Higgs search in H→WW decay channels with the CMS detector

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On behalf of the CMS collaboration

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Outline

- H->WW analysis overview: motivations, physical observables used, trigger and selection.
- Control of backgrounds from data
- Fake rate studies
- Results at 14 TeV CM energy
  - Exclusion and discovery regions
- Summary and Conclusions
- Projections to 10 TeV (see talk by Gregory Schott)
- Higgs production cross-section (NLO): 0.1-50 fb
- gluon fusion dominates at LHC
  - Especially at low $m_H$
  - Factor $\sim 10$ @ 100 GeV
- Here results for inclusive production

- $H \to WW(\ast)$ and $H \to ZZ(\ast)$ are main discovery channels
  - Highest BRs for $m_H > \sim 2m_W$
  - Clean leptonic decay modes
    - $BR(W \to l\nu)$: 10.8%; $BR(Z \to l^+l^-)$: 3.4%
  - Cover high $m_H$ region and down to below $2m_W$
Main search channel for a Higgs mass in the range: $2m_W < m_H < 2m_Z$, highest branching ratio >140 GeV: 95%@ $M_H=160$ GeV

Signal: 2 high-pT isolated leptons, MET and no central jets

Analyses:

- $H + 0$ jets $\rightarrow l
  l\nu\nu$ (dominated by gluon fusion)
  - the three lepton combinations are considered
- $H + 2$ jets $\rightarrow l
  l\nu\nu$; $H + 2$ jets $\rightarrow l
  \nuqq$ (dominated by VBF)
Reconstruction of physical observables

- **Electrons**
  - selections identifying fake electrons optimized against the W+jets bkg
  - tracker, ECAL, HCAL isolations optimized against the W+jets bkg

- **Muons**
  - reconstruction from muon spectrometer and tracker
  - tracker, ECAL, HCAL isolations applied

- **CaloCone5 jets** (iterative cone with $\Delta R=0.5$ and $E_T^{\text{tower}} > 0.5$ GeV)
  - no energy corrections
  - $|\eta| < 2.5$, $E_T > 15$ GeV
  - jets close to leptons ($\Delta R < 0.5$) are eliminated

- **$E_T^{\text{miss}}$**
  - sum of raw ECAL and HCAL towers energy, subtracted the muons energy
**Trigger paths and efficiencies**

**OR of the single lepton triggers used:**

- Single Isolated μ/e
- Single Relaxed μ/e

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<th>Single isolated μ</th>
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<th>Single isolated μ</th>
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<td>53%</td>
<td>62%</td>
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<td>88%</td>
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<td>58%</td>
<td>67%</td>
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Threshold [GeV]

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<tr>
<td>Single relaxed μ</td>
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<td>Single isolated e</td>
<td>12</td>
<td>15</td>
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<tr>
<td>Single relaxed e</td>
<td>15</td>
<td>18</td>
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</table>
**H→WW→llνν: selection**

- **Event topology:** 2 isolated high $p_T$ leptons + $E_T$ miss, no hadr. activity
- **Main backgrounds:** $t\bar{t}$, Drell-Yan, $WW, WZ, ZZ, tW, W+jets$

- **Preselection to select leptonic WW events**
  - Single lepton triggers
  - Exactly 2 isolated leptons opposite charge
    - $p_{T1,2} > 10$ GeV and at least one $p_T > 20$ GeV
  - $E_T^{miss} > 30$ GeV
  - $m_{ll} > 12$ GeV

- **ee, eμ and μμ considered**

- **Main selection observables**
  - Central jet veto
  - Angular correlations btw leptons
  - Dilepton mass, $E_T^{miss}$, leptons $p_T$

- **Other discriminants also used in NN analysis**

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**cut based:** mass-dependent optimization of an estimator in a N-dimensional space ($E_T^{miss}, \Delta\phi_{ll}, m(ll), p_T^{max}$ and $p_T^{min}$)

\[ n_\sigma \ (\text{cuts}) = \frac{N_S}{\sqrt{N_B + 0.04 \times N_B^2}} \]

**multivariate:** mass-dependent training of a multi layer neural network or BDT

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**After preselection and CJV**

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SUSY09 - Higgs search in $H\rightarrow WW$ decay channels with the CMS detector
Systematics and control from data

- Lepton efficiencies measured from $Z \rightarrow ll$ candle using tag and probe method

- In this analysis, control of background is crucial
  - $t \bar{t}$ and $WW$ from control region close to signal region but with low signal contribution
    - $t \bar{t}$ using signal preselection but inverting the CJV (2 jets)
    - $WW$ using signal preselection and $m_{ll}>115$ GeV
  - $W+\text{jets}$ from $P(\text{jet} \rightarrow \text{lepton})$ from jet triggers and using signal selection with only 1 identified lepton ($p_T>20$) and 1 jet ($p_T>10$)
Background determination from data

- measure the background rate in the signal region from sidebands
- sidebands as close as possible to the signal region to cancel systematics

$$N_{bkg}^{S} = \frac{\varepsilon_{bkg}^{S}}{\varepsilon_{bkg}^{N}} N_{bkg}^{N}$$

- efficiency in the signal region
- efficiency in the normalization region (sideband)

- applied to determine the $t\bar{t}$bar and WW contributions to the signal region
- the error in the evaluation of the number of events has to be evaluated
control region definition
- same selections of the analysis
- additional selections against Drell Yan
- anti jet-veto: at least two jets required in the event

error on the extrapolation to the signal region

jet energy scale rescale the jet energy by \((1+\lambda)\)
assuming a conservative 7% systematic error on JES, compute the average \(\Delta R/R\) on + and – side

statistical uncertainty: 1.5%

contamination: at the level of 10%, with an error of 20%: the effect on the uncertainty is at the level of 2%

\[
\frac{\Delta N_{tt}^S}{N_{tt}^S} = 16.5\% \oplus 1.5\% \oplus 2\% = 16.7\%
\]
Alternative for top antitop: b-tagging

- require at least two b-jets in the event

\[
\frac{\Delta N_{tt}^S}{N_{tt}^S} = \frac{\Delta R}{R} \bigoplus \frac{\Delta N_{tt}^B (\text{obs})}{N_{tt}^B (\text{obs})} \bigoplus \Delta (2 \ b - \text{jet selection})
\]

- mixed final state
- control region is bkg free
- less statistics

- jet energy scale \((1-\lambda)\)-scale on the jet energy observed statistics with about 530 events: 4.3%

- b-jets selection \((9%)^2\) (jet selection uncertainty)

\[
\frac{\Delta N_{tt}^S}{N_{tt}^S} = 16.5\% \oplus 18\% \oplus 4.3\% = 24.8\%
\]
WW Control region

To define a WW background control region in the HWW analysis, it has to be close enough to the signal region but still signal-less, that is tricky.

Instead, a similar selection to the cut based for HWW160 plus a cut in $m_{ll} > 115$ GeV/c$^2$ to reject signal was performed.

Selection: pre-selection + cuts
- pt_min > 20 if emu, ee
- MET > 45 if ee/mumu
  (the minimum cut otherwise)
- Ntracks <= 4
- deltaPhi (MET - lepton) > 60 deg

Cuts were optimized using:
$S/\sqrt{S + B + \sigma_B^2}$
where $\sigma_B = 0.25 \times B$

$$\frac{\Delta N_{WW}}{N_{WW}} - \frac{\sqrt{N_{WW}}}{N_{data}} \oplus \frac{\sigma_{bkg}}{N_{WW}} \simeq 22\%$$

$$\sigma_{bkg} \simeq 0.15 \times N_{bkg}$$
Fake rate studies

To evaluate the contribution of W+jets background in data, using fully simulated events, a very elaborated study of the electron and muon fake rates was performed.

Two steps:

- Measure the lepton-faking probability in a QCD sample that would be acquired with a prescaled jet trigger:

  \[
  f(P_T) = \frac{\text{leptons matching fakeable objects}}{\text{fakeable objects}} \quad \text{l-object}
  \]

  \[
  \text{d-object}
  \]

- Compute the background contribution using the measured fake rate and extrapolate the number of fakes in the signal region, from a sample composed by one identified lepton and a fakeable object.

  \[d\text{-objects are jets with } |\eta| < 2.5 \text{ and } p_T > 10 \text{ GeV}\]

  \[d\text{-objects are loosely isolated tracks}\]
Fake leptons contribution

- in W+jets one lepton (l) is a prompt decay of a W boson, fully identified in the analysis sequence
- count the (l+d) pairs that survive the analysis selections
- weight the survivals by the fake rate
- the shape of the selection variables in the (l+d) and (l+l) cases are compatible, hence the extrapolation is justified
- the difference on the W+jets events estimate with QCD and W+jets MC fake rates is used as systematic error
### Summary of systematic uncertainties

<table>
<thead>
<tr>
<th>Source</th>
<th>Signal (%)</th>
<th>Background (%)</th>
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<tbody>
<tr>
<td>Luminosity</td>
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<tr>
<td>Lepton &amp; trigger efficiencies</td>
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<td>Muon miscalibration and misalignment</td>
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<td>Electron miscalibration and misalignment</td>
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<td>PDF uncertainties</td>
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<tr>
<td>$t\bar{t}$ cross-section</td>
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<tr>
<td>WW cross-section</td>
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<td>WZ/ZZ/Wt cross-sections</td>
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<td>DY cross-section</td>
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<td>5</td>
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<tr>
<td>W+jets cross-sections (fakes)</td>
<td>—</td>
<td>100</td>
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<tr>
<td>MC statistics</td>
<td>5</td>
<td>10</td>
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</tbody>
</table>

Summary of the systematic uncertainties considered in the analysis. Relative contribution (in %) for signal and backgrounds.

June 7th, 2009
H→WW→llνν: results

- Likelihood ratio method
  - $S = \sqrt{-2\ln Q}$
    - $Q = \mathcal{L}_{S+B}/\mathcal{L}_B$
- Systematic errors included

14 TeV, $\int \mathcal{L} dt = 1\text{fb}^{-1}$

SM Higgs could be discovered for $m_H \sim 2m_W$ with 1 fb$^{-1}$

Sensitivity at 200 pb$^{-1}$
Conclusions

- New CMS analyses for $H \rightarrow WW$ in leptonic modes in the context of an initial scenario
- Simple cut based as well as multivariate selections have been studied
- Methods for background estimation and control from data have been established
- SM Higgs could be discovered at 5$\sigma$ around $m_H=160$ GeV in WW decay mode with $1fb^{-1}$
- Using $H \rightarrow ZZ$ and $H \rightarrow WW$ channels, SM Higgs could be excluded for $m_H>140$ GeV with $1fb^{-1}$
- 10 TeV bottom line: a loss of sensitivity by a factor $\sim2$
The CMS Detector

**SUPERCONDUCTING COIL**
- **FCAL**
- **ECAL**

**Tracker**
- |η|<2.4
- Silicium (200m²)
- **Pixel** (r_T<11cm)
  - 3 layers (barrel)
  - 2x2 disks (fwd)
- **SST** (r_T<120cm)
  - >8 hits, depending on η

**Muons**
- Drift tubes (|η|<1.2)
- Cathode strip chambers (0.9<|η|<2.4)
- Resistive plate chambers

**Weight**: 12,500 t
**Diameter**: 15 m
**Length**: 21.6 m

**e**: \( \sigma(E)/E \sim 0.5\% @100 \text{ GeV} \)
**μ**: \( \sigma(p)/p \sim 1\% @100 \text{ GeV} \)

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SUSY09 - Higgs search in H->WW decay channels with the CMS detector
Early discovery with H->WW->2l2ν counting experiment...

- **Elements of the CMS PTDR analysis**
  - $P_T$ Higgs and WW bkg. as at NLO (re-weighted in PYTHIA)
  - include box gg->WW bkg.
  - NLO Wt cross section after jet veto

- **Backgrounds from the data (and theory)**
  - tt from the data; uncertainty 16% at 5 fb$^{-1}$
  - WW from the data; uncertainty 17% at 5 fb$^{-1}$
  - Wt and gg->WW bkg from theor. uncertainty 22% and 30%

\[ E_T^{miss} > 50 \text{ GeV} \]
\[ \text{jet veto in } \eta < 2.4 \]
\[ 30 < p_T^{\text{max}} < 55 \text{ GeV} \]
\[ p_T^{\text{min}} > 25 \text{ GeV} \]
\[ 12 < m_{ll} < 40 \text{ GeV} \]
top quark background

- No central jets in the event

=> Crucial to reject top events, both in pairs and tW

- Procedure established to test the jet veto with data using Z+jets events by looking at the ratio between one and two jets bins

- Estimate the goodness of the extrapolation to the signal region, where the jet-veto is applied

- Check the agreement between data and MC in the region with several jets

- Use normalization regions as well
Extrapolation to $N_{\text{jet}} = 0$ Region

- Estimate the goodness of the extrapolation to the signal region, where the jet-veto is applied
- Check the agreement between data and MC in the region with several jets
- Verify the agreement to the simulation in all jet angular distributions

- Measure the $t\bar{t}$ in the 0-jet bin by looking for additional (soft) muons in the event
- Compute the contribution in the signal region assuming a known muon efficiency
- Muon efficiency can be tested in $N_{\text{jet}} \geq 2$ bins

![Graph showing $t\bar{t} \to b \bar{b} l\nu$]
Fake rate flavour decomposition

- The contribution of the various flavours of jets has been studied as well.

### W+jets

- **Jet flavour fraction**
- **Electrons fake rate after reconstruction, per jet flavour**

### QCD

- **Jet flavour fraction**
- **Probability (jet → fake e)/(5 GeV/c)**

**June 7th, 2009**

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SM Higgs mass constraints from the data and theory

**Experiment**

Indirect constraints from precision EW data:
- $M_H < 260$ GeV at 95 %CL (2004)
- $M_H < 166$ GeV (2006, ICHEP06)
- $M_H < 154$ GeV (2008, Physics at LHC 08)

Direct limit from LEP $M_H > 114.4$ GeV

**SM theory**

The triviality (upper) bound and vacuum stability (lower) bound as function of the cut-off scale $\Lambda$

“triviality”:
- Higgs self-coupling remains finite

Direct limit from LEP $M_H > 114.4$ GeV