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# Search for new phenomena in final states with two leptons and one or no $b$ -tagged jets at $\sqrt{s} = 13$ TeV using the ATLAS detector

The ATLAS Collaboration

A search for new phenomena is presented in final states with two leptons and one or no  $b$ -tagged jets. The event selection requires the two leptons to have opposite charge, the same flavor (electrons or muons), and a large invariant mass. The analysis is based on the full Run-2 proton–proton collision dataset recorded at a center-of-mass energy of  $\sqrt{s} = 13$  TeV by the ATLAS experiment at the LHC, corresponding to an integrated luminosity of  $139 \text{ fb}^{-1}$ . No significant deviation from the expected background is observed in the data. A four-fermion contact interaction between two quarks ( $b, s$ ) and two leptons ( $ee$  or  $\mu\mu$ ), inspired by the  $B$ -meson decay anomalies, is used as a benchmark signal model. This model is characterized by the energy scale and coupling,  $\Lambda$  and  $g_*$  respectively. Contact interactions with  $\Lambda/g_*$  lower than 2.0 (2.4) TeV are excluded for electrons (muons) at the 95% confidence level, still far below the value which is favored by the  $B$ -meson decay anomalies. In addition, model-independent limits are set as a function of the selection on the dilepton invariant mass, which allows the results to be reinterpreted in other signal scenarios.

Lepton flavor universality (LFU) is one of the fundamental predictions of the Standard Model (SM). LFU was tested extensively at LEP and SLD [1], and found to be compatible with the SM prediction. Several recent measurements hint at a possible violation of LFU in rare  $B$ -meson decays [2–13] into a  $K$ -meson and a pair of muons or electrons. Possible extensions to the SM suggest that the decay mechanism implies that physics beyond the SM (BSM) is present between the initial common state ( $b$ -quark) and the final state ( $s$ -quark and two charged electrons or muons). The BSM interaction can be modeled by using an effective field theory (EFT) with a four-point contact interaction between the common fermions involved ( $bs\ell\ell$ ,  $\ell = e, \mu$ ), where the scale and coupling of the underlying physics are denoted by  $\Lambda$  and  $g_*$ , respectively,<sup>1</sup> and can be searched for in final states with two opposite-charge and same-flavor leptons produced in association with exactly one  $b$ -quark or without any  $b$ -quarks. To explain the asymmetries measured in the  $B$ -meson decays, the  $bs\ell\ell$  interaction would have to be different between electrons and muons. At tree level, there is no interference with the SM, and therefore it is neglected. The phenomenological framework for this analysis was suggested in Ref. [15]. The associated  $B$ -meson decay anomalies could correspond to a  $bs\ell\ell$  operator with  $\Lambda/g_* \approx 30$  TeV [16, 17], which is well beyond the discovery reach of the present search. Furthermore, other works showed that this unique signature provides enhanced sensitivity to other signal scenarios as well [14, 18]. Figure 1 shows Feynman diagrams for  $B$ -meson decays via the SM and via a  $bs\ell\ell$  contact interaction, and for the production process via a  $bs\ell\ell$  contact interaction in proton–proton ( $pp$ ) collisions.

In this Letter, a search for new phenomena is presented, using  $pp$  collisions at a center-of-mass energy of  $\sqrt{s} = 13$  TeV produced by the Large Hadron Collider (LHC). Data recorded by the ATLAS detector [19] during 2015–2018 are used, corresponding to an integrated luminosity of  $139 \text{ fb}^{-1}$ . Final states with two oppositely charged electrons or muons are considered separately, and further categorized into events with either no  $b$ -tagged jets or exactly one  $b$ -tagged jet. The  $bs\ell\ell$  EFT is considered as a benchmark model, and model-independent results are also presented.

The ATLAS experiment at the LHC is a multipurpose particle detector with a forward–backward symmetric cylindrical geometry and a near  $4\pi$  coverage in solid angle.<sup>2</sup> It consists of an inner tracking detector surrounded by a thin superconducting solenoid providing a 2 T axial magnetic field, electromagnetic and hadronic calorimeters, and a muon spectrometer. The inner tracking detector (ID) covers the pseudorapidity range  $|\eta| < 2.5$ . It consists of silicon pixel, silicon microstrip, and transition radiation tracking detectors, with a new innermost layer, the insertable B-layer, added to the pixel detector before Run 2 [20, 21]. Lead/liquid-argon (LAr) sampling calorimeters provide electromagnetic (EM) energy measurements with high granularity. A steel/scintillator-tile hadronic calorimeter covers the central pseudorapidity range ( $|\eta| < 1.7$ ). The endcap and forward regions are instrumented with LAr calorimeters for EM and hadronic energy measurements up to  $|\eta| = 4.9$ . The muon spectrometer (MS) surrounds the calorimeters and is based on three large air-core toroidal superconducting magnets with eight coils each. The field integral of the toroids ranges between 2.0 and 6.0 T m across most of the detector. The muon spectrometer includes a system of precision tracking chambers and fast detectors for triggering.

Monte Carlo (MC) simulations are used to model the expected SM background and the benchmark signals. The POWHEG Box v1 MC generator [22–25] was used to simulate at next-to-leading-order (NLO) accuracy

<sup>1</sup> For a discussion regarding the validity of the EFT parameter space see e.g. Ref. [14].

<sup>2</sup> ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the center of the detector and the  $z$ -axis along the beam pipe. The  $x$ -axis points from the IP to the center of the LHC ring, and the  $y$ -axis points upwards. Cylindrical coordinates ( $r, \phi$ ) are used in the transverse plane,  $\phi$  being the azimuthal angle around the  $z$ -axis. The pseudorapidity is defined in terms of the polar angle  $\theta$  as  $\eta = -\ln \tan(\theta/2)$ . Angular distance is measured in units of  $\Delta R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$ . The transverse momentum is defined as  $p_T = p \sin \theta = p/\cosh \eta$ , and the transverse energy,  $E_T$ , is defined analogously.

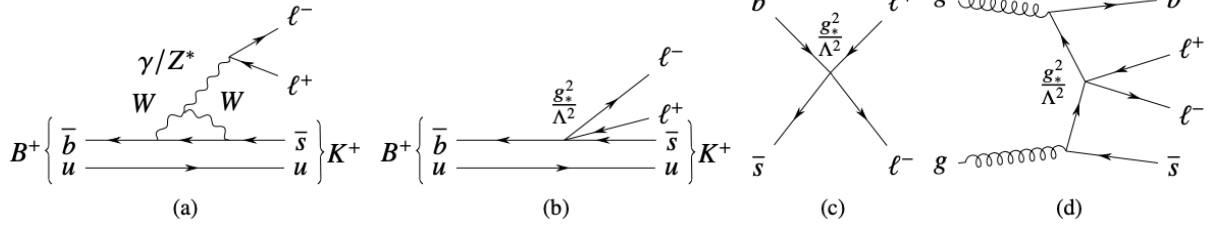


Figure 1: Representative Feynman diagrams for the decay of a  $B^+$  meson to a  $K^+$  meson in association with two leptons (a) in the SM and (b) in the EFT approach, and for production of two leptons via a  $bs\ell\ell$  contact interaction in  $pp$  collisions (c) without and (d) with a  $b$ -jet in the final state.

in perturbative QCD the hard-scattering process of  $Z/\gamma^*$ -boson production and decay. It was interfaced to PYTHIA 8.186 to model the parton shower, hadronization, and underlying event, with parameters set according to the AZNLO tune [26]. The CT10 parton distribution function (PDF) set [27] was used for the hard scattering process, whereas the CTEQ6L1 PDF set [28] was used for the parton shower. The effect of QED final-state radiation (FSR) was simulated with Photos++ 3.52 [29, 30]. The use of POWHEG BOX was validated by a generator-level comparison with a sample produced by SHERPA 2.2.1 [31] using NLO matrix elements for up to two partons, and leading-order (LO) matrix elements for up to four partons calculated with the Comix [32] and OPENLOOPS 1 [33–35] libraries. Samples of diboson ( $W$ -boson) events, denoted by  $VV$  ( $W$ +jets), were simulated with SHERPA 2.2.2 (2.2.1) [31] using matrix elements at NLO accuracy in QCD with up to one (two) additional partons and up to three (four) additional parton emissions at LO, while additional corrections were calculated using the Comix [32] and OPENLOOPS 1 [33–35] libraries. The NNPDF3.0nnlo set of PDFs [36] was used for  $VV$  and  $W$ +jets productions. For both  $VV$  and  $W$ +jets, the matrix elements were matched with the SHERPA parton shower [37] using the MEPS@NLO prescription [38–41] and the parameter tune developed by the SHERPA authors. The  $W$ +jets samples were normalized to a next-to-next-to-leading-order (NNLO) prediction [42]. The production of  $t\bar{t}$  and single-top-quark  $Wt$  events was modeled using the POWHEG BOX v2 generator at NLO with the NNPDF3.0nnlo PDF set, and the  $h_{\text{damp}}$  parameter set to  $1.5m_{\text{top}}$ . Events were interfaced to PYTHIA 8.230 [43] to model the parton shower, hadronization, and underlying event, using the A14 parameter tune [44] and the NNPDF2.3lo set of PDFs. For  $Wt$  events, the diagram removal scheme [45] was used to remove interference with  $t\bar{t}$  production. The production of  $t\bar{t}V$  events was modeled using the MADGRAPH5\_aMC@NLO v2.3.3 [46] generator at NLO with the NNPDF3.0nnlo PDF set. The events were interfaced to PYTHIA 8.210 using the A14 tune and the NNPDF2.3lo PDF set. The EVTGEN 1.2.0 (1.6.0) program [47] was used to decay bottom and charm hadrons for the  $t\bar{t}V$  and  $Z/\gamma^*$  ( $t\bar{t}$ ) processes. The  $bs\ell\ell$  EFT signal was generated at LO with up to two partons in the final state by MADGRAPH5\_aMC@NLO with the NNPDF2.3lo PDF set and the A14 tune of PYTHIA 8 parameters, using the CKKW-L merging algorithm [48] with a  $k_t$ -Durham parameter of 400 GeV. A model provided by the authors of Ref. [15] was used.<sup>3</sup> The cross section for the simulated signal with  $\Lambda/g_* = 1$  TeV is 0.113 pb, for both electrons and muons. The ATLAS detector response was simulated with GEANT4 [49, 50], except for signal samples, where a fast simulation [51] was used. The effect of multiple interactions in the same and neighboring bunch crossings (pileup) was modeled by overlaying simulated inelastic  $pp$  events generated by PYTHIA 8.186 [52] with the A3 tune [53] and the NNPDF2.3lo PDF set [36]. All MC distributions were reweighted so that the distribution of the average number of interactions per bunch crossing corresponds to the distribution in data.

Only events taken during stable beam conditions, and for which all relevant components of the detector

<sup>3</sup> The model can be found at the FeynRules database: <http://feynrules.irmp.ucl.ac.be/wiki/FCNC4F>.

were operational, are considered. Single-lepton triggers were used [54, 55], with  $p_T$  threshold of 60 GeV or 140 GeV for electrons, depending on the identification requirement, and 50 GeV for muons. Selected events must have a primary vertex with at least two tracks with a minimum  $p_T$  of 500 MeV, where the highest  $\sum_{\text{tracks}} p_T^2$  vertex is chosen as the primary one [56].

Electrons are reconstructed [57] from energy clusters in the electromagnetic calorimeter with ID tracks matched to them, and are required to fulfill the “tight likelihood” identification criteria as well as calorimeter- and track-based isolation criteria. Electrons must have a minimum transverse energy of 30 GeV, and must be within the region  $|\eta_{\text{cluster}}| < 2.47$ , excluding the barrel/endcap transition region,  $1.37 < |\eta_{\text{cluster}}| < 1.52$ . Muons are reconstructed [58] from combined tracks in the MS and the ID with a minimum  $p_T$  of 30 GeV, must fulfill the “high- $p_T$ ” identification criteria, which aim to optimize the momentum resolution for tracks with high transverse momentum, and must be within the region  $|\eta| < 2.5$ . For muons, track-based isolation criteria are required based on the scalar sum of the transverse momenta of the ID tracks associated with the primary vertex, excluding the muon track itself. Muon (electron) candidates are required to originate from the primary vertex by requiring the significance of the track’s transverse impact parameter calculated relative to the beam line,  $d_0/\sigma(d_0)$ , to be smaller than 3.0 (5.0). Furthermore, the longitudinal impact parameter  $z_0$ , defined as the difference between the  $z$ -coordinate of the point of closest approach to the beam line and the longitudinal position of the primary vertex, is required to satisfy  $|z_0 \sin(\theta)| < 0.5$  mm. Jets are reconstructed from energy deposits in topological clusters of calorimeter cells [59] with the particle-flow algorithm [60, 61], with a radius parameter of 0.4, with energy calibrated at particle level [62] and are required to be within  $|\eta| < 2.5$  and to have a minimum  $p_T$  of 30 GeV. For jets with  $|\eta| < 2.4$  and  $p_T < 60$  GeV, pileup contributions are suppressed by the use of the jet vertex tagger [63]. Jets are identified as containing  $b$ -hadrons using the DL1 algorithm [64, 65], with a  $b$ -tagging efficiency of  $\sim 77\%$  for  $b$ -jets, and a rejection factor of  $\sim 6$  for  $c$ -jets and  $\sim 110$  for other light jets, based on simulated  $t\bar{t}$  events. Finally, a sequential overlap-removal procedure is used, since a physics object can be reconstructed as several object types. The procedure is as follows: in the first step, electrons that share a track with a muon are removed; in the second step, any jet that has a  $\Delta R$  to an electron that is smaller than 0.2 is removed; and in the third step, electrons are removed if they are geometrically closer than  $\Delta R = 0.4$  to any remaining jet. Jets that have a  $\Delta R < 0.04 + 10 \text{ GeV}/p_T(\mu)$  to a muon are removed if they have at most two associated tracks with  $p_T(\text{track}) > 0.5$  GeV, otherwise the muon is removed.

Events are selected by requiring the presence of two same-flavor leptons (electrons or muons) with opposite electric charge, where at least one of the leptons is required to geometrically match the object which fired the trigger. To ensure high trigger efficiency, the  $p_T$  threshold for the leading lepton is raised to 65 GeV. Those selections are common to all of the regions defined in the analysis. Two channels are defined depending on the presence of a  $b$ -tagged jet, targeting two different production mechanisms. The  $b$ -veto category, also denoted by  $e^+e^-/\mu^+\mu^- + 0b$ , discards any event with a  $b$ -tagged jet, while the  $b$ -tag category, also denoted by  $e^+e^-/\mu^+\mu^- + 1b$ , requires exactly one  $b$ -tagged jet in each event. A set of signal regions (SRs) is defined with lower bounds on  $m_{\ell\ell}$ ,  $m_{\ell\ell}^{\min}$ , ranging from 400 GeV to 3200 (2000) GeV for the  $b$ -veto ( $b$ -tag) category with a step size of 100 GeV, where each SR is defined by requiring  $m_{\ell\ell} > m_{\ell\ell}^{\min}$ . Control regions (CR) are defined in order to normalize the contribution of the two dominant background processes originating from  $t\bar{t}$ ,  $Wt$  and  $t\bar{t}V$ , together denoted by “Top”, and  $Z/\gamma^* + \text{jets}$  processes. The  $Z/\gamma^* + \text{jets}$  CRs (Z-CRs) are defined by requiring events to be within  $130 \text{ GeV} < m_{\ell\ell} < 250 \text{ GeV}$ , while the intermediate mass range,  $250 \text{ GeV} < m_{\ell\ell} < 400 \text{ GeV}$ , serves as a validation region (VR) to test the background modeling. For each Z-CR and VR the same splitting based on the presence of  $b$ -tagged jets as in the SRs is applied. Finally, a top-CR is constructed by requiring exactly two  $b$ -tagged jets and the dilepton invariant mass to satisfy  $m_{\ell\ell} > 130$  GeV.

The regime with high invariant mass of the dilepton system,  $m_{\ell\ell}$ , in the Top background processes, suffers from having few events in the MC simulation. A fit-based extrapolation procedure is used to estimate the tails of the Top  $m_{\ell\ell}$  distributions with functions which have been used in other ATLAS searches [66]:

$$f^{\text{bkg1}}(m_{\ell\ell}) = e^{-a} m_{\ell\ell}^b m_{\ell\ell}^{c \log(m_{\ell\ell})} \quad \text{and} \quad f^{\text{bkg2}}(m_{\ell\ell}) = \frac{a}{(m_{\ell\ell} + b)^c},$$

where  $a, b, c$  are free parameters. Several fits are performed by using both functions, while varying the start and end point of the fit range. A  $\chi^2$  test is performed in order to describe the level of agreement between the different fits and the MC prediction. The fit with the lowest  $\chi^2$  provides the nominal choice of the function parameters values while all other fits with  $\chi^2$  probability smaller than a fixed value are used for the uncertainty estimation. This fixed value is chosen such that near the transition point between the simulation and the extrapolation, the overall uncertainty accounted by the experimental and modeling systematic along with the MC statistic uncertainties on the simulated background, are similar to the resulting uncertainty on the extrapolation. Furthermore, checks are performed in order to make sure that the fitted function reproduces the MC event yields at lower values of  $m_{\ell\ell}$  and that the cumulative distribution of the extrapolation is consistent with the small integrated event yields available in the MC samples. Finally, since the extrapolation is done for the combined Top sample, which includes all top-related processes, it was checked that those processes have a similar  $m_{\ell\ell}$  shape within uncertainties. For the Top background extrapolation, the transition points between simulation and extrapolation in the  $m_{\ell\ell}$  distribution are (1000, 1200, 1200/1300) GeV for the (0, 1, 2)- $b$ -tagged jets selections, respectively, in the electron/muon channels.

The background contribution of events with reconstructed objects which have been misidentified as leptons, referred to as ‘‘Multijet’’, is estimated using a data-driven approach. In the muon channel, this contribution is found to be negligible, while in the electron channel it is on the order of a few percent of the total background estimate. The matrix-method is used for the electron channel, similarly to the procedure described in Ref. [67]. The probabilities that a jet and a real electron satisfy the electron identification criteria are evaluated, for both the nominal and the ‘‘loose likelihood’’ identification criteria, while for the former no isolation criteria are applied. Then, these probabilities are used in order to estimate the Multijet contribution in the selected region. The Multijet background estimation suffers from having few events at high  $m_{\ell\ell}$ , and an extrapolation procedure similar to that for Top processes is used, with transition points at (800, 600, 600) GeV for the (0, 1, 2)- $b$ -tagged jets selections, respectively.

Experimental systematic uncertainties, related to the modeling of the detector response in the simulation, are considered. The uncertainty in the combined 2015–2018 integrated luminosity is 1.7% [68]. Uncertainties in electron and muon trigger, reconstruction, and identification efficiencies, and energy and momentum calibration and resolution are derived from data using  $Z \rightarrow \ell\ell$  and  $J/\psi \rightarrow \ell\ell$  decays [57, 69]. Uncertainties in the jet energy scale and resolution are evaluated from MC simulations and from data using Multijet,  $Z + \text{jets}$ , and  $\gamma + \text{jets}$  events [62]. Uncertainties in the  $b$ -tagging efficiency are derived from data [70] for  $b$ -jets,  $c$ -jets, and other light jets. MC simulations are used to extrapolate the efficiencies to regions beyond the kinematic reach of each calibration. In order to assess the systematic uncertainty due to pileup, the reweighting to match simulation to data is varied within its uncertainty. Finally, the uncertainty related to the extrapolation of the Top and Multijet backgrounds is evaluated as described earlier in the text.

Theoretical systematic uncertainties, related to the modeling of the background processes in the MC simulation, are considered as well. The  $Z/\gamma^* + \text{jets}$  PDF variation uncertainty is estimated using the 90% confidence level (CL) CT14nnlo PDF error set, following Refs. [67, 71–73]. The uncertainty due to  $\alpha_s$  is assessed by using the CT14nnlo PDF set where the value of  $\alpha_s$  is shifted by as much as 0.003 from the

Table 1: Summary of the relative systematic uncertainties for signal regions with  $m_{\ell\ell}^{\min} = 2000$  (1500) GeV before the fit is performed for the  $b$ -veto ( $b$ -tag) categories.

Source	$e^+e^- + 0b$ ( $1b$ ) [%]		$\mu^+\mu^- + 0b$ ( $1b$ ) [%]	
	Signal $0b$ ( $1b$ )	Background $0b$ ( $1b$ )	Signal $0b$ ( $1b$ )	Background $0b$ ( $1b$ )
Luminosity	1.7 (1.7)	1.6 (1.5)	1.7 (1.7)	1.7 (1.7)
Pileup	<0.5 (<0.5)	<0.5 (0.7)	<0.5 (<0.5)	<0.5 (<0.5)
Leptons	8.7 (8.6)	8.6 (6.3)	8.5 (6.5)	9.1 (4.2)
Jets	<0.5 (1.8)	<0.5 (3.4)	<0.5 (1.6)	<0.5 (1.9)
$b$ -tagging	<0.5 (1.4)	<0.5 (2.0)	<0.5 (1.4)	<0.5 (2.2)
Top bkg. extrapolation	-	3.5 (32.0)	-	<0.5 (36.0)
Multijet extrapolation	-	7.5 (15.0)	-	-
Top bkg. modeling	-	<0.5 (<0.5)	-	<0.5 (<0.5)
$Z/\gamma^*$ +jets bkg. modeling	-	9.4 (4.3)	-	10.0 (5.5)
MC statistics	0.6 (0.8)	1.9 (3.5)	0.7 (1.0)	1.7 (2.4)
Total	8.9 (9.1)	15.0 (37.0)	8.7 (7.1)	14.0 (37.0)

nominal value  $\alpha_s(m_Z) = 0.118$ , while QCD scale uncertainties are obtained by varying the renormalization and factorization scales simultaneously by a factor of two up and down. Furthermore, the uncertainty due to the choice of PDF set is estimated by using the NNPDF3.0 PDF set instead of the nominal choice of CT14nnlo [73]. Corrections due to photon-induced processes are estimated using the MRST2004qed PDF set [74]. NLO electroweak corrections for  $Z/\gamma^*$ +jets are applied as well except for QED FSR. For  $t\bar{t}$  and single-top-quark production, an uncertainty in the cross section originating from scale, PDF+ $\alpha_s$  and top-quark-mass uncertainties is applied. The nominal sample is compared with a sample generated with MADGRAPH5\_aMC@NLO to estimate the matrix-element uncertainty. For the parton-shower uncertainty, the nominal sample is compared with a sample simulated with POWHEG Box interfaced to HERWIG 7 [75]. To simulate higher parton radiation, the factorization and renormalization scales are varied by a factor of 0.5 in the matrix element while using the “up” variation from the A14 parameter tune in the parton shower. For lower parton radiation, the renormalization and factorization scales are varied by a factor of 2.0 while using the “down” variation in the parton shower. The impact of FSR is evaluated using parton-shower weights which vary the renormalization scale for QCD emission in the FSR by factors of 0.5 or 2.0. For  $t\bar{t}$  and single-top-quark events, the PDF uncertainty is derived using 30 eigenvector variations as specified in Ref. [73], in order to account for distribution shape uncertainties. For  $t\bar{t}$  production, the impact of factorization and renormalization scale uncertainties on the shapes of distributions is derived by varying those scales by a factor of 0.5 or 2.0 relative to the nominal selection. Finally, the nominal  $Wt$  sample is compared with a sample generated using the diagram subtraction scheme [45, 76].

The statistical uncertainties of the simulated event samples are also taken into account. Systematic uncertainties which are lower than 0.5% in a given region are not considered in the fit or in the limit derivation. Table 1 presents the systematic uncertainties for one signal region from each channel.

The signal and background yields are estimated using simultaneous maximum-likelihood fits of the signal-plus-background and background-only hypothesis. Systematic uncertainties are included as nuisance parameters (NPs), and are constrained in the fit. For each background in each region, an additional NP is included to cover the statistical uncertainty of the MC samples. Dedicated fit parameters are used as additional NPs to adjust the Top and  $Z/\gamma^*$ +jets background normalizations. A likelihood ratio test statistic

is used to assess the compatibility of the data with the background-only hypothesis to derive limits on the BSM signals, following the procedure described in Ref. [77]. For setting exclusion limits on the signal, the  $CL_s$  method [78] is used. This method is performed separately for each of the  $b$ -tag and  $b$ -veto categories in the electron and muon channels, by considering a single-bin SR and the relevant CRs per category.

The data agree well with the SM prediction in all of the VRs after the fit. The post-fit  $m_{\ell\ell}$  distributions in the SRs are presented in Figure 2 for the background-only hypothesis, while the fit is done only at the CRs (CR-only fit) and then used to estimate the background yields. The cumulative  $m_{\ell\ell}$  distribution for the signal regions after the CR-only fit to the data are shown in Figure 3 together with the yields in the different control and validation regions. The largest deviation from the SM prediction is observed in the  $e^+e^- + 1b$  category. Here, the local observed significance exceeds two standard deviations for  $m_{\ell\ell}^{\min} = 1500\text{--}2000$  GeV, while  $m_{\ell\ell}^{\min} = 1700$  GeV yields the largest observed local significance of 2.6 standard deviations from the prediction of the SM. The global significance for the largest local deviation is estimated by generating pseudo-experiments using all of the electron  $b$ -tag associated SRs, and found to be 1.5 standard deviations. In Figure 4, model-independent upper limits on the signal cross section times selection efficiency times detector acceptance ( $\sigma_{\text{vis}} = \sigma \cdot \epsilon \cdot \mathcal{A}$ ) are presented for each signal region selection. For the  $bs\ell\ell$  benchmark model, the strongest expected limits on the signal are found with a selection of  $m_{\ell\ell}^{\min} = 1900$  (1500) GeV in the  $e^+e^- + 0b$  ( $1b$ ) category, which corresponds to expected and observed lower limits on  $\Lambda/g_*$  of up to 2.2 (2.2) TeV and 2.0 (1.8) TeV, respectively, and with a selection of  $m_{\ell\ell}^{\min} = 1800$  (1600) GeV in the  $\mu^+\mu^- + 0b$  ( $1b$ ) category, which corresponds to expected and observed lower limits on  $\Lambda/g_*$  of up to 2.1 (2.1) TeV and 2.4 (2.0) TeV, respectively. The excluded values of  $\Lambda/g_*$  are far below the value which is favored by the anomalies, which is  $\approx 30$  TeV.



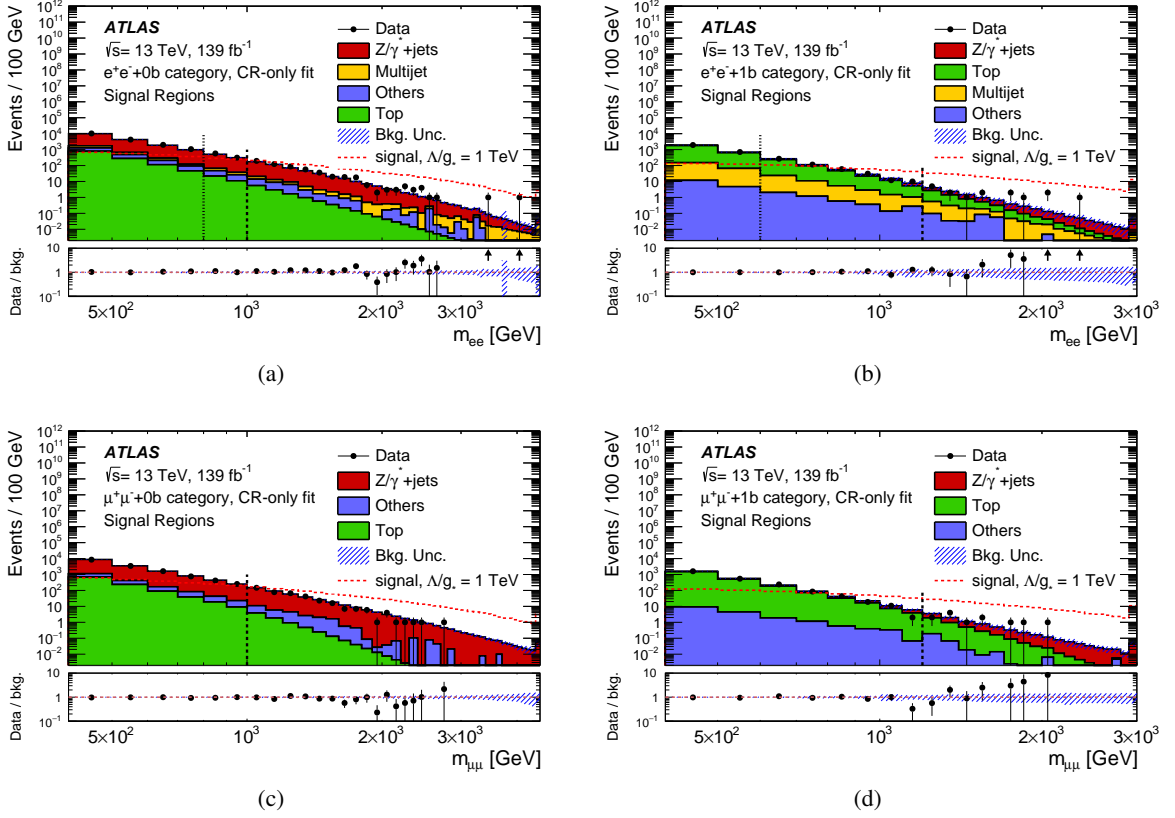


Figure 2: Data overlaid on SM background post-fit  $m_{\ell\ell}$  distributions in the SRs of the (a) electron  $b$ -veto, (b) electron  $b$ -tag, (c) muon  $b$ -veto and (d) muon  $b$ -tag categories. “Others” refers to diboson and  $W$ +jets events. MC statistical uncertainties and systematic uncertainties are considered (hatched band). The pre-fit signal distribution is presented as well for a hypothesis of  $\Lambda/g_* = 1$  TeV. The bottom panels show the ratio of the data to the background prediction, while the arrows correspond to bins where the ratio is beyond the limits of the figure. The last bin is an overflow bin, which contains the yields in the bins beyond it. The dashed and dotted lines mark the transition point where the extrapolation is used in the analysis for the Top and Multijet backgrounds, respectively.

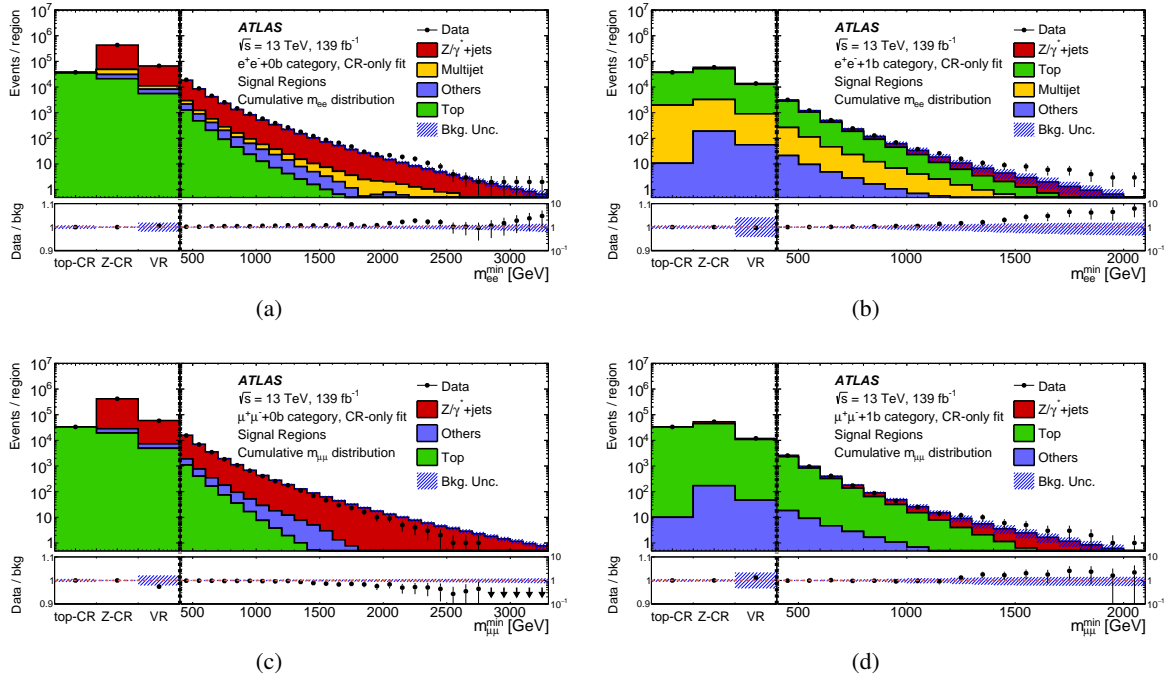


Figure 3: Data overlaid on SM background post-fit yields in the regions of the (a) electron  $b$ -veto, (b) electron  $b$ -tag, (c) muon  $b$ -veto and (d) muon  $b$ -tag categories. “Others” refers to diboson and  $W$ +jets events. MC statistical uncertainties and systematic uncertainties are considered (hatched band). The left part of each figure presents the yields in the CRs and the VR of each category, while the right part presents the yields in the SRs of each category. The bottom panels show the ratio of the data to the background prediction, while the arrows correspond to bins where the ratio is beyond the limits of the figure. The range of the y-axis is different between the left and right parts of the bottom panels, and the latter is presented at logarithmic scale. For the SRs, as the distribution is cumulative, each bin is contained in and therefore correlated with the lower mass bins.

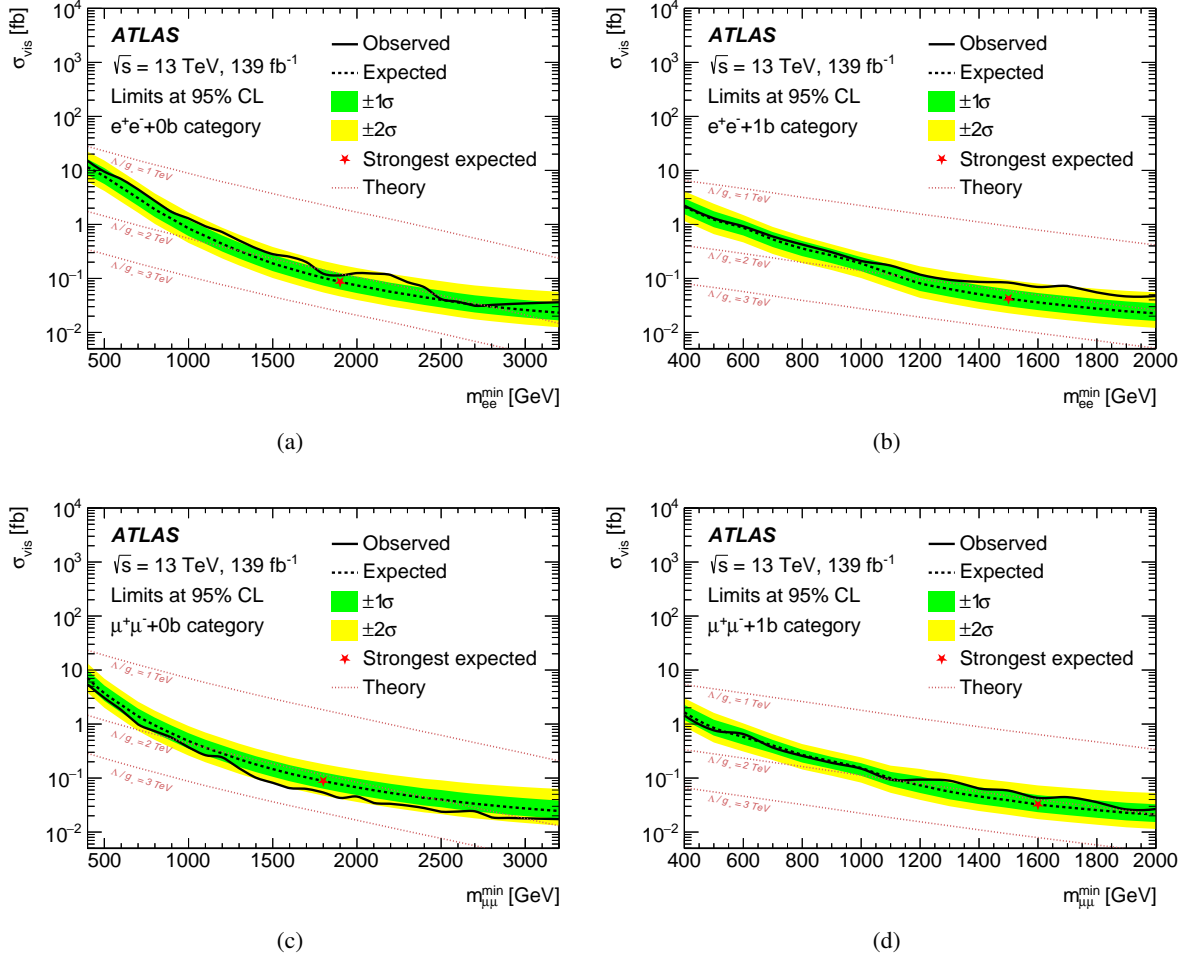


Figure 4: Model-independent observed (solid line) and expected (dashed line) upper limit on the visible cross section ( $\sigma_{\text{vis}} = \sigma \cdot \epsilon \cdot \mathcal{A}$ ) for the (a) electron  $b$ -veto, (b) electron  $b$ -tag, (c) muon  $b$ -veto and (d) muon  $b$ -tag categories. The uncertainty bands around the expected limit represent the 68% and 95% confidence intervals. The theory lines (dotted lines) correspond to particular  $\Lambda/g_*$  values of the signal model, and the red marker presents the strongest expected lower limit on  $\Lambda/g_*$ .

In summary, a search for new phenomena was conducted in final states with two leptons and one or no  $b$ -tagged jets. Two categories were considered for both electron pairs and muon pairs:  $b$ -tag and  $b$ -veto final states. The analysis was conducted using  $139 \text{ fb}^{-1}$  of  $pp$  collision data at  $\sqrt{s} = 13 \text{ TeV}$  recorded by the ATLAS detector at the Large Hadron Collider. No significant excess of events above the expected SM background is observed. Model-independent upper limits at 95% CL were set on the signal cross section in each of the signal regions. A first search for a  $bs\ell\ell$  contact interaction is presented, and values of  $\Lambda/g_*$  smaller than 2.0 (2.4) TeV are excluded using the observed limits for electrons (muons) at 95% CL, which is still far below the value which has been predicted in order to explain the  $B$ -meson decay anomalies.

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