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Aad, G.; ATLAS Collaboration

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Search for Lepton-Flavor Violation in Z-Boson Decays with τ Leptons with the ATLAS Detector

G. Aad *et al.*[*]
(ATLAS Collaboration)

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A search for lepton-flavor-violating $Z \to e\tau$ and $Z \to \mu\tau$ decays with pp collision data recorded by the ATLAS detector at the LHC is presented. This analysis uses 139 fb^{-1} of Run 2 pp collisions at $\sqrt{s} =$ 13 TeV and is combined with the results of a similar ATLAS search in the final state in which the τ lepton decays hadronically, using the same data set as well as Run 1 data. The addition of leptonically decaying τ leptons significantly improves the sensitivity reach for $Z \to \ell\tau$ decays. The $Z \to \ell\tau$ branching fractions are constrained in this analysis to $\mathcal{B}(Z \to e\tau) < 7.0 \times 10^{-6}$ and $\mathcal{B}(Z \to \mu\tau) < 7.2 \times 10^{-6}$ at 95% confidence level. The combination with the previously published analyses sets the strongest constraints to date: $\mathcal{B}(Z \to e\tau) < 5.0 \times 10^{-6}$ and $\mathcal{B}(Z \to \mu\tau) < 6.5 \times 10^{-6}$ at 95% confidence level.

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Three lepton families (flavors) exist in the standard model (SM) of particle physics [1–4], and the number of leptons of each family is conserved in their interactions. Nevertheless, this conservation is not postulated by any fundamental principle of the theory, and neutrino oscillations [5,6] indicate that processes violating this conservation do occur in nature. According to current knowledge, lepton-flavor-violating (LFV) processes in charged-lepton interactions can occur via neutrino mixing but are too rare to be detected by current experiments [7]. An observation of these would be an unambiguous sign of physics beyond the SM. LFV processes occur, for example, in models predicting the existence of heavy neutrinos [8], which may also explain the observed tiny masses and large mixing of the SM neutrinos. In such models, up to one in 10^5 Z bosons would undergo an LFV decay involving τ leptons. In an earlier analysis, the ATLAS experiment at the LHC set the strongest constraints on the branching fractions ($\mathcal{B}$) of the LFV decays of the Z boson involving a τ lepton by searching for such decays in which the τ lepton decays hadronically [9]. This result was achieved by analyzing proton-proton (pp) collision data corresponding to an integrated luminosity of 139 fb^{-1} at a center-of-mass energy $\sqrt{s} = 13$ TeV and 20.3 fb^{-1} at $\sqrt{s} = 8$ TeV. In that search, ATLAS measured the branching fractions to be $\mathcal{B}(Z \to e\tau) < 8.1 \times 10^{-6}$ and $\mathcal{B}(Z \to \mu\tau) < 9.5 \times 10^{-6}$ at 95% confidence level (C.L.), superseding former limits set by the LEP experiments of $\mathcal{B}(Z \to e\tau) < 9.8 \times 10^{-6}$ [10] and $\mathcal{B}(Z \to \mu\tau) < 1.2 \times 10^{-5}$ [11] at 95% C.L.

This Letter presents a complementary search for $Z \to \ell\tau$ decays ($\ell =$ light charged lepton, i.e., e or μ) in which the τ leptons decay into electrons or muons ($\ell\tau_{\ell'}$ channel) using 139 fb^{-1} of pp collision data at $\sqrt{s} = 13$ TeV collected by the ATLAS experiment [12–14]. The search is performed here for the first time at the LHC and is combined with the similar ATLAS search using hadronic τ-lepton decays ($\ell\tau_{\text{had}}$ channel) [9]. The two searches follow similar analysis strategies. Neural network classifiers are used for optimal discrimination of signal from backgrounds and their distributions are employed in a binned maximum-likelihood fit to achieve better sensitivity.

ATLAS is a multipurpose particle detector with a forward-backward symmetric cylindrical geometry and a near 4π coverage in solid angle [12,15,16]. It consists of an inner tracking detector surrounded by a superconducting solenoid, electromagnetic and hadronic calorimeters, and a muon spectrometer based on superconducting air-core toroidal magnets. This search analyzes pp collision events recorded by the ATLAS experiment using single-electron or single-muon triggers [17–19]. Prompt electrons and muons from the Z-boson decays and those from the τ-lepton decays are reconstructed and selected in the same way. Candidates for electrons [20], muons [21], jets [22–24], and visible decay products of hadronic τ-lepton decays ($\tau_{\text{had-vis}}$) [25,26] are reconstructed from energy deposits in the calorimeters and charged-particle tracks measured in the inner detector and the muon spectrometer. These candidates are selected with sets of requirements similar to those used in Ref. [9]. Electron candidates are required to pass the *medium* likelihood-based identification requirement [20] and have a transverse momentum

[*]Full author list given at the end of the article.

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$p_T > 15$ GeV and a pseudorapidity $|\eta| < 1.37$ or $1.52 < |\eta| < 2.47$. The latter selection vetoes electron candidates passing through the transition region between the barrel and end-cap electromagnetic calorimeters. Muon candidates are required to pass the *medium* identification requirement [27] and have a $p_T > 10$ GeV and $|\eta| < 2.5$. Both the electron and muon candidates must satisfy the *tight* isolation requirement [20,27], which is intended to reject misidentified candidates produced from the hadronization of quarks or gluons based on tracks and clusters reconstructed collinear to the candidates. Events with exactly one electron and one muon candidate are selected with the requirement that the lepton with higher transverse momentum has a $p_T > 27$ GeV. This selection lies above the threshold for constant efficiency of both single-lepton trigger selections. Events with same-flavor lepton pairs are rejected, in order to reduce the background from $Z \to \ell\ell$ decays. Events with a leading-p_T electron are used in the search for $Z \to e\tau$ decays ($e\tau_\mu$ channel), while those with a leading-p_T muon are used in the search for $Z \to \mu\tau$ decays ($\mu\tau_e$ channel), assuming the prompt lepton from the Z-boson decay is the leading one in p_T. In the $\mu\tau_e$ channel, the ratio of the electron's p_T reconstructed in the inner tracking detector to the transverse energy reconstructed in the electromagnetic calorimeter, $p_T^{\text{track}}(e)/E_T{}^{\text{cluster}}(e)$, is required to be smaller than 1.1 in order to reject $Z \to \mu\mu$ events. Opposite-charge lepton-pair events are analyzed in the search for signal events, while events with same-charge lepton pairs are used for estimates of background processes. Quark- or gluon-initiated particle showers (jets) are reconstructed using the anti-k_t algorithm [22,23] with a radius parameter $R = 0.4$. Jets fulfilling $p_T > 20$ GeV and $|\eta| < 2.5$ are identified as containing b hadrons if tagged by a dedicated multivariate algorithm [28]. To ensure the samples of selected events do not overlap with those used in the $\ell\tau_{\text{had}}$ channel, events with a $\tau_{\text{had-vis}}$ candidate are vetoed. The $\tau_{\text{had-vis}}$ candidates reconstructed from jets with a $p_T > 10$ GeV and with one or three associated tracks are selected in $|\eta| < 1.37$ or $1.52 < |\eta| < 2.5$. The $\tau_{\text{had-vis}}$ identification is performed by a recurrent neural network algorithm [25]. A $\tau_{\text{had-vis}}$ candidate is required to have a $p_T > 25$ GeV and pass the *tight* identification selection. The missing transverse momentum ($\boldsymbol{E}_T^{\text{miss}}$) is calculated as the negative $\boldsymbol{p_T}$ sum of all fully reconstructed and calibrated physics objects [29,30]. Additionally, the calculation includes inner detector tracks that originate from the vertex associated with the hard-scattering process but are not associated with any of the reconstructed objects.

The $Z \to \ell\tau \to \ell\ell' + 2\nu$ signal events are characterized by a final state which has two light charged leptons with different flavor and opposite electric charge, two neutrinos, and an invariant mass of all these particles compatible with the Z-boson mass. In most cases, these two leptons are emitted approximately back-to-back in the plane transverse to the proton beam direction. Since the τ lepton is typically boosted due to the large difference between its mass and the mass of its parent Z boson, the two neutrinos from its decay are usually almost collinear with the charged lepton from the τ-lepton decay. The dominant background contribution is from the lepton-flavor-conserving $Z \to \tau\tau \to \ell\ell' + 4\nu$ decays, where the two τ leptons decay leptonically. Subleading background contributions from other SM processes with final states with two prompt leptons include the decays of a top-antitop-quark pair ($t\bar{t}$), two gauge bosons (diboson), or a Higgs boson. Finally, small background contributions come from $Z \to \ell\ell$ decays, where one of the light charged leptons is misidentified with the wrong flavor, and events with "fake leptons." The latter type of background events includes mostly $W(\to \ell\nu) +$ jets events with leptons from heavy-flavor quark decays or with light-quark-initiated jets that are misidentified as electrons or muons. The signal and background events are separated by using a set of selection criteria that define a signal-enhanced sample, referred to as the signal region (SR). The selection criteria are listed in Table I. Three neural network (NN) binary classifiers similar to those used in

TABLE I. Selection criteria for events in the signal region. The invariant transverse mass of ℓ and $\boldsymbol{E}_T^{\text{miss}}$ is defined as $m_T(\ell, \boldsymbol{E}_T^{\text{miss}}) = \sqrt{2p_T(\ell)E_T^{\text{miss}}[1 - \cos(\phi_\ell - \phi_{E_T^{\text{miss}}})]}$.

Selection criterion	Purpose
Exactly two isolated light leptons (ℓ_0, ℓ_1) with opposite electric charge and different flavor (e or μ); $p_T(\ell_0) > p_T(\ell_1)$	Select events consistent with signal decays.
No $\tau_{\text{had-vis}}$ candidate	Complementarity to the $\ell\tau_{\text{had}}$ channel.
Transverse mass $m_T(\ell_1, \boldsymbol{E}_T^{\text{miss}}) < 35$ GeV $\lvert\Delta\phi(\ell_0, \boldsymbol{E}_T^{\text{miss}})\rvert > 1$ rad No b-tagged jets (using the 77% efficiency working point [28])	Reject top-quark and diboson events.
Invariant mass of the ℓ_0-ℓ_1 pair $m(\ell_0, \ell_1) > 40$ GeV	Reject events incompatible with Z-boson decays.
Neural network (optimized for signal vs $Z \to \tau\tau$) output > 0.2	Complementarity to the CRZ$\tau\tau$ region.
In $\mu\tau_e$ channel: $p_T^{\text{track}}(e)/E_T^{\text{cluster}}(e) < 1.1$	Reject $Z \to \mu\mu$ events.

Ref. [9] are trained on simulated events to distinguish signal events from $Z \to \tau\tau$, top-quark pair, and diboson background events individually. The input to these NNs is a mixture of low- and high-level kinematic variables, following the same strategy as in the $\ell\tau_{\text{had}}$ channel [9]. The low-level variables are the momentum components of the reconstructed electron and muon candidates, and the $\boldsymbol{E}_T^{\text{miss}}$. The high-level variables are kinematic properties of the e-μ-E_T^{miss} system, such as the collinear mass $m_{\text{coll}}(e,\mu)$, defined as the invariant mass of the e-μ-2ν system, where the two neutrinos are assumed to have a vectorial momentum sum that is equal in p_T and the azimuthal angle ϕ around the beam axis to the measured $\boldsymbol{E}_T^{\text{miss}}$ and equal in η to the subleading-p_T lepton momentum. The outputs of the individual NNs (NN_i with values between zero and one) are combined into a final discriminant as shown in Eq. (1), hereafter referred to as the "combined NN output":

$$\text{combined NN output} = 1 - \sqrt{\frac{1}{3}\sum_{i=1}^{3}(1-\text{NN}_i)^2}. \quad (1)$$

Events classified by the NN trained for $Z \to \tau\tau$ as backgroundlike are excluded from the SR and used in a control region to better determine the $Z \to \tau\tau$ background in the maximum-likelihood fit (see Table I). The signal acceptance in the SR is 19.5% for the $e\tau_\mu$ channel and 11.2% for the $\mu\tau_e$ channel, as determined from simulated signal samples. The lower acceptance in the $\mu\tau_e$ channel is due to the higher p_T threshold on the subleading-p_T lepton and the additional selection on $p_T^{\text{track}}/E_T^{\text{cluster}}$.

Predictions for signal and background contributions are based partly on Monte Carlo (MC) simulations and partly on estimates from data. Signal and background processes were simulated as in Ref. [9]. The signal events were simulated using PYTHIA8 [32] with matrix elements calculated at leading order (LO) in the strong coupling constant. Nominal signal samples were generated with a parity-conserving $Z\ell\tau$ vertex and unpolarized τ leptons. Scenarios where the decays are maximally parity violating were considered by reweighting the simulated events using TAUSPINNER [33], as discussed in Ref. [9]. The $Z \to \tau\tau$ background events were simulated with the SHERPA2.2.1 [34] generator using the NNPDF 3.0 NNLO PDF set [35] and next-to-leading-order (NLO) matrix elements for up to two partons, and LO matrix elements for up to four partons, calculated with the COMIX [36] and OPENLOOPS [37–39] libraries. Background $Z \to \ell\ell$ events were simulated using the POWHEG-BOX [40] generator with NLO matrix elements. All MC samples include a detailed simulation of the ATLAS detector with GEANT [41,42]. As in Ref. [9], the simulation of Z-boson production is improved through a correction derived from measurements in data. The simulated p_T spectra of the Z boson are reweighted to match the unfolded distribution measured by ATLAS in Ref. [43]. The predicted overall yields of signal and $Z \to \tau\tau$ events are determined by a binned maximum-likelihood fit to the combined data in the SR and in a control region enhanced in $Z \to \tau\tau$ events (CRZ$\tau\tau$). This eliminates the theoretical uncertainties in the total Z-boson production cross section (σ_Z), as well as the experimental uncertainties related to the acceptance of the common $\ell\ell'$ final state. The selection criteria for events in the CRZ$\tau\tau$ are the same as those for events in the SR, except that events are required to be classified as $Z \to \tau\tau$-like, i.e., with an output smaller than 0.2 for the $Z \to \tau\tau$ NN and greater than 0.2 for both the top-quark and diboson NNs. In the $\mu\tau_e$ channel, a small contribution to the total background originates from $Z \to \mu\mu$ events in which one muon is misreconstructed as an electron. Such electron candidates may originate from muons that fail the muon selection requirements and whose tracks are associated with a calorimeter energy cluster and reconstructed as electrons. They may also originate from muons undergoing bremsstrahlung. Such events are modeled with simulation and their predicted yield is based on the measured σ_Z [44]. The modeling is validated in a dedicated region which has the same selection as the $\mu\tau_e$ SR except for the inverse selection on $p_T^{\text{track}}(e)/E_T^{\text{cluster}}(e)$. Based on the observed level of agreement between data and simulation, a systematic uncertainty of 15% is assigned to the predicted yield of $Z \to \mu\mu$ events in the SR, with no further correction.

Events with fake leptons yield a small but still significant background contribution. In most cases, the fake lepton is the subleading one. These events are estimated from data using a "fake-factor method" similar to the one used in Ref. [9]. The fake factor is defined as the ratio $N_{\text{fake}}^{\text{pass-iso}}/N_{\text{fake}}^{\text{fail-iso}}$, where "fake" indicates events with at least one fake lepton and "pass-iso" or "fail-iso" indicate whether the subleading lepton passes or fails the isolation requirement. The fake factor is measured in events with pairs of same-sign leptons (SS). These events are enhanced in $W(\to \ell\nu) + \text{jets}$, which is the dominant source of events with fake leptons in the SR. Events in the SS region pass the same event selections as those in the SR except for a same-charge requirement. The fake factors are measured as functions of the transverse momentum and pseudorapidity of the leptons, separately for $e\tau_\mu$ and $\mu\tau_e$ events. The kinematic properties of events with fake leptons in the SR or in the CRs are estimated by the distributions of events with the subleading lepton failing the isolation requirement, but otherwise satisfying all other selection criteria for that region, multiplied by the fake factor. The total predicted yields of the events with fake leptons in the SR and CRs are instead determined by a combined maximum-likelihood fit to data, separately for $e\tau_\mu$ and $\mu\tau_e$ events. The remaining background processes are estimated using simulations. These backgrounds include events from the production and decay of top quarks [32,40], pairs of gauge bosons [34,35], and the Higgs boson [32,40]. The yield of the

events with top quarks is determined in the maximum-likelihood fit to data via the inclusion of a top-quark control region (CRTop). The selection requirements for the CRTop are the same as for the SR except that at least one b-tagged jet is required. The expected event yields of the remaining processes are determined based on their production cross section, the integrated luminosity, and the simulated selection efficiency.

A statistical analysis of the selected events is performed to assess the presence of signal events, following the same method used in Ref. [9]. A simultaneous binned maximum-likelihood fit to the combined NN output distribution in the SR, the $m_{\text{coll}}(e,\mu)$ distribution in the CRZ$\tau\tau$, and the event yield in CRTop is used to constrain uncertainties in the predictions and extract evidence of a possible signal. The fit is performed independently for the $e\tau$ and $\mu\tau$ channels. The fraction of $Z \to e\tau$ events selected in the $\mu\tau$ channel (and vice versa) is negligible and is therefore neglected. In order to improve the discrimination between signal and the events with fake leptons, the events in the SR are further split into two regions based on the transverse momentum of the subleading-p_T lepton ℓ_1. The low-p_T SR contains events with a $p_T(\ell_1) < 20(25)$ GeV in the $e\tau_\mu$ ($\mu\tau_e$) channel, while the high-p_T SR contains the events above these thresholds. Both SRs in the $e\tau_\mu$ channel have comparable sensitivity, while the low-p_T SR in the $\mu\tau_e$ channel is more sensitive than the high-p_T SR. Both SRs are fitted simultaneously. There are four unconstrained parameters in the fits: the parameter of interest determines the LFV branching fraction $\mathcal{B}(Z \to \ell\tau)$ by modifying an arbitrary prefit signal yield, μ_Z determines σ_Z times the overall acceptance and reconstruction efficiency of the $\ell\ell'$ final state in $Z \to \tau\tau$ and signal events, μ_{top} determines the yield of the top-quark events, and μ_{fakes} determines the yield of the events with fake leptons. Constrained parameters are also introduced to account for systematic uncertainties in the signal and background predictions, as in Ref. [9]. These include uncertainties in simulated events in the modeling of trigger, reconstruction, identification and isolation efficiencies, as well as energy calibrations and resolutions of reconstructed objects. No systematic uncertainties are assigned to the overall yields of events with Z-boson decays, fake leptons, or top quarks as these yields are determined from data. Uncertainties related to events with fake leptons include statistical uncertainties due to the size of the data sample used to measure the fake factors as well as to model their distributions in the SRs and CRs. Systematic uncertainties assigned to events with fake leptons account for: shape differences in the modeling of the combined NN output in the SS events; differences in the composition of the events with fake leptons between SS events and the events in the SRs; and uncertainties affecting the number of events with prompt leptons failing the isolation requirements as estimated by simulation. The dominant uncertainties of the search are statistical in nature.

TABLE II. Summary of the contributions to the uncertainty in the measured $\mathcal{B}(Z \to \ell\tau_{\ell'})$. The uncertainties related to light charged leptons include those in the trigger, reconstruction, identification, and isolation efficiencies, as well as energy calibrations. The uncertainties related to jets and $\boldsymbol{E}_T^{\text{miss}}$ include those in the energy calibration and resolution. The uncertainty in the $Z \to \mu\mu$ yield is only applicable in the $\mu\tau$ channel. The total systematic uncertainty can differ from the sum in quadrature of the different contributions due to correlations among uncertainties as a result of the likelihood fit to data.

	Uncertainty in $\mathcal{B}(Z \to \ell\tau)$ [$\times 10^{-6}$]	
Source of uncertainty	$e\tau$	$\mu\tau$
Statistical	± 3.5	± 3.9
Fake leptons (statistical)	± 0.1	± 0.1
Systematic	± 2.7	± 3.4
Light charged leptons	± 0.4	± 0.4
$\boldsymbol{E}_T^{\text{miss}}$	± 0.4	± 0.8
Jets	± 1.9	± 2.2
Flavor tagging	± 0.5	± 0.9
Z-boson modeling	<0.1	± 0.1
$Z \to \mu\mu$ yield		± 0.8
Other backgrounds	± 0.1	± 0.6
Fake leptons (systematic)	± 0.4	± 0.9
Total	± 4.4	± 5.2

Among the systematic uncertainties, the dominant ones are those in the jet calibration which enter through the calculation of the $\boldsymbol{E}_T^{\text{miss}}$ [24]. A summary of the uncertainties and their impact on the LFV branching fraction is given in Table II.

The observed and best-fit predicted distributions of the combined NN output in the SRs with the highest sensitivity as well as distributions of the collinear mass in the high-p_T SRs are shown in Fig. 1. The best-fit yield of $Z \to \ell\tau$ signal corresponds to the branching fractions $\mathcal{B}(Z \to e\tau) = [-2.6 \pm 3.5(\text{stat}) \pm 2.7(\text{syst})] \times 10^{-6}$ and $\mathcal{B}(Z \to \mu\tau) = [-4.4 \pm 3.9(\text{stat}) \pm 3.4(\text{syst})] \times 10^{-6}$. The best-fit yields of $Z \to \tau\tau$, top quarks, and events with fake leptons are close to the prefit predicted values and are determined with a relative precision of 2%–4%, except the events with fake leptons in the $\mu\tau_e$ channel, which have an uncertainty of 30%. As no significant excess of data over the predicted background is observed, a combined fit of the $\ell\tau_{\ell'}$ and $\ell\tau_{\text{had}}$ channels is used to set upper limits on $\mathcal{B}(Z \to \ell\tau)$. The analysis of the $\ell\tau_{\text{had}}$ channel with Run 2 data [9] uses a similar scheme of regions and unconstrained parameters. In the statistical combination, the parameters of interest are correlated among the different SRs and CRs. The other unconstrained parameters are uncorrelated as these account either for backgrounds specific to each channel or for different acceptances of the $\ell\tau_{\ell'}$ or $\ell\tau_{\text{had}}$ final states. Common systematic uncertainties are correlated, besides those related to the jet energy calibrations, which are uncorrelated.

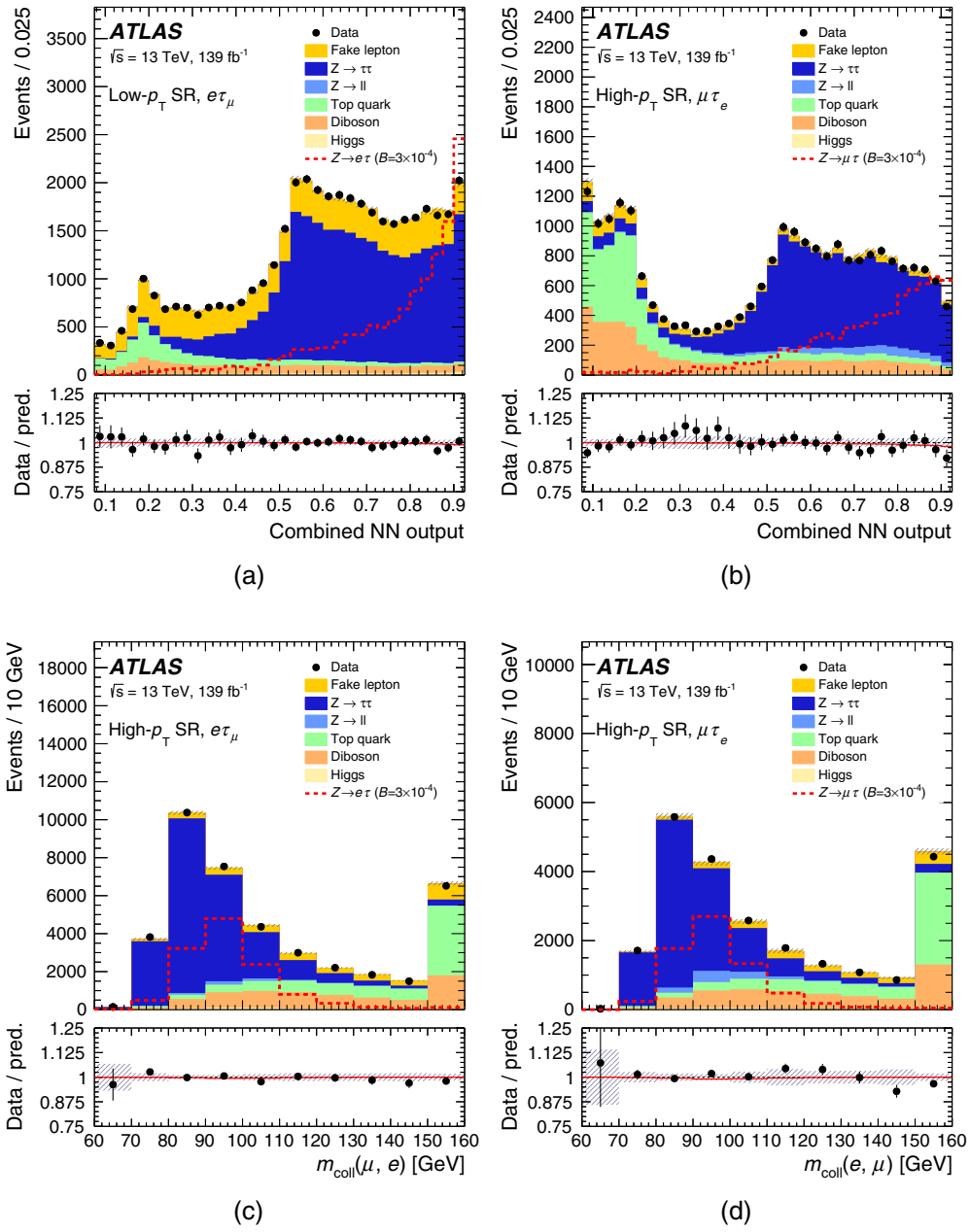

FIG. 1. Observed and best-fit predicted distributions in the SRs. Distributions of the combined NN output are shown in (a) for the low-p_T SR of the $e\tau_\mu$ channel, and in (b) for the high-p_T SR of the $\mu\tau_e$ channel. Distributions of the collinear mass in the high-p_T SR are shown in (c) and (d) for the $e\tau_\mu$ and $\mu\tau_e$ channels, respectively. The expected signal, normalized to an arbitrary $\mathcal{B}(Z \to \ell\tau) = 3 \times 10^{-4}$ for visualization purposes, is shown as a dashed histogram in each plot. In the panel below each plot, the ratios of the observed yield (dots) and the best-fit background-plus-signal yield (solid line) to the best-fit background yield are shown. The hatched uncertainty bands represent one standard deviation of the combined statistical and systematic uncertainties. The first and last bins in each plot include underflow and overflow events, respectively.

This conservative correlation scheme was chosen because of different best-fit values for the parameters associated with these uncertainties in the two channels. However, the fit with correlated jet energy calibration uncertainties yields compatible combined upper limits. The analysis of the $\ell\tau_{\text{had}}$ channel with Run 1 data is combined using the same correlation scheme as in Ref. [9]. The combined best-fit amount of $Z \to \ell\tau$ signal corresponds to the branching fractions $\mathcal{B}(Z \to e\tau) = [-1.4 \pm 2.5(\text{stat}) \pm 1.8(\text{syst})] \times 10^{-6}$ and $\mathcal{B}(Z \to \mu\tau) = [1.7 \pm 2.2(\text{stat}) \pm 1.6(\text{syst})] \times 10^{-6}$.

Since no significant deviation from the SM background hypothesis is observed, exclusion limits are set using the CL_S method [45]. The upper limits are shown in Table III for LFV

TABLE III. Observed and expected (median) upper limits on the signal branching fraction at 95% C.L., in different τ-polarization scenarios.

	Observed (expected) upper limit on $\mathcal{B}(Z \to \ell\tau)$ [$\times 10^{-6}$]	
Final state, polarization assumption	$e\tau$	$\mu\tau$
$\ell\tau_{\text{had}}$ Run 1 + Run 2, unpolarized τ [9]	8.1 (8.1)	9.5 (6.1)
$\ell\tau_{\text{had}}$ Run 2, left-handed τ [9]	8.2 (8.6)	9.5 (6.7)
$\ell\tau_{\text{had}}$ Run 2, right-handed τ [9]	7.8 (7.6)	10 (5.8)
$\ell\tau_{\ell'}$ Run 2, unpolarized τ	7.0 (8.9)	7.2 (10)
$\ell\tau_{\ell'}$ Run 2, left-handed τ	5.9 (7.5)	5.7 (8.5)
$\ell\tau_{\ell'}$ Run 2, right-handed τ	8.4 (11)	9.8 (13)
Combined $\ell\tau$ Run 1 + Run 2, unpolarized τ	5.0 (6.0)	6.5 (5.3)
Combined $\ell\tau$ Run 2, left-handed τ	4.5 (5.7)	5.6 (5.3)
Combined $\ell\tau$ Run 2, right-handed τ	5.4 (6.2)	7.7 (5.3)

decays with different assumptions about the τ-polarization state. The polarization of the τ lepton affects the energy of its visible decay products and thus the acceptance for signal events. In the scenario where the τ leptons are unpolarized, the observed upper limits at 95% C.L. on $\mathcal{B}(Z \to e\tau)$ and $\mathcal{B}(Z \to \mu\tau)$ are 5.0×10^{-6} and 6.5×10^{-6}, respectively.

In conclusion, this Letter reports the first analysis of the $\ell\tau_{\ell'}$ channel in the search for $Z \to \ell\tau$ decays at the LHC. This channel yields a sensitivity similar to the $\ell\tau_{\text{had}}$ channel. With the combined results of the two channels, the ATLAS experiment sets the most stringent constraints on LFV Z-boson decays involving τ leptons to date. The precision of these results is mainly limited by statistical uncertainties.

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(ATLAS Collaboration)

[1]*Department of Physics, University of Adelaide, Adelaide, Australia*
[2]*Department of Physics, University of Alberta, Edmonton AB, Canada*
[3a]*Department of Physics, Ankara University, Ankara, Turkey*
[3b]*Istanbul Aydin University, Application and Research Center for Advanced Studies, Istanbul, Turkey*
[3c]*Division of Physics, TOBB University of Economics and Technology, Ankara, Turkey*
[4]*LAPP, Univ. Savoie Mont Blanc, CNRS/IN2P3, Annecy, France*
[5]*High Energy Physics Division, Argonne National Laboratory, Argonne, Illinois, USA*
[6]*Department of Physics, University of Arizona, Tucson, Arizona, USA*
[7]*Department of Physics, University of Texas at Arlington, Arlington, Arlington, Texas, USA*
[8]*Physics Department, National and Kapodistrian University of Athens, Athens, Greece*
[9]*Physics Department, National Technical University of Athens, Zografou, Greece*
[10]*Department of Physics, University of Texas at Austin, Austin, Texas, USA*
[11a]*Bahcesehir University, Faculty of Engineering and Natural Sciences, Istanbul, Turkey*
[11b]*Istanbul Bilgi University, Faculty of Engineering and Natural Sciences, Istanbul, Turkey*
[11c]*Department of Physics, Bogazici University, Istanbul, Turkey*
[11d]*Department of Physics Engineering, Gaziantep University, Gaziantep, Turkey*
[12]*Institut de Física d'Altes Energies (IFAE), Barcelona Institute of Science and Technology, Barcelona, Spain*
[13a]*Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China*
[13b]*Physics Department, Tsinghua University, Beijing, China*
[13c]*Department of Physics, Nanjing University, Nanjing, China*
[13d]*University of Chinese Academy of Science (UCAS), Beijing, China*
[14]*Institute of Physics, University of Belgrade, Belgrade, Serbia*
[15]*Department for Physics and Technology, University of Bergen, Bergen, Norway*
[16]*Physics Division, Lawrence Berkeley National Laboratory and University of California, Berkeley, California, USA*
[17]*Institut für Physik, Humboldt Universität zu Berlin, Berlin, Germany*
[18]*Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern, Switzerland*
[19]*School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom*
[20a]*Facultad de Ciencias y Centro de Investigaciónes, Universidad Antonio Nariño, Bogotá, Colombia*
[20b]*Departamento de Física, Universidad Nacional de Colombia, Bogotá, Colombia, Colombia*
[21a]*Dipartimento di Fisica e Astronomia A. Righi, Università di Bologna, Bologna, Italy*
[21b]*INFN Sezione di Bologna, Bologna, Italy*
[22]*Physikalisches Institut, Universität Bonn, Bonn, Germany*
[23]*Department of Physics, Boston University, Boston, Massachusetts, USA*
[24]*Department of Physics, Brandeis University, Waltham, Massachusetts, USA*
[25a]*Transilvania University of Brasov, Brasov, Romania*
[25b]*Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest, Romania*
[25c]*Department of Physics, Alexandru Ioan Cuza University of Iasi, Iasi, Romania*
[25d]*National Institute for Research and Development of Isotopic and Molecular Technologies, Physics Department, Cluj-Napoca, Romania*
[25e]*University Politehnica Bucharest, Bucharest, Romania*
[25f]*West University in Timisoara, Timisoara, Romania*
[26a]*Faculty of Mathematics, Physics and Informatics, Comenius University, Bratislava, Slovak Republic*
[26b]*Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice, Slovak Republic*
[27]*Physics Department, Brookhaven National Laboratory, Upton, New York, USA*
[28]*Departamento de Física (FCEN) and IFIBA, Universidad de Buenos Aires and CONICET, Buenos Aires, Argentina*
[29]*California State University, Fresno, California, USA*
[30]*Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom*
[31a]*Department of Physics, University of Cape Town, Cape Town, South Africa*
[31b]*iThemba Labs, Western Cape, South Africa*
[31c]*Department of Mechanical Engineering Science, University of Johannesburg, Johannesburg, South Africa*
[31d]*National Institute of Physics, University of the Philippines Diliman, Philippines*
[31e]*University of South Africa, Department of Physics, Pretoria, South Africa*

[31f]School of Physics, University of the Witwatersrand, Johannesburg, South Africa
[32]Department of Physics, Carleton University, Ottawa ON, Canada
[33a]Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies—Université Hassan II, Casablanca, Morocco
[33b]Faculté des Sciences, Université Ibn-Tofail, Kénitra, Morocco
[33c]Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA-Marrakech, Morocco
[33d]LPMR, Faculté des Sciences, Université Mohamed Premier, Oujda, Morocco
[33e]Faculté des sciences, Université Mohammed V, Rabat, Morocco
[33f]Mohammed VI Polytechnic University, Ben Guerir, Morocco
[34]CERN, Geneva, Switzerland
[35]Enrico Fermi Institute, University of Chicago, Chicago, Illinois, USA
[36]LPC, Université Clermont Auvergne, CNRS/IN2P3, Clermont-Ferrand, France
[37]Nevis Laboratory, Columbia University, Irvington, New York, USA
[38]Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark
[39a]Dipartimento di Fisica, Università della Calabria, Rende, Italy
[39b]INFN Gruppo Collegato di Cosenza, Laboratori Nazionali di Frascati, Italy
[40]Physics Department, Southern Methodist University, Dallas, Texas, USA
[41]Physics Department, University of Texas at Dallas, Richardson, Texas, USA
[42]National Centre for Scientific Research "Demokritos", Agia Paraskevi, Greece
[43a]Department of Physics, Stockholm University, Sweden
[43b]Oskar Klein Centre, Stockholm, Stockholm, Sweden
[44]Deutsches Elektronen-Synchrotron DESY, Hamburg and Zeuthen, Germany
[45]Lehrstuhl für Experimentelle Physik IV, Technische Universität Dortmund, Dortmund, Germany
[46]Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden, Germany
[47]Department of Physics, Duke University, Durham, North Carolina, USA
[48]SUPA—School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom
[49]INFN e Laboratori Nazionali di Frascati, Frascati, Italy
[50]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany
[51]II. Physikalisches Institut, Georg-August-Universität Göttingen, Göttingen, Germany
[52]Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève, Switzerland
[53a]Dipartimento di Fisica, Università di Genova, Genova, Italy
[53b]INFN Sezione di Genova, Genova, Italy
[54]II. Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen, Germany
[55]SUPA—School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom
[56]LPSC, Université Grenoble Alpes, CNRS/IN2P3, Grenoble INP, Grenoble, France
[57]Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge, Massachusetts, USA
[58a]Department of Modern Physics and State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei, China
[58b]Institute of Frontier and Interdisciplinary Science and Key Laboratory of Particle Physics and Particle Irradiation (MOE), Shandong University, Qingdao, China
[58c]School of Physics and Astronomy, Shanghai Jiao Tong University, Key Laboratory for Particle Astrophysics and Cosmology (MOE), SKLPPC, Shanghai, China
[58d]Tsung-Dao Lee Institute, Shanghai, China
[59a]Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany
[59b]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany
[60a]Department of Physics, Chinese University of Hong Kong, Shatin, N.T., Hong Kong, China
[60b]Department of Physics, University of Hong Kong, Hong Kong, China
[60c]Department of Physics and Institute for Advanced Study, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China
[61]Department of Physics, National Tsing Hua University, Hsinchu, Taiwan
[62]IJCLab, Université Paris-Saclay, CNRS/IN2P3, 91405, Orsay, France
[63]Department of Physics, Indiana University, Bloomington, Indiana, USA
[64a]INFN Gruppo Collegato di Udine, Sezione di Trieste, Udine, Italy
[64b]ICTP, Trieste, Italy
[64c]Dipartimento Politecnico di Ingegneria e Architettura, Università di Udine, Udine, Italy
[65a]INFN Sezione di Lecce, Lecce, Italy
[65b]Dipartimento di Matematica e Fisica, Università del Salento, Lecce, Italy
[66a]INFN Sezione di Milano, Milano, Italy
[66b]Dipartimento di Fisica, Università di Milano, Milano, Italy
[67a]INFN Sezione di Napoli,Napoli, Italy

[67b]Dipartimento di Fisica, Università di Napoli, Napoli, Italy
[68a]INFN Sezione di Pavia, Pavia, Italy
[68b]Dipartimento di Fisica, Università di Pavia, Pavia, Italy
[69a]INFN Sezione di Pisa, Pisa, Italy
[69b]Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy
[70a]INFN Sezione di Roma, Roma, Italy
[70b]Dipartimento di Fisica, Sapienza Università di Roma, Roma, Italy
[71a]INFN Sezione di Roma Tor Vergata, Roma, Italy
[71b]Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy
[72a]INFN Sezione di Roma Tre, Roma, Italy
[72b]Dipartimento di Matematica e Fisica, Università Roma Tre, Roma, Italy
[73a]INFN-TIFPA, Trento, Italy
[73b]Università degli Studi di Trento, Trento, Italy
[74]Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck, Austria
[75]University of Iowa, Iowa City, Iowa, USA
[76]Department of Physics and Astronomy, Iowa State University, Ames, Iowa, USA
[77]Joint Institute for Nuclear Research, Dubna, Russia
[78a]Departamento de Engenharia Elétrica, Universidade Federal de Juiz de Fora (UFJF), Juiz de Fora, Brazil
[78b]Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro, Brazil
[78c]Instituto de Física, Universidade de São Paulo, São Paulo, Brazil
[79]KEK, High Energy Accelerator Research Organization, Tsukuba, Japan
[80]Graduate School of Science, Kobe University, Kobe, Japan
[81a]AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, Krakow, Poland
[81b]Marian Smoluchowski Institute of Physics, Jagiellonian University, Krakow, Poland
[82]Institute of Nuclear Physics Polish Academy of Sciences, Krakow, Poland
[83]Faculty of Science, Kyoto University, Kyoto, Japan
[84]Kyoto University of Education, Kyoto, Japan
[85]Research Center for Advanced Particle Physics and Department of Physics, Kyushu University, Fukuoka, Japan
[86]Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina
[87]Physics Department, Lancaster University, Lancaster, United Kingdom
[88]Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom
[89]Department of Experimental Particle Physics, Jožef Stefan Institute and Department of Physics, University of Ljubljana, Ljubljana, Slovenia
[90]School of Physics and Astronomy, Queen Mary University of London, London, United Kingdom
[91]Department of Physics, Royal Holloway University of London, Egham, United Kingdom
[92]Department of Physics and Astronomy, University College London, London, United Kingdom
[93]Louisiana Tech University, Ruston, Louisiana, USA
[94]Fysiska institutionen, Lunds universitet, Lund, Sweden
[95]Centre de Calcul de l'Institut National de Physique Nucléaire et de Physique des Particules (IN2P3), Villeurbanne, France
[96]Departamento de Física Teorica C-15 and CIAFF, Universidad Autónoma de Madrid, Madrid, Spain
[97]Institut für Physik, Universität Mainz, Mainz, Germany
[98]School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom
[99]CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille, France
[100]Department of Physics, University of Massachusetts, Amherst, Massachusetts, USA
[101]Department of Physics, McGill University, Montreal QC, Canada
[102]School of Physics, University of Melbourne, Victoria, Australia
[103]Department of Physics, University of Michigan, Ann Arbor, Michigan, USA
[104]Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan, USA
[105]B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Belarus
[106]Research Institute for Nuclear Problems of Byelorussian State University, Minsk, Belarus
[107]Group of Particle Physics, University of Montreal, Montreal QC, Canada
[108]P.N. Lebedev Physical Institute of the Russian Academy of Sciences, Moscow, Russia
[109]National Research Nuclear University MEPhI, Moscow, Russia
[110]D.V. Skobeltsyn Institute of Nuclear Physics, M.V. Lomonosov Moscow State University, Moscow, Russia
[111]Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany
[112]Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany
[113]Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya, Japan
[114]Department of Physics and Astronomy, University of New Mexico, Albuquerque, New Mexico, USA
[115]Institute for Mathematics, Astrophysics and Particle Physics, Radboud University/Nikhef, Nijmegen, Netherlands
[116]Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands

[117]Department of Physics, Northern Illinois University, DeKalb, Illinois, USA
[118a]Budker Institute of Nuclear Physics and NSU, SB RAS, Novosibirsk, Russia
[118b]Novosibirsk State University Novosibirsk, Novosibirsk, Russia
[119]Institute for High Energy Physics of the National Research Centre Kurchatov Institute, Protvino, Russia
[120]Institute for Theoretical and Experimental Physics named by A.I. Alikhanov of National Research Centre "Kurchatov Institute", Moscow, Russia
[121]Department of Physics, New York University, New York, New York, USA
[122]Ochanomizu University, Otsuka, Bunkyo-ku, Tokyo, Japan
[123]Ohio State University, Columbus, Ohio, USA
[124]Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman, Oklahoma, USA
[125]Department of Physics, Oklahoma State University, Stillwater, Oklahoma, USA
[126]Palacký University, Joint Laboratory of Optics, Olomouc, Czech Republic
[127]Institute for Fundamental Science, University of Oregon, Eugene, Oregon, USA
[128]Graduate School of Science, Osaka University, Osaka, Japan
[129]Department of Physics, University of Oslo, Oslo, Norway
[130]Department of Physics, Oxford University, Oxford, United Kingdom
[131]LPNHE, Sorbonne Université, Université de Paris, CNRS/IN2P3, Paris, France
[132]Department of Physics, University of Pennsylvania, Philadelphia, Pennsylvania, USA
[133]Konstantinov Nuclear Physics Institute of National Research Centre "Kurchatov Institute", PNPI, St. Petersburg, Russia
[134]Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, Pennsylvania, USA
[135a]Laboratório de Instrumentação e Física Experimental de Partículas—LIP, Lisboa, Portugal
[135b]Departamento de Física, Faculdade de Ciências, Universidade de Lisboa, Lisboa, Portugal
[135c]Departamento de Física, Universidade de Coimbra, Coimbra, Portugal
[135d]Centro de Física Nuclear da Universidade de Lisboa, Lisboa, Portugal
[135e]Departamento de Física, Universidade do Minho, Braga, Portugal
[135f]Departamento de Física Teórica y del Cosmos, Universidad de Granada, Granada (Spain), Spain
[135g]Dep Física and CEFITEC of Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Caparica, Portugal
[135h]Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal
[136]Institute of Physics of the Czech Academy of Sciences, Prague, Czech Republic
[137]Czech Technical University in Prague, Prague, Czech Republic
[138]Charles University, Faculty of Mathematics and Physics, Prague, Czech Republic
[139]Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom
[140]IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France
[141]Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz, California, USA
[142a]Departamento de Física, Pontificia Universidad Católica de Chile, Santiago, Chile
[142b]Universidad Andres Bello, Department of Physics, Santiago, Chile
[142c]Instituto de Alta Investigación, Universidad de Tarapacá, Arica, Chile
[142d]Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile
[143a]Universidade Federal de São João del Rei (UFSJ), São João del Rei, Brazil
[143b]Universidad de la Serena, La Serena, Chile
[144]Department of Physics, University of Washington, Seattle, Washington, USA
[145]Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom
[146]Department of Physics, Shinshu University, Nagano, Japan
[147]Department Physik, Universität Siegen, Siegen, Germany
[148]Department of Physics, Simon Fraser University, Burnaby BC, Canada
[149]SLAC National Accelerator Laboratory, Stanford, California, USA
[150]Department of Physics, Royal Institute of Technology, Stockholm, Sweden
[151]Departments of Physics and Astronomy, Stony Brook University, Stony Brook, New York, USA
[152]Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom
[153]School of Physics, University of Sydney, Sydney, Australia
[154]Institute of Physics, Academia Sinica, Taipei, Taiwan
[155a]E. Andronikashvili Institute of Physics, Iv. Javakhishvili Tbilisi State University, Tbilisi, Georgia
[155b]High Energy Physics Institute, Tbilisi State University, Tbilisi, Georgia
[156]Department of Physics, Technion, Israel Institute of Technology, Haifa, Israel
[157]Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel
[158]Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece
[159]International Center for Elementary Particle Physics and Department of Physics, University of Tokyo, Tokyo, Japan
[160]Department of Physics, Tokyo Institute of Technology, Tokyo, Japan
[161]Tomsk State University, Tomsk, Russia
[162]Department of Physics, University of Toronto, Toronto ON, Canada

[163a]TRIUMF, Vancouver BC, Canada
[163b]Department of Physics and Astronomy, York University, Toronto ON, Canada
[164]Division of Physics and Tomonaga Center for the History of the Universe, Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba, Japan
[165]Department of Physics and Astronomy, Tufts University, Medford, Massachusetts, USA
[166]Department of Physics and Astronomy, University of California Irvine, Irvine, California, USA
[167]Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden
[168]Department of Physics, University of Illinois, Urbana, Illinois, USA
[169]Instituto de Física Corpuscular (IFIC), Centro Mixto Universidad de Valencia—CSIC, Valencia, Spain
[170]Department of Physics, University of British Columbia, Vancouver BC, Canada
[171]Department of Physics and Astronomy, University of Victoria, Victoria BC, Canada
[172]Fakultät für Physik und Astronomie, Julius-Maximilians-Universität Würzburg, Würzburg, Germany
[173]Department of Physics, University of Warwick, Coventry, United Kingdom
[174]Waseda University, Tokyo, Japan
[175]Department of Particle Physics and Astrophysics, Weizmann Institute of Science, Rehovot, Israel
[176]Department of Physics, University of Wisconsin, Madison, Wisconsin, USA
[177]Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal, Germany
[178]Department of Physics, Yale University, New Haven, Connecticut, USA

[a]Deceased.
[b]Also at Department of Physics, King's College London, London, United Kingdom.
[c]Also at Istanbul University, Dept. of Physics, Istanbul, Turkey.
[d]Also at Instituto de Fisica Teorica, IFT-UAM/CSIC, Madrid, Spain.
[e]Also at TRIUMF, Vancouver BC, Canada.
[f]Also at Department of Physics, University of Fribourg, Fribourg, Switzerland.
[g]Also at Department of Physics and Astronomy, University of Louisville, Louisville, Kentucky, USA.
[h]Also at Departament de Fisica de la Universitat Autonoma de Barcelona, Barcelona, Spain.
[i]Also at Moscow Institute of Physics and Technology State University, Dolgoprudny, Russia.
[j]Also at Faculty of Physics, Sofia University, 'St. Kliment Ohridski', Sofia, Bulgaria.
[k]Also at Department of Physics, Ben Gurion University of the Negev, Beer Sheva, Israel.
[l]Also at Universita di Napoli Parthenope, Napoli, Italy.
[m]Also at Institute of Particle Physics (IPP), Victoria, Canada.
[n]Also at Bruno Kessler Foundation, Trento, Italy.
[o]Also at Department of Physics, St. Petersburg State Polytechnical University, St. Petersburg, Russia.
[p]Also at Borough of Manhattan Community College, City University of New York, New York, New York, USA.
[q]Also at Department of Physics, California State University, Fresno, USA.
[r]Also at Department of Financial and Management Engineering, University of the Aegean, Chios, Greece.
[s]Also at Centro Studi e Ricerche Enrico Fermi, Rome, Italy.
[t]Also at Department of Physics, California State University, East Bay, USA.
[u]Also at Institucio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona, Spain.
[v]Also at Graduate School of Science, Osaka University, Osaka, Japan.
[w]Also at Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany.
[x]Also at University of Chinese Academy of Sciences (UCAS), Beijing, China.
[y]Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan.
[z]Also at Yeditepe University, Physics Department, Istanbul, Turkey.
[aa]Also at CERN, Geneva, Switzerland.
[bb]Also at Joint Institute for Nuclear Research, Dubna, Russia.
[cc]Also at Hellenic Open University, Patras, Greece.
[dd]Also at Center for High Energy Physics, Peking University, China.
[ee]Also at The City College of New York, New York, New York, USA.
[ff]Also at Department of Physics, California State University, Sacramento, USA.
[gg]Also at Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève, Switzerland.
[hh]Also at Faculty of Physics, M.V. Lomonosov Moscow State University, Moscow, Russia.
[ii]Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany.
[jj]Also at CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille, France.
[kk]Also at Institute for Particle and Nuclear Physics, Wigner Research Centre for Physics, Budapest, Hungary.
[ll]Also at Giresun University, Faculty of Engineering, Giresun, Turkey.
[mm]Also at Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan, USA.
[nn]Also at Institute of Theoretical Physics, Ilia State University, Tbilisi, Georgia.