Another update of benchmark cross section study

Graeme Watt

CERN PH-TH

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Introduction: some philosophical thoughts

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[1] (and preferably accompanied by a journal publication)

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3. If a PDF fit is done, but it is not available in LHAPDF[1], does it make a sound? [G.W.]

- Consider only *public* sets, where "public" $\equiv$ available in LHAPDF, i.e. excludes ABM10/11, CT NNLO, HERAPDF1.6/1.7, ...
- Quantifying and understanding differences *between* groups is *as* (if not *more*) important as continued improvements *within* groups.

[1] (and preferably accompanied by a journal publication)

Status of PDFs from different groups in March 2010

- Then LHAPDF V5.8.2 (released 18th March 2010).
- Highlight major differences in data and theory between groups:

	MSTW08	**CTEQ6.6**	**NNPDF2.0**	HERAPDF1.0	ABKM09	GJR08/JR09
HERA DIS	✔	✔	✔	✔	✔	✔
Fixed-target DIS	✔	✔	✔	✗	✔	✔
Fixed-target DY	✔	✔	✔	✗	✔	✔
Tevatron W,Z	✔	✔	✔	✗	✗	✗
Tevatron jets	✔	✔	✔	✗	✗	✔/✗
GM-VFNS	✔	✔	✗	✔	✗	✗
NNLO	✔	✗	✗	✗	✔	✔

- "Global" $\equiv$ includes all five main categories of data.
- *Three* groups with **NLO** global fits, but only *one* at **NNLO**. Approx. NNLO for jets, massive $\mathcal{O}(\alpha_S^3)$ NC and $\mathcal{O}(\alpha_S^2)$ CC DIS.
- CTEQ6.6 only uses Tevatron Run I data, not Run II.
- NNPDF2.0 inadequate through use of ZM-VFNS for DIS.
- **NLO** comparisons initially presented in talk by **G.W.** at PDF4LHC meeting on 26th March 2010 and formed basis for subsequent *PDF4LHC Interim Report* [arXiv:1101.0536].

Status of PDFs from different groups in March 2011

- Then LHAPDF V5.8.5 (released 2nd February 2011).
- Highlight major differences in data and theory between groups:

	MSTW08	**CT10**	**NNPDF2.1**	HERAPDF1.0/1.5	ABKM09	GJR08/JR09
HERA DIS	✔	✔	✔	✔	✔	✔
Fixed-target DIS	✔	✔	✔	✗	✔	✔
Fixed-target DY	✔	✔	✔	✗	✔	✔
Tevatron W,Z	✔	✔	✔	✗	✗	✗
Tevatron jets	✔	✔	✔	✗	✗	✔/✗
GM-VFNS	✔	✔	✔	✔	✗	✗
NNLO	✔	✗	✗	✔	✔	✔

- *Three* groups with **NLO** global fits, but only *one* at **NNLO**.
- CT10 uses both Tevatron Run I and Run II data.
- NNPDF2.0 (ZM-VFNS) $\rightarrow$ NNPDF2.1 (GM-VFNS), allowing meaningful comparison to other NLO global fits.
- HERAPDF1.0 provided at NNLO (without uncertainties).
- **NLO** update and extension to **NNLO** comparisons presented in talk by **G.W.** at PDF4LHC meeting on 7th March 2011 and published in JHEP **09** (2011) 069 [arXiv:1106.5788].

Status of PDFs from different groups in November 2011

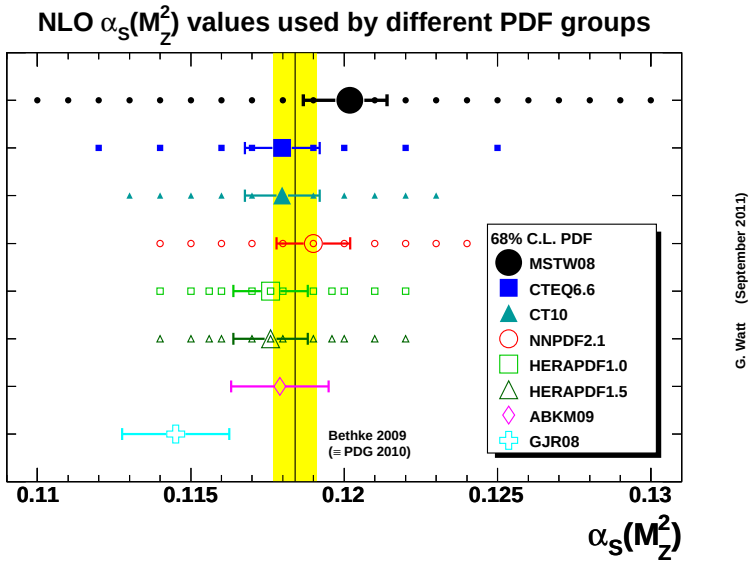
- Now LHAPDF V5.8.6 (released 2nd August 2011).
- Highlight major differences in data and theory between groups:

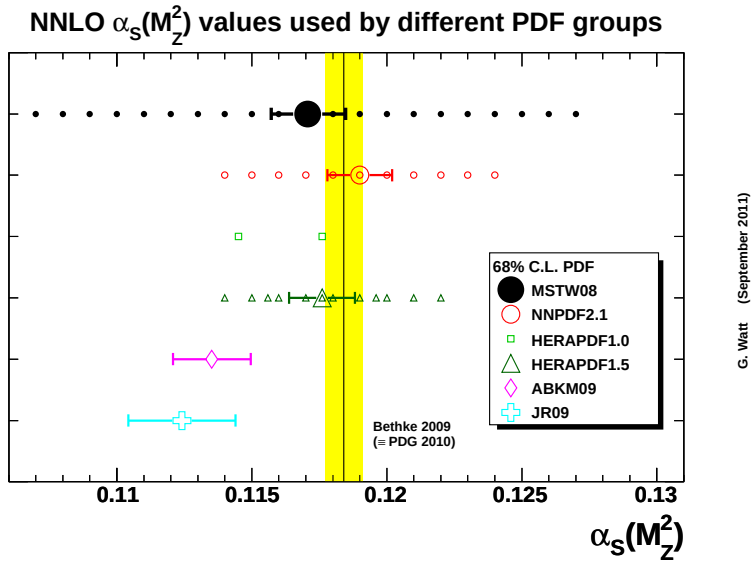
	MSTW08	**CT10**	**NNPDF2.1**	HERAPDF1.5	ABKM09	GJR08/JR09
HERA DIS	✔	✔	✔	✔	✔	✔
Fixed-target DIS	✔	✔	✔	✗	✔	✔
Fixed-target DY	✔	✔	✔	✗	✔	✔
Tevatron W,Z	✔	✔	✔	✗	✗	✗
Tevatron jets	✔	✔	✔	✗	✗	✔/✗
GM-VFNS	✔	✔	✔	✔	✗	✗
NNLO	✔	✗	✔	✔	✔	✔

- *Three* groups with **NLO** global fits, but only *two* at **NNLO**.
- NNPDF2.1 and HERAPDF1.5 now provided at NNLO.
- Update of comparisons presented in talk by **G.W.** at *Ringberg Workshop: New Trends in HERA Physics 2011* on 26th September 2011 and will appear in the proceedings [arXiv:1112.xxxx]. Updated plots now available from:

  http://projects.hepforge.org/mstwpdf/pdf4lhc/ringberg/

Default values of $\alpha_S(M_Z^2)$ used by different fitting groups

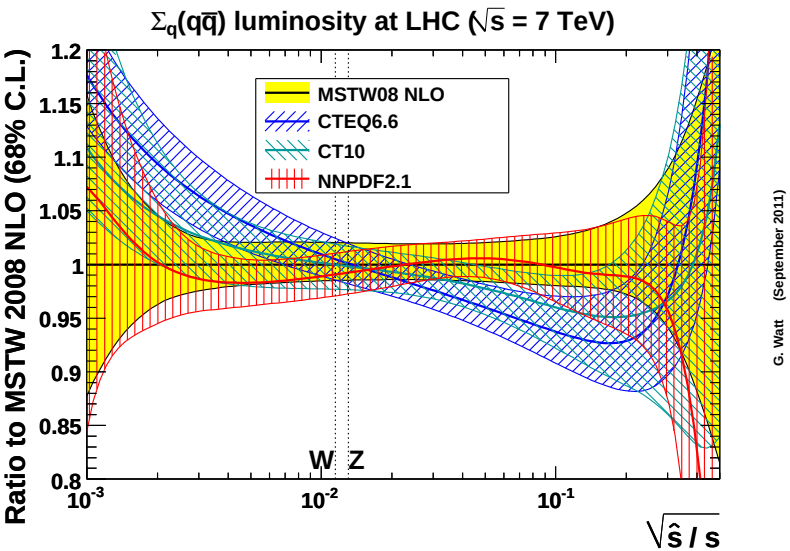


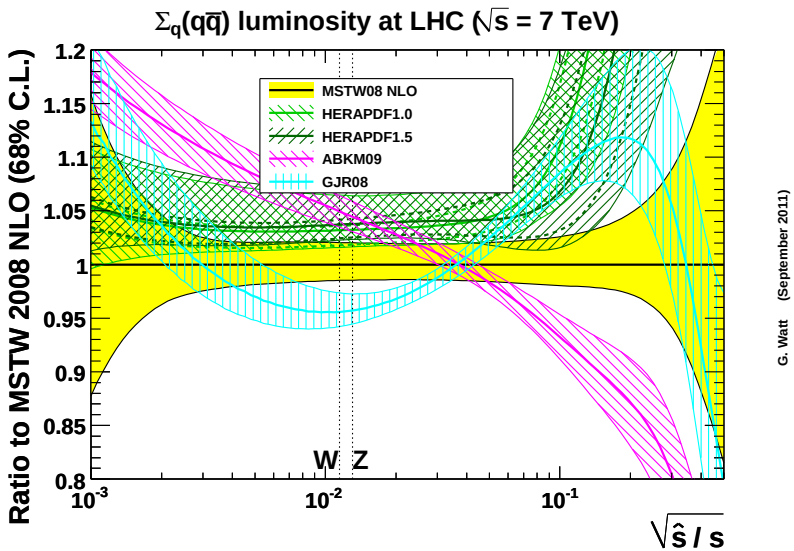


- $\alpha_S(M_Z^2)$ for MSTW08, ABKM09 and GJR08/JR09 fitted.
- $\alpha_S(M_Z^2)$ for other groups applied as an external constraint.
- Smaller symbols indicate alternative $\alpha_S(M_Z^2)$ values provided.
- Fitted NLO $\alpha_S(M_Z^2)$ always larger than NNLO $\alpha_S(M_Z^2)$: attempt by fit to mimic missing higher-order corrections.
- **NNPDF2.1**: $\alpha_S(M_Z^2) = 0.1191 \pm 0.0006^{\text{stat.}}$ (NLO) and $\alpha_S(M_Z^2) = 0.1173 \pm 0.0007^{\text{stat.}}$ (NNLO) for $\Delta\chi^2 = 1$.

Ratio of NLO quark–antiquark luminosity functions

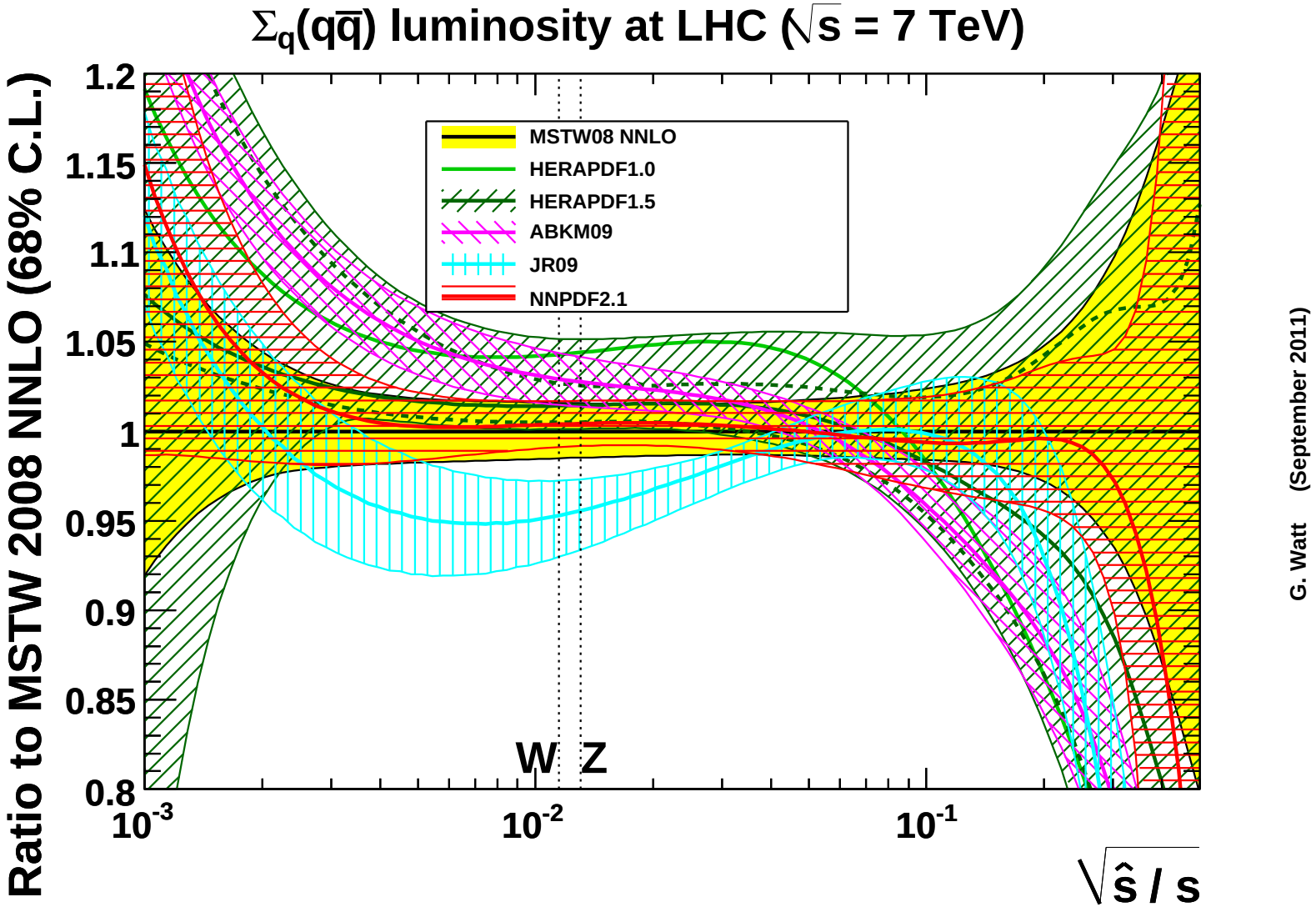
$$\frac{\partial \mathcal{L}_{\Sigma_q(q\bar{q})}}{\partial \hat{s}} = \frac{1}{s}\int_\tau^1 \frac{\mathrm{d}x}{x} \sum_{q=d,u,s,c,b} \left[q(x,\hat{s})\bar{q}(\tau/x,\hat{s}) + (q \leftrightarrow \bar{q})\right], \quad \tau \equiv \frac{\hat{s}}{s}$$





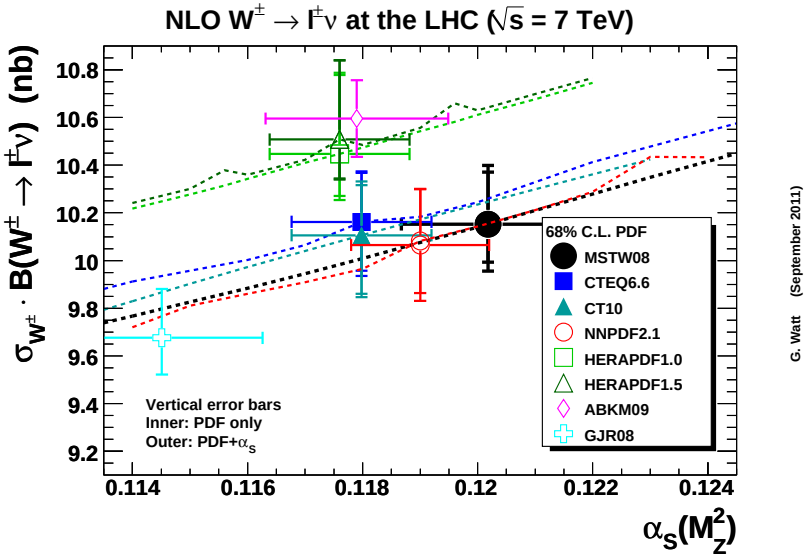
- Relevant values of $\sqrt{\hat{s}} = M_{W,Z}$ are indicated: good agreement for global fits (left), but more variation for other sets (right).

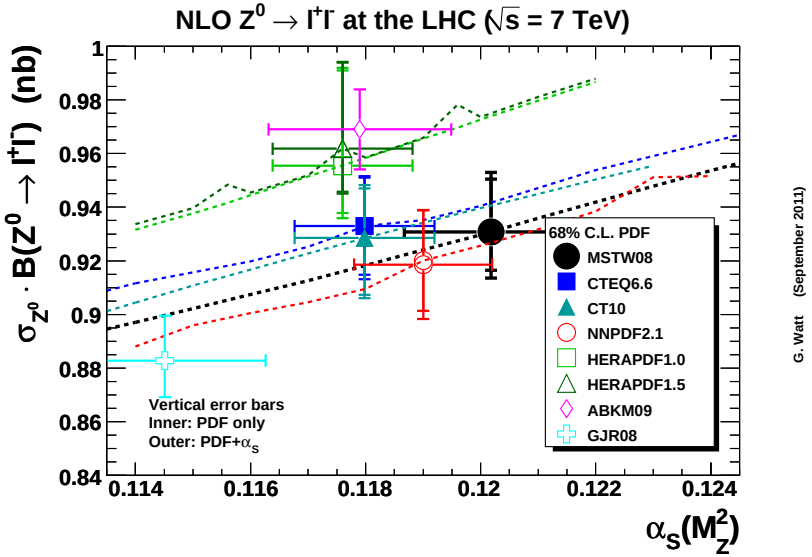
Ratio of NNLO quark–antiquark luminosity functions



- NNLO trend between groups similar to NLO (apart from HERAPDF).

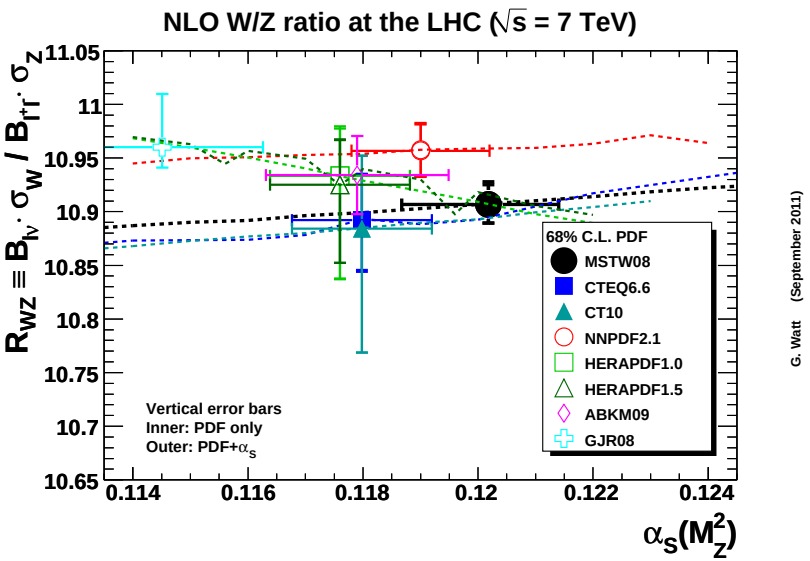
NLO $W^{\pm}$ and Z^0 total cross sections versus $\alpha_S(M_Z^2)$



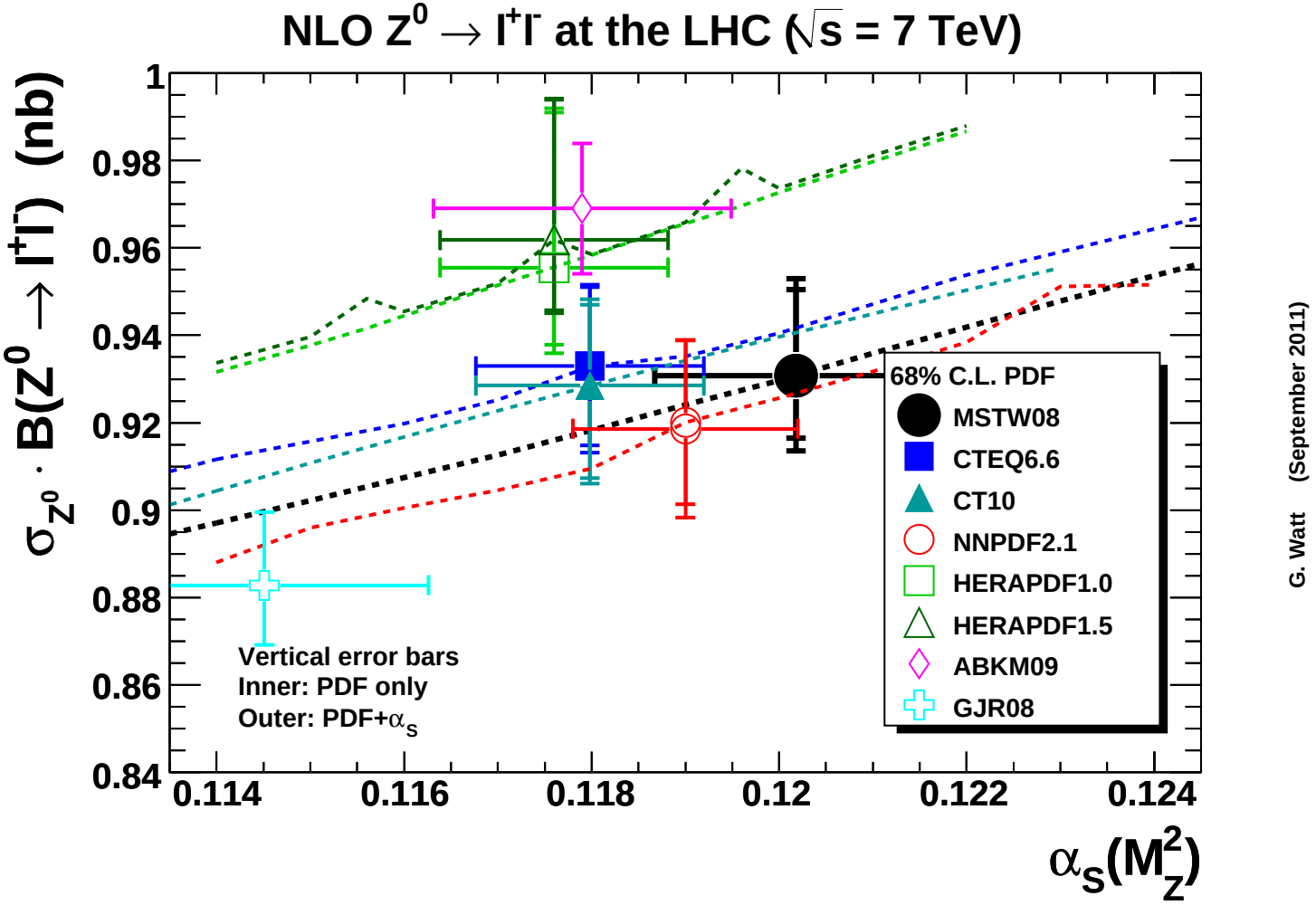


- Global fits in good agreement for $\sigma_{W^\pm}$ and σ_{Z^0} (left plots).
- Small PDF uncertainties in predictions for W/Z ratio:

$$\frac{\sigma_{W^+} + \sigma_{W^-}}{\sigma_{Z^0}} \sim \frac{u(x_1) + d(x_1)}{0.29\, u(\tilde{x}_1) + 0.37\, d(\tilde{x}_1)}$$

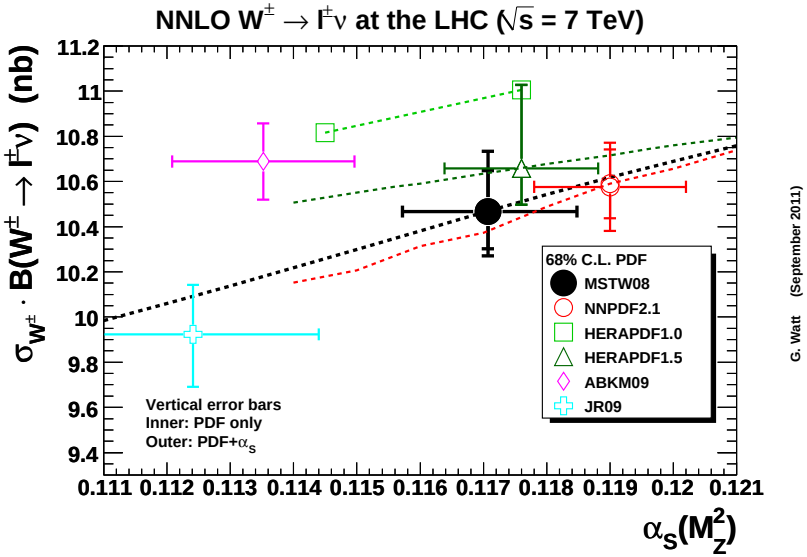


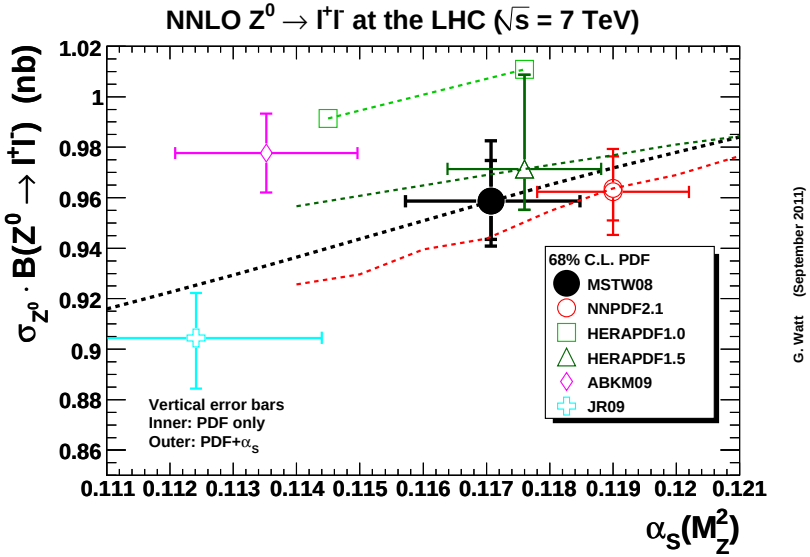
Aside: problem with HERAPDF1.5 NLO α_S variations?



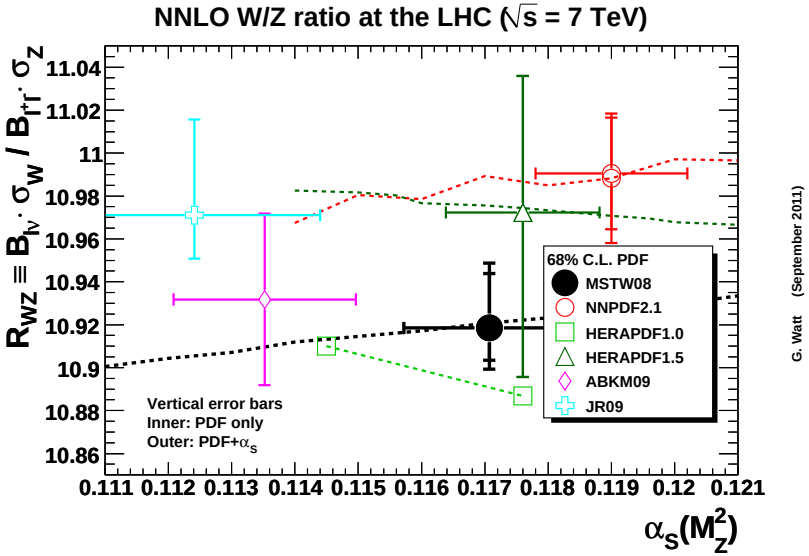
- Fits with $\alpha_S(M_Z^2) = 0.114, 0.115, \ldots, 0.122$ likely run with slightly different settings from $\alpha_S(M_Z^2) = 0.1156, 0.1176, 0.1196$?

NNLO $W^{\pm}$ and Z^0 total cross sections versus $\alpha_S(M_Z^2)$

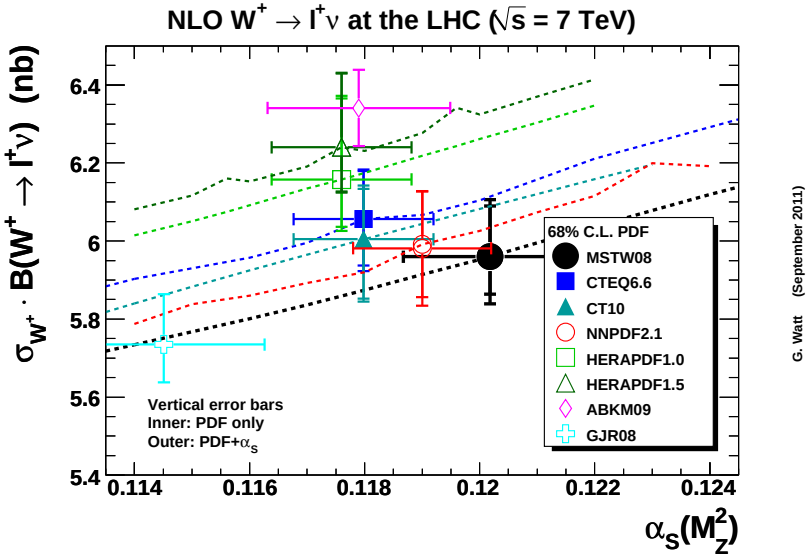


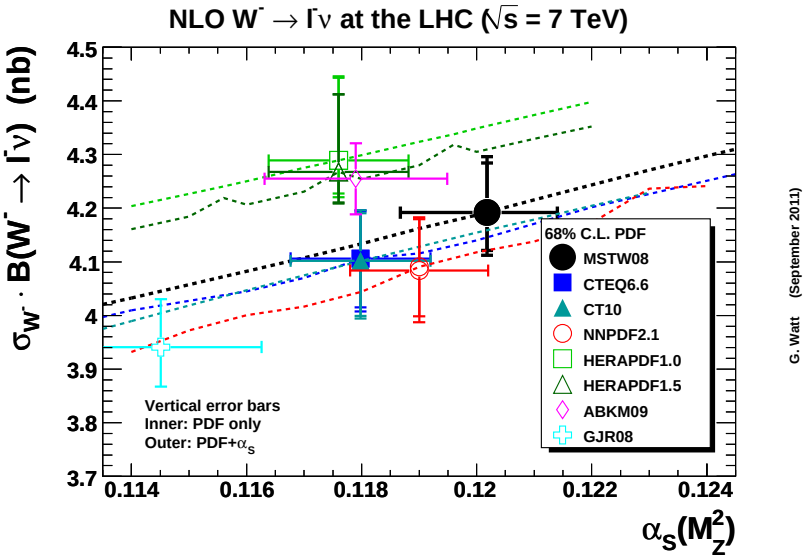


- HERAPDF1.5 closer to global fits at NNLO for $\sigma_{W^{\pm}}$ and σ_{Z^0} (left plots).
- W/Z ratio insensitive to NNLO corrections (and α_S):



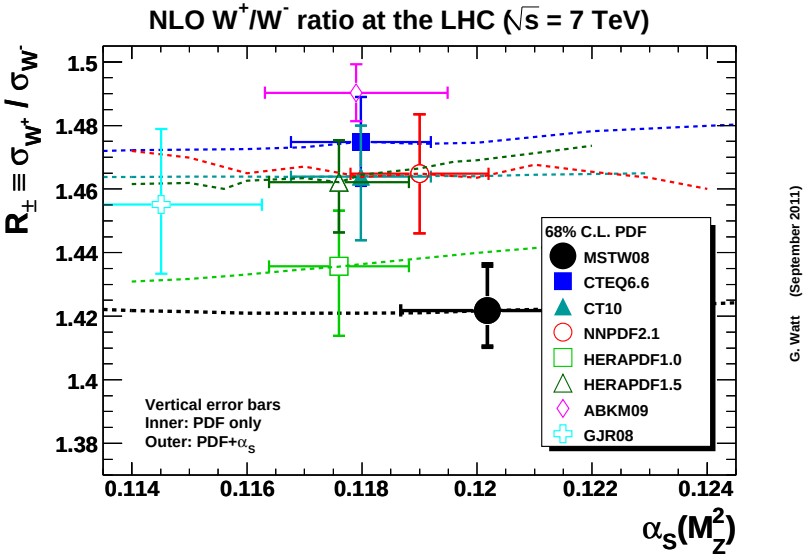
NLO W^+ and W^- total cross sections versus $\alpha_S(M_Z^2)$



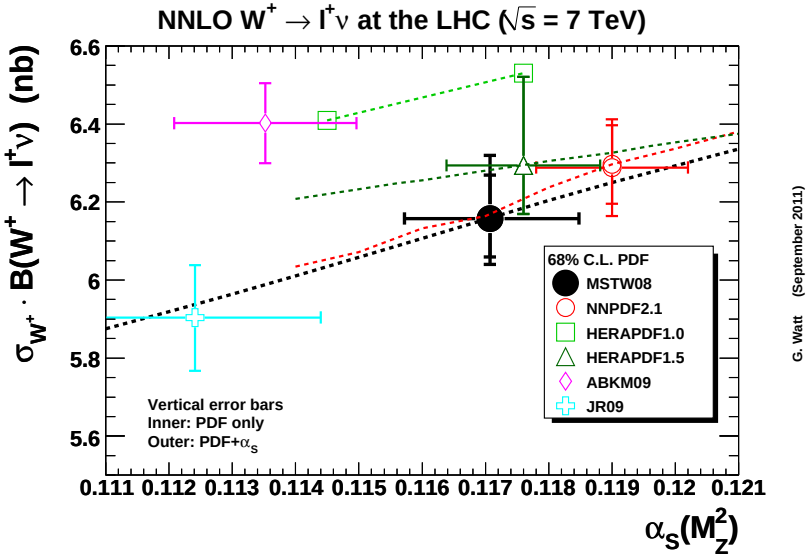


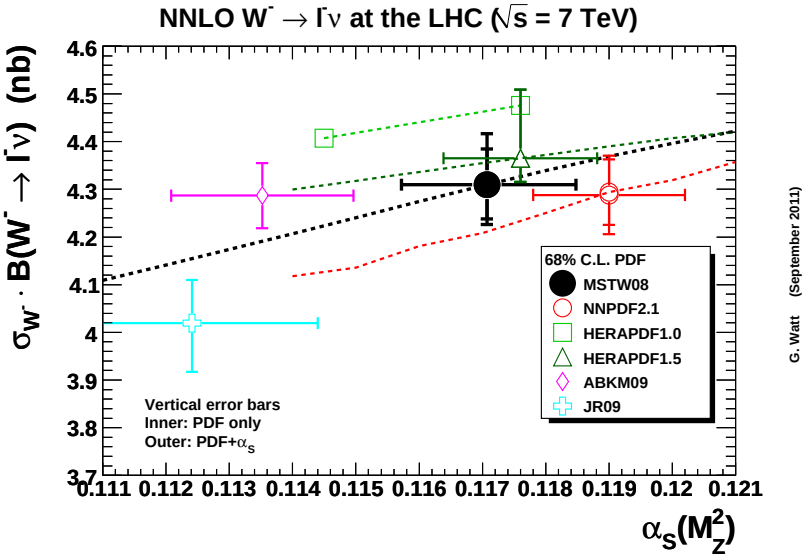
- Slightly more spread in separate σ_{W^+} and σ_{W^-}.
- Reflected in W^+/W^- ratio:

$$\frac{\sigma_{W^+}}{\sigma_{W^-}} \sim \frac{u(x_1)\bar{d}(x_2)}{d(x_1)\bar{u}(x_2)} \sim \frac{u(x_1)}{d(x_1)}$$

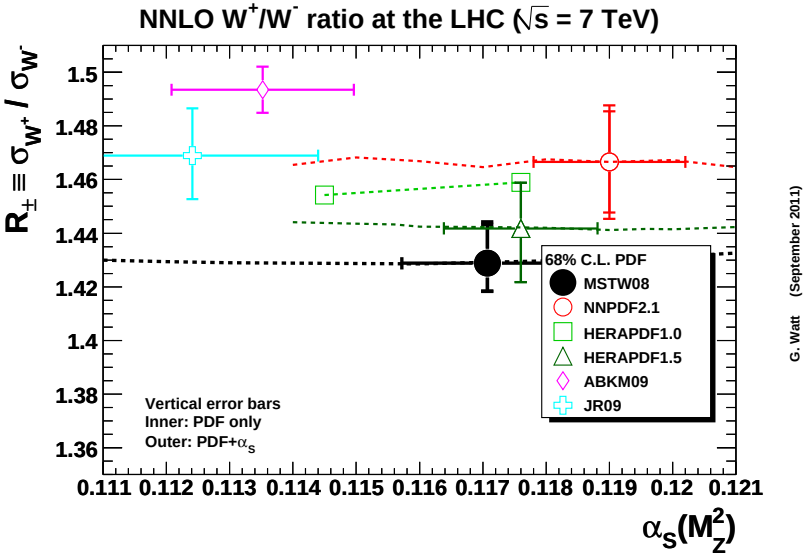


NNLO W^+ and W^- total cross sections versus $\alpha_S(M_Z^2)$



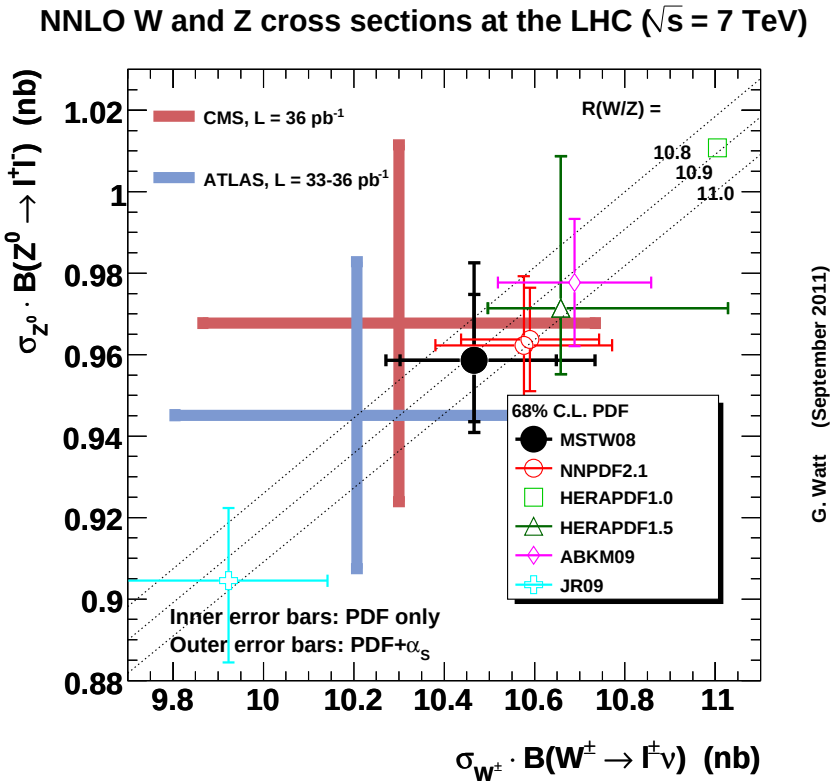


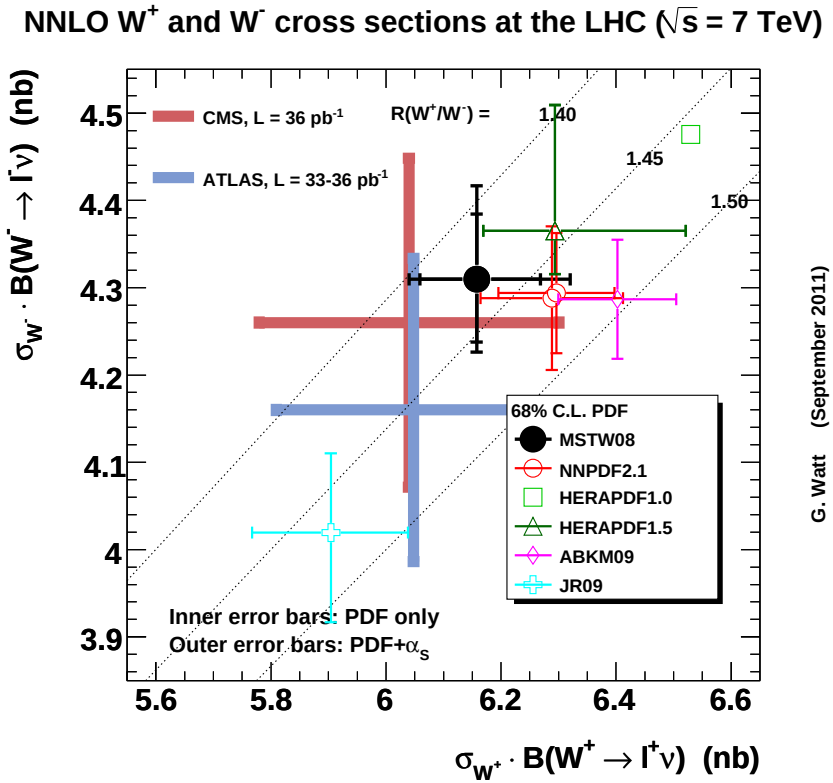
- HERAPDF1.5 closer to global fits at NNLO for σ_{W^+} and σ_{W^-} (left plots).
- W^+/W^- ratio insensitive to NNLO corrections (and α_S):



NNLO $W^{\pm}$ vs. Z^0 and W^+ vs. W^- total cross sections

- Consolidate two cross-section measurements (and their ratio).

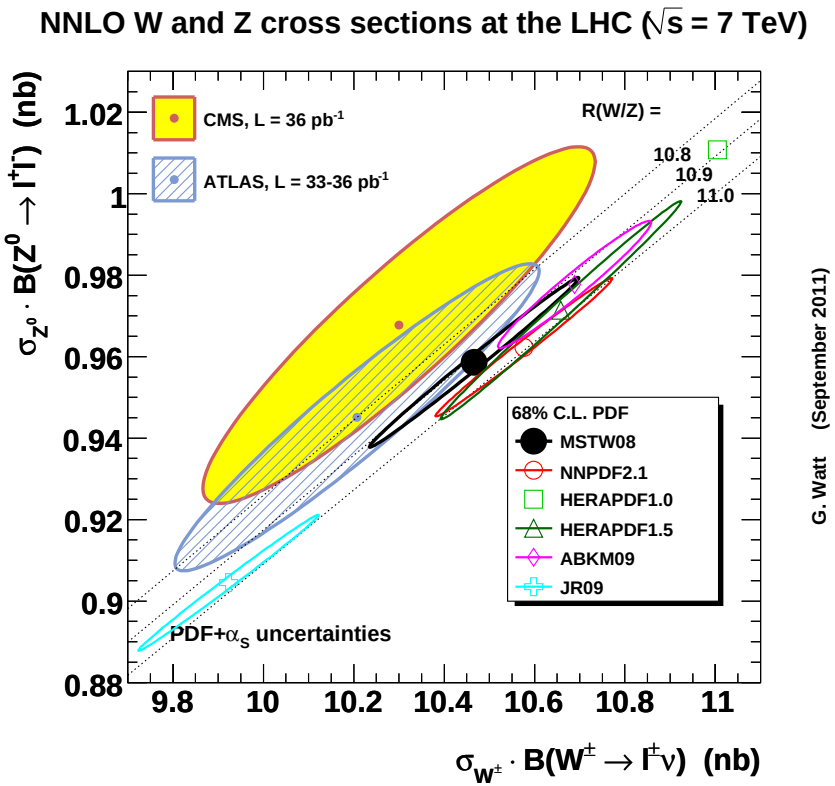


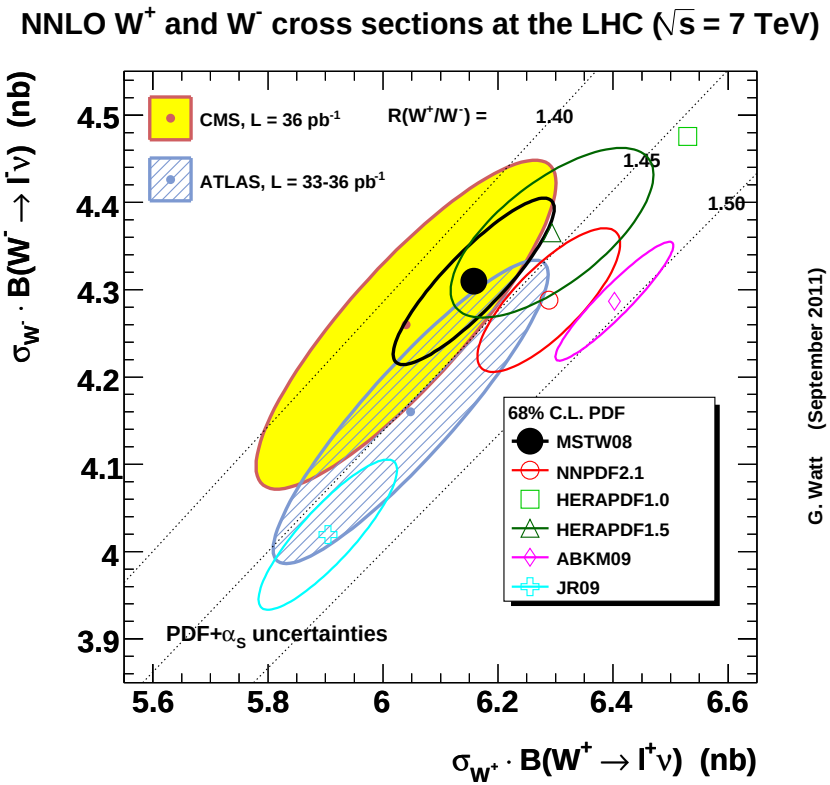


- Luminosity uncertainty of 3.4% (ATLAS) or 4% (CMS).
- Know correlation of both data and theory (from PDFs).

NNLO $W^{\pm}$ vs. Z^0 and W^+ vs. W^- total cross sections

- Correlation of ellipse $\Leftrightarrow$ uncertainty in ratio of cross sections.

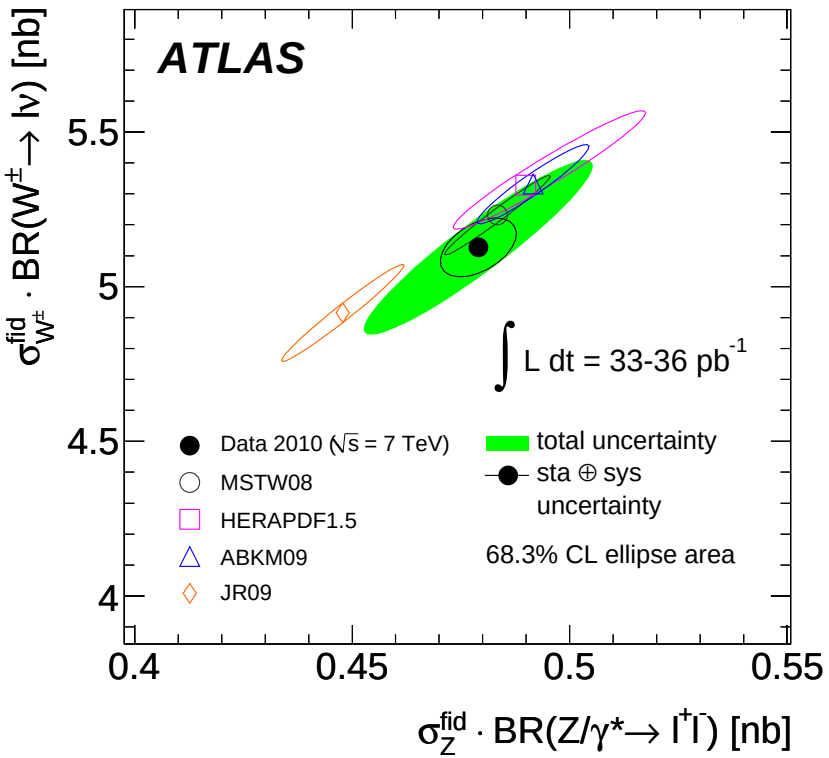


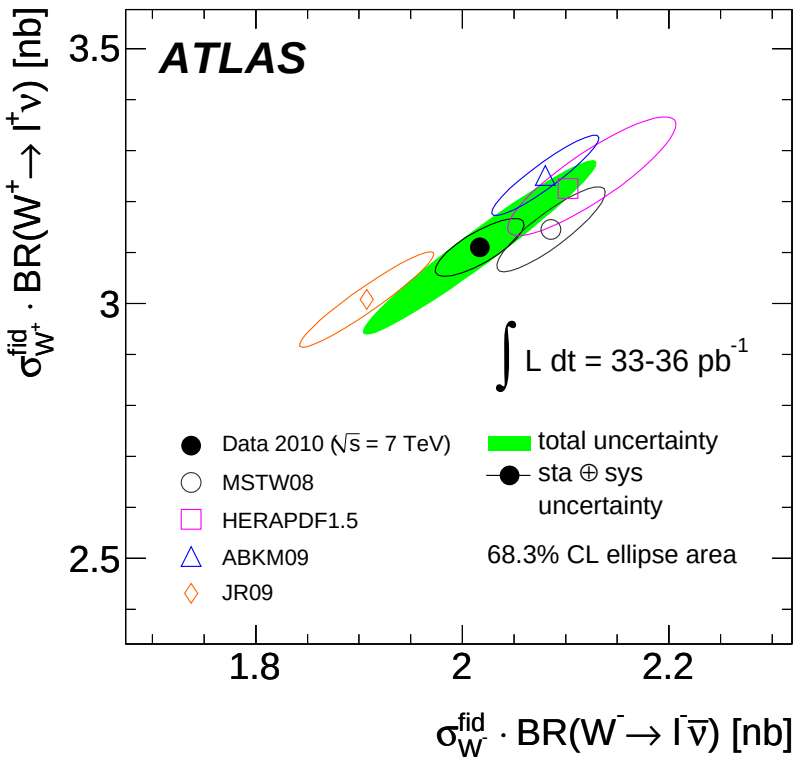


- Largest uncertainty in ATLAS/CMS total cross-section **ratios** from acceptance calculation $\Rightarrow$ compare to theory **within** acceptance.

NNLO $W^{\pm}$ vs. Z^0 and W^+ vs. W^- fiducial cross sections

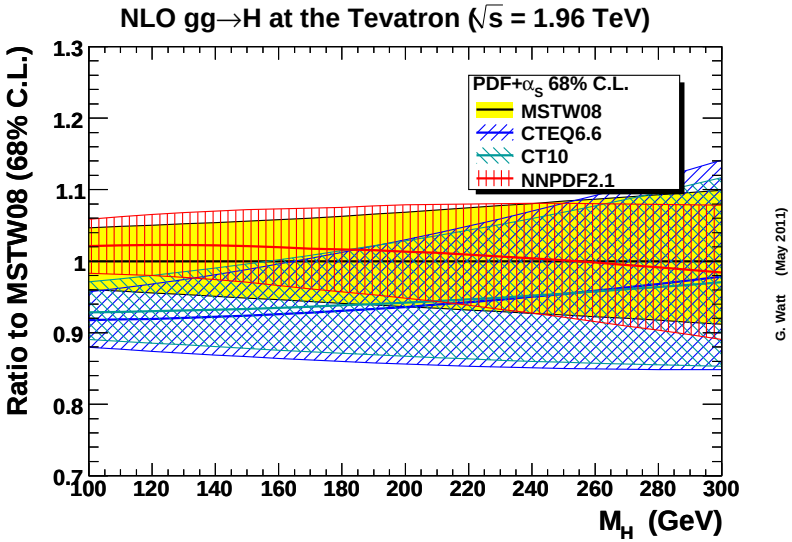
[ATLAS Collaboration, arXiv:1109.5141]

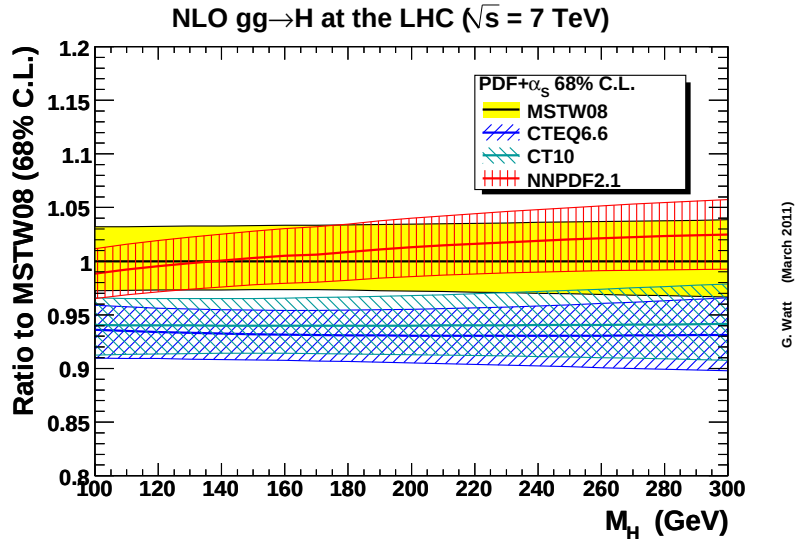


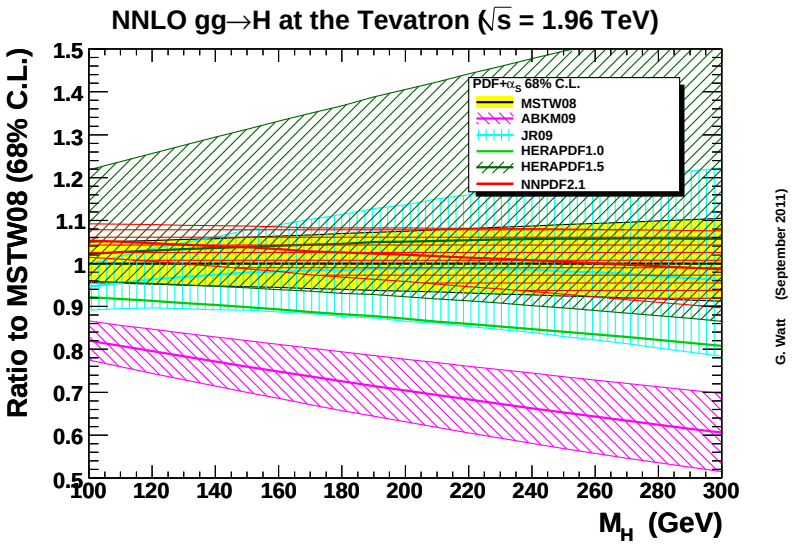


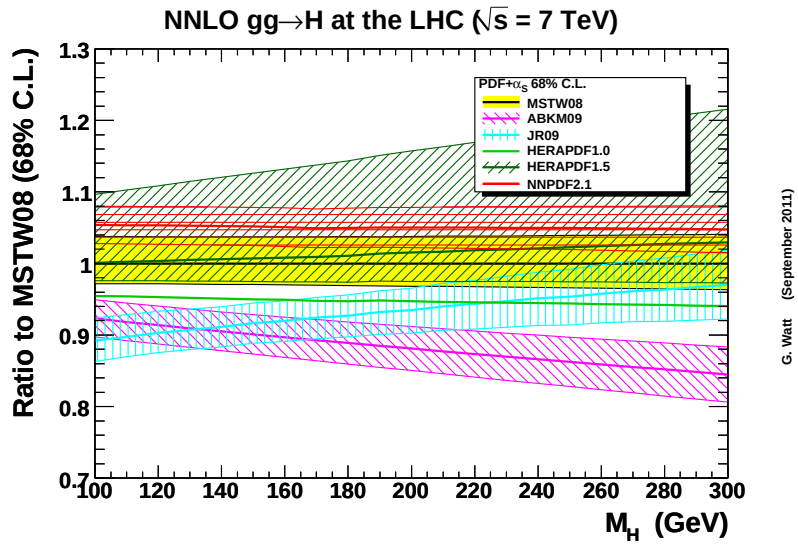
- **NNLO** comparisons possible using FEWZ or DYNNLO codes.
- More useful PDF constraints from differential distributions.

$gg \to H$ total cross sections versus SM Higgs mass M_H



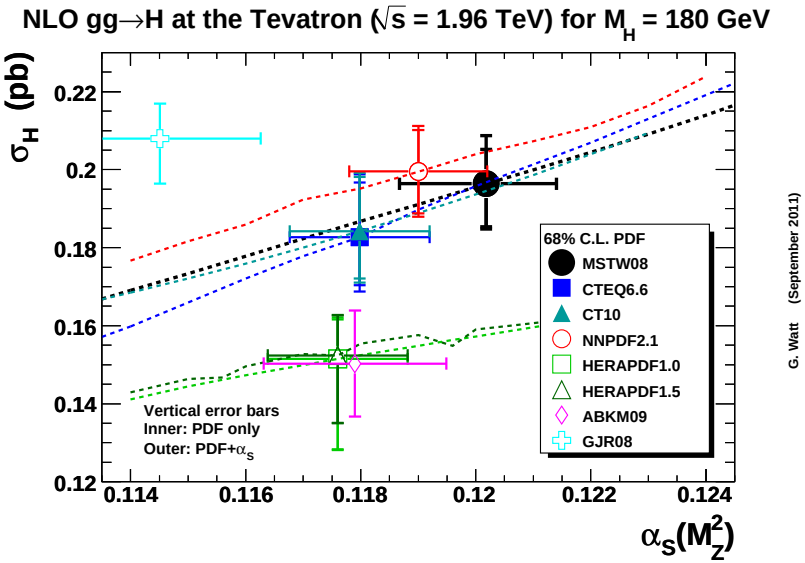


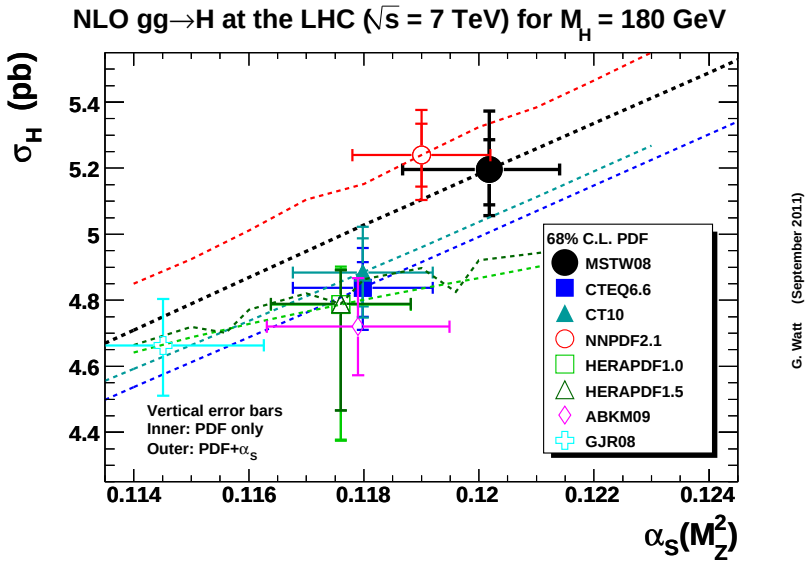


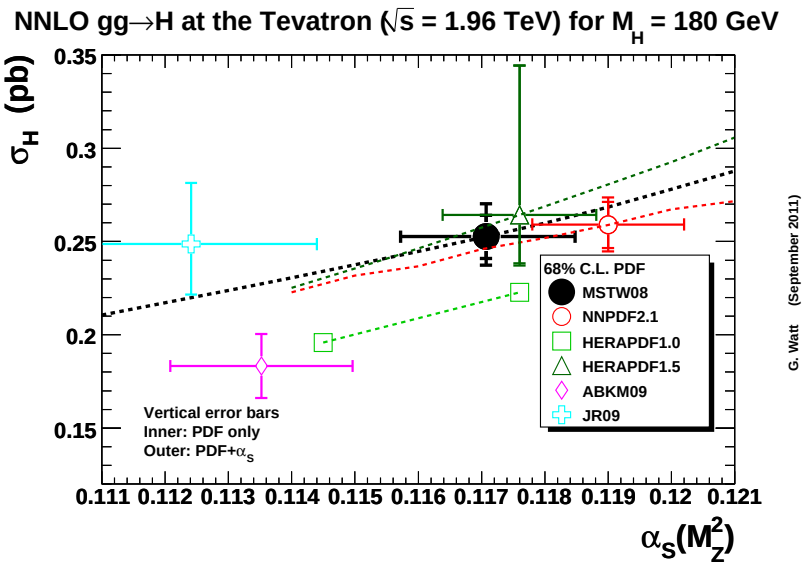


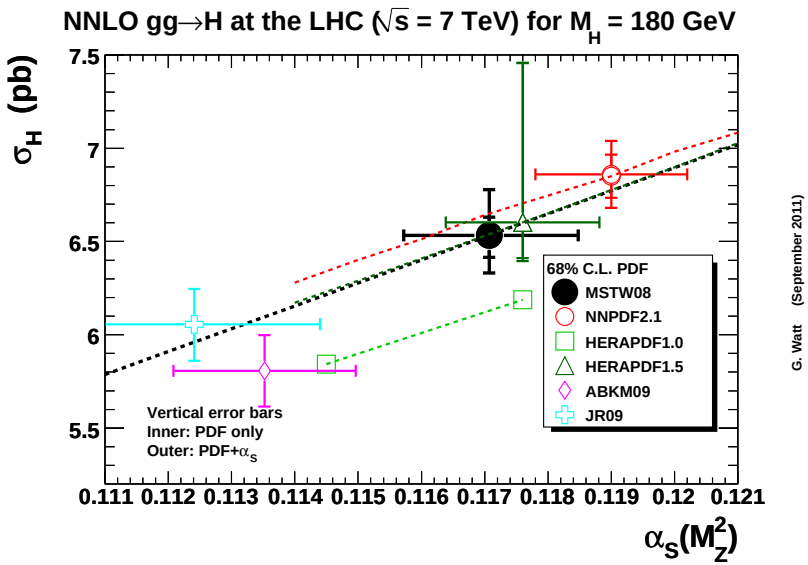
- HERAPDF1.5 and NNPDF2.1 results agree with **MSTW08**.

$gg \to H$ total cross sections versus $\alpha_S(M_Z^2)$



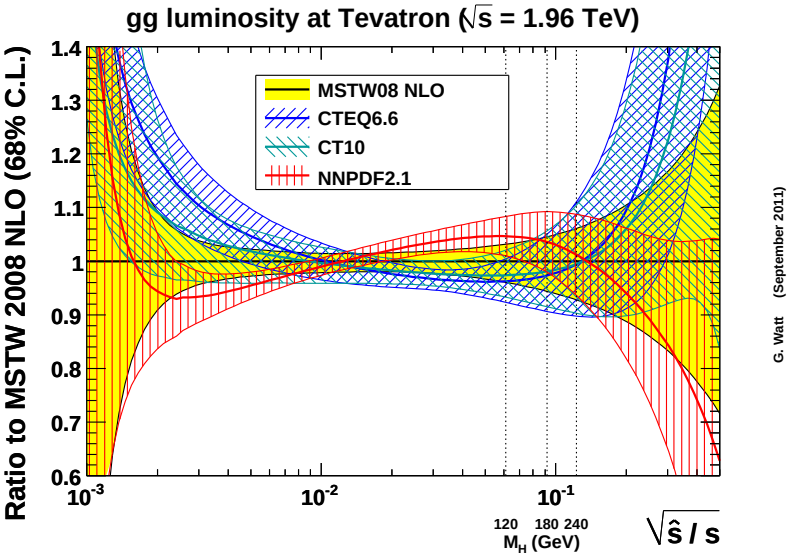


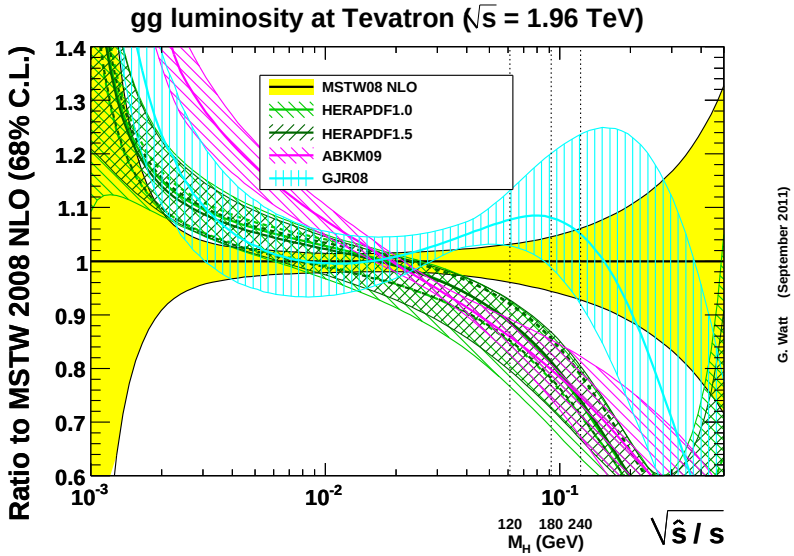


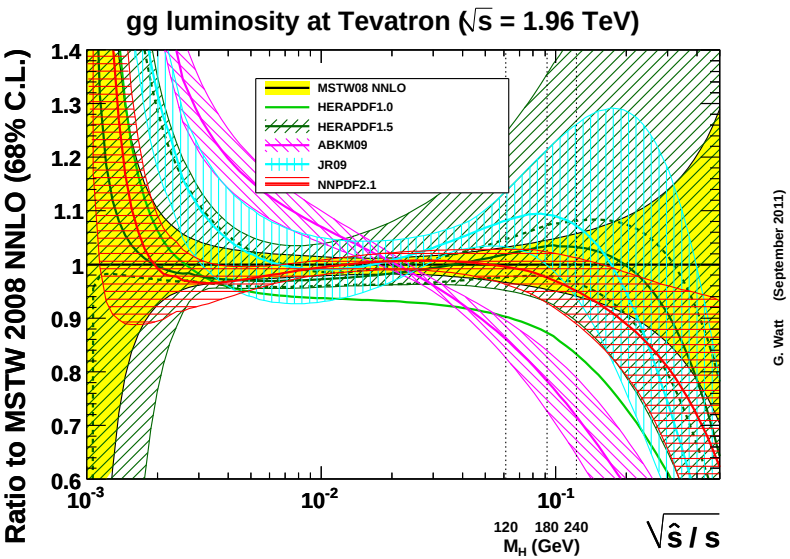


- $\alpha_S(M_Z^2)$ values can only *partly* explain low σ_H for ABKM09.

Ratio of gluon–gluon luminosity functions

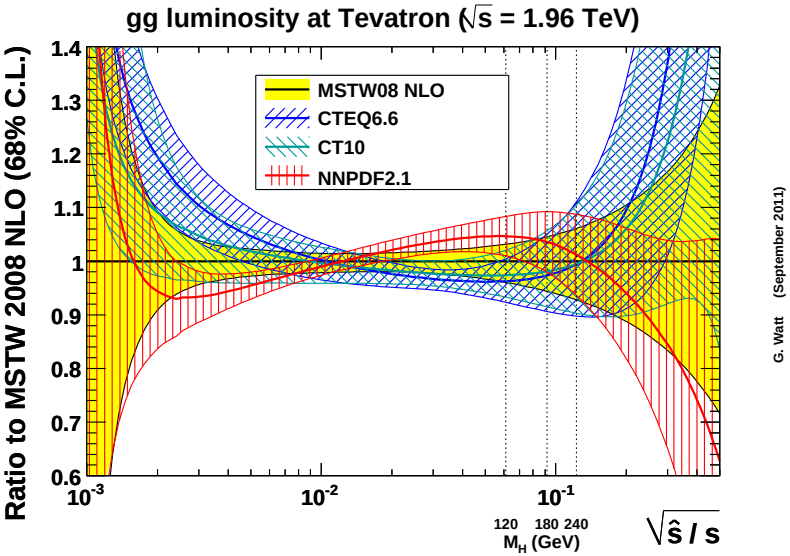


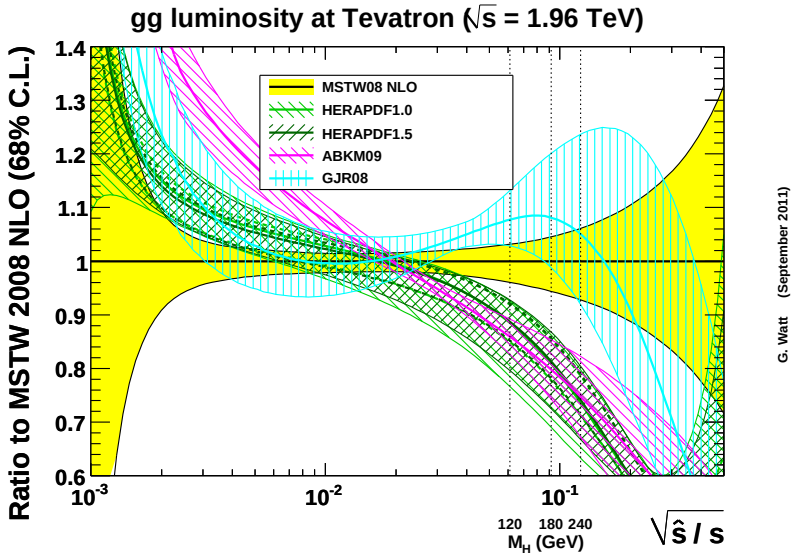


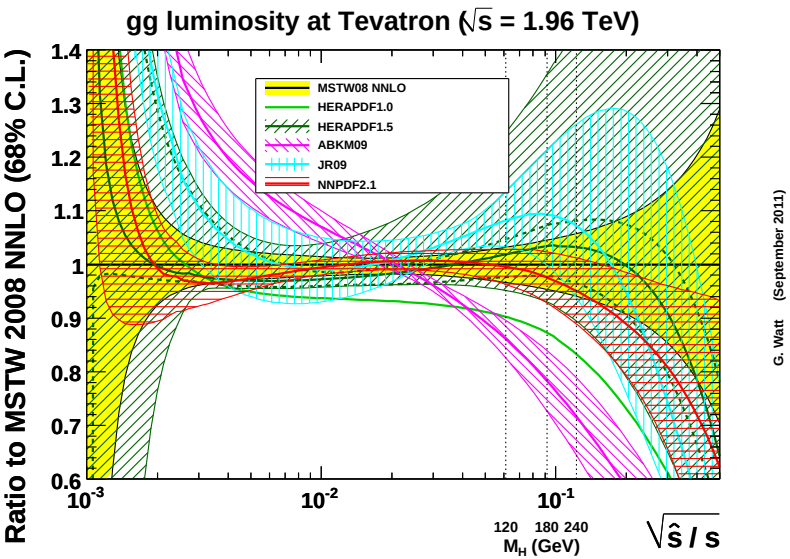


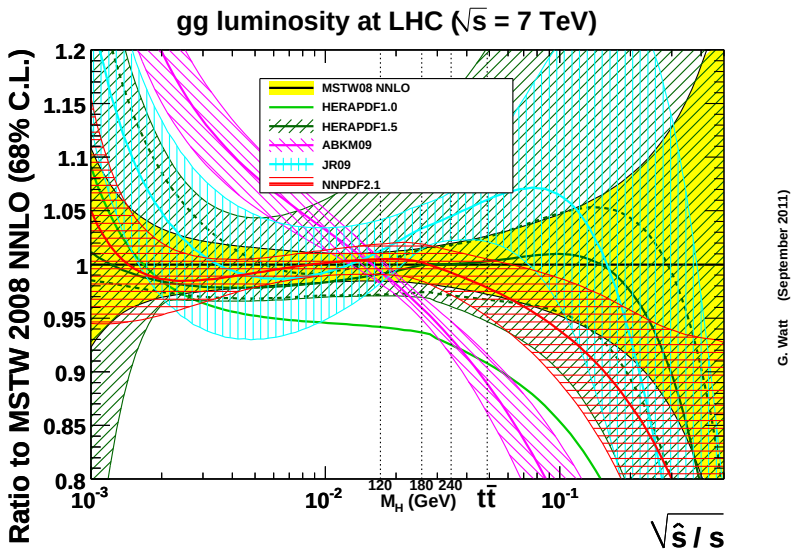
- Relevant values of $\sqrt{\hat{s}} = M_H$ are indicated.

Ratio of gluon–gluon luminosity functions



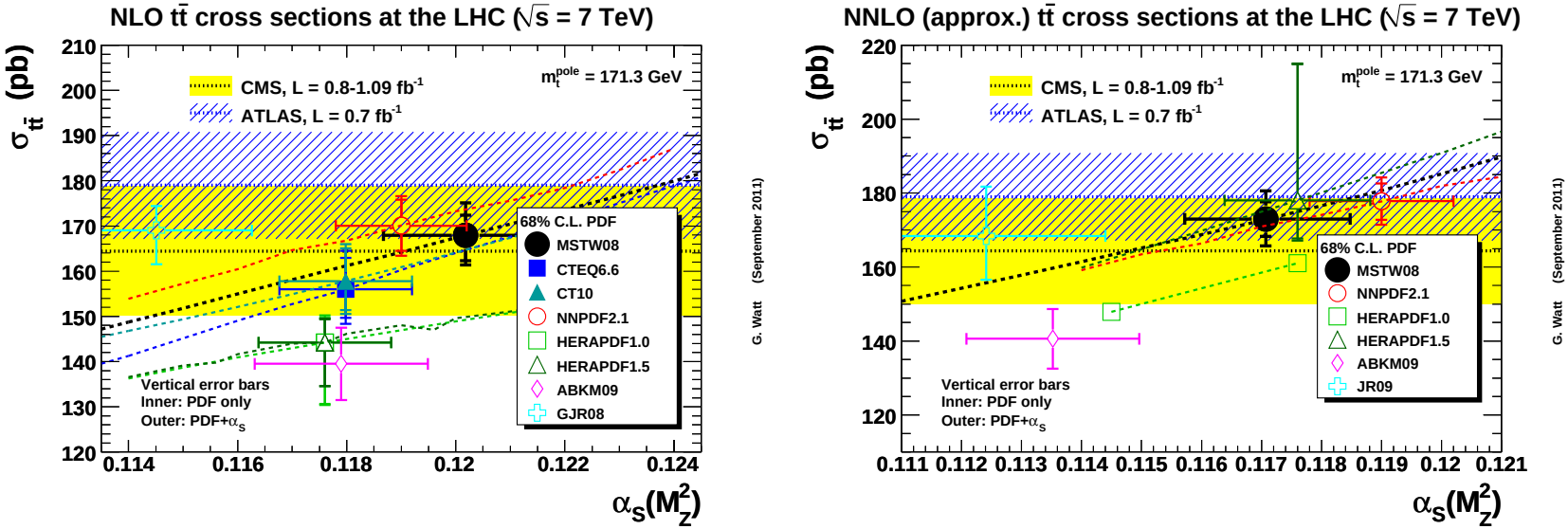






- Relevant values of $\sqrt{\hat{s}} = M_H, 2m_t$ are indicated.

$t\bar{t}$ total cross sections versus $\alpha_S(M_Z^2)$ at the LHC

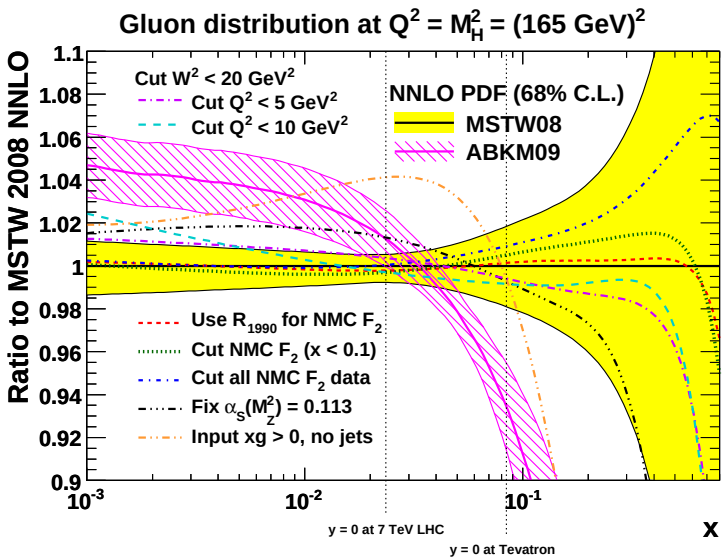


- NNLO (approx.) using HATHOR code [Aliev *et al.*, arXiv:1007.1327].
- Compare to single most precise current LHC measurements.
  - **CMS:** $\sigma_{t\bar{t}} = 164.4 \pm 2.8(\text{stat.}) \pm 11.9(\text{syst.}) \pm 7.4(\text{lumi.})$ pb (e/μ+jets+b-tag) [CMS PAS TOP-11-003]
  - **ATLAS:** $\sigma_{t\bar{t}} = 179.0 \pm 9.8(\text{stat.+syst.}) \pm 6.6(\text{lumi.})$ pb (using kinematic information of lepton+jets events) [ATLAS-CONF-2011-121]
- Tevatron: $m_t = 173.2 \pm 0.9$ GeV [TEVEWWG, arXiv:1107.5255]. Increasing m_t by 2 GeV decreases predicted $\sigma_{t\bar{t}}$ at LHC by 6%.

Sensitivity to minimum Q^2 cut in HERAPDF1.5 NNLO fit

$$\sigma_{t\bar{t}} = 178^{+4}_{-6}(\text{exp.})^{+37}_{-8}(\text{model+param.}) \pm 6(\alpha_S)\ \text{pb}$$

- $Q^2_{\text{min}} = 3.5\ \text{GeV}^2 \rightarrow 2.5\ \text{GeV}^2 \Rightarrow \sigma_{t\bar{t}} \rightarrow +9\ \text{pb}$.
- $Q^2_{\text{min}} = 3.5\ \text{GeV}^2 \rightarrow 5.0\ \text{GeV}^2 \Rightarrow \sigma_{t\bar{t}} \rightarrow +35\ \text{pb}$.
- High-x gluon sensitive to Q^2_{min} because **no** direct data constraint.



[Thorne, G.W., arXiv:1106.5789]

- **MSTW08** insensitive to $Q^2_{\text{min}} = 2 \rightarrow \{5, 10\}\ \text{GeV}^2$.
- Analogous to ABM claim about NMC F_L treatment [arXiv:1101.5261].
- **Conclusion:** jets stabilise fit (lessen sensitivity to details).

Summary

- Reasonably good agreement between:
  - NLO *global* fits from **MSTW08**, CT10 and NNPDF2.1.
  - NNLO *global* fits from **MSTW08** and NNPDF2.1.
- More variation with other PDF sets using more limited data sets and/or restrictive input PDF parameterisations.
- (But HERAPDF1.5 NNLO is surprisingly close to **MSTW08**.)
- Tevatron jet data are important to pin down the high-x gluon [R. S. Thorne and G.W., JHEP **08** (2011) 100, arXiv:1106.5789].

Some clarifying remarks about the benchmark exercise

- Original motivation was to demonstrate that non-global PDF sets give discrepant predictions and to discourage their use for LHC physics, **not** to represent all PDFs as being equally valid such that the spread of all 6 represents a realistic uncertainty.
- This plan seems to have backfired and the non-global PDF sets have received more publicity through these comparison plots which has instead promoted their wider use.
- Simplest and most efficient way to reduce PDF uncertainties $\Rightarrow$ discard non-global sets (*à la* PDF4LHC recipe).

Future of PDF-fitting: elements for discussion

- Currently:
  "Global" $\equiv$ "HERA + fixed-target + Tevatron".
  Redefine:
  "Global" $\equiv$ "HERA + fixed-target + Tevatron + LHC", or
  "Global" $\equiv$ "HERA + Tevatron + LHC", or ...?
- Do we really need 6 (!) independent PDF groups updating their fits with new LHC data (with still unaccounted discrepancies)?
- **Old paradigm:** wait for MRST(W)/CTEQ to incorporate new data into their (clunky and private) ~30-year-old fitting codes.
- **New paradigm (?):** open-source PDF fitting tools (e.g. HERAFitter) with combined experiment/theory expertise, allowing controlled studies of different approaches.