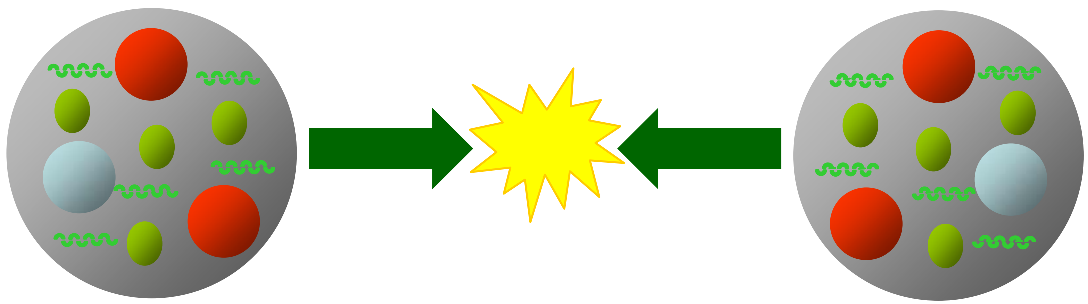
MSTW update



James Stirling

(with Alan Martin, Robert Thorne, Graeme Watt)

Outline

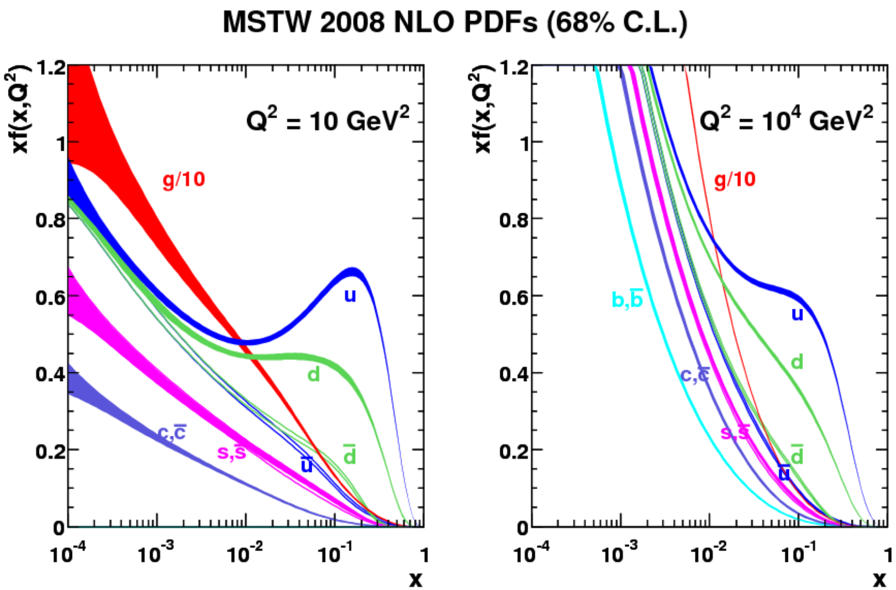
Published

- MSTW 2008 LO/NLO/NNLO – summary
- variable α_S fits – summary

Work in progress

- variable m_c, m_b fits
- $N_{f(max)} = 4$ GM-VFNS pdfs
- 'QCD+QED' pdfs

MSTW 2008 (arXiv:0901.0002)



- new data
- new theory/infrastructure
  - δf_i from new dynamic tolerance method: 68%cl (1σ) and 90%cl (*cf.* MRST) sets available
  - new definition of α_S (no more Λ_{QCD})
  - new GM-VFNS for c, b (see Martin et al., arXiv:0706.0459)
  - new fitting codes: FEWZ, VRAP, fastNLO
  - new grids: denser, broader coverage
  - slightly extended parametrisation at Q_0^2 :34-4=30 free parameters including α_S

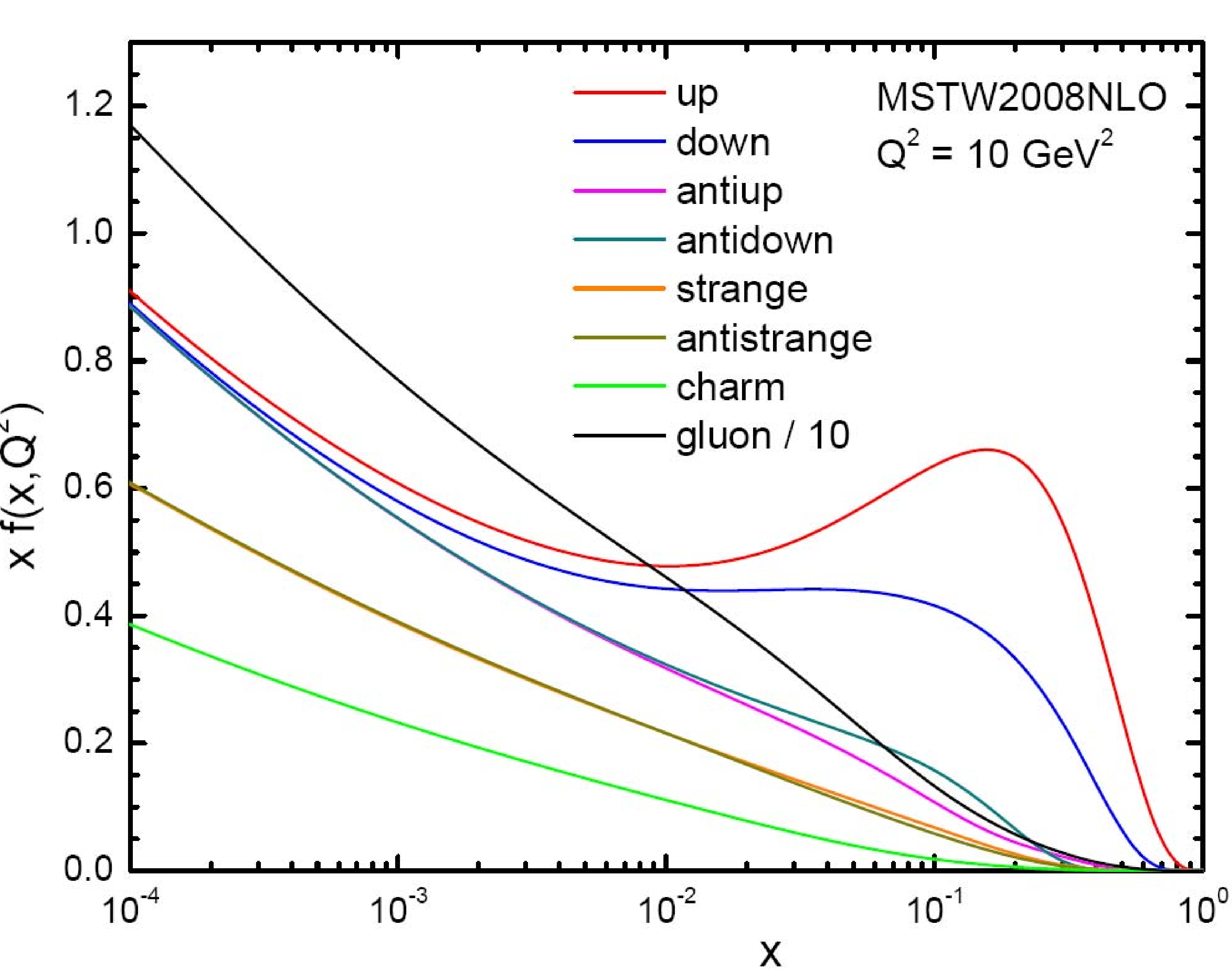
code, text and figures available at:
`http://projects.hepforge.org/mstwpdf/`

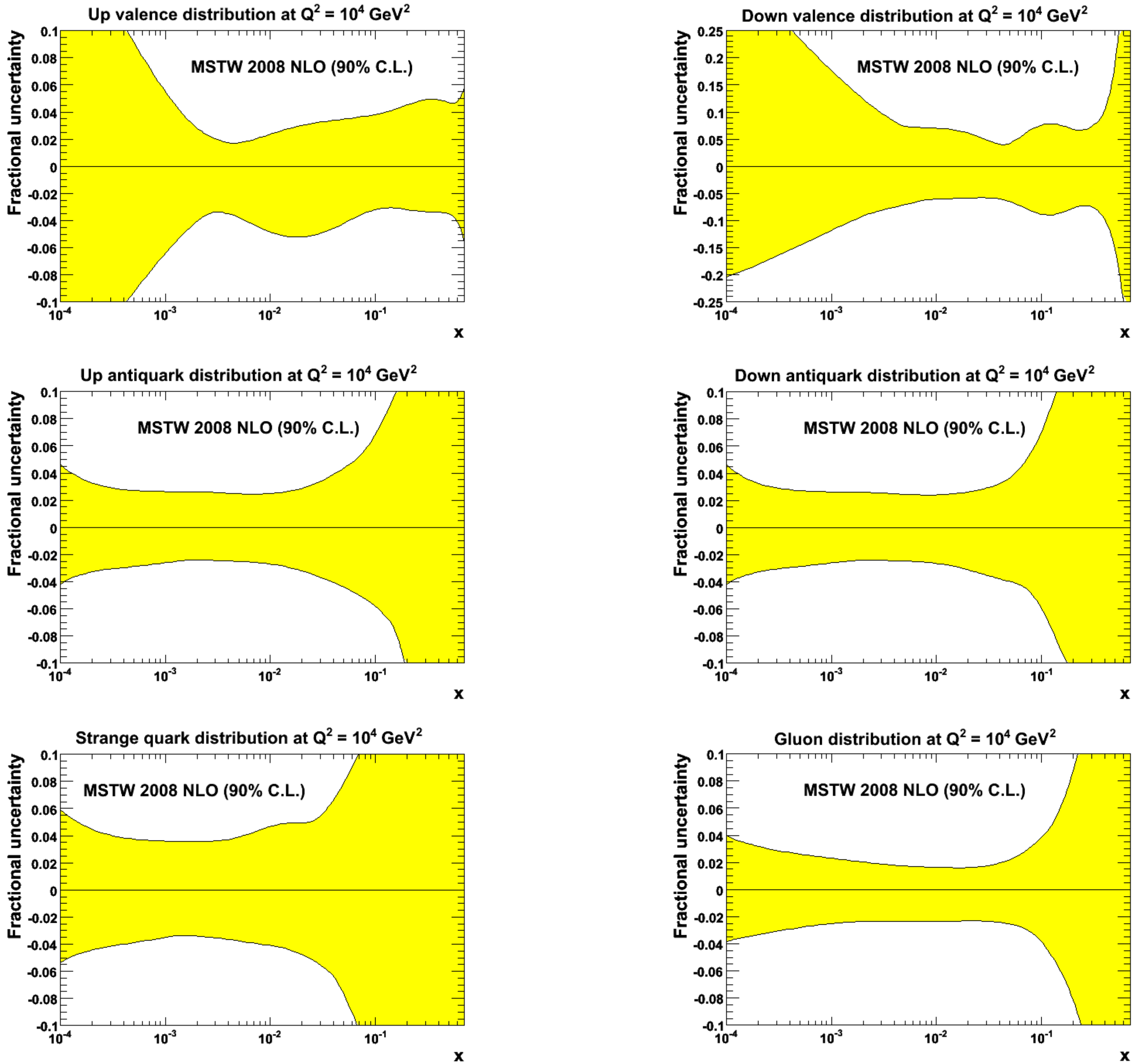
data sets used in MSTW2008 fit

Data set	$N_{\text{pts.}}$
H1 MB 99 e^+p NC	8
H1 MB 97 e^+p NC	64
H1 low Q^2 96–97 e^+p NC	80
H1 high Q^2 98–99 e^-p NC	126
H1 high Q^2 99–00 e^+p NC	147
ZEUS SVX 95 e^+p NC	30
ZEUS 96–97 e^+p NC	144
ZEUS 98–99 e^-p NC	92
ZEUS 99–00 e^+p NC	90
H1 99–00 e^+p CC	28
ZEUS 99–00 e^+p CC	30
H1/ZEUS $e^{\pm}p$ F_2^{charm}	83
H1 99–00 e^+p incl. jets	24
ZEUS 96–97 e^+p incl. jets	30
ZEUS 98–00 $e^{\pm}p$ incl. jets	30
DØ II $p\bar{p}$ incl. jets	110
CDF II $p\bar{p}$ incl. jets	76
CDF II $W \to l\nu$ asym.	22
DØ II $W \to l\nu$ asym.	10
DØ II Z rap.	28
CDF II Z rap.	29

Data set	$N_{\text{pts.}}$
BCDMS μp F_2	163
BCDMS μd F_2	151
NMC μp F_2	123
NMC μd F_2	123
NMC $\mu n/\mu p$	148
E665 μp F_2	53
E665 μd F_2	53
SLAC ep F_2	37
SLAC ed F_2	38
NMC/BCDMS/SLAC F_L	31
E866/NuSea pp DY	184
E866/NuSea pd/pp DY	15
NuTeV νN F_2	53
CHORUS νN F_2	42
NuTeV νN xF_3	45
CHORUS νN xF_3	33
CCFR $\nu N \to \mu\mu X$	86
NuTeV $\nu N \to \mu\mu X$	84
All data sets	**2743**

- Red = New w.r.t. MRST 2006 fit.


up
down
antiup
antidown
strange
antistrange
charm
gluon / 10
MSTW2008NLO
Q^2 = 10 GeV^2
x f(x,Q^2)
x
1.2
1.0
0.8
0.6
0.4
0.2
0.0
10^-4
10^-3
10^-2
10^-1
10^0



Up valence distribution at Q² = 10⁴ GeV²
Down valence distribution at Q² = 10⁴ GeV²
Up antiquark distribution at Q² = 10⁴ GeV²
Down antiquark distribution at Q² = 10⁴ GeV²
Strange quark distribution at Q² = 10⁴ GeV²
Gluon distribution at Q² = 10⁴ GeV²
MSTW 2008 NLO (90% C.L.)
Fractional uncertainty
x
10⁻⁴
10⁻³
10⁻²
10⁻¹

a note on α_S

- world average value (PDG 2008):

$$\alpha_S^{\overline{MS},NNLO}(M_Z^2) = 0.1176 \pm 0.002$$

- MSTW global fit value (minimum χ^2):

$$\alpha_S^{\overline{MS},NNLO}(M_Z^2) = 0.1171$$

- the pdf error sets are generated with α_S fixed at its 'best fit' value, therefore variation of (e.g. jets, top, etc at LHC) cross sections with α_S is not explicitly included in the 'pdf error'

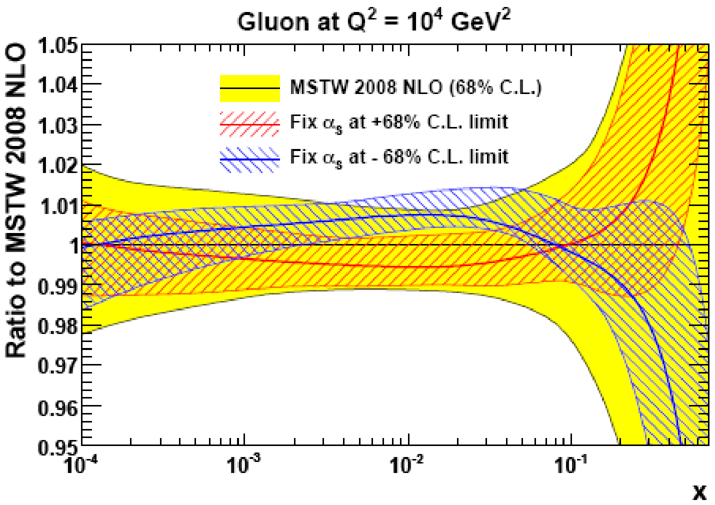
Note: $\alpha_S^{\overline{MS},NLO}(M_Z^2) = 0.1202$

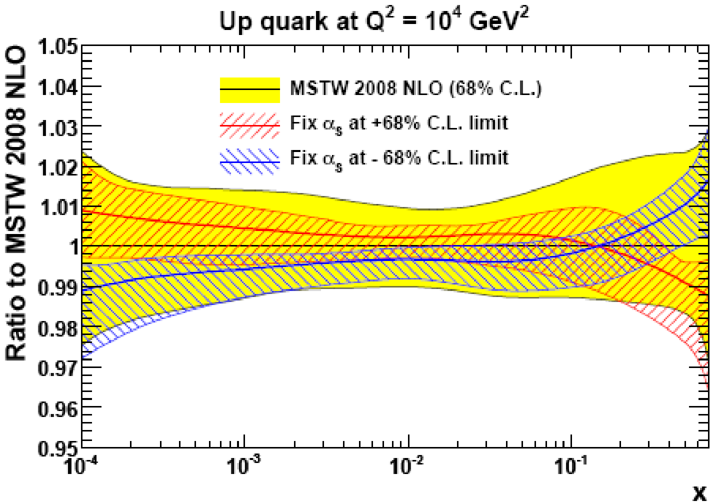
MSTW variable-α_S sets (arXiv:0905.3531)

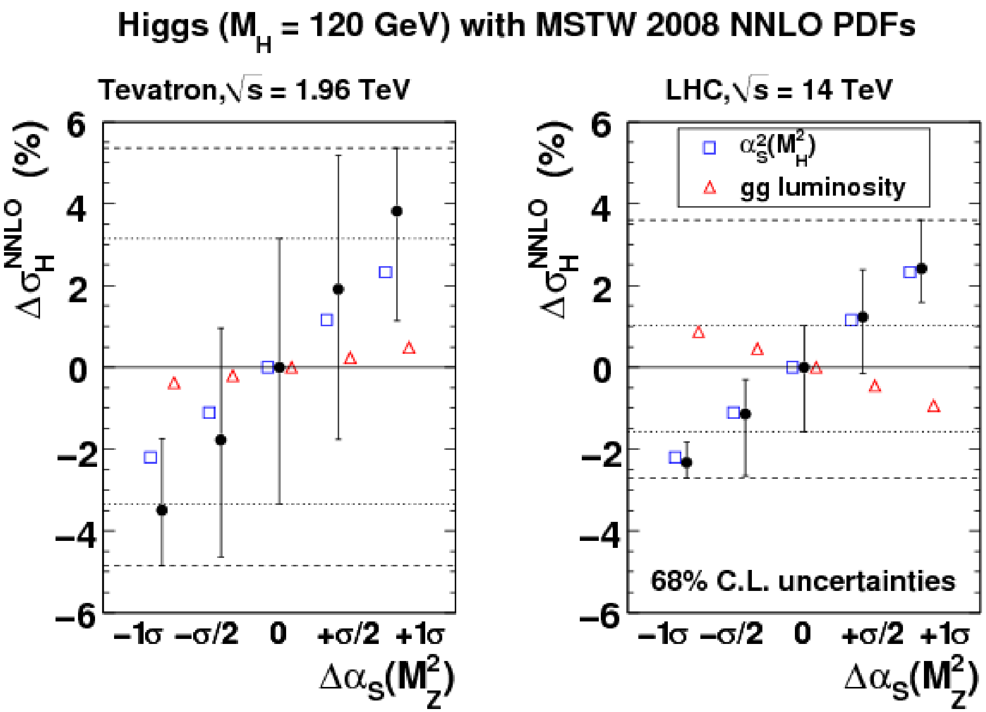
- allow α_S to vary in global fit

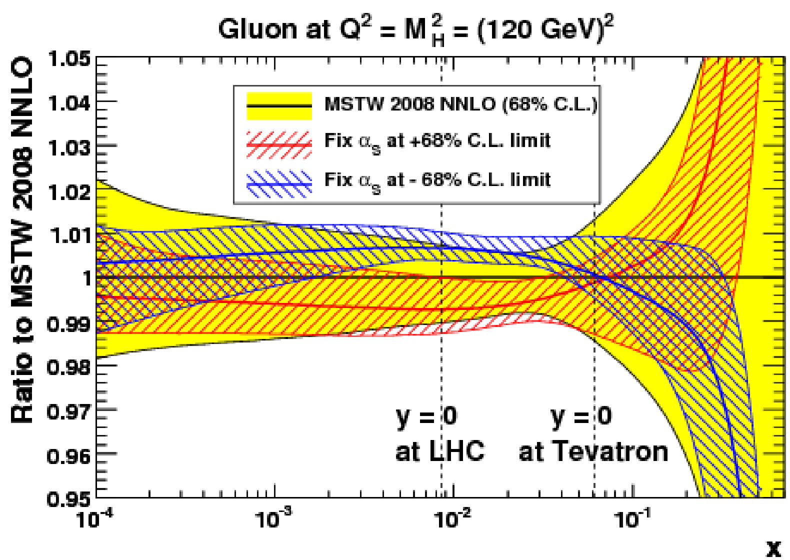
$$\alpha_S^{\overline{MS},NNLO}(M_Z^2) = 0.1171^{+0.0014}_{-0.0014}$$

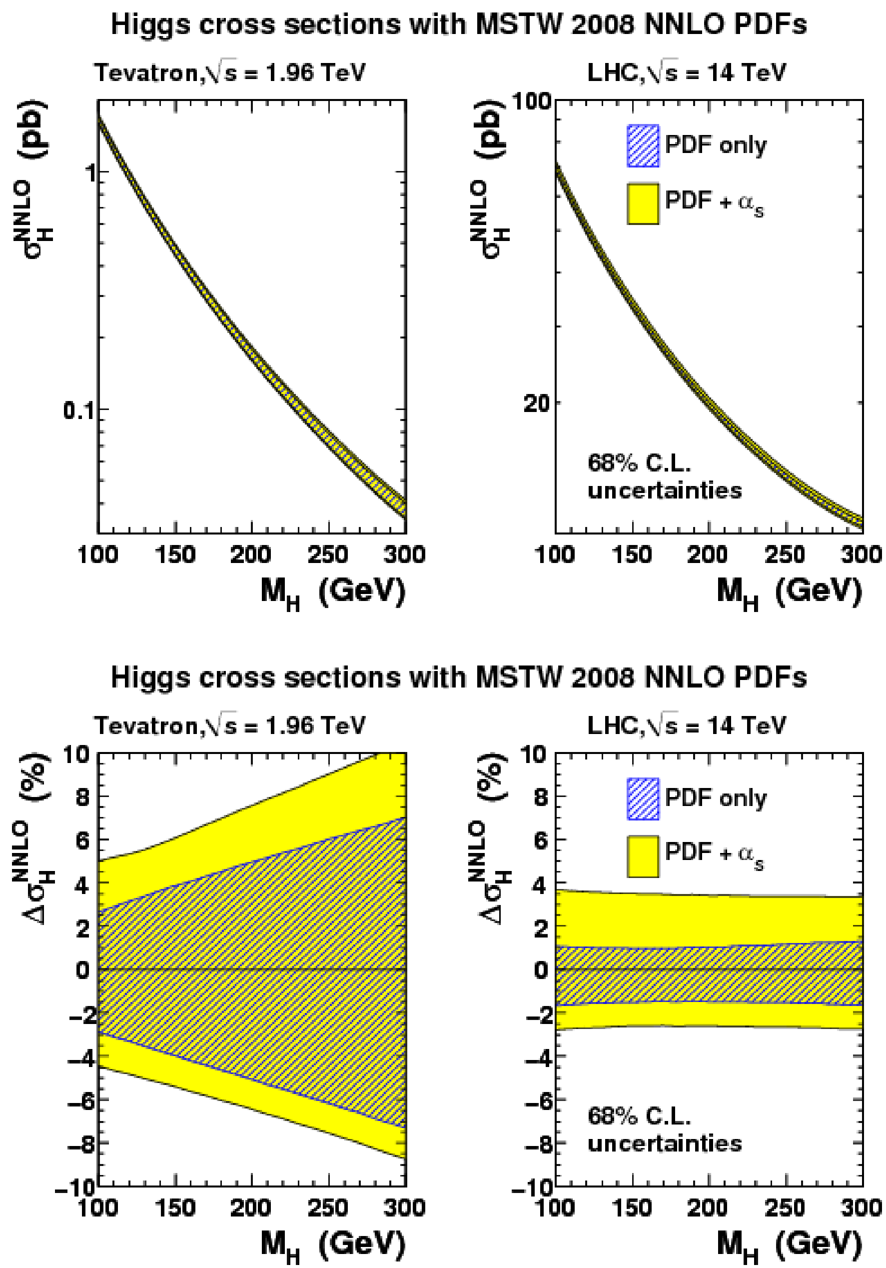
- for fixed $\alpha_S \pm \delta\alpha_S$, produce sets with 'pdf errors', as before
- note gluon – α_S anticorrelation at small x and quark – α_S anticorrelation at large x
- use resulting sets to quantify combined 'pdf + α_S' error on observables





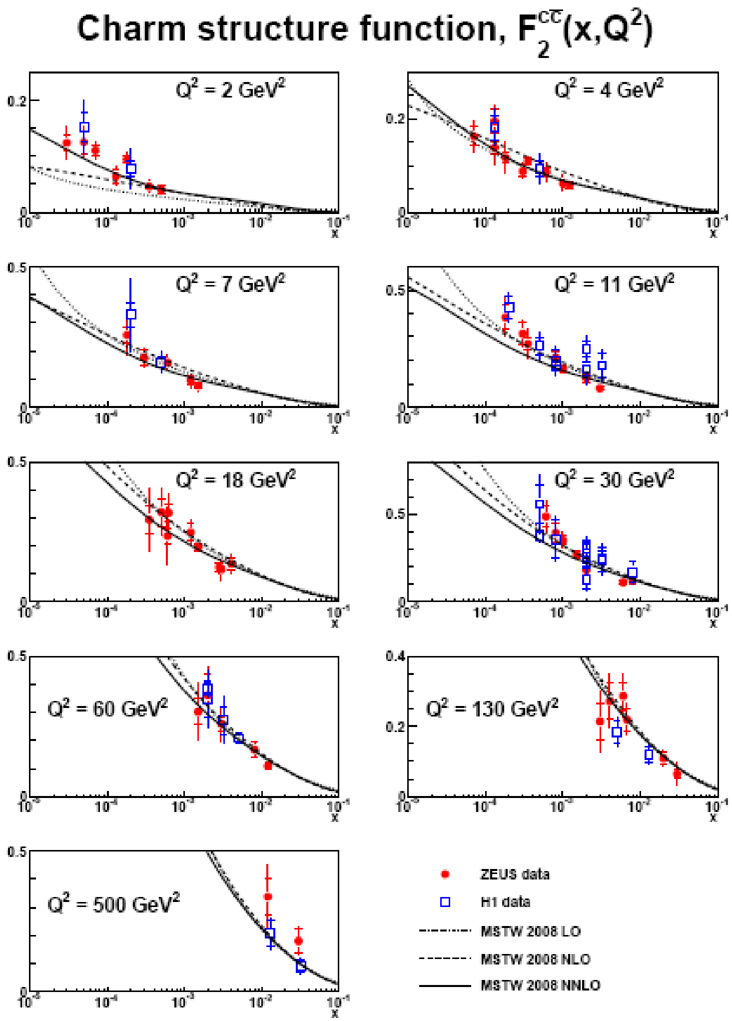

Higgs (M_H = 120 GeV) with MSTW 2008 NNLO PDFs
Tevatron, $\sqrt{s}$ = 1.96 TeV
LHC, $\sqrt{s}$ = 14 TeV
$\Delta\sigma_H^{NNLO}$ (%)
$\alpha_S^2(M_H^2)$
gg luminosity
68% C.L. uncertainties
−1σ −σ/2 0 +σ/2 +1σ
$\Delta\alpha_S(M_Z^2)$

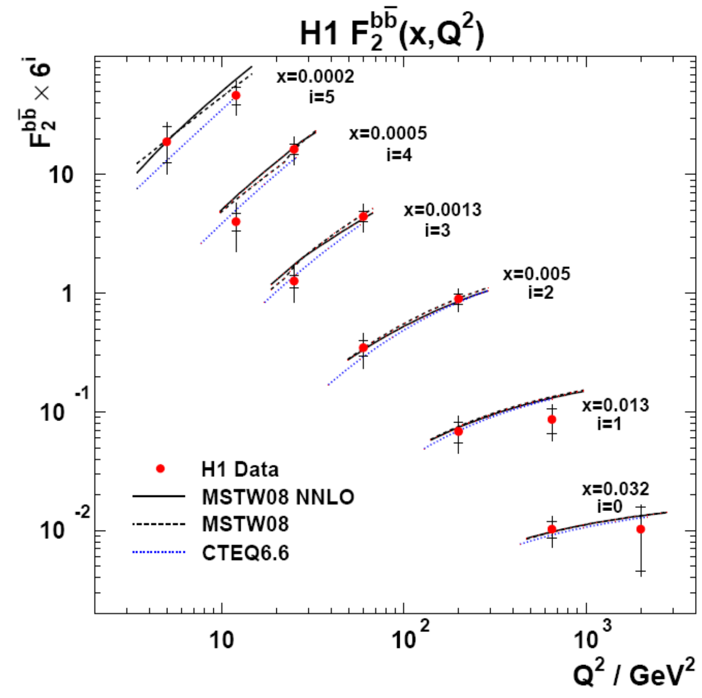

Gluon at $Q^2 = M_H^2 = (120\ \mathrm{GeV})^2$
Ratio to MSTW 2008 NNLO
MSTW 2008 NNLO (68% C.L.)
Fix α_S at +68% C.L. limit
Fix α_S at - 68% C.L. limit
y = 0
at LHC
y = 0
at Tevatron
x



Note: $\delta\sigma_{th}$ still dominated by scale variation uncertainty

charm and bottom structure functions





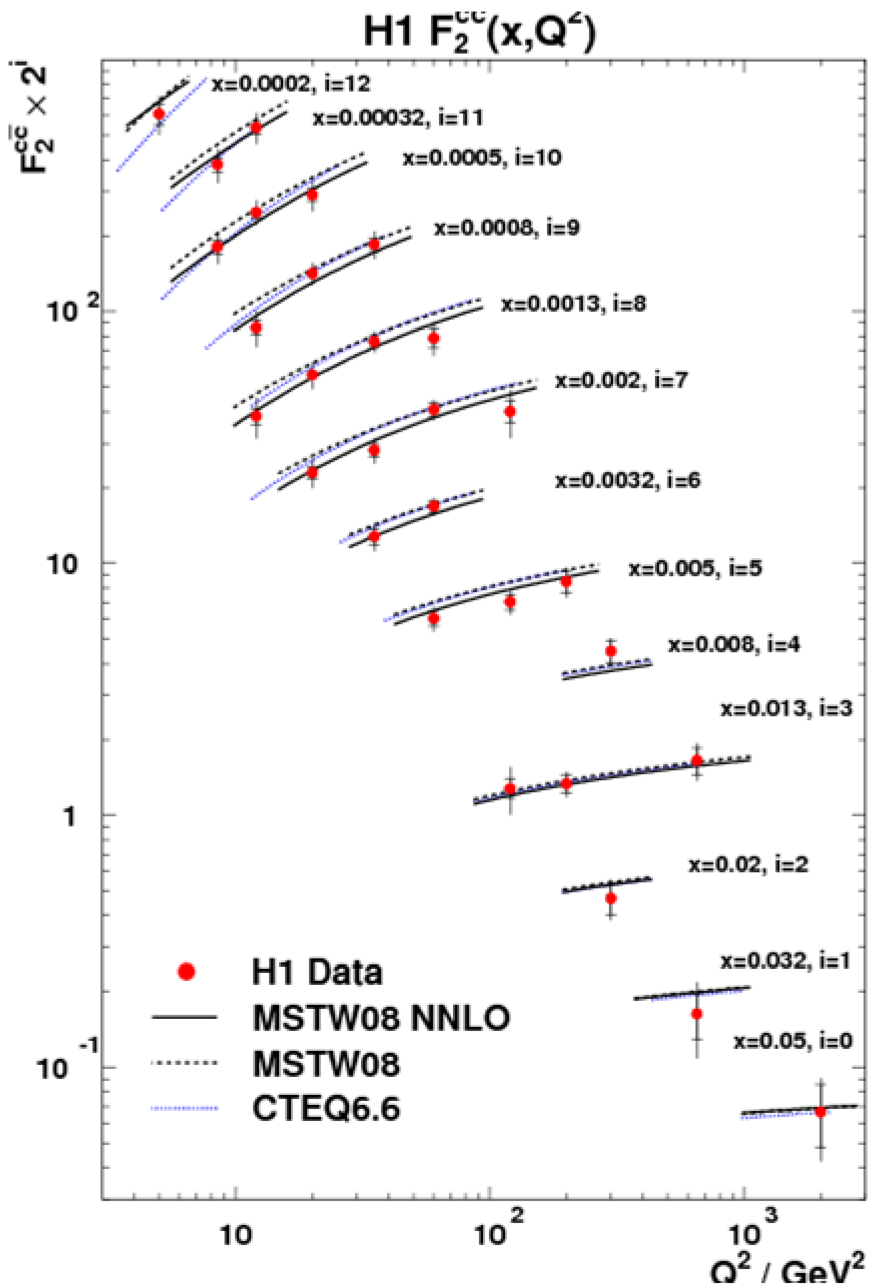
- MSTW 2008 uses *fixed* values of m_c = 1.4 GeV and m_b = 4.75 GeV in a GM-VFNS
- can study the sensitivity of the fit to these values

dependence on m_c at NLO in 2008 fits (preliminary)

m_c (GeV)	χ^2_{global} 2699 pts	$\chi^2_{F_2^c}$ 83 pts	$\alpha_s(M_Z^2)$
1.1	2730	264	0.1181
1.2	2626	188	0.1187
1.3	2563	134	0.1194
1.4	2543	107	0.1202
1.5	2545	97	0.1208
1.6	2574	104	0.1214
1.7	2627	129	0.1221

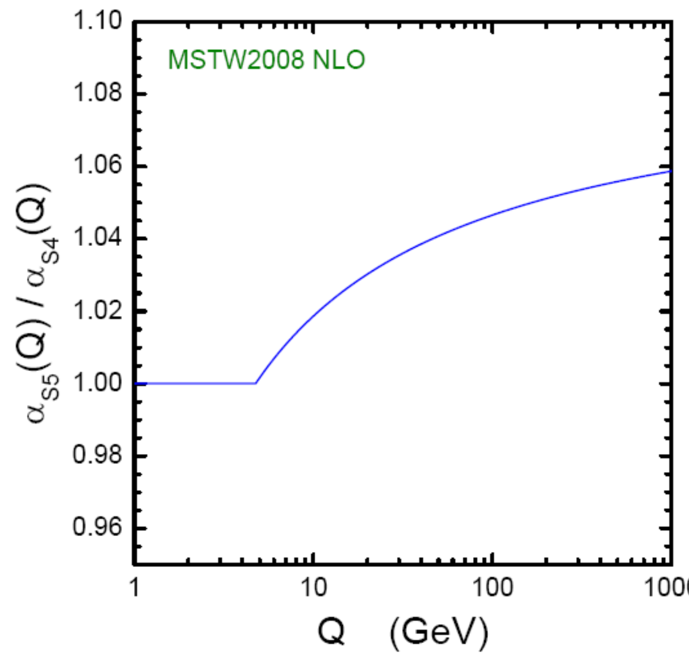
- correlation between m_c and α_S
- for low m_c overshoot low Q^2 medium x data badly
- preferred value (1.4 GeV) towards lower end of pole mass determination
- (asymmetric) uncertainty from global fit of order ± 0.15 GeV

- in contrast, only weak sensitivity to m_b


H1 $F_2^{c\bar{c}}(x,Q^2)$
$F_2^{c\bar{c}} \times 2^i$
x=0.0002, i=12
x=0.00032, i=11
x=0.0005, i=10
x=0.0008, i=9
x=0.0013, i=8
x=0.002, i=7
x=0.0032, i=6
x=0.005, i=5
x=0.008, i=4
x=0.013, i=3
x=0.02, i=2
x=0.032, i=1
x=0.05, i=0
H1 Data
MSTW08 NNLO
MSTW08
CTEQ6.6
Q^2 / GeV^2

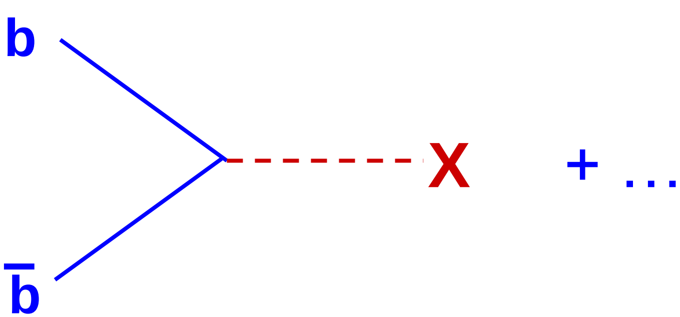
max. 4 flavour GM-VFNS pdfs

- MSTW 2008 sets have 5 quark flavours (u,d,s,c,b) asymptotically
- can generate 4 flavour (u,d,s,c) versions by
  - starting with same distributions at Q_0^2
  - switching off $g \to bb$ etc. splittings
  - using a 4-flavour α_S at high Q^2

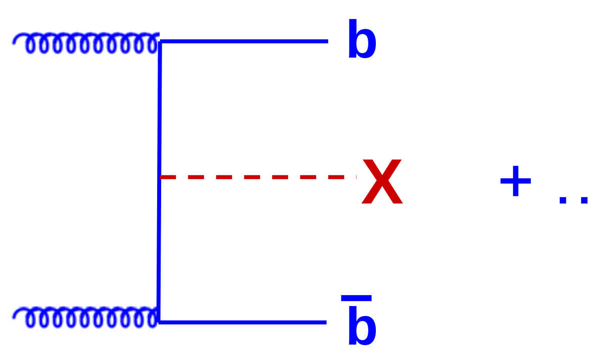


our previous FFNS sets: MRST2004 (LO, NLO) hep-ph/0603143

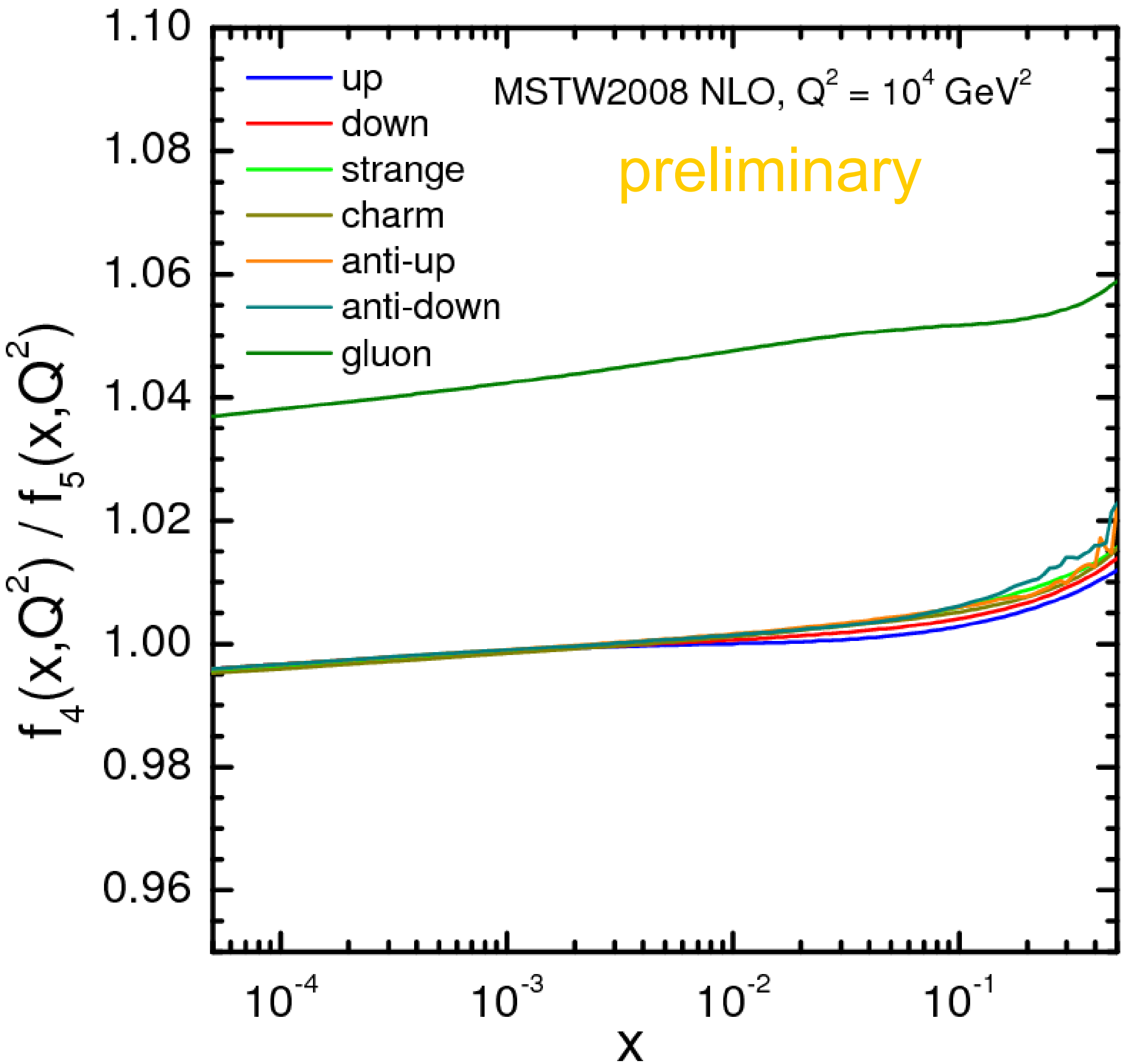
- this gives
  - $b_4 = 0$
  - $g_4 > g_5$
  - $q_4 \approx q_5$
- useful for study of hadroproduction of heavy objects (X = Z, H, …) that couple to b quarks



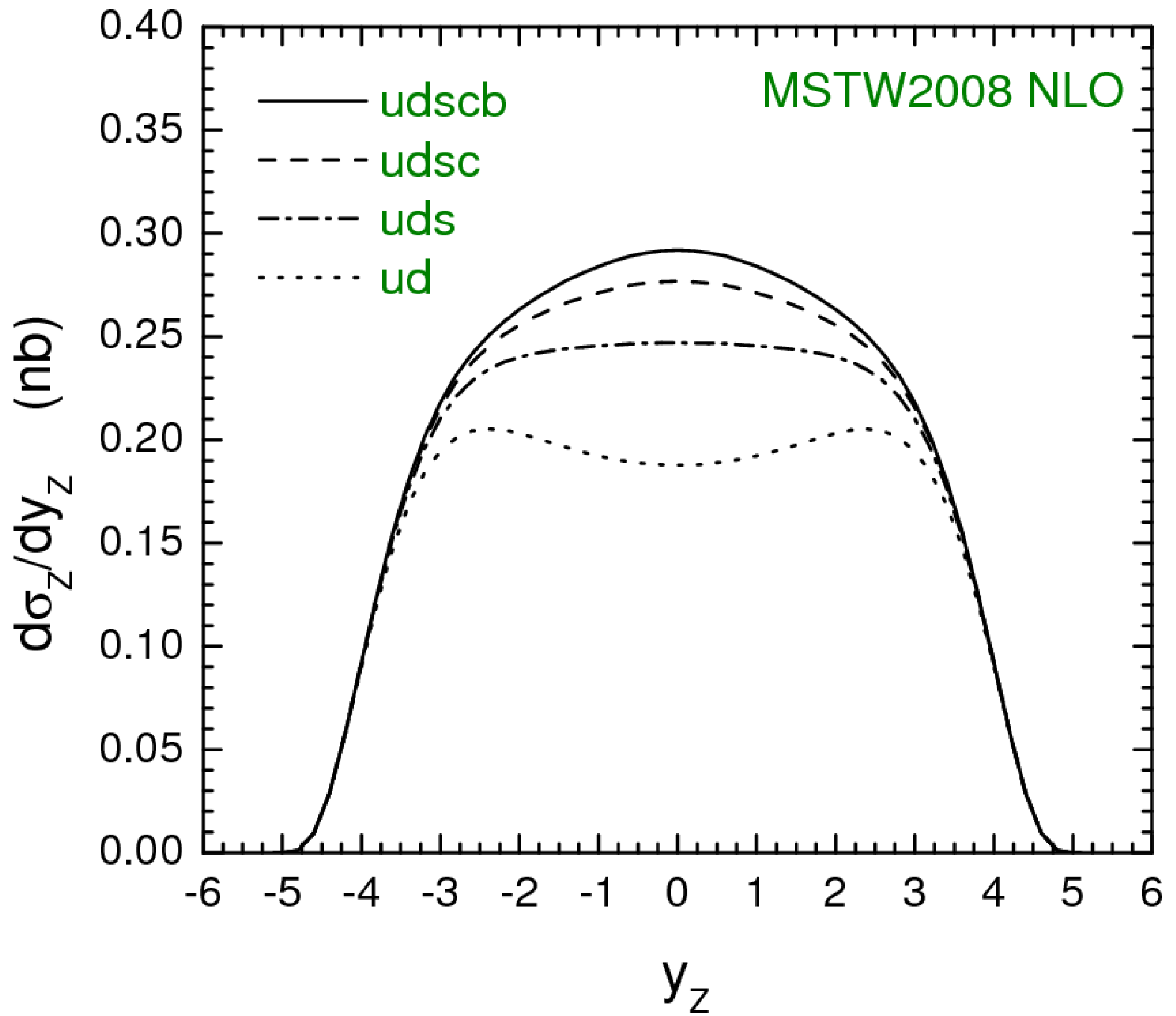
vs.



comparison of 4, 5 flavour pdfs



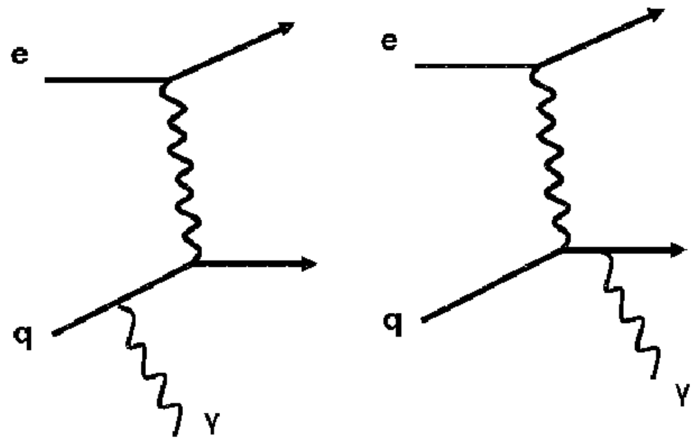
Z production at 14 TeV LHC



Note: 3% of $\sigma_{tot}(Z)$ comes from initial state b quarks (mainly bb$\rightarrow$ Z)

QED effects in pdfs

QED corrections to DIS include:



De Rujula, Petronzio, Savoy-Navarro 1979
Krifganz, Perlt 1988
Bluemlein 1990
Spiesberger 1994
Roth, Weinzierl 2004

$\Rightarrow$ mass singularity when $\gamma \parallel q$

$$\frac{\alpha}{2\pi} \langle e_q^2 \rangle \ln\left(\frac{Q^2}{m_q^2}\right) \simeq 0.01$$

for $Q = 100$ GeV, $m_q = 10$ MeV, $\langle e_q^2 \rangle = 5/18$.

included in standard radiative correction packages (HECTOR, HERACLES)

QED-improved DGLAP equations

- at leading order in α and α_S

$$\frac{\partial q_i(x,\mu^2)}{\partial \log \mu^2} = \frac{\alpha_S}{2\pi}\int_x^1 \frac{dy}{y}\left\{P_{qq}(y)\ q_i(\frac{x}{y},\mu^2) + P_{qg}(y,\alpha_S)\ g(\frac{x}{y},\mu^2)\right\}$$

$$+ \frac{\alpha}{2\pi}\int_x^1 \frac{dy}{y}\left\{\tilde{P}_{qq}(y)\ e_i^2 q_i(\frac{x}{y},\mu^2) + P_{q\gamma}(y)\ e_i^2\gamma(\frac{x}{y},\mu^2)\right\}$$

$$\frac{\partial g(x,\mu^2)}{\partial \log \mu^2} = \frac{\alpha_S}{2\pi}\int_x^1 \frac{dy}{y}\left\{P_{gq}(y)\ \sum_j q_j(\frac{x}{y},\mu^2)\right.$$

$$\left. + P_{gg}(y)\ g(\frac{x}{y},\mu^2)\right\}$$

$$\frac{\partial \gamma(x,\mu^2)}{\partial \log \mu^2} = \frac{\alpha}{2\pi}\int_x^1 \frac{dy}{y}\left\{P_{\gamma q}(y)\ \sum_j e_j^2\ q_j(\frac{x}{y},\mu^2)\right.$$

$$\left. + P_{\gamma\gamma}(y)\ \gamma(\frac{x}{y},\mu^2)\right\}$$

where

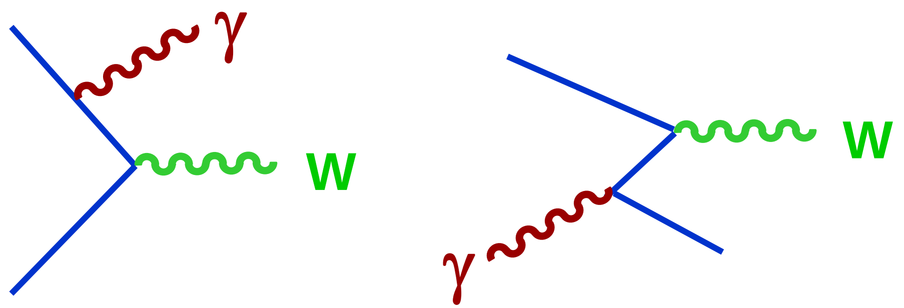
$$\tilde{P}_{qq} = C_F^{-1} P_{qq}, \qquad P_{\gamma q} = C_F^{-1} P_{gq},$$

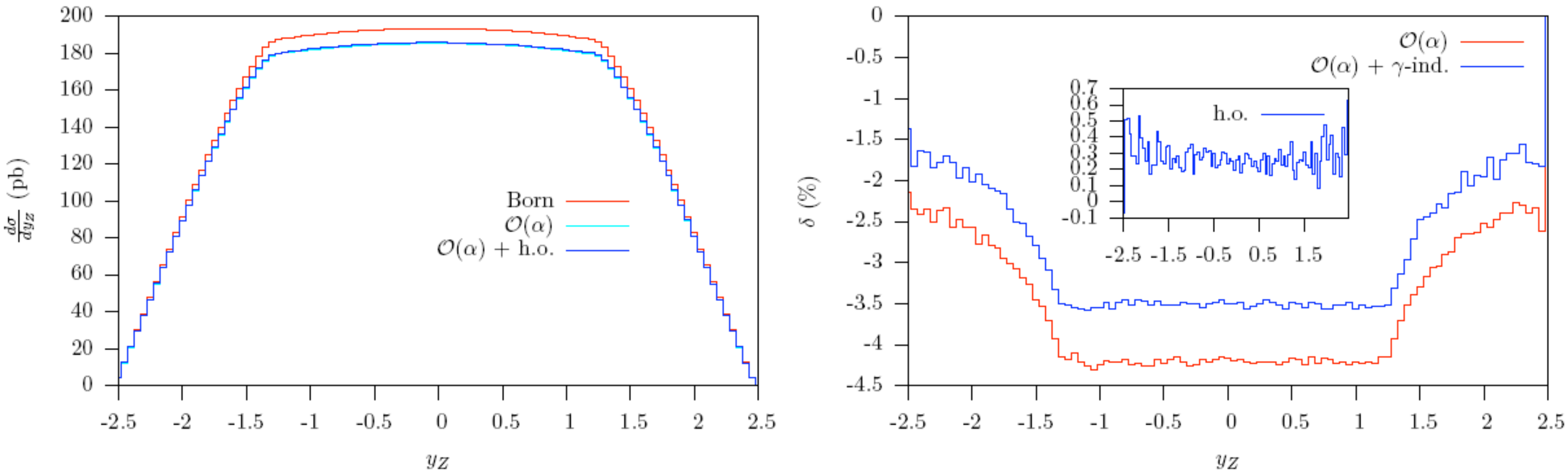
$$P_{q\gamma} = T_R^{-1} P_{qg}, \qquad P_{\gamma\gamma} = -\frac{2}{3}\sum_i e_i^2\ \delta(1-x)$$

- momentum conservation: $\int_0^1 dx\ x\left\{\sum_i q_i(x,\mu^2) + g(x,\mu^2) + \gamma(x,\mu^2)\right\} = 1$

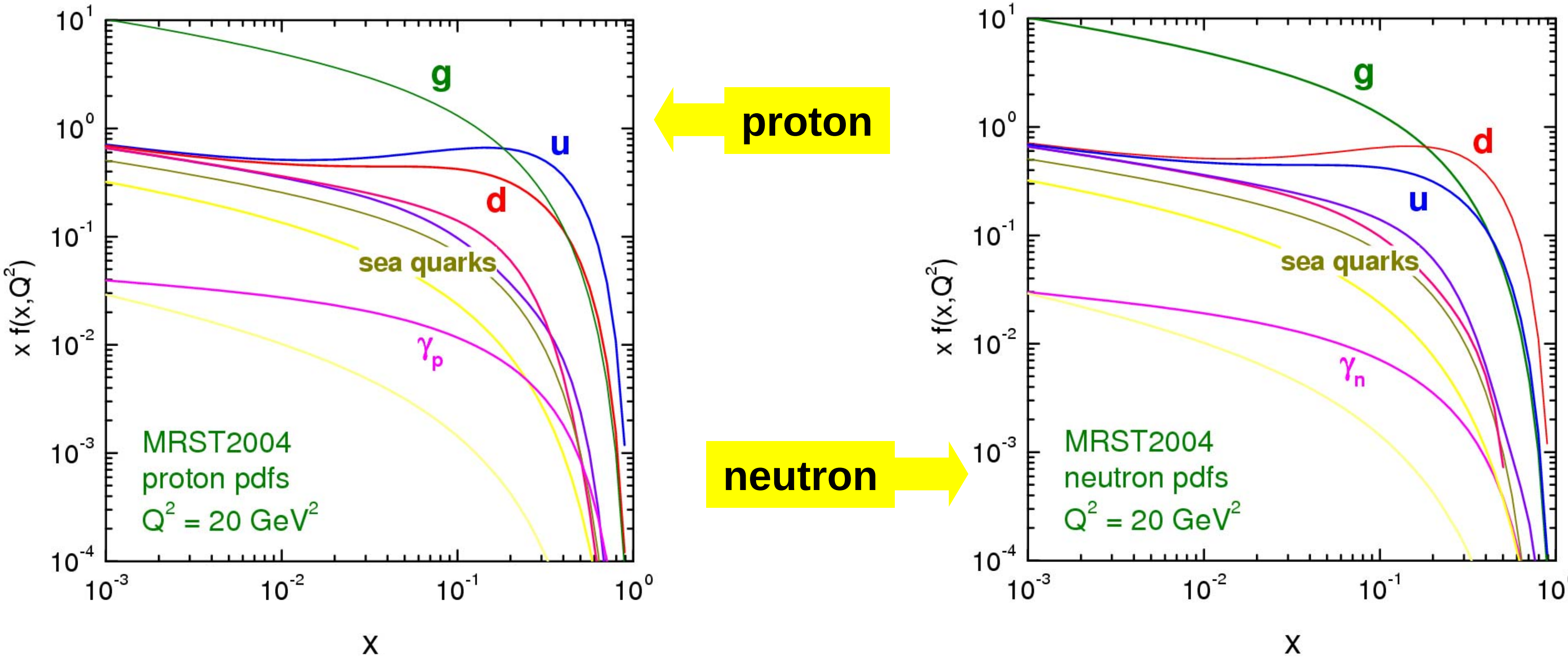
- effect on quark distributions negligible at small x where gluon contribution dominates DGLAP evolution
- at large x, effect only becomes noticeable (order percent) at very large Q^2, where it is equivalent to a shift in α_S of $\Delta\alpha_S \approx 0.0003$
- dynamic generation of photon parton distribution
- isospin violation: $u^p(x) \neq d^n(x)$ ($\rightarrow$ $\sin^2\theta_W$ a la NuTeV)
- MRST2004: first (and only?) consistent global pdf fit with QED corrections included [hep-ph/0411040]
- we will produce MSTW2008 version soon

- relevant for electroweak correction calculations for processes at Tevatron & LHC, e.g. W, Z, WH, …
  (see e.g. U. Baur et al, PRD 59 (2003) 013002)





Vicini et al, PDF4LHC, Sept 2008



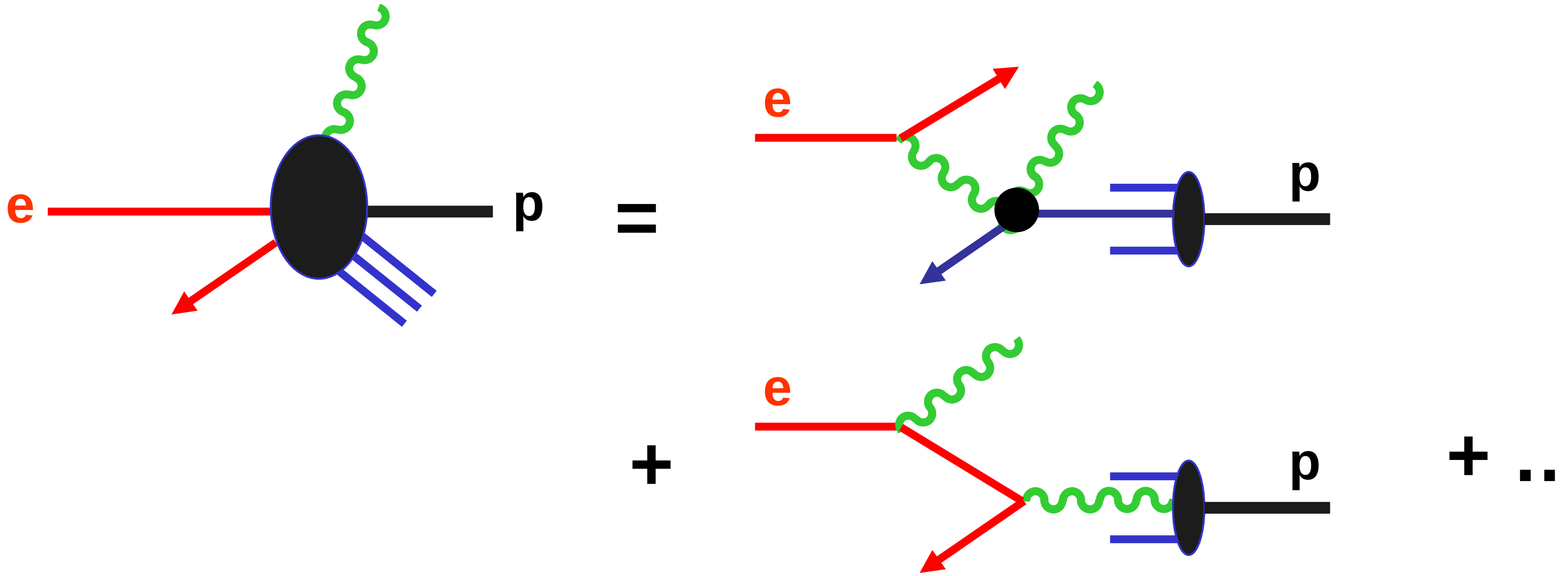
- Problem: definition of $\gamma(x,Q_0^2)$?

- MRST 2004 used:

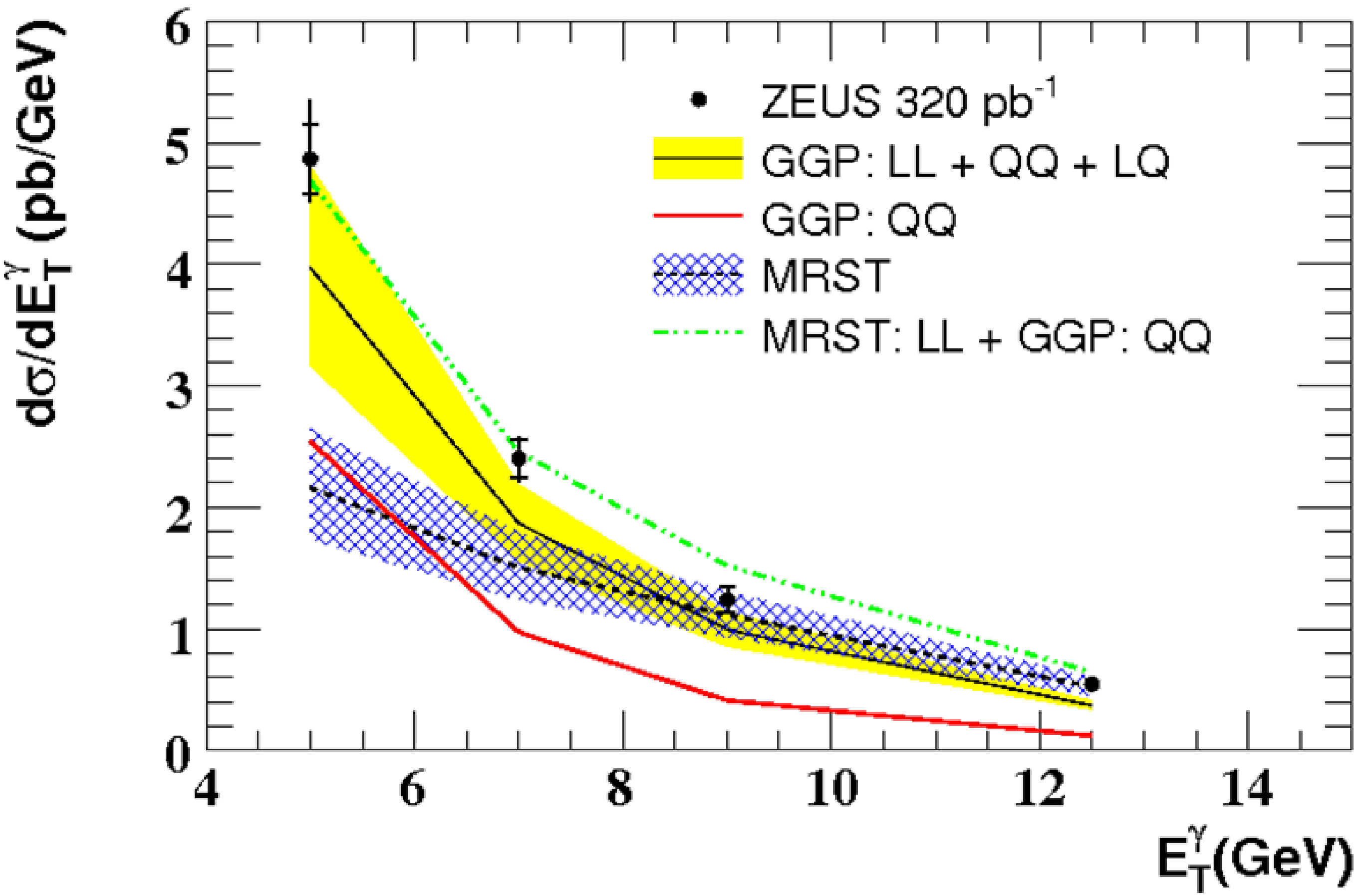
$$\gamma(x,Q_0^2) = \frac{\alpha}{2\pi} \sum_{q=u,d} e_q^2 \, P_{\gamma q}(x) * q_0(x) \; \log(Q_0^2/m_q^2)$$

… with m_q ~ 10 MeV (or ~300 MeV or …?!)

measurement of $\gamma_p(x,Q^2)$ at HERA?



- isolated hard photon production at HERA gets contribution from $\gamma(x,Q_0^2)$
- early ZEUS data used in MRST 2004 as cross check on photon pdf



GGP = Gehrmann-De Ridder, Gehrmann & Poulsen [Phys. Rev. Lett. 96 (132002) 2006]

QQ = hard photon emission off a DIS struck quark

MRST = e $\gamma \rightarrow$ e γ contribution using MRST 2004 QED pdfs

See presentation by Matthew Forrest (ZEUS) at DIS09: “Prompt-photon production in DIS”, and ZEUS publication to appear

extra slides

data sets used in fit

Data set	$N_{\text{pts.}}$
H1 MB 99 e^+p NC	8
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E665 μd F_2	53
SLAC ep F_2	37
SLAC ed F_2	38
NMC/BCDMS/SLAC F_L	31
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E866/NuSea pd/pp DY	15
NuTeV νN F_2	53
CHORUS νN F_2	42
NuTeV νN xF_3	45
CHORUS νN xF_3	33
CCFR $\nu N \to \mu\mu X$	86
NuTeV $\nu N \to \mu\mu X$	84
All data sets	**2743**

- Red = New w.r.t. MRST 2006 fit.

MSTW input parametrisation

At input scale $Q_0^2 = 1$ GeV^2:

$$xu_v = A_u\, x^{\eta_1}(1-x)^{\eta_2}(1+\epsilon_u\sqrt{x}+\gamma_u\, x)$$

$$xd_v = A_d\, x^{\eta_3}(1-x)^{\eta_4}(1+\epsilon_d\sqrt{x}+\gamma_d\, x)$$

$$xS = A_S\, x^{\delta_S}(1-x)^{\eta_S}(1+\epsilon_S\sqrt{x}+\gamma_S\, x)$$

$$x\bar{d}-x\bar{u} = A_\Delta\, x^{\eta_\Delta}(1-x)^{\eta_S+2}(1+\gamma_\Delta\, x+\delta_\Delta\, x^2)$$

$$xg = A_g\, x^{\delta_g}(1-x)^{\eta_g}(1+\epsilon_g\sqrt{x}+\gamma_g\, x)+A_{g'}\, x^{\delta_{g'}}(1-x)^{\eta_{g'}}$$

$$xs+x\bar{s} = A_+\, x^{\delta_S}(1-x)^{\eta_+}(1+\epsilon_S\sqrt{x}+\gamma_S\, x)$$

$$xs-x\bar{s} = A_-\, x^{\delta_-}(1-x)^{\eta_-}(1-x/x_0)$$

Note: 20 parameters allowed to go free for eigenvector PDF sets, *cf.* 15 for MRST sets

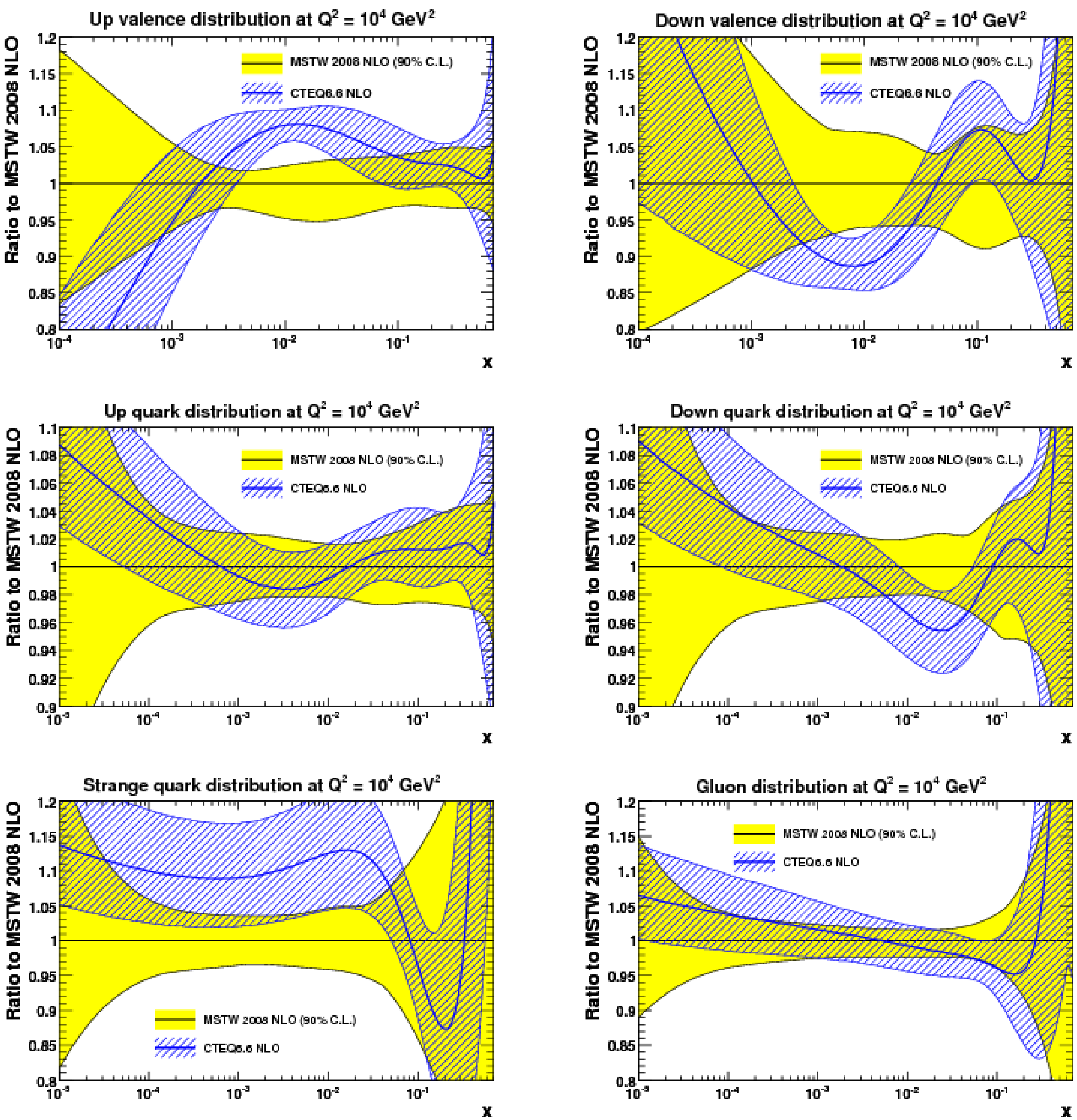
which data sets determine which partons?

Process	Subprocess	Partons	x range
$\ell^{\pm}\,\{p,n\} \to \ell^{\pm}\,X$	$\gamma^* q \to q$	$q, \bar{q}, g$	$x \gtrsim 0.01$
$\ell^{\pm}\,n/p \to \ell^{\pm}\,X$	$\gamma^*\,d/u \to d/u$	d/u	$x \gtrsim 0.01$
$pp \to \mu^+\mu^-\,X$	$u\bar{u}, d\bar{d} \to \gamma^*$	$\bar{q}$	$0.015 \lesssim x \lesssim 0.35$
$pn/pp \to \mu^+\mu^-\,X$	$(u\bar{d})/(u\bar{u}) \to \gamma^*$	$\bar{d}/\bar{u}$	$0.015 \lesssim x \lesssim 0.35$
$\nu(\bar{\nu})\,N \to \mu^-(\mu^+)\,X$	$W^* q \to q'$	$q, \bar{q}$	$0.01 \lesssim x \lesssim 0.5$
$\nu\,N \to \mu^-\mu^+\,X$	$W^* s \to c$	s	$0.01 \lesssim x \lesssim 0.2$
$\bar{\nu}\,N \to \mu^+\mu^-\,X$	$W^* \bar{s} \to \bar{c}$	$\bar{s}$	$0.01 \lesssim x \lesssim 0.2$
$e^{\pm}\,p \to e^{\pm}\,X$	$\gamma^* q \to q$	$g, q, \bar{q}$	$0.0001 \lesssim x \lesssim 0.1$
$e^+\,p \to \bar{\nu}\,X$	$W^+\,\{d,s\} \to \{u,c\}$	d, s	$x \gtrsim 0.01$
$e^{\pm}p \to e^{\pm}\,c\bar{c}\,X$	$\gamma^* c \to c,\ \gamma^* g \to c\bar{c}$	$c,\ g$	$0.0001 \lesssim x \lesssim 0.01$
$e^{\pm}p \to \text{jet} + X$	$\gamma^* g \to q\bar{q}$	g	$0.01 \lesssim x \lesssim 0.1$
$p\bar{p} \to \text{jet} + X$	$gg, qg, qq \to 2j$	g, q	$0.01 \lesssim x \lesssim 0.5$
$p\bar{p} \to (W^{\pm} \to \ell^{\pm}\nu)\,X$	$ud \to W, \bar{u}\bar{d} \to W$	$u, d, \bar{u}, \bar{d}$	$x \gtrsim 0.05$
$p\bar{p} \to (Z \to \ell^+\ell^-)\,X$	$uu, dd \to Z$	d	$x \gtrsim 0.05$

values of χ^2/N_{pts} for the data sets included in the MSTW2008 global fits

Data set	LO	NLO	NNLO
BCDMS μp F_2 [32]	165 / 153	182 / 163	170 / 163
BCDMS μd F_2 [102]	162 / 142	190 / 151	188 / 151
NMC μp F_2 [33]	137 / 115	121 / 123	115 / 123
NMC μd F_2 [33]	120 / 115	102 / 123	93 / 123
NMC $\mu n/\mu p$ [103]	131 / 137	130 / 148	135 / 148
E665 μp F_2 [104]	59 / 53	57 / 53	63 / 53
E665 μd F_2 [104]	49 / 53	53 / 53	63 / 53
SLAC ep F_2 [105, 106]	24 / 18	30 / 37	31 / 37
SLAC ed F_2 [105, 106]	12 / 18	30 / 38	26 / 38
NMC/BCDMS/SLAC F_L [32–34]	28 / 24	38 / 31	32 / 31
E866/NuSea pp DY [107]	239 / 184	228 / 184	237 / 184
E866/NuSea pd/pp DY [108]	14 / 15	14 / 15	14 / 15
NuTeV νN F_2 [37]	49 / 49	49 / 53	46 / 53
CHORUS νN F_2 [38]	21 / 37	26 / 42	29 / 42
NuTeV νN xF_3 [37]	62 / 45	40 / 45	34 / 45
CHORUS νN xF_3 [38]	44 / 33	31 / 33	26 / 33
CCFR $\nu N \to \mu\mu X$ [39]	63 / 86	66 / 86	69 / 86
NuTeV $\nu N \to \mu\mu X$ [39]	44 / 40	39 / 40	45 / 40
H1 MB 99 e^+p NC [31]	9 / 8	9 / 8	7 / 8
H1 MB 97 e^+p NC [109]	46 / 64	42 / 64	51 / 64
H1 low Q^2 96–97 e^+p NC [109]	54 / 80	44 / 80	45 / 80
H1 high Q^2 98–99 e^-p NC [110]	134 / 126	122 / 126	124 / 126
H1 high Q^2 99–00 e^+p NC [35]	153 / 147	131 / 147	133 / 147
ZEUS SVX 95 e^+p NC [111]	35 / 30	35 / 30	35 / 30
ZEUS 96–97 e^+p NC [112]	118 / 144	86 / 144	86 / 144
ZEUS 98–99 e^-p NC [113]	61 / 92	54 / 92	54 / 92
ZEUS 99–00 e^+p NC [114]	75 / 90	63 / 90	65 / 90
H1 99–00 e^+p CC [35]	28 / 28	29 / 28	29 / 28
ZEUS 99–00 e^+p CC [36]	36 / 30	38 / 30	37 / 30
H1/ZEUS ep $F_2^{\rm charm}$ [41–47]	110 / 83	107 / 83	95 / 83
H1 99–00 e^+p incl. jets [59]	109 / 24	19 / 24	—
ZEUS 96–97 e^+p incl. jets [57]	88 / 30	30 / 30	—
ZEUS 98–00 $e^\pm p$ incl. jets [58]	102 / 30	17 / 30	—
DØ II $p\bar{p}$ incl. jets [56]	193 / 110	114 / 110	123 / 110
CDF II $p\bar{p}$ incl. jets [54]	143 / 76	56 / 76	54 / 76
CDF II $W \to \ell\nu$ asym. [48]	50 / 22	29 / 22	30 / 22
DØ II $W \to \ell\nu$ asym. [49]	23 / 10	25 / 10	25 / 10
DØ II Z rap. [53]	25 / 28	19 / 28	17 / 28
CDF II Z rap. [52]	52 / 29	49 / 29	50 / 29
All data sets	**3066 / 2598**	**2543 / 2699**	**2480 / 2615**

MSTW2008(NLO) vs. CTEQ6.6



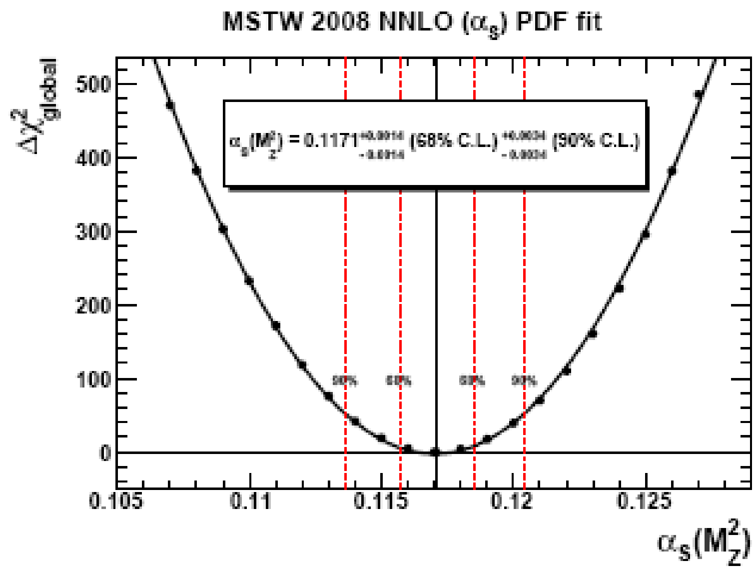
Note:

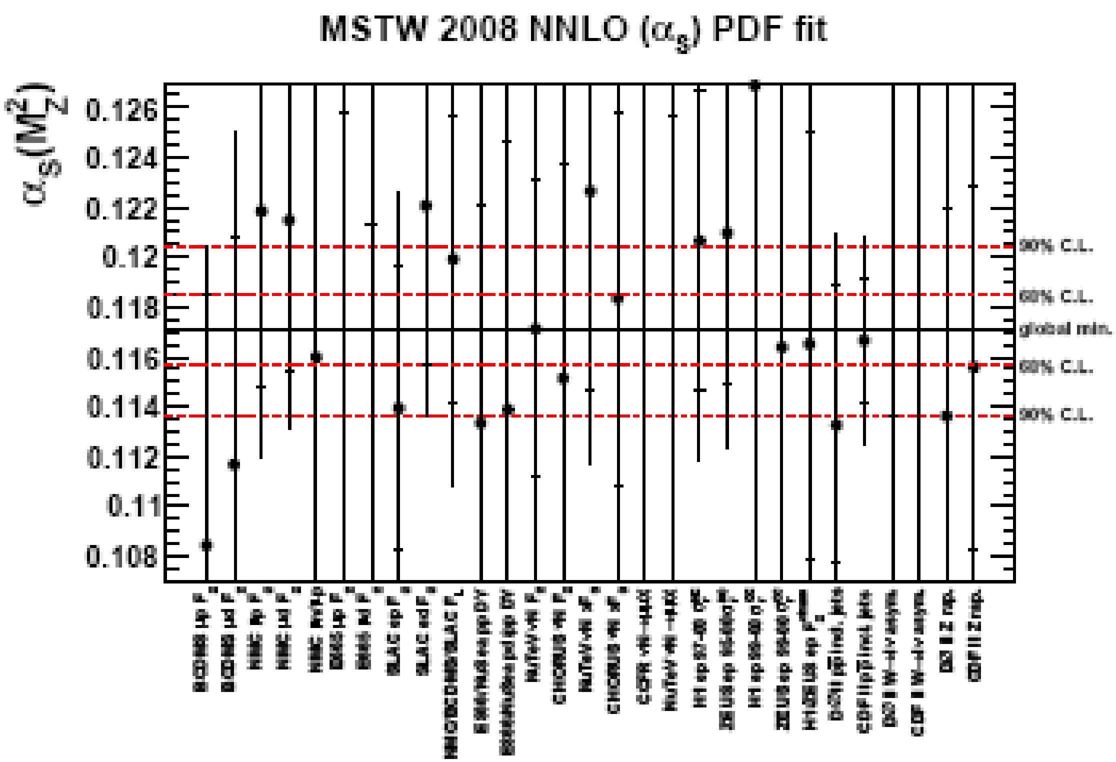
CTEQ error bands comparable with MSTW 90%cl set (different definition of tolerance)

CTEQ light quarks and gluons slightly larger at small x because of imposition of positivity on gluon at Q_0^2

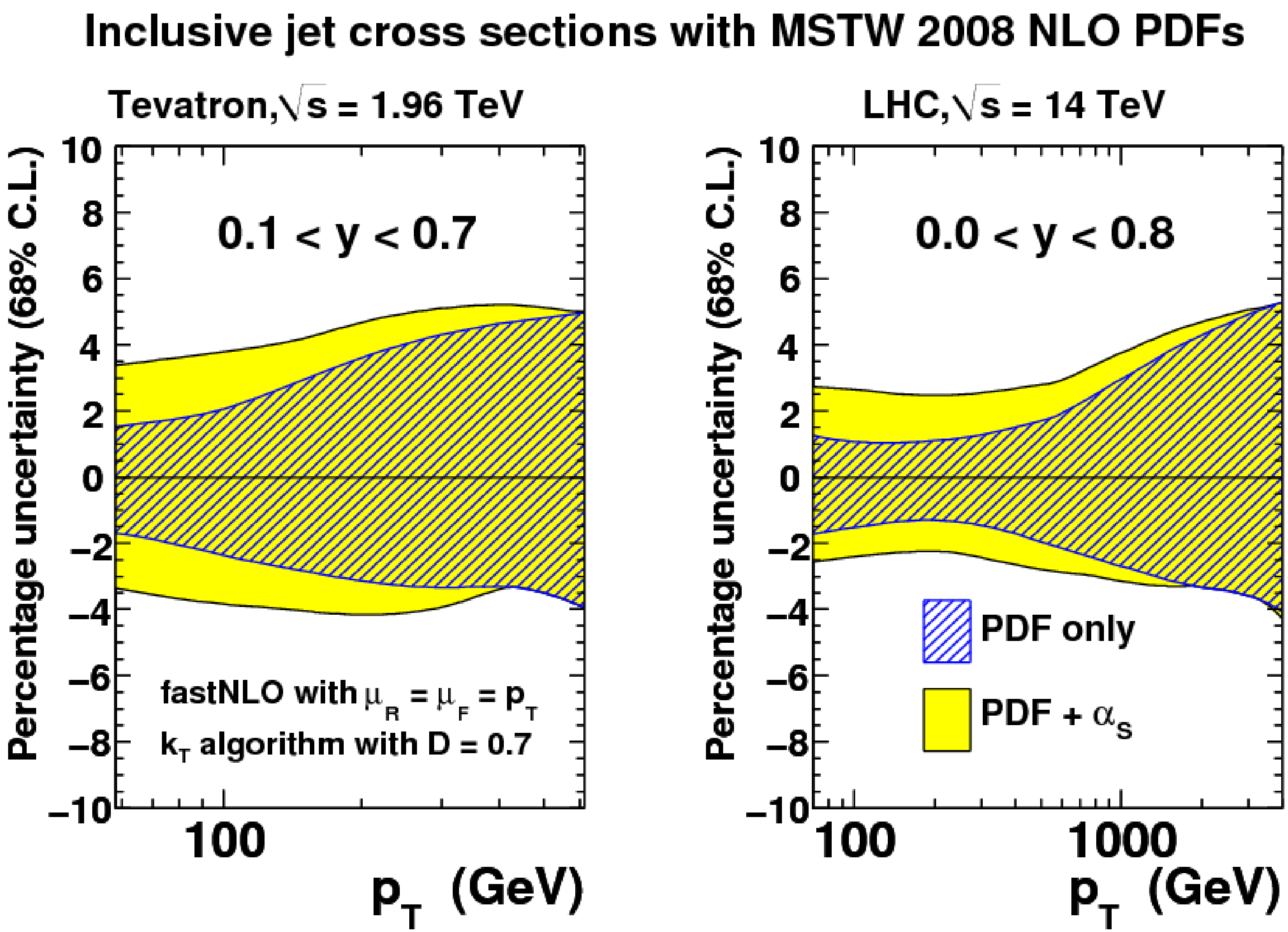
Also:

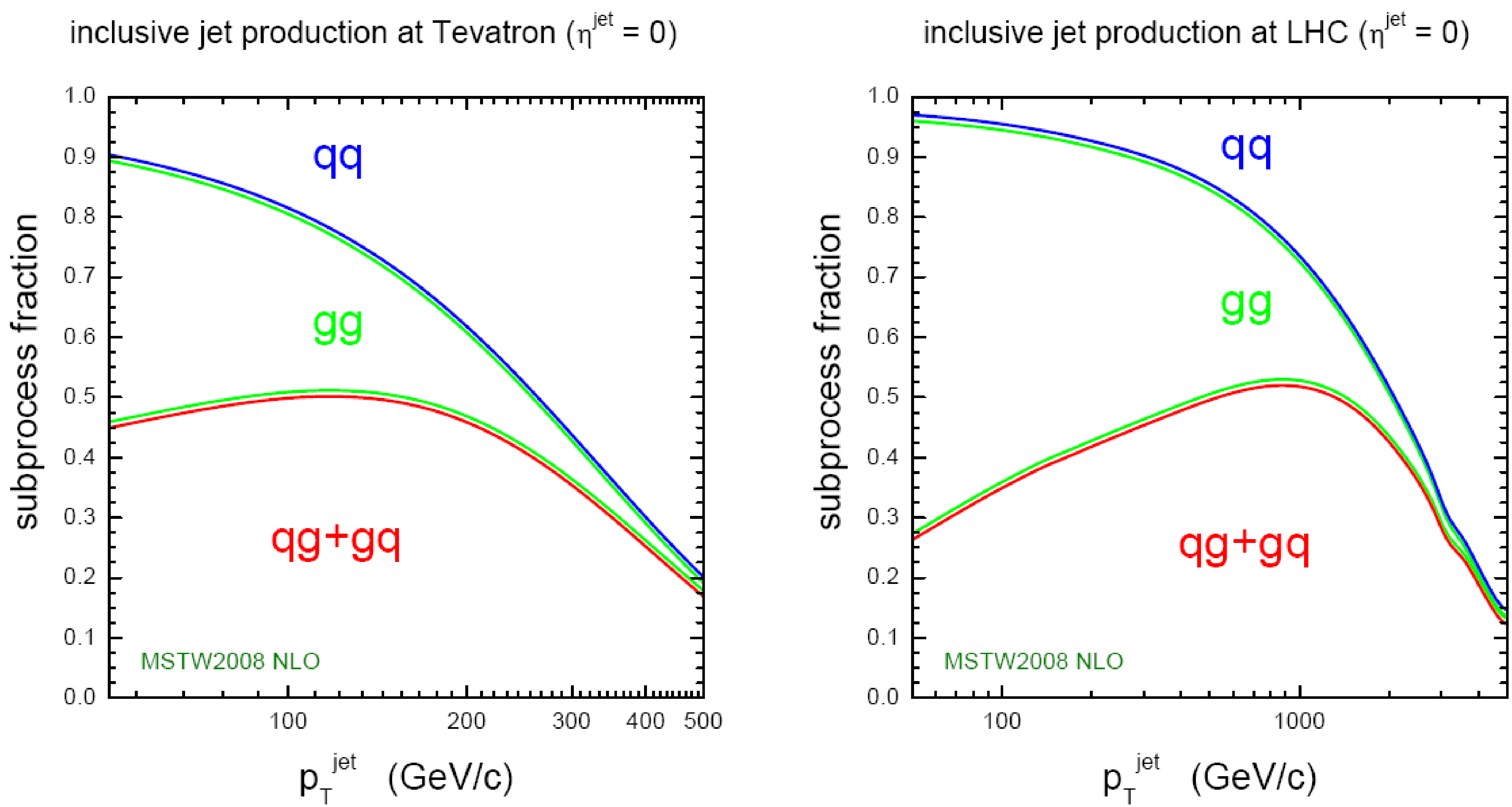
Alekhin et al
HERAPDF
NNPDF
…


MSTW 2008 NNLO (α_S) PDF fit
$\Delta\chi^2_{global}$
$\alpha_S(M_Z^2)$
0
100
200
300
400
500
0.105
0.11
0.115
0.12
0.125

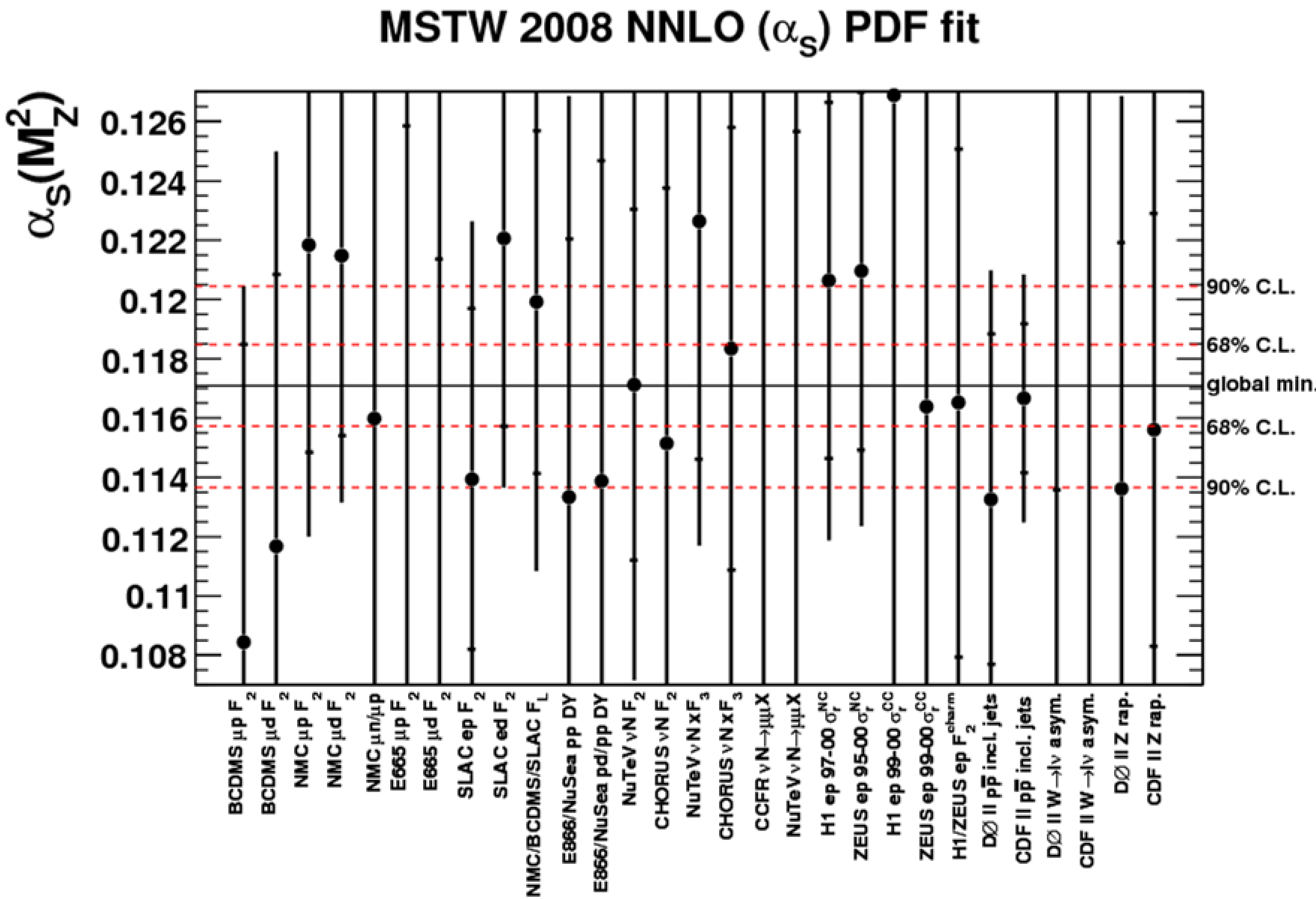

MSTW 2008 NNLO (α_S) PDF fit
$\alpha_S(M_Z^2)$
0.108
0.11
0.112
0.114
0.116
0.118
0.12
0.122
0.124
0.126

pdf, α_S uncertainties in jet cross sections

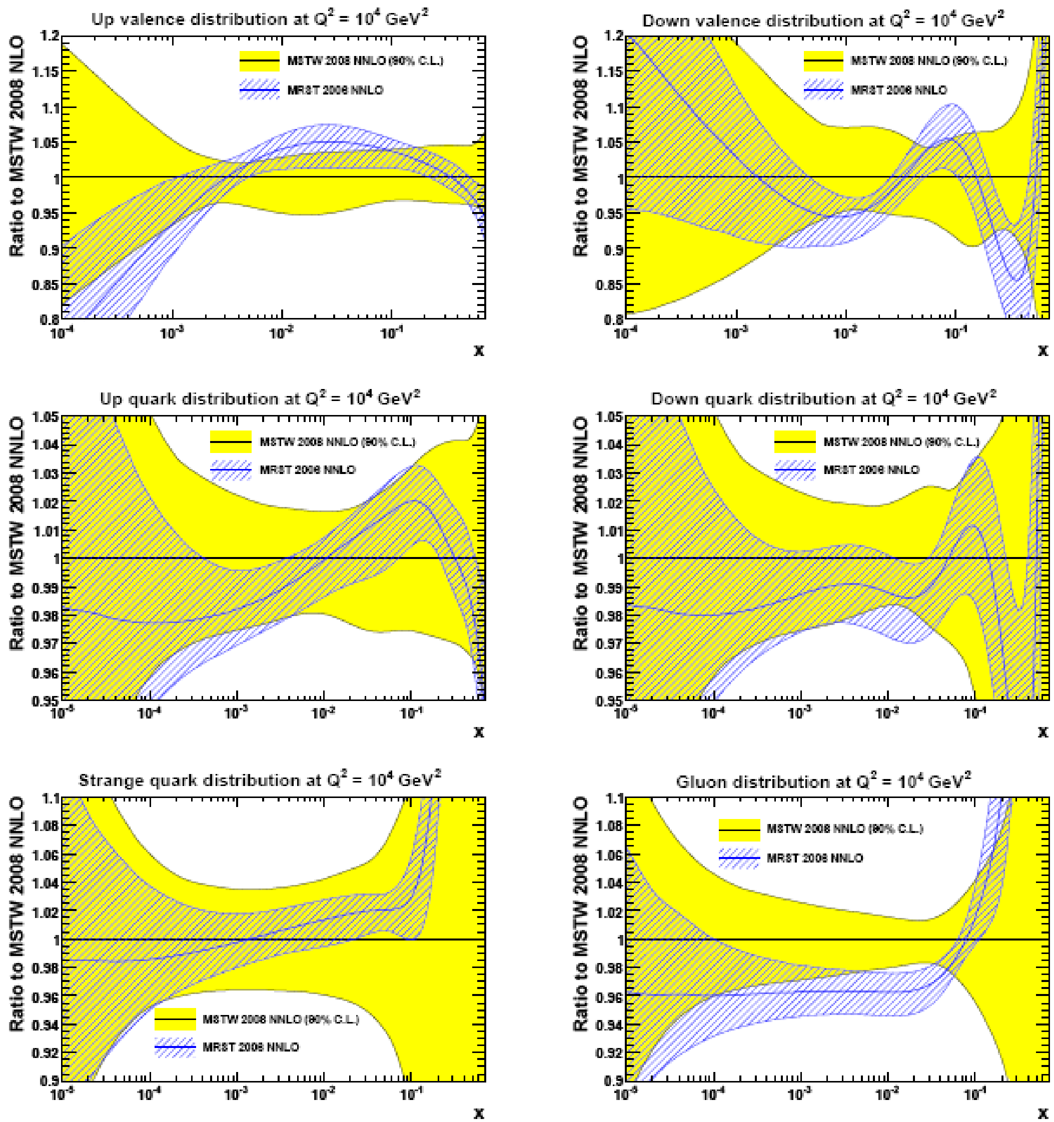




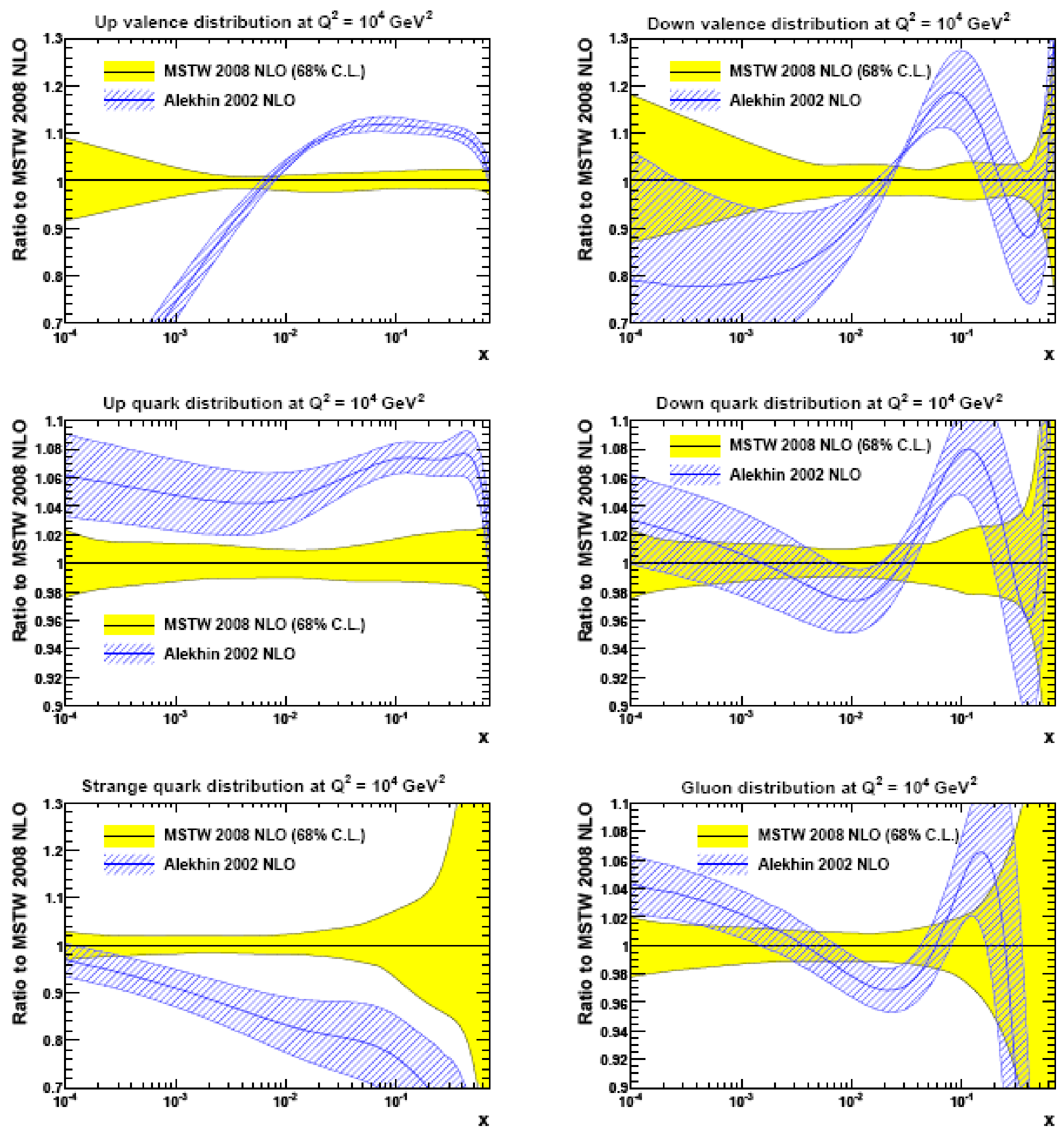
inclusive jet production at Tevatron (η^{jet} = 0)
inclusive jet production at LHC (η^{jet} = 0)
subprocess fraction
qq
gg
qg+gq
MSTW2008 NLO
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
100
200
300
400
500
1000
p_T^{jet} (GeV/c)


MSTW 2008 NNLO (α_S) PDF fit
$\alpha_S(M_Z^2)$
0.126
0.124
0.122
0.12
0.118
0.116
0.114
0.112
0.11
0.108
90% C.L.
68% C.L.
global min.
68% C.L.
90% C.L.
BCDMS μp F_2
BCDMS μd F_2
NMC μp F_2
NMC μd F_2
NMC μn/μp
E665 μp F_2
E665 μd F_2
SLAC ep F_2
SLAC ed F_2
NMC/BCDMS/SLAC F_L
E866/NuSea pp DY
E866/NuSea pd/pp DY
NuTeV νN F_2
CHORUS νN F_2
NuTeV νN xF_3
CHORUS νN xF_3
CCFR νN→μμX
NuTeV νN→μμX
H1 ep 97-00 σ_r^{NC}
ZEUS ep 95-00 σ_r^{NC}
H1 ep 99-00 σ_r^{CC}
ZEUS ep 99-00 σ_r^{CC}
H1/ZEUS ep F_2^{charm}
DØ II $p\bar{p}$ incl. jets
CDF II $p\bar{p}$ incl. jets
DØ II W→lν asym.
CDF II W→lν asym.
DØ II Z rap.
CDF II Z rap.

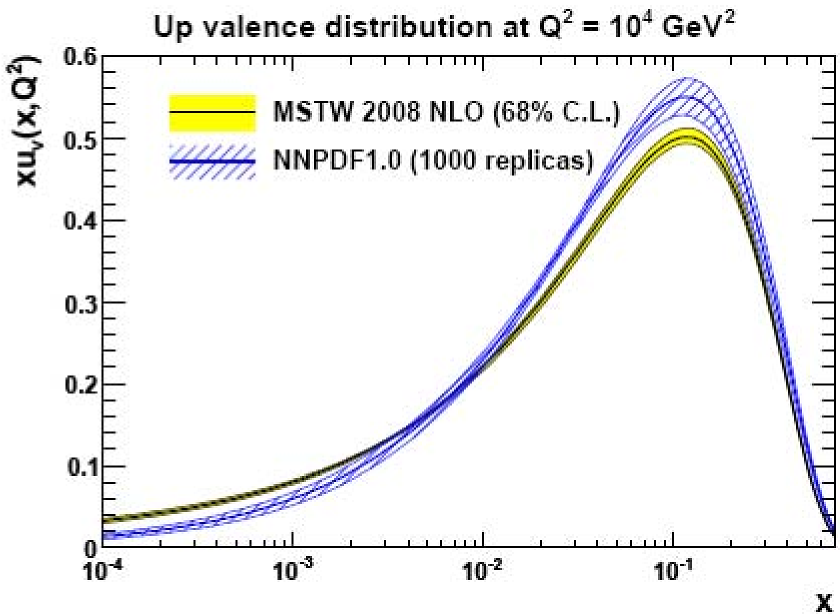
MSTW2008 *vs* MRST2006

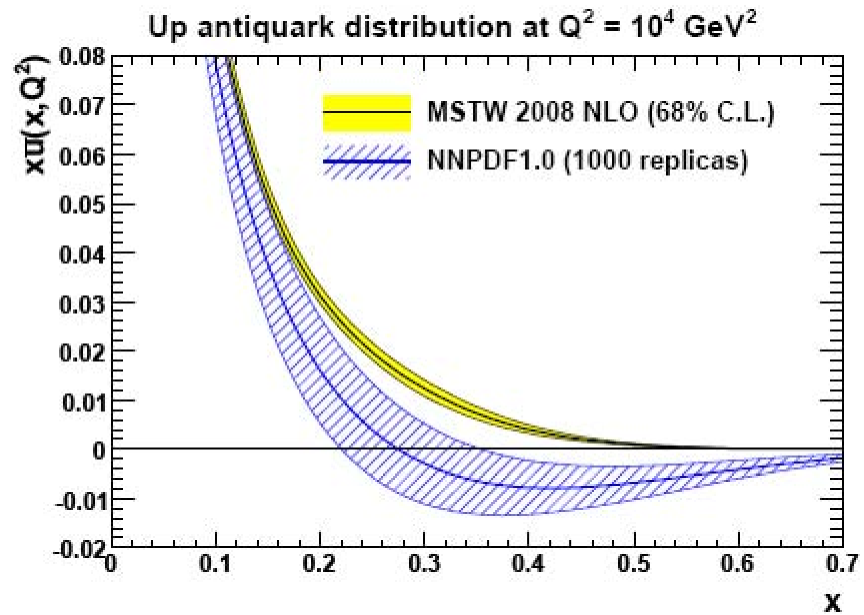


MSTW2008 *vs* Alekhin2002

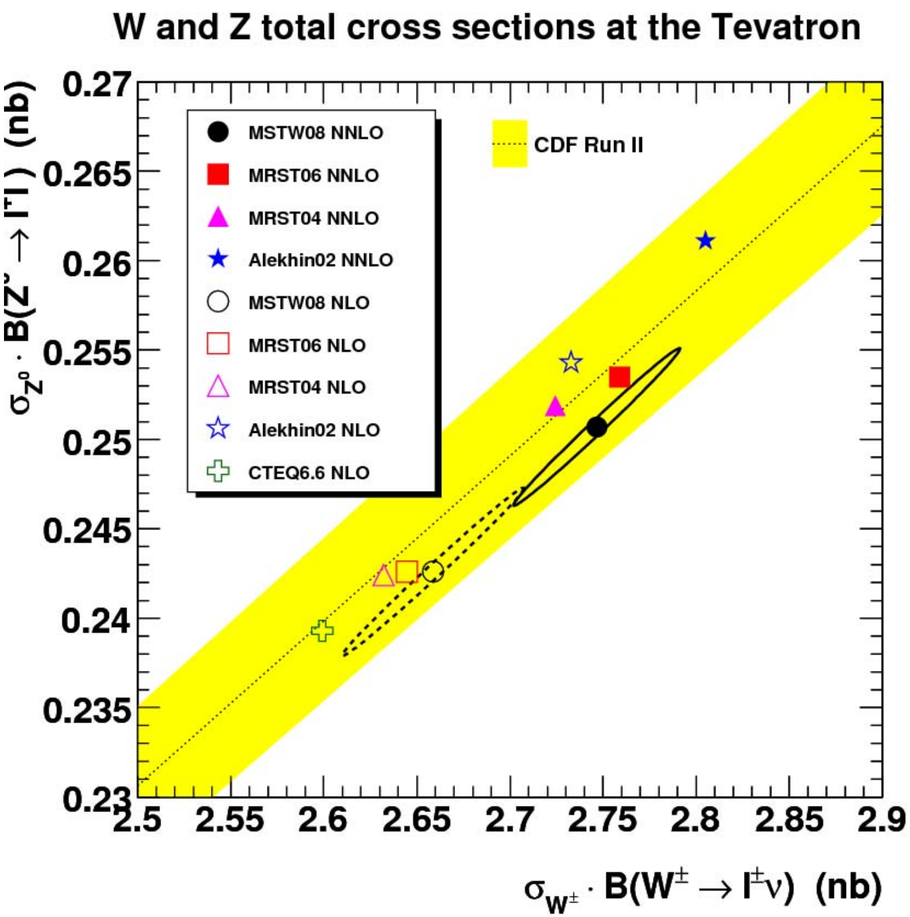


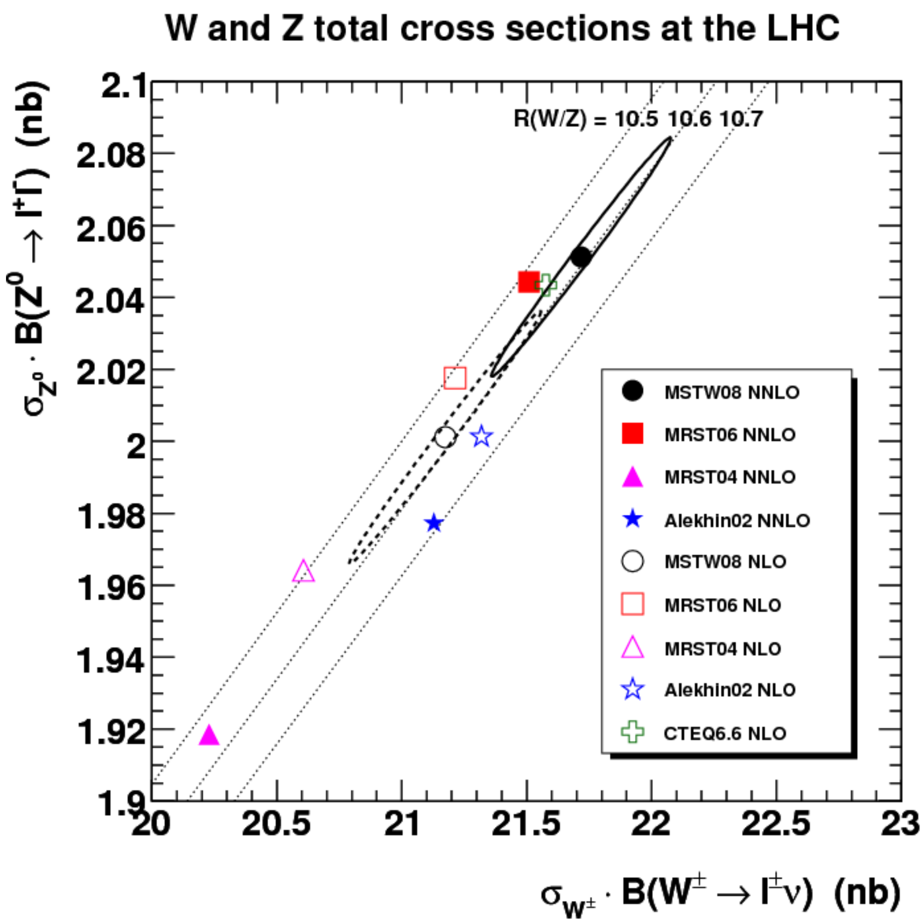
MSTW2008 *vs* NNPDF1.0





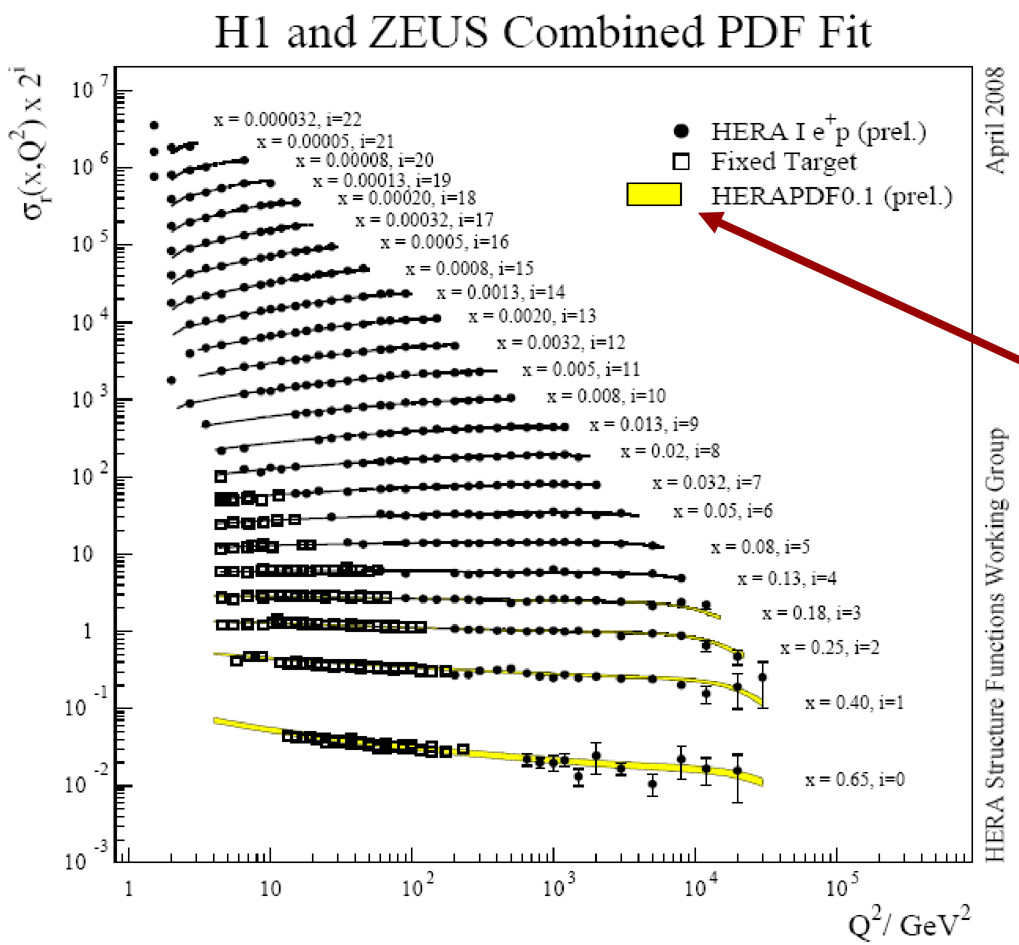
R(W/Z)=σ(W)/σ(Z) @ Tevatron & LHC





CDF 2007: R = 10.84 ± 0.15 (stat) ± 0.14 (sys)

scaling violations measured at HERA



NLO DGLAP fit

pdf uncertainties

$$\Delta\chi^2_{\text{global}} \equiv \chi^2_{\text{global}} - \chi^2_{\text{min}} = \sum_{i,j=1}^{n} H_{ij}(a_i - a_i^0)(a_j - a_j^0)$$

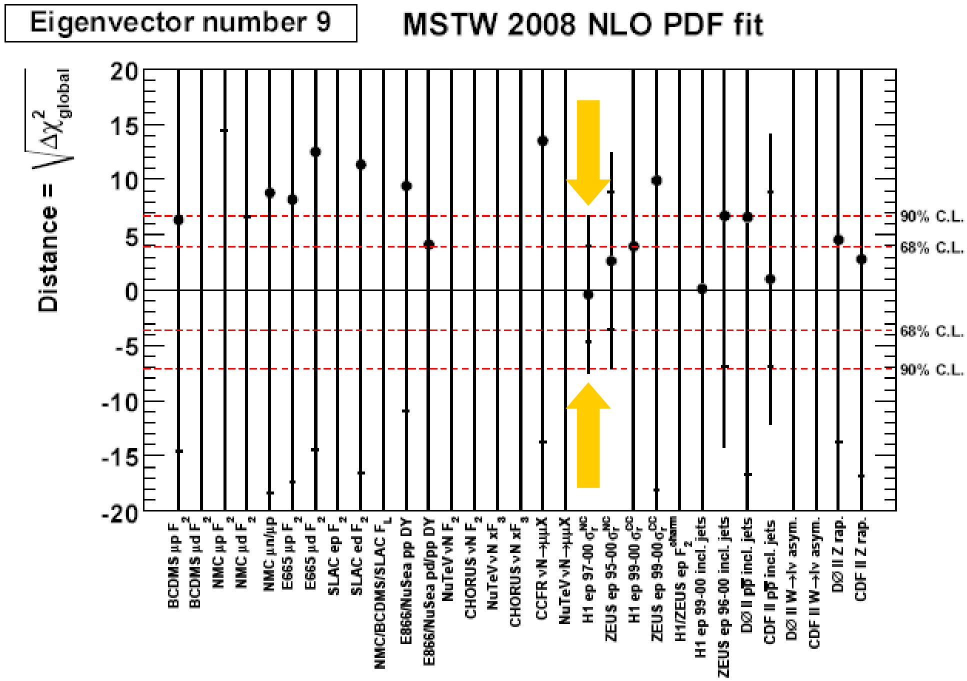
$$\vec{a} - \vec{a}^0 = \sum_{k=1,n} z_k \vec{e}_k \text{ where } (H^{-1})\cdot\vec{e}_k = \lambda_k \vec{e}_k,\ \vec{e}_k\cdot\vec{e}_l = \lambda_k \delta_{kl}$$

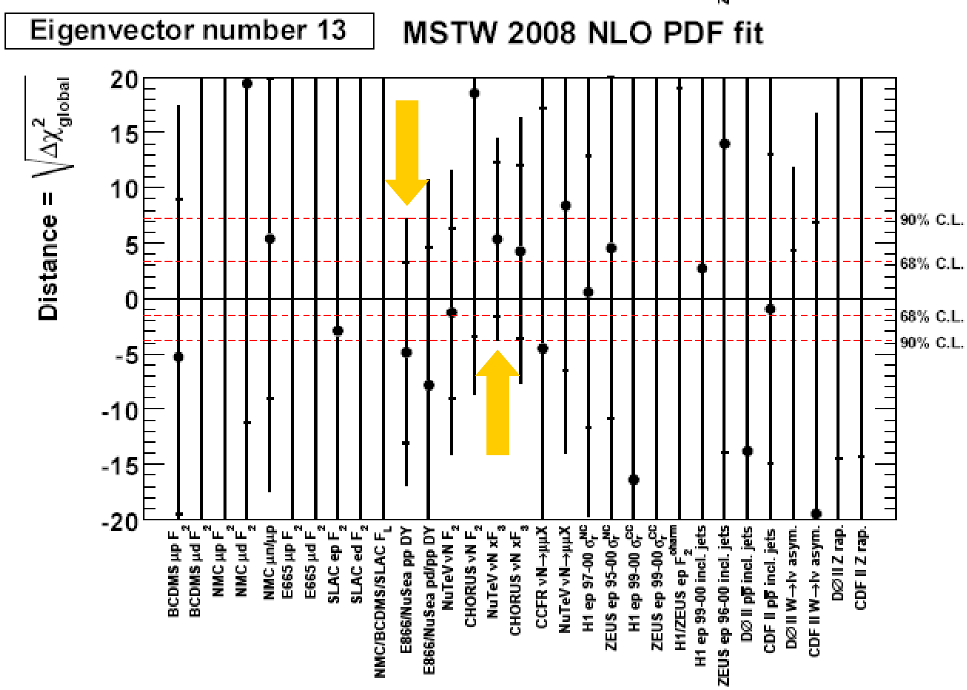
$$\text{then} \quad \Delta\chi^2_{\text{global}} = \sum_{k=1,n} z_k^2 \leq T^2 \quad (T = \text{tolerance})$$

this defines a set of n 'error' pdfs, spanning the allowed variation in the parameters, as determined by T:

$$\vec{a}(S_k^{\pm}) = \vec{a}^0 \pm T\vec{e}_k$$

rather than using a fixed value of T (*cf*. MRST, CTEQ), we determine the 'dynamic' tolerance for each eigenvector from the condition that all data sets should be described within their 68% or 90% or … confidence limit


Eigenvector number 9
MSTW 2008 NLO PDF fit
Distance = $\sqrt{\Delta\chi^2_{global}}$
90% C.L.
68% C.L.
68% C.L.
90% C.L.


Eigenvector number 13
MSTW 2008 NLO PDF fit
Distance = $\sqrt{\Delta\chi^2_{global}}$
90% C.L.
68% C.L.
68% C.L.
90% C.L.