Recent Progress in Study of PDFs from CT Global Analysis

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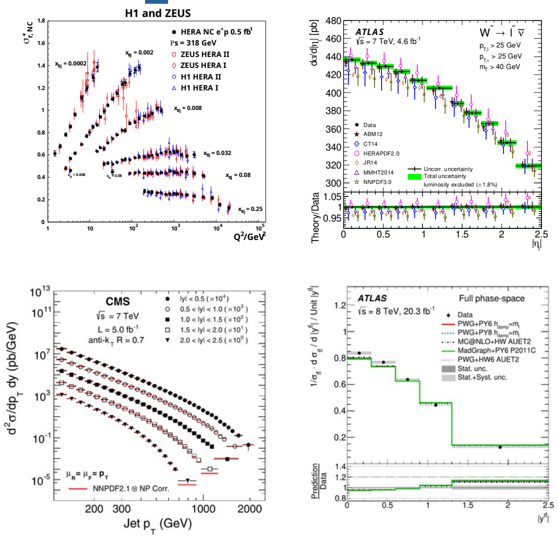
南華大學
UNIVERSITY OF SOUTH CHINA

CTEQ

$$\sigma = f_a(x_1,\mu^2) \otimes f_b(x_2,\mu^2) \otimes \hat{\sigma}_{ab}(\mu^2)$$

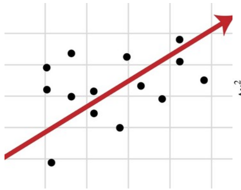
Expt. Data

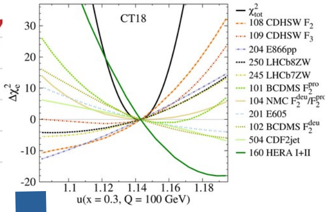


Statistic

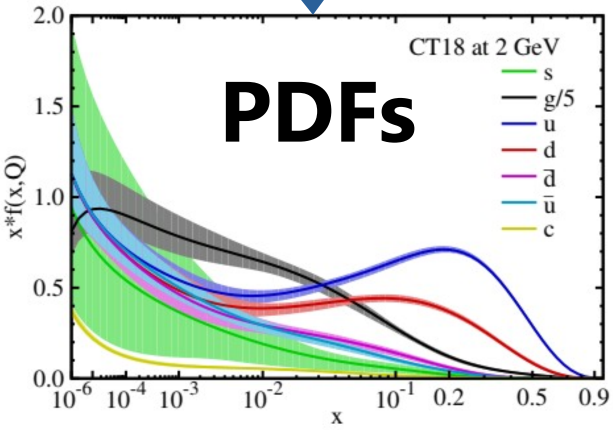
Regression analysis

Uncertainty Estimation

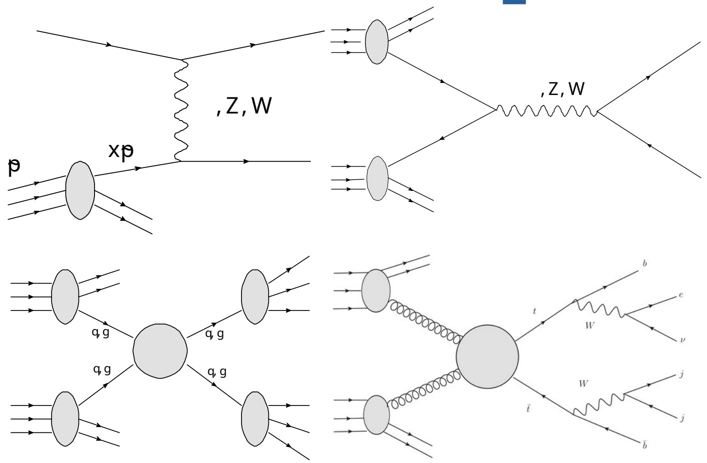




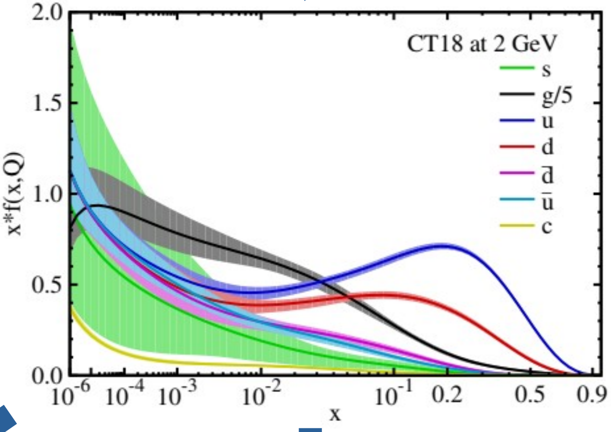
PDFs



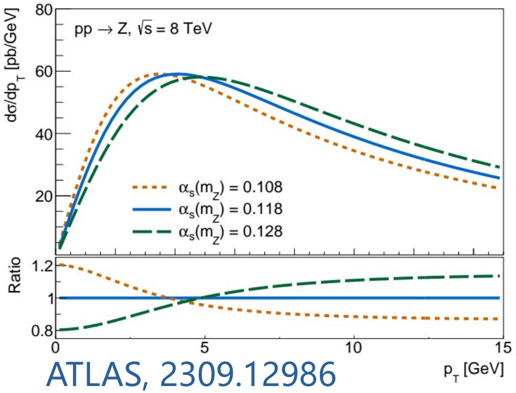
Theory



$$\sigma = f_a(x_1,\mu^2) \otimes f_b(x_2,\mu^2) \otimes \hat{\sigma}_{ab}(\mu^2)$$

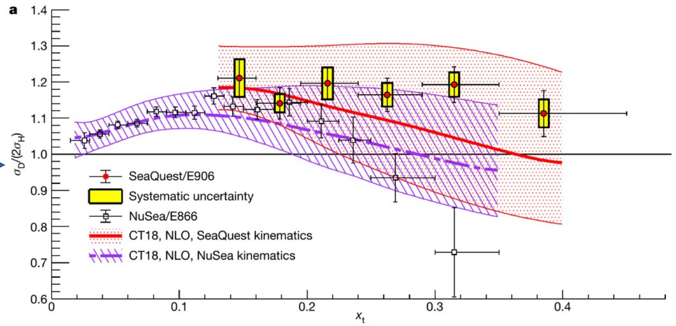


α_s



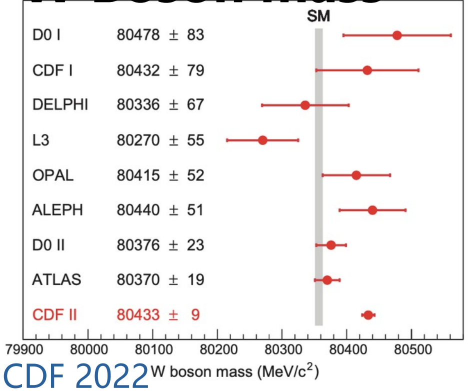
ATLAS, 2309.12986

$\sigma_D/(2\sigma_H)$



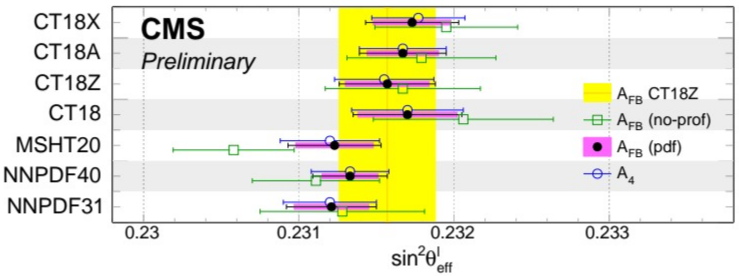
Nature 590, 561–565 (2021)

W Boson mass



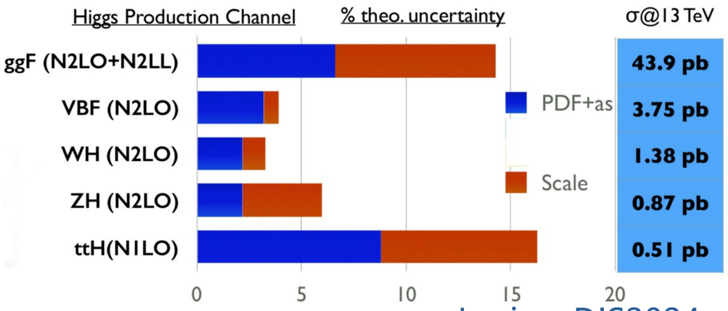
CDF 2022

$\sin^2\theta^l_{eff}$



CMS PAS SMP-22-010

Higgs Production



Lucian, DIS2024

CTEQ (Wu-Ki Tung Et Al.) group https://cteq-tea.gitlab.io/ CTEQ main page CTEQ-TEA projects

· RESEARCH PROJECTS AND RESULTS ·

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APS

PHYSICAL REVIEW D
covering particles, fields, gravitation, and cosmology

Editors' Suggestion

New parton distribution functions from a global analysis of quantum chromodynamics

Sayipjamal Dulat, Tie-Jiun Hou, Jun Gao, Marco Guzzi, Joey Huston, Pavel Nadolsky, Jon Pumplin, Carl Schmidt, Daniel Stump, and C.-P. Yuan

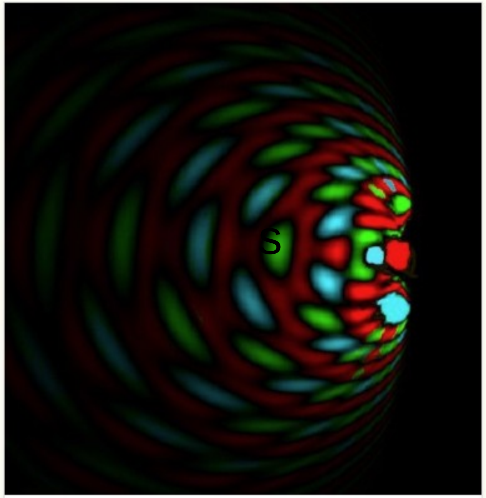
Phys. Rev. D **93**, 033006 – Published 16 February 2016

ABSTRACT

We present new parton distribution functions (PDFs) at next-to-next-to-leading order (NNLO) from the CTEQ-

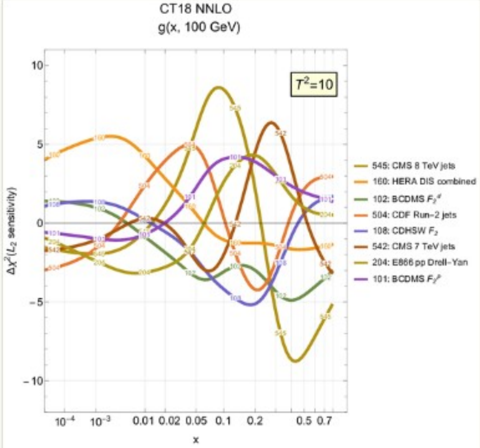
ARTICLES BY CTEQ-TEA AUTHORS

Representative publications of our research group and its collaborators listed in the INSPIRE-HEP database



CTEQ-TEA PARTON DISTRIBUTION FUNCTIONS

CTEQ-TEA (CT) parametrizations of parton distribution functions in the nucleon



FAST EXAMINATION OF DATA CONSTRAINTS ON PDFS

L2explorer estimates experimental constraints on PDFs from the LHAPDF library using L2 sensitivities

China:
A. Ablat,
S. Dulat,
Y. Fu,
T.-J. Hou,
I. Sitiwaldi

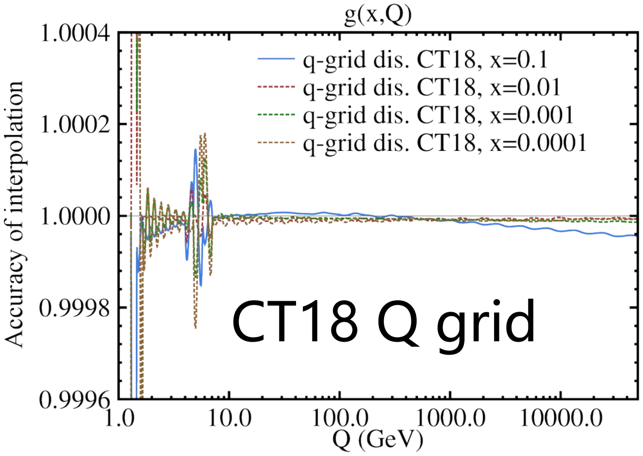
Mexico:
A. Courtoy

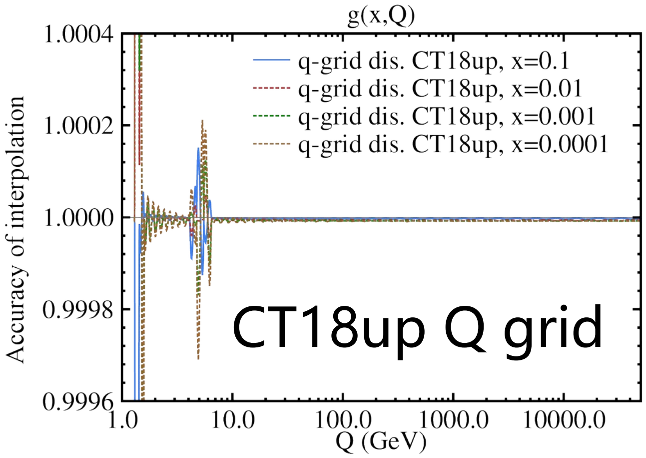
USA:
M. Guzzi,
T.J. Hobbs,
J. Huston,
H.-W. Lin,
C. Schmidt,
K. Xie,
C.-P. Yuan
and other coauthors

Toward a new generation of CT PDFs

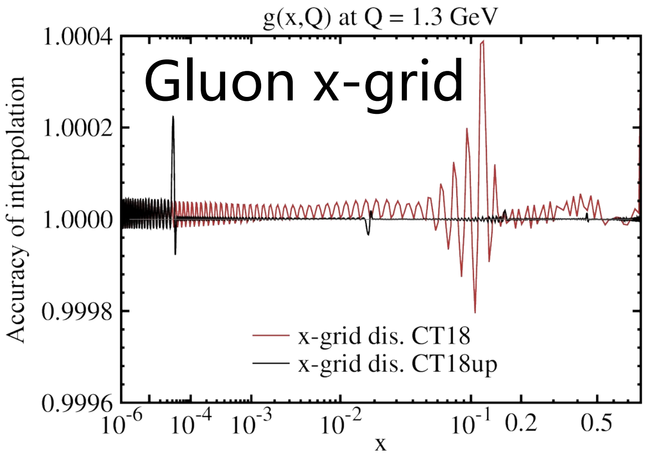
1. Upgrade of PDF grids
2. Multiple based on preliminary the selections NNLO fits with
   - vector boson [2305.10733]
   - $t\bar{t}$ data [2307.11153]
   - LHC Run-2 (di)jet [work in progress]
3. Work on implementation of N3LO contributions [work in progress]
4. Next-generation PDF uncertainty quantification:
   - Bézier curves [2311.08447]
   - multi-Gaussian approaches [2406.01664]
5. Physics applications
   - QCD+QED PDFs for a neutron [2305.10497]
   - PDF dependence of forward-backward asymmetry [2307.07839]
   - Gluon determination with the help of lattice input [work in progress]

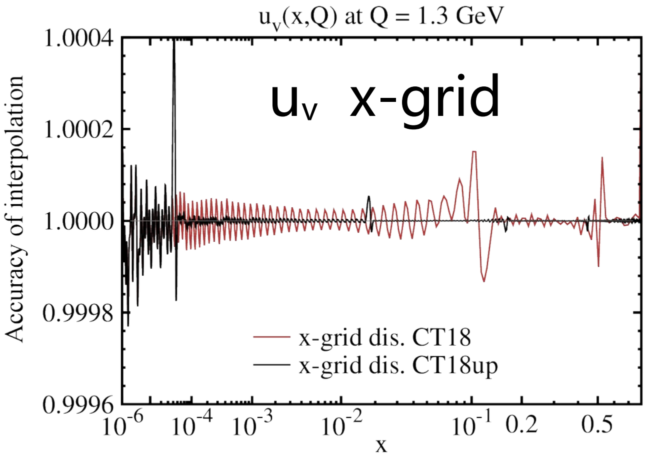
Upgrade of PDF grids





Ratio between PDF read from grids and fitting code



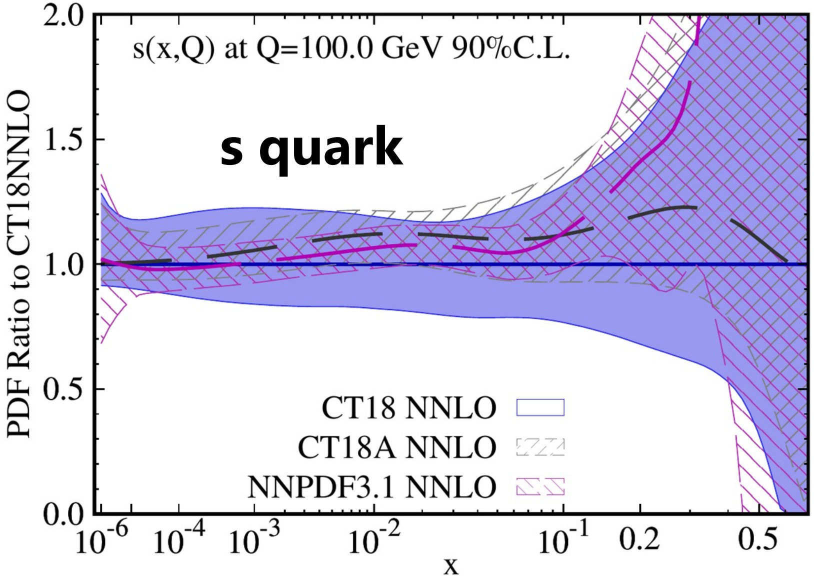


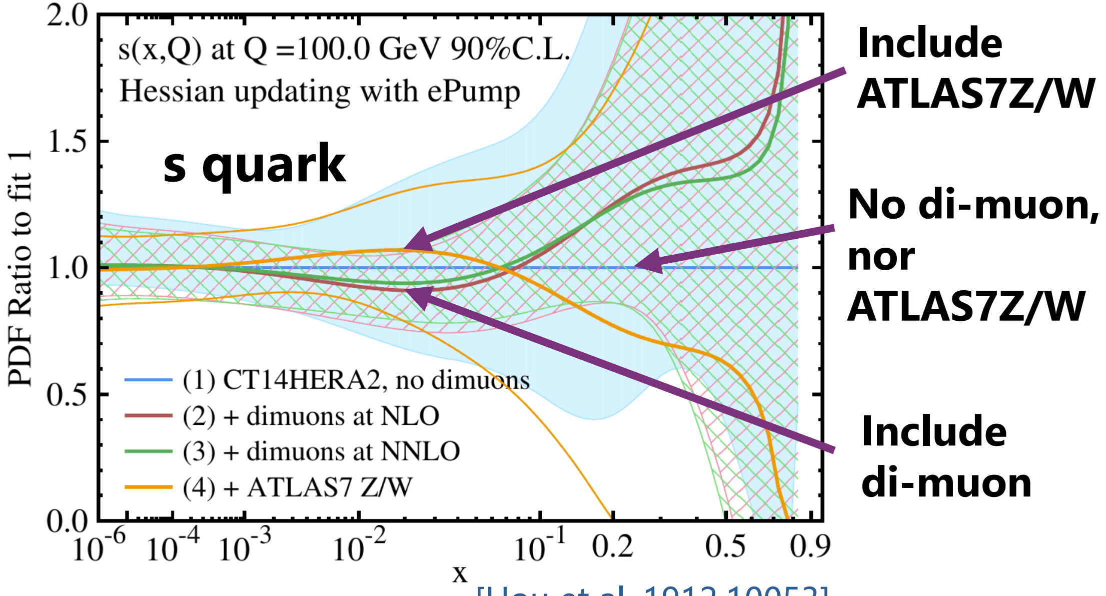
intervals in x	CT18	CT18up	intervals in x	CT18	CT18up
$[10^{-10}, 10^{-9}]$	1	1	$[0.1, 0.2]$	7	18
$[10^{-9}, 10^{-8}]$	11	11	$[0.2, 0.3]$	6	16
$[10^{-8}, 10^{-7}]$	12	12	$[0.3, 0.4]$	5	12
$[10^{-7}, 10^{-6}]$	11	11	$[0.4, 0.5]$	3	13
$[10^{-6}, 10^{-5}]$	12	12	$[0.5, 0.6]$	6	15
$[10^{-5}, 10^{-4}]$	11	15	$[0.6, 0.7]$	6	12
$[10^{-4}, 10^{-3}]$	12	23	$[0.7, 0.8]$	8	11
$[10^{-3}, 10^{-2}]$	11	23	$[0.8, 0.9]$	14	17
$[10^{-2}, 10^{-1}]$	12	40	$[0.9, 1.0]$	15	38
			Total	161	300

intervals in Q	CT18	CT18up
$[Q_0, m_c]$	2	4
$[m_c, m_b]$	8	11
$[m_b, m_t]$	14	18
$[m_t, Q_{\max}]$	13	16
Total	37	49

PDFs grid in .pds and LHAPDF format are updated from $[N_x, N_Q]$=[161, 37] to [300, 49] to have better precision

CT18 Drell-Yan data





[Hou et al, 1912.10053]

- Noticeable tensions between the SIDIS di-muon data and the precision ATLAS 7 TeV Z/W data were found in global analysis.
- Two versions of PDFs: **CT18**(w/o ATLAS 7 Z/W data) and **CT18A**(w/ ATLAS 7 Z/W data) were released

Ibrahim Sitiwaldi et al, 2305.10733

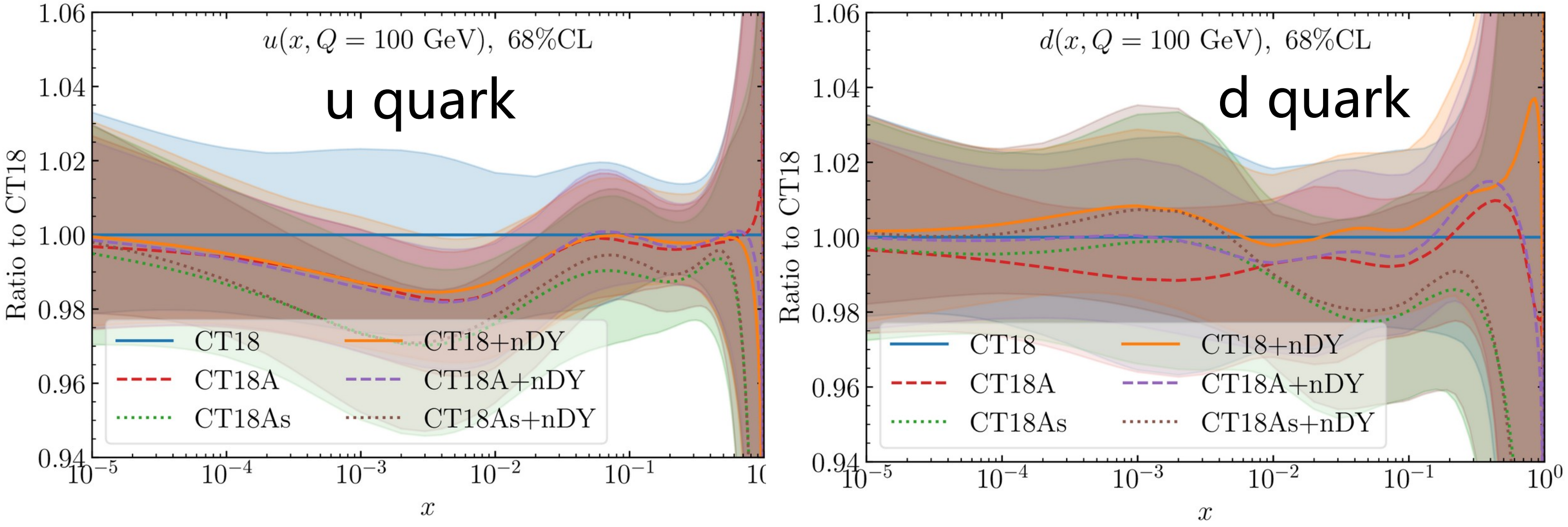
Post-CT18 LHC Drell-Yan data

ID	Exp	N_{pt}	χ^2/N_{pt}
215	ATLAS 5.02 TeV W,Z	27	$0.82^{+0.55}_{-0.16}$ ($1.15^{+1.22}_{-0.43}$)
211	ATLAS 8 TeV W	22	$2.42^{+2.49}_{-1.51}$ ($4.25^{+6.39}_{-3.34}$)
214	ATLAS 8 TeV Z3D	188	$1.12^{+0.46}_{-0.02}$ ($1.99^{+5.10}_{-1.85}$)
212	CMS 13 TeV Z	12	$2.48^{+4.76}_{-0.88}$ ($12.03^{+38.04}_{-21.84}$)
217	LHCb 8 TeV W	14	$1.35^{+0.59}_{-0.61}$ ($1.35^{+0.72}_{-0.64}$)
218	LHCb 13 TeV Z	16	$1.18^{+1.42}_{-0.60}$ ($1.49^{+1.74}_{-0.89}$)

CT18: w/o ATL7ZW

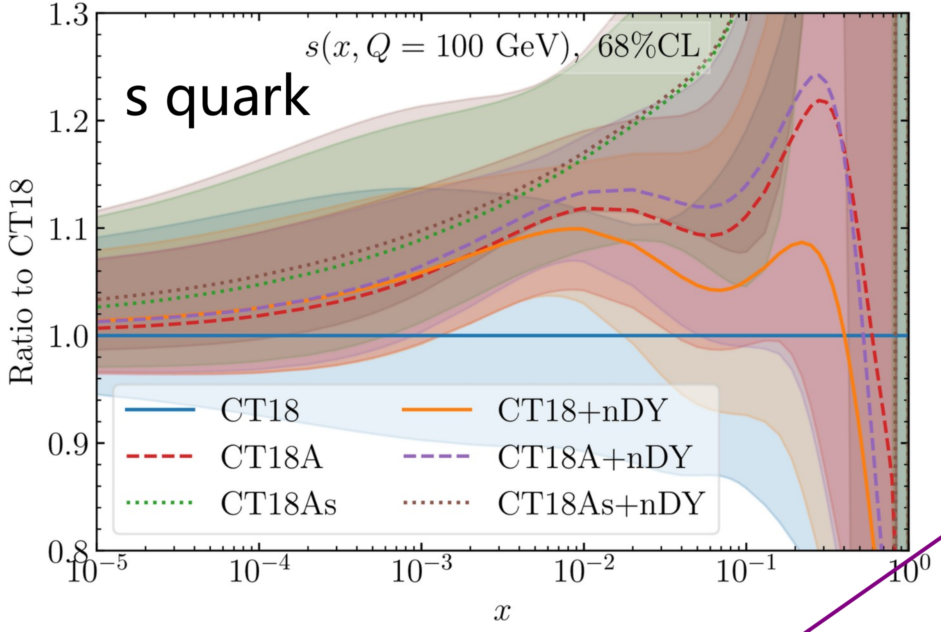
CT18A: w/ ATL7ZW

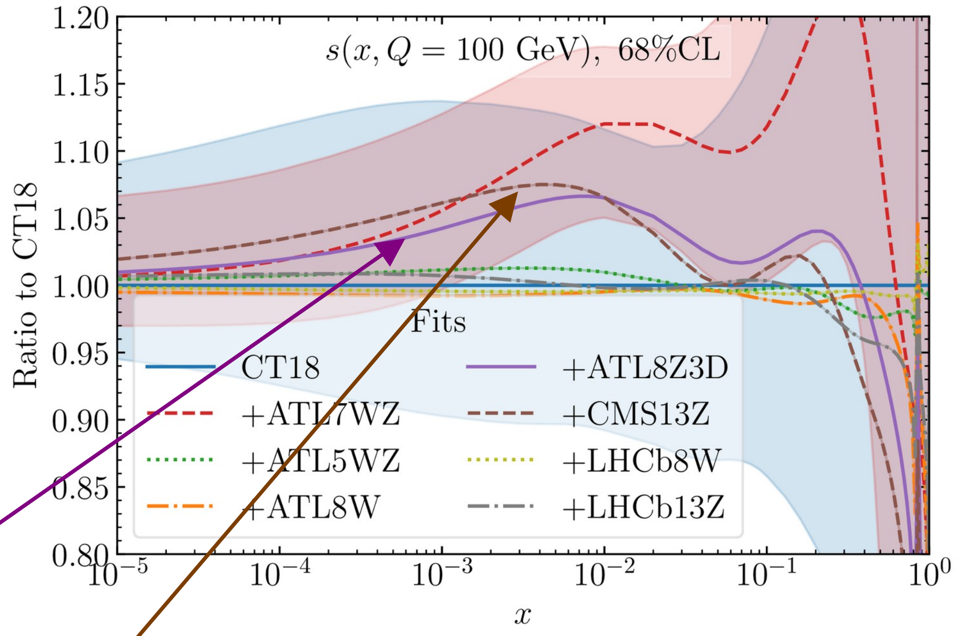
CT18As: CT18A w/ s asym.



New DY data drive new fitted PDFs closer to CT18A PDFs rather than CT18 PDFs.

CT18 or CT18A?





- The new Drell-Yan data **ATL8Z3D** and **CMS13Z** drive the strange PDF closer to CT18A than CT18.
- Mild tension in the strange PDF comes from the ATL8W and LHCb8W data sets.

LHC 13 TeV $t\bar{t}$ data set

Alim Ablat et al, 2307.11153

521	ATL13had	2006.09274	ATLAS all-hadronic channel at 13 TeV
528	CMS13ll	1811.06625	CMS dilepton channel at 13 TeV
581	CMS13lj	2108.02803	CMS lepton + jets channel at 13 TeV
587	ATL13lj	1908.07305	ATLAS lepton+jets channel at 13 TeV

- Distributions $m_{t\bar{t}}, y_{t\bar{t}}, y_{t\bar{t}}^{Boost} = \frac{1}{2}(y^{t,had} + y^{t,lep})$ and $H_T^{t\bar{t}} = p_T^{t,had} + P_T^{t,lep}$ are concerned.
- ATL13lj releases two binning: ATL-bin and CMS-bin

Npts	$m_{t\bar{t}}$	$y_{t\bar{t}}$	$y_{t\bar{t}}^{Boost}$	$H_T^{t\bar{t}}$	$p_{T,t}$	y_t
ATL bin	9	7	9	9		
CMS bin	7	10			6	10

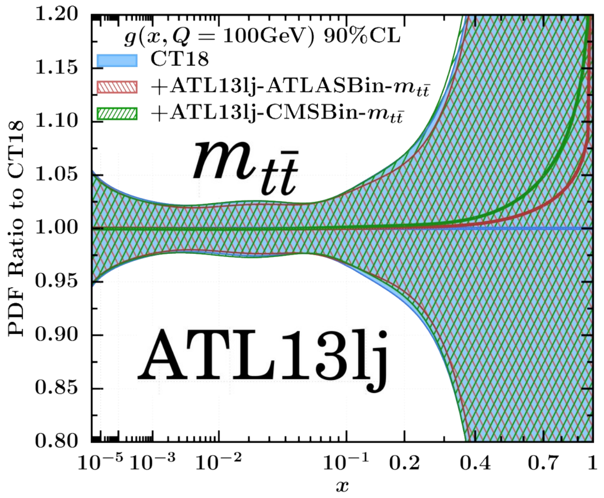
Bin-by-bin statistical correlations are made available for ATL bin.

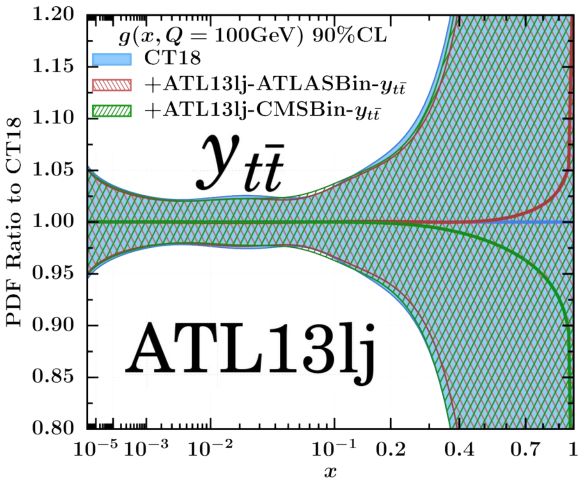
- NNLO theoretical prediction is done by using MATRIX.

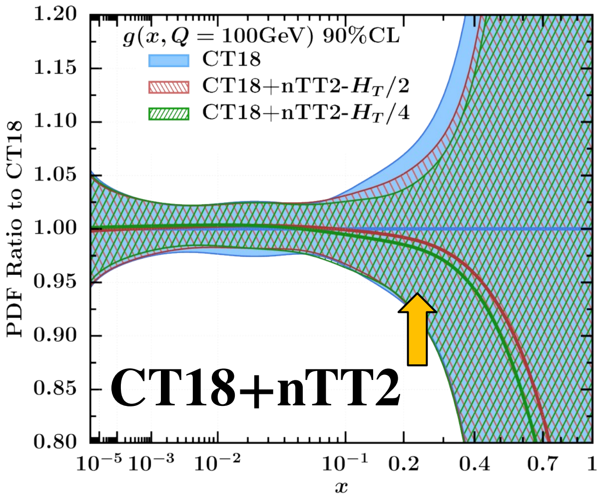
$$\text{NNLO=NLO(Applgrid, MCFM 6.8)} \times K\left(\frac{\text{NNLO(MATRIX)}}{\text{NLO(MCFM 6.8)}}\right)$$

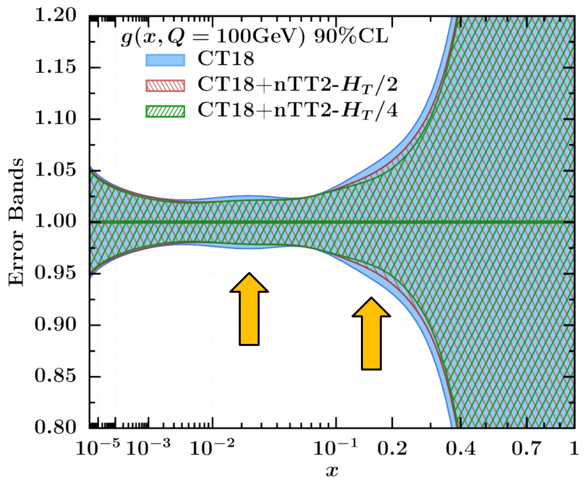
- Central-scale choices $\mu_R = \mu_f = H_T/4$ or $H_T/2$ are examined.

LHC 13 TeV $t\bar{t}$ data set: Stronger Impact







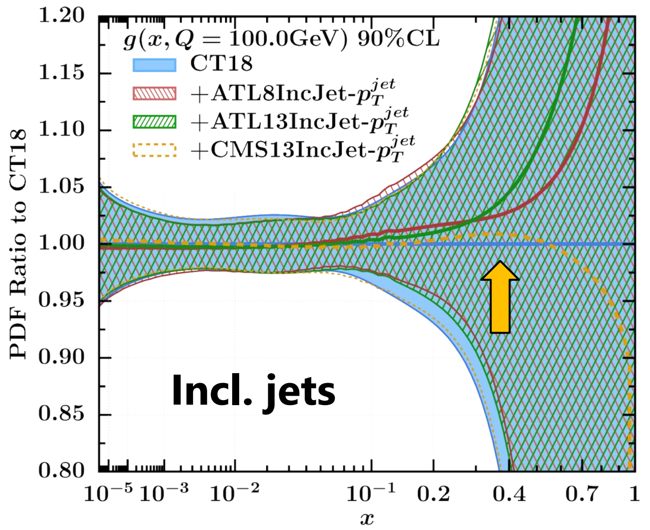


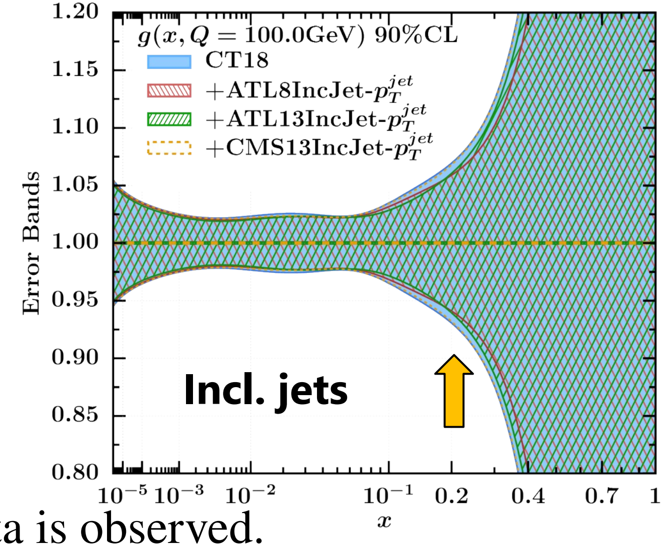
- The ATL13lj data provide minor impact to gluon PDF in large x region.
- The difference between CMS-bin and ATL-bin is mild.
- Statistical correlations have a negligible impact on the gluon PDF errors.
- nTT2 = ATL13had-$y_{t\bar{t}}$ + CMS13ll-$y_{t\bar{t}}$ + CMS13lj-$m_{t\bar{t}}$ + ATL13lj-$y_{t\bar{t}}$+$y^B_{t\bar{t}}$+ $m_{t\bar{t}}$+$H_T^{t\bar{t}}$ w/o stat. corr. (ATL bin)
- New $t\bar{t}$ data prefer softer gluon for x > 0.2.
- Stronger ability to reduce the uncertainty of gluon PDF as compare to that in CT18.

Preliminary

Incl. Jet v.s. dijet data set

Data	Ref	$\sqrt{s}$ [TeV]	$\mathcal{L}_{int}$ [fb^{-1}]	N_{pt}	anti-k_T R	Observable	Kinematics	Scale μ_R, μ_F
				Inclusive Jet				
ATLAS	[56]	8	20.3	171	0.6	$\frac{d^2\sigma}{dp_T d\|y\|}$	$\|y\| < 3.0$, $p_T^{jet} \in [70, 2500]$	p_T^{jet}, $\hat{H}_T$
ATLAS	[58]	13	3.2	177	0.4	$\frac{d^2\sigma}{dp_T d\|y\|}$	$\|y\| < 3.0$, $p_T^{jet} \in [100, 3937]$	p_T^{jet}, $\hat{H}_T$
CMS	[60]	13	36.5	78	0.7	$\frac{d^2\sigma}{dp_T d\|y\|}$	$\|y\| < 2.0$, $p_T^{jet} \in [97, 3103]$	p_T^{jet}, $\hat{H}_T$
				DiJet				
ATLAS	[61]	7	4.5	90	0.6	$\frac{d^2\sigma}{dm_{12} dy^*}$	$y^* < 3.0$, $m_{12} \in [260, 5040]$	m_{12}
CMS	[62]	7	5.0	54	0.7	$\frac{d^2\sigma}{dm_{12} d\|y_{max}\|}$	$y_{max} < 2.5$, $m_{12} \in [197, 5058]$	m_{12}
CMS	[63]	8	19.7	122	0.7	$\frac{d^3\sigma}{dp_{T,avg} dy^* dy^b}$	$y^* < 3.0$, $y^b < 3.0$, $m_{12} \in [133, 1784]$	m_{12}, $p_{T,1} e^{0.3y*}$
ATLAS	[58]	13	3.2	136	0.4	$\frac{d^2\sigma}{dm_{12} dy^*}$	$y^* < 3.0$, $m_{12} \in [260, 9066]$	m_{12}





- NNLO theoretical prediction was done by NNLOJET
- Scales choice $\mu_R = \mu_f = p_T^{jet}$ or H_T were examined.
- Incl. jet data prefer harder gluon in large x.
- Mild reduction in gluon PDF uncertainty from incl. jet data is observed.

Preliminary

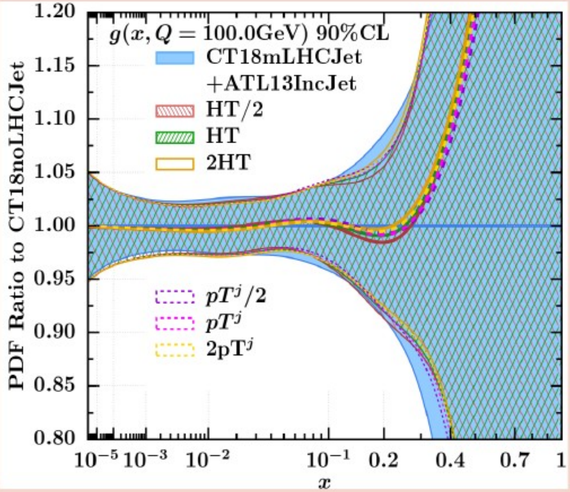
χ^2/N_{pt} for fits that add one inclusive jet or dijet data set to the CT18 (without LHC jets) baseline at a time

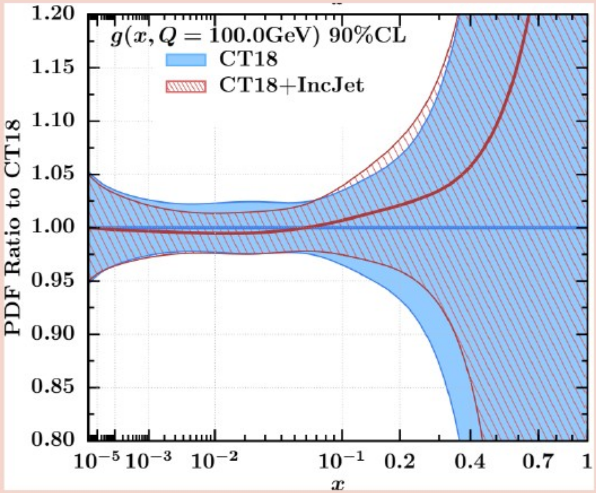
Inclusive jets		χ^2/N_{pt} using $\mu_{R,F} \propto HT$ or p_T^j					
Experiment	N_{pt}	$HT/2$	HT	$2HT$	$p_T^j/2$	p_T^j	$2p_T^j$
ATL8IncJet	171	1.7	1.74	1.87	1.75	1.66	1.7
ATL13IncJet	177	1.42	1.36	1.4	1.52	1.31	1.28
CMS13IncJet	78	1.2	1.16	1.2	1.08	1.09	1.1
Dijets		χ^2/N_{pt} using $\mu_{R,F} \propto HT$ or $p_T^* = p_T^{leading}\exp(0.3y^*)$					
Experiment	N_{pt}	$M_{jj}/2$	M_{jj}	$2M_{jj}$	$p_T^*/2$	p_T^*	$2p_T^*$
ATL7DiJet	90	0.81	0.79	0.87			
CMS7DiJet	54	1.55	1.55	1.63			
CMS8DiJet	122	0.95	1.2	1.9	1.25	1	1.01
ATL13DiJet	136	0.9	0.87	0.93			

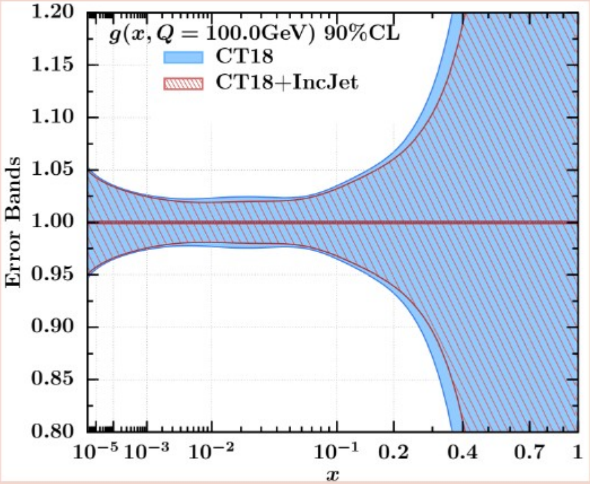
- Dijet data sets tend to have larger uncertainties than inc. jets, on facilitating PDFs better χ^2 for similar constraints on PDF.
- Dijet data are dominated by the CMS 8 TeV dataset

Incl. jet vs. dijet data sets: impact on the gluon

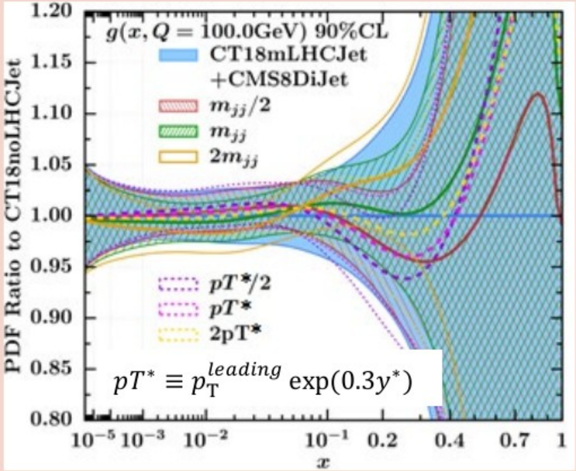
+ inclusive jets: small scale dependence, a harder $g(x,Q)$







+ dijets: significant scale, dependence, varied pulls on $g(x,Q)$



The impact of the Inc. jet data on $g(x,Q)$ is relatively independent of the scale choice. The final fit uses $\mu_{R,F} = p_T^j$, giving better χ^2.

The impact of dijet data substantially depends on scale choices, especially in the case of CMS8 TeV dijet.

Example

NNLO fits with new data at 8 and 13 TeV

for CT18+new data (CT18 in parentheses) NNLO fits; 68% CL

ID	Exp	N_{pt}	χ^2/N_{pt}
	Drell-Yan		
215	ATLAS 5.02 TeV W,Z	27	$0.82^{+0.55}_{-0.16}$ ($1.15^{+1.22}_{-0.43}$)
211	ATLAS 8 TeV W	22	$2.42^{+2.49}_{-1.51}$ ($4.25^{+6.39}_{-3.34}$)
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218	LHCb 13 TeV Z	16	$1.18^{+1.42}_{-0.60}$ ($1.49^{+1.74}_{-0.89}$)
	13 TeV $t\bar{t}$		
521	ATLAS all-hadronic $y_{t\bar{t}}$	12	$1.06^{+0.14}_{-0.09}$ ($1.05^{+0.21}_{-0.10}$)
528	CMS dilep $y_{t\bar{t}}$	10	$1.10^{+1.08}_{-0.68}$ ($1.03^{+1.60}_{-0.74}$)
587	ATLAS lep+Jet $m_{t\bar{t}} + y_{t\bar{t}} + y^B_{t\bar{t}} + H^{t\bar{t}}_T$	34	$0.92^{+0.32}_{-0.14}$ ($0.94^{+0.59}_{-0.16}$)
581	CMS lep+jet $m_{t\bar{t}}$	15	$1.44^{+1.18}_{-0.73}$ ($1.37^{+1.86}_{-0.82}$)
	Inclusive Jet		
553	ATLAS 8 IncJet	171	$1.76^{+0.20}_{-0.12}$ ($1.80^{+0.33}_{-0.16}$)
554	ATLAS 13 IncJet	177	$1.38^{+0.13}_{-0.10}$ ($1.39^{+0.20}_{-0.11}$)
555	CMS 13 IncJet	78	$1.10^{+0.24}_{-0.17}$ ($1.11^{+0.30}_{-0.16}$)

nDY

nTT

nIncJet

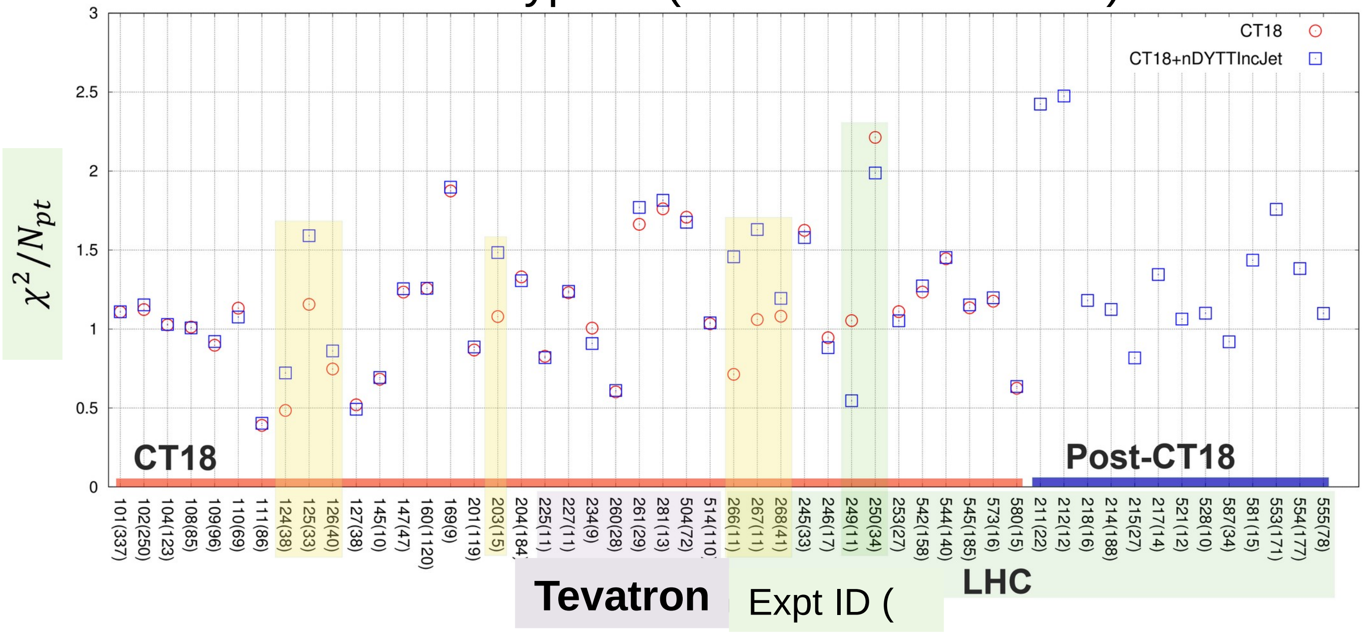
nDYTTIncJet

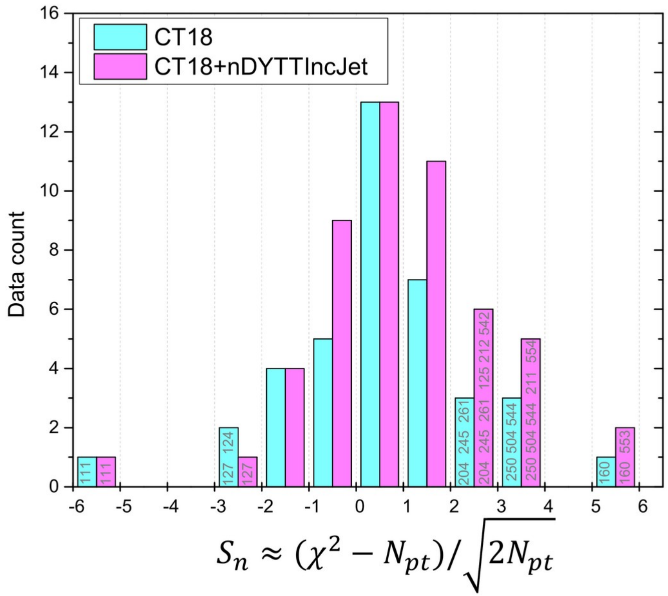
Fits with 1 type of new data

A fit with all 3 types

Preliminary

A 3-data-type fit (CT18+nDYTTIncJet)

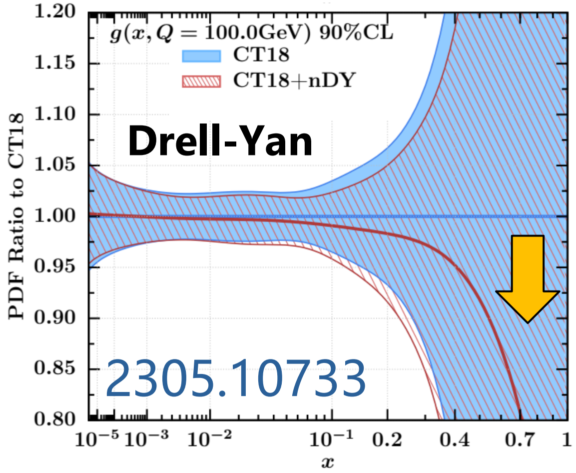


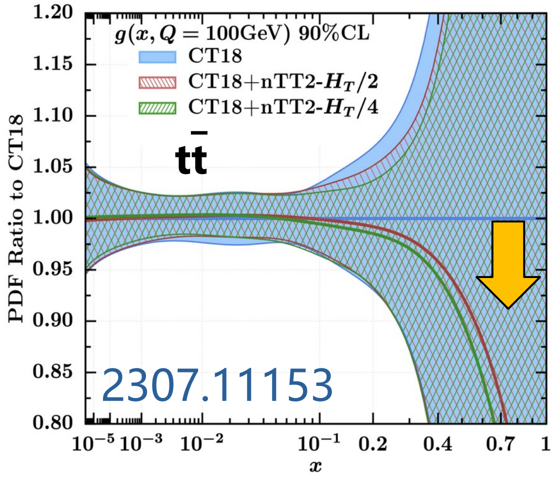


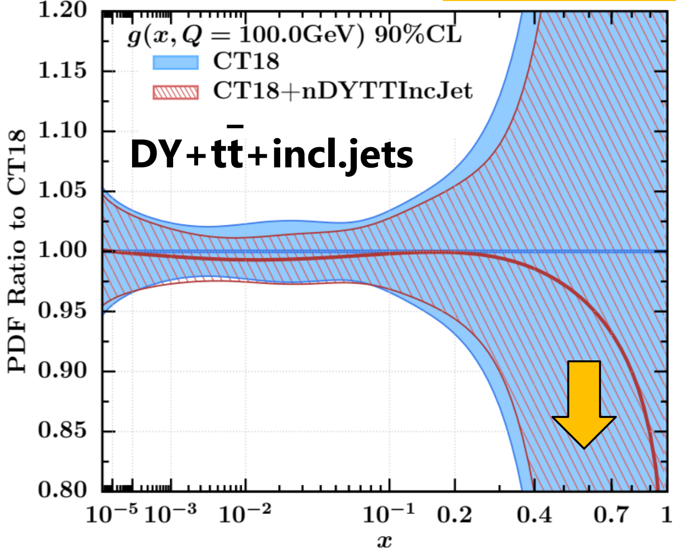
- The most precise new experiments tend to have an elevated, in the same pattern as observed for CT18
- χ^2/N_{pt} increases for experiments 124 and 125 (NuTeV), 126 and 127 (CCFR) and 203 (E866 DY), 266 and 267 (CMS 7TeV Ach), 268 (ATLAS 7TeV W, Ach).
- χ^2/N_{pt} decreases for experiments 249 (CMS 8 TeV Ach), 250 (LHCb 8 TeV W/Z)

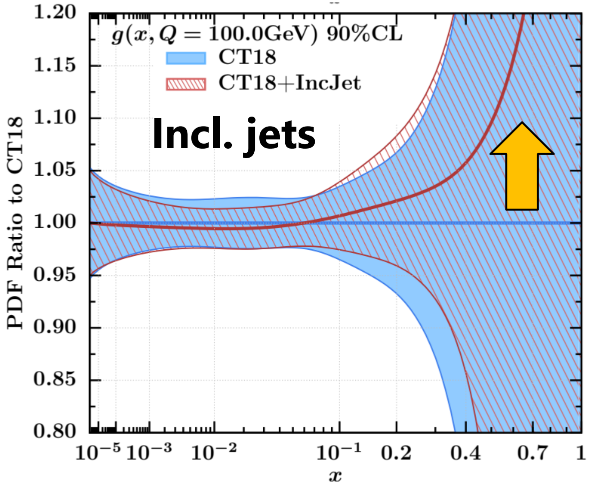
Pulls on the gluon PDF by the new data type

Preliminary

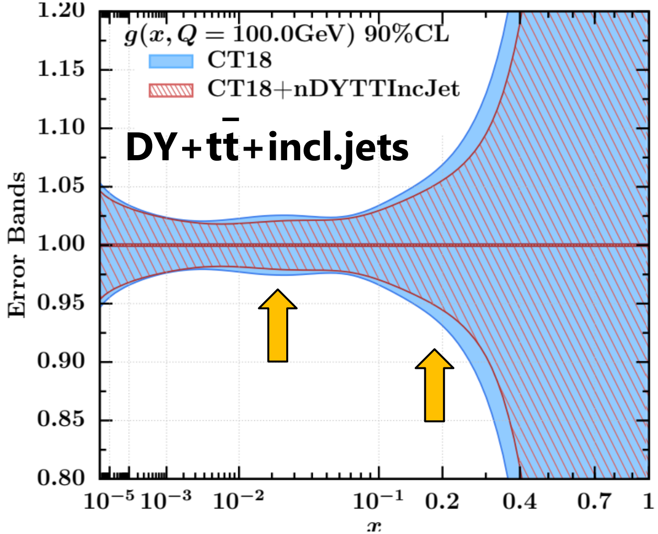








- After including DY, $t\bar{t}$, and inc. jet data simultaneously, we get a softer gluon.
- Note that new DY and $t\bar{t}$ data favor a softer gluon, new inc. jet data prefer a harder gluon.
- Mild changes in the gluon uncertainty



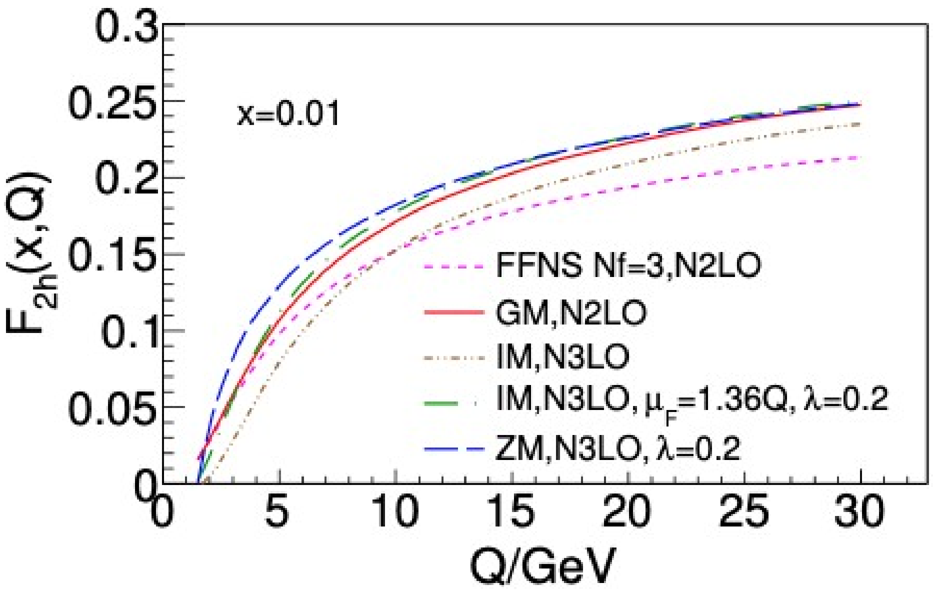
Necessary components of an N3LO PDF analysis

Component		Availability
Splitting functions		Partial N3LO
Hard cross sections	DIS, light flavors	Full N3LO
	NC DIS, heavy flavors	Full N3LO (Blümlein et al.), not yet in fitting codes
	Vector boson production	Full N3LO for some processes, fixed N3LO/N2LO K-factor tables
	CC DIS, jet, production	N2LO
	$pp\to w+c$, $pp\to z+b$, $pp\to b$	NLO (massive); NNLO (ZM)

- Looking forward to including all components exactly and fully to reduce the QCD scale uncertainty and guarantee the N3LO accuracy in the near future.
- CTEQ-TEA and other groups include some N3LO contributions in their fitting codes: remarkable progress of MSHT and NNPDF in aN3LO fits.
- These extended (N2LO+, or aN3LO) calculations agree with N2LO within their scale dependence

Work in progress

QCD cross sections @N3LO



- **DIS:** The CTEQ-TEA code implements complete flavor decompositions of DIS SFs at N3LO using approximate zero-mass Wilson coefficients with a rescaling variable (the **Intermediate-Mass VFN scheme**, cf. the figure)

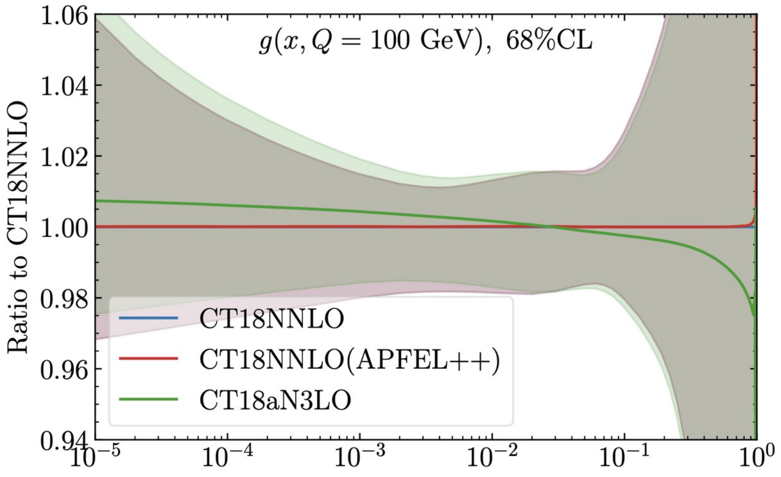
Boting Wang's and Keping Xie's Theses, SMU

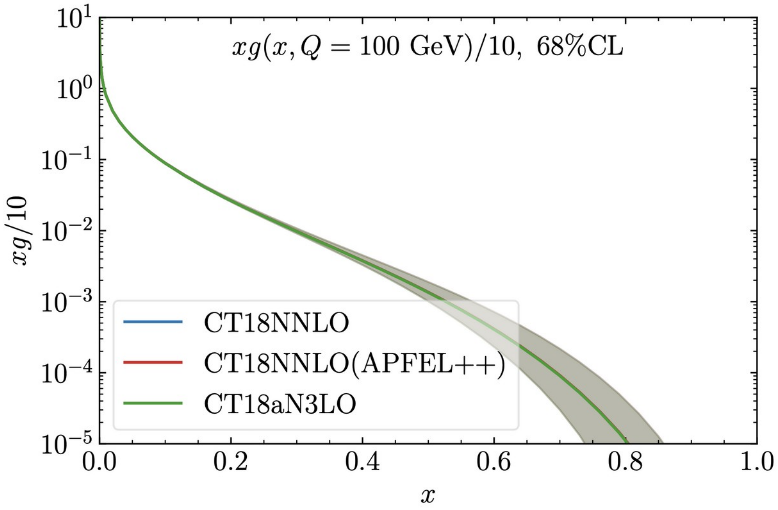
- **Working on the implementation of** massive N3LO heavy-quark coefficients to obtain N3LO

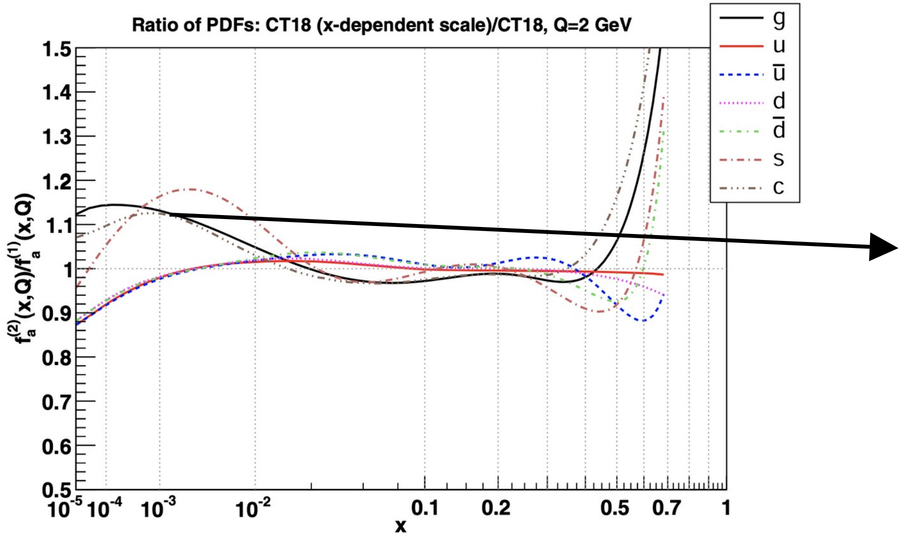
Factorization schemes	Mass dependence in the FC terms	Mass dependence of the FE and subtraction terms	Introduce heavy-quark PDFs at large Q
FFN	Exact	N/A	no
ZM	None	None	yes
IM	Approximate	Approximate	yes
GM	Exact	Approximate	yes

- **DGLAP evolution** is performed at N3LO with APFEL/APFEL++.
- **Drell-Yan:** Ongoing work to include N3LO DY effects using NNLO ApplFast + N3LO/N2LO K-factor tables

CT18aN3LO gluon





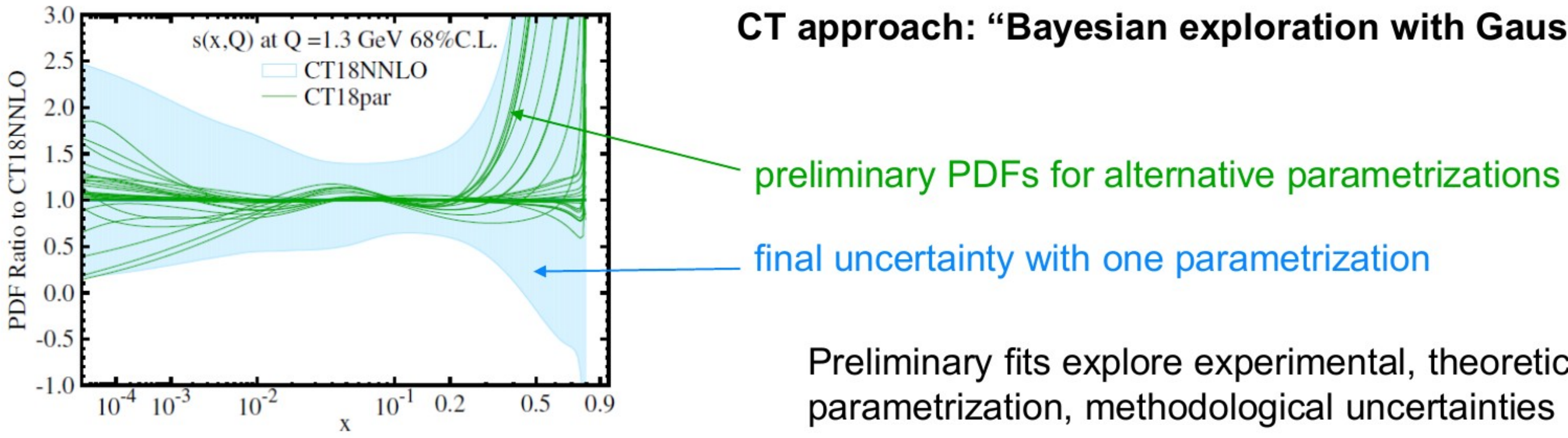


Some of the aN3LO gluon features reproduced by suitable scale choice in DIS NNLO (cfr. CT18X)

Taming PDF uncertainties

Several efforts to refine PDF uncertainty quantification:

- understand conceptual underpinnings of the multivariate inverse problem. Much can be learned from non-HEP statistics applications
- suppress aleatory and perturbative uncertainties (e.g., from higher-order contributions)
- comprehensively estimate epistemic uncertainties (e.g., due to the PDF parametrization forms)

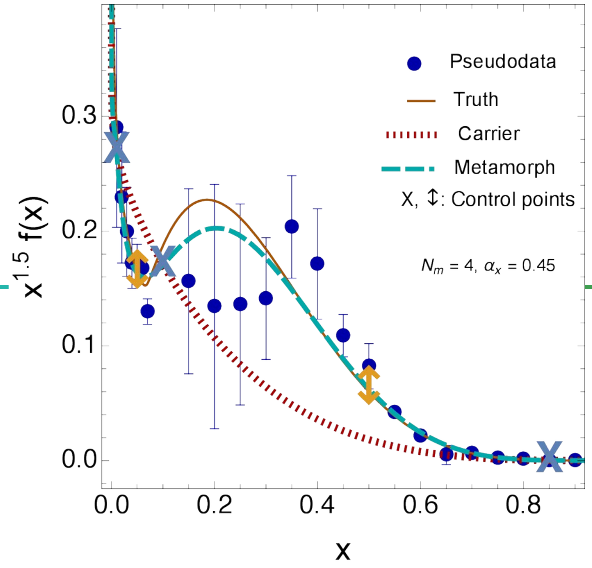


CT approach: "Bayesian exploration with Gaussian emulation"

Preliminary fits explore experimental, theoretical, parametrization, methodological uncertainties

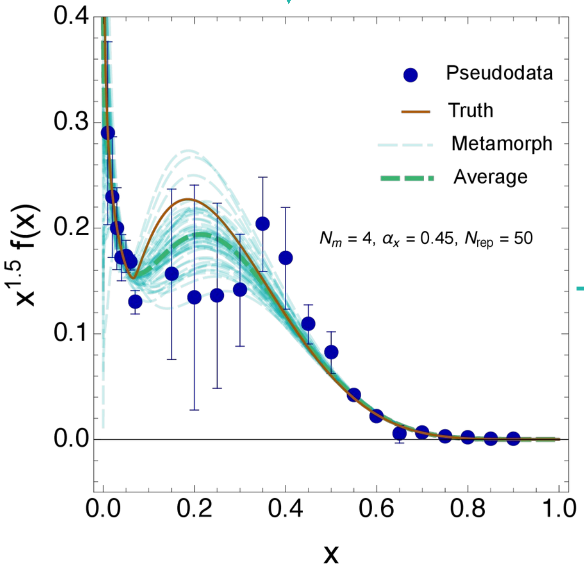
The final Hessian error set (50-60) approximates the total uncertainty due to the above factors.

Bézier-curves methodology for global analyses – A toy model



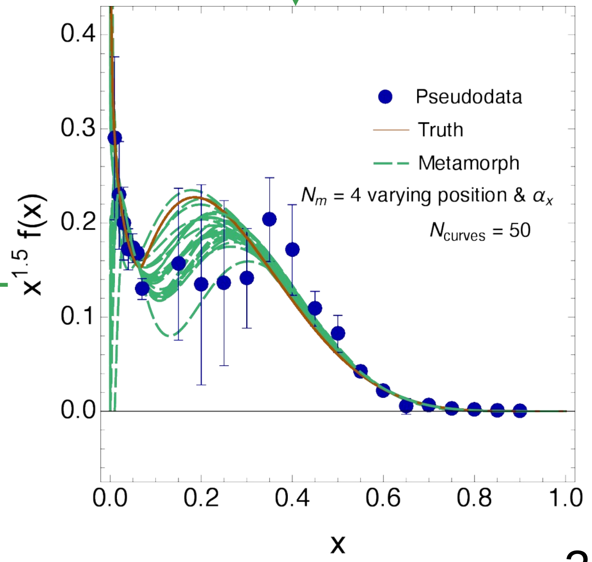
sampling on the distribution of data uncertainties

bootstrapped



sampling over parametrizations based on **Bézier curves**

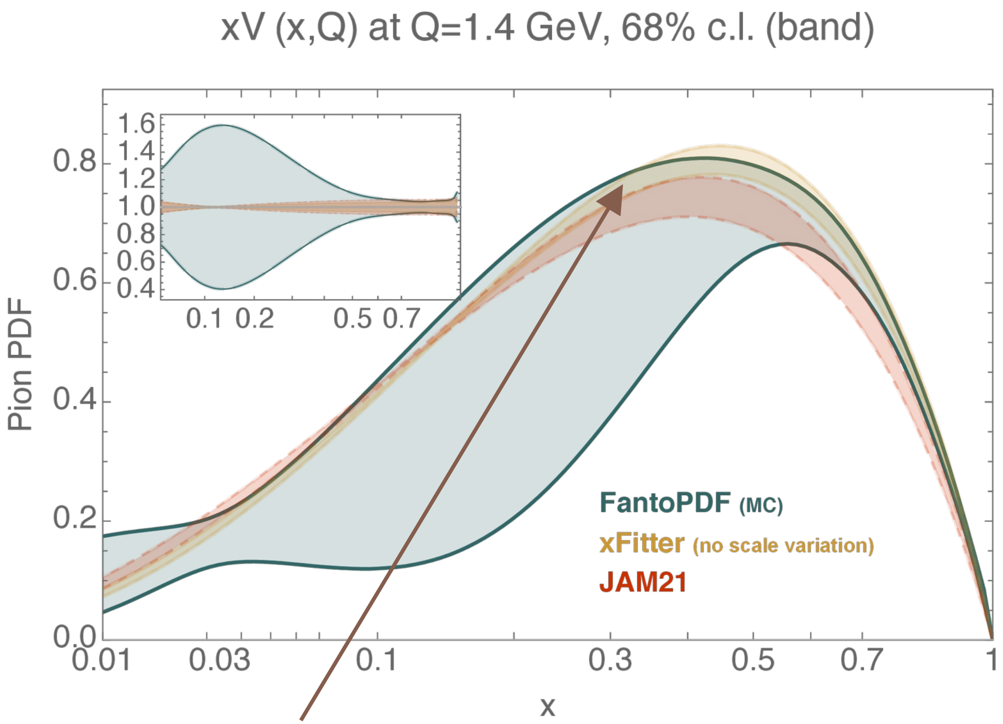
metamorph



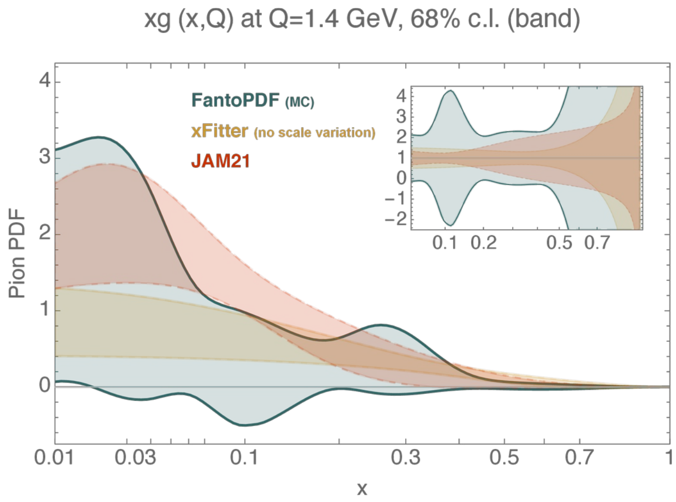
A C++ package with the *metamorph* parametrizations

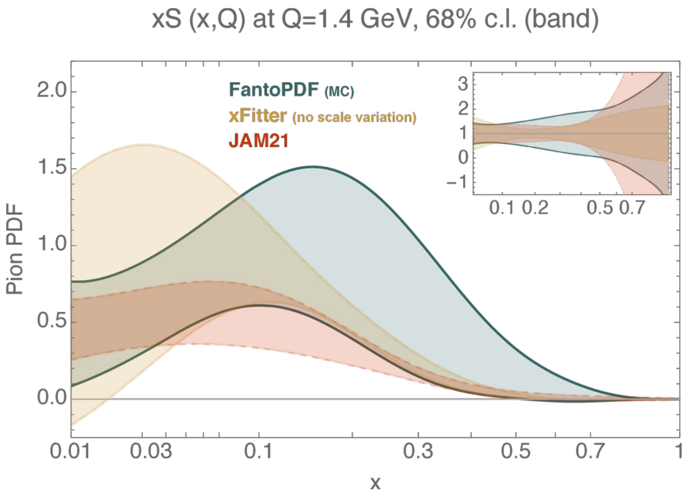
The Fantômas pion PDFs

L. Kotz et al, 2311.08447



without parametrization dependence





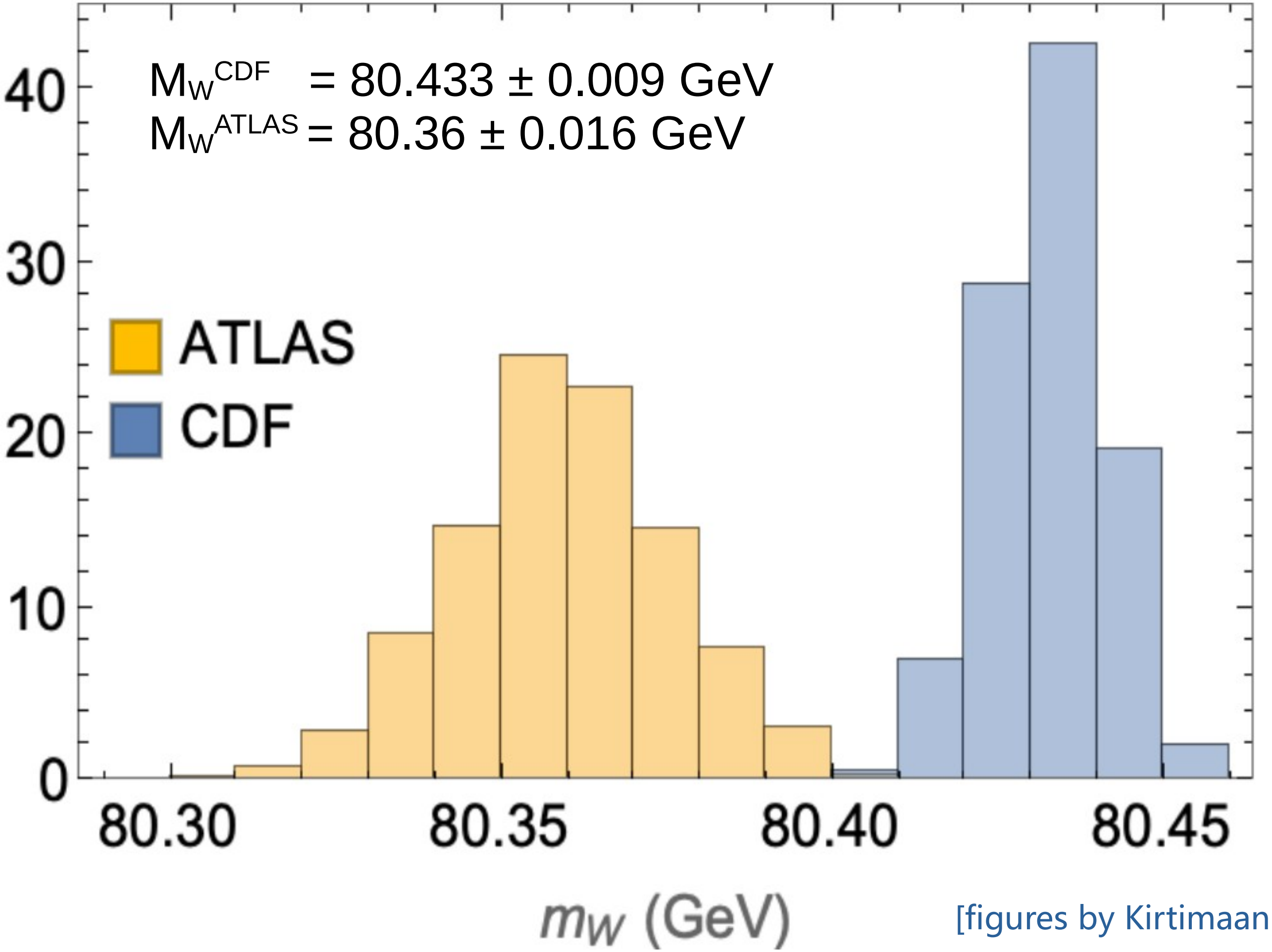
- Fantômas was incorporated into the xFitter fitting program
- Framework to access pion PDFs available on xFitter.

Statistic analysis

Improve precision:

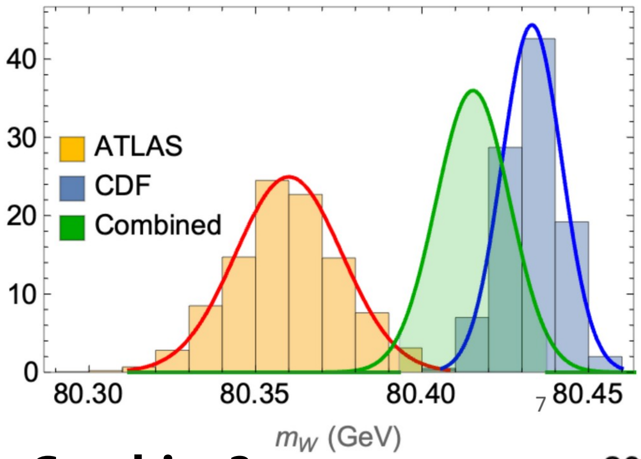
Repeat measurements with more precise balance

CDF Science,376 (2022)



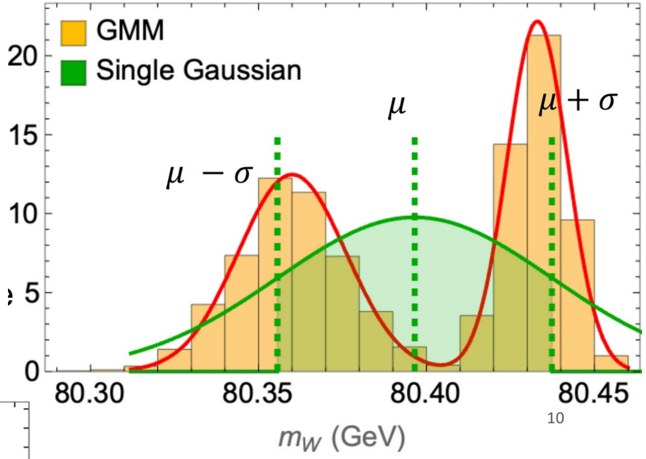
[figures by Kirtimaan Mohan, DIS2023]

Gaussian Mixture Model (GMM)



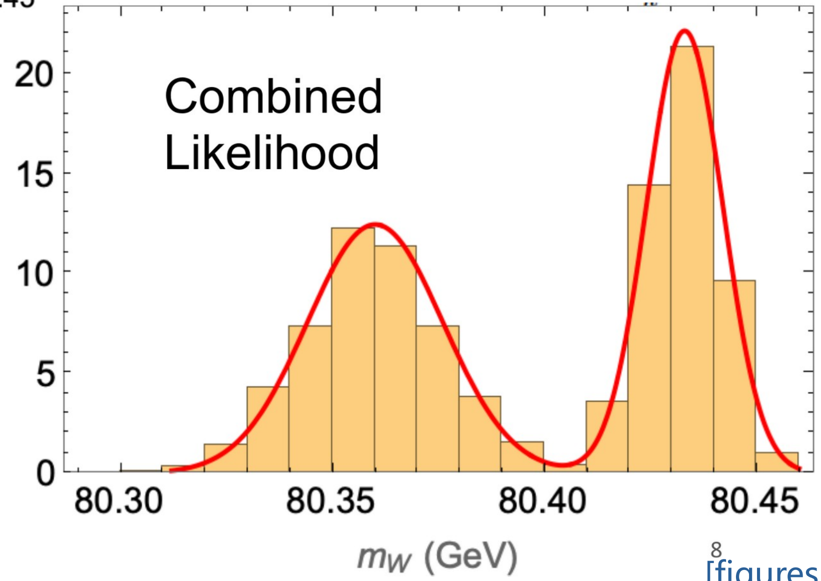
Gaussian Mixture Model

- parameterizing the likelihood as a sum of Gaussians
- 2 Gaussians is needed in this case



Combine?

- 2σ band does not cover both means
- Increase tolerance $\Delta\chi^2 = T^2$; $T > 1$
  Does not provide a faithful representation of the probability distribution

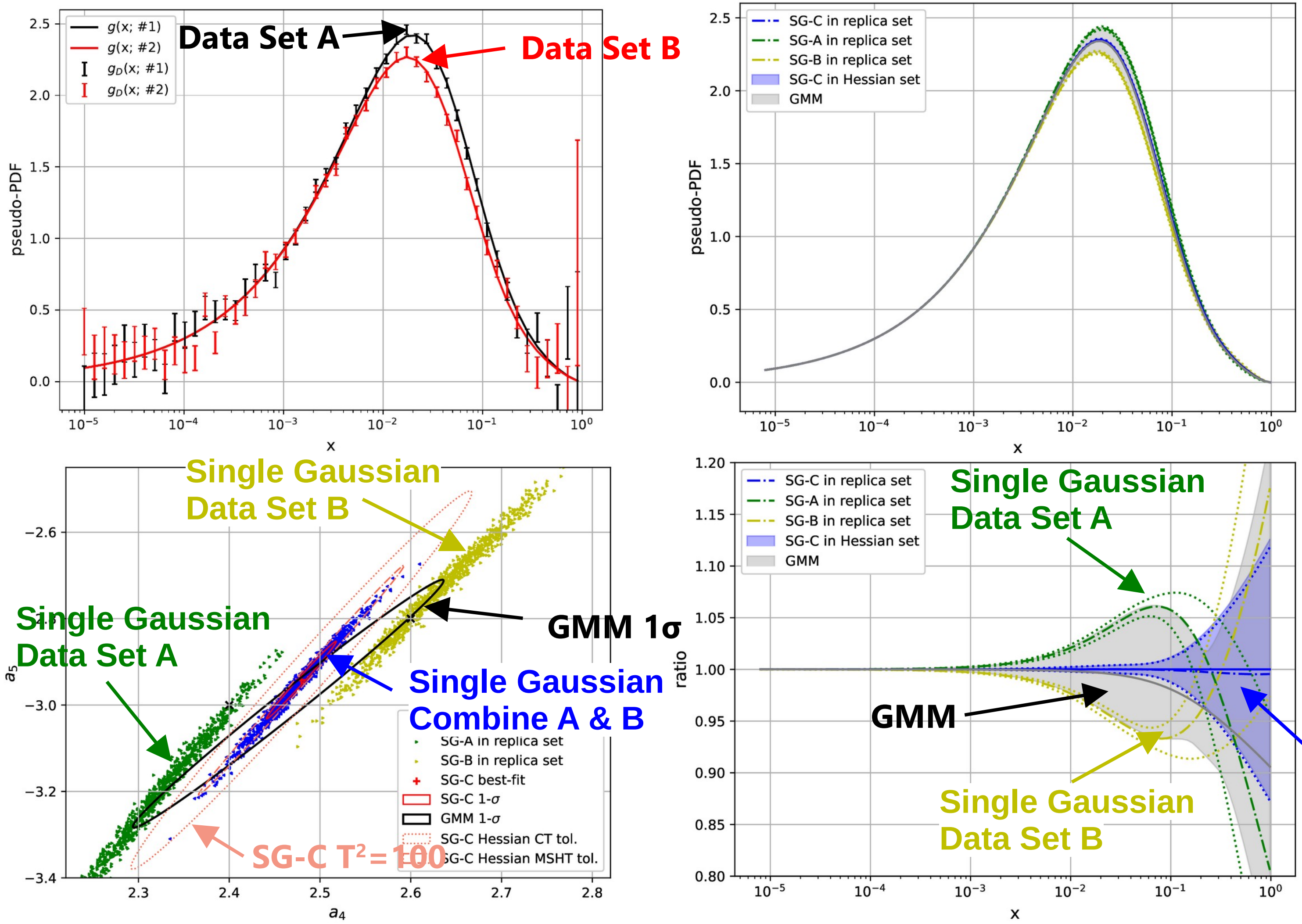


Model as a single Gaussian?

- not a faithful representation of the likelihood

[figures by Kirtimaan Mohan, DIS2023]

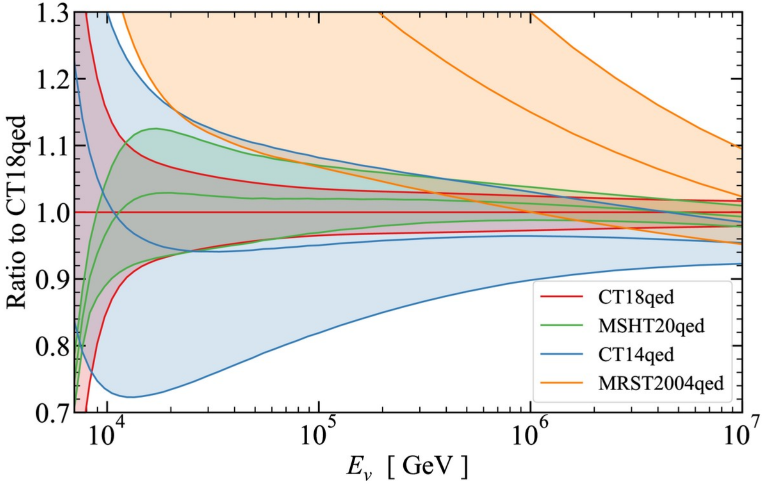
Gaussian Mixture Model (GMM)

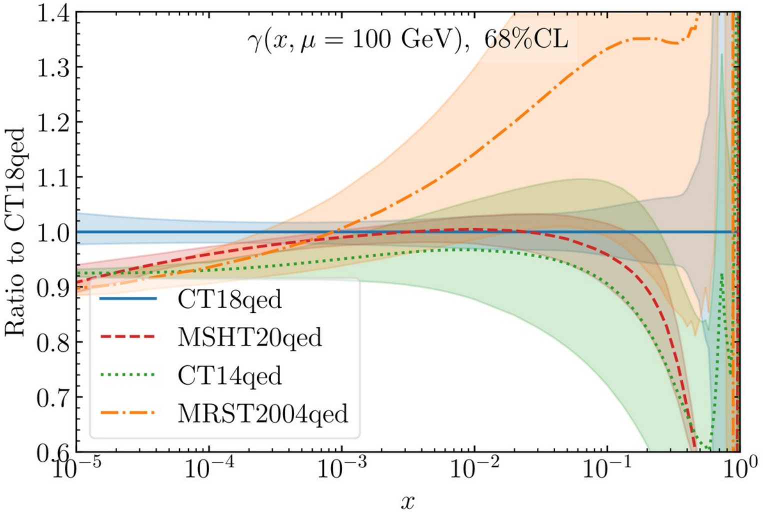


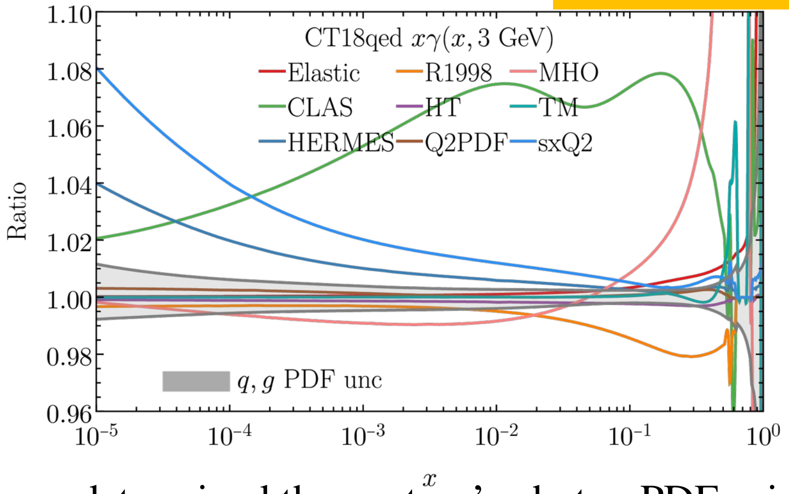
- Single Gaussian fit with combined data set A and B do not cover the likelihood of data set A or data set B
- Enlarge tolerance do not help too much
- The uncertainty band of GMM cover the means of data set A and B

K. Xie et al, 2305.10497

Neutron's photon PDF





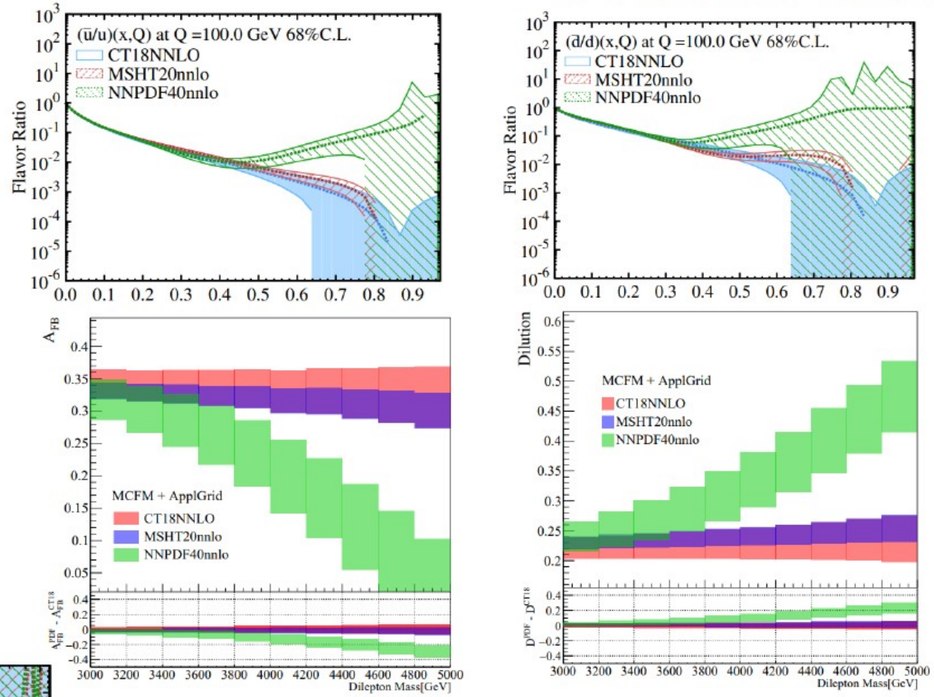


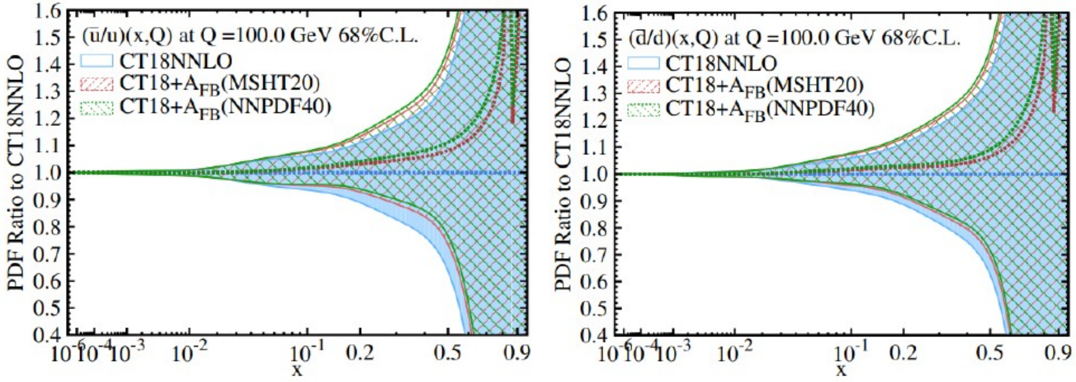
- We have determined the neutron's photon PDF using a similar methodology as for the proton one.
- The structure function is determined using pQCD at high Q2 and HERMES and CLAS/CB data a low Q2
- We estimated many low-Q2 uncertainties, including the isospin symmetry violation and the QED evolution effects. We also explored implications for W-boson production, etc.
- CT18qed and MSHT20qed are in a good agreement
- In comparison to the first generation of photon PDFs, the uncertainty is significantly reduced.

Impact of A_{FB} in the high-mass Drell-Yan process

Y. Fu et al., 2307.07839
C. Willis et al., 1809.09481

- A_{FB} at the LHC is sensitive to the energy dilution factor D (probability of $k_q^0 < k_{\bar{q}}^0$ in the Collins-Soper frame)
- $A_{FB}^h = \frac{N_F^h - N_B^h}{N_F^h + N_B^h} \approx (1-2D)A_{FB}^q$
- A_{FB} at high invariant mass region probes $\bar{u}/u$, $\bar{d}/d$ at $x > 0.2$





- CT18, MSHT20, and NNPDF4.0 predict very different $\bar{q}/q$ at $x > 0.2$
- The article quantified the potential effect of high-mass A_{FB} on large-x antiquarks

See also NNPDF (2209.08115), Fiaschi et al. (2211.06188)

Uncertainty of Gluon PDF

Jet data sets included in each fits

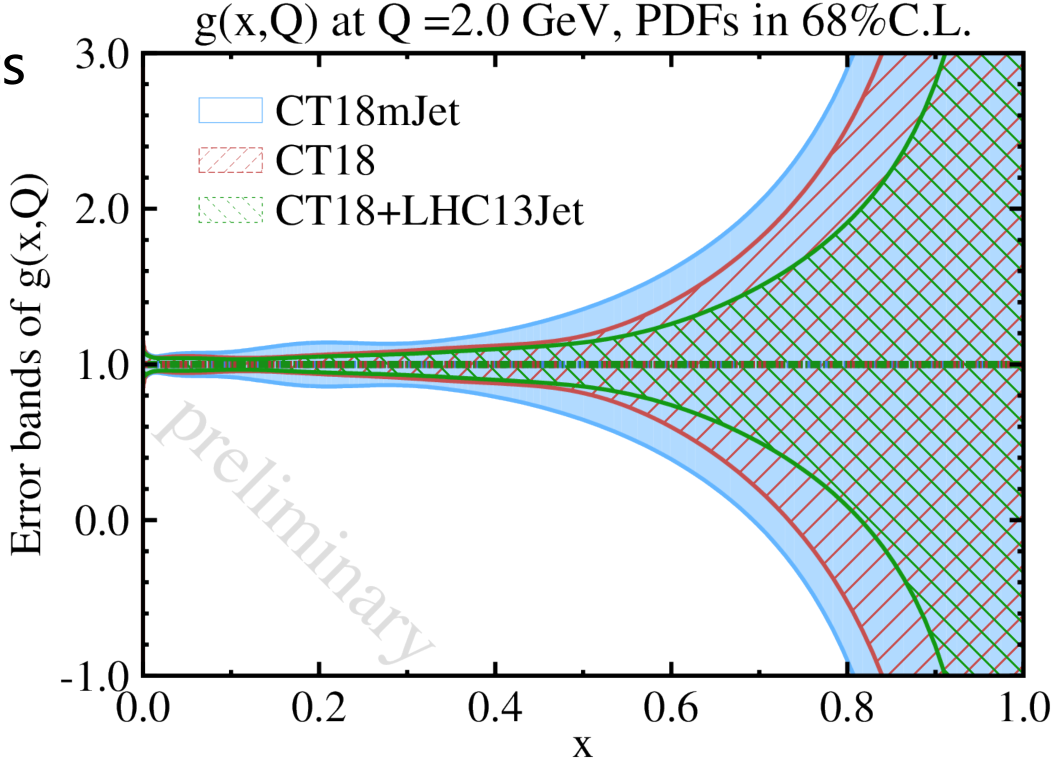
CT18mJet: no jet data

CT18:

CDF	0807.2204	1.13 fb^{-1}
D0	0802.2400	0.7 fb^{-1}
CMS7	1406.0324	5.0 fb^{-1}
ATL7	1410.8857	4.5 fb^{-1}
CMS8	1609.05331	19.7 fb^{-1}

CT18+LHC13jet:

ATL8	1706.03192	20.2 fb^{-1}
ATL13	1711.02692	3.2 fb^{-1}
CMS13	2111.10431	36.3 fb^{-1}



The uncertainty of the gluon PDF in the large-x region receives constraints from jet data.

Uncertair

Jet dat

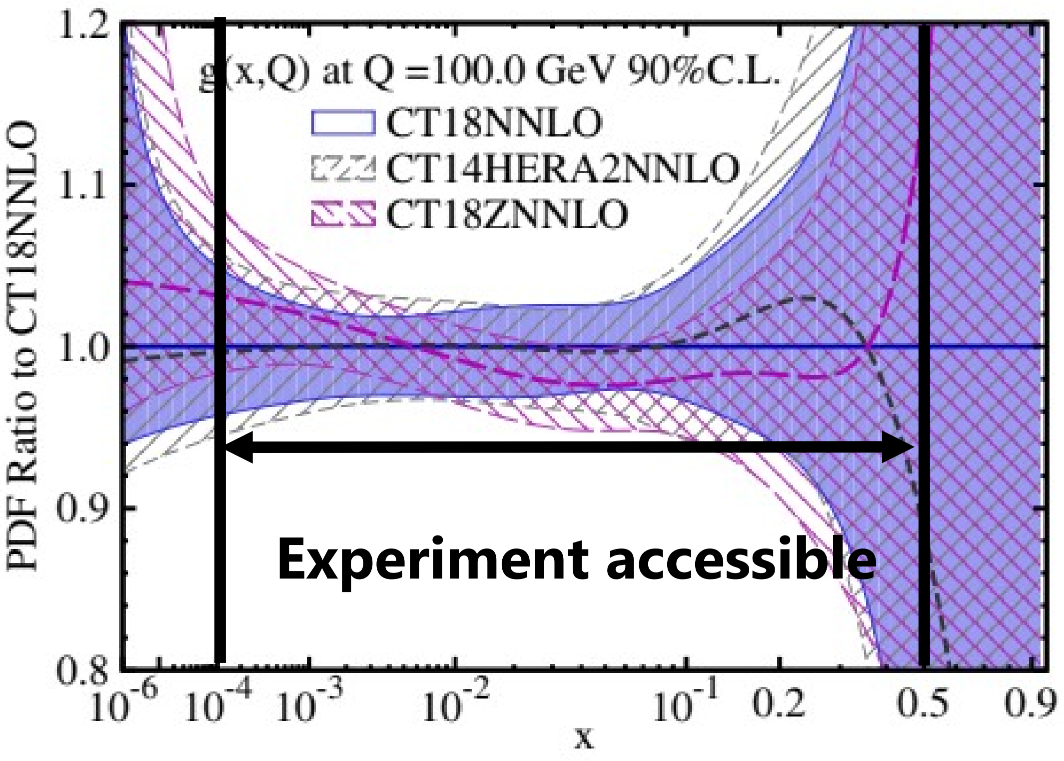
CT18m

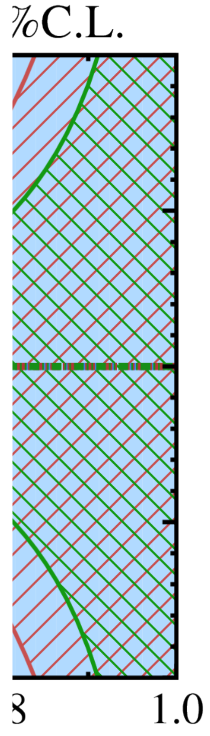
CT18:

CDF
D0
CMS7
ATL7
CMS8

CT18+

ATL8
ATL13
CMS13





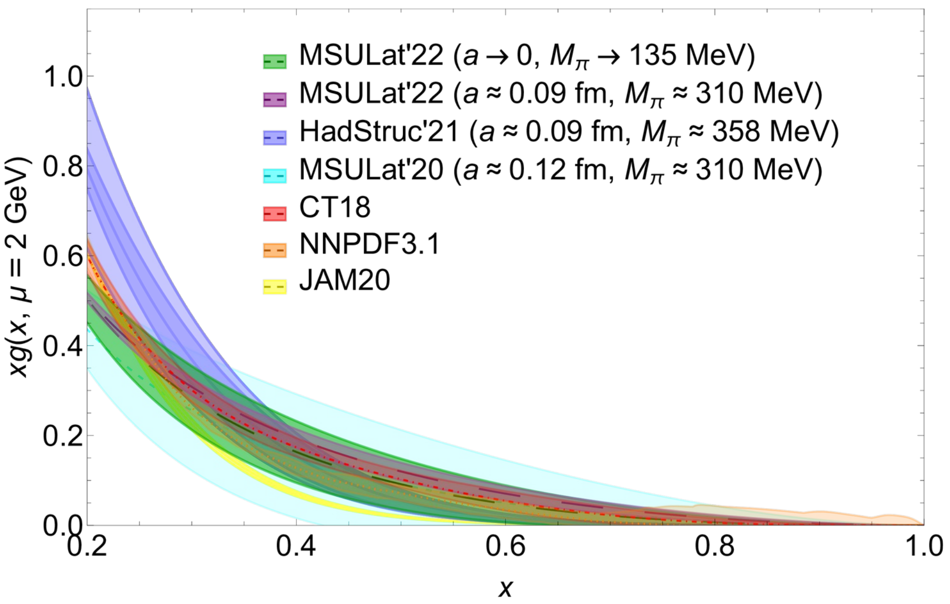
- PDFs are well determined in "middle-x" region: $10^{-4} \lesssim x \lesssim 0.4$
- Region of x→1 and x→0 are not experimental accessible.

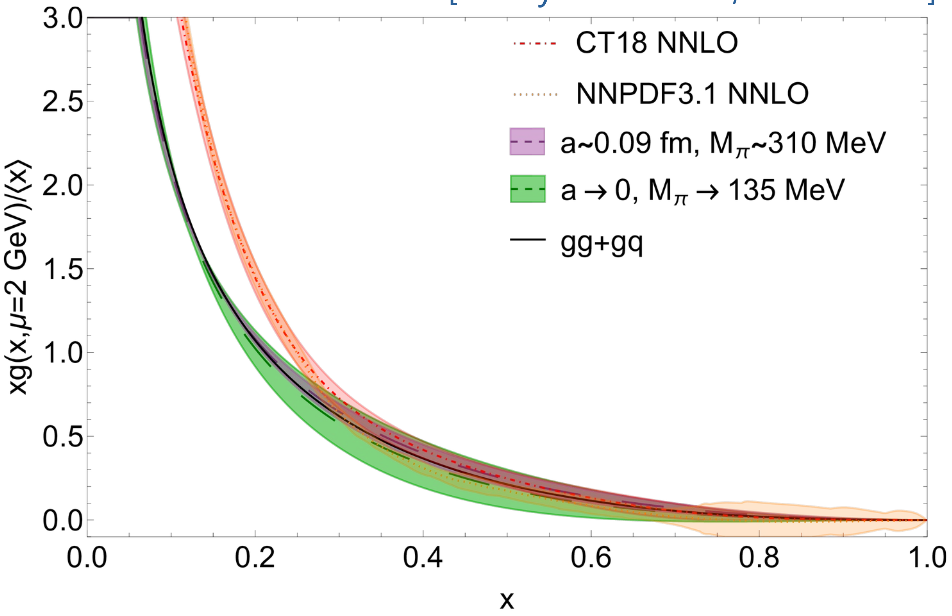
in the
from

CT18 with Lattice input on gluon

Result from MSULat/quasi-PDF method

[Zhouyou Fan et al, 2210.09985]





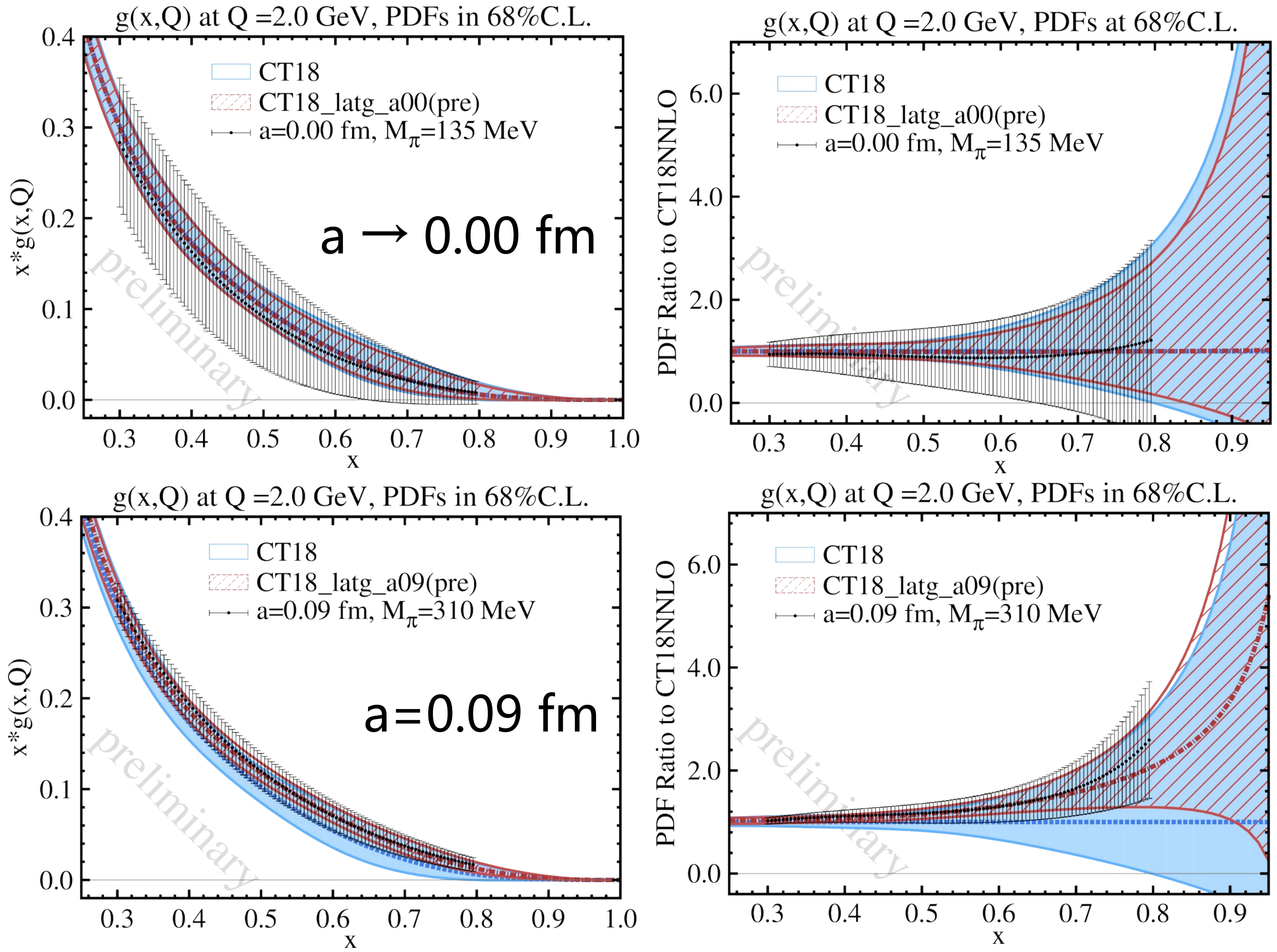
$$\mathcal{M}(\nu, z^2) = \int_0^1 dx \frac{xg(x,\mu^2)}{\langle x \rangle_g} R_{gg}(x\nu, z^2\mu^2)$$

- Clover on 2+1+1 HISQ
- $a \to 0$ fm, $M_\pi \to 135$ MeV and $a \approx 0.09$ fm, $M_\pi \approx 310$ MeV which represent the current and future levels of uncertainty.

- Good agreement with CT18 and NNPDF3.1
- Gluon PDF xg(x) extra at 2 GeV

Preliminary

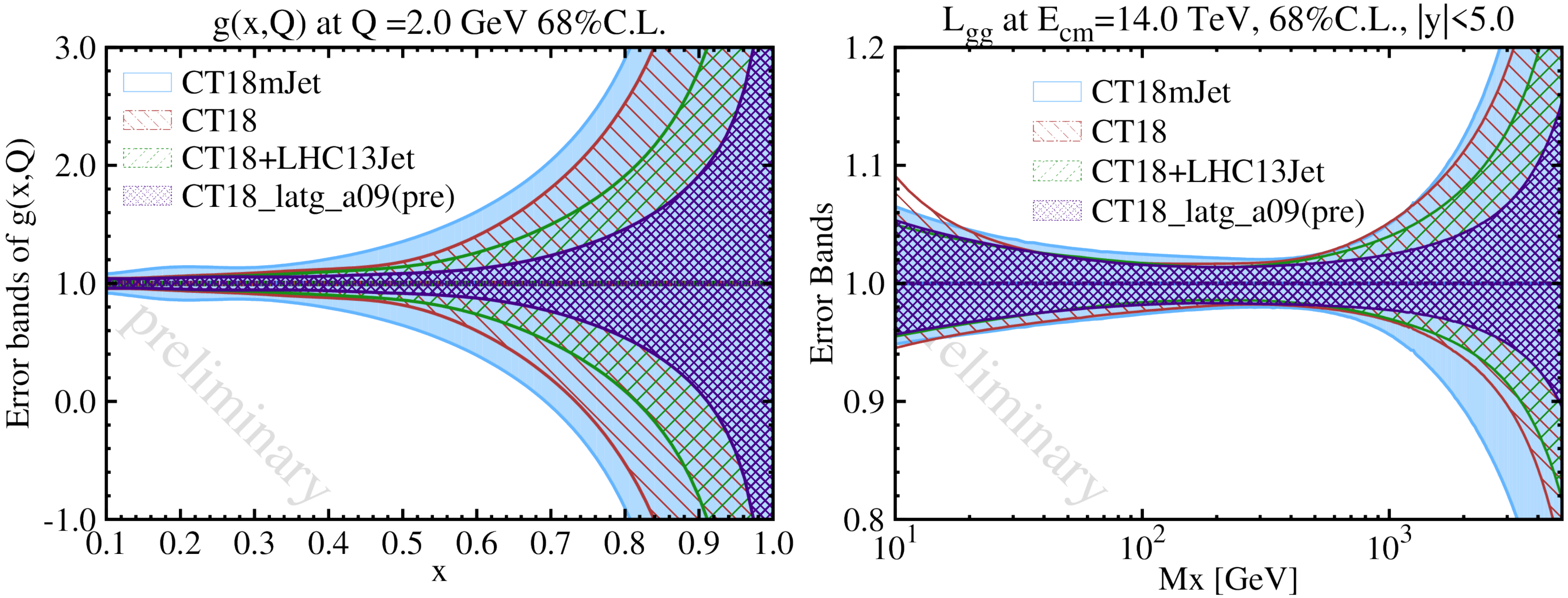
CT18 with Lattice input on gluon



- Inclusion of lattice input in the CT18 global analysis has the potential to reduce its uncertainty.
- Here, a→0.00 fm case represents the current status, while a=0.09 fm case represents future potential.

CT18 with Lattice input on gluon

Preliminary



- The precision of the gluon PDF in the large-x region could potentially be improved by both incorporating jet data and lattice QCD input.

Near-future plans

1. Final selection of experiments for NNLO PDFs planned for the next year
2. Work on N3LO contributions
3. Next-generation PDF uncertainty quantification
4. Recent and imminent releases
   - Study on impact of the LHC incl. jet data on the proton structure
   - QCD+QED PDFs for protons and neutrons
   - Subtracted S-ACOT-MPS PDFs
   - Fantômas 1.0 pion PDFs (Hessian)
   - Release of the Fantômas PDF parametrization package in xFitter
   - Impact of lattice large-x gluon data in the CTEQ-TEA global analysis

Thank you for your attention!