PDF hosted at the Radboud Repository of the Radboud University Nijmegen

The following full text is a preprint version which may differ from the publisher's version.

For additional information about this publication click this link.
http://hdl.handle.net/2066/92051

Please be advised that this information was generated on 2019-03-24 and may be subject to change.
Measurement of the production cross section for W-bosons in association with jets in pp collisions at \( \sqrt{s} = 7 \) TeV with the ATLAS detector

The ATLAS Collaboration

Abstract

This Letter reports on a first measurement of the inclusive \( W \) + jets cross section in proton-proton collisions at a centre-of-mass energy of 7 TeV at the LHC, with the ATLAS detector. Cross sections, in both the electron and muon decay modes of the \( W \) boson, are presented as a function of jet multiplicity and of the transverse momentum of the leading and next-to-leading jets in the event. Measurements are also presented of the ratio of cross sections \( \sigma(W + n) / \sigma(W + n-1) \) for inclusive jet multiplicities \( n = 1-4 \). The results, based on an integrated luminosity of 1.3 pb\(^{-1}\), have been corrected for all known detector effects and are quoted in a limited and well-defined range of jet and lepton kinematics. The measured cross sections are compared to particle-level predictions based on perturbative QCD. Next-to-leading order calculations, studied here for \( n \leq 2 \), are found in good agreement with the data. Leading-order multiparton event generators, normalized to the NNLO total cross section, describe the data well for all measured jet multiplicities.

1. Introduction

The study of massive vector boson (\( V \), where \( V = W \) or \( Z \)) production in association with one or more jets (\( V \) + jets) is an important test of quantum chromodynamics (QCD). In addition, \( V \) + jets processes are a significant background to studies of Standard Model processes such as \( t \bar{t} \) or single-top production, as well as searches for the Higgs boson and for physics beyond the Standard Model. Measurements of the cross section and kinematic properties of \( V \) + jets processes and comparisons to theoretical predictions are therefore of significant interest. This Letter reports on a first measurement at the Large Hadron Collider (LHC) of the \( W \) + jets cross section in proton-proton (pp) collisions at a centre-of-mass energy (\( \sqrt{s} \)) of 7 TeV, in both electron and muon decay modes of the \( W \)-boson, with the ATLAS detector. The measurement is based on an integrated luminosity of approximately 1.3 pb\(^{-1}\).

The cross section measurements are presented as a function of jet multiplicity and of the transverse momentum (\( p_T \)) of the leading and next-to-leading jets in each event. Measurements are also presented of the ratio of cross sections \( \sigma(W + n) / \sigma(W + n-1) \) for inclusive jet multiplicities \( n = 1-4 \). The results have been corrected for all known detector effects and are quoted in a limited and well-defined range of jet and lepton kinematics, fully covered by the detector acceptance, so as to avoid model-dependent extrapolations and to facilitate comparisons with theoretical predictions. Previous measurements of \( W \) + jets production in proton-antiproton collisions at \( \sqrt{s} = 1.96 \) TeV were published by the CDF Collaboration [1]. Theoretical calculations at next-to-leading-order (NLO) in perturbative QCD (pQCD) have been computed for up to four jets for \( W \) production [2, 3]. Comparisons are made in this Letter with NLO pQCD calculations for \( n \leq 2 \); higher jet multiplicities are compared only to leading-order (LO) calculations.

2. The ATLAS Detector

The ATLAS detector [4, 5] consists of an inner tracking system (inner detector, or ID) surrounded by a thin superconducting solenoid providing a 2T magnetic field, electromagnetic and hadronic calorimeters and a muon spectrometer (MS). The ID consists of pixel and silicon microstrip (SCT) detectors, surrounded by the transition radiation...
tracker (TRT). The electromagnetic calorimeter is a lead liquid-argon (LAr) detector. Hadron calorimetry is based on two different detector technologies, with scintillator tiles or LAr as active media, and with either steel, copper, or tungsten as the absorber material. The MS is based on three large superconducting toroids arranged with an eight-fold azimuthal coil symmetry around the calorimeters, and a system of three stations of chambers for the trigger and for precise measurements. The nominal $pp$ interaction point at the centre of the detector is defined as the origin of a right-handed coordinate system. The positive $z$-axis is defined by the direction from the interaction point to the centre of the LHC ring, with the positive $y$-axis pointing upwards, while the beam direction defines the $z$-axis. The azimuthal angle $\phi$ is measured around the beam axis and the polar angle $\theta$ is the angle from the $z$-axis. The pseudorapidity is defined as $\eta = -\ln \tan(\theta/2)$.

3. Simulated Event Samples

Simulated event samples were used for most of the background estimates, for the correction of the signal yield for detector effects and for comparisons of the results for detector effects with theoretical expectations. The detector simulation was performed using GEANT4. The simulated event samples are summarised in Table 1. The ALPGEN samples were generated with the MLM matching scheme and interfaced to HERWIG v6.510 for parton shower and fragmentation processes and to JIMMY v4.31 for underlying event simulation. Parton density functions (PDF) were: CTEQ6L1 for the ALPGEN and SHERPA samples, MRST 2007 LO$^*$ for PYTHIA, and MSTW2008 for FEWZ. For the POWHEG samples, the PDF set was CTEQ6.6M for the NLO matrix element calculations, while CTEQ6L1 was used for the parton showering and underlying event via the POWHEG interface to PYTHIA. The radiation of photons from charged leptons was treated in HERWIG and PYTHIA using PHOTOS v2.15.4. Tauola v1.0.2 was used for tau decays. The underlying event tune was the ATLAS MC09 tune for the ALPGEN samples, PYTHIA inclusive vector boson production, and PYTHIA QCD samples. The POWHEG sample used the ATLAS MC09 tune with one parameter adjusted. The AMBT1 tune was used for the PYTHIA W +jets samples. The samples generated with SHERPA used the default underlying event tune. Samples were generated with minimum bias interactions overlaid on top of the hard-scattering event in order to account for the multiple $pp$ interactions in the same beam crossing (pile-up) experienced in the data. The number of minimum bias interactions followed a Poisson distribution with a mean of two. These samples were then reweighted such that the distribution of the number of primary vertices matched that of the data.

The data used in this analysis were collected from March to August 2010. Application of beam, detector, and data-quality requirements resulted in a total integrated luminosity of 1.3 $\text{pb}^{-1}$. The uncertainty on the luminosity determination is estimated to be 11%\cite{26}. Criteria for electron and muon identification, as well as for event selection, followed closely those for the $W$ boson inclusive cross section analysis.

In the electron channel, a hardware-based level-one trigger system selected events containing one or more electron candidates, based on the presence of a cluster in the electromagnetic calorimeter with a transverse energy ($E_T$) greater than 14 GeV; this is the only difference in the electron channel with respect to the $W$ inclusive cross section analysis, and was motivated by the fact that, for this larger dataset, this trigger was the lowest-threshold, useful electromagnetic trigger without any additional higher-level trigger requirements. The impact of the trigger efficiency was negligible for electrons with $E_T > 20$ GeV. In the offline analysis, electrons were required to pass the standard “tight” electron selection criteria with $E_T > 20$ GeV and $|\eta| < 2.47$; electrons in the transition region between the barrel and endcap calorimeter ($1.37 < |\eta| < 1.52$) were rejected. Events were also rejected if there was a second electron passing the “medium” electron selection criteria and the same kinematic selections as above.

In the muon channel, the hardware-based trigger selected events containing one or more muon candidates, based on hit patterns in the MS, corresponding to $p_T > 10$ GeV. Offline, the muons were required to be identified in both ID and MS subsystems and to have $p_T > 20$ GeV and $|\eta| < 2.4$. The ID track was required to have $\geq 2$ hits in the pixel detector, $\geq 6$ hits in the SCT and, for tracks with $|\eta| < 2.0$, $\geq 1$ hit in the TRT. The muon impact parameter with respect to the primary vertex was required to be $< 0.1$ mm and $< 10$ mm in the $r - \phi$ and $r - z$ planes, respectively. The first of these requirements was added to further reduce non-prompt muons from decays of hadrons, and muons from cosmic rays. The difference between the ID and MS $p_T$, corrected for the mean energy loss in upstream material, was required to satisfy $|\Delta p_T^{ID} - \Delta p_T^{MS}| < 0.5 \times p_T^{ID}$. Compared to the criteria used in Ref.\cite{27}, this scaled requirement reduced the background from decays-in-flight of hadrons and improved the signal efficiency at high $p_T$. As in Ref.\cite{27}, the muons were required to be isolated, following a track-based isolation, but the cone size was reduced from $\Delta R = 0.4$ to $\Delta R = 0.2$ (where $\Delta R = \sqrt{(\Delta \eta)^2 + (\Delta \phi)^2}$ of the muon) and the isolation requirement was changed from $\Sigma p_T^{ID}/p_T < 0.2$ to $\Sigma p_T^{ID} < 1.8$ GeV to improve the QCD background rejection. With these optimised cuts, the QCD background was reduced by a factor of 1.7 for the inclusive 1-jet sample. In addition, a number of requirements were added on the tracks inside the isolation cone: the difference between the $z$ position of the track extrapolated to the beam line and
Table 1: Signal and background simulated event samples used in this analysis, including the production cross section (multiplied by the relevant branching ratio, BR). The variable $p_T$ is the average $p_T$ of the two outgoing partons involved in the hard-scattering process, evaluated before modifications from initial- and final-state radiation and from the underlying event. The $W$ inclusive cross section is given at next-to-next-to-leading-order (NNLO), the $t\bar{t}$ cross section is given at next-to-leading-order (plus next-to-next-to-leading-log, NNLL), and the dijet cross sections are given at leading-order (LO) in pQCD. The $W$ + jets and $Z$+jets samples were normalised using the inclusive cross sections. For PYTHIA, the inclusive $W$ sample is based on a 2 → 1 matrix element merged with a 2 → 2 matrix element and a leading-logarithmic parton shower; the $W$+jets samples are based on 2 → 2 matrix elements. Details of PDF sets, final-state photon radiation, and underlying event tunes are given in the text.

<table>
<thead>
<tr>
<th>Physics process</th>
<th>Generator</th>
<th>$\sigma \cdot BR$ (nb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W \rightarrow \ell\nu$ inclusive ($\ell = e, \mu, \tau$)</td>
<td>PYTHIA 6.4.21 [21]</td>
<td>10.46 NNLO [14]</td>
</tr>
<tr>
<td>$W^+ \rightarrow \ell^+\nu$</td>
<td></td>
<td>6.16 NNLO [14]</td>
</tr>
<tr>
<td>$W^- \rightarrow \ell^-\bar{\nu}$</td>
<td></td>
<td>4.30 NNLO [14]</td>
</tr>
<tr>
<td>$W \rightarrow \ell\nu +$ jets ($\ell = e, \mu, \tau$)</td>
<td>PYTHIA 6.4.21 [21]</td>
<td>1.07 NNLO [14]</td>
</tr>
<tr>
<td>$W \rightarrow \ell\nu +$ jets ($\ell = e, \mu, \tau$, $0 \leq N_{parton} \leq 5$)</td>
<td>ALPGEN 2.13 [22]</td>
<td></td>
</tr>
<tr>
<td>$W \rightarrow \ell\nu +$ jets ($\ell = e, \mu, \tau$, $0 \leq N_{parton} \leq 4$)</td>
<td>SHERPA 1.1.3 [23]</td>
<td></td>
</tr>
<tr>
<td>$Z \rightarrow \ell\ell +$ jets ($m_{\ell\ell} &gt; 40$ GeV, $0 \leq N_{parton} \leq 5$)</td>
<td>ALPGEN 2.13 [22]</td>
<td>1.2×10^6 LO [21]</td>
</tr>
<tr>
<td>Dijet ($e$ channel, $p_T &gt; 15$ GeV)</td>
<td>PYTHIA 6.4.21 [21]</td>
<td>10.6×10^6 LO [21]</td>
</tr>
<tr>
<td>Dijet ($\mu$ channel, $p_T &gt; 8$ GeV, $p_T^\mu &gt; 8$ GeV)</td>
<td>PYTHIA 6.4.21 [21]</td>
<td></td>
</tr>
</tbody>
</table>

The calculation of missing transverse energy ($E_T^{miss}$) and transverse mass ($M_T$) followed the prescription in Ref. [27]. $M_T$ was defined by the lepton and neutrino $p_T$ as $M_T = \sqrt{2p_T^e p_T^\nu (1 - \cos(\phi^e - \phi^\nu))}$, where the $(x, y)$ components of the neutrino momentum were inferred from the corresponding $E_T^{miss}$ components. $E_T^{miss}$ was calculated from the energy deposits of calorimeter cells inside three-dimensional clusters [28]. These clusters were then corrected to take into account the different response to hadrons compared to electrons or photons, as well as dead material and out-of-cluster energy losses [29]. In the muon channel, $E_T^{miss}$ was corrected for the muon momentum. Events were required to have $E_T^{miss} > 50$ GeV and $M_T > 40$ GeV. After requiring ≥1 primary vertex with ≥3 associated tracks in the event, the primary vertex was required to be within 150 mm along the beam direction relative to the centre of the detector. In events with multiple vertices along the beam axis, the vertex with the largest $\Sigma p_T^\mu$ of associated tracks was taken as the primary event vertex. Starting from approximately $9.6 \times 10^6$ triggered events in each of the electron and muon channels, this selection criteria reduced the sample to 4216 and 4911 events, respectively.

Jets were reconstructed using the anti-$k_t$ algorithm [30] with a radius parameter $R = 0.4$ [31]. The efficiency for reconstructing jets was found to be approximately 98% in simulation for jet $p_T$ of 20 GeV, rising to close to 100% efficiency for 30 GeV jets. Jets arising from detector noise or cosmic rays were rejected [32]. To take into account the differences in calorimeter response to electrons and hadrons, a $p_T$- and $\eta$-dependent factor, derived from simulated events, was applied to each jet to provide an average energy scale correction [31] back to particle-level. Jets were required to have $|\eta| < 2.8$ and $p_T > 20$ GeV. All jets within $\Delta R < 0.5$ of an electron or muon (that passed the lepton identification requirements) were removed, regardless of the jet $p_T$ or $\eta$.

Jets from pile-up interactions were removed by a cut on the jet-vertex fraction ($JVF$) which was computed for each jet in the event. After associating tracks to jets with a simple matching in $\Delta R$ (track, jet), requiring $\Delta R < 0.4$, the $JVF$ was computed for each jet as the scalar sum $p_T$ of all matched tracks from the primary vertex divided by the total jet-matched track $p_T$ from all vertices. Jets which fell outside of the fiducial tracking region ($|\eta| < 2.5$ or which had no matching tracks were not considered for the $JVF$ cut. Jets for which $JVF < 0.75$ were rejected. The application of the $JVF$ cut reduced the sensitivity of the measured jet multiplicity distribution to additional jets from pile-up.

5. Signal and Background Yields

The major background processes in the electron channel are QCD and lepton backgrounds. The latter consist of $W \rightarrow \tau\nu$ where the tau decays to an electron, $Z \rightarrow ee$ where one electron is not identified and hadronic energy in the event is mismeasured, and semileptonic $t\bar{t}$ decays ($t\bar{t} \rightarrow b\bar{b}q\bar{q}l\ell$). The QCD background in the electron channel has two components, one where a hadronic jet passes the electron selection and additional energy mis-
measurement in the event results in large \( E_{T}^{\text{miss}} \), and the other where a bottom- or charm-hadron decays to an electron. For the muon channel, the main backgrounds arise from semileptonic heavy flavour decays in multijet events and from the leptonic background from the following sources: \( W \rightarrow \tau \nu \) where the tau decays to a muon, \( Z \rightarrow \mu \mu \) where one muon is not identified, and semileptonic \( tt \) decays in the muon channel. The contributions of single-top and di-boson production to the measured cross section have been estimated to be slightly smaller than the \( W \rightarrow \tau \nu \) background, and are not subtracted from the data.

The number of leptonic background events surviving the above selection cuts was estimated with simulated event samples: ALPGEN for vector boson samples (PYTHIA was used for \( W \rightarrow \tau \nu + \text{jets} \) and POWHEG for \( tt \) background. The simulated leptonic background samples were normalised to the integrated luminosity of the data using the predicted NNLO or NLO+NNLL cross sections. The number of QCD background events was estimated by fitting, in each jet multiplicity bin, the \( E_{T}^{\text{miss}} \) distribution in the data (without the \( E_{T}^{\text{miss}} \) and \( M_{T} \) cuts) to a sum of two templates: one for the QCD background and another which included signal and the leptonic backgrounds. In both muon and electron channels, the shapes for the second template were obtained from simulation. In the electron channel, the template for the QCD background was obtained from the data because the mechanisms by which a jet fakes an electron are difficult to simulate. This template was derived from a data sample where looser electron identification criteria were applied on the shower shapes and the track-cluster matching requirements were inverted. The QCD background was computed from the results of the template fit. In the electron channel, the fit was performed in the region \( E_{T}^{\text{miss}} > 10 \text{ GeV} \) due to the poor understanding of the background below \( 10 \text{ GeV} \). The fit to the \( E_{T}^{\text{miss}} \) distribution was used only to determine the QCD background normalisation, taking into account contributions from leptonic background and signal in the low \( E_{T}^{\text{miss}} \) region. The \( W + \text{jets} \) signal yield for the cross section calculation was derived as the difference between the observed number of events in the signal region and the sum of background components. Figure 4 shows the \( E_{T}^{\text{miss}} \) distribution for events with one jet, with the fitted contributions from all background sources in the electron and muon channels respectively, after all the other selection requirements (except for the \( M_{T} \) cut) have been applied. The residual difference in \( E_{T}^{\text{miss}} \) between the data and the QCD template in the control region is covered by the systematic uncertainties. The number of observed events and the estimated number of background events are summarised in Table 2.

The yield of signal events was corrected back to the particle level, taking into account detector and reconstruction efficiency. The dominant corrections in the electron channel come from electron reconstruction efficiency (\( \approx 20\% \) correction). In the muon channel, the dominant corrections come from trigger and reconstruction efficiency (corrections of \( \approx 10 - 20\% \) and \( \approx 10\% \) respectively). The corrections were computed using the ALPGEN \( W + \text{jets} \) event generator plus full detector simulation, restricting the events to the same phase space as the data analysis. The phase space requirements were applied to generated quantities. In this analysis, particle-level jets were constructed in simulated events by applying the jet finder to all final state particles (excluding muons and neutrinos) with a lifetime longer than 10 ps, whether produced directly in the \( pp \) collision or from the decay of particles with shorter lifetimes. Correction factors were computed as one-dimensional functions of jet multiplicity and \( p_{T} \) of the leading and next-to-leading jets, and were treated as independent. Migration of events across bins of jet \( p_{T} \) was made small compared to the statistical uncertainty by selecting the bin widths to be at least a factor of two larger than the jet \( p_{T} \) resolution [32]. Tests with simulated data showed that these correction factors were sufficient to recover particle-level distributions. To treat the effect of final state QED radiation, the energy of the generated lepton was defined as the energy of the lepton after radiation plus the energy of all radiated photons within \( \Delta R = 0.1 \) around the lepton.

The correction factor for the trigger efficiency was obtained directly from the data as follows. In the electron channel, events were triggered either by an independent \( E_{T}^{\text{miss}} \) trigger or a loose electron trigger with an approximately 5 GeV threshold. The full \( W + \text{jets} \) selection was carried out in essentially the same way as described above in order to isolate a pure electron sample. The main difference was in the QCD background estimation, which was done with templates for the shape of the electron isolation distribution, where the isolation variable was defined as the sum of transverse energy in a cone of \( \Delta R = 0.4 \) around the electron divided by the transverse energy of the electron. These templates were obtained by inverting one or more of the electron shower shape requirements. The electron trigger efficiency was found to be close to 100% in both data and simulation. In the muon channel, the trigger efficiency was computed with a sample of unbiased offline reconstructed muons from \( Z \rightarrow \mu \mu \) decays. Average trigger efficiencies of \( 82.0 \pm 1.4\% \) and \( 86.9 \pm 0.1\% \) were obtained in data and simulation, respectively; the difference between data and simulation comes from a mismodelling of both the efficiency of the forward muon chambers and of the programming of the muon trigger electronics. The trigger efficiency (and its uncertainty) from the data was used for the correction factor.

6. Systematic Uncertainties

The primary sources of systematic uncertainty in the cross section for both electron and muon channels are uncertainties in the integrated luminosity and in the jet energy scale [31]. In the electron channel, the uncertainty due to the QCD background shape is also important. Both electron and muon channels are affected by uncertainties
in the lepton reconstruction efficiency. The luminosity uncertainty enters primarily through the signal normalisation but also has an effect on the estimation of the leptonic backgrounds; the luminosity uncertainty is therefore larger in the muon channel.

Uncertainties in the jet energy scale (JES) and jet energy resolution (JER) were determined primarily from simulations [31]. The JES uncertainty varies as a function of jet $p_T$ and $\eta$, and ranges from around 10% at 20 GeV to about 8% at 100 GeV. The JER uncertainty is 14% of the jet energy resolution. To take into account the differences in calorimeter response to quark- and gluon-initiated jets, an additional uncertainty of 5% was added in quadrature to the JES uncertainty, based on the average difference in simulation of the calorimeter response between jets in the $W$ + jets samples compared to those in the dijet samples (on which the JES calibration is based). Uncertainties in the JES due to nearby jets in $W$ + jets events were also studied but found to be small. To estimate the impact of the JES uncertainty, jet energies in the simulated events were shifted by the JES uncertainty, and the $E_T^{\text{miss}}$ vector was recomputed. In addition, calorimeter clusters not associated to a jet or electron, such as those coming from the underlying event, were scaled using a $p_T$-dependent uncertainty [27], ranging from ±20% for $p_T \simeq 500$ MeV to ±5% at high $p_T$. Similarly the jet energies were smeared with a Gaussian representing the JER uncertainty and the $E_T^{\text{miss}}$ vector was recomputed. The full analysis was repeated with these variations, and the cross sections were recomputed; the change in the cross section was taken as the systematic uncertainty. The impact of the JES and $E_T^{\text{miss}}$ uncertainties on the cross section uncertainty was approximately 10%.

A significant source of uncertainty in the electron channel is the potential bias in the sample selection for building the template shape of the QCD background; with the current selection requirements, the contribution from semileptonic heavy flavour decays is underestimated. The size of the effect was determined with simulated events by comparing the background estimates from two templates: one based on the electron selection used for this cross section measurement and the other based on the selection used for the QCD background estimation in the electron channel. The resulting uncertainty on the QCD background estimate, including significant contributions from the limited statistics of the simulated event samples, was as high as 50%, but the effect on the cross section for the inclusive 1-jet bin was about 5%. The fit region for the QCD background was varied by ±5 GeV to account for shape differences in the low $E_T^{\text{miss}}$ region; the resulting uncertainty on the cross section was 1 ± 2%.

The uncertainty in the electron identification efficiency was taken from the inclusive cross section measurement [27]. By examining the reconstruction efficiency in simulated events as a function of the $\Delta R$ separation between the jet and the electron, the reconstruction efficiency was found to be consistent with the value in Ref. [27]. Furthermore, in the region $\Delta R > 0.5$, the efficiency was found to be constant as a function of $\Delta R$ and as a function of jet multiplicity. The uncertainty in the muon reconstruction efficiency was estimated by comparing the efficiency measured with simulated events to that measured in the data with muons from $Z \rightarrow \mu \mu$ decays, following a method similar to that described in Ref. [27]. The resulting uncer-
tainties in the cross section were approximately 5.5% in both electron and muon channels.

Other uncertainties which were considered include the trigger efficiency, jet reconstruction efficiency, lepton momentum scale and resolution, pile-up, and biases in the procedure for correcting for detector effects (for example, by comparing correction factors obtained with ALPGEN to those obtained with SHERPA). Their effect on the cross section was found to be smaller than the uncertainties described above. For example, the uncertainty on the electron energy resolution was based on extrapolations from test-beam measurements [27] and had a < 0.1% effect on the cross section. All of the above systematic uncertainties (except for the bias in the template shape for the QCD background in the electron channel) were also applied to the estimates of the QCD and leptonic backgrounds in both electron and muon channels. In addition, for the leptonic backgrounds the uncertainty in the NNLO cross sections was taken to be 5% for W/Z production as in Ref. [27]. The t\bar{t} cross section uncertainty was taken to be approximately 7%, amounting to the sum in quadrature of PDF uncertainties (3%) and uncertainties estimated by varying renormalisation and factorisation scales (6%) [33, 34].

The systematic uncertainties in the cross section measurement are summarised in Table 3 for N_{\text{jet}} ≥ 1; most of the uncertainties are approximately independent of jet multiplicity, except for the uncertainty due to the jet energy scale and resolution, and the QCD background in the electron channel. The dominant systematic uncertainties are shown as a function of jet multiplicity and leading jet p_T in Figure 2. Both distributions are similar for electron and muon channels; the uncertainty is therefore shown as a function of leading jet p_T for the muon channel. The main contribution to the other uncertainties in the electron channel comes from the QCD background (especially at high jet multiplicities), the electron identification efficiency and the electron energy scale. For the muon channel, the main contribution is from the muon reconstruction efficiency.

In the cross section ratio measurement, the uncertainty due to the jet energy scale uncertainty remains the dominant effect, amounting to approximately 10% on the ratio. The luminosity uncertainty does not completely cancel in the ratio because the background estimates are affected by the luminosity uncertainty and the background levels vary as a function of jet multiplicity.

7. Results and Conclusions

The measured W+jets cross section (multiplied by the leptonic branching ratio) and the cross section ratios are shown as a function of corrected jet multiplicity in Tables 3 and 4 respectively, as well as in Figures 3 and 4. The measurement was not performed in the inclusive 4-jet bin in the electron channel because of the poor signal-to-background ratio.

<table>
<thead>
<tr>
<th>Electron channel process</th>
<th>N_{\text{jet}} ≥ 0</th>
<th>N_{\text{jet}} ≥ 1</th>
<th>N_{\text{jet}} ≥ 2</th>
<th>N_{\text{jet}} ≥ 3</th>
<th>N_{\text{jet}} ≥ 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>QCD</td>
<td>130^{+20}_{-60}</td>
<td>100^{+20}_{-40}</td>
<td>45^{+7}_{-20}</td>
<td>18^{+3}_{-8}</td>
<td>-</td>
</tr>
<tr>
<td>W → τν</td>
<td>113 ± 11</td>
<td>25 ± 5</td>
<td>4 ± 2</td>
<td>0.5 ± 0.4</td>
<td>-</td>
</tr>
<tr>
<td>Z → ee</td>
<td>10 ± 8</td>
<td>7 ± 6</td>
<td>3 ± 2</td>
<td>1 ± 1</td>
<td>-</td>
</tr>
<tr>
<td>tt</td>
<td>17 ± 2</td>
<td>17 ± 2</td>
<td>17 ± 2</td>
<td>14 ± 2</td>
<td>-</td>
</tr>
<tr>
<td>Observed in Data</td>
<td>4216</td>
<td>987</td>
<td>276</td>
<td>83</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Muon channel process</th>
<th>N_{\text{jet}} ≥ 0</th>
<th>N_{\text{jet}} ≥ 1</th>
<th>N_{\text{jet}} ≥ 2</th>
<th>N_{\text{jet}} ≥ 3</th>
<th>N_{\text{jet}} ≥ 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>QCD</td>
<td>30 ± 20</td>
<td>20 ± 13</td>
<td>4^{+10}_{-4}</td>
<td>2 ± 2</td>
<td>1 ± 1</td>
</tr>
<tr>
<td>W → τν</td>
<td>133 ± 12</td>
<td>24 ± 6</td>
<td>5 ± 2</td>
<td>0.9 ± 0.5</td>
<td>0.4 ± 0.3</td>
</tr>
<tr>
<td>Z → μν</td>
<td>170 ± 14</td>
<td>30 ± 4</td>
<td>8 ± 1</td>
<td>2 ± 0.5</td>
<td>0.6 ± 0.2</td>
</tr>
<tr>
<td>tt</td>
<td>18 ± 2</td>
<td>18 ± 2</td>
<td>18 ± 2</td>
<td>16 ± 2</td>
<td>11 ± 1</td>
</tr>
<tr>
<td>Observed in Data</td>
<td>4911</td>
<td>1049</td>
<td>292</td>
<td>95</td>
<td>36</td>
</tr>
</tbody>
</table>

Table 2: Summary of background yields and observed number of events for the electron and muon channels with systematic uncertainties, excluding the luminosity uncertainty. Statistical uncertainties are negligible compared to systematic uncertainties. The uncertainty in the backgrounds due to the luminosity uncertainty is 11% for all backgrounds except for the QCD background, since it was normalised to the data. The measurement was not performed in the inclusive 4-jet bin in the electron channel because of the poor signal-to-background ratio.
cross section (times leptonic branching ratio) is shown as a function of the \( p_T \) of the leading and next-to-leading jets in the event in Figure 3; the leading jet is shown for \( N_{\text{jet}} \geq 1 \) and the next-to-leading jet is shown for \( N_{\text{jet}} \geq 2 \).

Also shown in Figures 3, 4, and 5 are particle-level expectations from PYTHIA, ALPGEN and SHERPA simulations as well as a calculation using MCFM v5.8 [35]. PYTHIA is LO, while ALPGEN and SHERPA match higher-order predictions by comparing the acceptance before radiation with PYTHIA and ALPGEN (both using PHOTOS) and with SHERPA, comparing the acceptance after radiation, but summing up the photons within \( \Delta R = 0.1 \) around the lepton. This factor \((\simeq 1 - 2\%)\) was applied as a correction to the MCFM prediction.

The systematic uncertainty in the MCFM cross sections due to fragmentation was estimated by comparing AMBT1 [19] event generator tune with the tune from JIMMY [10] as well as by varying the AMBT1 tune to increase the underlying event activity by approximately 10%. Renormalisation and factorisation scale uncertainties were estimated by varying the scales, in all combinations, up and down, by factors of two. PDF uncertainties were computed by summing in quadrature the dependence on each of the 22 eigenvectors characterising the CTEQ6.6 PDF set; the uncertainty in

<table>
<thead>
<tr>
<th>Effect</th>
<th>( \pm 10% ) (dependent on jet ( \eta ) and ( p_T )) ( \oplus 5% )</th>
<th>( \pm 11% ), (-9%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jet energy scale and ( E_T^{\text{miss}} )</td>
<td>14% on each jet</td>
<td>( \pm 1% )</td>
</tr>
<tr>
<td>Jet energy resolution</td>
<td>( \pm 0.5% )</td>
<td>( \mp 0.7)</td>
</tr>
<tr>
<td>Electron trigger</td>
<td>( \pm 5.2% )</td>
<td>( \mp 5.5)</td>
</tr>
<tr>
<td>Electron identification</td>
<td>( \pm 3% )</td>
<td>( \mp 3.9), (-4.7)</td>
</tr>
<tr>
<td>Electron energy scale</td>
<td>4 - 7% in lowest jet ( p_T ) bin</td>
<td>( \pm 1.9)</td>
</tr>
<tr>
<td>Pile-up removal cut</td>
<td>from simulation</td>
<td>( \pm 2.2)</td>
</tr>
<tr>
<td>Residual pile-up effects</td>
<td>from template variation</td>
<td>(-1.5), (+5.2)</td>
</tr>
<tr>
<td>Luminosity</td>
<td>( \pm 11% )</td>
<td>(-10), (+13)</td>
</tr>
</tbody>
</table>

Table 3: Summary of the systematic uncertainties in the cross section. The uncertainties are shown only for \( N_{\text{jet}} \geq 1 \). The sign convention for the JES and lepton energy scale uncertainties is such that a positive change in the energy scale results in an increase in the jet or lepton energy observed in the data.
Figure 2: Summary of the systematic uncertainties on the cross section measurement shown as a function of jet multiplicity in the electron channel (left) and leading-jet $p_T$ in the muon channel (right). The jet energy scale uncertainty includes the uncertainty on $E_T^{miss}$. The main contribution to the “sum of other uncertainties” in the electron channel comes from the QCD background (especially at high jet multiplicities), the electron identification efficiency and the electron energy scale. For the muon channel, the main contribution is from the muon reconstruction efficiency.

Figure 3: $W$+jets cross-section results as a function of corrected jet multiplicity. Left: electron channel. Right: muon channel. The cross sections are quoted in a limited and well-defined kinematic region, described in the text. For the data, the statistical uncertainties are shown by the vertical bars, and the combined statistical and systematic uncertainties are shown by the hashed regions. Note that the uncertainties are correlated from bin to bin. Also shown are predictions from PYTHIA, ALPGEN, SHERPA and MCFM, and the ratio of theoretical predictions to data (PYTHIA is not shown in the ratio). The theoretical uncertainties are shown only for MCFM, which provides NLO predictions for $N_{jet} \leq 2$ and a LO prediction for $N_{jet} = 3$. 
and are quoted in a limited and well-defined range of jet results have been corrected for all known detector effects of the leading and next-to-leading jets in the event. The jet multiplicity with (in order) statistical, systematic, and luminosity uncertainties. The cross sections are quoted in a limited and well-defined kinematic region, described in the text. The measurement was not performed in the inclusive 4-jet bin in the electron channel because of the poor signal-to-background ratio. Theoretical predictions from MCFM are also shown, with all uncertainties combined. MCFM provides NLO predictions for $N_{\text{jet}} \leq 2$ and a LO prediction for $N_{\text{jet}} = 3$.

<table>
<thead>
<tr>
<th>Jet multiplicity</th>
<th>$W \rightarrow e\nu$ (nb)</th>
<th>MCFM $W \rightarrow e\nu$ (nb)</th>
<th>$W \rightarrow \mu\nu$ (nb)</th>
<th>MCFM $W \rightarrow \mu\nu$ (nb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\geq 0$</td>
<td>$4.53 \pm 0.07^{+0.35}<em>{-0.30}^{+0.58}</em>{-0.47}$</td>
<td>$5.08^{+0.11}_{-0.30}$</td>
<td>$4.58 \pm 0.07^{+0.38}<em>{-0.32}^{+0.61}</em>{-0.48}$</td>
<td>$5.27^{+0.11}_{-0.32}$</td>
</tr>
<tr>
<td>$\geq 1$</td>
<td>$0.84 \pm 0.03^{+0.13}<em>{-0.10}^{+0.11}</em>{-0.09}$</td>
<td>$0.81^{+0.02}_{-0.04}$</td>
<td>$0.84 \pm 0.03^{+0.11}<em>{-0.09}^{+0.11}</em>{-0.09}$</td>
<td>$0.84^{+0.02}_{-0.04}$</td>
</tr>
<tr>
<td>$\geq 2$</td>
<td>$0.21 \pm 0.01^{+0.04}<em>{-0.03}^{+0.03}</em>{-0.02}$</td>
<td>$0.21^{+0.01}_{-0.02}$</td>
<td>$0.23 \pm 0.02^{+0.04}<em>{-0.03}^{+0.03}</em>{-0.02}$</td>
<td>$0.21^{+0.01}_{-0.02}$</td>
</tr>
<tr>
<td>$\geq 3$</td>
<td>$0.047 \pm 0.007^{+0.014}<em>{-0.011}^{+0.008}</em>{-0.006}$</td>
<td>$0.05 \pm 0.02$</td>
<td>$0.064 \pm 0.008^{+0.016}<em>{-0.014}^{+0.010}</em>{-0.008}$</td>
<td>$0.05 \pm 0.02$</td>
</tr>
<tr>
<td>$\geq 4$</td>
<td>-</td>
<td>-</td>
<td>$0.019 \pm 0.005 \pm 0.006^{+0.004}_{-0.003}$</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 4: The measured cross section times leptonic branching ratio for $W$+jets in the electron and muon channels as a function of corrected jet multiplicity with (in order) statistical, systematic, and luminosity uncertainties. The cross sections are quoted in a limited and well-defined kinematic region, described in the text. The measurement was not performed in the inclusive 4-jet bin in the electron channel because of the poor signal-to-background ratio. Theoretical predictions from MCFM are also shown, with all uncertainties combined. MCFM provides NLO predictions for $N_{\text{jet}} \leq 2$ and a LO prediction for $N_{\text{jet}} = 3$.

<table>
<thead>
<tr>
<th>Jet multiplicity</th>
<th>$W \rightarrow e\nu$</th>
<th>MCFM $W \rightarrow e\nu$</th>
<th>$W \rightarrow \mu\nu$</th>
<th>MCFM $W \rightarrow \mu\nu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\geq 1/ \geq 0$</td>
<td>$0.185 \pm 0.007^{+0.025}_{-0.019}$</td>
<td>$0.159^{+0.006}_{-0.005}$</td>
<td>$0.183 \pm 0.007^{+0.023}_{-0.020}$</td>
<td>$0.160^{+0.006}_{-0.005}$</td>
</tr>
<tr>
<td>$\geq 2/ \geq 1$</td>
<td>$0.250 \pm 0.019^{+0.019}_{-0.010}$</td>
<td>$0.255^{+0.017}_{-0.022}$</td>
<td>$0.274 \pm 0.020^{+0.018}_{-0.011}$</td>
<td>$0.255^{+0.017}_{-0.021}$</td>
</tr>
<tr>
<td>$\geq 3/ \geq 2$</td>
<td>$0.224 \pm 0.037 \pm 0.022$</td>
<td>$0.241^{+0.108}_{-0.061}$</td>
<td>$0.278 \pm 0.041^{+0.024}_{-0.020}$</td>
<td>$0.242^{+0.104}_{-0.061}$</td>
</tr>
<tr>
<td>$\geq 4/ \geq 3$</td>
<td>-</td>
<td>-</td>
<td>$0.297 \pm 0.088^{+0.037}_{-0.026}$</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 5: The measured cross section ratio for $W$+jets in the electron and muon channels as a function of corrected jet multiplicity with (in order) statistical and systematic uncertainties. The cross section ratios are quoted in a limited and well-defined kinematic region, described in the text. The measurement was not performed in the inclusive 4-jet bin in the electron channel because of the poor signal-to-background ratio. Theoretical predictions from MCFM are also shown, with all uncertainties combined. MCFM provides NLO predictions for $N_{\text{jet}} \leq 2$ and a LO prediction for $N_{\text{jet}} = 3$.

$\alpha_s$ was also taken into account. An alternative PDF set, MSTW2008 [13], with its set of 68% C.L. eigenvectors was also examined, and the envelope of the uncertainties from CTEQ6.6 and MSTW2008 was taken as the final PDF uncertainty. The total resulting uncertainties are given in Tables 4 and 5.

In conclusion, this Letter presents a measurement of the $W$+jets cross section as a function of jet multiplicity in $pp$ collisions at $\sqrt{s} = 7$ TeV in both electron and muon decay modes of the $W$ boson, based on an integrated luminosity of 1.3 $pb^{-1}$ recorded with the ATLAS detector. Measurements are also presented of the ratio of cross sections $\sigma(W+ \geq n)/\sigma(W+ \geq n-1)$ for inclusive jet multiplicities $n = 1 - 4$, and of the $p_T$ distribution of the leading and next-to-leading jets in the event. The results have been corrected for all known detector effects and are quoted in a limited and well-defined range of jet and lepton kinematics. This range is fully covered by the detector acceptance, so as to avoid model-dependent extrapolations and to facilitate comparisons with theoretical predictions. As expected, the PYTHIA samples considered, which contain a $2 \rightarrow 1$ matrix element merged with a $2 \rightarrow 2$ matrix element and a leading-logarithmic parton shower, does not provide a good description of the data for jet multiplicities greater than one. Good agreement is observed with the predictions of the multi-parton matrix element generators ALPGEN and SHERPA. Calculations based on $O(\alpha_s^3)$ matrix elements in MCFM (available for jet multiplicities $n \leq 2$) are also in good agreement with the data.

8. Acknowledgements

We wish to thank CERN for the efficient commissioning and operation of the LHC during this initial high-
Figure 4: $W$+jets cross-section ratio results as a function of corrected jet multiplicity. Left: electron channel. Right: muon channel. The cross sections are quoted in a limited and well-defined kinematic region, described in the text. For the data, the statistical uncertainties are shown by the vertical bars, and the combined statistical and systematic uncertainties are shown by the hashed regions. Also shown are theoretical predictions from PYTHIA, ALPGEN, SHERPA, and MCFM. The theoretical uncertainties are shown only for MCFM, which provides NLO predictions for $N_{\text{jet}} \leq 2$ and a LO prediction for $N_{\text{jet}} = 3$.

energy data-taking period as well as the support staff from our institutions without whom ATLAS could not be operated efficiently.

We acknowledge the support of ANPCyT, Argentina; YerPhI, Armenia; ARC, Australia; BMWF, Austria; ANAS, Azerbaijan; SSTC, Belarus; CNPq and FAPESP, Brazil; NSERC, NRC and CFI, Canada; CERN; CONICYT, Chile; CAS, MOST and NSFC, China; COLCIENCIAS, Colombia; MSMT CR, MPO CR and VSC CR, Czech Republic; DLRF, DNSRC 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, MINEVA, GIF, DIP and BENOZOY CENTER, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; FOM and NWO, Netherlands; REN, Norway; MNISW, Poland; GRICES and FCT, Portugal; MERTYS (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 Wallace Foundation, Sweden; SER, SNSF and Cantons of Bern and Geneva, Switzerland; NSEC, 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

Figure 5: $W$+jets cross-section as a function of the $p_T$ of the two leading jets in the event. The $p_T$ of the leading jet is shown for events with $\geq 1$ jet while the $p_T$ of the next-to-leading jet is shown for events with $\geq 2$ jets. Left: electron channel. Right: muon channel. The cross sections are quoted in a limited and well-defined kinematic region, described in the text. For the data, the statistical uncertainties are shown by the vertical bars, and the combined statistical and systematic uncertainties are shown by the hashed regions. Also shown are theoretical predictions from PYTHIA, ALPGEN, SHERPA and MCFM, and the ratio of theoretical predictions to data (PYTHIA is not shown in the ratio). The theoretical uncertainties are shown only for MCFM, which provides NLO predictions for $N_{\text{jet}} \leq 2$ and a LO prediction for $N_{\text{jet}} = 3$. 
The ATLAS Collaboration

G. Aad\textsuperscript{18}, B. Abbott\textsuperscript{111}, J. Abdallah\textsuperscript{11}, A.A. Abdelalim\textsuperscript{49}, A. Abdesselam\textsuperscript{118}, O. Abdinov\textsuperscript{10}, B. Abi\textsuperscript{112}, M. Abolins\textsuperscript{88}, H. Abramowicz\textsuperscript{153}, H. Abreu\textsuperscript{115}, E. Achenholt\textsuperscript{88a,88b}, B.S. Acharya\textsuperscript{164a,164b}, M. Ackers\textsuperscript{95}, D.L. Adams\textsuperscript{24}, T.N. Addy\textsuperscript{36}, J. Adelman\textsuperscript{175}, M. Adier\textsuperscript{92}, S. Adolfiti\textsuperscript{98}, P. Adragna\textsuperscript{75}, T. Adye\textsuperscript{129}, T. Aecks\textsuperscript{22}, J.A. Aguilar-Saavedra\textsuperscript{124a,84}, M. Aharrouche\textsuperscript{84}, S.P. Ahlen\textsuperscript{81}, A. Ahmadi\textsuperscript{148}, M. Ahsan\textsuperscript{80}, G. Aielli\textsuperscript{133a,133b}, T. Akdogan\textsuperscript{18a}, T.P.A. Akesson\textsuperscript{83}, G. Akimoto\textsuperscript{155}, A.V. Akimov\textsuperscript{94}, M.S. Alam\textsuperscript{81}, M.A. Alam\textsuperscript{88}, S. Albrand\textsuperscript{50}, M. Aleksa\textsuperscript{99}, I.N. Aleksandrov\textsuperscript{65}, M. Allepuz\textsuperscript{89a,89b}, F. Alessandrini\textsuperscript{89a,89b}, C. Alexa\textsuperscript{25a}, G. Alexander\textsuperscript{153}, G. Alexandre\textsuperscript{49}, T. Alexopoulos\textsuperscript{80}, M. Alhubb\textsuperscript{14a,15}, M. Aliev\textsuperscript{15}, G. Alimonti\textsuperscript{89a}, J. Alison\textsuperscript{120}, M. Aliyev\textsuperscript{10}, P.P. Allport\textsuperscript{73}, S.E. Allwood-Spires\textsuperscript{53}, J. Almond\textsuperscript{82,102a,102b}, R. Alon\textsuperscript{171}, A. Alonso\textsuperscript{79}, J. Alonso\textsuperscript{14}, M.G. Alviggi\textsuperscript{102a,102b}, K. Anako\textsuperscript{66}, P. Amara\textsuperscript{29}, C. Amelung\textsuperscript{22}, V.V. Ammosov\textsuperscript{128}, A. Amorim\textsuperscript{124a,84}, G. Amorós\textsuperscript{167}, N. Amran\textsuperscript{53}, C. Anastopoulos\textsuperscript{139}, T. Andeen\textsuperscript{144}, C.F. Anders\textsuperscript{29}, K.J. Anderson\textsuperscript{90}, A. Andreazza\textsuperscript{89a,89b}, V. Andrieu\textsuperscript{8a,88}, M.-L. Andrieux\textsuperscript{55}, X.S. Anduaga\textsuperscript{70}, A. Angerami\textsuperscript{34}, F. Anghinolfi\textsuperscript{29}, N. Anjos\textsuperscript{24a,144a}, A. Ammon\textsuperscript{47}, A. Antonaki\textsuperscript{88}, M. Antonelli\textsuperscript{88a,89b,98}, J. Antos\textsuperscript{24b,144b}, F. Anulli\textsuperscript{89a}, S. Aoun\textsuperscript{49}, L. Aperio Bélia\textsuperscript{3}, R. Apollin\textsuperscript{118}, G. Arabidze\textsuperscript{58}, I. Aracena\textsuperscript{143}, Y. Arai\textsuperscript{46}, A.T.H. Arce\textsuperscript{44}, J.P. Archambault\textsuperscript{59}, S.F. Arfib\textsuperscript{45}, J.-F. Arguin\textsuperscript{14}, E. Arik\textsuperscript{49a,*}, M. Arik\textsuperscript{18a}, A.J. Armbruster\textsuperscript{87}, K.E. Arts\textsuperscript{109}, S.R. Armstrong\textsuperscript{24}, O. Arnaez\textsuperscript{81}, C. Arnaul\textsuperscript{115}, A. Artamonov\textsuperscript{95}, G. Artoni\textsuperscript{132a,132b}, D. Arutinov\textsuperscript{20}, S. Asa\textsuperscript{155}, R. Asfandiyar\textsuperscript{172}, S. Aske\textsuperscript{27}, B. Åsa\textsuperscript{146a,146b}, L. Asquith\textsuperscript{3}, K. Assamagan\textsuperscript{24}, A. Astbury\textsuperscript{98}, A. Astvatsatuov\textsuperscript{92}, G. Ati\textsuperscript{175}, B. Aubert\textsuperscript{4}, B. Auerbach\textsuperscript{175}, E. Auge\textsuperscript{115}, K. Augsten\textsuperscript{127}, M. Aurousseau\textsuperscript{4}, N. Austin\textsuperscript{73}, R. Avramidou\textsuperscript{9}, D. Axen\textsuperscript{168}, C. Ay\textsuperscript{54}, G. Auzelou\textsuperscript{93,d}, Y. Azuma\textsuperscript{155}, M.A. Baak\textsuperscript{29}, G. Baccaglioni\textsuperscript{89a,89b}, C. Bacci\textsuperscript{34a,134b}, A.M. Bach\textsuperscript{14}, H. Bacha\textsuperscript{130}, K. Bachas\textsuperscript{29}, G. Bagny\textsuperscript{29}, M. Backes\textsuperscript{49}, E. Badescu\textsuperscript{25a}, P. Bagna\textsuperscript{132a,132b}, S. Bahinipati\textsuperscript{2}, Y. Bai\textsuperscript{32a,126}, D.C. Bailey\textsuperscript{158}, T. Bain\textsuperscript{158}, J.T. Baines\textsuperscript{50a,50b}, O. Baroncelli\textsuperscript{19b}, A. Barbado\textsuperscript{144a}, F. Barbaro\textsuperscript{144b}, A. Barashkou\textsuperscript{169}, V. Banis\textsuperscript{27}, N. Bannister\textsuperscript{129}, R.M. Barnett\textsuperscript{144}, A. Barconelli\textsuperscript{134a}, A.J. Bar\textsuperscript{118}, F. Barone\textsuperscript{80}, J. Barreiro\textsuperscript{80}, J. Barreiro Guimarães da Costa\textsuperscript{57}, P. Barrillo\textsuperscript{115}, R. Bartoldus\textsuperscript{143}, A.E. Barton\textsuperscript{71}, D. Bartsch\textsuperscript{20}, R.L. Bates\textsuperscript{53}, L. Batkova\textsuperscript{44a}, J.R. Batley\textsuperscript{27}, A. Battaglia\textsuperscript{16}, M. Battistin\textsuperscript{29}, G. Battistoni\textsuperscript{89a}, F. Bauer\textsuperscript{136}, H.S. Bawa\textsuperscript{143}, B. Baur\textsuperscript{158}.
Physics, Box 19059, Arlington, TX 76019, United States of America
8 University of Athens, Nuclear & Particle Physics, Department of Physics, Panepistimiopolis, Zografou, GR 15771 Athens, Greece
9 National Technical University of Athens, Physics Department, 9-Iroon Polytechnio, GR 15780 Zografou, Greece
10 Institute of Physics, Azerbaijan Academy of Sciences, H. Javid Avenue 33, AZ 143 Baku, Azerbaijan
11 Institut de Física d’Altes Energies, IFAE, Edifici Cu, Universitat Autònoma de Barcelona, ES - 08193 Bellaterra (Barcelona), Spain
12 University of Belgrade(a), Institute of Physics, P.O. Box 57, 11001 Belgrade; Vinca Institute of Nuclear Sciences(b), M. Petrovica Alasa 12-14, 11000 Belgrade, Serbia, Serbia
13 University of Bergen, Department for Physics and Technology, Allegaten 55, NO - 5007 Bergen, Norway
14 Lawrence Berkeley National Laboratory and University of California, Physics Division, MS05B-6227, 1 Cyclotron Road, Berkeley, CA 94720, United States of America
15 Humboldt University, Institute of Physics, Berlin, Newtonstr. 15, D-12489 Berlin, Germany
16 University of Bern, Albert Einstein Center for Fundamental Physics, Laboratory for High Energy Physics, Siderstrasse 5, CH - 3012 Bern, Switzerland
17 University of Birmingham, School of Physics and Astronomy, Edgbaston, Birmingham B15 2TT, United Kingdom
18 Bogazici University(a), Faculty of Sciences, Department of Physics, TR - 80815 Bebek-Istanbul; Dögus University(b), Faculty of Arts and Sciences, Department of Physics, 34722, Kadiköy, Istanbul; Gaziantep University, Faculty of Engineering, Department of Physics Engineering, 27310, Sehitkamil, Gaziantep, Turkey; Istanbul Technical University(d), Faculty of Arts and Sciences, Department of Physics, 34469, Maslak, Istanbul, Turkey
19 INFN Sezione di Bologna(a): Università di Bologna, Dipartimento di Fisica(b), viale C. Berti Pichat, 6/2, IT - 40127 Bologna, Italy
20 University of Bonn, Physikalisches Institut, Nussallee 12, D - 53115 Bonn, Germany
21 Boston University, Department of Physics, 590 Commonwealth Avenue, Boston, MA 02215, United States of America
22 Brandeis University, Department of Physics, MS057, 415 South Street, Waltham, MA 02454, United States of America
23 Universidade Federal do Rio De Janeiro, COPPE/EE/IF (c), Caixa Postal 68528, Ilha do Fundao, BR - 21945-970 Rio de Janeiro; (d)Universidade de Sao Paulo, Instituto de Fisica, R.do Matao Trav. R.187, Sao Paulo - SP, 05508 - 900, Brazil
24 Brookhaven National Laboratory, Physics Department, Bldg. 510A, Upton, NY 11973, United States of America
25 National Institute of Physics and Nuclear Engineering(a) Bucharest-Magurele, Str. Atomistilor 407, P.O. Box MG-6, R-077125, Romania; University Politehnica Bucharest(b), Rectorat - AN 001, 313 Splaiul Independentei, sector 6, 060042 Bucuresti; West University(c) in Timisoara, Bd. Vasile Parvan 4, Timisoara, Romania
26 Universidad de Buenos Aires, FCEyN, Dto. Física, Pab I - C. Universitaria, 1428 Buenos Aires, Argentina
27 University of Cambridge, Cavendish Laboratory, J J Thomson Avenue, Cambridge CB3 0HE, United Kingdom
28 Carleton University, Department of Physics, 1125 Colonel By Drive, Ottawa ON K1S 5B6, Canada
29 CERN, CH - 1211 Geneva 23, Switzerland
30 University of Chicago, Enrico Fermi Institute, 5640 S. Ellis Avenue, Chicago, IL 60637, United States of America
31 Pontificia Universidad Católica de Chile, Facultad de Física, Departamento de Física(a), Avda. Vicuna Mackenna 4860, San Joaquin, Santiago; Universidad Técnica Federico Santa María, Departamento de Física(b), Avda. Española 1680, Casilla 110-V, Valparaíso, Chile
32 Institute of High Energy Physics, Chinese Academy of Sciences(a), P.O. Box 918, 19 Yuquan Road, Shijingshan District, CN - Beijing 100049; University of Science & Technology of China (USTC), Department of Modern Physics(b), Hefei, CN - Anhui 230026; Nanjing University, Department of Physics(c), Nanjing, CN - Jiangsu 210093; Shandong University, High Energy Physics Group(d), Jinan, CN - Shandong 250100, China
33 Laboratoire de Physique Corpusculaire, Clermont Université, Université Blaise Pascal, CNRS/IN2P3, FR - 63177 Aubiere Cedex, France
34 Columbia University, Nevis Laboratory, 136 So. Broadway, Irvington, NY 10533, United States of America
35 University of Copenhagen, Niels Bohr Institute, Blegdamsvej 17, DK - 2100 Kobenhavn 0, Denmark
36 INFN Gruppo Collegato di Cosenza(a); Università della Calabria, Dipartimento di Fisica(b), IT-87036 Arcavacata di Rende, Italy
37 Faculty of Physics and Applied Computer Science of the AGH-University of Science and Technology, (FPACS, AGH-UST), al. Mickiewicza 30, PL-30059 Cracow, Poland
38 The Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, ul. Radzikowskiego 152, PL - 31342 Krakow, Poland
39 Southern Methodist University, Physics Department, 106 Fondren Science Building, Dallas, TX 75275-0175, United States of America
40 University of Texas at Dallas, 800 West Campbell Road, Richardson, TX 75080-3021, United States of America
41 DESY, Notkestr. 85, D-22603 Hamburg and Platanenallee 6, D-15738 Zeuthen, Germany
42 TU Dortmund, Experimentelle Physik IV, DE - 44221 Dortmund, Germany
43 Technical University Dresden, Institut für Kern- und Teilchenphysik, Zellescher Weg 19, D-01069 Dresden, Germany
44 Duke University, Department of Physics, Durham, NC 27708, United States of America
45 University of Edinburgh, School of Physics & Astronomy, James Clerk Maxwell Building, The Kings Buildings, Mayfield Road, Edinburgh EH9 3JZ, United Kingdom
46 Fachhochschule Wiener Neustadt; Johannes Gutenbergstrasse 3 AT - 2700 Wiener Neustadt, Austria
47 INFN Laboratori Nazionali di Frascati, via Enrico Fermi 40, IT-00044 Frascati, Italy
48 Albert-Ludwigs-Universität, Fakultät für Mathematik und Physik, Hermann-Herder Str. 3, D - 79104 Freiburg i.Br., Germany
49 Université de Genève, Section de Physique, 24 rue Ernest Ansermet, CH - 1211 Genève 4, Switzerland
50 INFN Sezione di Genova(a), Università di Genova, Dipartimento di Fisica(b), via Dodecaneso 33, IT - 16146 Genova, Italy
51 Institute of Physics of the Georgian Academy of Sciences, 6 Tamarashvili St., GE - 380077 Tbilisi; Tbilisi State University, HEP Institute, University St. 9, GE - 38086 Tbilisi, Georgia
52 Justus-Liebig-Universität Giessen, II Physikalisches Institut, Heinrich-Buff-Ring 16, D-35392 Giessen, Germany
53 University of Glasgow, Department of Physics and Astronomy, Glasgow G12 8QQ, United Kingdom
54 Georg-August-Universität, II. Physikalisches Institut, Friedrich-Hund Platz 1, D-37077 Göttingen, Germany
55 LPSC, CNRS/IN2P3 and Univ. Joseph Fourier Grenoble, 53 avenue des Martyrs, FR-38026 Grenoble Cedex, France
56 Hampton University, Department of Physics, Hampton, VA 23668, United States of America
57 Harvard University, Laboratory for Particle Physics and Cosmology, 18 Hammond Street, Cambridge, MA 02138, United States of America
58 Ruprecht-Karls-Universität Heidelberg; Kirchhoff-Institut für Physik(a), Im Neuenheimer Feld 227, D-69120 Heidelberg; Physikalisches Institut(b), Philosophenweg 12, D-69120 Heidelberg; ZITI Ruprecht-Karls-Universität Heidelberg(c), Lehrstuhl für Informatik V, B6, 23-29, DE - 68131 Mannheim, Germany
59 Hiroshima University, Faculty of Science, 1-3-1 Kagamiyama, Higashihiroshima-shi, JP - Hiroshima 739-8526, Japan
60 Hiroshima Institute of Technology, Faculty of Applied Information Science, 2-1-1 Miyake Saeki-ku, Hiroshima-shi, JP - Hiroshima 731-5193, Japan
61 Indiana University, Department of Physics, Swain Hall West 117, Bloomington, IN 47405-7105, United States of America
62 Institut für Astro- und Teilchenphysik, Technikerstrasse 25, A - 6020 Innsbruck, Austria
63 University of Iowa, 203 Van Allen Hall, Iowa City, IA 52242-1479, United States of America
64 Iowa State University, Department of Physics and Astronomy, Ames High Energy Physics Group, Ames, IA 50011-3160, United States of America
65 Joint Institute for Nuclear Research, JINR Dubna, RU-141980 Moscow Region, Russia, Russia
66 KEK, High Energy Accelerator Research Organization, 1-1 Oho, Tsukuba-shi, Ibaraki-ken 305-0801, Japan
67 Kobe University, Graduate School of Science, 1-1 Rokkodai-cho, Nada-ku, JP Kobe 657-8501, Japan
68 Kyoto University, Faculty of Science, Oiwake-cho, Kitashirakawa, Sakyou-ku, Kyoto-shi, JP - Kyoto 606-8502, Japan
69 Kyoto University of Education, 1 Fukakusa, Fujimori, fushimi-ku, Kyoto-shi, JP - Kyoto 612-8522, Japan
70 Universidad Nacional de La Plata, FCE, Departamento de Física, IFLP (CONICET-UNLP), C.C. 67, 1900 La Plata, Argentina
71 Lancaster University, Physics Department, Lancaster LA1 4YB, United Kingdom
72 INFN Sezione di Lecce(a); Università del Salento, Dipartimento di Fisica(b) Via Arnesano IT - 73100 Lecce, Italy
73 University of Liverpool, Oliver Lodge Laboratory, P.O. Box 147, Oxford Street, Liverpool L69 3BX, United Kingdom
74 Jožef Stefan Institute and University of Ljubljana, Department of Physics, SI-1000 Ljubljana, Slovenia
75 Queen Mary University of London, Department of Physics, Mile End Road, London E1 4NS, United Kingdom
76 Royal Holloway, University of London, Department of Physics, Egham Hill, Egham, Surrey TW20 0EX, United Kingdom
77 University College London, Department of Physics and Astronomy, Gower Street, London WC1E 6BT, United Kingdom
78 Laboratoire de Physique Nucléaire et de Hautes Energies, Université Pierre et Marie Curie (Paris 6), Université Denis Diderot (Paris-7), CNRS/IN2P3, Tour 33, 4 place Jussieu, FR - 75252 Paris Cedex 05, France
79 Fysiska institutionen, Lunds universitet, Box 118, SE - 221 00 Lund, Sweden
80 Universidad Autonoma de Madrid, Facultad de Ciencias, Departamento de Física Teórica, ES - 28049 Madrid, Spain
81 Universität Mainz, Institut für Physik, Staudinger Weg 7, DE - 55099 Mainz, Germany
82 University of Manchester, School of Physics and Astronomy, Manchester M13 9PL, United Kingdom
83 CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille, France
84 University of Massachusetts, Department of Physics,
710 North Pleasant Street, Amherst, MA 01003, United States of America

McGill University, High Energy Physics Group, 3600 University Street, Montreal, Quebec H3A 2T8, Canada

University of Melbourne, School of Physics, AU - Parkville, Victoria 3010, Australia

The University of Michigan, Department of Physics, 2477 Randall Laboratory, 500 East University, Ann Arbor, MI 48109-1120, United States of America

Michigan State University, Department of Physics and Astronomy, High Energy Physics Group, East Lansing, MI 48824-2320, United States of America

INFN Sezione di Milano(a); Università di Milano, Dipartimento di Fisica(b), via Celoria 16, IT - 20133 Milano, Italy

B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Independence Avenue 68, Minsk 220072, Republic of Belarus

National Scientific & Educational Centre for Particle & High Energy Physics, NC PHEP BSU, M. Bogdanovich St. 153, Minsk 220040, Republic of Belarus

Massachusetts Institute of Technology, Department of Physics, Room 24-516, Cambridge, MA 02139, United States of America

University of Montreal, Group of Particle Physics, C.P. 6128, Succursale Centre-Ville, Montreal, Quebec, H3C 3J7, Canada

P.N. Lebedev Institute of Physics, Academy of Sciences, Leninsky pr. 53, RU - 117 924 Moscow, Russia

Institute for Theoretical and Experimental Physics (ITEP), B. Cheremushkinskaya ul. 25, RU 117 218 Moscow, Russia

Moscow Engineering & Physics Institute (MEPhI), Kashirskoe Shosse 31, RU - 115409 Moscow, Russia

M. V. Lomonosov Moscow State University Skobeltsyn Institute of Nuclear Physics (MSU SINP), 1(2), Leninskaya gory, GSP-1, Moscow 119991 Russian Federation, Russia

Ludwig-Maximilians-Universität München, Fakultät für Physik, Am Coulombwall 1, DE - 85748 Garching, Germany

Max-Planck-Institut für Physik, (Werner-Heisenberg-Institut), Föhringer Ring 6, 80805 München, Germany

Nagasaki Institute of Applied Science, 536 Abamachi, JP Nagasaki 851-0193, Japan

Nagoya University, Graduate School of Science, Furo-Cho, Chikusa-ku, Nagoya, 464-8602, Japan

INFN Sezione di Napoli(a); Università di Napoli, Dipartimento di Scienze Fisiche(b), Complesso Universitario di Monte Sant'Angelo, via Cinthia, IT - 80126 Napoli, Italy

University of New Mexico, Department of Physics and Astronomy, MSC07 4220, Albuquerque, NM 87131 USA, United States of America

Radboud University Nijmegen/NIKHEF, Department of Experimental High Energy Physics, Heyendaalseweg 135, NL-6525 AJ, Nijmegen, Netherlands

Nikhef National Institute for Subatomic Physics, and University of Amsterdam, Science Park 105, 1098 XG Amsterdam, Netherlands

Department of Physics, Northern Illinois University, LaTourette Hall Normal Road, DeKalb, IL 60115, United States of America

Budker Institute of Nuclear Physics (BINP), RU - Novosibirsk 630 090, Russia

New York University, Department of Physics, 4 Washington Place, New York NY 10003, USA, United States of America

Ohio State University, 191 West Woodruff Ave, Columbus, OH 43210-1117, United States of America

Okayama University, Faculty of Science, Tsushimanaka 3-1-1, Okayama 700-8530, Japan

University of Oklahoma, Homer L. Dodge Department of Physics and Astronomy, 440 West Brooks, Room 100, Norman, OK 73019-0225, United States of America

Oklahoma State University, Department of Physics, 145 Physical Sciences Building, Stillwater, OK 74078-3072, United States of America

Palacky University, 17.listopadu 50a, 772 07 Olomouc, Czech Republic

University of Oregon, Center for High Energy Physics, Eugene, OR 97403-1274, United States of America

LAL, Univ. Paris-Sud, IN2P3/CNRS, Orsay, France

Osaka University, Graduate School of Science, Machikaneyama-machi 1-1, Toyonaka, Osaka 560-0043, Japan

University of Oslo, Department of Physics, P.O. Box 1048, Blindern, NO - 0316 Oslo 3, Norway

Oxford University, Department of Physics, Denys Wilkinson Building, Keble Road, Oxford OX1 3RH, United Kingdom

INFN Sezione di Pavia(a); Università di Pavia, Dipartimento di Fisica Nucleare e Teorica(b), Via Bassi 6, IT-27100 Pavia, Italy

University of Pennsylvania, Department of Physics, High Energy Physics Group, 209 S. 33rd Street, Philadelphia, PA 19104, United States of America

Petersburg Nuclear Physics Institute, RU - 188 300 Gatchina, Russia

INFN Sezione di Pisa(a); Università di Pisa, Dipartimento di Fisica E. Fermi(b), Largo B. Pontecorvo 3, IT - 56127 Pisa, Italy

University of Pittsburgh, Department of Physics and Astronomy, 3941 O'Hara Street, Pittsburgh, PA 15260, United States of America

Laboratorio de Instrumentacao e Fisica Experimental de Particulas - LIP(c), Avenida Elias Garcia 14-1, PT - 1000-149 Lisboa, Portugal; Universidad de Granada, Departamento de Fisica Teorica y del Cosmos and CAFPE(b), E-18071 Granada, Spain

Institute of Physics, Academy of Sciences of the Czech Republic, Na Slovance 2, CZ - 18221 Praha 8, Czech Republic

Charles University in Prague, Faculty of Mathematics
and Physics, Institute of Particle and Nuclear Physics, V Holesovickach 2, CZ - 18000 Praha 8, Czech Republic
127 Czech Technical University in Prague, Zikova 4, CZ - 166 35 Praha 6, Czech Republic
128 State Research Center Institute for High Energy Physics, Moscow Region, 142281, Protvino, Pobeda street, 1, Russia
129 Rutherford Appleton Laboratory, Science and Technology Facilities Council, Harwell Science and Innovation Campus, Didcot OX11 0QX, United Kingdom
130 University of Regina, Physics Department, Canada
131 Ritsumeikan University, Noji Higashi 1 chome 1-1, JP - Kusatsu, Shiga 525-8577, Japan
132 INFN Sezione di Roma I(a); Università La Sapienza, Dipartimento di Fisica(b), Piazzale A. Moro 2, IT- 00185 Roma, Italy
133 INFN Sezione di Roma Tor Vergata(a); Università di Roma Tor Vergata, Dipartimento di Fisica(b), via della Ricerca Scientifica, IT-00133 Roma, Italy
134 INFN Sezione di Roma Tre(a); Università Roma Tre, Dipartimento di Fisica(b), via della Vasca Navale 84, IT-00146 Roma, Italy
135 Réseau Universitaire de Physique des Hautes Énergies (RUPHE): Université Hassan II, Faculté des Sciences Ain Chock(a), B.P. 5366, MA - Casablanca; Centre National de l’Energie des Sciences Techniques Nucléaires (CNESTEN)(b), B.P. 1382 R.P. 10001 Rabat 10001; Université Mohammed Premier(c) LPTPM, Faculté des Sciences, B.P.717. Bd. Mohamed VI, 60000, Oujda ; Université Mohammed V, Faculté des Sciences(d) 4 Avenue Ibn Battouta, BP 1014 RP, 10000 Rabat, Morocco
136 CEA, DSM/IRFU, Centre d’Etudes de Saclay, FR - 91191 Gif-sur-Yvette, France
137 University of California Santa Cruz, Santa Cruz Institute for Particle Physics (SCIPP), Santa Cruz, CA 95064, United States of America
138 University of Washington, Seattle, Department of Physics, Box 351560, Seattle, WA 98195-1560, United States of America
139 University of Sheffield, Department of Physics & Astronomy, Hounsfield Road, Sheffield S3 7RH, United Kingdom
140 Shinshu University, Department of Physics, Faculty of Science, 3-1-1 Asahi, Matsumoto-shi, JP - Nagano 390-8621, Japan
141 Universität Siegen, Fachbereich Physik, D 57068 Siegen, Germany
142 Simon Fraser University, Department of Physics, 8888 University Drive, CA - Burnaby, BC V5A 1S6, Canada
143 SLAC National Accelerator Laboratory, Stanford, California 94309, United States of America
144 Comenius University, Faculty of Mathematics, Physics & Informatics(a), Mlynska dolina F2, SK - 84248 Bratislava; Institute of Experimental Physics of the Slovak Academy of Sciences, Dept. of Subnuclear Physics(b), Watsonova 47, SK - 04353 Kosice, Slovak Republic
145 (a)University of Johannesburg, Department of Physics, PO Box 524, Auckland Park, Johannesburg 2006; (b)School of Physics, University of the Witwatersrand, Private Bag 3, Wits 2050, Johannesburg, South Africa, South Africa
146 Stockholm University: Department of Physics(a); The Oskar Klein Centre(b), AlbaNova, SE - 106 91 Stockholm, Sweden
147 Royal Institute of Technology (KTH), Physics Department, SE - 106 91 Stockholm, Sweden
148 Stony Brook University, Department of Physics and Astronomy, Nicolls Road, Stony Brook, NY 11794-3800, United States of America
149 University of Sussex, Department of Physics and Astronomy Pevensey 2 Building, Falmer, Brighton BN1 9QH, United Kingdom
150 University of Sydney, School of Physics, AU - Sydney NSW 2006, Australia
151 Institute of Physics, Academia Sinica, TW - Taipei 11529, Taiwan
152 Technion, Israel Inst. of Technology, Department of Physics, Technion City, IL - Haifa 32000, Israel
153 Tel Aviv University, Raymond and Beverly Sackler School of Physics and Astronomy, Ramat Aviv, IL - Tel Aviv 69978, Israel
154 Aristotle University of Thessaloniki, Faculty of Science, Department of Physics, Division of Nuclear & Particle Physics, University Campus, GR - 54124, Thessaloniki, Greece
155 The University of Tokyo, International Center for Elementary Particle Physics and Department of Physics, 7-3-1 Hongo, Bunkyo-ku, JP - Tokyo 113-0033, Japan
156 Tokyo Metropolitan University, Graduate School of Science and Technology, 1-1 Minami-Osawa, Hachioji, Tokyo 192-0397, Japan
157 Tokyo Institute of Technology, Department of Physics, 2-12-1 O-Okayama, Meguro, Tokyo 152-8551, Japan
158 University of Toronto, Department of Physics, 60 Saint George Street, Toronto M5S 1A7, Ontario, Canada
159 TRIUMF(a), 4004 Wesbrook Mall, Vancouver, B.C. V6T 2A3; (b)York University, Department of Physics and Astronomy, 4700 Keele St., Toronto, Ontario, M3J 1P3, Canada
160 University of Tsukuba, Institute of Pure and Applied Sciences, 1-1-1 Tennoudai, Tsukuba-shi, JP - Ibaraki 305-8571, Japan
161 Tufts University, Science & Technology Center, 4 Colby Street, Medford, MA 02155, United States of America
162 Universidad Antonio Narino, Centro de Investigaciones, Cra 3 Este No.47A-15, Bogota, Colombia
163 University of California, Irvine, Department of Physics & Astronomy, CA 92697-4575, United States of America
164 INFN Gruppo Collegato di Udine(a); ICTP(b), Strada
Costiera 11, IT-34014, Trieste; Università di Udine, Dipartimento di Fisica\(^{(c)}\), via delle Scienze 208, IT - 33100 Udine, Italy

165 University of Illinois, Department of Physics, 1110 West Green Street, Urbana, Illinois 61801, United States of America

166 University of Uppsala, Department of Physics and Astronomy, P.O. Box 516; SE -751 20 Uppsala, Sweden

167 Instituto de Física Corpuscular (IFIC) Centro Mixtio UVEG-CSIC, Apdo. 22085 ES-46071 Valencia, Dept. Física At. Mol. y Nuclear; Dept. Ing. Electrónica; Univ. of Valencia, and Inst. de Microelectronics de Barcelona (IMB-CNMC-SIC) 08193 Bellaterra, Spain

168 University of British Columbia, Department of Physics, 6224 Agricultural Road, CA - Vancouver, B.C. V6T 1Z1, Canada

169 University of Victoria, Department of Physics and Astronomy, P.O. Box 3055, Victoria B.C., V8W 3P6, Canada

170 Waseda University, WISE, 3-4-1 Okubo, Shinjuku-ku, Tokyo, 169-8555, Japan

171 The Weizmann Institute of Science, Department of Particle Physics, P.O. Box 26, IL - 76100 Rehovot, Israel

172 University of Wisconsin, Department of Physics, 1150 University Avenue, WI 53706 Madison, Wisconsin, United States of America

173 Julius-Maximilians-University of Würzburg, Physikalisches Institut, Am Hubland, 97074 Würzburg, Germany

174 Bergische Universität, Fachbereich C, Physik, Postfach 100127, Gauss-Strasse 20, D- 42097 Wuppertal, Germany

175 Yale University, Department of Physics, PO Box 208121, New Haven CT, 06520-8121, United States of America

176 Yerevan Physics Institute, Alikhanian Brothers Street 2, AM - 375036 Yerevan, Armenia

177 Centre de Calcul CNRS/IN2P3, Domaine scientifique de la Doua, 27 bd du 11 Novembre 1918, 69622 Villeurbanne Cedex, France

a Also at LIP, Portugal

b Also at Faculdade de Ciencias, Universidade de Lisboa, Portugal

c Also at CPPM, Marseille, France.
d Also at TRIUMF, Vancouver, Canada
e Also at FPACS, AGH-UST, Cracow, Poland
f Now at Universita' dell'Insubria, Dipartimento di Fisica e Matematica

g Also at Department of Physics, University of Coimbra, Portugal

h Now at CERN

i Also at Università di Napoli Parthenope, Napoli, Italy

j Also at Institute of Particle Physics (IPP), Canada

k Also at Università di Napoli Parthenope, via A. Acton 38, IT - 80133 Napoli, Italy

l Louisiana Tech University, 305 Wisteria Street, P.O. Box 3178, Ruston, LA 71272, United States of America

m Also at Universidade de Lisboa, Portugal

n At California State University, Fresno, USA

o Also at TRIUMF, 4004 Wesbrook Mall, Vancouver, B.C. V6T 2A3, Canada

p Also at Faculdade de Ciencias, Universidade de Lisboa, Portugal and at Centro de Física Nuclear da Universidade de Lisboa, Portugal

q Also at FPACS, AGH-UST, Cracow, Poland

r Also at California Institute of Technology, Pasadena, USA

s Louisiana Tech University, Ruston, USA
t Also at University of Montreal, Montreal, Canada
u Now at Chonnam National University, Chonnam, Korea 500-757
v Also at Institut für Experimentalphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany
w Also at Manhattan College, NY, USA

x Also at School of Physics and Engineering, Sun Yat-sen University, China

y Also at Taiwan Tier-1, ASGC, Academia Sinica, Taipei, Taiwan

z Also at School of Physics, Shandong University, Jinan, China

aa Also at California Institute of Technology, Pasadena, USA

ab Also at Rutherford Appleton Laboratory, Didcot, UK

ac Also at school of physics, Shandong University, Jinan

ad Also at Rutherford Appleton Laboratory, Didcot , UK

ae Also at TRIUMF, Vancouver, Canada

af Now at KEK

ag Also at Departamento de Fisica, Universidade de Minho, Portugal

ah University of South Carolina, Columbia, USA

ai Also at KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary

aj University of South Carolina, Dept. of Physics and Astronomy, 700 S. Main St, Columbia, SC 29208, United States of America

ak Also at Institute of Physics, Jagiellonian University, Cracow, Poland

al Louisiana Tech University, Ruston, USA

am Also at Centro de Fisica Nuclear da Universidade de Lisboa, Portugal

an Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany

ao University of South Carolina, Columbia, USA

ap Transfer to LHCB 31.01.2010

aq Also at Oxford University, Department of Physics, Denys Wilkinson Building, Keble Road, Oxford OX1 3RH, United Kingdom

ar Also at school of physics and engineering, Sun Yat-sen University, China

as Determine the Muon T0s using 2009 and 2010 beam splash events for MDT chambers and for each mezzanine card, starting from 2009/09/15

at Also at CEA
Also at LPNHE, Paris, France

\*v has been working on Muon MDT noise study and calibration since 2009/10, contact as Tiesheng Dai and Muon convener

\*w Also at Nanjing University, China

* Deceased