Update on PDF benchmarks

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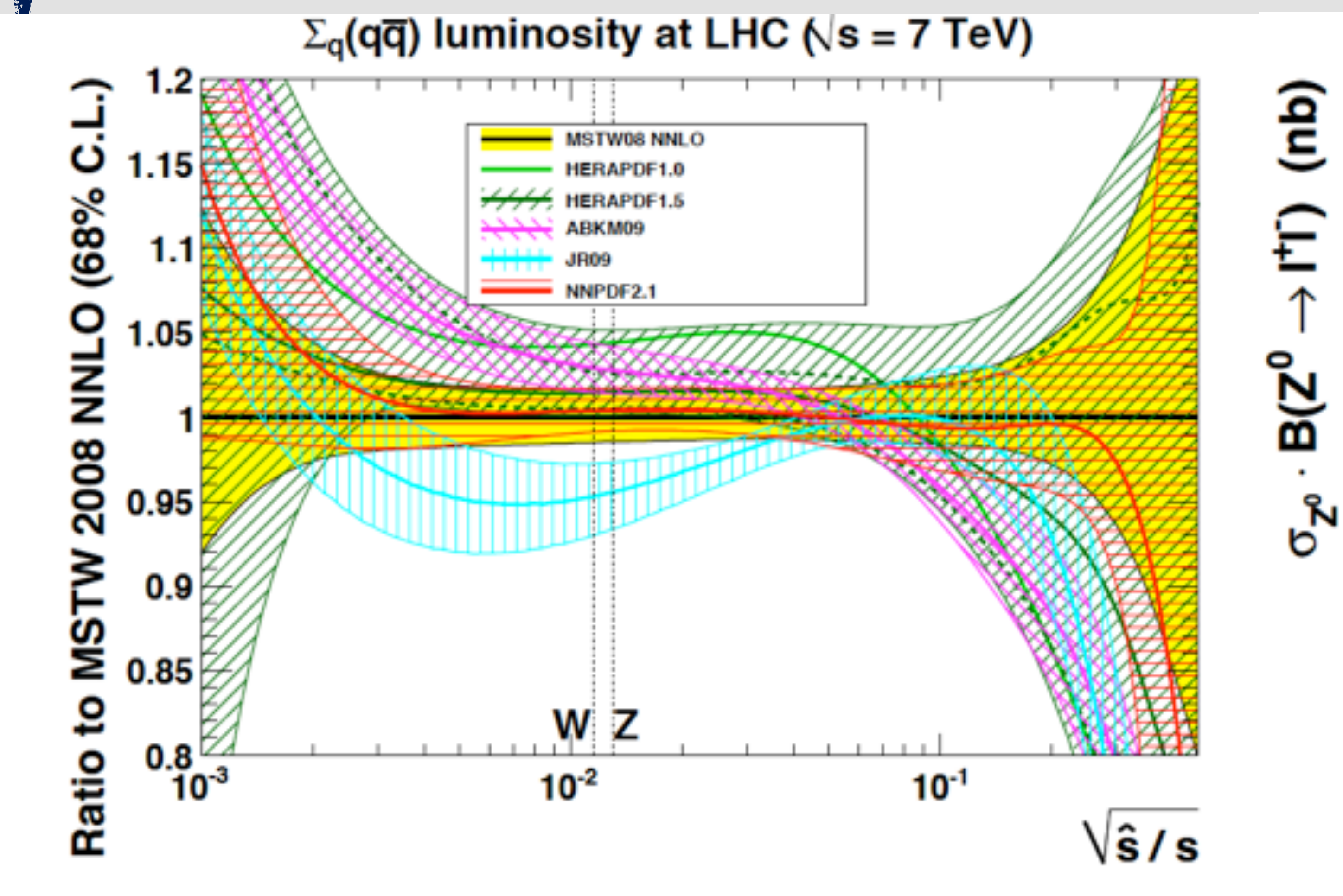
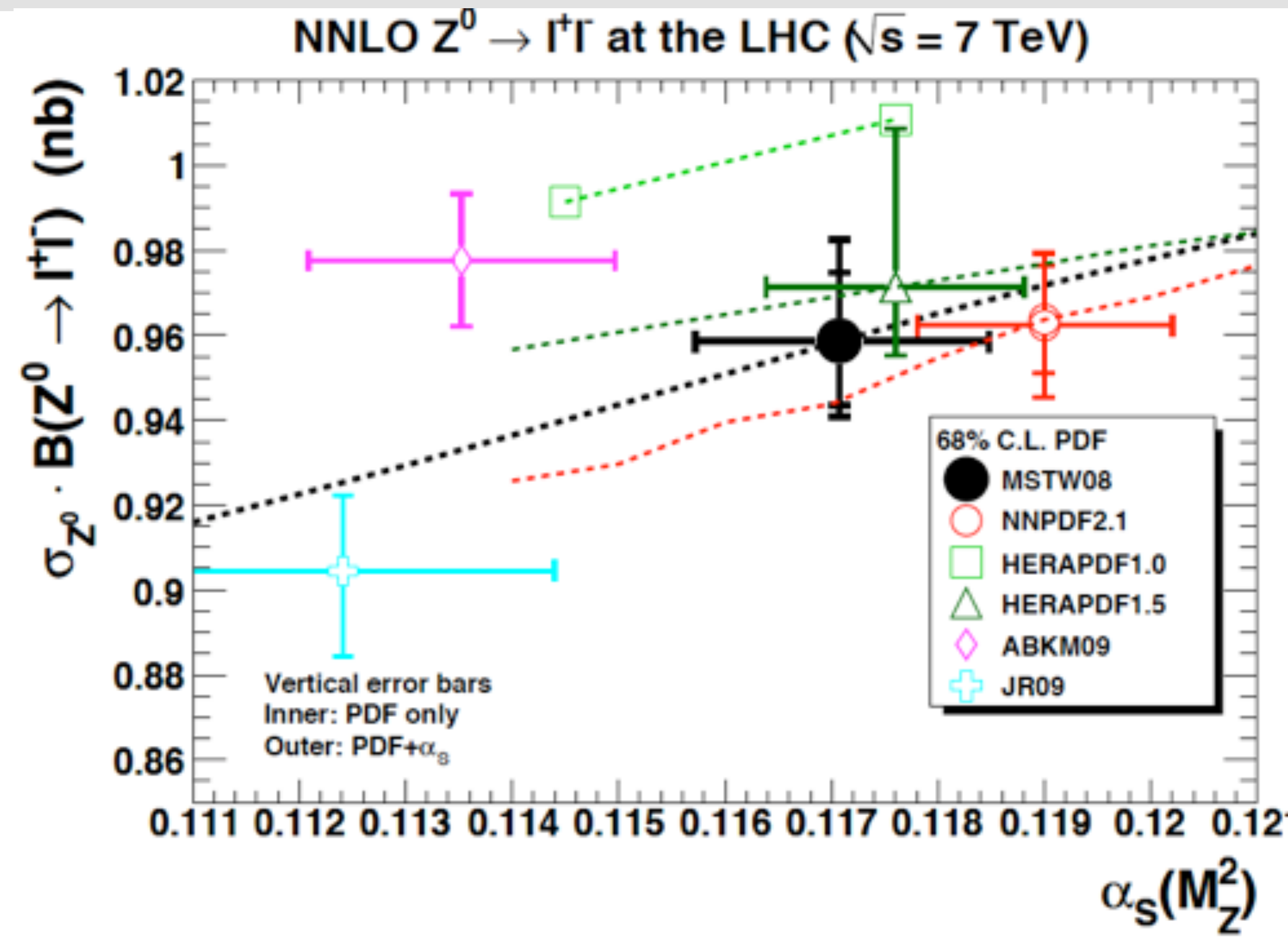
PDF4LHC Workshop 09/12/2012

(See also my PDF4LHC talk 10/2012 for more results)

PDF benchmarking - 2010/2011

- **Systematic PDF benchmarking** studies using 2010/2011 PDFs by **G. Watt** (arxiv:1106.5788,1201.1295)
- Instrumental to understand in a systematic way common aspects and differences between PDF sets. Input to the current **PDF4LHC interim report** and **recommendations**





- Our aim is to update t**his benchmarking exercise** with **2012 NNLO PDF**s and with all the available (inclusive and differential) **LHC data**

PDF benchmarking with LHC data

In collaboration with Richard D. Ball, Stefano Carrazza, Luigi Del Debbio, Stefano Forte, Jun Gao, Nathan Hartland, Joey Huston, Pavel Nadolsky, Daniel Stump, Robert S. Thorne, C.-P. Yuan

arXiv:1211.5142, submitted to JHEP

PDF benchmarking

- Since last benchmark study new PDF sets have been released:
  - **NNPDF2.3**: inclusion of ATLAS, CMS and LHCb W,Z and jet data (arXiv:1207.1303)
  - **ABM11**: HERA-I data, running heavy quark masses, N_F=5 PDF sets for different values of α_S (arXiv:1202.2281)
  - **CT10 NNLO**: update of CT10 NLO with the same dataset (arXiv:1206.3321)

- In addition, LHC **7 TeV differential distributions** with covariance matrix and **8 TeV inclusive cross sections** are also available
- Thus a **new detailed benchmarking exercise** is timely and useful for the community (*ie* as input for new PDF4LHC recommendations)

- **JR09** not included because PDF sets provided for single value of α_S = **0.1134**: not possible to **consistently compare** with all other PDF sets

PDF benchmarking

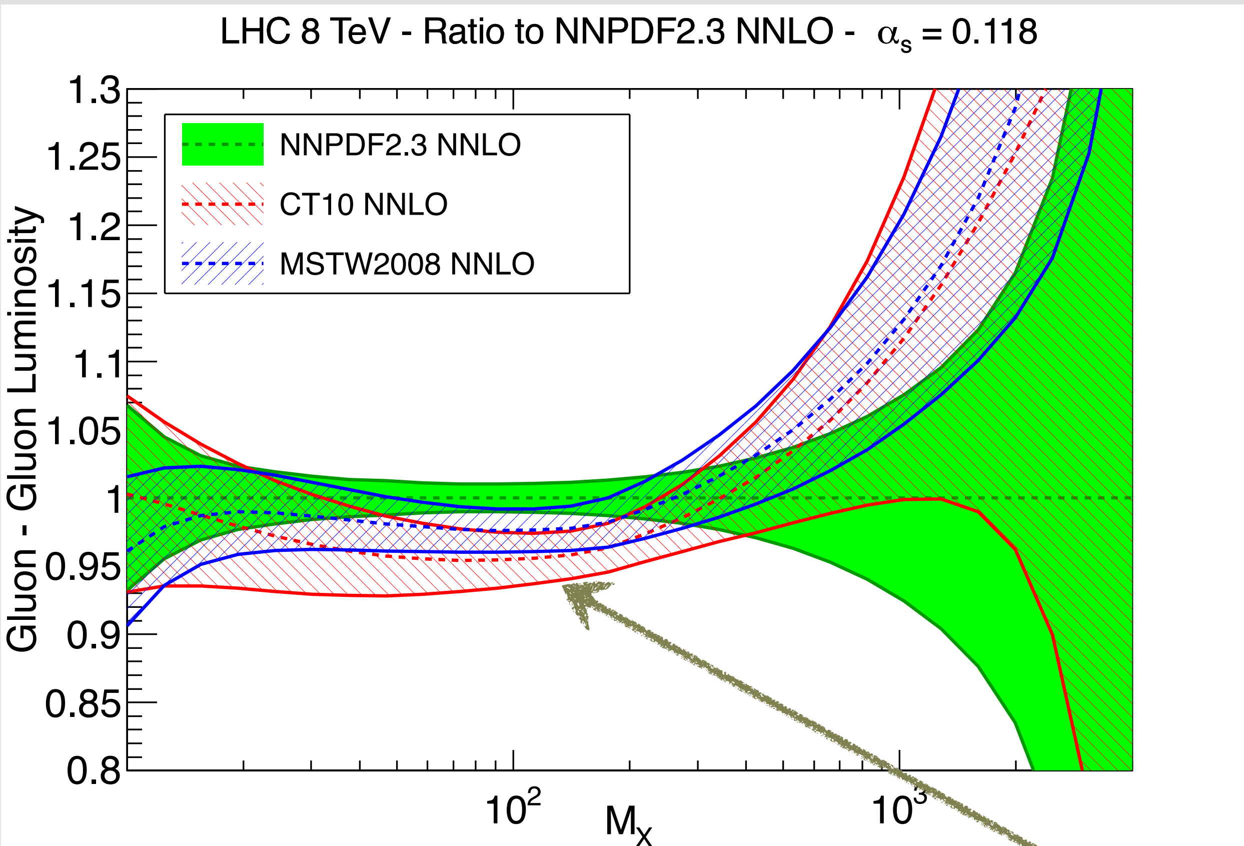
- We compare the **most updated NNLO PDFs** from NNPDF, CT, MSTW, ABM and HERAPDF collaborations
- We first compare **PDFs** and then **parton luminosities**
- We compute inclusive **benchmark cross sections** (including Higgs) and compare them with recent LHC 8 TeV data when available
- We compute also **differential distributions** for jets and W/Z production and compare them for LHC data with full the covariance matrix: **ATLAS W/Z** 2010 data, **ATLAS 2010 jets**, **CMS 2011 W electron asymmetry** and **LHCb 2010 W/Z** data
- Data/theory agreement is quantified by a χ^2 **estimator**
- In this talk we show a **small subset** of available benchmark results. The complete set of plots, results for NLO/NNLO, ratio plots, different α_S values available online in **HepForge:**

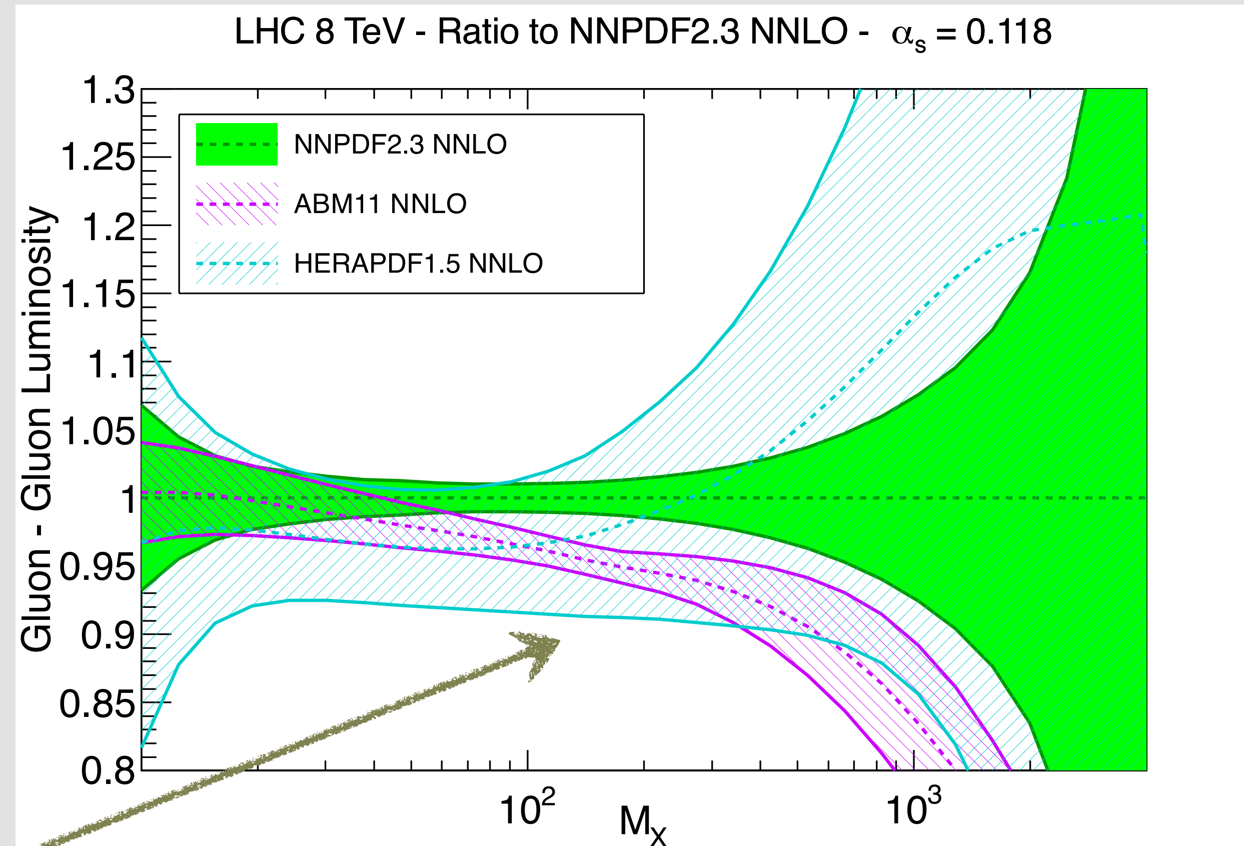
http://nnpdf.hepforge.org/html/pdfbench/catalog/

- Today emphasis is put on the **new results** since the Oct PDF4LHC talk

PDF Luminosities: Gluon-Gluon

$$\Phi_{ij}\left(M_X^2\right) = \frac{1}{s}\int_\tau^1 \frac{dx_1}{x_1} f_i\left(x_1, M_X^2\right) f_j\left(\tau/x_1, M_X^2\right)$$



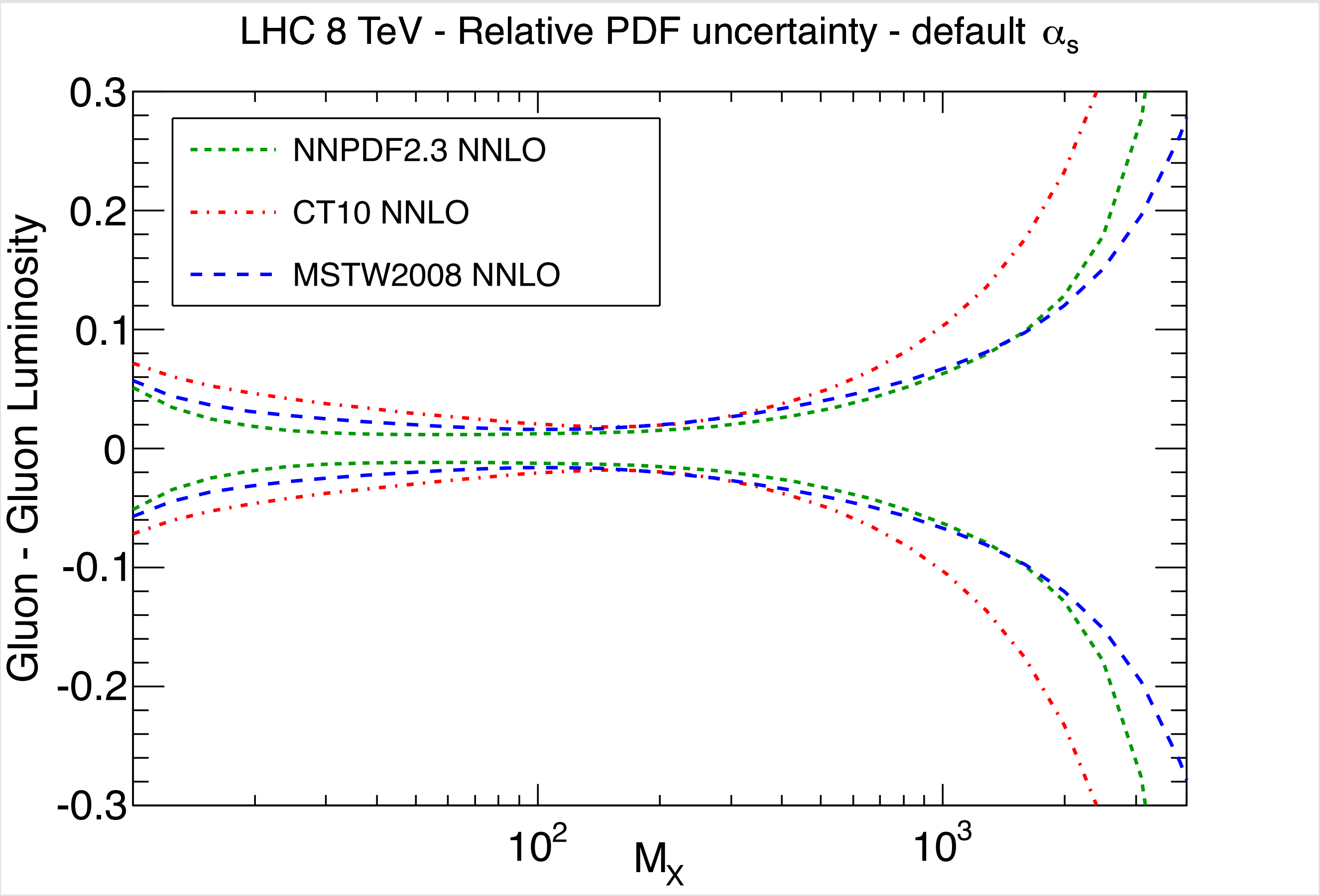


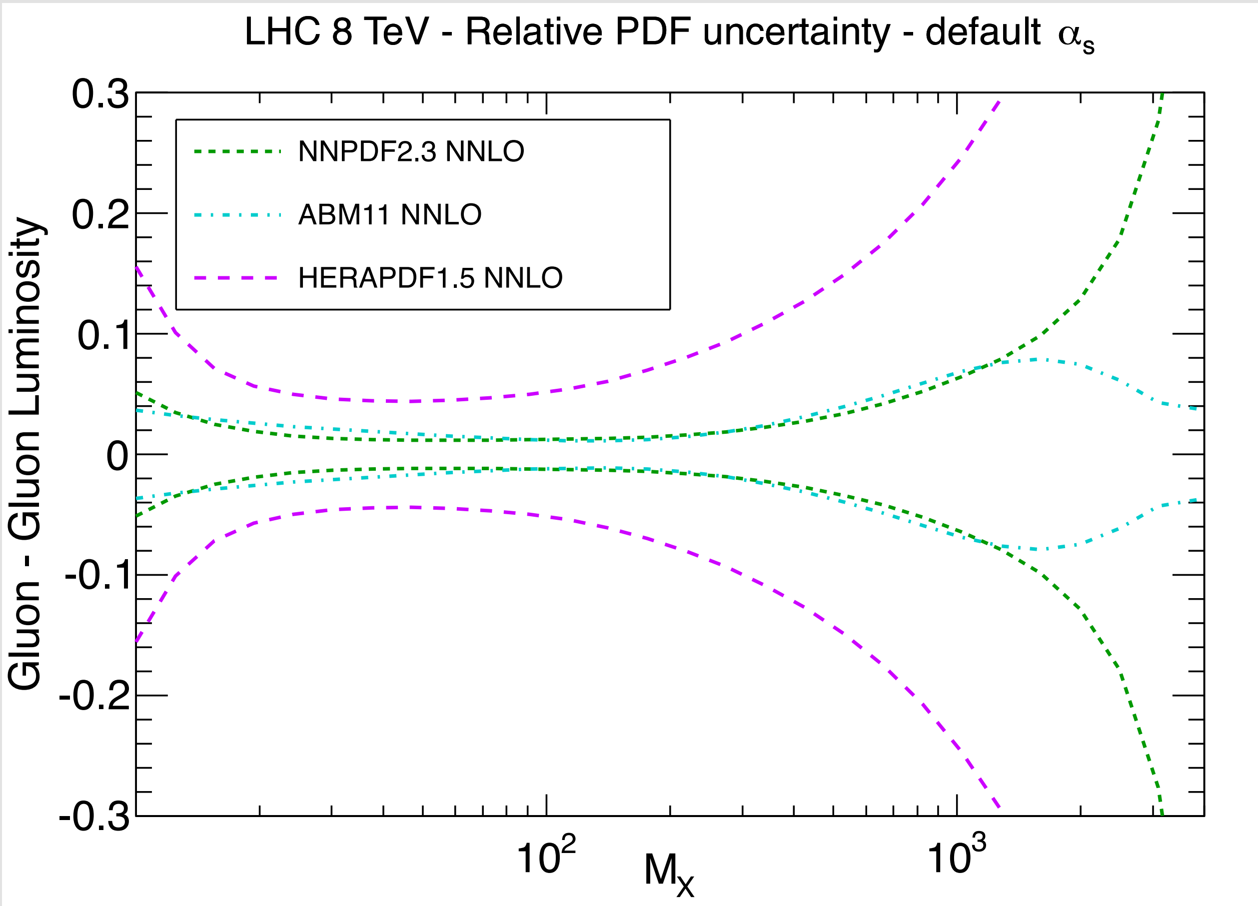
M_H=125 GeV

- **Good agreement** between **CT, MSTW, NNPDF** in the whole mass range
- ABM11 inconsistent with CT, MSTW, NNPDF except at low masses - but only for common α_S, much softer gluon luminosity if default **α_s=0.1134** were to be used
- HERAPDF1.5 consistent with MSTW with much **larger PDF uncertainties**

PDF Luminosities: Gluon-Gluon

$$\Phi_{ij}\left(M_X^2\right) = \frac{1}{s}\int_\tau^1 \frac{dx_1}{x_1} f_i\left(x_1, M_X^2\right) f_j\left(\tau/x_1, M_X^2\right)$$

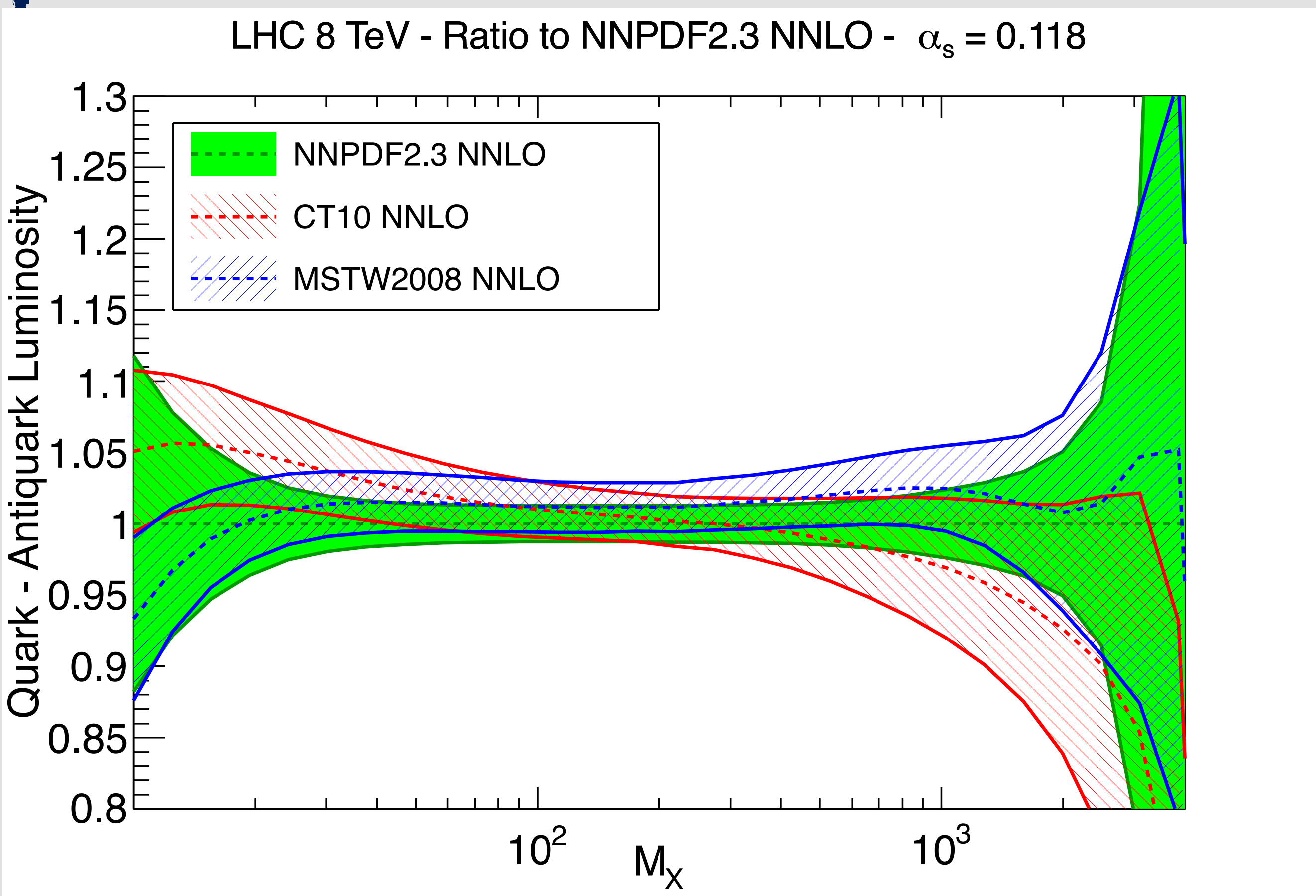


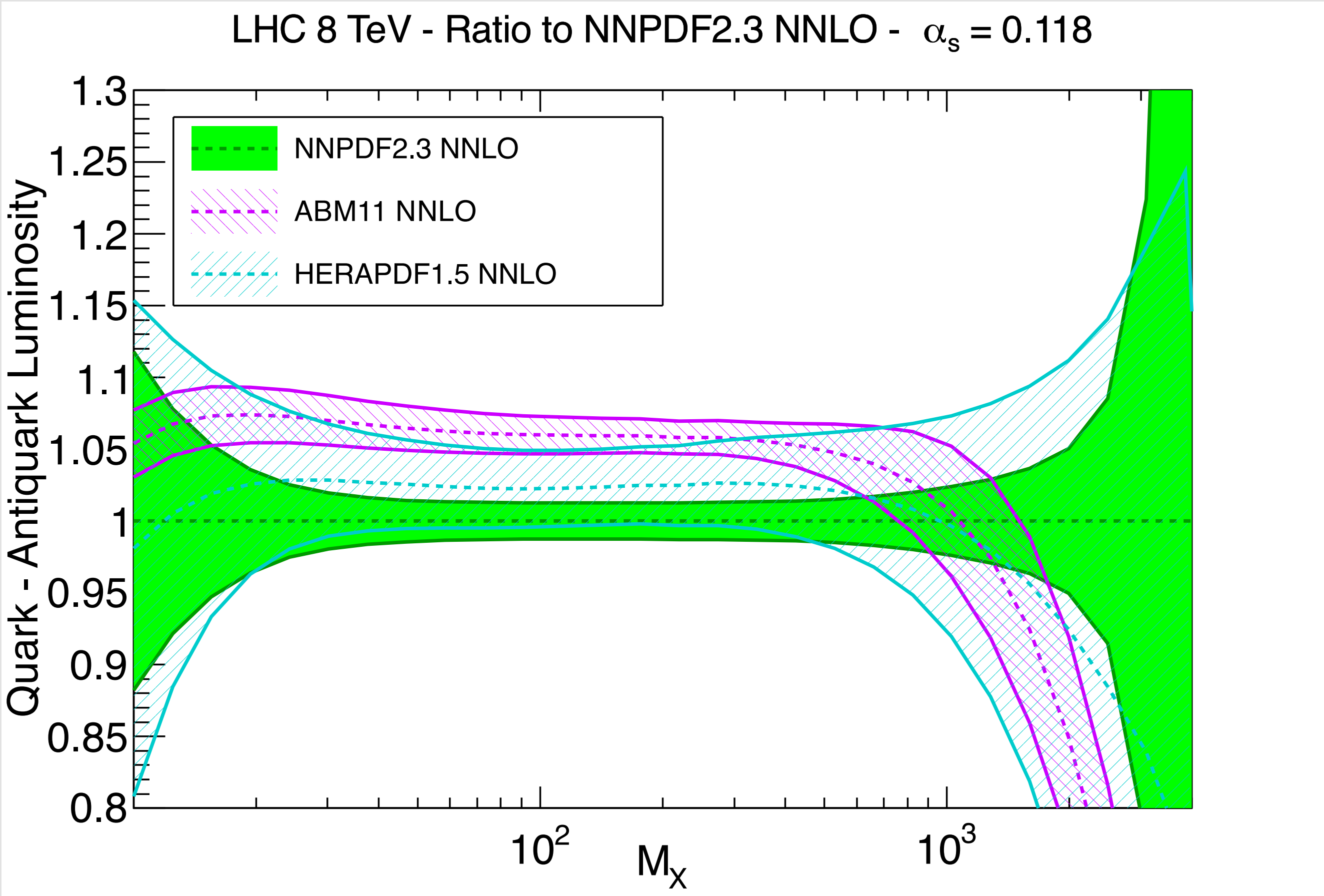


- Now we show the **relative PDF uncertainty** in the partonic luminosities
- Between **100 and 500 GeV**, PDF errors from CT/MSTW/NNPDF very similar
- ABM11 uncertainties **shrink** at large invariant masses (relevant for SUSY ...) as opposed to the other PDF sets

PDF Luminosities: Quark-AntiQuark

$$\Phi_{ij}\left(M_X^2\right) = \frac{1}{s}\int_\tau^1 \frac{dx_1}{x_1} f_i\left(x_1, M_X^2\right) f_j\left(\tau/x_1, M_X^2\right)$$

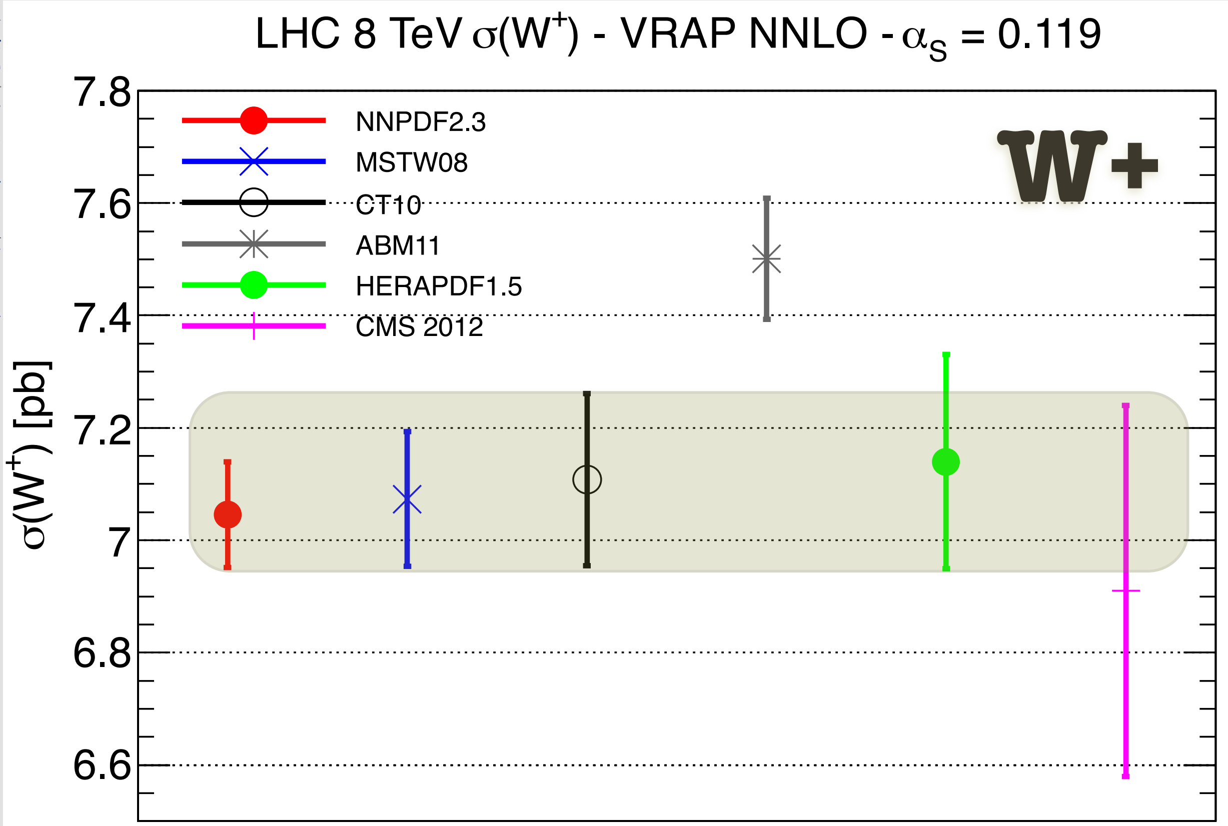


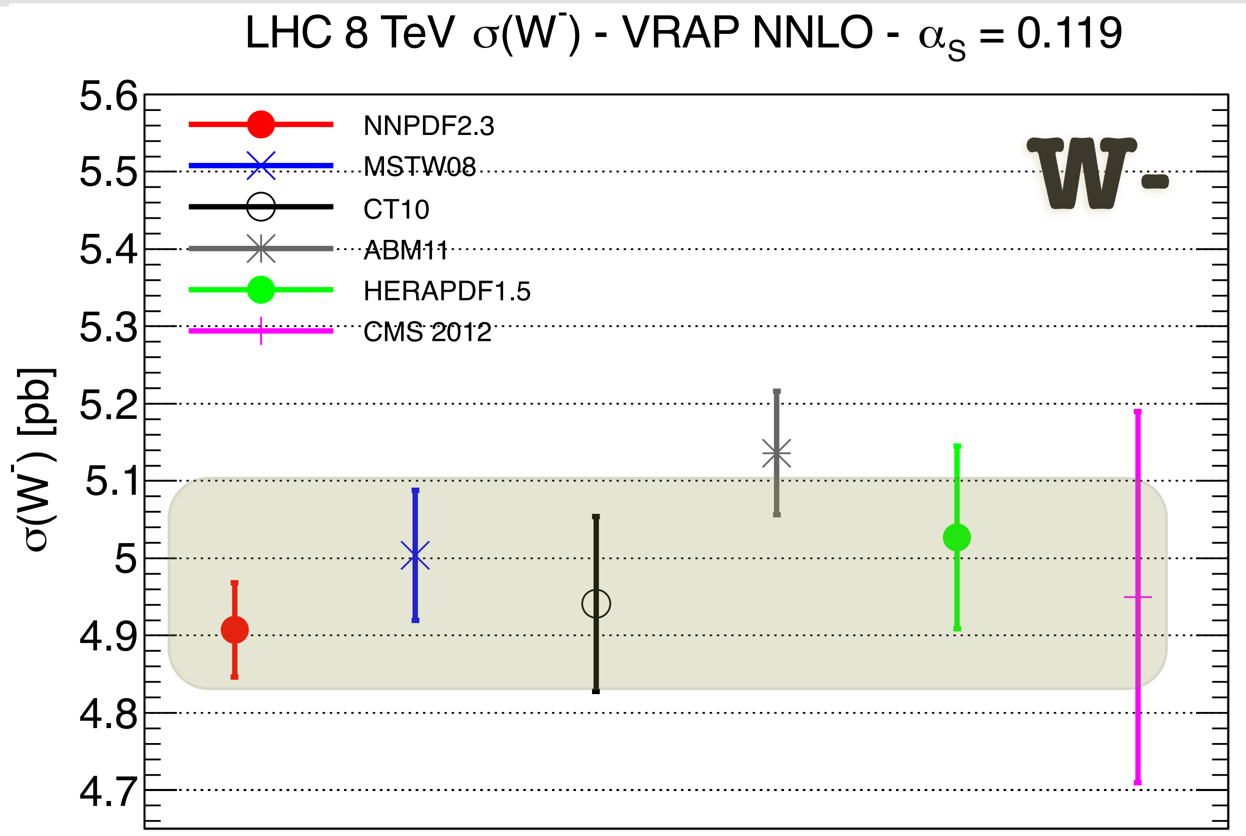


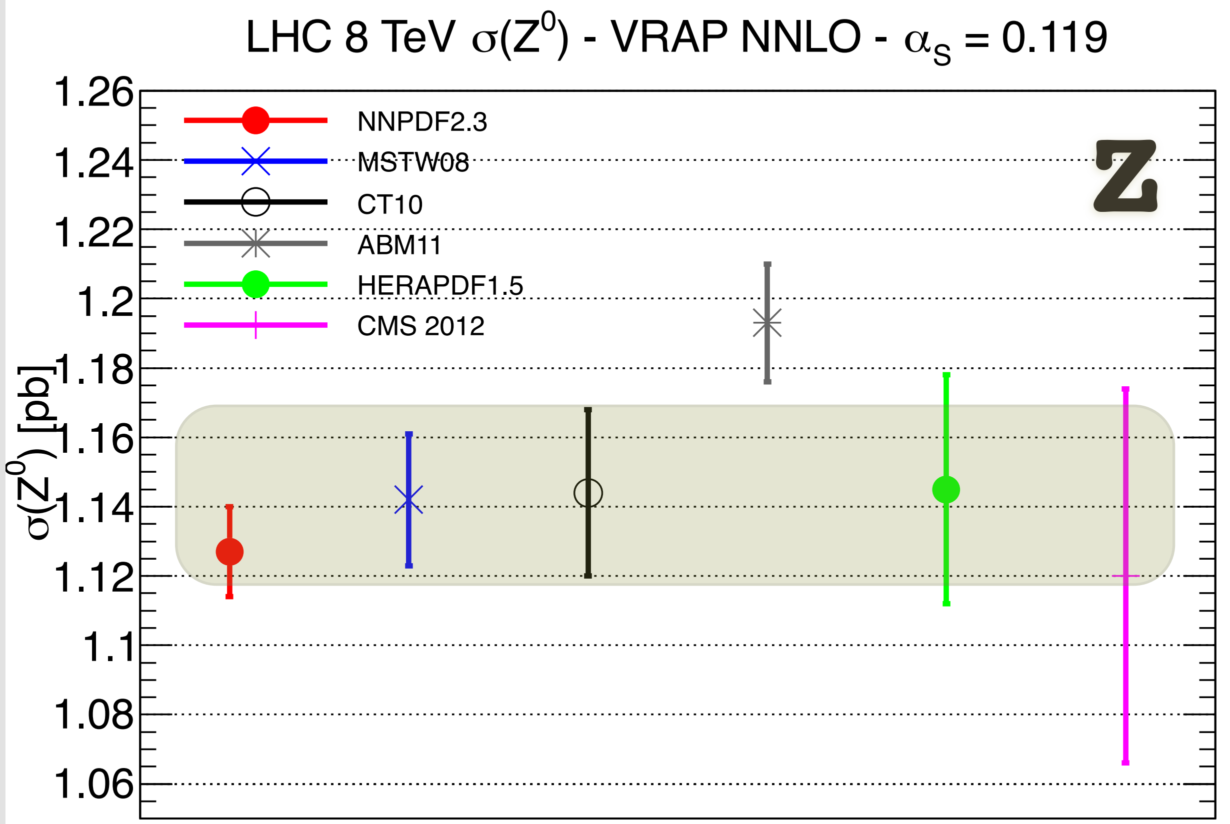
- **Good agreement** between NNPDF2.3, CT10 and MSTW08 in all the mass range. Also HERAPDF1.5 with somewhat larger uncertainties
- ABM11 **larger qqbar luminosity** below 1 TeV by a factor ~8% as compared to NNPDF2.3. Might be partly from use of a **FFN scheme**.

LHC 8 TeV Inclusive Cross Sections

Inclusive Cross Sections - W and Z

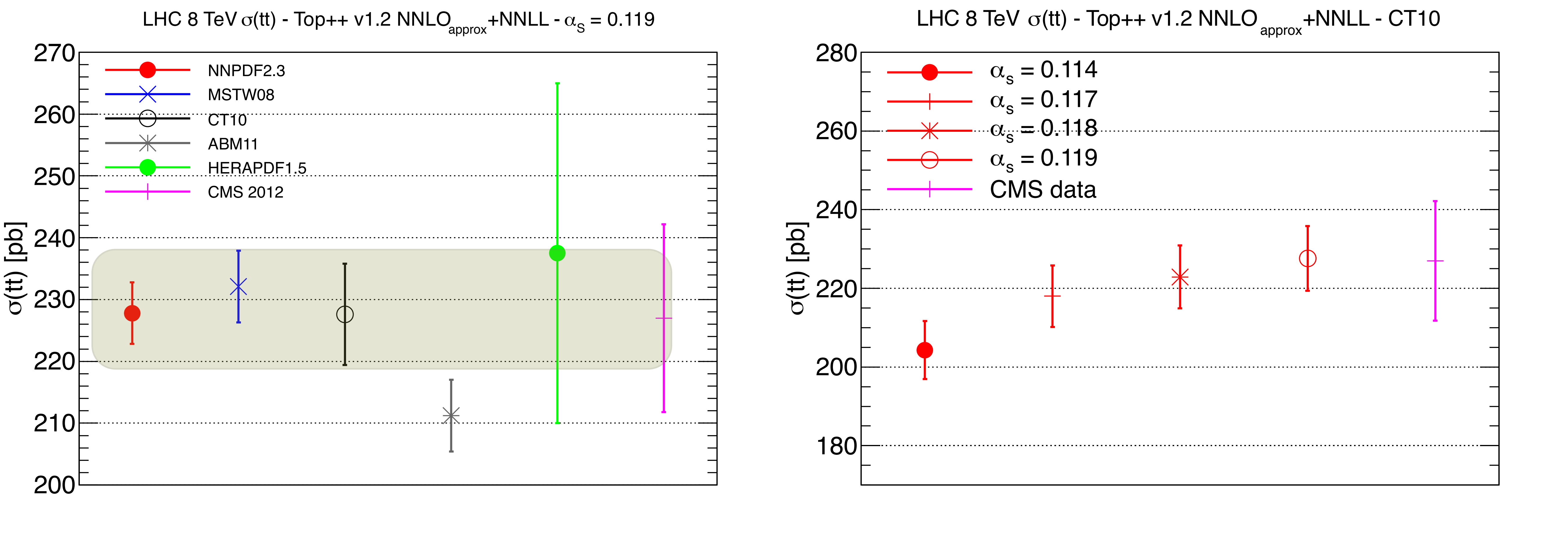






- **Good agreement between all sets** between them and with CMS 8 TeV data except ABM11 (larger cross sections)
- More stringent constraints from the **8 TeV W,Z differential distributions with covariance matrix**

Inclusive Cross Sections - Top

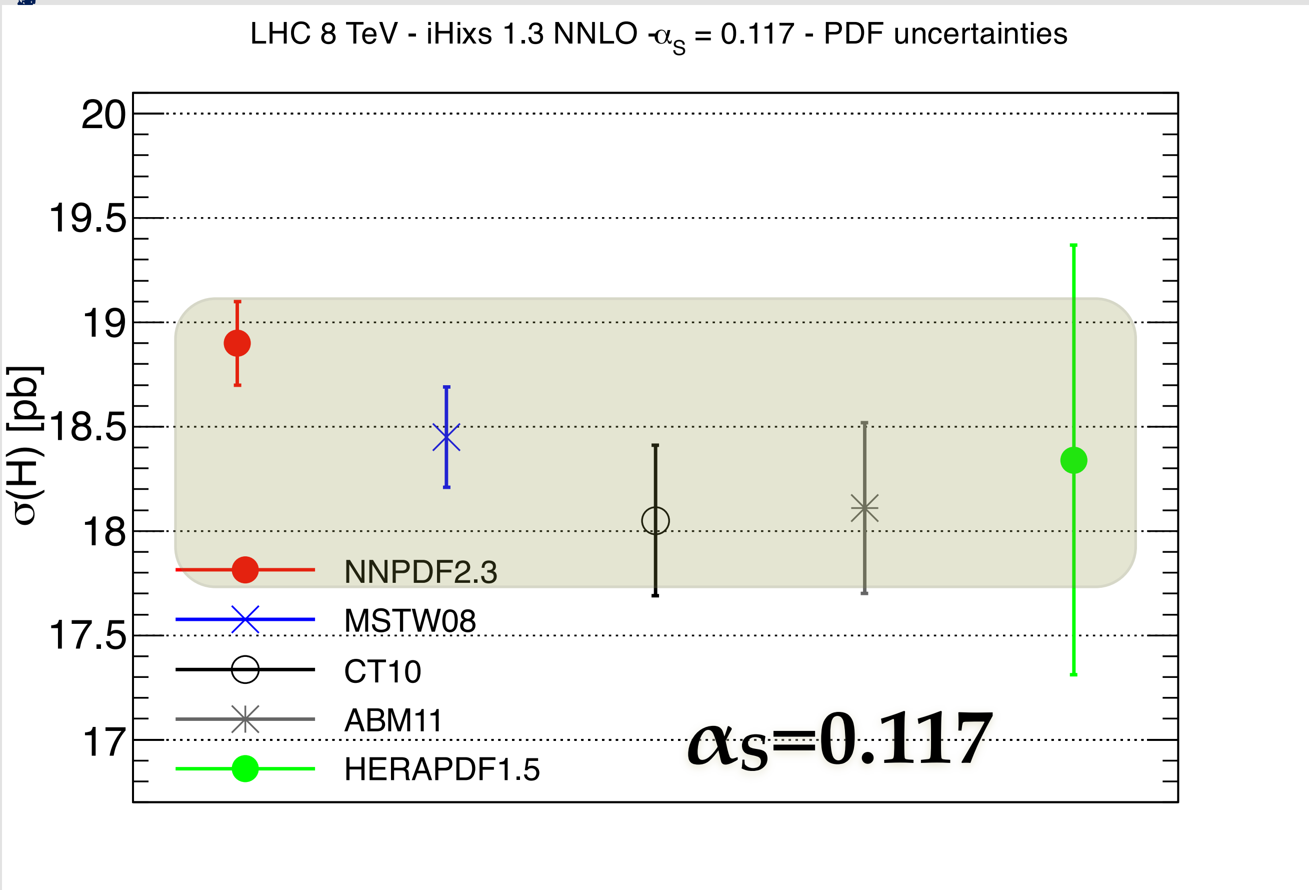


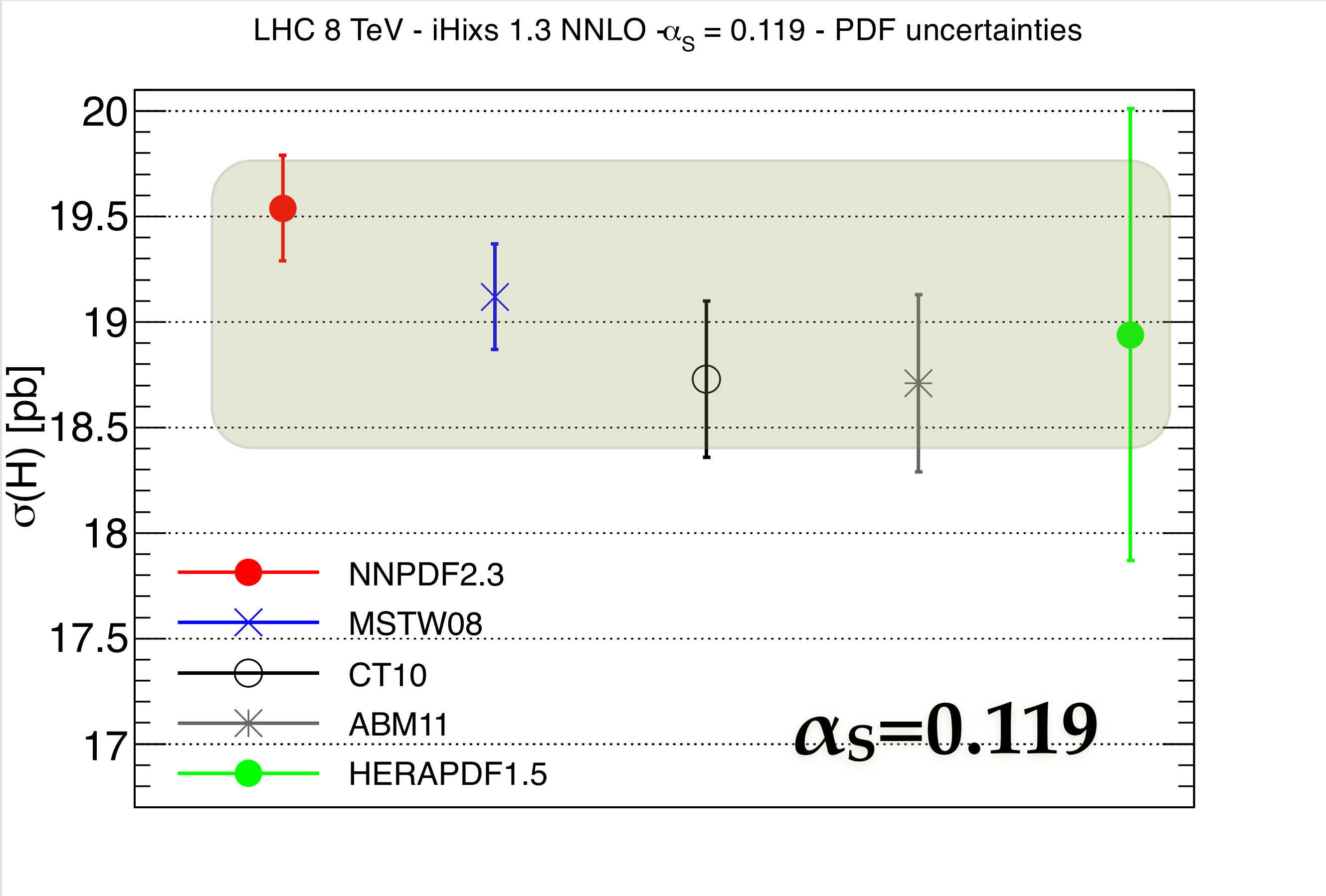
- Good agreement between all PDFs. **ABM11 a bit lower**, even for $\alpha_S = 0.119$. HERAPDF15 large uncertainties from unconstrained gluon

- LHC data **disfavor small values** of α_S. Sensitivity justifies **direct extraction from cross section** (CMS-TOP-12-022)
- Stringent constraints on PDFs the **final combined ATLAS+CMS 7 TeV data** and from **top differential distributions** from ATLAS and CMS: direct constraints **on the gluon PDF**
- Also **cross section ratios** between 8 TeV and 7 TeV provide useful for PDF information

NNLO PDFs and Higgs production

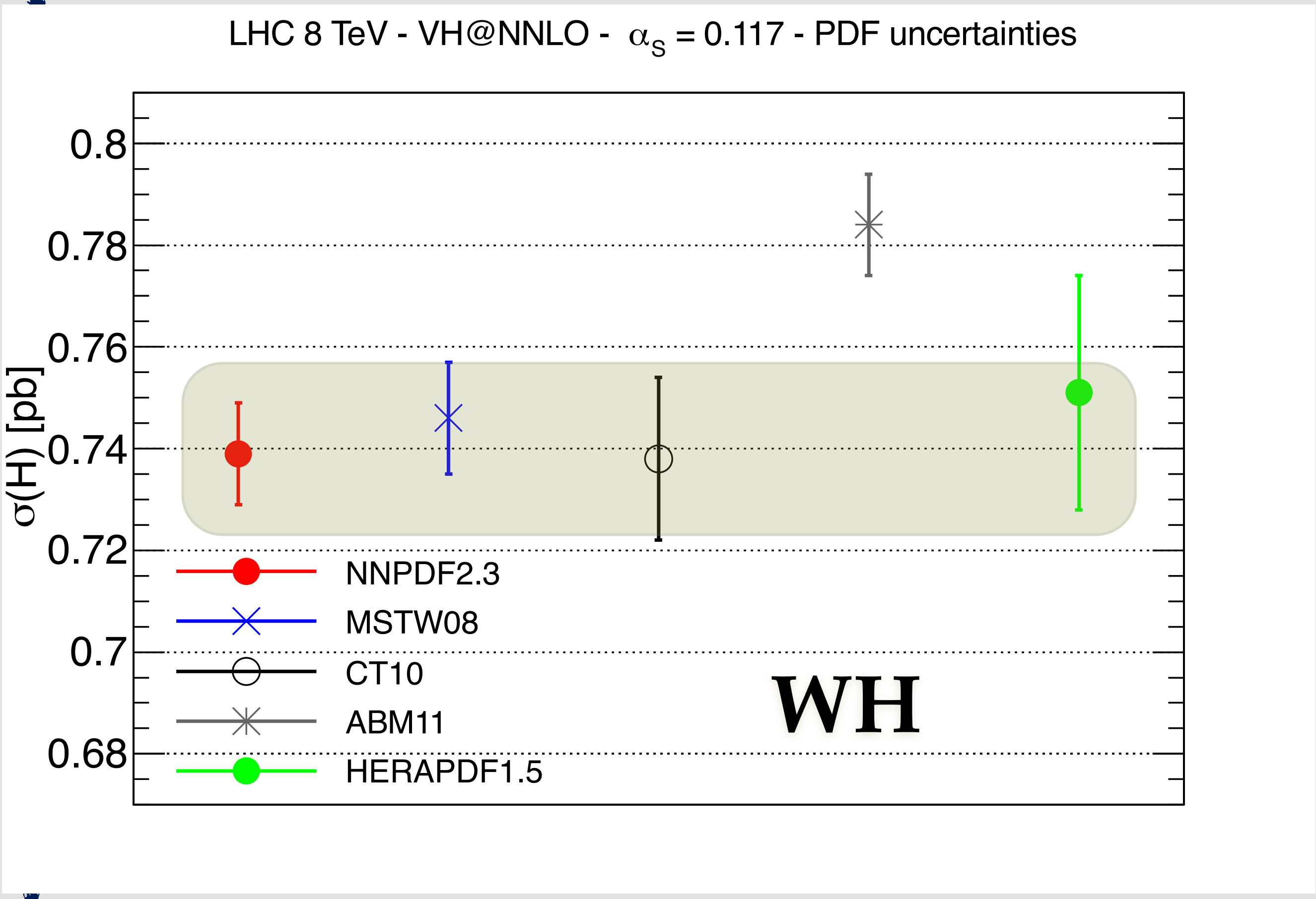
- **Higgs gluon fusion** computed with **iHixs** at NNLO with $\mathbf{Q=M_H=125}$ **GeV**
- **Relative** differences between PDF sets (when compared at the same $\boldsymbol{\alpha_s}$) are unaffected when the common value of $\boldsymbol{\alpha_s}$ is changed
- ABM11 similar to CT10, but much lower if default $\boldsymbol{\alpha_s=0.1134}$ used
- HERAPDF1.5 same central value as MSTW08, but **uncertainties factor 4 larger**

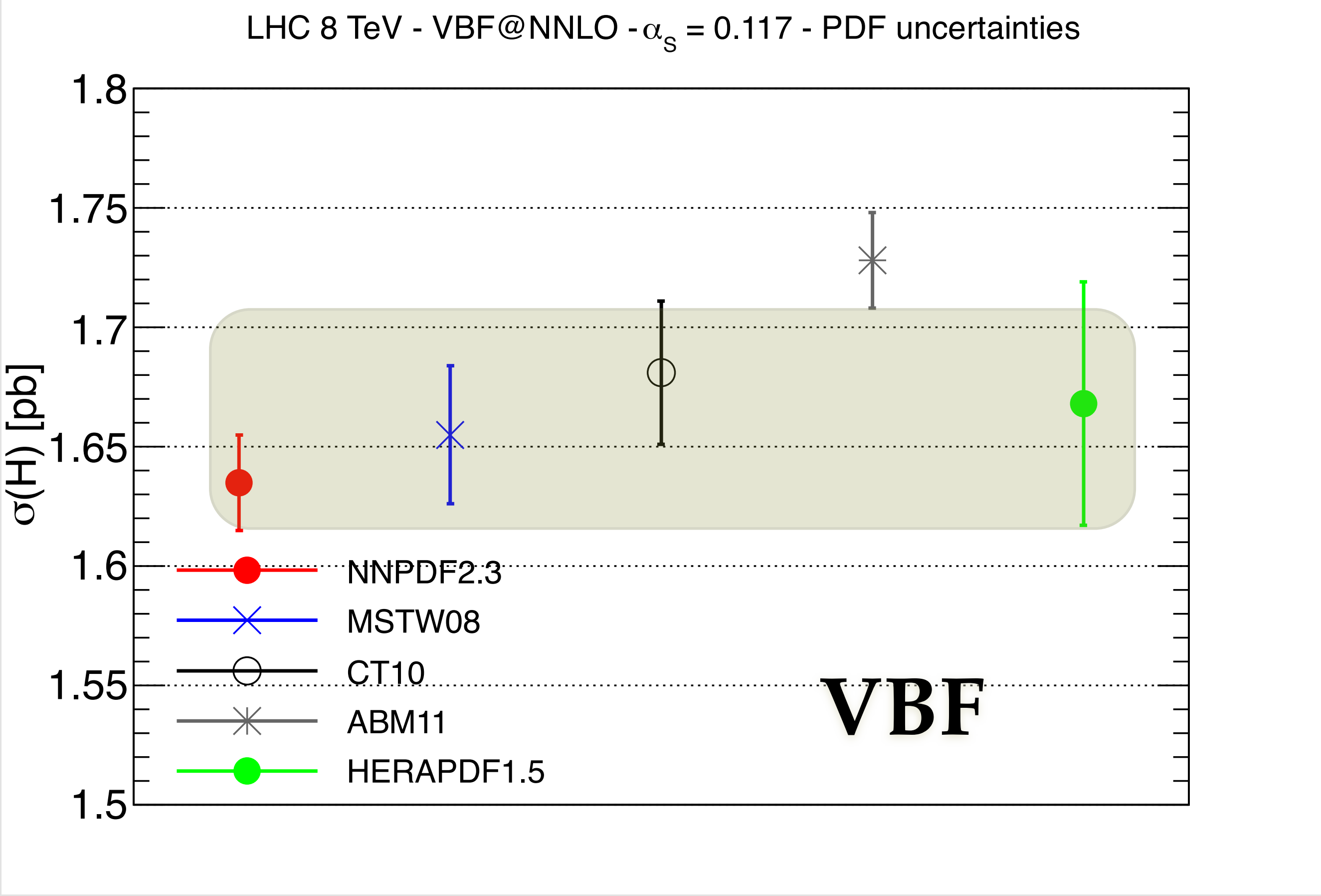




NNLO PDFs and Higgs production

- **Higgs Vector Boson Fusion** computed with **VBF@NNLO**, and **WH** production with **VH@NNLO**
- **Reasonable agreement** between NNPDF2.3, CT10 and MSTW08
- **ABM11 larger cross sections** from harder quark luminosity
- HERAPDF1.5 same central value as MSTW08, but **uncertainties factor 2 larger**





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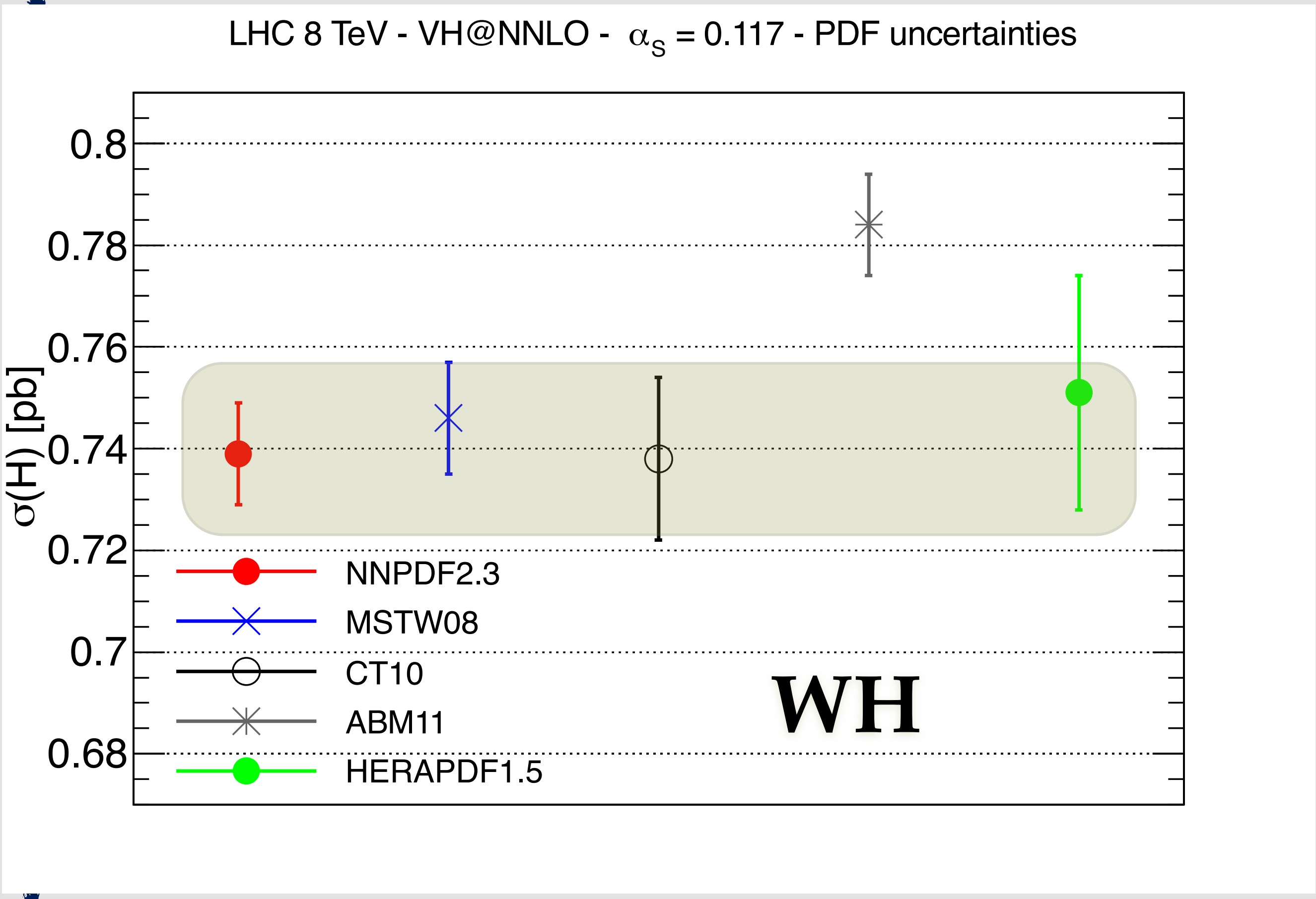
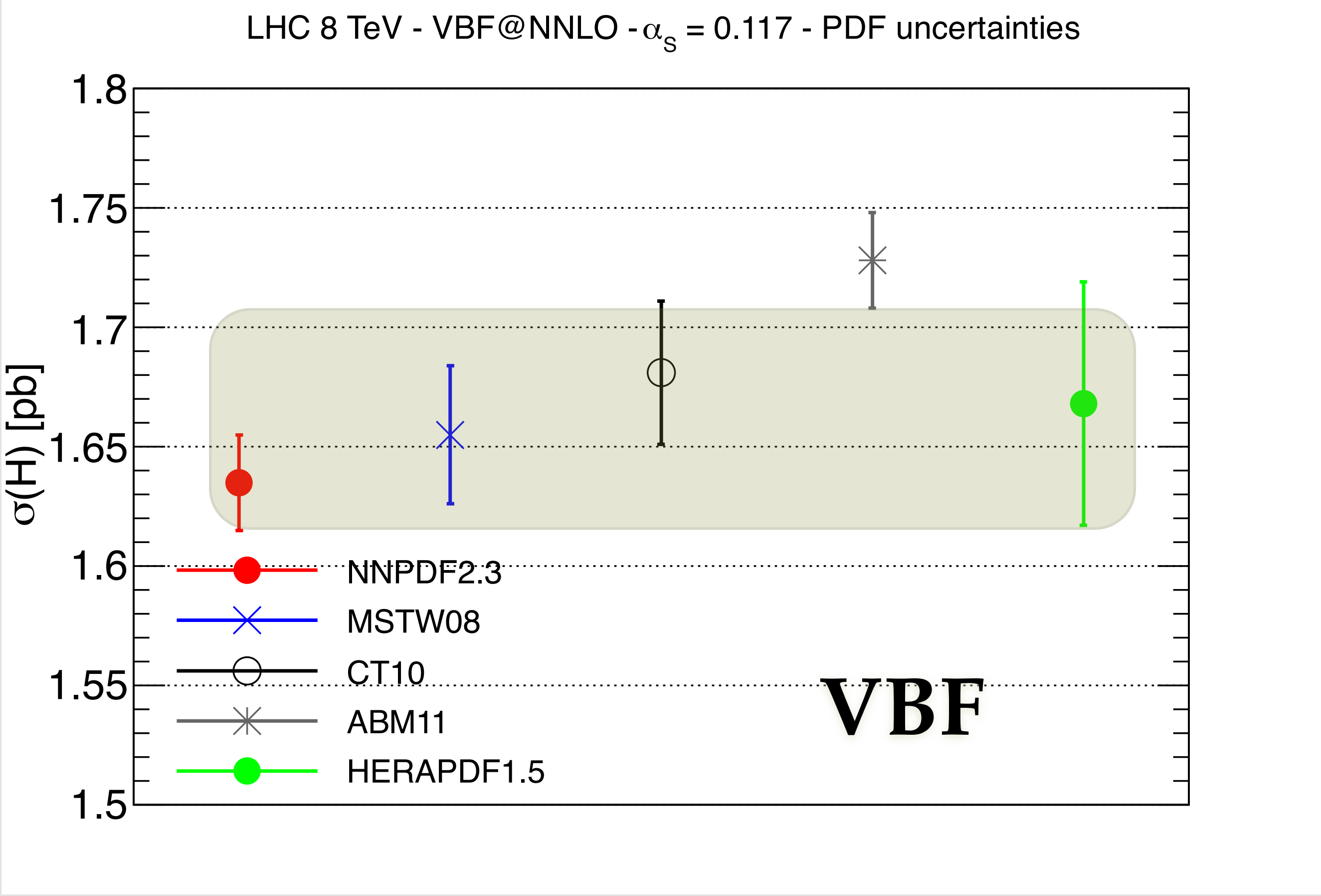




Quantifying fit quality

Different definitions of the covariance matrix possible. In a PDF fit, great care must be taken to avoid the **D'Agostini bias**: multiplicative systematic uncertainties need to correct the **theory from a previous fit,** while additive systematic uncertainties should correct the **experimental data.** See the discussion in **arXiv:0912.2276.** Note that the χ^2 definitions in terms of cov. matrix or systematic shifts are **equivalent**

The t0 prescription correctly treats multiplicative and additive uncertainties. The **"Exp"** definition suffers from D'A bias, but useful to compare results (after the fits). The "**Extended-t0**" prescription is unbiased but treat additive uncertainties approximately

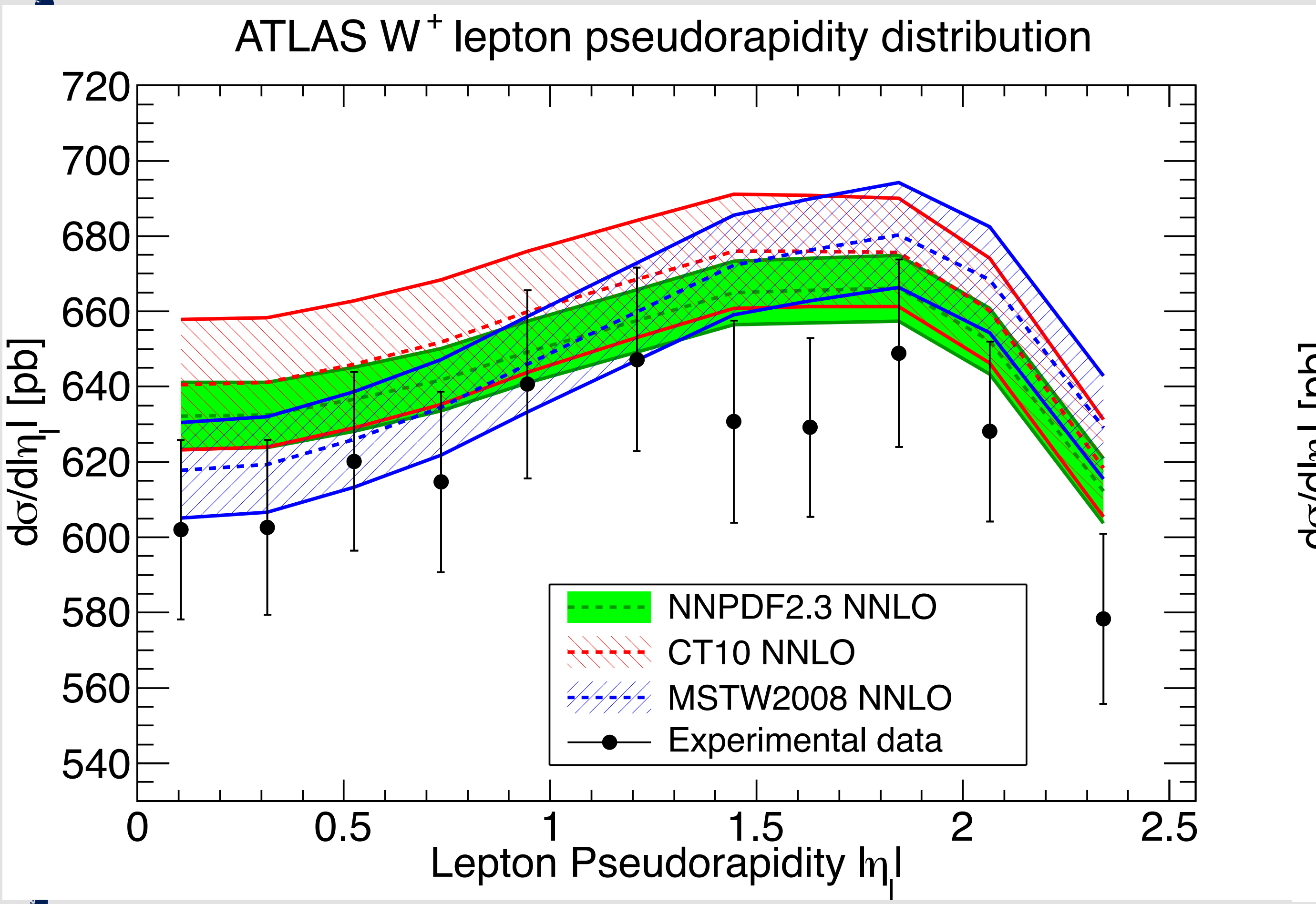
$$(\mathrm{cov})_{ij} = \delta_{ij} s_i^2 + \left(\sum_{\alpha=1}^{N_c} \sigma_{i,\alpha}^{(c)} \sigma_{j,\alpha}^{(c)} + \sum_{\alpha=1}^{N_{\mathcal{L}}} \sigma_{i,\alpha}^{(\mathcal{L})} \sigma_{j,\alpha}^{(\mathcal{L})} \right) D_i D_j \,, \quad \text{"Exp"}$$

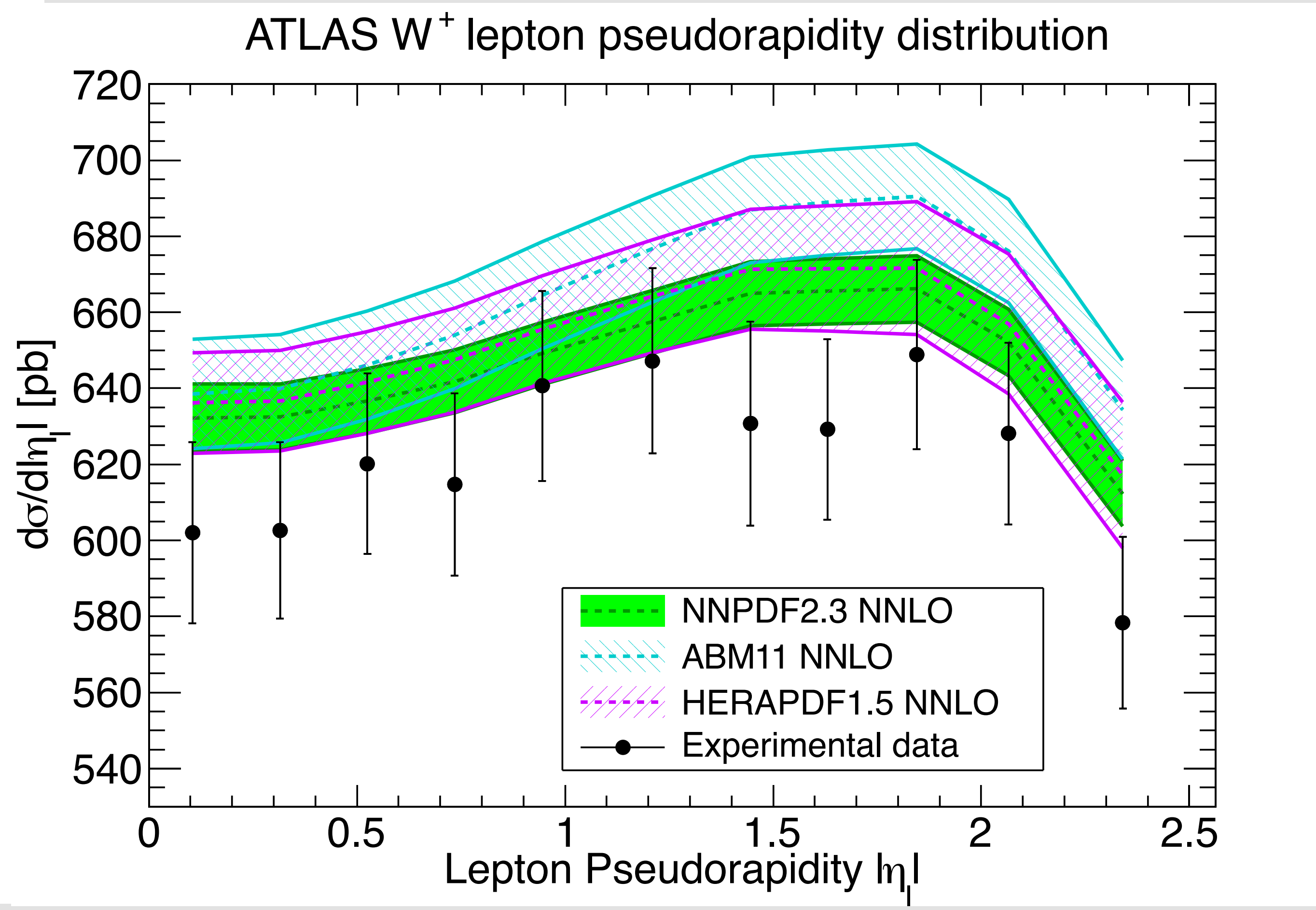
$$(\mathrm{cov})_{ij} = \delta_{ij} s_i^2 + \sum_{\alpha=1}^{N_c} \sigma_{i,\alpha}^{(c)} \sigma_{j,\alpha}^{(c)} D_i D_j + \sum_{\alpha=1}^{N_{\mathcal{L}}} \sigma_{i,\alpha}^{(\mathcal{L})} \sigma_{j,\alpha}^{(\mathcal{L})} T_i^{(0)} T_j^{(0)} \,, \quad \text{"}t_0\text{"}$$

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

$$\chi^2 = \sum_{i,j}^{N_{\mathrm{pt}}} (T_i - D_i)(\mathrm{cov}^{-1})_{ij} (T_j - D_j), \quad \longleftrightarrow \quad \chi_D^2 \equiv \sum_{k=1}^{N_{\mathrm{pt}}} \frac{1}{s_k^2} \left(D_k - T_k - \sum_{\alpha=1}^{N_\lambda} \beta_{k,\alpha} \lambda_\alpha \right)^2 ,$$

ATLAS 2010 W,Z distributions

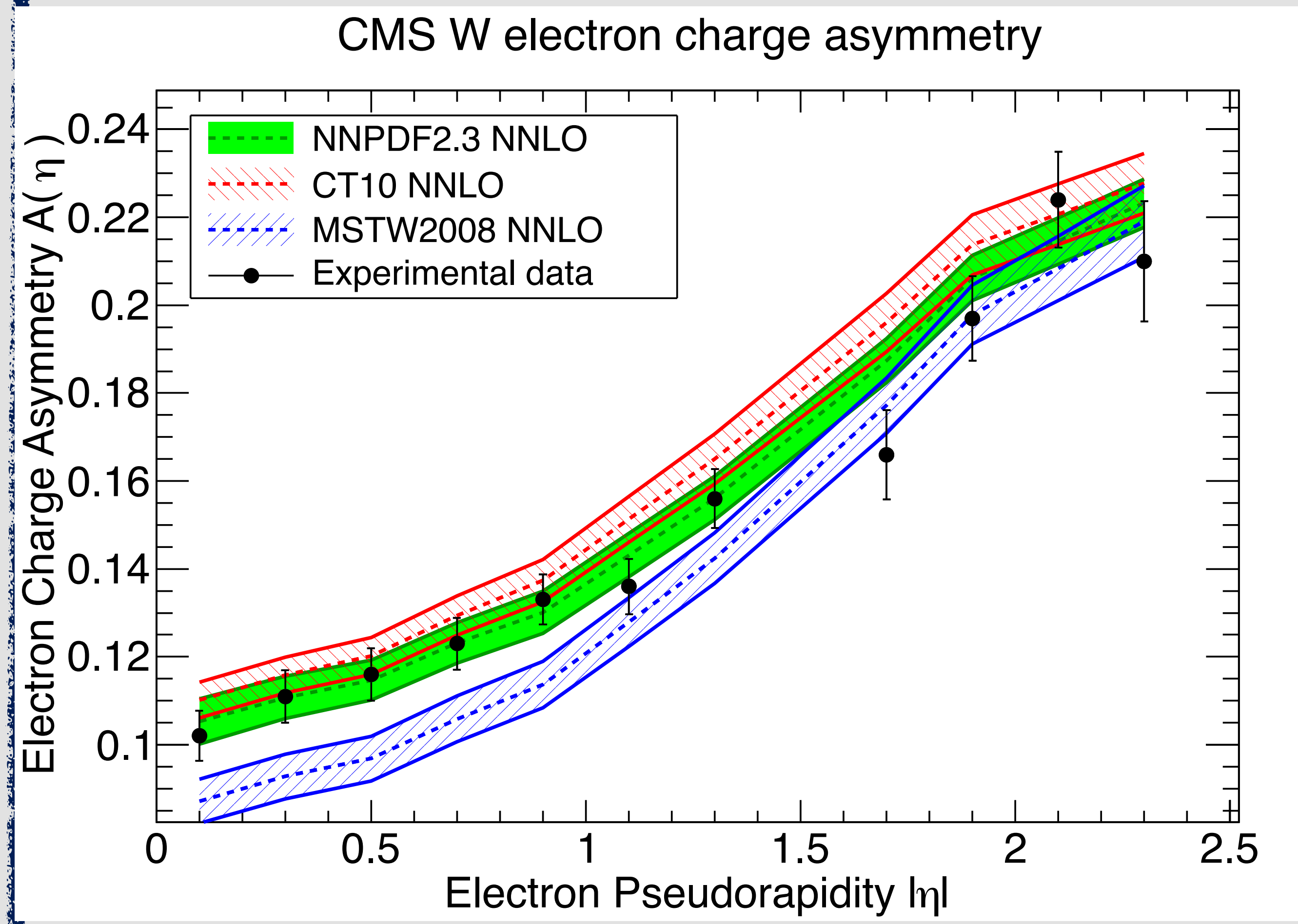


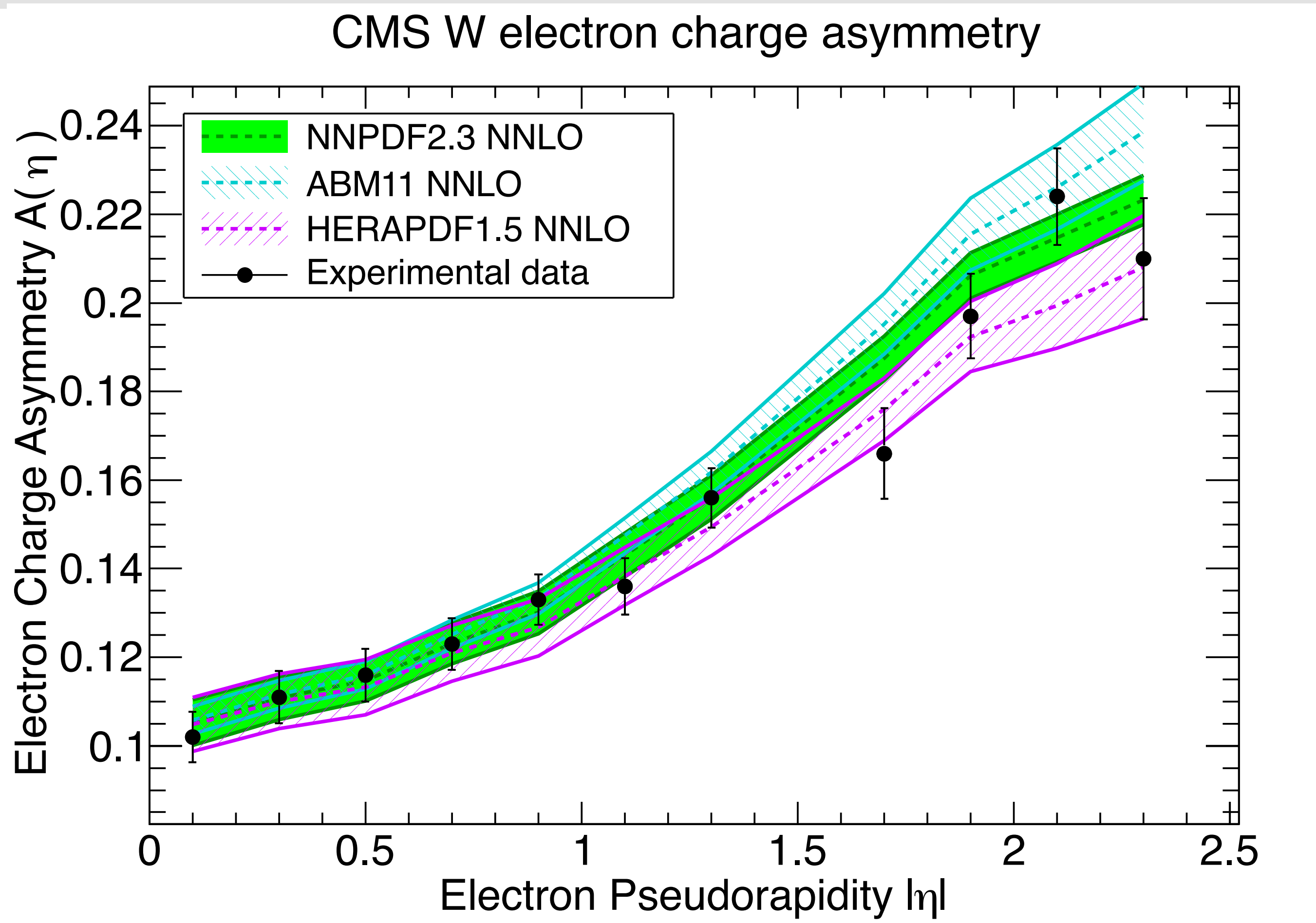


χ^2	**NNPDF2.3**	**MSTW08**	**CT10**	**ABM11**	**HERAPDF1.5**
ATLAS'10 W,Z	1.4	3.2	1.2	1.6	1.8

- **Sensitive to sea and valence quark**s: absolute normalization and flavor separation. Also handle on **strangeness**
- MSTW worse description. Problem understood due to not flexible enough parametrization for **u_V-d_V**, also nuclear corrections (**arXiv:1211.1215**)

CMS 2011 W electron asymmetry

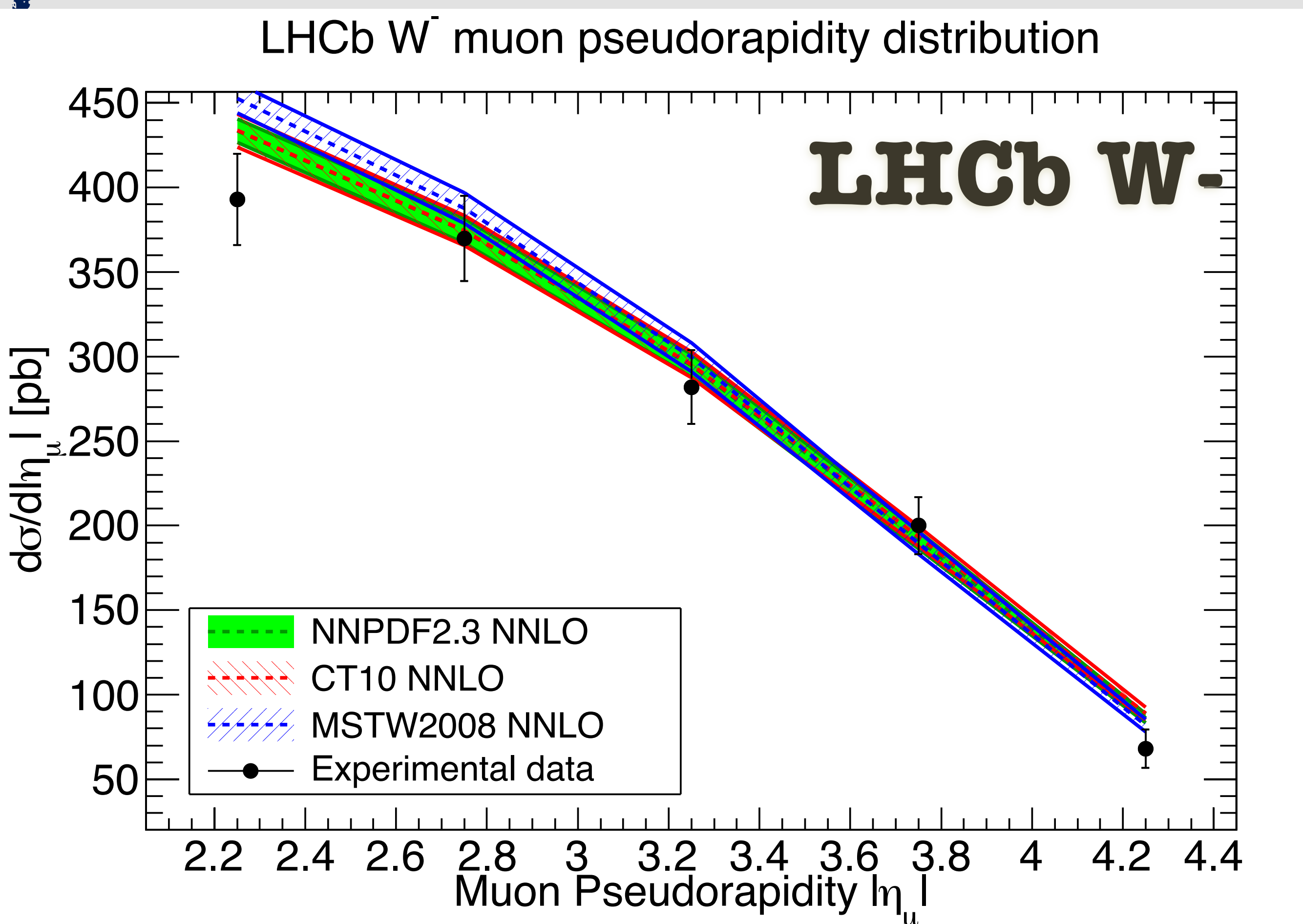


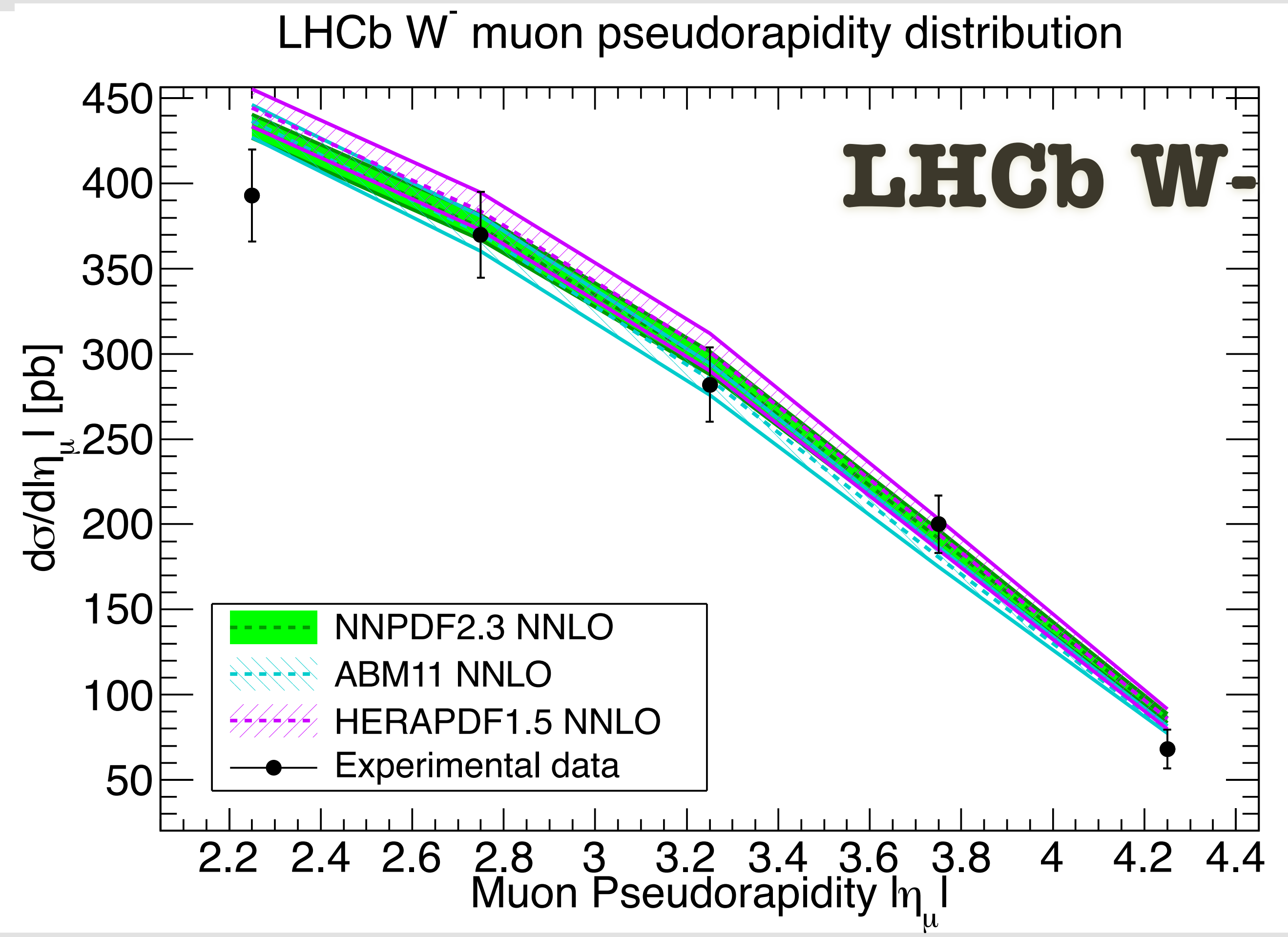


χ^2	NNPDF2.3	MSTW08	CT10	ABM11	HERAPDF1.5
CMS'11 Wasy	0.8	3.9	1.8	1.6	0.8

- W asymmetry direct probe of **light quark flavor separation**
- **MSTW** similar problems as with ATLAS data (**arXiv:1211.1215**)
- Also sensitive to strangeness: R. Plakakyte's PDF@CMS talk

LHCb 2010 W distributions

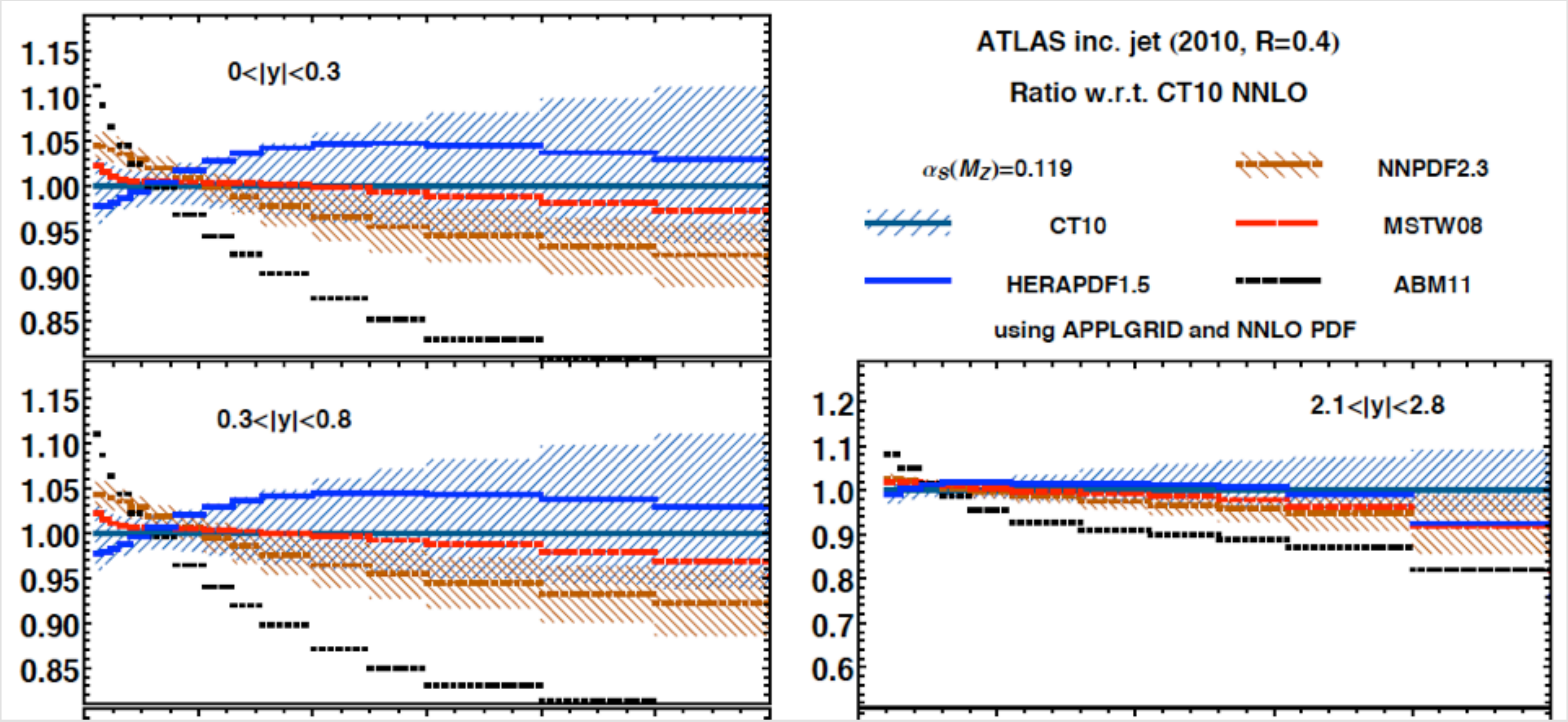




χ^2	NNPDF2.3	MSTW08	CT10	ABM11	HERAPDF1.5
LHCb'10 W	0.8	1.0	1.0	2.0	0.8

- LHCb forward data **unique probe of small-x PDFs**
- Moderate **discriminating power**. ABM11 worse description. HERAPDF1.5 NLO also very poor
- To be updated with full 2011 dataset soon: greatly improved **constraining power**

ATLAS 2010 Jet Production



χ^2	NNPDF2.3	MSTW08	CT10	ABM11	HERAPDF1.5
ATLAS'10 Jets	0.9	0.9	1.0	1.0	1.0

- **Similar description** between all PDF sets. Visual data/theory comparisons not that informative without **quantitative χ^2 tests**
- Very moderate constraining power. To be improved with **5 fb^{-1} 2011 jet data**.

ATLAS 2010 Jet Production

- Different **cov. matrix defs / scale settings** lead to different numerical values of χ^2

	NLO PDFs, $\alpha_s = 0.119$				
Dataset	NNPDF2.3	MSTW08	CT10	ABM11	HERAPDF1.5
ATLAS W, Z (Exp)	1.268	2.004	1.062	1.558	1.747
ATLAS W, Z (t_0)	1.292	2.024	1.026	1.487	1.676
CMS W el asy (Exp)	0.820	4.690	1.419	1.915	0.687
CMS W el asy (t_0)	0.820	4.690	1.419	1.915	0.687
LHCb W (Exp)	0.670	0.907	1.064	2.328	4.125
LHCb W (t_0)	0.662	0.896	1.046	2.298	4.100
ATLAS jets (Exp)	0.999	0.974	1.350	1.342	1.106
ATLAS jets (t_0)	0.836	0.825	1.234	1.317	1.032

Table 10: The χ^2/N_{pt} values for the available LHC data with published correlated uncertainties, computed using the five PDF sets considered. The experimental ("Exp") definition of $(\text{cov})_{ij}$ in Eq. (8) is compared to the t_0 definition in Eq. (9). Theoretical predictions have been computed at NLO with `APPLgrid` for a common value of the strong coupling $\alpha_s(M_Z) = 0.119$.

NLO PDF	α_s	Code	$(\text{cov})_{ij}$ definition		
			Exp	Ext. t_0 CT10	Ext. t_0 NNPDF2.3
CT10	0.118	`FastNLO`	0.95	0.55	0.60
CT10	0.118	`MEKS1`	1.00	0.57	0.61
CT10	0.118	`MEKS2`	0.89	0.55	0.59
NNPDF2.3	0.119	`FastNLO`	0.87	0.60	0.57
NNPDF2.3	0.119	`MEKS1`	0.90	0.58	0.55
NNPDF2.3	0.119	`MEKS2`	0.78	0.54	0.53
NNPDF2.3	0.119	`APPLgrid`	1.00	0.64	0.62

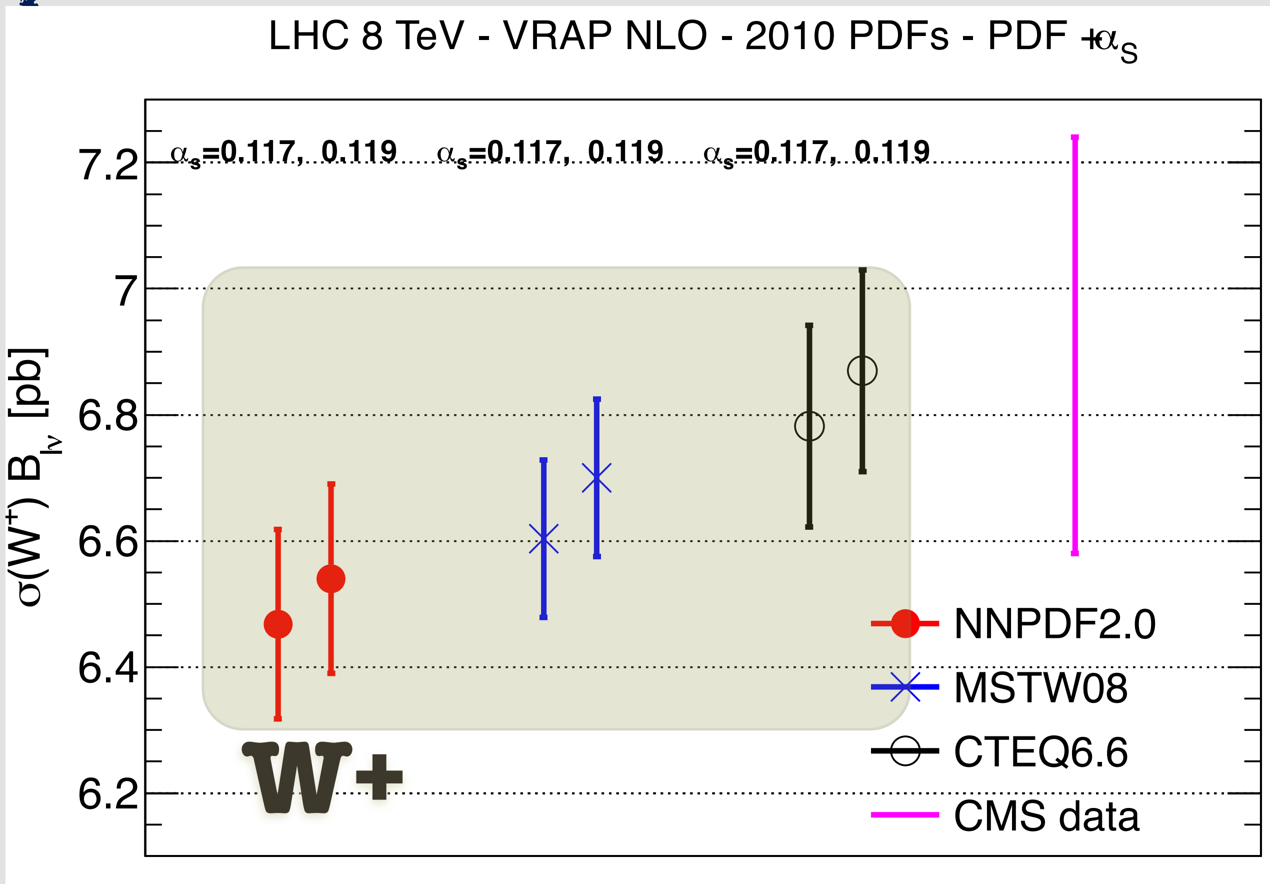
Table 11: The χ^2/N_{pt} values for the ATLAS inclusive jet production data obtained with the experimental and extended-t_0 definitions of the χ^2 function. The cross sections are computed at NLO using the specified NLO PDFs, α_s values, and the following codes: `FastNLO`, `MEKS` with $\mu_{F,R}$ equal to the individual jet p_T (`MEKS1`) or p_T of the hardest jet (`MEKS2`), and `APPLgrid`.

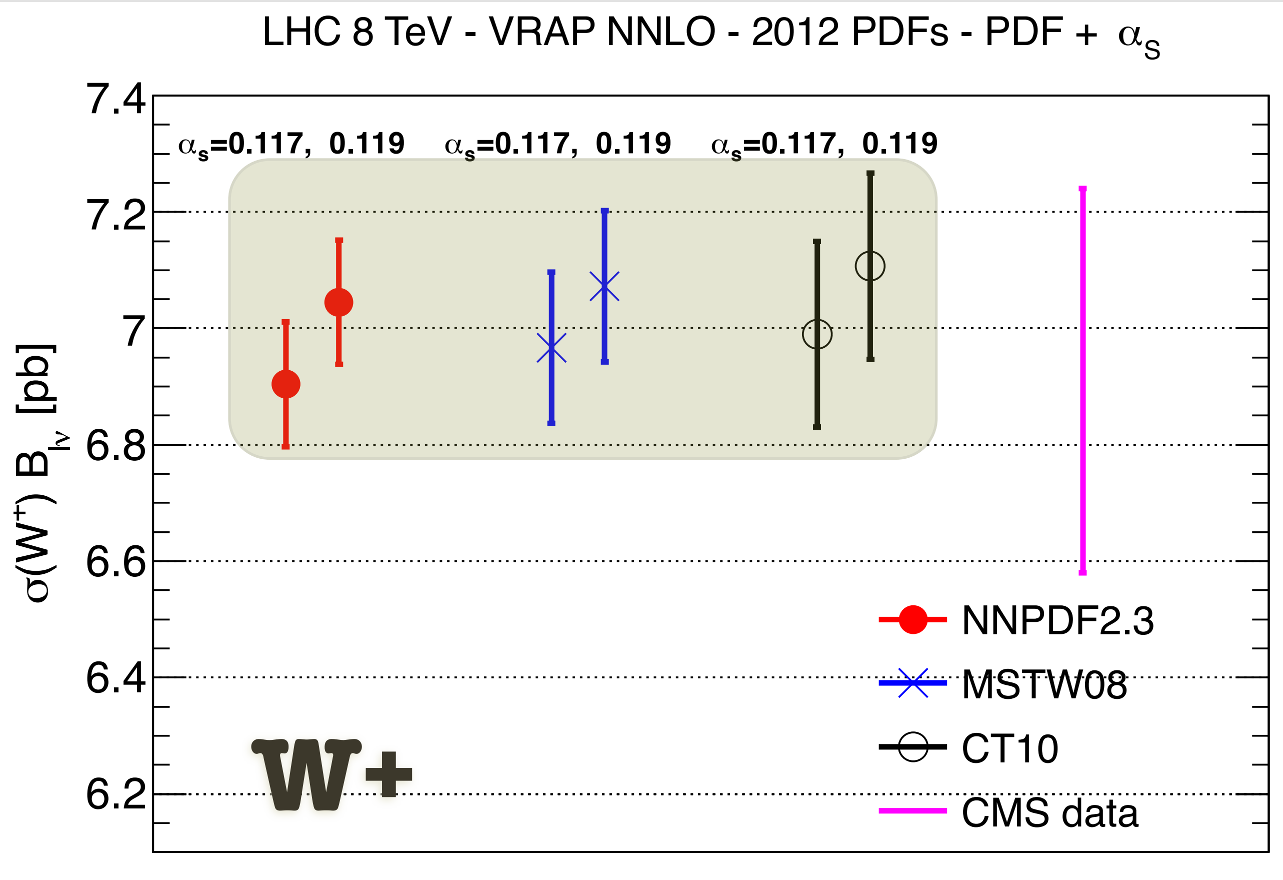
NNLO PDFs and Higgs production

- The **Higgs Cross Section Working Group** estimates **PDF+α_S** uncertainties using the current **PDF4LHC recommendations**. What would be the differences if the same prescription was upgraded to NNLO: Envelope of **NNPDF2.3, CT10, MSTW08**?

- Simplified toy calculation: **envelope** of cross sections including **PDF+α_S uncertainties** computed for **α_S=0.117** and **0.119.** PDF and **α_S** errors added in quadrature

- For most processes the envelope with NNLO PDFs leads to a **substantial improvement** with respect the original NLO envelope. Example: **W production**





2010 NLO PDFs: $\Delta_{PDF+\alpha_S}$ = 5.3%

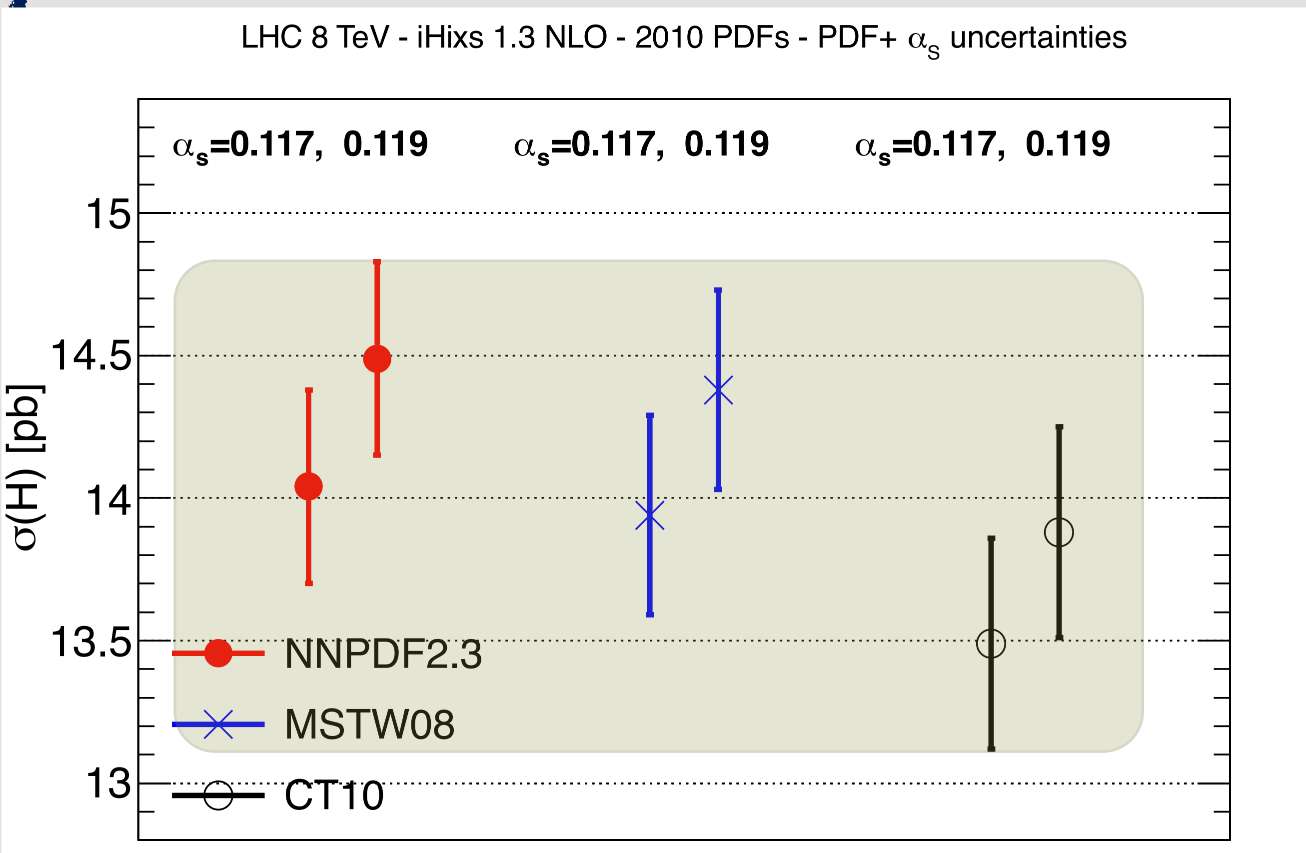
2012 NNLO PDFs: $\Delta_{PDF+\alpha_S}$ = 3.3%

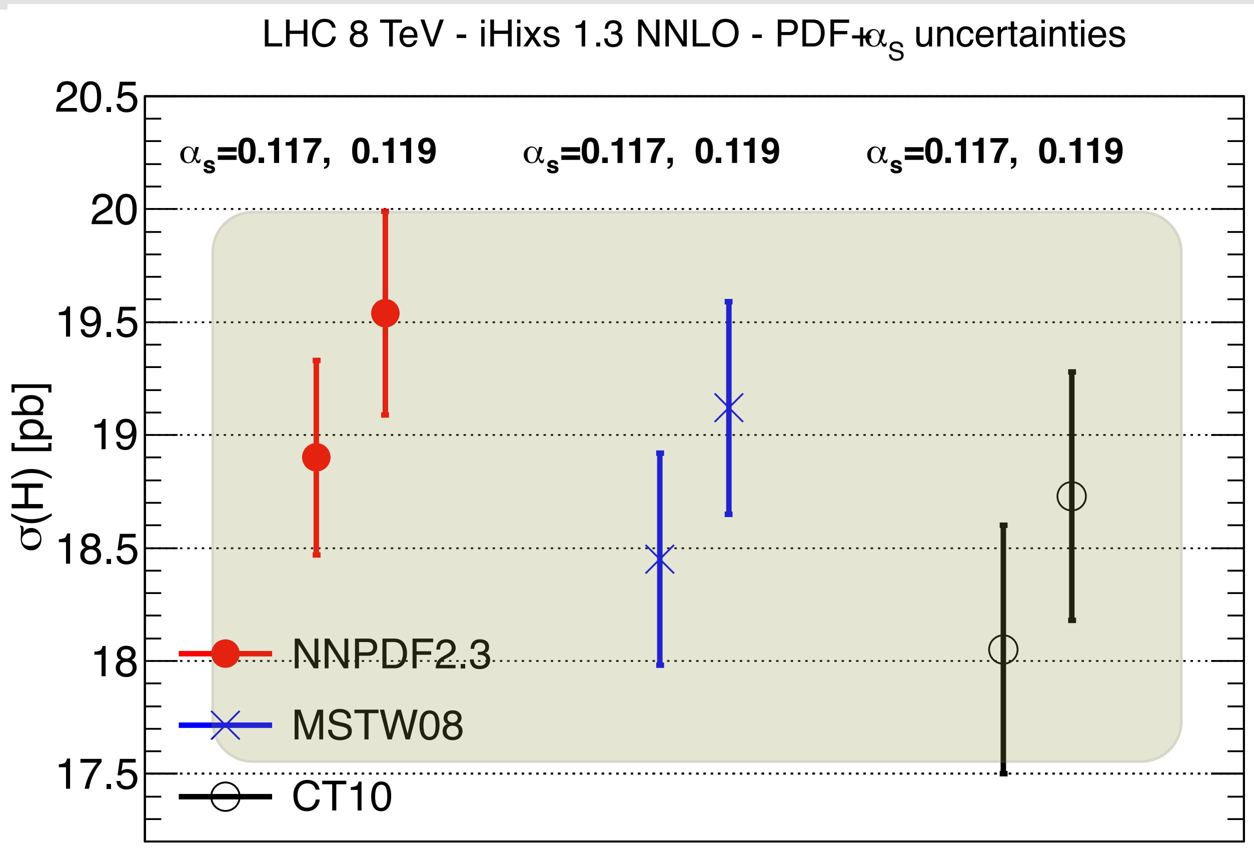
NNLO PDFs and Higgs production

- Simplified toy calculation: **envelope** of cross sections including **PDF+α_S uncertainties** computed for α_S **=0.117** and **0.119.** PDF and α_S errors in quadrature

- For a wide range of Higgs masses and most other processes (VBF, WH), NLO -> NNLO leads to substantial reduction of **PDF+α_S uncertainties ...**

- **...** except for the **ggF Higgs** with **M_H=125 GeV,** with a **slight increase** of **PDF+α_S** uncertainties by **10% :(**





2010 NLO PDFs: $\Delta_{PDF+\alpha_S}$ = 6.1%

2012 NNLO PDFs: $\Delta_{PDF+\alpha_S}$ = 6.6%

Beyond Benchmarking

(next step:
trying to understand the differences)

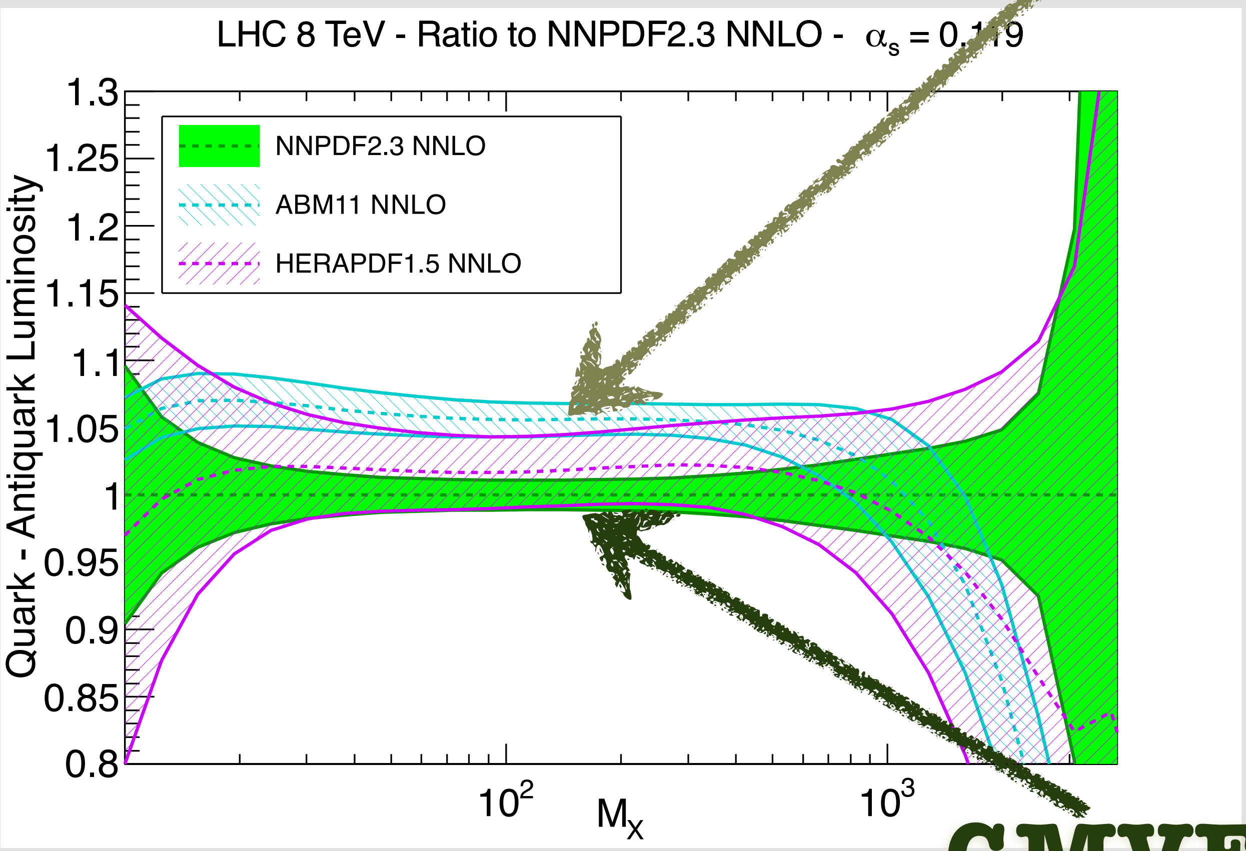
NNPDF Preliminary

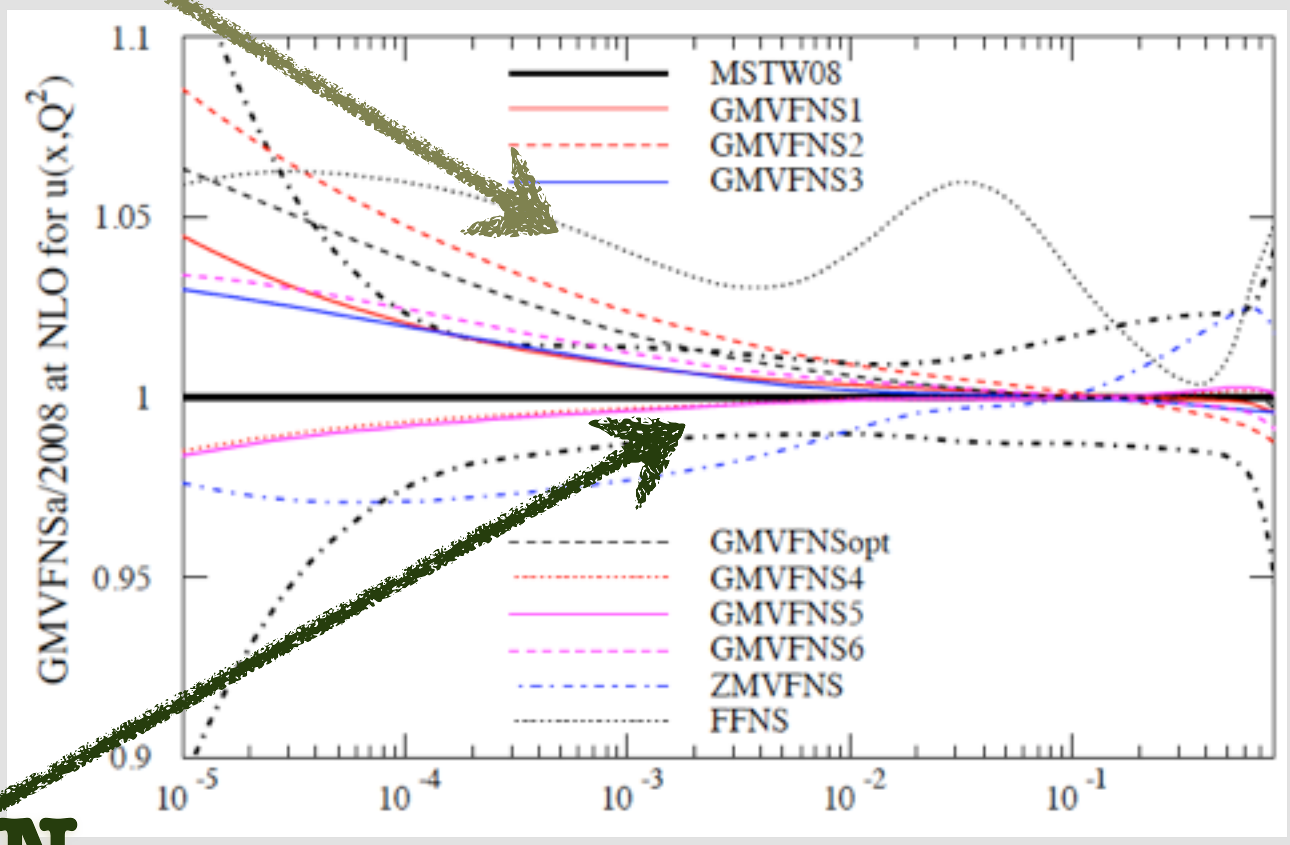
Variable vs Fixed Flavor Number Schemes

- Differences between ABM11 and other PDF sets partly arise from **different HQ treatment**: Fixed Flavor Number vs General Mass VFN (Thorne, arXiv:1201.6180)

- The FFN fit leads to a **harder small-x gluon**, and thus (via the momentum sum rule) a **softer large-x gluon**, and to a **harder quarks at small-x** at LHC scales through evolution

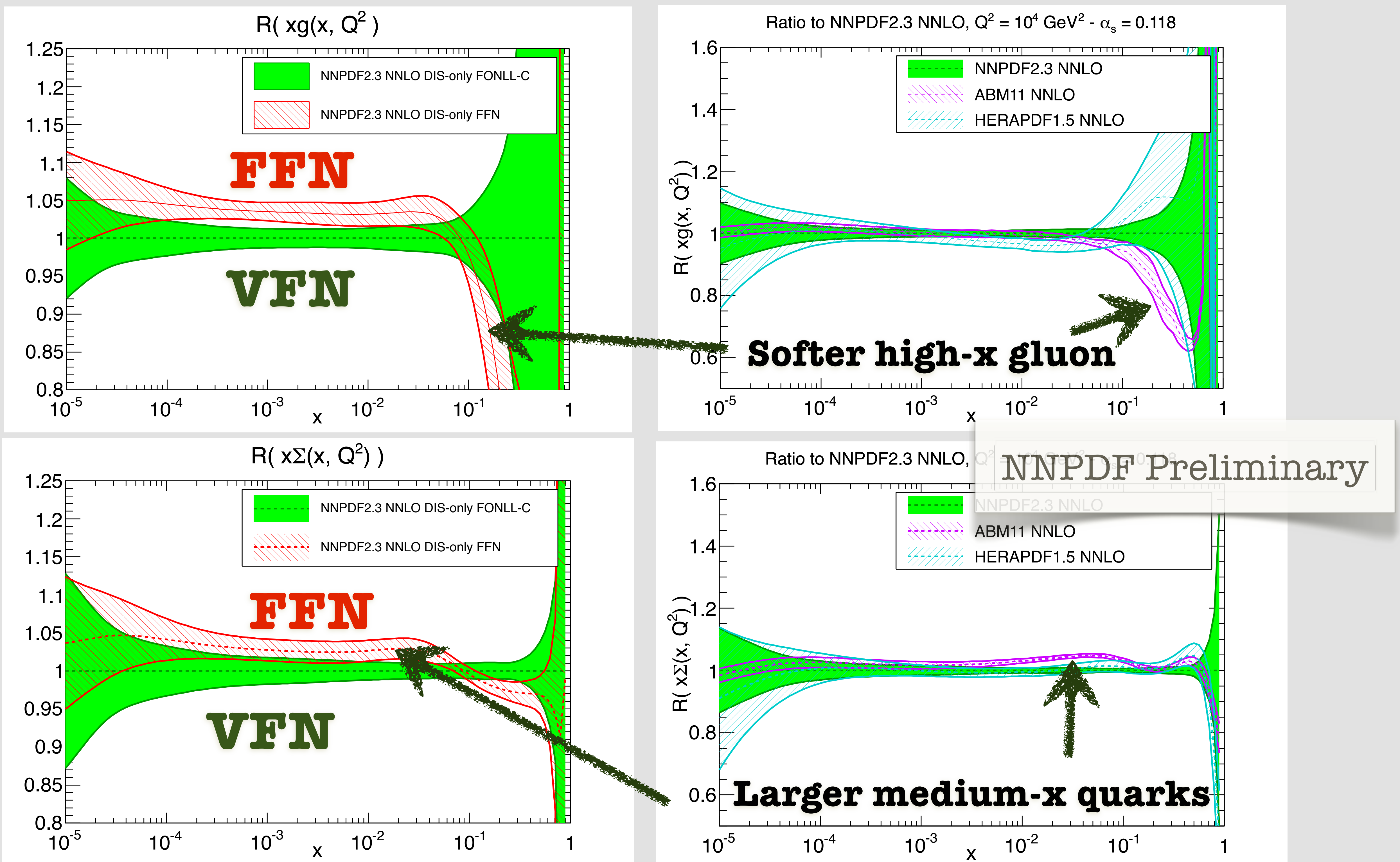
- Differences between various **GM-VFN** schemes much smaller that between **FFN** and **GM-VFN.** See also Les Houches heavy quark benchmark study.





Variable vs Fixed Flavor Number Schemes

- The impact of **FFN vs GM-VFN** also studied by **NNPDF:** consistent results with those of Thorne
- **Similar trend** observed as between NNPDF2.3 and ABM11: **softer large-x gluon**, **harder medium-x quarks**



Variable vs Fixed Flavor Number Schemes

- Are all heavy quark schemes equally valid? Or some of them **describe better** exp data?
- Compute the difference in χ^2 between the VFN and FFN fits with **various kinematical cuts**
- The **FFN fit quality is poorer than the VFN**, the difference is **statistically significan**t and specially relevant for the **inclusive HERA-I**: due to **missing resummation of DGLAP logarithms**

x_{min}	x_{max}	Q^2_{min}	Q^2_{max}	$\chi^2_{tot}(\mathrm{FFN}-\mathrm{VFN})$	N_{dat}^{tot}	$\chi^2_{hera}(\mathrm{FFN}-\mathrm{VFN})$	N_{dat}^{hera}
10^{-6}	1.0	3.0	10^6	28.26	2936	37.88	592
10^{-6}	1.0	3.0	10^6	68.88	1055	39.73	405
10^{-6}	1.0	3.0	10^6	28.54	422	10.65	202
10^{-6}	1.0	10^2	10^6	38.80	620	46.67	412
10^{-6}	0.1	10	10^6	49.67	583	32.43	350
10^{-6}	0.1	10^2	10^6	45.92	321	47.26	227
10^{-6}	0.1	10	10^3	31.17	510	13.52	298
10^{-6}	0.1	10^2	10^3	27.21	248	28.11	175

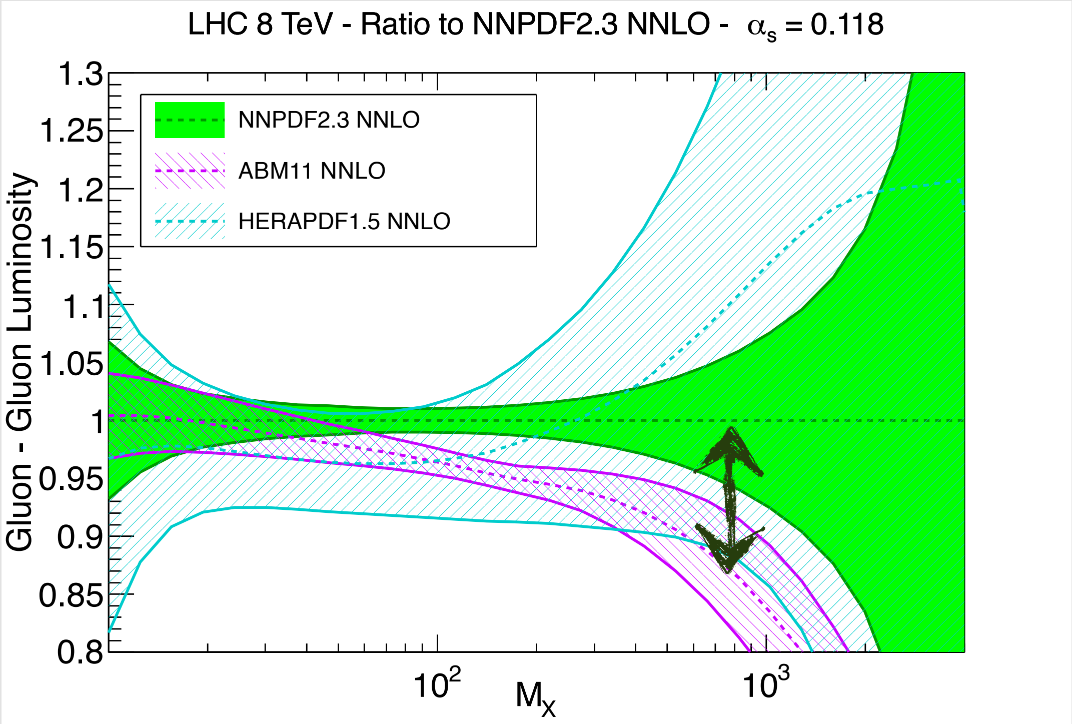
kin cuts **all DIS data** **HERA-I data**

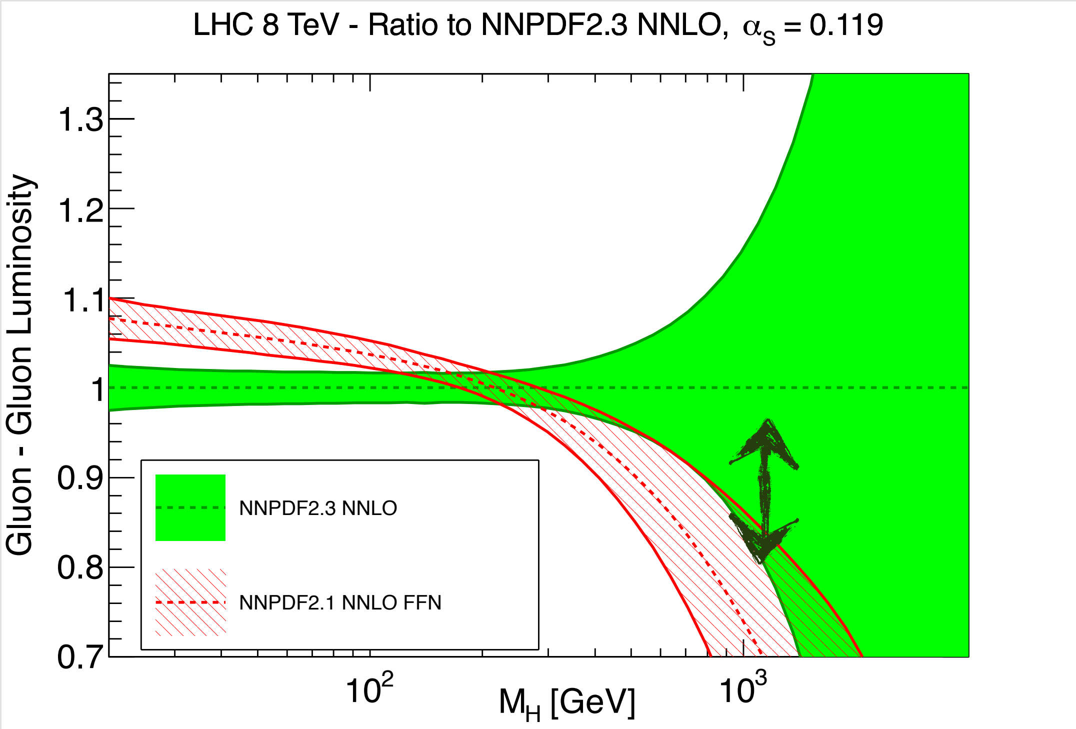
- Although FFN provides a reasonable description of HERA-I data, a **better fit quality** obtained by VFN thanks to **DGLAP resummation at moderate and large Q2**
- FFN and VFN similar χ^2 at **small Q2**

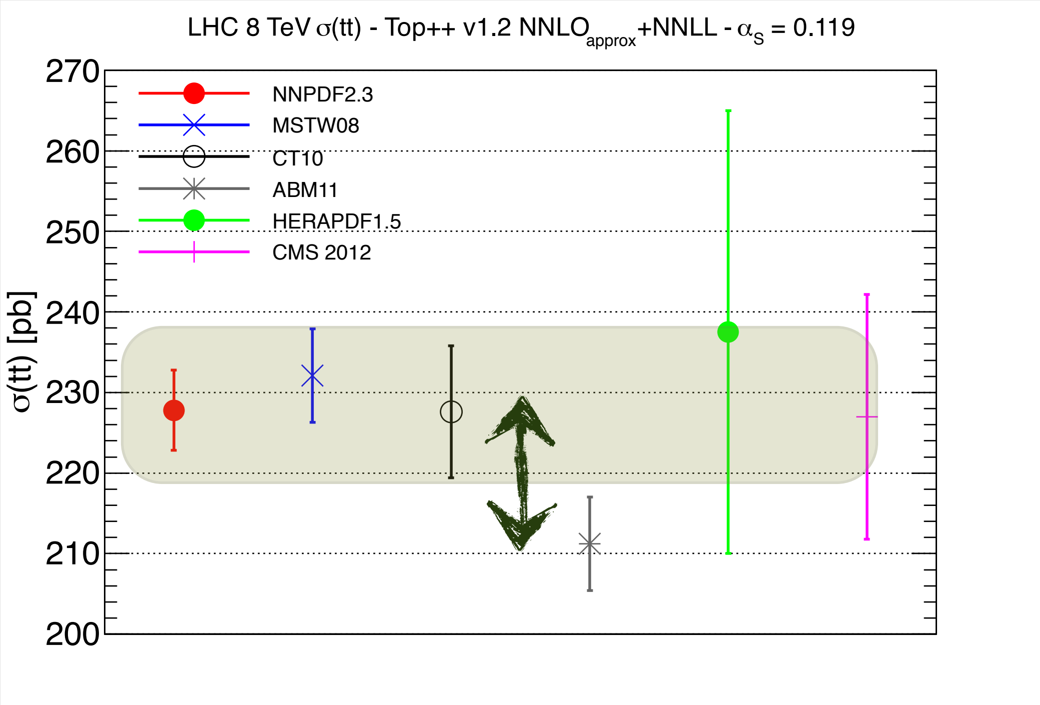
NNPDF Preliminary

Variable vs Fixed Flavor Number Schemes

- The different treatment of **DGLAP logarithms** (fixed order vs resummation) might explain most differences in LHC cross sections between ABM11 and NNPDF2.3 (even for common α_S)



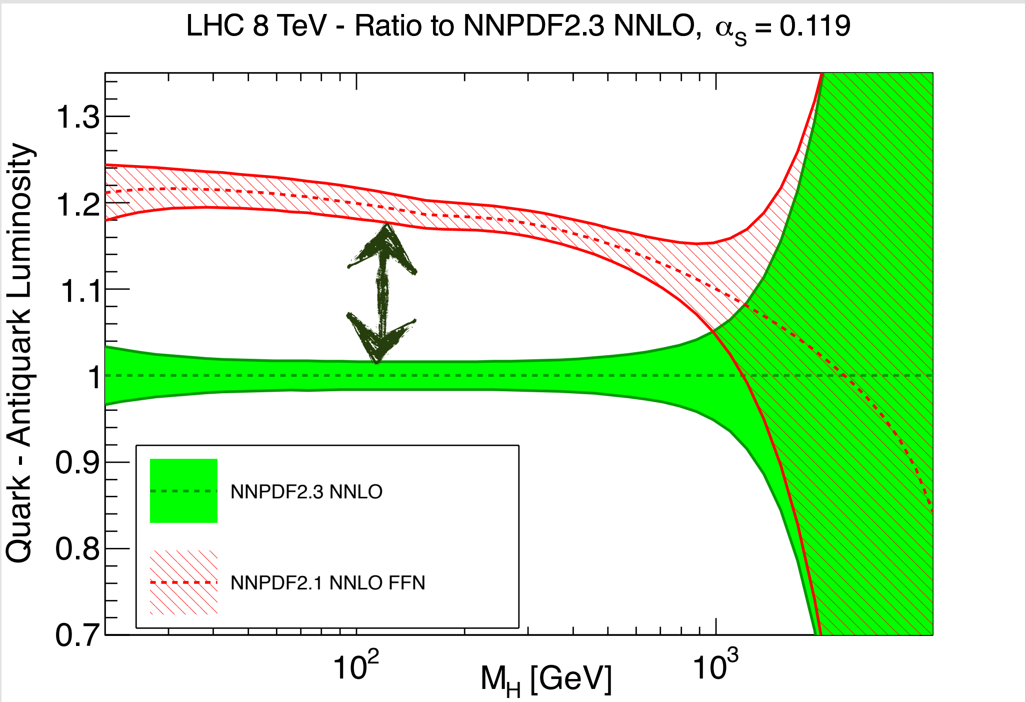


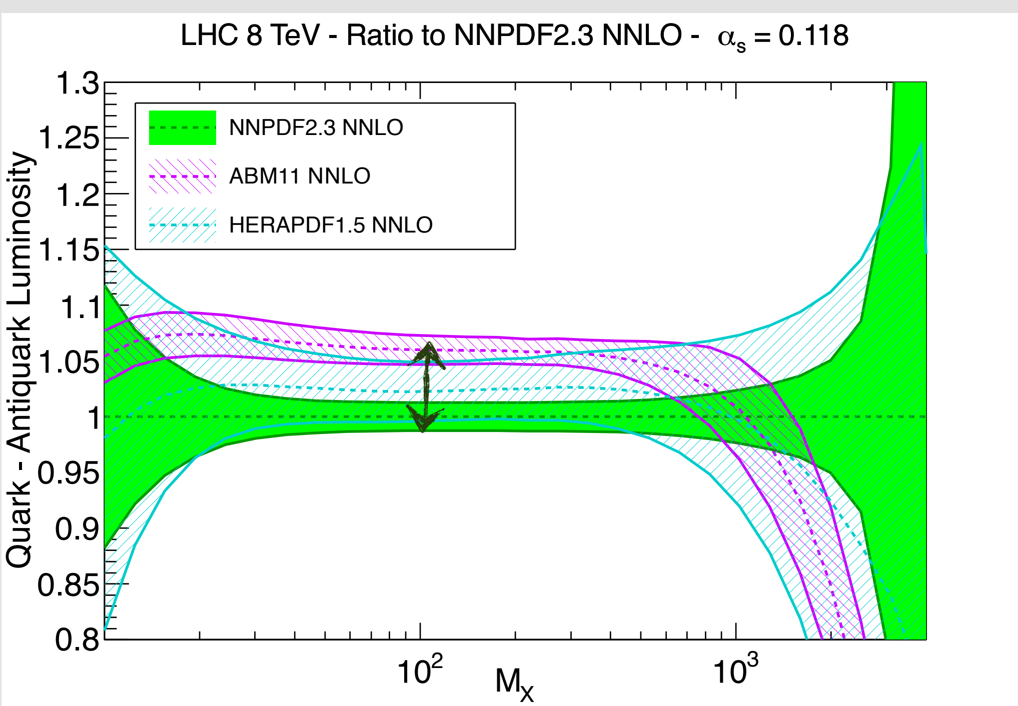


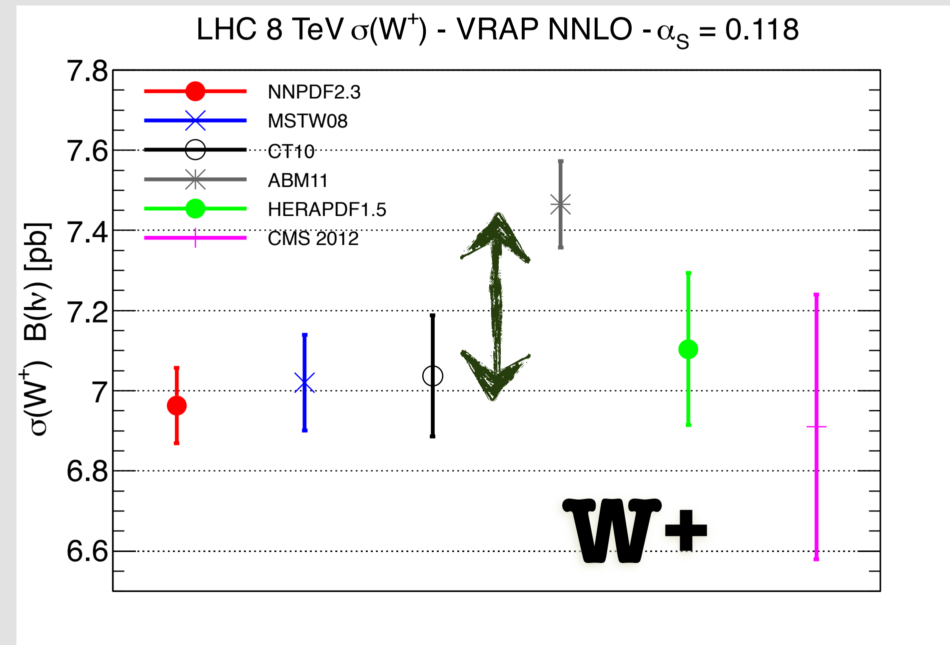
Softer **large-x gluon** -> Smaller **tT, ttH** cross sections

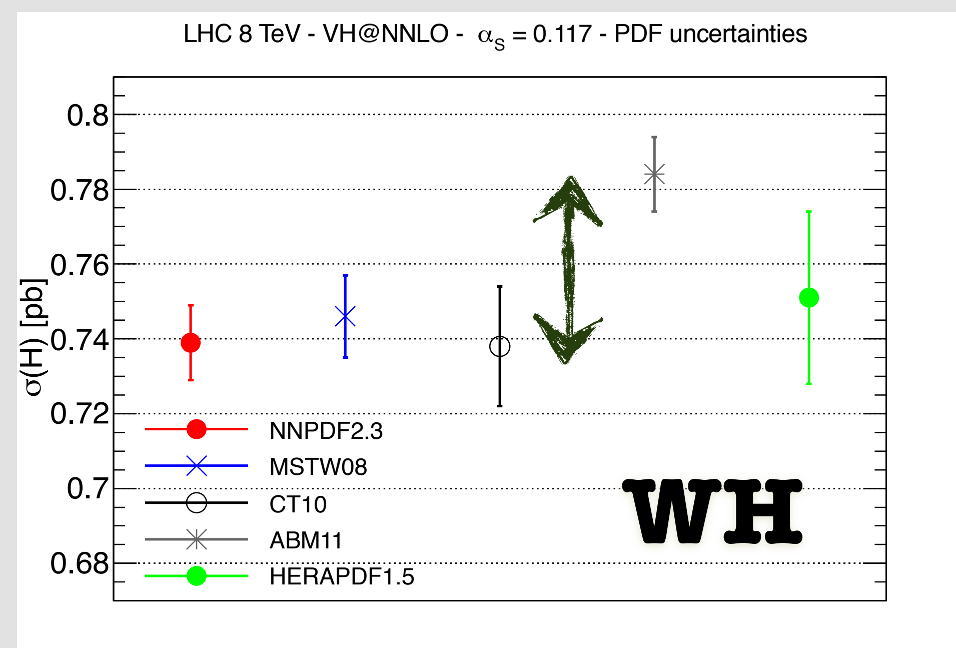
Variable vs Fixed Flavor Number Schemes

- The different treatment of **DGLAP logarithms** (fixed order vs resummation) might explain most differences in LHC cross sections between ABM11 and NNPDF2.3 (even for common α_S)









Harder **smaller-x quarks** -> Larger **W,Z, WH, VBF** cross sections

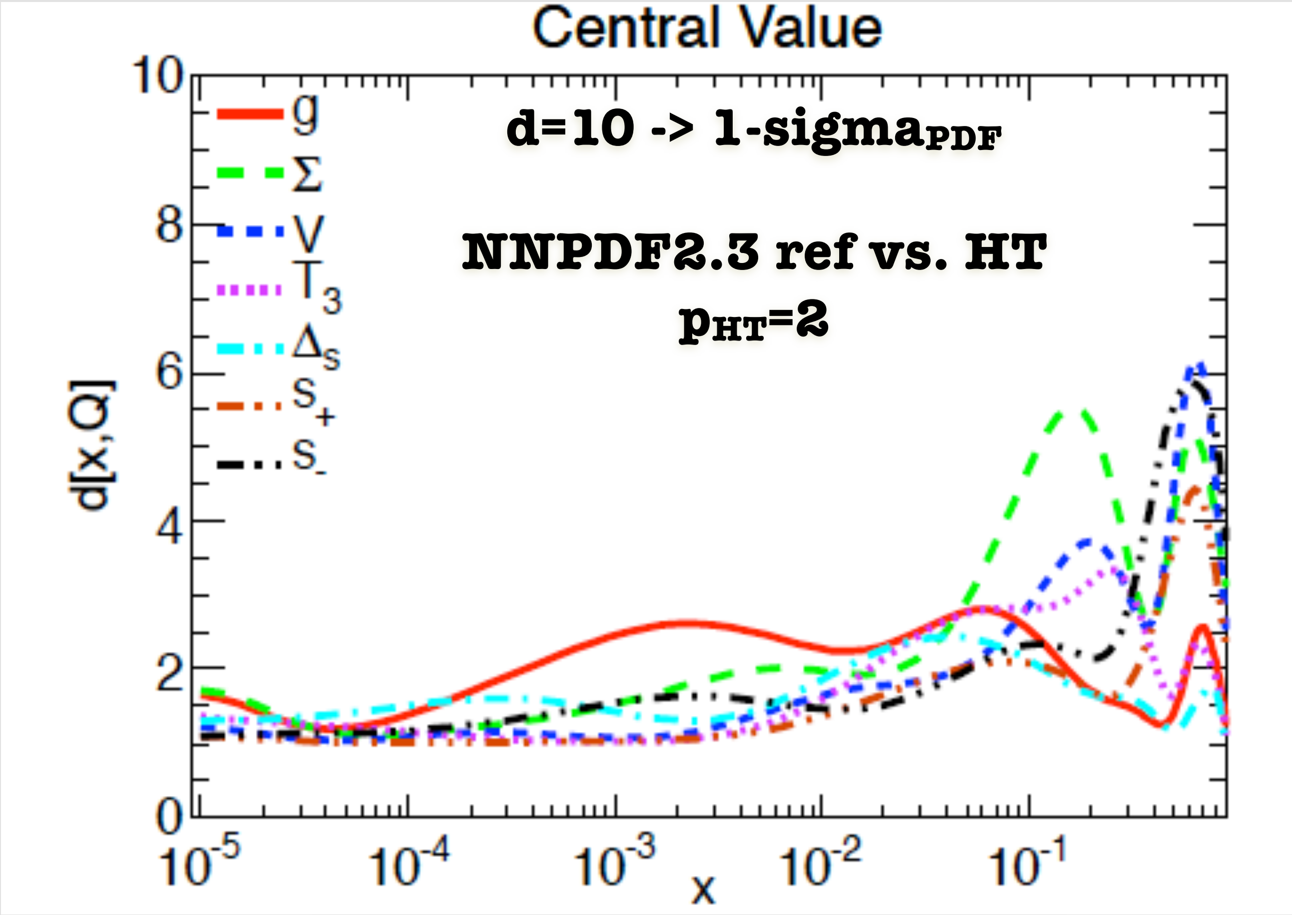
Impact of Higher Twists

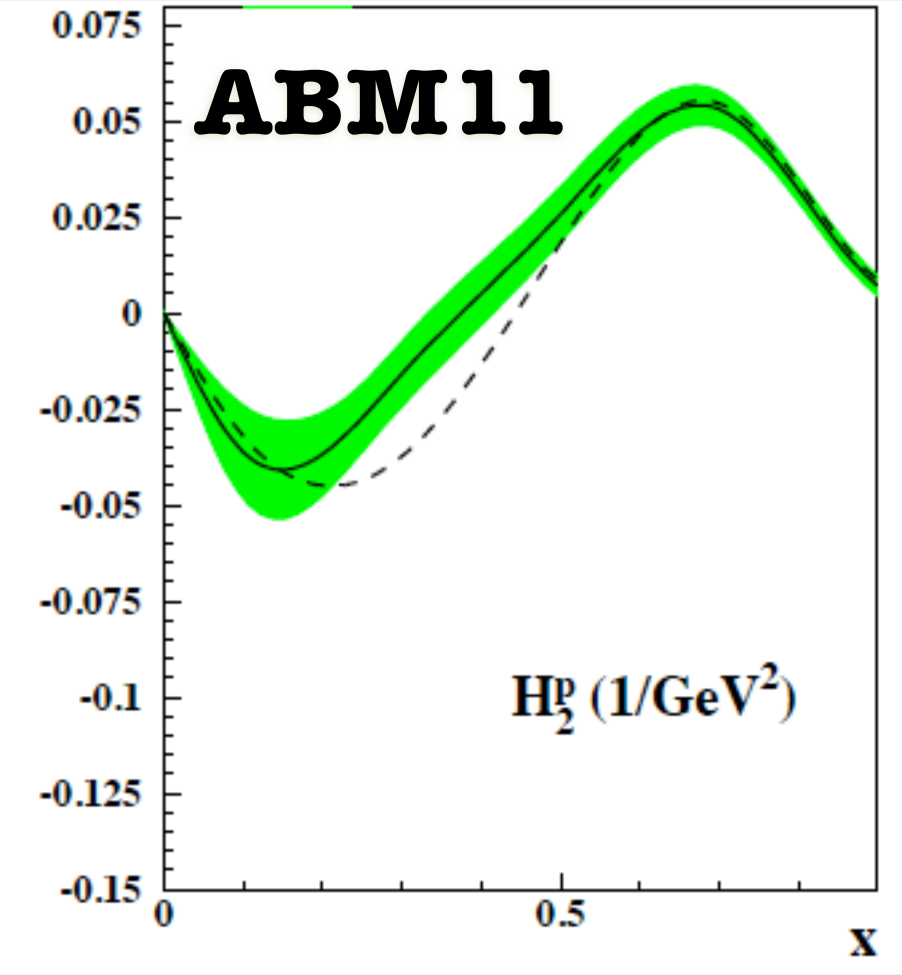
- **NNPDF2.3** adopts a kin cut of $\mathbf{W^2 > 12.5\ GeV^2}$ and includes exactly **kinematical higher twists** (target mass corrections)

- To explore possible impact of residual dynamical higher twists, redo NNPDF2.3 using the **ABM HT parametrization** varying the overall normalization

$$F_i^{\rm HT}(x,Q^2) = F_i^{\rm TMC}(x,Q^2) + p_{\rm HT}\frac{H_i^{\tau=4}}{Q^2} \ ,$$

- Even for a HT correction **twice** the size of ABM11, differences in PDFs **much smaller than PDF uncertainties.** Similar conclusions from MSTW study (arXiv:1106.5789)

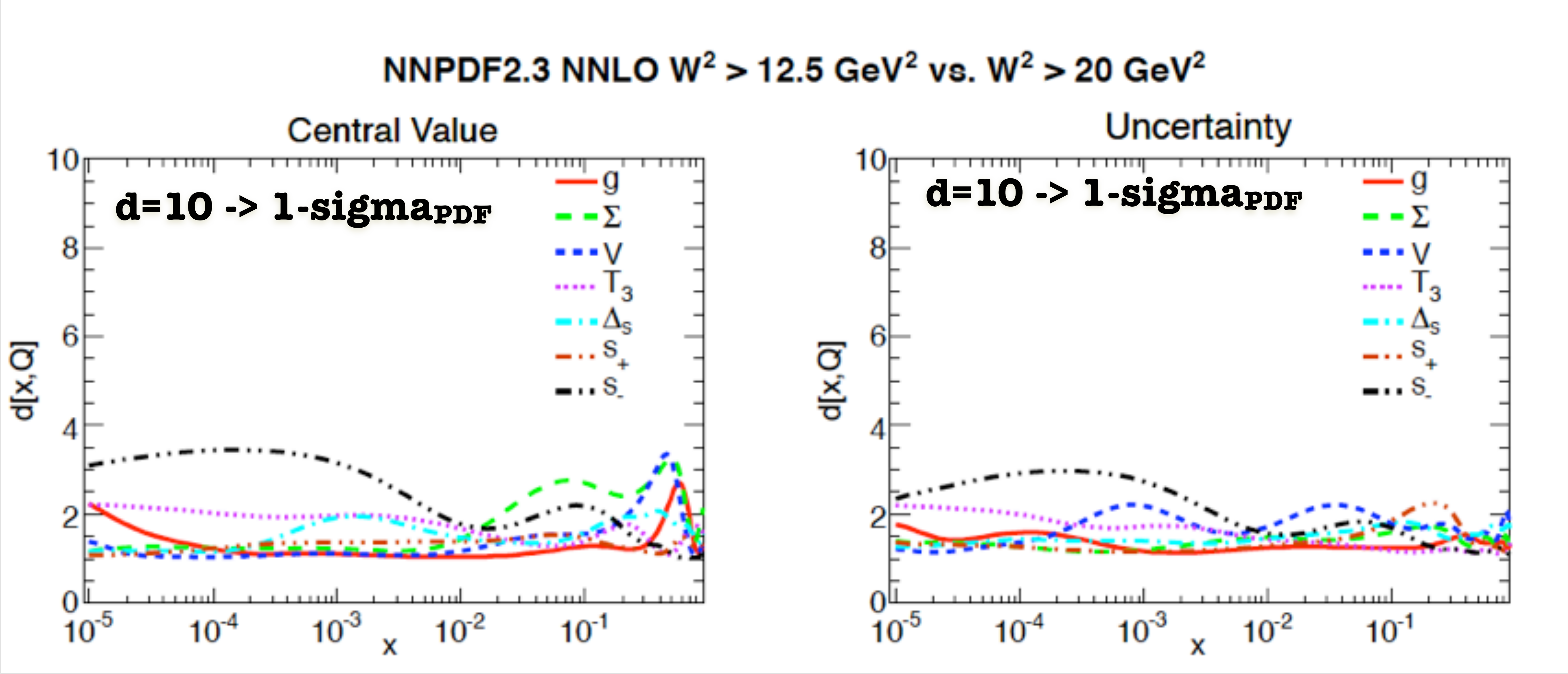




NNPDF Preliminary

Impact of Higher Twists

- **NNPDF2.3** adopts a kin cut of $\mathbf{W^2 > 12.5\ GeV^2}$ and includes exactly **kinematical higher twists** (target mass corrections)
- If **higher twists contaminate** the default NNPDF2.3, one should expect a systematic difference when the cut is raised say to $\mathbf{W^2 > 20\ GeV^2}$
- We find however no statistically significant differences varying the $\mathbf{W^2}$ cut: **higher twists are irrelevant** for the NNPDF fits



NNPDF Preliminary

Systematic errors in Jet data

- Some issues raised in the ABM paper **arXiv:1211.2642** about possible statistical inconsistencies in the treatment of **inclusive jet data** by other groups

- **The t0 prescription** correctly treats multiplicative and additive uncertainties. The "**Extended-t0**" prescription is unbiased but treat additive uncertainties approximately. Some of the jet systematics errors (like **JES**) should be treated as multiplicative instead of additive

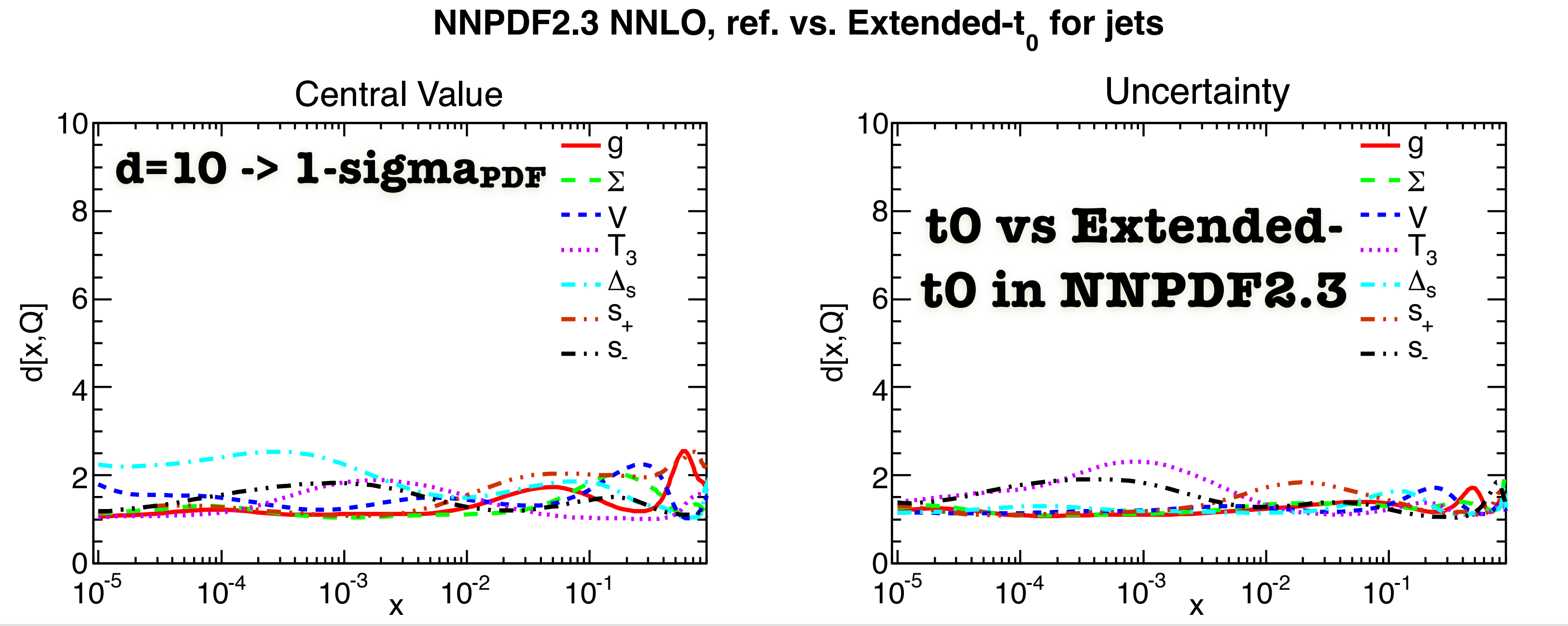
- The NNPDF2.3 fit is unchanged if all sys errors in jet data are treated as multiplicatively

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

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

χ^2	t0	Ext-t0
ATLAS	0.9	0.5
CDF	0.6	1.4
D0	0.8	1.0

NNPDF Preliminary



Summary

- We find **good agreement between CT10, MSTW08 and NNPDF2.3 NNLO sets** in most cases for PDFs, luminosities and physical cross sections

- ABM11 has **harder quarks and a softer large-x gluon** as compared CT/MSTW/NNPDF**.** Partly understood from **use of a FFN scheme**, **higher twist** do not seem to play any role. **FFN disfavoured by HERA data** due to **missing DGLAP logs**. Much larger differences if default α_S**=0.1135** used.

- HERAPDF1.5 agrees with CT/MSTW/NNPDF on **central values**, but has **larger PDF uncertainties** (consistently due to reduced dataset). **No tension** between HERA-only fits and fits to a wider dataset observed.

- We have compared all PDF sets to **available LHC 7 and 8 TeV data**, and for differential distributions made the **comparison quantitative** using a χ^2 estimator. LHC data already provides **important constraints on PDFs**, much more to come in next months/years!

- An **NNLO update** of the current **PDF4LHC envelope** results in substantial improvement of the **PDF+**α_S uncertainties for a wide range of processes.

- For a **Higgs at** M_H**=125 GeV**, such **NNLO update** yields similar **PDF+**α_S uncertainties as in the current prescription.

Extra Material

Impact of χ^2 definition

- When comparing χ^2 recall different definitions possible
- For example, one can use in the normalization term either the **experimental value** or a given **theory prediction (T_0 method),** which yields numerically smaller values
- Qualitative conclusions robust against χ^2 definitions. Other definitions also explored.

$$(\mathrm{cov})_{IJ} = \left(\sum_{l=1}^{N_c} \sigma_{I,l}\sigma_{J,l} + \delta_{IJ}\sigma_{I,s}^2 \right) F_I F_J + \left(\sum_{n=1}^{N_a} \sigma_{I,n}\sigma_{J,n} + \sum_{n=1}^{N_r} \sigma_{I,n}\sigma_{J,n} \right) F_I F_J$$

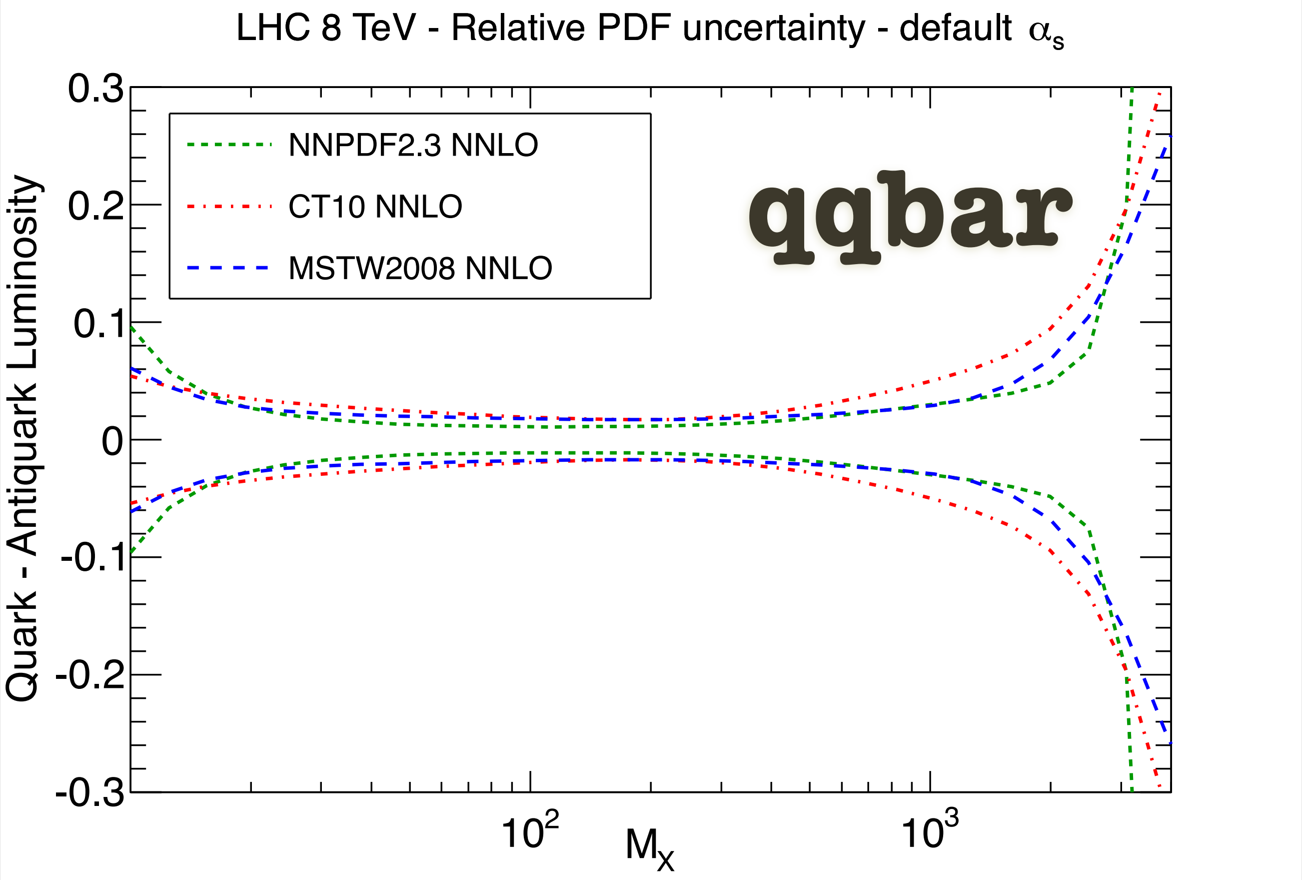
EXP

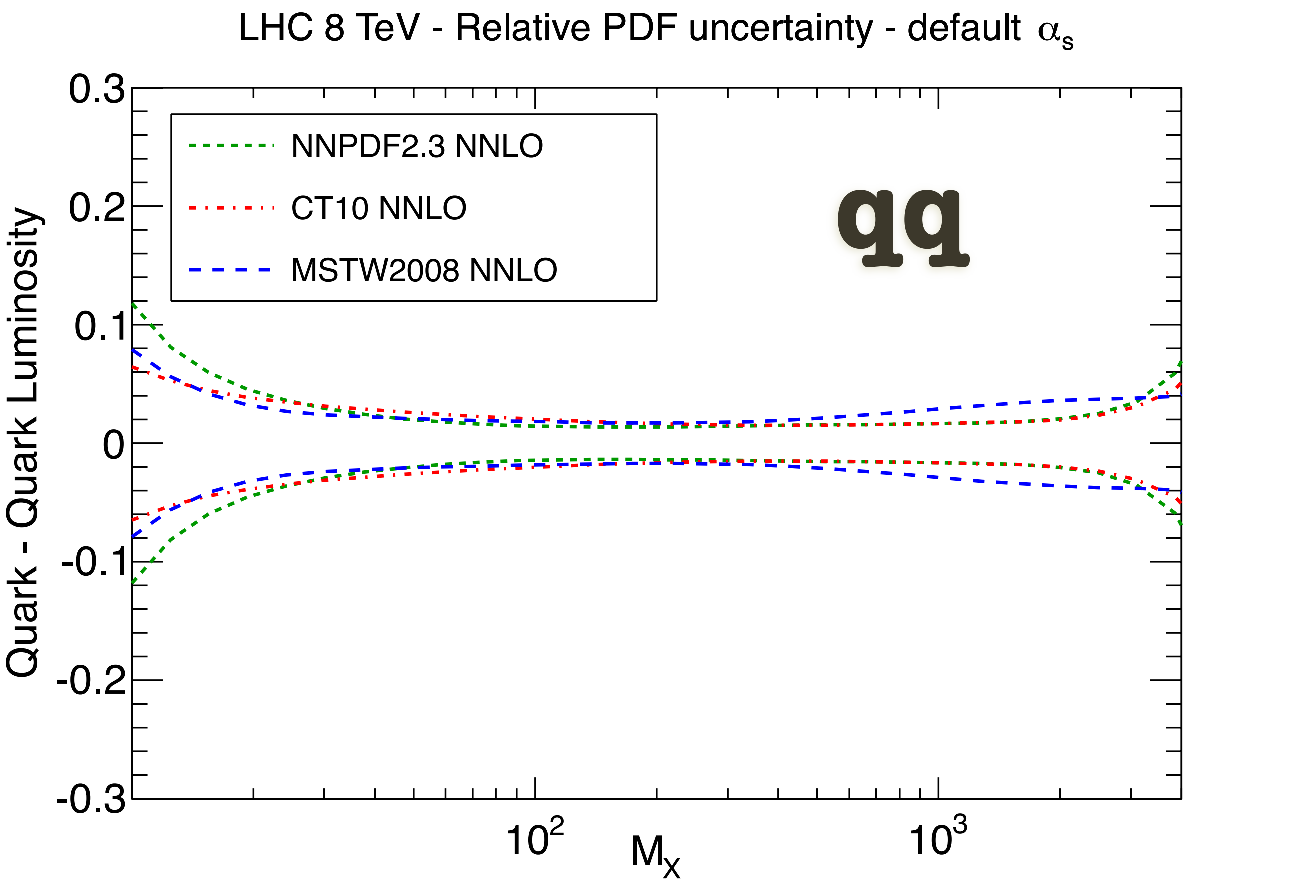
$$(\mathrm{cov_{t0}})_{IJ} = \left(\sum_{l=1}^{N_c} \sigma_{I,l}\sigma_{J,l} + \delta_{IJ}\sigma_{I,s}^2 \right) F_I F_J + \left(\sum_{n=1}^{N_a} \sigma_{I,n}\sigma_{J,n} + \sum_{n=1}^{N_r} \sigma_{I,n}\sigma_{J,n} \right) F_I^{(0)} F_J^{(0)}$$

T_0

	NNLO $\alpha_s = 0.119$				
Dataset	NNPDF2.3	MSTW08	CT10	ABM11	HERAPDF1.5
ATLAS W, Z (EXP)	1.435	3.201	1.160	2.061	1.872
ATLAS W, Z (T0)	1.385	3.043	1.082	1.965	1.817
CMS W el asy (EXP)	0.813	3.862	1.772	1.614	0.814
CMS W el asy (T0)	0.813	3.862	1.772	1.614	0.814
LHCb W, Z (EXP)	0.831	1.050	0.966	1.970	0.784
LHCb W, Z (T0)	0.784	0.968	0.905	1.906	0.727
ATLAS jets (EXP)	0.937	0.935	1.016	0.959	1.011
ATLAS jets (T0)	0.812	0.802	0.879	0.892	0.855

Quark Luminosities



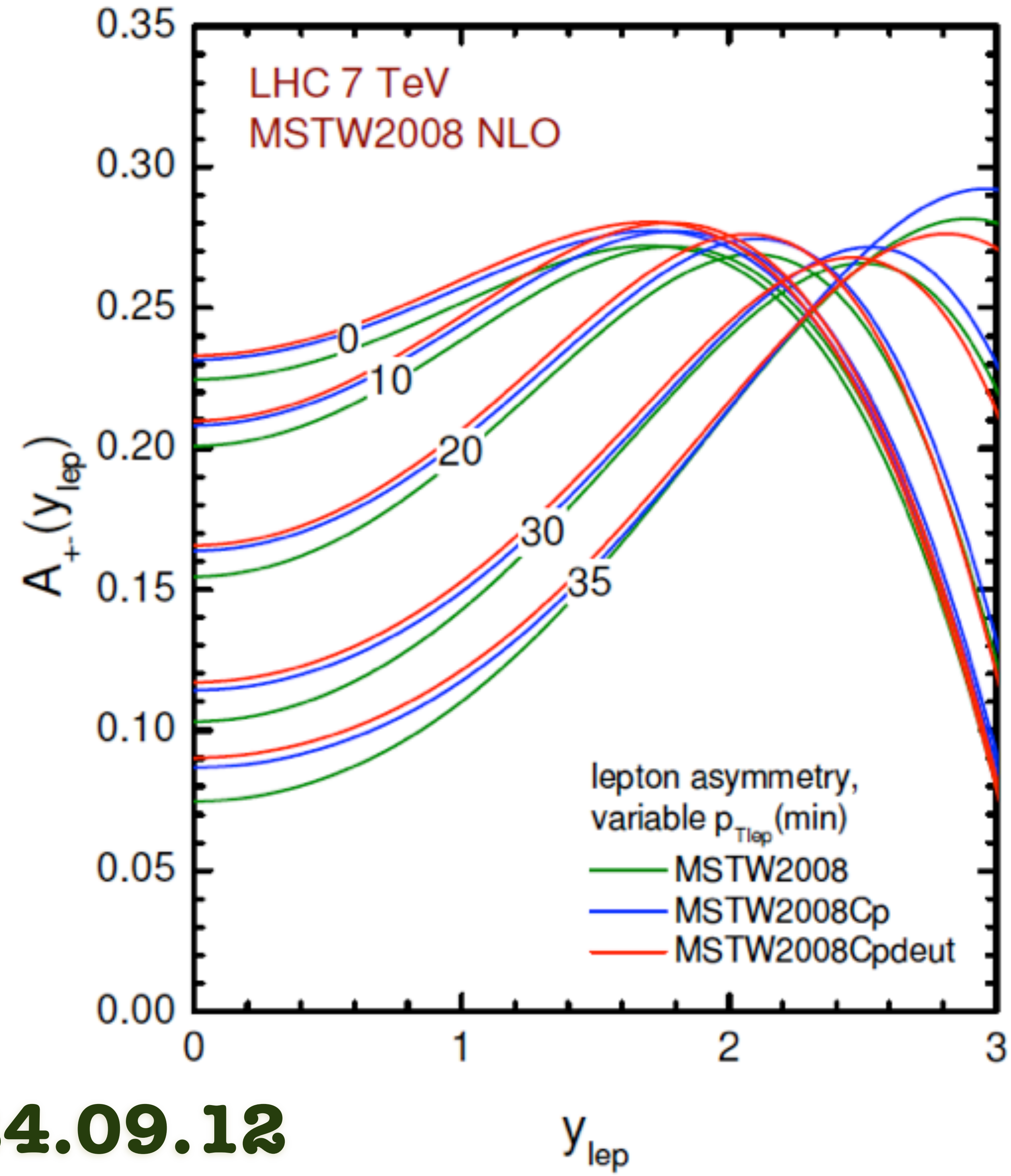


- **Quark-Antiquark luminosities** (relevant for SUSY, W', ...) have much larger uncertainties at large masses due to poorly known large-x antiquarks
- **Quark-Quark luminosities** (relevant for jets) better constrained at large masses

MSTW2008 and W asymmetry

Increases lepton asymmetry, but very preferentially for high p_T cut. (Curves made here with LO calculations).

Most of the effect already obtained for parameterisation extension, but some from deuterium study.



R. Thorne PDF4LHC 24.09.12

MSTW2008 and W asymmetry

Big change in high p_T cut asymmetry, but very specifically sensitive to $u_V(x,Q^2) - d_V(x,Q^2)$. What about other quantities? Other PDFs changed little. α_S free but tiny change. Expect little variation.

The % change in the cross sections ($M_H = 120\text{GeV}$).

	MSTWCp	MSTWCpdeut
W Tev	+0.6	+0.1
Z Tev	+0.8	+0.7
W^+ LHC (7TeV)	+0.7	+0.3
W^- LHC (7TeV)	-0.7	-0.4
Z LHC (7TeV)	+0.0	-0.1
W^+ LHC (14TeV)	+0.6	+0.3
W^- LHC (14TeV)	-0.6	-0.5
Z LHC (14TeV)	+0.1	-0.1
Higgs TeV	-0.5	-1.8
Higgs LHC (7TeV)	+0.2	-0.1
Higgs LHC (14TeV)	+0.1	+0.1

Extreme stability in total cross sections, all far inside uncertainties. Even $\sigma(W^+)/\sigma(W^-)$ barely more than 1%.

R. Thorne PDF4LHC 24.09.12

PDF benchmarking

- Several groups provide **regular updates of their PDF sets**. These differ by the choice of dataset, statistical methodology, treatment of higher order corrections and of the strong coupling, heavy quarks ...
- Benchmarking exercises between PDF groups have been performed in the past, and have been instrumental for **understanding differences and similarities between PDF sets**, and lead to improved convergence of some of them
- In this talk: updated benchmarking of the most recent PDF sets

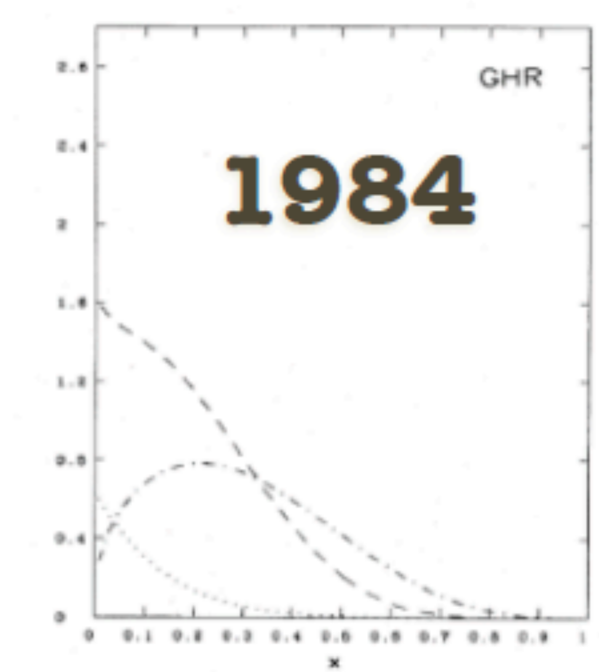


FIG. 25. Parton distributions of Glück, Hoffmann, and Reya (1982), at $Q^2=5$ GeV^2: valence quark distribution $x[u_v(x)+d_v(x)]$ (dotted-dashed line), $xG(x)$ (dashed line), and q_s (dotted line).

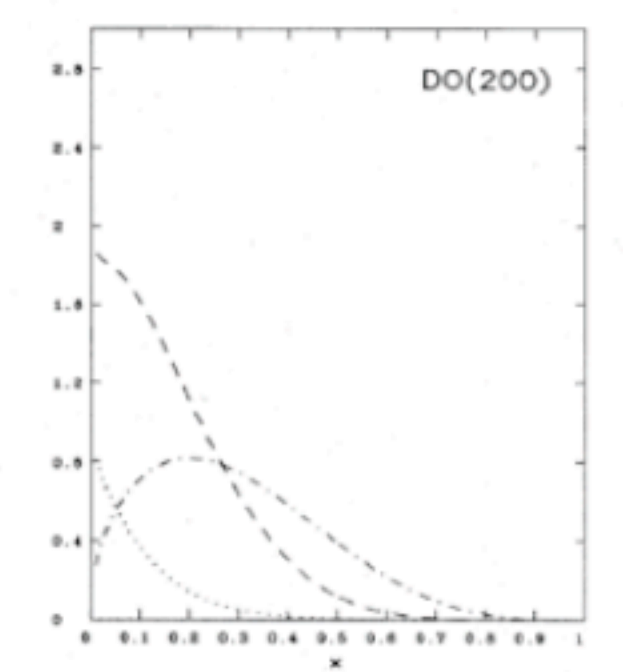
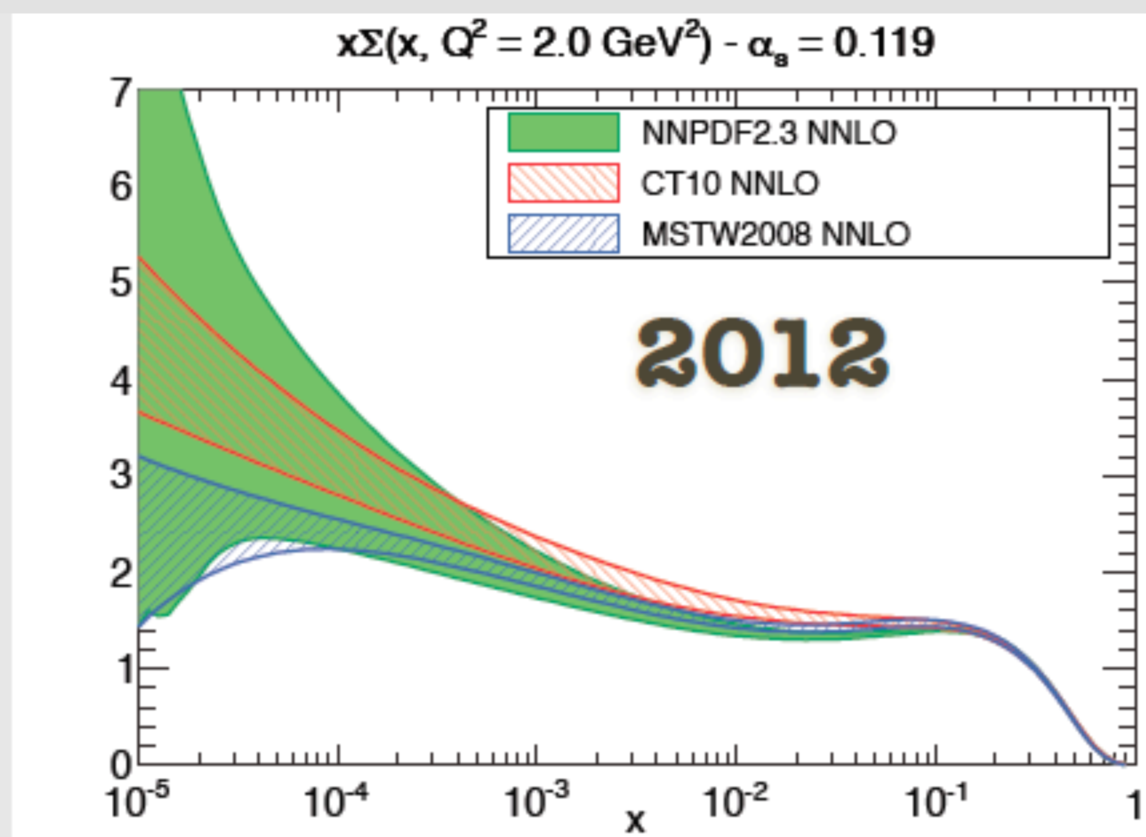


FIG. 27. "Soft-gluon" ($\Lambda=200$ MeV) parton distributions of Duke and Owens (1984) at $Q^2=5$ GeV^2: valence quark distribution $x[u_v(x)+d_v(x)]$ (dotted-dashed line), $xG(x)$ (dashed line), and $q_s(x)$ (dotted line).



PDF benchmarking

Collaboration	Authors	arXiv
ABM	S. Alekhin, J. Blümlein, S. Moch	1105.5349, 1101.5261, 1107.3657, 0908.3128, 0908.2766, ...
CTEQ/TEA	M. Guzzi J. Huston, H.-L. Lai, P. Nadolsky, J. Pumplin, D. Stump, C.-P. Yuan	1108.5112, 1101.0561, 1007.2241, 1004.4624, 0910.4183, 0904.2424, 0802.0007, ...
GJR	M. Glück, P. Jimenez-Delgado, E. Reya	1003.3168, 0909.1711, 0810.4274, ...
HERAPDF	H1 and ZEUS Collaborations	1107.4193, 1006.4471, 0906.1108, ...
MSTW	A. Martin, J. Stirling, R. Thorne, G. Watt	1107.2624, 1006.2753, 0905.3531, 0901.0002, ...
NNPDF	R. D. Ball, V. Bertone, F. Cerutti, L. Del Debbio, S. Forte, AG, N. P. Hartland, J. I. Latorre, J. Rojo, M. Ubiali	1110.2483, 1108.2758, 1107.2652, 1103.2369, 1102.3182, 1101.1300, 1005.0397, 1002.4407, 0912.2276, 0906.1958, ...

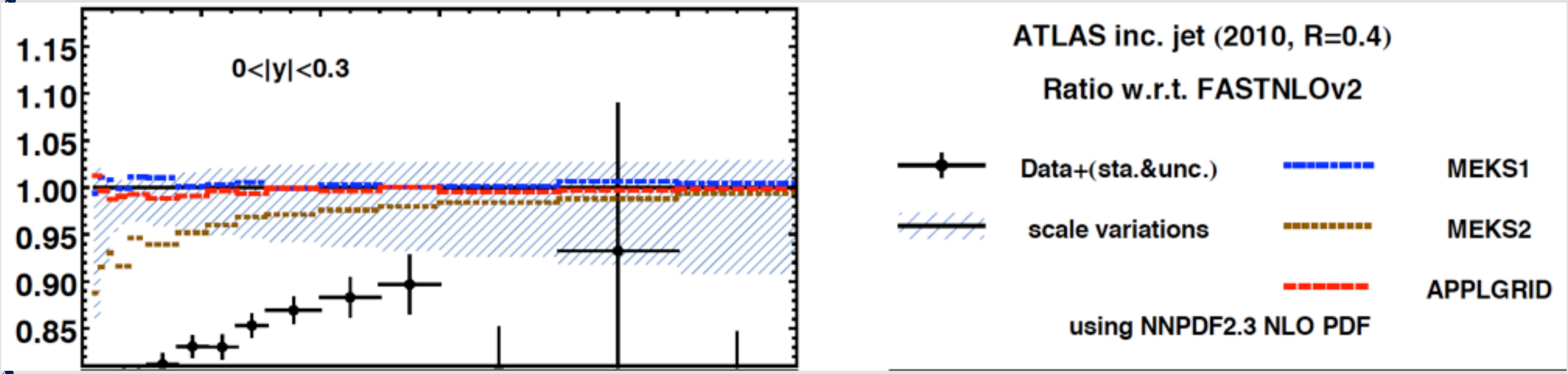
PDF benchmarking

	DATASET	PERT. ORDER	HQ TREATMENT	α_s	PARAM.	UNCERT.
ABM11	DIS Drell-Yan	NLO NNLO	FFN (BMSN)	Fit (multiple values available)	6 indep. PDFs Polynomial (25 param.)	Hessian ($\Delta\chi^2$=1)
CT10	Global	LO NLO NNLO	GM-VFNS (S-ACOT)	External (multiple values available)	6 indep. PDFs Polynomial (26 param.)	Hessian ($\Delta\chi^2$=100)
JR09	DIS Drell-Yan Jets	NLO NNLO	FFN VFN	Fit	5 indep. PDFs Polynomial (15 param.)	Hessian ($\Delta\chi^2$=1)
HERAPDF1.5	DIS (HERA)	NLO NNLO	GM-VFNS (TR)	External (multiple values available)	5 indep. PDFs Polynomial (14 param.)	Hessian ($\Delta\chi^2$=1)
MSTW08	Global	LO NLO NNLO	GM-VFNS (TR)	Fit (multiple values available)	7 indep. PDFs Polynomial (20 param.)	Hessian ($\Delta\chi^2$~25)
NNPDF2.1/2.3	Global	LO NLO NNLO	GM-VFNS (FONLL)	External (multiple values available)	7 indep. PDFs Neural Nets (259 param.)	Monte Carlo

PDF benchmarking - Settings

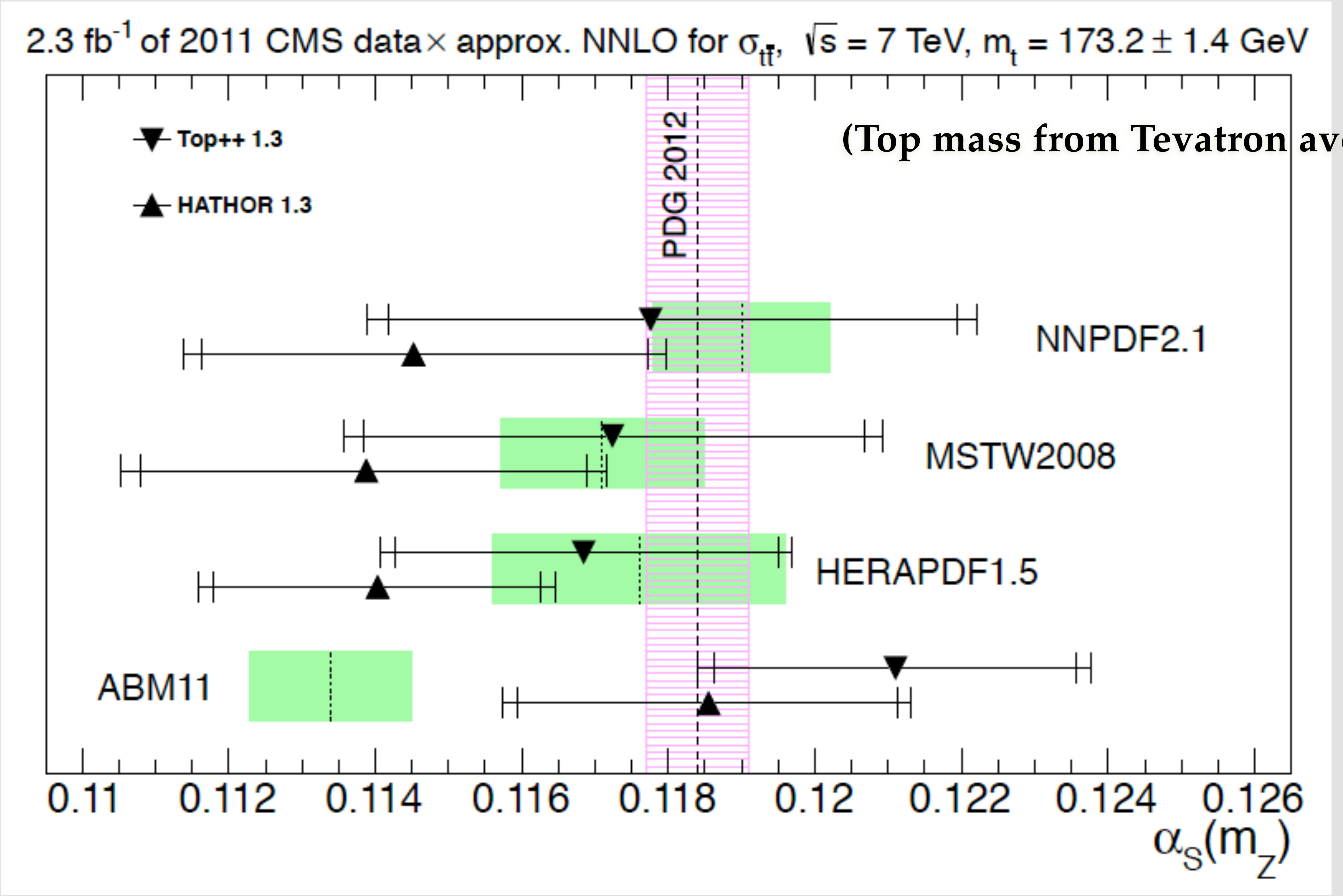
- Theory predictions computed with the following codes, interfaced to **LHAPDF5.8.8**
  - **Vrap** for inclusive **electroweak** boson production at **NNLO**
  - **iHixs** for inclusive **Higgs** production in gluon fusion at **NNLO**
  - **Top++** for inclusive **top quark pair** production at **NNLO$_{approx}$+NNLL**
  - **MCFM** and **NLOjet++** interfaced through **APPLgrid** for **electroweak distributions** and **jet production** at **NLO.** Also **DYNNLO** for electroweak distributions at **NNLO**

- **Scale variations** non negligible for jet data. Dedicated **benchmark comparison of jet codes** in progress. Here we use **APPLgrid** settings (as in ATLAS 2010 jet paper)



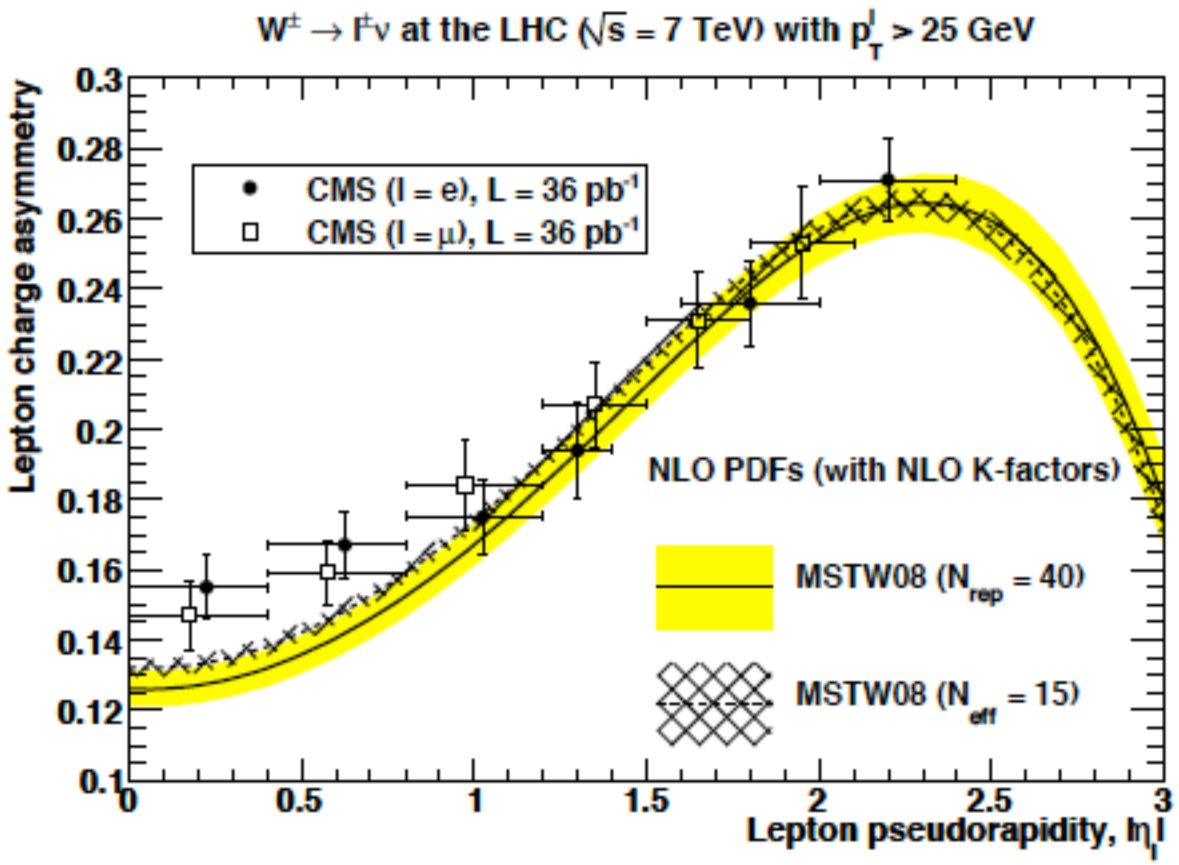
Inclusive Cross Sections - Top

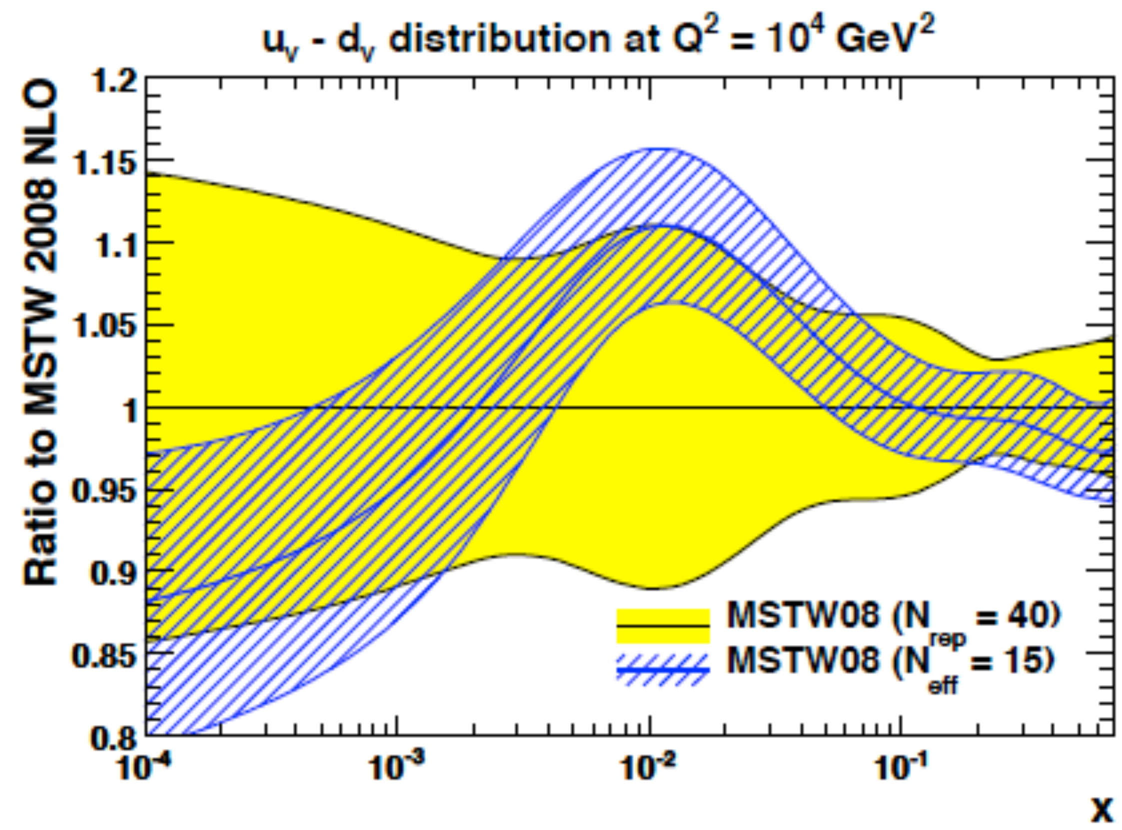
- LHC data **disfavor small values** of α_S. Sensitivity justifies **direct extraction from cross section** (CMS-TOP-12-022). NNPDF2.1, MSTW08 and HERAPDF **self-consistent**



(Top mass from Tevatron average)

MSTW08 and LHC W asymmetry





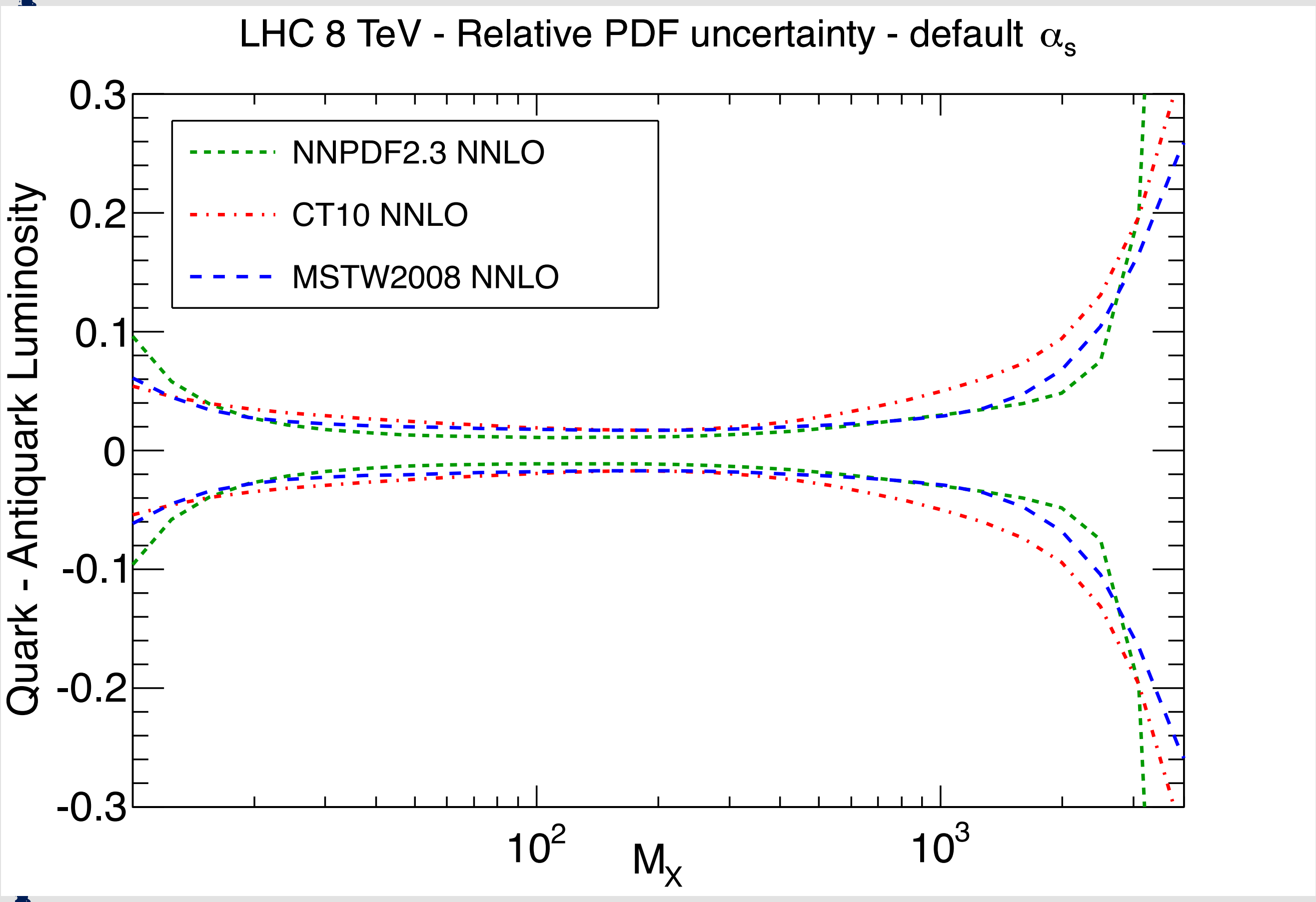
- Include CMS data by reweighting: $\chi^2/N_{\mathrm{pts.}} = 2.43 \to 1.32$.
- Reweighting shifts $u_V - d_V$ at $x \sim M_W/\sqrt{s} \sim 0.01$.

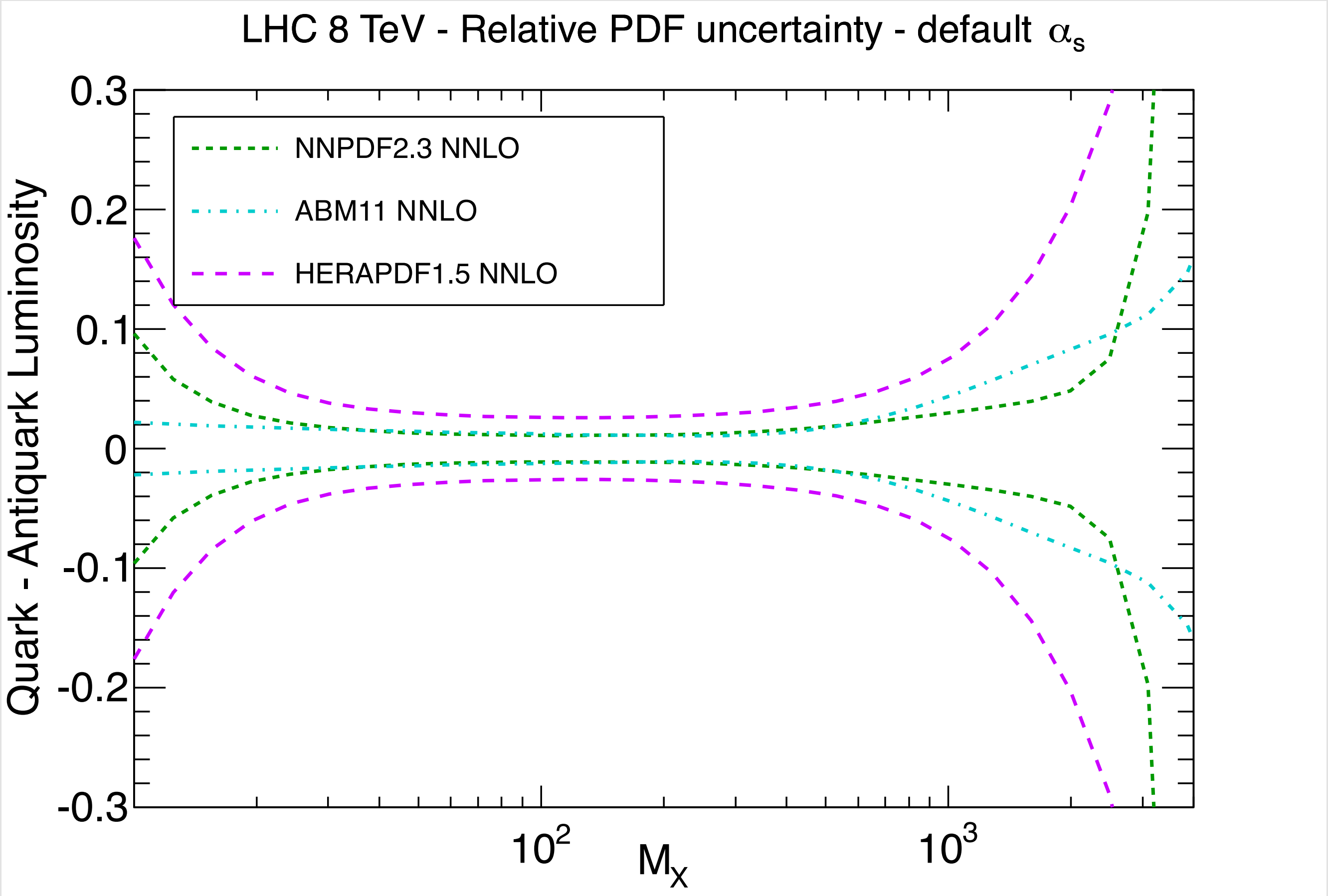
Including **LHC W asymmetry** data in MSTW08 improves substantially the fit quality. Shift in **near x=0.01 in the u_V-d_V difference.** arXiv:1205.4024

Extended parametrization + improved **deuteron corrections** also help. Tiny impact in inclusive cross sections.

PDF Luminosities: Quark-AntiQuark

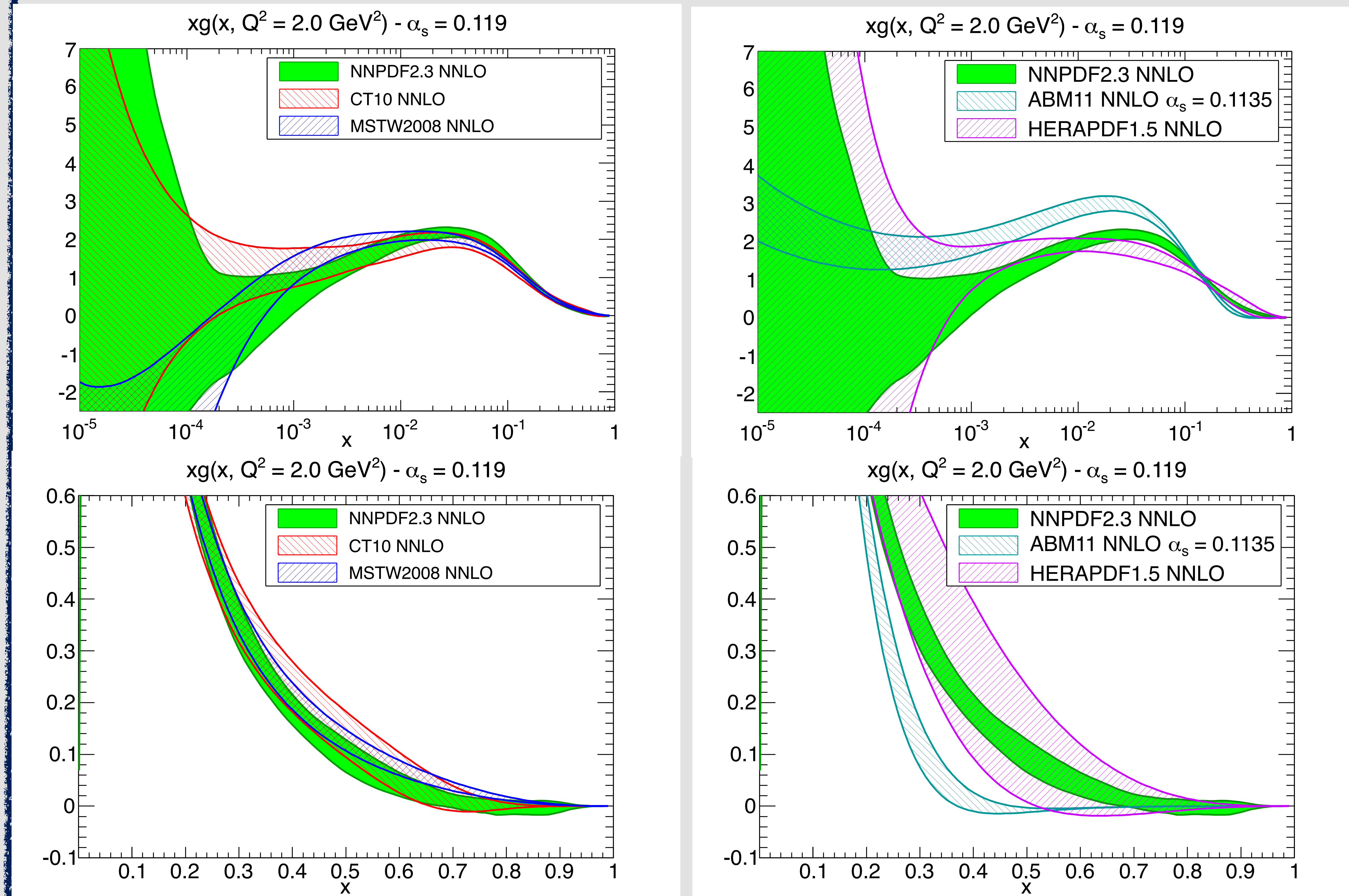
$$\Phi_{ij}\left(M_X^2\right) = \frac{1}{s}\int_\tau^1 \frac{dx_1}{x_1} f_i\left(x_1, M_X^2\right) f_j\left(\tau/x_1, M_X^2\right)$$





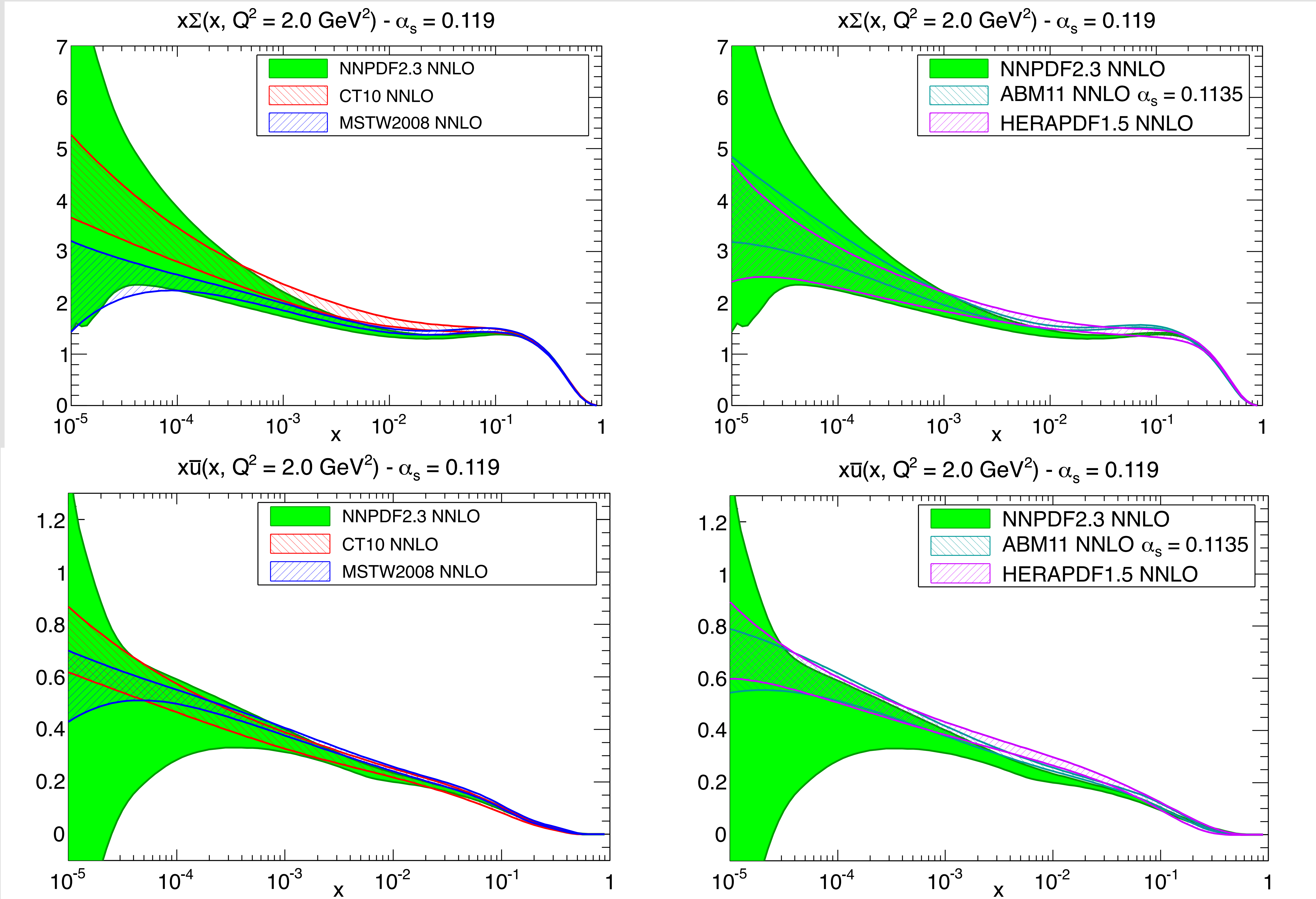
- Again, the **relative PDF uncertainty** in the partonic luminosities
- Between **100 and 500 GeV**, PDF errors from CT/HERAPDF/MSTW/NNPDF very similar

PDFs: Gluon

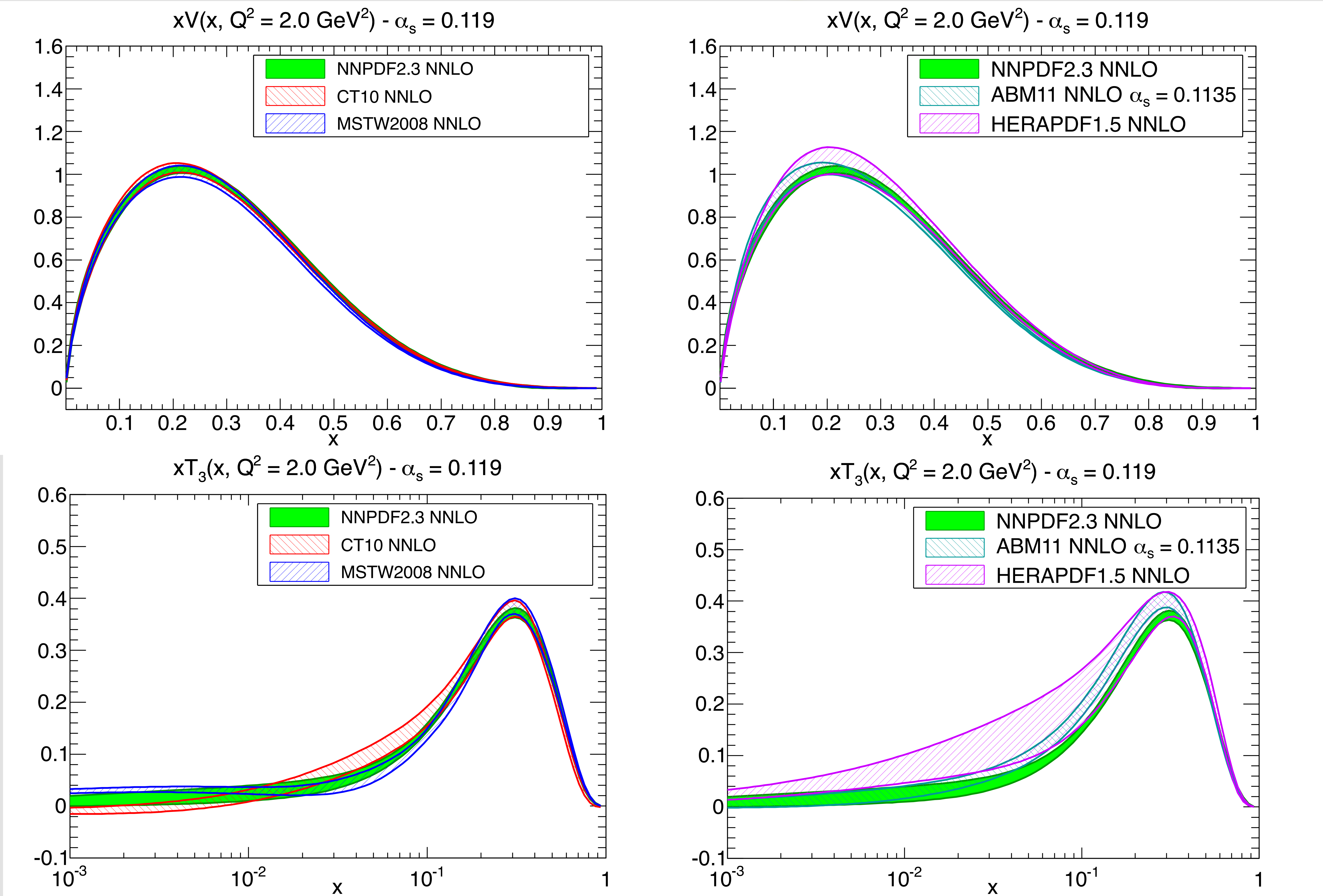


xg(x, Q² = 2.0 GeV²) - αs = 0.119
NNPDF2.3 NNLO
CT10 NNLO
MSTW2008 NNLO
ABM11 NNLO αs = 0.1135
HERAPDF1.5 NNLO
x

PDFs: Sea Quarks

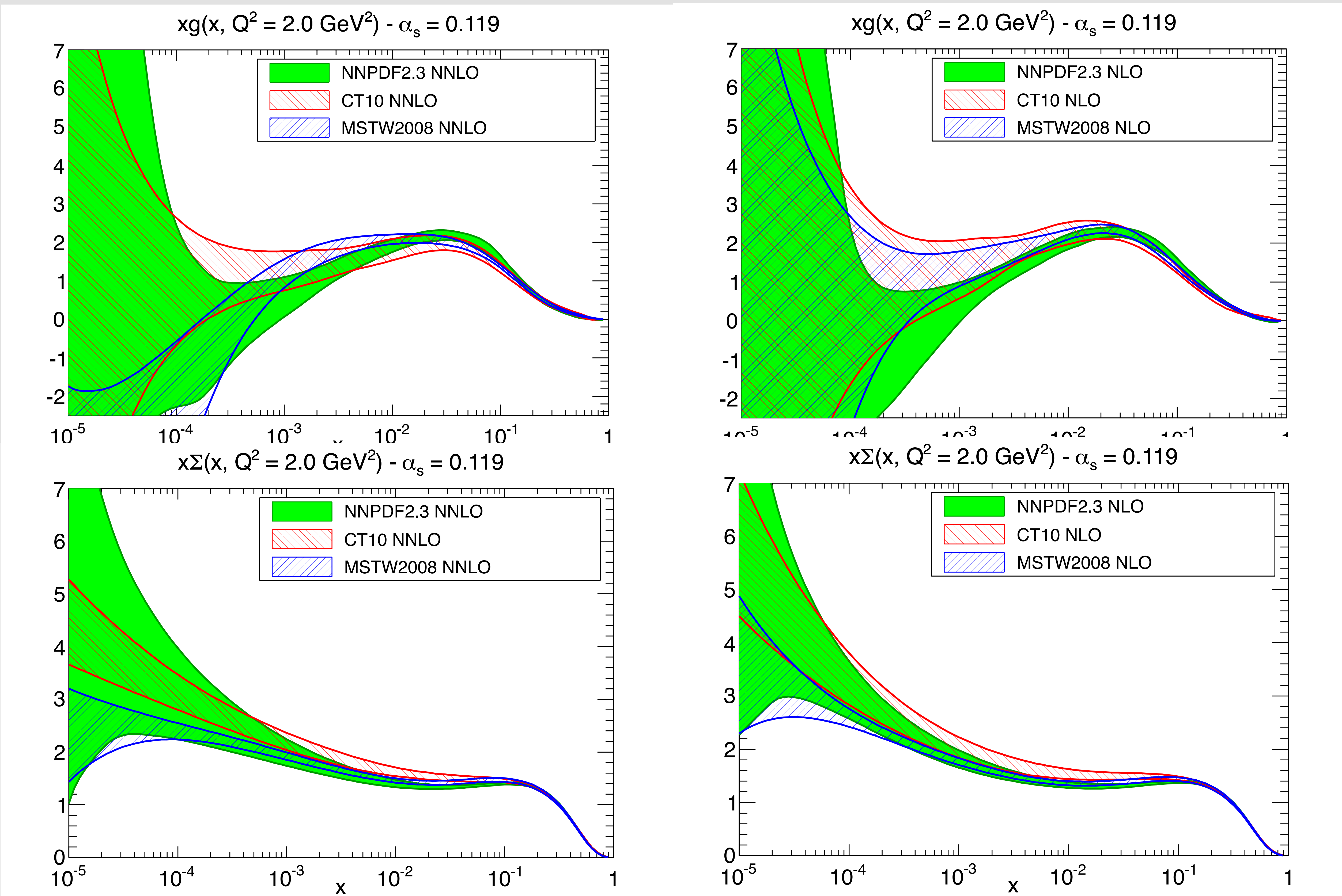


PDFs: Valence Quarks

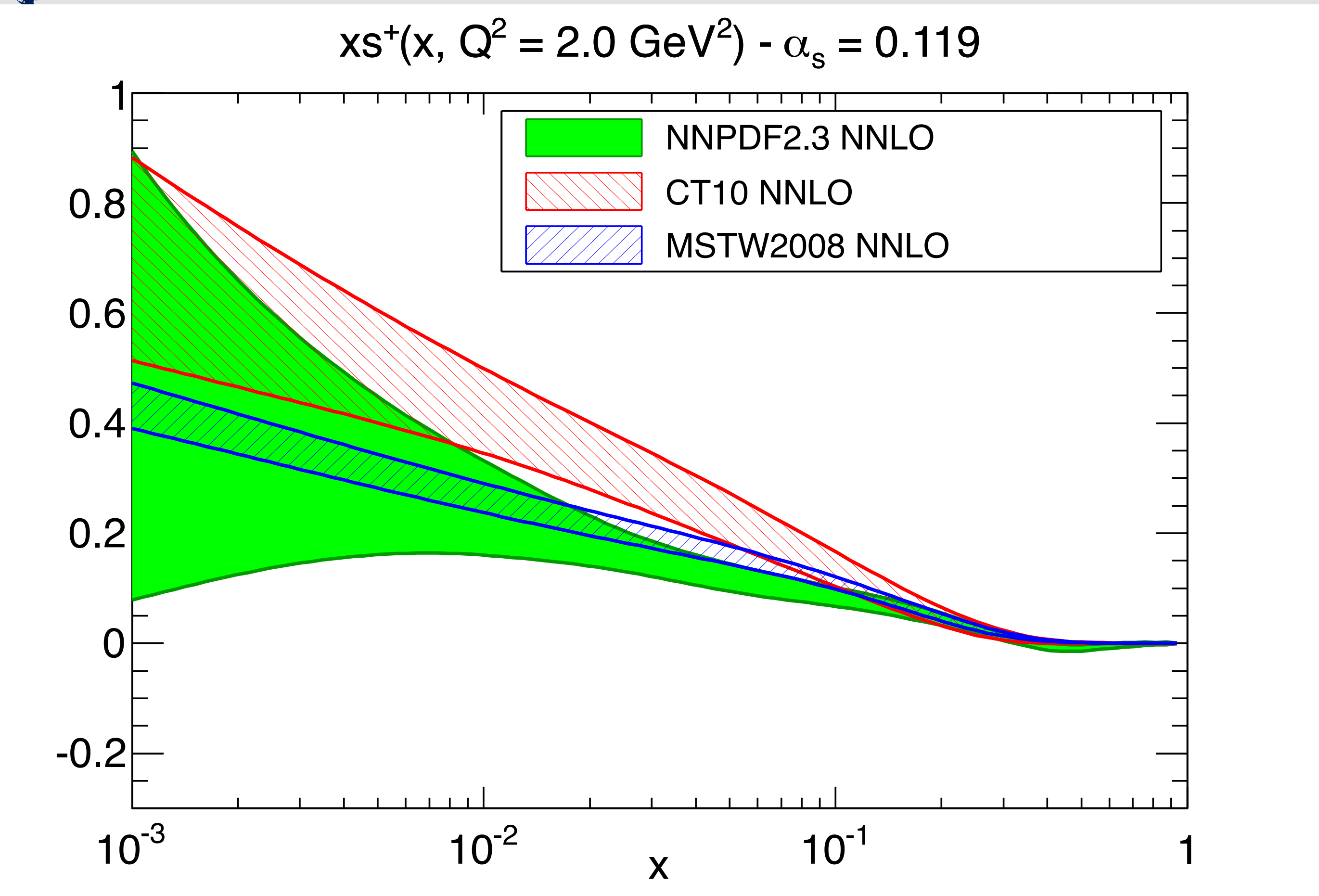


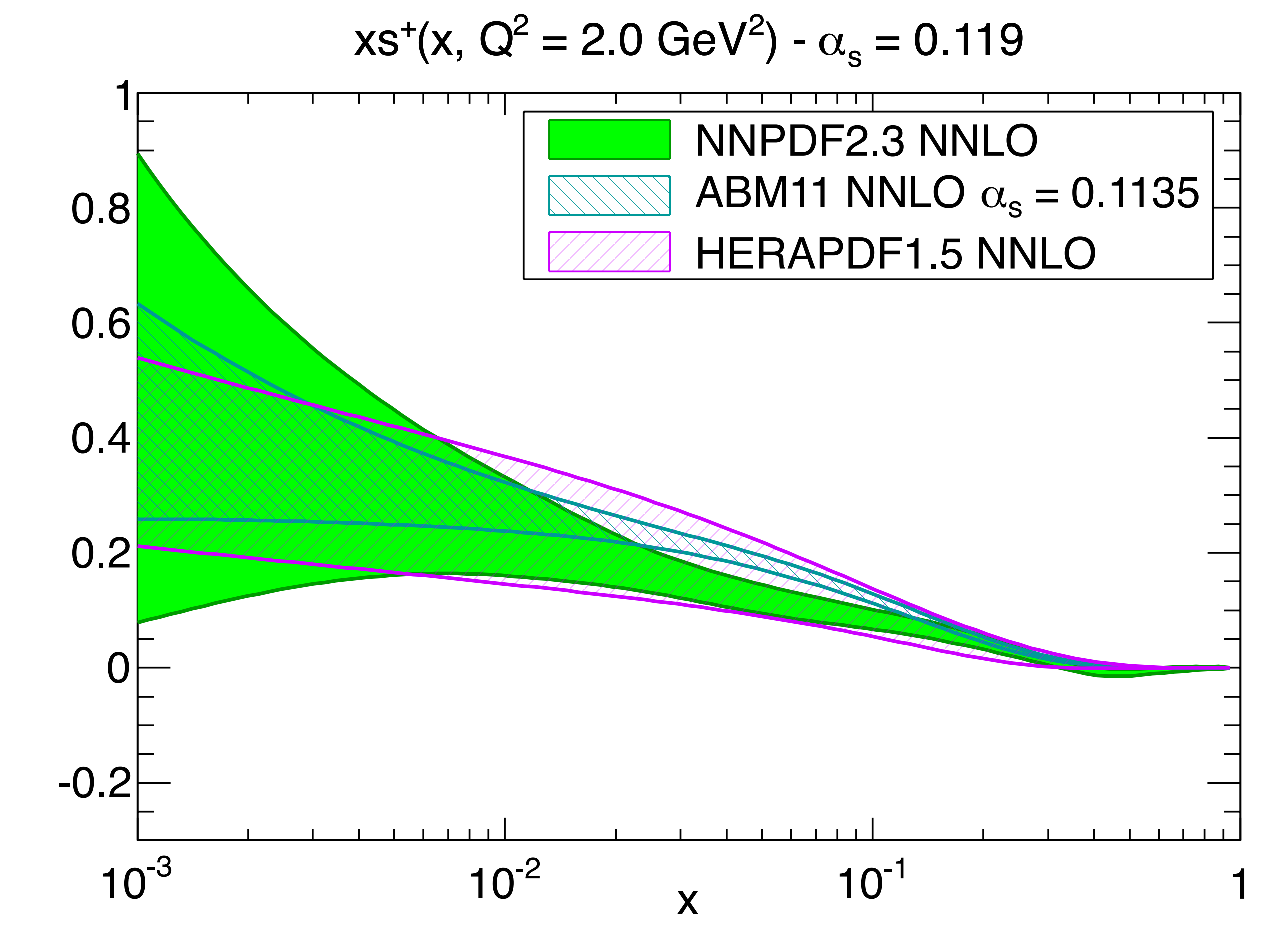
PDFs: NLO vs NNLO

- Good **PDF stability** when going from **NLO to NNLO**



PDFs: Strangeness

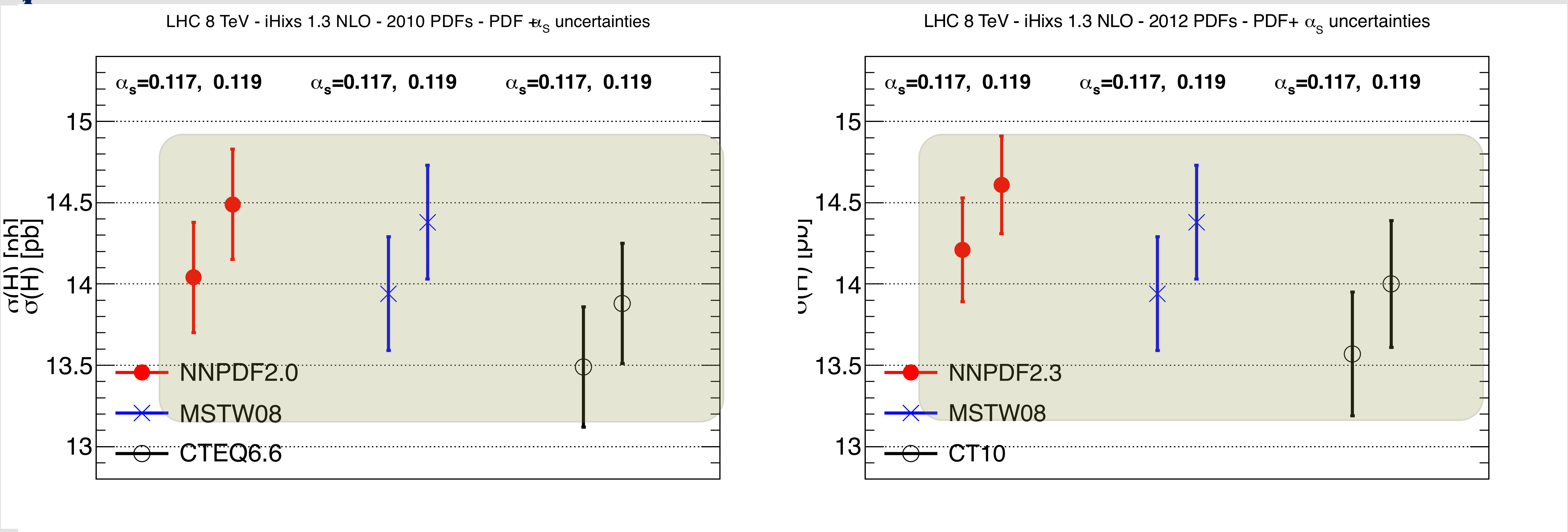




- Reasonable agreement for all PDF sets
- ATLAS W,Z data support **strange sea symmetric with non-strange sea**, but this leads to **poor description of NuTeV dimuon data** (also R. Thorne's talk at last PDF4LHC)
- NNPDF2.3 fits NuTeV and ATLAS data: **softer strangeness still favored**
- **Upcoming W+c data** will shed more light on strangeness

NNLO PDFs and Higgs production

- Compare to the **PDF+α_S uncertainties** of the **NLO envelope** with 2010 and 2012 PDFs
- Reasonable stability between **2010 and 2012 NLO PDFs**



2010 NLO PDFs: $\Delta_{PDF+\alpha_S}$ = 6.1% **2012 NLO PDFs: $\Delta_{PDF+\alpha_S}$ = 6.1%**