Search for an excess of events with an identical flavour lepton pair and significant missing transverse momentum in $\sqrt{s} = 7 \text{ TeV}$ proton-proton collisions with the ATLAS detector

The ATLAS Collaboration

Abstract. Results are presented of a search for supersymmetric particles decaying into final states with significant missing transverse momentum and exactly two identical flavour leptons ($e, \mu$) of opposite charge in $\sqrt{s} = 7 \text{ TeV}$ collisions at the Large Hadron Collider. This channel is particularly sensitive to supersymmetric particle cascade decays producing flavour correlated lepton pairs. Flavour uncorrelated backgrounds are subtracted using a sample of opposite flavour lepton pair events. Observation of an excess beyond Standard Model expectations following this subtraction procedure would offer one of the best routes to measuring the masses of supersymmetric particles. In a data sample corresponding to an integrated luminosity of $35 \text{ pb}^{-1}$ no such excess is observed. Model-independent limits are set on the contribution to these final states from new physics and are used to exclude regions of a phenomenological supersymmetric parameter space.

In this letter the first results are reported of a search for the production of supersymmetric (SUSY)\footnote{ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the centre of the detector and the z-axis coinciding with the axis of the beam pipe. The $x$-axis points from the IP to the centre of the LHC ring, and the $y$-axis points upward. Cylindrical coordinates ($\rho, \phi$) are used in the transverse plane, $\phi$ being the azimuthal angle around the beam pipe. The pseudorapidity is defined in terms of the polar angle $\theta$ as $\eta = -\ln \tan(\theta/2)$.} particles at ATLAS in events with exactly two leptons of identical flavour ($e, \mu$) and opposite charge, and significant missing transverse momentum ($E_{T}^{\text{miss}}$). This signature can be generated in SUSY events by the correlated production of leptons, for instance via the decay chains $\tilde{\chi}_2^0 \to \ell \ell^* \to \tilde{\chi}_1^0 \ell^+ \ell^-$ or $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \ell^+ \ell^-$. Such events offer one of the best routes to model-independent measurements of the masses of SUSY particles via end-points in the lepton pair invariant mass distribution\footnote{The determination of the mass of a particle from end-points in the invariant mass distribution of the final state is known as the ‘end-point’ technique.} and so are of great interest especially if SUSY is found. The dominant sources of Standard Model (SM) background generally possess equal branching fractions for the production of lepton pairs of identical and different flavour, and can therefore be removed with a ‘flavour subtraction’ procedure\footnote{The flavour subtraction procedure involves subtracting a control sample of events with opposite flavour leptons from the signal sample. This is done to remove the SM background which has equal branching fractions for both flavour combinations.} in which the observation in the $ee$ channel is subtracted from that in the $e\mu$ and $\mu\mu$ channels. Specifically targeting this important technique for measuring SUSY particle masses, this analysis benefits from reduced sensitivity to systematic uncertainties in background estimates compared with other techniques. The results reported here are complementary to those of inclusive SUSY particle searches using lepton pairs\footnote{The ATLAS detector provides a high efficiency for triggering on leptons with transverse momentum greater than 20 GeV/c.} and also to those of inclusive searches requiring jets, $E_{T}^{\text{miss}}$ and zero leptons\footnote{The ATLAS detector has excellent jet and lepton identification capabilities, providing a high efficiency for triggering on jets and leptons with transverse momentum greater than 20 GeV/c.} or one lepton\footnote{The ATLAS detector provides a high efficiency for triggering on leptons with transverse momentum greater than 20 GeV/c.}. A search by CMS for SUSY in events with lepton pairs is reported in Ref.\footnote{The CMS collaboration has also reported results on this search.}. The ATLAS detector\footnote{The ATLAS detector is a multipurpose particle physics apparatus with a forward-backward symmetric cylindrical geometry and near 4$\pi$ coverage in solid angle.} is a multipurpose particle physics apparatus with a forward-backward symmetric cylindrical geometry and near 4$\pi$ coverage in solid angle. The inner tracking detector (ID) consists of a silicon pixel detector, a silicon microstrip detector (SCT), and a transition radiation tracker (TRT) which also provides particle identification capability. The ID is surrounded by a thin superconducting solenoid providing a 2 T magnetic field, and by high-granularity liquid-argon (LAr) sampling electromagnetic calorimeters. Hadronic coverage is provided by an iron-scintillator tile calorimeter in the central rapidity range. The end-cap and forward regions are instrumented with LAr calorimetry for both electromagnetic and hadronic measurements. The muon spectrometer (MS) surrounds the calorimeters and consists of three large superconducting toroids, a system of precision tracking chambers, and detectors for triggering.

The $pp$-collision data used in this analysis were collected between March and November 2010 at the LHC operating at a centre-of-mass energy of 7 TeV. Application of basic beam, detector and data-quality requirements results in a total integrated luminosity of 35 pb$^{-1}$. The uncertainty on the luminosity is estimated to be 11%\footnote{The uncertainty on the luminosity is estimated to be 11% due to the rapidly increasing LHC luminosity and the commissioning of the trigger system, but always have a threshold that ensures a trigger efficiency for leptons with transverse momentum}. The data have been collected with a single lepton ($e$ or $\mu$) trigger. The detailed trigger requirements vary throughout the data-taking period due to the rapidly increasing LHC luminosity and the commissioning of the trigger system, but always have a threshold that ensures a trigger efficiency for leptons with transverse momentum. The trigger efficiency for leptons with transverse momentum
\( p_T > 20 \text{ GeV} \) at the plateau. The efficiency of the triggers is studied with data, and agrees well with expectations.

Monte Carlo (MC) simulated event samples are used to develop and validate the analysis procedure and to estimate the residual SM backgrounds following flavour subtraction. Samples of QCD jet events are generated with \textsc{pythia} \cite{pythia}, using the \textsc{mste2007ld+} modified leading-order parton distribution functions (PDF) \cite{pdf}, which are used with all leading-order (LO) MC codes. Production of top quark pairs is simulated with \textsc{mc@nlo} \cite{mc@nlo}, and (with a top quark mass of 172.5 GeV) and the next-to-leading order (NLO) PDF set \textsc{cteq6.6} \cite{cteq6} (NLO) PDF set is used.

Quark pairs is simulated with \textsc{mc@nlo} with all leading-order (LO) MC codes. Production of top quark pairs is simulated with \textsc{mc@nlo} \cite{mc@nlo}, and (with a top quark mass of 172.5 GeV) and the next-to-leading order (NLO) PDF set \textsc{cteq6.6} \cite{cteq6} (NLO) PDF set is used.

**Cue for electron and muon identification closely follow those described in Ref. \cite{atlas2011}.** Candidate electrons are required to pass “tight” electron selection criteria and isolation requirements, and have \( p_T > 20 \text{ GeV} \) and \( |\eta| < 2.47 \). Identified electrons are used to select events for both the signal region of the analysis and control regions used to estimate backgrounds. “Medium” electron selection criteria are mainly based on lateral shower shape requirements in the calorimeter, while \( E/p \) (where \( E \) is the shower energy in the calorimeter and \( p \) the track momentum in the ID) and TRT cuts are applied for the tight electron selection, which provides additional rejection against conversions and fades from hadrons. The electron isolation criteria require that the total transverse energy within a cone size \( \Delta R = \sqrt{(\Delta \eta)^2 + (\Delta \phi)^2} = 0.2 \) around the electron, is less than 0.15 of the electron \( p_T \). Events are always vetoed if a medium electron is found in the transition region between the barrel and end-cap electromagnetic calorimeter. 1.37 \( \leq |\eta| < 1.52 \). Muons are required to be identified either in both the ID and MS systems (combined muons) or as a match between an extrapolated ID track and one or more track segments in the MS. The ID track is required to have at least one pixel hit, more than five SCT hits, and a number of TRT hits that varies with \( \eta \). For combined muons, a good match between ID and MS tracks is required, and the \( p_T \) values measured by these two systems must be compatible within the resolution. Isolation requirements are imposed, whereby the summed \( p_T \) of other ID tracks above 500 MeV within a distance \( \Delta R < 0.2 \) around the muon track is required to be less than 1.8 GeV. Only muons with \( p_T > 20 \text{ GeV} \) and \( |\eta| < 2.4 \) are considered. For the final selection, the distance between the \( z \) coordinate of the primary vertex and that of the extrapolated muon track at the point of closest approach to the primary vertex must be less than 10 mm. Jets are reconstructed using the anti-\( k_t \) jet clustering algorithm \cite{antikt} with a distance parameter \( D = 0.4 \). The inputs to this algorithm are clusters of calorimeter cells seeded by cells with energy significantly above the measured noise. Jets are constructed by performing a four-vector sum over these clusters, treating each cluster as an \( (E, \mathbf{p}) \) four-vector with zero mass. Jets are corrected for calorimeter non-compensation, material and other effects using \( p_T \)- and \( \eta \)-dependent calibration factors obtained from Monte Carlo and validated with test-beam and collision-data studies \cite{atlas2012}. Only jets with \( p_T > 20 \text{ GeV} \) and \( |\eta| < 2.5 \) are considered. If a jet and a medium electron are both identified within a distance \( \Delta R < 0.2 \) of each other, the jet is discarded. Furthermore, identified medium electrons or muons are only considered if they satisfy \( \Delta R > 0.4 \) with respect to the closest remaining jet. Events are discarded if they contain any jet failing basic quality selection criteria, which rejects detector noise and non-collision backgrounds \cite{atlas2012}. The calculation of the missing transverse momentum, \( E_{T}^{\text{miss}} \), is based on the modulus of the vector sum of the \( p_T \) of the reconstructed objects (jets with \( p_T > 20 \text{ GeV} \), but over the full calorimeter coverage \(|\eta| < 4.9 \), and selected leptons), any additional non-isolated muons, and the calorimeter clusters not belonging to reconstructed objects.

“Signal region” events that contain lepton pairs of identical flavour \((e^+e^-)\) and different flavour \((e^+\mu^-)\) are selected, with the two populations subsequently used to calculate the excess of identical flavour events. Selected events must contain exactly two opposite sign leptons \((e \pm \mu \pm)\), with invariant mass \((m_{\ell\ell})\) greater than 5 GeV. The \( E_{T}^{\text{miss}} \) must exceed 100 GeV in order to reject SM \( Z/\gamma^*\) events whilst maintaining efficiency for a range of SUSY models. Events must also possess at least one reconstructed primary vertex with at least five associated tracks. A flavour subtraction is performed through the use of the quantity \( S \) defined as

\[
S = \frac{N(e^+e^-)}{\beta (1 - (1 - \tau_\ell)(1 - \tau_\mu))} - \frac{N(e^+\mu^-)}{(1 - (1 - \tau_\ell)(1 - \tau_\mu)) + \beta N(\mu^+\mu^-)}
\]

which measures the excess of identical-flavour events (first and third terms) over different-flavour events (second term), taking into account the electron and muon plateau trigger efficiencies \((\tau_\ell \text{ and } \tau_\mu)\) and the ratio of electron to muon efficiency times acceptance \(\beta\). The trigger efficiencies for offline reconstructed objects are \(\tau_\ell = (98.5 \pm 1.1)\%\) and \(\tau_\mu = (83.7 \pm 1.9)\%\), respectively, while \(\beta\) is determined from data to be 0.69 ± 0.03, with the quoted errors including both systematic and statistical uncertainties.

The value of \( S \) obtained from selected identical-flavour and different-flavour lepton SM events is expected to be small but non-zero, due primarily to \( Z/\gamma^* \) boson production. The contributions to \( S \) expected from SM processes are estimated using a combination of Monte Carlo simulation and data-driven techniques. Contributions from single top and diboson events are estimated using the MC samples described above, scaled to the luminosity of the data sample. Contributions from \( Z/\gamma^*\) jets, \( t\bar{t} \) and events containing fake leptons (from QCD jets and \( W +\) jets events) are estimated using MC samples normalised to data in an appropriate control region. The \( Z/\gamma^* \) control region contains lepton pair events satisfying the same selection criteria as the signal region but with \( E_{T}^{\text{miss}} < 20 \text{ GeV} \) and
an additional $81 < m_{t\bar{t}} < 101$ GeV requirement. The $t\bar{t}$ control region [5] contains “top-tagged” lepton pair events again satisfying the same selection criteria as signal candidates but with $60 < E_{T}^{miss} < 80$ GeV and an additional requirement of $\geq 2$ jets with $p_T > 20$ GeV. The top-tagging requirement is imposed through the use of the variable $m_{CT}$ [29], which can be calculated from the four-vectors of the selected jets and leptons:

$$m^2_{CT}(v_1,v_2) = [E_T(v_1) + E_T(v_2)]^2 - [p_T(v_1) - p_T(v_2)]^2,$$

where $v_i$ can be a lepton, a jet, or a lepton-jet combination, transverse momentum vectors are denoted by $p_T$ and transverse energies $E_T$ are defined as $E_T = \sqrt{p_T^2 + m^2}$. This quantity is bounded from above by analytical functions of the top quark and $W$ masses as described in Ref. [30]. Top-tagged events are required to possess $m_{CT}$ values calculated from combinations of jets and leptons consistent with the expected bounds from $t\bar{t}$ events, as well as lepton-jet invariant mass values consistent with top quark decays. An electron control region for fake lepton events requires events to possess $E_{T}^{miss} > 60$ GeV, $\Delta\phi$ between the $E_{T}^{miss}$ vector and a jet $< 0.1$ and an electron with $p_T > 30$ GeV. A single muon control region for fake lepton events requires events to possess $E_{T}^{miss} > 30$ GeV, a muon with $p_T < 40$ GeV and a transverse mass $m_{T}(\mu, E_{T}^{miss}) < 30$ GeV. The electron and muon identification criteria are relaxed, to obtain a ‘looser’ sample dominated by fakes. A loose-tight matrix method is then used to estimate the number of events with fake leptons in the signal region after final selection criteria. This method, which uses the probabilities derived from data for loosely selected leptons and hadrons to satisfy the tight selection criteria to predict the mixture of real and fake leptons in the final sample, is similar to that described in Ref. [31]. The dominant uncertainties in the data-normalised background estimates arise from limited numbers of events in the control regions, theoretical uncertainties (including choice of generator, initial and final state radiation), an approximate $\sim \pm 7\%$ jet energy scale uncertainty [22] and an approximate $\sim 14\%$ jet energy resolution uncertainty [32]. The latter uncertainties affect the shapes of the MC $E_{T}^{miss}$ distributions. Uncertainties on backgrounds estimated solely with MC are dominated by the jet energy scale and resolution.

The invariant mass distributions of lepton pairs in selected data events, prior to applying the $E_{T}^{miss}$ requirement, are presented in Figure [1] weighted by the multiplicative factors in Equation [4] to yield the identical flavour and different flavour contributions to $S$. After applying the $E_{T}^{miss} > 100$ GeV requirement 4, 13 and 13 events are observed in the $e^+e^-$, $e^+\mu^-$ and $\mu^+\mu^-$ channels respectively. The expected numbers of events in these channels, determined using the techniques described above, are listed in Table [1] and are in reasonable agreement (within statistical and systematic uncertainties) with the observations. The dominant contribution to each channel arises from $t\bar{t}$ production. Using the observed numbers of events in each channel together with the measured values of $\tau_e$, $\tau_\mu$ and $\beta$, the observed value of $S$ is found to be $S_{obs} = 1.98 \pm 0.15(\beta) \pm 0.02(\tau_e) \pm 0.06(\tau_\mu)$, where the un

### Table 1: Expected numbers of SM background events in the signal region for each of the three lepton flavour combinations.

<table>
<thead>
<tr>
<th></th>
<th>$e^+e^-$</th>
<th>$e^+\mu^-$</th>
<th>$\mu^+\mu^-$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>4</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Z/$\gamma^*$+jets</td>
<td>0.40±0.46</td>
<td>0.36±0.20</td>
<td>0.91±0.67</td>
</tr>
<tr>
<td>Dibosons</td>
<td>0.30±0.11</td>
<td>0.36±0.10</td>
<td>0.61±0.10</td>
</tr>
<tr>
<td>$t\bar{t}$</td>
<td>2.50±1.02</td>
<td>6.61±2.68</td>
<td>4.71±1.91</td>
</tr>
<tr>
<td>Single top</td>
<td>0.13±0.09</td>
<td>0.76±0.25</td>
<td>0.67±0.33</td>
</tr>
<tr>
<td>Fakes</td>
<td>0.31±0.21</td>
<td>-0.15±0.08</td>
<td>0.01±0.01</td>
</tr>
<tr>
<td>Total SM</td>
<td>3.64±1.24</td>
<td>8.08±2.78</td>
<td>6.91±2.20</td>
</tr>
</tbody>
</table>

**Fig. 1.** Invariant mass distribution of identical flavour lepton pair and $E_{T}^{miss}$ at ATLAS

- Data 2010 $\sqrt{s}$ = 7 TeV
- Different Flavour
- Standard Model
- $t\bar{t}$, WW, ZZ
- W+jets
-Jets

The stacked histograms show the expected distributions from MC samples normalised to the luminosity of the data. The band indicates the uncertainty on the expectation from finite statistics, cross section, luminosity, jet and lepton energy scales and resolutions. Also shown is the observed distribution for different flavour pairs, weighted according to Equation [4]. In the region with $m_{t\bar{t}} < 100$ GeV, the dominant contributions to the different flavour data events are expected to come from $t\bar{t}$, QCD and Z/$\gamma^*$+jets events.
Experiments means and uncertainties, to determine a value of \( \tau \) channel is drawn. The resulting sampled event counts distribution from which the observed number of events in each channel is then used to construct a Poisson distributions between the uncertainties in the estimates of these expectations. The fraction of resulting pseudo-experiments with \( S < S_{\text{obs}} \) gives the probability of the signal plus background hypothesis being falsely rejected. If the probability of being falsely rejected is \(< 5\%\), the point is excluded at 95\% confidence.

A similar procedure can be used to set limits within a specific new physics parameter space. In this case the mean numbers of signal events added to each channel are sampled according to the expectations from each point in the parameter space of the model together with the uncertainties in these expectations. The fraction of resulting pseudo-experiments with \( S < S_{\text{obs}} \) gives the probability of the signal plus background hypothesis being falsely rejected. If the probability of being falsely rejected is \(< 5\%\), the point is excluded at 95\% confidence.

As an example, two-dimensional grids in the parameter space of a 24 parameter MSSM model \( [34] \) are considered (to be referred to as ‘MSSM PhenoGrid2’). The 24 parameter MSSM is a generic MSSM on which flavour and CP violation have been imposed. For these grids the following parameters are fixed: \( m_A = 1000 \text{ GeV} \), \( \mu = 1.5 \text{ min}(m_{\tilde{g}}, m_{\tilde{q}}) \), \( \tan \beta = 4 \), \( A_t = \mu / \tan \beta \), \( A_b = \mu \tan \beta \), and \( A_t = \mu \tan \beta \). The masses of the 3rd generation sfermions are set to 2 TeV, and common squark mass and slepton mass parameters are assumed for the first two generations. Two grids in the \( m_{\tilde{g}} - m_{\tilde{q}} \) plane are studied: one with a compressed spectrum yielding a soft final state kinematics, defined by \( m_{\tilde{g}}^2 = M - 50 \text{ GeV} \), \( m_{\tilde{q}}^2 = M - 150 \text{ GeV} \) and \( m_{\tilde{g}}^2 = M - 100 \text{ GeV} \), where \( M \) is the minimum of the gluino and squark mass (‘compressed spectrum’); and one with a very light LSP, yielding a harder spec-

![Figure 2](image)

**Figure 2.** The distribution of observed \( S \) values from one million hypothetical signal-free experiments. The shape is driven by statistical Poisson fluctuations in the expected rates of identical flavour and different flavour events, dominated by \( tt \) events.
The ATLAS Collaboration: Search for events with an identical flavour lepton pair and $E_T^{miss}$ at ATLAS

5

trum of leptons, jets and $E_T^{miss}$, with $m_{\tilde{q} \tilde{g}} = M - 100$ GeV, $m_{\tilde{\chi}^0} = 100$ GeV and $m_{\tilde{\tau}_L} = M/2$ GeV (‘light neutralino’). Signal events are generated with HERWIG for the MSSM grids. The cross sections are calculated at NLO with PROSPINO [35]. Theoretical and experimental uncertainties are dominated by the uncertainty in the PDF sets [15] used for the cross section calculation. Experimental uncertainties are determined for each model and used when sampling the mean numbers of signal events in each channel. Theoretical uncertainties are evaluated by varying the factorisation and renormalisation scales and the $m^{\text{fact}}/m^{\text{ren}}$ ratio. Theoretical uncertainties are taken into account through a dependence on the jet energy scale and resolution. An 11% luminosity uncertainty is included. The results are shown in the $m_{\tilde{\tau}} - m_{\tilde{\chi}^0}$ plane in Figure 3. For ‘compressed spectrum’ (‘light neutralino’) models and $m_{\tilde{\chi}^0} = m_{\tilde{\tau}} + 10$ GeV, the 95% confidence lower limit on $m_{\tilde{\tau}}$ is 503 (558) GeV.

In summary, a flavour subtraction technique has been used to search for an excess beyond SM expectations of high missing transverse momentum events containing opposite charge identical flavour lepton pairs. No significant excess has been observed, allowing limits to be set on the model-independent quantity $S_{\nu}$, which measures the mean excess from new physics taking into account flavour-dependent acceptances and efficiencies.

We thank CERN for the very successful operation of the LHC, as well as the support staff from our institutions without whom ATLAS could not have operated efficiently.

We acknowledge the support of ANPCyT, Argentina; YerPhI, Armenia; ARC, Australia; BMWF, Austria; ANAS, Azerbaijan; STFC, Belarus; CNPq and FAPESP, Brazil; NSERC, NRC and CF, Canada; CERN; CONICYT, Chile; CAS, MOST and NSFC, China; COLCIENCIAS, Colombia; MSMT CR, MPO CR and VSC CR, Czech Republic; DLR, DMSRC and Lundbeck Foundation, Denmark; ARTEMIS, European Union; IN2P3-CNRS, CEA-DSM/-IRFU, France; GNAS, Georgia; BMBF, DFG, HGF, MPG and AvH Foundation, Germany; GSRT, Greece; ISF, MINE-RA, GIF, DIP and Benoziyo Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; FOM and NWO, Netherlands; RCN, Norway; MNiSW, Poland; GCRDS and FCT, Portugal; MERSYS (MECTS), Romania; MES of Russia and ROSATOM, Russian Federation; JINR; MSTD, Serbia; MSSR, Slovakia; ARRS and MVZT, Slovenia; DST/NRF, South Africa; MICINN, Spain; SRC and Wallenberg Foundation, Sweden; SER, SNSF and Cantons of Bern and Geneva, Switzerland; NSC, Taiwan; TAEK, Turkey; STFC, the Royal Society and Leverhulme Trust, United Kingdom; DOE and NSF, United States of America.

The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN and the ATLAS Tier-1 facilities at TRIUMF (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN-CNAF (Italy), NL-T1 - (Netherlands), PIC (Spain), ASGC (Taiwan), RAL (UK) and BNL (USA) and in the Tier-2 facilities worldwide.

References

4. D. Costanzo and D. R. Tovey, JHEP 04 (2009) 084.
5. ATLAS Collaboration, Search for supersymmetric particles in events with lepton pairs and large missing transverse momentum in $\sqrt{s} = 7$ TeV proton-proton collisions at the ATLAS experiment, in preparation.
22. ATLAS Collaboration, ATL-PHYS-PUB-2010-002
28. ATLAS Collaboration, ATLAS-CONF-2010-038
29. D. R. Tovey, JHEP 04 (2008) 034.
30. G. Polesello and D. R. Tovey, JHEP 03 (2010) 030
32. ATLAS Collaboration, Submitted to EPJC (2010), arXiv:1009.5908v2
33. ATLAS Collaboration, ATLAS-CONF-2010-054
The ATLAS Collaboration: Search for events with an identical flavour lepton pair and \( E_T^\text{miss} \) at ATLAS
The ATLAS Collaboration: Search for events with an identical flavour lepton pair and $E_{\text{T}}^{\text{miss}}$ at ATLAS
The ATLAS Collaboration: Search for events with an identical flavour lepton pair and $E_{\text{miss}}$ at ATLAS
The ATLAS Collaboration: Search for events with an identical flavour lepton pair and $E_T^{miss}$ at ATLAS

1 University at Albany, Albany NY, United States of America
2 Department of Physics, University of Alberta, Edmonton AB, Canada
3 (a)Department of Physics, Ankara University, Ankara; (b)Division of Physics, Dogus University, Istanbul; (c)Department of Physics Engineering, Gaziantep University, Gaziantep; (d)Department of Physics, Istanbul Technical University, Istanbul, Turkey
4 LAPP, CNRS/IN2P3 and Université de Savoie, Annecy-le-Vieux, France
5 High Energy Physics Division, Argonne National Laboratory, Argonne IL, United States of America
6 Department of Physics, University of Arizona, Tucson AZ, United States of America
7 Department of Physics, The University of Texas at Arlington, Arlington TX, United States of America
8 Physics Department, University of Athens, Athens, Greece
9 Physics Department, National Technical University of Athens, Zografou, Greece
10 Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan
11 Institut de Fisica d’Altes Energies and Universitat Autònoma de Barcelona and ICREA, Barcelona, Spain
12 (a)Institute of Physics, University of Belgrade, Belgrade; (b)Vinca Institute of Nuclear Sciences, Belgrade, Serbia
13 Department for Physics and Technology, University of Bergen, Bergen, Norway
14 Physics Division, Lawrence Berkeley National Laboratory and University of California, Berkeley CA, United States of America
15 Department of Physics, Humboldt University, Berlin, Germany
16 Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern, Switzerland
17 School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom
18 (a)Department of Physics, Bogazici University, Istanbul; (b)Division of Physics, Dogus University, Istanbul; (c)Department of Physics Engineering, Gaziantep University, Gaziantep; (d)Department of Physics, Istanbul Technical University, Istanbul, Turkey
19 (a)INFN Sezione di Bologna; (b)Dipartimento di Fisica, Università di Bologna, Bologna, Italy
20 Physikalisches Institut, University of Bonn, Bonn, Germany
21 Department of Physics, Boston University, Boston MA, United States of America
22 Department of Physics, Brandeis University, Waltham MA, United States of America
23 (a)Universidade Federal do Rio De Janeiro
24 Physics Department, Brookhaven National Laboratory, Upton NY, United States of America
25 (a)National Institute of Physics and Nuclear Engineering, Bucharest; (b)University Politehnica Bucharest, Bucharest; (c)West University in Timisoara, Timisoara, Romania
26 Departamento de Fisica, Universidad de Buenos Aires, Buenos Aires, Argentina
27 Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom
28 Department of Physics, Carleton University, Ottawa ON, Canada
29 CERN, Geneva, Switzerland
30 Enrico Fermi Institute, University of Chicago, Chicago IL, United States of America
31 (a)Departamento de Fisica, Pontificia Universidad Católica de Chile, Santiago; (b)Departamento de Fisica, Universidad Técnica Federico Santa María, Valparaíso, Chile
32 (a)Institute of High Energy Physics, Chinese Academy of Sciences, Beijing; (b)Department of Modern Physics, University of Science and Technology of China, Hefei; (c)Department of Physics, Nanjing University, Jiangsu; (d)High Energy Physics Group, Shandong University, Shandong, China
33 Laboratoire de Physique Corpusculaire, Clermont Université and Université Blaise Pascal and CNRS/IN2P3, Aubiere Cedex, France
34 Nevis Laboratory, Columbia University, Irvington NY, United States of America
35 Niels Bohr Institute, University of Copenhagen, København, Denmark
36 (a)INFN Gruppo Collegato di Cosenza;
37 Faculty of Physics and Applied Computer Science, AGH-University of Science and Technology, Krakow, Poland
38 The Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, Krakow, Poland
39 Physics Department, Southern Methodist University, Dallas TX, United States of America
40 Physics Department, University of Texas at Dallas, Richardson TX, United States of America
41 DESY, Hamburg and Zeuthen, Germany
42 Institut für Experimentelle Physik IV, Technische Universität Dortmund, Dortmund, Germany
43 Institut für Kern- und Teilchenphysik, Technical University Dresden, Dresden, Germany
The ATLAS Collaboration: Search for events with an identical flavour lepton pair and $E_T^{miss}$ at ATLAS

99 Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany
100 Nagasaki Institute of Applied Science, Nagasaki, Japan
101 Graduate School of Science, Nagoya University, Nagoya, Japan
102 (a)INFN Sezione di Napoli; (b)Dipartimento di Scienze Fisiche, Università di Napoli, Napoli, Italy
103 Department of Physics and Astronomy, University of New Mexico, Albuquerque NM, United States of America
104 Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands
105 Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands
106 Department of Physics, Northern Illinois University, DeKalb IL, United States of America
107 Budker Institute of Nuclear Physics (BINP), Novosibirsk, Russia
108 Department of Physics, New York University, New York NY, United States of America
109 Ohio State University, Columbus OH, United States of America
110 Faculty of Science, Okayama University, Okayama, Japan
111 Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman OK, United States of America
112 Department of Physics, Oklahoma State University, Stillwater OK, United States of America
113 Palacký University, RCPTM, Olomouc, Czech Republic
114 Center for High Energy Physics, University of Oregon, Eugene OR, United States of America
115 LAL, Univ. Paris-Sud and CNRS/IN2P3, Orsay, France
116 Graduate School of Science, Osaka University, Osaka, Japan
117 Department of Physics, University of Oslo, Oslo, Norway
118 Department of Physics, Oxford University, Oxford, United Kingdom
119 (a)INFN Sezione di Pavia; (b)Dipartimento di Fisica Nucleare e Teorica, Università di Pavia, Pavia, Italy
120 Department of Physics, University of Pennsylvania, Philadelphia PA, United States of America
121 Petersburg Nuclear Physics Institute, Gatchina, Russia
122 (a)INFN Sezione di Pisa; (b)Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy
123 Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh PA, United States of America
124 (a)Laboratorio de Instrumentacao e Fisica Experimental de Particulas - LIP, Lisbon, Portugal; (b)Departamento de Fisica Teorica y del Cosmos and CAFPE, Universidad de Granada, Granada, Spain
125 Institute of Physics, Academy of Sciences of the Czech Republic, Praha, Czech Republic
126 Faculty of Mathematics and Physics, Charles University in Prague, Praha, Czech Republic
127 Czech Technical University in Prague, Praha, Czech Republic
128 State Research Center Institute for High Energy Physics, Protvino, Russia
129 Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom
130 Physics Department, University of Regina, Regina SK, Canada
131 Ritsumeikan University, Kusatsu, Shiga, Japan
132 (a)INFN Sezione di Roma I; (b)Dipartimento di Fisica, Università La Sapienza, Roma, Italy
133 (a)INFN Sezione di Roma Tor Vergata; (b)Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy
134 (a)INFN Sezione di Roma Tre; (b)Dipartimento di Fisica, Università Roma Tre, Roma, Italy
135 (a)Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Énergies - Université Hassan II, Casablanca; (b)Centre National de l’Énergie des Sciences Techniques Nucleaires, Rabat; (c)Université Cadi Ayyad, Faculté des sciences Semlalia Département de Physique, B.P. 2390 Marrakech 40000; (d)Faculté des Sciences, Université Mohamed Premier and LPTPM, Oujda; (e)Faculté des Sciences, Université Mohammed V, Rabat, Morocco
136 DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l’Univers), CEA Saclay (Commissariat a l’Énergie Atomique), Gif-sur-Yvette, France
137 Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz CA, United States of America
138 Department of Physics, University of Washington, Seattle WA, United States of America
139 Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom
140 Department of Physics, Shinshu University, Nagano, Japan
141 Fachbereich Physik, Universität Siegen, Siegen, Germany
142 Department of Physics, Simon Fraser University, Burnaby BC, Canada
143 SLAC National Accelerator Laboratory, Stanford CA, United States of America
144 (a)Faculty of Mathematics, Physics & Informatics, Comenius University, Bratislava; (b)Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice, Slovak Republic
145 (a)Department of Physics, University of Johannesburg, Johannesburg; (b)School of Physics, University of the Witwatersrand, Johannesburg, South Africa
146 (a)Department of Physics, Stockholm University; (b)The Oskar Klein Centre, Stockholm, Sweden
147 Physics Department, Royal Institute of Technology, Stockholm, Sweden
148 Department of Physics and Astronomy, Stony Brook University, Stony Brook NY, United States of America
The ATLAS Collaboration: Search for events with an identical flavour lepton pair and $E_T^{miss}$ at ATLAS

149 Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom
150 School of Physics, University of Sydney, Sydney, Australia
151 Institute of Physics, Academia Sinica, Taipei, Taiwan
152 Department of Physics, Technion: Israel Inst. of Technology, Haifa, Israel
153 Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel
154 Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece
155 International Center for Elementary Particle Physics and Department of Physics, The University of Tokyo, Tokyo, Japan
156 Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo, Japan
157 Department of Physics, Tokyo Institute of Technology, Tokyo, Japan
158 Department of Physics, University of Toronto, Toronto ON, Canada
159 (a)TRIUMF, Vancouver BC; (b)Department of Physics and Astronomy, York University, Toronto ON, Canada
160 Institute of Pure and Applied Sciences, University of Tsukuba, Ibaraki, Japan
161 Science and Technology Center, Tufts University, Medford MA, United States of America
162 Centro de Investigaciones, Universidad Antonio Narino, Bogota, Colombia
163 Department of Physics and Astronomy, University of California Irvine, Irvine CA, United States of America
164 (a)INFN Gruppo Collegato di Udine; (b)ICTP, Trieste; (c)Dipartimento di Fisica, Università di Udine, Udine, Italy
165 Department of Physics, University of Illinois, Urbana IL, United States of America
166 Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden
167 Instituto de Física Corpuscular (IFIC) and Departamento de Física Atómica, Molecular y Nuclear and Departamento de Ingeniería Electrónica and Instituto de Microelectrónica de Barcelona (IMB-CNM), University of Valencia and CSIC, Valencia, Spain
168 Department of Physics, University of British Columbia, Vancouver BC, Canada
169 Department of Physics and Astronomy, University of Victoria, Victoria BC, Canada
170 Waseda University, Tokyo, Japan
171 Department of Particle Physics, The Weizmann Institute of Science, Rehovot, Israel
172 Department of Physics, University of Wisconsin, Madison WI, United States of America
173 Fakultät für Physik und Astronomie, Julius-Maximilians-Universität, Würzburg, Germany
174 Fachbereich C Physik, Bergische Universität Wuppertal, Wuppertal, Germany
175 Department of Physics, Yale University, New Haven CT, United States of America
176 Yerevan Physics Institute, Yerevan, Armenia
177 Domaine scientifique de la Doua, Centre de Calcul CNRS/IN2P3, Villeurbanne Cedex, France
164 (a)INFN Gruppo Collegato di Udine; (b)ICTP, Trieste; (c)Dipartimento di Fisica, Università di Udine, Udine, Italy
178 Also at Laboratorio de Instrumentacao e Fisica Experimental de Particulas - LIP, Lisboa, Portugal
179 Also at Faculdade de Ciencias and CFNUL, Universidade de Lisboa, Lisboa, Portugal
180 Also at CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France
181 Also at TRIUMF, Vancouver BC, Canada
182 Also at Department of Physics, California State University, Fresno CA, United States of America
183 Also at Faculty of Physics and Applied Computer Science, AGH-University of Science and Technology, Krakow, Poland
184 Also at Department of Physics, University of Coimbra, Coimbra, Portugal
185 Also at Università di Napoli Parthenope, Napoli, Italy
186 Also at Institute of Particle Physics (IPP), Canada
187 Also at Louisiana Tech University, Ruston LA, United States of America
188 Also at Group of Particle Physics, University of Montreal, Montreal QC, Canada
189 Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan
190 Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany
191 Also at Manhattan College, New York NY, United States of America
192 Also at School of Physics and Engineering, Sun Yat-sen University, Guangzhou, China
193 Also at Academia Sinica Grid Computing, Institute of Physics, Academia Sinica, Taipei, Taiwan
194 Also at High Energy Physics Group, Shandong University, Shandong, China
195 Also at California Institute of Technology, Pasadena CA, United States of America
196 Also at Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom
197 Also at Section de Physique, Université de Genève, Geneva, Switzerland
198 Also at Departamento de Fisica, Universidade de Minho, Braga, Portugal
199 Also at Department of Physics and Astronomy, University of South Carolina, Columbia SC, United States of America
200 Also at KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary
201 Also at Institute of Physics, Jagiellonian University, Krakow, Poland
202 Also at DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l’Univers), CEA Saclay (Commissariat a l’Energie Atomique), Gif-sur-Yvette, France
203 Also at Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France
204 Also at Department of Physics, Nanjing University, Jiangsu, China
* Deceased