Progress in CTEQ-TEA (Tung et al.) PDF Analysis

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In collaboration with
CTEQ-TEA

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DIS2015@SMU
Dallas, TX

CTEQ-TEA group

- CTEQ – Tung et al. (TEA)

in memory of Prof. Wu-Ki Tung,

who established CTEQ Collaboration in early 90's

- Current members:

Sayipjamal Dulat (Xinjiang U.),

Tie-Jiun Hou, Pavel Nadolsky (Southern Methodist U.), Jun Gao (Argonne Nat. Lab.), Marco Guzzi (U. of Manchester), Joey Huston, Jon Pumplin, Dan Stump, Carl Schmidt, CPY (Michigan State U.)

Outline

- Overview of CT14 PDFs
- Effect from LHC Run 1 (ATLAS, CMS, LHCb) and new Tevatron D0 Data to CT14
- Impact to Higgs and Top at LHC Run 2
- Conclusion

Overview of CT14 analysis

- CT10 includes only pre-LHC data
- CT14 is the first CT analysis including LHC Run 1 data
- CT14 also includes the new Tevatron D0 Run 2 data on W-electron charge asymmetry
- CT14 uses a more flexible parametrization in the non-perturbative PDFs.
- Here, I will only show the CT14 results at NNLO. We will also publish its results at NLO and LO.

Experimental Data for CT14

- Based on CT10 data set, but updated with new HERA F_L and F_2^c, and drop Tevatron Run 1 CDF and D0 inclusive jet
- Included some LHC Run 1 (at 7 TeV) data:

ATLAS and LHCb W/Z production,
ATLAS, CMS and LHCb W-lepton charge asymmetry,
ATLAS and CMS inclusive jet

- Replace old by new D0 (9.7 1/fb) W-electron rapidity asymmetry data

Theory Analysis in CT14

- CT14 has 28 shape parameters, and CT10 has 25.
- More flexible parametrization – gluon, d/u at large x, and both d/u and dbar/ubar at small x, strangeness (assuming sbar = s)
- Non-perturbative parametrization form:

$$x\, f_a(x) = x^{a_1}\,(1-x)^{a_2}\,P_a(x)$$

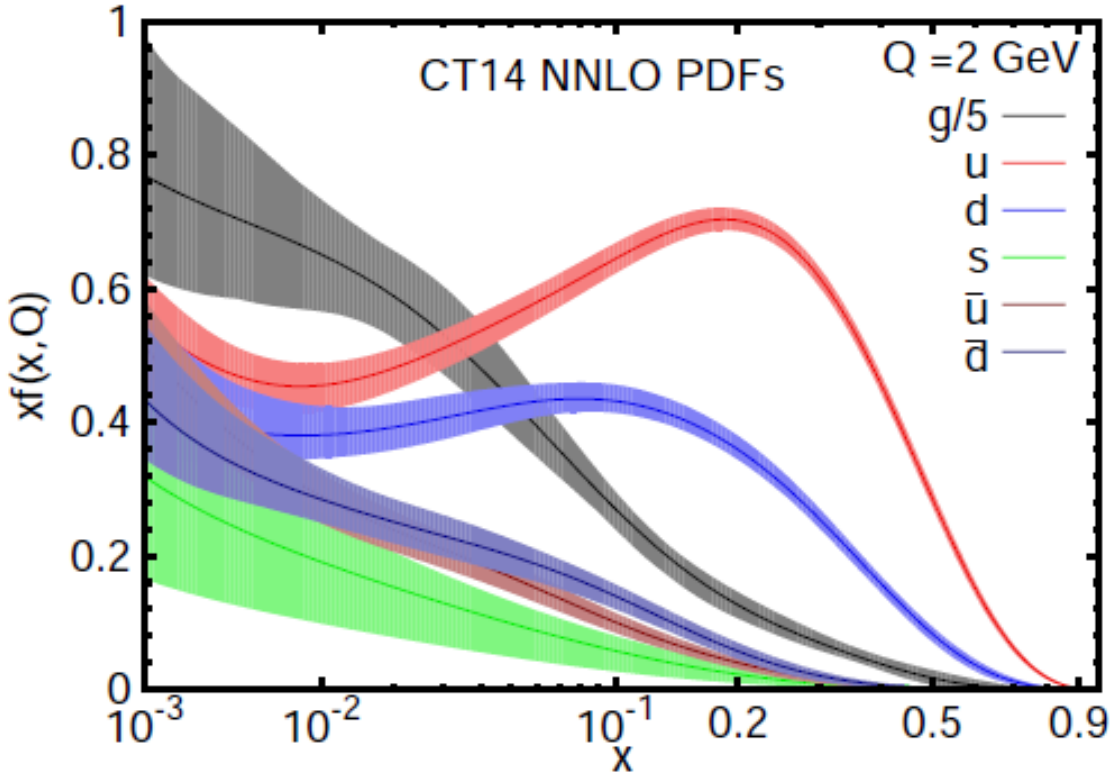
where $P_a(x)$ is expressed as a linear combination of Bernstein polynomials to reduce the correlation among its coefficients.

- Produce 90% C.L. error PDF sets from Hessian method, scaled by 1/1.645 to obtain 68% C.L. eigenvector sets.

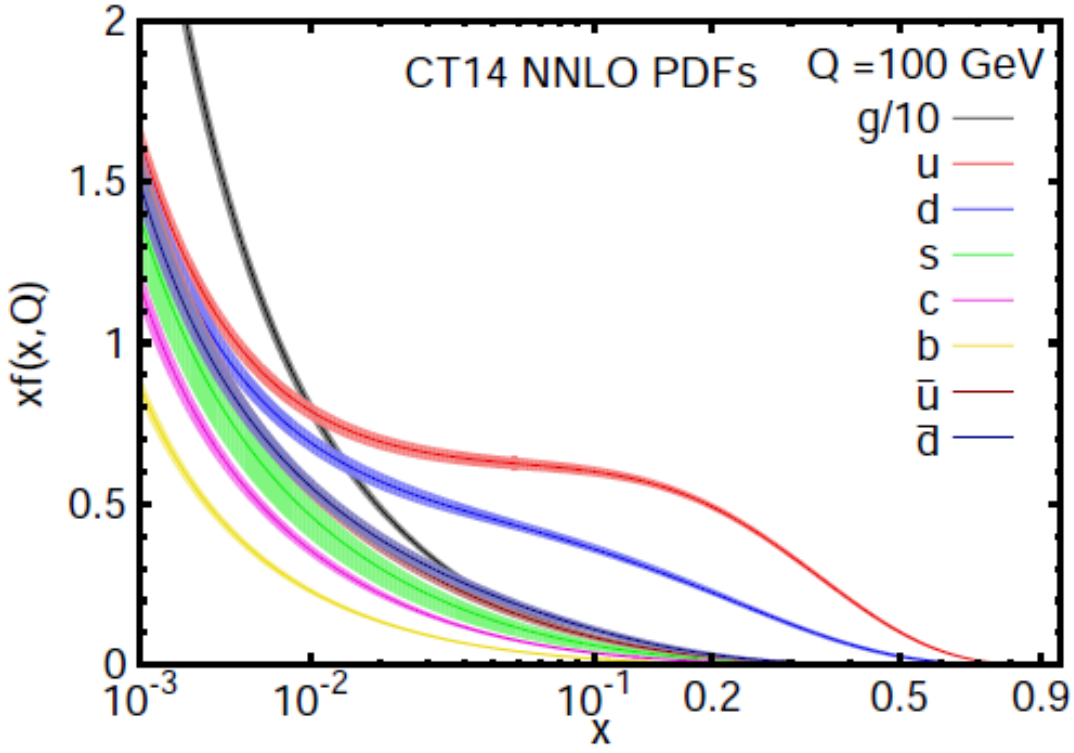
Theory Analysis in CT14

- Choose experimental data with $Q^2 > 4\ GeV^2$ and $W^2 > 12.6\ GeV^2$ to minimize high-twist, nuclear correction, etc., and focus on perturbative QCD predictions.
- PDFs are parametrized at Q=1.3 GeV.
- Take $\alpha_s(Mz) = 0.118$, but also provide α_s-series PDFs.
- Use s-ACOT-χ prescription for heavy quark partons, and take pole mass Mc =1.3 GeV and Mb=4.75 GeV
- NNLO calculations for DIS, DY, W, Z, except jet (at NLO).
- Correlated systematic errors are taken into account.
- Check Hessian method results by Lagrangian Multiplier method which does not assume quadratic approximation in chi-square.

CT14 PDFs

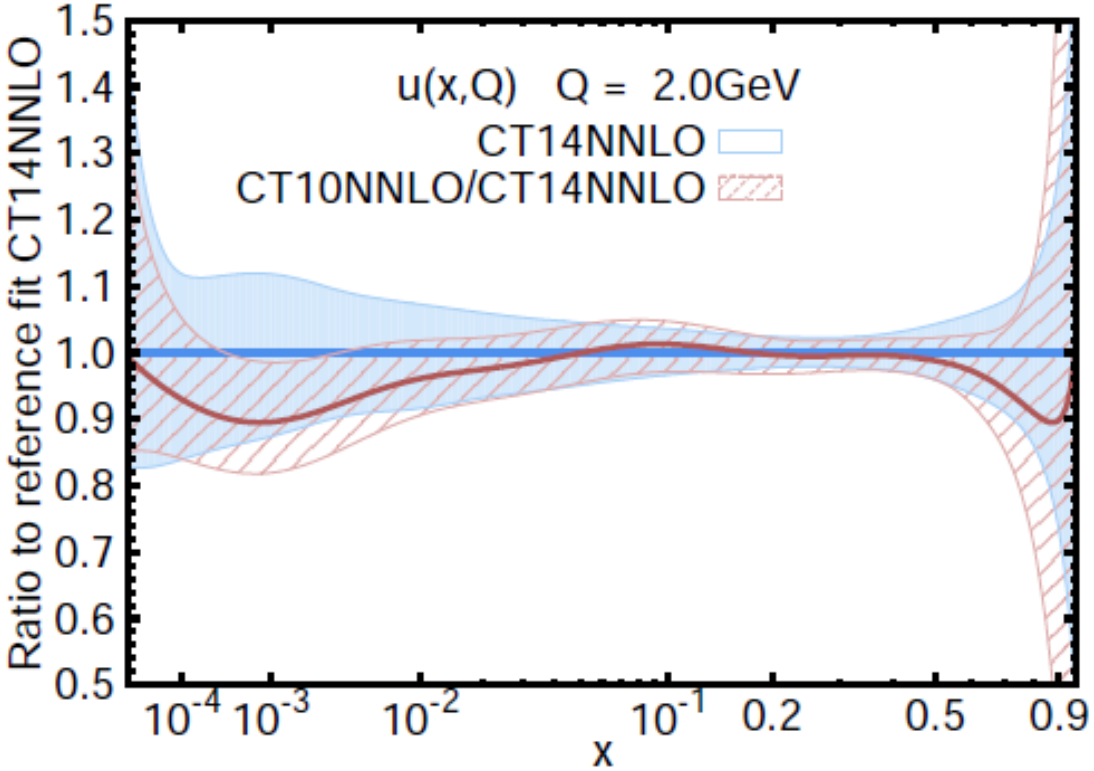


Q= 2 GeV

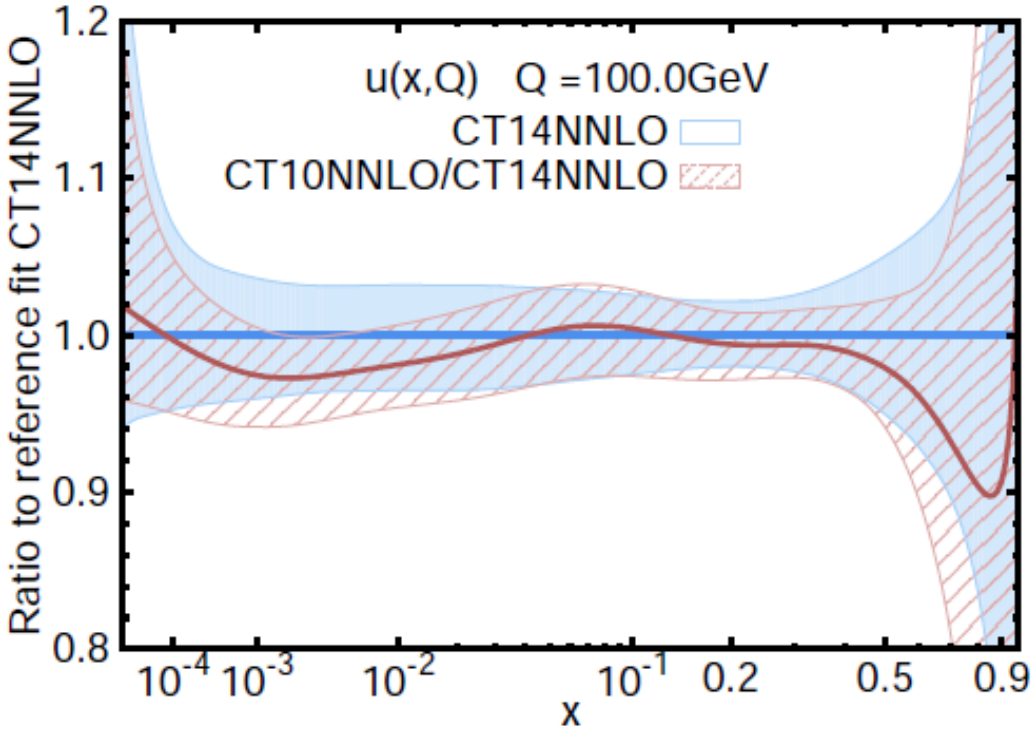


Q= 100 GeV

CT14 vs. CT10 in u-PDF

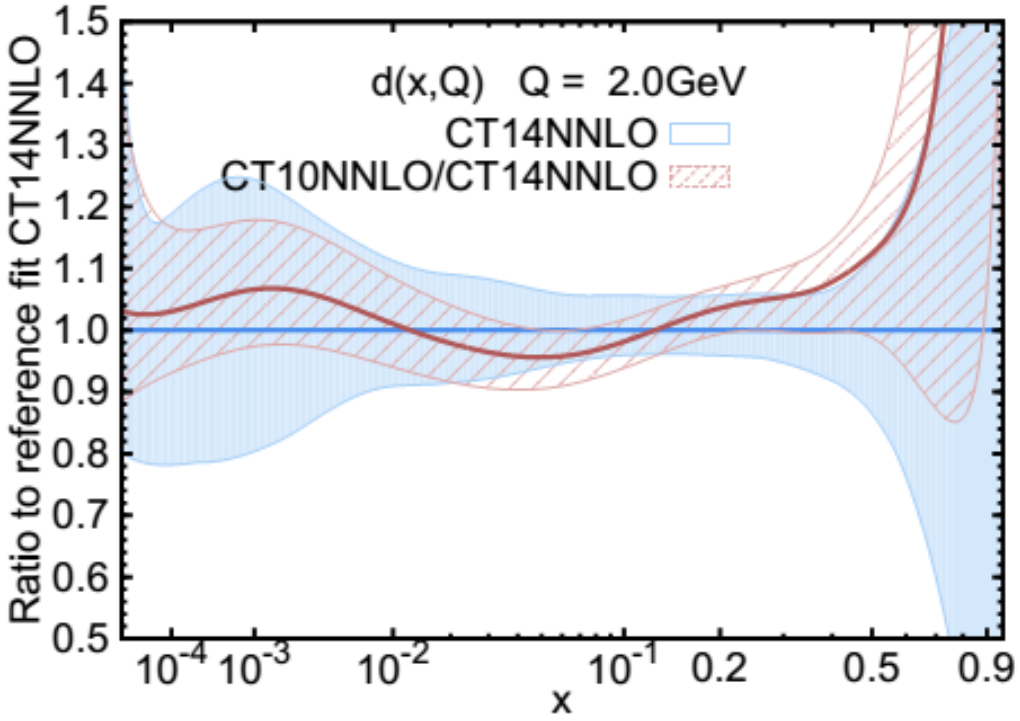


Q= 2 GeV

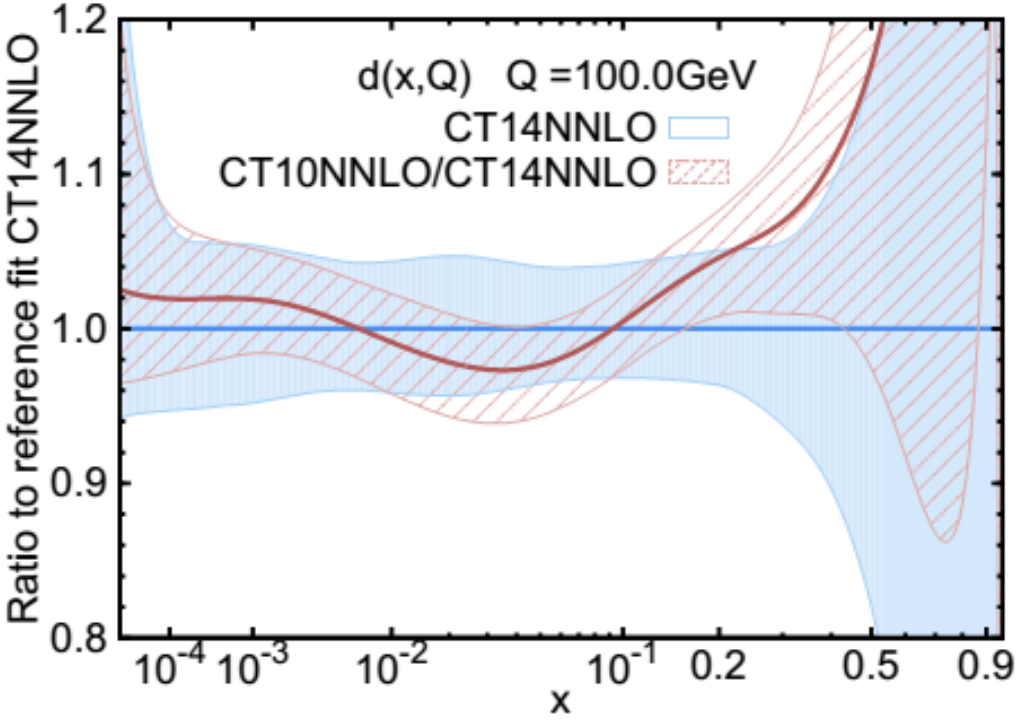


Q= 100 GeV

CT14 vs. CT10 in d-PDF



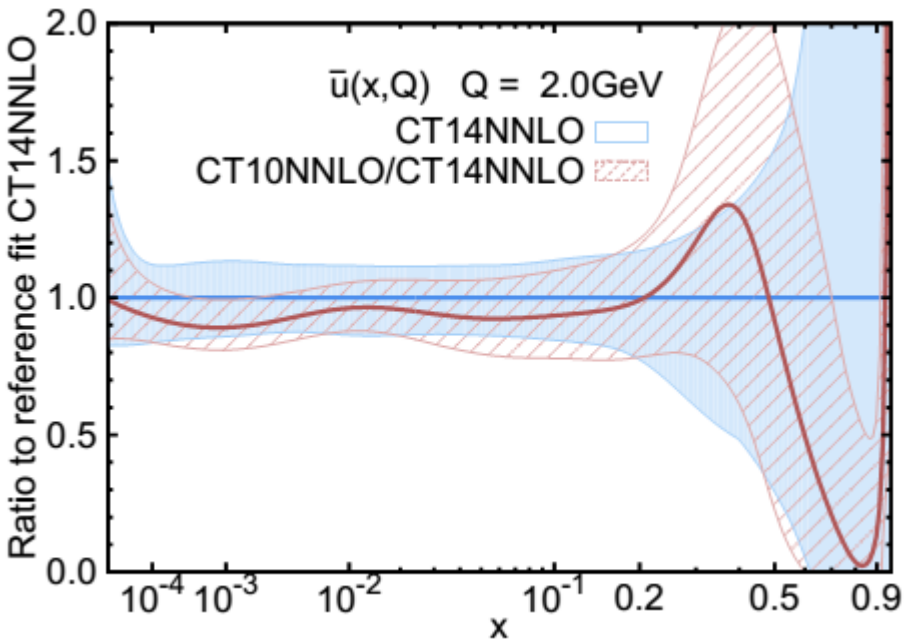
Q= 2 GeV

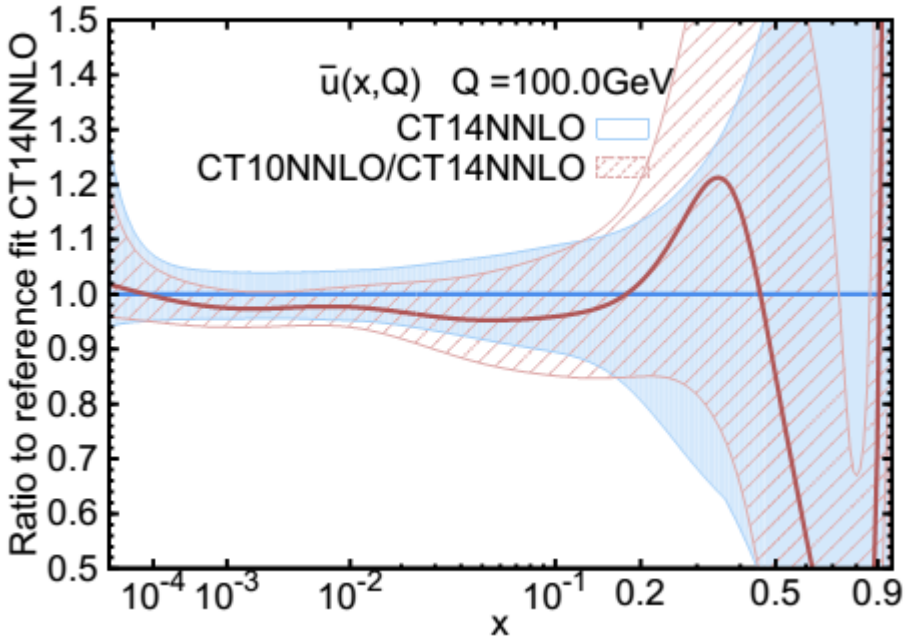


Q= 100 GeV

- d-PDF is smaller in CT14 than CT10 at x around 0.2

CT14 vs. CT10 in ubar-PDF

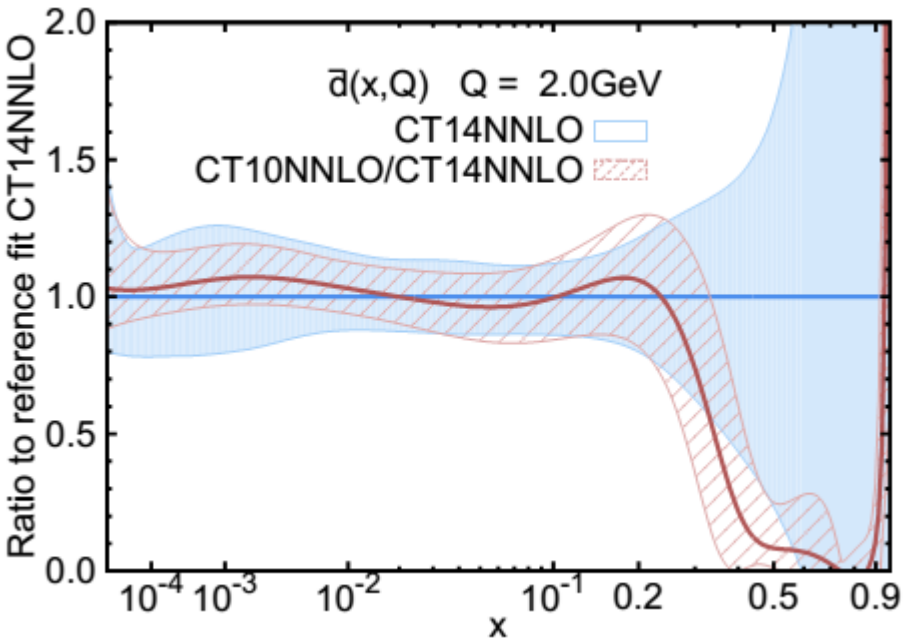




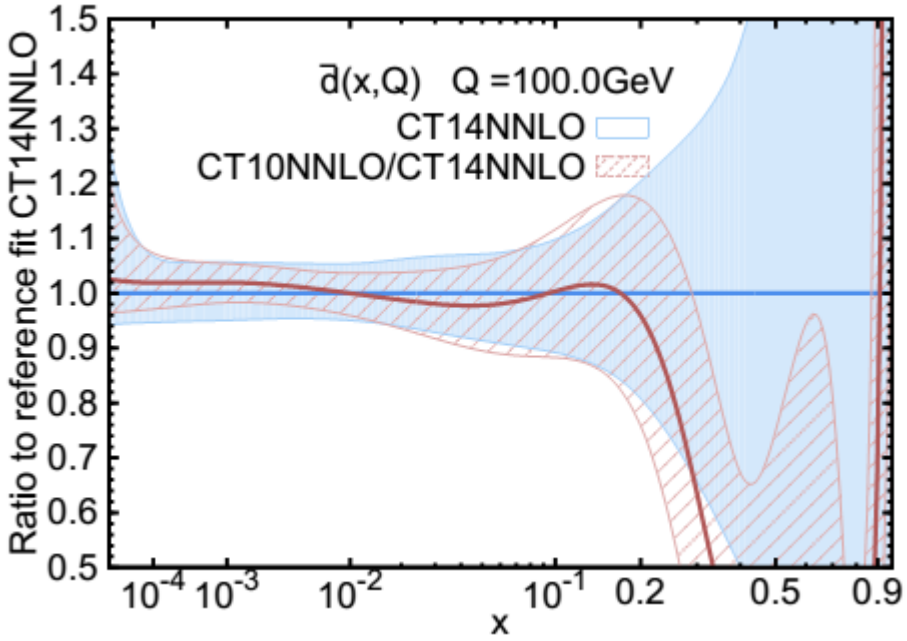
Q= 2 GeV

Q= 100 GeV

CT14 vs. CT10 in dbar-PDF



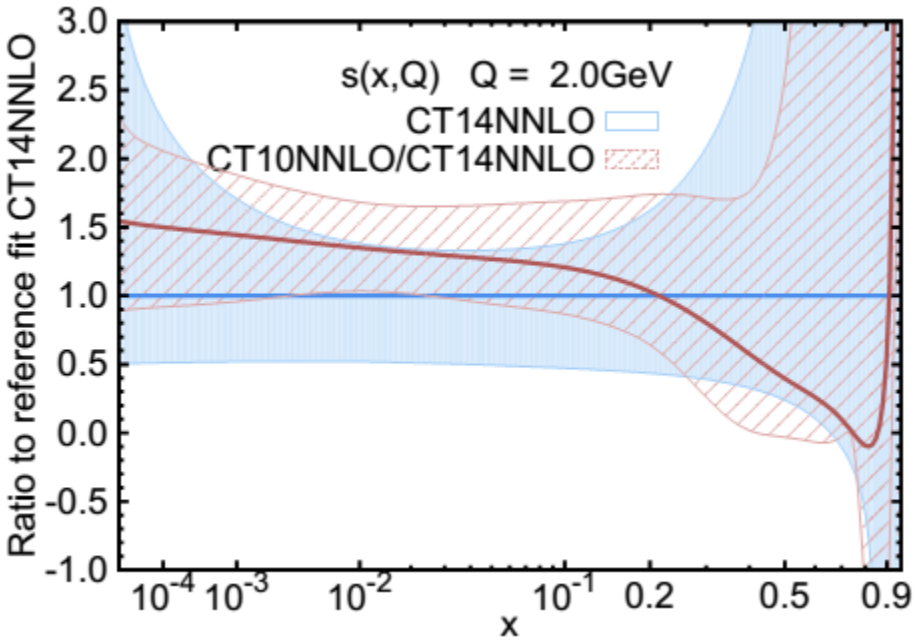
Q= 2 GeV



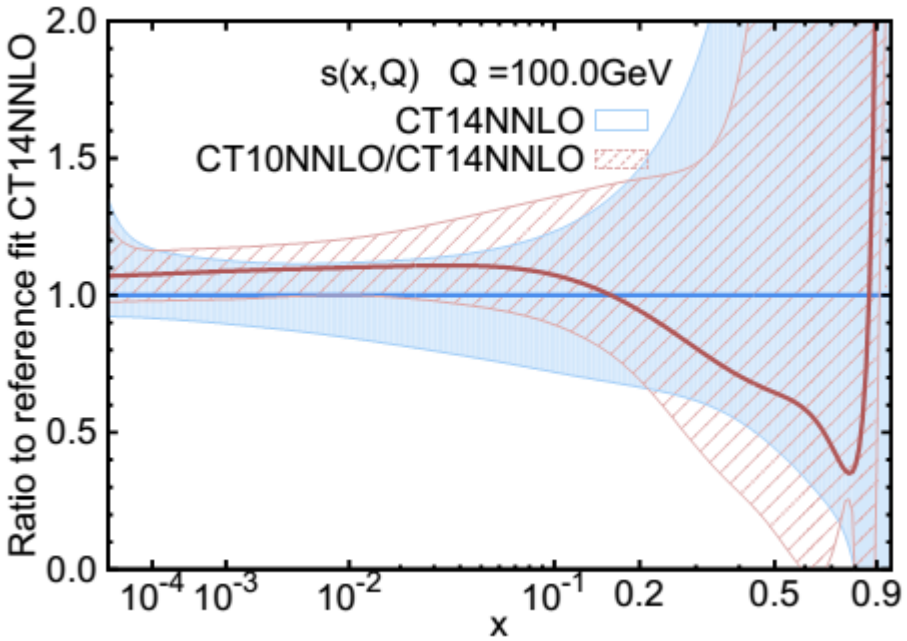
Q= 100 GeV

- dbar-PDF error band is larger in CT14 than CT10 for x larger than 0.3 due to more flexible parametrization.

CT14 vs. CT10 in s-PDF



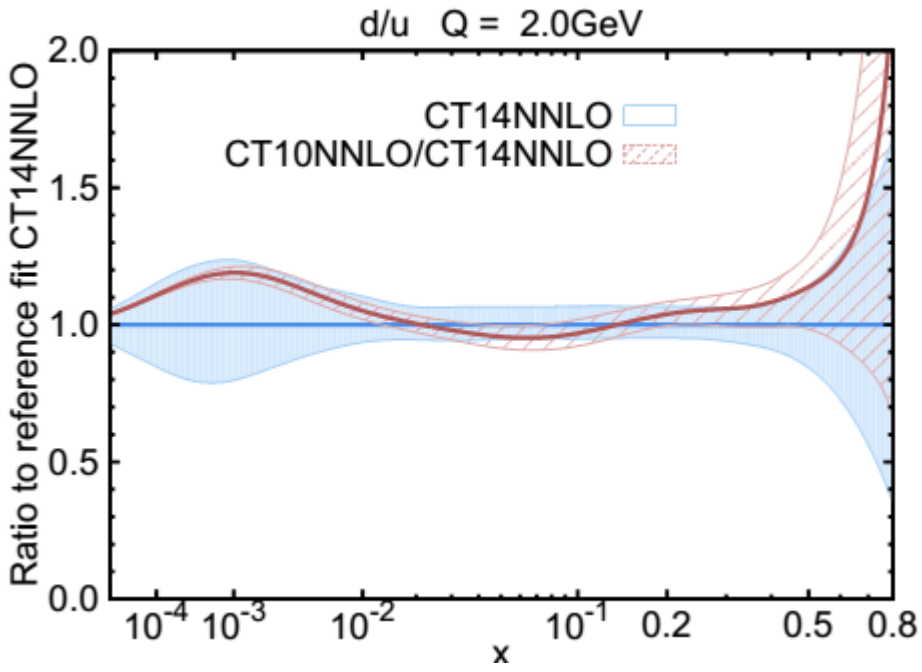
Q= 2 GeV



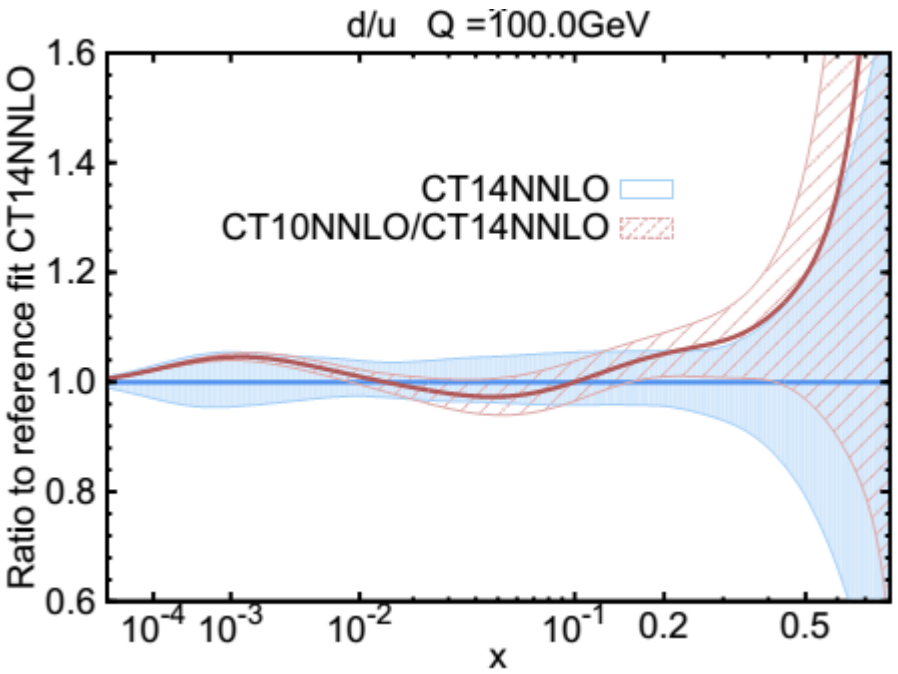
Q= 100 GeV

- s-PDF is smaller in CT14 than CT10 for x less than 0.1
- More discussion will be given later.

CT14 vs. CT10 in d/u



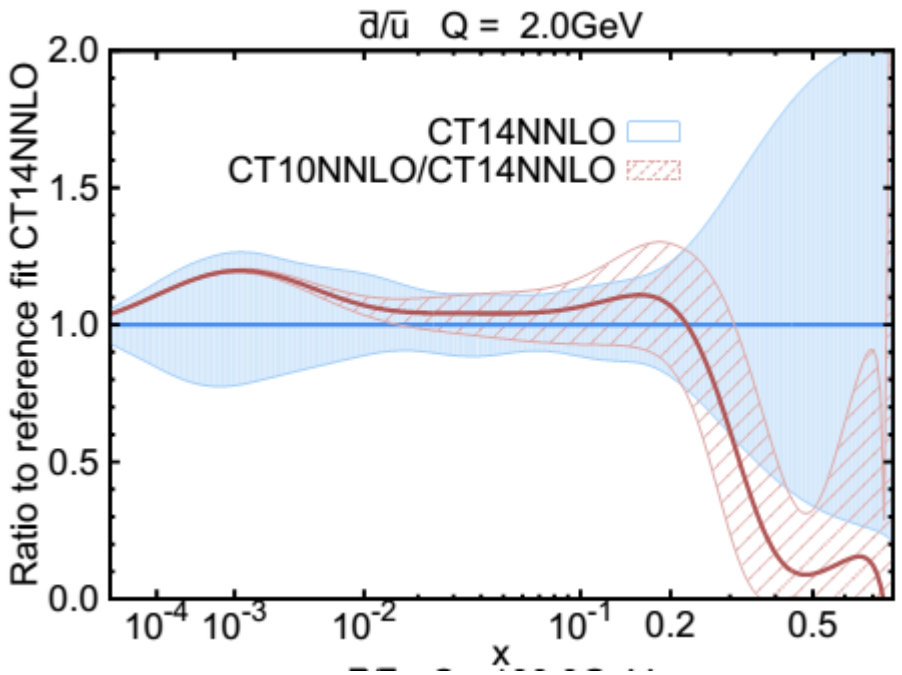
Q= 2 GeV



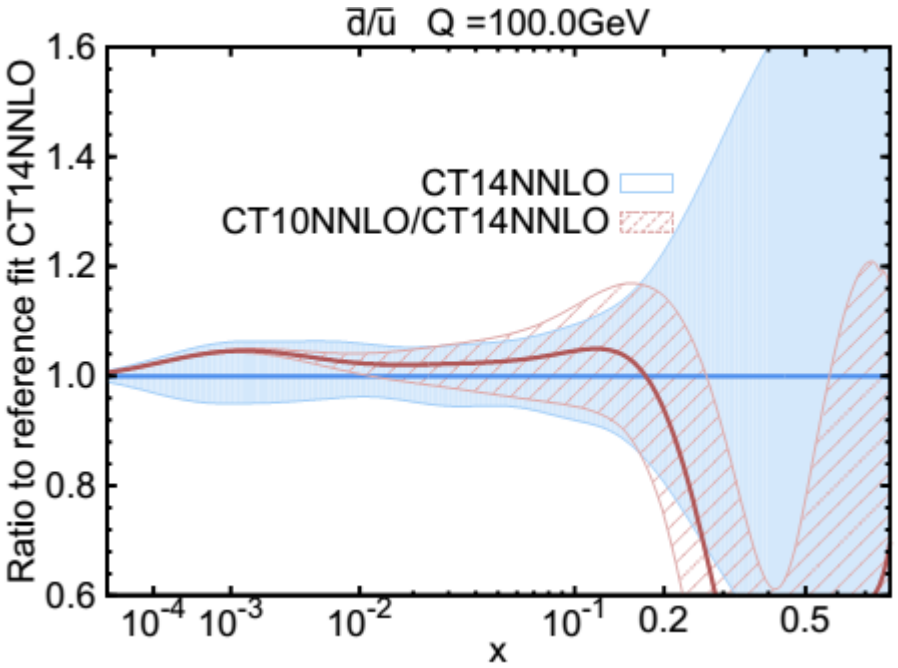
Q= 100 GeV

- d/u is smaller in CT14 than CT10 at x around 0.2
- More discussion will be given later.

CT14 vs. CT10 in dbar/ubar



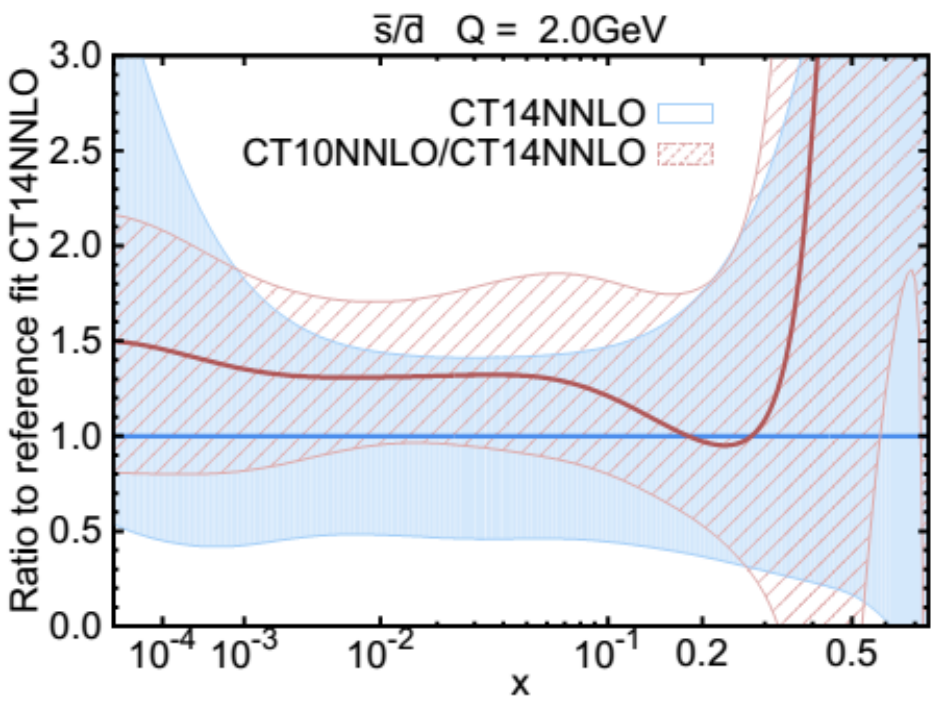
Q= 2 GeV



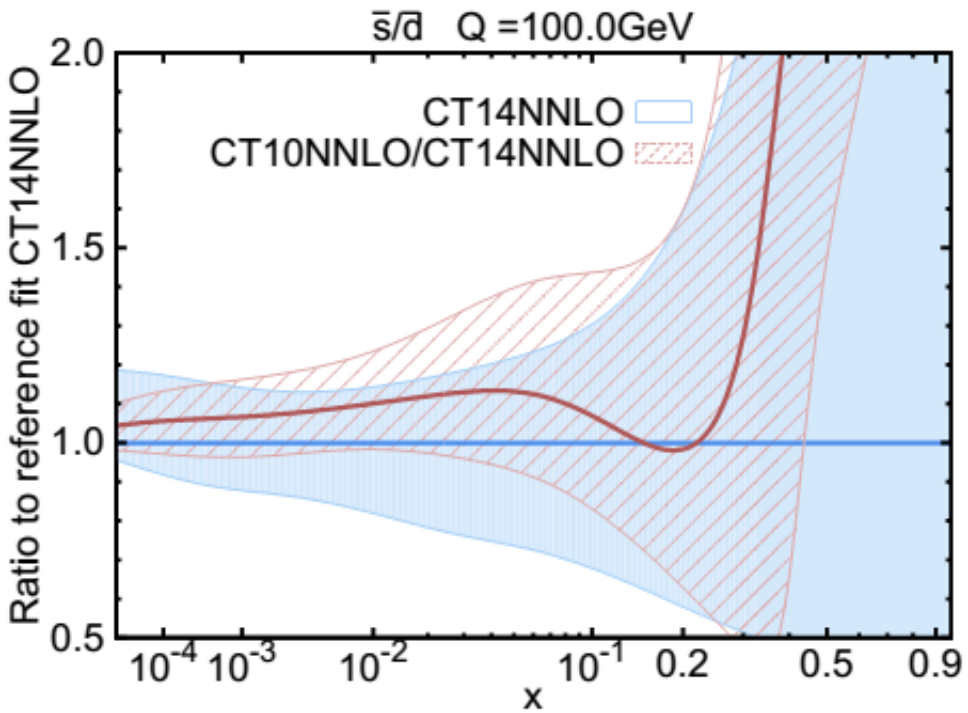
Q= 100 GeV

- dbar/ubar is smaller in CT14 than CT10 for x < 0.01
- dbar/ubar error band is larger in CT14 than CT10 for x larger than 0.3 due to more flexible parametrization.

CT14 vs. CT10 in sbar/dbar



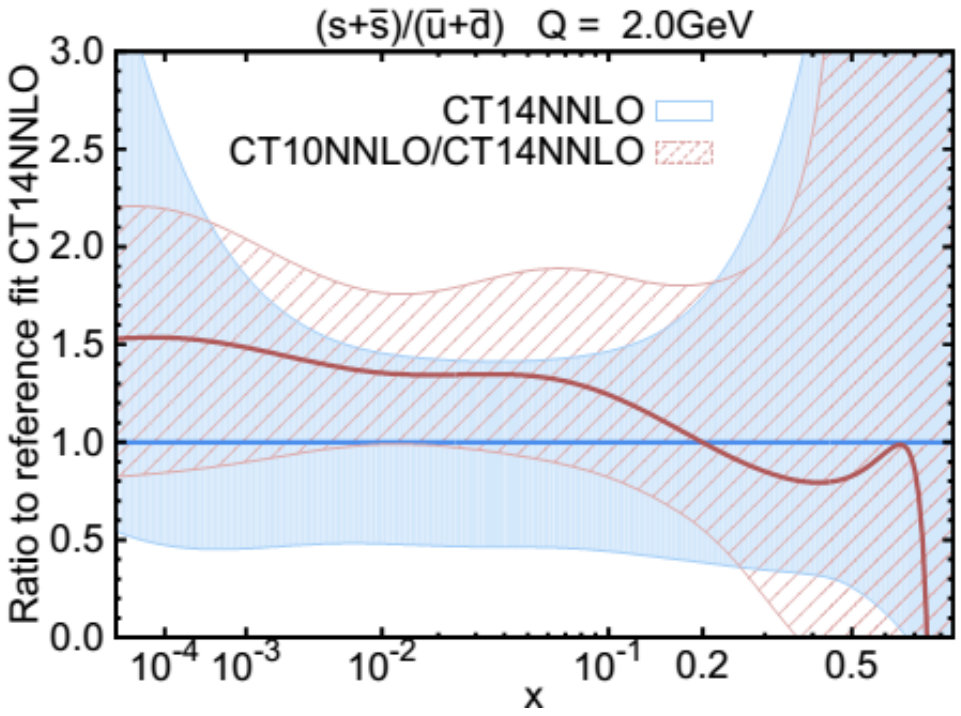
Q= 2 GeV



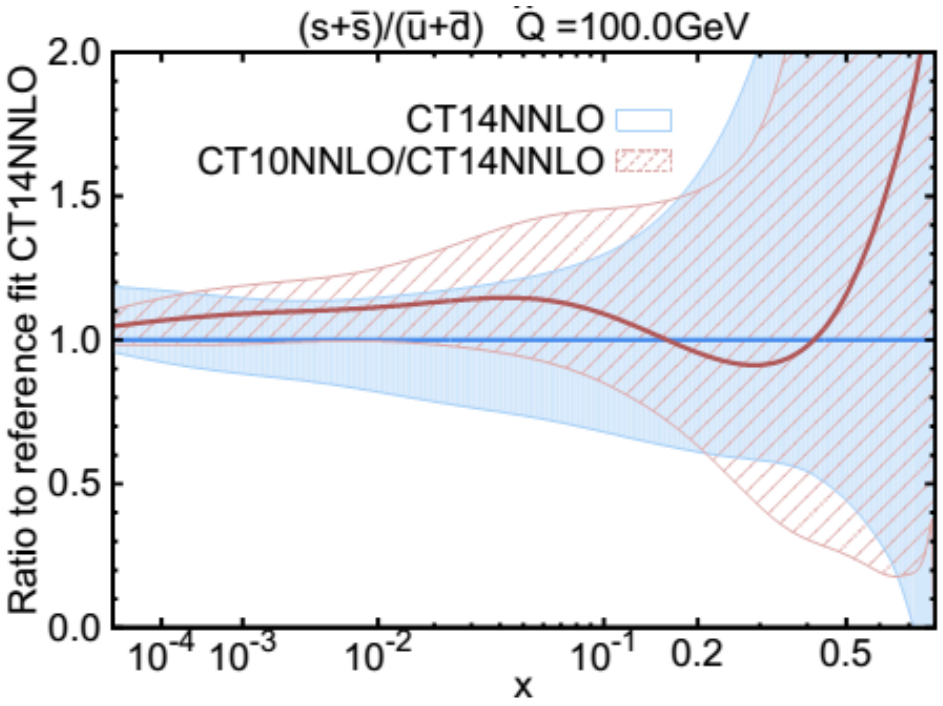
Q= 100 GeV

- More discussion will be given later.

CT14 vs. CT10 in (s+sbar)/(ubar+dbar)



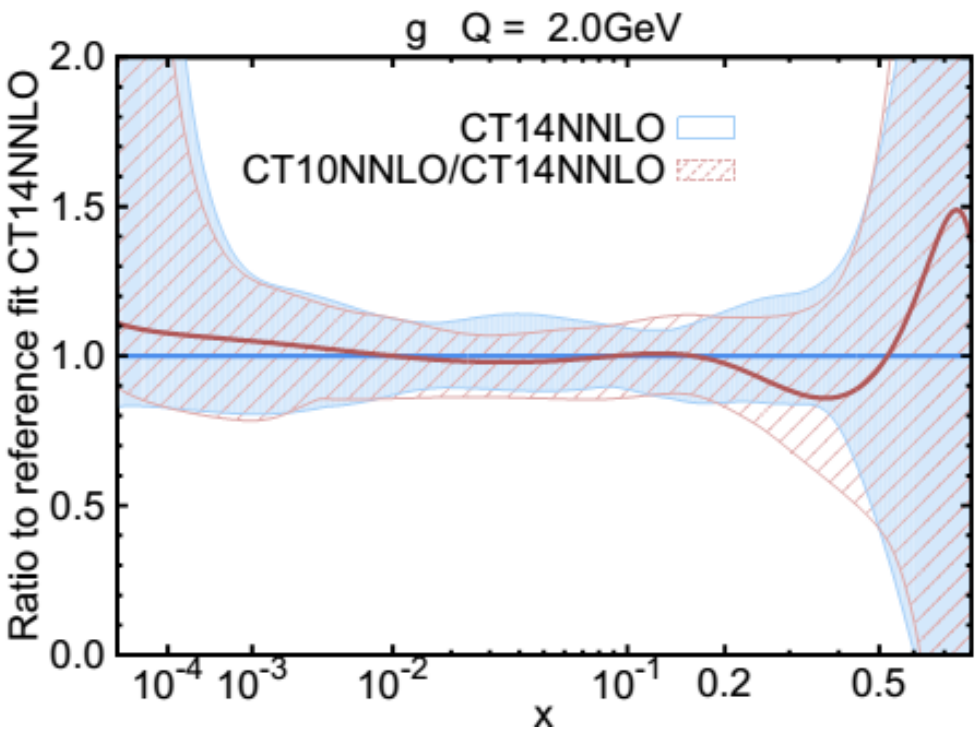
Q= 2 GeV



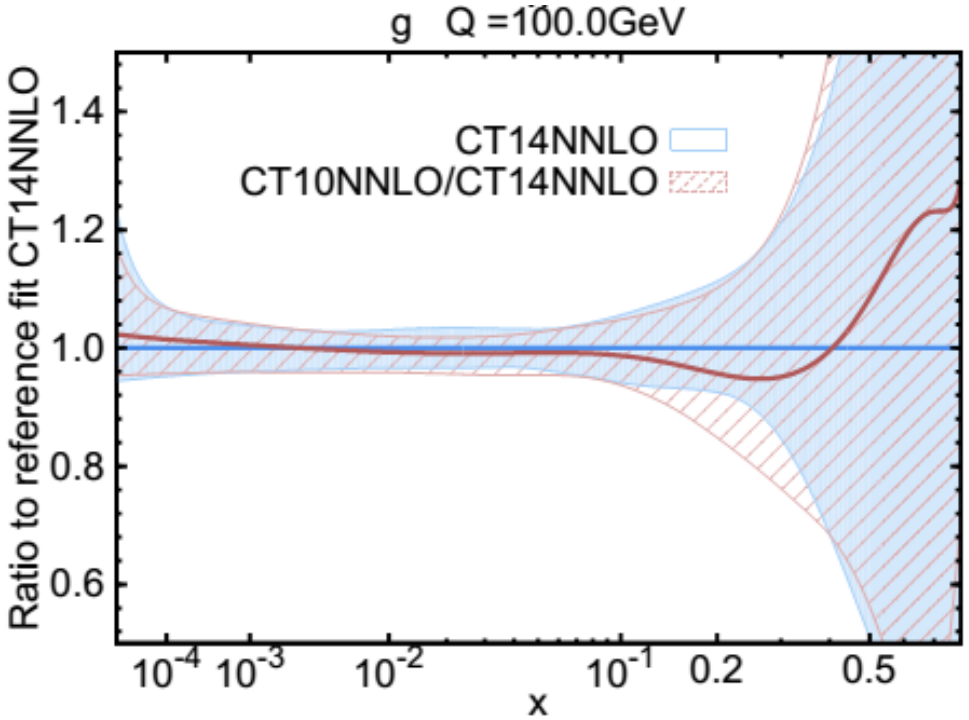
Q= 100 GeV

- More discussion will be given later.

CT14 vs. CT10 in gluon-PDF



Q= 2 GeV



Q= 100 GeV

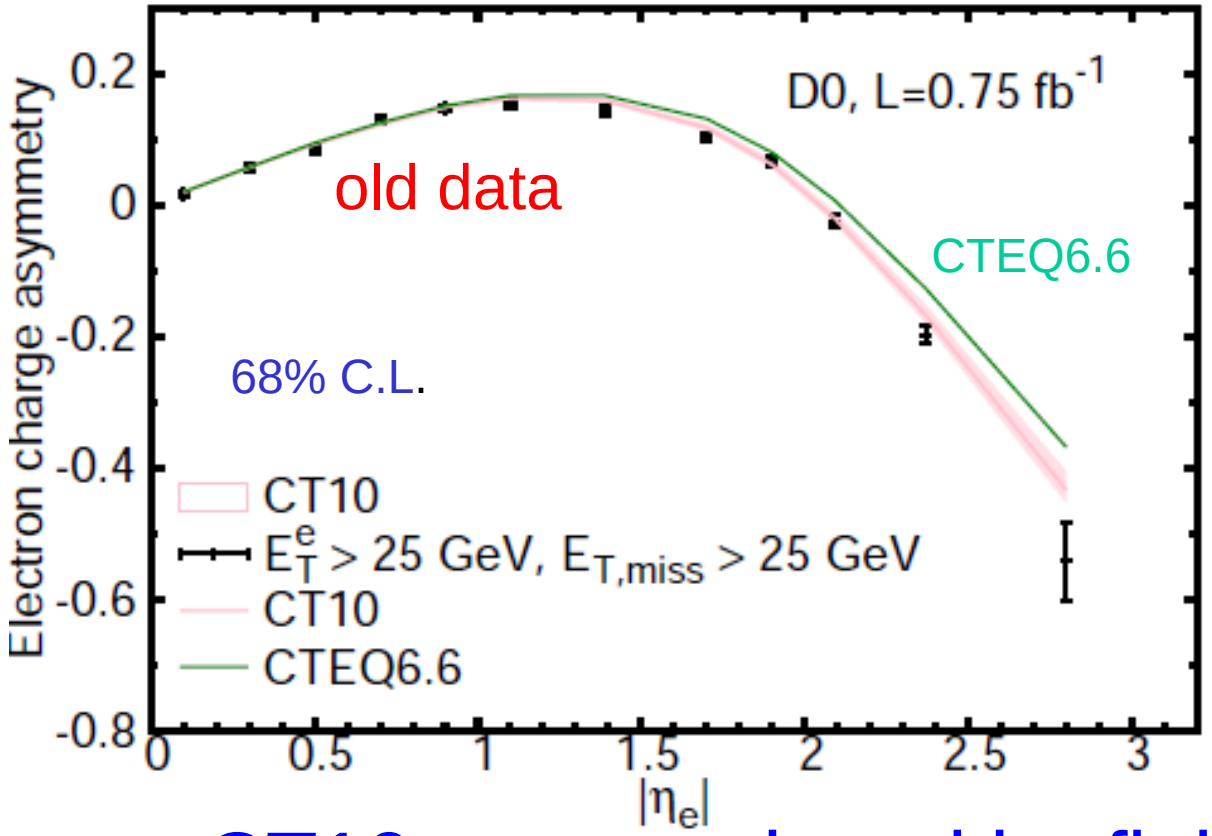
Checked by Lagrangian Multiplier Method

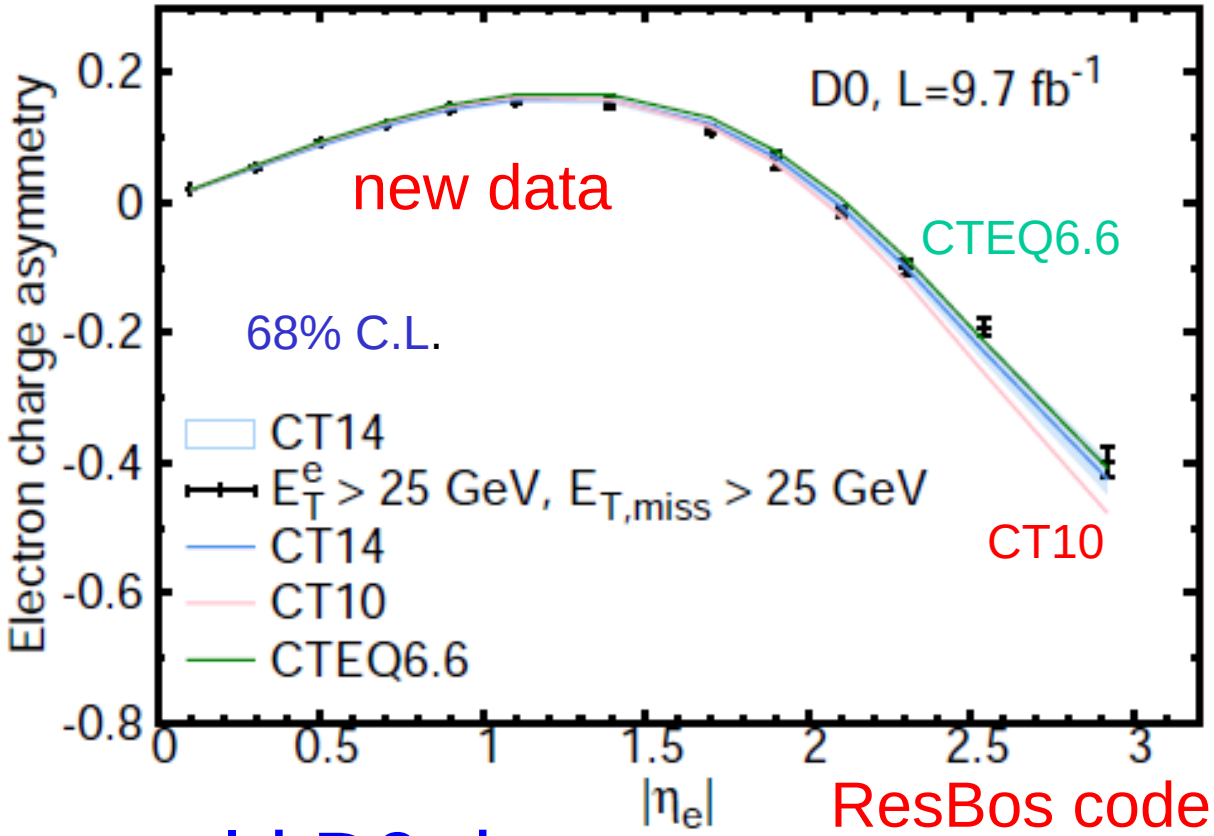
- dbar/ubar at x around 0.2 and 0.3, mainly constrained by E866 pd/pp data.
- dbar/ubar at x around 0.01, mainly constrained by NMC F2d/F2p data.
- d/u at x around 0.3, mainly constrained by NMC F2d/F2p, E866 pd/pp.
- Inclusion of LHC Run 1 W, Z and new Tevatron W data has impact on u, d, ubar and dbar.

Checked by Lagrangian Multiplier Method

- s at x around 0.1, mainly constrained by NuTeV di-muon data.
- s at x around 0.001, mainly constrained by CCFR, NuTeV, di-muon data.
- Inclusion of LHCb W-lepton rapidity asymmetry data has impact on s at small x.

Story about D0 Run 2 W-electron rapidity asymmetry data

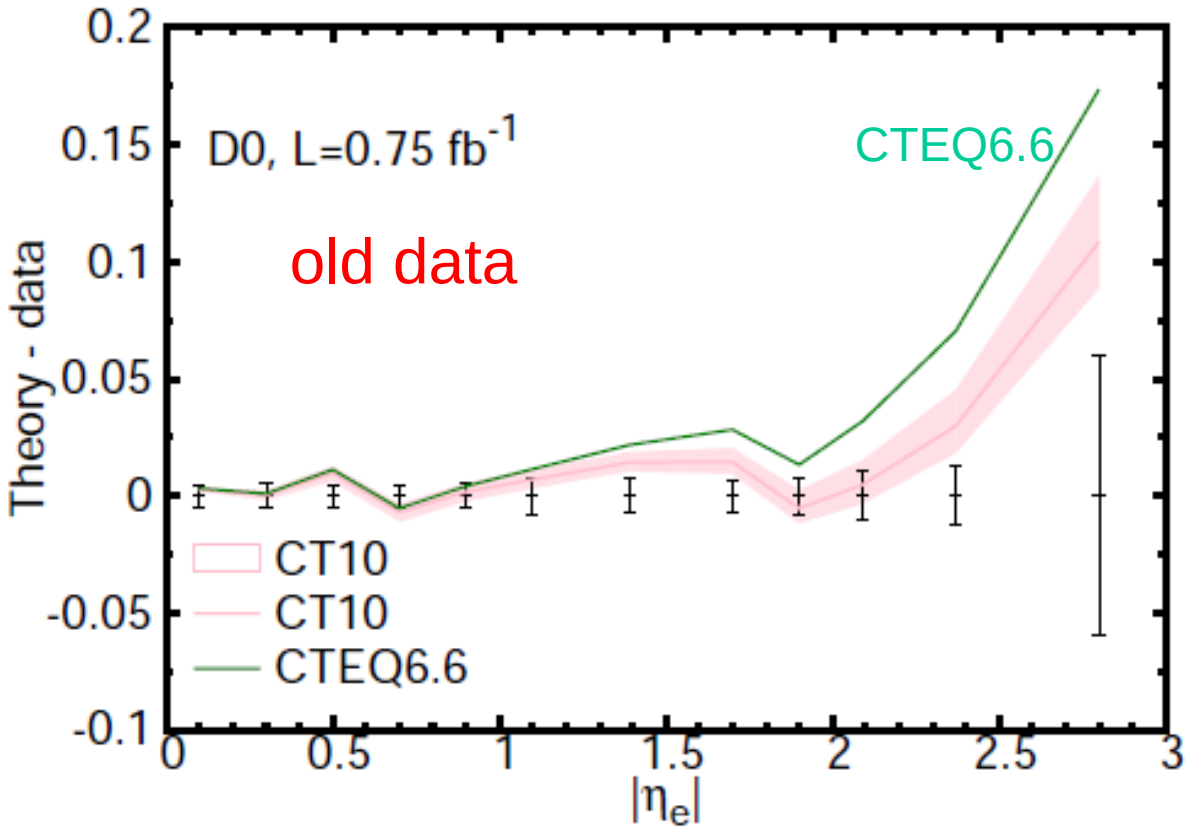


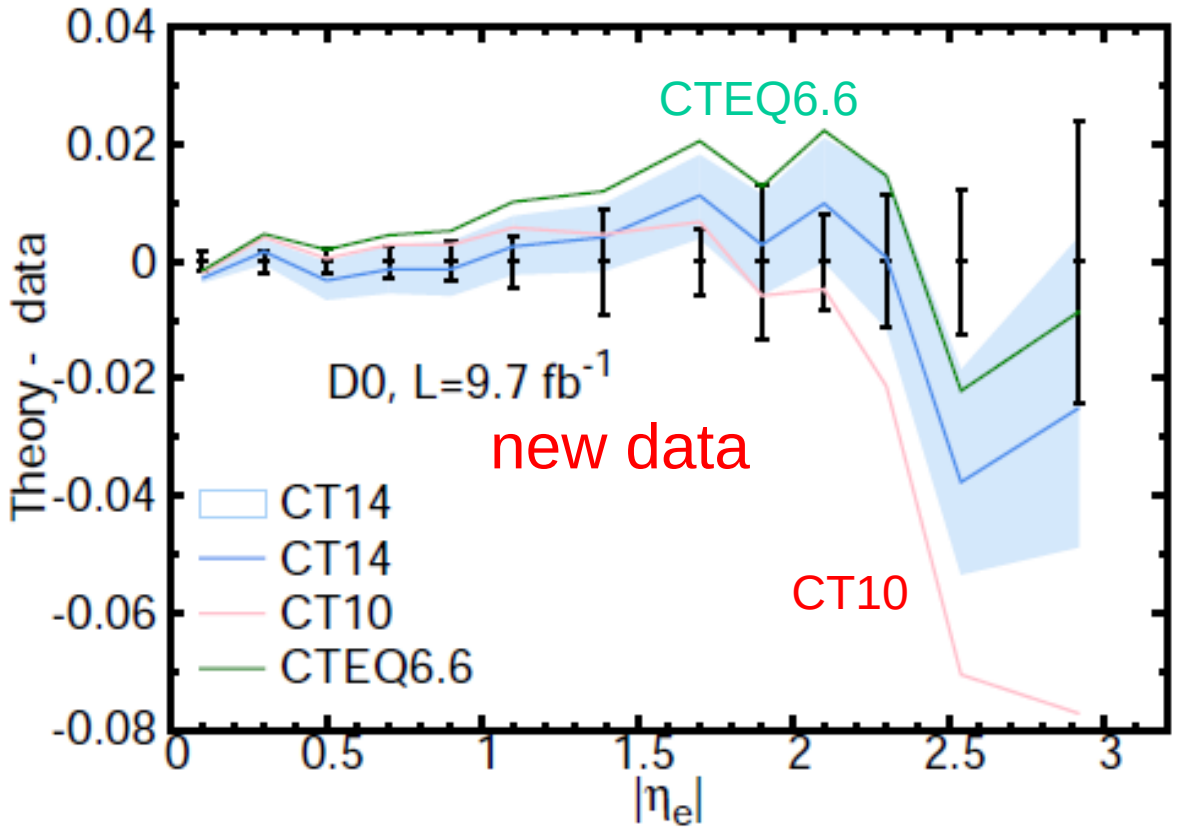


ResBos code

- CT10 was produced by fitting to old D0 data.
- CT14 uses new D0 data, closer to CTEQ6.6 than CT10 predictions in large rapidity.

Story about D0 Run 2 W-electron rapidity asymmetry data

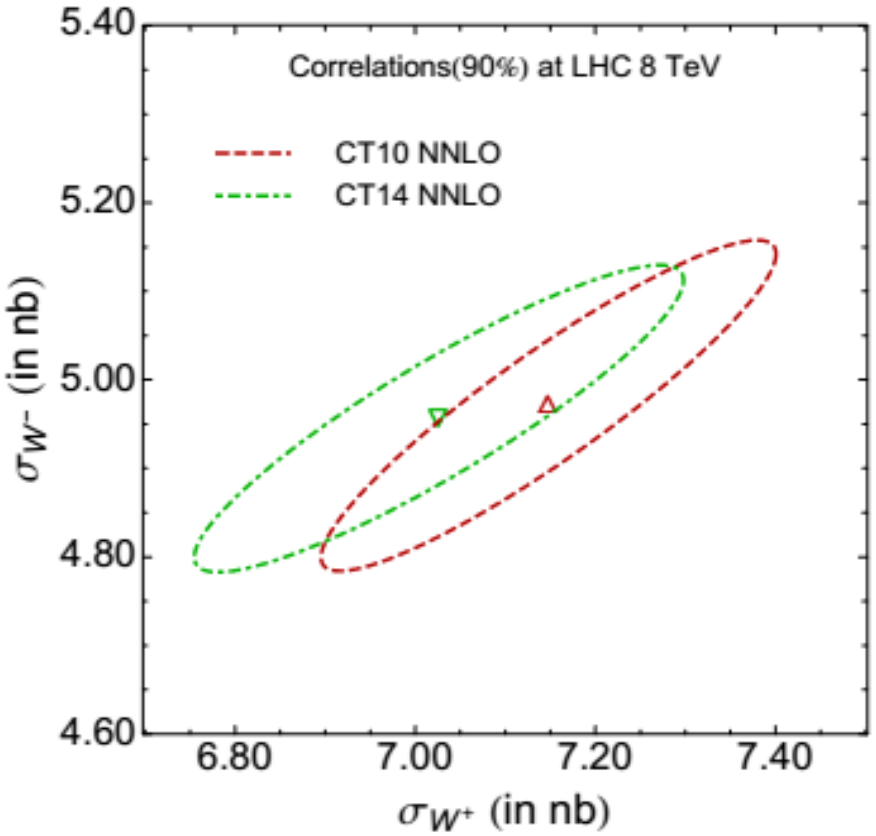


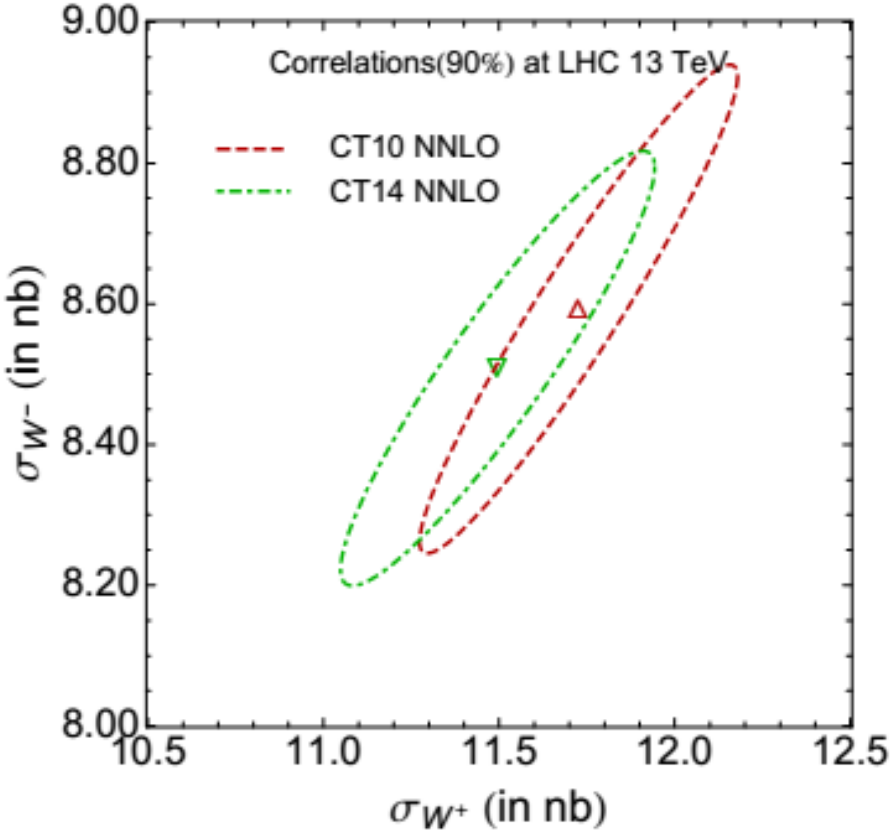


ResBos code

- CT10 was produced by fitting to old D0 data.
- CT14 uses new D0 data, closer to CTEQ6.6 than CT10 predictions in large rapidity.

Correlation ellipse for W- vs. W+ inclusive cross sections



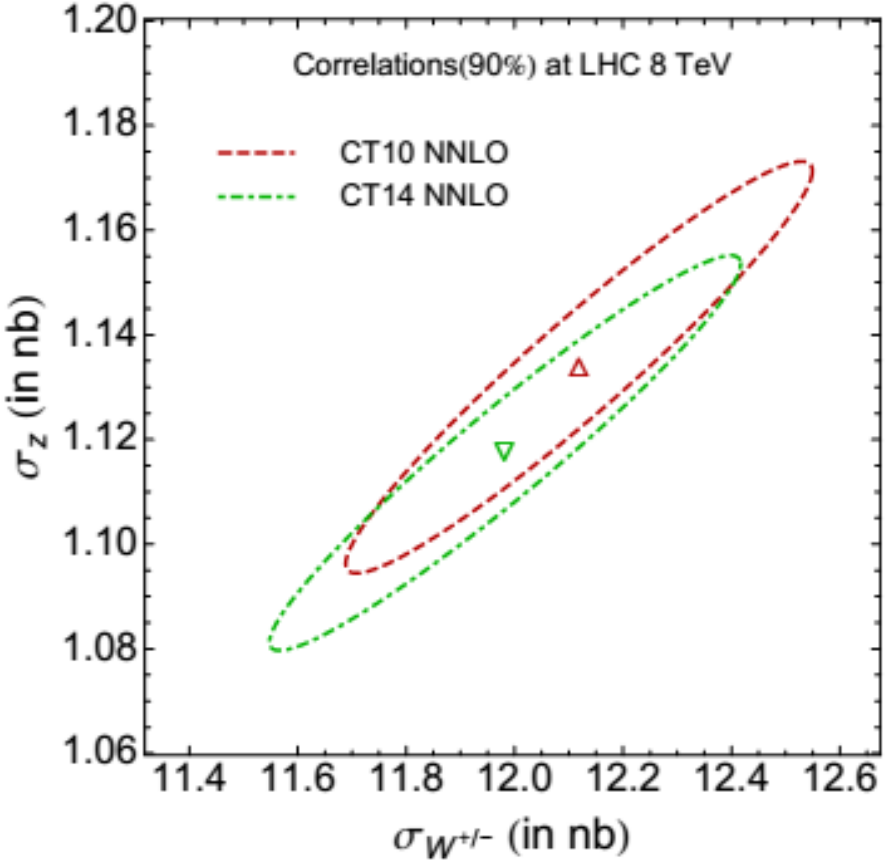


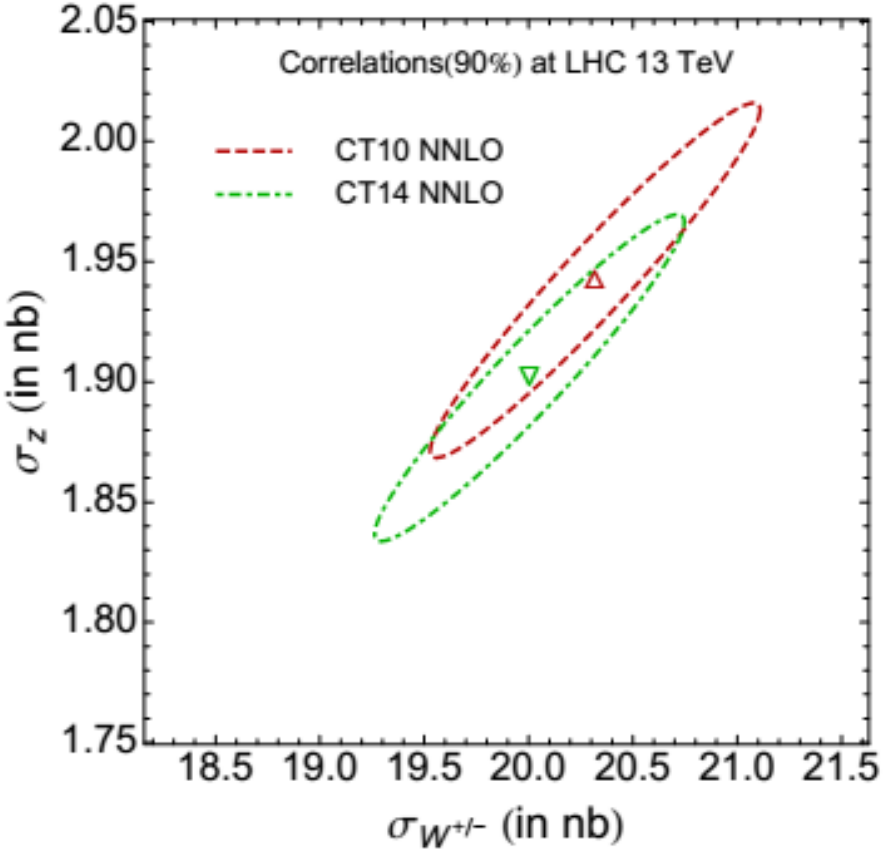
8 TeV

Vrap Code

13 TeV

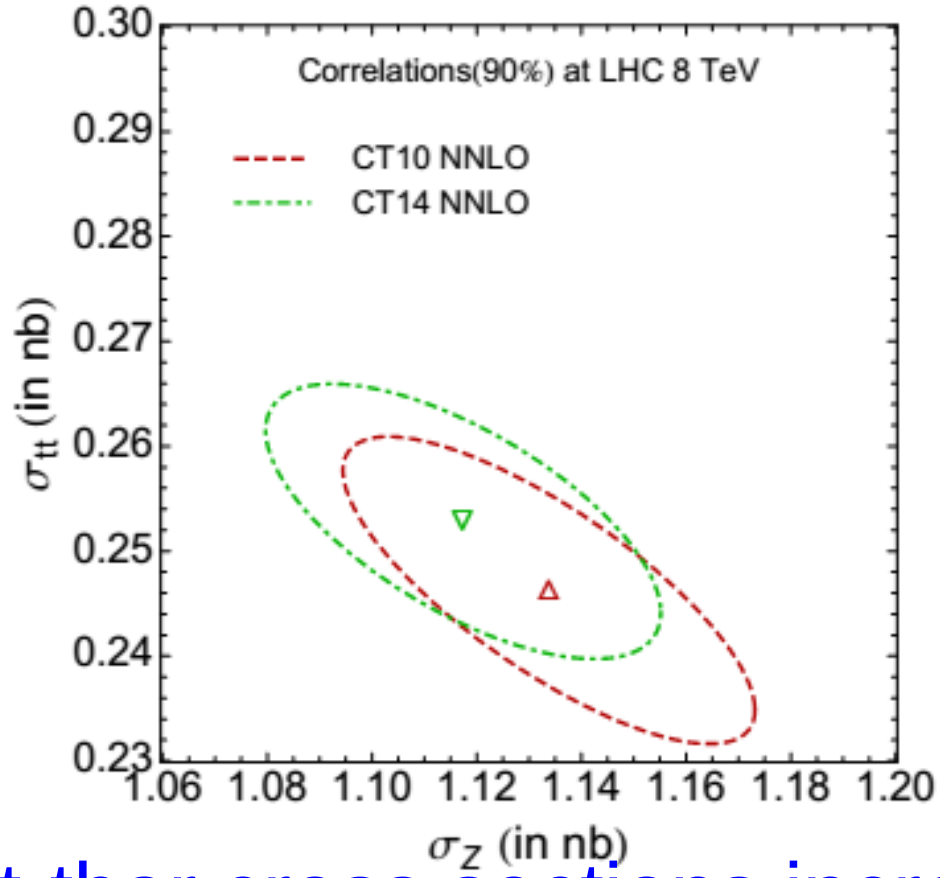
Z vs. W

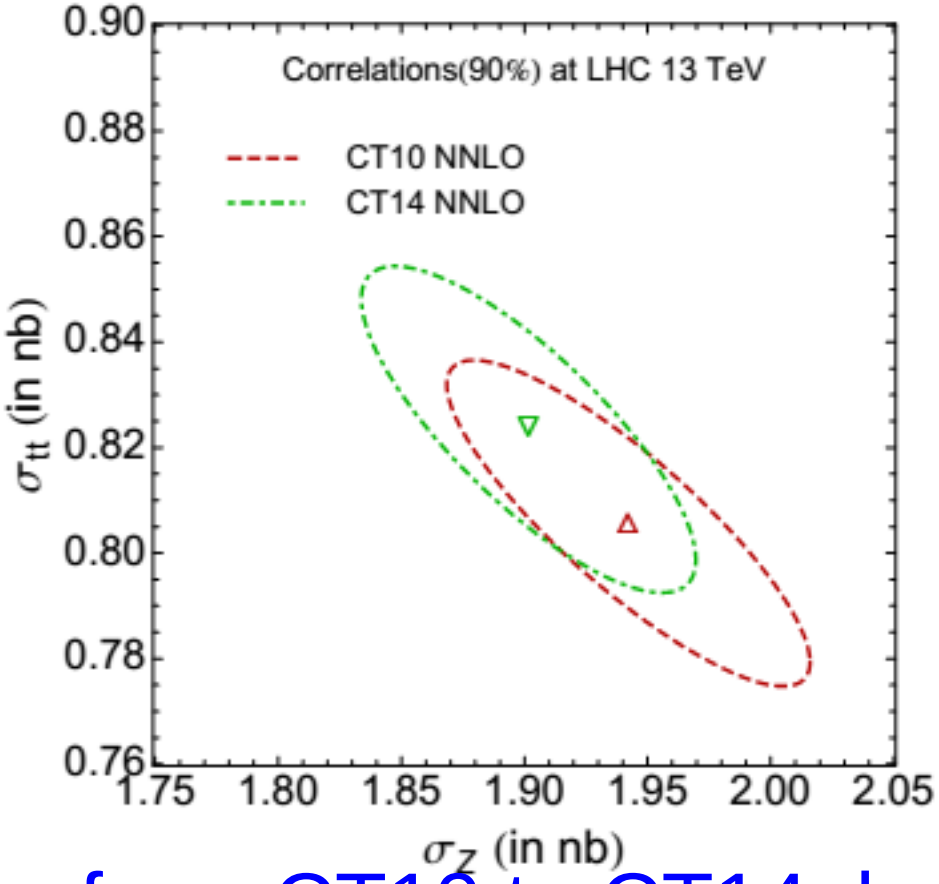




- W and Z cross sections decrease, from CT10 to CT14, but with similar correlation.

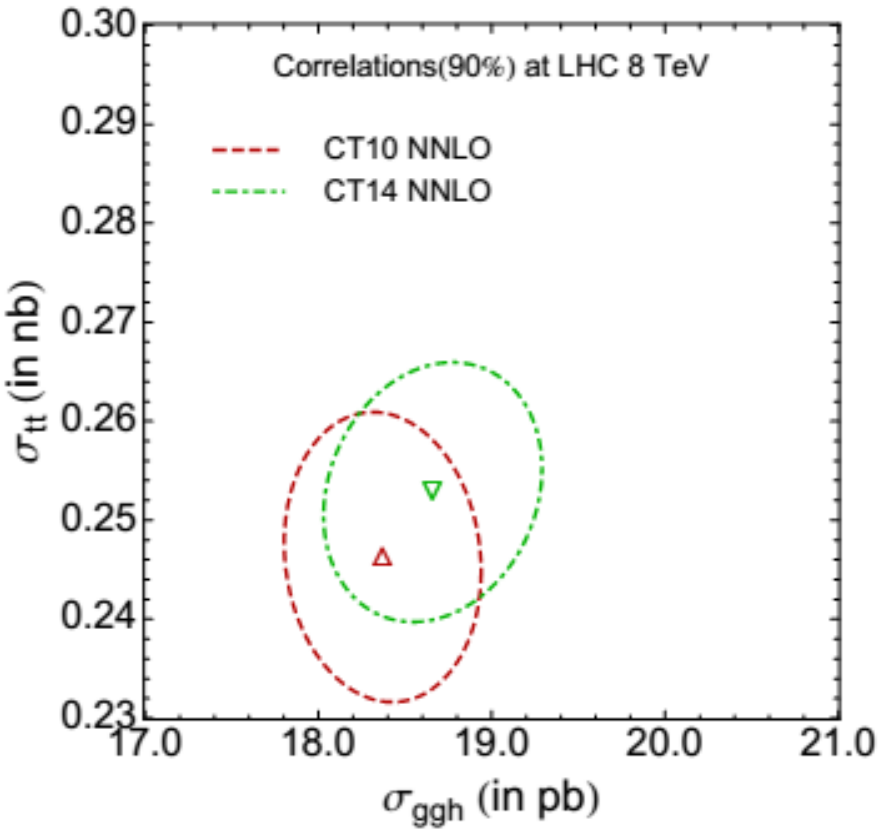
t-tbar vs. Z

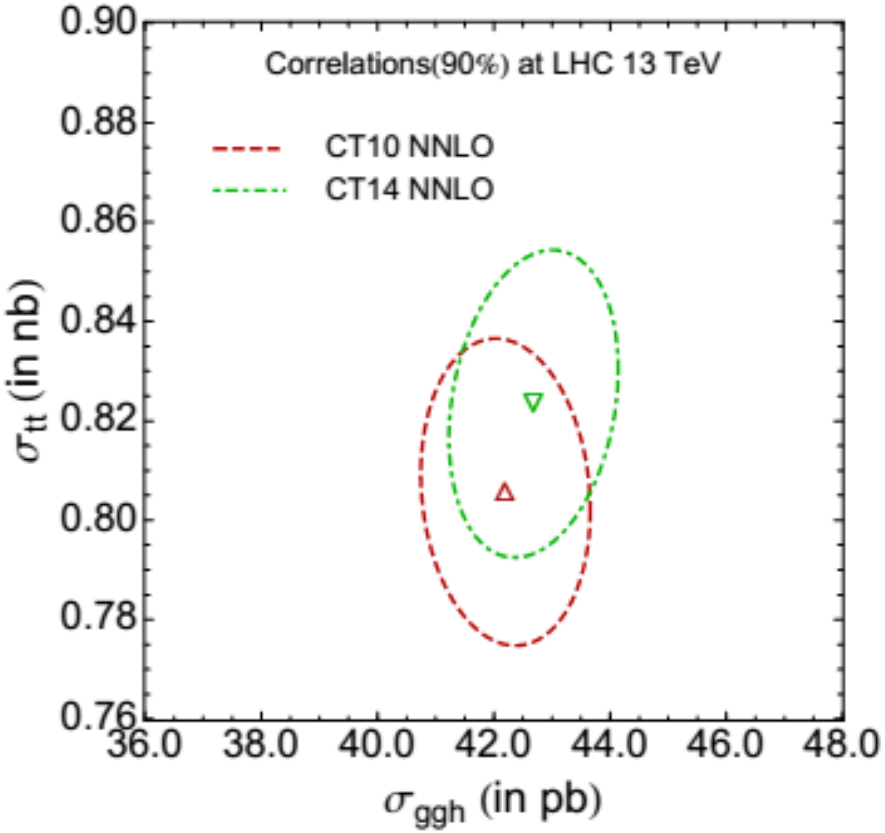




- t-tbar cross sections increase, from CT10 to CT14, but with similar correlation.

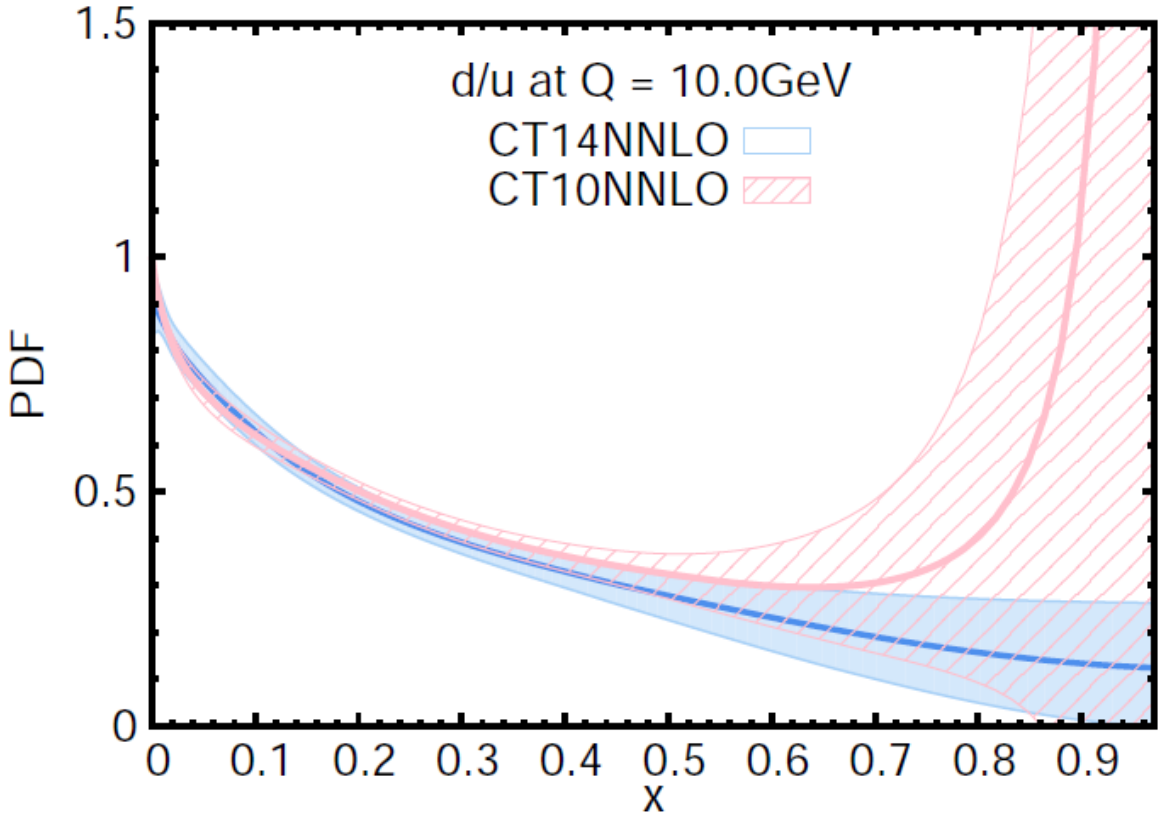
t-tbar vs. ggH





- t-tbar and ggH cross sections increase, from CT10 to CT14, with slightly increase in correlation.

CT14 vs. CT10 in d/u



At Q=10 GeV

- CT14, with more flexible parametrization and using Bernstein polynomial, assumes the ratio d/u approaches a constant as x -> 1
- CT14 agrees with CJ12 in large x region.

s-PDF related observables

ATLAS

$$r^s = \frac{\bar{s}(x,Q)}{\bar{d}(x,Q)} = 1.00^{+0.25}_{-0.28}, \quad at \quad x = 0.0234 \quad and \quad Q = 1.4GeV$$

$$r^s_{CT14} = \frac{\bar{s}(x,Q)}{\bar{d}(x,Q)} = 0.532 \pm 0.200$$

$$r^s_{CT10} = \frac{\bar{s}(x,Q)}{\bar{d}(x,Q)} = 0.761 \pm 0.167$$

NOMAD

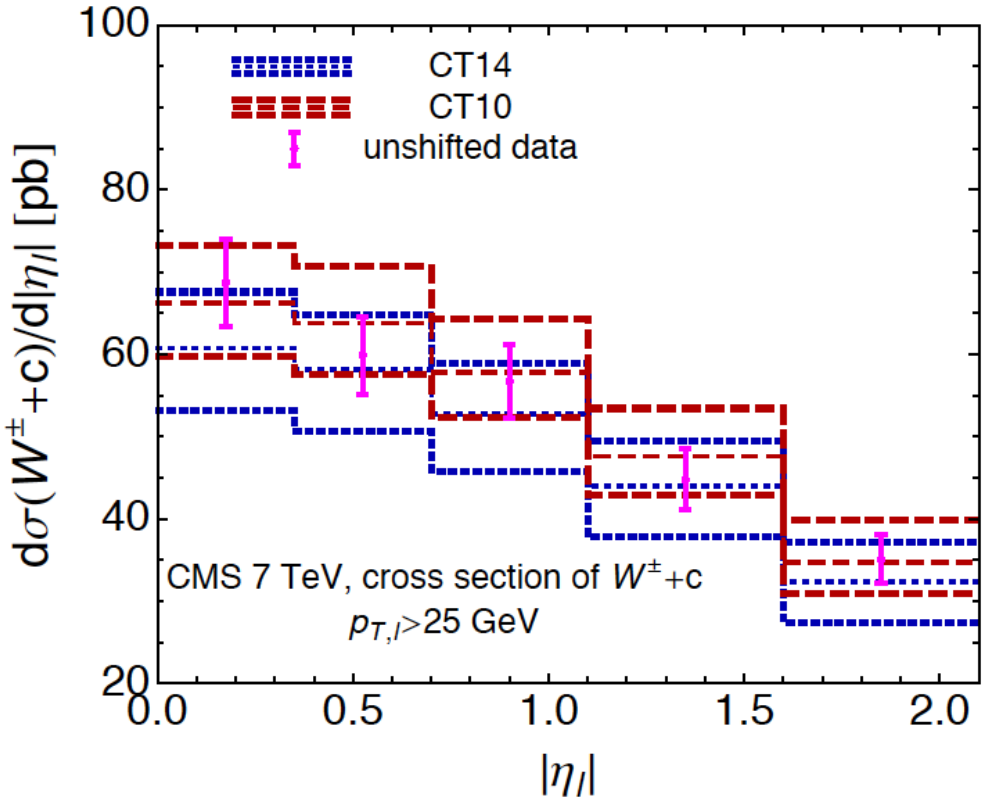
$$\kappa^s(Q^2) = \frac{\int_0^1 x(s(x,Q^2) + \bar{s}(x,Q^2))}{\int_0^1 x(\bar{d}(x,Q^2) + \bar{u}(x,Q^2))} = 0.591 \pm 0.019 \qquad \textbf{At } Q^2 = 20GeV^2$$

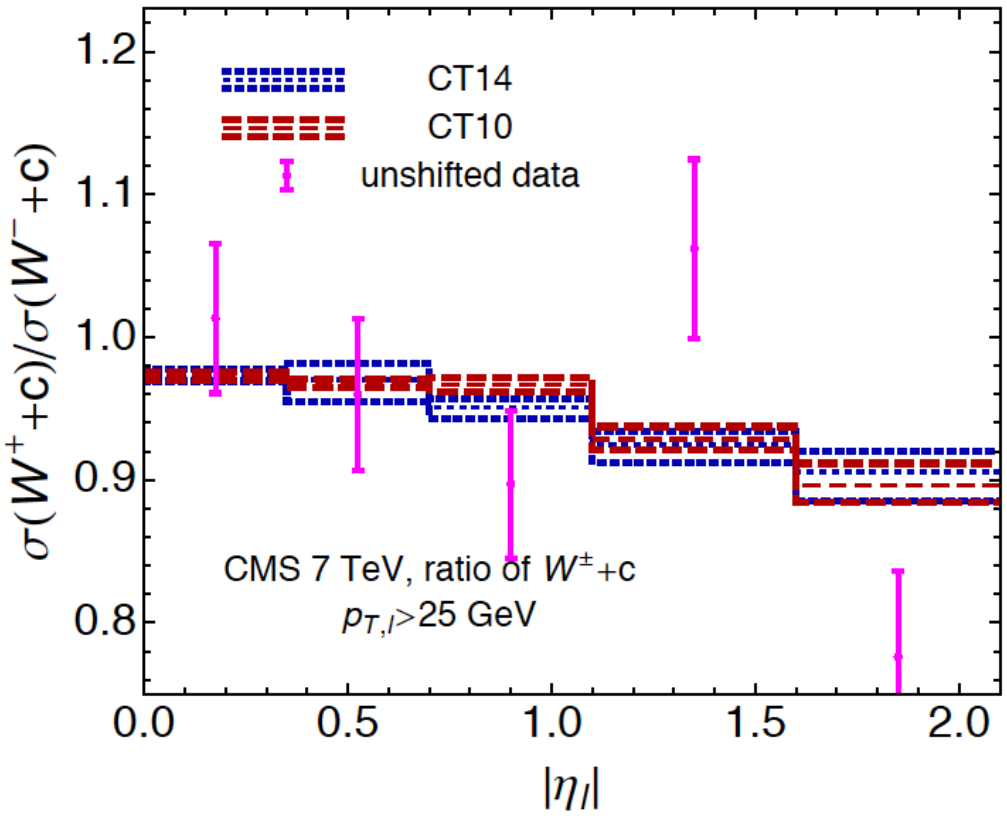
$$\kappa^s_{CT14} = \frac{\int_0^1 x(s+\bar{s})dx}{\int_0^1 x(\bar{d}+\bar{u})dx} = 0.616 \pm 0.139$$

68% CL PDF error

$$\kappa^s_{CT10} = \frac{\int_0^1 x(s+\bar{s})dx}{\int_0^1 x(\bar{d}+\bar{u})dx} = 0.727 \pm 0.111$$

CMS W+c





MCFM code

- not included in the global fit (and available only at NLO)

A comparison of ggH at NNLO

iHixs code

68% C.L. PDF error

	CT14	MMHT2014	NNPDF3.0
8 TeV	18.66 pb -2.2% +2.0%	18.65 pb -1.9% +1.4%	18.77 pb -1.8% +1.8%
13 TeV	42.68 pb -2.4% +2.0%	42.70 pb -1.8% +1.3%	42.97 pb -1.9% +1.9%

- CT14 has perfect agreement in central value with MMHT and NNPDF, and has largest error band which was checked by Lagrangian Multiplier method.
- CT10 : 18.37 pb -2.1%+1.7% at 8 TeV; 42.20 pb -2.5%+1.9% at 13 TeV.

See Talk by Tie-Jiun Hou @ WG5

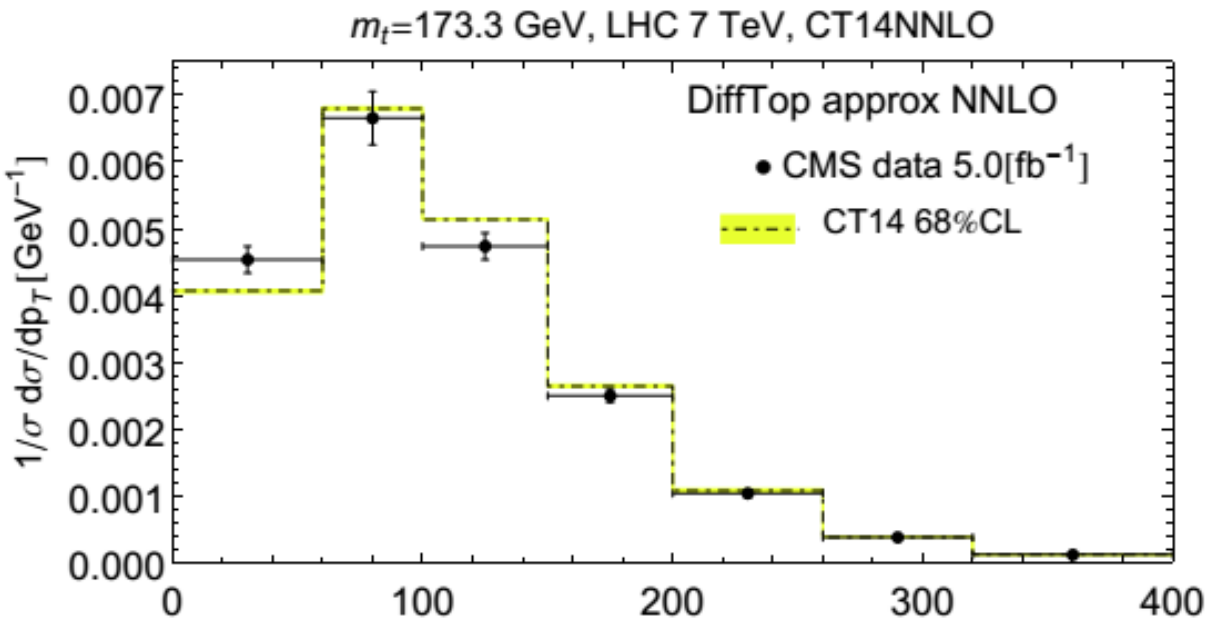
t-tbar cross section

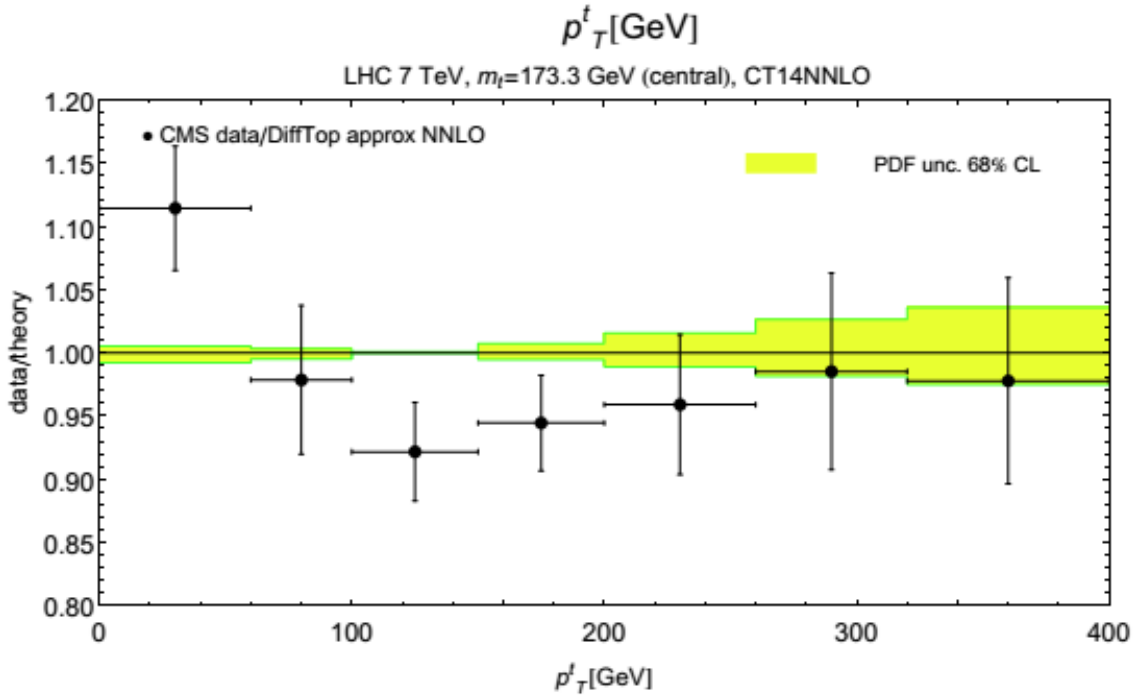
Top++ code

$\sqrt{S}$	CT10NNLO	CT14NNLO
7 TeV	$172.5^{+8.0\ (+4.6\%)}_{-6.5\ (-3.8\%)}$	$177.3^{+7.8\ (+4.4\%)}_{-6.6\ (-3.8\%)}$
8 TeV	$246.3^{+10.1\ (+4.1\%)}_{-8.2\ (-3.3\%)}$	$252.9^{+9.9\ (+3.9\%)}_{-8.7\ (-3.5\%)}$
13 TeV	$806.5^{+20.2\ (+2.5\%)}_{-17.7\ (-2.2\%)}$	$823.7^{+21.4\ (+2.6\%)}_{-21.9\ (-2.7\%)}$
14 TeV	$952.8^{+22.4\ (+2.3\%)}_{-19.9\ (-2.1\%)}$	$973.4^{+24.0\ (+2.5\%)}_{-24.8\ (-2.6\%)}$

TABLE V: The $t\bar{t}$ total inclusive cross sections given in [pb] are evaluated at LHC center of mass energies of 7, 8, 13 and 14TeV with the TOP++ code. The uncertainites shown in the table represent the PDF errors at the 68% confidence level.

pT of top quark @ CMS

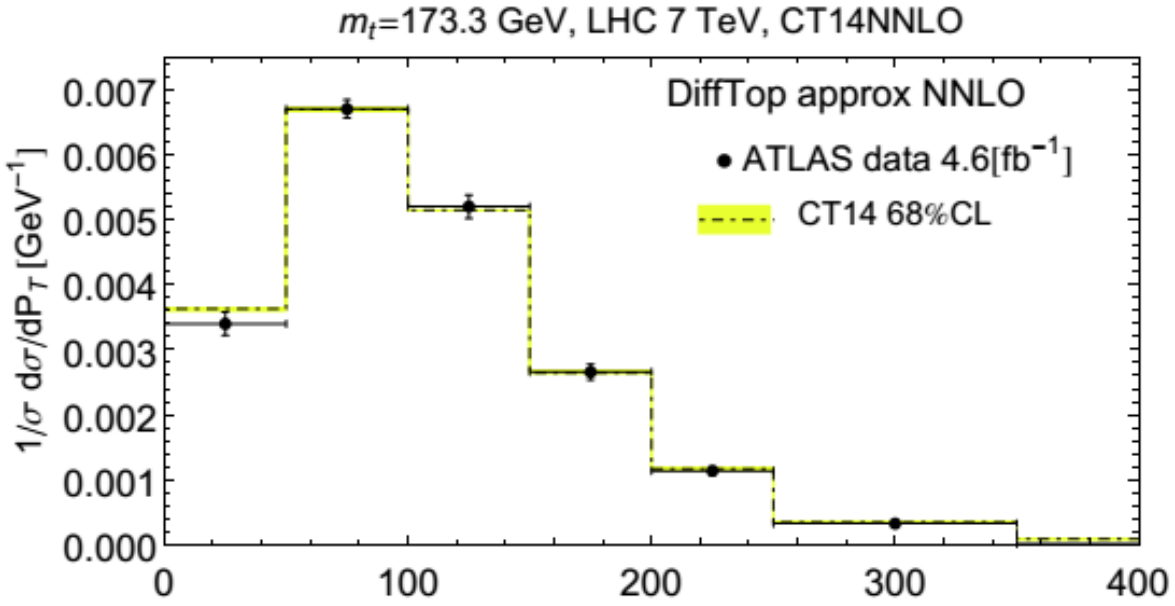


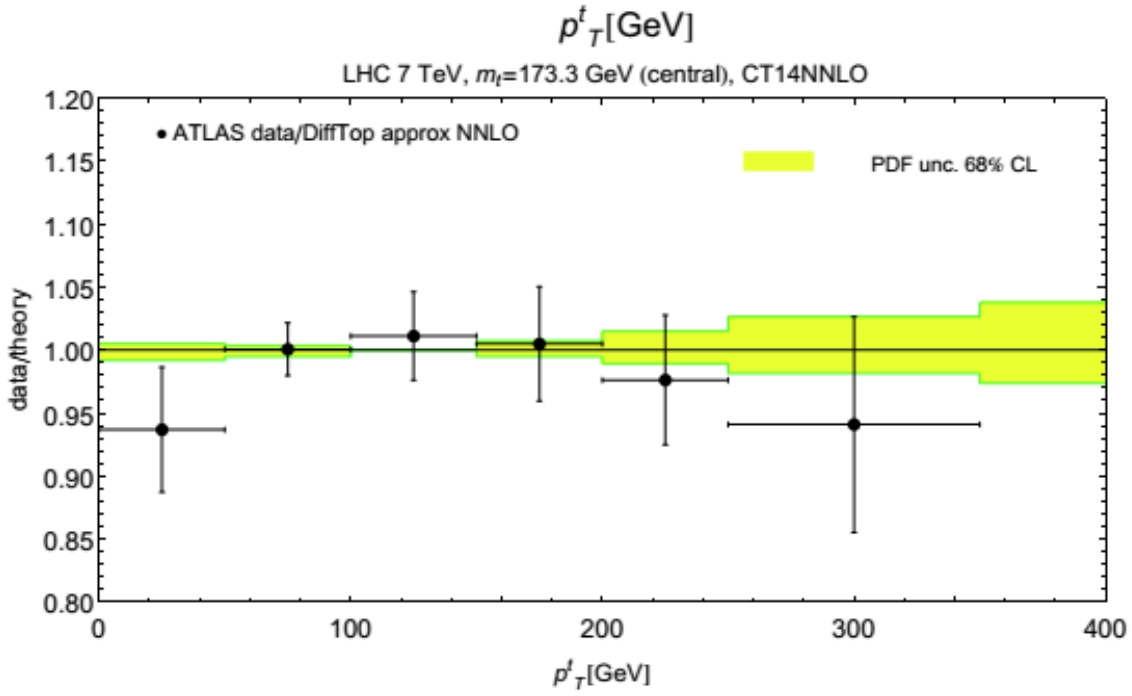


DIffTop code (M.Guzzi, K.Lipka and S.-O. Moch, JHEP 2014)

- CT14 PDF error is smaller than data error.

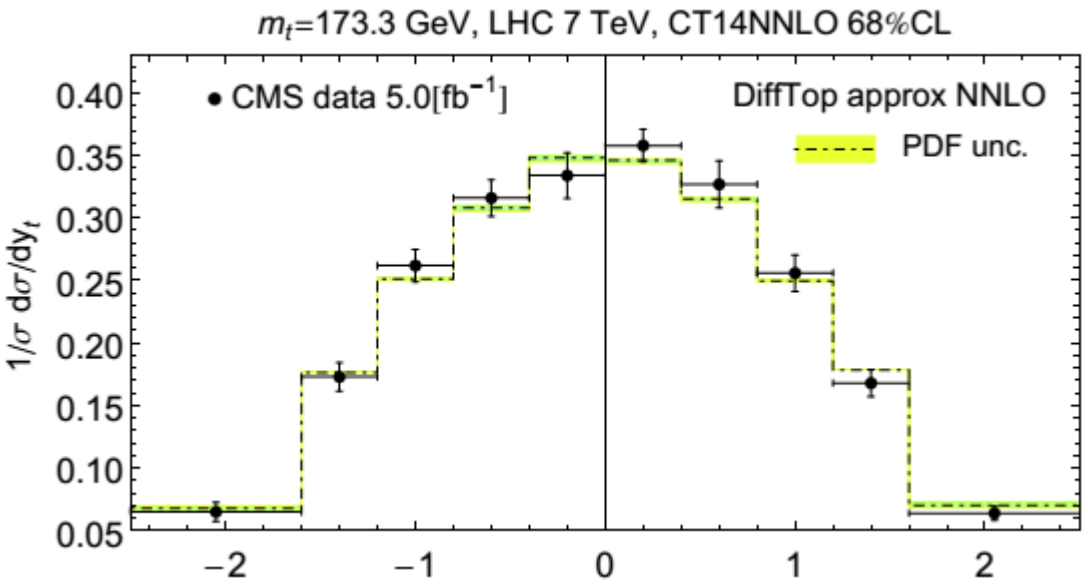
pT of top quark @ ATLAS

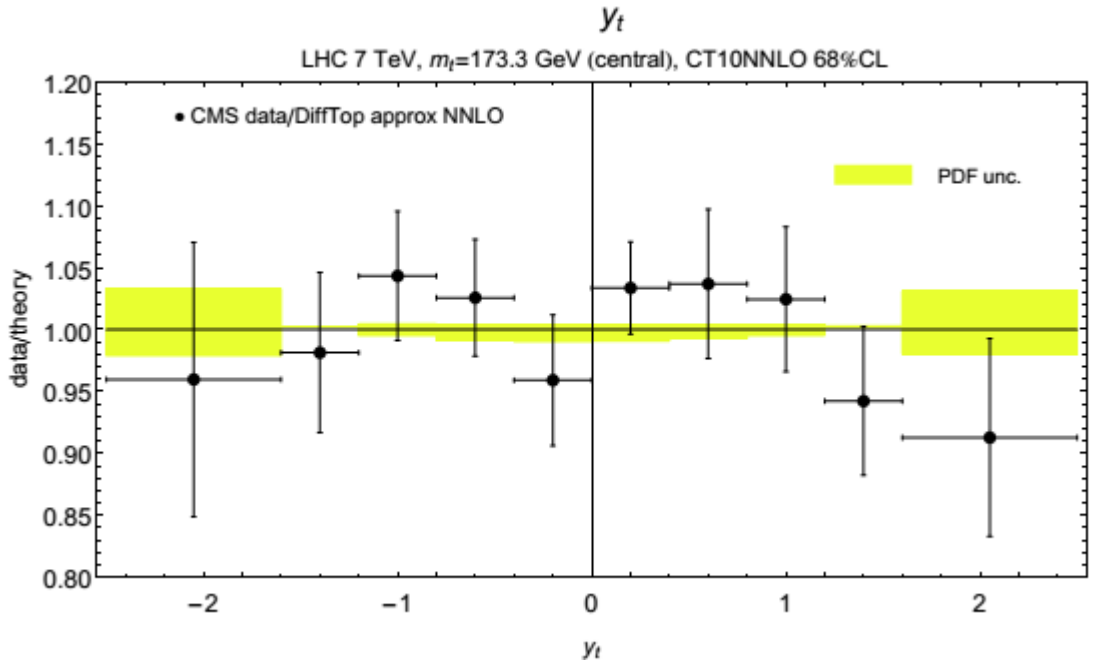




- CT14 PDF error is smaller than data error.

Rapidity of top quark @ CMS





- CT14 PDF error is smaller than data error.

Conclusion

- CT14 has more flexible parametrization form and makes a different assumption about the behavior of d/u as x near 1, and dbar/ubar as x approaches to 0.
- CT14 is different from CT10, after including the LHC Run 1 (ATLAS, CMS, LHCb) W, Z and jet data and the new Tevatron D0 W-electron asymmetry data.
- We have checked that CT14 PDF error band is smaller than error bar of the published LHC Run 1data (such as high and low mass Drell-Yan) not included in our fit.
- CT14, at NNLO, NLO and LO, is about to be released in public. (The draft of the paper is already written.)
- Additional CT14 PDF sets (such as intrinsic charm, etc.) will also be released.

See Talk by Tie-Jiun Hou @ WG5