PROCEEDINGS OF SCIENCE

Search for new physics with high-mass τ-lepton pairs in pp collisions at 13 TeV with the CMS detector

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A search for new physics in the high mass ditau final state is performed using data from proton-proton collisions at a center-of-mass energy of 13 TeV. The data were collected by the CMS experiment during 2015 with an integrated luminosity of 2.2 fb^{-1} [1]. Many theorical models that include extensions of the fundamental symmetry of the Standard Model predict the existence of massive neutral vector bosons, generically called Z'. The search of Z' decaying into tau pairs is particulary interesting since in some models this bosons would be coupled preferentially to the third generation of the SM fermions.

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1. Introduction

Although the Standard Model (SM) is the most successful theory at present that explains the behavior of the elementary particles and the interactions between them, there are several reasons to consider that this model does not represent a complete description of nature. Many theories have been proposed in order to address these questions by extending the SM symmetry group. A simple extension of the SM symmetry is to include an extra gauge symmetry that would lead to the existence of new massive neutral bosons, known as Z′. Since the universality of couplings is not mandatory for these models, the Z′ boson might couple preferentially with the third generation of fermions [2]. A search for new physics in the high mass ditau final state is performed using pp collisions at 13 TeV, using data collected by the CMS experiment during 2015 with an integrated luminosity of 2.2 fb^{-1}.

Searches for high mass resonances like the Z′ bosons have traditionally used as a benchmark the Sequential Standard Model (SSM) due its simplicity. Although the SSM is not a gauge-invariant theory [3], this model predicts a neutral boson, Z'_{SSM}, with identical couplings to quarks and leptons as the SM Z boson. This model is considered for the search of high mass resonances in the ditau final state. In this analysis, hadronic decay of the tau is refered as τ_h, while the leptonic decays are refered as τ_ℓ ($\ell = e$, μ).

Searches for a Z′ decaying into tau pairs have been performed by CMS and ATLAS experiments, using data samples from pp collisions at a center-of-mass energy of 7 and 8 TeV produced during the first run of the LHC. The CMS and ATLAS collaborations reported no evidence of a Z′ boson, and excluded its existence for masses below 1.4 TeV for the SSM [5, 6].

2. Trigger and Event Selection

The decay of high mass resonances to ditau leptons would be characterized by two well isolated high-p_T taus (see Ref. [7]) with oppositive charge, which would be oriented back-to-back in the transverse plane of the beam direction (ϕ). The final states considered for this analysis are $\tau_h\tau_h$, $\tau_\mu\tau_h$, $\tau_e\tau_h$ and $\tau_e\tau_\mu$[1]. The double-τ trigger was required for the $\tau_h\tau_h$ final state, while a single lepton trigger was required for the remaining final states ($\tau_\ell\tau_h$ and $\tau_e\tau_\mu$). The requirement on the transverse-momentum of electrons and muons is $p_T > 35$ GeV and $p_T > 30$ GeV respectivately, while τ_h is required to have $p_T > 20$ GeV for $\tau_\ell\tau_h$ and $p_T > 60$ GeV for $\tau_h\tau_h$ final states.

The selected events must satisfy $\cos\Delta\phi(\tau_1, \tau_2) < -0.95$ for oppositely charged τ-lepton pairs since they are expected to be back-to-back. Events are also required to have $\not{E}_T > 30$ GeV in order to address the presence of neutrinos in the τ decay and to reduce the QCD background. A variable known as "CDF-ζ" is included as an additional criteria in order to reduce the W+jets background and to consider the direction of the missing transverse momentum to be consistent with the high

[1] $\tau_\mu\tau_\mu$ and $\tau_e\tau_e$ are not considered due the difficulty to distiguish them from $Z' \to \mu\mu$ and $Z' \to ee$

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p_T ditau pair signal. CDF-ζ" (refered below as ζ) is defined as the unit vector along the bisector of the ditau candidates in ϕ [4]. Events are selected requiring $\zeta = p_\zeta - 3.1 \times p_\zeta^{vis} > -50$ GeV where the two proyection variables are defined as $p_\zeta^{vis} = (\vec{p}_{\tau_1} + \vec{p}_{\tau_2}) \cdot \hat{\zeta}$ and $p_\zeta = (\vec{p}_{\tau_1} + \vec{p}_{\tau_2} + \vec{\not{E}}_T) \cdot \hat{\zeta}$.

To improve the idenfitication of high-mass resonances from lower mass backgrounds, the whole kinematic information available (visible τ-lepton decay products and the $\not{E}_T$) is considered for the mass reconstruction:

$$m(\tau_1, \tau_2, \not{E}_T) = \sqrt{(E_{\tau_1} + E_{\tau_2} + \not{E}_T)^2 - (\vec{p}_{\tau_1} + \vec{p}_{\tau_2} + \vec{\not{E}}_T)^2}. \tag{2.1}$$

Then, the search looks for resonances in the high-mass region of the $m(\tau_1, \tau_2, \not{E}_T)$ distribution that would be consistent with new physics.

3. Background Estimation

The Background estimation is performed with a data-driven method, based on the creation of enriched control samples obtained by modifying the criteria used for the signal. The control regions are used to measure the efficiencies for background candidates to pass the signal selection requirements.

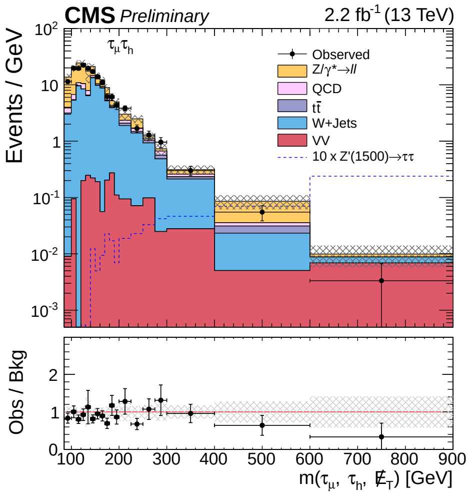
A relevant source of background for the $\tau_h\tau_h$ and $\tau_e\tau_h$ final states comes from QCD multijet events (80% and 20% respectivately). For the $\tau_h\tau_h$ final state, the QCD background contribution is estimated from a data sample of same-sign ditau candidates, scaled by the opposite-sign/same-sign ratio, which is measured with a control region that requires $\not{E}_T < 30$ GeV. The contribution of QCD for the $\tau_e\tau_h$ is estimated from a data sample of same-sign ditau candidates corrected by the probability of misidentifying a jet as a τ_h.

The W+jets background contributes 40% in the $\tau_\ell\tau_h$ final states. It is estimated from a data sample with ditau cantidates corrected by the probability that a jet is misidentified as a τ_h, which is measured using control regions with $\cos\Delta\phi(\tau_1, \tau_2)$ and ζ requirements inverted.

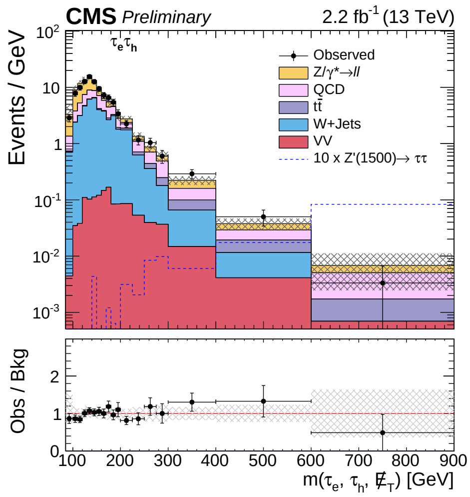
The contribution of the $t\bar{t}$ background in the $\tau_e\tau_\mu$ final state is 30% while is 2% in the other final states. It can be estimated since a high-purity $t\bar{t}$ sample can be obtained by demanding the presence of at least one b-quark jet.

Finally, the SM Drell-Yan processes is an irreducible background and contributes to all the final states (from 10% for $\tau_h\tau_h$ up to 40% in the other final states). Its contribution is estimated by comparating between simulation and data samples in low-mass control regions, which also require the condition $\not{E}_T < 30$ GeV [5].

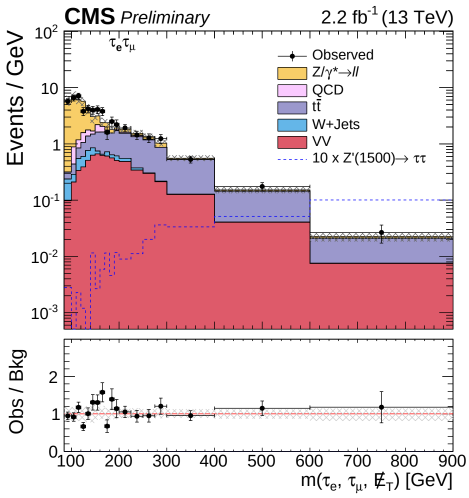
The reconstructed mass distribution (equation 2.1) for all final states is shown in Figure 1



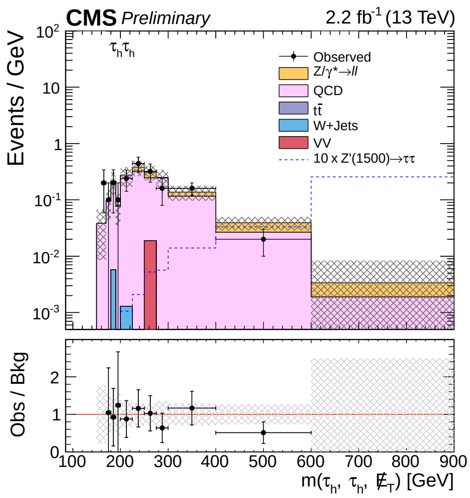
a: $\tau_\mu \tau_h$



b: $\tau_e \tau_h$



c: $\tau_e \tau_\mu$



d: $\tau_h \tau_h$

Figure 1: $m(\tau_1, \tau_2, \not{E}_T)$ distribution for all four final states: (a) $\tau_\mu \tau_h$, (b) τ_e $\tau_e \tau_h$, (c) $\tau_e \tau_\mu$, and (d) $\tau_h \tau_h$. The dashed line represents the mass distribution for a $Z'_{SSM} \to \tau\tau$ with mass of 1500 GeV, in which the event yield is scaled by a factor 10.

4. Results

A search for high mass resonances consistent with new physics in ditau final state has been perfomed. The data were collected by the CMS detector in pp collisions at $\sqrt{s} = 13$ TeV with an integrated luminosity of 2.2 fb^{-1}. The observed mass distributions in the $\tau_\mu \tau_h$, $\tau_e \tau_h$, $\tau_e \tau_\mu$ and $\tau_h \tau_h$ final states are consistent with the SM expectations and an upper limit at 95% CL on the product of cross section times branching fraction into τ-lepton pairs has been determined as a function of the Z$'$ mass. The presence of Z$'$ bosons decaying to τ leptons is excluded by the data for Z$'$ masses below 2.0 TeV in the SSM, see Figure 2.

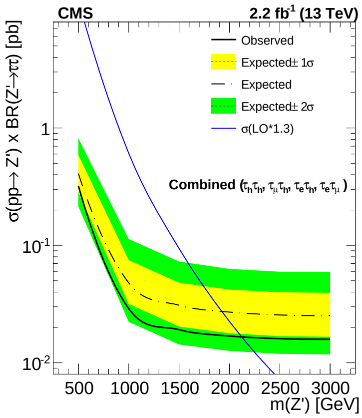


Figure 2: 95% CL upper limits on the product of the cross section times branching fraction into τ-lepton pairs as a function of Z'_{SSM} mass for all the final states

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