Measurement of Higgs Boson Couplings in the Di-tau Final State

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ABSTRACT

The Higgs boson decays to tau leptons was observed using Run 1 and 2016 Run 2 data recorded by the CMS experiment at the LHC. The observed significance of the \( H \rightarrow \tau \tau \) signal exceeds five standard deviations. Anomalous couplings to vector bosons are measured via the vector boson fusion production, and lead to the tightest constraints on HVV couplings at the 95% confidence level.

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**Main Production Mechanisms**

- Gluon-Gluon Fusion (gH)
- Vector Boson Fusion (VBF)
- Associated production with a vector boson

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**Event Categorization**

Events are categorized to target to ggH and VBF productions:

1) gg: Targeted gluon fusion events and constrain background
2) VBF: Events with 2 jets present, high di-jet mass/high Higgs pr
3) Boosted: Events with 1jet or failed selection of other categories

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**Signal Extraction and Result:**

- Significant excess around Higgs mass
- Maximum likelihood fit of 2D distributions in each category
- The observed significance of \( H \rightarrow \tau \tau \) is 4.9σ
- The combination with Run 1 measurement leads to the first observation of \( H \rightarrow \tau \tau \) with significance of 5.9σ

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**Combined Result with VH:**

- The observed significance of \( H \rightarrow \tau \tau \) in associated with a W or a Z boson is 2.3σ
- The combination with the ggH and VBF results set the tightest constraints on \( H \rightarrow \tau \tau \) at 13 TeV as \( \mu = 1.24 \pm 0.27 \) for a significance of 5.5σ

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**Tau Lepton Decay**

4 final states(\( \tau \tau, \mu \tau, \tau \mu, \mu \mu \)) with the largest branching fractions were considered in the analyses.

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**The First Observation of \( H \rightarrow \tau \tau \)**

- \( H \rightarrow \tau \tau \) is the first leptonic decay of Higgs accessible at the LHC thanks to the largest branching fraction out of all leptonic decay channels.

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**The Tightest Constraints on HVV from \( H \rightarrow \tau \tau \)**

- Although cross-section for VBF and VH productions which have HVV coupling are much lower than that of ggH production, \( H \rightarrow \tau \tau \) decay channel becomes a major channel to study HVV production coupling due to its large branching fraction and relatively clean signature.

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**Coupling Parameters**

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\begin{align*}
\phi_1 &= \arg\left(\frac{g_{1}}{m_{W}}\right), \\
\phi_2 &= \arg\left(\frac{g_{2}}{m_{Z}}\right), \\
\phi_3 &= \arg\left(\phi_{L}^{\mu \tau}\right) \\
\phi_{L}^{\mu \tau} &= \frac{g_{L}^{\mu \tau}}{m_{W}} \\
\end{align*}
\]

Using full kinematic build discriminant for processes

- Discriminant: ratio of probabilities
- Optimal observable: \( D = \frac{P_{SM}}{P_{SM} + P_{BSM}} \)

- MELA (Matrix Element Likelihood Approach):
  - Additional Optimal Observable for HVV Anomalous Couplings in VBF category

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**Combined Rest with \( H \rightarrow 4l \):**

This combination places the most stringent constraints on anomalous HVV couplings.