Search for New Light Higgs Bosons in Boosted Tau Final States at CMS

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Motivations

- Higgs discovery: important validation of SM
- Hierarchy problem: no explanation why $m_H \ll$ Planck scale
- MSSM: simplest SUSY extension of SM, addresses hierarchy problem, but $\mu$-term needs fine-tuning
- NMSSM: extension of MSSM by an extra singlet superfield, solves $\mu$-problem
- Recent Tevatron/LHC results allow up to $\sim 30\%$ BR for $H(125)$ to unseen decay modes

$$\Delta m_H^2 = -\frac{|\lambda_f|^2}{8\pi^2}\Lambda_{UV}^2 + \ldots$$

<table>
<thead>
<tr>
<th>NMSSM Higgs sector</th>
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<tbody>
<tr>
<td>$H^\pm$</td>
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<tr>
<td>$h_1, h_2, h_3$</td>
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<tr>
<td>$a_1, a_2$</td>
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Signature

- Search for H decays to light pseudoscalars, motivated by some 2HDM’s such as NMSSM
- Benchmark model: NMSSM $H \to aa \to 4\tau$
  - $m_H = 125$ GeV ($h_2$ in NMSSM)
  - $m_a = 5-15$ GeV ($a_1$ in NMSSM)
- 4 production modes: ggH, VBF, WH, and ZH
CMS Experiment

Key:
- **Muon**
- **Electron**
- **Charged Hadron (e.g. Pion)**
- **Neutral Hadron (e.g. Neutron)**
- **Photon**

Transverse slice through CMS

Iron return yoke interspersed with Muon chambers

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Why look for hadronically decaying taus?

- This analysis focuses on $\tau \rightarrow \tau \mu \tau h$
- $\text{Br}(\tau \rightarrow \text{hadrons}) \sim 65\%$, compared to $\text{Br}(\tau \rightarrow \mu)$ and $\text{Br}(\tau \rightarrow e) \sim 17\%$ each
- Excellent $\tau h$ reconstruction and ID performance at CMS (standard algorithm “hadrons-plus-strips”, HPS)
Boosted $\tau_\mu \tau_h$ ID

- $m_H \gg m_a \Rightarrow$ boosted $a$ decays to collimated $\tau$ pair
- Standard HPS algorithm for $\tau$ reconstruction fails due to overlapping $\tau$ decay products
- Boosted $\tau_\mu \tau_X$ ID:
  - remove soft $\mu$ from particle candidates of jet used to seed HPS $\tau$
  - significant recovery of $\tau$ ID efficiency (e.g. from $\sim 20\%$ before muon removal to $\sim 60\%$ after muon removal)
- At least one $\tau_\mu \tau_X$ object required per event

- $\tau_{\text{had}}$: 1 charged hadron + 1 neutral
m_{\mu+X}: signal-to-background discrimination after full selection (left plot)

Data control region: events passing all selection cuts EXCEPT \( \tau_h \) isolation
  - used to model predicted background \( m_{\mu+X} \) shape in search region
  - good data/MC agreement (example: right plot, tau decay modes)
Results

- Perform counting experiment in $m_{\mu+X} > 4$ GeV, look for excess above expected SM background
- No significant excess observed above expected background
- Use results to set upper limits on $\text{Br}(H \to aa) \cdot \text{Br}^2(a \to \tau\tau)$
• At $m_a = 11,13$ GeV, strongest limits on $\text{Br}(H\rightarrow aa) \cdot \text{Br}^2(a\rightarrow \tau\tau)$
• Model-independent limits ⇒ can be interpreted in context of different benchmarks
Conclusions

- Search for Higgs decays to light pseudoscalars
  - First public limits on a four-$\tau$ signature of this kind
- New method for boosted $\tau_\mu \tau_\nu$ ID
- Run II
  - Higher energies, new possibilities for BSM physics searches
  - Exploring other methods for identifying boosted tau topologies (e.g., tau jet substructure)
Backup
Selection sequence

- **HLT_IsoMu24_2p1** (HLT)
- **trig. μ p_T > 25 GeV**
- **trig. μ tight ID, isolation < 0.12**
- **τ_μ p_T > 5 GeV**
- **τ_μ soft ID**

Jet with τ_μ removed seeds τ_had

- **τ_τ DMF + medium iso**
- **CSV < 0.679** (b-veto)
- **q_{τμ}q_{τμ} > 0** (charge filters)
- **q_{τμ}q_{ττ} < 0**

**τ_had ID**

- **τ_τ DMF + medium iso**
- **CSV < 0.679** (b-veto)
- **q_{τμ}q_{τμ} > 0** (trigger matching)
- **q_{τμ}q_{ττ} < 0**

- **τ_τ DMF + medium iso**
- **CSV < 0.679** (b-veto)
- **q_{τμ}q_{τμ} > 0** (trigger matching)
- **q_{τμ}q_{ττ} < 0**

**M_T < 50**
- **m_{μ+X} > 4** (gg fusion analysis)
- **M_T > 50**
- **m_{μ+X} > 4** (gg + Wh analysis)

- **dz(τ_T,PV) < 0.2 cm** (compatibility with PV)
- **dz(τ_μ,PV) < 0.5 cm**

- **(M_T binning)**
Signal-to-background prediction, high $M_T$

CMS Simulation Preliminary

19.7 fb$^{-1}$ (8 TeV)

Events / bin

$m_{\mu+X}$ (GeV)

$M_T$

- $ggH \ m_a = 9$ GeV
- $WH \ m_h = 9$ GeV
- $VBF \ m_a = 9$ GeV
- $ZH \ m_h = 9$ GeV
- Single top
- $t\bar{t} +$ jets
- Drell-Yan + jets
- QCD (from data)

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