UNIVERSITY OF BIRMINGHAM
University of Birmingham Research at Birmingham

Measurement of the inelastic proton-proton cross section at √s = 13 TeV with the ATLAS detector at the LHC

ATLAS Collaboration

DOI:
10.1103/PhysRevLett.117.182002

License:
Creative Commons: Attribution (CC BY)

Document Version
Publisher's PDF, also known as Version of record

Citation for published version (Harvard):
ATLAS Collaboration 2016, 'Measurement of the inelastic proton-proton cross section at √s = 13 TeV with the ATLAS detector at the LHC', *Physical Review Letters*, vol. 117, no. 18, 182002.
https://doi.org/10.1103/PhysRevLett.117.182002

Link to publication on Research at Birmingham portal

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.

Download date: 19. Apr. 2024

Measurement of the Inelastic Proton-Proton Cross Section at $\sqrt{s} = 13$ TeV with the ATLAS Detector at the LHC

M. Aaboud *et al.*[*]
(ATLAS Collaboration)

(Received 9 June 2016; published 26 October 2016)

This Letter presents a measurement of the inelastic proton-proton cross section using 60 μb^{-1} of pp collisions at a center-of-mass energy $\sqrt{s}$ of 13 TeV with the ATLAS detector at the LHC. Inelastic interactions are selected using rings of plastic scintillators in the forward region ($2.07 < |\eta| < 3.86$) of the detector. A cross section of 68.1 ± 1.4 mb is measured in the fiducial region $\xi = M_X^2/s > 10^{-6}$, where M_X is the larger invariant mass of the two hadronic systems separated by the largest rapidity gap in the event. In this ξ range the scintillators are highly efficient. For diffractive events this corresponds to cases where at least one proton dissociates to a system with $M_X > 13$ GeV. The measured cross section is compared with a range of theoretical predictions. When extrapolated to the full phase space, a cross section of 78.1 ± 2.9 mb is measured, consistent with the inelastic cross section increasing with center-of-mass energy.

DOI: 10.1103/PhysRevLett.117.182002

The rise of the total proton-proton (pp) cross section with center-of-mass energy $\sqrt{s}$, predicted by Heisenberg [1] and observed at the CERN Intersecting Storage Rings [2], probes the nonperturbative regime of quantum chromodynamics (QCD). Arguments based on unitarity, analyticity, and factorization imply an upper bound on the high-energy behavior of total hadronic cross sections that prevents them from rising more rapidly than $\ln^2(s)$ [3–5].

Many experiments have measured σ_{inel} and found an increase with $\sqrt{s}$ [6]. The TOTEM and ATLAS collaborations determined σ_{inel} at $\sqrt{s} = 7$ and 8 TeV using the optical theorem and a measurement of the elastic cross section with Roman pot detectors [7–11]. Using a variety of alternative techniques, the ATLAS, CMS, ALICE, and LHCb experiments have made measurements of σ_{inel} at $\sqrt{s} = 7$ TeV [12–15] and $\sqrt{s} = 2.76$ TeV (ALICE) [14]. The Pierre Auger Collaboration measured the inelastic p-air cross section at $\sqrt{s} = 57$ TeV and extracted σ_{inel} using the Glauber model [16].

This Letter presents a measurement of the inelastic cross section σ_{inel} using pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector at the Large Hadron Collider (LHC). It is performed using two sets of scintillation counters in a data set corresponding to an integrated luminosity of 60.1 ± 1.1 μb^{-1} collected in June 2015. In inelastic interactions, one or both protons dissociate as a result of colored (nondiffractive) or colorless (diffractive) exchange. The counters are insensitive to elastic pp scattering and diffractive dissociation processes in which neither proton dissociates into a system, X, of mass $M_X > 13$ GeV, or equivalently, $\xi = M_X^2/s > 10^{-6}$. The cross-section measurement is reported in this fiducial region, $\xi > 10^{-6}$, and after extrapolation to the total inelastic cross section using models of inelastic interactions.

The ATLAS detector is a cylindrical particle detector composed of several subdetector layers [17]. The inner tracking detector (ID) is immersed in a 2 T magnetic field provided by a superconducting solenoid. Around the tracker is a system of electromagnetic and hadronic calorimeters, which use liquid argon and lead, copper, or tungsten absorber for the electromagnetic and forward ($|\eta| > 1.7$) [18] hadronic components of the detector, and scintillator-tile active material and steel absorber for the central ($|\eta| < 1.7$) hadronic component.

At $z = \pm 3.6$ m, thin plastic scintillation counters, the minimum-bias trigger scintillators (MBTS), are installed on the front face of each endcap calorimeter. These detectors cover the region $2.07 < |\eta| < 3.86$. They are similar to those described in Ref. [17] but were rebuilt during 2014, when the coverage was slightly extended from $2.08 < |\eta| < 3.75$ after the $\sqrt{s} = 7$ TeV run. The MBTS are divided into inner (4 counters in $149 < r < 445$ mm) and outer (8 counters in $444.5 < r < 895$ mm) octagonal rings.

The ATLAS experiment uses a multistage trigger to select events at about 1 kHz for offline analysis. Three trigger configurations were used to collect data for this analysis. The primary triggers use the MBTS detector and constant-fraction discriminators to select events when two proton bunches collide in the detector. To facilitate background studies, data were also collected with the same selection when no proton bunch ("empty") or a single proton bunch from only one of the two beams ("single

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

Published by the American Physical Society under the terms of the Creative Commons Attribution 3.0 License. Further distribution of this work must maintain attribution to the author(s) and the published article's title, journal citation, and DOI.

 © 2016 CERN, for the ATLAS Collaboration

beam") was passing through the center of ATLAS. All of these triggers require at least one MBTS hit above threshold. Two additional triggers were used to collect data to determine the MBTS trigger efficiency, requiring either hits in a forward ($5.6 < |\eta| < 5.9$) Cherenkov detector (LUCID) or a far forward ($|\eta| > 8.4$) tungsten-scintillator calorimeter detector (LHCf [19]) located at $z = \pm 17$ m and ± 140 m, respectively. The LHCf detector is an independent detector, but for the runs considered in this analysis, its trigger signals were incorporated into the ATLAS readout.

Monte Carlo (MC) simulation samples were produced to correct the fiducial measurement and to compare to the data. The detector response is modeled using a simulation based on GEANT4 [20–22]. The data and MC simulated events are passed through the same reconstruction and analysis software.

The primary MC samples are based on the PYTHIA8 generator [23,24] either with the A2 [25] set of tuned underlying-event parameters and the MSTW 2008 LO PDF set [26] or with the Monash [27] set of tuned parameters and the NNPDF 2.3 LO PDF set [28]. The samples are divided into four components: single-dissociation (SD, $pp \to pX$), double-dissociation (DD, $pp \to XY$), central-dissociation (CD, $pp \to pXp$), all involving colorless exchange, and nondiffractive dissociation (ND) wherein color flow is present between the two colliding protons. For all dissociation event types, the Monash tune is used.

PYTHIA8 uses a pomeron-based diffraction model [29] to describe colorless exchange with a default pomeron flux model by Schuler and Sjöstrand (SS) [30,31]. Alternative MC samples are generated with the pomeron flux model of Donnachie and Landshoff (DL) [32] and with the minimum-bias Rockefeller (MBR) model [33]. In the DL model, the pomeron Regge trajectory is given by $\alpha(t) = 1 + \varepsilon + \alpha' t$, where ε and α' are free parameters. In most samples used for this analysis, the value of α' is 0.25, the PYTHIA8 default. The ε parameter is varied from 0.06 to 0.10 (the PYTHIA8 default is 0.085). An additional sample produced with $\alpha' = 0.35$ is found to be statistically consistent with the $\alpha' = 0.25$ default samples in each aspect of this analysis. The ranges of ε and α' considered are motivated by previous total, inelastic, elastic, and diffractive cross-section measurements, including measurements of low-mass diffraction by the ATLAS and CMS collaborations [34,35]. For the DL and SS models the CD component is neglected. The MBR model is tuned to data as described in Ref. [33] and includes a small CD component.

The EPOS LHC and QGSJET-II event generators are also used to simulate pp collisions. EPOS LHC [36] uses a "cut pomeron" model for diffraction and differs significantly from PYTHIA8 in its modeling of hadronization and the underlying event. QGSJET-II [37,38] uses Reggeon field theory to describe pomeron-pomeron interactions. Both EPOS LHC and QGSJET-II have been developed primarily to model cosmic-ray showering in the atmosphere.

The fiducial region of the measurement is determined using MC simulation. In each generated event, the largest rapidity gap between any two final-state hadrons is used to define the boundary between two collections of hadrons. These collections define the dissociation systems in an event-generator-independent manner. The invariant mass of each collection is calculated, and the larger of the two masses, denoted M_X, is used to define $\xi = M_X^2/s$. The variable ξ is constrained to be $>6 \times 10^{-9}$ by the elastic limit of m_p^2/s where m_p is the proton mass. This measurement is restricted to $\xi > 10^{-6}$, the region in which the event selection efficiency exceeds 50%.

Two samples of data events passing the MBTS trigger requirements are selected: an inclusive sample and a single-sided sample. The inclusive selection requires at least two MBTS counters with a charge above 0.15 pC ($n_{\mathrm{MBTS}} \geq 2$). This threshold is chosen to be well above the electronic noise level of the counters. Requiring two hits rather than one substantially reduces background due to collision-induced radiation and activation. To constrain the diffractive component of the cross section and reduce the uncertainty in extrapolation to σ_{inel}, an additional single-sided selection is defined, requiring hits in at least two counters on one side of the detector and no hits on the other. In the data, 4 159 074 events pass the inclusive selection and 442 192 events pass the single-sided selection.

The fiducial cross section is determined by

$$\sigma_{\mathrm{inel}}^{\mathrm{fid}}(\xi > 10^{-6}) = \frac{N - N_{\mathrm{BG}}}{\epsilon_{\mathrm{trig}} \times \mathcal{L}} \times \frac{1 - f_{\xi<10^{-6}}}{\epsilon_{\mathrm{sel}}}, \qquad (1)$$

where N is the number of observed events passing the inclusive selection, N_{BG} is the number of background events, ϵ_{trig} and ϵ_{sel} are factors accounting for the trigger and event selection efficiencies, $1 - f_{\xi<10^{-6}}$ accounts for the migration of events with $\xi < 10^{-6}$ into the fiducial region, and $\mathcal{L}$ is the integrated luminosity of the sample.

Sources of background include interactions between the beam and residual gas in the beam pipe; interactions between the beam and collimators upstream of the detector, which can send charged particles through the detector parallel to the beam; collision-induced radiation; and activation backgrounds. Backgrounds from cosmic rays and instrumental noise are negligible. The mean number of pp collisions in the same LHC bunch crossing was 2.3×10^{-3} for the recorded data set. Thus, the contribution from multiple collisions is also negligible. The beam-related background components are extracted from single-beam events and dominate the total background. They are normalized by scaling the number of selected single-beam events by a factor of $37/4 \times 2$, accounting for the 37 colliding pairs of bunches and 4 bunches producing the single-beam data in this run. The factor of 2 accounts for the presence of two colliding bunches. The number of protons per bunch producing these single-beam events

agrees with that in the colliding bunches to within 10%. The radiation and activation-induced backgrounds are implicitly part of this background estimate. Double-counting of these components is removed using estimates from empty events. The total background contributions to the inclusive and single-sided data samples are determined to be 1.2% and 5.8%, respectively. The classification of single-sided events as double-sided due to noise or other backgrounds is estimated to be below 0.1%. A systematic uncertainty of 50% is assigned to the background based on studies of the background composition and the relative contributions of the background components. This uncertainty is treated as fully correlated between the single-sided and inclusive selections.

The trigger efficiency for events passing the inclusive selection, ϵ_{trig}, is measured with respect to events selected with the LUCID detector after subtracting the background. A trigger efficiency of 99.7% (97.4%) is measured for the inclusive (single-sided) event sample. In both cases the statistical uncertainty is below 0.1%. The efficiency is also measured with events selected by the LHCf detector and agrees within $\pm 0.3\%$ with the LUCID determination. This difference is taken as a systematic uncertainty.

The ratio of the number of events passing the single-sided event selection to the number passing the inclusive selection (R_{SS}) is used to adjust, for each model, the fractional contribution of the single- and double-diffractive dissociative cross section ($\sigma_{\text{SD}} + \sigma_{\text{DD}}$) to the inelastic cross section, $f_{\text{D}} = (\sigma_{\text{SD}} + \sigma_{\text{DD}})/\sigma_{\text{inel}}$ [12]. The measured value is $R_{\text{SS}} = 10.4\%$ with a total uncertainty of $\pm 0.4\%$. The dominant systematic uncertainty arises from the background subtraction in the single-sided sample. For each MC model, f_{D} is varied until it matches the observed R_{SS} value in data. The data uncertainty is used to set the error in the constrained f_{D} for each model. An additional uncertainty in the ratio of single- to double-diffractive events is determined by taking the diffractive events to be entirely SD or to be evenly divided between SD and DD.

Using this method, the fitted f_{D} in the PYTHIA8 samples is between 25% and 31%, depending on the model (the default value is 28%). For the QGSJET-II (EPOS LHC) model the fitted f_{D} is 35% (37%), differing significantly from the default value of 21% (28%). The observed R_{SS} and the MC predictions of its dependence on f_{D} are shown in Fig. 1. The fitted f_{D} is used when determining the acceptance corrections ϵ_{sel} and $f_{\xi<10^{-6}}$ for each model.

In Fig. 2 the n_{MBTS} distributions in data are compared to the ones from MC simulated samples utilizing the fitted f_{D} values for both the inclusive and single-sided selections. The estimated background is subtracted from the measured distribution, and the trigger efficiency measured in data is applied to the simulation. The data distributions and MC simulation are peaked at high multiplicity values. In the single-sided case, $n_{\text{MBTS}} = 12$ corresponds to hits in all counters on one side of the detector. The data agree best

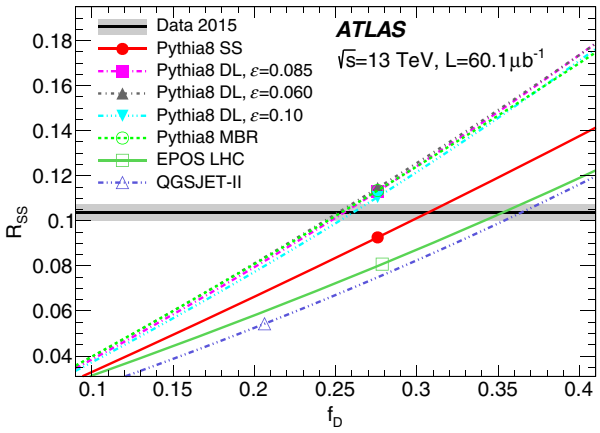

FIG. 1. The ratio of the number of single-sided to inclusive events (R_{SS}) as a function of the fraction of the cross section that is diffractive according to each model (f_{D}). The default value of f_{D} in each model is shown with a marker.

with the DL models, particularly in the low-n_{MBTS} range. The MBR-based distribution provides a slightly worse description of the data. The PYTHIA8 sample using the SS model does not describe data well in the low-multiplicity region. EPOS LHC and QGSJET-II also do not describe the data well, particularly in the single-sided hit multiplicity distribution. Therefore, the PYTHIA8 DL model with $\varepsilon = 0.085$ is chosen as the nominal MC model for the ϵ_{sel} and $f_{\xi<10^{-6}}$ corrections, and only the DL and MBR models are considered for systematic uncertainties related to the MC corrections.

The event selection efficiency, ϵ_{sel}, depends upon the MBTS counter sensitivity. This sensitivity is tested using isolated charged particles, reconstructed as ID tracks in the region $2.07 < |\eta| < 2.5$ where the coverages of the MBTS and ID overlap. Over the full coverage of the MBTS counters, the calorimeter is used to measure the counter efficiency with respect to particles that deposit sufficient energy in the calorimeter to seed a topological energy cluster [39]. Differences between the efficiencies in data and MC simulation are accounted for by adjusting the MBTS charge threshold in MC simulation until the simulated efficiencies match those observed in the data. The residual uncertainty in the counter efficiency after these corrections is $\pm 0.5\%$ for the outer and $\pm 1.0\%$ for the inner counters. Additionally, an uncertainty arising from the knowledge of the material in front of the MBTS detector is estimated using MC samples with an increased amount of material in front of the MBTS. Based on the MC samples, the uncertainty in the efficiency measurement due to modeling of hadronization and the underlying event is estimated to be negligible.

After adjusting the counter charge threshold, ϵ_{sel} is determined from the nominal PYTHIA8 DL MC simulations, using the fitted f_{D} corresponding to this model, to be 99.34% with a statistical uncertainty of $\pm 0.03\%$. The uncertainty in the MBTS counter efficiencies results in

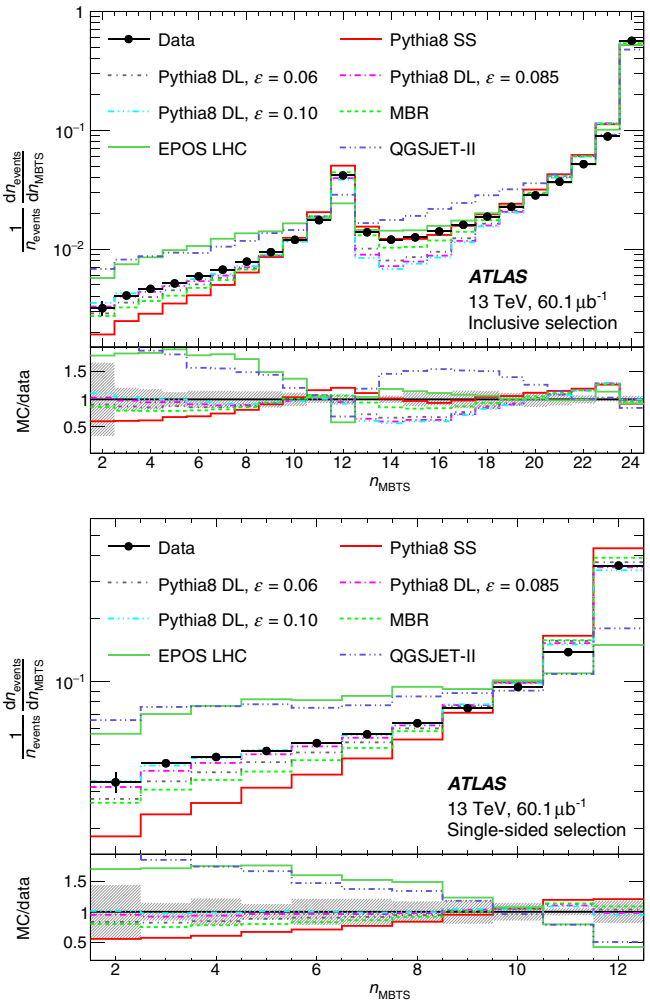

FIG. 2. The background-subtracted distribution of the number of MBTS counters (n_{MBTS}) above threshold in data and MC simulation for (top) the inclusive selection and (bottom) the single-sided selection. The ratio of the MC models to the data is also shown. The experimental uncertainty is shown as a shaded band around the data points. The models shown here use the f_D value determined from the R_{SS} measurement.

only a $\pm 0.1\%$ uncertainty in the overall event selection efficiency, because many counters are hit in typical events. In addition, an uncertainty of $\pm 0.2\%$ in ϵ_{sel} arises from the knowledge of the material in front of the MBTS.

The fraction of events passing the inclusive selection with $\xi < 10^{-6}$ represents an additional background component in the fiducial cross-section measurement. It is determined using the same PYTHIA8 DL MC to be $f_{\xi<10^{-6}} = (1.37 \pm 0.05)\%$, where the uncertainty is statistical.

Because the efficiency and migration corrections are correlated, they are combined in a single correction factor, $C_{\mathrm{MC}} = (1 - f_{\xi<10^{-6}})/\epsilon_{\mathrm{sel}}$, for which systematic uncertainties are assessed. The systematic uncertainties include the counter efficiency variations, the impact of the material uncertainty, the uncertainty in the fitted value of f_{D}, and the variation in C_{MC} found by comparing the PYTHIA8 DL and MBR models. Of these sources of uncertainty, the last is most important at $\pm 0.5\%$. The value of C_{MC} is $(99.3 \pm 0.5)\%$. The uncertainty also implicitly contains an uncertainty due to the CD contribution, since this is included in only some of the models.

TABLE I. Inputs to the calculation of the measured cross section and their systematic uncertainties.

Factor	Value	Relative uncertainty
Number of events passing the inclusive selection (N)	4 159 074	...
Number of background events (N_{BG})	51 187	$\pm 50\%$
Integrated luminosity [$\mu\mathrm{b}^{-1}$] ($\mathcal{L}$)	60.1	$\pm 1.9\%$
Trigger efficiency (ϵ_{trig})	99.7%	$\pm 0.3\%$
MC correction factor (C_{MC})	99.3%	$\pm 0.5\%$

The uncertainty in the integrated luminosity is $\pm 1.9\%$. It is derived, following a methodology similar to that detailed in Refs. [40,41], from a calibration of the luminosity scale using x-y beam-separation scans performed in August 2015. This calibration uncertainty is slightly smaller than what has been reported in Ref. [42] because the low-luminosity data set used in this Letter is not affected by the uncertainties related to high-luminosity runs.

The components of the fiducial cross-section calculation [Eq. (1)] are shown in Table I with their systematic uncertainties. The statistical uncertainties are negligible. The measured fiducial cross section is determined to be

$$\sigma_{\mathrm{inel}}^{\mathrm{fid}} = 68.1 \pm 0.6(\mathrm{exp}) \pm 1.3(\mathrm{lum})\ \mathrm{mb},$$

where the first uncertainty refers to all experimental uncertainties apart from the luminosity and the second refers to the luminosity only.

The PYTHIA8 DL model predicts values of 71.0 mb, 69.1 mb, and 68.1 mb for $\epsilon = 0.06$, 0.085, and 0.10, respectively, all of which are compatible with the measurement. The PYTHIA8 MBR model predicts 70.1 mb, also in agreement with the measurement. The EPOS LHC (71.2 mb) and QGSJET-II (72.7 mb) predictions exceed the data by 2–3σ. The PYTHIA8 SS model predicts 74.4 mb, and thus exceeds the measured value by $\sim 4\sigma$.

The extrapolation to σ_{inel} uses constraints from previous ATLAS measurements to minimize the model dependence of the component that falls outside the fiducial region. σ_{inel} can be written as

$$\sigma_{\mathrm{inel}} = \sigma_{\mathrm{inel}}^{\mathrm{fid}} + \sigma^{7\ \mathrm{TeV}}(\xi < 5 \times 10^{-6}) \times \frac{\sigma^{\mathrm{MC}}(\xi < 10^{-6})}{\sigma^{7\ \mathrm{TeV,MC}}(\xi < 5 \times 10^{-6})}. \quad (2)$$

The term $\sigma^{7\ \mathrm{TeV}}(\xi < 5 \times 10^{-6}) = \sigma_{\mathrm{inel}}^{7\ \mathrm{TeV}} - \sigma^{7\ \mathrm{TeV}}(\xi > 5 \times 10^{-6}) = 9.9 \pm 2.4$ mb is the difference between σ_{inel}

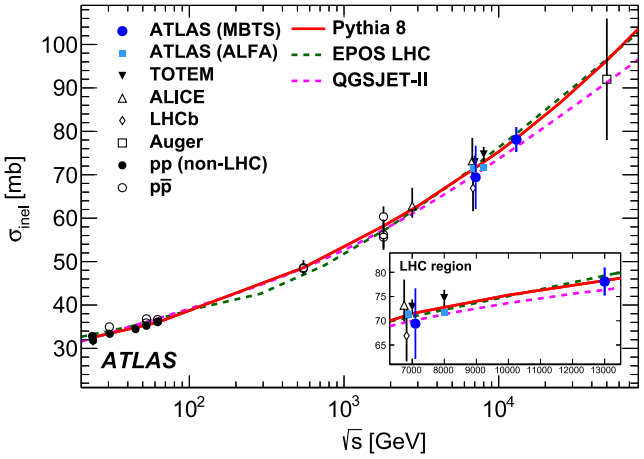

FIG. 3. The inelastic proton-proton cross section versus $\sqrt{s}$. Measurements from other hadron collider experiments [6,7,9,14,15] and the Pierre Auger experiment [16] are also shown. Some LHC data points have been slightly shifted in the horizontal position for display purposes. The data are compared to the PYTHIA8, EPOS LHC and QGSJET-II MC generator predictions. The uncertainty in the ATLAS ALFA measurement is smaller than the marker size.

measured at 7 TeV using the ALFA detector [8], $\sigma_{\text{inel}}^{7\text{ TeV}}$, and σ_{inel} measured at 7 TeV for $\xi > 5 \times 10^{-6}$ using the MBTS [12] (The 7 TeV result is corrected upward by 1.9% following an improved luminosity calibration [40]). The uncertainties of the two measurements are uncorrelated.

The PYTHIA8 DL and PYTHIA8 MBR MC samples are used to assess the systematic uncertainty in the MC-derived ratio of cross sections in Eq. (2), which is determined to be 1.015 ± 0.081. (The value of the ratio arises from an approximately 20% increased cross section from increasing $\sqrt{s}$ which is largely compensated by a 15% decrease due to the change in the ξ distribution.) These models also agree with the measurement of $\sigma^{7\text{ TeV}}(\xi < 5 \times 10^{-6})$ to within 2σ.

The measured value for σ_{inel} is

$$\sigma_{\text{inel}} = 78.1 \pm 0.6(\text{exp}) \pm 1.3(\text{lum}) \pm 2.6(\text{extrap})\ \text{mb}.$$

This and other inelastic cross-section measurements are compared to several Monte Carlo models in Fig. 3. Additional predictions range between 76.6 and 81.6 mb [43–47]. Compared to the measurement with the ALFA detector at $\sqrt{s} = 7$ TeV the cross section is higher by $(9 \pm 4)\%$.

In summary, a measurement of the inelastic cross section in 60 μb^{-1} of proton-proton collision data at $\sqrt{s} = 13$ TeV collected with the ATLAS detector at the LHC is presented. The measurement is performed in a fiducial region $\xi > 10^{-6}$, and the result is extrapolated to the inelastic cross section using measurements at $\sqrt{s} = 7$ TeV. The measured cross section agrees well with a variety of theoretical predictions and is consistent with the inelastic cross section increasing with center-of-mass energy, as observed at lower energies.

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, CEA-DSM/IRFU, France; GNSF, Georgia; BMBF, HGF, and MPG, Germany; GSRT, Greece; RGC, Hong Kong SAR, China; ISF, I-CORE and Benoziyo Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; FOM and 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, the Canada Council, CANARIE, CRC, Compute Canada, FQRNT, and the Ontario Innovation Trust, Canada; EPLANET, ERC, FP7, Horizon 2020 and Marie Skłodowska-Curie Actions, European Union; Investissements d'Avenir Labex and Idex, ANR, Région Auvergne and Fondation Partager le Savoir, France; DFG and AvH Foundation, Germany; Herakleitos, Thales and Aristeia programmes co-financed by EU-ESF and the Greek NSRF; BSF, GIF and Minerva, Israel; BRF, Norway; Generalitat de Catalunya, Generalitat Valenciana, 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. [48].

Swiss National Science Foundation

[1] W. Heisenberg, Production of mesons as a shock wave problem, Z. Phys. **133**, 65 (1952).

[2] U. Amaldi, R. Biancastelli, C. Bosio, G. Matthiae, J. V. Allaby, W. Bartel, G. Cocconi, A. N. Diddens, R. W. Dobinson, and A. M. Wetherell, The energy dependence of the proton-proton total cross-section for centre-of-mass

energies between 23 and 53 GeV, Phys. Lett. **44B**, 112 (1973).
[3] M. Froissart, Asymptotic behavior and subtractions in the Mandelstam representation, Phys. Rev. **123**, 1053 (1961).
[4] A. Martin, Extension of the axiomatic analyticity domain of scattering amplitudes by unitarity, Nuovo Cimento A **42**, 930 (1966).
[5] A. Martin, Froissart bound for inelastic cross sections, Phys. Rev. D **80**, 065013 (2009).
[6] K. A. Olive *et al.* (Particle Data Group), Review of particle physics, Chin. Phys. C **38**, 090001 (2014) and 2015 update, Section 50.
[7] G. Antchev *et al.* (TOTEM Collaboration), Luminosity-independent measurements of total, elastic and inelastic cross-sections at $\sqrt{s} = 7$ TeV, Europhys. Lett. **101**, 21004 (2013).
[8] ATLAS Collaboration, Measurement of the total cross section from elastic scattering in pp collisions at $\sqrt{s} =$ 7 TeV with the ATLAS detector, Nucl. Phys. **B889**, 486 (2014).
[9] G. Antchev *et al.* (TOTEM Collaboration), Luminosity-Independent Measurement of the Proton-Proton Total Cross Section at $\sqrt{s} = 8$ TeV, Phys. Rev. Lett. **111**, 012001 (2013).
[10] G. Antchev *et al.* (TOTEM Collaboration), CERN Report No. CERN-PH-EP-2015-325, 2015, http://cdsweb.cern.ch/record/2114603.
[11] ATLAS Collaboration, Measurement of the total cross section from elastic scattering in pp collisions at $\sqrt{s} =$ 8 TeV with the ATLAS detector, Phys. Lett. B **761**, 158 (2016).
[12] ATLAS Collaboration, Measurement of the inelastic proton-proton cross-section at $\sqrt{s} = 7$ TeV with the ATLAS detector, Nat. Commun. **2**, 463 (2011).
[13] CMS Collaboration, Measurement of the inelastic proton-proton cross section at $\sqrt{s} = 7$ TeV, Phys. Lett. B **722**, 5 (2013).
[14] B. Abelev *et al.* (ALICE Collaboration), Measurement of inelastic, single- and double-diffraction cross sections in proton-proton collisions at the LHC with ALICE, Eur. Phys. J. C **73**, 2456 (2013).
[15] R. Aaij *et al.* (LHCb Collaboration), Measurement of the inelastic pp cross-section at a centre-of-mass energy of $\sqrt{s} = 7$ TeV, J. High Energy Phys. 02 (2015) 129.
[16] P. Abreu *et al.* (Pierre Auger Collaboration), Measurement of the proton-air cross-section at $\sqrt{s} = 57$ TeV with the Pierre Auger Observatory, Phys. Rev. Lett. **109**, 062002 (2012).
[17] ATLAS Collaboration, The ATLAS experiment at the CERN Large Hadron Collider, J. Instrum. **3**, S08003 (2008).
[18] 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 beam pipe. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln\tan(\theta/2)$.
[19] O Adriani *et al.* (LHCf Collaboration), The LHCf detector at the CERN Large Hadron Collider, J. Instrum. **3**, S08006 (2008).
[20] J. Allison *et al.*, Geant4 developments and applications, IEEE Trans. Nucl. Sci. **53**, 270 (2006).
[21] S. Agostinelli *et al.*, Geant4—A Simulation Toolkit, Nucl. Instrum. Methods Phys. Res., Sect. A **506**, 250 (2003).
[22] ATLAS Collaboration, The ATLAS simulation infrastructure, Eur. Phys. J. C **70**, 823 (2010).
[23] T. Sjöstrand, S. Mrenna, and P. Skands, PYTHIA 6.4 physics and manual, J. High Energy Phys. 05 (2006) 026.
[24] T. Sjöstrand, S. Mrenna, and P. Skands, A brief introduction to PYTHIA 8.1, Comput. Phys. Commun. **178**, 852 (2008).
[25] ATLAS Collaboration, CERN Report No. ATL-PHYS-PUB-2012-003, 2012, http://cds.cern.ch/record/1474107.
[26] A. D. Martin, W. J. Stirling, R. S. Thorne, and G. Watt, Parton distributions for the LHC, Eur. Phys. J. C **63**, 189 (2009).
[27] P. Skands, S. Carrazza, and J. Rojo, Tuning PYTHIA 8.1: The Monash 2013 Tune, Eur. Phys. J. C **74**, 3024 (2014).
[28] R. D. Ball *et al.*, Parton distributions with LHC data, Nucl. Phys. **B867**, 244 (2013).
[29] G. Ingelman and P. Schlein, Jet structure in high mass diffractive scattering, Phys. Lett. **152B**, 256 (1985).
[30] G. A. Schuler and T. Sjöstrand, Hadronic diffractive cross sections and the rise of the total cross section, Phys. Rev. D **49**, 2257 (1994).
[31] S. Navin, Diffraction in Pythia, arXiv:1005.3894.
[32] A. Donnachie and P. Landshoff, Elastic scattering and diffraction dissociation, Nucl. Phys. **B244**, 322 (1984).
[33] R. Ciesielski and K. Goulianos, MBR Monte Carlo simulation in PYTHIA8, *Proc. Sci.* ICHEP2012 (2012) 3 [arXiv:1205.1446].
[34] ATLAS Collaboration, Rapidity gap cross sections measured with the ATLAS detector in pp collisions at $\sqrt{s} = 7$ TeV, Eur. Phys. J. C **72**, 1926 (2012).
[35] CMS Collaboration, Measurement of diffraction dissociation cross sections in pp collisions at s $= 7$ TeV, Phys. Rev. D **92**, 012003 (2015).
[36] T. Pierog, I. Karpenko, J. M. Katzy, E. Yatsenko, and K. Werner, EPOS LHC: Test of collective hadronization with data measured at the CERN Large Hadron Collider, Phys. Rev. C **92**, 034906 (2015).
[37] S. Ostapchenko, Monte Carlo treatment of hadronic interactions in enhanced Pomeron scheme: I. QGSJET-II model, Phys. Rev. D **83**, 014018 (2011).
[38] S. Ostapchenko, LHC data on inelastic diffraction and uncertainties in the predictions for longitudinal EAS development, Phys. Rev. D **89**, 074009 (2014).
[39] ATLAS Collaboration, Topological cell clustering in the ATLAS calorimeters and its performance in LHC Run 1, arXiv:1603.02934.
[40] ATLAS Collaboration, Improved luminosity determination in pp collisions at $\sqrt{s} = 7$ TeV using the ATLAS detector at the LHC, Eur. Phys. J. C **73**, 2518 (2013).
[41] ATLAS Collaboration, CERN Report No. CERN-PH-EP-2016-117, 2016, http://cds.cern.ch/record/2208146.
[42] ATLAS Collaboration, Measurement of the $W^{\pm}Z$-boson production cross sections in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS Detector, Phys. Lett. B **759**, 601 (2016).

[43] B. Z. Kopeliovich, I. K. Potashnikova, and B. Povh, Two-scale hadronic structure and elastic pp scattering: Predicted and measured, Phys. Rev. D **86**, 051502 (2012).
[44] M. J. Menon and P. V. R. G. Silva, An updated analysis on the rise of the hadronic total cross-section at the LHC energy region, Int. J. Mod. Phys. A **28**, 1350099 (2013).
[45] V. Khoze, A. Martin, and M. Ryskin, High energy elastic and diffractive cross sections, Eur. Phys. J. C **74**, 2756 (2014).
[46] E. Gotsman, E. Levin, and U. Maor, A model for strong interactions at high energy based on the CGC/saturation approach, Eur. Phys. J. C **75**, 18 (2015).
[47] D. A. Fagundes, A. Grau, G. Pancheri, Y. N. Srivastava, and O. Shekhovtsova, Soft edge of hadron scattering and mini-jet models for the total and inelastic pp cross-sections at LHC and beyond, Phys. Rev. D **91**, 114011 (2015).
[48] ATLAS Collaboration, CERN Report No. ATL-GEN-PUB-2016-002, 2016, http://cds.cern.ch/record/2202407.

M. Aaboud,[135d] G. Aad,[86] B. Abbott,[113] J. Abdallah,[64] O. Abdinov,[12] B. Abeloos,[117] R. Aben,[107] O. S. AbouZeid,[137] N. L. Abraham,[149] H. Abramowicz,[153] H. Abreu,[152] R. Abreu,[116] Y. Abulaiti,[146a,146b] B. S. Acharya,[163a,163b,b] L. Adamczyk,[40a] D. L. Adams,[27] J. Adelman,[108] S. Adomeit,[100] T. Adye,[131] A. A. Affolder,[75] T. Agatonovic-Jovin,[14] J. Agricola,[56] J. A. Aguilar-Saavedra,[126a,126f] S. P. Ahlen,[24] F. Ahmadov,[66,c] G. Aielli,[133a,133b] H. Akerstedt,[146a,146b] T. P. A. Åkesson,[82] A. V. Akimov,[96] G. L. Alberghi,[22a,22b] J. Albert,[168] S. Albrand,[57] M. J. Alconada Verzini,[72] M. Aleksa,[32] I. N. Aleksandrov,[66] C. Alexa,[28b] G. Alexander,[153] T. Alexopoulos,[10] M. Alhroob,[113] B. Ali,[128] M. Aliev,[74a,74b] G. Alimonti,[92a] J. Alison,[33] S. P. Alkire,[37] B. M. M. Allbrooke,[149] B. W. Allen,[116] P. P. Allport,[19] A. Aloisio,[104a,104b] A. Alonso,[38] F. Alonso,[72] C. Alpigiani,[138] M. Alstaty,[86] B. Alvarez Gonzalez,[32] D. Álvarez Piqueras,[166] M. G. Alviggi,[104a,104b] B. T. Amadio,[16] K. Amako,[67] Y. Amaral Coutinho,[26a] C. Amelung,[25] D. Amidei,[90] S. P. Amor Dos Santos,[126a,126c] A. Amorim,[126a,126b] S. Amoroso,[32] G. Amundsen,[25] C. Anastopoulos,[139] L. S. Ancu,[51] N. Andari,[19] T. Andeen,[11] C. F. Anders,[59b] G. Anders,[32] J. K. Anders,[75] K. J. Anderson,[33] A. Andreazza,[92a,92b] V. Andrei,[59a] S. Angelidakis,[9] I. Angelozzi,[107] P. Anger,[46] A. Angerami,[37] F. Anghinolfi,[32] A. V. Anisenkov,[109,d] N. Anjos,[13] A. Annovi,[124a,124b] C. Antel,[59a] M. Antonelli,[49] A. Antonov,[98,a] F. Anulli,[132a] M. Aoki,[67] L. Aperio Bella,[19] G. Arabidze,[91] Y. Arai,[67] J. P. Araque,[126a] A. T. H. Arce,[47] F. A. Arduh,[72] J-F. Arguin,[95] S. Argyropoulos,[64] M. Arik,[20a] A. J. Armbruster,[143] L. J. Armitage,[77] O. Arnaez,[32] H. Arnold,[50] M. Arratia,[30] O. Arslan,[23] A. Artamonov,[97] G. Artoni,[120] S. Artz,[84] S. Asai,[155] N. Asbah,[44] A. Ashkenazi,[153] B. Åsman,[146a,146b] L. Asquith,[149] K. Assamagan,[27] R. Astalos,[144a] M. Atkinson,[165] N. B. Atlay,[141] K. Augsten,[128] G. Avolio,[32] B. Axen,[16] M. K. Ayoub,[117] G. Azuelos,[95,e] M. A. Baak,[32] A. E. Baas,[59a] M. J. Baca,[19] H. Bachacou,[136] K. Bachas,[74a,74b] M. Backes,[148] M. Backhaus,[32] P. Bagiacchi,[132a,132b] P. Bagnaia,[132a,132b] Y. Bai,[35a] J. T. Baines,[131] O. K. Baker,[175] E. M. Baldin,[109,d] P. Balek,[171] T. Balestri,[148] F. Balli,[136] W. K. Balunas,[122] E. Banas,[41] Sw. Banerjee,[172,f] A. A. E. Bannoura,[174] L. Barak,[32] E. L. Barberio,[89] D. Barberis,[52a,52b] M. Barbero,[86] T. Barillari,[101] M-S Barisits,[32] T. Barklow,[143] N. Barlow,[30] S. L. Barnes,[85] B. M. Barnett,[131] R. M. Barnett,[16] Z. Barnovska,[5] A. Baroncelli,[134a] G. Barone,[25] A. J. Barr,[120] L. Barranco Navarro,[166] F. Barreiro,[83] J. Barreiro Guimarães da Costa,[35a] R. Bartoldus,[143] A. E. Barton,[73] P. Bartos,[144a] A. Basalaev,[123] A. Bassalat,[117] R. L. Bates,[55] S. J. Batista,[158] J. R. Batley,[30] M. Battaglia,[137] M. Bauce,[132a,132b] F. Bauer,[136] H. S. Bawa,[143,g] J. B. Beacham,[111] M. D. Beattie,[73] T. Beau,[81] P. H. Beauchemin,[161] P. Bechtle,[23] H. P. Beck,[18,h] K. Becker,[120] M. Becker,[84] M. Beckingham,[169] C. Becot,[110] A. J. Beddall,[20e] A. Beddall,[20b] V. A. Bednyakov,[66] M. Bedognetti,[107] C. P. Bee,[148] L. J. Beemster,[107] T. A. Beermann,[32] M. Begel,[27] J. K. Behr,[44] C. Belanger-Champagne,[88] A. S. Bell,[79] G. Bella,[153] L. Bellagamba,[22a] A. Bellerive,[31] M. Bellomo,[87] K. Belotskiy,[98] O. Beltramello,[32] N. L. Belyaev,[98] O. Benary,[153] D. Benchekroun,[135a] M. Bender,[100] K. Bendtz,[146a,146b] N. Benekos,[10] Y. Benhammou,[153] E. Benhar Noccioli,[175] J. Benitez,[64] D. P. Benjamin,[47] J. R. Bensinger,[25] S. Bentvelsen,[107] L. Beresford,[120] M. Beretta,[49] D. Berge,[107] E. Bergeaas Kuutmann,[164] N. Berger,[5] J. Beringer,[16] S. Berlendis,[57] N. R. Bernard,[87] C. Bernius,[110] F. U. Bernlochner,[23] T. Berry,[78] P. Berta,[129] C. Bertella,[84] G. Bertoli,[146a,146b] F. Bertolucci,[124a,124b] I. A. Bertram,[73] C. Bertsche,[44] D. Bertsche,[113] G. J. Besjes,[38] O. Bessidskaia Bylund,[146a,146b] M. Bessner,[44] N. Besson,[136] C. Betancourt,[50] A. Bethani,[57] S. Bethke,[101] A. J. Bevan,[77] R. M. Bianchi,[125] L. Bianchini,[25] M. Bianco,[32] O. Biebel,[100] D. Biedermann,[17] R. Bielski,[85] N. V. Biesuz,[124a,124b] M. Biglietti,[134a] J. Bilbao De Mendizabal,[51] T. R. V. Billoud,[95] H. Bilokon,[49] M. Bindi,[56] S. Binet,[117] A. Bingul,[20b] C. Bini,[132a,132b] S. Biondi,[22a,22b] T. Bisanz,[56] D. M. Bjergaard,[47] C. W. Black,[150] J. E. Black,[143] K. M. Black,[24] D. Blackburn,[138] R. E. Blair,[6] J.-B. Blanchard,[136] T. Blazek,[144a] I. Bloch,[44] C. Blocker,[25] W. Blum,[84,a] U. Blumenschein,[56] S. Blunier,[34a] G. J. Bobbink,[107] V. S. Bobrovnikov,[109,d] S. S. Bocchetta,[82] A. Bocci,[47] C. Bock,[100] M. Boehler,[50] D. Boerner,[174] J. A. Bogaerts,[32]

D. Bogavac,[14] A. G. Bogdanchikov,[109] C. Bohm,[146a] V. Boisvert,[78] P. Bokan,[14] T. Bold,[40a] A. S. Boldyrev,[163a,163c] M. Bomben,[81] M. Bona,[77] M. Boonekamp,[136] A. Borisov,[130] G. Borissov,[73] J. Bortfeldt,[32] D. Bortoletto,[120] V. Bortolotto,[61a,61b,61c] K. Bos,[107] D. Boscherini,[22a] M. Bosman,[13] J. D. Bossio Sola,[29] J. Boudreau,[125] J. Bouffard,[2] E. V. Bouhova-Thacker,[73] D. Boumediene,[36] C. Bourdarios,[117] S. K. Boutle,[55] A. Boveia,[32] J. Boyd,[32] I. R. Boyko,[66] J. Bracinik,[19] A. Brandt,[8] G. Brandt,[56] O. Brandt,[59a] U. Bratzler,[156] B. Brau,[87] J. E. Brau,[116] H. M. Braun,[174,a] W. D. Breaden Madden,[55] K. Brendlinger,[122] A. J. Brennan,[89] L. Brenner,[107] R. Brenner,[164] S. Bressler,[171] T. M. Bristow,[48] D. Britton,[55] D. Britzger,[44] F. M. Brochu,[30] I. Brock,[23] R. Brock,[91] G. Brooijmans,[37] T. Brooks,[78] W. K. Brooks,[34b] J. Brosamer,[16] E. Brost,[108] J. H Broughton,[19] P. A. Bruckman de Renstrom,[41] D. Bruncko,[144b] R. Bruneliere,[50] A. Bruni,[22a] G. Bruni,[22a] L. S. Bruni,[107] BH Brunt,[30] M. Bruschi,[22a] N. Bruscino,[23] P. Bryant,[33] L. Bryngemark,[82] T. Buanes,[15] Q. Buat,[142] P. Buchholz,[141] A. G. Buckley,[55] I. A. Budagov,[66] F. Buehrer,[50] M. K. Bugge,[119] O. Bulekov,[98] D. Bullock,[8] H. Burckhart,[32] S. Burdin,[75] C. D. Burgard,[50] B. Burghgrave,[108] K. Burka,[41] S. Burke,[131] I. Burmeister,[45] J. T. P. Burr,[120] E. Busato,[36] D. Büscher,[50] V. Büscher,[84] P. Bussey,[55] J. M. Butler,[24] C. M. Buttar,[55] J. M. Butterworth,[79] P. Butti,[107] W. Buttinger,[27] A. Buzatu,[55] A. R. Buzykaev,[109,d] S. Cabrera Urbán,[166] D. Caforio,[128] V. M. Cairo,[39a,39b] O. Cakir,[4a] N. Calace,[51] P. Calafiura,[16] A. Calandri,[86] G. Calderini,[81] P. Calfayan,[100] G. Callea,[39a,39b] L. P. Caloba,[26a] S. Calvente Lopez,[83] D. Calvet,[36] S. Calvet,[36] T. P. Calvet,[86] R. Camacho Toro,[33] S. Camarda,[32] P. Camarri,[133a,133b] D. Cameron,[119] R. Caminal Armadans,[165] C. Camincher,[57] S. Campana,[32] M. Campanelli,[79] A. Camplani,[92a,92b] A. Campoverde,[141] V. Canale,[104a,104b] A. Canepa,[159a] M. Cano Bret,[35e] J. Cantero,[114] R. Cantrill,[126a] T. Cao,[42] M. D. M. Capeans Garrido,[32] I. Caprini,[28b] M. Caprini,[28b] M. Capua,[39a,39b] R. Caputo,[84] R. M. Carbone,[37] R. Cardarelli,[133a] F. Cardillo,[50] I. Carli,[129] T. Carli,[32] G. Carlino,[104a] L. Carminati,[92a,92b] S. Caron,[106] E. Carquin,[34b] G. D. Carrillo-Montoya,[32] J. R. Carter,[30] J. Carvalho,[126a,126c] D. Casadei,[19] M. P. Casado,[13,i] M. Casolino,[13] D. W. Casper,[162] E. Castaneda-Miranda,[145a] R. Castelijn,[107] A. Castelli,[107] V. Castillo Gimenez,[166] N. F. Castro,[126a,j] A. Catinaccio,[32] J. R. Catmore,[119] A. Cattai,[32] J. Caudron,[23] V. Cavaliere,[165] E. Cavallaro,[13] D. Cavalli,[92a] M. Cavalli-Sforza,[13] V. Cavasinni,[124a,124b] F. Ceradini,[134a,134b] L. Cerda Alberich,[166] B. C. Cerio,[47] A. S. Cerqueira,[26b] A. Cerri,[149] L. Cerrito,[133a,133b] F. Cerutti,[16] M. Cerv,[32] A. Cervelli,[18] S. A. Cetin,[20d] A. Chafaq,[135a] D. Chakraborty,[108] S. K. Chan,[58] Y. L. Chan,[61a] P. Chang,[165] J. D. Chapman,[30] D. G. Charlton,[19] A. Chatterjee,[51] C. C. Chau,[158] C. A. Chavez Barajas,[149] S. Che,[111] S. Cheatham,[73] A. Chegwidden,[91] S. Chekanov,[6] S. V. Chekulaev,[159a] G. A. Chelkov,[66,k] M. A. Chelstowska,[90] C. Chen,[65] H. Chen,[27] K. Chen,[148] S. Chen,[35c] S. Chen,[155] X. Chen,[35f] Y. Chen,[68] H. C. Cheng,[90] H. J Cheng,[35a] Y. Cheng,[33] A. Cheplakov,[66] E. Cheremushkina,[130] R. Cherkaoui El Moursli,[135e] V. Chernyatin,[27,a] E. Cheu,[7] L. Chevalier,[136] V. Chiarella,[49] G. Chiarelli,[124a,124b] G. Chiodini,[74a] A. S. Chisholm,[19] A. Chitan,[28b] M. V. Chizhov,[66] K. Choi,[62] A. R. Chomont,[36] S. Chouridou,[9] B. K. B. Chow,[100] V. Christodoulou,[79] D. Chromek-Burckhart,[32] J. Chudoba,[127] A. J. Chuinard,[88] J. J. Chwastowski,[41] L. Chytka,[115] G. Ciapetti,[132a,132b] A. K. Ciftci,[4a] D. Cinca,[45] V. Cindro,[76] I. A. Cioara,[23] C. Ciocca,[22a,22b] A. Ciocio,[16] F. Cirotto,[104a,104b] Z. H. Citron,[171] M. Citterio,[92a] M. Ciubancan,[28b] A. Clark,[51] B. L. Clark,[58] M. R. Clark,[37] P. J. Clark,[48] R. N. Clarke,[16] C. Clement,[146a,146b] Y. Coadou,[86] M. Cobal,[163a,163c] A. Coccaro,[51] J. Cochran,[65] L. Colasurdo,[106] B. Cole,[37] A. P. Colijn,[107] J. Collot,[57] T. Colombo,[32] G. Compostella,[101] P. Conde Muiño,[126a,126b] E. Coniavitis,[50] S. H. Connell,[145b] I. A. Connelly,[78] V. Consorti,[50] S. Constantinescu,[28b] G. Conti,[32] F. Conventi,[104a,l] M. Cooke,[16] B. D. Cooper,[79] A. M. Cooper-Sarkar,[120] K. J. R. Cormier,[158] T. Cornelissen,[174] M. Corradi,[132a,132b] F. Corriveau,[88,m] A. Corso-Radu,[162] A. Cortes-Gonzalez,[32] G. Cortiana,[101] G. Costa,[92a] M. J. Costa,[166] D. Costanzo,[139] G. Cottin,[30] G. Cowan,[78] B. E. Cox,[85] K. Cranmer,[110] S. J. Crawley,[55] G. Cree,[31] S. Crépé-Renaudin,[57] F. Crescioli,[81] W. A. Cribbs,[146a,146b] M. Crispin Ortuzar,[120] M. Cristinziani,[23] V. Croft,[106] G. Crosetti,[39a,39b] A. Cueto,[83] T. Cuhadar Donszelmann,[139] J. Cummings,[175] M. Curatolo,[49] J. Cúth,[84] H. Czirr,[141] P. Czodrowski,[3] G. D'amen,[22a,22b] S. D'Auria,[55] M. D'Onofrio,[75] M. J. Da Cunha Sargedas De Sousa,[126a,126b] C. Da Via,[85] W. Dabrowski,[40a] T. Dado,[144a] T. Dai,[90] O. Dale,[15] F. Dallaire,[95] C. Dallapiccola,[87] M. Dam,[38] J. R. Dandoy,[33] N. P. Dang,[50] A. C. Daniells,[19] N. S. Dann,[85] M. Danninger,[167] M. Dano Hoffmann,[136] V. Dao,[50] G. Darbo,[52a] S. Darmora,[8] J. Dassoulas,[3] A. Dattagupta,[62] W. Davey,[23] C. David,[168] T. Davidek,[129] M. Davies,[153] P. Davison,[79] E. Dawe,[89] I. Dawson,[139] R. K. Daya-Ishmukhametova,[87] K. De,[8] R. de Asmundis,[104a] A. De Benedetti,[113] S. De Castro,[22a,22b] S. De Cecco,[81] N. De Groot,[106] P. de Jong,[107] H. De la Torre,[83] F. De Lorenzi,[65] A. De Maria,[56] D. De Pedis,[132a] A. De Salvo,[132a] U. De Sanctis,[149] A. De Santo,[149] J. B. De Vivie De Regie,[117] W. J. Dearnaley,[73] R. Debbe,[27] C. Debenedetti,[137] D. V. Dedovich,[66] N. Dehghanian,[3] I. Deigaard,[107] M. Del Gaudio,[39a,39b] J. Del Peso,[83] T. Del Prete,[124a,124b] D. Delgove,[117] F. Deliot,[136] C. M. Delitzsch,[51] A. Dell'Acqua,[32] L. Dell'Asta,[24] M. Dell'Orso,[124a,124b] M. Della Pietra,[104a,l] D. della Volpe,[51] M. Delmastro,[5] P. A. Delsart,[57]

D. A. DeMarco,[158] S. Demers,[175] M. Demichev,[66] A. Demilly,[81] S. P. Denisov,[130] D. Denysiuk,[136] D. Derendarz,[41] J. E. Derkaoui,[135d] F. Derue,[81] P. Dervan,[75] K. Desch,[23] C. Deterre,[44] K. Dette,[45] P. O. Deviveiros,[32] A. Dewhurst,[131] S. Dhaliwal,[25] A. Di Ciaccio,[133a,133b] L. Di Ciaccio,[5] W. K. Di Clemente,[122] C. Di Donato,[132a,132b] A. Di Girolamo,[32] B. Di Girolamo,[32] B. Di Micco,[134a,134b] R. Di Nardo,[32] A. Di Simone,[50] R. Di Sipio,[158] D. Di Valentino,[31] C. Diaconu,[86] M. Diamond,[158] F. A. Dias,[48] M. A. Diaz,[34a] E. B. Diehl,[90] J. Dietrich,[17] S. Diglio,[86] A. Dimitrievska,[14] J. Dingfelder,[23] P. Dita,[28b] S. Dita,[28b] F. Dittus,[32] F. Djama,[86] T. Djobava,[53b] J. I. Djuvsland,[59a] M. A. B. do Vale,[26c] D. Dobos,[32] M. Dobre,[28b] C. Doglioni,[82] J. Dolejsi,[129] Z. Dolezal,[129] M. Donadelli,[26d] S. Donati,[124a,124b] P. Dondero,[121a,121b] J. Donini,[36] J. Dopke,[131] A. Doria,[104a] M. T. Dova,[72] A. T. Doyle,[55] E. Drechsler,[56] M. Dris,[10] Y. Du,[35d] J. Duarte-Campderros,[153] E. Duchovni,[171] G. Duckeck,[100] O. A. Ducu,[95,n] D. Duda,[107] A. Dudarev,[32] A. Chr. Dudder,[84] E. M. Duffield,[16] L. Duflot,[117] M. Dührssen,[32] M. Dumancic,[171] M. Dunford,[59a] H. Duran Yildiz,[4a] M. Düren,[54] A. Durglishvili,[53b] D. Duschinger,[46] B. Dutta,[44] M. Dyndal,[44] C. Eckardt,[44] K. M. Ecker,[101] R. C. Edgar,[90] N. C. Edwards,[48] T. Eifert,[32] G. Eigen,[15] K. Einsweiler,[16] T. Ekelof,[164] M. El Kacimi,[135c] V. Ellajosyula,[86] M. Ellert,[164] S. Elles,[5] F. Ellinghaus,[174] A. A. Elliot,[168] N. Ellis,[32] J. Elmsheuser,[27] M. Elsing,[32] D. Emeliyanov,[131] Y. Enari,[155] O. C. Endner,[84] J. S. Ennis,[169] J. Erdmann,[45] A. Ereditato,[18] G. Ernis,[174] J. Ernst,[2] M. Ernst,[27] S. Errede,[165] E. Ertel,[84] M. Escalier,[117] H. Esch,[45] C. Escobar,[125] B. Esposito,[49] A. I. Etienvre,[136] E. Etzion,[153] H. Evans,[62] A. Ezhilov,[123] F. Fabbri,[22a,22b] L. Fabbri,[22a,22b] G. Facini,[33] R. M. Fakhrutdinov,[130] S. Falciano,[132a] R. J. Falla,[79] J. Faltova,[32] Y. Fang,[35a] M. Fanti,[92a,92b] A. Farbin,[8] A. Farilla,[134a] C. Farina,[125] E. M. Farina,[121a,121b] T. Farooque,[13] S. Farrell,[16] S. M. Farrington,[169] P. Farthouat,[32] F. Fassi,[135e] P. Fassnacht,[32] D. Fassouliotis,[9] M. Faucci Giannelli,[78] A. Favareto,[52a,52b] W. J. Fawcett,[120] L. Fayard,[117] O. L. Fedin,[123,o] W. Fedorko,[167] S. Feigl,[119] L. Feligioni,[86] C. Feng,[35d] E. J. Feng,[32] H. Feng,[90] A. B. Fenyuk,[130] L. Feremenga,[8] P. Fernandez Martinez,[166] S. Fernandez Perez,[13] J. Ferrando,[55] A. Ferrari,[164] P. Ferrari,[107] R. Ferrari,[121a] D. E. Ferreira de Lima,[59b] A. Ferrer,[166] D. Ferrere,[51] C. Ferretti,[90] A. Ferretto Parodi,[52a,52b] F. Fiedler,[84] A. Filipčič,[76] M. Filipuzzi,[44] F. Filthaut,[106] M. Fincke-Keeler,[168] K. D. Finelli,[150] M. C. N. Fiolhais,[126a,126c] L. Fiorini,[166] A. Firan,[42] A. Fischer,[2] C. Fischer,[13] J. Fischer,[174] W. C. Fisher,[91] N. Flaschel,[44] I. Fleck,[141] P. Fleischmann,[90] G. T. Fletcher,[139] R. R. M. Fletcher,[122] T. Flick,[174] A. Floderus,[82] L. R. Flores Castillo,[61a] M. J. Flowerdew,[101] G. T. Forcolin,[85] A. Formica,[136] A. Forti,[85] A. G. Foster,[19] D. Fournier,[117] H. Fox,[73] S. Fracchia,[13] P. Francavilla,[81] M. Franchini,[22a,22b] D. Francis,[32] L. Franconi,[119] M. Franklin,[58] M. Frate,[162] M. Fraternali,[121a,121b] D. Freeborn,[79] S. M. Fressard-Batraneanu,[32] F. Friedrich,[46] D. Froidevaux,[32] J. A. Frost,[120] C. Fukunaga,[156] E. Fullana Torregrosa,[84] T. Fusayasu,[102] J. Fuster,[166] C. Gabaldon,[57] O. Gabizon,[174] A. Gabrielli,[22a,22b] A. Gabrielli,[16] G. P. Gach,[40a] S. Gadatsch,[32] S. Gadomski,[51] G. Gagliardi,[52a,52b] L. G. Gagnon,[95] P. Gagnon,[62] C. Galea,[106] B. Galhardo,[126a,126c] E. J. Gallas,[120] B. J. Gallop,[131] P. Gallus,[128] G. Galster,[38] K. K. Gan,[111] J. Gao,[35b,86] Y. Gao,[48] Y. S. Gao,[143,g] F. M. Garay Walls,[48] C. García,[166] J. E. García Navarro,[166] M. Garcia-Sciveres,[16] R. W. Gardner,[33] N. Garelli,[143] V. Garonne,[119] A. Gascon Bravo,[44] K. Gasnikova,[44] C. Gatti,[49] A. Gaudiello,[52a,52b] G. Gaudio,[121a] L. Gauthier,[95] I. L. Gavrilenko,[96] C. Gay,[167] G. Gaycken,[23] E. N. Gazis,[10] Z. Gecse,[167] C. N. P. Gee,[131] Ch. Geich-Gimbel,[23] M. Geisen,[84] M. P. Geisler,[59a] C. Gemme,[52a] M. H. Genest,[57] C. Geng,[35b,p] S. Gentile,[132a,132b] C. Gentsos,[154] S. George,[78] D. Gerbaudo,[13] A. Gershon,[153] S. Ghasemi,[141] H. Ghazlane,[135b] M. Ghneimat,[23] B. Giacobbe,[22a] S. Giagu,[132a,132b] P. Giannetti,[124a,124b] B. Gibbard,[27] S. M. Gibson,[78] M. Gignac,[167] M. Gilchriese,[16] T. P. S. Gillam,[30] D. Gillberg,[31] G. Gilles,[174] D. M. Gingrich,[3,e] N. Giokaris,[9] M. P. Giordani,[163a,163c] F. M. Giorgi,[22a] F. M. Giorgi,[17] P. F. Giraud,[136] P. Giromini,[58] D. Giugni,[92a] F. Giuli,[120] C. Giuliani,[101] M. Giulini,[59b] B. K. Gjelsten,[119] S. Gkaitatzis,[154] I. Gkialas,[154] E. L. Gkougkousis,[117] L. K. Gladilin,[99] C. Glasman,[83] J. Glatzer,[50] P. C. F. Glaysher,[48] A. Glazov,[44] M. Goblirsch-Kolb,[25] J. Godlewski,[41] S. Goldfarb,[89] T. Golling,[51] D. Golubkov,[130] A. Gomes,[126a,126b,126d] R. Gonçalo,[126a] J. Goncalves Pinto Firmino Da Costa,[136] G. Gonella,[50] L. Gonella,[19] A. Gongadze,[66] S. González de la Hoz,[166] G. Gonzalez Parra,[13] S. Gonzalez-Sevilla,[51] L. Goossens,[32] P. A. Gorbounov,[97] H. A. Gordon,[27] I. Gorelov,[105] B. Gorini,[32] E. Gorini,[74a,74b] A. Gorišek,[76] E. Gornicki,[41] A. T. Goshaw,[47] C. Gössling,[45] M. I. Gostkin,[66] C. R. Goudet,[117] D. Goujdami,[135c] A. G. Goussiou,[138] N. Govender,[145b,q] E. Gozani,[152] L. Graber,[56] I. Grabowska-Bold,[40a] P. O. J. Gradin,[57] P. Grafström,[22a,22b] J. Gramling,[51] E. Gramstad,[119] S. Grancagnolo,[17] V. Gratchev,[123] P. M. Gravila,[28e] H. M. Gray,[32] E. Graziani,[134a] Z. D. Greenwood,[80,r] C. Grefe,[23] K. Gregersen,[79] I. M. Gregor,[44] P. Grenier,[143] K. Grevtsov,[5] J. Griffiths,[8] A. A. Grillo,[137] K. Grimm,[73] S. Grinstein,[13,s] Ph. Gris,[36] J.-F. Grivaz,[117] S. Groh,[84] J. P. Grohs,[46] E. Gross,[171] J. Grosse-Knetter,[56] G. C. Grossi,[80] Z. J. Grout,[79] L. Guan,[90] W. Guan,[172] J. Guenther,[63] F. Guescini,[51] D. Guest,[162] O. Gueta,[153] E. Guido,[52a,52b] T. Guillemin,[5] S. Guindon,[2] U. Gul,[55] C. Gumpert,[32] J. Guo,[35e] Y. Guo,[35b,p] R. Gupta,[42] S. Gupta,[120] G. Gustavino,[132a,132b] P. Gutierrez,[113] N. G. Gutierrez Ortiz,[79] C. Gutschow,[46] C. Guyot,[136] C. Gwenlan,[120]

C. B. Gwilliam,[75] A. Haas,[110] C. Haber,[16] H. K. Hadavand,[8] N. Haddad,[135e] A. Hadef,[86] S. Hageböck,[23] Z. Hajduk,[41] H. Hakobyan,[176,a] M. Haleem,[44] J. Haley,[114] G. Halladjian,[91] G. D. Hallewell,[86] K. Hamacher,[174] P. Hamal,[115] K. Hamano,[168] A. Hamilton,[145a] G. N. Hamity,[139] P. G. Hamnett,[44] L. Han,[35b] K. Hanagaki,[67,t] K. Hanawa,[155] M. Hance,[137] B. Haney,[122] S. Hanisch,[32] P. Hanke,[59a] R. Hanna,[136] J. B. Hansen,[38] J. D. Hansen,[38] M. C. Hansen,[23] P. H. Hansen,[38] K. Hara,[160] A. S. Hard,[172] T. Harenberg,[174] F. Hariri,[117] S. Harkusha,[93] R. D. Harrington,[48] P. F. Harrison,[169] F. Hartjes,[107] N. M. Hartmann,[100] M. Hasegawa,[68] Y. Hasegawa,[140] A. Hasib,[113] S. Hassani,[136] S. Haug,[18] R. Hauser,[91] L. Hauswald,[46] M. Havranek,[127] C. M. Hawkes,[19] R. J. Hawkings,[32] D. Hayakawa,[157] D. Hayden,[91] C. P. Hays,[120] J. M. Hays,[77] H. S. Hayward,[75] S. J. Haywood,[131] S. J. Head,[19] T. Heck,[84] V. Hedberg,[82] L. Heelan,[8] S. Heim,[122] T. Heim,[16] B. Heinemann,[16] J. J. Heinrich,[100] L. Heinrich,[110] C. Heinz,[54] J. Hejbal,[127] L. Helary,[32] S. Hellman,[146a,146b] C. Helsens,[32] J. Henderson,[120] R. C. W. Henderson,[73] Y. Heng,[172] S. Henkelmann,[167] A. M. Henriques Correia,[32] S. Henrot-Versille,[117] G. H. Herbert,[17] V. Herget,[173] Y. Hernández Jiménez,[166] G. Herten,[50] R. Hertenberger,[100] L. Hervas,[32] G. G. Hesketh,[79] N. P. Hessey,[107] J. W. Hetherly,[42] R. Hickling,[77] E. Higón-Rodriguez,[166] E. Hill,[168] J. C. Hill,[30] K. H. Hiller,[44] S. J. Hillier,[19] I. Hinchliffe,[16] E. Hines,[122] R. R. Hinman,[16] M. Hirose,[50] D. Hirschbuehl,[174] J. Hobbs,[148] N. Hod,[159a] M. C. Hodgkinson,[139] P. Hodgson,[139] A. Hoecker,[32] M. R. Hoeferkamp,[105] F. Hoenig,[100] D. Hohn,[23] T. R. Holmes,[16] M. Homann,[45] T. M. Hong,[125] B. H. Hooberman,[165] W. H. Hopkins,[116] Y. Horii,[103] A. J. Horton,[142] J-Y. Hostachy,[57] S. Hou,[151] A. Hoummada,[135a] J. Howarth,[44] M. Hrabovsky,[115] I. Hristova,[17] J. Hrivnac,[117] T. Hryn'ova,[5] A. Hrynevich,[94] C. Hsu,[145c] P. J. Hsu,[151,u] S.-C. Hsu,[138] D. Hu,[37] Q. Hu,[35b] S. Hu,[35e] Y. Huang,[44] Z. Hubacek,[128] F. Hubaut,[86] F. Huegging,[23] T. B. Huffman,[120] E. W. Hughes,[37] G. Hughes,[73] M. Huhtinen,[32] P. Huo,[148] N. Huseynov,[66,c] J. Huston,[91] J. Huth,[58] G. Iacobucci,[51] G. Iakovidis,[27] I. Ibragimov,[141] L. Iconomidou-Fayard,[117] E. Ideal,[175] Z. Idrissi,[135e] P. Iengo,[32] O. Igonkina,[107,v] T. Iizawa,[170] Y. Ikegami,[67] M. Ikeno,[67] Y. Ilchenko,[11,w] D. Iliadis,[154] N. Ilic,[143] T. Ince,[101] G. Introzzi,[121a,121b] P. Ioannou,[9,a] M. Iodice,[134a] K. Iordanidou,[37] V. Ippolito,[58] N. Ishijima,[118] M. Ishino,[155] M. Ishitsuka,[157] R. Ishmukhametov,[111] C. Issever,[120] S. Istin,[20a] F. Ito,[160] J. M. Iturbe Ponce,[85] R. Iuppa,[133a,133b] W. Iwanski,[41] H. Iwasaki,[67] J. M. Izen,[43] V. Izzo,[104a] S. Jabbar,[3] B. Jackson,[122] P. Jackson,[1] V. Jain,[2] K. B. Jakobi,[84] K. Jakobs,[50] S. Jakobsen,[32] T. Jakoubek,[127] D. O. Jamin,[114] D. K. Jana,[80] E. Jansen,[79] R. Jansky,[63] J. Janssen,[23] M. Janus,[56] G. Jarlskog,[82] N. Javadov,[66,c] T. Javůrek,[50] F. Jeanneau,[136] L. Jeanty,[16] J. Jejelava,[53a,x] G.-Y. Jeng,[150] D. Jennens,[89] P. Jenni,[50,y] C. Jeske,[169] S. Jézéquel,[5] H. Ji,[172] J. Jia,[148] H. Jiang,[65] Y. Jiang,[35b] S. Jiggins,[79] J. Jimenez Pena,[166] S. Jin,[35a] A. Jinaru,[28b] O. Jinnouchi,[157] H. Jivan,[145c] P. Johansson,[139] K. A. Johns,[7] W. J. Johnson,[138] K. Jon-And,[146a,146b] G. Jones,[169] R. W. L. Jones,[73] S. Jones,[7] T. J. Jones,[75] J. Jongmanns,[59a] P. M. Jorge,[126a,126b] J. Jovicevic,[159a] X. Ju,[172] A. Juste Rozas,[13,s] M. K. Köhler,[171] A. Kaczmarska,[41] M. Kado,[117] H. Kagan,[111] M. Kagan,[143] S. J. Kahn,[86] T. Kaji,[170] E. Kajomovitz,[47] C. W. Kalderon,[120] A. Kaluza,[84] S. Kama,[42] A. Kamenshchikov,[130] N. Kanaya,[155] S. Kaneti,[30] L. Kanjir,[76] V. A. Kantserov,[98] J. Kanzaki,[67] B. Kaplan,[110] L. S. Kaplan,[172] A. Kapliy,[33] D. Kar,[145c] K. Karakostas,[10] A. Karamaoun,[3] N. Karastathis,[10] M. J. Kareem,[56] E. Karentzos,[10] M. Karnevskiy,[84] S. N. Karpov,[66] Z. M. Karpova,[66] K. Karthik,[110] V. Kartvelishvili,[73] A. N. Karyukhin,[130] K. Kasahara,[160] L. Kashif,[172] R. D. Kass,[111] A. Kastanas,[15] Y. Kataoka,[155] C. Kato,[155] A. Katre,[51] J. Katzy,[44] K. Kawagoe,[71] T. Kawamoto,[155] G. Kawamura,[56] V. F. Kazanin,[109,d] R. Keeler,[168] R. Kehoe,[42] J. S. Keller,[44] J. J. Kempster,[78] K Kentaro,[103] H. Keoshkerian,[158] O. Kepka,[127] B. P. Kerševan,[76] S. Kersten,[174] R. A. Keyes,[88] M. Khader,[165] F. Khalil-zada,[12] A. Khanov,[114] A. G. Kharlamov,[109,d] T. J. Khoo,[51] V. Khovanskiy,[97] E. Khramov,[66] J. Khubua,[53b,z] S. Kido,[68] C. R. Kilby,[78] H. Y. Kim,[8] S. H. Kim,[160] Y. K. Kim,[33] N. Kimura,[154] O. M. Kind,[17] B. T. King,[75] M. King,[166] J. Kirk,[131] A. E. Kiryunin,[101] T. Kishimoto,[155] D. Kisielewska,[40a] F. Kiss,[50] K. Kiuchi,[160] O. Kivernyk,[136] E. Kladiva,[144b] M. H. Klein,[37] M. Klein,[75] U. Klein,[75] K. Kleinknecht,[84] P. Klimek,[108] A. Klimentov,[27] R. Klingenberg,[45] J. A. Klinger,[139] T. Klioutchnikova,[32] E.-E. Kluge,[59a] P. Kluit,[107] S. Kluth,[101] J. Knapik,[41] E. Kneringer,[63] E. B. F. G. Knoops,[86] A. Knue,[55] A. Kobayashi,[155] D. Kobayashi,[157] T. Kobayashi,[155] M. Kobel,[46] M. Kocian,[143] P. Kodys,[129] N. M. Koehler,[101] T. Koffas,[31] E. Koffeman,[107] T. Koi,[143] H. Kolanoski,[17] M. Kolb,[59b] I. Koletsou,[5] A. A. Komar,[96,a] Y. Komori,[155] T. Kondo,[67] N. Kondrashova,[44] K. Köneke,[50] A. C. König,[106] T. Kono,[67,aa] R. Konoplich,[110,bb] N. Konstantinidis,[79] R. Kopeliansky,[62] S. Koperny,[40a] L. Köpke,[84] A. K. Kopp,[50] K. Korcyl,[41] K. Kordas,[154] A. Korn,[79] A. A. Korol,[109,d] I. Korolkov,[13] E. V. Korolkova,[139] O. Kortner,[101] S. Kortner,[101] T. Kosek,[129] V. V. Kostyukhin,[23] A. Kotwal,[47] A. Kourkoumeli-Charalampidi,[121a,121b] C. Kourkoumelis,[9] V. Kouskoura,[27] A. B. Kowalewska,[41] R. Kowalewski,[168] T. Z. Kowalski,[40a] C. Kozakai,[155] W. Kozanecki,[136] A. S. Kozhin,[130] V. A. Kramarenko,[99] G. Kramberger,[76] D. Krasnopevtsev,[98] M. W. Krasny,[81] A. Krasznahorkay,[32] A. Kravchenko,[27] M. Kretz,[59c] J. Kretzschmar,[75] K. Kreutzfeldt,[54] P. Krieger,[158] K. Krizka,[33] K. Kroeninger,[45] H. Kroha,[101] J. Kroll,[122] J. Kroseberg,[23] J. Krstic,[14] U. Kruchonak,[66] H. Krüger,[23] N. Krumnack,[65]

A. Kruse,[172] M. C. Kruse,[47] M. Kruskal,[24] T. Kubota,[89] H. Kucuk,[79] S. Kuday,[4b] J. T. Kuechler,[174] S. Kuehn,[50] A. Kugel,[59c] F. Kuger,[173] A. Kuhl,[137] T. Kuhl,[44] V. Kukhtin,[66] R. Kukla,[136] Y. Kulchitsky,[93] S. Kuleshov,[34b] M. Kuna,[132a,132b] T. Kunigo,[69] A. Kupco,[127] H. Kurashige,[68] Y. A. Kurochkin,[93] V. Kus,[127] E. S. Kuwertz,[168] M. Kuze,[157] J. Kvita,[115] T. Kwan,[168] D. Kyriazopoulos,[139] A. La Rosa,[101] J. L. La Rosa Navarro,[26d] L. La Rotonda,[39a,39b] C. Lacasta,[166] F. Lacava,[132a,132b] J. Lacey,[31] H. Lacker,[17] D. Lacour,[81] V. R. Lacuesta,[166] E. Ladygin,[66] R. Lafaye,[5] B. Laforge,[81] T. Lagouri,[175] S. Lai,[56] S. Lammers,[62] W. Lampl,[7] E. Lançon,[136] U. Landgraf,[50] M. P. J. Landon,[77] M. C. Lanfermann,[51] V. S. Lang,[59a] J. C. Lange,[13] A. J. Lankford,[162] F. Lanni,[27] K. Lantzsch,[23] A. Lanza,[121a] S. Laplace,[81] C. Lapoire,[32] J. F. Laporte,[136] T. Lari,[92a] F. Lasagni Manghi,[22a,22b] M. Lassnig,[32] P. Laurelli,[49] W. Lavrijsen,[16] A. T. Law,[137] P. Laycock,[75] T. Lazovich,[58] M. Lazzaroni,[92a,92b] B. Le,[89] O. Le Dortz,[81] E. Le Guirriec,[86] E. P. Le Quilleuc,[136] M. LeBlanc,[168] T. LeCompte,[6] F. Ledroit-Guillon,[57] C. A. Lee,[27] S. C. Lee,[151] L. Lee,[1] B. Lefebvre,[88] G. Lefebvre,[81] M. Lefebvre,[168] F. Legger,[100] C. Leggett,[16] A. Lehan,[75] G. Lehmann Miotto,[32] X. Lei,[7] W. A. Leight,[31] A. Leisos,[154,cc] A. G. Leister,[175] M. A. L. Leite,[26d] R. Leitner,[129] D. Lellouch,[171] B. Lemmer,[56] K. J. C. Leney,[79] T. Lenz,[23] B. Lenzi,[32] R. Leone,[7] S. Leone,[124a,124b] C. Leonidopoulos,[48] S. Leontsinis,[10] G. Lerner,[149] C. Leroy,[95] A. A. J. Lesage,[136] C. G. Lester,[30] M. Levchenko,[123] J. Levêque,[5] D. Levin,[90] L. J. Levinson,[171] M. Levy,[19] D. Lewis,[77] A. M. Leyko,[23] M. Leyton,[43] B. Li,[35b,p] C. Li,[35b] H. Li,[148] H. L. Li,[33] L. Li,[47] L. Li,[35e] Q. Li,[35a] S. Li,[47] X. Li,[85] Y. Li,[141] Z. Liang,[35a] B. Liberti,[133a] A. Liblong,[158] P. Lichard,[32] K. Lie,[165] J. Liebal,[23] W. Liebig,[15] A. Limosani,[150] S. C. Lin,[151,dd] T. H. Lin,[84] B. E. Lindquist,[148] A. E. Lionti,[51] E. Lipeles,[122] A. Lipniacka,[15] M. Lisovyi,[59b] T. M. Liss,[165] A. Lister,[167] A. M. Litke,[137] B. Liu,[151,ee] D. Liu,[151] H. Liu,[90] H. Liu,[27] J. Liu,[86] J. B. Liu,[35b] K. Liu,[86] L. Liu,[165] M. Liu,[47] M. Liu,[35b] Y. L. Liu,[35b] Y. Liu,[35b] M. Livan,[121a,121b] A. Lleres,[57] J. Llorente Merino,[35a] S. L. Lloyd,[77] F. Lo Sterzo,[151] E. Lobodzinska,[44] P. Loch,[7] W. S. Lockman,[137] F. K. Loebinger,[85] A. E. Loevschall-Jensen,[38] K. M. Loew,[25] A. Loginov,[175,a] T. Lohse,[17] K. Lohwasser,[44] M. Lokajicek,[127] B. A. Long,[24] J. D. Long,[165] R. E. Long,[73] L. Longo,[74a,74b] K. A. Looper,[111] L. Lopes,[126a] D. Lopez Mateos,[58] B. Lopez Paredes,[139] I. Lopez Paz,[13] A. Lopez Solis,[81] J. Lorenz,[100] N. Lorenzo Martinez,[62] M. Losada,[21] P. J. Lösel,[100] X. Lou,[35a] A. Lounis,[117] J. Love,[6] P. A. Love,[73] H. Lu,[61a] N. Lu,[90] H. J. Lubatti,[138] C. Luci,[132a,132b] A. Lucotte,[57] C. Luedtke,[50] F. Luehring,[62] W. Lukas,[63] L. Luminari,[132a] O. Lundberg,[146a,146b] B. Lund-Jensen,[147] P. M. Luzi,[81] D. Lynn,[27] R. Lysak,[127] E. Lytken,[82] V. Lyubushkin,[66] H. Ma,[27] L. L. Ma,[35d] Y. Ma,[35d] G. Maccarrone,[49] A. Macchiolo,[101] C. M. Macdonald,[139] B. Maček,[76] J. Machado Miguens,[122,126b] D. Madaffari,[86] R. Madar,[36] H. J. Maddocks,[164] W. F. Mader,[46] A. Madsen,[44] J. Maeda,[68] S. Maeland,[15] T. Maeno,[27] A. Maevskiy,[99] E. Magradze,[56] J. Mahlstedt,[107] C. Maiani,[117] C. Maidantchik,[26a] A. A. Maier,[101] T. Maier,[100] A. Maio,[126a,126b,126d] S. Majewski,[116] Y. Makida,[67] N. Makovec,[117] B. Malaescu,[81] Pa. Malecki,[41] V. P. Maleev,[123] F. Malek,[57] U. Mallik,[64] D. Malon,[6] C. Malone,[143] S. Maltezos,[10] S. Malyukov,[32] J. Mamuzic,[166] G. Mancini,[49] B. Mandelli,[32] L. Mandelli,[92a] I. Mandić,[76] J. Maneira,[126a,126b] L. Manhaes de Andrade Filho,[26b] J. Manjarres Ramos,[159b] A. Mann,[100] A. Manousos,[32] B. Mansoulie,[136] J. D. Mansour,[35a] R. Mantifel,[88] M. Mantoani,[56] S. Manzoni,[92a,92b] L. Mapelli,[32] G. Marceca,[29] L. March,[51] G. Marchiori,[81] M. Marcisovsky,[127] M. Marjanovic,[14] D. E. Marley,[90] F. Marroquim,[26a] S. P. Marsden,[85] Z. Marshall,[16] S. Marti-Garcia,[166] B. Martin,[91] T. A. Martin,[169] V. J. Martin,[48] B. Martin dit Latour,[15] M. Martinez,[13,s] V. I. Martinez Outschoorn,[165] S. Martin-Haugh,[131] V. S. Martoiu,[28b] A. C. Martyniuk,[79] M. Marx,[138] A. Marzin,[32] L. Masetti,[84] T. Mashimo,[155] R. Mashinistov,[96] J. Masik,[85] A. L. Maslennikov,[109,d] I. Massa,[22a,22b] L. Massa,[22a,22b] P. Mastrandrea,[5] A. Mastroberardino,[39a,39b] T. Masubuchi,[155] P. Mättig,[174] J. Mattmann,[84] J. Maurer,[28b] S. J. Maxfield,[75] D. A. Maximov,[109,d] R. Mazini,[151] S. M. Mazza,[92a,92b] N. C. Mc Fadden,[105] G. Mc Goldrick,[158] S. P. Mc Kee,[90] A. McCarn,[90] R. L. McCarthy,[148] T. G. McCarthy,[101] L. I. McClymont,[79] E. F. McDonald,[89] J. A. Mcfayden,[79] G. Mchedlidze,[56] S. J. McMahon,[131] R. A. McPherson,[168,m] M. Medinnis,[44] S. Meehan,[138] S. Mehlhase,[100] A. Mehta,[75] K. Meier,[59a] C. Meineck,[100] B. Meirose,[43] D. Melini,[166] B. R. Mellado Garcia,[145c] M. Melo,[144a] F. Meloni,[18] A. Mengarelli,[22a,22b] S. Menke,[101] E. Meoni,[161] S. Mergelmeyer,[17] P. Mermod,[51] L. Merola,[104a,104b] C. Meroni,[92a] F. S. Merritt,[33] A. Messina,[132a,132b] J. Metcalfe,[6] A. S. Mete,[162] C. Meyer,[84] C. Meyer,[122] J-P. Meyer,[136] J. Meyer,[107] H. Meyer Zu Theenhausen,[59a] F. Miano,[149] R. P. Middleton,[131] S. Miglioranzi,[52a,52b] L. Mijović,[48] G. Mikenberg,[171] M. Mikestikova,[127] M. Mikuž,[76] M. Milesi,[89] A. Milic,[63] D. W. Miller,[33] C. Mills,[48] A. Milov,[171] D. A. Milstead,[146a,146b] A. A. Minaenko,[130] Y. Minami,[155] I. A. Minashvili,[66] A. I. Mincer,[110] B. Mindur,[40a] M. Mineev,[66] Y. Ming,[172] L. M. Mir,[13] K. P. Mistry,[122] T. Mitani,[170] J. Mitrevski,[100] V. A. Mitsou,[166] A. Miucci,[18] P. S. Miyagawa,[139] J. U. Mjörnmark,[82] T. Moa,[146a,146b] K. Mochizuki,[95] S. Mohapatra,[37] S. Molander,[146a,146b] R. Moles-Valls,[23] R. Monden,[69] M. C. Mondragon,[91] K. Mönig,[44] J. Monk,[38] E. Monnier,[86] A. Montalbano,[148] J. Montejo Berlingen,[32] F. Monticelli,[72] S. Monzani,[92a,92b] R. W. Moore,[3] N. Morange,[117] D. Moreno,[21] M. Moreno Llácer,[56]

P. Morettini,[52a] D. Mori,[142] T. Mori,[155] M. Morii,[58] M. Morinaga,[155] V. Morisbak,[119] S. Moritz,[84] A. K. Morley,[150] G. Mornacchi,[32] J. D. Morris,[77] S. S. Mortensen,[38] L. Morvaj,[148] M. Mosidze,[53b] J. Moss,[143] K. Motohashi,[157] R. Mount,[143] E. Mountricha,[27] S. V. Mouraviev,[96,a] E. J. W. Moyse,[87] S. Muanza,[86] R. D. Mudd,[19] F. Mueller,[101] J. Mueller,[125] R. S. P. Mueller,[100] T. Mueller,[30] D. Muenstermann,[73] P. Mullen,[55] G. A. Mullier,[18] F. J. Munoz Sanchez,[85] J. A. Murillo Quijada,[19] W. J. Murray,[169,131] H. Musheghyan,[56] M. Muškinja,[76] A. G. Myagkov,[130,ff] M. Myska,[128] B. P. Nachman,[143] O. Nackenhorst,[51] K. Nagai,[120] R. Nagai,[67,aa] K. Nagano,[67] Y. Nagasaka,[60] K. Nagata,[160] M. Nagel,[50] E. Nagy,[86] A. M. Nairz,[32] Y. Nakahama,[103] K. Nakamura,[67] T. Nakamura,[155] I. Nakano,[112] H. Namasivayam,[43] R. F. Naranjo Garcia,[44] R. Narayan,[11] D. I. Narrias Villar,[59a] I. Naryshkin,[123] T. Naumann,[44] G. Navarro,[21] R. Nayyar,[7] H. A. Neal,[90] P. Yu. Nechaeva,[96] T. J. Neep,[85] A. Negri,[121a,121b] M. Negrini,[22a] S. Nektarijevic,[106] C. Nellist,[117] A. Nelson,[162] S. Nemecek,[127] P. Nemethy,[110] A. A. Nepomuceno,[26a] M. Nessi,[32,gg] M. S. Neubauer,[165] M. Neumann,[174] R. M. Neves,[110] P. Nevski,[27] P. R. Newman,[19] D. H. Nguyen,[6] T. Nguyen Manh,[95] R. B. Nickerson,[120] R. Nicolaidou,[136] J. Nielsen,[137] A. Nikiforov,[17] V. Nikolaenko,[130,ff] I. Nikolic-Audit,[81] K. Nikolopoulos,[19] J. K. Nilsen,[119] P. Nilsson,[27] Y. Ninomiya,[155] A. Nisati,[132a] R. Nisius,[101] T. Nobe,[155] M. Nomachi,[118] I. Nomidis,[31] T. Nooney,[77] S. Norberg,[113] M. Nordberg,[32] N. Norjoharuddeen,[120] O. Novgorodova,[46] S. Nowak,[101] M. Nozaki,[67] L. Nozka,[115] K. Ntekas,[10] E. Nurse,[79] F. Nuti,[89] F. O'grady,[7] D. C. O'Neil,[142] A. A. O'Rourke,[44] V. O'Shea,[55] F. G. Oakham,[31,e] H. Oberlack,[101] T. Obermann,[23] J. Ocariz,[81] A. Ochi,[68] I. Ochoa,[37] J. P. Ochoa-Ricoux,[34a] S. Oda,[71] S. Odaka,[67] H. Ogren,[62] A. Oh,[85] S. H. Oh,[47] C. C. Ohm,[16] H. Ohman,[164] H. Oide,[32] H. Okawa,[160] Y. Okumura,[155] T. Okuyama,[67] A. Olariu,[28b] L. F. Oleiro Seabra,[126a] S. A. Olivares Pino,[48] D. Oliveira Damazio,[27] A. Olszewski,[41] J. Olszowska,[41] A. Onofre,[126a,126e] K. Onogi,[103] P. U. E. Onyisi,[11,w] M. J. Oreglia,[33] Y. Oren,[153] D. Orestano,[134a,134b] N. Orlando,[61b] R. S. Orr,[158] B. Osculati,[52a,52b] R. Ospanov,[85] G. Otero y Garzon,[29] H. Otono,[71] M. Ouchrif,[135d] F. Ould-Saada,[119] A. Ouraou,[136] K. P. Oussoren,[107] Q. Ouyang,[35a] M. Owen,[55] R. E. Owen,[19] V. E. Ozcan,[20a] N. Ozturk,[8] K. Pachal,[142] A. Pacheco Pages,[13] L. Pacheco Rodriguez,[136] C. Padilla Aranda,[13] M. Pagáčová,[50] S. Pagan Griso,[16] F. Paige,[27] P. Pais,[87] K. Pajchel,[119] G. Palacino,[159b] S. Palazzo,[39a,39b] S. Palestini,[32] M. Palka,[40b] D. Pallin,[36] E. St. Panagiotopoulou,[10] C. E. Pandini,[81] J. G. Panduro Vazquez,[78] P. Pani,[146a,146b] S. Panitkin,[27] D. Pantea,[28b] L. Paolozzi,[51] Th. D. Papadopoulou,[10] K. Papageorgiou,[154] A. Paramonov,[6] D. Paredes Hernandez,[175] A. J. Parker,[73] M. A. Parker,[30] K. A. Parker,[139] F. Parodi,[52a,52b] J. A. Parsons,[37] U. Parzefall,[50] V. R. Pascuzzi,[158] E. Pasqualucci,[132a] S. Passaggio,[52a] Fr. Pastore,[78] G. Pásztor,[31,hh] S. Pataraia,[174] J. R. Pater,[85] T. Pauly,[32] J. Pearce,[168] B. Pearson,[113] L. E. Pedersen,[38] M. Pedersen,[119] S. Pedraza Lopez,[166] R. Pedro,[126a,126b] S. V. Peleganchuk,[109,d] O. Penc,[127] C. Peng,[35a] H. Peng,[35b] J. Penwell,[62] B. S. Peralva,[26b] M. M. Perego,[136] D. V. Perepelitsa,[27] E. Perez Codina,[159a] L. Perini,[92a,92b] H. Pernegger,[32] S. Perrella,[104a,104b] R. Peschke,[44] V. D. Peshekhonov,[66] K. Peters,[44] R. F. Y. Peters,[85] B. A. Petersen,[32] T. C. Petersen,[38] E. Petit,[57] A. Petridis,[1] C. Petridou,[154] P. Petroff,[117] E. Petrolo,[132a] M. Petrov,[120] F. Petrucci,[134a,134b] N. E. Pettersson,[87] A. Peyaud,[136] R. Pezoa,[34b] P. W. Phillips,[131] G. Piacquadio,[143,ii] E. Pianori,[169] A. Picazio,[87] E. Piccaro,[77] M. Piccinini,[22a,22b] M. A. Pickering,[120] R. Piegaia,[29] J. E. Pilcher,[33] A. D. Pilkington,[85] A. W. J. Pin,[85] M. Pinamonti,[163a,163c,jj] J. L. Pinfold,[3] A. Pingel,[38] S. Pires,[81] H. Pirumov,[44] M. Pitt,[171] L. Plazak,[144a] M.-A. Pleier,[27] V. Pleskot,[84] E. Plotnikova,[66] P. Plucinski,[91] D. Pluth,[65] R. Poettgen,[146a,146b] L. Poggioli,[117] D. Pohl,[23] G. Polesello,[121a] A. Poley,[44] A. Policicchio,[39a,39b] R. Polifka,[158] A. Polini,[22a] C. S. Pollard,[55] V. Polychronakos,[27] K. Pommès,[32] L. Pontecorvo,[132a] B. G. Pope,[91] G. A. Popeneciu,[28c] A. Poppleton,[32] S. Pospisil,[128] K. Potamianos,[16] I. N. Potrap,[66] C. J. Potter,[30] C. T. Potter,[116] G. Poulard,[32] J. Poveda,[32] V. Pozdnyakov,[66] M. E. Pozo Astigarraga,[32] P. Pralavorio,[86] A. Pranko,[16] S. Prell,[65] D. Price,[85] L. E. Price,[6] M. Primavera,[74a] S. Prince,[88] K. Prokofiev,[61c] F. Prokoshin,[34b] S. Protopopescu,[27] J. Proudfoot,[6] M. Przybycien,[40a] D. Puddu,[134a,134b] M. Purohit,[27,kk] P. Puzo,[117] J. Qian,[90] G. Qin,[55] Y. Qin,[85] A. Quadt,[56] W. B. Quayle,[163a,163b] M. Queitsch-Maitland,[85] D. Quilty,[55] S. Raddum,[119] V. Radeka,[27] V. Radescu,[120] S. K. Radhakrishnan,[148] P. Radloff,[116] P. Rados,[89] F. Ragusa,[92a,92b] G. Rahal,[177] J. A. Raine,[85] S. Rajagopalan,[27] M. Rammensee,[32] C. Rangel-Smith,[164] M. G. Ratti,[92a,92b] F. Rauscher,[100] S. Rave,[84] T. Ravenscroft,[55] I. Ravinovich,[171] M. Raymond,[32] A. L. Read,[119] N. P. Readioff,[75] M. Reale,[74a,74b] D. M. Rebuzzi,[121a,121b] A. Redelbach,[173] G. Redlinger,[27] R. Reece,[137] K. Reeves,[43] L. Rehnisch,[17] J. Reichert,[122] H. Reisin,[29] C. Rembser,[32] H. Ren,[35a] M. Rescigno,[132a] S. Resconi,[92a] O. L. Rezanova,[109,d] P. Reznicek,[129] R. Rezvani,[95] R. Richter,[101] S. Richter,[79] E. Richter-Was,[40b] O. Ricken,[23] M. Ridel,[81] P. Rieck,[17] C. J. Riegel,[174] J. Rieger,[56] O. Rifki,[113] M. Rijssenbeek,[148] A. Rimoldi,[121a,121b] M. Rimoldi,[18] L. Rinaldi,[22a] B. Ristić,[51] E. Ritsch,[32] I. Riu,[13] F. Rizatdinova,[114] E. Rizvi,[77] C. Rizzi,[13] S. H. Robertson,[88,m] A. Robichaud-Veronneau,[88] D. Robinson,[30] J. E. M. Robinson,[44] A. Robson,[55] C. Roda,[124a,124b] Y. Rodina,[86] A. Rodriguez Perez,[13] D. Rodriguez Rodriguez,[166] S. Roe,[32] C. S. Rogan,[58] O. Røhne,[119]

A. Romaniouk,[98] M. Romano,[22a,22b] S. M. Romano Saez,[36] E. Romero Adam,[166] N. Rompotis,[138] M. Ronzani,[50] L. Roos,[81] E. Ros,[166] S. Rosati,[132a] K. Rosbach,[50] P. Rose,[137] O. Rosenthal,[141] N.-A. Rosien,[56] V. Rossetti,[146a,146b] E. Rossi,[104a,104b] L. P. Rossi,[52a] J. H. N. Rosten,[30] R. Rosten,[138] M. Rotaru,[28b] I. Roth,[171] J. Rothberg,[138] D. Rousseau,[117] C. R. Royon,[136] A. Rozanov,[86] Y. Rozen,[152] X. Ruan,[145c] F. Rubbo,[143] M. S. Rudolph,[158] F. Rühr,[50] A. Ruiz-Martinez,[31] Z. Rurikova,[50] N. A. Rusakovich,[66] A. Ruschke,[100] H. L. Russell,[138] J. P. Rutherfoord,[7] N. Ruthmann,[32] Y. F. Ryabov,[123] M. Rybar,[165] G. Rybkin,[117] S. Ryu,[6] A. Ryzhov,[130] G. F. Rzehorz,[56] A. F. Saavedra,[150] G. Sabato,[107] S. Sacerdoti,[29] H. F-W. Sadrozinski,[137] R. Sadykov,[66] F. Safai Tehrani,[132a] P. Saha,[108] M. Sahinsoy,[59a] M. Saimpert,[136] T. Saito,[155] H. Sakamoto,[155] Y. Sakurai,[170] G. Salamanna,[134a,134b] A. Salamon,[133a,133b] J. E. Salazar Loyola,[34b] D. Salek,[107] P. H. Sales De Bruin,[138] D. Salihagic,[101] A. Salnikov,[143] J. Salt,[166] D. Salvatore,[39a,39b] F. Salvatore,[149] A. Salvucci,[61a] A. Salzburger,[32] D. Sammel,[50] D. Sampsonidis,[154] A. Sanchez,[104a,104b] J. Sánchez,[166] V. Sanchez Martinez,[166] H. Sandaker,[119] R. L. Sandbach,[77] H. G. Sander,[84] M. Sandhoff,[174] C. Sandoval,[21] R. Sandstroem,[101] D. P. C. Sankey,[131] M. Sannino,[52a,52b] A. Sansoni,[49] C. Santoni,[36] R. Santonico,[133a,133b] H. Santos,[126a] I. Santoyo Castillo,[149] K. Sapp,[125] A. Sapronov,[66] J. G. Saraiva,[126a,126d] B. Sarrazin,[23] O. Sasaki,[67] Y. Sasaki,[155] K. Sato,[160] G. Sauvage,[5,a] E. Sauvan,[5] G. Savage,[78] P. Savard,[158,e] N. Savic,[101] C. Sawyer,[131] L. Sawyer,[80,r] J. Saxon,[33] C. Sbarra,[22a] A. Sbrizzi,[22a,22b] T. Scanlon,[79] D. A. Scannicchio,[162] M. Scarcella,[150] V. Scarfone,[39a,39b] J. Schaarschmidt,[171] P. Schacht,[101] B. M. Schachtner,[100] D. Schaefer,[32] L. Schaefer,[122] R. Schaefer,[44] J. Schaeffer,[84] S. Schaepe,[23] S. Schaetzel,[59b] U. Schäfer,[84] A. C. Schaffer,[117] D. Schaile,[100] R. D. Schamberger,[148] V. Scharf,[59a] V. A. Schegelsky,[123] D. Scheirich,[129] M. Schernau,[162] C. Schiavi,[52a,52b] S. Schier,[137] C. Schillo,[50] M. Schioppa,[39a,39b] S. Schlenker,[32] K. R. Schmidt-Sommerfeld,[101] K. Schmieden,[32] C. Schmitt,[84] S. Schmitt,[44] S. Schmitz,[84] B. Schneider,[159a] U. Schnoor,[50] L. Schoeffel,[136] A. Schoening,[59b] B. D. Schoenrock,[91] E. Schopf,[23] M. Schott,[84] J. Schovancova,[8] S. Schramm,[51] M. Schreyer,[173] N. Schuh,[84] A. Schulte,[84] M. J. Schultens,[23] H.-C. Schultz-Coulon,[59a] H. Schulz,[17] M. Schumacher,[50] B. A. Schumm,[137] Ph. Schune,[136] A. Schwartzman,[143] T. A. Schwarz,[90] H. Schweiger,[85] Ph. Schwemling,[136] R. Schwienhorst,[91] J. Schwindling,[136] T. Schwindt,[23] G. Sciolla,[25] F. Scuri,[124a,124b] F. Scutti,[89] J. Searcy,[90] P. Seema,[23] S. C. Seidel,[105] A. Seiden,[137] F. Seifert,[128] J. M. Seixas,[26a] G. Sekhniaidze,[104a] K. Sekhon,[90] S. J. Sekula,[42] D. M. Seliverstov,[123,a] N. Semprini-Cesari,[22a,22b] C. Serfon,[119] L. Serin,[117] L. Serkin,[163a,163b] M. Sessa,[134a,134b] R. Seuster,[168] H. Severini,[113] T. Sfiligoj,[76] F. Sforza,[32] A. Sfyrla,[51] E. Shabalina,[56] N. W. Shaikh,[146a,146b] L. Y. Shan,[35a] R. Shang,[165] J. T. Shank,[24] M. Shapiro,[16] P. B. Shatalov,[97] K. Shaw,[163a,163b] S. M. Shaw,[85] A. Shcherbakova,[146a,146b] C. Y. Shehu,[149] P. Sherwood,[79] L. Shi,[151,ll] S. Shimizu,[68] C. O. Shimmin,[162] M. Shimojima,[102] M. Shiyakova,[66,mm] A. Shmeleva,[96] D. Shoaleh Saadi,[95] M. J. Shochet,[33] S. Shojaii,[92a,92b] S. Shrestha,[111] E. Shulga,[98] M. A. Shupe,[7] P. Sicho,[127] A. M. Sickles,[165] P. E. Sidebo,[147] O. Sidiropoulou,[173] D. Sidorov,[114] A. Sidoti,[22a,22b] F. Siegert,[46] Dj. Sijacki,[14] J. Silva,[126a,126d] S. B. Silverstein,[146a] V. Simak,[128] Lj. Simic,[14] S. Simion,[117] E. Simioni,[84] B. Simmons,[79] D. Simon,[36] M. Simon,[84] P. Sinervo,[158] N. B. Sinev,[116] M. Sioli,[22a,22b] G. Siragusa,[173] S. Yu. Sivoklokov,[99] J. Sjölin,[146a,146b] M. B. Skinner,[73] H. P. Skottowe,[58] P. Skubic,[113] M. Slater,[19] T. Slavicek,[128] M. Slawinska,[107] K. Sliwa,[161] R. Slovak,[129] V. Smakhtin,[171] B. H. Smart,[5] L. Smestad,[15] J. Smiesko,[144a] S. Yu. Smirnov,[98] Y. Smirnov,[98] L. N. Smirnova,[99,nn] O. Smirnova,[82] M. N. K. Smith,[37] R. W. Smith,[37] M. Smizanska,[73] K. Smolek,[128] A. A. Snesarev,[96] S. Snyder,[27] R. Sobie,[168,m] F. Socher,[46] A. Soffer,[153] D. A. Soh,[151] G. Sokhrannyi,[76] C. A. Solans Sanchez,[32] M. Solar,[128] E. Yu. Soldatov,[98] U. Soldevila,[166] A. A. Solodkov,[130] A. Soloshenko,[66] O. V. Solovyanov,[130] V. Solovyev,[123] P. Sommer,[50] H. Son,[161] H. Y. Song,[35b,oo] A. Sood,[16] A. Sopczak,[128] V. Sopko,[128] V. Sorin,[13] D. Sosa,[59b] C. L. Sotiropoulou,[124a,124b] R. Soualah,[163a,163c] A. M. Soukharev,[109,d] D. South,[44] B. C. Sowden,[78] S. Spagnolo,[74a,74b] M. Spalla,[124a,124b] M. Spangenberg,[169] F. Spanò,[78] D. Sperlich,[17] F. Spettel,[101] R. Spighi,[22a] G. Spigo,[32] L. A. Spiller,[89] M. Spousta,[129] R. D. St. Denis,[55,a] A. Stabile,[92a] R. Stamen,[59a] S. Stamm,[17] E. Stanecka,[41] R. W. Stanek,[6] C. Stanescu,[134a] M. Stanescu-Bellu,[44] M. M. Stanitzki,[44] S. Stapnes,[119] E. A. Starchenko,[130] G. H. Stark,[33] J. Stark,[57] P. Staroba,[127] P. Starovoitov,[59a] S. Stärz,[32] R. Staszewski,[41] P. Steinberg,[27] B. Stelzer,[142] H. J. Stelzer,[32] O. Stelzer-Chilton,[159a] H. Stenzel,[54] G. A. Stewart,[55] J. A. Stillings,[23] M. C. Stockton,[88] M. Stoebe,[88] G. Stoicea,[28b] P. Stolte,[56] S. Stonjek,[101] A. R. Stradling,[8] A. Straessner,[46] M. E. Stramaglia,[18] J. Strandberg,[147] S. Strandberg,[146a,146b] A. Strandlie,[119] M. Strauss,[113] P. Strizenec,[144b] R. Ströhmer,[173] D. M. Strom,[116] R. Stroynowski,[42] A. Strubig,[106] S. A. Stucci,[27] B. Stugu,[15] N. A. Styles,[44] D. Su,[143] J. Su,[125] S. Suchek,[59a] Y. Sugaya,[118] M. Suk,[128] V. V. Sulin,[96] S. Sultansoy,[4c] T. Sumida,[69] S. Sun,[58] X. Sun,[35a] J. E. Sundermann,[50] K. Suruliz,[149] G. Susinno,[39a,39b] M. R. Sutton,[149] S. Suzuki,[67] M. Svatos,[127] M. Swiatlowski,[33] I. Sykora,[144a] T. Sykora,[129] D. Ta,[50] C. Taccini,[134a,134b] K. Tackmann,[44] J. Taenzer,[158] A. Taffard,[162] R. Tafirout,[159a] N. Taiblum,[153] H. Takai,[27] R. Takashima,[70] T. Takeshita,[140] Y. Takubo,[67] M. Talby,[86] A. A. Talyshev,[109,d] K. G. Tan,[89]

J. Tanaka,[155] M. Tanaka,[157] R. Tanaka,[117] S. Tanaka,[67] B. B. Tannenwald,[111] S. Tapia Araya,[34b] S. Tapprogge,[84] S. Tarem,[152] G. F. Tartarelli,[92a] P. Tas,[129] M. Tasevsky,[127] T. Tashiro,[69] E. Tassi,[39a,39b] A. Tavares Delgado,[126a,126b] Y. Tayalati,[135e] A. C. Taylor,[105] G. N. Taylor,[89] P. T. E. Taylor,[89] W. Taylor,[159b] F. A. Teischinger,[32] P. Teixeira-Dias,[78] K. K. Temming,[50] D. Temple,[142] H. Ten Kate,[32] P. K. Teng,[151] J. J. Teoh,[118] F. Tepel,[174] S. Terada,[67] K. Terashi,[155] J. Terron,[83] S. Terzo,[13] M. Testa,[49] R. J. Teuscher,[158,m] T. Theveneaux-Pelzer,[86] J. P. Thomas,[19] J. Thomas-Wilsker,[78] E. N. Thompson,[37] P. D. Thompson,[19] A. S. Thompson,[55] L. A. Thomsen,[175] E. Thomson,[122] M. Thomson,[30] M. J. Tibbetts,[16] R. E. Ticse Torres,[86] V. O. Tikhomirov,[96,pp] Yu. A. Tikhonov,[109,d] S. Timoshenko,[98] P. Tipton,[175] S. Tisserant,[86] K. Todome,[157] T. Todorov,[5,a] S. Todorova-Nova,[129] J. Tojo,[71] S. Tokár,[144a] K. Tokushuku,[67] E. Tolley,[58] L. Tomlinson,[85] M. Tomoto,[103] L. Tompkins,[143,qq] K. Toms,[105] B. Tong,[58] E. Torrence,[116] H. Torres,[142] E. Torró Pastor,[138] J. Toth,[86,rr] F. Touchard,[86] D. R. Tovey,[139] T. Trefzger,[173] A. Tricoli,[27] I. M. Trigger,[159a] S. Trincaz-Duvoid,[81] M. F. Tripiana,[13] W. Trischuk,[158] B. Trocmé,[57] A. Trofymov,[44] C. Troncon,[92a] M. Trottier-McDonald,[16] M. Trovatelli,[168] L. Truong,[163a,163c] M. Trzebinski,[41] A. Trzupek,[41] J. C-L. Tseng,[120] P. V. Tsiareshka,[93] G. Tsipolitis,[10] N. Tsirintanis,[9] S. Tsiskaridze,[13] V. Tsiskaridze,[50] E. G. Tskhadadze,[53a] K. M. Tsui,[61a] I. I. Tsukerman,[97] V. Tsulaia,[16] S. Tsuno,[67] D. Tsybychev,[148] Y. Tu,[61b] A. Tudorache,[28b] V. Tudorache,[28b] A. N. Tuna,[58] S. A. Tupputi,[22a,22b] S. Turchikhin,[66] D. Turecek,[128] D. Turgeman,[171] R. Turra,[92a,92b] A. J. Turvey,[42] P. M. Tuts,[37] M. Tyndel,[131] G. Ucchielli,[22a,22b] I. Ueda,[155] M. Ughetto,[146a,146b] F. Ukegawa,[160] G. Unal,[32] A. Undrus,[27] G. Unel,[162] F. C. Ungaro,[89] Y. Unno,[67] C. Unverdorben,[100] J. Urban,[144b] P. Urquijo,[89] P. Urrejola,[84] G. Usai,[8] A. Usanova,[63] L. Vacavant,[86] V. Vacek,[128] B. Vachon,[88] C. Valderanis,[100] E. Valdes Santurio,[146a,146b] N. Valencic,[107] S. Valentinetti,[22a,22b] A. Valero,[166] L. Valery,[13] S. Valkar,[129] J. A. Valls Ferrer,[166] W. Van Den Wollenberg,[107] P. C. Van Der Deijl,[107] H. van der Graaf,[107] N. van Eldik,[152] P. van Gemmeren,[6] J. Van Nieuwkoop,[142] I. van Vulpen,[107] M. C. van Woerden,[32] M. Vanadia,[132a,132b] W. Vandelli,[32] R. Vanguri,[122] A. Vaniachine,[130] P. Vankov,[107] G. Vardanyan,[176] R. Vari,[132a] E. W. Varnes,[7] T. Varol,[42] D. Varouchas,[81] A. Vartapetian,[8] K. E. Varvell,[150] J. G. Vasquez,[175] F. Vazeille,[36] T. Vazquez Schroeder,[88] J. Veatch,[56] V. Veeraraghavan,[7] L. M. Veloce,[158] F. Veloso,[126a,126c] S. Veneziano,[132a] A. Ventura,[74a,74b] M. Venturi,[168] N. Venturi,[158] A. Venturini,[25] V. Vercesi,[121a] M. Verducci,[132a,132b] W. Verkerke,[107] J. C. Vermeulen,[107] A. Vest,[46,ss] M. C. Vetterli,[142,e] O. Viazlo,[82] I. Vichou,[165,a] T. Vickey,[139] O. E. Vickey Boeriu,[139] G. H. A. Viehhauser,[120] S. Viel,[16] L. Vigani,[120] M. Villa,[22a,22b] M. Villaplana Perez,[92a,92b] E. Vilucchi,[49] M. G. Vincter,[31] V. B. Vinogradov,[66] C. Vittori,[22a,22b] I. Vivarelli,[149] S. Vlachos,[10] M. Vlasak,[128] M. Vogel,[174] P. Vokac,[128] G. Volpi,[124a,124b] M. Volpi,[89] H. von der Schmitt,[101] E. von Toerne,[23] V. Vorobel,[129] K. Vorobev,[98] M. Vos,[166] R. Voss,[32] J. H. Vossebeld,[75] N. Vranjes,[14] M. Vranjes Milosavljevic,[14] V. Vrba,[127] M. Vreeswijk,[107] R. Vuillermet,[32] I. Vukotic,[33] Z. Vykydal,[128] P. Wagner,[23] W. Wagner,[174] H. Wahlberg,[72] S. Wahrmund,[46] J. Wakabayashi,[103] J. Walder,[73] R. Walker,[100] W. Walkowiak,[141] V. Wallangen,[146a,146b] C. Wang,[35c] C. Wang,[35d,86] F. Wang,[172] H. Wang,[16] H. Wang,[42] J. Wang,[44] J. Wang,[150] K. Wang,[88] R. Wang,[6] S. M. Wang,[151] T. Wang,[23] T. Wang,[37] W. Wang,[35b] X. Wang,[175] C. Wanotayaroj,[116] A. Warburton,[88] C. P. Ward,[30] D. R. Wardrope,[79] A. Washbrook,[48] P. M. Watkins,[19] A. T. Watson,[19] M. F. Watson,[19] G. Watts,[138] S. Watts,[85] B. M. Waugh,[79] S. Webb,[84] M. S. Weber,[18] S. W. Weber,[173] J. S. Webster,[6] A. R. Weidberg,[120] B. Weinert,[62] J. Weingarten,[56] C. Weiser,[50] H. Weits,[107] P. S. Wells,[32] T. Wenaus,[27] T. Wengler,[32] S. Wenig,[32] N. Wermes,[23] M. Werner,[50] M. D. Werner,[65] P. Werner,[32] M. Wessels,[59a] J. Wetter,[161] K. Whalen,[116] N. L. Whallon,[138] A. M. Wharton,[73] A. White,[8] M. J. White,[1] R. White,[34b] D. Whiteson,[162] F. J. Wickens,[131] W. Wiedenmann,[172] M. Wielers,[131] P. Wienemann,[23] C. Wiglesworth,[38] L. A. M. Wiik-Fuchs,[23] A. Wildauer,[101] F. Wilk,[85] H. G. Wilkens,[32] H. H. Williams,[122] S. Williams,[107] C. Willis,[91] S. Willocq,[87] J. A. Wilson,[19] I. Wingerter-Seez,[5] F. Winklmeier,[116] O. J. Winston,[149] B. T. Winter,[23] M. Wittgen,[143] J. Wittkowski,[100] T. M. H. Wolf,[107] M. W. Wolter,[41] H. Wolters,[126a,126c] S. D. Worm,[131] B. K. Wosiek,[41] J. Wotschack,[32] M. J. Woudstra,[85] K. W. Wozniak,[41] M. Wu,[57] M. Wu,[33] S. L. Wu,[172] X. Wu,[51] Y. Wu,[90] T. R. Wyatt,[85] B. M. Wynne,[48] S. Xella,[38] D. Xu,[35a] L. Xu,[27] B. Yabsley,[150] S. Yacoob,[145a] D. Yamaguchi,[157] Y. Yamaguchi,[118] A. Yamamoto,[67] S. Yamamoto,[155] T. Yamanaka,[155] K. Yamauchi,[103] Y. Yamazaki,[68] Z. Yan,[24] H. Yang,[35e] H. Yang,[172] Y. Yang,[151] Z. Yang,[15] W-M. Yao,[16] Y. C. Yap,[81] Y. Yasu,[67] E. Yatsenko,[5] K. H. Yau Wong,[23] J. Ye,[42] S. Ye,[27] I. Yeletskikh,[66] A. L. Yen,[58] E. Yildirim,[84] K. Yorita,[170] R. Yoshida,[6] K. Yoshihara,[122] C. Young,[143] C. J. S. Young,[32] S. Youssef,[24] D. R. Yu,[16] J. Yu,[8] J. M. Yu,[90] J. Yu,[65] L. Yuan,[68] S. P. Y. Yuen,[23] I. Yusuff,[30,tt] B. Zabinski,[41] R. Zaidan,[64] A. M. Zaitsev,[130,ff] N. Zakharchuk,[44] J. Zalieckas,[15] A. Zaman,[148] S. Zambito,[58] L. Zanello,[132a,132b] D. Zanzi,[89] C. Zeitnitz,[174] M. Zeman,[128] A. Zemla,[40a] J. C. Zeng,[165] Q. Zeng,[143] K. Zengel,[25] O. Zenin,[130] T. Ženiš,[144a] D. Zerwas,[117] D. Zhang,[90] F. Zhang,[172] G. Zhang,[35b,oo] H. Zhang,[35c] J. Zhang,[6] L. Zhang,[50] R. Zhang,[23] R. Zhang,[35b,uu] X. Zhang,[35d] Z. Zhang,[117] X. Zhao,[42] Y. Zhao,[35d] Z. Zhao,[35b] A. Zhemchugov,[66] J. Zhong,[120] B. Zhou,[90] C. Zhou,[47] L. Zhou,[37] L. Zhou,[42] M. Zhou,[148] N. Zhou,[35f] C. G. Zhu,[35d]

H. Zhu,[35a] J. Zhu,[90] Y. Zhu,[35b] X. Zhuang,[35a] K. Zhukov,[96] A. Zibell,[173] D. Zieminska,[62] N. I. Zimine,[66] C. Zimmermann,[84] S. Zimmermann,[50] Z. Zinonos,[56] M. Zinser,[84] M. Ziolkowski,[141] L. Živković,[14] G. Zobernig,[172] A. Zoccoli,[22a,22b] M. zur Nedden,[17] and L. Zwalinski[32]

(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, AB, 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, CNRS/IN2P3 and Université Savoie Mont Blanc, Annecy-le-Vieux, 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, The University of Texas at Arlington, Arlington, Texas, USA*
[9]*Physics Department, University of Athens, Athens, Greece*
[10]*Physics Department, National Technical University of Athens, Zografou, Greece*
[11]*Department of Physics, The University of Texas at Austin, Austin, Texas, USA*
[12]*Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan*
[13]*Institut de Física d'Altes Energies (IFAE), The Barcelona Institute of Science and Technology, Barcelona, Spain, Spain*
[14]*Institute of Physics, University of Belgrade, Belgrade, Serbia*
[15]*Department for Physics and Technology, University of Bergen, Bergen, Norway*
[16]*Physics Division, Lawrence Berkeley National Laboratory and University of California, Berkeley, California, USA*
[17]*Department of Physics, Humboldt University, Berlin, Germany*
[18]*Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern, Switzerland*
[19]*School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom*
[20a]*Department of Physics, Bogazici University, Istanbul, Turkey*
[20b]*Department of Physics Engineering, Gaziantep University, Gaziantep, Turkey*
[20d]*Istanbul Bilgi University, Faculty of Engineering and Natural Sciences, Istanbul, Turkey, Turkey*
[20e]*Bahcesehir University, Faculty of Engineering and Natural Sciences, Istanbul, Turkey, Turkey*
[21]*Centro de Investigaciones, Universidad Antonio Narino, Bogota, Colombia*
[22a]*INFN Sezione di Bologna, Italy*
[22b]*Dipartimento di Fisica e Astronomia, Università di Bologna, Bologna, Italy*
[23]*Physikalisches Institut, University of Bonn, Bonn, Germany*
[24]*Department of Physics, Boston University, Boston, Massachusetts, USA*
[25]*Department of Physics, Brandeis University, Waltham, Massachusetts, USA*
[26a]*Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro, Brazil*
[26b]*Electrical Circuits Department, Federal University of Juiz de Fora (UFJF), Juiz de Fora, Brazil*
[26c]*Federal University of Sao Joao del Rei (UFSJ), Sao Joao del Rei, Brazil*
[26d]*Instituto de Fisica, Universidade de Sao Paulo, Sao Paulo, Brazil*
[27]*Physics Department, Brookhaven National Laboratory, Upton, New York, USA*
[28a]*Transilvania University of Brasov, Brasov, Romania, Romania*
[28b]*National Institute of Physics and Nuclear Engineering, Bucharest, Romania*
[28c]*National Institute for Research and Development of Isotopic and Molecular Technologies, Physics Department, Cluj Napoca, Romania*
[28d]*University Politehnica Bucharest, Bucharest, Romania*
[28e]*West University in Timisoara, Timisoara, Romania*
[29]*Departamento de Física, Universidad de Buenos Aires, Buenos Aires, Argentina*
[30]*Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom*
[31]*Department of Physics, Carleton University, Ottawa, ON, Canada*
[32]*CERN, Geneva, Switzerland*
[33]*Enrico Fermi Institute, University of Chicago, Chicago, Illinois, USA*
[34a]*Departamento de Física, Pontificia Universidad Católica de Chile, Santiago, Chile*
[34b]*Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile*
[35a]*Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China*
[35b]*Department of Modern Physics, University of Science and Technology of China, Anhui, China*
[35c]*Department of Physics, Nanjing University, Jiangsu, China*

[35d]School of Physics, Shandong University, Shandong, China
[35e]Department of Physics and Astronomy, Shanghai Key Laboratory for Particle Physics and Cosmology, Shanghai Jiao Tong University, Shanghai; (also affiliated with PKU-CHEP), China
[35f]Physics Department, Tsinghua University, Beijing 100084, China
[36]Laboratoire de Physique Corpusculaire, Clermont Université and Université Blaise Pascal and CNRS/IN2P3, Clermont-Ferrand, France
[37]Nevis Laboratory, Columbia University, Irvington, New York, USA
[38]Niels Bohr Institute, University of Copenhagen, Kobenhavn, Denmark
[39a]INFN Gruppo Collegato di Cosenza, Laboratori Nazionali di Frascati, Italy
[39b]Dipartimento di Fisica, Università della Calabria, Rende, Italy
[40a]AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, Krakow, Poland
[40b]Marian Smoluchowski Institute of Physics, Jagiellonian University, Krakow, Poland
[41]Institute of Nuclear Physics Polish Academy of Sciences, Krakow, Poland
[42]Physics Department, Southern Methodist University, Dallas, Texas, USA
[43]Physics Department, University of Texas at Dallas, Richardson, Texas, USA
[44]DESY, Hamburg and Zeuthen, Germany
[45]Lehrstuhl für Experimentelle Physik IV, Technische Universität Dortmund, Dortmund, Germany
[46]Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden, Germany
[47]Department of Physics, Duke University, Durham, North Carolina, USA
[48]SUPA—School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom
[49]INFN Laboratori Nazionali di Frascati, Frascati, Italy
[50]Fakultät für Mathematik und Physik, Albert-Ludwigs-Universität, Freiburg, Germany
[51]Section de Physique, Université de Genève, Geneva, Switzerland
[52a]INFN Sezione di Genova, Italy
[52b]Dipartimento di Fisica, Università di Genova, Genova, Italy
[53a]E. Andronikashvili Institute of Physics, Iv. Javakhishvili Tbilisi State University, Tbilisi, Georgia
[53b]High Energy Physics Institute, Tbilisi State University, Tbilisi, Georgia
[54]II Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen, Germany
[55]SUPA—School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom
[56]II Physikalisches Institut, Georg-August-Universität, Göttingen, Germany
[57]Laboratoire de Physique Subatomique et de Cosmologie, Université Grenoble-Alpes, CNRS/IN2P3, Grenoble, France
[58]Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge, Massachusetts, USA
[59a]Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany
[59b]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany
[59c]ZITI Institut für technische Informatik, Ruprecht-Karls-Universität Heidelberg, Mannheim, Germany
[60]Faculty of Applied Information Science, Hiroshima Institute of Technology, Hiroshima, Japan
[61a]Department of Physics, The Chinese University of Hong Kong, Shatin, N.T., Hong Kong, China
[61b]Department of Physics, The University of Hong Kong, Hong Kong, China
[61c]Department of Physics, The Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China
[62]Department of Physics, Indiana University, Bloomington, Indiana, USA
[63]Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck, Austria
[64]University of Iowa, Iowa City, Iowa, USA
[65]Department of Physics and Astronomy, Iowa State University, Ames, Iowa, USA
[66]Joint Institute for Nuclear Research, JINR Dubna, Dubna, Russia
[67]KEK, High Energy Accelerator Research Organization, Tsukuba, Japan
[68]Graduate School of Science, Kobe University, Kobe, Japan
[69]Faculty of Science, Kyoto University, Kyoto, Japan
[70]Kyoto University of Education, Kyoto, Japan
[71]Department of Physics, Kyushu University, Fukuoka, Japan
[72]Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina
[73]Physics Department, Lancaster University, Lancaster, United Kingdom
[74a]INFN Sezione di Lecce, Italy
[74b]Dipartimento di Matematica e Fisica, Università del Salento, Lecce, Italy
[75]Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom
[76]Department of Physics, Jožef Stefan Institute and University of Ljubljana, Ljubljana, Slovenia
[77]School of Physics and Astronomy, Queen Mary University of London, London, United Kingdom
[78]Department of Physics, Royal Holloway University of London, Surrey, United Kingdom
[79]Department of Physics and Astronomy, University College London, London, United Kingdom
[80]Louisiana Tech University, Ruston, Los Angeles, USA
[81]Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France

[82]Fysiska institutionen, Lunds universitet, Lund, Sweden
[83]Departamento de Fisica Teorica C-15, Universidad Autonoma de Madrid, Madrid, Spain
[84]Institut für Physik, Universität Mainz, Mainz, Germany
[85]School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom
[86]CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France
[87]Department of Physics, University of Massachusetts, Amherst, Massachusetts, USA
[88]Department of Physics, McGill University, Montreal, QC, Canada
[89]School of Physics, University of Melbourne, Victoria, Australia
[90]Department of Physics, The University of Michigan, Ann Arbor, Michigan, USA
[91]Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan, USA
[92a]INFN Sezione di Milano, Italy
[92b]Dipartimento di Fisica, Università di Milano, Milano, Italy
[93]B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Republic of Belarus
[94]National Scientific and Educational Centre for Particle and High Energy Physics, Minsk, Republic of Belarus
[95]Group of Particle Physics, University of Montreal, Montreal, QC, Canada
[96]P.N. Lebedev Physical Institute of the Russian Academy of Sciences, Moscow, Russia
[97]Institute for Theoretical and Experimental Physics (ITEP), Moscow, Russia
[98]National Research Nuclear University MEPhI, Moscow, Russia
[99]D.V. Skobeltsyn Institute of Nuclear Physics, M.V. Lomonosov Moscow State University, Moscow, Russia
[100]Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany
[101]Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany
[102]Nagasaki Institute of Applied Science, Nagasaki, Japan
[103]Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya, Japan
[104a]INFN Sezione di Napoli, Italy
[104b]Dipartimento di Fisica, Università di Napoli, Napoli, Italy
[105]Department of Physics and Astronomy, University of New Mexico, Albuquerque, New Mexico, USA
[106]Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands
[107]Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands
[108]Department of Physics, Northern Illinois University, DeKalb, Illinois, USA
[109]Budker Institute of Nuclear Physics, SB RAS, Novosibirsk, Russia
[110]Department of Physics, New York University, New York, New York, USA
[111]Ohio State University, Columbus, Ohio, USA
[112]Faculty of Science, Okayama University, Okayama, Japan
[113]Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman, Oklahoma, USA
[114]Department of Physics, Oklahoma State University, Stillwater, Oklahoma, USA
[115]Palacký University, RCPTM, Olomouc, Czech Republic
[116]Center for High Energy Physics, University of Oregon, Eugene, Oregon, USA
[117]LAL, Univ. Paris-Sud, CNRS/IN2P3, Université Paris-Saclay, Orsay, France
[118]Graduate School of Science, Osaka University, Osaka, Japan
[119]Department of Physics, University of Oslo, Oslo, Norway
[120]Department of Physics, Oxford University, Oxford, United Kingdom
[121a]INFN Sezione di Pavia, Italy
[121b]Dipartimento di Fisica, Università di Pavia, Pavia, Italy
[122]Department of Physics, University of Pennsylvania, Philadelphia, Pennsylvania, USA
[123]National Research Centre "Kurchatov Institute" B.P.Konstantinov Petersburg Nuclear Physics Institute, St. Petersburg, Russia
[124a]INFN Sezione di Pisa, Italy
[124b]Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy
[125]Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, Pennsylvania, USA
[126a]Laboratório de Instrumentação e Física Experimental de Partículas—LIP, Lisboa, Portugal
[126b]Faculdade de Ciências, Universidade de Lisboa, Lisboa, Portugal
[126c]Department of Physics, University of Coimbra, Coimbra, Portugal
[126d]Centro de Física Nuclear da Universidade de Lisboa, Lisboa, Portugal
[126e]Departamento de Fisica, Universidade do Minho, Braga, Portugal
[126f]Departamento de Fisica Teorica y del Cosmos and CAFPE, Universidad de Granada, Granada, Spain
[126g]Dep Fisica and CEFITEC of Faculdade de Ciencias e Tecnologia, Universidade Nova de Lisboa, Caparica, Portugal
[127]Institute of Physics, Academy of Sciences of the Czech Republic, Praha, Czech Republic
[128]Czech Technical University in Prague, Praha, Czech Republic
[129]Faculty of Mathematics and Physics, Charles University in Prague, Praha, Czech Republic
[130]State Research Center Institute for High Energy Physics (Protvino), NRC KI, Russia
[131]Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom

[132a]INFN Sezione di Roma, Italy
[132b]Dipartimento di Fisica, Sapienza Università di Roma, Roma, Italy
[133a]INFN Sezione di Roma Tor Vergata, Italy
[133b]Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy
[134a]INFN Sezione di Roma Tre, Italy
[134b]Dipartimento di Matematica e Fisica, Università Roma Tre, Roma, Italy
[135a]Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies—Université Hassan II, Casablanca, Morocco
[135b]Centre National de l'Energie des Sciences Techniques Nucleaires, Rabat, Morocco
[135c]Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA-Marrakech, Morocco
[135d]Faculté des Sciences, Université Mohamed Premier and LPTPM, Oujda, Morocco
[135e]Faculté des sciences, Université Mohammed V, Rabat, Morocco
[136]DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l'Univers), CEA Saclay (Commissariat à l'Energie Atomique et aux Energies Alternatives), Gif-sur-Yvette, France
[137]Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz, California, USA
[138]Department of Physics, University of Washington, Seattle, Washington, USA
[139]Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom
[140]Department of Physics, Shinshu University, Nagano, Japan
[141]Fachbereich Physik, Universität Siegen, Siegen, Germany
[142]Department of Physics, Simon Fraser University, Burnaby, BC, Canada
[143]SLAC National Accelerator Laboratory, Stanford, California, USA
[144a]Faculty of Mathematics, Physics & Informatics, Comenius University, Bratislava, Slovak Republic
[144b]Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice, Slovak Republic
[145a]Department of Physics, University of Cape Town, Cape Town, South Africa
[145b]Department of Physics, University of Johannesburg, Johannesburg, South Africa
[145c]School of Physics, University of the Witwatersrand, Johannesburg, South Africa
[146a]Department of Physics, Stockholm University, Sweden
[146b]The Oskar Klein Centre, Stockholm, Sweden
[147]Physics Department, Royal Institute of Technology, Stockholm, Sweden
[148]Departments of Physics & Astronomy and Chemistry, Stony Brook University, Stony Brook, New York, USA
[149]Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom
[150]School of Physics, University of Sydney, Sydney, Australia
[151]Institute of Physics, Academia Sinica, Taipei, Taiwan
[152]Department of Physics, Technion: Israel Institute of Technology, Haifa, Israel
[153]Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel
[154]Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece
[155]International Center for Elementary Particle Physics and Department of Physics, The University of Tokyo, Tokyo, Japan
[156]Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo, Japan
[157]Department of Physics, Tokyo Institute of Technology, Tokyo, Japan
[158]Department of Physics, University of Toronto, Toronto, ON, Canada
[159a]TRIUMF, Vancouver, BC, Canada
[159b]Department of Physics and Astronomy, York University, Toronto, ON, Canada
[160]Faculty of Pure and Applied Sciences, and Center for Integrated Research in Fundamental Science and Engineering, University of Tsukuba, Tsukuba, Japan
[161]Department of Physics and Astronomy, Tufts University, Medford, Massachusetts, USA
[162]Department of Physics and Astronomy, University of California Irvine, Irvine, California, USA
[163a]INFN Gruppo Collegato di Udine, Sezione di Trieste, Udine, Italy
[163b]ICTP, Trieste, Italy
[163c]Dipartimento di Chimica, Fisica e Ambiente, Università di Udine, Udine, Italy
[164]Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden
[165]Department of Physics, University of Illinois, Urbana, Illinois, USA
[166]Instituto de Fisica Corpuscular (IFIC) and Departamento de Fisica Atomica, Molecular y Nuclear and Departamento de Ingeniería Electrónica and Instituto de Microelectrónica de Barcelona (IMB-CNM), University of Valencia and CSIC, Valencia, Spain
[167]Department of Physics, University of British Columbia, Vancouver, BC, Canada
[168]Department of Physics and Astronomy, University of Victoria, Victoria, BC, Canada
[169]Department of Physics, University of Warwick, Coventry, United Kingdom
[170]Waseda University, Tokyo, Japan
[171]Department of Particle Physics, The Weizmann Institute of Science, Rehovot, Israel
[172]Department of Physics, University of Wisconsin, Madison, Wisconsin, USA
[173]Fakultät für Physik und Astronomie, Julius-Maximilians-Universität, Würzburg, Germany

[174]Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal, Germany
[175]Department of Physics, Yale University, New Haven, Connecticut, USA
[176]Yerevan Physics Institute, Yerevan, Armenia
[177]Centre de Calcul de l'Institut National de Physique Nucléaire et de Physique des Particules (IN2P3), Villeurbanne, France

[a]Deceased.
[b]Also at Department of Physics, King's College London, London, United Kingdom.
[c]Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan.
[d]Also at Novosibirsk State University, Novosibirsk, Russia.
[e]Also at TRIUMF, Vancouver BC, Canada.
[f]Also at Department of Physics & Astronomy, University of Louisville, Louisville, KY, USA.
[g]Also at Department of Physics, California State University, Fresno, CA, USA.
[h]Also at Department of Physics, University of Fribourg, Fribourg, Switzerland.
[i]Also at Departament de Fisica de la Universitat Autonoma de Barcelona, Barcelona, Spain.
[j]Also at Departamento de Fisica e Astronomia, Faculdade de Ciencias, Universidade do Porto, Portugal.
[k]Also at Tomsk State University, Tomsk, Russia.
[l]Also at Universita di Napoli Parthenope, Napoli, Italy.
[m]Also at Institute of Particle Physics (IPP), Canada.
[n]Also at National Institute of Physics and Nuclear Engineering, Bucharest, Romania.
[o]Also at Department of Physics, St. Petersburg State Polytechnical University, St. Petersburg, Russia.
[p]Also at Department of Physics, The University of Michigan, Ann Arbor, MI, USA.
[q]Also at Centre for High Performance Computing, CSIR Campus, Rosebank, Cape Town, South Africa.
[r]Also at Louisiana Tech University, Ruston, LA, USA.
[s]Also at Institucio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona, Spain.
[t]Also at Graduate School of Science, Osaka University, Osaka, Japan.
[u]Also at Department of Physics, National Tsing Hua University, Taiwan.
[v]Also at Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands.
[w]Also at Department of Physics, The University of Texas at Austin, Austin, TX, USA.
[x]Also at Institute of Theoretical Physics, Ilia State University, Tbilisi, Georgia.
[y]Also at CERN, Geneva, Switzerland.
[z]Also at Georgian Technical University (GTU), Tbilisi, Georgia.
[aa]Also at Ochadai Academic Production, Ochanomizu University, Tokyo, Japan.
[bb]Also at Manhattan College, New York, NY, USA.
[cc]Also at Hellenic Open University, Patras, Greece.
[dd]Also at Academia Sinica Grid Computing, Institute of Physics, Academia Sinica, Taipei, Taiwan.
[ee]Also at School of Physics, Shandong University, Shandong, China.
[ff]Also at Moscow Institute of Physics and Technology State University, Dolgoprudny, Russia.
[gg]Also at Section de Physique, Université de Genève, Geneva, Switzerland.
[hh]Also at Eotvos Lorand University, Budapest, Hungary.
[ii]Also at Departments of Physics & Astronomy and Chemistry, Stony Brook University, Stony Brook, NY, USA.
[jj]Also at International School for Advanced Studies (SISSA), Trieste, Italy.
[kk]Also at Department of Physics and Astronomy, University of South Carolina, Columbia, SC, USA.
[ll]Also at School of Physics and Engineering, Sun Yat-sen University, Guangzhou, China.
[mm]Also at Institute for Nuclear Research and Nuclear Energy (INRNE) of the Bulgarian Academy of Sciences, Sofia, Bulgaria.
[nn]Also at Faculty of Physics, M.V.Lomonosov Moscow State University, Moscow, Russia.
[oo]Also at Institute of Physics, Academia Sinica, Taipei, Taiwan.
[pp]Also at National Research Nuclear University MEPhI, Moscow, Russia.
[qq]Also at Department of Physics, Stanford University, Stanford, CA, USA.
[rr]Also at Institute for Particle and Nuclear Physics, Wigner Research Centre for Physics, Budapest, Hungary.
[ss]Also at Flensburg University of Applied Sciences, Flensburg, Germany.
[tt]Also at University of Malaya, Department of Physics, Kuala Lumpur, Malaysia.
[uu]Also at CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France.