PDF dependence of W/Z cross sections and lepton charge asymmetry at the LHC

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Working Group on Electroweak precision measurements at the LHC
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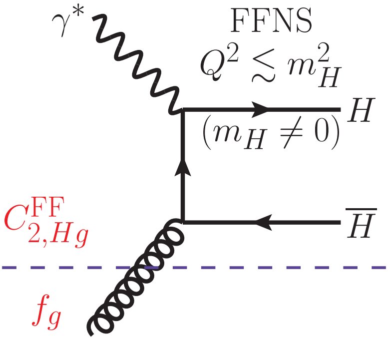
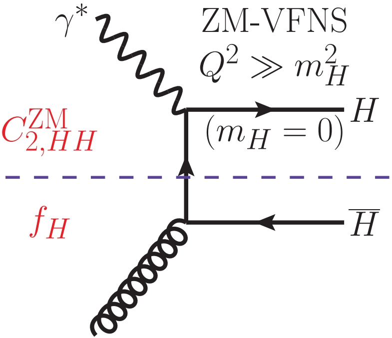
Outline of talk

Heavy quark contribution to DIS structure function F_2



Fixed flavour number scheme



Zero-mass variable flavour number scheme

- $\sigma_{W,Z}$ at LHC sensitive to light quark PDFs at $x \sim 0.01$ determined from HERA $F_2(x, Q^2)$ data with significant $F_2^{\rm charm}$.
- **G**eneral-**m**ass **v**ariable **f**lavour **n**umber **s**cheme (**GM-VFNS**) interpolates between two well-defined regions ($H \equiv c, b$): **FFNS** for $Q^2 \leq m_H^2$, **ZM-VFNS** for $Q^2 \gg m_H^2$.
- Ambiguous up to $\mathcal{O}(m_H^2/Q^2) \Rightarrow$ theory uncertainty on $\sigma_{W,Z}$.

Impact of heavy quarks in DIS on $\sigma_{W,Z}$ at LHC

Impact of GM-VFNS variation [R. Thorne, arXiv:1006.5925]

- Uncertainty $\sim 2\%$ at NLO, but less than 1% at NNLO.

Impact of (pole-mass) $m_{c,b}$ variation [MSTW, arXiv:1007.2624]

- Vary $m_c = 1.40 \pm 0.15$ GeV $\Rightarrow$ just over 1% change in $\sigma_{W,Z}$.
- Vary $m_b = 4.75 \pm 0.25$ GeV $\Rightarrow$ negligible change (0.1%).

LHC, $\sqrt{s} = 7$ TeV	$B_{\ell\nu} \cdot \sigma^W$	$B_{\ell^+\ell^-} \cdot \sigma^Z$
PDF only uncertainty	$^{+1.7\%}_{-1.6\%}$	$^{+1.7\%}_{-1.5\%}$
PDF+α_S uncertainty	$^{+2.5\%}_{-1.9\%}$	$^{+2.5\%}_{-1.9\%}$
PDF+α_S+$m_{c,b}$ uncertainty	$^{+2.7\%}_{-2.2\%}$	$^{+2.9\%}_{-2.4\%}$

- Combined HERA I data: upwards shift in $\sigma_{W,Z}$ by 1–2% [MSTW, arXiv:1006.2753]. HERA II and F_2^{charm} data to come.
- Future theoretical improvements: "optimal" GM-VFNS [R. Thorne, arXiv:1006.5925], possible use of $\overline{\mathrm{MS}}$ mass.

Current status of proton PDFs from different groups

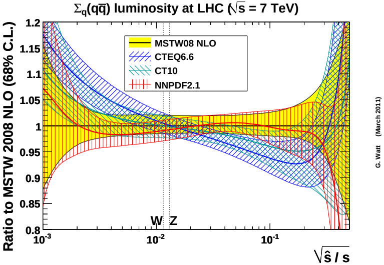
- Consider only *public* sets, where "public" $\equiv$ available in LHAPDF.
- Highlight major differences in data and theory between groups:

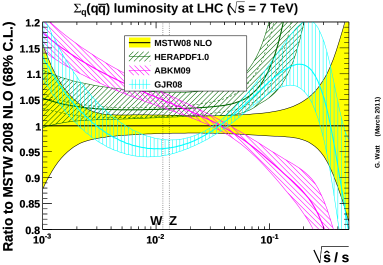
	MSTW08	**CTEQ6.6/CT10**	**NNPDF2.1**	HERAPDF1.0/1.5	ABKM09	GJR08/JR09
HERA DIS	✔	✔	✔	✔	✔	✔
Fixed-target DIS	✔	✔	✔	✗	✔	✔
Fixed-target DY	✔	✔	✔	✗	✔	✔
Tevatron W,Z	✔	✔	✔	✗	✗	✗
Tevatron jets	✔	✔	✔	✗	✗	✔
GM-VFNS	✔	✔	✔	✔	✗	✗
NNLO	✔	✗	✗	✔	✔	✔

- "Global" $\equiv$ 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.
- NNPDF2.0 (ZM-VFNS) $\rightarrow$ NNPDF2.1 (GM-VFNS), now allowing meaningful comparison to other NLO global fits. (Previous NNPDF2.0 $\sigma_{W,Z}$ lower than all other groups.)
- ABKM09 and GJR08/JR09 use FFNS for structure functions.

Ratio of NLO quark–antiquark luminosity functions

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

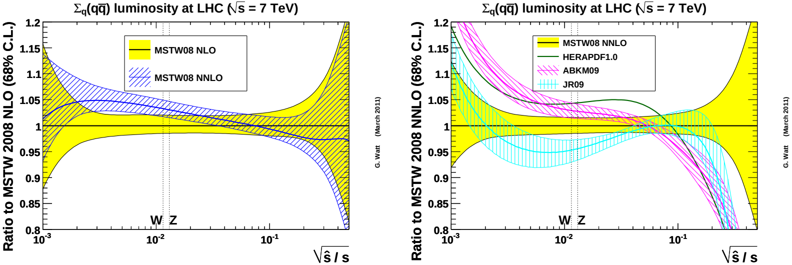




- Relevant values of $\sqrt{\hat{s}} = M_{W,Z}$ are indicated: good agreement for global fits (*left*), but more variation for other sets (*right*).

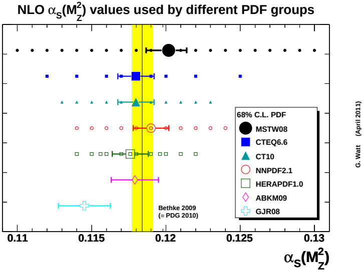
Ratio of NNLO quark–antiquark luminosity functions

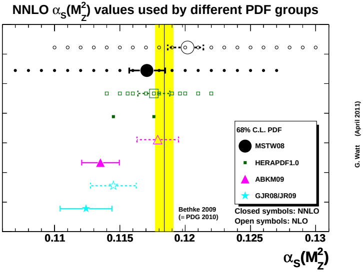
$$\frac{\partial \mathcal{L}_{\Sigma_q(q\bar{q})}}{\partial \hat{s}} = \frac{1}{s}\int_\tau^1 \frac{\mathrm{d}x}{x} \sum_{q=d,u,s,c,b} \left[f_q(x,\hat{s}) f_{\bar{q}}(\tau/x,\hat{s}) + (q \leftrightarrow \bar{q}) \right], \qquad \tau \equiv \frac{\hat{s}}{s}$$



- **Left plot:** compare MSTW NLO and NNLO luminosities.
- **Right plot:** NNLO trend between groups similar to NLO.

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.
- Plot cross sections versus $\alpha_S(M_Z^2)$ to show dependence (more important for $t\bar{t}$ and $gg \to H$ than W/Z production).

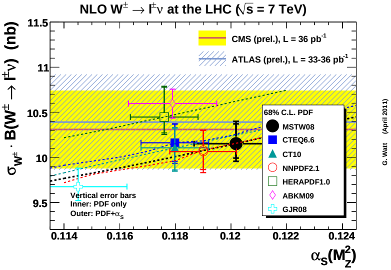
Settings for NLO/NNLO W and Z total cross sections

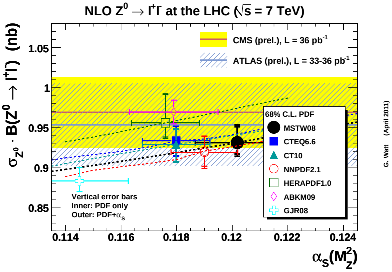
- Aim to isolate PDF (and α_S) dependence.
  $\Rightarrow$ Use **same** code for all PDF sets with common settings.
- "PDF+α_S" uncertainties (at 68% and 90% C.L.) computed using recommended prescription of each fitting group.
- No attempt made to evaluate other theoretical uncertainties. Single scale choice, $\mu_R = \mu_F = M_W, M_Z$. (Scale uncertainties less than 1% at NNLO.) No electroweak corrections included.
- Treatment of heavy quarks in 5-flavour ZM-VFNS.
- Use PDG 2008 electroweak parameters, no virtual photon (γ^*).
- On-shell W and Z production times leptonic branching ratios.
- Apply correction factors to ATLAS and CMS data calculated using VRAP at NNLO with MSTW08 PDFs (but same at NLO).

$$\text{ATLAS:}\quad \sigma(Z/\gamma^*, 66 < M_{\ell\ell} < 116~\text{GeV})\ /\ \sigma(Z\text{-only}, M_{\ell\ell} = M_Z) = 0.991$$

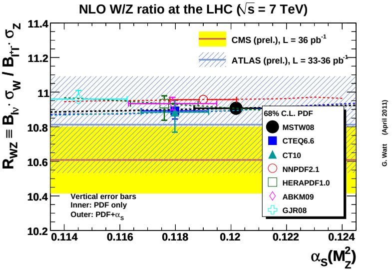
$$\text{CMS:}\quad \sigma(Z/\gamma^*, 60 < M_{\ell\ell} < 120~\text{GeV})\ /\ \sigma(Z\text{-only}, M_{\ell\ell} = M_Z) = 1.006$$

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



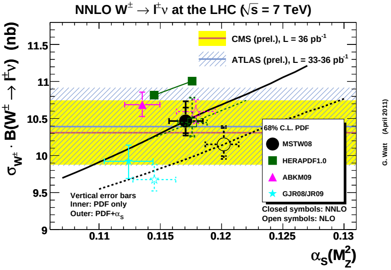


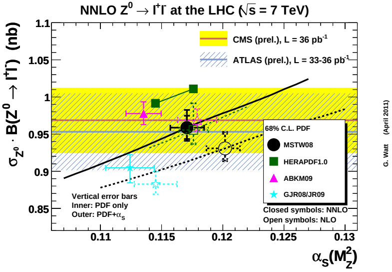
- Global fits in good agreement for $\sigma_{W^\pm}$ and σ_{Z^0} (left plots).
- Small uncertainties in predictions for W/Z ratio:



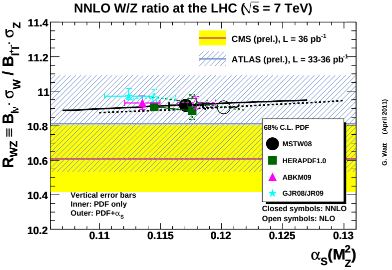
- **Preliminary** LHC data [ATLAS-CONF-2011-041, CMS PAS EWK-10-005].

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



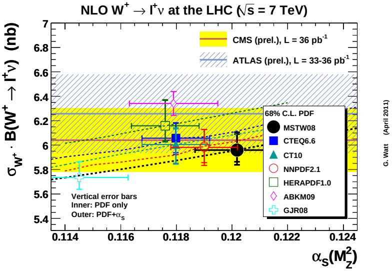


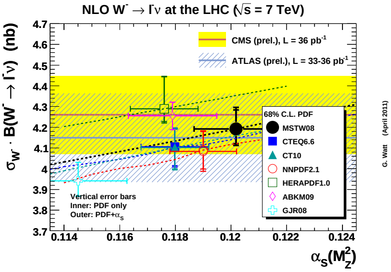
- NNLO corrections reduced by taking different $\alpha_S(M_Z^2)$ values at different orders.
- *W/Z ratio* insensitive to NNLO corrections (and α_S):



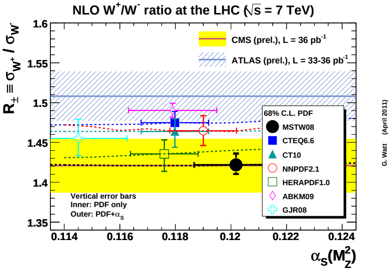
- Luminosity uncertainty 3–4%, comparable with PDF spread.

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



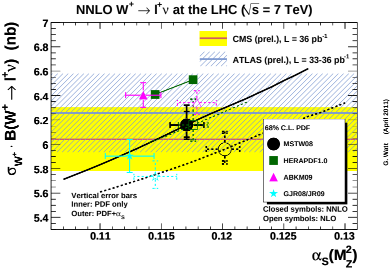


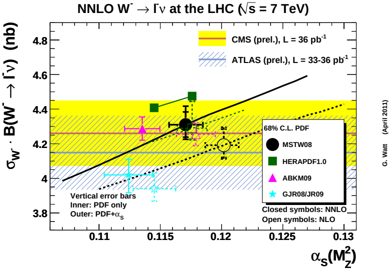
- Slightly more spread in separate σ_{W^+} and σ_{W^-}.
- Reflected in W^+/W^- ratio (sensitive to u/d ratio):



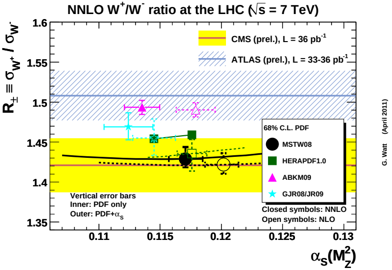
- ATLAS W^+/W^- ratio derived from ATLAS ellipse [ATLAS-CONF-2011-041].

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





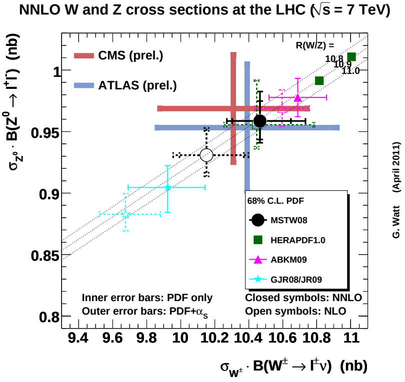
- W^+/W^- ratio insensitive to NNLO corrections (and α_S):

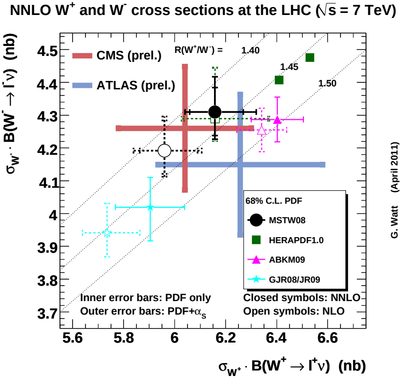


- Apparent discrepancy between CMS and ATLAS for ratio.
- CMS ratio favours **MSTW08**, ATLAS favours ABKM09 (?).

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

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

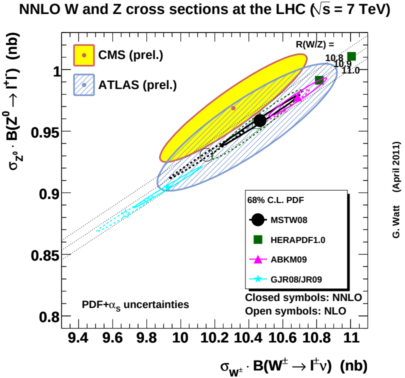


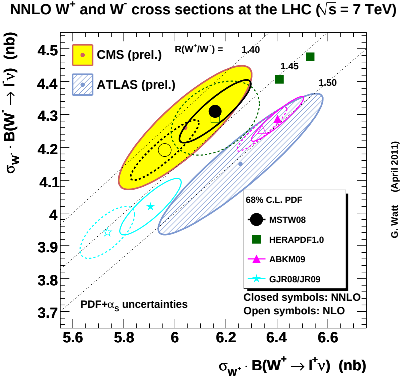


- Know correlation of both data and theory (from eigenvector PDFs).

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

- Correlation of ellipse ⇔ uncertainty in ratio of cross sections.





- Apparent discrepancy between CMS and ATLAS for W^+/W^-. CMS ratio favours **MSTW08**, ATLAS favours ABKM09 (?).

Acceptance for W^+/W^- total cross section ratio

- CMS [arXiv:1012.2466, CMS PAS EWK-10-005] use POWHEG (with CTEQ6.6/CT10, MSTW08NLO, NNPDF2.0), check with FEWZ.

$$\Rightarrow \frac{\sigma^{\rm tot}_{W^+}}{\sigma^{\rm tot}_{W^-}} = \begin{cases} 1.418 \pm 0.008(\text{stat.}) \pm 0.022(\text{syst.}) \pm 0.029(\text{th.}) & (e) \\ 1.423 \pm 0.008(\text{stat.}) \pm 0.019(\text{syst.}) \pm 0.031(\text{th.}) & (\mu) \\ 1.421 \pm 0.006(\text{stat.}) \pm 0.014(\text{syst.}) \pm 0.030(\text{th.}) & (e+\mu) \end{cases}$$

- ATLAS [arXiv:1010.2130, ATLAS-CONF-2011-041] use PYTHIA (with MRSTLO*) $\Rightarrow \sigma^{\rm tot}_{W^+}/\sigma^{\rm tot}_{W^-} = 1.51 \pm 0.03$ $(e+\mu)$ [from ATLAS ellipse].

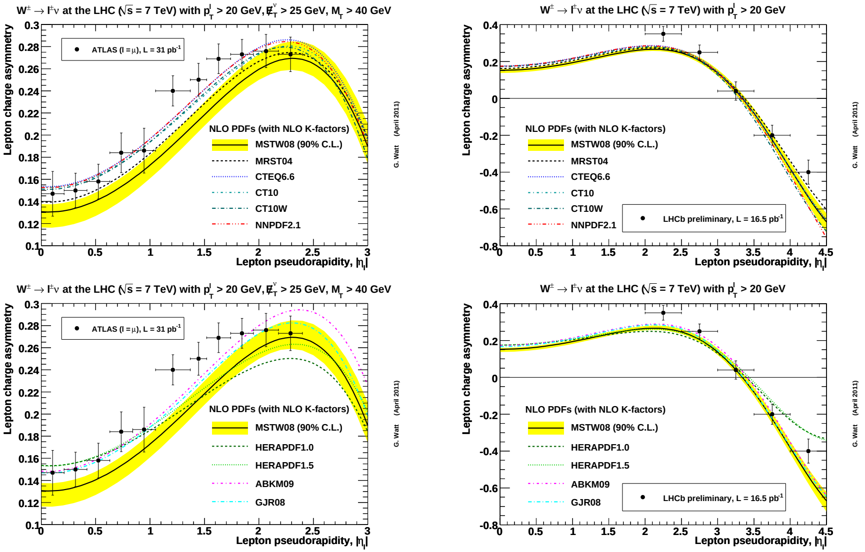
MC+PDF	A_{W^+}/A_{W^-} e	A_{W^+}/A_{W^-} μ	$\sigma^{\rm tot}_{W^+}/\sigma^{\rm tot}_{W^-}$ e	$\sigma^{\rm tot}_{W^+}/\sigma^{\rm tot}_{W^-}$ μ
PYTHIA+MRSTLO*	1.02	1.02	1.50	1.51
PYTHIA+CTEQ6.6	1.05	1.05	1.46	1.47
PYTHIA+HERAPDF1.0	1.03	1.04	1.48	1.49
MC@NLO+HERAPDF1.0	1.05	1.05	1.46	1.47
MC@NLO+CTEQ6.6	1.06	1.06	1.45	1.46

$$\frac{\sigma^{\rm tot}_{W^+}}{\sigma^{\rm tot}_{W^-}} = \frac{\sigma^{\rm fid}_{W^+}}{\sigma^{\rm fid}_{W^-}} \cdot \frac{A_{W^-}}{A_{W^+}}$$

Alternative acceptance calculations move ATLAS $\sigma^{\rm tot}_{W^+}/\sigma^{\rm tot}_{W^-}$ much closer to CMS.

- Precision requires better acceptance calculations and/or data to theory comparisons at level of fiducial cross section.

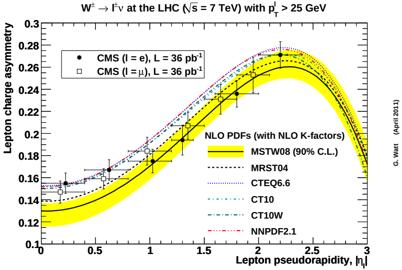
$W^{\pm} \to \ell^{\pm}\nu$ charge asymmetry from ATLAS and LHCb

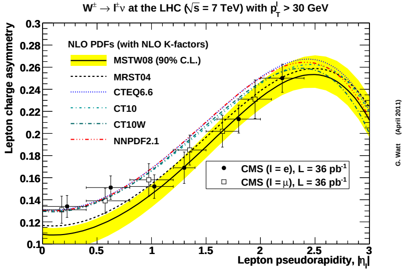


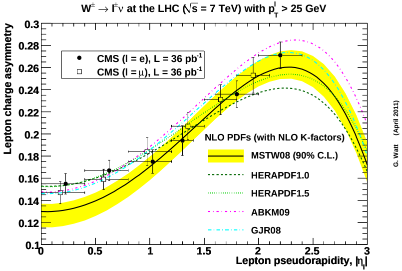
Data: ATLAS [arXiv:1103.2929]

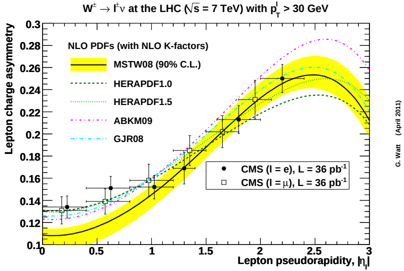
Data: LHCb preliminary

$W^\pm \to \ell^\pm \nu$ charge asymmetry from CMS [arXiv:1103.3470]





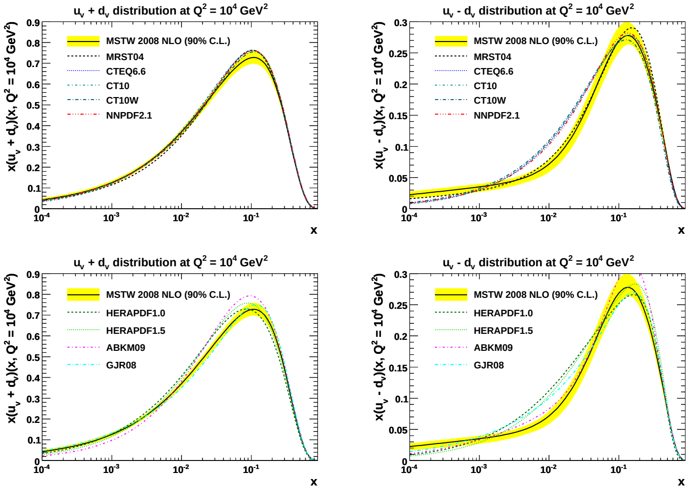




Data: CMS for $p_T^\ell > 25$ GeV

Data: CMS for $p_T^\ell > 30$ GeV

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



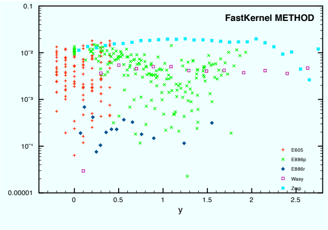
- **MSTW08** has input $xu_v \propto x^{0.29\pm0.02}$ and $xd_v \propto x^{0.97\pm0.11}$.
  Many other groups **assume** equal powers $\Rightarrow$ parameterisation bias.
  (NNPDF: restricted range of small-x preprocessing exponents.)

Methods for including hadron collider data in PDF fits

Problem: need fast NLO/NNLO calculation to allow PDF fitting.

Solutions:

1. Avoid explicit PDF refitting. Reweight existing Monte Carlo replica PDF sets ($\rightarrow$ M. Ubiali) or Hessian eigenvector PDF sets ($\rightarrow$ R. McNulty). Useful method, but short-term solution.
2. Grid interpolation methods: FASTNLO (NLOJET++), APPLGRID (NLOJET++, MCFM), FASTKERNEL (DY w/o ℓ cuts).



Methods used by three global fit groups:

	MSTW	CTEQ	NNPDF
Tevatron jets	FASTNLO	K-factors	FASTNLO
Tevatron W, Z	K-factors	K-factors	FASTKERNEL
Fixed-target DY	K-factors	K-factors	FASTKERNEL

3. Parameterised K-factors calculated for exact kinematic cuts. More traditional method, but often (unjustly?) criticised.

Practical implementation of K-factors in PDF fits

- **Example:** Z rapidity distribution in PDF fit calculated as

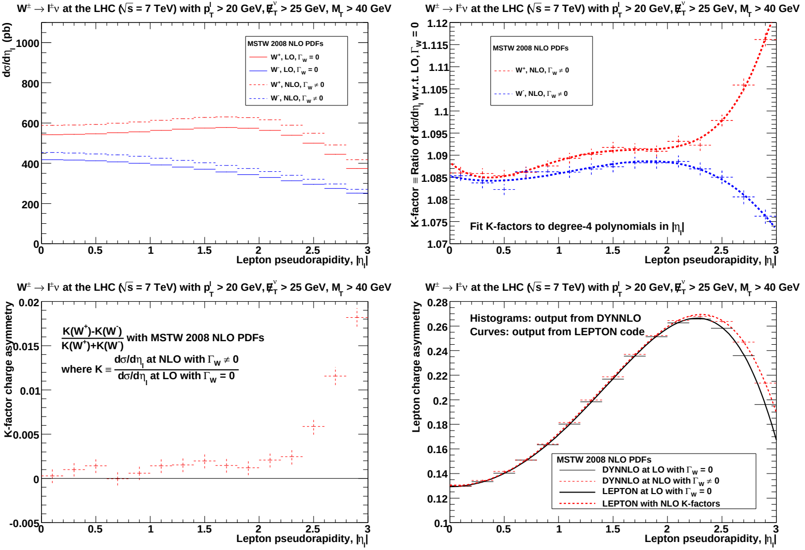
$$\frac{\mathrm{d}\sigma^{\mathrm{NNLO}}}{\mathrm{d}y} = \frac{\mathrm{d}\sigma^{\mathrm{LO}}}{\mathrm{d}y} K(y), \quad K(y) \equiv \left.\frac{\mathrm{d}\sigma^{\mathrm{NNLO}}/\mathrm{d}y}{\mathrm{d}\sigma^{\mathrm{LO}}/\mathrm{d}y}\right|_{\text{fixed NNLO PDF}},$$

  where $K(y)$ calculated beforehand for a fixed NNLO PDF (and α_S) choice in **both** numerator and denominator.
- Approximation made is that $K(y)$ is independent of PDF choice: can iterate or use a different PDF choice to check this assumption.
- Possible to go further and isolate α_S dependence from K-factor:

$$K(y) = 1 + \alpha_S\, D(y) + \alpha_S^2\, E(y),$$

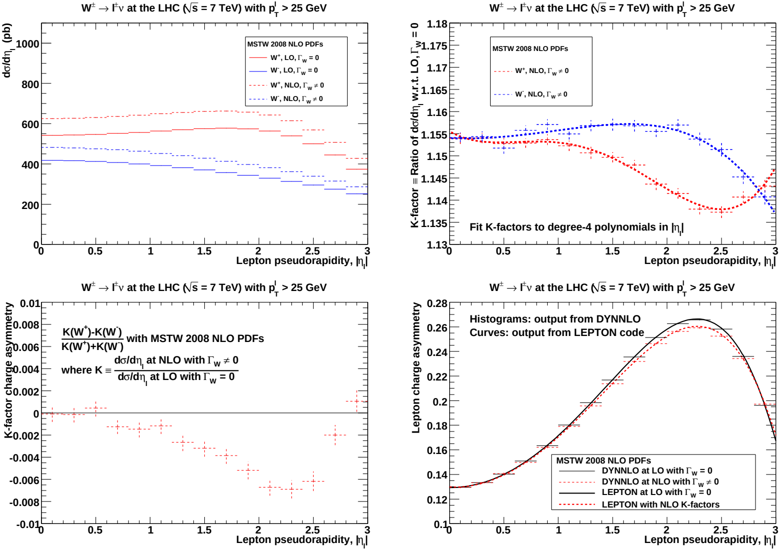
  where coefficients $D(y)$ and $E(y)$ are calculated for a fixed PDF choice. Method used for Drell–Yan data in MSTW08 fit.
- Illustrate method by looking at K-factors for LHC W/Z data.

NLO K-factors for ATLAS cuts [arXiv:1103.2929]



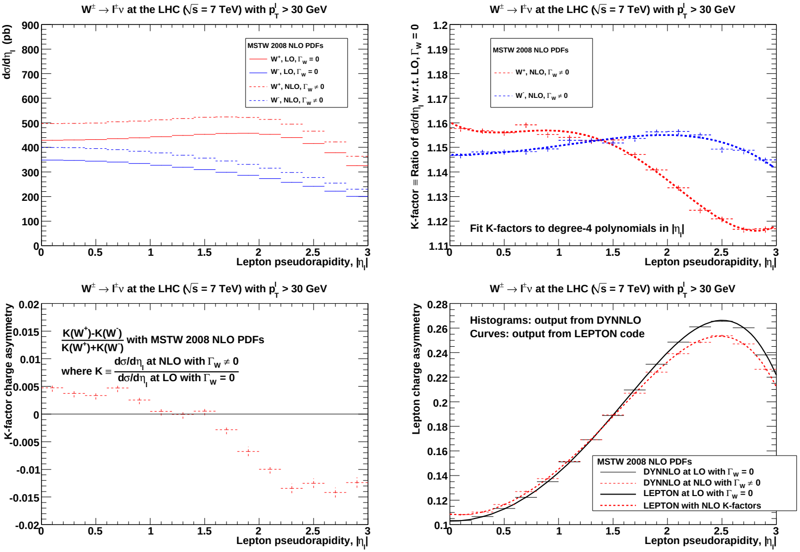
- PDF dependence of K-factor charge asymmetry should be negligible.

NLO K-factors for CMS cuts ($p_T^\ell > 25$ GeV) [arXiv:1103.3470]



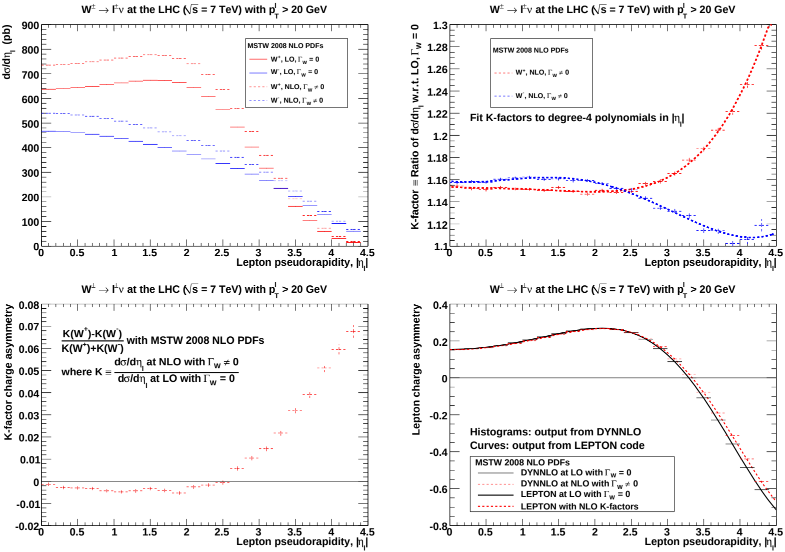
- CMS cuts slightly different from ATLAS, but equal at LO with $\Gamma_W = 0$.

NLO K-factors for CMS cuts ($p_T^\ell > 30$ GeV) [arXiv:1103.3470]



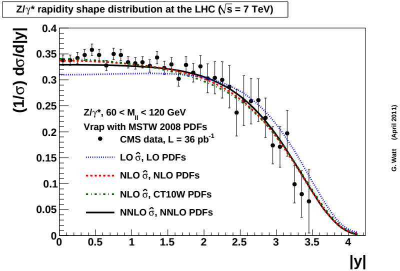
- K-factor charge asymmetry larger for $p_T^\ell > 30$ GeV than $p_T^\ell > 25$ GeV.

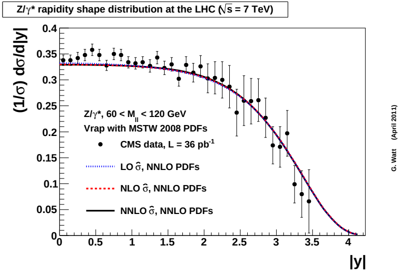
NLO K-factors for LHCb cuts [LHCb-CONF-2011-012]



- K-factor charge asymmetry still small at large $|\eta_\ell|$ relevant for LHCb.

Z/γ^* rapidity distribution at the LHC [CMS PAS EWK-10-010]





- **Left plot:** change PDF with order of $\hat{\sigma}$ calculation. NLO and NNLO clearly favoured over LO. CT10W close to MSTW08NLO.
- **Right plot:** same MSTW08NNLO PDF with varying $\hat{\sigma}$ order. $\Rightarrow$ PDF dependence of K-factor should be negligible.
- Could quantify accuracy by propagating PDF uncertainties:

$$\frac{\mathrm{d}\sigma_i^{\mathrm{NNLO}}}{\mathrm{d}y} = \frac{\mathrm{d}\sigma_0^{\mathrm{LO}}}{\mathrm{d}y} K_i(y), \quad K_i(y) \equiv \frac{\mathrm{d}\sigma_i^{\mathrm{NNLO}}/\mathrm{d}y}{\mathrm{d}\sigma_i^{\mathrm{LO}}/\mathrm{d}y},$$

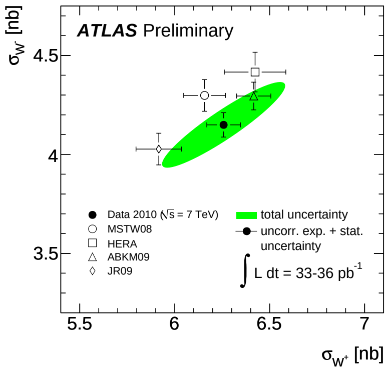
for eigenvector NNLO PDF set "i", where "0" is the central set.

Summary

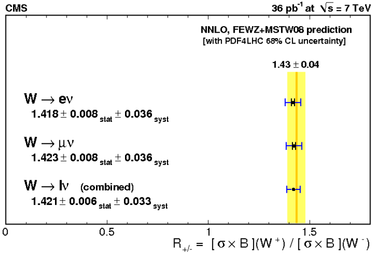
- Apparent discrepancy between ATLAS and CMS W^+/W^- total cross section ratio due to inadequate acceptance calculations. Data precision requires proper acceptance corrections and/or comparison of data and theory for fiducial cross section.
- LHC $W^\pm \to \ell^\pm \nu$ charge asymmetry data an important input to future fits (but still outstanding issues to be resolved concerning Tevatron data and nuclear effects in deuteron structure functions [MSTW, arXiv:1006.2753]).
- K-factor methods should be sufficiently accurate for inclusion in PDF fits of LHC data on $W^\pm \to \ell^\pm \nu$ charge asymmetry and Z/γ^* rapidity shape distribution (but not jets etc.).

ATLAS and CMS W^+/W^- total cross section ratios

[ATLAS-CONF-2011-041]



[CMS PAS EWK-10-005]



- PDF4LHC recipe inappropriate for PDF-sensitive measurement.

- ATLAS ellipse $\Rightarrow \sigma^{\rm tot}_{W^+}/\sigma^{\rm tot}_{W^-} = 1.51 \pm 0.03$ (total uncertainty).
- CMS $\sigma^{\rm tot}_{W^+}/\sigma^{\rm tot}_{W^-} = 1.421 \pm 0.034 \Rightarrow$ correlation for ellipse.

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.

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:

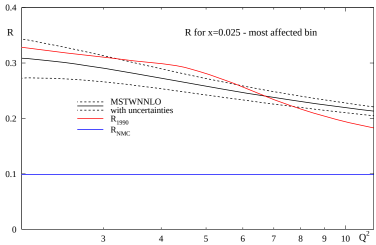
$$\alpha_S(M_Z^2) = 0.1171 \quad \pm 0.0014 \text{ (68\% C.L.)} \quad \pm 0.0034 \text{ (90\% C.L.)}$$

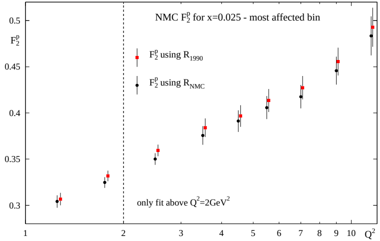
Treatment of F_L correction for NMC data [Studies by R. Thorne]

- 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]:

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

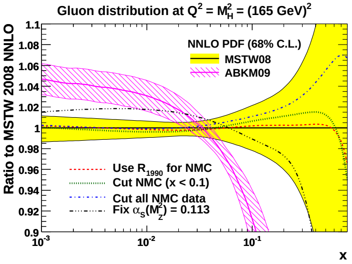
- Alternative NMC F_2 data using $R = R_{1990}$ ($\forall x$) close to $R_{\rm MSTW}$.





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.

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 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).

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).

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

- 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	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)

- $N_{\rm pts.} = 71$, $N_{\rm corr.} = 70$. Scale $\mu \propto p_T \equiv (p_{T1} + p_{T2})/2$.