Search for lepton flavor violation in Z decays in proton-proton collisions at √s = 8 TeV

The CMS Collaboration

Abstract

A search for lepton flavor violation in Z boson decays to one electron and one muon is performed. The data sample of proton-proton collisions at √s = 8 TeV collected by the CMS detector corresponds to an integrated luminosity of 19.7 fb⁻¹. An observed (expected) limit on the branching fraction of $\mathcal{B}(Z \rightarrow e\mu) < 7.3 \cdot 10^{-7} (6.7 \cdot 10^{-7})$ at 95% CL is obtained.
1 Introduction

The standard model (SM) of particle physics explicitly conserves lepton flavor in particle interactions in spite of the absence of an underlying symmetry. The observation of neutrino oscillation [1] proves neutral lepton flavor violation (LFV) and thus motivates a search for violations in charged lepton interactions. This analysis searches for LFV in the decay of the Z boson to an electron and a muon. The branching fraction of such a decay is predicted to be non-zero (via one-loop decays with flavor-oscillating neutrinos), but undetectable by any current or near-future experiment (e.g., $B(Z \to e\mu) < 4 \cdot 10^{-60}$ [2]), turning its observation into a direct proof of new physics. Models including massive Dirac or Majorana neutrinos, or R-parity violating supersymmetry are able to increase the branching fraction of lepton flavor violating Z decays to observable levels (e.g., $B(Z \to \mu\tau) \approx 10^{-8}$ or $B(Z \to e\mu) \approx 10^{-9}$) [2, 3]. Although low-energy experiments looking for decays such as $\mu \to 3e$ [4] set very stringent indirect limits on the branching fraction ($B(\bar{Z} \to e\mu) < 5 \cdot 10^{-13}$ [5]), it is worthwhile to study whether they hold at high energies as well.

The four LEP experiments performed searches for lepton flavor violating Z decays in $e^+e^-$-collisions. The results are limits set at 95% confidence level (CL), in particular $B(Z \to e\mu) < 1.7 \cdot 10^{-6}$ [6]. Recently, the ATLAS collaboration published a new limit on the branching fraction $B(Z \to e\mu) < 7.5 \cdot 10^{-7}$ at 95% CL [7]. The aim of this analysis is to either find evidence of the decay $Z \to e\mu$ or set a more stringent limit on its branching fraction.

The main background processes are decays of Z bosons to tau leptons as well as WW and $t\bar{t}$ events decaying leptonically. Further backgrounds arise from single top production in association with a W boson, other diboson processes (WZ and ZZ), and misidentified leptons from multijet or W+jets and Z+jets events. Since the background processes occur far more often than the signal process itself, a selection is developed that reduces the background significantly but keeps the expected signal yield as high as possible.

2 CMS detector

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 superconducting solenoid volume are a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter (ECAL), and a brass and scintillator hadron calorimeter (HCAL), 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. Extensive forward calorimetry complements the coverage provided by the barrel and endcap detectors.

The electron momentum is estimated by combining the energy measurement in the ECAL with the momentum measurement in the tracker. The momentum resolution for electrons with transverse momentum $p_T \approx 45$ GeV from $Z \to ee$ decays ranges from 1.7% for nonshowering electrons in the barrel region to 4.5% for showering electrons in the endcaps [8].

Muons are measured in the pseudorapidity range $|\eta| < 2.4$, with detection planes made using three technologies: drift tubes, cathode strip chambers, and resistive plate chambers. Matching muons to tracks measured in the silicon tracker results in a relative transverse momentum resolution for muons with $20 < p_T < 100$ GeV of 1.3–2.0% in the barrel and better than 6% in the endcaps. The $p_T$ resolution in the barrel is better than 10% for muons with $p_T$ up to 1 TeV [9].

The first level (L1) of the CMS trigger system, composed of custom hardware processors, uses information from the calorimeters and muon detectors to select the most interesting events
in a fixed time interval of less than 4 µs. The high-level trigger (HLT) processor farm further decreases the event rate from around 100 kHz to around 400 Hz, before data storage.

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 Ref. [10].

3 Data and simulated samples

This analysis uses the full dataset of proton-proton collisions collected by the CMS detector during the year 2012 at a center-of-mass energy of 8 TeV corresponding to an integrated luminosity of 19.7 fb⁻¹. To select events online, a trigger is chosen that requires either an electron with $p_T > 17$ GeV and a muon with $p_T > 8$ GeV, or an electron with $p_T > 8$ GeV and a muon with $p_T > 17$ GeV. Furthermore, both triggers impose quality criteria on identification and isolation of the electron in both calorimeter and tracker.

Leptonic Z-decays are generated with a cut on the dilepton invariant mass of 50 GeV by MADGRAPH 5.1.3.30 (LO, [11]). Processes related to top quarks are produced with POWHEG 1.0 (NLO, [12–14]), while diboson events are generated with MADGRAPH 5.1.3.30. The production of signal events is done by PYTHIA 6.4 (LO, [15]). The decay library for tau decays, TAUOLA [16], is used to decay generated final state tau leptons. Parton showering and hadronization is always done by PYTHIA 6.4 tuned to Z2* [17], and the parton distribution functions (PDF) used are CT10 [18] for NLO samples as well as CTEQ6l [19] for LO samples. Additional interactions from proton-proton collisions in the same bunch crossing (pileup) are simulated as well. Simulated events are reweighted to match the pileup distribution observed in data. Once events are generated, they are passed to a full simulation of the detector and any interactions are calculated by GEANT4 [20].

4 Event reconstruction and selection

4.1 Event reconstruction

All objects used in the event reconstruction are reconstructed by the particle-flow (PF) algorithm. The particle-flow event algorithm [21, 22] reconstructs and identifies each individual particle with an optimized combination of information from the various elements of the CMS detector. The energy of photons is directly obtained from the ECAL measurement, corrected for zero-suppression effects. The energy of electrons is determined from a combination of the electron momentum at the primary interaction vertex as determined by the tracker, the energy of the corresponding ECAL cluster, and the energy sum of all bremsstrahlung photons spatially compatible with originating from the electron track. The energy of muons is obtained from the curvature of the corresponding track. The energy of charged hadrons is determined from a combination of their momentum measured in the tracker and the matching ECAL and HCAL energy deposits, corrected for zero-suppression effects and for the response function of the calorimeters to hadronic showers. Finally, the energy of neutral hadrons is obtained from the corresponding corrected ECAL and HCAL energy. For further information please consult Ref. [21, 22].

In each event, the vertex with the highest sum of $p_T^2$ of tracks associated to it is chosen to be the primary vertex.

The nominal muon identification requires hits in both tracker and muon system which need to be matched by the global-muon fit [9]. The muon track itself must satisfy quality require-
ments based on tracker information. Moreover, requirements on the transverse and longitudinal impact parameters of the muon candidate with respect to the primary vertex are imposed. Any muon passing these requirements also has to have a transverse momentum greater than 10(20) GeV depending on the trigger threshold of 8(17) GeV and a pseudorapidity $|\eta|$ less than 2.4. Moreover, the muon is required to be isolated in order to reduce contamination from leptonic quark decays. The relative isolation is defined as

$$I_{\text{rel}} = \frac{\sum p_T^{\text{(charged)}} + \max (\sum E_T^{\text{(neutral)}}, \sum E_T^{\text{(photon)})} - \Delta \beta, 0)}{p_T(\mu)},$$  \hspace{1cm} (1)$$

where $p_T^{\text{(charged)}}$ corresponds to the transverse momentum of any charged particle, $E_T^{\text{(neutral)}}$ and $E_T^{\text{(photon)}}$ to the transverse energy of any neutral hadron or photon, and $\Delta \beta$ to half of the summed transverse momenta of all charged hadrons not associated to the primary vertex, all within a cone of $\Delta R = \sqrt{\Delta \eta^2 + \Delta \phi^2}$ around the muon candidate. Muons are required to satisfy $I_{\text{rel}} < 0.12$ in a cone of $\Delta R < 0.4$. If more than one muon passes the identification, the one with the highest $p_T$ is selected as the signal candidate.

In case of electrons, a special track fit is employed to account for effects of bremsstrahlung and multiple scattering \[23\]. Electron candidates are required to have $p_T > 10(20)$ GeV and $|\eta| < 2.5$. A boosted decision tree has been trained to identify electrons with information obtained from the track fit, ECAL shower shapes, as well as geometry and energy matching \[8\]. Requirements on the discriminating variable returned by this multivariate technique are imposed to identify electrons. To reduce conversions of photons radiated from muons, electrons with an additional muon inside a cone of $\Delta R < 0.3$ with $p_T > 3$ GeV and $|\eta| < 2.4$ are discarded. Additionally, the relative isolation of each electron is calculated analogously to the one of the muon but a different technique for pileup subtraction is used. This technique uses the geometric area of the isolation cone dependent on the pseudorapidity of the electron and the mean energy density of neutral particles in any jet in the event to estimate the contribution caused by pileup. The method is described in more detail in Ref. \[24\]. A slightly looser requirement on the electron isolation of $I_{\text{rel}} < 0.15$ is imposed. If more than one electron passes all of the above, the one with the highest $p_T$ is chosen.

This analysis uses jets reconstructed by the anti-$k_T$ algorithm \[25, 26\] with a radius parameter of $R = 0.5$. Biases of the measured jet energy introduced through nonlinearities of the calorimeter response are removed with a set of dedicated corrections \[27\]. Effects from pileup, as well as (run-dependent) $p_T$ and $\eta$ dependent energy scales are included in these corrections. Furthermore, the jet energy resolution is smeared in simulation to fit that observed in data. All corrections described are applied in this analysis.

The negative vectorial sum of all reconstructed particles’ transverse momenta is called missing transverse energy ($E_T^{\text{miss}}$). It quantifies the amount of energy carried by neutrinos or other particles that have not been detected. Since it is the last physics object to be reconstructed, it is highly dependent on any uncertainties from previous object reconstructions. The largest contribution to the reconstruction of $E_T^{\text{miss}}$ is due to jet energy uncertainties. To reduce this bias, a correction is applied \[28\]:

$$E_T^{\text{miss,corr}} = E_T^{\text{miss}} - \sum (\vec{p}_T^{\text{corr, jet}} - \vec{p}_T^{\text{jet}}).$$  \hspace{1cm} (2)$$

Further uncertainties arise from pileup where the sum of transverse momenta of charged and neutral particles is expected to be balanced. However, because of energy thresholds in the
calorimeters and non-linearity, neutral particles are measured with less accuracy leading to \(E_{T}^{\text{miss}}\) pointing in the direction of the \(p_{T}\) sum of neutral particles. A correction for this is also available and applied to events in this analysis [28].

### 4.2 Selection

The Z boson is reconstructed from one electron and one muon candidate, which are required to have opposite charge. In order to reduce contamination from multi-lepton backgrounds (e.g., WZ or ZZ), events with a third lepton are rejected. This third lepton must be identified as either an electron or a muon according to the criteria mentioned in this section, and have a \(p_{T}\) greater than 10 GeV. Restrictions in \(\eta\) are given by the detector acceptance, \(|\eta| < 2.4\) for muons, and \(|\eta| < 2.5\) for electrons, respectively. Moreover, the track of this third lepton must be constrained to the primary vertex via its impact parameters (\(|d_{xy}| < 0.045\ cm\) and \(|d_{z}| < 0.2\ cm\)). The third lepton must pass a loose isolation cut of \(I_{\text{rel}} < 0.3\) making this veto more powerful than simply requiring exactly one muon and one electron passing the nominal identification criteria. Finally, a cut on the combined electron-muon invariant mass of \(60 < m_{e\mu} < 120\ \text{GeV}\) is applied.

The following selection is optimized with respect to the discovery potential \(s/\sqrt{s + b + \Delta b}\) with \(s\) being the number of signal and \(b\) the number of background events expected. The uncertainty in the background estimate is represented by \(\Delta b\).

In order to reduce background from top quarks (e.g., \(t\bar{t}\) or \(tW/\bar{t}W\)), a jet veto is introduced. This veto takes effect if there is at least one jet associated to the selected primary vertex. If the leading jet has \(p_{T} > 40\ \text{GeV}\) the event is rejected. The corresponding distribution is available in Figure 1. All events depicted have passed the lepton identification criteria as well as the trigger and invariant mass cut. The background uncertainty includes uncertainties from statistical precision and systematic effects on the normalization described in more detail in Section 6. The veto reduces the background by 58\%, in particular it reduces the number of \(t\bar{t}\) events by 93\%, while reducing the signal yield by 10\%.

![Figure 1: The leading jet \(p_{T}\) for events where a well-identified electron and muon are selected, the trigger requirement is met and that satisfy \(60 < m_{e\mu} < 120\ \text{GeV}\). The signal is drawn on the bottom (not stacked). The background uncertainty band includes only uncertainties from statistical precision and systematic effects on the normalization.](image-url)
4.2 Selection

Figure 2: Distributions of the transverse mass (a), and the transverse momentum of the combined electron-muon four-vector (b) for events where a well-identified electron and muon are selected, the trigger requirement is met and that satisfy $60 < m_{e\mu} < 120$ GeV. The signal is drawn on the bottom in each plot (not stacked). The background uncertainty band includes only uncertainties from statistical precision and systematic effects on the normalization.

Another large background comes from leptonically decaying WW events. These are accompanied by two neutrinos and thus, a comparatively large amount of $E_T^{\text{miss}}$ is expected. To discriminate against this process, the transverse mass defined by

$$m_T^\mu = \sqrt{2 \cdot p_T^\mu E_T^{\text{miss}} (1 - \cos \Delta \phi)}$$

is required to have a value less than 60 GeV. Here, $p_T^\mu$ corresponds to the muon’s transverse momentum and $\Delta \phi$ to the angle between the muon candidate and $E_T^{\text{miss}}$. The distribution can be observed in Figure 2a. Furthermore, the Z boson is expected to have little boost in the transverse plane since only approximately 10% of all Drell-Yan (DY) events are accompanied by one or more jets. The leptons from top quark and diboson events however are expected to be boosted in the transverse plane because of more complex decay kinematics. To use this circumstance to our advantage, the $p_T$ of the Z candidate reconstructed from the selected electron and muon should be smaller than 10 GeV (see Fig. 2b). Although this requirement has a large effect on the signal itself (50% reduction), it greatly reduces background from events containing misidentified leptons as well as WW and top background (85%, 89% and 97% reduction, respectively).

The invariant mass of the reconstructed Z candidate of all events passing the selection up to this point is depicted in Figure 3. An upper limit on the LFV decay $Z \to e\mu$ is derived by comparing data and the sum of the expected SM backgrounds in the invariant mass signal region around the Z boson mass peak, $88 - 94$ GeV. More details can be found in Section 7.
5 Background evaluation

The Drell-Yan process with a decay into two tau leptons which in turn decay into a muon and an electron is a large background owing to its sizable cross section. Since the neutrinos from the subsequent leptonic tau decays cannot be measured by the detector, the final state is nearly indistinguishable from the signal. One handle to discriminate this background against the signal is the invariant mass of the reconstructed Z candidate as it is greatly reduced by the energy carried away by the neutrinos. Simulation is used to predict the shape of this background while the yield is taken from a theory calculation at next-to-next-to leading order [29, 30].

The production of top-quark pairs is another large background both because of its sizable cross section and a similar final state. This happens when each top quark decays into a b quark and a W boson which then decays leptonically. Contrary to background from DY events however, we are presented with multiple handles to identify this background: the jet multiplicity, $E_T^{miss}$ and the different boosts of electron and muon in the transverse plane. The shape of this background is estimated using simulation while the yield is taken from a CMS measurement [31].

Other backgrounds are diboson processes (WW, WZ and ZZ), single-top quark production and events with objects misidentified as leptons (multijet, W+jets, Z+jets). While diboson and single top events are estimated using simulation and cross sections from theory calculations [32, 33], background from misidentified leptons is estimated using a data-driven approach.

This approach defines a misidentification efficiency $\epsilon$ that quantifies the probability of a jet being identified as a lepton. This probability has been measured in multijet data samples by evaluating the rate at which an object identified as a lepton by relaxed criteria also passes the nominal requirements imposed on leptons [34, 35]. Data events in which electron and muon have the same charge and where one or both leptons pass relaxed identification criteria but
Table 1: Systematic uncertainties in the normalization relative to the total background yield in the signal region.

<table>
<thead>
<tr>
<th>Background process</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Z \to \ell\ell$ ($\ell = e, \mu, \tau$)</td>
<td>2.0%</td>
</tr>
<tr>
<td>WW, WZ, ZZ</td>
<td>3.1%</td>
</tr>
<tr>
<td>$t\bar{t}$</td>
<td>$&lt; 0.1%$</td>
</tr>
<tr>
<td>$tW/\bar{t}W$</td>
<td>$&lt; 0.1%$</td>
</tr>
<tr>
<td>Misidentified leptons</td>
<td>5.7%</td>
</tr>
<tr>
<td>Total background</td>
<td>6.8%</td>
</tr>
</tbody>
</table>

not the nominal ones are considered as background from misidentified leptons and scaled by a factor dependent on the misidentification efficiency. In case of only one lepton failing the nominal identification, this factor is $\varepsilon_{\ell}/(1 - \varepsilon_{\ell})$ with $\ell = e, \mu$. If neither lepton passes the nominal criteria, the factor becomes $\varepsilon_{e}/(1 - \varepsilon_{e}) \cdot \varepsilon_{\mu}/(1 - \varepsilon_{\mu})$ instead. In order to avoid double counting of events with two misidentified leptons, cases with two failing leptons are not added bin-by-bin but subtracted.

6 Systematic uncertainties

There are various systematic effects impacting the number of events in the mass range of interest. Uncertainties in the normalization of the backgrounds have several sources: cross section calculation uncertainties in case of theory predictions (for DY [29, 30], diboson [32] and singletop quark [33] events), and measurement uncertainties in case of experimentally obtained cross sections ($t\bar{t}$ [31], multijet and W/Z+jets [34, 35]), luminosity [36], and trigger as well as identification efficiencies. Uncertainties from predictions are used as a systematic uncertainty in the normalization, while in case of measured cross sections, the combined statistical and systematic uncertainty of the measurement is used. The measurement of the misidentification efficiencies has been performed in a background enriched control region selected by a minimum $p_T$ requirement on the leading jet in each event. Several sets of efficiencies have been determined using different $p_T$ thresholds. The uncertainty in the yield of background from misidentified leptons is estimated by comparing the yields obtained using the various sets of misidentification efficiencies. As expected, this gives the largest relative uncertainty overall (37.2%). The individual contributions to the normalization uncertainty relative to the total background yield in the signal region (see Section 7) are shown in Table 1. Identification and trigger efficiencies are varied within their measured uncertainties to estimate their impact on the result which in turn were measured using tag-and-probe methods [37]. Their impact is small ($< 1\%$ each) compared to the uncertainties arising from cross sections.

To account for systematic effects introduced by pileup, the matching of its simulated distribution to the observed one is repeated with a variation of the elastic proton-proton cross section by $\pm 5\%$. Influence of the jet energy scale and resolution are estimated by varying both energy correction and smearing independently within their uncertainties. Their impact on the result is very small ($\leq 0.2\%$). The same procedure is used to evaluate the systematic bias introduced by lepton energy scale and resolution uncertainties. The lepton energy scale uncertainties have a fairly large impact on the result (approximately 3\%) while the resolution is not quite as significant ($< 0.5\%$).

$E_T^{miss}$ is a compound object reconstructed from all energies and momenta measured in the detector. Therefore, any uncertainties in these measurements will inevitably impact $E_T^{miss}$. In order to
Table 2: Systematic uncertainties in the number of signal and background events within the
signal window and their sources.

<table>
<thead>
<tr>
<th>Source</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Background</td>
</tr>
<tr>
<td>Luminosity</td>
<td>2.6%</td>
</tr>
<tr>
<td>Pileup</td>
<td>3.3%</td>
</tr>
<tr>
<td>Trigger</td>
<td>0.3%</td>
</tr>
<tr>
<td>Muon Id</td>
<td>0.5%</td>
</tr>
<tr>
<td>Muon $p_T$ scale</td>
<td>2.9%</td>
</tr>
<tr>
<td>Muon $p_T$ resolution</td>
<td>0.4%</td>
</tr>
<tr>
<td>Electron Id</td>
<td>0.5%</td>
</tr>
<tr>
<td>Electron energy scale</td>
<td>3.1%</td>
</tr>
<tr>
<td>Electron energy resolution</td>
<td>0.3%</td>
</tr>
<tr>
<td>Jet energy scale</td>
<td>0.2%</td>
</tr>
<tr>
<td>Jet energy resolution</td>
<td>$&lt; 0.1%$</td>
</tr>
<tr>
<td>$E_T^{miss}$</td>
<td>0.6%</td>
</tr>
<tr>
<td>Dilepton $p_T$</td>
<td>0.4%</td>
</tr>
<tr>
<td>PDF</td>
<td>1.0%</td>
</tr>
<tr>
<td>Limited number of simulated events</td>
<td>10.6%</td>
</tr>
<tr>
<td>Normalization (Tab. 1)</td>
<td>6.8%</td>
</tr>
</tbody>
</table>

estimate the impact of the resulting uncertainty, all measured momenta and energies are varied
individually within their uncertainties and $E_T^{miss}$ is recalculated. This recalculated $E_T^{miss}$ is then
propagated through the analysis with momenta and energies varied within their uncertainties,
and the resulting uncertainties are added in quadrature. This way, an uncertainty of 0.6% in the
background and 2.2% in the signal estimate is obtained.

The requirement on the transverse momentum of the reconstructed Z candidate is in a region
potentially sensitive to initial state radiation and to the factorization scale. To account for pos-
sible systematic effects the transverse momentum distribution of the Z candidate is varied bin-
by-bin within uncertainties procured from a Z $p_T$ measurement [38] in case of signal and DY
simulation. In case of t ¯t, the distribution predicted by simulation is reweighted to that mea-
sured in data [39, 40]. To account for effects from the WW background, simulated samples
with factorization and renormalization scales modified by factors of 2 and 1/2 are utilized.

The impact of different parton density functions used in simulation is estimated using the pre-
scription given by the PDF4LHC Working Group [41–45]. Finally, the finite amount of simu-
lated events available is accounted for by assigning a dedicated uncertainty which is dominated
by the DY background simulation. All uncertainties mentioned in this section (listed in Table
2) enter the limit calculation.

7 Result

In data, 87 events are found within the specified mass range in good agreement with the
background prediction of $83 \pm 9$ (stat.) events (see also Table 3). A cumulative signal selec-
tion efficiency of 6.6% is obtained. Thus, for an upper limit on the branching fraction of
$B(Z \rightarrow e\mu) = 1 \cdot 10^{-6}$, up to $43.8 \pm 0.5$ (stat.) signal events could be expected. The number
of data, background and signal events in this range are passed to the limit calculation.

To calculate the expected and observed limit, a tool developed by both the ATLAS and the CMS
Table 3: Number of events found in data and expected from individual background processes as well as from the combined background prediction. The uncertainties shown are statistical only.

<table>
<thead>
<tr>
<th>Process</th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Z \rightarrow \tau\tau$</td>
<td>$41 \pm 9$</td>
</tr>
<tr>
<td>WW</td>
<td>$17 \pm 1$</td>
</tr>
<tr>
<td>Misidentified leptons</td>
<td>$12.8 \pm 0.5$</td>
</tr>
<tr>
<td>$Z \rightarrow ee/\mu\mu$</td>
<td>$10 \pm 2$</td>
</tr>
<tr>
<td>$t\bar{t}$</td>
<td>$1.3 \pm 0.5$</td>
</tr>
<tr>
<td>$tW/\bar{t}W$</td>
<td>$0.6 \pm 0.6$</td>
</tr>
<tr>
<td>WZ</td>
<td>$0.3 \pm 0.1$</td>
</tr>
<tr>
<td>ZZ</td>
<td>$&lt; 0.1$</td>
</tr>
<tr>
<td>Total background</td>
<td>$83 \pm 9$</td>
</tr>
<tr>
<td>Data</td>
<td>$87$</td>
</tr>
</tbody>
</table>

Collaborations for the LHC Higgs Combination Group [46, 47] is used. A parameter $\mu$ called signal strength modifier is introduced that satisfies

$$\sigma = \mu \cdot \sigma_{SM},$$ (4)

where $\sigma$ ($\sigma_{SM}$) corresponds to the measured (expected) cross section. This translates into the number of expected events from background ($b$) and signal ($s$): $N = \mu \cdot s + b$. The CL$_s$-method described in [48] is used to set a limit on the signal strength modifier. If the CL$_s$ value obtained is smaller than 0.05 for a given signal hypothesis, this hypothesis is excluded at 95% CL. The same logic can be used in the case of this analysis, where branching fractions are used instead of the cross sections. Using the number of expected signal and background events, this yields an expected upper limit of

$$B (Z \rightarrow e\mu) < (6.7^{+2.8}_{-2.0}) \cdot 10^{-7}.$$ (5)

Taking into account the observation of 87 events, an observed upper limit of

$$B (Z \rightarrow e\mu) < 7.3 \cdot 10^{-7}$$ (6)

is established which is consistent with the expectation within the given uncertainty.

8 Summary

A search for lepton flavor violation was conducted with a dedicated analysis designed as a cut-and-count selection. A selection was developed to separate signal from background and a statistical interpretation of the resulting event counts was done. The observed limit on the branching fraction at 95% CL was found to be $7.3 \cdot 10^{-7}$, in agreement with the expectation of $(6.7^{+2.8}_{-2.0}) \cdot 10^{-7}$. Results are similar to those obtained by the ATLAS collaboration [7].
References


References


