# Experimentalists' Contribution to the NLO MC Effort: search tools and systematic uncertainties

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for the

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# Proposed Experimental Contribution to the NLO MC Report

- **Search strategies in ATLAS and CMS**
  - Split into three periods
    - Short term – 7 TeV & 1 fb-1
      - Focus on SM Higgs with $H \rightarrow \gamma\gamma$, $H \rightarrow WW$ and $H \rightarrow ZZ$
      - MSSM and BSM examples
      - Limit settings and exclusions – theory and experimental uncertainties
    - Mid-term – 14 TeV low luminosity
      - Early stage SM+MSSM+BSM Higgs searches
      - With improved limits, signal significance and early measurements
    - Long term – 14 TeV high luminosity
      - SM+MSSM+BSM Higgs searches & measurements → **PO Group**
- **Current tools used in experiments**
  - Focus on precision predictions for Higgs x-sections and background modeling
  - Differential signal and background shapes – from data and MC - for filtering
- **Sources of systematic uncertainties and possible improvements**
- **Strategies from experiments for MC validation and tuning using data**

# Example: SM Higgs Search Tools for 7 TeV & 1 $fb^{-1}$

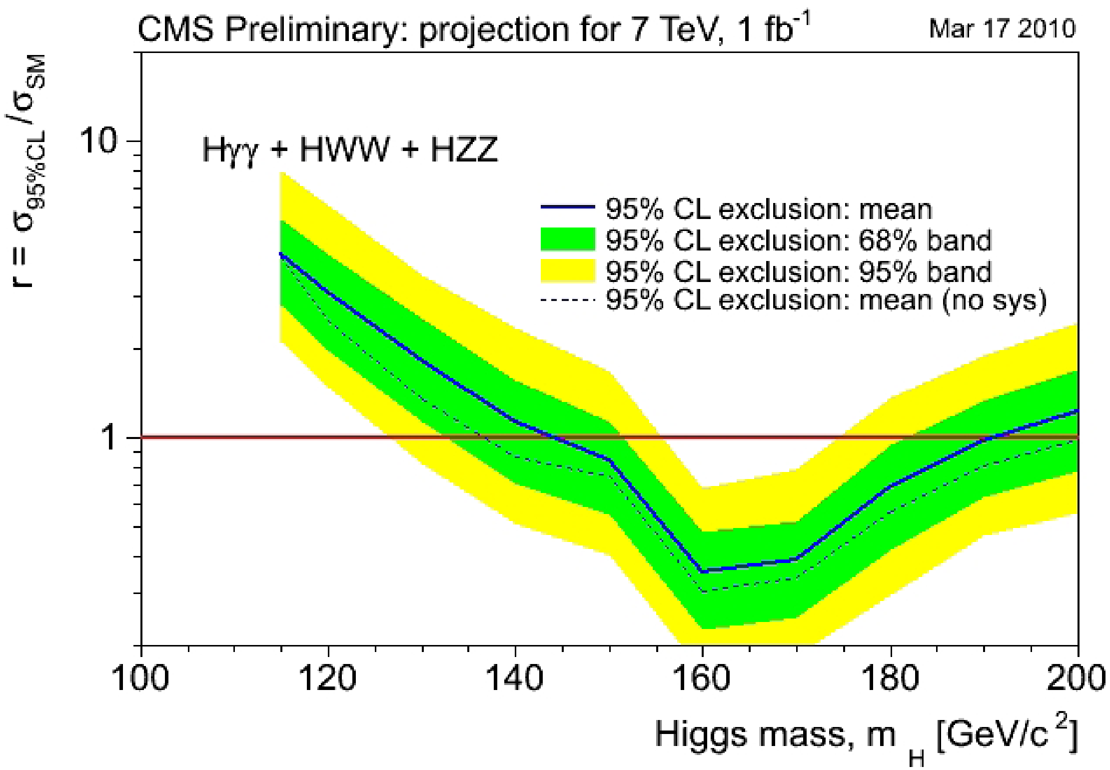
| **Higgs Mass range [GeV/$c^2$]** | **Production** | **Decay** | **Main backgrounds** | **Main discriminating quantities** | **$\sigma_{exp}/\sigma_{SM}$ vs Higgs mass @7 TeV & 1 fb-1** |
|---|---|---|---|---|---|
| **~ 114 – 150** | **ggH** | **$H \rightarrow \gamma\gamma$** | **QCD** | **Photon ID**<br>**Diphoton mass** | ~4 to 6 |
| **~ 114 – 150** | **qqH** | **$H \rightarrow \tau\tau$** | **Z, tt, W+jets** | **Forward jet tagging**<br>**Central jet veto**<br>**$M(\tau\tau)$** | - |
| **~ 140 – 200** | **ggH, qqH** | **$H \rightarrow WW$** | **WW,ZZ,tt, W/Z+jets** | **Exactly 2 leptons**<br>**$\Delta\varphi$(leptons)**<br>**Central jet veto**<br>**Missing ET** | ~0.2 to 1 |
| **~ 114 – 700** | **ggH** | **$H \rightarrow ZZ$** | ***ZZ, Zbb, tt*** | **Lepton isolation**<br>**Dilepton mass** | 2 to 10 |

Other production and decay modes are of course very important for Higgs physics but less sensitive in the 2010-2011 run with 7 TeV & 1 $fb^{-1}$

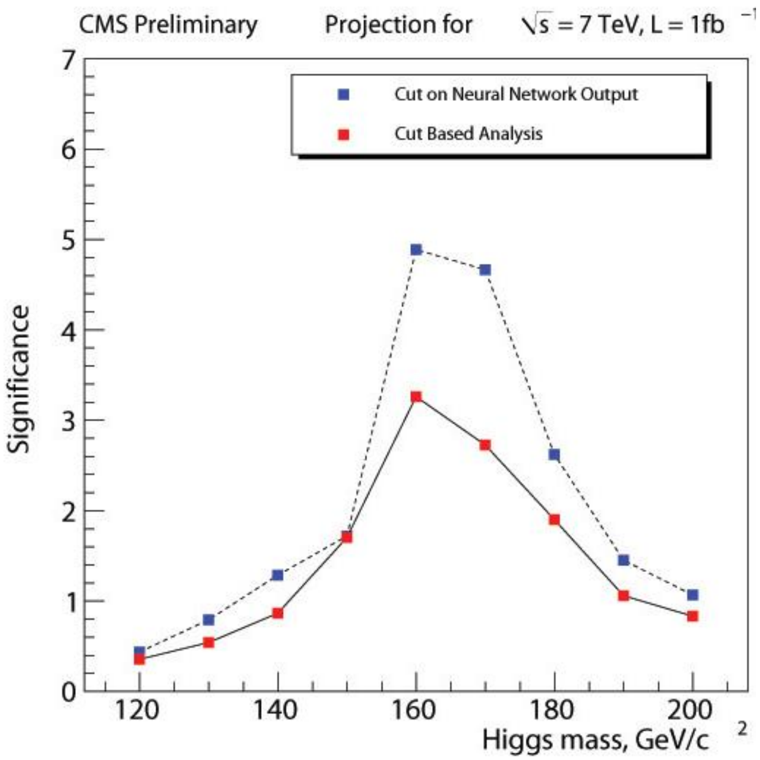
# Example: SM Higgs Expectations @ 7 TeV & 1 $fb^{-1}$

CMS NOTE -2010/008

Expected Exclusion Limits
Combination of H →WW, ZZ and γγ Searches

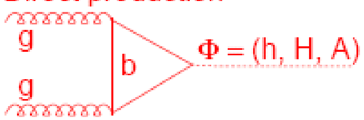
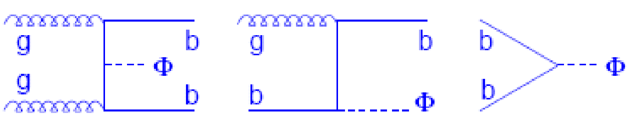
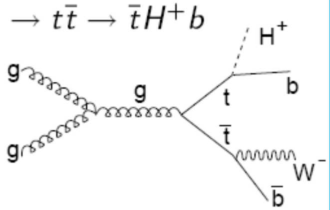
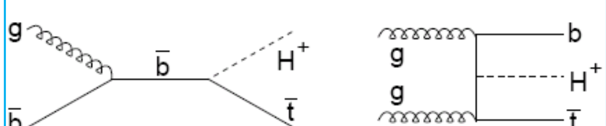



Expected significance of
H →WW →llνν search




Expected Higgs mass range to be excluded (1 experiment): 145-190 GeV

# Experiments Explore also MSSM and BSM Higgs @ 7 TeV & 1 fb$^{-1}$

| Particle | Dominant production processes | Decay | Final states investigated |
|---|---|---|---|
| Neutral Higgs Bosons h, H, A | Direct production   <br><br> Associated production with b−quarks<br>dominating production at large tan β   | $h/H/A \to b\bar{b}$<br>at large tan β , dominant decay, large background<br><br>$h/H/A \to \tau^+\tau^-$<br>L arge BR, clean final state<br><br>$h/H/A \to \mu^+\mu^-$<br>Very low BR but very good mass resolution | SM Higgs-like final states, from VBF $qqh/H$ — $\tau\tau$d<br>direct production with $h \to \gamma\gamma$<br><br>$h/H/A \to \tau^+\tau^- \to \ell\ell + 4\nu$<br>$\to \ell\tau_{jet} + 3\nu$<br>$\to \tau_{jet}\tau_{jet} + 2\nu$<br><br>$h/H/A \to \mu^+\mu^-$ |
| Charged Higgs Bosons H+, H- | Light $H^\pm$ $(m_{H^\pm} < m_{top})$:<br>$gg \to t\bar{t} \to \bar{t}H^+b$   <br><br> Heavy $H^\pm$ $(m_{H^\pm} > m_{top})$:<br>$g\bar{b} \to \bar{t}H^+$ and $gg \to \bar{t}bH^+$   | For $m_{H^\pm} < m_{top}$:<br>$H^\pm \to \tau^\pm\nu$<br><br>For $m_{H^\pm} > m_{top}$:<br>$H^\pm \to tb$ and $H^\pm \to \tau^\pm\nu$ | $tt \to (H^\pm b)(W^\mp b) \to$<br>$\to (\tau_{jet}\nu\nu b)(\ell^\mp\nu b)$<br>$\to (\tau_{jet}\nu\nu b)(qqb)$<br>$\to (\ell\nu\nu\nu b)(qqb)$<br><br>$gg, gb \to t[b]H^\pm \to$<br>$\to (Wb)[b](\tau\nu) \to (bqq)[b](\tau_{jet}\nu\nu)$<br>$\to (Wb)[b](tb) \to (b\ell\nu)[b](bqqb)$ |

# Systematic Uncertainties

(restating the obvious...) The final Higgs search sensitivity is affected by uncertainties on the signal and background normalization and shapes

Let us define two types of uncertainties:

**Theory-driven (TD) uncertainties** related to signal & background theoretical predictions:

- **total cross-section → event yield normalization**
- **differential cross-sections → shapes of discriminating quantities**

**Experiment driven (ED) uncertainties** those related to experimental effects and resolutions. They also affect the measured signal and background normalization and shapes but they **are uncorrelated to the theory driven uncertainties**

Note: **experiment driven uncertainties, eg. on luminosity, fake rates, lepton id, jet energy scale and resolutions, etc., are studied by the individual experiments for the specific analyses** – there are estimates based on full detector simulation but the final numbers for the analysis will be extracted from data – and may result smaller than predicted …

Here we **focus on the TD uncertainties** both for signal and background estimates.

# TD Uncertainties on Signal & Background Normalization and Shapes

| | **Normalization and Shape** | **Validation with data?** |
|---|---|---|
| **Signal** | From theory calculations and full event generators | NO (?)<br>So far no ideas for SM (non-Higgs) processes to test Higgs prediction other than the signal itself |
| **NLO MC goals for signal studies** | Document methods for uncertainty estimates & provide compilation of **signal normalization and shape expected uncertainties** | No experimental methods to validate Higgs predictions (?) |
| **Background** | From theory and extrapolations from measurement s with data | YES |
| **NLO MC goals for background studies** | Document methods for uncertainty estimates & provide compilation of **background normalization and shape expected uncertainties** | Measurements of backgrounds in control regions – comparison with MC predictions – MC tuning with data – accurate MC for extrapolating backgrounds from control to signal regions. |

# To quantify TD uncertainties, we need…

1. **Theorists to agree upon a choice of**
   - ❑ **MC input parameter uncertainty ranges** for signal and background MC's
     - PDF's recommendation already available (**J. Huston and A. Vicini talks**)
     - review and agree on other parameters ($\alpha_s$, QCD scale, etc) and their range of variation (see eg **F. Petriello talk** on ggF inclusive e differential studies)

2. **Experimentalists to agree upon**
   - ❑ **Base-line selection cuts for all search analyses**, for which the uncertainties will be evaluated – dependency of these uncertainties on cut value choices could be parameterized in some cases to show the trends.
   - ❑ **Methods to measure backgrounds** in **control regions and extrapolate in signal regions**

3. **Theorists and experimentalists to agree on the criteria to**
   - ❑ **Match generator level objects to experimentally observable objects** on which experimental cuts are applied -> help from PO subgroup (?)

# Summary

**Signal and background total and differential cross-sections** affect total **event yields** and **shapes of discriminating quantities** used for signal and background estimates → affect signal sensitivity estimates
Higher order corrections very relevant → use MC's @ NLO and beyond

**Experimental questions to address: validation with data:**

- how can experiments **test Higgs production mechanisms before Higgs observation**?
- how can **background processes (tt, WW, ZZ, W/Z+jets) be measured** and **compared to NLO MC predictions** in control regions, allowing a **reliable extrapolation in the signal region?**

Proposal for **experimentalists contributions to the NLO MC effort** (and Yellow Rep.chapter) consisting in reviewing **Higgs search tools,background measurement methods and systematic uncertainties,** with **focus on theory driven (total and differential cross-sections) uncertainties**

**Up for discussion**… **Large overlap with all other subgroups**…

# Backup

# Signal and Background MC Event Generators Used by LHC experiments

| Multi-Purpose Generators | | | |
|---|---|---|---|
| **Physics process** | **Generator** | **Version** | **Comment** |
| **EWK, QCD,**<br>**SM Higgs**<br>**MSSM Higgs**<br>**SUSY, Exotica** | **PYTHIA6** | v. 6.422 | Standard tune D6T with Q^2 shower<br>Plans/discussions to move to pt-ordered shower and Perugia tunes as default |
| **QCD Dijet** | **PYTHIA8** | v. 8.130 | Use will be extended |
| **QCD studies** | **HERWIG6** | v. 6.510 | Comparison to PY6<br>Also used as shower/hadronizer for MC@NLO |
| **QCD studies** | **HERWIG++** | v. 2.4.2 | Comparison to HW6/PY6 |
| **W/Z production** | **SHERPA** | v. 1.2.0 | |

see F. Cossutti, F. Stoeckli, *MC4LHC: CMS Input Document, March 2010*
http://indico.cern.ch/getFile.py/access?resId=0&materialId=paper&confId=74601

# Signal and Background MC Event Generators Used by LHC experiments

| Multi-Leg Matrix-Element Generators | | | |
|---|---|---|---|
| **Physics process** | **Generator** | **Version** | **Comment** |
| **QCD**<br>**VB(-pairs)+Jets**<br>**HQ(-pairs)+Jets**<br>**(di)photon(+VB)+Jets**<br>**Z‘ production** | **MADGRAPH** | v. 4.4.13 | Main CMS LO Multi-Leg generator<br>Interfaced to PY6 for shower/hadronization |
| **top-pair**<br>**VB(+HQ)+Jets**<br>**QCD high jet multiplicity** | **ALPGEN** | v.2.13 | For many legs generation (faster than MADGRAPH)<br>For systematic comparison to MADGRAPH |
| **NLO MC Event Generators** | | | |
| **top-pair, single top,**<br>**Drell-Yan, W-pairs**<br>**gluon-fusion Higgs** | **MC@NLO** | v. 3.41 | |
| **Drell-Yan, Higgs** | **POWHEG** | | Used for qqH, H->WW->qqln |