Progress on CTEQ-TEA PDFs

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CTEQ-TEA working group

CTEQ

- **CTEQ-T**ung **e**t **a**l. (TEA), in memory of Prof. Wu-Ki Tung, who established CTEQ Collaboration in early 90's

  - **Michigan State University**: J. Huston, J. Pumplin, D. Stump, C. Schmidt, **J. Winter**, C.-P. Yuan
  - **Southern Methodist University**: T.-J. Hou, P. Nadolsky, **B. T. Wang, K. P. Xie**
  - **Xinjiang University**: S. Dulat
  - **Shanghai Jiao Tong University**: J. Gao
  - **University of Manchester/Kennesaw State**: M. Guzzi

http://hep.pa.msu.edu/cteq/public/index.html

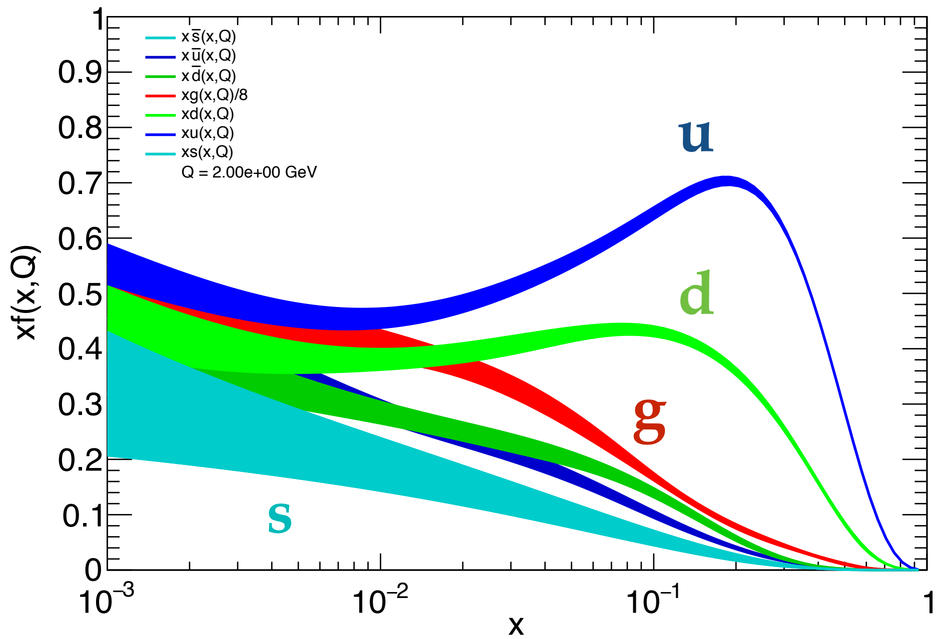
CT14 parton distribution functions

This page provides numerical table files for the computation of CT14 leading order (LO), next-to-leading order (NLO) and next-to-next-to-leading order (NNLO) parton distribution functions. They can be interpolated with the help of a **NEW** **standalone Fortran interface** and **demonstration program**, as well as the tables with interpolated values of the QCD coupling alpha_s and PDFs.

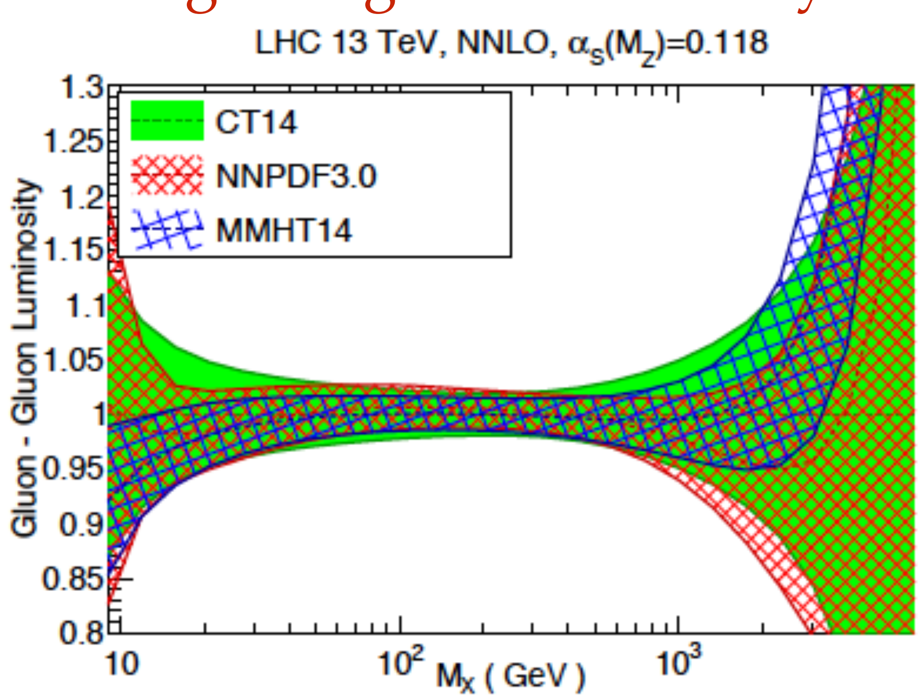
CT14 Parton distributions

- Last major release on general-purpose PDFs, CT14 NNLO/NLO sets including alternative α_s series and n_f=3, 4, 6 **[1506.07443]**

CT14 NNLO PDFs



gluon-gluon luminosity



- D0 W-electron asymmetry data superseded by the new one with full luminosity; combined HERA charm production, H1 FL data in NC DIS
- early LHC Run I data on W/Z charged lepton rapidity and asymmetry; inclusive jet production from ATLAS and CMS
- more flexible parametrization for gluon, d/u at large-x, both d/u and dbar/ubar at small-x, 28 eigenvectors comparing to 25 for CT10

CT14 remains as our official sets for general purpose use

Beyond CT14 nominal sets

- Progress have been made on studies of specialized sets, effects of new HERA data with CT14 setups, and towards the new CT17 family

  - **CT14 QEDinc PDFs**, models and constraints on photon PDFs, **[1509.02905]**
  - **CT14 MC PDFs**, replicas for certain applications (talk by J. Gao), **[1607.06066]**
  - **CT14 HERA2 PDFs**, effects of combined HERA1+2 data, **[1609.07968]**
  - **CT14 IC PDFs**, fitted charm component (talk by M. Guzzi), **[1704.xxxxx]**
  - **CT17** preliminary fits and related, **[17xx.xxxx]**

CT17p — data to be included

- Previous LHC and HERA 1 data included in CT14 will be superseded by updated Run 1 and HERA 1+2 data; adding new LHC data, especially on Z boson p_T and top quark differential distributions
  - **Combined HERA1+2 DIS [1506.06042]** update
  - **LHCb 7 TeV Z, W muon rapidity dist. [1505.07024]** update
  - **LHCb 8 TeV Z rapidity dist. [1503.00963]** update
  - **ATLAS 7 TeV inclusive jet [1410.8857]** update
  - **CMS 7 TeV inclusive jet (extended y range)[1406.0324]** update
  - **ATLAS 7 TeV Z pT dist. [1406.3660]** new
  - **LHCb 13 TeV Z rapidity dist. [1607.06495]** update
  - **CMS 8 TeV Z pT and rapidity dist. (double diff.) [1504.03511]** new
  - **CMS 8 TeV W, muon asymmetry dist. [1603.01803]** update
  - **ATLAS 7 TeV W/Z, lepton(s) rapidity dist. [1612.03016]** update
  - **CMS 7,8 TeV tT differential distributions** new
  - **ATLAS 7,8 TeV tT differential distributions** new

CT14 HERA2 PDFs

- CT14-like fits with HERA1 data replaced by HERA2 data (Run I and II combined)

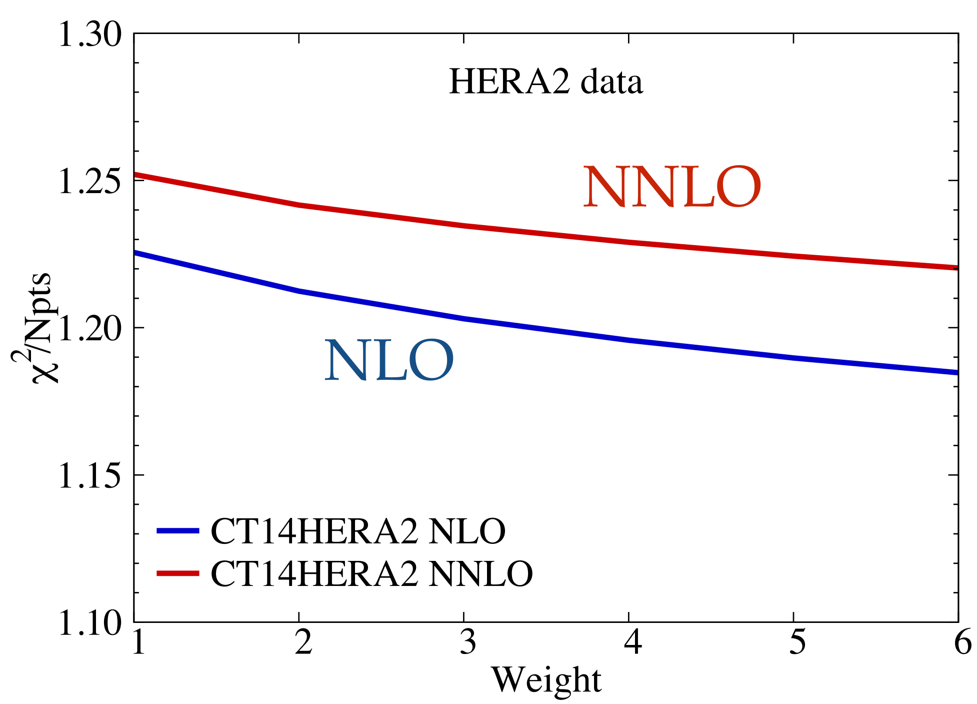
HERA1 data in CT14 NNLO

$Q_{\rm cut}$ [GeV]	no cut	2.00
$\chi^2/N_{pts}(N_{pts})$	(647)	1.02 (579)
NC e^+p	(434)	1.05 (366)
NC e^-p	(145)	0.74 (145)
CC e^+p	(34)	0.97 (34)
CC e^-p	(34)	0.53 (34)

HERA2 data in CT14 HERA2 NNLO

$Q_{\rm cut}$ [GeV]	no cut	2.00
$\chi^2/N_{pts}(N_{pts})$	(1306)	$\boxed{1.25\ (1120)}$
NC e^+p	(1066)	1.11 (880)
NC e^-p	(159)	$\boxed{1.45\ (159)}$
CC e^+p	(39)	1.10 (39)
CC e^-p	(42)	$\boxed{1.52\ (42)}$

X^2 / N_{pt} as increasing weight

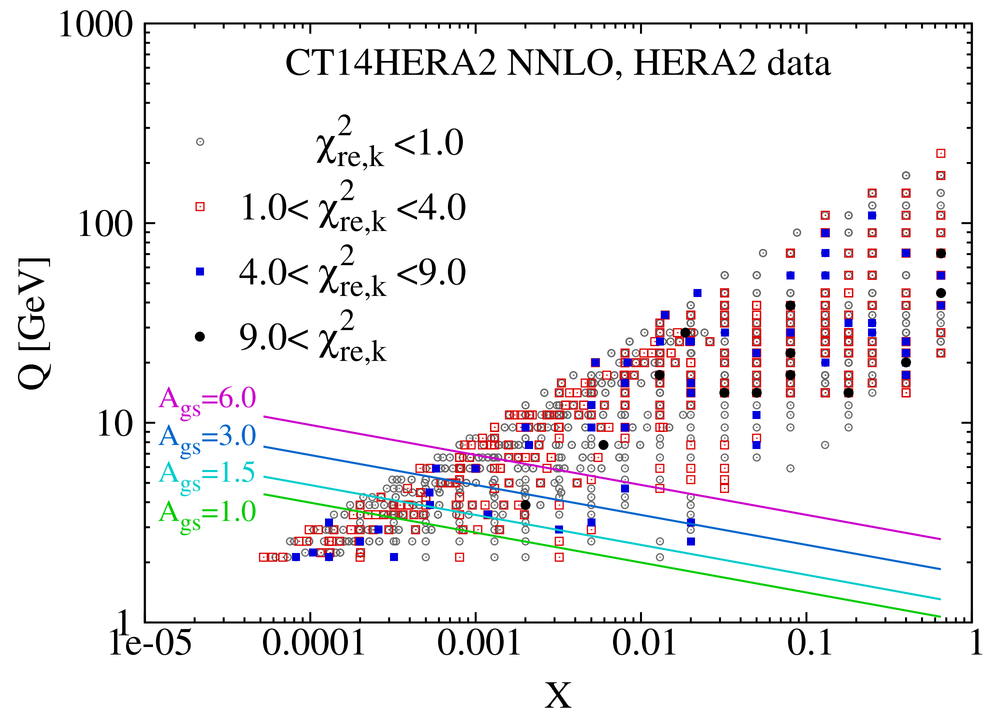


- NMC F_2^P data dropped; CMS 7 TeV inclusive jet data updated
- freeing one more parameter for strangeness parametrization
- overall HERA2 data fit reasonably well, except for the e-p data

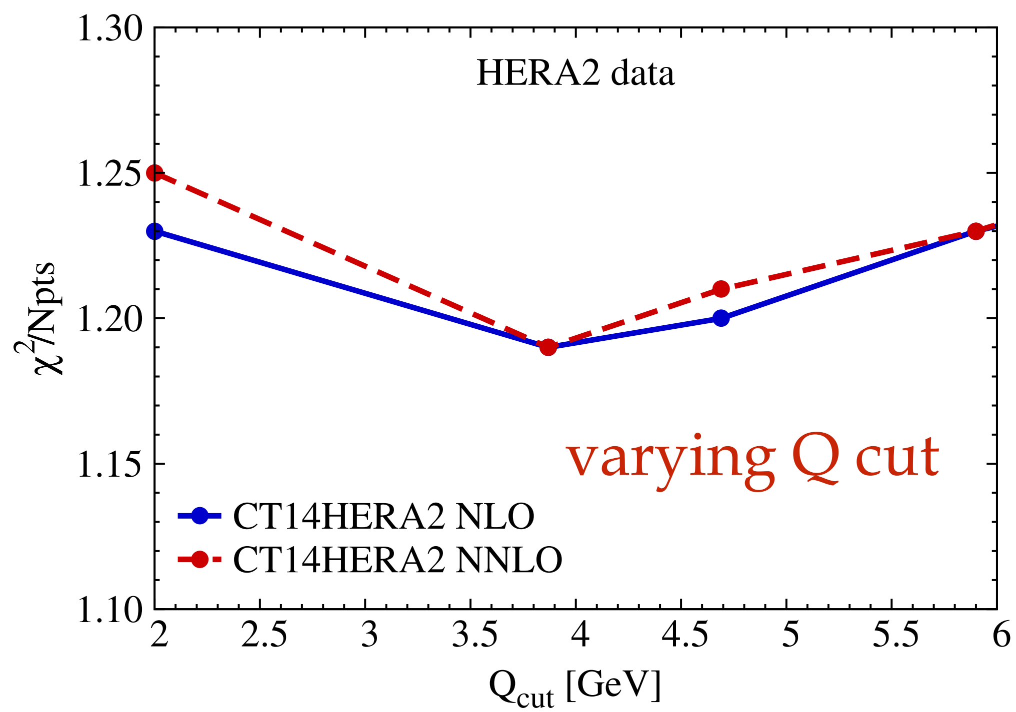
CT14 HERA2 PDFs

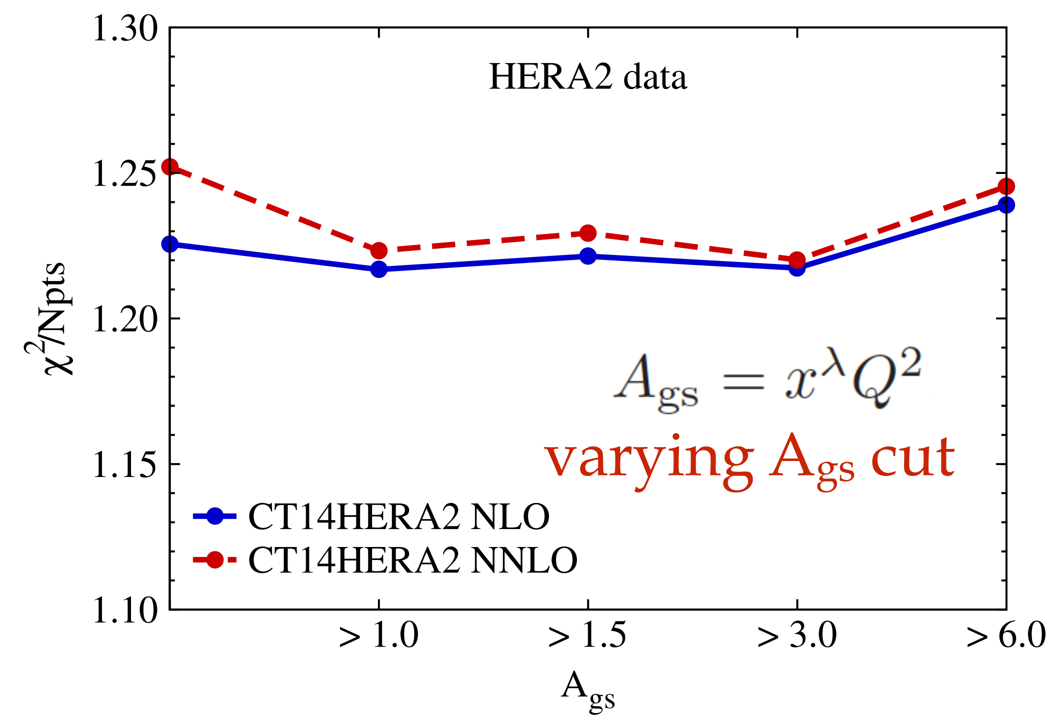
- CT14-like fits with HERA1 data replaced by HERA2 data (Run I and II combined)

residuals on kinematic plane



- data points with large residuals spread over the entire region
- change of selection cuts does not show systematic effects
- no clear indication of deviation from DGLAP evolution

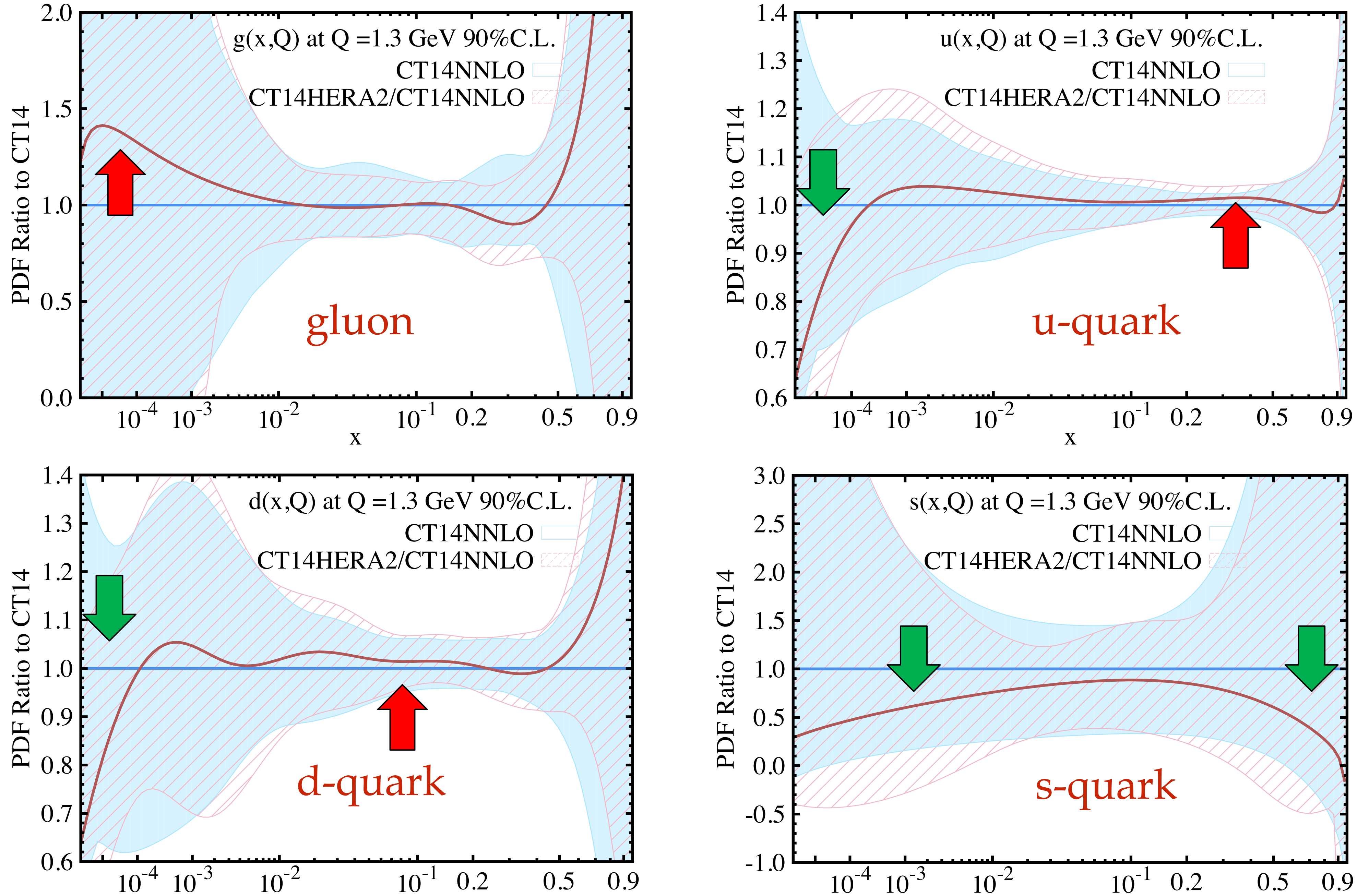




CT14 HERA2 PDFs

- CT14-like fits with HERA1 data replaced by HERA2 data (Run I and II combined)

CT14HERA2 (red) vs. CT14 PDFs (blue)

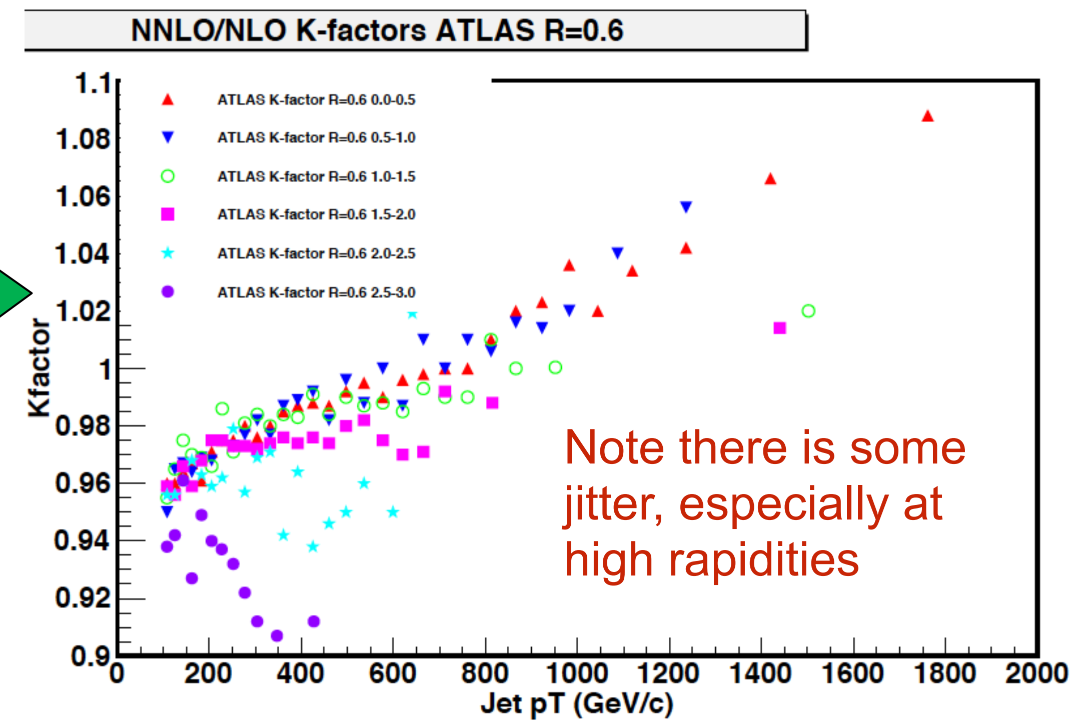


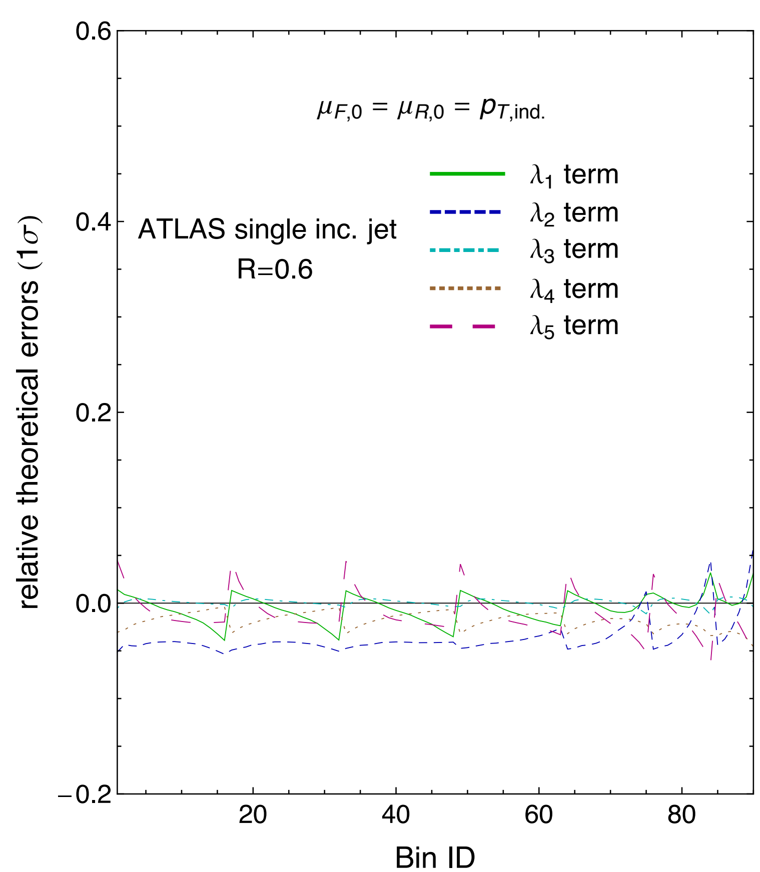
- effects due to new data and freeing one parameter; all changes well within CT14 uncertainties; continue to recommend CT14 nominal set for LHC Run2

CT17p — theory for LHC data

- FastNLO/APPLgrid NLO fast interface with tabulated NNLO/NLO K-factors; several issues arise given the percent-level precision required
  - Local generation of APPLgrid tables from MCFM and aMCFast
  - MC errors in the K-factors; dependence of the K-factors on the PDFs
  - MC errors in APPLgrid tables especially for fiducial cross sections at tail region

NNLO/NLO inclusive jet





- Inclusion of the theoretical error through scale variations with certain assumptions on correlations, e.g,

$$\sigma_{bin}^{NLO}(\mu_{F,0},\, \mu_{R,0},\, i)\left\{1+\alpha_s^2(\mu_{R,0})\sum_{j=1}^{5} e_j(i)x_j\right\}$$

- FastNLO tables generated from DiffTop for top-quark pair production

CT17p — agreement with and between data

- Preliminary studies on agreement with the new LHC data also on possible tension between different data

  - method: from the nominal fit (with all data sets included) start a scan with increasing weight for one data set (weight 10 for extreme case)
  - LHC data studied: LHCb 7 TeV W,Z rapidity, 8 TeV Z rapidity; ATLAS 7 TeV Z pT, 7 TeV inc. jet; CMS 7 TeV inc. jet
  - all results are PRELIMINARY; currently theo. predictions used for LHC jet and Z p_T data are at NLO only; still working on the NNLO K-factors

χ^2 in nominal and extreme fit

Data	χ^2/N_{pt} (nom.)	χ^2/N_{pt} (extr.)
LHCb 7	44/33	28/33
LHCb 8	38/17	22/17
ATL. 7 Z pT	48/8	21/8
ATL. 7 Jet	305/140	284/140
CMS 7 Jet	233/158	213/158

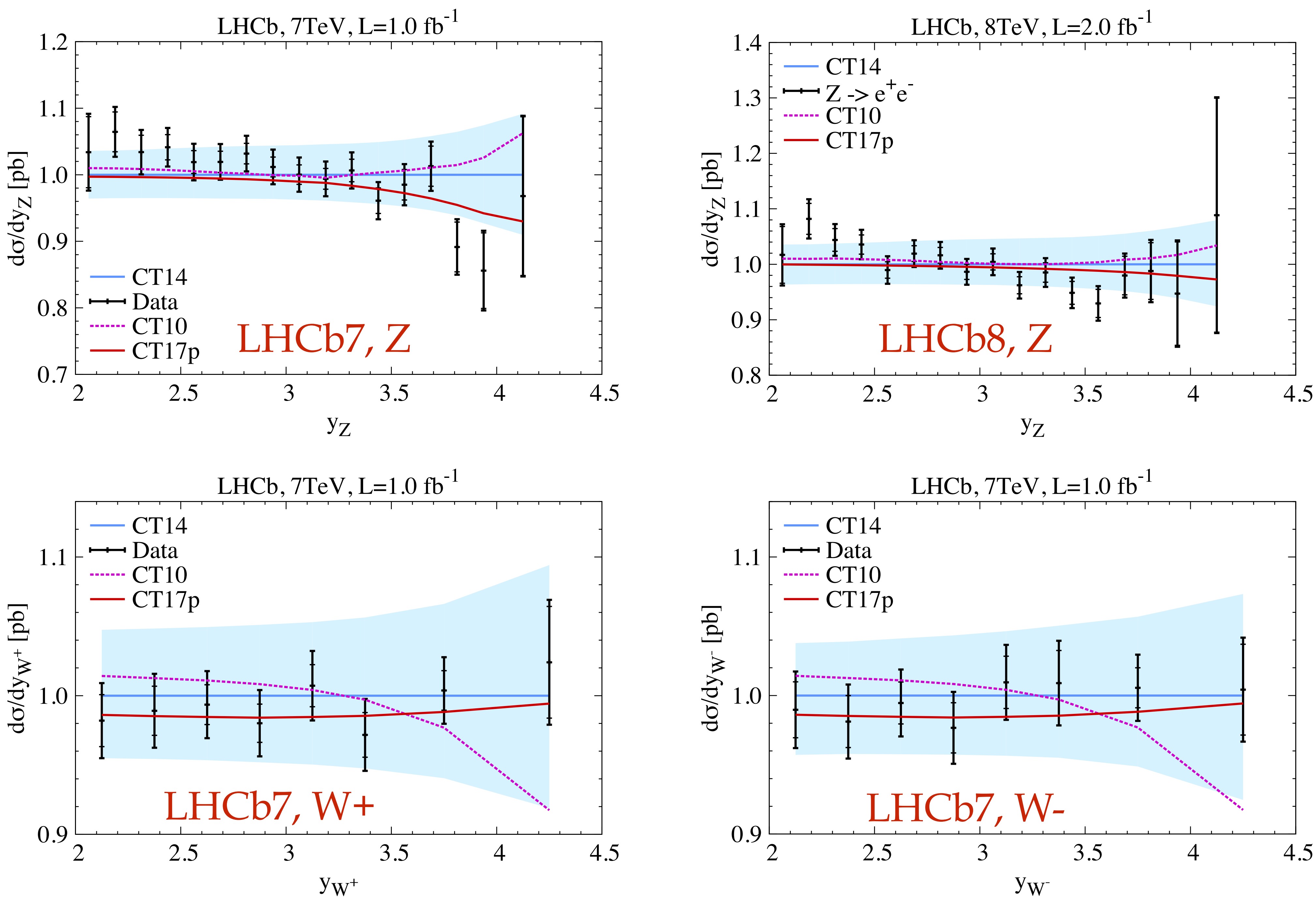
χ^2 change in two extreme scan

$\Delta\chi^2/N_{pt}$	LHCb7(extr.)	ATL. Jet(extr.)
LHCb 7	-15/33 ↓	+1/33
LHCb 8	-8/17 ↓	-3/17
ATL. 7 Z pT	-3/8	+16/8 ↑
ATL. 7 Jet	+4/140	-20/140 ↓
CMS 7 Jet	+6/158	+13/158 ↑

CT17p — LHCb 7 and 8 TeV W/Z data

- CT14 already show good agreement with the data; consistency of 7 and 8 TeV; refitting further bring CT17p close to central of the data

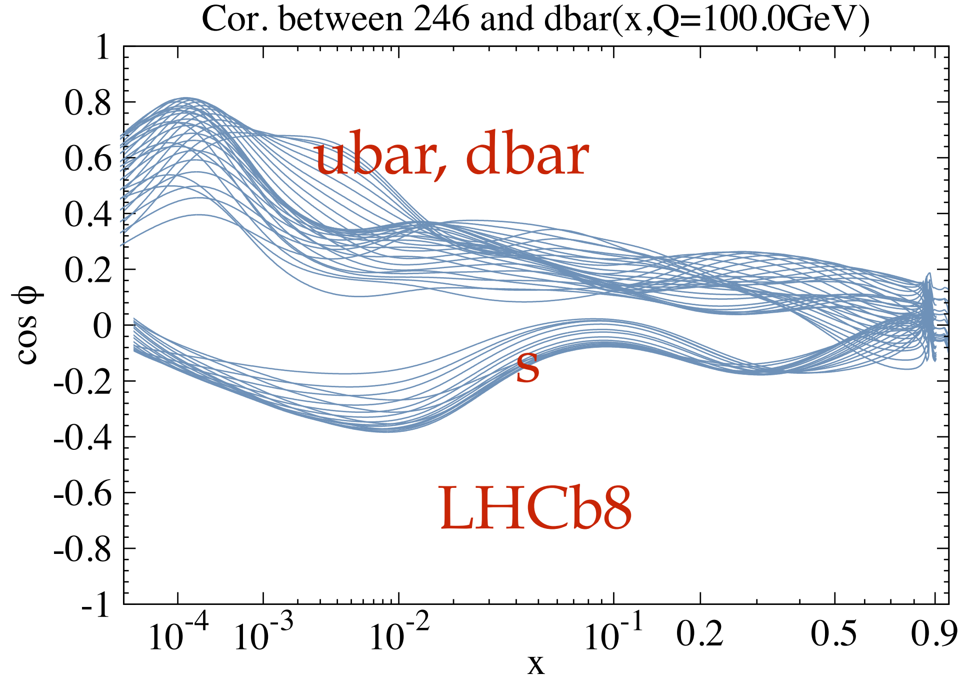
predictions vs. data, CT14 (blue), CT10(dotted), CT17p(red solid)



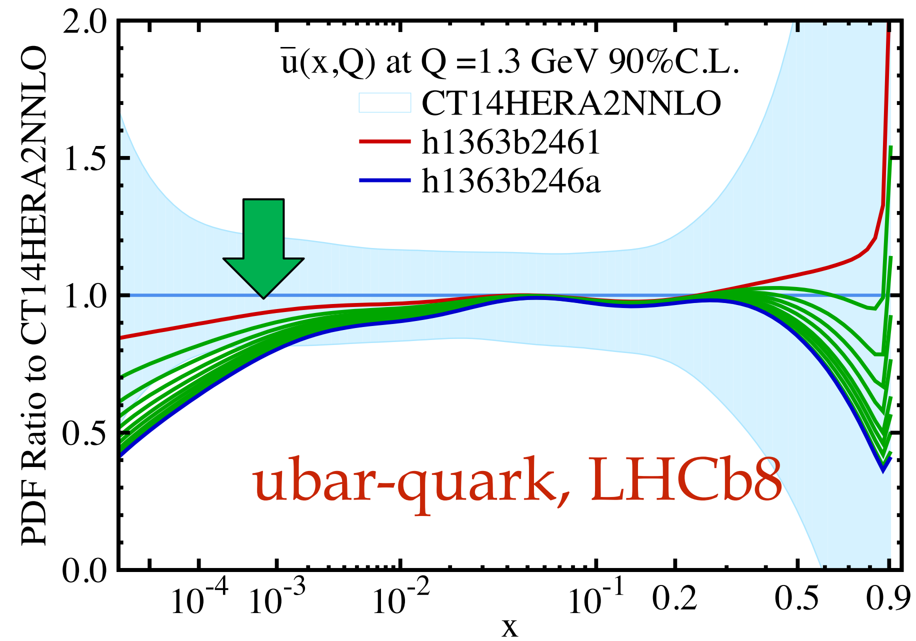
CT17p — LHCb 7 and 8 TeV W/Z data

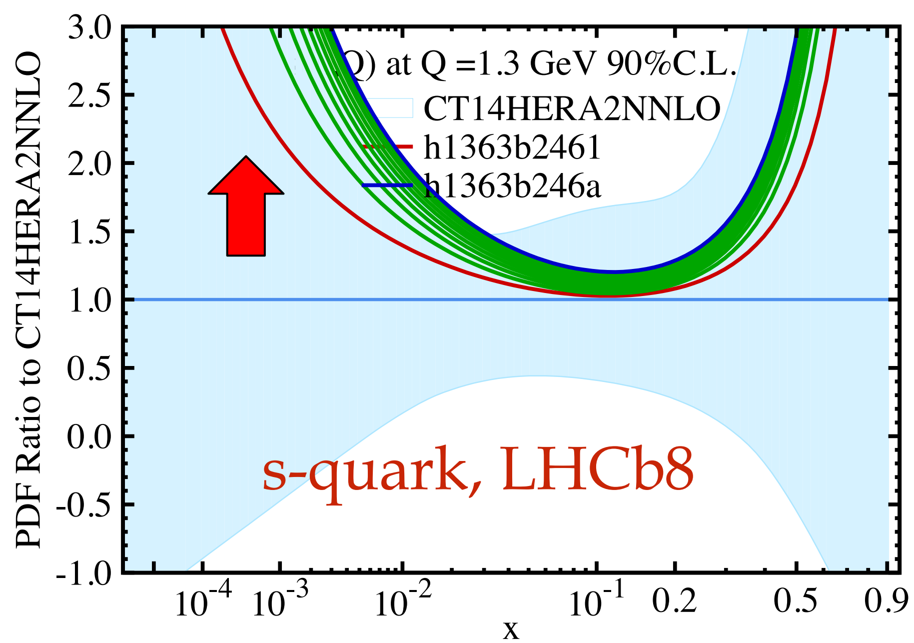
- ✦ LHCb data prefer smaller ubar and dbar both for 7 and 8 TeV, and larger strangeness; negligible impact on gluon PDF

PDF correlation



CT17p best-fit vs. CT14 HERA2



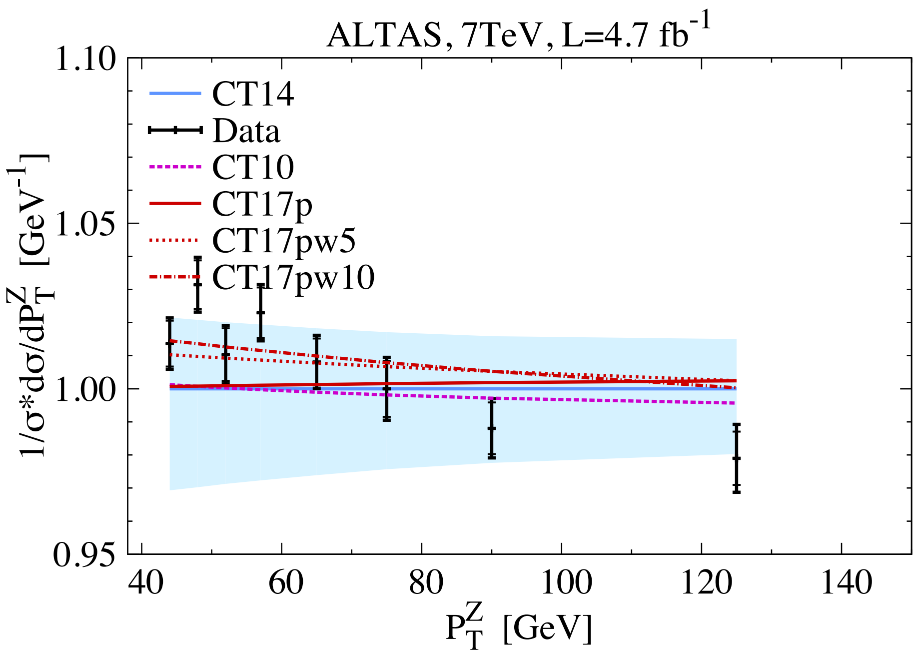


- ☆ red curve represents CT17p fit with weight=1 for all data set, dark green/blue lines for fits with increasing weight (up to 10) for the specified set
- ☆ large spread indicating strong effects from that data in direction from red to blue

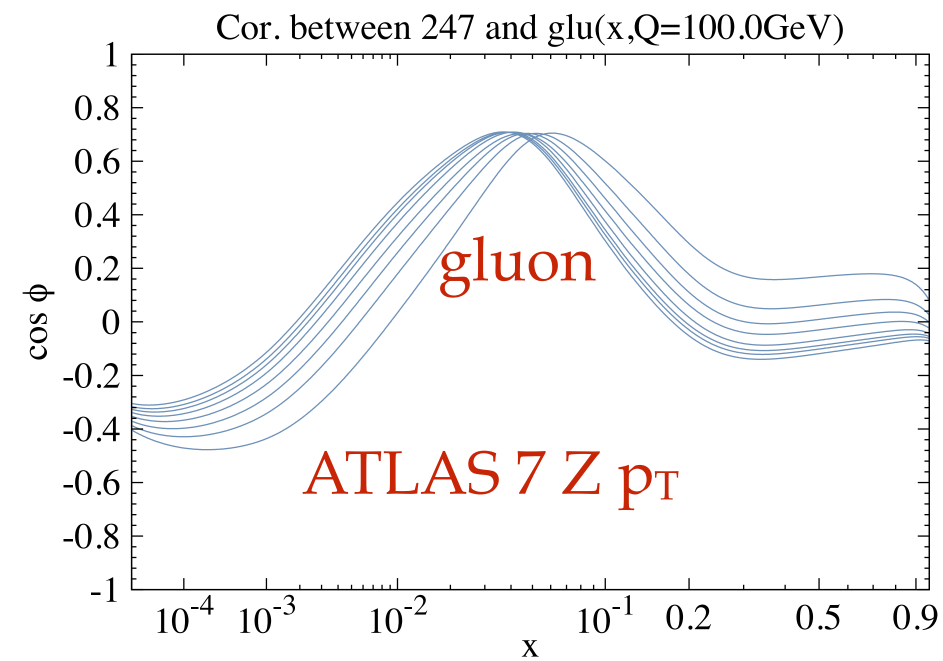
CT17p — ATLAS 7 TeV Z p_T

- Fitting 8 data points in range [40, 150] GeV, poor fit if w/o K-factors; prefer harder gluon ~0.02, softer gluon x>0.1; impact small on quarks

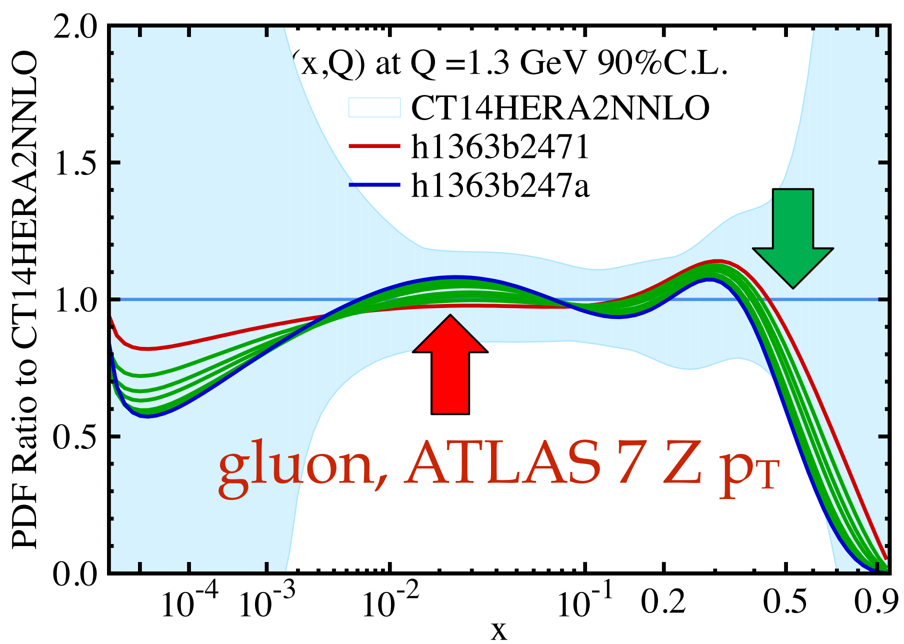
predictions vs. data

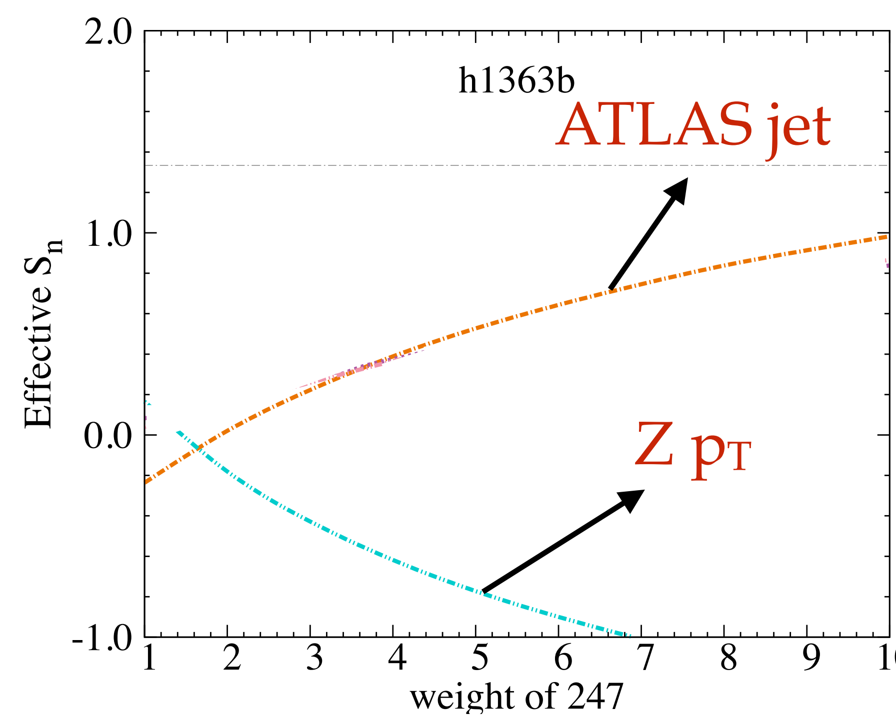


PDF correlation



CT17p best-fit vs. CT14 HERA2

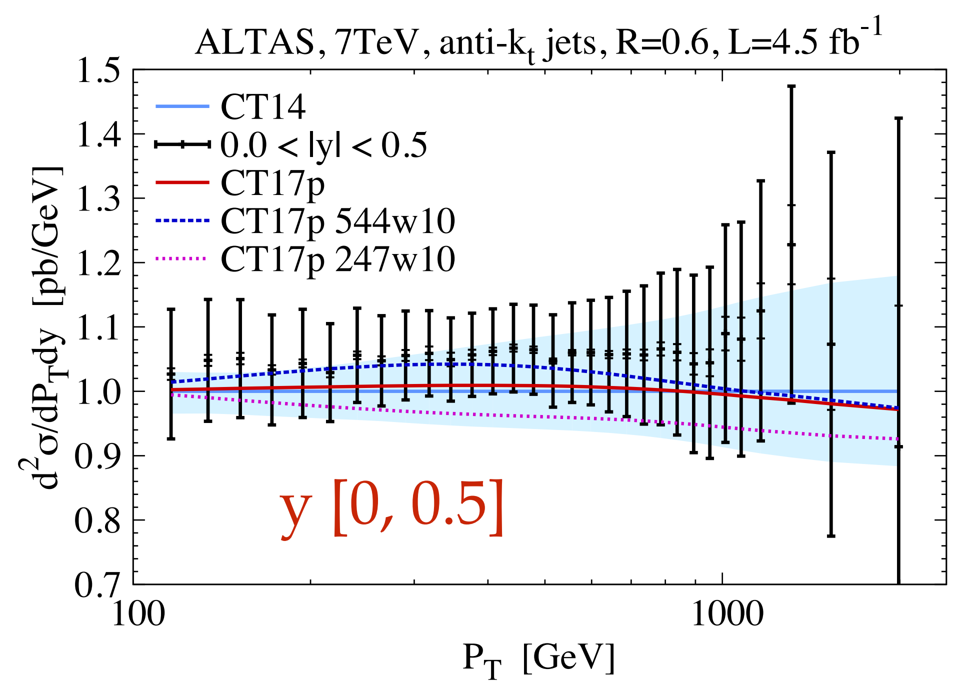


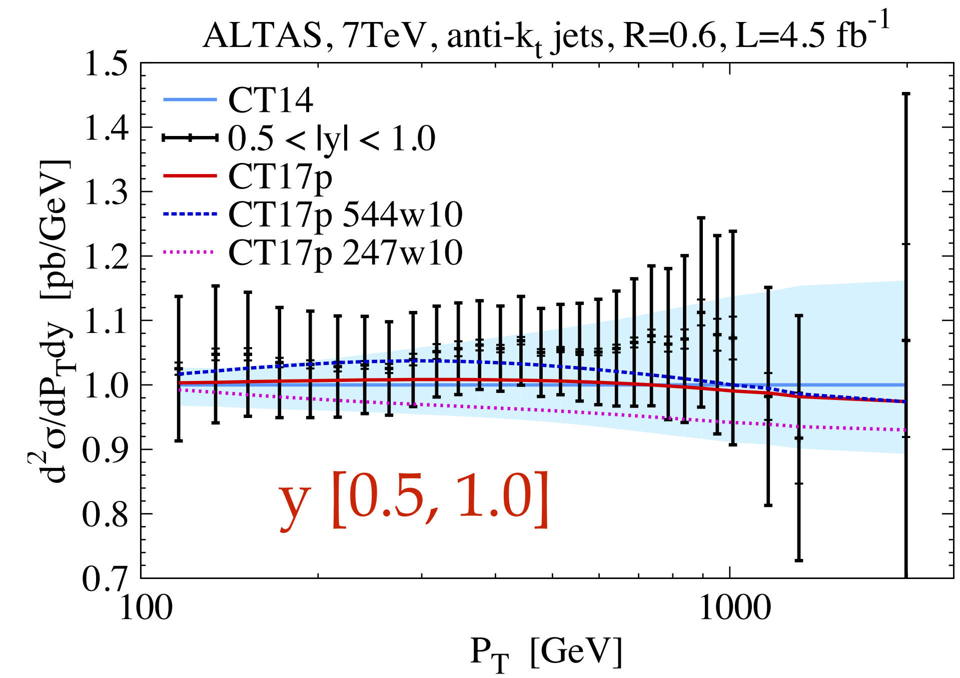


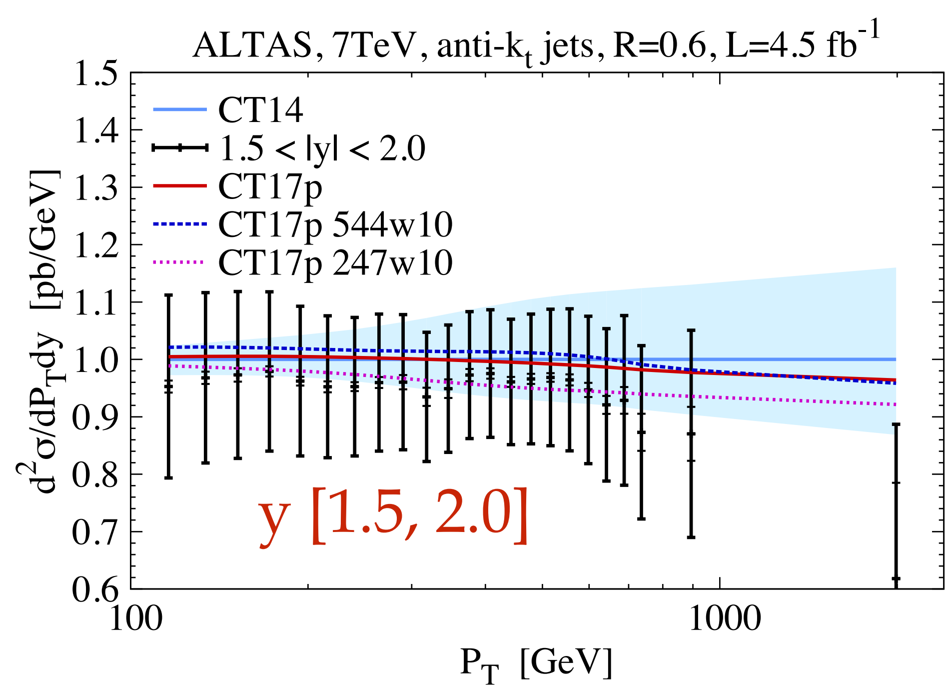
CT17p — ATLAS 7 TeV inc. jet

- Hard to get a good fit with all rapidity intervals; data prefer harder gluon x>0.1, softer gluon ~0.02, smaller d-quark x>0.5

predictions vs. data, CT17p(red), CT17p+w10(blue dashed)





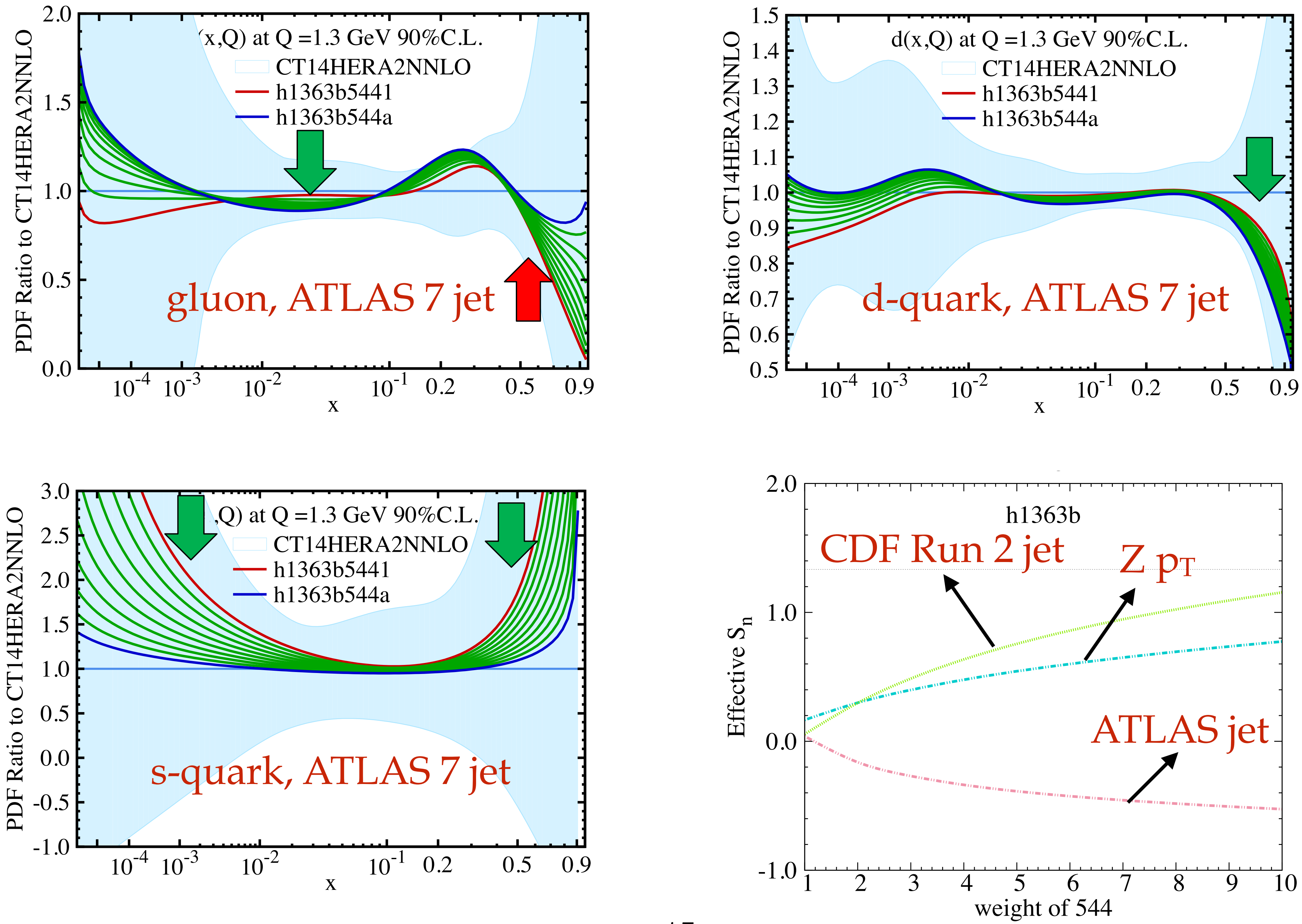


- different trends of theory vs. unshifted data in low and high rapidity bins; refitting failed to adjust theory in the same manner
- small statistical and uncorrelated sys. errors; most likely large chi2 is due to fluctuation of data itself

CT17p — ATLAS 7 TeV inc. jet

- Hard to get a good fit with all rapidity intervals; data prefer harder gluon x>0.1, softer gluon ~0.02, smaller d-quark x>0.5

CT17p best-fit vs. CT14 HERA2



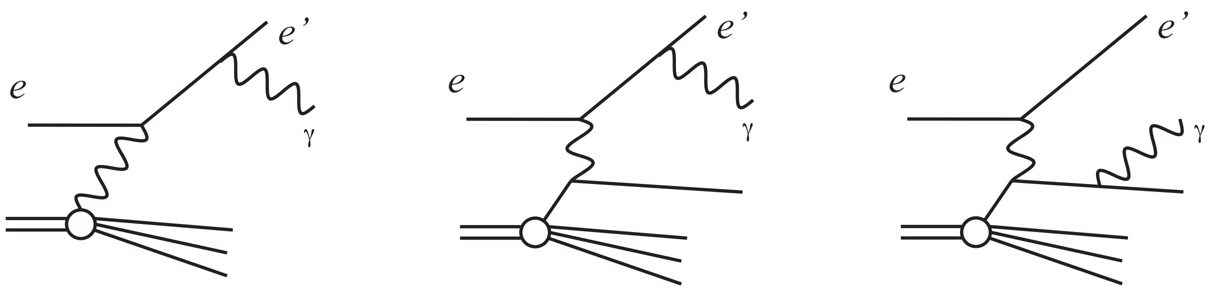
CT14 QEDinc PDFs

- CT14 set including photon PDF (NLO QCD+LO QED) based on radiative ansatz and with constraints from photon production in DIS

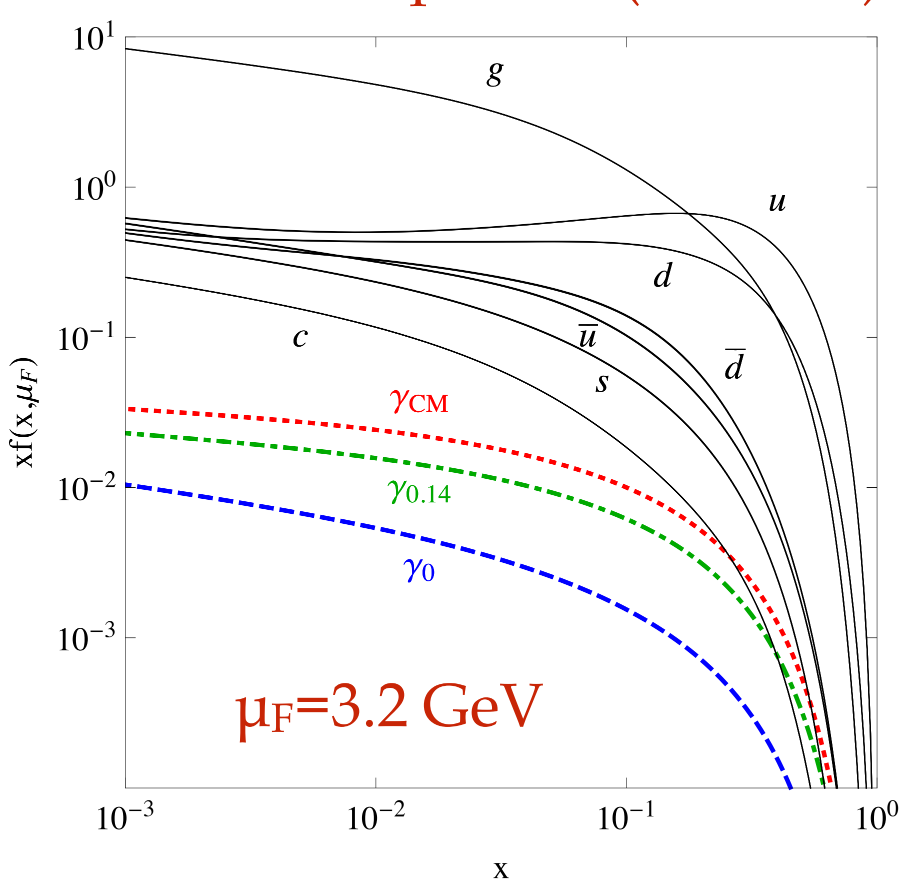
  - elastic part: equivalent photon approach, momentum frac. ~0.15%

  - inelastic part: radiative ansatz with one free parameter (momentum frac.), similar to MRST QED

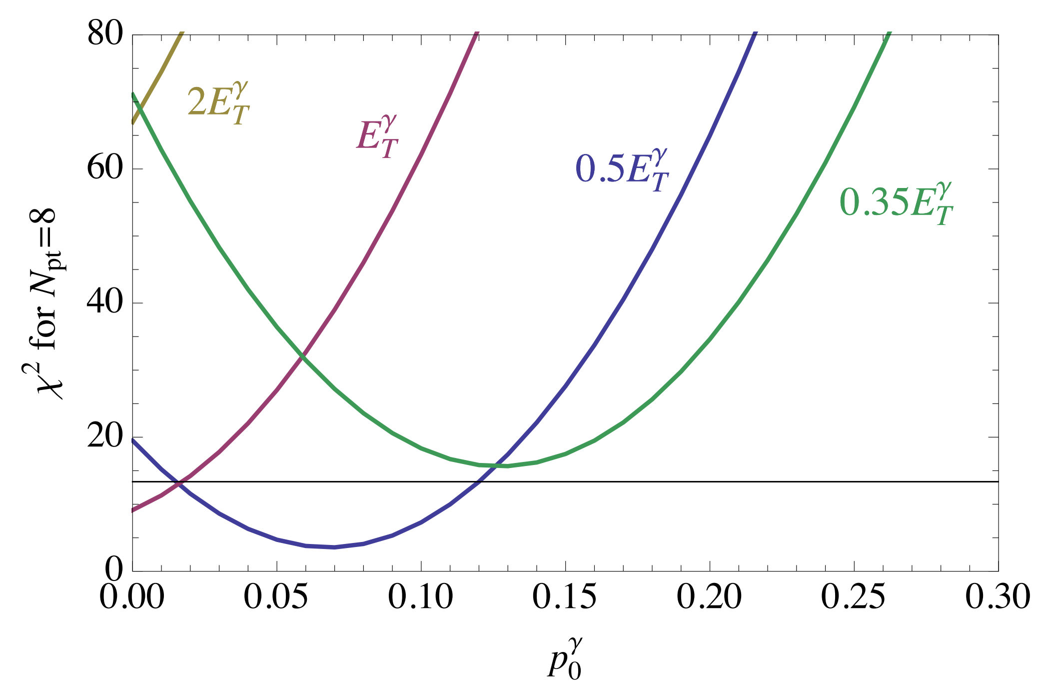
momentum frac. of inelastic part constrained from ZEUS isolated photon data



PDFs with photon (inelastic)



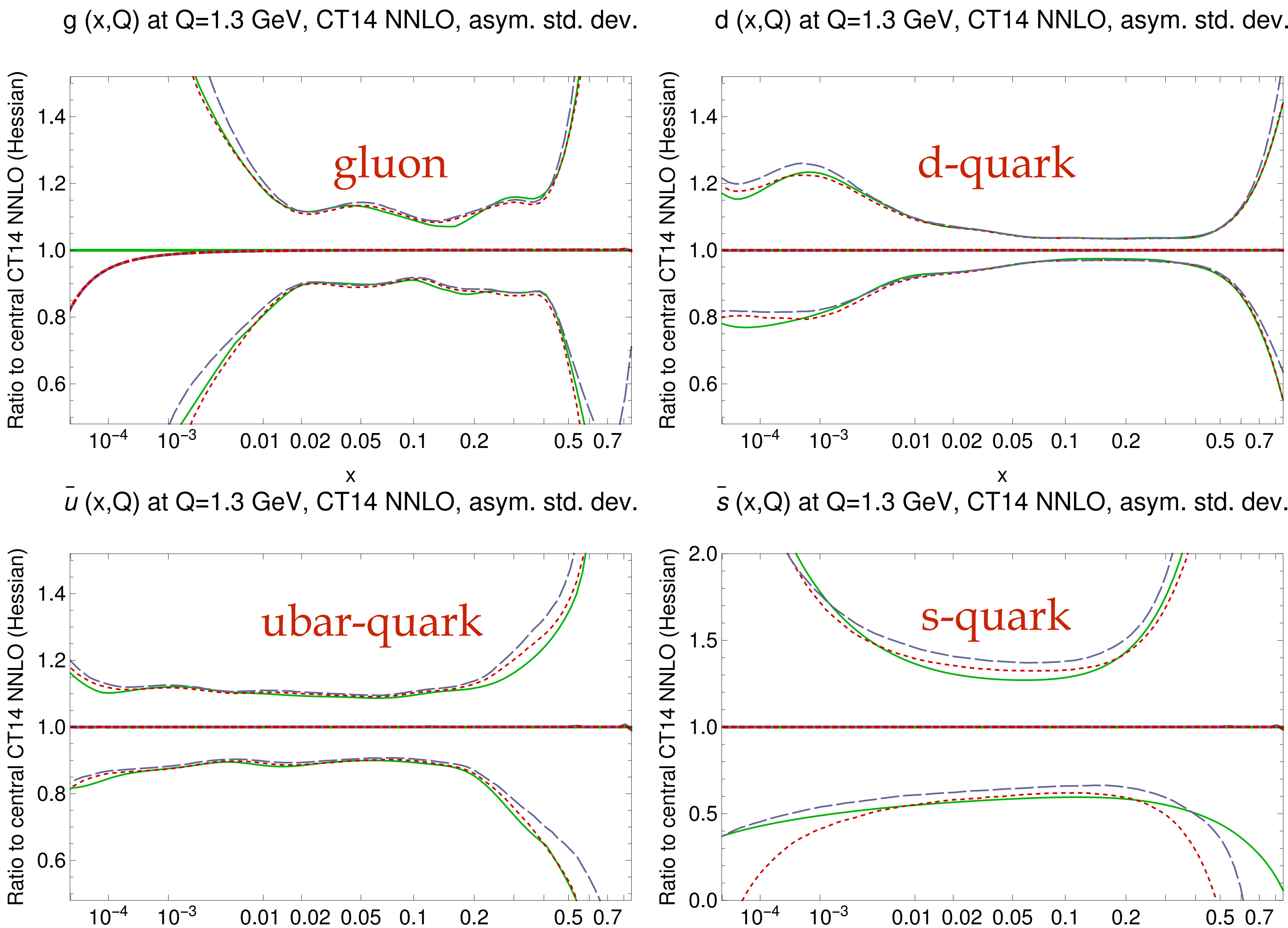
68% CL limit on photon carried mom. frac. of proton, 0.11% at Q=1.3 GeV



CT14 MC replicas

- Two ensembles of CT14 MC replicas, Linear sampling(MC1), Log sampling(MC2), both with 1000 replicas

Hessian, MC1, MC2: solid, short-dashed, long-dashed

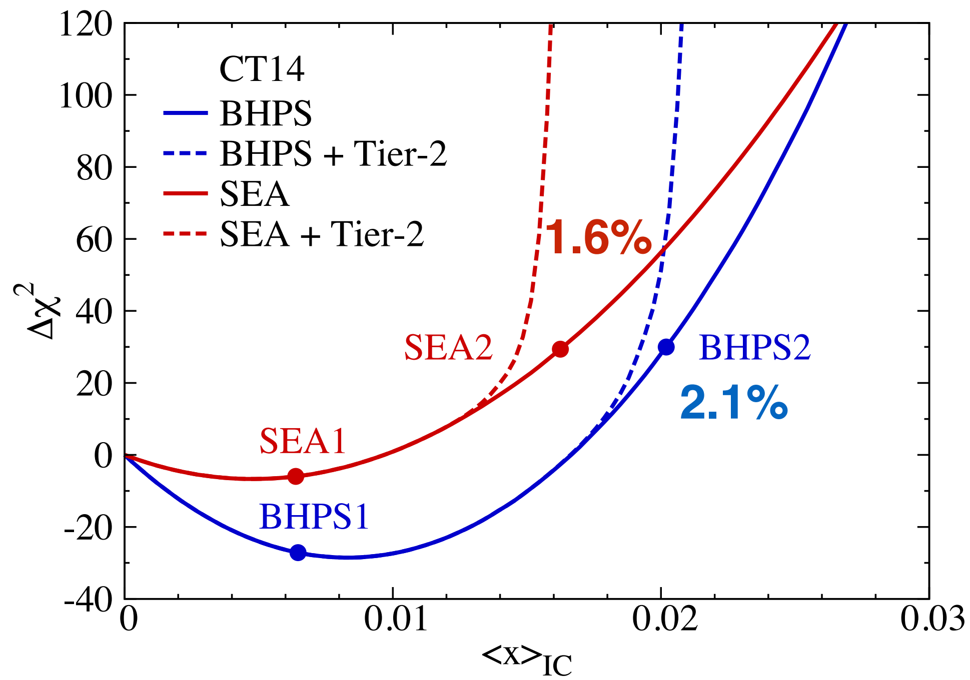


- reproducing statistical measures given by Hessian sets with small numbers of replicas; maintain positivity conditions as imposed in CT14

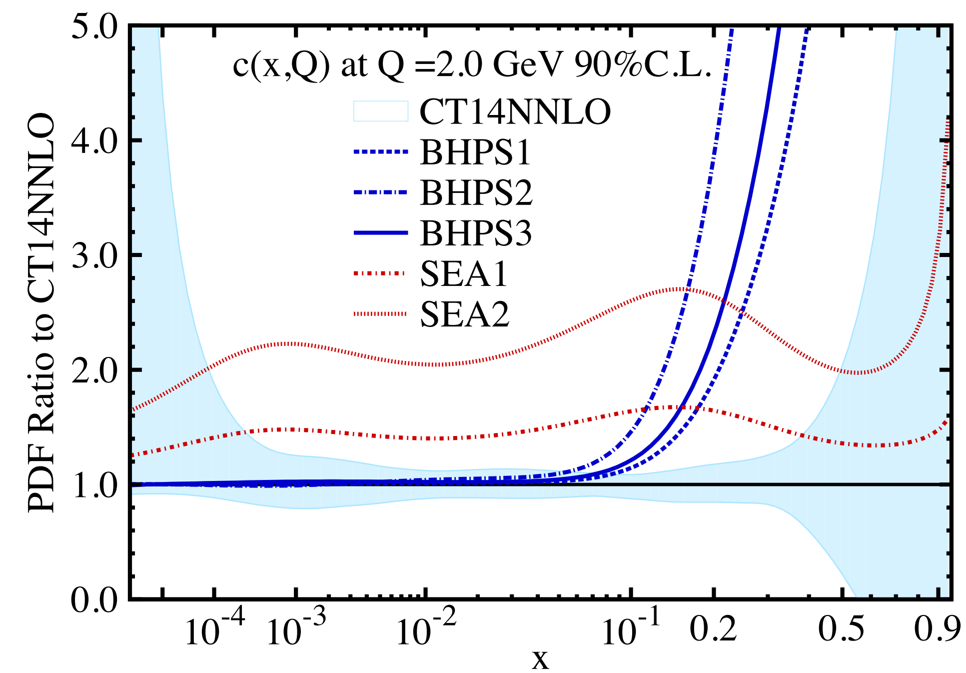
CT14 fitted charm

- Update on studies of the intrinsic charm models, BHPS and SEA-like, based on CT14 setups

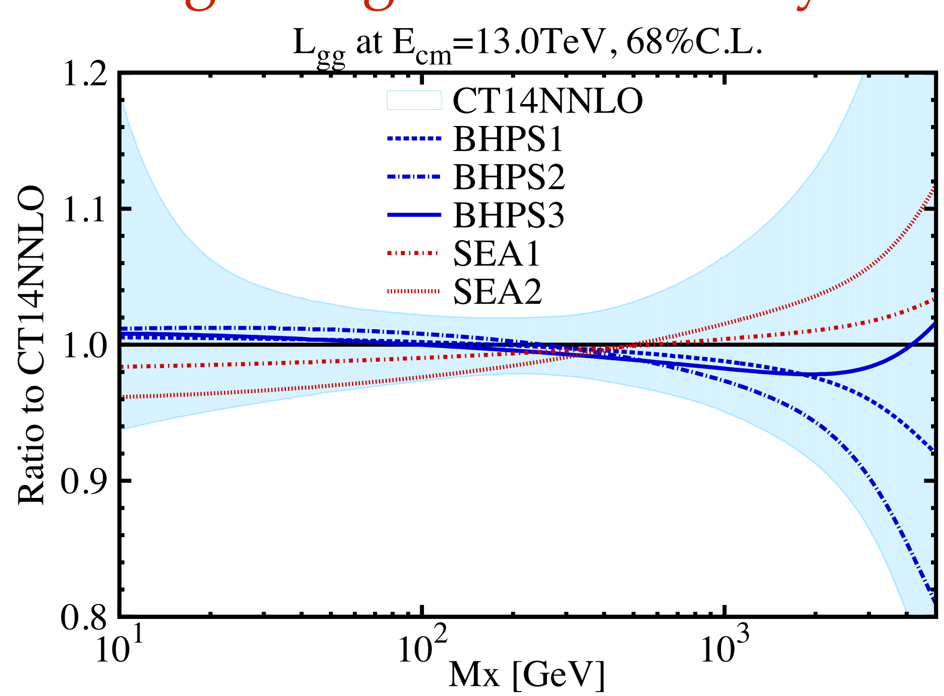
χ^2 change vs. mom. fraction



charm PDF



gluon-gluon luminosity



- for each model the 90% C.L. limit on the momentum fraction carried by charm are determined
- allow much larger charm PDF than in perturbative case; changes on other flavors small in general

Summary

- We are working towards a major update of the CTEQ-TEA PDFs with the new combined HERA data and new LHC Run 1 and Run 2 data, especially the Z boson pT data and top-quark pair distributions

- Percent-level precision of the LHC data requires careful examination of both the theoretical predictions used, e.g., MC uncertainties in NNLO predictions, remaining theoretical errors, and the agreement/tension between different data, e.g, if tension exists then may lose the constraining power and may even get lager uncertainties on the PDFs

- We use FastNLO or local generated APPLgrid tables for all the new LHC data, K-factors either can be calculated locally or from public

- After we better understand new constraints from the experiments, we plan to release the CT17 PDFs later this year

Thanks for your attention!

Backup

- Top-quark pair differential distributions

- Several distributions measured by ATLAS and CMS that have information on the high-x gluon

  m_{tT}, y_{tT}, p_t, y_t, p_{tT}; double, triple differential dist.

- Only one distribution should be used, unless a correlation model can be developed

  which one?

- We are currently doing exploratory studies at NLO using MCFM and DiffTop and at aNNLO using DiffTop

  starting with rapidity and pT of the top quark

- ATLAS and CMS have different trends; in this case, ATLAS favors harder gluon (than NNPDF3.0) at high x, CMS weaker gluon

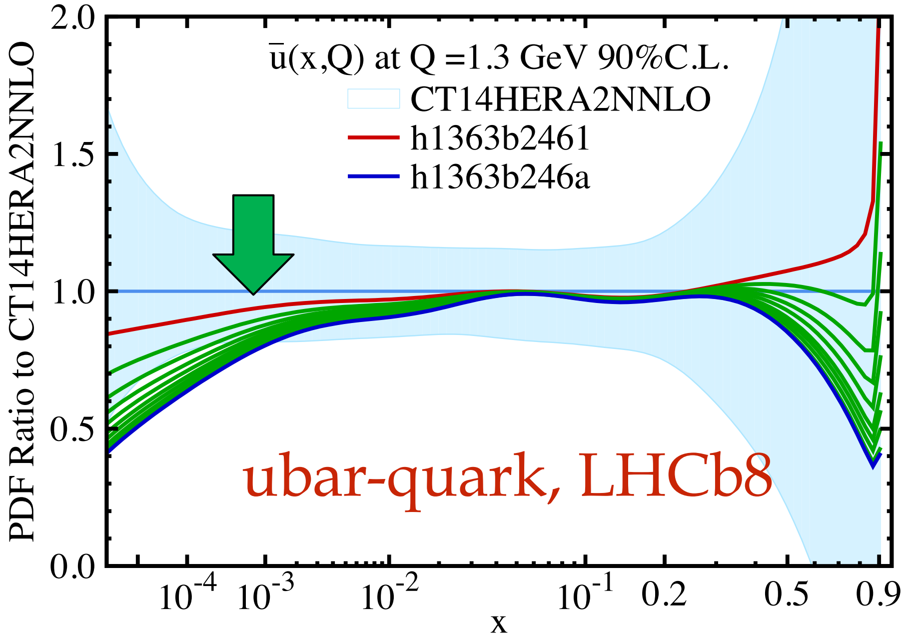
- A In general, the ATLAS and CMS top results are in tension internally, and with each other (the latter more so in the case of normalized distributions where the experimental errors are smaller)

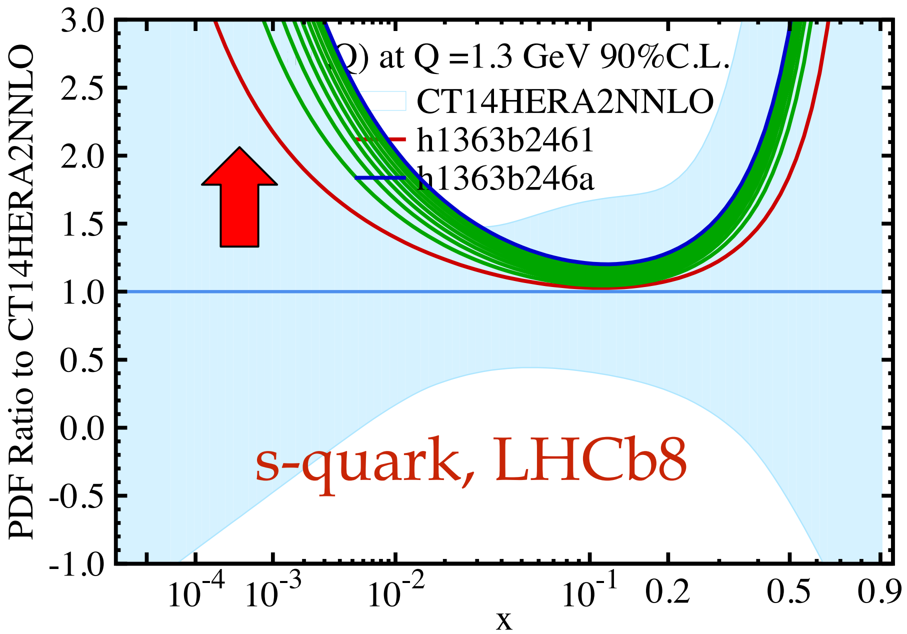
- If tension, then gluon PDF uncertainty may not decrease and may even increase

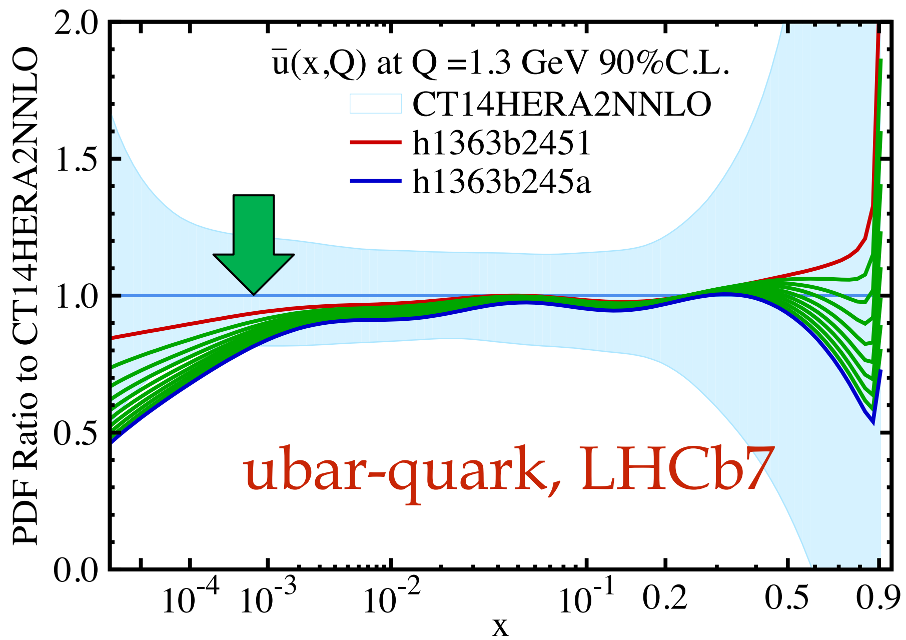
Backup

- LHCb data prefer smaller ubar and dbar both for 7 and 8 TeV, and larger strangeness; negligible impact on gluon PDF

CT17p best-fit vs. CT14 HERA2







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