Measurements of Differential Higgs Boson Production Cross Sections in the Leptonic WW Decay Mode with CMS

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Abstract

Measurements of differential production cross sections of the Higgs boson in pp collisions at $\sqrt{s}$ = 13 TeV are performed using events where the Higgs boson decays into a pair of W bosons which subsequently decay into an electron, a muon, and a pair of neutrinos. The analysis is based on data collected by the CMS detector at the LHC in 2016, 2017, and 2018, and corresponds to an integrated luminosity of 137 fb−1 . Production cross sections with respect to the transverse momentum of the Higgs boson and the number of hadronic jets are considered. Higgs boson signal spectra are extracted and simultaneously unfolded to correct for selection efficiency and resolution effects by means of maximum likelihood fits to the observed event distributions.

Motivation & Introduction

- **$H \rightarrow WW$ has large branching fraction. Ideal for:**
  - **Precision measurement of Higgs production cross section**
  - **Studying subleading production modes**
- **Different flavor leptonic decay of W is cleanest channel**
- **High precision theoretical predictions of differential cross sections allows for:**
  - **Probing higher order corrections**
  - **Deviations from the SM**
- **Cross section w.r.t. transverse momentum of Higgs is sensitive to Yukawa couplings of light quarks**

Analysis Strategy

- **Signal region events binned by observed p_T^H or N_{jet}**
- **m^{ll} and m_T^H discriminate well against background processes**
- **Fit using 2D (m^{ll}, m_T^H) distributions**
- **Number of signal events from each generator level bin extracted from this fit**
- **Control regions for $t\bar{t}$ pair production and Drell-Yan τ lepton pair production included in fit**
- **Unfolding, regularization and signal extraction done simultaneously in the fit**

Backgrounds

- **Dominant Backgrounds:**
  - **W^+W^- :** Modeled with MC. Normalization left free in fit, mostly constrained by high m^{ll} region
  - **$t\bar{t}$:** Modeled with MC. $t\bar{t}$ control region included in fit.
  - **Drell-Yan τ lepton pair production:** Modeled with MC. Drell-Yan control region included in fit.
- **Non-Dominant Backgrounds:**
  - **W^+W^- production via vector boson scattering, W or Z in association with γ/ γ*, Production of 2+ weak bosons with Z, More than 2 W bosons, data-driven non-prompt**

Selection

Selection	Requirements	Note
Preselection	leading two leptons have opposite sign and different flavour, $p_{\mathrm{T}}^{\ell_1} > 25\,\mathrm{GeV}$, $p_{\mathrm{T}}^{\ell_2} > 13\,\mathrm{GeV}$, $\lvert\eta\rvert < 2.5$ (2.4) for e (μ), $p_{\mathrm{T}}^{\mathrm{miss}} > 20\,\mathrm{GeV}$, $p_{\mathrm{T}}^{\ell\ell} > 30\,\mathrm{GeV}$, no additional leptons with $p_{\mathrm{T}} > 10\,\mathrm{GeV}$	
Signal region	$m^{\ell\ell} > 12\,\mathrm{GeV}$, $m_{\mathrm{T}}^{\mathrm{H}} > 60\,\mathrm{GeV}$, $m_{\mathrm{T}}^{\ell_2} > 30\,\mathrm{GeV}$, no b-tagged jets with $p_{\mathrm{T}} > 20\,\mathrm{GeV}$	Binned by $p_{\mathrm{T}}^{\mathrm{H}}$ or N_{jet} and categorized by lepton properties
$t\bar{t}$ control region	$m^{\ell\ell} > 50\,\mathrm{GeV}$, $m_{\mathrm{T}}^{\ell_2} > 30\,\mathrm{GeV}$, at least one b-tagged jet with $p_{\mathrm{T}} > 20\,\mathrm{GeV}$ if $N_{\mathrm{jet}} = 0$, else $p_{\mathrm{T}} > 30\,\mathrm{GeV}$	Binned by $p_{\mathrm{T}}^{\mathrm{H}}$ or N_{jet}
$\tau^+\tau^-$ control region	$40 < m^{\ell\ell} < 80\,\mathrm{GeV}$, $m_{\mathrm{T}}^{\mathrm{H}} < 60\,\mathrm{GeV}$, no b-tagged jets with $p_{\mathrm{T}} > 20\,\mathrm{GeV}$	Binned by $p_{\mathrm{T}}^{\mathrm{H}}$ or N_{jet}

Results

Unfolding & Signal Extraction:

- **The cross sections are determined from the simultaneous fit to all bins and categories of the signal events and two control regions, which gives the signal strength modifiers.**
- **Since initial normalizations of the signal templates are set to SM expectations, the scale factor extracted from the fit on the generator-level bins can be interpreted at their signal strength modifiers:**

$$\mu_i = \sigma_i^{obs} \Big/ \sigma_i^{SM}$$

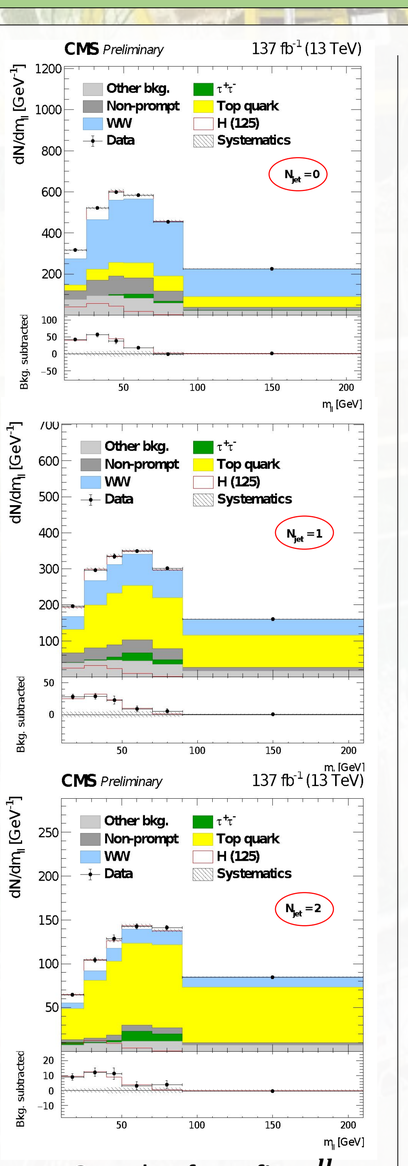
- **Thus, from the signal strength modifiers the differential cross sections can be inferred.**
- **Most of the systematic uncertainties are taken as nuisance parameters in the fit.**

- **Main systematic uncertainties:**
  - **Non-prompt background**
  - **WW background**
  - **Residual p_T^{miss} uncertainties**
  - **Lepton ID Efficiency Scale Factors**

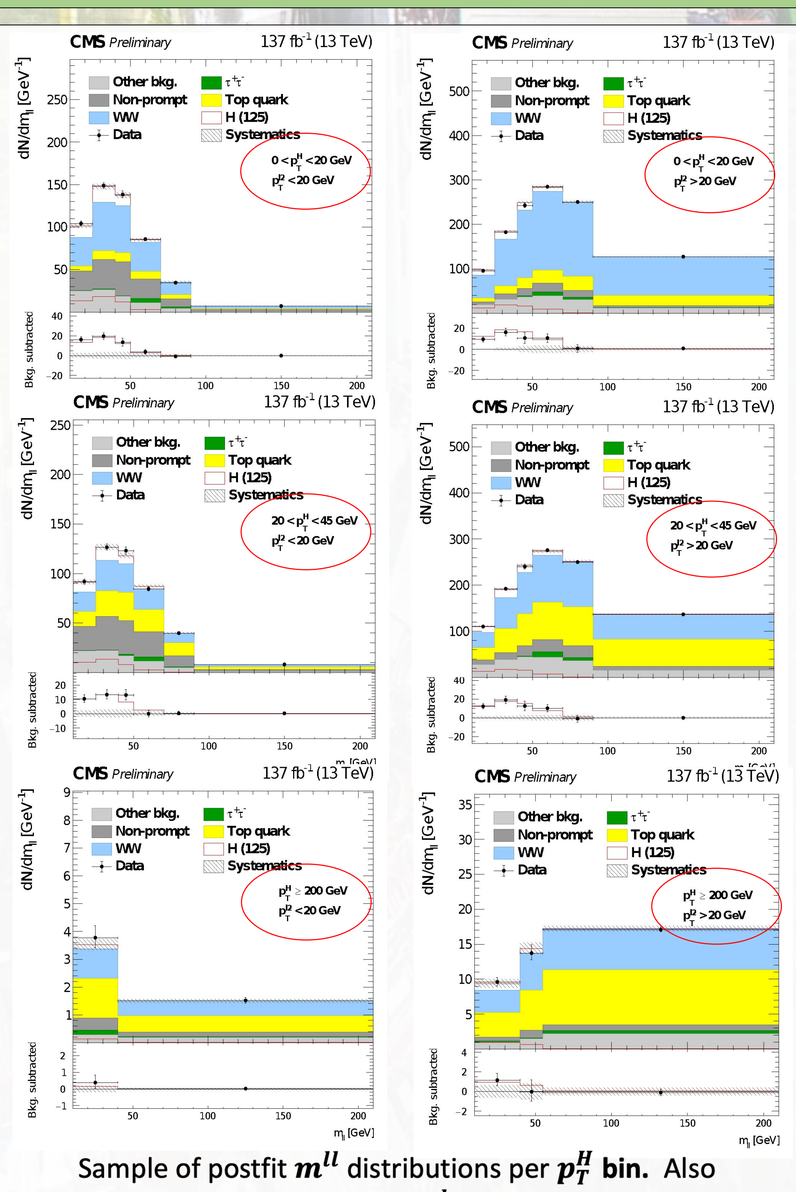
Lepton origin	Direct decay product of $H \rightarrow WW$
Lepton flavor and charge	Different flavor, opposite charge
Leading lepton p_{T}	$p_{\mathrm{T}}^{\ell_1} > 25\,\mathrm{GeV}$
Trailing lepton p_{T}	$p_{\mathrm{T}}^{\ell_2} > 13\,\mathrm{GeV}$
Pseudorapidity of the leptons	$\lvert\eta\rvert < 2.5$
Dilepton mass	$m^{\ell\ell} > 12\,\mathrm{GeV}$
Dilepton transverse momentum	$p_{\mathrm{T}}^{\ell\ell} > 30\,\mathrm{GeV}$
Transverse mass of trailing lepton	$m_{\mathrm{T}}^{\ell_2} > 30\,\mathrm{GeV}$
Higgs transverse mass	$m_{\mathrm{T}}^{\mathrm{H}} > 60\,\mathrm{GeV}$

$\sigma^{SM} = 82.5 \pm 4.2\ fb$

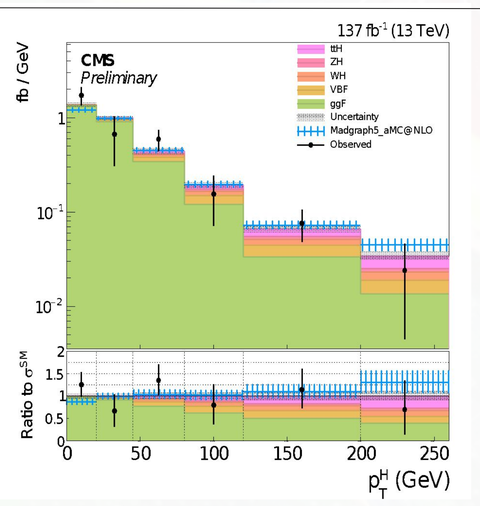
Fiducial Region Definition

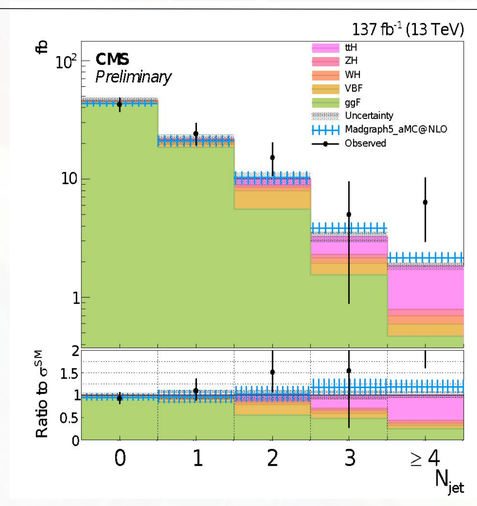


Sample of postfit m^{ll} distributions per N_{jet} bin.



Sample of postfit m^{ll} distributions per p_T^H bin. Also split by $p_T^{l_2}$.





$\mu^{fid} = 1.03^{+0.12}_{-0.11}(^{+0.05}_{-0.05}(stat.)^{+0.08}_{-0.07}(theo.)^{+0.03}_{-0.03}(lumi.)^{+0.07}_{-0.07}(exp.))$
$\sigma^{fid} = 85.0^{+9.9}_{-9.3}$ fb.

Observed differential fiducial cross sections in bins of p_T^H and N_{jet}. Overlaid with predictions from nominal and alternative signal models. Filled histogram in ratio plot shows the relative contributions of the Higgs boson production modes in each bin.

References

1. Measurements of differential Higgs boson production cross sections in the leptonic WW decay mode at s√=13 TeV, CMS Collaboration, CMS PAS HIG-19-002.