# Discussion of calculation of LHC cross sections and PDF/$\alpha_s$ uncertainties

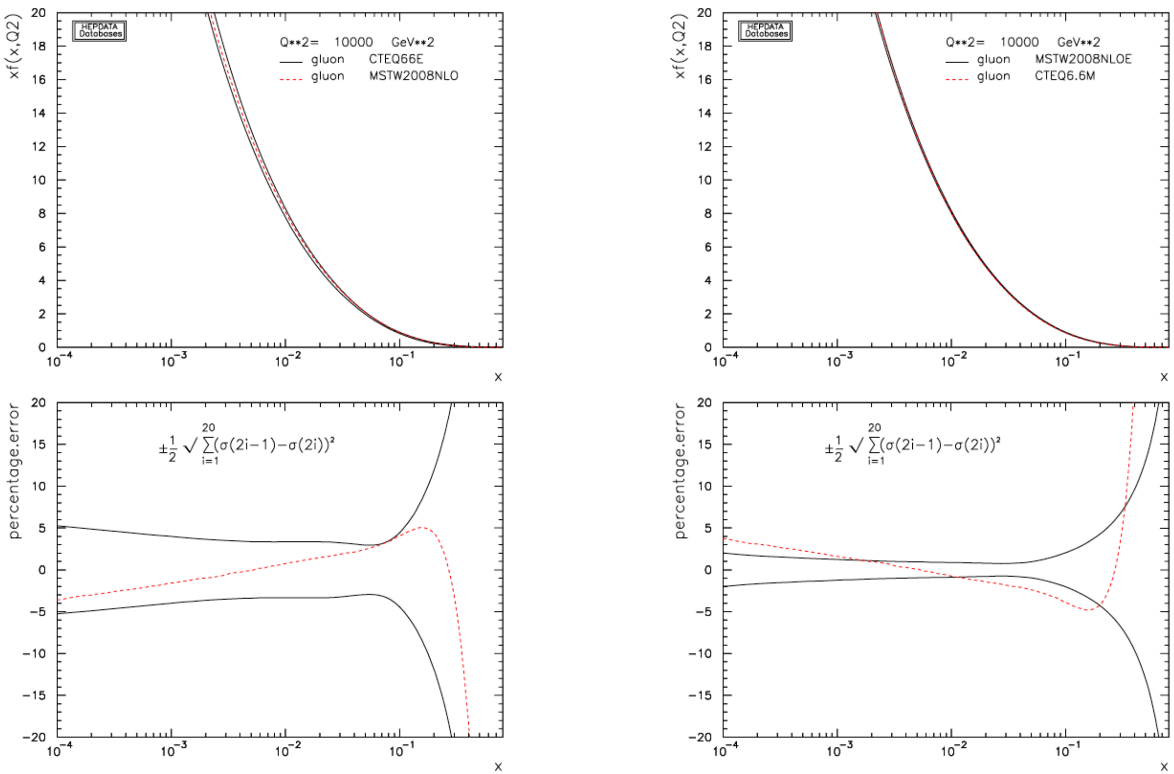
J. Huston
Michigan State University

# Cross sections and uncertainties

- In the ATLAS Higgs group, we've just gone through an exercise of compilation of predictions for Higgs production at LO/NLO/NNLO at a number of LHC center-of-mass energies
- This has involved a comparison of competing programs for some processes, a standardization of inputs, and a calculation of uncertainties, including those from PDF's/variation of $\alpha_s$
  - from eigenvectors in CTEQ/MSTW
  - using the NNPDF approach
- This is an exercise that other physics groups will be going through as well, both in ATLAS and in CMS
  - ATLAS Standard Model group now, for example
- There are a lot of tools/procedures out there now, and a lot of room for confusion

# For example

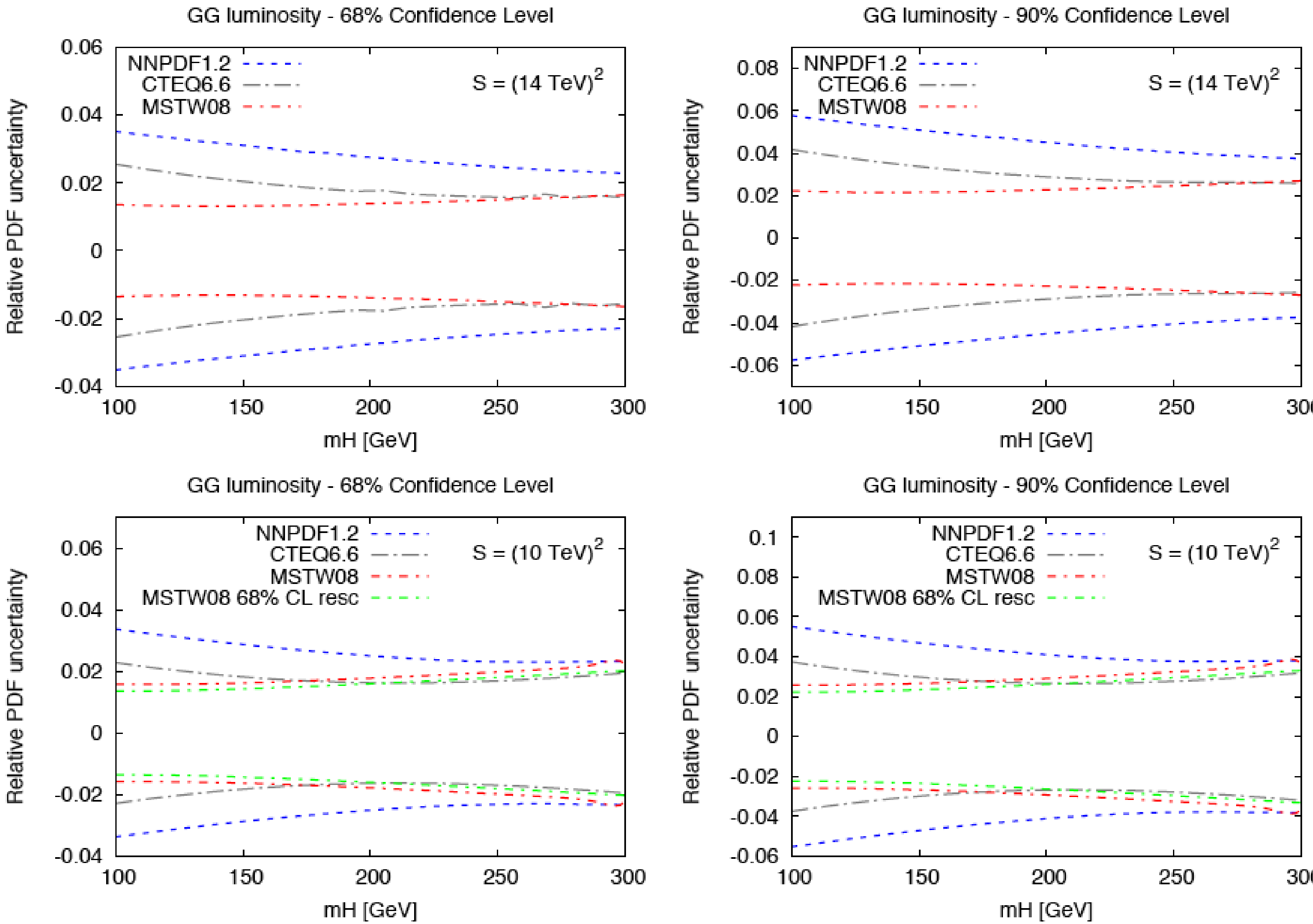
- Use the Durham PDF plotter for the gluon uncertainties at the LHC, comparing CTEQ6.6 and MSTW2008
- MSTW uncertainty appears substantially less than that of CTEQ6.6
  - as was typical in the past, where the $\Delta\chi^2$ used by CTEQ was ~100 and ~50 for MRST/MSTW
- But CTEQ uncertainty plotted is 90%CL; MSTW2008 is 68%CL




I've often seen plots in presentations showing PDF uncertainties without specifying whether they are at 68% or 90% CL (or sometimes even what PDF is plotted!)

# …but compare on a consistent basis

- See A. Vicini's talk from earlier today, for gg luminosity uncertainty



# PDF errors

- So now, seemingly, we have more consistency in the size of PDF errors, at least for this particular example
- The eigenvector sets 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 $\alpha_s$
- It has been traditional in the past for the PDF groups to publish PDF sets for variant values of $\alpha_s$, typically over a fairly wide range
  - experiments always like to demonstrate that they can reject a value of $\alpha_s(m_Z)$ of say 0.125
- MSTW has recently tried to better quantify the uncertainty due to the variation of $\alpha_s$, by performing global fits over a finer range, taking into account any correlations between the values of $\alpha_s$ and the PDF errors
- …more recent studies by CTEQ and NNPDF as shown in the talks today

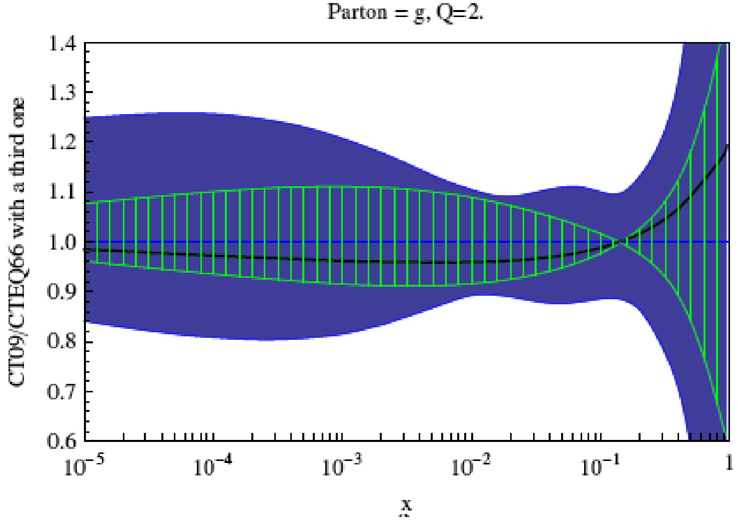
# Example

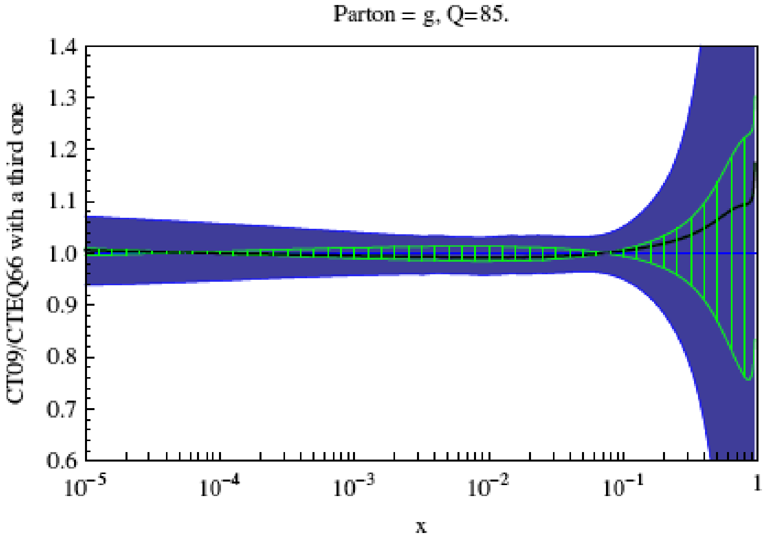
- Take CTEQ6.6 as base, and vary $\alpha_s(m_Z)$ +/-0.002 (in 0.001 steps) around central value of 0.118
- Blue is the PDF uncertainty from eigenvectors; green is the uncertainty in the gluon from varying $\alpha_s$
- 120 GeV (gg->)Higgs cross section at 14 TeV
  - $\alpha_s$=0.116: 36.9 pb
  - $\alpha_s$=0.117: 36.6 pb
  - $\alpha_s$=0.118: 36.3 pb (+/- 1.35 pb)
  - $\alpha_s$=0.119: 36.0 pb
  - $\alpha_s$=0.120: 35.8 pb

MSTW= 38.4 pb

- Variation in $\alpha_s$ gives +/-0.57 pb error, or about half that from the eigenvectors
- No strong correlation found, add in quadrature to give total error of 1.47 pb

paper in preparation: finer $\alpha_s$ sets will be available on LHAPDF



# $\alpha_s(m_Z)$ and uncertainty

- But of course life is not that simple
- Different values of $\alpha_s$ 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)
  - $\alpha_s(m_Z) = 0.1184 +/- 0.0007$
- What does the error represent?
  - Siggi said that only one of the results included in his world average was outside this range
  - suppose we're *conservative* and say that +/-0.002 is a 90% CL
  - joint CTEQ/NNPDF study to appear in Les Houches proceedings using this premise
- 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)?
- I told Albert that if he could persuade everyone of this, that I personally would nominate him for the Nobel Peace Prize

# (My) interim recommendation for ATLAS

- Cross sections should be calculated with MSTW2008 and CTEQ6.6
- 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 $\alpha_s$ eigenvector sets for MSTW2008
  - (my suggestion) as standard, use 90%CL limits, since central predictions often differ by more than 68%CL; naïve scaling between 68% and 90% may not work for MSTW2008 (non-quadratic behavior?)
- 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 + $\alpha_s$ error = 3 pb)
- Where possible, NNPDF predictions (and uncertainties) should be used as well in the comparisons; general mass formalism has been developed and should be implemented in near future

# Master Equation

- There's also the question of the form of the Master Equation for eigenvector errors
  - symmetric or not
- But typically the differences between the two are small
  - most of error comes from low number eigenvectors that tend to be symmetric

$$\Delta X^{+}_{max} = \sqrt{\sum_{i=1}^{N} [max(X_i^{+} - X_0, X_i^{-} - X_0, 0)]^2}$$

$$\Delta X^{-}_{max} = \sqrt{\sum_{i=1}^{N} [max(X_0 - X_i^{+}, X_0 - X_i^{-}, 0)]^2}$$

$$\Delta X = \frac{1}{2}\sqrt{\sum_{i=1}^{N} [X_i^{+} - X_i^{-}]^2}$$

# Why am I here?

- The recommendation from ATLAS was to raise this issue/procedure in front of the PDF4LHC working group to see if an ‘official’ recommendation could be adopted
- But before any discussion, two accords

# Binoth Les Houches Accord

- A general interface between NLO and Monte Carlo tools

Abstract: Many highly developed Monte Carlo tools for the evaluation of cross sections based on tree matrix elements exist and are used by experimental collaborations in high energy physics. As the evaluation of one-loop matrix elements has recently been undergoing enormous progress, the combination of one-loop matrix elements with existing Monte Carlo tools is on the horizon. This would lead to phenomenological predictions at the next-to-leading order level. This note summarises the discussion of the next-to-leading order multi-leg (NLM) working group on this issue which has been taking place during the workshop on Physics at TeV colliders at Les Houches, France, in June 2009. The result is a proposal for a standard interface between Monte Carlo tools and one-loop matrix element programs.

*Dedicated to the memory of, and in tribute to, Thomas Binoth, who led the effort to develop this proposal for Les Houches 2009. Thomas led the discussions, set up the subgroups, collected the contributions, and wrote and edited this paper. He made a promise that the paper would be on the arXiv the first week of January, and we are faithfully fulfilling his promise. In his honor, we would like to call this the Binoth Les Houches Accord.*
*The body of the paper is unchanged from the last version that can be found on his webpage* `http://www.ph.ed.ac.uk/~binoth/NLOLHA_CURRENT_VERSION.pdf`



Preprint typeset in JHEP style - PAPER VERSION

## A proposal for a standard interface between Monte Carlo tools and one-loop programs

**T. Binoth**
*The University of Edinburgh, Edinburgh EH9 3JZ, Scotland, United Kingdom*

**F. Boudjema** *
*LAPTH, 9 Chemin de Bellevue BP 110, 74941 Annecy-le-Vieux, France*

**G. Dissertori and A. Lazopoulos**
*Department of Physics, ETH Zurich, CH–8093 Zurich, Switzerland*

**A. Denner**
*Paul Scherrer Institut, Würenlingen und Villigen, CH-5232 Villigen PSI, Switzerland*

**S. Dittmaier**
*Albert-Ludwigs-Universität Freiburg, Physikalisches Institut, D-79104 Freiburg, Germany*

**R. Frederix, N. Greiner and S. Höche**
*University of Zurich, Winterthurerstrasse 190, CH-8057 Zurich, Switzerland*

**W. Giele, P. Skands and J. Winter**
*FNAL, P.O. Box 500, Batavia, IL 60510, USA*

**T. Gleisberg**
*SLAC, Stanford University, Stanford, CA 94309 USA*

**J. Archibald, G. Heinrich, F. Krauss and D. Maître**
*IPPP, University of Durham, South Rd, Durham DH1 3LE, United Kingdom*

**M. Huber**
*Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), D-80805 München, Germany*

**J. Huston**
*Michigan State University, East Lansing, MI 48840, USA*

**N. Kauer**
*Department of Physics, Royal Holloway, University of London, Egham TW20 0EX, UK*

# …to appear in Les Houches proceedings

## Common Ntuple Output format for NLO Calculations

*J. Campbell*[1], *J. Huston*[2], *P. Nadolsky*[3], *F.-P. Schilling*[4], *P. Uwer*[5], *J. Weng*[6]
[1]Theory Dept., Fermi National Accelerator Laboratory, Batavia (IL), USA
[2]Dept. of Physics and Astronomy, Michigan State University, East Lansing (MI), USA
[3]Dept. of Physics, Southern Methodist University, Dallas (TX), USA
[4]Inst. f. Exp. Kernphysik, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany
[5]Inst. f. Physik, Humboldt-Universität zu Berlin, Berlin, Germany
[6]Dept. of Physics, ETH Zürich, Zürich, Switzerland

**Abstract**

A proposal for a common Ntuple output format for NLO calculations based on ROOT is presented. It allows well defined parton level 4-vector calculations to be provided, even if the NLO code itself is not public, and provides a tool for theory-experiment interaction. A set of C++ classes is provided that can be used to fill, write and read the trees.

# Some more detail

Table 1: Variables stored in the proposed common ROOT ntuple output.

| ROOT Tree Branch | Description |
|---|---|
| `Npart/I` | number of partons (incoming and outgoing) |
| `Px[Npart]/D` | Px of partons |
| `Py[Npart]/D` | Py of partons |
| `Pz[Npart]/D` | Pz of partons |
| `E[Npart]/D` | E of partons |
| `x1/D` | Bjorken-x of incoming parton 1 |
| `x2/D` | Bjorken-x of incoming parton 2 |
| `id1/I` | PDG particle ID of incoming parton 1 |
| `id2/I` | PDF particle ID of incoming parton 2 |
| `fac_scale/D` | factorization scale |
| `ren_scale/D` | renormalization scale |
| `weight/D` | global event weight |
| `Nuwgt/I` | number of user weights |
| `user_wgts[Nuwgt]/D` | user event weights |
| `evt_no/L` | unique event number (identifier) |
| `Nptr/I` | number of event pointers |
| `evt_pointers[Nptr]/L` | event pointers (identifiers of related events) |
| `Npdfs/I` | number of PDF weights |
| `pdf_wgts[Npdfs]/D` | PDF weights |

The ntuple structure in ROOT tree format is shown in Table 1. Branches are available for the following information:

- 4-vector information for the initial and final state partons;
- the momentum fractions $x_1$ and $x_2$ and PDG identification codes $id1$ and $id2$ of the incoming partons;
- factorization and renormalization scales;
- total event weight;
- there is provision for additional user-specified weights to be stored, for example for specific initial states;
- the event weights for a set of error PDFs;
- a unique event number, as well as event pointers are provided that allow relations between events to be stored.