PDF uncertainties on Sudakov form factors and their effects on top studies

Joey Huston

Michigan State University

Using pdf uncertainties

- PDF uncertainties are important both for precision measurements (W/Z cross sections) as well as for studies of potential new physics (a la jet cross sections at high E_T)
- Most Monte Carlo/matrix element programs have "central" pdf's built in, or can easily interface to PDFLIB
- Determining the pdf uncertainty for a particular cross section/distribution might require the use of many pdf's
- **->LHAPDF**
  - a replacement for PDFLIB as the source for up-to-date pdf's
  - originated by Walter Giele; now maintained by Mike Whalley of Durham

- Using the interface is as easy as using PDFLIB (and much easier to update)
- call InitiPDFset(*name*)
  - called once at the beginning of the code; *name* is the file name of external PDF file that defines PDF set
- call InitPDF(*mem*)
  - *mem* specifies individual member of pdf set
- call evolvePDF(*x*,*Q*,*f*)
  - returns pdf momentum densities for flavor *f* at momentum fraction *x* and scale *Q*

Version 3 of LHAPDF

LHAPDF Version 3

released Sept 2004

http://durpdg.dur.ac.uk/lhapdf/ -> http://durpdg.dur.ac.uk/lhapdf3/
http://durpdg.dur.ac.uk/lhapdf2/
http://durpdg.dur.ac.uk/lhapdf1/

older versions are "frozen" and kept available

(1) More PDFs available:

New : ZEUS – LHpdf file using QCDNUM (thanks to Mandy Cooper-Sarkar)
H1 – LHgrid file (thanks to Christian Pascaud)
MRST2003c (nlo and nnlo) – LHpdf and LHgrid files

Legacy: CTEQ4, CTEQ5, GRV98 – all using the original interpolation codes – ie LHgrid files

From talk of Mike Whalley at HERALHC meeting at CERN in October

Using pdf uncertainties, continued…

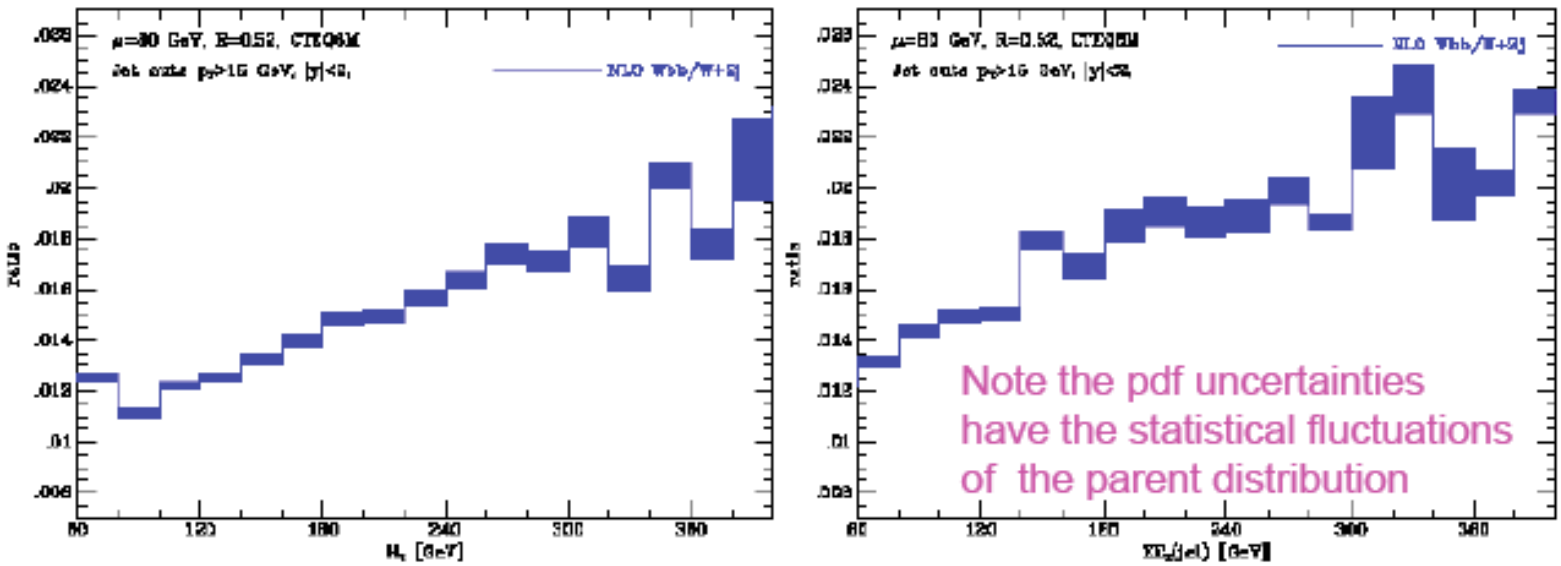
NLO programs can be slow, especially if you have to run 41 pdf's
But if new version of LHAPDF is used, can run full cross section with central pdf and store pdf*pdf luminosity for each event and then re-weight

- Total cross-section uncertainty: Using MCFM, ~~see CDF6849~~

J. Campbell and J. Huston:hep-ph/0405276->PRD

$$W b\bar{b} \rightarrow 2.5\% , \qquad W + 2j \rightarrow 1.5\%.$$

- Uncertainty in the $(W b\bar{b}/W + 2$ jet) ratio:



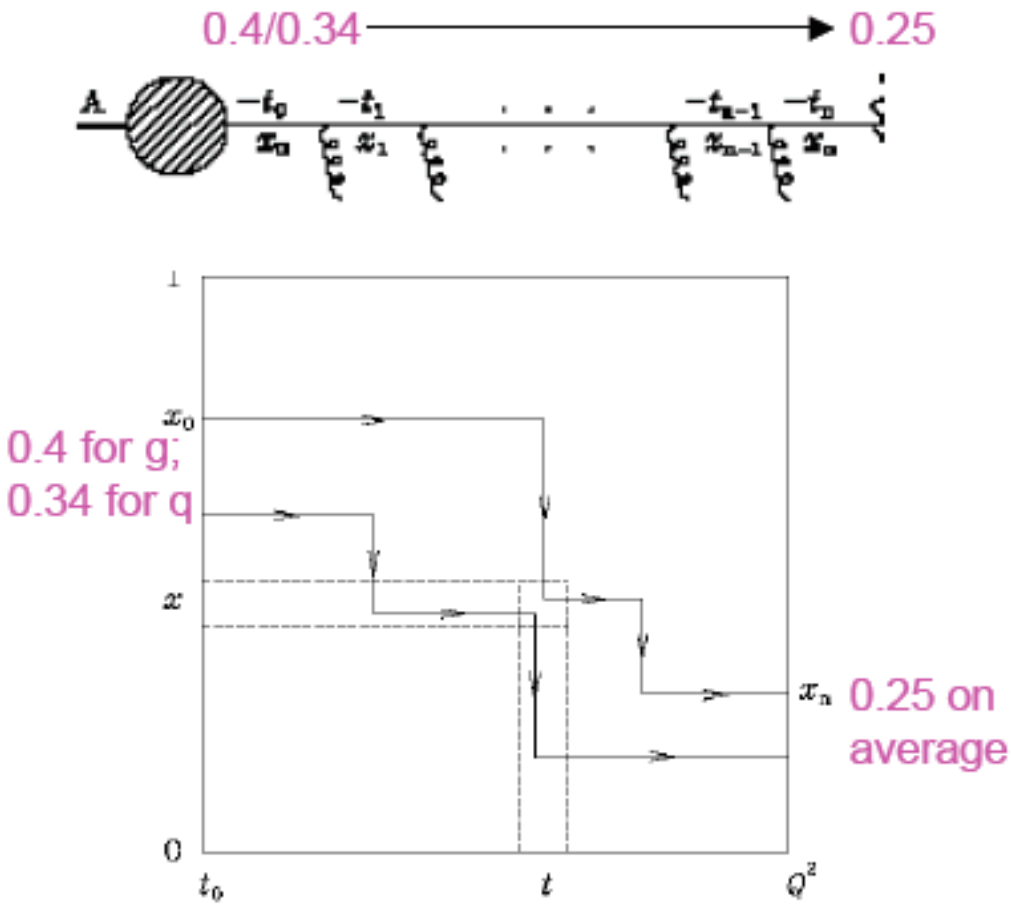
In Version 3 of LHAPDF, all pdf's can be stored in memory at the same time

PDF uncertainty for any cross section can be calculated by weights

PDF weight technique with parton showers

- An error may be introduced when using this technique with parton shower Monte Carlos
- The backward evolution in the initial state depends not only on the value of the pdf at a specific x and Q^2 value but also the slope of the pdf in going to higher x and lower Q^2
- In ISR, parton evolves backwards towards higher x and lower Q^2
- Backwards evolution Sudakov factors are weighted by the ratio of pdf's
- So the larger a pdf is at higher x and lower Q^2, the larger is the probability of a gluon emission having occurred

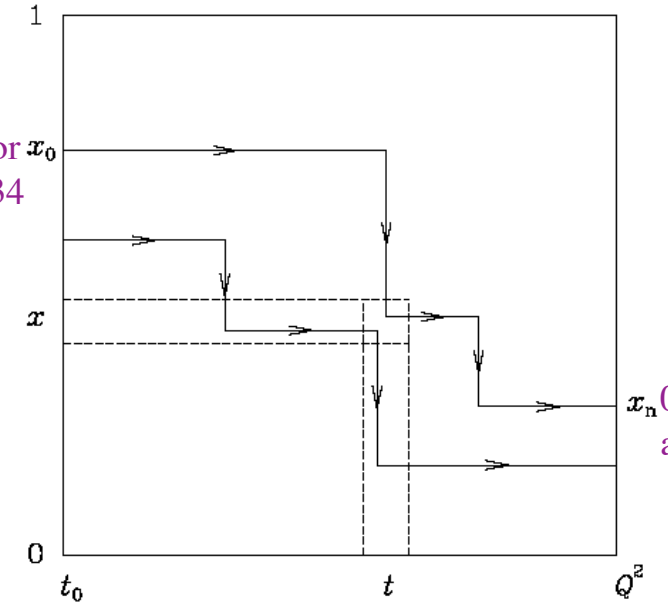
This technique has correct Sudakov only for CTEQ6, not for error pdf's.



At the Tevatron, for top production, quarks start at about x=0.34 at Q_o and end at x=0.25 at $Q^2=10^4$ GeV^2;
gluons start higher at x=0.4

ISR and pdf weighting

- In ISR, parton evolves backwards towards higher x and lower Q^2
- Backwards evolution Sudakov factors are weighted by the ratio of pdf's



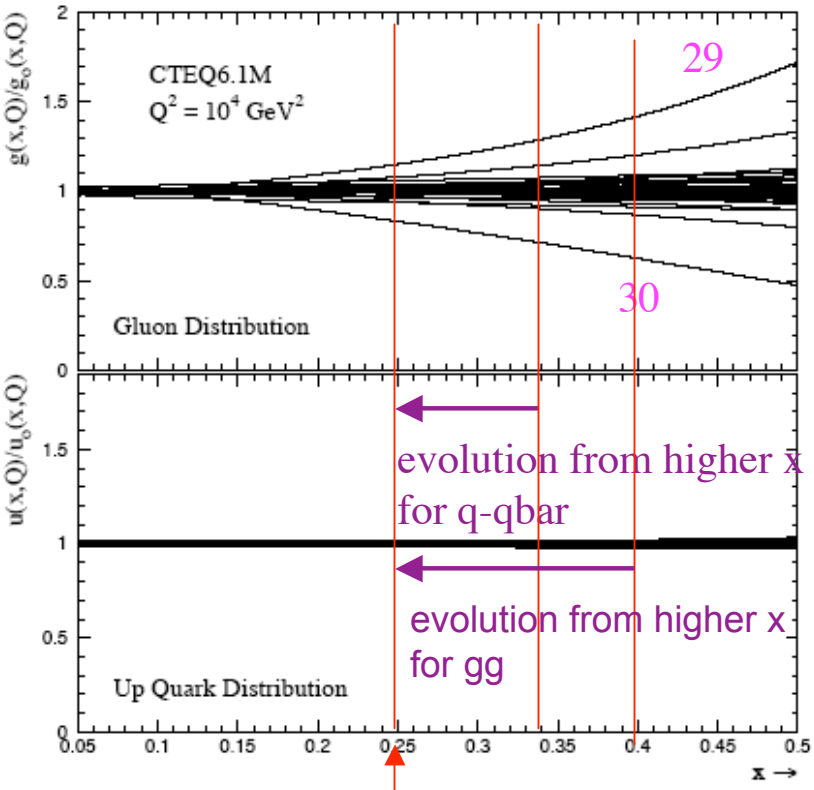
0.4 for g; 0.34 for q

0.25 on average

Q^2, the aving

- With pdf weighting technique, average Sudakov (from CTEQ6M) is correct; any error is due to a difference in slope between the error pdf and CTEQ6

little slope variation for u quark distribution for 40 error pdf's compared to cteq6.1 greater for gluon; pdf 29 has shallowest slope and pdf 30 has steepest



evolution from higher x for q-qbar

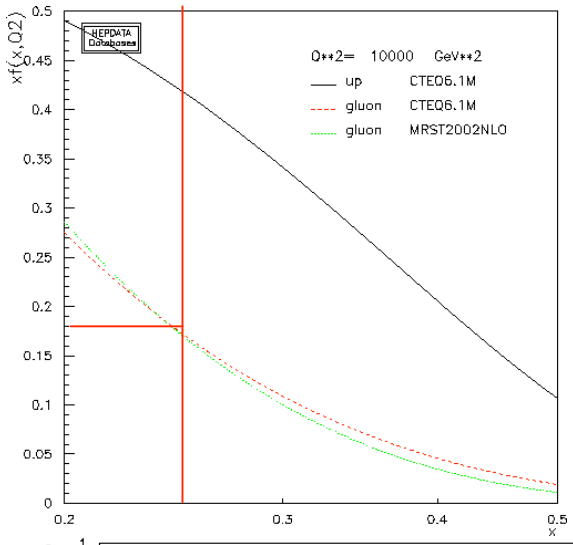
evolution from higher x for gg

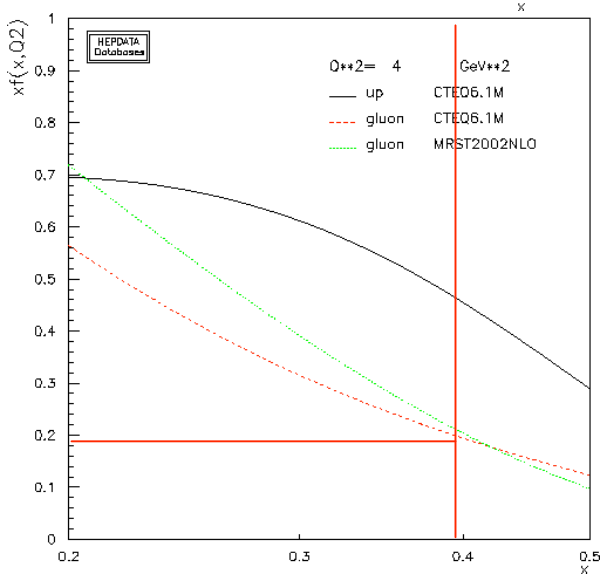
x value for central tt production

on average, q evolves from ~0.34 to 0.25; g from 0.4

Steepness of pdf's

- So expect pdf 29 to give more gluon radiation than CTEQ6M; pdf 30 to give less
  - other error pdf's should be no different than cteq6
- One way to proceed is to compare large statistics fully generated samples of cteq6, pdf29 and pdf30 to error pdf-weighted samples based on cteq6
  - which I think Un Ki and company are doing
  - see, for example, the talk by Eun-Ju Jeon at 9/3/04 joint physics meeting
- If little difference observed, then "average" Sudakov factor is sufficient
  - note that pdf factors for backwards evolution are close to unity, i.e. gluon at x=0.4 and Q^2=4 is close to gluon at x=0.25 and Q^2=1E4





gluon at x=0.25 and Q^2=1E4 about the same as gluon at x=0.4 and Q^2=4 GeV^2

Uncertainties on Sudakov form factors

…or the pdf uncertainty on the Sudakov form factor can be explicitly studied.

Uncertainties of Sudakov form factors

Stefan Gieseke

Institut für Theoretische Physik
Universität Karlsruhe, 76128 Karlsruhe, Germany
gieseke@particle.uni-karlsruhe.de

ABSTRACT: We study the uncertainties of Sudakov form factors as the basis for parton shower evolution in Monte Carlo event generators. We discuss the particular cases of systematic uncertainties of parton distribution functions and scale uncertainties.

KEYWORDS: Quantum Chromodynamics, Monte Carlo Event Generator, Parton Shower, Parton Distribution Functions.

Stefan is one of the key Herwig++ authors and I asked him to take a look at this question

2. Sudakov form factor for space–like branchings

The Sudakov form factor for spacelike backward evolution of a parton a from the hard scale $\tilde{q}_{\max}$ down to some scale $\tilde{q}$ can be written as [2, 3]

$$S_a(\tilde{q}, \tilde{q}_{\max}; x, \tilde{q}_0) = \exp\left[-\sum_b \mathcal{I}_{ba}(\tilde{q}, \tilde{q}_{\max}; x, \tilde{q}_0)\right] . \qquad (2.1)$$

The sum on the right hand side (rhs) is over all possible splittings into partons of type b and

$$\mathcal{I}_{ba}(\tilde{q}, \tilde{q}_{\max}; x, \tilde{q}_0) = \int_{\tilde{q}^2}^{\tilde{q}^2_{\max}} \frac{d\tilde{q}^2}{\tilde{q}^2} \int_{z_0}^{z_1} dz \frac{\alpha_S(z, \tilde{q}^2)}{2\pi} \frac{x' f_b(x', \tilde{q}^2)}{x f_a(x, \tilde{q}^2)} P_{ba}(z, \tilde{q}^2) . \qquad (2.2)$$

We assume a resolution scale $\tilde{q}_0$ below which the evolution terminates and further splittings would remain unresolvable. The limits of the z–integration, z_0 and z_1 depend implicitly on $\tilde{q}$ and $\tilde{q}_0$, hence the $\tilde{q}_0$ dependence[1] of $\mathcal{I}_{ba}$ and S_a. x is the light cone momentum fraction of the parent parton with respect to the originating hadron. This value is initially selected by the hard subprocess. $x' = x/z$ is the light cone momentum fraction of the new parent after the first space like branching and so forth. $P_{ba}(z, \tilde{q}^2)$ is the unregularized collinear splitting function, which, in the case of the evolution of massive partons, may also depend on the branching scale $\tilde{q}^2$. Note, that the splitting function is regularized as we use explicit cutoffs in the phase space for soft gluon emission. $f_a(x, \tilde{q}^2)$ is the parton distribution function (pdf) of a parton of type a inside a proton[2].

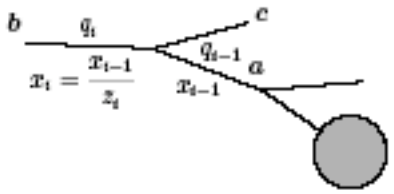
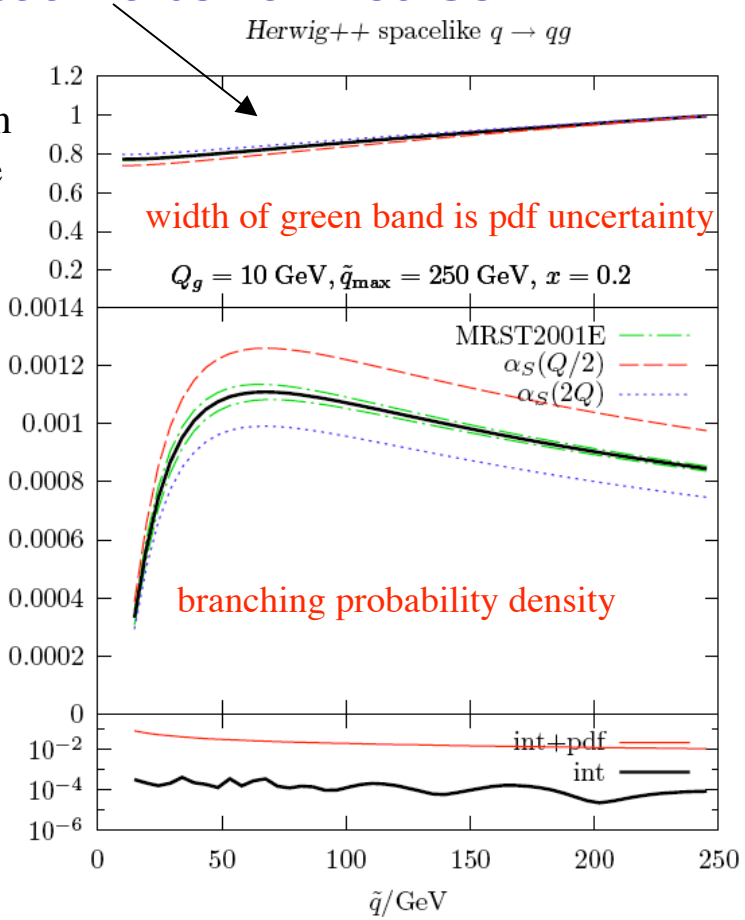


Figure 1: Kinematics for space–like branching $b \to ac$.

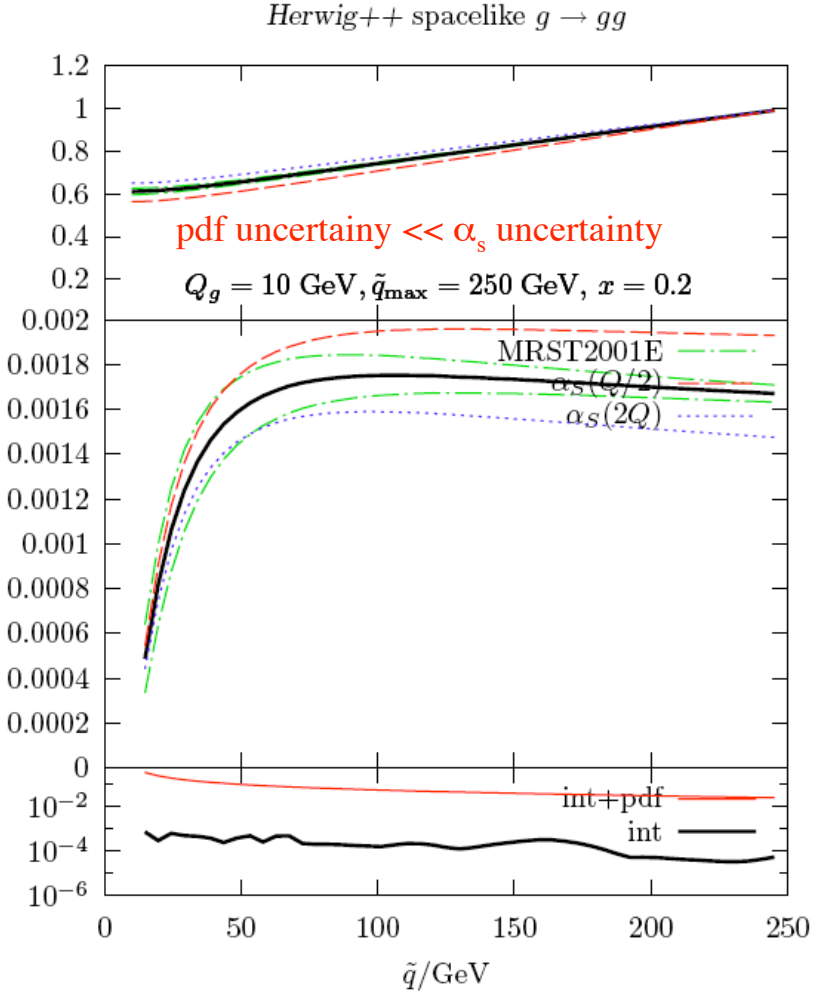
Uncertainties on Sudakov form factors

Probability that a quark at x=0.2 will not emit a gluon of greater than 10 GeV when evolving backwards from 250 GeV

so there's an 80% chance for a quark of x=0.2 to evolve backwards from 250 GeV to 10 GeV **without** emitting a gluon of more than 10 GeV



Gluons like to radiate more than quarks; probability is only 60% for a gluon of x=0.2



PDF uncertainty band (MRST2001E) is very small; CTEQ61 error band will be larger.

Effect of changing the cutoff

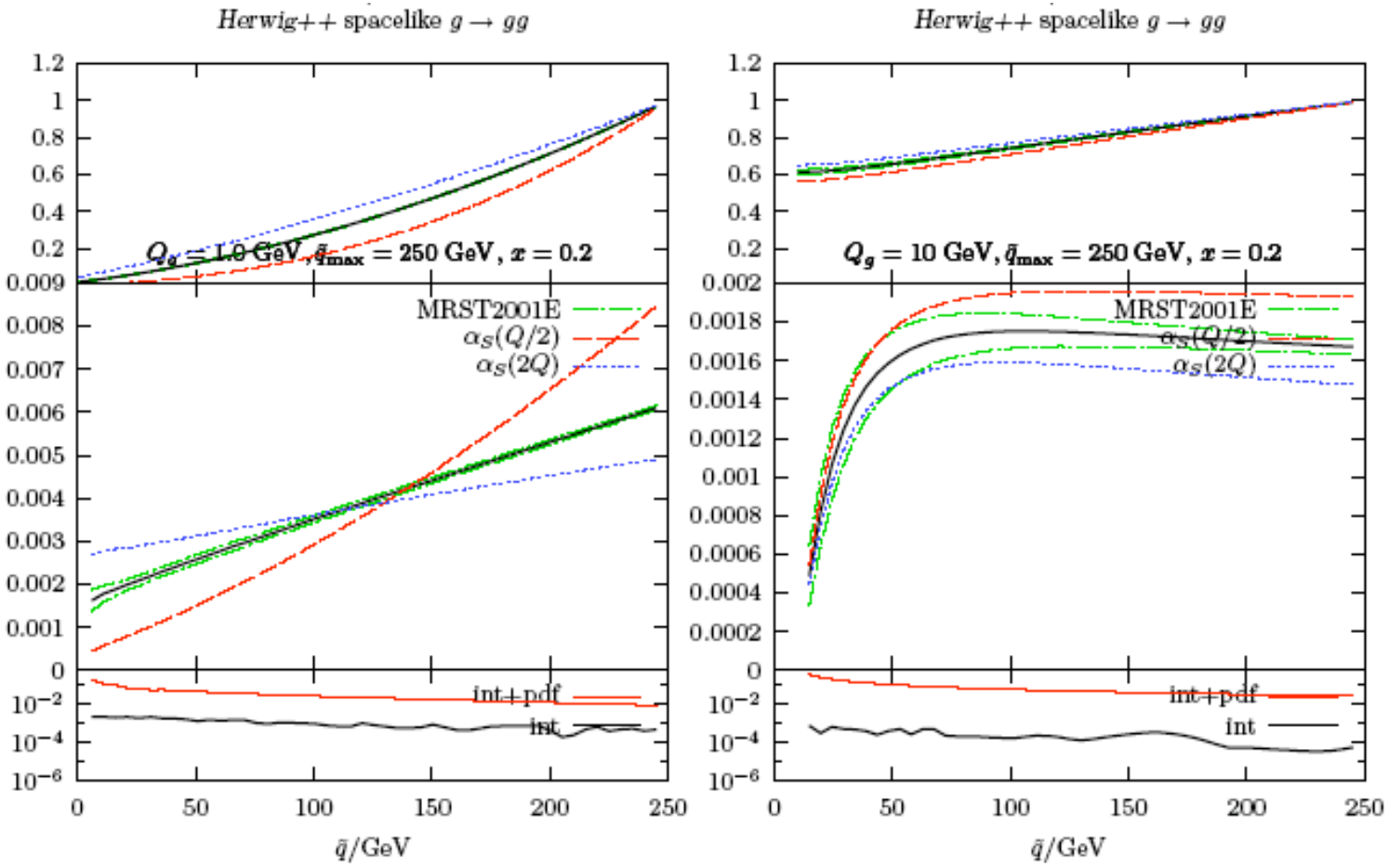


Figure 10: Increasing the cutoff Q_g in the $q \to qg$ and $g \to gg$ Sudakov form factors for at large $\tilde{q}_{\max}$ and x. See caption of Fig. 4 for labelling.

Summary #1

- pdf uncertainty for Sudakov form factors appears to be small
  - would be nice to confirm by direct check mentioned earlier
- pdf weighting technique then is useful not only for fixed order calculations but also for parton shower Monte Carlo studies
- It would be useful to have some example Sudakov form factors tabulated for collider observables, i.e. what's the probabililty of emitting a gluon of energy > some value when I start with a particular parton flavor at a particular x and Q^2 value
- Stefan will be visiting Fermilab at the end of the month and could give a talk at this meeting

Summary #2: TeV4LHC

- TeV4LHC: conferences.fnal.gov/tev4lhc/
- QCD
  - www.pa.msu.edu/~huston/tev4lhc/wg.htm
  - all of the issues I talked about today are there
- TopEW
  - www.hep.anl.gov/tait/tev4lhc/topew.html
- Higgs
  - www-clued0.fnal.gov/~iashvili/TeV4LHC_higgs/higgs.html
- Landscape

- Next meeting will be at Brookhaven Feb 3-5, 2005
- Follow-up meeting at CERN in late April, 2005
- Final meeting at Fermilab in the fall of 2005

You're all wondering, How can I enlist?

- Four listserver mailing groups have been set up:

  tev4lhc-qcd
  tev4lhc-higgs
  tev4lhc-topew
  tev4lhc-landscape

- If you would like to subscribe to the working groups, here are the instructions:
  - To subscribe to a mailing list called MYLIST

    1. Send an e-mail message to listserv@fnal.gov
    2. Leave the subject line blank
    3. Type "SUBSCRIBE MYLIST FIRSTNAME LASTNAME" (without the quotation marks) in the body of your message.

Appendix A: some TeV4LHC projects

This list can also be found at

www.pa.msu.edu/~huston/tev4lhc/wg.htm

Jet projects

1. inclusion of jet production in MC@NLO

2. jet algorithms at the Tevatron and LHC

   -impact of negative towers: to remove or not to remove, the D0 experience
   -impact of splitting/merging
      -understanding the effects of splitting/merging at the parton and hadron level
      -impact on boosted systems, e.g. W->jj in high pT top
   -understanding differences observed in jet reconstruction between CDF and D0 environments
      -reconstruct sample of MC events that produce problems in the CDF environment
   -utility of new algorithms such as JEF for final state reconstruction

3. UE subtraction

   -definition of UE + uncertainty for comparisons of data to NLO
   -impact of ISR on jets and jet predictions
   -operation in high multiple interaction environment

PDF projects

1. validity of NLO formalism/road to NNLO

2. benchmarks for NLO/NNLO fits

3. pdf uncertainties
   -universal delta_chisquare
   -pdf weighting; impact of Sudakov FF's
   -embedding LHAPDF into programs

4. inclusion of Tevatron data in global fits
   -"back-of-the-envelope" studies
      -W+c
      -gamma +b/c
      -Z+b

5. W as a benchmark at both Tevatron and LHC

6. heavy flavor pdf's and their uncertainties

Projects, continued…

ME/MC projects

1. W + jets comparisons at the Tevatron->predictions for the LHC
   -NLO->MCFM
   -CKKW
      -Mrenna
      -Sherpa
   -backgrounds to WW->H, the "Zeppenfeld plots"
   -jet shapes/comparisons to CKKW

2. parton shower/resummation
   -predictions for tt, Higgs
      -impact of new parton shower algorithms

UE/hadronization projects

1. UE tunes for Tevatron->predictions for LHC
   -understanding color re-connections and their apparent promiscuity
   -can we reproduce Tune A in the more modern MC's
      -Pythia 6.3
      -Jimmy

2. hadronization corrections for NLO processes

3. ISR/UE corrections->subtractions for NLO

4. understanding high interaction multiplicity environment

Summary #3: Les Houches 2005

- Physics at TeV Colliders
  - From 800 pb^{-1} at the Tevatron to 30 fb^{-1} at the LHC
  - May 2-20
    - right after CERN meeting of TeV4LHC
- 2 main working groups
  - SM and Higgs
  - BSM and Higgs modeling
- Register now at:

http://wwwlapp.in2p3.fr/conferences/LesHouches/Houches2005/index.html