PROCEEDINGS OF SCIENCE

Search for tau → 3mu decays with CMS experiment at LHC

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The search for the charged lepton flavor violating decay $\tau \rightarrow 3\mu$ has been performed at the CMS experiment at the LHC, using data collected in 2016 during proton-proton collisions. The data sample corresponds to an integrated luminosity of 33.2 fb^{-1}, recorded at a center-of-mass energy of 13 TeV. The results obtained by exploiting tau leptons produced in decays of heavy flavor B and D mesons and from W bosons have been combined and they are presented in this contribution. No significant excess was observed and an upper limit on the branching fraction of $\mathcal{B}(\tau \rightarrow 3\mu)$ of 8.0×10^{-8} at 90% confidence level was set.

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1. Introduction

In the Standard Model (SM) the lepton flavor is assumed to be conserved even if there is no fundamental symmetry that guarantees it. However, by extending the SM to account for the neutrino oscillations, lepton flavor violation (LFV), in decays involving charged leptons, become possible through neutrino loops, but they are characterized by very small branching ratios (BR). As a consequence, the observation of such processes at present day experiments would be an unambiguous signature of physics Beyond the Standard Model (BSM). The $\tau \rightarrow 3\mu$ process is a good test bench to probe LFV at collider experiments: its BR in the SM is $\mathcal{O}(10^{-54})$ [1], but it can be enhanced up to 10^{-10}- 10^{-8} in BSM scenarios, such as Minimal Supersymmetric SM with See-Saw mechanism [2] and R-parity violation [3] framework.

The search for $\tau \rightarrow 3\mu$ decay has already been carried out by several experiments and no evidence has been observed up to now. The current best experimental upper limit on $\mathcal{B}(\tau \rightarrow 3\mu)$, set by the Belle collaboration, is 2.1×10^{-8} at 90% confidence level (CL) [4]. This search was carried out also at the LHC by LHCb, which targeted tau production from heavy-flavor (HF) hadron decays, and by ATLAS, which exploited tau leptons coming from W bosons, leading respectively to upper limits of 4.6×10^{-8} [5] and 38×10^{-8} [6], both at 90% CL. Also the CMS experiment performed the $\tau \rightarrow 3\mu$ search, using both production channels (HF and W decays) for tau leptons in data collected during the 2016 proton proton collisions, with $\sqrt{s}$ = 13 TeV and corresponding to an integrated luminosity of 33.2 fb^{-1}.

2. The CMS experiment

The central feature of the CMS apparatus is a superconducting solenoid of 6 m internal diameter, providing a magnetic field of 3.8 T. Within the solenoid volume are a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter, and a brass and scintillator hadron calorimeter, each composed of a barrel and two endcap sections. Muons are measured in gas-ionization detectors embedded in the steel flux-return yoke outside the solenoid. Additional forward calorimetry complements the coverage provided by the barrel and endcap detectors. A more detailed description of the CMS detector, together with a definition of the coordinate system used and the relevant kinematic variables, can be found in [7].

Events of interest are selected using a two-tiered trigger system [8]. The first level (L1), composed of custom hardware processors, uses information from the calorimeters and muon detectors to select events at a rate of around 100 kHz within a fixed time interval of less than 4 μs. The second level, known as the high-level trigger (HLT), consists of a farm of processors running a version of the full event reconstruction software optimized for fast processing, and reduces the event rate to around 1 kHz before data storage.

In CMS, muons are identified by matching tracks in the silicon tracker with tracks in the muon detector and verifying the energy deposited in the calorimeters is consistent with that expected for them. The muon momentum is obtained from the curvature observed in the silicon tracker and the relative p_T resolution for muons with $p_T < 100$ GeV is 1% in the barrel and 3% in the endcaps [9].

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3. Event selection and categorization

The trigger used for the $\tau \to 3\mu$ search requires, at L1, either three muons, two muons or one muon with some conditions on the p_T and on the dimuon mass. Beyond these requirements, an event passes the HLT if it contains two muons with $p_T > 3$ GeV and a track with $p_T > 1.2$ GeV, which form a common vertex and have an invariant mass value (assuming that the track is a muon) compatible with the tau mass, i.e. in a range of 1.60-2.02 GeV. Other requirements are applied offline, vetoing the events in which the invariant mass of a pair of muons with opposite sign is compatible with the $\omega(783)$ or $\Phi(1020)$ resonances, or - in case of the W channel - with other hadronic resonances as η, $\rho(770)$, J/ψ, $\psi(1S)$, $\psi(2S)$, $\psi(3S)$ and the Z boson.

Data events are split into separate categories in order to enhance the sensitivity of the analysis. In the HF channel, three categories (labeled A, B, and C) are made up based on the 3mu invariant mass resolution ($\sigma_m/m \leq 0.7\%$, $0.7\% < \sigma_m/m < 1.0\%$, and $\sigma_m/m \geq 1.0\%$), while in the W channel events are split into two categories (labeled as "barrel" and "endcap"), based on the τ pseudorapidity, which is strongly correlated to the 3 muon invariant mass resolution.

4. Multivariate analysis

In order to better discriminate the signal from background, a multivariate analysis is performed in both channel, using a Boosted Decision Tree (BDT). For the training of the multivariate classifier, data events having a three muon invariant mass in the sideband regions (i.e. in the range of 1.60-1.74 or 1.82-2.00 GeV) have been considered as background and they have been used together with simulated signal events. Several input variables (18 for the W channel, 10 for the HF) were used to train the BDT: some of them are the quality of the muons, the p_T and η of the τ candidate, its isolation, the χ^2 of the vertex fit, the angle between the three-muon momentum vector and the vector connecting the primary and three-muon vertices and the missing energy (in case of W channel), computed as the negative vector sum of the transverse momenta of all other particles in the event.

Based on the BDT score, events are further split into 3 bins (in HF case) and 2 bins (in case of W channel). For each category, the last bin - the one with the lowest BDT score - is discarded, ending up with six categories (A1, A2, etc.) for the HF channel and two categories for the W one. The bin boundaries in each category are set so to maximize the expected upper limit on $\mathcal{B}(\tau \to 3\mu)$.

5. Signal extraction and results

In order to obtained the BR of $\tau \to 3\mu$ decay, a maximum likelihood fit is performed simultaneously on the 3 muon invariant mass distribution in the six (two) categories of the HF (W) channel. The data points in the sidebands are fitted with an exponential function, while the signal - simulated with a MonteCarlo (MC) - is fitted with a convolution of a Gaussian and a Crystal Ball function, with fixed mean and width in the HF case (as shown in Fig.1), and with a Gaussian function for the W channel (as shown in Fig.2). No evidence of significant excess is seen and observed (expected) upper limits of 9.2×10^{-8} (10.0×10^{-8}) and 20×10^{-8} (13×10^{-8}) have been set respectively for the two channel at 90% CL [10], by using a fully frequentist method based on modified profile likelihood test statistics and the CLs criterion [11, 12].

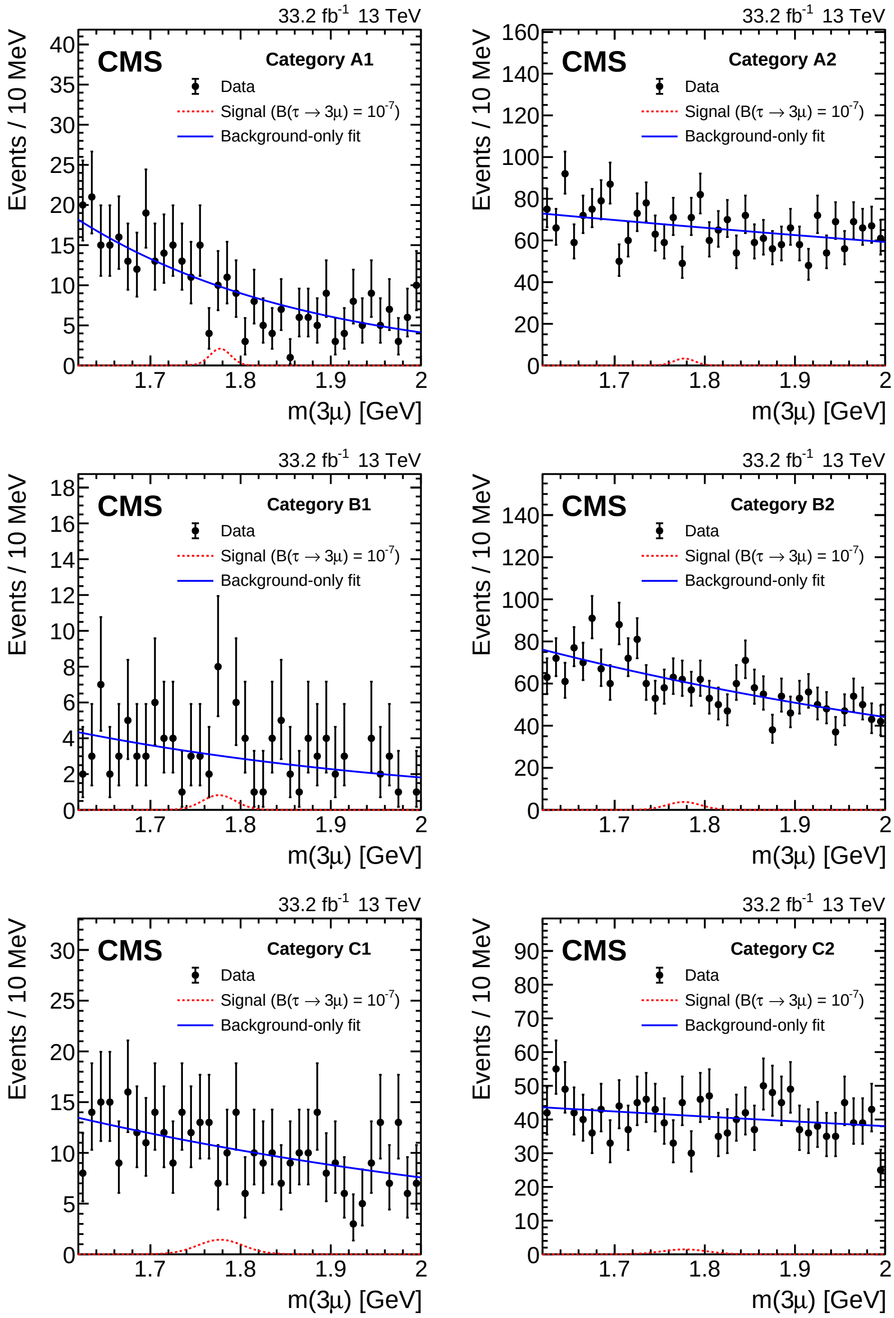

Figure 1: Three-muon invariant mass distributions in the six categories for the HF channel. Data are shown with filled circles and the vertical bars represent the statistical uncertainty. The solid and dashed lines represent respectively the background-only fit and the expected signal assuming $\mathcal{B}(\tau \to 3\mu) = 10^{-7}$.

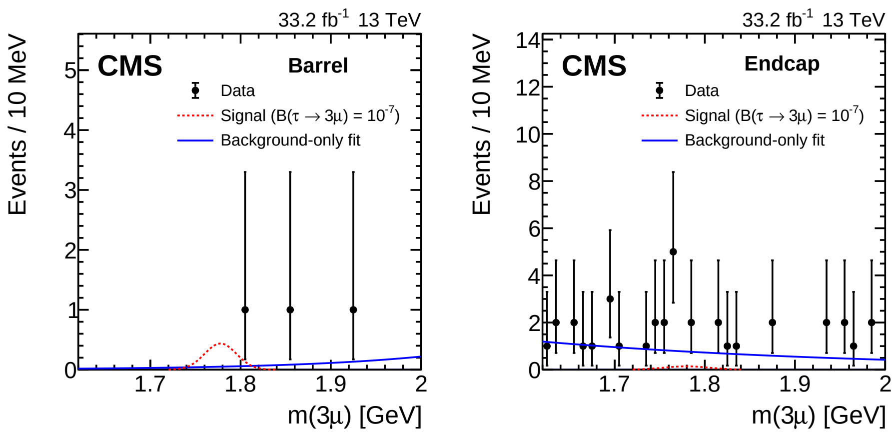

Figure 2: Three-muon invariant mass distributions in the two categories (barrel on the left, endcap on the right) for the W channel. Data are shown with filled circles and the vertical bars represent the statistical uncertainty. The solid and dashed lines represent respectively the background-only fit and the expected signal assuming $\mathcal{B}(\tau \rightarrow 3\mu) = 10^{-7}$.

Systematic uncertainties are considered uncorrelated between the two channels and they are treated as nuisance parameters. A log-normal probability density function is assumed for the nuisance parameters affecting the corrected signal yields. The events in common among the two channels (both from data and form MC) are removed from the HF channel in the combined fit. The final observed (expected) combined upper limit on $\mathcal{B}(\tau \rightarrow 3\mu)$ resulted to be 8.0×10^{-8} (6.9×10^{-8}) at 90% CL.

References

[1] X.-Y. Pham, *Lepton flavor changing in neutrinoless τ decays*, *Eur. Phys. J. C* **8** (1995) 513 [hep-ph/9810484].

[2] K.S. Babu and C. Kolda, *Higgs-Mediated $\tau \rightarrow \mu\mu\mu$ in the Supersymmetric Seesaw Model*, *Phys. Rev. Lett.* **89** (2002) 241802 [hep-ph/0206310v2].

[3] R. Barbier et al., *R-parity violating supersymmetry*, *Physics Reports* **420** (2005) 1 [hep-ph/0406039].

[4] Belle Collaboration, *Search for Lepton Flavor Violating Tau Decays into Three Leptons with 719 Million Produced Tau+Tau- Pairs*, *Phys. Lett. B* **687** (2010) 139 [hep-ex/1001.3221].

[5] LHCb Collaboration, *Search for the lepton flavour violating decay $\tau^- \rightarrow \mu^-\mu^+\mu^-$*, *JHEP* **02** (2015) 121 [hep-ex/1409.8548].

[6] ATLAS Collaboration, *Probing lepton flavour violation via neutrinoless $\tau \rightarrow 3\mu$ decays with the ATLAS detector*, *Eur. Phys. J. C* **76** (2016) 232 [hep-ex/1601.03567].

[7] CMS Collaboration, *The CMS Experiment at the CERN LHC*, *JINST* **3** (2008) S08004 [hep-ex/1601.03567].

[8] CMS Collaboration, *The CMS trigger system*, *JINST* **12** (2017) P01020 [physics.ins-det/1609.02366].

[9] CMS Collaboration, *Performance of the CMS muon detector and muon reconstruction with proton-proton collisions at* $\sqrt{s} = 13 TeV$, *JINST* **13** (2018) P06015 [physics.ins-det/1804.04528].

[10] CMS Collaboration, *Search for the lepton flavor violating decay* $\tau \rightarrow 3\mu$ *in proton-proton collisions at* $\sqrt{s}$ *= 13 TeV*, *JHEP* **01** (2021) 163 [hep-ex/2007.05658].

[11] T. Junk, *Confidence level computation for combining searches with small statistics*, *Nucl. Instrum. Meth. A* **434** (1999) 435 [hep-ex/9902006].

[12] A.L. Read, *Presentation of search results: The CLs technique*, *J. Phys. G* **28** (2002) 2693.