Search for new physics with tau final states at 13 TeV @CMS

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On behalf of CMS Collaboration
Outlines

• Introduction

  *What are we looking for?*

• 13 TeV Analysis

  - Z’: EXO-16-008 [https://cds.cern.ch/record/2160363](https://cds.cern.ch/record/2160363)
  - W’: EXO-16-006 [https://cds.cern.ch/record/2140976](https://cds.cern.ch/record/2140976)
  - WR: EXO-16-016 [https://cds.cern.ch/record/2159374](https://cds.cern.ch/record/2159374)
    EXO-16-023 [https://cds.cern.ch/record/2205270](https://cds.cern.ch/record/2205270)
  - LQ3: EXO-16-016, EXO-16-023
Introduction

In the Exotica group, we look for massive non-SM particles (W', Z', W_R, LQ3) decaying to at least one tau in association with other leptons or jets.

<table>
<thead>
<tr>
<th>considered final states</th>
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<tbody>
<tr>
<td>1 tau</td>
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<tr>
<td>2 taus</td>
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<table>
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<tr>
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<th>τ_h</th>
<th>τ_eτ_h</th>
<th>τ_μτ_h</th>
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since most of the non-SM particles couple to fermions equally, decays of X → τ_e/μ and X → τ_eτ_e/τ_μτ_μ are hard to distinguish from X → e/μ and X → ee/μμ and have a much smaller branching ratio. Thus, they’re not considered in the studies I will present today.
Additional gauge bosons emerge in many extended gauge models:

- **Sequential standard models (SSM)**: SM + additional massive boson with the same couplings constants as SM massive bosons.

- **LR model**: Extends the standard model gauge group with a right-handed charged boson as well as an additional neutral current.

Some theories predict enhanced coupling to 3rd generation:

- **Extended weak gauge group**: Extended $SU(2) \times SU(2)$ structure for weak interactions where the first two generations of fermions are charged under the weaker $SU(2)$ and the third generation feels the stronger $SU(2)$.
Typical Background Estimation

SM processes with taus (Drell-Yan / top / rare SM / W+jets*):
• simulate using Powheg/MadGraph + Pythia8 + detector. response
• derive scale factors and corrections
• validate/evaluate systematic uncertainties in control regions

SM processes with jets faking taus (QCD multi-jet/ W+jets*):
• “ABCD” data-driven method
• validate/evaluate syst. in control regions

- estimate jet->tau fake rate among regions B and D
- apply fake rate to region C

* different W+Jets estimation techniques were used depend on the analysis
Analysis: $Z' \rightarrow \tau^+ \tau^-$

EXO-16-008

Signal sample:
- $Z'$ with invariant mass between 500 to 3000 GeV

Final states:
- $\tau_h \tau_h$, $\tau_\mu \tau_h$, $\tau_e \tau_h$, $\tau_e \tau_\mu$
- general di-$\tau$ new resonance search using SSM $Z'$ as benchmark model

Selections:
- $\tau_h \ p_T > 20 \ (\tau_\ell \tau_h) \ 60 \ (\tau_h \tau_h)$ GeV
- opposite electric charge
- back-to-back
- missing $E_T > 30$ GeV
- no $b$ quarks

Limit extraction variable:

\[
m(\tau_1, \tau_2, E_T) = \sqrt{(E_{\tau_1} + E_{\tau_2} + E_T)^2 - (\vec{p}_{\tau_1} + \vec{p}_{\tau_2} + \vec{E}_T)^2}.
\]

- Tau2016, Beijing, China, Sep 21 2016 -
The presence of $Z'_{SSM}$ bosons decaying into $\tau$ lepton pairs is excluded for masses below 2.1 TeV.
Analysis: $W' \rightarrow \tau \nu$

EXO-16-006

Signal sample:
- $W'$ with invariant mass between 1000 to 5800 GeV

Final states:
- $\tau_h$
  - general $\tau + \text{MET}$ new resonance search using SSM $W'$ as benchmark model

Selections:
- $\tau_h \ p_T > 80$ GeV
- missing $E_T > 120$ GeV
- large separation angle between $\tau_h$ and missing $E_T$
- $0.7 < p_T/\text{missing } E_T < 1.3$

Limit extraction variable:

$$M_T = \sqrt{2 \ p_T \ E_T^{\text{miss}} \ (1 - \cos \Delta \phi(\tau, \vec{p}_T^{\text{miss}}))},$$
In summary, we have performed a search for new physics in final states with a tau decaying to that of a typical W boson. The multibin approach assumes a certain signal shape in specific models, a single-bin approach compares the number of observed events above a threshold, defined as the number of events in the signal region with a reinterpretation in various models by evaluating the signal efficiency.

The model-specific limits show the limit for a given fixed efficiency, for the given prediction in the SSM as a function of the W' mass. Figure 6: Left: Limits on the product of cross section and branching fraction into W' → τν, where only events with a hadronic tau decay are shown in blue [2].

Figure 25: The model-unspecific limit shows the limit for a given fixed efficiency, for the given expected and observed 95% CL limit from the 2012 data is shown in red. In comparison the expected and observed limits from the left plot are shown in blue.

An SSM W' boson is excluded in the mass range 1 TeV < M_{W'} < 3.3 TeV at 95% confidence level.

Model-independent limits, on the effective cross section for a W'-like signal.
Results from neutrino oscillation experiments imply neutrinos have mass. One way to confer mass to neutrinos, in the context of the “seesaw” mechanism, is provided by the left-right symmetry extension (LRSM), which predicts the existence of three new gauge bosons, $W_R^\pm$ and $Z'$. 

\[
\begin{align*}
\bar{d} & \rightarrow W_R^\pm N_\tau \\
u & \rightarrow W_R^\pm (\mp)q
\end{align*}
\]
Analysis: $W_R \rightarrow \tau_h \tau_h qq$

**Signal sample:**
- $W_R$ with invariant mass between 1000 to 3000 GeV with mass of $N_T$ between 0.1 to 0.8 x mass of $W_R$

**Final states:**
- $\tau_h \tau_h qq$
  general di-$\tau$ + di-jet new resonance search probing massive neutrino with $W_R$

**Selections:**
- 2 $\tau_h$ with $p_T > 70$ GeV
- 2 jets with $p_T > 50$ GeV
- missing $E_T > 50$ GeV
- invariant mass of $\tau_h \tau_h > 100$ GeV

**Limit extraction variable:**
$$m(\tau_1, \tau_2, j_1, j_2, E_T^{\text{miss}}) = \sqrt{(E_{\tau_1} + E_{\tau_2} + E_{j_1} + E_{j_2} + E_T^{\text{miss}})^2 - (p_{\tau_1} + p_{\tau_2} + p_{j_1} + p_{j_2} + E_T)^2}.$$
Results: $W_R \rightarrow \tau_h \tau_h qq$

Assuming only $N_T$ flavor contributes significantly to the $W_R$ decay width, $W_R$ masses below $2.35$ (1.63) TeV are excluded at a 95% confidence level, assuming the $N_T$ mass is $0.8$ (0.2) times the mass of $W_R$ boson.

Expected and observed limits, at 95% confidence level, as functions of $m(W_R)$ mass with $m(N_T) = 0.5 m(W_R)$
Signal sample:
- $W_R$ with invariant mass between 1000 to 4000 GeV with mass of $N_T = 0.5 \times \text{mass of } W_R$

Final states:
- $\tau_\mu \tau_h qq$, $\tau_e \tau_h qq$
  - general di-$\tau$ + di-jet new resonance search probing massive neutrino with $W_R$

Selections:
- $\tau_h$ with $p_T > 60$ GeV
- 2 jets with $p_T > 50$ GeV
- missing $E_T > 50$ GeV
- invariant mass of $\tau_\ell \tau_h > 150$ GeV

Limit extraction variable:

$$S_T = p_T(\ell) + p_T(\tau_h) + p_T(jet_1) + p_T(jet_2) + E_T^{miss}$$
Results: $W_R \rightarrow \tau \tau h qq$

Assuming the mass of neutrino to be half of the mass of right-handed W boson, $W_R$ boson masses below 3.2 TeV are excluded at 95% CL.
Leptoquark Introduction

Many extensions of the standard model (SM) predict new scalar or vector bosons, called leptoquarks (LQ), which carry non-zero lepton and baryon numbers:

- **SU(5) grand unification**: *the standard model gauge groups* $SU(3) \times SU(2) \times U(1)$ *are combined into a single simple gauge group*—$SU(5)$

- **Pati–Salam SU(4)**: *the lepton-ness (non-quark-ness) of leptons is identified as the 4th color, “lilac,” of a larger $SU(4)_c$ gauge group*

![Pair production of the LQ](image)
Analysis: $LQLQ \rightarrow \tau\tau bb$

Signal sample:
• $LQ3$ with invariant mass between 200 to 1500 GeV

Final states:
• $\tau_h \tau_h bb$, $\tau_\mu \tau_h bb$, $\tau_e \tau_h bb$

reinterpretation of the previous di-$\tau$ + di-jet new resonance search

Selections:
• $\tau_h$ with $p_T > 50$ GeV
• 2 jets with high $p_T$
• at least on b jet *
• missing $E_T > 50$ GeV
• opposite electric charge *
• cuts to reject top events

Limit extraction variable:
$$S_T = p_T(\ell) + p_T(\tau_h) + p_T(jet_1) + p_T(jet_2) + E_T^{miss}$$
* applied in EXO-16-23 only

EXO-16-016
EXO-16-023

12.9 fb⁻¹ (13 TeV)
Third-generation scalar leptoquarks with masses below 740 GeV are excluded, assuming a 100% branching fraction for the leptoquark decay to a $\tau$ lepton and a bottom quark.

Assuming 100% branching fraction for the leptoquark decay to a $\tau$ lepton and a bottom quark, the third-generation leptoquarks with masses below 900 GeV are excluded at 95% CL.
Summary

• Many exciting search results from the 13 TeV run

SSM $W'(\tau_h \nu)$
SSM $Z'(\tau \tau)$
$W_R(\tau_h \tau_h qq)$
$W_R(\tau_\ell \tau_h qq)$
$LQ3(\tau_h \tau_h bb)$
$LQ3(\tau_\ell \tau_h bb)$

$m(N_\nu) = 0.2 \ m(W_R)$
$m(N_\nu) = 0.8 \ m(W_R)$
$m(N_\nu) = 0.5 \ m(W_R)$

• More 13 TeV results coming soon