Updates of PDFs for the 2nd LHC run

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Abstract

In this talk I will present results on continuing updates in PDFs within the MSTW framework due to both theory improvements and the inclusion of new data sets, including most of the up-to-date LHC data. A new set of PDFs is close to being finalised, with no significant changes expected to the PDFs presented here.

Outline

1. Changes in theoretical procedures
2. Changes in data sets
3. Inclusion of LHC data
   - $W^{\pm}$, Z, $t\bar{t}$
   - Jet data
   - DY@CMS doubly differential
   - Jet data @ NNLO
4. NNLO PDF updates
5. Conclusions

Changes in theoretical procedures

- Continue use extended Chebyshev polynomials parametrization.
- Freedom in deuteron nuclear corrections as in recent MSTWCPdeut study (Eur.Phys.J. C73 (2013) 2318). Leads to change in $u_V - d_V$ distribution.
- Currently using "optimal" GM-VFNS choice (Phys.Rev. D86 (2012) 074017)
- Small correction to dimuon production (when charm produced away from interaction point → impacts strange dist.)
- 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.

A quick recap:
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.

- Amounts to having:

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

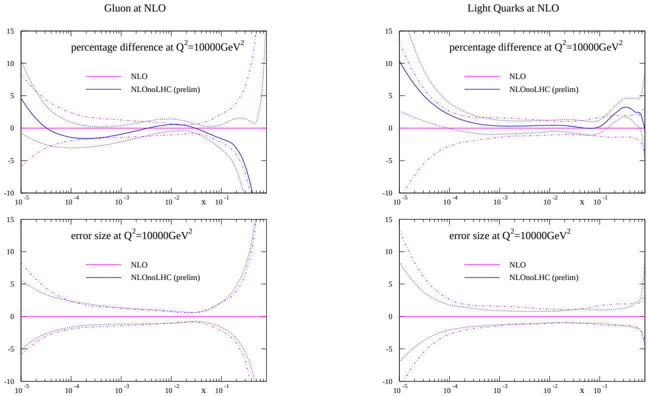
- Allows for direct inclusion of data sets without rescaling of data and uncertainties.
- Strange branching ratio: now avoid those determined by fits to dimuon data relying on PDF input. Also apply error which feeds into PDFs. Use $B_\mu = 0.092 \pm 10\%$ from hep-ex/9708014. Fits prefer $B_\mu = 0.087 - 0.091 \pm 15\%$, with NNLO at lower end.

Changes in data sets

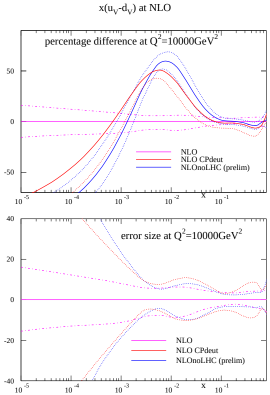
- Replacement of HERA run I neutral and charged current data from HERA and ZEUS with combined data set with full treatment of correlated errors. Fit data well with slightly better fit at NNLO.
- Inclusion of HERA combined data on $F_2^c(x, Q^2)$. Fit quality: $\sim$ 60-65 for 52 points.
- Inclusion of 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.
- Wait for Run II combination with inclusion of separate run II H1 and ZEUS data.

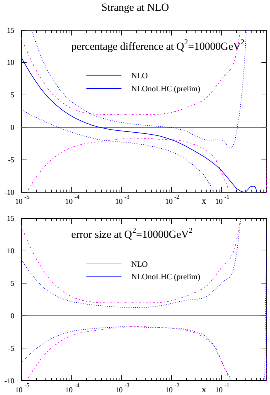
Inclusion of new(er) Tevatron data sets.

- Inclusion of
    - CDF W-asymmetry data
    - D0 electron asymmetry data $p_T > 25\mathrm{GeV}$ based on 0.75 fb^{-1}
    - (NEW) D0 muon asymmetry data for $p_T > 25\mathrm{GeV}$ 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.



Change in NLO PDFs from non-LHC data updates. Increase in d at high x. Overall small to moderate changes.





Change in NLO PDFs from non-LHC updates. Change in branching ratio for dimuon data not incorporated. We note the large changes in $(u_V - d_V)$ and strange distributions.

Inclusion of LHC data

Work done with *Harland-Lang* and *Thorne* using `FastNLO`, `APPLGrid`, `MCFM` and `DYNNLO`. Allows for direct inclusion ATLAS $W^{\pm}$, Z rapidity data directly in the fit.

- Before inclusion $\chi^2 \sim 1.6$ per point at NLO, $\chi^2 \sim 2$ per point at NNLO.
- Inclusion results in some extra improvement at NLO, $\chi^2 \sim 1.3$, with strongest pull on gluon PDF.
- Also goes to $\chi^2 \sim 1.3$ at NNLO. The most obvious change is in the strange quark. (Balance of W and Z production depends on strange dist.)

$W^{\pm}$, Z, $t\bar{t}$

- $W^{+} - W^{-}$ asymmetry no longer an issue at all, both for ATLAS and CMS asymmetry data. Slightly better at NLO. (Previously valence u-quark dist. fit poorly at low x.)
- Include LHCb data on
    - W^{+}, W^{-}
    - $Z \rightarrow e^{+}e^{-}$.

  Both fit well at NLO.
- Include
    - CMS data on $Z \rightarrow e^{+}e^{-}$
    - ATLAS high mass Drell-Yan data.

  Again both fit well.

Include data on $t\bar{t}$. More specifically:

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

Jet data

Work done with *B. Watt* and *R. Thorne*.

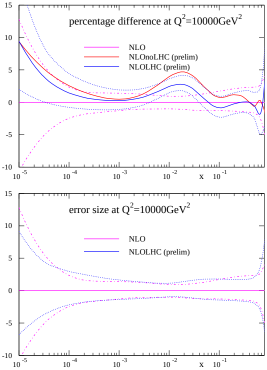
- At NLO also include CMS data together with ATLAS 7 TeV + 2.76 TeV data.
- Before (separately) ATLAS $\chi^2 = 112/114$ and CMS $\chi^2 = 186/133$ (included directly) – as good as any PDF.
- Simultaneous fit of CMS data together with ATLAS 7 TeV + 2.76 TeV leads to bigger improvement for CMS, but a tiny amount for ATLAS.
- The two experiments seem extremely compatible.
- At NLO final extracted $\alpha_S(M_Z^2) = 0.1193$.
- Side note: CMS inclusive jet data - revisited
  - Previously the single pion uncertainties delivered correlated.
  - Recently: decision within collaboration made to decorrelate single pion systematics.
  - Amounts to splitting the single pion source into five parts.
  - Small difference but hardly noticable

- Fit quality for LHC data at NLO

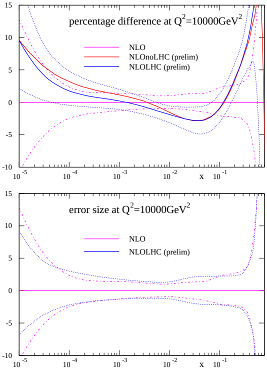
data set	N_{pts}	CPdeut	no LHC	prelim
ATLAS jets (2.76TeV+7TeV)	114	111.9	111.7	110.6
CMS jets (7TeV)	133	179.6	186.3	173.0
ATLAS W^+, W^-, Z	30	46.9	44.2	40.5
CMS W asymm $p_T > 35\mathrm{GeV}$	11	8.5	12.9	6.9
CMS asymm $p_T > 25\mathrm{GeV}, 30\mathrm{GeV}$	24	8.6	16.7	7.1
LHCb $Z \to e^+e^-$	9	13.2	12.7	12.3
LHCb W asymm $p_T > 20\mathrm{GeV}$	10	12.5	13.8	12.2
CMS $Z \to e^+e^-$	35	20.8	19.9	22.7
ATLAS High mass DY	13	20.3	20.3	21.3
TeV, ATLAS, CMS $\sigma_{t\bar{t}}$	13	8.0	9.7	7.2

- ATLAS W, Z data constrain a gluon eigenvector direction, as do $\sigma_{t\bar{t}}$ and CMS $Z \to e^+e^-$.
- CMS W asymm. data constrains some flavour decomposition.
- Also fit CMS double differential low and high mass Drell Yan data. No real change in PDFs. Fit very poor at NLO in lowest mass bins, even when weighted.

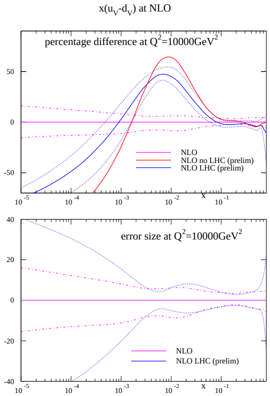
Up quark at NLO

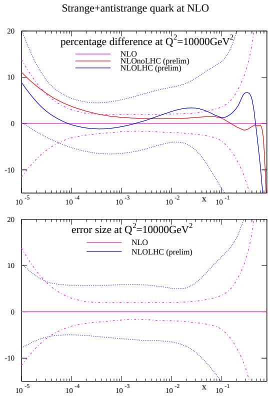


Down quark at NLO



Change in NLO PDFs from all, including LHC data updates.

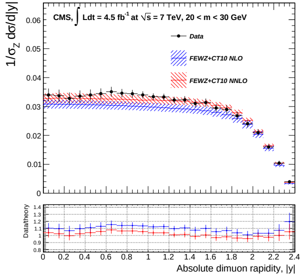


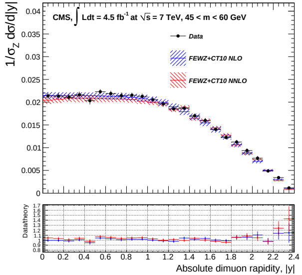


Change in NLO PDFs from all, including LHC data updates. Much expanded $s + \bar{s}$ uncertainty.

DY@CMS doubly differential

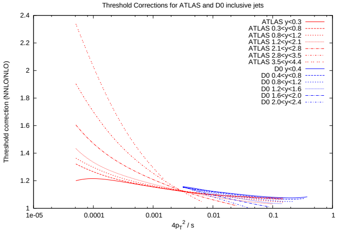
- Fit @ NLO rather poor. Fit quality considerably better at NNLO.
- Main sensitivity to s–eigenvector. However, predominantly di-muon dat a provide main data constraints.



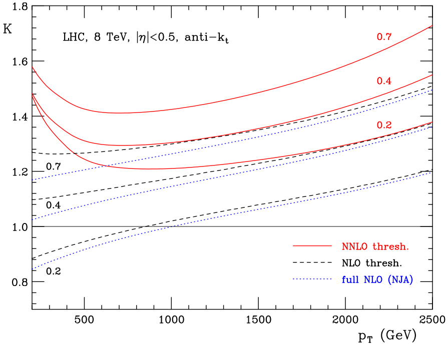


Jet data @ NNLO

- 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.

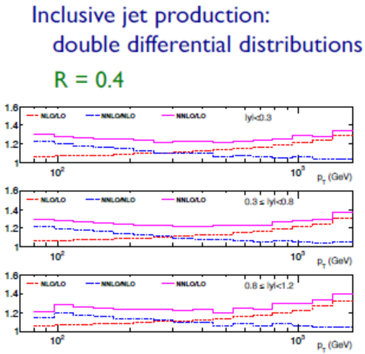


- Recent repeat of threshold calculations Kumar, Moch (arXiv:1309.5311) and comparison to exact NLO results for different jet radius R.
- Big variation with R at NLO and threshold calculation which has no R dependence matches best with $R \sim 0.3 - 0.4$.



- Very recent improved calculation from de Florian et al. (arXiv:1310.7192) has built in R dependence.
- Shows correct variation at NLO but little extra R dependence at NNLO. Still has problems at low p_T.

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

- At Tevatron NNLO still fit well because always rather near threshold and corections still hold at lowest p_T.
- In order to test robustness: 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 so still within one sigma.
- Different story for LHC data. In general much farther away from threshold, 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 $p_T = 100\ \mathrm{GeV}$ - rapidity independent.
- Prediction good. Fit quality a small amount worse than at NLO, though deteriorates slowly with larger K-factor.

Conclusions

- Ongoing updates on PDFs. Updated PDFs to be released soon.
- Inclusion of up-to-date HERA and Tevatron data.
- Furthermore, directly included most relevant published LHC data: ATLAS, CMS, LHCb W, Z rapidity data, $t\bar{t}$–cross section data and all published ATLAS and CMS inclusive jet data (don't include these as default at NNLO). Fit good with no PDF conflicts.
- So far few dramatic effects on PDFs. Mainly strange quark (and mainly at NNLO) 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.

- 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)	114	(113.7)	(128.9)	(112.8)
CMS jets (7TeV)	133	(184.9)	(181.3)	(181.3)
ATLAS W^+, W^-, Z	30	76.8	57.1	40.1
CMS W asymm $p_T > 35\mathrm{GeV}$	11	21.4	18.1	9.0
CMS asymm $p_T > 25\mathrm{GeV}, 30\mathrm{GeV}$	24	18.5	16.6	10.8
LHCb $Z \to e^+e^-$	9	20.9	20.5	20.0
LHCb W asymm $p_T > 20\mathrm{GeV}$	10	24.1	21.5	13.5
CMS $Z \to e^+e^-$	35	31.0	28.8	19.2
ATLAS High mass DY	13	17.9	16.5	17.8
TeV, ATLAS, CMS $\sigma_{t\bar{t}}$	13	8.0	11.2	6.5

- Large improvement in
  - ATLAS W, Z data, mainly from strange quark
  - CMS $Z \to e^+e^-$ data
  - (to some extent) CMS W asymm. and LHCb W^+, W^- data.
- CMS $Z \to e^+e^-$ data constrains a gluon eigenvector and CMS W asymm. data some flavour decomposition.

- 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)	114	(134.1)	(144.7)	(129.2)
CMS jets (7TeV)	133	(191.3)	(187.6)	(189.6)
ATLAS W^+, W^-, Z	30	76.8	57.1	40.1
CMS W asymm $p_T > 35\mathrm{GeV}$	11	21.4	18.1	9.0
CMS asymm $p_T > 25\mathrm{GeV}, 30\mathrm{GeV}$	24	18.5	16.6	10.8
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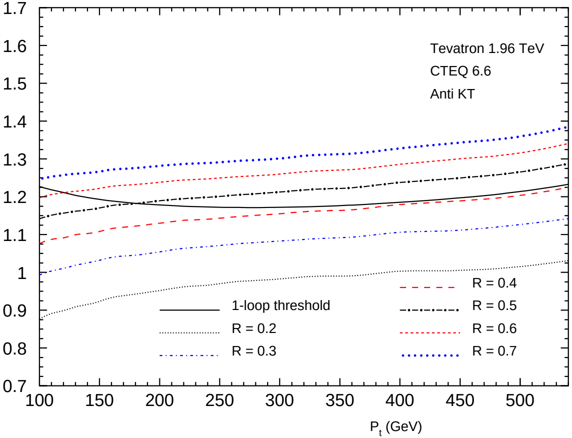
- ATLAS jet data deteriorates more than CMS. Difficult to guess relative size of K-factor at two different energies.

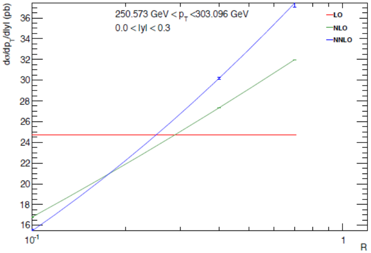
- HERA DIS data constrains many gross features, e.g. gluon, sea normalisation.
- Dimuon data constrains most of the 10 strange eigenvectors.
- Fixed target Drell Yan all $\bar{d} - \bar{u}$ differences, and high-x sea.
- Tevatron and now LHC data constrain flavour separation and some constraint on gluon.



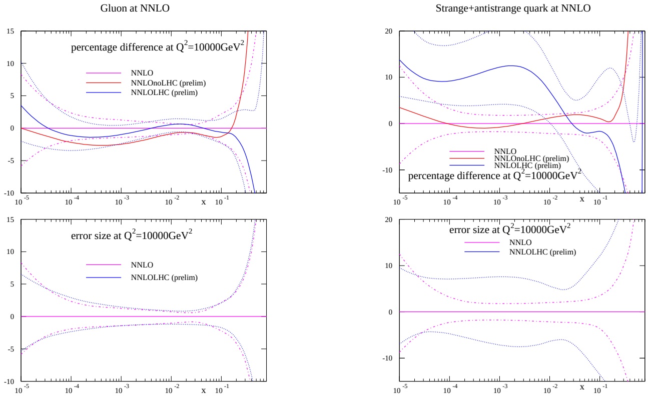
Tevatron 1.96 TeV
CTEQ 6.6
Anti KT
1-loop threshold
R = 0.2
R = 0.3
R = 0.4
R = 0.5
R = 0.6
R = 0.7
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
100
150
200
250
300
350
400
450
500
P_t (GeV)

NNLO corrections to pp $\to$ 2jets

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



- 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.



Change in NNLO PDFs from all, including LHC data updates. Gluon uncertainty at high-x slightly greater than at NLO.