Recent developments in the CTEQ-TEA global analysis

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CTP-XJU

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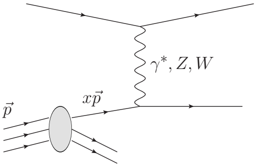
CTEQ-TEA group

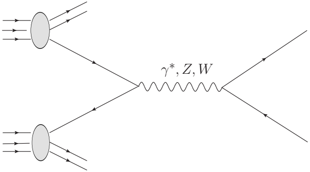
- CTEQ – Tung et al. (TEA)
  in memory of Prof. Wu-Ki Tung, who established CTEQ Collaboration in early 90's.
- Current members:
  Sayipjamal Dulat, Tie-Jiun Hou, Ibrahim Sitiwaldi (Xinjiang U.)
  Jun Gao (Shanghai Jiaotong U.)
  Marco Guzzi (Kennesaw State U.)
  Pavel Nadolsky, Timothy Hobbs, Keping Xie, Boting Wang (Southern Methodist U.)
  Joey Huston, Jon Pumplin, Carl Schmidt, Dan Stump, Jan Winter, C.-P. Yuan (Michigan State U.)

PDF $f(x, Q)$ is universal

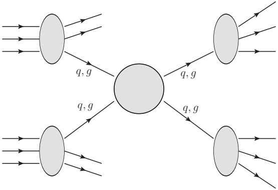
DIS



Drell-Yan

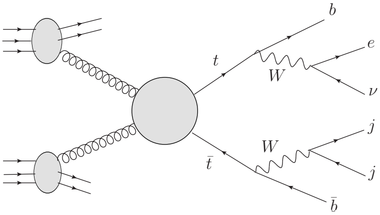


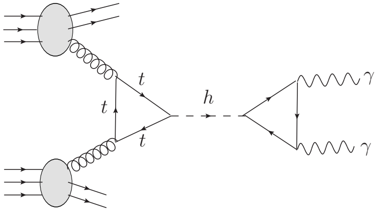
jet



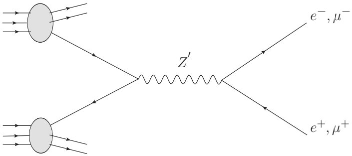
PDF(Parton distribution function) tell us the probability to find out a parton in a proton with particular momentum fraction x and energy Q.

$t\bar{t}$ Higgs





To determine the EW parameters via precision measurements requires knowing PDFs.



Probing New Physics requires knowing PDFs

PDF evolve

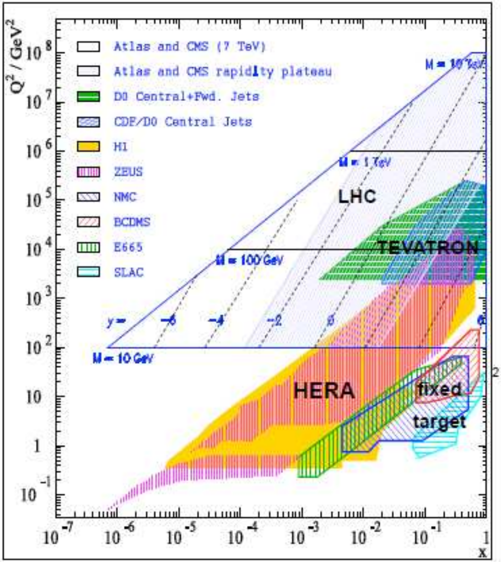
$$\frac{\partial q_i(x,\mu^2)}{\partial \ln \mu^2} = P^v_{qq} \otimes q_i + P^v_{q\bar{q}} \otimes \bar{q}_{\bar{i}} + P^s_{qq} \otimes \sum_k^{N_f} q_k + P^s_{q\bar{q}} \otimes \sum_k^{N_f} \bar{q}_{\bar{k}} + P_{qg} \otimes g$$

$$\frac{\partial \bar{q}_{\bar{i}}(x,\mu^2)}{\partial \ln \mu^2} = P^v_{q\bar{q}} \otimes q_i + P^v_{qq} \otimes \bar{q}_{\bar{i}} + P^s_{q\bar{q}} \otimes \sum_k^{N_f} q_k + P^s_{qq} \otimes \sum_k^{N_f} \bar{q}_{\bar{k}} + P_{qg} \otimes g$$

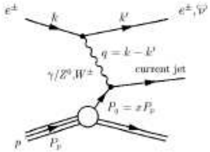
$$\frac{\partial g(x,\mu^2)}{\partial \ln \mu^2} = P_{gq} \otimes \sum_k^{N_f} (q_k + \bar{q}_k) + P_{gg} \otimes g$$

DGLAP tells us how to evolve from the low energy scale, the input energy scale, to the high energy scale, the energy scale of interaction. But it does not tell us about it's x-dependence. We need to use data to determine $f(x,Q)$ as a function of x at Q_0 scale.

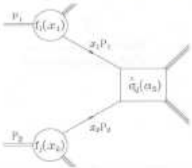
Experimental access to the proton structure



HERA: low and medium x



LHC: important constraints on g(x), flavour separation



Fixed Target: high x, nuclear PDFs

CT global analysis takes $Q_0 = 1.3\text{GeV} \gg \Lambda_{QCD}$, and assume

$$xf_a(x, Q_0, \{a_1, a_2, ...\}) = x^{a_1}(1-x)^{a_2} P_a(x)$$

- $x \to 0$: $f \propto x^{a_1}$, Regge-like behavior
- $x \to 1$: $f \propto (1-x)^{a_2}$, quark counting rules
- $P(x; a_3, a_4, ...)$: affects intermediate x; In CT14, Bernstein polynomial is applied.

For every proton flavor:

$$g, \quad u_v, \quad d_v, \quad s, \quad \bar{u}_s = u_s, \quad \bar{d}_s = d_s$$

Where $u = u_v + u_s$, and $d = d_v + d_s$.
In total, there are about 28 shape parameters used in CT14.

Requirements for PDF parametrization

- Valence quark number sum rule

$$\int_0^1 [u(x) - \bar{u}(x)]dx = 2, \int_0^1 [d(x) - \bar{d}(x)]dx = 1$$

$$\int_0^1 [s(x) - \bar{s}(x)]dx = 0$$

Where $u = u_v + \bar{u}$, $d = d_v + \bar{d}$. $(s(x) - \bar{s}(x))$ can be non-zero.

- Momentum sum rule

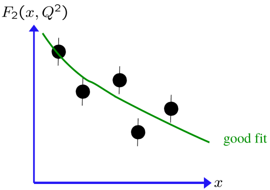
$$\sum_{a=q,\bar{q},g} \int_0^1 x f_{a/p}(x,Q)dx = 1$$

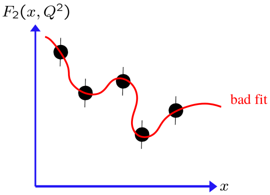
Where

$$\int_0^1 x\, g(x,Q)dx \sim 0.45$$

Requirements for PDF parametrization

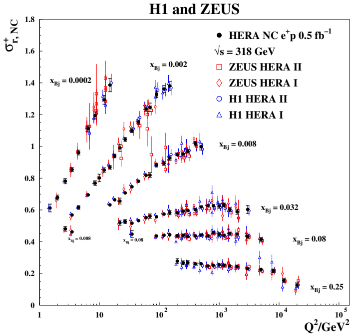
- A valid PDF set must not produce unphysical predictions for observables
  - Any concievable hadron cross section σ must be non-negative: $\sigma > 0$. This is typically realized by requiring $f_{a/p}(x,Q) > 0$.
  - Any cross section asymmetry A must lie in the range $-1 \leq A \leq 1$. This constrains the range of allowed PDF parametrizations.
- PDF parametrization for $f_{i/p}(x,Q)$ must be "flexible just enough" to reach agreement with the data, without reproducing random fluctuation.

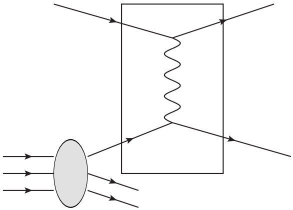




PDF is determined by comparing data and hard cross section

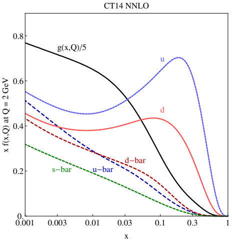
$$\sigma = f(x, Q^2, \{a\}) \otimes \hat{\sigma}$$

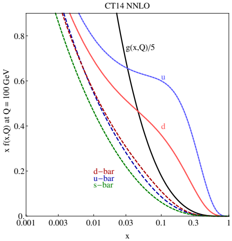


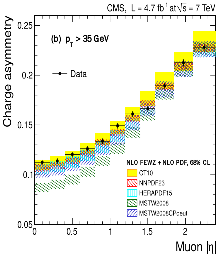


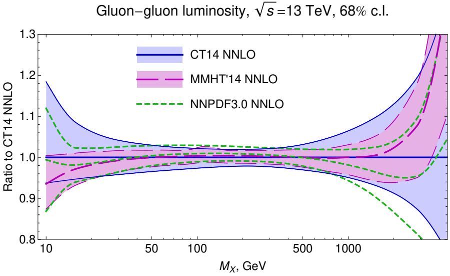
PDF	Hard part
LO	LO
NLO	NLO
NNLO	NNLO

PDF will then contribute to the precision measurment and search for new physics.









Criteria for determine PDFs

Define

$$\chi^2_{global} = \sum_i \frac{[D_i - \sum_k \lambda_k \beta_{ki} - T_i(\{a\})]^2}{\sigma_i^2} + \sum_k \lambda_k^2.$$

Where
D_i is the central value of data,
$T_i(\{a\})$ is the theoretical prediction of the data,
σ_i^2 is the qudratic sum of the statistical error and uncorrelated error,
β_{ki} is the matrix for correlated error,
and λ_k are the nuisance parameters.

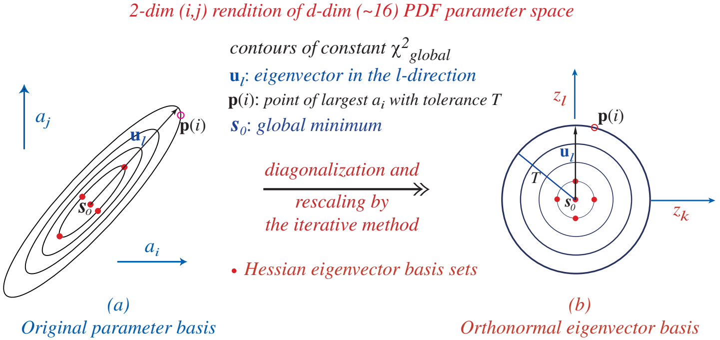
The PDF is obtained by minimize the global χ^2 function respect to $\{a\}$ and $\{\lambda\}$.

Probe the uncertainty of PDFs

The uncertainty of the PDF is estimated by the Hessian method.

$$\chi^2 = \chi_0^2 + \sum_{i,j} H_{ij} y_i y_j , \quad H_{ij} = \frac{1}{2} \left(\frac{\partial^2 \chi^2}{\partial y_i \partial y_j} \right)_0 ,$$

Where $y_i = a_i - a_i^0$ with a_i^0 to be the parameters at minimal χ_0^2.



Let $X = X(\{a_i\})$ to be the observable as a function of fitting parameter. Using the linear approximation of parameter $\{z_i\}$, the symmetry uncertainty of X is,

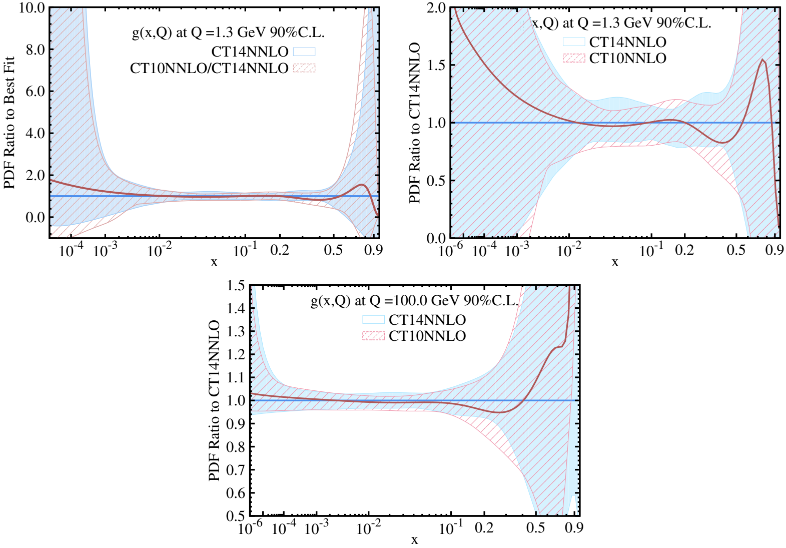
$$\Delta X = \frac{1}{2}\left(\sum_{i=1}^{N_p}\left[X(\{z_i^+\}) - X(\{z_i^-\})\right]^2\right)^{1/2},$$

Where $\{z_1^{\pm}\} = \{\pm T, 0....\}$, $\{z_2^{\pm}\} = \{0, \pm T, 0....\}$ and so on.
The asymmetry uncertainty of X is,

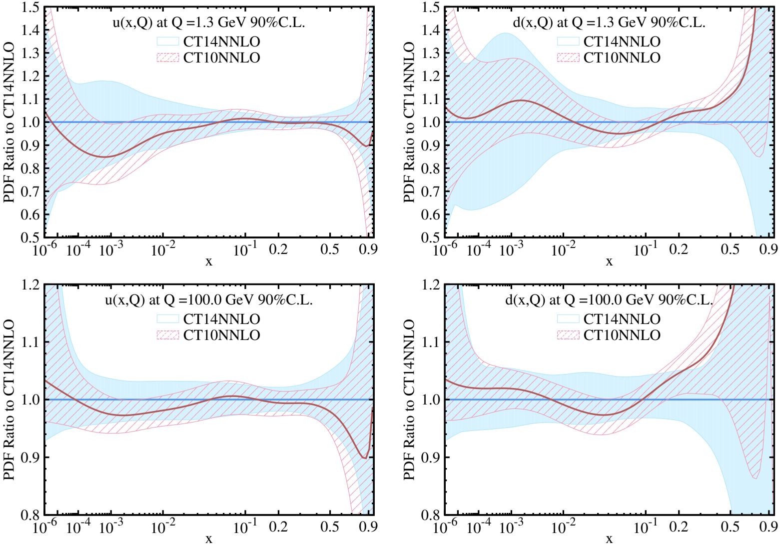
$$\delta^+ X = \sqrt{\sum_{i=1}^{N_a}\left[\max\left(X_i^{(+)} - X_0, X_i^{(-)} - X_0, 0\right)\right]^2},$$

$$\delta^- X = \sqrt{\sum_{i=1}^{N_a}\left[\max\left(X_0 - X_i^{(+)}, X_0 - X_i^{(-)}, 0\right)\right]^2},$$

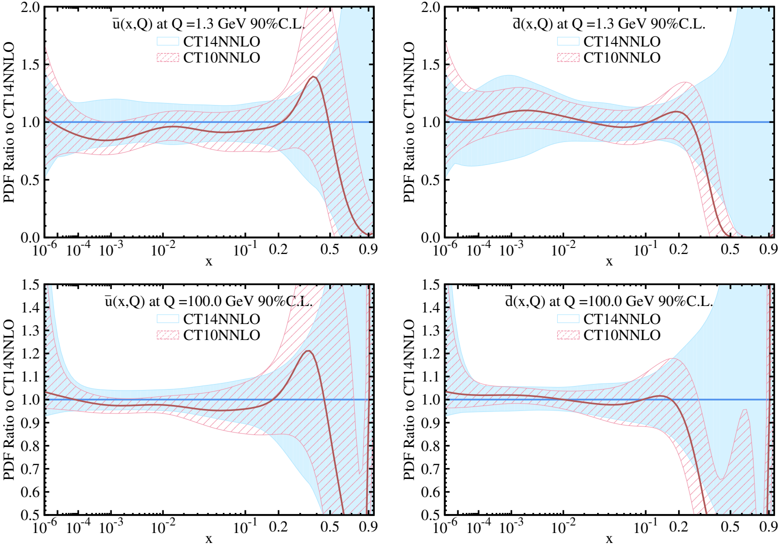
$g(x, Q)$


g(x,Q) at Q =1.3 GeV 90%C.L.
CT14NNLO
CT10NNLO/CT14NNLO
PDF Ratio to Best Fit
x
x,Q) at Q =1.3 GeV 90%C.L.
CT14NNLO
CT10NNLO
PDF Ratio to CT14NNLO
x
g(x,Q) at Q =100.0 GeV 90%C.L.
CT14NNLO
CT10NNLO
PDF Ratio to CT14NNLO
x

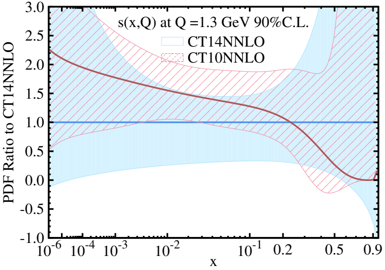
$u(x,Q)$ $d(x,Q)$

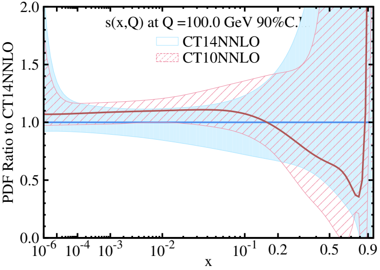

u(x,Q) at Q =1.3 GeV 90%C.L.
d(x,Q) at Q =1.3 GeV 90%C.L.
u(x,Q) at Q =100.0 GeV 90%C.L.
d(x,Q) at Q =100.0 GeV 90%C.L.
CT14NNLO
CT10NNLO
PDF Ratio to CT14NNLO
x

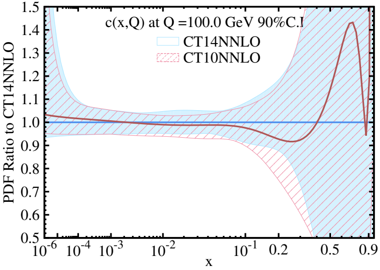
$\bar{u}(x,Q)$ $\bar{d}(x,Q)$



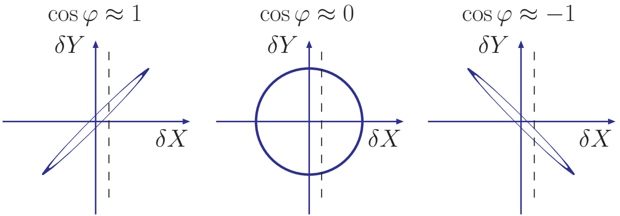
$S(x,Q)$ $c(x,Q)$


s(x,Q) at Q =1.3 GeV 90%C.L.
CT14NNLO
CT10NNLO
PDF Ratio to CT14NNLO
x


s(x,Q) at Q =100.0 GeV 90%C.L.
CT14NNLO
CT10NNLO
PDF Ratio to CT14NNLO
x


c(x,Q) at Q =100.0 GeV 90%C.L.
CT14NNLO
CT10NNLO
PDF Ratio to CT14NNLO
x

Is there a way to see the potential impact to PDF before real global analysis?



In the framework of the Hessian, the correlation between two variables X and Y can be worked out as.

$$\cos\varphi = \frac{\vec{\nabla}X \cdot \vec{\nabla}Y}{\Delta X \Delta Y} = \frac{1}{4\Delta X\,\Delta Y}\sum_{\alpha=1}^{N}\left(X_\alpha^{(+)} - X_\alpha^{(-)}\right)\left(Y_\alpha^{(+)} - Y_\alpha^{(-)}\right)$$

where the ΔX and ΔY are their symmetric uncertainties. By this correlation angle φ, the tolerance ellipse is defined by

$$X = X_0 + \Delta X \cos\theta,\; Y = Y_0 + \Delta Y \cos(\theta+\varphi),$$

- The correlation cosine between PDF $f(x,\mu)$ and theoretical prediction T_i contains no information of the experimental uncertainty.
- The correlation cosine $C_f(x_i,\mu_i)$ between PDF $f(x,\mu)$ and residual r_i contains no information of the experimental uncertainty in practice

$$C_f(x_i,\mu_i) = \frac{\vec{\nabla} f(x_i,\mu_i) \cdot \vec{\nabla} r_i}{\Delta f(x_i,\mu_i) \Delta r_i}, \quad \text{where}$$

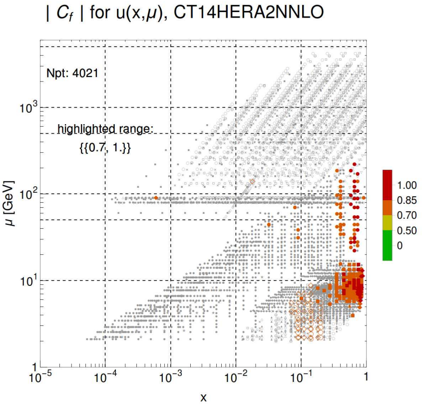
$$\chi^2 = \sum_i^N r_i^2 + \sum_k \lambda_k^2, \quad r_i(\vec{a}) = \frac{D_i - \sum_k \lambda_k \beta_{ki} - T_i(\{a\})}{\sigma_i}$$

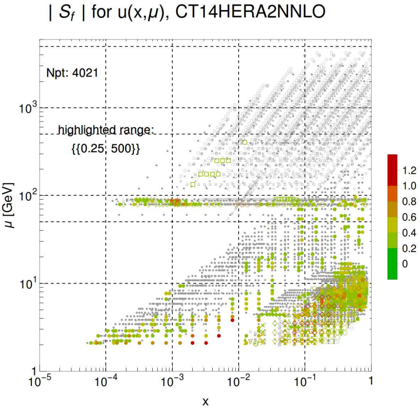
- Instead, we concern the "sensitivity" $S_f(x_i,\mu_i)$

$$S_f(x_i,\mu_i) = C_f(x_i,\mu_i) \frac{\Delta r_i}{\sqrt{\frac{\sum_i^N r_i^2}{N}}}$$

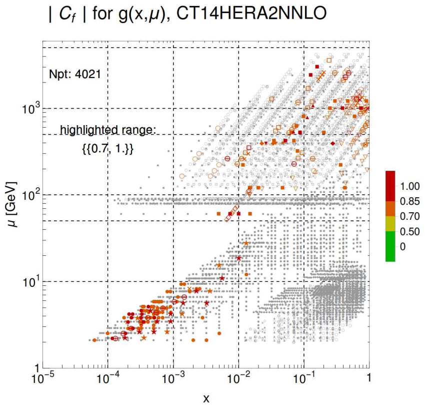
The sensitivity $S_f(x_i,\mu_i)$ help us to visualize the potential impact on PDF in $x-Q$ plane.

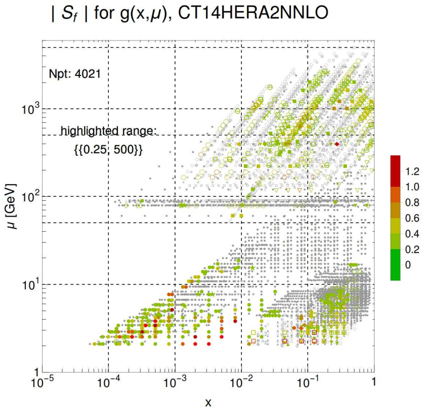
$$u(x,\mu)$$





$g(x,\mu)$


| C_f | for g(x,μ), CT14HERA2NNLO
Npt: 4021
highlighted range:
{{0.7, 1.}}
μ [GeV]
x
1.00
0.85
0.70
0.50
0


| S_f | for g(x,μ), CT14HERA2NNLO
Npt: 4021
highlighted range:
{{0.25, 500}}
μ [GeV]
x
1.2
1.0
0.8
0.6
0.4
0.2
0

Hessian Updating

- Updated Chi-square function :

$$\Delta\chi^2(Z) = \Delta\chi^2_{old}(Z) + (X_i^E - X_i(Z))C_{ij}^{-1}(X_j^E - X_j(Z))$$

- Hessian approximation :

$$\Delta\chi^2_{old}(Z) = T^2 Z^2 \quad (\mathrm{T} = \text{tolerance parameter})$$

$$X_i(Z) = X_i(0) + \Delta X_i \cdot Z \quad \text{with} \quad \Delta X_i^\alpha = \frac{1}{2}(X_i(+e)^\alpha - X_i(-e)^\alpha)$$

- Minimize to find new best fit:

$$Z^2_{new} = (1+M)^{-1}A \quad \text{with}$$

$$\mathrm{A}^\alpha = \tfrac{1}{T^2}(X_i^E - X_i(0))C_{ij}^{-1}\Delta X_j^\alpha,$$
$$\mathrm{M}^{\alpha\beta} = \tfrac{1}{T^2}\Delta X_i^\alpha C_{ij}^{-1}\Delta X_j^\beta$$

Updated PDF set

- New best-fit PDF :

$$f^0_{new} = f^0 + \Delta f \cdot Z$$

- New error PDFs :

$$f^{\pm(r)} = f^0_{new} \pm \frac{1}{\sqrt{1+\lambda^{(r)}}} \Delta f \cdot U^{(r)}$$

  where $\lambda^{(r)}$ and $U^{(r)}$ are the eigenvalues and eigenvectors of matrix M.

- Direct update of other observables:

$$Y^0_{new} = Y^0 + \Delta Y \cdot Z$$

$$|\Delta Y| = \Delta Y \cdot (1+M)^{-1} \Delta Y$$

ePump
Error PDF Updating Method Package

FullCT14HERA2.in — Edited

```
+++ N(EV pairs)                             N(Data Sets)   PDFtype(C/L/N)  Dyn_Tol?(Y/N)  Tol_squared
        27                                       33               C               Y           100.0
+++ ObservableFile                                      N(Observables)  Data?(Y/N)       Error_type     Weight
  CT14HERA2ex/tabs/E160.If1363                               1120           Y                1           1.0
  CT14HERA2ex/tabs/E101.If1363                                337           Y                1           1.0
  CT14HERA2ex/tabs/E102.If1363                                250           Y                1           1.0
  CT14HERA2ex/tabs/E104.If1363                                123           Y                1           1.0
  CT14HERA2ex/tabs/E108.If1363                                 85           Y                1           1.0
  CT14HERA2ex/tabs/E109.If1363                                 96           Y                1           1.0
  CT14HERA2ex/tabs/E110.If1363                                 69           Y                1           1.0
  CT14HERA2ex/tabs/E111.If1363                                 86           Y                1           1.0
  CT14HERA2ex/tabs/E124.If1363                                 38           Y                1           1.0
  CT14HERA2ex/tabs/E125.If1363                                 33           Y                1           1.0
  CT14HERA2ex/tabs/E126.If1363                                 40           Y                1           1.0
  CT14HERA2ex/tabs/E127.If1363                                 38           Y                1           1.0
  CT14HERA2ex/tabs/E147.If1363                                 47           Y                1           1.0
  CT14HERA2ex/tabs/E145.If1363                                 10           Y                1           1.0
  CT14HERA2ex/tabs/E169.If1363                                  9           Y                1           1.0
  CT14HERA2ex/tabs/E201.If1363                                119           Y                1           1.0
  CT14HERA2ex/tabs/E203.If1363                                 15           Y                1           1.0
  CT14HERA2ex/tabs/E204.If1363                                184           Y                1           1.0
  CT14HERA2ex/tabs/E225.If1363                                 11           Y                1           1.0
  CT14HERA2ex/tabs/E227.If1363                                 11           Y                1           1.0
  CT14HERA2ex/tabs/E234.If1363                                  9           Y                1           1.0
  CT14HERA2ex/tabs/E260.If1363                                 28           Y                1           1.0
  CT14HERA2ex/tabs/E261.If1363                                 29           Y                1           1.0
  CT14HERA2ex/tabs/E267.If1363                                 11           Y                1           1.0
  CT14HERA2ex/tabs/E268.If1363                                 41           Y                1           1.0
  CT14HERA2ex/tabs/E240.If1363                                 14           Y                1           1.0
  CT14HERA2ex/tabs/E241.If1363                                  5           Y                1           1.0
  CT14HERA2ex/tabs/E281.If1363                                 13           Y                1           1.0
  CT14HERA2ex/tabs/E266.If1363                                 11           Y                1           1.0
  CT14HERA2ex/tabs/E504.If1363                                 72           Y                1           1.0
  CT14HERA2ex/tabs/E514.If1363                                110           Y                1           1.0
  CT14HERA2ex/tabs/E535.If1363                                 90           Y                1           1.0
  CT14HERA2ex/tabs/E538.If1363                                133           Y                1           1.0
+++      PDFin                 PDFout
  PDFs/CT14HERA2ex/If1363    CT14HERA2ex/PDFtmp/If1363
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".in" file

How to use ePump

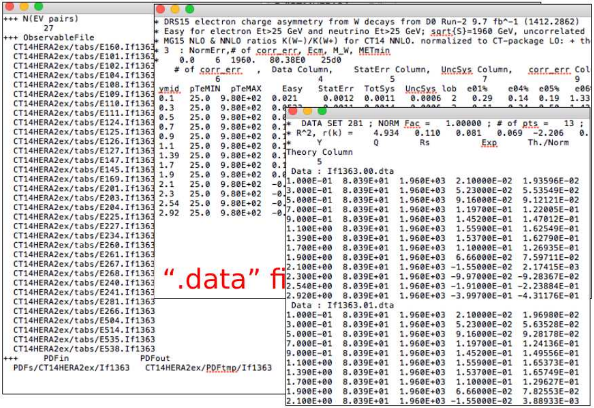
```
* DRS15 electron charge asymmetry from W decays from D0 Run-2 9.7 fb^-1 (1412.2862)
* Easy for electron Et>25 GeV and neutrino Et>25 GeV; sqrt{S}=1960 GeV, uncorrelated
* MG15 NLO & NNLO ratios K(W-)/K(W+) for CT14 NNLO. normalized to CT-package LO: + th
* 3  : NormErr,# of corr_err, Ecm, M_W, METmin
*    0.0    6  1960.   80.38E0   25d0
   # of corr_err   ,  Data Column,     StatErr Column,  UncSys Column,    corr_err Col
              6                 4                   5                  7             9
ymid  pTeMIN  pTeMAX     Easy    StatErr  TotSys   UncSys lob  e01%     e04%  e05%    e06
0.1   25.0  9.80E+02  0.021      0.0012  0.0011   0.0006  2   0.29    0.14  0.19  1.33
0.3   25.0  9.80E+02  0.0523     0.0011  0.0014   0.0006  2   0.11    0.34  0.50  1.43
0.5   25.0  9.80E+02  0.0916     0.0011  0.0018   0.0007  2   0.13    0.27  0.38  1.15
0.7   25.0  9.80E+02  0.1197     0.0011  0.0025   0.0007  2   0.06    0.28  0.41  1.1
0.9   25.0  9.80E+02  0.1452     0.0012  0.0032   0.0008  2   0.08    0.25  0.37  1.18
1.1   25.0  9.80E+02  0.1559     0.0018  0.0041   0.0013  2   0.06    0.24  0.35  1.55
1.39  25.0  9.80E+02  0.1537     0.0067  0.0061   0.0018  2   0.02    0.25  0.38  2.67
1.7   25.0  9.80E+02  0.1100     0.0031  0.0049   0.0016  2   0.10    0.2   0.31  3.86
1.9   25.0  9.80E+02  0.0666     0.0120  0.0053   0.0027  2   0.51    0.08  0.15  6.32
2.1   25.0  9.80E+02  -0.0155    0.0053  0.0061   0.0046  2   2.39    0.26  0.45 21.48
2.3   25.0  9.80E+02  -0.0997    0.0071  0.0088   0.0077  2   0.19    0.02  0.05  3.41
2.54  25.0  9.80E+02  -0.1910    0.0041  0.0116   0.0103  2   0.11    0.15  0.25  2.22
2.92  25.0  9.80E+02  -0.3997    0.0090  0.0223   0.0210  2   0.01    0.2   0.33  0.87
```

“.data” file

```
+++ N(EV pairs)
      27
+++ ObservableFile
  CT14HERA2ex/tabs/E160.If1363
  CT14HERA2ex/tabs/E101.If1363
  CT14HERA2ex/tabs/E102.If1363
  CT14HERA2ex/tabs/E104.If1363
  CT14HERA2ex/tabs/E108.If1363
  CT14HERA2ex/tabs/E109.If1363
  CT14HERA2ex/tabs/E110.If1363
  CT14HERA2ex/tabs/E111.If1363
  CT14HERA2ex/tabs/E124.If1363
  CT14HERA2ex/tabs/E125.If1363
  CT14HERA2ex/tabs/E126.If1363
  CT14HERA2ex/tabs/E127.If1363
  CT14HERA2ex/tabs/E147.If1363
  CT14HERA2ex/tabs/E145.If1363
  CT14HERA2ex/tabs/E169.If1363
  CT14HERA2ex/tabs/E201.If1363
  CT14HERA2ex/tabs/E203.If1363
  CT14HERA2ex/tabs/E204.If1363
  CT14HERA2ex/tabs/E225.If1363
  CT14HERA2ex/tabs/E227.If1363
  CT14HERA2ex/tabs/E234.If1363
  CT14HERA2ex/tabs/E260.If1363
  CT14HERA2ex/tabs/E261.If1363
  CT14HERA2ex/tabs/E267.If1363
  CT14HERA2ex/tabs/E268.If1363
  CT14HERA2ex/tabs/E240.If1363
  CT14HERA2ex/tabs/E241.If1363
  CT14HERA2ex/tabs/E281.If1363              13      Y      1      1.0
  CT14HERA2ex/tabs/E266.If1363              11      Y      1      1.0
  CT14HERA2ex/tabs/E504.If1363              72      Y      1      1.0
  CT14HERA2ex/tabs/E514.If1363             110      Y      1      1.0
  CT14HERA2ex/tabs/E535.If1363              90      Y      1      1.0
  CT14HERA2ex/tabs/E538.If1363             133      Y      1      1.0
+++      PDFin           PDFout
  PDFs/CT14HERA2ex/If1363   CT14HERA2ex/PDFtmp/If1363
```

“.in” file

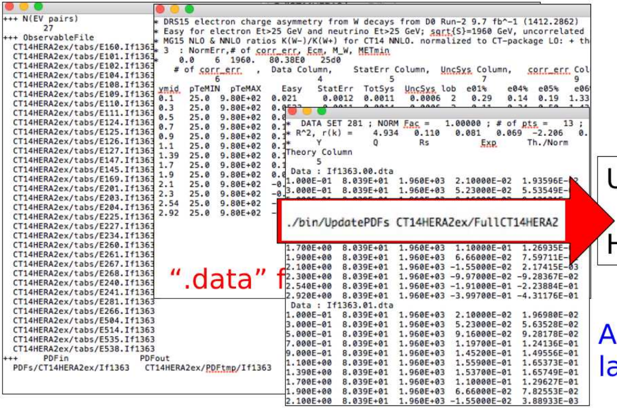
How to use ePump



".in" file

".theory" file

How to use ePump



Updated best-fit and Hessian Error PDFs

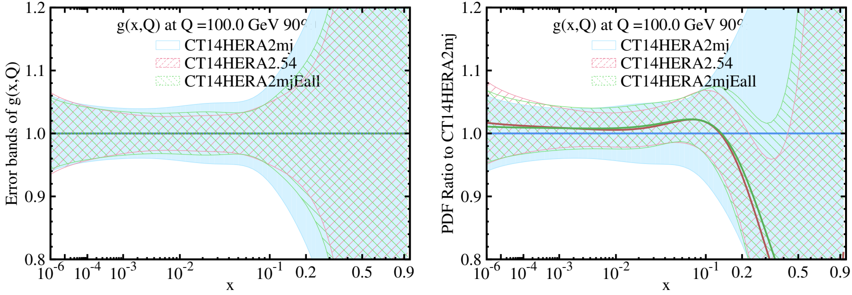
A few seconds later...

".in" file

".theory" file

Test 1: CT14HERA2 minus Jets

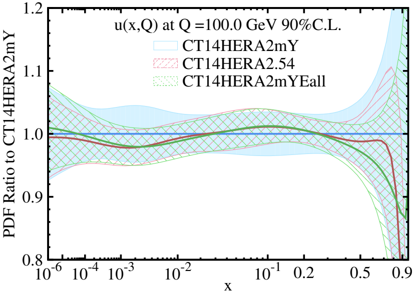
- Remove all CDF, D0, ATLAS 7TeV, CMS TeV jet data from CT14HERA2 and refit → CT14HERA2mj.
- Add back the 4 data sets to CT14HERA2mj by ePump and compare with CT14HERA2.



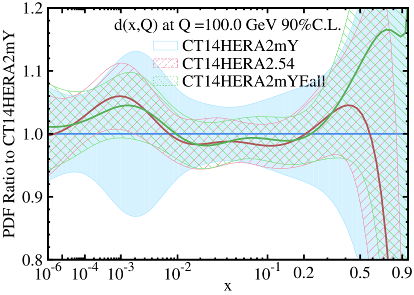
gluon - PDF

Test 2: CT14HERA2 minus Drell-Yan

- Remove 19 Drell-Yan data sets (fixed target exp., Tevatron and LHC) from CT14HERA2 and refit → CT14HERA2mY.
- Add back the 19 data sets to CT14HERA2mY by ePump and compare with CT14HERA2.



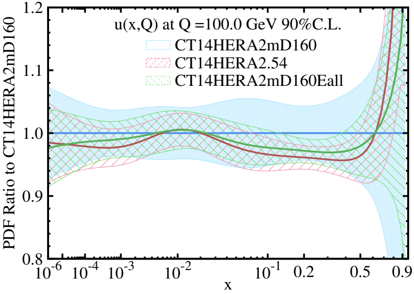
u-PDF

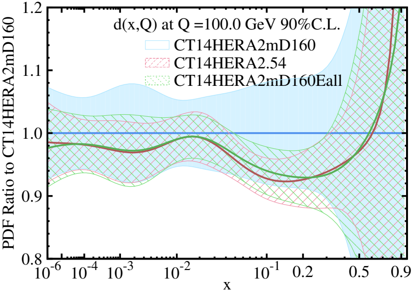


d-PDF

Test 3: CT14HERA2 minus DIS

- Remove 14 DIS data sets (excluding HERA1+2) from CT14HERA2 and refit → CT14HERA2mD160.
- Add back the 14 data sets to CT14HEA2mD160 by ePump and compare with CT14HERA2.

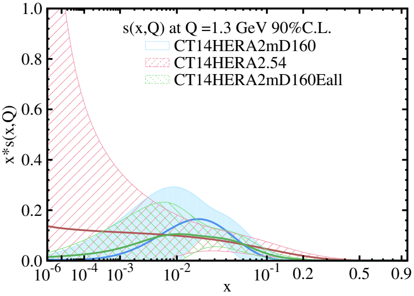




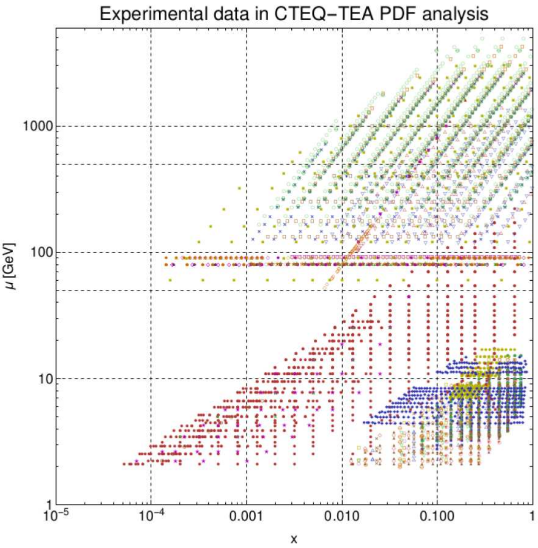
u-PDF **d-PDF**

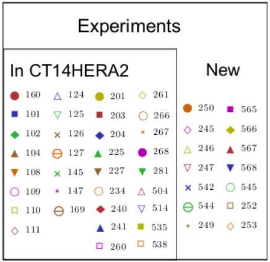
Test 3: CT14HERA2 minus DIS (2)

- Almost all of constraints on s-PDF are from NuTeV and CCFR neutrino dimuon data.



ePump work well in the x region constrained by data.

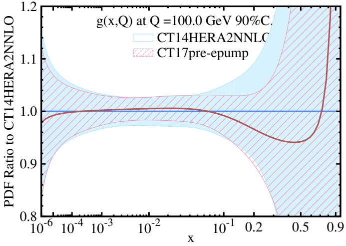


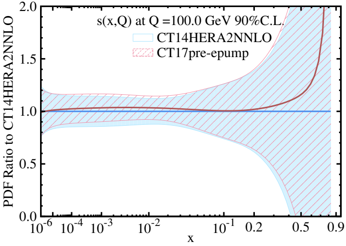


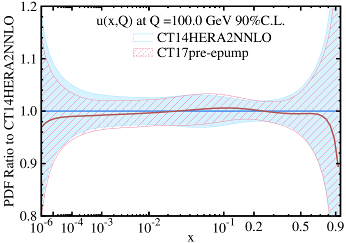
ID#	Experimental dataset		N_{pt}
245	LHCb 7 TeV Z/W muon forward-η Xsec (1.0 fb^{-1})	[71]	33
246	LHCb 8 TeV Z electron forward-η $d\sigma/dy_Z$ (2.0 fb^{-1})	[72]	17
247	ATLAS 7 TeV $d\sigma/dp_T^Z$ (4.7 fb^{-1})	[73]	8
249	CMS 8 TeV W muon, Xsec, $A_\mu(\eta^\mu)$ (18.8 fb^{-1})	[74]	33
250	LHCb 8 TeV W/Z muon, Xsec, $A_\mu(\eta^\mu)$ (2.0 fb^{-1})	[75]	42
252	ATLAS 8 TeV Z $(d^2\sigma/d\lvert y\rvert_{ll}dm_{ll})$ (20.3 fb^{-1})	[76]	48
253	ATLAS 8 TeV $(d^2\sigma/dp_T^Z dm_{ll})$ (20.3 fb^{-1})	[77]	45
542	CMS 7 TeV incl. jet, R=0.7, $(d^2\sigma/dp_T^j dy_j)$ (5 fb^{-1})	[36]	158
544	ATLAS 7 TeV incl. jet, R=0.6, $(d^2\sigma/dp_T^j dy_j)$ (4.5 fb^{-1})	[35]	140
545	CMS 8 TeV incl. jet, R=0.7, $(d^2\sigma/dp_T^j dy_j)$ (19.7 fb^{-1})	[37]	185
565	ATLAS 8 TeV $t\bar{t}$ $d\sigma/dp_T^t$ (20.3 fb^{-1})	[40]	8
566	ATLAS 8 TeV $t\bar{t}$ $d\sigma/dy_{<t/\bar{t}>}$ (20.3 fb^{-1})	[40]	5
567	ATLAS 8 TeV $t\bar{t}$ $d\sigma/dm_{t\bar{t}}$ (20.3 fb^{-1})	[40]	7
568	ATLAS 8 TeV $t\bar{t}$ $d\sigma/dy_{t\bar{t}}$ (20.3 fb^{-1})	[40]	5

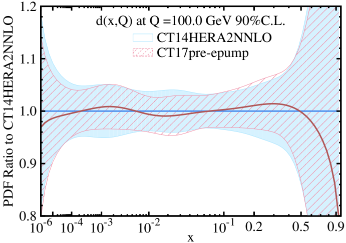
Adding New Data with ePump

$g(x, Q)$ $s(x, Q)$



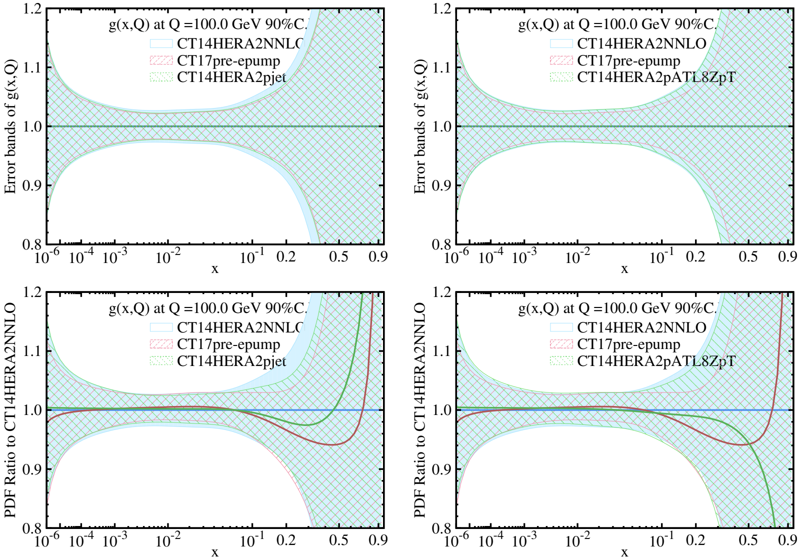




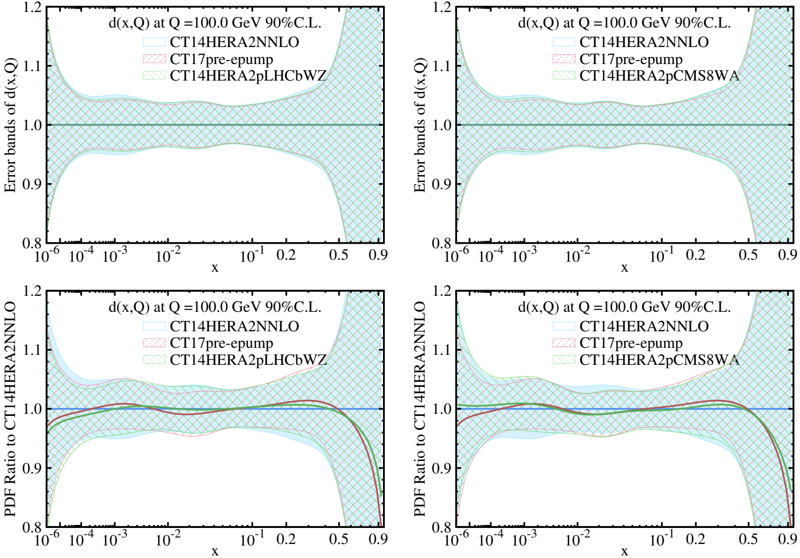


$u(x, Q)$ $d(x, Q)$

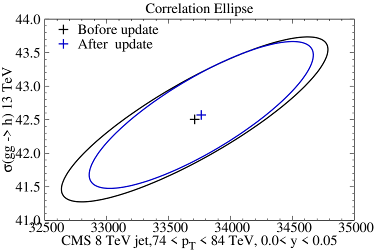
The update on gluon PDF is dominated by jet data.

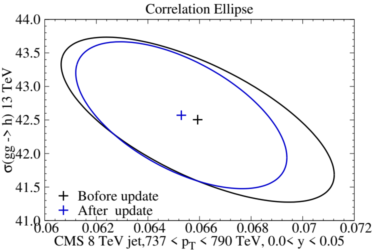


The update on d quark come from LHCb WZ production and CMS W-asym data.



Effect of Updating on $\sigma(gg \to H)$





	$\sigma(gg \to h)$ 7 TeV
CT14HERA2	14.60 $\pm$0.44
updated	14.62 $\pm$0.40
	$\sigma(gg \to h)$ 8 TeV
CT14HERA2	18.60 $\pm$0.55
updated	18.64 $\pm$0.49
	$\sigma(gg \to h)$ 13 TeV
CT14HERA2	42.56 $\pm$1.23
updated	42.69 $\pm$1.07
	$\sigma(gg \to h)$ 14 TeV
CT14HERA2	47.99 $\pm$1.39
updated	48.14 $\pm$1.20

Summary

- The **Sensitivity** $S_f(x_i, \mu_i)$ provide an easy way to visualize the potential impact to PDF in $x - Q$ plane (arxiv:1803.02777).
- The **PDFsense**, which can work out the sensitivity, is public available at
  http://metapdf.hepforge.org/PDFSense/
- **UpdatePDFs** function in **ePump** package is a fast and efficient method to estimate the effect of new data on the a current set of best-fit and Hessian error PDFs (arxiv:1806.07950).
- Extensively cross-checked against CT14 global fits
- ePump code is public available at
  http://hep.pa.msu.edu/epump/