LHC cross section benchmarking: introduction and CTEQ

J. Huston
Michigan State University
for the TEA (Tung et al) group

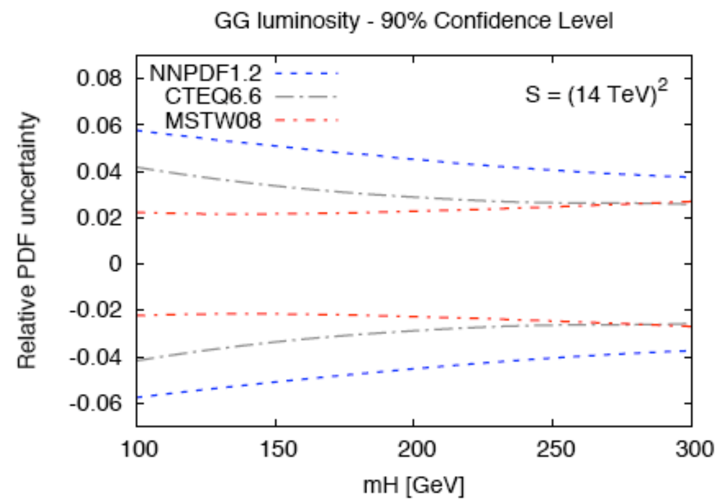
PDF4LHC meeting

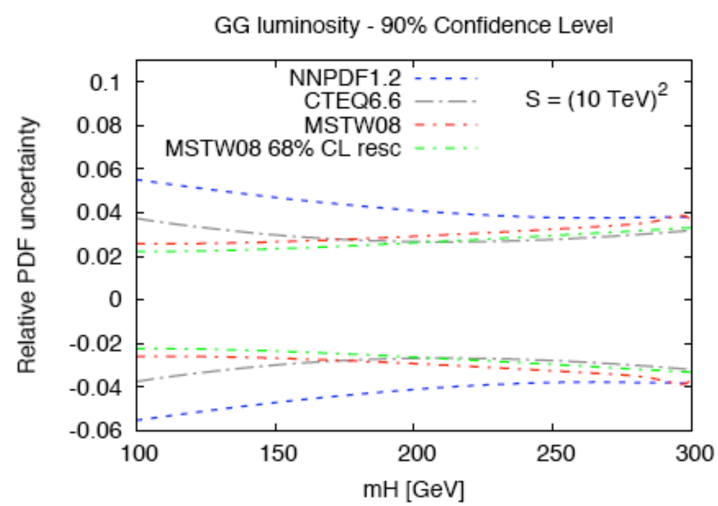
March 26, 2010

…but first, a brief introduction

- The calculation of PDF uncertainties for LHC cross sections is becoming more topical, as LHC cross sections are getting closer to reality
- The LHC experiments have gone/are going through exercises tabulating important cross sections and their uncertainties
- In many cases, the estimates of cross sections and uncertainties from the PDF groups (such as CTEQ, MSTW, NNPDF…) are closer than many people thought
- A discussion, started at Les Houches, was formalized within the PDF4LHC working group to perform some benchmarking tests to understand the commonalities and differences between the predictions and uncertainties of the different PDF groups
- At this meeting, we give initial reports

see for example, A. Vicini's talk at the last PDF4LHC meeting





PDF errors

- So now, seemingly, we have more consistency (at least in some cases) in the size of PDF errors
- The eigenvector sets (or NNPDF equivalent) represent the PDF uncertainty due to the experimental errors in the datasets used in the global fitting process
- Another uncertainty is that due to the variation in the value of α_s
- MSTW has recently tried to better quantify the uncertainty due to the variation of α_s, by performing global fits over a finer range, taking into account correlations between the values of α_s and the PDF errors
- …more recent studies by CTEQ and NNPDF as shown in the talks in the Jan PDF4LHC meeting, and in Les Houches writeup

$\alpha_s(m_Z)$ and uncertainty

- Different values of α_s and of its uncertainty are used
- CTEQ and NNPDF use the world average (actually 0.118 for CTEQ and 0.119 for NNPDF), where MSTW2008 uses 0.120, as determined from their best fit
- Latest world average (from Siggi Bethke->PDG)
  - α_s (m_Z) = 0.1184 +/- 0.0007
- What does the error represent?
  - Siggi said that only one of the results included in his world average was outside this range
  - suppose we say that +/-0.002 is a reasonable estimate of the uncertainty
- Could it be possible for all global PDF groups to use the world average value of α_s in their fits, plus a prescribed 90% range for its uncertainty (if not 0.002, then perhaps another acceptable value)?
- For the moment, we try determining uncertainties from α_s over a range of +/- 0.002 from the central value for each PDF group; we also calculate cross sections with a common value of α_s=0.119 for comparison purposes

(My) interim recommendation for ATLAS Higgs

- Cross sections should be calculated with MSTW2008, CTEQ6.6 (and NNPDF)
- Upper range of prediction should be given by upper limit of error prediction using prescription for combining α_s uncertainty with error PDFs
  - in quadrature for CTEQ6.6
  - using eigenvector sets for different values of α_s for MSTW2008
  - (my suggestion) as standard, use 90%CL limits
- Ditto for lower limit
- So for a Higgs mass of 120 GeV at 14 TeV, the gg cross section limits would be 34.8 pb (defined by the CTEQ6.6 lower limit) and 41.4 pb (defined by the MSTW2008 upper limit; combined eigenvector + α_s error = 3 pb)
  - with the difference between the central values primarily due to α_s
- One of the purposes of this benchmarking exercise is to see if we can come up with a universal prescription for calculating the uncertainty
- …which would go into a PDF4LHC writeup

PDF Benchmarking Exercise 2010

- Benchmark processes, all to be calculated

  (i) at NLO (in MSbar scheme)

  (ii) in 5-flavour quark schemes (definition of scheme to be specified)

  (iii) at 7 TeV [and 14 TeV] LHC

  (iv) for central value predictions and +-68%cl [and +- 90%cl] pdf uncertainties

  (v) and with +- α_s uncertainties

  (vi) repeat with $\alpha_s(m_Z)=0.119$

  (prescription for combining with pdf errors to be specified)

- Using (where processes available) MCFM 5.7
  - gzipped version prepared by John Campbell using the specified parameters and exact input files for each process (and the new CTEQ6.6 α_s series)->thanks John!
  - sent out on first week of March (and still available to any interested parties)
  - statistics ok for total cross section comparisons

Cross Sections

1. W^+, W^-, and Z total cross sections and rapidity distributions total cross section ratios W^+/W^- and $(W^+ + W^-)/Z$, rapidity distributions at y = -4,-3,...,+4 and also the W asymmetry: A_W(y) = $(dW^+/dy - dW^-/dy)/(dW^+/dy + dW^-/dy)$ using the following parameters taken from PDG 2009
   - M_Z=91.188 GeV
   - M_W=80.398 GeV
   - zero width approximation
   - G_F=0.116637 X 10^{-5} GeV^{-2}
   - other EW couplings derived using tree level relations
   - BR(Z-->ll) = 0.03366
   - BR(W-->lnu) = 0.1080
   - CKM mixing parameters from eq.(11.27) of PDG2009 CKM review

	0.97419	0.2257	0.00359
V_CKM =	0.2256	0.97334	0.0415
	0.00874	0.0407	0.999133

   - scales: $\mu_R = \mu_F = M_Z$ or M_W

Cross Sections

2. gg->H total cross sections at NLO

- M_H = 120, 180 and 240 GeV
- zero Higgs width approximation, no BR
- top loop only, with m_{top} = 171.3 GeV in sigma_0
- scales: $\mu_R = \mu_F = M_H$

3. ttbar total cross section at NLO

- m_{top} = 171.3 GeV
- zero top width approximation, no BR
- scales: $\mu_R = \mu_F = m_{top}$

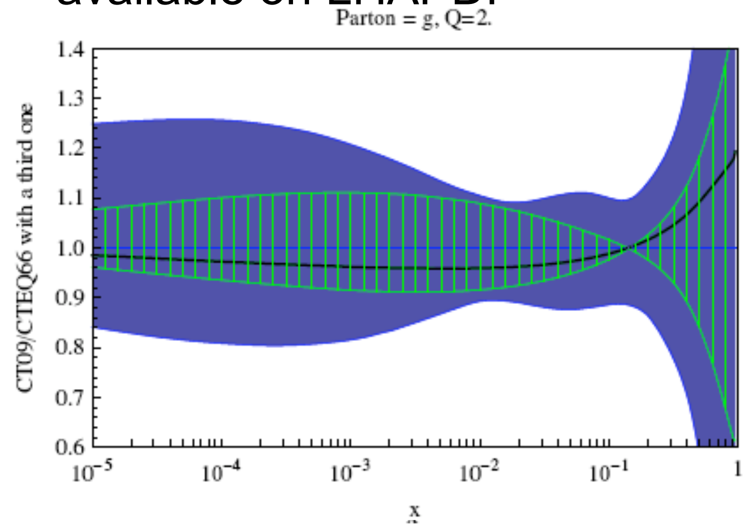
The following are optional

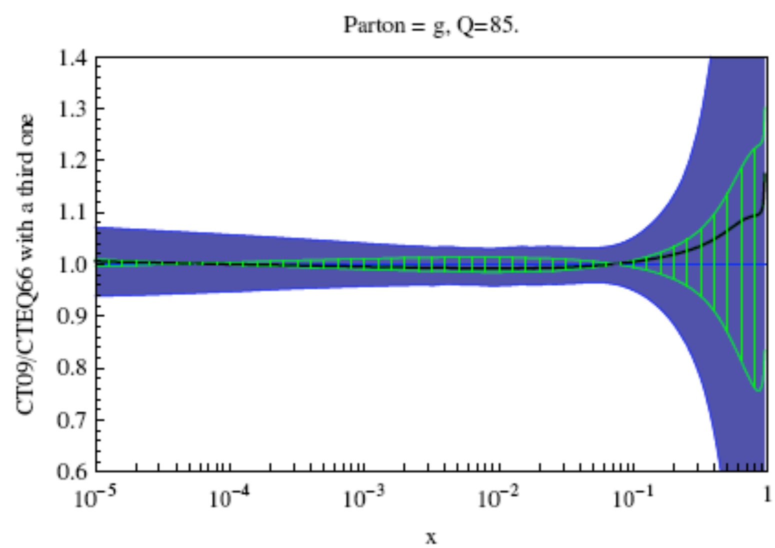
4. inclusive jet cross section distribution at NLO
   - use FastNLO "fnl0004" option with sqrt(s) = 14 TeV, D=0.7 k_T algorithm
   - jet rapidity bin: $0 < |y_J| < 0.8$
   - scales: mu_R = mu_F = p_T^J
5. Drell-Yan NLO dsigma /dM dy at y=0 for e.g. M = 7 and 14 GeV
   - scales: mu_R = muF = M
   - coupling = alpha_em(0) = 1/137.036

For CTEQ: α_s series

- Take CTEQ6.6 as base, and vary $\alpha_s(m_Z)$ +/-0.002 (in 0.001 steps) around central value of 0.118
- Blue is the PDF uncertainty from eigenvectors; green is the uncertainty in the gluon from varying α_s
- We have found that α_s error (+/-0.002 range) is typically smaller than PDF uncertainty and negligibly correlated with PDF uncertainty over this range
  - as shown for gluon distribution on right
  - similar to NNPDF study in Les Houches
  - details in new paper
- Because of this we add PDF error and α_s error in quadrature
- So the CTEQ prescription for calculating the total uncertainty (PDF $+\alpha_s$) involves the use of the 45 CTEQ6.6 PDFs and the two extreme α_s error PDF's (0.116 and 0.120)

paper in preparation: α_s sets available on LHAPDF





Results: 7 TeV

		our default error PDF's are 90% CL	divide by 1.65; not a direct determination	over range of 0.116 to 0.120	add in quadrature (90% + α_s)	
Process	$\sigma_{CTEQ6.6}$	PDF uncertainties (90% CL)	PDF uncertainties (68% CL)	α_s uncertainty	Total uncertainty (90% CL PDF + α_s)	$\sigma_{\alpha s=0.119}$
W^-	38.0 nb (+/-0.03 nb) stat error	+1.33 nb -1.39 nb	+0.81 nb -0.84 nb	+0.026 nb -0.045 nb	+1.33 nb -1.39 nb	38.1 nb
W^+	56.05 nb (+/-0.04nb)	+1.87 nb -1.81 nb	+1.13 nb -1.10 nb	+0.35 -0.75	+1.90 nb -1.96 nb	56.12 nb
Z	28.11 nb (+/- 0.02 nb)	+0.89 nb -0.90 nb	+0.54 nb -0.55 nb	+0.19 nb -0.31 nb	+0.91 nb -0.95 nb	28.17 nb
W^+/W^-	1.475	+0.07 -0.02	+0.04 -0.012	~0.002	+0.07 -0.02	1.473
$(W^++W^-)/Z$	3.346	+0.007 -0.007	+0.004 -0.004	+~0 -0.006	+0.007 -0.009	3.345

14 TeV

Process	$\sigma_{CTEQ6.6}$	PDF uncertainties (90% CL)	PDF uncertainties (68% CL)	α_s uncertainty	Total uncertainty (90% CL PDF + α_s)	$\sigma_{\alpha s=0.119}$
W^-	84.54 nb (+/-0.07 nb)	+3.42 nb -3.41 nb	+2.07 nb -2.07 nb	+0.83 nb -1.22 nb	+3.52 nb -3.62 nb	84.86 nb
W^+	115.18 nb (+/-0.10 nb)	+4.55 nb -4.23 nb	+2.76 nb -2.56 nb	+1.25 nb -1.68 nb	+4.72 nb -4.55 nb	115.68 nb
Z	61.57 nb (+/-0.05 nb)	+2.33 nb -2.27 nb	+1.41 nb -1.38 nb	+0.62 nb -0.84 nb	+2.41 nb -2.42 nb	61.82 nb
W^+/W^-	1.362	+0.06 -0.01	+0.036 -0.01	+0.03 ~-0	+0.062 -0.01	1.388
$(W^++W^-)/Z$	3.234	+0.021 -~0	+0.013 -~0	+0.011 -~0	+0.024 -~0	3.244

7 TeV

Process	$\sigma_{CTEQ6.6}$ *	PDF uncertainties (90% CL)	PDF uncertainties (68% CL)	α_s uncertainty	Total uncertainty (90% CL PDF + α_s)	$\sigma_{\alpha s=0.119}$
tt	156.2 pb (+/-0.15 pb)	+11.5 pb -10.4 pb	+7.0 pb -6.3 pb	+2.3 pb -1.45 pb	+11.7 pb -10.5 pb	157.6 pb
gg->Higgs (120 GeV)	10925 fb (+/-6 fb)	+299 fb -353 fb	+181 fb -214 fb	+135 fb -143 fb	+328 fb -371 fb	10851 fb
gg->Higgs (180 GeV)	4201 fb (+/- 3 fb)	+112 fb -126 fb	+68.8 fb -76.4 fb	+33.4 fb -30.3 fb	+116.9 fb -129.6 fb	4187 fb
gg->Higgs (240 GeV)	1989 fb (+/- 1.5 fb)	+68 fb -73 fb	+41.2 fb -44.2 fb	+7 fb -5 fb	+68 fb -73 fb	1988 fb
	*Higgs numbers not corrected for finite top mass effects	correction factors are 1.06 for 120, 1.15 for 180 and 1.31 for 240 GeV				

14 TeV

Process	$\sigma_{CTEQ6.6}$	PDF uncertainties (90% CL)	PDF uncertainties (68% CL)	α_s uncertainty	Total uncertainty (90% CL PDF + α_s)	$\sigma_{\alpha s=0.119}$
tt	871.0 pb (+/- 0.07 pb)	+28 pb -30 pb	+17 pb -18 pb	+1.5 pb -~0 pb	+28 pb -30 pb	871.6 pb
gg->Higgs (120 GeV)	36330 fb (+/- 27 fb)	+1228 fb -1486 fb	+744 fb -900 fb	+562 fb -585 fb	+1350 -1597 fb	36027 fb
gg->Higgs (180 GeV)	16053 fb (+/-12 fb)	+434 fb -525 fb	+263 fb -318 fb	+205 fb -213 fb	+480 fb -567 fb	15944 fb
gg->Higgs (240 GeV)	8544 fb (+/-6 fb)	+206 fb -242 fb	+125 fb -147 fb	+90 fb -90 fb	+225 fb -258 fb	8499 fb

Some observations

- PDF uncertainties dominate over α_s uncertainties (using +/-0.002 range)
- Cross sections using common values of α_s=0.119 very close to nominal CTEQ6.6 cross sections
- Relatively small uncertainties for gg initiated states, except for tT at 7 TeV, which starts to probe high x region
  - α_s uncertainty also small, in particular for tT production at 7 TeV

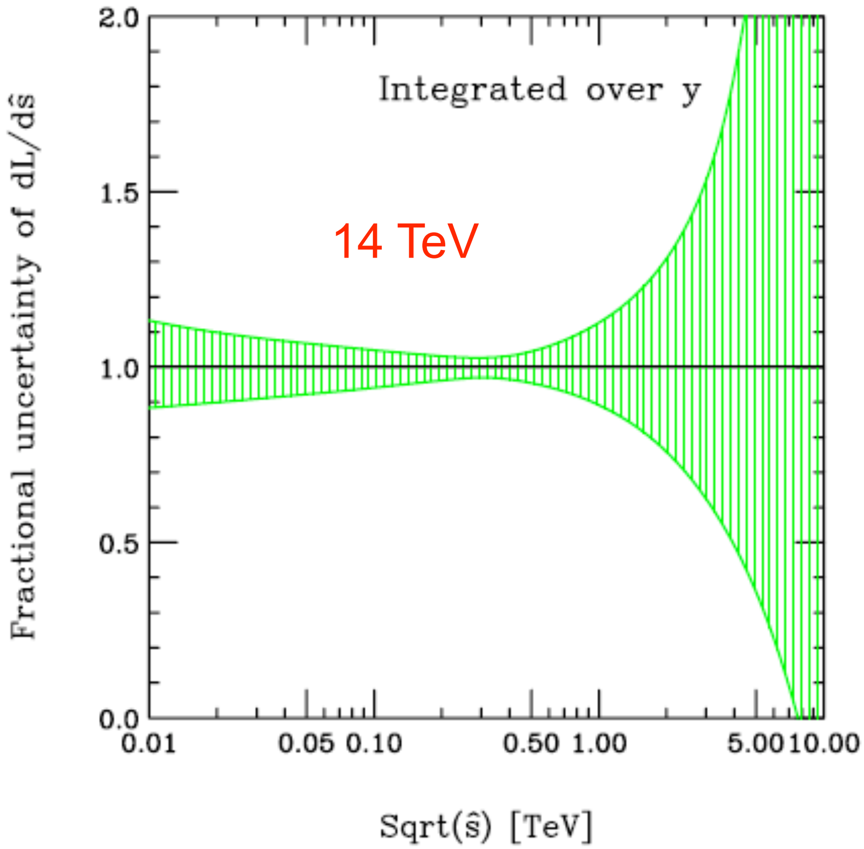


Fig. 4: Fractional uncertainty of gg luminosity integrated over y.

To do:

- Higher statistics for rapidity comparisons
- Examine correlations for 7 TeV as well as 14 TeV
- Cross-comparison of predictions from all groups
- Decide on universal prescription for uncertainties?

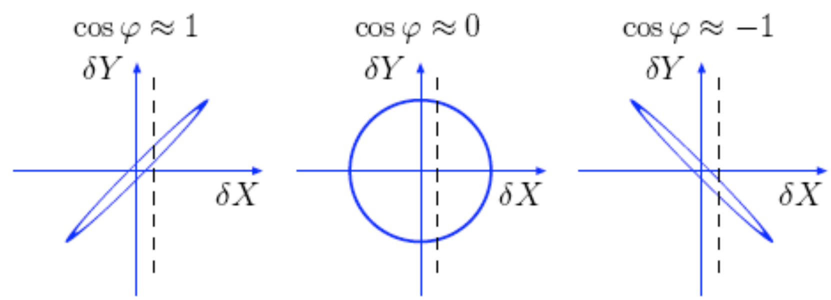


Figure 1: Dependence on the correlation ellipse formed in the $\Delta X - \Delta Y$ plane on the value of the correlation cosine $\cos\varphi$.