The CT14 Global Analysis of Q.C-D.

Daniel Stump

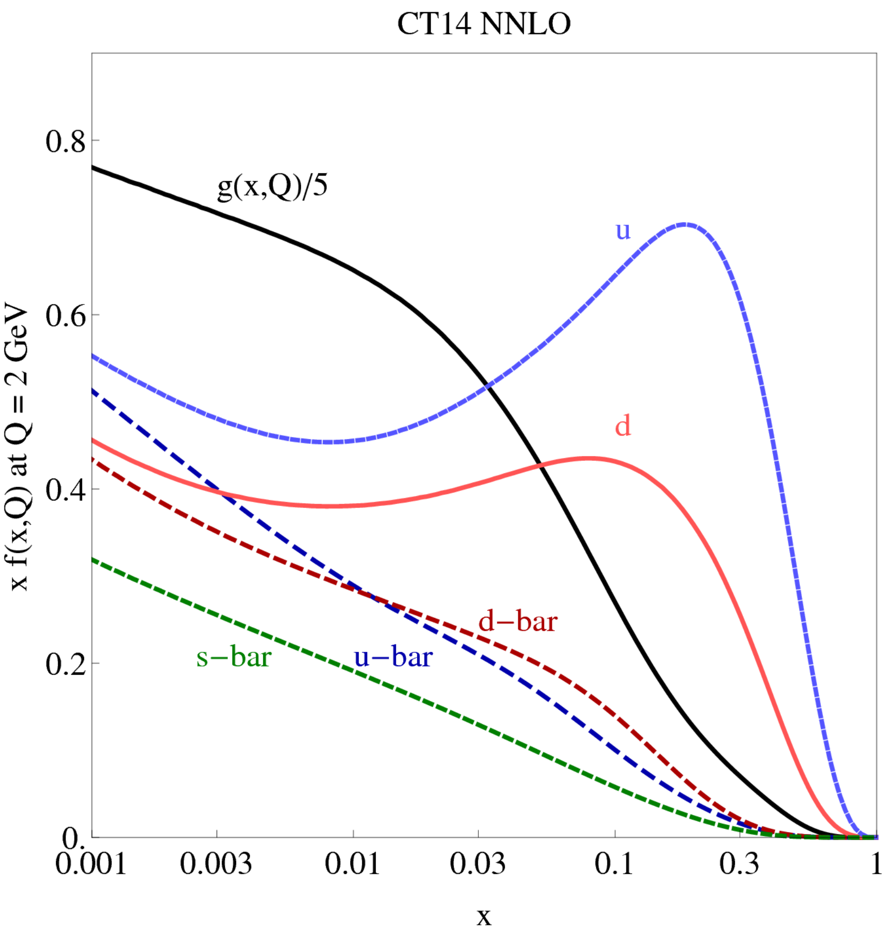
Department of Physics and Astronomy
Michigan State University

Sayipjamal Dulat, Tie-Jiun Hou, Jun Gao, Marco Guzzi,
Joey Huston, Pavel Nadolsky, Jon Pumplin, Carl Schmidt,
Daniel Stump, C.-P. Yuan,
"The CT14 Global Analysis of Quantum Chromodynamics,"
arXiv:1506.07443v1 [hep-ph]

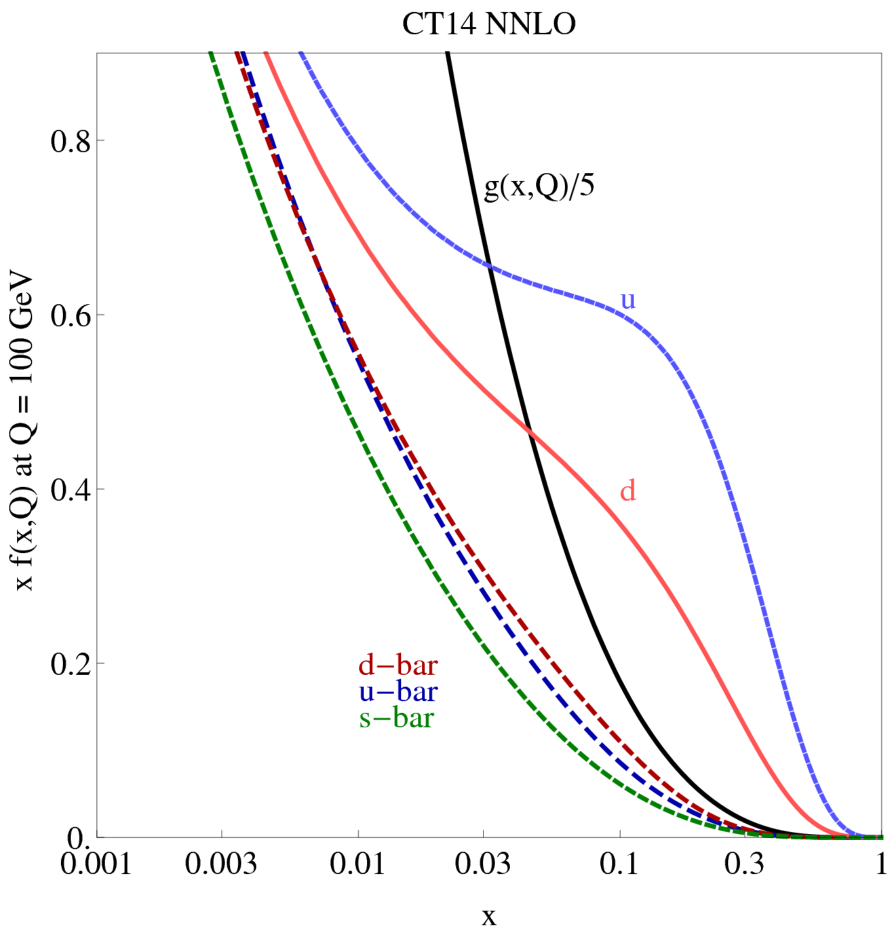
(CTEQ-TEA group)

1.
Overview of the CT14 PDFs

CT14 central PDFs at Q = 2 GeV

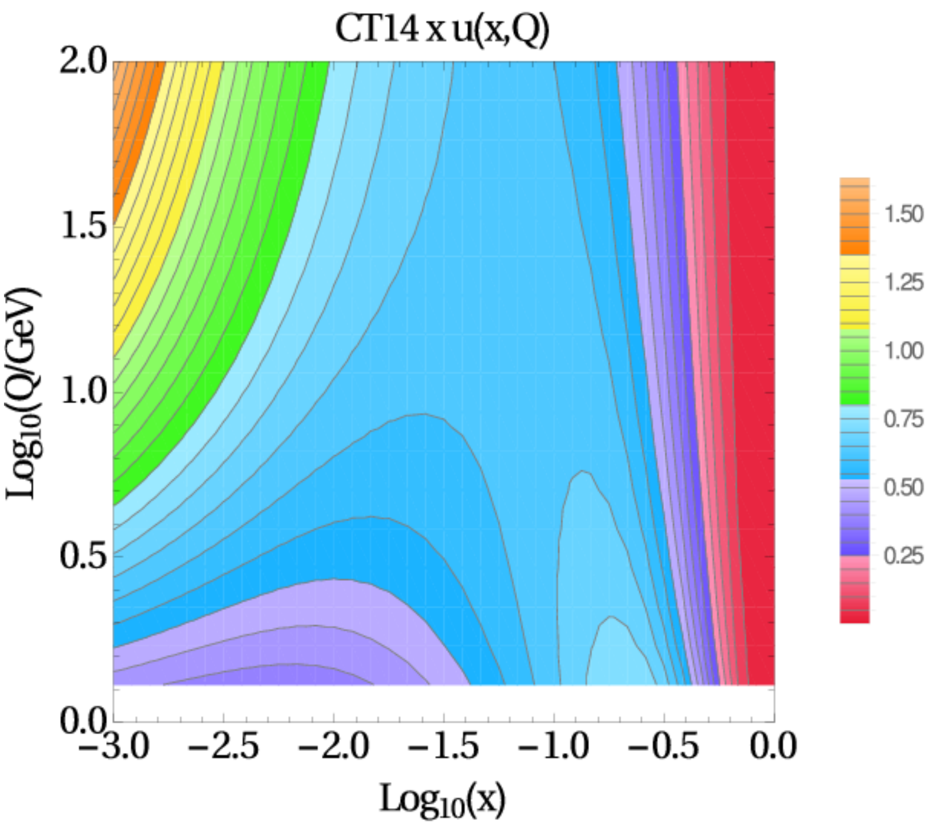


CT14 central PDFs at Q = 100 GeV

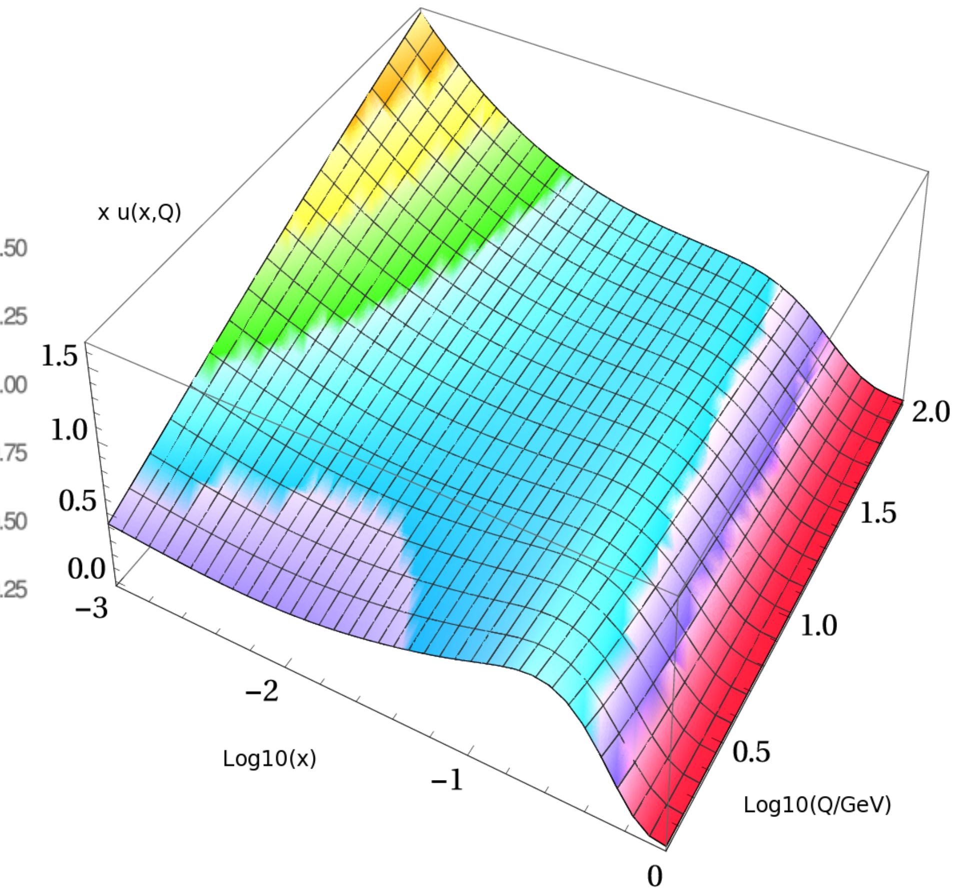


CT14 central u-quark PDF at all Q

1.3 GeV < Q < 100 GeV



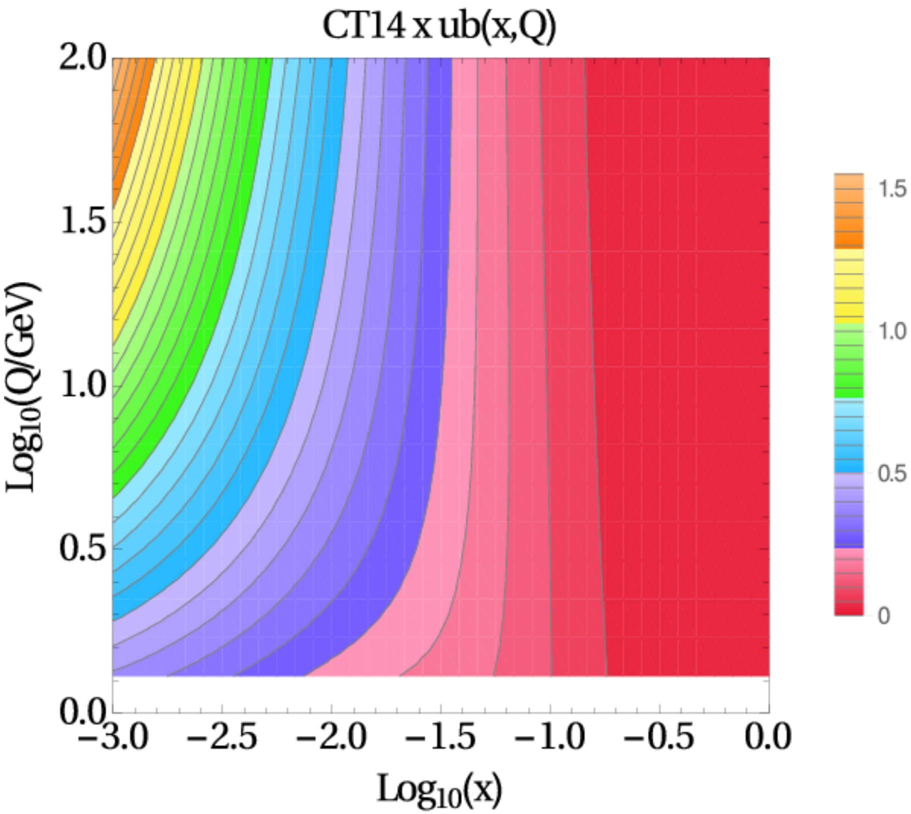
(contour plot)

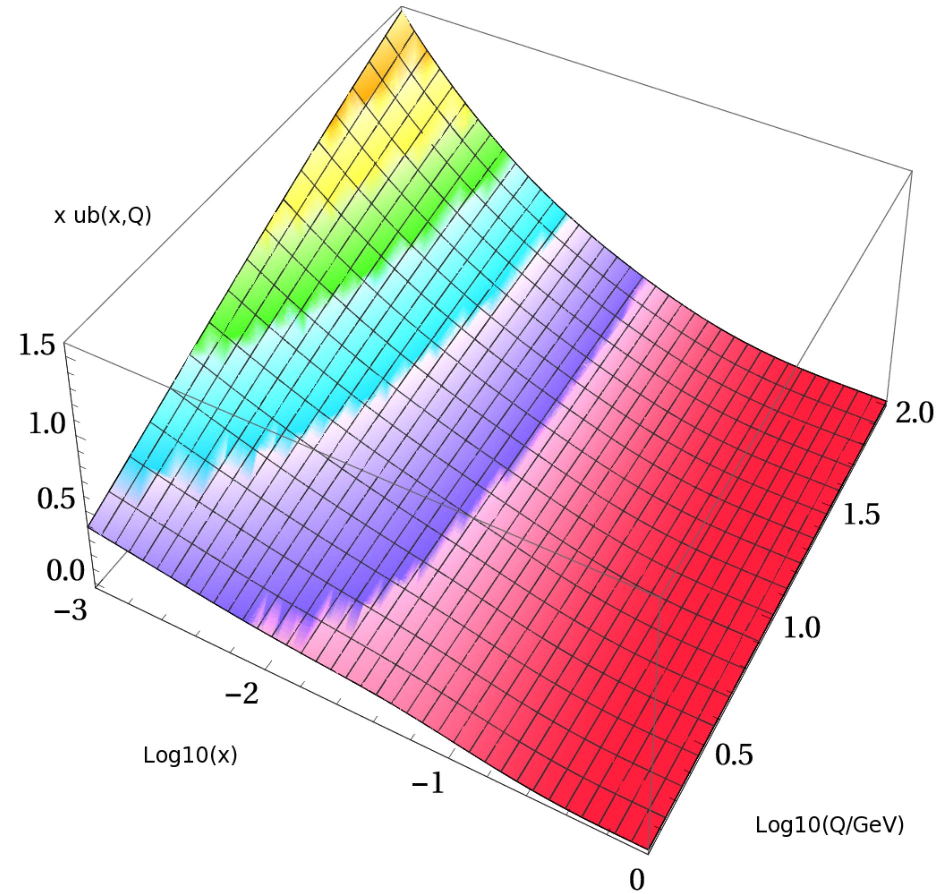


(surface plot)

CT14 central ub-quark PDF at all Q

1.3 GeV < Q < 100 GeV





To compare different PDF models, it is useful to define...

Four PDF moments For f = {g, d, u, s, db, ub, sb},

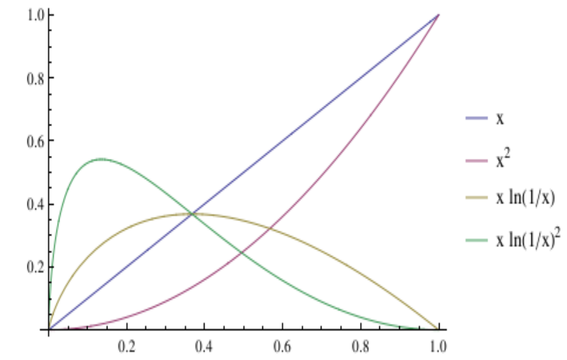
$$J1(f) = \int_0^1 f(x,Q)\, x\, dx \quad \text{sensitive to mid x}$$

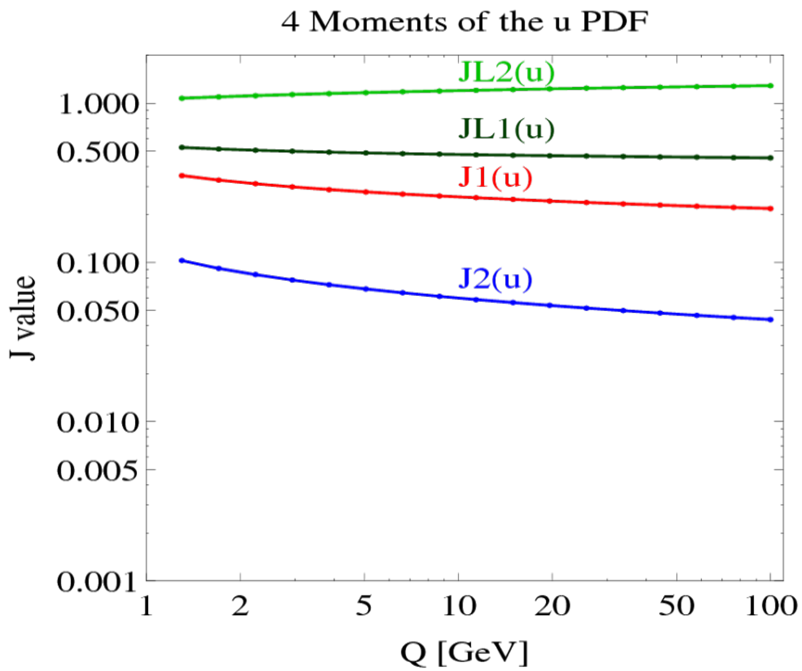
$$J2(f) = \int_0^1 f(x,Q)\, x^2\, dx \quad \text{sensitive to large x}$$

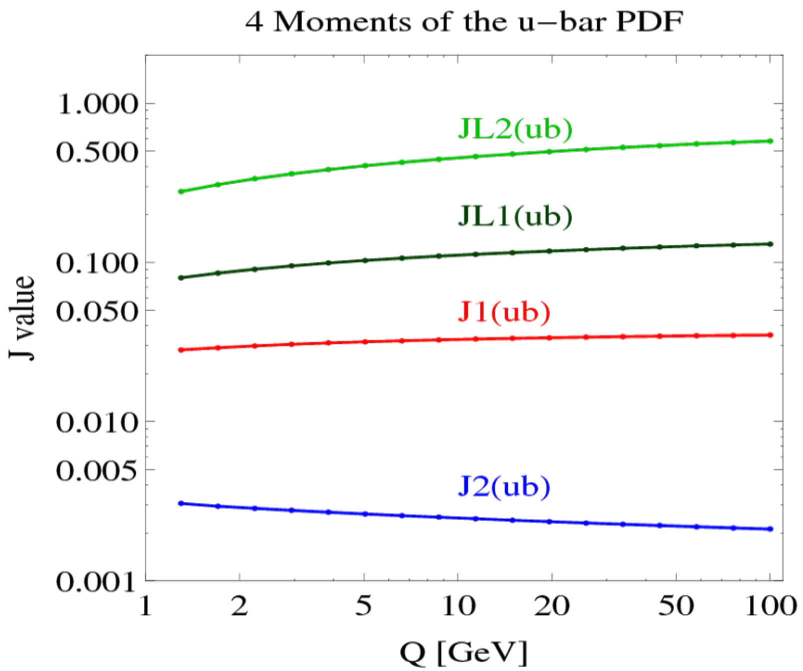
$$JL1(f) = \int_0^1 f(x,Q)\, x \ln(1/x)\, dx \quad \text{sensitive to small x}$$

$$JL2(f) = \int_0^1 f(x,Q)\, x \ln(1/x)^2\, dx \quad \text{sensitive to smaller x}$$

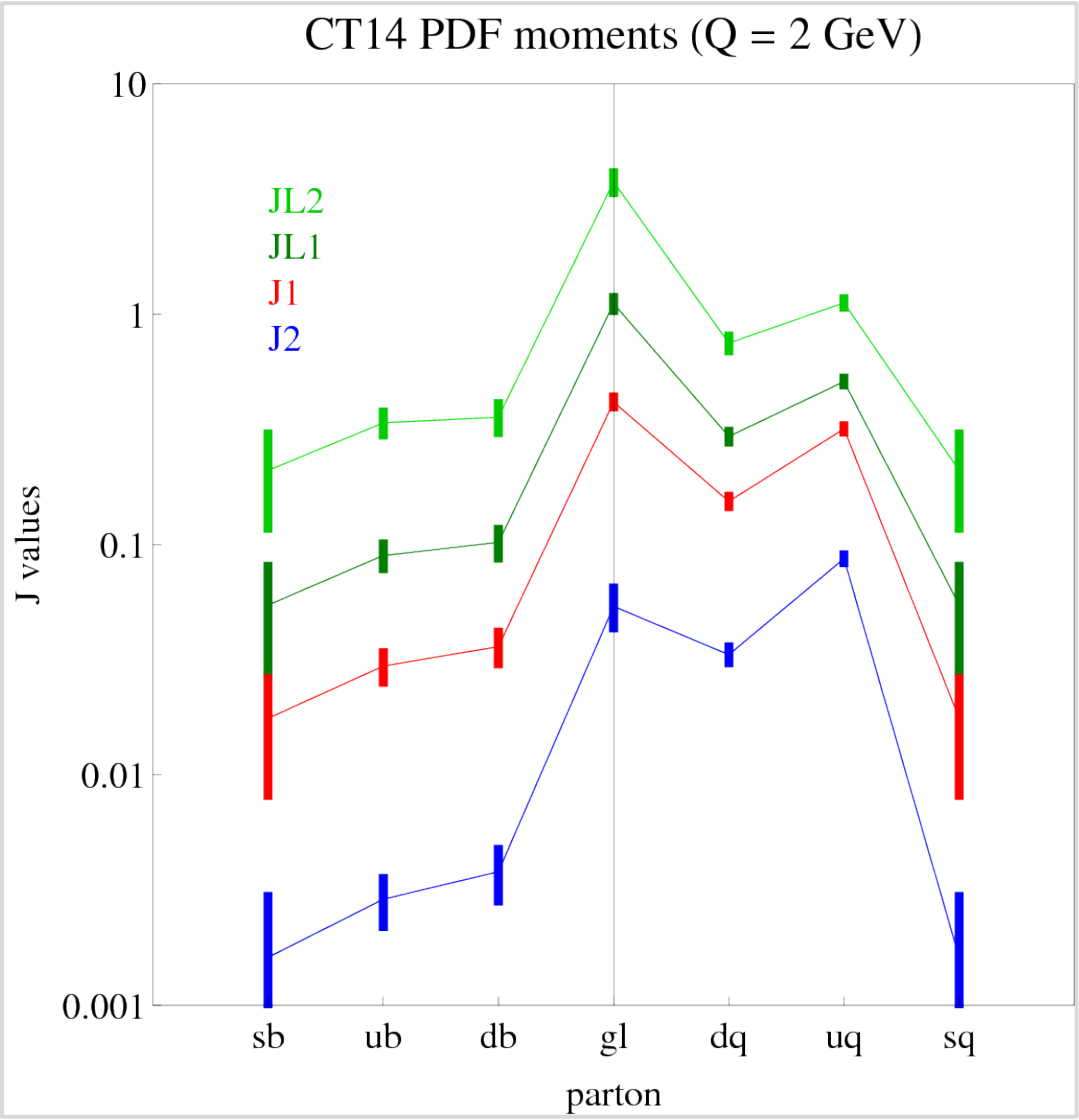
and compare the moments of the different models.







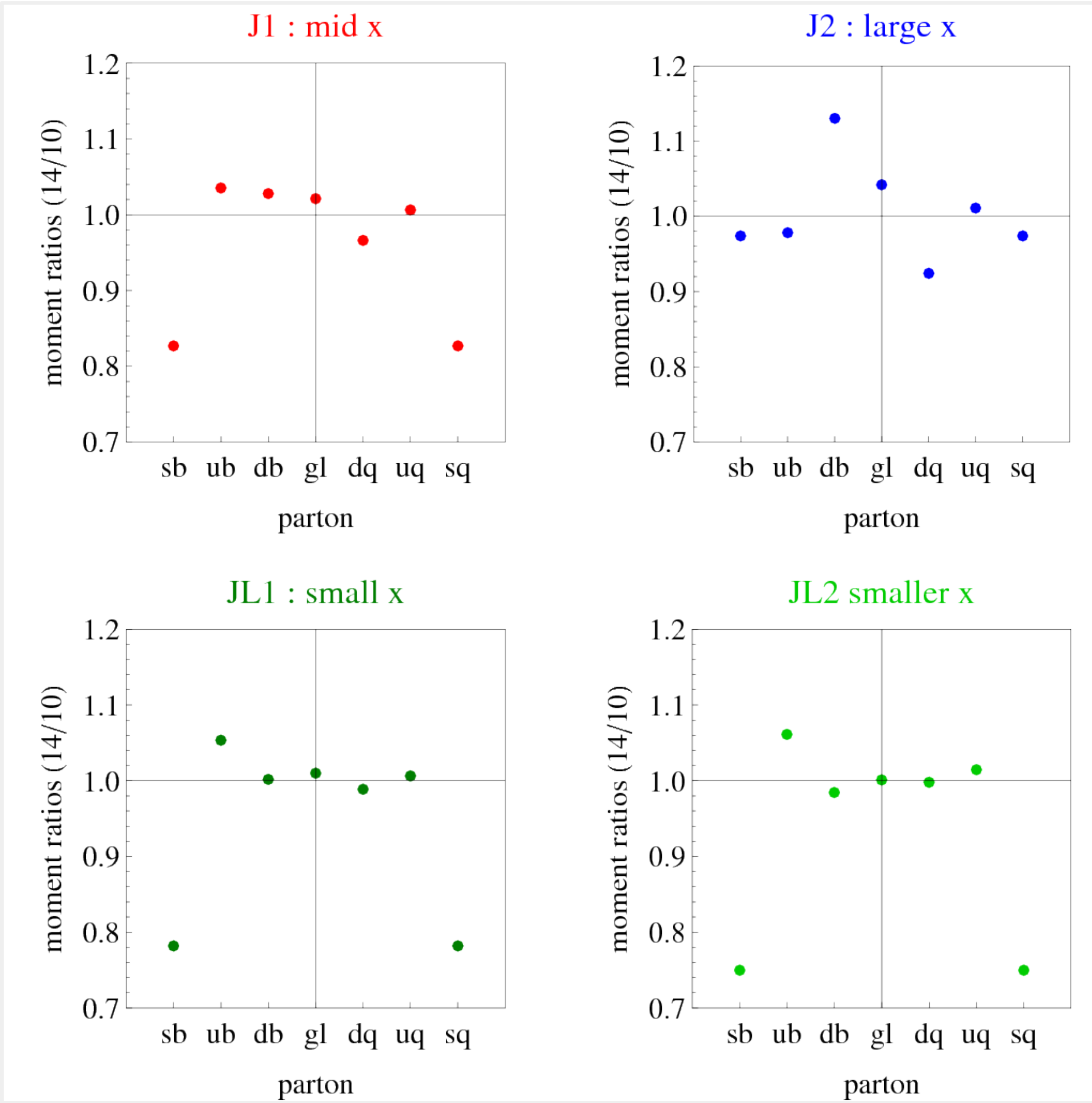
CT14 PDF moments ; J1, J2, JL1, JL2 @ Q=2 GeV



Note:

- central values;
- the uncertainty ranges are calculated from the CT14 hessian error pdfs;
- green ~ small x
  blue ~ large x

Use ***moment ratios*** to compare CT14 and CT10 (central) PDFs @ Q = 2.0 GeV.



Changes from CT10 to CT14:

- The biggest change is in the strange quark.

The CT14 strange PDF is approximately 20% smaller than the CT10 strange PDF ***(at 2 GeV)*** (Why?)

- The d-antiquark has changed at large x.

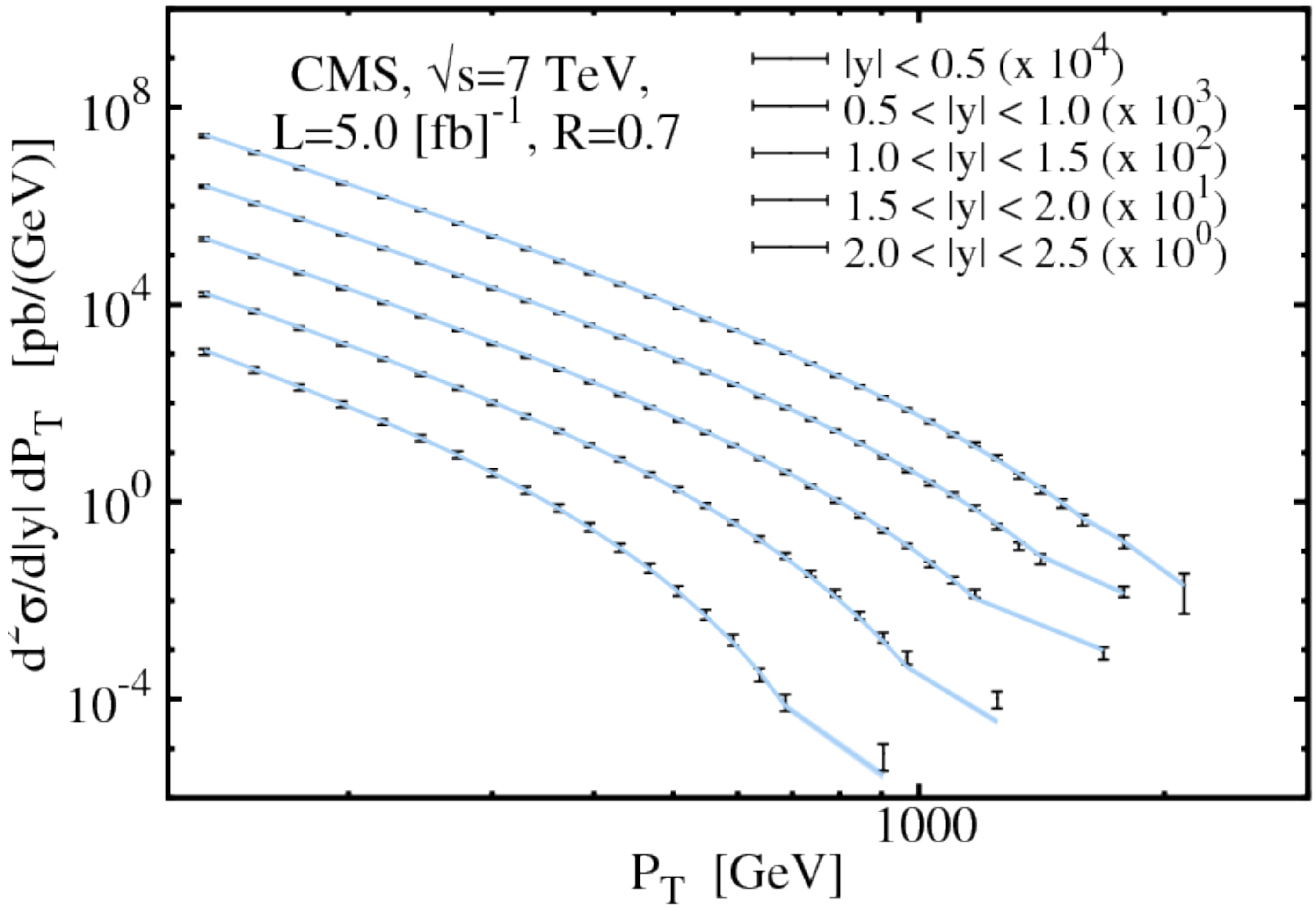
The CT14 d-bar PDF is approximately 15% larger that the CT10 d-bar PDF at large x. (Why?)

- The gluon has increased at mid and large x.
- Other changes are less than 5%.

2.
LHC data that is used in the CT14 global analysis

LHC measurements of inclusive jet production ;

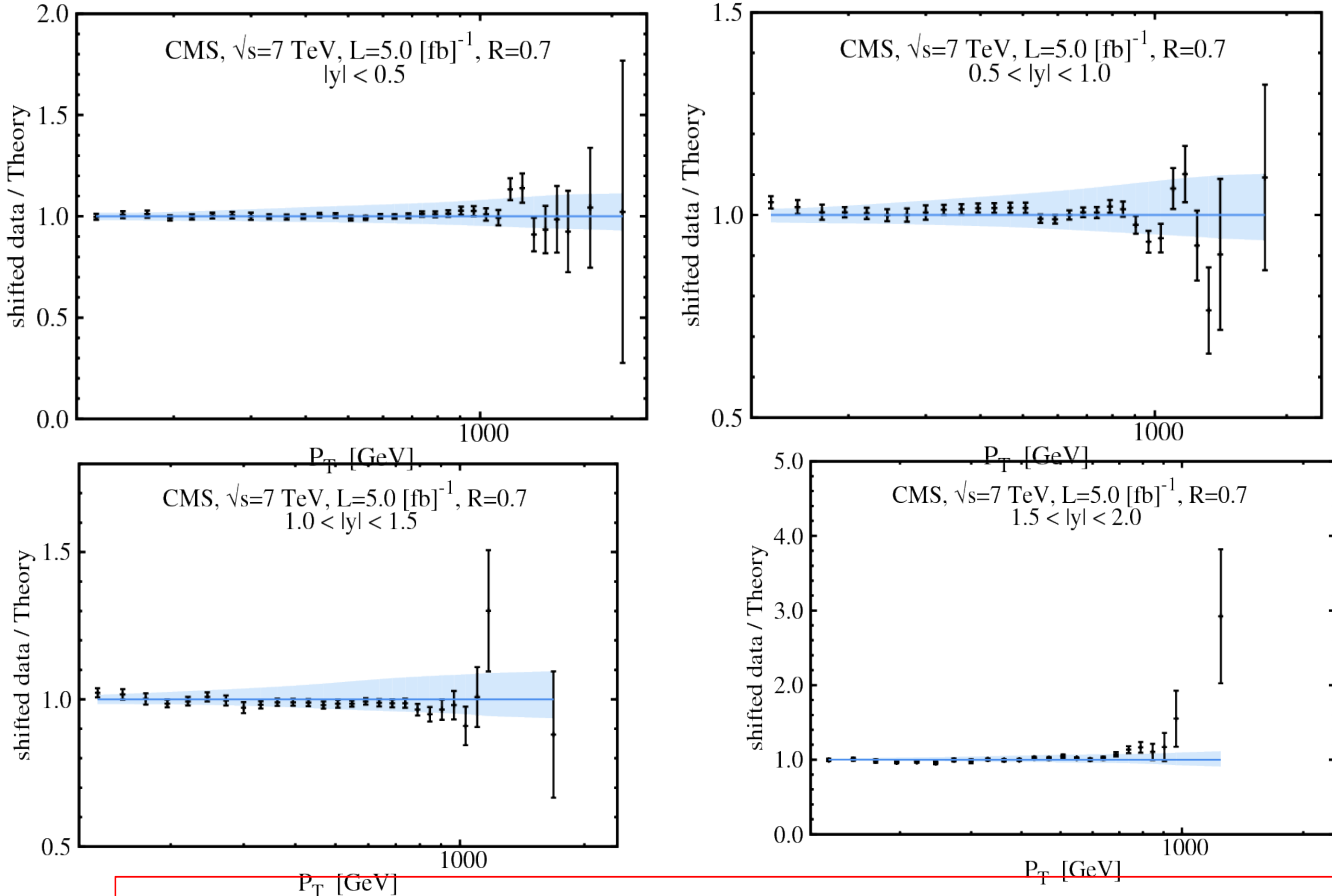
for example, CMS root-s = 7 TeV L = 5.0 $[fb]^{-1}$



Data and CT14 NNLO theory for CMS 7 TeV inclusive jet production

LHC measurements of inclusive jet production ;

for example, CMS root-s = 7 TeV L = 5.0 [fb]$^{-1}$



"Shifted data" compared to CT14 theory

Measurements of inclusive jet production in the CT14 global analysis

(Tevatron)

(and LHC)

	Experiment	N_{pt}	χ_e^2	χ^2/N
504	CDF Run-2 inclusive jet prod.	72	105	1.45
514	DØ Run-2 inclusive jet prod.	110	120	1.09
535	ATLAS 7 TeV 35 pb^{-1} incl. jet prod.	90	50	0.55
538	CMS 7 TeV 5 fb^{-1} incl. jet prod.	133	177	1.33

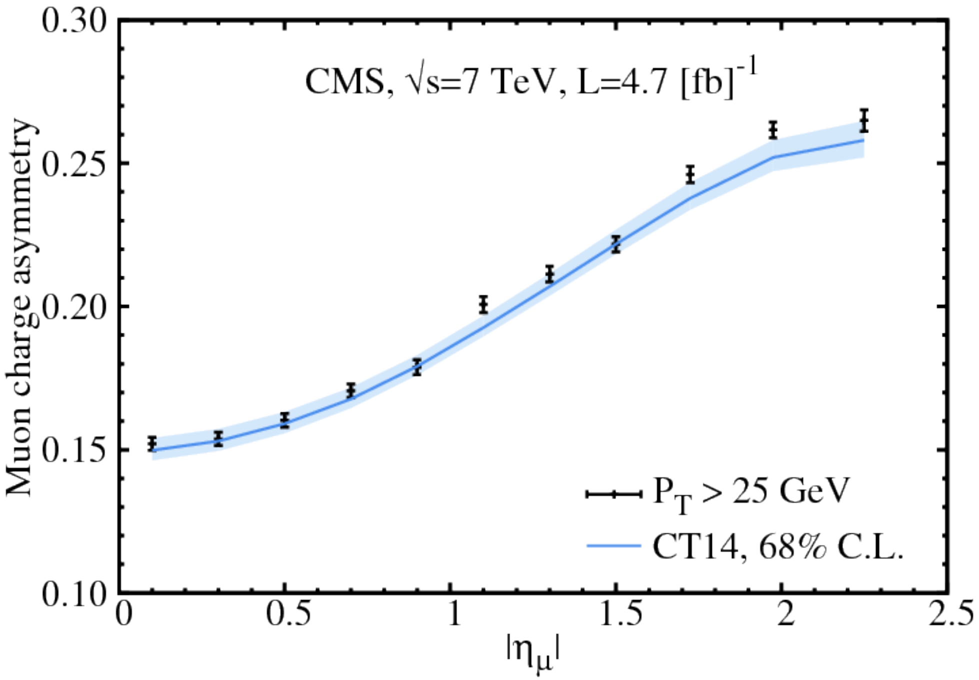
$$\chi_e^2 = \min_{A,R} \left\{ \sum_{i=1}^{N} \left[\frac{sD_i - T_i}{\sigma_i} \right]^2 + \sum_{k=1}^{N_{sy}} r_k^2 \right\}$$

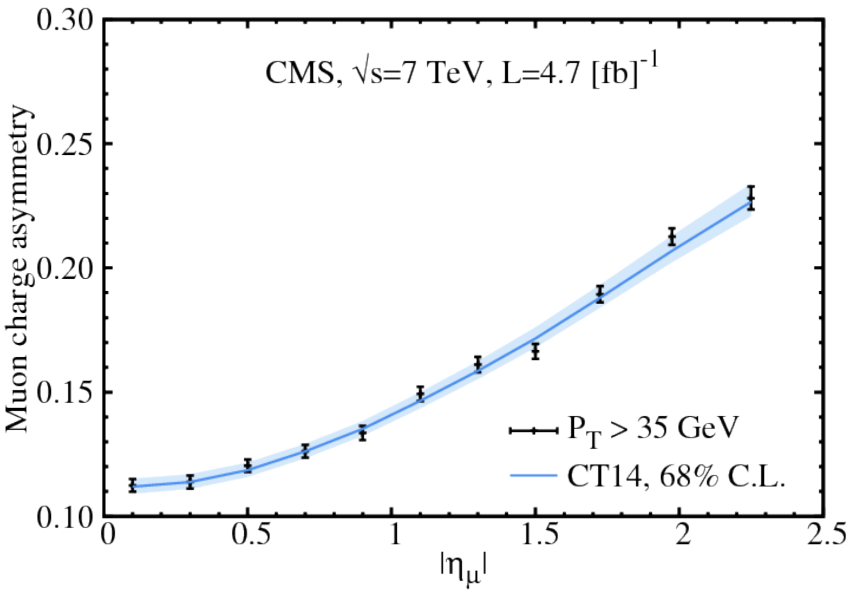
$$R = \{ r_k \; ; \; k = 1 \ldots N_{sy} \}$$ "nuisance pars."

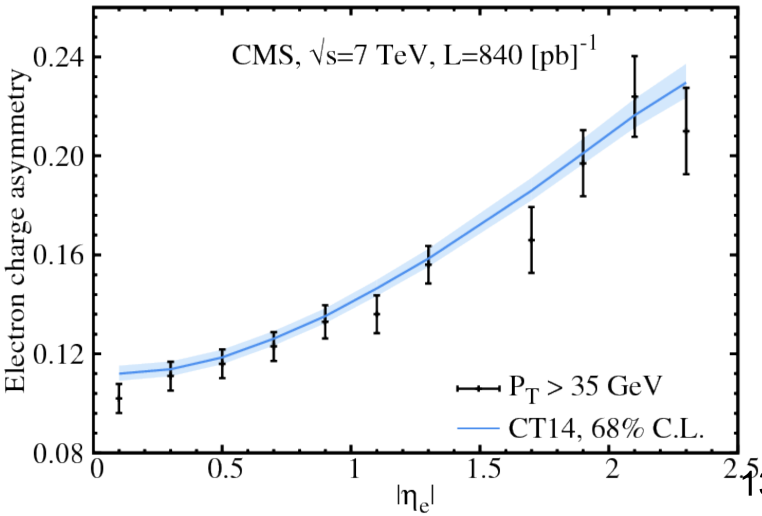
$$sD_i = D_i - \sum_{k=1}^{N_{sy}} \sigma_{ik} r_k$$ "shifted data"

LHC measurements of $W^{\pm}$ and Z^0 production ;

for example, CMS   root-s = 7 TeV   L = 4.7 $[fb]^{-1}$; W/lepton charge asymmetry

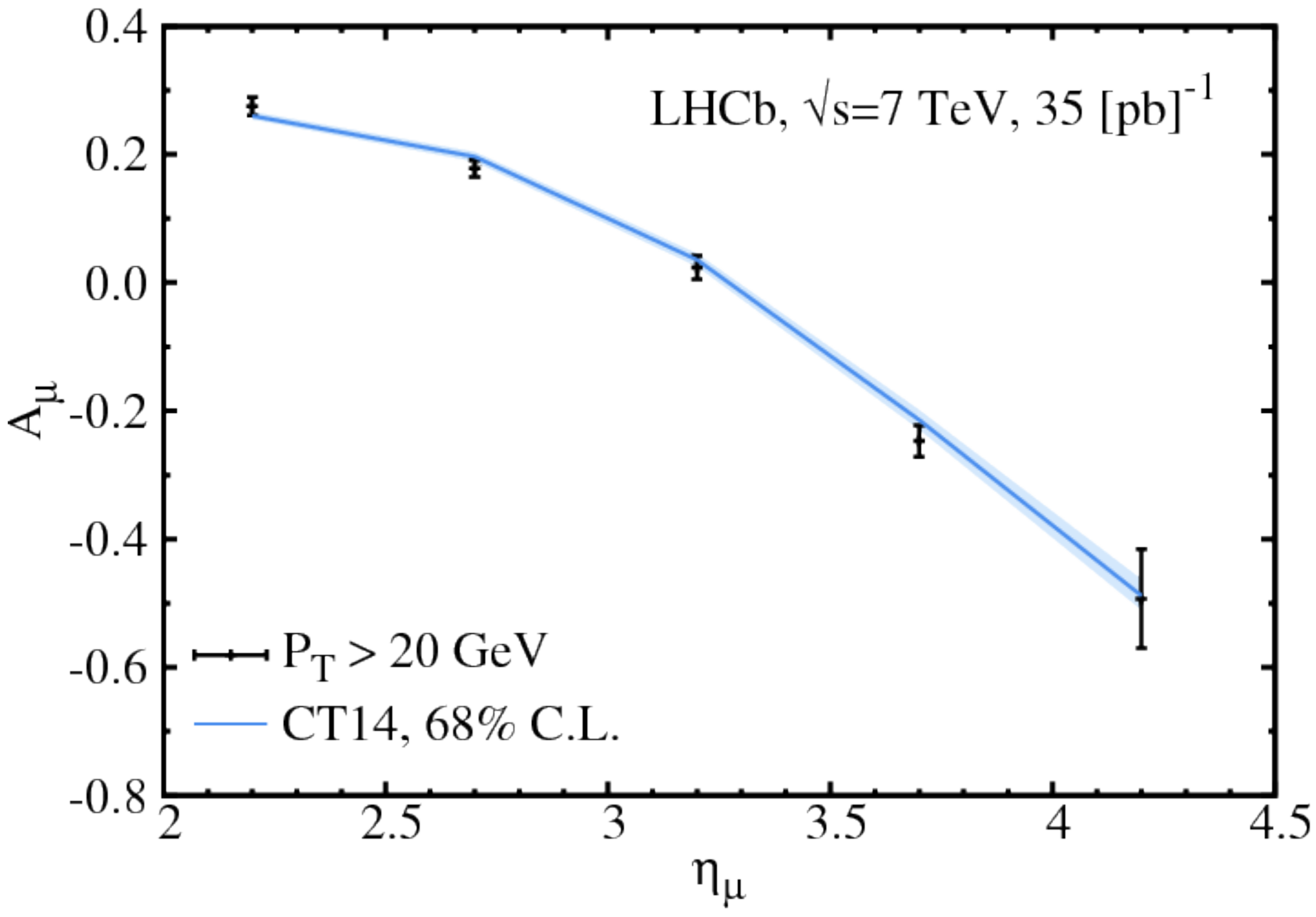






LHC measurements of $W^{\pm}$ and Z^0 production ;

for example, LHCb root-s = 7 TeV L = 35 $[pb]^{-1}$; W/μ charge asymmetry



Data related to $W^{\pm}$ and Z^0 production in the CT14 global analysis

(Tevatron)

	Experiment	N_{pt}	χ_e^2	χ^2/N
225	CDF Run-1 electron $A_{\mathrm{ch.}}, p_{T\ell} > 25\mathrm{GeV}$	11	8.9	0.81
227	CDF Run-2 electron $A_{\mathrm{ch.}}, p_{T\ell} > 25\mathrm{GeV}$	11	14	1.24
234	DØ Run-2 muon $A_{\mathrm{ch.}}, p_{T\ell} > 20\mathrm{GeV}$	9	8.3	0.92
260	DØ Run-2 Z rapidity	28	17	0.59
261	CDF Run-2 Z rapidity	133	177	1.33
281	DØ Run-2 9.7 fb^{-1} electron $A_{\mathrm{ch.}}, > 25\mathrm{GeV}$	13	35	2.67

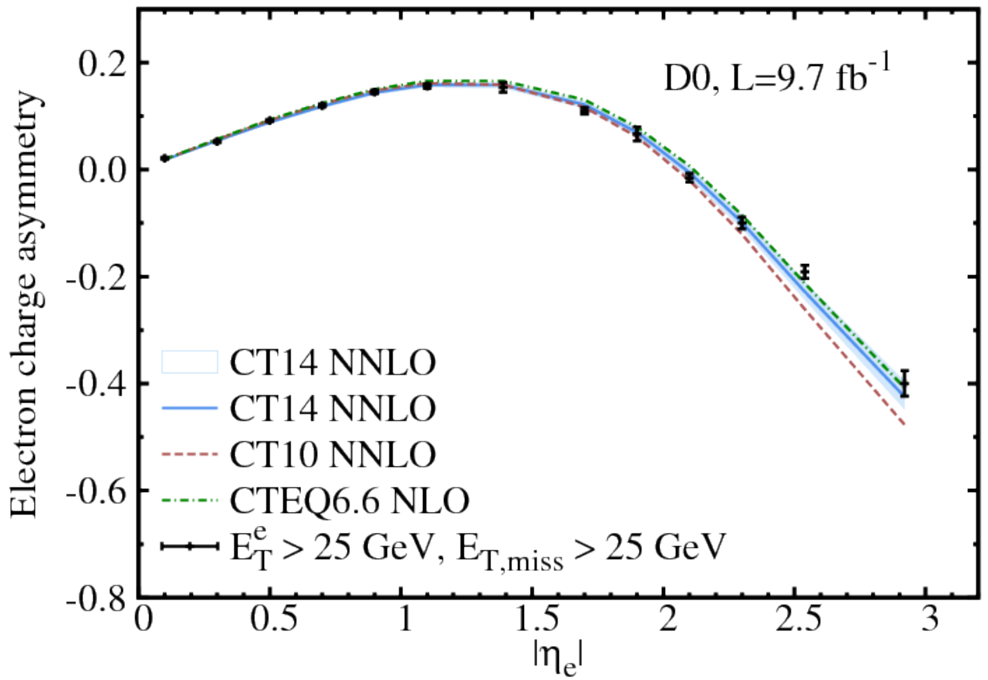
(LHC)

	Experiment	N_{pt}	χ_e^2	χ^2/N
240	LHCb 7 TeV 35 pb^{-1}, $W/Z\ d\sigma/dy_\ell$	14	9.9	0.71
241	LHCb 7 TeV 35 pb^{-1}, $A_{\mathrm{ch.}}$ ($\geq$20 GeV)	5	5.3	1.06
266	CMS 7 TeV 4.7 fb^{-1}, muon $A_{\mathrm{ch.}}$ ($\geq$5 GeV)	11	12.1	1.10
267	CMS 7 TeV 840 pb^{-1}, electron $A_{\mathrm{ch.}}$ ($\geq$35 GeV)	11	10.1	0.92
268	ATLAS 7 TeV 35 pb^{-1}, W/Z cross sec., $A_{\mathrm{ch.}}$	41	51	1.25

Data recently published by the D0 collaboration on

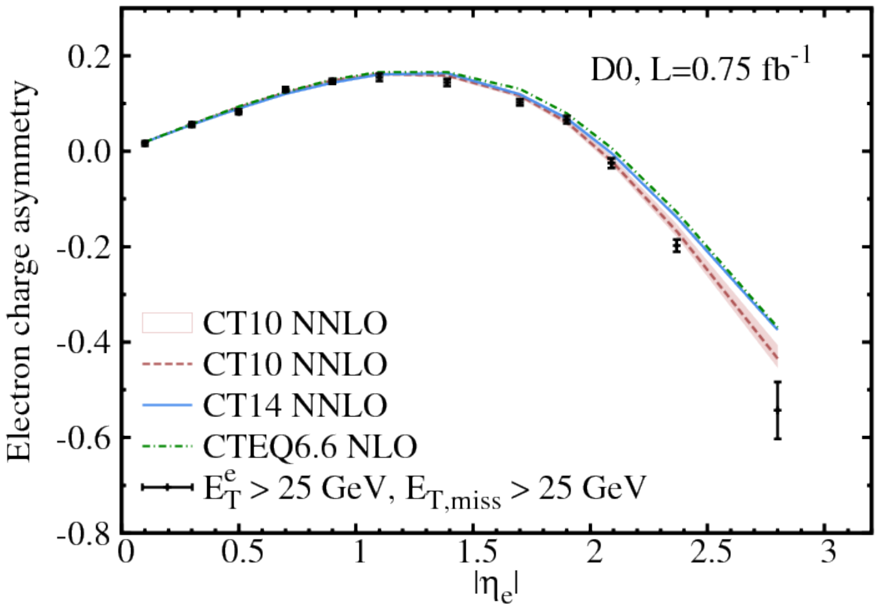
W/e charge asymmetry at Tevatron Run 2.

$$A_e$$



Run 2

Run 1

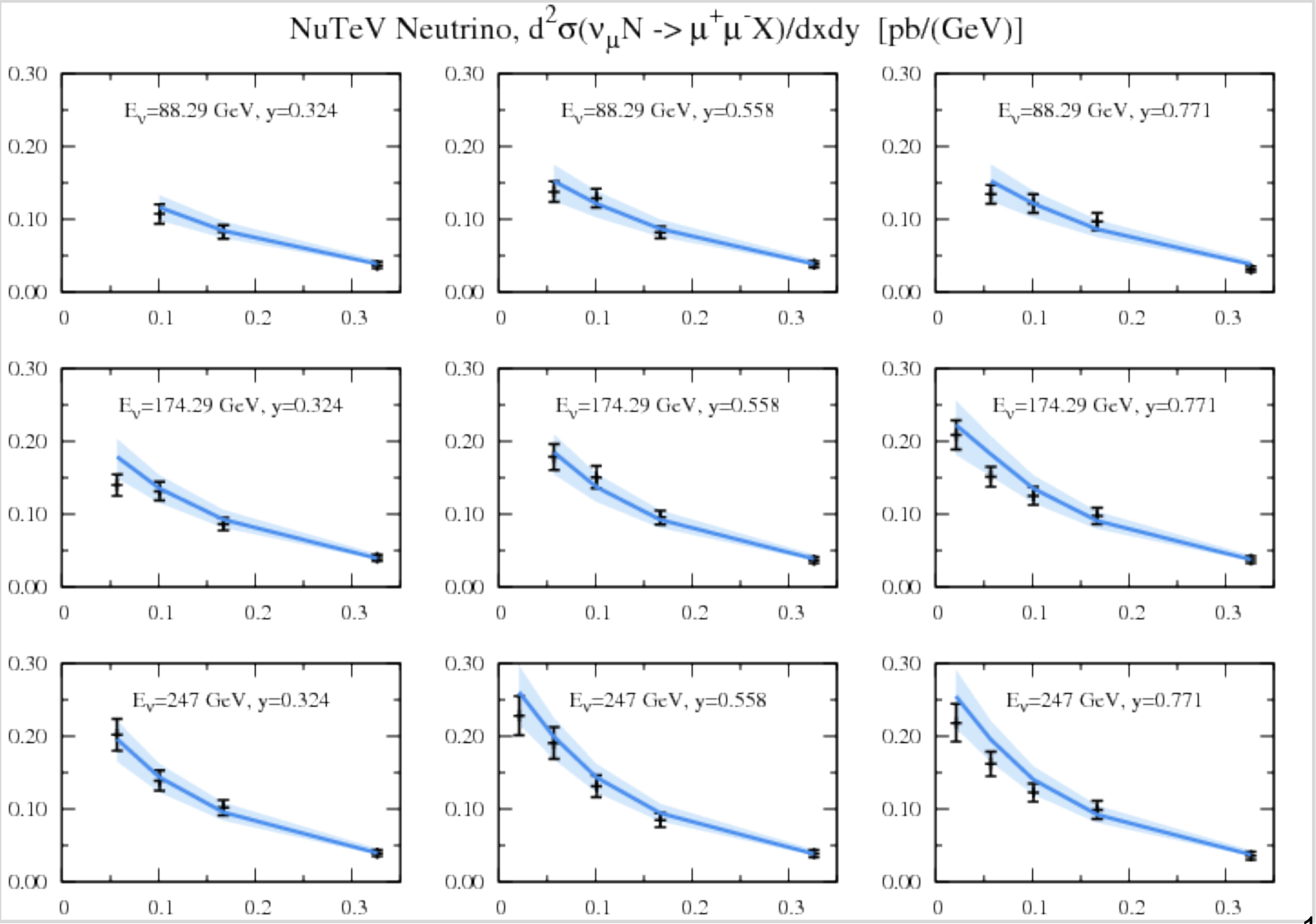


These measurements should tell us something about the u flavor versus d flavor.

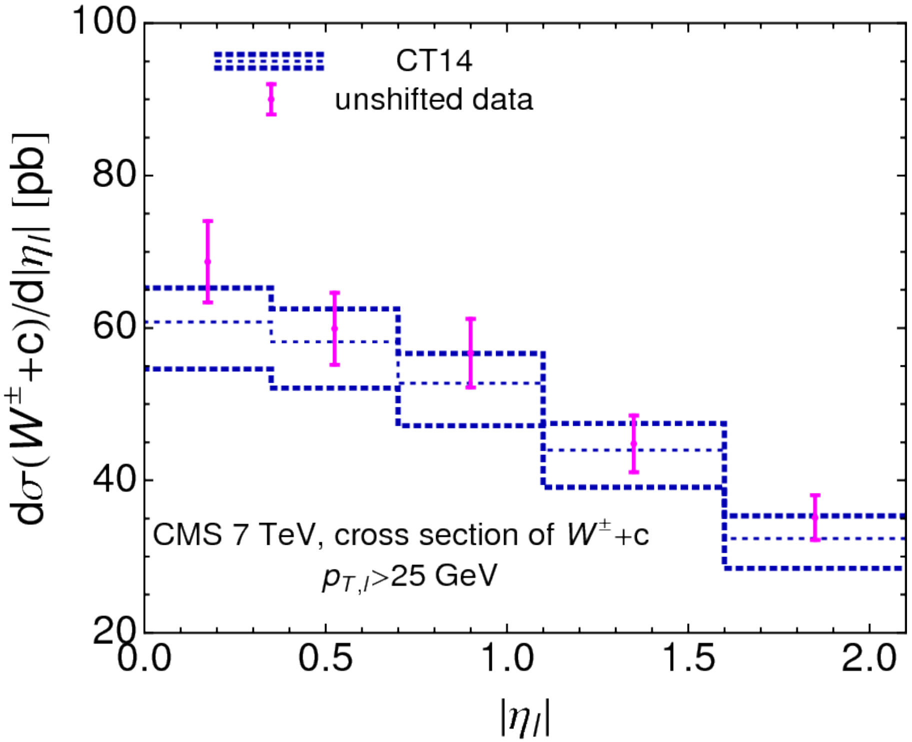
(Good agreement with the Run-2 data)

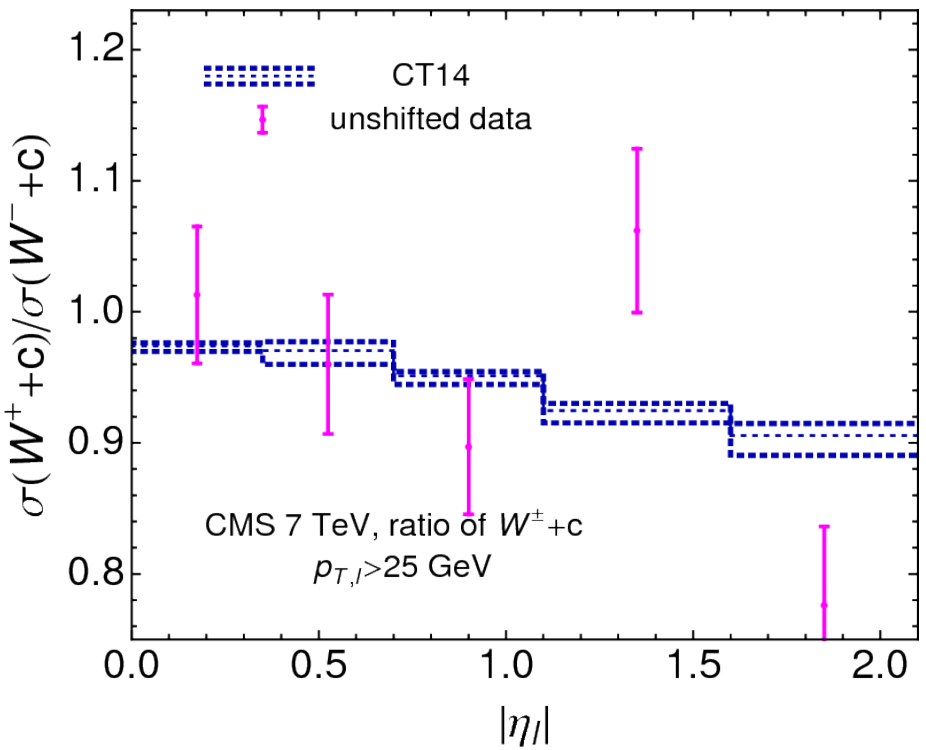
Comment on the strange quark PDF.
For CT14, s(x,Q) < s_{CT10}(x,Q), *roughly 20% smaller @ 2 GeV.* (Why?)
Examine data that is sensitive to the strange quark:
NuTeV and CCFR dimuon production by neutrinos and antineutrinos.

E.g., one fourth of the experiments:



Another process that is sensitive to the strange quark :
W + charm production at the LHC

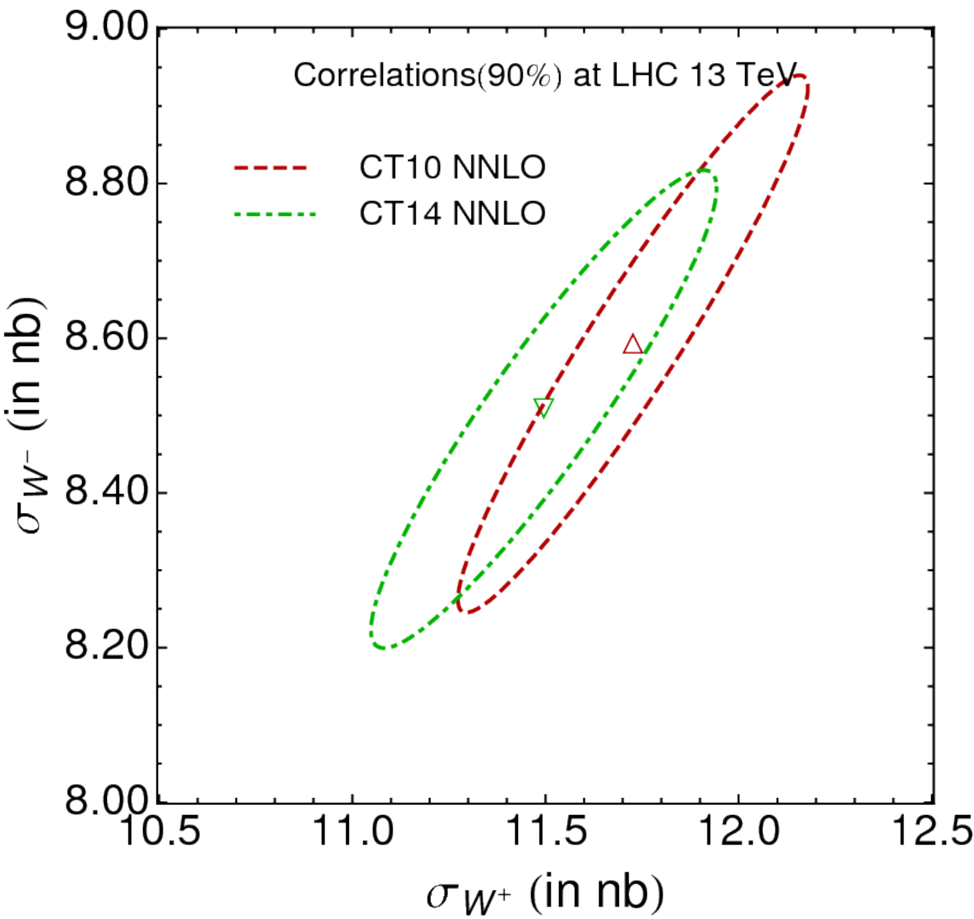


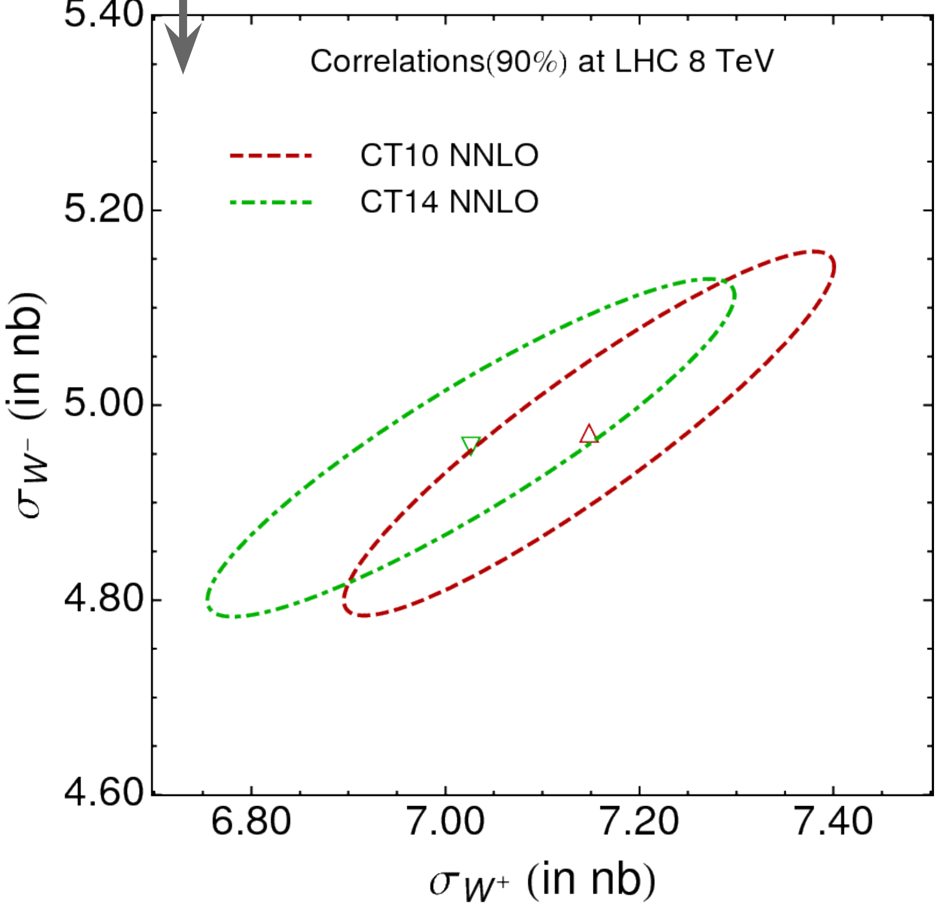


Comparison of the CT14 calculation for $W^{+/-}$ + c differential cross sections , compared to the CMS measurements , for 7 TeV.

3.
Impact of CT14 PDFs on Predictions at the LHC

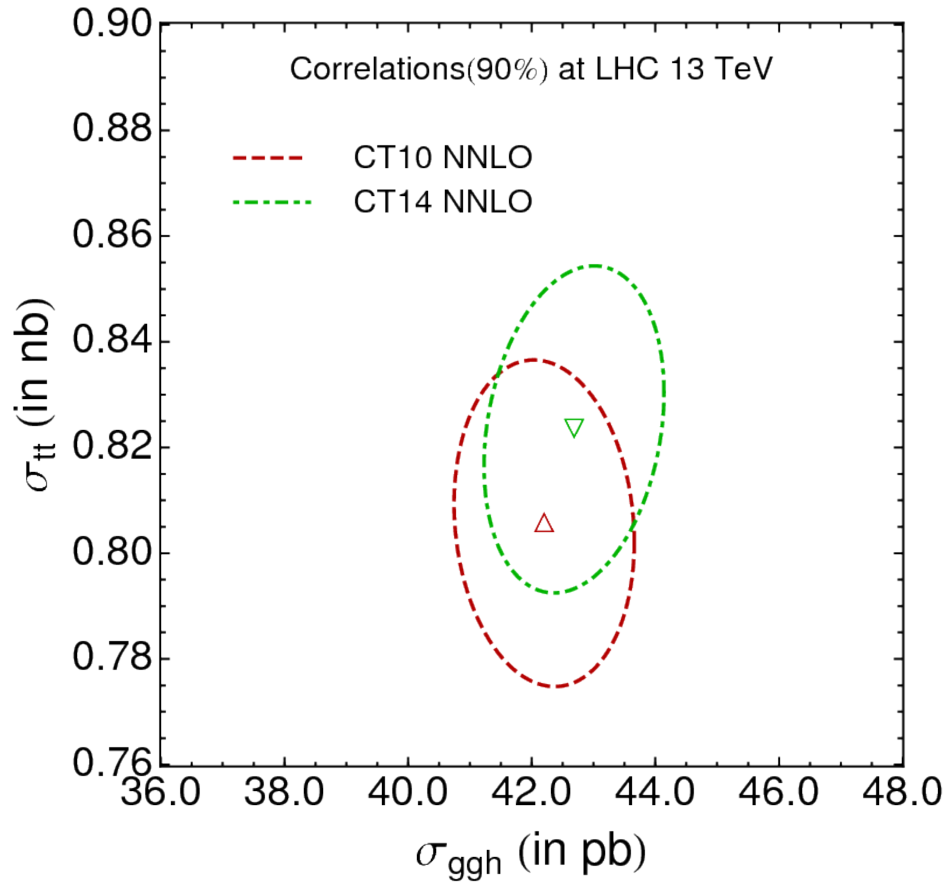
The total cross sections for W^+ and W^- production (highly correlated) at 8 TeV and 13 TeV.

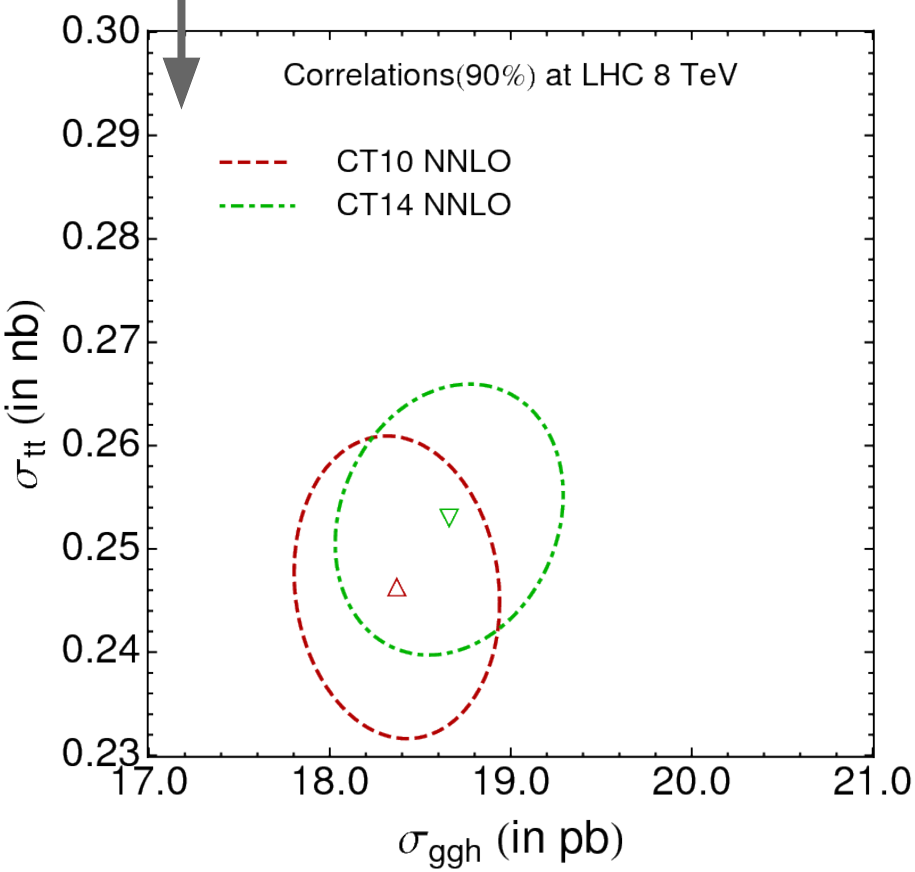




red: CT10
green: CT14

The total cross sections for higgs boson and top quark production (not very correlated) at 8 TeV and 13 TeV.



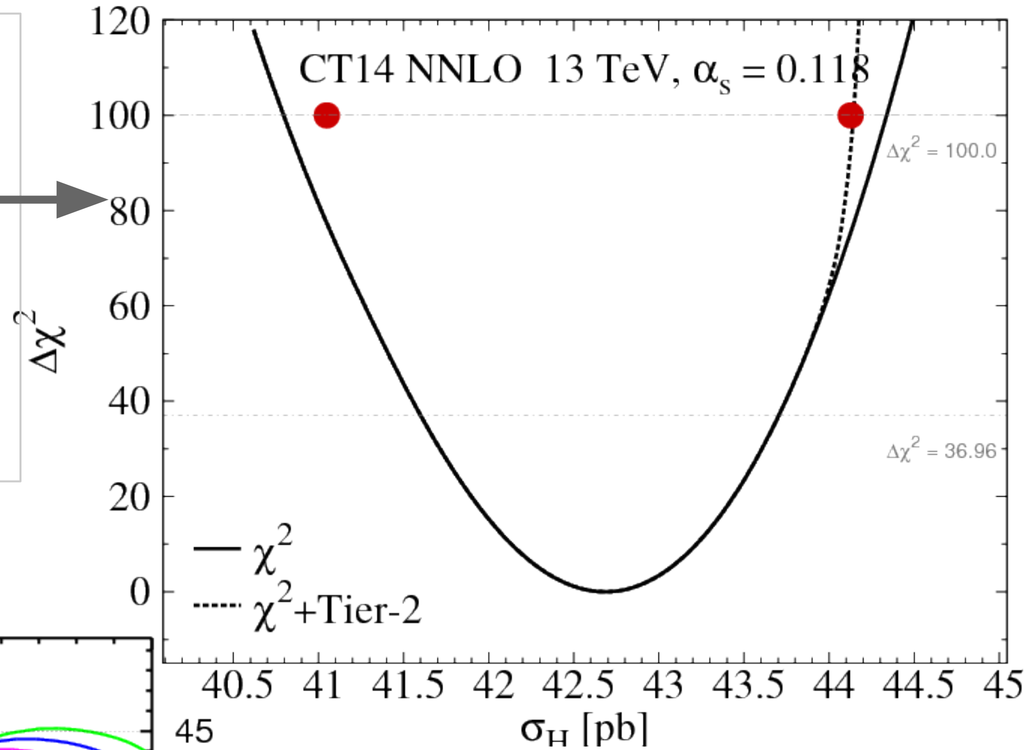


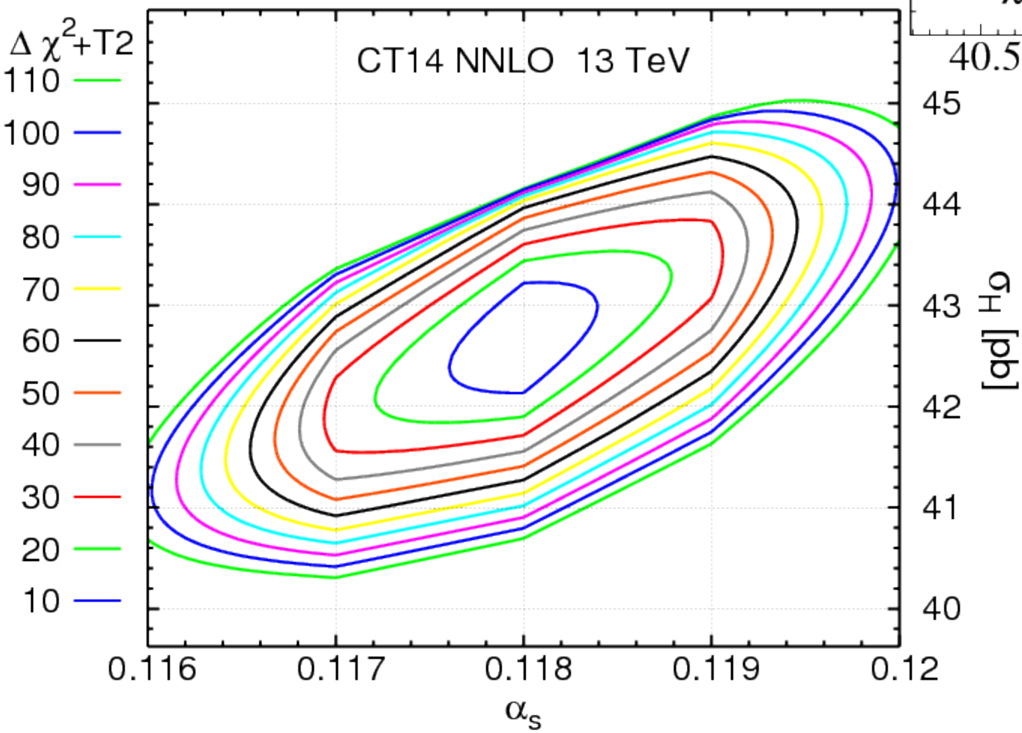
red: CT10
green: CT14

Higgs boson production at 13 TeV LHC.

χ^2 versus σ_h @ $\alpha_S = 0.118$

χ^2 (α_S , σ_h) contours





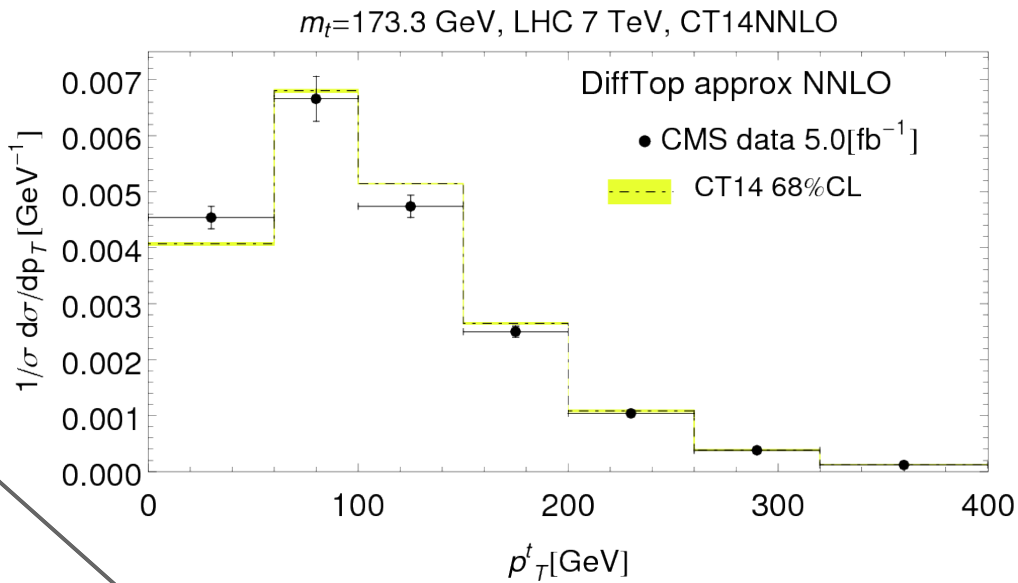
At 13 TeV,
42.7 +/- 2% (PDF)
+/- 1% (alpha-S)
68 pct c.l.
(See the comparisons to MMHT and NNPDF.)

Top-quark differential distributions

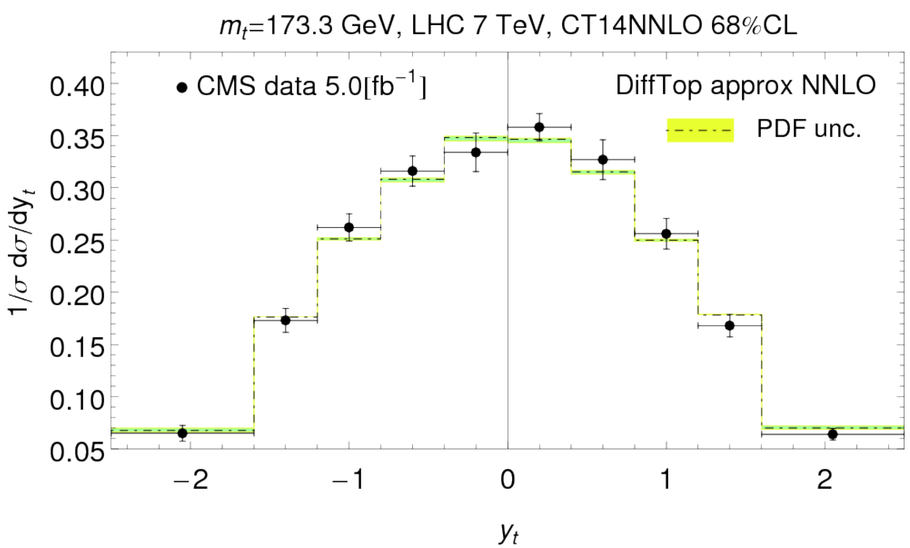
CMS 7 TeV data ;

ATLAS 7 TeV data ;

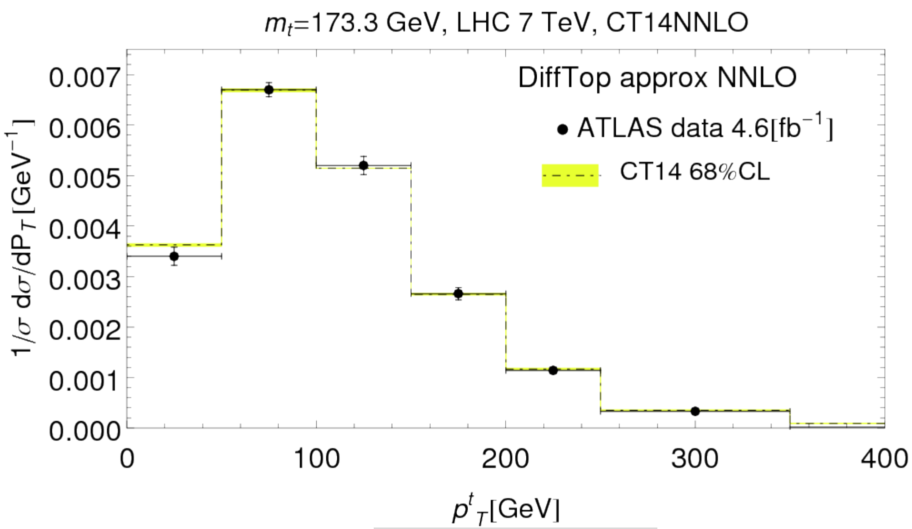
compared to CT14NNLO thy.



pT



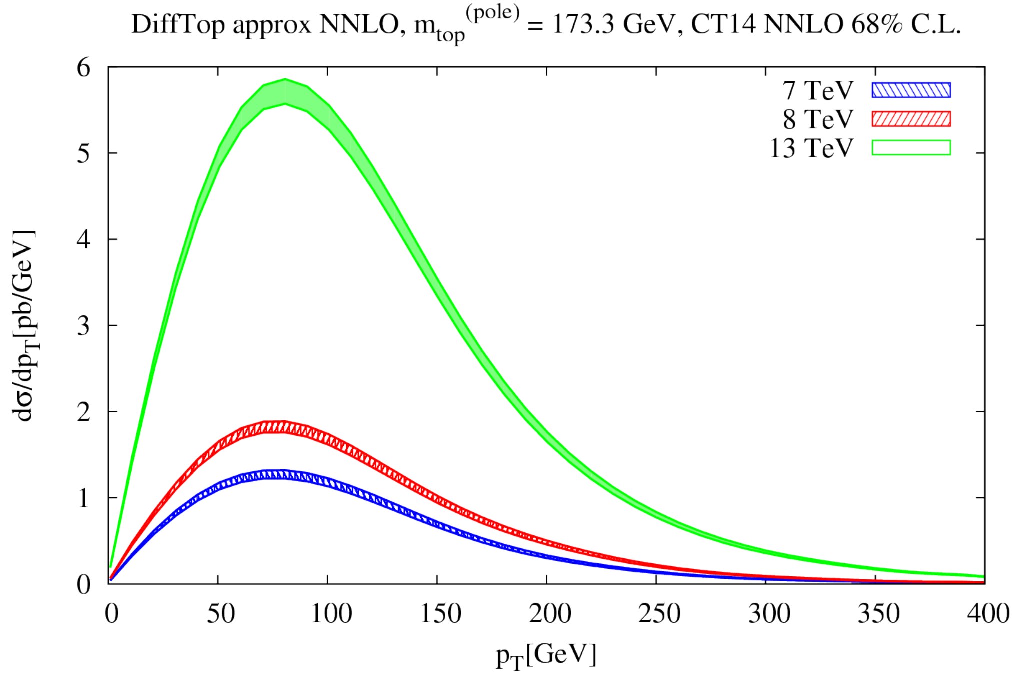
rapidity



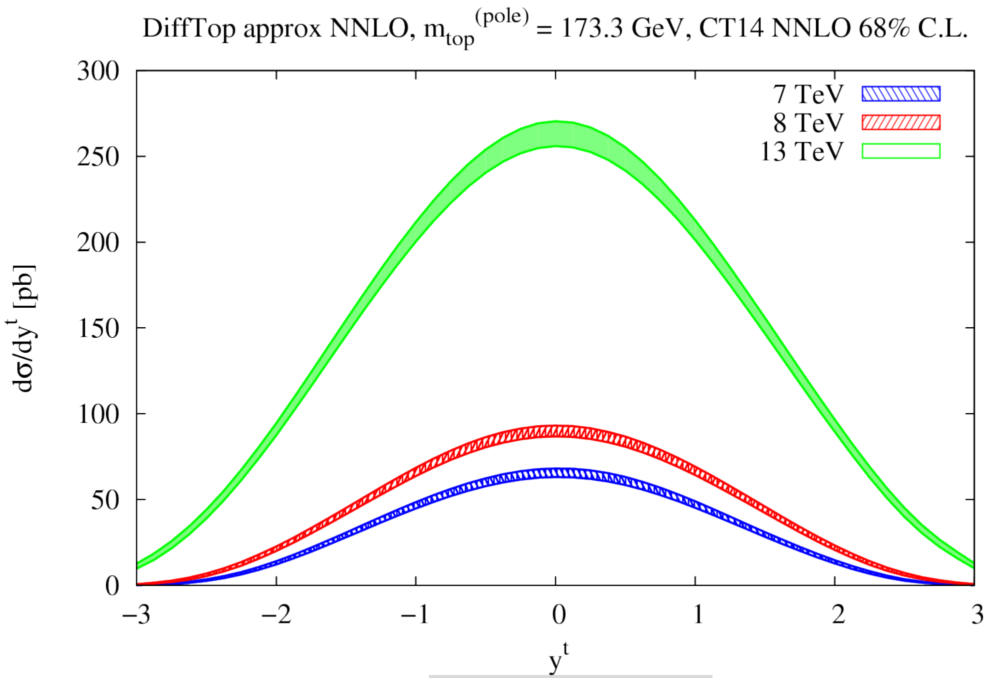
pT

Top-quark differential cross sections; predictions for CT14NNLO PDFs.

7 TeV 8 TeV 13 TeV



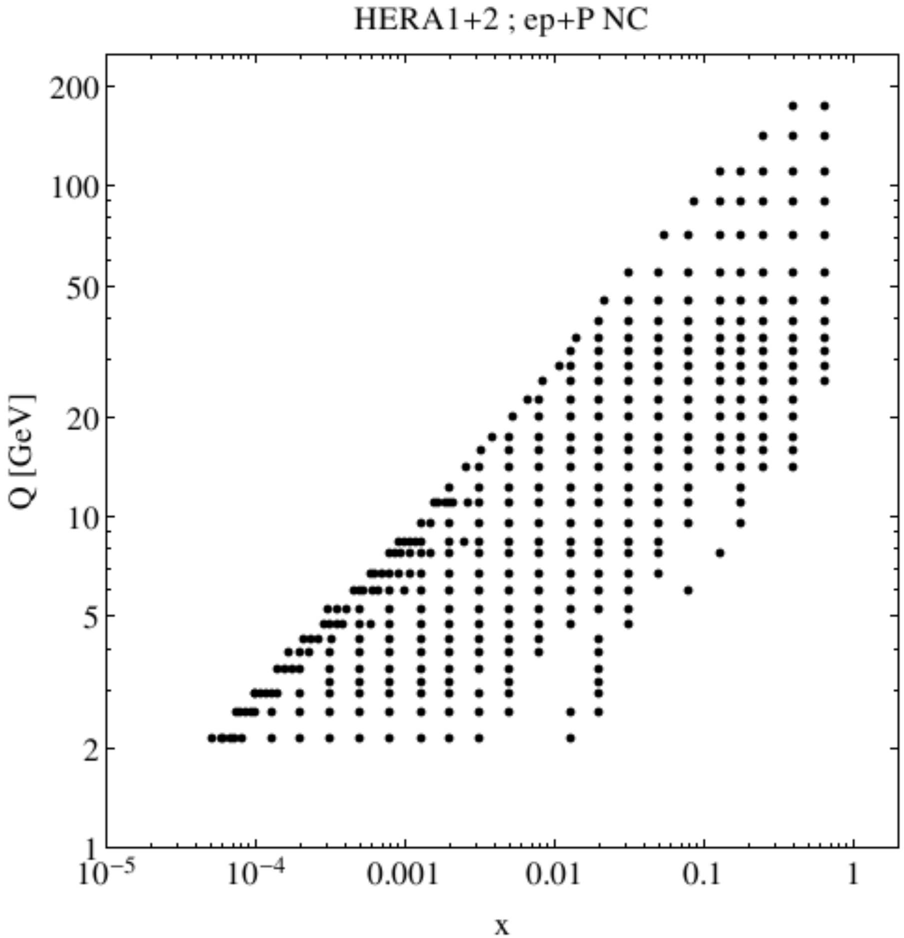
pT



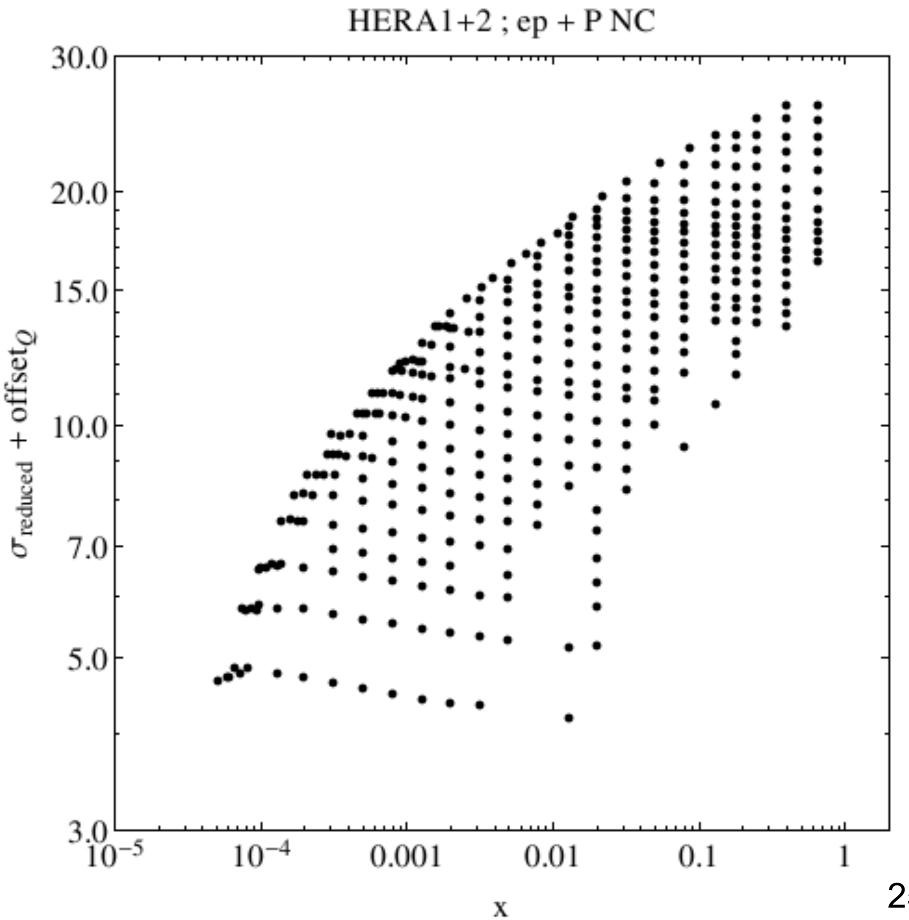
rapidity

4.
A *preliminary* and *partial* look at the HERA1+2 data

x Q grid for positron DIS, N.C.

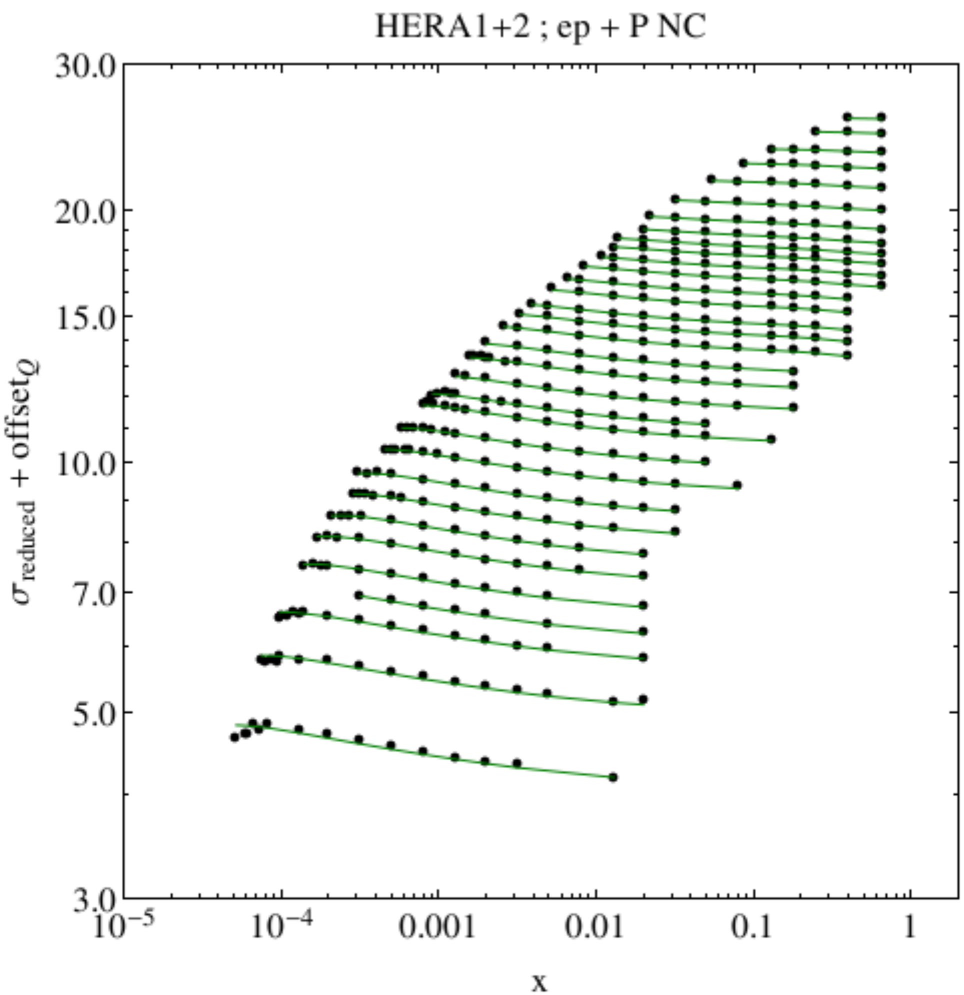


$\sigma_{reduced}$ + Offset(Q)

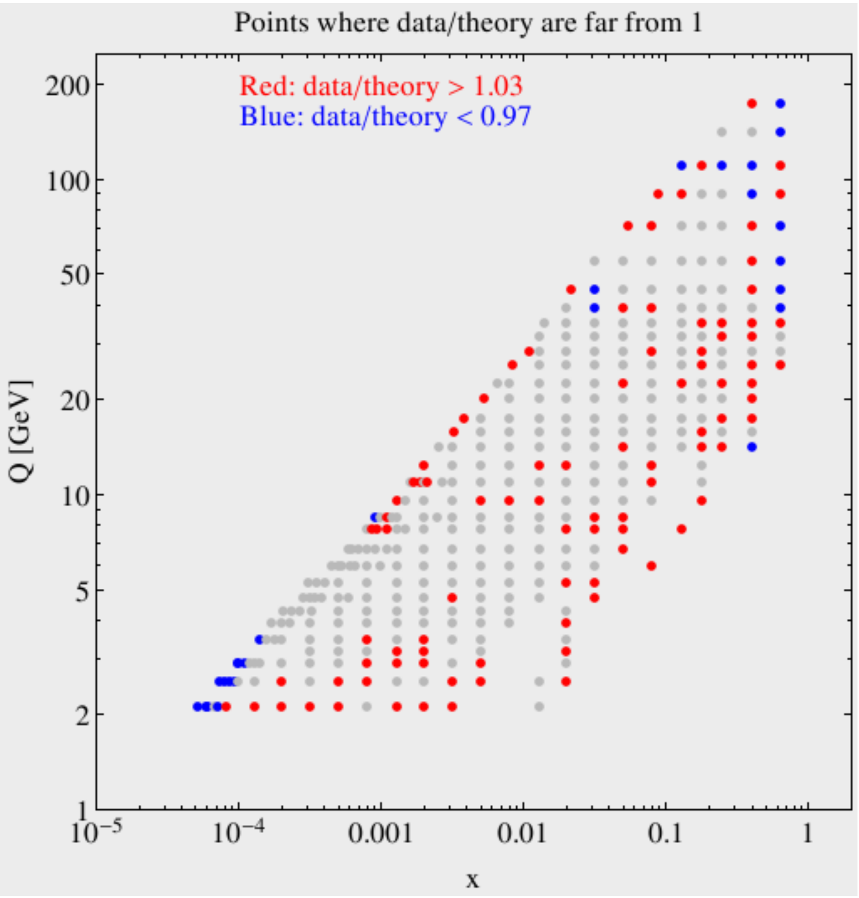


Comparison of data and theory (CT14)

Theory (CT14) and data ; positron DIS, N.C.



Points where data/theory is large.



Better comparison of data and theory (CT14)

To account for the systematic errors, we should compare

the "shifted data" (sD)

to the theory (T)

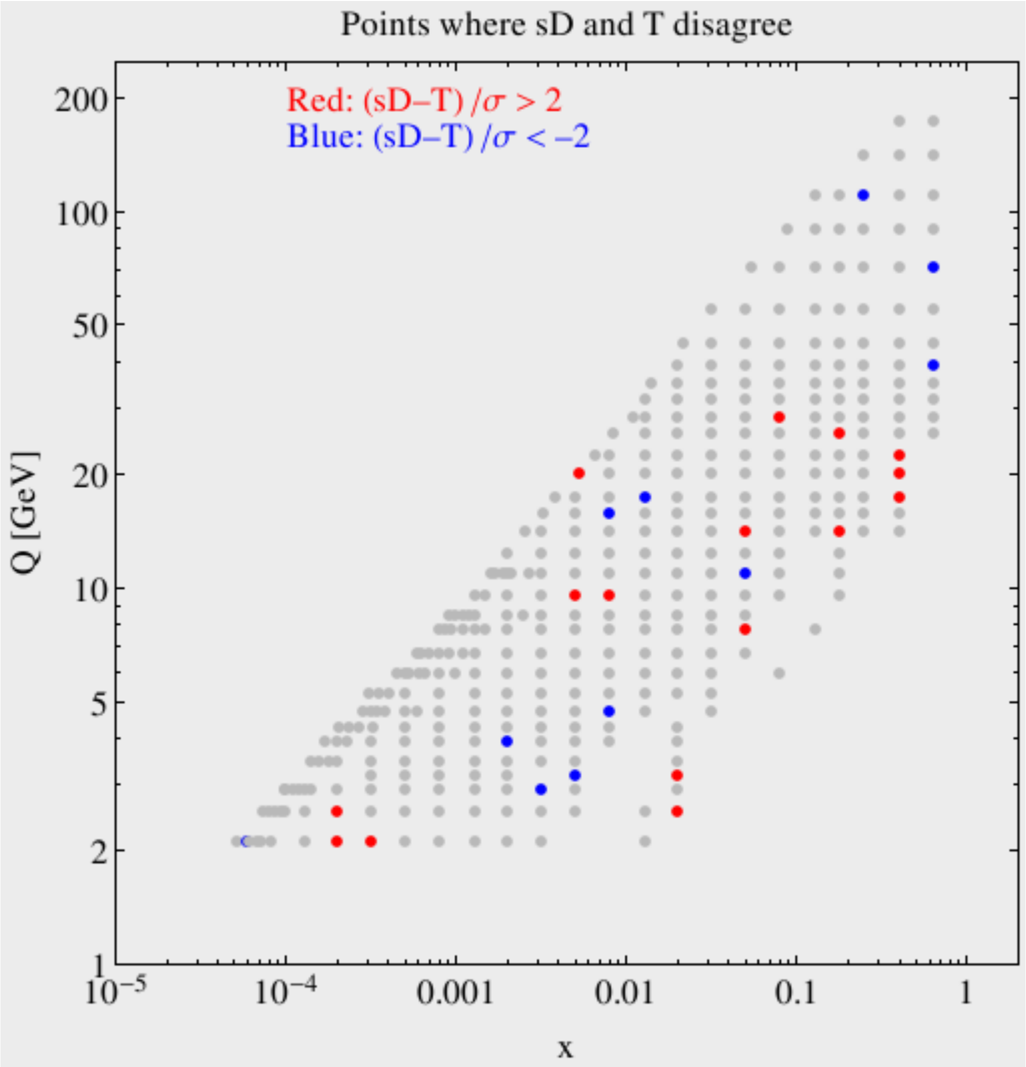
in units of the ***uncorrelated*** error (σ_{unc});

i.e.,

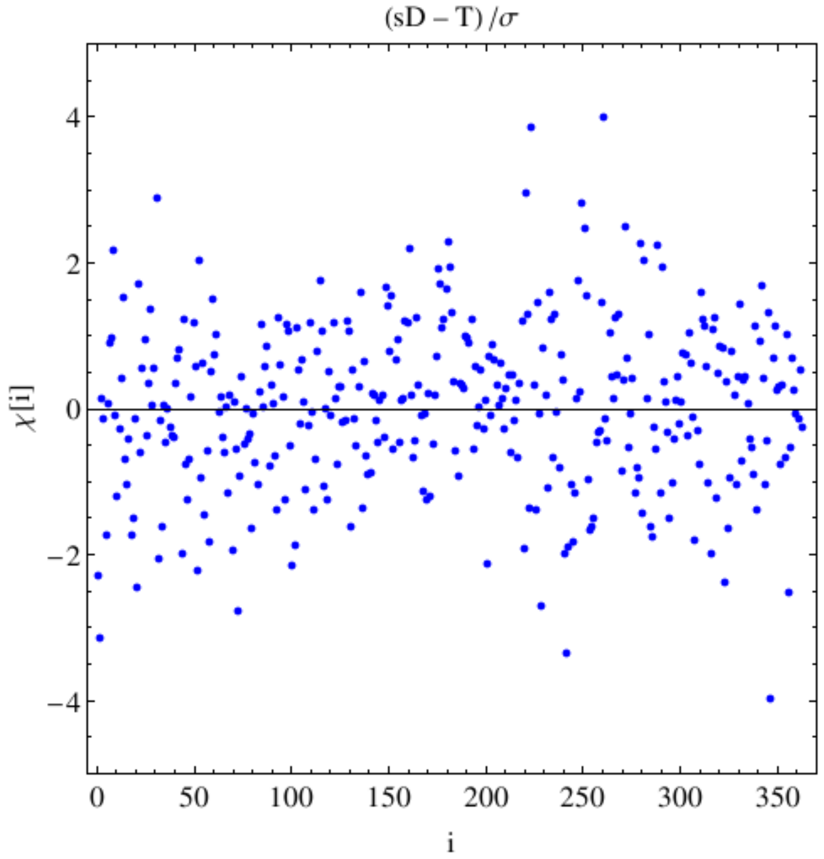
$$(sD - T) / \sigma_{unc}$$

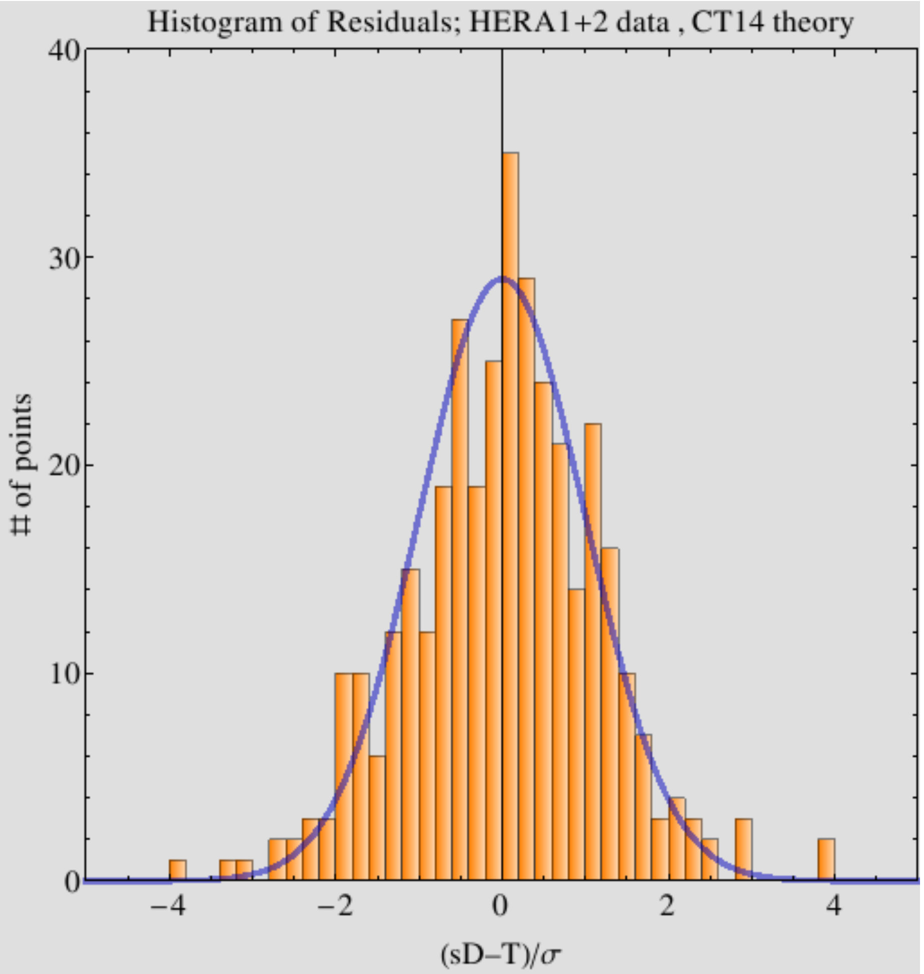
which should be normally distributed.

Points with $|(sD - T)/\sigma| > 2$

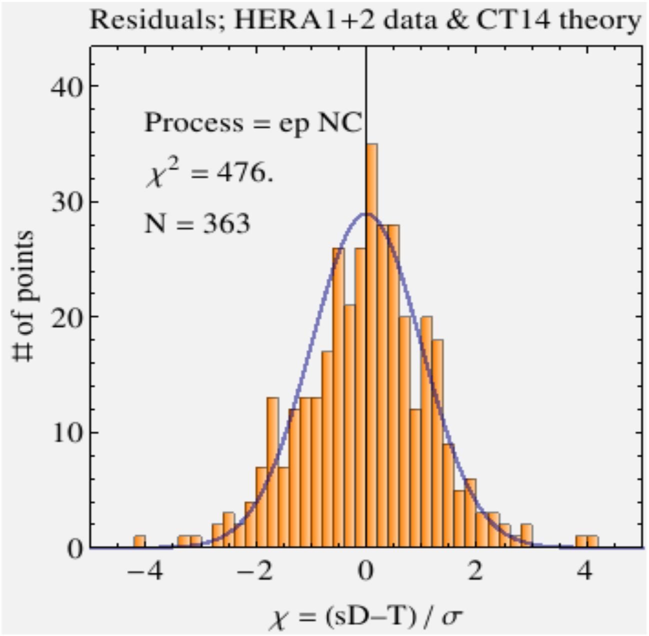


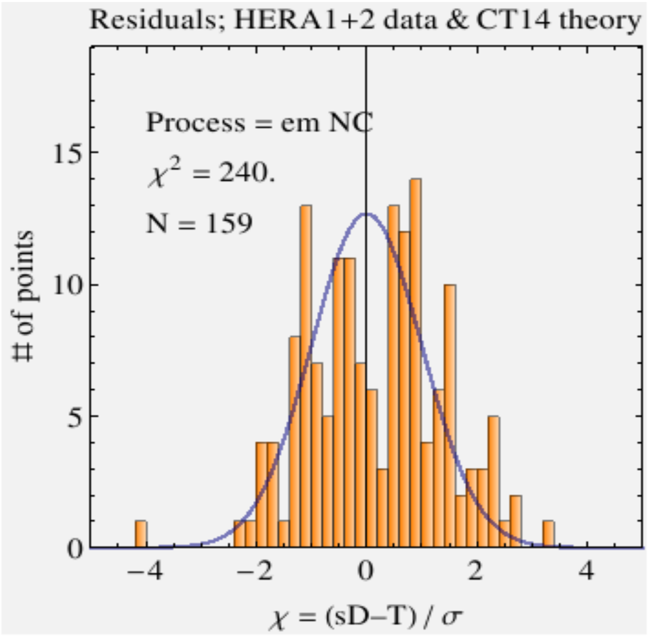
The residuals : data is displaced by optimized systematic errors ("sD") ; then compared to theory with CT14 PDFs

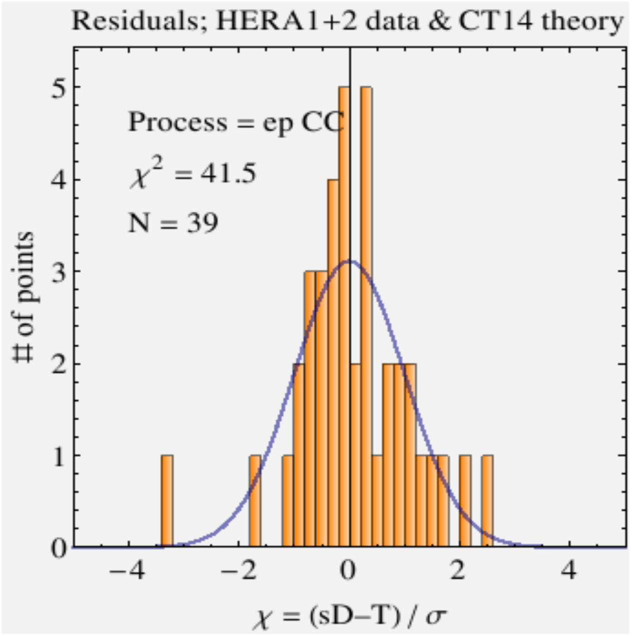


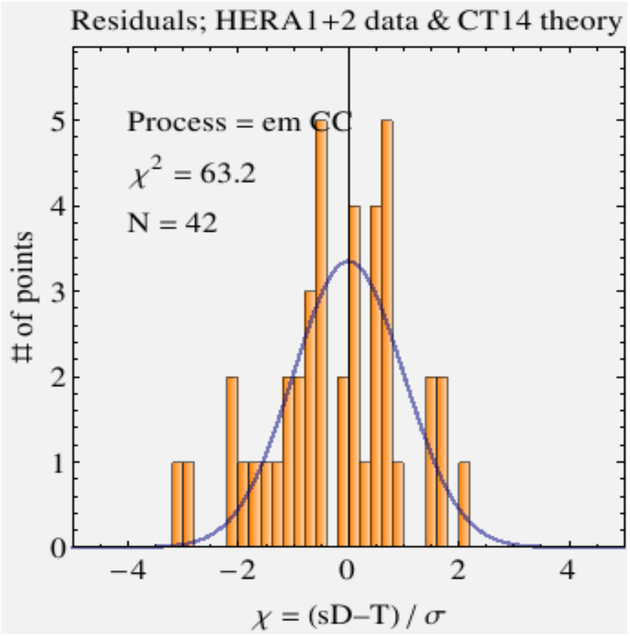


Four processes

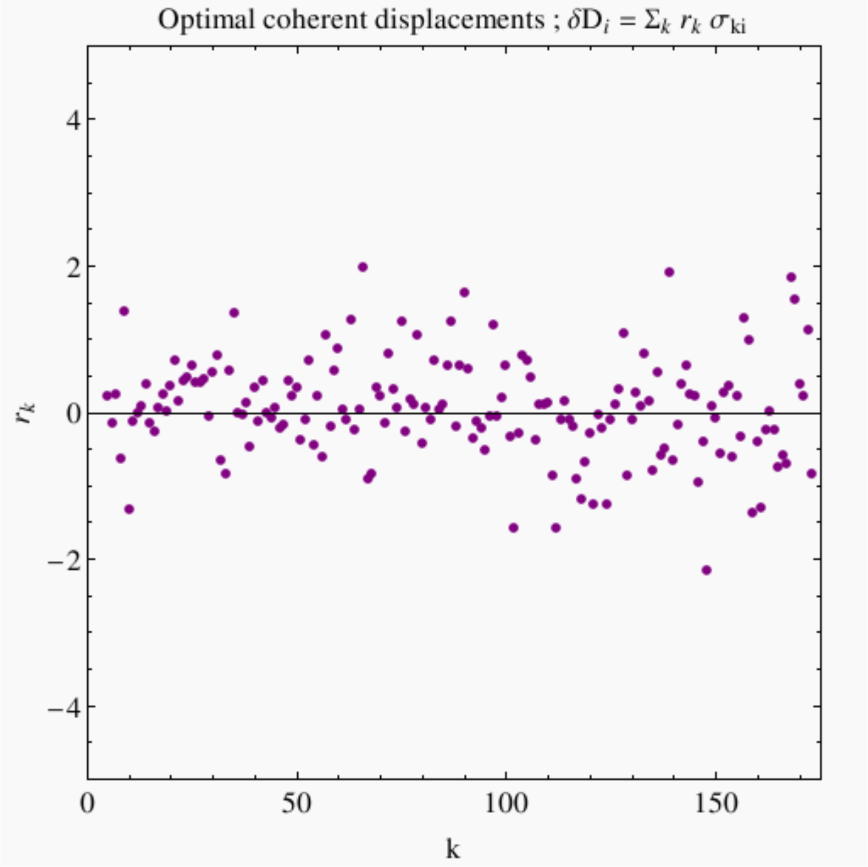


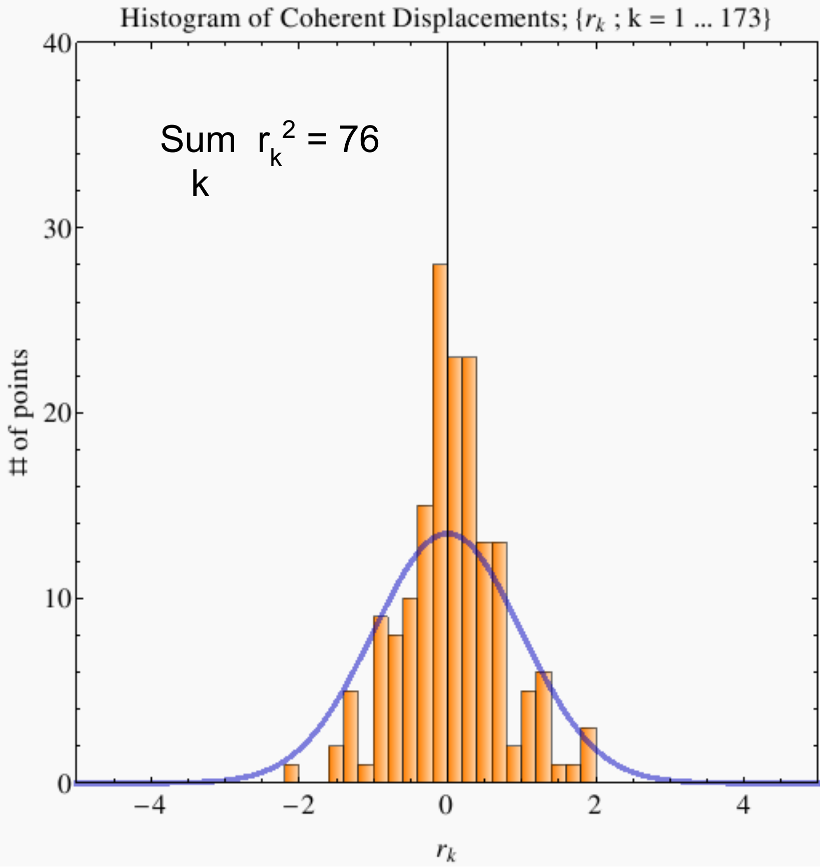


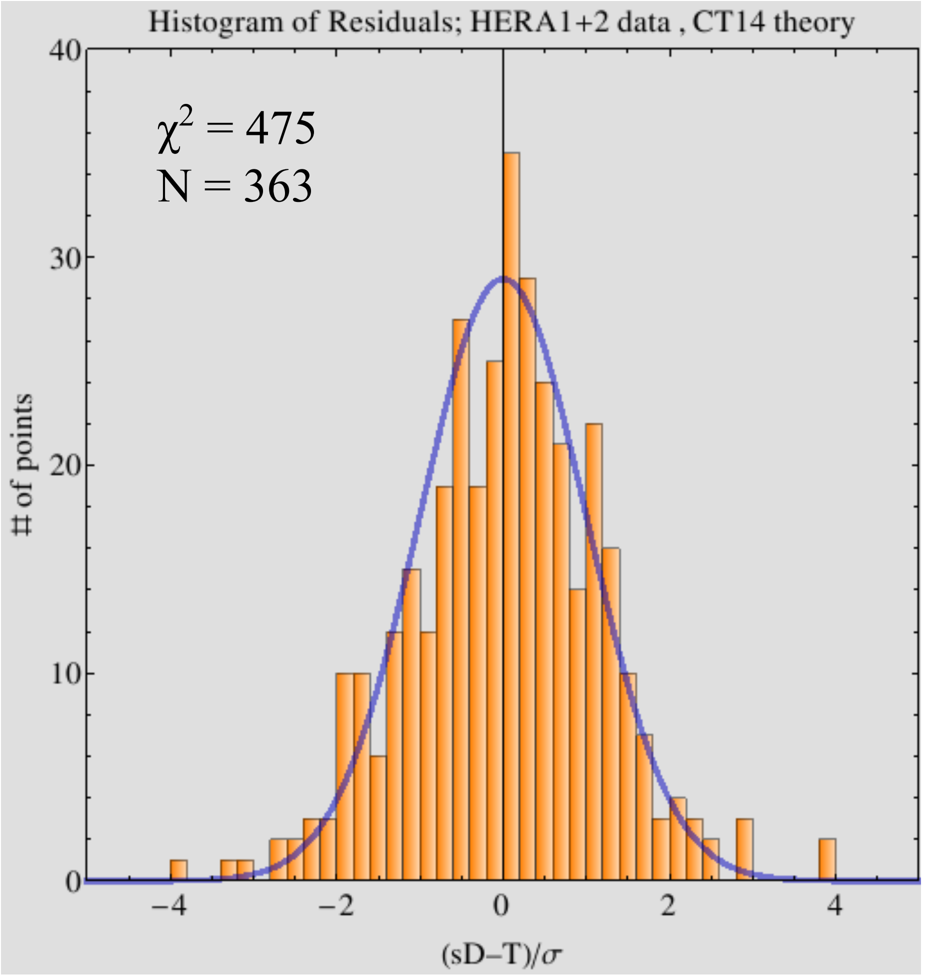




The nuisance parameters: i.e., the normalized coherent displacements; $sD_i = D_i + \delta D_i$ and $\delta D_i = \sum_k r_k \sigma_{ki}$



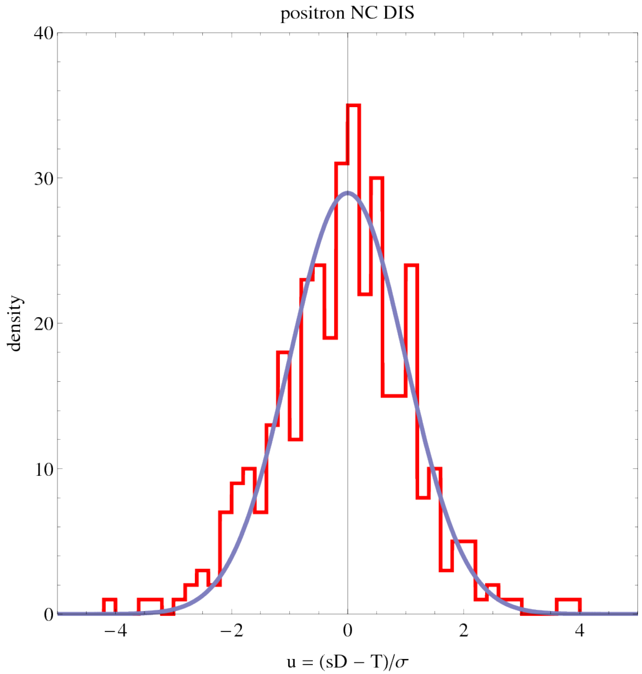


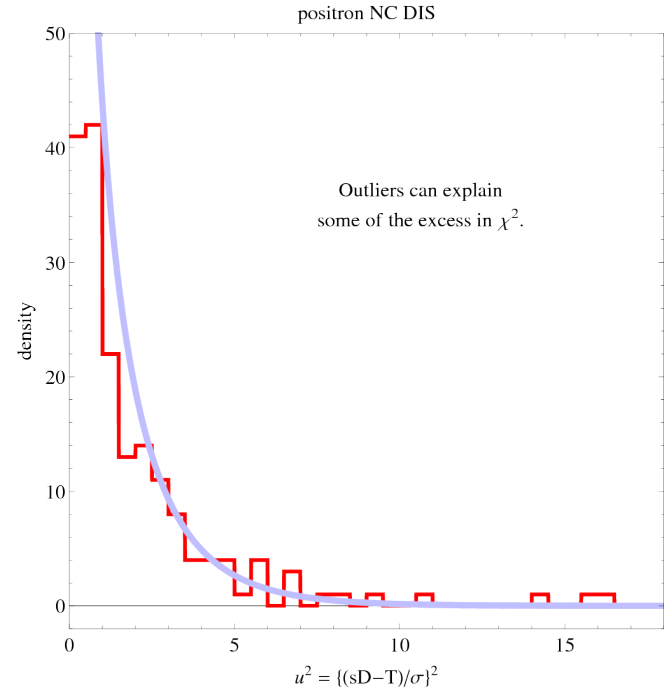


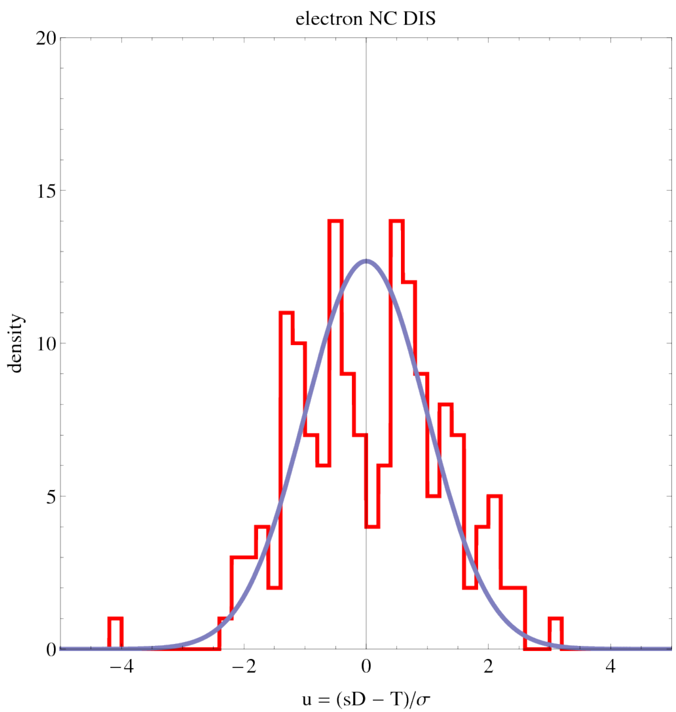
Challenge for a bright young person …

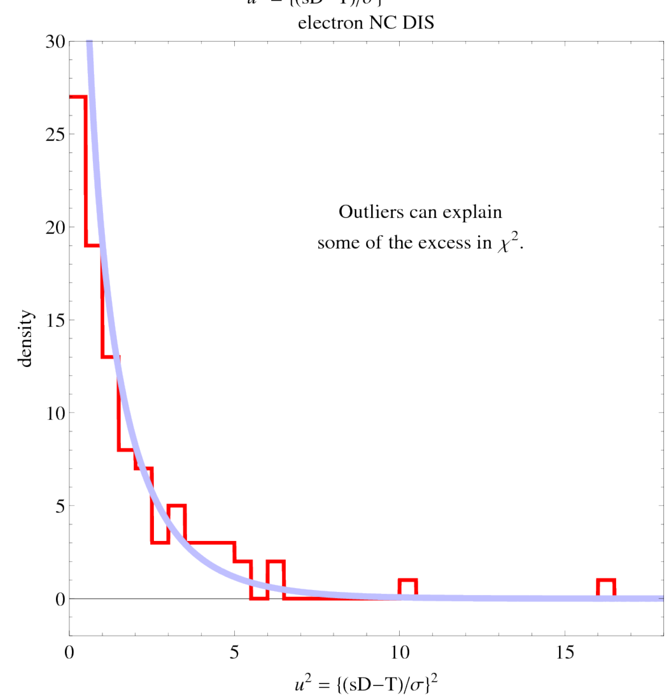
Analyze the histogram of residuals using

"Pearson's chi-squared goodness-of-fit test".


positron NC DIS
density
u = (sD − T)/σ


positron NC DIS
Outliers can explain
some of the excess in χ^2.
density
$u^2 = \{(sD-T)/\sigma\}^2$


electron NC DIS
density
u = (sD − T)/σ


electron NC DIS
Outliers can explain
some of the excess in χ^2.
density
$u^2 = \{(sD-T)/\sigma\}^2$

Conclusions

/1/ It is important to test QCD ; and to seek new physics.
The CT14 NNLO PDFs will be used to compare data and theory for the 8 TeV and 13 TeV LHC.

/2/ The best way to compare data and theory is to use *Pearson's chi-squared goodness-of-fit test*.
(Just using χ^2/N is not good enough.)

Topics where more work is needed

/1/ *Systematic errors.*
The current method is practical, and seems to give reasonable results; but it has some limitations.

/2/ *Parametrization.* (Val: 8 ; Glu: 5 ; Sea: 13 ; =26)
"Flexible parameterizations" are important. (See the Appendix.)
Can we make "parametrization" less ***ad hoc***?