

Updates of PDFs within the MSTW framework

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In collaboration with Lucian Harland-Lang, Patrick Motylinski and Alan Martin

and thanks to Ben Watt, Graeme Watt and James Stirling

Updates in Fits with the **MSTW** Framework.

I will present results on continuing updates in PDFs within the **MSTW** framework due to some theory improvements and a variety of new data sets, including most of the up-to-date **LHC** data. A new set of PDFs is very close to being finalised, with no significant changes expected to the PDFs shown here.

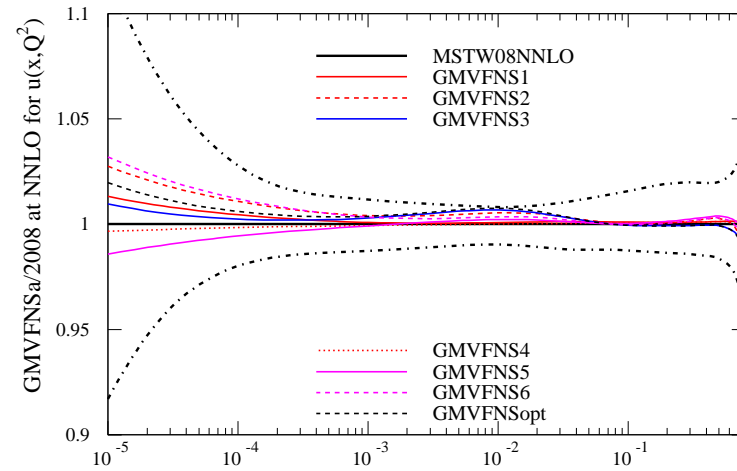
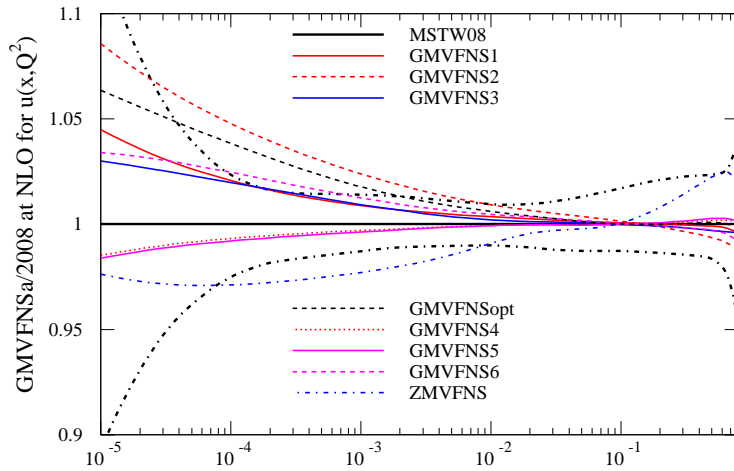
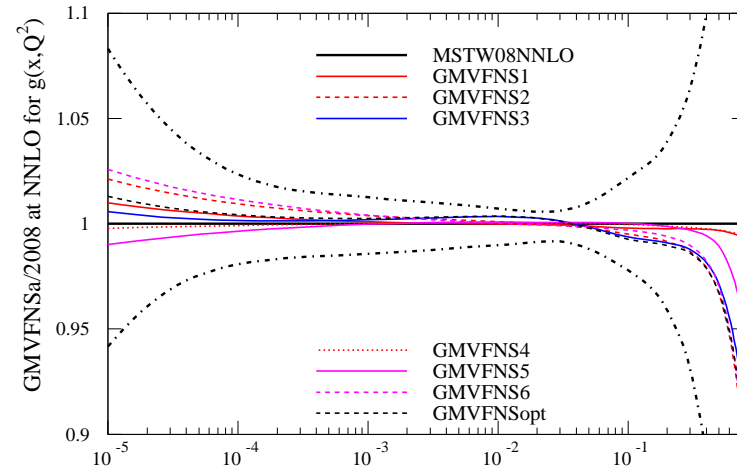
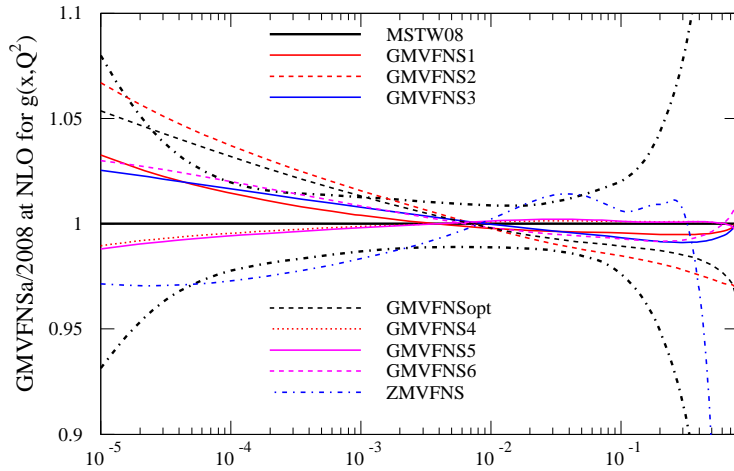
Changes in theoretical treatment or procedures.

Continue to use extended parameterisation with Chebyshev polynomials, and freedom in deuteron nuclear corrections (and heavy nuclear corrections), as in recent **MSTWCPdeut** study (**Eur.Phys.J. C73 (2013) 2318**) – change in $u_V - d_V$ distribution.

Now use “optimal” **GM-VFNS** choice (**Phys.Rev. D86 (2012) 074017**) which is smoother near to heavy flavour transition points (more so at **NLO**).

Correct dimuon cross-sections for missing small contribution, i.e. where charm is produced away from the interaction point. Previously assumed this was accounted for by acceptance corrections. Previous checks showed correction is a small effect on strange distribution.

Use **NMC** structure function data with $F_L(x, Q^2)$ correction very close to theoretical $F_L(x, Q^2)$ value. Very little effect.



Using smoother schemes leads to some change in PDFs, with tendency for slight increase at small x and slight decrease at high x for gluon. Much smaller at NNLO than NLO. No real change in $\alpha_S(M_z^2)$.

Errors multiplicative not additive. Using χ^2 definition

$$\chi^2 = \sum_{i=1}^{N_{pts}} \left(\frac{D_i + \sum_{k=1}^{N_{corr}} r_k \sigma_{k,i}^{corr} - T_i}{\sigma_i^{uncorr}} \right)^2 + \sum_{k=1}^{N_{corr}} r_k^2,$$

where $\sigma_{k,i}^{corr} = \beta_{k,i}^{corr} T_i$ and $\beta_{k,i}^{corr}$ are the percentage error. Additive would use $\sigma_{k,i}^{corr} = \beta_{k,i}^{corr} D_i$. Previously did this for all but normalisation uncertainty.

Effectively if

$$D_i + \sum_{k=1}^{N_{corr}} \beta_{k,i}^{corr} D_i \sim f * D_i \quad \text{or} \quad T_i - \sum_{k=1}^{N_{corr}} \beta_{k,i}^{corr} T_i \sim T_i / f,$$

then

$$\chi^2 \sim \left(\frac{D_i - T_i / f}{\sigma_i^{uncorr}} \right)^2 = \left(\frac{f * D_i - T_i}{f * \sigma_i^{uncorr}} \right)^2 \quad \text{rather than} \quad \chi^2 \sim \left(\frac{f * D_i - T_i}{\sigma_i^{uncorr}} \right)^2.$$

Use standard penalty for normalisation shifts, rather than previous quartic penalty. Extremely little difference.

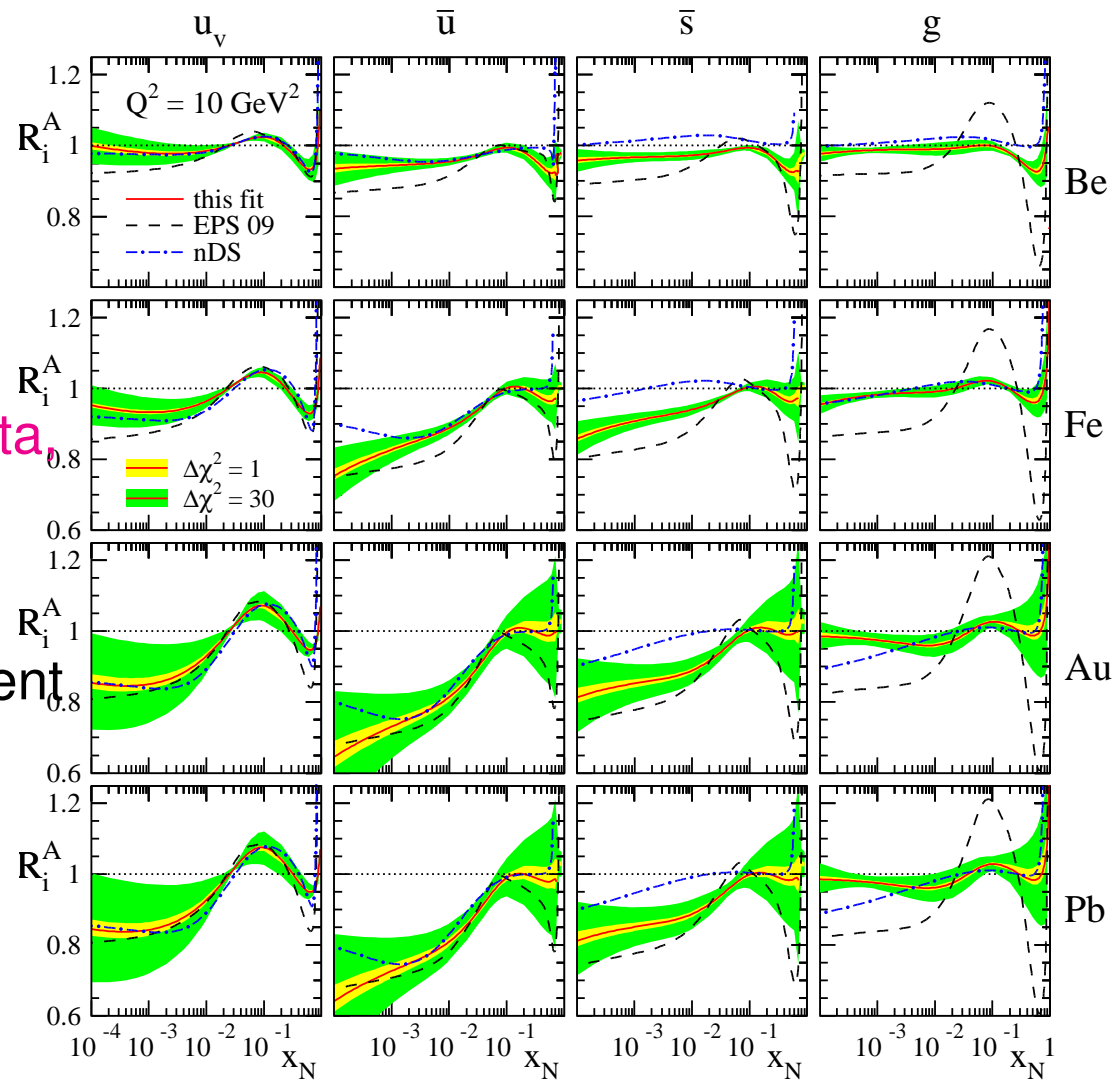
Strange branching ratio. Now avoid those determined by fits to dimuon data relying on PDF input. Also apply error which feeds into PDFs. Use $B_\mu = 0.092 \pm 10\%$ from [hep-ex/9708014](https://arxiv.org/abs/hep-ex/9708014). Fits prefer $B_\mu = 0.082 - 0.090 \pm 15\%$.

Have been using **de Florian, Sassot** nuclear corrections.

Update to more recent version, **de Florian, Sassot, Stratmann, Zurita**, Phys.Rev. D85 (2012) 074028.

Mainly similar, but different correction for small- x strange.

Improves global fit by ~ 25 units - **NuTeV F_2** , **HERA F_2** , **CMS jet**.



Only small change in strange quark, (no effect on **ATLAS, W,Z** fit).

Changes in data sets.

Replacement of HERA run I neutral and charged current data from HERA and ZEUS with combined data set with full treatment of correlated errors. Fit to data very good. Slightly better fit at NNLO.

Inclusion of HERA combined data on $F_2^c(x, Q^2)$. Fit quality $\sim 60-65$ for 52 points.

Inclusion of all direct published HERA $F_L(x, Q^2)$ measurements. Undershoot data a little at lower Q^2 , but χ^2 not much more than one per point.

No inclusion of separate run II H1 and ZEUS data yet. Wait for Run II combination.

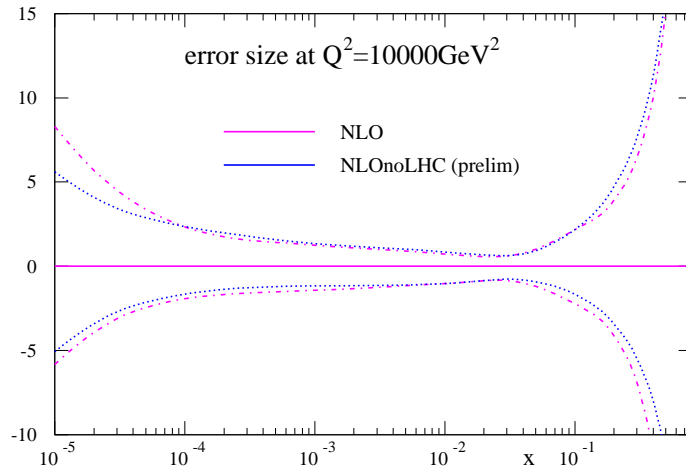
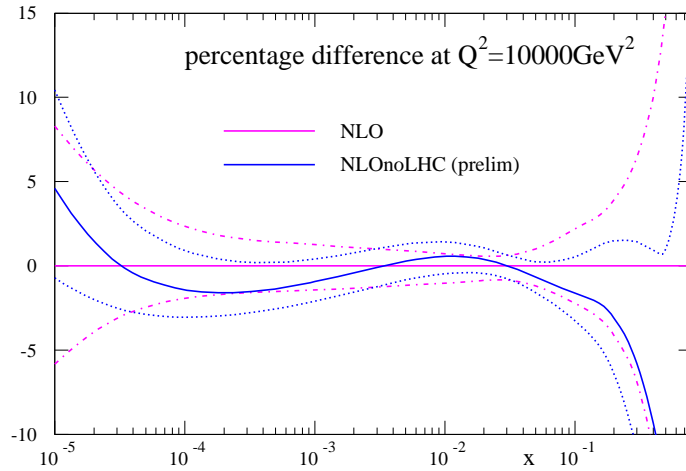
Inclusion of the CDF W -asymmetry data, the D0 electron asymmetry data $p_T > 25\text{GeV}$ based on 0.75 fb^{-1} and new D0 muon asymmetry data for $p_T > 25\text{GeV}$ based on 7.3 fb^{-1} .

Include final numbers for CDF Z -rapidity data – final numbers changed after MSTW2008 fit. (Also include very small photon contribution in theory.) Very little change.

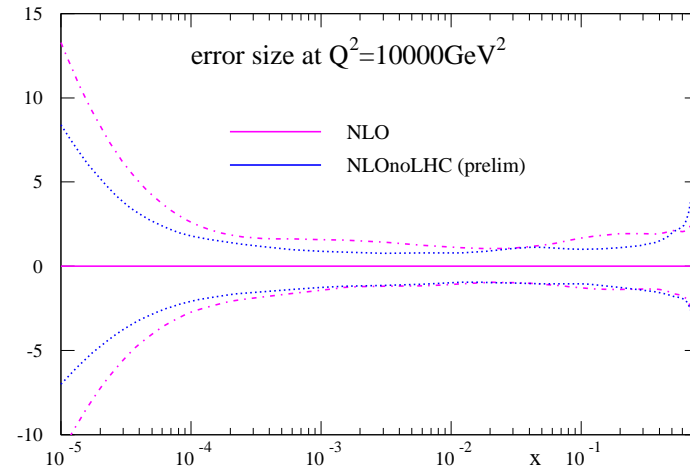
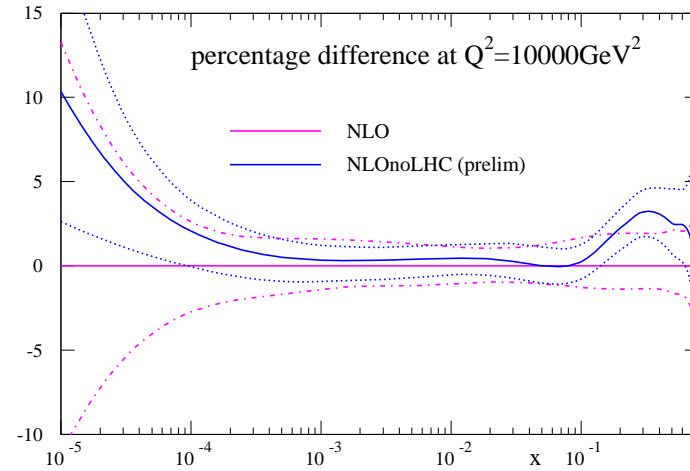
Not much change in PDFs (other than already seen in $u_V - d_V$).

At NLO $\alpha_S(M_Z^2) = 0.1199$ from 0.1202 and at NNLO $\alpha_S(M_Z^2) = 0.1180$ from 0.1171 .

Gluon at NLO

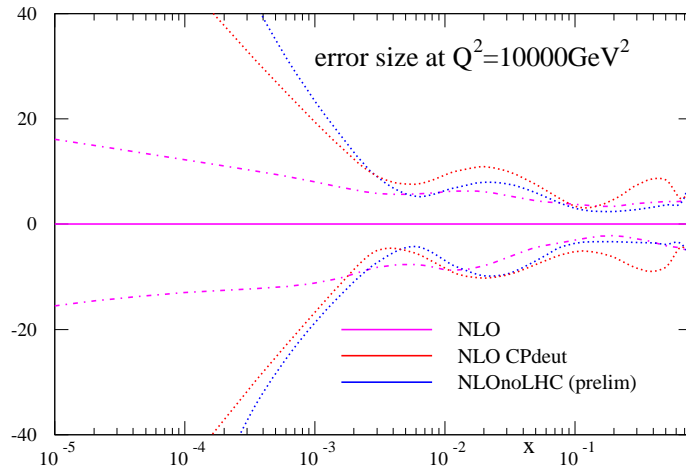
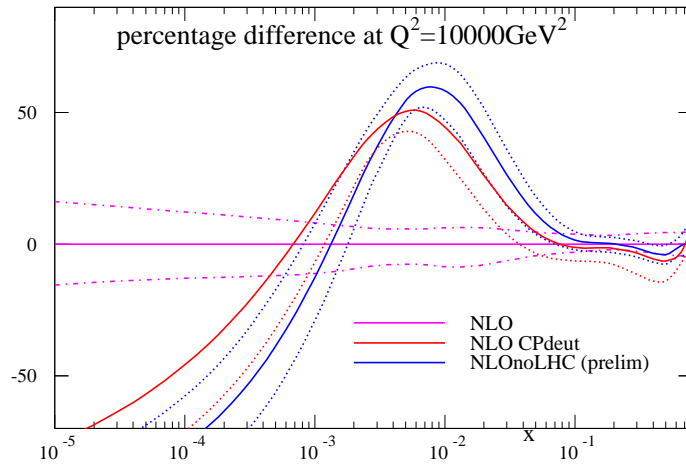


Light Quarks at NLO

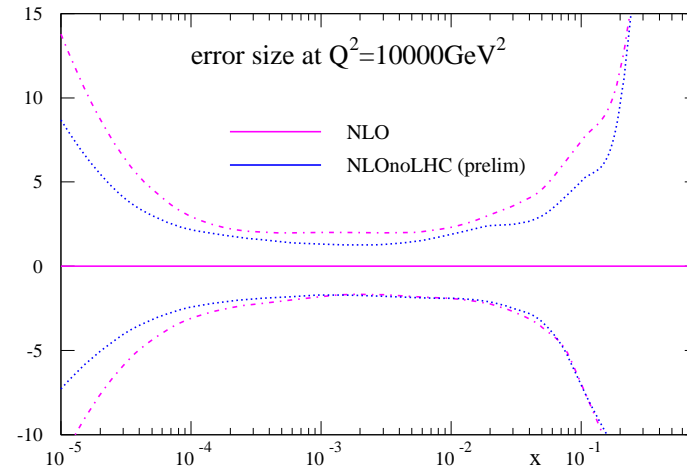
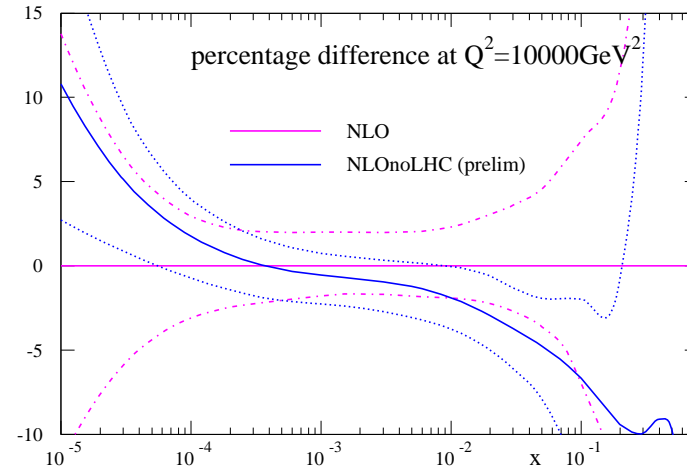


Change in **NLO** PDFs from non-**LHC** data updates. Increase in d at high x .

$x(u_V-d_V)$ at NLO



Strange at NLO

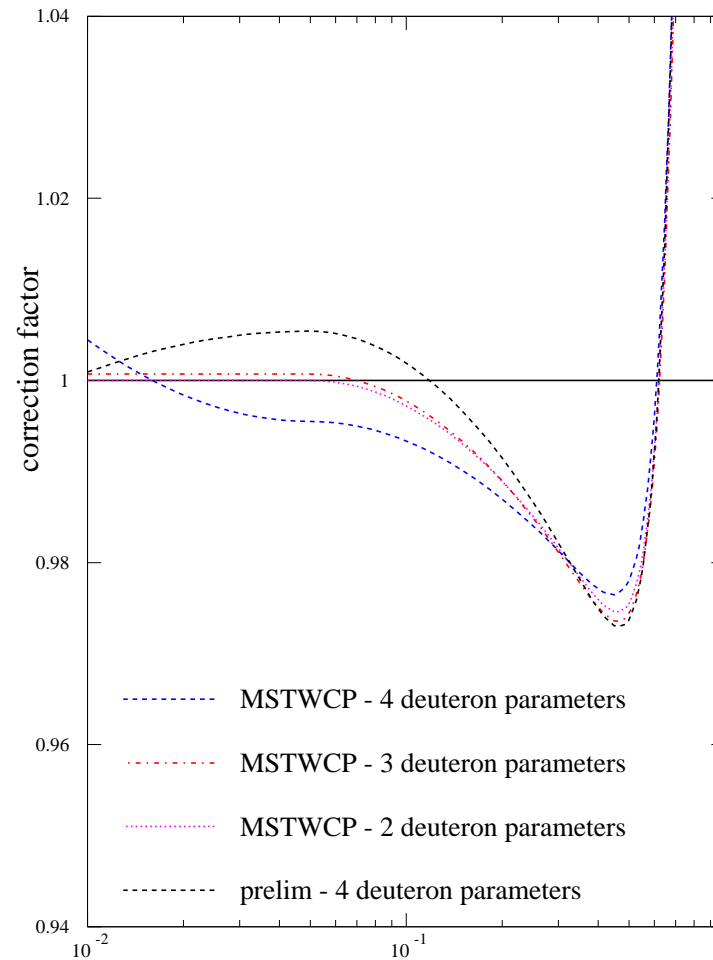


Change in **NLO** PDFs from non-**LHC** updates. Change in branching ratio for dimuon data not incorporated.

Result for fitted deuteron correction.

Previously big improvement in fit for **MSTWCP_{deut}**, but not exactly as expected at lower x .

Now more like that expected, and **4** parameters left free at **NLO** (and now **NNLO**). Uncertainty of about **0.5 – 1%**. Feeds into PDF uncertainty.



LHC data on $W,Z, t\bar{t}$

Now with Harland-Lang and Motylinski using APPLGrid – MCFM and DNNLO/FEWZ include the ATLAS W,Z rapidity data directly in the fit.

Before inclusion $\chi^2 \sim 1.6$ per point at NLO and actually $\chi^2 \sim 2$ per point at NNLO.

Inclusion leads some extra improvement at NLO, $\chi^2 \sim 1.3$, strongest pull on gluon PDF. Also goes to $\chi^2 \sim 1.3$ at NNLO. The most obvious change is in the strange quark.

$W^+ - W^-$ asymmetry no longer an issue at all both for ATLAS and CMS asymmetry data. Slightly better at NLO.

Include LHCb data on W^+, W^- , and $Z \rightarrow e^+e^-$. Both predicted/fit well at NLO. For the latter theory a bit low at NNLO at $y \sim 3.5$. Not evident in preliminary $Z \rightarrow \mu^+\mu^-$ data with higher precision.

Include CMS data on $Z \rightarrow e^+e^-$, and ATLAS high mass Drell-Yan data. Again both predicted/fit well.

Include data on $\sigma_{t\bar{t}}$ from Tevatron (combined cross section measurement from D0 and CDF), and all published data from ATLAS and CMS for 7TeV and one point at 8TeV. Use $m_t = 172.5 \text{ GeV}$ (value used in Tevatron combination) with an error of 1 GeV, with χ^2 penalty applied. Predictions and fit good, with NLO preferring masses slightly below $m_t = 172.5 \text{ GeV}$ and NNLO masses slightly above.

Fit CMS double differential Drell Yan data extending to low mass. NNLO fits enormously better than NLO at lowest mass $\sim 20 - 45 \text{ GeV}$.

LHC data on jets

At **NLO** also include **CMS** data together with **ATLAS 7 TeV + 2.76 TeV** data. Use **ATLAS/HERAPDF** study cuts, which eliminate lowest two p_T points in each bin and some highest p_T points.

The **ATLAS** $\chi^2 = 107/116$ and **CMS** $\chi^2 = 143/133$ before included directly – comparable to the best of the PDFs of other groups.

Simultaneous fit of **CMS** data together with **ATLAS 7 TeV + 2.76 TeV** leads to some improvement for **CMS**, and a small amount for **ATLAS**. The two experiments seem extremely compatible.

CMS inclusive jet data - updated. Previously the single pion uncertainties all correlated. Decision within collaboration made to decorrelate single pion systematics, i.e. to split the single pion source into 5 parts. Lowers χ^2 significantly, but no real change in PDFs. Allows slightly higher α_S .

At **NLO** final extracted $\alpha_S(M_Z^2) = 0.1199$.

LHC jets not included at **NNLO**.

Fit quality for LHC data at NLO

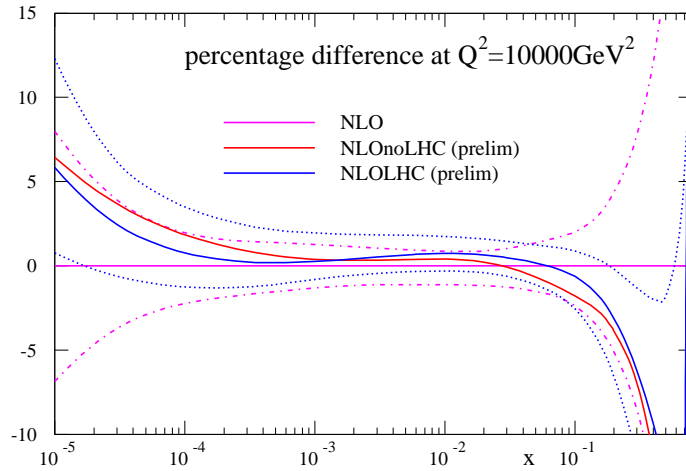
data set	N_{pts}	CPdeut	no LHC	prelim
ATLAS jets (2.76TeV+7TeV)	116	107	107	106
CMS jets (7TeV)	133	140	143	138
ATLAS W^+, W^-, Z	30	47	44	39
CMS W asymm $p_T > 35\text{GeV}$	11	9	16	7
CMS asymm $p_T > 25\text{GeV}, 30\text{GeV}$	24	9	17	7
LHCb $Z \rightarrow e^+e^-$	9	13	13	13
LHCb W asymm $p_T > 20\text{GeV}$	10	12	14	12
CMS $Z \rightarrow e^+e^-$	35	21	22	20
ATLAS High mass DY	13	20	20	21
TeV, ATLAS, CMS $\sigma_{t\bar{t}}$	13	8	10	7
CMS Low-high mass DY	132	385	396	373

ATLAS W, Z data constrains the gluon as do $\sigma_{t\bar{t}}$ and CMS $Z \rightarrow e^+e^-$ data.

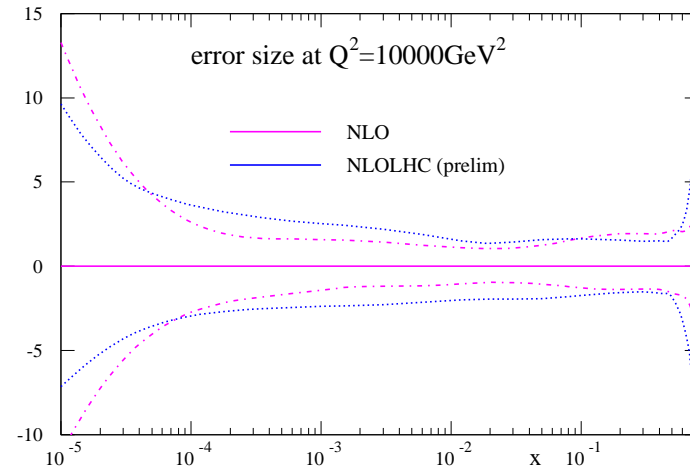
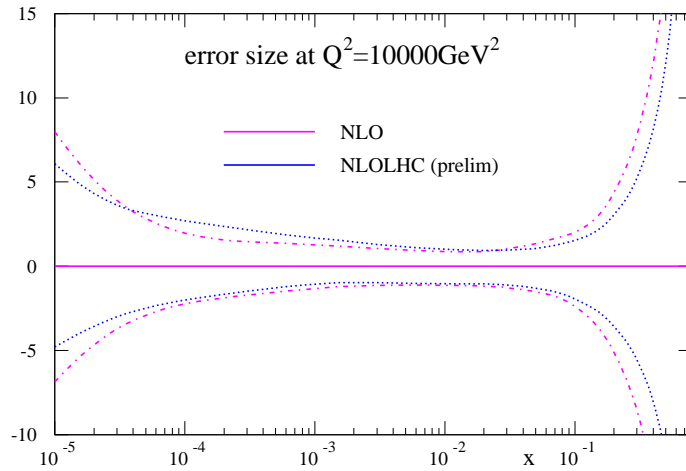
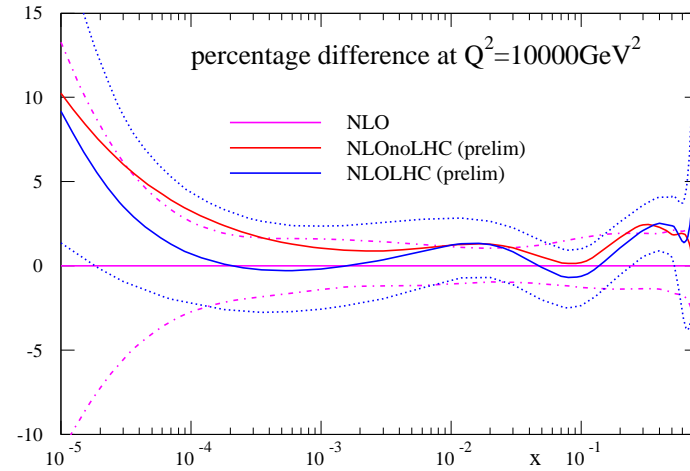
CMS W asymm. data constrains some flavour decomposition.

Fit CMS double differential low and high mass Drell Yan data. No real change in PDFs. Fit very poor.

Gluon at NLO

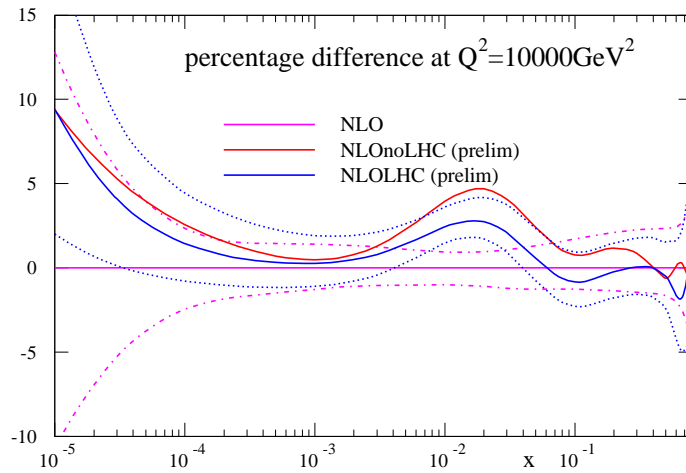


Light quarks at NLO

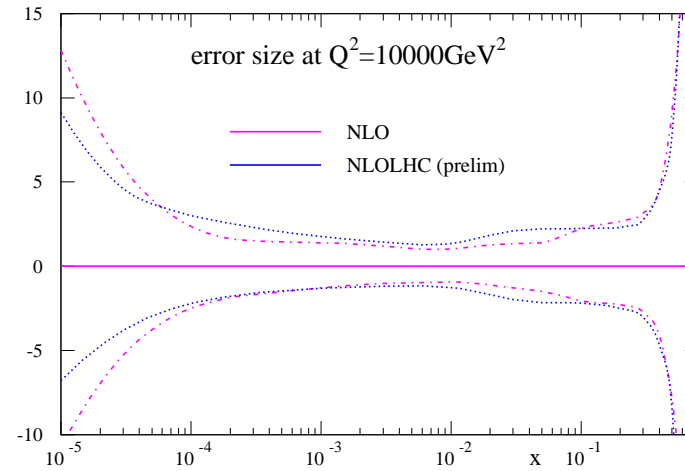
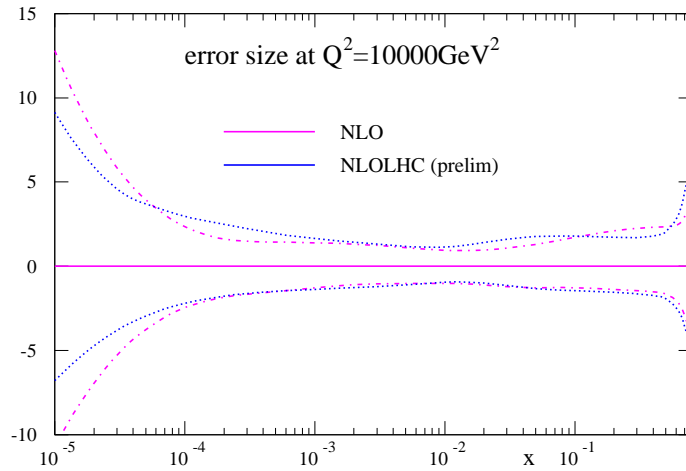
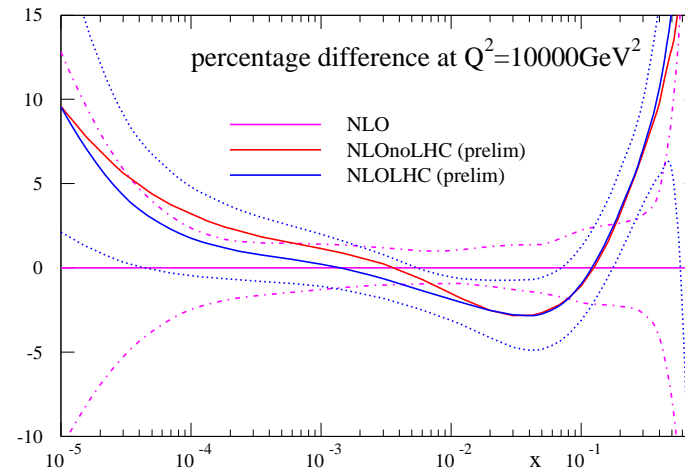


Change in **NLO** PDFs from all, including **LHC** data updates. (*Not absolutely final version*)

Up quark at NLO

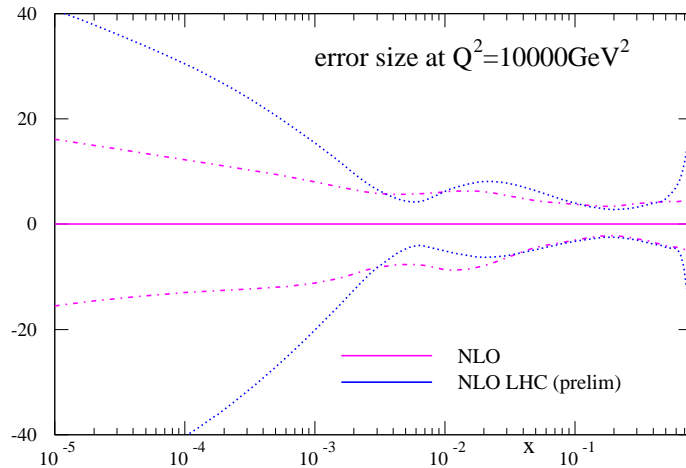
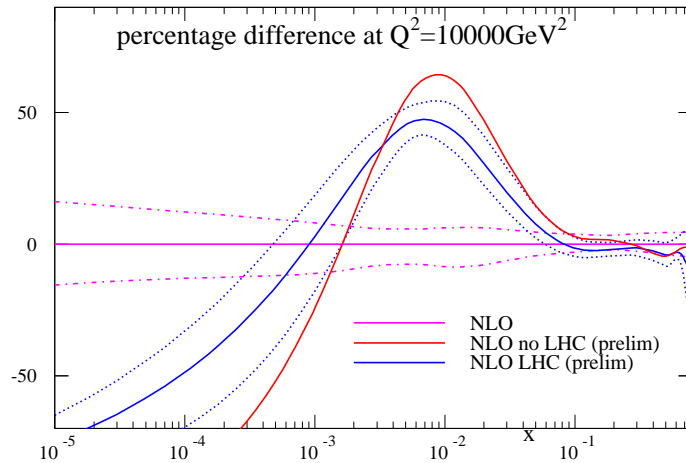


Down quark at NLO

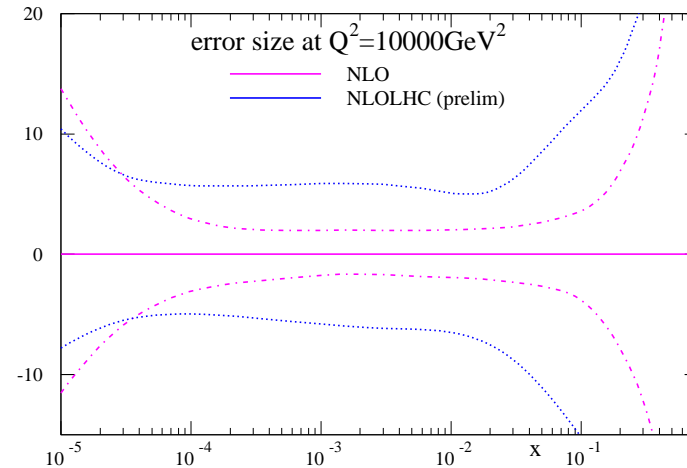
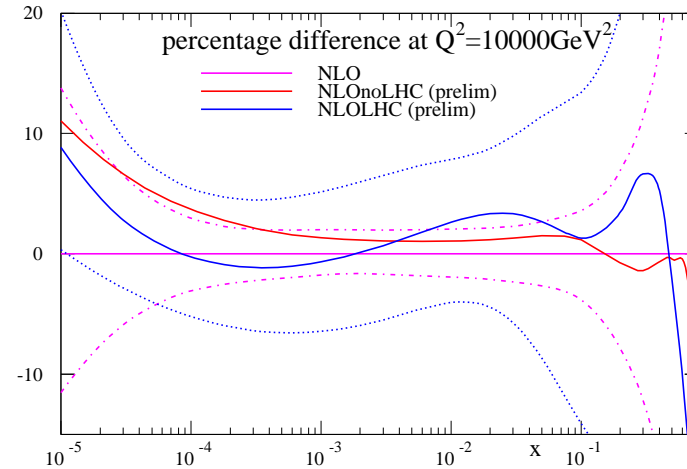


Change in **NLO** PDFs from all, including **LHC** data updates. (*Not absolutely final version*)

$x(u_v-d_v)$ at NLO



Strange+antistrange quark at NLO

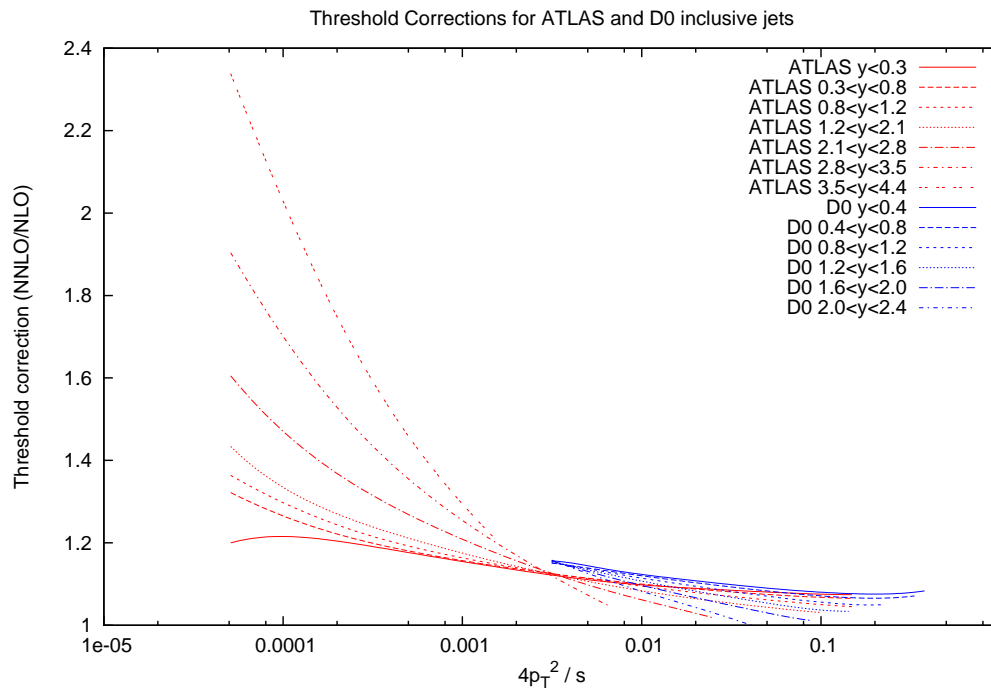


Change in **NLO** PDFs from all, including **LHC** data updates. Much expanded $s + \bar{s}$ uncertainty. (*Not absolutely final version - $s + \bar{s}$ sensitive to fine details within uncertainty.*)

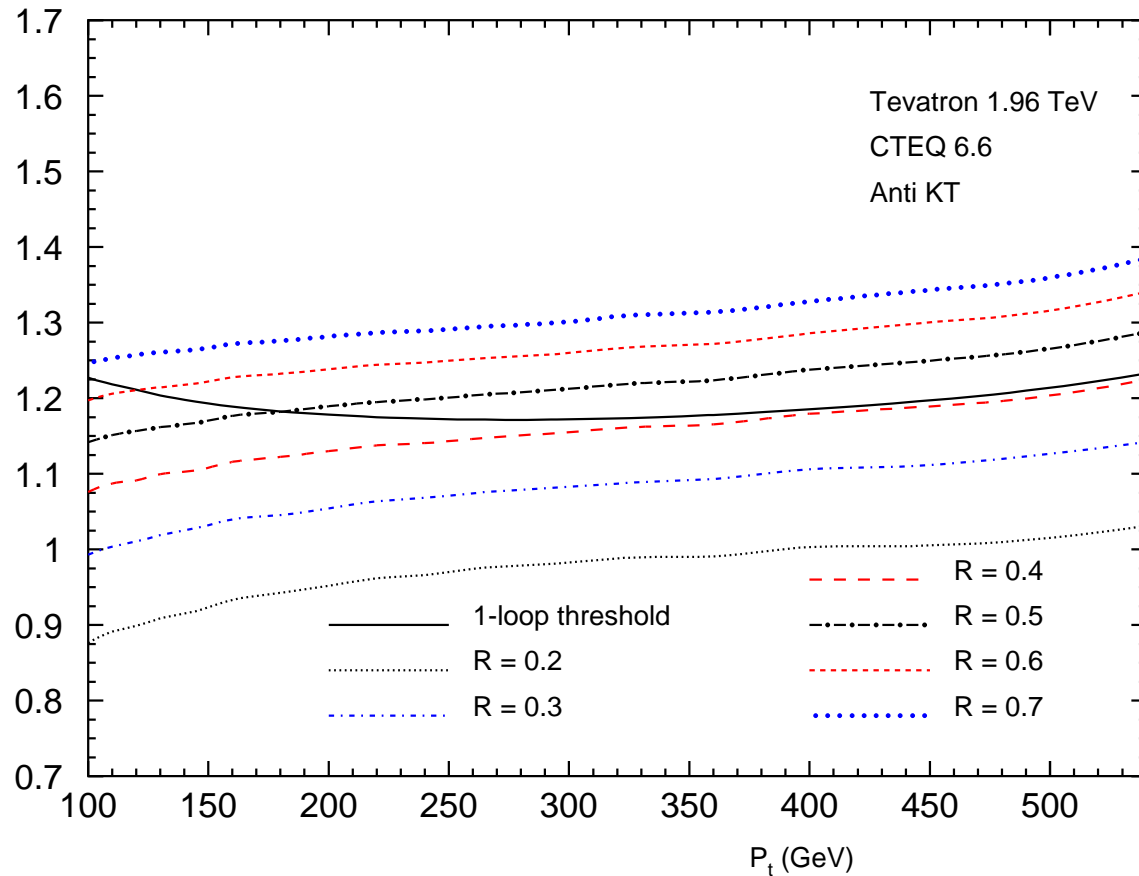
LHC jet data at NNLO?

For Tevatron data use approximate “threshold” corrections (Kidonakis and Owens), $\sim 10\%$ positive correction.

LHC corrections very similar for highish x probed at the Tevatron, but blow up when low x probed at the LHC, i.e. far from threshold.

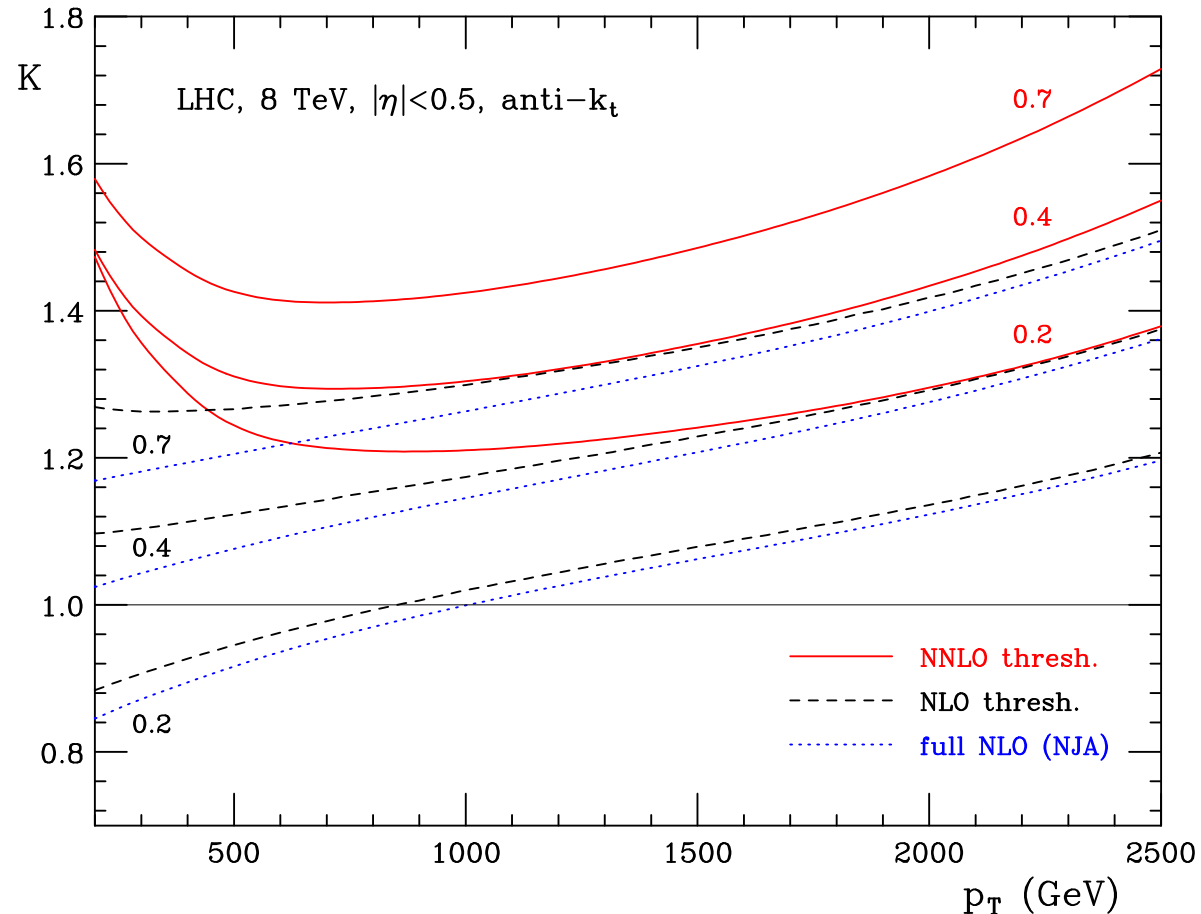


Enormous project of full NNLO calculation (Gehrmann-de-Ridder, Gehrmann, Glover and Pires) nearing completion. Some indications of full form of the correction.



Recent repeat of threshold calculations [Kumar, Moch \(arXiv:1309.5311\)](#) and comparison to exact **NLO** results for different jet radius R .

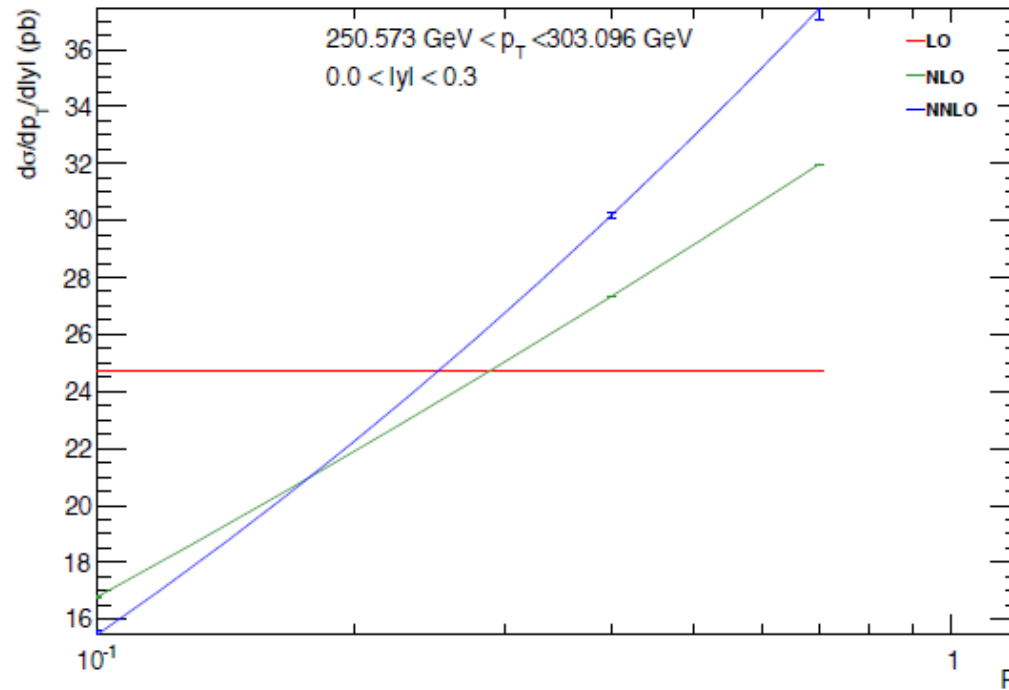
Big variation with R at **NLO** and threshold calculation which has no R dependence matches best with $R \sim 0.3 - 0.4$.



Very recent improved calculation from [de Florian et al. \(arXiv:1310.7192\)](https://arxiv.org/abs/1310.7192) has built in R dependence. Shows correct variation at NLO but little extra R dependence at NNLO. Still has problems at low p_T

NNLO corrections to $pp \rightarrow 2\text{jets}$

Single-jet inclusive: jet size dependence in anti- k_T algorithm



▶ 22

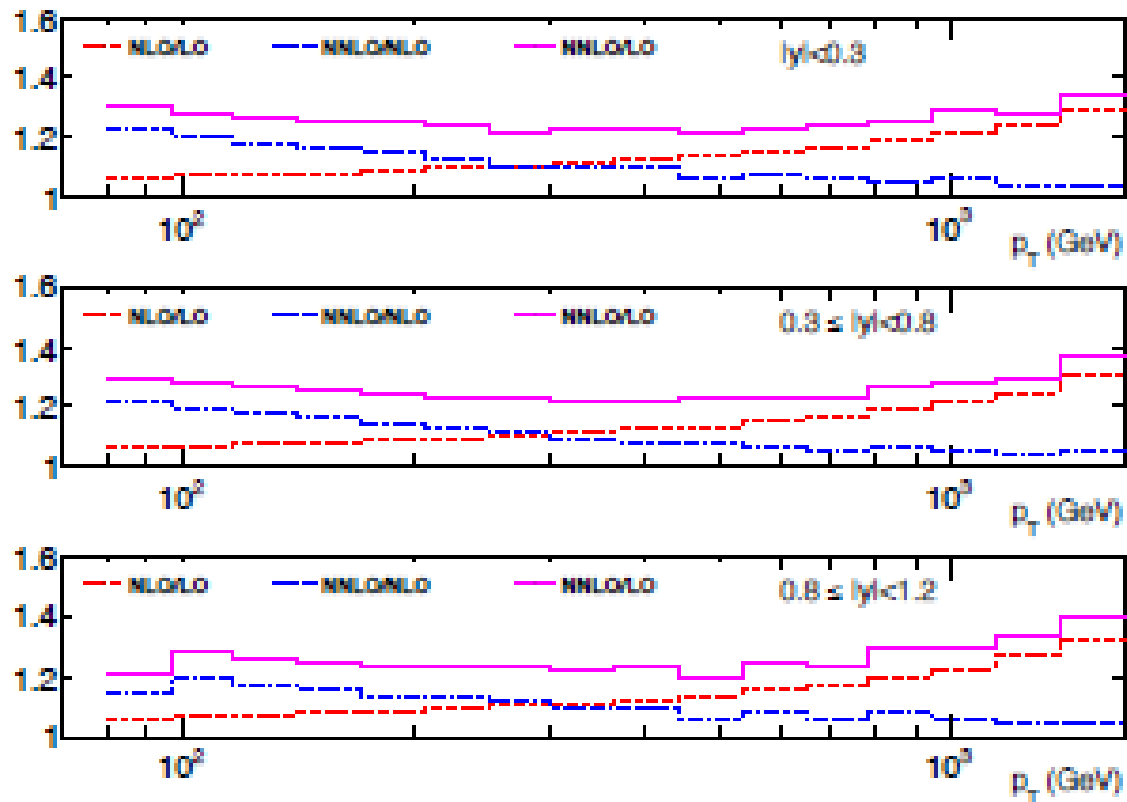
Aude Gehrmann-De Ridder

SM@LHC 2013 Freiburg

Compatible with existing full results. Here at NLO ratio for $R = 0.7$ to $R = 0.4$ is 1.25 but shrinks to 1.06 at NNLO.

Inclusive jet production: double differential distributions

$$R = 0.4$$



Appears to be fairly similar to “threshold” correction near threshold, now verified by [de Florian et al.](#). Overall $\sim 5-20\%$ positive correction growing at lower p_T .

NNLO PDF updates

As default at NNLO still fit Tevatron data which seems safe, since are always relatively near to threshold, and corrections do not obviously break down at lowest p_T .

Have also tried repeating MSTW2008 fits with extreme modified K-factors for NNLO jets, i.e. multiply standard correction by 0 or 2 and use constant $K = 1.15$. Even at extremes changes almost entirely within one sigma. Similar to scale changes at NLO.

However, omit LHC data. Lowest p_T not stable in threshold corrections, and large uncertainty at highest rapidity.

Try putting in very approx NNLO correction of $\sim 5 - 20\%$ positive correction growing at lower p_T . “Smaller” and “larger” K-factor with corrections of about $\sim 10\%$ and $\sim 20\%$ at $p_T = 100$ GeV - rapidity independent.

Prediction good. Fit quality a small amount worse than at NLO, though deteriorates slowly with larger K-factor.

Fit quality for LHC data at NNLO. Jet data not fitted but quality checked using “smaller” K -factor.

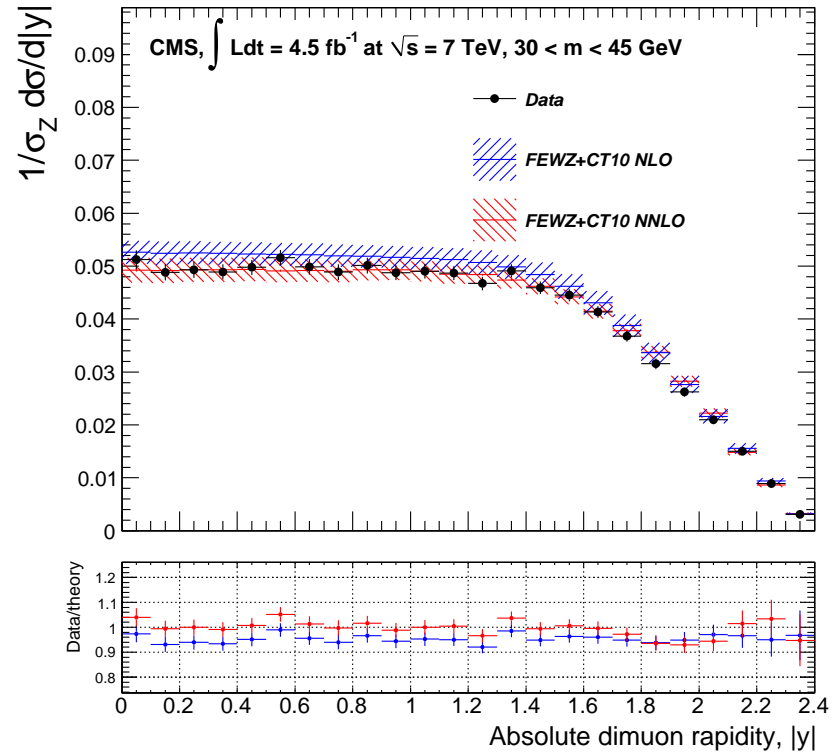
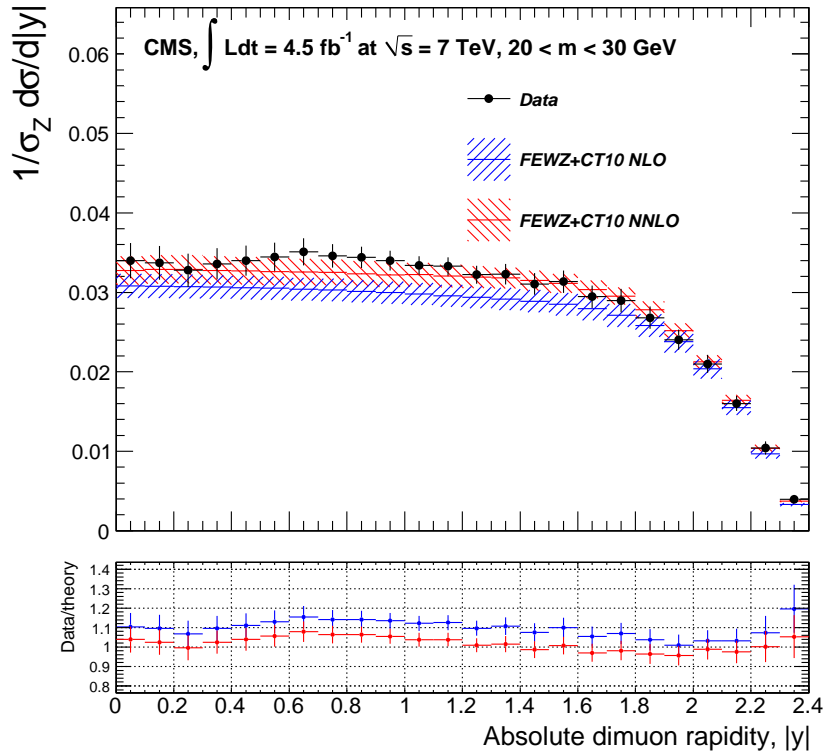
data set	N_{pts}	CPdeut	no LHC	prelim
ATLAS jets (2.76TeV+7TeV)	116	(107)	(123)	(119)
CMS jets (7TeV)	133	(142)	(137)	(135)
ATLAS W^+, W^-, Z	30	72	53	39
CMS W asymm $p_T > 35\text{GeV}$	11	18	15	9
CMS asymm $p_T > 25\text{GeV}, 30\text{GeV}$	24	18	17	10
LHCb $Z \rightarrow e^+e^-$	9	23	22	20
LHCb W asymm $p_T > 20\text{GeV}$	10	24	21	13
CMS $Z \rightarrow e^+e^-$	35	30	24	22
ATLAS High mass DY	13	18	16	17
TeV, ATLAS, CMS $\sigma_{t\bar{t}}$	13	8	11	8
CMS Low-high mass DY	132	159	151	149

Large improvement in ATLAS W, Z data, mainly from strange quark, and in CMS $Z \rightarrow e^+e^-$ data and to CMS W asymm. and LHCb W^+, W^- data.

CMS $Z \rightarrow e^+e^-$ data constrains gluon and CMS W asymm. data some flavour decomposition.

CMS Drell Yan data.

Fit very poor at **NLO** in lowest mass bins (where it is effectively **LO**), even when data highly weighted.



Enormously improved fit quality at **NNLO** due to improvement in cross-sections.

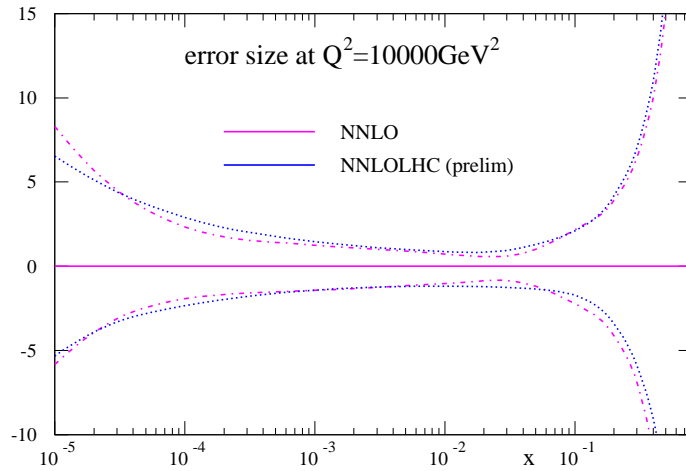
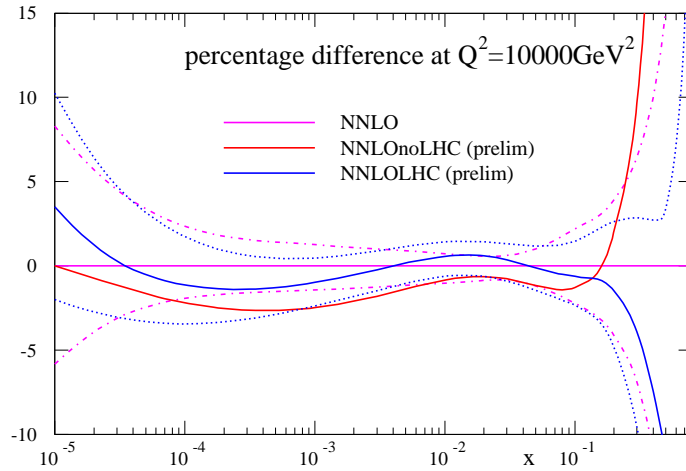
Sensitivity to strange fraction in quarks, but differs at **NLO** and **NNLO** and weak compared to direct constraint from di-muon data.

Fit quality for LHC data at NNLO. Jet data not fitted but quality checked using “larger” K -factor

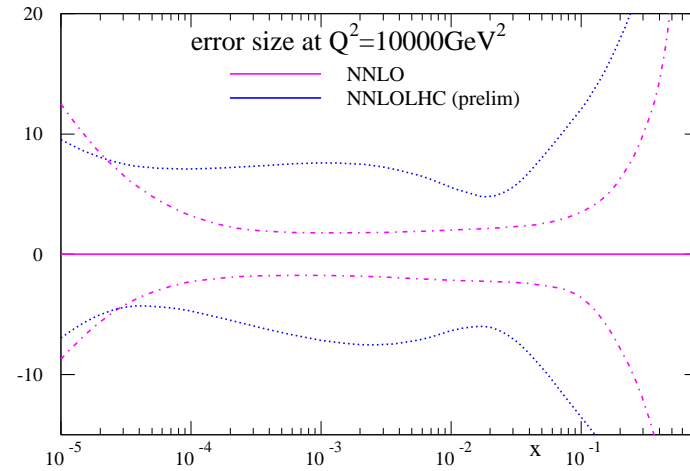
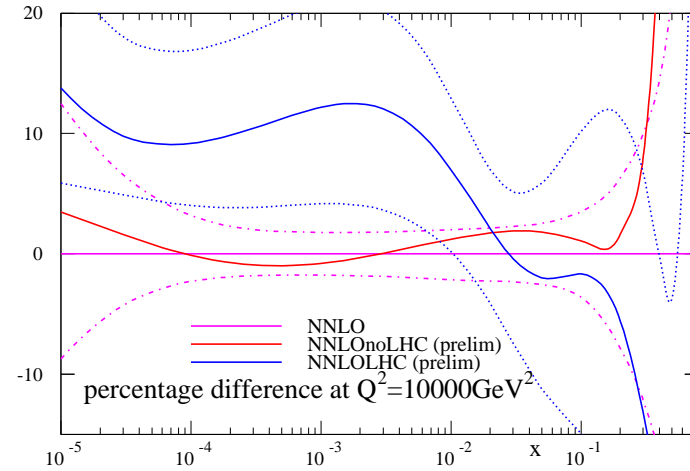
data set	N_{pts}	CPdeut	no LHC	prelim
ATLAS jets (2.76TeV+7TeV)	116	(117)	(132)	(128)
CMS jets (7TeV)	133	(145)	(137)	(139)
ATLAS W^+, W^-, Z	30	72	53	39
CMS W asymm $p_T > 35\text{GeV}$	11	18	15	9
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ATLAS jet data deteriorates more than CMS, which with increase in systematics is largely insensitive to K -factor, though even prefers smaller one. Difficult to guess relative size of K -factor at two different energies.

Gluon at NNLO



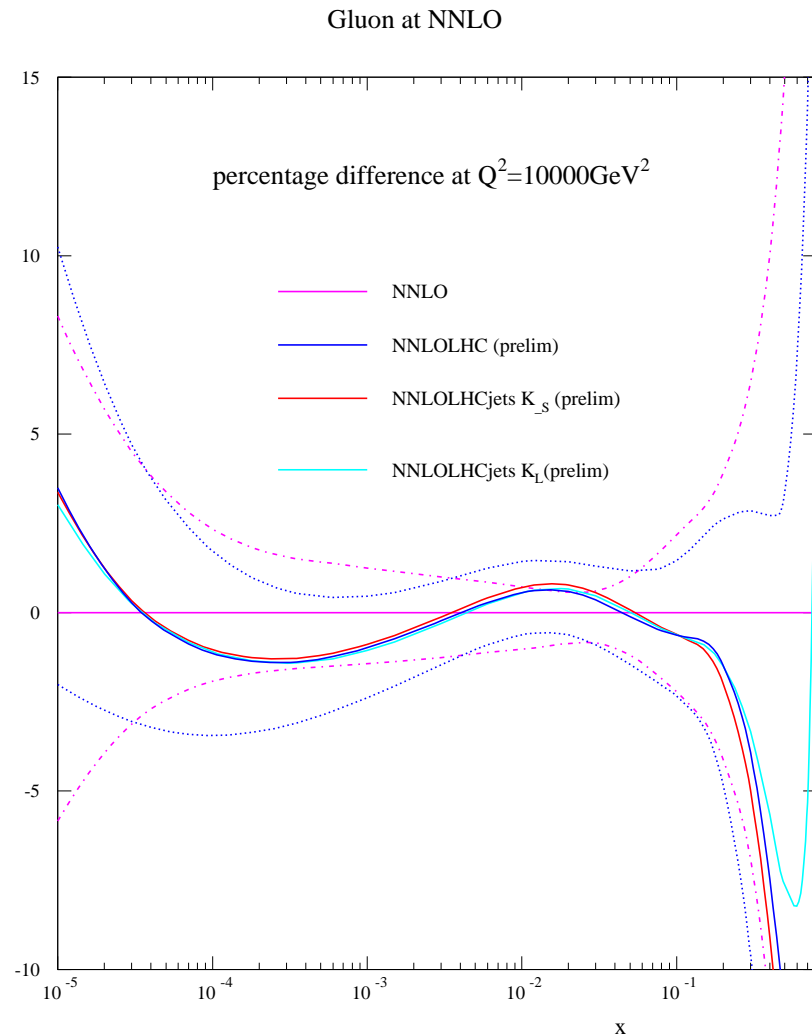
Strange+antistrange quark at NNLO



Change in **NNLO** PDFs from all, including **LHC** data updates. Gluon uncertainty at high- x slightly greater than at **NLO**. (*Not absolutely final version.*)

Ratio of $g(x, Q^2)$ for the default **NNLO** fit to that in **MSTW2008**, and also fits where jet data included with “smaller” and “larger” K -factor.

In both cases changes in gluon, $\alpha_S(M_Z^2)$ and fit to other data are extremely small.



For the “smaller” K -factor **ATLAS** $\chi^2 = 119/116 \rightarrow 106/116$ and **CMS** $\chi^2 = 138/133 \rightarrow 139/133$.

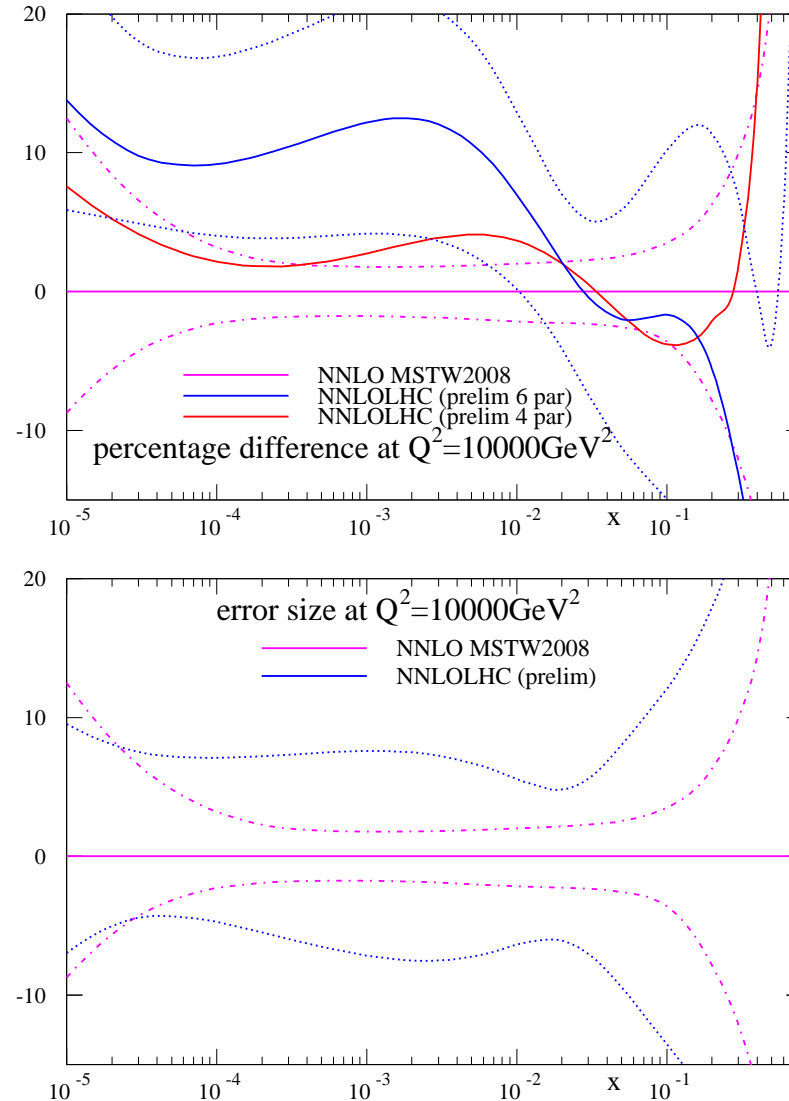
For the “larger” K -factor **ATLAS** $\chi^2 = 128/116 \rightarrow 118/116$ and **CMS** $\chi^2 = 139/133 \rightarrow 141/133$.

At NNLO strange quark with 4 polynomials becomes very large at very small x – larger than up and down.

Restrict fit at NLO and NNLO to 2 polynomials for strange for final fit (does not affect eigenvector choice).

At NNLO final extracted $\alpha_S(M_Z^2) = 0.1172$

Strange+antistrange quark at NNLO



$\alpha_S(m_Z^2)$ as a data point.

$\alpha_S(m_Z^2)$ coming out similar to 2008 fit. Still a NLO/NNLO difference. Both fairly compatible with global average. Try inputting this as data point.

Try world average (minus DIS data) of $\alpha_S(m_Z^2) = 0.1187 \pm 0.0007$ (rather small uncertainty).

At NLO already within one sigma, essentially no change – $\alpha_S(m_Z^2) = 0.1199 \rightarrow 0.1195$ with $\Delta\chi^2 < 2$.

At NNLO best fit gives $\alpha_S(m_Z^2) = 0.1172 \rightarrow 0.1177$, i.e. very close to 0.118. $\Delta\chi^2 < 2$

Also force $\alpha_S(m_Z^2) = 0.118$. At NNLO basically no further change. At NLO $\Delta\chi^2 \sim 16$, but no single set deteriorates very significantly.

Conclusions

Ongoing, but very near final, updates on PDFs – soon to release updated PDFs.

Improvement in parameterisation, heavy flavour treatments, nuclear corrections, and branching ratio for dimuon data. Inclusion of up-to-date [HERA](#) and [Tevatron](#) data.

Also directly included most relevant published [LHC](#) data, i.e. [ATLAS](#), [CMS](#), [LHCb](#) W , Z rapidity data, top cross section data and all published [ATLAS](#) and [CMS](#) inclusive jet data, though don't include these as default at [NNLO](#). Fit good (except one [NLO](#) exception) – no PDF conflicts.

So far few dramatic effects on PDFs. Mainly strange quark and low- x valence quarks, largely due to change in methodology, but also to newer data. Larger strange uncertainty from branching ratio error.

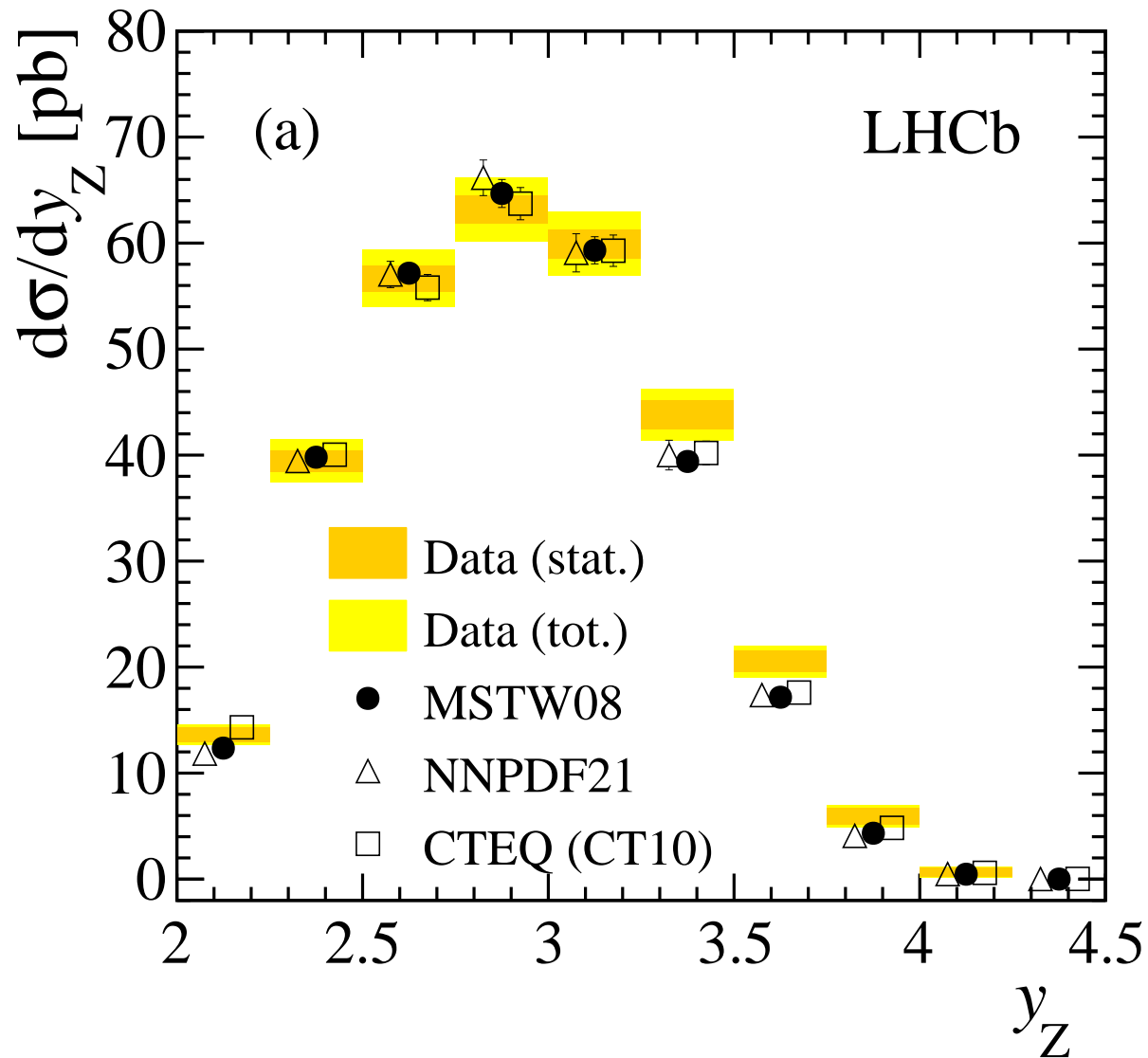
Some uncertainty in the manner [NNLO](#) may affect jets. Away from vicinity of threshold decide at present to wait for full [NNLO](#) calculation. However, comparison now suggests [NNLO](#) fit happy with moderate K -factors, with no real change in PDFs or coupling.

Back-up

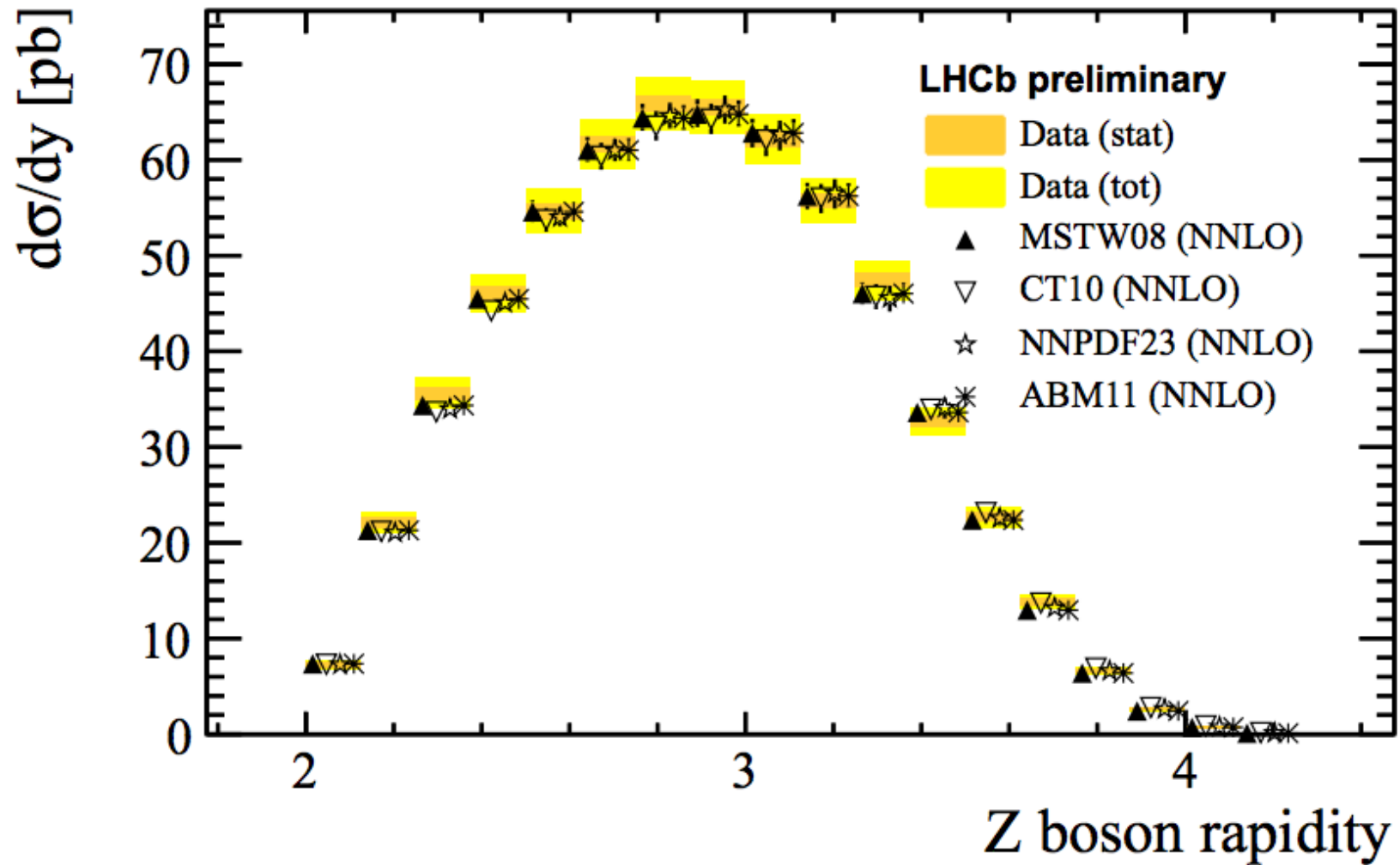
Change in various cross section predictions compared to uncertainty for **MSTW2008**.

	no LHC NLO	no LHC NNLO	LHC NLO	LHC NNLO	unc.
W Tevatron (1.96 TeV)	+1.0	+2.1	-0.5	+0.2	1.8
Z Tevatron (1.96 TeV)	+2.4	+2.6	+0.5	+0.1	1.9
W^+ LHC (7 TeV)	+2.5	+0.9	+0.3	-1.1	2.2
W^- LHC (7 TeV)	-0.3	+1.1	-0.8	-1.9	2.2
Z LHC (7 TeV)	+1.1	+1.1	+0.2	-1.5	2.2
W^+ LHC (14 TeV)	+3.0	+0.8	+0.7	-0.9	2.4
W^- LHC (14 TeV)	+0.6	+0.6	-0.3	-1.6	2.4
Z LHC (14 TeV)	+1.7	+0.6	+0.2	-0.6	2.4
Higgs Tevatron	-3.5	+2.8	-3.1	-3.2	5.1
Higgs LHC (7 TeV)	-1.2	+0.9	-1.4	-2.1	3.3
Higgs LHC (14 TeV)	-2.0	+0.1	-1.2	-2.3	3.1
$t\bar{t}$ Tevatron	+0.5	+4.9	-1.6	-0.7	3.2
$t\bar{t}$ LHC (7 TeV)	-3.1	+3.3	-2.9	-2.5	3.9
$t\bar{t}$ LHC (14 TeV)	-2.0	+1.7	-2.0	-2.0	3.1

Some changes of order size of uncertainty - none dramatic.



Points near to $y = 3.5$ overshoot predictions in general. Feature not present in prelim. higher luminosity $Z \rightarrow \mu^+\mu^-$ data.



Higher luminosity LHCb $Z \rightarrow \mu^+ \mu^-$ data.

Repeat **MSTW2008** fits with modified K-factors for **NNLO** jets, i.e. multiply standard correction by **0** or **2** and use constant $K = 1.15$.

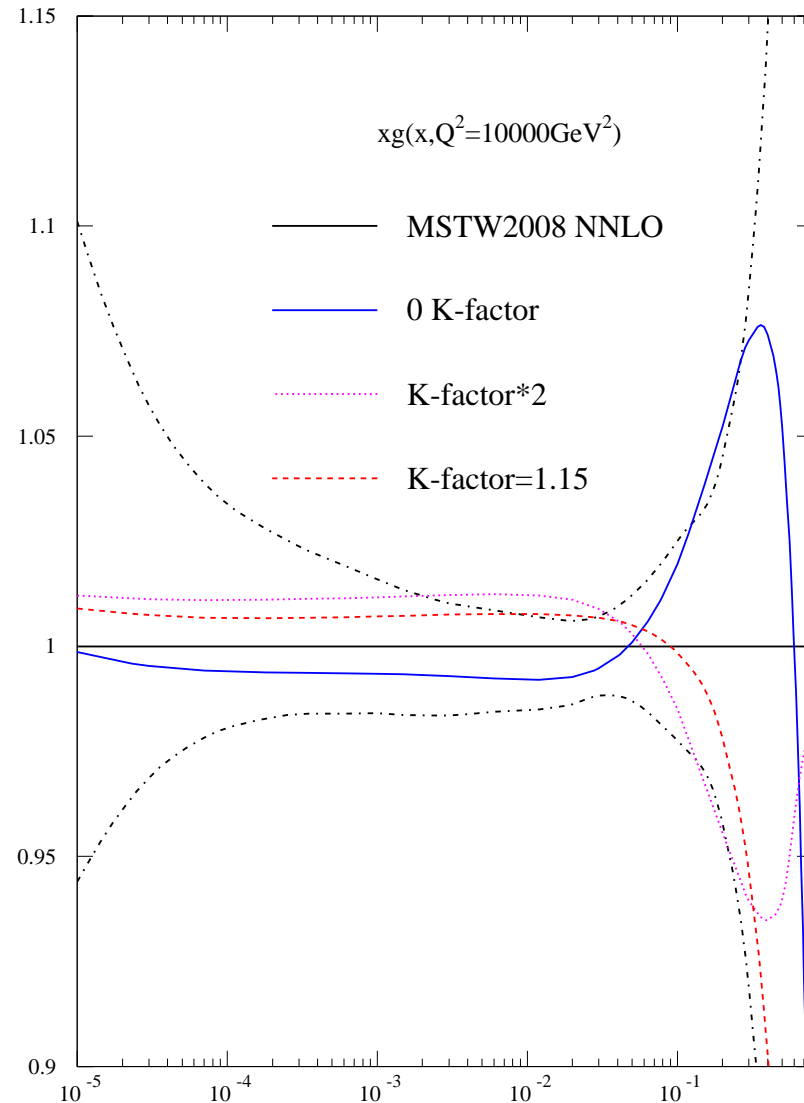
Extreme variations.

Changes in gluon relatively small. Larger K-factor slightly worse χ^2 . Zero K-factor slightly better χ^2 , $K = 1.15$ almost no change.

$$K = 0 \quad \alpha_S(M_Z^2) = 0.1181$$

$$K * 2 \quad \alpha_S(M_Z^2) = 0.1159$$

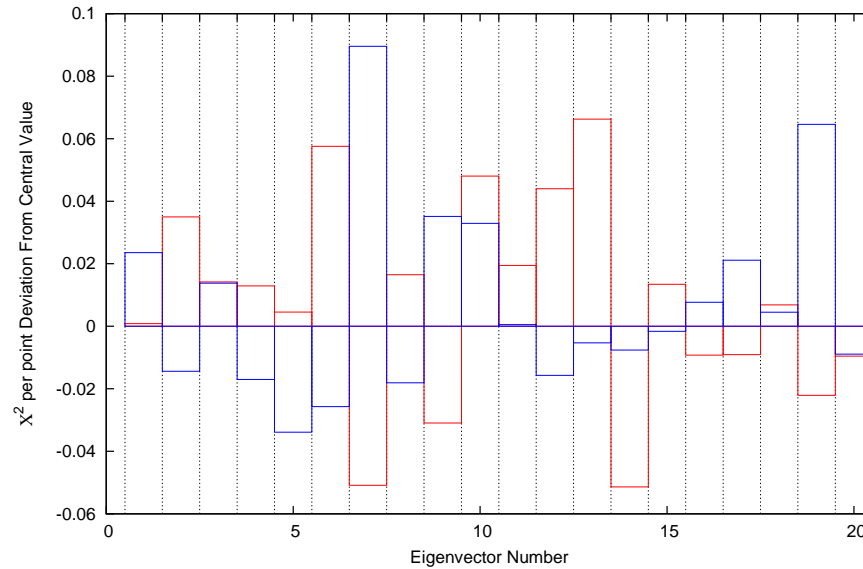
$$K = 1.15 \quad \alpha_S(M_Z^2) = 0.1167$$



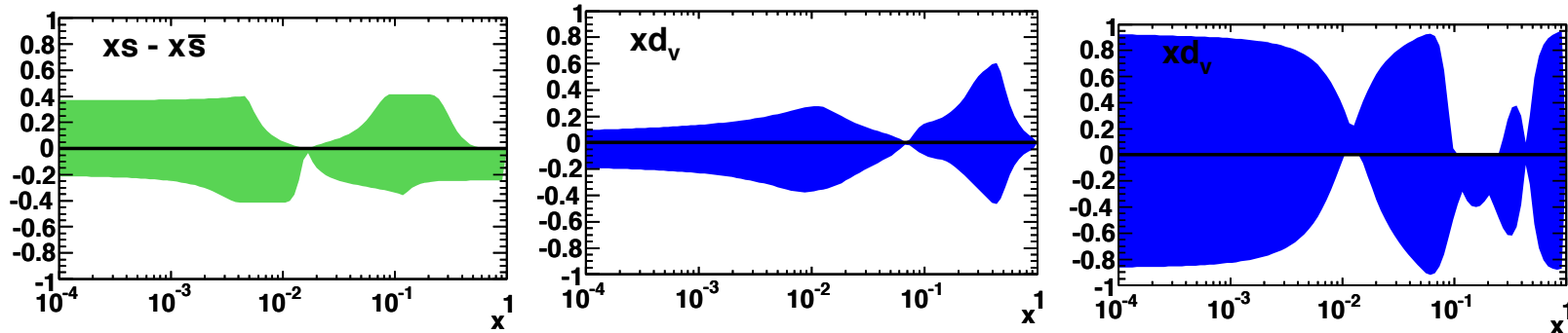
DIS jets - B. Watt

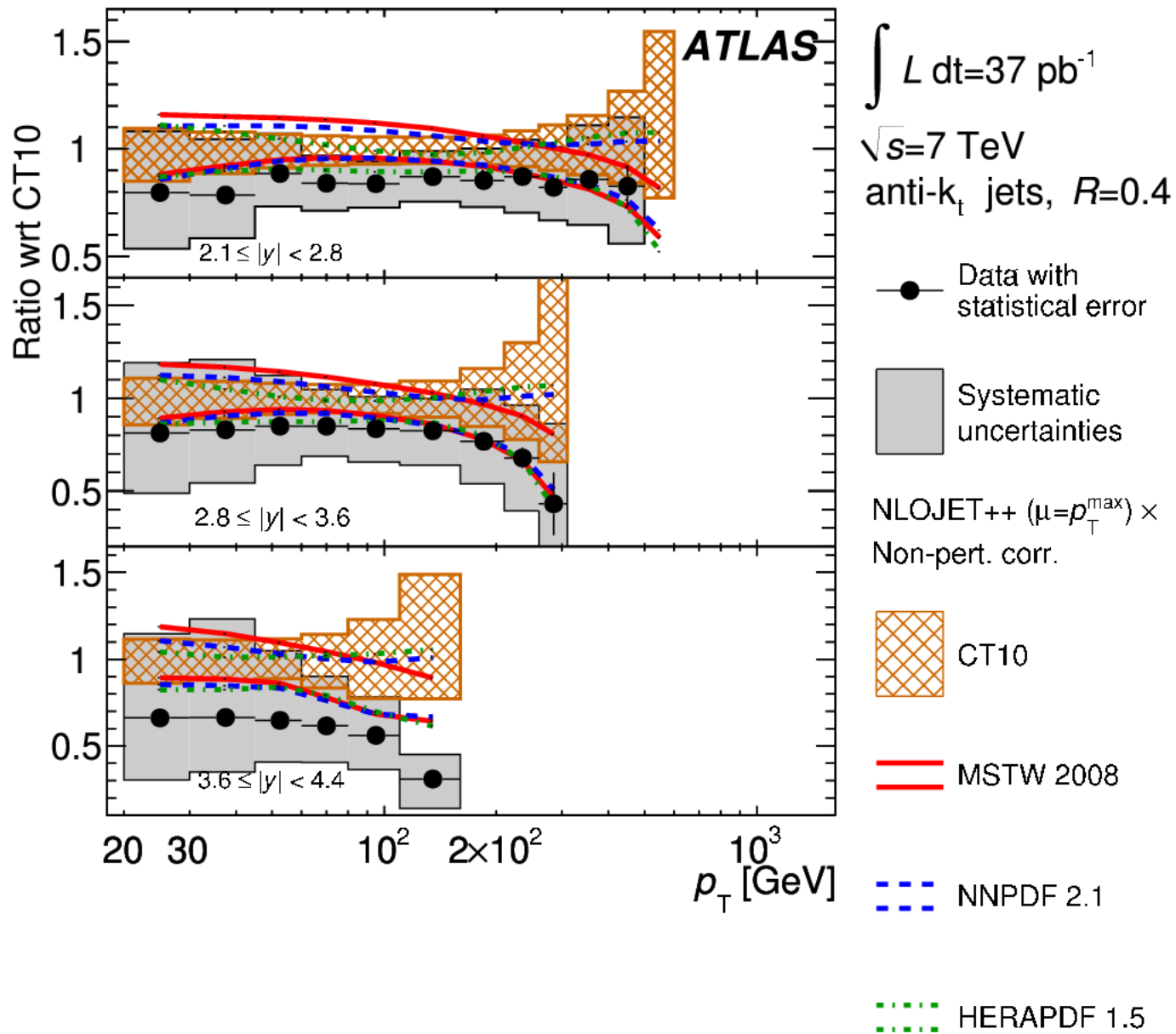
Interesting observation in eigenvector sensitivity to charged current ZEUS jet data using POWHEG.

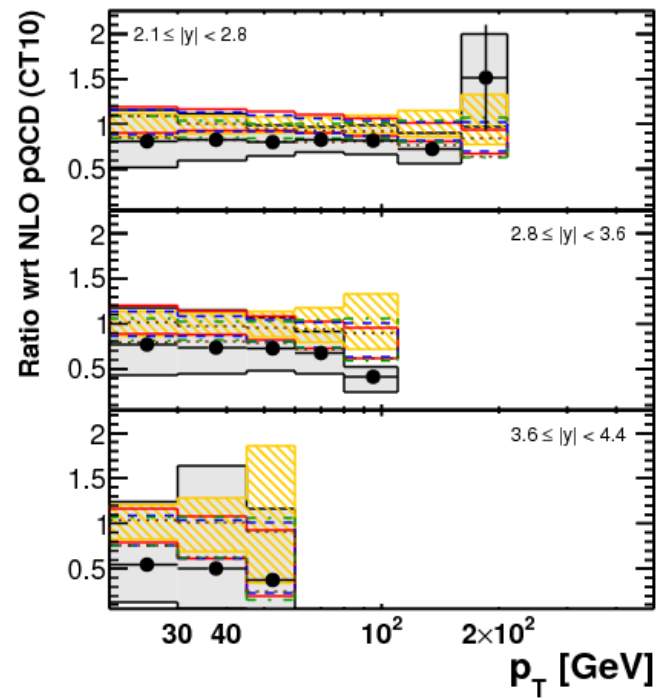
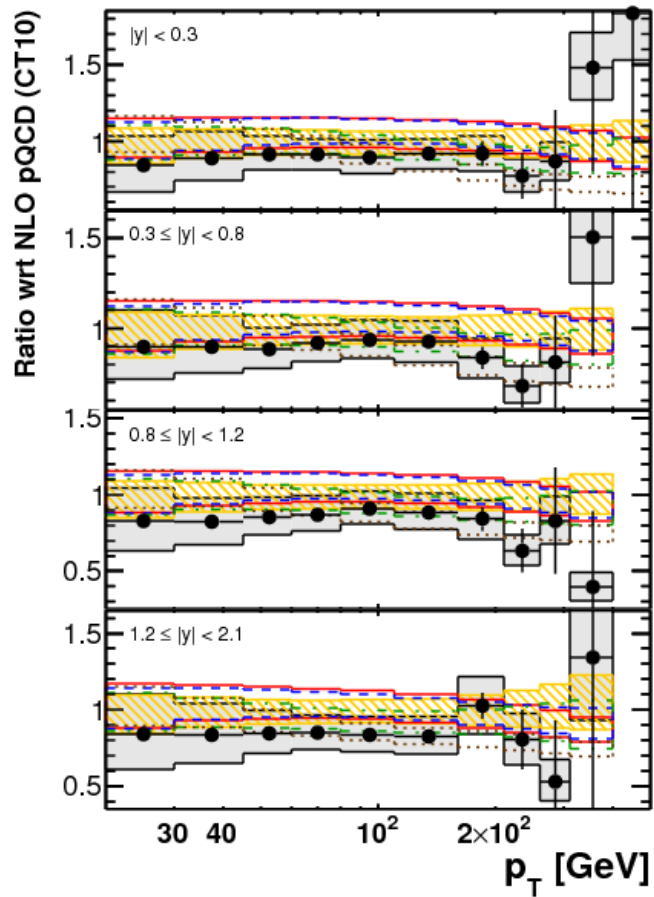
MSTW Eigenvectors for CC Fit (Powheg + NLO PDF)



Some sensitivity to $s - \bar{s}$.







ATLAS

$\int L dt = 0.20 \text{ pb}^{-1}$
 $\sqrt{s} = 2.76 \text{ TeV}$
 anti- k_T $R = 0.4$

● Data with statistical uncertainty
 □ Systematic uncertainties

NLO pQCD ⊗ non-pert. corrections

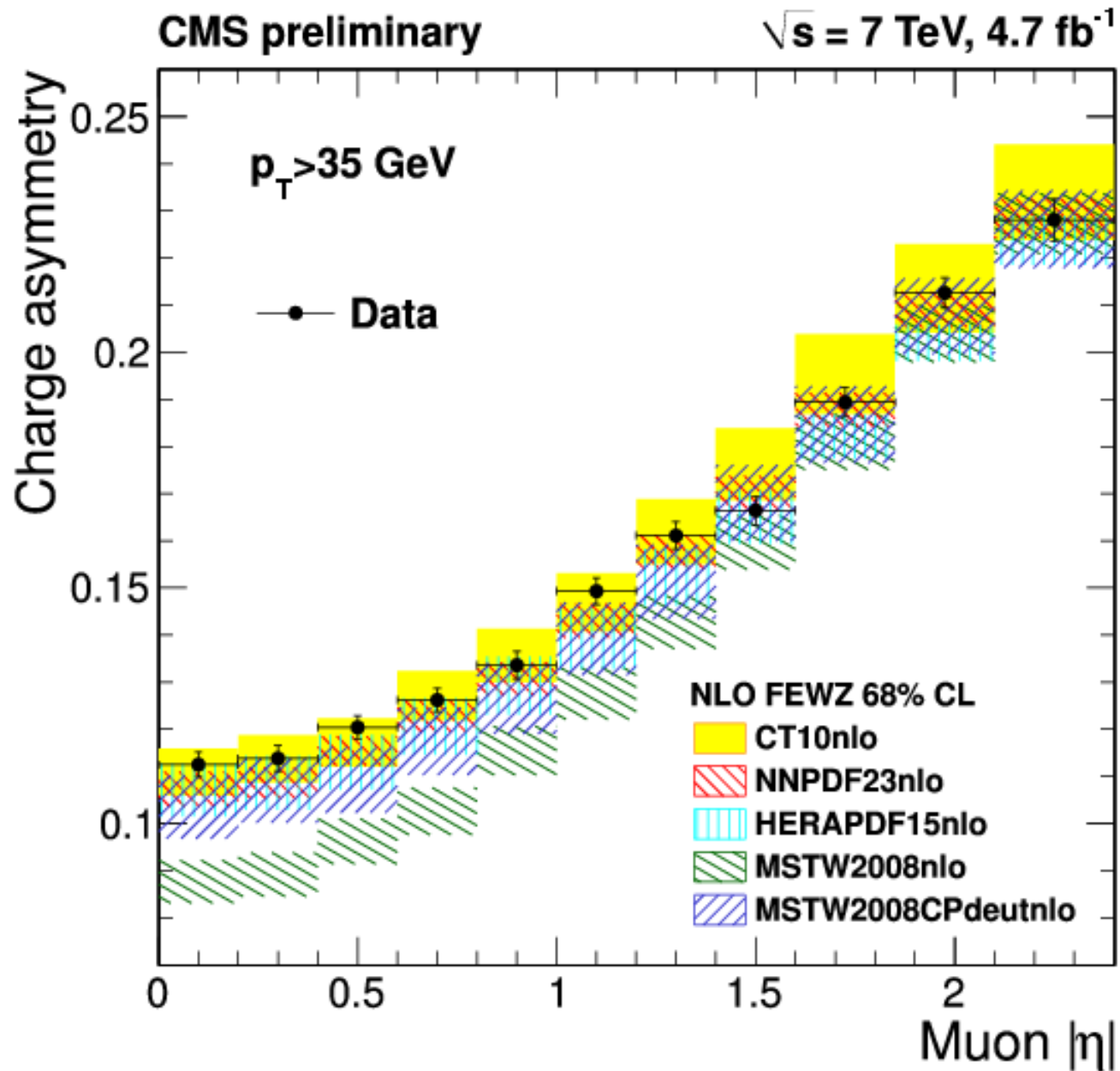
CT10

MSTW 2008

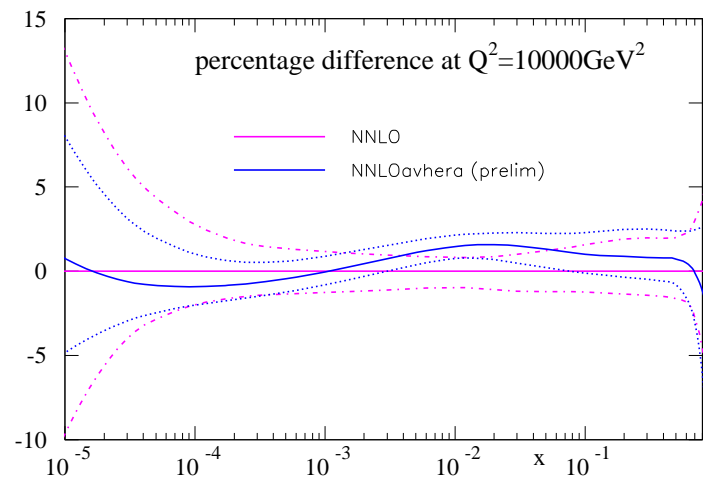
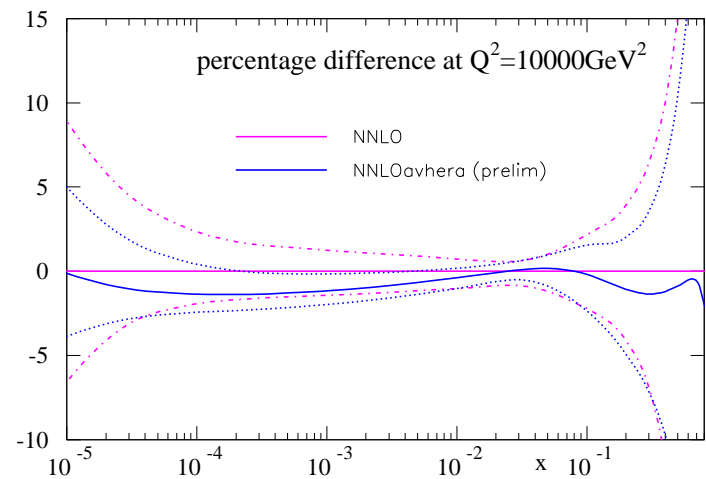
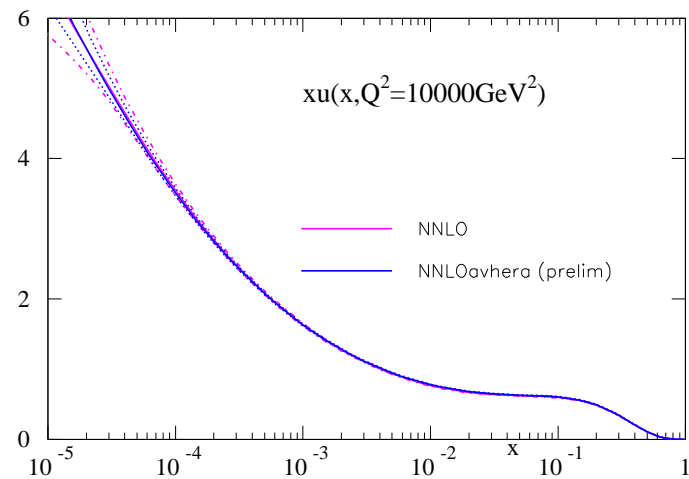
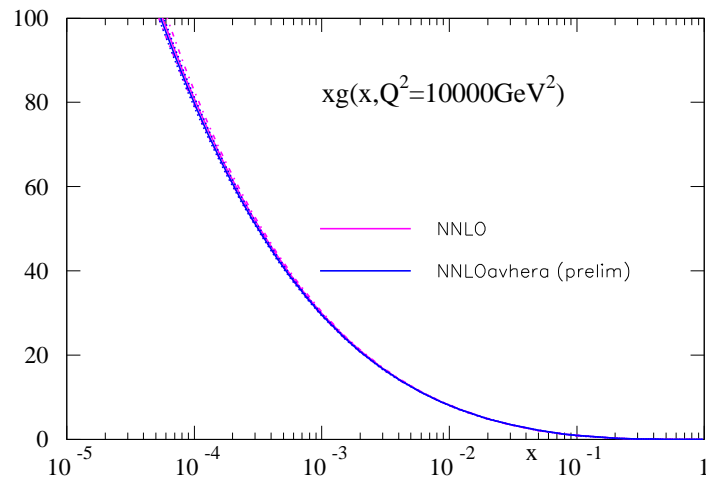
NNPDF 2.1

HERAPDF 1.5

ABM 11 NLO

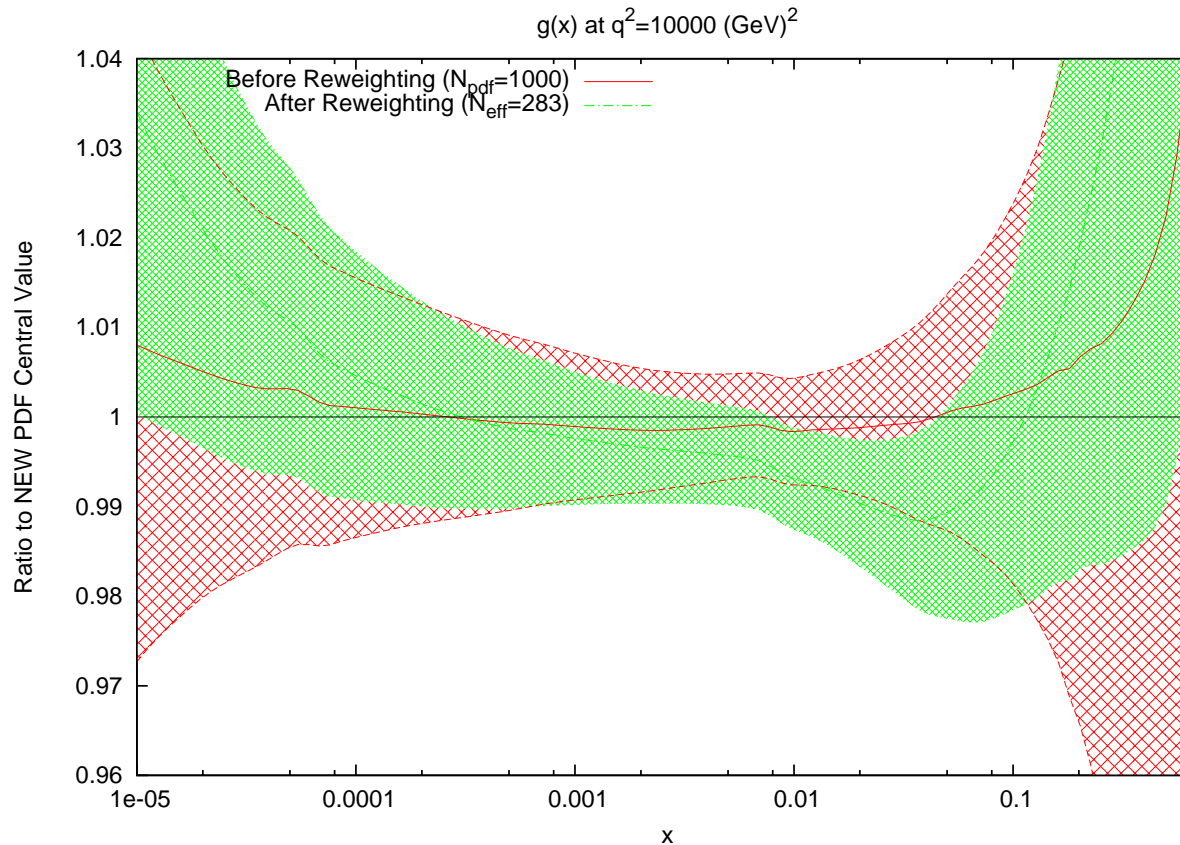


Comparison of various PDFs to [CMS](#) lepton asymmetry.



Change in **MSTW2008 NNLO** PDFs when fitting **HERA** combined data.

Dijets



Using reweighting exercise for **CMS** dijets results in a rather modified shape of gluon.

Not as high rapidity as other sets – dependence on renormalisation/factorisation scales not so severe.

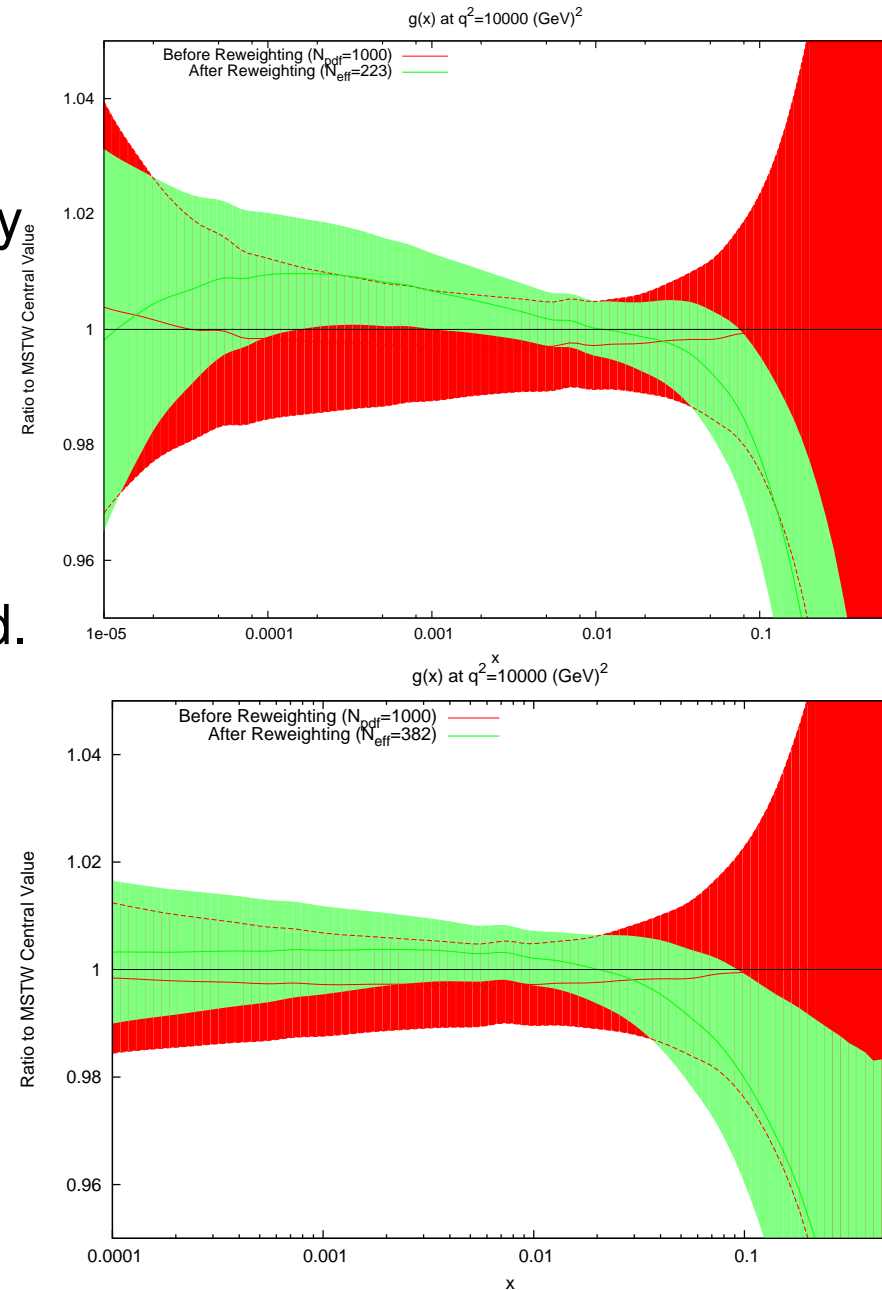
Reflection of different shape of higher order corrections?

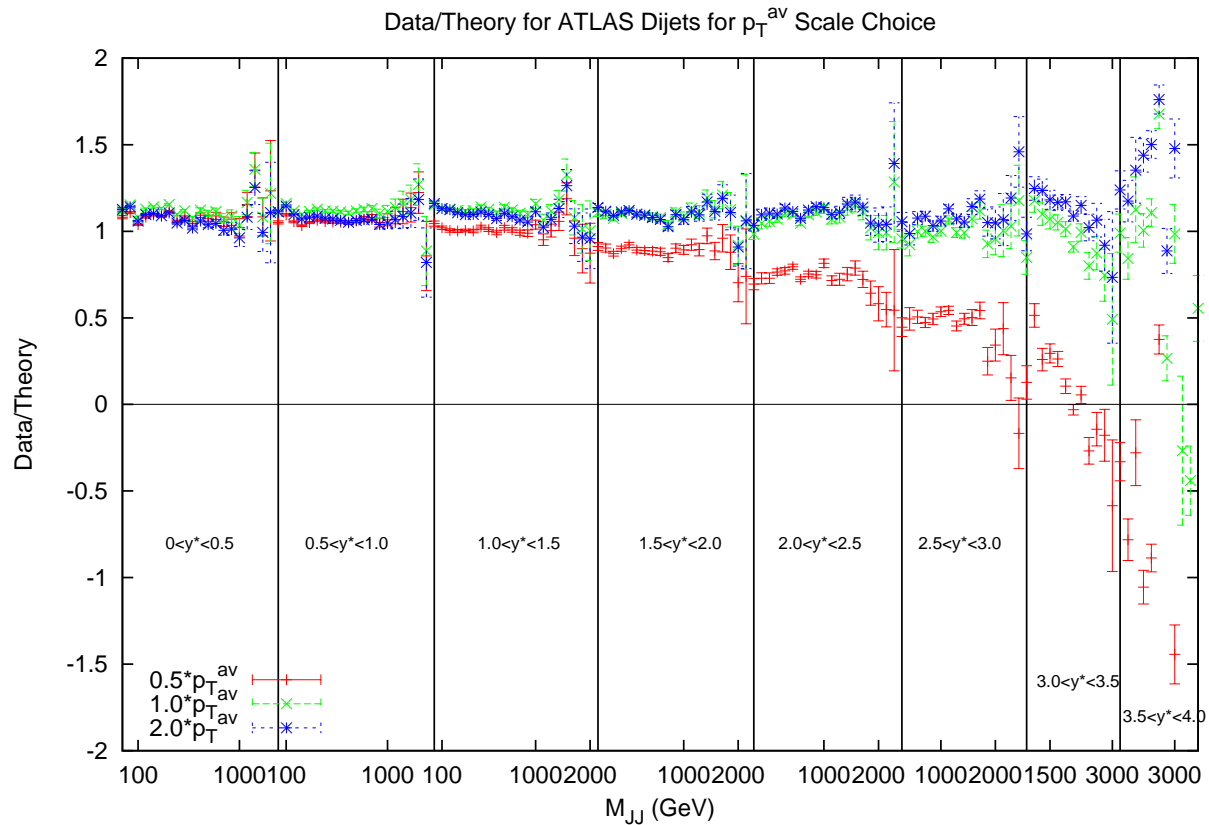
Different conclusions for fits to **D0** and **ATLAS** dijet data, though they are not not necessarily incompatible.

Similar to changes required by **LHC** inclusive jet data.

Different range of rapidity spanned. Need to use scale other than p_T to get good fits. $\mu = 2p_T$ best for **ATLAS** and $\mu = M_{JJ}$ best for **D0**.

For **ATLAS** rapidity dependent scale choices give results more like that for **CMS**, but with a worse fit and lower value of N_{eff} .





At high rapidity calculations unstable for scales equal to relatively low multiples of p_T .