Search for heavy resonances decaying into a photon and a hadronically decaying Higgs boson in pp collisions at √s = 13 TeV with the ATLAS detector

Aad, G.; ATLAS Collaboration

DOI
10.1103/PhysRevLett.125.251802

Publication date
2020

Document Version
Final published version

Published in
Physical Review Letters

Search for Heavy Resonances Decaying into a Photon and a Hadronically Decaying Higgs Boson in pp Collisions at $\sqrt{s} = 13$ TeV with the ATLAS Detector

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

(Received 16 August 2020; accepted 5 November 2020; published 18 December 2020)

This Letter presents a search for the production of new heavy resonances decaying into a Higgs boson and a photon using proton-proton collision data at $\sqrt{s} = 13$ TeV collected by the ATLAS detector at the LHC. The data correspond to an integrated luminosity of 139 fb^{-1}. The analysis is performed by reconstructing hadronically decaying Higgs boson ($H \to b\bar{b}$) candidates as single large-radius jets. A novel algorithm using information about the jet constituents in the center-of-mass frame of the jet is implemented to identify the two b quarks in the single jet. No significant excess of events is observed above the expected background. Upper limits are set on the production cross-section times branching fraction for narrow spin-1 resonances decaying into a Higgs boson and a photon in the resonance mass range from 0.7 to 4 TeV, cross-section times branching fractions are excluded between 11.6 fb and 0.11 fb at a 95% confidence level.

DOI: 10.1103/PhysRevLett.125.251802

Many extensions to the standard model, such as technicolor [1], little Higgs [2], or a more complex Higgs sector [3], predict new massive bosons. Some of these bosons may decay into a Higgs boson and a photon at the one-loop level [4]. Searches for such particles have been carried out by both the ATLAS [5] and CMS [6] Collaborations at the Large Hadron Collider (LHC).

This Letter reports on a generic search for a narrow, neutral, spin-1 boson (Z') that decays into a photon and a Higgs boson. The Higgs boson subsequently decays hadronically as $H \to b\bar{b}$, where the hadronic products from both b quarks are reconstructed as a single large-radius jet. The analysis uses data from $\sqrt{s} = 13$ TeV proton-proton (pp) collisions that were recorded by the ATLAS detector from 2015 to 2018 with a single-photon trigger [7], corresponding to an integrated luminosity of 139 fb^{-1}. The single-photon trigger uses loose photon identification requirements based on calorimetric shower-shape variables [8] and imposes a transverse momentum threshold of 140 GeV. It is fully efficient for events passing the offline analysis selection. The search identifies the two b quarks in the single jet by using a novel methodology based on information about the jet constituents calculated in the center-of-mass frame of the jet. This technique significantly improves the search sensitivity compared to the previous ATLAS [5] and CMS [6] analyses, in addition to the gains from the larger data sample.

The ATLAS detector [9,10] is a general-purpose particle detector with a cylindrical geometry[11]. It consists of an inner detector surrounded by a superconducting solenoid that produces a 2 T magnetic field, electromagnetic and hadronic calorimeters, and a muon spectrometer with a toroidal magnetic field. The inner detector provides precision tracking of charged particles with pseudorapidity $|\eta| < 2.5$. The calorimeter system covers the pseudorapidity range $|\eta| < 4.9$. It comprises sampling calorimeters with either liquid argon or scintillator tiles as the active medium. A two-level trigger system accepts events from the 40 MHz bunch crossings at a rate of 1 kHz for off-line analysis.

Monte Carlo (MC) simulated events are used to optimize the event selection and to help validate the analysis. The signal samples, with decays of $Z' \to H\gamma$ at the one-loop level [4], were generated for eight different mass points in a range from 700 to 4000 GeV via quark-antiquark annihilation, $q\bar{q} \to Z' \to H\gamma$, using the MADGRAPH leading-order (LO) v2.6.2 generator [12] interfaced to PYTHIA8.235 [13] with the NNPDF23LO parton distribution functions (PDFs) [14] for both generators and the A14 set of tuned parameters [15] for the underlying event. The total decay widths of the Z' resonances were set to 4.2 MeV, which is much smaller than the experimental mass resolution, which varies from around 35 GeV at the 700 GeV signal mass point to 150 GeV at the 4000 GeV signal mass point. The dominant SM background arises from events with prompt photons produced in association with jets (γ + jets). Less dominant SM backgrounds include a prompt photon produced in association with a W/Z boson ($W/Z + \gamma$) or a top-antitop

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

quark pair ($t\bar{t}+\gamma$). The MC sample of $\gamma+$jets events was simulated using the SHERPA2.2.2 generator [16] with up to two additional parton emissions at next-to-leading-order (NLO) accuracy and up to four additional partons at LO accuracy using Comix [17] and OpenLoops [18]. The events were then merged with the SHERPA parton shower [19] using the ME + PS@NLO prescription [20]. Samples are generated using the NNPDF3.0nnlo PDF set [21], along with the dedicated set of tuned parton-shower parameters developed by the SHERPA authors. The $W/Z+\gamma$ events were modeled with SHERPA2.1.1 at LO with the CT10 PDFs [22] for both generators and the underlying event. The $t\bar{t}+\gamma$ events were simulated using MADGRAPH5_aMC@NLO v2.2.3 at LO with the CTEQ6L1 PDFs [23], then interfaced to PYTHIA8.186 with the A14 parameter tune and the NNPDF23LO PDFs. In the signal samples and $t\bar{t}+\gamma$ background sample, EVTGEN [24] was used to model charm and b-hadron decays. The effect of multiple pp interactions in the same and neighboring bunch crossings (pileup) is included by overlaying minimum-bias events simulated with PYTHIA8.186 on each event of interest in all samples. The generated samples were processed through a GEANT4-based detector simulation [25,26] and the same ATLAS reconstruction software as the data.

An event is selected if it contains a $H\to b\bar{b}$ candidate and at least one isolated photon that satisfies the "tight" identification criteria [27,28]. A selected photon must have transverse momentum (p_T) greater than 200 GeV and be within the calorimeter barrel region $|\eta|<1.37$. Each $H\to b\bar{b}$ candidate is reconstructed as a single jet using the anti-k_t algorithm [29,30] with a large radius parameter ($R=1.0$), hereafter referred to as a large-R jet (J). The large-R jets are formed from topological energy clusters (topoclusters) [31] in the calorimeter and are trimmed [32] to mitigate the effects of pileup and soft radiation. The large-R jet constituents are reclustered into subjets using the k_t algorithm [33] with $R=0.2$, and the subjets that carry less than 5% of the p_T of the original large-R jet are removed. To overcome the limited angular resolution of the calorimeter, the mass of a large-R jet (m_J) is computed using a combination of calorimeter and tracking information [34]. Large-R jets are required to have $p_T>200$ GeV, $|\eta|<2.0$, 50 GeV $<m_J<$ 200 GeV, and an angular separation of $\Delta R>1.0$ from photon candidates. For the baseline event selection, at least one large-R jet and one photon are required to pass the selection described above.

The photon and large-R jet with the highest p_T in an event are combined to form a resonance candidate. The invariant mass of the resonance candidate ($m_{J\gamma}$) is used to distinguish signal from background. In addition, the large-R jet mass must be consistent with the Higgs boson mass ($m_H=125.80$ GeV), $m_H-\Delta_{m,D}<m_J<m_H+\Delta_{m,U}$. The parameters $\Delta_{m,D}$ and $\Delta_{m,U}$ are determined by maximizing the search sensitivity $\epsilon/(\sqrt{B}+3/2)$ [35], where ϵ is the resonance signal selection efficiency and B is the number of background events, as estimated from MC samples, within the resonance mass window, $|m_{J\gamma}-\bar{m}_{Z'}|<2\sigma_{m_{Z'}}$. Here $\bar{m}_{Z'}$ and $\sigma_{m_{Z'}}$ are the peak position and the core resolution of the reconstructed $m_{J\gamma}$ distribution of the $Z'\to H\gamma$ signal MC events, respectively. The above procedure is performed separately for each $m_{Z'}$ hypothesis. The optimized parameters $\Delta_{m,D}$ and $\Delta_{m,U}$ are then parameterized by fourth-order polynomial functions of the large-R jet p_T. The optimized mass window of the large-R jets varies from around [100,130] GeV at $p_T=0.5$ TeV to [90,160] GeV at $p_T=2$ TeV.

To further reduce the background, a novel algorithm [36–38] is applied to the large-R jet to identify the two b quarks that originated from the Higgs boson. It uses the kinematics of the jet constituents in the center-of-mass (c.m.) frame of the large-R jet (jet rest frame), where the final products of a two-body $H\to b\bar{b}$ decay can be easily separated into a back-to-back topology. In this approach, the topoclusters of the large-R jet and the tracks associated with the jet are boosted to the large-R jet's rest frame. In the jet rest frame, the topoclusters of the large-R jet are reclustered using the EEkT jet algorithm [39] to form exactly two c.m. subjets, assumed to originate from the Higgs boson decay. A track is considered to be associated with a c.m. subjet if the opening angle $\Delta\theta$ between the track and the c.m. subjet, calculated in the jet rest frame, satisfies the requirement that $2\times(1-\cos\Delta\theta)<0.8$. The c.m. subjets and their associated tracks are then boosted back to the laboratory frame and the standard ATLAS b-tagging algorithm based on a multivariate technique, MV2c10 [40,41], is applied to each c.m. subjet to identify those containing a b hadron (called c.m. b subjets). For this analysis, the working point of the MV2c10 tagger output is chosen to have an overall efficiency of 77%. This was determined using simulated Randall-Sundrum graviton [42] ($G\to HH$, $H\to b\bar{b}$) events, in which the p_T distribution of the large-R jets that contain a Higgs boson is reweighted to match the inclusive jet p_T distribution observed in data [43]. Compared to the previous method used to identify $H\to b\bar{b}$ reconstructed as large-R jets, MC studies [43] show that b-tagging based on c.m. subjets can reject more background than the b tagging based on the other subjet algorithm at a given signal identification efficiency: by 20%–50% for large-R jets with $p_T\leq$ 1.5 TeV and up to a factor of 10 or more for large-R jets with $p_T>1.5$ TeV. Among several tagging techniques [43] developed to improve the identification of $H\to b\bar{b}$ with $p_T>1$ TeV, the c.m. algorithm typically rejects 20% more background at a given signal efficiency.

Studies using MC simulated events show that the correlation between the b-tagging efficiencies of two c.m. b subjets is negligible, and thus the b-tagging efficiency of each c.m. b subjet in a large-R jet can be calibrated using boosted hadronic top-quark decays $t\to Wb$ from $t\bar{t}\to WbW\bar{b}$ events where one W boson decays hadronically and the other decays leptonically. The hadronic products of the boosted $t \to Wb$ decay are reconstructed as a single large-R jet, in which exactly two c.m. subjets are reconstructed in the jet rest frame: one corresponding to the b quark, and the other corresponding to the W boson. MC studies show that the b-tagging performance is almost identical for c.m. b subjets in the boosted hadronic top-quark decay events and $H \to b\bar{b}$ events. A standard combinatorial likelihood approach [44] is applied to extract the c.m. b-subjet tagging efficiency in order to calculate an MC-to-data scale factor, defined as the ratio of the c.m. b-subjet tagging efficiencies measured in data and simulated $t\bar{t}$ events [45]. The scale factor is found to be consistent with unity within its uncertainty and has no significant dependence on the kinematics of the c.m. subjet and the large-R jet. The uncertainty of the scale factor is about 5%, dominated by the systematic uncertainties such as the dependence of the calibration scale factor on the choice of the $t\bar{t}$ MC generators, and the dependence of the MV2c10 [40,41] b-tagging scale factors on the jet flavor.

The selected resonance candidates are retained for further analysis if one or both of the c.m. subjets in the large-R jet pass the b-tagging requirement, and are assigned to the single- or double-b-tagged category, respectively. Afterwards, optimizations of the selection requirements on the photon p_T (p_T^γ) and the large-R jet p_T (p_T^J) are carried out in sequence in order to further improve the search sensitivity. The optimizations are performed separately for the selected events in the single- and double-b-tagged categories with the same procedure as used for the large-R jet mass-window optimization described above. It yields $p_T^\gamma > p_T^0 + a \times m_{J\gamma}$ and $p_T^J > 0.8 \times (p_T^0 + a \times m_{J\gamma})$, where ${p_T}^0 = 12.0(121.8)$ GeV and $a = 0.35(0.22)$ for the selected events with $m_{J\gamma} \leq 2000(1500)$ GeV in the single-b-tagged (double-b-tagged) category. For events with $m_{J\gamma} > 2000(1500)$ GeV, the selection requirements on the photon and the large-R jet p_T are the same as those for events with $m_{J\gamma} = 2000(1500)$ GeV. Depending on the resonance mass, the final signal efficiency in the single- and double-b-tagged categories varies between 10% and 20%.

The final discrimination between signal and background is achieved by a simultaneous fit to the $m_{J\gamma}$ distributions of the selected data events in the single- and double-b-tagged categories. The signal probability density function (SPDF) is modeled as a sum of a Crystal Ball function [46] and a small Gaussian component that describes the tails produced by poorly reconstructed resonance candidates. The SPDF parameters extracted from MC simulated events are interpolated as polynomial functions of the resonance mass up to the third order. Afterwards, the parameters of the SPDF at a given resonance mass are fixed to the values determined using the parameterization. The background probability density function (BPDF) is modeled as $B(m_{J\gamma}) = (1-x)^{p_1} x^{p_2 + p_3 \log(x)}$ [47], where $x = m_{J\gamma}/\sqrt{s}$, $\sqrt{s} = 13$ TeV is the center-of-mass energy, and the three dimensionless shape parameters p_1, p_2, and p_3 are allowed to float in the fit. The choice of the BPDF is motivated and validated by using control data samples containing events that satisfy all the signal selection criteria in either the single- or double-b-tagged category, except for the b-tagging and large-R jet mass requirements. The selected large-R jet candidates in the control data samples are required to have masses lying in sidebands, whose width varies from 10 GeV to 30 GeV, separated from the Higgs boson signal band by 5 GeV, and to have both of the c.m. subjets failing the b-tagging requirement at the 85%-efficiency working point. MC simulated events show that the background $m_{J\gamma}$ distributions in the single- and double-b-tagged categories are well described by the events in the corresponding control sample.

The effect of systematic uncertainties from various sources was studied. The uncertainty of the integrated luminosity is 1.7% [48,49]. Uncertainties resulting from detector effects only affect the calculation of the signal selection efficiencies since the background is estimated from the data. Those uncertainties include effects from the energy and mass scales (2%–6.5%) of the large-R jets [50], the large-R jet energy resolution ($< 0.2\%$) and mass resolution (18%–30%), the trigger efficiencies ($< 0.1\%$), the photon energy scale and resolution ($< 2\%$) [28], the photon reconstruction, identification and isolation efficiencies ($< 0.1\%$) [8], the b-tagging efficiency of the c.m. subjet (3%–15%), and the pileup modeling ($< 0.5\%$) [51]. In principle, the detector modeling may also affect the SPDF. However, such effects are found to be negligible. The signal efficiency and acceptance are also affected by theoretical uncertainties, such as the PDF choice and initial- and final-state radiation modeling. These are also found to be small ($< 5\%$ from the PDF, $< 1\%$ from parton showering, and $< 1\%$ from renormalization-factorization scale). The above systematic uncertainties degrade the final limits by 10% at 700 GeV, increasing to around 20% at 2.5 TeV and back to 10% at 4 TeV. Another kind of uncertainty, referred to as the spurious signal, arises from a potential bias in the estimated number of signal events due to the choice of background parameterization. It was estimated by fitting the signal-plus-background model to control data sample $m_{J\gamma}$ distributions with a control region to signal region background-shape correction factor derived from simulation. The absolute number of fitted signal events at a given $m_{Z'}$ hypothesis value is taken as the number of spurious-signal events, which varies from a few events in the low mass region to less than 0.1 events in the high mass region, and is parameterized as an exponential function of $m_{Z'}$. The signal from a hypothetical Z' resonance is extracted as $\sigma \times \mathcal{B}$, defined as its production cross-section times the decay branching fraction $\mathcal{B}(Z' \to H\gamma)$, by performing an unbinned extended maximum-likelihood fit to the $m_{J\gamma}$ distributions of the selected events in the

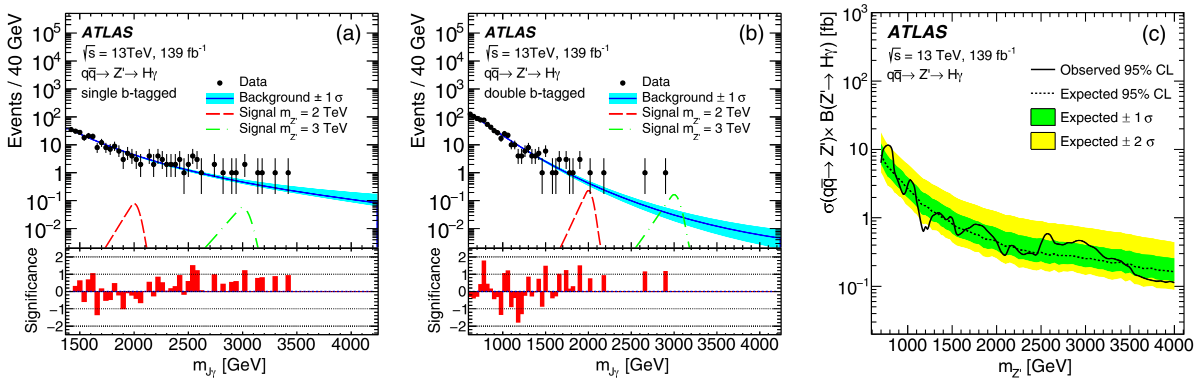

FIG. 1. (a),(b) Distribution of the reconstructed $m_{J\gamma}$ in the single- and double-b-tagged categories, with the background-only fits shown by the solid lines. The corresponding chi-square probabilities of the fits are 46% and 23%, after rebinning requiring at least five events in each bin. Hypothetical signal distributions for $m_{Z'} = 2$ TeV and $m_{Z'} = 3$ TeV with arbitrary normalizations are plotted for illustration purposes. The bottom panel gives the significance (deviation/statistical uncertainty) for each bin, calculated using the recommendation of Ref. [55]. The impact on the background fit from the statistical uncertainties of BPDF parameters is shown as a light band around the solid line. This effect is incorporated into the significance calculation. (c) Observed and expected 95% confidence-level limits on $\sigma \times \mathcal{B}$ as a function of $m_{Z'}$.

double- and single-b-tagged categories. The predicted SM value of the $H \to b\bar{b}$ decay branching ratio, 0.582 ± 0.007 [52], is used to calculate the upper limit on $\sigma \times \mathcal{B}$ from $\sigma \times \mathcal{B}(Z' \to H\gamma) \times \mathcal{B}(H \to b\bar{b})$. The fitting range for the double-b-tagged category is from 0.6 TeV to 4.2 TeV, while for the single-b-tagged category it is from 1.4 TeV to 4.2 TeV because of poor sensitivity in the low mass region. Systematic uncertainties are taken into account as nuisance parameters with Gaussian sampling distributions [5]. The lowest local (global) p value is 0.005 (0.412) at 775 GeV, corresponding to a local (global) significance of 2.6σ (0.22σ). No significant signal-like excess is observed and the data are found to be described very well by a background-only fit, as shown in Figs. 1(a) and 1(b). Hypothetical signal distributions for $m_{Z'} = 2$ TeV and $m_{Z'} = 3$ TeV with arbitrary normalizations are also plotted in Figs. 1(a) and 1(b) for illustration purposes. Combined upper limits on the signal $\sigma \times \mathcal{B}$ at the 95% confidence level are derived using a modified frequentist method [53,54], with toy MC experiment, taking into account both the statistical and systematic uncertainties. The result as a function of the resonance mass is shown in Fig. 1(c). The better sensitivity and larger integrated luminosity (139 fb^{-1}) of this search lowers the expected upper limits of this search as compared to that of the previous ATLAS search (139 fb^{-1}) [5]. The ratio of the current expected upper limits to that of the previous result is about $1/3$ ($1/15$) for resonances with masses below 1.2 TeV (above 2.5 TeV). A similar comparison with that of the previous CMS search (139 fb^{-1}) [6], where a multivariable approach based on a boosted decision tree was used to identify $H \to b\bar{b}$ decays, finds a ratio that varies between $2/5$ and $1/3$ for masses below 2.5 TeV.

In conclusion, this Letter reports on a search for the production of new heavy resonances decaying into a Higgs boson and a photon, using 139 fb^{-1} of $\sqrt{s} = 13$ TeV pp collision data collected by the ATLAS detector at the LHC. The analysis is performed by reconstructing the hadronic decay of the Higgs boson as a single large-radius jet, targeting the $H \to b\bar{b}$ mode. A novel algorithm using information about the jet constituents in the center-of-mass frame of the jet is implemented to identify the two b quarks in the jet and enhances the sensitivity of the search. No significant excess of events is observed above the expected background. Upper limits are set on the production cross-section times branching fraction for resonance decays into a Higgs boson and a photon in the resonance mass range from 0.7 to 4 TeV, which is significantly wider than in the previous ATLAS and CMS searches.

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; ANID, Chile; CAS, MOST and NSFC, China; COLCIENCIAS, Colombia; MSMT CR, MPO CR and VSC CR, Czech Republic; DNRF and DNSRC, Denmark; IN2P3-CNRS and CEA-DRF/IRFU, France; SRNSFG, Georgia; BMBF, HGF and MPG, Germany; GSRT, Greece; RGC and Hong Kong SAR, China; ISF and Benoziyo Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; NWO, Netherlands; RCN, Norway; MNiSW and NCN, Poland; FCT, Portugal; MNE/IFA, Romania; JINR; MES of Russia and NRC KI, Russian Federation; MESTD, Serbia; MSSR, Slovakia; ARRS and MIZŠ, Slovenia; DST/NRF, South Africa; MICINN, 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, USA. In addition, individual groups and members have received support from BCKDF, CANARIE, Compute Canada, CRC and IVADO, Canada; Beijing Municipal Science & Technology Commission, China; COST, ERC, ERDF, Horizon 2020 and Marie Skłodowska-Curie Actions, European Union; Investissements d'Avenir Labex, Investissements d'Avenir Idex and ANR, France; DFG and AvH Foundation, Germany; Herakleitos, Thales and Aristeia programmes co-financed by EU-ESF and the Greek NSRF, Greece; BSF-NSF and GIF, Israel; La Caixa Banking Foundation, CERCA Programme Generalitat de Catalunya and PROMETEO and GenT Programmes Generalitat Valenciana, Spain; Göran Gustafssons Stiftelse, Sweden; The Royal Society and Leverhulme Trust, United Kingdom. The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN, the ATLAS Tier-1 facilities at TRIUMF (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN-CNAF (Italy), NL-T1 (Netherlands), PIC (Spain), ASGC (Taiwan), RAL (UK) and BNL (USA), the Tier-2 facilities worldwide and large non-WLCG resource providers. Major contributors of computing resources are listed in Ref. [56].

[1] E. Eichten and K. Lane, Low-scale technicolor at the Tevatron and LHC, Phys. Lett. B **669**, 235 (2008).

[2] N. Arkani-Hamed, A. G. Cohen, and H. Georgi, Electroweak symmetry breaking from dimensional deconstruction, Phys. Lett. B **513**, 232 (2001).

[3] I. Low, J. Lykken, and G. Shaughnessy, Singlet scalars as Higgs boson imposters at the Large Hadron Collider, Phys. Rev. D **84**, 035027 (2011).

[4] B. A. Dobrescu, P. J. Fox, and J. Kearney, Higgs-photon resonances, Eur. Phys. J. C **77**, 704 (2017).

[5] ATLAS Collaboration, Search for heavy resonances decaying to a photon and a hadronically decaying $Z/W/H$ boson in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, Phys. Rev. D **98**, 032015 (2018).

[6] CMS Collaboration, Search for Narrow $H\gamma$ Resonances in Proton-Proton Collisions at $\sqrt{s} = 13$ TeV, Phys. Rev. Lett. **122**, 081804 (2019).

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

[8] ATLAS Collaboration, Measurement of the photon identification efficiencies with the ATLAS detector using LHC Run-1 data, Eur. Phys. J. C **76**, 666 (2016).

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

[10] B. Abbott *et al.*, Production and integration of the ATLAS Insertable B-Layer, J. Instrum. **13**, T05008 (2018).

[11] ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point in the center of the detector and the z axis along the beam pipe. The x axis points to the center of the LHC ring, and the y axis points upward. Cylindrical coordinates (r, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the z axis. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln\tan(\theta/2)$. The distance between two objects in $\eta - \phi$ space is $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$. Transverse momentum is defined by $p_{\mathrm{T}} = p\sin\theta$.

[12] J. Alwall, R. Frederix, S. Frixione, V. Hirschi, F. Maltoni, O. Mattelaer, H.-S. Shao, T. Stelzer, P. Torrielli, and M. Zaro, The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations, J. High Energy Phys. 07 (2014) 079.

[13] T. Sjöstrand, S. Mrenna, and P. Z. Skands, A brief introduction to PYTHIA 8.1, Comput. Phys. Commun. **178**, 852 (2008).

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

[15] ATLAS Collaboration, ATLAS Pythia 8 tunes to 7 TeV data, CERN Report No. ATL-PHYS-PUB-2014-021, 2014, https://cds.cern.ch/record/1966419.

[16] E. Bothmann *et al.*, Event generation with Sherpa 2.2, SciPost Phys. **7**, 034 (2019).

[17] T. Gleisberg and S. Höche, Comix, a new matrix element generator, J. High Energy Phys. 12 (2008) 039.

[18] F. Cascioli, P. Maierhofer, and S. Pozzorini, Scattering Amplitudes with Open Loops, Phys. Rev. Lett. **108**, 111601 (2012).

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

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

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

[22] H.-L. Lai, M. Guzzi, J. Huston, Z. Li, P. M. Nadolsky, J. Pumplin, and C.-P. Yuan, New parton distributions for collider physics, Phys. Rev. D **82**, 074024 (2010).

[23] J. Pumplin, M. Guzzi, J. Huston, Z. Li, P. M. Nadolsky, J. Pumplin, and C. P. Yuan, New Generation of Parton Distributions with Uncertainties from Global QCD Analysis, J. High Energy Phys. 07 (2002) 012.

[24] D. J. Lange, The EvtGen particle decay simulation package, Nucl. Instrum. Methods Phys. Res., Sect. A **462**, 152 (2001).

[25] S. Agostinelli *et al.*, Geant4—a simulation toolkit, Nucl. Instrum. Methods Phys. Res., Sect. A **506**, 250 (2003).

[26] ATLAS Collaboration, The ATLAS Simulation Infrastructure, Eur. Phys. J. C **70**, 823 (2010).

[27] ATLAS Collaboration, Photon identification in 2015 ATLAS data, CERN Report No. ATL-PHYS-PUB-2016-014, 2016, https://cds.cern.ch/record/2203125.

[28] ATLAS Collaboration, Electron and photon energy calibration with the ATLAS detector using data collected in 2015 at $\sqrt{s} = 13$ TeV, CERN Report No. ATL-PHYS-PUB-2016-015, 2016, https://cds.cern.ch/record/2203514.

[29] M. Cacciari, G. P. Salam, and G. Soyez, The anti-k_t jet clustering algorithm, J. High Energy Phys. 04 (2008) 063.

[30] M. Cacciari, G. P. Salam, and G. Soyez, FastJet user manual, Eur. Phys. J. C **72**, 1896 (2012).

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

[32] D. Krohn, J. Thaler, and L.-T. Wang, Jet trimming, J. High Energy Phys. 02 (2010) 084.

[33] S. Catani, Y. L. Dokshitzer, M. H. Seymour, and B. R. Webber, Longitudinally-invariant $k_\perp$-clustering algorithms for hadron-hadron collisions, Nucl. Phys. **B406**, 187 (1993).

[34] ATLAS Collaboration, Jet mass reconstruction with the ATLAS Detector in early Run 2 data, CERN Report No. ATLAS-CONF-2016-035, 2016, https://cds.cern.ch/record/2200211.

[35] G. Punzi, Sensitivity of searches for new signals and its optimization, eConf **C030908**, MODT002 (2003).

[36] C. Chen, Identification of a bottom quark-antiquark pair in a single jet with high transverse momentum and its application, Phys. Rev. D **92**, 093010 (2015).

[37] C. Chen, New approach to identifying boosted hadronically decaying particles using jet substructure in its center-of-mass frame, Phys. Rev. D **85**, 034007 (2012).

[38] ATLAS Collaboration, Measurement of the cross-section of high transverse momentum vector bosons reconstructed as single jets and studies of jet substructure in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector, New J. Phys. **16**, 113013 (2014).

[39] S. Catani, Y. L. Dokshitzer, M. Olsson, G. Turnock, and B. R. Webber, New clustering algorithm for multijet cross sections in e^+e^- annihilation, Phys. Lett. B **269**, 432 (1991).

[40] ATLAS Collaboration, Performance of b-jet identification in the ATLAS experiment, J. Instrum. **11**, P04008 (2016).

[41] ATLAS Collaboration, Optimisation of the ATLAS b-tagging performance for the 2016 LHC Run, CERN Report No. ATL-PHYS-PUB-2016-012, 2016, https://cds.cern.ch/record/2160731.

[42] L. Randall and R. Sundrum, Large Mass Hierarchy from a Small Extra Dimension, Phys. Rev. Lett. **83**, 3370 (1999).

[43] ATLAS Collaboration, Variable Radius, Exclusive-k_T, and Center-of-Mass Subjet Reconstruction for Higgs($\rightarrow b\bar{b}$) Tagging in ATLAS, CERN Report No. ATL-PHYS-PUB-2017-010, 2017, https://cds.cern.ch/record/2268678.

[44] ATLAS Collaboration, Calibration of b-tagging using dileptonic top pair events in a combinatorial likelihood approach with the ATLAS experiment, CERN Report No. ATLAS-CONF-2014-004, 2014, https://cds.cern.ch/record/1664335.

[45] ATLAS Collaboration, Simulation of top-quark production for the ATLAS experiment at $\sqrt{s} = 13$ TeV, CERN Report No. ATL-PHYS-PUB-2016-004, 2016, https://cds.cern.ch/record/2120417.

[46] M. Oreglia, A study of the reactions $\psi' \rightarrow \gamma\gamma\psi$, Ph.D. thesis, Stanford University, SLAC Report No. SLAC-R-236, 1980.

[47] R. M. Harris and K. Kousouris, Searches for dijet resonances at hadron colliders, Int. J. Mod. Phys. A **26**, 5005 (2011).

[48] ATLAS Collaboration, Luminosity determination in pp collisions at $\sqrt{s} = 8$ TeV using the ATLAS detector at the LHC, Eur. Phys. J. C **76**, 653 (2016).

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

[50] ATLAS Collaboration, *In-situ* measurements of the ATLAS large-radius jet response in 13 TeV pp collisions, CERN Report No. ATLAS-CONF-2017-063, 2017, https://cds.cern.ch/record/2275655.

[51] ATLAS Collaboration, Measurement of the Inelastic Proton-Proton Cross Section at $\sqrt{s} = 13$ TeV with the ATLAS Detector at the LHC, Phys. Rev. Lett. **117**, 182002 (2016).

[52] D. de Florian *et al.*, *Handbook of LHC Higgs cross sections: 4. Deciphering the nature of the Higgs sector* (CERN, Geneva, 2017), Vol. 2.

[53] T. Junk, Confidence level computation for combining searches with small statistics, Nucl. Instrum. Methods Phys. Res., Sect. A **434**, 435 (1999).

[54] A. L. Read, Presentation of search results: the CLs technique, J. Phys. G **28**, 2693 (2002).

[55] G. Choudalakis and D. Casadei, Plotting the differences between data and expectation, Eur. Phys. J. Plus **127**, 25 (2012).

[56] ATLAS Collaboration, ATLAS Computing Acknowledgements, CERN Report No. ATL-SOFT-PUB-2020-001, https://cds.cern.ch/record/2717821.

G. Aad,[102] B. Abbott,[128] D. C. Abbott,[103] A. Abed Abud,[36] K. Abeling,[53] D. K. Abhayasinghe,[94] S. H. Abidi,[167] O. S. AbouZeid,[40] N. L. Abraham,[156] H. Abramowicz,[161] H. Abreu,[160] Y. Abulaiti,[6] B. S. Acharya,[67a,67b,o] B. Achkar,[53] L. Adam,[100] C. Adam Bourdarios,[5] L. Adamczyk,[84a] L. Adamek,[167] J. Adelman,[121] M. Adersberger,[114] A. Adiguzel,[12c] S. Adorni,[54] T. Adye,[143] A. A. Affolder,[145] Y. Afik,[160] C. Agapopoulou,[65] M. N. Agaras,[38] A. Aggarwal,[119] C. Agheorghiesei,[27c] J. A. Aguilar-Saavedra,[139f,139a,ee] A. Ahmad,[36] F. Ahmadov,[80] W. S. Ahmed,[104] X. Ai,[18] G. Aielli,[74a,74b] S. Akatsuka,[86] M. Akbiyik,[100] T. P. A. Åkesson,[97] E. Akilli,[54] A. V. Akimov,[111] K. Al Khoury,[65] G. L. Alberghi,[23b,23a] J. Albert,[176] M. J. Alconada Verzini,[161] S. Alderweireldt,[36] M. Aleksa,[36] I. N. Aleksandrov,[80] C. Alexa,[27b] T. Alexopoulos,[10] A. Alfonsi,[120] F. Alfonsi,[23b,23a] M. Alhroob,[128] B. Ali,[141] S. Ali,[158] M. Aliev,[166] G. Alimonti,[69a] C. Allaire,[36] B. M. M. Allbrooke,[156] B. W. Allen,[131] P. P. Allport,[21] A. Aloisio,[70a,70b] F. Alonso,[89] C. Alpigiani,[148] E. Alunno Camelia,[74a,74b] M. Alvarez Estevez,[99] M. G. Alviggi,[70a,70b] Y. Amaral Coutinho,[81b] A. Ambler,[104] L. Ambroz,[134] C. Amelung,[26] D. Amidei,[106] S. P. Amor Dos Santos,[139a] S. Amoroso,[46] C. S. Amrouche,[54] F. An,[79] C. Anastopoulos,[149] N. Andari,[144] T. Andeen,[11] J. K. Anders,[20] S. Y. Andrean,[45a,45b] A. Andreazza,[69a,69b] V. Andrei,[61a] C. R. Anelli,[176]

S. Angelidakis,[9] A. Angerami,[39] A. V. Anisenkov,[122b,122a] A. Annovi,[72a] C. Antel,[54] M. T. Anthony,[149] E. Antipov,[129] M. Antonelli,[51] D. J. A. Antrim,[171] F. Anulli,[73a] M. Aoki,[82] J. A. Aparisi Pozo,[174] M. A. Aparo,[156] L. Aperio Bella,[46] N. Aranzabal,[36] V. Araujo Ferraz,[81a] R. Araujo Pereira,[81b] C. Arcangeletti,[51] A. T. H. Arce,[49] F. A. Arduh,[89] J-F. Arguin,[110] S. Argyropoulos,[52] J.-H. Arling,[46] A. J. Armbruster,[36] A. Armstrong,[171] O. Arnaez,[167] H. Arnold,[120] Z. P. Arrubarrena Tame,[114] G. Artoni,[134] H. Asada,[117] K. Asai,[126] S. Asai,[163] T. Asawatavonvanich,[165] N. Asbah,[59] E. M. Asimakopoulou,[172] L. Asquith,[156] J. Assahsah,[35d] K. Assamagan,[29] R. Astalos,[28a] R. J. Atkin,[33a] M. Atkinson,[173] N. B. Atlay,[19] H. Atmani,[65] K. Augsten,[141] V. A. Austrup,[182] G. Avolio,[36] M. K. Ayoub,[15a] G. Azuelos,[110,mm] H. Bachacou,[144] K. Bachas,[162] M. Backes,[134] F. Backman,[45a,45b] P. Bagnaia,[73a,73b] M. Bahmani,[85] H. Bahrasemani,[152] A. J. Bailey,[174] V. R. Bailey,[173] J. T. Baines,[143] C. Bakalis,[10] O. K. Baker,[183] P. J. Bakker,[120] E. Bakos,[16] D. Bakshi Gupta,[8] S. Balaji,[157] R. Balasubramanian,[120] E. M. Baldin,[122b,122a] P. Balek,[180] F. Balli,[144] W. K. Balunas,[134] J. Balz,[100] E. Banas,[85] M. Bandieramonte,[138] A. Bandyopadhyay,[24] Sw. Banerjee,[181,j] L. Barak,[161] W. M. Barbe,[38] E. L. Barberio,[105] D. Barberis,[55b,55a] M. Barbero,[102] G. Barbour,[95] T. Barillari,[115] M-S. Barisits,[36] J. Barkeloo,[131] T. Barklow,[153] R. Barnea,[160] B. M. Barnett,[143] R. M. Barnett,[18] Z. Barnovska-Blenessy,[60a] A. Baroncelli,[60a] G. Barone,[29] A. J. Barr,[134] L. Barranco Navarro,[45a,45b] F. Barreiro,[99] J. Barreiro Guimarães da Costa,[15a] U. Barron,[161] S. Barsov,[137] F. Bartels,[61a] R. Bartoldus,[153] G. Bartolini,[102] A. E. Barton,[90] P. Bartos,[28a] A. Basalaev,[46] A. Basan,[100] A. Bassalat,[65,jj] M. J. Basso,[167] R. L. Bates,[57] S. Batlamous,[35e] J. R. Batley,[32] B. Batool,[151] M. Battaglia,[145] M. Bauce,[73a,73b] F. Bauer,[144] P. Bauer,[24] H. S. Bawa,[31] A. Bayirli,[12c] J. B. Beacham,[49] T. Beau,[135] P. H. Beauchemin,[170] F. Becherer,[52] P. Bechtle,[24] H. C. Beck,[53] H. P. Beck,[20,q] K. Becker,[178] C. Becot,[46] A. Beddall,[12d] A. J. Beddall,[12a] V. A. Bednyakov,[80] M. Bedognetti,[120] C. P. Bee,[155] T. A. Beermann,[182] M. Begalli,[81b] M. Begel,[29] A. Behera,[155] J. K. Behr,[46] F. Beisiegel,[24] M. Belfkir,[5] A. S. Bell,[95] G. Bella,[161] L. Bellagamba,[23b] A. Bellerive,[34] P. Bellos,[9] K. Beloborodov,[122b,122a] K. Belotskiy,[112] N. L. Belyaev,[112] D. Benchekroun,[35a] N. Benekos,[10] Y. Benhammou,[161] D. P. Benjamin,[6] M. Benoit,[29] J. R. Bensinger,[26] S. Bentvelsen,[120] L. Beresford,[134] M. Beretta,[51] D. Berge,[19] E. Bergeaas Kuutmann,[172] N. Berger,[5] B. Bergmann,[141] L. J. Bergsten,[26] J. Beringer,[18] S. Berlendis,[7] G. Bernardi,[135] C. Bernius,[153] F. U. Bernlochner,[24] T. Berry,[94] P. Berta,[100] A. Berthold,[48] I. A. Bertram,[90] O. Bessidskaia Bylund,[182] N. Besson,[144] A. Bethani,[101] S. Bethke,[115] A. Betti,[42] A. J. Bevan,[93] J. Beyer,[115] D. S. Bhattacharya,[177] P. Bhattarai,[26] V. S. Bhopatkar,[6] R. Bi,[138] R. M. Bianchi,[138] O. Biebel,[114] D. Biedermann,[19] R. Bielski,[36] K. Bierwagen,[100] N. V. Biesuz,[72a,72b] M. Biglietti,[75a] T. R. V. Billoud,[141] M. Bindi,[53] A. Bingul,[12d] C. Bini,[73a,73b] S. Biondi,[23b,23a] C. J. Birch-sykes,[101] M. Birman,[180] T. Bisanz,[36] J. P. Biswal,[3] D. Biswas,[181,j] A. Bitadze,[101] C. Bittrich,[48] K. Bjørke,[133] T. Blazek,[28a] I. Bloch,[46] C. Blocker,[26] A. Blue,[57] U. Blumenschein,[93] G. J. Bobbink,[120] V. S. Bobrovnikov,[122b,122a] S. S. Bocchetta,[97] D. Bogavac,[14] A. G. Bogdanchikov,[122b,122a] C. Bohm,[45a] V. Boisvert,[94] P. Bokan,[172,53] T. Bold,[84a] A. E. Bolz,[61b] M. Bomben,[135] M. Bona,[93] J. S. Bonilla,[131] M. Boonekamp,[144] C. D. Booth,[94] A. G. Borbély,[57] H. M. Borecka-Bielska,[91] L. S. Borgna,[95] A. Borisov,[123] G. Borissov,[90] D. Bortoletto,[134] D. Boscherini,[23b] M. Bosman,[14] J. D. Bossio Sola,[104] K. Bouaouda,[35a] J. Boudreau,[138] E. V. Bouhova-Thacker,[90] D. Boumediene,[38] A. Boveia,[127] J. Boyd,[36] D. Boye,[33c] I. R. Boyko,[80] A. J. Bozson,[94] J. Bracinik,[21] N. Brahimi,[60d] G. Brandt,[182] O. Brandt,[32] F. Braren,[46] B. Brau,[103] J. E. Brau,[131] W. D. Breaden Madden,[57] K. Brendlinger,[46] R. Brener,[160] L. Brenner,[36] R. Brenner,[172] S. Bressler,[180] B. Brickwedde,[100] D. L. Briglin,[21] D. Britton,[57] D. Britzger,[115] I. Brock,[24] R. Brock,[107] G. Brooijmans,[39] W. K. Brooks,[146d] E. Brost,[29] P. A. Bruckman de Renstrom,[85] B. Brüers,[46] D. Bruncko,[28b] A. Bruni,[23b] G. Bruni,[23b] M. Bruschi,[23b] N. Bruscino,[73a,73b] L. Bryngemark,[153] T. Buanes,[17] Q. Buat,[155] P. Buchholz,[151] A. G. Buckley,[57] I. A. Budagov,[80] M. K. Bugge,[133] F. Bührer,[52] O. Bulekov,[112] B. A. Bullard,[59] T. J. Burch,[121] S. Burdin,[91] C. D. Burgard,[120] A. M. Burger,[129] B. Burghgrave,[8] J. T. P. Burr,[46] C. D. Burton,[11] J. C. Burzynski,[103] V. Büscher,[100] E. Buschmann,[53] P. J. Bussey,[57] J. M. Butler,[25] C. M. Buttar,[57] J. M. Butterworth,[95] P. Butti,[36] W. Buttinger,[36] C. J. Buxo Vazquez,[107] A. Buzatu,[158] A. R. Buzykaev,[122b,122a] G. Cabras,[23b,23a] S. Cabrera Urbán,[174] D. Caforio,[56] H. Cai,[138] V. M. M. Cairo,[153] O. Cakir,[4a] N. Calace,[36] P. Calafiura,[18] G. Calderini,[135] P. Calfayan,[66] G. Callea,[57] L. P. Caloba,[81b] A. Caltabiano,[74a,74b] S. Calvente Lopez,[99] D. Calvet,[38] S. Calvet,[38] T. P. Calvet,[102] M. Calvetti,[72a,72b] R. Camacho Toro,[135] S. Camarda,[36] D. Camarero Munoz,[99] P. Camarri,[74a,74b] M. T. Camerlingo,[75a,75b] D. Cameron,[133] C. Camincher,[36] S. Campana,[36] M. Campanelli,[95] A. Camplani,[40] V. Canale,[70a,70b] A. Canesse,[104] M. Cano Bret,[78] J. Cantero,[129] T. Cao,[161] Y. Cao,[173] M. D. M. Capeans Garrido,[36] M. Capua,[41b,41a] R. Cardarelli,[74a] F. Cardillo,[149] G. Carducci,[41b,41a] I. Carli,[142] T. Carli,[36] G. Carlino,[70a] B. T. Carlson,[138] E. M. Carlson,[176,168a] L. Carminati,[69a,69b] R. M. D. Carney,[153] S. Caron,[119] E. Carquin,[146d] S. Carrá,[46] G. Carratta,[23b,23a] J. W. S. Carter,[167] T. M. Carter,[50] M. P. Casado,[14,g] A. F. Casha,[167] E. G. Castiglia,[183] F. L. Castillo,[174] L. Castillo Garcia,[14] V. Castillo Gimenez,[174] N. F. Castro,[139a,139e] A. Catinaccio,[36] J. R. Catmore,[133]

A. Cattai,[36] V. Cavaliere,[29] V. Cavasinni,[72a,72b] E. Celebi,[12b] F. Celli,[134] K. Cerny,[130] A. S. Cerqueira,[81a] A. Cerri,[156] L. Cerrito,[74a,74b] F. Cerutti,[18] A. Cervelli,[23b,23a] S. A. Cetin,[12b] Z. Chadi,[35a] D. Chakraborty,[121] J. Chan,[181] W. S. Chan,[120] W. Y. Chan,[91] J. D. Chapman,[32] B. Chargeishvili,[159b] D. G. Charlton,[21] T. P. Charman,[93] M. Chatterjee,[20] C. C. Chau,[34] S. Che,[127] S. Chekanov,[6] S. V. Chekulaev,[168a] G. A. Chelkov,[80,hh] B. Chen,[79] C. Chen,[60a] C. H. Chen,[79] H. Chen,[15c] H. Chen,[29] J. Chen,[60a] J. Chen,[39] J. Chen,[26] S. Chen,[136] S. J. Chen,[15c] X. Chen,[15b] Y. Chen,[60a] Y-H. Chen,[46] H. C. Cheng,[63a] H. J. Cheng,[15a] A. Cheplakov,[80] E. Cheremushkina,[123] R. Cherkaoui El Moursli,[35e] E. Cheu,[7] K. Cheung,[64] T. J. A. Chevalérias,[144] L. Chevalier,[144] V. Chiarella,[51] G. Chiarelli,[72a] G. Chiodini,[68a] A. S. Chisholm,[21] A. Chitan,[27b] I. Chiu,[163] Y. H. Chiu,[176] M. V. Chizhov,[80] K. Choi,[11] A. R. Chomont,[73a,73b] Y. S. Chow,[120] L. D. Christopher,[33e] M. C. Chu,[63a] X. Chu,[15a,15d] J. Chudoba,[140] J. J. Chwastowski,[85] L. Chytka,[130] D. Cieri,[115] K. M. Ciesla,[85] V. Cindro,[92] I. A. Cioară,[27b] A. Ciocio,[18] F. Cirotto,[70a,70b] Z. H. Citron,[180,k] M. Citterio,[69a] D. A. Ciubotaru,[27b] B. M. Ciungu,[167] A. Clark,[54] M. R. Clark,[39] P. J. Clark,[50] S. E. Clawson,[101] C. Clement,[45a,45b] Y. Coadou,[102] M. Cobal,[67a,67c] A. Coccaro,[55b] J. Cochran,[79] R. Coelho Lopes De Sa,[103] H. Cohen,[161] A. E. C. Coimbra,[36] B. Cole,[39] A. P. Colijn,[120] J. Collot,[58] P. Conde Muiño,[139a,139h] S. H. Connell,[33c] I. A. Connelly,[57] S. Constantinescu,[27b] F. Conventi,[70a,nn] A. M. Cooper-Sarkar,[134] F. Cormier,[175] K. J. R. Cormier,[167] L. D. Corpe,[95] M. Corradi,[73a,73b] E. E. Corrigan,[97] F. Corriveau,[104,cc] M. J. Costa,[174] F. Costanza,[5] D. Costanzo,[149] G. Cowan,[94] J. W. Cowley,[32] J. Crane,[101] K. Cranmer,[125] R. A. Creager,[136] S. Crépé-Renaudin,[58] F. Crescioli,[135] M. Cristinziani,[24] V. Croft,[170] G. Crosetti,[41b,41a] A. Cueto,[5] T. Cuhadar Donszelmann,[171] H. Cui,[15a,15d] A. R. Cukierman,[153] W. R. Cunningham,[57] S. Czekierda,[85] P. Czodrowski,[36] M. M. Czurylo,[61b] M. J. Da Cunha Sargedas De Sousa,[60b] J. V. Da Fonseca Pinto,[81b] C. Da Via,[101] W. Dabrowski,[84a] F. Dachs,[36] T. Dado,[47] S. Dahbi,[33e] T. Dai,[106] C. Dallapiccola,[103] M. Dam,[40] G. D'amen,[29] V. D'Amico,[75a,75b] J. Damp,[100] J. R. Dandoy,[136] M. F. Daneri,[30] M. Danninger,[152] V. Dao,[36] G. Darbo,[55b] O. Dartsi,[5] A. Dattagupta,[131] T. Daubney,[46] S. D'Auria,[69a,69b] C. David,[168b] T. Davidek,[142] D. R. Davis,[49] I. Dawson,[149] K. De,[8] R. De Asmundis,[70a] M. De Beurs,[120] S. De Castro,[23b,23a] N. De Groot,[119] P. de Jong,[120] H. De la Torre,[107] A. De Maria,[15c] D. De Pedis,[73a] A. De Salvo,[73a] U. De Sanctis,[74a,74b] M. De Santis,[74a,74b] A. De Santo,[156] J. B. De Vivie De Regie,[65] D. V. Dedovich,[80] A. M. Deiana,[42] J. Del Peso,[99] Y. Delabat Diaz,[46] D. Delgove,[65] F. Deliot,[144] C. M. Delitzsch,[7] M. Della Pietra,[70a,70b] D. Della Volpe,[54] A. Dell'Acqua,[36] L. Dell'Asta,[74a,74b] M. Delmastro,[5] C. Delporte,[65] P. A. Delsart,[58] D. A. DeMarco,[167] S. Demers,[183] M. Demichev,[80] G. Demontigny,[110] S. P. Denisov,[123] L. D'Eramo,[121] D. Derendarz,[85] J. E. Derkaoui,[35d] F. Derue,[135] P. Dervan,[91] K. Desch,[24] K. Dette,[167] C. Deutsch,[24] M. R. Devesa,[30] P. O. Deviveiros,[36] F. A. Di Bello,[73a,73b] A. Di Ciaccio,[74a,74b] L. Di Ciaccio,[5] W. K. Di Clemente,[136] C. Di Donato,[70a,70b] A. Di Girolamo,[36] G. Di Gregorio,[72a,72b] B. Di Micco,[75a,75b] R. Di Nardo,[75a,75b] K. F. Di Petrillo,[59] R. Di Sipio,[167] C. Diaconu,[102] F. A. Dias,[120] T. Dias Do Vale,[139a] M. A. Diaz,[146a] F. G. Diaz Capriles,[24] J. Dickinson,[18] M. Didenko,[166] E. B. Diehl,[106] J. Dietrich,[19] S. Díez Cornell,[46] C. Diez Pardos,[151] A. Dimitrievska,[18] W. Ding,[15b] J. Dingfelder,[24] S. J. Dittmeier,[61b] F. Dittus,[36] F. Djama,[102] T. Djobava,[159b] J. I. Djuvsland,[17] M. A. B. Do Vale,[147] M. Dobre,[27b] D. Dodsworth,[26] C. Doglioni,[97] J. Dolejsi,[142] Z. Dolezal,[142] M. Donadelli,[81c] B. Dong,[60c] J. Donini,[38] A. D'onofrio,[15c] M. D'Onofrio,[91] J. Dopke,[143] A. Doria,[70a] M. T. Dova,[89] A. T. Doyle,[57] E. Drechsler,[152] E. Dreyer,[152] T. Dreyer,[53] A. S. Drobac,[170] D. Du,[60b] T. A. du Pree,[120] Y. Duan,[60d] F. Dubinin,[111] M. Dubovsky,[28a] A. Dubreuil,[54] E. Duchovni,[180] G. Duckeck,[114] O. A. Ducu,[36] D. Duda,[115] A. Dudarev,[36] A. C. Dudder,[100] E. M. Duffield,[18] M. D'uffizi,[101] L. Duflot,[65] M. Dührssen,[36] C. Dülsen,[182] M. Dumancic,[180] A. E. Dumitriu,[27b] M. Dunford,[61a] A. Duperrin,[102] H. Duran Yildiz,[4a] M. Düren,[56] A. Durglishvili,[159b] D. Duschinger,[48] B. Dutta,[46] D. Duvnjak,[1] G. I. Dyckes,[136] M. Dyndal,[36] S. Dysch,[101] B. S. Dziedzic,[85] M. G. Eggleston,[49] T. Eifert,[8] G. Eigen,[17] K. Einsweiler,[18] T. Ekelof,[172] H. El Jarrari,[35e] V. Ellajosyula,[172] M. Ellert,[172] F. Ellinghaus,[182] A. A. Elliot,[93] N. Ellis,[36] J. Elmsheuser,[29] M. Elsing,[36] D. Emeliyanov,[143] A. Emerman,[39] Y. Enari,[163] M. B. Epland,[49] J. Erdmann,[47] A. Ereditato,[20] P. A. Erland,[85] M. Errenst,[182] M. Escalier,[65] C. Escobar,[174] O. Estrada Pastor,[174] E. Etzion,[161] G. E. Evans,[139a,139b] H. Evans,[66] M. O. Evans,[156] A. Ezhilov,[137] F. Fabbri,[57] L. Fabbri,[23b,23a] V. Fabiani,[119] G. Facini,[178] R. M. Fakhrutdinov,[123] S. Falciano,[73a] P. J. Falke,[24] S. Falke,[36] J. Faltova,[142] Y. Fang,[15a] Y. Fang,[15a] G. Fanourakis,[44] M. Fanti,[69a,69b] M. Faraj,[67a,67c] A. Farbin,[8] A. Farilla,[75a] E. M. Farina,[71a,71b] T. Farooque,[107] S. M. Farrington,[50] P. Farthouat,[36] F. Fassi,[35e] P. Fassnacht,[36] D. Fassouliotis,[9] M. Faucci Giannelli,[50] W. J. Fawcett,[32] L. Fayard,[65] O. L. Fedin,[137,p] W. Fedorko,[175] A. Fehr,[20] M. Feickert,[173] L. Feligioni,[102] A. Fell,[149] C. Feng,[60b] M. Feng,[49] M. J. Fenton,[171] A. B. Fenyuk,[123] S. W. Ferguson,[43] J. Ferrando,[46] A. Ferrante,[173] A. Ferrari,[172] P. Ferrari,[120] R. Ferrari,[71a] D. E. Ferreira de Lima,[61b] A. Ferrer,[174] D. Ferrere,[54] C. Ferretti,[106] F. Fiedler,[100] A. Filipčič,[92] F. Filthaut,[119] K. D. Finelli,[25] M. C. N. Fiolhais,[139a,139c,b] L. Fiorini,[174] F. Fischer,[114] J. Fischer,[100] W. C. Fisher,[107] T. Fitschen,[21] I. Fleck,[151]

P. Fleischmann,[106] T. Flick,[182] B. M. Flierl,[114] L. Flores,[136] L. R. Flores Castillo,[63a] F. M. Follega,[76a,76b] N. Fomin,[17] J. H. Foo,[167] G. T. Forcolin,[76a,76b] B. C. Forland,[66] A. Formica,[144] F. A. Förster,[14] A. C. Forti,[101] E. Fortin,[102] M. G. Foti,[134] D. Fournier,[65] H. Fox,[90] P. Francavilla,[72a,72b] S. Francescato,[73a,73b] M. Franchini,[23b,23a] S. Franchino,[61a] D. Francis,[36] L. Franco,[5] L. Franconi,[20] M. Franklin,[59] G. Frattari,[73a,73b] A. N. Fray,[93] P. M. Freeman,[21] B. Freund,[110] W. S. Freund,[81b] E. M. Freundlich,[47] D. C. Frizzell,[128] D. Froidevaux,[36] J. A. Frost,[134] M. Fujimoto,[126] C. Fukunaga,[164] E. Fullana Torregrosa,[174] T. Fusayasu,[116] J. Fuster,[174] A. Gabrielli,[23b,23a] A. Gabrielli,[36] S. Gadatsch,[54] P. Gadow,[115] G. Gagliardi,[55b,55a] L. G. Gagnon,[110] G. E. Gallardo,[134] E. J. Gallas,[134] B. J. Gallop,[143] R. Gamboa Goni,[93] K. K. Gan,[127] S. Ganguly,[180] J. Gao,[60a] Y. Gao,[50] Y. S. Gao,[31,m] F. M. Garay Walls,[146a] C. García,[174] J. E. García Navarro,[174] J. A. García Pascual,[15a] C. Garcia-Argos,[52] M. Garcia-Sciveres,[18] R. W. Gardner,[37] N. Garelli,[153] S. Gargiulo,[52] C. A. Garner,[167] V. Garonne,[133] S. J. Gasiorowski,[148] P. Gaspar,[81b] A. Gaudiello,[55b,55a] G. Gaudio,[71a] P. Gauzzi,[73a,73b] I. L. Gavrilenko,[111] A. Gavrilyuk,[124] C. Gay,[175] G. Gaycken,[46] E. N. Gazis,[10] A. A. Geanta,[27b] C. M. Gee,[145] C. N. P. Gee,[143] J. Geisen,[97] M. Geisen,[100] C. Gemme,[55b] M. H. Genest,[58] C. Geng,[106] S. Gentile,[73a,73b] S. George,[94] T. Geralis,[44] L. O. Gerlach,[53] P. Gessinger-Befurt,[100] G. Gessner,[47] S. Ghasemi,[151] M. Ghasemi Bostanabad,[176] M. Ghneimat,[151] A. Ghosh,[65] A. Ghosh,[78] B. Giacobbe,[23b] S. Giagu,[73a,73b] N. Giangiacomi,[23b,23a] P. Giannetti,[72a] A. Giannini,[70a,70b] G. Giannini,[14] S. M. Gibson,[94] M. Gignac,[145] D. T. Gil,[84b] B. J. Gilbert,[39] D. Gillberg,[34] G. Gilles,[182] N. E. K. Gillwald,[46] D. M. Gingrich,[3,mm] M. P. Giordani,[67a,67c] P. F. Giraud,[144] G. Giugliarelli,[67a,67c] D. Giugni,[69a] F. Giuli,[74a,74b] S. Gkaitatzis,[162] I. Gkialas,[9,h] E. L. Gkougkousis,[14] P. Gkountoumis,[10] L. K. Gladilin,[113] C. Glasman,[99] J. Glatzer,[14] P. C. F. Glaysher,[46] A. Glazov,[46] G. R. Gledhill,[131] I. Gnesi,[41b,c] M. Goblirsch-Kolb,[26] D. Godin,[110] S. Goldfarb,[105] T. Golling,[54] D. Golubkov,[123] A. Gomes,[139a,139b] R. Goncalves Gama,[53] R. Gonçalo,[139a,139c] G. Gonella,[131] L. Gonella,[21] A. Gongadze,[80] F. Gonnella,[21] J. L. Gonski,[39] S. González de la Hoz,[174] S. Gonzalez Fernandez,[14] R. Gonzalez Lopez,[91] C. Gonzalez Renteria,[18] R. Gonzalez Suarez,[172] S. Gonzalez-Sevilla,[54] G. R. Gonzalvo Rodriguez,[174] L. Goossens,[36] N. A. Gorasia,[21] P. A. Gorbounov,[124] H. A. Gordon,[29] B. Gorini,[36] E. Gorini,[68a,68b] A. Gorišek,[92] A. T. Goshaw,[49] M. I. Gostkin,[80] C. A. Gottardo,[119] M. Gouighri,[35b] A. G. Goussiou,[148] N. Govender,[33c] C. Goy,[5] I. Grabowska-Bold,[84a] E. C. Graham,[91] J. Gramling,[171] E. Gramstad,[133] S. Grancagnolo,[19] M. Grandi,[156] V. Gratchev,[137] P. M. Gravila,[27f] F. G. Gravili,[68a,68b] C. Gray,[57] H. M. Gray,[18] C. Grefe,[24] K. Gregersen,[97] I. M. Gregor,[46] P. Grenier,[153] K. Grevtsov,[46] C. Grieco,[14] N. A. Grieser,[128] A. A. Grillo,[145] K. Grimm,[31,l] S. Grinstein,[14,x] J.-F. Grivaz,[65] S. Groh,[100] E. Gross,[180] J. Grosse-Knetter,[53] Z. J. Grout,[95] C. Grud,[106] A. Grummer,[118] J. C. Grundy,[134] L. Guan,[106] W. Guan,[181] C. Gubbels,[175] J. Guenther,[36] A. Guerguichon,[65] J. G. R. Guerrero Rojas,[174] F. Guescini,[115] D. Guest,[171] R. Gugel,[100] A. Guida,[46] T. Guillemin,[5] S. Guindon,[36] J. Guo,[60c] W. Guo,[106] Y. Guo,[60a] Z. Guo,[102] R. Gupta,[46] S. Gurbuz,[12c] G. Gustavino,[128] M. Guth,[52] P. Gutierrez,[128] C. Gutschow,[95] C. Guyot,[144] C. Gwenlan,[134] C. B. Gwilliam,[91] E. S. Haaland,[133] A. Haas,[125] C. Haber,[18] H. K. Hadavand,[8] A. Hadef,[60a] M. Haleem,[177] J. Haley,[129] J. J. Hall,[149] G. Halladjian,[107] G. D. Hallewell,[102] K. Hamano,[176] H. Hamdaoui,[35e] M. Hamer,[24] G. N. Hamity,[50] K. Han,[60a,w] L. Han,[15c] L. Han,[60a] S. Han,[18] Y. F. Han,[167] K. Hanagaki,[82,u] M. Hance,[145] D. M. Handl,[114] M. D. Hank,[37] R. Hankache,[135] E. Hansen,[97] J. B. Hansen,[40] J. D. Hansen,[40] M. C. Hansen,[24] P. H. Hansen,[40] E. C. Hanson,[101] K. Hara,[169] T. Harenberg,[182] S. Harkusha,[108] P. F. Harrison,[178] N. M. Hartman,[153] N. M. Hartmann,[114] Y. Hasegawa,[150] A. Hasib,[50] S. Hassani,[144] S. Haug,[20] R. Hauser,[107] L. B. Havener,[39] M. Havranek,[141] C. M. Hawkes,[21] R. J. Hawkings,[36] S. Hayashida,[117] D. Hayden,[107] C. Hayes,[106] R. L. Hayes,[175] C. P. Hays,[134] J. M. Hays,[93] H. S. Hayward,[91] S. J. Haywood,[143] F. He,[60a] Y. He,[165] M. P. Heath,[50] V. Hedberg,[97] S. Heer,[24] A. L. Heggelund,[133] C. Heidegger,[52] K. K. Heidegger,[52] W. D. Heidorn,[79] J. Heilman,[34] S. Heim,[46] T. Heim,[18] B. Heinemann,[46,kk] J. G. Heinlein,[136] J. J. Heinrich,[131] L. Heinrich,[36] J. Hejbal,[140] L. Helary,[46] A. Held,[125] S. Hellesund,[133] C. M. Helling,[145] S. Hellman,[45a,45b] C. Helsens,[36] R. C. W. Henderson,[90] Y. Heng,[181] L. Henkelmann,[32] A. M. Henriques Correia,[36] H. Herde,[26] Y. Hernández Jiménez,[33e] H. Herr,[100] M. G. Herrmann,[114] T. Herrmann,[48] G. Herten,[52] R. Hertenberger,[114] L. Hervas,[36] T. C. Herwig,[136] G. G. Hesketh,[95] N. P. Hessey,[168a] H. Hibi,[83] S. Higashino,[82] E. Higón-Rodriguez,[174] K. Hildebrand,[37] J. C. Hill,[32] K. K. Hill,[29] K. H. Hiller,[46] S. J. Hillier,[21] M. Hils,[48] I. Hinchliffe,[18] F. Hinterkeuser,[24] M. Hirose,[132] S. Hirose,[169] D. Hirschbuehl,[182] B. Hiti,[92] O. Hladik,[140] J. Hobbs,[155] N. Hod,[180] M. C. Hodgkinson,[149] A. Hoecker,[36] D. Hohn,[52] D. Hohov,[65] T. Holm,[24] T. R. Holmes,[37] M. Holzbock,[115] L. B. A. H. Hommels,[32] T. M. Hong,[138] J. C. Honig,[52] A. Hönle,[115] B. H. Hooberman,[173] W. H. Hopkins,[6] Y. Horii,[117] P. Horn,[48] L. A. Horyn,[37] S. Hou,[158] A. Hoummada,[35a] J. Howarth,[57] J. Hoya,[89] M. Hrabovsky,[130] J. Hrdinka,[77] J. Hrivnac,[65] A. Hrynevich,[109] T. Hryn'ova,[5] P. J. Hsu,[64] S.-C. Hsu,[148] Q. Hu,[29] S. Hu,[60c] Y. F. Hu,[15a,15d,oo] D. P. Huang,[95] X. Huang,[15c] Y. Huang,[60a] Y. Huang,[15a]

Z. Hubacek,[141] F. Hubaut,[102] M. Huebner,[24] F. Huegging,[24] T. B. Huffman,[134] M. Huhtinen,[36] R. Hulsken,[58] R. F. H. Hunter,[34] P. Huo,[155] N. Huseynov,[80,dd] J. Huston,[107] J. Huth,[59] R. Hyneman,[153] S. Hyrych,[28a] G. Iacobucci,[54] G. Iakovidis,[29] I. Ibragimov,[151] L. Iconomidou-Fayard,[65] P. Iengo,[36] R. Ignazzi,[40] O. Igonkina,[120,a,z] R. Iguchi,[163] T. Iizawa,[54] Y. Ikegami,[82] M. Ikeno,[82] N. Ilic,[119,167,cc] F. Iltzsche,[48] H. Imam,[35a] G. Introzzi,[71a,71b] M. Iodice,[75a] K. Iordanidou,[168a] V. Ippolito,[73a,73b] M. F. Isacson,[172] M. Ishino,[163] W. Islam,[129] C. Issever,[19,46] S. Istin,[160] J. M. Iturbe Ponce,[63a] R. Iuppa,[76a,76b] A. Ivina,[180] J. M. Izen,[43] V. Izzo,[70a] P. Jacka,[140] P. Jackson,[1] R. M. Jacobs,[46] B. P. Jaeger,[152] V. Jain,[2] G. Jäkel,[182] K. B. Jakobi,[100] K. Jakobs,[52] T. Jakoubek,[180] J. Jamieson,[57] K. W. Janas,[84a] R. Jansky,[54] M. Janus,[53] P. A. Janus,[84a] G. Jarlskog,[97] A. E. Jaspan,[91] N. Javadov,[80,dd] T. Javůrek,[36] M. Javurkova,[103] F. Jeanneau,[144] L. Jeanty,[131] J. Jejelava,[159a] P. Jenni,[52,d] N. Jeong,[46] S. Jézéquel,[5] H. Ji,[181] J. Jia,[155] Z. Jia,[15c] H. Jiang,[79] Y. Jiang,[60a] Z. Jiang,[153] S. Jiggins,[52] F. A. Jimenez Morales,[38] J. Jimenez Pena,[115] S. Jin,[15c] A. Jinaru,[27b] O. Jinnouchi,[165] H. Jivan,[33e] P. Johansson,[149] K. A. Johns,[7] C. A. Johnson,[66] E. Jones,[178] R. W. L. Jones,[90] S. D. Jones,[156] T. J. Jones,[91] J. Jongmanns,[61a] J. Jovicevic,[36] X. Ju,[18] J. J. Junggeburth,[115] A. Juste Rozas,[14,x] A. Kaczmarska,[85] M. Kado,[73a,73b] H. Kagan,[127] M. Kagan,[153] A. Kahn,[39] C. Kahra,[100] T. Kaji,[179] E. Kajomovitz,[160] C. W. Kalderon,[29] A. Kaluza,[100] A. Kamenshchikov,[123] M. Kaneda,[163] N. J. Kang,[145] S. Kang,[79] Y. Kano,[117] J. Kanzaki,[82] L. S. Kaplan,[181] D. Kar,[33e] K. Karava,[134] M. J. Kareem,[168b] I. Karkanias,[162] S. N. Karpov,[80] Z. M. Karpova,[80] V. Kartvelishvili,[90] A. N. Karyukhin,[123] E. Kasimi,[162] A. Kastanas,[45a,45b] C. Kato,[60d] J. Katzy,[46] K. Kawade,[150] K. Kawagoe,[88] T. Kawaguchi,[117] T. Kawamoto,[144] G. Kawamura,[53] E. F. Kay,[176] S. Kazakos,[14] V. F. Kazanin,[122b,122a] J. M. Keaveney,[33a] R. Keeler,[176] J. S. Keller,[34] E. Kellermann,[97] D. Kelsey,[156] J. J. Kempster,[21] J. Kendrick,[21] K. E. Kennedy,[39] O. Kepka,[140] S. Kersten,[182] B. P. Kerševan,[92] S. Ketabchi Haghighat,[167] M. Khader,[173] F. Khalil-Zada,[13] M. Khandoga,[144] A. Khanov,[129] A. G. Kharlamov,[122b,122a] T. Kharlamova,[122b,122a] E. E. Khoda,[175] A. Khodinov,[166] T. J. Khoo,[54] G. Khoriauli,[177] E. Khramov,[80] J. Khubua,[159b] S. Kido,[83] M. Kiehn,[36] E. Kim,[165] Y. K. Kim,[37] N. Kimura,[95] A. Kirchhoff,[53] D. Kirchmeier,[48] J. Kirk,[143] A. E. Kiryunin,[115] T. Kishimoto,[163] D. P. Kisliuk,[167] V. Kitali,[46] C. Kitsaki,[10] O. Kivernyk,[24] T. Klapdor-Kleingrothaus,[52] M. Klassen,[61a] C. Klein,[34] M. H. Klein,[106] M. Klein,[91] U. Klein,[91] K. Kleinknecht,[100] P. Klimek,[121] A. Klimentov,[29] T. Klingl,[24] T. Klioutchnikova,[36] F. F. Klitzner,[114] P. Kluit,[120] S. Kluth,[115] E. Kneringer,[77] E. B. F. G. Knoops,[102] A. Knue,[52] D. Kobayashi,[88] M. Kobel,[48] M. Kocian,[153] T. Kodama,[163] P. Kodys,[142] D. M. Koeck,[156] P. T. Koenig,[24] T. Koffas,[34] N. M. Köhler,[36] M. Kolb,[144] I. Koletsou,[5] T. Komarek,[130] T. Kondo,[82] K. Köneke,[52] A. X. Y. Kong,[1] A. C. König,[119] T. Kono,[126] V. Konstantinides,[95] N. Konstantinidis,[95] B. Konya,[97] R. Kopeliansky,[66] S. Koperny,[84a] K. Korcyl,[85] K. Kordas,[162] G. Koren,[161] A. Korn,[95] I. Korolkov,[14] E. V. Korolkova,[149] N. Korotkova,[113] O. Kortner,[115] S. Kortner,[115] V. V. Kostyukhin,[149,166] A. Kotsokechagia,[65] A. Kotwal,[49] A. Koulouris,[10] A. Kourkoumeli-Charalampidi,[71a,71b] C. Kourkoumelis,[9] E. Kourlitis,[6] V. Kouskoura,[29] R. Kowalewski,[176] W. Kozanecki,[101] A. S. Kozhin,[123] V. A. Kramarenko,[113] G. Kramberger,[92] D. Krasnopevtsev,[60a] M. W. Krasny,[135] A. Krasznahorkay,[36] D. Krauss,[115] J. A. Kremer,[100] J. Kretzschmar,[91] P. Krieger,[167] F. Krieter,[114] A. Krishnan,[61b] M. Krivos,[142] K. Krizka,[18] K. Kroeninger,[47] H. Kroha,[115] J. Kroll,[140] J. Kroll,[136] K. S. Krowpman,[107] U. Kruchonak,[80] H. Krüger,[24] N. Krumnack,[79] M. C. Kruse,[49] J. A. Krzysiak,[85] A. Kubota,[165] O. Kuchinskaia,[166] S. Kuday,[4b] D. Kuechler,[46] J. T. Kuechler,[46] S. Kuehn,[36] T. Kuhl,[46] V. Kukhtin,[80] Y. Kulchitsky,[108,ff] S. Kuleshov,[146b] Y. P. Kulinich,[173] M. Kuna,[58] A. Kupco,[140] T. Kupfer,[47] O. Kuprash,[52] H. Kurashige,[83] L. L. Kurchaninov,[168a] Y. A. Kurochkin,[108] A. Kurova,[112] M. G. Kurth,[15a,15d] E. S. Kuwertz,[36] M. Kuze,[165] A. K. Kvam,[148] J. Kvita,[130] T. Kwan,[104] F. La Ruffa,[41b,41a] C. Lacasta,[174] F. Lacava,[73a,73b] D. P. J. Lack,[101] H. Lacker,[19] D. Lacour,[135] E. Ladygin,[80] R. Lafaye,[5] B. Laforge,[135] T. Lagouri,[146c] S. Lai,[53] I. K. Lakomiec,[84a] J. E. Lambert,[128] S. Lammers,[66] W. Lampl,[7] C. Lampoudis,[162] E. Lançon,[29] U. Landgraf,[52] M. P. J. Landon,[93] M. C. Lanfermann,[54] V. S. Lang,[52] J. C. Lange,[53] R. J. Langenberg,[103] A. J. Lankford,[171] F. Lanni,[29] K. Lantzsch,[24] A. Lanza,[71a] A. Lapertosa,[55b,55a] J. F. Laporte,[144] T. Lari,[69a] F. Lasagni Manghi,[23b,23a] M. Lassnig,[36] V. Latonova,[140] T. S. Lau,[63a] A. Laudrain,[100] A. Laurier,[34] M. Lavorgna,[70a,70b] S. D. Lawlor,[94] M. Lazzaroni,[69a,69b] B. Le,[101] E. Le Guirriec,[102] A. Lebedev,[79] M. LeBlanc,[7] T. LeCompte,[6] F. Ledroit-Guillon,[58] A. C. A. Lee,[95] C. A. Lee,[29] G. R. Lee,[17] L. Lee,[59] S. C. Lee,[158] S. Lee,[79] B. Lefebvre,[168a] H. P. Lefebvre,[94] M. Lefebvre,[176] C. Leggett,[18] K. Lehmann,[152] N. Lehmann,[20] G. Lehmann Miotto,[36] W. A. Leight,[46] A. Leisos,[162,v] M. A. L. Leite,[81c] C. E. Leitgeb,[114] R. Leitner,[142] D. Lellouch,[180,a] K. J. C. Leney,[42] T. Lenz,[24] S. Leone,[72a] C. Leonidopoulos,[50] A. Leopold,[135] C. Leroy,[110] R. Les,[107] C. G. Lester,[32] M. Levchenko,[137] J. Levêque,[5] D. Levin,[106] L. J. Levinson,[180] D. J. Lewis,[21] B. Li,[15b] B. Li,[106] C-Q. Li,[60c,60d] F. Li,[60c] H. Li,[60a] H. Li,[60b] J. Li,[60c] K. Li,[148] L. Li,[60c] M. Li,[15a,15d] Q. Li,[15a,15d] Q. Y. Li,[60a] S. Li,[60d,60c] X. Li,[46] Y. Li,[46] Z. Li,[60b] Z. Li,[134] Z. Li,[104] Z. Liang,[15a]

M. Liberatore,[46] B. Liberti,[74a] A. Liblong,[167] K. Lie,[63c] S. Lim,[29] C. Y. Lin,[32] K. Lin,[107] R. A. Linck,[66] R. E. Lindley,[7] J. H. Lindon,[21] A. Linss,[46] A. L. Lionti,[54] E. Lipeles,[136] A. Lipniacka,[17] T. M. Liss,[173,ll] A. Lister,[175] J. D. Little,[8] B. Liu,[79] B. X. Liu,[152] H. B. Liu,[29] J. B. Liu,[60a] J. K. K. Liu,[37] K. Liu,[60d] M. Liu,[60a] M. Y. Liu,[60a] P. Liu,[15a] X. Liu,[60a] Y. Liu,[46] Y. Liu,[15a,15d] Y. L. Liu,[106] Y. W. Liu,[60a] M. Livan,[71a,71b] A. Lleres,[58] J. Llorente Merino,[152] S. L. Lloyd,[93] C. Y. Lo,[63b] E. M. Lobodzinska,[46] P. Loch,[7] S. Loffredo,[74a,74b] T. Lohse,[19] K. Lohwasser,[149] M. Lokajicek,[140] J. D. Long,[173] R. E. Long,[90] I. Longarini,[73a,73b] L. Longo,[36] K. A. Looper,[127] I. Lopez Paz,[101] A. Lopez Solis,[149] J. Lorenz,[114] N. Lorenzo Martinez,[5] A. M. Lory,[114] P. J. Lösel,[114] A. Lösle,[52] X. Lou,[45a,45b] X. Lou,[15a] A. Lounis,[65] J. Love,[6] P. A. Love,[90] J. J. Lozano Bahilo,[174] M. Lu,[60a] Y. J. Lu,[64] H. J. Lubatti,[148] C. Luci,[73a,73b] F. L. Lucio Alves,[15c] A. Lucotte,[58] F. Luehring,[66] I. Luise,[135] L. Luminari,[73a] B. Lund-Jensen,[154] M. S. Lutz,[161] D. Lynn,[29] H. Lyons,[91] R. Lysak,[140] E. Lytken,[97] F. Lyu,[15a] V. Lyubushkin,[80] T. Lyubushkina,[80] H. Ma,[29] L. L. Ma,[60b] Y. Ma,[95] D. M. Mac Donell,[176] G. Maccarrone,[51] A. Macchiolo,[115] C. M. Macdonald,[149] J. C. MacDonald,[149] J. Machado Miguens,[136] D. Madaffari,[174] R. Madar,[38] W. F. Mader,[48] M. Madugoda Ralalage Don,[129] N. Madysa,[48] J. Maeda,[83] T. Maeno,[29] M. Maerker,[48] V. Magerl,[52] N. Magini,[79] J. Magro,[67a,67c,r] D. J. Mahon,[39] C. Maidantchik,[81b] T. Maier,[114] A. Maio,[139a,139b,139d] K. Maj,[84a] O. Majersky,[28a] S. Majewski,[131] Y. Makida,[82] N. Makovec,[65] B. Malaescu,[135] Pa. Malecki,[85] V. P. Maleev,[137] F. Malek,[58] D. Malito,[41b,41a] U. Mallik,[78] D. Malon,[6] C. Malone,[32] S. Maltezos,[10] S. Malyukov,[80] J. Mamuzic,[174] G. Mancini,[70a,70b] I. Mandić,[92] L. Manhaes de Andrade Filho,[81a] I. M. Maniatis,[162] J. Manjarres Ramos,[48] K. H. Mankinen,[97] A. Mann,[114] A. Manousos,[77] B. Mansoulie,[144] I. Manthos,[162] S. Manzoni,[120] A. Marantis,[162] G. Marceca,[30] L. Marchese,[134] G. Marchiori,[135] M. Marcisovsky,[140] L. Marcoccia,[74a,74b] C. Marcon,[97] M. Marjanovic,[128] Z. Marshall,[18] M. U. F. Martensson,[172] S. Marti-Garcia,[174] C. B. Martin,[127] T. A. Martin,[178] V. J. Martin,[50] B. Martin dit Latour,[17] L. Martinelli,[75a,75b] M. Martinez,[14,x] P. Martinez Agullo,[174] V. I. Martinez Outschoorn,[103] S. Martin-Haugh,[143] V. S. Martoiu,[27b] A. C. Martyniuk,[95] A. Marzin,[36] S. R. Maschek,[115] L. Masetti,[100] T. Mashimo,[163] R. Mashinistov,[111] J. Masik,[101] A. L. Maslennikov,[122b,122a] L. Massa,[23b,23a] P. Massarotti,[70a,70b] P. Mastrandrea,[72a,72b] A. Mastroberardino,[41b,41a] T. Masubuchi,[163] D. Matakias,[29] A. Matic,[114] N. Matsuzawa,[163] P. Mättig,[24] J. Maurer,[27b] B. Maček,[92] D. A. Maximov,[122b,122a] R. Mazini,[158] I. Maznas,[162] S. M. Mazza,[145] J. P. Mc Gowan,[104] S. P. Mc Kee,[106] T. G. McCarthy,[115] W. P. McCormack,[18] E. F. McDonald,[105] A. E. McDougall,[120] J. A. Mcfayden,[18] G. Mchedlidze,[159b] M. A. McKay,[42] K. D. McLean,[176] S. J. McMahon,[143] P. C. McNamara,[105] C. J. McNicol,[178] R. A. McPherson,[176,cc] J. E. Mdhluli,[33e] Z. A. Meadows,[103] S. Meehan,[36] T. Megy,[38] S. Mehlhase,[114] A. Mehta,[91] B. Meirose,[43] D. Melini,[160] B. R. Mellado Garcia,[33e] J. D. Mellenthin,[53] M. Melo,[28a] F. Meloni,[46] A. Melzer,[24] E. D. Mendes Gouveia,[139a,139e] A. M. Mendes Jacques Da Costa,[21] L. Meng,[36] X. T. Meng,[106] S. Menke,[115] E. Meoni,[41b,41a] S. Mergelmeyer,[19] S. A. M. Merkt,[138] C. Merlassino,[134] P. Mermod,[54] L. Merola,[70a,70b] C. Meroni,[69a] G. Merz,[106] O. Meshkov,[113,111] J. K. R. Meshreki,[151] J. Metcalfe,[6] A. S. Mete,[6] C. Meyer,[66] J-P. Meyer,[144] M. Michetti,[19] R. P. Middleton,[143] L. Mijović,[50] G. Mikenberg,[180] M. Mikestikova,[140] M. Mikuž,[92] H. Mildner,[149] A. Milic,[167] C. D. Milke,[42] D. W. Miller,[37] A. Milov,[180] D. A. Milstead,[45a,45b] R. A. Mina,[153] A. A. Minaenko,[123] I. A. Minashvili,[159b] A. I. Mincer,[125] B. Mindur,[84a] M. Mineev,[80] Y. Minegishi,[163] Y. Mino,[86] L. M. Mir,[14] M. Mironova,[134] K. P. Mistry,[136] T. Mitani,[179] J. Mitrevski,[114] V. A. Mitsou,[174] M. Mittal,[60c] O. Miu,[167] A. Miucci,[20] P. S. Miyagawa,[93] A. Mizukami,[82] J. U. Mjörnmark,[97] T. Mkrtchyan,[61a] M. Mlynarikova,[142] T. Moa,[45a,45b] S. Mobius,[53] K. Mochizuki,[110] P. Mogg,[114] S. Mohapatra,[39] R. Moles-Valls,[24] K. Mönig,[46] E. Monnier,[102] A. Montalbano,[152] J. Montejo Berlingen,[36] M. Montella,[95] F. Monticelli,[89] S. Monzani,[69a] N. Morange,[65] A. L. Moreira De Carvalho,[139a] D. Moreno,[22a] M. Moreno Llácer,[174] C. Moreno Martinez,[14] P. Morettini,[55b] M. Morgenstern,[160] S. Morgenstern,[48] D. Mori,[152] M. Morii,[59] M. Morinaga,[179] V. Morisbak,[133] A. K. Morley,[36] G. Mornacchi,[36] A. P. Morris,[95] L. Morvaj,[155] P. Moschovakos,[36] B. Moser,[120] M. Mosidze,[159b] T. Moskalets,[144] P. Moskvitina,[119] J. Moss,[31,n] E. J. W. Moyse,[103] S. Muanza,[102] J. Mueller,[138] R. S. P. Mueller,[114] D. Muenstermann,[90] G. A. Mullier,[97] D. P. Mungo,[69a,69b] J. L. Munoz Martinez,[14] F. J. Munoz Sanchez,[101] P. Murin,[28b] W. J. Murray,[178,143] A. Murrone,[69a,69b] J. M. Muse,[128] M. Muškinja,[18] C. Mwewa,[33a] A. G. Myagkov,[123,hh] A. A. Myers,[138] G. Myers,[66] J. Myers,[131] M. Myska,[141] B. P. Nachman,[18] O. Nackenhorst,[47] A. Nag Nag,[48] K. Nagai,[134] K. Nagano,[82] Y. Nagasaka,[62] J. L. Nagle,[29] E. Nagy,[102] A. M. Nairz,[36] Y. Nakahama,[117] K. Nakamura,[82] T. Nakamura,[163] H. Nanjo,[132] F. Napolitano,[61a] R. F. Naranjo Garcia,[46] R. Narayan,[42] I. Naryshkin,[137] M. Naseri,[34] T. Naumann,[46] G. Navarro,[22a] P. Y. Nechaeva,[111] F. Nechansky,[46] T. J. Neep,[21] A. Negri,[71a,71b] M. Negrini,[23b] C. Nellist,[119] C. Nelson,[104] M. E. Nelson,[45a,45b] S. Nemecek,[140] M. Nessi,[36,f] M. S. Neubauer,[173] F. Neuhaus,[100] M. Neumann,[182] R. Newhouse,[175] P. R. Newman,[21] C. W. Ng,[138] Y. S. Ng,[19]

Y. W. Y. Ng,[171] B. Ngair,[35e] H. D. N. Nguyen,[102] T. Nguyen Manh,[110] E. Nibigira,[38] R. B. Nickerson,[134] R. Nicolaidou,[144] D. S. Nielsen,[40] J. Nielsen,[145] M. Niemeyer,[53] N. Nikiforou,[11] V. Nikolaenko,[123,hh] I. Nikolic-Audit,[135] K. Nikolopoulos,[21] P. Nilsson,[29] H. R. Nindhito,[54] A. Nisati,[73a] N. Nishu,[60c] R. Nisius,[115] I. Nitsche,[47] T. Nitta,[179] T. Nobe,[163] D. L. Noel,[32] Y. Noguchi,[86] I. Nomidis,[135] M. A. Nomura,[29] M. Nordberg,[36] J. Novak,[92] T. Novak,[92] O. Novgorodova,[48] R. Novotny,[141] L. Nozka,[130] K. Ntekas,[171] E. Nurse,[95] F. G. Oakham,[34,mm] H. Oberlack,[115] J. Ocariz,[135] A. Ochi,[83] I. Ochoa,[39] J. P. Ochoa-Ricoux,[146a] K. O'Connor,[26] S. Oda,[88] S. Odaka,[82] S. Oerdek,[53] A. Ogrodnik,[84a] A. Oh,[101] C. C. Ohm,[154] H. Oide,[165] M. L. Ojeda,[167] H. Okawa,[169] Y. Okazaki,[86] M. W. O'Keefe,[91] Y. Okumura,[163] A. Olariu,[27b] L. F. Oleiro Seabra,[139a] S. A. Olivares Pino,[146a] D. Oliveira Damazio,[29] J. L. Oliver,[1] M. J. R. Olsson,[171] A. Olszewski,[85] J. Olszowska,[85] Ö. O. Öncel,[24] D. C. O'Neil,[152] A. P. O'neill,[134] A. Onofre,[139a,139e] P. U. E. Onyisi,[11] H. Oppen,[133] R. G. Oreamuno Madriz,[121] M. J. Oreglia,[37] G. E. Orellana,[89] D. Orestano,[75a,75b] N. Orlando,[14] R. S. Orr,[167] V. O'Shea,[57] R. Ospanov,[60a] G. Otero y Garzon,[30] H. Otono,[88] P. S. Ott,[61a] G. J. Ottino,[18] M. Ouchrif,[35d] J. Ouellette,[29] F. Ould-Saada,[133] A. Ouraou,[144,a] Q. Ouyang,[15a] M. Owen,[57] R. E. Owen,[143] V. E. Ozcan,[12c] N. Ozturk,[8] J. Pacalt,[130] H. A. Pacey,[32] K. Pachal,[49] A. Pacheco Pages,[14] C. Padilla Aranda,[14] S. Pagan Griso,[18] G. Palacino,[66] S. Palazzo,[50] S. Palestini,[36] M. Palka,[84b] P. Palni,[84a] C. E. Pandini,[54] J. G. Panduro Vazquez,[94] P. Pani,[46] G. Panizzo,[67a,67c] L. Paolozzi,[54] C. Papadatos,[110] K. Papageorgiou,[9,h] S. Parajuli,[42] A. Paramonov,[6] C. Paraskevopoulos,[10] D. Paredes Hernandez,[63b] S. R. Paredes Saenz,[134] B. Parida,[180] T. H. Park,[167] A. J. Parker,[31] M. A. Parker,[32] F. Parodi,[55b,55a] E. W. Parrish,[121] J. A. Parsons,[39] U. Parzefall,[52] L. Pascual Dominguez,[135] V. R. Pascuzzi,[18] J. M. P. Pasner,[145] F. Pasquali,[120] E. Pasqualucci,[73a] S. Passaggio,[55b] F. Pastore,[94] P. Pasuwan,[45a,45b] S. Pataraia,[100] J. R. Pater,[101] A. Pathak,[181,j] J. Patton,[91] T. Pauly,[36] J. Pearkes,[153] B. Pearson,[115] M. Pedersen,[133] L. Pedraza Diaz,[119] R. Pedro,[139a] T. Peiffer,[53] S. V. Peleganchuk,[122b,122a] O. Penc,[140] H. Peng,[60a] B. S. Peralva,[81a] M. M. Perego,[65] A. P. Pereira Peixoto,[139a] L. Pereira Sanchez,[45a,45b] D. V. Perepelitsa,[29] E. Perez Codina,[168a] F. Peri,[19] L. Perini,[69a,69b] H. Pernegger,[36] S. Perrella,[36] A. Perrevoort,[120] K. Peters,[46] R. F. Y. Peters,[101] B. A. Petersen,[36] T. C. Petersen,[40] E. Petit,[102] V. Petousis,[141] A. Petridis,[1] C. Petridou,[162] F. Petrucci,[75a,75b] M. Pettee,[183] N. E. Pettersson,[103] K. Petukhova,[142] A. Peyaud,[144] R. Pezoa,[146d] L. Pezzotti,[71a,71b] T. Pham,[105] P. W. Phillips,[143] M. W. Phipps,[173] G. Piacquadio,[155] E. Pianori,[18] A. Picazio,[103] R. H. Pickles,[101] R. Piegaia,[30] D. Pietreanu,[27b] J. E. Pilcher,[37] A. D. Pilkington,[101] M. Pinamonti,[67a,67c] J. L. Pinfold,[3] C. Pitman Donaldson,[95] M. Pitt,[161] L. Pizzimento,[74a,74b] A. Pizzini,[120] M.-A. Pleier,[29] V. Plesanovs,[52] V. Pleskot,[142] E. Plotnikova,[80] P. Podberezko,[122b,122a] R. Poettgen,[97] R. Poggi,[54] L. Poggioli,[135] I. Pogrebnyak,[107] D. Pohl,[24] I. Pokharel,[53] G. Polesello,[71a] A. Poley,[152,168a] A. Policicchio,[73a,73b] R. Polifka,[142] A. Polini,[23b] C. S. Pollard,[46] V. Polychronakos,[29] D. Ponomarenko,[112] L. Pontecorvo,[36] S. Popa,[27a] G. A. Popeneciu,[27d] L. Portales,[5] D. M. Portillo Quintero,[58] S. Pospisil,[141] K. Potamianos,[46] I. N. Potrap,[80] C. J. Potter,[32] H. Potti,[11] T. Poulsen,[97] J. Poveda,[174] T. D. Powell,[149] G. Pownall,[46] M. E. Pozo Astigarraga,[36] A. Prades Ibanez,[174] P. Pralavorio,[102] M. M. Prapa,[44] S. Prell,[79] D. Price,[101] M. Primavera,[68a] M. L. Proffitt,[148] N. Proklova,[112] K. Prokofiev,[63c] F. Prokoshin,[80] S. Protopopescu,[29] J. Proudfoot,[6] M. Przybycien,[84a] D. Pudzha,[137] A. Puri,[173] P. Puzo,[65] D. Pyatiizbyantseva,[112] J. Qian,[106] Y. Qin,[101] A. Quadt,[53] M. Queitsch-Maitland,[36] M. Racko,[28a] F. Ragusa,[69a,69b] G. Rahal,[98] J. A. Raine,[54] S. Rajagopalan,[29] A. Ramirez Morales,[93] K. Ran,[15a,15d] D. M. Rauch,[46] F. Rauscher,[114] S. Rave,[100] B. Ravina,[57] I. Ravinovich,[180] J. H. Rawling,[101] M. Raymond,[36] A. L. Read,[133] N. P. Readioff,[149] M. Reale,[68a,68b] D. M. Rebuzzi,[71a,71b] G. Redlinger,[29] K. Reeves,[43] D. Reikher,[161] A. Reiss,[100] A. Rej,[151] C. Rembser,[36] A. Renardi,[46] M. Renda,[27b] M. B. Rendel,[115] A. G. Rennie,[57] S. Resconi,[69a] E. D. Resseguie,[18] S. Rettie,[95] B. Reynolds,[127] E. Reynolds,[21] O. L. Rezanova,[122b,122a] P. Reznicek,[142] E. Ricci,[76a,76b] R. Richter,[115] S. Richter,[46] E. Richter-Was,[84b] M. Ridel,[135] P. Rieck,[115] O. Rifki,[46] M. Rijssenbeek,[155] A. Rimoldi,[71a,71b] M. Rimoldi,[46] L. Rinaldi,[23b] T. T. Rinn,[173] G. Ripellino,[154] I. Riu,[14] P. Rivadeneira,[46] J. C. Rivera Vergara,[176] F. Rizatdinova,[129] E. Rizvi,[93] C. Rizzi,[36] S. H. Robertson,[104,cc] M. Robin,[46] D. Robinson,[32] C. M. Robles Gajardo,[146d] M. Robles Manzano,[100] A. Robson,[57] A. Rocchi,[74a,74b] E. Rocco,[100] C. Roda,[72a,72b] S. Rodriguez Bosca,[174] A. Rodriguez Rodriguez,[52] A. M. Rodríguez Vera,[168b] S. Roe,[36] J. Roggel,[182] O. Røhne,[133] R. Röhrig,[115] R. A. Rojas,[146d] B. Roland,[52] C. P. A. Roland,[66] J. Roloff,[29] A. Romaniouk,[112] M. Romano,[23b,23a] N. Rompotis,[91] M. Ronzani,[125] L. Roos,[135] S. Rosati,[73a] G. Rosin,[103] B. J. Rosser,[136] E. Rossi,[46] E. Rossi,[75a,75b] E. Rossi,[70a,70b] L. P. Rossi,[55b] L. Rossini,[46] R. Rosten,[14] M. Rotaru,[27b] B. Rottler,[52] D. Rousseau,[65] G. Rovelli,[71a,71b] A. Roy,[11] D. Roy,[33e] A. Rozanov,[102] Y. Rozen,[160] X. Ruan,[33e] T. A. Ruggeri,[1] F. Rühr,[52] A. Ruiz-Martinez,[174] A. Rummler,[36] Z. Rurikova,[52] N. A. Rusakovich,[80] H. L. Russell,[104] L. Rustige,[38,47] J. P. Rutherfoord,[7] E. M. Rüttinger,[149] M. Rybar,[142] G. Rybkin,[65] E. B. Rye,[133] A. Ryzhov,[123] J. A. Sabater Iglesias,[46] P. Sabatini,[53] L. Sabetta,[73a,73b] S. Sacerdoti,[65]

H. F-W. Sadrozinski,[145] R. Sadykov,[80] F. Safai Tehrani,[73a] B. Safarzadeh Samani,[156] M. Safdari,[153] P. Saha,[121] S. Saha,[104] M. Sahinsoy,[115] A. Sahu,[182] M. Saimpert,[36] M. Saito,[163] T. Saito,[163] H. Sakamoto,[163] D. Salamani,[54] G. Salamanna,[75a,75b] A. Salnikov,[153] J. Salt,[174] A. Salvador Salas,[14] D. Salvatore,[41b,41a] F. Salvatore,[156] A. Salvucci,[63a,63b,63c] A. Salzburger,[36] J. Samarati,[36] D. Sammel,[52] D. Sampsonidis,[162] D. Sampsonidou,[162] J. Sánchez,[174] A. Sanchez Pineda,[67a,36,67c] H. Sandaker,[133] C. O. Sander,[46] I. G. Sanderswood,[90] M. Sandhoff,[182] C. Sandoval,[22b] D. P. C. Sankey,[143] M. Sannino,[55b,55a] Y. Sano,[117] A. Sansoni,[51] C. Santoni,[38] H. Santos,[139a,139b] S. N. Santpur,[18] A. Santra,[174] K. A. Saoucha,[149] A. Sapronov,[80] J. G. Saraiva,[139a,139d] O. Sasaki,[82] K. Sato,[169] F. Sauerburger,[52] E. Sauvan,[5] P. Savard,[167,mm] R. Sawada,[163] C. Sawyer,[143] L. Sawyer,[96,gg] I. Sayago Galvan,[174] C. Sbarra,[23b] A. Sbrizzi,[67a,67c] T. Scanlon,[95] J. Schaarschmidt,[148] P. Schacht,[115] D. Schaefer,[37] L. Schaefer,[136] S. Schaepe,[36] U. Schäfer,[100] A. C. Schaffer,[65] D. Schaile,[114] R. D. Schamberger,[155] E. Schanet,[114] C. Scharf,[19] N. Scharmberg,[101] V. A. Schegelsky,[137] D. Scheirich,[142] F. Schenck,[19] M. Schernau,[171] C. Schiavi,[55b,55a] L. K. Schildgen,[24] Z. M. Schillaci,[26] E. J. Schioppa,[68a,68b] M. Schioppa,[41b,41a] K. E. Schleicher,[52] S. Schlenker,[36] K. R. Schmidt-Sommerfeld,[115] K. Schmieden,[36] C. Schmitt,[100] S. Schmitt,[46] L. Schoeffel,[144] A. Schoening,[61b] P. G. Scholer,[52] E. Schopf,[134] M. Schott,[100] J. F. P. Schouwenberg,[119] J. Schovancova,[36] S. Schramm,[54] F. Schroeder,[182] A. Schulte,[100] H-C. Schultz-Coulon,[61a] M. Schumacher,[52] B. A. Schumm,[145] Ph. Schune,[144] A. Schwartzman,[153] T. A. Schwarz,[106] Ph. Schwemling,[144] R. Schwienhorst,[107] A. Sciandra,[145] G. Sciolla,[26] M. Scornajenghi,[41b,41a] F. Scuri,[72a] F. Scutti,[105] L. M. Scyboz,[115] C. D. Sebastiani,[91] P. Seema,[19] S. C. Seidel,[118] A. Seiden,[145] B. D. Seidlitz,[29] T. Seiss,[37] C. Seitz,[46] J. M. Seixas,[81b] G. Sekhniaidze,[70a] S. J. Sekula,[42] N. Semprini-Cesari,[23b,23a] S. Sen,[49] C. Serfon,[29] L. Serin,[65] L. Serkin,[67a,67b] M. Sessa,[60a] H. Severini,[128] S. Sevova,[153] F. Sforza,[55b,55a] A. Sfyrla,[54] E. Shabalina,[53] J. D. Shahinian,[145] N. W. Shaikh,[45a,45b] D. Shaked Renous,[180] L. Y. Shan,[15a] M. Shapiro,[18] A. Sharma,[134] A. S. Sharma,[1] P. B. Shatalov,[124] K. Shaw,[156] S. M. Shaw,[101] M. Shehade,[180] Y. Shen,[128] A. D. Sherman,[25] P. Sherwood,[95] L. Shi,[95] C. O. Shimmin,[183] Y. Shimogama,[179] M. Shimojima,[116] J. D. Shinner,[94] I. P. J. Shipsey,[134] S. Shirabe,[165] M. Shiyakova,[80,aa] J. Shlomi,[180] A. Shmeleva,[111] M. J. Shochet,[37] J. Shojaii,[105] D. R. Shope,[154] S. Shrestha,[127] E. M. Shrif,[33e] M. J. Shroff,[176] E. Shulga,[180] P. Sicho,[140] A. M. Sickles,[173] E. Sideras Haddad,[33e] O. Sidiropoulou,[36] A. Sidoti,[23b,23a] F. Siegert,[48] Dj. Sijacki,[16] M. Silva Jr.,[181] M. V. Silva Oliveira,[36] S. B. Silverstein,[45a] S. Simion,[65] R. Simoniello,[100] C. J. Simpson-allsop,[21] S. Simsek,[12b] P. Sinervo,[167] V. Sinetckii,[113] S. Singh,[152] M. Sioli,[23b,23a] I. Siral,[131] S. Yu. Sivoklokov,[113] J. Sjölin,[45a,45b] A. Skaf,[53] E. Skorda,[97] P. Skubic,[128] M. Slawinska,[85] K. Sliwa,[170] R. Slovak,[142] V. Smakhtin,[180] B. H. Smart,[143] J. Smiesko,[28b] N. Smirnov,[112] S. Yu. Smirnov,[112] Y. Smirnov,[112] L. N. Smirnova,[113,s] O. Smirnova,[97] E. A. Smith,[37] H. A. Smith,[134] M. Smizanska,[90] K. Smolek,[141] A. Smykiewicz,[85] A. A. Snesarev,[111] H. L. Snoek,[120] I. M. Snyder,[131] S. Snyder,[29] R. Sobie,[176,cc] A. Soffer,[161] A. Søgaard,[50] F. Sohns,[53] C. A. Solans Sanchez,[36] E. Yu. Soldatov,[112] U. Soldevila,[174] A. A. Solodkov,[123] A. Soloshenko,[80] O. V. Solovyanov,[123] V. Solovyev,[137] P. Sommer,[149] H. Son,[170] A. Sonay,[14] W. Song,[143] W. Y. Song,[168b] A. Sopczak,[141] A. L. Sopio,[95] F. Sopkova,[28b] S. Sottocornola,[71a,71b] R. Soualah,[67a,67c] A. M. Soukharev,[122b,122a] D. South,[46] S. Spagnolo,[68a,68b] M. Spalla,[115] M. Spangenberg,[178] F. Spanò,[94] D. Sperlich,[52] T. M. Spieker,[61a] G. Spigo,[36] M. Spina,[156] D. P. Spiteri,[57] M. Spousta,[142] A. Stabile,[69a,69b] B. L. Stamas,[121] R. Stamen,[61a] M. Stamenkovic,[120] A. Stampekis,[21] E. Stanecka,[85] B. Stanislaus,[134] M. M. Stanitzki,[46] M. Stankaityte,[134] B. Stapf,[120] E. A. Starchenko,[123] G. H. Stark,[145] J. Stark,[58] P. Staroba,[140] P. Starovoitov,[61a] S. Stärz,[104] R. Staszewski,[85] G. Stavropoulos,[44] M. Stegler,[46] P. Steinberg,[29] A. L. Steinhebel,[131] B. Stelzer,[152,168a] H. J. Stelzer,[138] O. Stelzer-Chilton,[168a] H. Stenzel,[56] T. J. Stevenson,[156] G. A. Stewart,[36] M. C. Stockton,[36] G. Stoicea,[27b] M. Stolarski,[139a] S. Stonjek,[115] A. Straessner,[48] J. Strandberg,[154] S. Strandberg,[45a,45b] M. Strauss,[128] T. Strebler,[102] P. Strizenec,[28b] R. Ströhmer,[177] D. M. Strom,[131] R. Stroynowski,[42] A. Strubig,[50] S. A. Stucci,[29] B. Stugu,[17] J. Stupak,[128] N. A. Styles,[46] D. Su,[153] W. Su,[60c,148] X. Su,[60a] V. V. Sulin,[111] M. J. Sullivan,[91] D. M. S. Sultan,[54] S. Sultansoy,[4c] T. Sumida,[86] S. Sun,[106] X. Sun,[101] C. J. E. Suster,[157] M. R. Sutton,[156] S. Suzuki,[82] M. Svatos,[140] M. Swiatlowski,[168a] S. P. Swift,[2] T. Swirski,[177] A. Sydorenko,[100] I. Sykora,[28a] M. Sykora,[142] T. Sykora,[142] D. Ta,[100] K. Tackmann,[46,y] J. Taenzer,[161] A. Taffard,[171] R. Tafirout,[168a] E. Tagiev,[123] R. Takashima,[87] K. Takeda,[83] T. Takeshita,[150] E. P. Takeva,[50] Y. Takubo,[82] M. Talby,[102] A. A. Talyshev,[122b,122a] K. C. Tam,[63b] N. M. Tamir,[161] J. Tanaka,[163] R. Tanaka,[65] S. Tapia Araya,[173] S. Tapprogge,[100] A. Tarek Abouelfadl Mohamed,[107] S. Tarem,[160] K. Tariq,[60b] G. Tarna,[27b,e] G. F. Tartarelli,[69a] P. Tas,[142] M. Tasevsky,[140] E. Tassi,[41b,41a] A. Tavares Delgado,[139a] Y. Tayalati,[35e] A. J. Taylor,[50] G. N. Taylor,[105] W. Taylor,[168b] H. Teagle,[91] A. S. Tee,[90] R. Teixeira De Lima,[153] P. Teixeira-Dias,[94] H. Ten Kate,[36] J. J. Teoh,[120] K. Terashi,[163] J. Terron,[99] S. Terzo,[14] M. Testa,[51] R. J. Teuscher,[167,cc] S. J. Thais,[183] N. Themistokleous,[50] T. Theveneaux-Pelzer,[46] F. Thiele,[40] D. W. Thomas,[94]

J. O. Thomas,[42] J. P. Thomas,[21] E. A. Thompson,[46] P. D. Thompson,[21] E. Thomson,[136] E. J. Thorpe,[93] R. E. Ticse Torres,[53] V. O. Tikhomirov,[111,ii] Yu. A. Tikhonov,[122b,122a] S. Timoshenko,[112] P. Tipton,[183] S. Tisserant,[102] K. Todome,[23b,23a] S. Todorova-Nova,[142] S. Todt,[48] J. Tojo,[88] S. Tokár,[28a] K. Tokushuku,[82] E. Tolley,[127] R. Tombs,[32] K. G. Tomiwa,[33e] M. Tomoto,[82,117] L. Tompkins,[153] P. Tornambe,[103] E. Torrence,[131] H. Torres,[48] E. Torró Pastor,[174] M. Toscani,[30] C. Tosciri,[134] J. Toth,[102,bb] D. R. Tovey,[149] A. Traeet,[17] C. J. Treado,[125] T. Trefzger,[177] F. Tresoldi,[156] A. Tricoli,[29] I. M. Trigger,[168a] S. Trincaz-Duvoid,[135] D. A. Trischuk,[175] W. Trischuk,[167] B. Trocmé,[58] A. Trofymov,[65] C. Troncon,[69a] F. Trovato,[156] L. Truong,[33c] M. Trzebinski,[85] A. Trzupek,[85] F. Tsai,[46] J. C-L. Tseng,[134] P. V. Tsiareshka,[108,ff] A. Tsirigotis,[162,v] V. Tsiskaridze,[155] E. G. Tskhadadze,[159a] M. Tsopoulou,[162] I. I. Tsukerman,[124] V. Tsulaia,[18] S. Tsuno,[82] D. Tsybychev,[155] Y. Tu,[63b] A. Tudorache,[27b] V. Tudorache,[27b] T. T. Tulbure,[27a] A. N. Tuna,[59] S. Turchikhin,[80] D. Turgeman,[180] I. Turk Cakir,[4b,t] R. J. Turner,[21] R. Turra,[69a] P. M. Tuts,[39] S. Tzamarias,[162] E. Tzovara,[100] K. Uchida,[163] F. Ukegawa,[169] G. Unal,[36] M. Unal,[11] A. Undrus,[29] G. Unel,[171] F. C. Ungaro,[105] Y. Unno,[82] K. Uno,[163] J. Urban,[28b] P. Urquijo,[105] G. Usai,[8] Z. Uysal,[12d] V. Vacek,[141] B. Vachon,[104] K. O. H. Vadla,[133] T. Vafeiadis,[36] A. Vaidya,[95] C. Valderanis,[114] E. Valdes Santurio,[45a,45b] M. Valente,[54] S. Valentinetti,[23b,23a] A. Valero,[174] L. Valéry,[46] R. A. Vallance,[21] A. Vallier,[36] J. A. Valls Ferrer,[174] T. R. Van Daalen,[14] P. Van Gemmeren,[6] S. Van Stroud,[95] I. Van Vulpen,[120] M. Vanadia,[74a,74b] W. Vandelli,[36] M. Vandenbroucke,[144] E. R. Vandewall,[129] A. Vaniachine,[166] D. Vannicola,[73a,73b] R. Vari,[73a] E. W. Varnes,[7] C. Varni,[55b,55a] T. Varol,[158] D. Varouchas,[65] K. E. Varvell,[157] M. E. Vasile,[27b] G. A. Vasquez,[176] F. Vazeille,[38] D. Vazquez Furelos,[14] T. Vazquez Schroeder,[36] J. Veatch,[53] V. Vecchio,[101] M. J. Veen,[120] L. M. Veloce,[167] F. Veloso,[139a,139c] S. Veneziano,[73a] A. Ventura,[68a,68b] A. Verbytskyi,[115] V. Vercesi,[71a] M. Verducci,[72a,72b] C. M. Vergel Infante,[79] C. Vergis,[24] W. Verkerke,[120] A. T. Vermeulen,[120] J. C. Vermeulen,[120] C. Vernieri,[153] P. J. Verschuuren,[94] M. C. Vetterli,[152,mm] N. Viaux Maira,[146d] T. Vickey,[149] O. E. Vickey Boeriu,[149] G. H. A. Viehhauser,[134] L. Vigani,[61b] M. Villa,[23b,23a] M. Villaplana Perez,[3] E. M. Villhauer,[50] E. Vilucchi,[51] M. G. Vincter,[34] G. S. Virdee,[21] A. Vishwakarma,[50] C. Vittori,[23b,23a] I. Vivarelli,[156] M. Vogel,[182] P. Vokac,[141] S. E. von Buddenbrock,[33e] E. Von Toerne,[24] V. Vorobel,[142] K. Vorobev,[112] M. Vos,[174] J. H. Vossebeld,[91] M. Vozak,[101] N. Vranjes,[16] M. Vranjes Milosavljevic,[16] V. Vrba,[141] M. Vreeswijk,[120] N. K. Vu,[102] R. Vuillermet,[36] I. Vukotic,[37] S. Wada,[169] P. Wagner,[24] W. Wagner,[182] J. Wagner-Kuhr,[114] S. Wahdan,[182] H. Wahlberg,[89] R. Wakasa,[169] V. M. Walbrecht,[115] J. Walder,[143] R. Walker,[114] S. D. Walker,[94] W. Walkowiak,[151] V. Wallangen,[45a,45b] A. M. Wang,[59] A. Z. Wang,[181] C. Wang,[60a] C. Wang,[60c] F. Wang,[181] H. Wang,[18] H. Wang,[3] J. Wang,[63a] P. Wang,[42] Q. Wang,[128] R.-J. Wang,[100] R. Wang,[60a] R. Wang,[6] S. M. Wang,[158] W. T. Wang,[60a] W. Wang,[15c] W. X. Wang,[60a] Y. Wang,[60a] Z. Wang,[106] C. Wanotayaroj,[46] A. Warburton,[104] C. P. Ward,[32] R. J. Ward,[21] N. Warrack,[57] A. T. Watson,[21] M. F. Watson,[21] G. Watts,[148] B. M. Waugh,[95] A. F. Webb,[11] C. Weber,[29] M. S. Weber,[20] S. A. Weber,[34] S. M. Weber,[61a] A. R. Weidberg,[134] J. Weingarten,[47] M. Weirich,[100] C. Weiser,[52] P. S. Wells,[36] T. Wenaus,[29] B. Wendland,[47] T. Wengler,[36] S. Wenig,[36] N. Wermes,[24] M. Wessels,[61a] T. D. Weston,[20] K. Whalen,[131] A. M. Wharton,[90] A. S. White,[106] A. White,[8] M. J. White,[1] D. Whiteson,[171] B. W. Whitmore,[90] W. Wiedenmann,[181] C. Wiel,[48] M. Wielers,[143] N. Wieseotte,[100] C. Wiglesworth,[40] L. A. M. Wiik-Fuchs,[52] H. G. Wilkens,[36] L. J. Wilkins,[94] H. H. Williams,[136] S. Williams,[32] S. Willocq,[103] P. J. Windischhofer,[134] I. Wingerter-Seez,[5] E. Winkels,[156] F. Winklmeier,[131] B. T. Winter,[52] M. Wittgen,[153] M. Wobisch,[96] A. Wolf,[100] R. Wölker,[134] J. Wollrath,[52] M. W. Wolter,[85] H. Wolters,[139a,139c] V. W. S. Wong,[175] N. L. Woods,[145] S. D. Worm,[46] B. K. Wosiek,[85] K. W. Woźniak,[85] K. Wraight,[57] S. L. Wu,[181] X. Wu,[54] Y. Wu,[60a] J. Wuerzinger,[134] T. R. Wyatt,[101] B. M. Wynne,[50] S. Xella,[40] L. Xia,[178] J. Xiang,[63c] X. Xiao,[106] X. Xie,[60a] I. Xiotidis,[156] D. Xu,[15a] H. Xu,[60a] H. Xu,[60a] L. Xu,[29] T. Xu,[144] W. Xu,[106] Y. Xu,[15b] Z. Xu,[60b] Z. Xu,[153] B. Yabsley,[157] S. Yacoob,[33a] D. P. Yallup,[95] N. Yamaguchi,[88] Y. Yamaguchi,[165] A. Yamamoto,[82] M. Yamatani,[163] T. Yamazaki,[163] Y. Yamazaki,[83] J. Yan,[60c] Z. Yan,[25] H. J. Yang,[60c,60d] H. T. Yang,[18] S. Yang,[60a] T. Yang,[63c] X. Yang,[60b,58] Y. Yang,[163] Z. Yang,[60a] W-M. Yao,[18] Y. C. Yap,[46] E. Yatsenko,[60c] H. Ye,[15c] J. Ye,[42] S. Ye,[29] I. Yeletskikh,[80] M. R. Yexley,[90] E. Yigitbasi,[25] P. Yin,[39] K. Yorita,[179] K. Yoshihara,[79] C. J. S. Young,[36] C. Young,[153] J. Yu,[79] R. Yuan,[60b,I] X. Yue,[61a] M. Zaazoua,[35e] B. Zabinski,[85] G. Zacharis,[10] E. Zaffaroni,[54] J. Zahreddine,[135] A. M. Zaitsev,[123,hh] T. Zakareishvili,[159b] N. Zakharchuk,[34] S. Zambito,[36] D. Zanzi,[36] S. V. Zeißner,[47] C. Zeitnitz,[182] G. Zemaityte,[134] J. C. Zeng,[173] O. Zenin,[123] T. Ženiš,[28a] D. Zerwas,[65] M. Zgubič,[134] B. Zhang,[15c] D. F. Zhang,[15b] G. Zhang,[15b] J. Zhang,[6] Kaili. Zhang,[15a] L. Zhang,[15c] L. Zhang,[60a] M. Zhang,[173] R. Zhang,[181] S. Zhang,[106] X. Zhang,[60c] X. Zhang,[60b] Y. Zhang,[15a,15d] Z. Zhang,[63a] Z. Zhang,[65] P. Zhao,[49] Z. Zhao,[60a] A. Zhemchugov,[80] Z. Zheng,[106] D. Zhong,[173] B. Zhou,[106] C. Zhou,[181] H. Zhou,[7] M. S. Zhou,[15a,15d] M. Zhou,[155] N. Zhou,[60c] Y. Zhou,[7] C. G. Zhu,[60b] C. Zhu,[15a,15d] H. L. Zhu,[60a] H. Zhu,[15a] J. Zhu,[106] Y. Zhu,[60a] X. Zhuang,[15a] K. Zhukov,[111] V. Zhulanov,[122b,122a]

D. Zieminska,[66] N. I. Zimine,[80] S. Zimmermann,[52] Z. Zinonos,[115] M. Ziolkowski,[151] L. Živković,[16] G. Zobernig,[181] A. Zoccoli,[23b,23a] K. Zoch,[53] T. G. Zorbas,[149] R. Zou,[37] and L. Zwalinski[36]

(ATLAS Collaboration)

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

[33e]School of Physics, University of the Witwatersrand, Johannesburg, South Africa
[34]Department of Physics, Carleton University, Ottawa, Ontario, Canada
[35a]Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies—Université Hassan II, Casablanca, Morocco
[35b]Faculté des Sciences, Université Ibn-Tofail, Kénitra, Morocco
[35c]Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA-Marrakech, Morocco
[35d]Faculté des Sciences, Université Mohamed Premier and LPTPM, Oujda, Morocco
[35e]Faculté des sciences, Université Mohammed V, Rabat, Morocco
[36]CERN, Geneva, Switzerland
[37]Enrico Fermi Institute, University of Chicago, Chicago, Illinois, USA
[38]LPC, Université Clermont Auvergne, CNRS/IN2P3, Clermont-Ferrand, France
[39]Nevis Laboratory, Columbia University, Irvington, New York, USA
[40]Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark
[41a]Dipartimento di Fisica, Università della Calabria, Rende, Italy
[41b]INFN Gruppo Collegato di Cosenza, Laboratori Nazionali di Frascati, Italy
[42]Physics Department, Southern Methodist University, Dallas, Texas, USA
[43]Physics Department, University of Texas at Dallas, Richardson, Texas, USA
[44]National Centre for Scientific Research "Demokritos", Agia Paraskevi, Greece
[45a]Department of Physics, Stockholm University, Sweden
[45b]Oskar Klein Centre, Stockholm, Sweden
[46]Deutsches Elektronen-Synchrotron DESY, Hamburg and Zeuthen, Germany
[47]Lehrstuhl für Experimentelle Physik IV, Technische Universität Dortmund, Dortmund, Germany
[48]Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden, Germany
[49]Department of Physics, Duke University, Durham, North Carolina, USA
[50]SUPA—School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom
[51]INFN e Laboratori Nazionali di Frascati, Frascati, Italy
[52]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany
[53]II. Physikalisches Institut, Georg-August-Universität Göttingen, Göttingen, Germany
[54]Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève, Switzerland
[55a]Dipartimento di Fisica, Università di Genova, Genova, Italy
[55b]INFN Sezione di Genova, Italy
[56]II. Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen, Germany
[57]SUPA—School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom
[58]LPSC, Université Grenoble Alpes, CNRS/IN2P3, Grenoble INP, Grenoble, France
[59]Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge, Massachusetts, USA
[60a]Department of Modern Physics and State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei, China
[60b]Institute of Frontier and Interdisciplinary Science and Key Laboratory of Particle Physics and Particle Irradiation (MOE), Shandong University, Qingdao, China
[60c]School of Physics and Astronomy, Shanghai Jiao Tong University, KLPPAC-MoE, SKLPPC, Shanghai, China
[60d]Tsung-Dao Lee Institute, Shanghai, China
[61a]Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany
[61b]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany
[62]Faculty of Applied Information Science, Hiroshima Institute of Technology, Hiroshima, Japan
[63a]Department of Physics, Chinese University of Hong Kong, Shatin, N.T., Hong Kong, China
[63b]Department of Physics, University of Hong Kong, Hong Kong, China
[63c]Department of Physics and Institute for Advanced Study, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China
[64]Department of Physics, National Tsing Hua University, Hsinchu, Taiwan
[65]IJCLab, Université Paris-Saclay, CNRS/IN2P3, 91405, Orsay, France
[66]Department of Physics, Indiana University, Bloomington, Indiana, USA
[67a]INFN Gruppo Collegato di Udine, Sezione di Trieste, Udine, Italy
[67b]ICTP, Trieste, Italy
[67c]Dipartimento Politecnico di Ingegneria e Architettura, Università di Udine, Udine, Italy
[68a]INFN Sezione di Lecce, Italy
[68b]Dipartimento di Matematica e Fisica, Università del Salento, Lecce, Italy
[69a]INFN Sezione di Milano, Italy
[69b]Dipartimento di Fisica, Università di Milano, Milano, Italy
[70a]INFN Sezione di Napoli, Italy
[70b]Dipartimento di Fisica, Università di Napoli, Napoli, Italy

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

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

[167]*Department of Physics, University of Toronto, Toronto, Ontario, Canada*
[168a]*TRIUMF, Vancouver, British Columbia, Canada*
[168b]*Department of Physics and Astronomy, York University, Toronto, Ontario, Canada*
[169]*Division of Physics and Tomonaga Center for the History of the Universe, Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba, Japan*
[170]*Department of Physics and Astronomy, Tufts University, Medford, Massachusetts, USA*
[171]*Department of Physics and Astronomy, University of California Irvine, Irvine, California, USA*
[172]*Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden*
[173]*Department of Physics, University of Illinois, Urbana, Illinois, USA*
[174]*Instituto de Física Corpuscular (IFIC), Centro Mixto Universidad de Valencia—CSIC, Valencia, Spain*
[175]*Department of Physics, University of British Columbia, Vancouver, British Columbia, Canada*
[176]*Department of Physics and Astronomy, University of Victoria, Victoria, British Columbia, Canada*
[177]*Fakultät für Physik und Astronomie, Julius-Maximilians-Universität Würzburg, Würzburg, Germany*
[178]*Department of Physics, University of Warwick, Coventry, United Kingdom*
[179]*Waseda University, Tokyo, Japan*
[180]*Department of Particle Physics and Astrophysics, Weizmann Institute of Science, Rehovot, Israel*
[181]*Department of Physics, University of Wisconsin, Madison, Wisconsin, USA*
[182]*Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal, Germany*
[183]*Department of Physics, Yale University, New Haven, Connecticut, USA*

[a]Deceased.
[b]Also at Borough of Manhattan Community College, City University of New York, New York, New York, USA.
[c]Also at Centro Studi e Ricerche Enrico Fermi, Italy.
[d]Also at CERN, Geneva, Switzerland.
[e]Also at CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille, France.
[f]Also at Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève, Switzerland.
[g]Also at Departament de Fisica de la Universitat Autonoma de Barcelona, Barcelona, Spain.
[h]Also at Department of Financial and Management Engineering, University of the Aegean, Chios, Greece.
[i]Also at Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan, USA.
[j]Also at Department of Physics and Astronomy, University of Louisville, Louisville, Kentucky, USA.
[k]Also at Department of Physics, Ben Gurion University of the Negev, Beer Sheva, Israel.
[l]Also at Department of Physics, California State University, East Bay, California, USA.
[m]Also at Department of Physics, California State University, Fresno, USA.
[n]Also at Department of Physics, California State University, Sacramento, California, USA.
[o]Also at Department of Physics, King's College London, London, United Kingdom.
[p]Also at Department of Physics, St. Petersburg State Polytechnical University, St. Petersburg, Russia.
[q]Also at Department of Physics, University of Fribourg, Fribourg, Switzerland.
[r]Also at Dipartimento di Matematica, Informatica e Fisica, Università di Udine, Udine, Italy.
[s]Also at Faculty of Physics, M.V. Lomonosov Moscow State University, Moscow, Russia.
[t]Also at Giresun University, Faculty of Engineering, Giresun, Turkey.
[u]Also at Graduate School of Science, Osaka University, Osaka, Japan.
[v]Also at Hellenic Open University, Patras, Greece.
[w]Also at IJCLab, Université Paris-Saclay, CNRS/IN2P3, 91405 Orsay, France.
[x]Also at Institucio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona, Spain.
[y]Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany.
[z]Also at Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands.
[aa]Also at Institute for Nuclear Research and Nuclear Energy (INRNE) of the Bulgarian Academy of Sciences, Sofia, Bulgaria.
[bb]Also at Institute for Particle and Nuclear Physics, Wigner Research Centre for Physics, Budapest, Hungary.
[cc]Also at Institute of Particle Physics (IPP), Canada.
[dd]Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan.
[ee]Also at Instituto de Fisica Teorica, IFT-UAM/CSIC, Madrid, Spain.
[ff]Also at Joint Institute for Nuclear Research, Dubna, Russia.
[gg]Also at Louisiana Tech University, Ruston, Louisiana, USA.
[hh]Also at Moscow Institute of Physics and Technology State University, Dolgoprudny, Russia.
[ii]Also at National Research Nuclear University MEPhI, Moscow, Russia.
[jj]Also at Physics Department, An-Najah National University, Nablus, Palestine.
[kk]Also at Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany.
[ll]Also at The City College of New York, New York, New York, USA.

[mm]Also at TRIUMF, Vancouver, British Columbia, Canada.
[nn]Also at Universita di Napoli Parthenope, Napoli, Italy.
[oo]Also at University of Chinese Academy of Sciences (UCAS), Beijing, China.