Preliminary results on META PDFs v2 based on updated inputs

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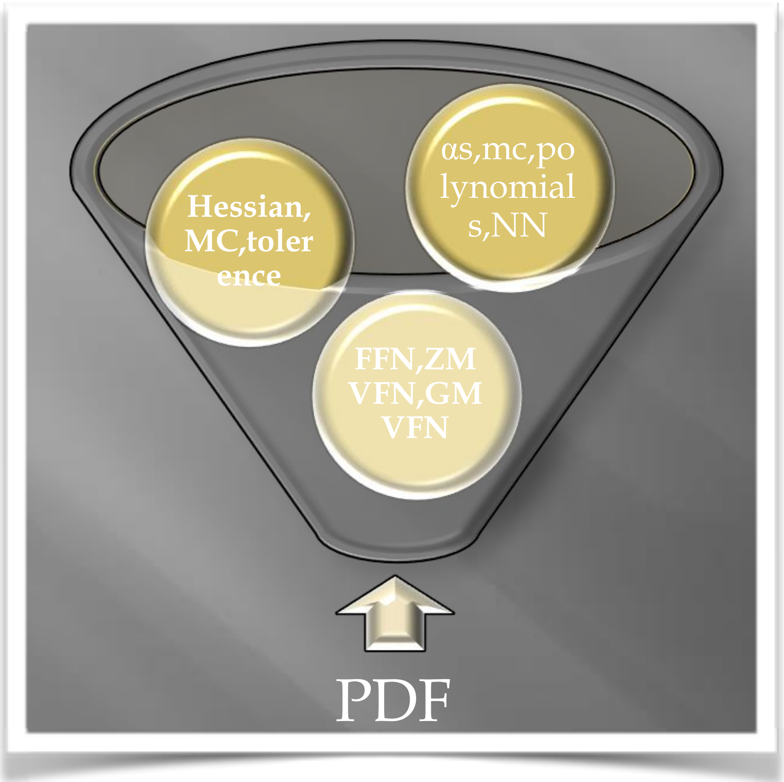
Outline

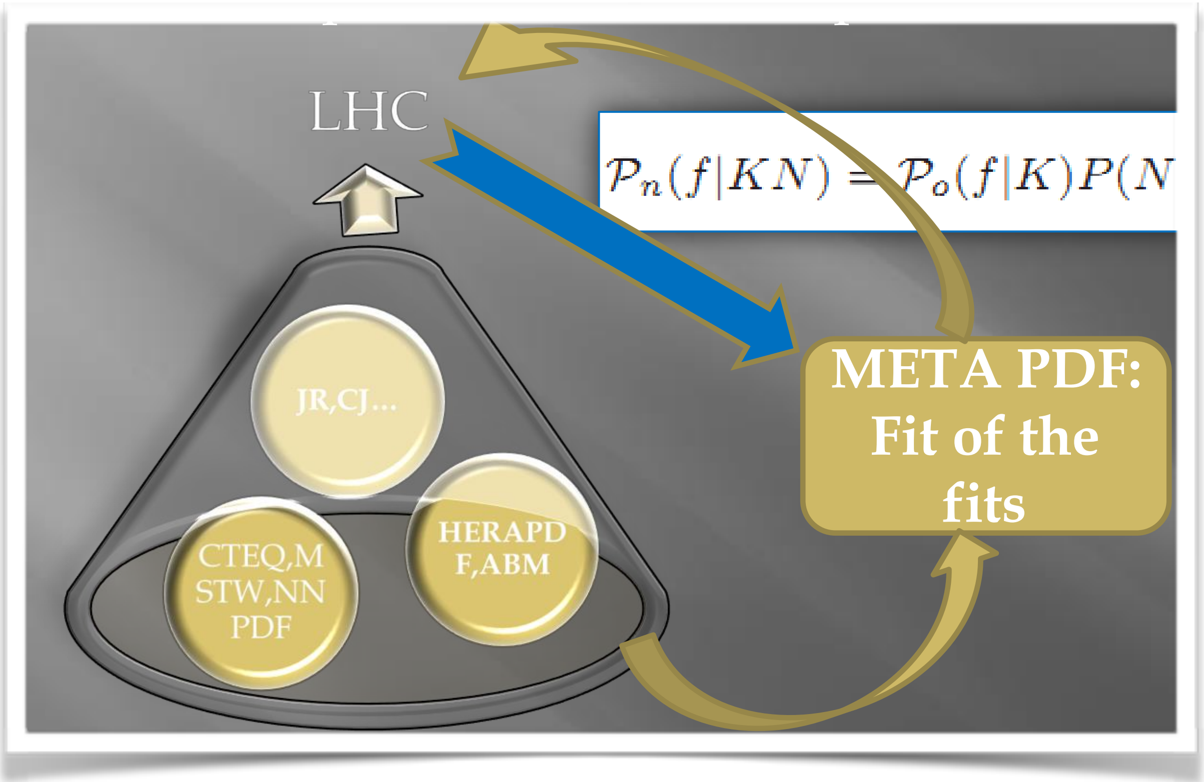
- Recap of the META PDFs
- Updated inputs
- Preliminary META PDF v2
- Summary

Motivation

- Typical LHC application utilizing PDFs requires combination of predictions from several PDF groups to avoid potential bias



diversity of PDFs



combination of PDFs

- prescriptions for combining PDF predictions: 2010 PDF4LHC; combined MC replicas, S. Forte, R. Thorne, G. Watt; META PDFs, J. Gao, P. Nadolsky, J. Huston; compressed MC replicas, J. Rojo, G. Watt, S. Carrazza, J. Latorre
- observable basis/PDF basis; Hessian representations/MC replicas; effective Gaussian prescription/including non-Gaussianity

The META analysis of PDFs

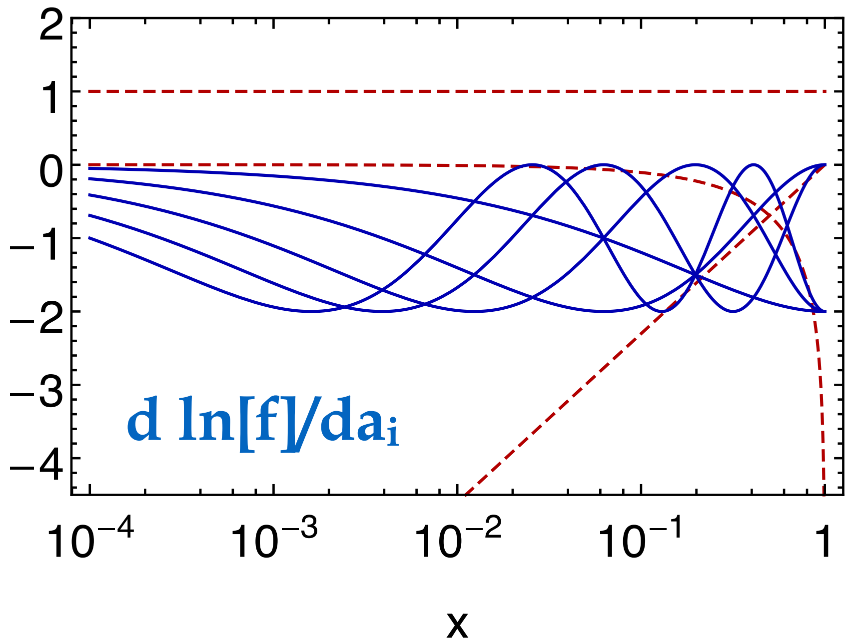
- A meta-analysis of PDFs [1401.0013] estimates central predictions and uncertainties of PDFs, using PDF ensembles from different groups in a simple and systematic way; provides a META PDF ensemble to predict LHC observables

The meta-parametrization

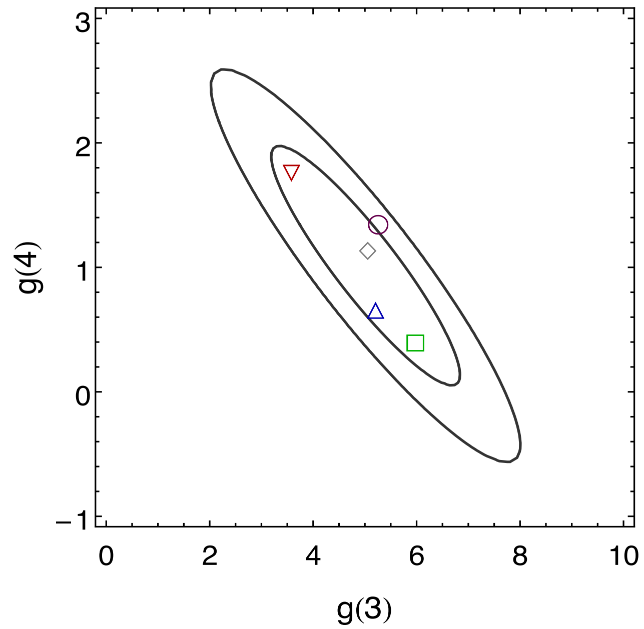
- construct a common physical basis, a meta-parametrization, to compare and combine PDFs from different groups (at $Q_0 > m_b$ with the same function form, same evolution)

- a meta-function form of the PDFs at an initial scale of Q_0=8 GeV, independently for 9 PDF flavors (66 parameters in total, flexible enough); find the meta-parameters for each input PDF set of selected PDF ensembles [remapping]

$$f(x, Q_0; \{a\}) = e^{a_1} x^{a_2} (1-x)^{a_3} e^{\sum_{i \geq 4} a_i \left[T_{i-3}(y(x)) - 1\right]}$$



a PDF->66 parameters



The META analysis of PDFs

- A meta-analysis of PDFs [1401.0013] estimates central predictions and uncertainties of PDFs, using PDF ensembles from different groups in a simple and systematic way; provides a META PDF ensemble to predict LHC observables

The meta-combinations

- select the input PDF ensembles (CT, MSTW, NNPDF, HERAPDF…) and generate large number of combined MC replicas
- calculate mean and covariance matrix of meta-parameters for selected inputs using MC error propagation [though not really necessary]
- construct a final ensemble of 68% c.l. Hessian eigenvector PDF sets [within effective Gaussian approach] to propagate the PDF uncertainties from the original PDF ensembles into LHC predictions
- allows various ``offline'' manipulations on PDF basis through usage of PDF eigenvectors, including Data set diagonalization [DSD, J. Pumplin] and Bayesian reweighting
- META PDFs v1 [50 eigenvectors], including the Higgs specific set, has been submitted to LHAPDF6

META PDFs, version 2 (preliminary)

- Most updates are on the input PDF ensembles; release of the code on generation and operations of the META PDFs

  - CT14 preliminary (59), MMHT2014 (51), NNPDF3.0 (101), HERAPDF2.0 preliminary (29+13), all having $a_s(M_Z)$=0.118 for error PDFs; CT14p and MMHT2014 have improved parametrizations; PDF evolution of all ensembles is validated against HOPPET;

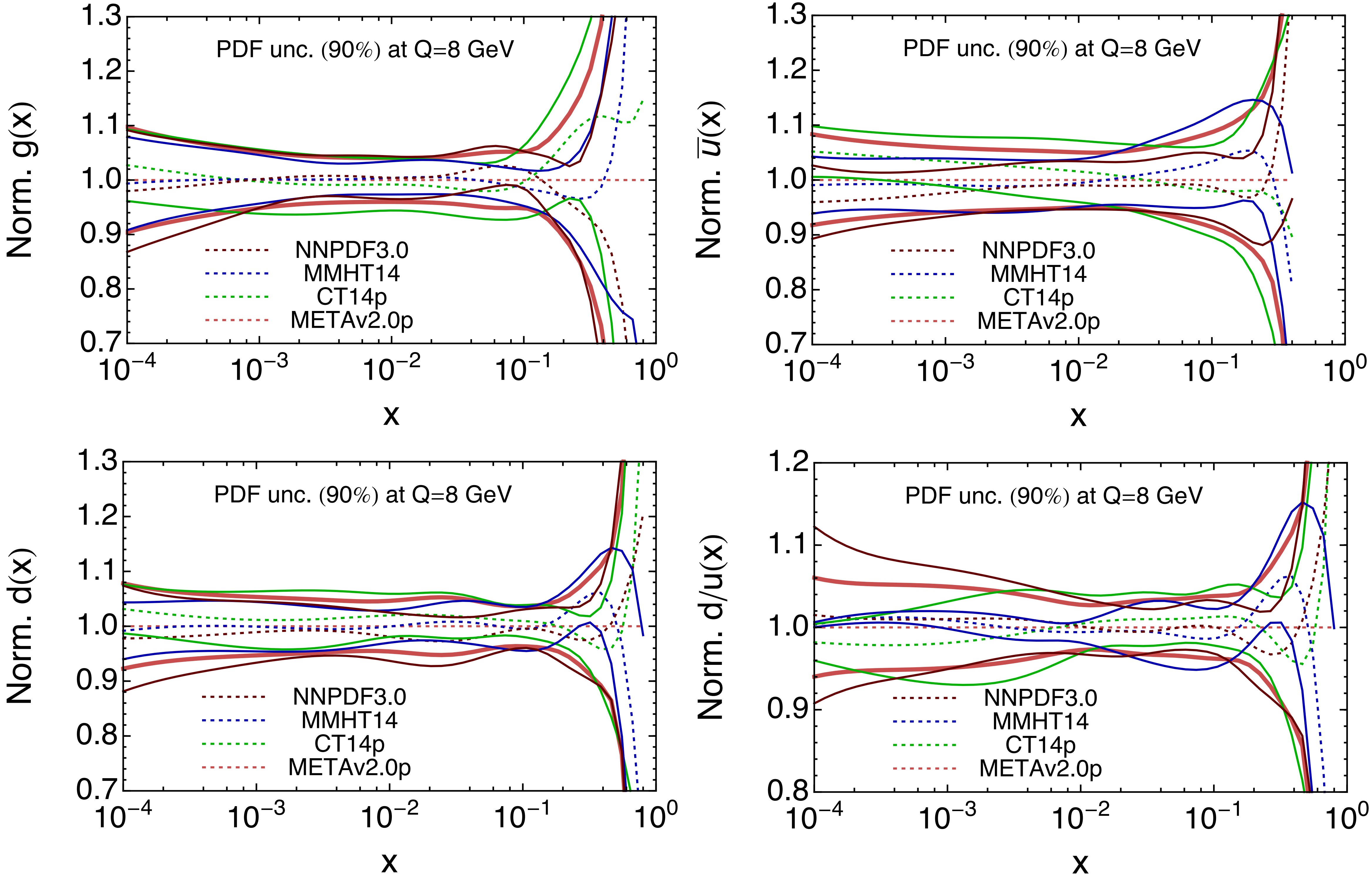
  - A sub-version of META2.0 includes HERAPDF2.0p (29+13) together with the global ensembles, but with a smaller weight (50 vs. 200) to account for a smaller HERA PDF data set;

  - The code for producing META PDFs is reorganized and will be released soon. It is semi-automated. One could reproduce the entire procedure within an hour. The functionality includes generation of MC replicas from all PDFs in LHAPDF5/6, fitting to the META parametrization with quality control, evolution from PDF parameters and generating LHAPDF5/6 grids, and analysis of the eigenvectors including data set rediagonalization to produce specialized PDFs;

  - Possible extensions: include module for PDF reweighting study using LHC data

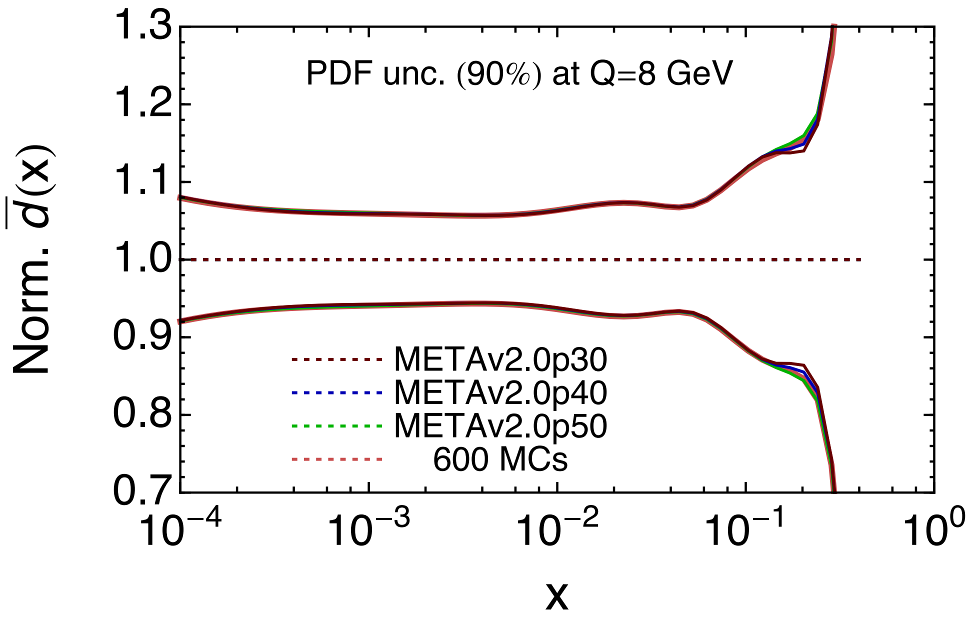
Comparison of PDF uncertainties

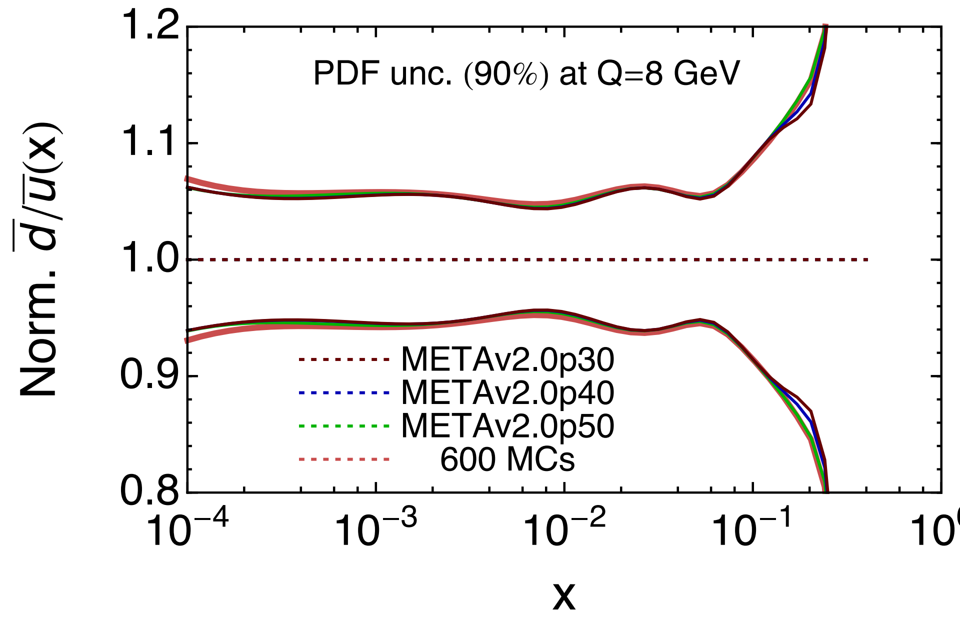
- META NNLO v2.0p: combining the 3 global PDF sets, preliminary CT14, MMHT2014, and NNPDF3.0

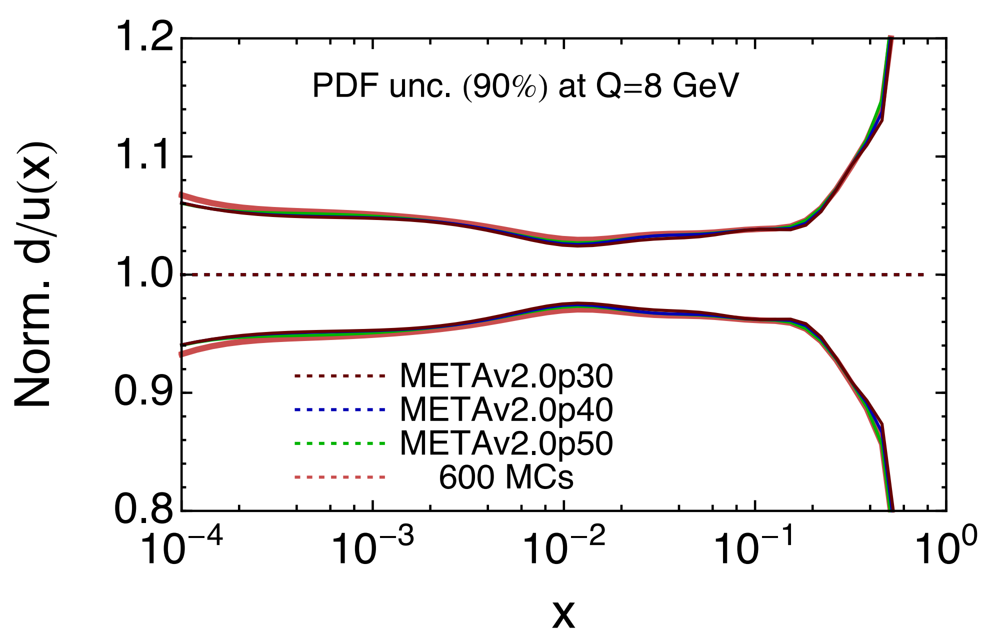


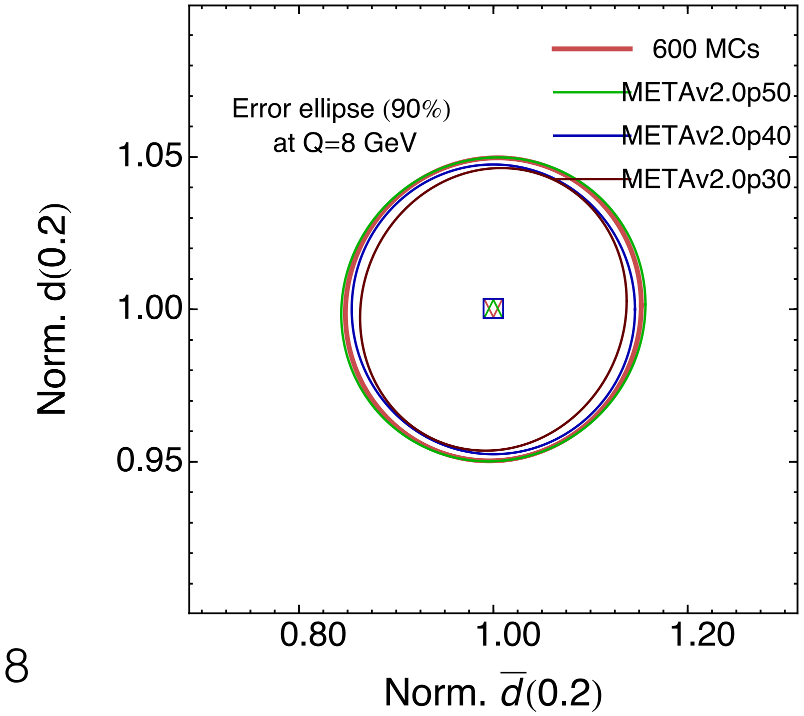
How many error PDFs are needed?

- META NNLO v2.0p: 50 eigenvectors reproduce properties of original MC replicas with high accuracy, and are ordered in their eigenvalues [approximately contributions to PDF uncertainties]; prefer to keep 40~30 eigenvectors for a general-purpose LHC META ensemble; one can use 41~31 PDFs instead of 81~61





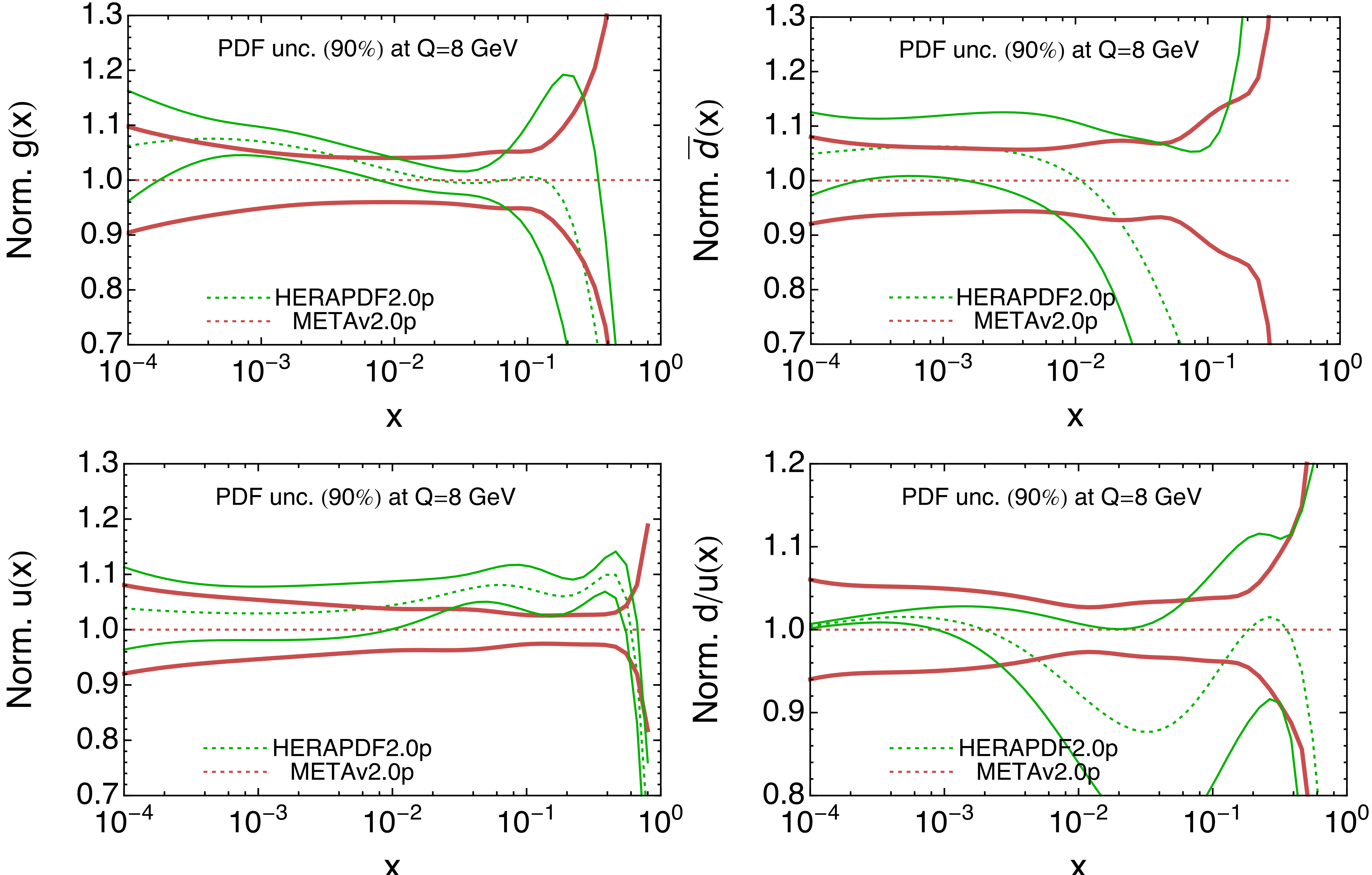




PDF uncertainties from the full MC sample; META2.0 ensembles with 50, 40, 30 eigenvectors

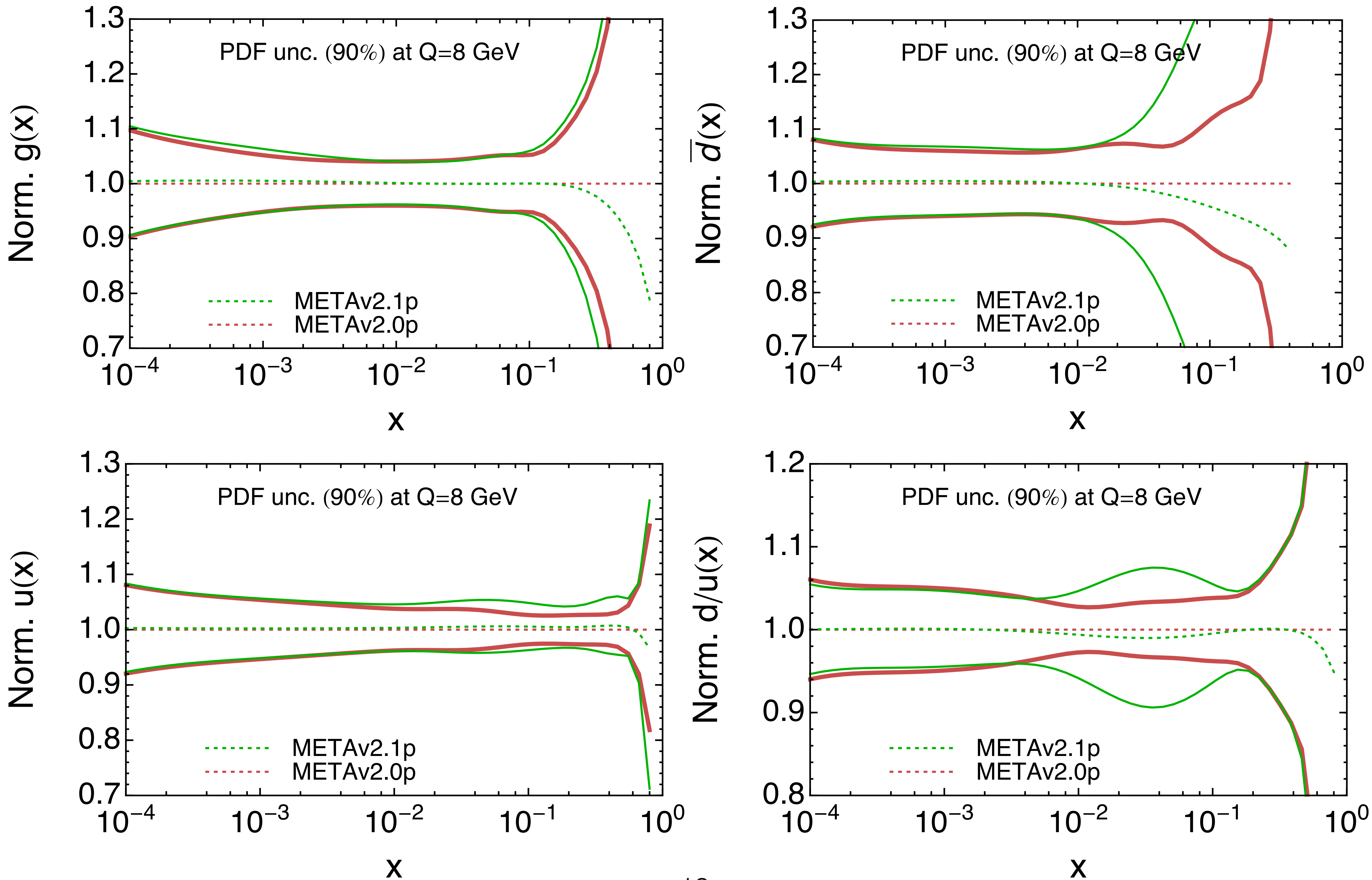
Comparison of META2.0 and HERAPDF2.0p

- HERAPDF2.0 (preliminary, including 29EIG.+13VAR.) compared with META NNLO v2.0p (based on three global ensembles)



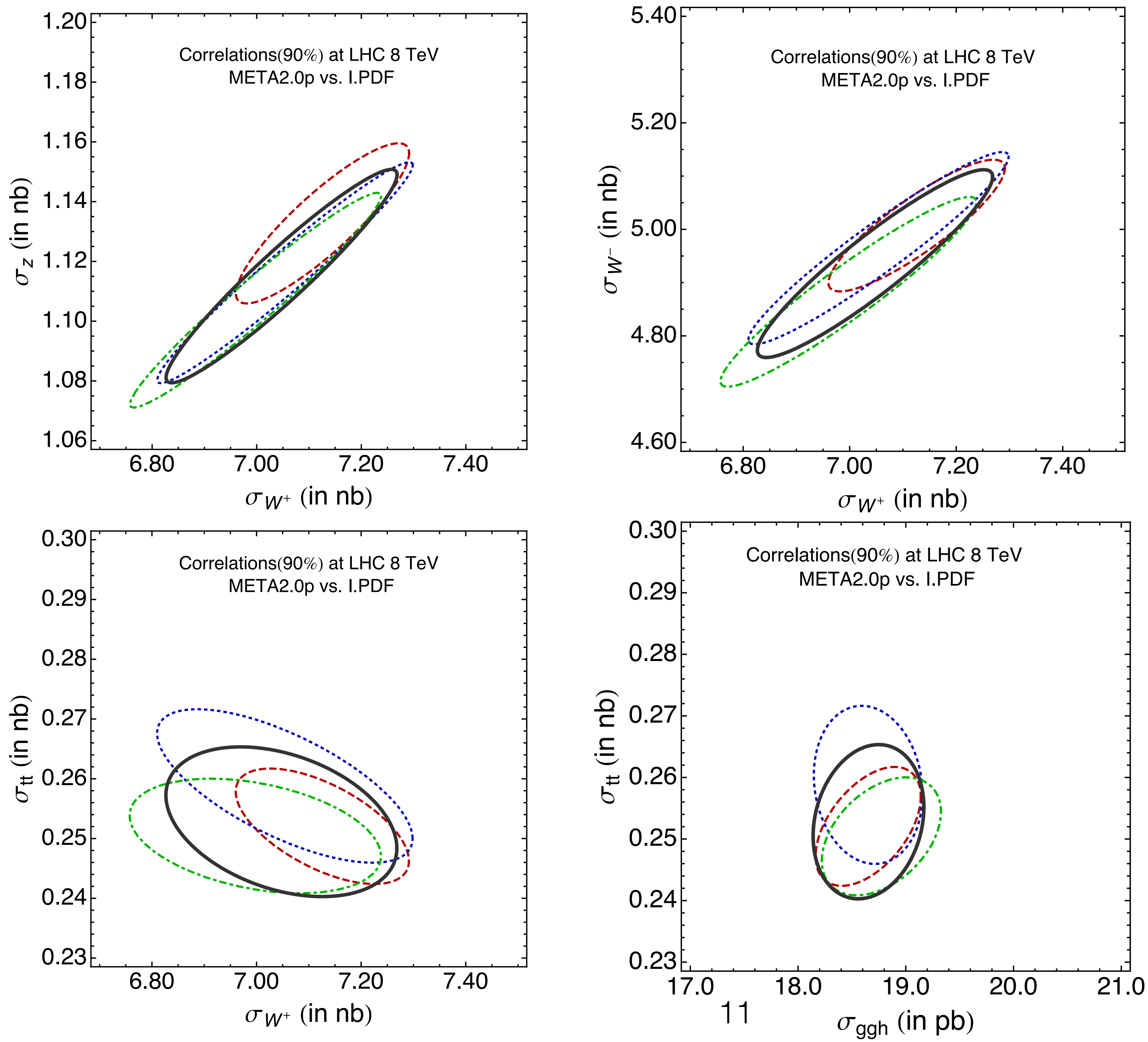
META2.1 vs. META2.0 (global only)

- META NNLO v2.1p includes HERAPDF2.0 (preliminary) with a smaller weight, 50 vs. 200 MC replicas



META2.0 predictions for LHC observables

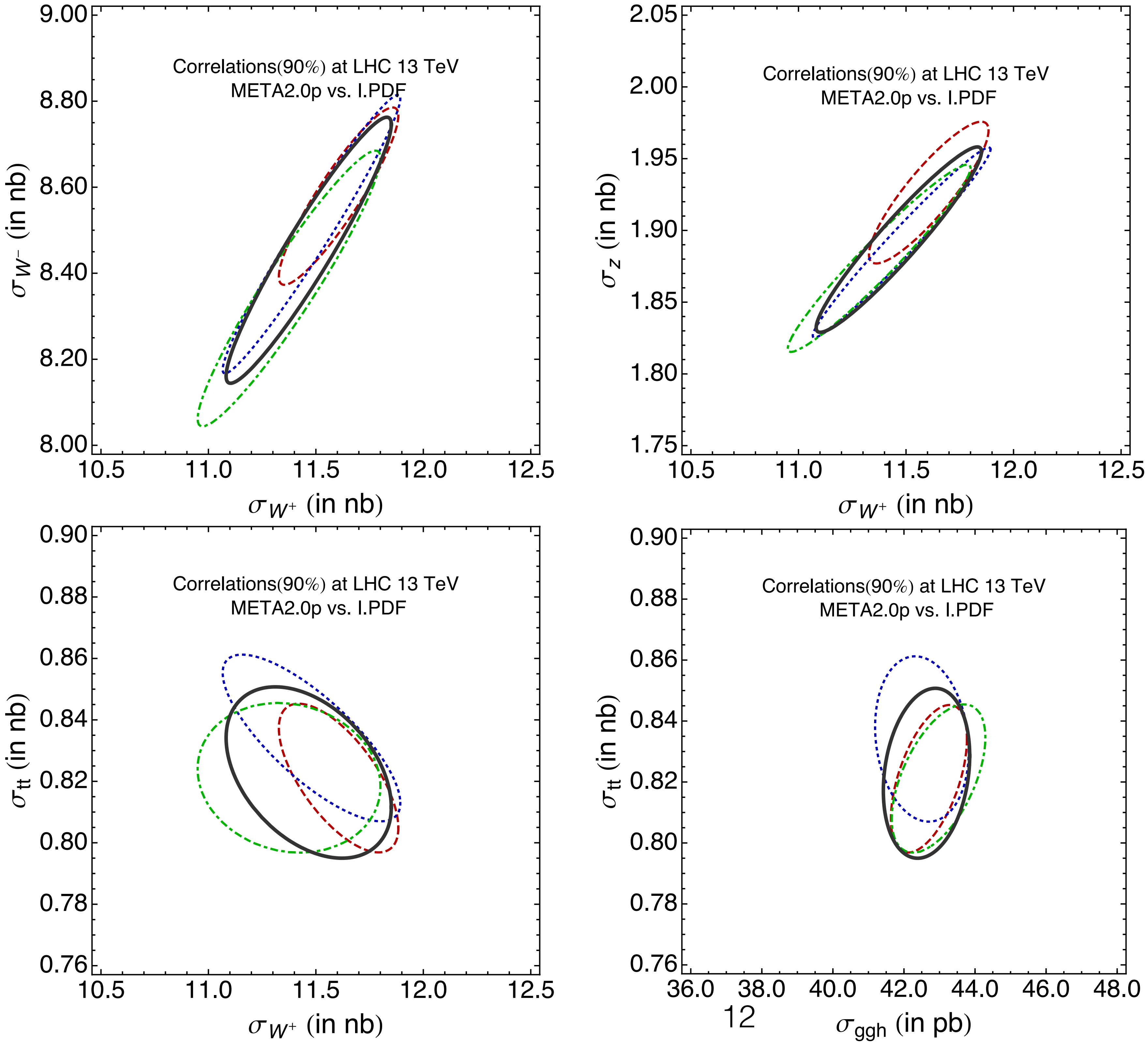
- Currently only have results for META NNLO v2.0p, will add later for v2.1p, inclusive observables at 8 TeV



- Blue, CT14p, red, MMHT14, green, NNPDF3.0, black, METAv2.0p, error ellipse at 90% cl; using Vrap0.9, iHixs1.3, and top++2.0

META2.0 predictions for LHC observables

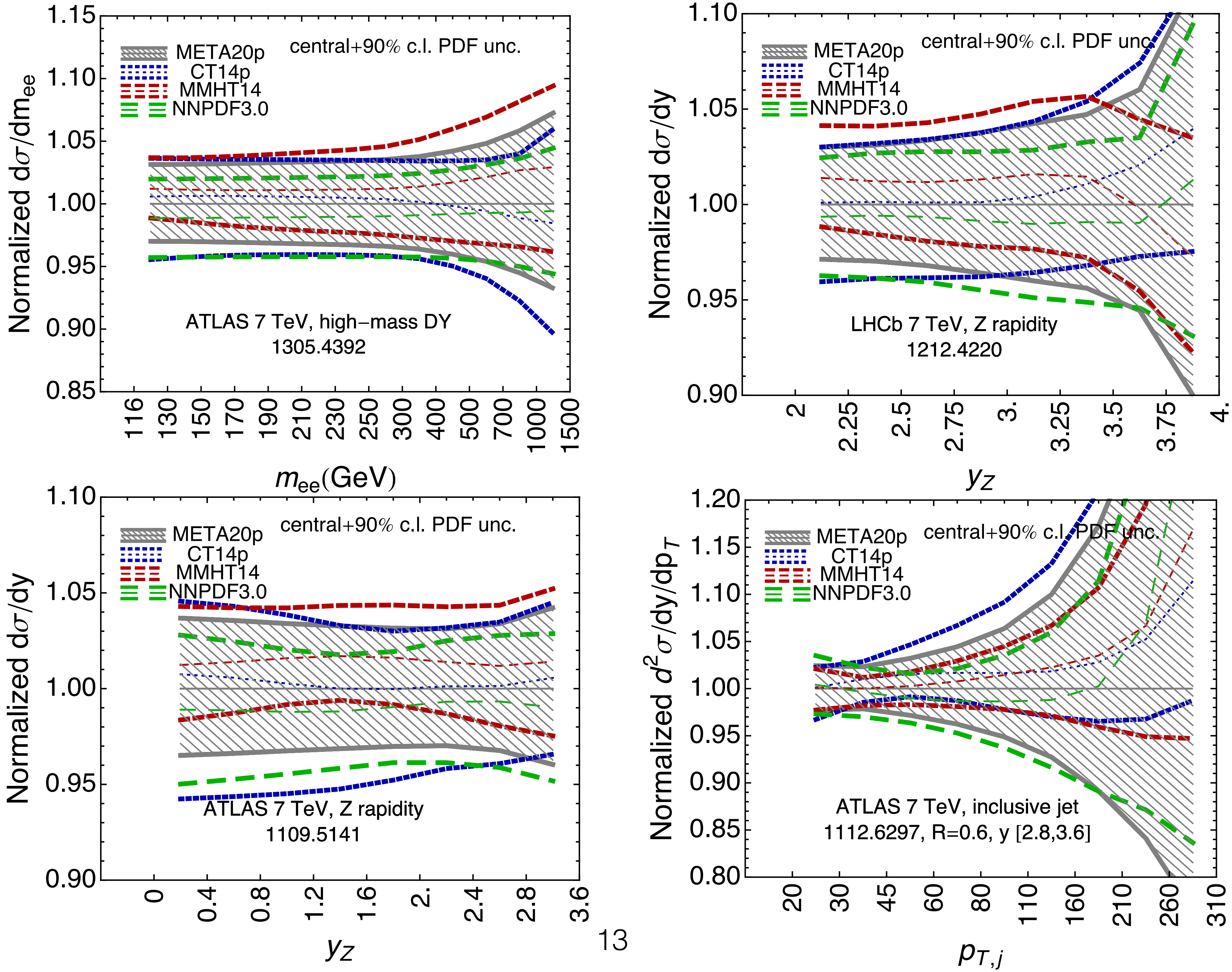
- Currently only have results for META NNLO v2.0p, will add later for v2.1, inclusive observables at 13 TeV



- Blue, CT14p, red, MMHT14, green, NNPDF3.0, black, METAv2.0p, error ellipse at 90% cl; using Vrap0.9, iHixs1.3, and top++2.0

META2.0 predictions for LHC observables

- Currently only have results for META NNLO v2.0p, will add later for v2.1p, differential dis. at 7 TeV [using NNPDF3.0 APPLgrid tables]



Advantages of the Hessian representation

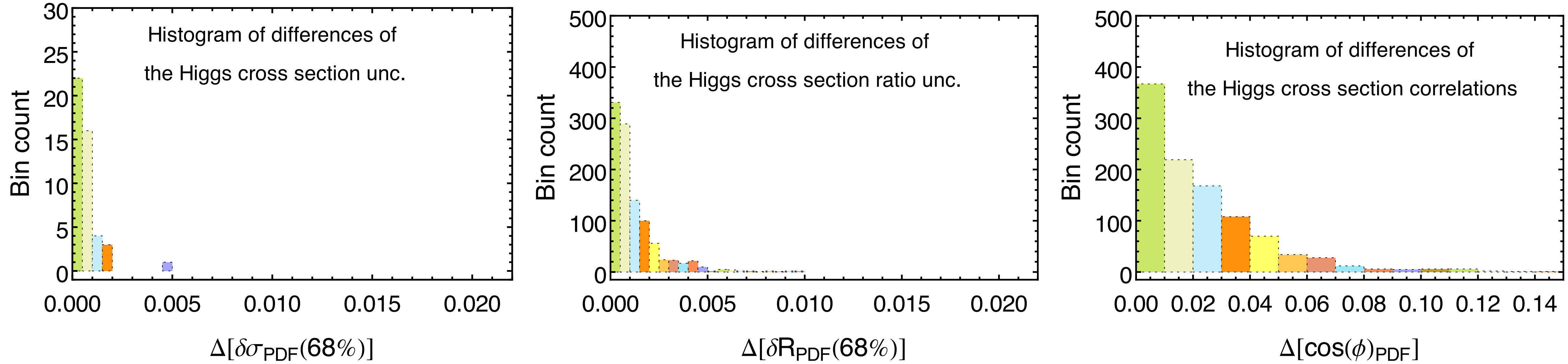
- Hessian PDF eigenvectors are often convenient for the experimental analysis; directly provide the correlation matrix of PDF errors among all observables; allow estimation of PDF errors with the help of nuisance parameters. The eigenvectors can be rotated [J. Pumplin] to optimize computations for a certain group of LHC observables, such as Higgs cross sections. These advantages are not automatic with MC sampling method.

production channel	$\sigma(inc.)$	$\sigma(\lvert y_H\rvert > 1)$	$\sigma(p_{T,H} > m_H)$	scales
$gg \to H$	iHixs1.3 [32] at NNLO	MCFM6.3 [33] at LO	—	m_H
$b\bar{b} \to H$	iHixs at NNLO	—	—	m_H
VBF	VBFNLO2.6 [34] at NLO	same	same	m_W
HZ	VHNNLO1.2 [35] at NNLO	CompHEP4.5 [36] at LO	CompHEP at LO	$m_Z + m_H$
$HW^\pm$	VHNNLO at NNLO	—	—	$m_W + m_H$
HW^+	CompHEP at LO	same	same	$m_W + m_H$
HW^-	CompHEP at LO	same	same	$m_W + m_H$
$H + 1jet$	MCFM at LO	same	same	m_H
$Ht\bar{t}$	MCFM at LO	CompHEP at LO	CompHEP at LO	$2m_t + m_H$
HH	Hpair [37] at NLO	—	—	$2m_H$

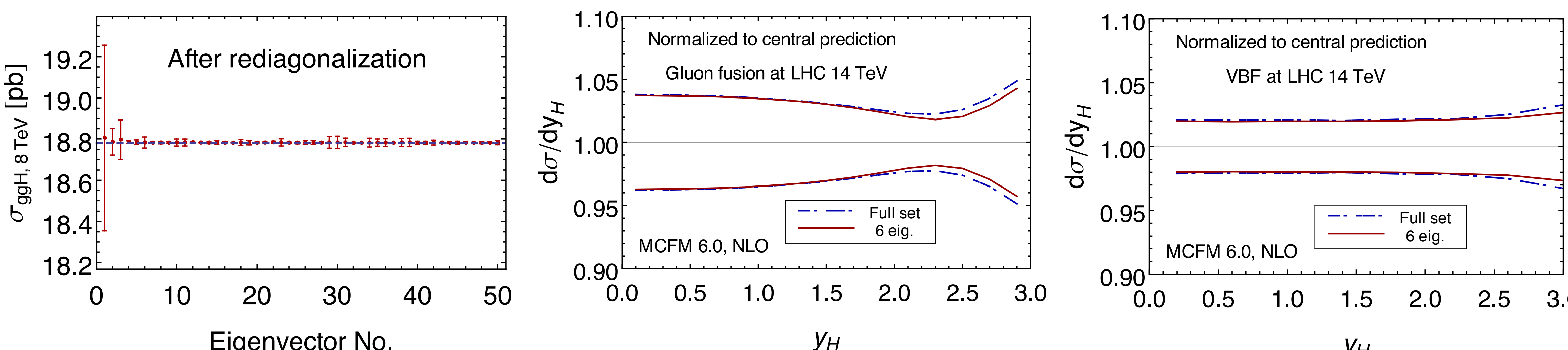
at LHC 8 and 14 TeV, 46 observables in total

Data Set Diagonalization

- In DSD we rotate the orthogonal eigenvectors to be ordered in importance of contributions to a large number of chosen observables, without losing information in the original set [linearity]; after rotation, the first few eigenvectors [6 for Higgs case] reproduce most of the PDF uncertainty for the selected group of observables. The rest of the eigenvectors can still be used for non-selected processes.



6 Higgs eigs. vs. full results



Data Set Diagonalization preserves PDF-induced correlations and PDF uncertainties with less eigenvectors

6 Higgs eigs. vs. full results

	GGH inc., 8 TeV, NNLO	GGH 0j exc., 8 TeV, NLO	GGH 1j exc., 8 TeV, NLO	GGH 2j inc., 8 TeV, LO	GGH 2j exc., 8 TeV, LO	GGH 2j full mass, 8 TeV, LO	VBF inc., 8 TeV, LO	VBF exc., 8 TeV, LO	GGH inc., 14 TeV, NNLO	GGH 0j exc., 14 TeV, NLO	GGH 1j exc., 14 TeV, NLO	GGH 2j inc., 14 TeV, LO	GGH 2j exc., 14 TeV, LO	GGH 2j full mass, 14 TeV, LO	VBF inc., 14 TeV, LO	VBF exc., 14 TeV, LO
VBF exc., 14 TeV, LO	−0.6 / ***−0.62***	−0.58 / ***−0.6***	−0.57 / ***−0.63***	0.1 / ***0.1***	0.1 / ***0.1***	0.06 / ***0.09***	0.92 / ***0.93***	0.92 / ***0.93***	−0.52 / ***−0.54***	−0.49 / ***−0.51***	−0.54 / ***−0.57***	0. / ***−0.01***	0. / ***−0.01***	−0.04 / ***−0.05***	1. / ***1.***	
VBF inc., 14 TeV, LO	−0.6 / ***−0.62***	−0.58 / ***−0.6***	−0.57 / ***−0.63***	0.1 / ***0.1***	0.1 / ***0.1***	0.06 / ***0.09***	0.92 / ***0.93***	0.92 / ***0.93***	−0.52 / ***−0.54***	−0.49 / ***−0.51***	−0.54 / ***−0.57***	0. / ***−0.01***	0. / ***−0.01***	−0.04 / ***−0.05***		
GGH 2j full mass, 14 TeV, LO	−0.11 / ***−0.16***	−0.23 / ***−0.28***	0.26 / ***0.21***	0.94 / ***0.98***	0.94 / ***0.98***	0.94 / ***0.98***	0.02 / ***0.***	0.02 / ***0.***	−0.35 / ***−0.4***	−0.44 / ***−0.49***	−0.23 / ***−0.27***	0.98 / ***0.99***	0.98 / ***0.99***			
GGH 2j exc., 14 TeV, LO	−0.18 / ***−0.17***	−0.3 / ***−0.29***	0.2 / ***0.21***	0.96 / ***0.98***	0.96 / ***0.98***	0.97 / ***0.98***	0.06 / ***0.04***	0.06 / ***0.04***	−0.41 / ***−0.41***	−0.5 / ***−0.5***	−0.29 / ***−0.27***	0.99 / ***0.99***				
GGH 2j inc., 14 TeV, LO	−0.18 / ***−0.17***	−0.3 / ***−0.29***	0.2 / ***0.21***	0.96 / ***0.98***	0.96 / ***0.98***	0.97 / ***0.98***	0.06 / ***0.04***	0.06 / ***0.04***	−0.41 / ***−0.41***	−0.5 / ***−0.5***	−0.29 / ***−0.27***					
GGH 1j exc., 14 TeV, NLO	0.98 / ***0.99***	0.99 / ***0.99***	0.85 / ***0.87***	−0.44 / ***−0.41***	−0.44 / ***−0.41***	−0.43 / ***−0.41***	−0.43 / ***−0.45***	−0.43 / ***−0.45***	0.97 / ***0.98***	0.94 / ***0.96***						
GGH 0j exc., 14 TeV, NLO	0.91 / ***0.93***	0.95 / ***0.97***	0.66 / ***0.73***	−0.59 / ***−0.62***	−0.59 / ***−0.62***	−0.58 / ***−0.62***	−0.42 / ***−0.42***	−0.42 / ***−0.42***	0.99 / ***0.99***							
GGH inc., 14 TeV, NNLO	0.95 / ***0.96***	0.97 / ***0.99***	0.74 / ***0.79***	−0.52 / ***−0.54***	−0.52 / ***−0.54***	−0.51 / ***−0.54***	−0.44 / ***−0.44***	−0.44 / ***−0.44***								
VBF exc., 8 TeV, LO	−0.48 / ***−0.49***	−0.47 / ***−0.47***	−0.44 / ***−0.48***	0.16 / ***0.15***	0.16 / ***0.15***	0.12 / ***0.14***	0.99 / ***0.99***									
VBF inc., 8 TeV, LO	−0.48 / ***−0.49***	−0.47 / ***−0.47***	−0.44 / ***−0.48***	0.16 / ***0.15***	0.16 / ***0.15***	0.12 / ***0.14***										
GGH 2j full mass, 8 TeV, LO	−0.32 / ***−0.32***	−0.42 / ***−0.43***	0.03 / ***0.06***	0.99 / ***0.99***	0.99 / ***0.99***											
GGH 2j exc., 8 TeV, LO	−0.33 / ***−0.32***	−0.44 / ***−0.43***	0.01 / ***0.05***	0.99 / ***0.99***												
GGH 2j inc., 8 TeV, LO	−0.33 / ***−0.32***	−0.44 / ***−0.43***	0.01 / ***0.05***													
GGH 1j exc., 8 TeV, NLO	0.9 / ***0.92***	0.84 / ***0.87***														
GGH 0j exc., 8 TeV, NLO	0.99 / ***0.99***															
GGH inc., 8 TeV, NNLO	2.5% / ***2.5%***	2.8% / ***2.8%***	2.1% / ***2.%***	5.% / ***4.8%***	5.% / ***4.8%***	5.% / ***4.9%***	2.4% / ***2.4%***	2.4% / ***2.4%***	2.5% / ***2.5%***	2.9% / ***2.9%***	2.3% / ***2.2%***	3.5% / ***3.5%***	3.5% / ***3.5%***	3.7% / ***3.7%***	2.1% / ***2.%***	2.1% / ***2.%***

Correlation table for Higgs cross sections

Red indicates $|\cos(\phi)|>0.7$

Numbers in Italic–bold (plain) for 6 eigenvecotrs (full set 50 eig.)

META PDF 1.0 (LHCH)

VBF–like cut applied for 2 or more jets final states

jet (anti–k_T, 0.4) selection with $|y|<4.5$ and $p_T>30$ GeV

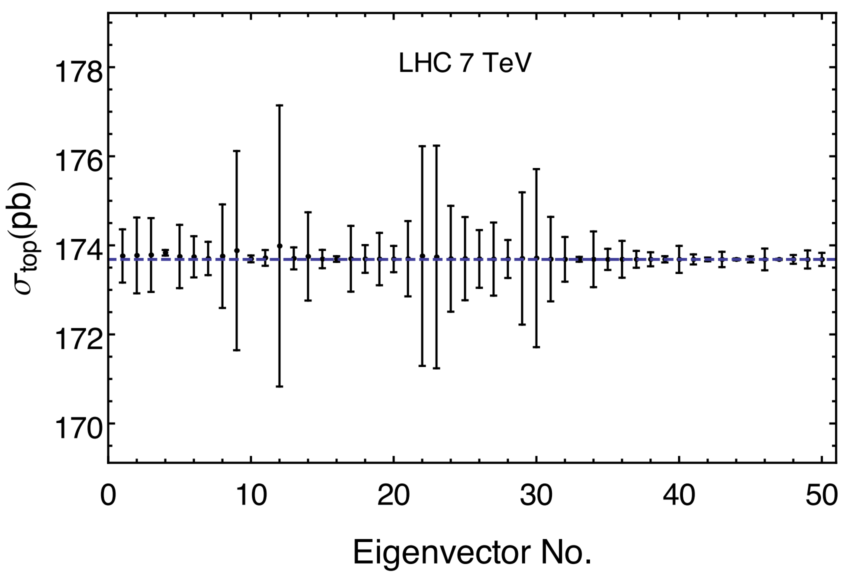
PDF errors and correlations of Higgs observables

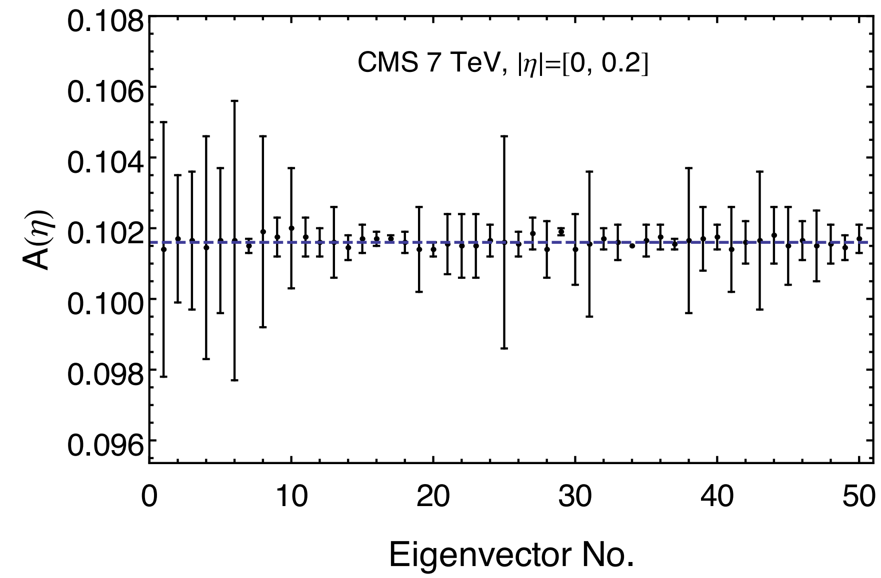
process	$\sigma_{cen.}$	δ_{Full}	$\delta_{Diag.}$
$gg \to H$ [pb]	18.77	$^{+0.48}_{-0.46}$	$^{+0.48}_{-0.44}$
	43.12	$^{+1.13}_{-1.07}$	$^{+1.13}_{-1.04}$
VBF [fb]	302.5	$^{+7.8}_{-6.7}$	$^{+7.6}_{-6.7}$
	878.2	$^{+19.7}_{-17.9}$	$^{+19.2}_{-17.3}$
HZ [fb]	396.3	$^{+8.4}_{-7.3}$	$^{+8.1}_{-7.4}$
	814.3	$^{+14.8}_{-13.2}$	$^{+13.8}_{-13.0}$
$HW^{\pm}$ [fb]	703.0	$^{+14.4}_{-14.4}$	$^{+14.3}_{-14.1}$
	1381	$^{+28}_{-22}$	$^{+26}_{-22}$
HH [fb]	7.81	$^{+0.33}_{-0.30}$	$^{+0.33}_{-0.30}$
	27.35	$^{+0.78}_{-0.72}$	$^{+0.78}_{-0.68}$
$t\bar{t}$ [pb]	248.4	$^{+9.1}_{-8.2}$	$^{+9.2}_{-8.1}$
	816.9	$^{+21.4}_{-19.6}$	$^{+21.4}_{-18.4}$
$Z/\gamma^*(l^+l^-)$ [nb]	1.129	$^{+0.025}_{-0.023}$	$^{+0.024}_{-0.023}$
	1.925	$^{+0.043}_{-0.041}$	$^{+0.040}_{-0.037}$
$W^+(l^+\nu)$ [nb]	7.13	$^{+0.14}_{-0.14}$	$^{+0.14}_{-0.13}$
	11.64	$^{+0.24}_{-0.23}$	$^{+0.22}_{-0.21}$
$W^-(l^-\bar{\nu})$ [nb]	4.99	$^{+0.12}_{-0.12}$	$^{+0.12}_{-0.11}$
	8.59	$^{+0.21}_{-0.20}$	$^{+0.19}_{-0.18}$
W^+W^- [pb]	4.14	$^{+0.08}_{-0.08}$	$^{+0.08}_{-0.07}$
	7.54	$^{+0.15}_{-0.14}$	$^{+0.14}_{-0.12}$
ZZ [pb]	0.703	$^{+0.016}_{-0.014}$	$^{+0.015}_{-0.014}$
	1.261	$^{+0.026}_{-0.024}$	$^{+0.024}_{-0.022}$
W^+Z [pb]	1.045	$^{+0.019}_{-0.018}$	$^{+0.019}_{-0.017}$
	1.871	$^{+0.033}_{-0.031}$	$^{+0.029}_{-0.027}$
W^-Z [pb]	0.788	$^{+0.020}_{-0.019}$	$^{+0.019}_{-0.018}$
	1.522	$^{+0.034}_{-0.032}$	$^{+0.033}_{-0.031}$

LHC benchmark cross sections including those are not taken into the DSD process

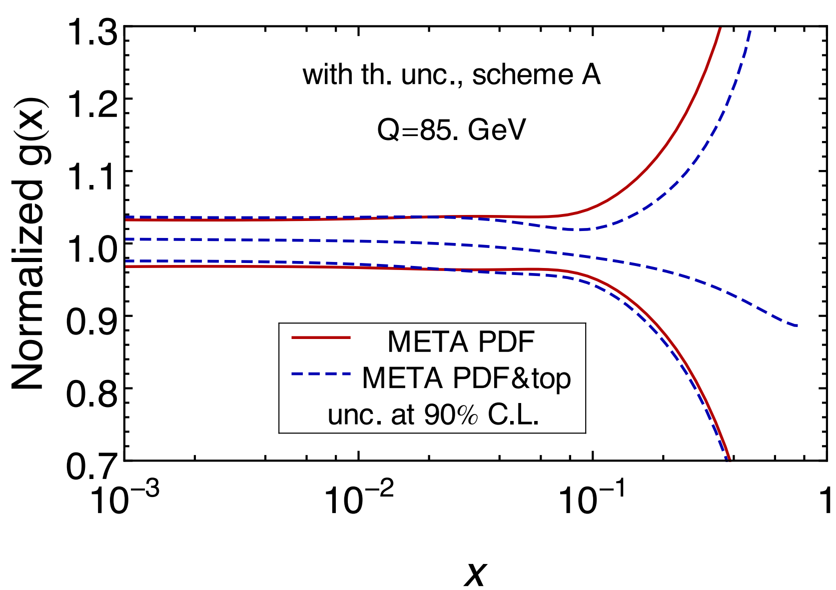
Including constraints of new LHC data

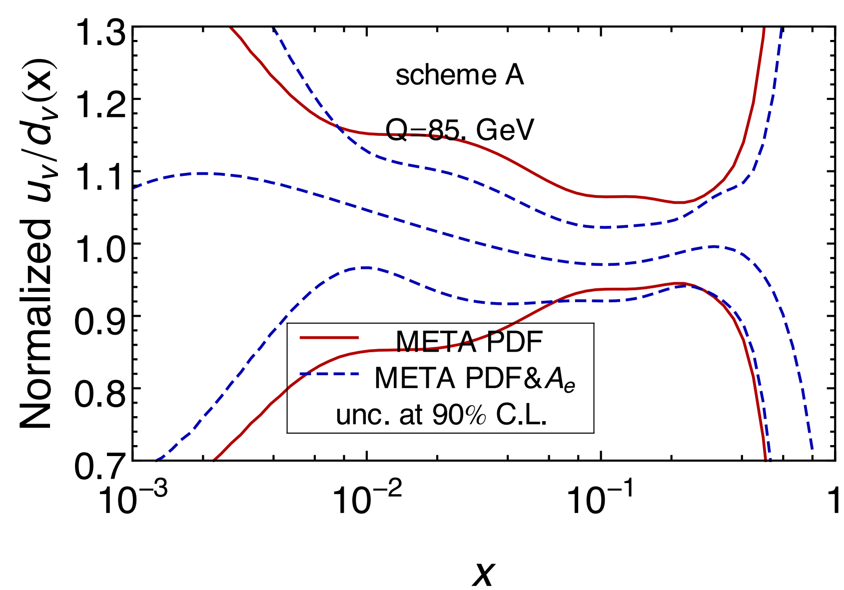
- One can identify possible constraints of new LHC data by eigenvector analysis; its effects on META PDFs can be included directly by including the chi2 [of the LHC data] into the covariance matrix and resolving the eigensystem [or can use MC reweighting, R. Thorne, G. Watt]; no need to start again from original MC replicas





Example: top pair cross sections, and W charged lepton asymmetry





unbiased reweighting [assuming no extra weight for META prior]

Summary

- We present a preliminary version 2 of META PDFs for general LHC study based on updated PDF inputs. The outputs are presented in Hessian form with 40~30 eigenvectors (41~31/81~61 PDFs).

- META PDFs with Hessian representation provides a simple and systematic way of combining different PDF ensembles in a physical basis within effective Gaussian approach. PDF eigenvectors are efficient and convenient in experimental analysis, including for Data Set Diagonalization and PDF reweighting.

- All production procedure is automated in a code that will be released soon, to combine LHA5/6 PDF ensembles with explicit quality control. The code also provides modules to generate optimized (rotated) Hessian META ensembles for classes of LHC observables and to include new experimental analyses in the META ensembles with the help of PDF reweighting.

Rotated eigenvectors for Higgs study

Backups

- The rotated eigenvectors keeps full property of the original eigenvectors [as a consequence of linearity]; the first 6 eigenvectors characterize the PDFs most relevant for Higgs study, while remaining ones probes other freedoms of PDFs