Strangeness in the CTEQ-TEA Global Analysis of QCD

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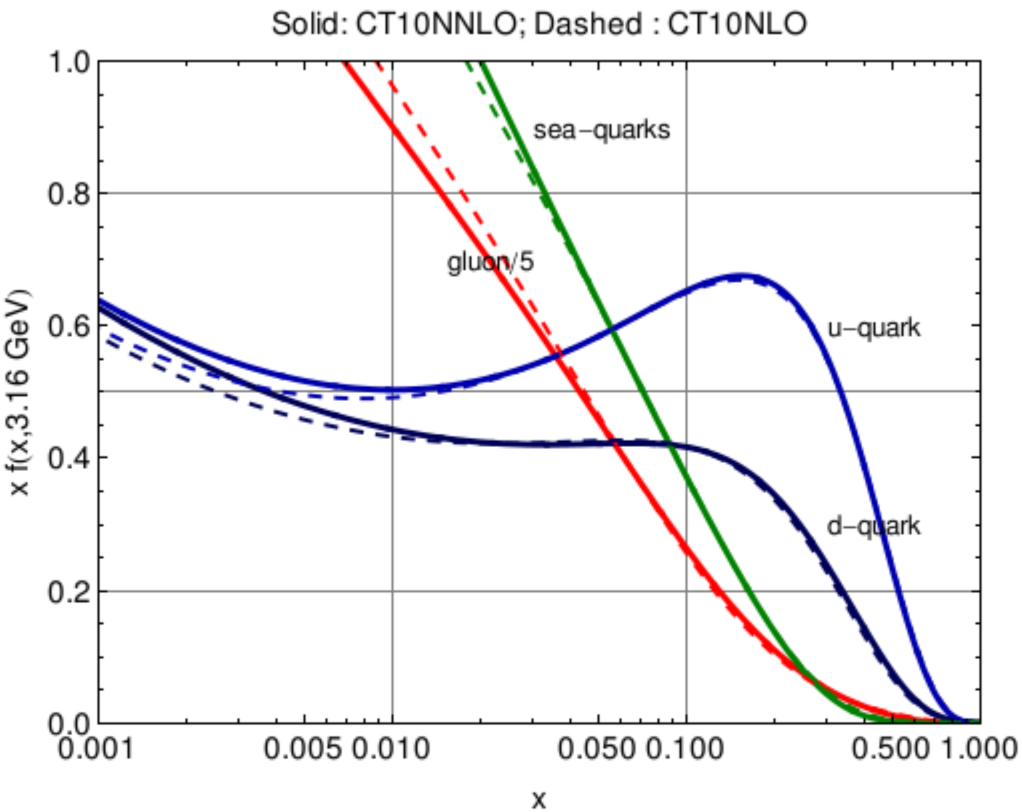
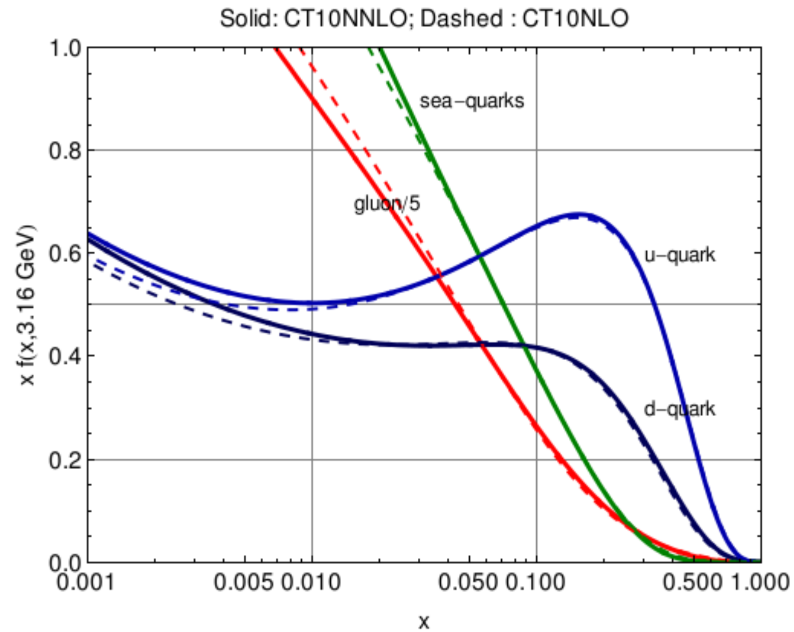
All PDFs look similar.

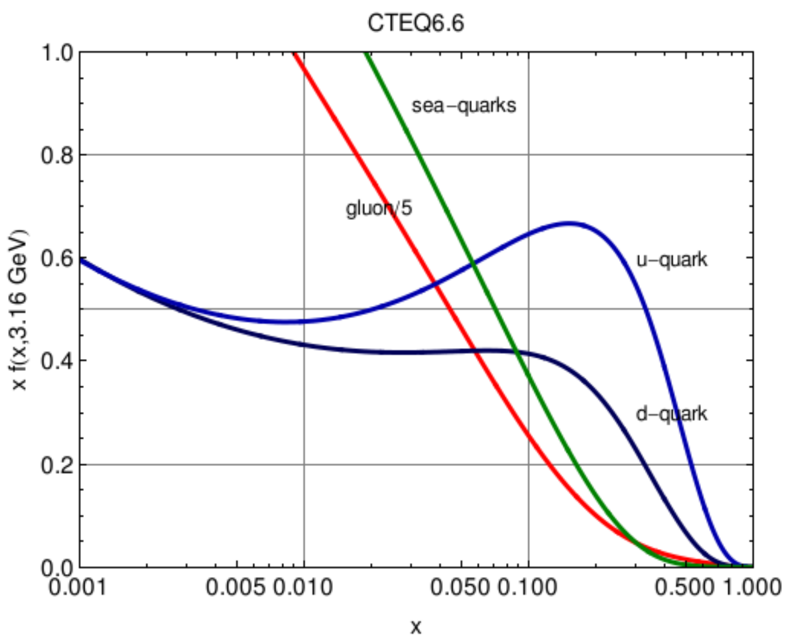
CT10nnlo
CT10nlo
Q^2=10GeV^2

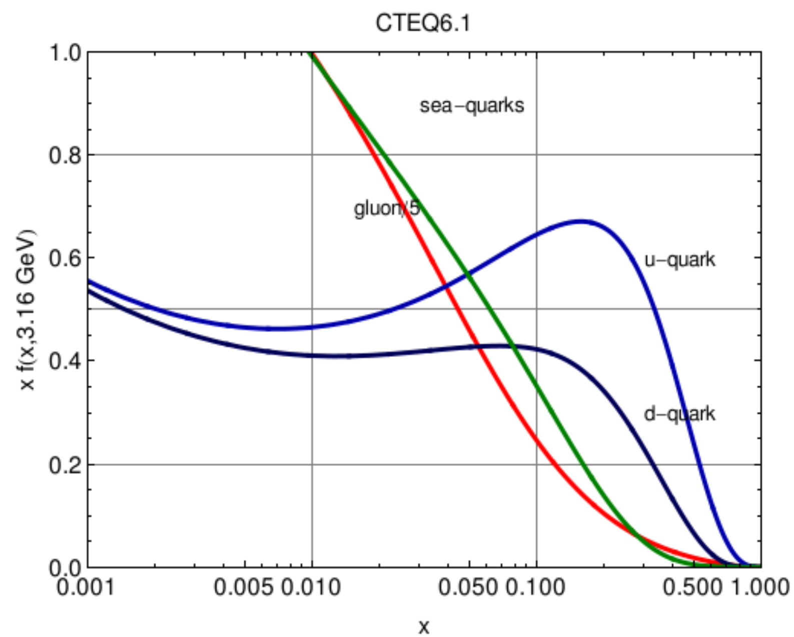


All PDFs look similar.

PDF	publ. date	# pars.
CT10NNLO	2012	24
CTEQ6.6	2008	22
CTEQ6.1	2003	20

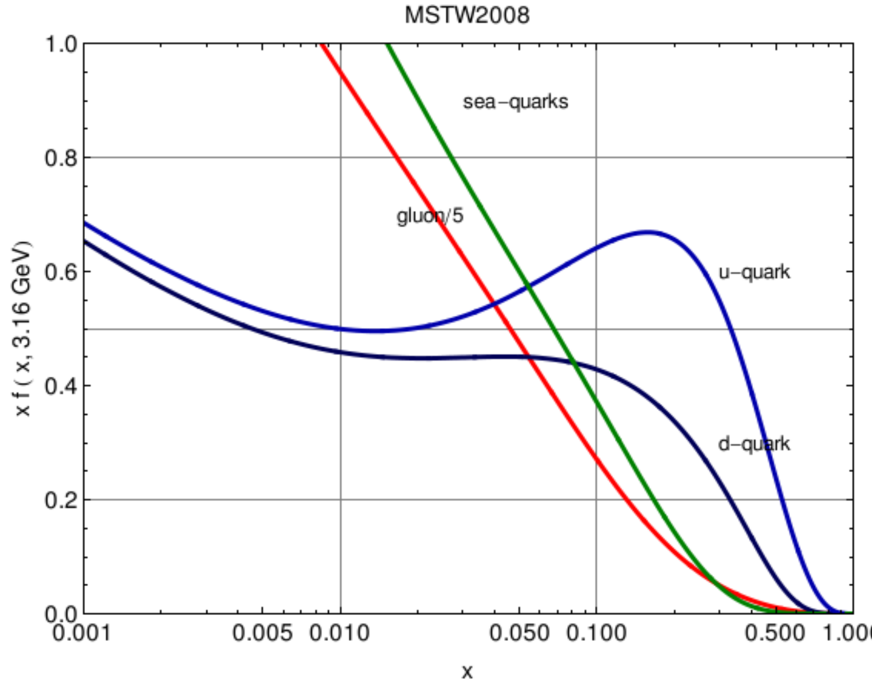


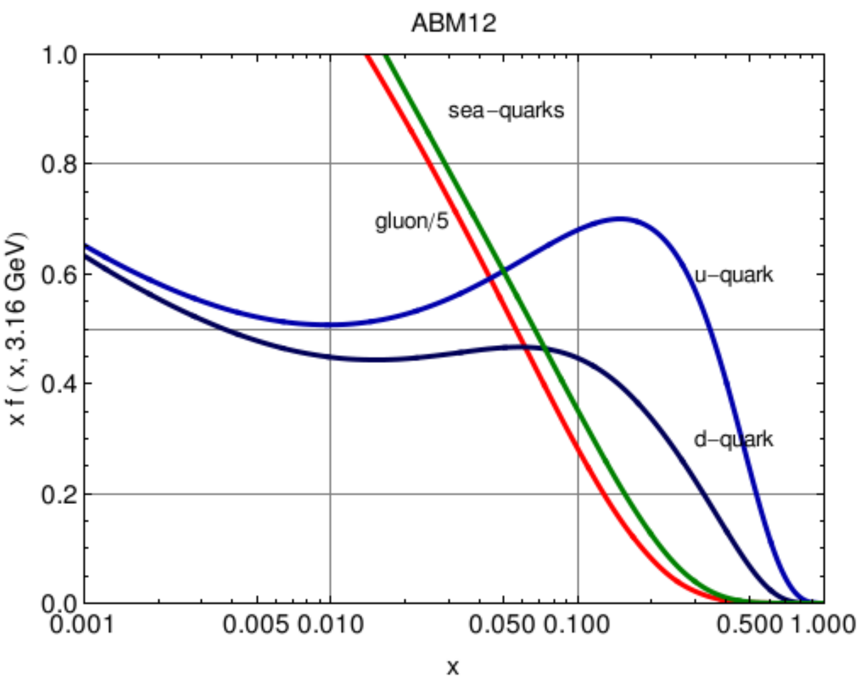


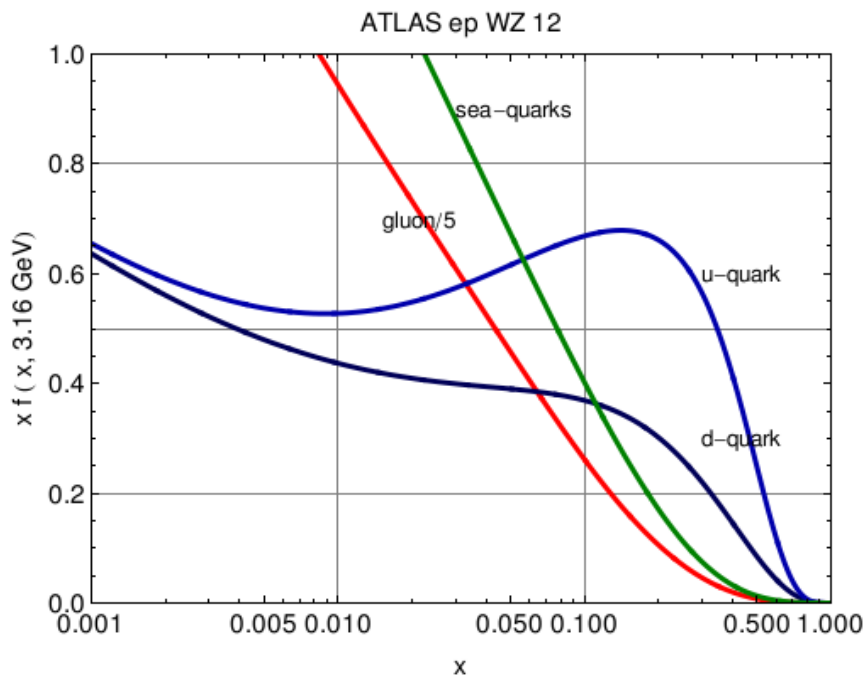


All PDFs look similar.

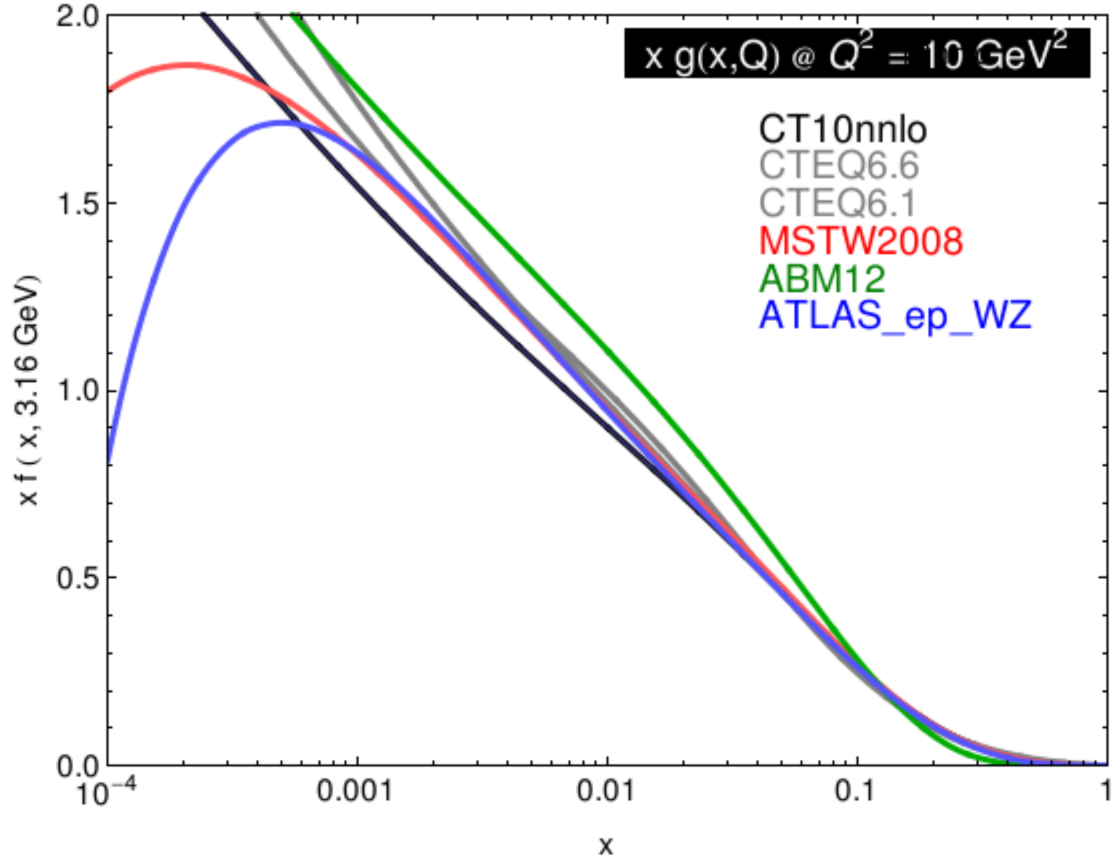
PDF	publ. date	# pars.
MSTW2008	2008	20
ABM12	2012	18
ATLASepWZ	2012	18



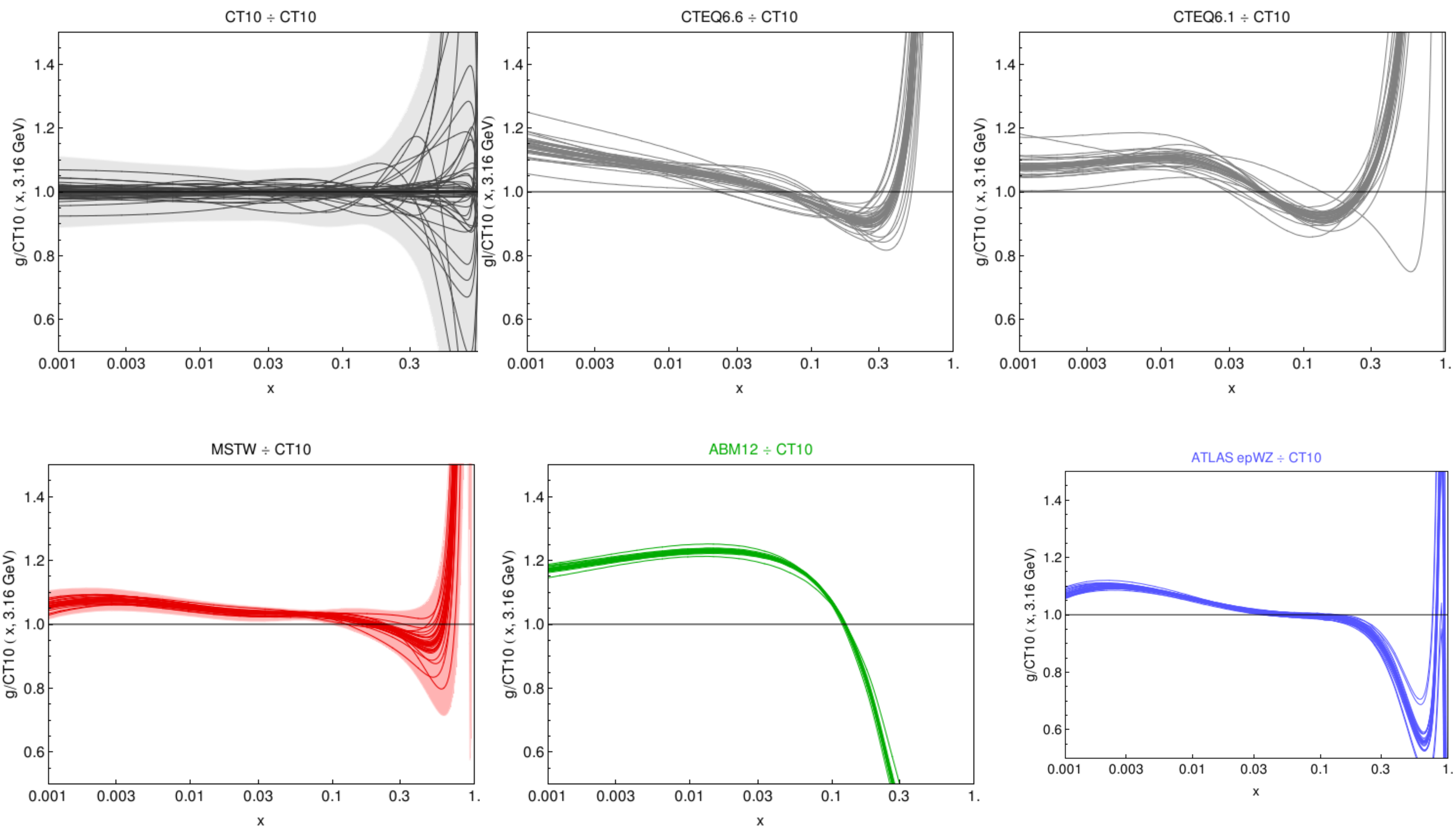




However, if we look closely, we may see differences in PDFs.
For example, consider ***gluon PDFs*** at Q^2 = 10 GeV^2 ...



Or, compare ***different gluon PDFs***,
as *ratios to the central CT10nnlo gluon PDF* ...



- All PDfs look similar.
- However, if we look closely we may see differences.
  - The “best fits” may differ;
  - The “errors” (uncertainties) may differ.
- Therefore, we should not rely on just one “preferred” set of PDFs.
- Just as we need more than one experiment, because different experiments will have different experimental “errors” (uncertainties), we need more than one theoretical analysis because different analyses will have different theoretical “errors” (uncertainties).

A **User Manual** for the CTEQ parton distribution functions

/1/ ***Parametrization***. In the CTEQ Global Analysis of QCD, we parametrize the PDFs with D (~24) independent parameters.

/2/ ***The central fit.*** We minimize χ^2 , summed over many experiments; the result is the "central fit".

/3/ ***Correlated systematic errors.*** We treat the systematic errors by introducing "nuisance parameters"; we minimize χ^2 w.r.t. the D PDF parameters and the Nsy nuisance parameters. (Nsy = the number of correlated systematic errors)

/4/ ***The error PDFs.*** We calculate a "Hessian matrix" ~ the matrix of second derivatives of χ^2 in the D dimensional parameter space; the eigenvectors of this matrix define D complete and orthogonal directions for displacements from the central fit. We construct 2D displacements from the center: + and - displacements along each eigenvector. We define these as our ***90% confidence level*** for each direction. Divide by 1.64 to get the 68% confidence lavel.

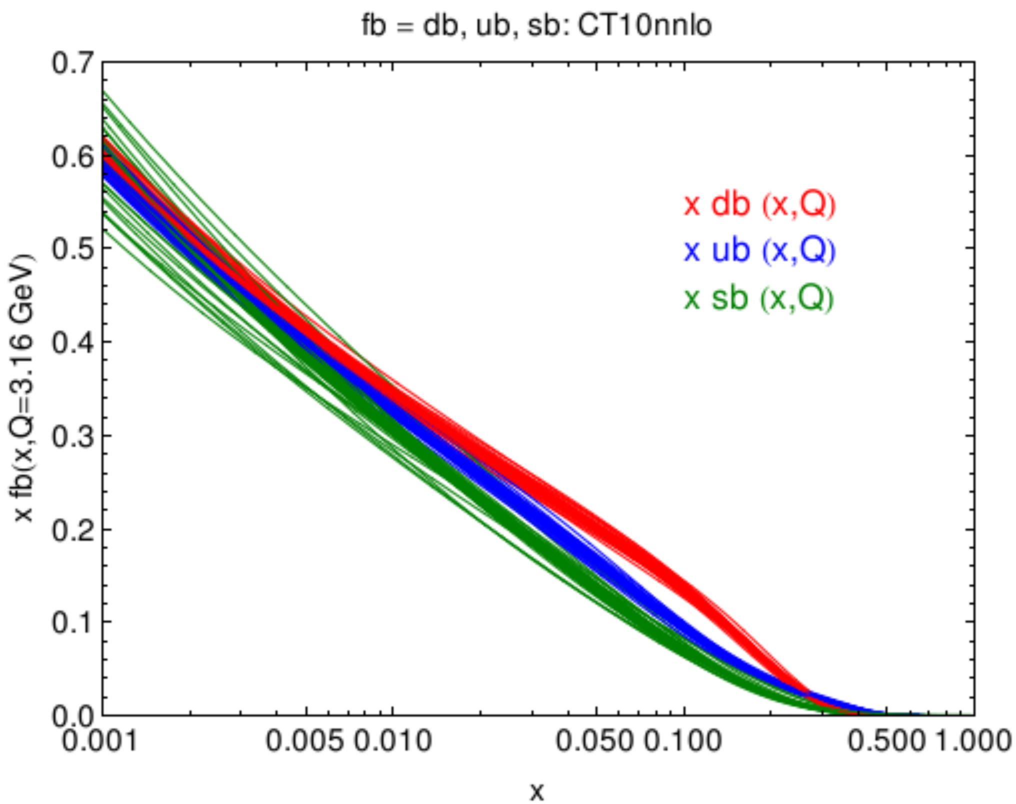
/5/ ***The LHAPDF format.***

/6/ ***The Master Formula.*** For an observable A that depends on the PDFs, our theoretical value of A is

$A_c + \delta A$; $(\delta A)^2 = \Sigma_n [(A_n^{(+)}-A_n^{(-)})/2]$^2 or similar

Strangeness in the Proton

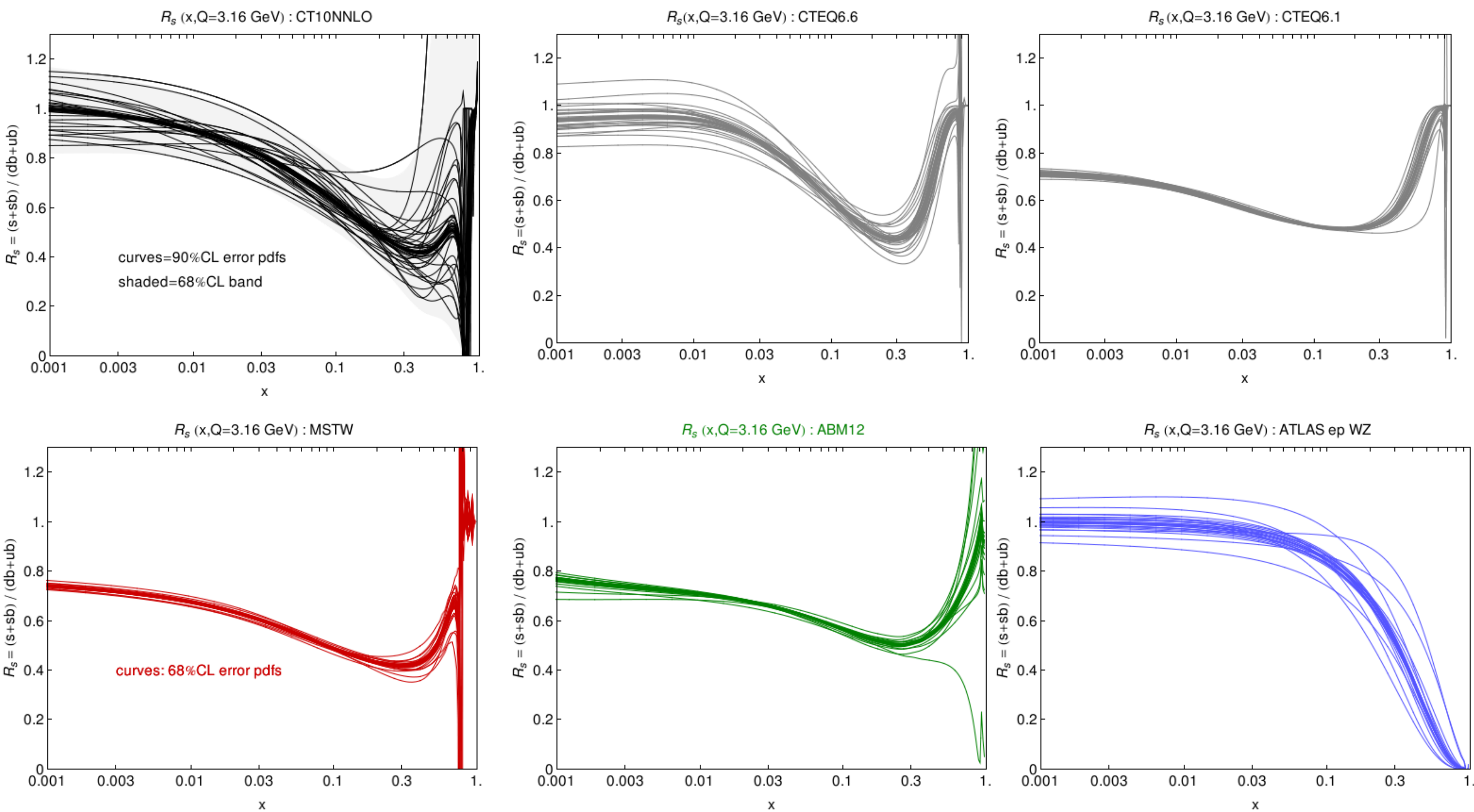
The figure shows CT10nnlo sea quark distributions.
(Q = 3.16 GeV)
The error PDFs indicate the size of the uncertainty.



Define the ***strangeness suppression function***
$R_s\ (x,Q)$ by

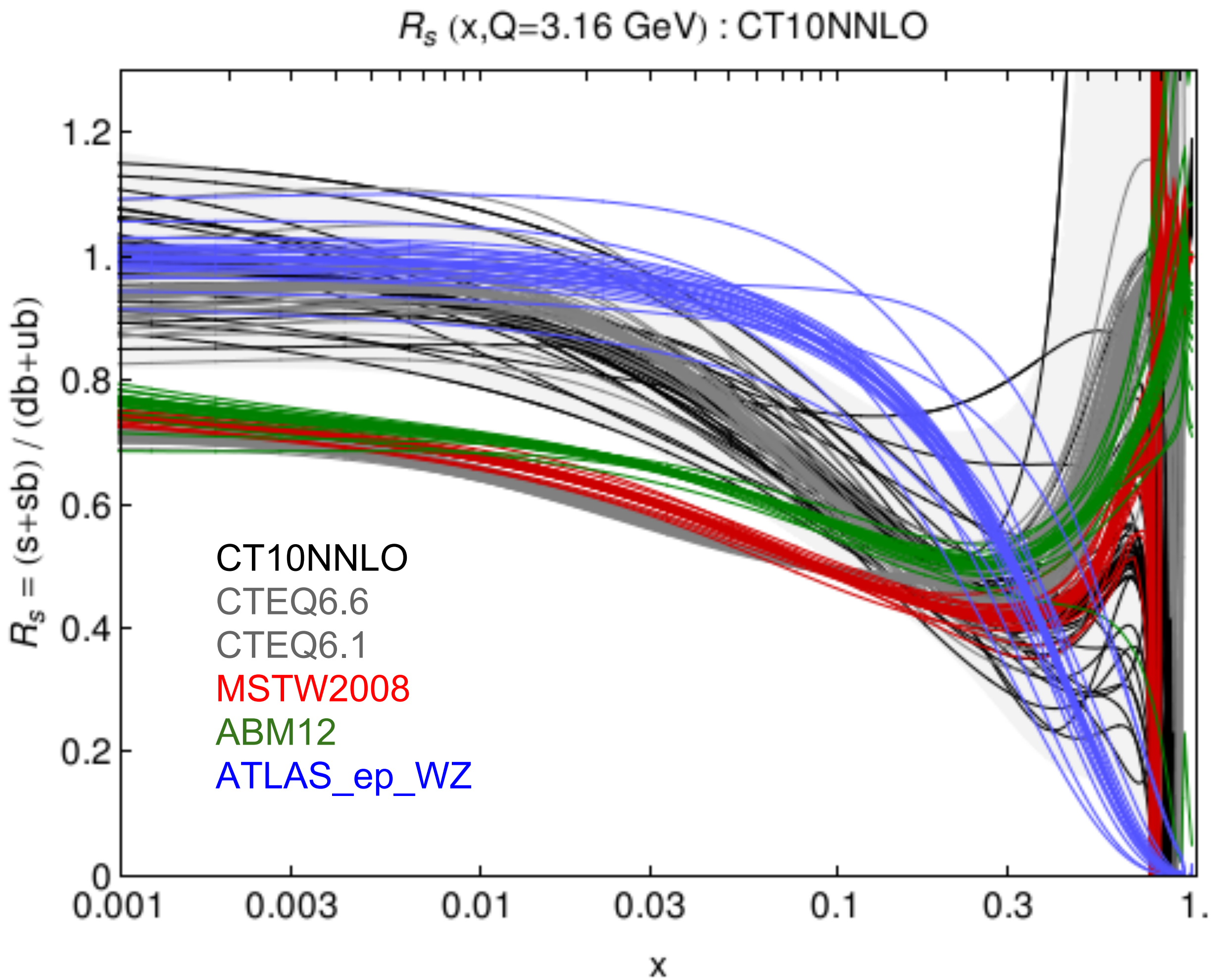
$$R_s\ (x,Q) = \frac{s(x,Q) + s_{\mathbf{b}}(x,Q)}{d_{\mathbf{b}}(x,Q)+u_{\mathbf{b}}(x,Q)}$$

Compare ***different strangeness suppression functions,***
$R_s(x,Q) = (s+s_b)/(d_b+u_b)\,(x,Q)$ at Q = 3.16 GeV ...



Daniel Stump ; QCD@LHC2014

If we look closely, we may see differences in PDFs.
For example the strangeness suppression functions …

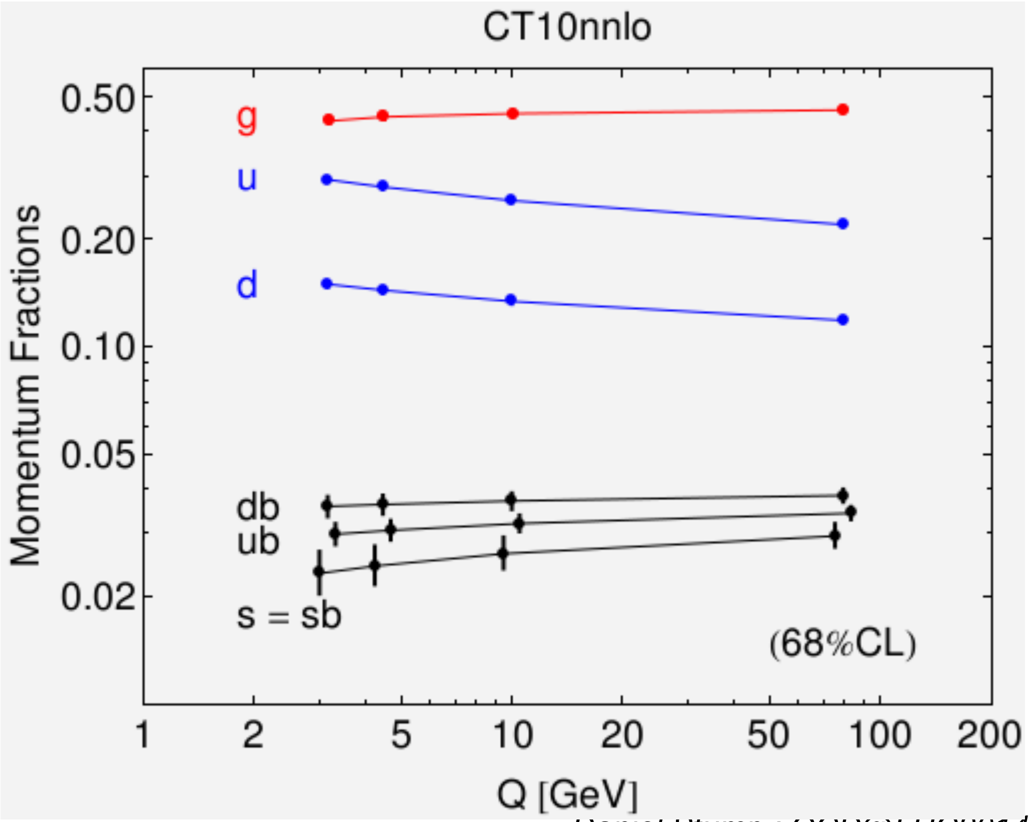


Both central values and uncertainties are different.

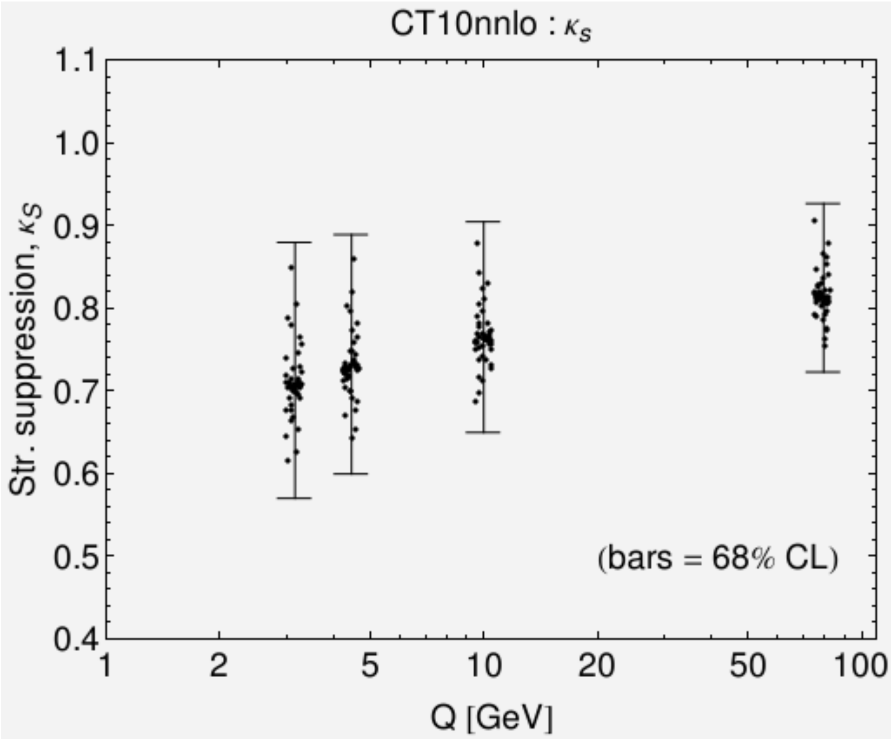
Define the ***strangeness suppression factor***
kappa$_s$ (Q) by

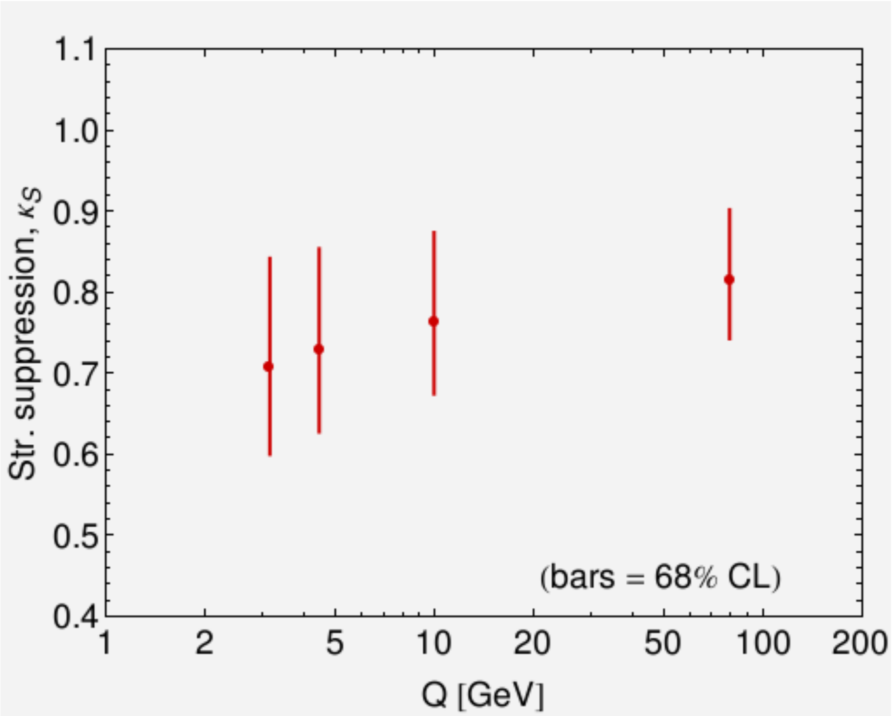
$$\kappa_s(Q) = \frac{\int_0^1 [\, s(x,Q)+s_b(x,Q)\,]\; x\,dx}{\int_0^1 [\, d_b(x,Q) + u_b(x,Q)\,]\; x\,dx}$$

integrated
momentum fractions

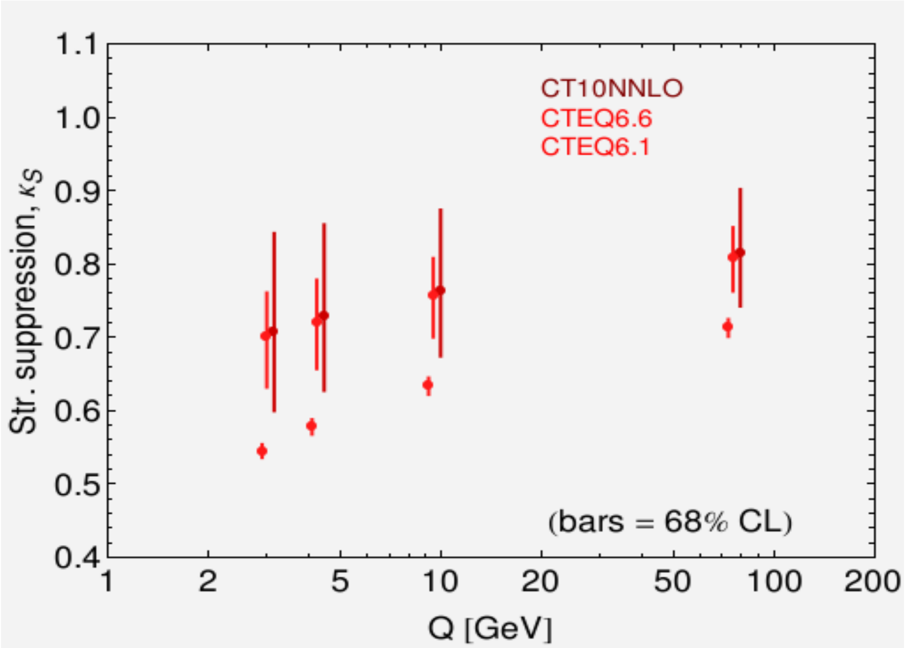


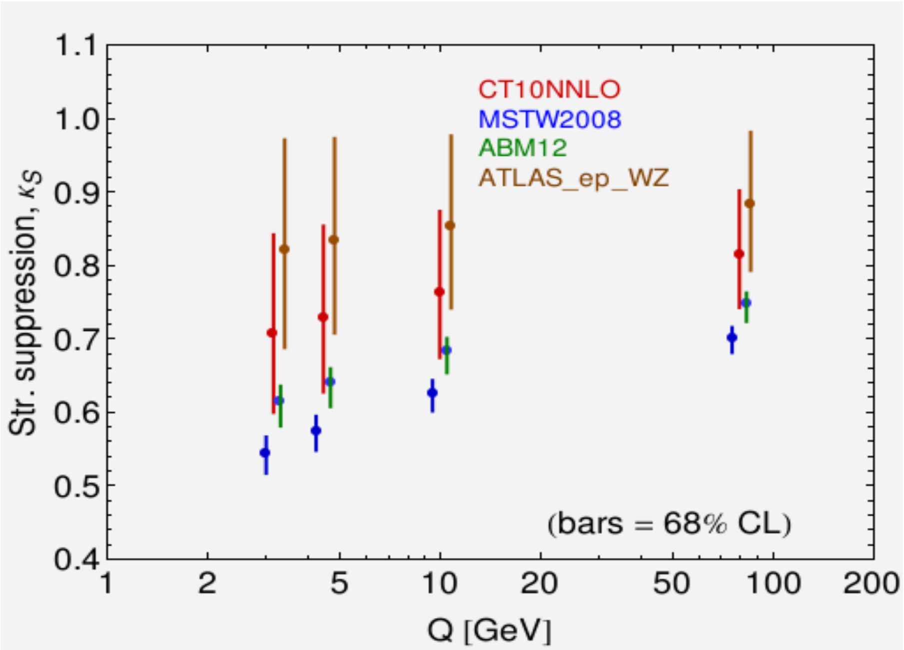
Calculations of κ_s using error PDFs





Comparison of κ_s for different PDFs

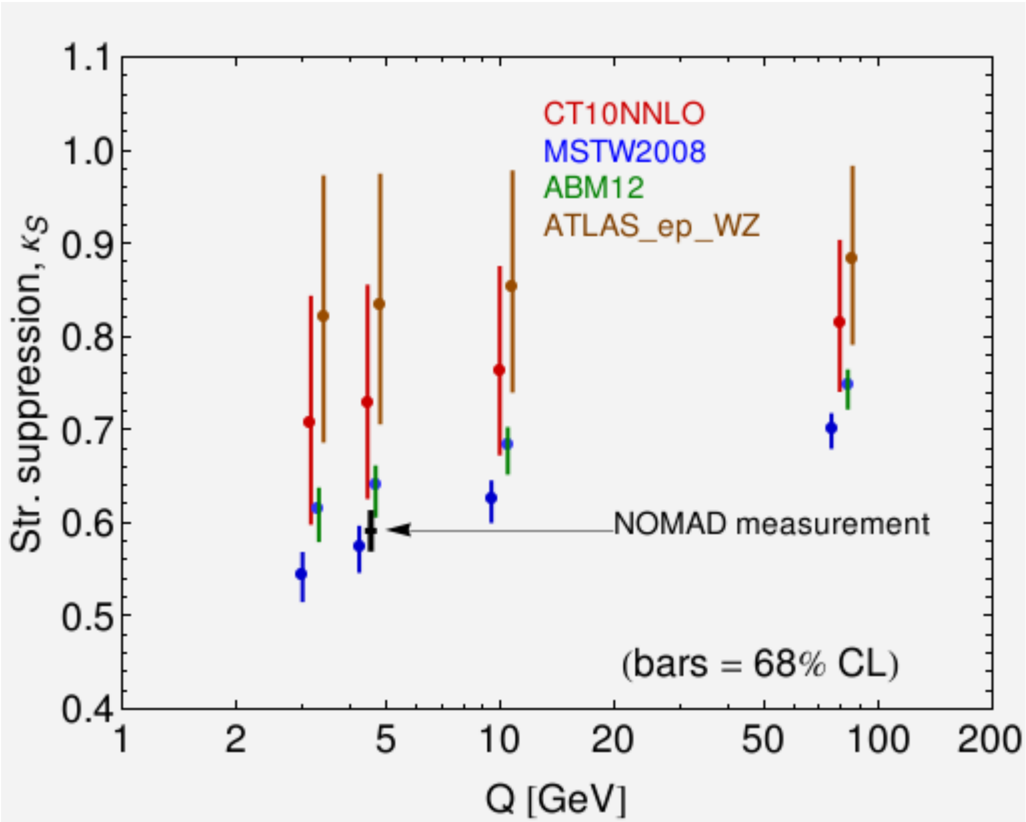




$Q^2 = \{\ 10\ \text{GeV}^2\ ,\ 20\ \text{GeV}^2\ ,\ 100\ \text{GeV}^2\ ,\ 6400\ \text{GeV}^2\ \}$

plotted with slight Q displacements to separate the points

The NOMAD measurement



Ref.: NOMAD Collaboration, Nucl.Phys. B876 (2013) 339-375 .

They make a ***very strong claim***:
$\kappa_S = 0.591 \pm 0.019$ at $Q^2 = 20$ GeV^2.
(Uncertainty is only ± 3 % !)

Critical questions ...

The CTEQ global analysis implies a larger ***uncertainty*** of the strange quark -- not consistent with this NOMAD claim.

NOMAD measurement:
Based on NOMAD data for (anti)neutrino → dimuon production;
i.e., the process ν + Fe → 2μ + X.

W+, W- and Z0 production at 7 and 8 TeV

The CMS collaboration has published total cross sections for inclusive Vector Boson production.

Refs: CMS collaboration, JHEP 10 (2011) 132;
CMS collaboration PRL 112, 191802 (2014) .

The LHC data provides constraints on Parton Distribution Functions.

How well does this data agree with pre-LHC PDFs?

Compare predictions of σ_{tot} for CT10NNLO PDFs.

For 7 TeV , in nb,	{stat, syst, thy, lumi}
$\sigma B(W+)$ 6.04	{±0.02 ±0.06 ±0.08 ±0.24}
$\sigma B(W-)$ 4.26	{±0.01 ±0.04 ±0.07 ±0.17}
$\sigma B(Z0)$ 0.974	{±0.007 ±0.007 ±0.018 ±0.039}

8 TeV , in nb,	{stat, syst, lumi}
7.11	{ ±0.03 ±0.14 ±0.18 }
5.09	{ ±0.04 ±0.11 ±0.13 }
1.15	{ ±0.01 ±0.02 ±0.03 }

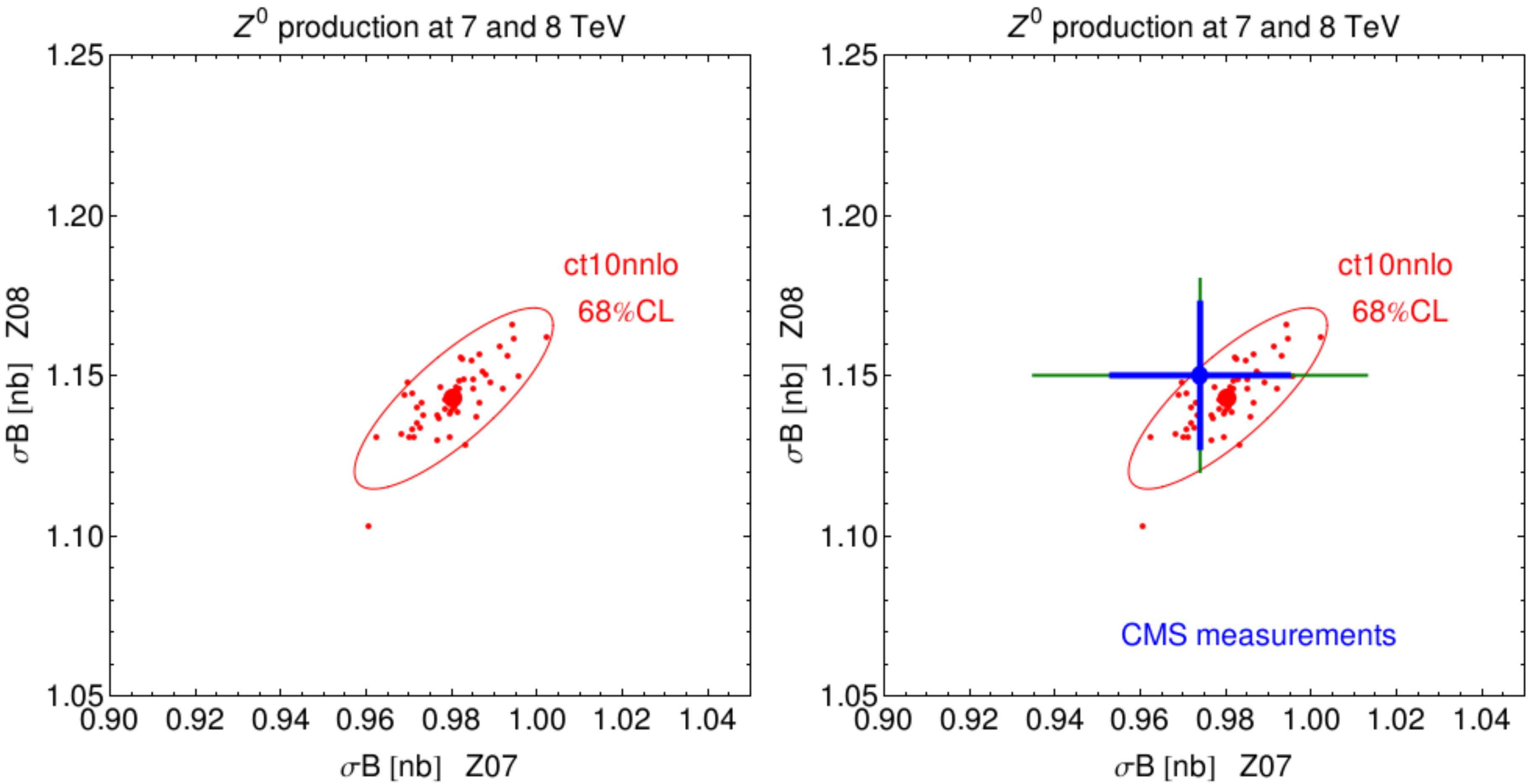
DYNNLO:
S. Catani, L. Cieri, G. Ferrera, D. de Florian, M. Grazzini, Phys. Rev. Lett. 103 (2009) 082001,
S. Catani, M. Grazzini, Phys. Rev. Lett. 98 (2007) 222002.

Predictions and CMS measurements

Inclusive Z0 production at 7 and 8 TeV

(α) predictions: CT10NNLO, DYNNLO v1-4;
central predictions, error PDFs, error ellipses = 68% CL

(β) experimental error bars: blue = stat+syst; green = luminosity

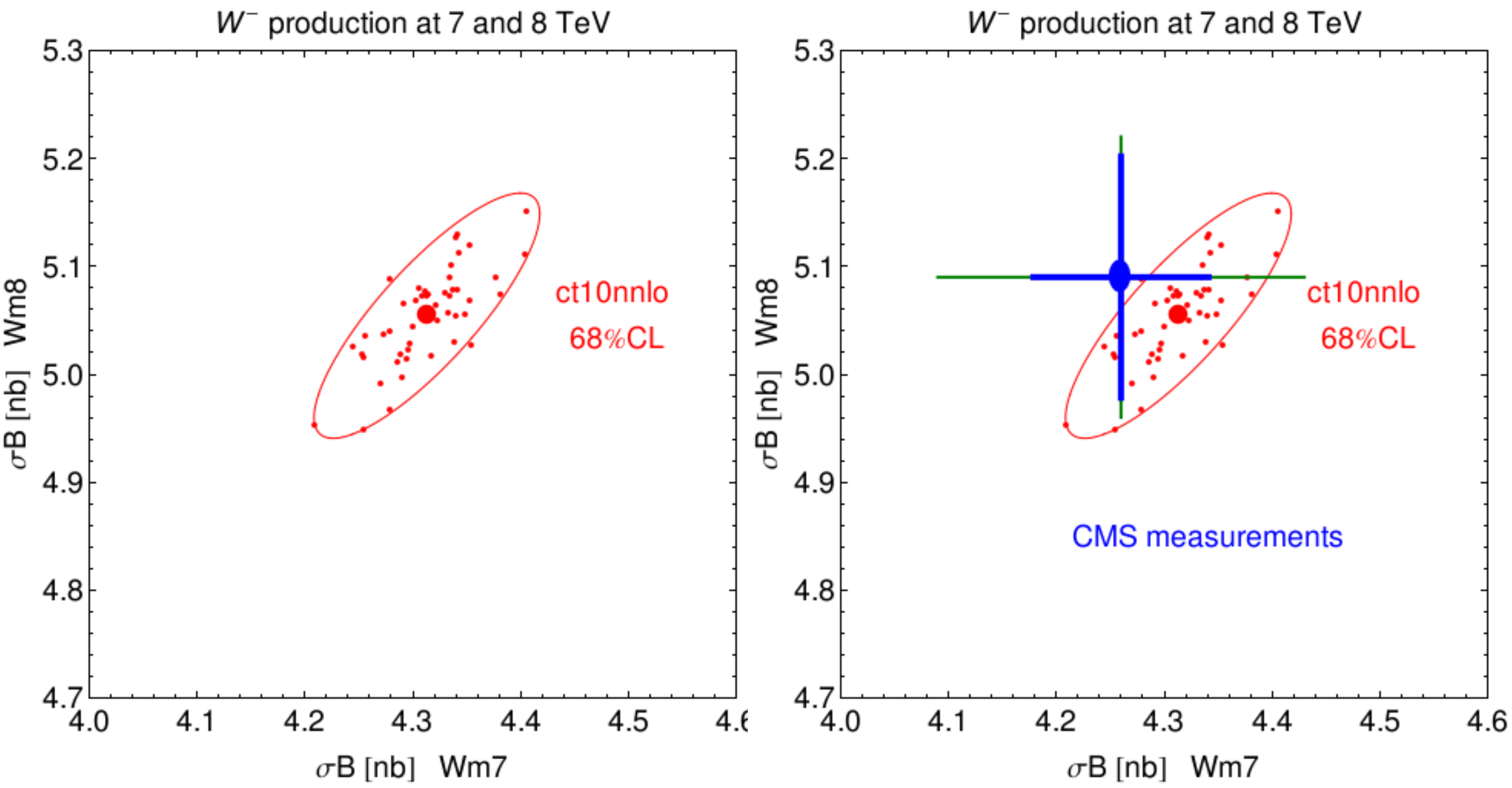


Predictions and CMS measurements

Inclusive W- production at 7 and 8 TeV

(α) predictions: CT10nnlo; DYNNLO v1-4

(β) experimental error bars: blue = stat+syst; green = luminosity

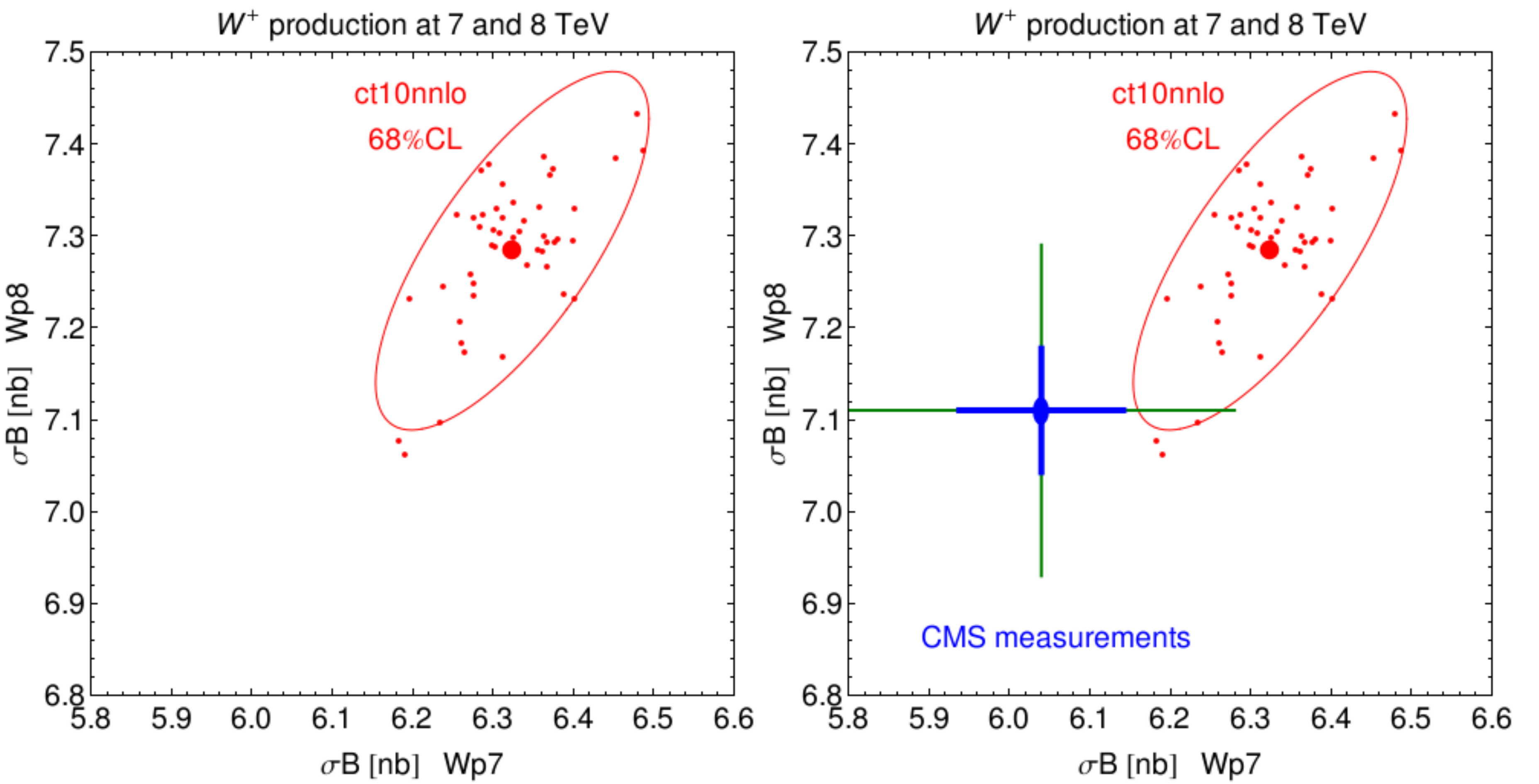


Predictions and CMS measurements

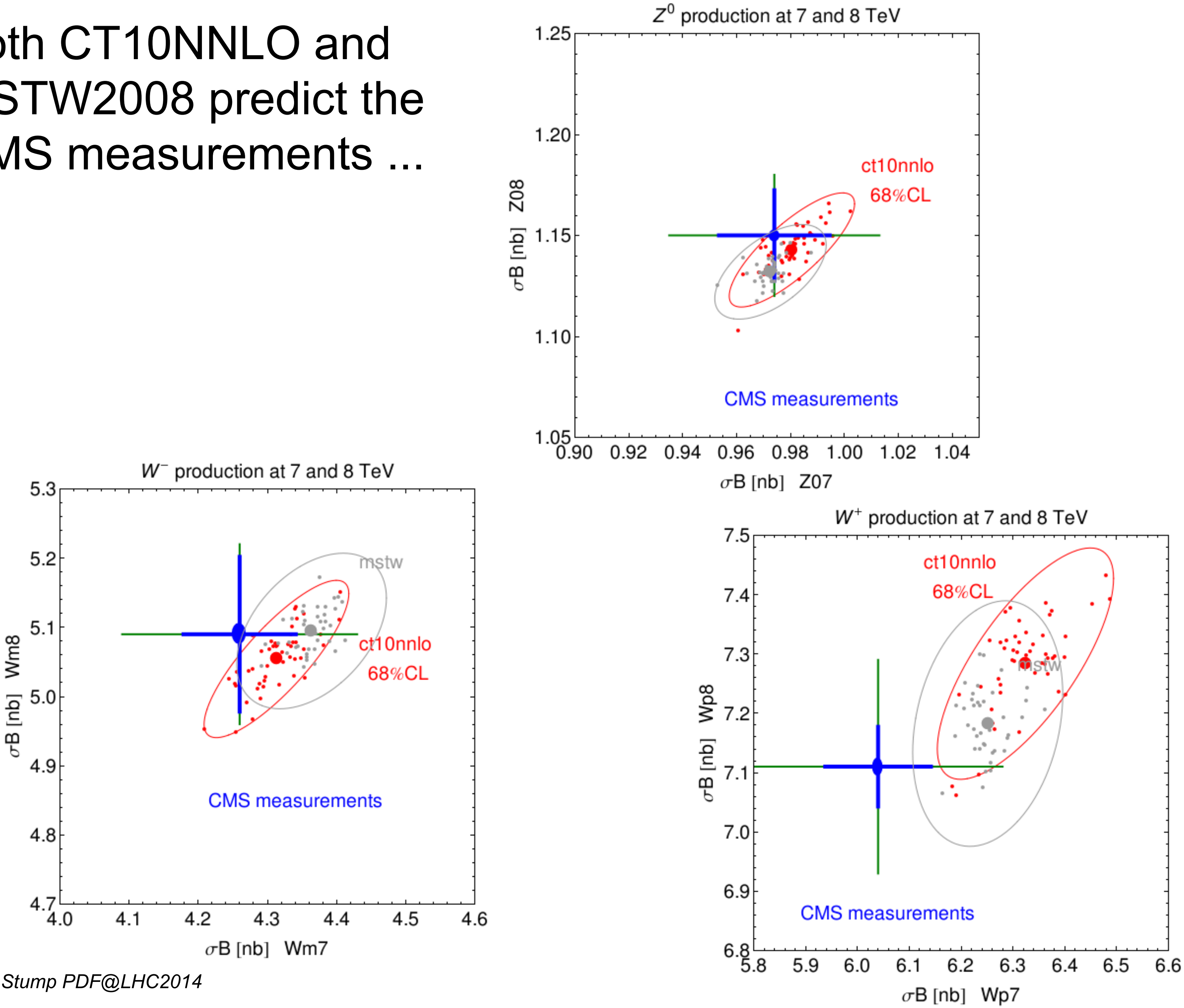
Inclusive W+ production at 7 and 8 TeV

(α) predictions: CT10nnlo, DYNNLO v1-4

(β) experimental error bars: blue = stat+syst; green = luminosity



Both CT10NNLO and MSTW2008 predict the CMS measurements ...



W+, W- and Z0 production at 7 and 8 TeV

How well do the CMS measurements of σ_{tot} agree with pre-LHC PDFs?

"They agree within the errors."
Can we make that more precise?

Uncertainties:

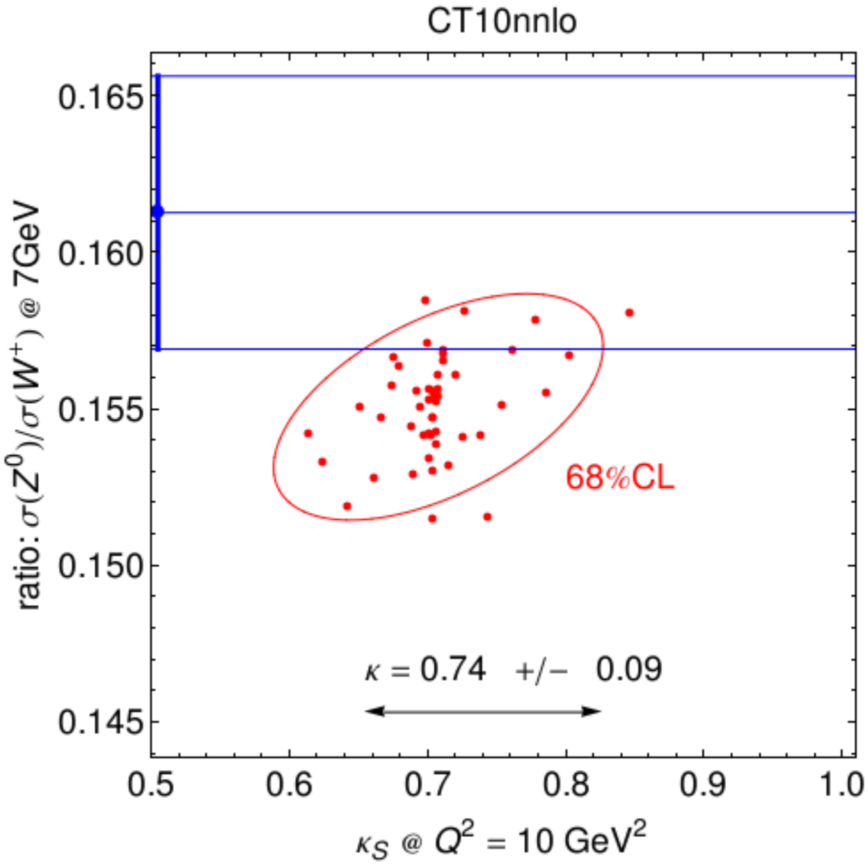
The experimental errors are comparable to the theoretical (i.e., PDF) errors.

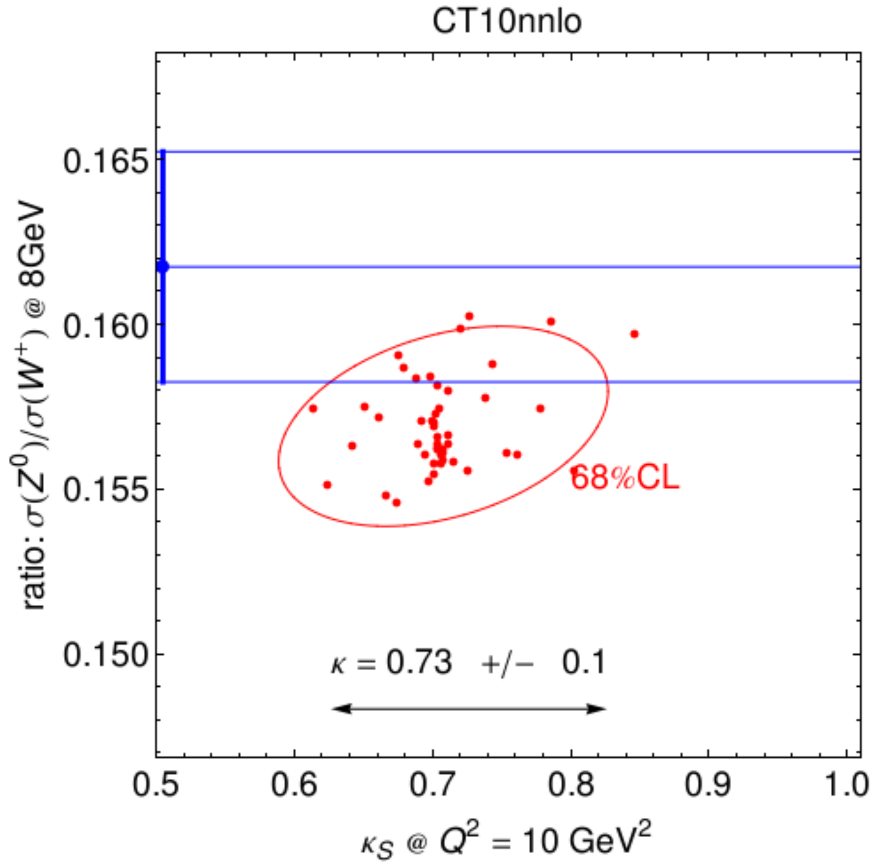
The luminosity errors alone are comparable to other errors.

What can we learn with uncertainties of this size?

(1) *Eliminate the luminosity errors* by calculating ratios;

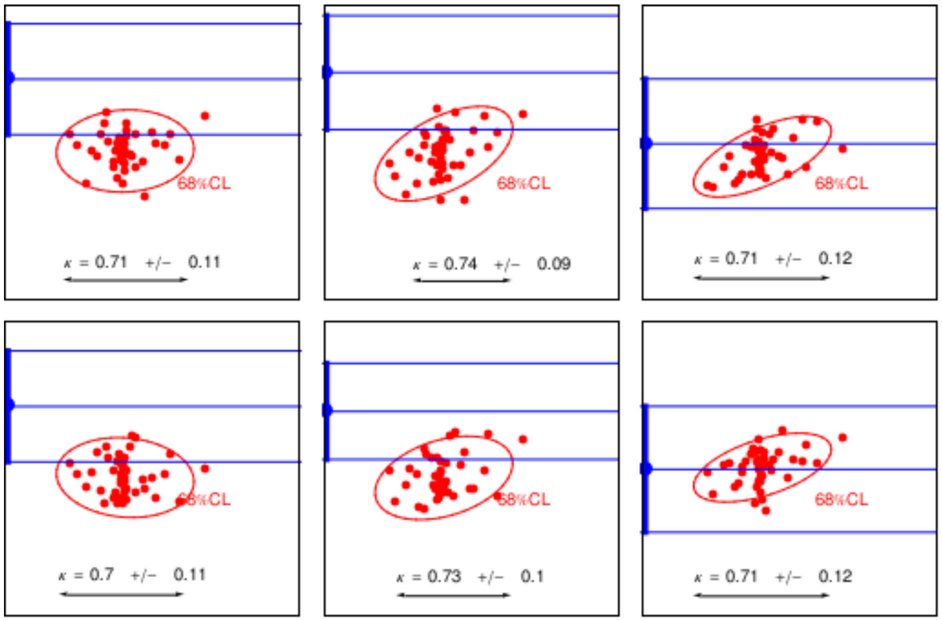
(2) calculate the ***correlation*** between κ_s *(at some chosen Q value)* and the ratio , e.g., $\sigma B(Z^0)/\sigma B(W^+)$ at $\sqrt{S}$;

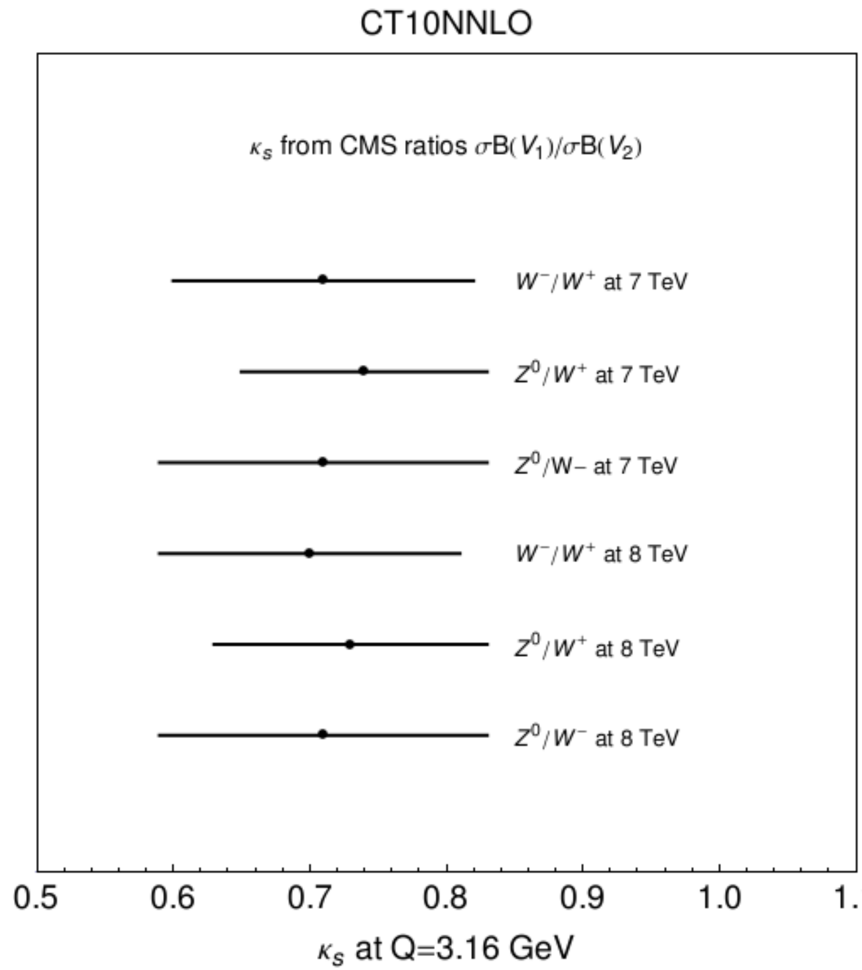




(3) read off the allowed range of κ_s .

(4) ***Results:*** For each ratio we obtain an estimate for κ_s (Q = 3.16 GeV).





So, the CTEQ analysis gives

κ_s = 0.72 ± 0.04 at $Q^2 = 10$ GeV^2 . (68%CL)

The uncertainty is underestimated because the errors are still correlated even after taking the ratios.

PRL **109,** 012001 (2012) PHYSICAL REVIEW LETTERS week ending 6 JULY 2012

Determination of the Strange-Quark Density of the Proton from ATLAS Measurements of the $W \to \ell\nu$ and $Z \to \ell\ell$ Cross Sections

G. Aad *et al.**
(ATLAS Collaboration)

(Received 19 March 2012; published 5 July 2012)

A QCD analysis is reported of ATLAS data on inclusive $W^{\pm}$ and Z boson production in pp collisions at the LHC, jointly with ep deep-inelastic scattering data from HERA. The ATLAS data exhibit sensitivity to the light quark sea composition and magnitude at Bjorken $x \sim 0.01$. Specifically, the data support the hypothesis of a symmetric composition of the light quark sea at low x. The ratio of the strange-to-down sea quark distributions is determined to be $1.00^{+0.25}_{-0.28}$ at absolute four-momentum transfer squared $Q^2 = 1.9\ \mathrm{GeV}^2$ and $x = 0.023$.

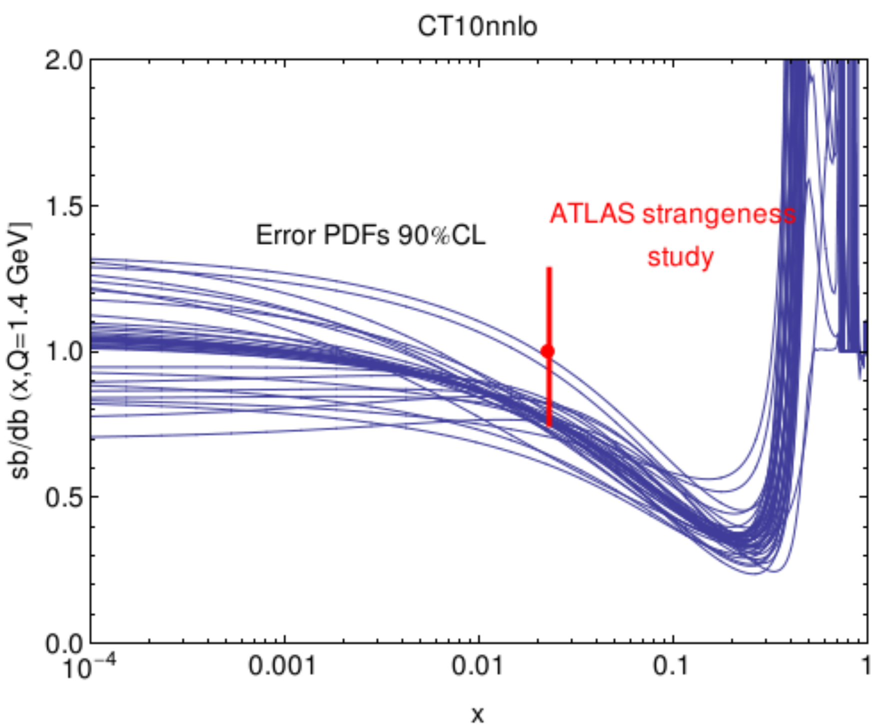
This ATLAS study claims an interesting result …

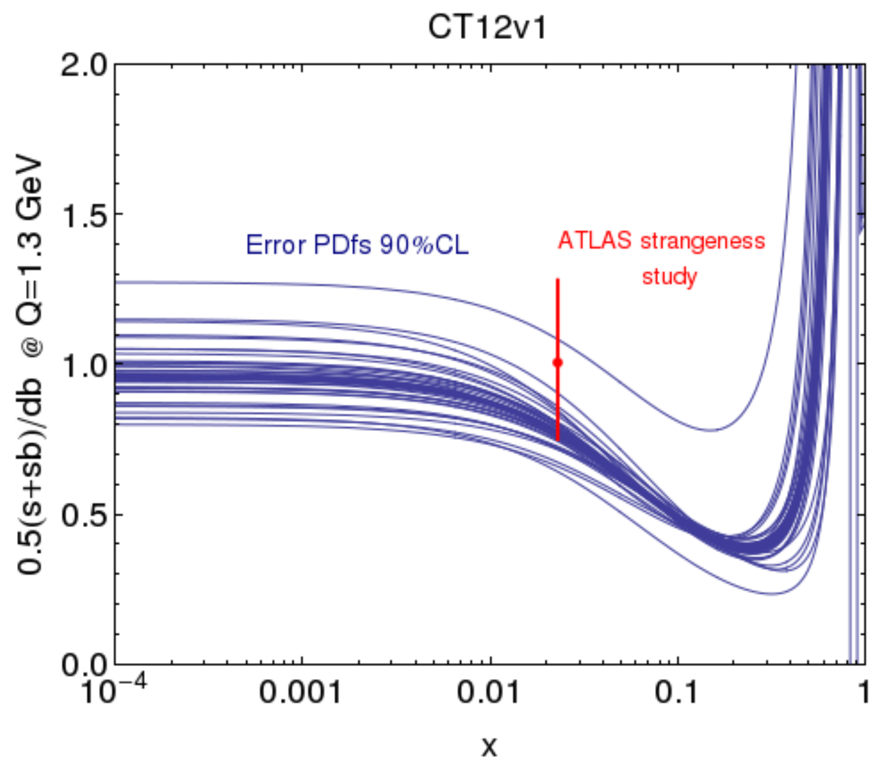
$$\frac{s_{\mathbf{b}}(x,Q)}{d_{\mathbf{b}}(x,Q)} = 1.00 \begin{array}{l} +0.25 \\ -0.28 \end{array}$$

at $x = 0.023$ and $Q^2 = 1.9\ \mathrm{GeV}^2$

The PDFs used in this study are called ATLAS_ep_WZ .

Compare s_b/d_b (x,Q) for Q^2=1.9 GeV^2 , for these CTEQ PDFs :
CT10NNLO = pre-LHC global analysis ;
CT12v1 = a new global analysis which includes ATLAS WZ data .





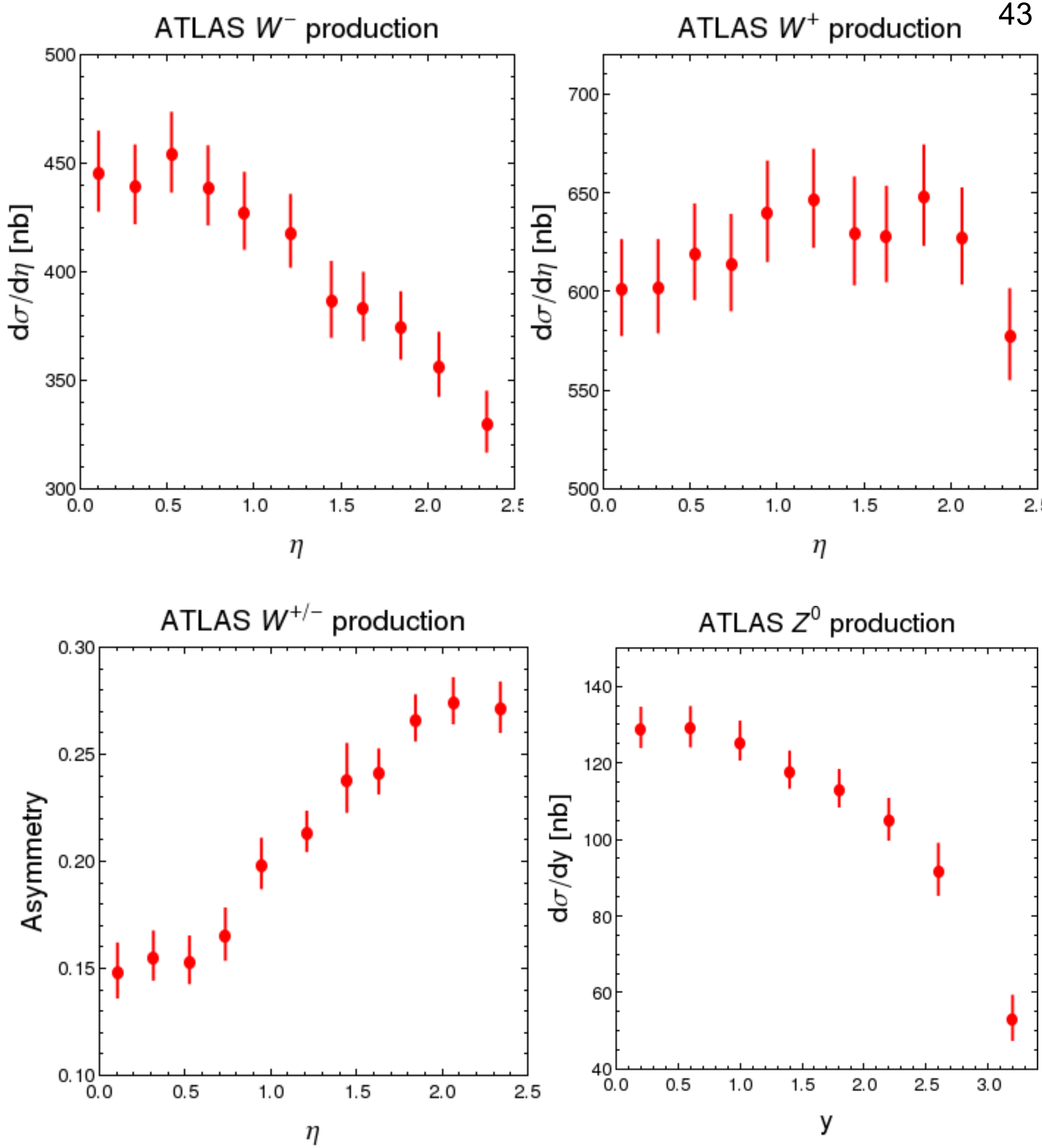
s_b / d_b (x,Q) for CT10NNLO PDFs at Q=1.4 GeV.

s_b / d_b (x,Q) for CT12v1 PDFs at Q=1.3 GeV.

ATLAS DATA on Inclusive Production of $W^{\pm}$ and Z^0 at 7 TeV ;

$d\sigma/d\eta$ with certain cuts on p_T

Red error bars show the ***total error*** = uncorrelated errors and correlated errors combined in quadrature.



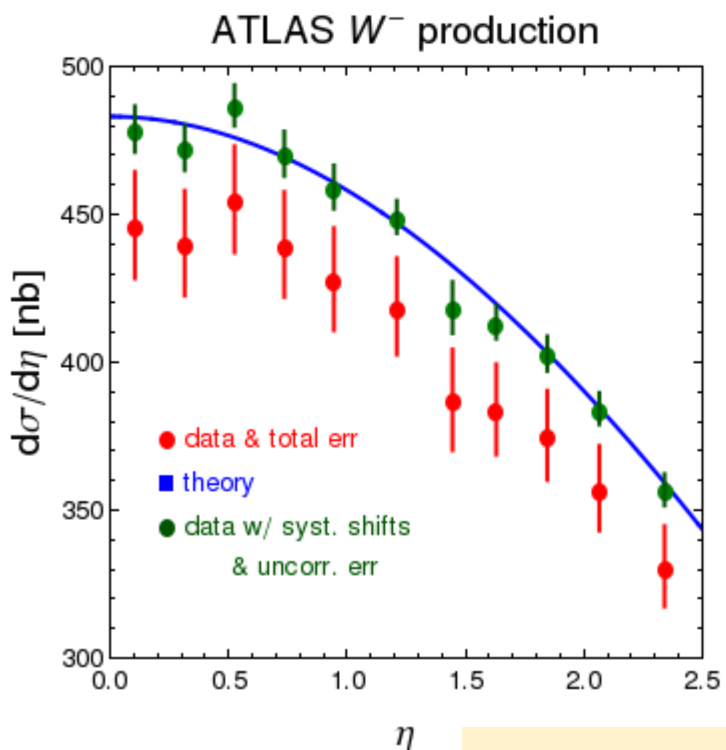
ATLAS data on Inclusive Production of $W^{\pm}$ at 7 TeV

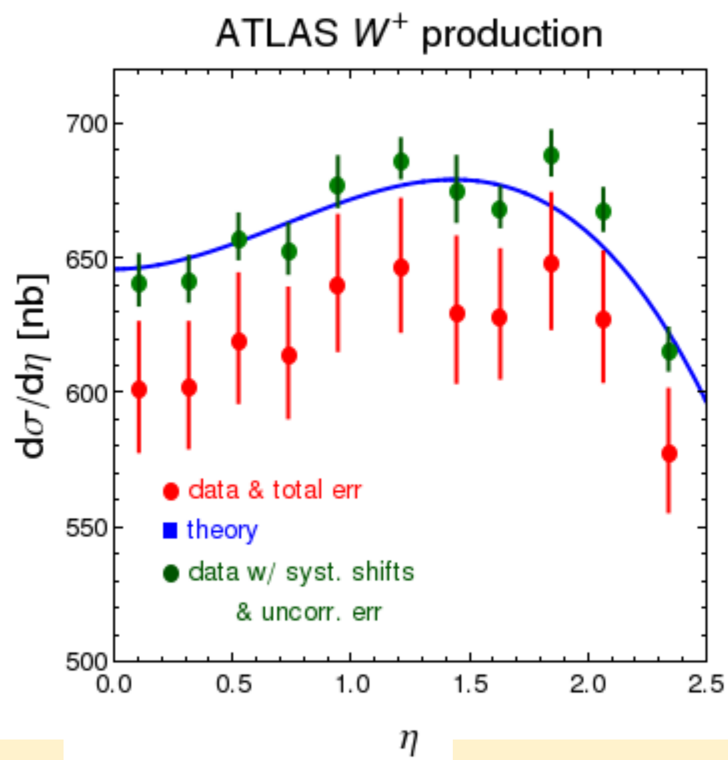
Data and total error

Theory *(CT12v1)*

Data with systematic displacements & uncorrelated error bars

(systematic errors; 30 sources of systematic error; nuisance parameters;)





χ_0^2 = 43.7 /11

χ_{sh}^2 = 7.93 /11

χ_0^2 = 29.8 /11

χ_{sh}^2 = 16.7 /11

$$\chi_0^2 = \sum_k \frac{(D_k - T_k)^2}{\sigma_{\rm tot}^2}$$

$$\chi_{\rm sh}^2 = \sum_k \frac{(D_{{\rm sh},k} - T_k)^2}{\sigma_{\rm unc}^2}$$

$$D_{{\rm sh},k} = D_k + \sum_{n=1}^{N_{\rm sy}} r_n \sigma_{k,n}$$

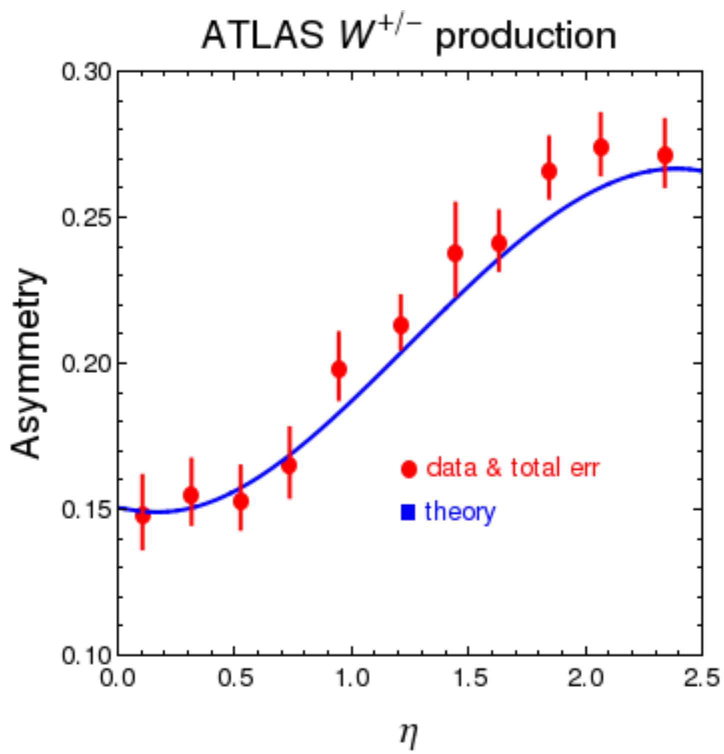
W asymmetry and Z^0 production at 7 TeV

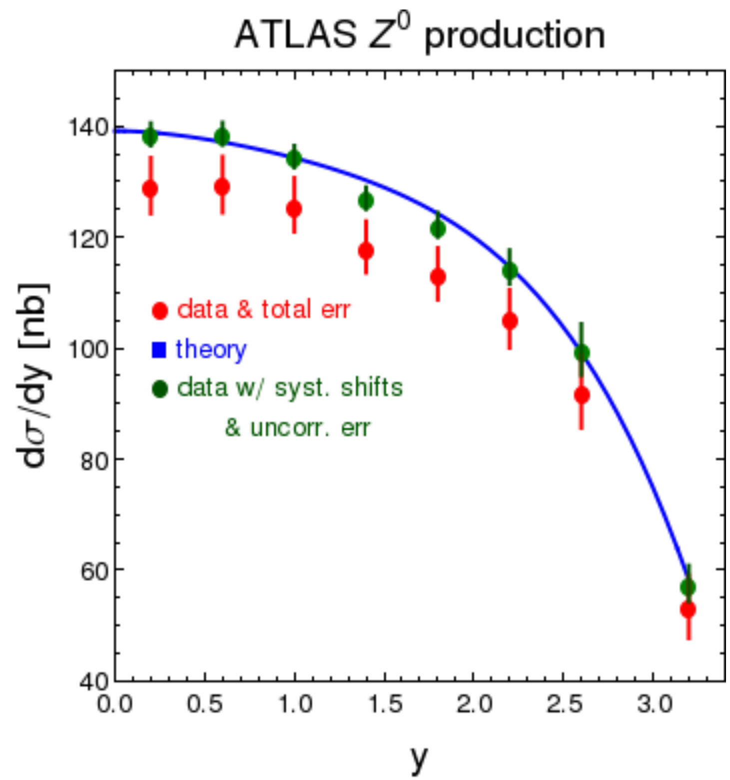
Data and total error

Theory *(CT12v1)*

Data with systematic displacements & uncorrelated error bars

systematic errors; 30 sources of systematic error; nuisance parameters;





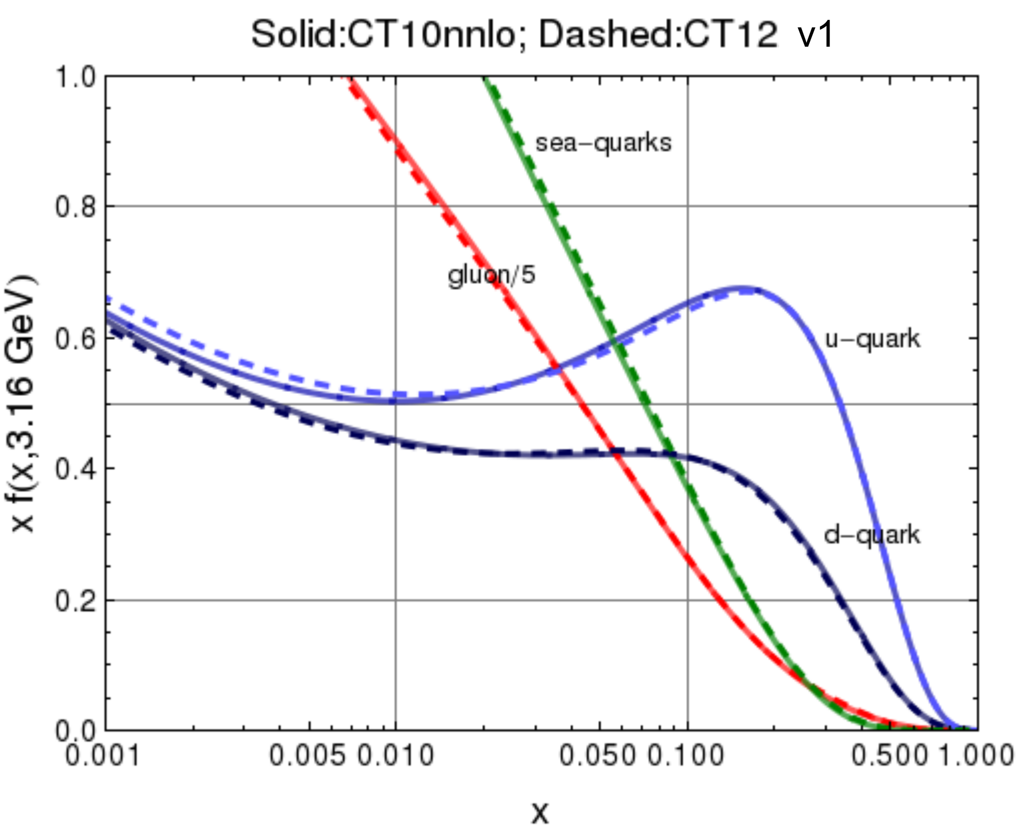
X_0^2 = 10.7 /11

X_{sh}^2 = 7.29 /11

X_0^2 = 26.0 /8

X_{sh}^2 = 3.70 /8

Taking into account the (31 !) correlated systematic errors, the CT10-like PDFs) fit the ATLAS data very well.



κ_s values at $Q^2 = 10$ GeV^2

CT10NNLO
0.71 ± 0.12

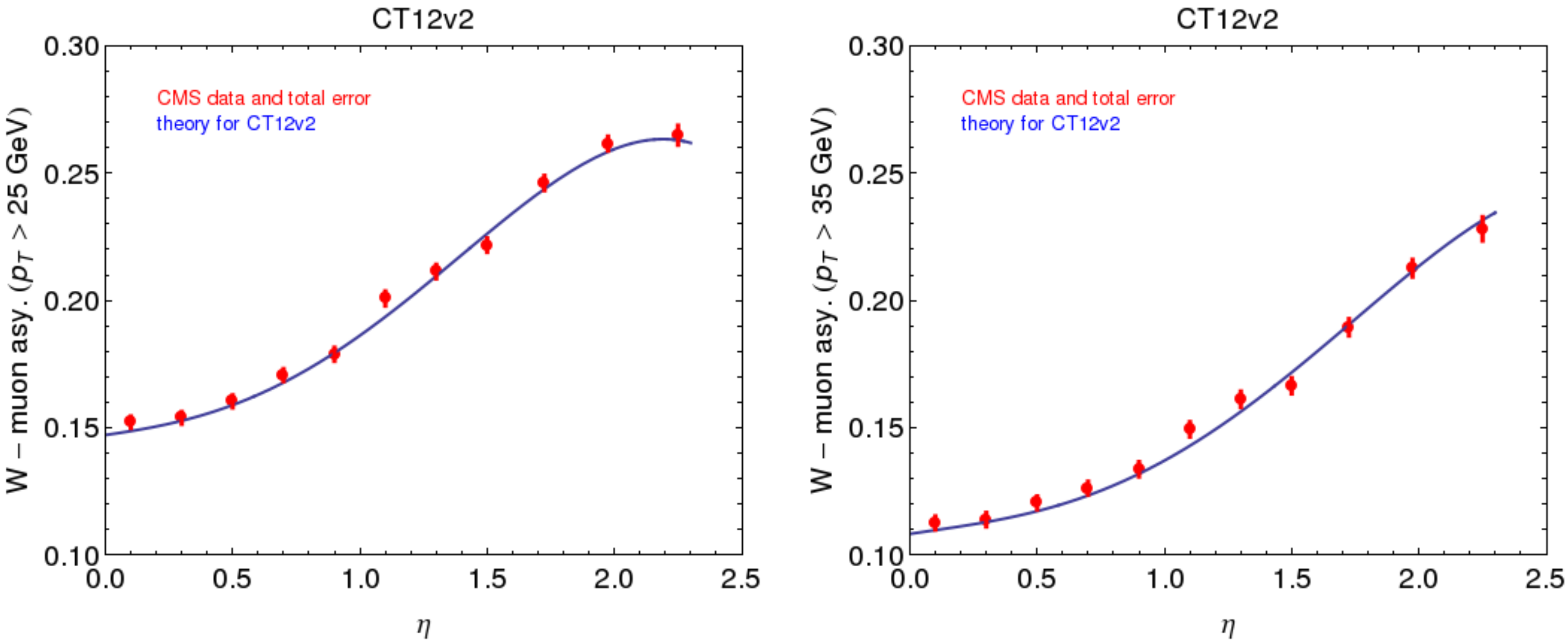
CT12v1
0.72 $\begin{matrix} +\,0.197 \\ -\,0.085 \end{matrix}$

{0.720487,0.197425,-0.0848227}

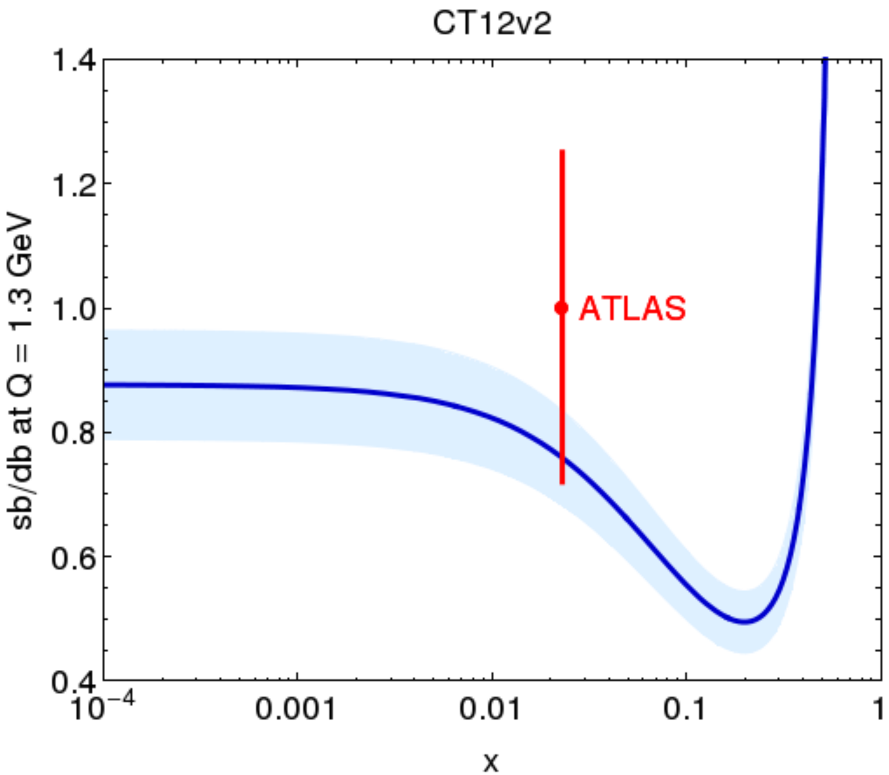
One more set of data: CMS 7 TeV 4.5 fb^{-1}

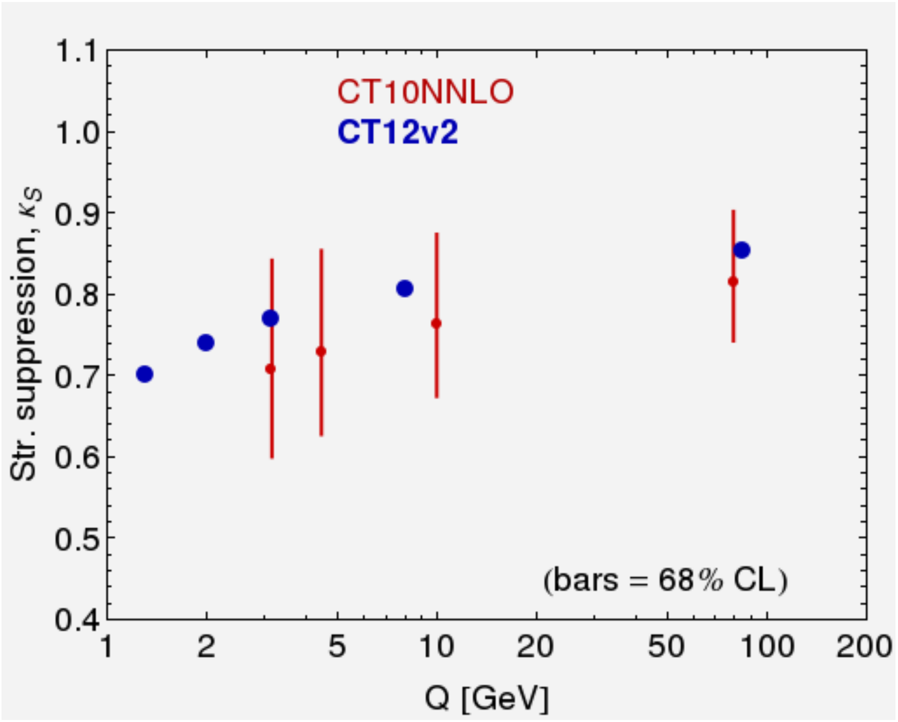
W→mu asymmetry with p_T>25 GeV
W→mu asymmetry with p_T>35 GeV

PDF set CT12v2 = a new set of PDFs for which this data was included in the global analysis.



The CT12v2 PDFs fit the CMS W-muon asymmetry data; they also have CT10-like large κ_s





Q^2=20GeV^2

compare CMS Study : R. Placakyte (DIS2014, Warsaw)

$\kappa_s = 0.52 \,{}^{+0.12}_{-0.10}(\text{exp}) \,{}^{+0.05}_{-0.06}(\text{mod}) \,{}^{+0.13}_{-0.10}(\text{par}) = 0.52 \,{}^{+0.18}_{-0.15}$

Strangeness in the CTEQ global analysis

- It is important to use a flexible parametrization for the PDFs; CT10 and CT12 have 24 PDF fitting parameters.
- Data specific to s and s_b:

.. CCFR neutrino/antineutrino → dimuons

.. NuTeV n / n_b → dimuons

.. ATLAS inclusive WZ

.. CMS σ_{tot} ; CMS W-lepton asymmetry

All four are consistent with CT12v1,CT12v2.

- κ_s = 0.72 +/- 0.10
- We do not use low-energy neutrino scattering data, such as NOMAD or CHORUS.

coming soon ...

CT14 PDFs

which includes a suite of LHC data