Update of benchmark cross section study and response to Tevatron Higgs criticism

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CERN PH-TH

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Outline of talk

Background and motivation for benchmark exercise

- January 2010: LHC Higgs Working Group formed and requested recommendation from **PDF4LHC Working Group** on PDFs and α_S values (and their uncertainties).
- Use most recent public **NLO PDFs** from all fitting groups to calculate LHC benchmark processes: $W^{\pm}$, Z^0, $t\bar{t}$, $gg \to H$.
  Aims:
  - Establish degree of compatibility and identify outliers.
  - Compare cross sections at **same** α_S values.
  - To what extent are differences in predictions due to different α_S values used by each group, rather than differences in PDFs?
- Results initially presented in talk by **G.W.** at PDF4LHC meeting at CERN on 26th March 2010 and formed basis for subsequent PDF4LHC *Interim Report* [arXiv:1101.0536] and PDF4LHC *Interim Recommendations* [arXiv:1101.0538] used in the *Handbook of LHC Higgs Cross Sections* [arXiv:1101.0593].

Motivation for updating PDF4LHC benchmark exercise

- Original exercise (at **NLO**) completed by **G.W.** in March 2010.
- $\sqrt{s} = 7$ TeV still relevant for LHC running in 2011.
- **New NLO PDFs** have appeared in the last year:
  - CTEQ6.6 → CT10 [arXiv:1007.2241]
  - NNPDF2.0 (ZM) → NNPDF2.1 (GM) [arXiv:1101.1300]
  - HERAPDF1.0 → HERAPDF1.5 [H1prelim-10-142, ZEUS-prel-10-018]
- **Comparisons at NNLO**, where W, Z, $gg \to H$ known exactly. (Also [Alekhin, Blümlein, Jimenez–Delgado, Moch, Reya, arXiv:1011.6259].) Public code HATHOR [arXiv:1007.1327] for approx. NNLO $t\bar{t}$.
- Use additional information to discriminate between PDFs:
  - First LHC data on W, Z, $t\bar{t}$ (not yet with full 2010 statistics).
  - $W \to \ell\nu$ charge asymmetry (ATLAS, CMS, LHCb).
  - Constraints from Tevatron jet data on high-x gluon (and α_S).

Status of proton PDFs from different groups in March 2010

- Consider only *public* sets, where "public" ≡ available in LHAPDF.
- 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" ≡ includes all five main categories of data.
- *Three* groups with **NLO** global fits, but only *one* at **NNLO**.
- GJR08 *almost* global but restrictive "dynamical" parameterisation.
- CTEQ6.6 only uses Tevatron Run I data, not Run II.
- NNPDF2.0 inadequate through use of ZM-VFNS for DIS.

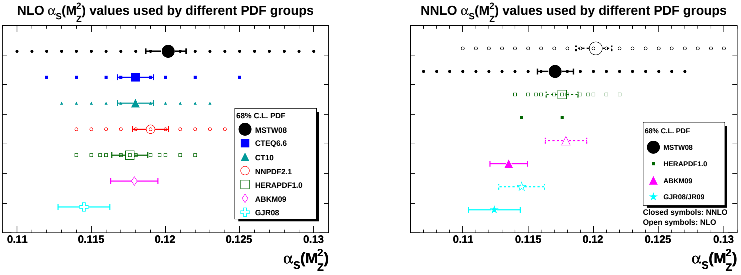
Status of proton PDFs from different groups in March 2011

- Now LHAPDF V5.8.5 (released 2nd February 2011).

	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.
- Only CT10, NNPDF2.1 and HERAPDF use *combined* HERA I.
- Only HERAPDF1.5 uses preliminary *combined* HERA II data.
- HERAPDF1.0 now provided at NNLO (without uncertainties).
- NNPDF2.0 (ZM-VFNS) $\rightarrow$ NNPDF2.1 (GM-VFNS), now allowing meaningful comparison to other NLO global fits.
- NNPDF2.5 NNLO (prel.) not considered here ($\rightarrow$ J. Rojo).

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



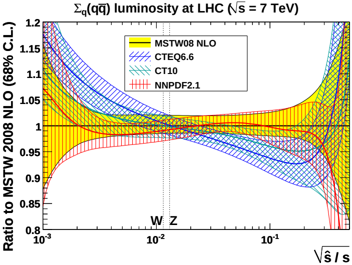
- $\alpha_S(M_Z^2)$ for MSTW08, ABKM09 and GJR08/JR09 fitted.
- $\alpha_S(M_Z^2)$ for other groups applied as an external constraint.
- Smaller symbols indicate alternative $\alpha_S(M_Z^2)$ values provided.
- Fitted NLO $\alpha_S(M_Z^2)$ always larger than NNLO $\alpha_S(M_Z^2)$: attempt to mimic missing higher-order corrections.

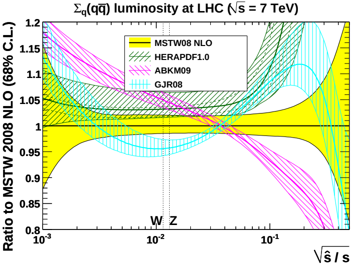
Settings for NLO and NNLO benchmark cross sections

- Aim to isolate PDF (and α_S) dependence.
  $\Rightarrow$ Use **same** code for all PDF sets with common settings.
- "PDF+α_S" uncertainties (at 68% and 90% C.L.) computed using recommended prescription of each fitting group.
- No attempt made to evaluate other theoretical uncertainties. Single scale choice, $\mu_R = \mu_F = M_W, M_Z, M_H, m_t$.
- Treatment of heavy quarks in 5-flavour ZM-VFNS.
- Only present *total* cross sections, not differential distributions.
- On-shell W and Z production times leptonic branching ratios.
- $t\bar{t}$ production (without decay) with $m_t = 171.3$ GeV.
  HATHOR [arXiv:1007.1327] for approximate NNLO calculation.
- $gg \to H$ (no decay) via t-quark loop (m_t dependence at LO).
  NNLO from GGH@NNLO [Harlander, Kilgore, hep-ph/0201206].

Ratio of NLO quark–antiquark luminosity functions

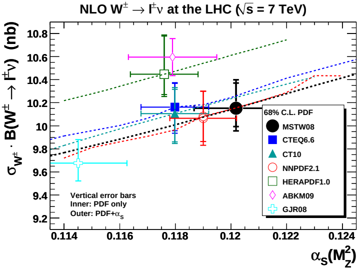
$$\frac{\partial \mathcal{L}_{\Sigma_q(q\bar{q})}}{\partial \hat{s}} = \frac{1}{s}\int_\tau^1 \frac{\mathrm{d}x}{x} \sum_{q=d,u,s,c,b} \left[f_q(x,\hat{s})f_{\bar{q}}(\tau/x,\hat{s}) + (q \leftrightarrow \bar{q})\right], \quad \tau \equiv \frac{\hat{s}}{s}$$

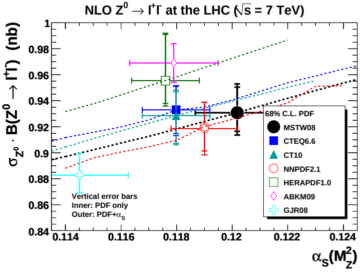




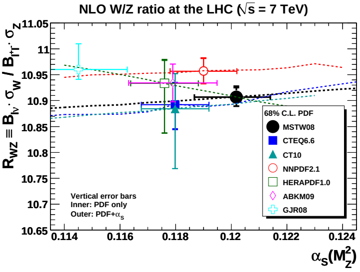
- Relevant values of $\sqrt{\hat{s}} = M_{W,Z}$ are indicated: good agreement for global fits (left), but more variation for other sets (right).

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



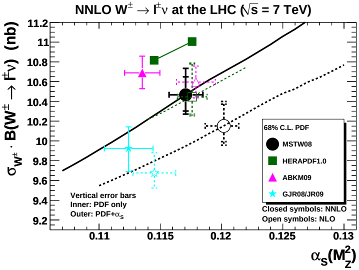


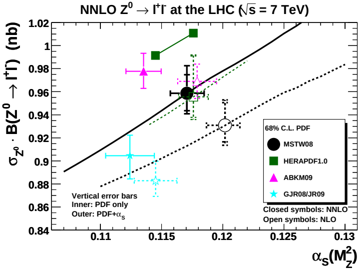
- Global fits in good agreement for $\sigma_{W^\pm}$ and σ_{Z^0} (left plots).
- Small uncertainties in predictions for W/Z ratio:



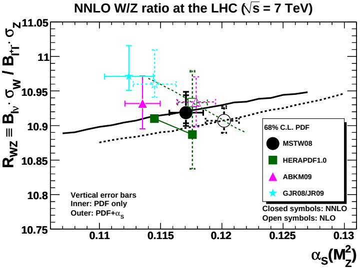
- Agrees with existing data from ATLAS [arXiv:1010.2130] and CMS [arXiv:1012.2466].

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



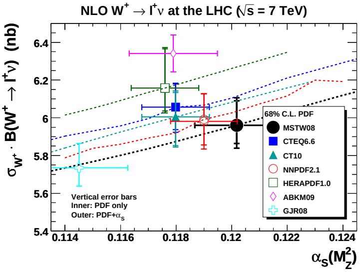


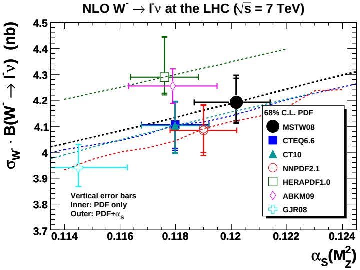
- NNLO corrections reduced by taking different $\alpha_S(M_Z^2)$ values at different orders.
- W/Z ratio insensitive to NNLO corrections (and α_S):



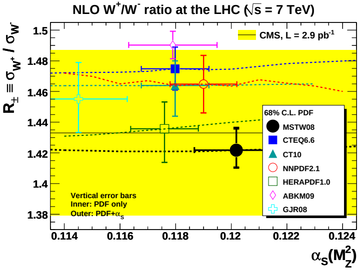
- Absolute LHC cross-section measurements limited by 11% luminosity uncertainty.

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



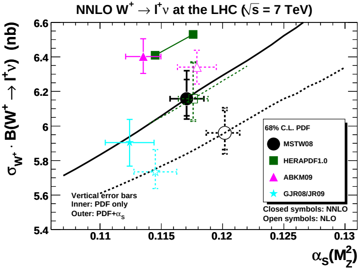


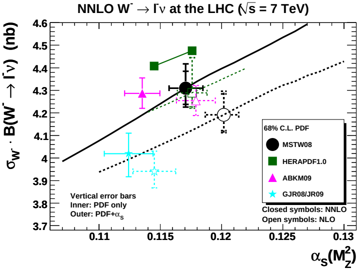
- Slightly more spread in separate σ_{W^+} and σ_{W^-}.
- Reflected in W^+/W^- ratio (sensitive to u/d ratio):



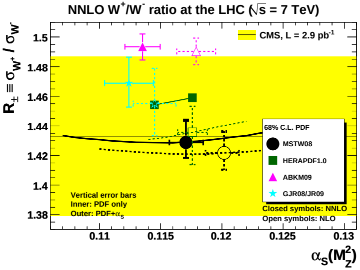
- Yellow band on plot is CMS measurement [arXiv:1012.2466].

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



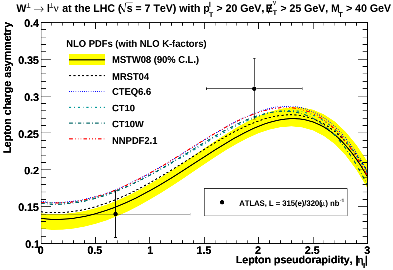


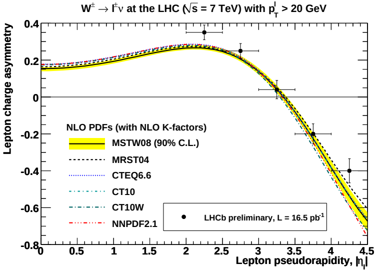
- W^+/W^- ratio insensitive to NNLO corrections (and α_S):

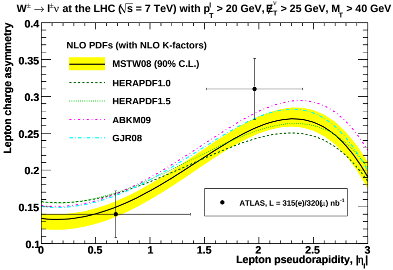


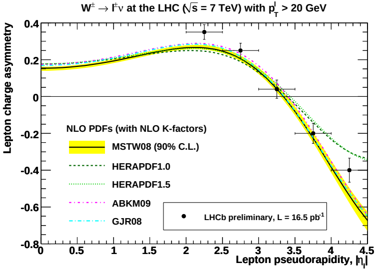
- Yellow band on plot is CMS measurement [arXiv:1012.2466].

$W^{\pm} \to \ell^{\pm}\nu$ charge asymmetry from ATLAS and LHCb





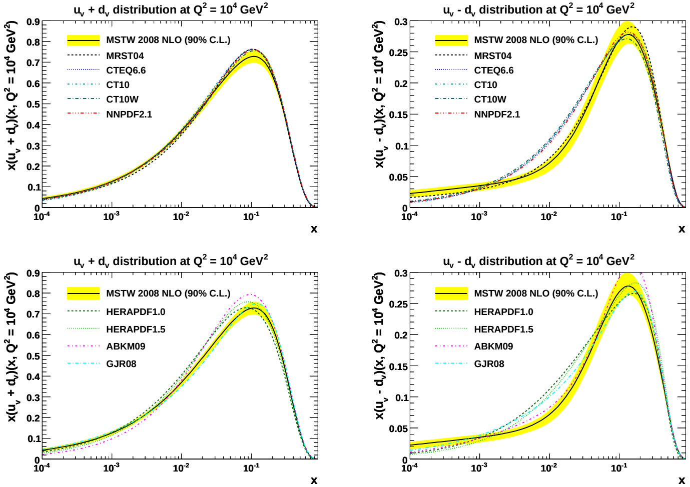




Data: ATLAS [arXiv:1010.2130]

Data: LHCb preliminary

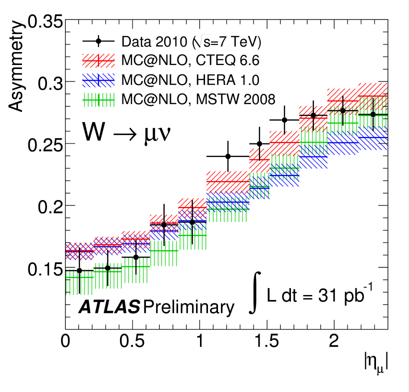
Comparison of $u_v \pm d_v$ for different NLO PDFs



- **MSTW08** has input $xu_v \propto x^{0.29\pm0.02}$ and $xd_v \propto x^{0.97\pm0.11}$.
  Many other groups **assume** equal powers $\Rightarrow$ parameterisation bias.
  (NNPDF: restricted range of small-x preprocessing exponents.)

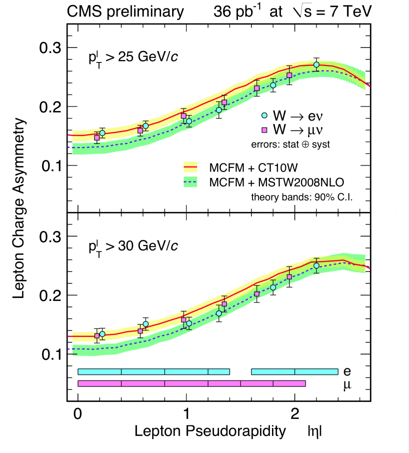
Latest results on charge asymmetry from ATLAS and CMS

ATLAS preliminary (31 pb^{-1})



[Plots from talks at "La Thuile 2011"]

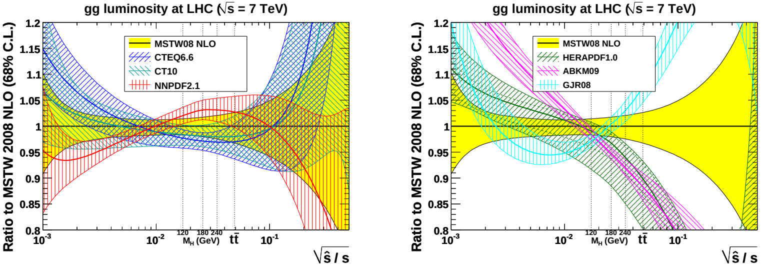
CMS preliminary (36 pb^{-1})



- Results with full 2010 data are starting to discriminate.
- $\Rightarrow$ Important input to next generation of global fits.

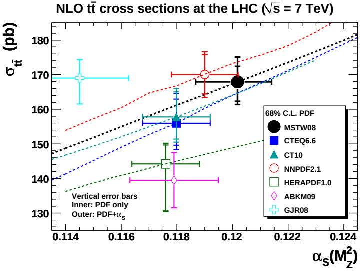
Ratio of NLO gluon–gluon luminosity functions

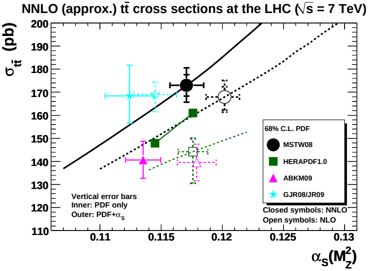
$$\frac{\partial \mathcal{L}_{gg}}{\partial \hat{s}} = \frac{1}{s}\int_\tau^1 \frac{\mathrm{d}x}{x}\, f_g(x,\hat{s}) f_g(\tau/x,\hat{s}), \qquad \tau \equiv \frac{\hat{s}}{s}$$



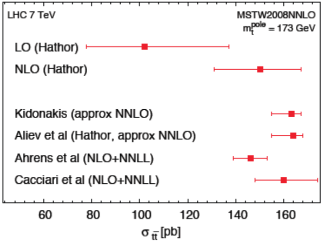
- Relevant values of $\sqrt{\hat{s}} = M_H, 2m_t$ are indicated: reasonable agreement for global fits (left), but more variation for other PDF sets (right), particularly at large $\sqrt{\hat{s}/s}$.

$t\bar{t}$ total cross section versus $\alpha_S(M_Z^2)$ for LHC at 7 TeV



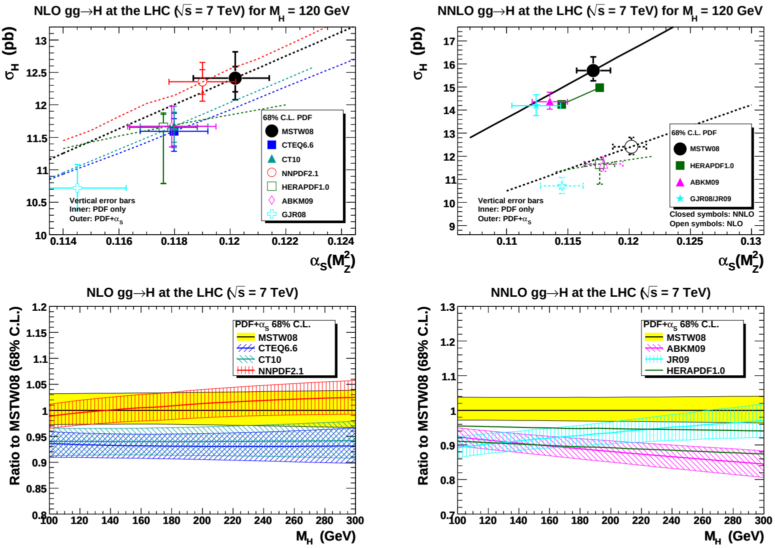


- More than 80% of NLO $t\bar{t}$ cross section from *gg* channel.
- Default settings for NNLO (approx.) calculation with HATHOR code [Aliev *et al.*, arXiv:1007.1327].
- NNLO (approx.) corrections seem small, but many "NNLO" choices.



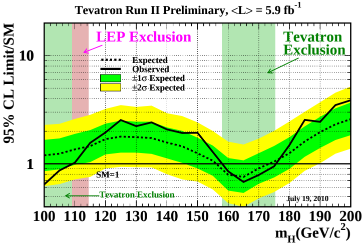
[Plot by G. Salam, ICHEP 2010]

$gg \to H$ total cross section versus $\alpha_S(M_Z^2)$ and M_H

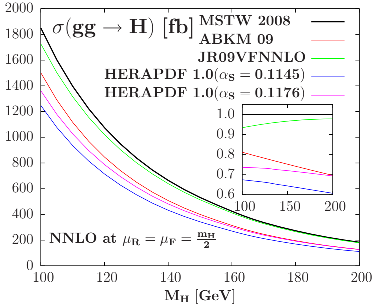


PDF (and α_S) dependence of Tevatron Higgs bounds

- Tevatron exclusion of SM Higgs boson at 95% C.L. for $158 < M_H < 175$ GeV.
- Theory prediction used only MSTW 2008 NNLO PDFs (with 90% C.L. PDF+α_S).



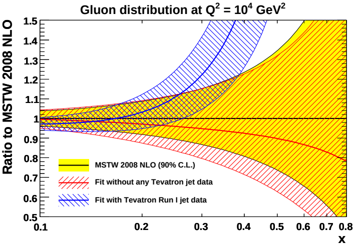
[TEVNPH WG, arXiv:1007.4587]

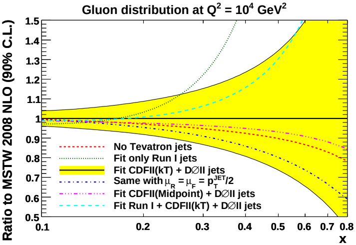


- Baglio, Djouadi, Ferrag, Godbole [arXiv:1101.1832]: other PDFs can lower Higgs cross section by up to 40%, requiring more than twice as much Tevatron data to recover the same sensitivity. Potentially very worrying!

Tevatron jet data as a constraint on the high-x gluon

- $gg \to H$ at Tevatron sensitive to high-x gluon distribution.
- Main data constraint from Tevatron inclusive jet production: **only** included in MSTW NNLO fits, **not** by other groups.
- **Problem:** NNLO $\hat{\sigma}$ unknown, approximate with NLO $\hat{\sigma}$ and 2-loop threshold corrections [Kidonakis, Owens, hep-ph/0007268].
- Jet cross sections calculated with FASTNLO [Kluge, Rabbertz, Wobisch, hep-ph/0609285]: includes 2-loop threshold corrections.
- Take different scale choices $\mu_R = \mu_F = \mu = \{p_T/2, p_T, 2p_T\}$ as some indication of the theoretical uncertainty.





Treatment of correlated systematic uncertainties

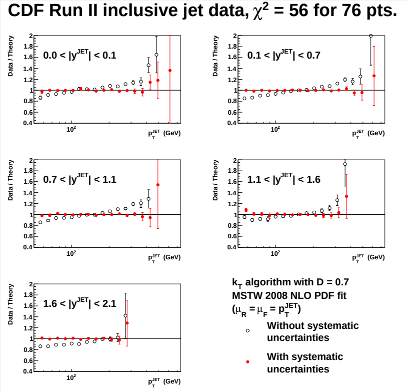
- **Goal:** compare description of Tevatron jet data in similar manner to PDF4LHC benchmark cross section study, i.e. use *same* code and settings for all PDF sets (with corresponding α_S).
- Important to account for *correlated* systematic uncertainties of experimental data points [CTEQ6, hep-ph/0201195]:

$$\chi^2 = \sum_{i=1}^{N_{\rm pts.}} \left(\frac{\hat{D}_i - T_i}{\sigma_i^{\rm uncorr.}} \right)^2 + \sum_{k=1}^{N_{\rm corr.}} r_k^2, \quad \text{where } \hat{D}_i \equiv D_i - \sum_{k=1}^{N_{\rm corr.}} r_k\, \sigma_{k,i}^{\rm corr.}.$$

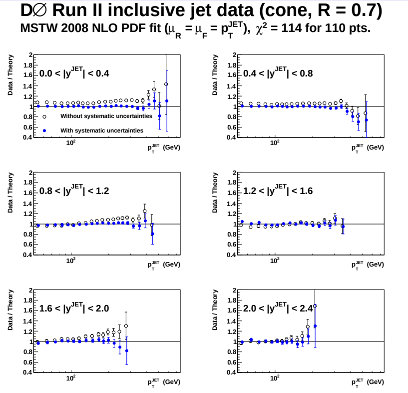
- Trade-off between systematic shifts r_k and gluon parameters.
- Restrict shift in luminosity uncertainty, $r_{k,\rm lumi.} \in [-1,+1]$. Otherwise find $r_{k,\rm lumi.} \sim$ 3–5 for some PDF sets with soft high-x gluon distributions (e.g. ABKM and HERAPDF).
- In MSTW08 global fit, CDF luminosity is determined by $\mathrm{d}\sigma_Z/\mathrm{d}y$.

Systematic shifts for Tevatron jet data in MSTW08 fit

CDF Run II (k_T) [hep-ex/0701051]



DØ Run II [arXiv:0802.2400]



- Error bars are only statistical uncertainties. Closed (open) points indicate data with (without) systematic shifts $|r_k| \lesssim 1$.

Description of CDF II inclusive jet (k_T) data [hep-ex/0701051]

- Values of $\chi^2/N_{\rm pts.}$ with (without) accounting for correlations:

NLO PDF (with NLO $\hat{\sigma}$)	$\mu = p_T/2$	$\mu = p_T$	$\mu = 2p_T$
MSTW08	0.75 (0.30)	**0.68** (0.28)	0.91 (0.84)
CTEQ6.6	1.25 (0.14)	1.66 (0.20)	2.38 (0.84)
CT10	1.03 (0.13)	1.20 (0.19)	1.81 (0.84)
NNPDF2.1	0.74 (0.29)	0.82 (0.25)	1.23 (0.69)
HERAPDF1.0 ($\alpha_S = 0.1176$)	2.43 (0.39)	3.26 (0.66)	4.03 (1.67)
ABKM09	1.62 (0.52)	2.21 (0.85)	3.26 (2.10)
GJR08	1.36 (0.23)	0.94 (0.13)	0.79 (0.36)

NNLO PDF (with NLO+2-loop $\hat{\sigma}$)	$\mu = p_T/2$	$\mu = p_T$	$\mu = 2p_T$
MSTW08	1.39 (0.42)	**0.69** (0.44)	0.97 (0.48)
HERAPDF1.0 ($\alpha_S = 0.1145$)	2.64 (0.36)	2.15 (0.36)	2.20 (0.46)
HERAPDF1.0 ($\alpha_S = 0.1176$)	2.24 (0.35)	1.17 (0.32)	1.23 (0.31)
ABKM09	2.55 (0.82)	2.76 (0.89)	3.41 (1.17)
JR09	0.75 (0.37)	1.26 (0.41)	2.21 (0.49)

- $N_{\rm pts.} = 76$, $N_{\rm corr.} = 17$. 90% C.L. region for **MSTW08** ($\mu = p_T$) given by $\chi^2/N_{\rm pts.} < 0.83$ (NLO) or $\chi^2/N_{\rm pts.} < 0.85$ (NNLO).

Description of DØ II inclusive jet (cone) data [arXiv:0802.2400]

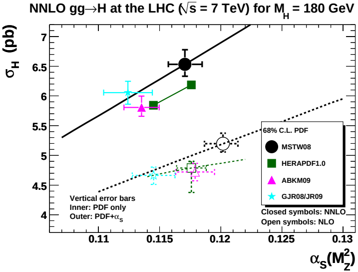
- Values of $\chi^2/N_{\rm pts.}$ with (without) accounting for correlations:

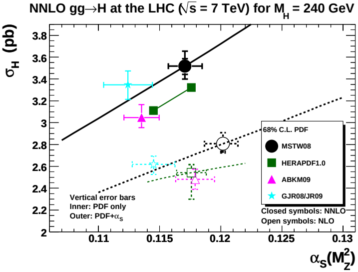
NLO PDF (with NLO $\hat{\sigma}$)	$\mu = p_T/2$	$\mu = p_T$	$\mu = 2p_T$
MSTW08	1.45 (0.89)	**1.08** (0.20)	1.05 (1.22)
CTEQ6.6	1.62 (1.15)	1.56 (0.59)	1.61 (1.35)
CT10	1.39 (0.88)	1.26 (0.37)	1.32 (1.29)
NNPDF2.1	1.41 (0.87)	1.29 (0.20)	1.22 (0.96)
HERAPDF1.0 ($\alpha_S = 0.1145$)	1.73 (0.27)	1.84 (0.74)	1.83 (2.79)
ABKM09	1.39 (0.35)	1.43 (1.07)	1.63 (3.66)
GJR08	1.90 (1.46)	1.34 (0.45)	1.03 (0.51)

NNLO PDF (with NLO+2-loop $\hat{\sigma}$)	$\mu = p_T/2$	$\mu = p_T$	$\mu = 2p_T$
MSTW08	1.95 (0.90)	**1.23** (0.44)	1.08 (0.35)
HERAPDF1.0 ($\alpha_S = 0.1145$)	2.11 (0.37)	1.68 (0.35)	1.41 (0.63)
HERAPDF1.0 ($\alpha_S = 0.1176$)	2.28 (0.95)	1.50 (0.40)	1.17 (0.21)
ABKM09	1.68 (0.79)	1.55 (1.21)	1.63 (2.04)
JR09	1.84 (0.47)	1.61 (0.36)	1.58 (0.50)

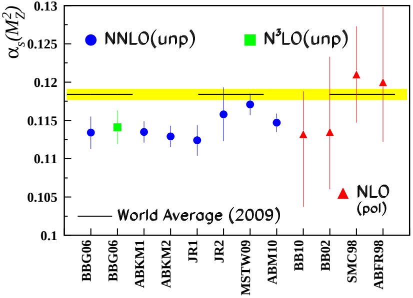
- $N_{\rm pts.} = 110$, $N_{\rm corr.} = 23$. 90% C.L. region for **MSTW08** ($\mu = p_T$) given by $\chi^2/N_{\rm pts.} < 1.28$ (NLO) or $\chi^2/N_{\rm pts.} < 1.46$ (NNLO).

What is the best choice of $\alpha_S(M_Z^2)$ and its uncertainty?





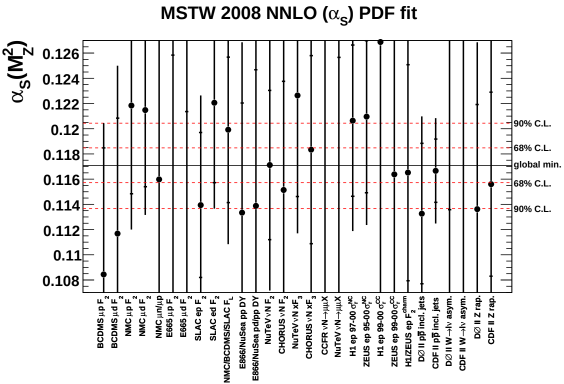
- Part of **MSTW**/ABKM discrepancy for Higgs cross sections due to taking very different values of $\alpha_S(M_Z^2)$.
- Common lore that DIS-only fits prefer **low** $\alpha_S(M_Z^2)$ values:



[Blümlein, Böttcher, arXiv:1005.3113]

Common lore that DIS-only fits prefer low α_S. Is it true?

ABKM09: $\alpha_S(M_Z^2) = 0.1135 \pm 0.0014$, cf. **MSTW08:** 0.1171 ± 0.0014.

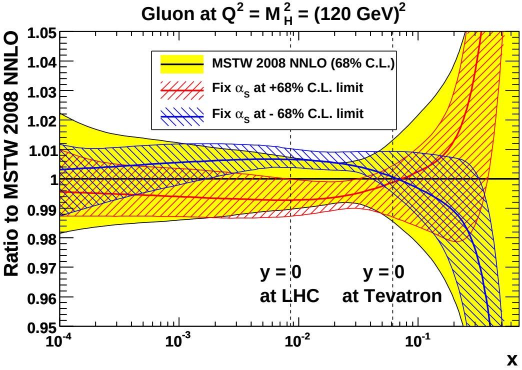


[MSTW, arXiv:0905.3531]

- **Answer:** Not all DIS data sets prefer low $\alpha_S(M_Z^2)$ values.
- True only for BCDMS, and for E665 and SLAC *ep* data.
- NMC, SLAC *ed* and HERA data prefer high $\alpha_S(M_Z^2)$ values.

Correlation between α_S and gluon distribution

- Known that α_S is **anticorrelated** with low-x gluon through scaling violations of HERA data: $\partial F_2/\partial \ln(Q^2) \sim \alpha_S\, g$. Then α_S is **correlated** with high-x gluon through *momentum sum rule*.



- **MSTW08:** $\alpha_S(M_Z^2) = 0.1171 \pm 0.0014$ [arXiv:0905.3531].
- Positive input gluon: $\alpha_S(M_Z^2) = 0.1157$, but $\Delta\chi^2_{\rm global} = 80$.

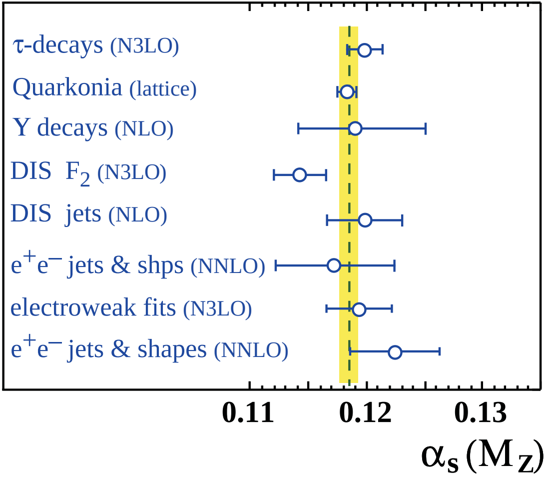
What is α_S from only DIS in the MSTW08 NNLO fit?

[Studies prompted by question from G. Altarelli, December 2010]

- Global fit: $\alpha_S(M_Z^2) = 0.1171 \pm 0.0014$ [arXiv:0905.3531].
- DIS-only fit gives $\alpha_S(M_Z^2) = 0.1104$ (BCDMS-dominated)[1], but input $xg < 0$ for $x > 0.4$ due to lack of data constraint. $\Rightarrow F_2^{\rm charm} < 0$ and $\chi^2/N_{\rm pts.} \sim 10$ for Tevatron jets.
- DIS-only fit fixing high-x gluon parameters gives $\alpha_S(M_Z^2) = 0.1172$.
- DIS-only fit without BCDMS gives $\alpha_S(M_Z^2) = 0.1193$.
- Global fit without BCDMS gives $\alpha_S(M_Z^2) = 0.1181$.
- **Conclusion:** Tevatron jet data vital to pin down high-x gluon, giving smaller low-x gluon and therefore larger α_S in the global fit compared to a DIS-only fit, at the expense of some deterioration in the fit quality of the BCDMS data.

[1] Some analyses cut $y > 0.3$ on BCDMS data to reduce energy scale uncertainty of scattered muon: increases $\alpha_S(M_Z^2)$ by 0.004 in BCDMS-only fit.

Input values to world average $\alpha_S(M_Z^2)$ [Bethke, arXiv:0908.1135]



- DIS F_2 from BBG06 [Blümlein, Böttcher, Guffanti, hep-ph/0607200].
- Non-singlet analysis: free of assumptions on gluon (in principle).

Non-singlet QCD analysis of DIS data [BBG06, hep-ph/0607200]

Order	$\alpha_S(M_Z^2)$ (expt.)
NLO	$0.1148^{+0.0019}_{-0.0019}$
NNLO	$0.1134^{+0.0019}_{-0.0021}$
NNNLO	$0.1141^{+0.0020}_{-0.0022}$

- Fit F_2^p and F_2^d for $x > 0.3$ (neglect singlet contribution), and $F_2^{\rm NS}$.
- But singlet makes up about 10% (2%) of F_2^p at $x = 0.3$ ($x = 0.5$).

- **Exercise:** perform MSTW08 NNLO DIS-only fit to F_2^p and F_2^d for $x > 0.3$ (282 points, 160 from BCDMS). $\Rightarrow$ $\alpha_S(M_Z^2) = 0.1103\ (0.1130)$ without (with) singlet included. (Lower than BBG06 due to lack of $y > 0.3$ cut on BCDMS.)
- **Conclusion:** low value of $\alpha_S(M_Z^2)$ found by BBG06 due to (i) dominance of BCDMS data and (ii) neglect of singlet.
- Closest possible to reliable extraction of $\alpha_S(M_Z^2)$ from DIS is MSTW08 NNLO combined analysis of DIS, DY and jet data:

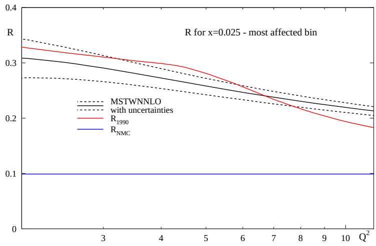
$$\alpha_S(M_Z^2) = 0.1171 \quad \pm 0.0014\ (68\%\ \text{C.L.}) \quad \pm 0.0034\ (90\%\ \text{C.L.})$$

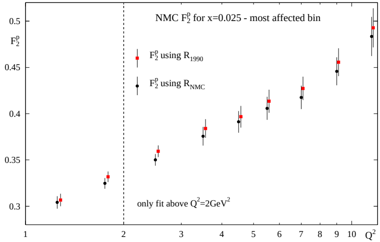
Treatment of F_L correction for NMC data [Studies by R. Thorne]

- Recent claim that bulk of **MSTW**/ABKM difference explained by F_L for NMC data [Alekhin, Blümlein, Moch, arXiv:1101.5261].
- ABKM fit NMC cross sections, **MSTW** fit NMC F_2 corrected for $R = \sigma_L/\sigma_T \simeq F_L/(F_2 - F_L)$, where [NMC, hep-ph/9610231]:

$$R(x, Q^2) = \begin{cases} R_{\mathrm{NMC}}(x) & \text{if } x < 0.12 \\ R_{1990}(x, Q^2) & \text{if } x > 0.12 \end{cases}.$$

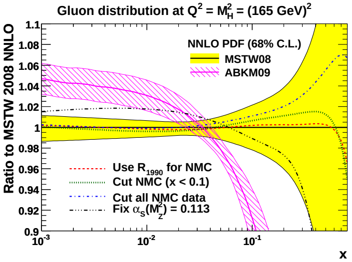
- Alternative NMC F_2 data using $R = R_{1990}$ $(\forall x)$ close to R_{MSTW}.





Effect of NMC F_L treatment on Higgs cross sections

NNLO PDF	$\alpha_S(M_Z^2)$	σ_H at Tevatron	σ_H at 7 TeV LHC
MSTW08	**0.1171**	**0.342 pb**	**7.91 pb**
Use R_{1990} for NMC	0.1167	−0.7%	−0.9%
Cut NMC ($x < 0.1$)	0.1162	−1.2%	−2.1%
Cut all NMC data	0.1158	−0.7%	−2.1%
Fix $\alpha_S(M_Z^2)$	0.1130	−11%	−7.6%
ABKM09	0.1135	−26%	−11%



- Higgs cross section insensitive to treatment of NMC F_L.
- Similar stability found by NNPDF [arXiv:1102.3182] (but at NLO with fixed α_S).
- Gluon and σ_H still far from ABKM with $\alpha_S(M_Z^2) = 0.113$.

- Greater sensitivity found by ABM [arXiv:1101.5261] perhaps due to inclusion of higher-twist and/or lack of Tevatron jets.

PDF4LHC WG Interim Recommendations [arXiv:1101.0538]

Steering Committee: Botje, Butterworth, Cooper-Sarkar, De Roeck, Feltesse, Forte, Glazov, Huston, McNulty, Sjöstrand, Thorne.

NLO prescription (68% C.L. uncertainties)

- "*For the calculation of uncertainties at the LHC, use the envelope provided by the central values and PDF+α_S errors from the* **MSTW08**, *CTEQ6.6 and NNPDF2.0 PDFs.*"
- "*As a central value, use the midpoint of this envelope.*"

NNLO prescription (68% C.L. uncertainties)

- "*As a central value, use the* **MSTW08** *prediction.*"
- Rescale the **MSTW08** NNLO uncertainty by "*the factor obtained by dividing the full uncertainty obtained from the envelope of* **MSTW**, *CTEQ and NNPDF results at NLO by the* **MSTW** *uncertainty at NLO*" (~ 2 for $gg \to H$ at LHC).

Some (personal) comments on existing recommendation

Current PDF4LHC recommendation described in three words:

Complicated : impractical for all but the simplest observables.

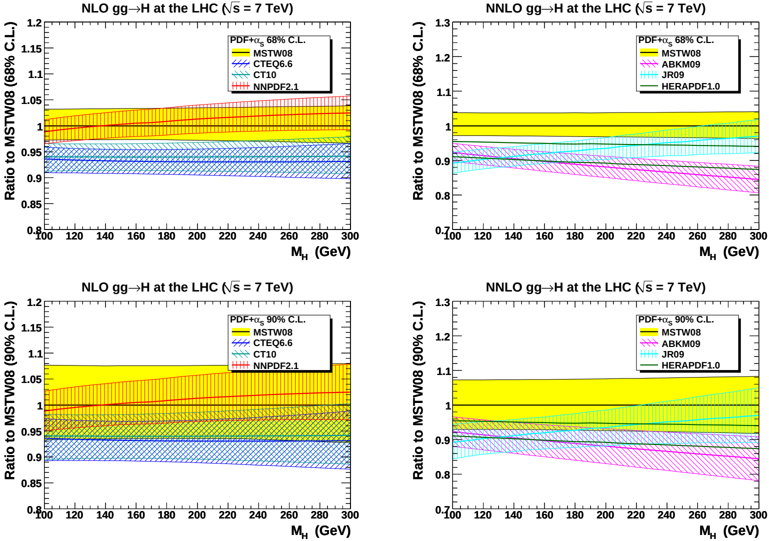
Arbitrary : more political than statistical (use of 3 groups).

Obsolete : CTEQ6.6 → CT10 and NNPDF2.0 → NNPDF2.1.

Do we need an official PDF4LHC recommendation at all?

- Importance of PDF uncertainties is process-dependent: overkill to use a complicated prescription universally.
- If **large** differences between groups: they should be understood. Show results with multiple predictions.
- If **small** differences between groups: envelope method will be similar to PDF uncertainty of any one group, so redundant.
- Frequent PDF releases, so recommendations soon outdated.

Suggestion for a better recommendation: use 90% C.L.

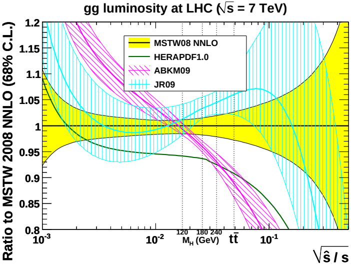


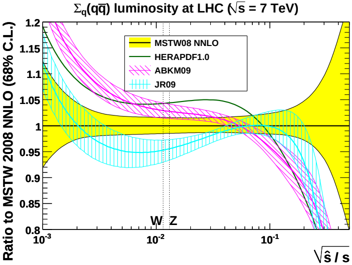
- "*Envelope at 68% C.L.*" similar to **only** MSTW08 90% C.L.

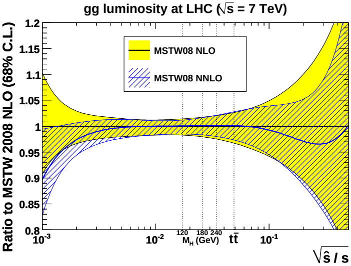
Summary

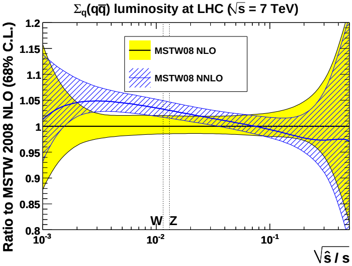
- Now reasonably good agreement between NLO *global* fits from **MSTW08**, CT10 and NNPDF2.1, all using GM-VFNS.
- More variation with other PDF sets, particularly at NNLO where **MSTW08** is the only public *global* PDF fit available.
- W^+/W^- ratio and $W^\pm \to \ell^\pm \nu$ charge asymmetry close to disfavouring some PDF sets: important input to future fits.
- $t\bar{t}$ and $gg \to H$ sensitive to gg luminosity and $\alpha_S(M_Z^2)$, but can use Tevatron jet data to *discriminate*. Fits not including Tevatron jet data should be used with caution (if at all).
- Proposal for a simpler recommendation: use only **MSTW08** with 90% C.L. PDF+α_S uncertainties. (Common prescription at NLO and NNLO; similar results to "*envelope at 68% C.L.*".)
- Tevatron Higgs exclusion analysis [arXiv:1007.4587] with only **MSTW08** at 90% C.L. is **robust** using exactly this prescription.

NNLO parton–parton luminosities



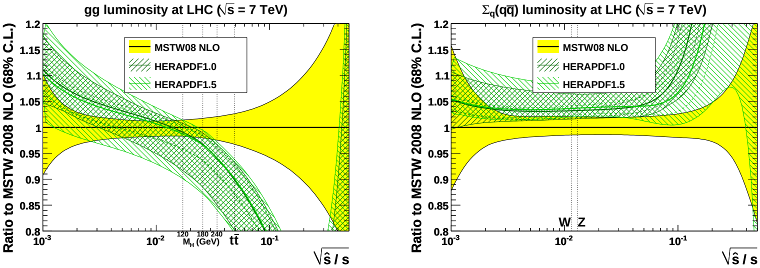






HERAPDF1.0/1.5 compared to MSTW 2008

Ratio of gg and $q\bar{q}$ luminosity functions to MSTW 2008:



- HERAPDF1.5 gg luminosity very similar to HERAPDF1.0.
- HERAPDF1.5 $q\bar{q}$ luminosity slightly closer to MSTW 2008.

Description of CDF II inclusive jet (cone) data [arXiv:0807.2204]

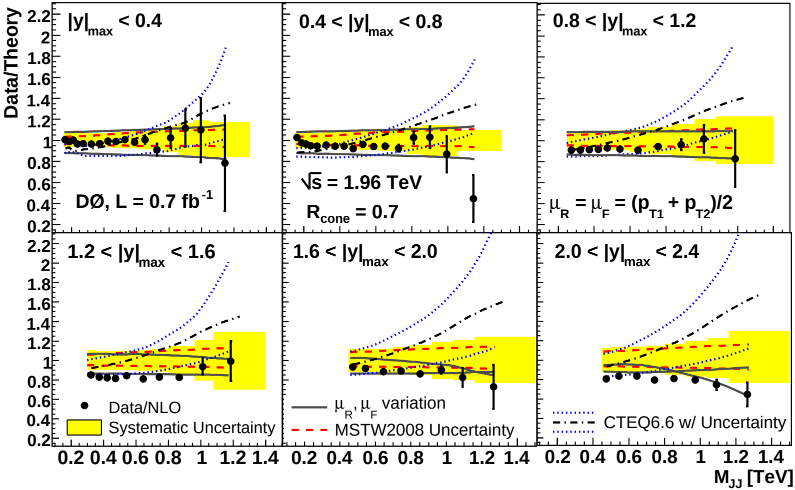
- Values of $\chi^2/N_{\rm pts.}$ with (without) accounting for correlations:

NLO PDF (with NLO $\hat{\sigma}$)	$\mu = p_T/2$	$\mu = p_T$	$\mu = 2p_T$
MSTW08	1.52 (0.61)	**1.40** (0.27)	1.16 (0.73)
CTEQ6.6	1.93 (0.41)	1.98 (0.21)	1.78 (0.78)
CT10	1.75 (0.38)	1.69 (0.19)	1.50 (0.76)
NNPDF2.1	1.69 (0.60)	1.56 (0.25)	1.44 (0.60)
HERAPDF1.0 ($\alpha_S = 0.1176$)	2.61 (0.23)	2.73 (0.49)	2.53 (1.58)
ABKM09	1.56 (0.26)	1.68 (0.65)	1.69 (2.01)
GJR08	2.11 (0.71)	1.75 (0.24)	1.52 (0.31)

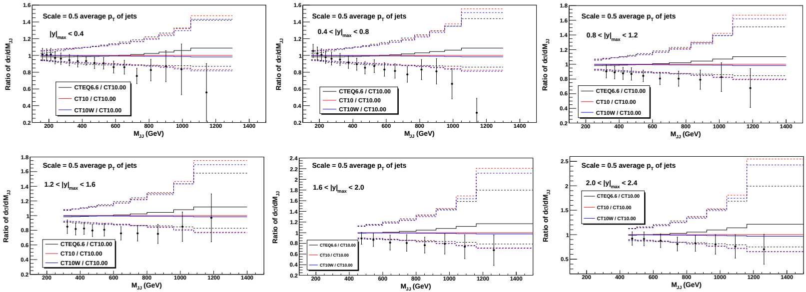
NNLO PDF (with NLO+2-loop $\hat{\sigma}$)	$\mu = p_T/2$	$\mu = p_T$	$\mu = 2p_T$
MSTW08	1.67 (0.62)	**1.39** (0.43)	1.62 (0.37)
HERAPDF1.0 ($\alpha_S = 0.1145$)	2.20 (0.25)	2.06 (0.27)	2.19 (0.40)
HERAPDF1.0 ($\alpha_S = 0.1176$)	2.08 (0.55)	1.76 (0.33)	1.99 (0.23)
ABKM09	1.70 (0.50)	1.94 (0.71)	2.26 (1.12)
JR09	1.57 (0.41)	2.05 (0.36)	2.82 (0.39)

- $N_{\rm pts.} = 72$, $N_{\rm corr.} = 25$. 90% C.L. region for **MSTW08** ($\mu = p_T$) given by $\chi^2/N_{\rm pts.} < 1.73$ (NLO) or $\chi^2/N_{\rm pts.} < 1.71$ (NNLO).

DØ Run II dijet invariant mass spectrum [arXiv:1002.4594]



Description of DØ Run II dijet data by CT10 [arXiv:1007.2241]



- Use *half* average p_T (similar to inclusive jet data in fit).
- Add DØ statistical and total systematic errors in quadrature.
- $\Rightarrow$ Agreement with DØ data within (large) PDF uncertainties.
- But should account for *correlated* systematic uncertainties . . .

Description of DØ II dijet invariant mass data [arXiv:1002.4594]

- Values of $\chi^2/N_{\mathrm{pts.}}$ with (without) accounting for correlations:

NLO PDF (with NLO $\hat{\sigma}$)	$\mu = p_T/2$	$\mu = p_T$	$\mu = 2p_T$
MSTW08	3.15 (1.63)	**2.25** (0.70)	1.56 (0.70)
CTEQ6.6	5.41 (2.22)	4.85 (1.79)	3.36 (1.52)
CT10	4.74 (1.87)	4.06 (1.32)	2.70 (1.21)
NNPDF2.1	2.67 (1.56)	1.93 (0.66)	1.47 (0.55)
HERAPDF1.0 ($\alpha_S = 0.1176$)	2.05 (0.38)	2.21 (0.77)	2.11 (2.28)
ABKM09	1.49 (0.33)	1.41 (0.80)	1.34 (2.78)
GJR08	10.7 (3.92)	7.91 (2.36)	5.30 (0.66)

NNLO PDF (with NLO $\hat{\sigma}$)	$\mu = p_T/2$	$\mu = p_T$	$\mu = 2p_T$
MSTW08	2.38 (0.63)	**1.80** (0.33)	1.31 (1.24)
HERAPDF1.0 ($\alpha_S = 0.1145$)	2.61 (0.48)	2.55 (0.89)	2.40 (2.40)
HERAPDF1.0 ($\alpha_S = 0.1176$)	2.72 (0.83)	2.31 (0.50)	1.96 (1.08)
ABKM09	1.36 (0.98)	1.49 (1.93)	1.57 (4.53)
JR09	3.29 (0.42)	2.55 (0.24)	1.88 (1.26)

- $N_{\mathrm{pts.}} = 71$, $N_{\mathrm{corr.}} = 70$. Scale $\mu \propto p_T \equiv (p_{T1} + p_{T2})/2$ poor. Scale choice $\mu = M_{\mathrm{JJ}} \approx 2p_T \cosh[(y_1 - y_2)/2]$ better?