CTEQ-TEA Parton distribution functions and α_s

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in collaboration with
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CTEQ-Tung Et Al.: recent activities

- Uncertainty induced by α_s in the CTEQ-TEA PDF analysis *(PRD, arXiv:1004.4624)*
- New PDFs for collider physics
  - CTEQ6.6 set (published in 2008) $\rightarrow$ CT09 $\rightarrow$ CT10, CT10W *(PRD, arXiv:1007.2241)*
  - new experimental data, statistical methods, and parametrization forms
- PDFs for Event Generators *(JHEP, arXiv:0910.4183)*
- Exploration of statistical aspects and PDF parametrization dependence *(PRD, arXiv:0909.0268 and 0909.5176)*

Uncertainty in α_s in the CTEQ-TEA PDF analysis

arXiv:1004.4624

- Two leading theoretical uncertainties in LHC processes are due to α_s and the PDFs
- These are not independent uncertainties; how can one quantify their correlation?
- Which central $\alpha_s(M_Z)$ and which error on $\alpha_s(M_Z)$ are to be used with the existing PDFs?
- What are the consequences for key LHC processes ($gg \to H^0$, etc.)?

Uncertainty in α_s in the CTEQ-TEA PDF analysis

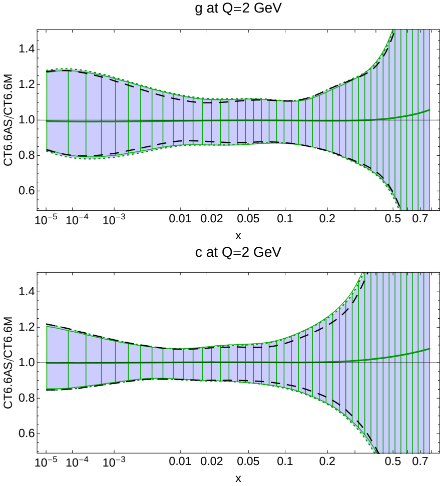
arXiv:1004.4624

Recent activity to examine these questions, e.g.:

- **MSTW** *(arXiv:0905.3531)*
  - $\alpha_s(M_Z)$ is an **output** of the global fit (constrained by the hadronic scattering only)
  - several sets of error PDFs, each with its own $\alpha_s(M_Z)$ value $\Rightarrow$ lengthier calculations
  - The α_s uncertainty and PDF uncertainty are inseparable
- **NNPDF** *(in 2009 Les Houches Proceedings, arXiv:1004.0962)*:
  - $\alpha_s(M_Z) = 0.119 \pm 0.002$ is taken as an **input**
  - α_s-PDF correlation is examined with ~ 1000 PDF replicas and found to be small
- **H1+ZEUS** *(arXiv:0911.0884)*: sensitivity of the HERAPDF set to $\delta\alpha_s(M_Z) = \pm 0.002$ is explored

Our findings

Total PDF+α_s errors ΔX are the **same** when found (a) from a full fit with floating α_s, or (b) by adding ΔX_{PDF} and ΔX_{α_s} in quadrature



- black – CTEQ6.6 PDF uncertainty
- Blue filled – PDF+α_s uncertainty of the fit with floating $\alpha_s(M_Z)$
- Green hatched – PDF+α_s uncertainty added in quadrature

Also, agreement in cross section predictions

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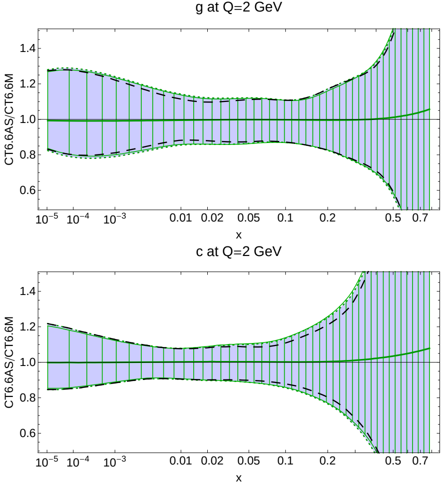


This agreement is
a rigorous consequence
of the quadratic
approximation for χ^2

Details of the CTEQ6.6FAS analysis

- Take the "world-average" $\alpha_s(M_Z) = 0.118 \pm 0.002$ as an **input**:

$$\alpha_s(M_Z)|_{\text{in}} = 0.118 \pm 0.002 \text{ at } 90\% \text{ C.L.}$$

- Find the theory parameter $\alpha_s(M_Z)$ as an **output** of a global fit (CTEQ6.6FAS):

$$\alpha_s(M_Z)|_{\text{out}} = 0.118 \pm 0.0019 \text{ at } 90\% \text{ C.L.}$$

- The combined PDF+α_s uncertainty is estimated as

$$\Delta X = \frac{1}{2}\sqrt{\sum_{i=1}^{22+1}\left(X_i^{(+)} - X_i^{(-)}\right)^2}$$

- **Problem:** each PDF set comes with its own $\alpha_s \Rightarrow$ cumbersome
- **A simple workaround exists!**

A quadrature sum reproduces the α_s-PDF correlation

H.-L. Lai, J. Pumplin

Theorem

In the quadratic approximation, the total α_s+PDF uncertainty $\Delta\sigma$ of the CTEQ6.6FAS set, with all correlation, reduces to

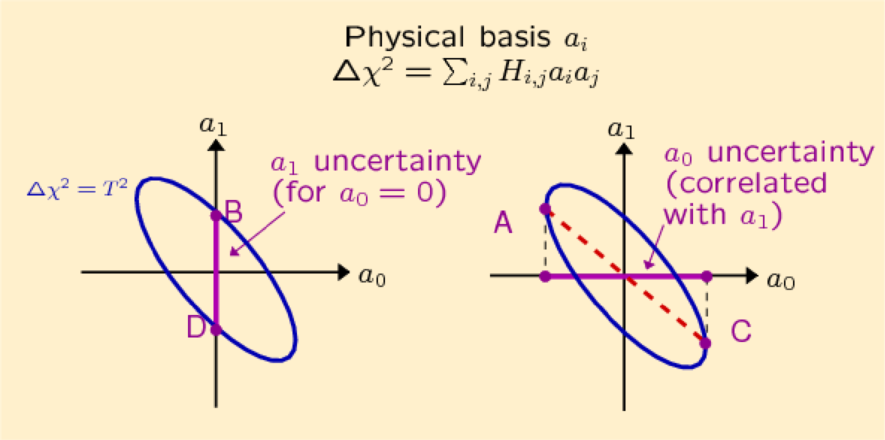
$$\Delta X = \sqrt{\Delta X^2_{CTEQ6.6} + \Delta X^2_{\alpha_s}},$$

where

- $\Delta X_{CTEQ6.6}$ *is the CTEQ6.6 PDF uncertainty from 44 PDFs with the same* $\alpha_s(M_Z) = 0.118$
- $\Delta X_{\alpha_s} = (X_{0.120} - X_{0.116})/2$ *is the* α_s *uncertainty computed with two central CTEQ6.6AS PDFs for* $\alpha_s(M_Z) = 0.116$ *and* 0.120

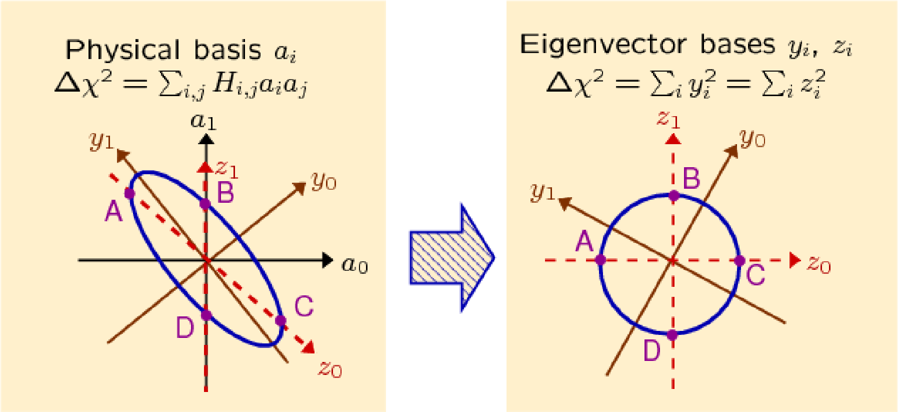
The full proof is given in the paper; the main idea is illustrated for the α_s parameter a_0 and 1 PDF parameter a_1

Illustration of the theorem for 2 parameters



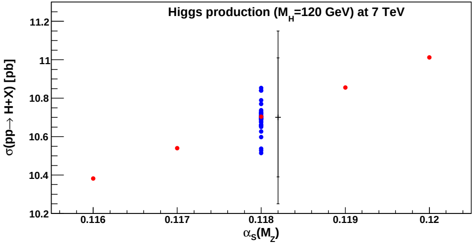
$$\Delta X_1^2 = \frac{1}{4}\left(X(B) - X(D)\right)^2 \qquad \Delta X_0^2 = \frac{1}{4}\left(X(A) - X(C)\right)^2$$

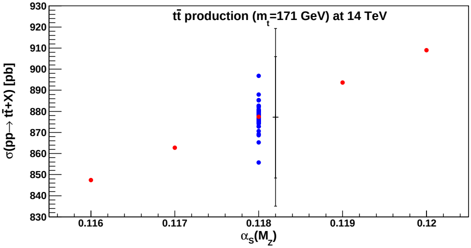
Illustration of the theorem for 2 parameters, cont.



$$\Delta X^2 = \frac{1}{4}\left[(X(A) - X(C))^2 + (X(B) - X(D))^2\right]$$
$$= \Delta X_0^2 + \Delta X_1^2$$

PDF and α_s uncertainties for $gg \to H$ and $t\bar{t}$ production





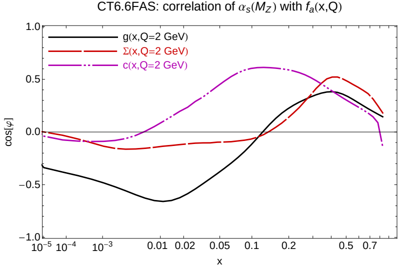
Full and reduced fits with variable α_s: cross sections

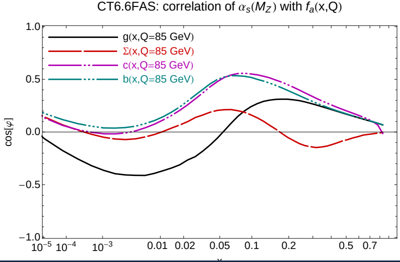
Process	CTEQ6.6+CTEQ6.6AS				CTEQ6.6FAS
$t\bar{t}$ (171 GeV)	σ_0	$\Delta\sigma_{PDF}$	$\Delta\sigma_{\alpha_s}$	$\Delta\sigma$	$\sigma_0 \pm \Delta\sigma$
LHC 7 TeV	157.41	10.97	7.54	13.31	160.10 ± 13.93
LHC 10 TeV	396.50	18.75	16.10	24.71	400.48 ± 25.74
LHC 14 TeV	877.19	28.79	30.78	42.15	881.62 ± 44.27
$gg \to H$ (120 GeV)	σ_0	$\Delta\sigma_{PDF}$	$\Delta\sigma_{\alpha_s}$	$\Delta\sigma$	$\sigma_0 \pm \Delta\sigma$
Tevatron 1.96 TeV	0.63	0.042	0.032	0.053	0.64 ± 0.055
LHC 7 TeV	10.70	0.31	0.32	0.45	10.70 ± 0.48
LHC 10 TeV	20.33	0.66	0.56	0.87	20.28 ± 0.93
LHC 14 TeV	35.75	1.31	0.94	1.61	35.63 ± 1.70
$gg \to H$ (160 GeV)	σ_0	$\Delta\sigma_{PDF}$	$\Delta\sigma_{\alpha_s}$	$\Delta\sigma$	$\sigma_0 \pm \Delta\sigma$
Tevatron 1.96 TeV	0.26	0.026	0.015	0.030	0.26 ± 0.031
LHC 7 TeV	5.86	0.16	0.18	0.24	5.88 ± 0.26
LHC 10 TeV	11.73	0.33	0.33	0.47	11.72 ± 0.50
LHC 14 TeV	21.48	0.68	0.56	0.88	21.43 ± 0.94
$gg \to H$ (250 GeV)	σ_0	$\Delta\sigma_{PDF}$	$\Delta\sigma_{\alpha_s}$	$\Delta\sigma$	$\sigma_0 \pm \Delta\sigma$
Tevatron 1.96 TeV	0.055	0.0099	0.0044	0.011	0.058 ± 0.012
LHC 7 TeV	2.30	0.085	0.081	0.12	2.32 ± 0.12
LHC 10 TeV	5.08	0.14	0.15	0.21	5.10 ± 0.22
LHC 14 TeV	10.03	0.26	0.27	0.37	10.04 ± 0.41

The full and reduced methods perfectly agree

Correlations between α_s and PDFs

Correlation cosine $\cos\phi$ between the best-fit $\alpha_s(M_Z)$ and PDFs, plotted as a function of the momentum fraction x.



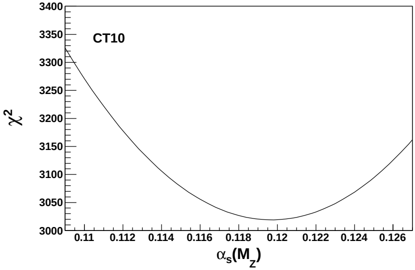


- solid – gluon PDF; anticorrelated at $x \sim 0.01$; from HERA NC-DIS
- dashed – singlet PDF; correlated at $x \sim 0.4$; from BCDMS and NMC NC-DIS
- dashed-dotted – heavy quark (c, b) PDFs; correlated at $x \sim 0.05$ - 0.2; from HERA

At large Q, these correlations are reduced by PDF evolution, except heavy-quark PDFs.

Full fit with floating α_s in CT10.AS Series

The Minimal χ^2 found from a full fit with floating α_s in CT10.AS series.



The $\Delta\chi^2 = 100$ range (at 90% C.L.) is 0.1197 ± 0.0061 **which is a rather weak constraint as compare to the world-average** $\alpha_s(M_Z) = 0.118 \pm 0.002$

Summary

CTEQ6.6AS and CT10.AS PDF sets (available in LHAPDF):

- from 4 alternative CTEQ6.6 fits (http://hep.pa.msu.edu/cteq/public/cteq6.html) for

$$\alpha_s(M_Z) = 0.116, 0.117, 0.119,\ 0.120$$

- sufficient to compute uncertainty in $\alpha_s(M_Z)$ at $\approx$ 68% and 90% C. L., including **the world-average** $\alpha_s(M_Z) = 0.118 \pm 0.002$ as an **input data point**
- **The CTEQ6.6AS** α_s uncertainty should be combined with the CTEQ6.6 PDF uncertainty as

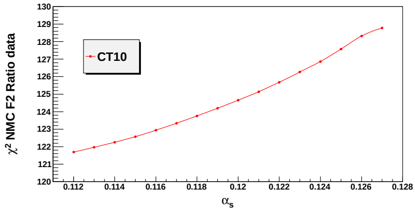
$$\Delta X = \sqrt{\Delta X^2_{CTEQ6.6} + \Delta X^2_{CTEQ6.6AS}}$$

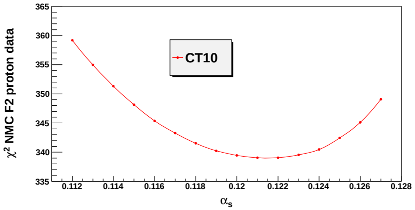
- The total uncertainty ΔX reproduces the full correlation between $\alpha_s(M_Z)$ and PDFs
- A larger range (from 0.113 to 0.123) of $\alpha_s(M_Z)$ for CT10/W.AS series is given at http://hep.pa.msu.edu/cteq/public/ct10.html

Backup slides

NMC F_2^d/F_2^p and F_2^p data vs. α_s

Minimal χ^2 from a full fit with floating α_s in CT10.AS series.





- We did not find a significant effect of NMC F_2^d/F_2^p data on α_s, though a smaller value is mildly preferred. ($\chi^2$is close to the number of data points, which is 123.)
- NMC F_2^p data prefers a larger α_s, but $\chi^2$is much larger than the number of data points, which is 201.)
- We will examine the NMC reduced cross section (instead of F_2) in the next version of CTEQ-TEA fits.