Phys. Lett. B 854 (2024) 138725

Contents lists available at ScienceDirect

Physics Letters B

journal homepage: www.elsevier.com/locate/physletb

Letter

Measurement of vector boson production cross sections and their ratios using pp collisions at $\sqrt{s} = 13.6$ TeV with the ATLAS detector

The ATLAS Collaboration *

ARTICLE INFO

Editor: M. Doser

Dataset link: https://hepdata.cedar.ac.uk

ABSTRACT

Fiducial and total $W^{\pm}$ and Z boson cross sections, their ratios and the ratio of top-antitop-quark pair and W-boson fiducial cross sections are measured in proton–proton collisions at a centre-of-mass energy of $\sqrt{s} = 13.6$ TeV, corresponding to an integrated luminosity of 29 fb^{-1} of data collected in 2022 by the ATLAS experiment at the Large Hadron Collider. The measured fiducial cross-section values for $W^+ \to \ell^+\nu$, $W^- \to \ell^-\bar{\nu}$, and $Z \to \ell^+\ell^-$ ($\ell = e$ or μ) boson productions are 4250 ± 150 pb, 3310 ± 120 pb, and 744 ± 20 pb, respectively, where the uncertainty is the total uncertainty, including that arising from the luminosity of about 2.2%. The measurements are in agreement with Standard-Model predictions calculated at next-to-next-to-leading-order in α_s, next-to-next-to-leading logarithmic accuracy and next-to-leading-order electroweak accuracy.

1. Introduction

Precision measurements of the $W^{\pm}$ and Z cross sections and their ratios at the Large Hadron Collider (LHC) provide an excellent probe of quantum chromodynamics (QCD) and of the proton structure. Measurements of $W^{\pm}$ and Z cross sections have been performed by the ATLAS Collaboration [1] at centre-of-mass energies of 2.76 TeV [2], 5 TeV [3], 7 TeV [4], 8 TeV [5,6], and 13 TeV [7,8] and by the CMS [9] Collaboration at centre-of-mass energies of 7 TeV [10,11], 8 TeV [12,13], and 13 TeV [14]. The experimental precision of such measurements performed within the fiducial region defined by the detector acceptance has reached percent level, with sub-percent level precision for cross-section ratios.

In this letter, measurements of the inclusive fiducial and total cross sections of $W^+ \to \ell^+\nu$, $W^- \to \ell^-\bar{\nu}$, their ratio, and their ratios to the $Z \to \ell^+\ell^-$ cross section are presented. The measurements are made at an increased LHC centre-of-mass energy of 13.6 TeV, using a data sample corresponding to 29 fb^{-1}, with ℓ referring to muons or electrons. The fiducial cross section for $Z \to \ell^+\ell^-$ production in the same data sample from this analysis has been published together with the top-antitop-quark pair $t\bar{t}$ production cross section and their ratio in Ref. [15]. Here, the first measurement of the ratios between $t\bar{t}$ and $W^{\pm}$-boson fiducial cross sections in the same data sample is also presented to probe different parton densities of the proton.

The measurements are performed by using profile-likelihood (PLH) fits [16] to the inclusive data in the four fiducial single-lepton channels $W^+ \to e^+\nu$, $W^+ \to \mu^+\nu$, $W^- \to e^-\bar{\nu}$, and $W^- \to \mu^-\bar{\nu}$, and the two fiducial dilepton channels $Z \to e^+e^-$ and $Z \to \mu^+\mu^-$ to extract the W and Z boson cross sections, and their ratios $\sigma_{W^+\to\ell^+\nu}$, $\sigma_{W^-\to\ell^-\bar{\nu}}$, $\sigma_{W^{\pm}\to\ell\nu}$, $\sigma_{Z\to\ell^+\ell^-}$, $R_{W^{\pm}/Z}$, and R_{W^+/W^-}. Similarly, combined fits of the four W-boson channels, the two Z-boson channels, and the two $t\bar{t}$ channels from Ref. [15] are used to extract the cross-section ratios $R_{t\bar{t}/W^{\pm}}$, $R_{t\bar{t}/W^+}$, and $R_{t\bar{t}/W^-}$.

The measurements are compared with theoretical predictions calculated at next-to-next-to-leading-order (NNLO). The predictions are supplemented by the resummation of logarithmically enhanced contributions in the low transverse-momentum region of the lepton pairs at next-to-next-to-leading-logarithmic (NNLL) accuracy in QCD, plus next-to-leading-order (NLO) electroweak (EW) accuracy, using various state-of-the-art parton distribution functions (PDFs). The dependence of the cross sections on the centre-of-mass energy is also tested.

* *E-mail address:* atlas.publications@cern.ch.

[1] 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 along the beam pipe. The x-axis points from the IP to the centre of the LHC ring, and the y-axis points upwards. Polar coordinates (r, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the z-axis. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln\tan(\theta/2)$ and is equal to the rapidity $y = \frac{1}{2}\ln\left(\frac{E+p_z c}{E-p_z c}\right)$ in the relativistic limit. Angular distance is measured in units of $\Delta R \equiv \sqrt{(\Delta y)^2 + (\Delta\phi)^2}$.

https://doi.org/10.1016/j.physletb.2024.138725
Received 20 March 2024; Received in revised form 6 May 2024; Accepted 13 May 2024
Available online 17 May 2024
0370-2693/© 2024 The Author(s). Published by Elsevier B.V. Funded by SCOAP[3]. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

2. The ATLAS detector

The ATLAS experiment [1,17] at the LHC is a multipurpose particle detector with a forward–backward symmetric cylindrical geometry and a near 4π coverage in solid angle.[1] It consists of an inner tracking detector (ID) surrounded by a thin superconducting solenoid providing a 2 T axial magnetic field, electromagnetic and hadronic calorimeters, and a muon spectrometer. The inner tracking detector covers the pseudorapidity range $|\eta| < 2.5$. It consists of silicon pixel, silicon microstrip, and transition radiation tracking detectors. Lead/liquid-argon (LAr) sampling calorimeters provide electromagnetic (EM) energy measurements with high granularity within the region $|\eta| < 3.2$. A steel/scintillator-tile hadronic calorimeter covers the central pseudorapidity range ($|\eta| < 1.7$). The endcap and forward regions are instrumented with LAr calorimeters for EM and hadronic energy measurements up to $|\eta| = 4.9$. The muon spectrometer surrounds the calorimeters and is based on three large superconducting air-core toroidal magnets with eight coils each. The field integral of the toroids ranges between 2.0 and 6.0 T m across most of the detector. The muon spectrometer includes a system of precision tracking chambers up to $|\eta| = 2.7$ and fast detectors for triggering up to $|\eta| = 2.4$. The luminosity is measured mainly by the LUCID–2 detector [18] which is located close to the beampipe. A two-level trigger system is used to select events [19]. The first-level trigger is implemented in hardware and uses a subset of the detector information to accept events at a rate below 100 kHz. This is followed by a software-based trigger that reduces the accepted event rate to 3 kHz on average, depending on the data-taking conditions. A software suite [20] is used in data simulation, in the reconstruction and analysis of real and simulated data, in detector operations, and in the trigger and data acquisition systems of the experiment.

3. Data and MC samples

The analysis is performed using data collected in 2022, the first year of the Run 3 data taking period, by the ATLAS detector in pp collisions at $\sqrt{s} = 13.6$ TeV, corresponding to an integrated luminosity of 29.0 ± 0.6 fb^{-1} [21], after applying data-quality requirements [22].

Monte Carlo (MC) simulated events are used to optimise the selection, determine all backgrounds except for the multi-jet process, calculate the detector acceptance factor and to perform the final signal-extraction fit.

The production of Z and W bosons decaying to e, μ signal or τ background final states was simulated with the Sherpa 2.2.12 generator [23] using NLO matrix elements (MEs) for up to two additional partons, and leading-order (LO) ME for up to five additional partons calculated with the Comix [23] and OpenLoops [24–26] libraries. They were matched with the Sherpa parton shower (PS) [27] using the MEPS@NLO prescription [28] and the set of tuned parameters developed by the Sherpa authors. The NNPDF 3.0 NNLO PDF set [29] was used and the samples were normalised to a NNLO prediction [30].

Samples of diboson final states were simulated with Sherpa 2.2.12, including off-shell effects and Higgs boson contributions where appropriate. Fully leptonic final states and semi-leptonic final states were generated using MEs at NLO accuracy in QCD for up to one additional parton and at LO accuracy for up to three additional parton emissions.

The production of a top-quark pair $t\bar{t}$ and the associated production of a single top-quark and a W boson (Wt) were modelled using the PowhegBox v2 generator [31–34] interfaced to Pythia 8.307 [35] with the parton shower tune A14 [36]. The MEs were calculated at NLO precision in QCD using the NNPDF 3.0 NNLO PDF set. The $t\bar{t}$ sample was normalised to the cross-section prediction at NNLO in perturbative QCD including the resummation of NNLL soft-gluon terms calculated using Top++ 2.0 [37–43].

The effect of multiple interactions in the same and neighbouring bunch crossings (pile-up) was modelled by overlaying [44] the original hard-scattering event with simulated inelastic pp events generated by EPOS 2.0.1.4 [45,46] and Pythia 8.307. The events generated with EPOS used the EPOS LHC tune, while the Pythia8 events used the NNPDF 2.3 LO PDF set [47] and the A3 tune [48]. The ATLAS detector response was simulated by the Geant4 toolkit [49] with the full simulation of the ATLAS detector [50]. The simulated samples were then processed with the same software framework as the data.

4. Object definition and event selection

Events are selected if they include at least one lepton that is matched to an object identified by a single-lepton trigger. The lowest transverse momentum p_{T} threshold in the single-lepton triggers is 26 GeV for electrons and 24 GeV for muons [19,51,52]. Events are also required to have at least one reconstructed collision vertex with two or more associated tracks with $p_{\mathrm{T}} > 500$ MeV. The vertex with the highest $\sum p_{\mathrm{T}}^2$ of the associated tracks is taken as the primary vertex.

Electron candidates are reconstructed from clusters in the EM calorimeter matched to charged tracks measured in the ID. The electron candidates are required to satisfy *Tight* identification criteria [53], validated to be still working well for data taking at 13.6 TeV, and to have $p_{\mathrm{T}} > 27$ GeV and $|\eta| < 2.47$, excluding the transition region between the barrel and endcap calorimeters, $1.37 < |\eta| < 1.52$.

Muon candidates are reconstructed from tracks in the muon spectrometer matched to tracks from the ID. The muon candidates are required to satisfy *Medium* identification criteria [54], adapted for data taking at 13.6 TeV, with $p_{\mathrm{T}} > 27$ GeV and $|\eta| < 2.5$.

Leptons must originate from the primary vertex by requiring $|z_0 \sin\theta| < 0.5$ mm, where z_0 is the z-coordinate of the track at the point of closest approach to the z-axis. Furthermore, the significance of the transverse impact parameter, defined by the distance of closest approach of the track to the primary vertex point in the $r-\phi$ projection $|d_0|$, divided by its estimated uncertainty $\sigma(d_0)$, is required to satisfy $|d_0|/\sigma(d_0) < 5$ for electrons and $|d_0|/\sigma(d_0) < 3$ for muons.

To select prompt leptons, tight isolation criteria are imposed on the charged leptons. Requirements are applied on the transverse momentum sum of all ID tracks within a variable cone around the lepton, $p_{\mathrm{T}}^{\mathrm{varcone30}}$, where the maximum cone size is $\Delta R = 0.3$, shrinking for larger p_{T} [53], and on the transverse energy $E_{\mathrm{T}}^{\mathrm{cone20}}$ in a cone of $\Delta R = 0.2$ around the lepton: $p_{\mathrm{T}}^{\mathrm{varcone30}}/p_{\mathrm{T}} < 0.06$ and $E_{\mathrm{T}}^{\mathrm{cone20}}/p_{\mathrm{T}} < 0.06$ for electrons and $p_{\mathrm{T}}^{\mathrm{varcone30}}/p_{\mathrm{T}} < 0.04$ and $E_{\mathrm{T}}^{\mathrm{cone20}}/p_{\mathrm{T}} < 0.15$ for muons.

Jets are used for the calculation of the missing transverse momentum (see below). They are reconstructed using a particle flow algorithm [55] that exploits both calorimeter and ID informations. The anti-k_t algorithm [56,57] with a radius parameter $R = 0.4$ is used. The jet energy calibration is based on Run 3 simulation and *in-situ* calibration [58], adapted for data taking at 13.6 TeV. Calibrated jet candidates are required to have $p_{\mathrm{T}} > 20$ GeV for $|\eta| < 2.5$ and $p_{\mathrm{T}} > 30$ GeV for $2.5 < |\eta| < 4.5$. To suppress jets originating from pile-up, jets with p_{T} below 60 GeV are required to satisfy a neural-network-based jet vertex tagger (NNJVT) discriminant, a successor of the jet vertex tagger algorithm [59] used during the Run 2 data taking period in the years 2015 to 2018.

To remove the ambiguity when one physical object is reconstructed as multiple objects, the following algorithm is used, with each operation applied in the given order. If any electron candidate is found sharing a track with any other electron candidates, the candidate with smaller p_{T} is removed. Any electron candidate found to share a track with a muon is removed. The closest jet found within a ΔR of 0.2 of an electron candidate is removed. Any electron candidate subsequently found within ΔR of 0.4 of a jet is removed. Jets with less than three tracks associated to it found within ΔR of 0.2 or with a muon inner-detector track ghost-associated to it are removed, then muon candidates found within ΔR of 0.4 of a jet are removed.

The missing transverse momentum $\vec{p}_{\mathrm{T}}^{\mathrm{miss}}$, with magnitude $E_{\mathrm{T}}^{\mathrm{miss}}$, is defined as the negative of the sum of the transverse momenta of the reconstructed and calibrated physical objects, and a soft term built from

Table 1
Summary of the event selection requirements.

Electron selections	$p_{\mathrm{T}} > 27$ GeV $\lvert\eta\rvert < 2.47$ and veto of $1.37 < \lvert\eta\rvert < 1.52$
Muon selections	$p_{\mathrm{T}} > 27$ GeV $\lvert\eta\rvert < 2.5$
W-boson selections	Exactly one lepton $E_{\mathrm{T}}^{\mathrm{miss}} > 25$ GeV $m_{\mathrm{T}} > 50$ GeV
Z-boson selections	Exactly two same flavour opposite charged leptons $66 < m_{\ell\ell} < 116$ GeV

all tracks that are associated with the primary vertex, excluding those used in the physics objects, is also included [60].

The object reconstruction for the $t\bar{t}$ analysis is described in detail in Ref. [15]. In addition to the objects defined above, jets containing b-hadrons are identified, using the 77% efficiency working point of the DL1d b-tagging algorithm [61,62].

The Z-boson decays into a pair of electrons or muons with opposite electric charge, thus two dilepton channels, ee and $\mu\mu$, are defined. In the case of the W-boson, the ones decaying into one lepton and a neutrino are considered, so four single lepton channels are defined according to the lepton flavour and electric charge: $e^-\bar{\nu}$, $e^+\nu$, $\mu^-\bar{\nu}$, and $\mu^+\nu$.

Events in the dilepton channels are required to have exactly two same-flavour leptons (electrons or muons) with opposite electric charge. The invariant mass of the dilepton pairs is required to be in the mass range $66 < m_{\ell\ell} < 116$ GeV. In the single-lepton channels, events are required to have exactly one identified and isolated lepton, $E_{\mathrm{T}}^{\mathrm{miss}}$ greater than 25 GeV, and a transverse mass $m_{\mathrm{T}}^{W} = \sqrt{2p_{\mathrm{T}}^{\mathrm{miss}} p_{\mathrm{T}}^{\ell}(1-\cos\Delta\phi_{\ell\nu})}$ greater than 50 GeV, where $\Delta\phi_{\ell\nu}$ is the azimuthal angle between the charged lepton transverse momentum $\vec{p}_{\mathrm{T}}^{\,\ell}$ and $\vec{p}_{\mathrm{T}}^{\,\mathrm{miss}}$.

The event selections for the W and Z boson analysis are summarised in Table 1. The $Z \to \ell\ell$ selection is the same as in Ref. [15] that also describes the event selection for the $t\bar{t}$ analysis. Selected $t\bar{t}$ candidates are required to have exactly one electron and one muon of opposite charge. No dilepton mass, $E_{\mathrm{T}}^{\mathrm{miss}}$ or m_{T}^{W} requirements are imposed but the events are required to have one or two b-tagged jets.

5. Background estimation and yields

Background contributions to the W and Z boson final states correspond to two main categories: EW and top-quark processes, estimated by using MC simulations, and the multi-jet (MJ) background, estimated using a data-driven technique.

The EW background contributions include single-boson and diboson productions. The single-boson productions correspond to $W^{\pm} \to \tau^{\pm}\nu$ and $Z \to \tau^+\tau^-$ for both channels, where the subsequent leptonic decays of the τ leptons are also treated as background, $Z \to e^+e^-$ and $Z \to \mu^+\mu^-$ for the W channels and $W^{\pm} \to e^{\pm}\nu$ and $W^{\pm} \to \mu^{\pm}\nu$ for the Z-boson channels. Diboson productions, WW, WZ, and ZZ can have similar signatures to W or Z events if one of the bosons decays hadronically or invisibly or if leptonic decay products fail to satisfy the object selection. Likewise, $t\bar{t}$ pair and Wt production can result in similar signatures to W or Z events, if one or two W bosons decay leptonically. For W-boson selections, the contribution of both the diboson and top-quark events to the background is small due to the lower production cross section. For Z-boson selections, all EW background contributions are at sub-percent level.

The MJ background stems from QCD jet production, where particles within the jets are mistakenly identified as prompt isolated leptons. It has major contributions from collimated charged and neutral pions and from non-prompt real leptons produced e.g. in semi-leptonic decays of heavy quarks or in-flight pion decays. Although this type of background processes is efficiently rejected by the isolation selection and, in the W-boson case, by the lepton p_{T}, $E_{\mathrm{T}}^{\mathrm{miss}}$, and m_{T}^{W} requirements, MJ processes still dominate the background in W-boson measurements at high pile-up due to the large production cross section and large $E_{\mathrm{T}}^{\mathrm{miss}}$ generated through jet energy mis-measurements in the event, contributing to around 3−7% of data events. Because of the difficulties in the precise simulation of these processes, data-driven techniques are used for the estimation of the MJ background [7].

The MJ background in the four W-boson channels is estimated by performing PLH fits to the data in a fitting region enriched with MJ contribution, where the signal and background kinematic distributions have sufficient discriminating power. The discriminating variables used in these fits are $E_{\mathrm{T}}^{\mathrm{miss}}$ and m_{T}^{W}. The signal region (SR) is defined by the full event selection, in particular, $E_{\mathrm{T}}^{\mathrm{miss}} > 25$ GeV and $m_{\mathrm{T}}^{W} > 50$ GeV. The fitting region (FR) is defined similarly to the SR except that $E_{\mathrm{T}}^{\mathrm{miss}} < 25$ GeV and $m_{\mathrm{T}}^{W} < 50$ GeV are required. The signal, EW, and top-quark background contributions in this region are estimated by using MC simulations, while the MJ distributions are derived in a control region (CR1) with similar kinematic selection as the FR, but where the lepton is required to fail to satisfy the track isolation requirement, denoted as anti-isolated. Similarly, another control region (CR2) is defined where the lepton is also required to fail isolation but has the same kinematic selection as the SR. The contamination from signal and other backgrounds in the CR1 and CR2 is estimated by using MC simulations and subtracted from the data to obtain the MJ templates in these regions. Pre-scaled supporting triggers with looser or without isolation requirements corresponding to a smaller integrated luminosity value than the nominal one are used to populate sufficiently the CR1 and CR2. These triggers have similar kinematic requirements to the nominal ones used to select events in the SR.

Several MJ templates are created for each W-boson decay channel by slicing the CR1 and CR2 as explained in the following. Four mutually exclusive isolation slices are defined by varying the track isolation variable progressively further from the signal region, while the calorimeter isolation is kept at the nominal value. The slices in the track isolation variable are equal in width and have an upper limit corresponding to 0.3 and 0.2 in the electron and muon channels, respectively. For each isolation slice, the normalisation of the corresponding MJ template in the FR is extracted using a PLH fit to the measured $E_{\mathrm{T}}^{\mathrm{miss}}$ or m_{T}^{W} distribution. A transfer factor, calculated using the ratio of the MJ yields in the CR1 and CR2, is used to obtain the SR MJ yield from the FR fit result. This procedure leads to two sets of four SR MJ yields (two fit variables and four isolation slices) for each of the four W-boson channels. To reduce the bias due to the track isolation on the MJ yield in the SR, the MJ estimates obtained from each isolation slice are used to build an extrapolation to the track isolation selection used in the SR.

Fig. 1 shows the linear (dashed line) and quadratic (solid line) fits to the relative MJ yields as a function of the track isolation slice, where the average value of the track isolation of the events in the respective isolation slice is used as the central value. For each point, the uncertainty of the MJ fit in the FR is propagated into the MJ yield and enters the uncertainty of the final extrapolation. The quadratic fits are observed to have better performance than the linear fits in each channel, verified with a χ^2 criterion. The combined mean of the two quadratic extrapolations using the $E_{\mathrm{T}}^{\mathrm{miss}}$ or m_{T}^{W} distribution is used as the central value for the final MJ yield in each channel, denoted $f_{\mathrm{MJ}}^{\mathrm{SR}}$ in the figure. The first contribution to the uncertainty in the mean is calculated as the sum in quadrature between the combined error from the m_{T}^{W} and $E_{\mathrm{T}}^{\mathrm{miss}}$ fits, and the difference between the m_{T}^{W} and $E_{\mathrm{T}}^{\mathrm{miss}}$ fit results. The second contribution to the systematic uncertainty is derived from the difference between the linear and quadratic fit results, which constitutes the dominant contribution.

In the Z-boson channels, a conservative upper limit on the MJ background is estimated from the number of charge misidentified leptons, calculated using the $m_{\ell\ell}$ sidebands from a same-sign lepton selection.

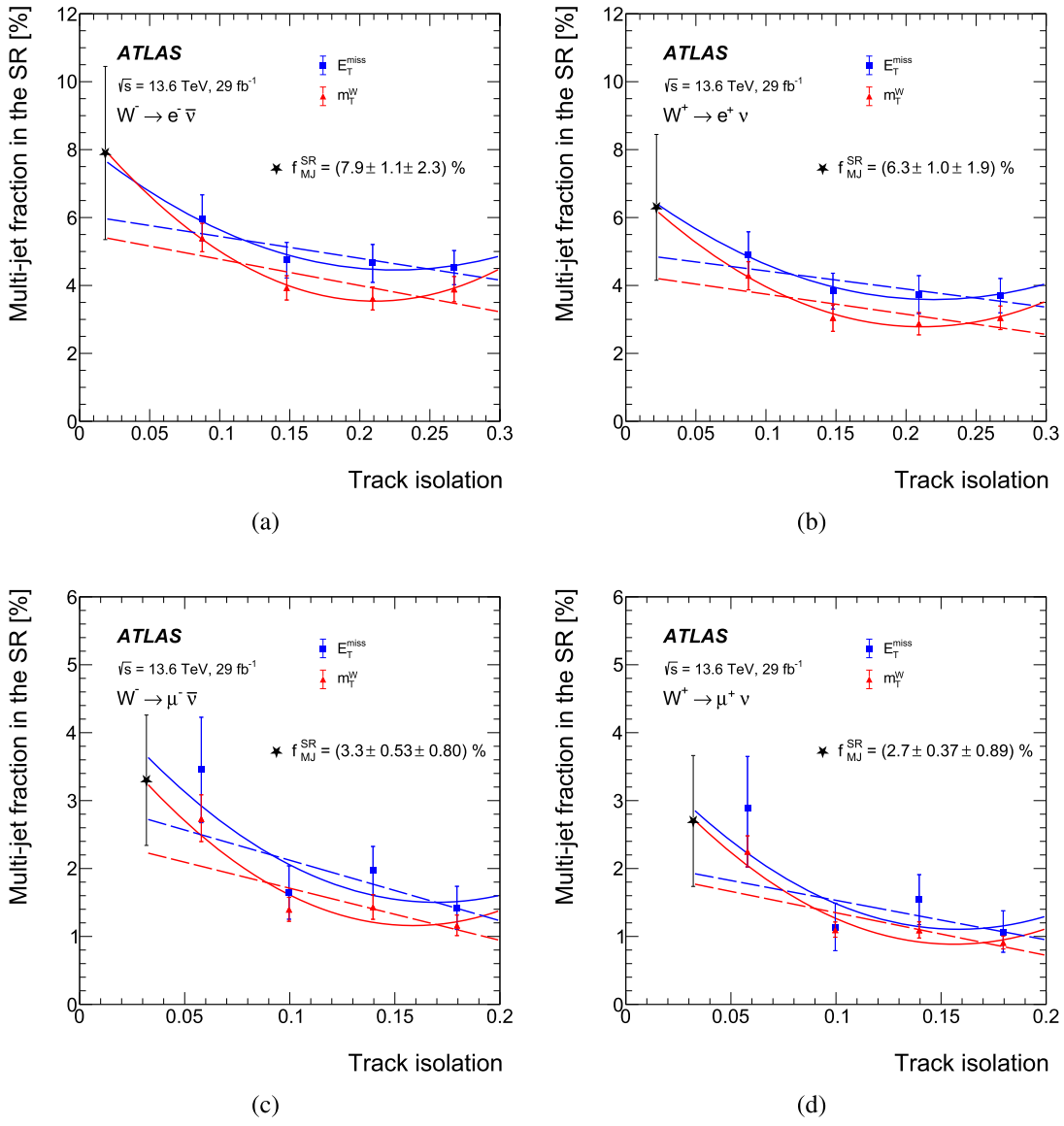


Fig. 1. Relative multi-jet yield in the SR as a function of the track isolation variable for the (a) $W^- \to e^-\bar{\nu}$, (b) $W^+ \to e^+\nu$, (c) $W^- \to \mu^-\bar{\nu}$, and (d) $W^+ \to \mu^+\nu$ channels, shown with squares and triangles, respectively for the $E_{\mathrm{T}}^{\mathrm{miss}}$ and m_{T}^{W} input measurements. The curves represent the extrapolation of the points to the SR using a quadratic function (solid curves) or a linear function (dashed lines). The x-axis corresponds to the position of the average of a track-isolation slice in the track isolation. The star represents the final MJ fraction ($f_{\mathrm{MJ}}^{\mathrm{SR}}$) and is calculated using the combined average of the quadratic fits in each channel. The first uncertainty corresponds to the combined uncertainty including the difference between the m_{T}^{W} and $E_{\mathrm{T}}^{\mathrm{miss}}$ quadratic fits, while the second uncertainty is due to the difference between linear and quadratic fit results.

In the case of the electron channel, this is found to be of sub-percent level, while the contribution in the muon channel is found to be even smaller. The systematic uncertainties are also negligible. The MJ contribution in the Z-boson channels is hence not considered in this analysis.

The event yields of background processes together with those from signal processes are shown in Table 2. Fig. 2 shows the m_{T}^{W} distributions in data and predictions for the four W-boson channels. The data agrees with the prediction within the uncertainties indicated by the hashed band. The $m_{\ell\ell}$ distributions for the $Z \to \ell\ell$ analysis are presented in Ref. [15].

6. Systematic uncertainties

The uncertainty of the integrated luminosity is 2.2%, based on the LUCID–2 detector [18] estimate, which is used for the primary luminosity measurements. For the electron efficiency corrections [53], extra systematic uncertainties are considered by comparing the simulations between Run 2 and Run 3. The uncertainty of the muon efficiency corrections is obtained using the Run 3 data sample and simulations by independently varying the inner detector and muon spectrometer components, as determined from $Z \to \mu^+\mu^-$ events, following Ref. [54]. The electron energy calibration uncertainty is derived using Run 2 data sample and simulations, as described in Ref. [53], with dedicated uncertainties covering the difference between Run 2 and Run 3 simulations. The muon energy calibration uncertainty is obtained using Run 3 data, based on the approach described in Ref. [54]. The lepton trigger uncertainties are obtained by comparing the trigger efficiency results of Run 3 data with simulations. The jet energy scale and resolution uncertainties are estimated by using the Run 2 data sample, as described in Ref. [58], and an additional uncertainty is used to cover the difference between Run 2 and Run 3 by comparing simulations, as described in Ref. [15]. A conservative 10% uncertainty per jet is considered to cover the differences between data and simulations in the measured NNJVT efficiencies. Besides the propagation of systematic uncertainties of all

Table 2
Event yields of data and predictions after selections. Only MC statistical uncertainties are shown for the EW and top-quark processes. For the multi-jet process, the normalisation uncertainty is displayed instead. Rounding has been applied to all the yields except for those of the data.

	$W^- \to e^-\bar{\nu}$	$W^+ \to e^+\nu$	$W^- \to \mu^-\bar{\nu}$	$W^+ \to \mu^+\nu$
$W \to e\nu$	$43,650,000 \pm 70,000$	$55,370,000 \pm 80,000$	–	–
$W \to \mu\nu$	–	–	$57,760,000 \pm 80,000$	$74,900,000 \pm 90,000$
$W \to \tau\nu$	$684,000 \pm 8,000$	$819,000 \pm 9,000$	$906,000 \pm 10,000$	$1,120,000 \pm 10,000$
$Z \to ee/\mu\mu$	$1,416,000 \pm 4,000$	$1,459,000 \pm 4,000$	$4,638,000 \pm 8,000$	$4,903,000 \pm 8,000$
$Z \to \tau\tau$	$88,000 \pm 1,000$	$91,000 \pm 1,000$	$107,000 \pm 1,000$	$111,000 \pm 1,000$
$t\bar{t}$+single-top	$863,800 \pm 400$	$905,400 \pm 500$	$802,200 \pm 400$	$843,400 \pm 400$
VV	$93,500 \pm 300$	$97,600 \pm 300$	$98,500 \pm 300$	$102,800 \pm 300$
Multi-jet	$4,000,000 \pm 1,000,000$	$4,000,000 \pm 1,000,000$	$2,100,000 \pm 700,000$	$2,200,000 \pm 800,000$
Total predicted	$51,000,000 \pm 1,000,000$	$63,000,000 \pm 1,000,000$	$66,400,000 \pm 700,000$	$84,200,000 \pm 800,000$
Data	50,748,537	62,610,338	65,053,470	82,360,980

	$Z \to e^+e^-$	$Z \to \mu^+\mu^-$
$Z \to ee$	$7,710,000 \pm 10,000$	–
$Z \to \mu\mu$	–	$13,961,000 \pm 10,000$
$Z \to \tau\tau$	$2,500 \pm 200$	$3,900 \pm 200$
$W \to \ell\nu$	139 ± 57	40 ± 27
$t\bar{t}$+single-top	$24,950 \pm 50$	$37,000 \pm 50$
VV	$14,960 \pm 80$	$23,800 \pm 100$
Total predicted	$7,750,000 \pm 10,000$	$14,030,000 \pm 10,000$
Data	7,812,978	14,242,875

other physics objects, those of the track soft term are also considered for $E_{\mathrm{T}}^{\mathrm{miss}}$ [60]. The uncertainty in the pile-up is determined by varying the average number of interactions per bunch-crossing by 4% in the simulation and it is accounted for with dedicated studies. The systematic uncertainties arising from normalisation of the multi-jet background are described in Section 5.

The theoretical uncertainties are categorised into two distinct components: the uncertainty δA on the *acceptance* A, the ratio of the number of events in the fiducial volume and the total phase space at the particle level, and the uncertainty δC on the *correction factor* C, the ratio of the expected signal events at the detector level and at the particle level in the fiducial volume, defined by lepton $p_{\mathrm{T}}^{\ell} > 27$ GeV, lepton $|\eta^{\ell}| < 2.5$, $E_{\mathrm{T}}^{\mathrm{miss}} > 25$ GeV and $m_{\mathrm{T}}^{W} > 50$ GeV for the W-boson processes and the same p_{T}^{ℓ} and $|\eta^{\ell}|$ selections and $66 < m_{\ell\ell} < 116$ GeV for the Z-boson processes. For each theoretical uncertainty, δA is propagated into the measurement of the total cross section, whereas δC is included as a nuisance parameter in the PLH fit used to extract the fiducial cross section.

Various sources of the theoretical uncertainty are evaluated using the SHERPA signal samples. The QCD scale uncertainty is defined by the symmetrised envelope of seven-point variations of the renormalisation and factorisation scales, corresponding to varying μ_R and μ_F independently by factors of 1/2 and 2 to the combinations of $(\mu_R, \mu_F) = (\mu_R/2, \mu_F/2), (2\mu_R, 2\mu_F), (\mu_R, 2\mu_F), (2\mu_R, \mu_F), (\mu_R, \mu_F/2)$, and $(\mu_R/2, \mu_F)$. The PDF uncertainty is estimated based on the internal replicas of the NNPDF 3.0 NNLO set, which enter the fit as individual nuisance parameters. The PDF choice uncertainty is estimated by comparing the predictions calculated with NNPDF 3.0 NNLO and with PDF4LHC21 [63]. The α_s uncertainty is calculated by comparing two different α_s values used in PDF4LHC21.

The contribution of each of the background processes based on simulated samples is at percent level or smaller. A conservative modelling uncertainty of 5% covering the PDF input, α_{s}, and QCD scale variations, is assigned for background processes from the W and Z bosons and the theoretical uncertainty is 10% for the diboson processes. The modelling uncertainties are 5.1% and 3.5% for the $t\bar{t}$ and single-top processes, respectively, as evaluated in Ref. [15].

The results for the Z boson production are derived from fits to the two Z-boson channels as reported in Ref. [15]. The other results are derived from simultaneous fits of the four W-boson and the two Z-boson channels. The lepton efficiency corrections, trigger efficiency and energy calibration uncertainties are treated as uncorrelated between electron and muon channels. The multi-jet background uncertainty is also considered to be uncorrelated. Other experimental uncertainties (uncertainty sources related to jet, $E_{\mathrm{T}}^{\mathrm{miss}}$, pile-up and luminosity) are considered to be fully correlated. The modelling uncertainties of electroweak and top-quark processes are regarded as fully uncorrelated. The uncertainties in signal modelling are fully correlated when combining electron and muon channels for the same boson. However, when combining channels of different bosons, these uncertainties are treated as uncorrelated sources due to the different production modes at the LHC.

The dominant uncertainty sources are channel dependent. The Z-boson cross sections are limited by the luminosity and lepton correction uncertainties. For the W-boson cross sections, the multi-jet background and jet-related uncertainties play important roles. However, for W^+/W^--boson cross-section ratios, the dominant experimental uncertainty sources largely cancel out. The multi-jet background uncertainties become dominant sources for W^+/W^--boson cross-section ratios since the multi-jet W^+ and W^- boson uncertainties in each lepton channel are regarded as independent sources. Similarly, in the ratio of $W^{\pm}$-boson and Z-boson cross sections, the jet and multi-jet background uncertainties only affect the W-boson cross section but have no impact on the Z-boson cross section so they become dominant sources. In terms of the ratio of the $t\bar{t}$ and W fiducial cross section, the $t\bar{t}$ modelling and multi-jet background uncertainties are significant as they do not cancel out and, additionally, uncertainties stemming from jet and lepton trigger efficiency, as well as background modelling except the multi-jet, also do not fully cancel out and so they also play important roles.

7. Results

The cross sections $\sigma_{W^+\to\ell^+\nu}$, $\sigma_{W^-\to\ell^-\bar{\nu}}$, $\sigma_{W^{\pm}\to\ell^{\pm}\nu}$, and $\sigma_{Z\to\ell^+\ell^-}$ are extracted from PLH fits to the inclusive data in the four fiducial single-lepton channels $W^+ \to e^+\nu$, $W^+ \to \mu^+\nu$, $W^- \to e^-\bar{\nu}$, and $W^- \to \mu^-\bar{\nu}$, and the two fiducial dilepton channels $Z \to e^+e^-$ and $Z \to \mu^+\mu^-$. The statistical model of the PLH fits is constructed in the following form:

$$L(\vec{n}; \mu_s, \vec{\theta}) = \prod_{c \in \text{channels}} \text{Pois}(n_{\text{data}} | \mu_{s,c} S_c(\vec{\theta}) + B_c(\vec{\theta})) \prod_{i \in \text{NPs}} G(\theta_i), \quad (1)$$

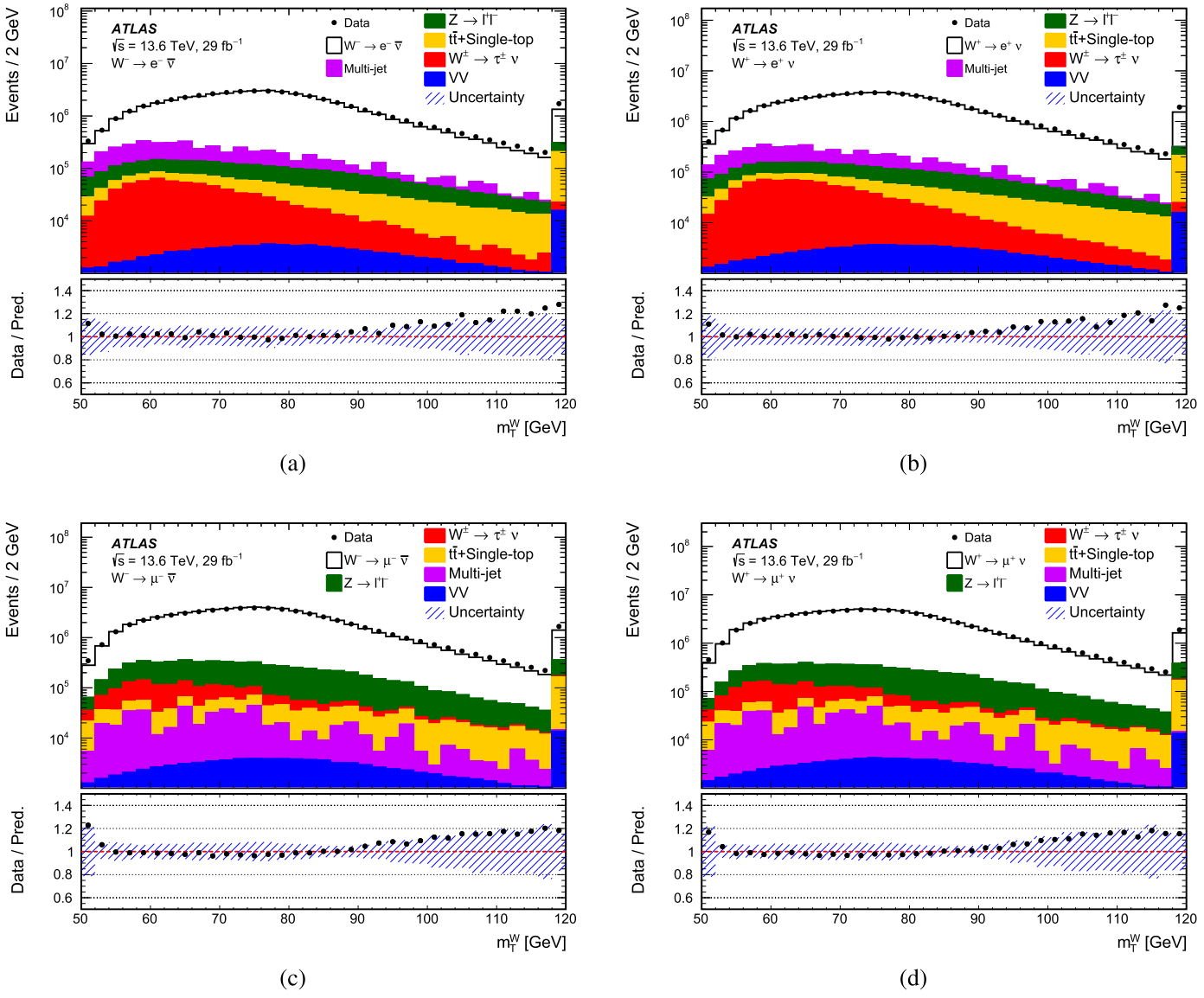


Fig. 2. Comparison of data (dots) and predictions (histograms) for the m_{T}^{W} distributions in the (a) $W^- \to e^-\bar{\nu}$, (b) $W^+ \to e^+\nu$, (c) $W^- \to \mu^-\bar{\nu}$, and (d) $W^+ \to \mu^+\nu$ channels. The hashed band in the ratio plot denotes the total systematic uncertainty in the prediction. The rightmost bins contain the overflow events.

where μ_s is the signal strength, which represents the ratio of the measured signal cross section over the predicted value, S_c is the expected number of signal events, and B_c is the expected background. The normalisation of the background contributions is determined by the fit and constrained by the background cross-section uncertainties. The quantity θ_i is a nuisance parameter (see Section 6) which is constrained by a Gaussian term $G(\theta_i)$. The probability model is the product of the Poisson distributions ("Pois") in each channel. The theoretical uncertainties of the W- and Z-boson signal processes are incorporated into the fitting by introducing normalisation factors on the signal samples. The normalisation factors are calculated by comparing the correction factors of the nominal and theoretical variations, and taking the relative difference.

The ratios of the fiducial cross sections are extracted using fits as well. For the W^+/W^--boson cross-section ratio, R_{W^+/W^-}, the W^+-boson signal strength μ_{W^+} is expressed as the product $R_{W^+/W^-}\mu_{W^-}$ in Eq. (1), thus the likelihood formula for the ratio is written as:

$$L(\vec{n};\mu_s,\vec{\theta}) = \prod_{c\in W^+ \text{ channels}} \mathrm{Pois}(n_{\mathrm{data}}|R_{W^+/W^-}\ \mu_{W^-}S_c(\vec{\theta}) + B_c(\vec{\theta}))\times$$

$$\prod_{c\in W^- \text{ channels}} \mathrm{Pois}(n_{\mathrm{data}}|\mu_{W^-}S_c(\vec{\theta}) + B_c(\vec{\theta}))\times$$

$$\prod_{c\in Z \text{ channels}} \mathrm{Pois}(n_{\mathrm{data}}|\mu_Z S_c(\vec{\theta}) + B_c(\vec{\theta})) \prod_{i\in \mathrm{NPs}} G(\theta_i)\,.$$

The ratios $R_{W^\pm/Z}$, $R_{t\bar{t}/W^\pm}$, $R_{t\bar{t}/W^+}$, and $R_{t\bar{t}/W^-}$ are extracted in the same manner. In the latter cases, the $t\bar{t}$ inputs and uncertainties are obtained from the $t\bar{t}$ cross-section analysis at 13.6 TeV [15].

Fiducial cross sections, σ^{fid}, are calculated by multiplying the signal-strength parameter μ with the nominal predicted fiducial cross section calculated with the SHERPA signal samples (see Section 3). Uncertainties in the signal-strength parameter μ are propagated into σ^{fid}.

Total cross sections, σ^{tot}, are calculated by dividing σ^{fid} by the acceptance A. This correction is calculated with the SHERPA signal samples by dividing the predicted fiducial cross section by the predicted total cross section at the particle level, the latter derived without any kinematic cuts in the W-boson case and only with an invariant mass window $66 < m_{\ell\ell} < 116$ GeV in the Z-boson case. The acceptance A includes theory uncertainties (Section 6), which are then propagated into σ^{tot}.

Table 3
Observed impact (in %) of the different sources of uncertainty on the measured fiducial cross sections. Flavour-tagging uncertainties and top-quark modelling uncertainties are taken from Ref. [15].

Category	$\sigma(Z \to ee)$	$\sigma(Z \to \mu\mu)$	$\sigma(Z \to \ell\ell)$	$\sigma(W^- \to e^-\bar{\nu})$	$\sigma(W^+ \to e^+\nu)$	$\sigma(W^- \to \mu^-\bar{\nu})$	$\sigma(W^+ \to \mu^+\nu)$
Luminosity	2.2	2.2	2.2	2.5	2.5	2.5	2.4
Pile-up	1.2	0.3	0.8	1.1	1.1	0.3	0.4
MC statistics	< 0.2	< 0.2	< 0.2	< 0.2	0.4	< 0.2	0.4
Lepton trigger	0.2	0.4	0.2	1.2	1.3	1.0	1.0
Electron reconstruction	1.4	–	0.9	0.7	0.8	–	–
Muon reconstruction	–	2.1	1.4	–	–	1.0	1.0
Multi-jet	–	–	–	2.9	2.4	1.3	1.1
Other background modelling	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	0.5	0.4
Jet energy scale	–	–	–	1.4	1.4	1.3	1.4
Jet energy resolution	–	–	–	< 0.2	0.3	0.2	0.2
NNJVT	–	–	–	1.6	1.5	1.3	1.3
$E_{\mathrm{T}}^{\mathrm{miss}}$ track soft term	–	–	–	< 0.2	0.4	< 0.2	< 0.2
PDF	0.2	0.2	< 0.2	0.8	0.8	0.6	0.5
QCD scale (ME and PS)	0.6	< 0.2	0.3	1.3	1.2	0.6	0.6
Flavour tagging	–	–	–	–	–	–	–
$t\bar{t}$ modelling	–	–	–	–	–	–	–
Total systematic impact [%]	3.0	3.1	2.7	5.0	4.5	3.8	3.6
Statistical impact [%]	0.04	0.03	0.02	0.02	0.01	0.01	0.01

Category	$\sigma(W^- \to \ell^-\bar{\nu})$	$\sigma(W^+ \to \ell^+\nu)$	$\sigma(W^\pm \to \ell\nu)$	R_{W^+/W^-}	$R_{W^\pm/Z}$	$R_{t\bar{t}/W^\pm}$
Luminosity	2.5	2.4	2.4	< 0.2	0.3	< 0.2
Pile-up	0.5	0.7	0.6	< 0.2	< 0.2	< 0.2
MC statistics	< 0.2	0.2	< 0.2	< 0.2	< 0.2	< 0.2
Lepton trigger	1.0	0.9	0.9	< 0.2	0.7	0.8
Electron reconstruction	0.4	0.5	0.4	< 0.2	0.5	0.4
Muon reconstruction	0.6	0.6	0.6	0.2	0.8	0.6
Multi-jet	1.2	1.2	1.2	1.6	1.1	1.0
Other background modelling	0.4	0.4	0.4	< 0.2	0.3	0.9
Jet energy scale	1.3	1.3	1.3	< 0.2	1.3	1.3
Jet energy resolution	< 0.2	0.2	< 0.2	< 0.2	< 0.2	< 0.2
NNJVT	1.4	1.3	1.3	< 0.2	1.3	< 0.2
$E_{\mathrm{T}}^{\mathrm{miss}}$ track soft term	< 0.2	0.3	0.3	< 0.2	0.3	0.3
PDF	0.5	0.5	0.3	0.5	0.2	0.4
QCD scale (ME and PS)	0.8	0.7	0.6	< 0.2	0.7	0.7
Flavour tagging	–	–	–	–	–	< 0.2
$t\bar{t}$ modelling	–	–	–	–	–	1.1
Total systematic impact [%]	3.7	3.5	3.5	1.7	2.4	2.5
Statistical impact [%]	0.01	0.01	0.01	0.01	0.02	0.32

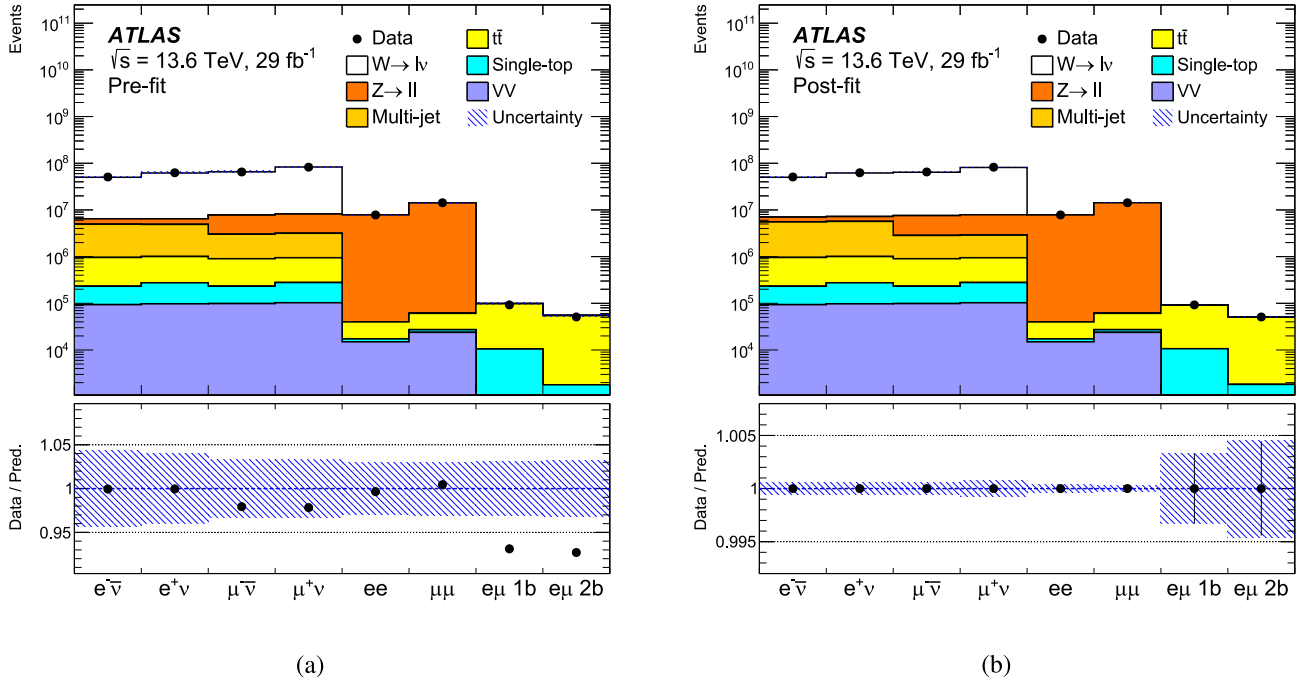


Fig. 3. Comparison of the number of data events in each channel (dots) with the predictions (stacked histograms) shown (a) before and (b) after the fits. The dashed error band in the pre-fit figure gives the total systematic uncertainty before the fit, while in the post-fit figure, it represents the statistical uncertainty derived from the fit.

Table 4
The measured cross sections using the profile likelihood method. The quoted uncertainty corresponds to the total uncertainty (the statistical uncertainty is negligibly small). Rounding has been applied to all quoted numbers.

Channel	$\sigma^{\text{fid}} \pm \delta\sigma_{\text{stat}\oplus\text{syst}}$ [pb]	Acceptance A	$\sigma^{\text{tot}} \pm \delta\sigma_{\text{stat}\oplus\text{syst}}$ [pb]
$Z \to e^+e^-$	740 ± 22	0.374 ± 0.011	1981 ± 82
$Z \to \mu^+\mu^-$	747 ± 23	0.374 ± 0.011	1997 ± 82
$Z \to \ell^+\ell^-$	744 ± 20	0.374 ± 0.011	1989 ± 77
$W^- \to e^-\bar{\nu}$	3380 ± 170	0.381 ± 0.009	8880 ± 490
$W^- \to \mu^-\bar{\nu}$	3310 ± 130	0.381 ± 0.009	8680 ± 390
$W^- \to \ell^-\bar{\nu}$	3310 ± 120	0.381 ± 0.009	8690 ± 390
$W^+ \to e^+\nu$	4350 ± 200	0.366 ± 0.009	11880 ± 620
$W^+ \to \mu^+\nu$	4240 ± 160	0.365 ± 0.010	11620 ± 530
$W^+ \to \ell^+\nu$	4250 ± 150	0.366 ± 0.009	11620 ± 520
$W^\pm \to \ell^\pm\nu$	7560 ± 270	0.372 ± 0.009	20310 ± 890

Ratio	$R \pm \delta R_{\text{stat}\oplus\text{syst}}$
W^+/W^-	1.286 ± 0.022
$W^\pm/Z$	10.17 ± 0.25
$t\bar{t}/W^-$	0.256 ± 0.008
$t\bar{t}/W^+$	0.199 ± 0.006
$t\bar{t}/W^\pm$	0.112 ± 0.003

The impact of the uncertainties in the measured fiducial cross sections arising from different sources is summarised in Table 3. The uncertainties are grouped into distinct categories. To estimate the impact associated with each category, the nuisance parameters belonging to the category are fixed at the best-fit values and set as constants. Then a fitting process is performed again, resulting in a decreased uncertainty compared to the nominal uncertainty values. The difference in quadrature between the new and the nominal uncertainty is the impact of this category. The luminosity uncertainty values vary slightly from one channel to another due to different background contributions in each channel. The statistical impact is obtained by repeating the fit after having fixed all nuisance parameters to their fitted values.

The comparison of data and predictions before and after fits in all regions is shown in Fig. 3. Good agreement is observed in the single lepton and same flavour di-lepton regions while in the $e\mu$ regions the data event yields are slightly lower than the predictions. The measured fiducial and total cross-section results and the corresponding acceptance with their respective uncertainties are summarised in Table 4. The Z-boson cross sections ($\sigma_{Z\to e^+e^-}$, $\sigma_{Z\to\mu^+\mu^-}$, and $\sigma_{Z\to\ell^+\ell^-}$) are obtained through individual fits to the two same flavour dilepton regions. The W-boson cross sections and the fiducial ratios (R_{W^+/W^-} and $R_{W^\pm/Z}$) are fitted using the four single lepton and the two same flavour dilepton regions. Several fits are performed, using the same inputs but changing the parameters of interest each time. The $W^+ \to e^+\nu$, $W^+ \to \mu^+\nu$, $W^- \to e^-\bar{\nu}$, and $W^- \to \mu^-\bar{\nu}$ cross sections are obtained simultaneously. The W^+- and W^--boson cross sections are also derived in a simultaneous fit. The $W^\pm$-boson cross section, the R_{W^+/W^-} ratio, and the $R_{W^\pm/Z}$ ratio are obtained in separate fits. The $t\bar{t}$ to W-boson cross-section ratios $R_{t\bar{t}/W^\pm}$, $R_{t\bar{t}/W^+}$, and $R_{t\bar{t}/W^-}$ are derived in separate fits to the four W-boson channels, the two Z-boson channels, and the two $t\bar{t}$ $e\mu$ channels from Ref. [15].

Fig. 4 compares the measured results for the W^-, W^+, and Z boson fiducial cross sections and $R_{W^\pm/Z}$ R_{W^+/W^-}, and $t\bar{t}/W$ ratios to the Standard-Model (SM) theory predictions with different PDF sets: PDF4LHC21 [63], CT18, CT18A [64], MSHT20 [65–67], NNPDF4.0 [68], ABMP16 [69], and ATLASpdf21 [70]. The predictions are calculated at NNLO+NNLL QCD and NLO EW accuracy using DYTURBO-1.3.1 [71–74] and RENESANCE-1.3.3 [75,76], and combining them with an additive prescription, as used in Ref. [4]. The nominal $t\bar{t}$ predictions for all PDFs are calculated at NNLO in QCD including the resummation of NNLL soft-gluon terms calculated using TOP++ 2.0 [37–43] based on $m_t = 172.5$ GeV. Theoretical uncertainties arising from normalisation and factorisation scale variations for missing higher orders, the variation of the strong coupling constant α_s, and variations of the input PDFs are evaluated. The latter source dominates in most cases as indicated with the inner error bars. Scale variations are taken as uncorrelated between different bosons and between bosons and $t\bar{t}$, but the PDF variations are treated as correlated.

For the W^-, W^+, and Z boson fiducial cross sections and their ratios, an overall good agreement is observed, while the $t\bar{t}/W$ ratio results are slightly lower than the predictions for most of the PDFs considered. This is consistent with the results of the Run 3 $t\bar{t}$ cross-section measurement [15], where the measured $t\bar{t}$ cross-section is measured to be lower than the predicted value. The predictions based on the PDF4LHC21 set with $m_t = 171.5$ GeV and $m_t = 173.5$ GeV are also included in Fig. 4.

The measured total cross section is shown as a function of $\sqrt{s}$, together compared with the CT14NNLO predictions [77] in Fig. 5. Good agreement is observed between data and prediction.

8. Conclusion

A measurement of the inclusive W- and Z-boson production cross sections with decays into final states with electrons or muons, their ratios, and the ratios of $t\bar{t}$ to W-boson fiducial cross sections were performed using LHC pp collision data corresponding to 29 fb^{-1} collected by the ATLAS experiment at a new centre-of-mass energy of 13.6 TeV. The cross sections are measured for Z-boson production in a fiducial phase space corresponding to $p_{\text{T}}^{\ell} > 27$ GeV, $|\eta_\ell| < 2.5$, and $66 < m_{\ell\ell} < 116$ GeV and for W-boson production in a fiducial region corresponding to $p_{\text{T}}^{\ell} > 27$ GeV, $|\eta_\ell| < 2.5$, $m_{\text{T}}^{W} > 50$ GeV, and $E_{\text{T}}^{\text{miss}} > 25$ GeV. The measured fiducial cross-section values for W^+, W^-, and Z boson productions are 4250 ± 150 pb, 3310 ± 120 pb, and 744 ± 20 pb, respectively, where the uncertainty corresponds to the total uncertainty, including that arising from the luminosity, which amounts to about 2.2%. The measured values for the ratios of fiducial cross sections are: $R_{W^+/W^-} = 1.286 \pm 0.022$, $R_{W^\pm/Z} = 10.17 \pm 0.25$, and $R_{t\bar{t}/W^\pm} = 0.112 \pm 0.003$, where the uncertainty is the total uncertainty. The total cross sections are also measured in the mass range $66\text{ GeV} < m_{\ell\ell} < 116$ GeV for Z-boson production and in the full phase space for W-boson production. Measurements are performed on σ_{W^+}, σ_{W^-}, $\sigma_{W^\pm}$, σ_Z, R_{W^+/W^-}, $R_{W^\pm/Z}$, $R_{t\bar{t}/W^\pm}$, $R_{t\bar{t}/W^+}$, and $R_{t\bar{t}/W^-}$. The measured W- and Z-boson cross sections are in good agreement with the SM predictions whereas the $t\bar{t}$ over W-boson fiducial cross-section ratios are slightly overestimated by some of the theoretical predictions.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

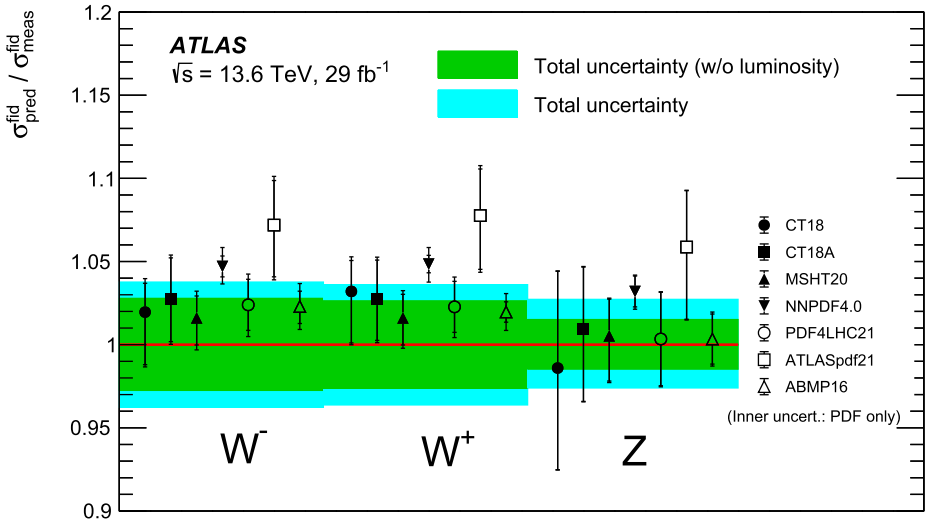
Data availability

The data for this manuscript are not available. The values in the plots and tables associated to this article are stored in HEPDATA (https://hepdata.cedar.ac.uk).

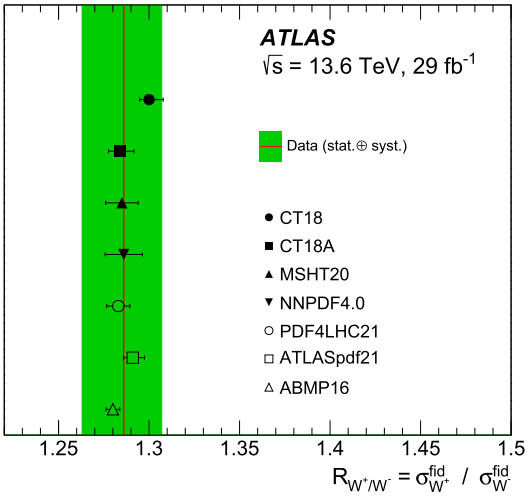
Acknowledgements

We thank CERN for the very successful operation of the LHC and its injectors, as well as the support staff at CERN and at our institutions worldwide without whom ATLAS could not be operated efficiently.

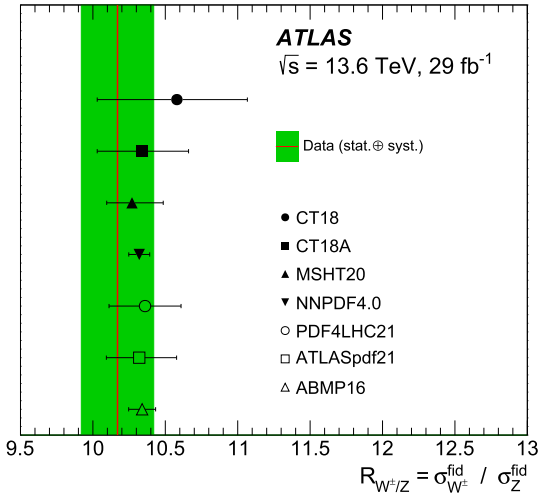
The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN, the ATLAS Tier-1 facilities at TRIUMF/SFU (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN-CNAF (Italy), NL-T1 (Netherlands), PIC (Spain), RAL (UK) and BNL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



(a)



(b)



(c)

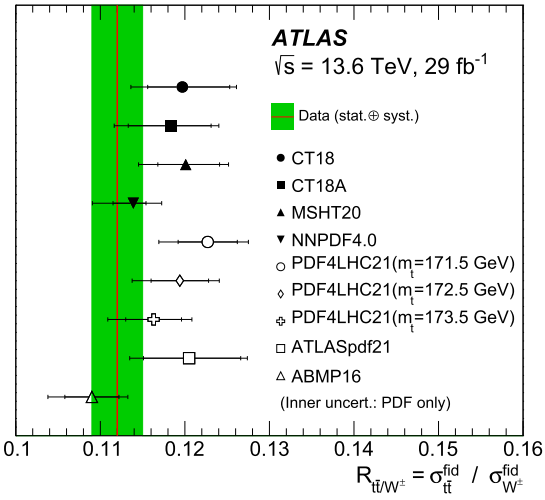
Fig. 4. The ratio of the predictions obtained with different PDF sets and the measured fiducial cross sections for (a) W^-, W^+, and Z bosons, (b) and (c) their ratios R_{W^+/W^-} and $R_{W^\pm/Z}$, (d), (e) and (f) ratios of $t\bar{t}$ over W-boson fiducial cross sections $R_{t\bar{t}/W^\pm}$, $R_{t\bar{t}/W^+}$, and $R_{t\bar{t}/W^-}$. The outer (inner) band in (a) corresponds to the total uncertainty including (excluding) the luminosity uncertainty. The vertical band in the other plots shows the total (systematic and statistical) uncertainty in the data. The error bars on the predictions correspond to the theory uncertainties with the inner error bars (where available) representing the contributions from the PDF uncertainty.

worldwide and large non-WLCG resource providers. Major contributors of computing resources are listed in Ref. [78].

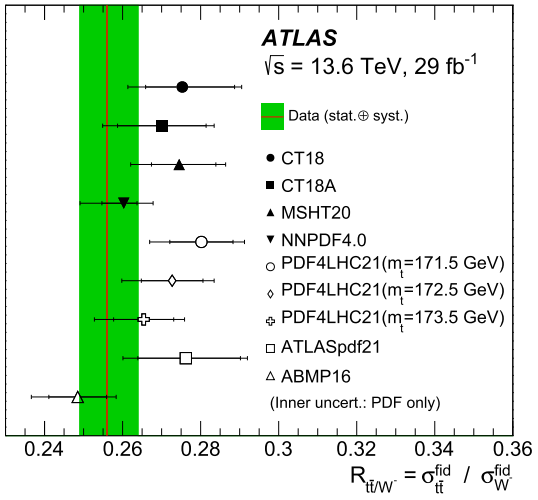
We gratefully acknowledge the support of ANPCyT, Argentina; YerPhI, Armenia; ARC, Australia; BMWFW and FWF, Austria; ANAS, Azerbaijan; CNPq and FAPESP, Brazil; NSERC, NRC and CFI, Canada; CERN; ANID, Chile; CAS, MOST and NSFC, China; Minciencias, Colombia; MEYS CR, Czech Republic; DNRF and DNSRC, Denmark; IN2P3-CNRS and CEA-DRF/IRFU, France; SRNSFG, Georgia; BMBF, HGF and MPG, Germany; GSRI, Greece; RGC and Hong Kong SAR, China; ISF and Benoziyo Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; NWO, Netherlands; RCN, Norway; MNiSW, Poland; FCT, Portugal; MNE/IFA, Romania; MESTD, Serbia; MSSR, Slovakia; ARRS and MIZŠ, Slovenia; DSI/NRF, South Africa; MICINN, Spain; SRC and Wallenberg Foundation, Sweden; SERI, SNSF and Cantons of Bern and Geneva, Switzerland; MOST, Taipei; TENMAK, Türkiye; STFC, United Kingdom; DOE and NSF, United States of America.

Individual groups and members have received support from BCKDF, Canarie, CRC and DRAC, Canada; PRIMUS 21/SCI/017, CERN-CZ and FORTE, Czech Republic; COST, ERC, ERDF, Horizon 2020, ICSC-NextGenerationEU and Marie Skłodowska-Curie Actions, European Union; Investissements d'Avenir Labex, Investissements d'Avenir Idex and ANR, France; DFG and AvH Foundation, Germany; Herakleitos, Thales and Aristeia programmes co-financed by EU-ESF and the Greek NSRF, Greece; BSF-NSF and MINERVA, Israel; Norwegian Financial Mechanism 2014-2021, Norway; NCN and NAWA, Poland; La Caixa Banking Foundation, CERCA Programme Generalitat de Catalunya and PROMETEO and GenT Programmes Generalitat Valenciana, Spain; Göran Gustafssons Stiftelse, Sweden; The Royal Society and Leverhulme Trust, United Kingdom.

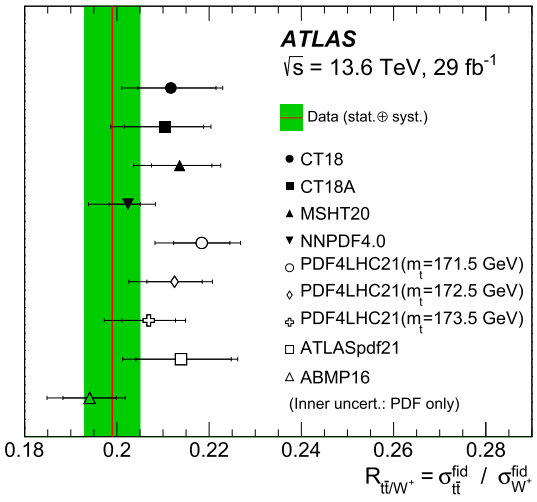
In addition, individual members wish to acknowledge support from CERN: European Organization for Nuclear Research (CERN PJAS); Chile: Agencia Nacional de Investigación y Desarrollo (FONDECYT



(d)



(e)



(f)

Fig. 4. (continued)

1190886, FONDECYT 1210400, FONDECYT 1230987); China: National Natural Science Foundation of China (NSFC - 12175119, NSFC 12275265, NSFC-12075060); Czech Republic: Czech Science Foundation (GACR - 24-11373S), Ministry of Education Youth and Sports (FORTE CZ.02.01.01/00/22_008/0004632); European Union: European Research Council (ERC - 948254, ERC 101089007), Horizon 2020 Framework Programme (MUCCA - CHIST-ERA-19-XAI-00), Italian Center for High Performance Computing, Big Data and Quantum Computing (ICSC, NextGenerationEU); France: Agence Nationale de la Recherche (ANR-20-CE31-0013, ANR-21-CE31-0013, ANR-21-CE31-0022), Investissements d'Avenir Labex (ANR-11-LABX-0012); Germany: Baden-Württemberg Stiftung (BW Stiftung-Postdoc Eliteprogramme), Deutsche Forschungsgemeinschaft (DFG - 469666862, DFG - CR 312/5-2); Italy: Istituto Nazionale di Fisica Nucleare (ICSC, NextGenerationEU); Japan: Japan Society for the Promotion of Science (JSPS KAKENHI Grant No. 22KK0227, JSPS KAKENHI JP21H05085, JSPS KAKENHI JP22H01227, JSPS KAKENHI JP22H04944); Netherlands: Netherlands Organisation for Scientific Research (NWO Veni 2020 - VI.Veni.202.179); Norway: Research Council of Norway (RCN-314472); Poland: Polish National Agency for Academic Exchange (PPN/PPO/2020/1/00002/U/00001), Polish National Science Centre (NCN 2021/42/E/ST2/00350, NCN OPUS nr 2022/47/B/ST2/03059, NCN UMO-2019/34/E/ST2/00393, UMO-2020/37/B/ST2/01043, UMO-2021/40/C/ST2/00187, UMO-2022/47/O/ST2/00148, UMO-2023/49/B/ST2/04085); Slovenia: Slovenian Research Agency (ARIS grant J1-3010); Spain: Generalitat Valenciana (Artemisa, FEDER, IDIFEDER/2018/048), Ministry of Science and Innovation (MCIN & NextGenEU -PCI2022-135018-2, MICIN & FEDER -PID2021-125273NB, RYC2019-028510-I, RYC2020-030254-I), PROMETEO and GenT Programmes Generalitat Valenciana (CIDEGENT/2019/023, CIDEGENT/2019/027); Sweden: Swedish Research Council (VR 2018-00482, VR 2022-03845, VR 2022-04683, VR 2023-03403, VR grant 2021-03651), Knut and Alice Wallenberg Foundation (KAW 2018.0157, KAW 2018.0458, KAW 2019.0447, KAW 2022.0358); Switzerland: Swiss National Science Foundation (SNSF - PCEFP2_194658); United Kingdom: Leverhulme Trust (Leverhulme Trust RPG-2020-004), Royal Society (NIF-R1-231091); United States of America: Neubauer Family Foundation.

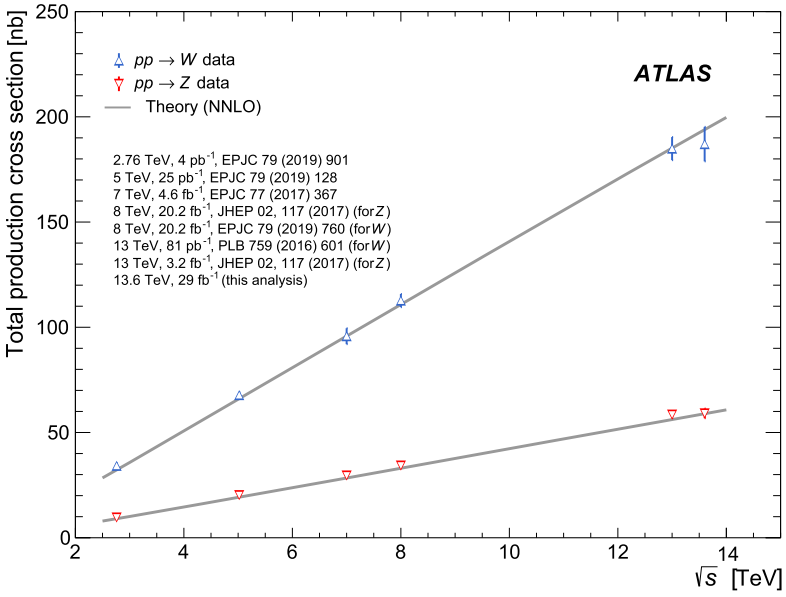


Fig. 5. The measured W and Z boson total production cross sections in the leptonic decay channel at different values of centre-of-mass energy. For comparison, the central values of the NNLO predictions based on the CT14NNLO PDF set are included.

References

[1] ATLAS Collaboration, The ATLAS experiment at the CERN Large Hadron Collider, J. Instrum. 3 (2008) S08003.

[2] ATLAS Collaboration, Measurement of $W^{\pm}$-boson and Z-boson production cross-sections in pp collisions at $\sqrt{s} = 2.76\,TeV$ with the ATLAS detector, Eur. Phys. J. C 79 (2019) 901, arXiv:1907.03567 [hep-ex].

[3] ATLAS Collaboration, Measurements of W and Z boson production in pp collisions at $\sqrt{s} = 5.02\,TeV$ with the ATLAS detector, Eur. Phys. J. C 79 (2019) 128, arXiv:1810.08424 [hep-ex]; Erratum: Eur. Phys. J. C 79 (2019) 374.

[4] ATLAS Collaboration, Precision measurement and interpretation of inclusive W^{+}, W^{-} and Z/γ^{*} production cross sections with the ATLAS detector, Eur. Phys. J. C 77 (2017) 367, arXiv:1612.03016 [hep-ex].

[5] ATLAS Collaboration, Measurement of the Drell–Yan triple-differential cross section in pp collisions at $\sqrt{s} = 8\,TeV$, J. High Energy Phys. 12 (2017) 059, arXiv:1710.05167 [hep-ex].

[6] ATLAS Collaboration, Measurement of the cross-section and charge asymmetry of W bosons produced in proton–proton collisions at $\sqrt{s} = 8\,TeV$ with the ATLAS detector, Eur. Phys. J. C 79 (2019) 760, arXiv:1904.05631 [hep-ex].

[7] ATLAS Collaboration, Measurement of $W^{\pm}$ and Z-boson production cross sections in pp collisions at $\sqrt{s} = 13\,TeV$ with the ATLAS detector, Phys. Lett. B 759 (2016) 601, arXiv:1603.09222 [hep-ex].

[8] ATLAS Collaboration, Measurement of the transverse momentum distribution of Drell–Yan lepton pairs in proton–proton collisions at $\sqrt{s} = 13\,TeV$ with the ATLAS detector, Eur. Phys. J. C 80 (2020) 616, arXiv:1912.02844 [hep-ex].

[9] CMS Collaboration, The CMS experiment at the CERN LHC, J. Instrum. 3 (2008) S08004.

[10] CMS Collaboration, Measurement of the inclusive W and Z production cross sections in pp collisions at $\sqrt{s} = 7\,TeV$ with the CMS experiment, J. High Energy Phys. 10 (2011) 132, arXiv:1107.4789 [hep-ex].

[11] CMS Collaboration, Measurement of the differential and double-differential Drell-Yan cross sections in proton–proton collisions at $\sqrt{s} = 7\,TeV$, J. High Energy Phys. 12 (2013) 030, arXiv:1310.7291 [hep-ex].

[12] CMS Collaboration, Measurement of inclusive W and Z boson production cross sections in pp collisions at $\sqrt{s} = 8\,TeV$, Phys. Rev. Lett. 112 (2014) 191802, arXiv:1402.0923 [hep-ex].

[13] CMS Collaboration, Measurements of differential and double-differential Drell-Yan cross sections in proton–proton collisions at $\sqrt{s} = 8\,TeV$, Eur. Phys. J. C 75 (2015) 147, arXiv:1412.1115 [hep-ex].

[14] CMS Collaboration, Measurements of the W boson rapidity, helicity, double-differential cross sections, and charge asymmetry in pp collisions at $\sqrt{s} = 13\,TeV$, Phys. Rev. D 102 (2020) 092012, arXiv:2008.04174 [hep-ex].

[15] ATLAS Collaboration, Measurement of the $t\bar{t}$ cross section and its ratio to the Z production cross section using pp collisions at $\sqrt{s} = 13.6$ TeV with the ATLAS detector, Phys. Lett. B 848 (2024) 138376, arXiv:2308.09529 [hep-ex].

[16] W.A. Rolke, A.M. Lopez, J. Conrad, Limits and confidence intervals in the presence of nuisance parameters, Nucl. Instrum. Methods A 551 (2005) 493, arXiv:physics/0403059.

[17] ATLAS Collaboration, The ATLAS experiment at the CERN Large Hadron Collider: a description of the detector configuration for Run 3, arXiv:2305.16623 [physics.ins-det], 2023.

[18] G. Avoni, et al., The new LUCID-2 detector for luminosity measurement and monitoring in ATLAS, J. Instrum. 13 (2018) P07017.

[19] ATLAS Collaboration, The ATLAS trigger system for LHC Run 3 and trigger performance in 2022, arXiv:2401.06630 [hep-ex], 2024.

[20] ATLAS Collaboration, The ATLAS collaboration software and firmware, ATL-SOFT-PUB-2021-001, https://cds.cern.ch/record/2767187, 2021.

[21] ATLAS Collaboration, Preliminary analysis of the luminosity calibration of the ATLAS 13.6 *TeV* data recorded in 2022, ATL-DAPR-PUB-2023-001, https://cds.cern.ch/record/2853525, 2023.

[22] ATLAS Collaboration, ATLAS data quality operations and performance for 2015–2018 data-taking, J. Instrum. 15 (2020) P04003, arXiv:1911.04632 [physics.ins-det].

[23] E. Bothmann, et al., Event generation with Sherpa 2.2, SciPost Phys. 7 (2019) 034, arXiv:1905.09127 [hep-ph].

[24] F. Buccioni, et al., OpenLoops 2, Eur. Phys. J. C 79 (2019) 866, arXiv:1907.13071 [hep-ph].

[25] F. Cascioli, P. Maierhöfer, S. Pozzorini, Scattering amplitudes with open loops, Phys. Rev. Lett. 108 (2012) 111601, arXiv:1111.5206 [hep-ph].

[26] A. Denner, S. Dittmaier, L. Hofer, Collier : a fortran-based complex one-loop library in extended regularizations, Comput. Phys. Commun. 212 (2017) 220, arXiv:1604.06792 [hep-ph].

[27] S. Schumann, F. Krauss, A parton shower algorithm based on Catani–Seymour dipole factorisation, J. High Energy Phys. 03 (2008) 038, arXiv:0709.1027 [hep-ph].

[28] S. Höche, F. Krauss, M. Schönherr, F. Siegert, QCD matrix elements + parton showers. The NLO case, J. High Energy Phys. 04 (2013) 027, arXiv:1207.5030 [hep-ph].

[29] NNPDF Collaboration, R.D. Ball, et al., Parton distributions for the LHC run II, J. High Energy Phys. 04 (2015) 040, arXiv:1410.8849 [hep-ph].

[30] C. Anastasiou, L. Dixon, K. Melnikov, F. Petriello, High-precision QCD at hadron colliders: electroweak gauge boson rapidity distributions at next-to-next-to leading order, Phys. Rev. D 69 (2004) 094008, arXiv:hep-ph/0312266.

[31] S. Frixione, G. Ridolfi, P. Nason, A positive-weight next-to-leading-order Monte Carlo for heavy flavour hadroproduction, J. High Energy Phys. 09 (2007) 126, arXiv:0707.3088 [hep-ph].

[32] P. Nason, A new method for combining NLO QCD with shower Monte Carlo algorithms, J. High Energy Phys. 11 (2004) 040, arXiv:hep-ph/0409146.

[33] S. Frixione, P. Nason, C. Oleari, Matching NLO QCD computations with parton shower simulations: the POWHEG method, J. High Energy Phys. 11 (2007) 070, arXiv:0709.2092 [hep-ph].

[34] S. Alioli, P. Nason, C. Oleari, E. Re, A general framework for implementing NLO calculations in shower Monte Carlo programs: the POWHEG BOX, J. High Energy Phys. 06 (2010) 043, arXiv:1002.2581 [hep-ph].

[35] C. Bierlich, et al., A comprehensive guide to the physics and usage of PYTHIA 8.3, SciPost Phys. Codeb. 2022 (2022) 8, arXiv:2203.11601 [hep-ph].

[36] ATLAS Collaboration, ATLAS Pythia 8 tunes to 7 *TeV* data, ATL-PHYS-PUB-2014-021, https://cds.cern.ch/record/1966419, 2014.

[37] M. Beneke, P. Falgari, S. Klein, C. Schwinn, Hadronic top-quark pair production with NNLL threshold resummation, Nucl. Phys. B 855 (2012) 695, arXiv:1109.1536 [hep-ph].

[38] M. Cacciari, M. Czakon, M. Mangano, A. Mitov, P. Nason, Top-pair production at hadron colliders with next-to-next-to-leading logarithmic soft-gluon resummation, Phys. Lett. B 710 (2012) 612, arXiv:1111.5869 [hep-ph].

[39] P. Bärnreuther, M. Czakon, A. Mitov, Percent-level-precision physics at the tevatron: next-to-next-to-leading order QCD corrections to $q\bar{q} \to t\bar{t} + X$, Phys. Rev. Lett. 109 (2012) 132001, arXiv:1204.5201 [hep-ph].

[40] M. Czakon, A. Mitov, NNLO corrections to top-pair production at hadron colliders: the all-fermionic scattering channels, J. High Energy Phys. 12 (2012) 054, arXiv:1207.0236 [hep-ph].

[41] M. Czakon, A. Mitov, NNLO corrections to top pair production at hadron colliders: the quark-gluon reaction, J. High Energy Phys. 01 (2013) 080, arXiv:1210.6832 [hep-ph].

[42] M. Czakon, P. Fiedler, A. Mitov, Total top-quark pair-production cross section at hadron colliders through $O(\alpha_S^4)$, Phys. Rev. Lett. 110 (2013) 252004, arXiv:1303.6254 [hep-ph].

[43] M. Czakon, A. Mitov, Top++: a program for the calculation of the top-pair cross-section at hadron colliders, Comput. Phys. Commun. 185 (2014) 2930, arXiv:1112.5675 [hep-ph].

[44] ATLAS Collaboration, Emulating the impact of additional proton–proton interactions in the ATLAS simulation by presampling sets of inelastic Monte Carlo events, Comput. Softw. Big Sci. 6 (2022) 3, arXiv:2102.09495 [hep-ex].

[45] S. Porteboeuf, T. Pierog, K. Werner, Producing hard processes regarding the complete event: the EPOS event generator, arXiv:1006.2967 [hep-ph], 2010.

[46] T. Pierog, I. Karpenko, J.M. Katzy, E. Yatsenko, K. Werner, EPOS LHC: test of collective hadronization with data measured at the CERN Large Hadron Collider, Phys. Rev. C 92 (2015) 034906, arXiv:1306.0121 [hep-ph].

[47] NNPDF Collaboration, R.D. Ball, et al., Parton distributions with LHC data, Nucl. Phys. B 867 (2013) 244, arXiv:1207.1303 [hep-ph].

[48] ATLAS Collaboration, The Pythia 8 A3 tune description of ATLAS minimum bias and inelastic measurements incorporating the Donnachie–Landshoff diffractive model, ATL-PHYS-PUB-2016-017, https://cds.cern.ch/record/2206965, 2016.

[49] GEANT4 Collaboration, S. Agostinelli, et al., Geant4 – a simulation toolkit, Nucl. Instrum. Methods A 506 (2003) 250.

[50] ATLAS Collaboration, The ATLAS simulation infrastructure, Eur. Phys. J. C 70 (2010) 823, arXiv:1005.4568 [physics.ins-det].

[51] ATLAS Collaboration, Performance of electron and photon triggers in ATLAS during LHC Run 2, Eur. Phys. J. C 80 (2020) 47, arXiv:1909.00761 [hep-ex].

[52] ATLAS Collaboration, Performance of the ATLAS muon triggers in Run 2, J. Instrum. 15 (2020) P09015, arXiv:2004.13447 [physics.ins-det].

[53] ATLAS Collaboration, Electron and photon performance measurements with the ATLAS detector using the 2015–2017 LHC proton–proton collision data, J. Instrum. 14 (2019) P12006, arXiv:1908.00005 [hep-ex].

[54] ATLAS Collaboration, Muon reconstruction and identification efficiency in ATLAS using the full Run 2 pp collision data set at $\sqrt{s} = 13\,TeV$, Eur. Phys. J. C 81 (2021) 578, arXiv:2012.00578 [hep-ex].

[55] ATLAS Collaboration, Jet reconstruction and performance using particle flow with the ATLAS detector, Eur. Phys. J. C 77 (2017) 466, arXiv:1703.10485 [hep-ex].

[56] M. Cacciari, G.P. Salam, G. Soyez, The anti-k_t jet clustering algorithm, J. High Energy Phys. 04 (2008) 063, arXiv:0802.1189 [hep-ph].

[57] M. Cacciari, G.P. Salam, G. Soyez, FastJet user manual, Eur. Phys. J. C 72 (2012) 1896, arXiv:1111.6097 [hep-ph].

[58] ATLAS Collaboration, Jet energy scale and resolution measured in proton–proton collisions at $\sqrt{s} = 13\,TeV$ with the ATLAS detector, Eur. Phys. J. C 81 (2021) 689, arXiv:2007.02645 [hep-ex].

[59] ATLAS Collaboration, Performance of pile-up mitigation techniques for jets in pp collisions at $\sqrt{s} = 8\,TeV$ using the ATLAS detector, Eur. Phys. J. C 76 (2016) 581, arXiv:1510.03823 [hep-ex].

[60] ATLAS Collaboration, E_T^{miss} performance in the ATLAS detector using 2015–2016 LHC pp collisions, ATLAS-CONF-2018-023, https://cds.cern.ch/record/2625233, 2018.

[61] ATLAS Collaboration, ATLAS flavour-tagging algorithms for the LHC Run 2 pp collision dataset, Eur. Phys. J. C 83 (2023) 681, arXiv:2211.16345 [physics.data-an].

[62] ATLAS Collaboration, Deep sets based neural networks for impact parameter flavour tagging in ATLAS, ATL-PHYS-PUB-2020-014, https://cds.cern.ch/record/2718948, 2020.

[63] R.D. Ball, et al., The PDF4LHC21 combination of global PDF fits for the LHC Run III, J. Phys. G 49 (2022) 080501, arXiv:2203.05506 [hep-ph].

[64] T.-J. Hou, et al., New CTEQ global analysis of quantum chromodynamics with high-precision data from the LHC, Phys. Rev. D 103 (2021) 014013, arXiv:1912.10053 [hep-ph].

[65] T. Cridge, L.A. Harland-Lang, A.D. Martin, R.S. Thorne, An investigation of the α_S and heavy quark mass dependence in the MSHT20 global PDF analysis, Eur. Phys. J. C 81 (2021) 744, arXiv:2106.10289 [hep-ph].

[66] S. Bailey, T. Cridge, L.A. Harland-Lang, A.D. Martin, R.S. Thorne, Parton distributions from LHC, HERA, Tevatron and fixed target data: MSHT20 PDFs, Eur. Phys. J. C 81 (2021) 341, arXiv:2012.04684 [hep-ph].

[67] T. Cridge, L.A. Harland-Lang, A.D. Martin, R.S. Thorne, QED parton distribution functions in the MSHT20 fit, Eur. Phys. J. C 82 (2022) 90, arXiv:2111.05357 [hep-ph].

[68] NNPDF Collaboration, R.D. Ball, et al., The path to proton structure at 1% accuracy, Eur. Phys. J. C 82 (2022) 428, arXiv:2109.02653 [hep-ph].

[69] S. Alekhin, J. Blümlein, S. Moch, R. Plačakytė, Parton distribution functions, α_s, and heavy-quark masses for LHC Run II, Phys. Rev. D 96 (2017) 014011, arXiv:1701.05838 [hep-ph].

[70] ATLAS Collaboration, Determination of the parton distribution functions of the proton using diverse ATLAS data from pp collisions at $\sqrt{s} = 7, 8$ and $13\,TeV$, Eur. Phys. J. C 82 (2022) 438, arXiv:2112.11266 [hep-ex].

[71] S. Camarda, et al., DYTurbo: fast predictions for Drell-Yan processes, Eur. Phys. J. C 80 (2020) 251, arXiv:1910.07049 [hep-ph]; Erratum: Eur. Phys. J. C 80 (2020) 440.

[72] S. Camarda, L. Cieri, G. Ferrera, Drell–Yan lepton-pair production: q_T resummation at N^{3}LL accuracy and fiducial cross sections at N^{3}LO, Phys. Rev. D 104 (2021) L111503, arXiv:2103.04974 [hep-ph].

[73] S. Camarda, L. Cieri, G. Ferrera, Fiducial perturbative power corrections within the $\mathbf{q}_T$ subtraction formalism, Eur. Phys. J. C 82 (2022) 575, arXiv:2111.14509 [hep-ph].

[74] S. Camarda, L. Cieri, G. Ferrera, Drell–Yan lepton-pair production: q_T resummation at N^{4}LL accuracy, Phys. Lett. B 845 (2023) 138125, arXiv:2303.12781 [hep-ph].

[75] R. Sadykov, V. Yermolchyk, Polarized NLO EW e^+e^- cross section calculations with ReneSANCe-v1.0.0, Comput. Phys. Commun. 256 (2020) 107445, arXiv:2001.10755 [hep-ph].

[76] S. Bondarenko, Y. Dydyshka, L. Kalinovskaya, R. Sadykov, V. Yermolchyk, Hadron-hadron collision mode in ReneSANCe-v1.3.0, Comput. Phys. Commun. 285 (2023) 108646, arXiv:2207.04332 [hep-ph].

[77] S. Dulat, et al., New parton distribution functions from a global analysis of quantum chromodynamics, Phys. Rev. D 93 (2016) 033006, arXiv:1506.07443 [hep-ph].

[78] ATLAS Collaboration, ATLAS computing acknowledgements, ATL-SOFT-PUB-2023-001, https://cds.cern.ch/record/2869272, 2023.

The ATLAS Collaboration

G. Aad [103], E. Aakvaag [16], B. Abbott [121], S. Abdelhameed [117a], K. Abeling [55], N.J. Abicht [49], S.H. Abidi [29], M. Aboelela [44], A. Aboulhorma [35e], H. Abramowicz [152], H. Abreu [151], Y. Abulaiti [118], B.S. Acharya [69a,69b,k], A. Ackermann [63a], C. Adam Bourdarios [4], L. Adamczyk [86a], S.V. Addepalli [26], M.J. Addison [102], J. Adelman [116], A. Adiguzel [21c], T. Adye [135], A.A. Affolder [137], Y. Afik [39], M.N. Agaras [13], J. Agarwala [73a,73b], A. Aggarwal [101], C. Agheorghiesei [27c], A. Ahmad [36], F. Ahmadov [38,x], W.S. Ahmed [105], S. Ahuja [96], X. Ai [62e], G. Aielli [76a,76b], A. Aikot [164], M. Ait Tamlihat [35e], B. Aitbenchikh [35a], M. Akbiyik [101], T.P.A. Åkesson [99], A.V. Akimov [37], D. Akiyama [169], N.N. Akolkar [24], S. Aktas [21a], K. Al Khoury [41], G.L. Alberghi [23b], J. Albert [166], P. Albicocco [53], G.L. Albouy [60], S. Alderweireldt [52], Z.L. Alegria [122], M. Aleksa [36], I.N. Aleksandrov [38], C. Alexa [27b], T. Alexopoulos [10], F. Alfonsi [23b], M. Algren [56], M. Alhroob [168], B. Ali [133], H.M.J. Ali [92], S. Ali [31], S.W. Alibocus [93], M. Aliev [33c], G. Alimonti [71a], W. Alkakhi [55], C. Allaire [66], B.M.M. Allbrooke [147], J.F. Allen [52], C.A. Allendes Flores [138f], P.P. Allport [20],

A. Aloisio [72a,72b], F. Alonso [91], C. Alpigiani [139], Z.M.K. Alsolami [92], M. Alvarez Estevez [100], A. Alvarez Fernandez [101], M. Alves Cardoso [56], M.G. Alviggi [72a,72b], M. Aly [102], Y. Amaral Coutinho [83b], A. Ambler [105], C. Amelung [36], M. Amerl [102], C.G. Ames [110], D. Amidei [107], K.J. Amirie [156], S.P. Amor Dos Santos [131a], K.R. Amos [164], S. An [84], V. Ananiev [126], C. Anastopoulos [140], T. Andeen [11], J.K. Anders [36], S.Y. Andrean [47a,47b], A. Andreazza [71a,71b], S. Angelidakis [9], A. Angerami [41,z], A.V. Anisenkov [37], A. Annovi [74a], C. Antel [56], E. Antipov [146], M. Antonelli [53], F. Anulli [75a], M. Aoki [84], T. Aoki [154], M.A. Aparo [147], L. Aperio Bella [48], C. Appelt [18], A. Apyan [26], S.J. Arbiol Val [87], C. Arcangeletti [53], A.T.H. Arce [51], E. Arena [93], J-F. Arguin [109], S. Argyropoulos [54], J.-H. Arling [48], O. Arnaez [4], H. Arnold [146], G. Artoni [75a,75b], H. Asada [112], K. Asai [119], S. Asai [154], N.A. Asbah [36], K. Assamagan [29], R. Astalos [28a], K.S.V. Astrand [99], S. Atashi [160], R.J. Atkin [33a], M. Atkinson [163], H. Atmani [35f], P.A. Atmasiddha [129], K. Augsten [133], S. Auricchio [72a,72b], A.D. Auriol [20], V.A. Austrup [102], G. Avolio [36], K. Axiotis [56], G. Azuelos [109,ad], D. Babal [28b], H. Bachacou [136], K. Bachas [153,o], A. Bachiu [34], F. Backman [47a,47b], A. Badea [39], T.M. Baer [107], P. Bagnaia [75a,75b], M. Bahmani [18], D. Bahner [54], K. Bai [124], J.T. Baines [135], L. Baines [95], O.K. Baker [173], E. Bakos [15], D. Bakshi Gupta [8], V. Balakrishnan [121], R. Balasubramanian [115], E.M. Baldin [37], P. Balek [86a], E. Ballabene [23b,23a], F. Balli [136], L.M. Baltes [63a], W.K. Balunas [32], J. Balz [101], I. Bamwidhi [117b], E. Banas [87], M. Bandieramonte [130], A. Bandyopadhyay [24], S. Bansal [24], L. Barak [152], M. Barakat [48], E.L. Barberio [106], D. Barberis [57b,57a], M. Barbero [103], M.Z. Barel [115], K.N. Barends [33a], T. Barillari [111], M-S. Barisits [36], T. Barklow [144], P. Baron [123], D.A. Baron Moreno [102], A. Baroncelli [62a], G. Barone [29], A.J. Barr [127], J.D. Barr [97], F. Barreiro [100], J. Barreiro Guimarães da Costa [14a], U. Barron [152], M.G. Barros Teixeira [131a], S. Barsov [37], F. Bartels [63a], R. Bartoldus [144], A.E. Barton [92], P. Bartos [28a], A. Basan [101], M. Baselga [49], A. Bassalat [66,b], M.J. Basso [157a], R. Bate [165], R.L. Bates [59], S. Batlamous [100], B. Batool [142], M. Battaglia [137], D. Battulga [18], M. Bauce [75a,75b], M. Bauer [36], P. Bauer [24], L.T. Bazzano Hurrell [30], J.B. Beacham [51], T. Beau [128], J.Y. Beaucamp [91], P.H. Beauchemin [159], P. Bechtle [24], H.P. Beck [19,n], K. Becker [168], A.J. Beddall [82], V.A. Bednyakov [38], C.P. Bee [146], L.J. Beemster [15], T.A. Beermann [36], M. Begalli [83d], M. Begel [29], A. Behera [146], J.K. Behr [48], J.F. Beirer [36], F. Beisiegel [24], M. Belfkir [117b], G. Bella [152], L. Bellagamba [23b], A. Bellerive [34], P. Bellos [20], K. Beloborodov [37], D. Benchekroun [35a], F. Bendebba [35a], Y. Benhammou [152], K.C. Benkendorfer [61], L. Beresford [48], M. Beretta [53], E. Bergeaas Kuutmann [162], N. Berger [4], B. Bergmann [133], J. Beringer [17a], G. Bernardi [5], C. Bernius [144], F.U. Bernlochner [24], F. Bernon [36,103], A. Berrocal Guardia [13], T. Berry [96], P. Berta [134], A. Berthold [50], S. Bethke [111], A. Betti [75a,75b], A.J. Bevan [95], N.K. Bhalla [54], S. Bhatta [146], D.S. Bhattacharya [167], P. Bhattarai [144], K.D. Bhide [54], V.S. Bhopatkar [122], R.M. Bianchi [130], G. Bianco [23b,23a], O. Biebel [110], R. Bielski [124], M. Biglietti [77a], C.S. Billingsley [44], M. Bindi [55], A. Bingul [21b], C. Bini [75a,75b], A. Biondini [93], G.A. Bird [32], M. Birman [170], M. Biros [134], S. Biryukov [147], T. Bisanz [49], E. Bisceglie [43b,43a], J.P. Biswal [135], D. Biswas [142], I. Bloch [48], A. Blue [59], U. Blumenschein [95], J. Blumenthal [101], V.S. Bobrovnikov [37], M. Boehler [54], B. Boehm [167], D. Bogavac [36], A.G. Bogdanchikov [37], C. Bohm [47a], V. Boisvert [96], P. Bokan [36], T. Bold [86a], M. Bomben [5], M. Bona [95], M. Boonekamp [136], C.D. Booth [96], A.G. Borbély [59], I.S. Bordulev [37], H.M. Borecka-Bielska [109], G. Borissov [92], D. Bortoletto [127], D. Boscherini [23b], M. Bosman [13], J.D. Bossio Sola [36], K. Bouaouda [35a], N. Bouchhar [164], L. Boudet [4], J. Boudreau [130], E.V. Bouhova-Thacker [92], D. Boumediene [40], R. Bouquet [57b,57a], A. Boveia [120],

J. Boyd [36], D. Boye [29], I.R. Boyko [38], L. Bozianu [56], J. Bracinik [20], N. Brahimi [4], G. Brandt [172], O. Brandt [32], F. Braren [48], B. Brau [104], J.E. Brau [124], R. Brener [170], L. Brenner [115], R. Brenner [162], S. Bressler [170], D. Britton [59], D. Britzger [111], I. Brock [24], G. Brooijmans [41], E. Brost [29], L.M. Brown [166], L.E. Bruce [61], T.L. Bruckler [127], P.A. Bruckman de Renstrom [87], B. Brüers [48], A. Bruni [23b], G. Bruni [23b], M. Bruschi [23b], N. Bruscino [75a,75b], T. Buanes [16], Q. Buat [139], D. Buchin [111], A.G. Buckley [59], O. Bulekov [37], B.A. Bullard [144], S. Burdin [93], C.D. Burgard [49], A.M. Burger [36], B. Burghgrave [8], O. Burlayenko [54], J.T.P. Burr [32], J.C. Burzynski [143], E.L. Busch [41], V. Büscher [101], P.J. Bussey [59], J.M. Butler [25], C.M. Buttar [59], J.M. Butterworth [97], W. Buttinger [135], C.J. Buxo Vazquez [108], A.R. Buzykaev [37], S. Cabrera Urbán [164], L. Cadamuro [66], D. Caforio [58], H. Cai [130], Y. Cai [14a,14e], Y. Cai [14c], V.M.M. Cairo [36], O. Cakir [3a], N. Calace [36], P. Calafiura [17a], G. Calderini [128], P. Calfayan [68], G. Callea [59], L.P. Caloba [83b], D. Calvet [40], S. Calvet [40], M. Calvetti [74a,74b], R. Camacho Toro [128], S. Camarda [36], D. Camarero Munoz [26], P. Camarri [76a,76b], M.T. Camerlingo [72a,72b], D. Cameron [36], C. Camincher [166], M. Campanelli [97], A. Camplani [42], V. Canale [72a,72b], A.C. Canbay [3a], E. Canonero [96], J. Cantero [164], Y. Cao [163], F. Capocasa [26], M. Capua [43b,43a], A. Carbone [71a,71b], R. Cardarelli [76a], J.C.J. Cardenas [8], G. Carducci [43b,43a], T. Carli [36], G. Carlino [72a], J.I. Carlotto [13], B.T. Carlson [130,p], E.M. Carlson [166,157a], J. Carmignani [93], L. Carminati [71a,71b], A. Carnelli [136], M. Carnesale [75a,75b], S. Caron [114], E. Carquin [138f], S. Carrá [71a], G. Carratta [23b,23a], A.M. Carroll [124], T.M. Carter [52], M.P. Casado [13,h], M. Caspar [48], F.L. Castillo [4], L. Castillo Garcia [13], V. Castillo Gimenez [164], N.F. Castro [131a,131e], A. Catinaccio [36], J.R. Catmore [126], T. Cavaliere [4], V. Cavaliere [29], N. Cavalli [23b,23a], Y.C. Cekmecelioglu [48], E. Celebi [21a], S. Cella [36], F. Celli [127], M.S. Centonze [70a,70b], V. Cepaitis [56], K. Cerny [123], A.S. Cerqueira [83a], A. Cerri [147], L. Cerrito [76a,76b], F. Cerutti [17a], B. Cervato [142], A. Cervelli [23b], G. Cesarini [53], S.A. Cetin [82], D. Chakraborty [116], J. Chan [17a], W.Y. Chan [154], J.D. Chapman [32], E. Chapon [136], B. Chargeishvili [150b], D.G. Charlton [20], M. Chatterjee [19], C. Chauhan [134], Y. Che [14c], S. Chekanov [6], S.V. Chekulaev [157a], G.A. Chelkov [38,a], A. Chen [107], B. Chen [152], B. Chen [166], H. Chen [14c], H. Chen [29], J. Chen [62c], J. Chen [143], M. Chen [127], S. Chen [154], S.J. Chen [14c], X. Chen [62c,136], X. Chen [14b,ac], Y. Chen [62a], C.L. Cheng [171], H.C. Cheng [64a], S. Cheong [144], A. Cheplakov [38], E. Cheremushkina [48], E. Cherepanova [115], R. Cherkaoui El Moursli [35e], E. Cheu [7], K. Cheung [65], L. Chevalier [136], V. Chiarella [53], G. Chiarelli [74a], N. Chiedde [103], G. Chiodini [70a], A.S. Chisholm [20], A. Chitan [27b], M. Chitishvili [164], M.V. Chizhov [38], K. Choi [11], Y. Chou [139], E.Y.S. Chow [114], K.L. Chu [170], M.C. Chu [64a], X. Chu [14a,14e], J. Chudoba [132], J.J. Chwastowski [87], D. Cieri [111], K.M. Ciesla [86a], V. Cindro [94], A. Ciocio [17a], F. Cirotto [72a,72b], Z.H. Citron [170], M. Citterio [71a], D.A. Ciubotaru [27b], A. Clark [56], P.J. Clark [52], N. Clarke Hall [97], C. Clarry [156], J.M. Clavijo Columbie [48], S.E. Clawson [48], C. Clement [47a,47b], J. Clercx [48], Y. Coadou [103], M. Cobal [69a,69c], A. Coccaro [57b], R.F. Coelho Barrue [131a], R. Coelho Lopes De Sa [104], S. Coelli [71a], B. Cole [41], J. Collot [60], P. Conde Muiño [131a,131g], M.P. Connell [33c], S.H. Connell [33c], E.I. Conroy [127], F. Conventi [72a,ae], H.G. Cooke [20], A.M. Cooper-Sarkar [127], F.A. Corchia [23b,23a], A. Cordeiro Oudot Choi [128], L.D. Corpe [40], M. Corradi [75a,75b], F. Corriveau [105,v], A. Cortes-Gonzalez [18], M.J. Costa [164], F. Costanza [4], D. Costanzo [140], B.M. Cote [120], J. Couthures [4], G. Cowan [96], K. Cranmer [171], D. Cremonini [23b,23a], S. Crépé-Renaudin [60], F. Crescioli [128], M. Cristinziani [142], M. Cristoforetti [78a,78b], V. Croft [115], J.E. Crosby [122], G. Crosetti [43b,43a], A. Cueto [100], Z. Cui [7], W.R. Cunningham [59], F. Curcio [164], J.R. Curran [52], P. Czodrowski [36], M.M. Czurylo [36], M.J. Da Cunha Sargedas De Sousa [57b,57a], J.V. Da Fonseca Pinto [83b], C. Da Via [102], W. Dabrowski [86a], T. Dado [49], S. Dahbi [149], T. Dai [107],

D. Dal Santo [19], C. Dallapiccola [104], M. Dam [42], G. D'amen [29], V. D'Amico [110], J. Damp [101], J.R. Dandoy [34], D. Dannheim [36], M. Danninger [143], V. Dao [146], G. Darbo [57b], S.J. Das [29,af], F. Dattola [48], S. D'Auria [71a,71b], A. D'avanzo [72a,72b], C. David [33a], T. Davidek [134], I. Dawson [95], H.A. Day-hall [133], K. De [8], R. De Asmundis [72a], N. De Biase [48], S. De Castro [23b,23a], N. De Groot [114], P. de Jong [115], H. De la Torre [116], A. De Maria [14c], A. De Salvo [75a], U. De Sanctis [76a,76b], F. De Santis [70a,70b], A. De Santo [147], J.B. De Vivie De Regie [60], D.V. Dedovich [38], J. Degens [93], A.M. Deiana [44], F. Del Corso [23b,23a], J. Del Peso [100], F. Del Rio [63a], L. Delagrange [128], F. Deliot [136], C.M. Delitzsch [49], M. Della Pietra [72a,72b], D. Della Volpe [56], A. Dell'Acqua [36], L. Dell'Asta [71a,71b], M. Delmastro [4], P.A. Delsart [60], S. Demers [173], M. Demichev [38], S.P. Denisov [37], L. D'Eramo [40], D. Derendarz [87], F. Derue [128], P. Dervan [93], K. Desch [24], C. Deutsch [24], F.A. Di Bello [57b,57a], A. Di Ciaccio [76a,76b], L. Di Ciaccio [4], A. Di Domenico [75a,75b], C. Di Donato [72a,72b], A. Di Girolamo [36], G. Di Gregorio [36], A. Di Luca [78a,78b], B. Di Micco [77a,77b], R. Di Nardo [77a,77b], K.F. Di Petrillo [39], M. Diamantopoulou [34], F.A. Dias [115], T. Dias Do Vale [143], M.A. Diaz [138a,138b], F.G. Diaz Capriles [24], M. Didenko [164], E.B. Diehl [107], S. Díez Cornell [48], C. Diez Pardos [142], C. Dimitriadi [162,24], A. Dimitrievska [20], J. Dingfelder [24], I-M. Dinu [27b], S.J. Dittmeier [63b], F. Dittus [36], M. Divisek [134], F. Djama [103], T. Djobava [150b], C. Doglioni [102,99], A. Dohnalova [28a], J. Dolejsi [134], Z. Dolezal [134], K. Domijan [86a], K.M. Dona [39], M. Donadelli [83d], B. Dong [108], J. Donini [40], A. D'Onofrio [72a,72b], M. D'Onofrio [93], J. Dopke [135], A. Doria [72a], N. Dos Santos Fernandes [131a], P. Dougan [102], M.T. Dova [91], A.T. Doyle [59], M.A. Draguet [127], E. Dreyer [170], I. Drivas-koulouris [10], M. Drnevich [118], M. Drozdova [56], D. Du [62a], T.A. du Pree [115], F. Dubinin [37], M. Dubovsky [28a], E. Duchovni [170], G. Duckeck [110], O.A. Ducu [27b], D. Duda [52], A. Dudarev [36], E.R. Duden [26], M. D'uffizi [102], L. Duflot [66], M. Dührssen [36], I. Duminica [27g], A.E. Dumitriu [27b], M. Dunford [63a], S. Dungs [49], K. Dunne [47a,47b], A. Duperrin [103], H. Duran Yildiz [3a], M. Düren [58], A. Durglishvili [150b], B.L. Dwyer [116], G.I. Dyckes [17a], M. Dyndal [86a], B.S. Dziedzic [36], Z.O. Earnshaw [147], G.H. Eberwein [127], B. Eckerova [28a], S. Eggebrecht [55], E. Egidio Purcino De Souza [128], L.F. Ehrke [56], G. Eigen [16], K. Einsweiler [17a], T. Ekelof [162], P.A. Ekman [99], S. El Farkh [35b], Y. El Ghazali [35b], H. El Jarrari [36], A. El Moussaouy [35a], V. Ellajosyula [162], M. Ellert [162], F. Ellinghaus [172], N. Ellis [36], J. Elmsheuser [29], M. Elsawy [117a], M. Elsing [36], D. Emeliyanov [135], Y. Enari [154], I. Ene [17a], S. Epari [13], P.A. Erland [87], D. Ernani Martins Neto [87], M. Errenst [172], M. Escalier [66], C. Escobar [164], E. Etzion [152], G. Evans [131a], H. Evans [68], L.S. Evans [96], A. Ezhilov [37], S. Ezzarqtouni [35a], F. Fabbri [23b,23a], L. Fabbri [23b,23a], G. Facini [97], V. Fadeyev [137], R.M. Fakhrutdinov [37], D. Fakoudis [101], S. Falciano [75a], L.F. Falda Ulhoa Coelho [36], F. Fallavollita [111], G. Falsetti [43b,43a], J. Faltova [134], C. Fan [163], Y. Fan [14a], Y. Fang [14a,14e], M. Fanti [71a,71b], M. Faraj [69a,69b], Z. Farazpay [98], A. Farbin [8], A. Farilla [77a], T. Farooque [108], S.M. Farrington [52], F. Fassi [35e], D. Fassouliotis [9], M. Faucci Giannelli [76a,76b], W.J. Fawcett [32], L. Fayard [66], P. Federic [134], P. Federicova [132], O.L. Fedin [37,a], M. Feickert [171], L. Feligioni [103], D.E. Fellers [124], C. Feng [62b], M. Feng [14b], Z. Feng [115], M.J. Fenton [160], L. Ferencz [48], R.A.M. Ferguson [92], S.I. Fernandez Luengo [138f], P. Fernandez Martinez [13], M.J.V. Fernoux [103], J. Ferrando [92], A. Ferrari [162], P. Ferrari [115,114], R. Ferrari [73a], D. Ferrere [56], C. Ferretti [107], D. Fiacco [75a,75b], F. Fiedler [101], P. Fiedler [133], A. Filipčič [94], E.K. Filmer [1], F. Filthaut [114], M.C.N. Fiolhais [131a,131c,c], L. Fiorini [164], W.C. Fisher [108], T. Fitschen [102], P.M. Fitzhugh [136], I. Fleck [142], P. Fleischmann [107], T. Flick [172], M. Flores [33d,aa], L.R. Flores Castillo [64a], L. Flores Sanz De Acedo [36], F.M. Follega [78a,78b],

N. Fomin [16], J.H. Foo [156], A. Formica [136], A.C. Forti [102], E. Fortin [36], A.W. Fortman [17a], M.G. Foti [17a], L. Fountas [9,i], D. Fournier [66], H. Fox [92], P. Francavilla [74a,74b], S. Francescato [61], S. Franchellucci [56], M. Franchini [23b,23a], S. Franchino [63a], D. Francis [36], L. Franco [114], V. Franco Lima [36], L. Franconi [48], M. Franklin [61], G. Frattari [26], Y.Y. Frid [152], J. Friend [59], N. Fritzsche [50], A. Froch [54], D. Froidevaux [36], J.A. Frost [127], Y. Fu [62a], S. Fuenzalida Garrido [138f], M. Fujimoto [103], K.Y. Fung [64a], E. Furtado De Simas Filho [83e], M. Furukawa [154], J. Fuster [164], A. Gaa [55], A. Gabrielli [23b,23a], A. Gabrielli [156], P. Gadow [36], G. Gagliardi [57b,57a], L.G. Gagnon [17a], S. Gaid [161], S. Galantzan [152], E.J. Gallas [127], B.J. Gallop [135], K.K. Gan [120], S. Ganguly [154], Y. Gao [52], F.M. Garay Walls [138a,138b], B. Garcia [29], C. García [164], A. Garcia Alonso [115], A.G. Garcia Caffaro [173], J.E. García Navarro [164], M. Garcia-Sciveres [17a], G.L. Gardner [129], R.W. Gardner [39], N. Garelli [159], D. Garg [80], R.B. Garg [144], J.M. Gargan [52], C.A. Garner [156], C.M. Garvey [33a], V.K. Gassmann [159], G. Gaudio [73a], V. Gautam [13], P. Gauzzi [75a,75b], I.L. Gavrilenko [37], A. Gavrilyuk [37], C. Gay [165], G. Gaycken [48], E.N. Gazis [10], A.A. Geanta [27b], C.M. Gee [137], A. Gekow [120], C. Gemme [57b], M.H. Genest [60], A.D. Gentry [113], S. George [96], W.F. George [20], T. Geralis [46], P. Gessinger-Befurt [36], M.E. Geyik [172], M. Ghani [168], K. Ghorbanian [95], A. Ghosal [142], A. Ghosh [160], A. Ghosh [7], B. Giacobbe [23b], S. Giagu [75a,75b], T. Giani [115], P. Giannetti [74a], A. Giannini [62a], S.M. Gibson [96], M. Gignac [137], D.T. Gil [86b], A.K. Gilbert [86a], B.J. Gilbert [41], D. Gillberg [34], G. Gilles [115], L. Ginabat [128], D.M. Gingrich [2,ad], M.P. Giordani [69a,69c], P.F. Giraud [136], G. Giugliarelli [69a,69c], D. Giugni [71a], F. Giuli [36], I. Gkialas [9,i], L.K. Gladilin [37], C. Glasman [100], G.R. Gledhill [124], G. Glemža [48], M. Glisic [124], I. Gnesi [43b,e], Y. Go [29], M. Goblirsch-Kolb [36], B. Gocke [49], D. Godin [109], B. Gokturk [21a], S. Goldfarb [106], T. Golling [56], M.G.D. Gololo [33g], D. Golubkov [37], J.P. Gombas [108], A. Gomes [131a,131b], G. Gomes Da Silva [142], A.J. Gomez Delegido [164], R. Gonçalo [131a], L. Gonella [20], A. Gongadze [150c], F. Gonnella [20], J.L. Gonski [144], R.Y. González Andana [52], S. González de la Hoz [164], R. Gonzalez Lopez [93], C. Gonzalez Renteria [17a], M.V. Gonzalez Rodrigues [48], R. Gonzalez Suarez [162], S. Gonzalez-Sevilla [56], L. Goossens [36], B. Gorini [36], E. Gorini [70a,70b], A. Gorišek [94], T.C. Gosart [129], A.T. Goshaw [51], M.I. Gostkin [38], S. Goswami [122], C.A. Gottardo [36], S.A. Gotz [110], M. Gouighri [35b], V. Goumarre [48], A.G. Goussiou [139], N. Govender [33c], I. Grabowska-Bold [86a], K. Graham [34], E. Gramstad [126], S. Grancagnolo [70a,70b], C.M. Grant [1,136], P.M. Gravila [27f], F.G. Gravili [70a,70b], H.M. Gray [17a], M. Greco [70a,70b], C. Grefe [24], A.S. Grefsrud [16], I.M. Gregor [48], K.T. Greif [160], P. Grenier [144], S.G. Grewe [111], A.A. Grillo [137], K. Grimm [31], S. Grinstein [13,r], J.-F. Grivaz [66], E. Gross [170], J. Grosse-Knetter [55], J.C. Grundy [127], L. Guan [107], J.G.R. Guerrero Rojas [164], G. Guerrieri [69a,69c], R. Gugel [101], J.A.M. Guhit [107], A. Guida [18], E. Guilloton [168], S. Guindon [36], F. Guo [14a,14e], J. Guo [62c], L. Guo [48], Y. Guo [107], R. Gupta [130], S. Gurbuz [24], S.S. Gurdasani [54], G. Gustavino [75a,75b], M. Guth [56], P. Gutierrez [121], L.F. Gutierrez Zagazeta [129], M. Gutsche [50], C. Gutschow [97], C. Gwenlan [127], C.B. Gwilliam [93], E.S. Haaland [126], A. Haas [118], M. Habedank [48], C. Haber [17a], H.K. Hadavand [8], A. Hadef [50], S. Hadzic [111], A.I. Hagan [92], J.J. Hahn [142], E.H. Haines [97], M. Haleem [167], J. Haley [122], J.J. Hall [140], G.D. Hallewell [103], L. Halser [19], K. Hamano [166], M. Hamer [24], G.N. Hamity [52], E.J. Hampshire [96], J. Han [62b], K. Han [62a], L. Han [14c], L. Han [62a], S. Han [17a], Y.F. Han [156], K. Hanagaki [84], M. Hance [137], D.A. Hangal [41], H. Hanif [143], M.D. Hank [129], J.B. Hansen [42], P.H. Hansen [42], K. Hara [158], D. Harada [56], T. Harenberg [172], S. Harkusha [37], M.L. Harris [104], Y.T. Harris [127], J. Harrison [13], N.M. Harrison [120], P.F. Harrison [168], N.M. Hartman [111],

N.M. Hartmann [110], R.Z. Hasan [96,135], Y. Hasegawa [141], S. Hassan [16], R. Hauser [108], C.M. Hawkes [20], R.J. Hawkings [36], Y. Hayashi [154], S. Hayashida [112], D. Hayden [108], C. Hayes [107], R.L. Hayes [115], C.P. Hays [127], J.M. Hays [95], H.S. Hayward [93], F. He [62a], M. He [14a,14e], Y. He [155], Y. He [48], Y. He [97], N.B. Heatley [95], V. Hedberg [99], A.L. Heggelund [126], N.D. Hehir [95,*], C. Heidegger [54], K.K. Heidegger [54], J. Heilman [34], S. Heim [48], T. Heim [17a], J.G. Heinlein [129], J.J. Heinrich [124], L. Heinrich [111,ab], J. Hejbal [132], A. Held [171], S. Hellesund [16], C.M. Helling [165], S. Hellman [47a,47b], R.C.W. Henderson [92], L. Henkelmann [32], A.M. Henriques Correia [36], H. Herde [99], Y. Hernández Jiménez [146], L.M. Herrmann [24], T. Herrmann [50], G. Herten [54], R. Hertenberger [110], L. Hervas [36], M.E. Hesping [101], N.P. Hessey [157a], M. Hidaoui [35b], N. Hidic [134], E. Hill [156], S.J. Hillier [20], J.R. Hinds [108], F. Hinterkeuser [24], M. Hirose [125], S. Hirose [158], D. Hirschbuehl [172], T.G. Hitchings [102], B. Hiti [94], J. Hobbs [146], R. Hobincu [27e], N. Hod [170], M.C. Hodgkinson [140], B.H. Hodkinson [127], A. Hoecker [36], D.D. Hofer [107], J. Hofer [48], T. Holm [24], M. Holzbock [111], L.B.A.H. Hommels [32], B.P. Honan [102], J.J. Hong [68], J. Hong [62c], T.M. Hong [130], B.H. Hooberman [163], W.H. Hopkins [6], M.C. Hoppesch [163], Y. Horii [112], S. Hou [149], A.S. Howard [94], J. Howarth [59], J. Hoya [6], M. Hrabovsky [123], A. Hrynevich [48], T. Hryn'ova [4], P.J. Hsu [65], S.-C. Hsu [139], T. Hsu [66], M. Hu [17a], Q. Hu [62a], S. Huang [64b], X. Huang [14a,14e], Y. Huang [140], Y. Huang [101], Y. Huang [14a], Z. Huang [102], Z. Hubacek [133], M. Huebner [24], F. Huegging [24], T.B. Huffman [127], C.A. Hugli [48], M. Huhtinen [36], S.K. Huiberts [16], R. Hulsken [105], N. Huseynov [12], J. Huston [108], J. Huth [61], R. Hyneman [144], G. Iacobucci [56], G. Iakovidis [29], L. Iconomidou-Fayard [66], J.P. Iddon [36], P. Iengo [72a,72b], R. Iguchi [154], Y. Iiyama [154], T. Iizawa [127], Y. Ikegami [84], N. Ilic [156], H. Imam [35a], M. Ince Lezki [56], T. Ingebretsen Carlson [47a,47b], G. Introzzi [73a,73b], M. Iodice [77a], V. Ippolito [75a,75b], R.K. Irwin [93], M. Ishino [154], W. Islam [171], C. Issever [18,48], S. Istin [21a,ah], H. Ito [169], R. Iuppa [78a,78b], A. Ivina [170], J.M. Izen [45], V. Izzo [72a], P. Jacka [132], P. Jackson [1], C.S. Jagfeld [110], G. Jain [157a], P. Jain [48], K. Jakobs [54], T. Jakoubek [170], J. Jamieson [59], M. Javurkova [104], L. Jeanty [124], J. Jejelava [150a,y], P. Jenni [54,f], C.E. Jessiman [34], C. Jia [62b], J. Jia [146], X. Jia [61], X. Jia [14a,14e], Z. Jia [14c], C. Jiang [52], S. Jiggins [48], J. Jimenez Pena [13], S. Jin [14c], A. Jinaru [27b], O. Jinnouchi [155], P. Johansson [140], K.A. Johns [7], J.W. Johnson [137], D.M. Jones [147], E. Jones [48], P. Jones [32], R.W.L. Jones [92], T.J. Jones [93], H.L. Joos [55,36], R. Joshi [120], J. Jovicevic [15], X. Ju [17a], J.J. Junggeburth [104], T. Junkermann [63a], A. Juste Rozas [13,r], M.K. Juzek [87], S. Kabana [138e], A. Kaczmarska [87], M. Kado [111], H. Kagan [120], M. Kagan [144], A. Kahn [129], C. Kahra [101], T. Kaji [154], E. Kajomovitz [151], N. Kakati [170], I. Kalaitzidou [54], C.W. Kalderon [29], N.J. Kang [137], D. Kar [33g], K. Karava [127], M.J. Kareem [157b], E. Karentzos [54], O. Karkout [115], S.N. Karpov [38], Z.M. Karpova [38], V. Kartvelishvili [92], A.N. Karyukhin [37], E. Kasimi [153], J. Katzy [48], S. Kaur [34], K. Kawade [141], M.P. Kawale [121], C. Kawamoto [88], T. Kawamoto [62a], E.F. Kay [36], F.I. Kaya [159], S. Kazakos [108], V.F. Kazanin [37], Y. Ke [146], J.M. Keaveney [33a], R. Keeler [166], G.V. Kehris [61], J.S. Keller [34], A.S. Kelly [97], J.J. Kempster [147], P.D. Kennedy [101], O. Kepka [132], B.P. Kerridge [135], S. Kersten [172], B.P. Kerševan [94], L. Keszeghova [28a], S. Ketabchi Haghighat [156], R.A. Khan [130], A. Khanov [122], A.G. Kharlamov [37], T. Kharlamova [37], E.E. Khoda [139], M. Kholodenko [37], T.J. Khoo [18], G. Khoriauli [167], J. Khubua [150b], Y.A.R. Khwaira [128], B. Kibirige [33g], D.W. Kim [47a,47b], Y.K. Kim [39], N. Kimura [97], M.K. Kingston [55], A. Kirchhoff [55], C. Kirfel [24], F. Kirfel [24], J. Kirk [135], A.E. Kiryunin [111], C. Kitsaki [10], O. Kivernyk [24], M. Klassen [159], C. Klein [34], L. Klein [167], M.H. Klein [44], S.B. Klein [56], U. Klein [93], P. Klimek [36], A. Klimentov [29], T. Klioutchnikova [36],

P. Kluit [115], S. Kluth [111], E. Kneringer [79], T.M. Knight [156], A. Knue [49], R. Kobayashi [88], D. Kobylianskii [170], S.F. Koch [127], M. Kocian [144], P. Kodyš [134], D.M. Koeck [124], P.T. Koenig [24], T. Koffas [34], O. Kolay [50], I. Koletsou [4], T. Komarek [123], K. Köneke [54], A.X.Y. Kong [1], T. Kono [119], N. Konstantinidis [97], P. Kontaxakis [56], B. Konya [99], R. Kopeliansky [41], S. Koperny [86a], K. Korcyl [87], K. Kordas [153,d], A. Korn [97], S. Korn [55], I. Korolkov [13], N. Korotkova [37], B. Kortman [115], O. Kortner [111], S. Kortner [111], W.H. Kostecka [116], V.V. Kostyukhin [142], A. Kotsokechagia [136], A. Kotwal [51], A. Koulouris [36], A. Kourkoumeli-Charalampidi [73a,73b], C. Kourkoumelis [9], E. Kourlitis [111,ab], O. Kovanda [124], R. Kowalewski [166], W. Kozanecki [136], A.S. Kozhin [37], V.A. Kramarenko [37], G. Kramberger [94], P. Kramer [101], M.W. Krasny [128], A. Krasznahorkay [36], A.C. Kraus [116], J.W. Kraus [172], J.A. Kremer [48], T. Kresse [50], J. Kretzschmar [93], K. Kreul [18], P. Krieger [156], S. Krishnamurthy [104], M. Krivos [134], K. Krizka [20], K. Kroeninger [49], H. Kroha [111], J. Kroll [132], J. Kroll [129], K.S. Krowpman [108], U. Kruchonak [38], H. Krüger [24], N. Krumnack [81], M.C. Kruse [51], O. Kuchinskaia [37], S. Kuday [3a], S. Kuehn [36], R. Kuesters [54], T. Kuhl [48], V. Kukhtin [38], Y. Kulchitsky [37,a], S. Kuleshov [138d,138b], M. Kumar [33g], N. Kumari [48], P. Kumari [157b], A. Kupco [132], T. Kupfer [49], A. Kupich [37], O. Kuprash [54], H. Kurashige [85], L.L. Kurchaninov [157a], O. Kurdysh [66], Y.A. Kurochkin [37], A. Kurova [37], M. Kuze [155], A.K. Kvam [104], J. Kvita [123], T. Kwan [105], N.G. Kyriacou [107], L.A.O. Laatu [103], C. Lacasta [164], F. Lacava [75a,75b], H. Lacker [18], D. Lacour [128], N.N. Lad [97], E. Ladygin [38], A. Lafarge [40], B. Laforge [128], T. Lagouri [173], F.Z. Lahbabi [35a], S. Lai [55], J.E. Lambert [166], S. Lammers [68], W. Lampl [7], C. Lampoudis [153,d], G. Lamprinoudis [101], A.N. Lancaster [116], E. Lançon [29], U. Landgraf [54], M.P.J. Landon [95], V.S. Lang [54], O.K.B. Langrekken [126], A.J. Lankford [160], F. Lanni [36], K. Lantzsch [24], A. Lanza [73a], J.F. Laporte [136], T. Lari [71a], F. Lasagni Manghi [23b], M. Lassnig [36], V. Latonova [132], A. Laudrain [101], A. Laurier [151], S.D. Lawlor [140], Z. Lawrence [102], R. Lazaridou [168], M. Lazzaroni [71a,71b], B. Le [102], E.M. Le Boulicaut [51], L.T. Le Pottier [17a], B. Leban [23b,23a], A. Lebedev [81], M. LeBlanc [102], F. Ledroit-Guillon [60], S.C. Lee [149], S. Lee [47a,47b], T.F. Lee [93], L.L. Leeuw [33c], H.P. Lefebvre [96], M. Lefebvre [166], C. Leggett [17a], G. Lehmann Miotto [36], M. Leigh [56], W.A. Leight [104], W. Leinonen [114], A. Leisos [153,q], M.A.L. Leite [83c], C.E. Leitgeb [18], R. Leitner [134], K.J.C. Leney [44], T. Lenz [24], S. Leone [74a], C. Leonidopoulos [52], A. Leopold [145], C. Leroy [109], R. Les [108], C.G. Lester [32], M. Levchenko [37], J. Levêque [4], L.J. Levinson [170], G. Levrini [23b,23a], M.P. Lewicki [87], C. Lewis [139], D.J. Lewis [4], A. Li [5], B. Li [62b], C. Li [62a], C-Q. Li [111], H. Li [62a], H. Li [62b], H. Li [14c], H. Li [14b], H. Li [62b], J. Li [62c], K. Li [139], L. Li [62c], M. Li [14a,14e], S. Li [14a,14e], S. Li [62d,62c], T. Li [5], X. Li [105], Z. Li [127], Z. Li [154], Z. Li [14a,14e], S. Liang [14a,14e], Z. Liang [14a], M. Liberatore [136], B. Liberti [76a], K. Lie [64c], J. Lieber Marin [83e], H. Lien [68], H. Lin [107], K. Lin [108], R.E. Lindley [7], J.H. Lindon [2], E. Lipeles [129], A. Lipniacka [16], A. Lister [165], J.D. Little [68], B. Liu [14a], B.X. Liu [14d], D. Liu [62d,62c], E.H.L. Liu [20], J.B. Liu [62a], J.K.K. Liu [32], K. Liu [62d], K. Liu [62d,62c], M. Liu [62a], M.Y. Liu [62a], P. Liu [14a], Q. Liu [62d,139,62c], X. Liu [62a], X. Liu [62b], Y. Liu [14d,14e], Y.L. Liu [62b], Y.W. Liu [62a], J. Llorente Merino [143], S.L. Lloyd [95], E.M. Lobodzinska [48], P. Loch [7], T. Lohse [18], K. Lohwasser [140], E. Loiacono [48], M. Lokajicek [132,*], J.D. Lomas [20], J.D. Long [163], I. Longarini [160], R. Longo [163], I. Lopez Paz [67], A. Lopez Solis [48], N. Lorenzo Martinez [4], A.M. Lory [110], M. Losada [117a], G. Löschcke Centeno [147], O. Loseva [37], X. Lou [47a,47b], X. Lou [14a,14e], A. Lounis [66], P.A. Love [92], G. Lu [14a,14e], M. Lu [66], S. Lu [129], Y.J. Lu [65], H.J. Lubatti [139], C. Luci [75a,75b], F.L. Lucio Alves [14c], F. Luehring [68], I. Luise [146], O. Lukianchuk [66], O. Lundberg [145], B. Lund-Jensen [145], N.A. Luongo [6],

M.S. Lutz [36], A.B. Lux [25], D. Lynn [29], R. Lysak [132], E. Lytken [99], V. Lyubushkin [38], T. Lyubushkina [38], M.M. Lyukova [146], M. Firdaus M. Soberi [52], H. Ma [29], K. Ma [62a], L.L. Ma [62b], W. Ma [62a], Y. Ma [122], J.C. MacDonald [101], P.C. Machado De Abreu Farias [83e], R. Madar [40], T. Madula [97], J. Maeda [85], T. Maeno [29], H. Maguire [140], V. Maiboroda [136], A. Maio [131a,131b,131d], K. Maj [86a], O. Majersky [48], S. Majewski [124], N. Makovec [66], V. Maksimovic [15], B. Malaescu [128], Pa. Malecki [87], V.P. Maleev [37], F. Malek [60,m], M. Mali [94], D. Malito [96], U. Mallik [80], S. Maltezos [10], S. Malyukov [38], J. Mamuzic [13], G. Mancini [53], M.N. Mancini [26], G. Manco [73a,73b], J.P. Mandalia [95], I. Mandić [94], L. Manhaes de Andrade Filho [83a], I.M. Maniatis [170], J. Manjarres Ramos [90], D.C. Mankad [170], A. Mann [110], S. Manzoni [36], L. Mao [62c], X. Mapekula [33c], A. Marantis [153,q], G. Marchiori [5], M. Marcisovsky [132], C. Marcon [71a], M. Marinescu [20], S. Marium [48], M. Marjanovic [121], A. Markhoos [54], M. Markovitch [66], E.J. Marshall [92], Z. Marshall [17a], S. Marti-Garcia [164], J. Martin [97], T.A. Martin [135], V.J. Martin [52], B. Martin dit Latour [16], L. Martinelli [75a,75b], M. Martinez [13,r], P. Martinez Agullo [164], V.I. Martinez Outschoorn [104], P. Martinez Suarez [13], S. Martin-Haugh [135], G. Martinovicova [134], V.S. Martoiu [27b], A.C. Martyniuk [97], A. Marzin [36], D. Mascione [78a,78b], L. Masetti [101], T. Mashimo [154], J. Masik [102], A.L. Maslennikov [37], P. Massarotti [72a,72b], P. Mastrandrea [74a,74b], A. Mastroberardino [43b,43a], T. Masubuchi [154], T. Mathisen [162], J. Matousek [134], N. Matsuzawa [154], J. Maurer [27b], A.J. Maury [66], B. Maček [94], D.A. Maximov [37], A.E. May [102], R. Mazini [149], I. Maznas [116], M. Mazza [108], S.M. Mazza [137], E. Mazzeo [71a,71b], C. Mc Ginn [29], J.P. Mc Gowan [166], S.P. Mc Kee [107], C.C. McCracken [165], E.F. McDonald [106], A.E. McDougall [115], J.A. Mcfayden [147], R.P. McGovern [129], R.P. Mckenzie [33g], T.C. Mclachlan [48], D.J. Mclaughlin [97], S.J. McMahon [135], C.M. Mcpartland [93], R.A. McPherson [166,v], S. Mehlhase [110], A. Mehta [93], D. Melini [164], B.R. Mellado Garcia [33g], A.H. Melo [55], F. Meloni [48], A.M. Mendes Jacques Da Costa [102], H.Y. Meng [156], L. Meng [92], S. Menke [111], M. Mentink [36], E. Meoni [43b,43a], G. Mercado [116], S. Merianos [153], C. Merlassino [69a,69c], L. Merola [72a,72b], C. Meroni [71a,71b], J. Metcalfe [6], A.S. Mete [6], E. Meuser [101], C. Meyer [68], J-P. Meyer [136], R.P. Middleton [135], L. Mijović [52], G. Mikenberg [170], M. Mikestikova [132], M. Mikuž [94], H. Mildner [101], A. Milic [36], D.W. Miller [39], E.H. Miller [144], L.S. Miller [34], A. Milov [170], D.A. Milstead [47a,47b], T. Min [14c], A.A. Minaenko [37], I.A. Minashvili [150b], L. Mince [59], A.I. Mincer [118], B. Mindur [86a], M. Mineev [38], Y. Mino [88], L.M. Mir [13], M. Miralles Lopez [59], M. Mironova [17a], A. Mishima [154], M.C. Missio [114], A. Mitra [168], V.A. Mitsou [164], Y. Mitsumori [112], O. Miu [156], P.S. Miyagawa [95], T. Mkrtchyan [63a], M. Mlinarevic [97], T. Mlinarevic [97], M. Mlynarikova [36], S. Mobius [19], P. Mogg [110], M.H. Mohamed Farook [113], A.F. Mohammed [14a,14e], S. Mohapatra [41], G. Mokgatitswane [33g], L. Moleri [170], B. Mondal [142], S. Mondal [133], K. Mönig [48], E. Monnier [103], L. Monsonis Romero [164], J. Montejo Berlingen [13], M. Montella [120], F. Montereali [77a,77b], F. Monticelli [91], S. Monzani [69a,69c], N. Morange [66], A.L. Moreira De Carvalho [48], M. Moreno Llácer [164], C. Moreno Martinez [56], P. Morettini [57b], S. Morgenstern [36], M. Morii [61], M. Morinaga [154], F. Morodei [75a,75b], L. Morvaj [36], P. Moschovakos [36], B. Moser [36], M. Mosidze [150b], T. Moskalets [44], P. Moskvitina [114], J. Moss [31,j], P. Moszkowicz [86a], A. Moussa [35d], E.J.W. Moyse [104], O. Mtintsilana [33g], S. Muanza [103], J. Mueller [130], D. Muenstermann [92], R. Müller [19], G.A. Mullier [162], A.J. Mullin [32], J.J. Mullin [129], D.P. Mungo [156], D. Munoz Perez [164], F.J. Munoz Sanchez [102], M. Murin [102], W.J. Murray [168,135], M. Muškinja [94], C. Mwewa [29], A.G. Myagkov [37,a], A.J. Myers [8], G. Myers [107], M. Myska [133], B.P. Nachman [17a], O. Nackenhorst [49],

K. Nagai [127], K. Nagano [84], J.L. Nagle [29,af], E. Nagy [103], A.M. Nairz [36], Y. Nakahama [84], K. Nakamura [84], K. Nakkalil [5], H. Nanjo [125], E.A. Narayanan [113], I. Naryshkin [37], L. Nasella [71a,71b], M. Naseri [34], S. Nasri [117b], C. Nass [24], G. Navarro [22a], J. Navarro-Gonzalez [164], R. Nayak [152], A. Nayaz [18], P.Y. Nechaeva [37], S. Nechaeva [23b,23a], F. Nechansky [48], L. Nedic [127], T.J. Neep [20], A. Negri [73a,73b], M. Negrini [23b], C. Nellist [115], C. Nelson [105], K. Nelson [107], S. Nemecek [132], M. Nessi [36,g], M.S. Neubauer [163], F. Neuhaus [101], J. Neundorf [48], P.R. Newman [20], C.W. Ng [130], Y.W.Y. Ng [48], B. Ngair [117a], H.D.N. Nguyen [109], R.B. Nickerson [127], R. Nicolaidou [136], J. Nielsen [137], M. Niemeyer [55], J. Niermann [55], N. Nikiforou [36], V. Nikolaenko [37,a], I. Nikolic-Audit [128], K. Nikolopoulos [20], P. Nilsson [29], I. Ninca [48], G. Ninio [152], A. Nisati [75a], N. Nishu [2], R. Nisius [111], J-E. Nitschke [50], E.K. Nkadimeng [33g], T. Nobe [154], T. Nommensen [148], M.B. Norfolk [140], B.J. Norman [34], M. Noury [35a], J. Novak [94], T. Novak [94], L. Novotny [133], R. Novotny [113], L. Nozka [123], K. Ntekas [160], N.M.J. Nunes De Moura Junior [83b], J. Ocariz [128], A. Ochi [85], I. Ochoa [131a], S. Oerdek [48,s], J.T. Offermann [39], A. Ogrodnik [134], A. Oh [102], C.C. Ohm [145], H. Oide [84], R. Oishi [154], M.L. Ojeda [48], Y. Okumura [154], L.F. Oleiro Seabra [131a], I. Oleksiyuk [56], S.A. Olivares Pino [138d], G. Oliveira Correa [13], D. Oliveira Damazio [29], D. Oliveira Goncalves [83a], J.L. Oliver [160], Ö.O. Öncel [54], A.P. O'Neill [19], A. Onofre [131a,131e], P.U.E. Onyisi [11], M.J. Oreglia [39], G.E. Orellana [91], D. Orestano [77a,77b], N. Orlando [13], R.S. Orr [156], L.M. Osojnak [129], R. Ospanov [62a], G. Otero y Garzon [30], H. Otono [89], P.S. Ott [63a], G.J. Ottino [17a], M. Ouchrif [35d], F. Ould-Saada [126], T. Ovsiannikova [139], M. Owen [59], R.E. Owen [135], V.E. Ozcan [21a], F. Ozturk [87], N. Ozturk [8], S. Ozturk [82], H.A. Pacey [127], A. Pacheco Pages [13], C. Padilla Aranda [13], G. Padovano [75a,75b], S. Pagan Griso [17a], G. Palacino [68], A. Palazzo [70a,70b], J. Pampel [24], J. Pan [173], T. Pan [64a], D.K. Panchal [11], C.E. Pandini [115], J.G. Panduro Vazquez [135], H.D. Pandya [1], H. Pang [14b], P. Pani [48], G. Panizzo [69a,69c], L. Panwar [128], L. Paolozzi [56], S. Parajuli [163], A. Paramonov [6], C. Paraskevopoulos [53], D. Paredes Hernandez [64b], A. Pareti [73a,73b], K.R. Park [41], T.H. Park [156], M.A. Parker [32], F. Parodi [57b,57a], E.W. Parrish [116], V.A. Parrish [52], J.A. Parsons [41], U. Parzefall [54], B. Pascual Dias [109], L. Pascual Dominguez [100], E. Pasqualucci [75a], S. Passaggio [57b], F. Pastore [96], P. Patel [87], U.M. Patel [51], J.R. Pater [102], T. Pauly [36], C.I. Pazos [159], J. Pearkes [144], M. Pedersen [126], R. Pedro [131a], S.V. Peleganchuk [37], O. Penc [36], E.A. Pender [52], G.D. Penn [173], K.E. Penski [110], M. Penzin [37], B.S. Peralva [83d], A.P. Pereira Peixoto [139], L. Pereira Sanchez [144], D.V. Perepelitsa [29,af], G. Perera [104], E. Perez Codina [157a], M. Perganti [10], H. Pernegger [36], S. Perrella [75a,75b], O. Perrin [40], K. Peters [48], R.F.Y. Peters [102], B.A. Petersen [36], T.C. Petersen [42], E. Petit [103], V. Petousis [133], C. Petridou [153,d], T. Petru [134], A. Petrukhin [142], M. Pettee [17a], A. Petukhov [37], K. Petukhova [134], R. Pezoa [138f], L. Pezzotti [36], G. Pezzullo [173], T.M. Pham [171], T. Pham [106], P.W. Phillips [135], G. Piacquadio [146], E. Pianori [17a], F. Piazza [124], R. Piegaia [30], D. Pietreanu [27b], A.D. Pilkington [102], M. Pinamonti [69a,69c], J.L. Pinfold [2], B.C. Pinheiro Pereira [131a], A.E. Pinto Pinoargote [136], L. Pintucci [69a,69c], K.M. Piper [147], A. Pirttikoski [56], D.A. Pizzi [34], L. Pizzimento [64b], A. Pizzini [115], M.-A. Pleier [29], V. Pleskot [134], E. Plotnikova [38], G. Poddar [95], R. Poettgen [99], L. Poggioli [128], I. Pokharel [55], S. Polacek [134], G. Polesello [73a], A. Poley [143,157a], A. Polini [23b], C.S. Pollard [168], Z.B. Pollock [120], E. Pompa Pacchi [75a,75b], N.I. Pond [97], D. Ponomarenko [114], L. Pontecorvo [36], S. Popa [27a], G.A. Popeneciu [27d], A. Poreba [36], D.M. Portillo Quintero [157a], S. Pospisil [133], M.A. Postill [140], P. Postolache [27c], K. Potamianos [168], P.A. Potepa [86a], I.N. Potrap [38], C.J. Potter [32], H. Potti [148], J. Poveda [164], M.E. Pozo Astigarraga [36], A. Prades Ibanez [164], J. Pretel [54], D. Price [102],

M. Primavera [70a], M.A. Principe Martin [100], R. Privara [123], T. Procter [59], M.L. Proffitt [139], N. Proklova [129], K. Prokofiev [64c], G. Proto [111], J. Proudfoot [6], M. Przybycien [86a], W.W. Przygoda [86b], A. Psallidas [46], J.E. Puddefoot [140], D. Pudzha [37], D. Pyatiizbyantseva [37], J. Qian [107], D. Qichen [102], Y. Qin [13], T. Qiu [52], A. Quadt [55], M. Queitsch-Maitland [102], G. Quetant [56], R.P. Quinn [165], G. Rabanal Bolanos [61], D. Rafanoharana [54], F. Raffaeli [76a,76b], F. Ragusa [71a,71b], J.L. Rainbolt [39], J.A. Raine [56], S. Rajagopalan [29], E. Ramakoti [37], I.A. Ramirez-Berend [34], K. Ran [48,14e], N.P. Rapheeha [33g], H. Rasheed [27b], V. Raskina [128], D.F. Rassloff [63a], A. Rastogi [17a], S. Rave [101], S. Ravera [57b,57a], B. Ravina [55], I. Ravinovich [170], M. Raymond [36], A.L. Read [126], N.P. Readioff [140], D.M. Rebuzzi [73a,73b], G. Redlinger [29], A.S. Reed [111], K. Reeves [26], J.A. Reidelsturz [172], D. Reikher [152], A. Rej [49], C. Rembser [36], M. Renda [27b], M.B. Rendel [111], F. Renner [48], A.G. Rennie [160], A.L. Rescia [48], S. Resconi [71a], M. Ressegotti [57b,57a], S. Rettie [36], J.G. Reyes Rivera [108], E. Reynolds [17a], O.L. Rezanova [37], P. Reznicek [134], H. Riani [35d], N. Ribaric [92], E. Ricci [78a,78b], R. Richter [111], S. Richter [47a,47b], E. Richter-Was [86b], M. Ridel [128], S. Ridouani [35d], P. Rieck [118], P. Riedler [36], E.M. Riefel [47a,47b], J.O. Rieger [115], M. Rijssenbeek [146], M. Rimoldi [36], L. Rinaldi [23b,23a], P. Rincke [55,162], T.T. Rinn [29], M.P. Rinnagel [110], G. Ripellino [162], I. Riu [13], J.C. Rivera Vergara [166], F. Rizatdinova [122], E. Rizvi [95], B.R. Roberts [17a], S.H. Robertson [105,v], D. Robinson [32], C.M. Robles Gajardo [138f], M. Robles Manzano [101], A. Robson [59], A. Rocchi [76a,76b], C. Roda [74a,74b], S. Rodriguez Bosca [36], Y. Rodriguez Garcia [22a], A. Rodriguez Rodriguez [54], A.M. Rodríguez Vera [116], S. Roe [36], J.T. Roemer [160], A.R. Roepe-Gier [137], J. Roggel [172], O. Røhne [126], R.A. Rojas [104], C.P.A. Roland [128], J. Roloff [29], A. Romaniouk [37], E. Romano [73a,73b], M. Romano [23b], A.C. Romero Hernandez [163], N. Rompotis [93], L. Roos [128], S. Rosati [75a], B.J. Rosser [39], E. Rossi [127], E. Rossi [72a,72b], L.P. Rossi [61], L. Rossini [54], R. Rosten [120], M. Rotaru [27b], B. Rottler [54], C. Rougier [90], D. Rousseau [66], D. Rousso [48], A. Roy [163], S. Roy-Garand [156], A. Rozanov [103], Z.M.A. Rozario [59], Y. Rozen [151], A. Rubio Jimenez [164], A.J. Ruby [93], V.H. Ruelas Rivera [18], T.A. Ruggeri [1], A. Ruggiero [127], A. Ruiz-Martinez [164], A. Rummler [36], Z. Rurikova [54], N.A. Rusakovich [38], H.L. Russell [166], G. Russo [75a,75b], J.P. Rutherfoord [7], S. Rutherford Colmenares [32], M. Rybar [134], E.B. Rye [126], A. Ryzhov [44], J.A. Sabater Iglesias [56], P. Sabatini [164], H.F-W. Sadrozinski [137], F. Safai Tehrani [75a], B. Safarzadeh Samani [135], S. Saha [1], M. Sahinsoy [111], A. Saibel [164], M. Saimpert [136], M. Saito [154], T. Saito [154], A. Sala [71a,71b], D. Salamani [36], A. Salnikov [144], J. Salt [164], A. Salvador Salas [152], D. Salvatore [43b,43a], F. Salvatore [147], A. Salzburger [36], D. Sammel [54], E. Sampson [92], D. Sampsonidis [153,d], D. Sampsonidou [124], J. Sánchez [164], V. Sanchez Sebastian [164], H. Sandaker [126], C.O. Sander [48], J.A. Sandesara [104], M. Sandhoff [172], C. Sandoval [22b], L. Sanfilippo [63a], D.P.C. Sankey [135], T. Sano [88], A. Sansoni [53], L. Santi [36,75b], C. Santoni [40], H. Santos [131a,131b], A. Santra [170], E. Sanzani [23b,23a], K.A. Saoucha [161], J.G. Saraiva [131a,131d], J. Sardain [7], O. Sasaki [84], K. Sato [158], C. Sauer [63b], E. Sauvan [4], P. Savard [156,ad], R. Sawada [154], C. Sawyer [135], L. Sawyer [98], C. Sbarra [23b], A. Sbrizzi [23b,23a], T. Scanlon [97], J. Schaarschmidt [139], U. Schäfer [101], A.C. Schaffer [66,44], D. Schaile [110], R.D. Schamberger [146], C. Scharf [18], M.M. Schefer [19], V.A. Schegelsky [37], D. Scheirich [134], M. Schernau [160], C. Scheulen [55], C. Schiavi [57b,57a], M. Schioppa [43b,43a], B. Schlag [144,l], K.E. Schleicher [54], S. Schlenker [36], J. Schmeing [172], M.A. Schmidt [172], K. Schmieden [101], C. Schmitt [101], N. Schmitt [101], S. Schmitt [48], L. Schoeffel [136], A. Schoening [63b], P.G. Scholer [34], E. Schopf [127], M. Schott [24], J. Schovancova [36], S. Schramm [56],

T. Schroer [56], H-C. Schultz-Coulon [63a], M. Schumacher [54], B.A. Schumm [137], Ph. Schune [136], A.J. Schuy [139], H.R. Schwartz [137], A. Schwartzman [144], T.A. Schwarz [107], Ph. Schwemling [136], R. Schwienhorst [108], A. Sciandra [29], G. Sciolla [26], F. Scuri [74a], C.D. Sebastiani [93], K. Sedlaczek [116], S.C. Seidel [113], A. Seiden [137], B.D. Seidlitz [41], C. Seitz [48], J.M. Seixas [83b], G. Sekhniaidze [72a], L. Selem [60], N. Semprini-Cesari [23b,23a], D. Sengupta [56], V. Senthilkumar [164], L. Serin [66], M. Sessa [76a,76b], H. Severini [121], F. Sforza [57b,57a], A. Sfyrla [56], Q. Sha [14a], E. Shabalina [55], A.H. Shah [32], R. Shaheen [145], J.D. Shahinian [129], D. Shaked Renous [170], L.Y. Shan [14a], M. Shapiro [17a], A. Sharma [36], A.S. Sharma [165], P. Sharma [80], P.B. Shatalov [37], K. Shaw [147], S.M. Shaw [102], Q. Shen [62c,5], D.J. Sheppard [143], P. Sherwood [97], L. Shi [97], X. Shi [14a], C.O. Shimmin [173], J.D. Shinner [96], I.P.J. Shipsey [127], S. Shirabe [89], M. Shiyakova [38,t], M.J. Shochet [39], J. Shojaii [106], D.R. Shope [126], B. Shrestha [121], S. Shrestha [120,ag], M.J. Shroff [166], P. Sicho [132], A.M. Sickles [163], E. Sideras Haddad [33g], A.C. Sidley [115], A. Sidoti [23b], F. Siegert [50], Dj. Sijacki [15], F. Sili [91], J.M. Silva [52], I. Silva Ferreira [83b], M.V. Silva Oliveira [29], S.B. Silverstein [47a], S. Simion [66], R. Simoniello [36], E.L. Simpson [102], H. Simpson [147], L.R. Simpson [107], N.D. Simpson [99], S. Simsek [82], S. Sindhu [55], P. Sinervo [156], S. Singh [156], S. Sinha [48], S. Sinha [102], M. Sioli [23b,23a], I. Siral [36], E. Sitnikova [48], J. Sjölin [47a,47b], A. Skaf [55], E. Skorda [20], P. Skubic [121], M. Slawinska [87], V. Smakhtin [170], B.H. Smart [135], S.Yu. Smirnov [37], Y. Smirnov [37], L.N. Smirnova [37,a], O. Smirnova [99], A.C. Smith [41], D.R. Smith [160], E.A. Smith [39], H.A. Smith [127], J.L. Smith [102], R. Smith [144], M. Smizanska [92], K. Smolek [133], A.A. Snesarev [37], S.R. Snider [156], H.L. Snoek [115], S. Snyder [29], R. Sobie [166,v], A. Soffer [152], C.A. Solans Sanchez [36], E.Yu. Soldatov [37], U. Soldevila [164], A.A. Solodkov [37], S. Solomon [26], A. Soloshenko [38], K. Solovieva [54], O.V. Solovyanov [40], P. Sommer [36], A. Sonay [13], W.Y. Song [157b], A. Sopczak [133], A.L. Sopio [97], F. Sopkova [28b], J.D. Sorenson [113], I.R. Sotarriva Alvarez [155], V. Sothilingam [63a], O.J. Soto Sandoval [138c,138b], S. Sottocornola [68], R. Soualah [161], Z. Soumaimi [35e], D. South [48], N. Soybelman [170], S. Spagnolo [70a,70b], M. Spalla [111], D. Sperlich [54], G. Spigo [36], S. Spinali [92], D.P. Spiteri [59], M. Spousta [134], E.J. Staats [34], R. Stamen [63a], A. Stampekis [20], M. Standke [24], E. Stanecka [87], W. Stanek-Maslouska [48], M.V. Stange [50], B. Stanislaus [17a], M.M. Stanitzki [48], B. Stapf [48], E.A. Starchenko [37], G.H. Stark [137], J. Stark [90], P. Staroba [132], P. Starovoitov [63a], S. Stärz [105], R. Staszewski [87], G. Stavropoulos [46], J. Steentoft [162], P. Steinberg [29], B. Stelzer [143,157a], H.J. Stelzer [130], O. Stelzer-Chilton [157a], H. Stenzel [58], T.J. Stevenson [147], G.A. Stewart [36], J.R. Stewart [122], M.C. Stockton [36], G. Stoicea [27b], M. Stolarski [131a], S. Stonjek [111], A. Straessner [50], J. Strandberg [145], S. Strandberg [47a,47b], M. Stratmann [172], M. Strauss [121], T. Strebler [103], P. Strizenec [28b], R. Ströhmer [167], D.M. Strom [124], R. Stroynowski [44], A. Strubig [47a,47b], S.A. Stucci [29], B. Stugu [16], J. Stupak [121], N.A. Styles [48], D. Su [144], S. Su [62a], W. Su [62d], X. Su [62a], D. Suchy [28a], K. Sugizaki [154], V.V. Sulin [37], M.J. Sullivan [93], D.M.S. Sultan [127], L. Sultanaliyeva [37], S. Sultansoy [3b], T. Sumida [88], S. Sun [171], O. Sunneborn Gudnadottir [162], N. Sur [103], M.R. Sutton [147], H. Suzuki [158], M. Svatos [132], M. Swiatlowski [157a], T. Swirski [167], I. Sykora [28a], M. Sykora [134], T. Sykora [134], D. Ta [101], K. Tackmann [48,s], A. Taffard [160], R. Tafirout [157a], J.S. Tafoya Vargas [66], Y. Takubo [84], M. Talby [103], A.A. Talyshev [37], K.C. Tam [64b], N.M. Tamir [152], A. Tanaka [154], J. Tanaka [154], R. Tanaka [66], M. Tanasini [146], Z. Tao [165], S. Tapia Araya [138f], S. Tapprogge [101], A. Tarek Abouelfadl Mohamed [108], S. Tarem [151], K. Tariq [14a], G. Tarna [27b], G.F. Tartarelli [71a], M.J. Tartarin [90], P. Tas [134], M. Tasevsky [132], E. Tassi [43b,43a], A.C. Tate [163], G. Tateno [154],

Y. Tayalati [35e,u], G.N. Taylor [106], W. Taylor [157b], R. Teixeira De Lima [144], P. Teixeira-Dias [96], J.J. Teoh [156], K. Terashi [154], J. Terron [100], S. Terzo [13], M. Testa [53], R.J. Teuscher [156,v], A. Thaler [79], O. Theiner [56], N. Themistokleous [52], T. Theveneaux-Pelzer [103], O. Thielmann [172], D.W. Thomas [96], J.P. Thomas [20], E.A. Thompson [17a], P.D. Thompson [20], E. Thomson [129], R.E. Thornberry [44], C. Tian [62a], Y. Tian [55], V. Tikhomirov [37,a], Yu.A. Tikhonov [37], S. Timoshenko [37], D. Timoshyn [134], E.X.L. Ting [1], P. Tipton [173], A. Tishelman-Charny [29], S.H. Tlou [33g], K. Todome [155], S. Todorova-Nova [134], S. Todt [50], L. Toffolin [69a,69c], M. Togawa [84], J. Tojo [89], S. Tokár [28a], K. Tokushuku [84], O. Toldaiev [68], R. Tombs [32], M. Tomoto [84,112], L. Tompkins [144,l], K.W. Topolnicki [86b], E. Torrence [124], H. Torres [90], E. Torró Pastor [164], M. Toscani [30], C. Tosciri [39], M. Tost [11], D.R. Tovey [140], I.S. Trandafir [27b], T. Trefzger [167], A. Tricoli [29], I.M. Trigger [157a], S. Trincaz-Duvoid [128], D.A. Trischuk [26], B. Trocmé [60], L. Truong [33c], M. Trzebinski [87], A. Trzupek [87], F. Tsai [146], M. Tsai [107], A. Tsiamis [153,d], P.V. Tsiareshka [37], S. Tsigaridas [157a], A. Tsirigotis [153,q], V. Tsiskaridze [156], E.G. Tskhadadze [150a], M. Tsopoulou [153], Y. Tsujikawa [88], I.I. Tsukerman [37], V. Tsulaia [17a], S. Tsuno [84], K. Tsuri [119], D. Tsybychev [146], Y. Tu [64b], A. Tudorache [27b], V. Tudorache [27b], A.N. Tuna [61], S. Turchikhin [57b,57a], I. Turk Cakir [3a], R. Turra [71a], T. Turtuvshin [38,w], P.M. Tuts [41], S. Tzamarias [153,d], E. Tzovara [101], F. Ukegawa [158], P.A. Ulloa Poblete [138c,138b], E.N. Umaka [29], G. Unal [36], A. Undrus [29], G. Unel [160], J. Urban [28b], P. Urrejola [138a], G. Usai [8], R. Ushioda [155], M. Usman [109], Z. Uysal [82], V. Vacek [133], B. Vachon [105], T. Vafeiadis [36], A. Vaitkus [97], C. Valderanis [110], E. Valdes Santurio [47a,47b], M. Valente [157a], S. Valentinetti [23b,23a], A. Valero [164], E. Valiente Moreno [164], A. Vallier [90], J.A. Valls Ferrer [164], D.R. Van Arneman [115], T.R. Van Daalen [139], A. Van Der Graaf [49], P. Van Gemmeren [6], M. Van Rijnbach [36], S. Van Stroud [97], I. Van Vulpen [115], P. Vana [134], M. Vanadia [76a,76b], W. Vandelli [36], E.R. Vandewall [122], D. Vannicola [152], L. Vannoli [53], R. Vari [75a], E.W. Varnes [7], C. Varni [17b], T. Varol [149], D. Varouchas [66], L. Varriale [164], K.E. Varvell [148], M.E. Vasile [27b], L. Vaslin [84], G.A. Vasquez [166], A. Vasyukov [38], L.M. Vaughan [122], R. Vavricka [101], T. Vazquez Schroeder [36], J. Veatch [31], V. Vecchio [102], M.J. Veen [104], I. Veliscek [29], L.M. Veloce [156], F. Veloso [131a,131c], S. Veneziano [75a], A. Ventura [70a,70b], S. Ventura Gonzalez [136], A. Verbytskyi [111], M. Verducci [74a,74b], C. Vergis [95], M. Verissimo De Araujo [83b], W. Verkerke [115], J.C. Vermeulen [115], C. Vernieri [144], M. Vessella [104], M.C. Vetterli [143,ad], A. Vgenopoulos [153,d], N. Viaux Maira [138f], T. Vickey [140], O.E. Vickey Boeriu [140], G.H.A. Viehhauser [127], L. Vigani [63b], M. Villa [23b,23a], M. Villaplana Perez [164], E.M. Villhauer [52], E. Vilucchi [53], M.G. Vincter [34], A. Visibile [115], C. Vittori [36], I. Vivarelli [23b,23a], E. Voevodina [111], F. Vogel [110], J.C. Voigt [50], P. Vokac [133], Yu. Volkotrub [86b], J. Von Ahnen [48], E. Von Toerne [24], B. Vormwald [36], V. Vorobel [134], K. Vorobev [37], M. Vos [164], K. Voss [142], M. Vozak [115], L. Vozdecky [121], N. Vranjes [15], M. Vranjes Milosavljevic [15], M. Vreeswijk [115], N.K. Vu [62d,62c], R. Vuillermet [36], O. Vujinovic [101], I. Vukotic [39], S. Wada [158], C. Wagner [104], J.M. Wagner [17a], W. Wagner [172], S. Wahdan [172], H. Wahlberg [91], M. Wakida [112], J. Walder [135], R. Walker [110], W. Walkowiak [142], A. Wall [129], E.J. Wallin [99], T. Wamorkar [6], A.Z. Wang [137], C. Wang [101], C. Wang [11], H. Wang [17a], J. Wang [64c], P. Wang [97], R. Wang [61], R. Wang [6], S.M. Wang [149], S. Wang [62b], S. Wang [14a], T. Wang [62a], W.T. Wang [80], W. Wang [14a], X. Wang [14c], X. Wang [163], X. Wang [62c], Y. Wang [62d], Y. Wang [14c], Z. Wang [107], Z. Wang [62d,51,62c], Z. Wang [107], A. Warburton [105], R.J. Ward [20], N. Warrack [59], S. Waterhouse [96], A.T. Watson [20], H. Watson [59], M.F. Watson [20], E. Watton [59,135], G. Watts [139], B.M. Waugh [97], J.M. Webb [54],

C. Weber [29], H.A. Weber [18], M.S. Weber [19], S.M. Weber [63a], C. Wei [62a], Y. Wei [54], A.R. Weidberg [127], E.J. Weik [118], J. Weingarten [49], C. Weiser [54], C.J. Wells [48], T. Wenaus [29], B. Wendland [49], T. Wengler [36], N.S. Wenke [111], N. Wermes [24], M. Wessels [63a], A.M. Wharton [92], A.S. White [61], A. White [8], M.J. White [1], D. Whiteson [160], L. Wickremasinghe [125], W. Wiedenmann [171], M. Wielers [135], C. Wiglesworth [42], D.J. Wilbern [121], H.G. Wilkens [36], J.J.H. Wilkinson [32], D.M. Williams [41], H.H. Williams [129], S. Williams [32], S. Willocq [104], B.J. Wilson [102], P.J. Windischhofer [39], F.I. Winkel [30], F. Winklmeier [124], B.T. Winter [54], J.K. Winter [102], M. Wittgen [144], M. Wobisch [98], T. Wojtkowski [60], Z. Wolffs [115], J. Wollrath [160], M.W. Wolter [87], H. Wolters [131a,131c], M.C. Wong [137], E.L. Woodward [41], S.D. Worm [48], B.K. Wosiek [87], K.W. Woźniak [87], S. Wozniewski [55], K. Wraight [59], C. Wu [20], M. Wu [14d], M. Wu [114], S.L. Wu [171], X. Wu [56], Y. Wu [62a], Z. Wu [4], J. Wuerzinger [111,ab], T.R. Wyatt [102], B.M. Wynne [52], S. Xella [42], L. Xia [14c], M. Xia [14b], J. Xiang [64c], M. Xie [62a], S. Xin [14a,14e], A. Xiong [124], J. Xiong [17a], D. Xu [14a], H. Xu [62a], L. Xu [62a], R. Xu [129], T. Xu [107], Y. Xu [14b], Z. Xu [52], Z. Xu [14c], B. Yabsley [148], S. Yacoob [33a], Y. Yamaguchi [155], E. Yamashita [154], H. Yamauchi [158], T. Yamazaki [17a], Y. Yamazaki [85], J. Yan [62c], S. Yan [59], Z. Yan [104], H.J. Yang [62c,62d], H.T. Yang [62a], S. Yang [62a], T. Yang [64c], X. Yang [36], X. Yang [14a], Y. Yang [44], Y. Yang [62a], Z. Yang [62a], W-M. Yao [17a], H. Ye [14c], H. Ye [55], J. Ye [14a], S. Ye [29], X. Ye [62a], Y. Yeh [97], I. Yeletskikh [38], B.K. Yeo [17b], M.R. Yexley [97], T.P. Yildirim [127], P. Yin [41], K. Yorita [169], S. Younas [27b], C.J.S. Young [36], C. Young [144], C. Yu [14a,14e], Y. Yu [62a], M. Yuan [107], R. Yuan [62d,62c], L. Yue [97], M. Zaazoua [62a], B. Zabinski [87], E. Zaid [52], Z.K. Zak [87], T. Zakareishvili [164], N. Zakharchuk [34], S. Zambito [56], J.A. Zamora Saa [138d,138b], J. Zang [154], D. Zanzi [54], O. Zaplatilek [133], C. Zeitnitz [172], H. Zeng [14a], J.C. Zeng [163], D.T. Zenger Jr [26], O. Zenin [37], T. Ženiš [28a], S. Zenz [95], S. Zerradi [35a], D. Zerwas [66], M. Zhai [14a,14e], D.F. Zhang [140], J. Zhang [62b], J. Zhang [6], K. Zhang [14a,14e], L. Zhang [62a], L. Zhang [14c], P. Zhang [14a,14e], R. Zhang [171], S. Zhang [107], S. Zhang [90], T. Zhang [154], X. Zhang [62c], X. Zhang [62b], Y. Zhang [62c], Y. Zhang [97], Y. Zhang [14c], Z. Zhang [17a], Z. Zhang [62b], Z. Zhang [66], H. Zhao [139], T. Zhao [62b], Y. Zhao [137], Z. Zhao [62a], Z. Zhao [62a], A. Zhemchugov [38], J. Zheng [14c], K. Zheng [163], X. Zheng [62a], Z. Zheng [144], D. Zhong [163], B. Zhou [107], H. Zhou [7], N. Zhou [62c], Y. Zhou [14b], Y. Zhou [14c], Y. Zhou [7], C.G. Zhu [62b], J. Zhu [107], X. Zhu [62d], Y. Zhu [62c], Y. Zhu [62a], X. Zhuang [14a], K. Zhukov [37], N.I. Zimine [38], J. Zinsser [63b], M. Ziolkowski [142], L. Živković [15], A. Zoccoli [23b,23a], K. Zoch [61], T.G. Zorbas [140], O. Zormpa [46], W. Zou [41], L. Zwalinski [36],

[1] *Department of Physics, University of Adelaide, Adelaide; Australia*
[2] *Department of Physics, University of Alberta, Edmonton AB; Canada*
[3] *[(a)] Department of Physics, Ankara University, Ankara; [(b)] Division of Physics, TOBB University of Economics and Technology, Ankara; Türkiye*
[4] *LAPP, Université Savoie Mont Blanc, CNRS/IN2P3, Annecy; France*
[5] *APC, Université Paris Cité, CNRS/IN2P3, Paris; France*
[6] *High Energy Physics Division, Argonne National Laboratory, Argonne IL; United States of America*
[7] *Department of Physics, University of Arizona, Tucson AZ; United States of America*
[8] *Department of Physics, University of Texas at Arlington, Arlington TX; United States of America*
[9] *Physics Department, National and Kapodistrian University of Athens, Athens; Greece*
[10] *Physics Department, National Technical University of Athens, Zografou; Greece*
[11] *Department of Physics, University of Texas at Austin, Austin TX; United States of America*
[12] *Institute of Physics, Azerbaijan Academy of Sciences, Baku; Azerbaijan*
[13] *Institut de Física d'Altes Energies (IFAE), Barcelona Institute of Science and Technology, Barcelona; Spain*
[14] *[(a)] Institute of High Energy Physics, Chinese Academy of Sciences, Beijing; [(b)] Physics Department, Tsinghua University, Beijing; [(c)] Department of Physics, Nanjing University, Nanjing; [(d)] School of Science, Shenzhen Campus of Sun Yat-sen University; [(e)] University of Chinese Academy of Science (UCAS), Beijing; China*
[15] *Institute of Physics, University of Belgrade, Belgrade; Serbia*
[16] *Department for Physics and Technology, University of Bergen, Bergen; Norway*
[17] *[(a)] Physics Division, Lawrence Berkeley National Laboratory, Berkeley CA; [(b)] University of California, Berkeley CA; United States of America*
[18] *Institut für Physik, Humboldt Universität zu Berlin, Berlin; Germany*
[19] *Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern; Switzerland*
[20] *School of Physics and Astronomy, University of Birmingham, Birmingham; United Kingdom*
[21] *[(a)] Department of Physics, Bogazici University, Istanbul; [(b)] Department of Physics Engineering, Gaziantep University, Gaziantep; [(c)] Department of Physics, Istanbul University, Istanbul; Türkiye*
[22] *[(a)] Facultad de Ciencias y Centro de Investigaciónes, Universidad Antonio Nariño, Bogotá; [(b)] Departamento de Física, Universidad Nacional de Colombia, Bogotá; Colombia*

[23] [(a)] Dipartimento di Fisica e Astronomia A. Righi, Università di Bologna, Bologna; [(b)] INFN Sezione di Bologna; Italy
[24] Physikalisches Institut, Universität Bonn, Bonn; Germany
[25] Department of Physics, Boston University, Boston MA; United States of America
[26] Department of Physics, Brandeis University, Waltham MA; United States of America
[27] [(a)] Transilvania University of Brasov, Brasov; [(b)] Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest; [(c)] Department of Physics, Alexandru Ioan Cuza University of Iasi, Iasi; [(d)] National Institute for Research and Development of Isotopic and Molecular Technologies, Physics Department, Cluj-Napoca; [(e)] National University of Science and Technology Politechnica, Bucharest; [(f)] West University in Timisoara, Timisoara; [(g)] Faculty of Physics, University of Bucharest, Bucharest; Romania
[28] [(a)] Faculty of Mathematics, Physics and Informatics, Comenius University, Bratislava; [(b)] Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice; Slovak Republic
[29] Physics Department, Brookhaven National Laboratory, Upton NY; United States of America
[30] Universidad de Buenos Aires, Facultad de Ciencias Exactas y Naturales, Departamento de Física, y CONICET, Instituto de Física de Buenos Aires (IFIBA), Buenos Aires; Argentina
[31] California State University, CA; United States of America
[32] Cavendish Laboratory, University of Cambridge, Cambridge; United Kingdom
[33] [(a)] Department of Physics, University of Cape Town, Cape Town; [(b)] iThemba Labs, Western Cape; [(c)] Department of Mechanical Engineering Science, University of Johannesburg, Johannesburg; [(d)] National Institute of Physics, University of the Philippines Diliman (Philippines); [(e)] University of South Africa, Department of Physics, Pretoria; [(f)] University of Zululand, KwaDlangezwa; [(g)] School of Physics, University of the Witwatersrand, Johannesburg; South Africa
[34] Department of Physics, Carleton University, Ottawa ON; Canada
[35] [(a)] Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies - Université Hassan II, Casablanca; [(b)] Faculté des Sciences, Université Ibn-Tofail, Kénitra; [(c)] Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA-Marrakech; [(d)] LPMR, Faculté des Sciences, Université Mohamed Premier, Oujda; [(e)] Faculté des sciences, Université Mohammed V, Rabat; [(f)] Institute of Applied Physics, Mohammed VI Polytechnic University, Ben Guerir; Morocco
[36] CERN, Geneva; Switzerland
[37] Affiliated with an institute covered by a cooperation agreement with CERN
[38] Affiliated with an international laboratory covered by a cooperation agreement with CERN
[39] Enrico Fermi Institute, University of Chicago, Chicago IL; United States of America
[40] LPC, Université Clermont Auvergne, CNRS/IN2P3, Clermont-Ferrand; France
[41] Nevis Laboratory, Columbia University, Irvington NY; United States of America
[42] Niels Bohr Institute, University of Copenhagen, Copenhagen; Denmark
[43] [(a)] Dipartimento di Fisica, Università della Calabria, Rende; [(b)] INFN Gruppo Collegato di Cosenza, Laboratori Nazionali di Frascati; Italy
[44] Physics Department, Southern Methodist University, Dallas TX; United States of America
[45] Physics Department, University of Texas at Dallas, Richardson TX; United States of America
[46] National Centre for Scientific Research "Demokritos", Agia Paraskevi; Greece
[47] [(a)] Department of Physics, Stockholm University; [(b)] Oskar Klein Centre, Stockholm; Sweden
[48] Deutsches Elektronen-Synchrotron DESY, Hamburg and Zeuthen; Germany
[49] Fakultät Physik, Technische Universität Dortmund, Dortmund; Germany
[50] Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden; Germany
[51] Department of Physics, Duke University, Durham NC; United States of America
[52] SUPA - School of Physics and Astronomy, University of Edinburgh, Edinburgh; United Kingdom
[53] INFN e Laboratori Nazionali di Frascati, Frascati; Italy
[54] Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg; Germany
[55] II. Physikalisches Institut, Georg-August-Universität Göttingen, Göttingen; Germany
[56] Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève; Switzerland
[57] [(a)] Dipartimento di Fisica, Università di Genova, Genova; [(b)] INFN Sezione di Genova; Italy
[58] II. Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen; Germany
[59] SUPA - School of Physics and Astronomy, University of Glasgow, Glasgow; United Kingdom
[60] LPSC, Université Grenoble Alpes, CNRS/IN2P3, Grenoble INP, Grenoble; France
[61] Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge MA; United States of America
[62] [(a)] Department of Modern Physics and State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei; [(b)] Institute of Frontier and Interdisciplinary Science and Key Laboratory of Particle Physics and Particle Irradiation (MOE), Shandong University, Qingdao; [(c)] School of Physics and Astronomy, Shanghai Jiao Tong University, Key Laboratory for Particle Astrophysics and Cosmology (MOE), SKLPPC, Shanghai; [(d)] Tsung-Dao Lee Institute, Shanghai; [(e)] School of Physics and Microelectronics, Zhengzhou University; China
[63] [(a)] Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg; [(b)] Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg; Germany
[64] [(a)] Department of Physics, Chinese University of Hong Kong, Shatin, N.T., Hong Kong; [(b)] Department of Physics, University of Hong Kong, Hong Kong; [(c)] Department of Physics and Institute for Advanced Study, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong; China
[65] Department of Physics, National Tsing Hua University, Hsinchu; Taiwan
[66] IJCLab, Université Paris-Saclay, CNRS/IN2P3, 91405, Orsay; France
[67] Centro Nacional de Microelectrónica (IMB-CNM-CSIC), Barcelona; Spain
[68] Department of Physics, Indiana University, Bloomington IN; United States of America
[69] [(a)] INFN Gruppo Collegato di Udine, Sezione di Trieste, Udine; [(b)] ICTP, Trieste; [(c)] Dipartimento Politecnico di Ingegneria e Architettura, Università di Udine, Udine; Italy
[70] [(a)] INFN Sezione di Lecce; [(b)] Dipartimento di Matematica e Fisica, Università del Salento, Lecce; Italy
[71] [(a)] INFN Sezione di Milano; [(b)] Dipartimento di Fisica, Università di Milano, Milano; Italy
[72] [(a)] INFN Sezione di Napoli; [(b)] Dipartimento di Fisica, Università di Napoli, Napoli; Italy
[73] [(a)] INFN Sezione di Pavia; [(b)] Dipartimento di Fisica, Università di Pavia, Pavia; Italy
[74] [(a)] INFN Sezione di Pisa; [(b)] Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa; Italy
[75] [(a)] INFN Sezione di Roma; [(b)] Dipartimento di Fisica, Sapienza Università di Roma, Roma; Italy
[76] [(a)] INFN Sezione di Roma Tor Vergata; [(b)] Dipartimento di Fisica, Università di Roma Tor Vergata, Roma; Italy
[77] [(a)] INFN Sezione di Roma Tre; [(b)] Dipartimento di Matematica e Fisica, Università Roma Tre, Roma; Italy
[78] [(a)] INFN-TIFPA; [(b)] Università degli Studi di Trento, Trento; Italy
[79] Universität Innsbruck, Department of Astro and Particle Physics, Innsbruck; Austria
[80] University of Iowa, Iowa City IA; United States of America
[81] Department of Physics and Astronomy, Iowa State University, Ames IA; United States of America
[82] Istinye University, Sariyer, Istanbul; Türkiye
[83] [(a)] Departamento de Engenharia Elétrica, Universidade Federal de Juiz de Fora (UFJF), Juiz de Fora; [(b)] Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro; [(c)] Instituto de Física, Universidade de São Paulo, São Paulo; [(d)] Rio de Janeiro State University, Rio de Janeiro; [(e)] Federal University of Bahia, Bahia; Brazil
[84] KEK, High Energy Accelerator Research Organization, Tsukuba; Japan
[85] Graduate School of Science, Kobe University, Kobe; Japan
[86] [(a)] AGH University of Krakow, Faculty of Physics and Applied Computer Science, Krakow; [(b)] Marian Smoluchowski Institute of Physics, Jagiellonian University, Krakow; Poland
[87] Institute of Nuclear Physics Polish Academy of Sciences, Krakow; Poland
[88] Faculty of Science, Kyoto University, Kyoto; Japan
[89] Research Center for Advanced Particle Physics and Department of Physics, Kyushu University, Fukuoka; Japan
[90] L2IT, Université de Toulouse, CNRS/IN2P3, UPS, Toulouse; France

[91] Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata; Argentina
[92] Physics Department, Lancaster University, Lancaster; United Kingdom
[93] Oliver Lodge Laboratory, University of Liverpool, Liverpool; United Kingdom
[94] Department of Experimental Particle Physics, Jožef Stefan Institute and Department of Physics, University of Ljubljana, Ljubljana; Slovenia
[95] School of Physics and Astronomy, Queen Mary University of London, London; United Kingdom
[96] Department of Physics, Royal Holloway University of London, Egham; United Kingdom
[97] Department of Physics and Astronomy, University College London, London; United Kingdom
[98] Louisiana Tech University, Ruston LA; United States of America
[99] Fysiska institutionen, Lunds universitet, Lund; Sweden
[100] Departamento de Física Teorica C-15 and CIAFF, Universidad Autónoma de Madrid, Madrid; Spain
[101] Institut für Physik, Universität Mainz, Mainz; Germany
[102] School of Physics and Astronomy, University of Manchester, Manchester; United Kingdom
[103] CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille; France
[104] Department of Physics, University of Massachusetts, Amherst MA; United States of America
[105] Department of Physics, McGill University, Montreal QC; Canada
[106] School of Physics, University of Melbourne, Victoria; Australia
[107] Department of Physics, University of Michigan, Ann Arbor MI; United States of America
[108] Department of Physics and Astronomy, Michigan State University, East Lansing MI; United States of America
[109] Group of Particle Physics, University of Montreal, Montreal QC; Canada
[110] Fakultät für Physik, Ludwig-Maximilians-Universität München, München; Germany
[111] Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München; Germany
[112] Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya; Japan
[113] Department of Physics and Astronomy, University of New Mexico, Albuquerque NM; United States of America
[114] Institute for Mathematics, Astrophysics and Particle Physics, Radboud University/Nikhef, Nijmegen; Netherlands
[115] Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam; Netherlands
[116] Department of Physics, Northern Illinois University, DeKalb IL; United States of America
[117] [(a)] New York University Abu Dhabi, Abu Dhabi; [(b)] United Arab Emirates University, Al Ain; United Arab Emirates
[118] Department of Physics, New York University, New York NY; United States of America
[119] Ochanomizu University, Otsuka, Bunkyo-ku, Tokyo; Japan
[120] Ohio State University, Columbus OH; United States of America
[121] Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman OK; United States of America
[122] Department of Physics, Oklahoma State University, Stillwater OK; United States of America
[123] Palacký University, Joint Laboratory of Optics, Olomouc; Czech Republic
[124] Institute for Fundamental Science, University of Oregon, Eugene, OR; United States of America
[125] Graduate School of Science, Osaka University, Osaka; Japan
[126] Department of Physics, University of Oslo, Oslo; Norway
[127] Department of Physics, Oxford University, Oxford; United Kingdom
[128] LPNHE, Sorbonne Université, Université Paris Cité, CNRS/IN2P3, Paris; France
[129] Department of Physics, University of Pennsylvania, Philadelphia PA; United States of America
[130] Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh PA; United States of America
[131] [(a)] Laboratório de Instrumentação e Física Experimental de Partículas - LIP, Lisboa; [(b)] Departamento de Física, Faculdade de Ciências, Universidade de Lisboa, Lisboa; [(c)] Departamento de Física, Universidade de Coimbra, Coimbra; [(d)] Centro de Física Nuclear da Universidade de Lisboa, Lisboa; [(e)] Departamento de Física, Universidade do Minho, Braga; [(f)] Departamento de Física Teórica y del Cosmos, Universidad de Granada, Granada (Spain); [(g)] Departamento de Física, Instituto Superior Técnico, Universidade de Lisboa, Lisboa; Portugal
[132] Institute of Physics of the Czech Academy of Sciences, Prague; Czech Republic
[133] Czech Technical University in Prague, Prague; Czech Republic
[134] Charles University, Faculty of Mathematics and Physics, Prague; Czech Republic
[135] Particle Physics Department, Rutherford Appleton Laboratory, Didcot; United Kingdom
[136] IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette; France
[137] Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz CA; United States of America
[138] [(a)] Departamento de Física, Pontificia Universidad Católica de Chile, Santiago; [(b)] Millennium Institute for Subatomic physics at high energy frontier (SAPHIR), Santiago; [(c)] Instituto de Investigación Multidisciplinario en Ciencia y Tecnología, y Departamento de Física, Universidad de La Serena; [(d)] Universidad Andres Bello, Department of Physics, Santiago; [(e)] Instituto de Alta Investigación, Universidad de Tarapacá, Arica; [(f)] Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso; Chile
[139] Department of Physics, University of Washington, Seattle WA; United States of America
[140] Department of Physics and Astronomy, University of Sheffield, Sheffield; United Kingdom
[141] Department of Physics, Shinshu University, Nagano; Japan
[142] Department Physik, Universität Siegen, Siegen; Germany
[143] Department of Physics, Simon Fraser University, Burnaby BC; Canada
[144] SLAC National Accelerator Laboratory, Stanford CA; United States of America
[145] Department of Physics, Royal Institute of Technology, Stockholm; Sweden
[146] Departments of Physics and Astronomy, Stony Brook University, Stony Brook NY; United States of America
[147] Department of Physics and Astronomy, University of Sussex, Brighton; United Kingdom
[148] School of Physics, University of Sydney, Sydney; Australia
[149] Institute of Physics, Academia Sinica, Taipei; Taiwan
[150] [(a)] E. Andronikashvili Institute of Physics, Iv. Javakhishvili Tbilisi State University, Tbilisi; [(b)] High Energy Physics Institute, Tbilisi State University, Tbilisi; [(c)] University of Georgia, Tbilisi; Georgia
[151] Department of Physics, Technion, Israel Institute of Technology, Haifa; Israel
[152] Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv; Israel
[153] Department of Physics, Aristotle University of Thessaloniki, Thessaloniki; Greece
[154] International Center for Elementary Particle Physics and Department of Physics, University of Tokyo, Tokyo; Japan
[155] Department of Physics, Tokyo Institute of Technology, Tokyo; Japan
[156] Department of Physics, University of Toronto, Toronto ON; Canada
[157] [(a)] TRIUMF, Vancouver BC; [(b)] Department of Physics and Astronomy, York University, Toronto ON; Canada
[158] Division of Physics and Tomonaga Center for the History of the Universe, Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba; Japan
[159] Department of Physics and Astronomy, Tufts University, Medford MA; United States of America
[160] Department of Physics and Astronomy, University of California Irvine, Irvine CA; United States of America
[161] University of Sharjah, Sharjah; United Arab Emirates
[162] Department of Physics and Astronomy, University of Uppsala, Uppsala; Sweden
[163] Department of Physics, University of Illinois, Urbana IL; United States of America
[164] Instituto de Física Corpuscular (IFIC), Centro Mixto Universidad de Valencia - CSIC, Valencia; Spain
[165] Department of Physics, University of British Columbia, Vancouver BC; Canada

[166] Department of Physics and Astronomy, University of Victoria, Victoria BC; Canada
[167] Fakultät für Physik und Astronomie, Julius-Maximilians-Universität Würzburg, Würzburg; Germany
[168] Department of Physics, University of Warwick, Coventry; United Kingdom
[169] Waseda University, Tokyo; Japan
[170] Department of Particle Physics and Astrophysics, Weizmann Institute of Science, Rehovot; Israel
[171] Department of Physics, University of Wisconsin, Madison WI; United States of America
[172] Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal; Germany
[173] Department of Physics, Yale University, New Haven CT; United States of America

[a] Also Affiliated with an institute covered by a cooperation agreement with CERN.
[b] Also at An-Najah National University, Nablus; Palestine.
[c] Also at Borough of Manhattan Community College, City University of New York, New York NY; United States of America.
[d] Also at Center for Interdisciplinary Research and Innovation (CIRI-AUTH), Thessaloniki; Greece.
[e] Also at Centro Studi e Ricerche Enrico Fermi; Italy.
[f] Also at CERN, Geneva; Switzerland.
[g] Also at Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève; Switzerland.
[h] Also at Departament de Fisica de la Universitat Autonoma de Barcelona, Barcelona; Spain.
[i] Also at Department of Financial and Management Engineering, University of the Aegean, Chios; Greece.
[j] Also at Department of Physics, California State University, Sacramento; United States of America.
[k] Also at Department of Physics, King's College London, London; United Kingdom.
[l] Also at Department of Physics, Stanford University, Stanford CA; United States of America.
[m] Also at Department of Physics, Stellenbosch University; South Africa.
[n] Also at Department of Physics, University of Fribourg, Fribourg; Switzerland.
[o] Also at Department of Physics, University of Thessaly; Greece.
[p] Also at Department of Physics, Westmont College, Santa Barbara; United States of America.
[q] Also at Hellenic Open University, Patras; Greece.
[r] Also at Institucio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona; Spain.
[s] Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg; Germany.
[t] Also at Institute for Nuclear Research and Nuclear Energy (INRNE) of the Bulgarian Academy of Sciences, Sofia; Bulgaria.
[u] Also at Institute of Applied Physics, Mohammed VI Polytechnic University, Ben Guerir; Morocco.
[v] Also at Institute of Particle Physics (IPP); Canada.
[w] Also at Institute of Physics and Technology, Mongolian Academy of Sciences, Ulaanbaatar; Mongolia.
[x] Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku; Azerbaijan.
[y] Also at Institute of Theoretical Physics, Ilia State University, Tbilisi; Georgia.
[z] Also at Lawrence Livermore National Laboratory, Livermore; United States of America.
[aa] Also at National Institute of Physics, University of the Philippines Diliman (Philippines); Philippines.
[ab] Also at Technical University of Munich, Munich; Germany.
[ac] Also at The Collaborative Innovation Center of Quantum Matter (CICQM), Beijing; China.
[ad] Also at TRIUMF, Vancouver BC; Canada.
[ae] Also at Università di Napoli Parthenope, Napoli; Italy.
[af] Also at University of Colorado Boulder, Department of Physics, Colorado; United States of America.
[ag] Also at Washington College, Chestertown, MD; United States of America.
[ah] Also at Yeditepe University, Physics Department, Istanbul; Türkiye.
[*] Deceased.