Search for the lepton flavour violating and baryon number violating decays\[ \tau^- \to \bar{p}\mu^+\mu^- \] and \[ \tau^- \to p\mu^-\mu^- \]

The LHCb collaboration

Abstract

A search is made for the lepton flavour violating and baryon number violating decays \( \tau^- \to \bar{p}\mu^+\mu^- \) and \( \tau^- \to p\mu^-\mu^- \) using data, corresponding to an integrated luminosity of 1.0 fb\(^{-1}\), collected at \( \sqrt{s} = 7 \text{ TeV} \) by LHCb in 2011. In LHCb, \( \tau^- \) leptons are copiously produced, almost exclusively from decays of \( B, D_s^- \) and \( D^- \) mesons. In the analysis of the data, the \( \tau^- \) production rate is normalised to the control channel \( D_s^- \to \phi(\mu^+\mu^-)\pi^- \). The observed numbers of events are consistent with the background expectations, and upper limits \( B(\tau^- \to \bar{p}\mu^+\mu^-) < 4.5(3.4) \times 10^{-7} \) and \( B(\tau^- \to p\mu^-\mu^-) < 6.0(4.6) \times 10^{-7} \) are set at 95% (90%) confidence level.

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1 Introduction

The experimental observation of neutrino oscillations was the first evidence of lepton flavour violation (LFV). The consequent introduction of mass terms for the neutrinos in the Standard Model (SM) already implies lepton family number violation also in the charged sector \(^1\), but with branching fractions smaller than \(10^{-40}\). New physics (NP) could significantly enhance the rates, but charged lepton flavour violating (cLFV) decays like \(\mu^- \to e^- \gamma, \mu^- \to e^+ e^-, \tau^- \to \ell^- \gamma\) and \(\tau^- \to e^+ \ell^- \ell^-\) (with \(\ell^- = e^-, \mu^-\)) have not been observed so far, even with steadily improving experimental sensitivity \(^2\). Numerous beyond the Standard Model theories predict enhanced LFV in \(\tau^-\) decays over \(\mu^-\) decays with branching fractions within experimental reach \(^3\). An observation of cLFV would thus be a clear sign for NP, while lowering the experimental upper limit will help to further constrain exotic theories.

At LHCb \(^4\) LFV \(\tau^-\) decays to muons are of particular interest as the 4\(\pi\) inclusive \(\tau^-\) production cross section is large (\(\sim 80 \mu b\)) and muon final states provide clean signatures in the detector. Building on the first LFV search at LHCb for the decay \(\tau^- \to \mu^+ \mu^- \mu^-\) \(^5\), a search for the two decay modes \(\tau^- \to \bar{p}\mu^+ \mu^-\) and \(\tau^- \to p\mu^- \mu^-\) which violate both lepton number (LNV) (and hence also lepton flavour) and baryon number (BNV) conservation, is now performed.

Violations of baryon number are strictly forbidden in the SM, but are allowed in some extensions. In decays that are both LNV and BNV, angular momentum conservation requires \(|\Delta(B-L)| = 0\) or 2, where \(B\) and \(L\) are net baryon and lepton numbers. Most extensions of the SM require \(|\Delta(B-L)| = 0\) \(^1\). In this analysis we explore lepton number and baryon number violation with two \(\tau^-\) decay modes with opposite-sign and same-sign dimuon pairs in the final state; both decay modes have \(|\Delta(B-L)| = 0\), but could have rather different NP interpretations \(^1\).

BaBar and Belle have searched for \(\tau^-\) decays with \(|\Delta(B-L)| = 0\) and \(|\Delta(B-L)| = 2\) using the modes \(\tau^- \to \Lambda h^-\), \(\Lambda h^-\) (with \(h = \pi, K\)). Limits of order \(10^{-7}\) were obtained, and the results are summarised in Ref \(^2\). BaBar has also searched for \(B\)-meson decays \(B^0 \to \Lambda^+_h l^-, B^- \to \Lambda l^-\) (both having \(|\Delta(B-L)| = 0\)) and \(B^- \to \Lambda l^-\) (\(|\Delta(B-L)| = 2\)), with 90\% confidence level (CL) upper limits in the range \(3.2 \times 10^{-8}\) \(^6\). No measurements currently exist for the \(\tau^- \to \bar{p}\mu^+ \mu^-\) and \(\tau^- \to p\mu^- \mu^-\) decay modes; this analysis presents the first such searches. These modes probe LNV and BNV similarly to the above-mentioned modes studied by BaBar and Belle.

A data sample, corresponding to an integrated luminosity of \(1.0 \text{fb}^{-1}\), is used to search for \(\tau^- \to \bar{p}\mu^+ \mu^-\) and \(\tau^- \to p\mu^- \mu^-\) decays. Three selections are implemented, two for the \(\tau^- \to \bar{p}\mu^+ \mu^-\) and \(\tau^- \to p\mu^- \mu^-\) signal modes, and one for the normalisation channel, which is \(D_s^- \to \phi(\mu^+ \mu^-)\pi^-\). Discrimination between potential signal and backgrounds is performed using particle identification cuts and a binned two-dimensional distribution in two variables: a likelihood based on the 3-body kinematics of the event, and the invariant mass of the \(p\mu\mu\) candidate. The analysis and limit setting procedures are similar to those used in the LHCb analysis of \(\tau^- \to \mu^+ \mu^- \mu^-\) \(^5\).

\(^1\)Charge conjugation is implied throughout this document.
2 Signal selection

The $\tau^- \rightarrow \bar{p}\mu^+\mu^-$ and $\tau^- \rightarrow p\mu^-\mu^-$ signal channels and the $D_s^- \rightarrow \phi(\mu^+\mu^-)\pi^-$ normalization channel require high quality muon, proton and pion candidates that are well reconstructed in the detector. This is achieved by imposing a minimum cut on transverse momentum and track quality. The candidates must also pass loose particle identification (PID) requirements and be displaced with respect to any primary $pp$ interaction vertex, requiring the reduced $\chi^2$ of their impact parameter to be greater than 9. The $\tau^-$ candidate formed from these tracks must then be of a good vertex quality (fit $\chi^2 < 15$), have large transverse momentum ($p_T > 4$ GeV/c) and have a lifetime consistent with that of a decaying heavy meson or the $\tau^-$ ($c\tau > 100 \mu$m).

In addition to these criteria, badly reconstructed events are removed by a set of fiducial cuts on lifetime and transverse momentum. A wide mass window of 250 MeV/$c^2$ for $\tau \rightarrow p\mu\mu$ decays is used to estimate the background contribution in the signal region, which is defined as a $\pm 15$ MeV/$c^2$ ($\sim 2.5\sigma$) window around the $\tau^-$ mass. A smaller mass window of $\pm 50$ MeV/$c^2$ is used for the $D_s^- \rightarrow \phi(\mu^+\mu^-)\pi^-$ channel. In the $\tau^- \rightarrow p\mu^-\mu^-$ channel signal events containing same-sign muon pairs with a mass lower than 250 MeV/$c^2$ are removed.

3 Signal and background discrimination

After the selection each event is given a probability to be signal or background according to the values of two independent likelihoods:

- **Three-body likelihood**: The three-body likelihood is a multivariate (MVA) operator that uses the properties of the reconstructed $\tau^-$ candidate decay to distinguish displaced three-body decays from $N$-body decays (with $N > 3$) and combinations of tracks from different vertices. This classifier is hereafter called $M_{3\text{body}}$.

- **Invariant mass likelihood**: The invariant mass of the $\tau^-$ candidate is also used to distinguish signal from background.

The multivariate classifier, $M_{3\text{body}}$, uses a boosted decision tree (BDT) with adaptive boosting as the classifier. Here the tuning from the $\tau^- \rightarrow \mu^+\mu^-\mu^-$ analysis is used (see [5]), which was developed using $\tau^- \rightarrow \mu^+\mu^-\mu^-$ signal and background Monte Carlo (MC) samples, both from simulation. $D_s^- \rightarrow \phi(\mu^+\mu^-)\pi^-$ decays are used to compare, between data and simulation, the shapes of the distributions of all the variables used as input to the $M_{3\text{body}}$; good agreement is found. The composition of the background MC was an admixture of $b\bar{b} \rightarrow \mu\mu X$ and $c\bar{c} \rightarrow \mu\mu X$ according to their expected relative abundances. Other training scenarios were also considered, such as the use of data sidebands, and $\tau^-$ only from $D_s^-$ decays. They have been found not to improve the performance. The

\footnote{The impact parameter $\chi^2$ is defined as the difference between the $\chi^2$ of the $pp$ interaction vertex (PV) reconstructed with and without the considered track.}
final probability density function (PDF) shapes for $\tau \rightarrow p\mu\mu$ signal are calibrated using $D_s^- \rightarrow \phi(\mu^+\mu^-)\pi^-$ data. The shape of the signal mass spectrum is modelled using the $D_s^- \rightarrow \phi(\mu^+\mu^-)\pi^-$ control channel.

For the three-body likelihood the binning in the limit calculation is chosen such that the separation power between the background-only and signal-plus-background hypotheses is maximised, whilst minimising the number of bins. The optimum number of bins is found to be 5.

Each event is subject to tight PID cuts, which are optimised on signal MC and the outer data sidebands ($|m - m_\tau| > 135\text{ MeV}/c^2$).

### 3.1 $\mathcal{M}_{3\text{body}}$ likelihood

The variables used in the $\mathcal{M}_{3\text{body}}$ likelihood include: vertex and track fit quality, isolation of the daughter tracks from other tracks, isolation of the $\tau/D_s$ vertex from other vertices, compatibility that the $\tau$ originates from the decay of a particle from the primary vertex, and the transverse momentum of the parent particle.

The $\mathcal{M}_{3\text{body}}$ response function as evaluated on signal MC (solid lines) and the data sidebands (dashed lines) is shown in Figs. 1(a) and 1(b), where the vertical lines indicate the binning used in the limit determination.

The $\mathcal{M}_{3\text{body}}$ is calibrated on data using the $D_s^- \rightarrow \phi(\mu^+\mu^-)\pi^-$ control channel, which is common to both $\tau \rightarrow p\mu\mu$ modes. The decay topology and kinematics of both $\tau^- \rightarrow \mu^+\mu^-\mu^-$ and $D_s^- \rightarrow \phi(\mu^+\mu^-)\pi^-$ are very similar; only a correction for the different production mechanisms of the $\tau^-$ and the $D_s^-$ has to be made. At LHCb, $\tau^-$ leptons are predominantly produced via a $D_s^-$ decay and thus have different lifetime and pointing distributions compared to the normalisation channel. These differences are calibrated by comparing the distributions for $\tau^- \rightarrow \mu^+\mu^-\mu^-$ and $D_s^- \rightarrow \phi(\mu^+\mu^-)\pi^-$ in the simulation.

The decay topology and kinematics of the $\tau \rightarrow p\mu\mu$ channels are also very similar, allowing the same tuning to be used for both analyses. Hence excellent agreement is also found between $\tau \rightarrow p\mu\mu$ and $D_s^- \rightarrow \phi(\mu^+\mu^-)\pi^-$ decay topology and kinematics, with the exception of a slightly softer muon $p_T$ spectrum for $\tau \rightarrow p\mu\mu$ events due to the lower Q-value of the $\tau^-$ decay. This is not corrected for in this analysis.

#### Table 1: PID cuts used in the selection of both $\tau^- \rightarrow \bar{p}\mu^+\mu^-$ and $\tau^- \rightarrow p\mu^-\mu^-$ modes.

<table>
<thead>
<tr>
<th>Cut</th>
</tr>
</thead>
<tbody>
<tr>
<td>DLL($\mu - \pi$) &gt; 1</td>
</tr>
<tr>
<td>DLL($\mu - K$) &gt; 20</td>
</tr>
<tr>
<td>DLL($p - \pi$) &gt; 15</td>
</tr>
<tr>
<td>DLL($p - K$) &gt; 9</td>
</tr>
</tbody>
</table>
3.2 Particle identification

A substantial fraction of the background events are not combinations of two real muons and a proton but have at least one pion, kaon or a ghost track among the reconstructed decay products.

A series of cuts on the LHCb PID likelihoods are therefore applied to both the signal MC and data to reduce the number of these events. The PID cuts are optimised to maximise the signal and background separation, via an iterative procedure which increments the cut values to find a maximum in a chosen figure of merit. The optimisation is performed using PID values in signal MC that have been corrected to match the measured PID distributions in data (using $\Lambda^0 \rightarrow p\pi^-$ and $J/\psi \rightarrow \mu^+\mu^-$ decays), and the outer data sidebands. The cut values are summarised in Table 1. Note that the same cut values are used for both $\tau^- \rightarrow \bar{p}\mu^+\mu^-$ and $\tau^- \rightarrow p\mu^-\mu^-$ channels.

3.3 Invariant mass likelihood

The signal mass is parameterised by a Gaussian, the width and mean of which are taken from signal MC and corrected by the ratio of the width and mean of $D^- \rightarrow \phi(\mu^+\mu^-)\pi^-$ decays as observed in data and simulation. The signal events are evaluated in six equally spaced bins in the $\pm 15$ MeV/$c^2$ ($\sim 2.5\sigma$) mass window around the expected $\tau^-$ mass [9], as shown in Fig. 2, where the solid and dashed lines represent $\tau^- \rightarrow \bar{p}\mu^+\mu^-$ and $\tau^- \rightarrow p\mu^-\mu^-$ signal MC, respectively.

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A ghost track is a spurious track made from a set of detector hits that do not relate to the passage of a real particle.
Figure 2: \(\mu\mu\mu\) mass distribution for signal MC. The solid and dashed lines are \(\tau^- \rightarrow \bar{\mu}\mu^+\mu^-\) and \(\tau^- \rightarrow \mu\mu^-\mu^-\), respectively. Vertical lines indicate the binning used in the limit determination.

4 Normalisation

To estimate the signal branching fraction we normalise the number of observed signal events to the number of events in the \(D_s^- \rightarrow \phi(\mu^+\mu^-)\pi^-\) calibration channel using:

\[
B(\tau \rightarrow \mu\mu\mu) = B(D_s^- \rightarrow \phi(\mu^+\mu^-)\pi^-) \times \frac{f_{D_s}^{\mu\mu\mu}}{B(D_s^- \rightarrow \tau^-\bar{\tau})} \times \frac{\epsilon_{\text{cal}}^{\text{REC&SEL}} \epsilon_{\text{cal}}^{\text{TRIG}\mid\text{SEL}} \epsilon_{\text{cal}}^{\text{PID}}}{\epsilon_{\text{sig}}^{\text{REC&SEL}} \epsilon_{\text{sig}}^{\text{TRIG}\mid\text{SEL}} \epsilon_{\text{sig}}^{\text{PID}}} \times \frac{N_{\text{sig}}}{N_{\text{cal}}},
\]

where \(\alpha\) is the overall normalisation factor and \(N_{\text{sig}}\) is the number of observed signal events. \(B(D_s^- \rightarrow \tau^-\bar{\nu}_\tau)\) is the branching fraction for \(D_s^- \rightarrow \tau^-\bar{\nu}_\tau\), taken from [10]. The quantity \(f_{D_s}^{\mu\mu\mu}\) is the fraction of \(\tau^-\) leptons which originate from \(D_s^-\) decays, calculated using the \(b\bar{b}\) and \(c\bar{c}\) cross sections as measured by LHCb [11,12] and the inclusive \(b \rightarrow \tau^-\) and \(c \rightarrow \tau^-\) branching fractions as measured by the LEP experiments [9]. Its introduction above is necessary as \(D_s^- \rightarrow \tau^-\bar{\nu}_\tau\) does not fully account for the production of \(\tau^-\) leptons.

The reconstruction and selection efficiency, \(\epsilon^{\text{REC&SEL}}\), is itself a combination of the detector acceptance for the particular decay, the efficiency to select muon candidates based on hits in the LHCb muon detector (basic muon ID) and the selection efficiency. The combined basic muon ID and selection efficiency is determined from the yield of MC events after the full selection has been applied. The sample of simulated events is smeared to describe the measured impact paramater resolution in data, and the difference in the ratio of signal and normalisation channels between smearings is assigned as a systematic uncertainty. Furthermore, the events are also reweighted to account for incorrect prompt and non-prompt production fractions during MC generation and the difference in the result if the weights are varied within their uncertainties is assigned as a systematic
uncertainty. This is found to be the dominant contribution to the uncertainty on the normalisation factor, and is due to theoretical uncertainties on the required branching fractions. The effects of different tracking and basic muon ID efficiencies in the simulation and data are also corrected using a data driven method. The uncertainty due to the hadronic interaction lengths of the proton and pion are accounted for in the systematic uncertainty on the tracking efficiency correction. For the basic muon ID correction the difference between the correction factors determined from data and from the ratio of data to MC is assigned as the systematic uncertainty. Finally, for the normalisation channel, the efficiency of the $\phi(1020)$ mass window cut determined from the MC is corrected to take account of the truncation of the $\phi(1020)$ Breit-Wigner lineshape at 1085 MeV/$c^2$ in the generator.

The trigger efficiency for selected events, $\epsilon^{\text{TRIG}}_{\text{SEL}}$, is calculated from simulated events. The systematic uncertainty is taken as the relative difference between trigger efficiencies of $B^- \rightarrow J/\psi K^-$ decays measured in data and in the simulation.

The PID efficiency for selected and triggered events, $\epsilon^{\text{PID}}$, is calculated using data calibration samples of $J/\psi \rightarrow \mu^+ \mu^-$ and $\Lambda^0 \rightarrow p\pi^-$ events, corrected to match the kinematics of the signal and normalisation channels. A systematic uncertainty of 1% per corrected final state track is assigned as determined in the charm cross section analysis ([12]), as well as a further 1% uncertainty to account for differences in kinematic binning.

The branching fraction of the control channel, $B(D^-_s \rightarrow \phi(\mu^+\mu^-)\pi^-)$, is determined from the combination of known branching fraction measurements via the equation:

$$B(D^-_s \rightarrow \phi(\mu^+\mu^-)\pi^-) = \frac{B(D^-_s \rightarrow \phi(K^+K^-)\pi^-)}{B(\phi \rightarrow K^+K^-)} B(\phi \rightarrow \mu^+\mu^-) = (1.33 \pm 0.12) \times 10^{-5},$$

(2)

where $B(D^-_s \rightarrow \phi(K^+K^-)\pi^-)$ is taken from the BaBar Dalitz analysis [13] which considers only the $\phi \rightarrow K^+K^-$ resonant part of the $D^-_s$ decay. The $D^-_s \rightarrow \phi(\mu^+\mu^-)\pi^-$ yield in data, $N_{\text{cal}}$, is extracted from a Gaussian and linear fit to the signal and background components, respectively, of the reconstructed $D^-_s$ mass distribution, as shown in Fig. 3. It is found to be

$$N(D^-_s \rightarrow \phi(\mu^+\mu^-)\pi^-) = 8330 \pm 110_{\text{stat}} \pm 83_{\text{syst}},$$

(3)

where the systematic uncertainty accounts for the difference in the number of candidates obtained after background subtraction is performed.

The normalisation factor, $\alpha$, is then calculated using all factors summarized in Table 2, where the uncertainties are taken as uncorrelated.
5 Results

5.1 Background estimate

The expected number of background events per bin in $M_{3\text{body}}$ and mass is calculated from an extended, unbinned maximum likelihood fit to the mass spectrum, in the $\tau^-$ mass range 1650 – 1900 MeV/$c^2$, excluding the signal region. The background PDF is defined as an exponential function.

Fits to the data are shown in Figures 4 and 5, where the solid lines show the combinatorial background PDF. The dashed lines show the linear fit, where the difference from the exponential fit is included as a systematic uncertainty in the limit calculation. The unblinded signal region is included for reference. The full tables of the expected and observed numbers of events are given in Appendix A.

From background studies we expect no peaking backgrounds in the signal windows.

5.2 Limits calculation and expected upper limits

We use the CL$_s$ method [14,15] as a statistical framework. It provides two estimators, CL$_s$ and CL$_b$, which give the level of compatibility with the signal plus background and background only hypotheses, respectively. CL$_s$ is used to set the exclusion (upper) limits.
on $\tau^- \to \bar{p}\mu^+\mu^-$ and $\tau^- \to p\mu^-\mu^-$ whereas CL$_b$ is used to claim incompatibility with the background hypothesis for an observation.

The distribution of expected CL$_s$ values is shown as a dashed line as a function of the assumed branching fractions in Fig. 6 (top: $\tau^- \to \bar{p}\mu^+\mu^-$, bottom: $\tau^- \to p\mu^-\mu^-$) under the hypothesis to observe background events only. The light (yellow) and dark (green) bands cover the regions of 68% and 95% containment respectively. The expected upper limits for the branching fractions of $\tau^- \to \bar{p}\mu^+\mu^-$ and $\tau^- \to p\mu^-\mu^-$ are found to be:

$$B(\tau^- \to \bar{p}\mu^+\mu^-) < 4.7 \times 10^{-7} \text{ at } 90\% \text{ CL}, \quad (4)$$
$$B(\tau^- \to p\mu^-\mu^-) < 5.4 \times 10^{-7} \text{ at } 90\% \text{ CL}, \quad (5)$$
$$B(\tau^- \to \bar{p}\mu^+\mu^-) < 5.9 \times 10^{-7} \text{ at } 95\% \text{ CL}, \quad (6)$$
$$B(\tau^- \to p\mu^-\mu^-) < 6.9 \times 10^{-7} \text{ at } 95\% \text{ CL}. \quad (7)$$

### 5.3 Observed limits

After the signal boxes are unblinded the distributions of observed CL$_s$ values are calculated. Figure 6 shows these as solid black lines as a function of the assumed branching fractions (top: $\tau^- \to \bar{p}\mu^+\mu^-$, bottom: $\tau^- \to p\mu^-\mu^-$). The observed upper limits for the

Table 2: Summary of the factors and their combined statistical and systematic uncertainties entering in the normalisation factor for $\tau^- \to \bar{p}\mu^+\mu^-$ (left) and $\tau^- \to p\mu^-\mu^-$ (right).

<table>
<thead>
<tr>
<th>Factor</th>
<th>$\tau^- \to \bar{p}\mu^+\mu^-$</th>
<th>$\tau^- \to p\mu^-\mu^-$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B(D_s^- \to \phi(\mu^+\mu^-)\pi^-)$</td>
<td>$(1.33 \pm 0.12) \times 10^{-5}$</td>
<td></td>
</tr>
<tr>
<td>$f_{D_s}^r$</td>
<td>0.78 ± 0.05</td>
<td></td>
</tr>
<tr>
<td>$B(D_s^- \to \tau^-\bar{\nu}_\tau)$</td>
<td>0.0561 ± 0.0024</td>
<td></td>
</tr>
<tr>
<td>$\epsilon_{\text{cal}}^{\text{REC&amp;SEL}} / \epsilon_{\text{sig}}^{\text{REC&amp;SEL}}$</td>
<td>1.10 ± 0.17</td>
<td>1.07 ± 0.16</td>
</tr>
<tr>
<td>$\epsilon_{\text{cal}}^{\text{TRIG\SEL}} / \epsilon_{\text{sig}}^{\text{TRIG\SEL}}$</td>
<td>1.73 ± 0.08</td>
<td>2.05 ± 0.10</td>
</tr>
<tr>
<td>$\epsilon_{\text{cal}}^{\text{PID}} / \epsilon_{\text{sig}}^{\text{PID}}$</td>
<td>1.39 ± 0.08</td>
<td>1.39 ± 0.07</td>
</tr>
<tr>
<td>$N_{\text{cal}}$</td>
<td>8 330 ± 138</td>
<td></td>
</tr>
<tr>
<td>$\alpha$</td>
<td>$(5.9 \pm 1.2) \times 10^{-8}$</td>
<td>$(6.8 \pm 1.4) \times 10^{-8}$</td>
</tr>
</tbody>
</table>
branching fractions of $\tau^- \rightarrow \bar{p}\mu^+\mu^-$ and $\tau^- \rightarrow p\mu^-\mu^-$ are found to be:

\[
B(\tau^- \rightarrow \bar{p}\mu^+\mu^-) < 3.4 \times 10^{-7} \text{ at 90\% CL}, \quad (8)
\]
\[
B(\tau^- \rightarrow p\mu^-\mu^-) < 4.6 \times 10^{-7} \text{ at 90\% CL}, \quad (9)
\]
\[
B(\tau^- \rightarrow \bar{p}\mu^+\mu^-) < 4.5 \times 10^{-7} \text{ at 95\% CL}, \quad (10)
\]
\[
B(\tau^- \rightarrow p\mu^-\mu^-) < 6.0 \times 10^{-7} \text{ at 95\% CL.} \quad (11)
\]

References


[5] LHCb Collaboration, Search for the lepton flavour violating decay $\tau^- \rightarrow \mu^+\mu^-\mu^-$, LHCb-CONF-2012-015.


Figure 4: Fit to the events observed in the sidebands in the $M_{3\text{body}}$ bins for the $\tau^- \rightarrow \bar{p}\mu^+\mu^-$ data. Solid lines are the exponential fit, dashed lines are the linear fit.
Figure 5: Fit to the events observed in the sidebands in the $M_{3\text{body}}$ bins for the $\tau^{-} \rightarrow p\mu^{-}\mu^{-}$ data. Solid lines are the exponential fit, dashed lines are the linear fit.
Figure 6: Distribution of $C_{L_{s}}$ values as a function of the assumed branching fractions, under the hypotheses to observe background events only, for $\tau^{-} \rightarrow \bar{p}_{\mu}^{+}\mu^{-}$ (top) and $\tau^{-} \rightarrow p\mu^{-}\mu^{-}$ (bottom). The dashed lines indicate the expected curves, the solid lines the observed. The light (yellow) and dark (green) bands cover the regions of 68% and 95% containment respectively.
Appendix

A Expected and observed pattern of events

Table 3: Numbers of estimated background events and numbers of observed events within the tau mass window in the different likelihood bins for the linear fits to the tau mass sidebands for $\tau^- \to \bar{p}\mu^{+}\mu^-$. The numbers of observed events are expected to vary according to Poisson statistics.

<table>
<thead>
<tr>
<th>$\mathcal{M}_{3\text{body}}$</th>
<th>Expected background</th>
<th>Observed events</th>
</tr>
</thead>
<tbody>
<tr>
<td>−1.00, −0.05</td>
<td>85.2 ± 3.3</td>
<td>91</td>
</tr>
<tr>
<td>−0.05, 0.20</td>
<td>29.5 ± 2.0</td>
<td>32</td>
</tr>
<tr>
<td>0.20, 0.40</td>
<td>9.8 ± 1.1</td>
<td>5</td>
</tr>
<tr>
<td>0.40, 0.70</td>
<td>5.48 ± 0.85</td>
<td>4</td>
</tr>
<tr>
<td>0.70, 1.00</td>
<td>0.78 ± 0.32</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 4: Numbers of estimated background events and numbers of observed events within the tau mass window in the different likelihood bins for the linear fits to the tau mass sidebands for $\tau^- \to p\mu^{-}\mu^-$. The numbers of observed events are expected to vary according to Poisson statistics.

<table>
<thead>
<tr>
<th>$\mathcal{M}_{3\text{body}}$</th>
<th>Expected background</th>
<th>Observed events</th>
</tr>
</thead>
<tbody>
<tr>
<td>−1.00, −0.05</td>
<td>47.4 ± 2.5</td>
<td>69</td>
</tr>
<tr>
<td>−0.05, 0.20</td>
<td>32.0 ± 2.0</td>
<td>33</td>
</tr>
<tr>
<td>0.20, 0.40</td>
<td>9.0 ± 1.1</td>
<td>7</td>
</tr>
<tr>
<td>0.40, 0.70</td>
<td>6.1 ± 0.90</td>
<td>4</td>
</tr>
<tr>
<td>0.70, 1.00</td>
<td>0.65 ± 0.11</td>
<td>0</td>
</tr>
</tbody>
</table>