

Observation of light-by-light scattering in ultraperipheral Pb+Pb collisions with the ATLAS detector

ATLAS Collaboration; Watson, Alan

DOI:

[10.1103/PhysRevLett.123.052001](https://doi.org/10.1103/PhysRevLett.123.052001)

License:

Creative Commons: Attribution (CC BY)

Document Version

Publisher's PDF, also known as Version of record

Citation for published version (Harvard):

ATLAS Collaboration & Watson, A 2019, 'Observation of light-by-light scattering in ultraperipheral Pb+Pb collisions with the ATLAS detector', *Physical Review Letters*, vol. 123, no. 5, 052001. <https://doi.org/10.1103/PhysRevLett.123.052001>

[Link to publication on Research at Birmingham portal](#)

Publisher Rights Statement:

Aad, G. et al, (2019) Observation of light-by-light scattering in ultraperipheral Pb+Pb collisions with the ATLAS detector, *Physical Review Letters*, vol. 123, article no. 052001, DOI: 10.1103/PhysRevLett.123.052001

General rights

Unless a licence is specified above, all rights (including copyright and moral rights) in this document are retained by the authors and/or the copyright holders. The express permission of the copyright holder must be obtained for any use of this material other than for purposes permitted by law.

- Users may freely distribute the URL that is used to identify this publication.
- Users may download and/or print one copy of the publication from the University of Birmingham research portal for the purpose of private study or non-commercial research.
- User may use extracts from the document in line with the concept of 'fair dealing' under the Copyright, Designs and Patents Act 1988 (?)
- Users may not further distribute the material nor use it for the purposes of commercial gain.

Where a licence is displayed above, please note the terms and conditions of the licence govern your use of this document.

When citing, please reference the published version.

Take down policy

While the University of Birmingham exercises care and attention in making items available there are rare occasions when an item has been uploaded in error or has been deemed to be commercially or otherwise sensitive.

If you believe that this is the case for this document, please contact UBIRA@lists.bham.ac.uk providing details and we will remove access to the work immediately and investigate.

Observation of Light-by-Light Scattering in Ultraperipheral Pb + Pb Collisions with the ATLAS Detector

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

 (Received 11 April 2019; published 31 July 2019)

This Letter describes the observation of the light-by-light scattering process, $\gamma\gamma \rightarrow \gamma\gamma$, in Pb + Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV. The analysis is conducted using a data sample corresponding to an integrated luminosity of 1.73 nb^{-1} , collected in November 2018 by the ATLAS experiment at the LHC. Light-by-light scattering candidates are selected in events with two photons produced exclusively, each with transverse energy $E_T^\gamma > 3$ GeV and pseudorapidity $|\eta_\gamma| < 2.4$, diphoton invariant mass above 6 GeV, and small diphoton transverse momentum and acoplanarity. After applying all selection criteria, 59 candidate events are observed for a background expectation of 12 ± 3 events. The observed excess of events over the expected background has a significance of 8.2 standard deviations. The measured fiducial cross section is $78 \pm 13(\text{stat}) \pm 7(\text{syst}) \pm 3(\text{lumi}) \text{ nb}$.

DOI: [10.1103/PhysRevLett.123.052001](https://doi.org/10.1103/PhysRevLett.123.052001)

Light-by-light scattering, $\gamma\gamma \rightarrow \gamma\gamma$, is a quantum-mechanical process that is forbidden in the classical theory of electrodynamics [1,2]. In the standard model (SM), the $\gamma\gamma \rightarrow \gamma\gamma$ reaction proceeds at one-loop level at order α_{EM}^4 (where α_{EM} is the fine-structure constant) via virtual box diagrams involving electrically charged fermions (leptons and quarks) or W^\pm bosons. However, in various extensions of the SM, extra contributions are possible, making the measurement of $\gamma\gamma \rightarrow \gamma\gamma$ scattering sensitive to new physics. Relevant examples are magnetic monopoles [3], vectorlike fermions [4], and axionlike particles [5,6]. The light-by-light cross section is also sensitive to the effect of possible non-SM operators in an effective field theory [7–9]. Light-by-light scattering graphs with electron loops also contribute to the anomalous magnetic moment of the electron and muon [10,11].

Strong evidence for this process in relativistic heavy-ion (Pb + Pb) collisions at the Large Hadron Collider (LHC) has been reported by the ATLAS [12] and CMS [13] collaborations with observed significances of 4.4 and 4.1 standard deviations, respectively. Exclusive light-by-light scattering can occur in these collisions at impact parameters larger than about twice the radius of the ions, as demonstrated for the first time in Ref. [14]. The strong interaction becomes less significant and the electromagnetic (EM) interaction becomes more important in these ultraperipheral

collision (UPC) events. In general, this allows us to study processes involving nuclear photoexcitation, photoproduction of hadrons, and two-photon interactions [15,16]. The EM fields produced by the colliding Pb nuclei can be described as a beam of quasireal photons with a small virtuality of $Q^2 < 1/R^2$, where R is the radius of the charge distribution, and so, $Q^2 < 10^{-3} \text{ GeV}^2$ [17,18]. The cross section for the elastic reaction $\text{Pb} + \text{Pb}(\gamma\gamma) \rightarrow \text{Pb} + \text{Pb}\gamma\gamma$ can then be calculated by convolving the appropriate photon flux with the elementary cross section for the process $\gamma\gamma \rightarrow \gamma\gamma$. Since the photon flux associated with each nucleus scales with the square of the number of protons, the cross section is strongly enhanced relative to proton-proton (pp) collisions.

The $\gamma\gamma \rightarrow \gamma\gamma$ reaction has also been measured in photon scattering in the Coulomb field of a nucleus (Delbrück scattering) [19–22] and in the photon-splitting process [23]. A related process, in which initial photons fuse to form a pseudoscalar meson that subsequently decays into a pair of photons, has been studied at electron-positron colliders [24–27].

The previous ATLAS and CMS measurements were based on the Pb + Pb dataset of 0.4 nb^{-1} recorded in 2015 at a nucleon-nucleon (NN) center-of-mass energy of $\sqrt{s_{\text{NN}}} = 5.02$ TeV [12,13]. The present Letter describes a new measurement exploiting 1.73 nb^{-1} of Pb + Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV, recorded in November 2018 with the ATLAS detector at the LHC. The analysis follows the approach originally proposed in Ref. [14], which was the basis of the initial ATLAS measurement.

The ATLAS detector [28] is a multipurpose particle detector that covers nearly the entire solid angle around the interaction point (IP) [29]. It consists of an inner detector

*Full author list given at the end of the article.

Published by the American Physical Society under the terms of the [Creative Commons Attribution 4.0 International license](https://creativecommons.org/licenses/by/4.0/). Further distribution of this work must maintain attribution to the author(s) and the published article's title, journal citation, and DOI. Funded by SCOAP³.

(ID) for charged-particle tracking in the pseudorapidity region $|\eta| < 2.5$, EM and hadronic calorimeters that provide energy measurements up to $|\eta| = 4.9$, and a muon spectrometer that covers $|\eta| < 2.7$. Forward calorimeters (FCAL) cover the range of $3.2 < |\eta| < 4.9$. The zero-degree calorimeters (ZDC), located along the beam axis at 140 m from the IP on both sides, detect neutral particles, including neutrons emitted from the nucleus.

The final-state signature of interest is the exclusive production of two photons, $\text{Pb} + \text{Pb}(\gamma\gamma) \rightarrow \text{Pb}^{(*)} + \text{Pb}^{(*)}\gamma\gamma$, where the diphoton final state is measured in the central detector, and the incoming Pb ions survive the EM interaction, with a possible EM excitation [30], denoted by (*). Hence, the final state consists of two low-energy photons and no further activity in the detector and, in particular, no reconstructed charged-particle tracks originating from the IP.

A two-level trigger system was used to select events online [31]. It consists of a level-1 trigger implemented using a combination of custom electronics and programmable logic, and a software-based high-level trigger (HLT). Candidate diphoton events were recorded using a dedicated trigger for events with moderate activity in the calorimeter but little additional activity in the detector. At level 1, a logical OR of two conditions was required: at least one EM cluster with $E_T > 1$ GeV in coincidence with a total E_T of 4–200 GeV measured in the calorimeter, or at least two EM clusters with $E_T > 1$ GeV with total E_T measured in the calorimeter below 50 GeV. The upper bound on the total E_T was optimized to be fully efficient for signal events while allowing the rejection of events from nonperipheral Pb + Pb collisions. At the HLT, the total FCAL E_T on each side of the IP was required to be consistent with noise (FCAL veto), and the number of hits in the pixel detector (part of the ID) was required to be, at most, 15.

Simulated $\gamma\gamma \rightarrow \gamma\gamma$ signal events were generated using the SUPERCHIC 3.0 Monte Carlo (MC) generator [32]. This program takes into account box diagrams with charged leptons, quarks, and W^\pm bosons. An alternative signal sample was generated using calculations from Ref. [33]. These calculations were then folded with the Pb + Pb photon flux taken from the STARLIGHT 2.0 MC generator [34]. The theoretical uncertainty of the cross section is mainly due to the limited knowledge of the nuclear form factors and initial photon fluxes. This is extensively studied in Refs. [13,35], and the relevant uncertainty is estimated to be 10% within the fiducial phase space of the measurement. Higher-order corrections, which are not included in the calculations, are also part of the theoretical uncertainty and amount to 1%–3% in the fiducial phase space [36,37].

The exclusive diphoton final state can also be produced via the strong interaction through a quark loop in the exchange of two gluons in a color-singlet state. This central exclusive production (CEP) process, $gg \rightarrow \gamma\gamma$, was also modeled using SUPERCHIC 3.0. This process has a large theoretical uncertainty, of $\mathcal{O}(100\%)$ [38]; hence

the absolute normalization of this background is determined using a control region in the data, as explained later. The $\gamma\gamma \rightarrow e^+e^-$ process is a potential background when both leptons are reconstructed as photons but is also used for calibration studies in the analysis. The process was modeled with the STARLIGHT 2.0 generator. Its production cross section is computed by combining the Pb + Pb photon flux with the leading-order formula for $\gamma\gamma \rightarrow e^+e^-$. Two-photon production of quark-antiquark pairs, with their subsequent decay into multiple hadrons, was modeled using HERWIG++ 2.7.1 [39], where the initial photon fluxes from pp collisions are implemented. The sample was then normalized to cover the differences in the photon fluxes between Pb + Pb and pp collisions. All simulated events make use of a detector simulation [40] based on GEANT4 [41] and are reconstructed with the standard ATLAS reconstruction software.

Photons are reconstructed from EM clusters in the calorimeter [42] and tracking information provided by the ID, which allows us to identify photon conversions [43]. An energy calibration specifically optimized for photons [44] is applied to account for energy loss before the calorimeter and both lateral and longitudinal shower leakage. Photons in MC samples are corrected [43] for known mismodeling of quantities that describe the properties (“shapes”) of the associated EM showers.

The photon particle identification (PID) in this analysis is based on a selection of these shower-shape variables, optimized for the signal events. Only photons with $E_T > 3$ GeV and $|\eta| < 2.37$, excluding the calorimeter transition region $1.37 < |\eta| < 1.52$, are considered. This allows for good separation between prompt photons and fake signatures due to calorimeter noise, cosmic-ray muons, or nonprompt photons originating from the decay of neutral hadrons. The photon PID is based on a neural network trained on background photons extracted from data and on photons from the signal MC sample. The selection of background photons follows the procedure established in Ref. [12].

Selected events are required to have exactly two photons satisfying the above selection criteria, with a diphoton invariant mass ($m_{\gamma\gamma}$) greater than 6 GeV. In order to suppress the $\gamma\gamma \rightarrow e^+e^-$ background, events are rejected if they have a charged-particle track with $p_T > 100$ MeV, $|\eta| < 2.5$, and at least six hits in the pixel and microstrip detectors, including at least one pixel hit. To further suppress $\gamma\gamma \rightarrow e^+e^-$ events with poorly reconstructed charged-particle tracks, candidate events are required to have no “pixel tracks” matched to a photon candidate within $|\Delta\eta| < 0.5$. Pixel tracks are reconstructed using information from the pixel detector only. They are required to have $p_T > 50$ MeV, $|\eta| < 2.5$, and at least three hits in the pixel detector. According to the MC simulation, these requirements reduce the fake photon background from the dielectron final state by a factor of 10^4 , while being 93% efficient for $\gamma\gamma \rightarrow \gamma\gamma$ signal events.

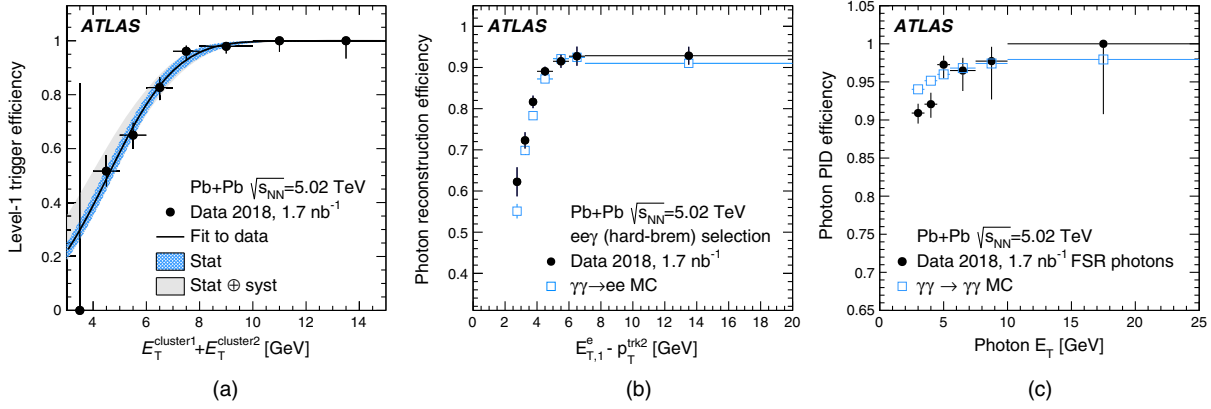


FIG. 1. (a) Measured level-1 trigger efficiency as a function of the reconstructed transverse energy in $\gamma\gamma \rightarrow e^+e^-$ events, (b) photon reconstruction efficiency as a function of the photon E_T (approximated with $E_{T,1}^e - p_T^{\text{trk2}}$, where trk2 denotes the track of the second leading electron), and (c) photon particle-identification efficiency as a function of the photon E_T .

To reduce other fake-photon backgrounds, such as cosmic-ray muons, the transverse momentum of the diphoton system ($p_T^{\gamma\gamma}$) is required to be below 1 GeV for $m_{\gamma\gamma} < 12$ GeV and below 2 GeV for $m_{\gamma\gamma} > 12$ GeV. To reduce prompt-photon background from CEP $gg \rightarrow \gamma\gamma$ reactions, an additional requirement on the reduced acoplanarity, $A_\phi = (1 - |\Delta\phi_{\gamma\gamma}|/\pi) < 0.01$, is used, which is expected to have $(86 \pm 1)\%$ selection efficiency for the signal. This efficiency is estimated using simulated signal events, and the uncertainty is due to modeling of the photon angular resolution in simulation. The above requirements define the fiducial region for the signal measurement.

Exclusive dielectron pairs from the reaction $\text{Pb} + \text{Pb}(\gamma\gamma) \rightarrow \text{Pb}^{(*)} + \text{Pb}^{(*)}e^+e^-$ are used for various aspects of the analysis, in particular, to validate the EM calorimeter energy scale and resolution [44]. To select $\gamma\gamma \rightarrow e^+e^-$ candidates, events are required to pass the same trigger as for the diphoton selection. Each electron is reconstructed from an EM energy cluster in the calorimeter matched to a track in the ID [45]. The $\gamma\gamma \rightarrow e^+e^-$ events are selected by requiring exactly two oppositely charged electrons, no further charged-particle tracks coming from the interaction region, and dielectron reduced acoplanarity, $A_\phi < 0.01$. The observed $\gamma\gamma \rightarrow e^+e^-$ event yield in data is compatible with that expected from simulation.

The level-1 trigger efficiency is estimated with $\gamma\gamma \rightarrow e^+e^-$ events passing an independent trigger. The level-1 trigger efficiency as a function of the electron EM cluster transverse energy sum, $E_T^{\text{cluster1}} + E_T^{\text{cluster2}}$, reaches 60% at 5 GeV and 75% at 6 GeV, with the fully efficient plateau reached at around 10 GeV, as shown in Fig. 1(a). The measured efficiency is parametrized and used to correct the trigger response in the simulation. To test the stability of the results, the analysis is repeated using tighter or looser dielectron event selection criteria, and the resulting differences are taken as a systematic uncertainty. The FCAL veto efficiency is estimated using $\gamma\gamma \rightarrow e^+e^-$ events selected with a dedicated control trigger without involving the FCAL requirement. It is estimated to be $(99.1 \pm 0.6)\%$.

Because of the high hit-reconstruction efficiency and relatively low conversion probability of signal photons in the pixel detector, the inefficiency of the pixel veto requirement at the trigger level is found to be negligible.

The photon reconstruction efficiency is extracted from data using $\gamma\gamma \rightarrow e^+e^-$ events, where one of the electrons emits a hard bremsstrahlung photon due to interaction with the material of the detector. The analysis is performed for events with exactly one identified electron and exactly two reconstructed charged-particle tracks, and a tag-and-probe method is used as described in Ref. [12]. The resulting photon reconstruction efficiency is shown in Fig. 1(b). It rises from about 60% at $E_T = 2.5$ GeV to 90% at $E_T = 6$ GeV and is used to derive simulation-to-data correction factors.

High- p_T exclusive dilepton production ($\gamma\gamma \rightarrow \ell^+\ell^-$, where $\ell = e, \mu$) with final-state radiation (FSR) is used to measure the photon PID efficiency, defined as the probability for a reconstructed photon to satisfy the identification criteria. Events with exactly two oppositely charged tracks with $p_T > 0.5$ GeV are selected from UPC triggered events. In addition, a requirement to reconstruct a photon candidate with $E_T > 2.5$ GeV and $|\eta| < 1.37$ or $1.52 < |\eta| < 2.37$ is imposed. A photon candidate is required to be separated from each track by fulfilling $\Delta R > 0.3$ [29] to avoid leakage between the photon and the electron clusters. The FSR event candidates are required to have $p_T^{\ell\ell\gamma} < 1$ GeV requirement, where $p_T^{\ell\ell\gamma}$ is the transverse momentum of the three-body system consisting of the two tracks and the photon candidate. Figure 1(c) shows the photon PID efficiency as a function of reconstructed photon E_T , where the measurement from data is compared with the one extracted from the signal MC sample. Based on these studies, MC events are corrected using photon E_T -dependent simulation-to-data correction factors. The systematic uncertainty on the photon reconstruction and PID efficiencies is estimated by parametrizing the correction factors as a function of the photon η instead of the photon E_T .

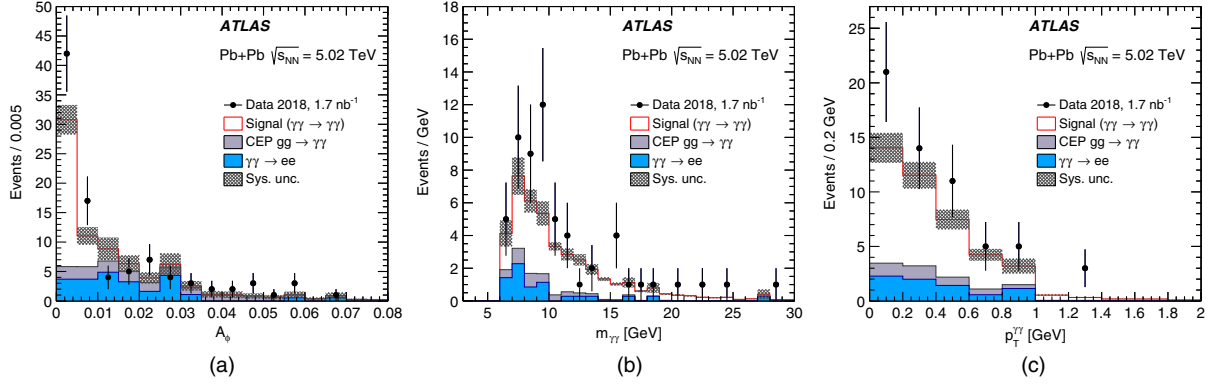


FIG. 2. (a) The diphoton A_ϕ distribution for events satisfying the signal selection, but before the $A_\phi < 0.01$ requirement. (b) Diphoton invariant mass and (c) diphoton transverse momentum for events satisfying the signal selection. Data (points) are compared with the sum of signal and background expectations (histograms). Systematic uncertainties of the signal and background processes, excluding that of the luminosity, are shown as shaded bands.

The two electrons exhibit balanced transverse momentum with an unbalance, $|p_T^{e^+} - p_T^{e^-}|$, expected to be below 30 MeV. This is much smaller than the EM calorimeter energy resolution, which, thus, can be measured by the difference $E_T^{\text{cluster}1} - E_T^{\text{cluster}2}$. Below 10 GeV electron E_T , the relative energy resolution is found to be between 8% and 10% and is well reproduced by the MC simulation. The EM energy scale is validated using the ratio of the electron cluster E_T^e to the electron track p_T^{trk} .

The $\gamma\gamma \rightarrow e^+e^-$ process can be a source of fake diphoton events, since misidentification of electrons as photons can occur when the electron track is not reconstructed or the electron emits a hard bremsstrahlung photon. The $\gamma\gamma \rightarrow e^+e^-$ yield in the signal region is evaluated using a data-driven method. Two control regions (CRs) are defined with exactly two photons passing the signal selection but also requiring one or two associated pixel tracks. The event yield observed in these two CRs is extrapolated to the signal region using the probability to miss the electron pixel track if the electron track is not reconstructed (p_{mistag}^e). It is measured in a region with exactly one charged-particle track and two photons with $A_\phi < 0.01$. In order to verify the stability of the p_{mistag}^e evaluation method, the A_ϕ requirement is dropped and the difference with the nominal selection is taken as a systematic uncertainty. This leads to $p_{\text{mistag}}^e = (47 \pm 9)\%$. The number of $\gamma\gamma \rightarrow e^+e^-$ events in the signal region is estimated to be $7 \pm 1(\text{stat}) \pm 3(\text{syst})$, where the uncertainty accounts for the CR statistical uncertainty, the p_{mistag}^e uncertainty, and the difference found between the two CRs.

The $A_\phi < 0.01$ requirement significantly reduces the CEP $gg \rightarrow \gamma\gamma$ background. Its remaining contribution is evaluated from a control region defined by applying the same selection as for the signal region, but inverting the A_ϕ requirement to $A_\phi > 0.01$ [see Fig. 2(a)], and correcting the measured event yield for the expected signal and $\gamma\gamma \rightarrow e^+e^-$ contributions. The CEP and $\gamma\gamma \rightarrow e^+e^-$ processes

exhibit a significantly broader A_ϕ distribution than the $\gamma\gamma \rightarrow \gamma\gamma$ process. In the CEP process gluons recoil against the Pb nucleus which then dissociates. The shape of the A_ϕ distribution for $\gamma\gamma \rightarrow e^+e^-$ events is mainly due to the curvature of the trajectory of the electrons in the detector magnetic field before they emit hard photons in their interactions with the ID material.

The estimated uncertainty in the CEP $gg \rightarrow \gamma\gamma$ background takes into account the statistical uncertainty of the number of events in the $A_\phi > 0.01$ control region (17%) as well as experimental and modeling uncertainties. It is found that all experimental uncertainties have negligible impact on the normalization of the CEP $gg \rightarrow \gamma\gamma$ background. The impact of the MC modeling of the A_ϕ shape is estimated using an alternative SUPERCHIC MC sample with no absorptive effects [46]. These effects reflect the absence of secondary particle emissions, which can take place in addition to the $gg \rightarrow \gamma\gamma$ process. After applying the data-driven normalization procedure, this leads to a 25% change in the CEP background yield in the signal region, which is taken as a systematic uncertainty. An additional check is done by varying the gluon parton distribution function (PDF). The differences between the MMHT 2014 [47], CT14 [48], and NNPDF3.1 [49] PDF sets have negligible impact on the shape of the CEP diphoton A_ϕ distribution. The background due to the CEP process in the signal region is estimated to be 4 ± 1 events. In addition, the energy deposition in the ZDC, which is sensitive to dissociation of Pb nuclei, is studied for events before the A_ϕ selection is imposed. Good agreement is observed between the normalized CEP expectation from MC simulation and the observed events with a signal corresponding to at least one neutron in the ZDC.

The background contribution from $\gamma\gamma \rightarrow q\bar{q}$ production is estimated using MC simulation based on HERWIG++ and is found to be negligible. Exclusive two-meson production can be a potential source of background for light-by-light scattering events, mainly due to their similar back-to-back

topology. Mesons can fake photons either by their intermediate decay into photons (neutral mesons: π^0 , η , η') or by misreconstructed charged-particle tracks (charged mesons: for example π^+ , π^- states). Estimates for such contributions are reported in Refs. [14,50–53] and these contributions are considered to be negligible in the signal region.

The background from other fake diphoton events (mainly those induced by cosmic-ray muons) is estimated using a control region with at least one track reconstructed in the muon system and further studied using the reconstructed photon-cluster time distribution. After imposing the p_T' requirements, this background is found to be negligible. Background from the $\gamma\gamma \rightarrow e^+e^-\gamma\gamma$ reaction is evaluated using the MADGRAPH5_AMC@NLO MC generator [54] and the Pb + Pb photon flux from STARLIGHT. This contribution is estimated to be below 1% of the expected signal and, therefore, has negligible impact on the results. The contribution from bottomonia production (for example, $\gamma\gamma \rightarrow \eta_b \rightarrow \gamma\gamma$ or $\gamma\text{Pb} \rightarrow \Upsilon \rightarrow \gamma\eta_b \rightarrow 3\gamma$) is calculated using parameters from Refs. [55,56] and considered to be negligible. The contribution from UPC events where both nuclei emit a bremsstrahlung photon is estimated using calculations from Ref. [57]. The cross section for single-bremsstrahlung photon production from a Pb ion in the fiducial region of the measurement is calculated to be below 10^{-4} pb so that the coincidence of two such occurrences is considered to be negligible.

After applying the signal selection, 59 events are observed in the data where $30 \pm 4(\text{syst})$ signal events and $12 \pm 1(\text{stat}) \pm 3(\text{syst})$ background events are expected. The probability that the data are compatible with the background-only hypothesis was evaluated in a narrower $0 < A_\phi < 0.005$ range which, in studies using simulated data, was found to be most sensitive. In this region, 42 events are observed in the data where $25 \pm 3(\text{syst})$ signal events and $6 \pm 1(\text{stat}) \pm 2(\text{syst})$ background events are expected. The data excess is quantified by calculating the background-only p value using a profile likelihood-ratio test statistic [58], resulting in an observed (expected) statistical significance of 8.2 (6.2) standard deviations. Photon kinematic distributions for events satisfying all selection criteria are shown in Figs. 2(b)–2(c). A further cross check of energy deposits in the ZDC for events in the signal region is performed. The activity in the ZDC agrees with the signal-plus-background expectation. The analysis is also repeated with a lower minimum photon E_T requirement of 2.5 GeV, yielding more signal events but also an increased relative background contribution. Consistent results were found using this relaxed signal selection.

The cross section for the $\gamma\gamma \rightarrow \gamma\gamma$ process is measured in a fiducial phase space, defined by a set of requirements on the diphoton final state, reflecting the selection at the reconstruction level [59]. Experimentally, the fiducial cross section is given by $\sigma_{\text{fid}} = (N_{\text{data}} - N_{\text{bkg}}) / (C \times \int L dt)$, where N_{data} is the number of selected events in data, N_{bkg} is

the number of background events, $\int L dt = 1.73 \pm 0.07 \text{ nb}^{-1}$ is the integrated luminosity of the data sample, and C is an overall correction factor that accounts for efficiencies and resolution effects. The C factor is defined as the ratio of the number of selected MC signal events passing the selection and after applying data/MC correction factors to the number of generated MC signal events satisfying the fiducial requirements. It is found to be $C = 0.350 \pm 0.024$. The uncertainty in C is estimated by varying the data/MC correction factors within their uncertainties, as well as using an alternative signal MC sample based on calculations from Ref. [33]. The probability of additional inelastic interactions in the same bunch crossing is estimated to be 0.3% and has negligible impact on the signal efficiency. The overall uncertainty is dominated by uncertainties in the photon reconstruction efficiency (4%) and the trigger efficiency (2%). The uncertainty of the integrated luminosity is derived, following a methodology similar to that detailed in Ref. [60], from a calibration of the luminosity scale using x - y beam-separation scans performed in November 2018.

The measured fiducial cross section is $78 \pm 13(\text{stat}) \pm 7(\text{syst}) \pm 3(\text{lumi}) \text{ nb}$, which can be compared with the predicted values of $45 \pm 5 \text{ nb}$ from Ref. [14], $51 \pm 5 \text{ nb}$ from Ref. [33], and $50 \pm 5 \text{ nb}$ from SUPERCHIC 3.0 MC simulation [32]. The experiment-to-prediction ratios are 1.73 ± 0.40 , 1.53 ± 0.33 , and 1.56 ± 0.33 , respectively.

In summary, this Letter reports the observation of light-by-light scattering in quasireal photon interactions from ultraperipheral Pb + Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}$ recorded in 2018 by the ATLAS experiment. After applying all selection criteria, 59 data events are observed in the signal region, while 12 ± 3 background events are expected. The dominant background processes, i.e., CEP $gg \rightarrow \gamma\gamma$, $\gamma\gamma \rightarrow e^+e^-$ as well as other fake-photon backgrounds, are estimated from data. The statistical significance against the background-only hypothesis is found to be 8.2 standard deviations.

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; SSTC, Belarus; CNPq and FAPESP, Brazil; NSERC, NRC, and CFI, Canada; CERN; CONICYT, Chile; CAS, MOST, and NSFC, China; COLCIENCIAS, Colombia; MSMT CR, MPO CR, and VSC CR, Czech Republic; DNRf and DNSRC, Denmark; IN2P3-CNRS and CEA-DRF/IRFU, France; SRNSFG, Georgia; BMBF, HGF, and MPG, Germany; GSRT, Greece; RGC, Hong Kong SAR, China; ISF and Benozio Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; NWO, Netherlands; RCN, Norway; MNiSW and NCN, Poland; FCT, Portugal;

MNE/IFA, Romania; MES of Russia and NRC KI, Russian Federation; JINR; MESTD, Serbia; MSSR, Slovakia; ARRS and MIZŠ, Slovenia; DST/NRF, South Africa; MINECO, Spain; SRC and Wallenberg Foundation, Sweden; SERI, SNSF, and Cantons of Bern and Geneva, Switzerland; MOST, Taiwan; TAEK, Turkey; STFC, United Kingdom; DOE and NSF, United States of America. In addition, individual groups and members have received support from BCKDF, CANARIE, CRC, and Compute Canada, Canada; COST, ERC, ERDF, Horizon 2020, and Marie Skłodowska-Curie Actions, European Union; Investissements d’Avenir Labex and Idex, ANR, France; DFG and AvH Foundation, Germany; Herakleitos, Thales, and Aristeia Programmes co-financed by EU-ESF and the Greek NSRF, Greece; BSF-NSF and GIF, Israel; CERCA Programme Generalitat de Catalunya, Spain; 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. [61].

[1] H. Euler and B. Köckel, The scattering of light by light in Dirac’s theory, *Naturwissenschaften* **23**, 246 (1935).
 [2] W. Heisenberg and H. Euler, Consequences of Dirac’s theory of positrons, *Z. Phys.* **98**, 714 (1936).
 [3] I. F. Ginzburg and A. Schiller, Search for a heavy magnetic monopole at the Fermilab Tevatron and CERN LHC, *Phys. Rev. D* **57**, R6599 (1998).
 [4] S. Fichtel, G. von Gersdorff, B. Lenzi, C. Royon, and M. Saimpert, Light-by-light scattering with intact protons at the LHC: From standard model to new physics, *J. High Energy Phys.* **02** (2015) 165.
 [5] S. Knapen, T. Lin, H. K. Lou, and T. Melia, Searching for Axionlike Particles with Ultraperipheral Heavy-Ion Collisions, *Phys. Rev. Lett.* **118**, 171801 (2017).
 [6] M. Bauer, M. Neubert, and A. Thamm, Collider probes of axion-like particles, *J. High Energy Phys.* **12** (2017) 044.
 [7] J. Ellis, N. E. Mavromatos, and T. You, Light-by-Light Scattering Constraint on Born-Infeld Theory, *Phys. Rev. Lett.* **118**, 261802 (2017).
 [8] P. N. Akmansoy and L. G. Medeiros, Constraining non-linear corrections to Maxwell electrodynamics using $\gamma\gamma$ scattering, *Phys. Rev. D* **99**, 115005 (2019).
 [9] V. A. Kostelecky and Z. Li, Gauge field theories with Lorentz-violating operators of arbitrary dimension, *Phys. Rev. D* **99**, 056016 (2019).
 [10] S. Laporta and E. Remiddi, The analytical value of the electron light-light graphs contribution to the muon ($g-2$) in QED, *Phys. Lett. B* **301**, 440 (1993).

[11] F. Jegerlehner and A. Nyffeler, The Muon $g-2$, *Phys. Rep.* **477**, 1 (2009).
 [12] ATLAS Collaboration, Evidence for light-by-light scattering in heavy-ion collisions with the ATLAS detector at the LHC, *Nat. Phys.* **13**, 852 (2017).
 [13] CMS Collaboration, Evidence for light-by-light scattering and searches for axion-like particles in ultraperipheral PbPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, *Phys. Lett. B* (to be published).
 [14] D. d’Enterria and G. G. da Silveira, Observing Light-by-Light Scattering at the Large Hadron Collider, *Phys. Rev. Lett.* **111**, 080405 (2013); Erratum, *Phys. Rev. Lett.* **116**, 129901(E) (2016).
 [15] C. A. Bertulani, S. R. Klein, and J. Nystrand, Physics of ultra-peripheral nuclear collisions, *Annu. Rev. Nucl. Part. Sci.* **55**, 271 (2005).
 [16] A. J. Baltz *et al.*, The physics of ultraperipheral collisions at the LHC, *Phys. Rep.* **458**, 1 (2008).
 [17] E. Fermi, On the theory of collisions between atoms and electrically charged particles, *Nuovo Cimento* **2**, 143 (1925).
 [18] E. J. Williams, Nature of the high energy particles of penetrating radiation and status of ionization and radiation formulae, *Phys. Rev.* **45**, 729 (1934).
 [19] R. R. Wilson, Scattering of 1.33 MeV Gamma-Rays by an Electric Field, *Phys. Rev.* **90**, 720 (1953).
 [20] G. Jarlskog, L. Jönsson, S. Prünster, H. D. Schulz, H. J. Willutzki, and G. G. Winter, Measurement of Delbrück scattering and observation of photon splitting at high energies, *Phys. Rev. D* **8**, 3813 (1973).
 [21] M. Schumacher, I. Borchert, F. Smend, and P. Rullhusen, Delbrück scattering of 2.75 MeV photons by lead, *Phys. Lett.* **59B**, 134 (1975).
 [22] S. Z. Akhmalaliev *et al.*, Delbrück scattering at energies of 140–450 MeV, *Phys. Rev. C* **58**, 2844 (1998).
 [23] S. Z. Akhmalaliev *et al.*, Experimental Investigation of High-Energy Photon Splitting in Atomic Fields, *Phys. Rev. Lett.* **89**, 061802 (2002).
 [24] JADE Collaboration, A measurement of the η radiative width $\Gamma_{\eta \rightarrow \gamma\gamma}$, *Phys. Lett.* **158B**, 511 (1985).
 [25] TPC/Two-Gamma Collaboration, Study of η formation in photon-photon collisions, *Phys. Rev. D* **33**, 844 (1986).
 [26] Crystal Ball Collaboration, Formation of the pseudoscalars π^0 , η , and η' in the reaction $\gamma\gamma \rightarrow \gamma\gamma$, *Phys. Rev. D* **38**, 1365 (1988).
 [27] KLOE-2 Collaboration, Measurement of η meson production in $\gamma\gamma$ interactions and $\Gamma(\eta \rightarrow \gamma\gamma)$ with the KLOE detector, *J. High Energy Phys.* **01** (2013) 119.
 [28] ATLAS Collaboration, The ATLAS experiment at the CERN Large Hadron Collider, *J. Instrum.* **3**, S08003 (2008).
 [29] ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the center of the detector and the z axis along the beam pipe. The x axis points from the IP to the center of the LHC ring, and the y axis points upward. Cylindrical coordinates (r, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the z axis. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln \tan(\theta/2)$. The distance between two objects in η - ϕ space is $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$. Transverse momentum is defined by $p_T = p \sin \theta$.

- [30] ALICE Collaboration, Measurement of the Cross Section for Electromagnetic Dissociation with Neutron Emission in Pb-Pb Collisions at $\sqrt{s_{NN}} = 2.76$ TeV, *Phys. Rev. Lett.* **109**, 252302 (2012).
- [31] ATLAS Collaboration, Performance of the ATLAS trigger system in 2015, *Eur. Phys. J. C* **77**, 317 (2017).
- [32] L. A. Harland-Lang, V. A. Khoze, and M. G. Ryskin, Exclusive LHC physics with heavy ions: SUPERCHIC 3, *Eur. Phys. J. C* **79**, 39 (2019).
- [33] M. Klusek-Gawenda, P. Lebiedowicz, and A. Szczurek, Light-by-light scattering in ultraperipheral Pb-Pb collisions at energies available at the CERN Large Hadron Collider, *Phys. Rev. C* **93**, 044907 (2016).
- [34] S. R. Klein, J. Nystrand, J. Seger, Y. Gorbunov, and J. Butterworth, STARLIGHT: A Monte Carlo simulation program for ultra-peripheral collisions of relativistic ions, *Comput. Phys. Commun.* **212**, 258 (2017).
- [35] C. Azevedo, V. P. Goncalves, and B. D. Moreira, Exclusive dilepton production in ultraperipheral $PbPb$ collisions at the LHC, *Eur. Phys. J. C* **79**, 432 (2019).
- [36] Z. Bern, A. De Freitas, L. J. Dixon, A. Ghinculov, and H. L. Wong, QCD and QED corrections to light-by-light scattering, *J. High Energy Phys.* **11** (2001) 031.
- [37] M. Klusek-Gawenda, W. Schäfer, and A. Szczurek, Two-gluon exchange contribution to elastic $\gamma\gamma \rightarrow \gamma\gamma$ scattering and production of two-photons in ultraperipheral ultra-relativistic heavy ion and proton-proton collisions, *Phys. Lett. B* **761**, 399 (2016).
- [38] T. Aaltonen *et al.* (CDF Collaboration), Observation of Exclusive $\gamma\gamma$ Production in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV, *Phys. Rev. Lett.* **108**, 081801 (2012).
- [39] M. Bähr *et al.*, HERWIG++ physics and manual, *Eur. Phys. J. C* **58**, 639 (2008).
- [40] ATLAS Collaboration, The ATLAS simulation infrastructure, *Eur. Phys. J. C* **70**, 823 (2010).
- [41] S. Agostinelli *et al.* (GEANT4 Collaboration), GEANT4—a simulation toolkit, *Nucl. Instrum. Methods A* **506**, 250 (2003).
- [42] ATLAS Collaboration, Electron and photon reconstruction and performance in ATLAS using a dynamical, topological cell clustering-based approach, Report No. ATL-PHYS-PUB-2017-022, 2017, <https://cds.cern.ch/record/2298955>.
- [43] 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).
- [44] ATLAS Collaboration, Electron and photon energy calibration with the ATLAS detector using 2015-2016 LHC proton-proton collision data, *J. Instrum.* **14**, P03017 (2019).
- [45] 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, [arXiv:1902.04655](https://arxiv.org/abs/1902.04655).
- [46] L. A. Harland-Lang, V. A. Khoze, and M. G. Ryskin, Exclusive physics at the LHC with SUPERCHIC 2, *Eur. Phys. J. C* **76**, 9 (2016).
- [47] L. A. Harland-Lang, A. D. Martin, P. Motylinski, and R. S. Thorne, Parton distributions in the LHC era: MMHT 2014 PDFs, *Eur. Phys. J. C* **75**, 204 (2015).
- [48] S. Dulat, T. J. Hou, J. Gao, M. Guzzi, J. Huston, P. Nadolsky, J. Pumplin, C. Schmidt, D. Stump, and C. P. Yuan, New parton distribution functions from a global analysis of quantum chromodynamics, *Phys. Rev. D* **93**, 033006 (2016).
- [49] NNPDF Collaboration, Parton distributions from high-precision collider data, *Eur. Phys. J. C* **77**, 663 (2017).
- [50] M. Klusek-Gawenda and A. Szczurek, Exclusive production of large invariant mass pion pairs in ultraperipheral ultra-relativistic heavy ion collisions, *Phys. Lett. B* **700**, 322 (2011).
- [51] M. Klusek-Gawenda, R. McNulty, R. Schicker, and A. Szczurek, Light-by-light scattering in ultraperipheral heavy-ion collisions at low diphoton masses, *Phys. Rev. D* **99**, 093013 (2019).
- [52] KRYSTHAL Collaboration, Central exclusive meson pair production in the perturbative regime at hadron colliders, *Eur. Phys. J. C* **71**, 1714 (2011).
- [53] KRYSTHAL Collaboration, Central exclusive production as a probe of the gluonic component of the η' and η mesons, *Eur. Phys. J. C* **73**, 2429 (2013).
- [54] 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.
- [55] D. Ebert, R. N. Faustov, and V. O. Galkin, Properties of heavy quarkonia and B_c mesons in the relativistic quark model, *Phys. Rev. D* **67**, 014027 (2003).
- [56] J. Segovia, P. G. Ortega, D. R. Entem, and F. Fernandez, Bottomonium spectrum revisited, *Phys. Rev. D* **93**, 074027 (2016).
- [57] C. A. Bertulani and G. Baur, Electromagnetic processes in relativistic heavy ion collisions, *Phys. Rep.* **163**, 299 (1988).
- [58] 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); Erratum, *Eur. Phys. J. C* **73**, 2501(E) (2013).
- [59] Two photons at particle level with $|\eta'| < 2.4$, $p_{T'} > 3$ GeV, $m_{\gamma\gamma} > 6$ GeV, $p_{T'} < 1$ GeV and $A_\phi < 0.01$.
- [60] ATLAS Collaboration, Luminosity determination in pp collisions at $\sqrt{s} = 8$ TeV using the ATLAS detector at the LHC, *Eur. Phys. J. C* **76**, 653 (2016).
- [61] ATLAS Collaboration, ATLAS computing acknowledgements, Report No. ATL-GEN-PUB-2016-002, 2016, <https://cds.cern.ch/record/2202407>.

B. Achkar,⁵³ S. Adachi,¹⁶³ L. Adam,⁹⁹ C. Adam Bourdarios,¹³² L. Adamczyk,^{83a} L. Adamek,¹⁶⁷ J. Adelman,¹²¹
 M. Adersberger,¹¹⁴ A. Adiguzel,^{12c,c} S. Adorni,⁵⁴ T. Adye,¹⁴⁴ A. A. Affolder,¹⁴⁶ Y. Afik,¹⁶⁰ C. Agapopoulou,¹³²
 M. N. Agaras,³⁸ A. Aggarwal,¹¹⁹ C. Agheorghiesei,^{27c} J. A. Aguilar-Saavedra,^{140f,140a,d} F. Ahmadov,⁷⁹ W. S. Ahmed,¹⁰³
 X. Ai,^{15a} G. Aielli,^{73a,73b} S. Akatsuka,⁸⁵ T. P. A. Åkesson,⁹⁶ E. Akilli,⁵⁴ A. V. Akimov,¹¹⁰ K. Al Khoury,¹³²
 G. L. Alberghi,^{23b,23a} J. Albert,¹⁷⁶ M. J. Alconada Verzini,⁸⁸ S. Alderweireldt,³⁶ M. Aleksa,³⁶ I. N. Aleksandrov,⁷⁹
 C. Alexa,^{27b} D. Alexandre,¹⁹ T. Alexopoulos,¹⁰ A. Alfonsi,¹²⁰ M. Alhroob,¹²⁸ B. Ali,¹⁴² G. Alimonti,^{68a} J. Alison,³⁷
 S. P. Alkire,¹⁴⁸ C. Allaire,¹³² B. M. M. Allbrooke,¹⁵⁶ B. W. Allen,¹³¹ P. P. Allport,²¹ A. Aloisio,^{69a,69b} A. Alonso,⁴⁰
 F. Alonso,⁸⁸ C. Alpigiani,¹⁴⁸ A. A. Alshehri,⁵⁷ M. Alvarez Estevez,⁹⁸ D. Álvarez Piqueras,¹⁷⁴ M. G. Alviggi,^{69a,69b}
 Y. Amaral Coutinho,^{80b} A. Ambler,¹⁰³ L. Ambroz,¹³⁵ C. Amelung,²⁶ D. Amidei,¹⁰⁵ S. P. Amor Dos Santos,^{140a}
 S. Amoroso,⁴⁶ C. S. Amrouche,⁵⁴ F. An,⁷⁸ C. Anastopoulos,¹⁴⁹ N. Andari,¹⁴⁵ T. Andeen,¹¹ C. F. Anders,^{61b} J. K. Anders,²⁰
 A. Andreazza,^{68a,68b} V. Andrei,^{61a} C. R. Anelli,¹⁷⁶ S. Angelidakis,³⁸ A. Angerami,³⁹ A. V. Anisenkov,^{122b,122a} A. Annovi,^{71a}
 C. Antel,^{61a} M. T. Anthony,¹⁴⁹ M. Antonelli,⁵¹ D. J. A. Antrim,¹⁷¹ F. Anulli,^{72a} M. Aoki,⁸¹ J. A. Aparisi Pozo,¹⁷⁴
 L. Aperio Bella,³⁶ G. Arabidze,¹⁰⁶ J. P. Araque,^{140a} V. Araujo Ferraz,^{80b} R. Araujo Pereira,^{80b} C. Arcangeletti,⁵¹
 A. T. H. Arce,⁴⁹ F. A. Arduh,⁸⁸ J-F. Arguin,¹⁰⁹ S. Argyropoulos,⁷⁷ J.-H. Arling,⁴⁶ A. J. Armbruster,³⁶ L. J. Armitage,⁹²
 A. Armstrong,¹⁷¹ O. Arnaez,¹⁶⁷ H. Arnold,¹²⁰ A. Artamonov,^{111,a} G. Artoni,¹³⁵ S. Artz,⁹⁹ S. Asai,¹⁶³ N. Asbah,⁵⁹
 E. M. Asimakopoulou,¹⁷² L. Asquith,¹⁵⁶ K. Assamagan,²⁹ R. Astalos,^{28a} R. J. Atkin,^{33a} M. Atkinson,¹⁷³ N. B. Atlay,¹⁵¹
 H. Atmani,¹³² K. Augsten,¹⁴² G. Avolio,³⁶ R. Avramidou,^{60a} M. K. Ayoub,^{15a} A. M. Azoulay,^{168b} G. Azuelos,^{109,e}
 M. J. Baca,²¹ H. Bachacou,¹⁴⁵ K. Bachas,^{67a,67b} M. Backes,¹³⁵ F. Backman,^{45a,45b} P. Bagnaia,^{72a,72b} M. Bahmani,⁸⁴
 H. Bahrasemani,¹⁵² A. J. Bailey,¹⁷⁴ V. R. Bailey,¹⁷³ J. T. Baines,¹⁴⁴ M. Bajic,⁴⁰ C. Bakalis,¹⁰ O. K. Baker,¹⁸³ P. J. Bakker,¹²⁰
 D. Bakshi Gupta,⁸ S. Balaji,¹⁵⁷ E. M. Baldin,^{122b,122a} P. Balek,¹⁸⁰ F. Balli,¹⁴⁵ W. K. Balunas,¹³⁵ J. Balz,⁹⁹ E. Banas,⁸⁴
 A. Bandyopadhyay,²⁴ Sw. Banerjee,^{181,f} A. A. E. Bannoura,¹⁸² L. Barak,¹⁶¹ W. M. Barbe,³⁸ E. L. Barberio,¹⁰⁴
 D. Barberis,^{55b,55a} M. Barbero,¹⁰¹ T. Barillari,¹¹⁵ M-S. Barisits,³⁶ J. Barkeloo,¹³¹ T. Barklow,¹⁵³ R. Barnea,¹⁶⁰ S. L. Barnes,^{60c}
 B. M. Barnett,¹⁴⁴ R. M. Barnett,¹⁸ Z. Barnovska-Blenessy,^{60a} A. Baroncelli,^{60a} G. Barone,²⁹ A. J. Barr,¹³⁵
 L. Barranco Navarro,^{45a,45b} F. Barreiro,⁹⁸ J. Barreiro Guimarães da Costa,^{15a} S. Barsov,¹³⁸ R. Bartoldus,¹⁵³ G. Bartolini,¹⁰¹
 A. E. Barton,⁸⁹ P. Bartos,^{28a} A. Basalaeu,⁴⁶ A. Bassalat,^{132,g} R. L. Bates,⁵⁷ S. J. Batista,¹⁶⁷ S. Batlamous,^{35e} J. R. Batley,³²
 B. Batool,¹⁵¹ M. Battaglia,¹⁴⁶ M. Baucé,^{72a,72b} F. Bauer,¹⁴⁵ K. T. Bauer,¹⁷¹ H. S. Bawa,^{31,h} J. B. Beacham,⁴⁹ T. Beau,¹³⁶
 P. H. Beauchemin,¹⁷⁰ F. Becherer,⁵² P. Bechtel,²⁴ H. C. Beck,⁵³ H. P. Beck,^{20,i} K. Becker,⁵² M. Becker,⁹⁹ C. Becot,⁴⁶
 A. Beddall,^{12d} A. J. Beddall,^{12a} V. A. Bednyakov,⁷⁹ M. Bedognetti,¹²⁰ C. P. Bee,¹⁵⁵ T. A. Beermann,⁷⁶ M. Begalli,^{80b}
 M. Begel,²⁹ A. Behera,¹⁵⁵ J. K. Behr,⁴⁶ F. Beisiegel,²⁴ A. S. Bell,⁹⁴ G. Bella,¹⁶¹ L. Bellagamba,^{23b} A. Bellerive,³⁴ P. Bellos,⁹
 K. Beloborodov,^{122b,122a} K. Belotskiy,¹¹² N. L. Belyaev,¹¹² D. Benckekroun,^{35a} N. Benekos,¹⁰ Y. Benhammou,¹⁶¹
 D. P. Benjamin,⁶ M. Benoit,⁵⁴ J. R. Bensinger,²⁶ S. Bentvelsen,¹²⁰ L. Beresford,¹³⁵ M. Beretta,⁵¹ D. Berge,⁴⁶
 E. Bergeas Kuutmann,¹⁷² N. Berger,⁵ B. Bergmann,¹⁴² L. J. Bergsten,²⁶ J. Beringer,¹⁸ S. Berlendis,⁷ N. R. Bernard,¹⁰²
 G. Bernardi,¹³⁶ C. Bernius,¹⁵³ T. Berry,⁹³ P. Berta,⁹⁹ C. Bertella,^{15a} I. A. Bertram,⁸⁹ G. J. Besjes,⁴⁰ O. Bessidskaia Bylund,¹⁸²
 N. Besson,¹⁴⁵ A. Bethani,¹⁰⁰ S. Bethke,¹¹⁵ A. Betti,²⁴ A. J. Bevan,⁹² J. Beyer,¹¹⁵ R. Bi,¹³⁹ R. M. Bianchi,¹³⁹ O. Biebel,¹¹⁴
 D. Biedermann,¹⁹ R. Bielski,³⁶ K. Bierwagen,⁹⁹ N. V. Biesuz,^{71a,71b} M. Biglietti,^{74a} T. R. V. Billoud,¹⁰⁹ M. Bindi,⁵³
 A. Bingul,^{12d} C. Bini,^{72a,72b} S. Biondi,^{23b,23a} M. Birman,¹⁸⁰ T. Bisanz,⁵³ J. P. Biswal,¹⁶¹ A. Bitadze,¹⁰⁰ C. Bittrich,⁴⁸
 K. Bjørke,¹³⁴ K. M. Black,²⁵ T. Blazek,^{28a} I. Bloch,⁴⁶ C. Blocker,²⁶ A. Blue,⁵⁷ U. Blumenschein,⁹² G. J. Bobbink,¹²⁰
 V. S. Bobrovnikov,^{122b,122a} S. S. Bocchetta,⁹⁶ A. Bocci,⁴⁹ D. Boerner,⁴⁶ D. Bogavac,¹⁴ A. G. Bogdanchikov,^{122b,122a}
 C. Bohm,^{45a} V. Boisvert,⁹³ P. Bokan,^{53,172} T. Bold,^{83a} A. S. Boldyrev,¹¹³ A. E. Bolz,^{61b} M. Bomben,¹³⁶ M. Bona,⁹²
 J. S. Bonilla,¹³¹ M. Boonekamp,¹⁴⁵ H. M. Borecka-Bielska,⁹⁰ A. Borisov,¹²³ G. Borissov,⁸⁹ J. Bortfeldt,³⁶ D. Bortoletto,¹³⁵
 V. Bortolotto,^{73a,73b} D. Boscherini,^{23b} M. Bosman,¹⁴ J. D. Bossio Sola,¹⁰³ K. Bouaouda,^{35a} J. Boudreau,¹³⁹
 E. V. Bouhova-Thacker,⁸⁹ D. Boumediene,³⁸ S. K. Boutle,⁵⁷ A. Boveia,¹²⁶ J. Boyd,³⁶ D. Boye,^{33b,j} I. R. Boyko,⁷⁹
 A. J. Bozson,⁹³ J. Bracinik,²¹ N. Brahimi,¹⁰¹ G. Brandt,¹⁸² O. Brandt,^{61a} F. Braren,⁴⁶ U. Bratzler,¹⁶⁴ B. Brau,¹⁰² J. E. Brau,¹³¹
 W. D. Breaden Madden,⁵⁷ K. Brendlinger,⁴⁶ L. Brenner,⁴⁶ R. Brenner,¹⁷² S. Bressler,¹⁸⁰ B. Brickwedde,⁹⁹ D. L. Briglin,²¹
 D. Britton,⁵⁷ D. Britzger,¹¹⁵ I. Brock,²⁴ R. Brock,¹⁰⁶ G. Brooijmans,³⁹ W. K. Brooks,^{147b} E. Brost,¹²¹ J. H. Broughton,²¹
 P. A. Bruckman de Renstrom,⁸⁴ D. Bruncko,^{28b} A. Bruni,^{23b} G. Bruni,^{23b} L. S. Bruni,¹²⁰ S. Bruno,^{73a,73b} B. H. Brunt,³²
 M. Bruschi,^{23b} N. Bruscino,¹³⁹ P. Bryant,³⁷ L. Bryngemark,⁹⁶ T. Buanes,¹⁷ Q. Buat,³⁶ P. Buchholz,¹⁵¹ A. G. Buckley,⁵⁷
 I. A. Budagov,⁷⁹ M. K. Bugge,¹³⁴ F. Bühner,⁵² O. Bulekov,¹¹² T. J. Burch,¹²¹ S. Burdin,⁹⁰ C. D. Burgard,¹²⁰ A. M. Burger,¹²⁹
 B. Burghgrave,⁸ K. Burka,⁸⁴ J. T. P. Burr,⁴⁶ J. C. Burzynski,¹⁰² V. Büscher,⁹⁹ E. Buschmann,⁵³ P. J. Bussey,⁵⁷ J. M. Butler,²⁵

C. M. Buttar,⁵⁷ J. M. Butterworth,⁹⁴ P. Butti,³⁶ W. Buttinger,³⁶ A. Buzatu,¹⁵⁸ A. R. Buzykaev,^{122b,122a} G. Cabras,^{23b,23a} S. Cabrera Urbán,¹⁷⁴ D. Caforio,⁵⁶ H. Cai,¹⁷³ V. M. M. Cairo,¹⁵³ O. Cakir,^{4a} N. Calace,³⁶ P. Calafiura,¹⁸ A. Calandri,¹⁰¹ G. Calderini,¹³⁶ P. Calfayan,⁶⁵ G. Callea,⁵⁷ L. P. Caloba,^{80b} S. Calvente Lopez,⁹⁸ D. Calvet,³⁸ S. Calvet,³⁸ T. P. Calvet,¹⁵⁵ M. Calvetti,^{71a,71b} R. Camacho Toro,¹³⁶ S. Camarda,³⁶ D. Camarero Munoz,⁹⁸ P. Camarri,^{73a,73b} D. Cameron,¹³⁴ R. Caminal Armadans,¹⁰² C. Camincher,³⁶ S. Campana,³⁶ M. Campanelli,⁹⁴ A. Camplani,⁴⁰ A. Campoverde,¹⁵¹ V. Canale,^{69a,69b} A. Canesse,¹⁰³ M. Cano Bret,^{60c} J. Cantero,¹²⁹ T. Cao,¹⁶¹ Y. Cao,¹⁷³ M. D. M. Capeans Garrido,³⁶ M. Capua,^{41b,41a} R. Cardarelli,^{73a} F. C. Cardillo,¹⁴⁹ G. Carducci,^{41b,41a} I. Carli,¹⁴³ T. Carli,³⁶ G. Carlino,^{69a} B. T. Carlson,¹³⁹ L. Carminati,^{68a,68b} R. M. D. Carney,^{45a,45b} S. Caron,¹¹⁹ E. Carquin,^{147b} S. Carrá,⁴⁶ J. W. S. Carter,¹⁶⁷ M. P. Casado,^{14,k} A. F. Casha,¹⁶⁷ D. W. Casper,¹⁷¹ R. Castelijin,¹²⁰ F. L. Castillo,¹⁷⁴ V. Castillo Gimenez,¹⁷⁴ N. F. Castro,^{140a,140e} A. Catinaccio,³⁶ J. R. Catmore,¹³⁴ A. Cattai,³⁶ J. Caudron,²⁴ V. Cavaliere,²⁹ E. Cavallaro,¹⁴ M. Cavalli-Sforza,¹⁴ V. Cavasinni,^{71a,71b} E. Celebi,^{12b} F. Ceradini,^{74a,74b} L. Cerda Alberich,¹⁷⁴ K. Cerny,¹³⁰ A. S. Cerqueira,^{80a} A. Cerri,¹⁵⁶ L. Cerrito,^{73a,73b} F. Cerutti,¹⁸ A. Cervelli,^{23b,23a} S. A. Cetin,^{12b} Z. Chadi,^{35a} D. Chakraborty,¹²¹ S. K. Chan,⁵⁹ W. S. Chan,¹²⁰ W. Y. Chan,⁹⁰ J. D. Chapman,³² B. Chargeishvili,^{159b} D. G. Charlton,²¹ T. P. Charman,⁹² C. C. Chau,³⁴ S. Che,¹²⁶ A. Chegwidden,¹⁰⁶ S. Chekanov,⁶ S. V. Chekulaev,^{168a} G. A. Chelkov,^{79,1} M. A. Chelstowska,³⁶ B. Chen,⁷⁸ C. Chen,^{60a} C. H. Chen,⁷⁸ H. Chen,²⁹ J. Chen,^{60a} J. Chen,³⁹ S. Chen,¹³⁷ S. J. Chen,^{15c} X. Chen,^{15b,m} Y. Chen,⁸² Y-H. Chen,⁴⁶ H. C. Cheng,^{63a} H. J. Cheng,^{15a,15d} A. Cheplakov,⁷⁹ E. Cheremushkina,¹²³ R. Cherkaoui El Moursli,^{35e} E. Cheu,⁷ K. Cheung,⁶⁴ T. J. A. Chevalérias,¹⁴⁵ L. Chevalier,¹⁴⁵ V. Chiarella,⁵¹ G. Chiarelli,^{71a} G. Chiodini,^{67a} A. S. Chisholm,^{36,21} A. Chitan,^{27b} I. Chiu,¹⁶³ Y. H. Chiu,¹⁷⁶ M. V. Chizhov,⁷⁹ K. Choi,⁶⁵ A. R. Chomont,^{72a,72b} S. Chouridou,¹⁶² Y. S. Chow,¹²⁰ M. C. Chu,^{63a} X. Chu,^{15a} J. Chudoba,¹⁴¹ A. J. Chuinard,¹⁰³ J. J. Chwastowski,⁸⁴ L. Chytka,¹³⁰ K. M. Ciesla,⁸⁴ D. Cinca,⁴⁷ V. Cindro,⁹¹ I. A. Cioară,^{27b} A. Ciocio,¹⁸ F. Ciroto,^{69a,69b} Z. H. Citron,¹⁸⁰ M. Citterio,^{68a} D. A. Ciubotaru,^{27b} B. M. Ciungu,¹⁶⁷ A. Clark,⁵⁴ M. R. Clark,³⁹ P. J. Clark,⁵⁰ C. Clement,^{45a,45b} Y. Coadou,¹⁰¹ M. Cobal,^{66a,66c} A. Coccaro,^{55b} J. Cochran,⁷⁸ H. Cohen,¹⁶¹ A. E. C. Coimbra,³⁶ L. Colasurdo,¹¹⁹ B. Cole,³⁹ A. P. Colijn,¹²⁰ J. Collot,⁵⁸ P. Conde Muiño,^{140a,n} E. Coniavitis,⁵² S. H. Connell,^{33b} I. A. Connelly,⁵⁷ S. Constantinescu,^{27b} F. Conventi,^{69a,o} A. M. Cooper-Sarkar,¹³⁵ F. Cormier,¹⁷⁵ K. J. R. Cormier,¹⁶⁷ L. D. Corpe,⁹⁴ M. Corradi,^{72a,72b} E. E. Corrigan,⁹⁶ F. Corriveau,^{103,p} A. Cortes-Gonzalez,³⁶ M. J. Costa,¹⁷⁴ F. Costanza,⁵ D. Costanzo,¹⁴⁹ G. Cowan,⁹³ J. W. Cowley,³² J. Crane,¹⁰⁰ K. Cranmer,¹²⁴ S. J. Crawley,⁵⁷ R. A. Creager,¹³⁷ S. Crépe-Renaudin,⁵⁸ F. Crescioli,¹³⁶ M. Cristinziani,²⁴ V. Croft,¹²⁰ G. Crosetti,^{41b,41a} A. Cueto,⁵ T. Cuhadar Donszelmann,¹⁴⁹ A. R. Cukierman,¹⁵³ S. Czekierda,⁸⁴ P. Czodrowski,³⁶ M. J. Da Cunha Sargedas De Sousa,^{60b} J. V. Da Fonseca Pinto,^{80b} C. Da Via,¹⁰⁰ W. Dabrowski,^{83a} T. Dado,^{28a} S. Dahbi,^{35e} T. Dai,¹⁰⁵ C. Dallapiccola,¹⁰² M. Dam,⁴⁰ G. D'amen,^{23b,23a} V. D'Amico,^{74a,74b} J. Damp,⁹⁹ J. R. Dandoy,¹³⁷ M. F. Daneri,³⁰ N. P. Dang,¹⁸¹ N. D. Dann,¹⁰⁰ M. Danninger,¹⁷⁵ V. Dao,³⁶ G. Darbo,^{55b} O. Dartsis,⁵ A. Dattagupta,¹³¹ T. Daubney,⁴⁶ S. D'Auria,^{68a,68b} W. Davey,²⁴ C. David,⁴⁶ T. Davidek,¹⁴³ D. R. Davis,⁴⁹ I. Dawson,¹⁴⁹ K. De,⁸ R. De Asmundis,^{69a} M. De Beurs,¹²⁰ S. De Castro,^{23b,23a} S. De Cecco,^{72a,72b} N. De Groot,¹¹⁹ P. de Jong,¹²⁰ H. De la Torre,¹⁰⁶ A. De Maria,^{15c} D. De Pedis,^{72a} A. De Salvo,^{72a} U. De Sanctis,^{73a,73b} M. De Santis,^{73a,73b} A. De Santo,¹⁵⁶ K. De Vasconcelos Corga,¹⁰¹ J. B. De Vivie De Regie,¹³² C. Debenedetti,¹⁴⁶ D. V. Dedovich,⁷⁹ A. M. Deiana,⁴² M. Del Gaudio,^{41b,41a} J. Del Peso,⁹⁸ Y. Delabat Diaz,⁴⁶ D. Delgove,¹³² F. Deliot,^{145,q} C. M. Delitzsch,⁷ M. Della Pietra,^{69a,69b} D. Della Volpe,⁵⁴ A. Dell'Acqua,³⁶ L. Dell'Asta,^{73a,73b} M. Delmastro,⁵ C. Delporte,¹³² P. A. Delsart,⁵⁸ D. A. DeMarco,¹⁶⁷ S. Demers,¹⁸³ M. Demichev,⁷⁹ G. Demontigny,¹⁰⁹ S. P. Denisov,¹²³ D. Denysiuk,¹²⁰ L. D'Eramo,¹³⁶ D. Derendarz,⁸⁴ J. E. Derkaoui,^{35d} F. Derue,¹³⁶ P. Dervan,⁹⁰ K. Desch,²⁴ C. Deterre,⁴⁶ K. Dette,¹⁶⁷ C. Deutsch,²⁴ M. R. Devesa,³⁰ P. O. Deviveiros,³⁶ A. Dewhurst,¹⁴⁴ S. Dhaliwal,²⁶ F. A. Di Bello,⁵⁴ A. Di Ciaccio,^{73a,73b} L. Di Ciaccio,⁵ W. K. Di Clemente,¹³⁷ C. Di Donato,^{69a,69b} A. Di Girolamo,³⁶ G. Di Gregorio,^{71a,71b} B. Di Micco,^{74a,74b} R. Di Nardo,¹⁰² K. F. Di Petrillo,⁵⁹ R. Di Sipio,¹⁶⁷ D. Di Valentino,³⁴ C. Diaconu,¹⁰¹ F. A. Dias,⁴⁰ T. Dias Do Vale,^{140a} M. A. Diaz,^{147a} J. Dickinson,¹⁸ E. B. Diehl,¹⁰⁵ J. Dietrich,¹⁹ S. Díez Cornell,⁴⁶ A. Dimitrievska,¹⁸ W. Ding,^{15b} J. Dingfelder,²⁴ F. Dittus,³⁶ F. Djama,¹⁰¹ T. Djobava,^{159b} J. I. Djuvslund,¹⁷ M. A. B. Do Vale,^{80c} M. Dobre,^{27b} D. Dodsworth,²⁶ C. Doglioni,⁹⁶ J. Dolejsi,¹⁴³ Z. Dolezal,¹⁴³ M. Donadelli,^{80d} B. Dong,^{60c} J. Donini,³⁸ A. D'onofrio,⁹² M. D'Onofrio,⁹⁰ J. Dopke,¹⁴⁴ A. Doria,^{69a} M. T. Dova,⁸⁸ A. T. Doyle,⁵⁷ E. Drechsler,¹⁵² E. Dreyer,¹⁵² T. Dreyer,⁵³ A. S. Drobac,¹⁷⁰ Y. Duan,^{60b} F. Dubinin,¹¹⁰ M. Dubovsky,^{28a} A. Dubreuil,⁵⁴ E. Duchovni,¹⁸⁰ G. Duckeck,¹¹⁴ A. Ducourthial,¹³⁶ O. A. Ducu,¹⁰⁹ D. Duda,¹¹⁵ A. Dudarev,³⁶ A. C. Dudder,⁹⁹ E. M. Duffield,¹⁸ L. Duflot,¹³² M. Dührssen,³⁶ C. Dülsen,¹⁸² M. Dumancic,¹⁸⁰ A. E. Dumitriu,^{27b} A. K. Duncan,⁵⁷ M. Dunford,^{61a} A. Duperrin,¹⁰¹ H. Duran Yildiz,^{4a} M. Düren,⁵⁶ A. Durglishvili,^{159b} D. Duschinger,⁴⁸ B. Dutta,⁴⁶ D. Duvnjak,¹ G. I. Dyckes,¹³⁷ M. Dyndal,³⁶ S. Dysch,¹⁰⁰ B. S. Dziedzic,⁸⁴ K. M. Ecker,¹¹⁵ R. C. Edgar,¹⁰⁵ T. Eifert,³⁶

G. Eigen,¹⁷ K. Einsweiler,¹⁸ T. Ekelof,¹⁷² H. El Jarrari,^{35e} M. El Kacimi,^{35c} R. El Kosseifi,¹⁰¹ V. Ellajosyula,¹⁷² M. Ellert,¹⁷²
 F. Ellinghaus,¹⁸² A. A. Elliot,⁹² N. Ellis,³⁶ J. Elmsheuser,²⁹ M. Elsing,³⁶ D. Emeliyanov,¹⁴⁴ A. Emerman,³⁹ Y. Enari,¹⁶³
 M. B. Epland,⁴⁹ J. Erdmann,⁴⁷ A. Ereditato,²⁰ M. Errenst,³⁶ M. Escalier,¹³² C. Escobar,¹⁷⁴ O. Estrada Pastor,¹⁷⁴ E. Etzion,¹⁶¹
 H. Evans,⁶⁵ A. Ezhilov,¹³⁸ F. Fabbri,⁵⁷ L. Fabbri,^{23b,23a} V. Fabiani,¹¹⁹ G. Facini,⁹⁴ R. M. Faisca Rodrigues Pereira,^{140a}
 R. M. Fakhrutdinov,¹²³ S. Falciano,^{72a} P. J. Falke,⁵ S. Falke,⁵ J. Faltova,¹⁴³ Y. Fang,^{15a} Y. Fang,^{15a} G. Fanourakis,⁴⁴
 M. Fanti,^{68a,68b} M. Faraj,^{66a,66c} A. Farbin,⁸ A. Farilla,^{74a} E. M. Farina,^{70a,70b} T. Farooque,¹⁰⁶ S. Farrell,¹⁸ S. M. Farrington,⁵⁰
 P. Farthouat,³⁶ F. Fassi,^{35e} P. Fassnacht,³⁶ D. Fassouliotis,⁹ M. Faucci Giannelli,⁵⁰ W. J. Fawcett,³² L. Fayard,¹³²
 O. L. Fedin,^{138,r} W. Fedorko,¹⁷⁵ M. Feickert,⁴² S. Feigl,¹³⁴ L. Feligioni,¹⁰¹ A. Fell,¹⁴⁹ C. Feng,^{60b} E. J. Feng,³⁶ M. Feng,⁴⁹
 M. J. Fenton,⁵⁷ A. B. Fenyuk,¹²³ J. Ferrando,⁴⁶ A. Ferrante,¹⁷³ A. Ferrari,¹⁷² P. Ferrari,¹²⁰ R. Ferrari,^{70a}
 D. E. Ferreira de Lima,^{61b} A. Ferrer,¹⁷⁴ D. Ferrere,⁵⁴ C. Ferretti,¹⁰⁵ F. Fiedler,⁹⁹ A. Filipčič,⁹¹ F. Filthaut,¹¹⁹ K. D. Finelli,²⁵
 M. C. N. Fiolhais,^{140a} L. Fiorini,¹⁷⁴ F. Fischer,¹¹⁴ W. C. Fisher,¹⁰⁶ I. Fleck,¹⁵¹ P. Fleischmann,¹⁰⁵ R. R. M. Fletcher,¹³⁷
 T. Flick,¹⁸² B. M. Flierl,¹¹⁴ L. F. Flores,¹³⁷ L. R. Flores Castillo,^{63a} F. M. Follega,^{75a,75b} N. Fomin,¹⁷ J. H. Foo,¹⁶⁷
 G. T. Forcolin,^{75a,75b} A. Formica,¹⁴⁵ F. A. Förster,¹⁴ A. C. Forti,¹⁰⁰ A. G. Foster,²¹ M. G. Foti,¹³⁵ D. Fournier,¹³² H. Fox,⁸⁹
 P. Francavilla,^{71a,71b} S. Francescato,^{72a,72b} M. Franchini,^{23b,23a} S. Franchino,^{61a} D. Francis,³⁶ L. Franconi,²⁰ M. Franklin,⁵⁹
 A. N. Fray,⁹² B. Freund,¹⁰⁹ W. S. Freund,^{80b} E. M. Freundlich,⁴⁷ D. C. Frizzell,¹²⁸ D. Froidevaux,³⁶ J. A. Frost,¹³⁵
 C. Fukunaga,¹⁶⁴ E. Fullana Torregrosa,¹⁷⁴ E. Fumagalli,^{55b,55a} T. Fusayasu,¹¹⁶ J. Fuster,¹⁷⁴ A. Gabrielli,^{23b,23a} A. Gabrielli,¹⁸
 G. P. Gach,^{83a} S. Gadatsch,⁵⁴ P. Gadow,¹¹⁵ G. Gagliardi,^{55b,55a} L. G. Gagnon,¹⁰⁹ C. Galea,^{27b} B. Galhardo,^{140a}
 G. E. Gallardo,¹³⁵ E. J. Gallas,¹³⁵ B. J. Gallop,¹⁴⁴ G. Galster,⁴⁰ R. Gamboa Goni,⁹² K. K. Gan,¹²⁶ S. Ganguly,¹⁸⁰ J. Gao,^{60a}
 Y. Gao,⁵⁰ Y. S. Gao,^{31,h} C. García,¹⁷⁴ J. E. García Navarro,¹⁷⁴ J. A. García Pascual,^{15a} C. Garcia-Argos,⁵²
 M. Garcia-Sciveres,¹⁸ R. W. Gardner,³⁷ N. Garelli,¹⁵³ S. Gargiulo,⁵² V. Garonne,¹³⁴ A. Gaudiello,^{55b,55a} G. Gaudio,^{70a}
 I. L. Gavrilenko,¹¹⁰ A. Gavrilyuk,¹¹¹ C. Gay,¹⁷⁵ G. Gaycken,⁴⁶ E. N. Gazis,¹⁰ A. A. Geanta,^{27b} C. N. P. Gee,¹⁴⁴ J. Geisen,⁵³
 M. Geisen,⁹⁹ M. P. Geisler,^{61a} C. Gemme,^{55b} M. H. Genest,⁵⁸ C. Geng,¹⁰⁵ S. Gentile,^{72a,72b} S. George,⁹³ T. Gerialis,⁴⁴
 L. O. Gerlach,⁵³ P. Gessinger-Befurt,⁹⁹ G. Gessner,⁴⁷ S. Ghasemi,¹⁵¹ M. Ghasemi Bostanabad,¹⁷⁶ M. Ghneimat,²⁴
 A. Ghosh,¹³² A. Ghosh,⁷⁷ B. Giacobbe,^{23b} S. Giagu,^{72a,72b} N. Giangiacomi,^{23b,23a} P. Giannetti,^{71a} A. Giannini,^{69a,69b}
 S. M. Gibson,⁹³ M. Gignac,¹⁴⁶ D. Gillberg,³⁴ G. Gilles,¹⁸² D. M. Gingrich,^{3,e} M. P. Giordani,^{66a,66c} F. M. Giorgi,^{23b}
 P. F. Giraud,¹⁴⁵ G. Giugliarelli,^{66a,66c} D. Giugni,^{68a} F. Giuli,^{73a,73b} S. Gkaitatzis,¹⁶² I. Gkialas,^{9,s} E. L. Gkoukousis,¹⁴
 P. Gkoutoumis,¹⁰ L. K. Gladilin,¹¹³ C. Glasman,⁹⁸ J. Glatzer,¹⁴ P. C. F. Glaysher,⁴⁶ A. Glazov,⁴⁶ M. Goblirsch-Kolb,²⁶
 S. Goldfarb,¹⁰⁴ T. Golling,⁵⁴ D. Golubkov,¹²³ A. Gomes,^{140a,140b} R. Goncalves Gama,⁵³ R. Gonçalves,^{140a,140b} G. Gonella,⁵²
 L. Gonella,²¹ A. Gongadze,⁷⁹ F. Gonnella,²¹ J. L. Gonski,⁵⁹ S. González de la Hoz,¹⁷⁴ S. Gonzalez-Sevilla,⁵⁴
 G. R. Gonzalvo Rodriguez,¹⁷⁴ L. Goossens,³⁶ P. A. Gorbounov,¹¹¹ H. A. Gordon,²⁹ B. Gorini,³⁶ E. Gorini,^{67a,67b}
 A. Gorišek,⁹¹ A. T. Goshaw,⁴⁹ C. Gössling,⁴⁷ M. I. Gostkin,⁷⁹ C. A. Gottardo,¹¹⁹ M. Gouighri,^{35b} D. Goujdami,^{35c}
 A. G. Goussiou,¹⁴⁸ N. Govender,^{33b,t} C. Goy,⁵ E. Gozani,¹⁶⁰ I. Grabowska-Bold,^{83a} E. C. Graham,⁹⁰ J. Gramling,¹⁷¹
 E. Gramstad,¹³⁴ S. Grancagnolo,¹⁹ M. Grandi,¹⁵⁶ V. Gratchev,¹³⁸ P. M. Gravila,^{27f} F. G. Gravili,^{67a,67b} C. Gray,⁵⁷
 H. M. Gray,¹⁸ C. Greife,²⁴ K. Gregersen,⁹⁶ I. M. Gregor,⁴⁶ P. Grenier,¹⁵³ K. Grevtsov,⁴⁶ C. Grieco,¹⁴ N. A. Grieser,¹²⁸
 J. Griffiths,⁸ A. A. Grillo,¹⁴⁶ K. Grimm,^{31,u} S. Grinstein,^{14,v} J.-F. Grivaz,¹³² S. Groh,⁹⁹ E. Gross,¹⁸⁰ J. Grosse-Knetter,⁵³
 Z. J. Grout,⁹⁴ C. Grud,¹⁰⁵ A. Grummer,¹¹⁸ L. Guan,¹⁰⁵ W. Guan,¹⁸¹ J. Guenther,³⁶ A. Guerguichon,¹³²
 J. G. R. Guerrero Rojas,¹⁷⁴ F. Guescini,¹¹⁵ D. Guest,¹⁷¹ R. Gugel,⁵² T. Guillemin,⁵ S. Guindon,³⁶ U. Gul,⁵⁷ J. Guo,^{60c}
 W. Guo,¹⁰⁵ Y. Guo,^{60a,w} Z. Guo,¹⁰¹ R. Gupta,⁴⁶ S. Gurbuz,^{12c} G. Gustavino,¹²⁸ P. Gutierrez,¹²⁸ C. Gutsche,⁹⁴ C. Guyot,¹⁴⁵
 C. Gwenlan,¹³⁵ C. B. Gwilliam,⁹⁰ A. Haas,¹²⁴ C. Haber,¹⁸ H. K. Hadavand,⁸ N. Haddad,^{35e} A. Hadeef,^{60a} S. Hageböck,³⁶
 M. Hagihara,¹⁶⁹ M. Haleem,¹⁷⁷ J. Haley,¹²⁹ G. Halladjian,¹⁰⁶ G. D. Hallowell,¹⁰¹ K. Hamacher,¹⁸² P. Hamal,¹³⁰
 K. Hamano,¹⁷⁶ H. Hamdaoui,^{35e} G. N. Hamity,¹⁴⁹ K. Han,^{60a,x} L. Han,^{60a} S. Han,^{15a,15d} K. Hanagaki,^{81,y} M. Hance,¹⁴⁶
 D. M. Handl,¹¹⁴ B. Haney,¹³⁷ R. Hankache,¹³⁶ P. Hanke,^{61a} E. Hansen,⁹⁶ J. B. Hansen,⁴⁰ J. D. Hansen,⁴⁰ M. C. Hansen,²⁴
 P. H. Hansen,⁴⁰ E. C. Hanson,¹⁰⁰ K. Hara,¹⁶⁹ A. S. Hard,¹⁸¹ T. Harenberg,¹⁸² S. Harkusha,¹⁰⁷ P. F. Harrison,¹⁷⁸
 N. M. Hartmann,¹¹⁴ Y. Hasegawa,¹⁵⁰ A. Hasib,⁵⁰ S. Hassani,¹⁴⁵ S. Haug,²⁰ R. Hauser,¹⁰⁶ L. B. Havener,³⁹ M. Havranek,¹⁴²
 C. M. Hawkes,²¹ R. J. Hawkins,³⁶ D. Hayden,¹⁰⁶ C. Hayes,¹⁵⁵ R. L. Hayes,¹⁷⁵ C. P. Hays,¹³⁵ J. M. Hays,⁹² H. S. Hayward,⁹⁰
 S. J. Haywood,¹⁴⁴ F. He,^{60a} M. P. Heath,⁵⁰ V. Hedberg,⁹⁶ L. Heelan,⁸ S. Heer,²⁴ K. K. Heidegger,⁵² W. D. Heidorn,⁷⁸
 J. Heilman,³⁴ S. Heim,⁴⁶ T. Heim,¹⁸ B. Heinemann,^{46,z} J. J. Heinrich,¹³¹ L. Heinrich,³⁶ C. Heinz,⁵⁶ J. Hejbal,¹⁴¹ L. Helary,^{61b}
 A. Held,¹⁷⁵ S. Hellesund,¹³⁴ C. M. Helling,¹⁴⁶ S. Hellman,^{45a,45b} C. Helsens,³⁶ R. C. W. Henderson,⁸⁹ Y. Heng,¹⁸¹
 S. Henkelmann,¹⁷⁵ A. M. Henriques Correia,³⁶ G. H. Herbert,¹⁹ H. Herde,²⁶ V. Herget,¹⁷⁷ Y. Hernández Jiménez,^{33c}

H. Herr,⁹⁹ M. G. Herrmann,¹¹⁴ T. Herrmann,⁴⁸ G. Herten,⁵² R. Hertenberger,¹¹⁴ L. Hervas,³⁶ T. C. Herwig,¹³⁷ G. G. Hesketh,⁹⁴ N. P. Hessey,^{168a} A. Higashida,¹⁶³ S. Higashino,⁸¹ E. Higón-Rodríguez,¹⁷⁴ K. Hildebrand,³⁷ E. Hill,¹⁷⁶ J. C. Hill,³² K. K. Hill,²⁹ K. H. Hiller,⁴⁶ S. J. Hillier,²¹ M. Hils,⁴⁸ I. Hinchliffe,¹⁸ F. Hinterkeuser,²⁴ M. Hirose,¹³³ S. Hirose,⁵² D. Hirschbuehl,¹⁸² B. Hiti,⁹¹ O. Hladik,¹⁴¹ D. R. Hlaluku,^{33c} X. Hoad,⁵⁰ J. Hobbs,¹⁵⁵ N. Hod,¹⁸⁰ M. C. Hodgkinson,¹⁴⁹ A. Hoecker,³⁶ F. Hoenig,¹¹⁴ D. Hohn,⁵² D. Hohov,¹³² T. R. Holmes,³⁷ M. Holzbock,¹¹⁴ L. B. A. H. Hommels,³² S. Honda,¹⁶⁹ T. Honda,⁸¹ T. M. Hong,¹³⁹ A. Hönle,¹¹⁵ B. H. Hooberman,¹⁷³ W. H. Hopkins,⁶ Y. Horii,¹¹⁷ P. Horn,⁴⁸ L. A. Horyn,³⁷ A. Hostiuc,¹⁴⁸ S. Hou,¹⁵⁸ A. Hoummada,^{35a} J. Howarth,¹⁰⁰ J. Hoya,⁸⁸ M. Hrabovsky,¹³⁰ J. Hrdinka,⁷⁶ I. Hristova,¹⁹ J. Hrivnac,¹³² A. Hrynevich,¹⁰⁸ T. Hryn'ova,⁵ P. J. Hsu,⁶⁴ S.-C. Hsu,¹⁴⁸ Q. Hu,²⁹ S. Hu,^{60c} Y. Huang,^{15a} Z. Hubacek,¹⁴² F. Hubaut,¹⁰¹ M. Huebner,²⁴ F. Huegging,²⁴ T. B. Huffman,¹³⁵ M. Huhtinen,³⁶ R. F. H. Hunter,³⁴ P. Huo,¹⁵⁵ A. M. Hupe,³⁴ N. Huseynov,^{79,aa} J. Huston,¹⁰⁶ J. Huth,⁵⁹ R. Hyneman,¹⁰⁵ S. Hyrych,^{28a} G. Iacobucci,⁵⁴ G. Iakovidis,²⁹ I. Ibragimov,¹⁵¹ L. Iconomidou-Fayard,¹³² Z. Idrissi,^{35e} P. I. Iengo,³⁶ R. Ignazzi,⁴⁰ O. Igonkina,^{120,ab} R. Iguchi,¹⁶³ T. Iizawa,⁵⁴ Y. Ikegami,⁸¹ M. Ikeno,⁸¹ D. Iliadis,¹⁶² N. Ilic,¹¹⁹ F. Iltzsche,⁴⁸ G. Introzzi,^{70a,70b} M. Iodice,^{74a} K. Iordanidou,^{168a} V. Ippolito,^{72a,72b} M. F. Isacson,¹⁷² M. Ishino,¹⁶³ M. Ishitsuka,¹⁶⁵ W. Islam,¹²⁹ C. Issever,¹³⁵ S. Istin,¹⁶⁰ F. Ito,¹⁶⁹ J. M. Iturbe Ponce,^{63a} R. Iuppa,^{75a,75b} A. Ivina,¹⁸⁰ H. Iwasaki,⁸¹ J. M. Izen,⁴³ V. Izzo,^{69a} P. Jacka,¹⁴¹ P. Jackson,¹ R. M. Jacobs,²⁴ B. P. Jaeger,¹⁵² V. Jain,² G. Jäkel,¹⁸² K. B. Jakobi,⁹⁹ K. Jakobs,⁵² S. Jakobsen,⁷⁶ T. Jakoubek,¹⁴¹ J. Jamieson,⁵⁷ K. W. Janas,^{83a} R. Jansky,⁵⁴ J. Janssen,²⁴ M. Janus,⁵³ P. A. Janus,^{83a} G. Jarlskog,⁹⁶ N. Javadov,^{79,aa} T. Javůrek,³⁶ M. Javurkova,⁵² F. Jeanneau,¹⁴⁵ L. Jeanty,¹³¹ J. Jejelava,^{159a,cc} A. Jelinskas,¹⁷⁸ P. Jenni,^{52,dd} J. Jeong,⁴⁶ N. Jeong,⁴⁶ S. Jézéquel,⁵ H. Ji,¹⁸¹ J. Jia,¹⁵⁵ H. Jiang,⁷⁸ Y. Jiang,^{60a} Z. Jiang,^{153,ee} S. Jiggins,⁵² F. A. Jimenez Morales,³⁸ J. Jimenez Pena,¹¹⁵ S. Jin,^{15c} A. Jinaru,^{27b} O. Jinnouchi,¹⁶⁵ H. Jivan,^{33c} P. Johansson,¹⁴⁹ K. A. Johns,⁷ C. A. Johnson,⁶⁵ K. Jon-And,^{45a,45b} R. W. L. Jones,⁸⁹ S. D. Jones,¹⁵⁶ S. Jones,⁷ T. J. Jones,⁹⁰ J. Jongmanns,^{61a} P. M. Jorge,^{140a} J. Jovicevic,³⁶ X. Ju,¹⁸ J. J. Jungeburth,¹¹⁵ A. Juste Rozas,^{14,v} A. Kaczmarska,⁸⁴ M. Kado,^{72a,72b} H. Kagan,¹²⁶ M. Kagan,¹⁵³ C. Kahra,⁹⁹ T. Kaji,¹⁷⁹ E. Kajomovitz,¹⁶⁰ C. W. Kalderon,⁹⁶ A. Kaluza,⁹⁹ A. Kamenshchikov,¹²³ L. Kanjir,⁹¹ Y. Kano,¹⁶³ V. A. Kantserov,¹¹² J. Kanzaki,⁸¹ L. S. Kaplan,¹⁸¹ D. Kar,^{33c} M. J. Kareem,^{168b} E. Karentzos,¹⁰ S. N. Karpov,⁷⁹ Z. M. Karpova,⁷⁹ V. Kartvelishvili,⁸⁹ A. N. Karyukhin,¹²³ L. Kashif,¹⁸¹ R. D. Kass,¹²⁶ A. Kastanas,^{45a,45b} Y. Kataoka,¹⁶³ C. Kato,^{60d,60c} J. Katzy,⁴⁶ K. Kawade,⁸² K. Kawagoe,⁸⁷ T. Kawaguchi,¹¹⁷ T. Kawamoto,¹⁶³ G. Kawamura,⁵³ E. F. Kay,¹⁷⁶ V. F. Kazanin,^{122b,122a} R. Keeler,¹⁷⁶ R. Kehoe,⁴² J. S. Keller,³⁴ E. Kellermann,⁹⁶ D. Kelsey,¹⁵⁶ J. J. Kempster,²¹ J. Kendrick,²¹ O. Kepka,¹⁴¹ S. Kersten,¹⁸² B. P. Kerševan,⁹¹ S. Ketabchi Haghighat,¹⁶⁷ M. Khader,¹⁷³ F. Khalil-Zada,¹³ M. Khandoga,¹⁴⁵ A. Khanov,¹²⁹ A. G. Kharlamov,^{122b,122a} T. Kharlamova,^{122b,122a} E. E. Khoda,¹⁷⁵ A. Khodinov,¹⁶⁶ T. J. Khoo,⁵⁴ E. Khramov,⁷⁹ J. Khubua,^{159b} S. Kido,⁸² M. Kiehn,⁵⁴ C. R. Kilby,⁹³ Y. K. Kim,³⁷ N. Kimura,^{66a,66c} O. M. Kind,¹⁹ B. T. King,^{90,a} D. Kirchmeier,⁴⁸ J. Kirk,¹⁴⁴ A. E. Kiryunin,¹¹⁵ T. Kishimoto,¹⁶³ D. P. Kisliuk,¹⁶⁷ V. Kitali,⁴⁶ O. Kivernyk,⁵ E. Kladiva,^{28b,a} T. Klapdor-Kleingrothaus,⁵² M. Klassen,^{61a} M. H. Klein,¹⁰⁵ M. Klein,⁹⁰ U. Klein,⁹⁰ K. Kleinknecht,⁹⁹ P. Klimek,¹²¹ A. Klimentov,²⁹ T. Klingl,²⁴ T. Klioutchnikova,³⁶ F. F. Klitzner,¹¹⁴ P. Kluit,¹²⁰ S. Kluth,¹¹⁵ E. Kneringer,⁷⁶ E. B. F. G. Knoops,¹⁰¹ A. Knue,⁵² D. Kobayashi,⁸⁷ T. Kobayashi,¹⁶³ M. Kobel,⁴⁸ M. Kocian,¹⁵³ P. Kodys,¹⁴³ P. T. Koenig,²⁴ T. Koffas,³⁴ N. M. Köhler,³⁶ T. Koi,¹⁵³ M. Kolb,^{61b} I. Koletsou,⁵ T. Komarek,¹³⁰ T. Kondo,⁸¹ N. Kondrashova,^{60c} K. Köneke,⁵² A. C. König,¹¹⁹ T. Kono,¹²⁵ R. Konoplich,^{124,ff} V. Konstantinides,⁹⁴ N. Konstantinidis,⁹⁴ B. Konya,⁹⁶ R. Kopeliansky,⁶⁵ S. Koperny,^{83a} K. Korcyl,⁸⁴ K. Kordas,¹⁶² G. Koren,¹⁶¹ A. Korn,⁹⁴ I. Korolkov,¹⁴ E. V. Korolkova,¹⁴⁹ N. Korotkova,¹¹³ O. Kortner,¹¹⁵ S. Kortner,¹¹⁵ T. Kosek,¹⁴³ V. V. Kostyukhin,²⁴ A. Kotwal,⁴⁹ A. Koulouris,¹⁰ A. Kourkouveli-Charalampidi,^{70a,70b} C. Kourkouvelis,⁹ E. Kourlitis,¹⁴⁹ V. Kouskoura,²⁹ A. B. Kowalewska,⁸⁴ R. Kowalewski,¹⁷⁶ C. Kozakai,¹⁶³ W. Kozanecki,¹⁴⁵ A. S. Kozhin,¹²³ V. A. Kramarenko,¹¹³ G. Kramberger,⁹¹ D. Krasnopevtsev,^{60a} M. W. Krasny,¹³⁶ A. Krasznahorkay,³⁶ D. Krauss,¹¹⁵ J. A. Kremer,^{83a} J. Kretschmar,⁹⁰ P. Krieger,¹⁶⁷ F. Krieter,¹¹⁴ A. Krishnan,^{61b} K. Krizka,¹⁸ K. Kroeninger,⁴⁷ H. Kroha,¹¹⁵ J. Kroll,¹⁴¹ J. Kroll,¹³⁷ J. Krstic,¹⁶ U. Kruchonak,⁷⁹ H. Krüger,²⁴ N. Krumnack,⁷⁸ M. C. Kruse,⁴⁹ J. A. Krzysiak,⁸⁴ T. Kubota,¹⁰⁴ O. Kuchinskaia,¹⁶⁶ S. Kuday,^{4b} J. T. Kuechler,⁴⁶ S. Kuehn,³⁶ A. Kugel,^{61a} T. Kuhl,⁴⁶ V. Kukhtin,⁷⁹ R. Kukla,¹⁰¹ Y. Kulchitsky,^{107,gg} S. Kuleshov,^{147b} Y. P. Kulinich,¹⁷³ M. Kuna,⁵⁸ T. Kunigo,⁸⁵ A. Kupco,¹⁴¹ T. Kupfer,⁴⁷ O. Kuprash,⁵² H. Kurashige,⁸² L. L. Kurchaninov,^{168a} Y. A. Kurochkin,¹⁰⁷ A. Kurova,¹¹² M. G. Kurth,^{15a,15d} E. S. Kuwertz,³⁶ M. Kuze,¹⁶⁵ A. K. Kvam,¹⁴⁸ J. Kvita,¹³⁰ T. Kwan,¹⁰³ A. La Rosa,¹¹⁵ L. La Rotonda,^{41b,41a} F. La Ruffa,^{41b,41a} C. Lacasta,¹⁷⁴ F. Lacava,^{72a,72b} D. P. J. Lack,¹⁰⁰ H. Lacker,¹⁹ D. Lacour,¹³⁶ E. Ladygin,⁷⁹ R. Lafaye,⁵ B. Laforge,¹³⁶ T. Lagouri,^{33c} S. Lai,⁵³ S. Lammers,⁶⁵ W. Lampl,⁷ C. Lampoudis,¹⁶² E. Lançon,²⁹ U. Landgraf,⁵² M. P. J. Landon,⁹² M. C. Lanfermann,⁵⁴ V. S. Lang,⁴⁶ J. C. Lange,⁵³ R. J. Langenberg,³⁶ A. J. Lankford,¹⁷¹ F. Lanni,²⁹ K. Lantzsck,²⁴ A. Lanza,^{70a} A. Lapertosa,^{55b,55a} S. Laplace,¹³⁶ J. F. Laporte,¹⁴⁵ T. Lari,^{68a} F. Lasagni Manghi,^{23b,23a} M. Lassnig,³⁶ T. S. Lau,^{63a} A. Laudrain,¹³² A. Laurier,³⁴

M. Lavorgna,^{69a,69b} M. Lazzaroni,^{68a,68b} B. Le,¹⁰⁴ O. Le Dortz,¹³⁶ E. Le Guirrec,¹⁰¹ M. LeBlanc,⁷ T. LeCompte,⁶
 F. Ledroit-Guillon,⁵⁸ C. A. Lee,²⁹ G. R. Lee,¹⁷ L. Lee,⁵⁹ S. C. Lee,¹⁵⁸ S. J. Lee,³⁴ B. Lefebvre,^{168a} M. Lefebvre,¹⁷⁶
 F. Legger,¹¹⁴ C. Leggett,¹⁸ K. Lehmann,¹⁵² N. Lehmann,¹⁸² G. Lehmann Miotto,³⁶ W. A. Leight,⁴⁶ A. Leisos,^{162,hh}
 M. A. L. Leite,^{80d} C. E. Leitgeb,¹¹⁴ R. Leitner,¹⁴³ D. Lellouch,^{180,a} K. J. C. Leney,⁴² T. Lenz,²⁴ B. Lenzi,³⁶ R. Leone,⁷
 S. Leone,^{71a} C. Leonidopoulos,⁵⁰ A. Leopold,¹³⁶ G. Lerner,¹⁵⁶ C. Leroy,¹⁰⁹ R. Les,¹⁶⁷ C. G. Lester,³² M. Levchenko,¹³⁸
 J. Levêque,⁵ D. Levin,¹⁰⁵ L. J. Levinson,¹⁸⁰ D. J. Lewis,²¹ B. Li,^{15b} B. Li,¹⁰⁵ C-Q. Li,^{60a} F. Li,^{60c} H. Li,^{60a} H. Li,^{60b} J. Li,^{60c}
 K. Li,¹⁵³ L. Li,^{60c} M. Li,^{15a} Q. Li,^{15a,15d} Q. Y. Li,^{60a} S. Li,^{60d,60c} X. Li,⁴⁶ Y. Li,⁴⁶ Z. Li,^{60b} Z. Liang,^{15a} B. Liberti,^{73a}
 A. Liblong,¹⁶⁷ K. Lie,^{63c} S. Liem,¹²⁰ C. Y. Lin,³² K. Lin,¹⁰⁶ T. H. Lin,⁹⁹ R. A. Linck,⁶⁵ J. H. Lindon,²¹ A. L. Lioni,⁵⁴
 E. Lipeles,¹³⁷ A. Lipniacka,¹⁷ M. Lisovyi,^{61b} T. M. Liss,^{173,ii} A. Lister,¹⁷⁵ A. M. Litke,¹⁴⁶ J. D. Little,⁸ B. Liu,^{78,ji} B. L. Liu,⁶
 H. B. Liu,²⁹ H. Liu,¹⁰⁵ J. B. Liu,^{60a} J. K. K. Liu,¹³⁵ K. Liu,¹³⁶ M. Liu,^{60a} P. Liu,¹⁸ Y. Liu,^{15a,15d} Y. L. Liu,¹⁰⁵ Y. W. Liu,^{60a}
 M. Livan,^{70a,70b} A. Lleres,⁵⁸ J. Llorente Merino,^{15a} S. L. Lloyd,⁹² C. Y. Lo,^{63b} F. Lo Sterzo,⁴² E. M. Lobodzinska,⁴⁶ P. Loch,⁷
 S. Loffredo,^{73a,73b} T. Lohse,¹⁹ K. Lohwasser,¹⁴⁹ M. Lokajicek,¹⁴¹ J. D. Long,¹⁷³ R. E. Long,⁸⁹ L. Longo,³⁶ K. A. Looper,¹²⁶
 J. A. Lopez,^{147b} I. Lopez Paz,¹⁰⁰ A. Lopez Solis,¹⁴⁹ J. Lorenz,¹¹⁴ N. Lorenzo Martinez,⁵ M. Losada,²² P. J. Lösel,¹¹⁴
 A. Lösle,⁵² X. Lou,⁴⁶ X. Lou,^{15a} A. Lounis,¹³² J. Love,⁶ P. A. Love,⁸⁹ J. J. Lozano Bahilo,¹⁷⁴ M. Lu,^{60a} Y. J. Lu,⁶⁴
 H. J. Lubatti,¹⁴⁸ C. Luci,^{72a,72b} A. Lucotte,⁵⁸ C. Luedtke,⁵² F. Luehring,⁶⁵ I. Luise,¹³⁶ L. Luminari,^{72a} B. Lund-Jensen,¹⁵⁴
 M. S. Lutz,¹⁰² D. Lynn,²⁹ R. Lysak,¹⁴¹ E. Lytken,⁹⁶ F. Lyu,^{15a} V. Lyubushkin,⁷⁹ T. Lyubushkina,⁷⁹ H. Ma,²⁹ L. L. Ma,^{60b}
 Y. Ma,^{60b} G. Maccarrone,⁵¹ A. Macchiolo,¹¹⁵ C. M. Macdonald,¹⁴⁹ J. Machado Miguens,¹³⁷ D. Madaffari,¹⁷⁴ R. Madar,³⁸
 W. F. Mader,⁴⁸ N. Madysa,⁴⁸ J. Maeda,⁸² K. Maekawa,¹⁶³ S. Maeland,¹⁷ T. Maeno,²⁹ M. Maerker,⁴⁸ A. S. Maevskiy,¹¹³
 V. Magerl,⁵² N. Magini,⁷⁸ D. J. Mahon,³⁹ C. Maidantchik,^{80b} T. Maier,¹¹⁴ A. Maio,^{140a,140b,140d} O. Majersky,^{28a}
 S. Majewski,¹³¹ Y. Makida,⁸¹ N. Makovec,¹³² B. Malaescu,¹³⁶ Pa. Malecki,⁸⁴ V. P. Maleev,¹³⁸ F. Malek,⁵⁸ U. Mallik,⁷⁷
 D. Malon,⁶ C. Malone,³² S. Maltezos,¹⁰ S. Malyukov,³⁶ J. Mamuzic,¹⁷⁴ G. Mancini,⁵¹ I. Mandić,⁹¹
 L. Manhaes de Andrade Filho,^{80a} I. M. Maniatis,¹⁶² J. Manjarres Ramos,⁴⁸ K. H. Mankinen,⁹⁶ A. Mann,¹¹⁴ A. Manousos,⁷⁶
 B. Mansoulie,¹⁴⁵ I. Manthos,¹⁶² S. Manzoni,¹²⁰ A. Marantis,¹⁶² G. Marceca,³⁰ L. Marchese,¹³⁵ G. Marchiori,¹³⁶
 M. Marcisovsky,¹⁴¹ C. Marcon,⁹⁶ C. A. Marin Tobon,³⁶ M. Marjanovic,³⁸ F. Marroquin,^{80b} Z. Marshall,¹⁸
 M. U. F. Martensson,¹⁷² S. Marti-Garcia,¹⁷⁴ C. B. Martin,¹²⁶ T. A. Martin,¹⁷⁸ V. J. Martin,⁵⁰ B. Martin dit Latour,¹⁷
 L. Martinelli,^{74a,74b} M. Martinez,^{14,v} V. I. Martinez Outschoorn,¹⁰² S. Martin-Haugh,¹⁴⁴ V. S. Martouli,^{27b} A. C. Martyniuk,⁹⁴
 A. Marzin,³⁶ S. R. Maschek,¹¹⁵ L. Masetti,⁹⁹ T. Mashimo,¹⁶³ R. Mashinistov,¹¹⁰ J. Masik,¹⁰⁰ A. L. Maslennikov,^{122b,122a}
 L. H. Mason,¹⁰⁴ L. Massa,^{73a,73b} P. Massarotti,^{69a,69b} P. Mastrandrea,^{71a,71b} A. Mastroberardino,^{41b,41a} T. Masubuchi,¹⁶³
 D. Matakias,¹⁰ A. Matic,¹¹⁴ P. Mättig,²⁴ J. Maurer,^{27b} B. Maček,⁹¹ S. J. Maxfield,⁹⁰ D. A. Maximov,^{122b,122a} R. Mazini,¹⁵⁸
 I. Maznas,¹⁶² S. M. Mazza,¹⁴⁶ S. P. Mc Kee,¹⁰⁵ T. G. McCarthy,¹¹⁵ L. I. McClymont,⁹⁴ W. P. McCormack,¹⁸
 E. F. McDonald,¹⁰⁴ J. A. McFayden,³⁶ M. A. McKay,⁴² K. D. McLean,¹⁷⁶ S. J. McMahan,¹⁴⁴ P. C. McNamara,¹⁰⁴
 C. J. McNicol,¹⁷⁸ R. A. McPherson,^{176,p} J. E. Mdhului,^{33c} Z. A. Meadows,¹⁰² S. Meehan,¹⁴⁸ T. Megy,⁵² S. Mehlhase,¹¹⁴
 A. Mehta,⁹⁰ T. Meideck,⁵⁸ B. Meirose,⁴³ D. Melini,¹⁷⁴ B. R. Mellado Garcia,^{33c} J. D. Mellenthin,⁵³ M. Melo,^{28a} F. Meloni,⁴⁶
 A. Melzer,²⁴ S. B. Menary,¹⁰⁰ E. D. Mendes Gouveia,^{140a,140e} L. Meng,³⁶ X. T. Meng,¹⁰⁵ S. Menke,¹¹⁵ E. Meoni,^{41b,41a}
 S. Mergelmeyer,¹⁹ S. A. M. Merkt,¹³⁹ C. Merlassino,²⁰ P. Mermod,⁵⁴ L. Merola,^{69a,69b} C. Meroni,^{68a} O. Meshkov,^{113,110}
 J. K. R. Meshreki,¹⁵¹ A. Messina,^{72a,72b} J. Metcalfe,⁶ A. S. Mete,¹⁷¹ C. Meyer,⁶⁵ J. Meyer,¹⁶⁰ J-P. Meyer,¹⁴⁵
 H. Meyer Zu Theenhausen,^{61a} F. Miano,¹⁵⁶ M. Michetti,¹⁹ R. P. Middleton,¹⁴⁴ L. Mijović,⁵⁰ G. Mikenberg,¹⁸⁰
 M. Mikesstikova,¹⁴¹ M. Mikuž,⁹¹ H. Mildner,¹⁴⁹ M. Milesi,¹⁰⁴ A. Milic,¹⁶⁷ D. A. Millar,⁹² D. W. Miller,³⁷ A. Milov,¹⁸⁰
 D. A. Milstead,^{45a,45b} R. A. Mina,^{153,ee} A. A. Minaenko,¹²³ M. Miñano Moya,¹⁷⁴ I. A. Minashvili,^{159b} A. I. Mincer,¹²⁴
 B. Mindur,^{83a} M. Mineev,⁷⁹ Y. Minegishi,¹⁶³ Y. Ming,¹⁸¹ L. M. Mir,¹⁴ A. Mirto,^{67a,67b} K. P. Mistry,¹³⁷ T. Mitani,¹⁷⁹
 J. Mitrevski,¹¹⁴ V. A. Mitsou,¹⁷⁴ M. Mittal,^{60c} A. Miucci,²⁰ P. S. Miyagawa,¹⁴⁹ A. Mizukami,⁸¹ J. U. Mjörnmark,⁹⁶
 T. Mkrtchyan,¹⁸⁴ M. Mlynarikova,¹⁴³ T. Moa,^{45a,45b} K. Mochizuki,¹⁰⁹ P. Mogg,⁵² S. Mohapatra,³⁹ R. Moles-Valls,²⁴
 M. C. Mondragon,¹⁰⁶ K. Mönig,⁴⁶ J. Monk,⁴⁰ E. Monnier,¹⁰¹ A. Montalbano,¹⁵² J. Montejo Berlingen,³⁶ M. Montella,⁹⁴
 F. Monticelli,⁸⁸ S. Monzani,^{68a} N. Morange,¹³² D. Moreno,²² M. Moreno Llácer,³⁶ C. Moreno Martinez,¹⁴ P. Morettini,^{55b}
 M. Morgenstern,¹²⁰ S. Morgenstern,⁴⁸ D. Mori,¹⁵² M. Morii,⁵⁹ M. Morinaga,¹⁷⁹ V. Morisbak,¹³⁴ A. K. Morley,³⁶
 G. Mornacchi,³⁶ A. P. Morris,⁹⁴ L. Morvaj,¹⁵⁵ P. Moschovakos,³⁶ B. Moser,¹²⁰ M. Mosidze,^{159b} T. Moskalets,¹⁴⁵
 H. J. Moss,¹⁴⁹ J. Moss,^{31,kk} K. Motohashi,¹⁶⁵ E. Mountricha,³⁶ E. J. W. Moyses,¹⁰² S. Muanza,¹⁰¹ J. Mueller,¹³⁹
 R. S. P. Mueller,¹¹⁴ D. Muenstermann,⁸⁹ G. A. Mullier,⁹⁶ J. L. Munoz Martinez,¹⁴ F. J. Munoz Sanchez,¹⁰⁰ P. Murin,^{28b}
 W. J. Murray,^{178,144} A. Murrone,^{68a,68b} M. Muškinja,¹⁸ C. Mwewa,^{33a} A. G. Myagkov,^{123,ll} J. Myers,¹³¹ M. Myska,¹⁴²

B. P. Nachman,¹⁸ O. Nackenhörst,⁴⁷ A. Nag Nag,⁴⁸ K. Nagai,¹³⁵ K. Nagano,⁸¹ Y. Nagasaka,⁶² M. Nagel,⁵² E. Nagy,¹⁰¹
 A. M. Nairz,³⁶ Y. Nakahama,¹¹⁷ K. Nakamura,⁸¹ T. Nakamura,¹⁶³ I. Nakano,¹²⁷ H. Nanjo,¹³³ F. Napolitano,^{61a}
 R. F. Naranjo Garcia,⁴⁶ R. Narayan,⁴² I. Naryshkin,¹³⁸ T. Naumann,⁴⁶ G. Navarro,²² H. A. Neal,^{105,a} P. Y. Nechaeva,¹¹⁰
 F. Nechansky,⁴⁶ T. J. Neep,²¹ A. Negri,^{70a,70b} M. Negri,^{23b} C. Nellist,⁵³ M. E. Nelson,¹³⁵ S. Nemecek,¹⁴¹ P. Nemethy,¹²⁴
 M. Nessi,^{36,mm} M. S. Neubauer,¹⁷³ F. Neuhaus,⁹⁹ M. Neumann,¹⁸² P. R. Newman,²¹ Y. S. Ng,¹⁹ Y. W. Y. Ng,¹⁷¹
 H. D. N. Nguyen,¹⁰¹ T. Nguyen Manh,¹⁰⁹ E. Nibigira,³⁸ R. B. Nickerson,¹³⁵ R. Nicolaidou,¹⁴⁵ D. S. Nielsen,⁴⁰ J. Nielsen,¹⁴⁶
 N. Nikipforou,¹¹ V. Nikolaenko,^{123,II} I. Nikolic-Audit,¹³⁶ K. Nikolopoulos,²¹ P. Nilsson,²⁹ H. R. Nindhito,⁵⁴ Y. Ninomiya,⁸¹
 A. Nisati,^{72a} N. Nishu,^{60c} R. Nisius,¹¹⁵ I. Nitsche,⁴⁷ T. Nitta,¹⁷⁹ T. Nobe,¹⁶³ Y. Noguchi,⁸⁵ I. Nomidis,¹³⁶ M. A. Nomura,²⁹
 M. Nordberg,³⁶ N. Norjoharuddeen,¹³⁵ T. Novak,⁹¹ O. Novgorodova,⁴⁸ R. Novotny,¹⁴² L. Nozka,¹³⁰ K. Ntekas,¹⁷¹
 E. Nurse,⁹⁴ F. G. Oakham,^{34,e} H. Oberlack,¹¹⁵ J. Ocariz,¹³⁶ A. Ochi,⁸² I. Ochoa,³⁹ J. P. Ochoa-Ricoux,^{147a} K. O'Connor,²⁶
 S. Oda,⁸⁷ S. Odaka,⁸¹ S. Oerdek,⁵³ A. Ogrodnik,^{83a} A. Oh,¹⁰⁰ S. H. Oh,⁴⁹ C. C. Ohm,¹⁵⁴ H. Oide,^{55b,55a} M. L. Ojeda,¹⁶⁷
 H. Okawa,¹⁶⁹ Y. Okazaki,⁸⁵ Y. Okumura,¹⁶³ T. Okuyama,⁸¹ A. Olariu,^{27b} L. F. Oleiro Seabra,^{140a} S. A. Olivares Pino,^{147a}
 D. Oliveira Damazio,²⁹ J. L. Oliver,¹ M. J. R. Olsson,¹⁷¹ A. Olszewski,⁸⁴ J. Olszowska,⁸⁴ D. C. O'Neil,¹⁵² A. Onofre,^{140a,140e}
 K. Onogi,¹¹⁷ P. U. E. Onyisi,¹¹ H. Oppen,¹³⁴ M. J. Oreglia,³⁷ G. E. Orellana,⁸⁸ Y. Oren,¹⁶¹ D. Orestano,^{74a,74b} N. Orlando,¹⁴
 R. S. Orr,¹⁶⁷ V. O'Shea,⁵⁷ R. Ospanov,^{60a} G. Otero y Garzon,³⁰ H. Otono,⁸⁷ P. S. Ott,^{61a} M. Ouchrif,^{35d} J. Ouellette,²⁹
 F. Ould-Saada,¹³⁴ A. Ouraou,¹⁴⁵ Q. Ouyang,^{15a} M. Owen,⁵⁷ R. E. Owen,²¹ V. E. Ozcan,^{12c} N. Ozturk,⁸ J. Pacalt,¹³⁰
 H. A. Pacey,³² K. Pachal,⁴⁹ A. Pacheco Pages,¹⁴ C. Padilla Aranda,¹⁴ S. Pagan Griso,¹⁸ M. Paganini,¹⁸³ G. Palacino,⁶⁵
 S. Palazzo,⁵⁰ S. Palestini,³⁶ M. Palka,^{83b} D. Pallin,³⁸ P. Palmi,^{83a} I. Panagoulas,¹⁰ C. E. Pandini,³⁶ J. G. Panduro Vazquez,⁹³
 P. Pani,⁴⁶ G. Panizzo,^{66a,66c} L. Paolozzi,⁵⁴ C. Papadatos,¹⁰⁹ K. Papageorgiou,^{9,s} A. Paramonov,⁶ D. Paredes Hernandez,^{63b}
 S. R. Paredes Saenz,¹³⁵ B. Parida,¹⁶⁶ T. H. Park,¹⁶⁷ A. J. Parker,⁸⁹ M. A. Parker,³² F. Parodi,^{55b,55a} E. W. P. Parrish,¹²¹
 J. A. Parsons,³⁹ U. Parzefall,⁵² L. Pascual Dominguez,¹³⁶ V. R. Pascuzzi,¹⁶⁷ J. M. P. Pasner,¹⁴⁶ E. Pasqualucci,^{72a}
 S. Passaggio,^{55b} F. Pastore,⁹³ P. Pasuwan,^{45a,45b} S. Patariaia,⁹⁹ J. R. Pater,¹⁰⁰ A. Pathak,¹⁸¹ T. Pauly,³⁶ B. Pearson,¹¹⁵
 M. Pedersen,¹³⁴ L. Pedraza Diaz,¹¹⁹ R. Pedro,^{140a} T. Peiffer,⁵³ S. V. Peleganchuk,^{122b,122a} O. Penc,¹⁴¹ H. Peng,^{60a}
 B. S. Peralva,^{80a} M. M. Perego,¹³² A. P. Pereira Peixoto,^{140a} D. V. Perepelitsa,²⁹ F. Peri,¹⁹ L. Perini,^{68a,68b} H. Pernegger,³⁶
 S. Perrella,^{69a,69b} K. Peters,⁴⁶ R. F. Y. Peters,¹⁰⁰ B. A. Petersen,³⁶ T. C. Petersen,⁴⁰ E. Petit,¹⁰¹ A. Petridis,¹ C. Petridou,¹⁶²
 P. Petroff,¹³² M. Petrov,¹³⁵ F. Petrucci,^{74a,74b} M. Pettee,¹⁸³ N. E. Pettersson,¹⁰² K. Petukhova,¹⁴³ A. Peyaud,¹⁴⁵ R. Pezoa,^{147b}
 L. Pezzotti,^{70a,70b} T. Pham,¹⁰⁴ F. H. Phillips,¹⁰⁶ P. W. Phillips,¹⁴⁴ M. W. Phipps,¹⁷³ G. Piacquadio,¹⁵⁵ E. Pianori,¹⁸
 A. Picazio,¹⁰² R. H. Pickles,¹⁰⁰ R. Piegaiia,³⁰ D. Pietreanu,^{27b} J. E. Pilcher,³⁷ A. D. Pilkington,¹⁰⁰ M. Pinamonti,^{73a,73b}
 J. L. Pinfold,³ M. Pitt,¹⁸⁰ L. Pizzimento,^{73a,73b} M.-A. Pleier,²⁹ V. Pleskot,¹⁴³ E. Plotnikova,⁷⁹ P. Podberezko,^{122b,122a}
 R. Poettgen,⁹⁶ R. Poggi,⁵⁴ L. Poggioli,¹³² I. Pogrebnnyak,¹⁰⁶ D. Pohl,²⁴ I. Pokharel,⁵³ G. Polesello,^{70a} A. Poley,¹⁸
 A. Policicchio,^{72a,72b} R. Polifka,¹⁴³ A. Polini,^{23b} C. S. Pollard,⁴⁶ V. Polychronakos,²⁹ D. Ponomarenko,¹¹² L. Pontecorvo,³⁶
 S. Popa,^{27a} G. A. Popeneciu,^{27d} D. M. Portillo Quintero,⁵⁸ S. Pospisil,¹⁴² K. Potamianos,⁴⁶ I. N. Potrap,⁷⁹ C. J. Potter,³²
 H. Potti,¹¹ T. Poulsen,⁹⁶ J. Poveda,³⁶ T. D. Powell,¹⁴⁹ G. Pownall,⁴⁶ M. E. Pozo Astigarraga,³⁶ P. Pralavorio,¹⁰¹ S. Prell,⁷⁸
 D. Price,¹⁰⁰ M. Primavera,^{67a} S. Prince,¹⁰³ M. L. Proffitt,¹⁴⁸ N. Proklova,¹¹² K. Prokofiev,^{63c} F. Prokoshin,⁷⁹
 S. Protopopescu,²⁹ J. Proudfoot,⁶ M. Przybycien,^{83a} D. Pudza,¹³⁸ A. Puri,¹⁷³ P. Puzo,¹³² J. Qian,¹⁰⁵ Y. Qin,¹⁰⁰ A. Quadt,⁵³
 M. Queitsch-Maitland,⁴⁶ A. Qureshi,¹ P. Rados,¹⁰⁴ F. Ragusa,^{68a,68b} G. Rahal,⁹⁷ J. A. Raine,⁵⁴ S. Rajagopalan,²⁹
 A. Ramirez Morales,⁹² K. Ran,^{15a,15d} T. Rashid,¹³² S. Raspopov,⁵ D. M. Rauch,⁴⁶ F. Rauscher,¹¹⁴ S. Rave,⁹⁹ B. Ravina,¹⁴⁹
 I. Ravinovich,¹⁸⁰ J. H. Rawling,¹⁰⁰ M. Raymond,³⁶ A. L. Read,¹³⁴ N. P. Readioff,⁵⁸ M. Reale,^{67a,67b} D. M. Rebuffi,^{70a,70b}
 A. Redelbach,¹⁷⁷ G. Redlinger,²⁹ K. Reeves,⁴³ L. Rehnisch,¹⁹ J. Reichert,¹³⁷ D. Reikher,¹⁶¹ A. Reiss,⁹⁹ A. Rej,¹⁵¹
 C. Rember,³⁶ M. Renda,^{27b} M. Rescigno,^{72a} S. Resconi,^{68a} E. D. Resseguie,¹³⁷ S. Rettie,¹⁷⁵ E. Reynolds,²¹
 O. L. Rezanova,^{122b,122a} P. Reznicek,¹⁴³ E. Ricci,^{75a,75b} R. Richter,¹¹⁵ S. Richter,⁴⁶ E. Richter-Was,^{83b} O. Ricken,²⁴
 M. Ridel,¹³⁶ P. Rieck,¹¹⁵ C. J. Riegel,¹⁸² O. Rifki,⁴⁶ M. Rijssenbeek,¹⁵⁵ A. Rimoldi,^{70a,70b} M. Rimoldi,⁴⁶ L. Rinaldi,^{23b}
 G. Ripellino,¹⁵⁴ B. Ristić,⁸⁹ I. Riu,¹⁴ J. C. Rivera Vergara,¹⁷⁶ F. Rizatdinova,¹²⁹ E. Rizvi,⁹² C. Rizzi,³⁶ R. T. Roberts,¹⁰⁰
 S. H. Robertson,^{103,p} M. Robin,⁴⁶ D. Robinson,³² J. E. M. Robinson,⁴⁶ C. M. Robles Gajardo,^{147b} A. Robson,⁵⁷ E. Rocco,⁹⁹
 C. Roda,^{71a,71b} S. Rodriguez Bosca,¹⁷⁴ A. Rodriguez Perez,¹⁴ D. Rodriguez Rodriguez,¹⁷⁴ A. M. Rodríguez Vera,^{168b}
 S. Roe,³⁶ O. Røhne,¹³⁴ R. Röhrig,¹¹⁵ C. P. A. Roland,⁶⁵ J. Roloff,⁵⁹ A. Romaniouk,¹¹² M. Romano,^{23b,23a} N. Rompotis,⁹⁰
 M. Ronzani,¹²⁴ L. Roos,¹³⁶ S. Rosati,^{72a} K. Rosbach,⁵² G. Rosin,¹⁰² B. J. Rosser,¹³⁷ E. Rossi,⁴⁶ E. Rossi,^{74a,74b} E. Rossi,^{69a,69b}
 L. P. Rossi,^{55b} L. Rossini,^{68a,68b} R. Rosten,¹⁴ M. Rotaru,^{27b} J. Rothberg,¹⁴⁸ D. Rousseau,¹³² G. Rovelli,^{70a,70b} A. Roy,¹¹
 D. Roy,^{33c} A. Rozanov,¹⁰¹ Y. Rozen,¹⁶⁰ X. Ruan,^{33c} F. Rubbo,¹⁵³ F. Rühr,⁵² A. Ruiz-Martinez,¹⁷⁴ A. Rummler,³⁶

Z. Rurikova,⁵² N. A. Rusakovich,⁷⁹ H. L. Russell,¹⁰³ L. Rustige,^{38,47} J. P. Rutherford,⁷ E. M. Rüttinger,^{46,nn} Y. F. Ryabov,¹³⁸
M. Rybar,³⁹ G. Rybkin,¹³² E. B. Rye,¹³⁴ A. Ryzhov,¹²³ G. F. Rzechorz,⁵³ P. Sabatini,⁵³ G. Sabato,¹²⁰ S. Sacerdoti,¹³²
H. F.-W. Sadrozinski,¹⁴⁶ R. Sadykov,⁷⁹ F. Safai Tehrani,^{72a} B. Safarzadeh Samani,¹⁵⁶ P. Saha,¹²¹ S. Saha,¹⁰³ M. Sahinsoy,^{61a}
A. Sahu,¹⁸² M. Saimpert,⁴⁶ M. Saito,¹⁶³ T. Saito,¹⁶³ H. Sakamoto,¹⁶³ A. Sakharov,^{124,ff} D. Salamani,⁵⁴ G. Salamanna,^{74a,74b}
J. E. Salazar Loyola,^{147b} P. H. Sales De Bruin,¹⁷² A. Salmikov,¹⁵³ J. Salt,¹⁷⁴ D. Salvatore,^{41b,41a} F. Salvatore,¹⁵⁶
A. Salvucci,^{63a,63b,63c} A. Salzburger,³⁶ J. Samarati,³⁶ D. Sammel,⁵² D. Sampsonidis,¹⁶² D. Sampsonidou,¹⁶² J. Sánchez,¹⁷⁴
A. Sanchez Pineda,^{66a,66c} H. Sandaker,¹³⁴ C. O. Sander,⁴⁶ I. G. Sanderswood,⁸⁹ M. Sandhoff,¹⁸² C. Sandoval,²²
D. P. C. Sankey,¹⁴⁴ M. Sannino,^{55b,55a} Y. Sano,¹¹⁷ A. Sansoni,⁵¹ C. Santoni,³⁸ H. Santos,^{140a,140b} S. N. Santpur,¹⁸ A. Santra,¹⁷⁴
A. Saponov,⁷⁹ J. G. Saraiva,^{140a,140d} O. Sasaki,⁸¹ K. Sato,¹⁶⁹ E. Sauvan,⁵ P. Savard,^{167,e} N. Savic,¹¹⁵ R. Sawada,¹⁶³
C. Sawyer,¹⁴⁴ L. Sawyer,^{95,oo} C. Sbarra,^{23b} A. Sbrizzi,^{23a} T. Scanlon,⁹⁴ J. Schaarschmidt,¹⁴⁸ P. Schacht,¹¹⁵
B. M. Schachtner,¹¹⁴ D. Schaefer,³⁷ L. Schaefer,¹³⁷ J. Schaeffer,⁹⁹ S. Schaepe,³⁶ U. Schäfer,⁹⁹ A. C. Schaffer,¹³²
D. Schaile,¹¹⁴ R. D. Schamberger,¹⁵⁵ N. Scharmberg,¹⁰⁰ V. A. Schegelsky,¹³⁸ D. Scheirich,¹⁴³ F. Schenck,¹⁹ M. Schernau,¹⁷¹
C. Schiavi,^{55b,55a} S. Schier,¹⁴⁶ L. K. Schildgen,²⁴ Z. M. Schillaci,²⁶ E. J. Schioppa,³⁶ M. Schioppa,^{41b,41a} K. E. Schleicher,⁵²
S. Schlenker,³⁶ K. R. Schmidt-Sommerfeld,¹¹⁵ K. Schmieden,³⁶ C. Schmitt,⁹⁹ S. Schmitt,⁴⁶ S. Schmitz,⁹⁹
J. C. Schmoeckel,⁴⁶ U. Schnoor,⁵² L. Schoeffel,¹⁴⁵ A. Schoening,^{61b} P. G. Scholer,⁵² E. Schopf,¹³⁵ M. Schott,⁹⁹
J. F. P. Schouwenberg,¹¹⁹ J. Schovancova,³⁶ S. Schramm,⁵⁴ F. Schroeder,¹⁸² A. Schulte,⁹⁹ H.-C. Schultz-Coulon,^{61a}
M. Schumacher,⁵² B. A. Schumm,¹⁴⁶ Ph. Schune,¹⁴⁵ A. Schwartzman,¹⁵³ T. A. Schwarz,¹⁰⁵ Ph. Schwemling,¹⁴⁵
R. Schwienhorst,¹⁰⁶ A. Sciandra,¹⁴⁶ G. Sciolla,²⁶ M. Scodreggio,⁴⁶ M. Scornajenghi,^{41b,41a} F. Scuri,^{71a} F. Scutti,¹⁰⁴
L. M. Scyboz,¹¹⁵ C. D. Sebastiani,^{72a,72b} P. Seema,¹⁹ S. C. Seidel,¹¹⁸ A. Seiden,¹⁴⁶ T. Seiss,³⁷ J. M. Seixas,^{80b}
G. Sekhniaidze,^{69a} K. Sekhon,¹⁰⁵ S. J. Sekula,⁴² N. Semprini-Cesari,^{23b,23a} S. Sen,⁴⁹ S. Senkin,³⁸ C. Serfon,⁷⁶ L. Serin,¹³²
L. Serkin,^{66a,66b} M. Sessa,^{60a} H. Severini,¹²⁸ F. Sforza,¹⁷⁰ A. Sfyrila,⁵⁴ E. Shabalina,⁵³ J. D. Shahinian,¹⁴⁶ N. W. Shaikh,^{45a,45b}
D. Shaked Renous,¹⁸⁰ L. Y. Shan,^{15a} R. Shang,¹⁷³ J. T. Shank,²⁵ M. Shapiro,¹⁸ A. Sharma,¹³⁵ A. S. Sharma,¹
P. B. Shatalov,¹¹¹ K. Shaw,¹⁵⁶ S. M. Shaw,¹⁰⁰ A. Shcherbakova,¹³⁸ Y. Shen,¹²⁸ N. Sherafati,³⁴ A. D. Sherman,²⁵
P. Sherwood,⁹⁴ L. Shi,^{158,pp} S. Shimizu,⁸¹ C. O. Shimmin,¹⁸³ Y. Shimogama,¹⁷⁹ M. Shimojima,¹¹⁶ I. P. J. Shipsey,¹³⁵
S. Shirabe,⁸⁷ M. Shiyakova,^{79,qq} J. Shlomi,¹⁸⁰ A. Shmeleva,¹¹⁰ M. J. Shochet,³⁷ S. Shojaii,¹⁰⁴ D. R. Shope,¹²⁸ S. Shrestha,¹²⁶
E. M. Shrif,^{33c} E. Shulga,¹⁸⁰ P. Sicho,¹⁴¹ A. M. Sickles,¹⁷³ P. E. Sidebo,¹⁵⁴ E. Sideras Haddad,^{33c} O. Sidiropoulou,³⁶
A. Sidoti,^{23b,23a} F. Siegert,⁴⁸ Dj. Sijacki,¹⁶ M. Silva Jr.,¹⁸¹ M. V. Silva Oliveira,^{80a} S. B. Silverstein,^{45a} S. Simion,¹³²
E. Simioni,⁹⁹ R. Simoniello,⁹⁹ S. Simsek,^{12b} P. Sinervo,¹⁶⁷ V. Sinetckii,^{113,110} N. B. Sinev,¹³¹ M. Sioli,^{23b,23a} I. Siral,¹⁰⁵
S. Yu. Sivoklovok,¹¹³ J. Sjölin,^{45a,45b} E. Skorda,⁹⁶ P. Skubic,¹²⁸ M. Slawinska,⁸⁴ K. Sliwa,¹⁷⁰ R. Slovak,¹⁴³ V. Smakhtin,¹⁸⁰
B. H. Smart,¹⁴⁴ J. Smiesko,^{28a} N. Smirnov,¹¹² S. Yu. Smirnov,¹¹² Y. Smirnov,¹¹² L. N. Smirnova,^{113,rr} O. Smirnova,⁹⁶
J. W. Smith,⁵³ M. Smizanska,⁸⁹ K. Smolek,¹⁴² A. Smykiewicz,⁸⁴ A. A. Snesarev,¹¹⁰ H. L. Snoek,¹²⁰ I. M. Snyder,¹³¹
S. Snyder,²⁹ R. Sobie,^{176,p} A. M. Soffa,¹⁷¹ A. Soffer,¹⁶¹ A. Søggaard,⁵⁰ F. Sohns,⁵³ C. A. Solans Sanchez,³⁶ E. Yu. Soldatov,¹¹²
U. Soldevila,¹⁷⁴ A. A. Solodkov,¹²³ A. Soloshenko,⁷⁹ O. V. Solovyanov,¹²³ V. Solovyev,¹³⁸ P. Sommer,¹⁴⁹ H. Son,¹⁷⁰
W. Song,¹⁴⁴ W. Y. Song,^{168b} A. Sopczak,¹⁴² F. Sopkova,^{28b} C. L. Sotiropoulou,^{71a,71b} S. Sottocornola,^{70a,70b}
R. Soualah,^{66a,66c,ss} A. M. Soukharev,^{122b,122a} D. South,⁴⁶ S. Spagnolo,^{67a,67b} M. Spalla,¹¹⁵ M. Spangenberg,¹⁷⁸ F. Spanò,⁹³
D. Sperlich,⁵² T. M. Spieker,^{61a} R. Spighi,^{23b} G. Spigo,³⁶ M. Spina,¹⁵⁶ D. P. Spiteri,⁵⁷ M. Spousta,¹⁴³ A. Stabile,^{68a,68b}
B. L. Stamas,¹²¹ R. Stamen,^{61a} M. Stamenkovic,¹²⁰ E. Stanecka,⁸⁴ R. W. Stanek,⁶ B. Stanislaus,¹³⁵ M. M. Stanitzki,⁴⁶
M. Stankaityte,¹³⁵ B. Stapf,¹²⁰ E. A. Starchenko,¹²³ G. H. Stark,¹⁴⁶ J. Stark,⁵⁸ S. H. Stark,⁴⁰ P. Staroba,¹⁴¹ P. Starovoitov,^{61a}
S. Stärz,¹⁰³ R. Staszewski,⁸⁴ G. Stavropoulos,⁴⁴ M. Stegler,⁴⁶ P. Steinberg,²⁹ A. L. Steinhebel,¹³¹ B. Stelzer,¹⁵²
H. J. Stelzer,¹³⁹ O. Stelzer-Chilton,^{168a} H. Stenzel,⁵⁶ T. J. Stevenson,¹⁵⁶ G. A. Stewart,³⁶ M. C. Stockton,³⁶ G. Stoicea,^{27b}
M. Stolarski,^{140a} P. Stolte,⁵³ S. Stonjek,¹¹⁵ A. Straessner,⁴⁸ J. Strandberg,¹⁵⁴ S. Strandberg,^{45a,45b} M. Strauss,¹²⁸
P. Strizenec,^{28b} R. Ströhmer,¹⁷⁷ D. M. Strom,¹³¹ R. Stroynowski,⁴² A. Strubig,⁵⁰ S. A. Stucci,²⁹ B. Stugu,¹⁷ J. Stupak,¹²⁸
N. A. Styles,⁴⁶ D. Su,¹⁵³ S. Suchek,^{61a} V. V. Sulin,¹¹⁰ M. J. Sullivan,⁹⁰ D. M. S. Sultan,⁵⁴ S. Sultansoy,^{4c} T. Sumida,⁸⁵
S. Sun,¹⁰⁵ X. Sun,³ K. Suruliz,¹⁵⁶ C. J. E. Suster,¹⁵⁷ M. R. Sutton,¹⁵⁶ S. Suzuki,⁸¹ M. Svatos,¹⁴¹ M. Swiatlowski,³⁷
S. P. Swift,² T. Swirski,¹⁷⁷ A. Sydorenko,⁹⁹ I. Sykora,^{28a} M. Sykora,¹⁴³ T. Sykora,¹⁴³ D. Ta,⁹⁹ K. Tackmann,^{46,tt} J. Taenzer,¹⁶¹
A. Taffard,¹⁷¹ R. Tafirout,^{168a} H. Takai,²⁹ R. Takashima,⁸⁶ K. Takeda,⁸² T. Takeshita,¹⁵⁰ E. P. Takeva,⁵⁰ Y. Takubo,⁸¹
M. Talby,¹⁰¹ A. A. Talyshv,^{122b,122a} N. M. Tamir,¹⁶¹ J. Tanaka,¹⁶³ M. Tanaka,¹⁶⁵ R. Tanaka,¹³² S. Tapia Araya,¹⁷³
S. Tapprogge,⁹⁹ A. Tarek Abouelfadl Mohamed,¹³⁶ S. Tarem,¹⁶⁰ G. Tarna,^{27b,uu} G. F. Tartarelli,^{68a} P. Tas,¹⁴³ M. Tasevsky,¹⁴¹
T. Tashiro,⁸⁵ E. Tassi,^{41b,41a} A. Tavares Delgado,^{140a,140b} Y. Tayalati,^{35e} A. J. Taylor,⁵⁰ G. N. Taylor,¹⁰⁴ W. Taylor,^{168b}

A. S. Tee,⁸⁹ R. Teixeira De Lima,¹⁵³ P. Teixeira-Dias,⁹³ H. Ten Kate,³⁶ J. J. Teoh,¹²⁰ S. Terada,⁸¹ K. Terashi,¹⁶³ J. Terron,⁹⁸
 S. Terzo,¹⁴ M. Testa,⁵¹ R. J. Teuscher,^{167,p} S. J. Thais,¹⁸³ T. Thevenaux-Pelzer,⁴⁶ F. Thiele,⁴⁰ D. W. Thomas,⁹³
 J. O. Thomas,⁴² J. P. Thomas,²¹ A. S. Thompson,⁵⁷ P. D. Thompson,²¹ L. A. Thomsen,¹⁸³ E. Thomson,¹³⁷ E. J. Thorpe,⁹²
 Y. Tian,³⁹ R. E. Tisce Torres,⁵³ V. O. Tikhomirov,^{110,vv} Yu. A. Tikhonov,^{122b,122a} S. Timoshenko,¹¹² P. Tipton,¹⁸³
 S. Tisserant,¹⁰¹ K. Todome,^{23b,23a} S. Todorova-Nova,⁵ S. Todt,⁴⁸ J. Tojo,⁸⁷ S. Tokár,^{28a} K. Tokushuku,⁸¹ E. Tolley,¹²⁶
 K. G. Tomiwa,^{33c} M. Tomoto,¹¹⁷ L. Tompkins,^{153,ee} K. Toms,¹¹⁸ B. Tong,⁵⁹ P. Tornambe,¹⁰² E. Torrence,¹³¹ H. Torres,⁴⁸
 E. Torró Pastor,¹⁴⁸ C. Tosciri,¹³⁵ J. Toth,^{101,ww} D. R. Tovey,¹⁴⁹ A. Traeet,¹⁷ C. J. Treado,¹²⁴ T. Trefzger,¹⁷⁷ F. Tresoldi,¹⁵⁶
 A. Tricoli,²⁹ I. M. Trigger,^{168a} S. Trincaz-Duvold,¹³⁶ W. Trischuk,¹⁶⁷ B. Trocmé,⁵⁸ A. Trofymov,¹³² C. Troncon,^{68a}
 M. Trovatelli,¹⁷⁶ F. Trovato,¹⁵⁶ L. Truong,^{33b} M. Trzebinski,⁸⁴ A. Trzupek,⁸⁴ F. Tsai,⁴⁶ J. C.-L. Tseng,¹³⁵
 P. V. Tsiareshka,^{107,gg} A. Tsirigotis,¹⁶² N. Tsirintanis,⁹ V. Tsiskaridze,¹⁵⁵ E. G. Tskhadadze,^{159a} M. Tsooulou,¹⁶²
 I. I. Tsukerman,¹¹¹ V. Tsulaia,¹⁸ S. Tsuno,⁸¹ D. Tsybychev,¹⁵⁵ Y. Tu,^{63b} A. Tudorache,^{27b} V. Tudorache,^{27b} T. T. Tulbure,^{27a}
 A. N. Tuna,⁵⁹ S. Turchikhin,⁷⁹ D. Turgeman,¹⁸⁰ I. Turk Cakir,^{4b,xx} R. J. Turner,²¹ R. T. Turra,^{68a} P. M. Tuts,³⁹ S. Tzamarias,¹⁶²
 E. Tzovara,⁹⁹ G. Uccielli,⁴⁷ K. Uchida,¹⁶³ I. Ueda,⁸¹ M. Ughetto,^{45a,45b} F. Ukegawa,¹⁶⁹ G. Unal,³⁶ A. Undrus,²⁹ G. Unel,¹⁷¹
 F. C. Ungaro,¹⁰⁴ Y. Unno,⁸¹ K. Uno,¹⁶³ J. Urban,^{28b} P. Urquijo,¹⁰⁴ G. Usai,⁸ J. Usui,⁸¹ Z. Uysal,^{12d} L. Vacavant,¹⁰¹
 V. Vacek,¹⁴² B. Vachon,¹⁰³ K. O. H. Vadla,¹³⁴ A. Vaidya,⁹⁴ C. Valderanis,¹¹⁴ E. Valdes Santurio,^{45a,45b} M. Valente,⁵⁴
 S. Valentineti,^{23b,23a} A. Valero,¹⁷⁴ L. Valéry,⁴⁶ R. A. Vallance,²¹ A. Vallier,³⁶ J. A. Valls Ferrer,¹⁷⁴ T. R. Van Daalen,¹⁴
 P. Van Gemmeren,⁶ I. Van Vulpen,¹²⁰ M. Vanadia,^{73a,73b} W. Vandelli,³⁶ A. Vaniachine,¹⁶⁶ D. Vannicola,^{72a,72b} R. Vari,^{72a}
 E. W. Varnes,⁷ C. Varni,^{55b,55a} T. Varol,⁴² D. Varouchas,¹³² K. E. Varvell,¹⁵⁷ M. E. Vasile,^{27b} G. A. Vasquez,¹⁷⁶
 J. G. Vasquez,¹⁸³ F. Vazeille,³⁸ D. Vazquez Furelos,¹⁴ T. Vazquez Schroeder,³⁶ J. Veatch,⁵³ V. Vecchio,^{74a,74b} M. J. Veen,¹²⁰
 L. M. Veloce,¹⁶⁷ F. Veloso,^{140a,140c} S. Veneziano,^{72a} A. Ventura,^{67a,67b} N. Venturi,³⁶ A. Verbitskyi,¹¹⁵ V. Vercesi,^{70a}
 M. Verducci,^{71a,71b} C. M. Vergel Infante,⁷⁸ C. Vergis,²⁴ W. Verkerke,¹²⁰ A. T. Vermeulen,¹²⁰ J. C. Vermeulen,¹²⁰
 M. C. Vetterli,^{152,e} N. Viaux Maira,^{147b} M. Vicente Barreto Pinto,⁵⁴ T. Vickey,¹⁴⁹ O. E. Vickey Boeriu,¹⁴⁹
 G. H. A. Viehhauser,¹³⁵ L. Vigani,^{61b} M. Villa,^{23b,23a} M. Villaplana Perez,^{68a,68b} E. Vilucchi,⁵¹ M. G. Vincter,³⁴
 V. B. Vinogradov,⁷⁹ A. Vishwakarma,⁴⁶ C. Vittori,^{23b,23a} I. Vivarelli,¹⁵⁶ M. Vogel,¹⁸² P. Vokac,¹⁴² S. E. von Buddenbrock,^{33c}
 E. Von Toerne,²⁴ V. Vorobel,¹⁴³ K. Vorobev,¹¹² M. Vos,¹⁷⁴ J. H. Vosseveld,⁹⁰ M. Vozak,¹⁰⁰ N. Vranjes,¹⁶
 M. Vranjes Milosavljevic,¹⁶ V. Vrba,¹⁴² M. Vreeswijk,¹²⁰ T. Šfiligoj,⁹¹ R. Vuillermet,³⁶ I. Vukotic,³⁷ T. Ženiš,^{28a}
 L. Živković,¹⁶ P. Wagner,²⁴ W. Wagner,¹⁸² J. Wagner-Kuhr,¹¹⁴ S. Wahdan,¹⁸² H. Wahlberg,⁸⁸ K. Wakamiya,⁸²
 V. M. Walbrecht,¹¹⁵ J. Walder,⁸⁹ R. Walker,¹¹⁴ S. D. Walker,⁹³ W. Walkowiak,¹⁵¹ V. Wallangen,^{45a,45b} A. M. Wang,⁵⁹
 C. Wang,^{60c} C. Wang,^{60b} F. Wang,¹⁸¹ H. Wang,¹⁸ H. Wang,³ J. Wang,¹⁵⁷ J. Wang,^{61b} P. Wang,⁴² Q. Wang,¹²⁸ R.-J. Wang,⁹⁹
 R. Wang,^{60a} R. Wang,⁶ S. M. Wang,¹⁵⁸ W. T. Wang,^{60a} W. Wang,^{15c,yy} W. X. Wang,^{60a,yy} Y. Wang,^{60a,zz} Z. Wang,^{60c}
 C. Wanotayaroj,⁴⁶ A. Warburton,¹⁰³ C. P. Ward,³² D. R. Wardrope,⁹⁴ N. Warrack,⁵⁷ A. Washbrook,⁵⁰ A. T. Watson,²¹
 M. F. Watson,²¹ G. Watts,¹⁴⁸ B. M. Waugh,⁹⁴ A. F. Webb,¹¹ S. Webb,⁹⁹ C. Weber,¹⁸³ M. S. Weber,²⁰ S. A. Weber,³⁴
 S. M. Weber,^{61a} A. R. Weidberg,¹³⁵ J. Weingarten,⁴⁷ M. Weirich,⁹⁹ C. Weiser,⁵² P. S. Wells,³⁶ T. Wenaus,²⁹ T. Wengler,³⁶
 S. Wenig,³⁶ N. Wermes,²⁴ M. D. Werner,⁷⁸ M. Wessels,^{61a} T. D. Weston,²⁰ K. Whalen,¹³¹ N. L. Whallon,¹⁴⁸
 A. M. Wharton,⁸⁹ A. S. White,¹⁰⁵ A. White,⁸ M. J. White,¹ D. Whiteson,¹⁷¹ B. W. Whitmore,⁸⁹ W. Wiedenmann,¹⁸¹
 M. Wielers,¹⁴⁴ N. Wieseotte,⁹⁹ C. Wiglesworth,⁴⁰ L. A. M. Wiik-Fuchs,⁵² F. Wilk,¹⁰⁰ H. G. Wilkens,³⁶ L. J. Wilkins,⁹³
 H. H. Williams,¹³⁷ S. Williams,³² C. Willis,¹⁰⁶ S. Willocq,¹⁰² J. A. Wilson,²¹ I. Wingerter-Seez,⁵ E. Winkels,¹⁵⁶
 F. Winklmeier,¹³¹ O. J. Winston,¹⁵⁶ B. T. Winter,⁵² M. Wittgen,¹⁵³ M. Wobisch,⁹⁵ A. Wolf,⁹⁹ T. M. H. Wolf,¹²⁰ R. Wolff,¹⁰¹
 R. W. Wölker,¹³⁵ J. Wollrath,⁵² M. W. Wolter,⁸⁴ H. Wolters,^{140a,140c} V. W. S. Wong,¹⁷⁵ N. L. Woods,¹⁴⁶ S. D. Worm,²¹
 B. K. Wosiek,⁸⁴ K. W. Woźniak,⁸⁴ K. Wraight,⁵⁷ S. L. Wu,¹⁸¹ X. Wu,⁵⁴ Y. Wu,^{60a} T. R. Wyatt,¹⁰⁰ B. M. Wynne,⁵⁰ S. Xella,⁴⁰
 Z. Xi,¹⁰⁵ L. Xia,¹⁷⁸ D. Xu,^{15a} H. Xu,^{60a,uu} L. Xu,²⁹ T. Xu,¹⁴⁵ W. Xu,¹⁰⁵ Z. Xu,^{60b} Z. Xu,¹⁵³ B. Yabsley,¹⁵⁷ S. Yacoub,^{33a}
 K. Yajima,¹³³ D. P. Yallup,⁹⁴ D. Yamaguchi,¹⁶⁵ Y. Yamaguchi,¹⁶⁵ A. Yamamoto,⁸¹ F. Yamane,⁸² M. Yamatani,¹⁶³
 T. Yamazaki,¹⁶³ Y. Yamazaki,⁸² Z. Yan,²⁵ H. J. Yang,^{60c,60d} H. T. Yang,¹⁸ S. Yang,⁷⁷ X. Yang,^{60b,58} Y. Yang,¹⁶³ W.-M. Yao,¹⁸
 Y. C. Yap,⁴⁶ Y. Yasu,⁸¹ E. Yatsenko,^{60c,60d} J. Ye,⁴² S. Ye,²⁹ I. Yeletsikh,⁷⁹ M. R. Yexley,⁸⁹ E. Yigitbasi,²⁵ K. Yorita,¹⁷⁹
 K. Yoshihara,¹³⁷ C. J. S. Young,³⁶ C. Young,¹⁵³ J. Yu,⁷⁸ R. Yuan,^{60b,aaa} X. Yue,^{61a} S. P. Y. Yuen,²⁴ B. Zabinski,⁸⁴
 G. Zacharis,¹⁰ E. Zaffaroni,⁵⁴ J. Zahreddine,¹³⁶ A. M. Zaitsev,^{123,ll} T. Zakareishvili,^{159b} N. Zakharchuk,³⁴ S. Zambito,⁵⁹
 D. Zanzi,³⁶ D. R. Zaripovas,⁵⁷ S. V. Zeißner,⁴⁷ C. Zeitnitz,¹⁸² G. Zemaityte,¹³⁵ J. C. Zeng,¹⁷³ O. Zenin,¹²³ D. Zerwas,¹³²
 M. Zgubič,¹³⁵ D. F. Zhang,^{15b} F. Zhang,¹⁸¹ G. Zhang,^{60a} G. Zhang,^{15b} H. Zhang,^{15c} J. Zhang,⁶ L. Zhang,^{15c} L. Zhang,^{60a}
 M. Zhang,¹⁷³ R. Zhang,^{60a} R. Zhang,²⁴ X. Zhang,^{60b} Y. Zhang,^{15a,15d} Z. Zhang,^{63a} Z. Zhang,¹³² P. Zhao,⁴⁹ Y. Zhao,^{60b}

Z. Zhao,^{60a} A. Zhemchugov,⁷⁹ Z. Zheng,¹⁰⁵ D. Zhong,¹⁷³ B. Zhou,¹⁰⁵ C. Zhou,¹⁸¹ M. S. Zhou,^{15a,15d} M. Zhou,¹⁵⁵ N. Zhou,^{60c}
 Y. Zhou,⁷ C. G. Zhu,^{60b} H. L. Zhu,^{60a} H. Zhu,^{15a} J. Zhu,¹⁰⁵ Y. Zhu,^{60a} X. Zhuang,^{15a} K. Zhukov,¹¹⁰ V. Zhulanov,^{122b,122a}
 D. Zieminska,⁶⁵ N. I. Zimine,⁷⁹ S. Zimmermann,⁵² Z. Zinonos,¹¹⁵ M. Ziolkowski,¹⁵¹ G. Zobernig,¹⁸¹ A. Zoccoli,^{23b,23a}
 K. Zoch,⁵³ T. G. Zorbas,¹⁴⁹ R. Zou,³⁷ and L. Zwalinski³⁶

(ATLAS Collaboration)

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

- ³⁴*Department of Physics, Carleton University, Ottawa, Ontario, Canada*
- ^{35a}*Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies—Université Hassan II, Casablanca, Morocco*
- ^{35b}*Faculté des Sciences, Université Ibn-Tofail, Kénitra, Morocco*
- ^{35c}*Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA-Marrakech, Morocco*
- ^{35d}*Faculté des Sciences, Université Mohamed Premier and LPTPM, Oujda, Morocco*
- ^{35e}*Faculté des sciences, Université Mohammed V, Rabat, Morocco*
- ³⁶*CERN, Geneva, Switzerland*
- ³⁷*Enrico Fermi Institute, University of Chicago, Chicago, Illinois, USA*
- ³⁸*LPC, Université Clermont Auvergne, CNRS/IN2P3, Clermont-Ferrand, France*
- ³⁹*Nevis Laboratory, Columbia University, Irvington, New York, USA*
- ⁴⁰*Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark*
- ^{41a}*Dipartimento di Fisica, Università della Calabria, Rende, Italy*
- ^{41b}*INFN Gruppo Collegato di Cosenza, Laboratori Nazionali di Frascati, Italy*
- ⁴²*Physics Department, Southern Methodist University, Dallas, Texas, USA*
- ⁴³*Physics Department, University of Texas at Dallas, Richardson, Texas, USA*
- ⁴⁴*National Centre for Scientific Research “Demokritos”, Agia Paraskevi, Greece*
- ^{45a}*Department of Physics, Stockholm University, Sweden*
- ^{45b}*Oskar Klein Centre, Stockholm, Sweden*
- ⁴⁶*Deutsches Elektronen-Synchrotron DESY, Hamburg and Zeuthen, Germany*
- ⁴⁷*Lehrstuhl für Experimentelle Physik IV, Technische Universität Dortmund, Dortmund, Germany*
- ⁴⁸*Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden, Germany*
- ⁴⁹*Department of Physics, Duke University, Durham, North Carolina, USA*
- ⁵⁰*SUPA—School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom*
- ⁵¹*INFN e Laboratori Nazionali di Frascati, Frascati, Italy*
- ⁵²*Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany*
- ⁵³*II. Physikalisches Institut, Georg-August-Universität Göttingen, Göttingen, Germany*
- ⁵⁴*Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève, Switzerland*
- ^{55a}*Dipartimento di Fisica, Università di Genova, Genova, Italy*
- ^{55b}*INFN Sezione di Genova, Italy*
- ⁵⁶*II. Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen, Germany*
- ⁵⁷*SUPA—School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom*
- ⁵⁸*LPSC, Université Grenoble Alpes, CNRS/IN2P3, Grenoble INP, Grenoble, France*
- ⁵⁹*Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge, Massachusetts, USA*
- ^{60a}*Department of Modern Physics and State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei, China*
- ^{60b}*Institute of Frontier and Interdisciplinary Science and Key Laboratory of Particle Physics and Particle Irradiation (MOE), Shandong University, Qingdao, China*
- ^{60c}*School of Physics and Astronomy, Shanghai Jiao Tong University, KLPPAC-MoE, SKLPPC, Shanghai, China*
- ^{60d}*Tsung-Dao Lee Institute, Shanghai, China*
- ^{61a}*Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany*
- ^{61b}*Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany*
- ⁶²*Faculty of Applied Information Science, Hiroshima Institute of Technology, Hiroshima, Japan*
- ^{63a}*Department of Physics, Chinese University of Hong Kong, Shatin, N.T., Hong Kong, China*
- ^{63b}*Department of Physics, University of Hong Kong, Hong Kong, China*
- ^{63c}*Department of Physics and Institute for Advanced Study, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China*
- ⁶⁴*Department of Physics, National Tsing Hua University, Hsinchu, Taiwan*
- ⁶⁵*Department of Physics, Indiana University, Bloomington, Indiana, USA*
- ^{66a}*INFN Gruppo Collegato di Udine, Sezione di Trieste, Udine, Italy*
- ^{66b}*ICTP, Trieste, Italy*
- ^{66c}*Dipartimento Politecnico di Ingegneria e Architettura, Università di Udine, Udine, Italy*
- ^{67a}*INFN Sezione di Lecce, Italy*
- ^{67b}*Dipartimento di Matematica e Fisica, Università del Salento, Lecce, Italy*
- ^{68a}*INFN Sezione di Milano, Italy*
- ^{68b}*Dipartimento di Fisica, Università di Milano, Milano, Italy*
- ^{69a}*INFN Sezione di Napoli, Italy*
- ^{69b}*Dipartimento di Fisica, Università di Napoli, Napoli, Italy*
- ^{70a}*INFN Sezione di Pavia, Italy*
- ^{70b}*Dipartimento di Fisica, Università di Pavia, Pavia, Italy*

- ^{71a}*INFN Sezione di Pisa, Italy*
^{71b}*Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy*
^{72a}*INFN Sezione di Roma, Italy*
^{72b}*Dipartimento di Fisica, Sapienza Università di Roma, Roma, Italy*
^{73a}*INFN Sezione di Roma Tor Vergata, Italy*
^{73b}*Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy*
^{74a}*INFN Sezione di Roma Tre, Italy*
^{74b}*Dipartimento di Matematica e Fisica, Università Roma Tre, Roma, Italy*
^{75a}*INFN-TIFPA, Italy*
^{75b}*Università degli Studi di Trento, Trento, Italy*
⁷⁶*Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck, Austria*
⁷⁷*University of Iowa, Iowa City, Iowa, USA*
⁷⁸*Department of Physics and Astronomy, Iowa State University, Ames, Iowa, USA*
⁷⁹*Joint Institute for Nuclear Research, Dubna, Russia*
^{80a}*Departamento de Engenharia Elétrica, Universidade Federal de Juiz de Fora (UFJF), Juiz de Fora, Brazil*
^{80b}*Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro, Brazil*
^{80c}*Universidade Federal de São João del Rei (UFSJ), São João del Rei, Brazil*
^{80d}*Instituto de Física, Universidade de São Paulo, São Paulo, Brazil*
⁸¹*KEK, High Energy Accelerator Research Organization, Tsukuba, Japan*
⁸²*Graduate School of Science, Kobe University, Kobe, Japan*
^{83a}*AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, Krakow, Poland*
^{83b}*Marian Smoluchowski Institute of Physics, Jagiellonian University, Krakow, Poland*
⁸⁴*Institute of Nuclear Physics Polish Academy of Sciences, Krakow, Poland*
⁸⁵*Faculty of Science, Kyoto University, Kyoto, Japan*
⁸⁶*Kyoto University of Education, Kyoto, Japan*
⁸⁷*Research Center for Advanced Particle Physics and Department of Physics, Kyushu University, Fukuoka, Japan*
⁸⁸*Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina*
⁸⁹*Physics Department, Lancaster University, Lancaster, United Kingdom*
⁹⁰*Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom*
⁹¹*Department of Experimental Particle Physics, Jožef Stefan Institute and Department of Physics, University of Ljubljana, Ljubljana, Slovenia*
⁹²*School of Physics and Astronomy, Queen Mary University of London, London, United Kingdom*
⁹³*Department of Physics, Royal Holloway University of London, Egham, United Kingdom*
⁹⁴*Department of Physics and Astronomy, University College London, London, United Kingdom*
⁹⁵*Louisiana Tech University, Ruston, Louisiana, USA*
⁹⁶*Fysiska institutionen, Lunds universitet, Lund, Sweden*
⁹⁷*Centre de Calcul de l'Institut National de Physique Nucléaire et de Physique des Particules (IN2P3), Villeurbanne, France*
⁹⁸*Departamento de Física Teórica C-15 and CIAFF, Universidad Autónoma de Madrid, Madrid, Spain*
⁹⁹*Institut für Physik, Universität Mainz, Mainz, Germany*
¹⁰⁰*School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom*
¹⁰¹*CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille, France*
¹⁰²*Department of Physics, University of Massachusetts, Amherst, Massachusetts, USA*
¹⁰³*Department of Physics, McGill University, Montreal, Quebec, Canada*
¹⁰⁴*School of Physics, University of Melbourne, Victoria, Australia*
¹⁰⁵*Department of Physics, University of Michigan, Ann Arbor, Michigan, USA*
¹⁰⁶*Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan, USA*
¹⁰⁷*B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Belarus*
¹⁰⁸*Research Institute for Nuclear Problems of Byelorussian State University, Minsk, Belarus*
¹⁰⁹*Group of Particle Physics, University of Montreal, Montreal, Quebec, Canada*
¹¹⁰*P.N. Lebedev Physical Institute of the Russian Academy of Sciences, Moscow, Russia*
¹¹¹*Institute for Theoretical and Experimental Physics of the National Research Centre Kurchatov Institute, Moscow, Russia*
¹¹²*National Research Nuclear University MEPhI, Moscow, Russia*
¹¹³*D.V. Skobel'syn Institute of Nuclear Physics, M.V. Lomonosov Moscow State University, Moscow, Russia*
¹¹⁴*Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany*
¹¹⁵*Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany*
¹¹⁶*Nagasaki Institute of Applied Science, Nagasaki, Japan*
¹¹⁷*Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya, Japan*
¹¹⁸*Department of Physics and Astronomy, University of New Mexico, Albuquerque, New Mexico, USA*
¹¹⁹*Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands*
¹²⁰*Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands*

- ¹²¹*Department of Physics, Northern Illinois University, DeKalb, Illinois, USA*
- ^{122a}*Budker Institute of Nuclear Physics and NSU, SB RAS, Novosibirsk, Russia*
- ^{122b}*Novosibirsk State University Novosibirsk, Russia*
- ¹²³*Institute for High Energy Physics of the National Research Centre Kurchatov Institute, Protvino, Russia*
- ¹²⁴*Department of Physics, New York University, New York, New York, USA*
- ¹²⁵*Ochanomizu University, Otsuka, Bunkyo-ku, Tokyo, Japan*
- ¹²⁶*The Ohio State University, Columbus, Ohio, USA*
- ¹²⁷*Faculty of Science, Okayama University, Okayama, Japan*
- ¹²⁸*Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman, Oklahoma, USA*
- ¹²⁹*Department of Physics, Oklahoma State University, Stillwater, Oklahoma, USA*
- ¹³⁰*Palacký University, RCPTM, Joint Laboratory of Optics, Olomouc, Czech Republic*
- ¹³¹*Center for High Energy Physics, University of Oregon, Eugene, Oregon, USA*
- ¹³²*LAL, Université Paris-Sud, CNRS/IN2P3, Université Paris-Saclay, Orsay, France*
- ¹³³*Graduate School of Science, Osaka University, Osaka, Japan*
- ¹³⁴*Department of Physics, University of Oslo, Oslo, Norway*
- ¹³⁵*Department of Physics, Oxford University, Oxford, United Kingdom*
- ¹³⁶*LPNHE, Sorbonne Université, Paris Diderot Sorbonne Paris Cité, CNRS/IN2P3, Paris, France*
- ¹³⁷*Department of Physics, University of Pennsylvania, Philadelphia, Pennsylvania, USA*
- ¹³⁸*Konstantinov Nuclear Physics Institute of National Research Centre “Kurchatov Institute”, PNPI, St. Petersburg, Russia*
- ¹³⁹*Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, Pennsylvania, USA*
- ^{140a}*Laboratório de Instrumentação e Física Experimental de Partículas—LIP, Portugal*
- ^{140b}*Departamento de Física, Faculdade de Ciências, Universidade de Lisboa, Lisboa, Portugal*
- ^{140c}*Departamento de Física, Universidade de Coimbra, Coimbra, Portugal*
- ^{140d}*Centro de Física Nuclear da Universidade de Lisboa, Lisboa, Portugal*
- ^{140e}*Departamento de Física, Universidade do Minho, Braga, Portugal*
- ^{140f}*Universidad de Granada, Granada (Spain), Spain*
- ^{140g}*Dep Física and CEFITEC of Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Caparica, Portugal*
- ¹⁴¹*Institute of Physics of the Czech Academy of Sciences, Prague, Czech Republic*
- ¹⁴²*Czech Technical University in Prague, Prague, Czech Republic*
- ¹⁴³*Charles University, Faculty of Mathematics and Physics, Prague, Czech Republic*
- ¹⁴⁴*Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom*
- ¹⁴⁵*IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France*
- ¹⁴⁶*Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz, California, USA*
- ^{147a}*Departamento de Física, Pontificia Universidad Católica de Chile, Santiago, Chile*
- ^{147b}*Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile*
- ¹⁴⁸*Department of Physics, University of Washington, Seattle, Washington, USA*
- ¹⁴⁹*Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom*
- ¹⁵⁰*Department of Physics, Shinshu University, Nagano, Japan*
- ¹⁵¹*Department Physik, Universität Siegen, Siegen, Germany*
- ¹⁵²*Department of Physics, Simon Fraser University, Burnaby, British Columbia, Canada*
- ¹⁵³*SLAC National Accelerator Laboratory, Stanford, California, USA*
- ¹⁵⁴*Physics Department, Royal Institute of Technology, Stockholm, Sweden*
- ¹⁵⁵*Departments of Physics and Astronomy, Stony Brook University, Stony Brook, New York, USA*
- ¹⁵⁶*Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom*
- ¹⁵⁷*School of Physics, University of Sydney, Sydney, Australia*
- ¹⁵⁸*Institute of Physics, Academia Sinica, Taipei, Taiwan*
- ^{159a}*E. Andronikashvili Institute of Physics, Iv. Javakhishvili Tbilisi State University, Tbilisi, Georgia*
- ^{159b}*High Energy Physics Institute, Tbilisi State University, Tbilisi, Georgia*
- ¹⁶⁰*Department of Physics, Technion, Israel Institute of Technology, Haifa, Israel*
- ¹⁶¹*Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel*
- ¹⁶²*Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece*
- ¹⁶³*International Center for Elementary Particle Physics and Department of Physics, University of Tokyo, Tokyo, Japan*
- ¹⁶⁴*Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo, Japan*
- ¹⁶⁵*Department of Physics, Tokyo Institute of Technology, Tokyo, Japan*
- ¹⁶⁶*Tomsk State University, Tomsk, Russia*
- ¹⁶⁷*Department of Physics, University of Toronto, Toronto, Ontario, Canada*
- ^{168a}*TRIUMF, Vancouver, British Columbia, Canada*
- ^{168b}*Department of Physics and Astronomy, York University, Toronto, Ontario, Canada*
- ¹⁶⁹*Division of Physics and Tomonaga Center for the History of the Universe, Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba, Japan*

- ¹⁷⁰*Department of Physics and Astronomy, Tufts University, Medford, Massachusetts, USA*
¹⁷¹*Department of Physics and Astronomy, University of California Irvine, Irvine, California, USA*
¹⁷²*Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden*
¹⁷³*Department of Physics, University of Illinois, Urbana, Illinois, USA*
¹⁷⁴*Instituto de Física Corpuscular (IFIC), Centro Mixto Universidad de Valencia—CSIC, Valencia, Spain*
¹⁷⁵*Department of Physics, University of British Columbia, Vancouver, British Columbia, Canada*
¹⁷⁶*Department of Physics and Astronomy, University of Victoria, Victoria, British Columbia, Canada*
¹⁷⁷*Fakultät für Physik und Astronomie, Julius-Maximilians-Universität Würzburg, Würzburg, Germany*
¹⁷⁸*Department of Physics, University of Warwick, Coventry, United Kingdom*
¹⁷⁹*Waseda University, Tokyo, Japan*
¹⁸⁰*Department of Particle Physics, Weizmann Institute of Science, Rehovot, Israel*
¹⁸¹*Department of Physics, University of Wisconsin, Madison, Wisconsin, USA*
¹⁸²*Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal, Germany*
¹⁸³*Department of Physics, Yale University, New Haven, Connecticut, USA*
¹⁸⁴*Yerevan Physics Institute, Yerevan, Armenia*

^aDeceased.

^bAlso at Department of Physics, King's College London, London, United Kingdom.

^cAlso at Istanbul University, Department of Physics, Istanbul, Turkey.

^dAlso at Instituto de Física Teórica, IFT-UAM/CSIC, Madrid, Spain.

^eAlso at TRIUMF, Vancouver, British Columbia, Canada.

^fAlso at Department of Physics and Astronomy, University of Louisville, Louisville, Kentucky, USA.

^gAlso at Physics Department, An-Najah National University, Nablus, Palestine.

^hAlso at Department of Physics, California State University, Fresno, USA.

ⁱAlso at Department of Physics, University of Fribourg, Fribourg, Switzerland.

^jAlso at Physics Dept, University of South Africa, Pretoria, South Africa.

^kAlso at Departament de Física de la Universitat Autònoma de Barcelona, Barcelona, Spain.

^lAlso at Tomsk State University, Tomsk, and Moscow Institute of Physics and Technology State University, Dolgoprudny, Russia.

^mAlso at The Collaborative Innovation Center of Quantum Matter (CICQM), Beijing, China.

ⁿAlso at Departamento de Física, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal.

^oAlso at Università di Napoli Parthenope, Napoli, Italy.

^pAlso at Institute of Particle Physics (IPP), Canada.

^qAlso at Department of Physics, University of Adelaide, Adelaide, Australia.

^rAlso at Department of Physics, St. Petersburg State Polytechnical University, St. Petersburg, Russia.

^sAlso at Department of Financial and Management Engineering, University of the Aegean, Chios, Greece.

^tAlso at Centre for High Performance Computing, CSIR Campus, Rosebank, Cape Town, South Africa.

^uAlso at Department of Physics, California State University, East Bay, USA.

^vAlso at Institutio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona, Spain.

^wAlso at Department of Physics, University of Michigan, Ann Arbor, Michigan, USA.

^xAlso at LAL, Université Paris-Sud, CNRS/IN2P3, Université Paris-Saclay, Orsay, France.

^yAlso at Graduate School of Science, Osaka University, Osaka, Japan.

^zAlso at Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany.

^{aa}Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan.

^{bb}Also at Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands.

^{cc}Also at Institute of Theoretical Physics, Ilia State University, Tbilisi, Georgia.

^{dd}Also at CERN, Geneva, Switzerland.

^{ee}Also at Department of Physics, Stanford University, Stanford, California, USA.

^{ff}Also at Manhattan College, New York, New York, USA.

^{gg}Also at Joint Institute for Nuclear Research, Dubna, Russia.

^{hh}Also at Hellenic Open University, Patras, Greece.

ⁱⁱAlso at The City College of New York, New York, New York, USA.

^{jj}Also at Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China.

^{kk}Also at Department of Physics, California State University, Sacramento, USA.

^{ll}Also at Moscow Institute of Physics and Technology State University, Dolgoprudny, Russia.

^{mm}Also at Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève, Switzerland.

ⁿⁿAlso at Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom.

^{oo}Also at Louisiana Tech University, Ruston, Louisiana, USA.

^{pp}Also at School of Physics, Sun Yat-sen University, Guangzhou, China.

^{qq}Also at Institute for Nuclear Research and Nuclear Energy (INRNE) of the Bulgarian Academy of Sciences, Sofia, Bulgaria.

^{rr} Also at Faculty of Physics, M.V. Lomonosov Moscow State University, Moscow, Russia.

^{ss} Also at Department of Applied Physics and Astronomy, University of Sharjah, Sharjah, United Arab Emirates.

^{tt} Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany.

^{uu} Also at CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille, France.

^{vv} Also at National Research Nuclear University MEPHI, Moscow, Russia.

^{ww} Also at Institute for Particle and Nuclear Physics, Wigner Research Centre for Physics, Budapest, Hungary.

^{xx} Also at Giresun University, Faculty of Engineering, Giresun, Turkey.

^{yy} Also at Institute of Physics, Academia Sinica, Taipei, Taiwan.

^{zz} Also at LPNHE, Sorbonne Université, Paris Diderot Sorbonne Paris Cité, CNRS/IN2P3, Paris, France.

^{aaa} Also at Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan, USA.