UNIVERSITY OF AMSTERDAM

UvA-DARE (Digital Academic Repository)

Studies of the Energy Dependence of Diboson Polarization Fractions and the Radiation-Amplitude-Zero Effect in WZ Production with the ATLAS Detector

Aad, G.; ATLAS Collaboration

DOI
10.1103/PhysRevLett.133.101802

Publication date
2024

Document Version
Final published version

Published in
Physical Review Letters

License
CC BY

Link to publication

Citation for published version (APA):
Aad, G., & ATLAS Collaboration (2024). Studies of the Energy Dependence of Diboson Polarization Fractions and the Radiation-Amplitude-Zero Effect in *WZ* Production with the ATLAS Detector. *Physical Review Letters*, *133*(10), Article 101802. https://doi.org/10.1103/PhysRevLett.133.101802

General rights
It is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), other than for strictly personal, individual use, unless the work is under an open content license (like Creative Commons).

Disclaimer/Complaints regulations
If you believe that digital publication of certain material infringes any of your rights or (privacy) interests, please let the Library know, stating your reasons. In case of a legitimate complaint, the Library will make the material inaccessible and/or remove it from the website. Please Ask the Library: https://uba.uva.nl/en/contact, or a letter to: Library of the University of Amsterdam, Secretariat, P.O. Box 19185, 1000 GD Amsterdam, The Netherlands. You will be contacted as soon as possible.

UvA-DARE is a service provided by the library of the University of Amsterdam (https://dare.uva.nl)

Download date:07 Sept 2026

Studies of the Energy Dependence of Diboson Polarization Fractions and the Radiation-Amplitude-Zero Effect in WZ Production with the ATLAS Detector

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

(Received 27 February 2024; revised 21 May 2024; accepted 3 July 2024; published 5 September 2024)

This Letter presents the first study of the energy dependence of diboson polarization fractions in $WZ \to \ell\nu\ell'\ell'(\ell, \ell' = e, \mu)$ production. The dataset used corresponds to an integrated luminosity of 140 fb^{-1} of proton-proton collisions at a center-of-mass energy of 13 TeV recorded by the ATLAS detector. Two fiducial regions with an enhanced presence of events featuring two longitudinally polarized bosons are defined. A nonzero fraction of events with two longitudinally polarized bosons is measured with an observed significance of 5.3 standard deviations in the region with $100 < p_T^Z \leq 200$ GeV and 1.6 standard deviations in the region with $p_T^Z > 200$ GeV, where p_T^Z is the transverse momentum of the Z boson. This Letter also reports the first study of the radiation-amplitude-zero effect. Events with two transversely polarized bosons are analyzed for the $\Delta Y(\ell_W Z)$ and $\Delta Y(WZ)$ distributions defined respectively as the rapidity difference between the lepton from the W boson decay and the Z boson and the rapidity difference between the W boson and the Z boson. Significant suppression of events near zero is observed in both distributions. Unfolded $\Delta Y(\ell_W Z)$ and $\Delta Y(WZ)$ distributions are also measured and compared to theoretical predictions.

DOI: 10.1103/PhysRevLett.133.101802

In the Standard Model (SM) of particle physics, the longitudinal polarization components of the W and Z bosons are generated by the Goldstone bosons from electroweak symmetry breaking via the Higgs mechanism. Physics beyond the SM could cause different effects on the polarization of W (or Z) bosons in diboson processes [1,2]. A sensitive test of the mechanism of electroweak symmetry breaking and gauge symmetry can thus be obtained by studying different polarization states in diboson processes. This Letter presents the first study of the energy dependence of WZ diboson polarization fractions in two fiducial regions with an enhanced presence of events featuring two longitudinally polarized bosons. In addition, it reports the first study of the radiation-amplitude-zero (RAZ) effect in WZ production with two transversely polarized bosons [3,4]. The WZ candidates are reconstructed using leptonic decay modes of the gauge bosons into electrons and muons, $WZ \to \ell\nu\ell'\ell'$ $(\ell, \ell' = e, \mu)$. The dataset used corresponds to an integrated luminosity of 140 fb^{-1} of proton-proton collisions at a center-of-mass energy of 13 TeV recorded by the ATLAS detector from 2015 to 2018.

At leading-order (LO) in quantum chromodynamics (QCD), WZ production occurs through quark-antiquark interactions in the s, t, and u channels. The dominant helicity amplitude with two transversely polarized bosons is exactly zero when the scattering angle of the W boson in the WZ rest frame with respect to the incoming antiquark direction approaches 90° [3,4]. This is a direct consequence of the gauge structure in the SM. This RAZ effect leads to a dip around 0 in the $\Delta Y(WZ)$ and $\Delta Y(\ell_W Z)$ distributions, with $\Delta Y(WZ)$ defined as the rapidity difference between the W and Z bosons, and $\Delta Y(\ell_W Z)$ defined as the rapidity difference between the lepton from the W decay and the Z boson. The RAZ effect has been observed for $W\gamma$ [5–7] for which it is found that the sensitivity for $W\gamma$ resonances is enhanced in this radiation valley [8]. However, the RAZ effect has not yet been observed for WZ due to the W boson polarizations in WZ production [9]. In addition, the next-to-leading order (NLO) QCD corrections dilute the RAZ effect and make it hard to observe experimentally [10,11]. To reduce jet activity and to increase the significance of the dips, a selection criterion on the transverse momentum of the WZ system (p_T^{WZ}) is applied.

The diboson polarization fractions f_{00}, f_{TT}, f_{0T}, and f_{T0} as defined in Ref. [12] are interpreted as probabilities of correlated polarization states of the W and Z bosons. Here, 00 (TT) indicates that both bosons are longitudinally (transversely) polarized, and $0T$ ($T0$) indicates that the W (Z) boson is longitudinally polarized and the Z (W) boson is transversely polarized. The ATLAS Collaboration

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

Published by the American Physical Society under the terms of the Creative Commons Attribution 4.0 International license. Further distribution of this work must maintain attribution to the author(s) and the published article's title, journal citation, and DOI. Funded by SCOAP[3].

 © 2024 CERN, for the ATLAS Collaboration

has measured both single and diboson polarization fractions using inclusive WZ events [12], which are dominated by TT events with low momentum W and Z bosons [1,2,13]. This analysis focuses on WZ events with Z bosons required to have high transverse momenta (p_T^Z). The combination of high p_T^Z and low p_T^{WZ} significantly reduces the TT contribution and increases f_{00}. As a result, f_{00} increases from 5%–7% in the inclusive region to 20%–30% in the region with high p_T^Z and low p_T^{WZ} [14].

The ATLAS detector [15] is a multipurpose particle physics detector with cylindrical geometry [16]. It consists of an inner tracking detector (ID) surrounded by a superconducting solenoid providing a 2 T axial magnetic field, sampling electromagnetic (ECAL) and hadronic calorimeters using liquid argon as active material and lead, copper or tungsten as absorber material, and a muon spectrometer (MS) based on three air-core toroidal superconducting magnets. The ATLAS trigger system consists of a hardware-based level-1 trigger followed by a software-based high-level trigger [17]. Events used for this analysis are selected with single-lepton (e or μ) triggers [17–19]. An extensive software suite [20] is used in the reconstruction and analysis of real and simulated data, in detector operations, and in the trigger and data acquisition systems of the experiment.

Electron candidates are reconstructed from energy clusters in the ECAL matched to ID tracks. Electrons are identified using a likelihood function based on shower shape variables in the ECAL, track variables, and the quality of the track-cluster matching. Electrons are required to satisfy a "medium" likelihood requirement [21] and have $p_T > 15$ GeV and $|\eta| < 2.47$ excluding the crack region $1.37 < |\eta| < 1.52$. Muons are reconstructed by matching the tracks in the MS with tracks in the ID. Muons are required to pass a "medium" identification selection [22] and have $p_T > 15$ GeV and $|\eta| < 2.7$. Electrons and muons must be compatible with the hypothesis that they originate from the primary vertex [21,22]. They are also required to be isolated from other particles using both calorimeter-cluster and ID-track information [23].

Jets are reconstructed with the anti-k_t algorithm with a radius parameter of 0.4, using a particle-flow procedure [24] with clusters of energy deposited in the calorimeter and tracks reconstructed in the ID as inputs. Jets are required to have $p_T > 30$ GeV and $|\eta| < 4.5$. To suppress pile-up jets, jets with $p_T < 60$ GeV and $|\eta| < 2.4$ have to pass a requirement on the jet vertex tagger [25]. The missing transverse momentum vector with magnitude denoted by E_T^{miss}, is calculated as the negative vector sum of the transverse momentum of all identified "hard" physics objects (electrons, muons, jets), with a contribution from an additional soft term based on ID tracks matched to the primary vertex but not assigned to any of the "hard" objects [26]. Ambiguities in the identity of reconstructed leptons, jets, and photons are resolved with an overlap-removal procedure described in Ref. [27].

Candidate WZ events are selected using triggers that require at least one electron or muon. To ensure the trigger efficiency is well determined, at least one of the candidate leptons in the event must be trigger matched and have $p_T > 25$ GeV for data taken in 2015 or $p_T > 27$ GeV for data taken from 2016 to 2018. Events are required to contain exactly three lepton candidates satisfying the selection criteria described above. To reduce contributions from the $ZZ^{(*)} \to \ell\ell\ell'\ell'$ process, events with a fourth lepton candidate satisfying looser selection criteria are rejected. For this looser selection, the lepton p_T requirement is reduced to $p_T > 5$ GeV. Electrons are allowed to be reconstructed in the region $1.37 < |\eta| < 1.52$, and "loose" identification requirements [21,22] are used for both the electrons and muons. A less stringent requirement is also applied for electron isolation [12]. Candidate events are required to have at least one pair of leptons with the same flavor and opposite charge, with an invariant mass that is consistent with the Z boson pole mass (91.188 GeV [28]) to within 10 GeV. This pair is considered to be the Z boson candidate. If more than one pair can be formed, the pair whose invariant mass is closest to the Z boson pole mass is taken as the Z boson candidate. The remaining third lepton is assigned to the W boson decay. To suppress backgrounds with nonprompt leptons from hadron (including b-flavored and c-flavored hadrons) decays and jets misidentified as leptons, the W lepton is required to pass tighter isolation requirements and have $p_T > 20$ GeV. The transverse mass of the W candidate, defined as $m_{\text{T}}^W = \sqrt{2p_T^\ell E_T^{\text{miss}}[1-\cos\Delta\phi]}$, is required to be greater than 30 GeV, where $\Delta\phi$ is the angle between the third lepton and the E_T^{miss} in the transverse plane, and p_T^ℓ the transverse momentum of the third lepton. These selection criteria are used to select inclusive WZ events. The overall acceptance times efficiency after these selections ranges from 40% to 60% depending on the channel.

The W-mass constraint method is used to calculate the longitudinal component of the neutrino momentum ($p_z(\nu)$). The E_T^{miss} of the event is assumed to come from the neutrino, and $p_z(\nu)$ is estimated by constraining the invariant mass of the third lepton and the neutrino to be the pole mass of the W boson (80.385 GeV [28]). A quadratic equation leads to two solutions. If they are real, the one with the smaller magnitude of $|p_z(\nu)|$ is chosen; otherwise, the real part is chosen [29]. The effect of these choices is consistent between the data and Monte Carlo (MC) and does not bias our measurements.

For RAZ studies, an additional criterion of $p_T^{WZ} < 20, 40,$ or 70 GeV is applied to define three regions with reduced jet activity in each event. Diboson polarization fractions are measured in two regions enhanced in events with 00 polarization (00-enhanced), defined with two additional criteria applied on the inclusive region: $p_T^{WZ} < 70$ GeV, and either $100 < p_T^Z \leq 200$ GeV or $p_T^Z > 200$ GeV.

MC simulated samples are used to model the signal WZ process with different polarization states, as well as other physics processes with at least three prompt leptons. Simulated events are processed through the full ATLAS detector simulation based on GEANT4 [30,31], and reconstructed with the same algorithms as those used for the data. To simulate pileup effects, additional pp interactions are added to the MC samples in proportion to the mean interactions per bunch crossing occurring in the various data periods.

For inclusive WZ production, NLO QCD [3,32] and NLO electroweak corrections [33–35] have been calculated. Next-to-next-to-leading-order QCD corrections are also known in the on shell case, including off shell effects [36,37] and combined with electroweak corrections [38]. Diboson polarizations in WZ production have been studied at NLO QCD [39,40] and NLO QCD + electroweak accuracy [41,42]. However, the automated MC simulation with two polarized vector bosons and full spin correlations is only available at LO in the narrow-width approximation. In this analysis, polarized WZ events are generated at LO using MADGRAPH_AMC@NLO2.7.3 [43]. The boson polarizations are defined in the WZ center-of-mass frame. To account for the real part of NLO QCD corrections, events are simulated with no jets and with one jet at LO, and the two samples are merged with PYTHIA8 [44] using the CKKW-L scheme [45]. Jets are defined to have $p_T > 25$ GeV and $|\eta| < 2.5$ at the parton level. In addition, PYTHIA8 is used for the simulation of parton showering, hadronization, and the underlying event. The NNPDF3.0nlo parton distribution functions set [46] is used for the parton process generation. Separate MC samples are generated corresponding to the four states 00, $0T$, $T0$, and TT, respectively. For each polarization state, different samples are generated for $p_T^Z > 150$ GeV and $p_T^Z \leq 150$ GeV in order to increase statistics for events with high p_T^Z. Separate samples are also generated for events with at least one boson decay to τ lepton, and the τ lepton decays leptonically to an electron or a muon. An inclusive MC sample is created by adding the four polarized samples. These MC sets are referred to as MADGRAPH0,1j@LO, and the inclusive cross section is scaled to the NLO QCD prediction [47–49]. Scale factors are also derived to reweight simulated MADGRAPH0,1j@LO events to agree with data for three jet multiplicity bins (0 jets, 1 jet, and ≥ 2 jets) in the inclusive region to account for missing higher-order QCD effects.

To cross check the modeling of polarized WZ events, an inclusive $WZ \to \ell\nu\ell'\ell'$ sample is generated at NLO in QCD with SHERPA2.2.2 [50]. PYTHIA8 is used for the modeling of the parton shower, hadronization, and underlying event. The inclusive MADGRAPH0,1j@LO sample is compared to this SHERPA sample. In addition, the MADGRAPH0,1j@LO sample is also compared to the NLO QCD and NLO QCD + electroweak calculations [40–42] for each polarization state. In general good agreement is observed for polarization fractions and kinematic distributions in both inclusive and 00-enhanced signal regions.

Owing to the requirement of three isolated charged leptons in the final state, only about 10% of events come from background processes. To estimate background processes with three prompt leptons in the final state, $q\bar{q}$-initiated and gg-initiated $ZZ^{(*)}$ processes are simulated using SHERPA2.2.2. It provides a matrix element calculation accurate to NLO in QCD for zero- and one-jet final states, and LO accuracy for two- and three-jet final states. Both $t\bar{t}Z$ and $t\bar{t}W$ processes are generated at NLO in QCD using the MADGRAPH_AMC@NLO2.6.5 generator and interfaced with PYTHIA8 for the modeling of the parton shower. Triboson (VVV with $V = W$, Z) events are simulated using the SHERPA generator at NLO in QCD with 0 partons and at LO accuracy with one and two additional partons. These background samples are normalized to cross sections with higher-order corrections applied [51–54]. Backgrounds with at least one misidentified lepton (labeled as "nonprompt background") are evaluated using a data-driven technique described in Refs. [12,55].

Instrumental systematic uncertainties are related to the lepton trigger, reconstruction and identification efficiencies [22,56], lepton isolation criteria [23], lepton energy (momentum) scale and resolution [22,57], jet energy scale and resolution [58], jet vertex tagging [59,60], b-jet identification [61], modeling of E_T^{miss} [26] and pileup, and integrated luminosity [62,63].

Theoretical uncertainties associated with the signal and other background processes are evaluated using simulation. Shape and acceptance uncertainties on the WZ process due to renormalization and factorization scales [64], PDFs [65], and parton shower, are also considered. The normalization uncertainties on the processes included in the "Prompt" background category are between 10% and 20% [66–68]. Systematic uncertainties due to the potential mismodeling of NLO QCD and electroweak corrections are estimated by applying reweighting corrections estimated from Ref. [42] as a function of different sets of variables: the cosine of the scattering angle of the W boson in the WZ rest frame with respect to the z axis ($\cos\theta_V$) and $\Delta Y(\ell_W Z)$ for NLO QCD corrections, and average p_T of the three charged leptons and $\Delta Y(\ell_W Z)$ for NLO electroweak corrections. Additionally, uncertainties from the implementation of the NLO electroweak corrections are estimated by taking the difference between the additive and the multiplicative prescription as described in [38]. The interference effects among different polarization states are found to be negligible. The methods used are similar to the ones described in Ref. [69].

For the RAZ measurement, good agreement is observed between data and SM predictions for the $\Delta Y(WZ)$ and $\Delta Y(\ell_W Z)$ distributions in the three regions with $p_T^{WZ} < 20$, 40, or 70 GeV. Since a dip is expected only for the TT

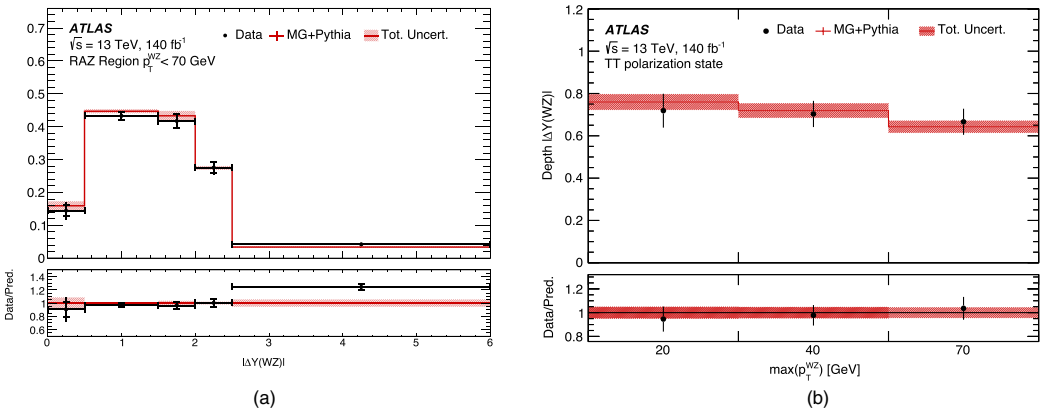

FIG. 1. (a) Comparison between the $00+0T+T0$-subtracted normalized unfolded $|\Delta Y(WZ)|$ data distribution and the SM prediction for TT events with $p_T^{WZ} < 70$ GeV; (b) The depth of the RAZ dip for the unfolded $|\Delta Y(WZ)|$ distribution of the TT polarization as a function of the p_T^{WZ} cut value used. The measured data are shown as black points, and the vertical error bars show the size of the total uncertainty, with tick marks used to reflect the size of the statistical uncertainty only. The MADGRAPH0,1j@LO prediction for the TT polarization state is shown in red.

component, the estimated contributions from all background processes (∼10%) and WZ 00, $0T$, and $T0$ polarization states (∼27%) are subtracted from data. The WZ 00, $0T$, and $T0$ contributions are normalized to the SM predicted cross sections. The measured $|\Delta Y(\ell_W Z)|$ and $|\Delta Y(WZ)|$ distributions for the TT polarization state are corrected for detector effects using an iterative Bayesian unfolding method [70,71] to estimate the actual particle level normalized differential cross sections in these three p_T^{WZ} regions. The unfolding procedure corrects for migrations between bins in the rapidity-difference distributions during the reconstruction of the events and applies fiducial as well as reconstruction efficiency corrections. Corrections are derived using the polarized MADGRAPH0,1j@LO samples. To reduce bias due to the assumed true distribution, the method is applied iteratively, at the cost of an increased statistical uncertainty. Three iterations are used in the final unfolding procedure. Figure 1(a) shows the comparison between the unfolded $|\Delta Y(WZ)|$ distribution and the TT-only prediction for events with $p_T^{WZ} < 70$ GeV. Good agreement is observed between these two distributions except the last bin where the discrepancy is 3.1 standard deviations. In addition, the unfolding procedure is applied to inclusive events (no subtraction of contributions from 00, $0T$, and $T0$ polarization states) in all three RAZ regions. Good agreement is also found in this case between unfolded $|\Delta Y(\ell_W Z)|$ and $|\Delta Y(WZ)|$ distributions and the SM predictions.

The depth of the RAZ dip, represented by the variable $\mathcal{D}$, is defined as $\mathcal{D} = 1\text{–}2 \times N^{\text{unf}}_{\text{central}}/N^{\text{unf}}_{\text{sides}}$, where $N^{\text{unf}}_{\text{central}}$ ($N^{\text{unf}}_{\text{sides}}$) indicates the number of events with $|\Delta Y(WZ)| < 0.5$ ($0.5 < |\Delta Y(\ell_W Z)| < 1.5$) after the unfolding. A positive value of $\mathcal{D}$ indicates the existence of a dip. A comparison between the measured and predicted $\mathcal{D}$ values using the $|\Delta Y(WZ)|$ distribution as a function of the p_T^{WZ} cut value used is shown in Fig. 1(b). The same procedure is also applied for the $\Delta Y(\ell_W Z)$ distribution, and again good agreement is observed between data and predictions for the depth of the dip observed.

Table I shows the expected signal and background event yields as well as the observed data in the two 00-enhanced regions. To measure the polarization fractions, a dedicated boosted decision tree (BDT) is trained independently to separate the 00 polarization state from the other polarization states ($0T$, $T0$, and TT) in each of the two signal regions defined by p_T^Z. The BDTs are implemented using the TMVA package [72], and the simulated MADGRAPH0,1j@LO samples are used for training. Seven variables are used for both signal regions: $\Delta Y(\ell_W Z)$, $p_T(WZ)$, the subleading lepton transverse momentum from the Z boson decay, the transverse momentum of the lepton from the W boson decay, E_T^{miss}, the cosine of the angle

TABLE I. Number of events for the expected signal, background, and data observed in the two signal regions with $p_T^{WZ} <$ 70 GeV and either $100 < p_T^Z \leq 200$ GeV or $p_T^Z > 200$ GeV. Contributions from W_0Z_0, W_0Z_T, W_TZ_0, and W_TZ_T processes are estimated from the MC simulation before the fit is performed. The uncertainties include both statistical and systematic contributions.

Process	$100 < p_T^Z \leq 200$ GeV	$p_T^Z > 200$ GeV
W_0Z_0	222 ± 5	47.6 ± 1.5
$W_0Z_T + W_TZ_0$	323 ± 12	23.7 ± 0.8
W_TZ_T	856 ± 31	124 ± 4
Prompt background	169 ± 18	24.1 ± 2.7
Nonprompt background	68 ± 29	2.8 ± 1.1
Total expected	1640 ± 60	222 ± 8
Data	1740	236

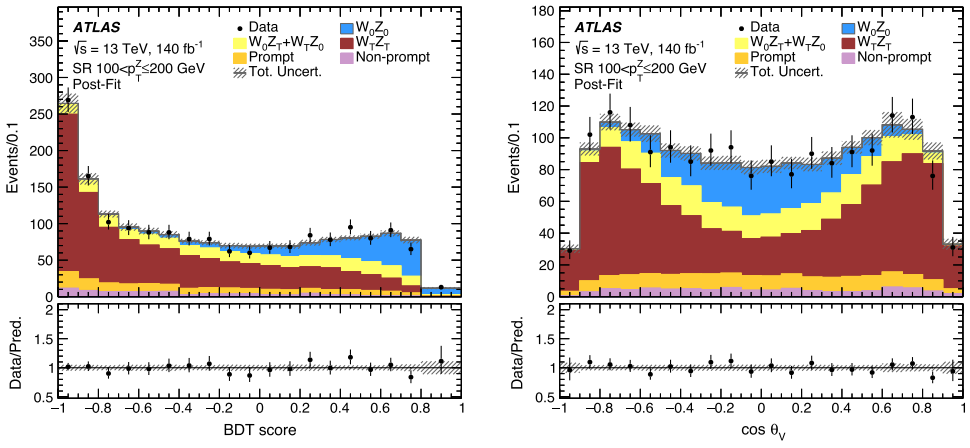

FIG. 2. The comparison between the data and the postfit SM predictions for (a) the BDT distribution and (b) the vector boson scattering angle $\cos\theta_V$ for the fiducial region with $100 < p_T^Z \leq 200$ GeV. The bottom panels show the ratios of the data to the postfit SM predictions. The uncertainty bands include both the MC statistical and systematic uncertainties.

between the direction of the lepton from the W decay in the W rest frame and the direction of the W boson in the WZ rest frame, and the cosine of the angle between the direction of the negatively charged lepton from the Z decay in the Z rest frame and the direction of the Z boson in the WZ rest frame.

Binned maximum-likelihood fits [73] are performed using the BDT score distributions in the two signal regions. Each source of systematic uncertainty is implemented in the likelihood function as a nuisance parameter with a Gaussian constraint. Three unconstrained parameters, f_{00}, f_{0T+T0}, and a signal strength modifier common to all three polarization templates, are used in the fit. The f_{0T} and f_{T0} contributions are merged into a single contribution f_{0T+T0} with the relative ratio according to the SM predictions, because they cannot be separated by our BDT. The fit includes the corrections for detector efficiency and acceptance effects, obtained from a comparison of particle-level and reconstruction-level Monte Carlo simulations. The BDT score distributions with background normalizations, signal normalization, and nuisance parameters adjusted by the profile-likelihood fit are shown in Fig. 2(a) for the fiducial region with $100 < p_T^Z \leq 200$ GeV. The comparison between the data and the postfit predictions is also shown for $\cos\theta_V$ in Fig. 2(b).

The postfit f_{00} and f_{0T+T0} parameters together with the expected and observed significances for f_{00} are detailed in Table II. For the region with $100 < p_T^Z \leq 200$ GeV, the observed (expected) significance is found to be $5.2(4.3)\sigma$. In addition, the implicit f_{TT} parameter is shown as determined by $f_{TT} = 1 - f_{00} - f_{0T+T0}$ alongside its uncertainty as determined by Gaussian error propagation. The values of the observed correlations between f_{00} and f_{0T+T0} as determined by the fits are -0.84 for the region with $100 < p_T^Z \leq 200$ GeV and -0.82 for the region with $p_T^Z > 200$ GeV.

The predicted fiducial polarization fractions listed in Table II are calculated at the particle level in a fiducial phase space chosen to closely follow the event selection criteria using the MADGRAPH0,1j@LO samples reweighted to include higher-order QCD effects and NLO electroweak corrections [42]. Prompt leptons are dressed by adding the four-momenta of nearby prompt photons within a small cone of $\Delta R < 0.1$. The distance between the two leptons from the Z boson decay is required to have $\Delta R(\ell_Z^-, \ell_Z^+) > 0.2$, and the distance between the negatively charged lepton from the Z boson decay and the charged lepton from the W boson decay is required to have $\Delta R(\ell_Z^-, \ell_W) > 0.3$. The dressed charged leptons are

TABLE II. Measured diboson polarization fractions in the two signal regions with $p_T^{WZ} < 70$ GeV and $100 < p_T^Z \leq 200$ GeV or $p_T^Z > 200$ GeV using three unconstrained parameters. The SM predicted fractions for all four polarization states are also shown.

	Measurement			Prediction	
	$100 < p_T^Z \leq 200$ GeV	$p_T^Z > 200$ GeV		$100 < p_T^Z \leq 200$ GeV	$p_T^Z > 200$ GeV
f_{00}	$0.19 \pm {}^{0.03}_{0.03}(\text{stat}) \pm {}^{0.02}_{0.02}(\text{syst})$	$0.13 \pm {}^{0.09}_{0.08}(\text{stat}) \pm {}^{0.02}_{0.02}(\text{syst})$	f_{00}	0.152 ± 0.006	0.234 ± 0.007
f_{0T+T0}	$0.18 \pm {}^{0.07}_{0.08}(\text{stat}) \pm {}^{0.05}_{0.06}(\text{syst})$	$0.23 \pm {}^{0.17}_{0.18}(\text{stat}) \pm {}^{0.06}_{0.10}(\text{syst})$	f_{0T}	0.120 ± 0.002	0.062 ± 0.002
f_{TT}	$0.63 \pm {}^{0.05}_{0.05}(\text{stat}) \pm {}^{0.04}_{0.04}(\text{syst})$	$0.64 \pm {}^{0.12}_{0.12}(\text{stat}) \pm {}^{0.06}_{0.06}(\text{syst})$	f_{T0}	0.109 ± 0.001	0.058 ± 0.001
f_{00} obs (exp) sig.	$5.2(4.3)\sigma$	$1.6(2.5)\sigma$	f_{TT}	0.619 ± 0.007	0.646 ± 0.008

required to have $|\eta| < 2.5$. Leptons from the $Z(W)$ boson decay are required to have $p_T > 15(20)$ GeV. The invariant mass of the two leptons from the Z decay is required to be within $|m_{\ell\ell} - m_Z| < 10$ GeV, and the transverse mass of the W boson is required to be $m_T^W > 30$ GeV. The WZ system is required to have $p_T^{WZ} < 70$ GeV, and either $100 < p_T^Z \leq 200$ GeV or $p_T^Z > 200$ GeV.

Another fit is performed using two unconstrained parameters, f_{00} and the total number of WZ events. The mixed f_{0T+T0} and doubly transversal f_{TT} contributions are combined into a single contribution (f_{XX}) defined as $f_{XX} = 1 - f_{00}$. The 00 fraction is found to be $f_{00} = 0.17 \pm {}^{0.02}_{0.02}(\text{stat}) \pm {}^{0.01}_{0.02}(\text{syst})$ for the region with $100 < p_T^Z \leq 200$ GeV and $0.16 \pm {}^{0.05}_{0.05}(\text{stat}) \pm {}^{0.02}_{0.03}(\text{syst})$ for the region with $p_T^Z > 200$ GeV. The corresponding observed (expected) significance for a nonzero f_{00} value is $7.7(6.9)\sigma$ for the first region and $3.2(4.2)\sigma$ for the second region. This fit results in better sensitivities for f_{00}; however, it may be less conservative as the ratio of f_{0T+T0} and f_{TT} is assumed to have the value predicted by the SM.

In summary, studies of the RAZ effect and the energy dependence of diboson polarization fractions in WZ production are presented in this Letter. The measurements use leptonic decay modes of the gauge bosons to electrons or muons. Significant dips are observed in the $\Delta Y(\ell_W Z)$ and $\Delta Y(WZ)$ distributions for inclusive TT events with different p_T^{WZ} cuts applied, indicating the presence of the RAZ effect in WZ production at the LHC. Unfolded $|\Delta Y(\ell_W Z)|$ and $|\Delta Y(WZ)|$ distributions are also measured and compared to theoretical predictions. Diboson polarization fractions are measured in two signal regions with enhanced longitudinal polarization for both bosons. The measured fractions are found to be consistent with the SM predictions. A nonzero fraction of events where both bosons are longitudinally polarized is measured with an observed significance of 5.2σ (1.6σ) in the phase space with $100 < p_T^Z \leq 200$ GeV ($p_T^Z > 200$ GeV).

Acknowledgments—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 worldwide, and large non-WLCG resource providers. Major contributors of computing resources are listed in Ref. [74]. 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; CERN-CZ, PRIMUS 21/SCI/017, and UNCE SCI/013, 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 programs cofinanced 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 1190886, FONDECYT 1210400, FONDECYT 1230812, FONDECYT 1230987); China: Chinese Ministry of Science and Technology (MOST-2023YFA1605700), National Natural Science Foundation of China (NSFC—12175119, NSFC 12275265, NSFC-12075060); Czech Republic: PRIMUS Research Programme (PRIMUS/21/SCI/017); EU: H2020 European Research Council (ERC—101002463); European Union: European Research Council (ERC—948254, ERC 101089007), Horizon 2020 Framework Programme (MUCCA—CHIST-ERA-19-XAI-00), European Union, Future Artificial Intelligence Research (FAIR-NextGenerationEU PE00000013), 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 JP21H05085,

JSPS KAKENHI JP22H01227, JSPS KAKENHI JP22H04944, JSPS KAKENHI JP22KK0227); 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); Slovenia: Slovenian Research Agency (ARIS Grant No. J1-3010); Spain: BBVA Foundation (LEO22-1-603), 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, RYC2021-031273-I, RYC2022-038164-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 Grant No. 2021-03651), Knut and Alice Wallenberg Foundation (KAW 2017.0100, 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: U.S. Department of Energy (ECA DE-AC02-76SF00515), Neubauer Family Foundation. We thank Duc Ninh Le, Da Liu, and Giovanni Pelliccioli for providing calculations with higher-order QCD and electroweak corrections in WZ production with different polarizations.

[1] R. Franceschini, G. Panico, A. Pomarol, F. Riva, and A. Wulzer, Electroweak precision tests in high-energy diboson processes, J. High Energy Phys. 02 (2018) 111.

[2] D. Liu and L.-T. Wang, Prospects for precision measurement of diboson processes in the semileptonic decay channel in future LHC runs, Phys. Rev. D **99**, 055001 (2019).

[3] S. Frixione, P. Nason, and G. Ridolfi, Strong corrections to WZ production at hadron colliders, Nucl. Phys. **B383**, 3 (1992).

[4] U. Baur, T. Han, and J. Ohnemus, Amplitude zeros in $W^{\pm}Z$ production, Phys. Rev. Lett. **72**, 3941 (1994).

[5] D0 Collaboration, First study of the radiation-amplitude zero in $W\gamma$ production and limits on anomalous $WW\gamma$ couplings at $\sqrt{s} = 1.96$ TeV, Phys. Rev. Lett. **100**, 241805 (2008).

[6] CMS Collaboration, Measurement of the $W\gamma$ and $Z\gamma$ inclusive cross sections in pp collisions at $\sqrt{s} = 7$ TeV and limits on anomalous triple gauge boson couplings, Phys. Rev. D **89**, 092005 (2014).

[7] CMS Collaboration, Measurement of $W^{\pm}\gamma$ differential cross sections in proton–proton collisions at $\sqrt{s} = 13$ TeV and effective field theory constraints, Phys. Rev. D **105**, 052003 (2022).

[8] R. Capdevilla, R. Harnik, and A. Martin, The radiation valley and exotic resonances in $W\gamma$ production at the LHC, J. High Energy Phys. 03 (2020) 117.

[9] C. L. Bilchak, R. W. Brown, and J. D. Stroughair, $W^{\pm}$ and Z^0 polarization in pair production: Dominant helicities, Phys. Rev. D **29**, 375 (1984).

[10] U. Baur, T. Han, and J. Ohnemus, WZ production at hadron colliders: Effects of nonstandard WWZ couplings and QCD corrections, Phys. Rev. D **51**, 3381 (1995).

[11] C. Frye, M. Freytsis, J. Scholtz, and M. J. Strassler, Precision diboson observables for the LHC, J. High Energy Phys. 03 (2016) 171.

[12] ATLAS Collaboration, Observation of gauge boson joint-polarisation states in $W^{\pm}Z$ production from pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, Phys. Lett. B **843**, 137895 (2023).

[13] S. S. D. Willenbrock, Pair production of W and Z bosons and the Goldstone boson equivalence theorem, Ann. Phys. (N.Y.) **186**, 15 (1988).

[14] L. Huang, S. D. Lane, I. M. Lewis, and Z. Liu, Electroweak restoration at the LHC and beyond: The Vh channel, Phys. Rev. D **103**, 053007 (2021).

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

[16] The ATLAS experiment uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the center of the detector. The x axis points from the IP to the center of the LHC ring, the y axis points upward, and the z axis is along one of the proton beam directions. Cylindrical coordinates (r, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the beam pipe. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln\tan(\theta/2)$. Transverse momentum ($p_T$) is defined relative to the beam axis and is calculated as $p_T = p\sin\theta$ where p is the momentum. The distance ΔR is defined as $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$.

[17] ATLAS Collaboration, Performance of the ATLAS trigger system in 2015, Eur. Phys. J. C **77**, 317 (2017).

[18] ATLAS Collaboration, Performance of electron and photon triggers in ATLAS during LHC Run 2, Eur. Phys. J. C **80**, 47 (2020).

[19] ATLAS Collaboration, Trigger menu in 2018, Report No. ATL-DAQ-PUB-2019-001, 2019, https://cds.cern.ch/record/2693402.

[20] ATLAS Collaboration, The ATLAS Collaboration software and firmware, Report No. ATL-SOFT-PUB-2021-001, 2021, https://cds.cern.ch/record/2767187.

[21] ATLAS Collaboration, Electron and photon performance measurements with the ATLAS detector using the 2015–2017 LHC proton–proton collision data, J. Instrum. **14**, P12006 (2019).

[22] 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**, 578 (2021).

[23] ATLAS Collaboration, Evidence for the associated production of the Higgs boson and a top quark pair with the ATLAS detector, Phys. Rev. D **97**, 072003 (2018).

[24] ATLAS Collaboration, Jet reconstruction and performance using particle flow with the ATLAS detector, Eur. Phys. J. C **77**, 466 (2017).

[25] 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**, 581 (2016).

[26] ATLAS Collaboration, Performance of missing transverse momentum reconstruction with the ATLAS detector using proton–proton collisions at $\sqrt{s} = 13$ TeV, Eur. Phys. J. C **78**, 903 (2018).

[27] ATLAS Collaboration, Evidence for the production of three massive vector bosons with the ATLAS detector, Phys. Lett. B **798**, 134913 (2019).

[28] P. Zyla *et al.* (Particle Data Group), Review of particle physics, Prog. Theor. Exp. Phys. **2020**, 083C01 (2020).

[29] ATLAS Collaboration, Measurement of $W^{\pm}Z$ production cross sections and gauge boson polarisation in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, Eur. Phys. J. C **79**, 535 (2019).

[30] S. Agostinelli *et al.*, GEANT4—A simulation toolkit, Nucl. Instrum. Methods Phys. Res., Sect. A **506**, 250 (2003).

[31] ATLAS Collaboration, The ATLAS simulation infrastructure, Eur. Phys. J. C **70**, 823 (2010).

[32] J. Ohnemus, Order-α_s calculation of hadronic $W^{\pm}$Z production, Phys. Rev. D **44**, 3477 (1991).

[33] A. Bierweiler, T. Kasprzik, and J. H. Kühn, Vector-boson pair production at the LHC to $\mathcal{O}(\alpha^3)$ accuracy, J. High Energy Phys. 12 (2013) 071.

[34] J. Baglio, L. D. Ninh, and M. M. Weber, Erratum: Massive gauge boson pair production at the LHC: A next-to-leading order story [Phys. Rev. D 88, 113005 (2013)], Phys. Rev. D **94**, 099902(E) (2016).

[35] B. Biedermann, A. Denner, and L. Hofer, Next-to-leading-order electroweak corrections to the production of three charged leptons plus missing energy at the LHC, J. High Energy Phys. 10 (2017) 043.

[36] M. Grazzini, S. Kallweit, D. Rathlev, and M. Wiesemann, $W^{\pm}Z$ production at hadron colliders in NNLO QCD, Phys. Lett. B **761**, 179 (2016).

[37] M. Grazzini, S. Kallweit, D. Rathlev, and M. Wiesemann, $W^{\pm}Z$ production at the LHC: Fiducial cross sections and distributions in NNLO QCD, J. High Energy Phys. 05 (2017) 139.

[38] M. Grazzini, S. Kallweit, J. M. Lindert, S. Pozzorini, and M. Wiesemann, NNLO QCD + NLO EW with Matrix + OpenLoops: Precise predictions for vector-boson pair production, J. High Energy Phys. 02 (2020) 087.

[39] A. Denner and G. Pelliccioli, NLO QCD predictions for doubly-polarized WZ production at the LHC, Phys. Lett. B **814**, 136107 (2021).

[40] G. Pelliccioli and G. Zanderighi, Polarised-boson pairs at the LHC with NLOPS accuracy, Eur. Phys. J. C **84**, 16 (2024).

[41] J. Baglio and L. D. Ninh, Fiducial polarization observables in hadronic WZ production: A next-to-leading order QCD + EW study, J. High Energy Phys. 04 (2019) 065.

[42] T. N. Dao and D. N. Le, Enhancing the doubly-longitudinal polarization in WZ production at the LHC, Commun. Phys. **33**, 223 (2023).

[43] D. B. Franzosi, O. Mattelaer, R. Ruiz, and S. Shil, Automated predictions from polarized matrix elements, J. High Energy Phys. 04 (2020) 082.

[44] T. Sjöstrand, S. Mrenna, and P. Skands, A brief introduction to PYTHIA8.1, Comput. Phys. Commun. **178**, 852 (2008).

[45] L. Lönnblad, Correcting the colour-dipole cascade model with fixed order matrix elements, J. High Energy Phys. 05 (2002) 046.

[46] R. D. Ball *et al.* (NNPDF Collaboration), Parton distributions with LHC data, Nucl. Phys. **B867**, 244 (2013).

[47] L. Dixon, Z. Kunszt, and A. Signer, Vector boson pair production in hadronic collisions at $O(\alpha_s)$: Lepton correlations and anomalous couplings, Phys. Rev. D **60**, 114037 (1999).

[48] J. M. Campbell and R. K. Ellis, Update on vector boson pair production at hadron colliders, Phys. Rev. D **60**, 113006 (1999).

[49] J. M. Campbell, R. K. Ellis, and C. Williams, Vector boson pair production at the LHC, J. High Energy Phys. 07 (2011) 018.

[50] E. Bothmann *et al.*, Event generation with SHERPA2.2, SciPost Phys. **7**, 034 (2019).

[51] M. Grazzini, S. Kallweit, and D. Rathlev, ZZ production at the LHC: Fiducial cross sections and distributions in NNLO QCD, Phys. Lett. B **750**, 407 (2015).

[52] T. Binoth, G. Ossola, C. G. Papadopoulos, and R. Pittau, NLO QCD corrections to tri-boson production, J. High Energy Phys. 06 (2008) 082.

[53] R. Frederix and I. Tsinikos, On improving NLO merging for ttW production, J. High Energy Phys. 11 (2021) 029.

[54] A. Denner, D. Lombardi, and G. Pelliccioli, Complete NLO corrections to off-shell ttZ production at the LHC, J. High Energy Phys. 09 (2023) 072.

[55] ATLAS Collaboration, Search for supersymmetry at $\sqrt{s} = 8$ TeV in final states with jets and two same-sign leptons or three leptons with the ATLAS detector, J. High Energy Phys. 06 (2014) 035.

[56] ATLAS Collaboration, Electron reconstruction and identification in the ATLAS experiment using the 2015 and 2016 LHC proton–proton collision data at $\sqrt{s} = 13$ TeV, Eur. Phys. J. C **79**, 639 (2019).

[57] ATLAS Collaboration, Electron and photon energy calibration with the ATLAS detector using 2015–2016 LHC proton–proton collision data, J. Instrum. **14**, P03017 (2019).

[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**, 689 (2021).

[59] ATLAS Collaboration, Tagging and suppression of pileup jets with the ATLAS detector, Report No. ATLAS-CONF-2014-018, 2014, https://cds.cern.ch/record/1700870.

[60] ATLAS Collaboration, Identification and rejection of pile-up jets at high pseudorapidity with the ATLAS detector, Eur. Phys. J. C **77**, 580 (2017); **77**, 712(E) (2017).

[61] ATLAS Collaboration, ATLAS b-jet identification performance and efficiency measurement with $t\bar{t}$ events in pp collisions at $\sqrt{s} = 13$ TeV, Eur. Phys. J. C **79**, 970 (2019).
[62] ATLAS Collaboration, Luminosity determination in pp collisions at $\sqrt{s} = 13$ TeV using the ATLAS detector at the LHC, Report No. ATLAS-CONF-2019-021, 2019, https://cds.cern.ch/record/2677054.
[63] G. Avoni *et al.*, The new LUCID-2 detector for luminosity measurement and monitoring in ATLAS, J. Instrum. **13**, P07017 (2018).
[64] ATLAS Collaboration, Multi-boson simulation for 13 TeV ATLAS analyses, Report No. ATL-PHYS-PUB-2016-002, 2016, https://cds.cern.ch/record/2119986.
[65] J. Butterworth *et al.*, PDF4LHC recommendations for LHC Run II, J. Phys. G **43**, 023001 (2016).
[66] ATLAS Collaboration, Observation of the associated production of a top quark and a Z boson in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, J. High Energy Phys. 07 (2020) 124.
[67] ATLAS Collaboration, Observation of electroweak production of a same-sign W boson pair in association with two jets in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, Phys. Rev. Lett. **123**, 161801 (2019).
[68] ATLAS Collaboration, Measurement of the $t\bar{t}Z$ and $t\bar{t}W$ cross sections in proton–proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, Phys. Rev. D **99**, 072009 (2019).
[69] ATLAS Collaboration, Evidence of pair production of longitudinally polarised vector bosons and study of CP properties in $ZZ \to 4\ell$ events with the ATLAS detector at $\sqrt{s} = 13$ TeV, J. High Energy Phys. 12 (2023) 107.
[70] G. D'Agostini, A multidimensional unfolding method based on Bayes' theorem, Nucl. Instrum. Methods Phys. Res., Sect. A **362**, 487 (1995).
[71] G. D'Agostini, Improved iterative Bayesian unfolding, arXiv:1010.0632.
[72] A. Hoecker *et al.*, TMVA—Toolkit for multivariate data analysis, arXiv:physics/0703039.
[73] K. Cranmer, G. Lewis, L. Moneta, A. Shibata, and W. Verkerke, HistFactory: A tool for creating statistical models for use with RooFit and RooStats, Report No. CERN-OPEN-2012-016, 2012, https://cds.cern.ch/record/1456844.
[74] ATLAS Collaboration, ATLAS computing acknowledgements, Report No. ATL-SOFT-PUB-2023-001, 2023, https://cds.cern.ch/record/2869272.

End Matter

Appendix—The unfolded distribution of the $\Delta Y(\ell_W Z)$ considering as signal the TT component for events with $p_T^{WZ} < 70$ GeV is shown in Fig. 3(a). A comparison between the measured and predicted $\mathcal{D}$ values using the $|\Delta Y(\ell_W Z)|$ distribution as a function of the p_T^{WZ} cut value used is shown in Fig. 3(b). Good agreement is observed between data and predictions for the unfolded distributions and the depth of the dip.

Unfolded $|\Delta Y(WZ)|$ and $|\Delta Y(\ell_W Z)|$ distributions for inclusive WZ events with $p_T^{WZ} < 20, 40$, or 70 GeV are also measured and compared to theoretical predictions. This alternative signal definition considers all polarization states together and avoids assumptions on the 00, $0T$, and $T0$ cross

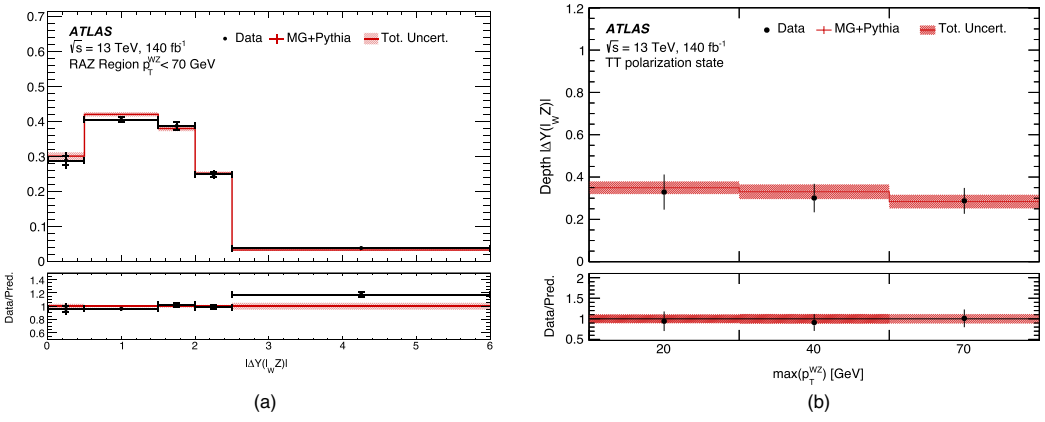

FIG. 3. (a) Comparison between the $00 + 0T + T0$-subtracted normalized unfolded $|\Delta Y(\ell_W Z)|$ data distribution and the SM prediction for TT events with $p_T^{WZ} < 70$ GeV; (b) The depth of the RAZ dip for the unfolded $|\Delta Y(\ell_W Z)|$ distribution of the TT polarization as a function of the p_T^{WZ} cut value used. The measured data are shown as black points, and the vertical error bars show the size of the total uncertainty, with tick marks used to reflect the size of the statistical uncertainty only. The MADGRAPH0,1j@LO prediction for the TT polarization state is shown in red.

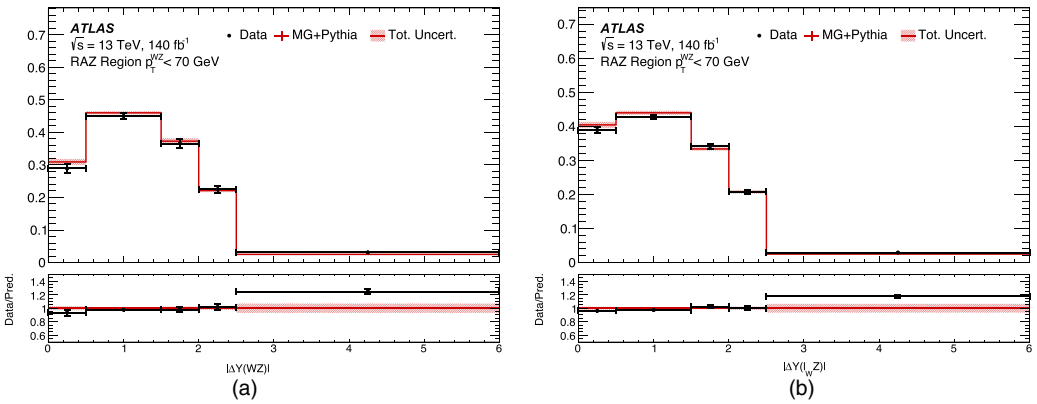

FIG. 4. Comparison between the unfolded (a) $|\Delta Y(WZ)|$ and (b) $|\Delta Y(\ell_W Z)|$ distributions and the SM prediction for inclusive WZ events with $p_T^{WZ} < 70$ GeV. The measured data are shown as black points with horizontal bars indicating the bin range and the vertical inner (outer) error bars representing the statistical (total) uncertainty. The MADGRAPH0,1j@LO prediction for the sum of all polarization states is shown in red.

sections. Figure 4 shows the comparison plots for events with $p_T^{WZ} < 70$ GeV. The uncertainties on the unfolded distributions are dominated by the data statistical uncertainty in all bins. In general, the SM predictions agree well with the measured normalized differential cross sections within the quoted uncertainties. The largest difference is observed in the last bin of the $|\Delta Y(WZ)|$ distribution reaching a local significance of 2.6 standard deviations.

G. Aad,[103] E. Aakvaag,[16] B. Abbott,[121] 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,b] 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,c] W. S. Ahmed,[105] S. Ahuja,[96] X. Ai,[62e] G. Aielli,[76a,76b] A. Aikot,[164] M. Ait Tamlihat,[35e] B. Aitbenchikh,[35a] I. Aizenberg,[170] 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,[142] B. Ali,[133] H. M. J. Ali,[92] S. Ali,[149] 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] 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,d] A. V. Anisenkov,[37] A. Annovi,[74a] C. Antel,[56] M. T. Anthony,[140] E. Antipov,[146] M. Antonelli,[53] F. Anulli,[75a] M. Aoki,[84] T. Aoki,[154] J. A. Aparisi Pozo,[164] 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,[115] 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,e] D. Babal,[28b] H. Bachacou,[136] K. Bachas,[153,f] 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] 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,g] 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,h] 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] M. Bhamjee,[33c] 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] C. J. Birch-sykes,[102] 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] 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] 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] C. D. Burton,[11] 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] F. Cardillo,[164] G. Carducci,[43b,43a] T. Carli,[36] G. Carlino,[72a] J. I. Carlotto,[13] B. T. Carlson,[130,i] 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,j] 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,k] 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,l] 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] 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,m] 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,n] A. Cortes-Gonzalez,[18] M. J. Costa,[164] F. Costanza,[4] D. Costanzo,[140] B. M. Cote,[120] 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] H. Cui,[14a,14e] 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] M. Danninger,[143] V. Dao,[36] G. Darbo,[57b] S. J. Das,[29,o] F. Dattola,[48] S. D'Auria,[71a,71b] A. D'avanzo,[72a,72b] C. David,[33a] T. Davidek,[134] B. Davis-Purcell,[34] 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] 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. M. Dona,[39] M. Donadelli,[83c] 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,[87] 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,[109] 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] 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] P. J. Falke,[24] F. Fallavollita,[111] 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,k] 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] F. Fiedler,[101] P. Fiedler,[133] A. Filipčič,[94] E. K. Filmer,[1] F. Filthaut,[114] M. C. N. Fiolhais,[131a,131c,p] 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,q] 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,r] 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] W. S. Freund,[83b] 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. 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,s] J. M. Gargan,[52] C. A. Garner,[156] C. M. Garvey,[33a] P. Gaspar,[83b] 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,e] M. P. Giordani,[69a,69c] P. F. Giraud,[136] G. Giugliarelli,[69a,69c] D. Giugni,[71a] F. Giuli,[36] I. Gkialas,[9,r] L. K. Gladilin,[37] C. Glasman,[100] G. R. Gledhill,[124] G. Glemža,[48] M. Glisic,[124] I. Gnesi,[43b,t] 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,131c] 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] 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,u] J.-F. Grivaz,[66] E. Gross,[170] J. Grosse-Knetter,[55] J. C. Grundy,[127] L. Guan,[107] C. Gubbels,[165] J. G. R. Guerrero Rojas,[164] G. Guerrieri,[69a,69c] F. Guescini,[111] 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,[48] R. Gupta,[130] S. Gurbuz,[24] S. S. Gurdasani,[54] G. Gustavino,[36] 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,a] C. Heidegger,[54] K. K. Heidegger,[54] W. D. Heidorn,[81] J. Heilman,[34] S. Heim,[48] T. Heim,[17a] J. G. Heinlein,[129] J. J. Heinrich,[124] L. Heinrich,[111,v] 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] 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. Hong,[62c] T. M. Hong,[130] B. H. Hooberman,[163] W. H. Hopkins,[6] 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] I. Ibragimov,[142] L. Iconomidou-Fayard,[66] J. P. Iddon,[36] P. Iengo,[72a,72b] R. Iguchi,[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,w] H. Ito,[169] R. Iuppa,[78a,78b] A. Ivina,[170] J. M. Izen,[45] V. Izzo,[72a] P. Jacka,[132,133] P. Jackson,[1] B. P. Jaeger,[143] C. S. Jagfeld,[110] G. Jain,[157a] P. Jain,[54] K. Jakobs,[54] T. Jakoubek,[170] J. Jamieson,[59] K. W. Janas,[86a] M. Javurkova,[104] L. Jeanty,[124] J. Jejelava,[150a,x] P. Jenni,[54,y] 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,u] M. K. Juzek,[87] S. Kabana,[138e] A. Kaczmarska,[87] M. Kado,[111] H. Kagan,[120] M. Kagan,[144] A. Kahn,[41] 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] I. Karkanias,[153] 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,a] Y. A. R. Khwaira,[66] B. Kibirige,[33g] A. Kilgallon,[124] 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] M. Kobel,[50] 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,z] 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,v] 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] 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,k] 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] I. K. Lakomiec,[86a] J. E. Lambert,[166] S. Lammers,[68] W. Lampl,[7] C. Lampoudis,[153,z] 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] A. Lapertosa,[57b,57a] 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,aa] 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,[62b] H. Li,[14c] H. Li,[14b] H. Li,[62b] J. Li,[62c] K. Li,[139] L. Li,[62c] M. Li,[14a,14e] Q. Y. Li,[62a] S. Li,[14a,14e] S. Li,[62d,62c,bb] 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] K. Lin,[108] R. E. Lindley,[7] J. H. Lindon,[2] E. Lipeles,[129] A. Lipniacka,[16] A. Lister,[165] J. D. Little,[4] B. Liu,[14a] B. X. Liu,[143] 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,a] J. D. Lomas,[20] J. D. Long,[163] I. Longarini,[160] L. Longo,[70a,70b] R. Longo,[163] I. Lopez Paz,[67] A. Lopez Solis,[48] N. Lorenzo Martinez,[4] A. M. Lory,[110] 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,a] 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] D. M. Mac Donell,[166] G. Maccarrone,[53] 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,cc] 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,aa] 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] T. A. Martin,[168] V. J. Martin,[52] B. Martin dit Latour,[16] L. Martinelli,[75a,75b] M. Martinez,[13,u] 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] G. Mchedlidze,[150b] R. P. Mckenzie,[33g] T. C. Mclachlan,[48] D. J. Mclaughlin,[97] S. J. McMahon,[135] C. M. Mcpartland,[93] R. A. McPherson,[166,n] 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] C. Merlassino,[69a,69c] L. Merola,[72a,72b] C. Meroni,[71a,71b] J. Metcalfe,[6] A. S. Mete,[6] 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,[54] P. Moskvitina,[114] J. Moss,[31,dd] 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,k] 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,o] E. Nagy,[103] A. M. Nairz,[36] Y. Nakahama,[84] K. Nakamura,[84] K. Nakkalil,[5] H. Nanjo,[125] R. Narayan,[44] E. A. Narayanan,[113] I. Naryshkin,[37] 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,ee] M. S. Neubauer,[163] F. Neuhaus,[101] J. Neundorf,[48] R. Newhouse,[165] 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,k] I. Nikolic-Audit,[128] K. Nikolopoulos,[20] P. Nilsson,[29] I. Ninca,[48] H. R. Nindhito,[56] G. Ninio,[152] A. Nisati,[75a] N. Nishu,[2] R. Nisius,[111] J-E. Nitschke,[50] E. K. Nkadimeng,[33g] T. Nobe,[154] D. L. Noel,[32] T. Nommensen,[148] M. B. Norfolk,[140] R. R. B. Norisam,[97] B. J. Norman,[34] M. Noury,[35a] J. Novak,[94] T. Novak,[48] 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,ff] 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] 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] V. O'Shea,[59] 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] K. Y. Oyulmaz,[21a] 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,[96] 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,[152] 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,o] E. Perez Codina,[157a] M. Perganti,[10] H. Pernegger,[36] 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,z] T. Petru,[134] A. Petrukhin,[142] M. Pettee,[17a] N. E. Pettersson,[36] 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,[101,136] 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. Plesanovs,[54] 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] 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,[1] 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. 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] 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] 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,n] 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] K. Rybacki,[92] 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,z] 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] D. P. C. Sankey,[135] T. Sano,[88] A. Sansoni,[53] L. Santi,[75a,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] F. Sauerburger,[54] E. Sauvan,[4] P. Savard,[156,e] R. Sawada,[154] C. Sawyer,[135] L. Sawyer,[98] I. Sayago Galvan,[164] 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] F. Schenck,[18] M. Schernau,[160] C. Scheulen,[55] C. Schiavi,[57b,57a] M. Schioppa,[43b,43a] B. Schlag,[144,s] 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,[101] 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] P. Seema,[18] 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] L. Serkin,[69a,69b] 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] A. Shcherbakova,[37] 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,gg] J. Shlomi,[170] M. J. Shochet,[39] J. Shojaii,[106] D. R. Shope,[126] B. Shrestha,[121] S. Shrestha,[120,hh] E. M. Shrif,[33g] 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] 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,k] 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,n] 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,[107] 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,ff] 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,ii] G. N. Taylor,[106] W. Taylor,[157b] A. S. Tee,[171] 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,n] 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] Y. Tian,[55] V. Tikhomirov,[37,k] Yu. A. Tikhonov,[37] S. Timoshenko,[37] D. Timoshyn,[134] E. X. L. Ting,[1] P. Tipton,[173] 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,s] 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] A. Traeet,[16] 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,z] P. V. Tsiareshka,[37] S. Tsigaridas,[157a] A. Tsirigotis,[153,aa] 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,jj] P. M. Tuts,[41] S. Tzamarias,[153,z] 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. Urquijo,[106] 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,[126] 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] R. Vavricka,[101] F. Vazeille,[40] 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,e] A. Vgenopoulos,[153,z] 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] R.-J. Wang,[101] 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] M. Weirich,[101] 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,v] T. R. Wyatt,[102] B. M. Wynne,[52] S. Xella,[42] L. Xia,[14c] M. Xia,[14b] J. Xiang,[64c] M. Xie,[62a] X. 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,[44] T. Zhang,[154] X. Zhang,[62c] X. Zhang,[62b] Y. Zhang,[62c,5] Y. Zhang,[97] Y. Zhang,[14c] Z. Zhang,[17a] 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,[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] and L. Zwalinski[36]

(ATLAS Collaboration)

[1]*Department of Physics, University of Adelaide, Adelaide, Australia*
[2]*Department of Physics, University of Alberta, Edmonton, Alberta, Canada*
[3a]*Department of Physics, Ankara University, Ankara, Türkiye*
[3b]*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, Illinois, USA*
[7]*Department of Physics, University of Arizona, Tucson, Arizona, USA*
[8]*Department of Physics, University of Texas at Arlington, Arlington, Texas, USA*
[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, Texas, USA*
[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*
[14a]*Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China*
[14b]*Physics Department, Tsinghua University, Beijing, China*
[14c]*Department of Physics, Nanjing University, Nanjing, China*
[14d]*School of Science, Shenzhen Campus of Sun Yat-sen University, China*
[14e]*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*
[17a]*Physics Division, Lawrence Berkeley National Laboratory, Berkeley, California, USA*
[17b]*University of California, Berkeley, California, USA*
[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
[21a]Department of Physics, Bogazici University, Istanbul, Türkiye
[21b]Department of Physics Engineering, Gaziantep University, Gaziantep, Türkiye
[21c]Department of Physics, Istanbul University, Istanbul, Türkiye
[22a]Facultad de Ciencias y Centro de Investigaciónes, Universidad Antonio Nariño, Bogotá, Colombia
[22b]Departamento de Física, Universidad Nacional de Colombia, Bogotá, Colombia
[23a]Dipartimento di Fisica e Astronomia A. Righi, Università di Bologna, Bologna, Italy
[23b]INFN Sezione di Bologna, Italy
[24]Physikalisches Institut, Universität Bonn, Bonn, Germany
[25]Department of Physics, Boston University, Boston, Massachusetts, USA
[26]Department of Physics, Brandeis University, Waltham, Massachusetts, USA
[27a]Transilvania University of Brasov, Brasov, Romania
[27b]Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest, Romania
[27c]Department of Physics, Alexandru Ioan Cuza University of Iasi, Iasi, Romania
[27d]National Institute for Research and Development of Isotopic and Molecular Technologies, Physics Department, Cluj-Napoca, Romania
[27e]National University of Science and Technology Politechnica, Bucharest, Romania
[27f]West University in Timisoara, Timisoara, Romania
[27g]Faculty of Physics, University of Bucharest, Bucharest, Romania
[28a]Faculty of Mathematics, Physics and Informatics, Comenius University, Bratislava, Slovak Republic
[28b]Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice, Slovak Republic
[29]Physics Department, Brookhaven National Laboratory, Upton, New York, USA
[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, California, USA
[32]Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom
[33a]Department of Physics, University of Cape Town, Cape Town, South Africa
[33b]iThemba Labs, Western Cape, South Africa
[33c]Department of Mechanical Engineering Science, University of Johannesburg, Johannesburg, South Africa
[33d]National Institute of Physics, University of the Philippines Diliman (Philippines), Philippines
[33e]University of South Africa, Department of Physics, Pretoria, South Africa
[33f]University of Zululand, KwaDlangezwa, South Africa
[33g]School of Physics, University of the Witwatersrand, Johannesburg, South Africa
[34]Department of Physics, Carleton University, Ottawa, Ontario, Canada
[35a]Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies—Université Hassan II, Casablanca, Morocco
[35b]Faculté des Sciences, Université Ibn-Tofail, Kénitra, Morocco
[35c]Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA-Marrakech, Morocco
[35d]LPMR, Faculté des Sciences, Université Mohamed Premier, Oujda, Morocco
[35e]Faculté des sciences, Université Mohammed V, Rabat, Morocco
[35f]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, Illinois, USA
[40]LPC, Université Clermont Auvergne, CNRS/IN2P3, Clermont-Ferrand, France
[41]Nevis Laboratory, Columbia University, Irvington, New York, USA
[42]Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark
[43a]Dipartimento di Fisica, Università della Calabria, Rende, Italy
[43b]INFN Gruppo Collegato di Cosenza, Laboratori Nazionali di Frascati, Italy
[44]Physics Department, Southern Methodist University, Dallas, Texas, USA
[45]Physics Department, University of Texas at Dallas, Richardson, Texas, USA
[46]National Centre for Scientific Research "Demokritos", Agia Paraskevi, Greece
[47a]Department of Physics, Stockholm University, Sweden
[47b]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, North Carolina, USA

[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
[57a]Dipartimento di Fisica, Università di Genova, Genova, Italy
[57b]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, Massachusetts, USA
[62a]Department of Modern Physics and State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei, China
[62b]Institute of Frontier and Interdisciplinary Science and Key Laboratory of Particle Physics and Particle Irradiation (MOE), Shandong University, Qingdao, China
[62c]School of Physics and Astronomy, Shanghai Jiao Tong University, Key Laboratory for Particle Astrophysics and Cosmology (MOE), SKLPPC, Shanghai, China
[62d]Tsung-Dao Lee Institute, Shanghai, China
[62e]School of Physics and Microelectronics, Zhengzhou University, China
[63a]Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany
[63b]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany
[64a]Department of Physics, Chinese University of Hong Kong, Shatin, N.T., Hong Kong, China
[64b]Department of Physics, University of Hong Kong, Hong Kong, China
[64c]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, Indiana, USA
[69a]INFN Gruppo Collegato di Udine, Sezione di Trieste, Udine, Italy
[69b]ICTP, Trieste, Italy
[69c]Dipartimento Politecnico di Ingegneria e Architettura, Università di Udine, Udine, Italy
[70a]INFN Sezione di Lecce, Italy
[70b]Dipartimento di Matematica e Fisica, Università del Salento, Lecce, Italy
[71a]INFN Sezione di Milano, Italy
[71b]Dipartimento di Fisica, Università di Milano, Milano, Italy
[72a]INFN Sezione di Napoli, Italy
[72b]Dipartimento di Fisica, Università di Napoli, Napoli, Italy
[73a]INFN Sezione di Pavia, Italy
[73b]Dipartimento di Fisica, Università di Pavia, Pavia, Italy
[74a]INFN Sezione di Pisa, Italy
[74b]Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy
[75a]INFN Sezione di Roma, Italy
[75b]Dipartimento di Fisica, Sapienza Università di Roma, Roma, Italy
[76a]INFN Sezione di Roma Tor Vergata, Italy
[76b]Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy
[77a]INFN Sezione di Roma Tre, Italy
[77b]Dipartimento di Matematica e Fisica, Università Roma Tre, Roma, Italy
[78a]INFN-TIFPA, Italy
[78b]Università degli Studi di Trento, Trento, Italy
[79]Universität Innsbruck, Department of Astro and Particle Physics, Innsbruck, Austria
[80]University of Iowa, Iowa City, Iowa, USA
[81]Department of Physics and Astronomy, Iowa State University, Ames, Iowa, USA
[82]Istinye University, Sariyer, Istanbul, Türkiye
[83a]Departamento de Engenharia Elétrica, Universidade Federal de Juiz de Fora (UFJF), Juiz de Fora, Brazil
[83b]Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro, Brazil
[83c]Instituto de Física, Universidade de São Paulo, São Paulo, Brazil
[83d]Rio de Janeiro State University, Rio de Janeiro, Brazil
[83e]Federal University of Bahia, Bahia, Brazil

[84]KEK, High Energy Accelerator Research Organization, Tsukuba, Japan
[85]Graduate School of Science, Kobe University, Kobe, Japan
[86a]AGH University of Krakow, Faculty of Physics and Applied Computer Science, Krakow, Poland
[86b]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, Louisiana, USA
[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, Massachusetts, USA
[105]Department of Physics, McGill University, Montreal, Quebec, Canada
[106]School of Physics, University of Melbourne, Victoria, Australia
[107]Department of Physics, University of Michigan, Ann Arbor, Michigan, USA
[108]Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan, USA
[109]Group of Particle Physics, University of Montreal, Montreal, Quebec, 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, New Mexico, USA
[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, Illinois, USA
[117a]New York University Abu Dhabi, Abu Dhabi, United Arab Emirates
[117b]United Arab Emirates University, Al Ain, United Arab Emirates
[118]Department of Physics, New York University, New York, New York, USA
[119]Ochanomizu University, Otsuka, Bunkyo-ku, Tokyo, Japan
[120]Ohio State University, Columbus, Ohio, USA
[121]Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman, Oklahoma, USA
[122]Department of Physics, Oklahoma State University, Stillwater, Oklahoma, USA
[123]Palacký University, Joint Laboratory of Optics, Olomouc, Czech Republic
[124]Institute for Fundamental Science, University of Oregon, Eugene, Oregon, USA
[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, Pennsylvania, USA
[130]Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, Pennsylvania, USA
[131a]Laboratório de Instrumentação e Física Experimental de Partículas—LIP, Lisboa, Portugal
[131b]Departamento de Física, Faculdade de Ciências, Universidade de Lisboa, Lisboa, Portugal
[131c]Departamento de Física, Universidade de Coimbra, Coimbra, Portugal
[131d]Centro de Física Nuclear da Universidade de Lisboa, Lisboa, Portugal
[131e]Departamento de Física, Universidade do Minho, Braga, Portugal
[131f]Departamento de Física Teórica y del Cosmos, Universidad de Granada, Granada (Spain), Spain
[131g]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, California, USA
[138a]Departamento de Física, Pontificia Universidad Católica de Chile, Santiago, Chile
[138b]Millennium Institute for Subatomic physics at high energy frontier (SAPHIR), Santiago, Chile
[138c]Instituto de Investigación Multidisciplinario en Ciencia y Tecnología, y Departamento de Física, Universidad de La Serena, Chile
[138d]Universidad Andres Bello, Department of Physics, Santiago, Chile
[138e]Instituto de Alta Investigación, Universidad de Tarapacá, Arica, Chile
[138f]Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile
[139]Department of Physics, University of Washington, Seattle, Washington, USA
[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, British Columbia, Canada
[144]SLAC National Accelerator Laboratory, Stanford, California, USA
[145]Department of Physics, Royal Institute of Technology, Stockholm, Sweden
[146]Departments of Physics and Astronomy, Stony Brook University, Stony Brook, New York, USA
[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
[150a]E. Andronikashvili Institute of Physics, Iv. Javakhishvili Tbilisi State University, Tbilisi, Georgia
[150b]High Energy Physics Institute, Tbilisi State University, Tbilisi, Georgia
[150c]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, Ontario, Canada
[157a]TRIUMF, Vancouver, British Columbia, Canada
[157b]Department of Physics and Astronomy, York University, Toronto, Ontario, 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, Massachusetts, USA
[160]Department of Physics and Astronomy, University of California Irvine, Irvine, California, USA
[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, Illinois, USA
[164]Instituto de Física Corpuscular (IFIC), Centro Mixto Universidad de Valencia—CSIC, Valencia, Spain
[165]Department of Physics, University of British Columbia, Vancouver, British Columbia, Canada
[166]Department of Physics and Astronomy, University of Victoria, Victoria, British Columbia, 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, Wisconsin, USA
[172]Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal, Germany
[173]Department of Physics, Yale University, New Haven, Connecticut, USA

[a]Deceased.
[b]Also at Department of Physics, King's College London, London, United Kingdom.
[c]Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan.
[d]Also at Lawrence Livermore National Laboratory, Livermore, USA.
[e]Also at TRIUMF, Vancouver, British Columbia, Canada.
[f]Also at Department of Physics, University of Thessaly, Greece.
[g]Also at An-Najah National University, Nablus, Palestine.
[h]Also at Department of Physics, University of Fribourg, Fribourg, Switzerland.
[i]Also at Department of Physics, Westmont College, Santa Barbara, USA.
[j]Also at Departament de Fisica de la Universitat Autonoma de Barcelona, Barcelona, Spain.

[k]Also at Affiliated with an institute covered by a cooperation agreement with CERN.
[l]Also at The Collaborative Innovation Center of Quantum Matter (CICQM), Beijing, China.
[m]Also at Università di Napoli Parthenope, Napoli, Italy.
[n]Also at Institute of Particle Physics (IPP), Canada.
[o]Also at Department of Physics, University of Colorado Boulder, Colorado, USA.
[p]Also at Borough of Manhattan Community College, City University of New York, New York, New York, USA.
[q]Also at National Institute of Physics, University of the Philippines, Diliman, Quezon City, Philippines.
[r]Also at Department of Financial and Management Engineering, University of the Aegean, Chios, Greece.
[s]Also at Department of Physics, Stanford University, Stanford, California, USA.
[t]Also at Centro Studi e Ricerche Enrico Fermi, Italy.
[u]Also at Institucio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona, Spain.
[v]Also at Technical University of Munich, Munich, Germany.
[w]Also at Physics Department, Yeditepe University, Istanbul, Türkiye.
[x]Also at Institute of Theoretical Physics, Ilia State University, Tbilisi, Georgia.
[y]Also at CERN, Geneva, Switzerland.
[z]Also at Center for Interdisciplinary Research and Innovation (CIRI-AUTH), Thessaloniki, Greece.
[aa]Also at Hellenic Open University, Patras, Greece.
[bb]Also at Center for High Energy Physics, Peking University, China.
[cc]Also at Department of Physics, Stellenbosch University, South Africa.
[dd]Also at Department of Physics, California State University, Sacramento, USA.
[ee]Also at Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève, Switzerland.
[ff]Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany.
[gg]Also at Institute for Nuclear Research and Nuclear Energy (INRNE) of the Bulgarian Academy of Sciences, Sofia, Bulgaria.
[hh]Also at Washington College, Chestertown, Maryland, USA.
[ii]Also at Institute of Applied Physics, Mohammed VI Polytechnic University, Ben Guerir, Morocco.
[jj]Also at Institute of Physics and Technology, Mongolian Academy of Sciences, Ulaanbaatar, Mongolia.