PDF benchmarking for LHC processes: MSTW report

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Background and motivation for benchmark exercise

- LHC Higgs Working Group requested recommendation from **PDF4LHC** on PDFs and α_S values (and their uncertainties) to be used for cross section calculations.
- Proposal made by J. Stirling in **PDF4LHC** EVO discussion to use different PDFs to calculate LHC benchmark processes: $W^{\pm}$, Z^0, $t\bar{t}$, $gg \to H$ ($M_H = 120, 180, 240$ GeV).
  Aims:
  1. Establish degree of compatibility and identify outliers.
  2. Compare cross sections at **same** α_S values.
  3. To what extent are differences in predictions due to different α_S values used by each group, rather than differences in PDFs?
- Results should form basis for recommendation to LHC Higgs WG.

Most recent public NLO PDF sets from fitting groups

- If NNLO is available for a given process, it should be used.
- But **only** MSTW08, ABKM09 and JR09 have NNLO PDFs.
- ⇒ Compare at NLO with 5-flavour PDFs from all groups:

MSTW08 [arXiv:0901.0002]
GM-VFNS global fit to DIS, DY and jet data.

CTEQ6.6 [arXiv:0802.0007]
GM-VFNS global fit to DIS, DY and jet data.

NNPDF2.0 [arXiv:1002.4407]
ZM-VFNS global fit to DIS, DY and jet data.

HERAPDF1.0 [arXiv:0911.0884]
GM-VFNS fit only to inclusive HERA data.

ABKM09 [arXiv:0908.2766, with NLO update in January 2010]
FFNS fit to DIS and DY data.

GJR08 [arXiv:0709.0614]
FFNS 'dynamical' fit to DIS, DY and jet data.

PDF uncertainties from experimental errors on fitted data

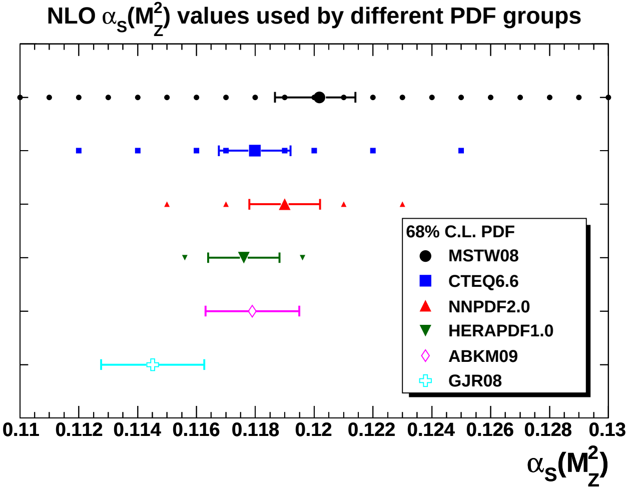
- All groups other than NNPDF provide eigenvector PDF sets. Use asymmetric uncertainties (apart from ABKM09):

$$(\Delta F)_+ = \sqrt{\sum_{k=1}^{n} \left\{\max\left[\, F(S_k^+) - F(S_0),\ F(S_k^-) - F(S_0),\ 0\right]\right\}^2},$$

$$(\Delta F)_- = \sqrt{\sum_{k=1}^{n} \left\{\max\left[\, F(S_0) - F(S_k^+),\ F(S_0) - F(S_k^-),\ 0\right]\right\}^2},$$

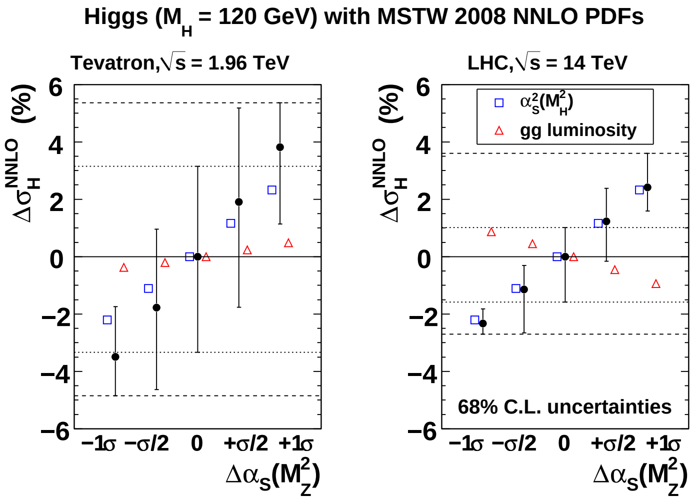
  where $n = 20, 22, 10, 25, 13$ for MSTW08, CTEQ6.6, HERAPDF1.0, ABKM09, GJR08, respectively.
- HERAPDF1.0 provides additional 'model' and 'parameterisation' asymmetric errors: add in quadrature to 'experimental' errors.
- NNPDF2.0: average and standard deviation over 100 replicas.
- MSTW08 provides both 68% C.L. and 90% C.L. sets. Other groups: assume uncertainties related by a factor **1.64485**. Will only show 68% C.L. results in this talk.

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



- $\alpha_S(M_Z^2)$ for MSTW08, ABKM09 and GJR08 obtained from fit.
- For other groups assume ± 0.0012 (± 0.0020) for 68% (90%) C.L.

"PDF+α_S" uncertainties: MSTW08 case [arXiv:0905.3531]



- **Dotted** lines: "PDF only". **Dashed** lines: "PDF+α_S".

"PDF+α_S" uncertainties: prescriptions of other groups

CTEQ6.6 and HERAPDF1.0 : add α_S uncertainties in **quadrature**.

NNPDF2.0 [arXiv:1003.1241] : take number of replicas for each α_S value from a Gaussian distribution. This gives

$$N_{\rm rep}^{(j)} = 0, 25, 100, 25, 0$$

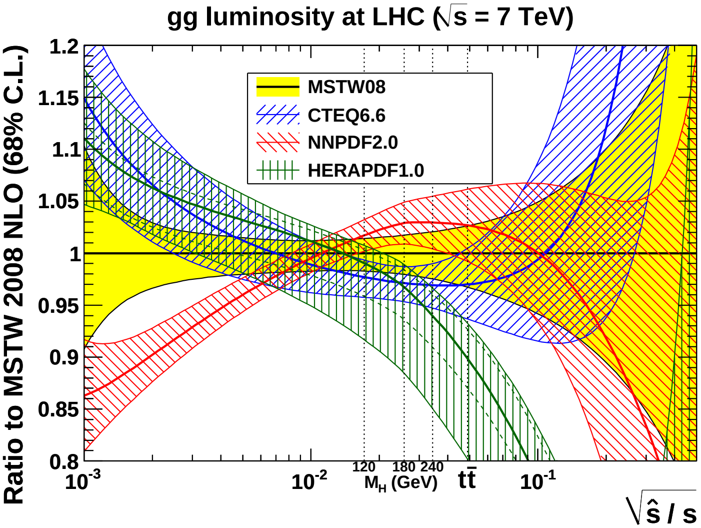
for $\alpha_S^{(j)}(M_Z^2) = 0.115, 0.117, 0.119, 0.121, 0.123$, then take averages over $N_{\rm rep} = \sum_j N_{\rm rep}^{(j)} = 150$ replicas.

ABKM09 and GJR08 : $\alpha_S(M_Z^2)$ is one of fit parameters used to produce **eigenvector** sets $\Rightarrow$ **mixing** of $\alpha_S(M_Z^2)$ with PDF uncertainties, so a "PDF+α_S" uncertainty is obtained automatically. It is not straightforward to calculate a "PDF only" uncertainty.

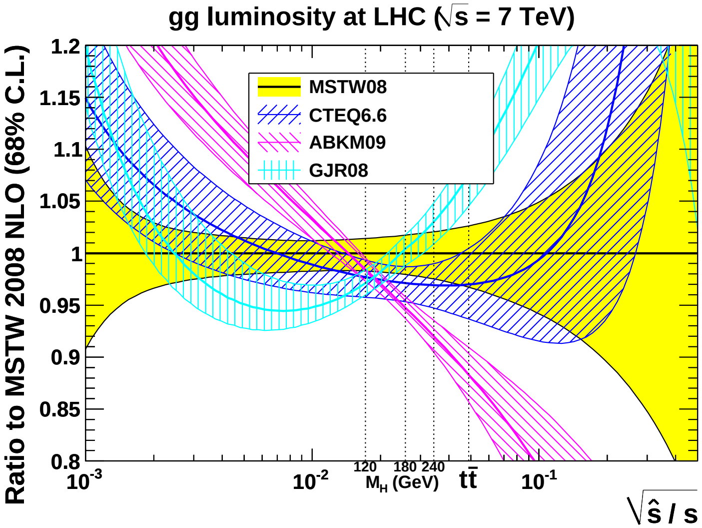
Settings for benchmark cross sections

- Modified MCFM5.7 package with agreed parameters and input files produced by J. Campbell (with J. Huston).
- Private code (by J. Stirling) for total cross sections is much faster and was used to obtain many results before receiving the MCFM package. $\Rightarrow$ Results presented here obtained using private code and only for total cross sections (at 7 TeV).
- Total cross sections (with MSTW08 PDFs) checked against MCFM package. **Agreement** to within numerical integration error (at most 0.1%) for all processes apart from Z^0.
- Discrepancy in Z^0 traced to ambiguity in benchmark specification. MCFM uses $\sin^2(\theta_w) = 1 - (M_W/M_Z)^2 = 0.22265$, whereas we use the effective angle $\sin^2(\theta_w) = 0.23149$ [PDG], leading to a Z^0 total cross section 1.4% lower than MCFM. MCFM also includes a small $\mathcal{O}(0.1\%)$ γ^* component even in the zero-width approximation for the Z^0. These differences are **not important** provided we use the same code for all PDFs.

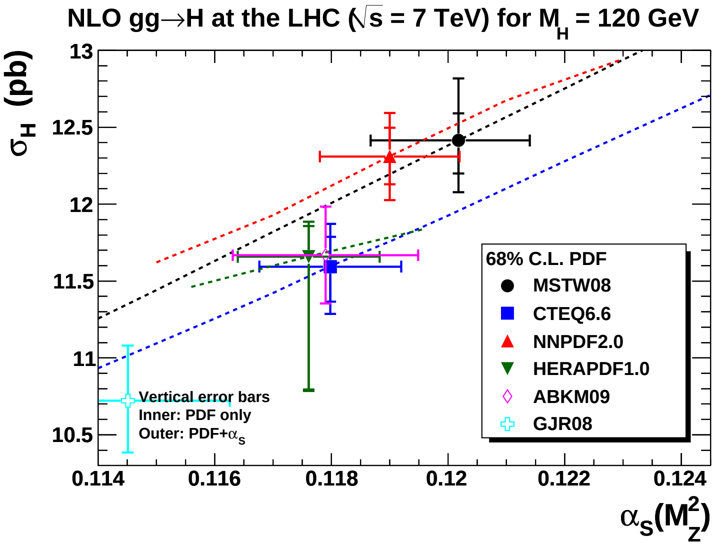
Ratio of gluon–gluon luminosity functions (1)



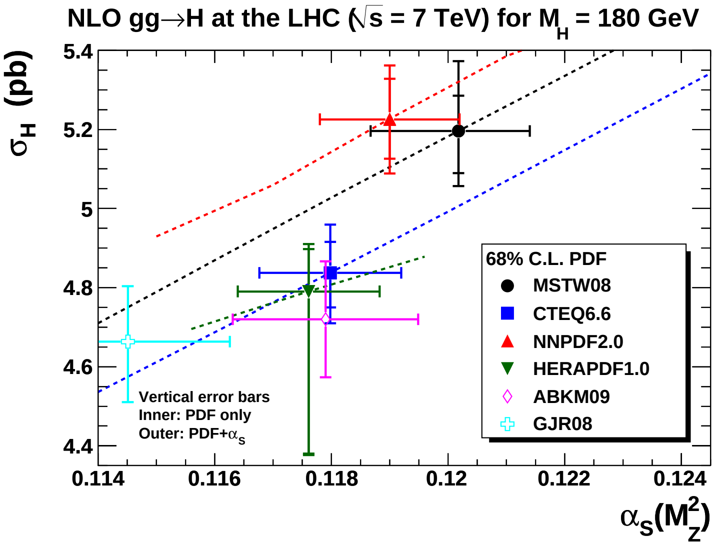
Ratio of gluon–gluon luminosity functions (2)



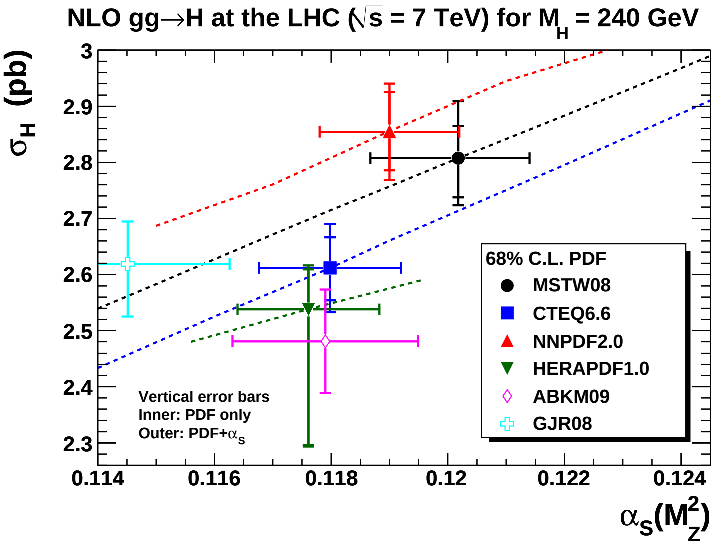
Higgs ($M_H = 120$ GeV) total cross section vs. $\alpha_S(M_Z^2)$



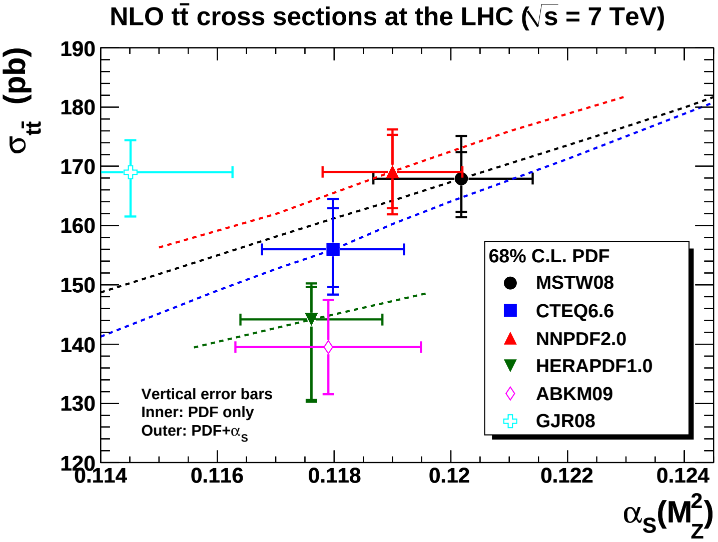
Higgs ($M_H = 180$ GeV) total cross section vs. $\alpha_S(M_Z^2)$



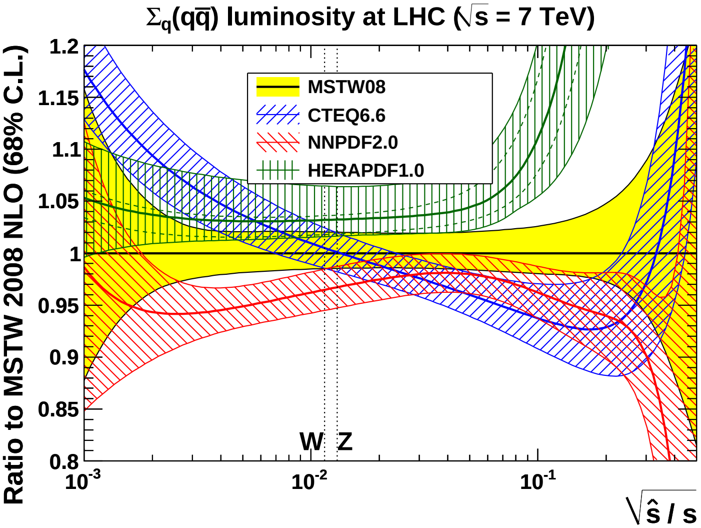
Higgs ($M_H = 240$ GeV) total cross section vs. $\alpha_S(M_Z^2)$



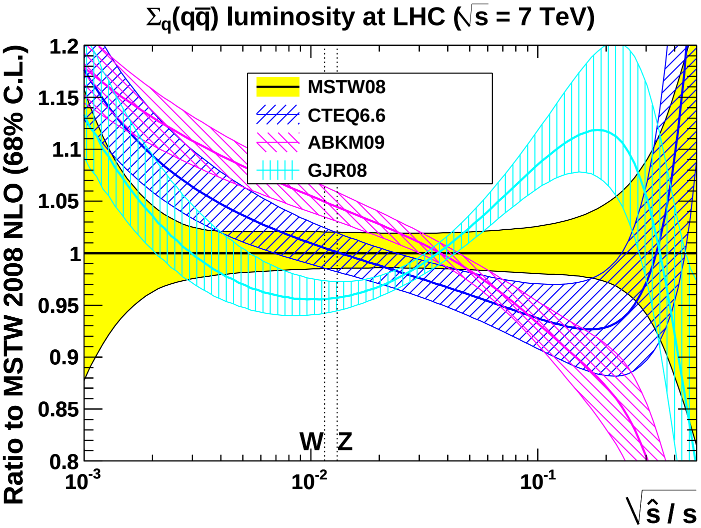
$t\bar{t}$ total cross section vs. $\alpha_S(M_Z^2)$



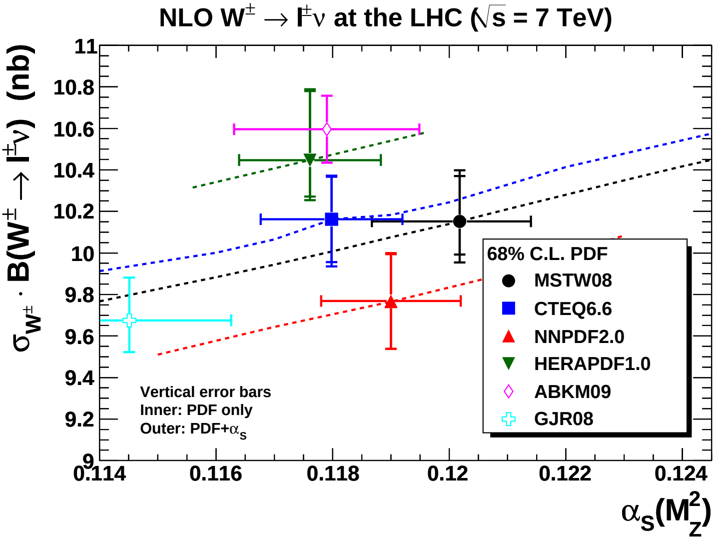
Ratio of quark–antiquark luminosity functions (1)



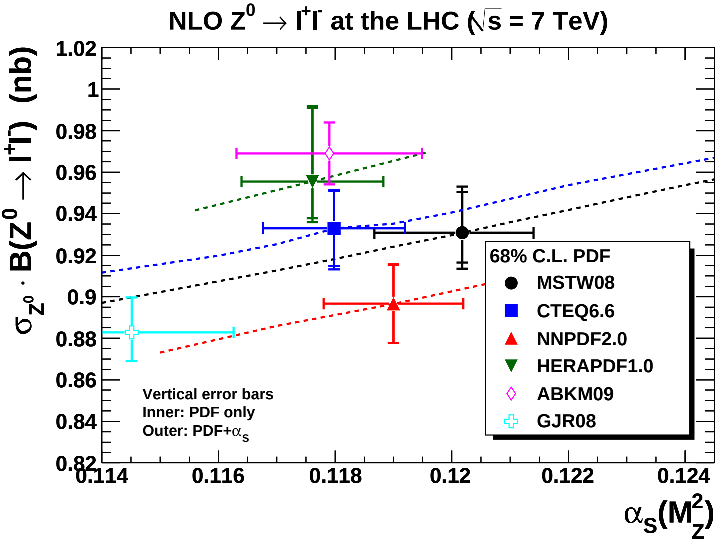
Ratio of quark–antiquark luminosity functions (2)



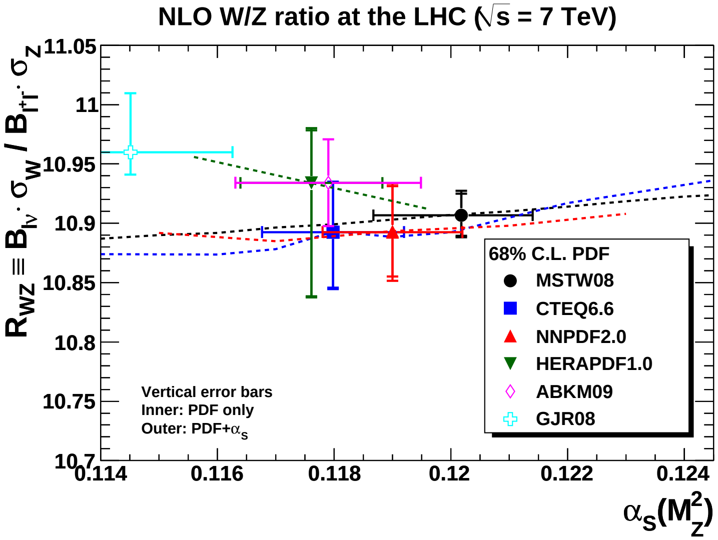
$W \equiv W^+ + W^-$ total cross section vs. $\alpha_S(M_Z^2)$



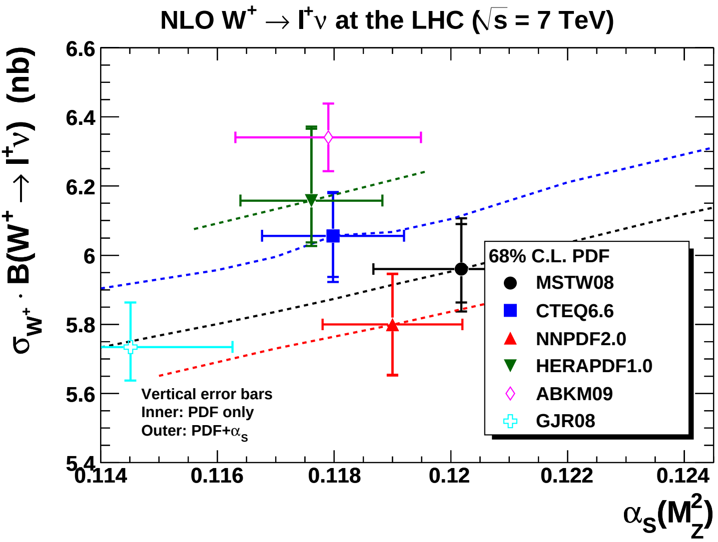
Z^0 total cross section vs. $\alpha_S(M_Z^2)$



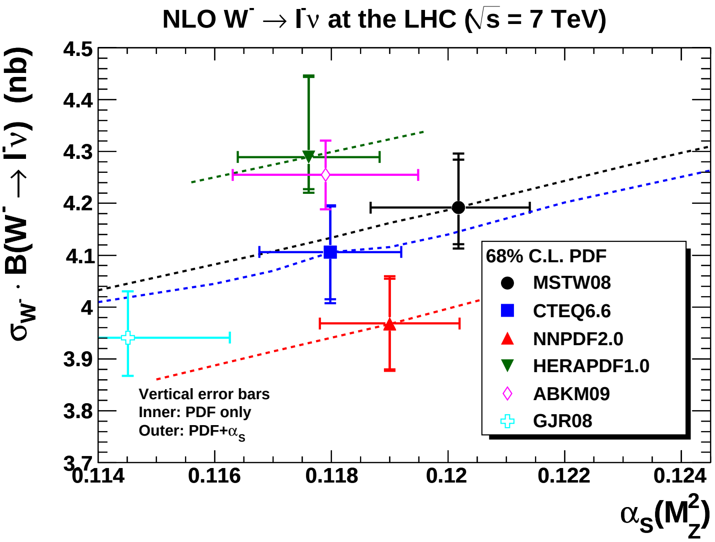
Ratio of W to Z total cross sections vs. $\alpha_S(M_Z^2)$



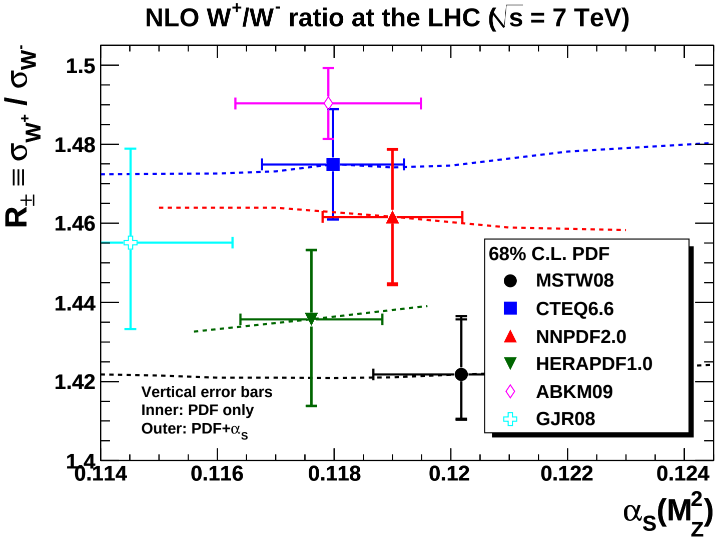
W^+ total cross section vs. $\alpha_S(M_Z^2)$



W^- total cross section vs. $\alpha_S(M_Z^2)$



Ratio of W^+ to W^- total cross sections vs. $\alpha_S(M_Z^2)$



Summary

- Presented results on total cross sections versus $\alpha_S(M_Z^2)$ for LHC ($\sqrt{s} = 7$ TeV) benchmark processes: $W^\pm$, Z^0, $t\bar{t}$, $gg \to H$ ($M_H = 120, 180, 240$ GeV), with 68% confidence-level "PDF only" and "PDF+α_S" uncertainties.
- Same plots (and more) also at 90% C.L. available from: `http://projects.hepforge.org/mstwpdf/pdf4lhc/` Webpage will be updated as more results become available.
- Comparing predictions at the **same** $\alpha_S(M_Z^2)$ value allows a fairer comparison, but sizeable differences between PDF groups.
- Looking at parton luminosities can often give a more global picture of PDF differences compared to total cross sections.