Measurement of Higgs bosons decaying to Tau lepton pairs and Constraints on Anomalous HVV couplings.

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The Higgs Boson and Taus

- Tau Identification:
  - Tau Decays \textit{hadronically} ($\tau_h$) and \textit{leptonically}
  - Hadron Plus Strips to identify $\pi$’s in $\tau_h$ decays

- Use taus to investigate properties of the Higgs:
  - Good Branching Fractions
  - Excellent online selection
  - Higgs couples to mass. Tau is the most massive lepton
Signals and Final States

- Production Mechanisms:
  - Vector Boson Fusion (VBF)
  - Gluon Gluon Fusion (ggH)

- Final States

\[ \tau_h \tau_h, e\tau_h, \mu\tau_h, e\mu \]

- Main Backgrounds:
  - QCD background
  - Drell – Yan
  - \( t\bar{t} \)

- Challenges:
  - Jets faking taus
  - Leptons faking taus
Event Categorization and Fit Model

• 3 Event Categorizations:
  • For a final fit, most categories and channel use a **2D fit** in the limits to extract **significance for the mass of the \( \tau \tau \) system**
  • **0-jet category** is used to constrain backgrounds, VBF and Boosted for signal extraction
    • Shown below is the 0-jet category for each channel

<table>
<thead>
<tr>
<th>Categorization</th>
<th>( \tau_h \tau_h )</th>
<th>( \mu \tau_h )</th>
<th>( e \tau_h )</th>
<th>( e \mu )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - Jet</td>
<td>( m_{\tau \tau} )</td>
<td>( m_{vis} : \tau_{DM} )</td>
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<td>( m_{vis} : \mu_{pt} )</td>
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• 0-jet criteria: no jet > 30 GeV, \(|\eta| < 4.7\), and loose particle flow I.D.

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**\( e \mu \) and \( \tau_h \tau_h \) don’t resonate sharply around \( Z \) ... for \( \tau_h \tau_h \) 1D is used for high \( pt \) threshold**

**0jet has better separation in visible mass**
Background Methods

- Several Control Regions (CR) are used to measure background for W+Jets, Z+Jets, $tt\bar{t}$, and QCD.

$$QCD = O.S. \ \text{Loose Iso.} \times \left( \frac{S.S. \ \text{Sig. Iso.}}{S.S. \ \text{Loose Iso.}} \right)$$

- QCD yield estimated in sideband region.

- $m_{\tau\tau}$ in the 0 jet category shows QCD dominance.
Unrolled Distributions $m_{\tau\tau}:m_{jj}$

- 2D categories are **split** and **unrolled**, VBF category in the $\mu\tau_h$ channel shown

- The Z and Higgs are well **separated** with the Z at 90 GeV and Higgs at 125 GeV
Unrolled Distributions $m_{\tau\tau}:m_{jj}$
Unrolled Distributions $m_{\tau\tau}:m_{jj}$

- 2D categories are split and unrolled, shown below.
- The Z and Higgs are well separated in the CMS distribution, with the Z at 90 GeV and Higgs at 125 GeV.
The $S/(S+B)$ weighted distribution is shown on the right.

- $p$-value scan shows $5\sigma$ sensitivity.
Performance of 2D Fit

- The $S/(S+B)$ weighted distribution is shown on the right.
- p-value scan shows $5\sigma$ sensitivity.
Using MELA in $H \rightarrow \tau \tau$

- Matrix Element Likelihood Analysis (MELA) can be used to constrain couplings in HVV processes such as Higgs coupling to ZZ, WW, Z\gamma, γγ, and gg:

  - Build discriminant with MELA to make an optimal observable

  $$ D_{0-} = \frac{P_{0-}}{P_{0+} + P_{0-}} $$

- For the future, use discriminant in conjunction with Machine Learning for 2D or 3D fit!
Future Studies

- We may use **Machine Learning** and **MELA** in the final 2D or 3D fit.

- R.O.C. Curve with BDTs trained in VBF category

- \( M_{sv} \) shown after preliminary BDT cut in Boosted Category
References

• CMS Detector Public Page: [Link]
• HIG-17-011 Observation of the SM scalar boson decaying to a pair of tau leptons with the CMS experiment at the LHC, CMS PAS HIG-16-043 [Link]
• Constraints on anomalous Higgs boson couplings using production and decay information in the four-lepton final state, HIG-17-011 [Link]
• Constraints on anomalous HVV couplings in production of Higgs bosons decaying to tau lepton pairs, CMS CADI HIG-17-034
Thank you
Backup
Full Event Categorization and Fit Model

- 3 Event Categorizations:
  - For a final fit most categories and channel use a 2D fit in the limits to extract significance for the mass of the $\tau\tau$ system

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<td>Boosted</td>
<td>$m_{\tau\tau}:\text{Higgs}_{\text{pt}}$</td>
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- $m_{\tau\tau}$ is precisely measured using SV-Fit

98% $ggH$ signal, $e\mu$ and $\tau\tau$ don’t resonate sharply around $Z$ ... for $\tau\tau$ 1D is used for high $pt$ threshold

0 jet has better separation in visible mass. Low DY lepton faking tau in 3-prong DM.