Search for the exotic decay of the Higgs boson in the \( h \rightarrow \alpha\alpha \rightarrow bb\tau\tau \) channel

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On behalf of CMS Collaboration

Introduction

- Indirect constraint by ATLAS and CMS on \( R_{h} = BR(h \rightarrow SM) < 34\% \) at 95% CL [1]
- Large region for exotic Higgs decays: \( h \rightarrow \alpha\alpha \)
- Many models include exotic decays of a SM-like Higgs boson like 2HDM+S
- The results are interpreted in the four types of 2HDM+S without FCNC at tree level [2]
- \( R_{h} \) - SM particles through RSM physics depends on \( \tan\beta \) and \( m_{h} \)
- The largest \( R_{h} \rightarrow 2\tau \) for \( \tan\beta=4.5 \) for type-III with \( \tan\beta=2.0 \)

Baseline selection

Three di-tau final states are probe:
- \( e\tau \), \( \mu\tau \), \( e\mu \)
- For each final state events pass a different trigger: single electron in \( e\tau \), single muon or muon + tau in \( \mu\tau \) and electron + muon in \( e\mu \)
- Table 1: Baseline selection criteria on the objects selected in the various final states.

<table>
<thead>
<tr>
<th>( p_{T}(h) ) (GeV)</th>
<th>( p_{T}(\tau) ) (GeV)</th>
<th>( \eta(h) )</th>
<th>( \eta(\tau) )</th>
<th>( \Delta R ) (e, ( \tau ))</th>
<th>Isolation (e)</th>
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<td>( p_{T}(\nu) ) (GeV)</td>
<td>( p_{T}(\bar{\nu}) ) (GeV)</td>
<td>(e, ( \tau ))</td>
<td>Isolation (( \nu ))</td>
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Background Estimation

- In the \( e\mu \) final state, the \( W + jets \) background is estimated from simulation.
- The QCD background is estimated from same-sign data. All same-sign processes are subtracted from same-sign data.
- A correction is applied to extrapolate the normalization obtained in the same-sign region to the signal region.
- Single top, diboson and \( t\bar{t} \) processes estimated from simulation.
- SM Higgs boson processes considered as background.

Jet \( \tau \) fake background estimation

- Backgrounds with jets misidentified as a \( \tau \) candidate are estimated from data using the fake rate method (consist mostly of \( W+jets \) and QCD multijets events).
- The probabilities for jets misidentified as a \( \tau \) candidates, denoted \( f_{\tau} \), are estimated from \( Z \rightarrow \mu\mu \) events in data separately for each \( \tau \) decay mode and parameterized with as a function of the \( p_{T} \).
- Events that pass all the selection criteria for the signal region, except that the \( \tau \) candidate fails the isolation condition, are reweighted with a weight \( f(1-f) \) to estimate the contribution of events with jets in the signal region.

MC Simulations

- Background samples:
  - \( DY + jets \), scaled to NLO cross section MADGRAPH (k-factor = 1.16)
  - \( W + jets \), scaled to NLO cross section MADGRAPH (k-factor = 1.21)
  - \( t\bar{t} \) and single top, scaled to NLO cross section, POWHEG
  - Diboson WW, WZ, ZZ, VV, scaled to NLO cross section, AMC@NLO
  - SM Higgs Decays, scaled to NLO cross section, POWHEG

- Signal samples:
  - \( gg \rightarrow h \rightarrow \alpha\alpha \rightarrow \mu\mu + jets \) for 10 mass points (15 to 60 GeV)
  - \( VBF \) and VH di-tau mass distribution set equal to ggH and rescaled

Selection Optimization

- Selection criteria are applied to optimize the expected limits on the signal cross section times the branching fraction.
- They are based on the transverse mass of the missing \( p_{T} \) and the leptons, \( m_{T} \), and on \( D_{0} \) (Table 2)

<table>
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<th>( m_{T} ) (GeV)</th>
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<tr>
<td>15</td>
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<td>30</td>
<td>45</td>
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<td>45</td>
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Categorization

We have four categories based on the visible invariant mass of the di-tau lepton and the leading b-jet because the data and the signal have very different distributions.

- The thresholds that define the categories depend on the final states and are shown with the vertical red lines in the figures 1 and 2 below.
- First categories have very few backgrounds (1, 2).
- Intermediary categories contain low \( m_{T} \) signal (2, 3).
- High category is signal free and used to constrain the background (4).

Conclusions

- Systematic uncertainties related to physics objects and related to background estimation are implemented.
- Maximum likelihood fit based on the invariant di-tau mass distributions in different channels and categories.
- Upper limits on \( B(h \rightarrow \alpha\alpha) \) for the most favorable 2HDM+S scenarios are between 6% - 24%.

References

3. CMS PAS HIG-17/04, “Search for exotic decay of the Higgs boson in a pair of light pseudoscalars in the final state with both quarks and two leptons.”