Status Report from NNPDF

Juan Rojo

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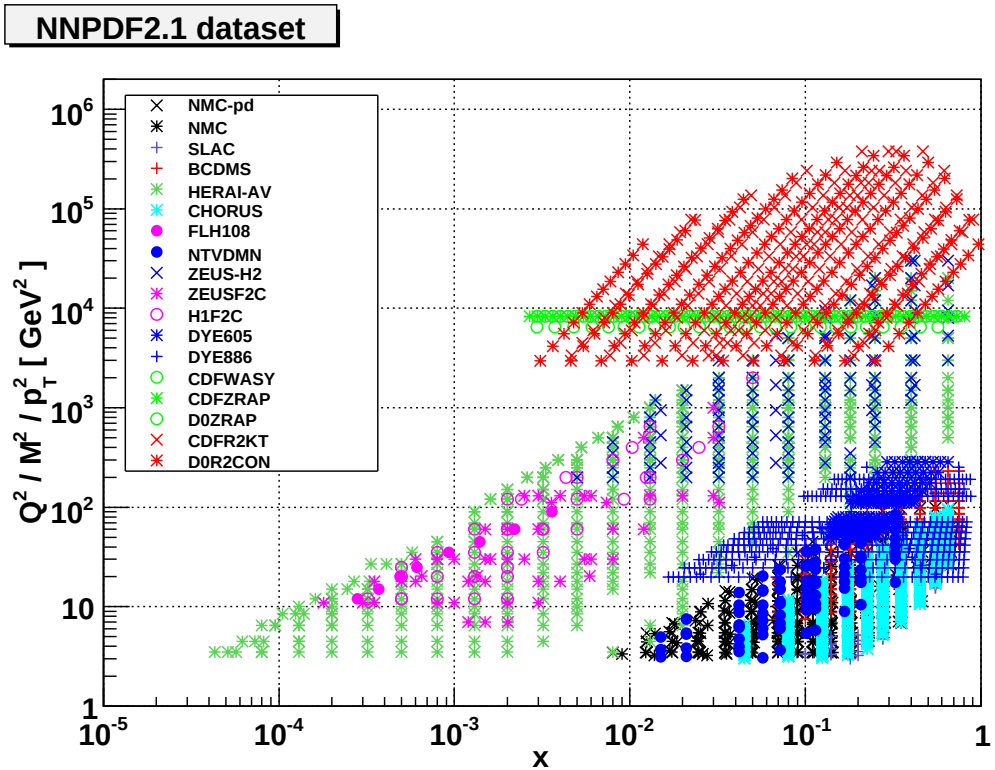
Outline

- Final NNPDF2.1 results
  `NNPDF21_100(0).LHgrid` available from NNPDF website
  Also available in next LHAPDF release
- Theoretical uncertainties in LHC observables from heavy quark mass and GM-VFN scheme choice uncertainties
- The Tevatron W lepton asymmetry data: data (in)consistency and impact in NNPDF2.0

THE NNPDF2.1 SET: FINAL RESULTS

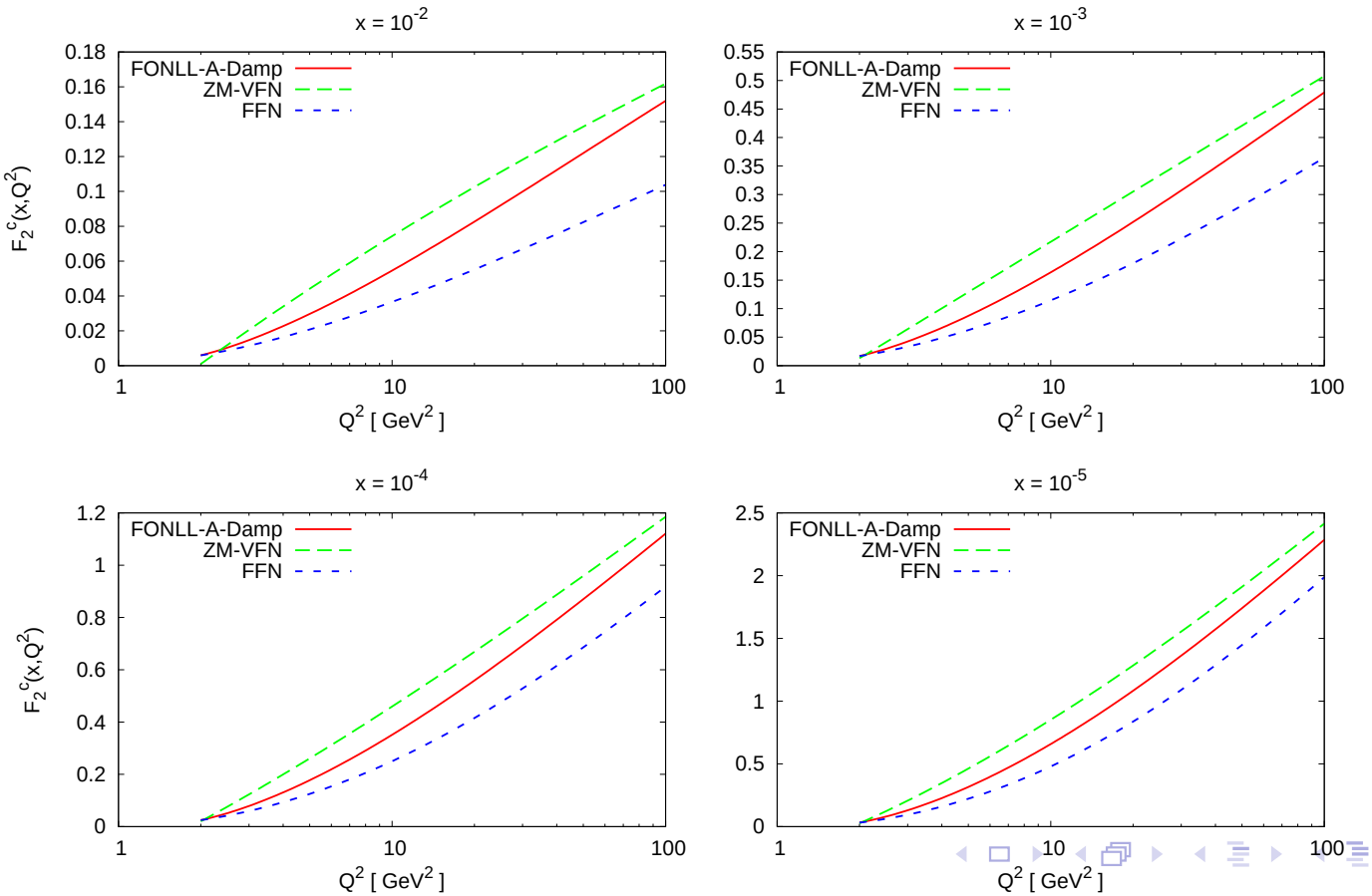
The NNPDF2.1 analysis: Settings



- FONLL-A-Damp GM-VFN scheme for NC and CC DIS observables
- Same data as in NNPDF2.0 + HERA F_2^c data
- More conservative kinematical cuts: $Q^2_{\rm min} = 3$ GeV^2
- $m_c = Q_0 = \sqrt{2}$ GeV, $m_b = 4.75$ GeV

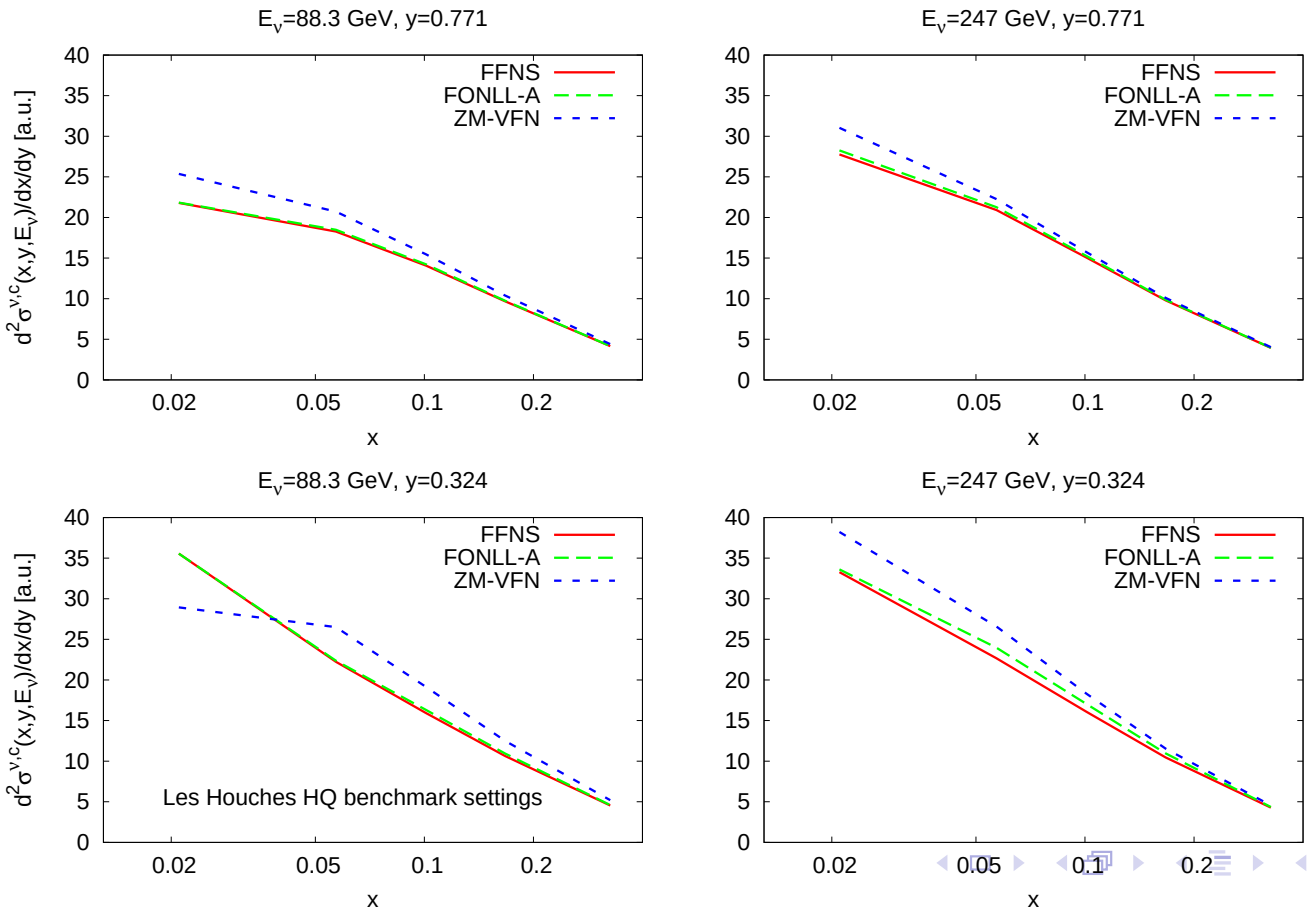
FONLL-A Structure Functions

- FONLL-A implemented for NC and CC structure functions
- Numerical accuracy benchmarked againts Les Houches HQ tables
- FONLL-A interpolates between FFN at low Q^2 and ZM-VFN at large Q^2



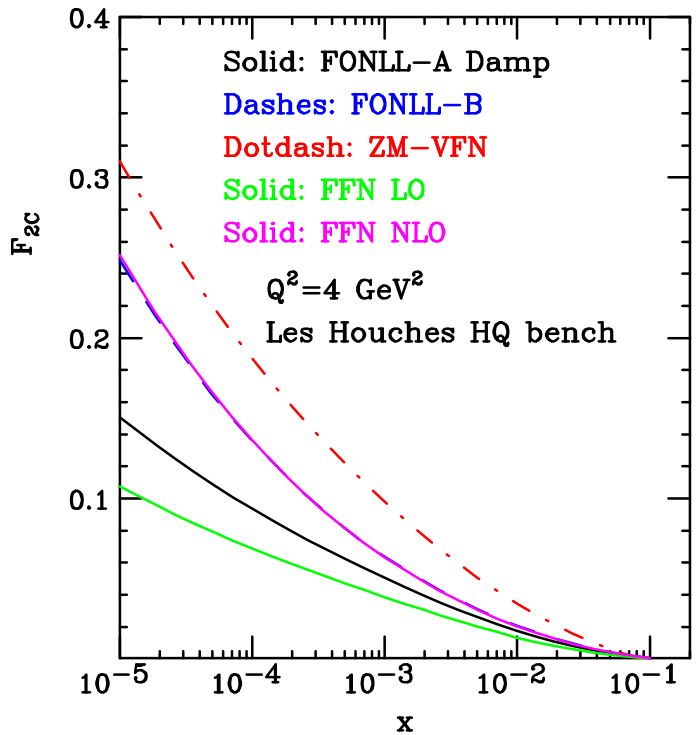
FONLL-A Structure Functions

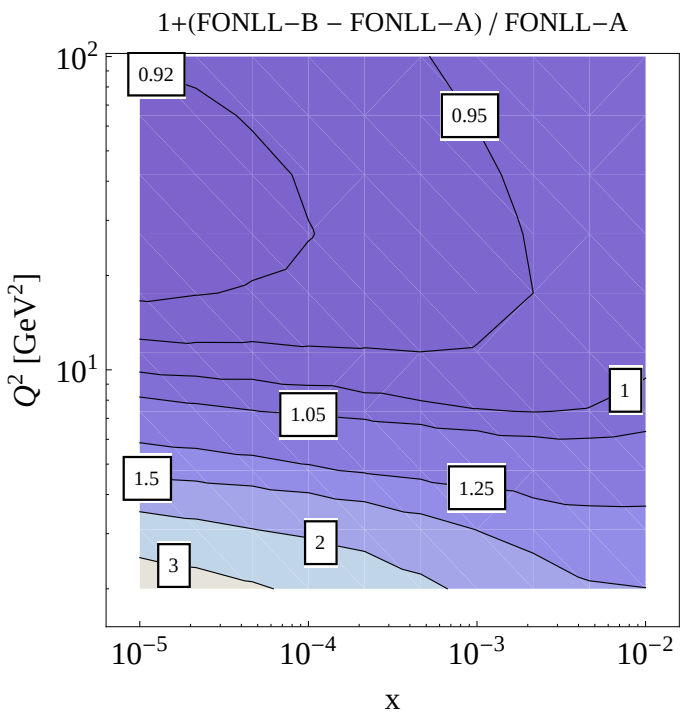
- FONLL-A GM-VFN scheme implemented for NC and CC structure functions
- Numerical accuracy benchmarked againts Les Houches HQ tables
- FONLL-A close to FFN for CC SFs for dimuon kinematics



HERA F_2^c data

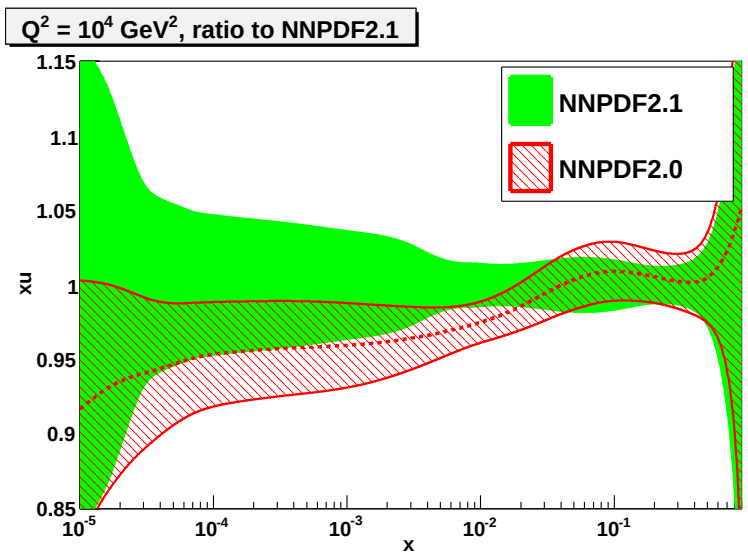
- FONLL-A does not include $\mathcal{O}\left(\alpha_s^2\right)$ terms, phenomenologically relevant at small-Q^2
  Same for other schemes like S-ACOT-χ
- Exclude HERA F_2^c data is $Q^2 \leq 10$ GeV^2 for $x \leq 10^{-3}$
- Work in progress: Implementation of FONLL-B in FastKernel

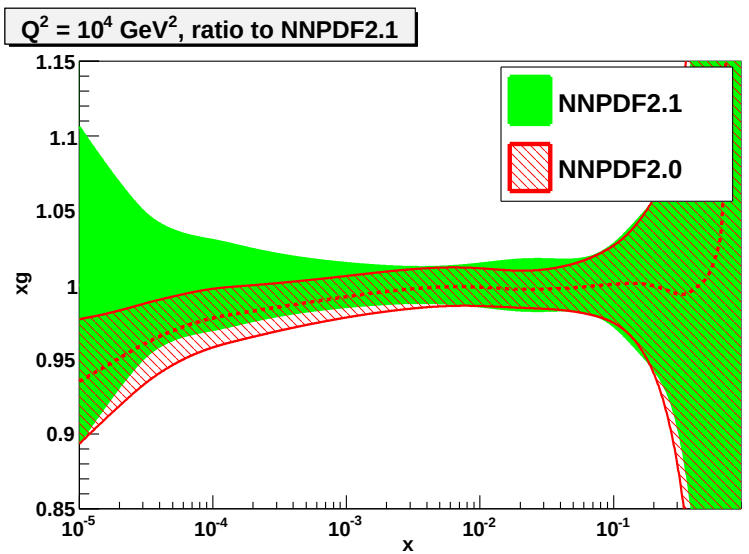




NNPDF2.1 vs. NNPDF2.0

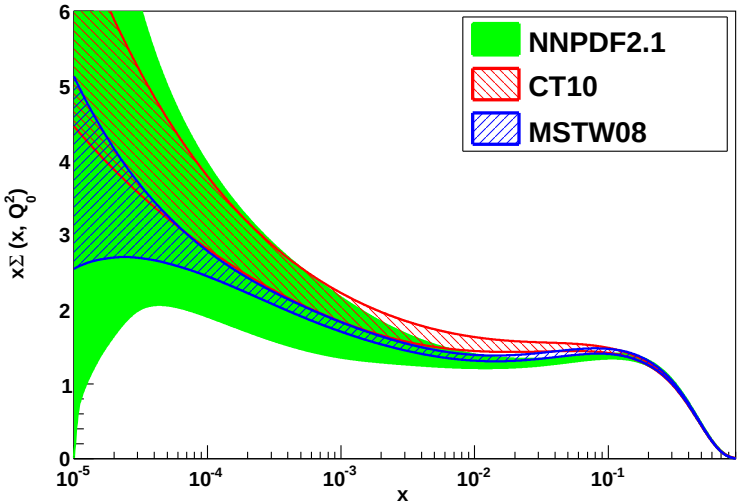
$\mathbf{xu(x, Q^2)}$ $\mathbf{xg(x, Q^2)}$

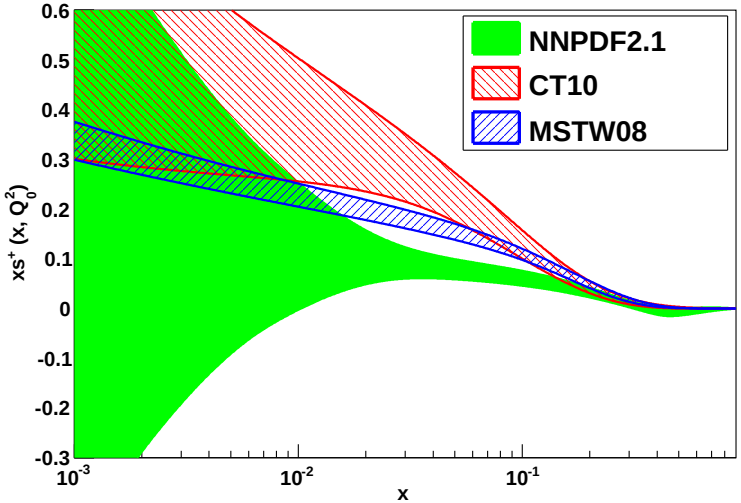


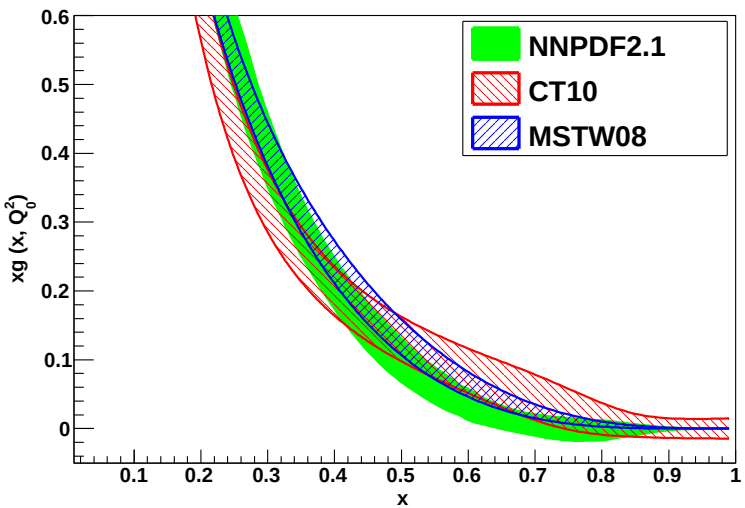


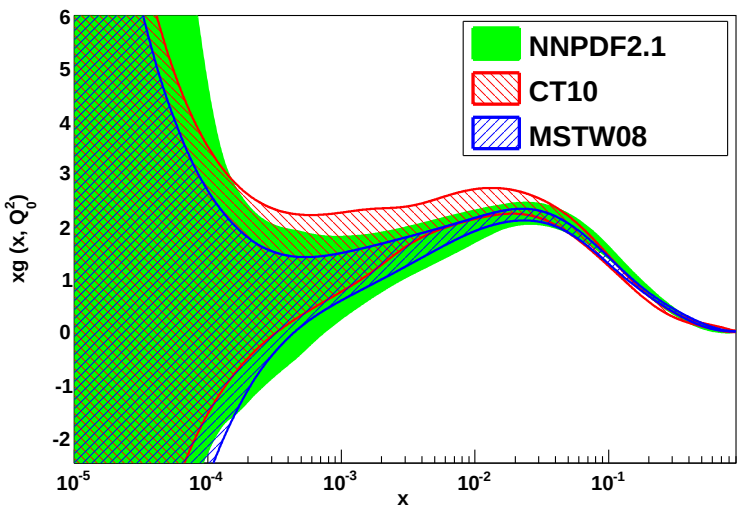
- At LHC scales, harder gluon and light quarks at small-x from GM-VFN
- All PDFs compatible at the 1–sigma level

Comparison with CT10 and MSTW08









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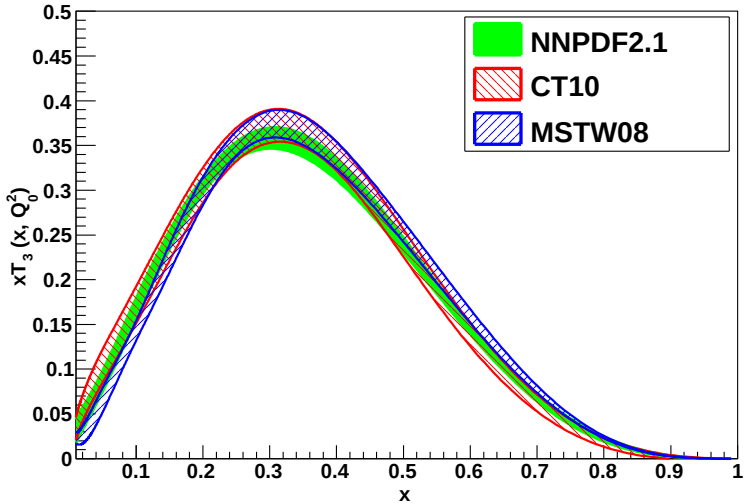

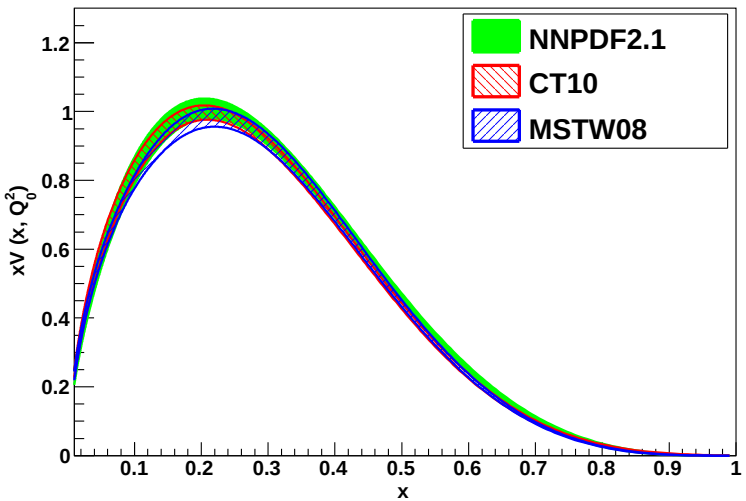

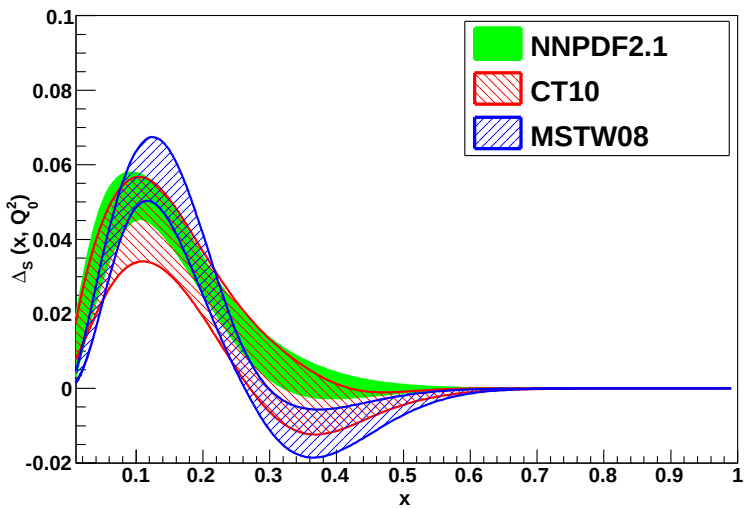

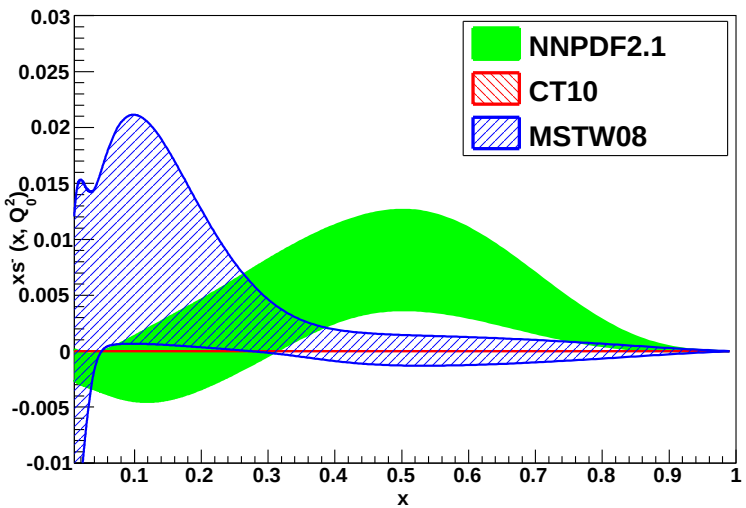

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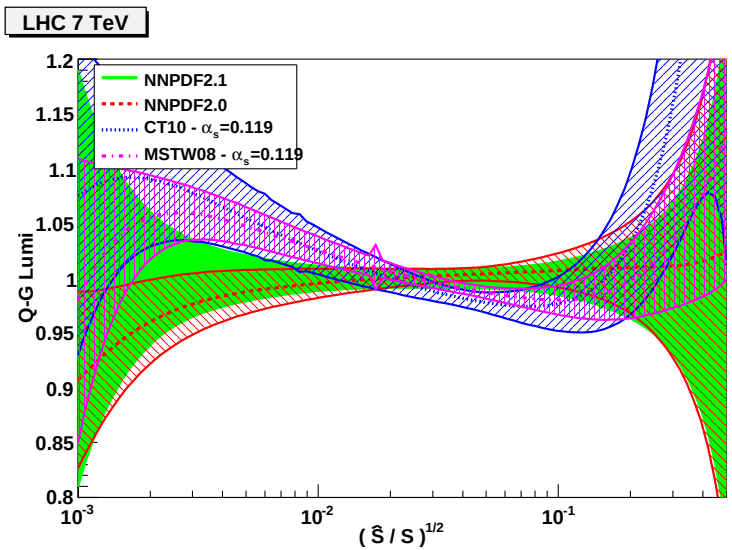
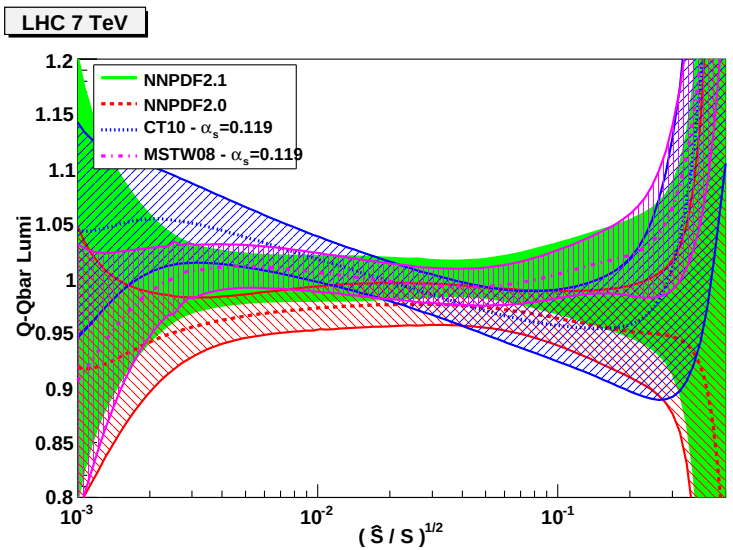
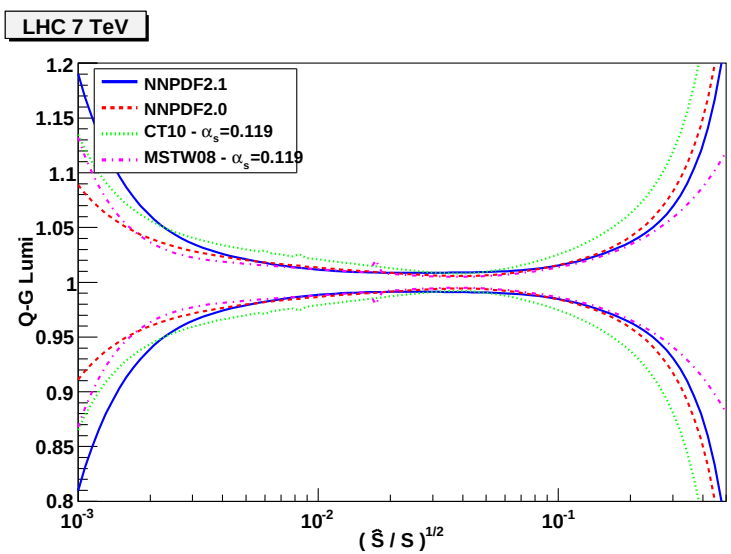
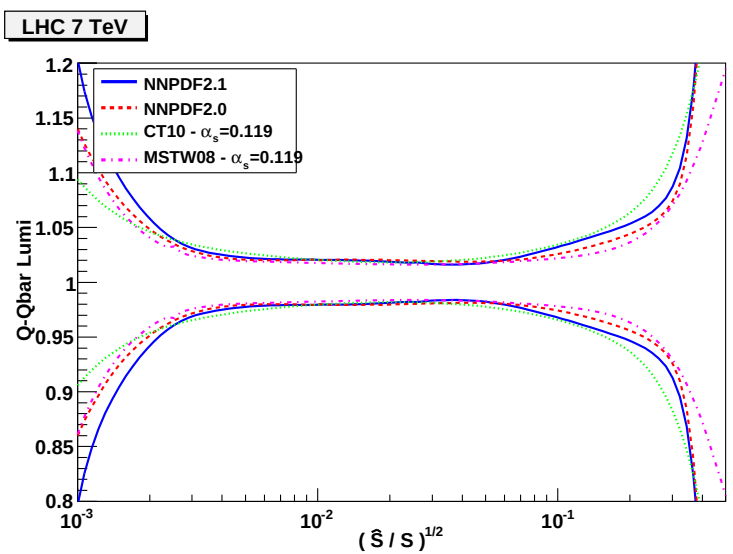


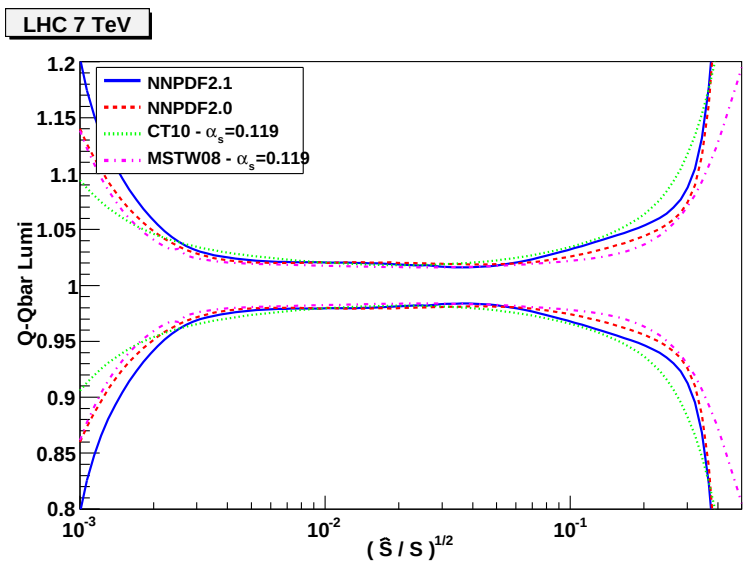


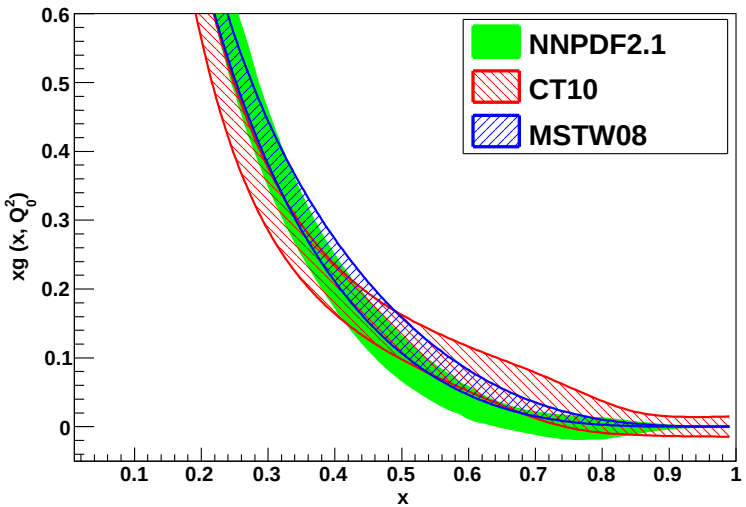




Comparison with CT10 and MSTW08

AbsErr $[\mathcal{L}_{qq}(M_X)]$ **xg**(x, Q^2)





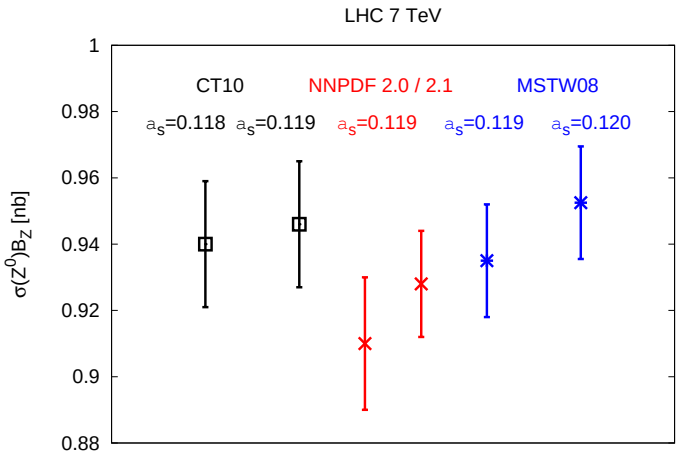
- General agreement between the three global fits ...
- ... yet important differences to be still understood: gluon, strangeness, ...
- PDF uncertainties in parton luminosities in intermediate M_X region also in reasonable agreement

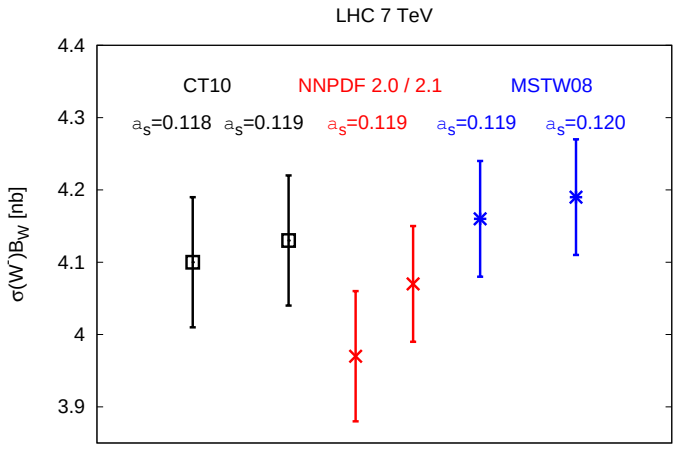
Fit quality

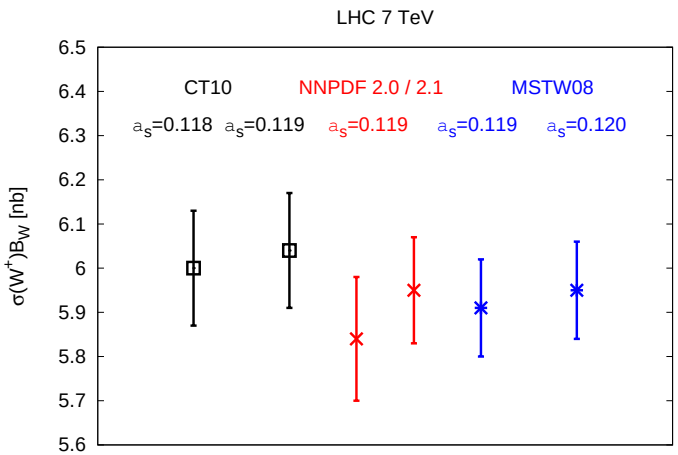
Experiment	$\chi^2_{2.1}$	$\chi^2_{2.0}$	$\chi^2_{\rm ct10}$
NMC-pd	**0.97**	1.04	**1.28**
NMC	1.72	1.73	1.71
SLAC	1.28	1.42	-
BCDMS	**1.24**	1.30	**1.13**
HERAI-AV	**1.07**	**1.15**	**1.17**
CHORUS	1.15	1.24	-
NTVDMN	0.76	0.73	0.93
ZEUS-H2	1.29	1.33	-
ZEUSF2C	0.78	-	0.85
H1F2C	1.50	-	1.40
DYE605	0.84	0.87	0.81
DYE866	1.27	1.29	1.21
CDFWASY	1.86	1.84	-
CDFZRAP	1.65	1.85	1.44
D0ZRAP	0.60	0.60	0.54
CDFR2KT	**0.97**	1.01	**1.55**
D0R2CON	**0.84**	0.86	**1.13**

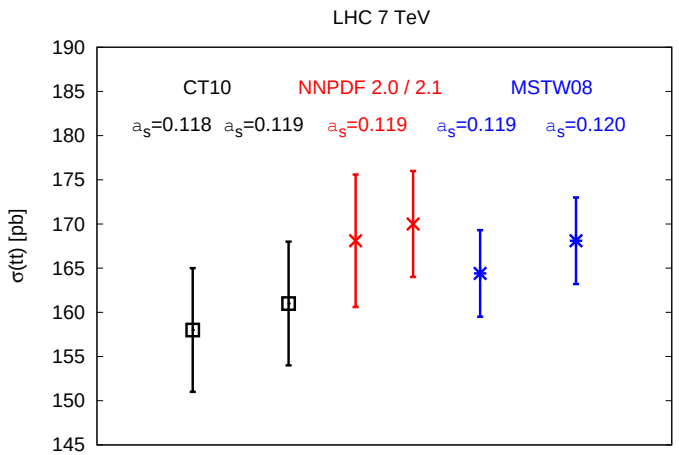
- Fit quality to DIS data improves as compared to NNPDF2.0, specially for HERA-I, CHORUS and BCDMS
- Quality of fit to hadronic data unchanged
- Comparison with CT10 results $\rightarrow$ In NNPDF2.1 better fit to **NMCrat**, **HERA-I** and **Tevatron jet** data, CT10 better for **BCDMS**
  (Thanks to Pavel for CT10 numbers)
- Differences w.r.t CT10 large-x gluon may arise from different fit quality to Tevatron jet data

LHC observables - 7 and 14 TeV

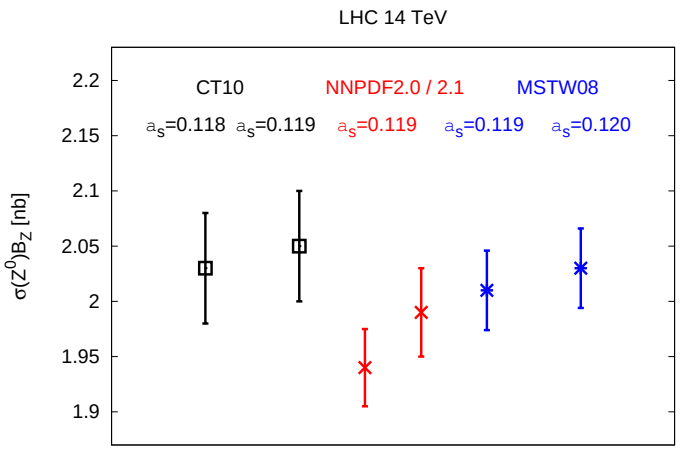


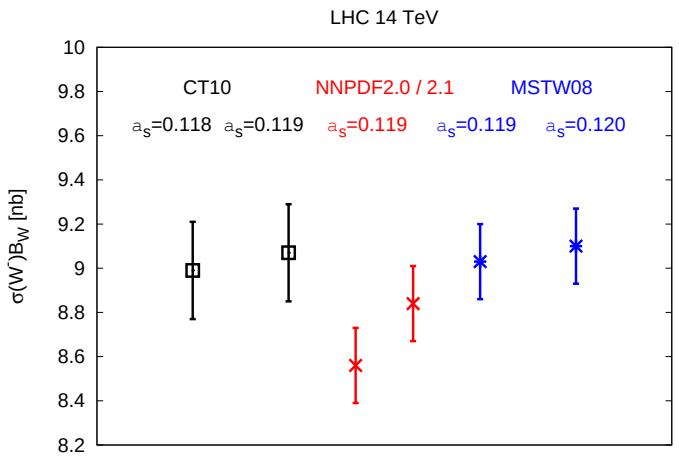


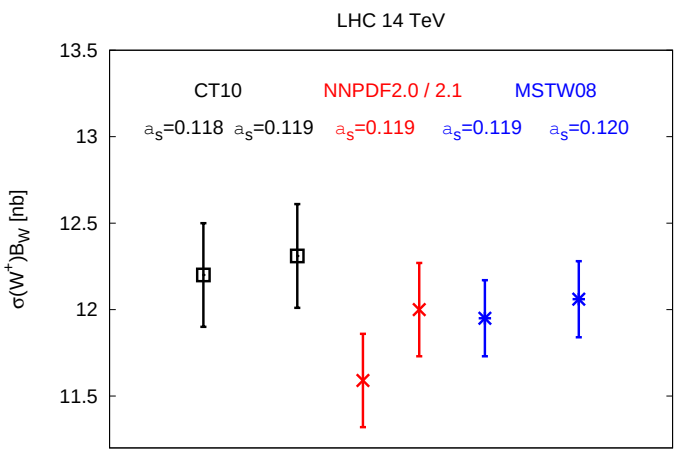


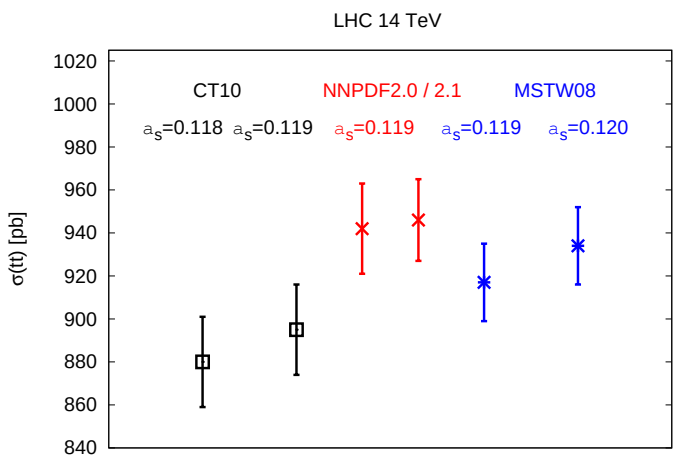


LHC observables - 7 and 14 TeV









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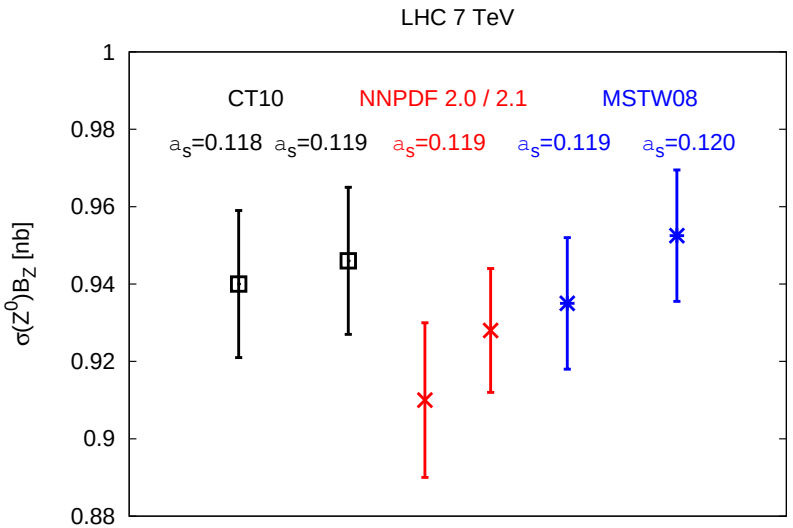
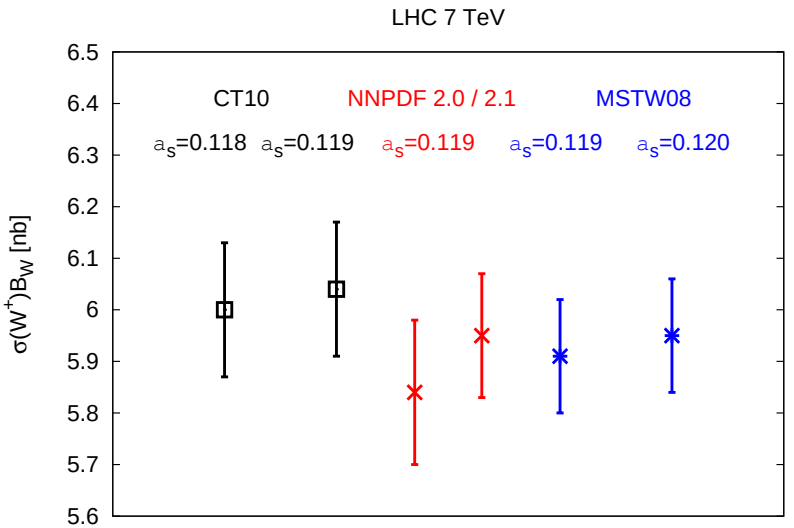
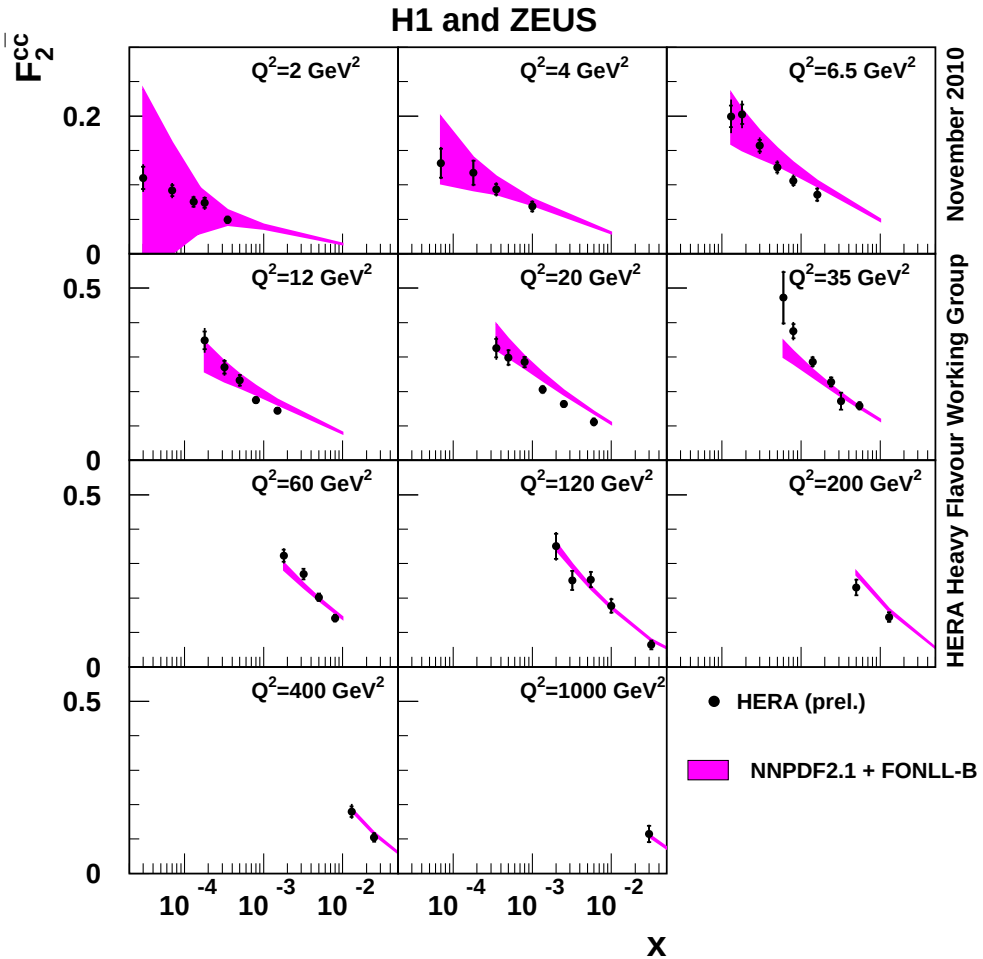




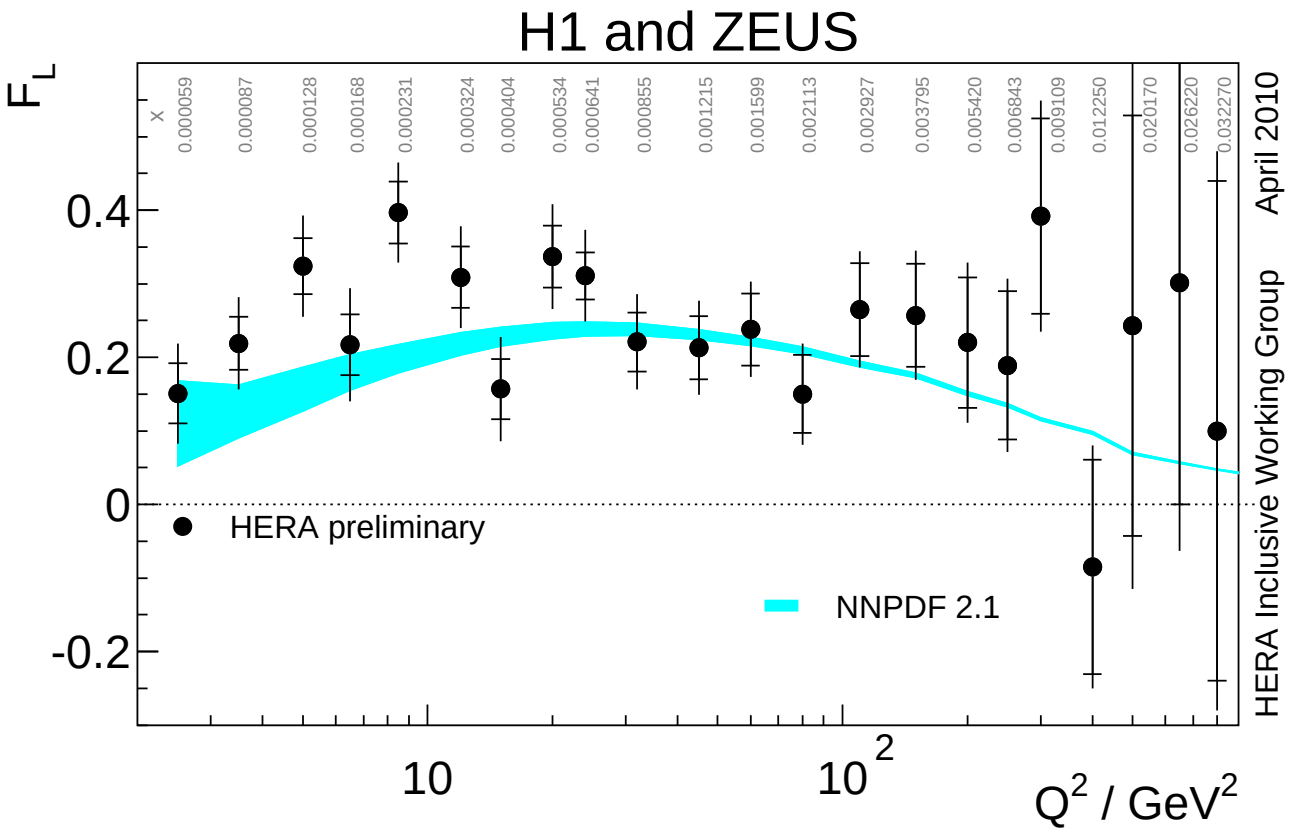
- The GM-VFN as compared to ZM-VFN $\longrightarrow \sim$ 1(1.5)–sigma shift in LHC observables at 7(14) TeV
- NNPDF2.1 consistent with 2.0 predictions at the 1–sigma level
- NNPDF2.1 predictions in agreement with MSTW08/CT10 for W/Z, larger differences for H, $t\bar{t}$ (from different large-x gluon)
- Using common α_s increases the agreement

Comparison with the combined F_2^c HERA data



- NNPDF2.1+FONLL-B in agreement with combined F_2^c data (Thanks to K. Lipka)
- FONLL-A and FONLL-B very close for $Q^2 \geq 10$ GeV^2, FONLL-B better at small-Q^2 since FFN $\mathcal{O}\left(\alpha_s^2\right)$ terms included
- The combined F_2^c data will impose important constraints on the small-x gluon PDF

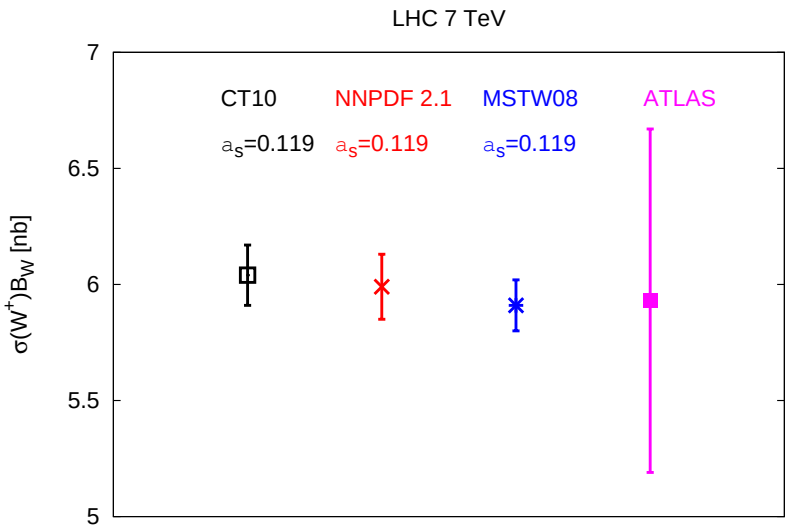
Comparison with the combined F_L HERA data

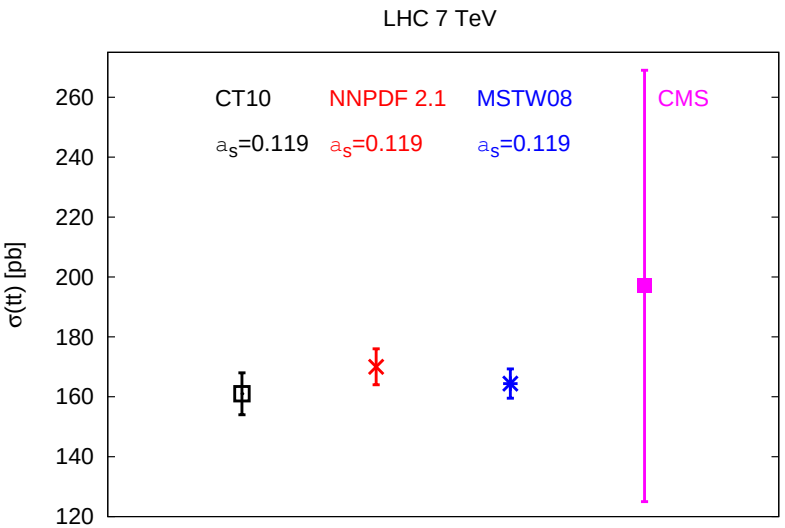


- NNPDF2.1 in agreement with combined F_L HERA data (Thanks to S. Glazov)

Summary

Finally, the time to **scrutinize** LHC data has arrived!!





Full summary in my afternoon talk ....

Thanks for your attention!

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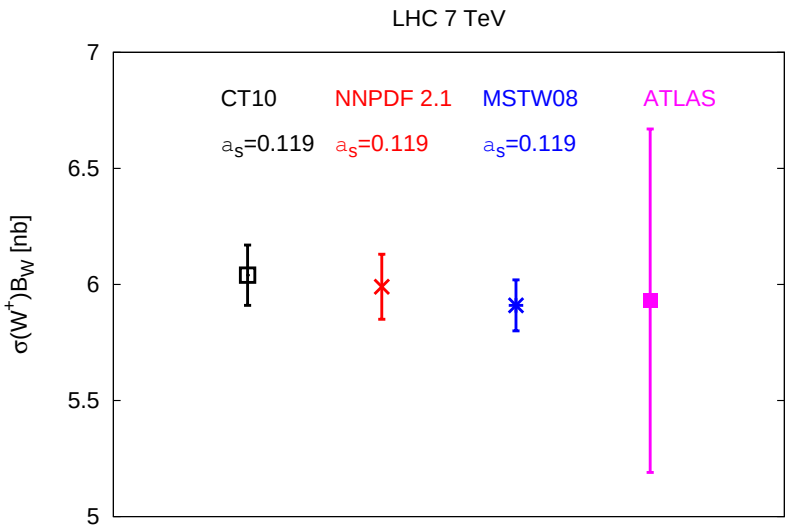

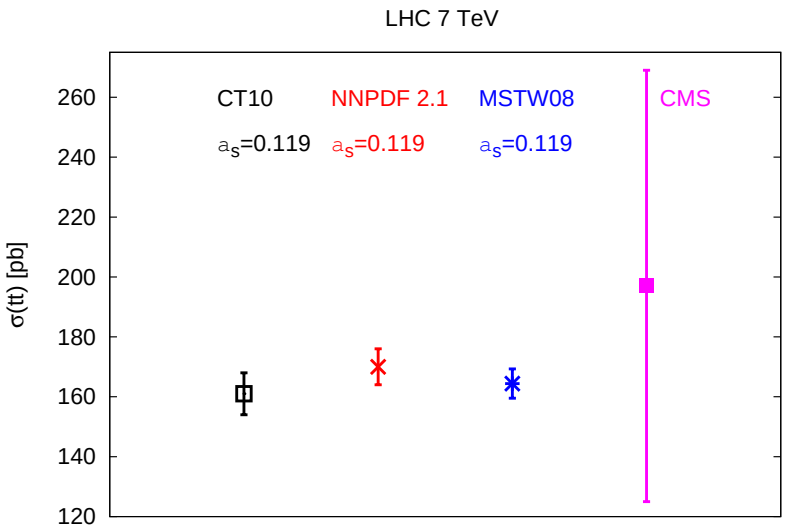

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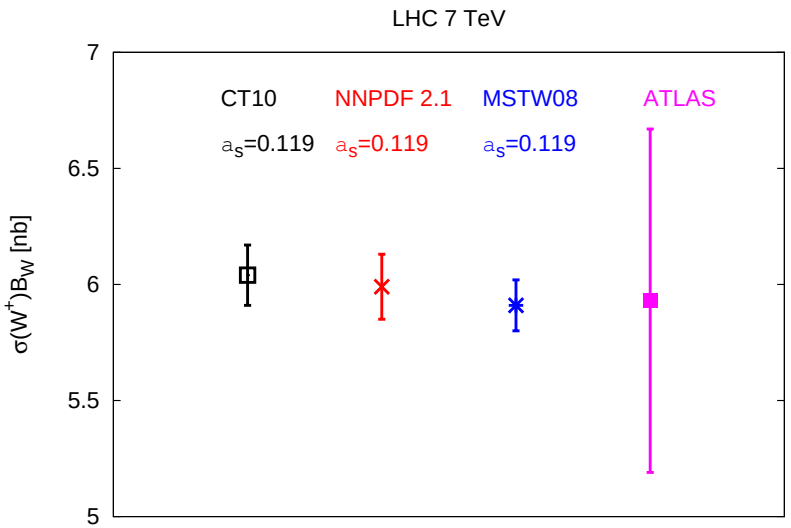

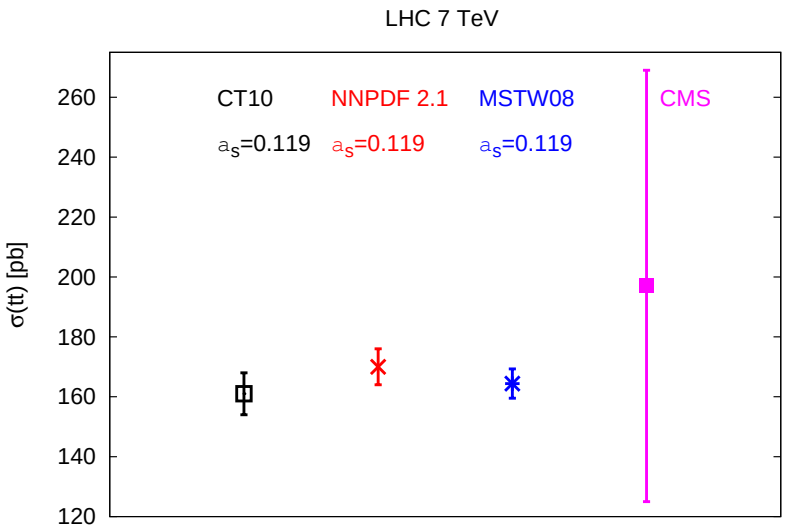

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THEORETICAL UNCERTAINTIES: HEAVY QUARK MASSES AND GM-VFN DEFINITION

NNPDF2.1 with varying m_h

- NNPDF2.1 fits with varying m_c and m_b have been produced
- Can be used to determine the combined PDF+m_c uncertainty with exact error propagation
- Two examples here: Combined PDF+m_c uncertainty in W/Z production and combined PDF+m_b uncertainty in $b\bar{b} \to H$ production
- Exact $PDF + m_h$ uncertainty computation keeping all correlations $\to$ Similar to combined $PDF + \alpha_s$ uncertainty

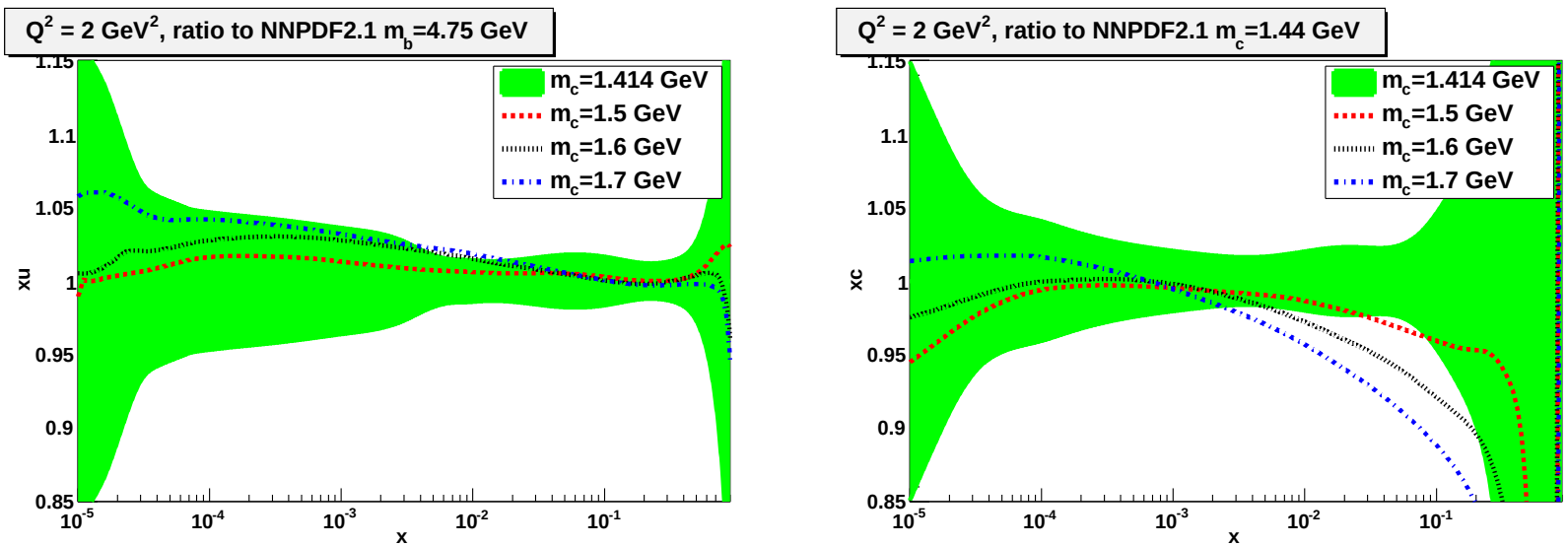
$$\langle \mathcal{F} \rangle_{\rm rep} = \frac{1}{N_{\rm rep}} \sum_{i=1}^{N_{m_c}} \sum_{j=1}^{N_{m_b}} \sum_{k_{ij}=1}^{N_{\rm rep}^{(i,j)}} \mathcal{F}\left({\rm PDF}^{(k_{ij},i,j)}, m_c^{(i)}, m_b^{(j)} \right) \ ,$$

$$N_{\rm rep}^{(i,j)} \propto \exp\left(-\frac{\left(m_c^{(i)} - m_c^{(0)}\right)^2}{2\delta_{m_c}^2} - \frac{\left(m_b^{(j)} - m_b^{(0)}\right)^2}{2\delta_{m_b}^2} \right) \ .$$

Choice of central value m_h and uncertainty δm_h **defined by user**

NNPDF2.1 with varying m_h

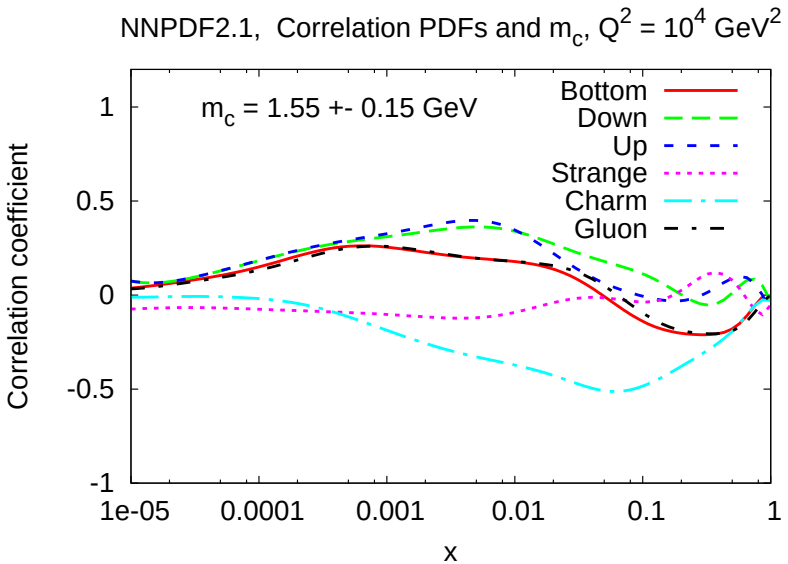
$\mathbf{xu(x,Q^2)}$ $\mathbf{xc(x,Q^2)}$

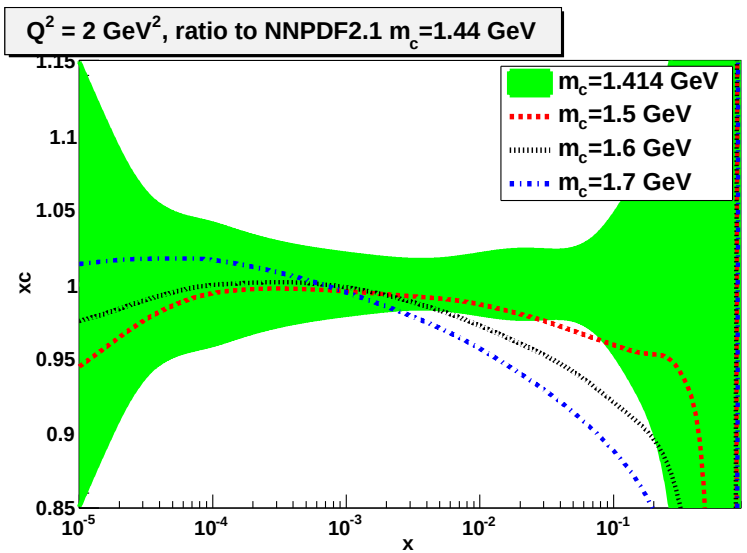


- Up quark harder at small-x and Charm quark softer at medium-x for larger m_c
- For $m_c \in [1.4, 1.7]$ GeV^2, variations in $u(x, Q_0^2)$ within 1–sigma error
- Qualitative analysis confirmed by computation of correlation coefficients
  Assume $\delta_{m_c} = 0.15$ GeV, any other choice possible

NNPDF2.1 with varying m_h

$$\rho\left[\mathbf{PDF}(\mathbf{x},\mathbf{Q^2}),\mathbf{m_c}\right] \qquad \mathbf{xc}(\mathbf{x},\mathbf{Q^2})$$





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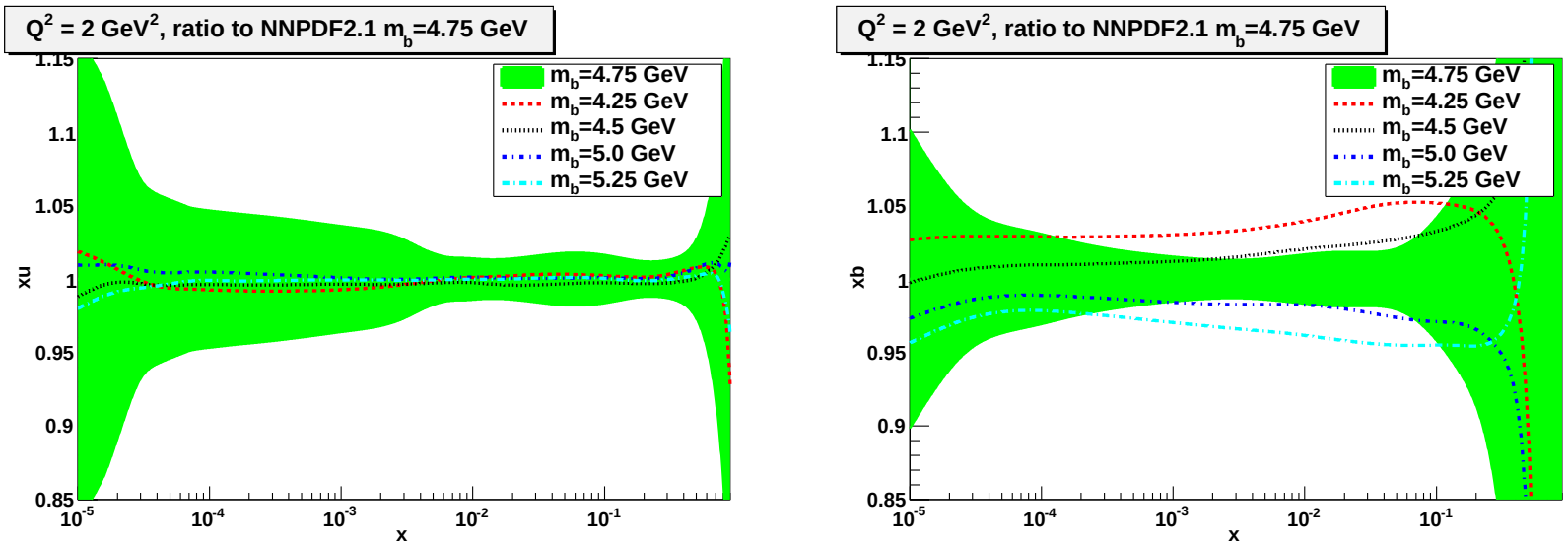
- For $m_c \in [1.4, 1.7]$ GeV^2, variations in $u(x, Q_0^2)$ within 1–sigma error
- Qualitative analysis confirmed by computation of correlation coefficients
  Assume $\delta_{m_c} = 0.15$ GeV, any other choice possible

NNPDF2.1 with varying m_h

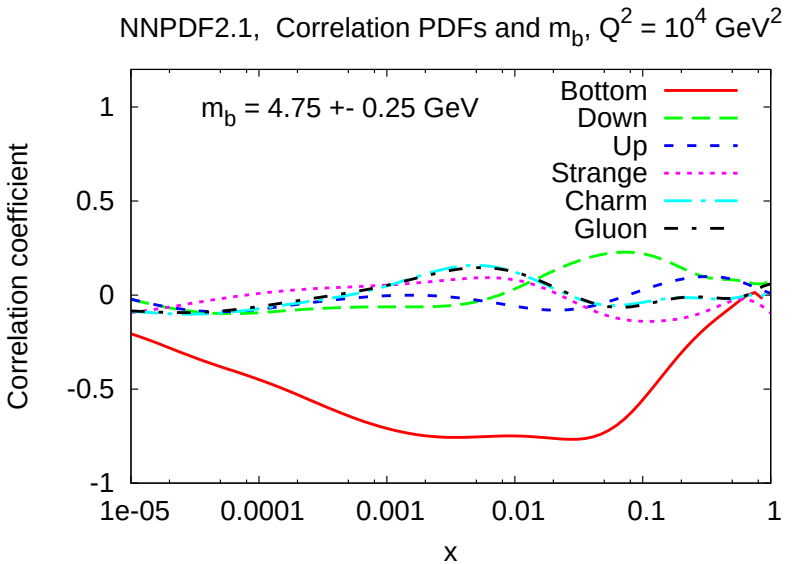
$\mathbf{xu(x, Q^2)}$ $\mathbf{xb(x, Q^2)}$

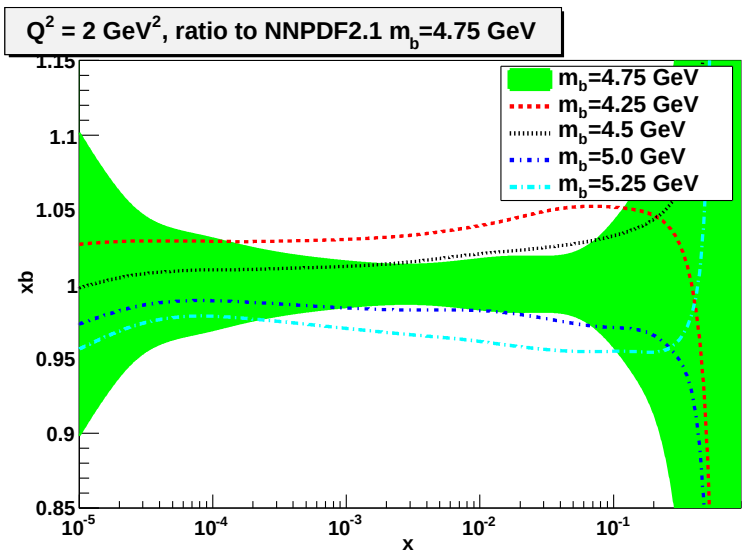


- Only the Bottom PDF affected by m_b variations
- Strong anticorrelation between $b(x, Q^2)$ and m_b for $10^{-4} \gtrsim x \gtrsim 0.1$
- Qualitative analysis confirmed by computation of correlation coefficients

NNPDF2.1 with varying m_h

$$\rho\left[\mathbf{PDF}(\mathbf{x},\mathbf{Q^2}),\mathbf{m_b}\right] \qquad \mathbf{xb}(\mathbf{x},\mathbf{Q^2})$$





- Only the Bottom PDF affected by m_b variations
- Strong anticorrelation between $b(x,Q^2)$ and m_b for $10^{-4} \gtrsim x \gtrsim 0.1$
- Qualitative analysis confirmed by computation of correlation coefficients

W/Z production: Uncertainties due to HQs

- Two sources of TH uncertainties related to HQs
- (1) From uncertainty in $m_c \rightarrow \delta_{m_c}$
  Assume $\delta_{m_c} = 0.15$ GeV, use exact error propagation
- (2) From freedom in the GM-VFN definition
  Estimate TH uncertainties as difference between FONLL-A-Damp and FONLL-A-plain results

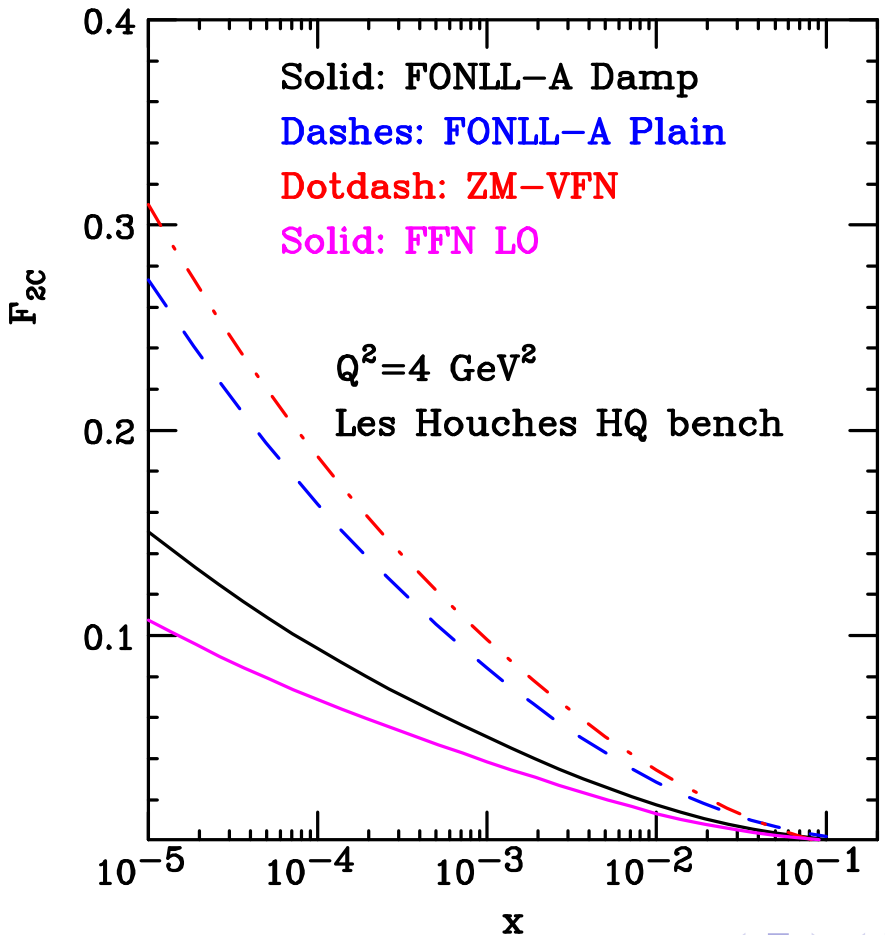
$$F_{2,h}^{\mathrm{FONLL-Damp}}(x,Q^2) = F_{2,h}^{(n_l)}(x,Q^2) + \theta\left(Q^2 - m_h^2\right)\left(1 - \frac{m_h^2}{Q^2}\right)^2 F_{2,h}^{(d)}(x,Q^2).$$

$$F_{2,h}^{\mathrm{FONLL-plain}}(x,Q^2) = F_{2,h}^{(n_l)}(x,Q^2) + \theta\left(Q^2 - m_h^2\right) F_{2,h}^{(d)}(x,Q^2).$$

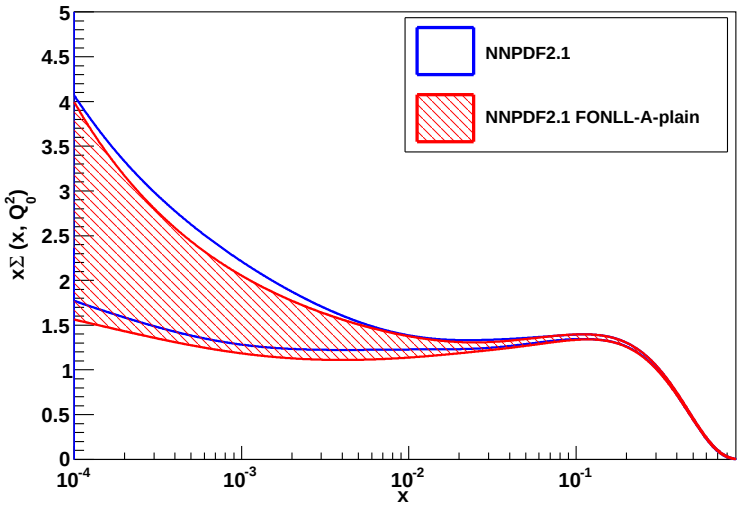
$$F_{2,h}^{(d)}(x,Q^2) = F_{2,h}^{(n_l+1)}(x,Q^2) - F_{2,h}^{(n_l,0)}(x,Q^2)$$

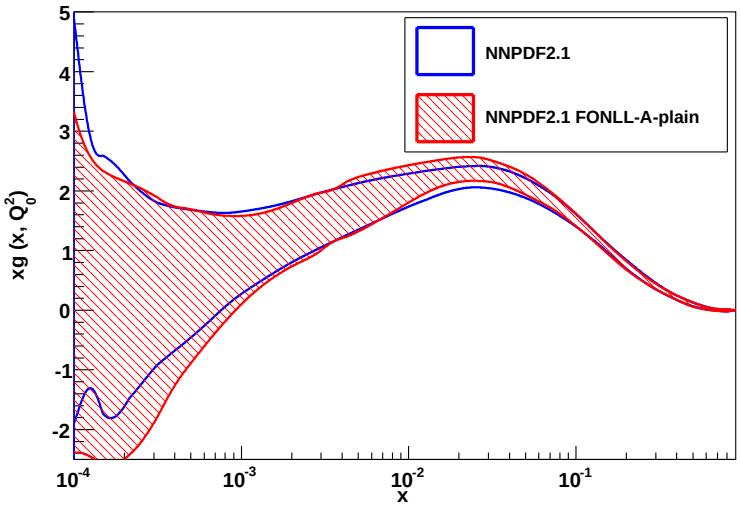
W/Z production: Uncertainties due to HQs

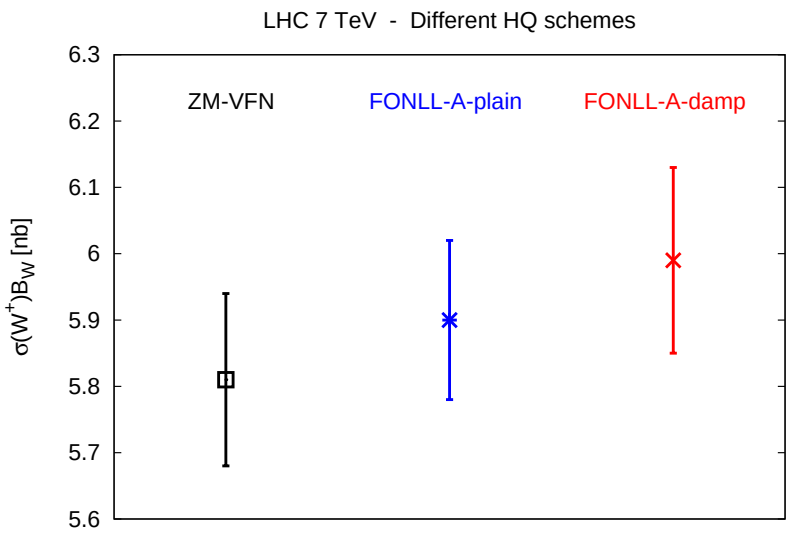
TH uncertainties due to GM scheme definition as difference between FONLL-A-Damp and FONLL-A-plain



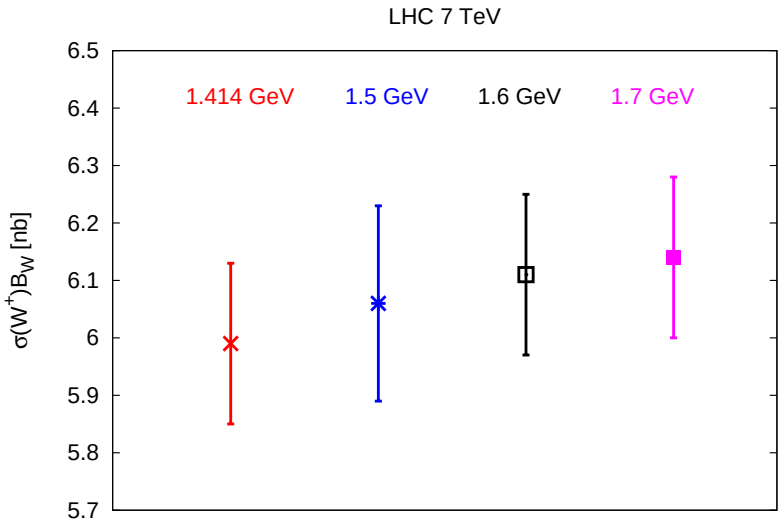
W/Z production: Uncertainties due to HQs







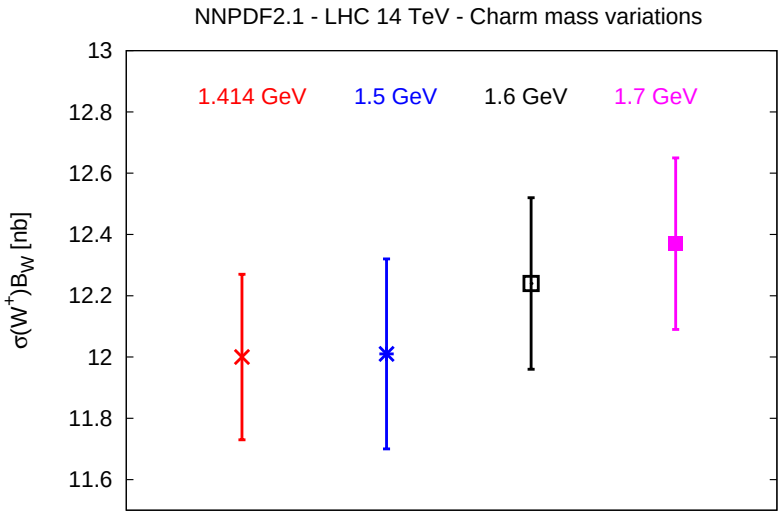
W/Z production: Uncertainties due to HQs



- At 7 TeV, theoretical HQ uncertainty increases $\sim 30\%$ total uncertainty on W/Z cross section

LHC 7 TeV	$W^+B_{l\nu}$ [nb]	$W^-B_{l\nu}$ [nb]	$Z^0B_{l\bar{l}}$ [nb]
$m_c = 1.414$ GeV	5.99 ± 0.14	4.09 ± 0.09	0.932 ± 0.02
$\delta_{\rm PDF}$	0.14	0.09	0.019
$\delta_{\rm PDF+m_c}$	0.15	0.10	0.021
$\delta_{\rm PDF+m_c+GM}$	**0.19**	**0.12**	**0.025**

W/Z production: Uncertainties due to HQs

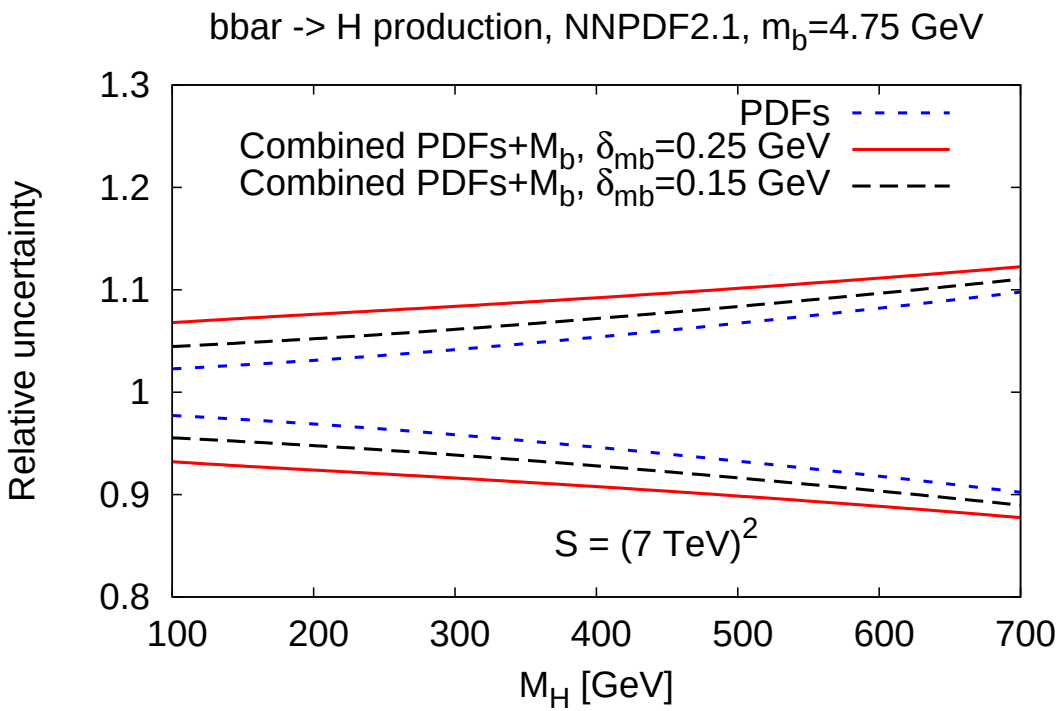


- At 14 TeV, theoretical HQ uncertainty increases $\sim 40\%$ total uncertainty on W/Z cross section
- Conclusions in qualitative agreement with MSTW08 studies

LHC 14 TeV	$W^+ B_{l\nu}$ [nb]	$W^- B_{l\nu}$ [nb]	$Z^0 B_{l\bar{l}}$ [nb]
$m_c = 1.414$ GeV	12.00 ± 0.27	8.84 ± 0.17	1.99 ± 0.036
$\delta_{\rm PDF}$	0.27	0.17	0.036
$\delta_{\rm PDF+m_c}$	0.30	0.20	0.044
$\delta_{\rm PDF+m_c+GM}$	**0.35**	**0.24**	**0.053**

HQ uncertainties in $b\bar{b} \longrightarrow H$ production

- Processes with Born contributions with $b(x, Q^2)$ very sensitive to choice of m_b: t–channel single-top, $b\bar{b} \longrightarrow H$
- Important to compute combined PDF+m_b with exact error propagation
- In $b\bar{b} \longrightarrow H$, $\delta_{m_b} = 0.15(0.25)$ GeV can increase PDF-only uncertainty by factor 2(3) for small m_H

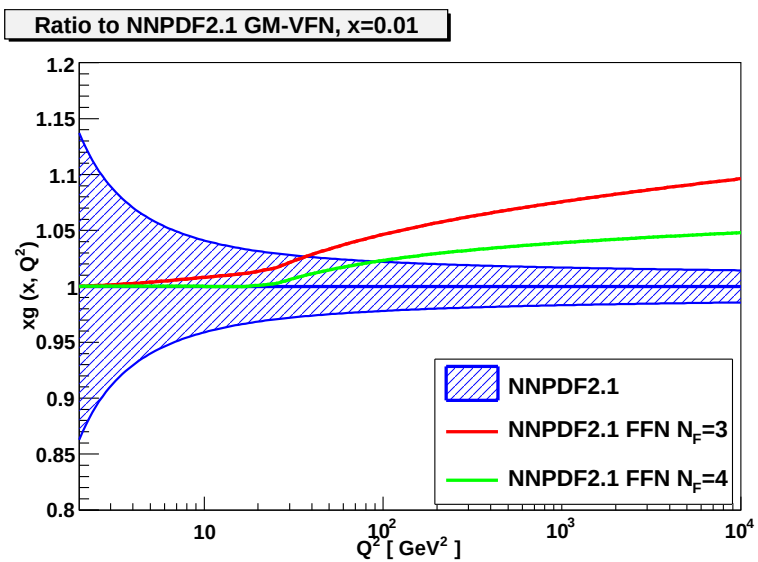


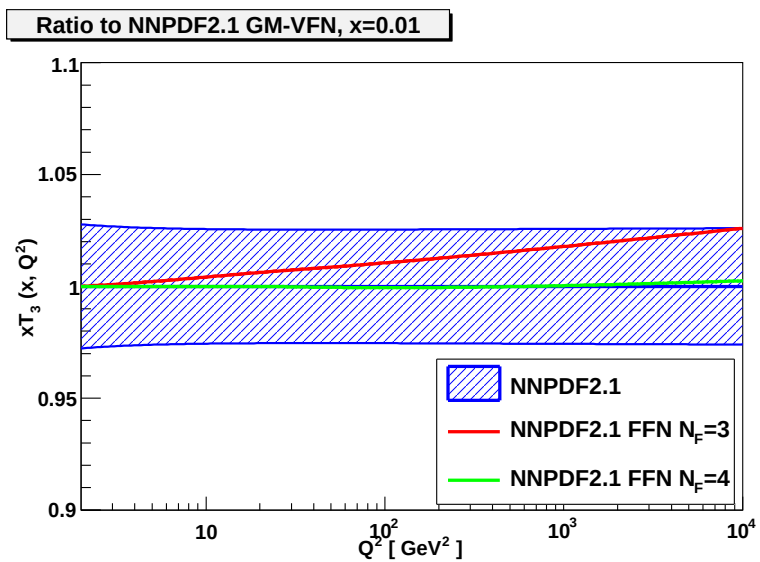
Fixed Flavor Number sets sets

- The NNPDF2.1 GM-VFN varies N_F at HQ thresholds from $N_f = 3$ to $N_f = 6$
- FFN scheme sets with $N_f = 3$, $N_f = 4$ and $N_f = 5$ are also provided
- FFN PDFs obtained from GM-VFN PDFs matching at HQ thresholds

$$\mathrm{PDFs}^{(N_f)}(Q^2 = m_h^2) = \mathrm{PDFs}^{(N_f+1)}(Q^2 = m_h^2)$$

Same strategy as MSTW08 and CT10





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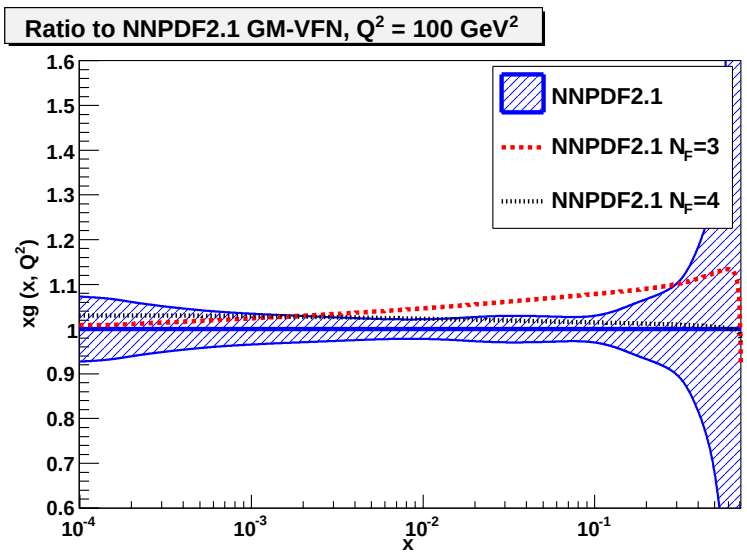
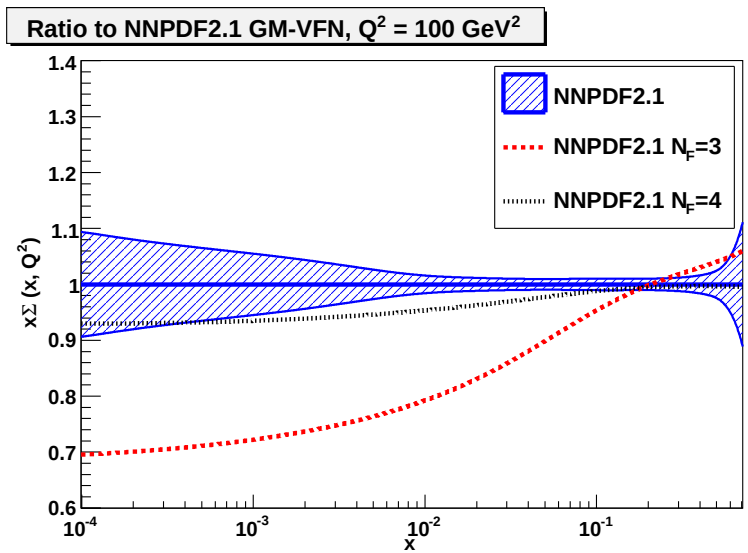




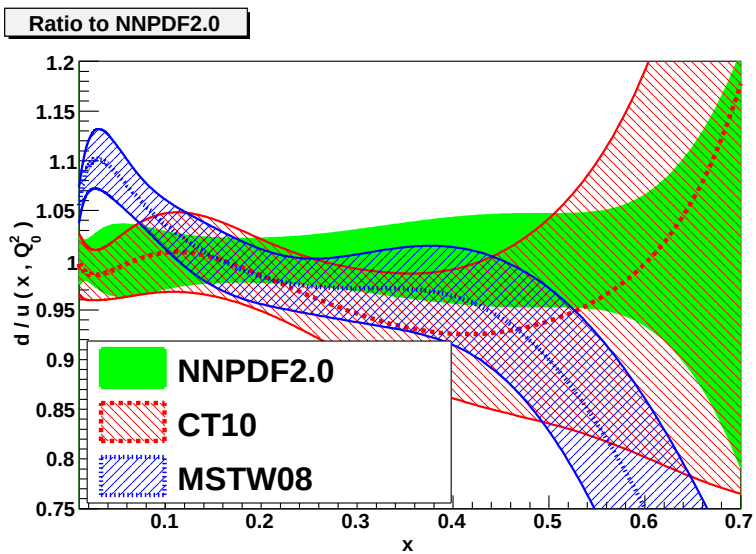
THE TEVATRON W LEPTON ASYMMETRY: DATASET CONSISTENCY AND CONSTRAINTS IN NNPDF2.0

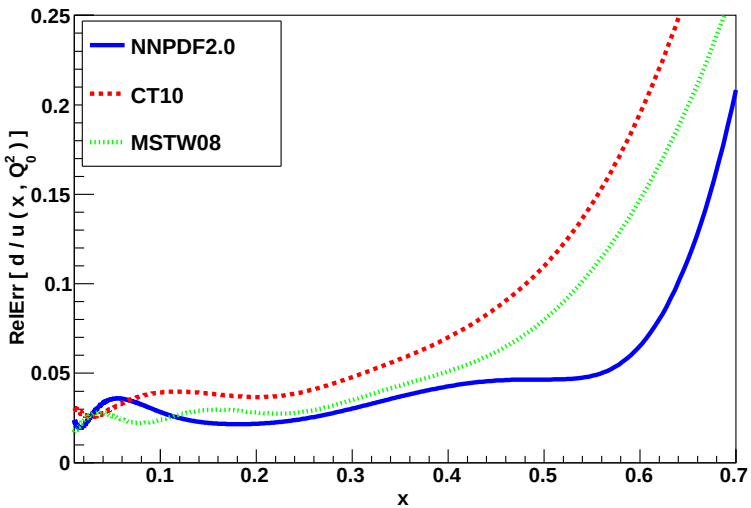
Motivation

- Tevatron W lepton asymmetry data $\rightarrow$ Traditional constrain of d/u ratio in global fits together with FT deuterium data
- Recent CT10 and MSTW08 studies suggest tension between the new high statistics D0 data and global fit $\rightarrow$ Dataset inconsistency? Nuclear corrections? Restrictive parametrizations?
- Determine impact of D0 lepton asy data in NNPDF2.0 using Bayesian Reweighting (M. Ubiali talk, PDF4LHC Trento 10)
- No nuclear corrections to deuterium data considered
- Study published D0 data for muon (arxiv:0709.4254) and electron (arxiv:0807.3367) W lepton asymmetries

The d/u ratio at large-x

$\mathbf{d/u(x,Q^2)}$ $\qquad$ $\mathbf{RelErr}\left[\mathbf{d/u(x,Q^2)}\right]$





- NNPDF2.0 harder d/u ratio, specially as compared to CT10
- NNPDF2.0 has the more accurate d/u of the global sets
- Differences expected even before fitting

The d/u ratio at large-x

Set	$N_{\rm dat}$	NNPDF2.0	MSTW08	CT10
D0 μ ($E_T^\mu > 20$ GeV)	10	0.62	1.51	0.70
D0 e, $E_T^e > 25$ GeV (Bin A)	12	2.12	**9.20**	**4.07**
D0 e, 25 GeV$< E_T^e <$ 35 GeV (Bin B)	12	**4.75**	1.66	**9.48**
D0 e, $E_T^e > 35$ GeV (Bin C)	12	**5.06**	**13.4**	**11.7**

- Very different fit quality to different datasets $\longrightarrow$ From different d/u ratios?
- Muon data fitted OK for all sets

D0 W lepton asy data: Fit quality

Add one D0 dataset into NNPDF2.0 at a time

Set	$N_{\rm eff}/1000$	$\alpha_{\rm opt}$	χ^2_{nofit}	$\chi^2_{\rm fit}$	$\chi^2_{\rm tot}$
D0 μ ($E_T > 20$ GeV)	0.795	0.7	0.62	**0.51**	1.14
D0 e bin A ($E_T > 25$ GeV)	0.262	1.7	2.12	**1.55**	1.13
D0 μ + e bin A	0.356	1.3	1.44	**1.11**	1.13
D0 e bin B (25 GeV$< E_T <$ 35 GeV)	0.061	1.3	4.75	**1.12**	1.16
D0 e bin C ($E_T > 35$ GeV)	0.068	2.7	5.06	**2.51**	1.16

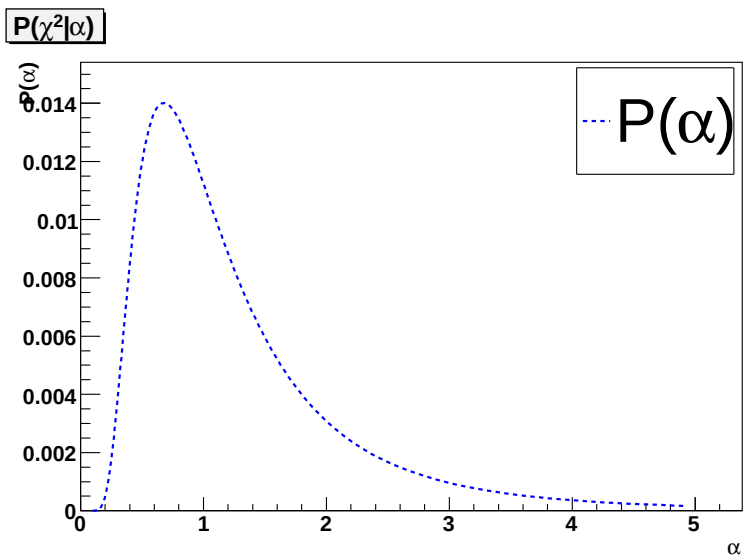
- μ + eBinA $\rightarrow$ Consistent with NNPDF2.0, good fit quality
- eBinB $\rightarrow$ Can be fitted, but worsening of global fit quality
- eBinC $\rightarrow$ Inconsistent with itself, with BinB and with global fit

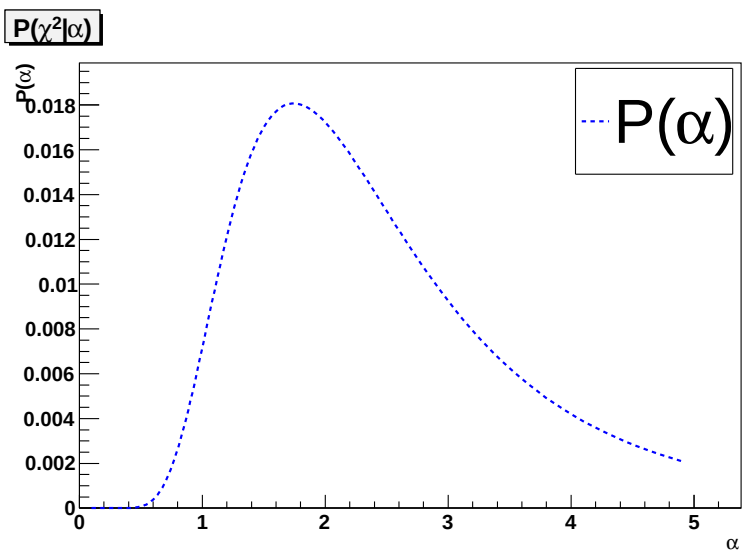
Dataset consistency check

Define $P(\alpha)$ → Probability density of the tolerance α → Measure of the internal consistency datasets

$$\mathcal{P}(\alpha) \propto \frac{1}{\alpha} \sum_{k=1}^{N} w_k w_k(\alpha). \tag{1}$$

Muons **Electrons Bin A**



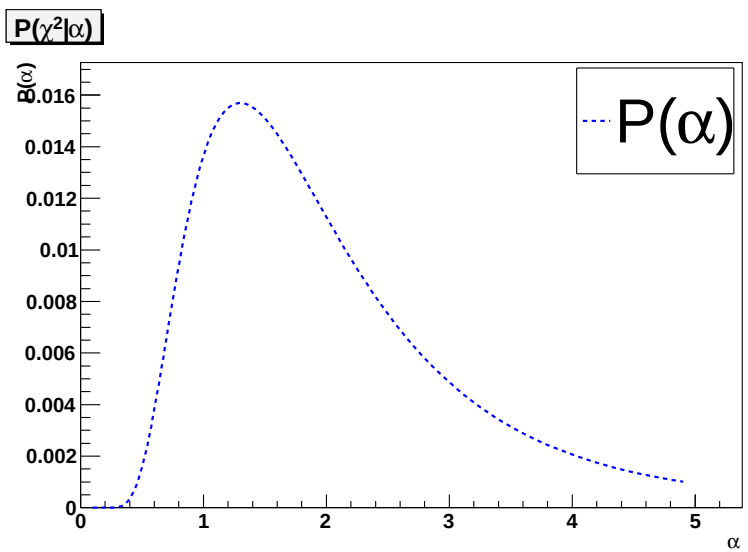


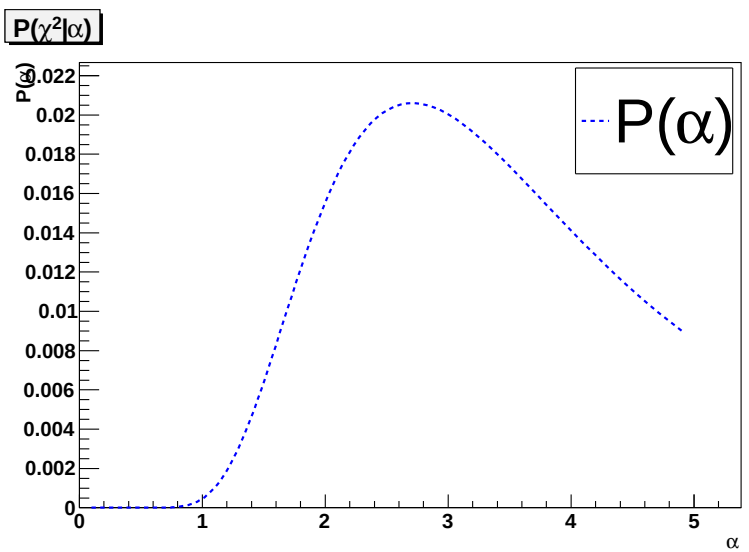
Dataset consistency check

Define $P(\alpha)$ → Probability density of the tolerance α → Measure of the internal consistency datasets

$$\mathcal{P}(\alpha) \propto \frac{1}{\alpha} \sum_{k=1}^{N} w_k w_k(\alpha). \tag{1}$$

Electrons Bin B **Electrons Bin C**





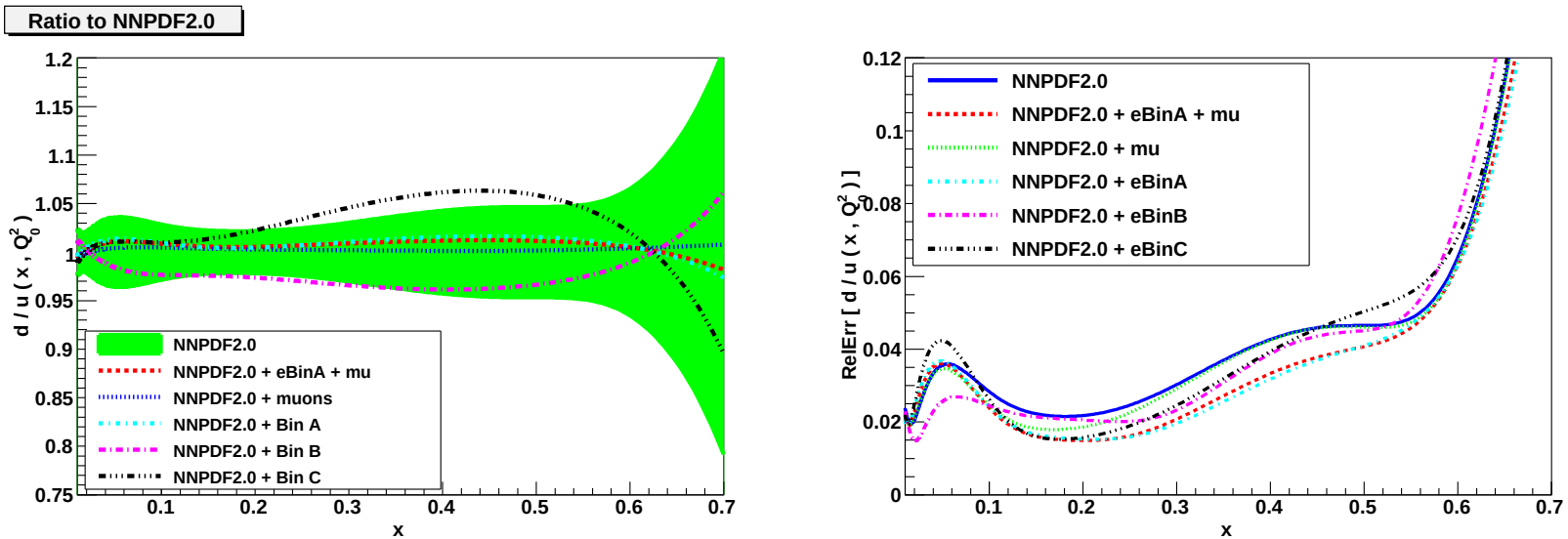
D0 electron Bin C internally inconsistent

Impact on global fit description

Set	$\chi^2_{2.0}$	$\chi^2_{2.0+\mu}$	$\chi^2_{2.0+\mathrm{binA}}$	$\chi^2_{2.0+\mathrm{binA+muon}}$	$\chi^2_{2.0+\mathrm{binB}}$	$\chi^2_{2.0+\mathrm{binC}}$
NMC-pd	0.99	0.98	0.98	0.98	0.97	**1.13**
SLACp	1.55	1.55	1.53	1.54	1.50	**1.63**
SLACd	1.12	1.12	1.07	1.09	1.05	**1.24**
BCDMSp	1.35	1.35	1.33	1.34	**1.41**	1.35
BCDMSd	1.16	1.16	1.16	1.16	**1.24**	1.14
DYE886p	1.31	1.32	1.29	1.30	1.28	**1.36**
DYE886r	0.83	0.79	**0.67**	0.71	**1.08**	0.72
CDFWASY	1.88	1.88	**1.78**	1.82	**2.05**	**1.60**
CDFZRAP	1.74	1.77	1.75	1.77	**1.37**	**1.97**
CDFR2KT	1.02	1.02	0.95	0.97	**1.21**	0.93
D0R2CON	0.86	0.86	0.84	0.84	**0.91**	0.84
TOTAL	1.14	1.14	1.13	1.13	**1.16**	**1.16**

- $\mu+$ eBinA $\rightarrow$ Nicely consistent with global fit
- D0 electron Bin B and C $\rightarrow$ Tension with global fit, but seems unrelated to deuterium data only
  Relation with CT10 and MSTW08 results?

Impact of D0 W lepton asy in d/u



- μ + inclusive e data $\rightarrow$ Consistent with NNPDF2.0, useful for error reduction in d/u ratio
- Exclusive e data $\rightarrow$ Pull in opposite directions, always within $\sim$ 1–sigma error

Tevatron W lepton asymmetry: Summary

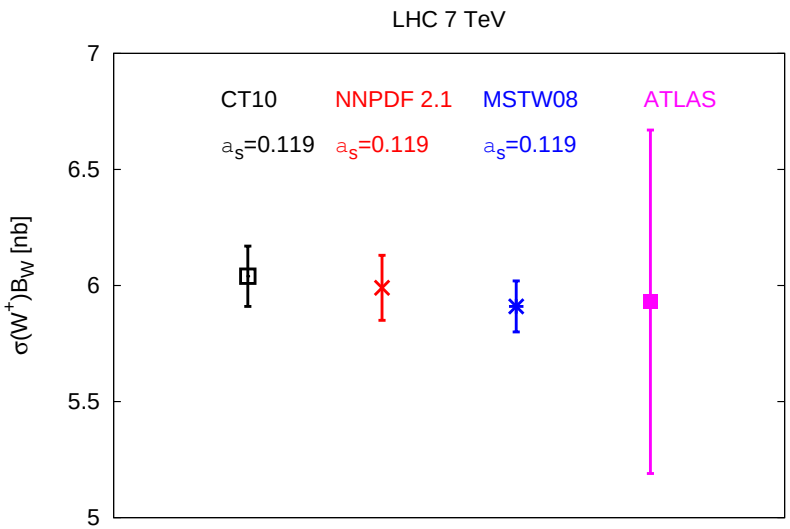
- D0 μ + inclusive e data $\rightarrow$ Maximally consistent set, constrains on d/u at large-x
- D0 $25 \leq p_T^e \leq 35$ GeV set $\rightarrow$ Tension with global fit
- D0 $p_T^e \geq 35$ GeV set $\rightarrow$ Internally inconsistent + Inconsistent with Bin B + Tension with global fit
- Tension between the D0 electron exclusive data and global fit unrelated to nuclear corrections $\rightarrow$ Experimental problems in the p_T separation? Underestimated systematics?

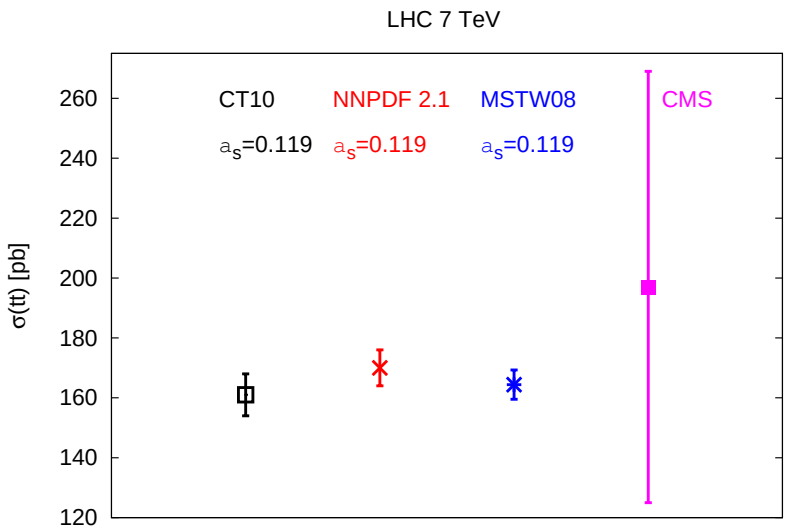
Summary

- NNPDF2.1 is from now on the **reference NLO NNPDF set**
- Careful estimation of the TH uncertainties associated to the choice of HQ mass and GM-VFN scheme, similar conclusions to MSTW08
- Choice of m_h and δ_{m_h} (like α_s) should be left to PDF user
- D0 inclusive W lepton asy data perfectly consistent with NNPDF2.0, tension induced by exclusive data unrelated to deuterium corrections
- Ongoing projects: NNLO NNPDFs, NNPDFs for LO Monte Carlos, PDFs with small-x resummation, ...
- Agreement between new PDF sets has improved w.r.t. PDF4LHC benchmark study, but much work still to do!

Summary

Finally, the time to **scrutinize** LHC data has arrived!!





Thanks for your attention!

EXTRA MATERIAL

Bayesian reweighting

- Given the probability distribution of the PDFs represented by $N_{\rm rep}$ instances, $\{\mathrm{PDF_i}\}$, $\mathrm{i} = 1, \mathrm{N_{rep}}$
- Given a set of new experimental data (or simulated pseudo-data) $y = \{y_1, y_2, \cdots, y_n\}$
- Given a general functional of the PDFs, $\mathcal{O}\left[\{\mathrm{PDF}\}\right]$

The impact of the new data y on the PDFs can be determined using Bayesian inference without refitting : PDF reweighting

$$\langle \mathcal{O} \rangle_{\rm old} = \sum_{k=1}^{N_{\rm rep}} \frac{1}{N_{\rm rep}} \mathcal{O}[f_k] \quad \rightarrow \quad \langle \mathcal{O} \rangle_{\rm new} = \sum_{k=1}^{N} w_k \, \mathcal{O}[f_k]$$

$$w_k \equiv \mathcal{N}_\chi (\chi^2(y, f_k))^{n/2-1} e^{-\frac{1}{2}\chi^2(y,f_k)},$$

$\chi^2(y, f_k) \rightarrow \chi^2$ of new data for the prediction of $\mathrm{PDF_k}$

No need of any refitting!

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- Given a general functional of the PDFs, $\mathcal{O}\left[\{\mathrm{PDF}\}\right]$

The impact of the new data y on the PDFs can be determined using Bayesian inference without refitting : PDF reweighting

$$\langle \mathcal{O} \rangle_{\rm old} = \sum_{k=1}^{N_{\rm rep}} \frac{1}{N_{\rm rep}} \mathcal{O}[f_k] \quad \rightarrow \quad \langle \mathcal{O} \rangle_{\rm new} = \sum_{k=1}^{N} w_k \, \mathcal{O}[f_k]$$

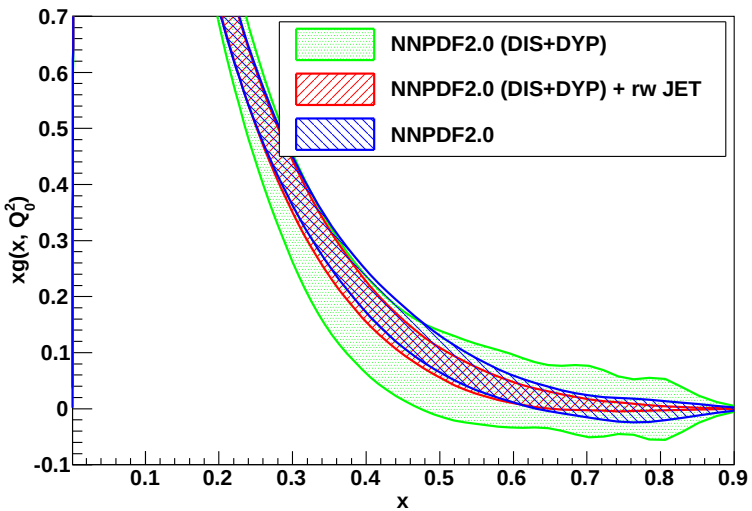
$$w_k \equiv \mathcal{N}_\chi (\chi^2(y, f_k))^{n/2-1} e^{-\frac{1}{2}\chi^2(y,f_k)},$$

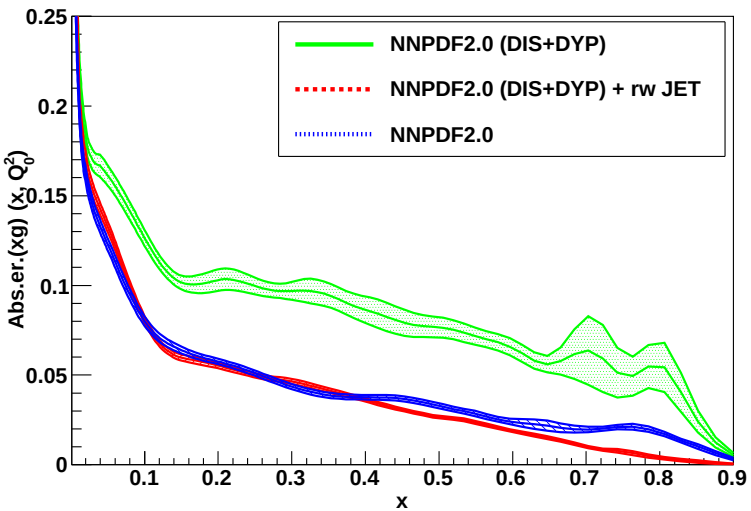
$\chi^2(y, f_k) \rightarrow \chi^2$ of new data for the prediction of $\mathrm{PDF_k}$

No need of any refitting!

Validation: Tevatron inclusive jets

- Tevatron inclusive jets constrain large-x gluon
- Compare refitting with reweighting → Statistically identical results
- Reweighting can be used to include in fit observables for which no fast calculation tool is available

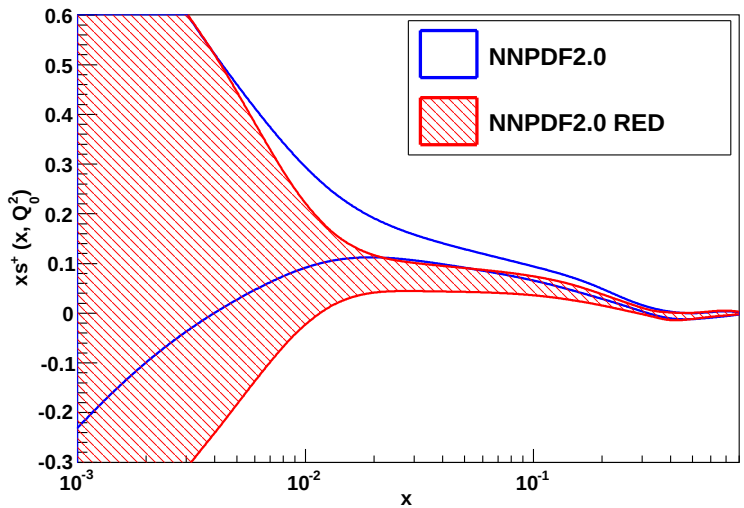


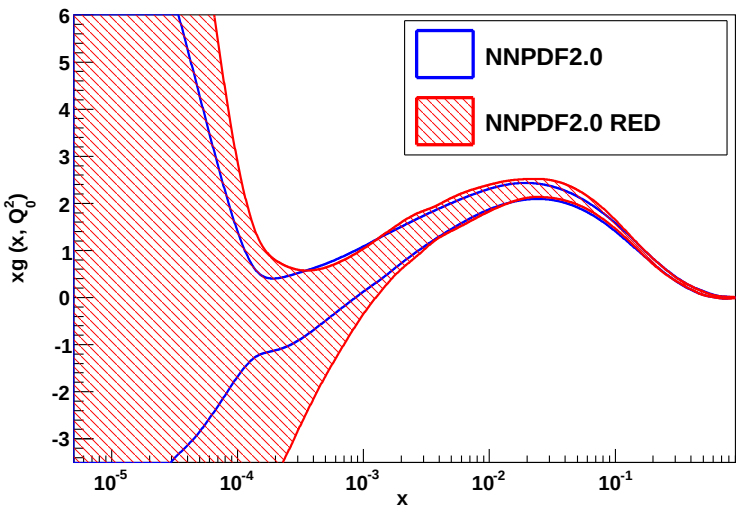


RW can be used to estimate impact of future machines (LHeC, MEIC, JLAB12, ...)

Comparison between NNPDF2.0 and NNPDF2.1

New kinematical cut $Q^2_{\rm min}$ and ZM for dimuons

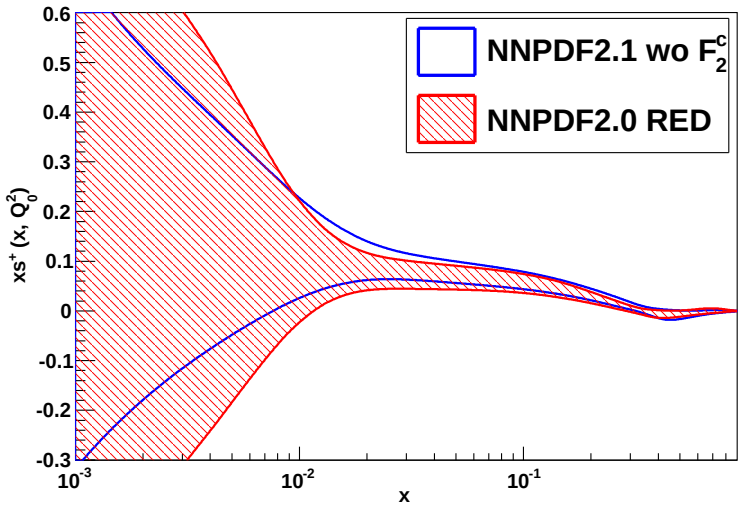


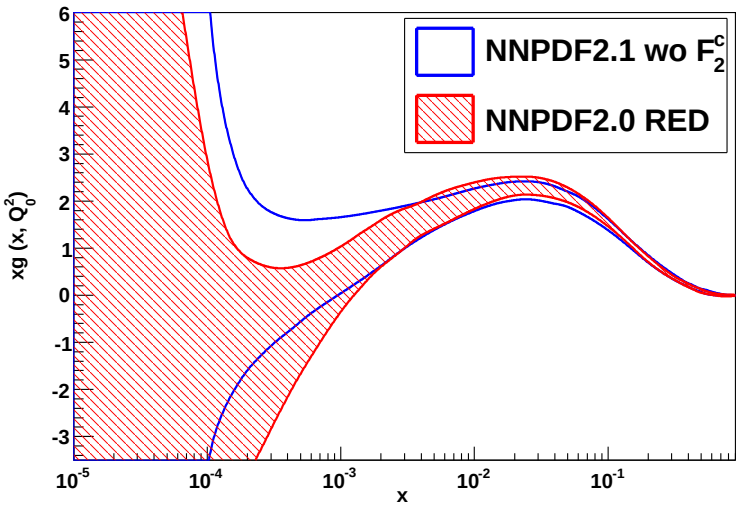


- Larger small-x gluon uncertainties from reduced dataset
- Softer strangeness when going from I-ZM to ZM

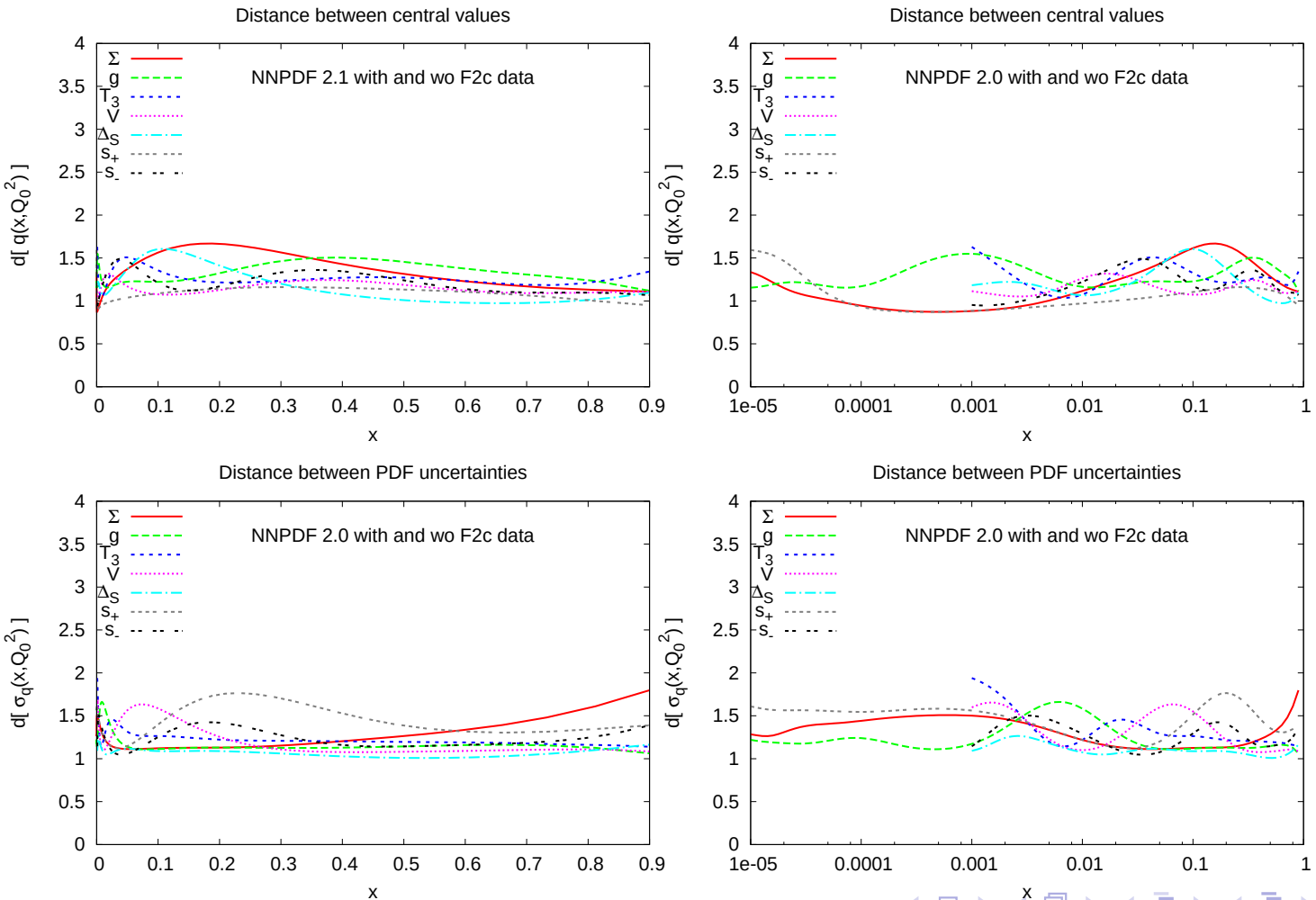
Comparison between NNPDF2.0 and NNPDF2.1

Impact of GM-VFN scheme for NC and CC SFs





- Harder small-x gluon from GM-VFN
- Harder strangeness (but less that with I-ZM)

Comparison between NNPDF2.0 and NNPDF2.1

Impact of the HERA F_2^c data