



# PDFs and Higgs cross sections

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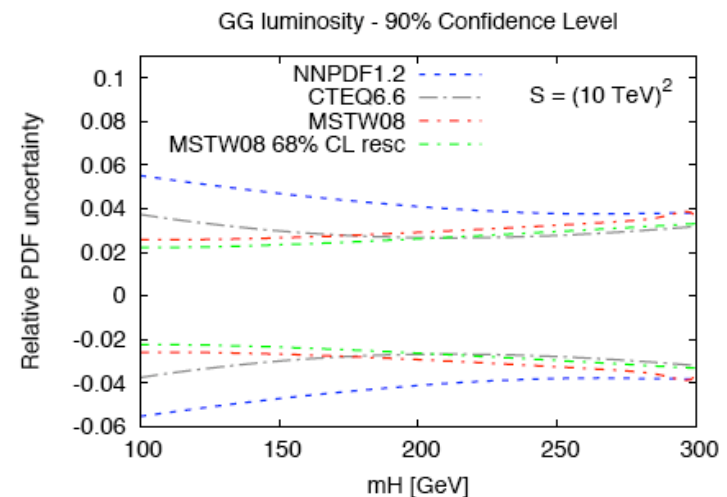
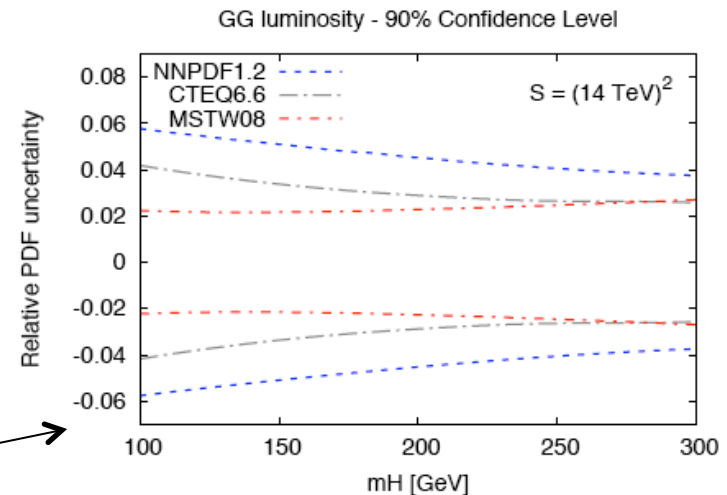
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# PDF uncertainties



- 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 the March 26 PDF4LHC meeting, we gave initial reports

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





# $\alpha_s(m_Z)$ and uncertainty

- Different values of  $\alpha_s$  and of its uncertainty are used in global fits
- 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 Sigi Bethke  $\rightarrow$  PDG)
  - ◆  $\alpha_s(m_Z) = 0.1184 \pm 0.0007$
- What does the error represent?
  - ◆ Sigi said that only one of the results included in his world average was outside this range
  - ◆ suppose we say that  $\pm 0.002$  is a reasonable estimate of the uncertainty
- Could it be possible for all global PDF groups to use the world average value of  $\alpha_s$  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  $\alpha_s$  over a range of  $\pm 0.002$  from the central value for each PDF group; we also calculate cross sections with a common value of  $\alpha_s = 0.119$  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  $\alpha_s$  uncertainty with error PDFs
  - ◆ in quadrature for CTEQ6.6
  - ◆ using eigenvector sets for different values of  $\alpha_s$  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 lower limit would be defined by the CTEQ6.6 lower limit (PDF+ $\alpha_s$  error) and the upper limit defined by the MSTW2008 upper limit (PDF+ $\alpha_s$  error)
  - ◆ with the difference between the central values primarily due to  $\alpha_s$
- 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



- Benchmark processes, all to be calculated
  - (i) at NLO (in  $\overline{\text{MS}}$  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  $\pm 68\%$ cl [and  $\pm 90\%$ cl] pdf uncertainties
  - (v) and with  $\pm \alpha_s$  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  $\alpha_s$  series)
- One of benchmark processes relevant for this workshop:  $gg \rightarrow H$  total cross sections at NLO
  - ◆  $M_H = 120, 180$  and  $240$  GeV
  - ◆ zero Higgs width approximation, no BR
  - ◆ top loop only, with  $m_{\text{top}} = 171.3$  GeV in  $\text{sigma}_0$
  - ◆ scales:  $\mu_R = \mu_F = M_H$

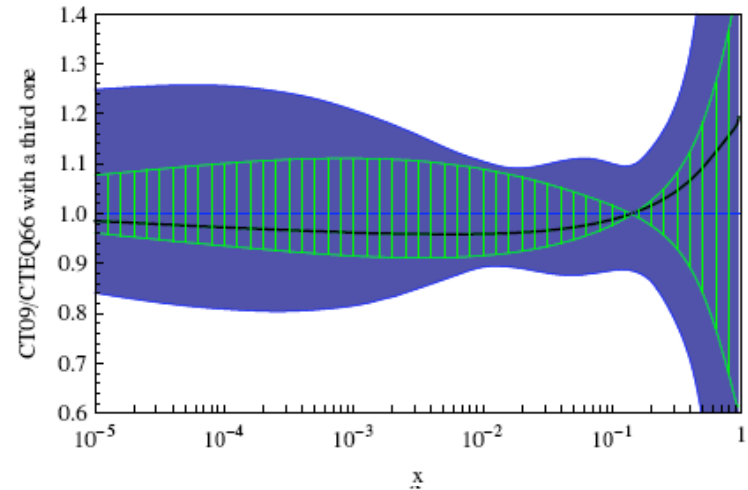
# For CTEQ: $\alpha_s$ series



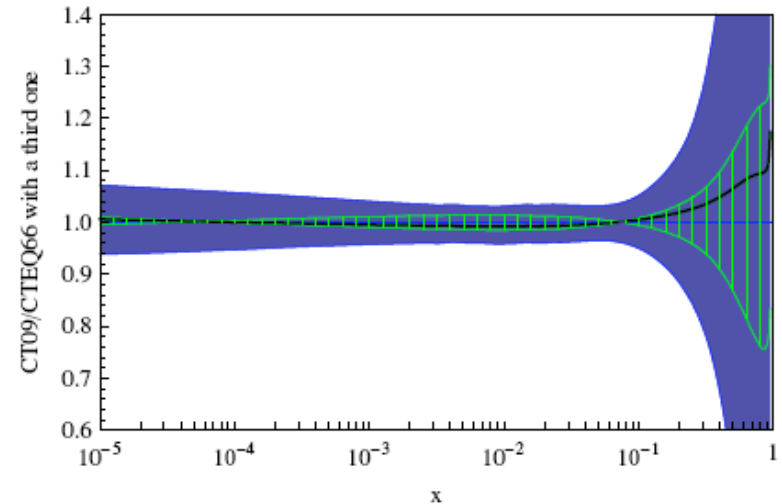
- Take CTEQ6.6 as base, and vary  $\alpha_s(m_Z) \pm 0.002$  (in 0.001 steps) around central value of 0.118
- Blue is the PDF uncertainty from eigenvectors; green is the uncertainty in the gluon from varying  $\alpha_s$
- We have found that change in gluon due to  $\alpha_s$  error ( $\pm 0.002$  range) is typically smaller than PDF uncertainty with a small correlation with PDF uncertainty over this range
  - ◆ as shown for gluon distribution on right
- Because of this small correlation, PDF error and  $\alpha_s$  error can be added 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  $\alpha_s$  error PDF's (0.116 and 0.120)

paper in preparation:  $\alpha_s$  sets available on LHAPDF

Parton = g, Q=2.



Parton = g, Q=85.





Process	$\sigma_{\text{CTEQ6.6}}^*$	PDF uncertainties (90% CL)	PDF uncertainties (68% CL)	$\alpha_s$ uncertainty	Total uncertainty (90% CL PDF + $\alpha_s$ )	$\sigma_{\alpha_s=0.119}$
gg->Higgs (120 GeV)	11596 fb (+/- 6 fb)	+317 fb -374 fb	+192 fb -227 fb	+326 fb - 343 fb	+455 fb -507 fb	11754 fb
gg->Higgs (180 GeV)	4838 fb (+/- 3 fb)	+129 fb -145 fb	+79 fb -89 fb	+152 fb -152 fb	+199 fb -210 fb	4914 fb
gg->Higgs (240 GeV)	2611 fb (+/- 1.5 fb)	+89 fb -96 fb	+54 fb -58 fb	+94 fb -87 fb	+129 fb -130 fb	2660 fb
	* Higgs numbers corrected for finite top mass effects	correction factors are 1.06 for 120, 1.15 for 180 and 1.31 for 240 GeV				



Process	$\sigma_{\text{CTEQ6.6}}^*$	PDF uncertainties (90% CL)	PDF uncertainties (68% CL)	$\alpha_s$ uncertainty	Total uncertainty (90% CL PDF + $\alpha_s$ )	$\sigma_{\alpha_s=0.119}$
gg->Higgs (120 GeV)	38554 fb (+/- 27 fb)	+1302 fb -1575 fb	+789 fb -954 fb	+965 fb -1018 fb	+1621 -1875 fb	39020 fb
gg->Higgs (180 GeV)	18461 fb (+/-12 fb)	+499 fb -604 fb	+302 fb -366 fb	+489 fb -469 fb	+699 fb -765 fb	18710 fb
gg->Higgs (240 GeV)	11193 fb (+/-6 fb)	+270 fb -317 fb	+164 fb -193 fb	+324 fb -277 fb	+422 fb -421 fb	11367 fb
	*Higgs numbers corrected for finite top mass effects					



# Higgs cross sections and uncertainties



- Linear dependence of Higgs cross section at NLO with  $\alpha_s$  can be observed
- $\alpha_s$  and gluon distribution are anti-correlated in this range, but the Higgs cross section has a large K-factor (NLO/LO), so  $\alpha_s$  dependence from the higher order contribution
- Predictions are from new CTEQ paper; not exactly the same setup as for MCFM benchmark predictions, so numerical values aren't identical, but linear  $\alpha_s$  dependence is clear

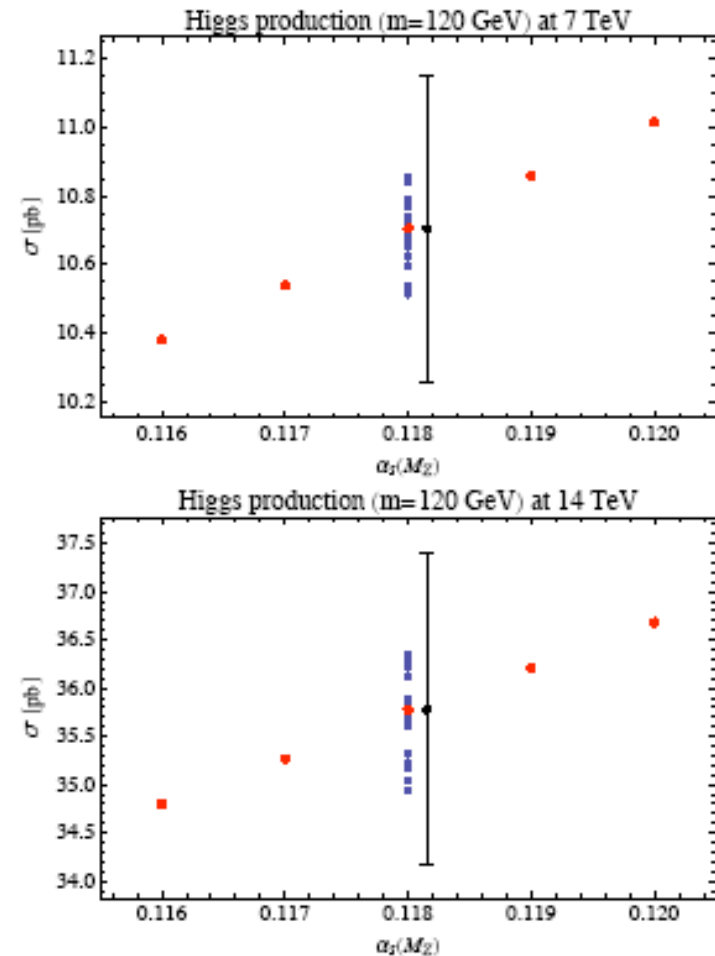
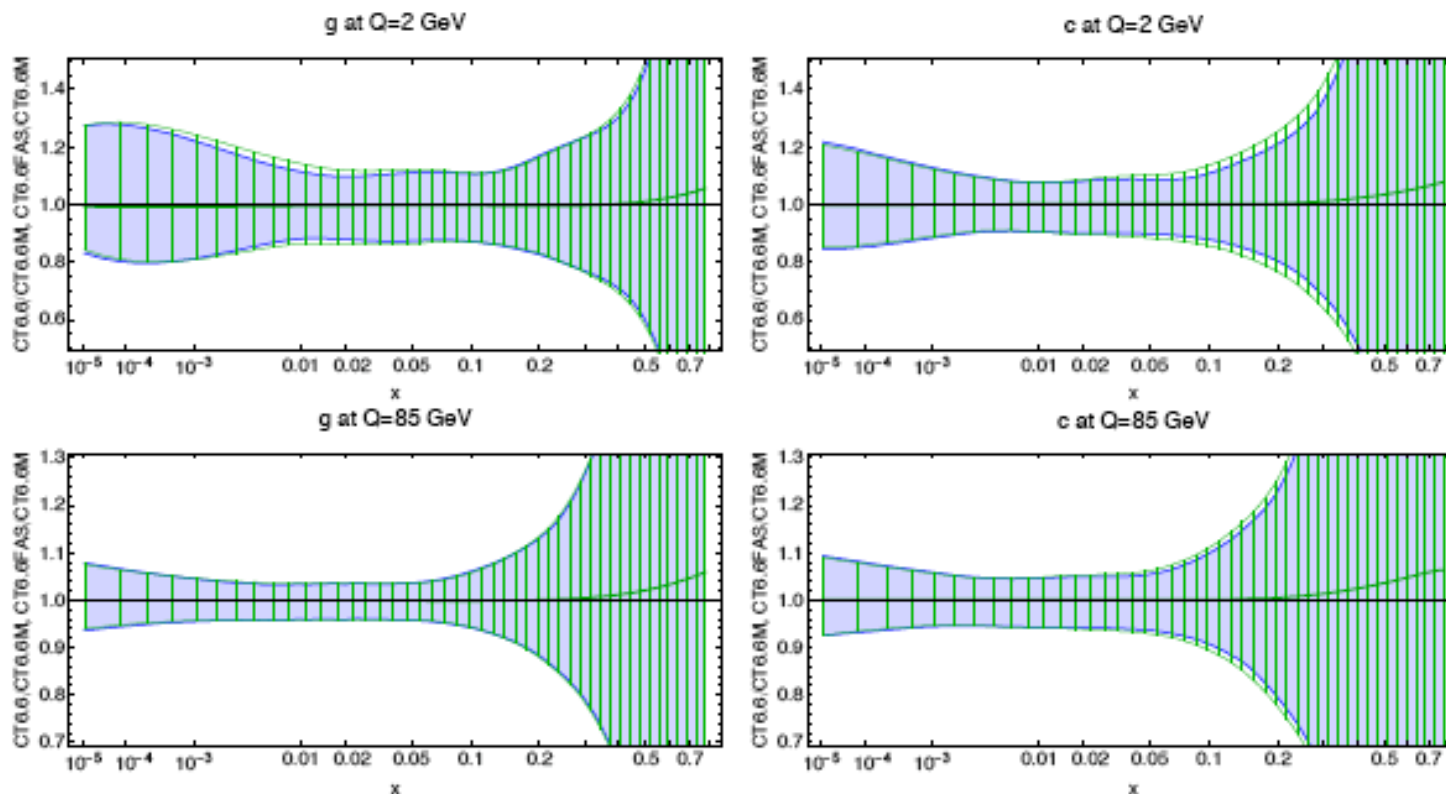


Figure 7: Cross section for Higgs production (mass = 120 GeV) at the LHC, with center of mass energy 7 TeV and 14 TeV, as a function of  $\alpha_s(M_Z)$ . The predictions for the 45 alternative PDF sets are shown for  $\alpha_s(M_Z) = 0.118$ . For the other values of  $\alpha_s(M_Z)$  (= 0.116, 0.117, 0.119, 0.120) only the central prediction is shown. The combined uncertainty range (CTEQ6.6+CT66AS) is shown as the error bar; cf. Table 1.



# Exact treatment

- Comparison of PDF errors when adding in quadrature compared to exact treatment



very nice discussion of quadrature treatment in new CTEQ paper

Figure 5: Comparison of CT66FAS uncertainty bands and CTEQ66+CT66AS uncertainty bands, normalized to the standard CTEQ6.6 fit, for gluon and charm PDFs at  $Q = 2$  and  $85$  GeV.



# Correlations

- Correlation cosine: defines degree of correlation between two quantities

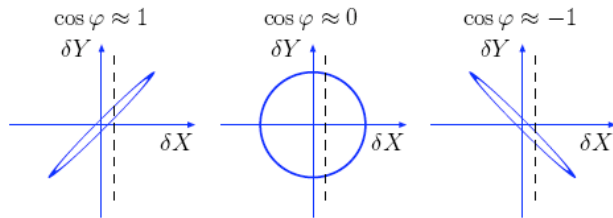
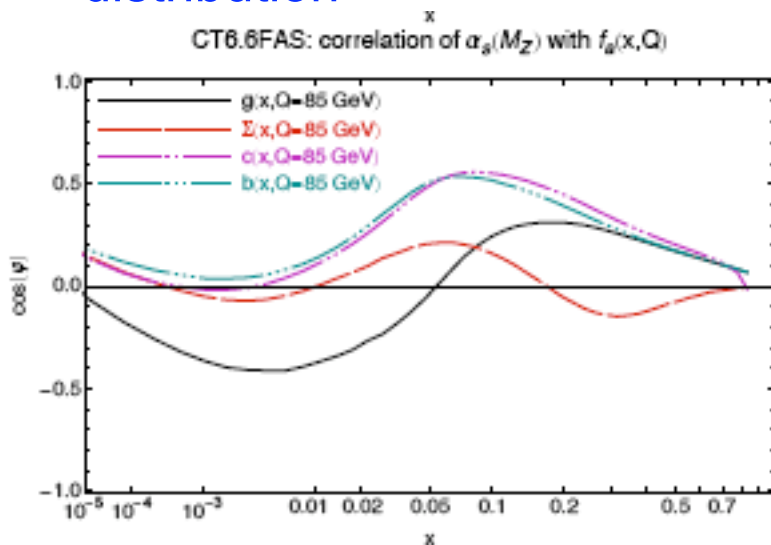
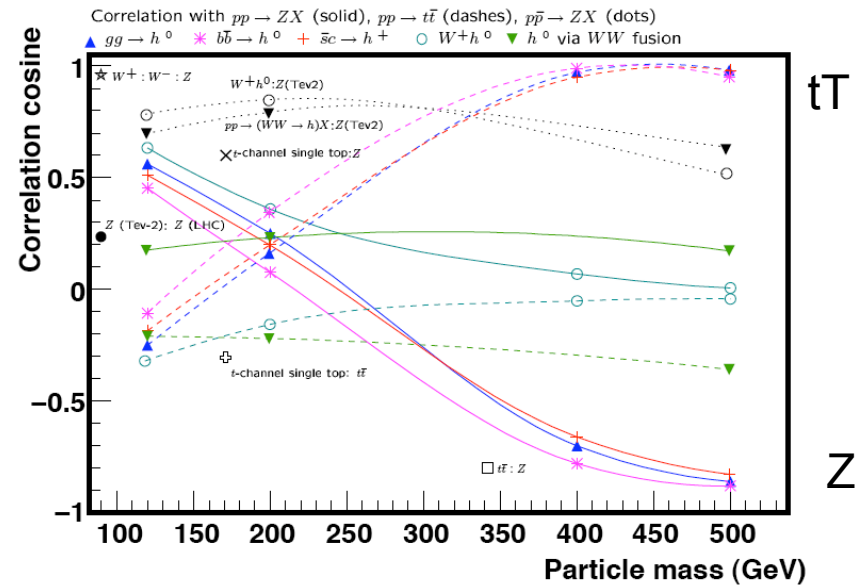


Figure 1: Dependence on the correlation ellipse formed in the  $\Delta X - \Delta Y$  plane on the value of the correlation cosine  $\cos \varphi$ .

- Below is cosine for different PDFs, including the gluon distribution



- Also useful to examine correlations between cross sections, as shown below for 14 TeV



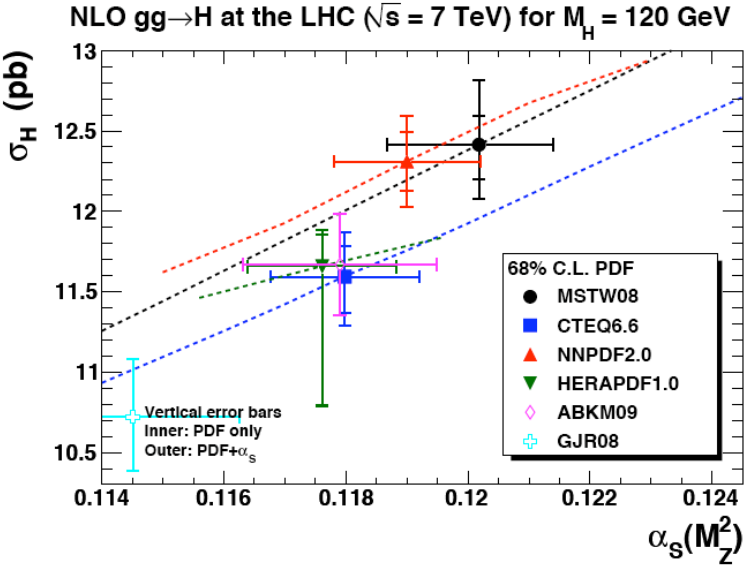
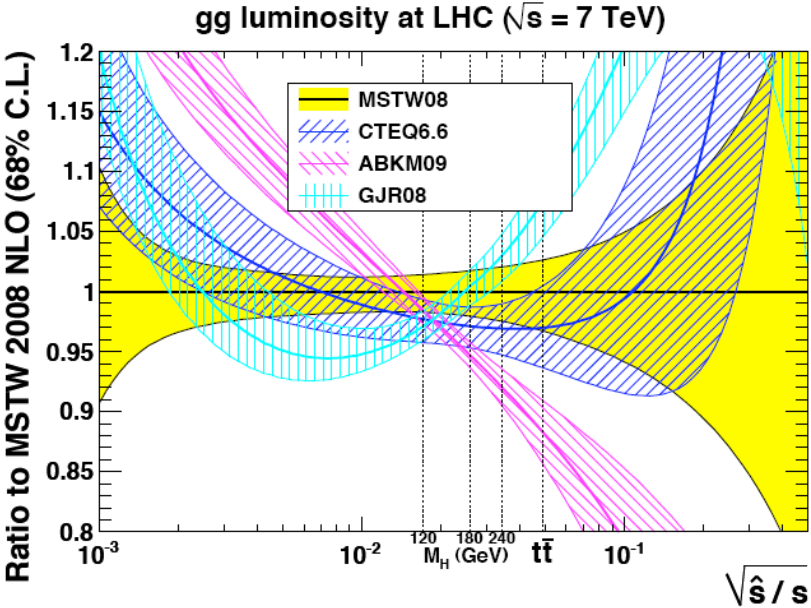
- Will expand this further for 7 TeV

Origin of observed (mild) correlations will be discussed in new CTEQ paper (and in Pavel's talk at DIS2010)

# Some results from the benchmarking



- ...from G. Watt's presentation at PDF4LHC meeting on March 26
- Slide everyone's prediction along the  $\alpha_s$  curve to 0.119 (for example) and predictions agree reasonably well
  - ◆ within 68% CL PDF errors





# Summary

- PDF4LHC/Les Houches benchmarking exercise has provided useful understanding of commonalities/differences among the different PDF groups
  - ◆ and hopefully we can continue towards more standardization
- Benchmark cross sections will be made available in a reference document, with predictions from all participating PDF groups
- ...and recommendations on how to estimate PDF/ $\alpha_s$  uncertainties for LHC cross sections where such uncertainties are *critical/non-critical*
- gg->Higgs is one case for NNLO corrections are large, so NNLO cross sections are necessary
- Available from only a few groups to date
- Since most of the impact arises from the matrix element and not the change in PDF's, I've suggested providing *approximate* NNLO predictions in cases where NNLO PDFs are not available
  - ◆ NNLO ME + NLO PDF

# Summary



- From the CTEQ-TEA side
  - ◆  $\alpha_s$  paper to be released soon
    - ▲ comparing addition in quadrature with exact calculations
    - ▲  $\alpha_s$  series PDFs already available on LHAPDF
  - ◆ new generation of PDFs (CT10 and CT10W) will be introduced at DIS2010
  - ◆ NNLO PDF set in progress