Parton Distributions in the Higgs Boson Era

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Deep-Inelastic Scattering 2013 Workshop
Marseille, 22/04/2013

Disclaimer

- **Not a systematic review** of recent developments in PDF analysis

  Comprehensive review on progress in PDFs by Forte and Watt, arXiv:1301.6754

  Detailed benchmarking of PDFs with LHC data by Ball et al., arXiv:1211.5142

- Rather, personal view of the **present status of Parton Distributions** and their relevance for **LHC phenomenology in the Higgs Boson era**

- Complete references will be provided in the **talk write-up** (soon in the arXiv)

- Emphasis on **theory and methodology aspects**, overview of experimental measurements relevant for PDFs in **Voica**'s talks

High Energy Physics in the headlines

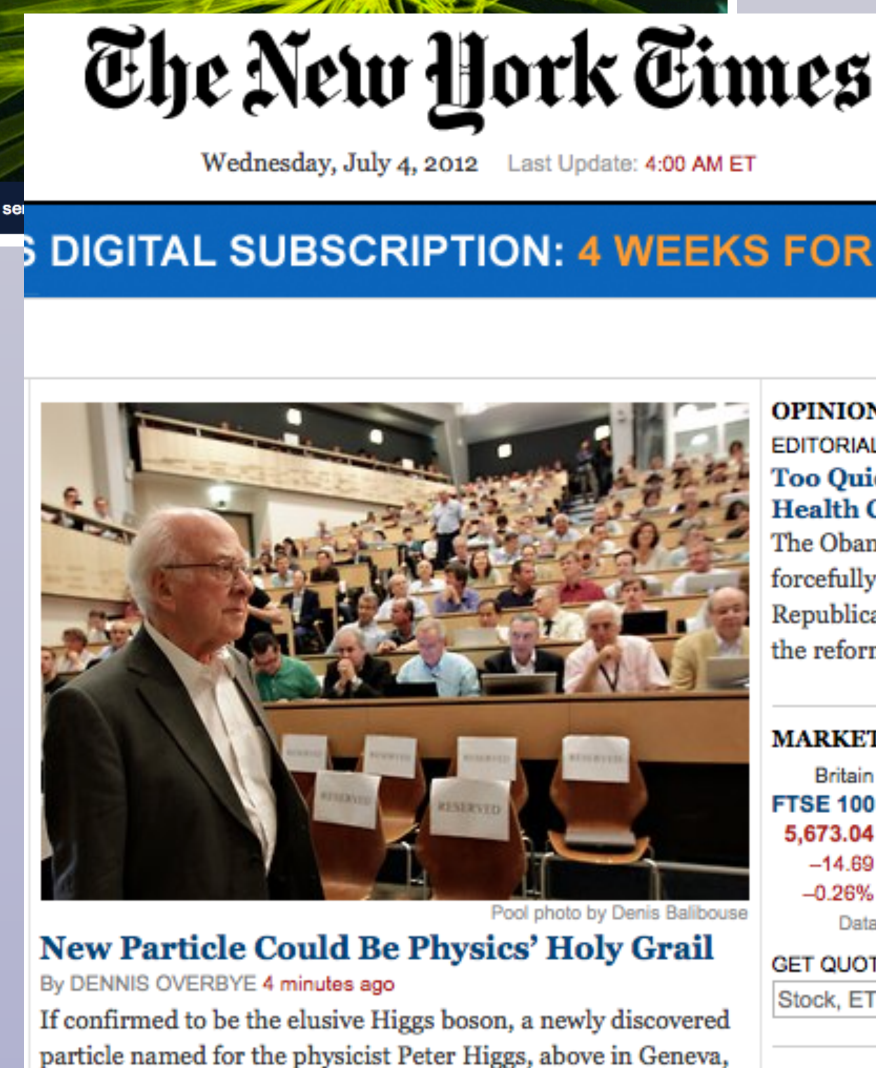
- Higgs Boson: the **most important discovery** in particle physics in 25 years
- Higgs discovery opens the door to a **new era in particle physics**
- **Parton Distributions** are an essential ingredient for **any theory predictions** at the Large Hadron Collider


El CERN anuncia el descubrimiento de una partícula que podría ser el bosón de Higgs

El CERN anuncia el descubrimiento de una partícula que podría ser el bosón de Higgs, cuya existencia está predicha por el modelo estándar de la física de partículas

Ciencia | 04/07/2012 - 09:46h | Actualizado el 04/07/2012 - 11:27h

El bosón de Higgs podría ser


The New York Times

Wednesday, July 4, 2012 Last Update: 4:00 AM ET

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New Particle Could Be Physics' Holy Grail

By DENNIS OVERBYE 4 minutes ago

If confirmed to be the elusive Higgs boson, a newly discovered particle named for the physicist Peter Higgs, above in Geneva,


Thursday, March 14, 2013
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News / World

Higgs boson particle: Physicists confident 'God particle' discovered

Scientists announced Thursday that the particle discovered through the ATLAS and CMS experiments at the Large Hadron Collider last summer is, in fact, the long-sought Higgs boson.

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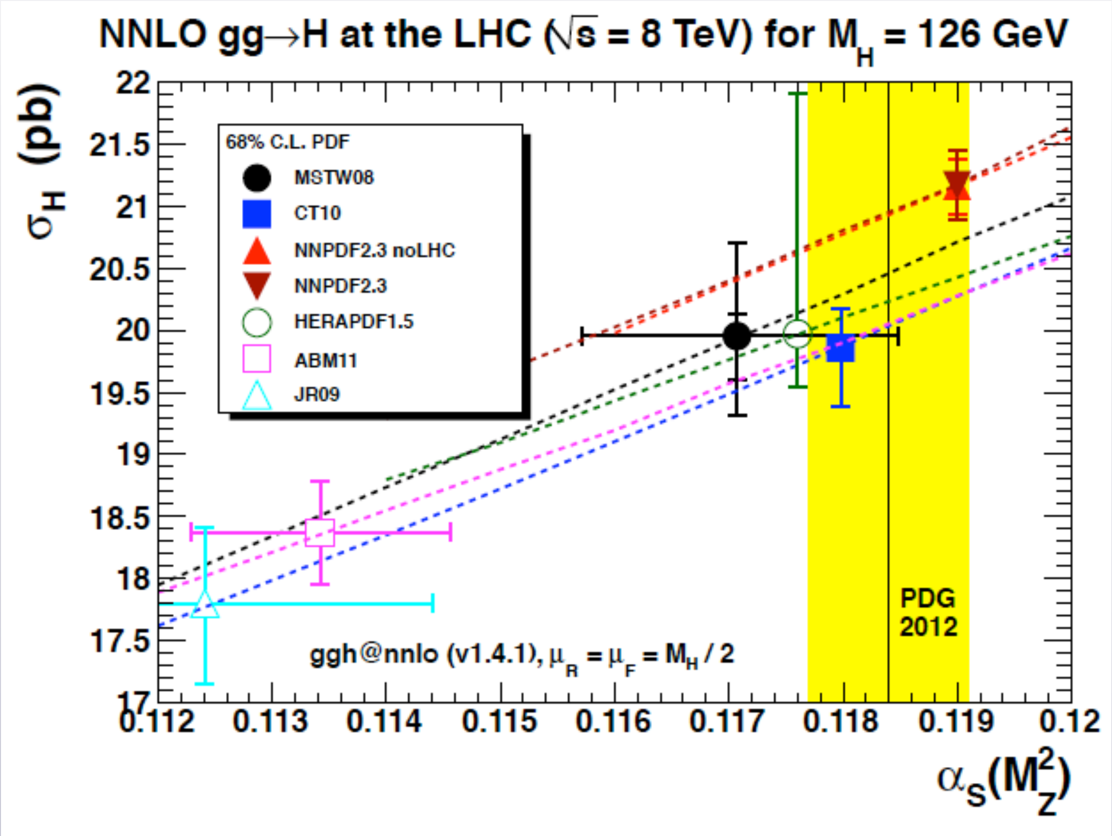
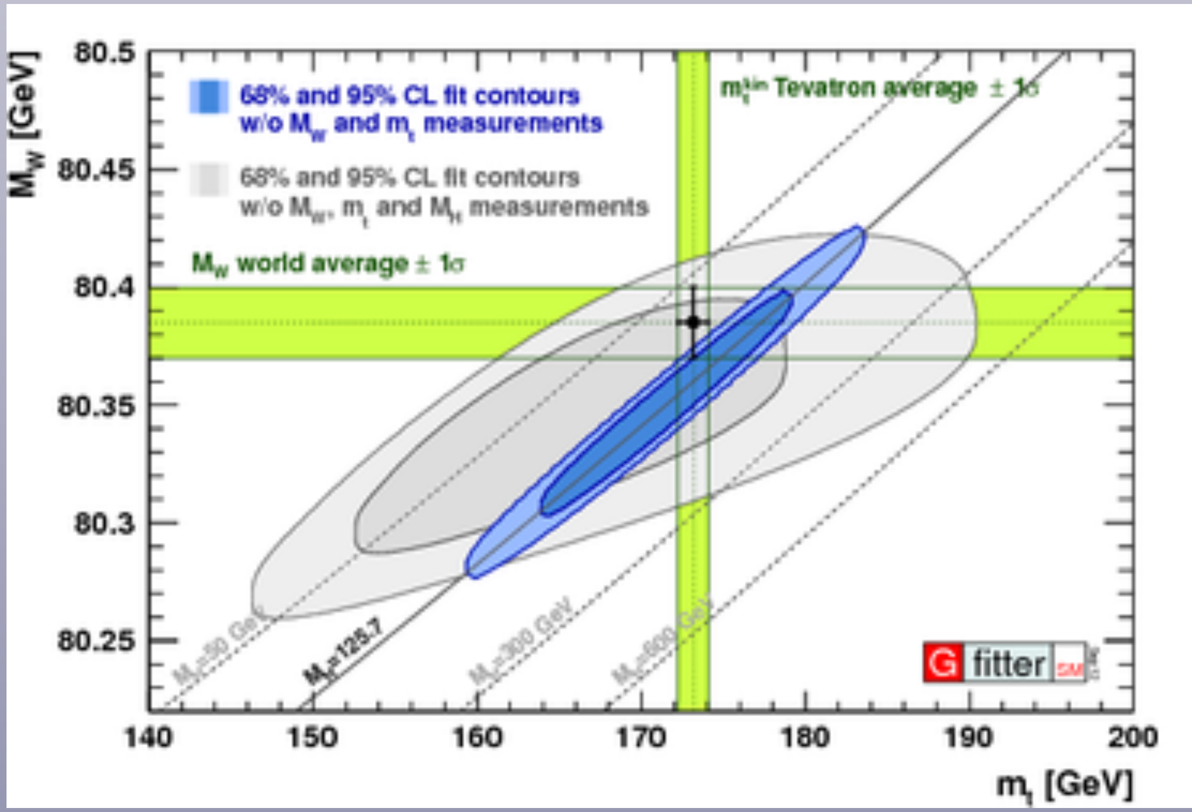
THE TORONTO STAR

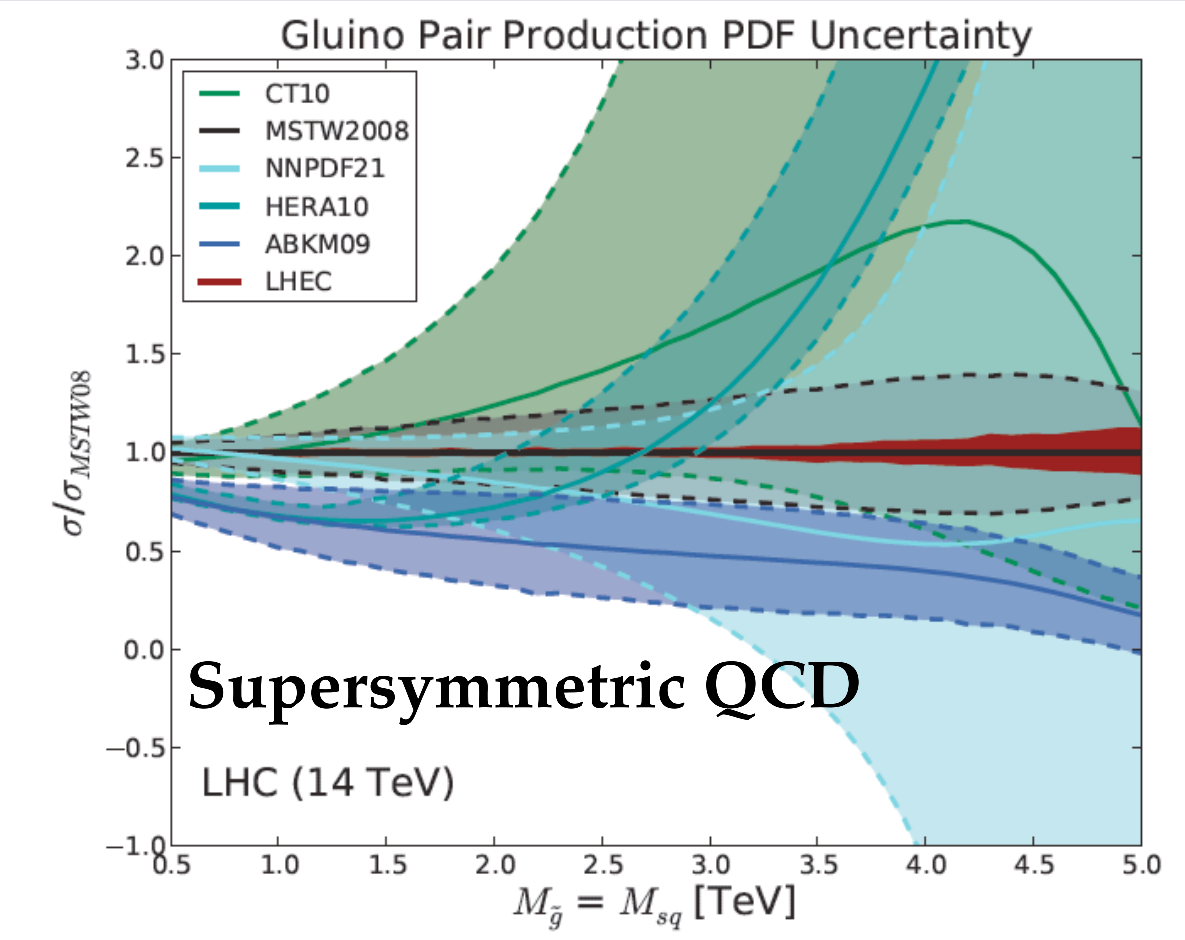
Parton Distributions and LHC phenomenology



1) PDFs fundamental limit for Higgs boson characterization in terms of couplings



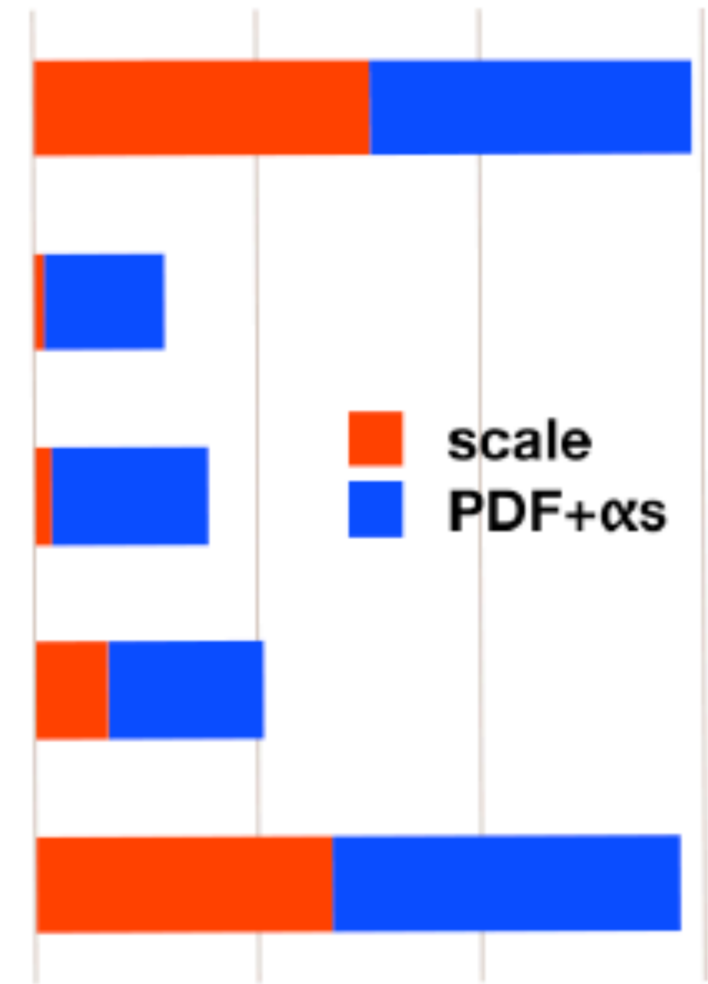
2) Very large PDF uncertainties (>100%) for new heavy particle production



3) PDFs dominant systematic for precision measurements, like W boson mass, that test internal consistency of the Standard Model

Parton Distributions and LHC phenomenology

		σ (8 TeV)	uncertainty
NNLL QCD +NLO EW	gg→H	19.5 pb	14.7%
	VBF	1.56 pb	2.9%
NNLO QCD +NLO EW	WH	0.70 pb	3.9%
	ZH	0.39 pb	5.1%
NLO QCD	ttH	0.13 pb	14.4%



J. Campbell, ICHEP12

1) PDFs fundamental limit for Higgs boson characterization in terms of couplings

Improving our understanding of Parton Distributions is a key input to probe for New Physics that might translate into the deviation of the Higgs couplings wrt the SM values

PDF analysis

V. Radescu

	MSTW08	CTEQ6.6/CT10	NNPDF2.1/2.3	HERAPDF1.0/1.5	ABKM09/ABM11	GJR08/JR09
PDF order	LO, NLO, NNLO	LO, NLO, NNLO	LO, NLO, NNLO	NLO, NNLO	NLO, NNLO	NLO, NNLO
HERA DIS	✔ (old)	✔ (old/new)	✔ (new)	✔ (new/newest)	✔ (new)	✔ (new)
Fixed target DIS	✔	✔	✔	-	✔	✔
Fixed target DY	✔	✔	✔	-	✔	✔
Tevatron W, Z	✔	✔	some	-	some	some
Tevatron jets	✔	✔	✔	-	✔	✔
LHC	-	-	-/W,Z+jets	-	-	-
HF Scheme	RTGMVF	SACOT GMVFN	FONLL GMVFN	RT GMVFN	BMSN FFNS	FFNS
Alphas (NLO)	0.120	0.118(f)	0.119	0.1176(f)	0.1179	0.1145
Alphas (NNLO)	0.1171	0.118(f)	0.1174	0.1176(f)	0.1135	0.1124

- All sets now available at **NNLO**, global fits also begin to include **LHC data**
- A recent addition is the **CJ12 set** (CTEQ-JLAB PDFs), with emphasis on the use of **large-x data** and the treatment of **nuclear corrections** and higher twist effects (arxiv:1212.1702)
- Now review PDF progress in **theoretical results**, **methodological aspects** and **experimental constraints**

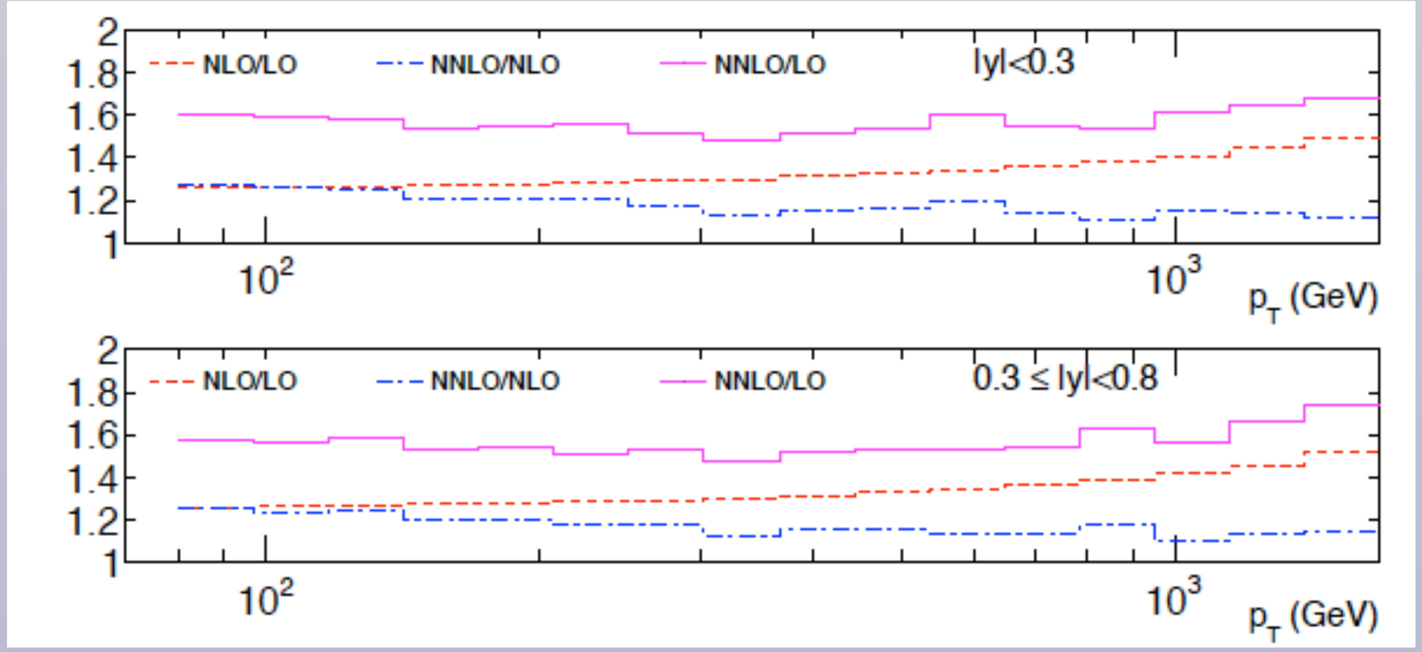
Theory

Meth

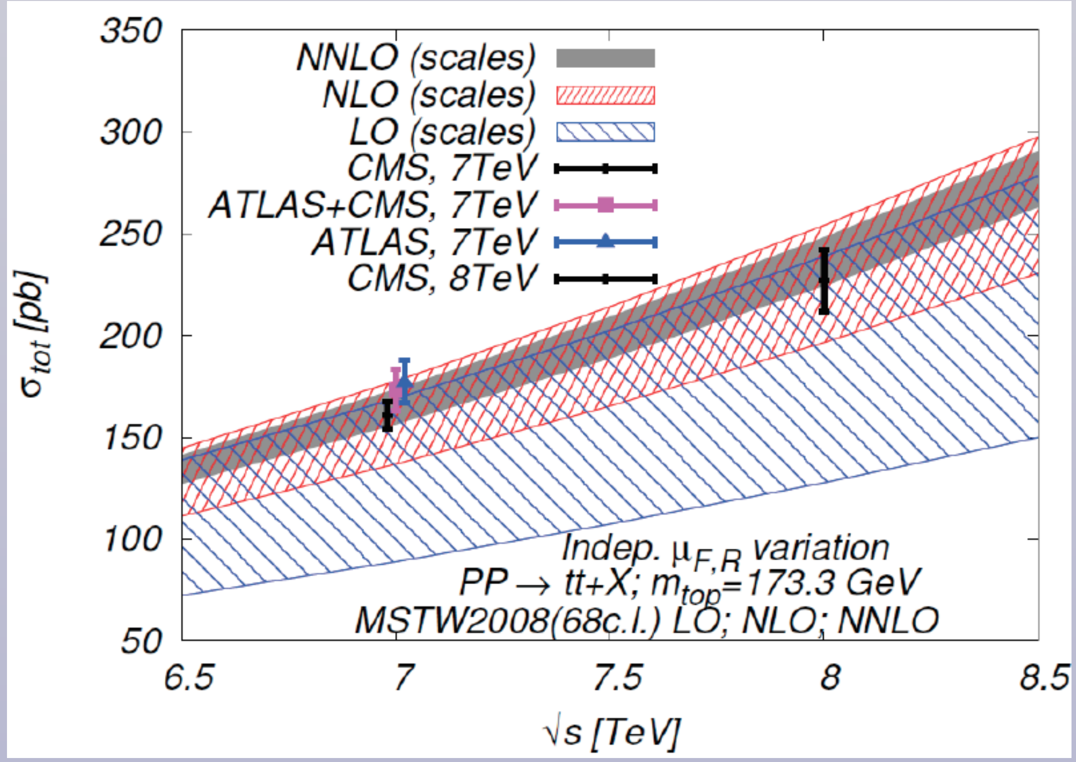
Data

Higher order calculations and tools

- Only a small number of **processes relevant for PDFs** available at **NNLO**
- Recently important progress was made on some key processes:
  - **NNLO inclusive jet production** in the gluon-gluon channel has been completed
  - The full **NNLO top quark production cross section** is also available (**top++2.0**)
  - **Higgs + 1 jet** also available now at **NNLO** (**arxiv:1302.6216**), can expect to have the closely related **Z + 1 jet** and **W + 1 jet** available soon, important for gluon constraints and quark flavor separation



Approximate K-factors in **jet production** (**arxiv:1301.7310**)



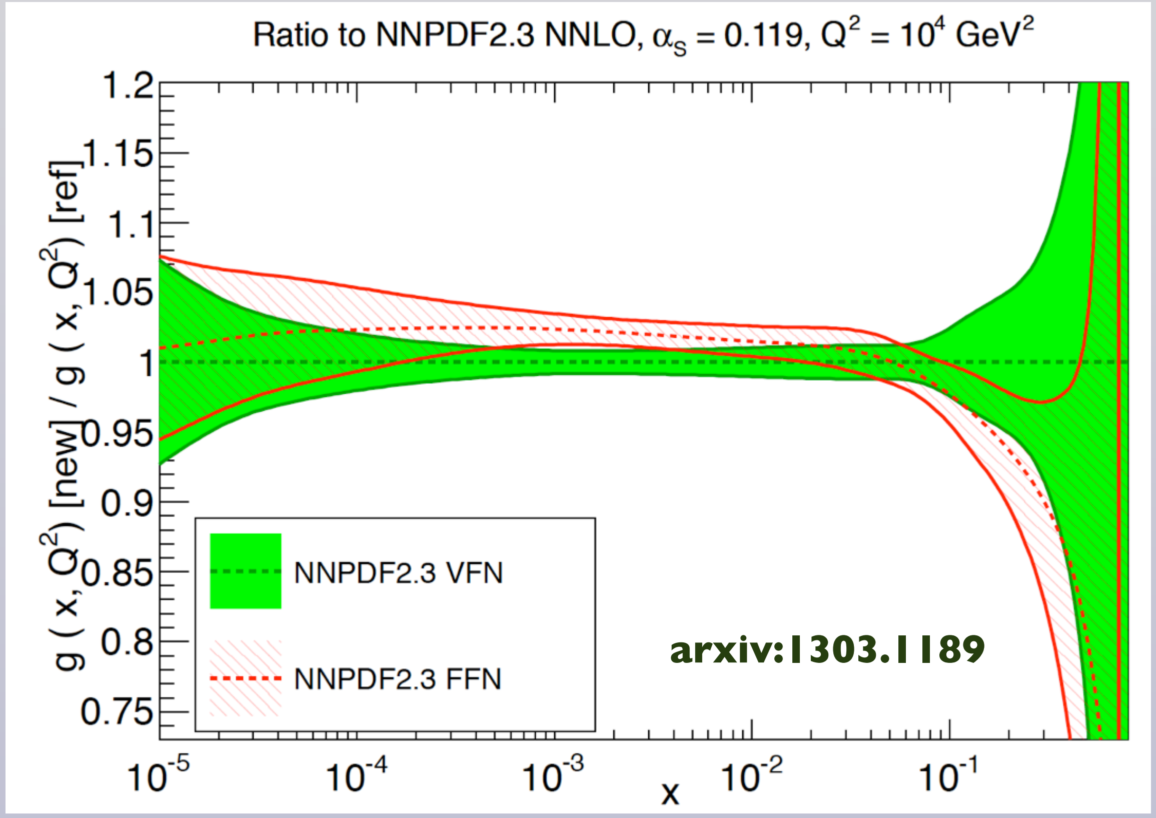
NNLO **top quark pair** production (**arxiv:1303.6254**)

- Another crucial ingredient for modern PDF fits is the availability of **fast NLO interfaces**
- **FastNLO v2** and **APPLgrid** use **NLOjet++** to provide **fast NLO calculations for jet processes**, APPLgrid also uses **MCFM** to provide **Drell-Yan, W, Z, W+charm and QQ** fast interfaces

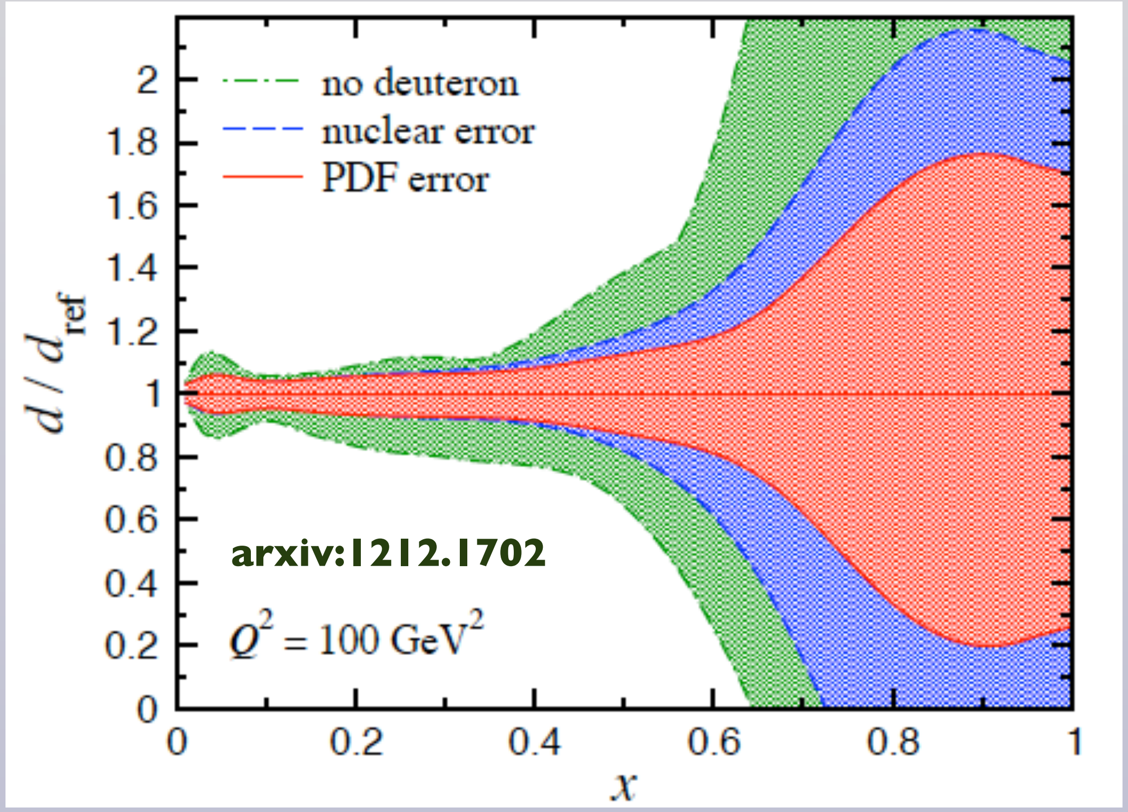
Theory

Theoretical uncertainties on PDFs

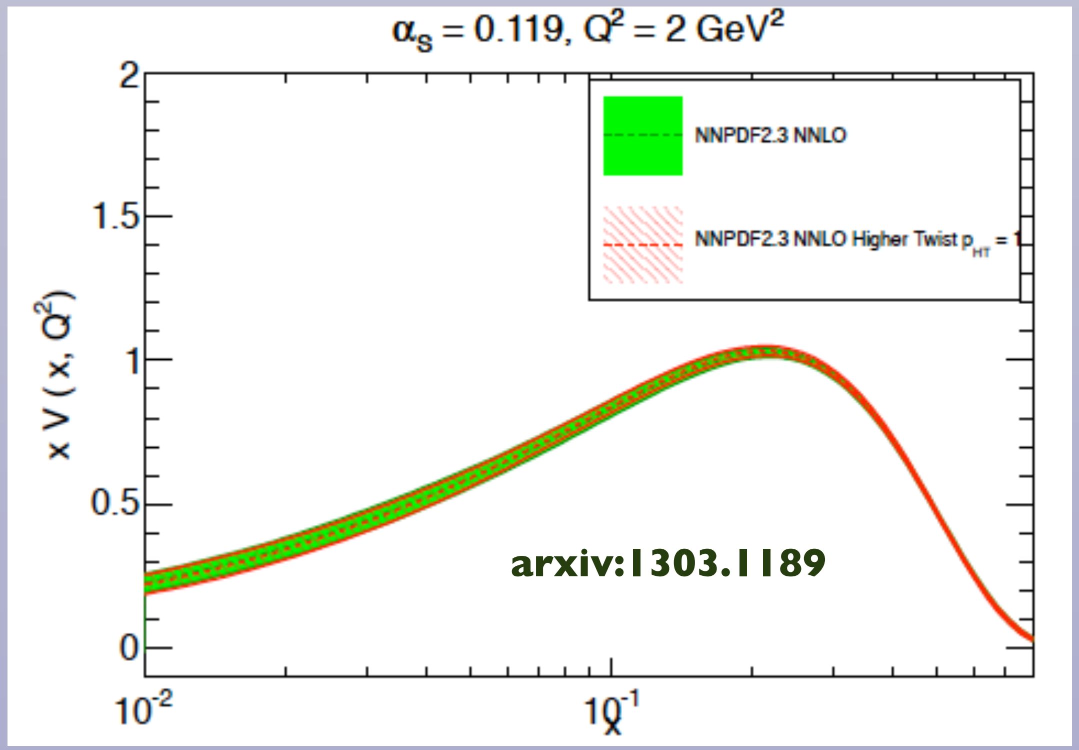
Impact of **VFN vs FFN** (NNPDF, Thorne): FFN leads to softer large-x gluon and harder quarks.



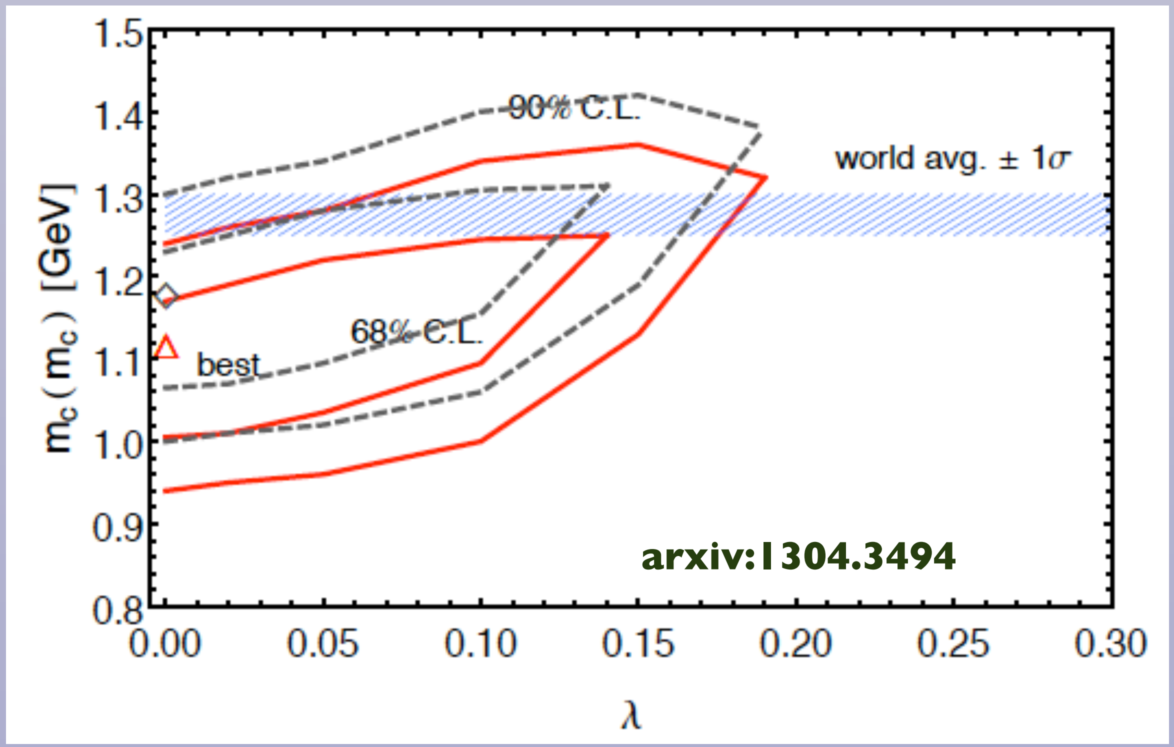
Impact of **deuteron corrections** on PDFs and the **d/u ratio at large-x** (CJ12, NNPDF, MSTW)



PDFs and alphas **stable** against **higher twists** for standard W^2 cuts (ABM, MSTW, NNPDF)



Sensitivity to value of **charm mass**, determinations of **running mass from HERA** (ABM, HERAPDF, CT)

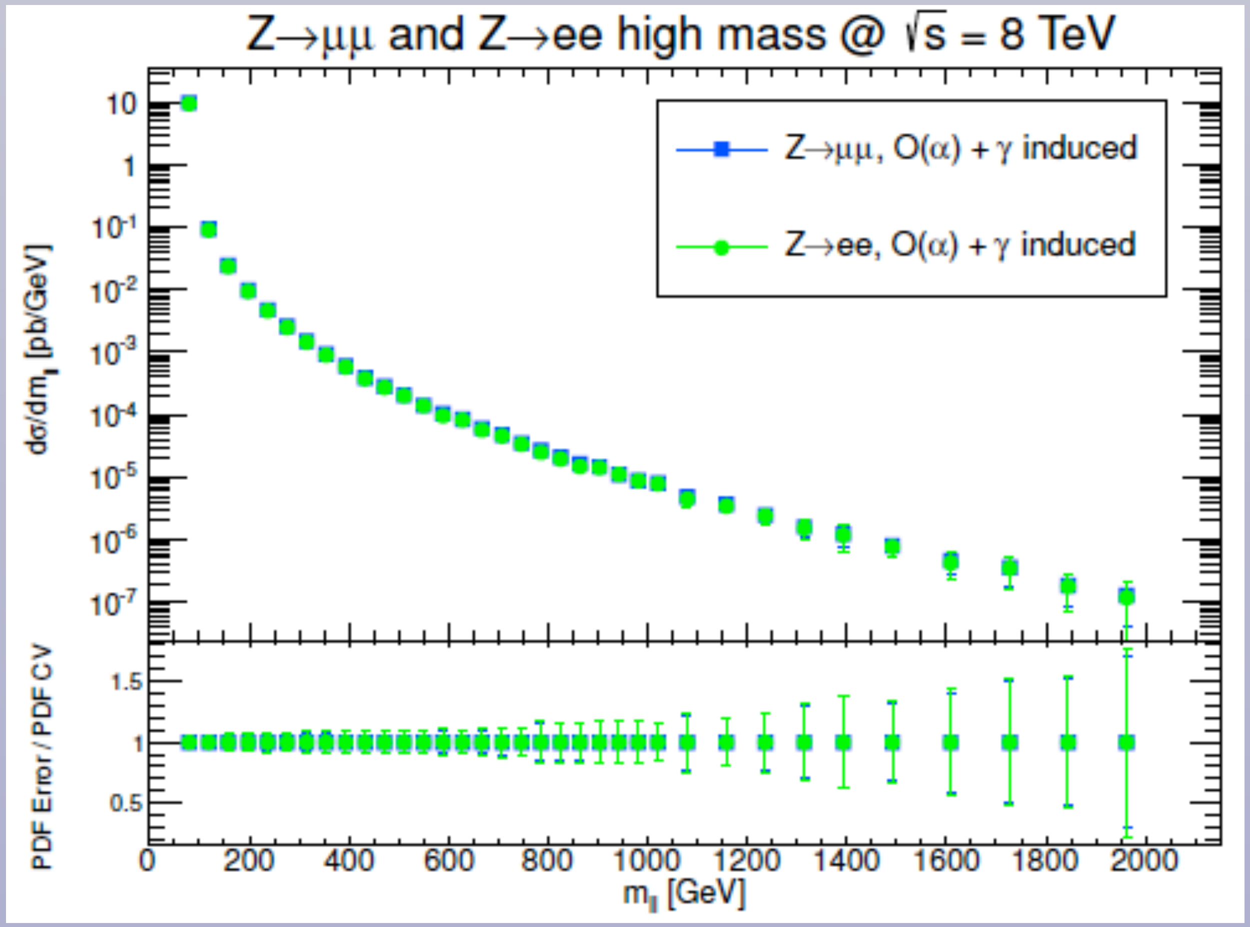


Theory

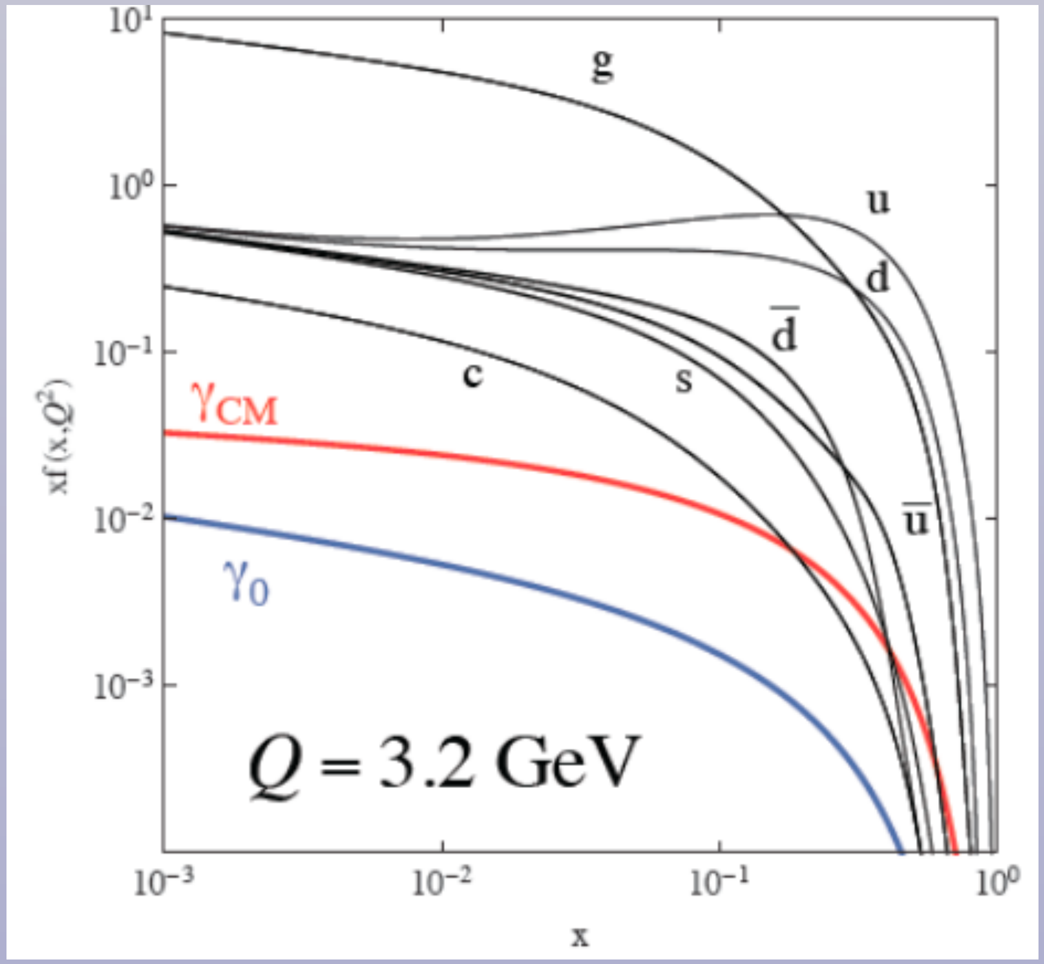
QED corrections

- **Photon-initiated diagrams** are required for consistent electroweak calculations
- The **DGLAP QCD equations** can be modified with **QED corrections,** introducing a **photon PDF**
- Only available set with QED corrections is MRST2004QED, where **photon PDF** derived from non-perturbative model. The upcoming **NNPDF2.3 QED set** is based on photon PDF **derived from DIS and LHC data** (see S. Carrazza's talk). QED updates also planned in CT and MSTW
- Crucial for electroweak LHC phenomenology: **W', Z' searches**, $\mathbf{M_W}$ fits, **WW production**, ...

NNPDF2.3 QED: Substantial (>50%) contribution for high mass Z production



CT QED: Photon PDFs can be larger than antiquarks at large-x



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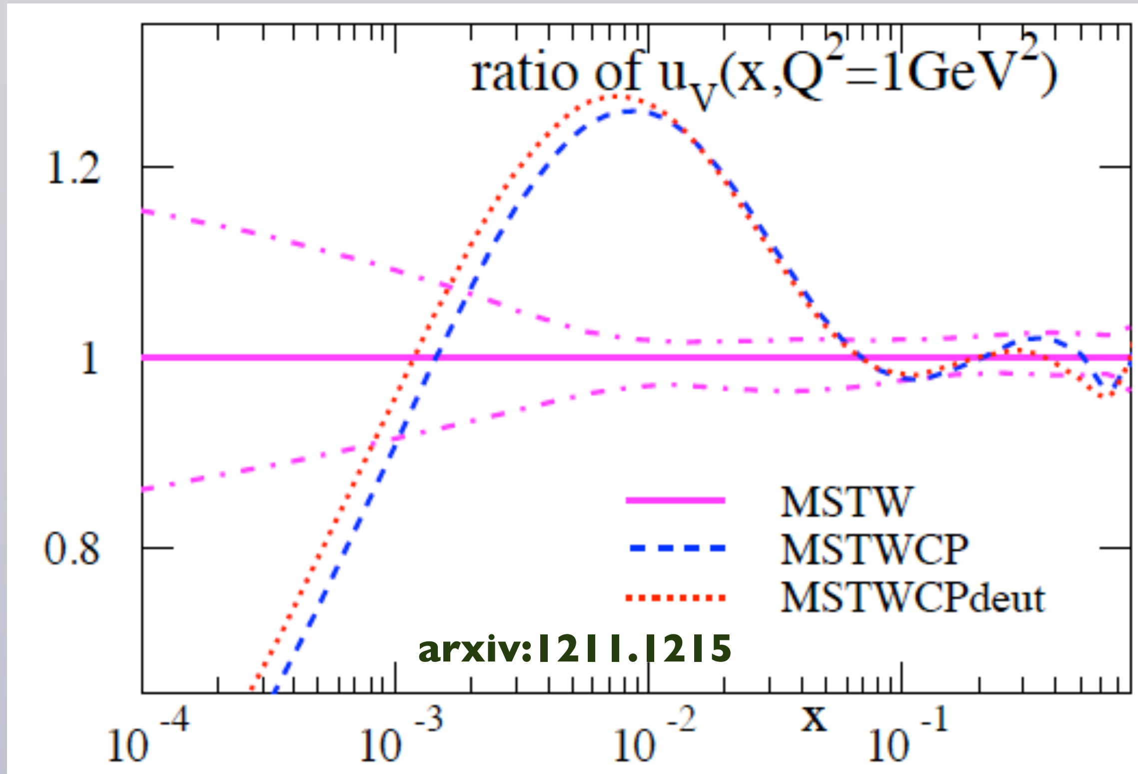
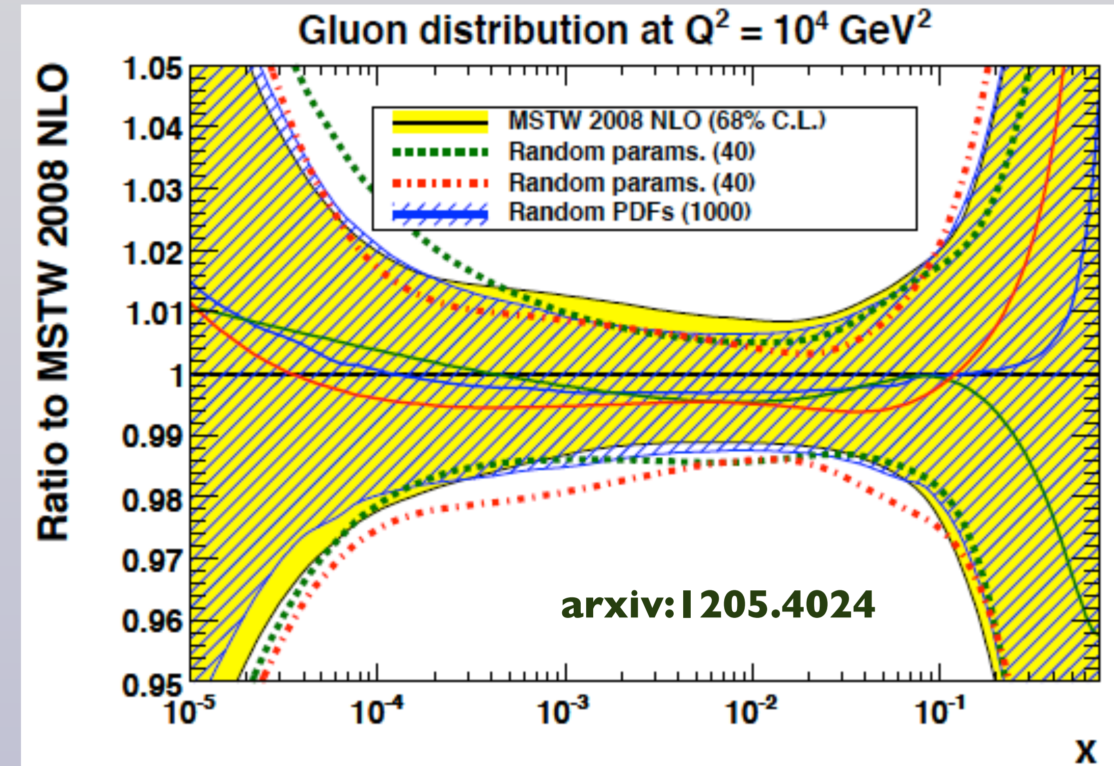
Methodological studies

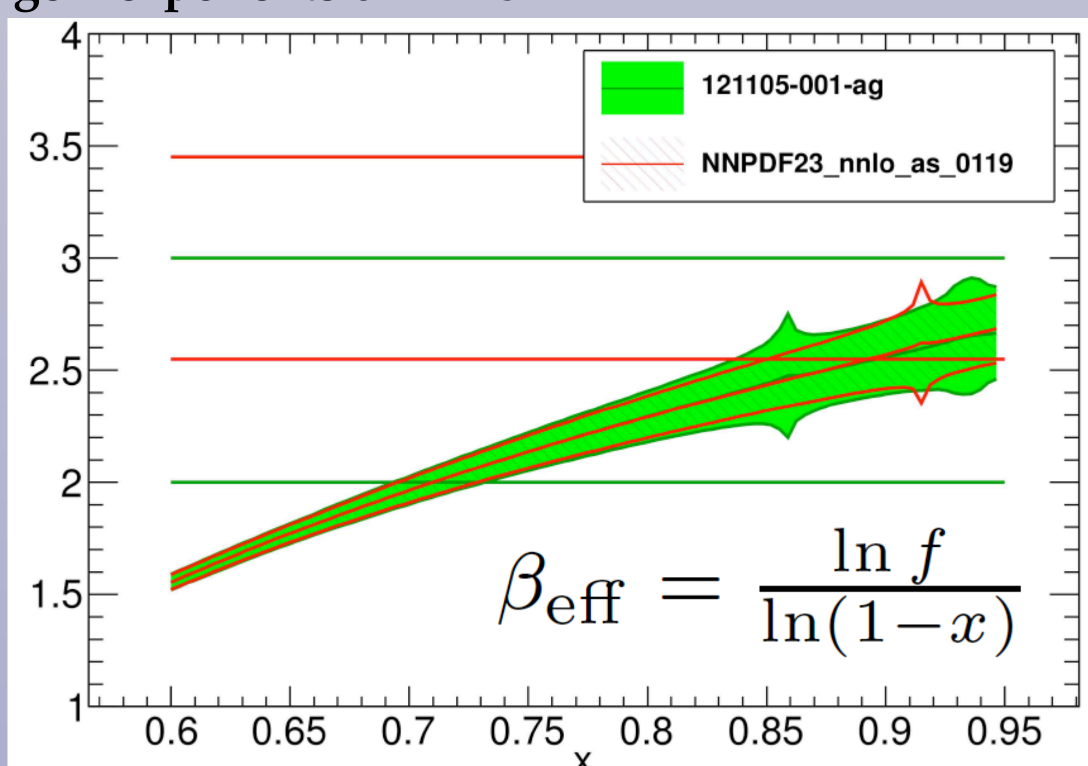
MSTW: Extended PDF parametrizations using **Chebyshev polynomials**



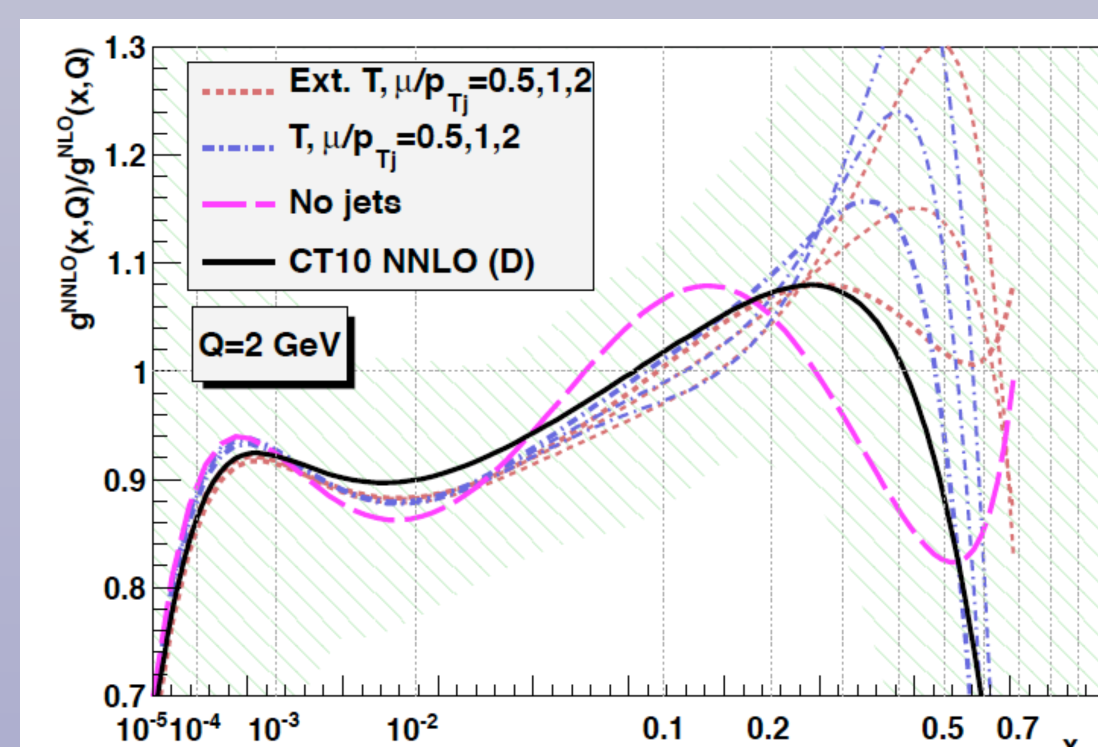
Thorne, Watt: PDF reweighting and **Monte Carlo PDFs for Hessian PDF sets**



NNPDF: Determination of **effective small-x and large-x exponents** of PDFs



CT: Studies of impact of treatment of jet data **systematic uncertainties**



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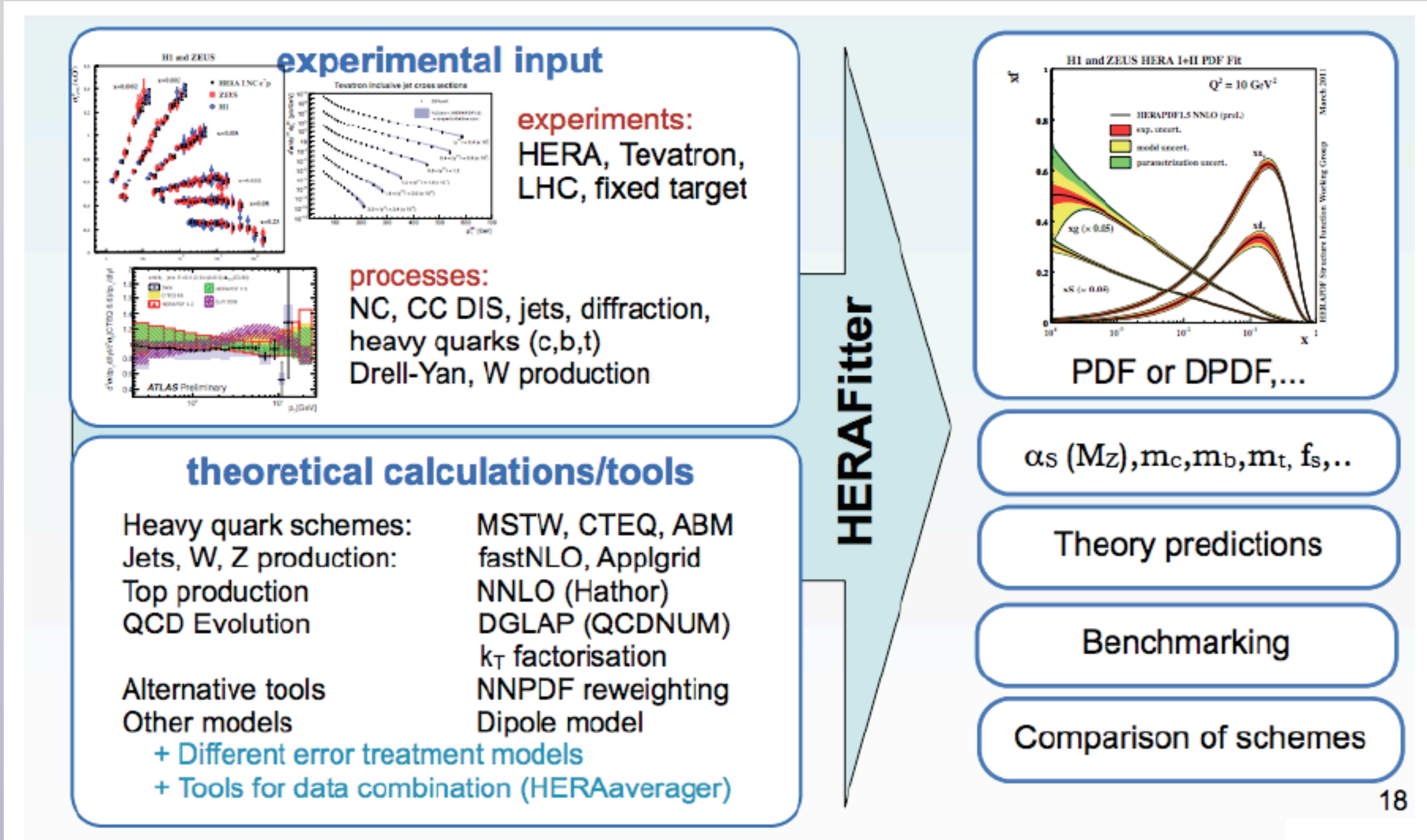
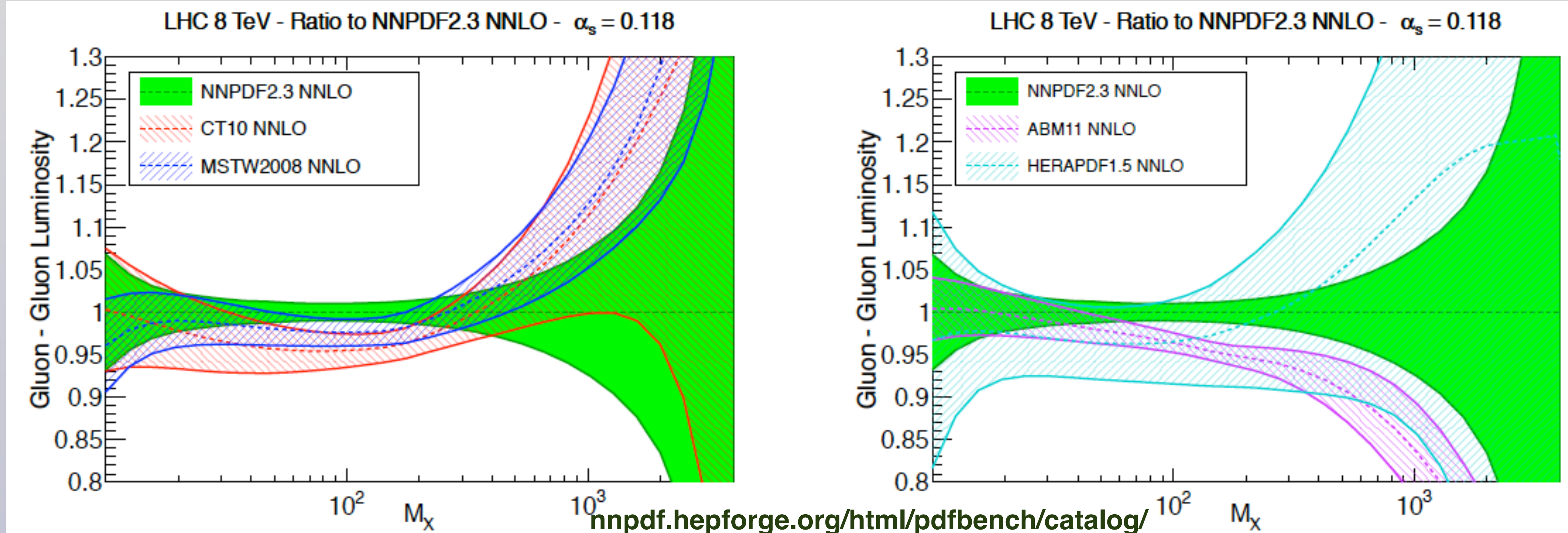
HERAfitter



- **Open source tool for PDF studies**, built upon the HERAPDF framework
- Used by ATLAS, CMS, H1 and CMS to **validate their data** (χ^2 tests, ...), **quantify impact on PDFs** and **study dependence on underlying theory** (heavy quark schemes, charm mass, ...)
- **Beta3** version recently released, code available from *www.herafitter.org/HERAFitter*

PDF benchmarking with LHC data



- **Systematic** comparison of recent NNLO sets at the level of PDFs, parton luminosities, and predictions for LHC data, both for **total cross sections** and **differential distributions**
- The comparison is made **quantitative** though suitable **χ^2 estimators**
- **Reasonable agreement** between **CT, MSTW and NNPDF**. HERAPDF similar central values but **larger uncertainties** (due to reduced dataset). ABM11 **softer large-x gluon** and **harder quarks**

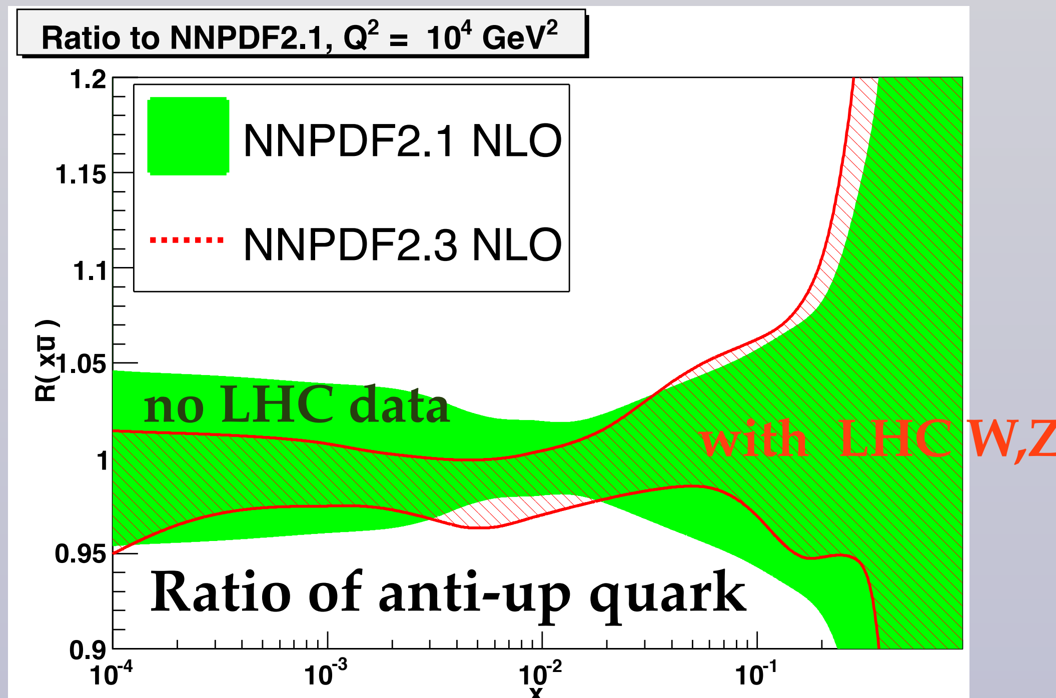
	NNLO $\alpha_s = 0.119$				
Dataset	NNPDF2.3	MSTW08	CT10	ABM11	HERAPDF1.5
ATLAS W, Z	1.435	3.201	1.160	2.061	1.872
CMS W el asy	0.813	3.862	1.772	1.614	0.814
LHCb W	0.831	1.050	0.966	1.970	0.784
ATLAS jets	0.937	0.935	1.016	0.959	1.011

Data

PDF sets with LHC data

- A major improvement since DIS12 is **use of LHC data** on **jets and W,Z production** by the PDF groups

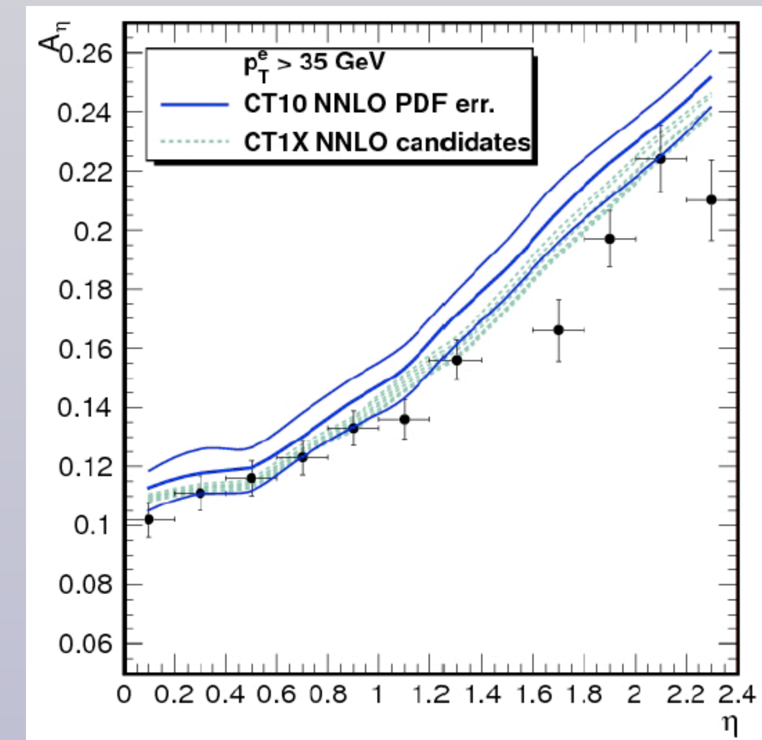
- **NNPDF2.3** is only publicly available PDF set that includes constrains from **LHC jet and W,Z data**, and other groups have presented **preliminary updates** quantifying the impact of LHC measurements



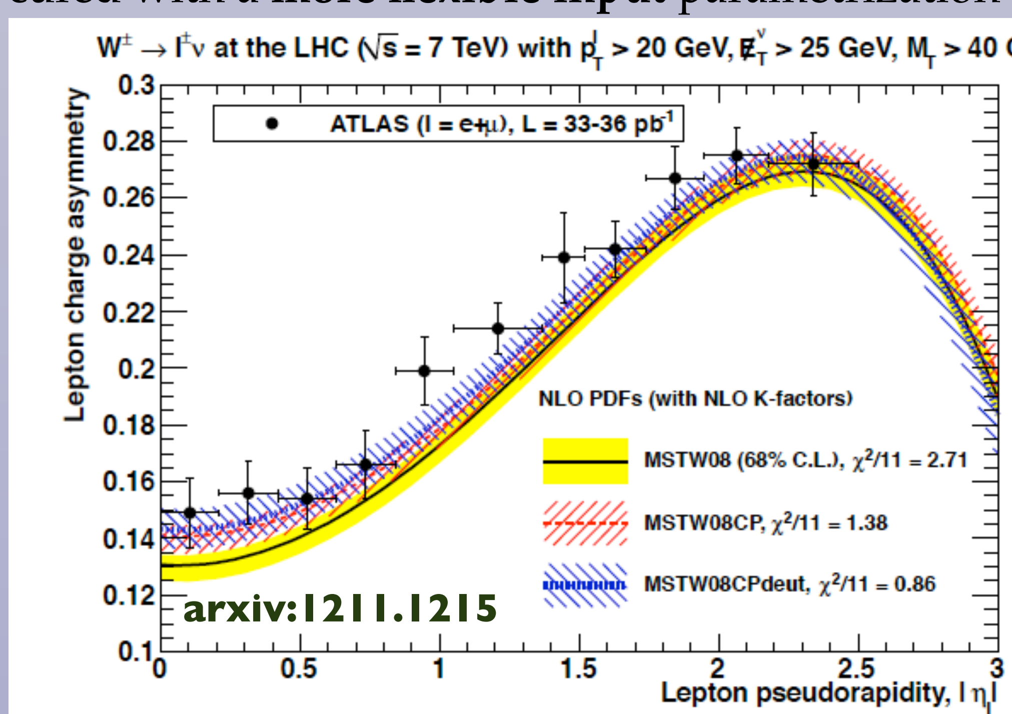
CT: studies of impact of LHC **jet and W,Z** production

Good overall agreement

Slightly **increased PDF errors** due to need of more flexible PDF param

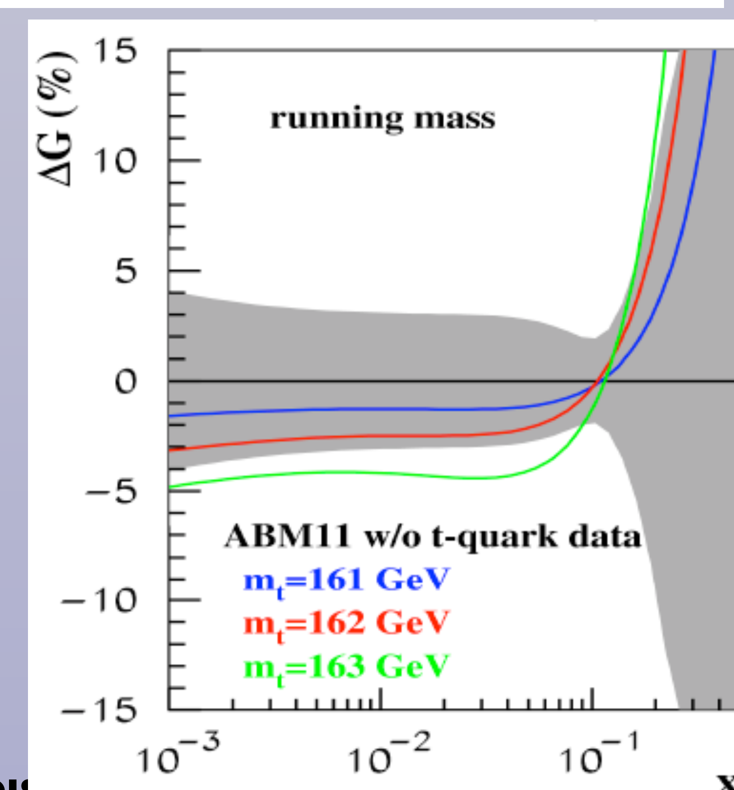


MSTW: poor description of **W asymmetry data** cured with a **more flexible input** parametrization



ABM: studied impact of LHC **top quark data** into gluon PDF (PDF4LHC, 19.04.13)

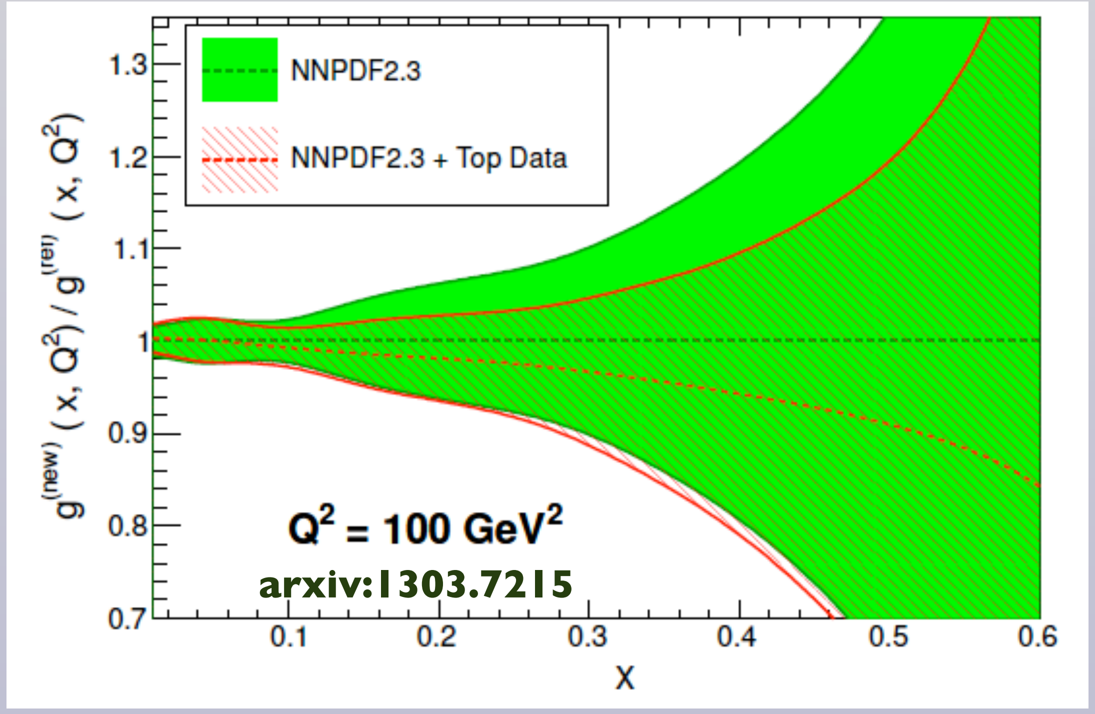
Also studies of impact of **W and Z data** at LHC (arxiv:1303.1073)



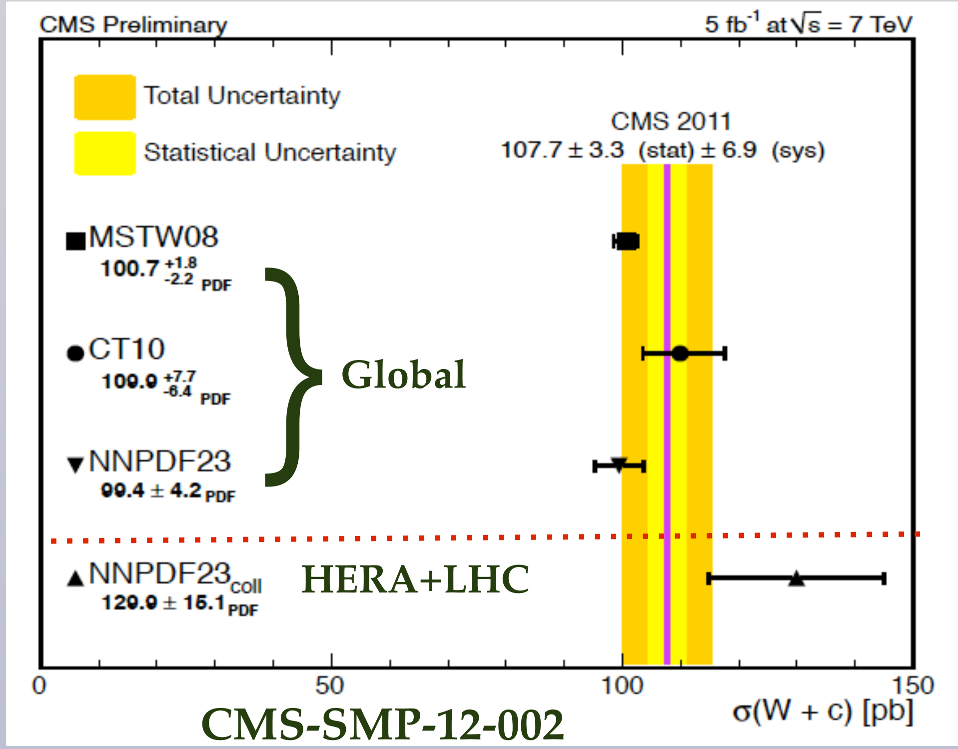
Experimental constraints

On top of traditional processes, like **jets** and **W, Z production**, a **wide range of new processes** that provide PDF information is now available at the **LHC** (see **Voica's** talk)

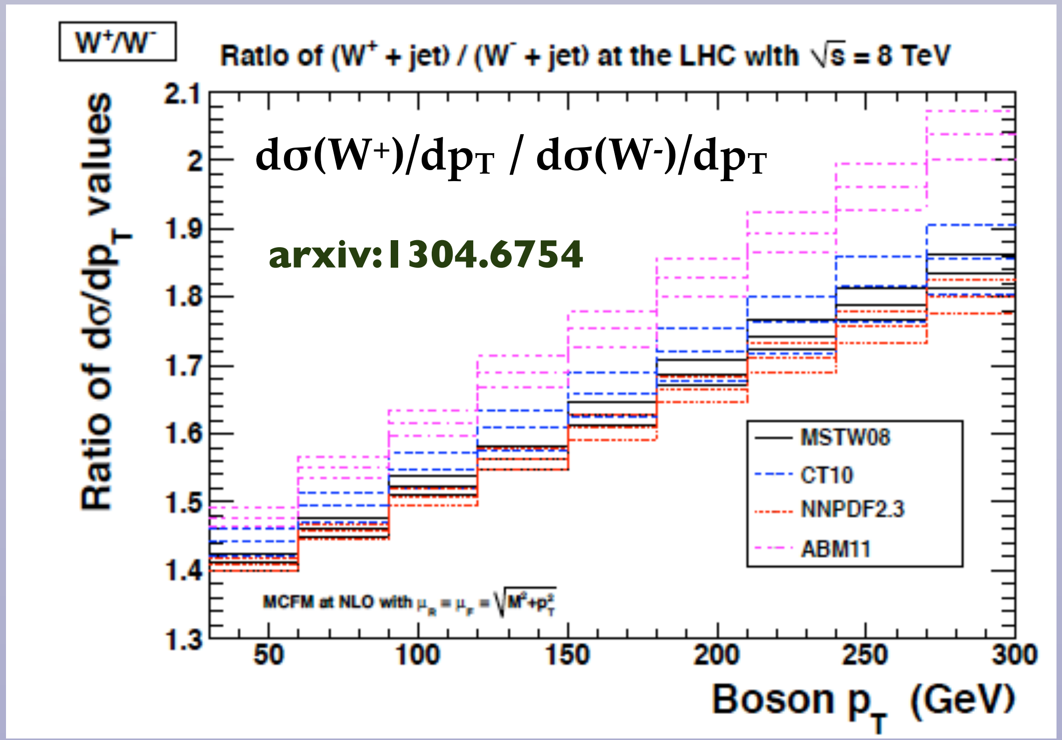
- **Top quarks:** constrain **large-x gluon**



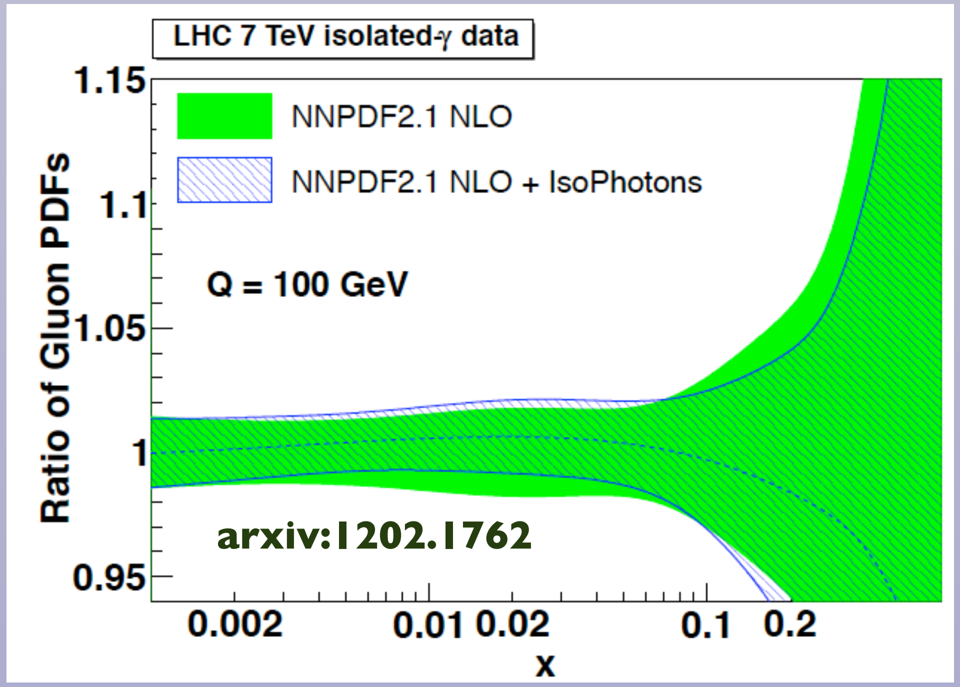
- **W+charm**: sensitivity to **strangeness**



- **high p_T W and Z: gluon** and on **d/u ratio**



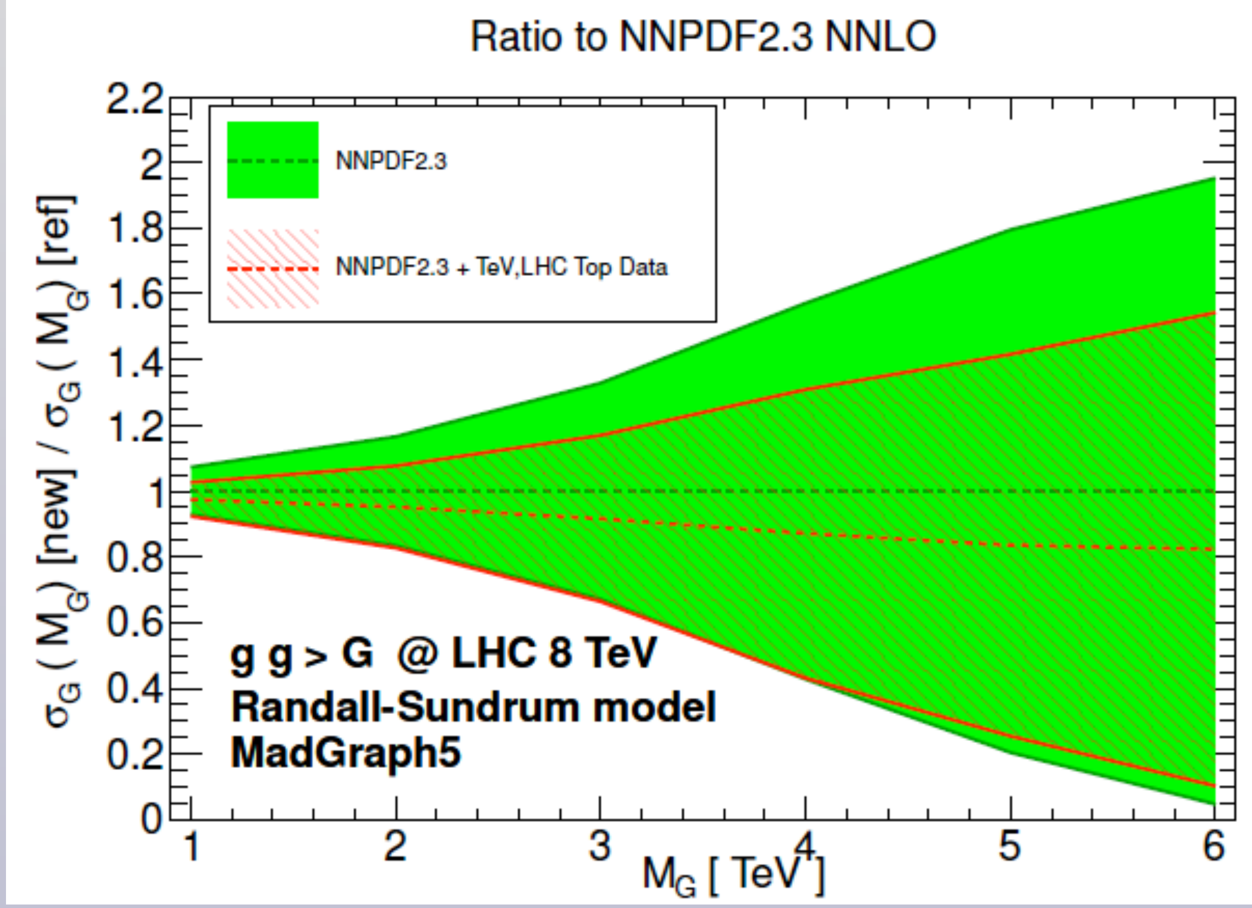
- **Isolated photons**: complementary probe of the **gluon,** same x-range as for gg Higgs production

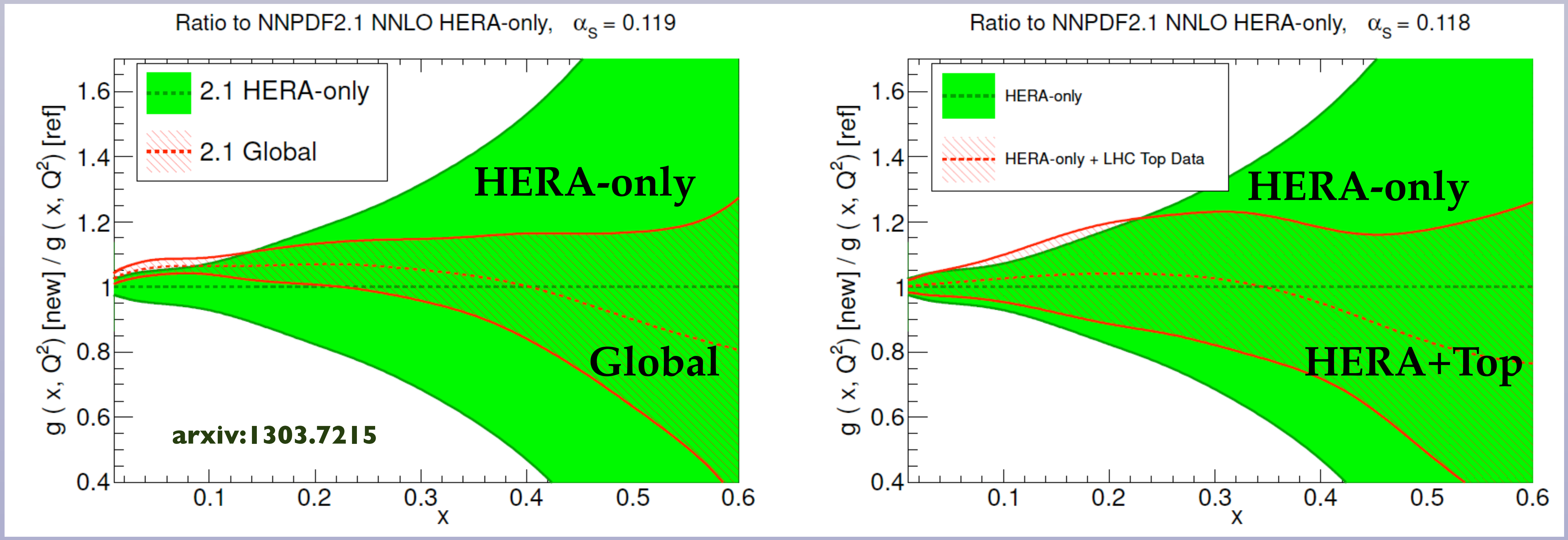


Data

Top quarks as gluon luminometers

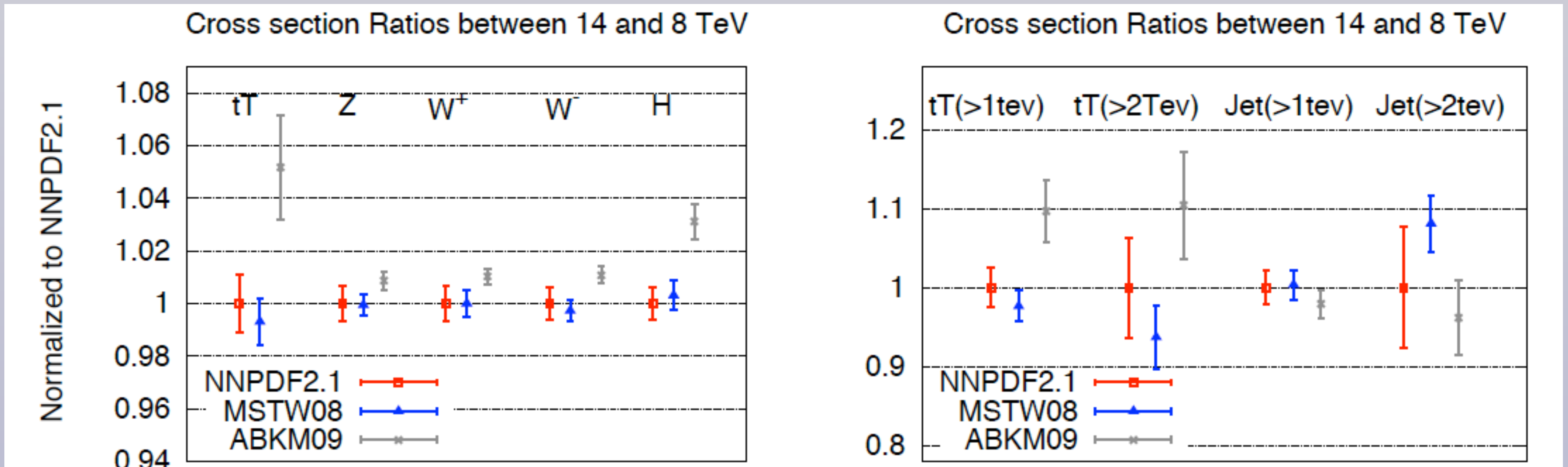
- The **full NNLO calculation** implies that top quark production is the **only hadron collider observable directly sensitive to the gluon** which can be consistently **included in a NNLO PDF fit** without any approximation
- Important implications for **high mass gluon initiated BSM processes**
- The gluon PDF in a fit with **HERA+top data** is remarkably similar at large-x to the gluon of the **global PDF fit**, driven by jet data



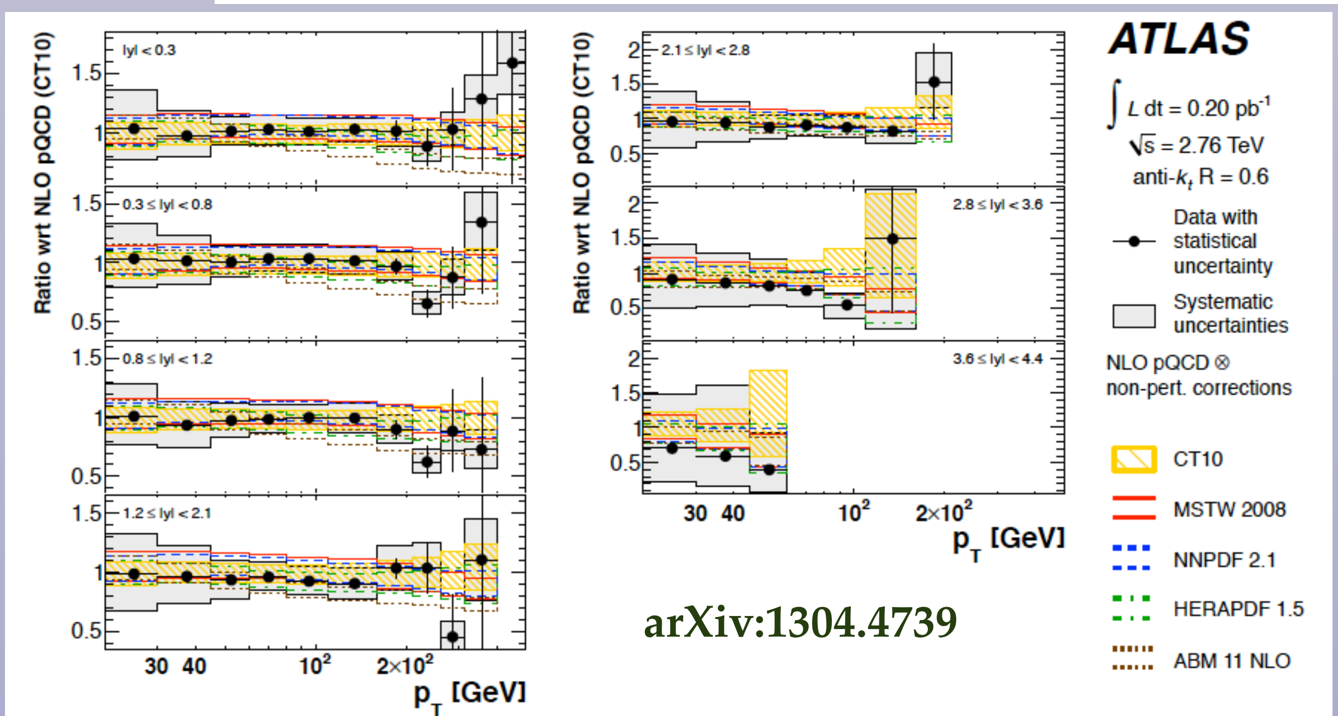


Data Cross section ratios between 2.76,7, 8 and 14 TeV

- The **staged increase of the LHC beam energy** provides a new class of interesting precision observables: **cross section ratios** for different beam energies
- Can be computed with **high precision** due to **correlation of theoretical errors** at different energies
- **Experimentally** these ratios can also be measured accurately since many systematics, like luminosity or jet energy scale, **cancel partially in the ratios**
- These ratios allow **stringent precision tests of the SM**, in particular **PDF discrimination**



arXiv:1206.3557



arXiv:1304.4739

- Cross section ratios should thus be pursued as a **novel approach to constrain PDF**
- First measurement of cross section ratios by **ATLAS: jet cross sections between 7 and 2.76 TeV**
- Reduced experimental and theory (scale) uncertainties, potentially can **improve the sensitivity to PDFs of 7 TeV ATLAS jet data alone**

ToDo

TH

EXP

PDF whishlist at the LHC

- Inclusive **jets:** *full NNLO calculation*, *exp. data extending to higher pt with smaller systematics*
- Inclusive **W and Z production** and asymmetries: *update to 2011, 2012 data, correlation between W,Z and between experiments*, *photon-induced effects*
- Isolated **photons and photon+jets**: *full NNLO, fast interface*, *experimental covariance matrix, extend high pt coverage, covariance matrix, reduced systematics*
- **W production with charm**: *results from ATLAS, update to 2012 data*, *quantify impact in strangeness*
- **W and Z production at high p_T**: *full NNLO*, *experimental measurements in format suitable for PDF analysis*
- Off resonance **Drell-Yan and W production at high mass**: *update to 8 TeV*, *validation of NNLO codes and electroweak corrections*
- Low mass Drell-Yan production: *Understand better theory systematics*
- **Top quark** cross-sections and differential distributions: *full NNLO for differential*, *update to full 8 TeV dataset*
- **Cross-section ratios** between 2.76, 7 and 8 TeV: *measure in other processes on top of jets*

Theory speculations

- Approximations to the **Higgs coefficient functions at N3LO** available. Do we need/want **PDFs at (approximate) N3LO**? What is the best path towards such accuracy?

- Some of the best known cross sections at LHC (Higgs, top) available at **NNLO+NNLL**. Do we want/need **PDF sets with fixed order + threshold resumation**? Are all the tools needed available? What about PDFs with **high-energy resummation?**

- **Electroweak corrections** are required to fit TeV hard-scattering data. It is enough to include EW in matrix element calculations? Do we need any kind of **EW corrections in PDF evolution**? Are the calculations suitable for use in PDF analysis?

- NLO event generators are state-of-the-art at LHC. Do we need specific **PDFs for NLO event generators**? Can we simultaneously fit hard-scattering and semi-hard data with a single PDF set?

- What about **intrinsic charm**? Does it matter for LHC phenomenology? Any role in the **LHCb charm sector asymmetries**? Recent progress by CT and NNPDF here

- Can we imagine **new avenues to use global PDF fits for New Physics searches**? What about including BSM in DGLAP? Past studies by CT (arxiv:1010.4315), but in my opinion **full potential largely unexplored**

Summary

- **Parton Distributions** are an **essential ingredient** of the LHC physics program
- **Precision PDFs** are required for most LHC analysis, from **Higgs boson characterization**, **searches for new massive particles** to **self-consistency tests of the Standard Model**
- A huge amount of work devoted in the last year to provide an **improved theory**, study the constraints from the **wealth of new experimental data** and adopt a **more robust methodology** in **PDF analysis**

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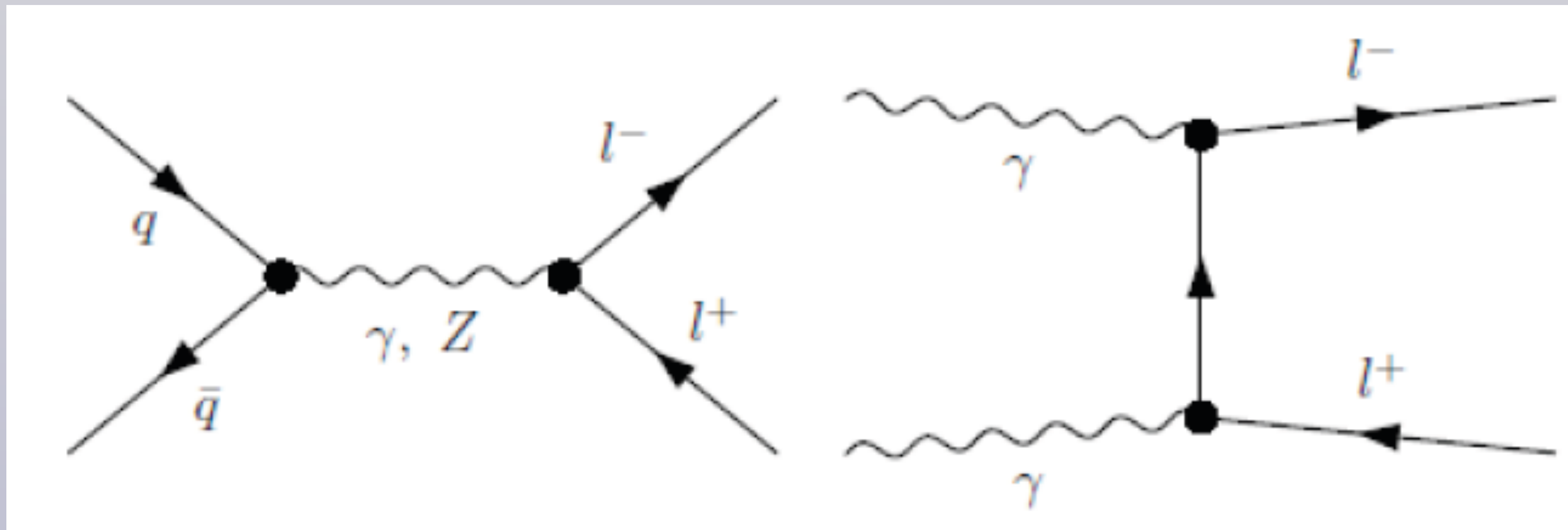
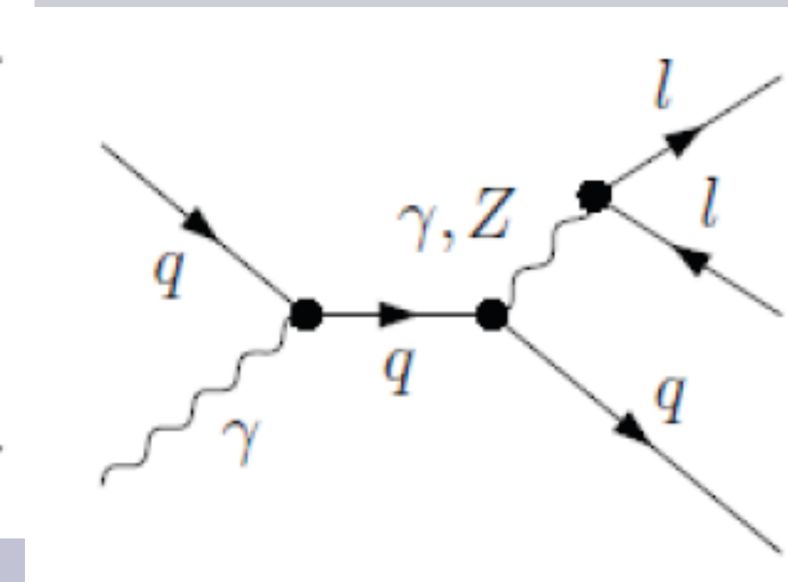
Thanks for your attention!

EXTRA MATERIAL

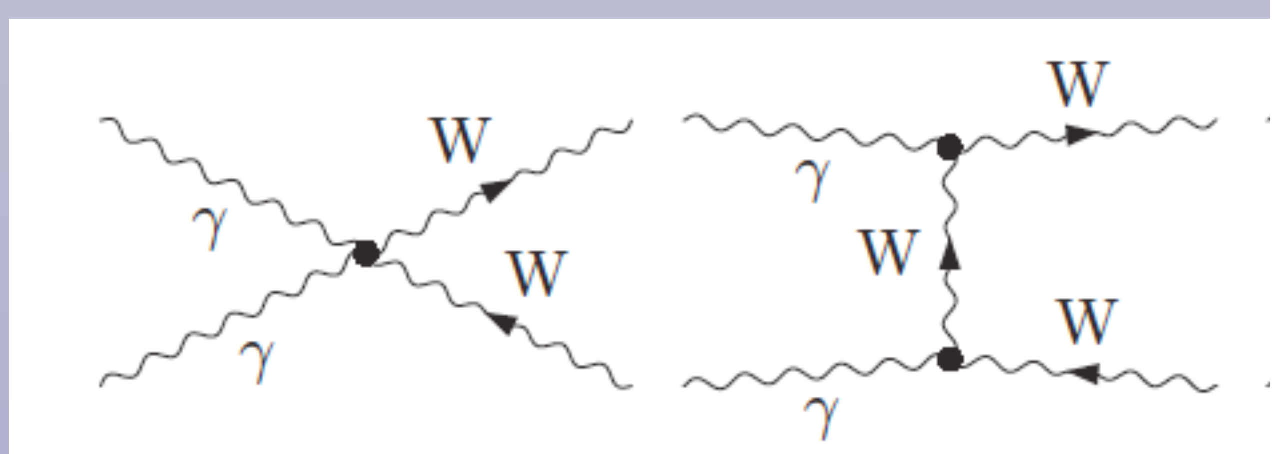
QED phenomenology

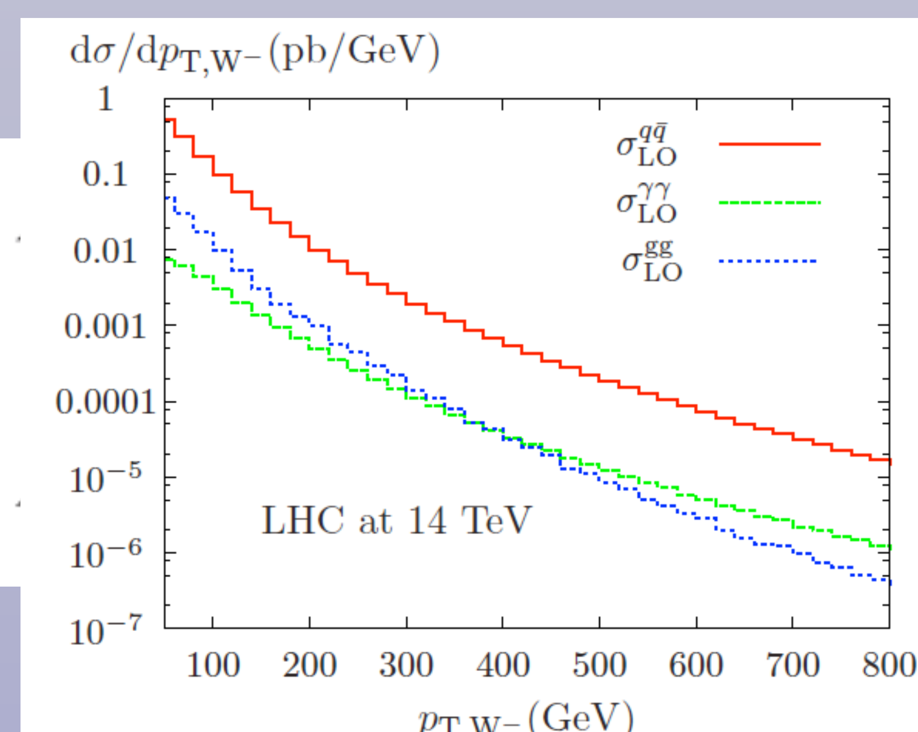
- **Photon initiated contributions** can be a substantial contribution to Z and W production at the LHC far from Jacobian peak





- **High mass W pair production** also receives large contributions from photon diagrams





arxiv:1203.3147

χ^2 definitions

- **Various definitions of the χ^2 available**: differ in treatment of systematics and normalization uncertainties
- **Multiplicative normalization errors** must be treated with the **T_0 prescription**, to avoid the D'Agostini bias in the PDF fit
- Non-negligible dependence in χ^2 definition, in particular for experiments, like **inclusive jets**, with **substantial correlated systematic** uncertainties

D = data
T = theory

$$(\mathrm{cov})_{ij} = \delta_{ij}s_i^2 + \left(\sum_{\alpha=1}^{N_c}\sigma_{i,\alpha}^{(c)}\sigma_{j,\alpha}^{(c)} + \sum_{\alpha=1}^{N_{\mathcal{L}}}\sigma_{i,\alpha}^{(\mathcal{L})}\sigma_{j,\alpha}^{(\mathcal{L})}\right) D_i D_j \,, \quad \text{"Exp"}$$

$$(\mathrm{cov})_{ij} = \delta_{ij}s_i^2 + \sum_{\alpha=1}^{N_c}\sigma_{i,\alpha}^{(c)}\sigma_{j,\alpha}^{(c)} D_i D_j + \sum_{\alpha=1}^{N_{\mathcal{L}}}\sigma_{i,\alpha}^{(\mathcal{L})}\sigma_{j,\alpha}^{(\mathcal{L})} T_i^{(0)} T_j^{(0)} \,, \quad \text{"}t_0\text{"}$$

$$(\mathrm{cov})_{ij} = \delta_{ij}s_i^2 + \left(\sum_{\alpha=1}^{N_c}\sigma_{i,\alpha}^{(c)}\sigma_{j,\alpha}^{(c)} + \sum_{\alpha=1}^{N_{\mathcal{L}}}\sigma_{i,\alpha}^{(\mathcal{L})}\sigma_{j,\alpha}^{(\mathcal{L})}\right) T_i^{(0)} T_j^{(0)} \,, \quad \text{"Extended} - t_0\text{"}$$

Stat **Sys** **Lumi**

VFN vs FFN fit quality

- **The FFN variant** of the NNPDF2.3 global fit leads to a **worse fit quality** than the default NNPDF2.3, based on the FONLL-C VFN scheme
- The **deterioration of fit quality** concentrates on the **large-Q^2 HERA** data. Related to the missing DGLAP log resummation in FFN?

$$\Delta\chi^2 = \chi^2_{\mathrm{FFN}} - \chi^2_{\mathrm{VFN}}$$

$x_{\rm min}$	$x_{\rm max}$	$Q^2_{\rm min}$ (GeV)	$Q^2_{\rm max}$ (GeV)	$\Delta\chi^2$ (DIS)	$N_{\rm dat}^{\rm DIS}$	$\Delta\chi^2$ (HERA-I)	$N_{\rm dat}^{\rm hera-I}$
$4\cdot10^{-5}$	1	3	10^6	72.2	2936	77.1	592
$4\cdot10^{-5}$	0.1	3	10^6	87.1	1055	67.8	405
$4\cdot10^{-5}$	0.01	3	10^6	40.9	422	17.8	202
$4\cdot10^{-5}$	1	10	10^6	53.6	2109	76.4	537
$4\cdot10^{-5}$	1	100	10^6	91.4	620	97.7	412
$4\cdot10^{-5}$	0.1	10	10^6	84.9	583	67.4	350
$4\cdot10^{-5}$	0.1	100	10^6	87.7	321	87.1	227

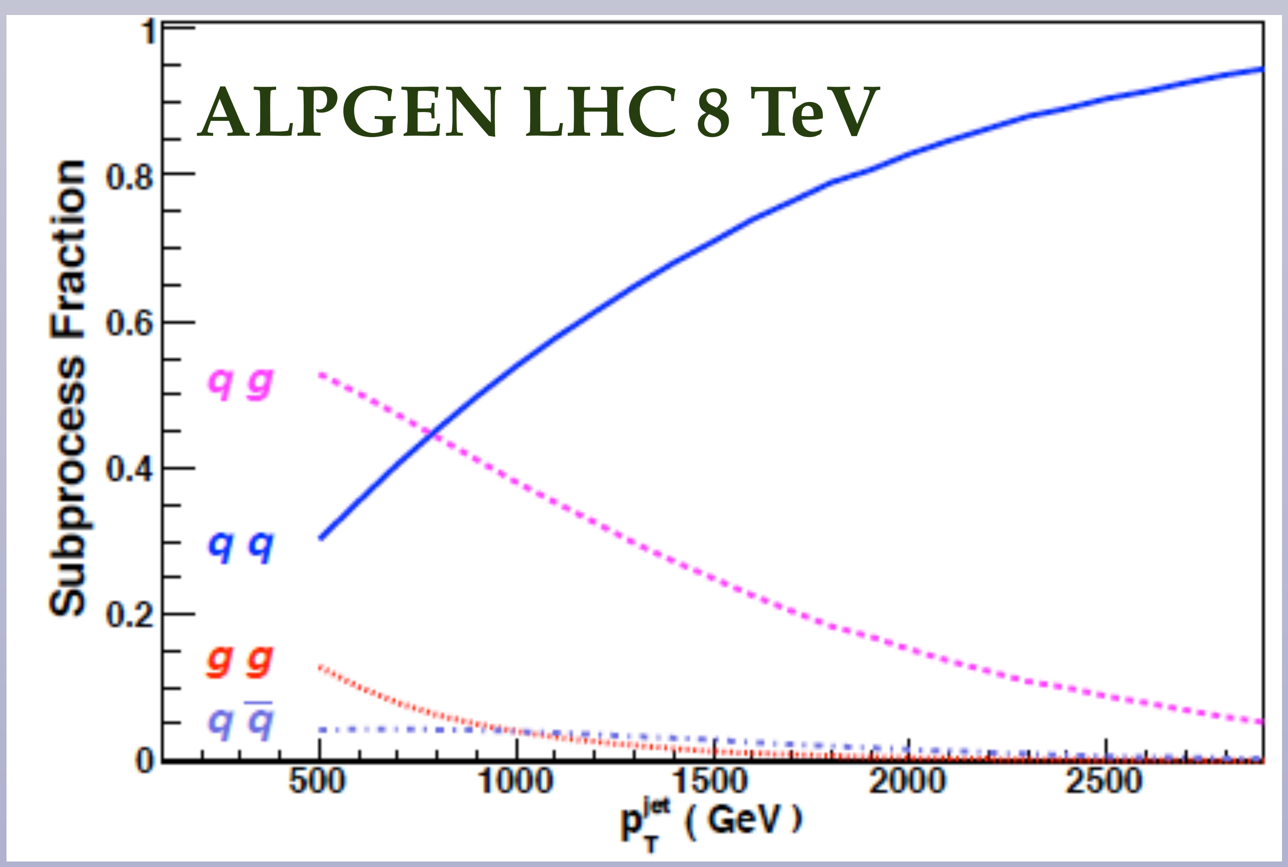
Jet production

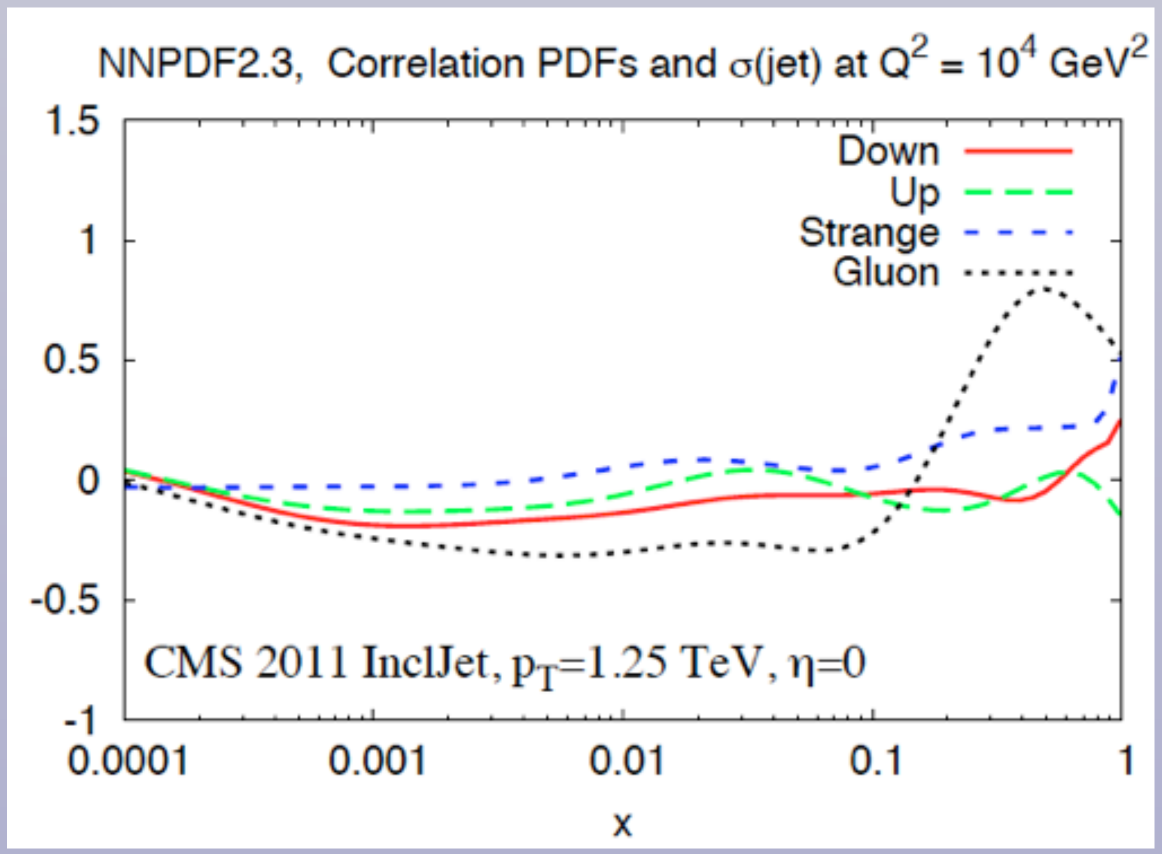
- Traditional source of information on the **gluon** in global PDF fits (as well as for α_S)
- For **p_T < 800 GeV**, **quark-gluon** scattering dominates, for higher p_T one is probing **quark-quark**
- The **higher the p_T**, the **higher the Bjorken-**x value one is probing

Important since large-x PDFs have very large uncertainties

- Theoretical calculations: **NLO**, partial NNLO also available for gg

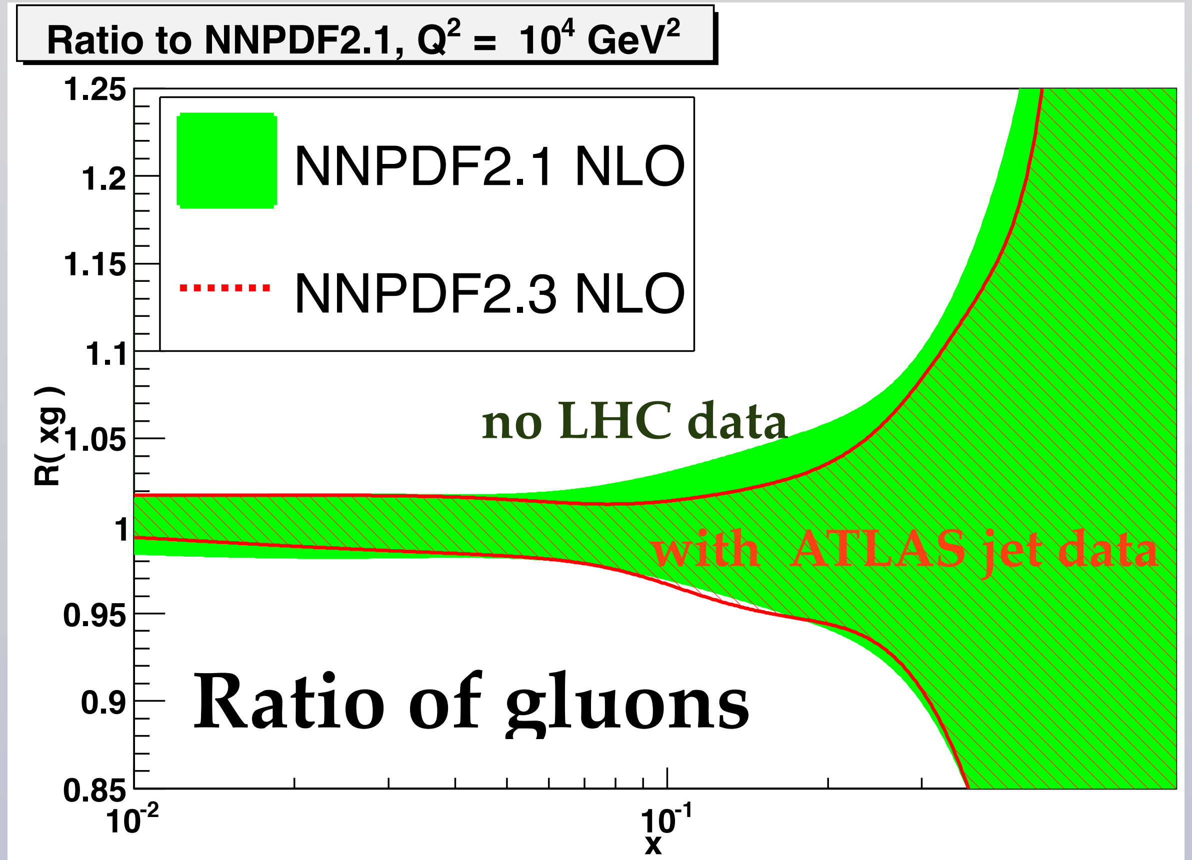
Also substantial dependence on non-perturbative parameters from hadronization and UE

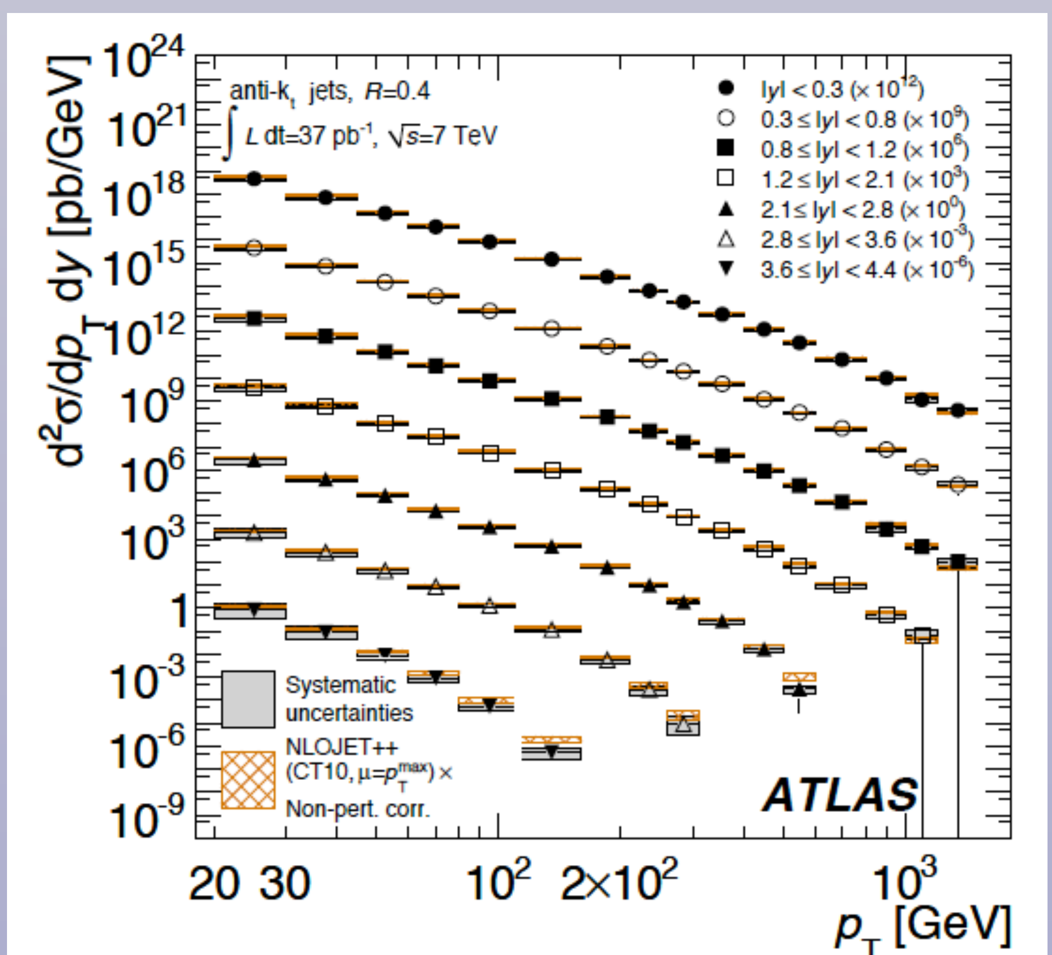


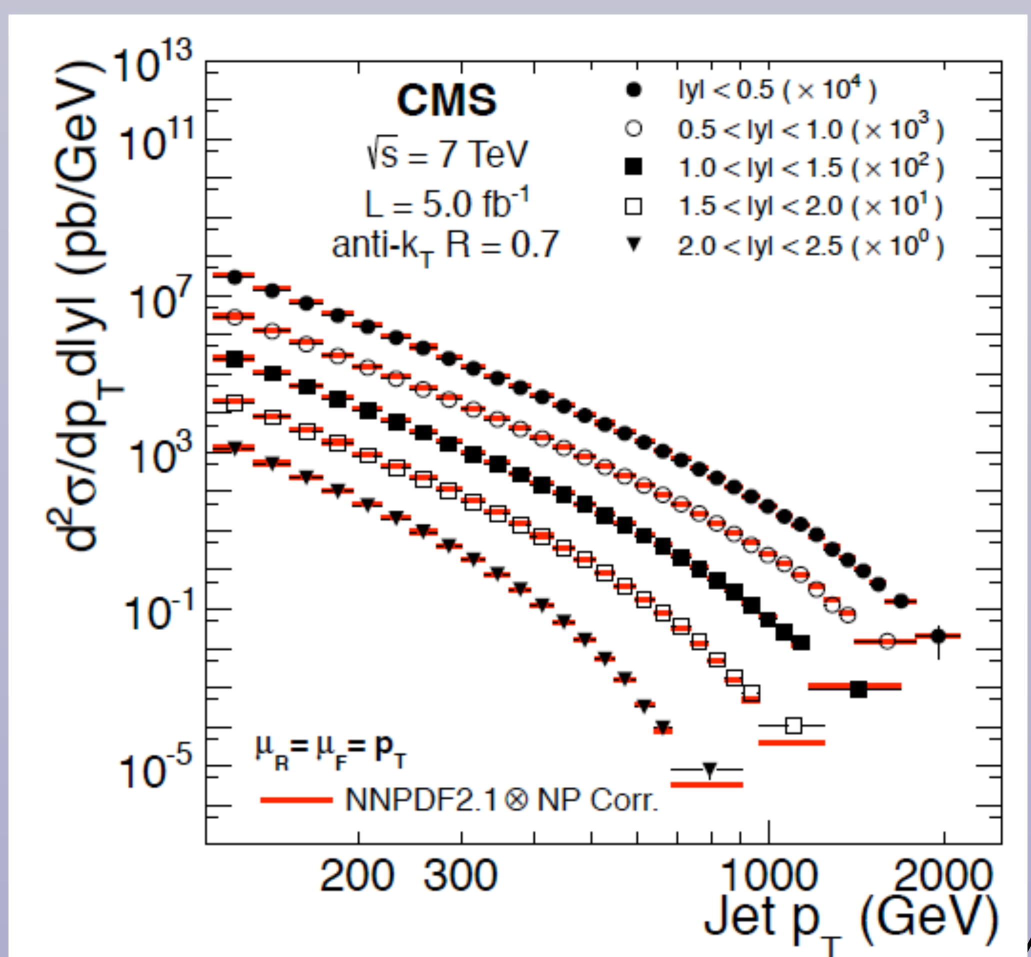


Jet production

- LHC results: **ATLAS 2010 data, CMS 2011 data** publicly available with covariance matrix
- ATLAS 2010 data: systematic uncertainties large, moderate improvement in gluon PDF
- Dijet data typically worse description than inclusive jets due to *scale choice issues*
- PDF sensitivity enhanced in **cross-section ratios between LHC energies**

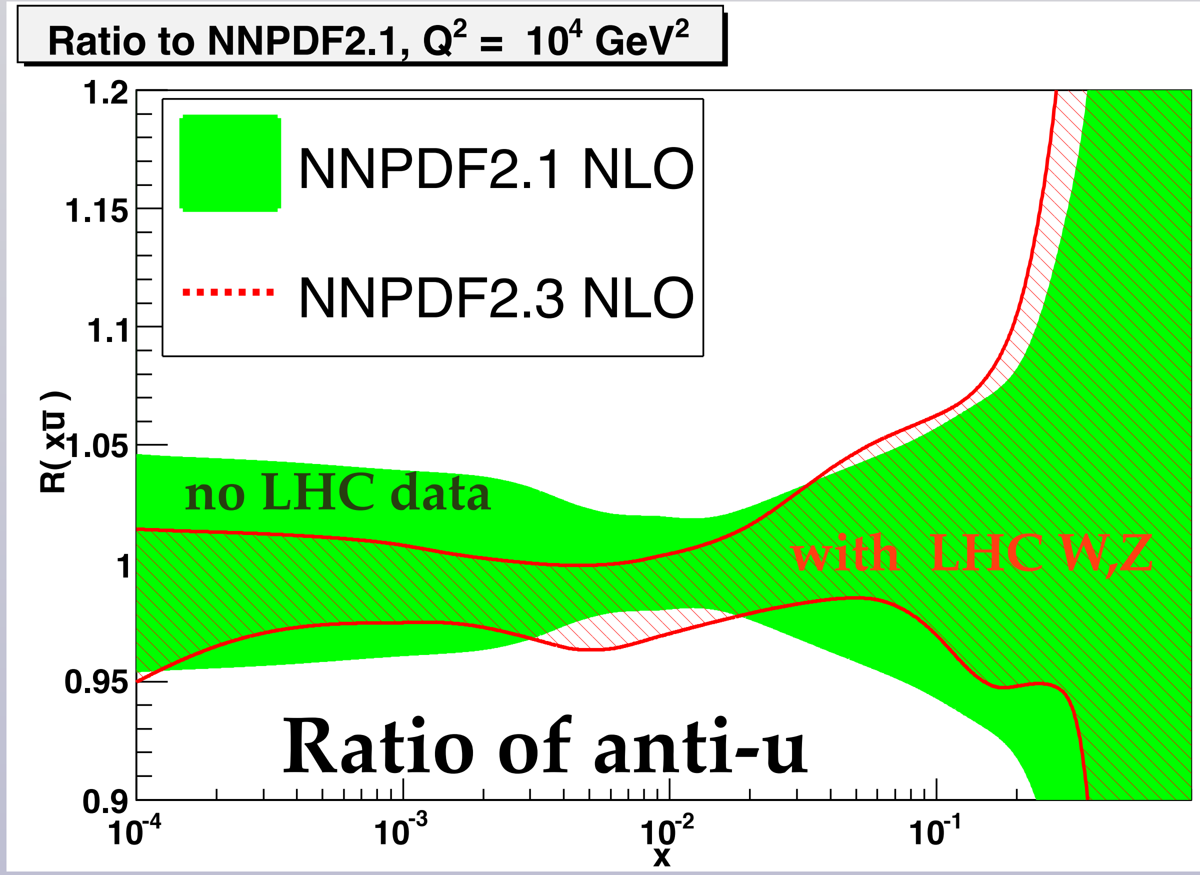


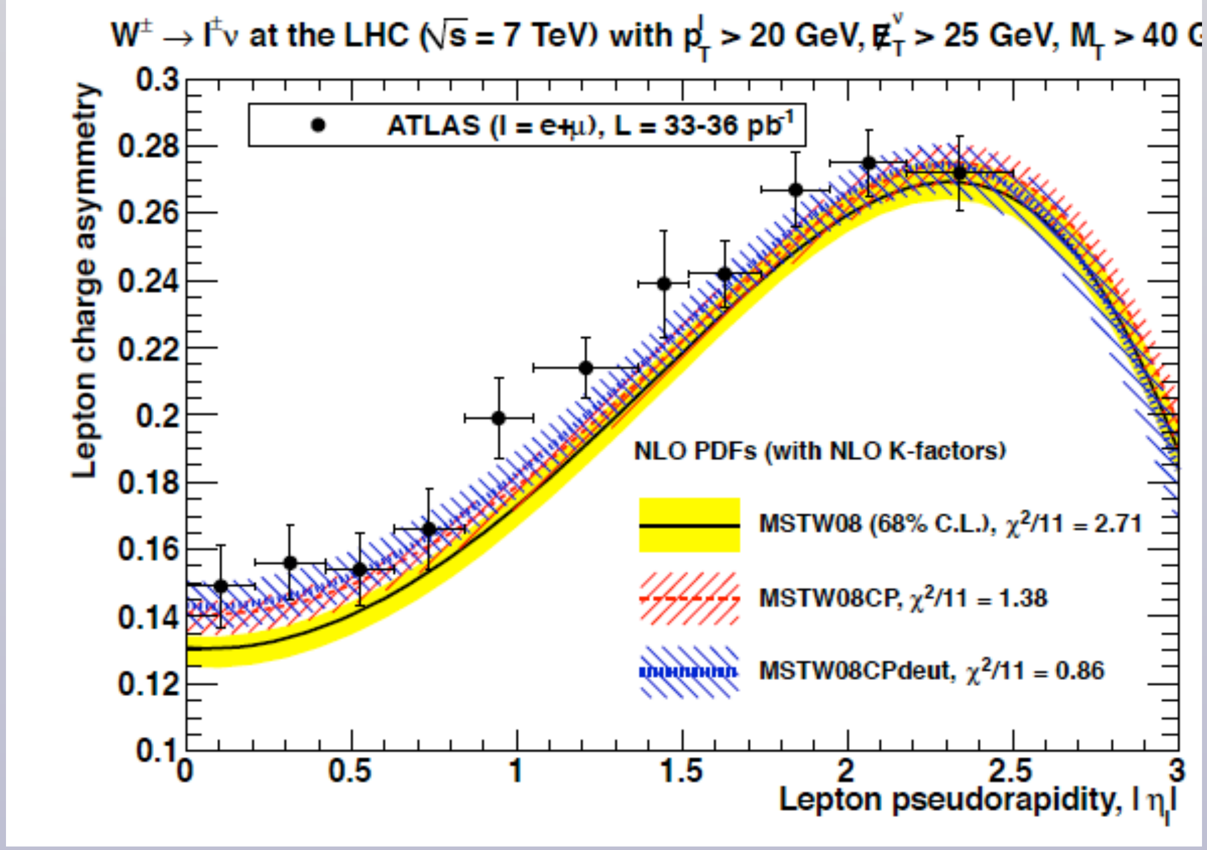




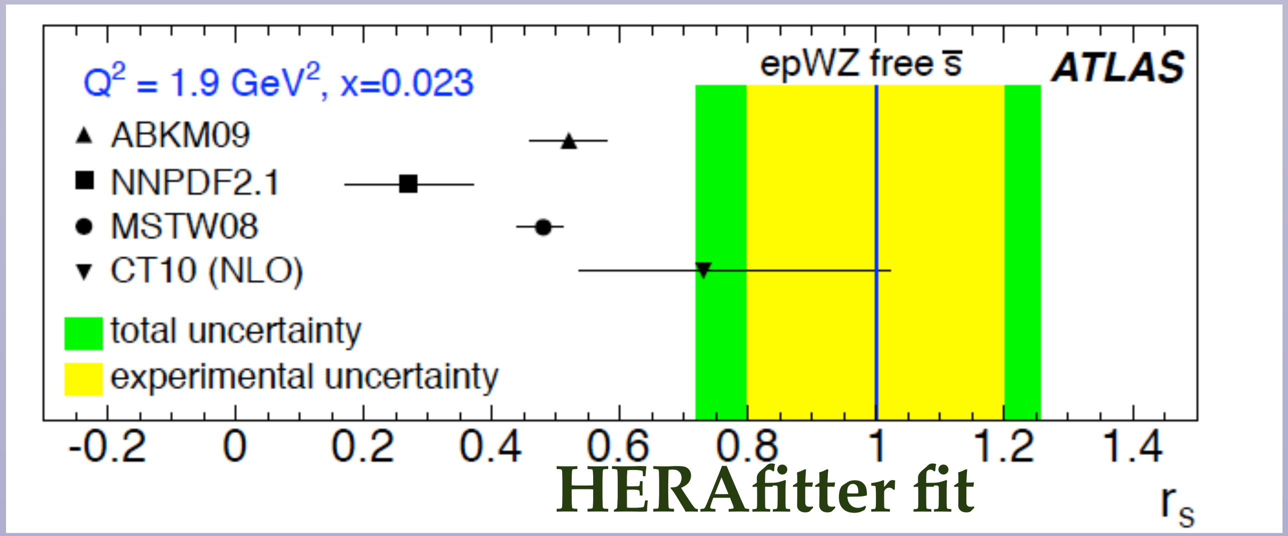
Inclusive vector boson production

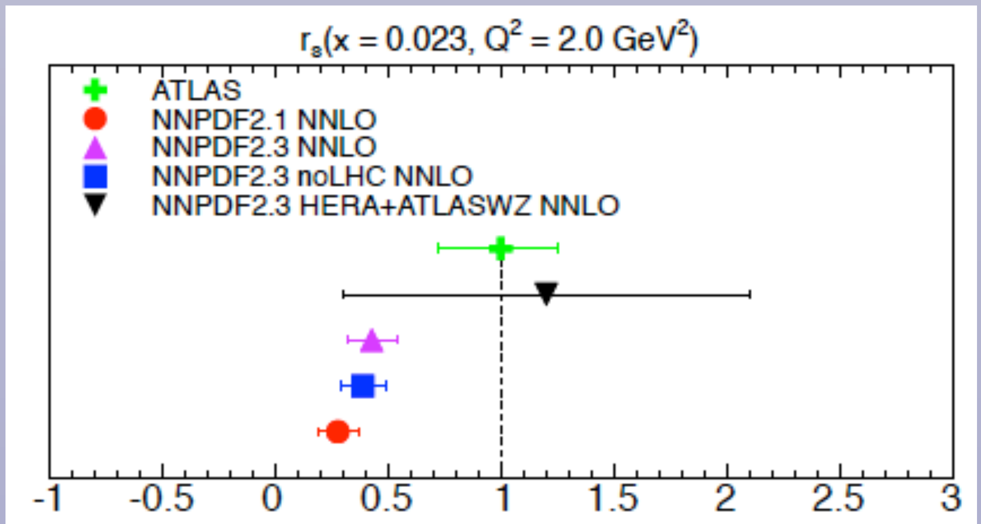
- Inclusive electroweak production **improves the PDF uncertainties in antiquarks** (NNPDF2.3), and **validates an extended MSTW parametrization** based on Chebyshev polynomials





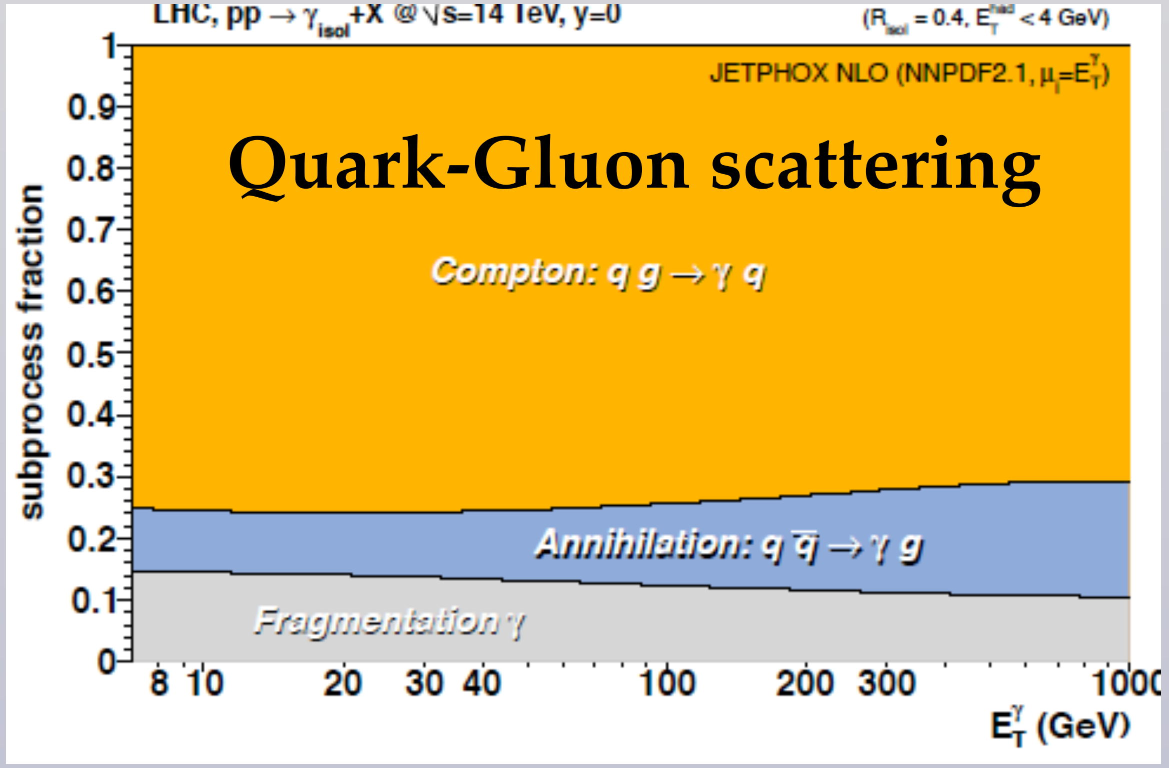
- A **QCD analysis of the ATLAS W, Z data** allows to determine **the strange PDF**. ATLAS analysis based on **HERAfitter** indicates **strange ≃ down**. **NNPDF2.3** analysis confirms central value, **but larger uncertainties**

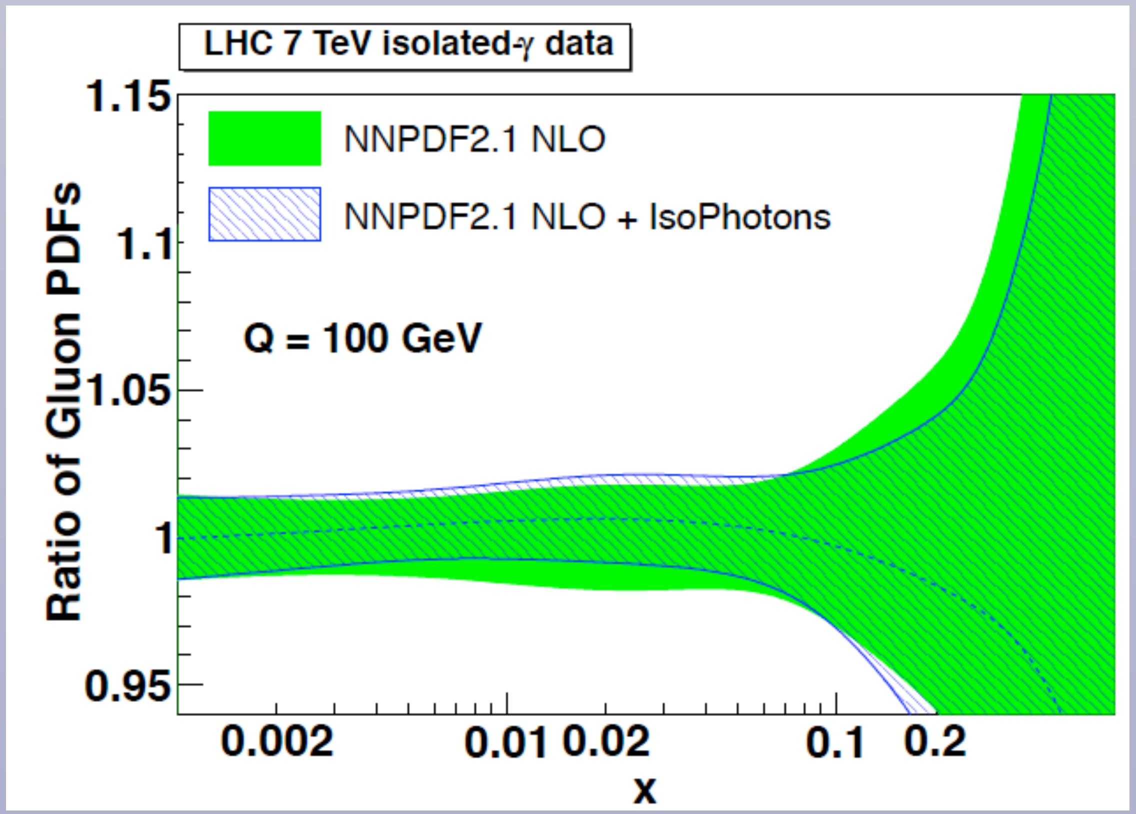


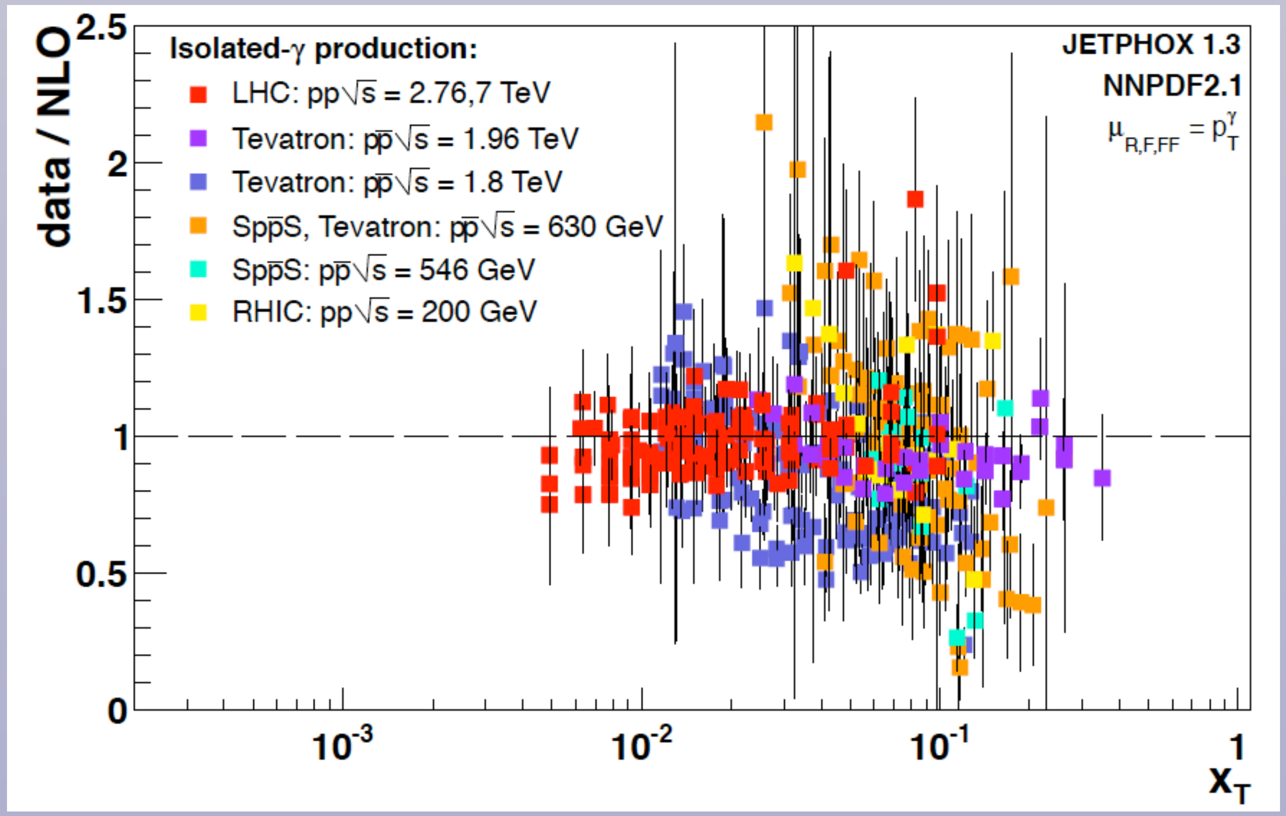


Isolated photons

- **Photon** production **directly sensitive to the gluon** via QCD Compton scattering (also **Mark's talk**)
- Photon production was used in **early PDF fits** for gluon constraints, then replaced by jets due to poor data/theory agreement of **some fixed-target data**
- Recently reanalysis of all **isolated collider** photon data with the most updated theory, **JetPhox+NNPDF2.1,** and found **overall agreement**
- **Moderate reduction of gluon PDF error**s from LHC photon data, in the region relevant for Higgs production in gluon fusion
- Need a **fast interface** to include photon data in PDF fits
- Need more precise data for **photon+jet production**





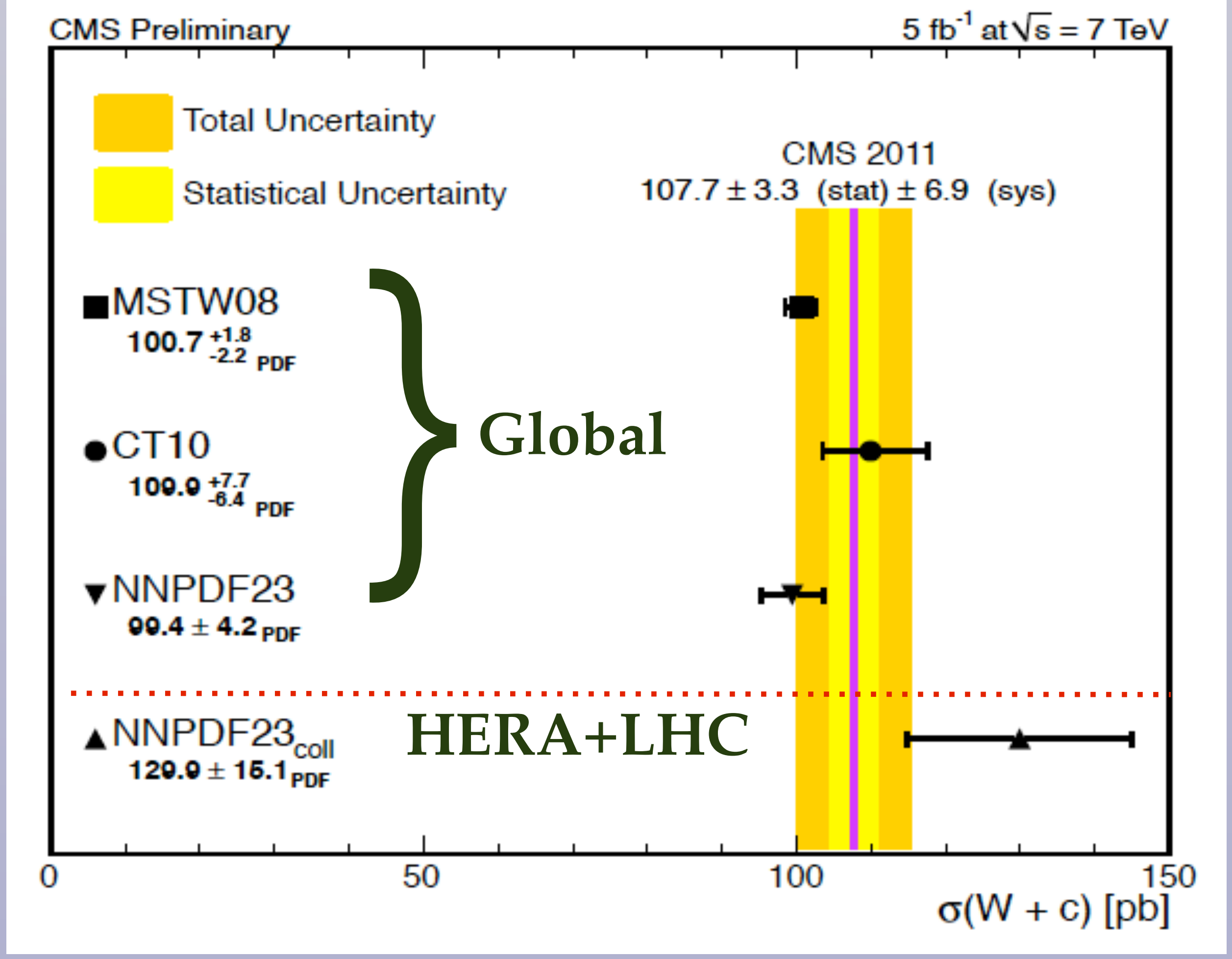


D'Enterria and J. R, arXiv:1202.1762

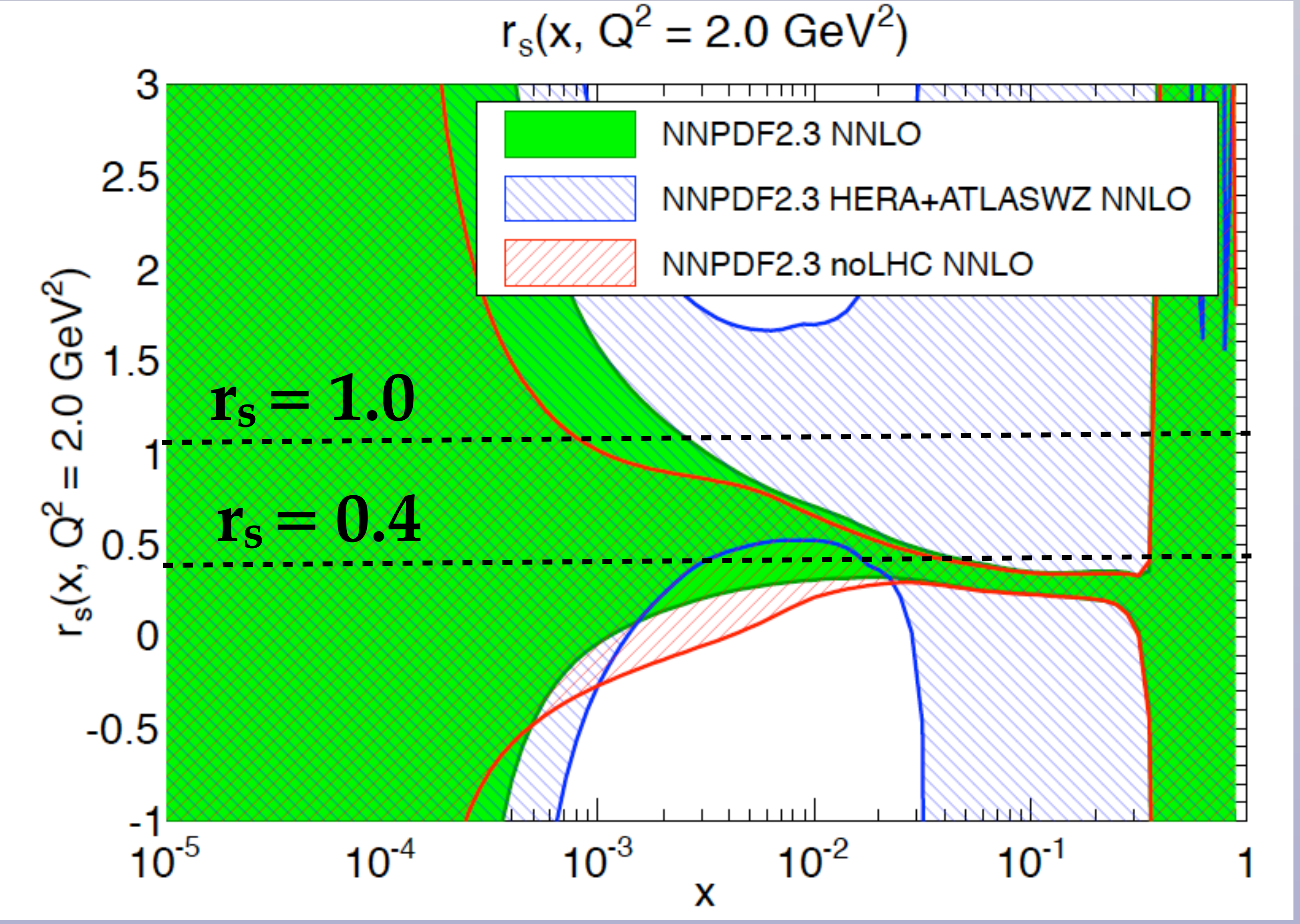
W production with charm quarks

- A PDF fit based only on **HERA, Tevatron and LHC** data (with inclusive W, Z data) favors a **symmetric strange PDF, $r_s \sim 1$**, but with large uncertainties
- **Qualitatively**, the CMS W+c direct measurement **consistent with the strangeness suppression measured in neutrino charm data, $r_s \sim 0.5$**, symmetric strange disfavored (consistent within uncertainties)
- Ongoing (NNPDF, HERAfitter): include the W+c differential distributions in **PDF fits to quantify** impact on strangeness
- No public results from ATLAS yet

$$r_s(x,Q^2) = \frac{s(x,Q^2)+\bar{s}(x,Q^2)}{2\bar{d}(x,Q^2)}$$

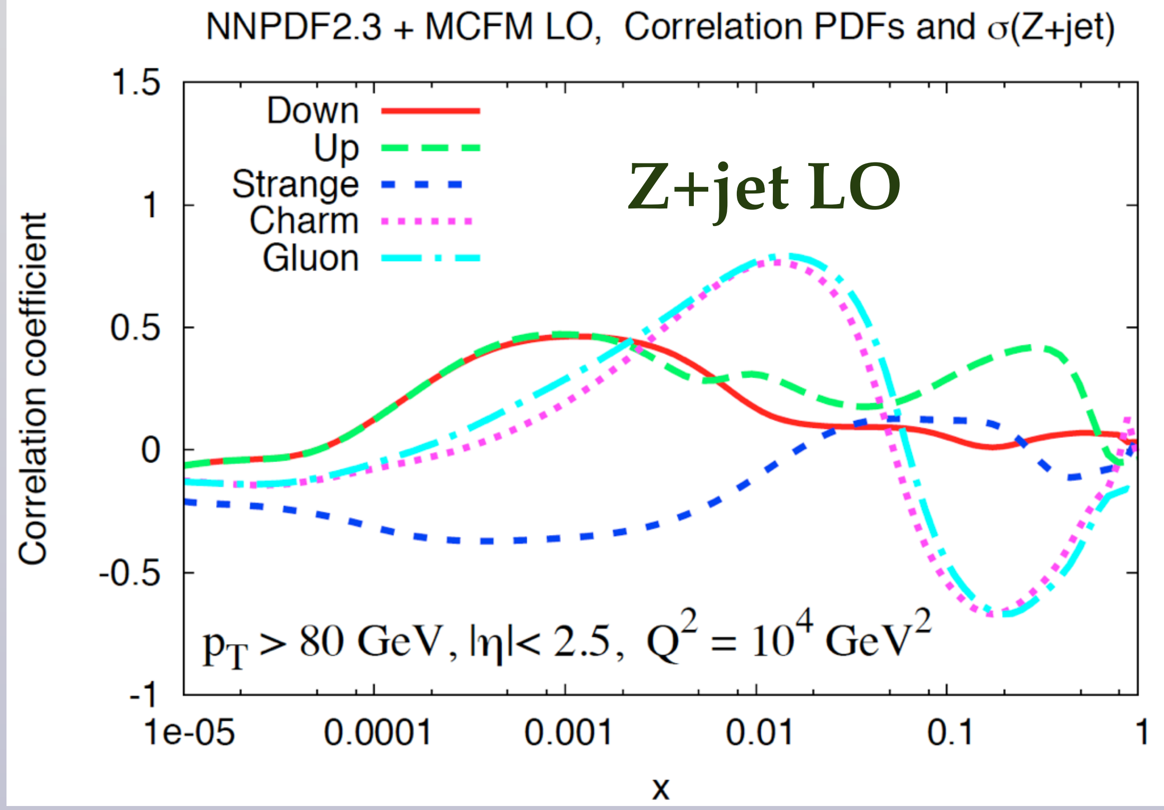


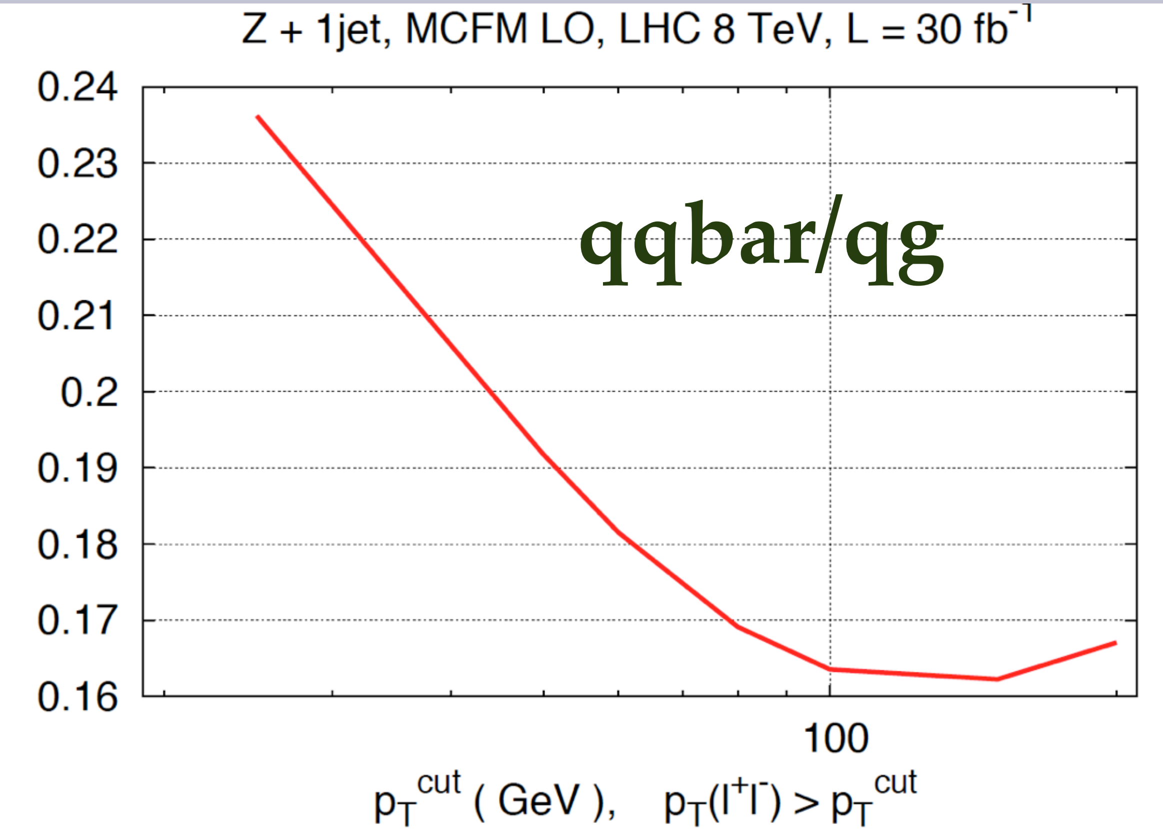
CMS-SMP-12-002



Probing the gluon with high p_T Z production

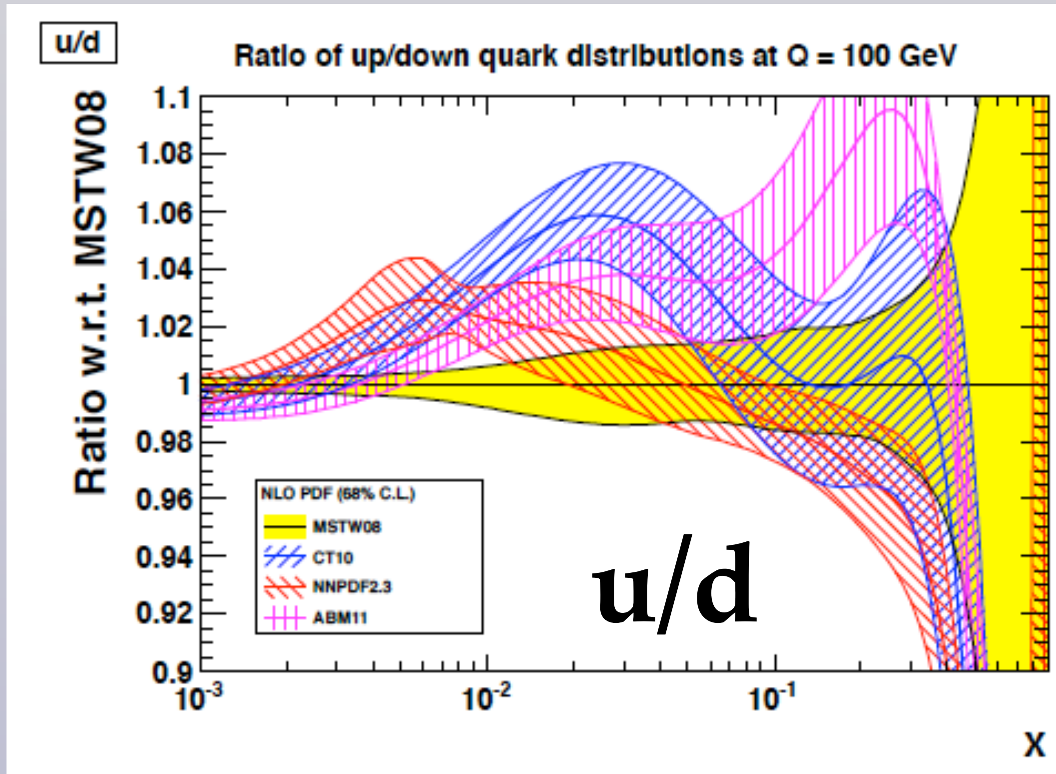
- In global PDF fits, the medium and large-x **gluon** is directly constrained by **jet data** only
- Given the crucial role of the gluon for LHC physics, **complementary LHC observables directly sensitive the gluon** would be beneficial
- One possibility is **Z/W boson production at large pT** (in association with jets). Cross section > 80% **dominated by gluon-quark scattering**
- Measurement should be only with leptons, double differential in p_T and rapidity, thus **small systematic errors** feasible
- Similar kinematic region as for **Higgs production** in gluon fusion

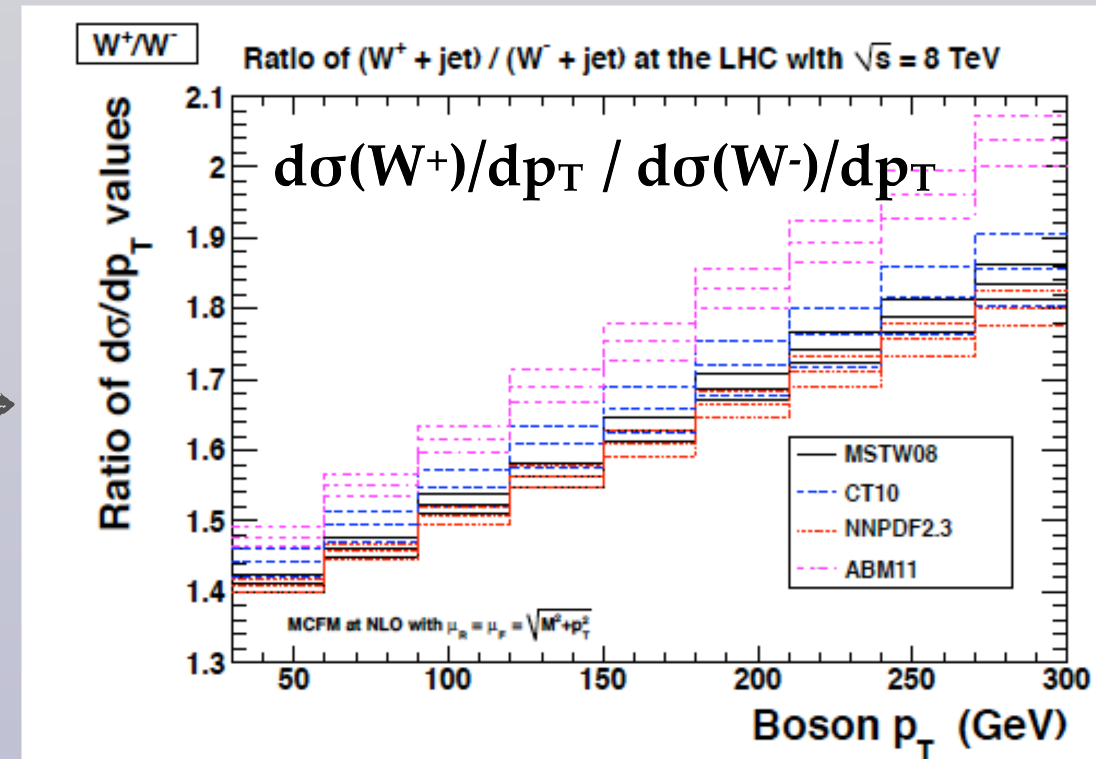


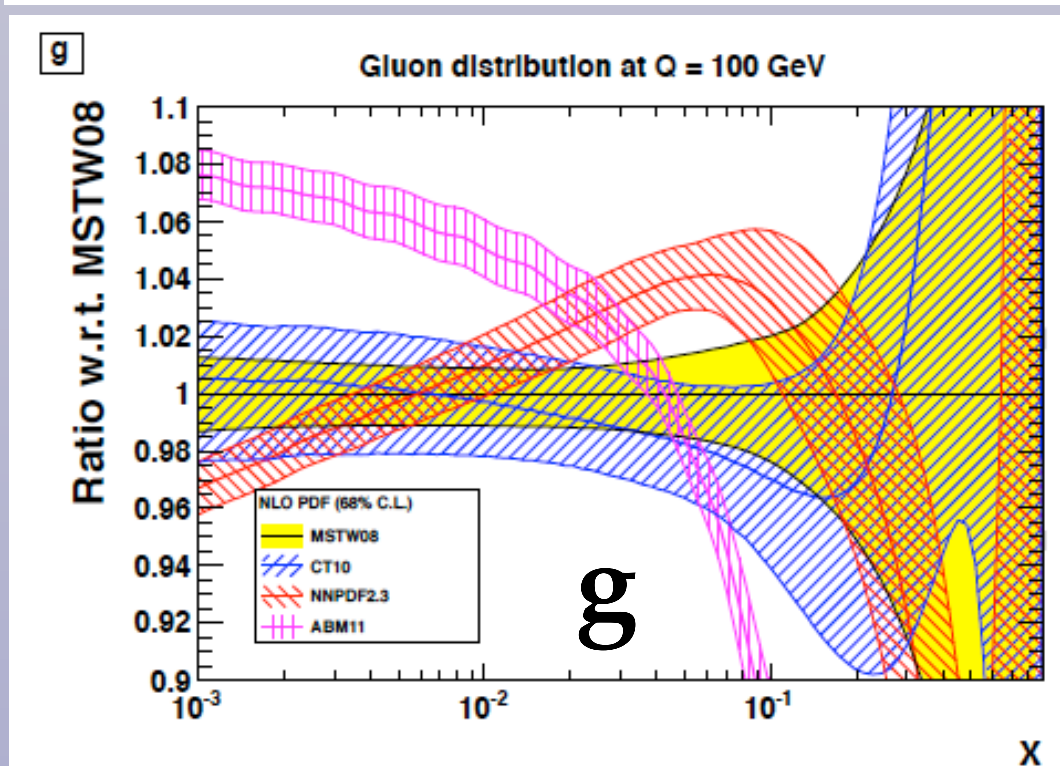


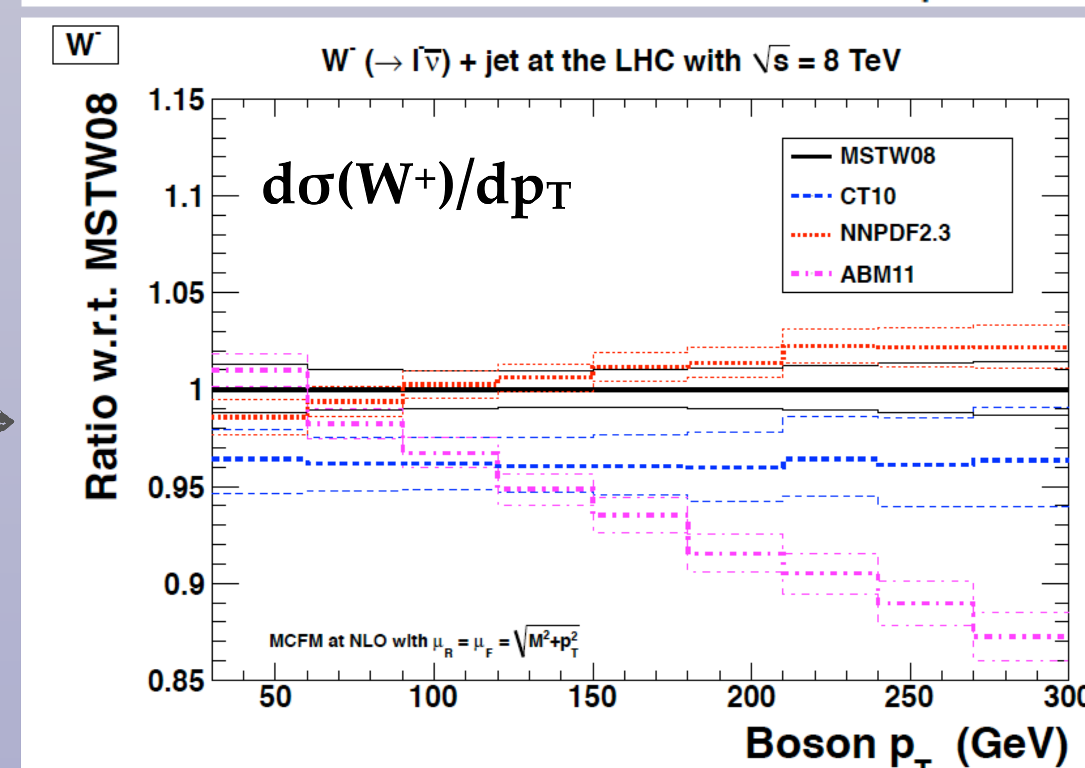
Probing the gluon with high p_T W/Z ratios

- While the **absolute W and Z pt distributions** sensitive to the **gluon PDF**, the **ratio of W+ and W-** sensitive to the **up/down ratio** (with reduced theoretical and experimental uncertainties): see **Graeme's talk**









 Malik and Watt, arxiv:1304.2424

High Mass Drell-Yan

- In global PDF fits, **fixed target Drell-Yan data** are **instrumental for quark flavor separation**, but several issues: **low energies** (thus larger scale errors), **nuclear corrections**, **no covariance matrix**: we would like to replace them with collider data

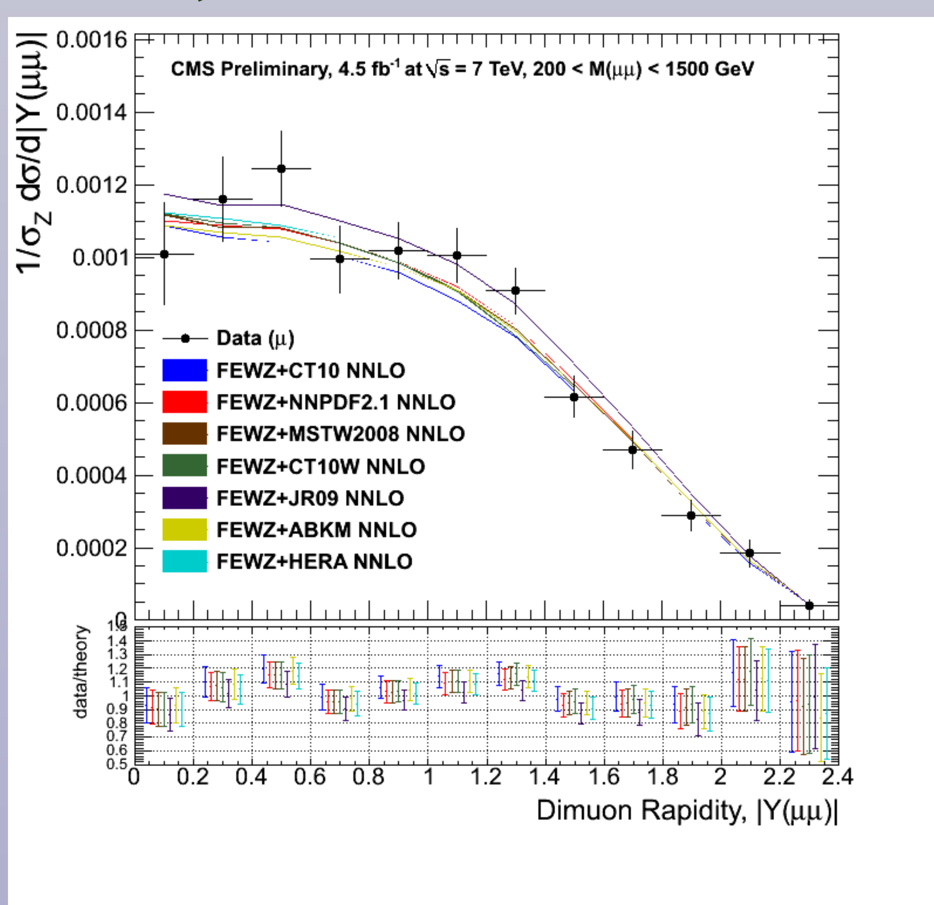
$$x_1^0 = \sqrt{\tau} e^{y} = \frac{M}{\sqrt{s}} e^{y} \, , \qquad x_2^0 = \sqrt{\tau} e^{-y} = \frac{M}{\sqrt{s}} e^{-y}$$

- At the LHC, **large mass DY** can be used to large-x quarks and antiquarks: **essential for high mass New Physics searches**

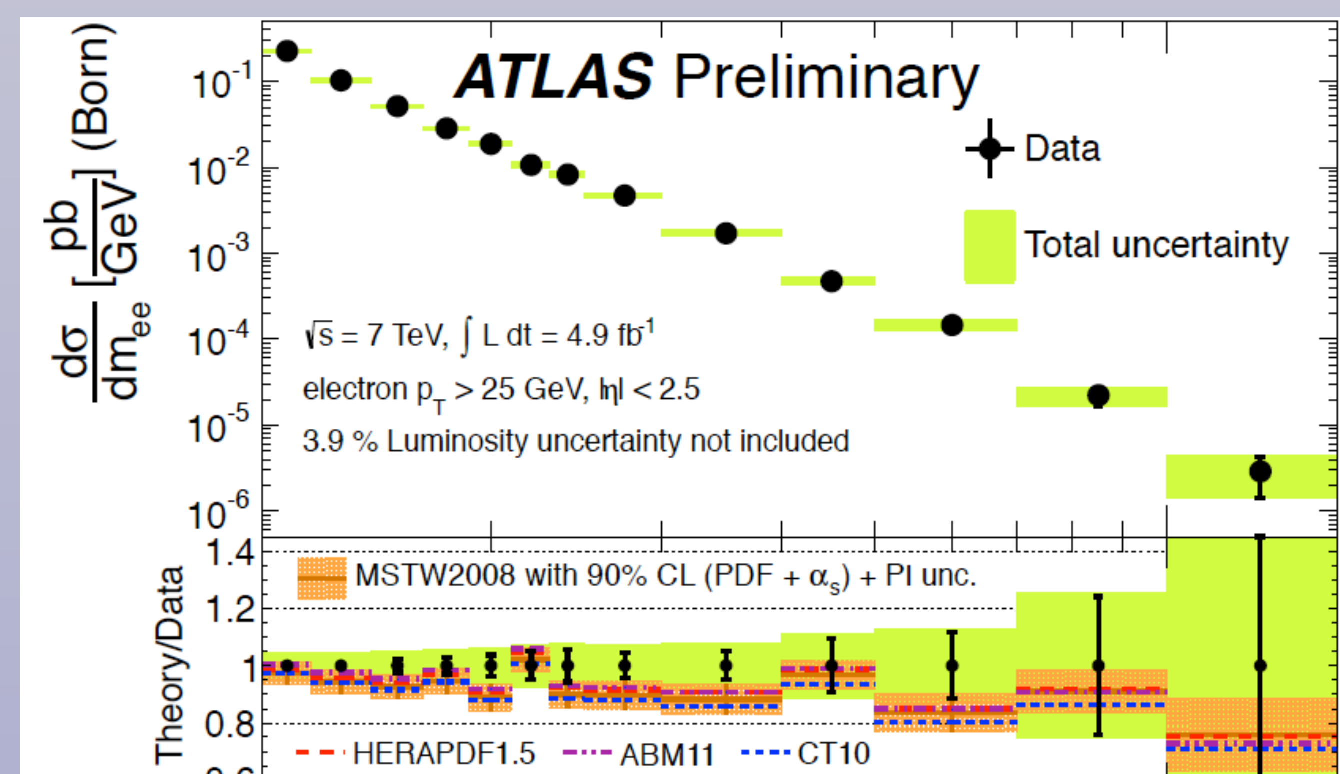
- At large masses, crucial to properly account **for electroweak corrections and photon induced processes**

- **Preliminary 7 TeV data** available both from ATLAS and CMS

CMS, $200 < M_{ee} < 1500$ GeV



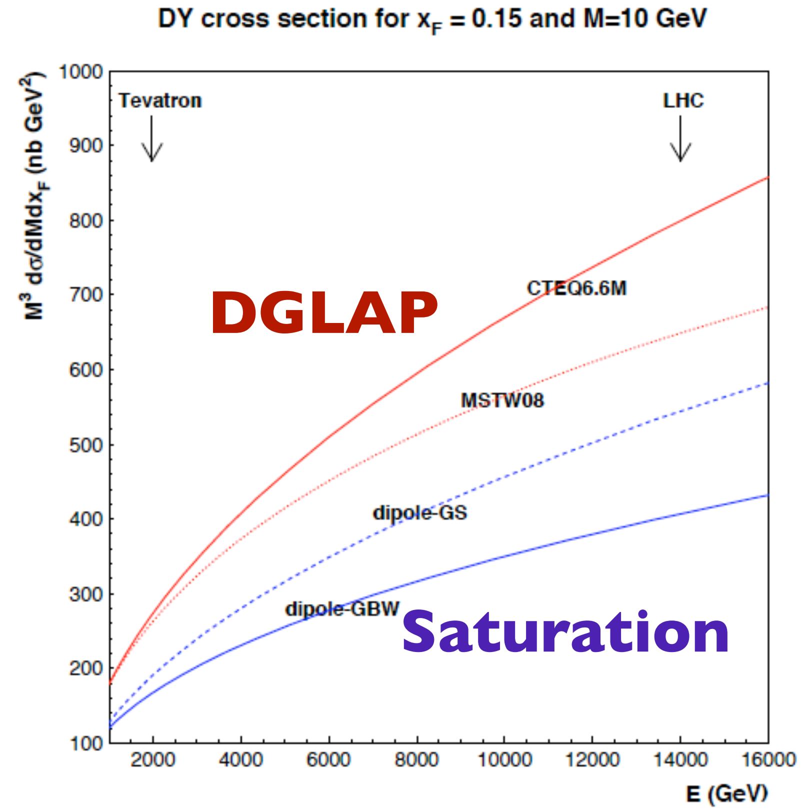
ATLAS, $116 < M_{ee} < 1500$ GeV

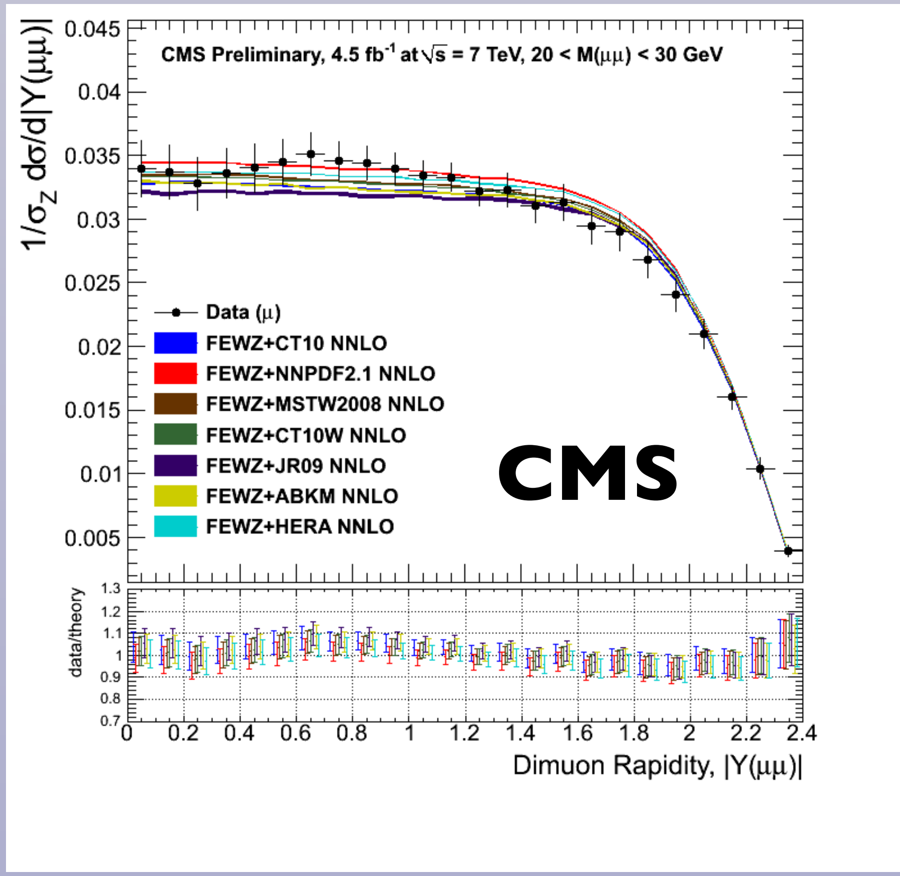


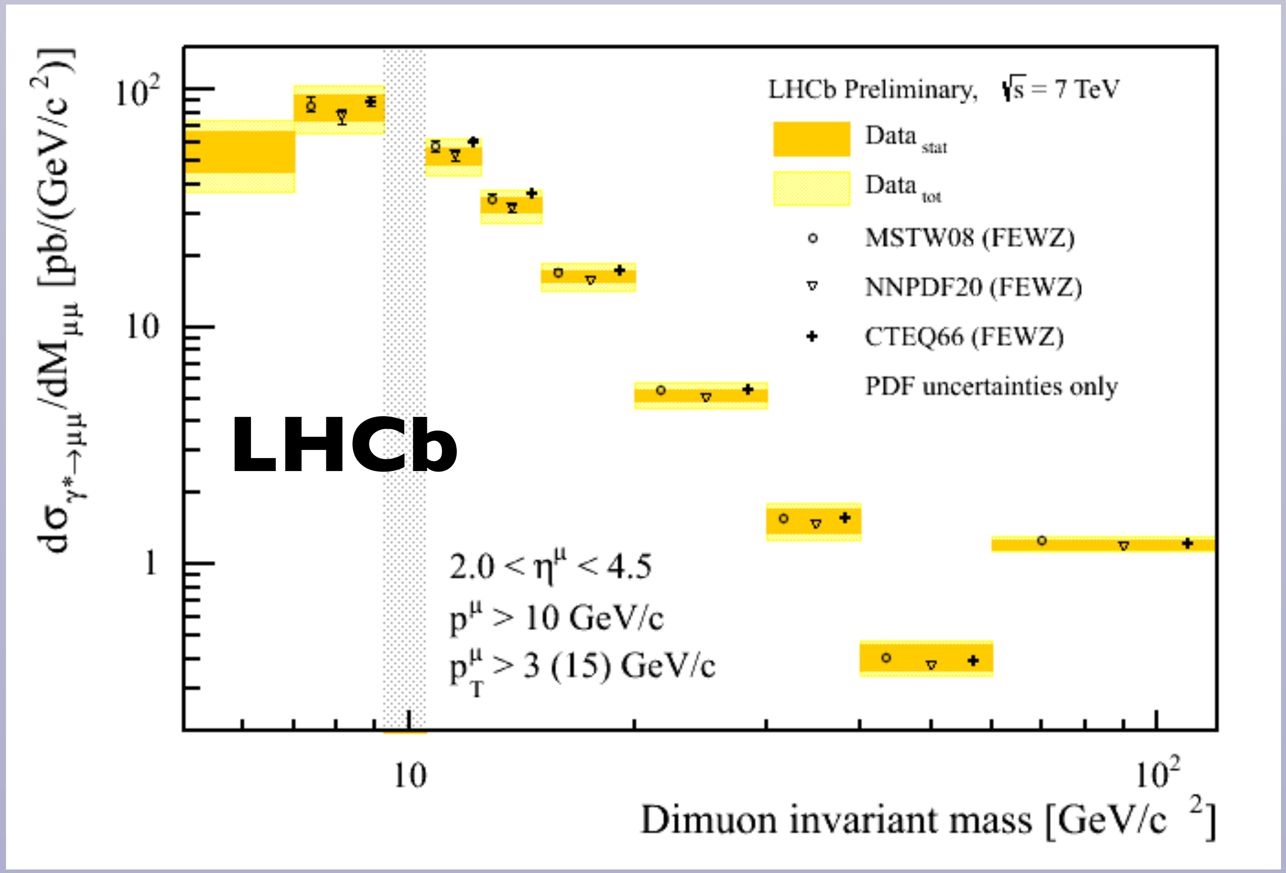
116 GeV < M < 1500 GeV

Low Mass Drell-Yan

- **Low mass DY** could constraints small-x gluon, but need resummed calculations for reliable results
- Potentially relevant for tests of **new regimes of QCD**, like saturation models, or high energy scenarios
- Data available from CMS and LHCb, what about ATLAS?
- PDF sensitivity enhanced by the **forward region** in LHCb kinematics







Top quarks as gluon luminometers

- Top quark pair production at the LHC is **directly sensitive to the gluon luminosity**, thus provides a potential new observable to constrain gluons in **global PDF analysis**

- The availability of the **full NNLO calculation** provides the first ever hadronic observable, **directly sensitive to the gluon**, that can be included in a **NNLO global fit**

In addition, reduced non-perturbative corrections as compared to photons and jets

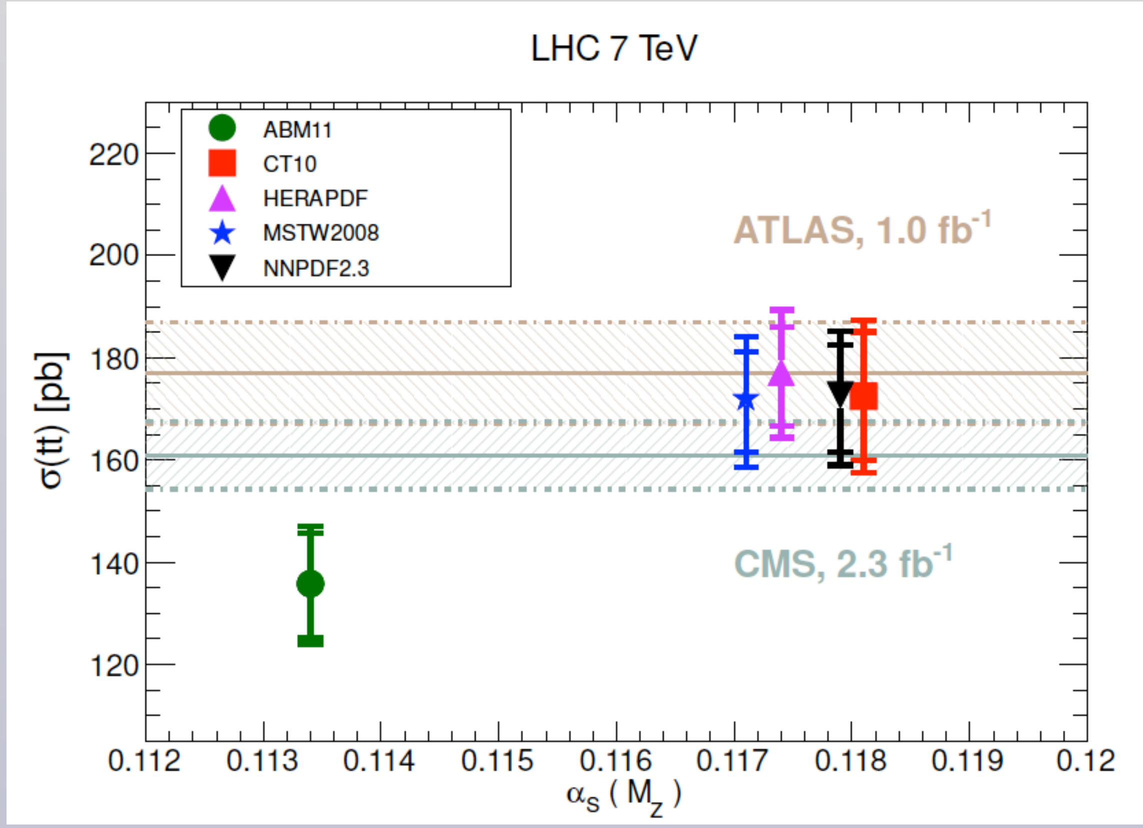
	TeVatron	LHC 7 TeV	LHC 8 TeV	LHC 14 TeV
gg	15.4%	84.8%	86.2%	90.2%
$qg + \bar{q}g$	-1.7%	-1.6%	-1.1%	0.5%
qq	86.3%	16.8%	14.9%	9.3%

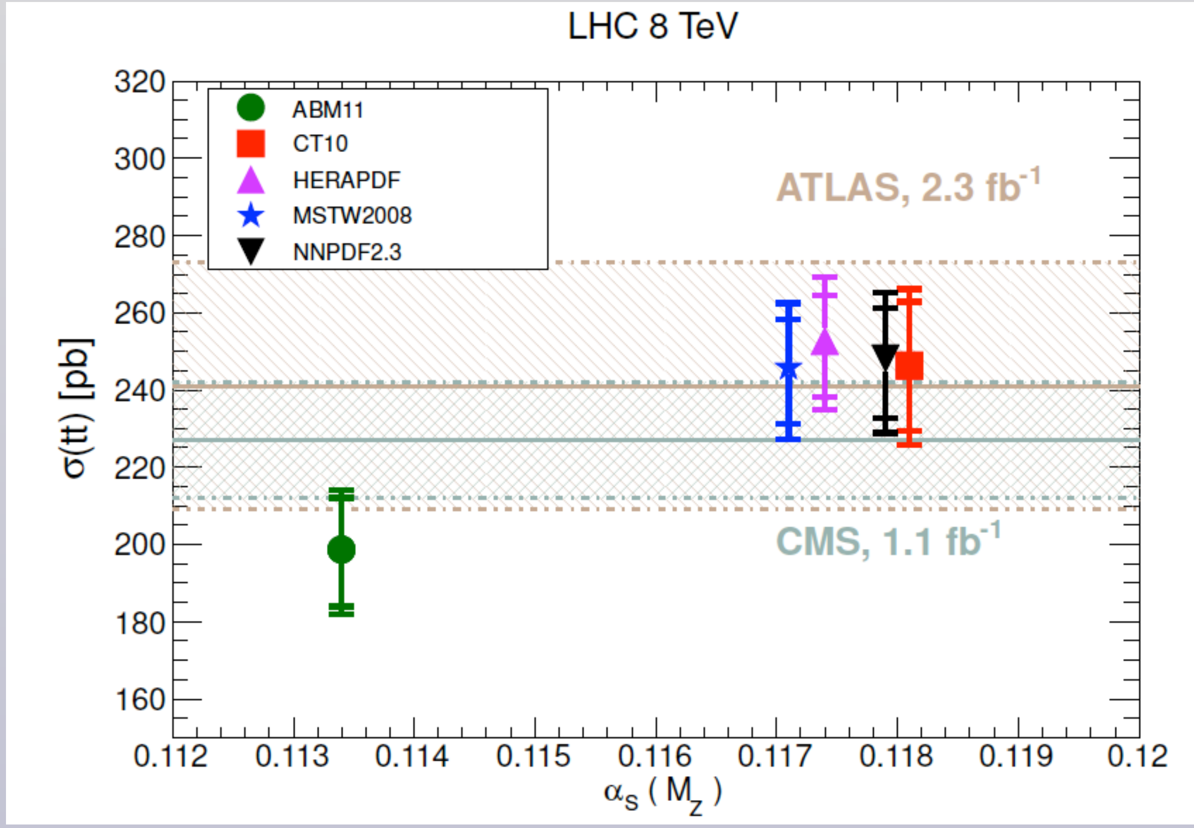
Contribution to the NNLO+NNLL cross section from different subprocesses

In recent paper we explored the **phenomenology of the NNLO top cross-section,** here show an overview of selected results

Czakon, Mangano, Mitov, Rojo, arXiv:1303.7215

Top quarks as gluon luminometers





Most PDF sets provide a **good quantitative description** of Tevatron and LHC top data

$$\chi^2 = \sum_{i=1}^{N_{\rm dat}} \frac{\left(\sigma_{t\bar{t}}^{(\rm exp)} - \sigma_{t\bar{t}}^{(\rm th)}\right)^2}{\delta_{\rm tot}^{(\rm exp)2}}$$

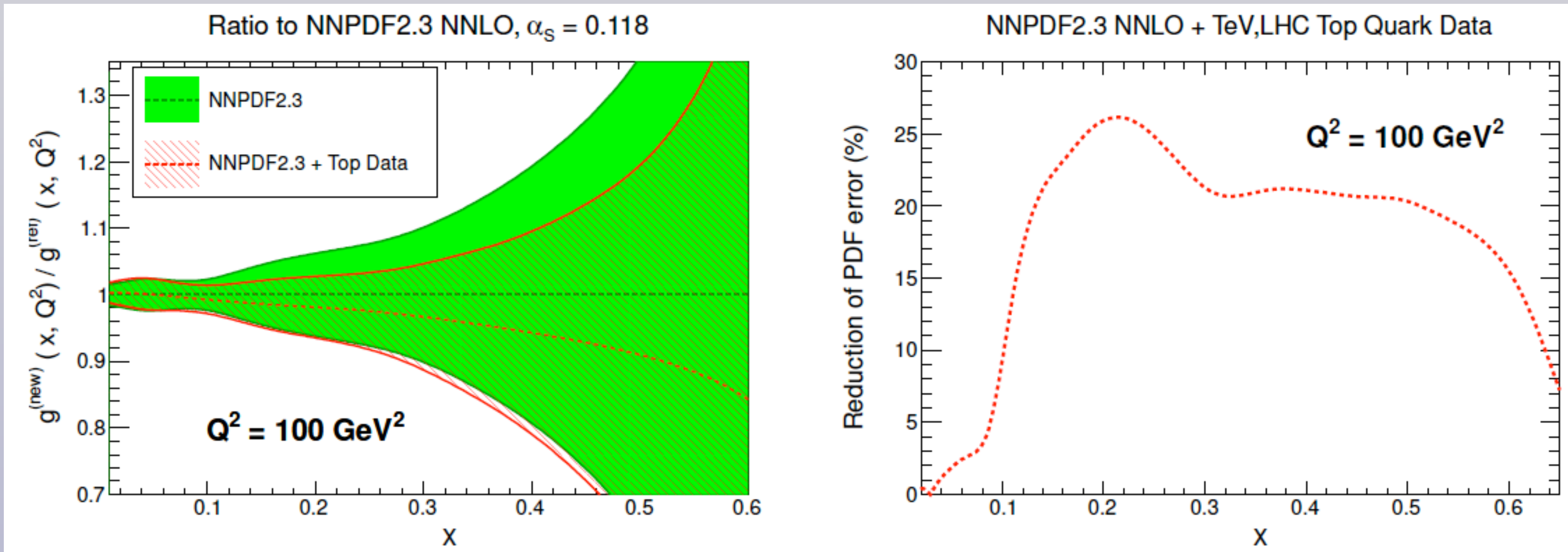
$$P = \frac{1}{N_{\rm dat}} \sum_{i=1}^{N_{\rm dat}} \frac{\left(\sigma_{t\bar{t}}^{(\rm exp)} - \sigma_{t\bar{t}}^{(\rm th)}\right)^2}{\delta_{\rm tot}^{(\rm exp)2} + \delta_{\rm tot}^{(\rm th)2}}$$

	$\chi^2_{\rm tev}$	$\chi^2_{\rm lhc7}$	$\chi^2_{\rm lhc8}$	$\chi^2_{\rm tot}$	$\chi^2_{\rm tot}/N_{\rm dat}$	P
AMB11	3.5	31.4	5.3	40.2	8.0	3.2
CT10	0.4	3.3	1.7	5.3	1.1	0.3
HERAPDF15	0.0	6.1	3.1	9.2	1.8	0.5
MSTW08	1.3	3.1	1.6	6.0	1.2	0.4
NNPDF2.3	0.9	3.4	2.0	6.3	1.3	0.4

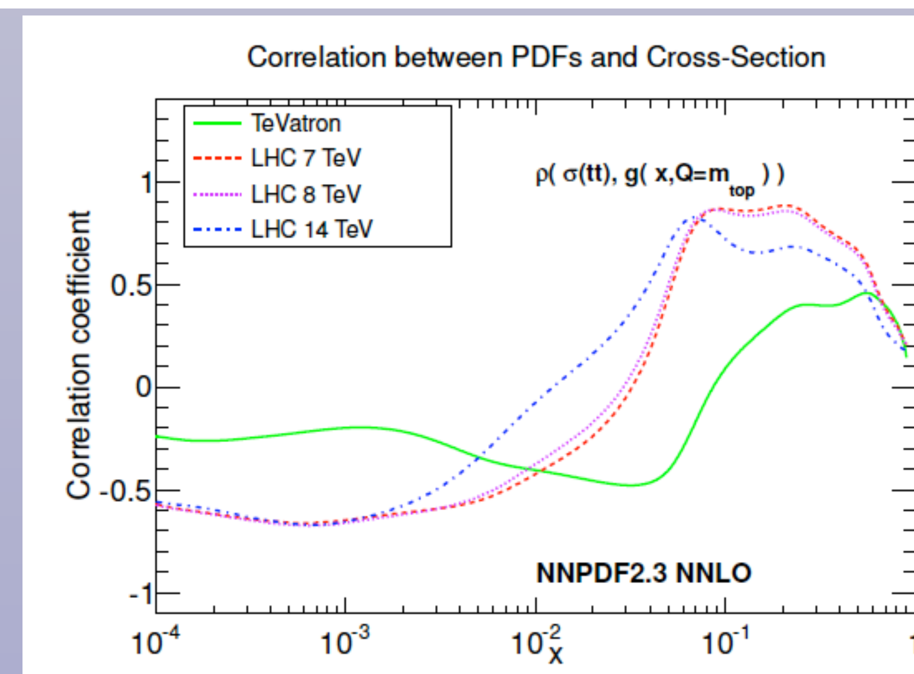
LHC top data already discriminates between PDF sets

Top quarks as gluon luminometers

- Top quark cross-section data **discriminates between PDF sets**
- In addition, it can also be used to **reduce the PDF uncertainties** within a single PDF set
- Included the most precise top quark data into the **NNPDF2.3** global PDF analysis



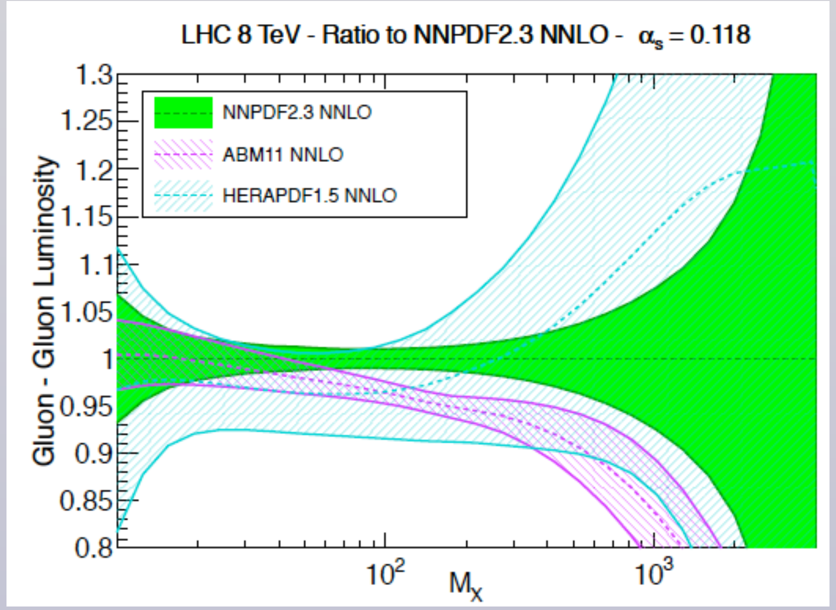
- Top quark cross-section data **reduces the PDF uncertainty** in the **large-x gluon** by up to **20%**
- The impact is restricted to the region between **0.1<x<0.5**, where the correlation between the gluon and the top cross section is most significant



Juan Rojo

Top quarks as gluon luminometers

- PDF fits based on **reduced datasets**, such as HERAPDF, display **large PDF uncertainties for the gluon** due to the lack of direct constraints

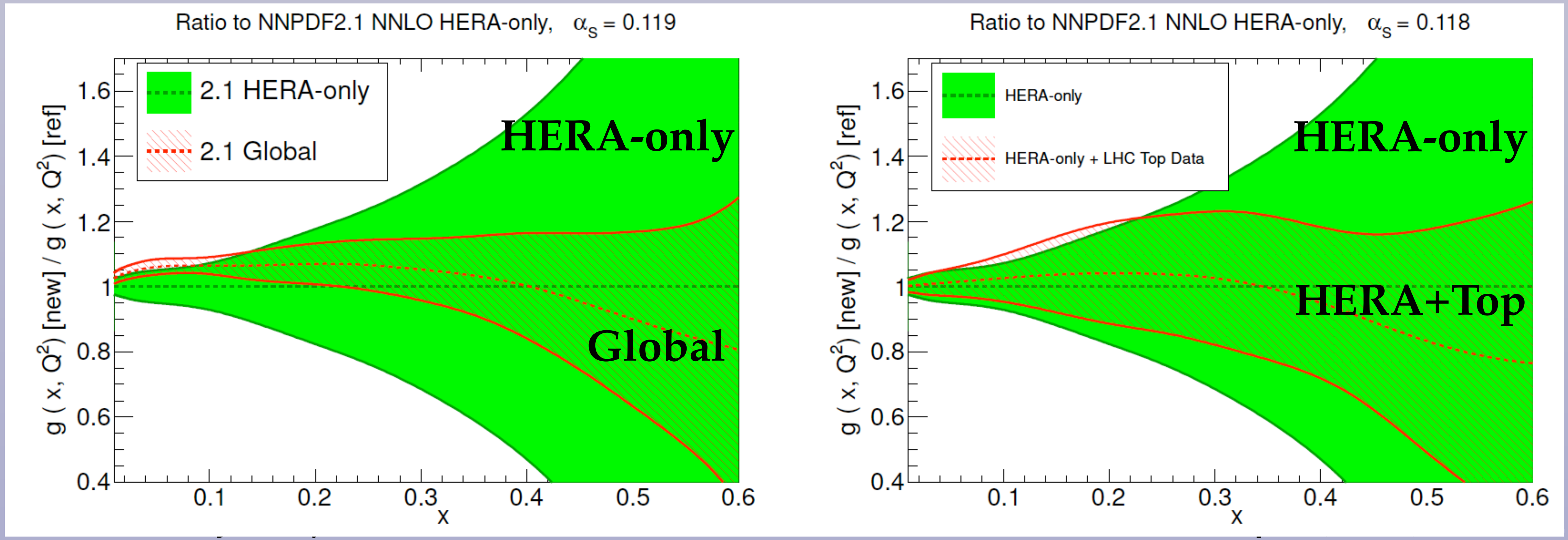


gg luminosity

- Top quark data can be included in a **NNLO fit based on HERA data**

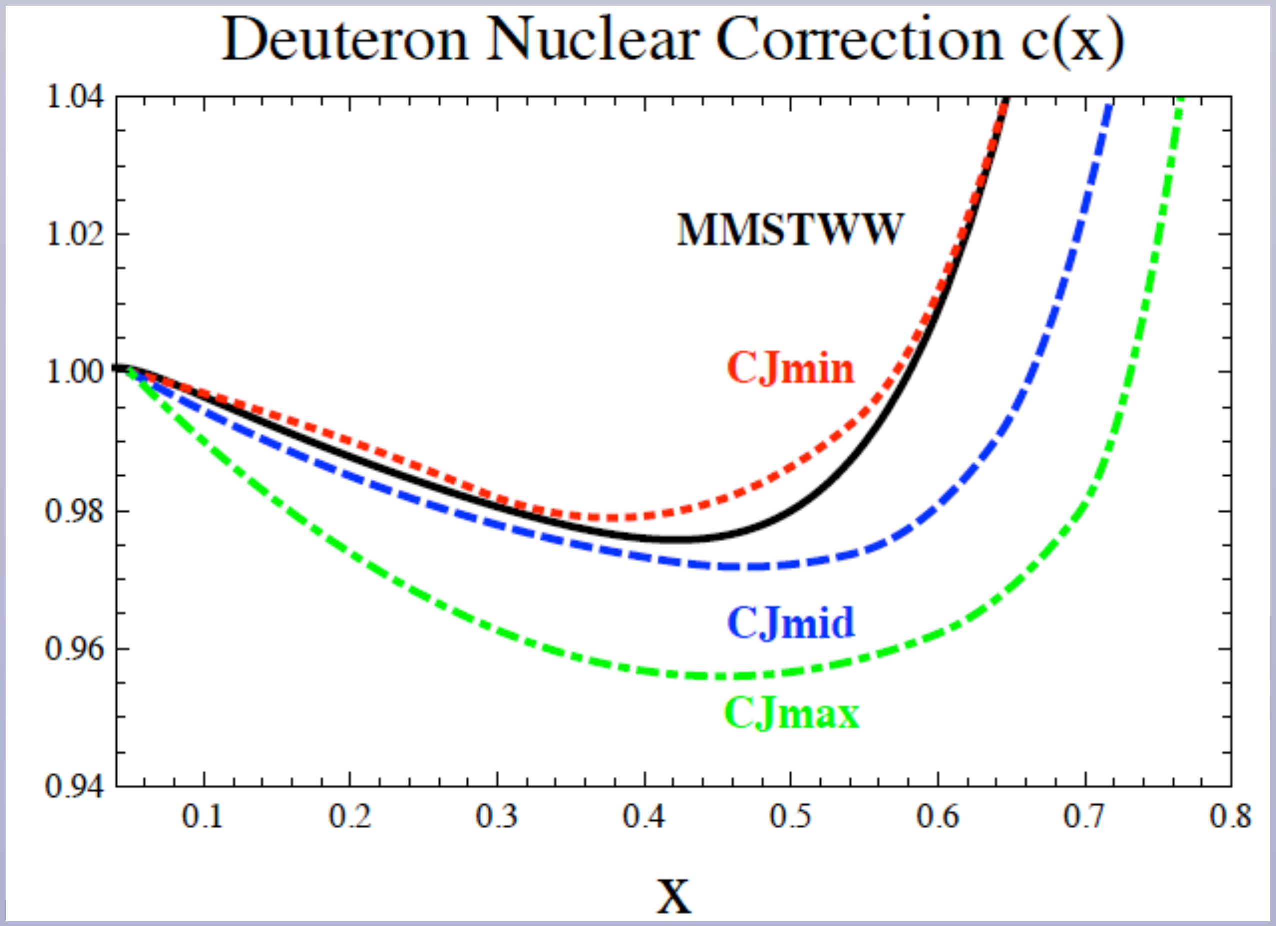
  Substantial reduction of PDF uncertainties

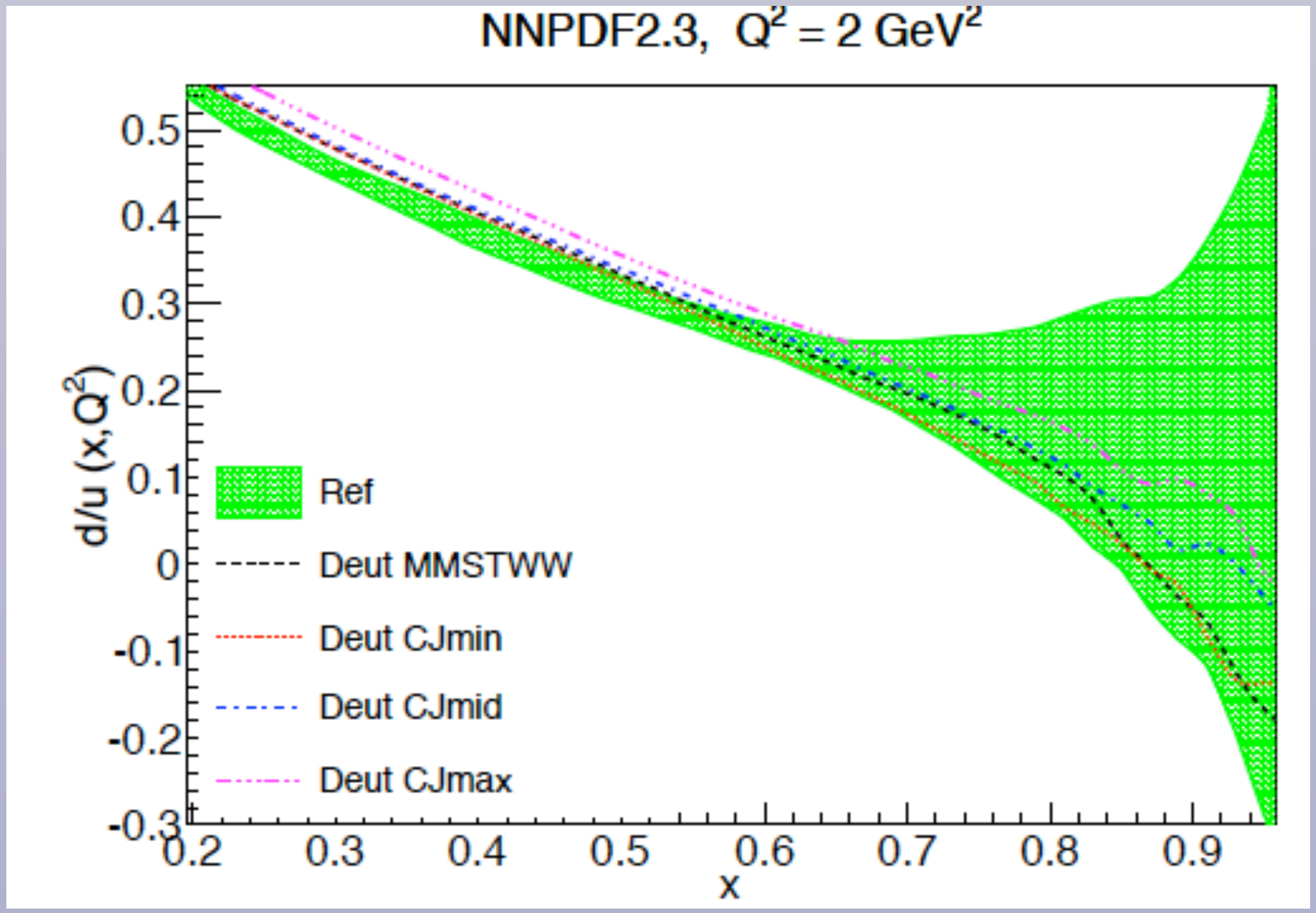
  The HERA+Top gluon PDF is close to the gluon from the global PDF fit



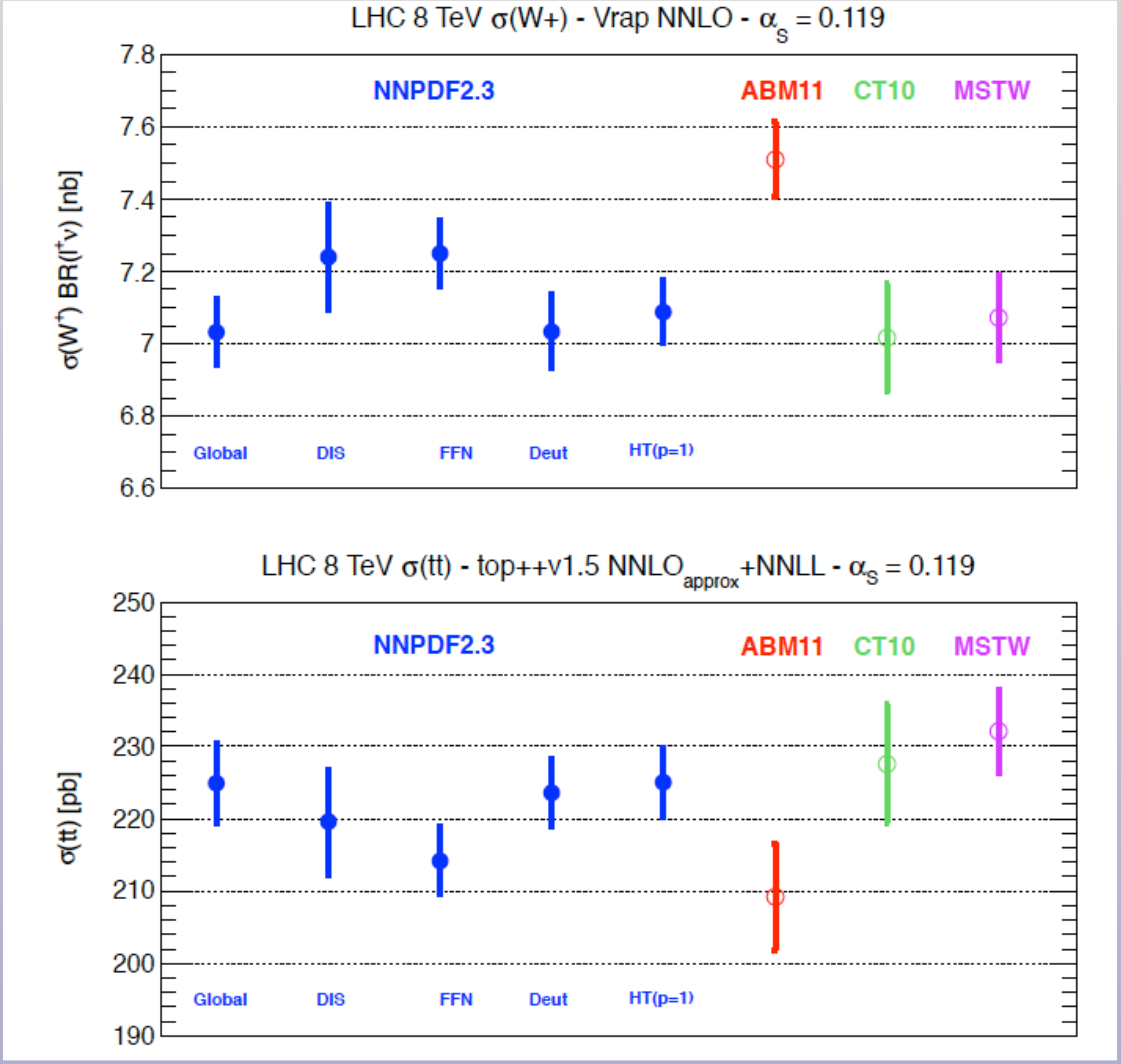
Deuteron corrections

- NNPDF explored the impact on their fit for different models of nuclear corrections
- Small impact at the level of inclusive LHC observables
- For MMSTWW phenomenological model, **fit quality essentially unaffected**
- Relevant for **d/u ratio for 0.1 < x < 0.5**
- Determination of **d/u not reliable at large-x** due to blow-up of PDF uncertainties





Theoretical uncertainties and LHC predictions



- The use of **DIS only data** and a **FFN scheme** both move NNPDF closer to the ABM11 predictions
- **Higher twists** and **deuteron corrections** minimal impact at the level of LHC benchmark processes