



Search for resonances decaying into photon pairs in 139 fb^{-1} of pp collisions at $\sqrt{s} = 13 \text{ TeV}$ with the ATLAS detector

The ATLAS Collaboration*



ARTICLE INFO

Article history:

Received 1 March 2021

Received in revised form 14 September 2021

Accepted 14 September 2021

Available online 17 September 2021

Editor: M. Doser

ABSTRACT

Searches for new resonances in the diphoton final state, with spin 0 as predicted by theories with an extended Higgs sector and with spin 2 using a warped extra-dimension benchmark model, are presented using 139 fb^{-1} of $\sqrt{s} = 13 \text{ TeV}$ pp collision data collected by the ATLAS experiment at the LHC. No significant deviation from the Standard Model is observed and upper limits are placed on the production cross-section times branching ratio to two photons as a function of the resonance mass.

© 2021 The Author(s). Published by Elsevier B.V. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>). Funded by SCOAP³.

1. Introduction

Many theories of physics beyond the Standard Model (SM) predict the presence of new high-mass states which can currently only be produced in the high-energy collisions at the Large Hadron Collider (LHC). One powerful experimental signature of these new states is a resonance in the diphoton invariant mass spectrum, as this final state provides excellent invariant mass resolution which can be used to separate the signal from the SM background processes.

This Letter presents a search for new high-mass resonances decaying into two photons using 139 fb^{-1} of $\sqrt{s} = 13 \text{ TeV}$ proton-proton (pp) collision data recorded by the ATLAS detector from 2015 to 2018 at the LHC. This analysis searches for a generic resonance using two benchmark signal models: a spin-0 resonant state (X), which is predicted by many models that include extensions to the Higgs sector [1–7]; and a spin-2 graviton (G^*), taken here to be the lightest Kaluza–Klein (KK) [8] excitation in a Randall–Sundrum model [9,10] with one warped extra dimension (RS1). Previous searches for high-mass diphoton resonances using the 2015–2016 pp collision data have been reported by the ATLAS and CMS collaborations [11,12]. Modifications with respect to the analysis in Ref. [11] include a common event selection for the spin-0 and spin-2 resonance searches, the use of the functional decomposition method [13] to assess the spurious-signal uncertainty, and updates to the photon reconstruction, identification, isolation and energy calibration.

This search uses functional forms to describe the signal and background components in a fit of the diphoton invariant mass spectrum, $m_{\gamma\gamma}$, to determine the signal yield. In the absence of a significant signal excess, limits are placed on the production cross-

section times branching ratio, $\sigma \times B(X \rightarrow \gamma\gamma)$. For the spin-0 case, the limits are computed in terms of the fiducial cross-section, defined as the product of the cross-section times the branching ratio to two photons within a fiducial acceptance which closely follows the selection criteria applied to the reconstructed data. In the spin-2 analysis, limits are instead placed on the total cross-section times branching ratio to the two-photon final state. These limits are provided as a function of resonance mass and width in the spin-0 search and as a function of graviton mass and coupling $k/\bar{M}_{\text{Pl}}$ for the spin-2 resonance search. As the graviton natural width is related to the coupling via $\Gamma_{G^*} = 1.44(k/\bar{M}_{\text{Pl}})^2 m_{G^*}$, the graviton is expected to be a narrow resonance [14] for the couplings considered in this search, i.e. $k/\bar{M}_{\text{Pl}} < 0.1$.

2. ATLAS detector

The ATLAS experiment [15–17] at the LHC is a multipurpose particle detector with a forward-backward symmetric cylindrical geometry and a near 4π coverage in solid angle.¹ It consists of an inner tracking detector surrounded by a thin superconducting solenoid providing a 2 T axial magnetic field, electromagnetic and hadronic calorimeters, and a muon spectrometer. The inner tracking detector covers the pseudorapidity range $|\eta| < 2.5$. It consists of silicon pixel, silicon microstrip, and transition radiation tracking detectors. Lead/liquid-argon (LAr) sampling calorimeters provide electromagnetic (EM) energy measurements with high granular-

¹ ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the centre of the detector and the z -axis along the beam pipe. The x -axis points from the IP to the centre of the LHC ring, and the y -axis points upwards. 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 $\eta = -\ln \tan(\theta/2)$. Angular distance is measured in units of $\Delta R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$.

* E-mail address: atlas.publications@cern.ch.

ity. A hadron sampling calorimeter made of steel and scintillator tiles covers the central pseudorapidity range ($|\eta| < 1.7$). The endcap and forward regions are instrumented with LAr calorimeters for EM and hadronic energy measurements up to $|\eta| = 4.9$. The muon spectrometer surrounds the calorimeters and is based on three large air-core toroidal superconducting magnets with eight coils each. The field integral of the toroids ranges between 2.0 and 6.0 Tm across most of the detector. A two-level trigger system is used to select events. The first-level trigger is implemented in hardware and uses a subset of the detector information to keep the accepted rate below 100 kHz. A software-based trigger reduces the accepted event rate to an average of 1 kHz depending on the data-taking conditions.

3. Data and simulated event samples

The search is carried out using the $\sqrt{s} = 13$ TeV pp collision dataset with a bunch spacing of 25 ns collected from 2015 to 2018, with stable beam conditions and all ATLAS subsystems operational, which corresponds to an integrated luminosity of $139.0 \pm 2.4 \text{ fb}^{-1}$ [18]. The data were recorded using a diphoton trigger that required two electromagnetic clusters with transverse energies E_T above 35 and 25 GeV, respectively, both fulfilling photon identification criteria based on shower shapes in the electromagnetic calorimeter. The efficiency of the diphoton trigger with respect to the full event selection is above 99% for 2015–2016 and above 98% for 2017–2018 [19].

Simulated Monte Carlo (MC) events are used to optimize the analysis selections and characterize the signal and background. Interference effects between the resonant signal and all background processes are expected to be small for a narrow-width signal and are neglected in this analysis to keep it as model-independent as possible.

To model the spin-0 resonance signals, MC samples were generated for a hypothetical resonance mass m_χ in the range 200–3000 GeV assuming a decay width Γ_χ of 4 MeV to describe a hypothetical resonance in the narrow-width approximation (NWA). Four production modes were generated to assess the model dependence of the fiducial selection. The gluon–gluon fusion (ggF) samples were generated at next-to-leading order (NLO) in pQCD using MADGRAPH5_AMC@NLO [20], with a set-up matching that described in Ref. [11]. Vector-boson fusion (VBF) samples were generated at NLO in pQCD with POWHEGBox v2 [21–23] interfaced with PYTHIA 8 [24] using the CT10 parton distribution function (PDF) set [25] and the AZNLO tune [26] of the parameter values. Simulated samples for production of a scalar resonance in association with a vector boson or $t\bar{t}$ pair were generated at leading order (LO) in pQCD with PYTHIA 8 using the NNPDF23LO PDF set [27] and the A14 tune [28]. Additional gluon–gluon fusion samples were produced for various fixed decay widths, ranging from 4 MeV up to 10% of m_χ .

To model the spin-2 resonance signals, MC samples incorporating the RS1 model were generated at LO in pQCD using PYTHIA 8 with the NNPDF23LO PDF set and the A14 tune, with masses m_{G^*} in the range 500–5000 GeV and fixed coupling values $k/\bar{M}_{\text{Pl}}$ ranging from 0.01 to 0.1.

The irreducible background in this search, coming from events with two prompt photons, was simulated using the SHERPA [29,30] event generator, version 2.2.4. Matrix elements were calculated with up to one additional parton at NLO and with two or three partons at LO in pQCD and merged with the SHERPA parton-shower simulation using the ME+PS@NLO prescription [31–34]. The NNPDF3.0 NNLO PDF set [35] was used in conjunction with a dedicated parton-shower tune in the SHERPA generator.

The effects of multiple pp interactions in the same bunch crossing as the hard scatter and in neighbouring ones are included

using simulated events generated with PYTHIA 8. Simulated events were weighted to reproduce the distribution of the average number of interactions per bunch crossing observed in data.

All simulated signal events were processed using a full simulation of the ATLAS detector [36] based on GEANT4 [37]. The background $\gamma\gamma$ events were processed using a fast simulation of the ATLAS detector [38], where the full simulation of the calorimeter is replaced with a parameterization of the calorimeter response. All simulated events were reconstructed with the same reconstruction algorithms as those used for data.

4. Object and event selection

Photon candidates are reconstructed from topological clusters of energy deposits in the EM calorimeter and calibrated as described in Ref. [39]. The event selection requires at least two photon candidates with $E_T > 25$ GeV and $|\eta| < 2.37$, excluding the barrel-to-endcap transition regions of the calorimeter, $1.37 < |\eta| < 1.52$. The two highest- E_T photons and additional information from the tracking systems are used to identify the diphoton production vertex [40].

To reduce the background from jets, photon candidates are required to fulfil *tight* identification criteria based on shower shapes in the EM calorimeter and energy leakage into the hadronic calorimeter [39]. A looser identification is considered for background estimations that benefit from a larger sample size. The *tight* identification is optimized in sub-ranges of photon E_T and $|\eta|$ to have an identification efficiency greater than 90% for the E_T range considered in this analysis. The calorimeter isolation transverse energy E_T^{iso} is required to be smaller than $0.022E_T + 2.45$ GeV, where E_T^{iso} is defined as the sum of transverse energies of the positive-energy topological clusters [41] within a cone of size $\Delta R = 0.4$ around the photon candidate. The core of the photon shower is excluded, and E_T^{iso} is corrected for the leakage of the photon shower into the isolation cone. The contributions from the underlying event and pile-up are subtracted using the techniques described in Refs. [42,43]. The track isolation is defined as the scalar sum of the transverse momenta of tracks with $p_T > 1$ GeV which satisfy some loose track-quality criteria, are not associated with a photon conversion and originate from the diphoton production vertex in a $\Delta R = 0.2$ cone around the photon candidate. It is required to be less than $0.05E_T$.

The diphoton invariant mass $m_{\gamma\gamma}$ is evaluated using the energies of the leading- and subleading- E_T photons, their separation $\Delta\phi$ in azimuthal angle and $\Delta\eta$ in pseudorapidity determined from their positions in the calorimeter, and the position of the diphoton production vertex. Additional kinematic requirements are placed on the photon E_T relative to the diphoton invariant mass: the leading photon must have $E_T/m_{\gamma\gamma} > 0.3$ and the subleading photon must satisfy $E_T/m_{\gamma\gamma} > 0.25$. These requirements were optimized to retain improved significance with respect to Ref. [11] while allowing the analysis to have a unified selection for the spin-0 and spin-2 models. For the spin-0 model, the new selections result in a slightly worse expected limit for the NWA scalar models below 700 GeV but up to 30% better expected limits above. For the spin-2 model, these updated selections lead to an improvement in the expected limit by 15% to 50% depending on m_{G^*} for masses up to 2 TeV.

In total, 433 919 data events with $m_{\gamma\gamma} > 150$ GeV are selected.

The fiducial volume for the spin-0 interpretation is defined by requiring two photons at generator level with $|\eta| < 2.37$, and $E_T/m_{\gamma\gamma} > 0.3$ and $E_T/m_{\gamma\gamma} > 0.25$ for the leading and subleading photons, respectively. The particle isolation, defined as the scalar sum of p_T of all the stable particles (except neutrinos) found within a $\Delta R = 0.4$ cone around the photon direction, is required to be less than $0.05E_T + 6$ GeV.

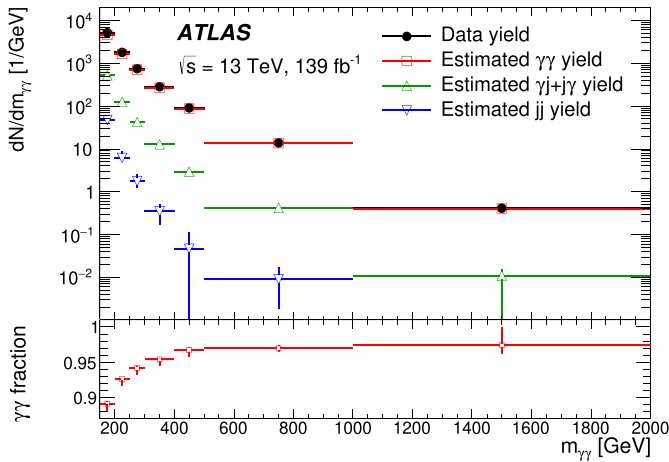


Fig. 1. Diphoton invariant mass distributions of the data after event selection and their decomposition into contributions from genuine diphoton ($\gamma\gamma$), photon+jet (γj and $j\gamma$) and dijet (jj) events as determined using the two-dimensional sideband method. The bottom panel shows the sample's purity in diphoton events. Each point in the distributions is plotted in the centre of the corresponding bin. The total uncertainties, including statistical and systematic components added in quadrature, are shown as error bars.

5. Signal modelling

Parametric models of the diphoton invariant mass distributions of the signal are used to test for different resonance masses and Γ_X or $k/\overline{M}_{\text{Pl}}$. The detector resolution is modelled by a double-sided Crystal Ball (DSCB) function [44,45], with parameters expressed as a function of m_X . The DSCB function is convolved with the true lineshape, which is parameterized as the product of a relativistic Breit-Wigner (BW) function and mass-dependent factors accounting for the parton luminosity and the matrix elements of the processes. This convolution is performed independently for the spin-0 and spin-2 models. The lineshapes for the spin-0 model are derived from the functional forms defined in the MADGRAPH5_AMC@NLO MC simulation of the ggF process, where a BW function of width Γ_X is combined with a mass-dependent gluon-gluon luminosity functional form. The lineshapes for the spin-2 model are derived from the functional forms defined in the PYTHIA 8 MC simulation of the RS1 model [46], where a BW function of width $1.44(k/\overline{M}_{\text{Pl}})^2 m_{G^*}$ is combined with mass-dependent gluon-gluon and quark-antiquark luminosity functional forms.

6. Background estimates

The unified spin-0 and spin-2 search selections in this analysis allow the use of a common background modelling procedure. The largest background component comes from the non-resonant production of photon pairs ($\gamma\gamma$ events); smaller backgrounds come from events containing a photon and a jet (γj events) and events with two jets (jj events), where the jets are misidentified as photons. The relative contribution of these processes is determined using the two-dimensional sideband method described in Ref. [47] and shown in Fig. 1. The overall $\gamma\gamma$ purity of the selected events increases with $m_{\gamma\gamma}$ from around 89% at 150–200 GeV to around 97% above 400 GeV with an uncertainty of 0.5–3%. No significant difference in purity is seen between the LHC data-taking periods, and the remaining background is dominated by γj events.

The analytic form of the continuum background is determined by fitting a template built from reconstructed SHERPA $\gamma\gamma$ MC events and γj events derived from a dedicated data control region where the photon identification requirements are inverted. The diphoton invariant mass distribution is fitted in the range above 150 GeV. The lower value of the range is chosen to allow for

enough events in the $m_{\gamma\gamma}$ side-bands to ensure a good description by the analytic form, while the upper value of the range is chosen such as the procedure remains stable in injection tests. The search region for a resonant signal covers the region 160–3000 GeV for a NWA spin-0 resonance, 400–2800 GeV for a wide spin-0 resonance, and 500–2800 GeV for a graviton resonance. The procedure described in Ref. [40] is used to ensure that the chosen analytic function is flexible enough to model any potential variations in the background template. The analytic form is chosen from the family of functions previously used to describe the diphoton invariant mass spectrum [48]. Additional background templates are constructed from variations due to the uncertainties in the measured background composition, shape of the γj component and theoretical uncertainties such as the choice of PDF and the variation of renormalization and factorization scales. The function with the fewest degrees of freedom that maintains enough flexibility to model all variations of the template shape is chosen, and it takes the form

$$f(x; b, a_0, a_1) = N(1 - x^{1/3})^b \chi^{a_0 + a_1 \log(x)} \quad (1)$$

where N , b , a_0 , a_1 are free parameters and $x = m_{\gamma\gamma}/\sqrt{s}$.

Fits to these background templates are used to estimate the bias due to this choice of analytic function; any fitted signal yield is considered as a 'spurious-signal' systematic uncertainty. Up to masses of 2 TeV this uncertainty is dominated by the statistical fluctuations of the background template due to the limited number of generated MC events, leading to fluctuations that are significant compared to the expected statistical uncertainty on the data. To suppress the impact of these fluctuations, each background template is smoothed using the functional decomposition (FD) method [13]. This method uses a linear combination of orthonormal exponential functions to fit a background template and the fit result is binned and used as a smoothed template for the spurious-signal determination only.

To illustrate the FD process, an example fit to a pseudo-experiment and the resulting spurious-signal uncertainty is shown in Fig. 2. This pseudo-experiment dataset is generated from the functional form given in Eq. (1), where the parameters are determined by fitting simulated $\gamma\gamma$ events. First, the FD method is used to fit the pseudo-experiment, resulting in a smoothed FD template; this template and the pseudo-experiment are shown in Fig. 2(a). The spurious-signal estimated by fitting the smoothed FD template with the signal-plus-background model has fewer fluctuations and a smaller amplitude than the one estimated by fitting the unsmoothed template as shown in Fig. 2(b); it can be larger than 50% of the statistical uncertainty with the unsmoothed template while it decreases from 40% at 160 GeV to 20% at 500 GeV and less than 10% above 1 TeV with the smoothed template. To verify that the smoothing maintains the underlying shape of the $m_{\gamma\gamma}$ distribution, this process is repeated for an ensemble of pseudo-experiments and the mean number of extracted signal events is compared between the smoothed and unsmoothed templates. The resulting bias in the determination of the spurious-signal uncertainty, shown in Fig. 2(c), agrees between the unsmoothed and smoothed template ensembles and is found to be much smaller than the uncertainty from a single pseudo-experiment. It should be noted that the mean spurious-signal is not exactly equal to 0 because of the limited number of pseudo-experiments. Finally, by using this smoothed template approach, an improved description of the spurious-signal uncertainty is obtained, leading to an improvement of 2–28% in the expected sensitivity of this search as shown in Fig. 2(d).

The spurious-signal uncertainty for this background function choice is 40–10% of the statistical uncertainty of the fitted signal yield for NWA signals with masses ranging from 160 GeV to

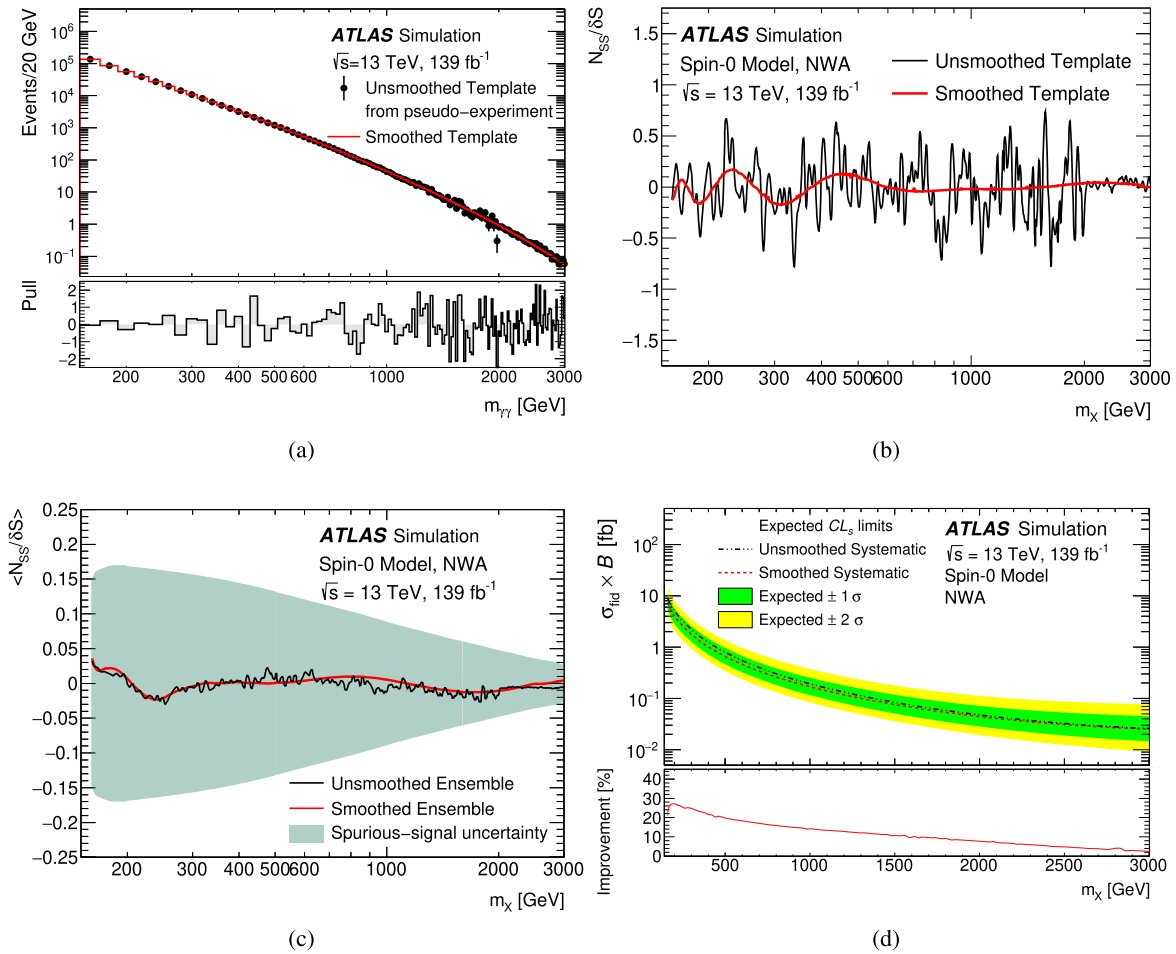


Fig. 2. An illustration of the smoothing method used to determine the spurious-signal systematic uncertainty. (a) An example FD fit to the $m_{\gamma\gamma}$ spectrum of a pseudo-experiment dataset generated from the functional form fit to simulated $\gamma\gamma$ events. (b) Number of spurious-signal events relative to the statistical uncertainty of the input dataset calculated using signal-plus-background fits to the input dataset (black) and the smoothed FD template (red). The background function used in these fits is the same function used to generate the pseudo-experiment dataset, and the variance of the unsmoothed template highlights the role of the number of events in the MC sample in the systematic uncertainty determination. (c) Mean of the relative spurious-signal calculated by repeating the signal-plus-background fits on a large ensemble of pseudo-experiments and the FD smoothed templates. The shaded area indicates the size of the spurious-signal uncertainty from the single smoothed template pseudo-experiment of Fig. 2. (d) The effect of the reduced systematic uncertainty on the expected fiducial cross-section limits for the NWA spin-0 signal hypothesis. The use of smoothed templates leads to a limit improvement of 2–28%.

3000 GeV. This uncertainty increases to 70–20% for wider signals with masses ranging from 400 GeV to 2800 GeV.

7. Statistical procedure

The statistical analysis of the data uses binned maximum-likelihood fits of the $m_{\gamma\gamma}$ distribution. The systematic uncertainties listed in Table 1 are accounted for in the fits by using nuisance parameters constrained by Gaussian penalty terms in the likelihood function. They include the experimental uncertainties in the luminosity determination, pile-up profile, trigger efficiency, and photon identification and reconstruction. Additional systematic uncertainties in the signal shape come from the uncertainties in the photon energy resolution and scale. For the spin-0 model, the correction factors inside the fiducial volume, used to compute the limit on the fiducial cross-section, are determined using gluon-gluon fusion MC events. They are compared with the ones computed for the other production modes, leading to a small mass-dependent systematic uncertainty in the signal yield.

A local p -value (p_0) for the background-only hypothesis is calculated using the asymptotic approximation [49]. Global significance values are computed using background-only pseudo-experiments to account for the trial factors because the searches scan both the signal mass and a range of width (coupling) hy-

potheses. For these calculations, a maximum-likelihood fit is performed on each pseudo-experiment with the signal mass, width, and signal rate as free parameters within a specific search range. For the spin-0 case, the search ranges are defined to be $m_X = [400, 2800]$ GeV and $\Gamma_X/m_X = [0, 10]$ %; the spin-2 case is restricted to the ranges $m_{G^*} = [500, 2800]$ GeV and $k/\overline{M}_{Pl} = [0.01, 0.1]$.

In the absence of a signal, the expected and observed 95% confidence level (CL) exclusion limits on the cross-section times branching ratio to two photons are computed using a modified frequentist approach CL_s [50,51], assuming the asymptotic approximation for the test-statistic distribution. In regions where very few events are observed and the expected signal yield is also small, the asymptotic approximation is found to deviate from the limits based on pseudo-experiments. To account for this effect, for masses greater than 1000 GeV, pseudo-experiments are used to verify the expected and observed limits, and used in place of the asymptotic limit where differences are observed.

For the spin-2 model, the limits on the total production cross-section can be translated into a lower limit on the graviton mass. For that purpose the spin-2 exclusion limits are extended up to $m_{G^*} = 5000$ GeV for all coupling hypotheses.

Table 1

Summary of the systematic uncertainties. The mass-dependent values are highlighted with a star * and are given for signal masses between 160 and 2800 GeV unless stated otherwise.

Signal yield			
Luminosity	$\pm 1.7\%$	Trigger	$\pm 0.5\%$
Photon identification	$\pm 0.5\%$	Photon isolation	$\pm 1.5\%$
Photon energy scale/resolution	negligible	Pile-up reweighting*	$\pm(2-0.2)\%$
Spin-0 production process*	$\pm(7-3)\%$		
Signal modelling*			
Photon energy resolution	+14% -9.3%	+51% -29%	
Photon energy scale	$\pm(0.5-0.6)\%$		
Pile-up reweighting	negligible		
Spurious-signal, Spin-0*			
NWA	114–0.04 events ($m_X = 160\text{--}2800$ GeV)		
$\Gamma_X/m_X = 2\%$	107–0.14 events ($m_X = 400\text{--}2800$ GeV)		
$\Gamma_X/m_X = 6\%$	223–0.38 events ($m_X = 400\text{--}2800$ GeV)		
$\Gamma_X/m_X = 10\%$	437–0.50 events ($m_X = 400\text{--}2800$ GeV)		
Spurious-signal, Spin-2*			
$k/\overline{M}_{\text{Pl}} = 0.01$	4.71–0.04 events ($m_{G^*} = 500\text{--}2800$ GeV)		
$k/\overline{M}_{\text{Pl}} = 0.05$	19.0–0.09 events ($m_{G^*} = 500\text{--}2800$ GeV)		
$k/\overline{M}_{\text{Pl}} = 0.1$	31.2–0.20 events ($m_{G^*} = 500\text{--}2800$ GeV)		

* mass-dependent.

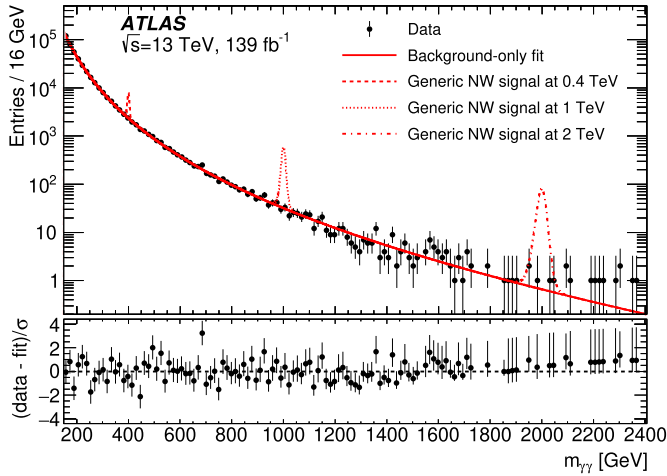


Fig. 3. Background-only fit to the data (black dots) as a function of the diphoton invariant mass $m_{\gamma\gamma}$ with several generic narrow-width signal shapes overlaid (dotted lines), scaled to 10 times the value of the corresponding expected upper limit at 95% CL on the fiducial cross-section times branching ratio, with pole masses of $m_X = 0.4, 1$ and 2 TeV. The normalized residuals between the data and the fit are shown in the bottom panel with σ denoting only the statistical error of the data. There is no data event with $m_{\gamma\gamma} > 2.36$ TeV.

8. Results

The diphoton invariant mass distribution of the events passing the selection is shown in Fig. 3, along with the background-only fit. The highest-mass diphoton candidate selected in data has a mass of 2.36 TeV.

The probability of compatibility with the background-only hypothesis, quantified with the local p -value expressed in standard deviations, is shown in Fig. 4 as a function of the hypothesized resonance mass and width. The most significant excess is observed for a mass of $\simeq 684$ GeV for the spin-0 NWA model and for the spin-2 $k/\bar{M}_{\text{Pl}} = 0.01$ model, corresponding to a 3.29σ local significance. The corresponding global significance is 1.30σ and 1.36σ for the two models, respectively.

The observed and expected limits, shown in Fig. 5 for two values of the signal width, are in good agreement, consistent with the absence of a signal.

Table 2

Summary of the observed upper limits on the fiducial and the total production cross-section times branching ratio to two photons for the spin-0 and spin-2 models, respectively.

Spin-0		
m_X	400 GeV	2800 GeV
NWA	1.1 fb	0.03 fb
$\Gamma_X/m_X = 2\%$	2.5 fb	0.03 fb
$\Gamma_X/m_X = 6\%$	4.4 fb	0.03 fb
$\Gamma_X/m_X = 10\%$	8.3 fb	0.04 fb
Spin-2		
m_{G^*}	500 GeV	5000 GeV
$k/\bar{M}_{\text{Pl}} = 0.01$	1.9 fb	0.04 fb
$k/\bar{M}_{\text{Pl}} = 0.05$	2.3 fb	0.04 fb
$k/\bar{M}_{\text{Pl}} = 0.1$	3.2 fb	0.04 fb

The observed limits for different masses and different values of Γ_X/m_X or $k/\bar{M}_{\text{Pl}}$ are summarized in Table 2. For all signals considered in this analysis, the largest single improvement in the limits with respect to Ref. [11] comes from the increased integrated luminosity. The RS1 model is excluded for m_{G^*} below 2.2, 3.9 and 4.5 TeV for $k/\bar{M}_{\text{Pl}}$ values of 0.01, 0.05 and 0.1, respectively.

9. Conclusion

Searches for new resonances in high-mass diphoton final states with the ATLAS experiment at the LHC are presented. The searches use the full LHC Run 2 proton–proton collision dataset at a centre-of-mass energy of $\sqrt{s} = 13$ TeV, corresponding to an integrated luminosity of 139 fb^{-1} . The analyses are optimized to search for spin-0 resonances with masses above 200 GeV and for spin-2 resonances predicted by the Randall–Sundrum model with masses above 500 GeV.

The data are consistent with the Standard Model background expectation. In the spin-0 resonance search, the observed 95% CL upper limits on the fiducial cross-section times branching ratio for a narrow-width signal range from 12.5 fb at 160 GeV to about 0.03 fb at 2800 GeV. In the spin-2 resonance search, the observed limits on the total cross-section times branching ratio for $k/\bar{M}_{\text{Pl}} = 0.1$ range from 3.2 fb to about 0.04 fb for a graviton mass between 500 and 5000 GeV, and the RS1 graviton is excluded for masses below 4500 GeV for this coupling hypothesis.

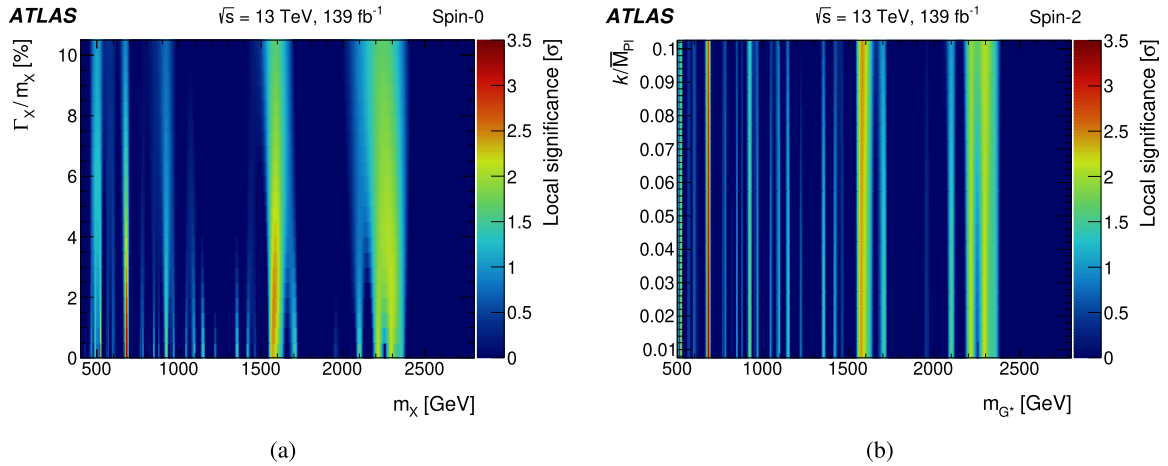


Fig. 4. Probability of compatibility, in terms of local p_0 quantified in standard deviations σ , with the background-only hypothesis as a function of (a) the assumed signal mass m_X and relative width Γ_X/m_X for the spin-0 resonance search and (b) the assumed signal mass m_{G^*} and $k/\bar{M}_{Pl}$ for the spin-2 resonance search.

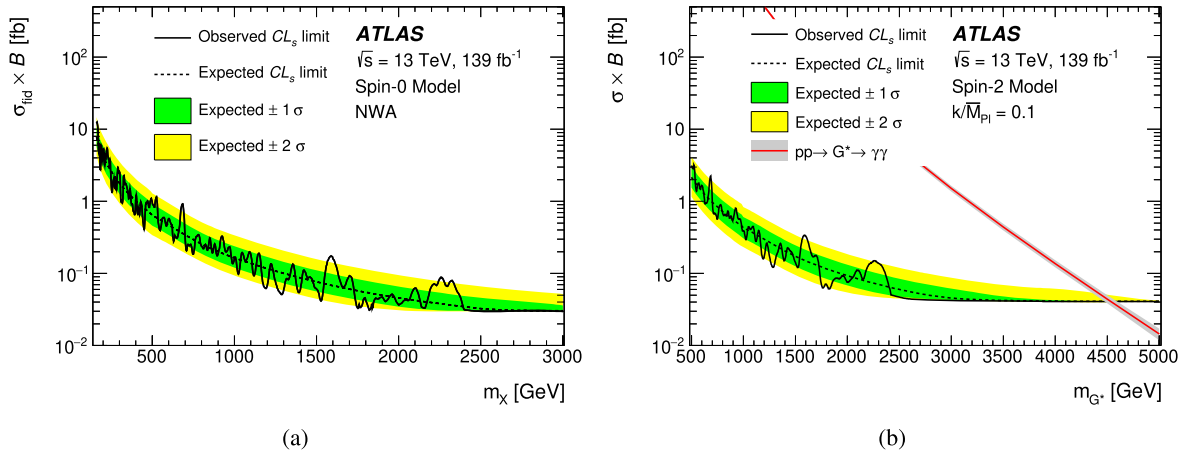


Fig. 5. The expected and observed upper limits at 95% CL on (a) the fiducial and (b) the total production cross-section times branching ratio to two photons of (a) a NWA spin-0 resonance as a function of its mass m_X and (b) the lightest KK graviton as a function of its mass m_{G^*} for $k/\bar{M}_{Pl} = 0.1$. For masses greater than 1000 GeV, pseudo-experiments are used to verify the expected and observed limits, and used in place of the asymptotic limit where differences are observed. Cross-section predictions for the RS1 model are shown in (b), where the grey band illustrates the PDF uncertainty.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

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; Minciencias, Colombia; MSMT CR, MPO CR and VSC CR, Czech Republic; DNR and DNSRC, Denmark; IN2P3-CNRS and CEA-DRF/IRFU, France; SRNSFG, Georgia; BMBF, HGF and MPG, Germany; GSRI, Greece; RGC and Hong Kong SAR, China; ISF and Benoziyo Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; NWO, Netherlands; RCN, Norway; 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; DSI/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, United States of America. In addition, individual groups and members have received support from BCKDF, CANARIE, Compute Canada and CRC, Canada; 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; Norwegian Financial Mechanism 2014-2021, Norway; 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. [52].

References

- [1] T. Lee, A theory of spontaneous T violation, in: G. Feinberg (Ed.), *Phys. Rev. D* 8 (1973) 1226.
- [2] A. Hill, J. van der Bij, Strongly interacting singlet - doublet Higgs model, *Phys. Rev. D* 36 (1987) 3463.
- [3] M. Veltman, F. Yndurain, Radiative corrections to WW scattering, *Nucl. Phys. B* 325 (1989) 1.
- [4] T. Binoth, J. van der Bij, Influence of strongly coupled, hidden scalars on Higgs signals, *Z. Phys. C* 75 (1997) 17, arXiv:hep-ph/9608245.
- [5] R.M. Schabinger, J.D. Wells, Minimal spontaneously broken hidden sector and its impact on Higgs boson physics at the CERN Large Hadron Collider, *Phys. Rev. D* 72 (2005) 093007, arXiv:hep-ph/0509209.
- [6] B. Patt, F. Wilczek, Higgs-field portal into hidden sectors, arXiv:hep-ph/0605188, 2006.
- [7] G.M. Pruna, T. Robens, Higgs singlet extension parameter space in the light of the LHC discovery, *Phys. Rev. D* 88 (2013) 115012, arXiv:1303.1150 [hep-ph].
- [8] T. Appelquist, A. Chodos, P. Freund, *Modern Kaluza-Klein Theories*, Frontiers in Physics, vol. 65, Addison-Wesley, 1987.
- [9] L. Randall, R. Sundrum, Large mass hierarchy from a small extra dimension, *Phys. Rev. Lett.* 83 (1999) 3370, arXiv:hep-ph/9905221.
- [10] L. Randall, R. Sundrum, An alternative to compactification, *Phys. Rev. Lett.* 83 (1999) 4690, arXiv:hep-th/9906064.
- [11] ATLAS Collaboration, Search for new phenomena in high-mass diphoton final states using 37 fb^{-1} of proton-proton collisions collected at $\sqrt{s} = 13\text{ TeV}$ with the ATLAS detector, *Phys. Lett. B* 775 (2017) 105, arXiv:1707.04147 [hep-ex].
- [12] CMS Collaboration, Search for physics beyond the standard model in high-mass diphoton events from proton-proton collisions at $\sqrt{s} = 13\text{ TeV}$, *Phys. Rev. D* 98 (2018) 092001, arXiv:1809.00327 [hep-ex].
- [13] R. Edgar, D. Amidei, C. Grud, K. Sekhon, Functional decomposition: a new method for search and limit setting, arXiv:1805.04536 [physics.data-an], 2018.
- [14] H. Davoudiasl, J. Hewett, T. Rizzo, Phenomenology of the Randall-Sundrum gauge hierarchy model, *Phys. Rev. Lett.* 84 (2000) 2080, arXiv:hep-ph/9909255.
- [15] ATLAS Collaboration, The ATLAS experiment at the CERN Large Hadron Collider, *J. Instrum.* 3 (2008), S08003.
- [16] ATLAS Collaboration, ATLAS insertable B-layer technical design report, ATLAS-TDR-19; CERN-LHCC-2010-013, <https://cds.cern.ch/record/1291633>, 2010, Addendum: ATLAS-TDR-19-ADD-1; CERN-LHCC-2012-009 <https://cds.cern.ch/record/1451888>, 2012.
- [17] B. Abbott, et al., Production and integration of the ATLAS insertable B-layer, *J. Instrum.* 13 (2018) T05008, arXiv:1803.00844 [physics.ins-det].
- [18] Luminosity determination in pp collisions at $\sqrt{s} = 13\text{ TeV}$ using the ATLAS detector at the LHC, tech. rep. ATLAS-CONF-2019-021, CERN, 2019, <https://cds.cern.ch/record/2677054>.
- [19] ATLAS Collaboration, Performance of electron and photon triggers in ATLAS during LHC Run 2, *Eur. Phys. J. C* 80 (2020) 47, arXiv:1909.00761 [hep-ex].
- [20] J. Alwall, et al., 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, arXiv:1405.0301 [hep-ph].
- [21] P. Nason, A new method for combining NLO QCD with shower Monte Carlo algorithms, *J. High Energy Phys.* 11 (2004) 040, arXiv:hep-ph/0409146.
- [22] S. Frixione, P. Nason, C. Oleari, Matching NLO QCD computations with parton shower simulations: the POWHEG method, *J. High Energy Phys.* 11 (2007) 070, arXiv:0709.2092 [hep-ph].
- [23] S. Alioli, P. Nason, C. Oleari, E. Re, A general framework for implementing NLO calculations in shower Monte Carlo programs: the POWHEG BOX, *J. High Energy Phys.* 06 (2010) 043, arXiv:1002.2581 [hep-ph].
- [24] T. Sjöstrand, et al., An introduction to PYTHIA 8.2, *Comput. Phys. Commun.* 191 (2015) 159, arXiv:1410.3012 [hep-ph].
- [25] H.-L. Lai, et al., New parton distributions for collider physics, *Phys. Rev. D* 82 (2010) 074024, arXiv:1007.2241 [hep-ph].
- [26] ATLAS Collaboration, Measurement of the Z/γ^* boson transverse momentum distribution in pp collisions at $\sqrt{s} = 7\text{ TeV}$ with the ATLAS detector, *J. High Energy Phys.* 09 (2014) 145, arXiv:1406.3660 [hep-ex].
- [27] R.D. Ball, et al., Parton distributions with LHC data, *Nucl. Phys. B* 867 (2013) 244, arXiv:1207.1303 [hep-ph].
- [28] ATLAS Collaboration, ATLAS Pythia 8 tunes to 7 TeV data, ATL-PHYS-PUB-2014-021, <https://cds.cern.ch/record/1966419>, 2014.
- [29] T. Gleisberg, et al., Event generation with SHERPA 1.1, *J. High Energy Phys.* 02 (2009) 007, arXiv:0811.4622 [hep-ph].
- [30] E. Bothmann, et al., Event generation with Sherpa 2.2, *SciPost Phys.* 7 (2019) 034, arXiv:1905.09127 [hep-ph].
- [31] S. Hoeche, F. Krauss, M. Schonherr, F. Siegert, A critical appraisal of NLO+PS matching methods, *J. High Energy Phys.* 09 (2012) 049, arXiv:1111.1220 [hep-ph].
- [32] S. Hoeche, F. Krauss, M. Schönerr, F. Siegert, QCD matrix elements + parton showers. The NLO case, *J. High Energy Phys.* 04 (2013) 027, arXiv:1207.5030 [hep-ph].
- [33] S. Catani, F. Krauss, R. Kuhn, B. Webber, QCD matrix elements + parton showers, *J. High Energy Phys.* 11 (2001) 063, arXiv:hep-ph/0109231.
- [34] S. Hoeche, F. Krauss, S. Schumann, F. Siegert, QCD matrix elements and truncated showers, *J. High Energy Phys.* 05 (2009) 053, arXiv:0903.1219 [hep-ph].
- [35] R.D. Ball, et al., Parton distributions for the LHC run II, *J. High Energy Phys.* 04 (2015) 040, arXiv:1410.8849 [hep-ph].
- [36] ATLAS Collaboration, The ATLAS simulation infrastructure, *Eur. Phys. J. C* 70 (2010) 823, arXiv:1005.4568 [physics.ins-det].
- [37] GEANT4 Collaboration, S. Agostinelli, et al., Geant4 – a simulation toolkit, *Nucl. Instrum. Methods Phys. Res., Sect. A* 506 (2003) 250.
- [38] ATLAS Collaboration, The simulation principle and performance of the ATLAS fast calorimeter simulation FastCaloSim, ATL-PHYS-PUB-2010-013, <https://cds.cern.ch/record/1300517>, 2010.
- [39] ATLAS Collaboration, Electron and photon performance measurements with the ATLAS detector using the 2015–2017 LHC proton-proton collision data, *J. Instrum.* 14 (2019) P12006, arXiv:1908.00005 [hep-ex].
- [40] ATLAS Collaboration, Measurement of Higgs boson production in the diphoton decay channel in pp collisions at center-of-mass energies of 7 and 8 TeV with the ATLAS detector, *Phys. Rev. D* 90 (2014) 112015, arXiv:1408.7084 [hep-ex].
- [41] ATLAS Collaboration, Topological cell clustering in the ATLAS calorimeters and its performance in LHC Run 1, *Eur. Phys. J. C* 77 (2017) 490, arXiv:1603.02934 [hep-ex].
- [42] M. Cacciari, G.P. Salam, G. Soyez, The catchment area of jets, *J. High Energy Phys.* 04 (2008) 005, arXiv:0802.1188 [hep-ph].
- [43] M. Cacciari, G.P. Salam, S. Sapeta, On the characterisation of the underlying event, *J. High Energy Phys.* 04 (2010) 065, arXiv:0912.4926 [hep-ph].
- [44] ATLAS Collaboration, Search for scalar diphoton resonances in the mass range 65–600 GeV with the ATLAS detector in pp collision data at $\sqrt{s} = 8\text{ TeV}$, *Phys. Rev. Lett.* 113 (2014) 171801, arXiv:1407.6583 [hep-ex].
- [45] M. Oreglia, A study of the reactions $\psi' \rightarrow \gamma\gamma\psi$, SLAC-R-0236, www.slac.stanford.edu/cgi-wrap/getdoc/slac-r-236.pdf, 1980.
- [46] J. Bijnens, P. Eerola, M. Maul, A. Mansson, T. Sjostrand, QCD signatures of narrow graviton resonances in hadron colliders, *Phys. Lett. B* 503 (2001) 341, arXiv:hep-ph/0101316.
- [47] ATLAS Collaboration, Measurement of isolated-photon pair production in pp collisions at $\sqrt{s} = 7\text{ TeV}$ with the ATLAS detector, *J. High Energy Phys.* 01 (2013) 086, arXiv:1211.1913 [hep-ex].
- [48] ATLAS Collaboration, Search for resonances in diphoton events at $\sqrt{s} = 13\text{ TeV}$ with the ATLAS detector, *J. High Energy Phys.* 09 (2016) 001, arXiv:1606.03833 [hep-ex].
- [49] G. Cowan, K. Cranmer, E. Gross, O. Vitells, Asymptotic formulae for likelihood-based tests of new physics, *Eur. Phys. J. C* 71 (2011) 1554, arXiv:1007.1727 [physics.data-an]; Erratum: *Eur. Phys. J. C* 73 (2013) 2501.
- [50] T. Junk, Confidence level computation for combining searches with small statistics, *Nucl. Instrum. Methods Phys. Res., Sect. A* 434 (1999) 435, arXiv:hep-ex/9902006.
- [51] A.L. Read, Presentation of search results: the CL_s technique, *J. Phys. G* 28 (2002) 2693.
- [52] ATLAS Collaboration, ATLAS computing acknowledgements, ATL-SOFT-PUB-2021-003, <https://cds.cern.ch/record/2776662>.

The ATLAS Collaboration

G. Aad¹⁰², B. Abbott¹²⁹, D.C. Abbott¹⁰³, A. Abed Abud³⁶, K. Abeling⁵³, D.K. Abhayasinghe⁹⁴, S.H. Abidi¹⁶⁸, O.S. AbouZeid⁴⁰, N.L. Abraham¹⁵⁷, H. Abramowicz¹⁶², H. Abreu¹⁶¹, Y. Abulaiti⁶, B.S. Acharya^{67a,67b,o}, B. Achkar⁵³, L. Adam¹⁰⁰, C. Adam Bourdarios⁵, L. Adamczyk^{84a}, L. Adamek¹⁶⁸, J. Adelman¹²¹, A. Adiguzel^{12c,ad}, S. Adorni⁵⁴, T. Adye¹⁴⁴, A.A. Affolder¹⁴⁶, Y. Afik¹⁶¹, C. Agapopoulou⁶⁵, M.N. Agaras³⁸, A. Aggarwal¹¹⁹, C. Agheorghiesei^{27c}, J.A. Aguilar-Saavedra^{140f,140a,ac}, A. Ahmad³⁶, F. Ahmadov⁸⁰, W.S. Ahmed¹⁰⁴, X. Ai¹⁸, G. Aielli^{74a,74b}, S. Akatsuka⁸⁶, M. Akbiyik¹⁰⁰, T.P.A. Åkesson⁹⁷, E. Akilli⁵⁴, A.V. Akimov¹¹¹, K. Al Khoury⁶⁵, G.L. Alberghi^{23b}, J. Albert¹⁷⁷, M.J. Alconada Verzini¹⁶²,

S. Alderweireldt³⁶, M. Aleksa³⁶, I.N. Aleksandrov⁸⁰, C. Alexa^{27b}, T. Alexopoulos¹⁰, A. Alfonsi¹²⁰, F. Alfonsi^{23b,23a}, M. Alhroob¹²⁹, B. Ali¹⁴², S. Ali¹⁵⁹, M. Aliev¹⁶⁷, G. Alimonti^{69a}, C. Allaire³⁶, B.M.M. Allbrooke¹⁵⁷, B.W. Allen¹³², P.P. Allport²¹, A. Aloisio^{70a,70b}, F. Alonso⁸⁹, C. Alpigiani¹⁴⁹, E. Alunno Camelia^{74a,74b}, M. Alvarez Estevez⁹⁹, M.G. Alviggi^{70a,70b}, Y. Amaral Coutinho^{81b}, A. Ambler¹⁰⁴, L. Ambroz¹³⁵, C. Amelung³⁶, D. Amidei¹⁰⁶, S.P. Amor Dos Santos^{140a}, S. Amoroso⁴⁶, C.S. Amrouche⁵⁴, F. An⁷⁹, C. Anastopoulos¹⁵⁰, N. Andari¹⁴⁵, T. Andeen¹¹, J.K. Anders²⁰, S.Y. Andrean^{45a,45b}, A. Andreazza^{69a,69b}, V. Andrei^{61a}, C.R. Anelli¹⁷⁷, S. Angelidakis⁹, A. Angerami³⁹, A.V. Anisenkov^{122b,122a}, A. Annovi^{72a}, C. Antel⁵⁴, M.T. Anthony¹⁵⁰, E. Antipov¹³⁰, M. Antonelli⁵¹, D.J.A. Antrim¹⁸, F. Anulli^{73a}, M. Aoki⁸², J.A. Aparisi Pozo¹⁷⁵, M.A. Aparo¹⁵⁷, L. Aperio Bella⁴⁶, N. Aranzabal³⁶, V. Araujo Ferraz^{81a}, R. Araujo Pereira^{81b}, C. Arcangeletti⁵¹, A.T.H. Arce⁴⁹, J-F. Arguin¹¹⁰, S. Argyropoulos⁵², J.-H. Arling⁴⁶, A.J. Armbruster³⁶, A. Armstrong¹⁷², O. Arnaez¹⁶⁸, H. Arnold¹²⁰, Z.P. Arrubarrena Tame¹¹⁴, G. Artoni¹³⁵, H. Asada¹¹⁷, K. Asai¹²⁷, S. Asai¹⁶⁴, T. Asawatavonvanich¹⁶⁶, N.A. Asbah⁵⁹, E.M. Asimakopoulou¹⁷³, L. Asquith¹⁵⁷, J. Assahsah^{35d}, K. Assamagan²⁹, R. Astalos^{28a}, R.J. Atkin^{33a}, M. Atkinson¹⁷⁴, N.B. Atlay¹⁹, H. Atmani⁶⁵, P.A. Atmasiddha¹⁰⁶, K. Augsten¹⁴², V.A. Austrup¹⁸³, G. Avolio³⁶, M.K. Ayoub^{15a}, G. Azuelos^{110,ak}, D. Babal^{28a}, H. Bachacou¹⁴⁵, K. Bachas¹⁶³, F. Backman^{45a,45b}, P. Bagnaia^{73a,73b}, H. Bahrasemani¹⁵³, A.J. Bailey¹⁷⁵, V.R. Bailey¹⁷⁴, J.T. Baines¹⁴⁴, C. Bakalis¹⁰, O.K. Baker¹⁸⁴, P.J. Bakker¹²⁰, E. Bakos¹⁶, D. Bakshi Gupta⁸, S. Balaji¹⁵⁸, R. Balasubramanian¹²⁰, E.M. Baldin^{122b,122a}, P. Balek¹⁸¹, F. Balli¹⁴⁵, W.K. Balunas¹³⁵, J. Balz¹⁰⁰, E. Banas⁸⁵, M. Bandieramonte¹³⁹, A. Bandyopadhyay¹⁹, Sw. Banerjee^{182,j}, L. Barak¹⁶², W.M. Barbe³⁸, E.L. Barberio¹⁰⁵, D. Barberis^{55b,55a}, M. Barbero¹⁰², G. Barbour⁹⁵, T. Barillari¹¹⁵, M-S. Barisits³⁶, J. Barkeloo¹³², T. Barklow¹⁵⁴, R. Barnea¹⁶¹, B.M. Barnett¹⁴⁴, R.M. Barnett¹⁸, Z. Barnovska-Blenessy^{60a}, A. Baroncelli^{60a}, G. Barone²⁹, A.J. Barr¹³⁵, L. Barranco Navarro^{45a,45b}, F. Barreiro⁹⁹, J. Barreiro Guimarães da Costa^{15a}, U. Barron¹⁶², S. Barsov¹³⁸, F. Bartels^{61a}, R. Bartoldus¹⁵⁴, G. Bartolini¹⁰², A.E. Barton⁹⁰, P. Bartos^{28a}, A. Basalae⁴⁶, A. Basan¹⁰⁰, A. Bassalat^{65,ah}, M.J. Basso¹⁶⁸, R.L. Bates⁵⁷, S. Batlamous^{35e}, J.R. Batley³², B. Batool¹⁵², M. Battaglia¹⁴⁶, M. Bause^{73a,73b}, F. Bauer^{145,*}, P. Bauer²⁴, H.S. Bawa³¹, A. Bayirli^{12c}, J.B. Beacham⁴⁹, T. Beau¹³⁶, P.H. Beauchemin¹⁷¹, F. Becherer⁵², P. Bechtel²⁴, H.C. Beck⁵³, H.P. Beck^{20,q}, K. Becker¹⁷⁹, C. Becot⁴⁶, A. Beddall^{12d}, A.J. Beddall^{12a}, V.A. Bednyakov⁸⁰, M. Bedognetti¹²⁰, C.P. Bee¹⁵⁶, T.A. Beermann¹⁸³, M. Begalli^{81b}, M. Begel²⁹, A. Behera¹⁵⁶, J.K. Behr⁴⁶, F. Beisiegel²⁴, M. Belfkir⁵, A.S. Bell⁹⁵, G. Bella¹⁶², L. Bellagamba^{23b}, A. Bellerive³⁴, P. Bellos⁹, K. Beloborodov^{122b,122a}, K. Belotskiy¹¹², N.L. Belyaev¹¹², D. Benchebkroun^{35a}, N. Benekos¹⁰, Y. Benhammou¹⁶², D.P. Benjamin⁶, M. Benoit²⁹, J.R. Bensinger²⁶, S. Bentvelsen¹²⁰, L. Beresford¹³⁵, M. Beretta⁵¹, D. Berge¹⁹, E. Bergeaas Kuutmann¹⁷³, N. Berger⁵, B. Bergmann¹⁴², L.J. Bergsten²⁶, J. Beringer¹⁸, S. Berlendis⁷, G. Bernardi¹³⁶, C. Bernius¹⁵⁴, F.U. Bernlochner²⁴, T. Berry⁹⁴, P. Berta¹⁰⁰, A. Berthold⁴⁸, I.A. Bertram⁹⁰, O. Bessidskaia Bylund¹⁸³, N. Besson¹⁴⁵, S. Bethke¹¹⁵, A. Betti⁴², A.J. Bevan⁹³, J. Beyer¹¹⁵, S. Bhatta¹⁵⁶, D.S. Bhattacharya¹⁷⁸, P. Bhattarai²⁶, V.S. Bhopatkar⁶, R. Bi¹³⁹, R.M. Bianchi¹³⁹, O. Biebel¹¹⁴, D. Biedermann¹⁹, R. Bielski³⁶, K. Bierwagen¹⁰⁰, N.V. Biesuz^{72a,72b}, M. Biglietti^{75a}, T.R.V. Billoud¹⁴², M. Bindi⁵³, A. Bingul^{12d}, C. Bini^{73a,73b}, S. Biondi^{23b,23a}, C.J. Birch-sykes¹⁰¹, M. Birman¹⁸¹, T. Bisanz³⁶, J.P. Biswal³, D. Biswas^{182,j}, A. Bitadze¹⁰¹, C. Bittrich⁴⁸, K. Björke¹³⁴, T. Blazek^{28a}, I. Bloch⁴⁶, C. Blocker²⁶, A. Blue⁵⁷, U. Blumenschein⁹³, J. Blumenthal¹⁰⁰, G.J. Bobbink¹²⁰, V.S. Bobrovnikov^{122b,122a}, S.S. Bocchetta⁹⁷, D. Bogavac¹⁴, A.G. Bogdanchikov^{122b,122a}, C. Boehm^{45a}, V. Boisvert⁹⁴, P. Bokan^{173,53}, T. Bold^{84a}, A.E. Bolz^{61b}, M. Bomben¹³⁶, M. Bona⁹³, J.S. Bonilla¹³², M. Boonekamp¹⁴⁵, C.D. Booth⁹⁴, A.G. Borbély⁵⁷, H.M. Borecka-Bielska⁹¹, L.S. Borgna⁹⁵, A. Borisov¹²³, G. Borissov⁹⁰, D. Bortoletto¹³⁵, D. Boscherini^{23b}, M. Bosman¹⁴, J.D. Bossio Sola¹⁰⁴, K. Bouaouda^{35a}, J. Boudreau¹³⁹, E.V. Bouhova-Thacker⁹⁰, D. Boumediene³⁸, A. Boveia¹²⁸, J. Boyd³⁶, D. Boye^{33c}, I.R. Boyko⁸⁰, A.J. Bozson⁹⁴, J. Bracinik²¹, N. Brahimi^{60d,60c}, G. Brandt¹⁸³, O. Brandt³², F. Braren⁴⁶, B. Brau¹⁰³, J.E. Brau¹³², W.D. Breaden Madden⁵⁷, K. Brendlinger⁴⁶, R. Brenner¹⁶¹, L. Brenner³⁶, R. Brenner¹⁷³, S. Bressler¹⁸¹, B. Brickwedde¹⁰⁰, D.L. Briglin²¹, D. Britton⁵⁷, D. Britzger¹¹⁵, I. Brock²⁴, R. Brock¹⁰⁷, G. Brooijmans³⁹, W.K. Brooks^{147e}, E. Brost²⁹, P.A. Bruckman de Renstrom⁸⁵, B. Brüers⁴⁶, D. Bruncko^{28b}, A. Bruni^{23b}, G. Bruni^{23b}, M. Bruschi^{23b}, N. Bruscino^{73a,73b}, L. Bryngemark¹⁵⁴, T. Buanes¹⁷, Q. Buat¹⁵⁶, P. Buchholz¹⁵², A.G. Buckley⁵⁷, I.A. Budagov⁸⁰, M.K. Bugge¹³⁴, O. Bulekov¹¹², B.A. Bullard⁵⁹, T.J. Burch¹²¹, S. Burdin⁹¹, C.D. Burgard¹²⁰, A.M. Burger¹³⁰, B. Burghgrave⁸, J.T.P. Burr⁴⁶, C.D. Burton¹¹, J.C. Burzynski¹⁰³, V. Büscher¹⁰⁰, E. Buschmann⁵³, P.J. Bussey⁵⁷, J.M. Butler²⁵, C.M. Buttar⁵⁷,

J.M. Butterworth⁹⁵, P. Butti³⁶, W. Buttinger¹⁴⁴, C.J. Buxo Vazquez¹⁰⁷, A. Buzatu¹⁵⁹,
A.R. Buzykaev^{122b,122a}, G. Cabras^{23b}, S. Cabrera Urbán¹⁷⁵, D. Caforio⁵⁶, H. Cai¹³⁹, V.M.M. Cairo¹⁵⁴,
O. Cakir^{4a}, N. Calace³⁶, P. Calafiura¹⁸, G. Calderini¹³⁶, P. Calfayan⁶⁶, G. Callea⁵⁷, L.P. Caloba^{81b},
A. Caltabiano^{74a,74b}, S. Calvente Lopez⁹⁹, D. Calvet³⁸, S. Calvet³⁸, T.P. Calvet¹⁰², M. Calvetti^{72a,72b},
R. Camacho Toro¹³⁶, S. Camarda³⁶, D. Camarero Munoz⁹⁹, P. Camarri^{74a,74b}, M.T. Camerlingo^{75a,75b},
D. Cameron¹³⁴, C. Camincher³⁶, S. Campana³⁶, M. Campanelli⁹⁵, A. Camplani⁴⁰, V. Canale^{70a,70b},
A. Canesse¹⁰⁴, M. Cano Bret⁷⁸, J. Cantero¹³⁰, T. Cao¹⁶², Y. Cao¹⁷⁴, M. Capua^{41b,41a}, R. Cardarelli^{74a},
F. Cardillo¹⁷⁵, G. Carducci^{41b,41a}, I. Carli¹⁴³, T. Carli³⁶, G. Carlino^{70a}, B.T. Carlson¹³⁹,
E.M. Carlson^{177,169a}, L. Carminati^{69a,69b}, R.M.D. Carney¹⁵⁴, S. Caron¹¹⁹, E. Carquin^{147e}, S. Carrá⁴⁶,
G. Carratta^{23b,23a}, J.W.S. Carter¹⁶⁸, T.M. Carter⁵⁰, M.P. Casado^{14,g}, A.F. Casha¹⁶⁸, E.G. Castiglia¹⁸⁴,
F.L. Castillo¹⁷⁵, L. Castillo Garcia¹⁴, V. Castillo Gimenez¹⁷⁵, N.F. Castro^{140a,140e}, A. Catinaccio³⁶,
J.R. Catmore¹³⁴, A. Cattai³⁶, V. Cavaliere²⁹, V. Cavasinni^{72a,72b}, E. Celebi^{12b}, F. Celli¹³⁵, K. Cerny¹³¹,
A.S. Cerqueira^{81a}, A. Cerri¹⁵⁷, L. Cerrito^{74a,74b}, F. Cerutti¹⁸, A. Cervelli^{23b}, S.A. Cetin^{12b}, Z. Chadi^{35a},
D. Chakraborty¹²¹, J. Chan¹⁸², W.S. Chan¹²⁰, W.Y. Chan⁹¹, J.D. Chapman³², B. Chargeishvili^{160b},
D.G. Charlton²¹, T.P. Charman⁹³, M. Chatterjee²⁰, C.C. Chau³⁴, S. Che¹²⁸, S. Chekanov⁶,
S.V. Chekulaev^{169a}, G.A. Chelkov^{80,qf}, B. Chen⁷⁹, C. Chen^{60a}, C.H. Chen⁷⁹, H. Chen^{15c}, H. Chen²⁹,
J. Chen^{60a}, J. Chen³⁹, J. Chen²⁶, S. Chen¹³⁷, S.J. Chen^{15c}, X. Chen^{15b}, Y. Chen^{60a}, Y.-H. Chen⁴⁶,
H.C. Cheng^{63a}, H.J. Cheng^{15a}, A. Cheplakov⁸⁰, E. Cheremushkina¹²³, R. Cherkaoui El Moursli^{35e},
E. Cheu⁷, K. Cheung⁶⁴, T.J.A. Chevaléras¹⁴⁵, L. Chevalier¹⁴⁵, V. Chiarella⁵¹, G. Chiarelli^{72a},
G. Chiodini^{68a}, A.S. Chisholm²¹, A. Chitan^{27b}, I. Chiu¹⁶⁴, Y.H. Chiu¹⁷⁷, M.V. Chizhov⁸⁰, K. Choi¹¹,
A.R. Chomont^{73a,73b}, Y. Chou¹⁰³, Y.S. Chow¹²⁰, L.D. Christopher^{33f}, M.C. Chu^{63a}, X. Chu^{15a,15d},
J. Chudoba¹⁴¹, J.J. Chwastowski⁸⁵, L. Chytka¹³¹, D. Cieri¹¹⁵, K.M. Ciesla⁸⁵, V. Cindro⁹², I.A. Cioară^{27b},
A. Ciochio¹⁸, F. Ciotto^{70a,70b}, Z.H. Citron^{181,k}, M. Citterio^{69a}, D.A. Ciubotaru^{27b}, B.M. Ciungu¹⁶⁸,
A. Clark⁵⁴, P.J. Clark⁵⁰, S.E. Clawson¹⁰¹, C. Clement^{45a,45b}, L. Clissa^{23b,23a}, Y. Coadou¹⁰², M. Cobal^{67a,67c},
A. Coccaro^{55b}, J. Cochran⁷⁹, R. Coelho Lopes De Sa¹⁰³, H. Cohen¹⁶², A.E.C. Coimbra³⁶, B. Cole³⁹,
A.P. Colijn¹²⁰, J. Collot⁵⁸, P. Conde Muiño^{140a,140h}, S.H. Connell^{33c}, I.A. Connolly⁵⁷, S. Constantinescu^{27b},
F. Conventi^{70a,qf}, A.M. Cooper-Sarkar¹³⁵, F. Cormier¹⁷⁶, K.J.R. Cormier¹⁶⁸, L.D. Corpe⁹⁵,
M. Corradi^{73a,73b}, E.E. Corrigan⁹⁷, F. Corriveau^{104,aa}, M.J. Costa¹⁷⁵, F. Costanza⁵, D. Costanzo¹⁵⁰,
G. Cowan⁹⁴, J.W. Cowley³², J. Crane¹⁰¹, K. Cranmer¹²⁶, R.A. Creager¹³⁷, S. Crépe-Renaudin⁵⁸,
F. Crescioli¹³⁶, M. Cristinziani²⁴, V. Croft¹⁷¹, G. Crosetti^{41b,41a}, A. Cueto⁵, T. Cuhadar Donszelmann¹⁷²,
H. Cui^{15a,15d}, A.R. Cukierman¹⁵⁴, W.R. Cunningham⁵⁷, S. Czekierda⁸⁵, P. Czodrowski³⁶,
M.M. Czurylo^{61b}, M.J. Da Cunha Sargedas De Sousa^{60b}, J.V. Da Fonseca Pinto^{81b}, C. Da Via¹⁰¹,
W. Dabrowski^{84a}, F. Dachs³⁶, T. Dado⁴⁷, S. Dahbi^{33f}, T. Dai¹⁰⁶, C. Dallapiccola¹⁰³, M. Dam⁴⁰,
G. D'amen²⁹, V. D'Amico^{75a,75b}, J. Damp¹⁰⁰, J.R. Dandoy¹³⁷, M.F. Daneri³⁰, M. Danninger¹⁵³, V. Dao³⁶,
G. Darbo^{55b}, O. Dartsis⁵, A. Dattagupta¹³², T. Daubney⁴⁶, S. D'Auria^{69a,69b}, C. David^{169b}, T. Davidek¹⁴³,
D.R. Davis⁴⁹, I. Dawson¹⁵⁰, K. De⁸, R. De Asmundis^{70a}, M. De Beurs¹²⁰, S. De Castro^{23b,23a},
N. De Groot¹¹⁹, P. de Jong¹²⁰, H. De la Torre¹⁰⁷, A. De Maria^{15c}, D. De Pedis^{73a}, A. De Salvo^{73a},
U. De Sanctis^{74a,74b}, M. De Santis^{74a,74b}, A. De Santo¹⁵⁷, J.B. De Vivie De Regie⁶⁵, D.V. Dedovich⁸⁰,
A.M. Deiana⁴², J. Del Peso⁹⁹, Y. Delabat Diaz⁴⁶, D. Delgove⁶⁵, F. Deliot¹⁴⁵, C.M. Delitzsch⁷,
M. Della Pietra^{70a,70b}, D. Della Volpe⁵⁴, A. Dell'Acqua³⁶, L. Dell'Asta^{74a,74b}, M. Delmastro⁵,
C. Delporte⁶⁵, P.A. Delsart⁵⁸, S. Demers¹⁸⁴, M. Demichev⁸⁰, G. Demontigny¹¹⁰, S.P. Denisov¹²³,
L. D'Eramo¹²¹, D. Derendarz⁸⁵, J.E. Derkaoui^{35d}, F. Derue¹³⁶, P. Dervan⁹¹, K. Desch²⁴, K. Dette¹⁶⁸,
C. Deutsch²⁴, M.R. Devesa³⁰, P.O. Deviveiros³⁶, F.A. Di Bello^{73a,73b}, A. Di Ciaccio^{74a,74b}, L. Di Ciaccio⁵,
C. Di Donato^{70a,70b}, A. Di Girolamo³⁶, G. Di Gregorio^{72a,72b}, A. Di Luca^{76a,76b}, B. Di Micco^{75a,75b},
R. Di Nardo^{75a,75b}, K.F. Di Petrillo⁵⁹, R. Di Sipio¹⁶⁸, C. Diaconu¹⁰², F.A. Dias¹²⁰, T. Dias Do Vale^{140a},
M.A. Diaz^{147a}, F.G. Diaz Capriles²⁴, J. Dickinson¹⁸, M. Didenko¹⁶⁷, E.B. Diehl¹⁰⁶, J. Dietrich¹⁹,
S. Díez Cornell⁴⁶, C. Díez Pardos¹⁵², A. Dimitrievska¹⁸, W. Ding^{15b}, J. Dingfelder²⁴, S.J. Dittmeier^{61b},
F. Dittus³⁶, F. Djama¹⁰², T. Djobava^{160b}, J.I. Djuvsland¹⁷, M.A.B. Do Vale¹⁴⁸, M. Dobre^{27b},
D. Dodsworth²⁶, C. Doglioni⁹⁷, J. Dolejsi¹⁴³, Z. Dolezal¹⁴³, M. Donadelli^{81c}, B. Dong^{60c}, J. Donini³⁸,
A. D'Onofrio^{15c}, M. D'Onofrio⁹¹, J. Dopke¹⁴⁴, A. Doria^{70a}, M.T. Dova⁸⁹, A.T. Doyle⁵⁷, E. Drechsler¹⁵³,
E. Dreyer¹⁵³, T. Dreyer⁵³, A.S. Drobac¹⁷¹, D. Du^{60b}, T.A. du Pree¹²⁰, Y. Duan^{60d}, F. Dubinin¹¹¹,
M. Dubovsky^{28a}, A. Dubreuil⁵⁴, E. Duchovni¹⁸¹, G. Duckeck¹¹⁴, O.A. Ducu^{36,27b}, D. Duda¹¹⁵,
A. Dudarev³⁶, A.C. Dudder¹⁰⁰, E.M. Duffield¹⁸, M. D'uffizi¹⁰¹, L. Duflost⁶⁵, M. Dührssen³⁶, C. Dülse¹⁸³,

M. Dumancic¹⁸¹, A.E. Dumitriu^{27b}, M. Dunford^{61a}, S. Dungs⁴⁷, A. Duperrin¹⁰², H. Duran Yildiz^{4a}, M. Dören⁵⁶, A. Durglishvili^{160b}, D. Duschinger⁴⁸, B. Dutta⁴⁶, D. Duvnjak¹, G.I. Dyckes¹³⁷, M. Dyndal³⁶, S. Dysch¹⁰¹, B.S. Dziedzic⁸⁵, M.G. Eggleston⁴⁹, T. Eifert⁸, G. Eigen¹⁷, K. Einsweiler¹⁸, T. Ekelof¹⁷³, H. El Jarrari^{35e}, V. Ellajosyula¹⁷³, M. Ellert¹⁷³, F. Ellinghaus¹⁸³, A.A. Elliot⁹³, N. Ellis³⁶, J. Elmsheuser²⁹, M. Elsing³⁶, D. Emeliyanov¹⁴⁴, A. Emernan³⁹, Y. Enari¹⁶⁴, M.B. Epland⁴⁹, J. Erdmann⁴⁷, A. Ereditato²⁰, P.A. Erland⁸⁵, M. Errenst¹⁸³, M. Escalier⁶⁵, C. Escobar¹⁷⁵, O. Estrada Pastor¹⁷⁵, E. Etzion¹⁶², G. Evans^{140a}, H. Evans⁶⁶, M.O. Evans¹⁵⁷, A. Ezhilov¹³⁸, F. Fabbri⁵⁷, L. Fabbri^{23b,23a}, V. Fabiani¹¹⁹, G. Facini¹⁷⁹, R.M. Fakhruddinov¹²³, S. Falciano^{73a}, P.J. Falke²⁴, S. Falke³⁶, J. Faltova¹⁴³, Y. Fang^{15a}, Y. Fang^{15a}, G. Fanourakis⁴⁴, M. Fanti^{69a,69b}, M. Faraj^{67a,67c}, A. Farbin⁸, A. Farilla^{75a}, E.M. Farina^{71a,71b}, T. Farooque¹⁰⁷, S.M. Farrington⁵⁰, P. Farthouat³⁶, F. Fassi^{35e}, P. Fassnacht³⁶, D. Fassouliotis⁹, M. Faucci Giannelli⁵⁰, W.J. Fawcett³², L. Fayard⁶⁵, O.L. Fedin^{138,p}, W. Fedorko¹⁷⁶, M. Feickert¹⁷⁴, L. Feligioni¹⁰², A. Fell¹⁵⁰, C. Feng^{60b}, M. Feng⁴⁹, M.J. Fenton¹⁷², A.B. Fenyuk¹²³, S.W. Ferguson⁴³, J. Ferrando⁴⁶, A. Ferrari¹⁷³, P. Ferrari¹²⁰, R. Ferrari^{71a}, D.E. Ferreira de Lima^{61b}, A. Ferrer¹⁷⁵, D. Ferrere⁵⁴, C. Ferretti¹⁰⁶, F. Fiedler¹⁰⁰, A. Filipčič⁹², F. Filthaut¹¹⁹, K.D. Finelli²⁵, M.C.N. Fiolhais^{140a,140c,a}, L. Fiorini¹⁷⁵, F. Fischer¹¹⁴, W.C. Fisher¹⁰⁷, T. Fitschen²¹, I. Fleck¹⁵², P. Fleischmann¹⁰⁶, T. Flick¹⁸³, B.M. Flierl¹¹⁴, L. Flores¹³⁷, L.R. Flores Castillo^{63a}, F.M. Follega^{76a,76b}, N. Fomin¹⁷, J.H. Foo¹⁶⁸, G.T. Forcolin^{76a,76b}, B.C. Forland⁶⁶, A. Formica¹⁴⁵, F.A. Förster¹⁴, A.C. Forti¹⁰¹, E. Fortin¹⁰², M.G. Foti¹³⁵, D. Fournier⁶⁵, H. Fox⁹⁰, P. Francavilla^{72a,72b}, S. Francescato^{73a,73b}, M. Franchini^{23b,23a}, S. Franchino^{61a}, D. Francis³⁶, L. Franco⁵, L. Franconi²⁰, M. Franklin⁵⁹, G. Frattari^{73a,73b}, A.N. Fray⁹³, P.M. Freeman²¹, B. Freund¹¹⁰, W.S. Freund^{81b}, E.M. Freundlich⁴⁷, D.C. Frizzell¹²⁹, D. Froidevaux³⁶, J.A. Frost¹³⁵, M. Fujimoto¹²⁷, C. Fukunaga¹⁶⁵, E. Fullana Torregrosa¹⁷⁵, T. Fusayasu¹¹⁶, J. Fuster¹⁷⁵, A. Gabrielli^{23b,23a}, A. Gabrielli³⁶, S. Gadatsch⁵⁴, P. Gadow¹¹⁵, G. Gagliardi^{55b,55a}, L.G. Gagnon¹¹⁰, G.E. Gallardo¹³⁵, E.J. Gallas¹³⁵, B.J. Gallop¹⁴⁴, R. Gamboa Goni⁹³, K.K. Gan¹²⁸, S. Ganguly¹⁸¹, J. Gao^{60a}, Y. Gao⁵⁰, Y.S. Gao^{31,m}, F.M. Garay Walls^{147a}, C. García¹⁷⁵, J.E. García Navarro¹⁷⁵, J.A. García Pascual^{15a}, C. Garcia-Argos⁵², M. Garcia-Sciveres¹⁸, R.W. Gardner³⁷, N. Garelli¹⁵⁴, S. Gargiulo⁵², C.A. Garner¹⁶⁸, V. Garonne¹³⁴, S.J. Gasiorowski¹⁴⁹, P. Gaspar^{81b}, A. Gaudiello^{55b,55a}, G. Gaudio^{71a}, P. Gauzzi^{73a,73b}, I.L. Gavrilenko¹¹¹, A. Gavrilyuk¹²⁴, C. Gay¹⁷⁶, G. Gaycken⁴⁶, E.N. Gazis¹⁰, A.A. Geanta^{27b}, C.M. Gee¹⁴⁶, C.N.P. Gee¹⁴⁴, J. Geisen⁹⁷, M. Geisen¹⁰⁰, C. Gemme^{55b}, M.H. Genest⁵⁸, C. Geng¹⁰⁶, S. Gentile^{73a,73b}, S. George⁹⁴, T. Gerialis⁴⁴, L.O. Gerlach⁵³, P. Gessinger-Befurt¹⁰⁰, G. Gessner⁴⁷, M. Ghasemi Bostanabad¹⁷⁷, M. Ghneimat¹⁵², A. Ghosh⁶⁵, A. Ghosh⁷⁸, B. Giacobbe^{23b}, S. Giagu^{73a,73b}, N. Giangiacomi¹⁶⁸, P. Giannetti^{72a}, A. Giannini^{70a,70b}, G. Giannini¹⁴, S.M. Gibson⁹⁴, M. Gignac¹⁴⁶, D.T. Gil^{84b}, B.J. Gilbert³⁹, D. Gillberg³⁴, G. Gilles¹⁸³, N.E.K. Gillwald⁴⁶, D.M. Gingrich^{3,ak}, M.P. Giordani^{67a,67c}, P.F. Giraud¹⁴⁵, G. Giugliarelli^{67a,67c}, D. Giugni^{69a}, F. Giuli^{74a,74b}, S. Gkaitatzis¹⁶³, I. Gkialas^{9,h}, E.L. Gkougkousis¹⁴, P. Gkoutoumis¹⁰, L.K. Gladilin¹¹³, C. Glasman⁹⁹, J. Glatzer¹⁴, P.C.F. Glaysheer⁴⁶, A. Glazov⁴⁶, G.R. Gledhill¹³², I. Gnesi^{41b,c}, M. Goblirsch-Kolb²⁶, D. Godin¹¹⁰, S. Goldfarb¹⁰⁵, T. Golling⁵⁴, D. Golubkov¹²³, A. Gomes^{140a,140b}, R. Goncalves Gama⁵³, R. Gonçalves^{140a,140c}, G. Gonella¹³², L. Gonella²¹, A. Gongadze⁸⁰, F. Gonnella²¹, J.L. Gonski³⁹, S. González de la Hoz¹⁷⁵, S. Gonzalez Fernandez¹⁴, R. Gonzalez Lopez⁹¹, C. Gonzalez Renteria¹⁸, R. Gonzalez Suarez¹⁷³, S. Gonzalez-Sevilla⁵⁴, G.R. Gonzalvo Rodriguez¹⁷⁵, L. Goossens³⁶, N.A. Gorasia²¹, P.A. Gorbounov¹²⁴, H.A. Gordon²⁹, B. Gorini³⁶, E. Gorini^{68a,68b}, A. Gorišek⁹², A.T. Goshaw⁴⁹, M.I. Gostkin⁸⁰, C.A. Gottardo¹¹⁹, M. Goughri^{35b}, A.G. Goussiou¹⁴⁹, N. Govender^{33c}, C. Goy⁵, I. Grabowska-Bold^{84a}, E.C. Graham⁹¹, J. Gramling¹⁷², E. Gramstad¹³⁴, S. Grancagnolo¹⁹, M. Grandi¹⁵⁷, V. Gratchev¹³⁸, P.M. Gravila^{27f}, F.G. Gravili^{68a,68b}, C. Gray⁵⁷, H.M. Gray¹⁸, C. Grefe²⁴, K. Gregersen⁹⁷, I.M. Gregor⁴⁶, P. Grenier¹⁵⁴, K. Grevtsov⁴⁶, C. Grieco¹⁴, N.A. Grieser¹²⁹, A.A. Grillo¹⁴⁶, K. Grimm^{31,l}, S. Grinstein^{14,w}, J.-F. Grivaz⁶⁵, S. Groh¹⁰⁰, E. Gross¹⁸¹, J. Grosse-Knetter⁵³, Z.J. Grout⁹⁵, C. Grud¹⁰⁶, A. Grummer¹¹⁸, J.C. Grundy¹³⁵, L. Guan¹⁰⁶, W. Guan¹⁸², C. Gubbels¹⁷⁶, J. Guenther⁷⁷, A. Guerguichon⁶⁵, J.G.R. Guerrero Rojas¹⁷⁵, F. Guescini¹¹⁵, D. Guest⁷⁷, R. Gugel¹⁰⁰, A. Guida⁴⁶, T. Guillemin⁵, S. Guindon³⁶, J. Guo^{60c}, W. Guo¹⁰⁶, Y. Guo^{60a}, Z. Guo¹⁰², R. Gupta⁴⁶, S. Gurbuz^{12c}, G. Gustavino¹²⁹, M. Guth⁵², P. Gutierrez¹²⁹, C. Gutsche⁹⁵, C. Guyot¹⁴⁵, C. Gwenlan¹³⁵, C.B. Gwilliam⁹¹, E.S. Haaland¹³⁴, A. Haas¹²⁶, C. Haber¹⁸, H.K. Hadavand⁸, A. Hadeef¹⁰⁰, M. Haleem¹⁷⁸, J. Haley¹³⁰, J.J. Hall¹⁵⁰, G. Halladjian¹⁰⁷, G.D. Hallowell¹⁰², K. Hamano¹⁷⁷, H. Hamdaoui^{35e}, M. Hamer²⁴, G.N. Hamity⁵⁰, K. Han^{60a}, L. Han^{15c}, L. Han^{60a}, S. Han¹⁸, Y.F. Han¹⁶⁸, K. Hanagaki^{82,u}, M. Hance¹⁴⁶, D.M. Handl¹¹⁴, M.D. Hank³⁷, R. Hankache¹³⁶, E. Hansen⁹⁷, J.B. Hansen⁴⁰,

J.D. Hansen⁴⁰, M.C. Hansen²⁴, P.H. Hansen⁴⁰, E.C. Hanson¹⁰¹, K. Hara¹⁷⁰, T. Harenberg¹⁸³, S. Harkusha¹⁰⁸, P.F. Harrison¹⁷⁹, N.M. Hartman¹⁵⁴, N.M. Hartmann¹¹⁴, Y. Hasegawa¹⁵¹, A. Hasib⁵⁰, S. Hassani¹⁴⁵, S. Haug²⁰, R. Hauser¹⁰⁷, M. Havranek¹⁴², C.M. Hawkes²¹, R.J. Hawking³⁶, S. Hayashida¹¹⁷, D. Hayden¹⁰⁷, C. Hayes¹⁰⁶, R.L. Hayes¹⁷⁶, C.P. Hays¹³⁵, J.M. Hays⁹³, H.S. Hayward⁹¹, S.J. Haywood¹⁴⁴, F. He^{60a}, Y. He¹⁶⁶, M.P. Heath⁵⁰, V. Hedberg⁹⁷, A.L. Heggelund¹³⁴, N.D. Hehir⁹³, C. Heidegger⁵², K.K. Heidegger⁵², W.D. Heidorn⁷⁹, J. Heilman³⁴, S. Heim⁴⁶, T. Heim¹⁸, B. Heinemann^{46,ai}, J.G. Heinlein¹³⁷, J.J. Heinrich¹³², L. Heinrich³⁶, J. Hejbal¹⁴¹, L. Helary⁴⁶, A. Held¹²⁶, S. Hellesund¹³⁴, C.M. Helling¹⁴⁶, S. Hellman^{45a,45b}, C. Helsens³⁶, R.C.W. Henderson⁹⁰, L. Henkelmann³², A.M. Henriques Correia³⁶, H. Herde²⁶, Y. Hernández Jiménez^{33f}, H. Herr¹⁰⁰, M.G. Herrmann¹¹⁴, T. Herrmann⁴⁸, G. Herten⁵², R. Hertenberger¹¹⁴, L. Hervas³⁶, G.G. Hesketh⁹⁵, N.P. Hessey^{169a}, H. Hibi⁸³, S. Higashino⁸², E. Higón-Rodríguez¹⁷⁵, K. Hildebrand³⁷, J.C. Hill³², K.K. Hill²⁹, K.H. Hiller⁴⁶, S.J. Hillier²¹, M. Hils⁴⁸, I. Hinchliffe¹⁸, F. Hinterkeuser²⁴, M. Hirose¹³³, S. Hirose¹⁷⁰, D. Hirschbuehl¹⁸³, B. Hiti⁹², O. Hladik¹⁴¹, J. Hobbs¹⁵⁶, R. Hobincu^{27e}, N. Hod¹⁸¹, M.C. Hodgkinson¹⁵⁰, A. Hoecker³⁶, D. Hohn⁵², D. Hohov⁶⁵, T. Holm²⁴, T.R. Holmes³⁷, M. Holzbock¹¹⁵, L.B.A.H. Hommels³², T.M. Hong¹³⁹, J.C. Honig⁵², A. Hönle¹¹⁵, B.H. Hooberman¹⁷⁴, W.H. Hopkins⁶, Y. Hori¹¹⁷, P. Horn⁴⁸, L.A. Horyn³⁷, S. Hou¹⁵⁹, A. Hoummada^{35a}, J. Howarth⁵⁷, J. Hoya⁸⁹, M. Hrabovsky¹³¹, J. Hrivnac⁶⁵, A. Hrynevich¹⁰⁹, T. Hryn'ova⁵, P.J. Hsu⁶⁴, S.-C. Hsu¹⁴⁹, Q. Hu³⁹, S. Hu^{60c}, Y.F. Hu^{15a,15d,am}, D.P. Huang⁹⁵, X. Huang^{15c}, Y. Huang^{60a}, Y. Huang^{15a}, Z. Hubacek¹⁴², F. Hubaut¹⁰², M. Huebner²⁴, F. Huegging²⁴, T.B. Huffman¹³⁵, M. Huhtinen³⁶, R. Hulsken⁵⁸, R.F.H. Hunter³⁴, N. Huseynov^{80,ab}, J. Huston¹⁰⁷, J. Huth⁵⁹, R. Hyneman¹⁵⁴, S. Hyrych^{28a}, G. Iacobucci⁵⁴, G. Iakovidis²⁹, I. Ibragimov¹⁵², L. Iconomidou-Fayard⁶⁵, P. Iengo³⁶, R. Ignazzi⁴⁰, R. Iguchi¹⁶⁴, T. Iizawa⁵⁴, Y. Ikegami⁸², M. Ikeno⁸², A. Ilg²⁰, N. Ilic^{119,168,aa}, F. Iltzsche⁴⁸, H. Imam^{35a}, G. Introzzi^{71a,71b}, M. Iodice^{75a}, K. Iordanidou^{169a}, V. Ippolito^{73a,73b}, M.F. Isacson¹⁷³, M. Ishino¹⁶⁴, W. Islam¹³⁰, C. Issever^{19,46}, S. Istin¹⁶¹, J.M. Iturbe Ponce^{63a}, R. Iuppa^{76a,76b}, A. Ivina¹⁸¹, J.M. Izen⁴³, V. Izzo^{70a}, P. Jacka¹⁴¹, P. Jackson¹, R.M. Jacobs⁴⁶, B.P. Jaeger¹⁵³, V. Jain², G. Jäkel¹⁸³, K.B. Jakobi¹⁰⁰, K. Jakobs⁵², T. Jakoubek¹⁸¹, J. Jamieson⁵⁷, K.W. Janas^{84a}, R. Jansky⁵⁴, M. Janus⁵³, P.A. Janus^{84a}, G. Jarlskog⁹⁷, A.E. Jaspan⁹¹, N. Javadov^{80,ab}, T. Javůrek³⁶, M. Javurkova¹⁰³, F. Jeanneau¹⁴⁵, L. Jeanty¹³², J. Jejelava^{160a}, P. Jenni^{52,d}, N. Jeong⁴⁶, S. Jézéquel⁵, J. Jia¹⁵⁶, Z. Jia^{15c}, H. Jiang⁷⁹, Y. Jiang^{60a}, Z. Jiang¹⁵⁴, S. Jiggins⁵², F.A. Jimenez Morales³⁸, J. Jimenez Pena¹¹⁵, S. Jin^{15c}, A. Jinaru^{27b}, O. Jinnouchi¹⁶⁶, H. Jivan^{33f}, P. Johansson¹⁵⁰, K.A. Johns⁷, C.A. Johnson⁶⁶, E. Jones¹⁷⁹, R.W.L. Jones⁹⁰, S.D. Jones¹⁵⁷, T.J. Jones⁹¹, J. Jovicevic³⁶, X. Ju¹⁸, J.J. Jungbunrath¹¹⁵, A. Juste Rozas^{14,w}, A. Kaczmarska⁸⁵, M. Kado^{73a,73b}, H. Kagan¹²⁸, M. Kagan¹⁵⁴, A. Kahn³⁹, C. Kahra¹⁰⁰, T. Kaji¹⁸⁰, E. Kajomovitz¹⁶¹, C.W. Kalderon²⁹, A. Kaluza¹⁰⁰, A. Kamenshchikov¹²³, M. Kaneda¹⁶⁴, N.J. Kang¹⁴⁶, S. Kang⁷⁹, Y. Kano¹¹⁷, J. Kanzaki⁸², L.S. Kaplan¹⁸², D. Kar^{33f}, K. Karava¹³⁵, M.J. Kareem^{169b}, I. Karkanas¹⁶³, S.N. Karpov⁸⁰, Z.M. Karpova⁸⁰, V. Kartvelishvili⁹⁰, A.N. Karyukhin¹²³, E. Kasimi¹⁶³, A. Kastanas^{45a,45b}, C. Kato^{60d}, J. Katzy⁴⁶, K. Kawade¹⁵¹, K. Kawagoe⁸⁸, T. Kawaguchi¹¹⁷, T. Kawamoto¹⁴⁵, G. Kawamura⁵³, E.F. Kay¹⁷⁷, F.I. Kaya¹⁷¹, S. Kazakos¹⁴, V.F. Kazanin^{122b,122a}, J.M. Keaveney^{33a}, R. Keeler¹⁷⁷, J.S. Keller³⁴, E. Kellermann⁹⁷, D. Kelsey¹⁵⁷, J.J. Kempster²¹, J. Kendrick²¹, K.E. Kennedy³⁹, O. Kepka¹⁴¹, S. Kersten¹⁸³, B.P. Kerševan⁹², S. Ketabchi Haghighat¹⁶⁸, F. Khalil-Zada¹³, M. Khandoga¹⁴⁵, A. Khanov¹³⁰, A.G. Kharlamov^{122b,122a}, T. Kharlamova^{122b,122a}, E.E. Khoda¹⁷⁶, T.J. Khoo⁷⁷, G. Khoraiuli¹⁷⁸, E. Khramov⁸⁰, J. Khubua^{160b}, S. Kido⁸³, M. Kiehn³⁶, E. Kim¹⁶⁶, Y.K. Kim³⁷, N. Kimura⁹⁵, A. Kirchhoff⁵³, D. Kirchmeier⁴⁸, J. Kirk¹⁴⁴, A.E. Kiryunin¹¹⁵, T. Kishimoto¹⁶⁴, D.P. Kisliuk¹⁶⁸, V. Kitali⁴⁶, C. Kitsaki¹⁰, O. Kivernyk²⁴, T. Klapdor-Kleingrothaus⁵², M. Klassen^{61a}, C. Klein³⁴, M.H. Klein¹⁰⁶, M. Klein⁹¹, U. Klein⁹¹, K. Kleinknecht¹⁰⁰, P. Klimek³⁶, A. Klimentov²⁹, F. Klimpel³⁶, T. Klingl²⁴, T. Klioutchnikova³⁶, F.F. Klitzner¹¹⁴, P. Kluit¹²⁰, S. Kluth¹¹⁵, E. Kneringer⁷⁷, E.B.F.G. Knoop¹⁰², A. Knue⁵², D. Kobayashi⁸⁸, M. Kobel⁴⁸, M. Kocian¹⁵⁴, T. Kodama¹⁶⁴, P. Kodys¹⁴³, D.M. Koeck¹⁵⁷, P.T. Koenig²⁴, T. Koffas³⁴, N.M. Köhler³⁶, M. Kolb¹⁴⁵, I. Koletsou⁵, T. Komarek¹³¹, T. Kondo⁸², K. Köneke⁵², A.X.Y. Kong¹, A.C. König¹¹⁹, T. Kono¹²⁷, V. Konstantinides⁹⁵, N. Konstantinidis⁹⁵, B. Konya⁹⁷, R. Kopeliansky⁶⁶, S. Koperny^{84a}, K. Korcyl⁸⁵, K. Kordas¹⁶³, G. Koren¹⁶², A. Korn⁹⁵, I. Korolkov¹⁴, E.V. Korolkova¹⁵⁰, N. Korotkova¹¹³, O. Kortner¹¹⁵, S. Kortner¹¹⁵, V.V. Kostyukhin^{150,167}, A. Kotskechagia⁶⁵, A. Kotwal⁴⁹, A. Koulouris¹⁰, A. Kourkoulis-Charalampidi^{71a,71b}, C. Kourkoulis⁹, E. Kourlitis⁶, V. Kouskoura²⁹, R. Kowalewski¹⁷⁷, W. Kozanecki¹⁰¹, A.S. Kozhin¹²³, V.A. Kramarenko¹¹³, G. Kramberger⁹², D. Krasnopevtsev^{60a}, M.W. Krasny¹³⁶, A. Krasznahorkay³⁶, D. Krauss¹¹⁵, J.A. Kremer¹⁰⁰,

J. Kretzschmar⁹¹, K. Kreul¹⁹, P. Krieger¹⁶⁸, F. Krieter¹¹⁴, S. Krishnamurthy¹⁰³, A. Krishnan^{61b}, M. Krivos¹⁴³, K. Krizka¹⁸, K. Kroeninger⁴⁷, H. Kroha¹¹⁵, J. Kroll¹⁴¹, J. Kroll¹³⁷, K.S. Krowpman¹⁰⁷, U. Kruchonak⁸⁰, H. Krüger²⁴, N. Krumnack⁷⁹, M.C. Kruse⁴⁹, J.A. Krzysiak⁸⁵, A. Kubota¹⁶⁶, O. Kuchinskaia¹⁶⁷, S. Kудay^{4b}, D. Kuechler⁴⁶, J.T. Kuechler⁴⁶, S. Kuehn³⁶, T. Kuhl⁴⁶, V. Kukhtin⁸⁰, Y. Kulchitsky^{108,ae}, S. Kuleshov^{147c}, Y.P. Kulinich¹⁷⁴, M. Kuna⁵⁸, A. Kupco¹⁴¹, T. Kupfer⁴⁷, O. Kuprash⁵², H. Kurashige⁸³, L.L. Kurchaninov^{169a}, Y.A. Kurochkin¹⁰⁸, A. Kurova¹¹², M.G. Kurth^{15a,15d}, E.S. Kuwertz³⁶, M. Kuze¹⁶⁶, A.K. Kvam¹⁴⁹, J. Kvita¹³¹, T. Kwan¹⁰⁴, C. Lacasta¹⁷⁵, F. Lacava^{73a,73b}, D.P.J. Lack¹⁰¹, H. Lacker¹⁹, D. Lacour¹³⁶, E. Ladygin⁸⁰, R. Lafaye⁵, B. Laforge¹³⁶, T. Lagouri^{147d}, S. Lai⁵³, I.K. Lakomic^{84a}, J.E. Lambert¹²⁹, S. Lammers⁶⁶, W. Lampl⁷, C. Lampoudis¹⁶³, E. Lançon²⁹, U. Landgraf⁵², M.P.J. Landon⁹³, V.S. Lang⁵², J.C. Lange⁵³, R.J. Langenberg¹⁰³, A.J. Lankford¹⁷², F. Lanni²⁹, K. Lantzsch²⁴, A. Lanza^{71a}, A. Lapertosa^{55b,55a}, J.F. Laporte¹⁴⁵, T. Lari^{69a}, F. Lasagni Manghi^{23b}, M. Lassnig³⁶, V. Latonova¹⁴¹, T.S. Lau^{63a}, A. Laudrain¹⁰⁰, A. Laurier³⁴, M. Lavorgna^{70a,70b}, S.D. Lawlor⁹⁴, M. Lazzaroni^{69a,69b}, B. Le¹⁰¹, E. Le Guirriec¹⁰², A. Lebedev⁷⁹, M. LeBlanc⁷, T. LeCompte⁶, F. Ledroit-Guillon⁵⁸, A.C.A. Lee⁹⁵, C.A. Lee²⁹, G.R. Lee¹⁷, L. Lee⁵⁹, S.C. Lee¹⁵⁹, S. Lee⁷⁹, B. Lefebvre^{169a}, H.P. Lefebvre⁹⁴, M. Lefebvre¹⁷⁷, C. Leggett¹⁸, K. Lehmann¹⁵³, N. Lehmann²⁰, G. Lehmann Miotto³⁶, W.A. Light⁴⁶, A. Leisos^{163,v}, M.A.L. Leite^{81c}, C.E. Leitgeb¹¹⁴, R. Leitner¹⁴³, K.J.C. Leney⁴², T. Lenz²⁴, S. Leone^{72a}, C. Leonidopoulos⁵⁰, A. Leopold¹³⁶, C. Leroy¹¹⁰, R. Les¹⁰⁷, C.G. Lester³², M. Levchenko¹³⁸, J. Levêque⁵, D. Levin¹⁰⁶, L.J. Levinson¹⁸¹, D.J. Lewis²¹, B. Li^{15b}, B. Li¹⁰⁶, C-Q. Li^{60c,60d}, F. Li^{60c}, H. Li^{60a}, H. Li^{60b}, J. Li^{60c}, K. Li¹⁴⁹, L. Li^{60c}, M. Li^{15a,15d}, Q.Y. Li^{60a}, S. Li^{60d,60c,b}, X. Li⁴⁶, Y. Li⁴⁶, Z. Li^{60b}, Z. Li¹³⁵, Z. Li¹⁰⁴, Z. Li⁹¹, Z. Liang^{15a}, M. Liberatore⁴⁶, B. Liberti^{74a}, K. Lie^{63c}, S. Lim²⁹, C.Y. Lin³², K. Lin¹⁰⁷, R.A. Linck⁶⁶, R.E. Lindley⁷, J.H. Lindon²¹, A. Linss⁴⁶, A.L. Lioni⁵⁴, E. Lipeles¹³⁷, A. Lipniacka¹⁷, T.M. Liss^{174,qj}, A. Lister¹⁷⁶, J.D. Little⁸, B. Liu⁷⁹, B.X. Liu¹⁵³, H.B. Liu²⁹, J.B. Liu^{60a}, J.K.K. Liu³⁷, K. Liu^{60d,60c}, M. Liu^{60a}, M.Y. Liu^{60a}, P. Liu^{15a}, X. Liu^{60a}, Y. Liu⁴⁶, Y. Liu^{15a,15d}, Y.L. Liu¹⁰⁶, Y.W. Liu^{60a}, M. Livan^{71a,71b}, A. Lleres⁵⁸, J. Llorente Merino¹⁵³, S.L. Lloyd⁹³, C.Y. Lo^{63b}, E.M. Lobodzinska⁴⁶, P. Loch⁷, S. Loffredo^{74a,74b}, T. Lohse¹⁹, K. Lohwasser¹⁵⁰, M. Lokajicek¹⁴¹, J.D. Long¹⁷⁴, R.E. Long⁹⁰, I. Longarini^{73a,73b}, L. Longo³⁶, I. Lopez Paz¹⁰¹, A. Lopez Solis¹⁵⁰, J. Lorenz¹¹⁴, N. Lorenzo Martinez⁵, A.M. Lory¹¹⁴, A. Lösle⁵², X. Lou^{45a,45b}, X. Lou^{15a}, A. Lounis⁶⁵, J. Love⁶, P.A. Love⁹⁰, J.J. Lozano Bahilo¹⁷⁵, M. Lu^{60a}, Y.J. Lu⁶⁴, H.J. Lubatti¹⁴⁹, C. Luci^{73a,73b}, F.L. Lucio Alves^{15c}, A. Lucotte⁵⁸, F. Luehring⁶⁶, I. Luise¹⁵⁶, L. Luminari^{73a}, B. Lund-Jensen¹⁵⁵, N.A. Luongo¹³², M.S. Lutz¹⁶², D. Lynn²⁹, H. Lyons⁹¹, R. Lysak¹⁴¹, E. Lytken⁹⁷, F. Lyu^{15a}, V. Lyubushkin⁸⁰, T. Lyubushkina⁸⁰, H. Ma²⁹, L.L. Ma^{60b}, Y. Ma⁹⁵, D.M. Mac Donell¹⁷⁷, G. Maccarrone⁵¹, C.M. Macdonald¹⁵⁰, J.C. MacDonald¹⁵⁰, J. Machado Miguens¹³⁷, R. Madar³⁸, W.F. Mader⁴⁸, M. Madugoda Ralalage Don¹³⁰, N. Madysa⁴⁸, J. Maeda⁸³, T. Maeno²⁹, M. Maerker⁴⁸, V. Magerl⁵², N. Magini⁷⁹, J. Magro^{67a,67c,r}, D.J. Mahon³⁹, C. Maidantchik^{81b}, A. Maio^{140a,140b,140d}, K. Maj^{84a}, O. Majersky^{28a}, S. Majewski¹³², Y. Makida⁸², N. Makovec⁶⁵, B. Malaescu¹³⁶, Pa. Malecki⁸⁵, V.P. Maleev¹³⁸, F. Malek⁵⁸, D. Malito^{41b,41a}, U. Mallik⁷⁸, C. Malone³², S. Maltezos¹⁰, S. Malyukov⁸⁰, J. Mamuzic¹⁷⁵, G. Mancini⁵¹, J.P. Mandalia⁹³, I. Mandić⁹², L. Manhaes de Andrade Filho^{81a}, I.M. Maniatis¹⁶³, J. Manjarres Ramos⁴⁸, K.H. Mankinen⁹⁷, A. Mann¹¹⁴, A. Manousos⁷⁷, B. Mansoulie¹⁴⁵, I. Manthos¹⁶³, S. Manzoni¹²⁰, A. Marantis^{163,v}, G. Marceca³⁰, L. Marchese¹³⁵, G. Marchiori¹³⁶, M. Marcisovsky¹⁴¹, L. Marcoccia^{74a,74b}, C. Marcon⁹⁷, M. Marjanovic¹²⁹, Z. Marshall¹⁸, M.U.F. Martensson¹⁷³, S. Marti-Garcia¹⁷⁵, C.B. Martin¹²⁸, T.A. Martin¹⁷⁹, V.J. Martin⁵⁰, B. Martin dit Latour¹⁷, L. Martinelli^{75a,75b}, M. Martinez^{14,w}, P. Martinez Agullo¹⁷⁵, V.I. Martinez Outschoorn¹⁰³, S. Martin-Haugh¹⁴⁴, V.S. Martoiu^{27b}, A.C. Martyniuk⁹⁵, A. Marzin³⁶, S.R. Maschek¹¹⁵, L. Masetti¹⁰⁰, T. Mashimo¹⁶⁴, R. Mashinistov¹¹¹, J. Masik¹⁰¹, A.L. Maslennikov^{122b,122a}, L. Massa^{23b}, P. Massarotti^{70a,70b}, P. Mastrandrea^{72a,72b}, A. Mastroberardino^{41b,41a}, T. Masubuchi¹⁶⁴, D. Matakias²⁹, A. Matic¹¹⁴, N. Matsuzawa¹⁶⁴, P. Mättig²⁴, J. Maurer^{27b}, B. Maček⁹², D.A. Maximov^{122b,122a}, R. Mazini¹⁵⁹, I. Maznas¹⁶³, S.M. Mazza¹⁴⁶, J.P. Mc Gowan¹⁰⁴, S.P. Mc Kee¹⁰⁶, T.G. McCarthy¹¹⁵, W.P. McCormack¹⁸, E.F. McDonald¹⁰⁵, A.E. McDougall¹²⁰, J.A. Mcfayden¹⁸, G. Mchedlidze^{160b}, M.A. McKay⁴², K.D. McLean¹⁷⁷, S.J. McMahon¹⁴⁴, P.C. McNamara¹⁰⁵, C.J. McNicol¹⁷⁹, R.A. McPherson^{177,aa}, J.E. Mdhuli^{33f}, Z.A. Meadows¹⁰³, S. Meehan³⁶, T. Megy³⁸, S. Mehlhase¹¹⁴, A. Mehta⁹¹, B. Meirose⁴³, D. Melini¹⁶¹, B.R. Mellado Garcia^{33f}, J.D. Mellenthin⁵³, M. Melo^{28a}, F. Meloni⁴⁶, A. Melzer²⁴, E.D. Mendes Gouveia^{140a,140e}, A.M. Mendes Jacques Da Costa²¹, H.Y. Meng¹⁶⁸, L. Meng³⁶, X.T. Meng¹⁰⁶, S. Menke¹¹⁵, E. Meoni^{41b,41a}, S. Mergelmeyer¹⁹, S.A.M. Merkt¹³⁹, C. Merlassino¹³⁵, P. Mermod^{54,*}, L. Merola^{70a,70b}, C. Meroni^{69a}, G. Merz¹⁰⁶, O. Meshkov^{113,111},

J.K.R. Meshreki¹⁵², J. Metcalfe⁶, A.S. Mete⁶, C. Meyer⁶⁶, J.-P. Meyer¹⁴⁵, M. Michetti¹⁹, R.P. Middleton¹⁴⁴, L. Mijović⁵⁰, G. Mikenberg¹⁸¹, M. Mikestikova¹⁴¹, M. Mikuž⁹², H. Mildner¹⁵⁰, A. Milic¹⁶⁸, C.D. Milke⁴², D.W. Miller³⁷, L.S. Miller³⁴, A. Milov¹⁸¹, D.A. Milstead^{45a,45b}, A.A. Minaenko¹²³, I.A. Minashvili^{160b}, L. Mince⁵⁷, A.I. Mincer¹²⁶, B. Mindur^{84a}, M. Mineev⁸⁰, Y. Minegishi¹⁶⁴, Y. Mino⁸⁶, L.M. Mir¹⁴, M. Mironova¹³⁵, T. Mitani¹⁸⁰, J. Mitrevski¹¹⁴, V.A. Mitsou¹⁷⁵, M. Mittal^{60c}, O. Miu¹⁶⁸, A. Miucci²⁰, P.S. Miyagawa⁹³, A. Mizukami⁸², J.U. Mjörnmark⁹⁷, T. Mkrtchyan^{61a}, M. Mlynarikova¹²¹, T. Moa^{45a,45b}, S. Mobius⁵³, K. Mochizuki¹¹⁰, P. Moder⁴⁶, P. Mogg¹¹⁴, S. Mohapatra³⁹, R. Moles-Valls²⁴, K. Mönig⁴⁶, E. Monnier¹⁰², A. Montalbano¹⁵³, J. Montejo Berlingen³⁶, M. Montella⁹⁵, F. Monticelli⁸⁹, S. Monzani^{69a}, N. Morange⁶⁵, A.L. Moreira De Carvalho^{140a}, D. Moreno^{22a}, M. Moreno Llácer¹⁷⁵, C. Moreno Martinez¹⁴, P. Morettini^{55b}, M. Morgenstern¹⁶¹, S. Morgenstern⁴⁸, D. Mori¹⁵³, M. Morii⁵⁹, M. Morinaga¹⁸⁰, V. Morisbak¹³⁴, A.K. Morley³⁶, G. Mornacchi³⁶, A.P. Morris⁹⁵, L. Morvaj³⁶, P. Moschovakos³⁶, B. Moser¹²⁰, M. Mosidze^{160b}, T. Moskalets¹⁴⁵, P. Moskvitina¹¹⁹, J. Moss^{31,n}, E.J.W. Moyse¹⁰³, S. Muanza¹⁰², J. Mueller¹³⁹, R.S.P. Mueller¹¹⁴, D. Muenstermann⁹⁰, G.A. Mullier⁹⁷, D.P. Mungo^{69a,69b}, J.L. Munoz Martinez¹⁴, F.J. Munoz Sanchez¹⁰¹, P. Murin^{28b}, W.J. Murray^{179,144}, A. Murrone^{69a,69b}, J.M. Muse¹²⁹, M. Muškinja¹⁸, C. Mwewa^{33a}, A.G. Myagkov^{123,af}, A.A. Myers¹³⁹, G. Myers⁶⁶, J. Myers¹³², M. Myska¹⁴², B.P. Nachman¹⁸, O. Nackenhorst⁴⁷, A. Nag Nag⁴⁸, K. Nagai¹³⁵, K. Nagano⁸², Y. Nagasaka⁶², J.L. Nagle²⁹, E. Nagy¹⁰², A.M. Nairz³⁶, Y. Nakahama¹¹⁷, K. Nakamura⁸², T. Nakamura¹⁶⁴, H. Nanjo¹³³, F. Napolitano^{61a}, R.F. Naranjo Garcia⁴⁶, R. Narayan⁴², I. Naryshkin¹³⁸, M. Naseri³⁴, T. Naumann⁴⁶, G. Navarro^{22a}, P.Y. Nechaeva¹¹¹, F. Nechansky⁴⁶, T.J. Neep²¹, A. Negri^{71a,71b}, M. Negrini^{23b}, C. Nellist¹¹⁹, C. Nelson¹⁰⁴, M.E. Nelson^{45a,45b}, S. Nemecek¹⁴¹, M. Nessi^{36,f}, M.S. Neubauer¹⁷⁴, F. Neuhaus¹⁰⁰, M. Neumann¹⁸³, R. Newhouse¹⁷⁶, P.R. Newman²¹, C.W. Ng¹³⁹, Y.S. Ng¹⁹, Y.W.Y. Ng¹⁷², B. Ngair^{35e}, H.D.N. Nguyen¹⁰², T. Nguyen Manh¹¹⁰, E. Nibigira³⁸, R.B. Nickerson¹³⁵, R. Nicolaïdou¹⁴⁵, D.S. Nielsen⁴⁰, J. Nielsen¹⁴⁶, M. Niemeyer⁵³, N. Nikiforou¹¹, V. Nikolaenko^{123,af}, I. Nikolic-Audit¹³⁶, K. Nikolopoulos²¹, P. Nilsson²⁹, H.R. Nindhito⁵⁴, A. Nisati^{73a}, N. Nishu^{60c}, R. Nisius¹¹⁵, I. Nitsche⁴⁷, T. Nitta¹⁸⁰, T. Nobe¹⁶⁴, D.L. Noel³², Y. Noguchi⁸⁶, I. Nomidis¹³⁶, M.A. Nomura²⁹, M. Nordberg³⁶, J. Novak⁹², T. Novak⁹², O. Novgorodova⁴⁸, R. Novotny¹¹⁸, L. Nozka¹³¹, K. Ntekas¹⁷², E. Nurse⁹⁵, F.G. Oakham^{34,ak}, J. Ocariz¹³⁶, A. Ochi⁸³, I. Ochoa^{140a}, J.P. Ochoa-Ricoux^{147a}, K. O'Connor²⁶, S. Oda⁸⁸, S. Odaka⁸², S. Oerdek⁵³, A. Ogrodnik^{84a}, A. Oh¹⁰¹, C.C. Ohm¹⁵⁵, H. Oide¹⁶⁶, R. Oishi¹⁶⁴, M.L. Ojeda¹⁶⁸, H. Okawa¹⁷⁰, Y. Okazaki⁸⁶, M.W. O'Keefe⁹¹, Y. Okumura¹⁶⁴, A. Olariu^{27b}, L.F. Oleiro Seabra^{140a}, S.A. Olivares Pino^{147a}, D. Oliveira Damazio²⁹, J.L. Oliver¹, M.J.R. Olsson¹⁷², A. Olszewski⁸⁵, J. Olszowska⁸⁵, Ö.O. Öncel²⁴, D.C. O'Neil¹⁵³, A.P. O'Neill¹³⁵, A. Onofre^{140a,140e}, P.U.E. Onyisi¹¹, H. Oppen¹³⁴, R.G. Oreamuno Madriz¹²¹, M.J. Oreglia³⁷, G.E. Orellana⁸⁹, D. Orestano^{75a,75b}, N. Orlando¹⁴, R.S. Orr¹⁶⁸, V. O'Shea⁵⁷, R. Ospanov^{60a}, G. Otero y Garzon³⁰, H. Otono⁸⁸, P.S. Ott^{61a}, G.J. Ottino¹⁸, M. Ouchrif^{35d}, J. Ouellette²⁹, F. Ould-Saada¹³⁴, A. Ouraou^{145,*}, Q. Ouyang^{15a}, M. Owen⁵⁷, R.E. Owen¹⁴⁴, V.E. Ozcan^{12c}, N. Ozturk⁸, J. Pacalt¹³¹, H.A. Pacey³², K. Pachal⁴⁹, A. Pacheco Pages¹⁴, C. Padilla Aranda¹⁴, S. Pagan Griso¹⁸, G. Palacino⁶⁶, S. Palazzo⁵⁰, S. Palestini³⁶, M. Palka^{84b}, P. Palni^{84a}, C.E. Pandini⁵⁴, J.G. Panduro Vazquez⁹⁴, P. Pani⁴⁶, G. Panizzo^{67a,67c}, L. Paolozzi⁵⁴, C. Papadatos¹¹⁰, K. Papageorgiou^{9,h}, S. Parajuli⁴², A. Paramonov⁶, C. Paraskevopoulos¹⁰, D. Paredes Hernandez^{63b}, S.R. Paredes Saenz¹³⁵, B. Parida¹⁸¹, T.H. Park¹⁶⁸, A.J. Parker³¹, M.A. Parker³², F. Parodi^{55b,55a}, E.W. Parrish¹²¹, J.A. Parsons³⁹, U. Parzefall⁵², L. Pascual Dominguez¹³⁶, V.R. Pascuzzi¹⁸, J.M.P. Pasner¹⁴⁶, F. Pasquali¹²⁰, E. Pasqualucci^{73a}, S. Passaggio^{55b}, F. Pastore⁹⁴, P. Pasuwan^{45a,45b}, S. Pataria¹⁰⁰, J.R. Pater¹⁰¹, A. Pathak^{182,j}, J. Patton⁹¹, T. Pauly³⁶, J. Pearkes¹⁵⁴, M. Pedersen¹³⁴, L. Pedraza Diaz¹¹⁹, R. Pedro^{140a}, T. Peiffer⁵³, S.V. Peleganchuk^{122b,122a}, O. Penc¹⁴¹, C. Peng^{63b}, H. Peng^{60a}, B.S. Peralva^{81a}, M.M. Perego⁶⁵, A.P. Pereira Peixoto^{140a}, L. Pereira Sanchez^{45a,45b}, D.V. Perepelitsa²⁹, E. Perez Codina^{169a}, L. Perini^{69a,69b}, H. Pernegger³⁶, S. Perrella³⁶, A. Perrevoort¹²⁰, K. Peters⁴⁶, R.F.Y. Peters¹⁰¹, B.A. Petersen³⁶, T.C. Petersen⁴⁰, E. Petit¹⁰², V. Petousis¹⁴², C. Petridou¹⁶³, F. Petrucci^{75a,75b}, M. Pettee¹⁸⁴, N.E. Pettersson¹⁰³, K. Petukhova¹⁴³, A. Peyaud¹⁴⁵, R. Pezoa^{147e}, L. Pezzotti^{71a,71b}, T. Pham¹⁰⁵, P.W. Phillips¹⁴⁴, M.W. Phipps¹⁷⁴, G. Piacquadio¹⁵⁶, E. Pianori¹⁸, A. Picazio¹⁰³, R.H. Pickles¹⁰¹, R. Piegaia³⁰, D. Pietreanu^{27b}, J.E. Pilcher³⁷, A.D. Pilkington¹⁰¹, M. Pinamonti^{67a,67c}, J.L. Pinfold³, C. Pitman Donaldson⁹⁵, M. Pitt¹⁶², L. Pizzimento^{74a,74b}, A. Pizzini¹²⁰, M.-A. Pleier²⁹, V. Plesanovs⁵², V. Pleskot¹⁴³, E. Plotnikova⁸⁰, P. Podberezko^{122b,122a}, R. Poettgen⁹⁷, R. Poggi⁵⁴, L. Poggioli¹³⁶, I. Pogrebnyak¹⁰⁷, D. Pohl²⁴, I. Pokharel⁵³, G. Polesello^{71a}, A. Poley^{153,169a},

A. Policicchio^{73a,73b}, R. Polifka¹⁴³, A. Polini^{23b}, C.S. Pollard⁴⁶, V. Polychronakos²⁹, D. Ponomarenko¹¹², L. Pontecorvo³⁶, S. Popa^{27a}, G.A. Popeneciu^{27d}, L. Portales⁵, D.M. Portillo Quintero⁵⁸, S. Pospisil¹⁴², K. Potamianos⁴⁶, I.N. Potrap⁸⁰, C.J. Potter³², H. Potti¹¹, T. Poulsen⁹⁷, J. Poveda¹⁷⁵, T.D. Powell¹⁵⁰, G. Pownall⁴⁶, M.E. Pozo Astigarraga³⁶, A. Prades Ibanez¹⁷⁵, P. Pralavorio¹⁰², M.M. Prapa⁴⁴, S. Prell⁷⁹, D. Price¹⁰¹, M. Primavera^{68a}, M.L. Proffitt¹⁴⁹, N. Proklova¹¹², K. Prokofiev^{63c}, F. Prokoshin⁸⁰, S. Protopopescu²⁹, J. Proudfoot⁶, M. Przybycien^{84a}, D. Pudzha¹³⁸, A. Puri¹⁷⁴, P. Puzo⁶⁵, D. Pyatiizbyantseva¹¹², J. Qian¹⁰⁶, Y. Qin¹⁰¹, A. Quadt⁵³, M. Queitsch-Maitland³⁶, G. Rabanal Bolanos⁵⁹, M. Racko^{28a}, F. Ragusa^{69a,69b}, G. Rahal⁹⁸, J.A. Raine⁵⁴, S. Rajagopalan²⁹, A. Ramirez Morales⁹³, K. Ran^{15a,15d}, D.F. Rassloff^{61a}, D.M. Rauch⁴⁶, F. Rauscher¹¹⁴, S. Rave¹⁰⁰, B. Ravina⁵⁷, I. Ravinovich¹⁸¹, J.H. Rawling¹⁰¹, M. Raymond³⁶, A.L. Read¹³⁴, N.P. Readioff¹⁵⁰, M. Reale^{68a,68b}, D.M. Rebuszi^{71a,71b}, G. Redlinger²⁹, K. Reeves⁴³, D. Reikher¹⁶², A. Reiss¹⁰⁰, A. Rej¹⁵², C. Rembser³⁶, A. Renardi⁴⁶, M. Renda^{27b}, M.B. Rendel¹¹⁵, A.G. Rennie⁵⁷, S. Resconi^{69a}, E.D. Resseguie¹⁸, S. Rettie⁹⁵, B. Reynolds¹²⁸, E. Reynolds²¹, O.L. Rezanova^{122b,122a}, P. Reznicek¹⁴³, E. Ricci^{76a,76b}, R. Richter¹¹⁵, S. Richter⁴⁶, E. Richter-Was^{84b}, M. Ridel¹³⁶, P. Rieck¹¹⁵, O. Rifki⁴⁶, M. Rijssenbeek¹⁵⁶, A. Rimoldi^{71a,71b}, M. Rimoldi⁴⁶, L. Rinaldi^{23b,23a}, T.T. Rinn¹⁷⁴, G. Ripellino¹⁵⁵, I. Riu¹⁴, P. Rivadeneira⁴⁶, J.C. Rivera Vergara¹⁷⁷, F. Rizatdinova¹³⁰, E. Rizvi⁹³, C. Rizzi³⁶, S.H. Robertson^{104,aa}, M. Robin⁴⁶, D. Robinson³², C.M. Robles Gajardo^{147e}, M. Robles Manzano¹⁰⁰, A. Robson⁵⁷, A. Rocchi^{74a,74b}, C. Roda^{72a,72b}, S. Rodriguez Bosca¹⁷⁵, A. Rodriguez Rodriguez⁵², A.M. Rodríguez Vera^{169b}, S. Roe³⁶, J. Roggel¹⁸³, O. Röhne¹³⁴, R. Röhrig¹¹⁵, R.A. Rojas^{147e}, B. Roland⁵², C.P.A. Roland⁶⁶, J. Roloff²⁹, A. Romaniouk¹¹², M. Romano^{23b}, N. Rompotis⁹¹, M. Ronzani¹²⁶, L. Roos¹³⁶, S. Rosati^{73a}, G. Rosin¹⁰³, B.J. Rosser¹³⁷, E. Rossi⁴⁶, E. Rossi^{75a,75b}, E. Rossi^{70a,70b}, L.P. Rossi^{55b}, L. Rossini⁴⁶, R. Rosten¹⁴, M. Rotaru^{27b}, B. Rottler⁵², D. Rousseau⁶⁵, G. Rovelli^{71a,71b}, A. Roy¹¹, D. Roy^{33f}, A. Rozanov¹⁰², Y. Rozen¹⁶¹, X. Ruan^{33f}, T.A. Ruggeri¹, F. Rühr⁵², A. Ruiz-Martinez¹⁷⁵, A. Rummler³⁶, Z. Rurikova⁵², N.A. Rusakovich⁸⁰, H.L. Russell¹⁰⁴, L. Rustige^{38,47}, J.P. Rutherford⁷, E.M. Rüttinger¹⁵⁰, M. Rybar¹⁴³, G. Rybkin⁶⁵, E.B. Rye¹³⁴, A. Ryzhov¹²³, J.A. Sabater Iglesias⁴⁶, P. Sabatini¹⁷⁵, L. Sabetta^{73a,73b}, S. Sacerdoti⁶⁵, H.F.-W. Sadrozinski¹⁴⁶, R. Sadykov⁸⁰, F. Safai Tehrani^{73a}, B. Safarzadeh Samani¹⁵⁷, M. Safdari¹⁵⁴, P. Saha¹²¹, S. Saha¹⁰⁴, M. Sahinsoy¹¹⁵, A. Sahu¹⁸³, M. Saimpert³⁶, M. Saito¹⁶⁴, T. Saito¹⁶⁴, H. Sakamoto¹⁶⁴, D. Salamani⁵⁴, G. Salamanna^{75a,75b}, A. Salnikov¹⁵⁴, J. Salt¹⁷⁵, A. Salvador Salas¹⁴, D. Salvatore^{41b,41a}, F. Salvatore¹⁵⁷, A. Salvucci^{63a}, A. Salzburger³⁶, J. Samarati³⁶, D. Sammel⁵², D. Sampsonidis¹⁶³, D. Sampsonidou^{60d,60c}, J. Sánchez¹⁷⁵, A. Sanchez Pineda^{67a,36,67c}, H. Sandaker¹³⁴, C.O. Sander⁴⁶, I.G. Sanderswood⁹⁰, M. Sandhoff¹⁸³, C. Sandoval^{22b}, D.P.C. Sankey¹⁴⁴, M. Sannino^{55b,55a}, Y. Sano¹¹⁷, A. Sansoni⁵¹, C. Santoni³⁸, H. Santos^{140a,140b}, S.N. Santpur¹⁸, A. Santra¹⁷⁵, K.A. Saoucha¹⁵⁰, A. Sapronov⁸⁰, J.G. Saraiva^{140a,140d}, O. Sasaki⁸², K. Sato¹⁷⁰, F. Sauerburger⁵², E. Sauvan⁵, P. Savard^{168,ak}, R. Sawada¹⁶⁴, C. Sawyer¹⁴⁴, L. Sawyer⁹⁶, I. Sayago Galvan¹⁷⁵, C. Sbarra^{23b}, A. Sbrizzi^{67a,67c}, T. Scanlon⁹⁵, J. Schaarschmidt¹⁴⁹, P. Schacht¹¹⁵, D. Schaefer³⁷, L. Schaefer¹³⁷, U. Schäfer¹⁰⁰, A.C. Schaffer⁶⁵, D. Schaile¹¹⁴, R.D. Schamberger¹⁵⁶, E. Schanet¹¹⁴, C. Scharf¹⁹, N. Scharmberg¹⁰¹, V.A. Schegelsky¹³⁸, D. Scheirich¹⁴³, F. Schenck¹⁹, M. Schernau¹⁷², C. Schiavi^{55b,55a}, L.K. Schildgen²⁴, Z.M. Schillaci²⁶, E.J. Schioppa^{68a,68b}, M. Schioppa^{41b,41a}, K.E. Schleicher⁵², S. Schlenker³⁶, K.R. Schmidt-Sommerfeld¹¹⁵, K. Schmieden¹⁰⁰, C. Schmitt¹⁰⁰, S. Schmitt⁴⁶, L. Schoeffel¹⁴⁵, A. Schoening^{61b}, P.G. Scholer⁵², E. Schopf¹³⁵, M. Schott¹⁰⁰, J.F.P. Schouwenberg¹¹⁹, J. Schovancova³⁶, S. Schramm⁵⁴, F. Schroeder¹⁸³, A. Schulte¹⁰⁰, H.-C. Schultz-Coulon^{61a}, M. Schumacher⁵², B.A. Schumm¹⁴⁶, Ph. Schune¹⁴⁵, A. Schwartzman¹⁵⁴, T.A. Schwarz¹⁰⁶, Ph. Schwemling¹⁴⁵, R. Schwienhorst¹⁰⁷, A. Sciandra¹⁴⁶, G. Sciolla²⁶, F. Scuri^{72a}, F. Scutti¹⁰⁵, L.M. Scyboz¹¹⁵, C.D. Sebastiani⁹¹, K. Sedlaczek⁴⁷, P. Seema¹⁹, S.C. Seidel¹¹⁸, A. Seiden¹⁴⁶, B.D. Seidlitz²⁹, T. Seiss³⁷, C. Seitz⁴⁶, J.M. Seixas^{81b}, G. Sekhniaidze^{70a}, S.J. Sekula⁴², N. Semprini-Cesari^{23b,23a}, S. Sen⁴⁹, C. Serfon²⁹, L. Serin⁶⁵, L. Serkin^{67a,67b}, M. Sessa^{60a}, H. Severini¹²⁹, S. Sevova¹⁵⁴, F. Sforza^{55b,55a}, A. Sfyrla⁵⁴, E. Shabalina⁵³, J.D. Shahinian¹³⁷, N.W. Shaikh^{45a,45b}, D. Shaked Renous¹⁸¹, L.Y. Shan^{15a}, M. Shapiro¹⁸, A. Sharma³⁶, A.S. Sharma¹, P.B. Shatalov¹²⁴, K. Shaw¹⁵⁷, S.M. Shaw¹⁰¹, M. Shehade¹⁸¹, Y. Shen¹²⁹, A.D. Sherman²⁵, P. Sherwood⁹⁵, L. Shi⁹⁵, C.O. Shimmin¹⁸⁴, Y. Shimogama¹⁸⁰, M. Shimojima¹¹⁶, J.D. Shinner⁹⁴, I.P.J. Shipsey¹³⁵, S. Shirabe¹⁶⁶, M. Shiyakova^{80,y}, J. Shlomi¹⁸¹, A. Shmeleva¹¹¹, M.J. Shochet³⁷, J. Shojaii¹⁰⁵, D.R. Shope¹⁵⁵, S. Shrestha¹²⁸, E.M. Shrif^{33f}, M.J. Shroff¹⁷⁷, E. Shulga¹⁸¹, P. Sicho¹⁴¹, A.M. Sickles¹⁷⁴, E. Sideras Haddad^{33f}, O. Sidiropoulou³⁶, A. Sidoti^{23b}, F. Siegert⁴⁸, Dj. Sijacki¹⁶, M.Jr. Silva¹⁸²,

M.V. Silva Oliveira³⁶, S.B. Silverstein^{45a}, S. Simion⁶⁵, R. Simoniello¹⁰⁰, C.J. Simpson-allso²¹, S. Simsek^{12b}, P. Sinervo¹⁶⁸, V. Sinetckii¹¹³, S. Singh¹⁵³, S. Sinha^{33f}, M. Sioli^{23b,23a}, I. Siral¹³², S.Yu. Sivoklokov¹¹³, J. Sjölin^{45a,45b}, A. Skaf⁵³, E. Skorda⁹⁷, P. Skubic¹²⁹, M. Slawinska⁸⁵, K. Sliwa¹⁷¹, V. Smakhtin¹⁸¹, B.H. Smart¹⁴⁴, J. Smiesko^{28b}, N. Smirnov¹¹², S.Yu. Smirnov¹¹², Y. Smirnov¹¹², L.N. Smirnova^{113,s}, O. Smirnova⁹⁷, E.A. Smith³⁷, H.A. Smith¹³⁵, M. Smizanska⁹⁰, K. Smolek¹⁴², A. Smykiewicz⁸⁵, A.A. Snesarev¹¹¹, H.L. Snoek¹²⁰, I.M. Snyder¹³², S. Snyder²⁹, R. Sobie^{177,aa}, A. Soffer¹⁶², A. Sogaard⁵⁰, F. Sohns⁵³, C.A. Solans Sanchez³⁶, E.Yu. Soldatov¹¹², U. Soldevila¹⁷⁵, A.A. Solodkov¹²³, A. Soloshenko⁸⁰, O.V. Solovyanov¹²³, V. Solovyev¹³⁸, P. Sommer¹⁵⁰, H. Son¹⁷¹, A. Sonay¹⁴, W. Song¹⁴⁴, W.Y. Song^{169b}, A. Sopczak¹⁴², A.L. Sopio⁹⁵, F. Sopkova^{28b}, S. Sottocornola^{71a,71b}, R. Soualah^{67a,67c}, A.M. Soukharev^{122b,122a}, D. South⁴⁶, S. Spagnolo^{68a,68b}, M. Spalla¹¹⁵, M. Spangenberg¹⁷⁹, F. Spanò⁹⁴, D. Sperlich⁵², T.M. Spieker^{61a}, G. Spigo³⁶, M. Spina¹⁵⁷, D.P. Spiteri⁵⁷, M. Spousta¹⁴³, A. Stabile^{69a,69b}, B.L. Stamas¹²¹, R. Stamen^{61a}, M. Stamenkovic¹²⁰, A. Stampeki²¹, E. Stanecka⁸⁵, B. Stanislaus¹³⁵, M.M. Stanitzki⁴⁶, M. Stankaityte¹³⁵, B. Stapf¹²⁰, E.A. Starchenko¹²³, G.H. Stark¹⁴⁶, J. Stark⁵⁸, P. Staroba¹⁴¹, P. Starovoitov^{61a}, S. Stärz¹⁰⁴, R. Staszewski⁸⁵, G. Stavropoulos⁴⁴, M. Stegler⁴⁶, P. Steinberg²⁹, A.L. Steinhebel¹³², B. Stelzer^{153,169a}, H.J. Stelzer¹³⁹, O. Stelzer-Chilton^{169a}, H. Stenzel⁵⁶, T.J. Stevenson¹⁵⁷, G.A. Stewart³⁶, M.C. Stockton³⁶, G. Stoicea^{27b}, M. Stolarski^{140a}, S. Stonjek¹¹⁵, A. Straessner⁴⁸, J. Strandberg¹⁵⁵, S. Strandberg^{45a,45b}, M. Strauss¹²⁹, T. Strebler¹⁰², P. Strizenec^{28b}, R. Ströhmer¹⁷⁸, D.M. Strom¹³², R. Stroynowski⁴², A. Strubig^{45a,45b}, S.A. Stucci²⁹, B. Stugu¹⁷, J. Stupak¹²⁹, N.A. Styles⁴⁶, D. Su¹⁵⁴, W. Su^{60d,149,60c}, X. Su^{60a}, N.B. Suarez¹³⁹, V.V. Sulin¹¹¹, M.J. Sullivan⁹¹, D.M.S. Sultan⁵⁴, S. Sultansoy^{4c}, T. Sumida⁸⁶, S. Sun¹⁰⁶, X. Sun¹⁰¹, C.J.E. Suster¹⁵⁸, M.R. Sutton¹⁵⁷, S. Suzuki⁸², M. Svatos¹⁴¹, M. Swiatlowski^{169a}, S.P. Swift², T. Swirski¹⁷⁸, A. Sydorenko¹⁰⁰, I. Sykora^{28a}, M. Sykora¹⁴³, T. Sykora¹⁴³, D. Ta¹⁰⁰, K. Tackmann^{46,x}, J. Taenzer¹⁶², A. Taffard¹⁷², R. Tafirout^{169a}, E. Tagiev¹²³, R.H.M. Taibah¹³⁶, R. Takashima⁸⁷, K. Takeda⁸³, T. Takeshita¹⁵¹, E.P. Takeva⁵⁰, Y. Takubo⁸², M. Talby¹⁰², A.A. Talyshv^{122b,122a}, K.C. Tam^{63b}, N.M. Tamir¹⁶², J. Tanaka¹⁶⁴, R. Tanaka⁶⁵, S. Tapia Araya¹⁷⁴, S. Tapprogge¹⁰⁰, A. Tarek Abouelfadl Mohamed¹⁰⁷, S. Tarem¹⁶¹, K. Tariq^{60b}, G. Tarna^{27b,e}, G.F. Tartarelli^{69a}, P. Tas¹⁴³, M. Tasevsky¹⁴¹, E. Tassi^{41b,41a}, G. Tateno¹⁶⁴, A. Tavares Delgado^{140a}, Y. Tayalati^{35e}, A.J. Taylor⁵⁰, G.N. Taylor¹⁰⁵, W. Taylor^{169b}, H. Teagle⁹¹, A.S. Tee⁹⁰, R. Teixeira De Lima¹⁵⁴, P. Teixeira-Dias⁹⁴, H. Ten Kate³⁶, J.J. Teoh¹²⁰, K. Terashi¹⁶⁴, J. Terron⁹⁹, S. Terzo¹⁴, M. Testa⁵¹, R.J. Teuscher^{168,aa}, N. Themistokleous⁵⁰, T. Theveneaux-Pelzer¹⁹, D.W. Thomas⁹⁴, J.P. Thomas²¹, E.A. Thompson⁴⁶, P.D. Thompson²¹, E. Thomson¹³⁷, E.J. Thorpe⁹³, V.O. Tikhomirov^{111,ag}, Yu.A. Tikhonov^{122b,122a}, S. Timoshenko¹¹², P. Tipton¹⁸⁴, S. Tisserant¹⁰², K. Todome^{23b,23a}, S. Todorova-Nova¹⁴³, S. Todt⁴⁸, J. Tojo⁸⁸, S. Tokár^{28a}, K. Tokushuku⁸², E. Tolley¹²⁸, R. Tombs³², K.G. Tomiwa^{33f}, M. Tomoto^{82,117}, L. Tompkins¹⁵⁴, P. Tornambe¹⁰³, E. Torrence¹³², H. Torres⁴⁸, E. Torró Pastor¹⁷⁵, M. Toscani³⁰, C. Toscirì¹³⁵, J. Toth^{102,z}, D.R. Tovey¹⁵⁰, A. Traet¹⁷, C.J. Treado¹²⁶, T. Trefzger¹⁷⁸, F. Tresoldi¹⁵⁷, A. Tricoli²⁹, I.M. Trigger^{169a}, S. Trincaz-Duvold¹³⁶, D.A. Trischuk¹⁷⁶, W. Trischuk¹⁶⁸, B. Trocmé⁵⁸, A. Trofymov⁶⁵, C. Troncon^{69a}, F. Trovato¹⁵⁷, L. Truong^{33c}, M. Trzebinski⁸⁵, A. Trzupek⁸⁵, F. Tsai⁴⁶, P.V. Tsiarehsha^{108,ae}, A. Tsirigotis^{163,v}, V. Tsiskaridze¹⁵⁶, E.G. Tskhadadze^{160a}, M. Tsopoulou¹⁶³, I.I. Tsukerman¹²⁴, V. Tsulaia¹⁸, S. Tsuno⁸², D. Tsybychev¹⁵⁶, Y. Tu^{63b}, A. Tudorache^{27b}, V. Tudorache^{27b}, A.N. Tuna³⁶, S. Turchikhin⁸⁰, D. Turgeman¹⁸¹, I. Turk Cakir^{4b,t}, R.J. Turner²¹, R. Turra^{69a}, P.M. Tuts³⁹, S. Tzamarias¹⁶³, E. Tzovara¹⁰⁰, K. Uchida¹⁶⁴, F. Ukegawa¹⁷⁰, G. Unal³⁶, M. Unal¹¹, A. Undrus²⁹, G. Unel¹⁷², F.C. Ungaro¹⁰⁵, Y. Unno⁸², K. Uno¹⁶⁴, J. Urban^{28b}, P. Urquijo¹⁰⁵, G. Usai⁸, Z. Uysal^{12d}, V. Vacek¹⁴², B. Vachon¹⁰⁴, K.O.H. Vadla¹³⁴, T. Vafeiadis³⁶, A. Vaidya⁹⁵, C. Valderanis¹¹⁴, E. Valdes Santurio^{45a,45b}, M. Valente^{169a}, S. Valentini^{23b,23a}, A. Valero¹⁷⁵, L. Valéry⁴⁶, R.A. Vallance²¹, A. Vallier³⁶, J.A. Valls Ferrer¹⁷⁵, T.R. Van Daalen¹⁴, P. Van Gemmeren⁶, S. Van Stroud⁹⁵, I. Van Vulpen¹²⁰, M. Vanadia^{74a,74b}, W. Vandelli³⁶, M. Vandenbroucke¹⁴⁵, E.R. Vandewall¹³⁰, D. Vannicola^{73a,73b}, R. Vari^{73a}, E.W. Varnes⁷, C. Varni^{55b,55a}, T. Varol¹⁵⁹, D. Varouchas⁶⁵, K.E. Varvell¹⁵⁸, M.E. Vasile^{27b}, G.A. Vasquez¹⁷⁷, F. Vazeille³⁸, D. Vazquez Furelos¹⁴, T. Vazquez Schroeder³⁶, J. Veatch⁵³, V. Vecchio¹⁰¹, M.J. Veen¹²⁰, L.M. Veloce¹⁶⁸, F. Veloso^{140a,140c}, S. Veneziano^{73a}, A. Ventura^{68a,68b}, A. Verbytskyi¹¹⁵, V. Vercesi^{71a}, M. Verducci^{72a,72b}, C.M. Vergel Infante⁷⁹, C. Vergis²⁴, W. Verkerke¹²⁰, A.T. Vermeulen¹²⁰, J.C. Vermeulen¹²⁰, C. Vernieri¹⁵⁴, P.J. Verschuuren⁹⁴, M.C. Vetterli^{153,ak}, N. Viaux Maira^{147e}, T. Vickey¹⁵⁰, O.E. Vickey Boeriu¹⁵⁰, G.H.A. Viehhauser¹³⁵, L. Vigani^{61b}, M. Villa^{23b,23a}, M. Villaplana Perez¹⁷⁵, E.M. Villhauer⁵⁰,

E. Vilucchi⁵¹, M.G. Vinciter³⁴, G.S. Virdee²¹, A. Vishwakarma⁵⁰, C. Vittori^{23b,23a}, I. Vivarelli¹⁵⁷, M. Vogel¹⁸³, P. Vokac¹⁴², J. Von Ahnen⁴⁶, S.E. von Buddenbrock^{33f}, E. Von Toerne²⁴, V. Vorobel¹⁴³, K. Vorobev¹¹², M. Vos¹⁷⁵, J.H. Vosseveld⁹¹, M. Vozak¹⁰¹, N. Vranjes¹⁶, M. Vranjes Milosavljevic¹⁶, V. Vrba^{142,*}, M. Vreeswijk¹²⁰, N.K. Vu¹⁰², R. Vuillermet³⁶, I. Vukotic³⁷, S. Wada¹⁷⁰, P. Wagner²⁴, W. Wagner¹⁸³, J. Wagner-Kuhr¹¹⁴, S. Wahdan¹⁸³, H. Wahlberg⁸⁹, R. Wakasa¹⁷⁰, V.M. Walbrecht¹¹⁵, J. Walder¹⁴⁴, R. Walker¹¹⁴, S.D. Walker⁹⁴, W. Walkowiak¹⁵², V. Wallangen^{45a,45b}, A.M. Wang⁵⁹, A.Z. Wang¹⁸², C. Wang^{60a}, C. Wang^{60c}, H. Wang¹⁸, H. Wang³, J. Wang^{63a}, P. Wang⁴², Q. Wang¹²⁹, R.-J. Wang¹⁰⁰, R. Wang^{60a}, R. Wang⁶, S.M. Wang¹⁵⁹, W.T. Wang^{60a}, W. Wang^{15c}, W.X. Wang^{60a}, Y. Wang^{60a}, Z. Wang¹⁰⁶, C. Wanotayaroj⁴⁶, A. Warburton¹⁰⁴, C.P. Ward³², R.J. Ward²¹, N. Warrack⁵⁷, A.T. Watson²¹, M.F. Watson²¹, G. Watts¹⁴⁹, B.M. Waugh⁹⁵, A.F. Webb¹¹, C. Weber²⁹, M.S. Weber²⁰, S.A. Weber³⁴, S.M. Weber^{61a}, Y. Wei¹³⁵, A.R. Weidberg¹³⁵, J. Weingarten⁴⁷, M. Weirich¹⁰⁰, C. Weiser⁵², P.S. Wells³⁶, T. Wenaus²⁹, B. Wendland⁴⁷, T. Wengler³⁶, S. Wenig³⁶, N. Vermes²⁴, M. Wessels^{61a}, T.D. Weston²⁰, K. Whalen¹³², A.M. Wharton⁹⁰, A.S. White¹⁰⁶, A. White⁸, M.J. White¹, D. Whiteson¹⁷², B.W. Whitmore⁹⁰, W. Wiedenmann¹⁸², C. Wiel⁴⁸, M. WIELERS¹⁴⁴, N. Wieseotte¹⁰⁰, C. Wigglesworth⁴⁰, L.A.M. Wiik-Fuchs⁵², H.G. Wilkens³⁶, L.J. Wilkins⁹⁴, D.M. Williams³⁹, H.H. Williams¹³⁷, S. Williams³², S. Willocq¹⁰³, P.J. Windischhofer¹³⁵, I. Wingerter-Seez⁵, E. Winkels¹⁵⁷, F. Winklmeier¹³², B.T. Winter⁵², M. Wittgen¹⁵⁴, M. Wobisch⁹⁶, A. Wolf¹⁰⁰, R. Wölker¹³⁵, J. Wollrath⁵², M.W. Wolter⁸⁵, H. Wolters^{140a,140c}, V.W.S. Wong¹⁷⁶, A.F. Wongel⁴⁶, N.L. Woods¹⁴⁶, S.D. Worm⁴⁶, B.K. Wosiek⁸⁵, K.W. Woźniak⁸⁵, K. Wraight⁵⁷, S.L. Wu¹⁸², X. Wu⁵⁴, Y. Wu^{60a}, J. Wuerzinger¹³⁵, T.R. Wyatt¹⁰¹, B.M. Wynne⁵⁰, S. Xella⁴⁰, J. Xiang^{63c}, X. Xiao¹⁰⁶, X. Xie^{60a}, I. Xiotidis¹⁵⁷, D. Xu^{15a}, H. Xu^{60a}, H. Xu^{60a}, L. Xu²⁹, R. Xu¹³⁷, T. Xu¹⁴⁵, W. Xu¹⁰⁶, Y. Xu^{15b}, Z. Xu^{60b}, Z. Xu¹⁵⁴, B. Yabsley¹⁵⁸, S. Yacoob^{33a}, D.P. Yallup⁹⁵, N. Yamaguchi⁸⁸, Y. Yamaguchi¹⁶⁶, A. Yamamoto⁸², M. Yamatani¹⁶⁴, T. Yamazaki¹⁶⁴, Y. Yamazaki⁸³, J. Yan^{60c}, Z. Yan²⁵, H.J. Yang^{60c,60d}, H.T. Yang¹⁸, S. Yang^{60a}, T. Yang^{63c}, X. Yang^{60a}, X. Yang^{60b,58}, Y. Yang¹⁶⁴, Z. Yang^{106,60a}, W.-M. Yao¹⁸, Y.C. Yap⁴⁶, H. Ye^{15c}, J. Ye⁴², S. Ye²⁹, I. Yeletsikh⁸⁰, M.R. Yexley⁹⁰, E. Yigitbasi²⁵, P. Yin³⁹, K. Yorita¹⁸⁰, K. Yoshihara⁷⁹, C.J.S. Young³⁶, C. Young¹⁵⁴, J. Yu⁷⁹, R. Yuan^{60b,i}, X. Yue^{61a}, M. Zaazoua^{35e}, B. Zabinski⁸⁵, G. Zacharis¹⁰, E. Zaffaroni⁵⁴, J. Zahreddine¹³⁶, A.M. Zaitsev^{123,af}, T. Zakareishvili^{160b}, N. Zakharchuk³⁴, S. Zambito³⁶, D. Zanzi³⁶, S.V. Zeiřner⁴⁷, C. Zeitnitz¹⁸³, G. Zemaityte¹³⁵, J.C. Zeng¹⁷⁴, O. Zenin¹²³, T. Ženiř^{28a}, D. Zerwas⁶⁵, M. Zgubič¹³⁵, B. Zhang^{15c}, D.F. Zhang^{15b}, G. Zhang^{15b}, J. Zhang⁶, K. Zhang^{15a}, L. Zhang^{15c}, L. Zhang^{60a}, M. Zhang¹⁷⁴, R. Zhang¹⁸², S. Zhang¹⁰⁶, X. Zhang^{60c}, X. Zhang^{60b}, Y. Zhang^{15a,15d}, Z. Zhang^{63a}, Z. Zhang⁶⁵, P. Zhao⁴⁹, Y. Zhao¹⁴⁶, Z. Zhao^{60a}, A. Zhemchugov⁸⁰, Z. Zheng¹⁰⁶, D. Zhong¹⁷⁴, B. Zhou¹⁰⁶, C. Zhou¹⁸², H. Zhou⁷, M. Zhou¹⁵⁶, N. Zhou^{60c}, Y. Zhou⁷, C.G. Zhu^{60b}, C. Zhu^{15a,15d}, H.L. Zhu^{60a}, H. Zhu^{15a}, J. Zhu¹⁰⁶, Y. Zhu^{60a}, X. Zhuang^{15a}, K. Zhukov¹¹¹, V. Zhulanov^{122b,122a}, D. Zieminska⁶⁶, N.I. Zimine⁸⁰, S. Zimmermann^{52,*}, Z. Zinonos¹¹⁵, M. Ziolkowski¹⁵², L. Živković¹⁶, G. Zobernig¹⁸², A. Zoccoli^{23b,23a}, K. Zoch⁵³, T.G. Zorbas¹⁵⁰, R. Zou³⁷, L. Zwalinski³⁶

¹ Department of Physics, University of Adelaide, Adelaide, Australia

² Physics Department, SUNY Albany, Albany NY, United States of America

³ Department of Physics, University of Alberta, Edmonton AB, Canada

⁴ (a) Department of Physics, Ankara University, Ankara, (b) Istanbul Aydin University, Application and Research Center for Advanced Studies, Istanbul, (c) Division of Physics, TOBB University of Economics and Technology, Ankara; Turkey

⁵ LAPP, Univ. Savoie Mont Blanc, CNRS/IN2P3, Annecy, France

⁶ High Energy Physics Division, Argonne National Laboratory, Argonne IL, United States of America

⁷ Department of Physics, University of Arizona, Tucson AZ, United States of America

⁸ Department of Physics, University of Texas at Arlington, Arlington TX, United States of America

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 TX, United States of America

¹² (a) Bahcesehir University, Faculty of Engineering and Natural Sciences, Istanbul, (b) Istanbul Bilgi University, Faculty of Engineering and Natural Sciences, Istanbul, (c) Department of Physics, Bogazici University, Istanbul, (d) 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

¹⁵ (a) Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, (b) Physics Department, Tsinghua University, Beijing, (c) Department of Physics, Nanjing University, Nanjing,

(d) 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 CA, United States of America

¹⁹ Institut für Physik, Humboldt Universität zu Berlin, Berlin, Germany

²⁰ Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern, Switzerland

²¹ School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom

²² (a) Facultad de Ciencias y Centro de Investigaciones, Universidad Antonio Nariño, Bogotá, (b) Departamento de Física, Universidad Nacional de Colombia, Bogotá; Colombia

²³ (a) Dipartimento di Fisica e Astronomia A. Righi, Università di Bologna, Bologna, (b) INFN Sezione di Bologna; Italy

²⁴ Physikalisches Institut, Universität Bonn, Bonn, Germany

- ²⁵ Department of Physics, Boston University, Boston MA, United States of America
- ²⁶ Department of Physics, Brandeis University, Waltham MA, United States of America
- ²⁷ ^(a) Transilvania University of Brasov, Brasov, ^(b) Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest, ^(c) Department of Physics, Alexandru Ioan Cuza University of Iasi, Iasi, ^(d) National Institute for Research and Development of Isotopic and Molecular Technologies, Physics Department, Cluj-Napoca, ^(e) University Politehnica Bucharest, Bucharest, ^(f) West University in Timisoara, Timisoara; Romania
- ²⁸ ^(a) Faculty of Mathematics, Physics and Informatics, Comenius University, Bratislava, ^(b) Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice; Slovak Republic
- ²⁹ Physics Department, Brookhaven National Laboratory, Upton NY, United States of America
- ³⁰ Departamento de Física, Universidad de Buenos Aires, Buenos Aires, Argentina
- ³¹ California State University, CA, United States of America
- ³² Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom
- ³³ ^(a) Department of Physics, University of Cape Town, Cape Town, ^(b) iThemba Labs, Western Cape, ^(c) Department of Mechanical Engineering Science, University of Johannesburg, Johannesburg, ^(d) National Institute of Physics, University of the Philippines Diliman (Philippines), ^(e) University of South Africa, Department of Physics, Pretoria, ^(f) School of Physics, University of the Witwatersrand, Johannesburg; South Africa
- ³⁴ Department of Physics, Carleton University, Ottawa ON, Canada
- ³⁵ ^(a) Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies - Université Hassan II, Casablanca, ^(b) Faculté des Sciences, Université Ibn-Tofail, Kénitra, ^(c) Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA-Marrakech, ^(d) LPMR, Faculté des Sciences, Université Mohamed Premier, Oujda, ^(e) Faculté des sciences, Université Mohammed V, Rabat, ^(f) Mohammed VI Polytechnic University, Ben Guerir; Morocco
- ³⁶ CERN, Geneva, Switzerland
- ³⁷ Enrico Fermi Institute, University of Chicago, Chicago IL, United States of America
- ³⁸ LPC, Université Clermont Auvergne, CNRS/IN2P3, Clermont-Ferrand, France
- ³⁹ Nevis Laboratory, Columbia University, Irvington NY, United States of America
- ⁴⁰ Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark
- ⁴¹ ^(a) Dipartimento di Fisica, Università della Calabria, Rende, ^(b) INFN Gruppo Collegato di Cosenza, Laboratori Nazionali di Frascati; Italy
- ⁴² Physics Department, Southern Methodist University, Dallas TX, United States of America
- ⁴³ Physics Department, University of Texas at Dallas, Richardson TX, United States of America
- ⁴⁴ National Centre for Scientific Research "Demokritos", Agia Paraskevi, Greece
- ⁴⁵ ^(a) Department of Physics, Stockholm University, ^(b) 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 NC, United States of America
- 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
- ⁵⁵ ^(a) Dipartimento di Fisica, Università di Genova, Genova, ^(b) 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 MA, United States of America
- ⁶⁰ ^(a) Department of Modern Physics and State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei, ^(b) Institute of Frontier and Interdisciplinary Science and Key Laboratory of Particle Physics and Particle Irradiation (MOE), Shandong University, Qingdao, ^(c) School of Physics and Astronomy, Shanghai Jiao Tong University, Key Laboratory for Particle Astrophysics and Cosmology (MOE), SKLPPC, Shanghai, ^(d) Tsung-Dao Lee Institute, Shanghai; China
- ⁶¹ ^(a) Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg, ^(b) Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg; Germany
- ⁶² Faculty of Applied Information Science, Hiroshima Institute of Technology, Hiroshima, Japan
- ⁶³ ^(a) Department of Physics, Chinese University of Hong Kong, Shatin, N.T., Hong Kong, ^(b) Department of Physics, University of Hong Kong, Hong Kong, ^(c) 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 IN, United States of America
- ⁶⁷ ^(a) INFN Gruppo Collegato di Udine, Sezione di Trieste, Udine, ^(b) ICTP, Trieste, ^(c) Dipartimento Politecnico di Ingegneria e Architettura, Università di Udine, Udine; Italy
- ⁶⁸ ^(a) INFN Sezione di Lecce, ^(b) Dipartimento di Matematica e Fisica, Università del Salento, Lecce; Italy
- ⁶⁹ ^(a) INFN Sezione di Milano, ^(b) Dipartimento di Fisica, Università di Milano, Milano; Italy
- ⁷⁰ ^(a) INFN Sezione di Napoli, ^(b) Dipartimento di Fisica, Università di Napoli, Napoli; Italy
- ⁷¹ ^(a) INFN Sezione di Pavia, ^(b) Dipartimento di Fisica, Università di Pavia, Pavia; Italy
- ⁷² ^(a) INFN Sezione di Pisa, ^(b) Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa; Italy
- ⁷³ ^(a) INFN Sezione di Roma, ^(b) Dipartimento di Fisica, Sapienza Università di Roma, Roma; Italy
- ⁷⁴ ^(a) INFN Sezione di Roma Tor Vergata, ^(b) Dipartimento di Fisica, Università di Roma Tor Vergata, Roma; Italy
- ⁷⁵ ^(a) INFN Sezione di Roma Tre, ^(b) Dipartimento di Matematica e Fisica, Università Roma Tre, Roma; Italy
- ⁷⁶ ^(a) INFN-TIFPA, ^(b) Università degli Studi di Trento, Trento; Italy
- ⁷⁷ Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck, Austria
- ⁷⁸ University of Iowa, Iowa City IA, United States of America
- ⁷⁹ Department of Physics and Astronomy, Iowa State University, Ames IA, United States of America
- ⁸⁰ Joint Institute for Nuclear Research, Dubna, Russia
- ⁸¹ ^(a) Departamento de Engenharia Elétrica, Universidade Federal de Juiz de Fora (UFJF), Juiz de Fora, ^(b) Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro, ^(c) 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
- ⁸⁴ ^(a) AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, Krakow, ^(b) 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, Jozef 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 LA, United States of America
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 Teórica 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 MA, United States of America
¹⁰⁴ Department of Physics, McGill University, Montreal QC, Canada
¹⁰⁵ School of Physics, University of Melbourne, Victoria, Australia
¹⁰⁶ Department of Physics, University of Michigan, Ann Arbor MI, United States of America
¹⁰⁷ Department of Physics and Astronomy, Michigan State University, East Lansing MI, United States of America
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 QC, 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 NM, United States of America
¹¹⁹ Institute for Mathematics, Astrophysics and Particle Physics, Radboud University/Nikhef, Nijmegen, Netherlands
¹²⁰ Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands
¹²¹ Department of Physics, Northern Illinois University, DeKalb IL, United States of America
¹²² (a) Budker Institute of Nuclear Physics and NSU, SB RAS, Novosibirsk, (b) 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 (a) New York University Abu Dhabi, Abu Dhabi, (b) United Arab Emirates University, Al Ain, (c) University of Sharjah, Sharjah; United Arab Emirates
¹²⁶ Department of Physics, New York University, New York NY, United States of America
¹²⁷ Ochanomizu University, Otsuka, Bunkyo-ku, Tokyo, Japan
¹²⁸ Ohio State University, Columbus OH, United States of America
¹²⁹ Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman OK, United States of America
¹³⁰ Department of Physics, Oklahoma State University, Stillwater OK, United States of America
¹³¹ Palacký University, Joint Laboratory of Optics, Olomouc, Czech Republic
¹³² Institute for Fundamental Science, University of Oregon, Eugene, OR, United States of America
¹³³ Graduate School of Science, Osaka University, Osaka, Japan
¹³⁴ Department of Physics, University of Oslo, Oslo, Norway
¹³⁵ Department of Physics, Oxford University, Oxford, United Kingdom
¹³⁶ LPNHE, Sorbonne Université, Université de Paris, CNRS/IN2P3, Paris, France
¹³⁷ Department of Physics, University of Pennsylvania, Philadelphia PA, United States of America
¹³⁸ Konstantinov Nuclear Physics Institute of National Research Centre "Kurchatov Institute", PNPI, St. Petersburg, Russia
¹³⁹ Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh PA, United States of America
¹⁴⁰ (a) Laboratório de Instrumentação e Física Experimental de Partículas - LIP, Lisboa, (b) Departamento de Física, Faculdade de Ciências, Universidade de Lisboa, Lisboa, (c) Departamento de Física, Universidade de Coimbra, Coimbra, (d) Centro de Física Nuclear da Universidade de Lisboa, Lisboa, (e) Departamento de Física, Universidade do Minho, Braga, (f) Departamento de Física Teórica y del Cosmos, Universidad de Granada, Granada (Spain), (g) Dep Física and CEFITEC of Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Caparica, (h) Instituto Superior Técnico, Universidade de Lisboa, Lisboa; Portugal
¹⁴¹ Institute of Physics of the Czech Academy of Sciences, Prague, Czech Republic
¹⁴² Czech Technical University in Prague, Prague, Czech Republic
¹⁴³ Charles University, Faculty of Mathematics and Physics, Prague, Czech Republic
¹⁴⁴ Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom
¹⁴⁵ IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France
¹⁴⁶ Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz CA, United States of America
¹⁴⁷ (a) Departamento de Física, Pontificia Universidad Católica de Chile, Santiago, (b) Universidad de la Serena, La Serena, (c) Universidad Andres Bello, Department of Physics, Santiago, (d) Instituto de Alta Investigación, Universidad de Tarapacá, Arica, (e) Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso; Chile
¹⁴⁸ Universidade Federal de São João del Rei (UFSJ), São João del Rei, Brazil
¹⁴⁹ Department of Physics, University of Washington, Seattle WA, United States of America
¹⁵⁰ Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom
¹⁵¹ Department of Physics, Shinshu University, Nagano, Japan
¹⁵² Department Physik, Universität Siegen, Siegen, Germany
¹⁵³ Department of Physics, Simon Fraser University, Burnaby BC, Canada
¹⁵⁴ SLAC National Accelerator Laboratory, Stanford CA, United States of America
¹⁵⁵ Department of Physics, Royal Institute of Technology, Stockholm, Sweden
¹⁵⁶ Departments of Physics and Astronomy, Stony Brook University, Stony Brook NY, United States of America
¹⁵⁷ Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom
¹⁵⁸ School of Physics, University of Sydney, Sydney, Australia
¹⁵⁹ Institute of Physics, Academia Sinica, Taipei, Taiwan
¹⁶⁰ (a) E. Andronikashvili Institute of Physics, Iv. Javakishvili Tbilisi State University, Tbilisi, (b) High Energy Physics Institute, Tbilisi State University, Tbilisi; Georgia
¹⁶¹ Department of Physics, Technion, Israel Institute of Technology, Haifa, Israel
¹⁶² Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel
¹⁶³ Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece
¹⁶⁴ International Center for Elementary Particle Physics and Department of Physics, University of Tokyo, Tokyo, Japan
¹⁶⁵ Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo, Japan
¹⁶⁶ Department of Physics, Tokyo Institute of Technology, Tokyo, Japan
¹⁶⁷ Tomsk State University, Tomsk, Russia
¹⁶⁸ Department of Physics, University of Toronto, Toronto ON, Canada

- ¹⁶⁹ (a) TRIUMF, Vancouver BC, (b) Department of Physics and Astronomy, York University, Toronto ON, Canada
¹⁷⁰ Division of Physics and Tomonaga Center for the History of the Universe, Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba, Japan
¹⁷¹ Department of Physics and Astronomy, Tufts University, Medford MA, United States of America
¹⁷² Department of Physics and Astronomy, University of California Irvine, Irvine CA, United States of America
¹⁷³ Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden
¹⁷⁴ Department of Physics, University of Illinois, Urbana IL, United States of America
¹⁷⁵ Instituto de Física Corpuscular (IFIC), Centro Mixto Universidad de Valencia - CSIC, Valencia, Spain
¹⁷⁶ Department of Physics, University of British Columbia, Vancouver BC, Canada
¹⁷⁷ Department of Physics and Astronomy, University of Victoria, Victoria BC, Canada
¹⁷⁸ Fakultät für Physik und Astronomie, Julius-Maximilians-Universität Würzburg, Würzburg, Germany
¹⁷⁹ Department of Physics, University of Warwick, Coventry, United Kingdom
¹⁸⁰ Waseda University, Tokyo, Japan
¹⁸¹ Department of Particle Physics and Astrophysics, Weizmann Institute of Science, Rehovot, Israel
¹⁸² Department of Physics, University of Wisconsin, Madison WI, United States of America
¹⁸³ Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal, Germany
¹⁸⁴ Department of Physics, Yale University, New Haven CT, United States of America

- ^a Also at Borough of Manhattan Community College, City University of New York, New York NY, United States of America.
^b Also at Center for High Energy Physics, Peking University, China.
^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 Física de la Universitat Autònoma 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 MI, United States of America.
^j Also at Department of Physics and Astronomy, University of Louisville, Louisville, KY, United States of America.
^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, United States of America.
^m Also at Department of Physics, California State University, Fresno, United States of America.
ⁿ Also at Department of Physics, California State University, Sacramento, United States of America.
^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 Institutio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona, Spain.
^x Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany.
^y Also at Institute for Nuclear Research and Nuclear Energy (INRNE) of the Bulgarian Academy of Sciences, Sofia, Bulgaria.
^z Also at Institute for Particle and Nuclear Physics, Wigner Research Centre for Physics, Budapest, Hungary.
^{aa} Also at Institute of Particle Physics (IPP), Canada.
^{ab} Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan.
^{ac} Also at Instituto de Física Teórica, IFT-UAM/CSIC, Madrid, Spain.
^{ad} Also at Istanbul University, Dept. of Physics, Istanbul, Turkey.
^{ae} Also at Joint Institute for Nuclear Research, Dubna, Russia.
^{af} Also at Moscow Institute of Physics and Technology State University, Dolgoprudny, Russia.
^{ag} Also at National Research Nuclear University MEPhI, Moscow, Russia.
^{ah} Also at Physics Department, An-Najah National University, Nablus, Palestine.
^{ai} Also at Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany.
^{aj} Also at The City College of New York, New York NY, United States of America.
^{ak} Also at TRIUMF, Vancouver BC, Canada.
^{al} Also at Università di Napoli Parthenope, Napoli, Italy.
^{am} Also at University of Chinese Academy of Sciences (UCAS), Beijing, China.
^{*} Deceased.