Minutes of the
LHC HIGGS Cross Section Working Group meeting
in Freiburg, the 12-13 April 2010

Monday, April 12, 2010

Morning opening session

1) Welcome

Markus Shumacher opened the Freiburg workshop with welcoming words.

2) Goal of the meeting:

Chiara Mariotti discussed the mandate of the Higgs cross section working group. The group officially started towards the end of January 2010. The first task was to produce the cross sections and BR and uncertainties with the state of the art computations for sqrt(s)=7 TeV for all the SM and MSSM Higgs production mode.
Comparison between NLO MC generators is another task. A definition of pseudo observables is also under study. We need close collaborations with PDF4LHC, MC4LHC and Statistic Forum to achieve our goals. The next step will be a compilation of theoretical work to refer to when writing papers on Higgs at LHC.
ACTION ITEM: each subgroup has to compile an exhaustive list of references to quote in the future papers.

As an integrated luminosity of 100pb^-1 by the end of 2010 and 1fb^-1 by the end of 2011 is expected, LHC will start to compete with Tevatron in 2011. Following a suggestion from the Physics Coordination of ATLAS and ATLAS an exercise on combination should be performed in collaboration with the Statistics Forum in each experiment.
ACTION ITEM: Overall contacts will prepare for the combination exercise of the 7 TeV public results of ATLAS and CMS.

During the discussion session, the suggestion on the common efforts with Tevatron on Higgs cross sections and the combination was raised. By combining Tevatron WW and VH results with LHC, certainly we will get better exclusion. However, we felt that we should proceed first with LHC alone. We may start the discussion with Tevatron in near future as many of them are also working in ATLAS and CMS.

3) Prospect for early Higgs boson discovery at LHC

Guillelmo Gomez-Ceballos reviewed the Higgs physics at early LHC stage, stressing the key experimental points on trigger, reconstruction, background estimation. Guillelmo has shown the CMS projection at 7 TeV

with Higgs decaying into WW, ZZ and gamma+gamma. One experiment may exclude Higgs mass between 145 and 190 GeV with 1fb-1 of Luminosity, and can reach around 165 GeV 3-4 sigma standard deviation significance.

During the discussion, it was explained each experiment as a Neural Network analysis for WW, and a cut-based as well. Higgs signal cross section is based on NNLO estimation for the 7 TeV predictions. A question was raised about a realistic achievable luminosity for the 7 TeV run, perhaps we can expect at least 0.5fb^-1. Suggestion to try to analyze other channels like VBF, VH and ttH was made.

Tuesday, April 12, 2010

Afternoon closing discussion session.

Rei Tanaka reminded the group tasks and opened the discussions for future group activities.

- Common setup

It was reminded to use the common SM input parameters for Higgs cross section calculations, but also for SM background calculations. This is also for Monte Carlo event generations. We should define the common Higgs cross section calculation mass points and intervals for different channels. A brief discussion was made on PDF sets on the common alpha_s value and the 68% or 90%C.L. error definitions. This has been discussed in the PDF4LHC, but no agreements have been achieved so far.
ACTION ITEM: the PDF4LHC should decided within 2 weeks, otherwise we will take a decision for the group, in order to be able to produce final results for the July meeting.

- Beyond SM and MSSM Higgs?

Many people pushed to enlarge the group activity to include other physics models such as other supersymmetry breaking scenarios, invisible Higgs decay, Higgsless scenario, Extra-dimension models etc.. We decided that it is OK as an option to future expansion of our group, provided that: *a)* there are solid interests among experimentalists in ATLAS and CMS, *b)* manpower is found and *c)* the two priority items are not delayed.

- Higgs combination:

As explained by Chiara on the first day, it is recommended from ATLAS and CMS Physics Coordinations to Statistics Forums to do the MC exercise of the Higgs combination. Our Higgs cross section working group is requested to provide the common recipe on the theoretical and experimental error handling. But how we can be involved in the Higgs combination has not been decided yet, and have to be discussed with ATLAS and CMS Physics Coordinations. Some discussion on the involvement of theorists took place. Some felt that it is a strictly experimental business. Others think that anyway

we are comparing with SM and MSSM models and thus we need the models predictions as correct as possible from theorists, thus theorists should be involved in the combination. It will be discussed further and the solution should be found soon, based also on the past LEP experience.

- Publications

It was stressed to collect all the relevant theoretical works, and ATLAS and CMS will use it for their papers. It was proposed to write a CERN Yellow Report on Higgs cross sections before end of 7TeV run.

- Communication tools

It was encouraged to use the SharePoint as an useful tool for exchanging the information. The question was raised on the need for the code repository. SVN, GIT and GENSER were looked in and there are pros and cons.
ACTION ITEM: we should further study the possibilities and make to decision soon (volunteers?)

- Future workshop

The next workshop will be held at **CERN during July 5 (Mon.) - 6 (Tue.)** during the CERN theory institute. Registration will be possible soon. The 3rd workshop will be held in Bari in November 2010 organized by our CMS colleagues. For 2011, it was recommended to fix the dates and the places soon. Please make a proposal to overall contacts before the next CERN workshop in July.

We thanked Freiburg organizers for their perfect organization of the first workshop, and looking forward to seeing you soon in Geneva.

SUB GROUPS REPORT:

1. ggF subgroup:

The session starts with the talk by Grazzini who illustrates, on behalf of the other contact persons of the ggH group, the three calculations for LHC at 7 TeV and gives his comments on them. After the talk the discussion is open, chaired by Reisaburo.
The discussion is focused on the new calculation and estimate of the uncertainties by Baglio-Djouadi. Concerning the role of resummation, Grazzini claims that not including it leads to ignoring some solid work that has been done. Including resummation leads to a relevant quantitative effect but also increases our confidence on the perturbative result. The net effect of ignoring resummation at 7 TeV is a 10% loss in cross section and an increase in the uncertainty. Djouadi explains why they did not include resummation. The first reason is that resummed PDFs are not available. Thorne explains that he does not expect the impact of resummation on the gluon density to be very large, so using NNLL+NNLO coefficient functions and NNLO PDFs should be acceptable. Djouadi says that the main reason for not including NNLL resummation is that it is available only for total cross sections, whereas the experimental analysis is based on differential distributions. Grazzini replies that the main point is to make sure that the distributions relevant in the analysis are correctly described by the Monte Carlo. If this is the case than there's nothing wrong in using the best available information on the total cross section as over all normalization. Djouadi commented that the experimentalists should prepare themselves to use the cross section with cuts from the very start. If he had a message to take home, that will be the one!

Then the scale uncertainties are discussed. Grazzini claims that allowing free variations of renormalization and factorization scales between one half and twice the mass of the Higgs allows the ratio of the scales to vary between 1/4 and 4. For this reason in the calculation with de Florian they impose the constraint 0.5<muf/mur<2. With this constraint the scale uncertainty at NNLO is slightly smaller. The same choice is adopted by Petriello and collaborators (although with mh/2 as central value). Djouadi replies that in his opinion this choice underestimates the scale uncertainty.

The discussion then moves to the question of the uncertainty from the large-mtop approximation. The calculation by Djouadi assumes an uncertainty of about 2%. Grazzini claims that according to the recent studies by Harlander, Steinhauser and collaborators, the uncertainty is about 0.5% for a light Higgs. In the discussion it becomes clear that the 2% assumption is due to the way in which the calculation by Baglio-Djouadi is done. In the way the calculation is done by the other two groups this uncertainty is smaller. Spira points out that the uncertainty from the definition of mb is at the percent level.

Then the discussion moves on the uncertainty from alphas. Grazzini claims that a theoretical uncertainty of 0.003 is probably too large. Thorne points out

that the difference between NLO ad NNLO alphas in the PDF fit is already an indication that this uncertainty is present, but that at NNLO this uncertainty should be smaller. Djouadi says that the uncertainty they use is consistent to what claimed by MSTW. The discussion ends with the general consensus that the issue of uncertainties is delicate and difficult to address and it would need more detailed investigations.

2. VBF subgroup:

Talks:
1) talk on "Inclusive VBF cross sections" by Daniela Rebuzzi
- discussion of new NNLO calculation
-results on inclusive cross sections from HAWK and VBFNLO (dependence on PDFs and PDF uncertainty)

2) talk on "NLO VBF event generators" by Carlo Oleari
- NLO shower Montecarlos, POWHEG
- results for VBF from POWHEG + HERWIG/PYTIA

Discussion:
1) HAWK:
-Djouadi: since HAWK is CPU time expensive, can one provide a grid?
-Dittmaier: it might be more appropriate to reweight distributions
2) NNLO corrections to VBF
-Djouadi: VBF is not that well understood for cuts, the statement that all non-factorizable corrections are small should be made more precise (small compared to what?)
-del Duca: extension of NNLO calculation for cuts is nontrivial
-Rebuzzi: According to Fabio Maltoni a group is working on exclusive VBF at NNLO (timescale at least 6 months)
-Grazzini: where will 2% accuracy matter at LHC?
- Rebuzzi: for VBF, exclusive calculations are extremely important and there NNLO might also matter
-Zeppenfeld: VBF channels typically involve few hundred events and therefore require no excessive accuracy

Next steps and plans (slide 12 of Daniela's talk):
- finer grid in Higgs boson masses and higher masses
- systematic study of PDF and alpha_s uncertainties
- comparison of different codes
- improvement of existing codes
- studies for exclusive observables

3. WH/ZH subgroup:

The talks were based on the contents of the introductory EVO meeting of the subgroup and presented started activities as well as plans for the near future. For details consult the slides of the talks of Robert Harlander and Giacinto Piacquadio and the minutes of the EVO conference.

Issues of the discussion session:
* Question to Massimiliano Grazzini about the possibility to get a prediction in NNLO QCD fully differential upon generalizing the recent calculation for Drell-Yan by Grazzini et al.. Grazzini considered this calculation feasible with current techniques.
* Question/suggestion by Michael Duehrssen whether it was possible to use Drell-Yan data in order to calculate VH by folding it with the decay rate V^* -> VH.
* Question whether taking the ratio sigma(pp->VH)/sigma(pp->V) would decrease the PDF uncertainty, which was denied by Robert Thorne.
* Question by Bruce Mellado about a jet veto. In order to have a correct estimate of the jet veto efficiency, even at LO one should use Sherpa or Alpgen to have the real emission WH+1jet correct from the ME.
* Comment by Stefan Dittmaier that a future generalization of HAWK (presently limited to VBF) to WH/ZH production with subsequent W/Z decays will in particular cure the unphysical behaviour of the EW corrections.

4. ttH subgroup:

The tTH session consisted of two talks, one experimental and one theoretical, reporting about existing experimental/theoretical studies and what has been done or will be done in the context of this workshop.

Most of the planned work for the moment is on the theory side. Before Freiburg the group agreed on a set-up file to be used for the theory runs and on a set of distributions that could be useful to experimental analyses. Distributions with tTH or tTbB final state can be obtained at NLO, while distributions involving more than four partons in the final state are at the moment only available at LO.

Runs have been planned to evaluate both total and differential NLO cross sections for the ttH final state. In particular, we intend to provide a careful estimate of the theoretical systematic error from:
i) residual renormalization/factorization scale dependence;
ii) alpha_s;
iii) PDFs;
iv) possible other input parameters.
With respect to ii) and iii), the tTH runs presented in Freiburg did not adopt the temporary recipe suggested on the workshop webpage, and used alphas consistent with the set of PDFs. However, we are following closely the ongoing discussion to determine the best way to decouple the error from alpha_s from the error from PDFs and will adapt our procedure accordingly when overall agreement within this working group is reached.

During the discussion following the talks several people showed interest in having a public tTH code. In particular it was suggested to interface it with POWHEG. Doubts were raised as to weather effort should be invested in interfacing the tTH code as opposed to the tTbB code (with bB coming from H->bB). The possibility of interfacing existing tTH NLO codes to POWHEG will be investigated.

It was also noticed that studies of discriminating variables based on spin-spin correlation were started during the 2009 Les Houches workshop, and they show that high combinatorial make these difficult to use in practice.

Finally, it was emphasized that estimates of pp->tTH,H->bB based on the narrow width approximation should be limited to the region of light Higgs and this should be made clear in plots and papers that use this approximation in order to avoid confusion down the line.

5. MSSM Neutral group:

1) brief summary of what was presented:

M.W. gave a summary of what was done so far in the working group. First emphasis was put on the mhmax scenario and here the gluon-gluon-fusion and b-associated production modes were looked at.
For the gluon-gluon-fusion process numbers are available with the agreed upon input parameters and using a recipe to re-weight SM-like contributions to the production cross sections by using HIGLU, ggh@nnlo and FeynHiggs. Central values for this are already done and scale uncertainties will be next.

For the b-associated production a comparison between the NLO calculation in the 4-flavor scheme and the NNLO calculation in the 5-flavor scheme was done and for the chosen scale of mu=mH/4 a rather good agreement was found. For the 5-flavor scheme numbers including scale and pdf uncertainties are available. Rescaling to the MSSM couplings is expected to be working satisfactorially. A comparison of different PDFs was done and shows good agreement, but large differences in the uncertainties between CTEQ6.6 and MSTW2008.

2) what was discussed during the discussion session:

The following items were discussed:
- the cross sections shown are just inclusive cross sections, but for typical analysis cuts these are obviously different. It was deemed to be useful to also look at exclusive cross sections and also at distributions. The process bg->bH is available in MCFM and can be used as a starting point. The possibility of including b-associated production in POWHEG was briefly discussed, but this will be more of a medium-term project. In the mean time studies of different parton-shower-generators (Pythia, Sherpa,...) should be performed.

3) what was agreed
- pursue also other MSSM scenarios
- for the ggF: explore also the influence of SUSY-particles to the production. This is possible at the moment at LO, but NLO results in the full MSSM are available from Anastasiou et al. or in the future from a calculation from Muehlleitner, Rzehak, Spira.
- also look at the changes to other production mechanisms in the MSSM
- close collaboration with the BR subgroup on these issues

4) recommendations for next steps
- finish scale and pdf uncertainties for the current prescription for the gluon-gluon-fusion

6. MSSM Charged group:

Talks
1. H+ Experimental Status (Martin Flechl)
- Summary of the recent ATLAS H+ Cross Section Efforts
- Input for H+ cross sections:
  ttbar cross section -> Moch et al;
  BR(t->bH+), BR(H+->...) -> FeynHiggs
  sigma(gb/gg->tH+[b]) -> Tilman's numbers
- focus on the mh-max scenario, and on scenarios tailored for H+->chargino neutralino studies
- Scale Uncertainties, heavy H+: 20%
- PDF uncertainties (CTEQ6.6M), 7 TeV: 11% (mH+=200 GeV) to 30% (mH+=600 GeV)
- 30-40% discrepancy 4FS vs 5FS calculation
- discussion on sqrt(s) dependence

2. H+ Theoretical Developments (Sami Lehti for Michael Krämer)
- 4FS vs 5FS: short explanation
- 4FS vs 5FS: first preliminary comparison with MSTW08: better agreement than with MRST04, but still central numbers not within uncertainties of the other calculation needs further investigation
- EWK corrections might be important for light H+
- MC@NLO implementation of 5FS available
- open issues: 4FS vs 5FS; extend calculation to pp->tHplus + b-jet; matching 4FS and 5FS

Discussion
- 4FS vs 5FS issue not solved
- Michael Spira: scale uncertainties (agreement within) not a valid criterium of agreement 4FS vs 5FS
- Q: Has a 4FS vs 5FS comparison done with CTEQ? A: No, only MSTW provides 5FS pdfs so that would not be possible
- Comment: slower convergence between 4FS and 5FS expected due to the nature of the process
- a tool for calculating the top->H+ branching ratio advertized (SUSY-HIT)

Next steps
- update results for 7 TeV
- Study 4FS vs 5FS systematically
- reinvestigate PDF uncertainties with MSTW
- comparison using different tools for BR(t->bH+): FeynHiggs, HDecay, SUSY-HIT, ...

7. PDF subgroup:

The talks and discussion for the PDF subgroup revolved around the topic of the range of predictions for LHC cross sections and their uncertainties when using different PDF sets. On of the main points of interest was the values of α_S used by different PDF groups and the manner of including the uncertainty from this specific source. The benchmark exercise performed by the PDF4LHC group to compare the predictions from different groups in a consistent manner was introduced (Huston). The idea of each group providing predictions at a common value of α_S, in addition to the nominal α_S value, was introduced (Huston) and discussed. Another idea (Huston) also discussed was the adoption of a common (world average) value of α_S by each PDF group. This was followed up in an e-mail discussion since the evo sound connection broke down. It was supported by CTEQ and NNPDF, but opposed by MSTW, though all agreed that values of α_S should not be in conflict with the values obtained from alternative determinations. The range of available PDF sets, and the differences between them, depending on data sets fit, manner of obtaining best fits and uncertainties, values and range of α_S used and variety of heavy quark treatments was summarised (Thorne).
For Higgs cross-sections at 7TeV, good agreement was noticed between MSTW2008, CTEQ6.6 and NNPDF2.0, though other PDF sets showed some more significant discrepancies at the higher masses. CTEQ and MSTW differed to a fairly significant extent for some masses. Agreement was better if comparison was made at a common value of α_S using publically available sets from all groups, the agreed value for comparison being 0.119. A maximum difference was found around $m_H=180GeV$, where one-sigma error bands barely overlap. There was discussion on whether the value of α_S could be different at different orders, and there seemed to be some support for including an additional "theory uncertainty" on α_S at NLO. The use of NNLO calculations and PDFs when possible was emphasised. The possible methods of treating the combined α_S and PDF uncertainty was summarised (Vicini), noting that for Higgs cross sections the simple approach of adding these uncertainties in quadrature was not very different from more sophisticated or complicated prescriptions. The spread of predictions obtained using the PDFs from the three groups was seen to be similar if the envelope of the three with the same $alpha_S$ of 0.119 was used along with the α_S uncertainty, or if the envelope of the three at their choices of α_S, 0.120, 0.118 and 0.119 respectively with no additional α_S uncertainty was used (Vicini). A slightly larger spread, due to an effectively larger α_S uncertainty reflecting the variation of central values for the PDF sets, would be obtained by taking each at their preferred α_S and then including the α_S uncertainty.

8. Branching Ratios sub-group:

* SM talk by Ansgar
 - evaluation of BRs in the SM (with Hdecay and Prophecy4f)
 - evaluation of theory uncertainties
 - open issues (see slides)

* MSSM talk by Sven
 - MSSM specific issues (overlap with MSSM group)
 - start of a comparison of codes (FeynHiggs, CPSuperH, Hdecay)
 - discussion of "different" phenomenology that the MSSM offers

* Relevance of width effects:
 -Ansgar: in the SM relevant for larger MH (MH > 400 GeV)
 -Georg: in the MSSM width effects can be relevant at smaller MA values, there Gamma/M can become relatively large, several Higgs bosons can be close in mass, and mass differences can easily be smaller than the Higgs boson widths.
 -Sven: on the other hand: large MA values result in small Higgs-VV couplings, and a SM-like problem does not exist in the MSSM.
 - v.d.Bij: in non-minimal SM even light Higgs bosons can have a very large width. Are we prepared?
 -all: heavy Higgs cannot be a SM Higgs (e.g. MH > 500 GeV)

* Scope of the group:
 -v.d.Bij: also non-minimal SM should be covered (e.g. the one with a light Higgs and a large width)
 -Djouadi: include also the NMSSM
 -Georg: already the MSSM `offers' a lot:
  - large Gamma/M for relatively small masses
  - overlapping Higgs signals
  - invisible Higgs decays
  This should be exhausted (first)
 -Ansgar, Sven: man power problem. Full MSSM treatment is already very demanding.

* near future work:
 all(?): focus on the Higgs mass spectrum that is accessible with early data. Sometimes width effects can be ignored, because detector resolution is worse. Should be investigated?
 -Ansgar, Michael: discussion whether/how H -> ff gamma c/should be included
 -Nikitenko: also include charged Higgs decays (also t -> H+ b)
 -Lethi: offered help with BR(t -> H+ b): comparison of codes
  (in private after the session)

* which codes should be considered/compared:
 SM talk: so far Hdecay and Prophecy4f. What else?

MSSM talk: FeynHiggs, CPSuperH, Hdecay (how to include Prophecy4f results?)
- Djouadi: also look at Suspect results
- Sven: can be included once Suspect sends comparison data

* next steps SM:
-> see last slide (general agreement about this)

* next steps MSSM:
- continue comparison
- identification of "best" calculations (sse slides)
most controversial: how to combine various codes/predictions to allow the "best" prediction for any MSSM parameter point

9. NLO MC - subgroup

In the NLO MC session, two presentations were made. The theory review talk was given by Carlo Oleari since neither Fabio Maltoni or Paolo Nason could make it to the workshop. The content of the talk was based on the NLO MC review report Fabio Maltoni and Paolo Nason have started putting together in preparation for the workshop. The talk has emphasize that Shower NLO tools for Higgs production do exist, are fairly mature, and have been thoroughly compared among themselves and with general purpose generators. It has been noticed, however, that the use of this tools by the experimental collaboration is still quite limited. A goal of our working group is to promote the use of these tools, and eventually identify the reasons for the relatively slow penetration of new tools in the experiment's work. Jae Yu presented a review of the current status of NLO MC tools at both ATLAS and CMS experiments. The talk contained the list of MC tools and their version numbers currently implemented in the experiments, SM parameters used in the tools, wish list from experiments and the list of tasks the NLO MC group proposes as its responsibility. It appears that the latest publically available tools are being used in both the experiments while some Higgs process, in particular MSSM Higgs sector - are not completely implemented. Some communication gaps between theory and experiment community seem to be apparent. The NLO MC group will work on improving this communication as well.

Despite the group's desire on receiving opinions on the presented tasks, the discussions focused on the prospect of completion of the review report the group plans to release soon. One of the questions was concerning MSSM charged Higgs tool comparisons to which Carlo and Jae responded that it will be done but given the limited manpower in the group it could be in a longer time scale. Another discussion topic of importance was making theoretical calculations public and keeping them in a more persistent and common repository for consistency and longevity. There are tools for this purpose.

For the future tasks, the group first plans to complete the report as much as possible – though the experimental part of the report needs to be discussed – prior to the next workshop at CERN. The group plans to establish well-organized and up-to-date wiki pages with compilation of advanced NLO and NNLO tools and recommendation.

10. PO - subgroup

Presentation: Sven, Giampiero

Discussion:

answering by Michael, Giampiero, Sven

questions: Zeppenfeld, Quast, Defilippis, Gomez - Ceballos, van der Bij, Weiglein, Felcini …

main themes: differences with Lep and impact on the PO-fitting scenario;
time scale for measuring Higgs `details' and impact on subgroup priorities;
public versus private `data', what to use in fits;
large versus small Higgs `mass', experimental goals versus theoretical consistency in absence of NP;
unfolding of experimental distributions & fits;
background treatment;
new MCTools;
extension of PO definition to include larger scenarios;
model independency of POs

Goals:

-- aim for Higgs PO definitions that are as model independent as possible;
-- where it turns out to be needed aim for tools that experimentalists can use in future analysis to extract these Higgs POs (obviously not a short term goal);

- Medium term goal:

-- start with H -> gamma gamma as the conceptually easiest case;
-- define (different) ROs, depending on Higgs decay channel, e.g. M(gamma gamma) for H -> gamma gamma, H -> ZZ [M4l invariant mass, with cuts on l momenta and M2l ranges?], etc;
-- study what to use for H -> WW