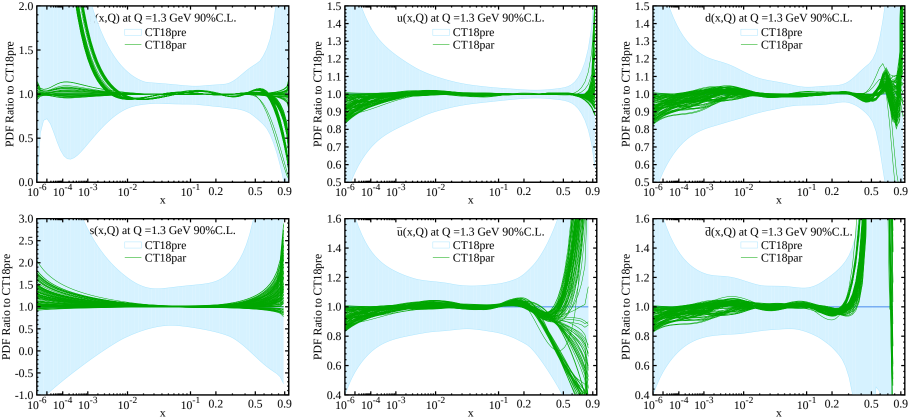
see for example http://metapdf.hepforge.org/PDFSense

LHC data sets included in CT18

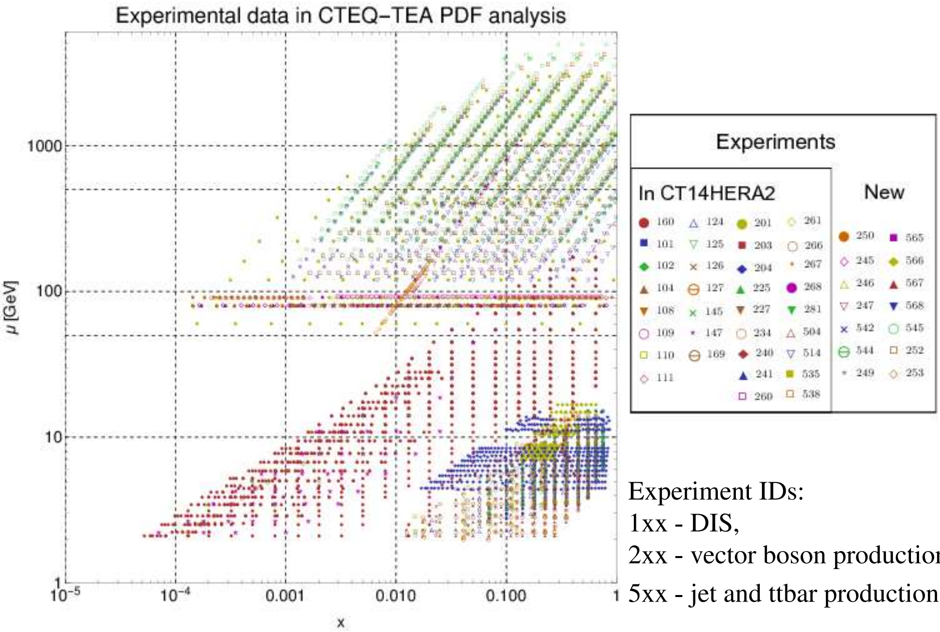
245	1505.07024	LHCb Z (W) muon rapidity at 7 TeV(applgrid)
246	1503.00963	LHCb 8 TeV Z rapidity (applgrid);
249	1603.01803	CMS W lepton asymmetry at 8 TeV (applgrid)
250	1511.08039	LHCb Z (W) muon rapidity at 8 TeV(applgrid)
253	1512.02192	ATLAS 7 TeV Z p_T (applgrid)
542	1406.0324	CMS incl. jet at 7 TeV with R=0.7 (fastNLO)
544	1410.8857	ATLAS incl. jet at 7 TeV with R=0.6 (applgrid)
545	1609.05331	CMS incl. jet at 8 TeV with R=0.7 (fastNLO)
573	1703.01630	CMS 8 TeV tT (p_T, y_t) double diff. distributions (fastNNLO)
580	1511.04716	ATLAS 8 TeV tT p_T and m_{tT} diff. distributions (fastNNLO)
248	1612.03016	ATLAS 7 TeV Z and W rapidity (applgrid) $\rightarrow$ CT18Z

- also uses special small x factorization scale, mc=1.4 GeV
- serious changes in PDFs, so warrants a separate PDF

Non-perturbative parameterization forms



CT18par – sample result of using various non-perturbative parametrization forms.



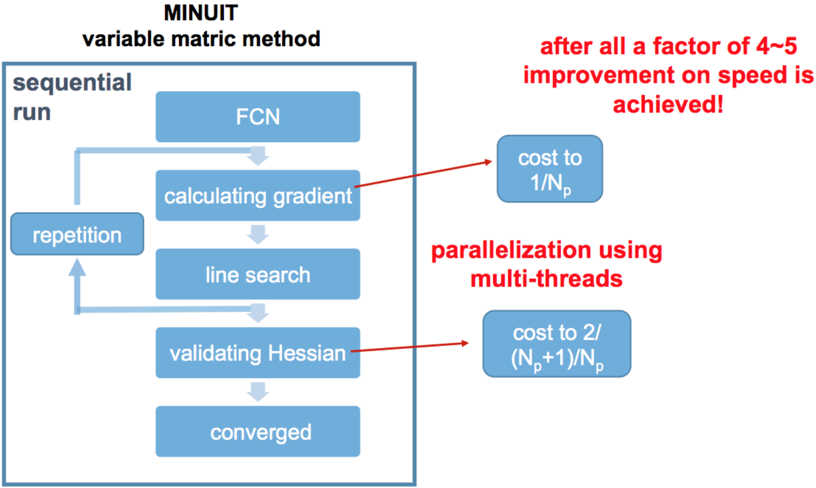
Experiment IDs:
1xx - DIS,
2xx - vector boson production,
5xx - jet and ttbar production

Data treatment in CT18

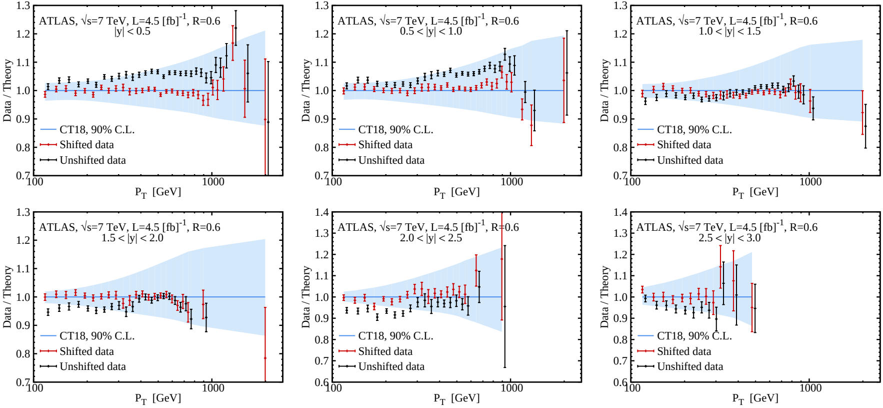
Obs.	Expt.	fast table	NLO code	K-factors	R,F scales
Inclusive jet	ATL 7 CMS 7/8	APPLgrid fastNLO	NLOJet++	NNLOJet	p_T, p_T^1
p_T^Z	ATL 8	APPLgrid	MCFM	NNLOJet	$\sqrt{Q^2 + p_{T,Z}^2}$
W/Z rapidity W asymmetry	LHCb 7/8 ATL 7 CMS 8	APPLgrid	MCFM/aMCfast	FEWZ/MCFM	$M_{W,Z}$
DY (low,high mass)	ATL 7/8 CMS 8	APPLgrid	MCFM/aMCfast	FEWZ/MCFM	Q_{ll}
$t\bar{t}$	ATL 8 CMS 8	fastNNLO			$\frac{H_T}{4}, \frac{m_T}{2}$

Fitting code changes

upgrade to a parallelized version of the fitting code, through rearrangement of the minimization algorithm, rather than a redistribution of the data sets

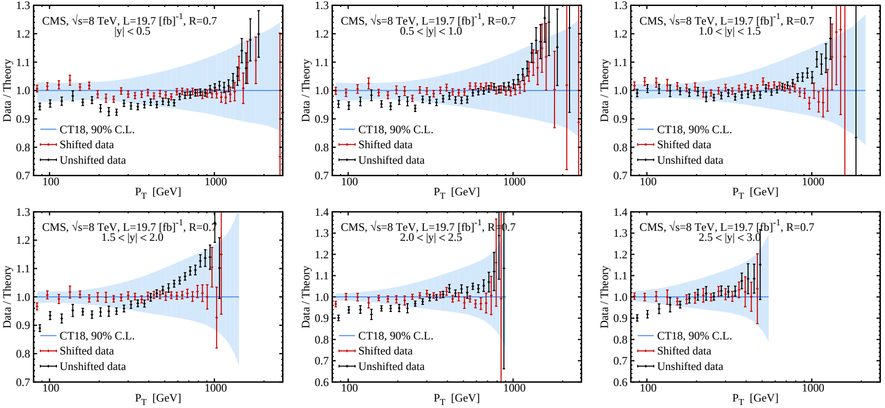


De-correlation for incl. jet



- The corr. error ”jes16” and ”jes62” of ATLAS 7 TeV incl. jet data are decorrelated according to Table 6 of 1706.03192.
- In the case of CMS 7 TeV incl. jet, the correlated error ”JEC2” is decorrelated base on 1410.6765.
- Moderate impact on gluon uncertainty

De-correlation for incl. jet



- Drop the low pileup data from 21-74 GeV
- Treatment of systematic error for CMS 8 TeV incl. jet is done as described as in 1607.03663.
- $\chi^2 = 168$ (for 185 points)before fitting; 132 after fitting
- Results in some reduction in gluon uncertainty at moderate and high x

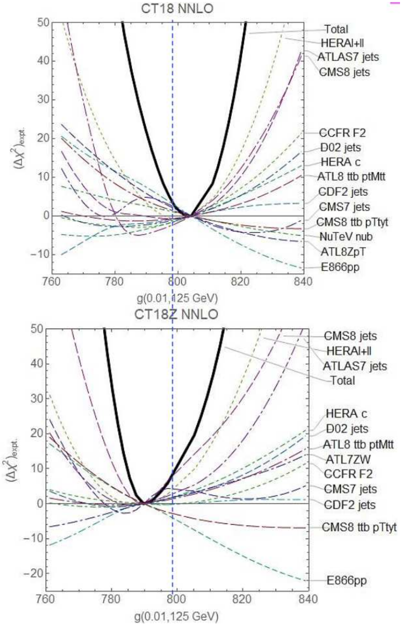
Top Quark Pair differential distributions

- Modest effect observed if $t\bar{t}$ data are included together with the Tevatron and LHC jet production data.
- Its impact on gluon PDF is consistent with jet data, though jet data provide stronger constraint.

We currently include the following data

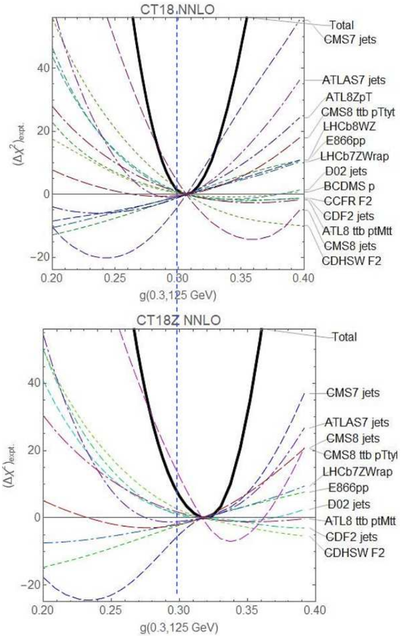
Data	Npts	χ^2/Npts(no fit)	χ^2/Npts
ATLAS 8 TeV abs. $d\sigma/dp_T$, $d\sigma/dm_{t\bar{t}}$	15	1.01	1.04
CMS 8 TeV Nor. $d^2\sigma/dp_T dy_t$	16	1.92	1.89

Lagrange Multiplier scan: $g(0.01, 125\text{GeV})$



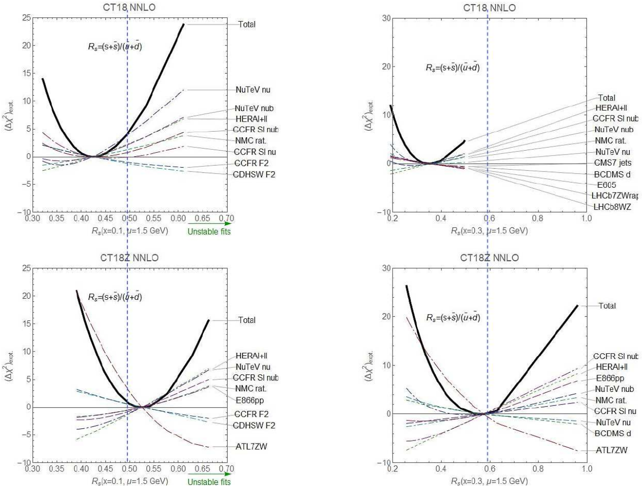
- Top: CT18
  - HERA1+II data set provides the dominant constraint, followed by ATLAS, CDF2,D02 jet production, HERA charm...
  - tt double differential cross sections provide weaker constraints
- Lower: CT18Z
  - a 1% lower NNLO gluon in the Higgs production region than for CT14/ CT18

Lagrange Multiplier scan: $g(0.3, 125\text{GeV})$



- Top: CT18
- Lower: CT18Z
- Opposite pulls from ATLAS7/ CMS7 jet production on one hand, and CMS8 jet production on the other hand
- Similarly, ATLAS tt distributions (dmtt, dpTt) and CMS double tt distributions (dpTtdyt) at 8 TeV impose weak opposite pulls
- Constraints from ATLAS8 Z pT production are moderate

Lagrange Multiplier scan: $(s+\bar{s})/(\bar{u}+\bar{d})$ at $x = 0.1, 0.3$

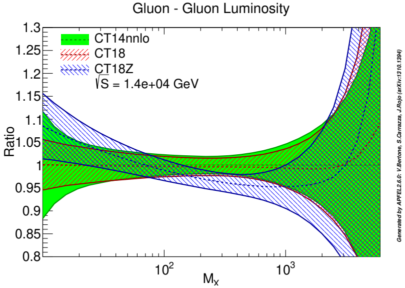


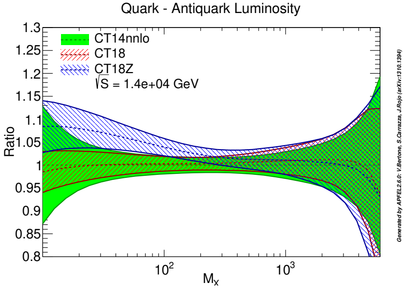
- LHCb W and Z (7,8 TeV) data prefer a larger s-PDF in the small-x region.
- NuTeV dimuon data strongly prefer a smaller R_s value, while the ATLAS8 Z p_T data prefer a slightly larger R_s value.
- ATLAS 7ZW data strongly prefer a larger R_s value.

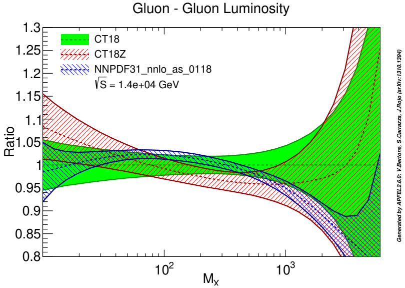
χ^2 of new data in CT18

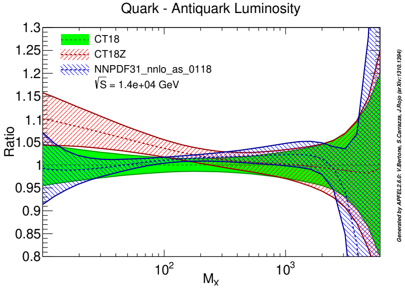
ID	Observable	Npts	CT18 χ^2/N	CT18Z χ^2/N
245	LHCb 7 TeV ZW	33	1.5	1.2
246	LHCb 8 TeV Z	17	1.4	1.2
248	ATLAS 7 TeV ZW			2.4
249	CMS 8 TeV W asym.	11	0.5	0.5
250	LHCb 8 TeV WZ	34	2.1	1.7
253	ATLAS 8 TeV DY $d^2\sigma/dydM$	27	1.6	1.4
542	CMS 7 TeV jet	158	1.3	1.3
544	ATLAS 7 TeV jet	140	1.5	1.5
545	CMS 8 TeV jet	185	1.3	1.2
573	CMS 8 TeV $d^2\sigma_{t\bar{t}}/dp_T^t dy^t$	16	1.9	1.9
580	ATLAS 8 TeV $d\sigma_{t\bar{t}}/dp_T^t$ and $d\sigma_{t\bar{t}}/dm_{t\bar{t}}$	15	1.1	1.4
Total		3493/3681	1.2	1.2

PDF Luminosity

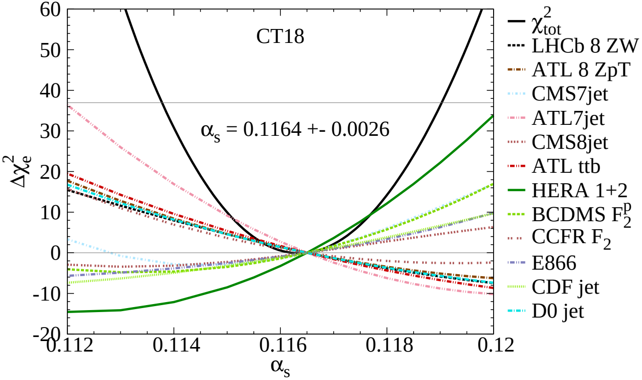








$\alpha_s(M_z)$



- The fixed target F_2 data and HERA DIS data prefer smaller α_s value.
- The ATLAS 8TeV Z p_T, ATLAS 8 ttb and ATLAS 7 TeV incl. jet data, bring the central value of $\alpha_s(M_z)$ from $0.115^{+0.006}_{-0.004}$ (CT14) to 0.1164 ± 0.0026 (CT18).

Summary

- We observe some impact on PDFs from ATLAS and CMS incl. jet data, LHCb WZ production and ATLAS 8 TeV Z p_T data.
- CT18Z is the alternative PDF with the inclusion of ATLAS 7TeV ZW data, which has strong impact to PDF, associate with $m_c = 1.4$GeV.
- Basically final versions of CT18/CT18Z, with paper draft in preparation