Measurements of the Higgs Boson decaying to Tau Pairs at CMS

Somnath Choudhury
Indian Institute of Science, Bangalore
(for the CMS collaboration)
LHC Run 2 Results

- $H(125) \rightarrow 2\tau$

- $H(125)$ in gluon fusion and VBF
- $H(125)$ in associated W/Z mode
- Combination of production modes
H(125) \rightarrow \tau\tau
(glueon fusion and VBF process)
Higgs boson in $\tau\tau$ decay mode is the most promising channel to explore the Higgs-Yukawa coupling to fermions (decay rate to $\tau\tau$ is less than $bb$, but this channel has much less background).

Analysing Run-1 data, in 4 production modes led to the first evidence of Higgs boson coupling to fermions.

Observed (expected) significance of 3.2 (3.7) $\sigma$.

Hadron Plus Strips (HPS) algorithm updated for run2 with dynamic strip reconstruction.

Tau leptons are reconstructed either in 1 prong or 3 prong modes.

Developed MVA based discriminators to suppress misidentification of the taus by jets, electrons and muon.

Full tau pair mass reconstruction using dedicated algorithm using secondary vertex and lifetime information.
Event Categorisation

Event categorization has been changed in LHC Run-2

3 primary categories (mainly) based on the jet multiplicity of the di-tau events
In each category, events are further spitted depending on tau decay modes:
- muon $p_T$ (in 0-jet),
- $p_T$ of the Higgs boson (in boosted) and
- mass of two forward jets (in VBF mode)

2D distributions are then unrolled to 1D distributions which will be the input for the statistical interpretations

<table>
<thead>
<tr>
<th></th>
<th>$\tau\tau$</th>
<th>$\mu\tau$</th>
<th>$e\tau$</th>
<th>$e\mu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0jet</td>
<td>$m_{\tau\tau}$</td>
<td>$m_{\text{vis:}\tau}$ DM</td>
<td>$m_{\text{vis:}\tau}$ DM</td>
<td>$m_{\text{vis:}\mu}$ $p_T$</td>
</tr>
<tr>
<td>boosted</td>
<td>$m_{\tau\tau}$ : H $p_T$</td>
<td>$m_{\tau\tau}$ : H $p_T$</td>
<td>$m_{\tau\tau}$ : H $p_T$</td>
<td>$m_{\tau\tau}$ : H $p_T$</td>
</tr>
<tr>
<td>vbf</td>
<td>$m_{\tau\tau}$ : $m_{jj}$</td>
<td>$m_{\tau\tau}$ : $m_{jj}$</td>
<td>$m_{\tau\tau}$ : $m_{jj}$</td>
<td>$m_{\tau\tau}$ : $m_{jj}$</td>
</tr>
</tbody>
</table>
Background Estimation

Z→ττ simulation:
Madgraph N-Jet binned Drell-Yan Samples, corrections derived from Z(μμ) CR and applied

DY ℓ→τ fakes simulation:
Madgraph N-Jet binned Drell-Yan Samples, corrections derived from Z(μμ) CR and applied. Additional ℓ→τ fake corrections.

W+Jets/VV: datadriven in control region for ℓτ

QCD: datadriven in control region, for ℓτ, ττ, eμ

TTbar: powheg MC eμ, ℓτ, ττ: datadriven all channels

Somnath Choudhury
Results

Background composition and signal sensitivity varies in each slices
Observed and predicted 2D distributions in the VBF category of the $\tau_h\tau_h$ decay channel (From low $m_{jj}$ to high $m_{jj}$).
Higher S/B and higher purity for VBF production compared to ggH production mode.
Visible excess of data on top of the SM prediction.
Observed and predicted 2D distributions in the boosted category of the $\tau_h\tau_h$ decay channel in increasing $p_T$
Reorder the bins based on \( \log(S/S+B) \)

Sensitive bins are shifted to the right-side of the distribution and less sensitive to left

Bins are weighted according to \( S/S+B \)

Higgs signal peaks around 125 GeV
4.9 (4.7) $\sigma$ observed (expected) significance
- Combining with run1 we would have 5.9 $\sigma$ (the first observation of the Higgs coupling to tau leptons in a single experiment)
- Signal strength of 1.09 $\pm$ 0.26
- $\tau_h\tau_h$ is the most sensitive channel
- VBF is the most sensitive category
H(125) → \tau \tau

(VH process)
- 8 final states are explored: \( eee\mu, eee\tau, e\mu\mu\tau, e\mu\mu\mu, \mu\mu\mu\mu, \mu\mu\mu\tau, \mu\mu\mu\mu, \mu\mu\mu\mu \)

- Clean signatures with ZZ as irreducible background. Other are WZ and Z+jets

- \( L_T \) (scalar sum of the lepton \( p_T \) from H decay) is used to improve the sensitivity

- High \( L_T \) category is more sensitive

- The excess of data in most of the bins near Higgs mass

---

**CMS HIG-18-007**

---

**ZH**

---

**CMS**

- Observed
- ZZ \( \rightarrow 4l \)
- Other
- Reducible
- Uncertainty

**35.9 \text{ fb}^{-1} (13 \text{ TeV})**

**ZH combined**

**Events / 20 GeV**

---

**(Obs. - Bkg.) / Bkg.**

- VH, H \( \rightarrow \tau \tau \) (\( \mu=2.5 \))
- VH, H \( \rightarrow \tau \tau \) (\( \mu=2.5 \))

**m_{\tau\tau} (GeV)**

---

**Somnath Choudhury**
WH semi-leptonic

- $e\mu_{T_h}$, $\mu\mu_{T_h}$ channels

WZ is the irreducible background. Other backgrounds like Z+jets and top pair are highly suppressed by requiring 2 leptons to be same sign.

WH hadronic

- $e\tau_h^-, \mu\tau_h^-$ channels

Larger background w.r.t other VH channels.

The excess of data in most of the bins near Higgs signal

To extract the limit, all 4 WH channels are fitted simultaneously.
Event Excess

The signal strength is $2.5 \pm 1.4$

ZH and WH production modes have similar sensitivity
Combination
Observation of the Higgs boson in $\tau\tau$ decay
5.5 (4.8) $\sigma$ observed (expected) significance
The combined signal strength is $1.24 \pm 0.28$

Higgs couplings to bosons and fermions are compatible with SM expectation
Higgs boson decays to W or Z pairs, are considered as part of the signal
First observation of the SM Higgs boson to a pair of tau leptons with a single experiment

5.9 observed significance by combining 2016 (excluding VH) + Run-1 data
5.5 observed significance by 2016 data

The best fit value is consistent with 1.0 within one standard deviation

The coupling to both fermions and bosons are compatible with those predicted by SM

Next steps:
Measuring the Higgs coupling to tau lepton more precisely, as we accumulate more data
Measuring the Higgs anomalous coupling in $\tau\tau$ final state
CP properties, ……

New results will appear soon!