



Deposited via The University of Sheffield.

White Rose Research Online URL for this paper:

<https://eprints.whiterose.ac.uk/id/eprint/207733/>

Version: Published Version

---

**Article:**

Aad, G., Abbott, B., Abbott, D.C. et al. (2023) Observation of single-top-quark production in association with a photon using the ATLAS detector. *Physical Review Letters*, 131. 181901. ISSN: 0031-9007

<https://doi.org/10.1103/physrevlett.131.181901>

---

**Reuse**

This article is distributed under the terms of the Creative Commons Attribution (CC BY) licence. This licence allows you to distribute, remix, tweak, and build upon the work, even commercially, as long as you credit the authors for the original work. More information and the full terms of the licence here:

<https://creativecommons.org/licenses/>

**Takedown**

If you consider content in White Rose Research Online to be in breach of UK law, please notify us by emailing [eprints@whiterose.ac.uk](mailto:eprints@whiterose.ac.uk) including the URL of the record and the reason for the withdrawal request.

## Observation of Single-Top-Quark Production in Association with a Photon Using the ATLAS Detector

G. Aad *et al.*\*  
(ATLAS Collaboration)

(Received 6 February 2023; revised 3 August 2023; accepted 9 August 2023; published 30 October 2023)

This Letter reports the observation of single top quarks produced together with a photon, which directly probes the electroweak coupling of the top quark. The analysis uses  $139 \text{ fb}^{-1}$  of 13 TeV proton-proton collision data collected with the ATLAS detector at the Large Hadron Collider. Requiring a photon with transverse momentum larger than 20 GeV and within the detector acceptance, the fiducial cross section is measured to be  $688 \pm 23(\text{stat})_{-71}^{+75}(\text{syst}) \text{ fb}$ , to be compared with the standard model prediction of  $515_{-42}^{+36} \text{ fb}$  at next-to-leading order in QCD.

DOI: 10.1103/PhysRevLett.131.181901

Measurements of rare associated-production processes of the top quark ( $t$ ) are crucial in probing the top quark's electroweak couplings, which are fundamental quantities of the standard model (SM). While pair production ( $t\bar{t}$ ) has been observed in association with a Higgs boson [1,2],  $W$  boson [3],  $Z$  boson [3,4], or photon ( $\gamma$ ) [5], single-top-quark production has so far only been observed in association with a  $Z$  [6,7] or  $W$  boson [8,9]. These processes play a crucial role in constraining nonresonant contributions from physics beyond the SM (BSM), parametrized in the framework of the SM effective field theory [10–14]. This Letter reports the observation of single-top-quark production in association with a photon in the dominant  $t$ -channel mode with the ATLAS detector [15] at the Large Hadron Collider (LHC). The full 13 TeV proton-proton ( $pp$ ) dataset is used, corresponding to an integrated luminosity of  $139 \text{ fb}^{-1}$  [16]. The CMS Collaboration previously reported evidence for this process using  $35.9 \text{ fb}^{-1}$  of  $pp$  data collected at 13 TeV [17].

In single-top-quark production, a photon can be radiated from any of the charged particles in the initial and final states, but the radiation before the top-quark decay is of particular interest. This process, in the following denoted as  $tq\gamma$ , where  $q$  stands for the additional quark produced in the  $t$  channel, represents a direct probe of the top-photon coupling and offers sensitivity to BSM contributions comparable to established probes, e.g., photon-associated top-quark pair production ( $t\bar{t}\gamma$ ) [18,19]. This Letter only considers semileptonic top-quark decays in  $tq\gamma$  production

as they provide better sensitivity than hadronic decays. An example Feynman diagram is shown in Fig. 1. The signature of this process consists of a photon, an electron or muon ( $\ell$ ), missing transverse momentum ( $E_T^{\text{miss}}$ ) from the neutrino ( $\nu$ ), a  $b$  jet from the top-quark decay, and a forward jet characteristic of  $t$ -channel production. The jet arising from the second  $b$  quark from gluon splitting is often not  $b$  tagged because of its low transverse momentum and forward direction. The photon can also be radiated from the top quark's charged decay products, called the  $t(\rightarrow \ell\nu b\gamma)q$  process.

Two cross section measurements are performed in fiducial phase spaces. A measurement of the cross section of the combined  $tq\gamma$  and  $t(\rightarrow \ell\nu b\gamma)q$  processes is performed in a fiducial phase space at stable-particle level. In addition, the cross section for  $tq\gamma$  production alone is measured in a fiducial phase space that allows for a direct comparison with fixed-order predictions where, in contrast to the phase space at stable-particle level, parton showering and hadronization are not considered.

The ATLAS detector is a multipurpose particle physics detector with cylindrical geometry [20]. It consists of an

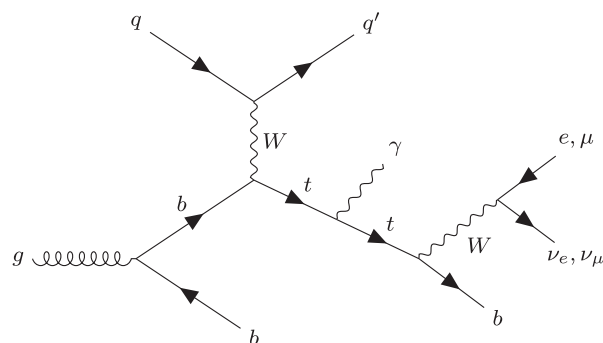


FIG. 1. Representative Feynman diagram at leading order in  $\alpha_s$  for  $tq\gamma$  production with semileptonic top-quark decay.

\*Full author list given at the end of the Letter.

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

inner tracker surrounded by a superconducting solenoid, sampling electromagnetic and hadronic calorimeters, and a muon spectrometer with three toroidal superconducting magnets with eight coils each. A two-level trigger system is used to select events for storage. Events used in this analysis were selected online by sets of single-electron or single-muon triggers with their lowest transverse-momentum ( $p_T$ ) thresholds being 20–26 GeV, depending on the data-taking year [21–23]. An extensive software suite [24] 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 selection of the primary proton-interaction vertex as well as the reconstruction and identification of electrons, muons, photons, and jets follow Ref. [25], with the difference that jets are considered with  $|\eta|$  up to 4.5, which accounts for the forward jet from the  $t$ -channel production. The definition of  $E_T^{\text{miss}}$  and the  $b$ -tagging algorithm (DL1r [26]) for the jets are identical to those in Ref. [25].

Signal and most background processes are estimated with Monte Carlo (MC) simulations, which include pileup effects. The full GEANT4-based [27] ATLAS detector simulation is used [28] with corrections applied for the different reconstructed objects [29–34].

Two signal regions (SRs) are defined, based on the presence or absence of the forward jet (fj) in the event. In both SRs, the presence of one photon, one electron, or muon matched to a trigger object, one tight  $b$ -tagged jet, no additional loose  $b$ -tagged jets, and  $E_T^{\text{miss}} > 30$  GeV is required. In addition, the 0fj SR ( $\geq 1$ fj SR) must contain no (at least one) forward jet with  $2.5 < |\eta| < 4.5$ . The tight and loose operating points of the  $b$ -tagging algorithm correspond to efficiencies of 70% and 85% and to misidentification rates of 8% (0.2%) and 35% (2.5%) for  $c$  jets (light-flavor jets), estimated in  $t\bar{t}$  MC simulations. In both SRs, the electron-photon invariant mass must be outside the range 80–100 GeV to suppress the  $Z \rightarrow ee$  contribution with an electron misidentified as a photon.

The measured combined  $tq\gamma$  and  $t(\rightarrow \ell\nu b\gamma)q$  rate is unfolded to a fiducial phase space that is defined at stable-particle level, where “stable” refers to lifetimes larger than 30 ps, and is translated into a fiducial cross section times branching ratio. The definitions of photons, photon isolation, electrons, muons, jets, and  $b$ -tagged jets at stable-particle level follow Ref. [35], except that jets are considered with  $|\eta|$  up to 4.9. This phase space is defined close to the SRs by requiring one electron or muon with  $p_T > 25$  GeV and  $|\eta| < 2.5$ , at least one photon with  $p_T > 20$  GeV and  $|\eta| < 2.37$ , at least one  $b$ -tagged jet with  $p_T > 25$  GeV and  $|\eta| < 2.5$ , and at least one neutrino that is not produced in a hadron decay. Jets are required to be separated by more than  $\Delta R = 0.4$  from any lepton and isolated photon. No photon must be within  $\Delta R = 0.4$  of any jet or lepton. The SM fiducial cross section at

stable-particle level times branching ratio, where the branching ratio of the semileptonic top-quark decay is denoted by  $\mathcal{B}(t \rightarrow \ell\nu b)$ , is calculated at next-to-leading order (NLO) in QCD using the signal samples for  $tq\gamma$  and  $t(\rightarrow \ell\nu b\gamma)q$  defined below:  $\sigma_{tq\gamma} \times \mathcal{B}(t \rightarrow \ell\nu b) + \sigma_{t(\rightarrow \ell\nu b\gamma)q} = 217_{-15}^{+27}$  fb. The branching ratio for  $t \rightarrow \ell\nu b$  is set to 32.46%, consistent with the value in the signal MC samples. The uncertainty includes variations of the parton distribution functions (PDFs) and of the scales, uncertainties in the parton-shower model, the choice of matrix-element generator, the modeling of initial- and final-state radiation, and a 20% uncertainty in the  $t(\rightarrow \ell\nu b\gamma)q$  process normalization (cf. the Appendix). The  $t(\rightarrow \ell\nu b\gamma)q$  process constitutes  $\approx 20\%$  of the events in the fiducial region.

Additionally, the measured  $tq\gamma$  rate is unfolded to a fiducial phase space and is translated into a fiducial cross section times branching ratio. The phase space is defined before hadronization and parton showering by requiring at least one photon with  $p_T > 20$  GeV and  $|\eta| < 2.37$  that must be Frixione isolated [36] with a chosen isolation radius of  $\Delta R = 0.2$ . Following Ref. [37], the fixed-order SM fiducial cross section times branching ratio is calculated with MADGRAPH5\_AMC@NLO [38] at NLO in QCD as  $\sigma_{tq\gamma} \times \mathcal{B}(t \rightarrow \ell\nu b) = 515_{-42}^{+36}$  fb. The cross section calculation uses the five-flavor scheme, with  $b$  quarks included in the proton. Renormalization and factorization scales as well as the PDF set are chosen as in Ref. [37]. The uncertainties are estimated from scale and PDF variations and from a comparison with the corresponding calculation in the four-flavor scheme (no third-generation quarks in the proton) [37,39].

The  $tq\gamma$  process was simulated in the four-flavor scheme at NLO in QCD with MADGRAPH5\_AMC@NLO using the NNPDF3.0 [40] PDF set and MADSPIN [41] for  $t \rightarrow Wb \rightarrow \ell\nu b$  decay. Photons must be Frixione isolated and have  $p_T > 10$  GeV and  $|\eta| < 5.0$ . Renormalization and factorization scales were set to  $\frac{1}{2} \sum_i \sqrt{m_i^2 + p_{T,i}^2}$ , where the sum is over all final-state particles before the top-quark decay. PYTHIA8 [42] was used for parton showering and hadronization. PYTHIA8 always used the leading-order (LO) NNPDF2.3 PDF set [43], the A14 tune [44], and EVTGEN [45]. The  $t(\rightarrow \ell\nu b\gamma)q$  process was simulated via single-top-quark production in the  $t$  channel (without photon radiation) using POWHEG [46] in the four-flavor scheme at NLO with the NNPDF3.0 PDF set, interfaced to PYTHIA8 and MADSPIN for the semileptonic top-quark decay. Photon radiation in the decay was treated by the parton-shower simulation. Initially, the  $tq\gamma$  process is normalized to the cross section at NLO in QCD obtained with MADGRAPH5\_AMC@NLO and the same settings used for the sample production, and the  $t(\rightarrow \ell\nu b\gamma)q$  process is normalized to the production cross section at NLO in QCD [47,48]. The overlap between the  $tq\gamma$  and  $t(\rightarrow \ell\nu b\gamma)q$

samples is removed using kinematic information about the generated particles (cf. the Appendix).

The most important background processes with prompt photons are  $t\bar{t}\gamma$  production, which refers to photon radiation in  $t\bar{t}$  production and  $t\bar{t}$  production with radiative decay ( $t \rightarrow \ell\nu b\gamma$  and  $t \rightarrow q\bar{q}'b\gamma$ ), and  $W\gamma$  + jets production. Their contribution to the SRs is estimated using MC simulations (cf. the Appendix), normalized to data in dedicated control regions (CRs) enriched in  $t\bar{t}\gamma$  and  $W\gamma$  + jets events. The CRs are inclusive in forward jets and the same selection criteria as for the SRs are used, except for the  $b$ -tagging requirements. In the  $t\bar{t}\gamma$  CR, an additional loose  $b$ -tagged jet must be present to account for the second  $b$  quark in this process. In the  $W\gamma$  CR, there must be at least one loose  $b$ -tagged jet and no tight  $b$ -tagged jets. This suppresses contamination of the CR with processes with one or several  $b$  quarks in the final state. Other background contributions that are modeled by MC simulations (cf. the Appendix) are the following production processes:  $Z\gamma$  + jets,  $t\bar{t}$ , single top quark,  $W/Z$  + jets, and diboson. The events from these MC samples, apart from  $Z\gamma$  + jets events, are categorized into events with prompt photons (“other prompt  $\gamma$ ”), electrons misidentified as photons ( $e \rightarrow \gamma$ ), and hadrons misidentified as photons ( $h \rightarrow \gamma$ ). All background MC samples use the same setup as in Ref. [25]. An additional small background contribution arises from events with fake leptons, i.e., other objects that are misidentified as electron or muon, and is estimated from data using the asymptotic matrix method with loosened lepton criteria [49,50].

The MC predictions for background processes with  $e \rightarrow \gamma$  fakes, most notably dileptonic  $t\bar{t}$  events, are corrected by comparing the  $e \rightarrow \gamma$  probability in data and MC simulation using  $Z \rightarrow e^+e^-$  events (see Supplemental Material [51]). Events with  $E_T^{\text{miss}} < 30$  GeV and no  $b$ -tagged jet are selected if the invariant mass of either an  $e^+e^-$  pair or an  $e\gamma$  pair is close to the  $Z$ -boson mass, where the photon in the latter case is likely from  $e \rightarrow \gamma$ . Data-to-MC corrections are derived as functions of the photon  $\eta$  and the different types of photon reconstruction [29]. No strong dependence of the corrections on the photon  $p_T$  is found. The corrections are validated by comparing data with the prediction in a region with  $E_T^{\text{miss}} < 30$  GeV and at least one  $b$ -tagged jet.

The MC predictions for background processes with  $h \rightarrow \gamma$  fakes, mostly lepton + jets  $t\bar{t}$  events, are also corrected using data [51]. Selections with partially inverted photon-identification and/or inverted photon-isolation criteria are used, respectively, to define regions that are kinematically close to the analysis regions but enriched in events with  $h \rightarrow \gamma$ . Considering the low correlation between the identification and isolation criteria, the ABCD method (see, for example, Ref. [52]) is used to estimate the number of  $h \rightarrow \gamma$  events in the analysis regions. This residual small correlation is taken from MC simulations and is corrected for in the estimate. The  $h \rightarrow \gamma$  rate estimate is performed in two

bins of photon  $p_T$  and as a function of photon reconstruction types and  $\eta$ , and is used to correct the overall normalization of the contribution from  $h \rightarrow \gamma$  events.

According to these signal and background predictions, the signal fraction [“ $tq\gamma$ ” plus “ $t(\rightarrow \ell\nu b\gamma)q$ ”] in the 0fj ( $\geq 1$ fj) SR is 5% (10%) and the main backgrounds are  $t\bar{t}\gamma$  with 29% (34%),  $e \rightarrow \gamma$  fake-photon events with 24% (25%),  $W\gamma$  + jets with 20% (12%), and  $h \rightarrow \gamma$  fake events with 7% (7%). Smaller backgrounds originate from  $Z\gamma$  + jets, the other prompt  $\gamma$  contribution, and events with fake leptons.

Uncertainties in the photon identification [29,53] and isolation efficiencies [29] are considered, as are those in the electron and muon trigger, reconstruction, identification, and isolation efficiencies [29,54,55]; the photon and electron energy [29] and muon momentum scale and resolution [55]; the jet pileup rejection [33], and jet energy scale [32,56], resolution [32], and  $b$ -tagging efficiency [31,57,58]; and the  $E_T^{\text{miss}}$  reconstruction [34].

Uncertainties in the inclusive cross sections and in the modeling (scale variations, comparisons of generator setups, etc.) of the different processes are considered (cf. the Appendix). Since the analysis includes CRs for the  $t\bar{t}\gamma$  and  $W\gamma$  + jets processes, their normalization is estimated directly from data.

Uncertainties in the  $e \rightarrow \gamma$  corrections are estimated by varying the background contributions, the  $Z$ -boson MC modeling, the  $Z$ -boson mass range, and the photon energy scale (see Supplemental Material [51]). Uncertainties in the  $h \rightarrow \gamma$  corrections originate from the statistical uncertainties, the limited number of MC events, contributions from non- $h \rightarrow \gamma$  events, and variations of the correlation between the inverted identification and isolation criteria [51].

Neural networks (NNs) are trained to separate the signal from the background in the SRs. KERAS [59] with the TENSORFLOW [60] back end is used with binary cross-entropy as the loss function. The NN output nodes use a sigmoid activation function. In the 0fj and  $\geq 1$ fj SRs, 12 and 15 input variables are used, respectively. These comprise individual kinematic properties ( $p_T$  and/or  $\eta$ ) of the photon, the lepton, the  $b$ -tagged jet, and the highest- $p_T$  forward jet, kinematic combinations (scalar  $p_T$  sum, invariant and transverse masses, angular distances, transverse momentum, energy) of these objects, and the  $E_T^{\text{miss}}$ , as well as the lepton type and the  $b$ -tagging properties of the  $b$ -tagged jet [31]. The top quark is reconstructed from the  $b$ -tagged jet, the lepton, and the  $E_T^{\text{miss}}$ . The top-quark mass is the NN input variable giving the largest separation in both SRs as it separates  $tq\gamma$  from backgrounds without a top quark, top-quark events with  $t \rightarrow \ell\nu b\gamma$ , as well as top-quark pair production where the chosen objects are less likely associated with the same top-quark decay. Figure 2 shows this variable in the  $W\gamma$  CR as an example, illustrating that the data are described by the MC simulation within the uncertainties.

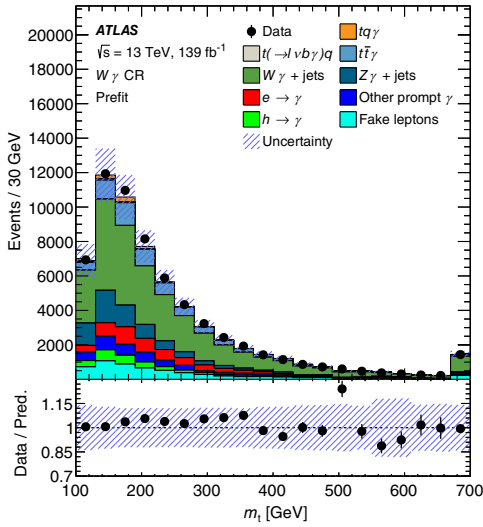


FIG. 2. Distribution of the reconstructed top-quark mass in the  $W\gamma$  CR before the profile-likelihood fit. The hashed band represents the uncertainties and the first and last bins include the underflow and overflow.

To test for the presence of  $tq\gamma$  production and measure the signal cross sections, a profile-likelihood fit using asymptotic formulas [61] is performed simultaneously in the SRs and CRs with systematic uncertainties treated as nuisance parameters. The uncertainty due to the limited number of MC events is included [62]. In the 0fj ( $\geq 1$ fj) SRs, the 0fj ( $\geq 1$ fj) NN output distributions are used in the fit. In the  $t\bar{t}\gamma$  CR, the 0fj ( $\geq 1$ fj) NN output is used for events with no (at least one) forward jet, and the inclusive event yield is used in the  $W\gamma$  CR. The  $t\bar{t}\gamma$  and  $W\gamma$  + jets normalizations are free parameters of the fit. The result of the fit is shown in Fig. 3. The predicted sum of all backgrounds is not compatible with the data. The observed

(expected) significance of the  $tq\gamma$  signal is  $9.3\sigma$  ( $6.8\sigma$ ). The fitted  $t\bar{t}\gamma$  and  $W\gamma$  + jets normalizations are consistent with the nominal prediction within the uncertainties of  $+14\%$  and  $+20\%$  (the  $t\bar{t}\gamma$  uncertainty is  $-13\%$  and  $-17\%$ ). The observed significance exceeds (is less than)  $5\sigma$  when the 0fj SR ( $\geq 1$ fj SR) is excluded from the fit. However, the inclusion of the 0fj SR significantly improves the precision of the measured signal cross sections.

The measured fiducial cross section at stable-particle level is  $\sigma_{iq\gamma} \times \mathcal{B}(t \rightarrow \ell\nu b) + \sigma_{t(\rightarrow \ell\nu b\gamma)q} = 303 \pm 9(\text{stat})_{-32}^{+33}(\text{syst})$  fb. The measured fiducial cross section of  $tq\gamma$  production is  $\sigma_{iq\gamma} \times \mathcal{B}(t \rightarrow \ell\nu b) = 688 \pm 23(\text{stat})_{-71}^{+75}(\text{syst})$  fb. Both phase-space definitions require the photon  $p_T$  to be at least 20 GeV. The precision of both measured fiducial cross sections of about 11% is mainly limited by systematic uncertainties. The main sources of systematic uncertainty in the measurement of the fiducial cross section at stable-particle level (of  $tq\gamma$  production) are the modeling of  $t\bar{t}\gamma$  production with  $\pm 5.5\%$  ( $\pm 5.5\%$ ), the limited number of MC events for the background processes with  $\pm 3.6\%$  ( $\pm 3.5\%$ ) and for the  $tq\gamma$  process with  $\pm 3.0\%$  ( $\pm 3.3\%$ ), and the modeling of the  $t(\rightarrow \ell\nu b\gamma)q$  process with  $\pm 3.3\%$  ( $\pm 1.9\%$ ) and of the  $t\bar{t}$  process with  $\pm 2.3\%$  ( $\pm 2.4\%$ ). The uncertainty in the modeling of the  $t(\rightarrow \ell\nu b\gamma)q$  process has a larger impact on the measurement at stable-particle level, because the  $t(\rightarrow \ell\nu b\gamma)q$  contribution is considered as part of the signal and is hence not fixed to the SM expectation.

The measured fiducial cross section at stable-particle level (of  $tq\gamma$  production) is compatible with the SM predictions at NLO in  $\alpha_s$  of  $217_{-15}^{+27}$  fb ( $515_{-42}^{+36}$  fb) within 2.0 (2.1) standard deviations. The 30%–40% higher measured cross sections are consistent with the results of the CMS measurement [17], which yielded  $1.42 \pm 0.43$  times the SM prediction in a slightly different fiducial phase space. It will need to be studied whether the small tension

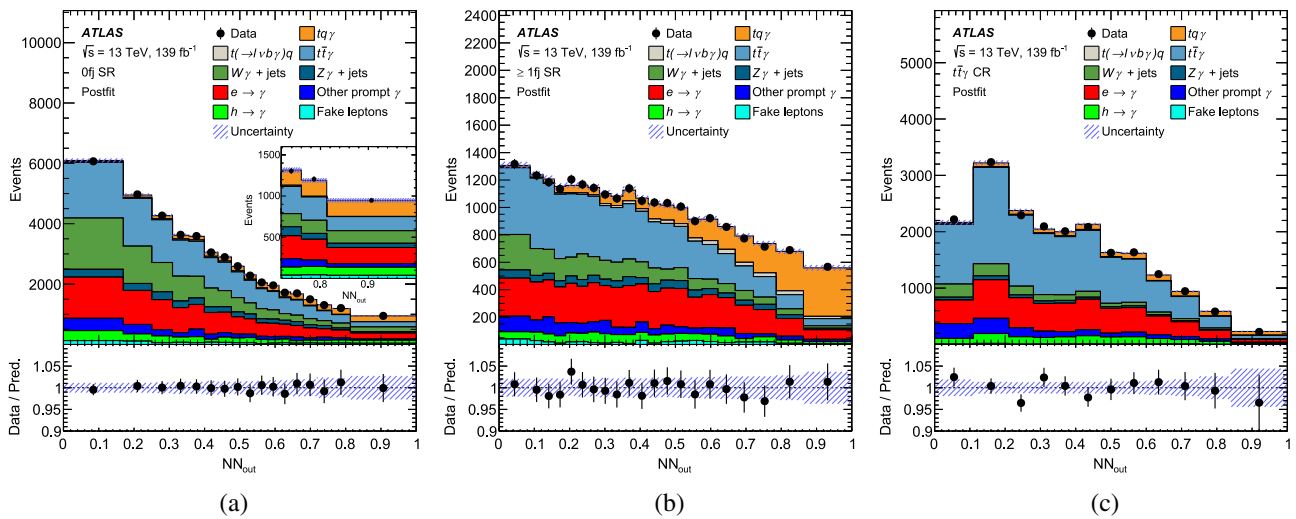


FIG. 3. Distributions of the NN outputs in (a) the 0fj SR, (b) the  $\geq 1$ fj SR, and (c) the  $t\bar{t}\gamma$  CR in data and the expected contribution of the signal and background processes after the profile-likelihood fit. The hashed band represents the uncertainties in the SM prediction. The inset in (a) presents a close-up of the last three bins of the NN output.

between measurements and theory predictions becomes more significant in future works on  $tq\gamma$  production. Corrections at approximate next-to-next-to-leading order (NNLO) in a similar phase space were found to enhance the  $tq\gamma$  cross section by 5.1% [63]. In conclusion, this Letter observed the associated production of a single top quark and a photon and measured its cross section in fiducial phase spaces with a precision of 11%. It hence completes the picture of top-quark-associated production with the gauge bosons in the electroweak sector and establishes a new direct probe of the coupling of the top quark to the photon, which plays an important role to deepen the understanding of the top-quark's electroweak coupling.

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 Benozio 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, USA. 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 Programmes 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 (UK), and BNL (USA), the Tier-2 facilities worldwide, and large non-WLCG resource providers. Major contributors of computing resources are listed in Ref. [64].

*Appendix: Systematic uncertainties.*—This appendix contains additional information about signal and background MC samples and their systematic uncertainties.

In order to remove the overlap between the  $tq\gamma$  and  $t(\rightarrow \ell\nu b\gamma)q$  samples, events from the  $t(\rightarrow \ell\nu b\gamma)q$  sample are kept when the hypothesis of a radiative-decay photon better approximates the true  $W$ -boson or top-quark mass, i.e. either the  $\ell\nu\gamma$  or the  $\ell\nu b\gamma$  invariant mass is closer than the  $\ell\nu$  or  $\ell\nu b$  invariant mass to the  $W$ -boson or top-quark mass, respectively. The uncertainty associated with this procedure in the prediction of the fiducial cross section at stable-particle level is conservatively estimated to be 20%, based on  $tq\gamma$  events that are falsely categorized as  $t(\rightarrow \ell\nu b\gamma)q$ .

The background MC samples include the following production processes: photon radiation in  $t\bar{t}$  production (NLO),  $t\bar{t}$  with radiative decay (LO),  $W\gamma/Z\gamma$  + jets (NLO for up to one additional parton, LO for up to three) [65–75],  $t\bar{t}$  [76–79], single top quark [46,80],  $W/Z$  + jets (NLO for up to two additional partons, LO for up to four), and diboson (NLO for up to one additional parton, LO for up to three). The overlap between samples with photons generated in the matrix element and those with photons from the parton shower is removed using generator-level information. The numbers of events from several MC samples are normalized to cross sections calculated to higher orders in  $\alpha_s$ : NNLO plus next-to-next-to-leading-logarithm precision for  $t\bar{t}$  production [81–87], NNLO precision for  $W$  + jets and  $Z$  + jets production [88], and NLO (NNLO) precision for single-top-quark production in the  $t$  and  $s$  channel [47,48] ( $tW$  channel [89]). For  $t\bar{t}$  production with radiative decay, a LO-to-NLO correction factor of 1.67 is determined by subtracting the NLO MADGRAPH5\_AMC@NLO prediction for the  $t\bar{t}\gamma$  process from an NLO calculation of the full process [90].

The uncertainties in the inclusive cross sections amount to 6% for  $t\bar{t}$  [43,87,91–93], 5.3% for single-top-quark production [89,94,95], 5% for  $W$  + jets and  $Z$  + jets [96], 30% for  $Z\gamma$  + jets, and 50% for diboson production, mostly in association with  $b$  jets. An additional uncertainty of 30% is assigned for the normalization of  $W\gamma$  production in association with  $b$  jets. The possible phase-space dependence of the LO-to-NLO correction factor for  $t\bar{t}$  production with radiative decay is estimated by changing the correction factor from 1.67 to 1.97, motivated by the correction determined in Ref. [35]. A 30% uncertainty is assigned to the normalization of the  $t(\rightarrow \ell\nu b\gamma)q$  process, conservatively taken to be of the order of the difference between the predicted  $t(\rightarrow \ell\nu b\gamma)q$  event yields at LO and NLO. Uncertainties in the fake-lepton background arise from the uncertainties in the prompt-lepton subtraction in the matrix method and from a 50% normalization uncertainty.

The uncertainty in the integrated luminosity is 1.7% [16]. The uncertainty in the simulation of pileup is estimated by varying the average expected number of interactions per bunch crossing by 3%.

Modeling uncertainties are evaluated as follows. Renormalization and factorization scales as well as PDFs are varied in the signal and background MC samples. The uncertainty from the choice of MC generator is estimated by comparing the nominal  $t(\rightarrow \ell\nu b\gamma)q$ ,  $t\bar{t}$ , and  $tW$  samples with alternative samples generated with MADGRAPH5\_AMC@NLO interfaced to PYTHIA8. For the  $tW$  sample, the difference between the diagram-subtraction scheme and the nominal diagram-removal scheme [80] is used as an uncertainty. The uncertainty from the choice of parton-shower program is estimated by comparing the nominal signal,  $t\bar{t}\gamma$ ,  $t\bar{t}$ , and  $tW$  samples with samples interfaced to HERWIG7 [97,98]. The  $t\bar{t}$  sample is compared with a sample with the value of the  $h_{\text{damp}}$  parameter, controlling the  $p_T$  of the first gluon emission in the POWHEG generator, increased from  $1.5m_{\text{top}}$  to  $3m_{\text{top}}$  [99]. The uncertainty in the modeling of initial- and final-state radiation is estimated by systematic variations in the A14 tune [44] in the signal,  $t\bar{t}\gamma$  and  $t\bar{t}$  samples. In addition, an uncertainty in the  $t(\rightarrow \ell\nu b\gamma)q$  sample is estimated by comparing the shapes predicted by the nominal sample with the shapes predicted by a LO sample with the decay  $t(\rightarrow \ell\nu b\gamma)q$  simulated directly in the hard process with MADGRAPH5\_AMC@NLO using the NNPDF3.0 PDF set and interfaced with PYTHIA8.

- 
- [1] ATLAS Collaboration, Observation of Higgs boson production in association with a top quark pair at the LHC with the ATLAS detector, *Phys. Lett. B* **784**, 173 (2018).
- [2] CMS Collaboration, Observation of  $t\bar{t}H$  Production, *Phys. Rev. Lett.* **120**, 231801 (2018).
- [3] CMS Collaboration, Measurement of the cross section for top quark pair production in association with a  $W$  or  $Z$  boson in proton-proton collisions at  $\sqrt{s} = 13$  TeV, *J. High Energy Phys.* **08** (2018) 011.
- [4] ATLAS Collaboration, Measurement of the  $t\bar{t}Z$  and  $t\bar{t}W$  cross sections in proton-proton collisions at  $\sqrt{s} = 13$  TeV with the ATLAS detector, *Phys. Rev. D* **99**, 072009 (2019).
- [5] ATLAS Collaboration, Observation of top-quark pair production in association with a photon and measurement of the  $t\bar{t}\gamma$  production cross section in  $pp$  collisions at  $\sqrt{s} = 7$  TeV using the ATLAS detector, *Phys. Rev. D* **91**, 072007 (2015).
- [6] ATLAS Collaboration, Observation of the associated production of a top quark and a  $Z$  boson in  $pp$  collisions at  $\sqrt{s} = 13$  TeV with the ATLAS detector, *J. High Energy Phys.* **07** (2020) 124.
- [7] CMS Collaboration, Observation of Single Top Quark Production in Association with a  $Z$  Boson in Proton-Proton Collisions at  $\sqrt{s} = 13$  TeV, *Phys. Rev. Lett.* **122**, 132003 (2019).
- [8] ATLAS Collaboration, Measurement of the production cross-section of a single top quark in association with a  $W$  boson at 8 TeV with the ATLAS experiment, *J. High Energy Phys.* **01** (2016) 064.
- [9] CMS Collaboration, Observation of the Associated Production of a Single Top Quark and a  $W$  Boson in  $pp$  Collisions at  $\sqrt{s} = 8$  TeV, *Phys. Rev. Lett.* **112**, 231802 (2014).
- [10] A. Buckley, C. Englert, J. Ferrando, D. J. Miller, L. Moore, M. Russel, and C. D. White, Constraining top quark effective theory in the LHC run II era, *J. High Energy Phys.* **04** (2016) 015.
- [11] N. P. Hartland, F. Maltoni, E. R. Nocera, J. Rojo, E. Slade, E. Vryonidou, and C. Zhang, A Monte Carlo global analysis of the standard model effective field theory: The top quark sector, *J. High Energy Phys.* **04** (2019) 100.
- [12] G. Durieux, A. Irlles, V. Miralles, A. Peñuelas, M. Perelló, R. Pöschl, and M. Vos, The electro-weak couplings of the top and bottom quarks—Global fit and future prospects, *J. High Energy Phys.* **12** (2019) 98; **01** (2021) 195(E).
- [13] I. Brivio, S. Bruggisser, F. Maltoni, R. Moutafis, T. Plehn, E. Vryonidou, S. Westhoff, and C. Zhang, O new physics, where art thou? A global search in the top sector, *J. High Energy Phys.* **02** (2020) 131.
- [14] V. Miralles, M. M. López, M. M. Llácer, A. Peñuelas, M. Perelló, and M. Vos, The top quark electro-weak couplings after LHC run 2, *J. High Energy Phys.* **02** (2022) 032.
- [15] ATLAS Collaboration, The ATLAS experiment at the CERN Large Hadron Collider, *J. Instrum.* **3**, S08003 (2008).
- [16] ATLAS Collaboration, Luminosity determination in  $pp$  collisions at  $\sqrt{s} = 13$  TeV using the ATLAS detector at the LHC, Report No. ATLAS-CONF-2019-021, 2019, <https://cds.cern.ch/record/2677054>.
- [17] CMS Collaboration, Evidence for the Associated Production of a Single Top Quark and a Photon in Proton-Proton Collisions at  $\sqrt{s} = 13$  TeV, *Phys. Rev. Lett.* **121**, 221802 (2018).
- [18] M. Fael and T. Gehrmann, Probing top quark electromagnetic dipole moments in single-top-plus-photon production, *Phys. Rev. D* **88**, 033003 (2013).
- [19] S. M. Etesami, S. Khatibi, and M. Mohammadi Najafabadi, Measuring anomalous  $WW\gamma$  and  $t\bar{t}\gamma$  couplings using top +  $\gamma$  production at the LHC, *Eur. Phys. J. C* **76**, 533 (2016).
- [20] 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  $(r, \phi)$  are used in the transverse plane,  $\phi$  being the azimuthal angle around the  $z$  axis. The pseudorapidity is defined in terms of the polar angle  $\theta$  as  $\eta = -\ln \tan(\theta/2)$ . Angular distance is measured in units of  $\Delta R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$ .
- [21] ATLAS Collaboration, Performance of the ATLAS trigger system in 2015, *Eur. Phys. J. C* **77**, 317 (2017).
- [22] ATLAS Collaboration, Performance of electron and photon triggers in ATLAS during LHC run 2, *Eur. Phys. J. C* **80**, 47 (2020).
- [23] ATLAS Collaboration, Performance of the ATLAS muon triggers in run 2, *J. Instrum.* **15**, P09015 (2020).

- [24] ATLAS Collaboration, The ATLAS Collaboration software and firmware, Report No. ATL-SOFT-PUB-2021-001, 2021, <https://cds.cern.ch/record/2767187>.
- [25] ATLAS Collaboration, Search for flavour-changing neutral-current couplings between the top quark and the photon with the ATLAS detector at  $\sqrt{s} = 13$  TeV, *Phys. Lett. B* **842**, 137379 (2022).
- [26] ATLAS Collaboration, ATLAS flavour-tagging algorithms for the LHC run 2  $pp$  collision dataset, *Eur. Phys. J. C* **83**, 681 (2023).
- [27] S. Agostinelli *et al.*, GEANT4—a simulation toolkit, *Nucl. Instrum. Methods Phys. Res., Sect. A* **506**, 250 (2003).
- [28] ATLAS Collaboration, The ATLAS simulation infrastructure, *Eur. Phys. J. C* **70**, 823 (2010).
- [29] 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).
- [30] ATLAS Collaboration, Muon reconstruction and identification efficiency in ATLAS using the full run 2  $pp$  collision data set at  $\sqrt{s} = 13$  TeV, *Eur. Phys. J. C* **81**, 578 (2021).
- [31] ATLAS Collaboration, ATLAS  $b$ -jet identification performance and efficiency measurement with  $t\bar{t}$  events in  $pp$  collisions at  $\sqrt{s} = 13$  TeV, *Eur. Phys. J. C* **79**, 970 (2019).
- [32] ATLAS Collaboration, Jet energy scale and resolution measured in proton-proton collisions at  $\sqrt{s} = 13$  TeV with the ATLAS detector, *Eur. Phys. J. C* **81**, 689 (2020).
- [33] ATLAS Collaboration, Performance of pile-up mitigation techniques for jets in  $pp$  collisions at  $\sqrt{s} = 8$  TeV using the ATLAS detector, *Eur. Phys. J. C* **76**, 581 (2016).
- [34] 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).
- [35] ATLAS Collaboration, Measurements of inclusive and differential fiducial cross-sections of  $t\bar{t}\gamma$  production in leptonic final states at  $\sqrt{s} = 13$  TeV in ATLAS, *Eur. Phys. J. C* **79**, 382 (2019).
- [36] S. Frixione, Isolated photons in perturbative QCD, *Phys. Lett. B* **429**, 369 (1998).
- [37] D. Pagani, H.-S. Shao, I. Tsinikos, and M. Zaro, Automated EW corrections with isolated photons:  $t\bar{t}\gamma$ ,  $t\bar{t}\gamma\gamma$  and  $t\gamma j$  as case studies, *J. High Energy Phys.* **09** (2021) 155.
- [38] J. Alwall, R. Frederix, S. Frixione, V. Hirschi, F. Maltoni, O. Mattelaer, H.-S. Shao, T. Stelzer, P. Torrielli, and M. Zaro, The automated computation of tree-level and next-to-leading-order differential cross sections, and their matching to parton shower simulations, *J. High Energy Phys.* **07** (2014) 079.
- [39] D. Pagani, I. Tsinikos, and E. Vryonidou, NLO QCD + EW predictions for  $tHj$  and  $tZj$  production at the LHC, *J. High Energy Phys.* **08** (2020) 082.
- [40] R. D. Ball *et al.* (NNPDF Collaboration), Parton distributions for the LHC run II, *J. High Energy Phys.* **04** (2015) 040.
- [41] P. Artoisenet, R. Frederix, O. Mattelaer, and R. Rietkerk, Automatic spin-entangled decays of heavy resonances in Monte Carlo simulations, *J. High Energy Phys.* **03** (2013) 015.
- [42] T. Sjöstrand, S. Ask, J. R. Christiansen, R. Corke, N. Desai, P. Ilten, S. Mrenna, S. Prestel, C. O. Rasmussen, and P. Z. Skands, An introduction to PYTHIA8.2, *Comput. Phys. Commun.* **191**, 159 (2015).
- [43] R. D. Ball *et al.* (NNPDF Collaboration), Parton distributions with LHC data, *Nucl. Phys.* **B867**, 244 (2013).
- [44] ATLAS Collaboration, ATLAS PYTHIA8 tunes to 7 TeV data, Report No. ATL-PHYS-PUB-2014-021, 2014, <https://cds.cern.ch/record/1966419>.
- [45] D. J. Lange, The EVTGEN particle decay simulation package, *Nucl. Instrum. Methods Phys. Res., Sect. A* **462**, 152 (2001).
- [46] R. Frederix, E. Re, and P. Torrielli, Single-top  $t$ -channel hadroproduction in the four-flavour scheme with POWHEG and aMC@NLO, *J. High Energy Phys.* **09** (2012) 130.
- [47] P. Kant, O. M. Kind, T. Kintscher, T. Lohse, T. Martini, S. Mölbitz, P. Rieck, and P. Uwer, HatHor for single top-quark production: Updated predictions and uncertainty estimates for single top-quark production in hadronic collisions, *Comput. Phys. Commun.* **191**, 74 (2015).
- [48] M. Aliev, H. Lacker, U. Langenfeld, S. Moch, P. Uwer, and M. Wiedermann, HATHOR—Hadronic top and heavy quarks cross section calculator, *Comput. Phys. Commun.* **182**, 1034 (2011).
- [49] D0 Collaboration, Measurement of the  $t\bar{t}$  production cross section in  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96$  TeV using kinematic characteristics of lepton + jets events, *Phys. Rev. D* **76**, 092007 (2007).
- [50] ATLAS Collaboration, Tools for estimating fake/non-prompt lepton backgrounds with the ATLAS detector at the LHC, [arXiv:2211.16178](https://arxiv.org/abs/2211.16178).
- [51] See Supplemental Material at <http://link.aps.org/supplemental/10.1103/PhysRevLett.131.181901> for technical descriptions of the estimation of the  $e \rightarrow \gamma$  and  $h \rightarrow \gamma$  backgrounds.
- [52] CDF Collaboration, Measurement of  $\sigma B(W \rightarrow e\nu)$  and  $\sigma B(Z^0 \rightarrow e^+e^-)$  in  $p\bar{p}$  collisions at  $\sqrt{s} = 1800$  GeV, *Phys. Rev. D* **44**, 29 (1991).
- [53] ATLAS Collaboration, Measurement of the photon identification efficiencies with the ATLAS detector using LHC run 2 data collected in 2015 and 2016, *Eur. Phys. J. C* **79**, 205 (2019).
- [54] 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).
- [55] ATLAS Collaboration, Muon reconstruction performance of the ATLAS detector in proton-proton collision data at  $\sqrt{s} = 13$  TeV, *Eur. Phys. J. C* **76**, 292 (2016).
- [56] ATLAS Collaboration, Jet energy scale measurements and their systematic uncertainties in proton-proton collisions at  $\sqrt{s} = 13$  TeV with the ATLAS detector, *Phys. Rev. D* **96**, 072002 (2017).
- [57] ATLAS Collaboration, Calibration of the light-flavour jet mistagging efficiency of the  $b$ -tagging algorithms with  $Z +$  jets events using  $139 \text{ fb}^{-1}$  of ATLAS proton-proton collision data at  $\sqrt{s} = 13$  TeV, *Eur. Phys. J. C* **83**, 728 (2023).
- [58] ATLAS Collaboration, Measurement of the  $c$ -jet mistagging efficiency in  $t\bar{t}$  events using  $pp$  collision data at  $\sqrt{s} = 13$  TeV collected with the ATLAS detector, *Eur. Phys. J. C* **82**, 95 (2022).
- [59] F. Chollet *et al.*, KERAS, 2015, <https://keras.io>.
- [60] M. Abadi *et al.*, TENSORFLOW: Large-scale machine learning on heterogeneous distributed systems, <https://www.tensorflow.org> (2015).

- [61] G. Cowan, K. Cranmer, E. Gross, and O. Vitells, Asymptotic formulae for likelihood-based tests of new physics, *Eur. Phys. J. C* **71**, 1554 (2011).
- [62] R. Barlow and C. Beeston, Fitting using finite Monte Carlo samples, *Comput. Phys. Commun.* **77**, 219 (1993).
- [63] N. Kidonakis and N. Yamanaka, QCD corrections in  $tq\bar{q}$  production at hadron colliders, *Eur. Phys. J. C* **82**, 670 (2022).
- [64] ATLAS Collaboration, ATLAS computing acknowledgements, Report No. ATL-SOFT-PUB-2021-003, 2021, <https://cds.cern.ch/record/2776662>.
- [65] E. Bothmann *et al.*, Event generation with Sherpa 2.2, *SciPost Phys.* **7**, 034 (2019).
- [66] T. Gleisberg and S. Höche, Comix, a new matrix element generator, *J. High Energy Phys.* **12** (2008) 039.
- [67] S. Schumann and F. Krauss, A parton shower algorithm based on Catani–Seymour dipole factorisation, *J. High Energy Phys.* **03** (2008) 038.
- [68] S. Höche, F. Krauss, M. Schönherr, and F. Siegert, A critical appraisal of NLO + PS matching methods, *J. High Energy Phys.* **09** (2012) 049.
- [69] S. Höche, F. Krauss, M. Schönherr, and F. Siegert, QCD matrix elements + parton showers. The NLO case, *J. High Energy Phys.* **04** (2013) 027.
- [70] S. Catani, F. Krauss, B. R. Webber, and R. Kuhn, QCD matrix elements + parton showers, *J. High Energy Phys.* **11** (2001) 063.
- [71] S. Höche, F. Krauss, S. Schumann, and F. Siegert, QCD matrix elements and truncated showers, *J. High Energy Phys.* **05** (2009) 053.
- [72] F. Buccioni, J.-N. Lang, J. M. Lindert, P. Maierhöfer, S. Pozzorini, H. Zhang, and M. F. Zoller, OpenLoops 2, *Eur. Phys. J. C* **79**, 866 (2019).
- [73] F. Cascioli, P. Maierhöfer, and S. Pozzorini, Scattering Amplitudes with Open Loops, *Phys. Rev. Lett.* **108**, 111601 (2012).
- [74] F. Buccioni, S. Pozzorini, and M. Zoller, On-the-fly reduction of open loops, *Eur. Phys. J. C* **78**, 70 (2018).
- [75] A. Denner, S. Dittmaier, and L. Hofer, Collier: A FORTRAN-based complex one-loop library in extended regularizations, *Comput. Phys. Commun.* **212**, 220 (2017).
- [76] S. Frixione, G. Ridolfi, and P. Nason, A positive-weight next-to-leading-order Monte Carlo for heavy flavour hadroproduction, *J. High Energy Phys.* **09** (2007) 126.
- [77] P. Nason, A new method for combining NLO QCD with shower Monte Carlo algorithms, *J. High Energy Phys.* **11** (2004) 040.
- [78] 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.
- [79] 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.
- [80] S. Frixione, E. Laenen, P. Motylinski, C. White, and B. R. Webber, Single-top hadroproduction in association with a  $W$  boson, *J. High Energy Phys.* **07** (2008) 029.
- [81] M. Beneke, P. Falgari, S. Klein, and C. Schwinn, Hadronic top-quark pair production with NNLL threshold resummation, *Nucl. Phys.* **B855**, 695 (2012).
- [82] M. Cacciari, M. Czakon, M. Mangano, A. Mitov, and P. Nason, Top-pair production at hadron colliders with next-to-next-to-leading logarithmic soft-gluon resummation, *Phys. Lett. B* **710**, 612 (2012).
- [83] P. Bärnreuther, M. Czakon, and A. Mitov, Percent-Level-Precision Physics at the Tevatron: Next-to-Next-to-Leading Order QCD Corrections to  $q\bar{q} \rightarrow t\bar{t} + X$ , *Phys. Rev. Lett.* **109**, 132001 (2012).
- [84] M. Czakon and A. Mitov, NNLO corrections to top-pair production at hadron colliders: The all-fermionic scattering channels, *J. High Energy Phys.* **12** (2012) 054.
- [85] M. Czakon and A. Mitov, NNLO corrections to top pair production at hadron colliders: The quark-gluon reaction, *J. High Energy Phys.* **01** (2013) 080.
- [86] M. Czakon, P. Fiedler, and A. Mitov, Total Top-Quark Pair-Production Cross Section at Hadron Colliders through  $O(\alpha_s^4)$ , *Phys. Rev. Lett.* **110**, 252004 (2013).
- [87] M. Czakon and A. Mitov, Top++: A program for the calculation of the top-pair cross-section at hadron colliders, *Comput. Phys. Commun.* **185**, 2930 (2014).
- [88] C. Anastasiou, L. Dixon, K. Melnikov, and F. Petriello, High-precision QCD at hadron colliders: Electroweak gauge boson rapidity distributions at next-to-next-to leading order, *Phys. Rev. D* **69**, 094008 (2004).
- [89] N. Kidonakis, Two-loop soft anomalous dimensions for single top quark associated production with a  $W^-$  or  $H^-$ , *Phys. Rev. D* **82**, 054018 (2010).
- [90] K. Melnikov, M. Schulze, and A. Scharf, QCD corrections to top quark pair production in association with a photon at hadron colliders, *Phys. Rev. D* **83**, 074013 (2011).
- [91] J. Butterworth *et al.*, PDF4LHC recommendations for LHC run II, *J. Phys. G* **43**, 023001 (2016).
- [92] A. D. Martin, W. J. Stirling, R. S. Thorne, and G. Watt, Uncertainties on  $\alpha_s$  in global PDF analyses and implications for predicted hadronic cross sections, *Eur. Phys. J. C* **64**, 653 (2009).
- [93] J. Gao, M. Guzzi, J. Huston, H.-L. Lai, Z. Li, P. Nadolsky, J. Pumplin, D. Stump, and C.-P. Yuan, CT10 next-to-next-to-leading order global analysis of QCD, *Phys. Rev. D* **89**, 033009 (2014).
- [94] N. Kidonakis, Next-to-next-to-leading-order collinear and soft gluon corrections for t-channel single top quark production, *Phys. Rev. D* **83**, 091503(R) (2011).
- [95] N. Kidonakis, Next-to-next-to-leading logarithm resummation for s-channel single top quark production, *Phys. Rev. D* **81**, 054028 (2010).
- [96] ATLAS Collaboration, Monte Carlo generators for the production of a  $W$  or  $Z/\gamma^*$  boson in association with jets at ATLAS in run 2, Report No. ATL-PHYS-PUB-2016-003, 2016, <https://cds.cern.ch/record/2120133>.
- [97] M. Bähr *et al.*, HERWIG++ physics and manual, *Eur. Phys. J. C* **58**, 639 (2008).
- [98] J. Bellm *et al.*, HERWIG 7.0/HERWIG++ 3.0 release note, *Eur. Phys. J. C* **76**, 196 (2016).
- [99] ATLAS Collaboration, Study of top-quark pair modelling and uncertainties using ATLAS measurements at  $\sqrt{s} = 13$  TeV, Report No. ATL-PHYS-PUB-2020-023, 2020, <https://cds.cern.ch/record/2730443>.

G. Aad<sup>101</sup>, B. Abbott<sup>119</sup>, D. C. Abbott<sup>102</sup>, K. Abeling<sup>55</sup>, S. H. Abidi<sup>29</sup>, A. Abouhorma<sup>35e</sup>, H. Abramowicz<sup>150</sup>, H. Abreu<sup>149</sup>, Y. Abulaiti<sup>116</sup>, A. C. Abusleme Hoffman<sup>136a</sup>, B. S. Acharya<sup>68a,68b,b</sup>, B. Achkar<sup>55</sup>, L. Adam<sup>99</sup>, C. Adam Bourdarios<sup>4</sup>, L. Adamczyk<sup>84a</sup>, L. Adamek<sup>154</sup>, S. V. Addepalli<sup>26</sup>, J. Adelman<sup>114</sup>, A. Adiguzel<sup>21c</sup>, S. Adorni<sup>56</sup>, T. Adye<sup>133</sup>, A. A. Affolder<sup>135</sup>, Y. Afik<sup>36</sup>, M. N. Agaras<sup>13</sup>, J. Agarwala<sup>72a,72b</sup>, A. Aggarwal<sup>99</sup>, C. Agheorghiesei<sup>27c</sup>, J. A. Aguilar-Saavedra<sup>129f</sup>, A. Ahmad<sup>36</sup>, F. Ahmadov<sup>38,c</sup>, W. S. Ahmed<sup>103</sup>, S. Ahuja<sup>94</sup>, X. Ai<sup>48</sup>, G. Aielli<sup>75a,75b</sup>, I. Aizenberg<sup>168</sup>, M. Akbiyik<sup>99</sup>, T. P. A. Åkesson<sup>97</sup>, A. V. Akimov<sup>37</sup>, K. Al Khoury<sup>41</sup>, G. L. Alberghi<sup>23b</sup>, J. Albert<sup>164</sup>, P. Albicocco<sup>53</sup>, M. J. Alconada Verzini<sup>89</sup>, S. Alderweireldt<sup>52</sup>, M. Aleksa<sup>36</sup>, I. N. Aleksandrov<sup>38</sup>, C. Alexa<sup>27b</sup>, T. Alexopoulos<sup>10</sup>, A. Alfonsi<sup>113</sup>, F. Alfonsi<sup>23b</sup>, M. Alhroob<sup>119</sup>, B. Ali<sup>131</sup>, S. Ali<sup>147</sup>, M. Aliev<sup>37</sup>, G. Alimonti<sup>70a</sup>, C. Allaire<sup>36</sup>, B. M. M. Allbrooke<sup>145</sup>, P. P. Allport<sup>20</sup>, A. Aloisio<sup>71a,71b</sup>, F. Alonso<sup>89</sup>, C. Alpigiani<sup>137</sup>, E. Alunno Camelia<sup>75a,75b</sup>, M. Alvarez Estevez<sup>98</sup>, M. G. Alvigi<sup>71a,71b</sup>, Y. Amaral Coutinho<sup>81b</sup>, A. Ambler<sup>103</sup>, C. Amelung<sup>36</sup>, C. G. Ames<sup>108</sup>, D. Amidei<sup>105</sup>, S. P. Amor Dos Santos<sup>129a</sup>, S. Amoroso<sup>48</sup>, K. R. Amos<sup>162</sup>, C. S. Amrouche<sup>56</sup>, V. Ananiev<sup>124</sup>, C. Anastopoulos<sup>138</sup>, N. Andari<sup>134</sup>, T. Andeen<sup>11</sup>, J. K. Anders<sup>19</sup>, S. Y. Andrean<sup>47a,47b</sup>, A. Andreazza<sup>70a,70b</sup>, S. Angelidakis<sup>9</sup>, A. Angerami<sup>41,d</sup>, A. V. Anisenkov<sup>37</sup>, A. Annovi<sup>73a</sup>, C. Antel<sup>56</sup>, M. T. Anthony<sup>138</sup>, E. Antipov<sup>120</sup>, M. Antonelli<sup>53</sup>, D. J. A. Antrim<sup>17a</sup>, F. Anulli<sup>74a</sup>, M. Aoki<sup>82</sup>, J. A. Aparisi Pozo<sup>162</sup>, M. A. Aparo<sup>145</sup>, L. Aperio Bella<sup>48</sup>, C. Appelt<sup>18</sup>, N. Aranzabal<sup>36</sup>, V. Araujo Ferraz<sup>81a</sup>, C. Arcangeletti<sup>53</sup>, A. T. H. Arce<sup>51</sup>, E. Arena<sup>91</sup>, J-F. Arguin<sup>107</sup>, S. Argyropoulos<sup>54</sup>, J.-H. Arling<sup>48</sup>, A. J. Armbruster<sup>36</sup>, O. Arnaez<sup>154</sup>, H. Arnold<sup>113</sup>, Z. P. Arrubarrena Tame<sup>108</sup>, G. Artoni<sup>74a,74b</sup>, H. Asada<sup>110</sup>, K. Asai<sup>117</sup>, S. Asai<sup>152</sup>, N. A. Asbah<sup>61</sup>, E. M. Asimakopoulou<sup>160</sup>, J. Assahsah<sup>35d</sup>, K. Assamagan<sup>29</sup>, R. Astalos<sup>28a</sup>, R. J. Atkin<sup>33a</sup>, M. Atkinson<sup>161</sup>, N. B. Atlay<sup>18</sup>, H. Atmani<sup>62b</sup>, P. A. Atmasiddha<sup>105</sup>, K. Augsten<sup>131</sup>, S. Auricchio<sup>71a,71b</sup>, A. D. Auriol<sup>20</sup>, V. A. Austrup<sup>170</sup>, G. Avner<sup>149</sup>, G. Avolio<sup>36</sup>, K. Axiotis<sup>56</sup>, M. K. Ayoub<sup>14c</sup>, G. Azuelos<sup>107,e</sup>, D. Babal<sup>28a</sup>, H. Bachacou<sup>134</sup>, K. Bachas<sup>151,f</sup>, A. Bachiou<sup>34</sup>, F. Backman<sup>47a,47b</sup>, A. Badea<sup>61</sup>, P. Bagnaia<sup>74a,74b</sup>, M. Bahmani<sup>18</sup>, A. J. Bailey<sup>162</sup>, V. R. Bailey<sup>161</sup>, J. T. Baines<sup>133</sup>, C. Bakalis<sup>10</sup>, O. K. Baker<sup>171</sup>, P. J. Bakker<sup>113</sup>, E. Bakos<sup>15</sup>, D. Bakshi Gupta<sup>8</sup>, S. Balaji<sup>146</sup>, R. Balasubramanian<sup>113</sup>, E. M. Baldin<sup>37</sup>, P. Balek<sup>132</sup>, E. Ballabene<sup>70a,70b</sup>, F. Balli<sup>134</sup>, L. M. Baltes<sup>63a</sup>, W. K. Balunas<sup>32</sup>, J. Balz<sup>99</sup>, E. Banas<sup>85</sup>, M. Bandieramonte<sup>128</sup>, A. Bandyopadhyay<sup>24</sup>, S. Bansal<sup>24</sup>, L. Barak<sup>150</sup>, E. L. Barberio<sup>104</sup>, D. Barberis<sup>57b,57a</sup>, M. Barbero<sup>101</sup>, G. Barbour<sup>95</sup>, K. N. Barends<sup>33a</sup>, T. Barillari<sup>109</sup>, M.-S. Barisits<sup>36</sup>, J. Barkeloo<sup>122</sup>, T. Barklow<sup>142</sup>, R. M. Barnett<sup>17a</sup>, P. Baron<sup>121</sup>, D. A. Baron Moreno<sup>100</sup>, A. Baroncelli<sup>62a</sup>, G. Barone<sup>29</sup>, A. J. Barr<sup>125</sup>, L. Barranco Navarro<sup>47a,47b</sup>, F. Barreiro<sup>98</sup>, J. Barreiro Guimarães da Costa<sup>14a</sup>, U. Barron<sup>150</sup>, M. G. Barros Teixeira<sup>129a</sup>, S. Barsov<sup>37</sup>, F. Bartels<sup>63a</sup>, R. Bartoldus<sup>142</sup>, A. E. Barton<sup>90</sup>, P. Bartos<sup>28a</sup>, A. Basalae<sup>48</sup>, A. Basan<sup>99</sup>, M. Baselga<sup>49</sup>, I. Bashta<sup>76a,76b</sup>, A. Bassalat<sup>66,g</sup>, M. J. Basso<sup>154</sup>, C. R. Basson<sup>100</sup>, R. L. Bates<sup>59</sup>, S. Batlamous<sup>35e</sup>, J. R. Batley<sup>32</sup>, B. Batool<sup>140</sup>, M. Battaglia<sup>135</sup>, M. Bauce<sup>74a,74b</sup>, P. Bauer<sup>24</sup>, A. Bayirli<sup>21a</sup>, J. B. Beacham<sup>51</sup>, T. Beau<sup>126</sup>, P. H. Beauchemin<sup>157</sup>, F. Becherer<sup>54</sup>, P. Bechtel<sup>24</sup>, H. P. Beck<sup>19,h</sup>, K. Becker<sup>166</sup>, C. Becot<sup>48</sup>, A. J. Beddall<sup>21d</sup>, V. A. Bednyakov<sup>38</sup>, C. P. Bee<sup>144</sup>, L. J. Beamster<sup>15</sup>, T. A. Beermann<sup>36</sup>, M. Begalli<sup>81b,81d</sup>, M. Begel<sup>29</sup>, A. Behera<sup>144</sup>, J. K. Behr<sup>48</sup>, C. Beirao Da Cruz E Silva<sup>36</sup>, J. F. Beirer<sup>55,36</sup>, F. Beisiegel<sup>24</sup>, M. Belfkir<sup>158</sup>, G. Bella<sup>150</sup>, L. Bellagamba<sup>23b</sup>, A. Bellerive<sup>34</sup>, P. Bellos<sup>20</sup>, K. Beloborodov<sup>37</sup>, K. Belotskiy<sup>37</sup>, N. L. Belyaev<sup>37</sup>, D. Benckekroun<sup>35a</sup>, F. Bende<sup>35a</sup>, Y. Benhammou<sup>150</sup>, D. P. Benjamin<sup>29</sup>, M. Benoit<sup>29</sup>, J. R. Bensinger<sup>26</sup>, S. Bentvelsen<sup>113</sup>, L. Beresford<sup>36</sup>, M. Beretta<sup>53</sup>, D. Berge<sup>18</sup>, E. Bergeas Kuutmann<sup>160</sup>, N. Berger<sup>4</sup>, B. Bergmann<sup>131</sup>, J. Beringer<sup>17a</sup>, S. Berlendis<sup>7</sup>, G. Bernardi<sup>5</sup>, C. Bernius<sup>142</sup>, F. U. Bernlochner<sup>24</sup>, T. Berry<sup>94</sup>, P. Berta<sup>132</sup>, A. Berthold<sup>50</sup>, I. A. Bertram<sup>90</sup>, O. Bessidskaia Bylund<sup>170</sup>, S. Bethke<sup>109</sup>, A. Betti<sup>74a,74b</sup>, A. J. Bevan<sup>93</sup>, M. Bhamjee<sup>33c</sup>, S. Bhatta<sup>144</sup>, D. S. Bhattacharya<sup>165</sup>, P. Bhattarai<sup>26</sup>, V. S. Bhopatkar<sup>6</sup>, R. Bi<sup>128</sup>, R. Bi<sup>29,i</sup>, R. M. Bianchi<sup>128</sup>, O. Biebel<sup>108</sup>, R. Bielski<sup>122</sup>, N. V. Biesuz<sup>73a,73b</sup>, M. Biglietti<sup>76a</sup>, T. R. V. Billoud<sup>131</sup>, M. Bindi<sup>55</sup>, A. Bingul<sup>21b</sup>, C. Bini<sup>74a,74b</sup>, S. Biondi<sup>23b,23a</sup>, A. Biondini<sup>91</sup>, C. J. Birch-sykes<sup>100</sup>, G. A. Bird<sup>20,133</sup>, M. Birman<sup>168</sup>, T. Bisanz<sup>36</sup>, D. Biswas<sup>169,j</sup>, A. Bitadze<sup>100</sup>, K. Björke<sup>124</sup>, I. Bloch<sup>48</sup>, C. Blocker<sup>26</sup>, A. Blue<sup>59</sup>, U. Blumenschein<sup>93</sup>, J. Blumenthal<sup>99</sup>, G. J. Bobbink<sup>113</sup>, V. S. Bobrovnikov<sup>37</sup>, M. Boehler<sup>54</sup>, D. Bogavac<sup>36</sup>, A. G. Bogdanchikov<sup>37</sup>, C. Bohm<sup>47a</sup>, V. Boisvert<sup>94</sup>, P. Bokan<sup>48</sup>, T. Bold<sup>84a</sup>, M. Bomben<sup>5</sup>, M. Bona<sup>93</sup>, M. Boonekamp<sup>134</sup>, C. D. Booth<sup>94</sup>, A. G. Borbély<sup>59</sup>, H. M. Borecka-Bielska<sup>107</sup>, L. S. Borgna<sup>95</sup>, G. Borissov<sup>90</sup>, D. Bortoletto<sup>125</sup>, D. Boscherini<sup>23b</sup>, M. Bosman<sup>13</sup>, J. D. Bossio Sola<sup>36</sup>, K. Bouaouda<sup>35a</sup>, J. Boudreau<sup>128</sup>, E. V. Bouhova-Thacker<sup>90</sup>

D. Boumediene<sup>40</sup> R. Bouquet<sup>5</sup> A. Boveia<sup>118</sup> J. Boyd<sup>36</sup> D. Boye<sup>29</sup> I. R. Boyko<sup>38</sup> J. Bracinek<sup>20</sup>  
 N. Brahimi<sup>62d,62c</sup> G. Brandt<sup>170</sup> O. Brandt<sup>32</sup> F. Braren<sup>48</sup> B. Brau<sup>102</sup> J. E. Brau<sup>122</sup> W. D. Breaden Madden<sup>59</sup>  
 K. Brendlinger<sup>48</sup> R. Brenner<sup>168</sup> L. Brenner<sup>36</sup> R. Brenner<sup>160</sup> S. Bressler<sup>168</sup> B. Brickwedde<sup>99</sup> D. Britton<sup>59</sup>  
 D. Britzger<sup>109</sup> I. Brock<sup>24</sup> G. Brooijmans<sup>41</sup> W. K. Brooks<sup>136f</sup> E. Brost<sup>29</sup> P. A. Bruckman de Renstrom<sup>85</sup>  
 B. Briuers<sup>48</sup> D. Bruncko<sup>28b,a</sup> A. Bruni<sup>23b</sup> G. Bruni<sup>23b</sup> M. Bruschi<sup>23b</sup> N. Bruscolo<sup>74a,74b</sup> L. Bryngemark<sup>142</sup>  
 T. Buanes<sup>16</sup> Q. Buat<sup>137</sup> P. Buchholz<sup>140</sup> A. G. Buckley<sup>59</sup> I. A. Budagov<sup>38,a</sup> M. K. Bugge<sup>124</sup> O. Bulekov<sup>37</sup>  
 B. A. Bullard<sup>61</sup> S. Burdin<sup>91</sup> C. D. Burgard<sup>48</sup> A. M. Burger<sup>40</sup> B. Burghgrave<sup>8</sup> J. T. P. Burr<sup>32</sup> C. D. Burton<sup>11</sup>  
 J. C. Burzynski<sup>141</sup> E. L. Busch<sup>41</sup> V. Büscher<sup>99</sup> P. J. Bussey<sup>59</sup> J. M. Butler<sup>25</sup> C. M. Buttar<sup>59</sup>  
 J. M. Butterworth<sup>95</sup> W. Buttinger<sup>133</sup> C. J. Buxo Vazquez<sup>106</sup> A. R. Buzykaev<sup>37</sup> G. Cabras<sup>23b</sup> S. Cabrera Urbán<sup>162</sup>  
 D. Caforio<sup>58</sup> H. Cai<sup>128</sup> Y. Cai<sup>14a,14d</sup> V. M. M. Cairo<sup>36</sup> O. Cakir<sup>3a</sup> N. Calace<sup>36</sup> P. Calafiura<sup>17a</sup>  
 G. Calderini<sup>126</sup> P. Calfayan<sup>67</sup> G. Callea<sup>59</sup> L. P. Caloba<sup>81b</sup> D. Calvet<sup>40</sup> S. Calvet<sup>40</sup> T. P. Calvet<sup>101</sup>  
 M. Calvetti<sup>73a,73b</sup> R. Camacho Toro<sup>126</sup> S. Camarda<sup>36</sup> D. Camarero Munoz<sup>98</sup> P. Camarri<sup>75a,75b</sup>  
 M. T. Camerlingo<sup>76a,76b</sup> D. Cameron<sup>124</sup> C. Camincher<sup>164</sup> M. Campanelli<sup>95</sup> A. Camplani<sup>42</sup> V. Canale<sup>71a,71b</sup>  
 A. Canesse<sup>103</sup> M. Cano Bret<sup>79</sup> J. Cantero<sup>162</sup> Y. Cao<sup>161</sup> F. Capocasa<sup>26</sup> M. Capua<sup>43b,43a</sup> A. Carbone<sup>70a,70b</sup>  
 R. Cardarelli<sup>75a</sup> J. C. J. Cardenas<sup>8</sup> F. Cardillo<sup>162</sup> T. Carli<sup>36</sup> G. Carlino<sup>71a</sup> B. T. Carlson<sup>128,k</sup>  
 E. M. Carlson<sup>164,155a</sup> L. Carminati<sup>70a,70b</sup> M. Carnesale<sup>74a,74b</sup> S. Caron<sup>112</sup> E. Carquin<sup>136f</sup> S. Carrá<sup>70a,70b</sup>  
 G. Carratta<sup>23b,23a</sup> F. Carrio Argos<sup>33g</sup> J. W. S. Carter<sup>154</sup> T. M. Carter<sup>52</sup> M. P. Casado<sup>131</sup> A. F. Casha<sup>154</sup>  
 E. G. Castiglia<sup>171</sup> F. L. Castillo<sup>63a</sup> L. Castillo Garcia<sup>13</sup> V. Castillo Gimenez<sup>162</sup> N. F. Castro<sup>129a,129e</sup>  
 A. Catinaccio<sup>36</sup> J. R. Catmore<sup>124</sup> V. Cavaliere<sup>29</sup> N. Cavalli<sup>23b,23a</sup> V. Cavasinni<sup>73a,73b</sup> E. Celebi<sup>21a</sup> F. Celli<sup>125</sup>  
 M. S. Centonze<sup>69a,69b</sup> K. Cerny<sup>121</sup> A. S. Cerqueira<sup>81a</sup> A. Cerri<sup>145</sup> L. Cerrito<sup>75a,75b</sup> F. Cerutti<sup>17a</sup> A. Cervelli<sup>23b</sup>  
 S. A. Cetin<sup>21d</sup> Z. Chadi<sup>35a</sup> D. Chakraborty<sup>114</sup> M. Chala<sup>129f</sup> J. Chan<sup>169</sup> W. S. Chan<sup>113</sup> W. Y. Chan<sup>152</sup>  
 J. D. Chapman<sup>32</sup> B. Chargeishvili<sup>148b</sup> D. G. Charlton<sup>20</sup> T. P. Charman<sup>93</sup> M. Chatterjee<sup>19</sup> S. Chekanov<sup>6</sup>  
 S. V. Chekulaev<sup>155a</sup> G. A. Chelkov<sup>38,m</sup> A. Chen<sup>105</sup> B. Chen<sup>150</sup> B. Chen<sup>164</sup> C. Chen<sup>62a</sup> H. Chen<sup>14c</sup> H. Chen<sup>29</sup>  
 J. Chen<sup>62c</sup> J. Chen<sup>26</sup> S. Chen<sup>152</sup> S. J. Chen<sup>14c</sup> X. Chen<sup>62c</sup> X. Chen<sup>14b,n</sup> Y. Chen<sup>62a</sup> C. L. Cheng<sup>169</sup>  
 H. C. Cheng<sup>64a</sup> A. Cheplakov<sup>38</sup> E. Cheremushkina<sup>48</sup> E. Cherepanova<sup>113</sup> R. Cherkaoui El Moursli<sup>35e</sup> E. Cheu<sup>7</sup>  
 K. Cheung<sup>65</sup> L. Chevalier<sup>134</sup> V. Chiarella<sup>53</sup> G. Chiarelli<sup>73a</sup> G. Chiodini<sup>69a</sup> A. S. Chisholm<sup>20</sup> A. Chitan<sup>27b</sup>  
 Y. H. Chiu<sup>164</sup> M. V. Chizhov<sup>38</sup> K. Choi<sup>11</sup> A. R. Chomont<sup>74a,74b</sup> Y. Chou<sup>102</sup> E. Y. S. Chow<sup>113</sup>  
 T. Chowdhury<sup>33g</sup> L. D. Christopher<sup>33g</sup> K. L. Chu<sup>64a</sup> M. C. Chu<sup>64a</sup> X. Chu<sup>14a,14d</sup> J. Chudoba<sup>130</sup>  
 J. J. Chwastowski<sup>85</sup> D. Cieri<sup>109</sup> K. M. Ciesla<sup>84a</sup> V. Cindro<sup>92</sup> A. Ciocio<sup>17a</sup> F. Ciroto<sup>71a,71b</sup> Z. H. Citron<sup>168,o</sup>  
 M. Citterio<sup>70a</sup> D. A. Ciubotaru<sup>27b</sup> B. M. Ciungu<sup>154</sup> A. Clark<sup>56</sup> P. J. Clark<sup>52</sup> J. M. Clavijo Columbie<sup>48</sup>  
 S. E. Clawson<sup>100</sup> C. Clement<sup>47a,47b</sup> J. Clercx<sup>48</sup> L. Clissa<sup>23b,23a</sup> Y. Coadou<sup>101</sup> M. Cobal<sup>68a,68c</sup> A. Coccaro<sup>57b</sup>  
 R. F. Coelho Barrue<sup>129a</sup> R. Coelho Lopes De Sa<sup>102</sup> S. Coelli<sup>70a</sup> H. Cohen<sup>150</sup> A. E. C. Coimbra<sup>70a,70b</sup> B. Cole<sup>41</sup>  
 J. Collot<sup>60</sup> P. Conde Muiño<sup>129a,129g</sup> S. H. Connell<sup>33c</sup> I. A. Connelly<sup>59</sup> E. I. Conroy<sup>125</sup> F. Conventi<sup>71a,p</sup>  
 H. G. Cooke<sup>20</sup> A. M. Cooper-Sarkar<sup>125</sup> F. Cormier<sup>163</sup> L. D. Corpe<sup>36</sup> M. Corradi<sup>74a,74b</sup> E. E. Corrigan<sup>97</sup>  
 F. Corriveau<sup>103,q</sup> A. Cortes-Gonzalez<sup>18</sup> M. J. Costa<sup>162</sup> F. Costanza<sup>4</sup> D. Costanzo<sup>138</sup> B. M. Cote<sup>118</sup>  
 G. Cowan<sup>94</sup> J. W. Cowley<sup>32</sup> K. Cranmer<sup>116</sup> S. Crépe-Renaudin<sup>60</sup> F. Crescioli<sup>126</sup> M. Cristinziani<sup>140</sup>  
 M. Cristoforetti<sup>77a,77b,r</sup> V. Croft<sup>157</sup> G. Crosetti<sup>43b,43a</sup> A. Cueto<sup>36</sup> T. Cuhadar Donszelmann<sup>159</sup> H. Cui<sup>14a,14d</sup>  
 Z. Cui<sup>7</sup> A. R. Cukierman<sup>142</sup> W. R. Cunningham<sup>59</sup> F. Curcio<sup>43b,43a</sup> P. Czodrowski<sup>36</sup> M. M. Czurylo<sup>63b</sup>  
 M. J. Da Cunha Sargedas De Sousa<sup>62a</sup> J. V. Da Fonseca Pinto<sup>81b</sup> C. Da Via<sup>100</sup> W. Dabrowski<sup>84a</sup> T. Dado<sup>49</sup>  
 S. Dahbi<sup>33g</sup> T. Dai<sup>105</sup> C. Dallapiccola<sup>102</sup> M. Dam<sup>42</sup> G. D'amen<sup>29</sup> V. D'Amico<sup>76a,76b</sup> J. Damp<sup>99</sup>  
 J. R. Dandoy<sup>127</sup> M. F. Daneri<sup>30</sup> M. Danninger<sup>141</sup> V. Dao<sup>36</sup> G. Darbo<sup>57b</sup> S. Darmora<sup>6</sup> S. J. Das<sup>29,i</sup>  
 A. Dattagupta<sup>122</sup> S. D'Auria<sup>70a,70b</sup> C. David<sup>155b</sup> T. Davidek<sup>132</sup> D. R. Davis<sup>51</sup> B. Davis-Purcell<sup>34</sup> I. Dawson<sup>93</sup>  
 K. De<sup>8</sup> R. De Asmundis<sup>71a</sup> M. De Beurs<sup>113</sup> S. De Castro<sup>23b,23a</sup> N. De Groot<sup>112</sup> P. de Jong<sup>113</sup>  
 H. De la Torre<sup>106</sup> A. De Maria<sup>14c</sup> A. De Salvo<sup>74a</sup> U. De Sanctis<sup>75a,75b</sup> M. De Santis<sup>75a,75b</sup> A. De Santo<sup>145</sup>  
 J. B. De Vivie De Regie<sup>60</sup> D. V. Dedovich<sup>38</sup> J. Degens<sup>113</sup> A. M. Deiana<sup>44</sup> F. Del Corso<sup>23b,23a</sup> J. Del Peso<sup>98</sup>  
 F. Del Rio<sup>63a</sup> F. Deliot<sup>134</sup> C. M. Delitzsch<sup>49</sup> M. Della Pietra<sup>71a,71b</sup> D. Della Volpe<sup>56</sup> A. Dell'Acqua<sup>36</sup>  
 L. Dell'Asta<sup>70a,70b</sup> M. Delmastro<sup>4</sup> P. A. Delsart<sup>60</sup> S. Demers<sup>171</sup> M. Demichev<sup>38</sup> S. P. Denisov<sup>37</sup>  
 L. D'ErAMO<sup>114</sup> D. Derendarz<sup>85</sup> F. Derue<sup>126</sup> P. Dervan<sup>91</sup> K. Desch<sup>24</sup> K. Dette<sup>154</sup> C. Deutsch<sup>24</sup>  
 P. O. Deviveiros<sup>36</sup> F. A. Di Bello<sup>74a,74b</sup> A. Di Ciaccio<sup>75a,75b</sup> L. Di Ciaccio<sup>4</sup> A. Di Domenico<sup>74a,74b</sup>

C. Di Donato<sup>71a,71b</sup> A. Di Girolamo<sup>36</sup> G. Di Gregorio<sup>73a,73b</sup> A. Di Luca<sup>77a,77b</sup> B. Di Micco<sup>76a,76b</sup>  
 R. Di Nardo<sup>76a,76b</sup> C. Diaconu<sup>101</sup> F. A. Dias<sup>113</sup> T. Dias Do Vale<sup>141</sup> M. A. Diaz<sup>136a,136b</sup> F. G. Diaz Capriles<sup>24</sup>  
 M. Didenko<sup>162</sup> E. B. Diehl<sup>105</sup> L. Diehl<sup>54</sup> S. Díez Cornell<sup>48</sup> C. Díez Pardos<sup>140</sup> C. Dimitriadi<sup>24,160</sup>  
 A. Dimitrievska<sup>17a</sup> W. Ding<sup>14b</sup> J. Dingfelder<sup>24</sup> I-M. Dinu<sup>27b</sup> S. J. Dittmeier<sup>63b</sup> F. Dittus<sup>36</sup> F. Djama<sup>101</sup>  
 T. Djobava<sup>148b</sup> J. I. Djuvsland<sup>16</sup> D. Dodsworth<sup>26</sup> C. Doglioni<sup>100,97</sup> J. Dolejsi<sup>132</sup> Z. Dolezal<sup>132</sup>  
 M. Donadelli<sup>81c</sup> B. Dong<sup>62c</sup> J. Donini<sup>40</sup> A. D'Onofrio<sup>14c</sup> M. D'Onofrio<sup>91</sup> J. Dopke<sup>133</sup> A. Doria<sup>71a</sup>  
 M. T. Dova<sup>89</sup> A. T. Doyle<sup>59</sup> M. A. Draguet<sup>125</sup> E. Drechsler<sup>141</sup> E. Dreyer<sup>168</sup> I. Drivas-koulouris<sup>10</sup>  
 A. S. Drobac<sup>157</sup> D. Du<sup>62a</sup> T. A. du Pree<sup>113</sup> F. Dubinin<sup>37</sup> M. Dubovsky<sup>28a</sup> E. Duchovni<sup>168</sup> G. Duckeck<sup>108</sup>  
 O. A. Ducu<sup>36</sup> D. Duda<sup>109</sup> A. Dudarev<sup>36</sup> M. D'uffizi<sup>100</sup> L. Dufлот<sup>66</sup> M. Dührssen<sup>36</sup> C. Dülsen<sup>170</sup>  
 A. E. Dumitriu<sup>27b</sup> M. Dunford<sup>63a</sup> S. Dungs<sup>49</sup> K. Dunne<sup>47a,47b</sup> A. Duperrin<sup>101</sup> H. Duran Yildiz<sup>3a</sup> M. Düren<sup>58</sup>  
 A. Durglishvili<sup>148b</sup> B. L. Dwyer<sup>114</sup> G. I. Dyckes<sup>17a</sup> M. Dyndal<sup>84a</sup> S. Dysch<sup>100</sup> B. S. Dziedzic<sup>85</sup>  
 Z. O. Earnshaw<sup>145</sup> B. Eckerova<sup>28a</sup> M. G. Eggleston<sup>51</sup> E. Egidio Purcino De Souza<sup>81b</sup> L. F. Ehrke<sup>56</sup> G. Eigen<sup>16</sup>  
 K. Einsweiler<sup>17a</sup> T. Ekelof<sup>160</sup> P. A. Ekman<sup>97</sup> Y. El Ghazali<sup>35b</sup> H. El Jarrari<sup>35e,147</sup> A. El Moussaouy<sup>35a</sup>  
 V. Ellajosyula<sup>160</sup> M. Ellert<sup>160</sup> F. Ellinghaus<sup>170</sup> A. A. Elliot<sup>93</sup> N. Ellis<sup>36</sup> J. Elmsheuser<sup>29</sup> M. Elsing<sup>36</sup>  
 D. Emeliyanov<sup>133</sup> A. Emerman<sup>41</sup> Y. Enari<sup>152</sup> I. Ene<sup>17a</sup> S. Epari<sup>13</sup> J. Erdmann<sup>49,s</sup> A. Ereditato<sup>19</sup>  
 P. A. Erland<sup>85</sup> M. Errenst<sup>170</sup> M. Escalier<sup>66</sup> C. Escobar<sup>162</sup> E. Etzion<sup>150</sup> G. Evans<sup>129a</sup> H. Evans<sup>67</sup>  
 M. O. Evans<sup>145</sup> A. Ezhilov<sup>37</sup> S. Ezzarqtouni<sup>35a</sup> F. Fabbri<sup>59</sup> L. Fabbri<sup>23b,23a</sup> G. Facini<sup>95</sup> V. Fadeyev<sup>135</sup>  
 R. M. Fakhrutdinov<sup>37</sup> S. Falciano<sup>74a</sup> P. J. Falke<sup>24</sup> S. Falke<sup>36</sup> J. Faltova<sup>132</sup> Y. Fan<sup>14a</sup> Y. Fang<sup>14a,14d</sup>  
 G. Fanourakis<sup>46</sup> M. Fanti<sup>70a,70b</sup> M. Faraj<sup>68a,68b</sup> A. Farbin<sup>8</sup> A. Farilla<sup>76a</sup> T. Farooque<sup>106</sup> S. M. Farrington<sup>52</sup>  
 F. Fassi<sup>35e</sup> D. Fassouliotis<sup>9</sup> M. Fauci Giannelli<sup>75a,75b</sup> W. J. Fawcett<sup>32</sup> L. Fayard<sup>66</sup> O. L. Fedin<sup>37,m</sup>  
 G. Fedotov<sup>37</sup> M. Feickert<sup>161</sup> L. Feligioni<sup>101</sup> A. Fell<sup>138</sup> D. E. Fellers<sup>122</sup> C. Feng<sup>62b</sup> M. Feng<sup>14b</sup>  
 M. J. Fenton<sup>159</sup> A. B. Fenyuk<sup>37</sup> L. Ferencz<sup>48</sup> S. W. Ferguson<sup>45</sup> J. Ferrando<sup>48</sup> A. Ferrari<sup>160</sup> P. Ferrari<sup>113</sup>  
 R. Ferrari<sup>72a</sup> D. Ferrere<sup>56</sup> C. Ferretti<sup>105</sup> F. Fiedler<sup>99</sup> A. Filipčić<sup>92</sup> E. K. Filmer<sup>1</sup> F. Filthaut<sup>112</sup>  
 M. C. N. Fiolhais<sup>129a,129c,t</sup> L. Fiorini<sup>162</sup> F. Fischer<sup>140</sup> W. C. Fisher<sup>106</sup> T. Fitschen<sup>20,66</sup> I. Fleck<sup>140</sup>  
 P. Fleischmann<sup>105</sup> T. Flick<sup>170</sup> L. Flores<sup>127</sup> M. Flores<sup>33d,u</sup> L. R. Flores Castillo<sup>64a</sup> F. M. Follega<sup>77a,77b</sup>  
 N. Fomin<sup>16</sup> J. H. Foo<sup>154</sup> B. C. Forland<sup>67</sup> A. Formica<sup>134</sup> A. C. Forti<sup>100</sup> E. Fortin<sup>101</sup> A. W. Fortman<sup>61</sup>  
 M. G. Foti<sup>17a</sup> L. Fountas<sup>9,v</sup> D. Fournier<sup>66</sup> H. Fox<sup>90</sup> P. Francavilla<sup>73a,73b</sup> S. Francescato<sup>61</sup> M. Franchini<sup>23b,23a</sup>  
 S. Franchino<sup>63a</sup> D. Francis<sup>36</sup> L. Franco<sup>112</sup> L. Franconi<sup>19</sup> M. Franklin<sup>61</sup> G. Frattari<sup>26</sup> A. C. Freegard<sup>93</sup>  
 P. M. Freeman<sup>20</sup> W. S. Freund<sup>81b</sup> N. Fritzsche<sup>50</sup> A. Froch<sup>54</sup> D. Froidevaux<sup>36</sup> J. A. Frost<sup>125</sup> Y. Fu<sup>62a</sup>  
 M. Fujimoto<sup>117</sup> E. Fullana Torregrosa<sup>162,a</sup> J. Fuster<sup>162</sup> A. Gabrielli<sup>23b,23a</sup> A. Gabrielli<sup>36</sup> P. Gadow<sup>48</sup>  
 G. Gagliardi<sup>57b,57a</sup> L. G. Gagnon<sup>17a</sup> G. E. Gallardo<sup>125</sup> E. J. Gallas<sup>125</sup> B. J. Gallop<sup>133</sup> R. Gamboa Goni<sup>93</sup>  
 K. K. Gan<sup>118</sup> S. Ganguly<sup>152</sup> J. Gao<sup>62a</sup> Y. Gao<sup>52</sup> F. M. Garay Walls<sup>136a,136b</sup> B. Garcia<sup>29,i</sup> C. García<sup>162</sup>  
 J. E. García Navarro<sup>162</sup> J. A. García Pascual<sup>14a</sup> M. Garcia-Sciveres<sup>17a</sup> R. W. Gardner<sup>39</sup> D. Garg<sup>79</sup>  
 R. B. Garg<sup>142,w</sup> S. Gargiulo<sup>54</sup> C. A. Garner<sup>154</sup> V. Garonne<sup>29</sup> S. J. Gasiorowski<sup>137</sup> P. Gaspar<sup>81b</sup> G. Gaudio<sup>72a</sup>  
 V. Gautam<sup>13</sup> P. Gauzzi<sup>74a,74b</sup> I. L. Gavrilenko<sup>37</sup> A. Gavrilyuk<sup>37</sup> C. Gay<sup>163</sup> G. Gaycken<sup>48</sup> E. N. Gazis<sup>10</sup>  
 A. A. Geanta<sup>27b</sup> C. M. Gee<sup>135</sup> J. Geisen<sup>97</sup> M. Geisen<sup>99</sup> C. Gemme<sup>57b</sup> M. H. Genest<sup>60</sup> S. Gentile<sup>74a,74b</sup>  
 S. George<sup>94</sup> W. F. George<sup>20</sup> T. Geralis<sup>46</sup> L. O. Gerlach<sup>55</sup> P. Gessinger-Befurt<sup>36</sup> M. Ghasemi Bostanabad<sup>164</sup>  
 M. Ghneimat<sup>140</sup> A. Ghosal<sup>140</sup> A. Ghosh<sup>159</sup> A. Ghosh<sup>7</sup> B. Giacobbe<sup>23b</sup> S. Giagu<sup>74a,74b</sup> N. Giangiacomi<sup>154</sup>  
 P. Giannetti<sup>73a</sup> A. Giannini<sup>62a</sup> S. M. Gibson<sup>94</sup> M. Gignac<sup>135</sup> D. T. Gil<sup>84b</sup> A. K. Gilbert<sup>84a</sup> B. J. Gilbert<sup>41</sup>  
 D. Gillberg<sup>34</sup> G. Gilles<sup>113</sup> N. E. K. Gillwald<sup>48</sup> L. Ginabat<sup>126</sup> D. M. Gingrich<sup>2,e</sup> M. P. Giordani<sup>68a,68c</sup>  
 P. F. Giraud<sup>134</sup> G. Giugliarelli<sup>68a,68c</sup> D. Giugni<sup>70a</sup> F. Giuli<sup>36</sup> I. Gkialas<sup>9,v</sup> L. K. Gladilin<sup>37</sup> C. Glasman<sup>98</sup>  
 G. R. Gledhill<sup>122</sup> M. Glisic<sup>122</sup> I. Gnesi<sup>43b,x</sup> Y. Go<sup>29,i</sup> M. Goblirsch-Kolb<sup>26</sup> D. Godin<sup>107</sup> S. Goldfarb<sup>104</sup>  
 T. Golling<sup>56</sup> M. G. D. Gololo<sup>33g</sup> D. Golubkov<sup>37</sup> J. P. Gombas<sup>106</sup> A. Gomes<sup>129a,129b</sup> G. Gomes Da Silva<sup>140</sup>  
 A. J. Gomez Delegido<sup>162</sup> R. Goncalves Gama<sup>55</sup> R. Gonçalves<sup>129a,129c</sup> G. Gonella<sup>122</sup> L. Gonella<sup>20</sup> A. Gongadze<sup>38</sup>  
 F. Gonnella<sup>20</sup> J. L. Gonski<sup>41</sup> R. Y. González Andana<sup>52</sup> S. González de la Hoz<sup>162</sup> S. Gonzalez Fernandez<sup>13</sup>  
 R. Gonzalez Lopez<sup>91</sup> C. Gonzalez Renteria<sup>17a</sup> R. Gonzalez Suarez<sup>160</sup> S. Gonzalez-Sevilla<sup>56</sup>  
 G. R. Gonzalvo Rodriguez<sup>162</sup> L. Goossens<sup>36</sup> N. A. Gorasia<sup>20</sup> P. A. Gorbounov<sup>37</sup> B. Gorini<sup>36</sup> E. Gorini<sup>69a,69b</sup>  
 A. Gorišek<sup>92</sup> A. T. Goshaw<sup>51</sup> M. I. Gostkin<sup>38</sup> C. A. Gottardo<sup>112</sup> M. Gouighri<sup>35b</sup> V. Goumarre<sup>48</sup>  
 A. G. Goussiou<sup>137</sup> N. Govender<sup>33c</sup> C. Goy<sup>4</sup> I. Grabowska-Bold<sup>84a</sup> K. Graham<sup>34</sup> E. Gramstad<sup>124</sup>

S. Grancagnolo<sup>18</sup> M. Grandi<sup>145</sup> V. Gratchev,<sup>37,a</sup> P. M. Gravila<sup>27f</sup> F. G. Gravili<sup>69a,69b</sup> H. M. Gray<sup>17a</sup>  
M. Greco<sup>69a,69b</sup> C. Grefe<sup>24</sup> I. M. Gregor<sup>48</sup> P. Grenier<sup>142</sup> C. Grieco<sup>13</sup> A. A. Grillo<sup>135</sup> K. Grimm<sup>31,y</sup>  
S. Grinstein<sup>13,z</sup> J.-F. Grivaz<sup>66</sup> E. Gross<sup>168</sup> J. Grosse-Knetter<sup>55</sup> C. Grud,<sup>105</sup> A. Grummer<sup>111</sup> J. C. Grundy<sup>125</sup>  
L. Guan<sup>105</sup> W. Guan<sup>169</sup> C. Gubbels<sup>163</sup> J. G. R. Guerrero Rojas<sup>162</sup> G. Guerrieri<sup>68a,68c</sup> F. Guescini<sup>109</sup>  
R. Gugel<sup>99</sup> J. A. M. Guhit<sup>105</sup> A. Guida<sup>48</sup> T. Guillemain<sup>4</sup> E. Guilloton<sup>166,133</sup> S. Guindon<sup>36</sup> F. Guo<sup>14a,14d</sup>  
J. Guo<sup>62c</sup> L. Guo<sup>66</sup> Y. Guo<sup>105</sup> R. Gupta<sup>48</sup> S. Gurbuz<sup>24</sup> S. S. Gurdasani<sup>54</sup> G. Gustavino<sup>36</sup> M. Guth<sup>56</sup>  
P. Gutierrez<sup>119</sup> L. F. Gutierrez Zagazeta<sup>127</sup> C. Gutschow<sup>95</sup> C. Guyot<sup>134</sup> C. Gwenlan<sup>125</sup> C. B. Gwilliam<sup>91</sup>  
E. S. Haaland<sup>124</sup> A. Haas<sup>116</sup> M. Habedank<sup>48</sup> C. Haber<sup>17a</sup> H. K. Hadavand<sup>8</sup> A. Hadeef<sup>99</sup> S. Hadzic<sup>109</sup>  
M. Haleem<sup>165</sup> J. Haley<sup>120</sup> J. J. Hall<sup>138</sup> G. D. Hallewell<sup>101</sup> L. Halser<sup>19</sup> K. Hamano<sup>164</sup> H. Hamdaoui<sup>35e</sup>  
M. Hamer<sup>24</sup> G. N. Hamity<sup>52</sup> J. Han<sup>62b</sup> K. Han<sup>62a</sup> L. Han<sup>14c</sup> L. Han<sup>62a</sup> S. Han<sup>17a</sup> Y. F. Han<sup>154</sup>  
K. Hanagaki<sup>82</sup> M. Hance<sup>135</sup> D. A. Hangal<sup>41,d</sup> M. D. Hank<sup>39</sup> R. Hankache<sup>100</sup> J. B. Hansen<sup>42</sup> J. D. Hansen<sup>42</sup>  
P. H. Hansen<sup>42</sup> K. Hara<sup>156</sup> D. Harada<sup>56</sup> T. Harenberg<sup>170</sup> S. Harkusha<sup>37</sup> Y. T. Harris<sup>125</sup> N. M. Harrison<sup>118</sup>  
P. F. Harrison<sup>166</sup> N. M. Hartman<sup>142</sup> N. M. Hartmann<sup>108</sup> Y. Hasegawa<sup>139</sup> A. Hasib<sup>52</sup> S. Haug<sup>19</sup> R. Hauser<sup>106</sup>  
M. Havranek<sup>131</sup> C. M. Hawkes<sup>20</sup> R. J. Hawkins<sup>36</sup> S. Hayashida<sup>110</sup> D. Hayden<sup>106</sup> C. Hayes<sup>105</sup>  
R. L. Hayes<sup>163</sup> C. P. Hays<sup>125</sup> J. M. Hays<sup>93</sup> H. S. Hayward<sup>91</sup> F. He<sup>62a</sup> Y. He<sup>153</sup> Y. He<sup>126</sup> M. P. Heath<sup>52</sup>  
V. Hedberg<sup>97</sup> A. L. Heggelund<sup>124</sup> N. D. Hehir<sup>93</sup> C. Heidegger<sup>54</sup> K. K. Heidegger<sup>54</sup> W. D. Heidorn<sup>80</sup>  
J. Heilman<sup>34</sup> S. Heim<sup>48</sup> T. Heim<sup>17a</sup> J. G. Heinlein<sup>127</sup> J. J. Heinrich<sup>122</sup> L. Heinrich<sup>36</sup> J. Hejbal<sup>130</sup>  
L. Helary<sup>48</sup> A. Held<sup>116</sup> S. Hellesund<sup>124</sup> C. M. Helling<sup>163</sup> S. Hellman<sup>47a,47b</sup> C. Hensens<sup>36</sup> R. C. W. Henderson<sup>90</sup>  
L. Henkelmann<sup>32</sup> A. M. Henriques Correia<sup>36</sup> H. Herde<sup>142</sup> Y. Hernández Jiménez<sup>144</sup> H. Herr<sup>99</sup> M. G. Herrmann<sup>108</sup>  
T. Herrmann<sup>50</sup> G. Herten<sup>54</sup> R. Hertenberger<sup>108</sup> L. Hervas<sup>36</sup> N. P. Hessey<sup>155a</sup> H. Hibi<sup>83</sup>  
E. Higón-Rodríguez<sup>162</sup> S. J. Hillier<sup>20</sup> I. Hinchliffe<sup>17a</sup> F. Hinterkeuser<sup>24</sup> M. Hirose<sup>123</sup> S. Hirose<sup>156</sup>  
D. Hirschbuehl<sup>170</sup> T. G. Hitchings<sup>100</sup> B. Hiti<sup>92</sup> J. Hobbs<sup>144</sup> R. Hobincu<sup>27e</sup> N. Hod<sup>168</sup> M. C. Hodgkinson<sup>138</sup>  
B. H. Hodgkinson<sup>32</sup> A. Hoecker<sup>36</sup> J. Hofer<sup>48</sup> D. Hohn<sup>54</sup> T. Holm<sup>24</sup> M. Holzbock<sup>109</sup> L. B. A. H. Hommels<sup>32</sup>  
B. P. Honan<sup>100</sup> J. Hong<sup>62c</sup> T. M. Hong<sup>128</sup> Y. Hong<sup>55</sup> J. C. Honig<sup>54</sup> A. Hönle<sup>109</sup> B. H. Hooberman<sup>161</sup>  
W. H. Hopkins<sup>6</sup> Y. Horii<sup>110</sup> S. Hou<sup>147</sup> A. S. Howard<sup>92</sup> J. Howarth<sup>59</sup> J. Hoya<sup>89</sup> M. Hrabovsky<sup>121</sup>  
A. Hrynevich<sup>37</sup> T. Hryn'ova<sup>4</sup> P. J. Hsu<sup>65</sup> S.-C. Hsu<sup>137</sup> Q. Hu<sup>41,d</sup> Y. F. Hu<sup>14a,14d,aa</sup> D. P. Huang<sup>95</sup>  
S. Huang<sup>64b</sup> X. Huang<sup>14c</sup> Y. Huang<sup>62a</sup> Y. Huang<sup>14a</sup> Z. Huang<sup>100</sup> Z. Hubacek<sup>131</sup> M. Huebner<sup>24</sup>  
F. Hugging<sup>24</sup> T. B. Huffman<sup>125</sup> M. Huhtinen<sup>36</sup> S. K. Huiberts<sup>16</sup> R. Hulsken<sup>103</sup> N. Huseynov<sup>12,m</sup>  
J. Huston<sup>106</sup> J. Huth<sup>61</sup> R. Hyneman<sup>142</sup> S. Hyrych<sup>28a</sup> G. Iacobucci<sup>56</sup> G. Iakovidis<sup>29</sup> I. Ibragimov<sup>140</sup>  
L. Iconomidou-Fayard<sup>66</sup> P. Iengo<sup>71a,71b</sup> R. Iguchi<sup>152</sup> T. Iizawa<sup>56</sup> Y. Ikegami<sup>82</sup> A. Ilg<sup>19</sup> N. Ilic<sup>154</sup>  
H. Imam<sup>35a</sup> T. Ingebretsen Carlson<sup>47a,47b</sup> G. Introzzi<sup>72a,72b</sup> M. Iodice<sup>76a</sup> V. Ippolito<sup>74a,74b</sup> M. Ishino<sup>152</sup>  
W. Islam<sup>169</sup> C. Issever<sup>18,48</sup> S. Istin<sup>21a,bb</sup> H. Ito<sup>167</sup> J. M. Iturbe Ponce<sup>64a</sup> R. Iuppa<sup>77a,77b</sup> A. Ivina<sup>168</sup>  
J. M. Izen<sup>45</sup> V. Izzo<sup>71a</sup> P. Jacka<sup>130,131</sup> P. Jackson<sup>1</sup> R. M. Jacobs<sup>48</sup> B. P. Jaeger<sup>141</sup> C. S. Jagfeld<sup>108</sup>  
G. Jäkel<sup>170</sup> K. Jakobs<sup>54</sup> T. Jakoubek<sup>168</sup> J. Jamieson<sup>59</sup> K. W. Janas<sup>84a</sup> G. Jarlskog<sup>97</sup> A. E. Jaspán<sup>91</sup>  
T. Javůrek<sup>36</sup> M. Javurkova<sup>102</sup> F. Jeanneau<sup>134</sup> L. Jeanty<sup>122</sup> J. Jejelava<sup>148a,cc</sup> P. Jenni<sup>54,dd</sup> C. E. Jessiman<sup>34</sup>  
S. Jézéquel<sup>4</sup> J. Jia<sup>144</sup> X. Jia<sup>61</sup> X. Jia<sup>14a,14d</sup> Z. Jia<sup>14c</sup> Y. Jiang<sup>62a</sup> S. Jiggins<sup>52</sup> J. Jimenez Pena<sup>109</sup> S. Jin<sup>14c</sup>  
A. Jinaru<sup>27b</sup> O. Jinnouchi<sup>153</sup> H. Jivan<sup>33g</sup> P. Johansson<sup>138</sup> K. A. Johns<sup>7</sup> C. A. Johnson<sup>67</sup> D. M. Jones<sup>32</sup>  
E. Jones<sup>166</sup> P. Jones<sup>32</sup> R. W. L. Jones<sup>90</sup> T. J. Jones<sup>91</sup> J. Jovicevic<sup>15</sup> X. Ju<sup>17a</sup> J. J. Jungburth<sup>36</sup>  
A. Juste Rozas<sup>13,z</sup> S. Kabana<sup>136e</sup> A. Kaczmarek<sup>85</sup> M. Kado<sup>74a,74b</sup> H. Kagan<sup>118</sup> M. Kagan<sup>142</sup> A. Kahn<sup>41</sup>  
A. Kahn<sup>127</sup> C. Kahra<sup>99</sup> T. Kaji<sup>167</sup> E. Kajomovitz<sup>149</sup> N. Kakati<sup>168</sup> C. W. Kalderon<sup>29</sup> A. Kamenshchikov<sup>154</sup>  
N. J. Kang<sup>135</sup> Y. Kano<sup>110</sup> D. Kar<sup>33g</sup> K. Karava<sup>125</sup> M. J. Kareem<sup>155b</sup> E. Karentzos<sup>54</sup> I. Karkanas<sup>151</sup>  
S. N. Karpov<sup>38</sup> Z. M. Karpova<sup>38</sup> V. Kartvelishvili<sup>90</sup> A. N. Karyukhin<sup>37</sup> E. Kasimi<sup>151</sup> C. Kato<sup>62d</sup> J. Katzy<sup>48</sup>  
S. Kaur<sup>34</sup> K. Kawade<sup>139</sup> K. Kawagoe<sup>88</sup> T. Kawaguchi<sup>110</sup> T. Kawamoto<sup>134</sup> G. Kawamura<sup>55</sup> E. F. Kay<sup>164</sup>  
F. I. Kaya<sup>157</sup> S. Kazakos<sup>13</sup> V. F. Kazanin<sup>37</sup> Y. Ke<sup>144</sup> J. M. Keaveney<sup>33a</sup> R. Keeler<sup>164</sup> G. V. Kehris<sup>61</sup>  
J. S. Keller<sup>34</sup> A. S. Kelly<sup>95</sup> D. Kelsey<sup>145</sup> J. J. Kempster<sup>20</sup> J. Kendrick<sup>20</sup> K. E. Kennedy<sup>41</sup> O. Kepka<sup>130</sup>  
B. P. Kerridge<sup>166</sup> S. Kersten<sup>170</sup> B. P. Kerševan<sup>92</sup> L. Keszeghova<sup>28a</sup> S. Ketabchi Haghighat<sup>154</sup> M. Khandoga<sup>126</sup>  
A. Khanov<sup>120</sup> A. G. Kharlamov<sup>37</sup> T. Kharlamova<sup>37</sup> E. E. Khoda<sup>137</sup> T. J. Khoo<sup>18</sup> G. Khorauli<sup>165</sup>  
J. Khubua<sup>148b</sup> Y. A. R. Khwaira<sup>66</sup> M. Kiehn<sup>36</sup> A. Kilgallon<sup>122</sup> D. W. Kim<sup>47a,47b</sup> E. Kim<sup>153</sup> Y. K. Kim<sup>39</sup>  
N. Kimura<sup>95</sup> A. Kirchhoff<sup>55</sup> D. Kirchmeier<sup>50</sup> C. Kirfel<sup>24</sup> J. Kirk<sup>133</sup> A. E. Kiryunin<sup>109</sup> T. Kishimoto<sup>152</sup>

D. P. Kisliuk,<sup>154</sup> C. Kitsaki,<sup>10</sup> O. Kivernyk,<sup>24</sup> M. Klassen,<sup>63a</sup> C. Klein,<sup>34</sup> L. Klein,<sup>165</sup> M. H. Klein,<sup>105</sup> M. Klein,<sup>91</sup> U. Klein,<sup>91</sup> P. Klimek,<sup>36</sup> A. Klimentov,<sup>29</sup> F. Klimpel,<sup>109</sup> T. Klingl,<sup>24</sup> T. Klioutchnikova,<sup>36</sup> F. F. Klitzner,<sup>108</sup> P. Kluit,<sup>113</sup> S. Kluth,<sup>109</sup> E. Kneringer,<sup>78</sup> T. M. Knight,<sup>154</sup> A. Knue,<sup>54</sup> D. Kobayashi,<sup>88</sup> R. Kobayashi,<sup>86</sup> M. Kocian,<sup>142</sup> T. Kodama,<sup>152</sup> P. Kodyš,<sup>132</sup> D. M. Koeck,<sup>145</sup> P. T. Koenig,<sup>24</sup> T. Koffas,<sup>34</sup> N. M. Köhler,<sup>36</sup> M. Kolb,<sup>134</sup> I. Koletsou,<sup>4</sup> T. Komarek,<sup>121</sup> K. Köneke,<sup>54</sup> A. X. Y. Kong,<sup>1</sup> T. Kono,<sup>117</sup> N. Konstantinidis,<sup>95</sup> B. Konya,<sup>97</sup> R. Kopeliantsky,<sup>67</sup> S. Koperny,<sup>84a</sup> K. Korcyl,<sup>85</sup> K. Kordas,<sup>151</sup> G. Koren,<sup>150</sup> A. Korn,<sup>95</sup> S. Korn,<sup>55</sup> I. Korolkov,<sup>13</sup> N. Korotkova,<sup>37</sup> B. Kortman,<sup>113</sup> O. Kortner,<sup>109</sup> S. Kortner,<sup>109</sup> W. H. Kostecka,<sup>114</sup> V. V. Kostyukhin,<sup>140</sup> A. Kotsokechagia,<sup>66</sup> A. Kotwal,<sup>51</sup> A. Koulouris,<sup>36</sup> A. Kourkouveli-Charalampidi,<sup>72a,72b</sup> C. Kourkouvelis,<sup>9</sup> E. Kourlitis,<sup>6</sup> O. Kovanda,<sup>145</sup> R. Kowalewski,<sup>164</sup> W. Kozanecki,<sup>134</sup> A. S. Kozhin,<sup>37</sup> V. A. Kramarenko,<sup>37</sup> G. Kramberger,<sup>92</sup> P. Kramer,<sup>99</sup> M. W. Krasny,<sup>126</sup> A. Krasznahorkay,<sup>36</sup> J. A. Kremer,<sup>99</sup> T. Kresse,<sup>50</sup> J. Kretzschmar,<sup>91</sup> K. Kreul,<sup>18</sup> P. Krieger,<sup>154</sup> F. Krieter,<sup>108</sup> S. Krishnamurthy,<sup>102</sup> A. Krishnan,<sup>63b</sup> M. Krivos,<sup>132</sup> K. Krizka,<sup>17a</sup> K. Kroeninger,<sup>49</sup> H. Kroha,<sup>109</sup> J. Kroll,<sup>130</sup> J. Kroll,<sup>127</sup> K. S. Krowpman,<sup>106</sup> U. Kruchonak,<sup>38</sup> H. Krüger,<sup>24</sup> N. Krumnack,<sup>80</sup> M. C. Kruse,<sup>51</sup> J. A. Krzysiak,<sup>85</sup> A. Kubota,<sup>153</sup> O. Kuchinskaia,<sup>37</sup> S. Kuday,<sup>3a</sup> D. Kuechler,<sup>48</sup> J. T. Kuechler,<sup>48</sup> S. Kuehn,<sup>36</sup> T. Kuhl,<sup>48</sup> V. Kukhtin,<sup>38</sup> Y. Kulchitsky,<sup>37,m</sup> S. Kuleshov,<sup>136d,136b</sup> M. Kumar,<sup>33g</sup> N. Kumari,<sup>101</sup> M. Kuna,<sup>60</sup> A. Kupco,<sup>130</sup> T. Kupfer,<sup>49</sup> A. Kupich,<sup>37</sup> O. Kuprash,<sup>54</sup> H. Kurashige,<sup>83</sup> L. L. Kurchaninov,<sup>155a</sup> Y. A. Kurochkin,<sup>37</sup> A. Kurova,<sup>37</sup> E. S. Kuwertz,<sup>36</sup> M. Kuze,<sup>153</sup> A. K. Kvam,<sup>102</sup> J. Kvita,<sup>121</sup> T. Kwan,<sup>103</sup> K. W. Kwok,<sup>64a</sup> C. Lacasta,<sup>162</sup> F. Lacava,<sup>74a,74b</sup> H. Lacker,<sup>18</sup> D. Lacour,<sup>126</sup> N. N. Lad,<sup>95</sup> E. Ladygin,<sup>38</sup> B. Laforge,<sup>126</sup> T. Lagouri,<sup>136e</sup> S. Lai,<sup>55</sup> I. K. Lakomic,<sup>84a</sup> N. Lalloue,<sup>60</sup> J. E. Lambert,<sup>119</sup> S. Lammers,<sup>67</sup> W. Lampl,<sup>7</sup> C. Lampoudis,<sup>151</sup> A. N. Lancaster,<sup>114</sup> E. Lançon,<sup>29</sup> U. Landgraf,<sup>54</sup> M. P. J. Landon,<sup>93</sup> V. S. Lang,<sup>54</sup> R. J. Langenberg,<sup>102</sup> A. J. Lankford,<sup>159</sup> F. Lanni,<sup>29</sup> K. Lantzsch,<sup>24</sup> A. Lanza,<sup>72a</sup> A. Lapertosa,<sup>57b,57a</sup> J. F. Laporte,<sup>134</sup> T. Lari,<sup>70a</sup> F. Lasagni Manghi,<sup>23b</sup> M. Lassnig,<sup>36</sup> V. Latonova,<sup>130</sup> T. S. Lau,<sup>64a</sup> A. Laudrain,<sup>99</sup> A. Laurier,<sup>34</sup> S. D. Lawlor,<sup>94</sup> Z. Lawrence,<sup>100</sup> M. Lazzaroni,<sup>70a,70b</sup> B. Le,<sup>100</sup> B. Leban,<sup>92</sup> A. Lebedev,<sup>80</sup> M. LeBlanc,<sup>36</sup> T. LeCompte,<sup>6</sup> F. Ledroit-Guillon,<sup>60</sup> A. C. A. Lee,<sup>95</sup> G. R. Lee,<sup>16</sup> L. Lee,<sup>61</sup> S. C. Lee,<sup>147</sup> S. Lee,<sup>47a,47b</sup> L. L. Leeuw,<sup>33c</sup> H. P. Lefebvre,<sup>94</sup> M. Lefebvre,<sup>164</sup> C. Leggett,<sup>17a</sup> K. Lehmann,<sup>141</sup> G. Lehmann Miotto,<sup>36</sup> W. A. Leight,<sup>102</sup> A. Leisos,<sup>151,ee</sup> M. A. L. Leite,<sup>81c</sup> C. E. Leitgeb,<sup>48</sup> R. Leitner,<sup>132</sup> K. J. C. Leney,<sup>44</sup> T. Lenz,<sup>24</sup> S. Leone,<sup>73a</sup> C. Leonidopoulos,<sup>52</sup> A. Leopold,<sup>143</sup> C. Leroy,<sup>107</sup> R. Les,<sup>106</sup> C. G. Lester,<sup>32</sup> M. Levchenko,<sup>37</sup> J. Levêque,<sup>4</sup> D. Levin,<sup>105</sup> L. J. Levinson,<sup>168</sup> D. J. Lewis,<sup>20</sup> B. Li,<sup>14b</sup> B. Li,<sup>62b</sup> C. Li,<sup>62a</sup> C-Q. Li,<sup>62c,62d</sup> H. Li,<sup>62a</sup> H. Li,<sup>62b</sup> H. Li,<sup>14c</sup> H. Li,<sup>62b</sup> J. Li,<sup>62c</sup> K. Li,<sup>137</sup> L. Li,<sup>62c</sup> M. Li,<sup>14a,14d</sup> Q. Y. Li,<sup>62a</sup> S. Li,<sup>62d,62c,ff</sup> T. Li,<sup>62b</sup> X. Li,<sup>103</sup> Z. Li,<sup>62b</sup> Z. Li,<sup>125</sup> Z. Li,<sup>103</sup> Z. Li,<sup>91</sup> Z. Liang,<sup>14a</sup> M. Liberatore,<sup>48</sup> B. Liberti,<sup>75a</sup> K. Lie,<sup>64c</sup> J. Lieber Marin,<sup>81b</sup> K. Lin,<sup>106</sup> R. A. Linck,<sup>67</sup> R. E. Lindley,<sup>7</sup> J. H. Lindon,<sup>2</sup> A. Lins,<sup>48</sup> E. Lipeles,<sup>127</sup> A. Lipniacka,<sup>16</sup> T. M. Liss,<sup>161,gg</sup> A. Lister,<sup>163</sup> J. D. Little,<sup>4</sup> B. Liu,<sup>14a</sup> B. X. Liu,<sup>141</sup> D. Liu,<sup>62d,62c</sup> J. B. Liu,<sup>62a</sup> J. K. K. Liu,<sup>32</sup> K. Liu,<sup>62d,62c</sup> M. Liu,<sup>62a</sup> M. Y. Liu,<sup>62a</sup> P. Liu,<sup>14a</sup> Q. Liu,<sup>62d,137,62c</sup> X. Liu,<sup>62a</sup> Y. Liu,<sup>48</sup> Y. Liu,<sup>14c,14d</sup> Y. L. Liu,<sup>105</sup> Y. W. Liu,<sup>62a</sup> M. Livan,<sup>72a,72b</sup> J. Llorente Merino,<sup>141</sup> S. L. Lloyd,<sup>93</sup> E. M. Lobodzinska,<sup>48</sup> P. Loch,<sup>7</sup> S. Loffredo,<sup>75a,75b</sup> T. Lohse,<sup>18</sup> K. Lohwasser,<sup>138</sup> M. Lokajicek,<sup>130,a</sup> J. D. Long,<sup>161</sup> I. Longarini,<sup>74a,74b</sup> L. Longo,<sup>69a,69b</sup> R. Longo,<sup>161</sup> I. Lopez Paz,<sup>36</sup> A. Lopez Solis,<sup>48</sup> J. Lorenz,<sup>108</sup> N. Lorenzo Martinez,<sup>4</sup> A. M. Lory,<sup>108</sup> A. Lösle,<sup>54</sup> X. Lou,<sup>47a,47b</sup> X. Lou,<sup>14a,14d</sup> A. Lounis,<sup>66</sup> J. Love,<sup>6</sup> P. A. Love,<sup>90</sup> J. J. Lozano Bahilo,<sup>162</sup> G. Lu,<sup>14a,14d</sup> M. Lu,<sup>79</sup> S. Lu,<sup>127</sup> Y. J. Lu,<sup>65</sup> H. J. Lubatti,<sup>137</sup> C. Luci,<sup>74a,74b</sup> F. L. Lucio Alves,<sup>14c</sup> A. Lucotte,<sup>60</sup> F. Luehring,<sup>67</sup> I. Luise,<sup>144</sup> O. Lukianchuk,<sup>66</sup> O. Lundberg,<sup>143</sup> B. Lund-Jensen,<sup>143</sup> N. A. Luongo,<sup>122</sup> M. S. Lutz,<sup>150</sup> D. Lynn,<sup>29</sup> H. Lyons,<sup>91</sup> R. Lysak,<sup>130</sup> E. Lytken,<sup>97</sup> F. Lyu,<sup>14a</sup> V. Lyubushkin,<sup>38</sup> T. Lyubushkina,<sup>38</sup> H. Ma,<sup>29</sup> L. L. Ma,<sup>62b</sup> Y. Ma,<sup>95</sup> D. M. Mac Donell,<sup>164</sup> G. Maccarrone,<sup>53</sup> J. C. MacDonald,<sup>138</sup> R. Madar,<sup>40</sup> W. F. Mader,<sup>50</sup> J. Maeda,<sup>83</sup> T. Maeno,<sup>29</sup> M. Maerker,<sup>50</sup> V. Magerl,<sup>54</sup> J. Magro,<sup>68a,68c</sup> H. Maguire,<sup>138</sup> D. J. Mahon,<sup>41</sup> C. Maidantchik,<sup>81b</sup> A. Maio,<sup>129a,129b,129d</sup> K. Maj,<sup>84a</sup> O. Majersky,<sup>28a</sup> S. Majewski,<sup>122</sup> N. Makovec,<sup>66</sup> V. Maksimovic,<sup>15</sup> B. Malaescu,<sup>126</sup> Pa. Malecki,<sup>85</sup> V. P. Maleev,<sup>37</sup> F. Malek,<sup>60</sup> D. Malito,<sup>43b,43a</sup> U. Mallik,<sup>79</sup> C. Malone,<sup>32</sup> S. Maltezos,<sup>10</sup> S. Malyukov,<sup>38</sup> J. Mamuzic,<sup>13</sup> G. Mancini,<sup>53</sup> G. Manco,<sup>72a,72b</sup> J. P. Mandalia,<sup>93</sup> I. Mandić,<sup>92</sup> L. Manhaes de Andrade Filho,<sup>81a</sup> I. M. Maniatis,<sup>151</sup> M. Manisha,<sup>134</sup> J. Manjarres Ramos,<sup>50</sup> D. C. Mankad,<sup>168</sup> K. H. Mankinen,<sup>97</sup> A. Mann,<sup>108</sup> A. Manousos,<sup>78</sup> B. Mansoulie,<sup>134</sup> S. Manzoni,<sup>36</sup> A. Marantis,<sup>151,ee</sup> G. Marchiori,<sup>5</sup> M. Marcisovsky,<sup>130</sup> L. Marcoccia,<sup>75a,75b</sup> C. Marcon,<sup>97</sup> M. Marinescu,<sup>20</sup> M. Marjanovic,<sup>119</sup> Z. Marshall,<sup>17a</sup> S. Marti-Garcia,<sup>162</sup>

T. A. Martin<sup>166</sup> V. J. Martin<sup>52</sup> B. Martin dit Latour<sup>16</sup> L. Martinelli<sup>74a,74b</sup> M. Martinez<sup>13,z</sup> P. Martinez Agullo<sup>162</sup>  
V. I. Martinez Outschoorn<sup>102</sup> P. Martinez Suarez<sup>13</sup> S. Martin-Haugh<sup>133</sup> V. S. Martoiu<sup>27b</sup> A. C. Martyniuk<sup>95</sup>  
A. Marzin<sup>36</sup> S. R. Maschek<sup>109</sup> L. Masetti<sup>99</sup> T. Mashimo<sup>152</sup> J. Masik<sup>100</sup> A. L. Maslennikov<sup>37</sup> L. Massa<sup>23b</sup>  
P. Massarotti<sup>71a,71b</sup> P. Mastrandrea<sup>73a,73b</sup> A. Mastroberardino<sup>43b,43a</sup> T. Masubuchi<sup>152</sup> T. Mathisen<sup>160</sup>  
A. Matic<sup>108</sup> N. Matsuzawa<sup>152</sup> J. Maurer<sup>27b</sup> B. Maček<sup>92</sup> D. A. Maximov<sup>37</sup> R. Mazini<sup>147</sup> I. Maznas<sup>151</sup>  
M. Mazza<sup>106</sup> S. M. Mazza<sup>135</sup> C. Mc Ginn<sup>29</sup> J. P. Mc Gowan<sup>103</sup> S. P. Mc Kee<sup>105</sup> T. G. McCarthy<sup>109</sup>  
W. P. McCormack<sup>17a</sup> E. F. McDonald<sup>104</sup> A. E. McDougall<sup>113</sup> J. A. Mcfayden<sup>145</sup> G. Mchedlidze<sup>148b</sup>  
R. P. Mckenzie<sup>33g</sup> T. C. McLachlan<sup>48</sup> D. J. McLaughlin<sup>95</sup> K. D. McLean<sup>164</sup> S. J. McMahon<sup>133</sup>  
P. C. McNamara<sup>104</sup> R. A. McPherson<sup>164,q</sup> J. E. Mdhluli<sup>33g</sup> S. Meehan<sup>36</sup> T. Megy<sup>40</sup> S. Mehlhase<sup>108</sup>  
A. Mehta<sup>91</sup> B. Meirose<sup>45</sup> D. Melini<sup>149</sup> B. R. Mellado Garcia<sup>33g</sup> A. H. Melo<sup>55</sup> F. Meloni<sup>48</sup>  
E. D. Mendes Gouveia<sup>129a</sup> A. M. Mendes Jacques Da Costa<sup>20</sup> H. Y. Meng<sup>154</sup> L. Meng<sup>90</sup> S. Menke<sup>109</sup>  
M. Mentink<sup>36</sup> E. Meoni<sup>43b,43a</sup> C. Merlassino<sup>125</sup> L. Merola<sup>71a,71b</sup> C. Meroni<sup>70a</sup> G. Merz<sup>105</sup> O. Meshkov<sup>37</sup>  
J. K. R. Meshreki<sup>140</sup> J. Metcalfe<sup>6</sup> A. S. Mete<sup>6</sup> C. Meyer<sup>67</sup> J-P. Meyer<sup>134</sup> M. Michetti<sup>18</sup> R. P. Middleton<sup>133</sup>  
L. Mijović<sup>52</sup> G. Mikenberg<sup>168</sup> M. Mikestikova<sup>130</sup> M. Mikuž<sup>92</sup> H. Mildner<sup>138</sup> A. Milic<sup>154</sup> C. D. Milke<sup>44</sup>  
D. W. Miller<sup>39</sup> L. S. Miller<sup>34</sup> A. Milov<sup>168</sup> D. A. Milstead<sup>47a,47b</sup> T. Min<sup>14c</sup> A. A. Minaenko<sup>37</sup> I. A. Minashvili<sup>148b</sup>  
L. Mince<sup>59</sup> A. I. Mincer<sup>116</sup> B. Mindur<sup>84a</sup> M. Mineev<sup>38</sup> Y. Minegishi<sup>152</sup> Y. Mino<sup>86</sup> L. M. Mir<sup>13</sup>  
M. Miralles Lopez<sup>162</sup> M. Mironova<sup>125</sup> T. Mitani<sup>167</sup> A. Mitra<sup>166</sup> V. A. Mitsou<sup>162</sup> O. Miu<sup>154</sup> P. S. Miyagawa<sup>93</sup>  
Y. Miyazaki<sup>88</sup> A. Mizukami<sup>82</sup> J. U. Mjörnmark<sup>97</sup> T. Mkrtchyan<sup>63a</sup> M. Mlynarikova<sup>114</sup> T. Moa<sup>47a,47b</sup>  
S. Mobius<sup>55</sup> K. Mochizuki<sup>107</sup> P. Moder<sup>48</sup> P. Mogg<sup>108</sup> A. F. Mohammed<sup>14a,14d</sup> S. Mohapatra<sup>41</sup>  
G. Mokgatitswane<sup>33g</sup> B. Mondal<sup>140</sup> S. Mondal<sup>131</sup> K. Mönig<sup>48</sup> E. Monnier<sup>101</sup> L. Monsonis Romero<sup>162</sup>  
J. Montejo Berlingen<sup>36</sup> M. Montella<sup>118</sup> F. Monticelli<sup>89</sup> N. Morange<sup>66</sup> A. L. Moreira De Carvalho<sup>129a</sup>  
M. Moreno Llácer<sup>162</sup> C. Moreno Martinez<sup>13</sup> P. Morettini<sup>57b</sup> S. Morgenstern<sup>166</sup> M. Morii<sup>61</sup> M. Morinaga<sup>152</sup>  
V. Morisbak<sup>124</sup> A. K. Morley<sup>36</sup> F. Morodei<sup>74a,74b</sup> L. Morvaj<sup>36</sup> P. Moschovakos<sup>36</sup> B. Moser<sup>36</sup> M. Mosidze<sup>148b</sup>  
T. Moskalets<sup>54</sup> P. Moskvitina<sup>112</sup> J. Moss<sup>31,hh</sup> E. J. W. Moyse<sup>102</sup> S. Muanza<sup>101</sup> J. Mueller<sup>128</sup>  
D. Muenstermann<sup>90</sup> R. Müller<sup>19</sup> G. A. Mullier<sup>97</sup> J. J. Mullin<sup>127</sup> D. P. Mungo<sup>70a,70b</sup> J. L. Munoz Martinez<sup>13</sup>  
D. Munoz Perez<sup>162</sup> F. J. Munoz Sanchez<sup>100</sup> M. Murin<sup>100</sup> W. J. Murray<sup>166,133</sup> A. Murrone<sup>70a,70b</sup> J. M. Muse<sup>119</sup>  
M. Muškinja<sup>17a</sup> C. Mwewa<sup>29</sup> A. G. Myagkov<sup>37,m</sup> A. J. Myers<sup>8</sup> A. A. Myers<sup>128</sup> G. Myers<sup>67</sup> M. Myska<sup>131</sup>  
B. P. Nachman<sup>17a</sup> O. Nackenhorst<sup>49</sup> A. Nag<sup>50</sup> K. Nagai<sup>125</sup> K. Nagano<sup>82</sup> J. L. Nagle<sup>29,i</sup> E. Nagy<sup>101</sup>  
A. M. Nairz<sup>36</sup> Y. Nakahama<sup>82</sup> K. Nakamura<sup>82</sup> H. Nanjo<sup>123</sup> R. Narayan<sup>44</sup> E. A. Narayanan<sup>111</sup> I. Naryshkin<sup>37</sup>  
M. Naseri<sup>34</sup> C. Nass<sup>24</sup> G. Navarro<sup>22a</sup> J. Navarro-Gonzalez<sup>162</sup> R. Nayak<sup>150</sup> P. Y. Nechaeva<sup>37</sup> F. Nechansky<sup>48</sup>  
T. J. Neep<sup>20</sup> A. Negri<sup>72a,72b</sup> M. Negrini<sup>23b</sup> C. Nellist<sup>112</sup> C. Nelson<sup>103</sup> K. Nelson<sup>105</sup> S. Nemecek<sup>130</sup>  
M. Nessi<sup>36,ii</sup> M. S. Neubauer<sup>161</sup> F. Neuhaus<sup>99</sup> J. Neundorff<sup>48</sup> R. Newhouse<sup>163</sup> P. R. Newman<sup>20</sup> C. W. Ng<sup>128</sup>  
Y. S. Ng<sup>18</sup> Y. W. Y. Ng<sup>159</sup> B. Ngair<sup>35e</sup> H. D. N. Nguyen<sup>107</sup> R. B. Nickerson<sup>125</sup> R. Nicolaidou<sup>134</sup> J. Nielsen<sup>135</sup>  
M. Niemeyer<sup>55</sup> N. Nikiforou<sup>36</sup> V. Nikolaenko<sup>37,m</sup> I. Nikolic-Audit<sup>126</sup> K. Nikolopoulos<sup>20</sup> P. Nilsson<sup>29</sup>  
H. R. Nindhito<sup>56</sup> A. Nisati<sup>74a</sup> N. Nishu<sup>2</sup> R. Nisius<sup>109</sup> J-E. Nitschke<sup>50</sup> E. K. Nkadimeng<sup>33g</sup>  
S. J. Noacco Rosende<sup>89</sup> T. Nobe<sup>152</sup> D. L. Noel<sup>32</sup> Y. Noguchi<sup>86</sup> T. Nommensen<sup>146</sup> M. A. Nomura<sup>29</sup>  
M. B. Norfolk<sup>138</sup> R. R. B. Norisam<sup>95</sup> B. J. Norman<sup>34</sup> J. Novak<sup>92</sup> T. Novak<sup>48</sup> O. Novgorodova<sup>50</sup>  
L. Novotny<sup>131</sup> R. Novotny<sup>111</sup> L. Nozka<sup>121</sup> K. Ntekas<sup>159</sup> E. Nurse<sup>95</sup> F. G. Oakham<sup>34,e</sup> J. Ocariz<sup>126</sup> A. Ochi<sup>83</sup>  
I. Ochoa<sup>129a</sup> S. Oda<sup>88</sup> S. Oerde<sup>160</sup> A. Ogrodnik<sup>84a</sup> A. Oh<sup>100</sup> C. C. Ohm<sup>143</sup> H. Oide<sup>153</sup> R. Oishi<sup>152</sup>  
M. L. Ojeda<sup>48</sup> Y. Okazaki<sup>86</sup> M. W. O'Keefe<sup>91</sup> Y. Okumura<sup>152</sup> A. Olariu<sup>27b</sup> L. F. Oleiro Seabra<sup>129a</sup>  
S. A. Olivares Pino<sup>136e</sup> D. Oliveira Damazio<sup>29</sup> D. Oliveira Goncalves<sup>81a</sup> J. L. Oliver<sup>159</sup> M. J. R. Olsson<sup>159</sup>  
A. Olszewski<sup>85</sup> J. Olszowska<sup>85,a</sup> Ö. O. Öncel<sup>54</sup> D. C. O'Neil<sup>141</sup> A. P. O'Neill<sup>19</sup> A. Onofre<sup>129a,129e</sup>  
P. U. E. Onyisi<sup>11</sup> M. J. Oreglia<sup>39</sup> G. E. Orellana<sup>89</sup> D. Orestano<sup>76a,76b</sup> N. Orlando<sup>13</sup> R. S. Orr<sup>154</sup> V. O'Shea<sup>59</sup>  
R. Ospanov<sup>62a</sup> G. Otero y Garzon<sup>30</sup> H. Otono<sup>88</sup> P. S. Ott<sup>63a</sup> G. J. Ottino<sup>17a</sup> M. Ouchrif<sup>35d</sup> J. Ouellette<sup>29,i</sup>  
F. Ould-Saada<sup>124</sup> M. Owen<sup>59</sup> R. E. Owen<sup>133</sup> K. Y. Oyulmaz<sup>21a</sup> V. E. Ozcan<sup>21a</sup> N. Ozturk<sup>8</sup> S. Ozturk<sup>21d</sup>  
J. Pacalt<sup>121</sup> H. A. Pacey<sup>32</sup> K. Pachal<sup>51</sup> A. Pacheco Pages<sup>13</sup> C. Padilla Aranda<sup>13</sup> G. Padovano<sup>74a,74b</sup>  
S. Pagan Griso<sup>17a</sup> G. Palacino<sup>67</sup> A. Palazzo<sup>69a,69b</sup> S. Palazzo<sup>52</sup> S. Palestini<sup>36</sup> M. Palka<sup>84b</sup> J. Pan<sup>171</sup>  
T. Pan<sup>64a</sup> D. K. Panchal<sup>11</sup> C. E. Pandini<sup>113</sup> J. G. Panduro Vazquez<sup>94</sup> H. Pang<sup>14b</sup> P. Pani<sup>48</sup> G. Panizzo<sup>68a,68c</sup>  
L. Paolozzi<sup>56</sup> C. Papadatos<sup>107</sup> S. Parajuli<sup>44</sup> A. Paramonov<sup>6</sup> C. Paraskevopoulos<sup>10</sup> D. Paredes Hernandez<sup>64b</sup>

T. H. Park<sup>154</sup> M. A. Parker<sup>32</sup> F. Parodi<sup>57b,57a</sup> E. W. Parrish<sup>114</sup> V. A. Parrish<sup>52</sup> J. A. Parsons<sup>41</sup> U. Parzefall<sup>54</sup>  
 B. Pascual Dias<sup>107</sup> L. Pascual Dominguez<sup>150</sup> V. R. Pascuzzi<sup>17a</sup> F. Pasquali<sup>113</sup> E. Pasqualucci<sup>74a</sup> S. Passaggio<sup>57b</sup>  
 F. Pastore<sup>94</sup> P. Pasuwan<sup>47a,47b</sup> J. R. Pater<sup>100</sup> J. Patton<sup>91</sup> T. Pauly<sup>36</sup> J. Pearkes<sup>142</sup> M. Pedersen<sup>124</sup> R. Pedro<sup>129a</sup>  
 S. V. Peleganchuk<sup>37</sup> O. Penc<sup>130</sup> C. Peng<sup>64b</sup> H. Peng<sup>62a</sup> M. Penzin<sup>37</sup> B. S. Peralva<sup>81a,81d</sup>  
 A. P. Pereira Peixoto<sup>60</sup> L. Pereira Sanchez<sup>47a,47b</sup> D. V. Perepelitsa<sup>29,i</sup> E. Perez Codina<sup>155a</sup> M. Perganti<sup>10</sup>  
 L. Perini<sup>70a,70b,a</sup> H. Pernegger<sup>36</sup> S. Perrella<sup>36</sup> A. Perrevoort<sup>112</sup> O. Perrin<sup>40</sup> K. Peters<sup>48</sup> R. F. Y. Peters<sup>100</sup>  
 B. A. Petersen<sup>36</sup> T. C. Petersen<sup>42</sup> E. Petit<sup>101</sup> V. Petousis<sup>131</sup> C. Petridou<sup>151</sup> A. Petrukhin<sup>140</sup> M. Pettee<sup>17a</sup>  
 N. E. Pettersson<sup>36</sup> A. Petukhov<sup>37</sup> K. Petukhova<sup>132</sup> A. Peyaud<sup>134</sup> R. Pezoa<sup>136f</sup> L. Pezzotti<sup>36</sup> G. Pezzullo<sup>171</sup>  
 T. Pham<sup>104</sup> P. W. Phillips<sup>133</sup> M. W. Phipps<sup>161</sup> G. Piacquadio<sup>144</sup> E. Pianori<sup>17a</sup> F. Piazza<sup>70a,70b</sup> R. Piegaia<sup>30</sup>  
 D. Pietreanu<sup>27b</sup> A. D. Pilkington<sup>100</sup> M. Pinamonti<sup>68a,68c</sup> J. L. Pinfold<sup>2</sup> B. C. Pinheiro Pereira<sup>129a</sup>  
 C. Pitman Donaldson<sup>95</sup> D. A. Pizzi<sup>34</sup> L. Pizzimento<sup>75a,75b</sup> A. Pizzini<sup>113</sup> M.-A. Pleier<sup>29</sup> V. Plesanovs<sup>54</sup>  
 V. Pleskot<sup>132</sup> E. Plotnikova<sup>38</sup> G. Poddar<sup>4</sup> R. Poettgen<sup>97</sup> R. Poggi<sup>56</sup> L. Poggioli<sup>126</sup> I. Pogrebnyak<sup>106</sup>  
 D. Pohl<sup>24</sup> I. Pokharel<sup>55</sup> S. Polacek<sup>132</sup> G. Polesello<sup>72a</sup> A. Poley<sup>141,155a</sup> R. Polifka<sup>131</sup> A. Polini<sup>23b</sup>  
 C. S. Pollard<sup>125</sup> Z. B. Pollock<sup>118</sup> V. Polychronakos<sup>29</sup> D. Ponomarenko<sup>37</sup> L. Pontecorvo<sup>36</sup> S. Popa<sup>27a</sup>  
 G. A. Popeneciu<sup>27d</sup> D. M. Portillo Quintero<sup>155a</sup> S. Pospisil<sup>131</sup> P. Postolache<sup>27c</sup> K. Potamianos<sup>125</sup> I. N. Potrap<sup>38</sup>  
 C. J. Potter<sup>32</sup> H. Potti<sup>1</sup> T. Poulsen<sup>48</sup> J. Poveda<sup>162</sup> G. Pownall<sup>48</sup> M. E. Pozo Astigarraga<sup>36</sup>  
 A. Prades Ibanez<sup>162</sup> M. M. Prapa<sup>46</sup> J. Pretel<sup>54</sup> D. Price<sup>100</sup> M. Primavera<sup>69a</sup> M. A. Principe Martin<sup>98</sup>  
 M. L. Proffitt<sup>137</sup> N. Proklova<sup>37</sup> K. Prokofiev<sup>64c</sup> G. Proto<sup>75a,75b</sup> S. Protopopescu<sup>29</sup> J. Proudfoot<sup>6</sup>  
 M. Przybycien<sup>84a</sup> J. E. Puddefoot<sup>138</sup> D. Pudzha<sup>37</sup> P. Puzo<sup>66</sup> D. Pyatiizbyantseva<sup>37</sup> J. Qian<sup>105</sup> Y. Qin<sup>100</sup>  
 T. Qiu<sup>93</sup> A. Quadt<sup>55</sup> M. Queitsch-Maitland<sup>24</sup> G. Rabanal Bolanos<sup>61</sup> D. Rafanoharana<sup>54</sup> F. Ragusa<sup>70a,70b</sup>  
 J. L. Rainbolt<sup>39</sup> J. A. Raine<sup>56</sup> S. Rajagopalan<sup>29</sup> E. Ramakoti<sup>37</sup> K. Ran<sup>14a,14d</sup> V. Raskina<sup>126</sup> D. F. Rassloff<sup>63a</sup>  
 S. Rave<sup>99</sup> B. Ravina<sup>59</sup> I. Ravinovich<sup>168</sup> M. Raymond<sup>36</sup> A. L. Read<sup>124</sup> N. P. Readioff<sup>138</sup> D. M. Rebuffi<sup>72a,72b</sup>  
 G. Redlinger<sup>29</sup> K. Reeves<sup>45</sup> J. A. Reidelsturz<sup>170</sup> D. Reikher<sup>150</sup> A. Reiss<sup>99</sup> A. Rej<sup>140</sup> C. Rembser<sup>36</sup>  
 A. Renardi<sup>48</sup> M. Renda<sup>27b</sup> M. B. Rendel<sup>109</sup> A. G. Rennie<sup>59</sup> S. Resconi<sup>70a</sup> M. Ressegotti<sup>57b,57a</sup>  
 E. D. Resseguie<sup>17a</sup> S. Rettie<sup>95</sup> B. Reynolds<sup>118</sup> E. Reynolds<sup>17a</sup> M. Rezaei Estabragh<sup>170</sup> O. L. Rezanova<sup>37</sup>  
 P. Reznicek<sup>132</sup> E. Ricci<sup>77a,77b</sup> R. Richter<sup>109</sup> S. Richter<sup>47a,47b</sup> E. Richter-Was<sup>84b</sup> M. Ridel<sup>126</sup> P. Rieck<sup>116</sup>  
 P. Riedler<sup>36</sup> M. Rijssenbeek<sup>144</sup> A. Rimoldi<sup>72a,72b</sup> M. Rimoldi<sup>48</sup> L. Rinaldi<sup>23b,23a</sup> T. T. Rinn<sup>29</sup>  
 M. P. Rinnagel<sup>108</sup> G. Ripellino<sup>143</sup> I. Riu<sup>13</sup> P. Rivadeneira<sup>48</sup> J. C. Rivera Vergara<sup>164</sup> F. Rizatdinova<sup>120</sup>  
 E. Rizvi<sup>93</sup> C. Rizzi<sup>56</sup> B. A. Roberts<sup>166</sup> B. R. Roberts<sup>17a</sup> S. H. Robertson<sup>103,q</sup> M. Robin<sup>48</sup> D. Robinson<sup>32</sup>  
 C. M. Robles Gajardo<sup>136f</sup> M. Robles Manzano<sup>99</sup> A. Robson<sup>59</sup> A. Rocchi<sup>75a,75b</sup> C. Roda<sup>73a,73b</sup>  
 S. Rodriguez Bosca<sup>63a</sup> Y. Rodriguez Garcia<sup>22a</sup> A. Rodriguez Rodriguez<sup>54</sup> A. M. Rodriguez Vera<sup>155b</sup> S. Roe<sup>36</sup>  
 J. T. Roemer<sup>159</sup> A. R. Roepe-Gier<sup>119</sup> J. Roggel<sup>170</sup> O. Røhne<sup>124</sup> R. A. Rojas<sup>164</sup> B. Roland<sup>54</sup> C. P. A. Roland<sup>67</sup>  
 J. Roloff<sup>29</sup> A. Romaniouk<sup>37</sup> E. Romano<sup>72a,72b</sup> M. Romano<sup>23b</sup> A. C. Romero Hernandez<sup>161</sup> N. Rompotis<sup>91</sup>  
 L. Roos<sup>126</sup> S. Rosati<sup>74a</sup> B. J. Rosser<sup>39</sup> E. Rossi<sup>4</sup> E. Rossi<sup>71a,71b</sup> L. P. Rossi<sup>57b</sup> L. Rossini<sup>48</sup> R. Rosten<sup>118</sup>  
 M. Rotaru<sup>27b</sup> B. Rottler<sup>54</sup> D. Rousseau<sup>66</sup> D. Rousso<sup>32</sup> G. Rovelli<sup>72a,72b</sup> A. Roy<sup>161</sup> A. Rozanov<sup>101</sup>  
 Y. Rozen<sup>149</sup> X. Ruan<sup>33g</sup> A. Rubio Jimenez<sup>162</sup> A. J. Ruby<sup>91</sup> T. A. Ruggeri<sup>1</sup> F. Rühr<sup>54</sup> A. Ruiz-Martinez<sup>162</sup>  
 A. Rummel<sup>36</sup> Z. Rurikova<sup>54</sup> N. A. Rusakovich<sup>38</sup> H. L. Russell<sup>164</sup> J. P. Rutherford<sup>7</sup> E. M. Rüttinger<sup>138</sup>  
 K. Rybacki<sup>90</sup> M. Rybar<sup>132</sup> E. B. Rye<sup>124</sup> A. Ryzhov<sup>37</sup> J. A. Sabater Iglesias<sup>56</sup> P. Sabatini<sup>162</sup> L. Sabetta<sup>74a,74b</sup>  
 H. F.-W. Sadrozinski<sup>135</sup> F. Safai Tehrani<sup>74a</sup> B. Safarzadeh Samani<sup>145</sup> M. Safdari<sup>142</sup> S. Saha<sup>103</sup> M. Sahinsoy<sup>109</sup>  
 M. Saimpert<sup>134</sup> M. Saito<sup>152</sup> T. Saito<sup>152</sup> D. Salamani<sup>36</sup> G. Salamanna<sup>76a,76b</sup> A. Salmikov<sup>142</sup> J. Salt<sup>162</sup>  
 A. Salvador Salas<sup>13</sup> D. Salvatore<sup>43b,43a</sup> F. Salvatore<sup>145</sup> A. Salzburger<sup>36</sup> D. Sammel<sup>54</sup> D. Sampsonidis<sup>151</sup>  
 D. Sampsonidou<sup>62d,62c</sup> J. Sánchez<sup>162</sup> A. Sanchez Pineda<sup>4</sup> V. Sanchez Sebastian<sup>162</sup> H. Sandaker<sup>124</sup>  
 C. O. Sander<sup>48</sup> J. A. Sandesara<sup>102</sup> M. Sandhoff<sup>170</sup> C. Sandoval<sup>22b</sup> D. P. C. Sankey<sup>133</sup> A. Sansoni<sup>53</sup>  
 L. Santi<sup>74a,74b</sup> C. Santoni<sup>40</sup> H. Santos<sup>129a,129b</sup> S. N. Santpur<sup>17a</sup> A. Santra<sup>168</sup> K. A. Saoucha<sup>138</sup>  
 J. G. Saraiva<sup>129a,129d</sup> J. Sardain<sup>101</sup> O. Sasaki<sup>82</sup> K. Sato<sup>156</sup> C. Sauer<sup>63b</sup> F. Sauerburger<sup>54</sup> E. Sauvan<sup>4</sup>  
 P. Savard<sup>154,e</sup> R. Sawada<sup>152</sup> C. Sawyer<sup>133</sup> L. Sawyer<sup>96</sup> I. Sayago Galvan<sup>162</sup> C. Sbarra<sup>23b</sup> A. Sbrizzi<sup>23b,23a</sup>  
 T. Scanlon<sup>95</sup> J. Schaarschmidt<sup>137</sup> P. Schacht<sup>109</sup> D. Schaefer<sup>39</sup> U. Schäfer<sup>99</sup> A. C. Schaffer<sup>66</sup> D. Schaile<sup>108</sup>  
 R. D. Schamberger<sup>144</sup> E. Schanet<sup>108</sup> C. Scharf<sup>18</sup> V. A. Schegelsky<sup>37</sup> D. Scheirich<sup>132</sup> F. Schenck<sup>18</sup>  
 M. Schernau<sup>159</sup> C. Scheulen<sup>55</sup> C. Schiavi<sup>57b,57a</sup> Z. M. Schillaci<sup>26</sup> E. J. Schioppa<sup>69a,69b</sup> M. Schioppa<sup>43b,43a</sup>

B. Schlag<sup>99</sup>, K. E. Schleicher<sup>54</sup>, S. Schlenker<sup>36</sup>, K. Schmieden<sup>99</sup>, C. Schmitt<sup>99</sup>, S. Schmitt<sup>48</sup>, L. Schoeffel<sup>134</sup>,  
A. Schoening<sup>63b</sup>, P. G. Scholer<sup>54</sup>, E. Schopf<sup>125</sup>, M. Schott<sup>99</sup>, J. Schovancova<sup>36</sup>, S. Schramm<sup>56</sup>, F. Schroeder<sup>170</sup>,  
H.-C. Schultz-Coulon<sup>63a</sup>, M. Schumacher<sup>54</sup>, B. A. Schumm<sup>135</sup>, Ph. Schune<sup>134</sup>, A. Schwartzman<sup>142</sup>,  
T. A. Schwarz<sup>105</sup>, Ph. Schwemling<sup>134</sup>, R. Schwienhorst<sup>106</sup>, A. Sciandra<sup>135</sup>, G. Sciolla<sup>26</sup>, F. Scuri<sup>73a</sup>, F. Scutti<sup>104</sup>,  
C. D. Sebastiani<sup>91</sup>, K. Sedlaczek<sup>49</sup>, P. Seema<sup>18</sup>, S. C. Seidel<sup>111</sup>, A. Seiden<sup>135</sup>, B. D. Seidlitz<sup>41</sup>, T. Seiss<sup>39</sup>,  
C. Seitz<sup>48</sup>, J. M. Seixas<sup>81b</sup>, G. Sekhniaidze<sup>71a</sup>, S. J. Sekula<sup>44</sup>, L. Selem<sup>4</sup>, N. Semprini-Cesari<sup>23b,23a</sup>, S. Sen<sup>51</sup>,  
D. Sengupta<sup>56</sup>, V. Senthilkumar<sup>162</sup>, L. Serin<sup>66</sup>, L. Serkin<sup>68a,68b</sup>, M. Sessa<sup>76a,76b</sup>, H. Severini<sup>119</sup>, S. Sevova<sup>142</sup>,  
F. Sforza<sup>57b,57a</sup>, A. Sfyrla<sup>56</sup>, E. Shabalina<sup>55</sup>, R. Shaheen<sup>143</sup>, J. D. Shahinian<sup>127</sup>, N. W. Shaikh<sup>47a,47b</sup>,  
D. Shaked Renous<sup>168</sup>, L. Y. Shan<sup>14a</sup>, M. Shapiro<sup>17a</sup>, A. Sharma<sup>36</sup>, A. S. Sharma<sup>163</sup>, P. Sharma<sup>79</sup>, S. Sharma<sup>48</sup>,  
P. B. Shatalov<sup>37</sup>, K. Shaw<sup>145</sup>, S. M. Shaw<sup>100</sup>, Q. Shen<sup>62c</sup>, P. Sherwood<sup>95</sup>, L. Shi<sup>95</sup>, C. O. Shimmin<sup>171</sup>,  
Y. Shimogama<sup>167</sup>, J. D. Shinner<sup>94</sup>, I. P. J. Shipsey<sup>125</sup>, S. Shirabe<sup>60</sup>, M. Shiyakova<sup>38,ji</sup>, J. Shlomi<sup>168</sup>,  
M. J. Shochet<sup>39</sup>, J. Shojaii<sup>104</sup>, D. R. Shope<sup>143</sup>, S. Shrestha<sup>118</sup>, E. M. Shrif<sup>33g</sup>, M. J. Shroff<sup>164</sup>, P. Sicho<sup>130</sup>,  
A. M. Sickles<sup>161</sup>, E. Sideras Haddad<sup>33g</sup>, O. Sidiropoulou<sup>36</sup>, A. Sidoti<sup>23b</sup>, F. Siegert<sup>50</sup>, Dj. Sijacki<sup>15</sup>, R. Sikora<sup>84a</sup>,  
F. Sili<sup>89</sup>, J. M. Silva<sup>20</sup>, M. V. Silva Oliveira<sup>36</sup>, S. B. Silverstein<sup>47a</sup>, S. Simion<sup>66</sup>, R. Simoniello<sup>36</sup>, E. L. Simpson<sup>59</sup>,  
N. D. Simpson<sup>97</sup>, S. Simsek<sup>21d</sup>, S. Sindhu<sup>55</sup>, P. Sinervo<sup>154</sup>, V. Sinetckii<sup>37</sup>, S. Singh<sup>141</sup>, S. Singh<sup>154</sup>, S. Sinha<sup>48</sup>,  
S. Sinha<sup>33g</sup>, M. Sioli<sup>23b,23a</sup>, I. Siral<sup>122</sup>, S. Yu. Sivoklokov<sup>37,a</sup>, J. Sjölin<sup>47a,47b</sup>, A. Skaf<sup>55</sup>, E. Skorda<sup>97</sup>,  
P. Skubic<sup>119</sup>, M. Slawinska<sup>85</sup>, V. Smakhtin<sup>168</sup>, B. H. Smart<sup>133</sup>, J. Smiesko<sup>132</sup>, S. Yu. Smirnov<sup>37</sup>, Y. Smirnov<sup>37</sup>,  
L. N. Smirnova<sup>37,m</sup>, O. Smirnova<sup>97</sup>, E. A. Smith<sup>39</sup>, H. A. Smith<sup>125</sup>, J. L. Smith<sup>91</sup>, R. Smith<sup>142</sup>, M. Smizanska<sup>90</sup>,  
K. Smolek<sup>131</sup>, A. Smykiewicz<sup>85</sup>, A. A. Snesarev<sup>37</sup>, H. L. Snoek<sup>113</sup>, S. Snyder<sup>29</sup>, R. Sobie<sup>164,q</sup>, A. Soffer<sup>150</sup>,  
C. A. Solans Sanchez<sup>36</sup>, E. Yu. Soldatov<sup>37</sup>, U. Soldevila<sup>162</sup>, A. A. Solodkov<sup>37</sup>, S. Solomon<sup>54</sup>, A. Soloshenko<sup>38</sup>,  
K. Solovieva<sup>54</sup>, O. V. Solovyanov<sup>37</sup>, V. Solovyev<sup>37</sup>, P. Sommer<sup>36</sup>, A. Sonay<sup>13</sup>, W. Y. Song<sup>155b</sup>, A. Sopczak<sup>131</sup>,  
A. L. Soppio<sup>95</sup>, F. Sopkova<sup>28b</sup>, V. Sothilingam<sup>63a</sup>, S. Sottocornola<sup>72a,72b</sup>, R. Soualah<sup>115b</sup>, Z. Soumami<sup>35e</sup>,  
D. South<sup>48</sup>, S. Spagnolo<sup>69a,69b</sup>, M. Spalla<sup>109</sup>, F. Spanò<sup>94</sup>, D. Sperlich<sup>54</sup>, G. Spigo<sup>36</sup>, M. Spina<sup>145</sup>, S. Spinali<sup>90</sup>,  
D. P. Spiteri<sup>59</sup>, M. Spousta<sup>132</sup>, E. J. Staats<sup>34</sup>, A. Stabile<sup>70a,70b</sup>, R. Stamen<sup>63a</sup>, M. Stamenkovic<sup>113</sup>, A. Stampekis<sup>20</sup>,  
M. Standke<sup>24</sup>, E. Stanecka<sup>85</sup>, B. Stanislaus<sup>17a</sup>, M. M. Stanitzki<sup>48</sup>, M. Stankaityte<sup>125</sup>, B. Stapf<sup>48</sup>,  
E. A. Starchenko<sup>37</sup>, G. H. Stark<sup>135</sup>, J. Stark<sup>101,kk</sup>, D. M. Starke<sup>155b</sup>, P. Staroba<sup>130</sup>, P. Starovoitov<sup>63a</sup>, S. Stärz<sup>103</sup>,  
R. Staszewski<sup>85</sup>, G. Stavropoulos<sup>46</sup>, J. Steentoft<sup>160</sup>, P. Steinberg<sup>29</sup>, A. L. Steinhebel<sup>122</sup>, B. Stelzer<sup>141,155a</sup>,  
H. J. Stelzer<sup>128</sup>, O. Stelzer-Chilton<sup>155a</sup>, H. Stenzel<sup>58</sup>, T. J. Stevenson<sup>145</sup>, G. A. Stewart<sup>36</sup>, M. C. Stockton<sup>36</sup>,  
G. Stoicea<sup>27b</sup>, M. Stolarski<sup>129a</sup>, S. Stonjek<sup>109</sup>, A. Straessner<sup>50</sup>, J. Strandberg<sup>143</sup>, S. Strandberg<sup>47a,47b</sup>,  
M. Strauss<sup>119</sup>, T. Strebler<sup>101</sup>, P. Striznec<sup>28b</sup>, R. Ströhmer<sup>165</sup>, D. M. Strom<sup>122</sup>, L. R. Strom<sup>48</sup>, R. Stroynowski<sup>44</sup>,  
A. Strubig<sup>47a,47b</sup>, S. A. Stucci<sup>29</sup>, B. Stugu<sup>16</sup>, J. Stupak<sup>119</sup>, N. A. Styles<sup>48</sup>, D. Su<sup>142</sup>, S. Su<sup>62a</sup>, W. Su<sup>62d,137,62c</sup>,  
X. Su<sup>62a,66</sup>, K. Sugizaki<sup>152</sup>, V. V. Sulin<sup>37</sup>, M. J. Sullivan<sup>91</sup>, D. M. S. Sultan<sup>77a,77b</sup>, L. Sultanaliyeva<sup>37</sup>,  
S. Sultansoy<sup>3b</sup>, T. Sumida<sup>86</sup>, S. Sun<sup>105</sup>, S. Sun<sup>169</sup>, O. Sunneborn Gudnadottir<sup>160</sup>, M. R. Sutton<sup>145</sup>, M. Svatos<sup>130</sup>,  
M. Swiatlowski<sup>155a</sup>, T. Swirski<sup>165</sup>, I. Sykora<sup>28a</sup>, M. Sykora<sup>132</sup>, T. Sykora<sup>132</sup>, D. Ta<sup>99</sup>, K. Tackmann<sup>48,ii</sup>,  
A. Taffard<sup>159</sup>, R. Tafirout<sup>155a</sup>, J. S. Tafoya Vargas<sup>66</sup>, R. H. M. Taibah<sup>126</sup>, R. Takashima<sup>87</sup>, K. Takeda<sup>83</sup>,  
E. P. Takeva<sup>52</sup>, Y. Takubo<sup>82</sup>, M. Talby<sup>101</sup>, A. A. Talyshev<sup>37</sup>, K. C. Tam<sup>64b</sup>, N. M. Tamir<sup>150</sup>, A. Tanaka<sup>152</sup>,  
J. Tanaka<sup>152</sup>, R. Tanaka<sup>66</sup>, M. Tanasini<sup>57b,57a</sup>, J. Tang<sup>62c</sup>, Z. Tao<sup>163</sup>, S. Tapia Araya<sup>80</sup>, S. Tapprogge<sup>99</sup>,  
A. Tarek Abouelfadl Mohamed<sup>106</sup>, S. Tarem<sup>149</sup>, K. Tariq<sup>62b</sup>, G. Tarna<sup>27b</sup>, G. F. Tartarelli<sup>70a</sup>, P. Tas<sup>132</sup>,  
M. Tasevsky<sup>130</sup>, E. Tassi<sup>43b,43a</sup>, A. C. Tate<sup>161</sup>, G. Tateno<sup>152</sup>, Y. Tayalati<sup>35e</sup>, G. N. Taylor<sup>104</sup>, W. Taylor<sup>155b</sup>,  
H. Teagle<sup>91</sup>, A. S. Tec<sup>169</sup>, R. Teixeira De Lima<sup>142</sup>, P. Teixeira-Dias<sup>94</sup>, J. J. Teoh<sup>154</sup>, K. Terashi<sup>152</sup>, J. Terron<sup>98</sup>,  
S. Terzo<sup>13</sup>, M. Testa<sup>53</sup>, R. J. Teuscher<sup>154,q</sup>, A. Thaler<sup>78</sup>, N. Themistokleous<sup>52</sup>, T. Theveneaux-Pelzer<sup>18</sup>,  
O. Thielmann<sup>170</sup>, D. W. Thomas<sup>94</sup>, J. P. Thomas<sup>20</sup>, E. A. Thompson<sup>48</sup>, P. D. Thompson<sup>20</sup>, E. Thomson<sup>127</sup>,  
E. J. Thorpe<sup>93</sup>, Y. Tian<sup>55</sup>, V. Tikhomirov<sup>37,m</sup>, Yu. A. Tikhonov<sup>37</sup>, S. Timoshenko<sup>37</sup>, E. X. L. Ting<sup>1</sup>, P. Tipton<sup>171</sup>,  
S. Tisserant<sup>101</sup>, S. H. Tlou<sup>33g</sup>, A. Tnourji<sup>40</sup>, K. Todome<sup>23b,23a</sup>, S. Todorova-Nova<sup>132</sup>, S. Todt<sup>50</sup>, M. Togawa<sup>82</sup>,  
J. Tojo<sup>88</sup>, S. Tokár<sup>28a</sup>, K. Tokushuku<sup>82</sup>, R. Tombs<sup>32</sup>, M. Tomoto<sup>82,110</sup>, L. Tompkins<sup>142,w</sup>, P. Tornambe<sup>102</sup>,  
E. Torrence<sup>122</sup>, H. Torres<sup>50</sup>, E. Torró Pastor<sup>162</sup>, M. Toscani<sup>30</sup>, C. Toscirì<sup>39</sup>, D. R. Tovey<sup>138</sup>, A. Traeet<sup>16</sup>,  
I. S. Trandafir<sup>27b</sup>, T. Trefzger<sup>165</sup>, A. Tricoli<sup>29</sup>, I. M. Trigger<sup>155a</sup>, S. Trincaz-Duvoid<sup>126</sup>, D. A. Trischuk<sup>163</sup>,  
B. Trocmé<sup>60</sup>, A. Trofymov<sup>66</sup>, C. Troncon<sup>70a</sup>, L. Truong<sup>33c</sup>, M. Trzebinski<sup>85</sup>, A. Trzuppek<sup>85</sup>, F. Tsai<sup>144</sup>,  
M. Tsai<sup>105</sup>, A. Tsiamis<sup>151</sup>, P. V. Tsiarehka<sup>37</sup>, S. Tsigaridas<sup>155a</sup>, A. Tsigotis<sup>151,ee</sup>, V. Tsiskaridze<sup>144</sup>

E. G. Tskhadadze,<sup>148a</sup> M. Tsopoulou,<sup>151</sup> Y. Tsujikawa,<sup>86</sup> I. I. Tsukerman,<sup>37</sup> V. Tsulaia,<sup>17a</sup> S. Tsuno,<sup>82</sup> O. Tsur,<sup>149</sup>  
D. Tsybychev,<sup>144</sup> Y. Tu,<sup>64b</sup> A. Tudorache,<sup>27b</sup> V. Tudorache,<sup>27b</sup> A. N. Tuna,<sup>36</sup> S. Turchikhin,<sup>38</sup> I. Turk Cakir,<sup>3a</sup>  
R. Turra,<sup>70a</sup> T. Turtuvshin,<sup>38</sup> P. M. Tuts,<sup>41</sup> S. Tzamarias,<sup>151</sup> P. Tzanis,<sup>10</sup> E. Tzovara,<sup>99</sup> K. Uchida,<sup>152</sup>  
F. Ukegawa,<sup>156</sup> P. A. Ulloa Poblete,<sup>136c</sup> G. Unal,<sup>36</sup> M. Unal,<sup>11</sup> A. Undrus,<sup>29</sup> G. Unel,<sup>159</sup> K. Uno,<sup>152</sup> J. Urban,<sup>28b</sup>  
P. Urquijo,<sup>104</sup> G. Usai,<sup>8</sup> R. Ushioda,<sup>153</sup> M. Usman,<sup>107</sup> Z. Uysal,<sup>21b</sup> V. Vacek,<sup>131</sup> B. Vachon,<sup>103</sup>  
K. O. H. Vadla,<sup>124</sup> T. Vafeiadis,<sup>36</sup> C. Valderanis,<sup>108</sup> E. Valdes Santurio,<sup>47a,47b</sup> M. Valente,<sup>155a</sup> S. Valentineti,<sup>23b,23a</sup>  
A. Valero,<sup>162</sup> A. Vallier,<sup>101,kk</sup> J. A. Valls Ferrer,<sup>162</sup> T. R. Van Daalen,<sup>137</sup> P. Van Gemmeren,<sup>6</sup> S. Van Stroud,<sup>95</sup>  
I. Van Vulpen,<sup>113</sup> M. Vanadia,<sup>75a,75b</sup> W. Vandelli,<sup>36</sup> M. Vandenbroucke,<sup>134</sup> E. R. Vandewall,<sup>120</sup> D. Vannicola,<sup>150</sup>  
L. Vannoli,<sup>57b,57a</sup> R. Vari,<sup>74a</sup> E. W. Varnes,<sup>7</sup> C. Varni,<sup>17a</sup> T. Varol,<sup>147</sup> D. Varouchas,<sup>66</sup> L. Varriale,<sup>162</sup>  
K. E. Varvell,<sup>146</sup> M. E. Vasile,<sup>27b</sup> L. Vaslin,<sup>40</sup> G. A. Vasquez,<sup>164</sup> F. Vazeille,<sup>40</sup> T. Vazquez Schroeder,<sup>36</sup> J. Veatch,<sup>31</sup>  
V. Vecchio,<sup>100</sup> M. J. Veen,<sup>113</sup> I. Veliscek,<sup>125</sup> L. M. Veloce,<sup>154</sup> F. Veloso,<sup>129a,129c</sup> S. Veneziano,<sup>74a</sup>  
A. Ventura,<sup>69a,69b</sup> A. Verbytskyi,<sup>109</sup> M. Verducci,<sup>73a,73b</sup> C. Vergis,<sup>24</sup> M. Verissimo De Araujo,<sup>81b</sup> W. Verkerke,<sup>113</sup>  
J. C. Vermeulen,<sup>113</sup> C. Vernieri,<sup>142</sup> P. J. Verschuuren,<sup>94</sup> M. Vessella,<sup>102</sup> M. L. Vesterbacka,<sup>116</sup> M. C. Vetterli,<sup>141,e</sup>  
A. Vgenopoulos,<sup>151</sup> N. Viaux Maira,<sup>136f</sup> T. Vickey,<sup>138</sup> O. E. Vickey Boeriu,<sup>138</sup> G. H. A. Viehhauser,<sup>125</sup>  
L. Vigani,<sup>63b</sup> M. Villa,<sup>23b,23a</sup> M. Villaplana Perez,<sup>162</sup> E. M. Villhauer,<sup>52</sup> E. Vilucchi,<sup>53</sup> M. G. Vinciter,<sup>34</sup>  
G. S. Virdee,<sup>20</sup> A. Vishwakarma,<sup>52</sup> C. Vittori,<sup>23b,23a</sup> I. Vivarelli,<sup>145</sup> V. Vladimirov,<sup>166</sup> E. Voevodina,<sup>109</sup> F. Vogel,<sup>108</sup>  
P. Vokac,<sup>131</sup> J. Von Ahnen,<sup>48</sup> E. Von Toerne,<sup>24</sup> B. Vormwald,<sup>36</sup> V. Vorobel,<sup>132</sup> K. Vorobev,<sup>37</sup> M. Vos,<sup>162</sup>  
J. H. Vosseveld,<sup>91</sup> M. Vozak,<sup>113</sup> L. Vozdecky,<sup>93</sup> N. Vranjes,<sup>15</sup> M. Vranjes Milosavljevic,<sup>15</sup> M. Vreeswijk,<sup>113</sup>  
R. Vuillermet,<sup>36</sup> O. Vujanovic,<sup>99</sup> I. Vukotic,<sup>39</sup> S. Wada,<sup>156</sup> C. Wagner,<sup>102</sup> W. Wagner,<sup>170</sup> S. Wahdan,<sup>170</sup>  
H. Wahlberg,<sup>89</sup> R. Wakasa,<sup>156</sup> M. Wakida,<sup>110</sup> V. M. Walbrecht,<sup>109</sup> J. Walder,<sup>133</sup> R. Walker,<sup>108</sup> W. Walkowiak,<sup>140</sup>  
A. M. Wang,<sup>61</sup> A. Z. Wang,<sup>169</sup> C. Wang,<sup>62a</sup> C. Wang,<sup>62c</sup> H. Wang,<sup>17a</sup> J. Wang,<sup>64a</sup> P. Wang,<sup>44</sup> R.-J. Wang,<sup>99</sup>  
R. Wang,<sup>61</sup> R. Wang,<sup>6</sup> S. M. Wang,<sup>147</sup> S. Wang,<sup>62b</sup> T. Wang,<sup>62a</sup> W. T. Wang,<sup>79</sup> W. X. Wang,<sup>62a</sup> X. Wang,<sup>14c</sup>  
X. Wang,<sup>161</sup> X. Wang,<sup>62c</sup> Y. Wang,<sup>62d</sup> Y. Wang,<sup>14c</sup> Z. Wang,<sup>105</sup> Z. Wang,<sup>62d,51,62c</sup> Z. Wang,<sup>105</sup> A. Warburton,<sup>103</sup>  
R. J. Ward,<sup>20</sup> N. Warrack,<sup>59</sup> A. T. Watson,<sup>20</sup> M. F. Watson,<sup>20</sup> G. Watts,<sup>137</sup> B. M. Waugh,<sup>95</sup> A. F. Webb,<sup>11</sup>  
C. Weber,<sup>29</sup> M. S. Weber,<sup>19</sup> S. A. Weber,<sup>34</sup> S. M. Weber,<sup>63a</sup> C. Wei,<sup>62a</sup> Y. Wei,<sup>125</sup> A. R. Weidberg,<sup>125</sup>  
J. Weingarten,<sup>49</sup> M. Weirich,<sup>99</sup> C. Weiser,<sup>54</sup> C. J. Wells,<sup>48</sup> T. Wenaus,<sup>29</sup> B. Wendland,<sup>49</sup> T. Wengler,<sup>36</sup>  
N. S. Wenke,<sup>109</sup> N. Wermes,<sup>24</sup> M. Wessels,<sup>63a</sup> K. Whalen,<sup>122</sup> A. M. Wharton,<sup>90</sup> A. S. White,<sup>61</sup> A. White,<sup>8</sup>  
M. J. White,<sup>1</sup> D. Whiteson,<sup>159</sup> L. Wickremasinghe,<sup>123</sup> W. Wiedenmann,<sup>169</sup> C. Wiel,<sup>50</sup> M. Wielers,<sup>133</sup>  
N. Wieseotte,<sup>99</sup> C. Wiglesworth,<sup>42</sup> L. A. M. Wiik-Fuchs,<sup>54</sup> D. J. Wilbern,<sup>119</sup> H. G. Wilkens,<sup>36</sup> D. M. Williams,<sup>41</sup>  
H. H. Williams,<sup>127</sup> S. Williams,<sup>32</sup> S. Willocq,<sup>102</sup> P. J. Windischhofer,<sup>125</sup> F. Winklmeier,<sup>122</sup> B. T. Winter,<sup>54</sup>  
M. Wittgen,<sup>142</sup> M. Wobisch,<sup>96</sup> A. Wolf,<sup>99</sup> R. Wölker,<sup>125</sup> J. Wollrath,<sup>159</sup> M. W. Wolter,<sup>85</sup> H. Wolters,<sup>129a,129c</sup>  
V. W. S. Wong,<sup>163</sup> A. F. Wongel,<sup>48</sup> S. D. Worm,<sup>48</sup> B. K. Wosiek,<sup>85</sup> K. W. Woźniak,<sup>85</sup> K. Wraight,<sup>59</sup> J. Wu,<sup>14a,14d</sup>  
M. Wu,<sup>64a</sup> S. L. Wu,<sup>169</sup> X. Wu,<sup>56</sup> Y. Wu,<sup>62a</sup> Z. Wu,<sup>134,62a</sup> J. Wuerzinger,<sup>125</sup> T. R. Wyatt,<sup>100</sup> B. M. Wynne,<sup>52</sup>  
S. Xella,<sup>42</sup> L. Xia,<sup>14c</sup> M. Xia,<sup>14b</sup> J. Xiang,<sup>64c</sup> X. Xiao,<sup>105</sup> M. Xie,<sup>62a</sup> X. Xie,<sup>62a</sup> J. Xiong,<sup>17a</sup> I. Kiotidis,<sup>145</sup>  
D. Xu,<sup>14a</sup> H. Xu,<sup>62a</sup> H. Xu,<sup>62a</sup> L. Xu,<sup>62a</sup> R. Xu,<sup>127</sup> T. Xu,<sup>105</sup> W. Xu,<sup>105</sup> Y. Xu,<sup>14b</sup> Z. Xu,<sup>62b</sup> Z. Xu,<sup>142</sup>  
B. Yabsley,<sup>146</sup> S. Yacoob,<sup>33a</sup> N. Yamaguchi,<sup>88</sup> Y. Yamaguchi,<sup>153</sup> H. Yamauchi,<sup>156</sup> T. Yamazaki,<sup>17a</sup>  
Y. Yamazaki,<sup>83</sup> J. Yan,<sup>62c</sup> S. Yan,<sup>125</sup> Z. Yan,<sup>25</sup> H. J. Yang,<sup>62c,62d</sup> H. T. Yang,<sup>17a</sup> S. Yang,<sup>62a</sup> T. Yang,<sup>64c</sup>  
X. Yang,<sup>62a</sup> X. Yang,<sup>14a</sup> Y. Yang,<sup>44</sup> Z. Yang,<sup>62a,105</sup> W.-M. Yao,<sup>17a</sup> Y. C. Yap,<sup>48</sup> H. Ye,<sup>14c</sup> J. Ye,<sup>44</sup> S. Ye,<sup>29</sup>  
X. Ye,<sup>62a</sup> Y. Yeh,<sup>95</sup> I. Yeletsikh,<sup>38</sup> M. R. Yexley,<sup>90</sup> P. Yin,<sup>41</sup> K. Yorita,<sup>167</sup> C. J. S. Young,<sup>54</sup> C. Young,<sup>142</sup>  
M. Yuan,<sup>105</sup> R. Yuan,<sup>62b,mm</sup> L. Yue,<sup>95</sup> X. Yue,<sup>63a</sup> M. Zaazoua,<sup>35c</sup> B. Zabinski,<sup>85</sup> E. Zaid,<sup>52</sup> T. Zakareishvili,<sup>148b</sup>  
N. Zakharchuk,<sup>34</sup> S. Zambito,<sup>56</sup> J. Zang,<sup>152</sup> D. Zanzi,<sup>54</sup> O. Zaplatilek,<sup>131</sup> S. V. Zeiβner,<sup>49</sup> C. Zeitnitz,<sup>170</sup>  
J. C. Zeng,<sup>161</sup> D. T. Zenger Jr.,<sup>26</sup> O. Zenin,<sup>37</sup> T. Ženiš,<sup>28a</sup> S. Zenz,<sup>93</sup> S. Zerradi,<sup>35a</sup> D. Zerwas,<sup>66</sup> B. Zhang,<sup>14c</sup>  
D. F. Zhang,<sup>138</sup> G. Zhang,<sup>14b</sup> J. Zhang,<sup>6</sup> K. Zhang,<sup>14a,14d</sup> L. Zhang,<sup>14c</sup> R. Zhang,<sup>169</sup> S. Zhang,<sup>105</sup> T. Zhang,<sup>152</sup>  
X. Zhang,<sup>62c</sup> X. Zhang,<sup>62b</sup> Z. Zhang,<sup>17a</sup> Z. Zhang,<sup>66</sup> H. Zhao,<sup>137</sup> P. Zhao,<sup>51</sup> T. Zhao,<sup>62b</sup> Y. Zhao,<sup>135</sup>  
Z. Zhao,<sup>62a</sup> A. Zhemchugov,<sup>38</sup> Z. Zheng,<sup>142</sup> D. Zhong,<sup>161</sup> B. Zhou,<sup>105</sup> C. Zhou,<sup>169</sup> H. Zhou,<sup>7</sup> N. Zhou,<sup>62c</sup>  
Y. Zhou,<sup>7</sup> C. G. Zhu,<sup>62b</sup> C. Zhu,<sup>14a,14d</sup> H. L. Zhu,<sup>62a</sup> H. Zhu,<sup>14a</sup> J. Zhu,<sup>105</sup> Y. Zhu,<sup>62a</sup> X. Zhuang,<sup>14a</sup>  
K. Zhukov,<sup>37</sup> V. Zhulanov,<sup>37</sup> N. I. Zimine,<sup>38</sup> J. Zinsser,<sup>63b</sup> M. Ziolkowski,<sup>140</sup> L. Živković,<sup>15</sup> A. Zoccoli,<sup>23b,23a</sup>  
K. Zoch,<sup>56</sup> T. G. Zorbas,<sup>138</sup> O. Zormpa,<sup>46</sup> W. Zou,<sup>41</sup> and L. Zwalinski<sup>36</sup>

(ATLAS Collaboration)

- <sup>1</sup>*Department of Physics, University of Adelaide, Adelaide, Australia*
- <sup>2</sup>*Department of Physics, University of Alberta, Edmonton, Alberta, Canada*
- <sup>3a</sup>*Department of Physics, Ankara University, Ankara, Türkiye*
- <sup>3b</sup>*Division of Physics, TOBB University of Economics and Technology, Ankara, Türkiye*
- <sup>4</sup>*LAPP, Université Savoie Mont Blanc, CNRS/IN2P3, Annecy, France*
- <sup>5</sup>*APC, Université Paris Cité, CNRS/IN2P3, Paris, France*
- <sup>6</sup>*High Energy Physics Division, Argonne National Laboratory, Argonne, Illinois, USA*
- <sup>7</sup>*Department of Physics, University of Arizona, Tucson, Arizona, USA*
- <sup>8</sup>*Department of Physics, University of Texas at Arlington, Arlington, Texas, USA*
- <sup>9</sup>*Physics Department, National and Kapodistrian University of Athens, Athens, Greece*
- <sup>10</sup>*Physics Department, National Technical University of Athens, Zografou, Greece*
- <sup>11</sup>*Department of Physics, University of Texas at Austin, Austin, Texas, USA*
- <sup>12</sup>*Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan*
- <sup>13</sup>*Institut de Física d'Altes Energies (IFAE), Barcelona Institute of Science and Technology, Barcelona, Spain*
- <sup>14a</sup>*Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China*
- <sup>14b</sup>*Physics Department, Tsinghua University, Beijing, China*
- <sup>14c</sup>*Department of Physics, Nanjing University, Nanjing, China*
- <sup>14d</sup>*University of Chinese Academy of Science (UCAS), Beijing, China*
- <sup>15</sup>*Institute of Physics, University of Belgrade, Belgrade, Serbia*
- <sup>16</sup>*Department for Physics and Technology, University of Bergen, Bergen, Norway*
- <sup>17a</sup>*Physics Division, Lawrence Berkeley National Laboratory, Berkeley, California, USA*
- <sup>17b</sup>*University of California, Berkeley, California, USA*
- <sup>18</sup>*Institut für Physik, Humboldt Universität zu Berlin, Berlin, Germany*
- <sup>19</sup>*Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern, Switzerland*
- <sup>20</sup>*School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom*
- <sup>21a</sup>*Department of Physics, Bogazici University, Istanbul, Türkiye*
- <sup>21b</sup>*Department of Physics Engineering, Gaziantep University, Gaziantep, Türkiye*
- <sup>21c</sup>*Department of Physics, Istanbul University, Istanbul, Türkiye*
- <sup>21d</sup>*Istinye University, Sariyer, Istanbul, Türkiye*
- <sup>22a</sup>*Facultad de Ciencias y Centro de Investigaciones, Universidad Antonio Nariño, Bogotá, Colombia*
- <sup>22b</sup>*Departamento de Física, Universidad Nacional de Colombia, Bogotá, Colombia*
- <sup>23a</sup>*Dipartimento di Fisica e Astronomia A. Righi, Università di Bologna, Bologna, Italy*
- <sup>23b</sup>*INFN Sezione di Bologna, Italy*
- <sup>24</sup>*Physikalisches Institut, Universität Bonn, Bonn, Germany*
- <sup>25</sup>*Department of Physics, Boston University, Boston, Massachusetts, USA*
- <sup>26</sup>*Department of Physics, Brandeis University, Waltham, Massachusetts, USA*
- <sup>27a</sup>*Transilvania University of Brasov, Brasov, Romania*
- <sup>27b</sup>*Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest, Romania*
- <sup>27c</sup>*Department of Physics, Alexandru Ioan Cuza University of Iasi, Iasi, Romania*
- <sup>27d</sup>*National Institute for Research and Development of Isotopic and Molecular Technologies, Physics Department, Cluj-Napoca, Romania*
- <sup>27e</sup>*University Politehnica Bucharest, Bucharest, Romania*
- <sup>27f</sup>*West University in Timisoara, Timisoara, Romania*
- <sup>27g</sup>*Faculty of Physics, University of Bucharest, Bucharest, Romania*
- <sup>28a</sup>*Faculty of Mathematics, Physics and Informatics, Comenius University, Bratislava, Slovak Republic*
- <sup>28b</sup>*Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice, Slovak Republic*
- <sup>29</sup>*Physics Department, Brookhaven National Laboratory, Upton, New York, USA*
- <sup>30</sup>*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*
- <sup>31</sup>*California State University, California, USA*
- <sup>32</sup>*Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom*
- <sup>33a</sup>*Department of Physics, University of Cape Town, Cape Town, South Africa*
- <sup>33b</sup>*iThemba Labs, Western Cape, South Africa*
- <sup>33c</sup>*Department of Mechanical Engineering Science, University of Johannesburg, Johannesburg, South Africa*

- <sup>33d</sup>*National Institute of Physics, University of the Philippines Diliman (Philippines), Philippines*
- <sup>33c</sup>*University of South Africa, Department of Physics, Pretoria, South Africa*
- <sup>33f</sup>*University of Zululand, KwaDlangezwa, South Africa*
- <sup>33g</sup>*School of Physics, University of the Witwatersrand, Johannesburg, South Africa*
- <sup>34</sup>*Department of Physics, Carleton University, Ottawa, Ontario, Canada*
- <sup>35a</sup>*Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies—Université Hassan II, Casablanca, Morocco*
- <sup>35b</sup>*Faculté des Sciences, Université Ibn-Tofail, Kénitra, Morocco*
- <sup>35c</sup>*Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA-Marrakech, Morocco*
- <sup>35d</sup>*LPMR, Faculté des Sciences, Université Mohamed Premier, Oujda, Morocco*
- <sup>35e</sup>*Faculté des sciences, Université Mohammed V, Rabat, Morocco*
- <sup>35f</sup>*Institute of Applied Physics, Mohammed VI Polytechnic University, Ben Guerir, Morocco*
- <sup>36</sup>*CERN, Geneva, Switzerland*
- <sup>37</sup>*Affiliated with an institute covered by a cooperation agreement with CERN*
- <sup>38</sup>*Affiliated with an international laboratory covered by a cooperation agreement with CERN*
- <sup>39</sup>*Enrico Fermi Institute, University of Chicago, Chicago, Illinois, USA*
- <sup>40</sup>*LPC, Université Clermont Auvergne, CNRS/IN2P3, Clermont-Ferrand, France*
- <sup>41</sup>*Nevis Laboratory, Columbia University, Irvington, New York, USA*
- <sup>42</sup>*Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark*
- <sup>43a</sup>*Dipartimento di Fisica, Università della Calabria, Rende, Italy*
- <sup>43b</sup>*INFN Gruppo Collegato di Cosenza, Laboratori Nazionali di Frascati, Italy*
- <sup>44</sup>*Physics Department, Southern Methodist University, Dallas, Texas, USA*
- <sup>45</sup>*Physics Department, University of Texas at Dallas, Richardson, Texas, USA*
- <sup>46</sup>*National Centre for Scientific Research “Demokritos”, Agia Paraskevi, Greece*
- <sup>47a</sup>*Department of Physics, Stockholm University, Sweden*
- <sup>47b</sup>*Oskar Klein Centre, Stockholm, Sweden*
- <sup>48</sup>*Deutsches Elektronen-Synchrotron DESY, Hamburg and Zeuthen, Germany*
- <sup>49</sup>*Fakultät Physik, Technische Universität Dortmund, Dortmund, Germany*
- <sup>50</sup>*Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden, Germany*
- <sup>51</sup>*Department of Physics, Duke University, Durham, North Carolina, USA*
- <sup>52</sup>*SUPA—School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom*
- <sup>53</sup>*INFN e Laboratori Nazionali di Frascati, Frascati, Italy*
- <sup>54</sup>*Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany*
- <sup>55</sup>*II. Physikalisches Institut, Georg-August-Universität Göttingen, Göttingen, Germany*
- <sup>56</sup>*Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève, Switzerland*
- <sup>57a</sup>*Dipartimento di Fisica, Università di Genova, Genova, Italy*
- <sup>57b</sup>*INFN Sezione di Genova, Italy*
- <sup>58</sup>*II. Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen, Germany*
- <sup>59</sup>*SUPA—School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom*
- <sup>60</sup>*LPSC, Université Grenoble Alpes, CNRS/IN2P3, Grenoble INP, Grenoble, France*
- <sup>61</sup>*Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge, Massachusetts, USA*
- <sup>62a</sup>*Department of Modern Physics and State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei, China*
- <sup>62b</sup>*Institute of Frontier and Interdisciplinary Science and Key Laboratory of Particle Physics and Particle Irradiation (MOE), Shandong University, Qingdao, China*
- <sup>62c</sup>*School of Physics and Astronomy, Shanghai Jiao Tong University, Key Laboratory for Particle Astrophysics and Cosmology (MOE), SKLPPC, Shanghai, China*
- <sup>62d</sup>*Tsung-Dao Lee Institute, Shanghai, China*
- <sup>63a</sup>*Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany*
- <sup>63b</sup>*Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany*
- <sup>64a</sup>*Department of Physics, Chinese University of Hong Kong, Shatin, N.T., Hong Kong, China*
- <sup>64b</sup>*Department of Physics, University of Hong Kong, Hong Kong, China*
- <sup>64c</sup>*Department of Physics and Institute for Advanced Study, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China*
- <sup>65</sup>*Department of Physics, National Tsing Hua University, Hsinchu, Taiwan*
- <sup>66</sup>*IJCLab, Université Paris-Saclay, CNRS/IN2P3, 91405, Orsay, France*
- <sup>67</sup>*Department of Physics, Indiana University, Bloomington, Indiana, USA*
- <sup>68a</sup>*INFN Gruppo Collegato di Udine, Sezione di Trieste, Udine, Italy*
- <sup>68b</sup>*ICTP, Trieste, Italy*
- <sup>68c</sup>*Dipartimento Politecnico di Ingegneria e Architettura, Università di Udine, Udine, Italy*

- <sup>69a</sup>*INFN Sezione di Lecce, Italy*  
<sup>69b</sup>*Dipartimento di Matematica e Fisica, Università del Salento, Lecce, Italy*  
<sup>70a</sup>*INFN Sezione di Milano, Italy*  
<sup>70b</sup>*Dipartimento di Fisica, Università di Milano, Milano, Italy*  
<sup>71a</sup>*INFN Sezione di Napoli, Italy*  
<sup>71b</sup>*Dipartimento di Fisica, Università di Napoli, Napoli, Italy*  
<sup>72a</sup>*INFN Sezione di Pavia, Italy*  
<sup>72b</sup>*Dipartimento di Fisica, Università di Pavia, Pavia, Italy*  
<sup>73a</sup>*INFN Sezione di Pisa, Italy*  
<sup>73b</sup>*Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy*  
<sup>74a</sup>*INFN Sezione di Roma, Italy*  
<sup>74b</sup>*Dipartimento di Fisica, Sapienza Università di Roma, Roma, Italy*  
<sup>75a</sup>*INFN Sezione di Roma Tor Vergata, Italy*  
<sup>75b</sup>*Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy*  
<sup>76a</sup>*INFN Sezione di Roma Tre, Italy*  
<sup>76b</sup>*Dipartimento di Matematica e Fisica, Università Roma Tre, Roma, Italy*  
<sup>77a</sup>*INFN-TIFPA, Italy*  
<sup>77b</sup>*Università degli Studi di Trento, Trento, Italy*  
<sup>78</sup>*Universität Innsbruck, Department of Astro and Particle Physics, Innsbruck, Austria*  
<sup>79</sup>*University of Iowa, Iowa City, Iowa, USA*  
<sup>80</sup>*Department of Physics and Astronomy, Iowa State University, Ames, Iowa, USA*  
<sup>81a</sup>*Departamento de Engenharia Elétrica, Universidade Federal de Juiz de Fora (UFJF), Juiz de Fora, Brazil*  
<sup>81b</sup>*Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro, Brazil*  
<sup>81c</sup>*Instituto de Física, Universidade de São Paulo, São Paulo, Brazil*  
<sup>81d</sup>*Rio de Janeiro State University, Rio de Janeiro, Brazil*  
<sup>82</sup>*KEK, High Energy Accelerator Research Organization, Tsukuba, Japan*  
<sup>83</sup>*Graduate School of Science, Kobe University, Kobe, Japan*  
<sup>84a</sup>*AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, Krakow, Poland*  
<sup>84b</sup>*Marian Smoluchowski Institute of Physics, Jagiellonian University, Krakow, Poland*  
<sup>85</sup>*Institute of Nuclear Physics Polish Academy of Sciences, Krakow, Poland*  
<sup>86</sup>*Faculty of Science, Kyoto University, Kyoto, Japan*  
<sup>87</sup>*Kyoto University of Education, Kyoto, Japan*  
<sup>88</sup>*Research Center for Advanced Particle Physics and Department of Physics, Kyushu University, Fukuoka, Japan*  
<sup>89</sup>*Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina*  
<sup>90</sup>*Physics Department, Lancaster University, Lancaster, United Kingdom*  
<sup>91</sup>*Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom*  
<sup>92</sup>*Department of Experimental Particle Physics, Jožef Stefan Institute and Department of Physics, University of Ljubljana, Ljubljana, Slovenia*  
<sup>93</sup>*School of Physics and Astronomy, Queen Mary University of London, London, United Kingdom*  
<sup>94</sup>*Department of Physics, Royal Holloway University of London, Egham, United Kingdom*  
<sup>95</sup>*Department of Physics and Astronomy, University College London, London, United Kingdom*  
<sup>96</sup>*Louisiana Tech University, Ruston, Los Angeles, USA*  
<sup>97</sup>*Fysiska institutionen, Lunds universitet, Lund, Sweden*  
<sup>98</sup>*Departamento de Física Teórica C-15 and CIAFF, Universidad Autónoma de Madrid, Madrid, Spain*  
<sup>99</sup>*Institut für Physik, Universität Mainz, Mainz, Germany*  
<sup>100</sup>*School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom*  
<sup>101</sup>*CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille, France*  
<sup>102</sup>*Department of Physics, University of Massachusetts, Amherst, Massachusetts, USA*  
<sup>103</sup>*Department of Physics, McGill University, Montreal, Quebec, Canada*  
<sup>104</sup>*School of Physics, University of Melbourne, Victoria, Australia*  
<sup>105</sup>*Department of Physics, University of Michigan, Ann Arbor, Michigan, USA*  
<sup>106</sup>*Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan, USA*  
<sup>107</sup>*Group of Particle Physics, University of Montreal, Montreal, Quebec, Canada*  
<sup>108</sup>*Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany*  
<sup>109</sup>*Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany*  
<sup>110</sup>*Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya, Japan*  
<sup>111</sup>*Department of Physics and Astronomy, University of New Mexico, Albuquerque, New Mexico, USA*  
<sup>112</sup>*Institute for Mathematics, Astrophysics and Particle Physics, Radboud University/Nikhef, Nijmegen, Netherlands*  
<sup>113</sup>*Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands*  
<sup>114</sup>*Department of Physics, Northern Illinois University, DeKalb, Illinois, USA*

- <sup>115a</sup>*New York University Abu Dhabi, Abu Dhabi, United Arab Emirates*  
<sup>115b</sup>*University of Sharjah, Sharjah, United Arab Emirates*  
<sup>116</sup>*Department of Physics, New York University, New York, New York, USA*  
<sup>117</sup>*Ochanomizu University, Otsuka, Bunkyo-ku, Tokyo, Japan*  
<sup>118</sup>*Ohio State University, Columbus, Ohio, USA*  
<sup>119</sup>*Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman, Oklahoma, USA*  
<sup>120</sup>*Department of Physics, Oklahoma State University, Stillwater, Oklahoma, USA*  
<sup>121</sup>*Palacký University, Joint Laboratory of Optics, Olomouc, Czech Republic*  
<sup>122</sup>*Institute for Fundamental Science, University of Oregon, Eugene, Oregon, USA*  
<sup>123</sup>*Graduate School of Science, Osaka University, Osaka, Japan*  
<sup>124</sup>*Department of Physics, University of Oslo, Oslo, Norway*  
<sup>125</sup>*Department of Physics, Oxford University, Oxford, United Kingdom*  
<sup>126</sup>*LPNHE, Sorbonne Université, Université Paris Cité, CNRS/IN2P3, Paris, France*  
<sup>127</sup>*Department of Physics, University of Pennsylvania, Philadelphia, Pennsylvania, USA*  
<sup>128</sup>*Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, Pennsylvania, USA*  
<sup>129a</sup>*Laboratório de Instrumentação e Física Experimental de Partículas—LIP, Lisboa, Portugal*  
<sup>129b</sup>*Departamento de Física, Faculdade de Ciências, Universidade de Lisboa, Lisboa, Portugal*  
<sup>129c</sup>*Departamento de Física, Universidade de Coimbra, Coimbra, Portugal*  
<sup>129d</sup>*Centro de Física Nuclear da Universidade de Lisboa, Lisboa, Portugal*  
<sup>129e</sup>*Departamento de Física, Universidade do Minho, Braga, Portugal*  
<sup>129f</sup>*Departamento de Física Teórica y del Cosmos, Universidad de Granada, Granada (Spain), Spain*  
<sup>129g</sup>*Departamento de Física, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal*  
<sup>130</sup>*Institute of Physics of the Czech Academy of Sciences, Prague, Czech Republic*  
<sup>131</sup>*Czech Technical University in Prague, Prague, Czech Republic*  
<sup>132</sup>*Charles University, Faculty of Mathematics and Physics, Prague, Czech Republic*  
<sup>133</sup>*Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom*  
<sup>134</sup>*IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France*  
<sup>135</sup>*Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz, California, USA*  
<sup>136a</sup>*Departamento de Física, Pontificia Universidad Católica de Chile, Santiago, Chile*  
<sup>136b</sup>*Millennium Institute for Subatomic physics at high energy frontier (SAPHIR), Santiago, Chile*  
<sup>136c</sup>*Instituto de Investigación Multidisciplinario en Ciencia y Tecnología, y Departamento de Física, Universidad de La Serena, Chile*  
<sup>136d</sup>*Universidad Andres Bello, Department of Physics, Santiago, Chile*  
<sup>136e</sup>*Instituto de Alta Investigación, Universidad de Tarapacá, Arica, Chile*  
<sup>136f</sup>*Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile*  
<sup>137</sup>*Department of Physics, University of Washington, Seattle, Washington, USA*  
<sup>138</sup>*Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom*  
<sup>139</sup>*Department of Physics, Shinshu University, Nagano, Japan*  
<sup>140</sup>*Department Physik, Universität Siegen, Siegen, Germany*  
<sup>141</sup>*Department of Physics, Simon Fraser University, Burnaby, British Columbia, Canada*  
<sup>142</sup>*SLAC National Accelerator Laboratory, Stanford, California, USA*  
<sup>143</sup>*Department of Physics, Royal Institute of Technology, Stockholm, Sweden*  
<sup>144</sup>*Departments of Physics and Astronomy, Stony Brook University, Stony Brook, New York, USA*  
<sup>145</sup>*Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom*  
<sup>146</sup>*School of Physics, University of Sydney, Sydney, Australia*  
<sup>147</sup>*Institute of Physics, Academia Sinica, Taipei, Taiwan*  
<sup>148a</sup>*E. Andronikashvili Institute of Physics, Iv. Javakhishvili Tbilisi State University, Tbilisi, Georgia*  
<sup>148b</sup>*High Energy Physics Institute, Tbilisi State University, Tbilisi, Georgia*  
<sup>148c</sup>*University of Georgia, Tbilisi, Georgia*  
<sup>149</sup>*Department of Physics, Technion, Israel Institute of Technology, Haifa, Israel*  
<sup>150</sup>*Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel*  
<sup>151</sup>*Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece*  
<sup>152</sup>*International Center for Elementary Particle Physics and Department of Physics, University of Tokyo, Tokyo, Japan*  
<sup>153</sup>*Department of Physics, Tokyo Institute of Technology, Tokyo, Japan*  
<sup>154</sup>*Department of Physics, University of Toronto, Toronto, Ontario, Canada*  
<sup>155a</sup>*TRIUMF, Vancouver, British Columbia, Canada*  
<sup>155b</sup>*Department of Physics and Astronomy, York University, Toronto, Ontario, Canada*  
<sup>156</sup>*Division of Physics and Tomonaga Center for the History of the Universe, Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba, Japan*  
<sup>157</sup>*Department of Physics and Astronomy, Tufts University, Medford, Massachusetts, USA*  
<sup>158</sup>*United Arab Emirates University, Al Ain, United Arab Emirates*

<sup>159</sup>*Department of Physics and Astronomy, University of California Irvine, Irvine, California, USA*

<sup>160</sup>*Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden*

<sup>161</sup>*Department of Physics, University of Illinois, Urbana, Illinois, USA*

<sup>162</sup>*Instituto de Física Corpuscular (IFIC), Centro Mixto Universidad de Valencia—CSIC, Valencia, Spain*

<sup>163</sup>*Department of Physics, University of British Columbia, Vancouver, British Columbia, Canada*

<sup>164</sup>*Department of Physics and Astronomy, University of Victoria, Victoria, British Columbia, Canada*

<sup>165</sup>*Fakultät für Physik und Astronomie, Julius-Maximilians-Universität Würzburg, Würzburg, Germany*

<sup>166</sup>*Department of Physics, University of Warwick, Coventry, United Kingdom*

<sup>167</sup>*Waseda University, Tokyo, Japan*

<sup>168</sup>*Department of Particle Physics and Astrophysics, Weizmann Institute of Science, Rehovot, Israel*

<sup>169</sup>*Department of Physics, University of Wisconsin, Madison, Wisconsin, USA*

<sup>170</sup>*Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal, Germany*

<sup>171</sup>*Department of Physics, Yale University, New Haven, Connecticut, USA*

<sup>a</sup>Deceased.

<sup>b</sup>Also at Department of Physics, King's College London, London, United Kingdom.

<sup>c</sup>Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan.

<sup>d</sup>Also at Lawrence Livermore National Laboratory, Livermore, USA.

<sup>e</sup>Also at TRIUMF, Vancouver, British Columbia, Canada.

<sup>f</sup>Also at Department of Physics, University of Thessaly, Greece.

<sup>g</sup>Also at An-Najah National University, Nablus, Palestine.

<sup>h</sup>Also at Department of Physics, University of Fribourg, Fribourg, Switzerland.

<sup>i</sup>Also at University of Colorado Boulder, Department of Physics, Colorado, USA.

<sup>j</sup>Also at Department of Physics and Astronomy, University of Louisville, Louisville, Kentucky, USA.

<sup>k</sup>Also at Department of Physics, Westmont College, Santa Barbara, USA.

<sup>l</sup>Also at Departament de Física de la Universitat Autònoma de Barcelona, Barcelona, Spain.

<sup>m</sup>Also at Affiliated with an institute covered by a cooperation agreement with CERN.

<sup>n</sup>Also at The Collaborative Innovation Center of Quantum Matter (CICQM), Beijing, China.

<sup>o</sup>Also at Department of Physics, Ben Gurion University of the Negev, Beer Sheva, Israel.

<sup>p</sup>Also at Università di Napoli Parthenope, Napoli, Italy.

<sup>q</sup>Also at Institute of Particle Physics (IPP), Canada.

<sup>r</sup>Also at Bruno Kessler Foundation, Trento, Italy.

<sup>s</sup>Also at RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany.

<sup>t</sup>Also at Borough of Manhattan Community College, City University of New York, New York, New York, USA.

<sup>u</sup>Also at National Institute of Physics, University of the Philippines Diliman (Philippines), Philippines.

<sup>v</sup>Also at Department of Financial and Management Engineering, University of the Aegean, Chios, Greece.

<sup>w</sup>Also at Department of Physics, Stanford University, Stanford, California, USA.

<sup>x</sup>Also at Centro Studi e Ricerche Enrico Fermi, Italy.

<sup>y</sup>Also at Department of Physics, California State University, East Bay, USA.

<sup>z</sup>Also at Institutio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona, Spain.

<sup>aa</sup>Also at University of Chinese Academy of Sciences (UCAS), Beijing, China.

<sup>bb</sup>Also at Yeditepe University, Physics Department, Istanbul, Türkiye.

<sup>cc</sup>Also at Institute of Theoretical Physics, Ilia State University, Tbilisi, Georgia.

<sup>dd</sup>Also at CERN, Geneva, Switzerland.

<sup>ee</sup>Also at Hellenic Open University, Patras, Greece.

<sup>ff</sup>Also at Center for High Energy Physics, Peking University, China.

<sup>gg</sup>Also at The City College of New York, New York, New York, USA.

<sup>hh</sup>Also at Department of Physics, California State University, Sacramento, USA.

<sup>ii</sup>Also at Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève, Switzerland.

<sup>jj</sup>Also at Institute for Nuclear Research and Nuclear Energy (INRNE) of the Bulgarian Academy of Sciences, Sofia, Bulgaria.

<sup>kk</sup>Also at L2IT, Université de Toulouse, CNRS/IN2P3, UPS, Toulouse, France.

<sup>ll</sup>Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany.

<sup>mm</sup>Also at Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan, USA.