NNPDF3.1
AND CONNECTION TO XFITTER

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xFitter meeting, St. Hilda College, Oxford

21st March 2017

The NNPDF collaboration:

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Z. Dim, S. Forte (Milano), A. Guffanti (Torino)

E. Nocera, L. Rottoli (Oxford)

NNPDF

Outline of the talk

- The NNPDF3.1 set
    - Intrinsic charm
    - HERA-II data
    - Impact of new data (Z pT)
- Tools
    - MC2hessian
    - SMPDFs
- Future perspective
    - Theory uncertainties in PDFs
    - Resummed PDFs
- Conclusions and outlook

NNPDF3.1

A fast-paced progress …

2016 First PDF set with fitted charm

2015 First PDF set with threshold resummation

2014 NNPDF3.0: first PDF set validated with closure test

2013 NNPDF2.3QED: first PDF set with fitted photon PDF

NNPDF2.3: first PDF set with LHC data

2012 Reweighting PDFs

2011 NNPDF2.1:Heavy quark mass effects

Determination of α_S from PDF fit

2010 NNPDF2.0:First NNPDF global set

2009 NNPDF1.2: Determination of the proton strangeness: solved NuTeV anomaly

2008 NNPDF1.0: First NNPDF set - only DIS data

… to the future

Spring 2017

NNPDF3.1

Summer 2017

NNPDF3.1QED (à la LUXqed)

Updated determination of α_S and m_c

PDF fits with (scale)theory uncertainties

PDF set with small-x resummation

The NNPDF3.1 analysis

- 2014: **NNPDF3.0** set with methodology tested by closure test and new data

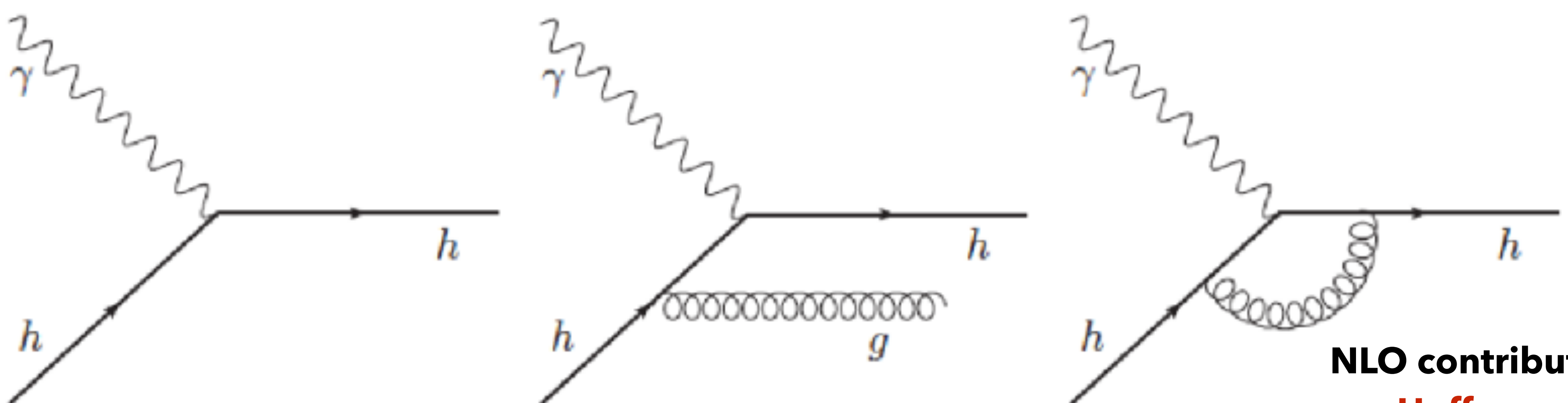
- Plethora of new precise measurements and new available precise theoretical calculations call for an updated analysis

    * combined HERA I-II data
    * top differential distributions
    * transverse momentum distribution of the Z
    * legacy data from Tevatron
    * full dataset 7 TeV and 8 TeV from LHCb…

- Main methodological improvement is fitted charm PDFs

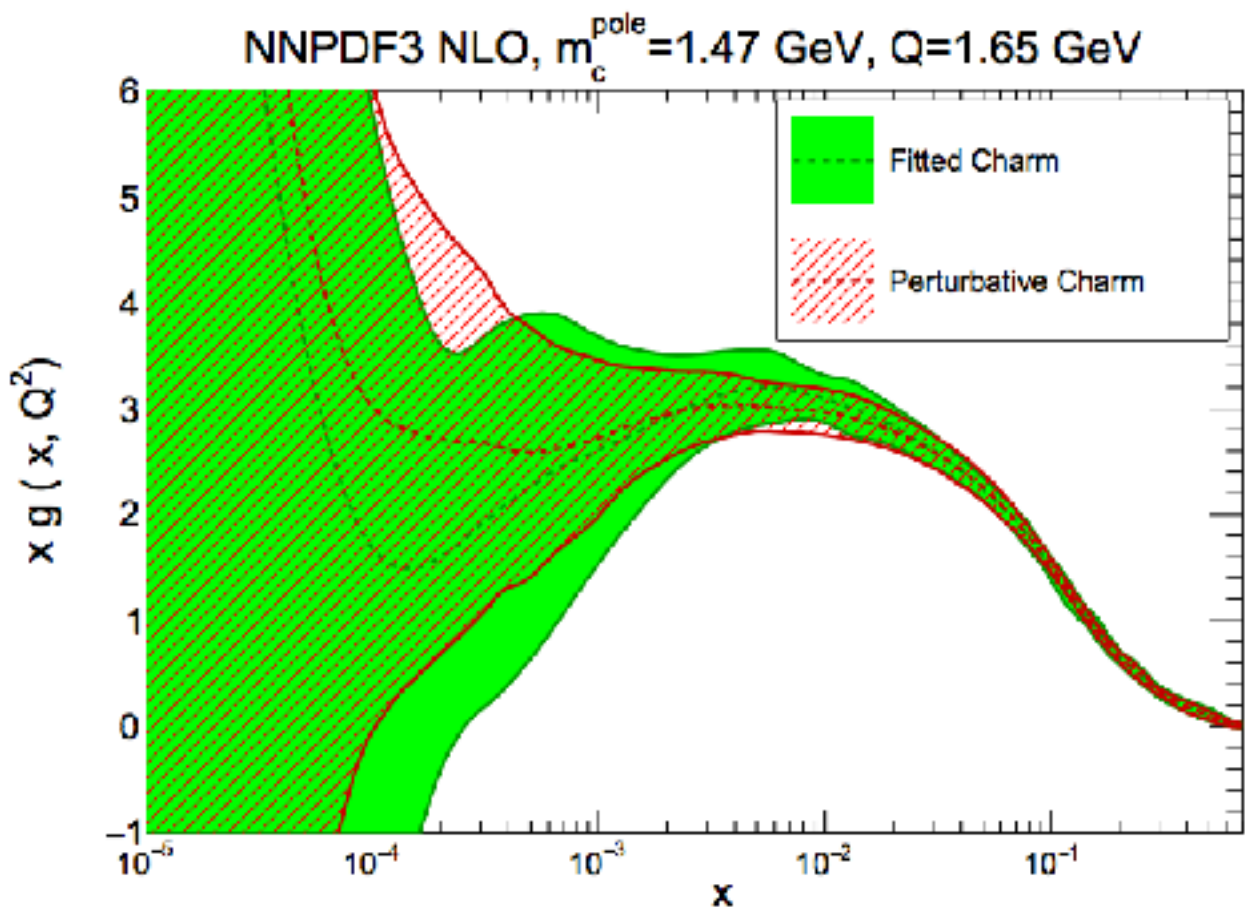
Fitted charm

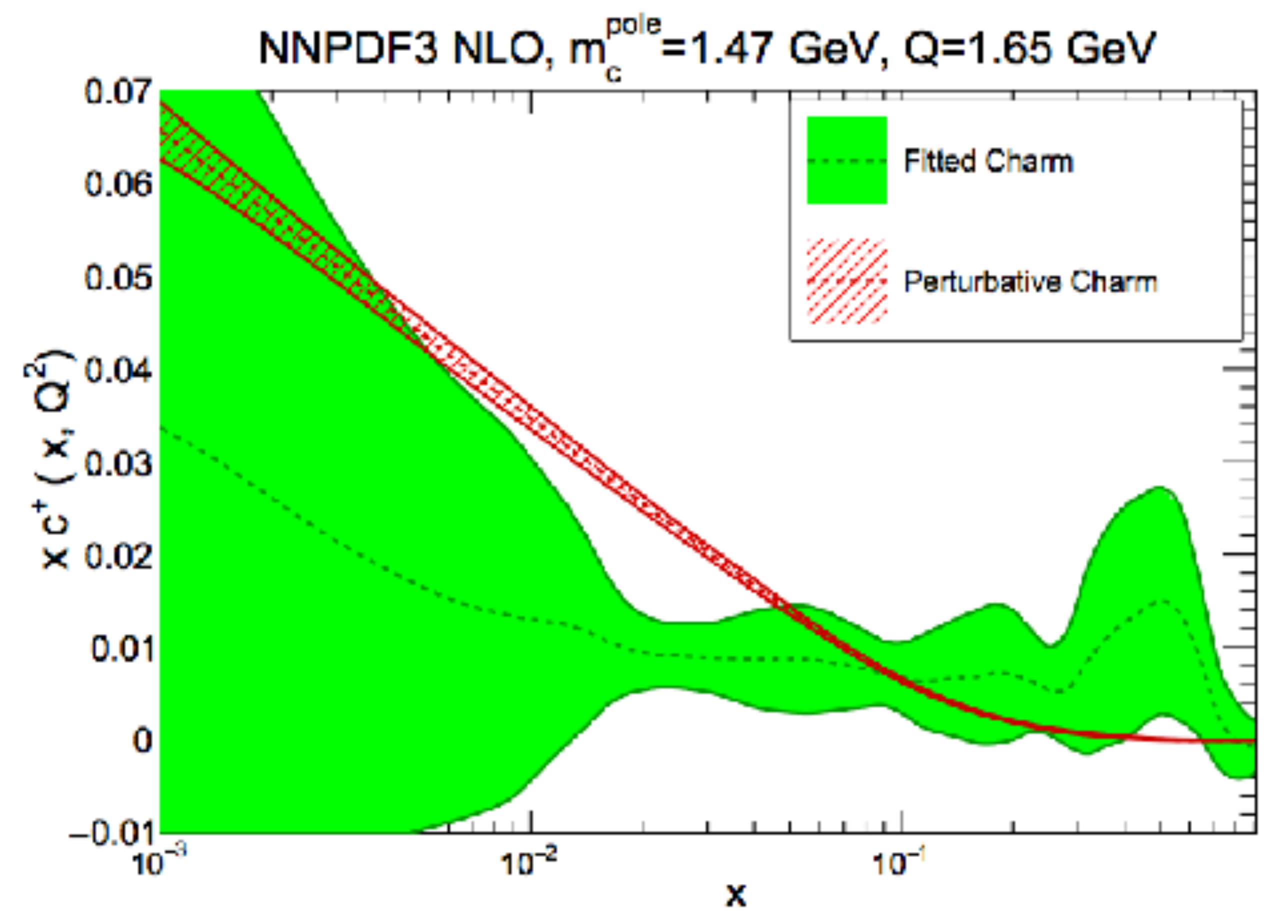
- Most global fits assume scale-independent charm content of the proton vanishes
- Why fit the intrinsic component of the charm?
  - ☑ Stabilise the dependence on mc
  - ☑ Quantify the non-perturbative component of charm
  - ☑ Compare determination with available models
- In any scheme in which mass of the charm is not neglected (FFN scheme or GM-VFNS) calculations need to be modified in order to account for massive charm initiate processes



NLO contributions computed
Hoffmann and Moore
Kretzer and Schienbein

Fitted charm

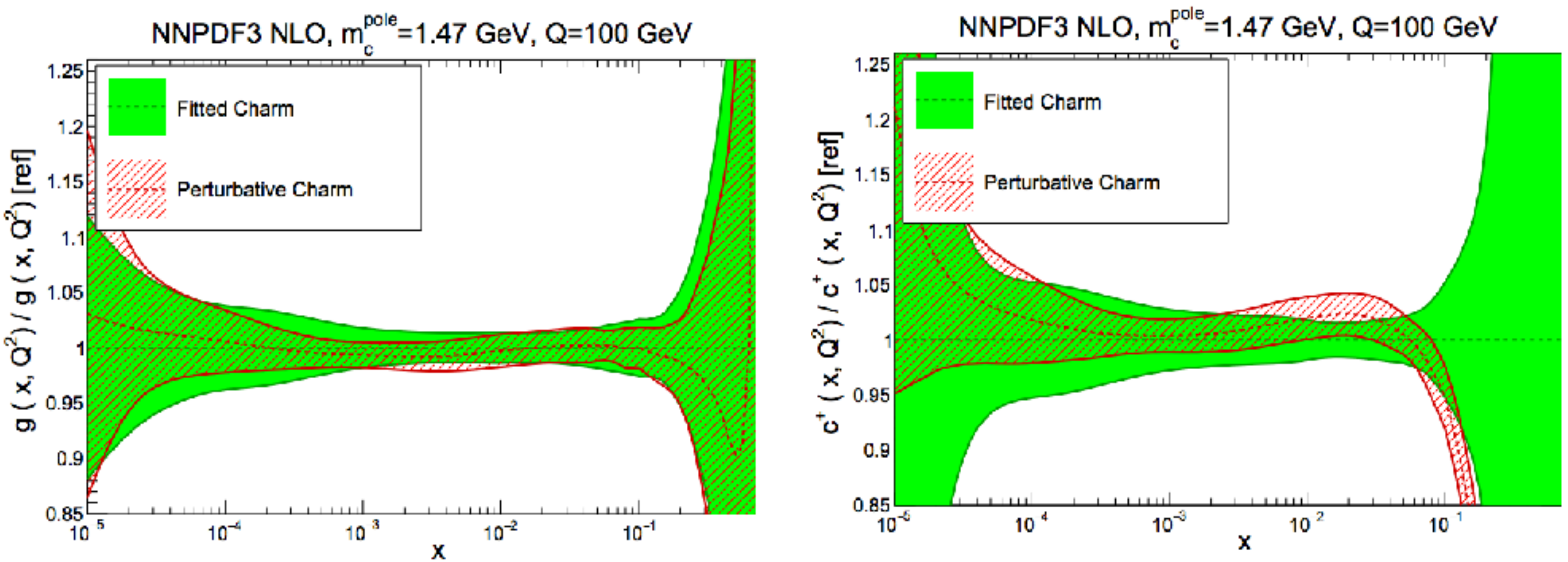




- NNPDF3.0IC: Updated theory and added a neural network for total charm PDF, with same number of parameters as other light quarks
- At low scales gluon very stable but FC very different from PC
- At high scales, gluon still very stable but with larger uncertainty, charm stable for intermediate-small x where pert. evolution dominates, larger difference for x> 10^{-2} where boundary conditions dominate

Eur.Phys.J. C76 (2016) no.11, 647

Fitted charm



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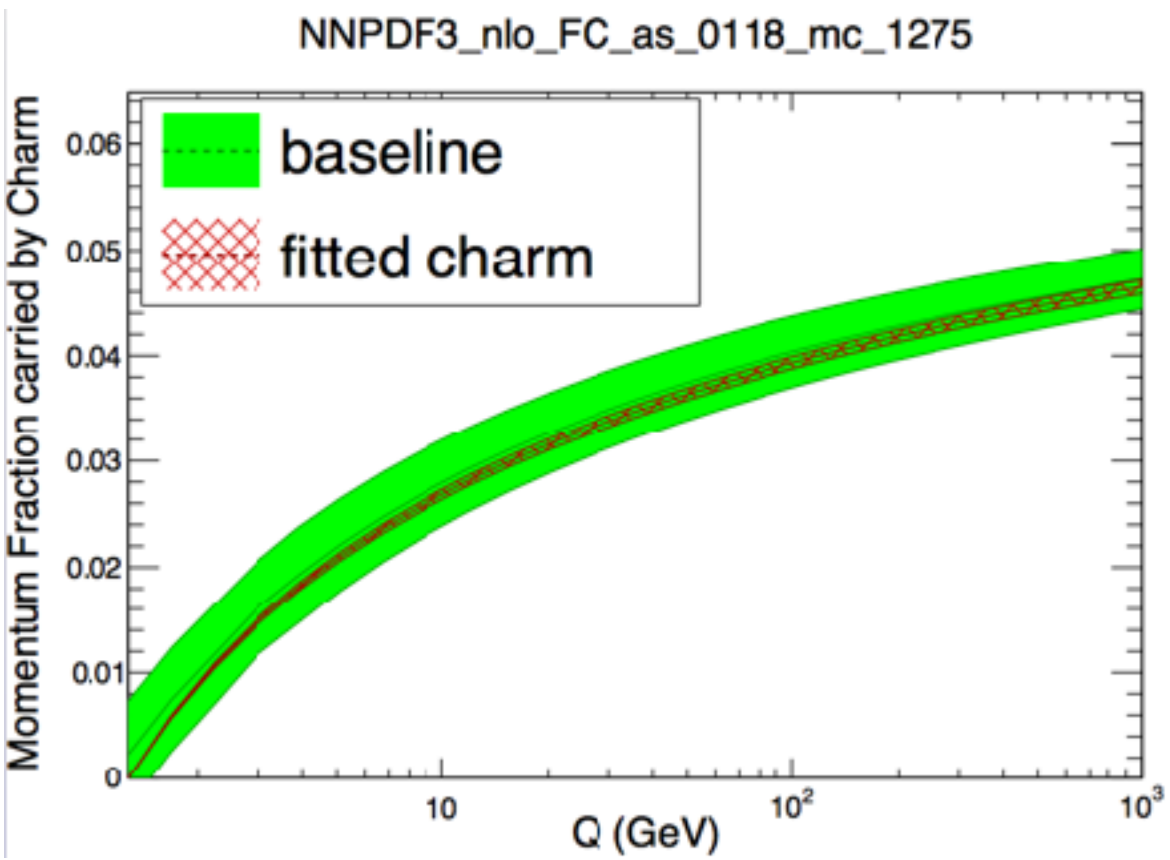

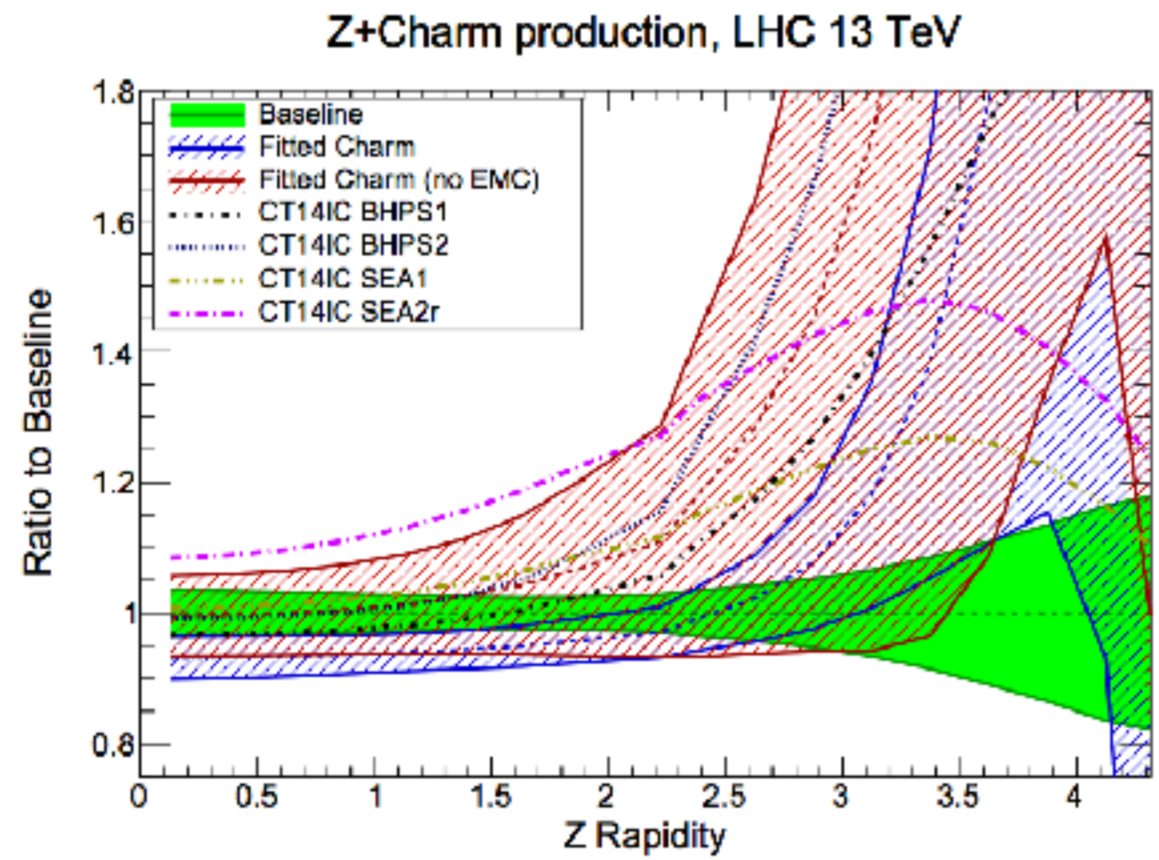

- At the input scale charm can carry up to 0.75% of the proton momentum (versus 0% in the pert. charm). At LHC scales fraction of momentum has large uncertainty.
- Implications for charm-initiated processes, especially at forward rapidities which probe larger values of x (Photon + D-meson production at large pT and Z+c at large rapidities)

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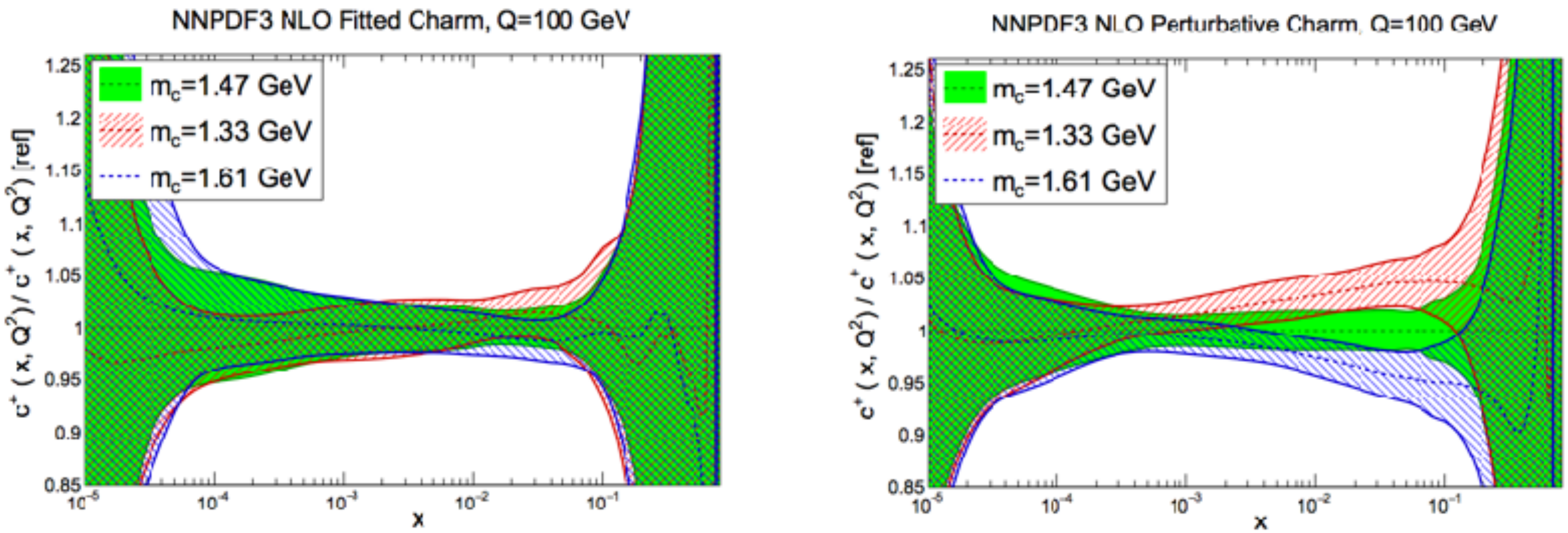
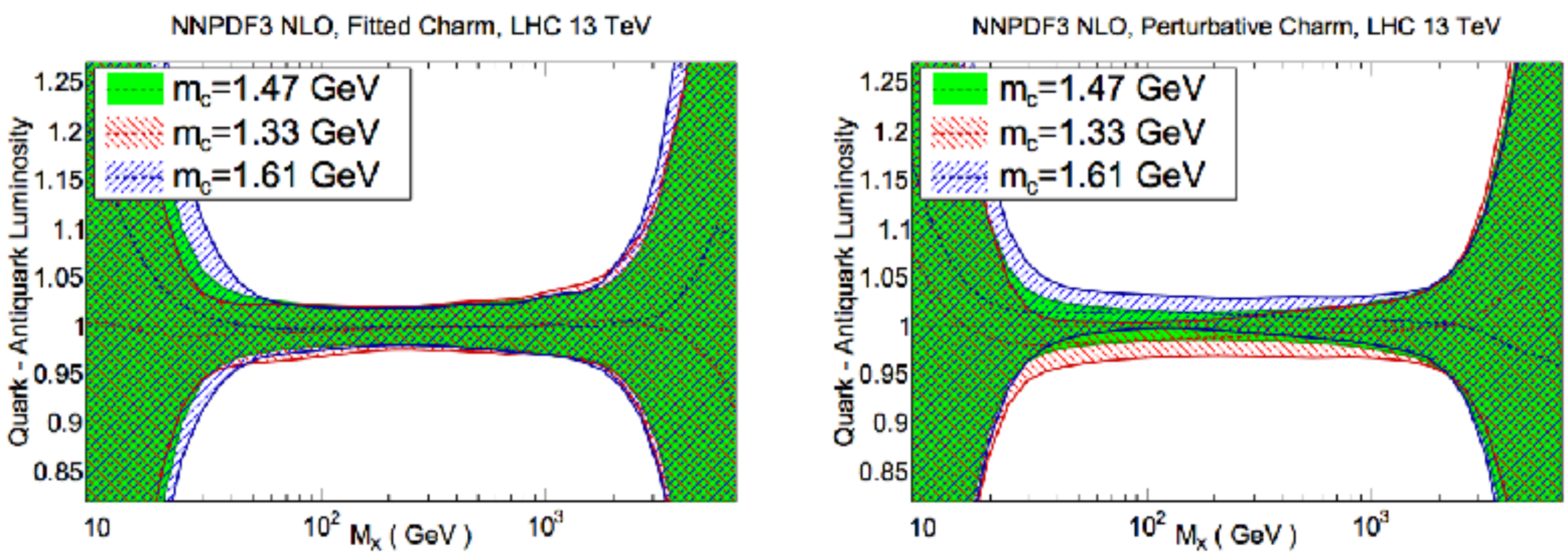
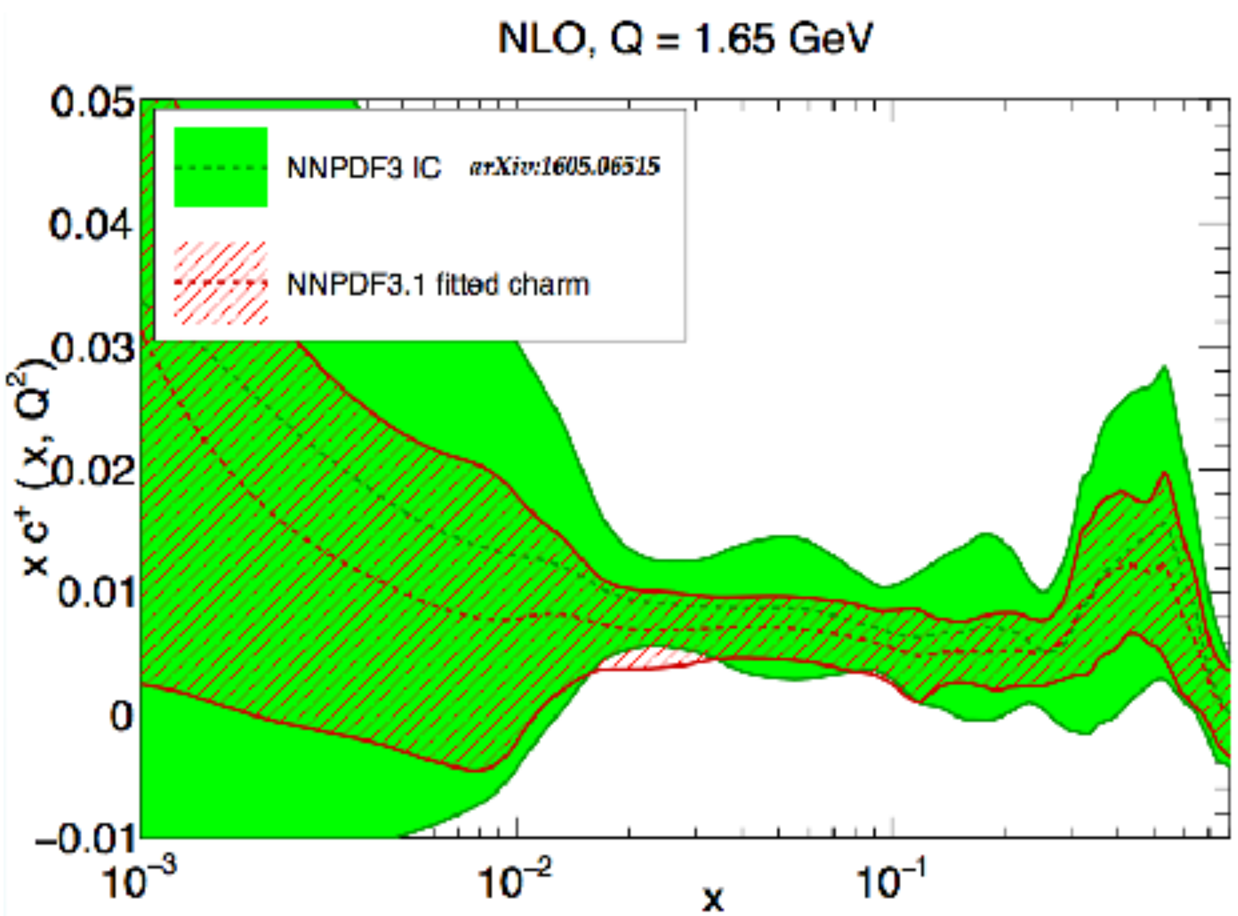
Fitted charm

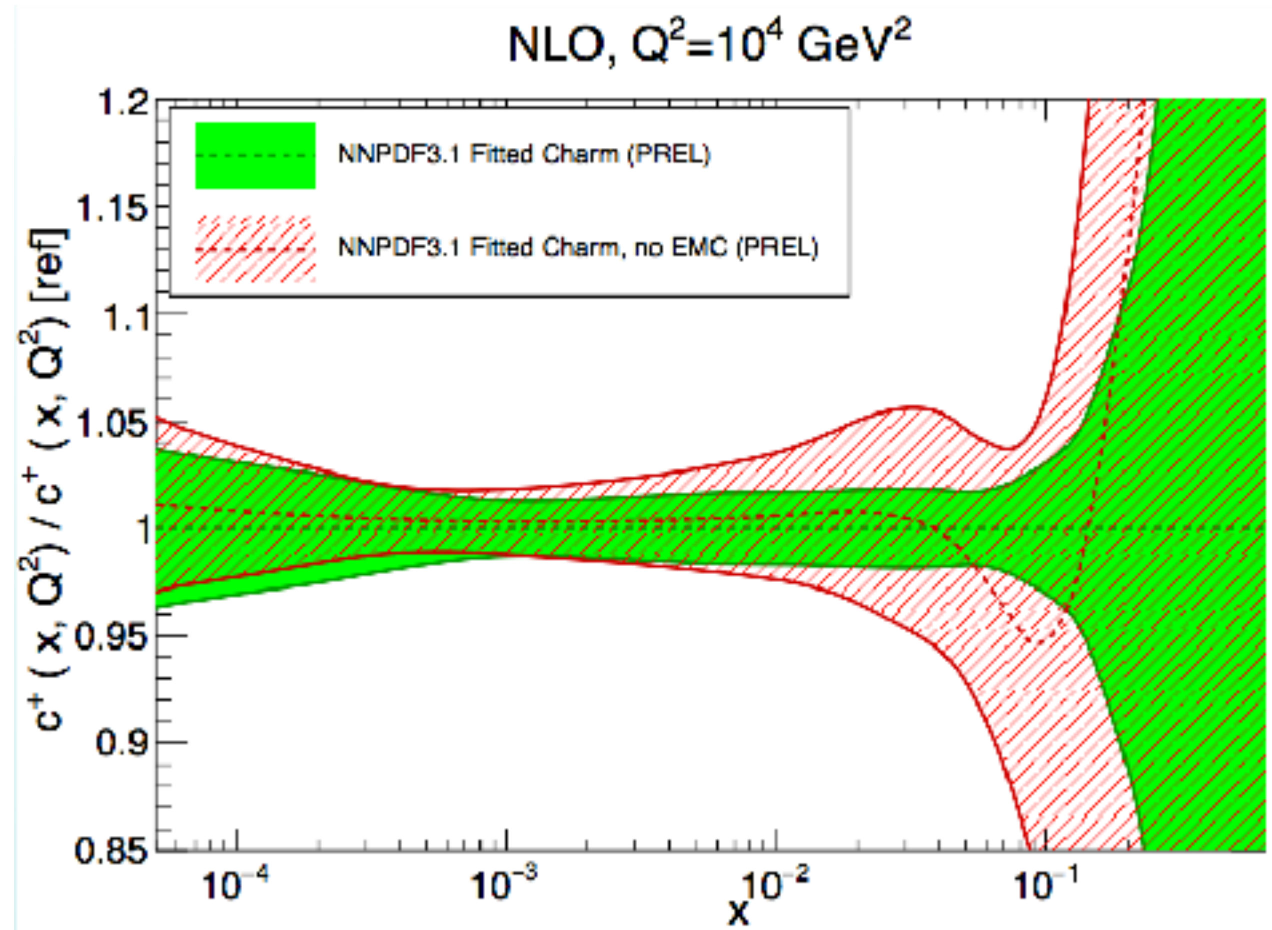


- PDFs and luminosities much more stable for charm mass variation
- Envelope of PDF+mc uncertainties smaller in fits with fitted charm!



Fitted charm in 3.1



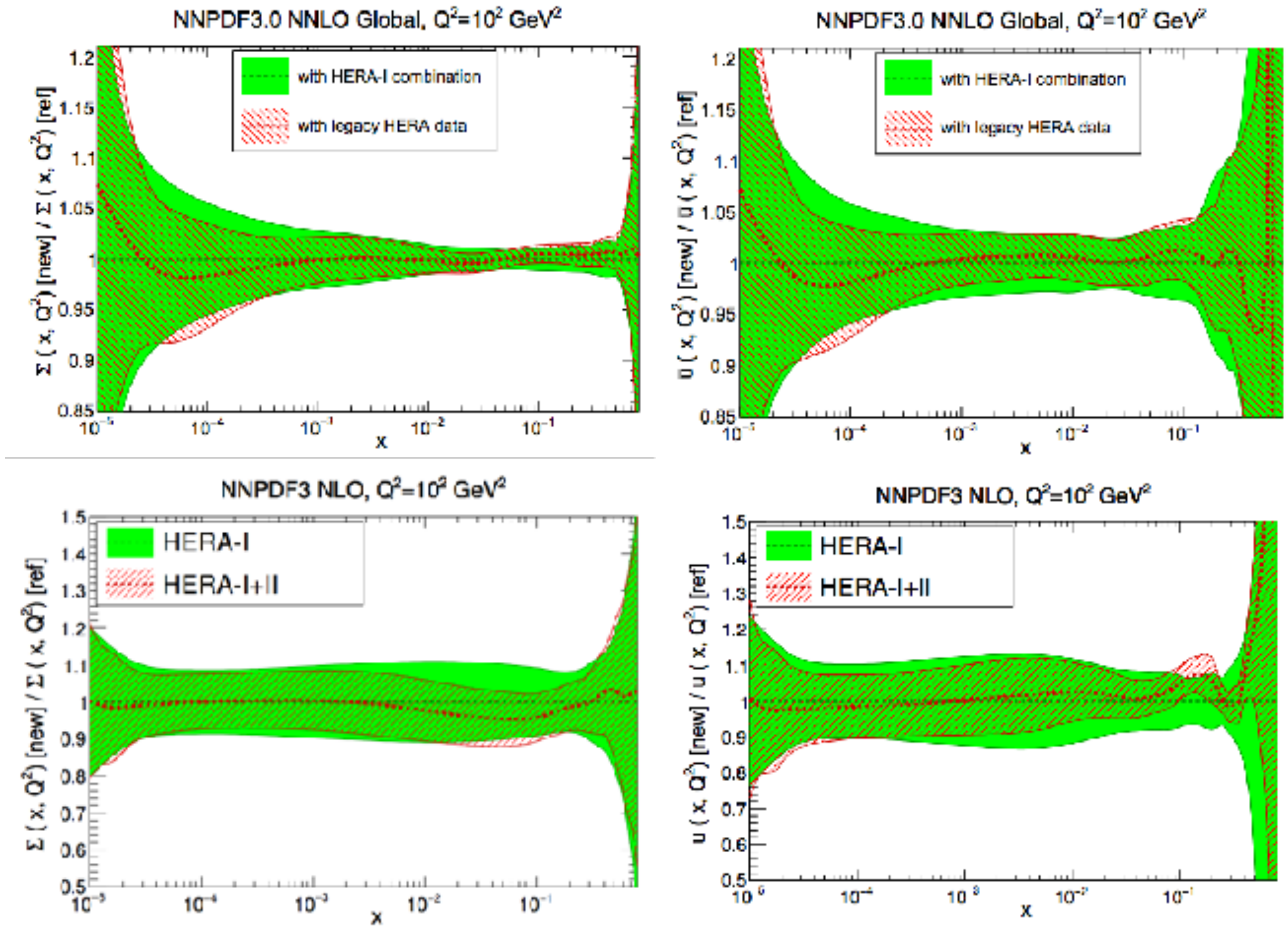


- Additional datasets included in the NNPDF3.1, particularly the Tevatron legacy data and LHCb measurements at 7 and 8 TeV further constrain the charm PDF.
- Results consistent wth the NNPDF3.0IC set but with smaller uncertainty
- Impact of EMC data reduced when added on top of the new data included in NNPDF3.1
- Fitted charm improves data description
- Both fitted and perturbative charm fits will be released

HERA legacy data

- Legacy combination of all HERA inclusive structure function data Run I+II supersedes HERA-I combination and separate HERA-II measurements from H1 and ZEUS (included in NNPDF3.0)

- Impact is moderate on PDF uncertainties, stronger when comparing HERA-I only with HERA-I+II



J. Rojo,1508.07731

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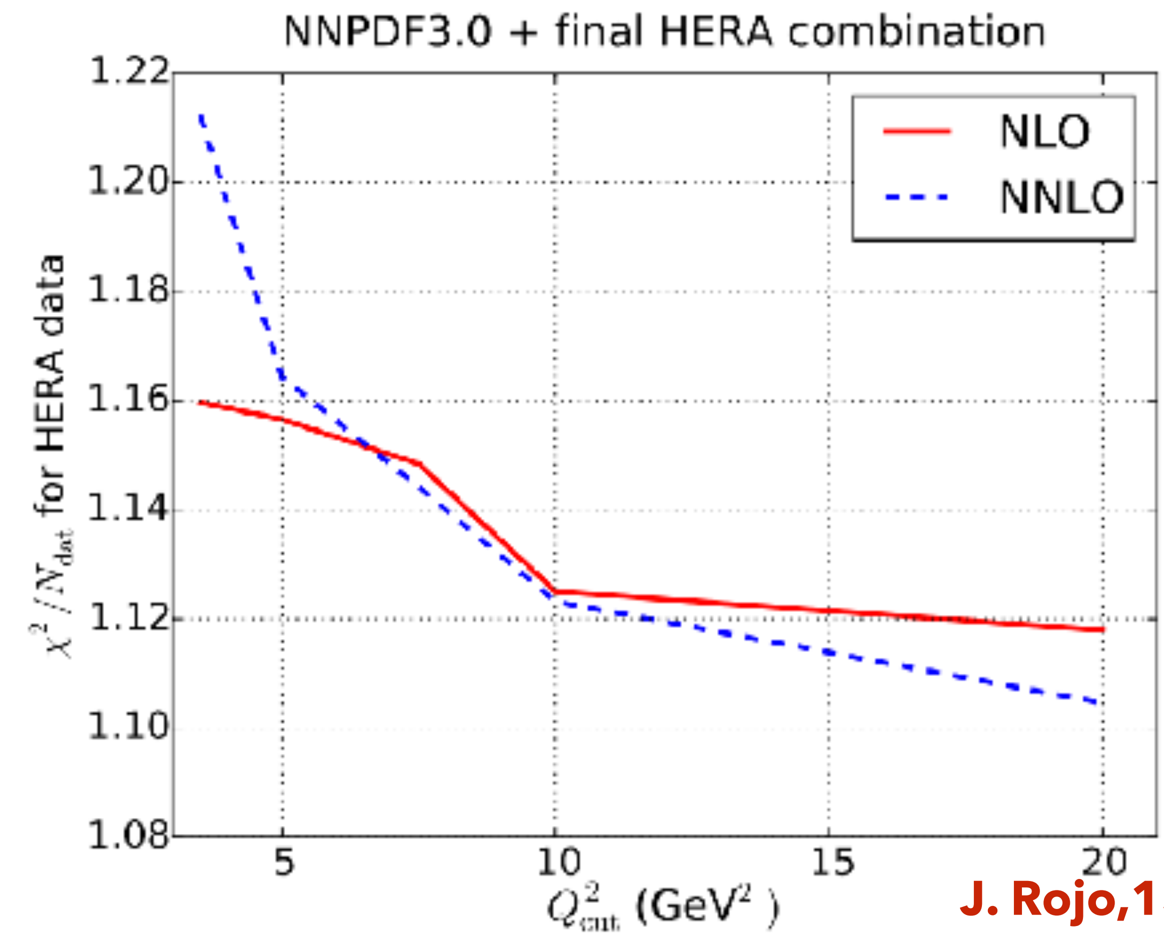
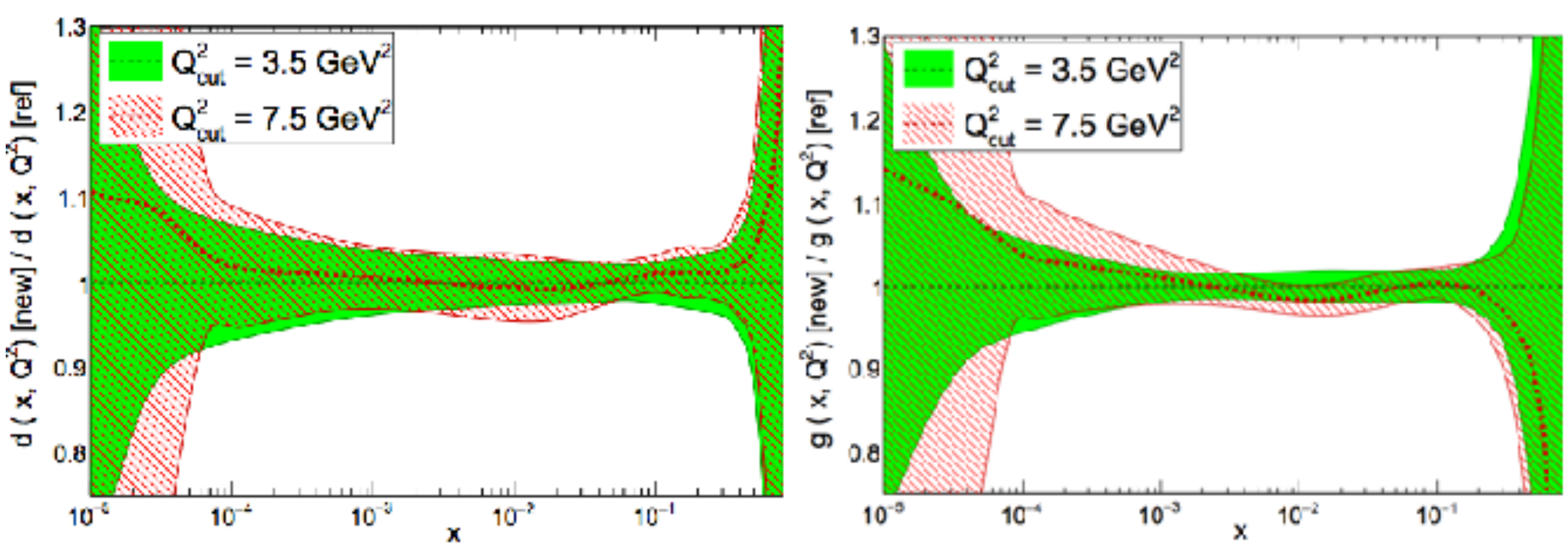
- Sizeable dependence of chi2 of data with respect to the Q2min, but PDFs only affected at small-x. Need small-x resummation?



J. Rojo,1508.07731



Data implementation

- PDF evolution and DIS structure functions up to NNLO computed with **APFEL** in **FONLL** scheme
- Hadronic data computed using **APPLgrid/fastNLO** interfaced to MCFM/ aMC@NLO/NLOjet++ & bin-by-bin NNLO/NLO C factors for each process
- **APFELgrid** used to combined PDF evolution and interpolated coefficient functions

$$\sigma = \sum_{i,j}^{n_f} \sum_{\alpha,\beta}^{n_x} W_{ij\alpha\beta}\, f_i(x_\alpha, Q_0^2) f_j(x_\beta, Q_0^2)$$

APFEL

the APPLgrid project

Observable	APPLGRID	APFELcomb
W^+ production	1.03 ms	0.41 ms (2.5x)
Inclusive jet production	2.45 ms	20.1 μs (120x)

APPLgrid, Carli et al EPJC66 (2010) 503-524 & FASTNLO, Kluge et al
APFELgrid, Bertone et al 1605.02070
aMCfast, Berton et al JHEP 1408 (2014) 166
MCgrid, Del Debbio et al Comput.Phys.Commun. 185 (2014) 2115-2126

New LHC data

NNPDF3.0 + **NNPDF3.1**

ATLAS jets 2.76 TeV and 7 TeV **+ 2011 data 7 TeV**	gluon large x
ATLAS high-mass DY at 7 TeV **+ low mass**	**q/q~ separation**
ATLAS W pT data at 7 TeV	g and q at moderate x
ATLAS & CMS differential Z pT data at 7 & 8 TeV	**g and q at moderate x**
CMS (Y,M) double diff distributions 7 TeV **+ 8 TeV**	flavour separation
CMS jets at 7 TeV **+ 2.76 and 8 TeV jet data**	**gluon large x**
CMS muon charge asymmetry at 7 TeV **+ 8 TeV**	quark separation
CMS W+c at 7 TeV	strangeness
LHCb Z rapidity distribution at 7 TeV **+ 8 TeV (full data)**	small/large x quarks
ATLAS+CMS tt total xsec at 7/8 TeV	gluon large x
ATLAS+CMS tt differential xsec at 7/8 TeV	gluon large x
D0 legacy W asymmetry data	q/q~ separation

New observables

- NNLO calculations are essential to reduce theoretical uncertainties in PDF analyses
- Stunning progress has been made on some key processes for PDF determination
- Not all of them yet fully exploited (jets and direct photon production)

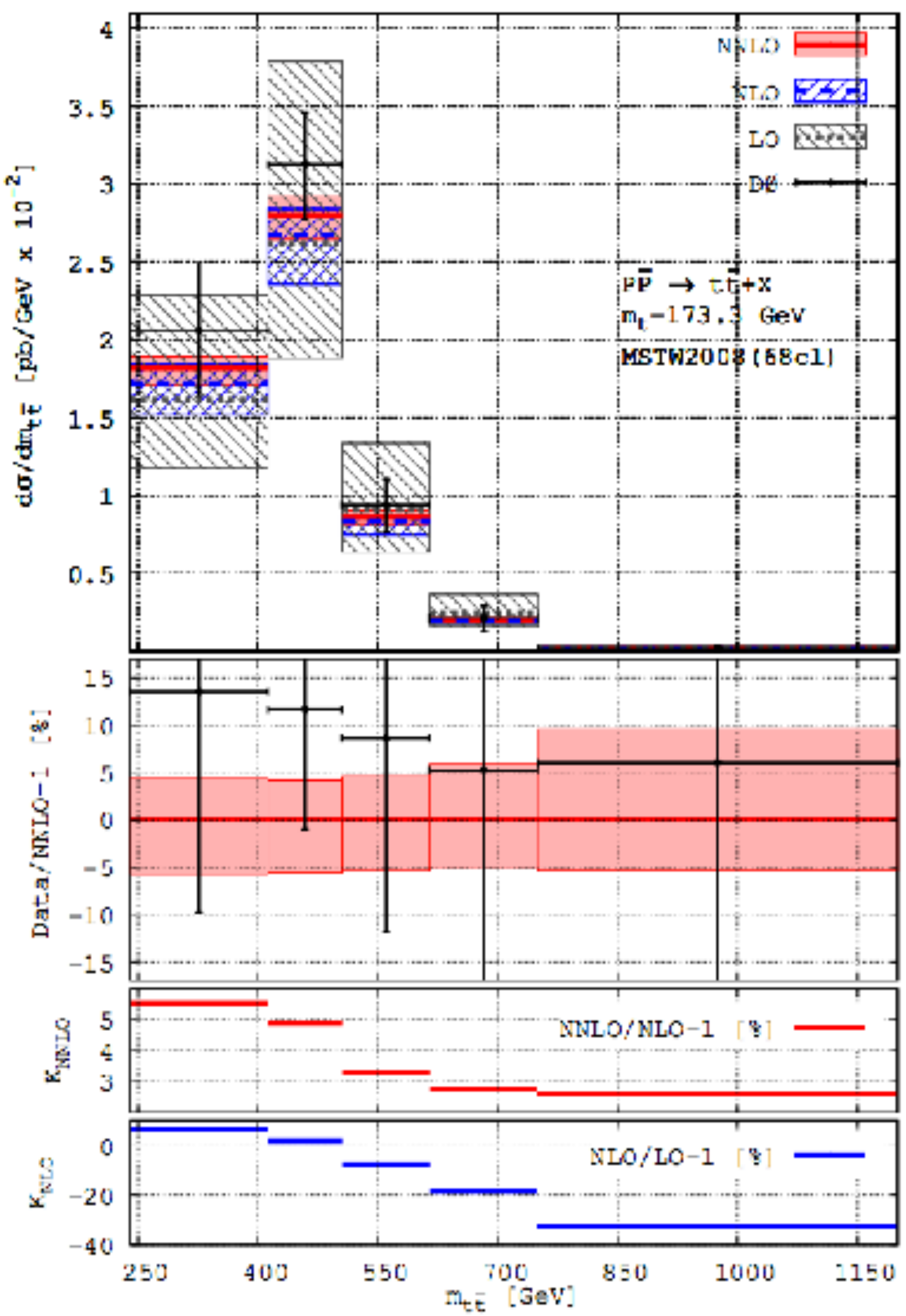
✓ NNLO top pair production (total and differential)
  Czakon, Fiedler, Mitov [PRL 116(2016) 082003]
  Czakon, Mitov [JHEP 1301(2015)]

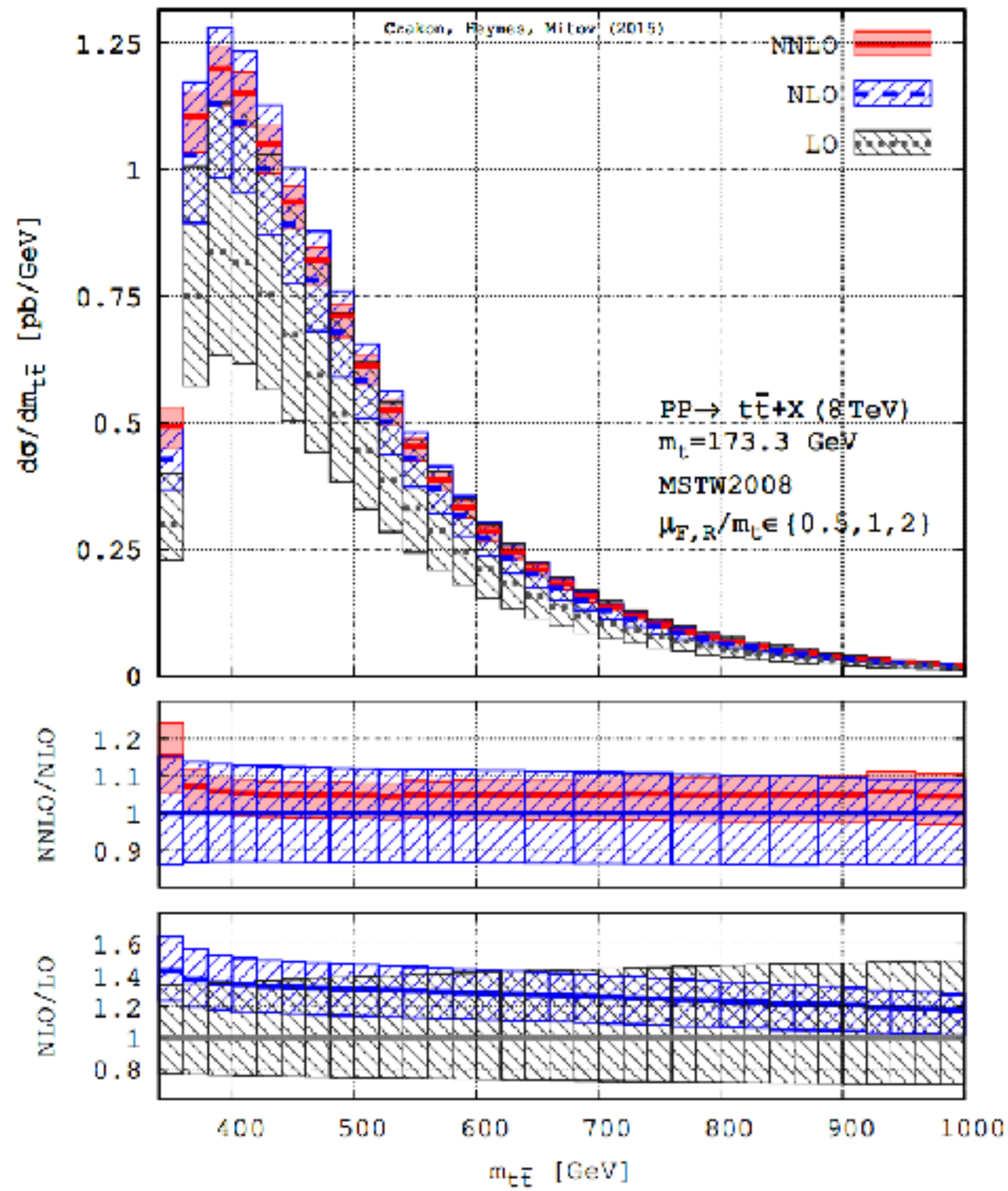
✓ W/Z+j and W/Z transverse momentum distributions
  Gehrmann-De Ridder et al [1605.04295]
  Boughezal, Liu, Petriello [1602.08140]
  Boughezal, Liu, Petriello [1602.06965]
  Boughezal et al [PRL 116(2016) 152001 & 062002]
  Gehrmann-De Ridder et al [1507.02850]

✓ Inclusive jet cross section
  Currie et al [JHEP 1401 (2014) 110]
  Gehrmann-De Ridder et al [PRL 110 (2016) 162003]

✓ Direct photon production
  Campbell, Ellis, Williams [1612.04333]

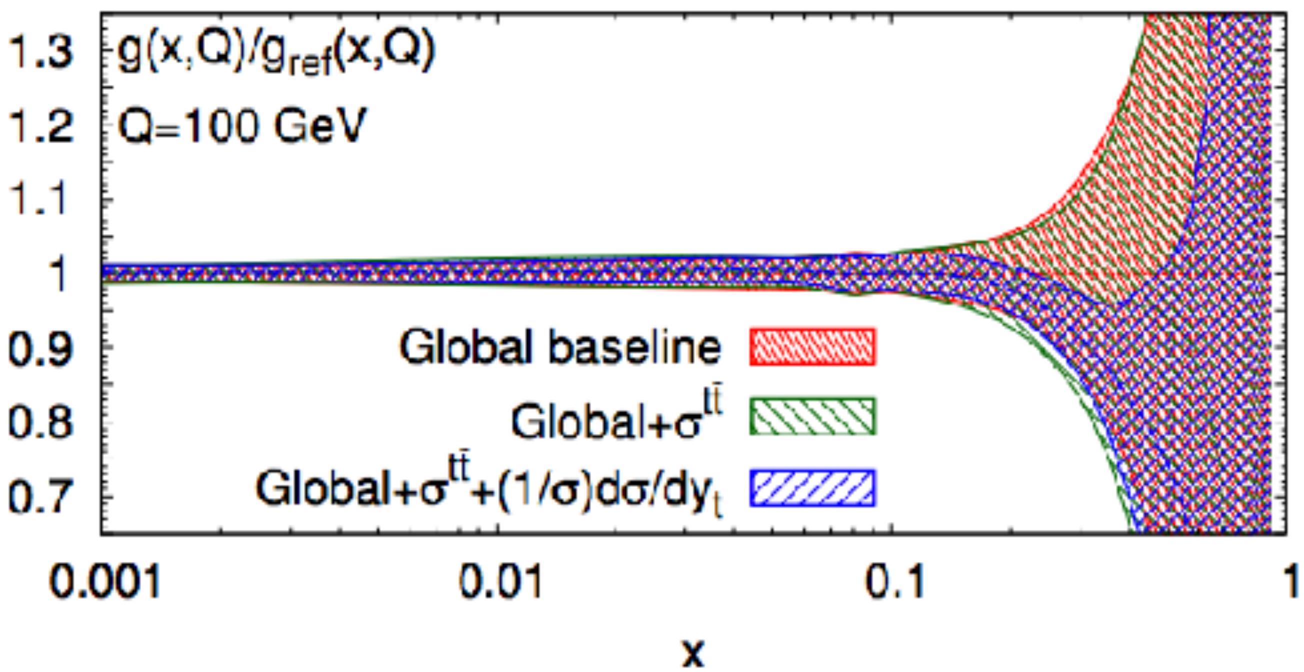
Top differential distributions

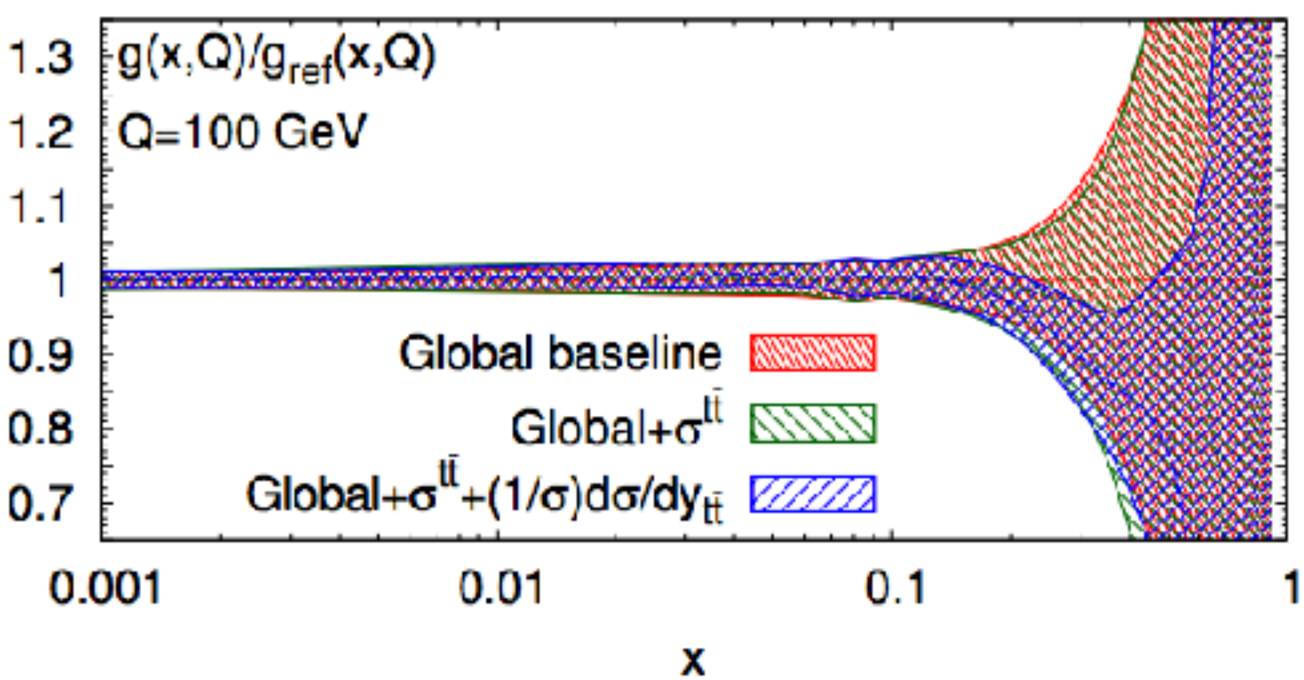


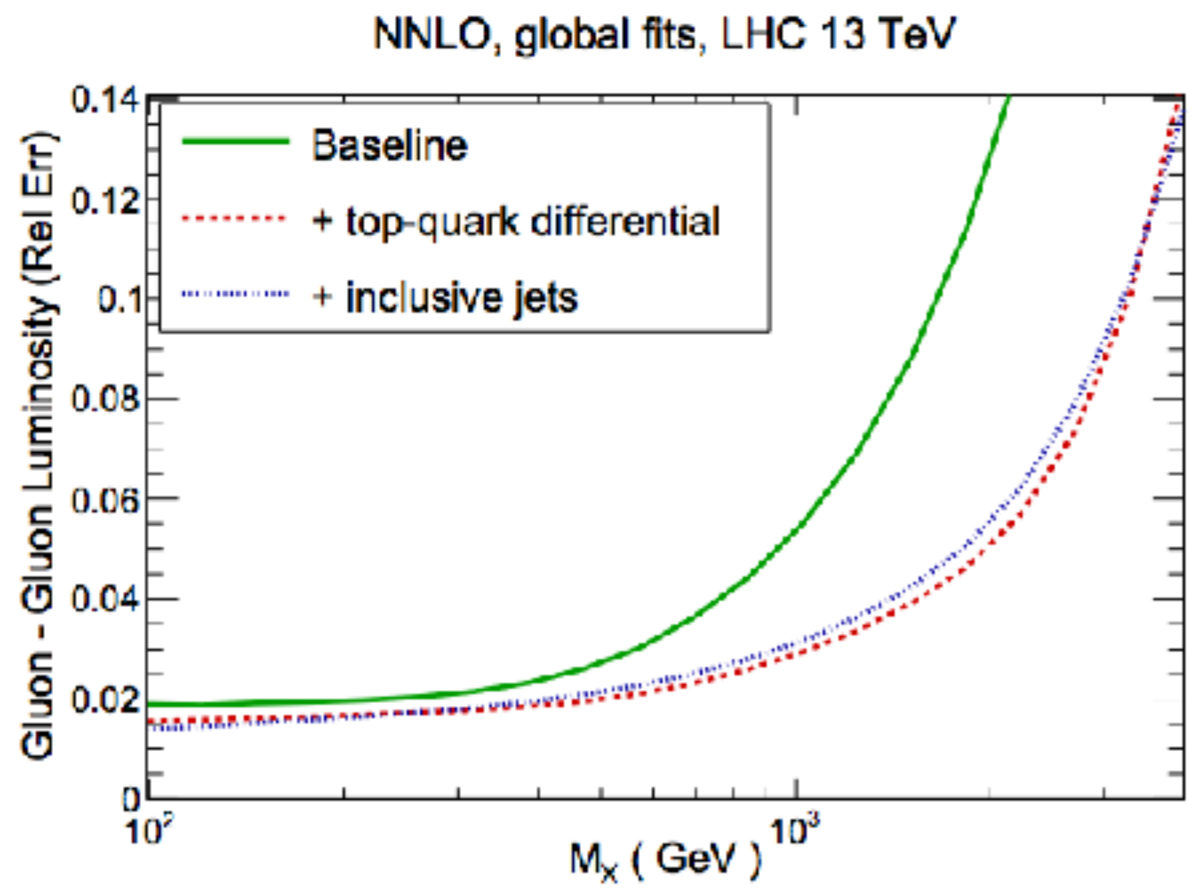


Czakon, Fiedler, Mitov [PRL 116(2016) 082003]

Top differential distributions



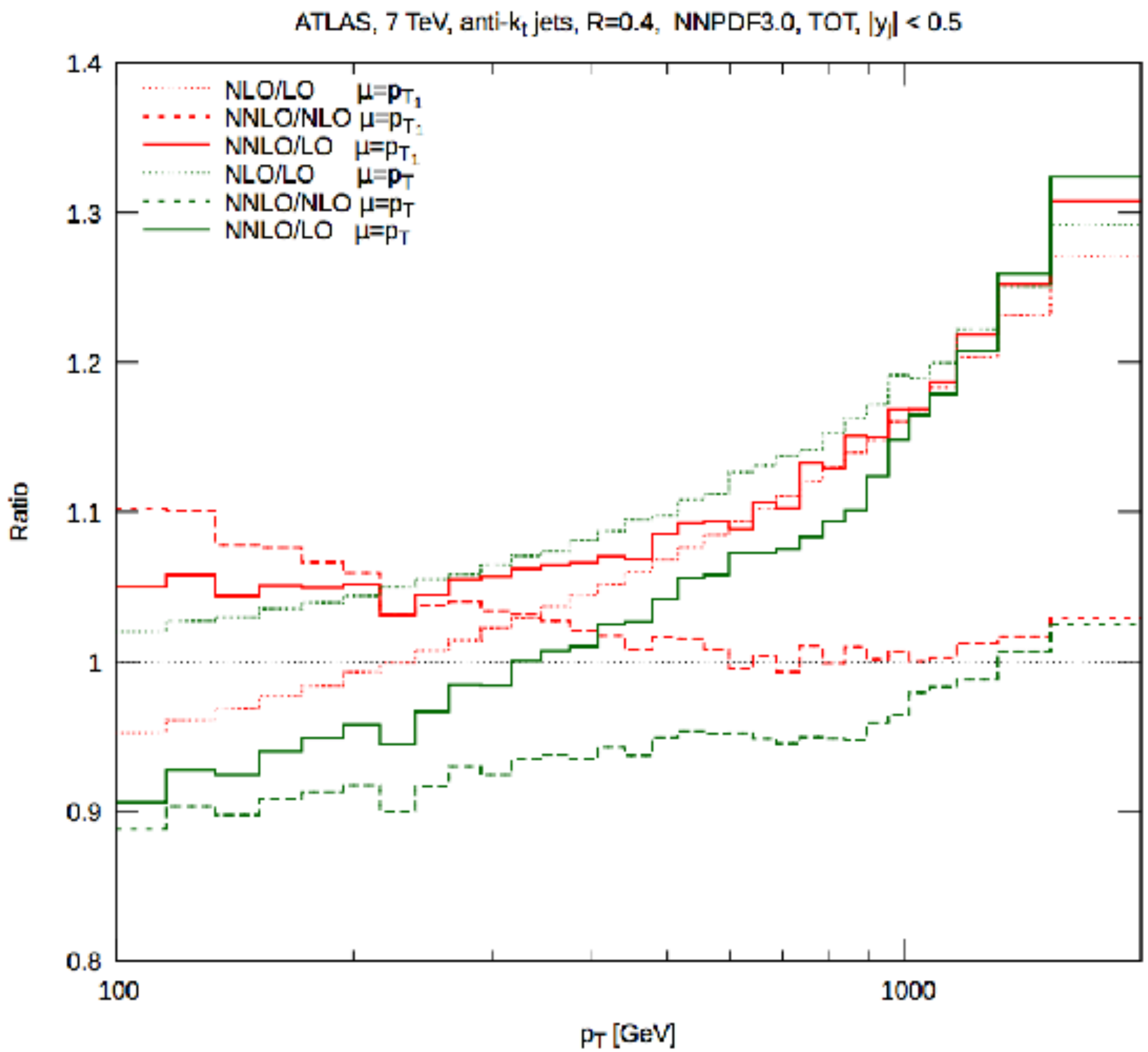




- Most constraining is inclusion of y_t list from ATLAS and y_{tt} from CMS jointly with total xsec
- Competitive reduction of gluon uncertainty with jets measurement
- Slight tension between ATLAS and CMS in NNPDF3.1 ($\chi^2_{ATLAS} \sim 1.6$, $\chi^2_{CMS} \sim 0.9$)

Czakon, Hartland, Mitov, Nocera and Rojo, arXiv: 1611.08609

Inclusive-jet data

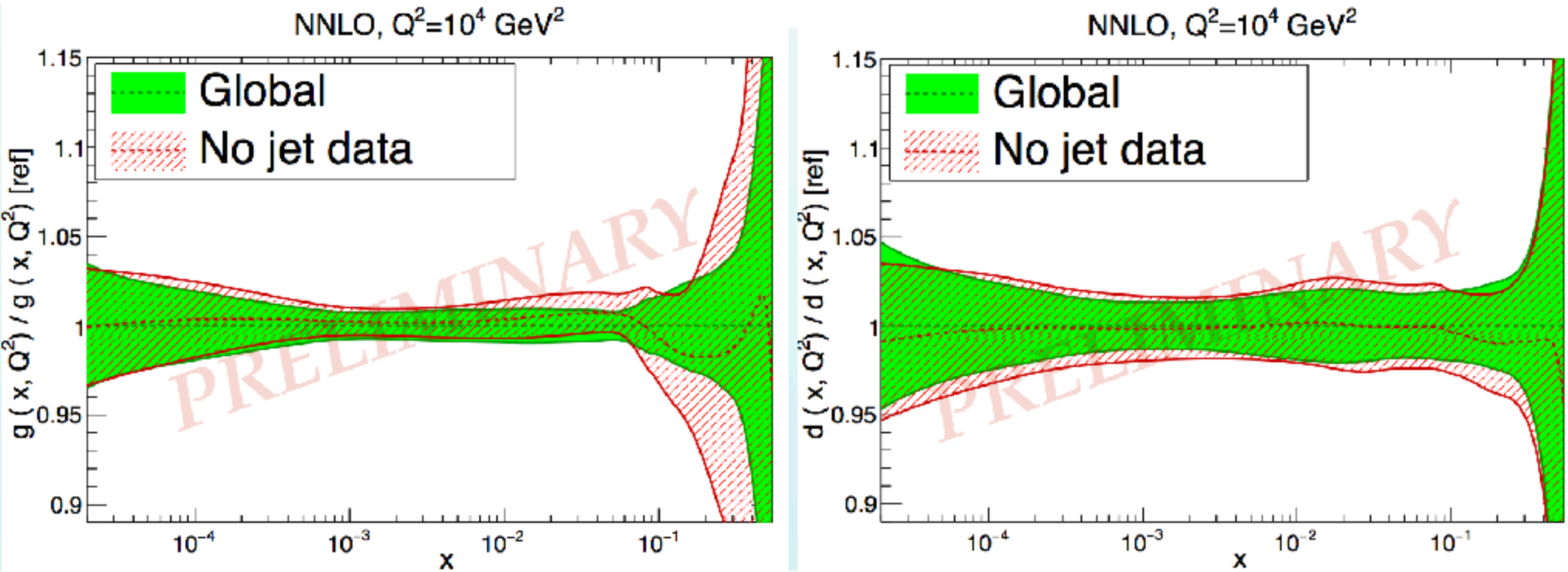


Currie et al [JHEP 1401 (2014) 110]

J. Currie, Cracow Jan 2017

- NNLO corrections known for all partonic channels (leading colour contribution only)
- Different scales predict opposite behaviour of the K-factor
- NNLO/NLO K-factors available only for ATLAS 7 TeV data
- In NNPDF3.1 use NLO matrix elements for jets computed with individual jet pT as central scale and NLO scale uncertainty added as additional uncorrelated uncertainty

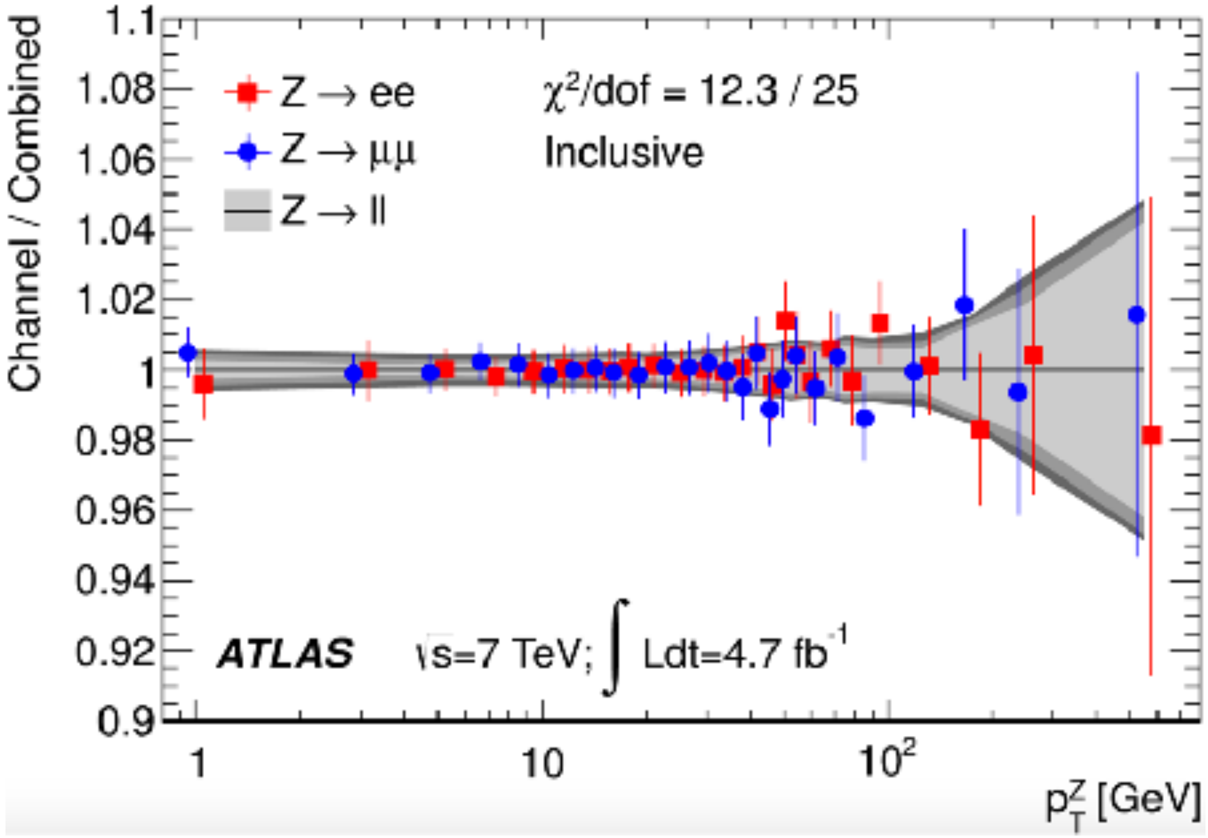
Inclusive-jet data

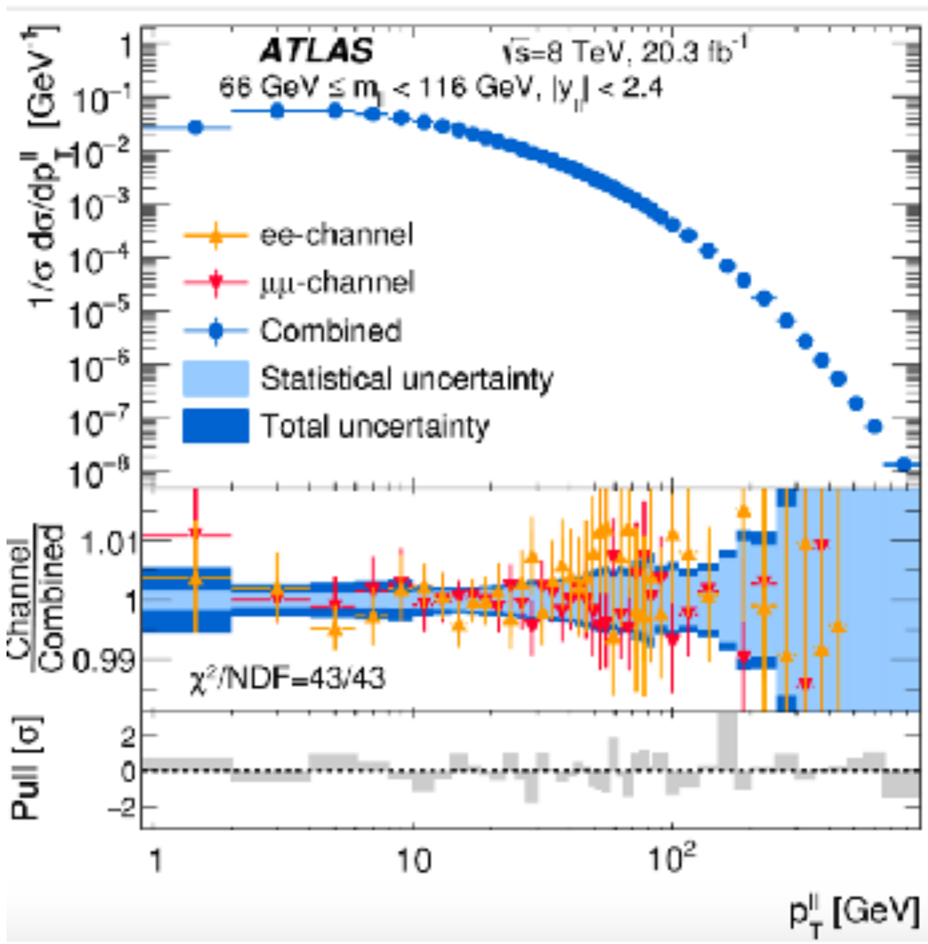


- In NNPDF3.1 included only central rapidity bin with good fit quality $\chi^2_{NLO} = 1.06$, $\chi^2_{NNLO} = 1.12$
- Jet data still quite constraining for the large-x gluon, though impact less dramatic as in previous NNPDF releases due to the presence of other gluon-sensitive measurements in the fit

Z p_T distributions

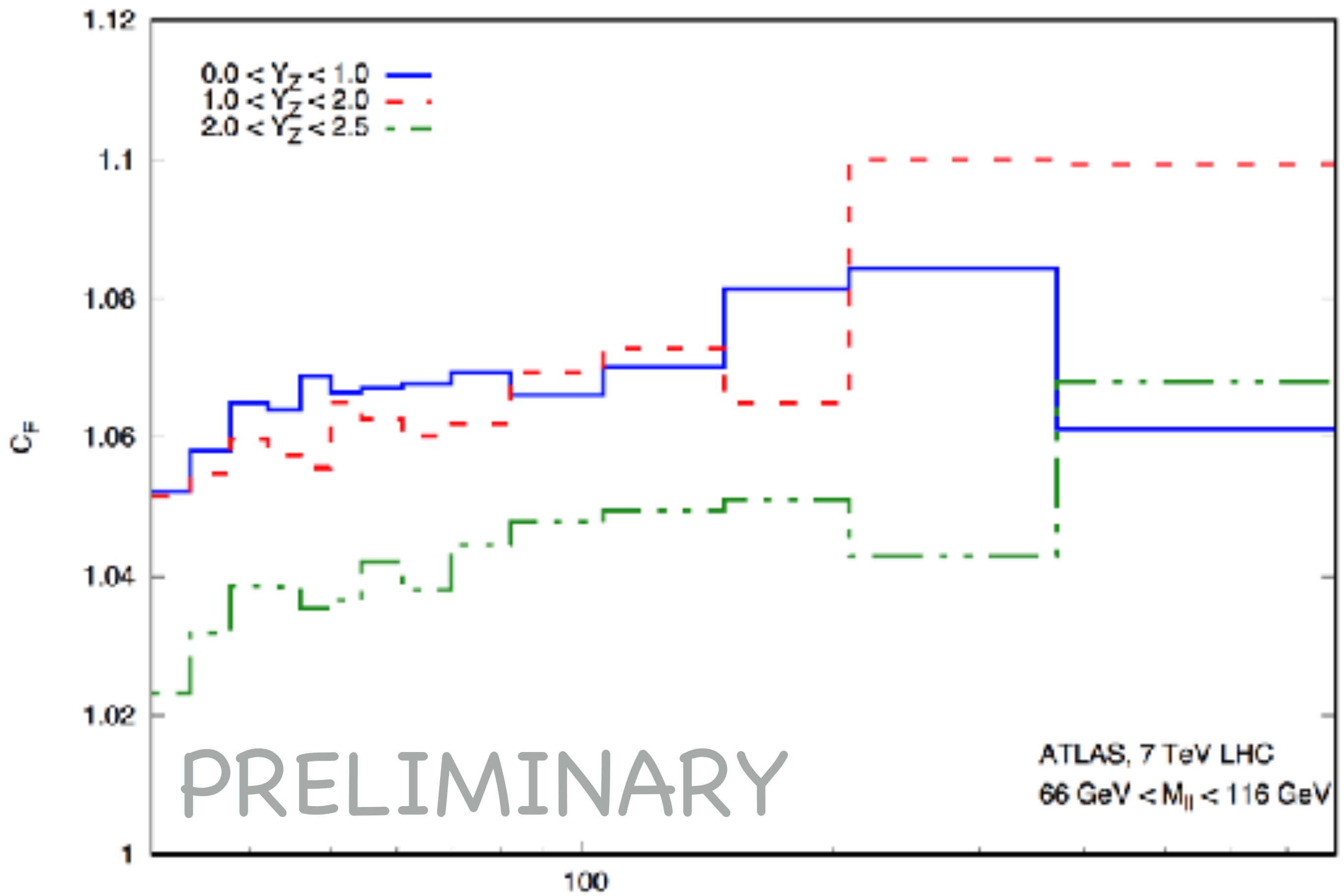
- Experimental precision < 1% up to pT~200 GeV
- Interesting case-study to probe current theory-experiment frontier





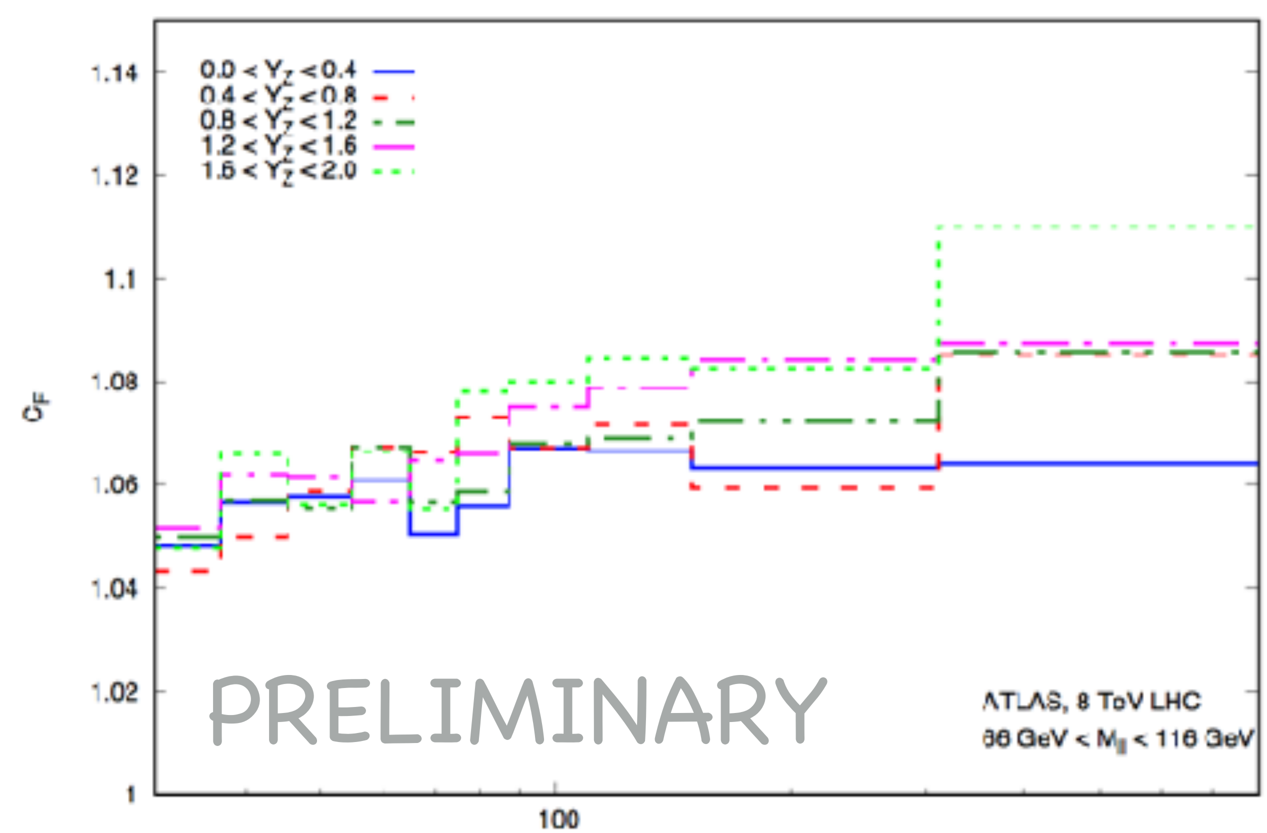
- ☑ ATLAS Z pT @LHC7, normalised distributions, 3 rapidity bins (0.0 < Y < 1.0, 1.0 < Y <2.0 , 2.0<Y<2.5)
  ~50 data in perturbative region pT > 30 GeV
- ☑ ATLAS Z pT @LHC8, normalised/unnormalised distributions, 6 rapidity bins in Z peak + low/high M
  ~150 data in perturbative region pT > 30 GeV
- ☑ CMS Z pT @LHC8, normalised/unnormalised distributions, 5 rapidity bins in Z peak
  ~50 data in perturbative region pT > 30 GeV

Z p_T distributions



- NNLO calculation performed using N-jettiness subtraction scheme, by using recent calculation of Z+j at NNLO [Boughezal et al, PRL 116 (2016)] and relaxing cut on final state jet

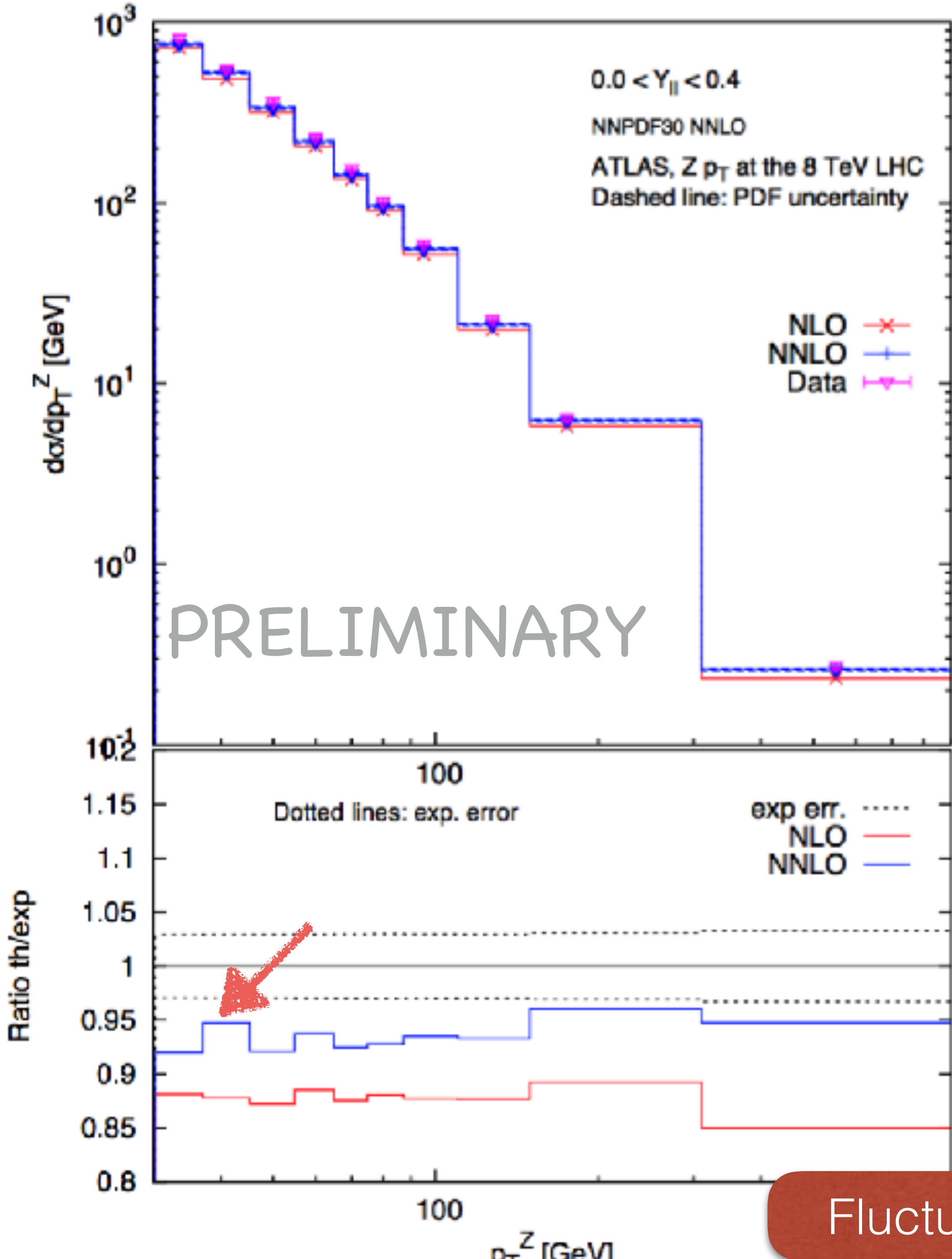
$$\mu_R = \mu_F = \sqrt{(p_T^Z)^2 + M_{ll}^2}$$



- NNLO/NLO K-factors 5% - 10% increase with p_T
- EW corrections only relevant for the highest pT bins in the Z-mass peak and for high-mass ATLAS measurement

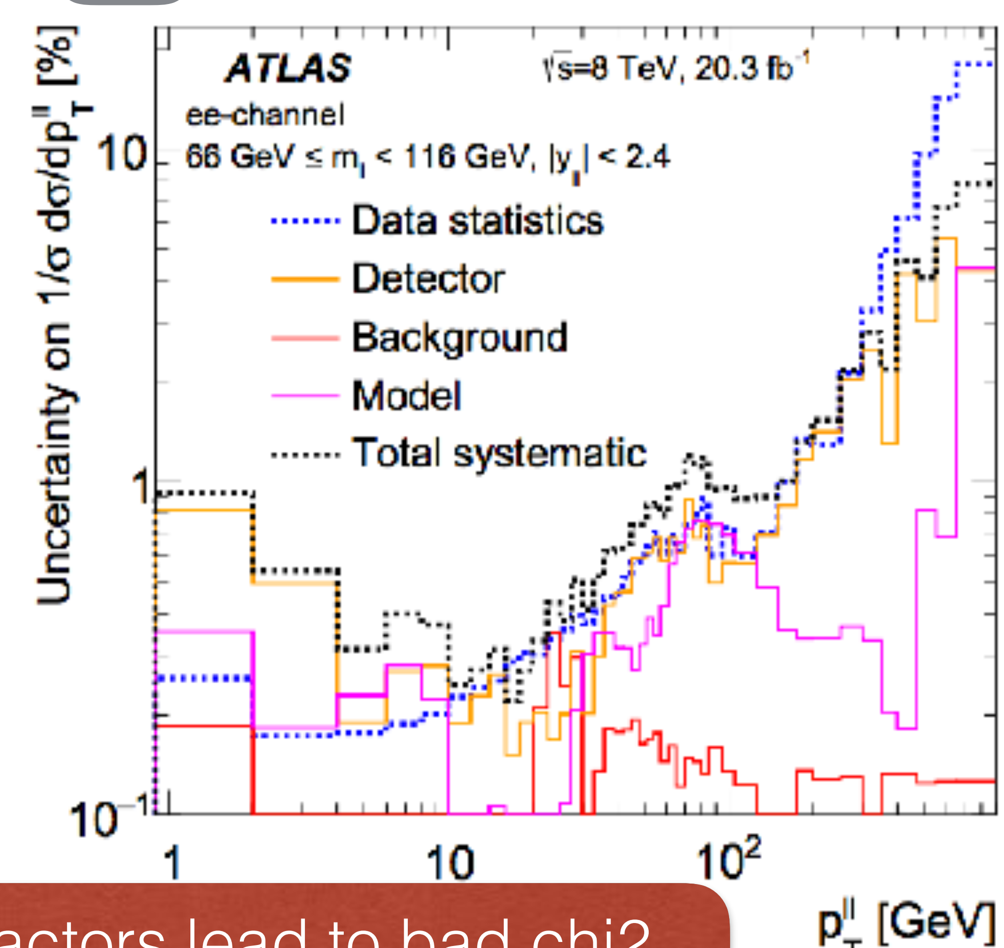
Boughezal, Guffanti, Petriello, MU - in progress

Z p_T distributions



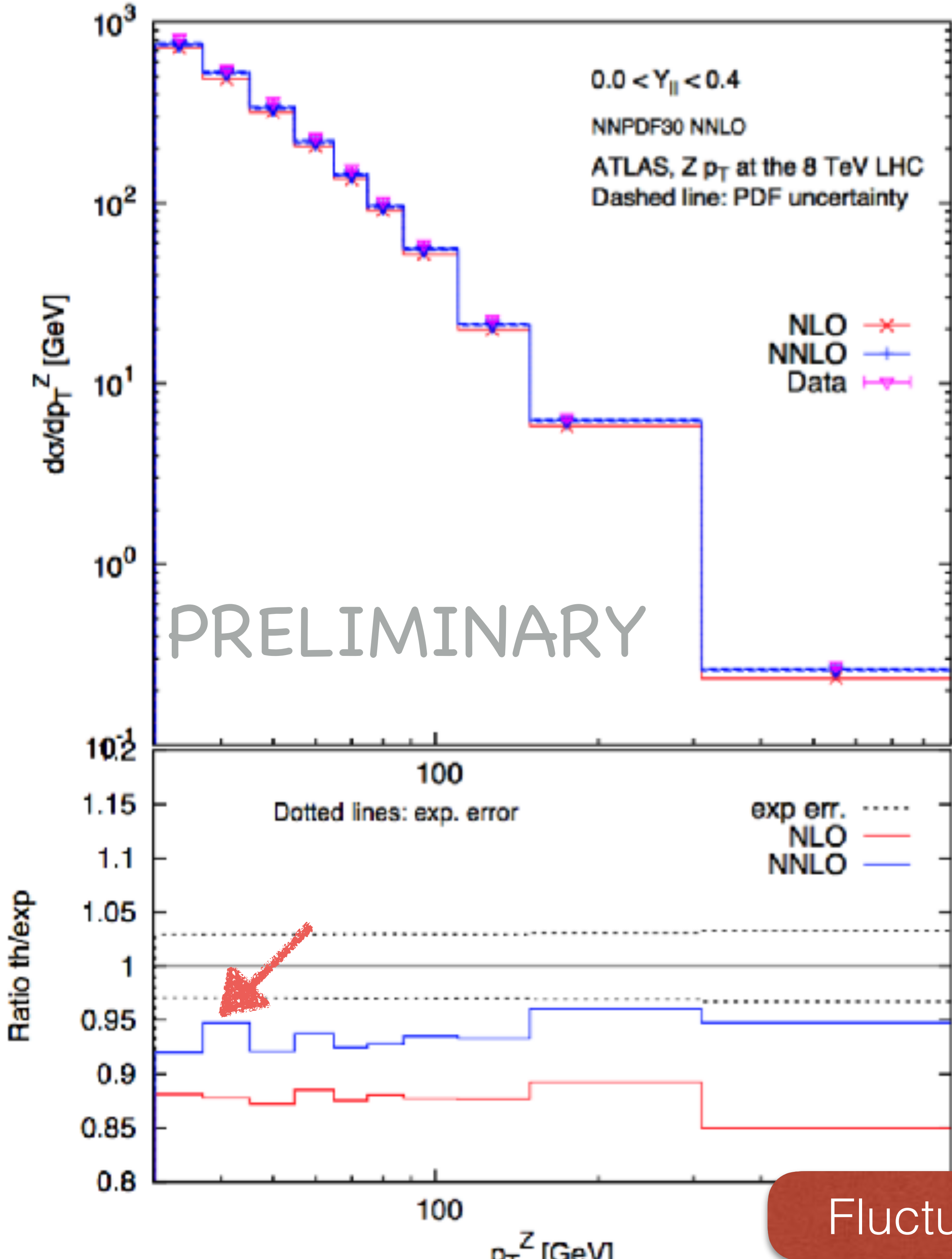
NLO	NNLO
$\chi^2_{\rm stat} = 140$	$\chi^2_{\rm stat} = 51.$
$\chi^2_{\rm uncor} = 115$	$\chi^2_{\rm uncor} = 42.$
$\chi^2_{\rm diag} = 1.70$	$\chi^2_{\rm diag} = 0.62$
$\chi^2_{\rm full} = 2.80$	$\chi^2_{\rm full} = 5.61$

/d.o.f.



Fluctuations in K-factors lead to bad chi2

Z p_T distributions



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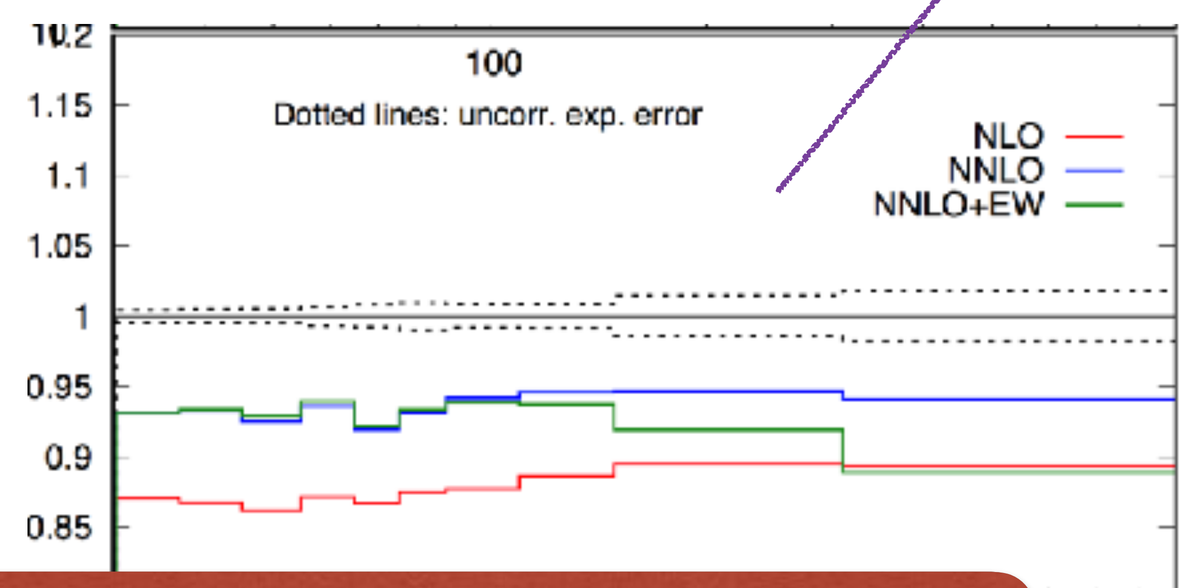
2.0

10x more statistics



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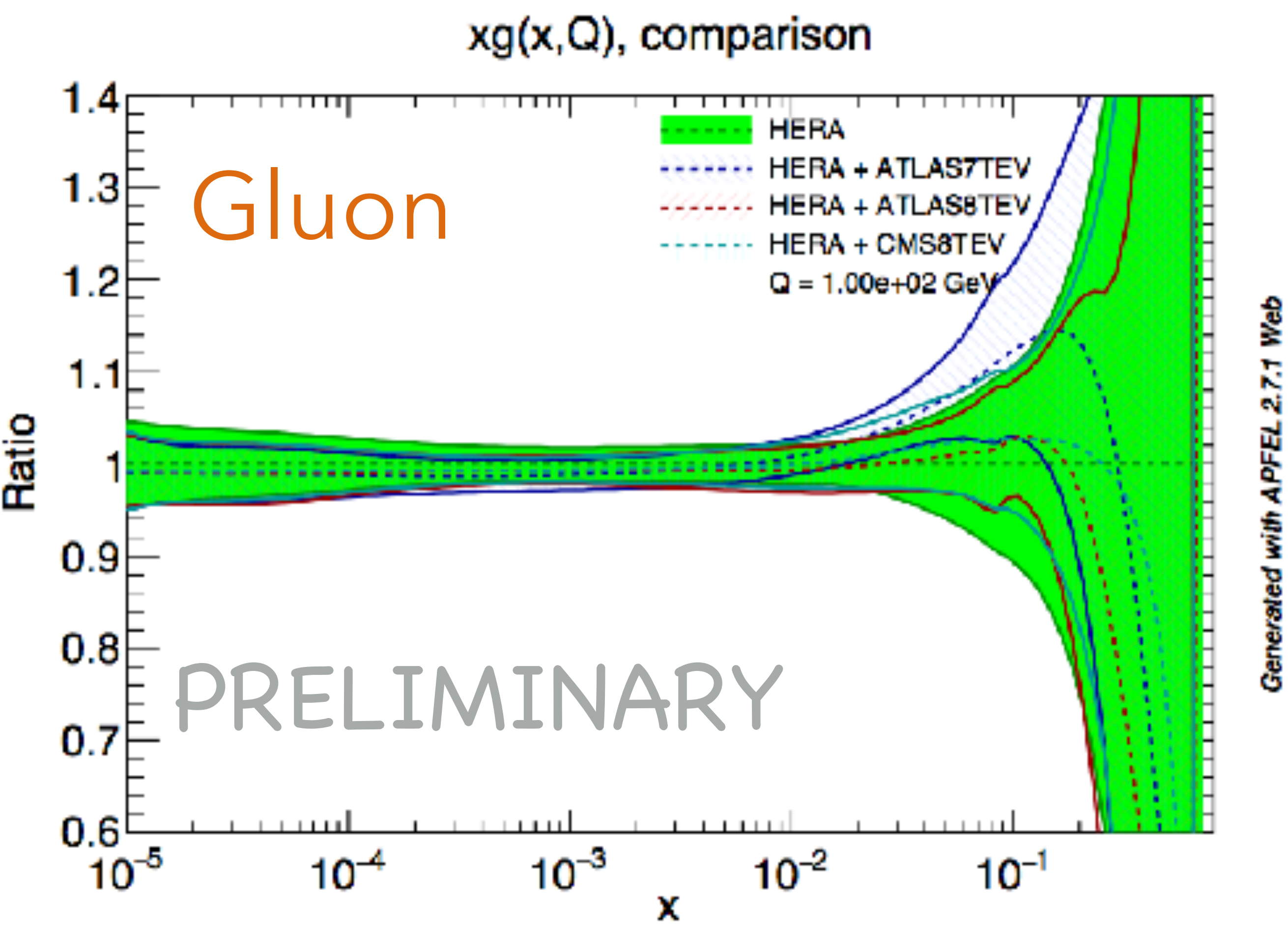
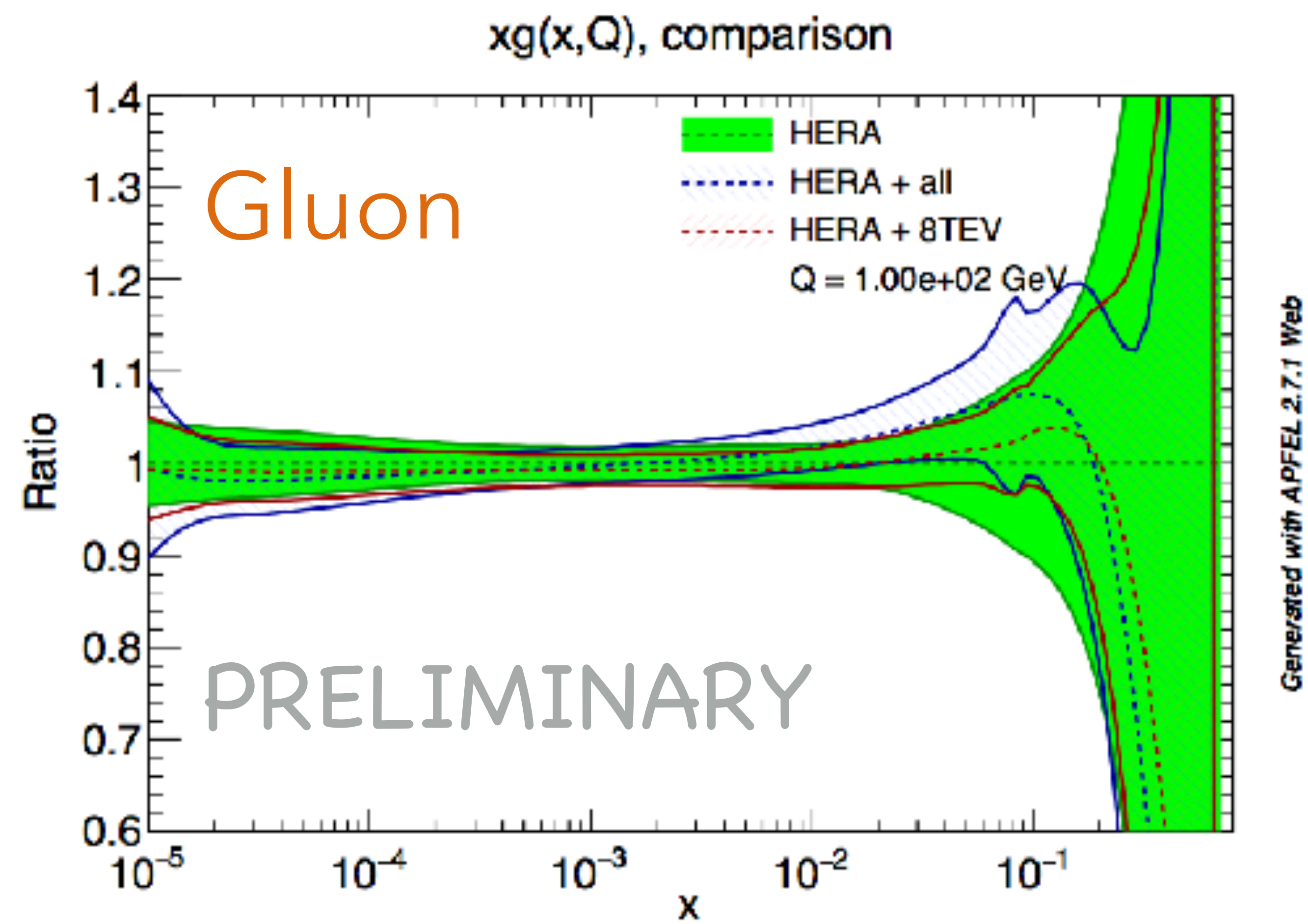
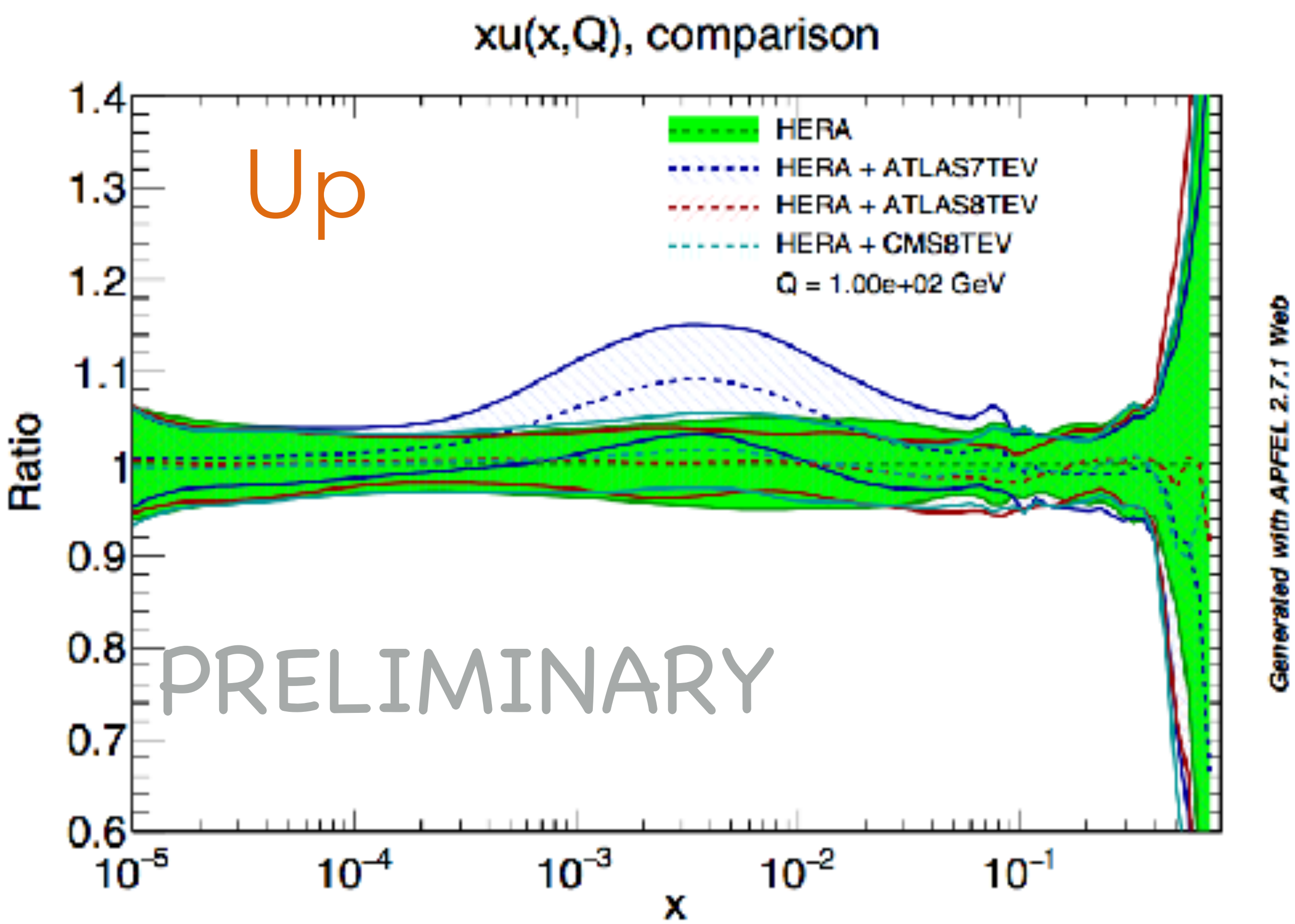


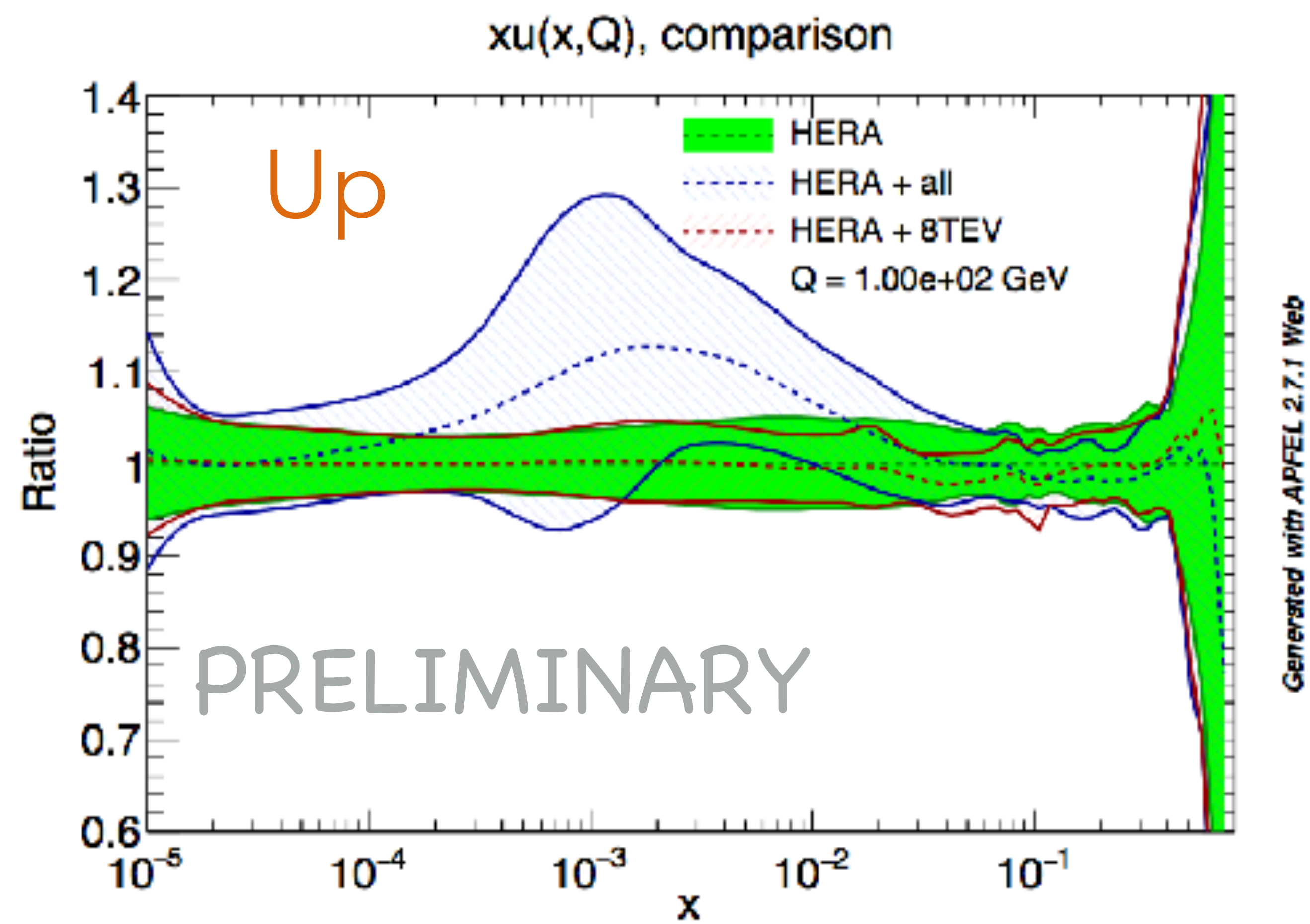


- Impact of Z pT distributions is quite strong, they increase the singlet and decrease the gluon in regions in which we expect them to be correlated with measurement
- ATLAS and CMS data at 8 TeV (unnormalised) decrease uncertainty of gluon and light quark distributions at both in HERA-only fits and in global fits.
- ATLAS 7 TeV data (normalised) can be fitted individually but point to a different minimum. Covariance matrix for normalised experiments built for the whole pT spectrum, pT cuts modify correlations between bins. Need pT resummation?

Boughezal, Guffanti, Petriello, MU - in progress

Z p_T distributions





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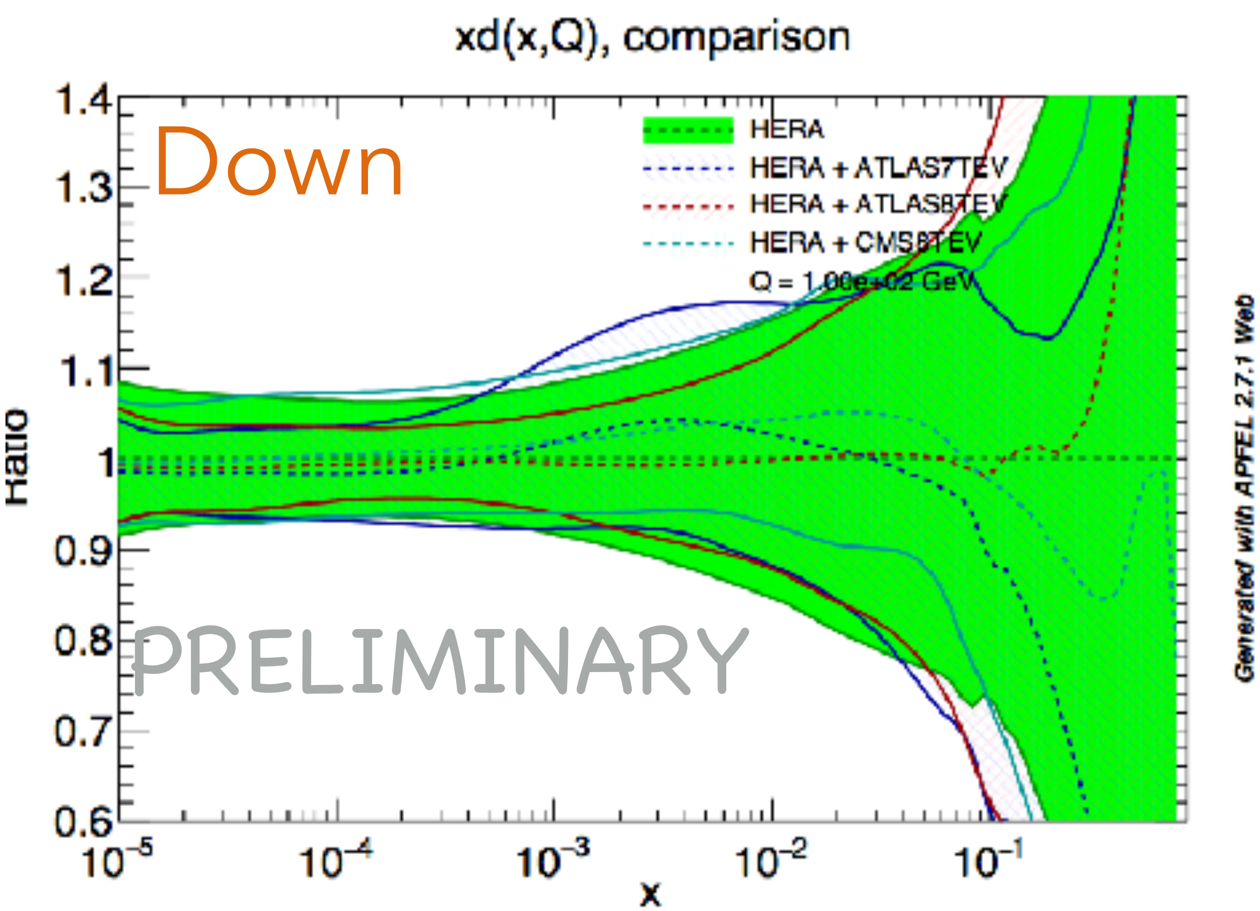

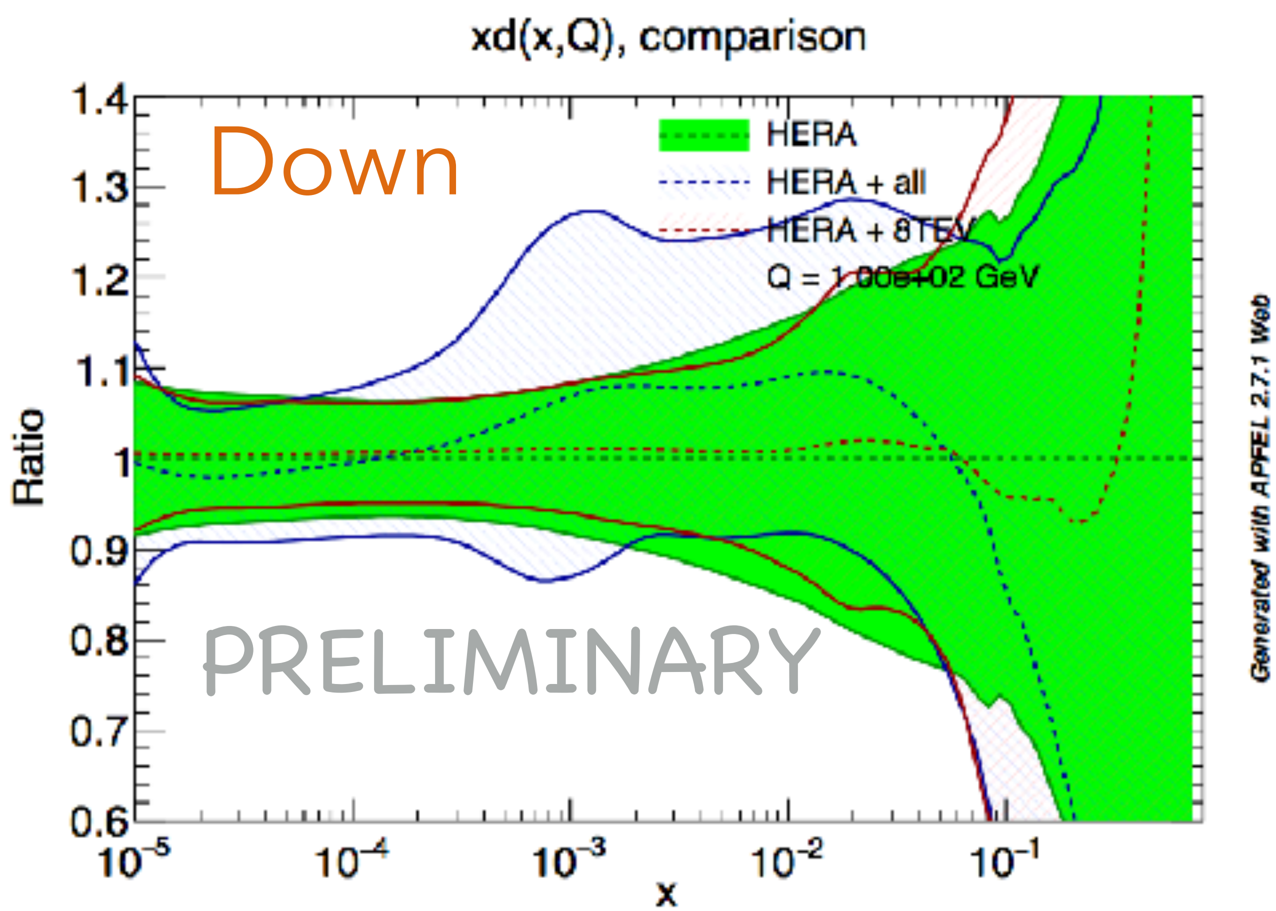

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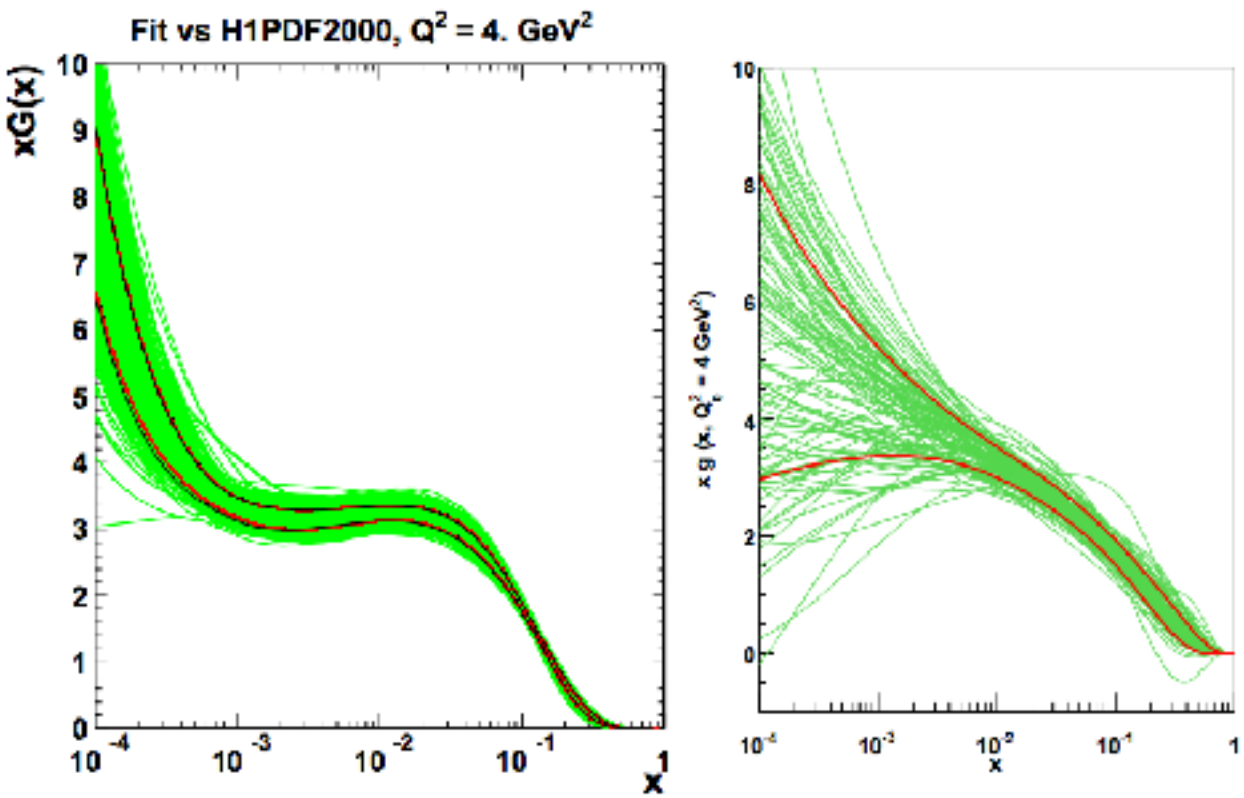
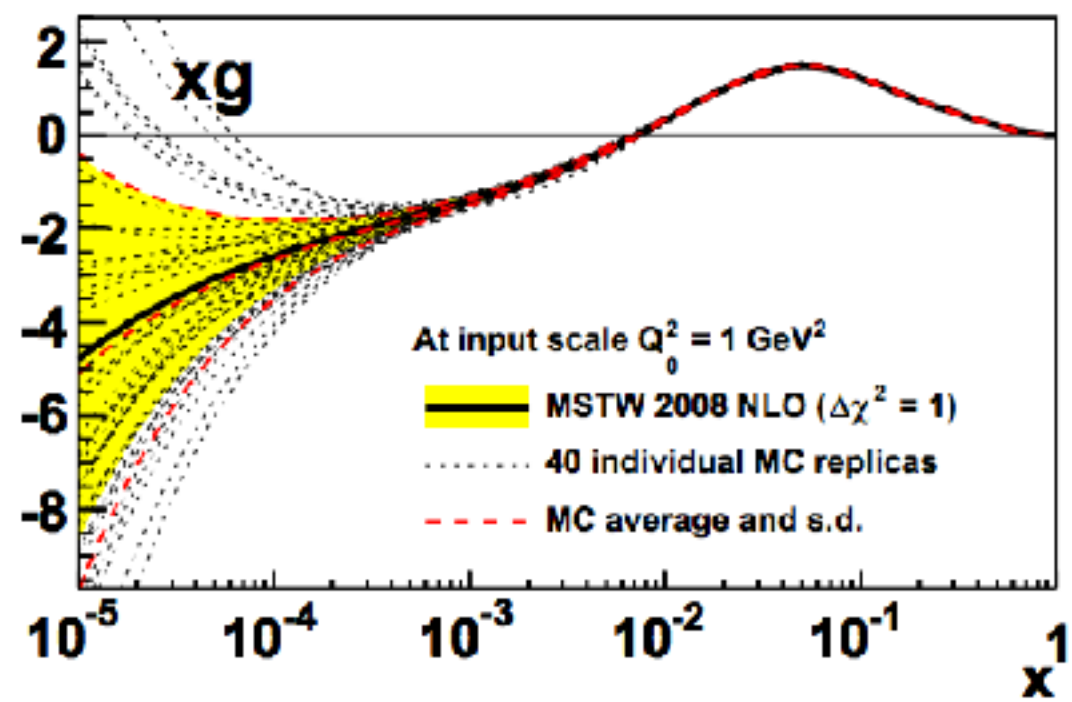
Tools

PDF error representation



- Lots of discussion in the past on the differences between Monte Carlo and Hessian representation of PDF sets
- Many tools recently developed to traslate one representation into another

- Hessian to Monte Carlo representation and compression algorithms allow to transform a Hessian set to a MC one (MCgen)
- At the basis of the PDF4LHC recommendation

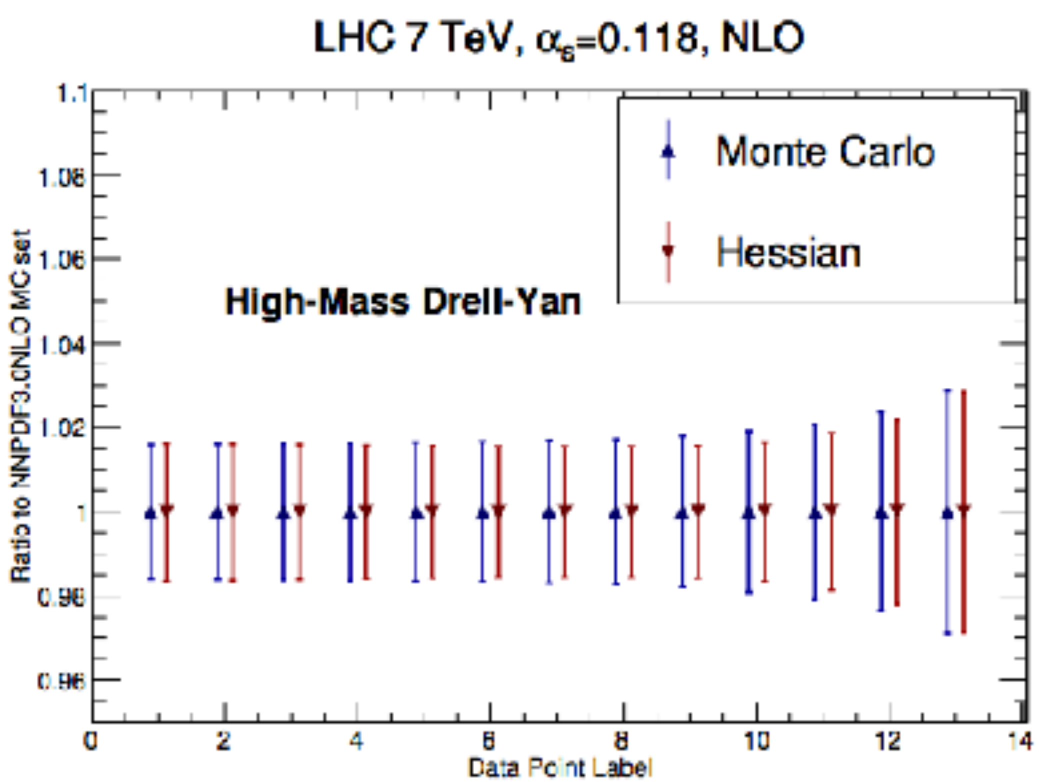


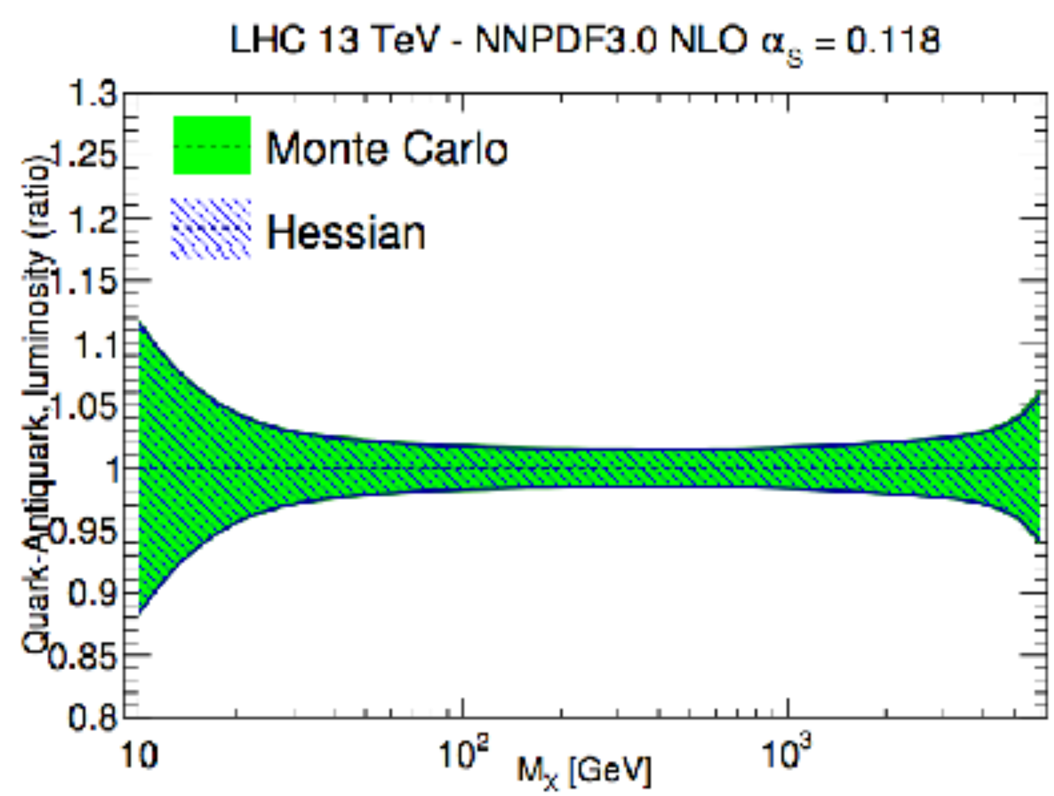
Carrazza et al, Eur.Phys.J. C75 (2015) 474

Watt, Thorne, JHEP 1208 (2012) 052
T-J Hou, arXiv:1607.06066

mc²hessian

- Mc2hessian: a method to get an unbiased Hessian representation of a MC PDF set
- The idea:
  - Use Monte Carlo replicas as a basis function for Hessian representation
  - Conversion MC -> Hessian based on relative uncertainty estimators
  - Symmetric eigenvectors determined by Genetic Algorithm
  - Find optimal number of eigenvector





Carrazza et al, Eur.Phys.J. C75 (2015)

SMPDF

- PDF4LHC combinations starts from set of 900 replicas of three independent global PDF analyses

LHAPDF6 grid	Pert order	ErrorType	$N_{\rm mem}$	$\alpha_s(m_Z^2)$
PDF4LHC15_nnlo_mc	NNLO	replicas	100	0.118
PDF4LHC15_nnlo_100	NNLO	symmhessian	100	0.118
PDF4LHC15_nnlo_30	NNLO	symmhessian	30	0.118

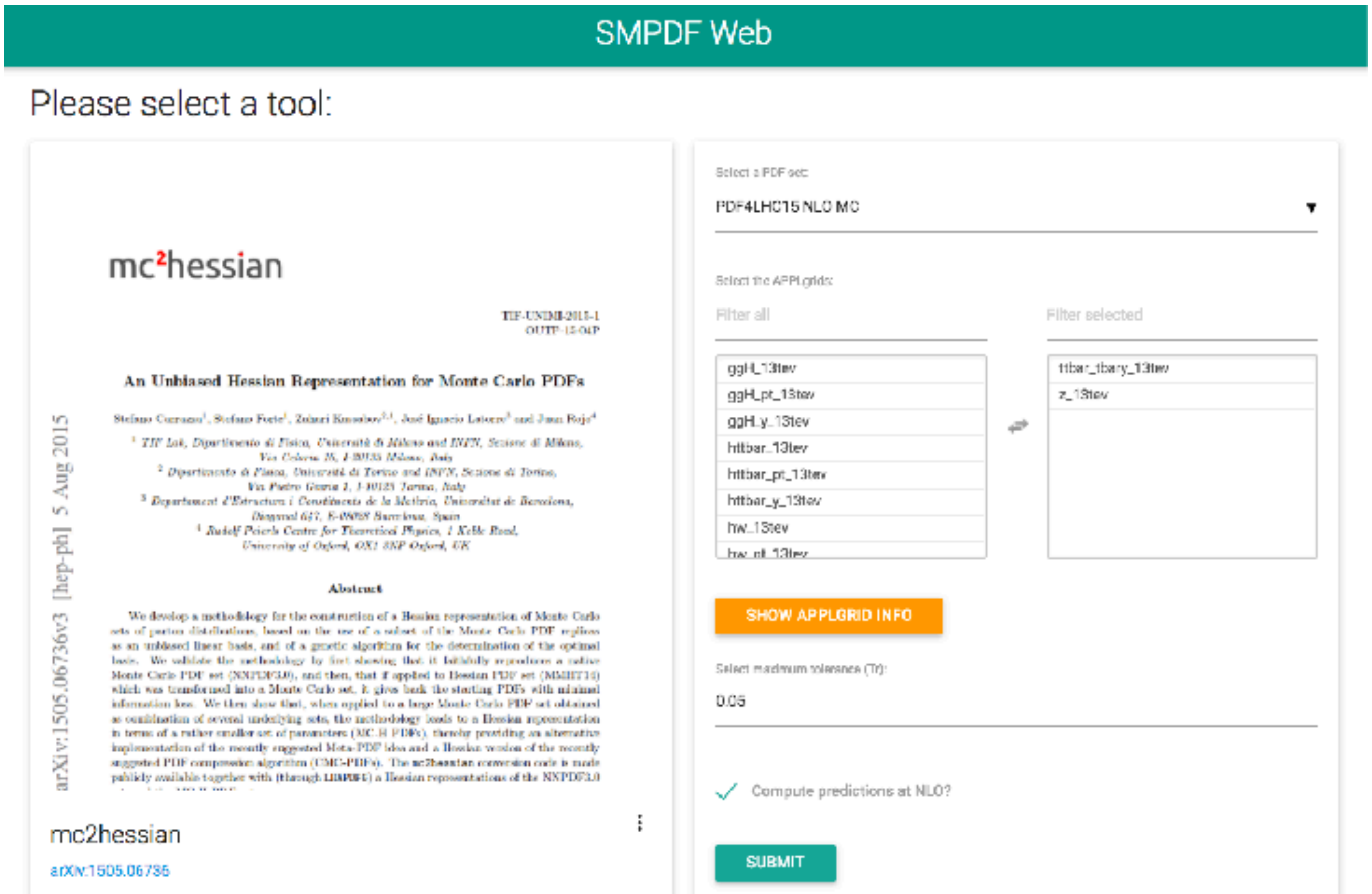
- At least 30 (lowest accuracy) or 100 (higher) error sets: computationally heavy
- Specialised Minimal PDFs are based on an efficient and accurate PDF process-specific Hessian reduction algorithm
- Accuracy versus number of eigenvalue can be tuned by users

Process	MC900		NNPDF3.0		MMHT14	
	$T_R = 5\%$	$T_R = 10\%$	$T_R = 5\%$	$T_R = 10\%$	$T_R = 5\%$	$T_R = 10\%$
h	15	11	13	8	8	7
$t\bar{t}$	4	4	5	4	3	3
W, Z	14	11	13	8	10	9

T_R = Max deviation wrt prior

Carrazza et al, Eur.Phys.J. C76 (2016)

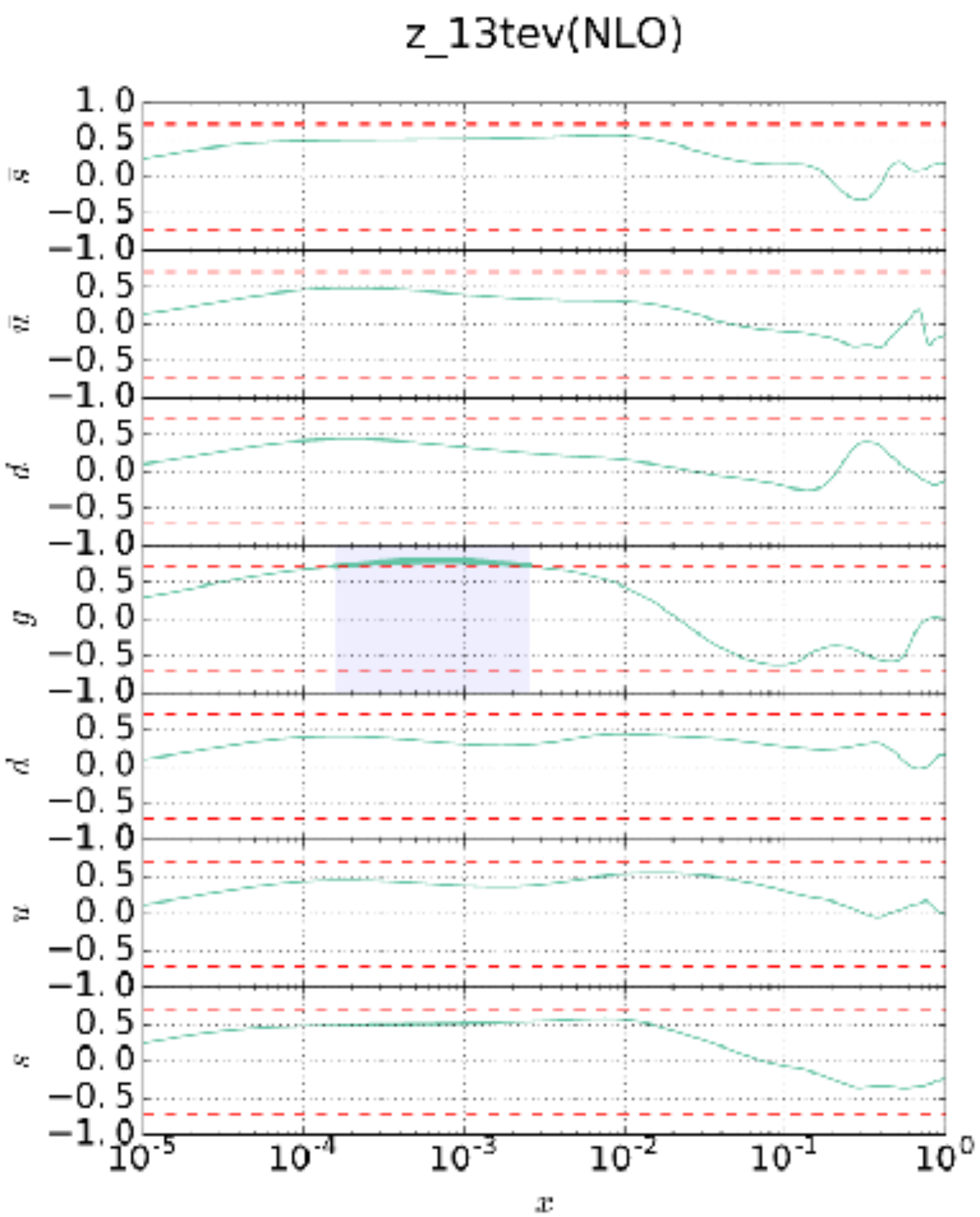
SMPDF

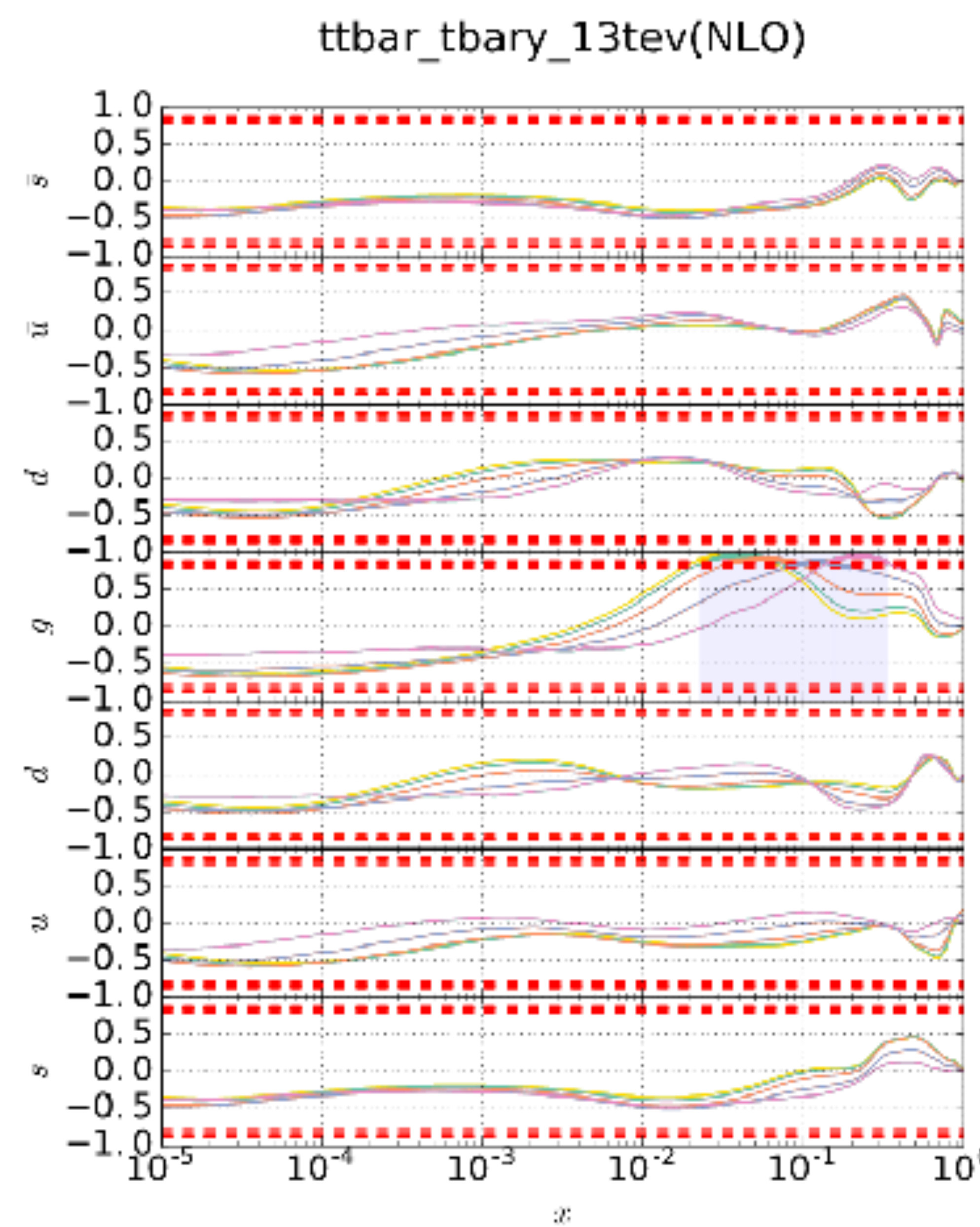


- Web interface allows automated generation of SMPDF sets for the desired prior PDF and observable as well as Hessian representation of a give MC set

Carrazza, Kassabov 1606.09248

SMPDF

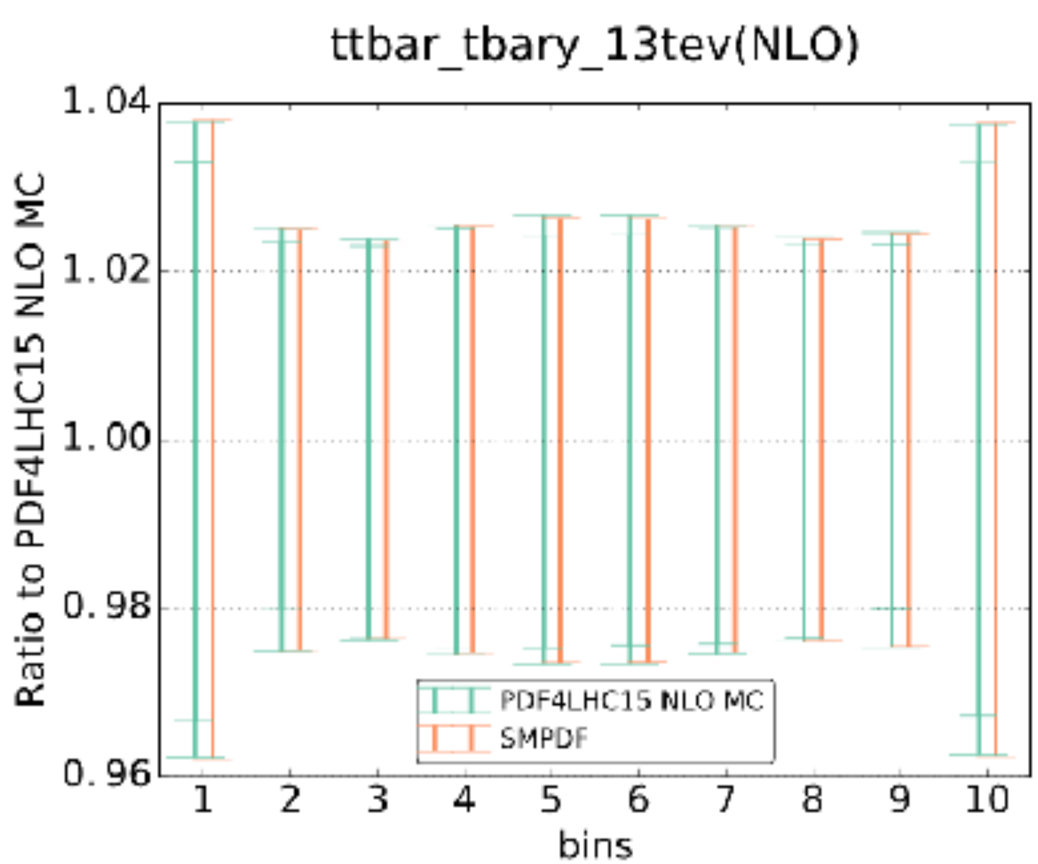


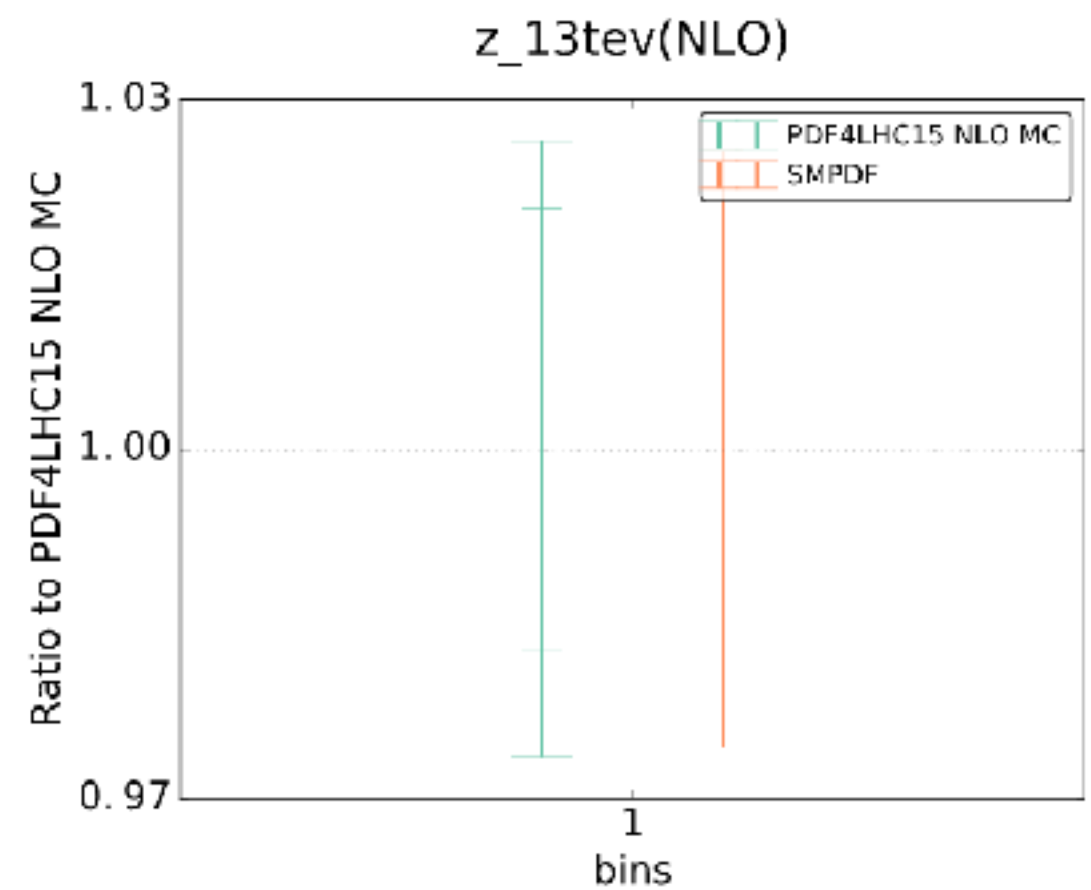


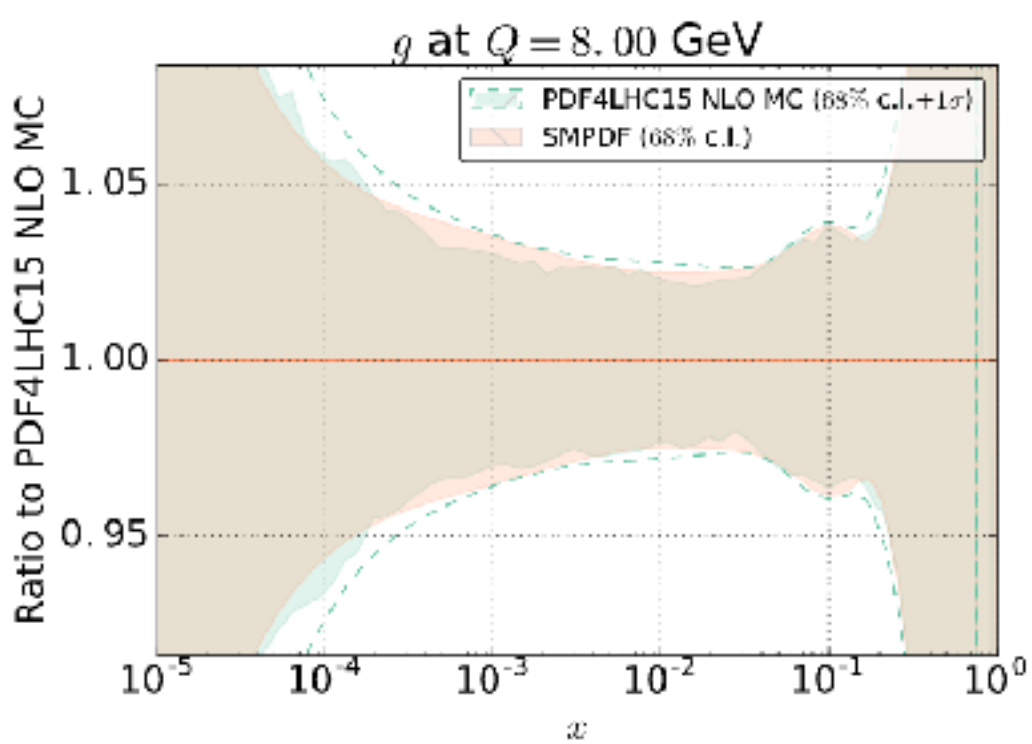
PDF - observables correlation

And observable-observable PDF induce correlation available

SMPDF



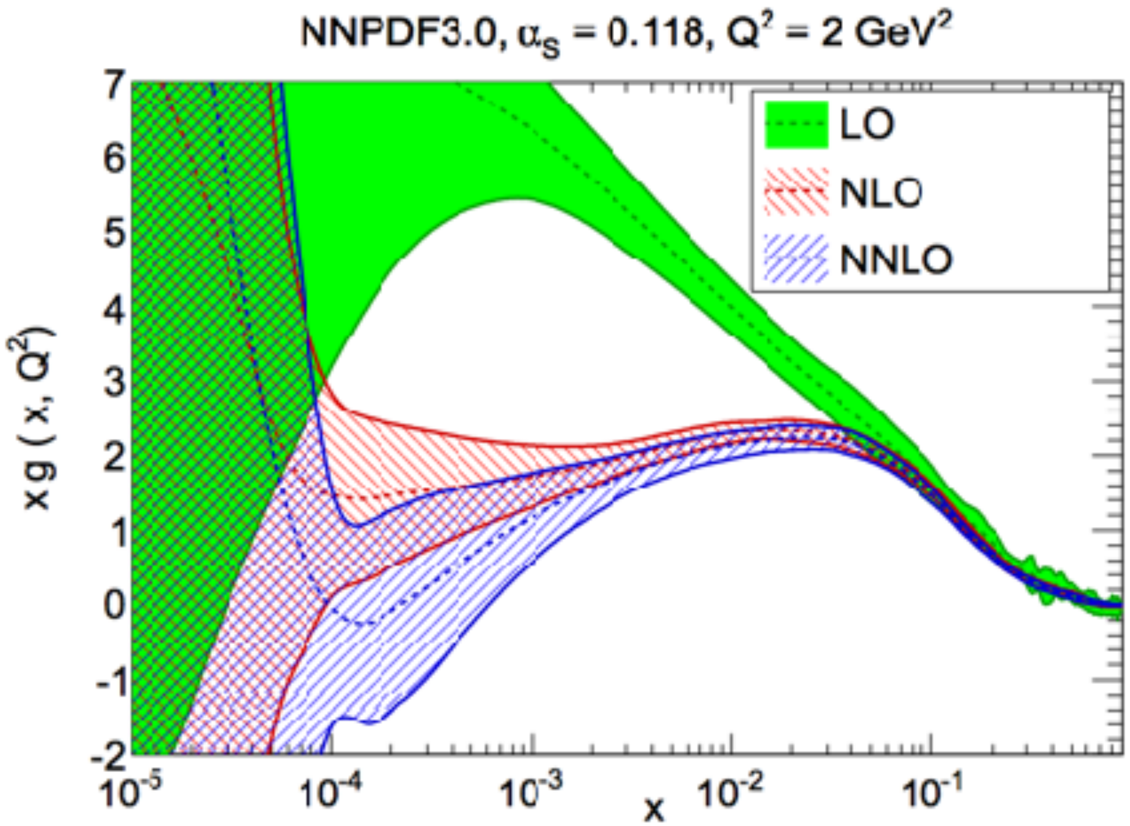


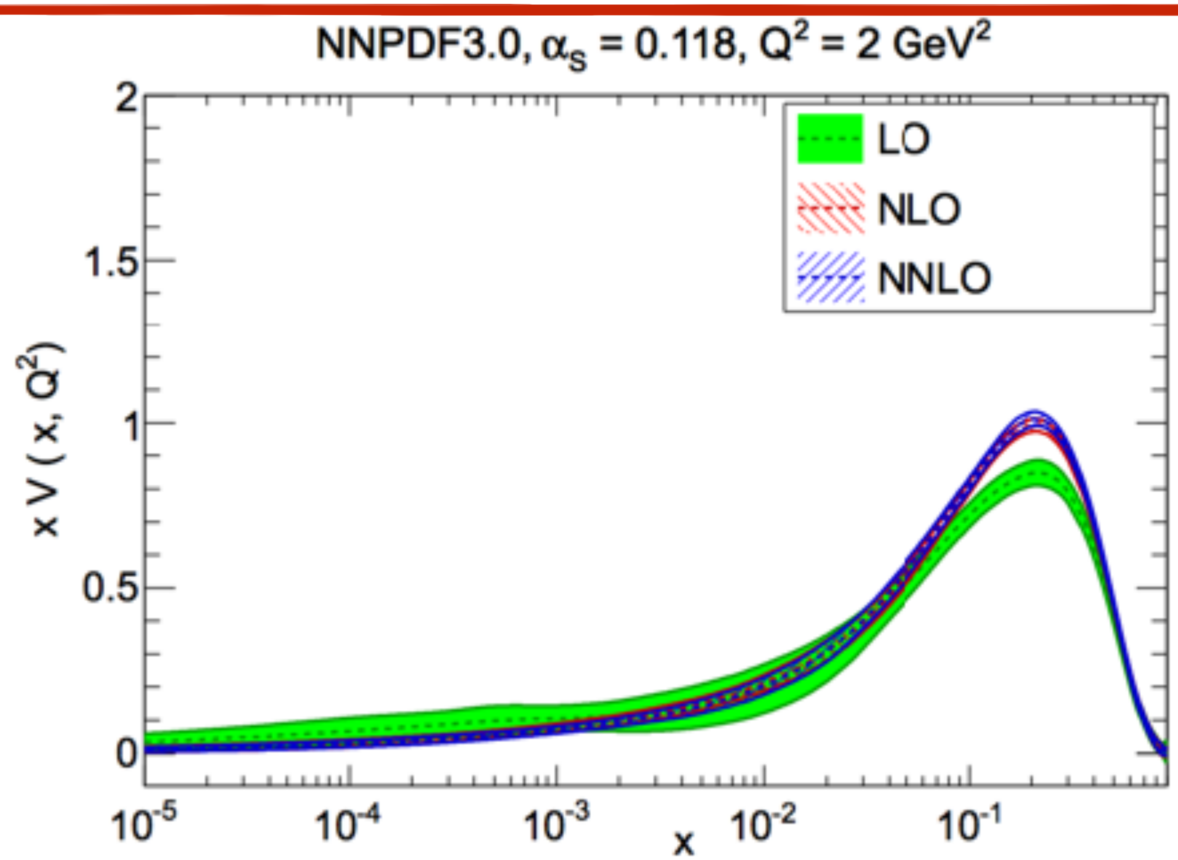


PDF uncertainty (68% c. l.) on selected observables and comparison between SMPDF and prior PDF

New frontiers

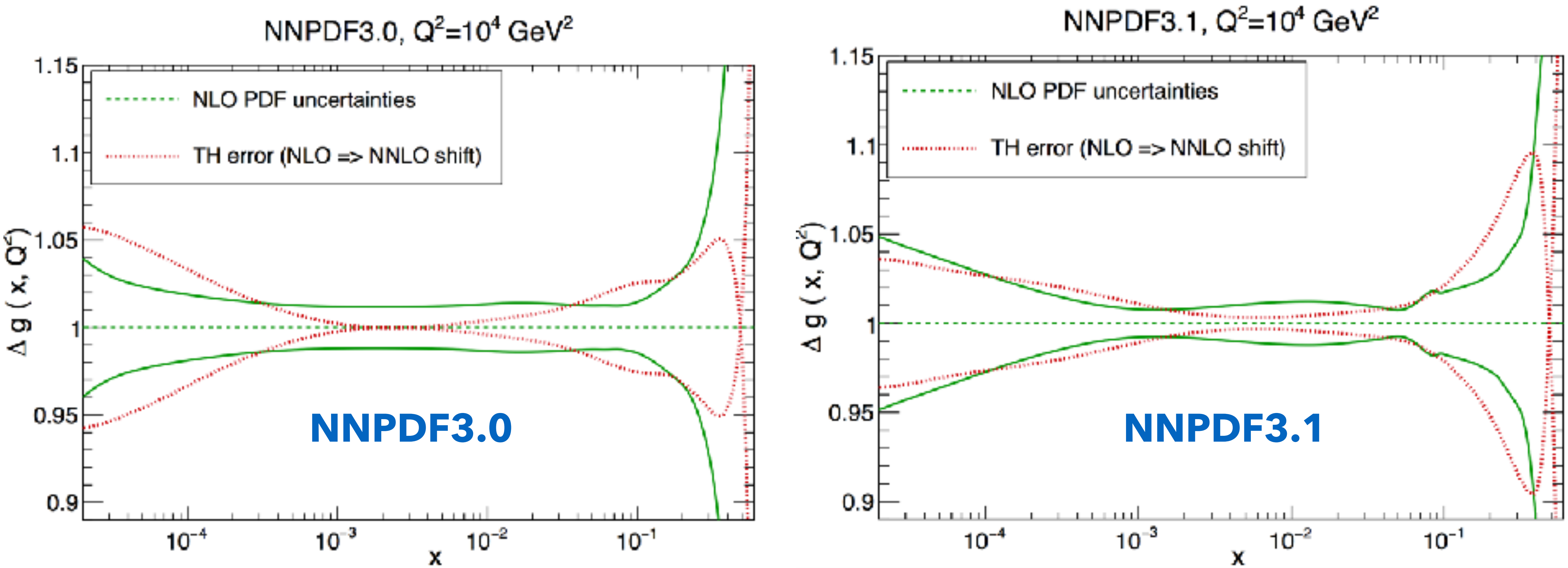
Theory uncertainties





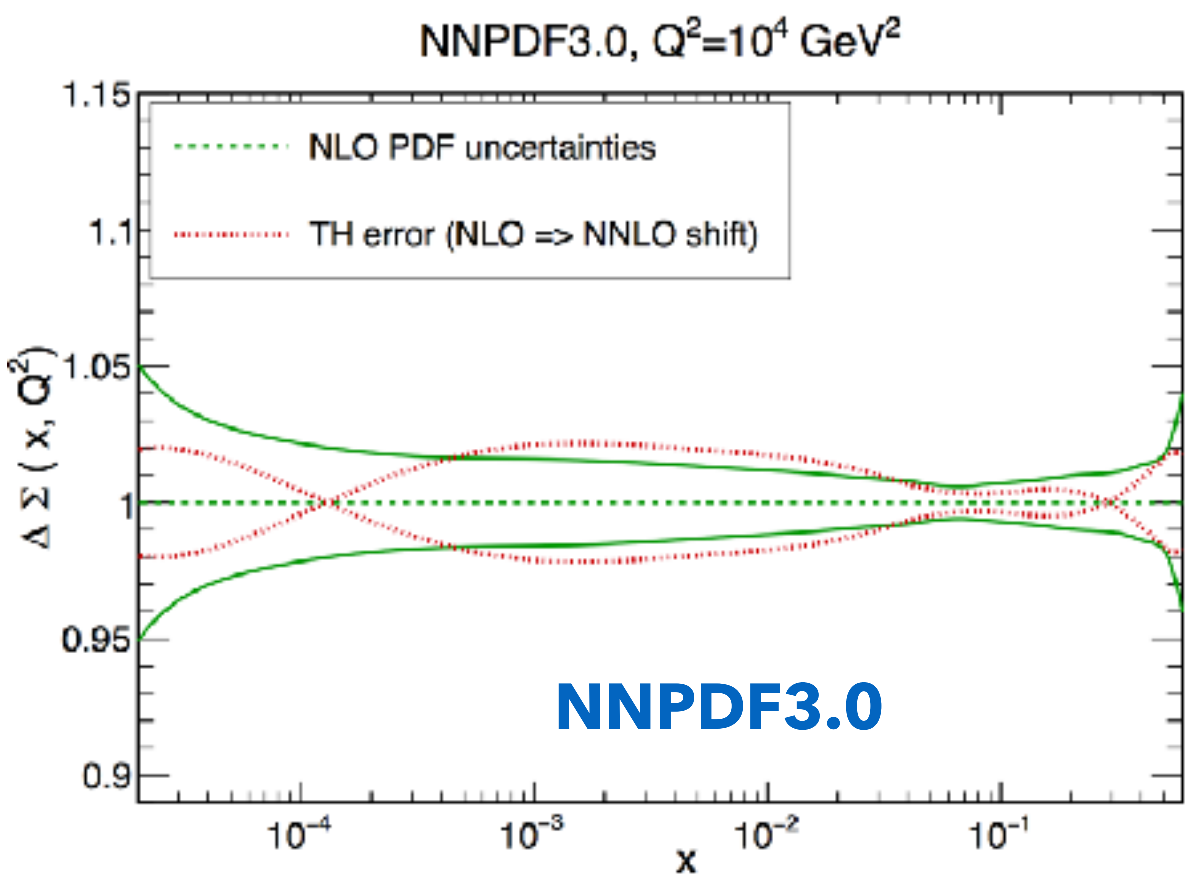
- PDF fits performed with given fixed perturbative order, value of α_S and heavy quark masses (estimated by combining PDF sets determined with different values
- PDF uncertainties only reflect lack of information from data given the theory
- Changes in theory may cause shifts outside the error band, can we estimate that?
- LO fits are merely qualitative, NLO quantitative and NNLO precise, but how much?

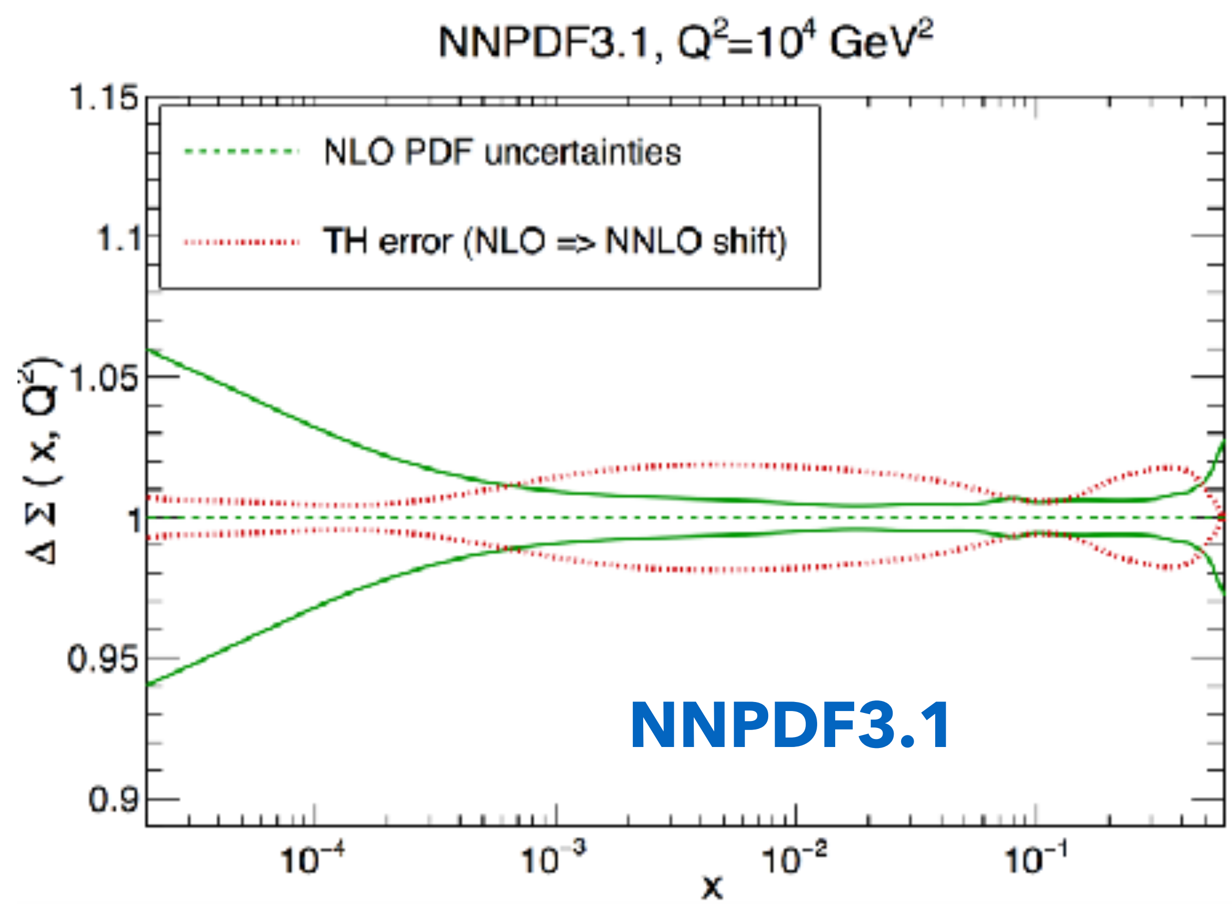
Theory uncertainties



- As PDF uncertainties get smaller the role of theoretical uncertainties becomes increasingly crucial, especially for well-constrained PDF/PDF combinations
- Fit with scale variation?
- How to keep into account theoretical correlations between different processes?

Theory uncertainties





- As PDF uncertainties get smaller the role of theoretical uncertainties becomes increasingly crucial, especially for well-constrained PDF/PDF combinations
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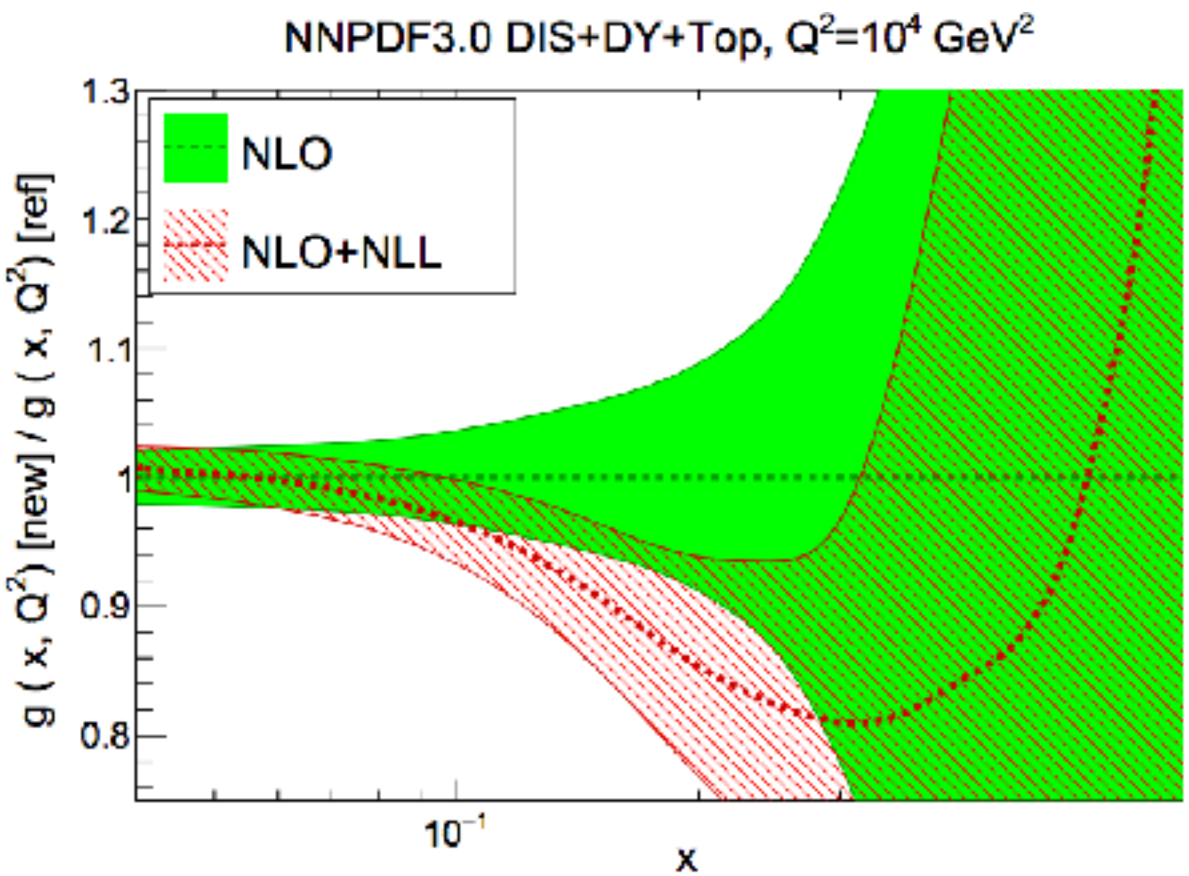
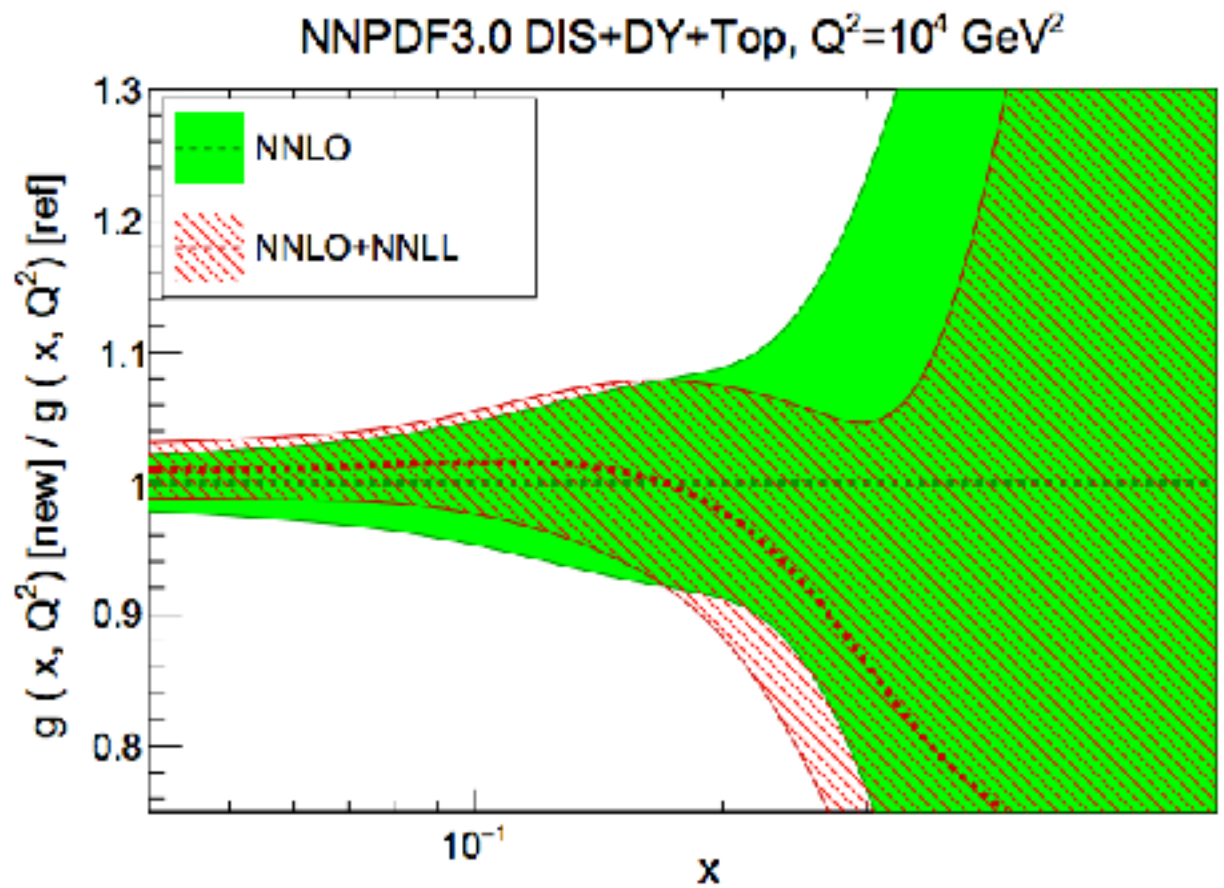
Large-x resummation

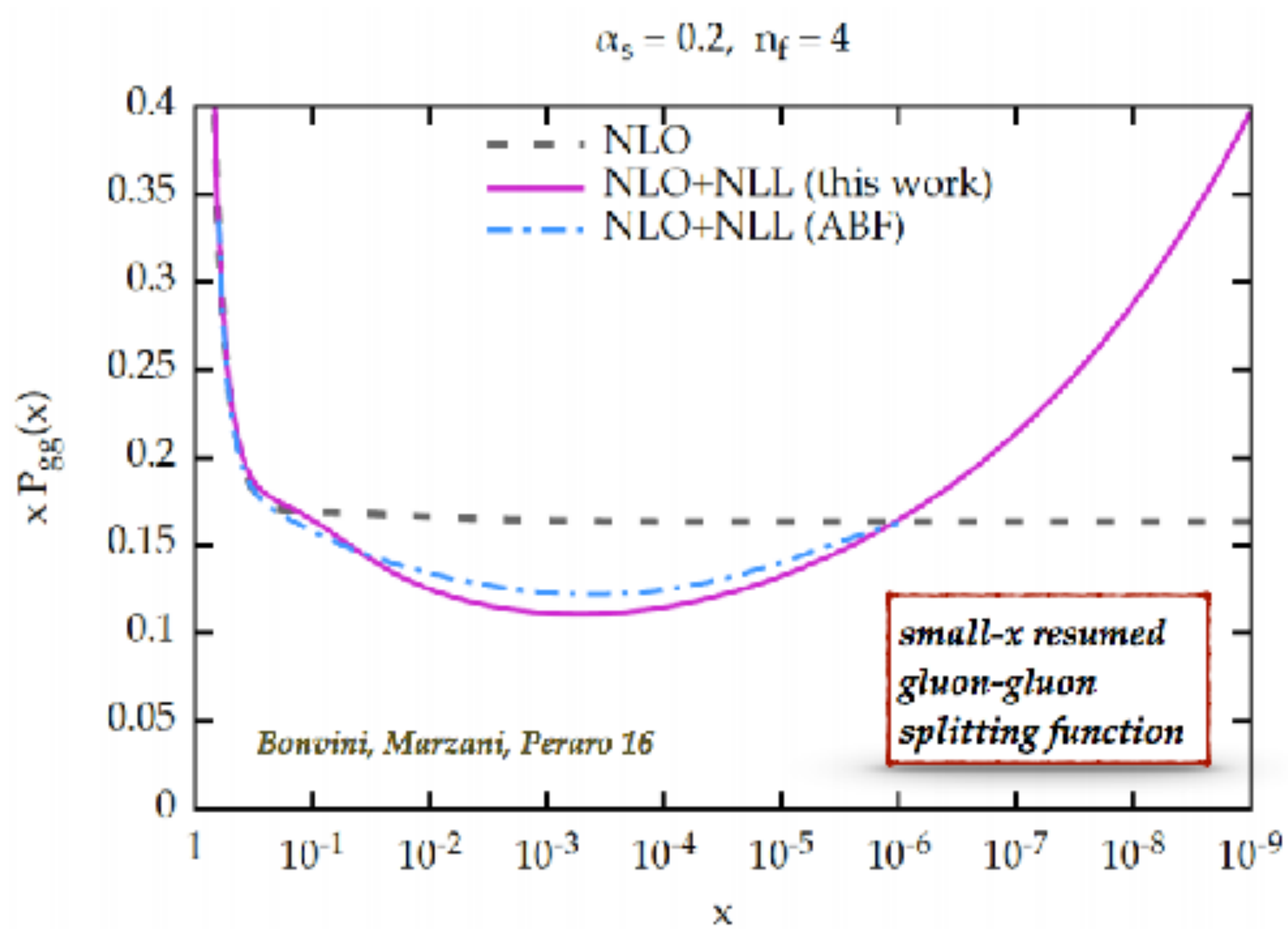


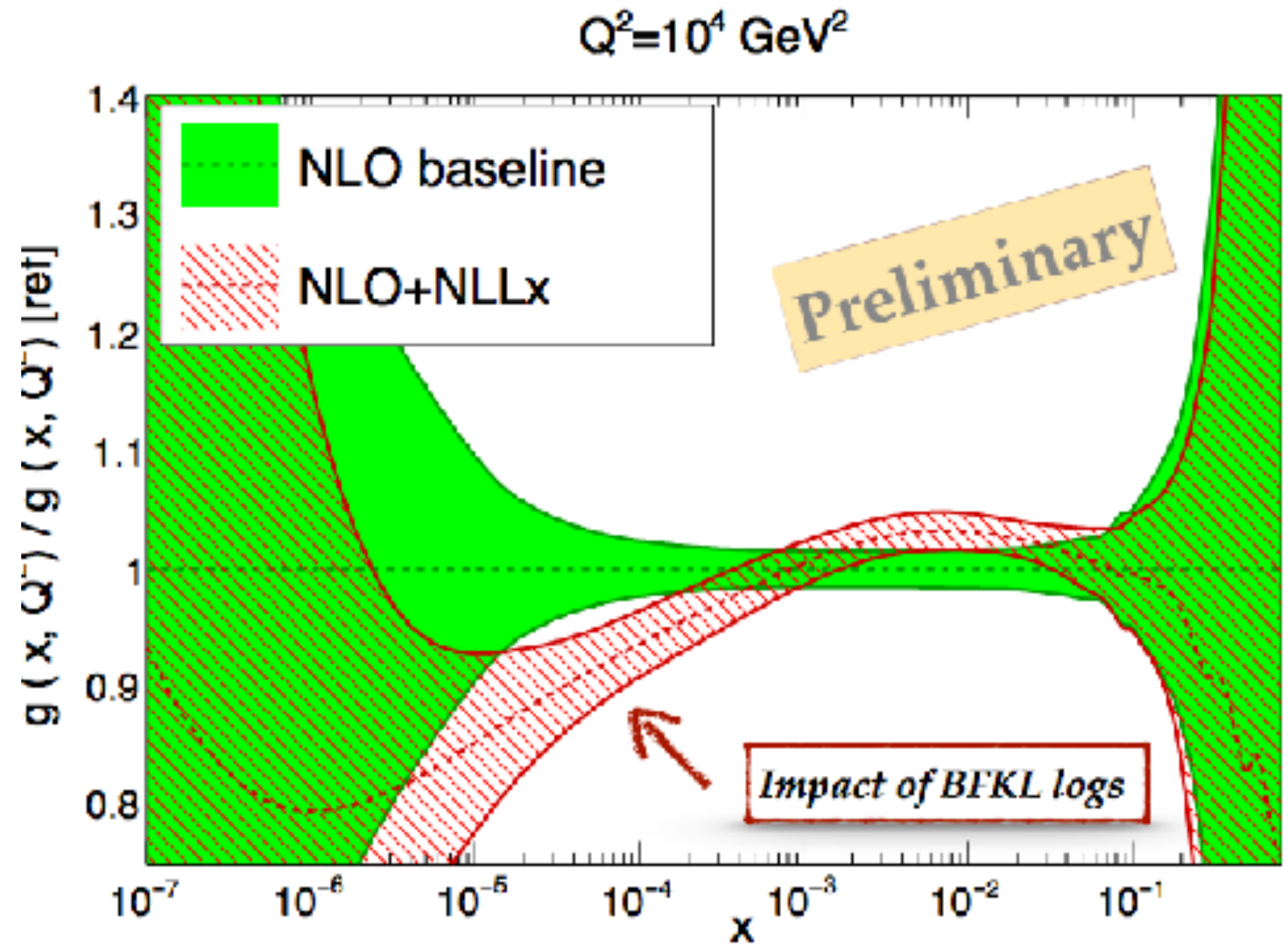


Bonvini et al, JHEP 1509 (2015) 191

- Threshold-resummed PDFs made recently available **[Bonvini et al, JHEP 1509 (2015) 191]**
- Gluon suppressed as compared to fixed-order PDFs mostly due to enhancement of NLO+NLL xsecs used in the fit of DIS structure functions and DY distributions
- This suppression partially or totally compensates enhancements in partonic cross sections. Phenomenologically relevant for new physics processes **[Beenakker et al. EPJC76 (2016)2, 53]**
- Future: implementation in global fit?

Small-x resummation





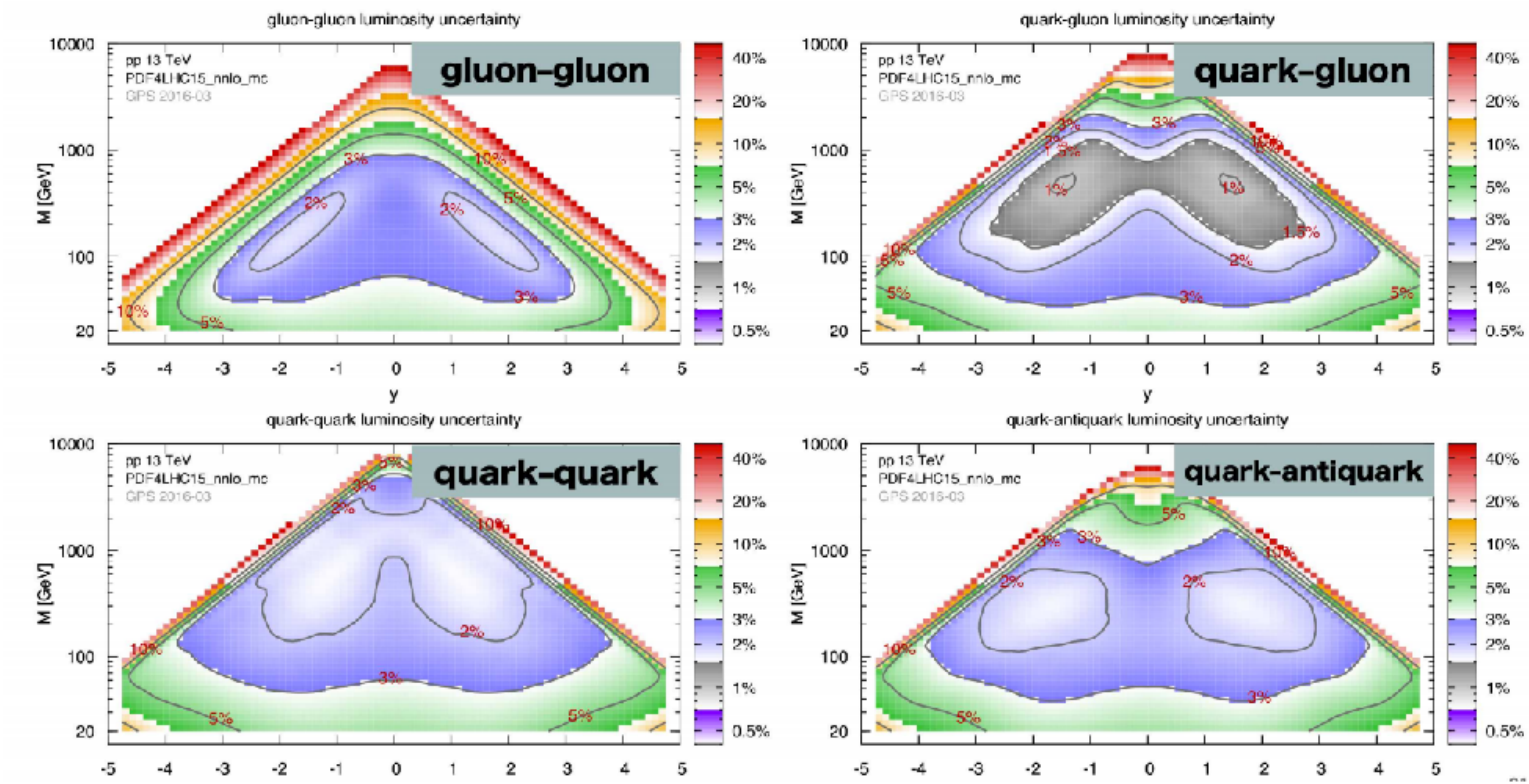
- Do we need to go beyond fixed order?
  - At very small-x enhance 1/x terms become dominant and need to be resumed
  - Steep rise in small-x gluon may lead to saturation
- A global PDF analysis with NLO+NLLx matched theory could answer that
- Ongoing studies (Bonvini, Marzani, Peraro & NNPDF collaboration), at the moment PDF evolution includes small-x resummation in ZM-VFNS, work in progress on massive coefficient functions and mass effects in evolution

Conclusions

- NNPDF3.1 includes many new precise data from HERA combination to Tevatron legacy data to new LHC data (some never fitted before such as Z pT and top differential distributions)
- Fitted charm improves the quality of the fit
- Precision of the data and correlation-dominated uncertainties very challenging for PDF fitters: is an additional uncorrelated uncertainty to account for C factor fluctuation the way forward? Or NNLO code interfaces? What about uncertainty of systematics uncertainties?
- New tools: MC2Hessian, SMPDFs
- New frontiers: theory uncertainties, beyond fixed order, photon PDFs

Back-up slides

PDF uncertainties



G. Salam, LHCP

Do we trust 1% accuracy in parton luminosities?

Fitted charm

- Most global fits assume scale-independent charm content of the proton vanishes

- Why fit the intrinsic component of the charm?
  - ☑ Stabilise the dependence on mc
  - ☑ Quantify the non-perturbative component of charm
  - ☑ Compare determination with available models

- In any scheme in which mass of the charm is not neglected (FFN scheme or GM-VFNS) calculations need to be modified in order to account for massive charm initiate processes

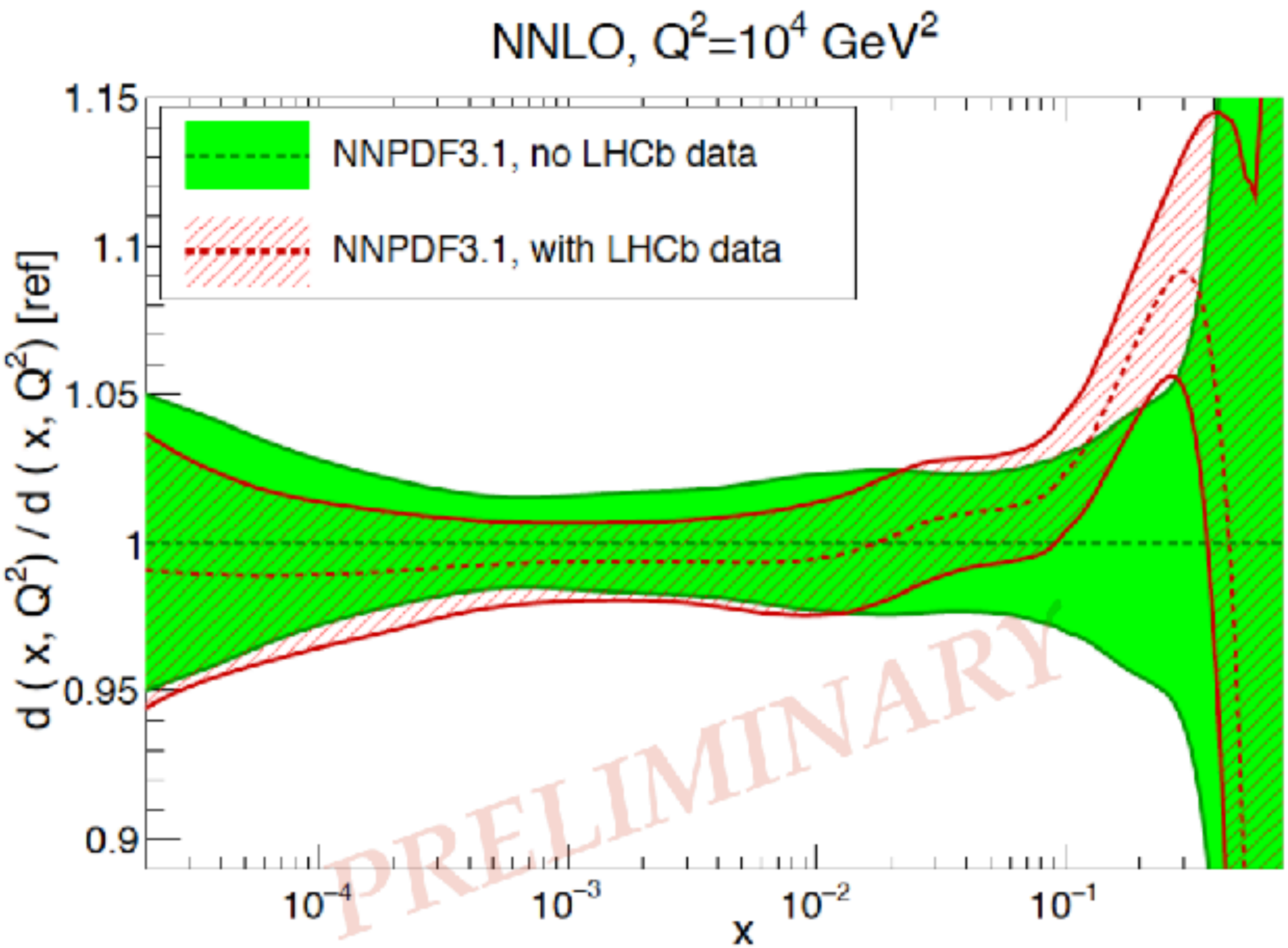
$$\Delta F_h(x,Q^2) = \sum_{i=h,\bar{h}} \Bigg\{ \Bigg[\left(C_i^{(3),0}\left(\frac{Q^2}{m_h^2}\right) - C_i^{(4),0} \right) + \alpha_s^{(4)}(Q^2)\left(C_i^{(3),1}\left(\frac{Q^2}{m_h^2}\right) - C_i^{(4),1} \right) \Bigg] - \alpha_s^{(4)}(Q^2) C_i^{(3),0}\left(\frac{Q^2}{m_h^2}\right) \otimes \left(K_{hh}^{(1)}(m_h^2) + P_{qq}^{(0)} L \right) \Bigg\} \otimes f_i^{(4)}(Q^2) - \alpha_s^{(4)}(Q^2) \sum_{i=h,\bar{h}} \left(C_i^{(3),0}\left(\frac{Q^2}{m_h^2}\right) - C_i^{(4),0} \right) \otimes P_{qg}^{(0)} L \otimes f_g^{(4)}(Q^2) + \mathcal{O}(\alpha_s^2)$$

Ball et al, arXiv:1510.01009
Ball et al, arXiv: 1510.02491

correction vanishes at large Q

LHCb 7 and 8 TeV data

- LHCb published complete 7 TeV and 8 TeV Z and W measurements in electron and muon channels in the forward region
- Forward W/Z production data improve flavour-separation especially at large-x
- Good theoretical description and sizeable impact



Z p_T distributions

HERA + ZpT data fits

$\chi^2_{ATLAS7tev}$	$\chi^2_{ATLAS8tev,m}$	$\chi^2_{ATLAS8tev,y}$	$\chi^2_{CMS8tev}$	χ^2_{tot}
(21.8)	(1.00)	(1.56)	(1.55)	1.168
1.39	(1.39)	(2.04)	(1.41)	1.176
(19.6)	0.91	0.70	(1.61)	1.146
(16.2)	(1.04)	(1.56)	1.21	1.176
(18.0)	0.90	0.77	1.42	1.156
1.64	1.05	1.17	1.27	1.171
(27.6)	(1.10)	(2.83)	(2.46)	1.168
1.58	(1.54)	(3.36)	(2.11)	1.186
(23.0)	0.99	1.05	(3.01)	1.168
(20.5)	(1.13)	(3.15)	1.91	1.198
(21.4)	0.99	1.29	2.44	1.207
2.13	1.18	1.98	2.21	1.253
(30.6)	(1.15)	(4.65)	(3.46)	1.168
1.74	(1.69)	(4.79)	(3.06)	1.185
(25.5)	1.02	1.66	(4.79)	1.193
(19.5)	(1.28)	(5.44)	2.51	1.225
(24.5)	1.03	2.09	3.59	1.251
2.35	1.24	2.81	3.19	1.301

+ 1% uncorrelated uncertainty

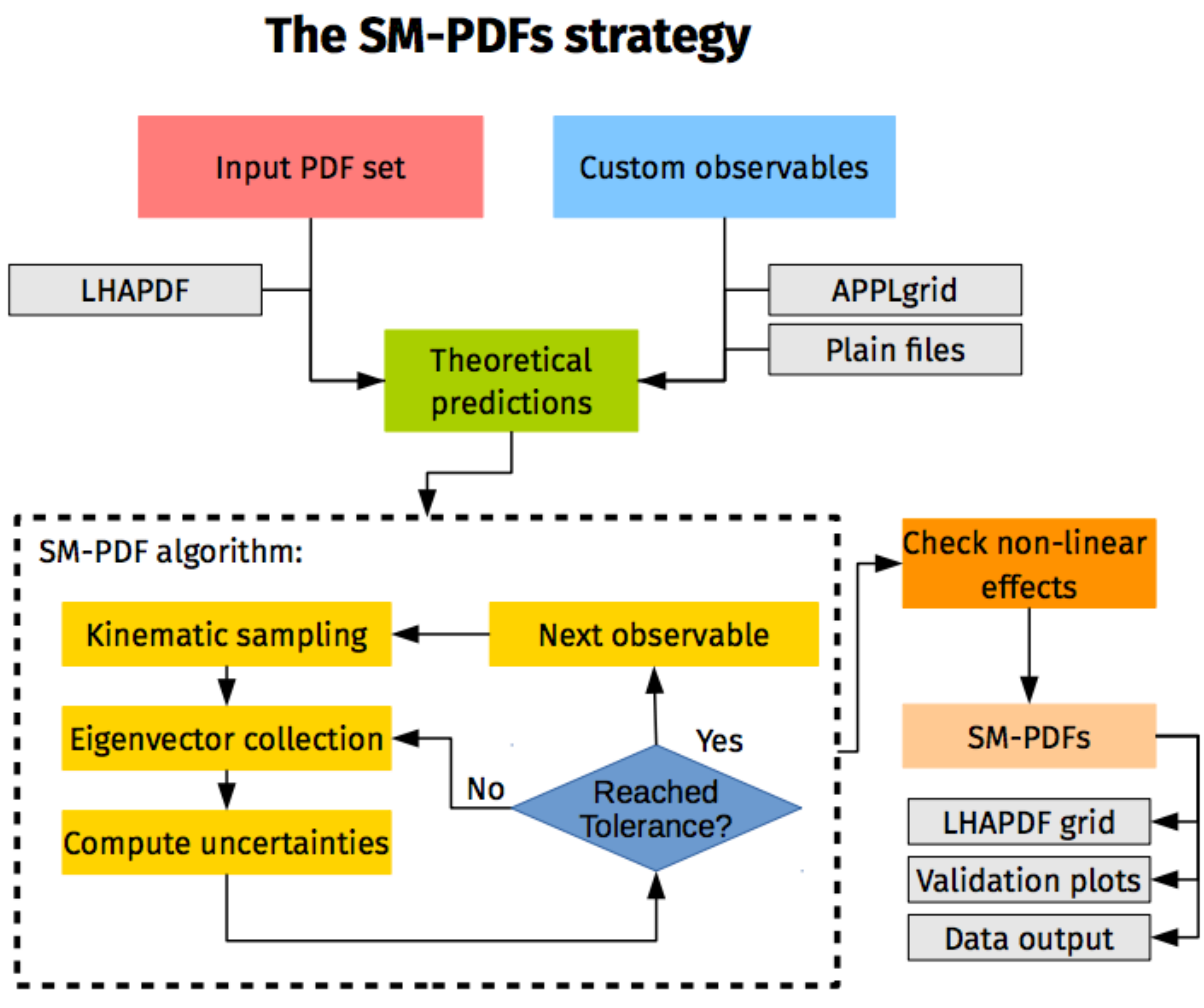
+ 0.5% uncorrelated uncertainty

+ 0% uncorrelated uncertainty

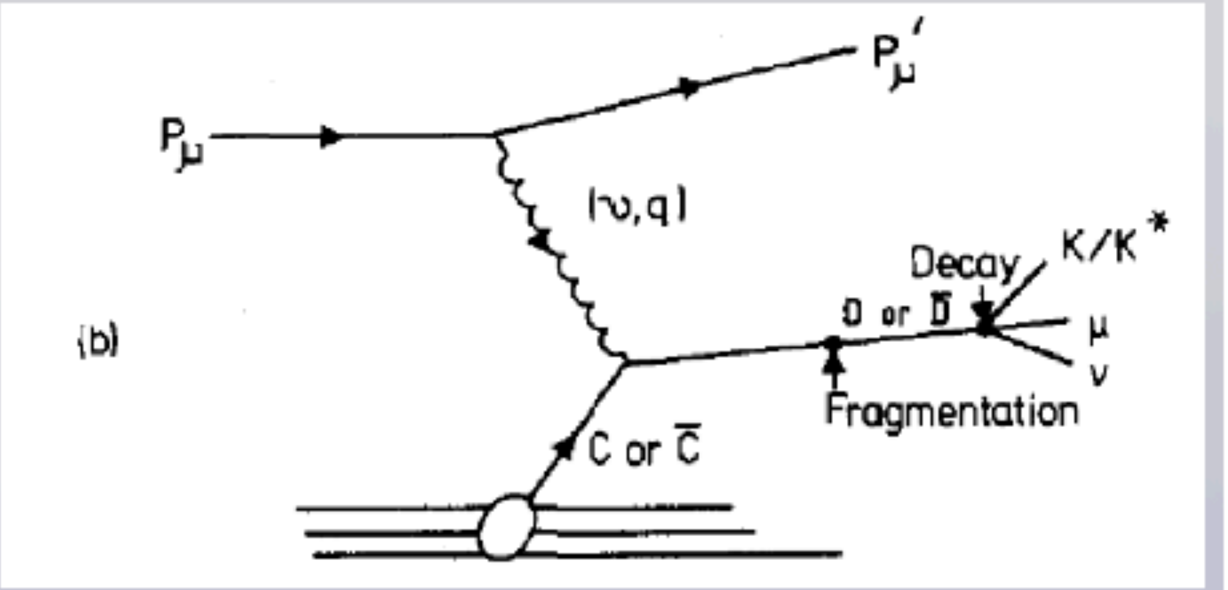
PRELIMINARY

Boughezal, Guffanti, Petriello, MU - in progress

SM-PDFs


The SM-PDFs strategy
Input PDF set
Custom observables
LHAPDF
APPLgrid
Plain files
Theoretical predictions
SM-PDF algorithm:
Kinematic sampling
Next observable
Eigenvector collection
Yes
No
Reached Tolerance?
Compute uncertainties
Check non-linear effects
SM-PDFs
LHAPDF grid
Validation plots
Data output

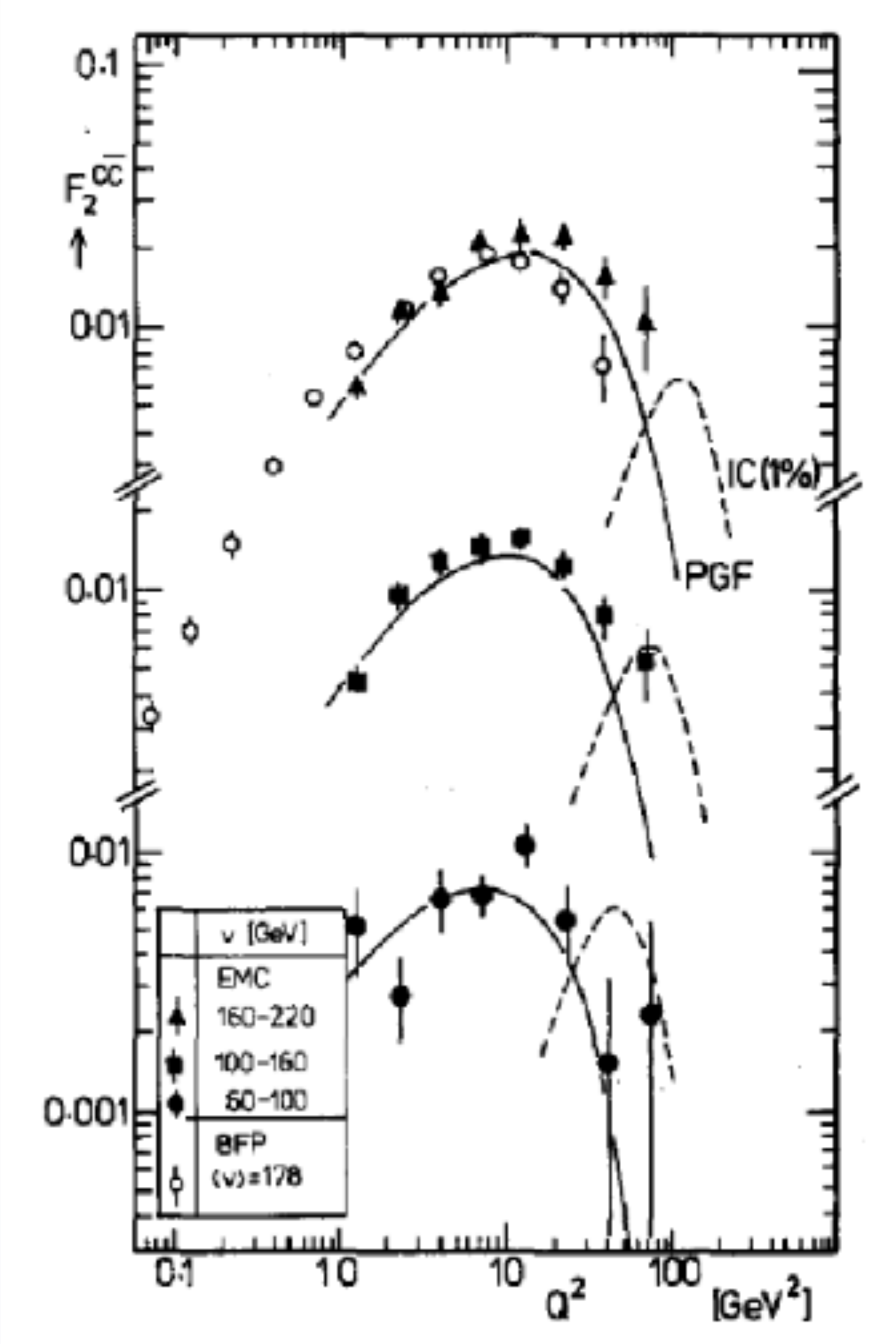
Fitted charm



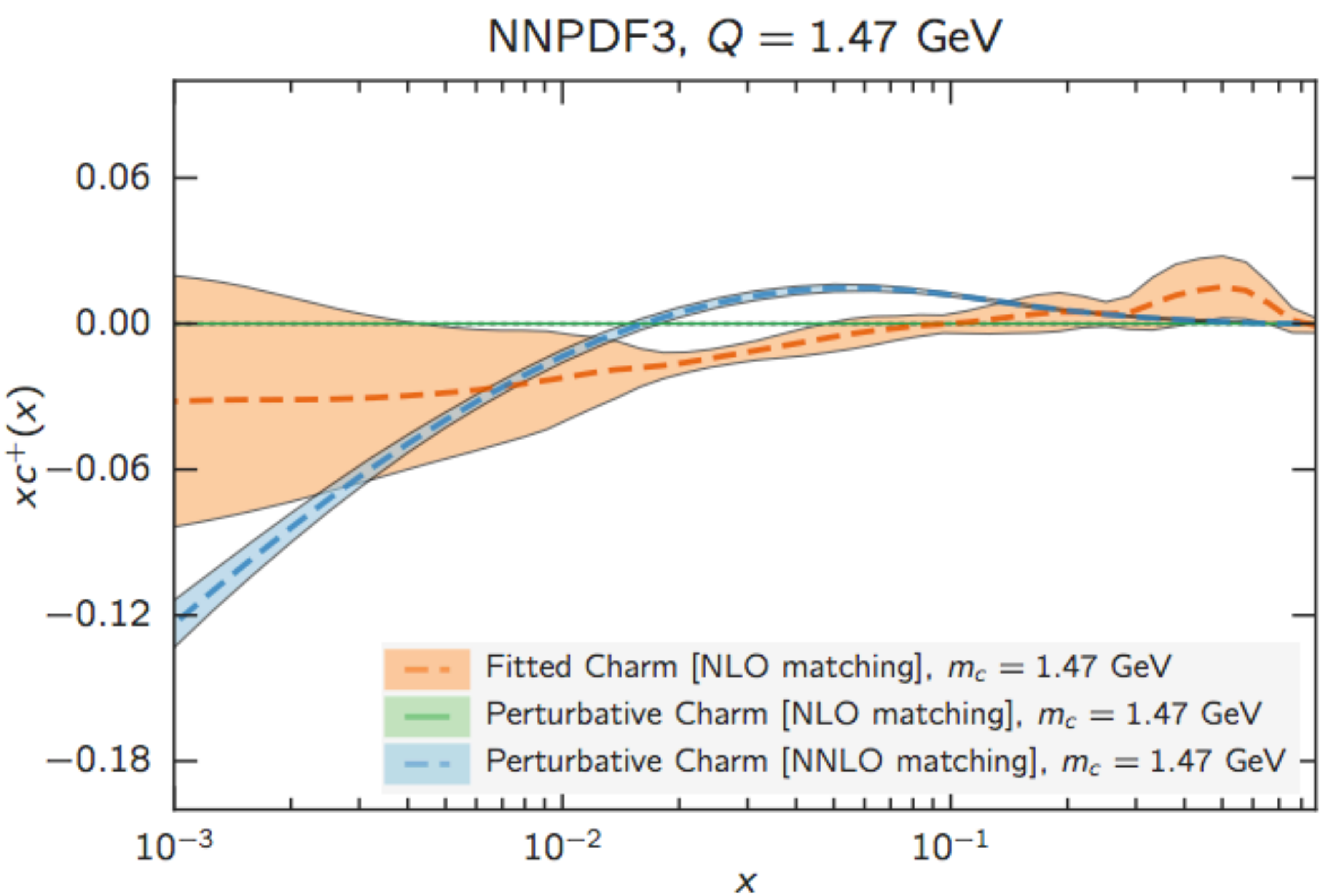
NPB213(31) 1983

- Since more than 30 years, the EMC charm structure function data advocated as **evidence for intrinsic charm**
- However, previous global PDF fits with fitted charm **unable to achieve satisfactory description** of this experiment
- *Eg* **arXiv:1408.1708** (Jimenez-Delgado et al) finds **χ^2/N_{dat}=4.4** in their FFN IC global analysis

→ The **fitted charm** results shown in this talk include the **EMC charm production data**



Fitted charm



The photon PDF

- **NNPDF23QED** provides γ PDF and its uncertainty at (N)NLO QCD + LO QED, by reweighting photon PDF
  Ball et al [Nucl.Phys. B877 (2013)]

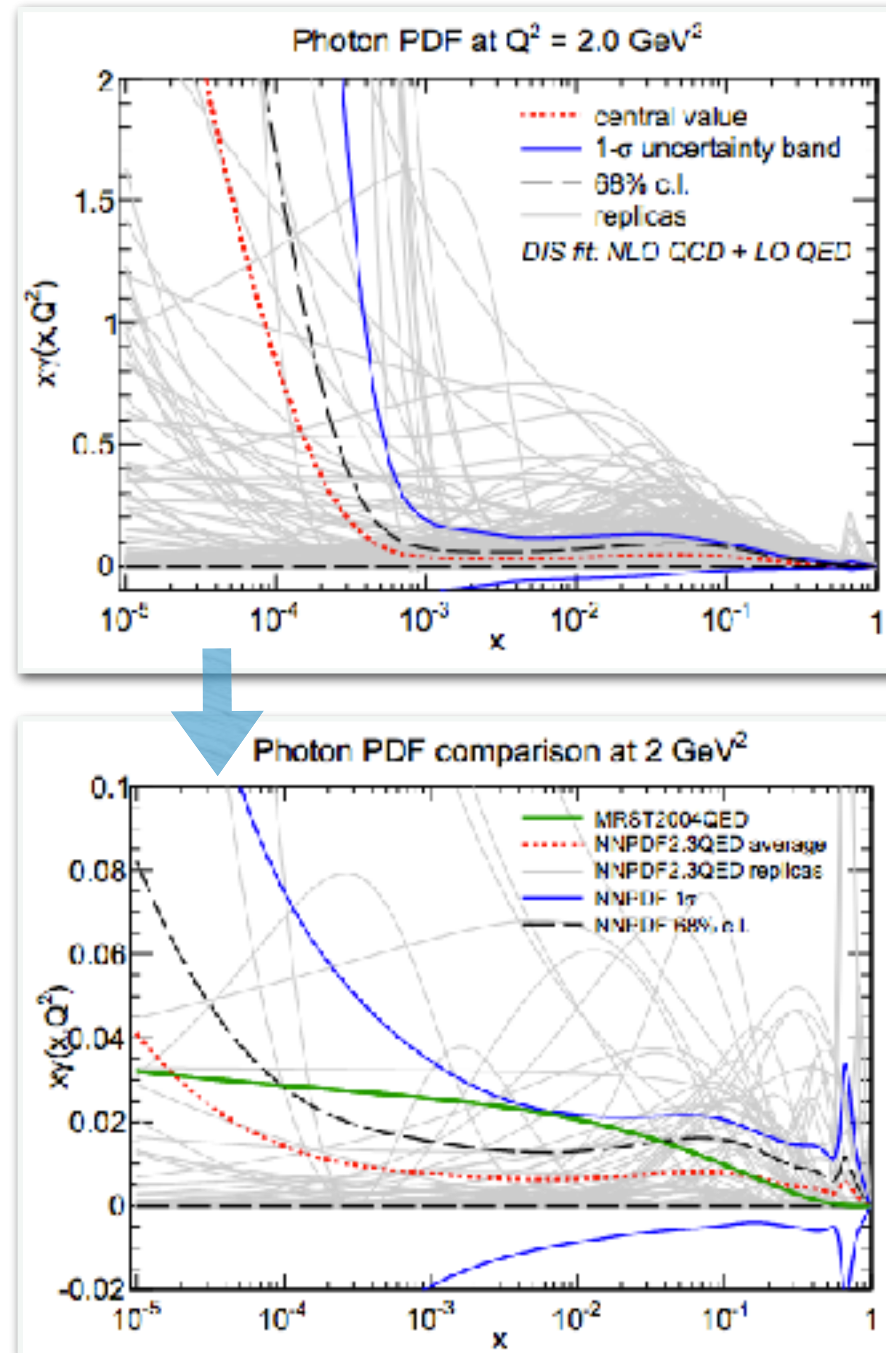
- **CT14QED** set based on two-parameter ansatz from model of photon radiate from valence quarks (extension to MRST2004QED model)
  Schmidt et al [1509.02905]

$$f_{\gamma/p}(x,Q_0) = \frac{\alpha}{2\pi}\left(A_u e_u^2 \tilde{P}_{\gamma q}\circ u^0(x) + A_d e_d^2 \tilde{P}_{\gamma q}\circ d^0(x)\right)$$
$$f_{\gamma/n}(x,Q_0) = \frac{\alpha}{2\pi}\left(A_u e_u^2 \tilde{P}_{\gamma q}\circ d^0(x) + A_d e_d^2 \tilde{P}_{\gamma q}\circ u^0(x)\right)$$

- γ PDF poorly determined by DIS data. Need hadron collider processes where γ contributes at LO (on-shell W,Z production and low/high mass DY)

- NNPDF plan: fit photon along with other PDFs (thanks to upgrade of APFEL - simultaneous diagonalization of QCD and QED evolution matrices - and APFELgrid - now includes photon-induced processes)

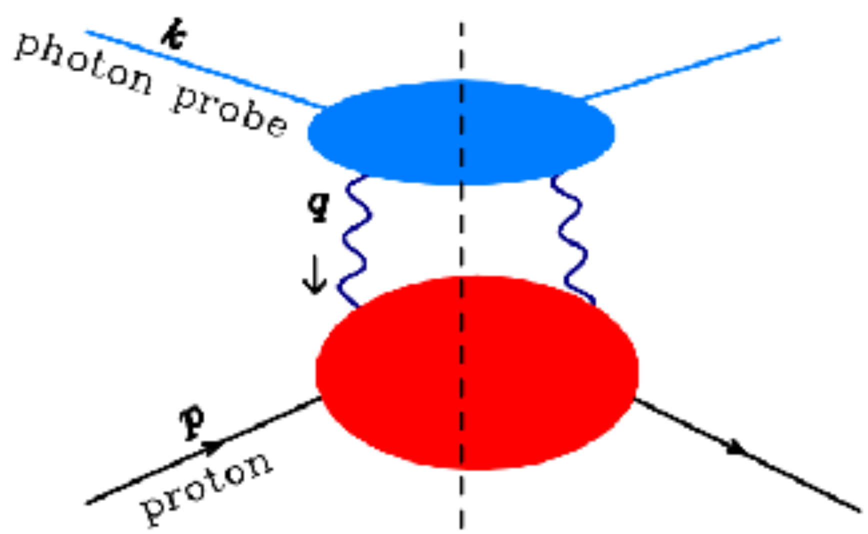
DIS



DIS+LHC

LUX, master equation

The Master Equation



$$\sigma = \int \frac{d^4 q}{(2\pi)^4} \frac{e^4_{\rm phys}(q^2)}{q^4}$$
$$\times \langle k|\tilde{J}_p^{\mu}(-q) J_p^{\nu}(0)|k\rangle$$
$$\times \langle p|\tilde{J}_\mu(q) J_\nu(0)|p\rangle$$

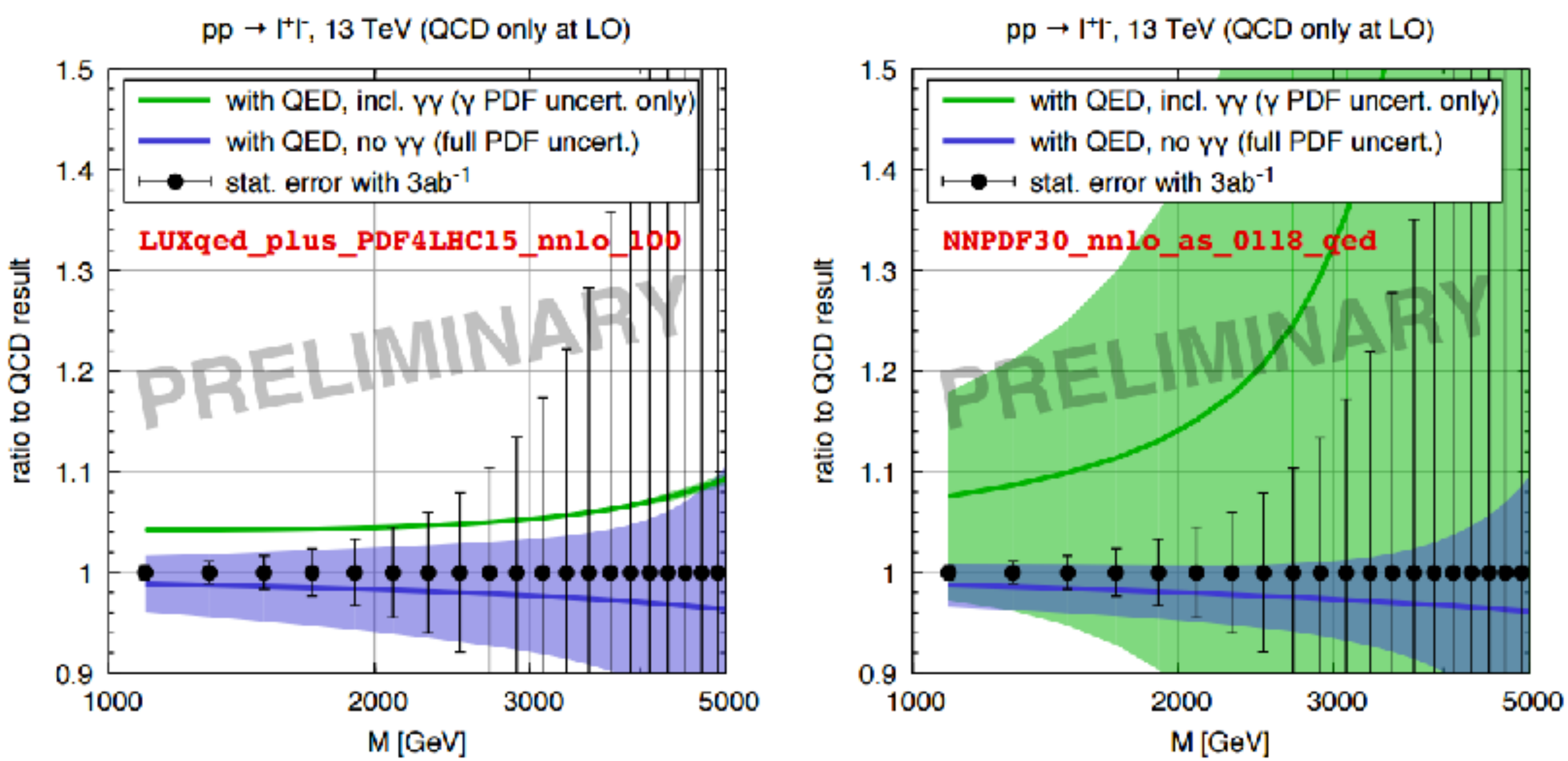
Kinematics constraints:

$$Q^2 = -q^2 > 0,$$
$$0 < x_{\rm bj} = Q^2/(2p\cdot q) \le 1.$$

- Same kinematic restrictions as in DIS.
- $\frac{1}{4\pi}\langle p|\tilde{J}_\mu(q) J_\nu(0)|p\rangle = -g_{\mu\nu} F_1(Q^2, x_{\rm bj}) + \frac{p^\mu p^\nu}{p\cdot q} F_2(Q^2, x_{\rm bj}) + \ldots$
(Notice: full F_1 and F_2, not only inelastic)
- Photon induced process can be given in terms of F_1, F_2
- Hence: the photon PDF must be calculable in terms of F_1, F_2.

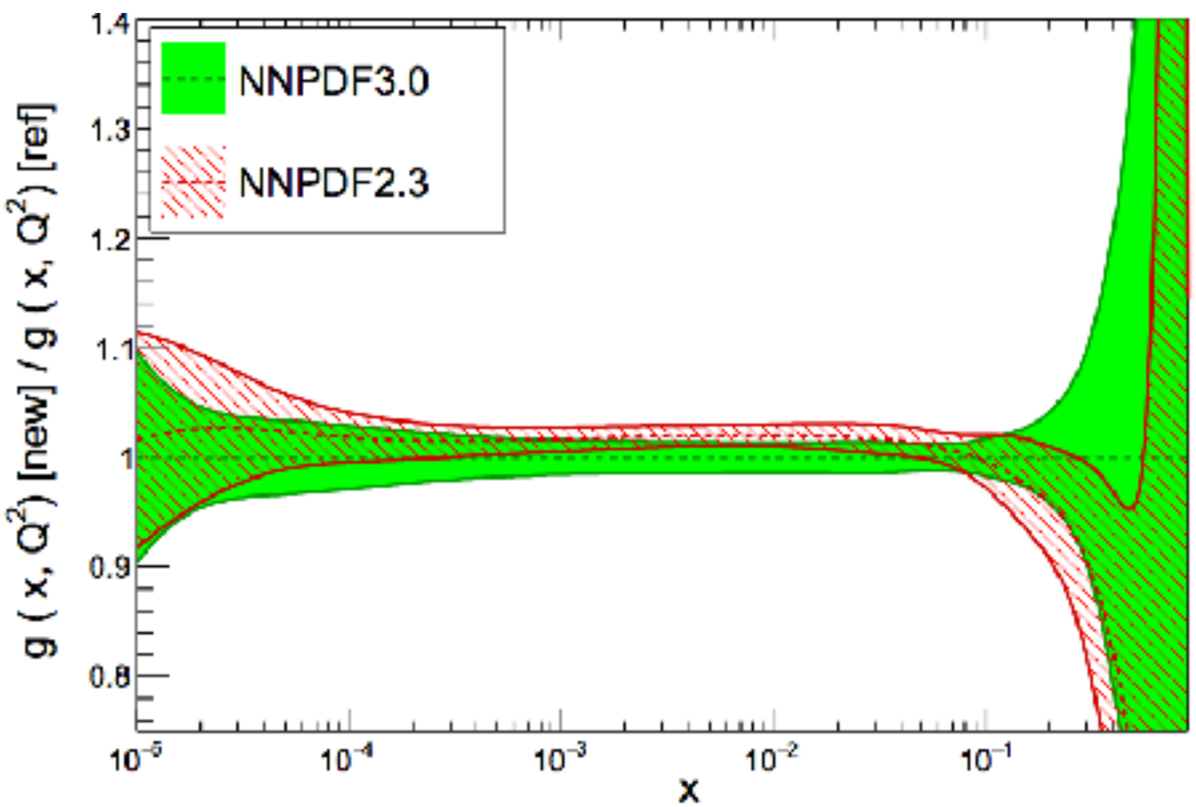
Photon PDF

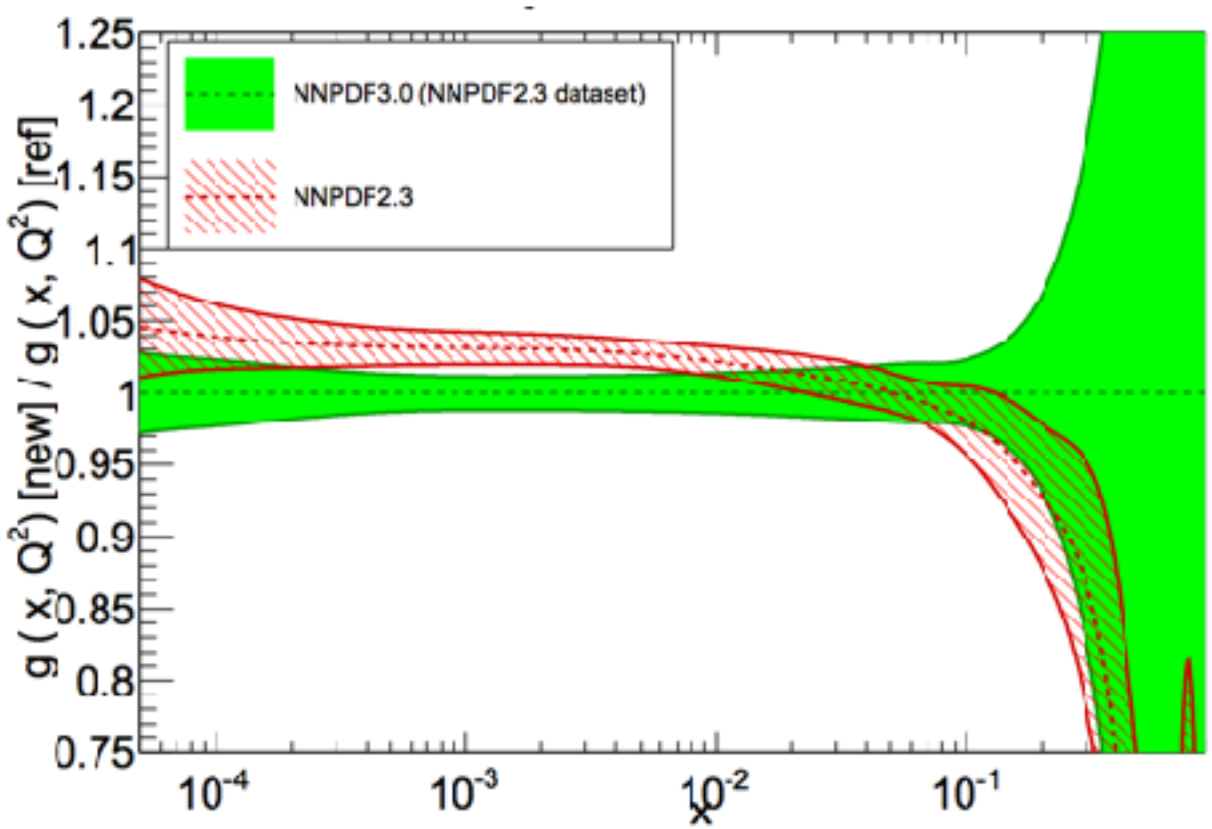
- Data-driven NNPDF approach inducing a large uncertainty on photon PDF
- Breakthrough: LUX PDF [Manohar, Nason, Salam, Zanderighi,1607.04266]
- Take a BSM interaction, compute the cross section with the Master Formula or with the Parton Model formula
- Extract photon PDF by identifying the two cross sections.
- Theory constraint reduces uncertainty by a huge factor

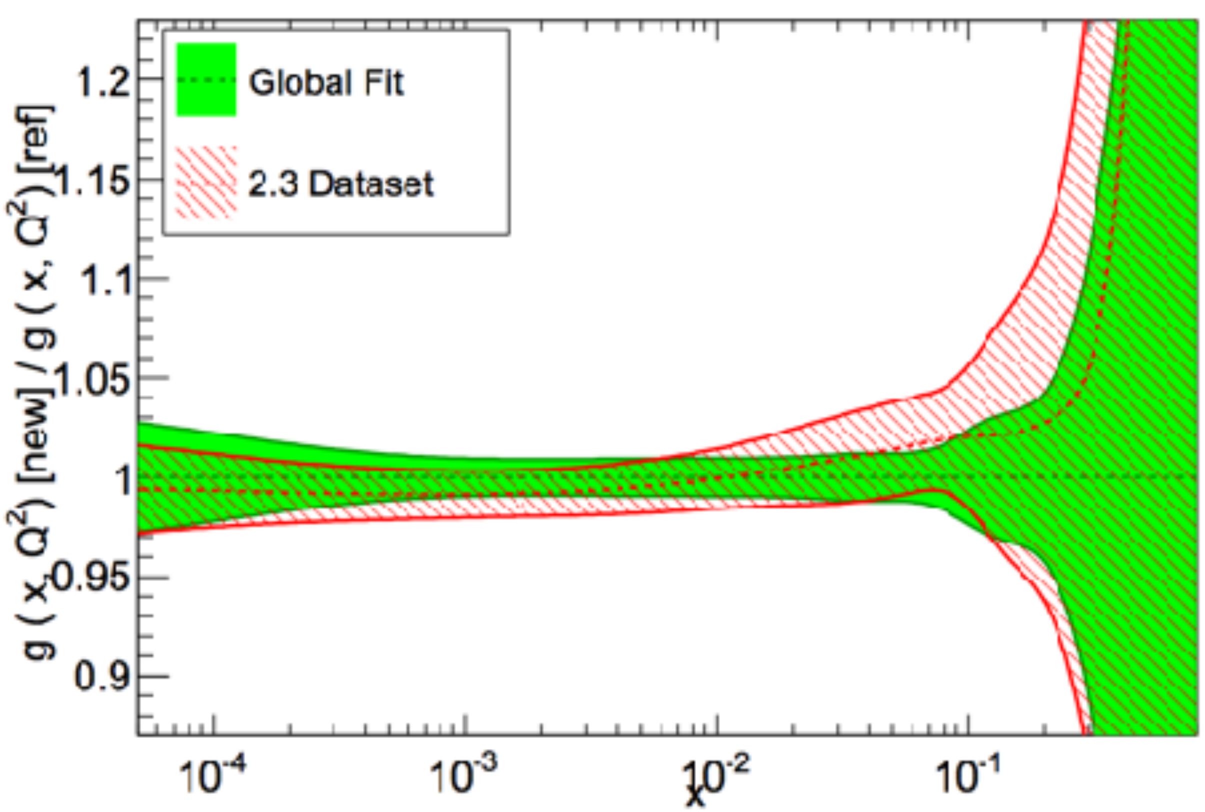


P. Nason, talk in Durham

Key issue: methodology



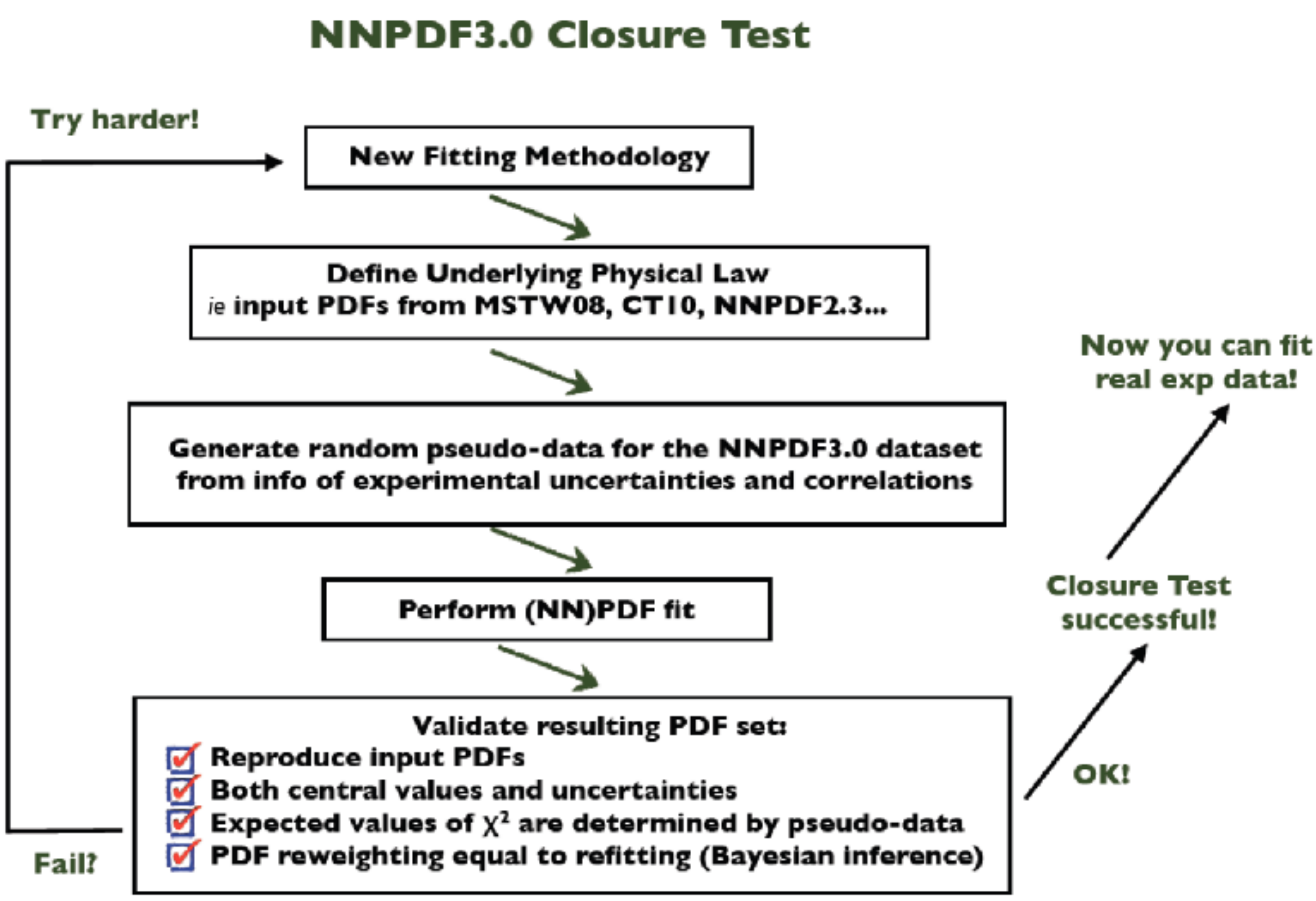




- NNPDF2.3 -> NNPDF3.0: included many new data (LHC and combined HERA) & change in fitting methodology (genetic algorithm and stopping criterion)
- Main changes in the gluon are due to the change in methodology
- How to make sure that we have a “perfect” methodology?

Closure test

NNPDF collaboration, JHEP 1504 (2015) 040



Closure test

- Level-0: if pseudo-data are identical to the input theory, then agreement with theory should be arbitrarily good, i.e. $\chi^2 \to 0$
- Level-1: let pseudo-data fluctuate about their central values within data uncertainty, then $\chi^2 \to 1$
- Level-2: generate Monte Carlo replicas of pseudo-data with fluctuations, then $\chi^2 \to 2$