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Search for the $\tau \to \mu\mu\mu$ decay at CMS

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Summary. — The results of a search for the $\tau \to 3\mu$ charged-lepton flavour violating decay in the CMS experiment are presented. The analysis is carried out on data collected during 2016 on proton-proton collisions at the centre-of-mass energy of 13 TeV, corresponding to an integrated luminosity of 33 fb^{-1}. The analysis selects τ leptons produced in B and D meson decays. No evidence of signal is observed and an upper limit of 8.8×10^{-8} is set on the $\tau \to 3\mu$ branching ratio at 90% of confidence level.

1. – Physics case

In the Standard Model (SM) with massless neutrinos, lepton flavour numbers are exactly conserved. The observation of neutrino oscillations, however, proves that neutrinos are massive particles and allows for lepton flavour violating (LFV) processes, such as the neutrinoless $\tau \to 3\mu$ decay. Nevertheless, these processes are predicted at very low branching ratios (BR). For instance, the $\tau \to 3\mu$ decay is predicted with a probability of O(10^{-14}) [1], below the current world best experimental sensitivity. The very low decay fractions make LFV processes good candidates for new physics (NP) searches. Moreover, proton-proton collisions are a good source of τ leptons and the three-muons final state makes the $\tau \to 3\mu$ signal most suited to identification in the CMS detector [2].

2. – State of the art

The $\tau \to 3\mu$ decay has already been searched for at positron-electron asymmetric colliders. Currently, the world best limits have been set by the Belle Collaboration (KEKB) at 2.1×10^{-8} at 90% CL [3], and by the BaBar Collaboration (SLAC) at 3.3×10^{-8} at 90% CL [4].

The decay has also been investigated at hadron colliders by the LHCb and ATLAS Collaborations (LHC), which obtained an upper limit of 4.6×10^{-8} at 90% CL [5] and 3.76×10^{-7} at 90% CL [6], respectively.

3. – Tau lepton production channels in CMS

The CMS detector can take advantage of both the heavy flavour (HF) and the W bosons production channels. The former benefits from a large τ lepton production cross-section, due to the presence of b-type and c-type quarks, the latter from a stronger event signature, given by the large W boson mass, the presence of a large missing transverse energy and the isolation of the final-state muons.

During the 2016 data-taking period, an integrated luminosity of 33 fb^{-1} has been collected. This results in about 10^{12} and 10^{9} τ leptons produced in the HF and W channel, respectively. Assuming a branching ratio of the order of 10^{-8}, about 10^{4} $\tau \to 3\mu$ events can be expected in the HF channel and 10 in the W channel.

This report describes the first search for the rare decay $\tau \to 3\mu$ at CMS. The HF channel analysis and its result [7] is presented, while for the W channel, still under internal approval at the time of this talk, a preliminary estimation of the final limit is given.

4. – Offline reconstruction and identification

The goal of the analysis is to reconstruct a three-muons signature lying in the τ mass region within the data collected by CMS during 2016, inside the detector acceptance (which corresponds to a transverse momentum greater than 1 GeV and a pseudo-rapidity absolute value lower than 2.4). The offline selection is improved using a dedicated on-line High Level Trigger (HLT), which selects events containing two muons and a track originating from a common vertex. The signal-background separation is performed by a multivariate discriminator trained on simulated signal events and background events lying outside the τ mass region.

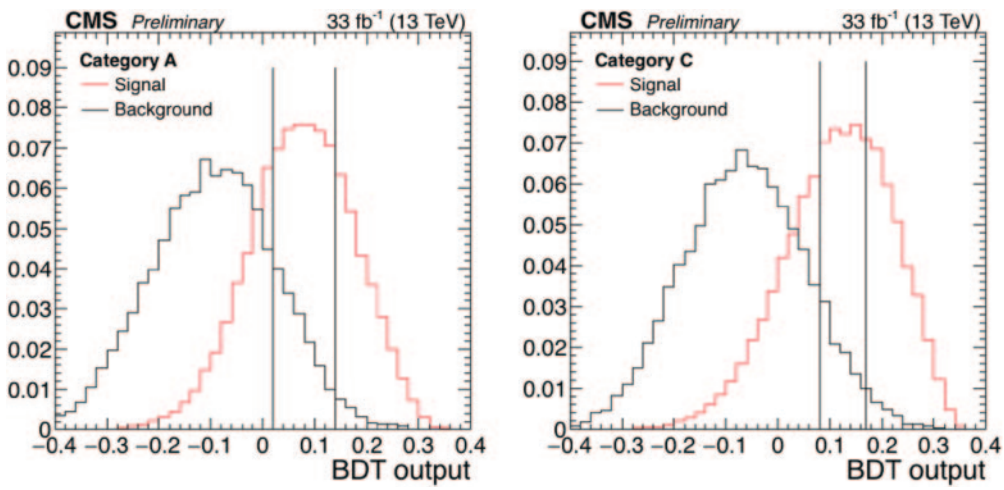

Fig. 1. – BDT score distribution for two of the three categories of mass resolution. Category A is the category with the best mass resolution, while category C is the category with the worst mass resolution. The red line corresponds to simulated signal events, the black line corresponds to real background data. All distributions are normalized to unity. The two vertical black lines mark the sub-division of each category [7].

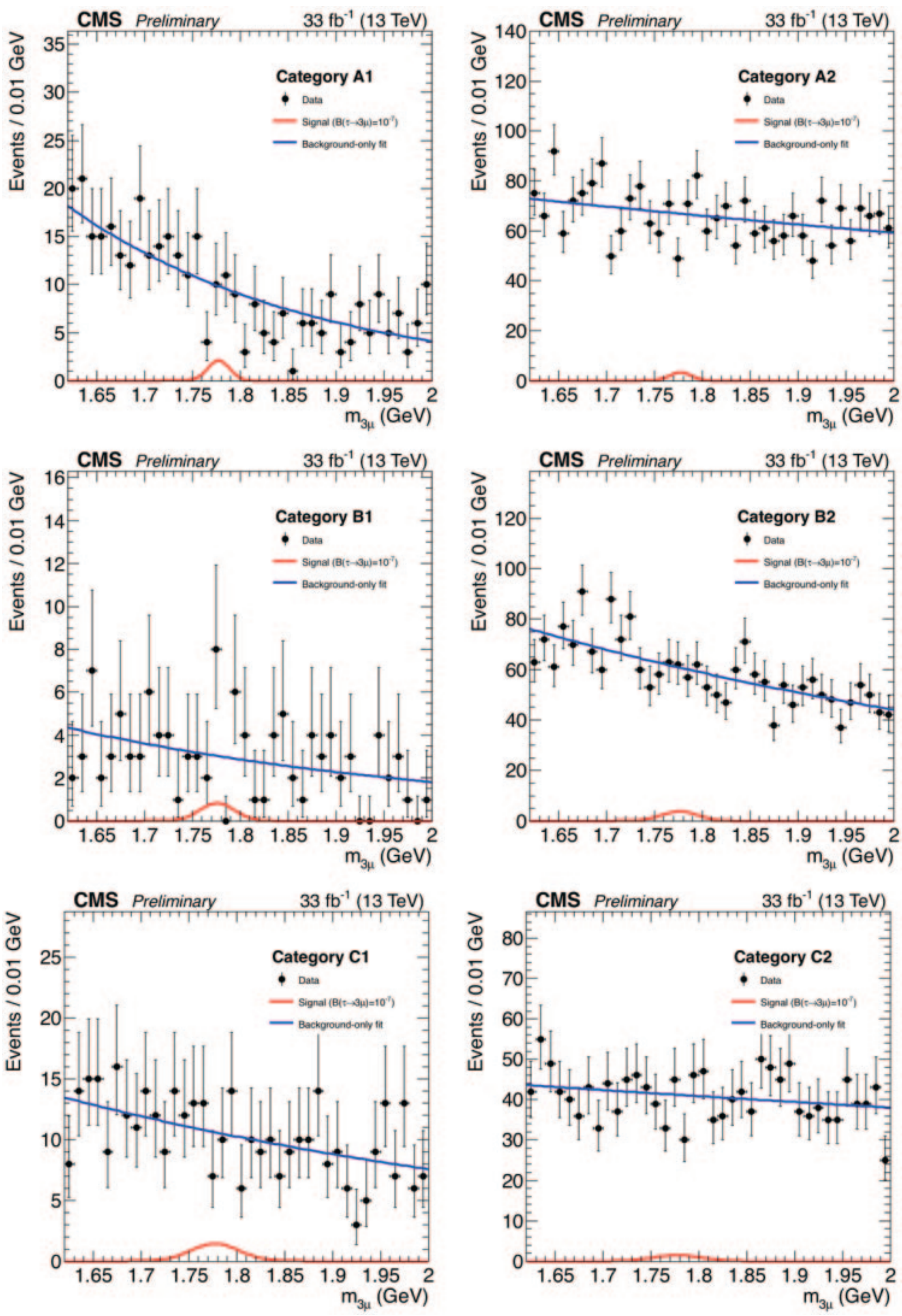

Fig. 2. – Trimuon mass distributions in the six independent event categories used in the HF analysis. Data are shown with points. The background-only fit and the expected signal for $\mathrm{BR}(\tau \to 3\mu) = 10^{-7}$ are shown with lines [7].

The multivariate selection is performed by a Boosted Decision Tree (BDT), which has shown a better performance than a simple cut-based analysis. To better improve the final significance, events are dividend into six different categories, and the final result is obtained for each category separately. Three categories are defined as a function of the mass resolution of the three offline-reconstructed muons. Each of these categories is sub-divided into three sub-categories based on the BDT output score, in order to maximise the expected final limit. A cut on the BDT score is finally performed, so that only two sub-categories survive for each of the three mass-resolution categories. Figure 1 shows the BDT distribution for two of the three categories of mass resolution, and their sub-division.

The signal yield is extracted with an unbinned maximum likelihood fit on the three-muons mass distribution, composed of those events surviving the BDT cut aforementioned. The signal is modelled with a Crystal-Ball function, while three different background shapes are tested (exponential, 2nd and 3rd grade polynomials). The result of the fit is shown in fig. 2. The significance is extracted using the profiled-likelihood approach. Systematics uncertainties are treated as nuisance parameters.

5. – Systematics

Systematics errors are mostly due to the normalization of the MC control samples, which results in a 15% relative error on the signal yield. This systematic source comprises the D$\rightarrow \tau\nu$ and B$\rightarrow \tau\nu$ MC sample normalization, the D$\rightarrow \tau\nu$, D$\rightarrow \phi(\rightarrow \mu\mu)\pi$ and B$\rightarrow \tau\nu$ branching ratio values and the D$\rightarrow \phi(\rightarrow \mu\mu)\pi$ acceptance. Other systematic sources are the muon and pion reconstruction efficiency (2.6%), the BDT cut (5%), the functional form of the signal (2.6%) and the functional form of the background (less than 1%).

6. – Results and future prospectives

No significant excess of signal events is observed in any category for the HF production channel, as shown in fig. 2, and an upper limit of 8.8×10^{-8} is set at 90% CL (1.1×10^{-7} at 95% CL).

For the W boson production channel, a similar procedure of offline reconstruction and signal selection has been adopted; a preliminary expected upper limit of 1.1×10^{-7} has been estimated at 90% CL.

The analysis on 2017 and 2018 data will benefit from the increase of integrate luminosity (108 fb^{-1} has been collected during this period) and from an enhanced version of the HLT selection, thus allowing for a competitive result before the Belle II analysis.

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