Article:

Aad, G. orcid.org/0000-0002-6665-4934, Abbott, B. orcid.org/0000-0002-5888-2734, Abeling, K. orcid.org/0000-0002-1002-1652 et al. (2928 more authors) (2024) Observation of WZγ Production in pp Collisions at √s=13 TeV with the ATLAS Detector. Physical Review Letters, 132 (2). 021802. ISSN 0031-9007

https://doi.org/10.1103/physrevlett.132.021802

Observation of $WZ\gamma$ Production in pp Collisions at $\sqrt{s} = 13$ TeV with the ATLAS Detector

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

(Received 29 May 2023; revised 30 September 2023; accepted 8 November 2023; published 12 January 2024)

This Letter reports the observation of $WZ\gamma$ production and a measurement of its cross section using $140.1 \pm 1.2\ \mathrm{fb}^{-1}$ of proton-proton collision data recorded at a center-of-mass energy of 13 TeV by the ATLAS detector at the Large Hadron Collider. The $WZ\gamma$ production cross section, with both the W and Z bosons decaying leptonically, $pp \to WZ\gamma \to \ell'^{\pm}\nu\ell^{+}\ell^{-}\gamma$ ($\ell^{(\prime)} = e, \mu$), is measured in a fiducial phase-space region defined such that the leptons and the photon have high transverse momentum and the photon is isolated. The cross section is found to be $2.01 \pm 0.30(\mathrm{stat}) \pm 0.16(\mathrm{syst})$ fb. The corresponding standard model predicted cross section calculated at next-to-leading order in perturbative quantum chromodynamics and at leading order in the electroweak coupling constant is 1.50 ± 0.06 fb. The observed significance of the $WZ\gamma$ signal is 6.3σ, compared with an expected significance of 5.0σ.

DOI: 10.1103/PhysRevLett.132.021802

Electroweak (EW) production of triboson states, $V\gamma\gamma$, $VV\gamma$, and VVV ($V = W$ or Z), in high-energy proton-proton (pp) collisions provides one of the primary means to probe the quartic interactions between EW gauge bosons and to carry out indirect searches for physics beyond the standard model (SM). Although such studies are experimentally challenging because of the small cross sections involved and the presence of significant background contributions, the ATLAS and CMS experiments at the Large Hadron Collider (LHC) have observed some of the relevant channels. The ATLAS and CMS collaborations have observed $Z\gamma\gamma$ production at pp center-of-mass energies $\sqrt{s}$ of 8 and 13 TeV [1–4], while $W\gamma\gamma$ production has recently been observed by ATLAS at $\sqrt{s} = 13$ TeV [5]. The combined production of three massive gauge bosons, VVV, has been observed at $\sqrt{s} = 13$ TeV by CMS [6], and the observation of WWW production was reported by ATLAS [7], also at $\sqrt{s} = 13$ TeV. Recently, $WW\gamma$ production has been observed by CMS at $\sqrt{s} = 13$ TeV [8]. No evidence for $WZ\gamma$ or $ZZ\gamma$ production has yet been obtained. For these channels, only upper limits of approximately 2–4 times the predicted SM cross section on the combined production of the $WW\gamma$ and $WZ\gamma$ triboson states at $\sqrt{s} = 8$ TeV have been reported by the ATLAS [9] and CMS [10] Collaboration.

This Letter reports the observation of $WZ\gamma$ production in pp collisions with both the W and the Z boson decaying leptonically, $pp \to WZ\gamma \to \ell'^{\pm}\nu\ell^{+}\ell^{-}\gamma$, where ℓ' and ℓ are an electron or a muon, using $140.1 \pm 1.2\ \mathrm{fb}^{-1}$ [11,12] of data at $\sqrt{s} = 13$ TeV recorded with the ATLAS detector. The $\ell'^{\pm}\nu\ell^{+}\ell^{-}\gamma$ production cross section is measured in a fiducial phase-space region defined such that the leptons and the photon have high transverse momentum and the photon is isolated, and including kinematic requirements that enhance the relative contribution from processes where the photon is produced directly in the initial hard-scattering interaction, as illustrated in Figs. 1(a)–1(c), including the quartic interaction contribution of primary interest of Fig. 1(b), rather than being radiated from a final-state charged lepton (final-state radiation, FSR), as illustrated in Figs. 1(d)–1(e).

The ATLAS experiment [13] at the LHC is a multipurpose particle detector with a forward-backward symmetric cylindrical geometry covering nearly the entire solid angle around the collision point [14]. Its major components are an inner tracking detector (ID) surrounded by a thin superconducting solenoid providing a 2 T axial magnetic field, electromagnetic (ECAL) and hadron (HCAL) calorimeters, and a muon spectrometer (MS). A two-level trigger system is used to select events for storage. Events used in this analysis were selected online by single-electron or single-muon triggers. An extensive software suite [15] is used in data simulation, in the reconstruction and analysis of real and simulated data, in detector operations, and in the trigger and data acquisition systems of the experiment.

The energy of photon and electron candidates is reconstructed from deposits in topologically connected ECAL cells, and calibrated using information about charged-particle tracks reconstructed in the ID [16]. Photon (electron) energy clusters are required to have a pseudorapidity in the range $|\eta| < 2.37$ ($|\eta| < 2.47$), excluding the transition region $1.37 < |\eta| < 1.52$ between the ECAL barrel

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

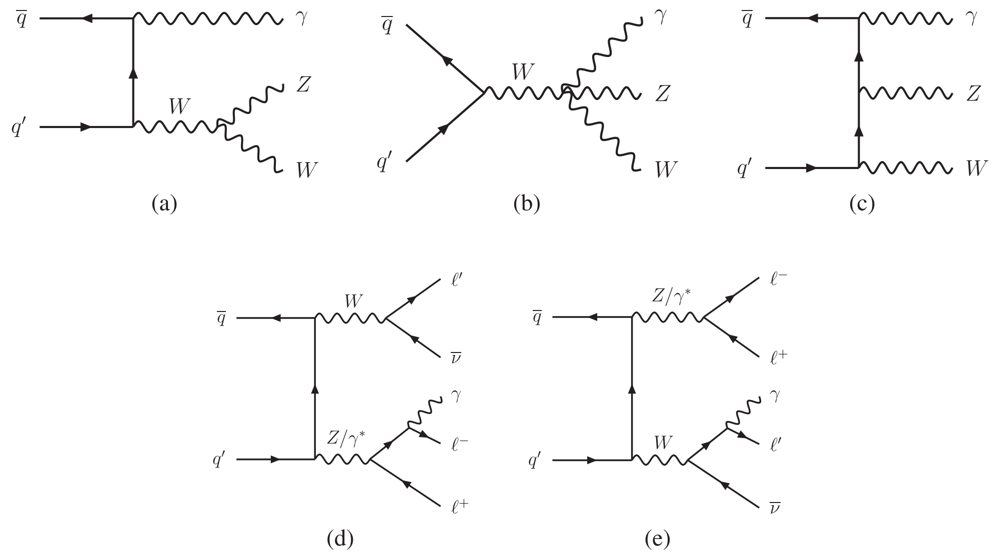

FIG. 1. Representative leading-order Feynman diagrams for (a)–(c) $WZ\gamma$ production and (d),(e) $\ell'^{\pm}\nu\ell^+\ell^-\gamma$ production via the FSR processes $Z \to \ell^+\ell^-\gamma$ and $W \to \ell'\nu\gamma$.

and end caps. Muon candidates are reconstructed [17] from tracks in the MS that are matched to a corresponding track in the ID, and their pseudorapidity must satisfy $|\eta| < 2.5$. Lepton candidates must originate from the primary vertex [18] and are selected by requiring $|d_0|/\sigma_{d_0} < 5.0(3.0)$ for electrons (muons) and $|z_0 \sin(\theta)| < 0.5$ mm for both lepton flavors, where d_0 and σ_{d_0} are the track's transverse impact parameter and its uncertainty, z_0 is the longitudinal impact parameter, and θ is the polar angle of the track's direction. The shower shapes produced in the ECAL and HCAL along with the track information are used to identify photons and electrons. Photon shower shapes must satisfy the "tight" photon identification criteria of Ref. [16]. Signal electrons must satisfy the tight likelihood identification criteria of Ref. [16], while signal muons must satisfy the "medium" identification criteria of Ref. [17]. Photon, electron, and muon candidates are required to be isolated from other particles. The isolation criteria limit the summed transverse momenta of tracks and the summed transverse energies of topological clusters [19] that are allowed in separately defined conical regions around the direction of the photon or lepton. Photon and electron candidates must satisfy the "loose" and "gradient" isolation criteria of Ref. [16], respectively. Muon candidates must satisfy the "PflowTight" isolation criteria of Ref. [17].

The neutrino's transverse momentum (p_{T}) is estimated from the missing transverse momentum in the event $E_{\mathrm{T}}^{\mathrm{miss}}$, calculated as the magnitude of the negative vector sum of the transverse momenta of all identified high-p_{T} physics objects, together with the contribution from an additional "soft term," which is calculated from ID tracks matched to the primary vertex, but not assigned to any of the high-p_{T} objects [20].

The $WZ\gamma$ signal region (SR) is defined by requiring an e^+e^- or $\mu^+\mu^-$ pair together with an additional $e^{\pm}$ or $\mu^{\pm}$ and at least one photon. The three selected leptons must satisfy $p_{\mathrm{T}}^{\ell} > 20$ GeV, and at least one lepton must have $p_{\mathrm{T}}^{\ell} > 30$ GeV. At least one of the electrons or muons must be matched to the trigger-level electron or muon that triggered the event. The highest-p_{T} photon in the event is taken as the signal photon and must have $p_{\mathrm{T}}^{\gamma} > 15$ GeV. The event is required to have $E_{\mathrm{T}}^{\mathrm{miss}} > 20$ GeV. To reduce the background from $ZZ\gamma$ production, the event must not contain additional leptons with $p_{\mathrm{T}}^{\ell} > 10$ GeV satisfying the medium [16,17] requirement for electron and muon identification and the PflowLoose [17] requirement for muon isolation. For the $e^+\nu_e\mu^+\mu^-\gamma$ and $\mu^+\nu_\mu e^+e^-\gamma$ final states, the leptons forming the $\mu^+\mu^-$ or e^+e^- pair, respectively, are referred to as "Z leptons." For the $e^{\pm}\nu_e e^+e^-\gamma$ and $\mu^{\pm}\nu_\mu\mu^+\mu^-\gamma$ final states, the leptons forming the $\ell^+\ell^-$ pair with invariant mass closest to the nominal Z boson mass [21], m_Z, are assigned as the Z leptons. The third lepton remaining after assigning the Z-lepton pair is called the "W lepton." If the W lepton is an electron, the invariant mass of the W lepton and the photon, $m(e_W, \gamma)$, is required to satisfy $|m(e_W, \gamma) - m_Z| > 10$ GeV to reduce the number of ZZ events where one of the Z bosons decays into an e^+e^- pair and either the e^+ or the e^- is misidentified as a photon. The angular separation $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$ between each lepton and the photon is required to satisfy $\Delta R(\ell, \gamma) > 0.4$. This ensures reliable reconstruction of the lepton and the photon and also reduces the contribution from radiative decay (FSR) of the W boson ($W \to \ell^{\pm}\nu\gamma$) and Z boson ($Z \to \ell^+\ell^-\gamma$). The contribution from events where the photon is produced from FSR of the Z boson is further reduced by requiring the invariant mass $m_{\ell\ell}$ of the Z-lepton pair to exceed 81 GeV.

The expected signal contribution to the selected event sample is obtained using a sample of inclusive $\ell'^{\pm}\nu\ell^+\ell^-\gamma$

signal events with invariant mass of the same-flavor opposite-charge (SFOC) lepton-pair greater than 20 GeV and with the lepton-neutrino pair's invariant mass exceeding 2 GeV, generated by SHERPA2.2.11 [22] with the NNPDF3.0 NNLO [23] parton distribution function (PDF) set. Matrix elements including all diagrams with three electroweak couplings were calculated with zero parton emissions at next-to-leading order (NLO), or with one or two partons at leading order (LO) in QCD, and at LO in the EW coupling constant and merged with the SHERPA parton shower [24] (PS) according to the CKKW procedure [25]. Photons radiated from the initial- and final-state charged particles were also generated, with a minimum photon energy requirement of 7 GeV at parton level in the matrix element calculation.

The dominant backgrounds originate from processes with a nonprompt lepton or photon from a hadron decay or a jet misidentified as a prompt lepton or photon, e.g., $Z(\to \ell^+\ell^-)\gamma + X$, $t\bar{t}\gamma$, $WZ + X$, and $ZZ(\to \ell'^+\ell'^-\ell^+\ell^-) + X$. Such backgrounds are referred to as nonprompt backgrounds and estimated using data-driven techniques based on selecting event samples containing a loose lepton and/or a loose photon among the selected signal leptons and photon, so as to be enriched in lepton- and/or photonlike jets. Loose electrons must satisfy the medium likelihood identification requirement of Ref. [16] and fail the tight identification or gradient isolation requirements. Loose muons must be nonisolated and/or be matched more loosely ($3.0 < |d_0|/\sigma_{d_0} < 10.0$) than signal muons to the primary vertex. Loose photons must fail to meet either the loose isolation or the tight identification criteria but satisfy looser ones. The number of nonprompt background events $N^{\text{nonprompt}}$ in the SR is estimated as

$$N^{\text{nonprompt}} = \sum_i F_i^\ell (N_{\text{B},i}^{\text{data}} - N_{\text{B},i}^{\text{prompt}}) + \sum_j F_j^\gamma (N_{\text{C},j}^{\text{data}} - N_{\text{C},j}^{\text{prompt}}) - \sum_{i,j} F_i^\ell F_j^\gamma (N_{\text{D},i,j}^{\text{data}} - N_{\text{D},i,j}^{\text{prompt}}),$$

where F_i^ℓ (F_j^γ) is a "fake factor" defined as the ratio of the probability that a leptonlike (photonlike) jet meets the signal selection criteria to the probability that it meets the loose selection criteria, determined in bin i (j) of the loose lepton (photon) p_T; subscripts B, C, and D represent regions where events are selected with the same set of criteria as the SR but with one loose lepton, one loose photon, or one loose lepton and one loose photon, respectively; $N_{\text{X},i(j)}^{\text{data}}$ and $N_{\text{X},i(j)}^{\text{prompt}}$ represent the yields of data and of processes with prompt leptons and photons, i.e., $WZ\gamma$, $ZZ\gamma$, $ZZ(e \to \gamma)$, $Z\gamma\gamma$, in region X ($X = B$, C, D) and bin i (j). The fake factor F^ℓ is determined from a dijet event sample selected by requiring exactly one signal lepton or one loose lepton candidate balanced by a jet, as detailed in Ref. [26]. The fake factor F^γ is determined from a $Z +$ jets event sample selected by requiring a SFOC lepton pair and either one signal photon or one loose photon candidate. The yields of photonlike jet events in the signal and loose photon regions of the $Z +$ jets sample are estimated using the data-driven method described in Ref. [27].

TABLE I. The data event yield and postfit signal and background yields in the SR and CRs for $ZZ\gamma$ and $ZZ(e \to \gamma)$. The uncertainties include both the statistical and systematic contributions. The uncertainty in the total yield can be smaller than the quadrature sum of the contributions because of correlations resulting from the fit.

Process	SR	$ZZ\gamma$ CR	$ZZ(e \to \gamma)$ CR
$WZ\gamma$	92 ± 15	0.21 ± 0.07	0.56 ± 0.14
$ZZ\gamma$	10.7 ± 2.3	23 ± 5	1.8 ± 0.4
$ZZ(e \to \gamma)$	3.0 ± 0.6	0.028 ± 0.020	30 ± 6
$Z\gamma\gamma$	1.05 ± 0.32	0.15 ± 0.06	0.29 ± 0.10
Nonprompt background	30 ± 6	...	...
Pileup γ	1.9 ± 0.7	...	...
Total yield	139 ± 12	23 ± 5	33 ± 6
Data	139	23	33

The $ZZ\gamma$ background contribution is estimated using a SHERPA2.2.11 [22] Monte Carlo (MC) event sample generated with the same configuration as used for the $WZ\gamma$ signal sample. The normalization of the $ZZ\gamma$ background is constrained using a $ZZ\gamma$ control region (CR) defined similar to the $WZ\gamma$ SR, except that the requirement on $m_{\ell\ell}$ is loosened to $m_{\ell\ell} > 40$ GeV, the requirement on E_T^{miss} is removed, and the veto on additional leptons is replaced by a requirement that a fourth lepton must be present with $p_\text{T} > 10$ GeV, satisfying looser identification and isolation criteria than for signal leptons.

The background from ZZ events in which a Z boson decays into an e^+e^- pair and either the electron or positron is misidentified as a photon, denoted by $ZZ(e \to \gamma)$, was modeled with an inclusive sample of $pp \to ZZ \to 4\ell$ MC events generated by POWHEG BOX [28–30], which was interfaced to PYTHIA8.2.10 [31] for parton showering and simulation of the underlying event. The CT10 NLO PDF set was used for the hard-scatter process, while the CTEQ[6L1] [32] PDF set was used for the PS. Each reconstructed photon selected from this sample is required to be an electron in the generator's event record. The normalization of the $ZZ(e \to \gamma)$ background is constrained using a CR defined similar to the $WZ\gamma$ SR, but with the E_T^{miss} and $|m(e_W, \gamma) - m_Z|$ criteria inverted to require $E_\text{T}^{\text{miss}} < 20$ GeV and $|m(e_W, \gamma) - m_Z| < 10$ GeV.

The background from $Z\gamma\gamma$ production where one of the photons is misidentified as an electron is estimated using an MC event sample generated with SHERPA2.2.10 [22] at NLO,

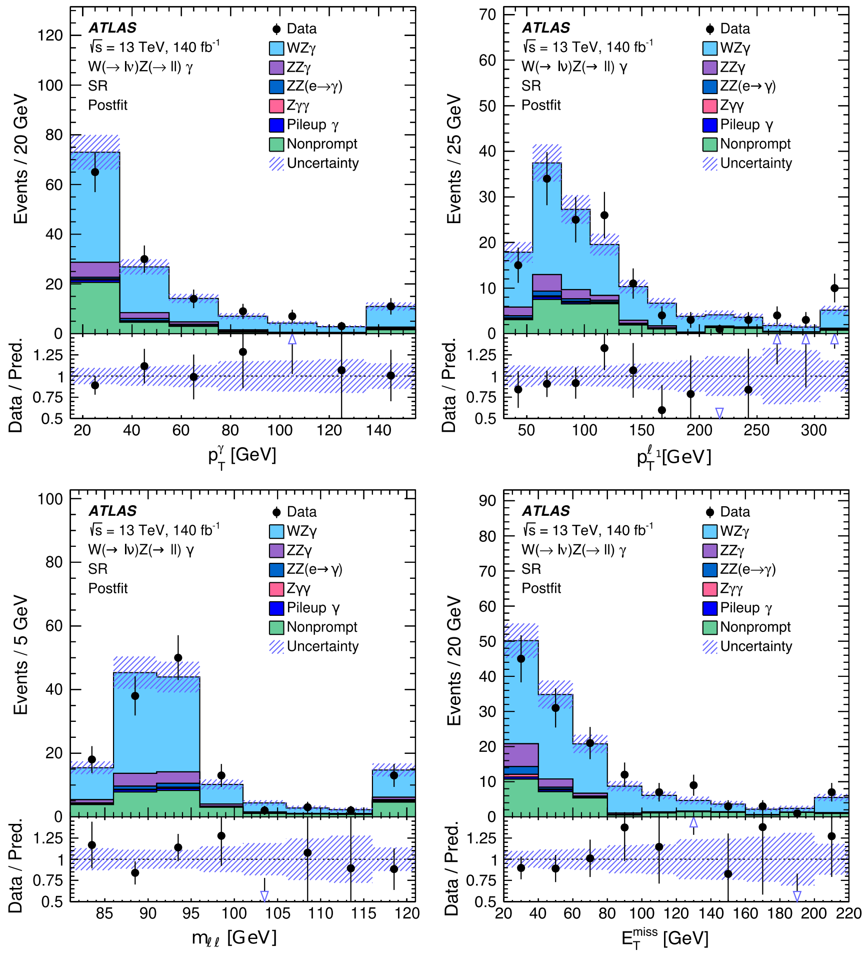

FIG. 2. Distributions of photon p_{T}^{γ} (top left), leading lepton $p_{\mathrm{T}}^{\ell_1}$ (top right), $m_{\ell\ell}$ (bottom left), and $E_{\mathrm{T}}^{\mathrm{miss}}$ (bottom right) in the SR. Lower (in each figure): the ratio of the data points to the postfit total prediction. The arrows indicate that the ratio lies outside the range covered by the vertical axis. The uncertainty bands include both the statistical and systematic uncertainties as obtained by the fit. The overflow content of each histogram is added to the last bin.

with up to two additional partons at LO accuracy, and the NNPDF3.0 NNLO [23] set of PDFs.

Pileup background, denoted by "pileup γ," where the photon and the trilepton system in a selected event are produced in separate pp interactions, arises because the reconstructed photon's point of origin is determined relatively poorly. This background contribution is estimated using a method similar to that introduced in Ref. [27], where a sample of simulated pileup events is obtained at particle level by overlaying the photon from a $\gamma + \mathrm{jets}$ MC event onto an event from an inclusive $pp \to WZ \to \ell' \nu \ell \ell$ MC sample.

The $WZ\gamma$ production cross section is measured in a fiducial phase-space region (FR) defined at particle level by kinematic requirements closely matching those used to define the detector-level SR, using photons, electrons, muons, and neutrinos in the MC event record that do not originate from the decay of a τ lepton or a hadron. The p_{T} values of the three signal leptons and the neutrino must exceed 20 GeV, and the p_{T} of the leading lepton must be greater than 30 GeV. The p_{T} of the signal photon must be above 15 GeV. A pseudorapidity requirement $|\eta^{\ell}| < 2.5$ ($|\eta^{\gamma}| < 2.37$) is imposed on leptons (photons). The four-momenta of photons within a cone of size $\Delta R = 0.1$ around each electron or muon are added to the electron or muon four-momentum, a procedure commonly referred to as "dressing." Each remaining prompt photon must satisfy an isolation criterion at particle level, which requires the scalar sum of the p_{T} of all stable particles within a cone of size $\Delta R = 0.2$ around the photon to be less than 7% of the photon p_{T}^{γ}. The angular separation between each lepton and the photon is required to satisfy $\Delta R(\ell, \gamma) > 0.4$. The Z candidate mass $m_{\ell\ell}$ must exceed 81 GeV.

The $WZ\gamma$ signal event contribution in the SR is determined using a profile-likelihood fit [33] for a signal-strength parameter $\mu_{WZ\gamma}$, which measures the signal contribution relative to the SM expectation. The value of $\mu_{WZ\gamma}$ is extracted simultaneously with the normalizations $\mu_{ZZ\gamma}$ and μ_{ZZ} of the $ZZ\gamma$ and $ZZ(e \to \gamma)$ backgrounds, respectively, by including the dedicated $ZZ\gamma$ and $ZZ(e \to \gamma)$

control regions in the fit. The fit is carried out for all leptonic final states combined and hence uses three bins in total: one SR and two CRs.

Systematic uncertainties affecting the predicted SM yields contain contributions from electron and muon triggers, reconstruction, identification [17,34], and isolation requirements, energy and momentum scales [17,35], modeling of $E_{\mathrm{T}}^{\mathrm{miss}}$ [36], and theoretical modeling of $WZ\gamma$ events. The last of these is estimated by varying the renormalization and factorization scales, and the PDFs and α_{s}, according to prescriptions in Refs. [37,38]. Other contributions include uncertainties from the determination of lepton and photon fake factors and modeling of prompt backgrounds in looser lepton and/or photon regions, uncertainties in the $Z\gamma\gamma$ cross section and pileup background, and signal and background uncertainties due to limited sample size. The dominant systematic uncertainty in the measured cross section in the FR $\sigma_{WZ\gamma}$ arises from the data sample size in the loose lepton and/or photon region and is 5.4%, followed by a 2.5% uncertainty from the photon identification and isolation efficiency and a 2.4% uncertainty related to calibrations of muon isolation, identification, and reconstruction efficiencies, as well as momentum resolution and scale. The systematic uncertainties are included in the fit as nuisance parameters constrained by Gaussian probability density functions, except for statistical uncertainties of the signal and backgrounds, which are constrained by Poisson probability density functions.

The background-only hypothesis is rejected with an observed (expected) significance of 6.3 (5.0) standard deviations. The observed signal strength is $\mu_{WZ\gamma} = 1.34 \pm 0.20(\mathrm{stat}) \pm 0.10(\mathrm{syst}) \pm 0.07(\mathrm{theory})$, the uncertainty being dominated by a statistical uncertainty of 15%. The obtained $\mu_{WZ\gamma}$ is consistent with those obtained separately from the four final states. The fitted values of $\mu_{ZZ\gamma}$ and μ_{ZZ} are 1.19 ± 0.25 and 0.98 ± 0.19, respectively. The postfit yields of the signal, backgrounds, and data are shown in Table I. $WZ\gamma$ events where signal electrons or muons are products of τ-lepton decays constitute 5% of the total $WZ\gamma$ yield in the SR and are scaled by $\mu_{WZ\gamma}$. Figure 2 compares the data with the postfit signal and background predictions for the photon p_{T}^{γ}, leading-lepton p_{T}^{ℓ}, $m_{\ell\ell}$, and $E_{\mathrm{T}}^{\mathrm{miss}}$ distributions in the SR. Good agreement is observed for all distributions.

The predicted SM fiducial cross section $\sigma_{\mathrm{fid}}^{\mathrm{SM}}$, obtained using the SHERPA2.2.11 event generator is $1.50 \pm 0.01(\mathrm{stat}) \pm 0.02(\mathrm{PDF} + \alpha_{\mathrm{s}}) \pm 0.06(\mathrm{scale})$ fb. This value does not include the effect of NLO EW corrections, which has been found to be $K_{\mathrm{EW}} = \sigma_{\mathrm{fid}}^{\mathrm{NLO\ EW}}/\sigma_{\mathrm{fid}}^{\mathrm{LO}} = 1.05$ [39] for the subprocess $pp \to WZ\gamma \to e^+\nu_e\mu^+\mu^-\gamma$. The measured cross section in the FR is $\sigma_{WZ\gamma} = \mu_{WZ\gamma}\,\sigma_{\mathrm{fid}}^{\mathrm{SM}} = 2.01 \pm 0.30(\mathrm{stat}) \pm 0.16(\mathrm{syst})$ fb, which is consistent with the SM prediction to within 1.5 standard deviations.

In conclusion, the process $pp \to WZ\gamma$ has been observed by the ATLAS detector at the LHC. Events with three prompt leptons, containing one same-flavor opposite-charge pair, plus one prompt photon and missing transverse momentum were selected from a 140 fb^{-1} dataset collected from $\sqrt{s} = 13$ TeV proton-proton collisions. The background-only hypothesis is rejected with an observed (expected) significance of 6.3 (5.0) standard deviations. The $pp \to WZ\gamma \to \ell'^{\pm}\nu\ell^+\ell^-\gamma$ ($\ell^{(\prime)} = e, \mu$) cross section in the fiducial phase space defined by kinematic requirements on the $\ell'\nu\ell\ell\gamma$ system and by isolation requirements on the photon is measured to be 2.01 ± 0.34 fb.

We thank CERN for the very successful operation of the LHC, as well as the support staff from our institutions without whom ATLAS could not be operated efficiently. We 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; MEiN, 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, Taiwan; TENMAK, Türkiye; STFC, United Kingdom; DOE and NSF, U.S. In addition, individual groups and members have received support from BCKDF, CANARIE, Compute Canada, and CRC, Canada; PRIMUS 21/SCI/017 and UNCE SCI/013, Czech Republic; COST, ERC, ERDF, Horizon 2020, 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 Programs Generalitat Valenciana, Spain; Göran Gustafssons Stiftelse, Sweden; The Royal Society and Leverhulme Trust, United Kingdom. The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN, the ATLAS Tier-1 facilities at TRIUMF (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN-CNAF (Italy), NL-T1 (Netherlands), PIC (Spain), ASGC (Taiwan), RAL (United Kingdom), and BNL (U.S.), the tier-2 facilities worldwide, and large non-WLCG resource providers. Major contributors of computing resources are listed in Ref. [40].

[1] ATLAS Collaboration, Measurements of $Z\gamma$ and $Z\gamma\gamma$ production in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector, Phys. Rev. D **93**, 112002 (2016).

[2] ATLAS Collaboration, Measurement of $Z\gamma\gamma$ production in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, Eur. Phys. J. C **83**, 539 (2023).

[3] CMS Collaboration, Measurements of the $pp \to W\gamma\gamma$ and $pp \to Z\gamma\gamma$ cross sections and limits on anomalous quartic gauge couplings at $\sqrt{s} = 8$ TeV, J. High Energy Phys. 10 (2017) 072.

[4] CMS Collaboration, Measurements of the $pp \to W^{\pm}\gamma\gamma$ and $pp \to Z\gamma\gamma$ cross sections at $\sqrt{s} = 13$ TeV and limits on anomalous quartic gauge couplings, J. High Energy Phys. 10 (2021) 174.

[5] ATLAS Collaboration, Observation of $W\gamma\gamma$ triboson production in proton-proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, arXiv:2308.03041.

[6] CMS Collaboration, Observation of the production of three massive gauge bosons at $\sqrt{s} = 13$ TeV, Phys. Rev. Lett. **125**, 151802 (2020).

[7] ATLAS Collaboration, Observation of WWW production in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, Phys. Rev. Lett. **129**, 061803 (2022).

[8] CMS Collaboration, Observation of $WW\gamma$ production and search for Hγ production in proton-proton collisions at $\sqrt{s} = 13$ TeV, arXiv:2310.05164.

[9] ATLAS Collaboration, Study of $WW\gamma$ and $WZ\gamma$ production in pp collisions at $\sqrt{s} = 8$ TeV and search for anomalous quartic gauge couplings with the ATLAS experiment, Eur. Phys. J. C **77**, 646 (2017).

[10] CMS Collaboration, A search for $WW\gamma$ and $WZ\gamma$ production and constraints on anomalous quartic gauge couplings in pp collisions at $\sqrt{s} = 8$ TeV, Phys. Rev. D **90**, 032008 (2014).

[11] ATLAS Collaboration, Luminosity determination in pp collisions at $\sqrt{s} = 13$ TeV using the ATLAS detector at the LHC, Eur. Phys. J. C **83**, 982 (2023).

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

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

[14] ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the center of the detector and the z axis along the beam pipe. The x axis points from the IP to the center of the LHC ring, and the y axis points upward. Cylindrical coordinates (r, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the z axis. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln\tan(\theta/2)$. Momentum in the transverse plane is denoted by p_{T}.

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

[16] 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).

[17] ATLAS Collaboration, Muon reconstruction and identification efficiency in ATLAS using the full run $2pp$ collision data set at $\sqrt{s} = 13$ TeV, Eur. Phys. J. C **81**, 578 (2021).

[18] The primary vertex is selected from the primary vertex candidates as the one with the highest sum of the squared transverse momenta of its associated tracks.

[19] ATLAS Collaboration, Topological cell clustering in the ATLAS calorimeters and its performance in LHC run 1, Eur. Phys. J. C **77**, 490 (2017).

[20] 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).

[21] R. L. Workman *et al.*, Review of particle physics, Prog. Theor. Exp. Phys. **2022**, 083C01 (2022).

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

[23] R. D. Ball *et al.* (NNPDF Collaboration), Parton distributions for the LHC run II, J. High Energy Phys. 04 (2015) 040.

[24] S. Schumann and F. Krauss, A parton shower algorithm based on Catani-Seymour dipole factorisation, J. High Energy Phys. 03 (2008) 038.

[25] S. Höche, F. Krauss, S. Schumann, and F. Siegert, QCD matrix elements and truncated showers, J. High Energy Phys. 05 (2009) 053.

[26] ATLAS Collaboration, Measurements of $W^+W^- + \geq 1$ jet production cross-sections in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, J. High Energy Phys. 06 (2021) 003.

[27] ATLAS Collaboration, Measurement of the $Z(\to \ell^+\ell^-)\gamma$ production cross-section in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, J. High Energy Phys. 03 (2020) 054.

[28] P. Nason, A new method for combining NLO QCD with shower Monte Carlo algorithms, J. High Energy Phys. 11 (2004) 040.

[29] S. Frixione, P. Nason, and C. Oleari, Matching NLO QCD computations with parton shower simulations: The POWHEG method, J. High Energy Phys. 11 (2007) 070.

[30] S. Alioli, P. Nason, C. Oleari, and E. Re, A general framework for implementing NLO calculations in shower Monte Carlo programs: The POWHEG BOX, J. High Energy Phys. 06 (2010) 043.

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

[32] J. Pumplin, D. R. Stump, J. Huston, H.-L. Lai, P. Nadolsky, and W.-K. Tung, New generation of parton distributions with uncertainties from global QCD analysis, J. High Energy Phys. 07 (2002) 012.

[33] K. Cranmer, G. Lewis, L. Moneta, A. Shibata, and W. Verkerke, HistFactory: A tool for creating statistical models for use with RooFit and RooStats, Technical Report No. CERN-OPEN-2012-016, New York Univ., 2012, https://cds.cern.ch/record/1456844.

[34] 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).

[35] ATLAS Collaboration, Electron and photon energy calibration with the ATLAS detector using 2015–2016 LHC proton-proton collision data, J. Instrum. **14**, P03017 (2019).
[36] 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).
[37] ATLAS Collaboration, Multi-boson simulation for 13 TeV ATLAS analyses, Report No. ATL-PHYS-PUB-2016-002, 2016, https://cds.cern.ch/record/2119986.
[38] J. Butterworth *et al.*, PDF4LHC recommendations for LHC run II, J. Phys. G **43**, 023001 (2016).
[39] H. Cheng and D. Wackeroth, NLO electroweak and QCD corrections to the production of a photon with three charged lepton plus missing energy at the LHC, Phys. Rev. D **105**, 096009 (2022).
[40] ATLAS Collaboration, ATLAS computing acknowledgements, Report No. ATL-SOFT-PUB-2023-001, 2023, https://cds.cern.ch/record/2869272.

G. Aad,[102] B. Abbott,[120] K. Abeling,[55] N. J. Abicht,[49] S. H. Abidi,[29] A. Aboulhorma,[35e] H. Abramowicz,[151] H. Abreu,[150] Y. Abulaiti,[117] A. C. Abusleme Hoffman,[137a] B. S. Acharya,[69a,69b,b] C. Adam Bourdarios,[4] L. Adamczyk,[86a] L. Adamek,[155] S. V. Addepalli,[26] M. J. Addison,[101] J. Adelman,[115] A. Adiguzel,[21c] T. Adye,[134] A. A. Affolder,[136] Y. Afik,[36] M. N. Agaras,[13] J. Agarwala,[73a,73b] A. Aggarwal,[100] C. Agheorghiesei,[27c] A. Ahmad,[36] F. Ahmadov,[38,c] W. S. Ahmed,[104] S. Ahuja,[95] X. Ai,[62e,d] G. Aielli,[76a,76b] M. Ait Tamlihat,[35e] B. Aitbenchikh,[35a] I. Aizenberg,[169] M. Akbiyik,[100] T. P. A. Åkesson,[98] A. V. Akimov,[37] D. Akiyama,[168] N. N. Akolkar,[24] K. Al Khoury,[41] G. L. Alberghi,[23b] J. Albert,[165] P. Albicocco,[53] G. L. Albouy,[60] S. Alderweireldt,[52] M. Aleksa,[36] I. N. Aleksandrov,[38] C. Alexa,[27b] T. Alexopoulos,[10] A. Alfonsi,[114] F. Alfonsi,[23b] M. Algren,[56] M. Alhroob,[120] B. Ali,[132] H. M. J. Ali,[91] S. Ali,[148] S. W. Alibocus,[92] M. Aliev,[37] G. Alimonti,[71a] W. Alkakhi,[55] C. Allaire,[66] B. M. M. Allbrooke,[146] J. F. Allen,[52] C. A. Allendes Flores,[137f] P. P. Allport,[20] A. Aloisio,[72a,72b] F. Alonso,[90] C. Alpigiani,[138] M. Alvarez Estevez,[99] A. Alvarez Fernandez,[100] M. Alves Cardoso,[56] M. G. Alviggi,[72a,72b] M. Aly,[101] Y. Amaral Coutinho,[83b] A. Ambler,[104] C. Amelung,[36] M. Amerl,[101] C. G. Ames,[109] D. Amidei,[106] S. P. Amor Dos Santos,[130a] K. R. Amos,[163] V. Ananiev,[125] C. Anastopoulos,[139] T. Andeen,[11] J. K. Anders,[36] S. Y. Andrean,[47a,47b] A. Andreazza,[71a,71b] S. Angelidakis,[9] A. Angerami,[41,e] A. V. Anisenkov,[37] A. Annovi,[74a] C. Antel,[56] M. T. Anthony,[139] E. Antipov,[145] M. Antonelli,[53] D. J. A. Antrim,[17a] F. Anulli,[75a] M. Aoki,[84] T. Aoki,[153] J. A. Aparisi Pozo,[163] M. A. Aparo,[146] L. Aperio Bella,[48] C. Appelt,[18] A. Apyan,[26] N. Aranzabal,[36] C. Arcangeletti,[53] A. T. H. Arce,[51] E. Arena,[92] J-F. Arguin,[108] S. Argyropoulos,[54] J.-H. Arling,[48] O. Arnaez,[4] H. Arnold,[114] Z. P. Arrubarrena Tame,[109] G. Artoni,[75a,75b] H. Asada,[111] K. Asai,[118] S. Asai,[153] N. A. Asbah,[61] J. Assahsah,[35d] K. Assamagan,[29] R. Astalos,[28a] S. Atashi,[160] R. J. Atkin,[33a] M. Atkinson,[162] N. B. Atlay,[18] H. Atmani,[62b] P. A. Atmasiddha,[106] K. Augsten,[132] S. Auricchio,[72a,72b] A. D. Auriol,[20] V. A. Austrup,[101] G. Avolio,[36] K. Axiotis,[56] G. Azuelos,[108,f] D. Babal,[28b] H. Bachacou,[135] K. Bachas,[152,g] A. Bachiu,[34] F. Backman,[47a,47b] A. Badea,[61] P. Bagnaia,[75a,75b] M. Bahmani,[18] A. J. Bailey,[163] V. R. Bailey,[162] J. T. Baines,[134] L. Baines,[94] C. Bakalis,[10] O. K. Baker,[172] E. Bakos,[15] D. Bakshi Gupta,[8] R. Balasubramanian,[114] E. M. Baldin,[37] P. Balek,[86a] E. Ballabene,[23b,23a] F. Balli,[135] L. M. Baltes,[63a] W. K. Balunas,[32] J. Balz,[100] E. Banas,[87] M. Bandieramonte,[129] A. Bandyopadhyay,[24] S. Bansal,[24] L. Barak,[151] M. Barakat,[48] E. L. Barberio,[105] D. Barberis,[57b,57a] M. Barbero,[102] G. Barbour,[96] K. N. Barends,[33a] T. Barillari,[110] M-S. Barisits,[36] T. Barklow,[143] P. Baron,[122] D. A. Baron Moreno,[101] A. Baroncelli,[62a] G. Barone,[29] A. J. Barr,[126] J. D. Barr,[96] L. Barranco Navarro,[47a,47b] F. Barreiro,[99] J. Barreiro Guimarães da Costa,[14a] U. Barron,[151] M. G. Barros Teixeira,[130a] S. Barsov,[37] F. Bartels,[63a] R. Bartoldus,[143] A. E. Barton,[91] P. Bartos,[28a] A. Basan,[100] M. Baselga,[49] A. Bassalat,[66,h] M. J. Basso,[156a] C. R. Basson,[101] R. L. Bates,[59] S. Batlamous,[35e] J. R. Batley,[32] B. Batool,[141] M. Battaglia,[136] D. Battulga,[18] M. Bauce,[75a,75b] M. Bauer,[36] P. Bauer,[24] L. T. Bazzano Hurrell,[30] J. B. Beacham,[51] T. Beau,[127] P. H. Beauchemin,[158] F. Becherer,[54] P. Bechtle,[24] H. P. Beck,[19,i] K. Becker,[167] A. J. Beddall,[82] V. A. Bednyakov,[38] C. P. Bee,[145] L. J. Beemster,[15] T. A. Beermann,[36] M. Begalli,[83d] M. Begel,[29] A. Behera,[145] J. K. Behr,[48] J. F. Beirer,[55] F. Beisiegel,[24] M. Belfkir,[159] G. Bella,[151] L. Bellagamba,[23b] A. Bellerive,[34] P. Bellos,[20] K. Beloborodov,[37] N. L. Belyaev,[37] D. Benchekroun,[35a] F. Bendebba,[35a] Y. Benhammou,[151] M. Benoit,[29] J. R. Bensinger,[26] S. Bentvelsen,[114] L. Beresford,[48] M. Beretta,[53] E. Bergeaas Kuutmann,[161] N. Berger,[4] B. Bergmann,[132] J. Beringer,[17a] G. Bernardi,[5] C. Bernius,[143] F. U. Bernlochner,[24] F. Bernon,[36,102]

T. Berry,[95] P. Berta,[133] A. Berthold,[50] I. A. Bertram,[91] S. Bethke,[110] A. Betti,[75a,75b] A. J. Bevan,[94] M. Bhamjee,[33c] S. Bhatta,[145] D. S. Bhattacharya,[166] P. Bhattarai,[26] V. S. Bhopatkar,[121] R. Bi,[29,j] R. M. Bianchi,[129] G. Bianco,[23b,23a] O. Biebel,[109] R. Bielski,[123] M. Biglietti,[77a] T. R. V. Billoud,[132] M. Bindi,[55] A. Bingul,[21b] C. Bini,[75a,75b] A. Biondini,[92] C. J. Birch-sykes,[101] G. A. Bird,[20,134] M. Birman,[169] M. Biros,[133] T. Bisanz,[49] E. Bisceglie,[43b,43a] D. Biswas,[141] A. Bitadze,[101] K. Bjørke,[125] I. Bloch,[48] C. Blocker,[26] A. Blue,[59] U. Blumenschein,[94] J. Blumenthal,[100] G. J. Bobbink,[114] V. S. Bobrovnikov,[37] M. Boehler,[54] B. Boehm,[166] D. Bogavac,[36] A. G. Bogdanchikov,[37] C. Bohm,[47a] V. Boisvert,[95] P. Bokan,[48] T. Bold,[86a] M. Bomben,[5] M. Bona,[94] M. Boonekamp,[135] C. D. Booth,[95] A. G. Borbély,[59] I. S. Bordulev,[37] H. M. Borecka-Bielska,[108] L. S. Borgna,[96] G. Borissov,[91] D. Bortoletto,[126] D. Boscherini,[23b] M. Bosman,[13] J. D. Bossio Sola,[36] K. Bouaouda,[35a] N. Bouchhar,[163] J. Boudreau,[129] E. V. Bouhova-Thacker,[91] D. Boumediene,[40] R. Bouquet,[5] A. Boveia,[119] J. Boyd,[36] D. Boye,[29] I. R. Boyko,[38] J. Bracinik,[20] N. Brahimi,[62d] G. Brandt,[171] O. Brandt,[32] F. Braren,[48] B. Brau,[103] J. E. Brau,[123] R. Brener,[169] L. Brenner,[114] R. Brenner,[161] S. Bressler,[169] D. Britton,[59] D. Britzger,[110] I. Brock,[24] G. Brooijmans,[41] W. K. Brooks,[137f] E. Brost,[29] L. M. Brown,[165] L. E. Bruce,[61] T. L. Bruckler,[126] P. A. Bruckman de Renstrom,[87] B. Brüers,[48] D. Bruncko,[28b,a] A. Bruni,[23b] G. Bruni,[23b] M. Bruschi,[23b] N. Bruscino,[75a,75b] T. Buanes,[16] Q. Buat,[138] D. Buchin,[110] A. G. Buckley,[59] M. K. Bugge,[125] O. Bulekov,[37] B. A. Bullard,[143] S. Burdin,[92] C. D. Burgard,[49] A. M. Burger,[40] B. Burghgrave,[8] O. Burlayenko,[54] J. T. P. Burr,[32] C. D. Burton,[11] J. C. Burzynski,[142] E. L. Busch,[41] V. Büscher,[100] P. J. Bussey,[59] J. M. Butler,[25] C. M. Buttar,[59] J. M. Butterworth,[96] W. Buttinger,[134] C. J. Buxo Vazquez,[107] A. R. Buzykaev,[37] G. Cabras,[23b] S. Cabrera Urbán,[163] L. Cadamuro,[66] D. Caforio,[58] H. Cai,[129] Y. Cai,[14a,14e] V. M. M. Cairo,[36] O. Cakir,[3a] N. Calace,[36] P. Calafiura,[17a] G. Calderini,[127] P. Calfayan,[68] G. Callea,[59] L. P. Caloba,[83b] D. Calvet,[40] S. Calvet,[40] T. P. Calvet,[102] M. Calvetti,[74a,74b] R. Camacho Toro,[127] S. Camarda,[36] D. Camarero Munoz,[26] P. Camarri,[76a,76b] M. T. Camerlingo,[72a,72b] D. Cameron,[125] C. Camincher,[165] M. Campanelli,[96] A. Camplani,[42] V. Canale,[72a,72b] A. Canesse,[104] M. Cano Bret,[80] J. Cantero,[163] Y. Cao,[162] F. Capocasa,[26] M. Capua,[43b,43a] A. Carbone,[71a,71b] R. Cardarelli,[76a] J. C. J. Cardenas,[8] F. Cardillo,[163] T. Carli,[36] G. Carlino,[72a] J. I. Carlotto,[13] B. T. Carlson,[129,k] E. M. Carlson,[165,156a] L. Carminati,[71a,71b] A. Carnelli,[135] M. Carnesale,[75a,75b] S. Caron,[113] E. Carquin,[137f] S. Carrá,[71a,71b] G. Carratta,[23b,23a] F. Carrio Argos,[33g] J. W. S. Carter,[155] T. M. Carter,[52] M. P. Casado,[13,l] M. Caspar,[48] E. G. Castiglia,[172] F. L. Castillo,[4] L. Castillo Garcia,[13] V. Castillo Gimenez,[163] N. F. Castro,[130a,130e] A. Catinaccio,[36] J. R. Catmore,[125] V. Cavaliere,[29] N. Cavalli,[23b,23a] V. Cavasinni,[74a,74b] Y. C. Cekmecelioglu,[48] E. Celebi,[21a] F. Celli,[126] M. S. Centonze,[70a,70b] K. Cerny,[122] A. S. Cerqueira,[83a] A. Cerri,[146] L. Cerrito,[76a,76b] F. Cerutti,[17a] B. Cervato,[141] A. Cervelli,[23b] G. Cesarini,[53] S. A. Cetin,[82] Z. Chadi,[35a] D. Chakraborty,[115] M. Chala,[130f] J. Chan,[170] W. Y. Chan,[153] J. D. Chapman,[32] E. Chapon,[135] B. Chargeishvili,[149b] D. G. Charlton,[20] T. P. Charman,[94] M. Chatterjee,[19] C. Chauhan,[133] S. Chekanov,[6] S. V. Chekulaev,[156a] G. A. Chelkov,[38,m] A. Chen,[106] B. Chen,[151] B. Chen,[165] H. Chen,[14c] H. Chen,[29] J. Chen,[62c] J. Chen,[142] M. Chen,[126] S. Chen,[153] S. J. Chen,[14c] X. Chen,[62c] X. Chen,[14b,n] Y. Chen,[62a] C. L. Cheng,[170] H. C. Cheng,[64a] S. Cheong,[143] A. Cheplakov,[38] E. Cheremushkina,[48] E. Cherepanova,[114] R. Cherkaoui El Moursli,[35e] E. Cheu,[7] K. Cheung,[65] L. Chevalier,[135] V. Chiarella,[53] G. Chiarelli,[74a] N. Chiedde,[102] G. Chiodini,[70a] A. S. Chisholm,[20] A. Chitan,[27b] M. Chitishvili,[163] M. V. Chizhov,[38] K. Choi,[11] A. R. Chomont,[75a,75b] Y. Chou,[103] E. Y. S. Chow,[114] T. Chowdhury,[33g] K. L. Chu,[169] M. C. Chu,[64a] X. Chu,[14a,14e] J. Chudoba,[131] J. J. Chwastowski,[87] D. Cieri,[110] K. M. Ciesla,[86a] V. Cindro,[93] A. Ciocio,[17a] F. Cirotto,[72a,72b] Z. H. Citron,[169,o] M. Citterio,[71a] D. A. Ciubotaru,[27b] B. M. Ciungu,[155] A. Clark,[56] P. J. Clark,[52] J. M. Clavijo Columbie,[48] S. E. Clawson,[48] C. Clement,[47a,47b] J. Clercx,[48] L. Clissa,[23b,23a] Y. Coadou,[102] M. Cobal,[69a,69c] A. Coccaro,[57b] R. F. Coelho Barrue,[130a] R. Coelho Lopes De Sa,[103] S. Coelli,[71a] H. Cohen,[151] A. E. C. Coimbra,[71a,71b] B. Cole,[41] J. Collot,[60] P. Conde Muiño,[130a,130g] M. P. Connell,[33c] S. H. Connell,[33c] I. A. Connelly,[59] E. I. Conroy,[126] F. Conventi,[72a,p] H. G. Cooke,[20] A. M. Cooper-Sarkar,[126] A. Cordeiro Oudot Choi,[127] F. Cormier,[164] L. D. Corpe,[40] M. Corradi,[75a,75b] F. Corriveau,[104,q] A. Cortes-Gonzalez,[18] M. J. Costa,[163] F. Costanza,[4] D. Costanzo,[139] B. M. Cote,[119] G. Cowan,[95] K. Cranmer,[170] D. Cremonini,[23b,23a] S. Crépé-Renaudin,[60] F. Crescioli,[127] M. Cristinziani,[141] M. Cristoforetti,[78a,78b] V. Croft,[114] J. E. Crosby,[121] G. Crosetti,[43b,43a] A. Cueto,[99] T. Cuhadar Donszelmann,[160] H. Cui,[14a,14e] Z. Cui,[7] W. R. Cunningham,[59] F. Curcio,[43b,43a] P. Czodrowski,[36] M. M. Czurylo,[63b] M. J. Da Cunha Sargedas De Sousa,[62a]

J. V. Da Fonseca Pinto,[83b] C. Da Via,[101] W. Dabrowski,[86a] T. Dado,[49] S. Dahbi,[33g] T. Dai,[106] C. Dallapiccola,[103] M. Dam,[42] G. D'amen,[29] V. D'Amico,[109] J. Damp,[100] J. R. Dandoy,[128] M. F. Daneri,[30] M. Danninger,[142] V. Dao,[36] G. Darbo,[57b] S. Darmora,[6] S. J. Das,[29,j] S. D'Auria,[71a,71b] C. David,[156b] T. Davidek,[133] B. Davis-Purcell,[34] I. Dawson,[94] H. A. Day-hall,[132] K. De,[8] R. De Asmundis,[72a] N. De Biase,[48] S. De Castro,[23b,23a] N. De Groot,[113] P. de Jong,[114] H. De la Torre,[107] A. De Maria,[14c] A. De Salvo,[75a] U. De Sanctis,[76a,76b] A. De Santo,[146] J. B. De Vivie De Regie,[60] D. V. Dedovich,[38] J. Degens,[114] A. M. Deiana,[44] F. Del Corso,[23b,23a] J. Del Peso,[99] F. Del Rio,[63a] F. Deliot,[135] 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,[172] M. Demichev,[38] S. P. Denisov,[37] L. D'Eramo,[40] D. Derendarz,[87] F. Derue,[127] P. Dervan,[92] 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,[5] A. Di Luca,[78a,78b] B. Di Micco,[77a,77b] R. Di Nardo,[77a,77b] C. Diaconu,[102] M. Diamantopoulou,[34] F. A. Dias,[114] T. Dias Do Vale,[142] M. A. Diaz,[137a,137b] F. G. Diaz Capriles,[24] M. Didenko,[163] E. B. Diehl,[106] L. Diehl,[54] S. Díez Cornell,[48] C. Diez Pardos,[141] C. Dimitriadi,[161,24,161] A. Dimitrievska,[17a] J. Dingfelder,[24] I-M. Dinu,[27b] S. J. Dittmeier,[63b] F. Dittus,[36] F. Djama,[102] T. Djobava,[149b] J. I. Djuvsland,[16] C. Doglioni,[101,98] J. Dolejsi,[133] Z. Dolezal,[133] M. Donadelli,[83c] B. Dong,[107] J. Donini,[40] A. D'Onofrio,[77a,77b] M. D'Onofrio,[92] J. Dopke,[134] A. Doria,[72a] N. Dos Santos Fernandes,[130a] M. T. Dova,[90] A. T. Doyle,[59] M. A. Draguet,[126] E. Dreyer,[169] I. Drivas-koulouris,[10] A. S. Drobac,[158] M. Drozdova,[56] D. Du,[62a] T. A. du Pree,[114] F. Dubinin,[37] M. Dubovsky,[28a] E. Duchovni,[169] G. Duckeck,[109] O. A. Ducu,[27b] D. Duda,[52] A. Dudarev,[36] E. R. Duden,[26] M. D'uffizi,[101] L. Duflot,[66] M. Dührssen,[36] C. Dülsen,[171] A. E. Dumitriu,[27b] M. Dunford,[63a] S. Dungs,[49] K. Dunne,[47a,47b] A. Duperrin,[102] H. Duran Yildiz,[3a] M. Düren,[58] A. Durglishvili,[149b] B. L. Dwyer,[115] G. I. Dyckes,[17a] M. Dyndal,[86a] S. Dysch,[101] B. S. Dziedzic,[87] Z. O. Earnshaw,[146] G. H. Eberwein,[126] B. Eckerova,[28a] S. Eggebrecht,[55] M. G. Eggleston,[51] E. Egidio Purcino De Souza,[127] L. F. Ehrke,[56] G. Eigen,[16] K. Einsweiler,[17a] T. Ekelof,[161] P. A. Ekman,[98] S. El Farkh,[35b] Y. El Ghazali,[35b] H. El Jarrari,[35e,148] A. El Moussaouy,[35a] V. Ellajosyula,[161] M. Ellert,[161] F. Ellinghaus,[171] A. A. Elliot,[94] N. Ellis,[36] J. Elmsheuser,[29] M. Elsing,[36] D. Emeliyanov,[134] Y. Enari,[153] I. Ene,[17a] S. Epari,[13] J. Erdmann,[49] P. A. Erland,[87] M. Errenst,[171] M. Escalier,[66] C. Escobar,[163] E. Etzion,[151] G. Evans,[130a] H. Evans,[68] L. S. Evans,[95] M. O. Evans,[146] A. Ezhilov,[37] S. Ezzarqtouni,[35a] F. Fabbri,[59] L. Fabbri,[23b,23a] G. Facini,[96] V. Fadeyev,[136] R. M. Fakhrutdinov,[37] S. Falciano,[75a] L. F. Falda Ulhoa Coelho,[36] P. J. Falke,[24] J. Faltova,[133] C. Fan,[162] Y. Fan,[14a] Y. Fang,[14a,14e] M. Fanti,[71a,71b] M. Faraj,[69a,69b] Z. Farazpay,[97] A. Farbin,[8] A. Farilla,[77a] T. Farooque,[107] S. M. Farrington,[52] F. Fassi,[35e] D. Fassouliotis,[9] M. Faucci Giannelli,[76a,76b] W. J. Fawcett,[32] L. Fayard,[66] P. Federic,[133] P. Federicova,[131] O. L. Fedin,[37,m] G. Fedotov,[37] M. Feickert,[170] L. Feligioni,[102] D. E. Fellers,[123] C. Feng,[62b] M. Feng,[14b] Z. Feng,[114] M. J. Fenton,[160] A. B. Fenyuk,[37] L. Ferencz,[48] R. A. M. Ferguson,[91] S. I. Fernandez Luengo,[137f] M. J. V. Fernoux,[102] J. Ferrando,[48] A. Ferrari,[161] P. Ferrari,[114,113] R. Ferrari,[73a] D. Ferrere,[56] C. Ferretti,[106] F. Fiedler,[100] A. Filipčič,[93] E. K. Filmer,[1] F. Filthaut,[113] M. C. N. Fiolhais,[130a,130c,r] L. Fiorini,[163] W. C. Fisher,[107] T. Fitschen,[101] P. M. Fitzhugh,[135] I. Fleck,[141] P. Fleischmann,[106] T. Flick,[171] L. Flores,[128] M. Flores,[33d,s] L. R. Flores Castillo,[64a] L. Flores Sanz De Acedo,[36] F. M. Follega,[78a,78b] N. Fomin,[16] J. H. Foo,[155] B. C. Forland,[68] A. Formica,[135] A. C. Forti,[101] E. Fortin,[36] A. W. Fortman,[61] M. G. Foti,[17a] L. Fountas,[9,t] D. Fournier,[66] H. Fox,[91] P. Francavilla,[74a,74b] S. Francescato,[61] S. Franchellucci,[56] M. Franchini,[23b,23a] S. Franchino,[63a] D. Francis,[36] L. Franco,[113] L. Franconi,[48] M. Franklin,[61] G. Frattari,[26] A. C. Freegard,[94] W. S. Freund,[83b] Y. Y. Frid,[151] N. Fritzsche,[50] A. Froch,[54] D. Froidevaux,[36] J. A. Frost,[126] Y. Fu,[62a] M. Fujimoto,[118] E. Fullana Torregrosa,[163,a] K. Y. Fung,[64a] E. Furtado De Simas Filho,[83b] M. Furukawa,[153] J. Fuster,[163] A. Gabrielli,[23b,23a] A. Gabrielli,[155] P. Gadow,[36] G. Gagliardi,[57b,57a] L. G. Gagnon,[17a] E. J. Gallas,[126] B. J. Gallop,[134] K. K. Gan,[119] S. Ganguly,[153] J. Gao,[62a] Y. Gao,[52] F. M. Garay Walls,[137a,137b] B. Garcia,[29,j] C. García,[163] A. Garcia Alonso,[114] A. G. Garcia Caffaro,[172] J. E. García Navarro,[163] M. Garcia-Sciveres,[17a] G. L. Gardner,[128] R. W. Gardner,[39] N. Garelli,[158] D. Garg,[80] R. B. Garg,[143,u] J. M. Gargan,[52] C. A. Garner,[155] S. J. Gasiorowski,[138] P. Gaspar,[83b] G. Gaudio,[73a] V. Gautam,[13] P. Gauzzi,[75a,75b] I. L. Gavrilenko,[37] A. Gavrilyuk,[37] C. Gay,[164] G. Gaycken,[48] E. N. Gazis,[10] A. A. Geanta,[27b] C. M. Gee,[136] C. Gemme,[57b] M. H. Genest,[60] S. Gentile,[75a,75b] S. George,[95] W. F. George,[20] T. Geralis,[46] P. Gessinger-Befurt,[36] M. E. Geyik,[171] M. Ghneimat,[141] K. Ghorbanian,[94] A. Ghosal,[141] A. Ghosh,[160]

A. Ghosh,[7] B. Giacobbe,[23b] S. Giagu,[75a,75b] P. Giannetti,[74a] A. Giannini,[62a] S. M. Gibson,[95] M. Gignac,[136] D. T. Gil,[86b] A. K. Gilbert,[86a] B. J. Gilbert,[41] D. Gillberg,[34] G. Gilles,[114] N. E. K. Gillwald,[48] L. Ginabat,[127] D. M. Gingrich,[2,f] M. P. Giordani,[69a,69c] P. F. Giraud,[135] G. Giugliarelli,[69a,69c] D. Giugni,[71a] F. Giuli,[36] I. Gkialas,[9,t] L. K. Gladilin,[37] C. Glasman,[99] G. R. Gledhill,[123] G. Glemža,[48] M. Glisic,[123] I. Gnesi,[43b,v] Y. Go,[29,j] M. Goblirsch-Kolb,[36] B. Gocke,[49] D. Godin,[108] B. Gokturk,[21a] S. Goldfarb,[105] T. Golling,[56] M. G. D. Gololo,[33g] D. Golubkov,[37] J. P. Gombas,[107] A. Gomes,[130a,130b] G. Gomes Da Silva,[141] A. J. Gomez Delegido,[163] R. Gonçalo,[130a,130c] G. Gonella,[123] L. Gonella,[20] A. Gongadze,[149c] F. Gonnella,[20] J. L. Gonski,[41] R. Y. González Andana,[52] S. González de la Hoz,[163] S. Gonzalez Fernandez,[13] R. Gonzalez Lopez,[92] C. Gonzalez Renteria,[17a] R. Gonzalez Suarez,[161] S. Gonzalez-Sevilla,[56] G. R. Gonzalvo Rodriguez,[163] L. Goossens,[36] P. A. Gorbounov,[37] B. Gorini,[36] E. Gorini,[70a,70b] A. Gorišek,[93] T. C. Gosart,[128] A. T. Goshaw,[51] M. I. Gostkin,[38] S. Goswami,[121] C. A. Gottardo,[36] M. Gouighri,[35b] V. Goumarre,[48] A. G. Goussiou,[138] N. Govender,[33c] I. Grabowska-Bold,[86a] K. Graham,[34] E. Gramstad,[125] S. Grancagnolo,[70a,70b] M. Grandi,[146] P. M. Gravila,[27f] F. G. Gravili,[70a,70b] H. M. Gray,[17a] M. Greco,[70a,70b] C. Grefe,[24] I. M. Gregor,[48] P. Grenier,[143] C. Grieco,[13] A. A. Grillo,[136] K. Grimm,[31] S. Grinstein,[13,w] J.-F. Grivaz,[66] E. Gross,[169] J. Grosse-Knetter,[55] C. Grud,[106] J. C. Grundy,[126] L. Guan,[106] W. Guan,[29] C. Gubbels,[164] J. G. R. Guerrero Rojas,[163] G. Guerrieri,[69a,69c] F. Guescini,[110] R. Gugel,[100] J. A. M. Guhit,[106] A. Guida,[18] T. Guillemin,[4] E. Guilloton,[167,134] S. Guindon,[36] F. Guo,[14a,14e] J. Guo,[62c] L. Guo,[48] Y. Guo,[106] R. Gupta,[48] S. Gurbuz,[24] S. S. Gurdasani,[54] G. Gustavino,[36] M. Guth,[56] P. Gutierrez,[120] L. F. Gutierrez Zagazeta,[128] C. Gutschow,[96] C. Gwenlan,[126] C. B. Gwilliam,[92] E. S. Haaland,[125] A. Haas,[117] M. Habedank,[48] C. Haber,[17a] H. K. Hadavand,[8] A. Hadef,[100] S. Hadzic,[110] J. J. Hahn,[141] E. H. Haines,[96] M. Haleem,[166] J. Haley,[121] J. J. Hall,[139] G. D. Hallewell,[102] L. Halser,[19] K. Hamano,[165] H. Hamdaoui,[35e] M. Hamer,[24] G. N. Hamity,[52] E. J. Hampshire,[95] J. Han,[62b] K. Han,[62a] L. Han,[14c] L. Han,[62a] S. Han,[17a] Y. F. Han,[155] K. Hanagaki,[84] M. Hance,[136] D. A. Hangal,[41,e] H. Hanif,[142] M. D. Hank,[128] R. Hankache,[101] J. B. Hansen,[42] J. D. Hansen,[42] P. H. Hansen,[42] K. Hara,[157] D. Harada,[56] T. Harenberg,[171] S. Harkusha,[37] M. L. Harris,[103] Y. T. Harris,[126] J. Harrison,[13] N. M. Harrison,[119] P. F. Harrison,[167] N. M. Hartman,[110] N. M. Hartmann,[109] Y. Hasegawa,[140] A. Hasib,[52] S. Haug,[19] R. Hauser,[107] C. M. Hawkes,[20] R. J. Hawkings,[36] Y. Hayashi,[153] S. Hayashida,[111] D. Hayden,[107] C. Hayes,[106] R. L. Hayes,[114] C. P. Hays,[126] J. M. Hays,[94] H. S. Hayward,[92] F. He,[62a] M. He,[14a,14e] Y. He,[154] Y. He,[127] N. B. Heatley,[94] V. Hedberg,[98] A. L. Heggelund,[125] N. D. Hehir,[94] C. Heidegger,[54] K. K. Heidegger,[54] W. D. Heidorn,[81] J. Heilman,[34] S. Heim,[48] T. Heim,[17a] B. Heinemann,[48,x] J. G. Heinlein,[128] J. J. Heinrich,[123] L. Heinrich,[110,y] J. Hejbal,[131] L. Helary,[48] A. Held,[170] S. Hellesund,[16] C. M. Helling,[164] S. Hellman,[47a,47b] R. C. W. Henderson,[91] L. Henkelmann,[32] A. M. Henriques Correia,[36] H. Herde,[98] Y. Hernández Jiménez,[145] L. M. Herrmann,[24] T. Herrmann,[50] G. Herten,[54] R. Hertenberger,[109] L. Hervas,[36] M. E. Hesping,[100] N. P. Hessey,[156a] H. Hibi,[85] S. J. Hillier,[20] J. R. Hinds,[107] F. Hinterkeuser,[24] M. Hirose,[124] S. Hirose,[157] D. Hirschbuehl,[171] T. G. Hitchings,[101] B. Hiti,[93] J. Hobbs,[145] R. Hobincu,[27e] N. Hod,[169] M. C. Hodgkinson,[139] B. H. Hodkinson,[32] A. Hoecker,[36] J. Hofer,[48] T. Holm,[24] M. Holzbock,[110] L. B. A. H. Hommels,[32] B. P. Honan,[101] J. Hong,[62c] T. M. Hong,[129] B. H. Hooberman,[162] W. H. Hopkins,[6] Y. Horii,[111] S. Hou,[148] A. S. Howard,[93] J. Howarth,[59] J. Hoya,[6] M. Hrabovsky,[122] A. Hrynevich,[48] T. Hryn'ova,[4] P. J. Hsu,[65] S.-C. Hsu,[138] Q. Hu,[41] Y. F. Hu,[14a,14e] S. Huang,[64b] X. Huang,[14c] Y. Huang,[139] Y. Huang,[14a] Z. Huang,[101] Z. Hubacek,[132] M. Huebner,[24] F. Huegging,[24] T. B. Huffman,[126] C. A. Hugli,[48] M. Huhtinen,[36] S. K. Huiberts,[16] R. Hulsken,[104] N. Huseynov,[12,m] J. Huston,[107] J. Huth,[61] R. Hyneman,[143] G. Iacobucci,[56] G. Iakovidis,[29] I. Ibragimov,[141] L. Iconomidou-Fayard,[66] P. Iengo,[72a,72b] R. Iguchi,[153] T. Iizawa,[84] Y. Ikegami,[84] N. Ilic,[155] 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,[92] M. Ishino,[153] W. Islam,[170] C. Issever,[18,48] S. Istin,[21a,z] H. Ito,[168] J. M. Iturbe Ponce,[64a] R. Iuppa,[78a,78b] A. Ivina,[169] J. M. Izen,[45] V. Izzo,[72a] P. Jacka,[131,132] P. Jackson,[1] R. M. Jacobs,[48] B. P. Jaeger,[142] C. S. Jagfeld,[109] P. Jain,[54] G. Jäkel,[171] K. Jakobs,[54] T. Jakoubek,[169] J. Jamieson,[59] K. W. Janas,[86a] A. E. Jaspan,[92] M. Javurkova,[103] F. Jeanneau,[135] L. Jeanty,[123] J. Jejelava,[149a,aa] P. Jenni,[54,bb] C. E. Jessiman,[34] S. Jézéquel,[4] C. Jia,[62b] J. Jia,[145] X. Jia,[61] X. Jia,[14a,14e] Z. Jia,[14c] Y. Jiang,[62a] S. Jiggins,[48] J. Jimenez Pena,[13] S. Jin,[14c] A. Jinaru,[27b] O. Jinnouchi,[154] P. Johansson,[139] K. A. Johns,[7] J. W. Johnson,[136] D. M. Jones,[32] E. Jones,[48] P. Jones,[32] R. W. L. Jones,[91] T. J. Jones,[92]

R. Joshi,[119] J. Jovicevic,[15] X. Ju,[17a] J. J. Junggeburth,[36] T. Junkermann,[63a] A. Juste Rozas,[13,w] M. K. Juzek,[87] S. Kabana,[137e] A. Kaczmarska,[87] M. Kado,[110] H. Kagan,[119] M. Kagan,[143] A. Kahn,[41] A. Kahn,[128] C. Kahra,[100] T. Kaji,[168] E. Kajomovitz,[150] N. Kakati,[169] I. Kalaitzidou,[54] C. W. Kalderon,[29] A. Kamenshchikov,[155] S. Kanayama,[154] N. J. Kang,[136] D. Kar,[33g] K. Karava,[126] M. J. Kareem,[156b] E. Karentzos,[54] I. Karkanias,[152] O. Karkout,[114] S. N. Karpov,[38] Z. M. Karpova,[38] V. Kartvelishvili,[91] A. N. Karyukhin,[37] E. Kasimi,[152] J. Katzy,[48] S. Kaur,[34] K. Kawade,[140] M. P. Kawale,[120] T. Kawamoto,[135] E. F. Kay,[36] F. I. Kaya,[158] S. Kazakos,[107] V. F. Kazanin,[37] Y. Ke,[145] J. M. Keaveney,[33a] R. Keeler,[165] G. V. Kehris,[61] J. S. Keller,[34] A. S. Kelly,[96] J. J. Kempster,[146] K. E. Kennedy,[41] P. D. Kennedy,[100] O. Kepka,[131] B. P. Kerridge,[167] S. Kersten,[171] B. P. Kerševan,[93] S. Keshri,[66] L. Keszeghova,[28a] S. Ketabchi Haghighat,[155] M. Khandoga,[127] A. Khanov,[121] A. G. Kharlamov,[37] T. Kharlamova,[37] E. E. Khoda,[138] T. J. Khoo,[18] G. Khoriauli,[166] J. Khubua,[149b] Y. A. R. Khwaira,[66] A. Kilgallon,[123] D. W. Kim,[47a,47b] Y. K. Kim,[39] N. Kimura,[96] A. Kirchhoff,[55] C. Kirfel,[24] F. Kirfel,[24] J. Kirk,[134] A. E. Kiryunin,[110] C. Kitsaki,[10] O. Kivernyk,[24] M. Klassen,[63a] C. Klein,[34] L. Klein,[166] M. H. Klein,[106] M. Klein,[92] S. B. Klein,[56] U. Klein,[92] P. Klimek,[36] A. Klimentov,[29] T. Klioutchnikova,[36] P. Kluit,[114] S. Kluth,[110] E. Kneringer,[79] T. M. Knight,[155] A. Knue,[54] R. Kobayashi,[88] S. F. Koch,[126] M. Kocian,[143] P. Kodyš,[133] D. M. Koeck,[123] P. T. Koenig,[24] T. Koffas,[34] M. Kolb,[135] I. Koletsou,[4] T. Komarek,[122] K. Köneke,[54] A. X. Y. Kong,[1] T. Kono,[118] N. Konstantinidis,[96] B. Konya,[98] R. Kopeliansky,[68] S. Koperny,[86a] K. Korcyl,[87] K. Kordas,[152,cc] G. Koren,[151] A. Korn,[96] S. Korn,[55] I. Korolkov,[13] N. Korotkova,[37] B. Kortman,[114] O. Kortner,[110] S. Kortner,[110] W. H. Kostecka,[115] V. V. Kostyukhin,[141] A. Kotsokechagia,[135] A. Kotwal,[51] A. Koulouris,[36] A. Kourkoumeli-Charalampidi,[73a,73b] C. Kourkoumelis,[9] E. Kourlitis,[110,y] O. Kovanda,[146] R. Kowalewski,[165] W. Kozanecki,[135] A. S. Kozhin,[37] V. A. Kramarenko,[37] G. Kramberger,[93] P. Kramer,[100] M. W. Krasny,[127] A. Krasznahorkay,[36] J. W. Kraus,[171] J. A. Kremer,[100] T. Kresse,[50] J. Kretzschmar,[92] K. Kreul,[18] P. Krieger,[155] S. Krishnamurthy,[103] M. Krivos,[133] K. Krizka,[20] K. Kroeninger,[49] H. Kroha,[110] J. Kroll,[131] J. Kroll,[128] K. S. Krowpman,[107] U. Kruchonak,[38] H. Krüger,[24] N. Krumnack,[81] M. C. Kruse,[51] J. A. Krzysiak,[87] O. Kuchinskaia,[37] S. Kuday,[3a] S. Kuehn,[36] R. Kuesters,[54] T. Kuhl,[48] V. Kukhtin,[38] Y. Kulchitsky,[37,m] S. Kuleshov,[137d,137b] M. Kumar,[33g] N. Kumari,[102] A. Kupco,[131] T. Kupfer,[49] A. Kupich,[37] O. Kuprash,[54] H. Kurashige,[85] L. L. Kurchaninov,[156a] O. Kurdysh,[66] Y. A. Kurochkin,[37] A. Kurova,[37] M. Kuze,[154] A. K. Kvam,[103] J. Kvita,[122] T. Kwan,[104] N. G. Kyriacou,[106] L. A. O. Laatu,[102] C. Lacasta,[163] F. Lacava,[75a,75b] H. Lacker,[18] D. Lacour,[127] N. N. Lad,[96] E. Ladygin,[38] B. Laforge,[127] T. Lagouri,[137e] S. Lai,[55] I. K. Lakomiec,[86a] N. Lalloue,[60] J. E. Lambert,[165] S. Lammers,[68] W. Lampl,[7] C. Lampoudis,[152,cc] A. N. Lancaster,[115] E. Lançon,[29] U. Landgraf,[54] M. P. J. Landon,[94] V. S. Lang,[54] R. J. Langenberg,[103] O. K. B. Langrekken,[125] A. J. Lankford,[160] F. Lanni,[36] K. Lantzsch,[24] A. Lanza,[73a] A. Lapertosa,[57b,57a] J. F. Laporte,[135] T. Lari,[71a] F. Lasagni Manghi,[23b] M. Lassnig,[36] V. Latonova,[131] A. Laudrain,[100] A. Laurier,[150] S. D. Lawlor,[95] Z. Lawrence,[101] M. Lazzaroni,[71a,71b] B. Le,[101] E. M. Le Boulicaut,[51] B. Leban,[93] A. Lebedev,[81] M. LeBlanc,[36] F. Ledroit-Guillon,[60] A. C. A. Lee,[96] S. C. Lee,[148] S. Lee,[47a,47b] T. F. Lee,[92] L. L. Leeuw,[33c] H. P. Lefebvre,[95] M. Lefebvre,[165] C. Leggett,[17a] G. Lehmann Miotto,[36] M. Leigh,[56] W. A. Leight,[103] W. Leinonen,[113] A. Leisos,[152,dd] M. A. L. Leite,[83c] C. E. Leitgeb,[48] R. Leitner,[133] K. J. C. Leney,[44] T. Lenz,[24] S. Leone,[74a] C. Leonidopoulos,[52] A. Leopold,[144] C. Leroy,[108] R. Les,[107] C. G. Lester,[32] M. Levchenko,[37] J. Levêque,[4] D. Levin,[106] L. J. Levinson,[169] M. P. Lewicki,[87] D. J. Lewis,[4] A. Li,[5] B. Li,[62b] C. Li,[62a] C-Q. Li,[62c] H. Li,[62a] H. Li,[62b] H. Li,[14c] H. Li,[62b] K. Li,[138] L. Li,[62c] M. Li,[14a,14e] Q. Y. Li,[62a] S. Li,[14a,14e] S. Li,[62d,62c,ee] T. Li,[5] X. Li,[104] Z. Li,[126] Z. Li,[104] Z. Li,[92] Z. Li,[14a,14e] Z. Liang,[14a] M. Liberatore,[135] B. Liberti,[76a] K. Lie,[64c] J. Lieber Marin,[83b] H. Lien,[68] K. Lin,[107] R. E. Lindley,[7] J. H. Lindon,[2] A. Linss,[48] E. Lipeles,[128] A. Lipniacka,[16] A. Lister,[164] J. D. Little,[4] B. Liu,[14a] B. X. Liu,[142] D. Liu,[62d,62c] J. B. Liu,[62a] J. K. K. Liu,[32] K. Liu,[62d,62c] M. Liu,[62a] M. Y. Liu,[62a] P. Liu,[14a] Q. Liu,[62d,138,62c] X. Liu,[62a] Y. Liu,[14d,14e] Y. L. Liu,[106] Y. W. Liu,[62a] J. Llorente Merino,[142] S. L. Lloyd,[94] E. M. Lobodzinska,[48] P. Loch,[7] S. Loffredo,[76a,76b] T. Lohse,[18] K. Lohwasser,[139] E. Loiacono,[48] M. Lokajicek,[131,a] J. D. Lomas,[20] J. D. Long,[162] I. Longarini,[160] L. Longo,[70a,70b] R. Longo,[162] I. Lopez Paz,[67] A. Lopez Solis,[48] J. Lorenz,[109] N. Lorenzo Martinez,[4] A. M. Lory,[109] G. Löschcke Centeno,[146] O. Loseva,[37] X. Lou,[47a,47b] X. Lou,[14a,14e] A. Lounis,[66] J. Love,[6] P. A. Love,[91] G. Lu,[14a,14e] M. Lu,[80] S. Lu,[128] Y. J. Lu,[65] H. J. Lubatti,[138] C. Luci,[75a,75b] F. L. Lucio Alves,[14c] A. Lucotte,[60] F. Luehring,[68] I. Luise,[145] O. Lukianchuk,[66] O. Lundberg,[144]

B. Lund-Jensen,[144] N. A. Luongo,[123] M. S. Lutz,[151] D. Lynn,[29] H. Lyons,[92] R. Lysak,[131] E. Lytken,[98] V. Lyubushkin,[38] T. Lyubushkina,[38] M. M. Lyukova,[145] H. Ma,[29] K. Ma,[62a] L. L. Ma,[62b] Y. Ma,[121] D. M. Mac Donell,[165] G. Maccarrone,[53] J. C. MacDonald,[100] R. Madar,[40] W. F. Mader,[50] J. Maeda,[85] T. Maeno,[29] M. Maerker,[50] H. Maguire,[139] V. Maiboroda,[135] A. Maio,[130a,130b,130d] K. Maj,[86a] O. Majersky,[48] S. Majewski,[123] N. Makovec,[66] V. Maksimovic,[15] B. Malaescu,[127] Pa. Malecki,[87] V. P. Maleev,[37] F. Malek,[60] M. Mali,[93] D. Malito,[95] U. Mallik,[80] S. Maltezos,[10] S. Malyukov,[38] J. Mamuzic,[13] G. Mancini,[53] G. Manco,[73a,73b] J. P. Mandalia,[94] I. Mandić,[93] L. Manhaes de Andrade Filho,[83a] I. M. Maniatis,[169] J. Manjarres Ramos,[102,ff] D. C. Mankad,[169] A. Mann,[109] B. Mansoulie,[135] S. Manzoni,[36] A. Marantis,[152,dd] G. Marchiori,[5] M. Marcisovsky,[131] C. Marcon,[71a,71b] M. Marinescu,[20] M. Marjanovic,[120] E. J. Marshall,[91] Z. Marshall,[17a] S. Marti-Garcia,[163] T. A. Martin,[167] V. J. Martin,[52] B. Martin dit Latour,[16] L. Martinelli,[75a,75b] M. Martinez,[13,w] P. Martinez Agullo,[163] V. I. Martinez Outschoorn,[103] P. Martinez Suarez,[13] S. Martin-Haugh,[134] V. S. Martoiu,[27b] A. C. Martyniuk,[96] A. Marzin,[36] D. Mascione,[78a,78b] L. Masetti,[100] T. Mashimo,[153] J. Masik,[101] A. L. Maslennikov,[37] L. Massa,[23b] P. Massarotti,[72a,72b] P. Mastrandrea,[74a,74b] A. Mastroberardino,[43b,43a] T. Masubuchi,[153] T. Mathisen,[161] J. Matousek,[133] N. Matsuzawa,[153] J. Maurer,[27b] B. Maček,[93] D. A. Maximov,[37] R. Mazini,[148] I. Maznas,[152] M. Mazza,[107] S. M. Mazza,[136] E. Mazzeo,[71a,71b] C. Mc Ginn,[29] J. P. Mc Gowan,[104] S. P. Mc Kee,[106] E. F. McDonald,[105] A. E. McDougall,[114] J. A. Mcfayden,[146] R. P. McGovern,[128] G. Mchedlidze,[149b] R. P. Mckenzie,[33g] T. C. Mclachlan,[48] D. J. Mclaughlin,[96] K. D. McLean,[165] S. J. McMahon,[134] P. C. McNamara,[105] C. M. Mcpartland,[92] R. A. McPherson,[165,q] S. Mehlhase,[109] A. Mehta,[92] D. Melini,[150] B. R. Mellado Garcia,[33g] A. H. Melo,[55] F. Meloni,[48] A. M. Mendes Jacques Da Costa,[101] H. Y. Meng,[155] L. Meng,[91] S. Menke,[110] M. Mentink,[36] E. Meoni,[43b,43a] C. Merlassino,[126] L. Merola,[72a,72b] C. Meroni,[71a,71b] G. Merz,[106] O. Meshkov,[37] J. Metcalfe,[6] A. S. Mete,[6] C. Meyer,[68] J-P. Meyer,[135] R. P. Middleton,[134] L. Mijović,[52] G. Mikenberg,[169] M. Mikestikova,[131] M. Mikuž,[93] H. Mildner,[100] A. Milic,[36] C. D. Milke,[44] D. W. Miller,[39] L. S. Miller,[34] A. Milov,[169] D. A. Milstead,[47a,47b] T. Min,[14c] A. A. Minaenko,[37] I. A. Minashvili,[149b] L. Mince,[59] A. I. Mincer,[117] B. Mindur,[86a] M. Mineev,[38] Y. Mino,[88] L. M. Mir,[13] M. Miralles Lopez,[163] M. Mironova,[17a] A. Mishima,[153] M. C. Missio,[113] T. Mitani,[168] A. Mitra,[167] V. A. Mitsou,[163] O. Miu,[155] P. S. Miyagawa,[94] Y. Miyazaki,[89] A. Mizukami,[84] T. Mkrtchyan,[63a] M. Mlinarevic,[96] T. Mlinarevic,[96] M. Mlynarikova,[36] S. Mobius,[19] K. Mochizuki,[108] P. Moder,[48] P. Mogg,[109] A. F. Mohammed,[14a,14e] S. Mohapatra,[41] G. Mokgatitswane,[33g] L. Moleri,[169] B. Mondal,[141] S. Mondal,[132] K. Mönig,[48] E. Monnier,[102] L. Monsonis Romero,[163] J. Montejo Berlingen,[13,84] M. Montella,[119] F. Montereali,[77a,77b] F. Monticelli,[90] S. Monzani,[69a,69c] N. Morange,[66] A. L. Moreira De Carvalho,[130a] M. Moreno Llácer,[163] C. Moreno Martinez,[56] P. Morettini,[57b] S. Morgenstern,[36] M. Morii,[61] M. Morinaga,[153] A. K. Morley,[36] F. Morodei,[75a,75b] L. Morvaj,[36] P. Moschovakos,[36] B. Moser,[36] M. Mosidze,[149b] T. Moskalets,[54] P. Moskvitina,[113] J. Moss,[31,gg] E. J. W. Moyse,[103] O. Mtintsilana,[33g] S. Muanza,[102] J. Mueller,[129] D. Muenstermann,[91] R. Müller,[19] G. A. Mullier,[161] A. J. Mullin,[32] J. J. Mullin,[128] D. P. Mungo,[155] D. Munoz Perez,[163] F. J. Munoz Sanchez,[101] M. Murin,[101] W. J. Murray,[167,134] A. Murrone,[71a,71b] J. M. Muse,[120] M. Muškinja,[17a] C. Mwewa,[29] A. G. Myagkov,[37,m] A. J. Myers,[8] A. A. Myers,[129] G. Myers,[68] M. Myska,[132] B. P. Nachman,[17a] O. Nackenhorst,[49] A. Nag,[50] K. Nagai,[126] K. Nagano,[84] J. L. Nagle,[29,j] E. Nagy,[102] A. M. Nairz,[36] Y. Nakahama,[84] K. Nakamura,[84] K. Nakkalil,[5] H. Nanjo,[124] R. Narayan,[44] E. A. Narayanan,[112] I. Naryshkin,[37] M. Naseri,[34] S. Nasri,[159] C. Nass,[24] G. Navarro,[22a] J. Navarro-Gonzalez,[163] R. Nayak,[151] A. Nayaz,[18] P. Y. Nechaeva,[37] F. Nechansky,[48] L. Nedic,[126] T. J. Neep,[20] A. Negri,[73a,73b] M. Negrini,[23b] C. Nellist,[114] C. Nelson,[104] K. Nelson,[106] S. Nemecek,[131] M. Nessi,[36,hh] M. S. Neubauer,[162] F. Neuhaus,[100] J. Neundorf,[48] R. Newhouse,[164] P. R. Newman,[20] C. W. Ng,[129] Y. W. Y. Ng,[48] B. Ngair,[35e] H. D. N. Nguyen,[108] R. B. Nickerson,[126] R. Nicolaidou,[135] J. Nielsen,[136] M. Niemeyer,[55] J. Niermann,[55,36] N. Nikiforou,[36] V. Nikolaenko,[37,m] I. Nikolic-Audit,[127] K. Nikolopoulos,[20] P. Nilsson,[29] I. Ninca,[48] H. R. Nindhito,[56] G. Ninio,[151] A. Nisati,[75a] N. Nishu,[2] R. Nisius,[110] J-E. Nitschke,[50] E. K. Nkadimeng,[33g] S. J. Noacco Rosende,[90] T. Nobe,[153] D. L. Noel,[32] T. Nommensen,[147] M. B. Norfolk,[139] R. R. B. Norisam,[96] B. J. Norman,[34] J. Novak,[93] T. Novak,[48] L. Novotny,[132] R. Novotny,[112] L. Nozka,[122] K. Ntekas,[160] N. M. J. Nunes De Moura Junior,[83b] E. Nurse,[96] J. Ocariz,[127] A. Ochi,[85] I. Ochoa,[130a] S. Oerdek,[161] J. T. Offermann,[39] A. Ogrodnik,[133] A. Oh,[101] C. C. Ohm,[144] H. Oide,[84] R. Oishi,[153] M. L. Ojeda,[48] Y. Okazaki,[88] M. W. O'Keefe,[92] Y. Okumura,[153]

L. F. Oleiro Seabra,[130a] S. A. Olivares Pino,[137d] D. Oliveira Damazio,[29] D. Oliveira Goncalves,[83a] J. L. Oliver,[160] A. Olszewski,[87] Ö. O. Öncel,[54] D. C. O'Neil,[142] A. P. O'Neill,[19] A. Onofre,[130a,130e] P. U. E. Onyisi,[11] M. J. Oreglia,[39] G. E. Orellana,[90] D. Orestano,[77a,77b] N. Orlando,[13] R. S. Orr,[155] V. O'Shea,[59] L. M. Osojnak,[128] R. Ospanov,[62a] G. Otero y Garzon,[30] H. Otono,[89] P. S. Ott,[63a] G. J. Ottino,[17a] M. Ouchrif,[35d] J. Ouellette,[29] F. Ould-Saada,[125] M. Owen,[59] R. E. Owen,[134] K. Y. Oyulmaz,[21a] V. E. Ozcan,[21a] N. Ozturk,[8] S. Ozturk,[82] H. A. Pacey,[32] A. Pacheco Pages,[13] C. Padilla Aranda,[13] G. Padovano,[75a,75b] S. Pagan Griso,[17a] G. Palacino,[68] A. Palazzo,[70a,70b] S. Palestini,[36] J. Pan,[172] T. Pan,[64a] D. K. Panchal,[11] C. E. Pandini,[114] J. G. Panduro Vazquez,[95] H. Pang,[14b] P. Pani,[48] G. Panizzo,[69a,69c] L. Paolozzi,[56] C. Papadatos,[108] S. Parajuli,[44] A. Paramonov,[6] C. Paraskevopoulos,[10] D. Paredes Hernandez,[64b] T. H. Park,[155] M. A. Parker,[32] F. Parodi,[57b,57a] E. W. Parrish,[115] V. A. Parrish,[52] J. A. Parsons,[41] U. Parzefall,[54] B. Pascual Dias,[108] L. Pascual Dominguez,[151] F. Pasquali,[114] E. Pasqualucci,[75a] S. Passaggio,[57b] F. Pastore,[95] P. Pasuwan,[47a,47b] P. Patel,[87] U. M. Patel,[51] J. R. Pater,[101] T. Pauly,[36] J. Pearkes,[143] M. Pedersen,[125] R. Pedro,[130a] S. V. Peleganchuk,[37] O. Penc,[36] E. A. Pender,[52] H. Peng,[62a] K. E. Penski,[109] M. Penzin,[37] B. S. Peralva,[83d] A. P. Pereira Peixoto,[60] L. Pereira Sanchez,[47a,47b] D. V. Perepelitsa,[29,j] E. Perez Codina,[156a] M. Perganti,[10] L. Perini,[71a,71b,a] H. Pernegger,[36] O. Perrin,[40] K. Peters,[48] R. F. Y. Peters,[101] B. A. Petersen,[36] T. C. Petersen,[42] E. Petit,[102] V. Petousis,[132] C. Petridou,[152,cc] A. Petrukhin,[141] M. Pettee,[17a] N. E. Pettersson,[36] A. Petukhov,[37] K. Petukhova,[133] A. Peyaud,[135] R. Pezoa,[137f] L. Pezzotti,[36] G. Pezzullo,[172] T. M. Pham,[170] T. Pham,[105] P. W. Phillips,[134] G. Piacquadio,[145] E. Pianori,[17a] F. Piazza,[71a,71b] R. Piegaia,[30] D. Pietreanu,[27b] A. D. Pilkington,[101] M. Pinamonti,[69a,69c] J. L. Pinfold,[2] B. C. Pinheiro Pereira,[130a] A. E. Pinto Pinoargote,[135] K. M. Piper,[146] A. Pirttikoski,[56] C. Pitman Donaldson,[96] D. A. Pizzi,[34] L. Pizzimento,[64b] A. Pizzini,[114] M.-A. Pleier,[29] V. Plesanovs,[54] V. Pleskot,[133] E. Plotnikova,[38] G. Poddar,[4] R. Poettgen,[98] L. Poggioli,[127] I. Pokharel,[55] S. Polacek,[133] G. Polesello,[73a] A. Poley,[142,156a] R. Polifka,[132] A. Polini,[23b] C. S. Pollard,[167] Z. B. Pollock,[119] V. Polychronakos,[29] E. Pompa Pacchi,[75a,75b] D. Ponomarenko,[113] L. Pontecorvo,[36] S. Popa,[27a] G. A. Popeneciu,[27d] A. Poreba,[36] D. M. Portillo Quintero,[156a] S. Pospisil,[132] M. A. Postill,[139] P. Postolache,[27c] K. Potamianos,[167] P. A. Potepa,[86a] I. N. Potrap,[38] C. J. Potter,[32] H. Potti,[1] T. Poulsen,[48] J. Poveda,[163] M. E. Pozo Astigarraga,[36] A. Prades Ibanez,[163] J. Pretel,[54] D. Price,[101] M. Primavera,[70a] M. A. Principe Martin,[99] R. Privara,[122] T. Procter,[59] M. L. Proffitt,[138] N. Proklova,[128] K. Prokofiev,[64c] G. Proto,[110] S. Protopopescu,[29] J. Proudfoot,[6] M. Przybycien,[86a] W. W. Przygoda,[86b] J. E. Puddefoot,[139] D. Pudzha,[37] D. Pyatiizbyantseva,[37] J. Qian,[106] D. Qichen,[101] Y. Qin,[101] T. Qiu,[52] A. Quadt,[55] M. Queitsch-Maitland,[101] G. Quetant,[56] 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] K. Ran,[48,14e] N. P. Rapheeha,[33g] H. Rasheed,[27b] V. Raskina,[127] D. F. Rassloff,[63a] S. Rave,[100] B. Ravina,[55] I. Ravinovich,[169] M. Raymond,[36] A. L. Read,[125] N. P. Readioff,[139] D. M. Rebuzzi,[73a,73b] G. Redlinger,[29] A. S. Reed,[110] K. Reeves,[26] J. A. Reidelsturz,[171] D. Reikher,[151] A. Rej,[141] C. Rembser,[36] A. Renardi,[48] M. Renda,[27b] M. B. Rendel,[110] F. Renner,[48] A. G. Rennie,[59] S. Resconi,[71a] M. Ressegotti,[57b,57a] S. Rettie,[36] J. G. Reyes Rivera,[107] B. Reynolds,[119] E. Reynolds,[17a] O. L. Rezanova,[37] P. Reznicek,[133] N. Ribaric,[91] E. Ricci,[78a,78b] R. Richter,[110] S. Richter,[47a,47b] E. Richter-Was,[86b] M. Ridel,[127] S. Ridouani,[35d] P. Rieck,[117] P. Riedler,[36] M. Rijssenbeek,[145] A. Rimoldi,[73a,73b] M. Rimoldi,[48] L. Rinaldi,[23b,23a] T. T. Rinn,[29] M. P. Rinnagel,[109] G. Ripellino,[161] I. Riu,[13] P. Rivadeneira,[48] J. C. Rivera Vergara,[165] F. Rizatdinova,[121] E. Rizvi,[94] B. A. Roberts,[167] B. R. Roberts,[17a] S. H. Robertson,[104,q] M. Robin,[48] D. Robinson,[32] C. M. Robles Gajardo,[137f] M. Robles Manzano,[100] A. Robson,[59] A. Rocchi,[76a,76b] C. Roda,[74a,74b] S. Rodriguez Bosca,[63a] Y. Rodriguez Garcia,[22a] A. Rodriguez Rodriguez,[54] A. M. Rodríguez Vera,[156b] S. Roe,[36] J. T. Roemer,[160] A. R. Roepe-Gier,[136] J. Roggel,[171] O. Røhne,[125] R. A. Rojas,[103] C. P. A. Roland,[68] J. Roloff,[29] A. Romaniouk,[37] E. Romano,[73a,73b] M. Romano,[23b] A. C. Romero Hernandez,[162] N. Rompotis,[92] L. Roos,[127] S. Rosati,[75a] B. J. Rosser,[39] E. Rossi,[126] E. Rossi,[72a,72b] L. P. Rossi,[57b] L. Rossini,[48] R. Rosten,[119] M. Rotaru,[27b] B. Rottler,[54] C. Rougier,[102,ff] D. Rousseau,[66] D. Rousso,[32] A. Roy,[162] S. Roy-Garand,[155] A. Rozanov,[102] Y. Rozen,[150] X. Ruan,[33g] A. Rubio Jimenez,[163] A. J. Ruby,[92] V. H. Ruelas Rivera,[18] T. A. Ruggeri,[1] A. Ruggiero,[126] A. Ruiz-Martinez,[163] A. Rummler,[36] Z. Rurikova,[54] N. A. Rusakovich,[38] H. L. Russell,[165] G. Russo,[75a,75b] J. P. Rutherfoord,[7] S. Rutherford Colmenares,[32] K. Rybacki,[91] M. Rybar,[133] E. B. Rye,[125] A. Ryzhov,[44] J. A. Sabater Iglesias,[56] P. Sabatini,[163] L. Sabetta,[75a,75b] H. F-W. Sadrozinski,[136] F. Safai Tehrani,[75a] B. Safarzadeh Samani,[146]

M. Safdari,[143] S. Saha,[165] M. Sahinsoy,[110] M. Saimpert,[135] M. Saito,[153] T. Saito,[153] D. Salamani,[36] A. Salnikov,[143] J. Salt,[163] A. Salvador Salas,[13] D. Salvatore,[43b,43a] F. Salvatore,[146] A. Salzburger,[36] D. Sammel,[54] D. Sampsonidis,[152,cc] D. Sampsonidou,[123] J. Sánchez,[163] A. Sanchez Pineda,[4] V. Sanchez Sebastian,[163] H. Sandaker,[125] C. O. Sander,[48] J. A. Sandesara,[103] M. Sandhoff,[171] C. Sandoval,[22b] D. P. C. Sankey,[134] T. Sano,[88] A. Sansoni,[53] L. Santi,[75a,75b] C. Santoni,[40] H. Santos,[130a,130b] S. N. Santpur,[17a] A. Santra,[169] K. A. Saoucha,[139] J. G. Saraiva,[130a,130d] J. Sardain,[7] O. Sasaki,[84] K. Sato,[157] C. Sauer,[63b] F. Sauerburger,[54] E. Sauvan,[4] P. Savard,[155,f] R. Sawada,[153] C. Sawyer,[134] L. Sawyer,[97] I. Sayago Galvan,[163] C. Sbarra,[23b] A. Sbrizzi,[23b,23a] T. Scanlon,[96] J. Schaarschmidt,[138] P. Schacht,[110] D. Schaefer,[39] U. Schäfer,[100] A. C. Schaffer,[66,44] D. Schaile,[109] R. D. Schamberger,[145] C. Scharf,[18] M. M. Schefer,[19] V. A. Schegelsky,[37] D. Scheirich,[133] F. Schenck,[18] M. Schernau,[160] C. Scheulen,[55] C. Schiavi,[57b,57a] E. J. Schioppa,[70a,70b] M. Schioppa,[43b,43a] B. Schlag,[143,u] K. E. Schleicher,[54] S. Schlenker,[36] J. Schmeing,[171] M. A. Schmidt,[171] K. Schmieden,[100] C. Schmitt,[100] S. Schmitt,[48] L. Schoeffel,[135] A. Schoening,[63b] P. G. Scholer,[54] E. Schopf,[126] M. Schott,[100] J. Schovancova,[36] S. Schramm,[56] F. Schroeder,[171] T. Schroer,[56] H-C. Schultz-Coulon,[63a] M. Schumacher,[54] B. A. Schumm,[136] Ph. Schune,[135] A. J. Schuy,[138] H. R. Schwartz,[136] A. Schwartzman,[143] T. A. Schwarz,[106] Ph. Schwemling,[135] R. Schwienhorst,[107] A. Sciandra,[136] G. Sciolla,[26] F. Scuri,[74a] C. D. Sebastiani,[92] K. Sedlaczek,[115] P. Seema,[18] S. C. Seidel,[112] A. Seiden,[136] B. D. Seidlitz,[41] C. Seitz,[48] J. M. Seixas,[83b] G. Sekhniaidze,[72a] S. J. Sekula,[44] L. Selem,[60] N. Semprini-Cesari,[23b,23a] D. Sengupta,[56] V. Senthilkumar,[163] L. Serin,[66] L. Serkin,[69a,69b] M. Sessa,[76a,76b] H. Severini,[120] F. Sforza,[57b,57a] A. Sfyrla,[56] E. Shabalina,[55] R. Shaheen,[144] J. D. Shahinian,[128] D. Shaked Renous,[169] L. Y. Shan,[14a] M. Shapiro,[17a] A. Sharma,[36] A. S. Sharma,[164] P. Sharma,[80] S. Sharma,[48] P. B. Shatalov,[37] K. Shaw,[146] S. M. Shaw,[101] A. Shcherbakova,[37] Q. Shen,[62c,5] P. Sherwood,[96] L. Shi,[96] X. Shi,[14a] C. O. Shimmin,[172] Y. Shimogama,[168] J. D. Shinner,[95] I. P. J. Shipsey,[126] S. Shirabe,[56,hh] M. Shiyakova,[38,ii] J. Shlomi,[169] M. J. Shochet,[39] J. Shojaii,[105] D. R. Shope,[125] B. Shrestha,[120] S. Shrestha,[119,jj] E. M. Shrif,[33g] M. J. Shroff,[165] P. Sicho,[131] A. M. Sickles,[162] E. Sideras Haddad,[33g] A. Sidoti,[23b] F. Siegert,[50] Dj. Sijacki,[15] R. Sikora,[86a] F. Sili,[90] J. M. Silva,[20] M. V. Silva Oliveira,[29] S. B. Silverstein,[47a] S. Simion,[66] R. Simoniello,[36] E. L. Simpson,[59] H. Simpson,[146] L. R. Simpson,[106] N. D. Simpson,[98] S. Simsek,[82] S. Sindhu,[55] P. Sinervo,[155] S. Singh,[155] S. Sinha,[48] S. Sinha,[101] M. Sioli,[23b,23a] I. Siral,[36] E. Sitnikova,[48] S. Yu. Sivoklokov,[37,a] J. Sjölin,[47a,47b] A. Skaf,[55] E. Skorda,[20] P. Skubic,[120] M. Slawinska,[87] V. Smakhtin,[169] B. H. Smart,[134] J. Smiesko,[36] S. Yu. Smirnov,[37] Y. Smirnov,[37] L. N. Smirnova,[37,m] O. Smirnova,[98] A. C. Smith,[41] E. A. Smith,[39] H. A. Smith,[126] J. L. Smith,[92] R. Smith,[143] M. Smizanska,[91] K. Smolek,[132] A. A. Snesarev,[37] S. R. Snider,[155] H. L. Snoek,[114] S. Snyder,[29] R. Sobie,[165,q] A. Soffer,[151] C. A. Solans Sanchez,[36] E. Yu. Soldatov,[37] U. Soldevila,[163] A. A. Solodkov,[37] S. Solomon,[26] A. Soloshenko,[38] K. Solovieva,[54] O. V. Solovyanov,[40] V. Solovyev,[37] P. Sommer,[36] A. Sonay,[13] W. Y. Song,[156b] J. M. Sonneveld,[114] A. Sopczak,[132] A. L. Sopio,[96] F. Sopkova,[28b] V. Sothilingam,[63a] S. Sottocornola,[68] R. Soualah,[116b] Z. Soumaimi,[35e] D. South,[48] S. Spagnolo,[70a,70b] M. Spalla,[110] D. Sperlich,[54] G. Spigo,[36] M. Spina,[146] S. Spinali,[91] D. P. Spiteri,[59] M. Spousta,[133] E. J. Staats,[34] A. Stabile,[71a,71b] R. Stamen,[63a] M. Stamenkovic,[114] A. Stampekis,[20] M. Standke,[24] E. Stanecka,[87] M. V. Stange,[50] B. Stanislaus,[17a] M. M. Stanitzki,[48] B. Stapf,[48] E. A. Starchenko,[37] G. H. Stark,[136] J. Stark,[102,ff] D. M. Starko,[156b] P. Staroba,[131] P. Starovoitov,[63a] S. Stärz,[104] R. Staszewski,[87] G. Stavropoulos,[46] J. Steentoft,[161] P. Steinberg,[29] B. Stelzer,[142,156a] H. J. Stelzer,[129] O. Stelzer-Chilton,[156a] H. Stenzel,[58] T. J. Stevenson,[146] G. A. Stewart,[36] J. R. Stewart,[121] M. C. Stockton,[36] G. Stoicea,[27b] M. Stolarski,[130a] S. Stonjek,[110] A. Straessner,[50] J. Strandberg,[144] S. Strandberg,[47a,47b] M. Strauss,[120] T. Strebler,[102] P. Strizenec,[28b] R. Ströhmer,[166] D. M. Strom,[123] L. R. Strom,[48] R. Stroynowski,[44] A. Strubig,[47a,47b] S. A. Stucci,[29] B. Stugu,[16] J. Stupak,[120] N. A. Styles,[48] D. Su,[143] S. Su,[62a] W. Su,[62d] X. Su,[62a,66] K. Sugizaki,[153] V. V. Sulin,[37] M. J. Sullivan,[92] D. M. S. Sultan,[78a,78b] L. Sultanaliyeva,[37] S. Sultansoy,[3b] T. Sumida,[88] S. Sun,[106] S. Sun,[170] O. Sunneborn Gudnadottir,[161] N. Sur,[102] M. R. Sutton,[146] H. Suzuki,[157] M. Svatos,[131] M. Swiatlowski,[156a] T. Swirski,[166] I. Sykora,[28a] M. Sykora,[133] T. Sykora,[133] D. Ta,[100] K. Tackmann,[48,kk] A. Taffard,[160] R. Tafirout,[156a] J. S. Tafoya Vargas,[66] E. P. Takeva,[52] Y. Takubo,[84] M. Talby,[102] A. A. Talyshev,[37] K. C. Tam,[64b] N. M. Tamir,[151] A. Tanaka,[153] J. Tanaka,[153] R. Tanaka,[66] M. Tanasini,[57b,57a] Z. Tao,[164] S. Tapia Araya,[137f] S. Tapprogge,[100] A. Tarek Abouelfadl Mohamed,[107] S. Tarem,[150] K. Tariq,[14a] G. Tarna,[102,27b] G. F. Tartarelli,[71a]

P. Tas,[133] M. Tasevsky,[131] E. Tassi,[43b,43a] A. C. Tate,[162] G. Tateno,[153] Y. Tayalati,[35e,ll] G. N. Taylor,[105] W. Taylor,[156b] H. Teagle,[92] A. S. Tee,[170] R. Teixeira De Lima,[143] P. Teixeira-Dias,[95] J. J. Teoh,[155] K. Terashi,[153] J. Terron,[99] S. Terzo,[13] M. Testa,[53] R. J. Teuscher,[155,q] A. Thaler,[79] O. Theiner,[56] N. Themistokleous,[52] T. Theveneaux-Pelzer,[102] O. Thielmann,[171] D. W. Thomas,[95] J. P. Thomas,[20] E. A. Thompson,[17a] P. D. Thompson,[20] E. Thomson,[128] Y. Tian,[55] V. Tikhomirov,[37,m] Yu. A. Tikhonov,[37] S. Timoshenko,[37] D. Timoshyn,[133] E. X. L. Ting,[1] P. Tipton,[172] S. H. Tlou,[33g] A. Tnourji,[40] K. Todome,[23b,23a] S. Todorova-Nova,[133] S. Todt,[50] M. Togawa,[84] J. Tojo,[89] S. Tokár,[28a] K. Tokushuku,[84] O. Toldaiev,[68] R. Tombs,[32] M. Tomoto,[84,111] L. Tompkins,[143,u] K. W. Topolnicki,[86b] E. Torrence,[123] H. Torres,[102,ff] E. Torró Pastor,[163] M. Toscani,[30] C. Tosciri,[39] M. Tost,[11] D. R. Tovey,[139] A. Traeet,[16] I. S. Trandafir,[27b] T. Trefzger,[166] A. Tricoli,[29] I. M. Trigger,[156a] S. Trincaz-Duvoid,[127] D. A. Trischuk,[26] B. Trocmé,[60] C. Troncon,[71a] L. Truong,[33c] M. Trzebinski,[87] A. Trzupek,[87] F. Tsai,[145] M. Tsai,[106] A. Tsiamis,[152,cc] P. V. Tsiareshka,[37] S. Tsigaridas,[156a] A. Tsirigotis,[152,dd] V. Tsiskaridze,[155] E. G. Tskhadadze,[149a] M. Tsopoulou,[152,cc] Y. Tsujikawa,[88] I. I. Tsukerman,[37] V. Tsulaia,[17a] S. Tsuno,[84] O. Tsur,[150] K. Tsuri,[118] D. Tsybychev,[145] Y. Tu,[64b] A. Tudorache,[27b] V. Tudorache,[27b] A. N. Tuna,[36] S. Turchikhin,[38] I. Turk Cakir,[3a] R. Turra,[71a] T. Turtuvshin,[38,mm] P. M. Tuts,[41] S. Tzamarias,[152,cc] P. Tzanis,[10] E. Tzovara,[100] K. Uchida,[153] F. Ukegawa,[157] P. A. Ulloa Poblete,[137c,137b] E. N. Umaka,[29] G. Unal,[36] M. Unal,[11] A. Undrus,[29] G. Unel,[160] J. Urban,[28b] P. Urquijo,[105] G. Usai,[8] R. Ushioda,[154] M. Usman,[108] Z. Uysal,[21b] L. Vacavant,[102] V. Vacek,[132] B. Vachon,[104] K. O. H. Vadla,[125] T. Vafeiadis,[36] A. Vaitkus,[96] C. Valderanis,[109] E. Valdes Santurio,[47a,47b] M. Valente,[156a] S. Valentinetti,[23b,23a] A. Valero,[163] E. Valiente Moreno,[163] A. Vallier,[102,ff] J. A. Valls Ferrer,[163] D. R. Van Arneman,[114] T. R. Van Daalen,[138] A. Van Der Graaf,[49] P. Van Gemmeren,[6] M. Van Rijnbach,[125,36] S. Van Stroud,[96] I. Van Vulpen,[114] M. Vanadia,[76a,76b] W. Vandelli,[36] M. Vandenbroucke,[135] E. R. Vandewall,[121] D. Vannicola,[151] L. Vannoli,[57b,57a] R. Vari,[75a] E. W. Varnes,[7] C. Varni,[17b] T. Varol,[148] D. Varouchas,[66] L. Varriale,[163] K. E. Varvell,[147] M. E. Vasile,[27b] L. Vaslin,[40] G. A. Vasquez,[165] F. Vazeille,[40] T. Vazquez Schroeder,[36] J. Veatch,[31] V. Vecchio,[101] M. J. Veen,[103] I. Veliscek,[126] L. M. Veloce,[155] F. Veloso,[130a,130c] S. Veneziano,[75a] A. Ventura,[70a,70b] A. Verbytskyi,[110] M. Verducci,[74a,74b] C. Vergis,[24] M. Verissimo De Araujo,[83b] W. Verkerke,[114] J. C. Vermeulen,[114] C. Vernieri,[143] M. Vessella,[103] M. C. Vetterli,[142,f] A. Vgenopoulos,[152,cc] N. Viaux Maira,[137f] T. Vickey,[139] O. E. Vickey Boeriu,[139] G. H. A. Viehhauser,[126] L. Vigani,[63b] M. Villa,[23b,23a] M. Villaplana Perez,[163] E. M. Villhauer,[52] E. Vilucchi,[53] M. G. Vincter,[34] G. S. Virdee,[20] A. Vishwakarma,[52] A. Visibile,[114] C. Vittori,[36] I. Vivarelli,[146] V. Vladimirov,[167] E. Voevodina,[110] F. Vogel,[109] P. Vokac,[132] J. Von Ahnen,[48] E. Von Toerne,[24] B. Vormwald,[36] V. Vorobel,[133] K. Vorobev,[37] M. Vos,[163] K. Voss,[141] J. H. Vossebeld,[92] M. Vozak,[114] L. Vozdecky,[94] N. Vranjes,[15] M. Vranjes Milosavljevic,[15] M. Vreeswijk,[114] R. Vuillermet,[36] O. Vujinovic,[100] I. Vukotic,[39] S. Wada,[157] C. Wagner,[103] J. M. Wagner,[17a] W. Wagner,[171] S. Wahdan,[171] H. Wahlberg,[90] R. Wakasa,[157] M. Wakida,[111] J. Walder,[134] R. Walker,[109] W. Walkowiak,[141] A. Wall,[128] T. Wamorkar,[6] A. Z. Wang,[170] C. Wang,[100] C. Wang,[62c] H. Wang,[17a] J. Wang,[64a] R.-J. Wang,[100] R. Wang,[61] R. Wang,[6] S. M. Wang,[148] S. Wang,[62b] T. Wang,[62a] W. T. Wang,[80] W. Wang,[14a] X. Wang,[14c] X. Wang,[162] X. Wang,[62c] Y. Wang,[62d] Y. Wang,[14c] Z. Wang,[106] Z. Wang,[62d,51,62c] Z. Wang,[106] A. Warburton,[104] R. J. Ward,[20] N. Warrack,[59] A. T. Watson,[20] H. Watson,[59] M. F. Watson,[20] E. Watton,[59,134] G. Watts,[138] B. M. Waugh,[96] C. Weber,[29] H. A. Weber,[18] M. S. Weber,[19] S. M. Weber,[63a] C. Wei,[62a] Y. Wei,[126] A. R. Weidberg,[126] E. J. Weik,[117] J. Weingarten,[49] M. Weirich,[100] C. Weiser,[54] C. J. Wells,[48] T. Wenaus,[29] B. Wendland,[49] T. Wengler,[36] N. S. Wenke,[110] N. Wermes,[24] M. Wessels,[63a] K. Whalen,[123] A. M. Wharton,[91] A. S. White,[61] A. White,[8] M. J. White,[1] D. Whiteson,[160] L. Wickremasinghe,[124] W. Wiedenmann,[170] C. Wiel,[50] M. Wielers,[134] C. Wiglesworth,[42] D. J. Wilbern,[120] H. G. Wilkens,[36] D. M. Williams,[41] H. H. Williams,[128] S. Williams,[32] S. Willocq,[103] B. J. Wilson,[101] P. J. Windischhofer,[39] F. I. Winkel,[30] F. Winklmeier,[123] B. T. Winter,[54] J. K. Winter,[101] M. Wittgen,[143] M. Wobisch,[97] Z. Wolffs,[114] R. Wölker,[126] J. Wollrath,[160] M. W. Wolter,[87] H. Wolters,[130a,130c] A. F. Wongel,[48] S. D. Worm,[48] B. K. Wosiek,[87] K. W. Woźniak,[87] S. Wozniewski,[55] K. Wraight,[59] C. Wu,[20] J. Wu,[14a,14e] M. Wu,[64a] M. Wu,[113] S. L. Wu,[170] X. Wu,[56] Y. Wu,[62a] Z. Wu,[135] J. Wuerzinger,[110,y] T. R. Wyatt,[101] B. M. Wynne,[52] S. Xella,[42] L. Xia,[14c] M. Xia,[14b] J. Xiang,[64c] X. Xiao,[106] M. Xie,[62a] X. Xie,[62a] S. Xin,[14a,14e] J. Xiong,[17a] D. Xu,[14a] H. Xu,[62a] L. Xu,[62a] R. Xu,[128] T. Xu,[106] Y. Xu,[14b] Z. Xu,[52] Z. Xu,[14a]

B. Yabsley,[147] S. Yacoob,[33a] N. Yamaguchi,[89] Y. Yamaguchi,[154] E. Yamashita,[153] H. Yamauchi,[157] T. Yamazaki,[17a] Y. Yamazaki,[85] J. Yan,[62c] S. Yan,[126] Z. Yan,[25] H. J. Yang,[62c,62d] H. T. Yang,[62a] S. Yang,[62a] T. Yang,[64c] X. Yang,[62a] X. Yang,[14a] Y. Yang,[44] Y. Yang,[62a] Z. Yang,[62a] W-M. Yao,[17a] Y. C. Yap,[48] H. Ye,[14c] H. Ye,[55] J. Ye,[44] S. Ye,[29] X. Ye,[62a] Y. Yeh,[96] I. Yeletskikh,[38] B. K. Yeo,[17b] M. R. Yexley,[96] P. Yin,[41] K. Yorita,[168] S. Younas,[27b] C. J. S. Young,[36] C. Young,[143] Y. Yu,[62a] M. Yuan,[106] R. Yuan,[62b,nn] L. Yue,[96] M. Zaazoua,[62a] B. Zabinski,[87] E. Zaid,[52] T. Zakareishvili,[149b] N. Zakharchuk,[34] S. Zambito,[56] J. A. Zamora Saa,[137d,137b] J. Zang,[153] D. Zanzi,[54] O. Zaplatilek,[132] C. Zeitnitz,[171] H. Zeng,[14a] J. C. Zeng,[162] D. T. Zenger Jr.,[26] O. Zenin,[37] T. Ženiš,[28a] S. Zenz,[94] S. Zerradi,[35a] D. Zerwas,[66] M. Zhai,[14a,14e] B. Zhang,[14c] D. F. Zhang,[139] J. Zhang,[62b] J. Zhang,[6] K. Zhang,[14a,14e] L. Zhang,[14c] P. Zhang,[14a,14e] R. Zhang,[170] S. Zhang,[106] T. Zhang,[153] X. Zhang,[62c] X. Zhang,[62b] Y. Zhang,[62c,5] Y. Zhang,[96] Z. Zhang,[17a] Z. Zhang,[66] H. Zhao,[138] P. Zhao,[51] T. Zhao,[62b] Y. Zhao,[136] Z. Zhao,[62a] A. Zhemchugov,[38] K. Zheng,[162] X. Zheng,[62a] Z. Zheng,[143] D. Zhong,[162] B. Zhou,[106] H. Zhou,[7] N. Zhou,[62c] Y. Zhou,[7] C. G. Zhu,[62b] J. Zhu,[106] Y. Zhu,[62c] Y. Zhu,[62a] X. Zhuang,[14a] K. Zhukov,[37] V. Zhulanov,[37] N. I. Zimine,[38] J. Zinsser,[63b] M. Ziolkowski,[141] L. Živković,[15] A. Zoccoli,[23b,23a] K. Zoch,[56] T. G. Zorbas,[139] 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]University Politehnica Bucharest, 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*
[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]*Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina*
[91]*Physics Department, Lancaster University, Lancaster, United Kingdom*
[92]*Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom*
[93]*Department of Experimental Particle Physics, Jožef Stefan Institute and Department of Physics, University of Ljubljana, Ljubljana, Slovenia*
[94]*School of Physics and Astronomy, Queen Mary University of London, London, United Kingdom*
[95]*Department of Physics, Royal Holloway University of London, Egham, United Kingdom*
[96]*Department of Physics and Astronomy, University College London, London, United Kingdom*

[97]Louisiana Tech University, Ruston, Louisiana, USA
[98]Fysiska institutionen, Lunds universitet, Lund, Sweden
[99]Departamento de Física Teorica C-15 and CIAFF, Universidad Autónoma de Madrid, Madrid, Spain
[100]Institut für Physik, Universität Mainz, Mainz, Germany
[101]School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom
[102]CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille, France
[103]Department of Physics, University of Massachusetts, Amherst, Massachusetts, USA
[104]Department of Physics, McGill University, Montreal, Quebec, Canada
[105]School of Physics, University of Melbourne, Victoria, Australia
[106]Department of Physics, University of Michigan, Ann Arbor, Michigan, USA
[107]Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan, USA
[108]Group of Particle Physics, University of Montreal, Montreal, Quebec, Canada
[109]Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany
[110]Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany
[111]Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya, Japan
[112]Department of Physics and Astronomy, University of New Mexico, Albuquerque, New Mexico, USA
[113]Institute for Mathematics, Astrophysics and Particle Physics, Radboud University/Nikhef, Nijmegen, Netherlands
[114]Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands
[115]Department of Physics, Northern Illinois University, DeKalb, Illinois, USA
[116a]New York University Abu Dhabi, Abu Dhabi, United Arab Emirates
[116b]University of Sharjah, Sharjah, United Arab Emirates
[117]Department of Physics, New York University, New York, New York, USA
[118]Ochanomizu University, Otsuka, Bunkyo-ku, Tokyo, Japan
[119]The Ohio State University, Columbus, Ohio, USA
[120]Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman, Oklahoma, USA
[121]Department of Physics, Oklahoma State University, Stillwater, Oklahoma, USA
[122]Palacký University, Joint Laboratory of Optics, Olomouc, Czech Republic
[123]Institute for Fundamental Science, University of Oregon, Eugene, Oregon, USA
[124]Graduate School of Science, Osaka University, Osaka, Japan
[125]Department of Physics, University of Oslo, Oslo, Norway
[126]Department of Physics, Oxford University, Oxford, United Kingdom
[127]LPNHE, Sorbonne Université, Université Paris Cité, CNRS/IN2P3, Paris, France
[128]Department of Physics, University of Pennsylvania, Philadelphia, Pennsylvania, USA
[129]Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, Pennsylvania, USA
[130a]Laboratório de Instrumentação e Física Experimental de Partículas—LIP, Lisboa, Portugal
[130b]Departamento de Física, Faculdade de Ciências, Universidade de Lisboa, Lisboa, Portugal
[130c]Departamento de Física, Universidade de Coimbra, Coimbra, Portugal
[130d]Centro de Física Nuclear da Universidade de Lisboa, Lisboa, Portugal
[130e]Departamento de Física, Universidade do Minho, Braga, Portugal
[130f]Departamento de Física Teórica y del Cosmos, Universidad de Granada, Granada (Spain), Spain
[130g]Departamento de Física, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal
[131]Institute of Physics of the Czech Academy of Sciences, Prague, Czech Republic
[132]Czech Technical University in Prague, Prague, Czech Republic
[133]Charles University, Faculty of Mathematics and Physics, Prague, Czech Republic
[134]Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom
[135]IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France
[136]Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz, California, USA
[137a]Departamento de Física, Pontificia Universidad Católica de Chile, Santiago, Chile
[137b]Millennium Institute for Subatomic physics at high energy frontier (SAPHIR), Santiago, Chile
[137c]Instituto de Investigación Multidisciplinario en Ciencia y Tecnología, y Departamento de Física, Universidad de La Serena, Chile
[137d]Universidad Andres Bello, Department of Physics, Santiago, Chile
[137e]Instituto de Alta Investigación, Universidad de Tarapacá, Arica, Chile
[137f]Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile
[138]Department of Physics, University of Washington, Seattle, Washington, USA
[139]Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom
[140]Department of Physics, Shinshu University, Nagano, Japan
[141]Department Physik, Universität Siegen, Siegen, Germany
[142]Department of Physics, Simon Fraser University, Burnaby, British Columbia, Canada
[143]SLAC National Accelerator Laboratory, Stanford, California, USA
[144]Department of Physics, Royal Institute of Technology, Stockholm, Sweden

[145]Departments of Physics and Astronomy, Stony Brook University, Stony Brook, New York, USA
[146]Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom
[147]School of Physics, University of Sydney, Sydney, Australia
[148]Institute of Physics, Academia Sinica, Taipei, Taiwan
[149a]E. Andronikashvili Institute of Physics, Iv. Javakhishvili Tbilisi State University, Tbilisi, Georgia
[149b]High Energy Physics Institute, Tbilisi State University, Tbilisi, Georgia
[149c]University of Georgia, Tbilisi, Georgia
[150]Department of Physics, Technion, Israel Institute of Technology, Haifa, Israel
[151]Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel
[152]Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece
[153]International Center for Elementary Particle Physics and Department of Physics, University of Tokyo, Tokyo, Japan
[154]Department of Physics, Tokyo Institute of Technology, Tokyo, Japan
[155]Department of Physics, University of Toronto, Toronto, Ontario, Canada
[156a]TRIUMF, Vancouver, British Columbia, Canada
[156b]Department of Physics and Astronomy, York University, Toronto, Ontario, Canada
[157]Division of Physics and Tomonaga Center for the History of the Universe, Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba, Japan
[158]Department of Physics and Astronomy, Tufts University, Medford, Massachusetts, USA
[159]United Arab Emirates University, Al Ain, United Arab Emirates
[160]Department of Physics and Astronomy, University of California Irvine, Irvine, California, USA
[161]Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden
[162]Department of Physics, University of Illinois, Urbana, Illinois, USA
[163]Instituto de Física Corpuscular (IFIC), Centro Mixto Universidad de Valencia—CSIC, Valencia, Spain
[164]Department of Physics, University of British Columbia, Vancouver, British Columbia, Canada
[165]Department of Physics and Astronomy, University of Victoria, Victoria, British Columbia, Canada
[166]Fakultät für Physik und Astronomie, Julius-Maximilians-Universität Würzburg, Würzburg, Germany
[167]Department of Physics, University of Warwick, Coventry, United Kingdom
[168]Waseda University, Tokyo, Japan
[169]Department of Particle Physics and Astrophysics, Weizmann Institute of Science, Rehovot, Israel
[170]Department of Physics, University of Wisconsin, Madison, Wisconsin, USA
[171]Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal, Germany
[172]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 Department of Modern Physics and State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei.
[e]Also at Lawrence Livermore National Laboratory, Livermore, USA.
[f]Also at TRIUMF, Vancouver, British Columbia, Canada.
[g]Also at Department of Physics, University of Thessaly, Greece.
[h]Also at An-Najah National University, Nablus, Palestine.
[i]Also at Department of Physics, University of Fribourg, Fribourg, Switzerland.
[j]Also at University of Colorado Boulder, Department of Physics, Colorado, USA.
[k]Also at Department of Physics, Westmont College, Santa Barbara, USA.
[l]Also at Departament de Fisica de la Universitat Autonoma de Barcelona, Barcelona, Spain.
[m]Also at Affiliated with an institute covered by a cooperation agreement with CERN.
[n]Also at The Collaborative Innovation Center of Quantum Matter (CICQM), Beijing, China.
[o]Also at Department of Physics, Ben Gurion University of the Negev, Beer Sheva, Israel.
[p]Also at Università di Napoli Parthenope, Napoli, Italy.
[q]Also at Institute of Particle Physics (IPP), Canada.
[r]Also at Borough of Manhattan Community College, City University of New York, New York, New York, USA.
[s]Also at National Institute of Physics, University of the Philippines Diliman (Philippines), Philippines.
[t]Also at Department of Financial and Management Engineering, University of the Aegean, Chios, Greece.
[u]Also at Department of Physics, Stanford University, Stanford, California, USA.
[v]Also at Centro Studi e Ricerche Enrico Fermi, Italy.
[w]Also at Institucio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona, Spain.
[x]Also at Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany.
[y]Also at Technical University of Munich, Munich, Germany.
[z]Also at Yeditepe University, Physics Department, Istanbul, Türkiye.

[aa]Also at Institute of Theoretical Physics, Ilia State University, Tbilisi, Georgia.
[bb]Also at CERN, Geneva, Switzerland.
[cc]Also at Center for Interdisciplinary Research and Innovation (CIRI-AUTH), Thessaloniki, Greece.
[dd]Also at Hellenic Open University, Patras, Greece.
[ee]Also at Center for High Energy Physics, Peking University, China.
[ff]Also at L2IT, Université de Toulouse, CNRS/IN2P3, UPS, Toulouse, France.
[gg]Also at Department of Physics, California State University, Sacramento, USA.
[hh]Also at Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève, Switzerland.
[ii]Also at Institute for Nuclear Research and Nuclear Energy (INRNE) of the Bulgarian Academy of Sciences, Sofia, Bulgaria.
[jj]Also at Washington College, Chestertown, Maryland, USA.
[kk]Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany.
[ll]Also at Institute of Applied Physics, Mohammed VI Polytechnic University, Ben Guerir, Morocco.
[mm]Also at Institute of Physics and Technology, Ulaanbaatar, Mongolia.
[nn]Also at Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan, USA.