



Measurement of the WW cross section in $\sqrt{s} = 7$ TeV pp collisions with the ATLAS detector and limits on anomalous gauge couplings \star

ATLAS Collaboration \star

ARTICLE INFO

Article history:

Received 28 March 2012
 Received in revised form 26 April 2012
 Accepted 2 May 2012
 Available online 7 May 2012
 Editor: H. Weerts

ABSTRACT

This Letter reports a measurement of the WW production cross section in $\sqrt{s} = 7$ TeV pp collisions using data corresponding to an integrated luminosity of 1.02 fb^{-1} collected with the ATLAS detector. Using leptonic decays of oppositely charged W bosons, the total measured cross section is $\sigma(pp \rightarrow WW) = 54.4 \pm 4.0$ (stat.) ± 3.9 (syst.) ± 2.0 (lumi.) pb, consistent with the Standard Model prediction of $\sigma(pp \rightarrow WW) = 44.4 \pm 2.8$ pb. Limits on anomalous electroweak triple-gauge couplings are extracted from a fit to the transverse-momentum distribution of the leading charged lepton in the event.

© 2012 CERN. Published by Elsevier B.V. All rights reserved.

1. Introduction

Measurements of WW production at the LHC provide important tests of the Standard Model (SM), in particular of the WWZ and $WW\gamma$ triple gauge couplings (TGCs) resulting from the non-Abelian nature of the $SU(2)_L \times U(1)_Y$ symmetry group. Precise measurements of TGCs are sensitive probes of new physics in the electroweak sector and are complementary to direct searches. Furthermore, since WW production is a background to possible new processes such as the production of the SM Higgs boson, a precise measurement of the WW cross section is an important step in the search for new physics.

This Letter describes the measurements of the WW cross section and of TGCs in pp collisions at $\sqrt{s} = 7$ TeV. The dominant SM WW production mechanisms are s -channel and t -channel quark-antiquark annihilation, with a 3% contribution from gluon-gluon fusion. The cross section is measured in the fiducial phase space of the detector using $WW \rightarrow l\nu l\nu$ decays in final states with electrons and muons, and is extrapolated to the total phase space. The fiducial phase space includes geometric and kinematic acceptance. The total production cross section of oppositely charged W bosons is measured according to the equation [1]

$$\sigma(pp \rightarrow WW) = \frac{N_{\text{data}} - N_{\text{bg}}}{A_{WW} C_{WW} \mathcal{L} \mathcal{B}}, \quad (1)$$

where N_{data} and N_{bg} are the number of observed data events and estimated background events, respectively, A_{WW} is the kinematic and geometric acceptance, C_{WW} is the ratio of the number of measured events to the number of events produced in the fiducial phase space, \mathcal{L} is the integrated luminosity of the data sample,

and \mathcal{B} is the branching ratio for both W bosons to decay to $e\nu$ or $\mu\nu$ (including decays through tau leptons with additional neutrinos). The fiducial cross section is defined as $\sigma \times A_{WW} \times \mathcal{B}$ [1].

Previous measurements of WW production using the CMS and ATLAS detectors, both based on the data recorded in 2010 and corresponding to an integrated luminosity of 36 pb^{-1} , have found $\sigma(pp \rightarrow WW) = 41.1 \pm 15.3$ (stat.) ± 5.8 (syst.) ± 4.5 (lumi.) pb [2] and $\sigma(pp \rightarrow WW) = 41_{-16}^{+20}$ (stat.) ± 5 (syst.) ± 1 (lumi.) pb [3], respectively. CMS has additionally used these data to set limits on anomalous gauge-coupling parameters at higher center of mass energies than corresponding measurements at the Tevatron [4] and LEP [5].

2. ATLAS detector

The ATLAS detector [6] consists of an inner tracking system (inner detector, or ID) surrounded by a superconducting solenoid providing a 2 T magnetic field, electromagnetic and hadronic calorimeters, and a muon spectrometer (MS) incorporating three large superconducting toroid magnets arranged with an eight-fold azimuthal coil symmetry around the calorimeters. The ID consists of silicon pixel and microstrip detectors, surrounded by a transition radiation tracker. The electromagnetic calorimeter is a lead/liquid-argon (LAr) detector. Hadron calorimetry is based on two different detector technologies, with scintillator tiles or LAr as active media, and with either steel, copper, or tungsten as the absorber material. The MS comprises three layers of chambers for the trigger and for track measurements.

A three-level trigger system is used to select events. The level-1 trigger is implemented in hardware and uses a subset of detector information to reduce the event rate to a design value of at most 75 kHz. This is followed by two software-based trigger levels, level-2 and the event filter, which together reduce the event rate to about 200 Hz recorded for analysis.

\star © CERN for the benefit of the ATLAS Collaboration.

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

The nominal pp interaction point at the center of the detector is defined as the origin of a right-handed coordinate system. The positive x -axis is defined by the direction from the interaction point to the center of the LHC ring, with the positive y -axis pointing upwards, while the z -axis is along the beam direction. The azimuthal angle ϕ is measured around the beam axis and the polar angle θ is the angle from the z -axis. The pseudorapidity is defined as $\eta = -\ln \tan(\theta/2)$.

3. Data sample and event selection

The data used for this analysis correspond to an integrated luminosity of $1.02 \pm 0.04 \text{ fb}^{-1}$ [7], recorded between April and June of 2011. Events are selected with triggers requiring either a single electron with $p_T > 20 \text{ GeV}$ and $|\eta| < 2.5$ or a single muon with $p_T > 18 \text{ GeV}$ and $|\eta| < 2.4$. Additional data collected with a trigger requiring a single muon with $p_T > 40 \text{ GeV}$, $|\eta| < 1.05$, and looser identification criteria are used to increase efficiency. The combination of triggers results in $\approx 100\%$ (98%) trigger efficiency for events with WW decays to $e\nu\mu\nu$ and $e\nu\nu$ ($\mu\nu\mu\nu$) passing the selection described below.

The WW event selection begins with the identification of electrons and muons, requiring exactly two of these particles with opposite charge. Electrons are reconstructed with a clustering algorithm in the electromagnetic calorimeter and matched to an ID track. To distinguish electrons from hadrons, selection criteria [8] are applied based on the quality of the position and momentum match between the extrapolated track and the calorimeter cluster, the consistency of the longitudinal and lateral shower profiles with an incident electron, and the observed transition radiation in the TRT. Electrons are required to lie within the fiducial regions of the calorimeters ($|\eta| < 1.37$ or $1.52 < |\eta| < 2.47$), have $p_T > 25 \text{ GeV}$ ($p_T > 20 \text{ GeV}$ for the lower p_T electron in the $e\nu\nu$ decay channel), and be isolated in the calorimeter and tracker. Calorimeter isolation requires the summed transverse energies deposited in calorimeter cells, excluding those belonging to the electron cluster, in a cone of radius $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.3$ around the electron direction to be $< 4 \text{ GeV}$. Tracker isolation requires the summed p_T of ID tracks in a cone of radius $\Delta R = 0.2$ centered on and excluding the electron track to be $< 10\%$ of the electron p_T .

The muon reconstruction algorithm begins with a track from the MS to determine the muon's η , and then combines it with an ID track to determine the muon's momentum [9]. Muons are required to have $p_T > 20 \text{ GeV}$ and $|\eta| < 2.4$, and in the $\mu\nu\mu\nu$ channel at least one muon must have $p_T > 25 \text{ GeV}$. Decays of hadrons to muons are suppressed using calorimeter and track isolation. The calorimeter isolation requires the summed transverse energies deposited in calorimeter cells in a cone of radius $\Delta R = 0.2$ around the muon track to be less than 15% of the muon's p_T . The track isolation requirement is the same as for electrons. The tracks associated with muon and electron candidates must have longitudinal and transverse impact parameters consistent with originating from the primary reconstructed vertex. The primary vertex is defined as the vertex with the highest $\sum p_T^2$ of associated ID tracks.

The presence of neutrinos is characterized by an imbalance of transverse momentum in the event. The missing transverse momentum (E_T^{miss}) is the modulus of the event $-\vec{p}_T$ vector, calculated by summing the transverse momentum determined from each calorimeter cell's energy and direction with respect to the primary vertex. Cells with $|\eta| < 4.5$ are used in the calculation and a correction is applied to account for the momentum of measured muons.

Misreconstructed leptons and jets, as well as leptons from tau decays, are suppressed by applying cuts on $E_T^{\text{miss}} \times \sin \Delta\phi$ when

Table 1

The estimated background event yields in the selected WW data sample. The first uncertainty is statistical, the second systematic.

Production process	$e\nu\mu\nu$ selection	$e\nu\nu$ selection	$\mu\nu\mu\nu$ selection
DY	$13.0 \pm 2.1 \pm 1.6$	$12.5 \pm 2.3 \pm 1.4$	$10.9 \pm 2.5 \pm 1.4$
Top	$11.9 \pm 1.8 \pm 2.4$	$3.1 \pm 0.5 \pm 0.6$	$3.8 \pm 0.6 \pm 0.8$
$W + \text{jet}$	$10.0 \pm 1.6 \pm 2.1$	$4.1 \pm 1.3 \pm 0.9$	$4.2 \pm 1.1 \pm 1.3$
Diboson	$5.1 \pm 1.0 \pm 0.7$	$2.1 \pm 0.8 \pm 0.3$	$2.9 \pm 0.4 \pm 0.4$
Total background	$40.0 \pm 3.3 \pm 3.6$	$21.7 \pm 2.8 \pm 1.8$	$21.8 \pm 2.8 \pm 2.1$

$\Delta\phi < \pi/2$. Here, $\Delta\phi$ is the azimuthal angle between the missing transverse momentum and the nearest charged lepton or jet; small $\Delta\phi$ indicates that E_T^{miss} is dominated by a mismeasured lepton or jet, or by the presence of neutrinos in the direction of the lepton or jet, as would occur in a tau decay. The lower cuts on E_T^{miss} , or $E_T^{\text{miss}} \times \sin \Delta\phi$ for $\Delta\phi < \pi/2$, are 25 GeV in the $e\nu\mu\nu$ channel, 40 GeV in the $e\nu\nu$ channel, and 45 GeV in the $\mu\nu\mu\nu$ channel. The thresholds in the $e\nu\nu$ and $\mu\nu\mu\nu$ channels are more stringent than in the $e\nu\mu\nu$ channel to suppress the background from Drell-Yan (DY) production of ee and $\mu\mu$ pairs.

Background from top-quark production is rejected by vetoing events containing a reconstructed jet with $p_T > 25 \text{ GeV}$ and $|\eta| < 4.5$. Jets are reconstructed with the anti- k_t algorithm [10] with a radius parameter of $R = 0.4$. A further 30% reduction of top-quark background is achieved by rejecting events with a jet with $p_T > 20 \text{ GeV}$, $|\eta| < 2.5$, and identified as originating from a b -quark (b -jet). The identification of b -jets combines information from the impact parameters and the reconstructed vertices of tracks within the jet [11]. The additional b -jet rejection reduces WW acceptance by 1.3%.

Resonances with dilepton decays are removed by requiring ee and $\mu\mu$ invariant masses to be greater than 15 GeV and not within 15 GeV of the Z -boson mass. To suppress backgrounds from heavy-flavour hadron decays, events with an $e\mu$ invariant mass below 10 GeV are also removed. The complete event selection yields 202 $e\nu\mu\nu$, 59 $e\nu\nu$, and 64 $\mu\nu\mu\nu$ candidates.

4. Background estimation

The selected data sample contains $26 \pm 3\%$ background to the WW production process (Table 1). In decreasing order of size, the main background processes are: DY production of dileptons, with significant E_T^{miss} arising from misreconstructed jet(s) or charged lepton(s); $t\bar{t}$ and tWb production, where the b -quarks in the $Wb\bar{b}$ final state are not rejected by the jet veto; ($W \rightarrow l\nu$) + jet, where the jet is misidentified as a lepton; $WZ \rightarrow l\nu ll$ production, where one lepton is not reconstructed; ($W \rightarrow l\nu$) + γ , where the photon converts in the inner detector and is misreconstructed as an electron; $ZZ \rightarrow ll\nu\nu$ production; and cosmic-ray muons overlapping a pp collision (which is negligible).

Backgrounds are estimated using a combination of Monte Carlo (MC) samples including a full GEANT [12] simulation of the ATLAS detector [13], and control samples (independent of the measurement sample) from data. The simulation includes the modeling of multiple pp interactions in the same bunch crossing (pile-up), as well as corrections (determined from data) to improve the modeling of reconstructed objects.

The DY background is estimated using the ALPGEN [14] Monte Carlo generator interfaced to PYTHIA [15] for parton showering. To test the modeling of E_T^{miss} , data are compared to simulated Z/γ^* events where the lepton pair forms an invariant mass within 15 GeV of the Z -boson mass. The DY MC accurately models the number of events above the thresholds on E_T^{miss} or $E_T^{\text{miss}} \times \sin \Delta\phi$ used to select WW events, after subtracting the $\approx 20\%$ non-DY

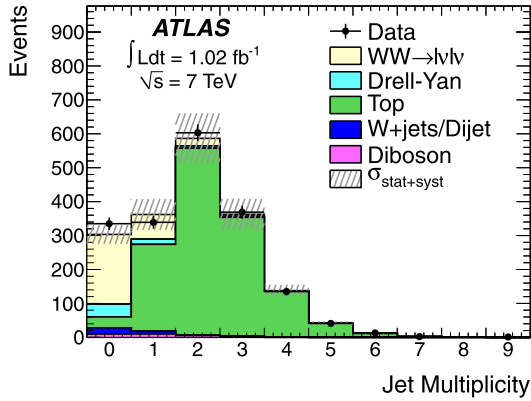


Fig. 1. The multiplicity distribution of jets with $p_T > 25$ GeV for the combined dilepton channels, after all WW selection cuts except the jet veto requirement. The systematic uncertainties shown in the > 0 -jet bins include only those on the integrated luminosity and the theoretical cross sections.

contributions. A 12% relative systematic uncertainty on the DY prediction is taken from the statistical precision of the MC validation in the control sample.

Background from top-quark production arises when the final-state b -quarks have low transverse momentum ($p_T < 20$ GeV), are not identified as b -jets (for $20 < p_T < 25$ GeV), or are in the far forward region ($|\eta| > 4.5$). To model this background, MC@NLO [16] samples of $t\bar{t}$ and ACERMC [17] samples of tWb production are used, respectively, with corrections derived from the data. An overall normalization factor is determined from the ratio of events in data to those predicted by the top-quark MC using the WW selection without any jet rejection. This sample is dominated by top-quark decays, as shown in Fig. 1; a 24% contribution from other processes is subtracted in the normalization. The subtraction of the WW component is based on the SM prediction of WW production, with an uncertainty that covers the difference between the prediction and the cross section measurement reported in this Letter. The relative cross sections of $t\bar{t}$ to tWb are set by the generator calculations of $\sigma = 164.6$ pb and $\sigma = 15.6$ pb, respectively.

A key aspect of the top-quark background prediction is the modeling of the jet veto acceptance. To reduce the associated uncertainties, a data-based correction is derived using a top-quark-dominated sample based on the WW selection but with the requirement of at least one b -jet with $p_T > 25$ GeV [18]. In this sample, the ratio P_1 of events with one jet to the total number of events is sensitive to the modeling of the jet energy spectrum in top-quark events. A multiplicative correction based on the ratio $P_1^{\text{data}}/P_1^{\text{MC}}$ is applied to reduce the uncertainties resulting from the jet veto requirement. The residual uncertainty on the background prediction due to jet energy scale and resolution is small (4%) compared to uncertainties from the b -quark identification efficiency (6%), parton shower modeling (12%), statistical uncertainty on the $P_1^{\text{data}}/P_1^{\text{MC}}$ -based correction (12%), and unmodeled $t\bar{t}$ - tWb interference and higher order QCD corrections (15%). As a cross-check, the normalization of the top-quark background is extracted from a fit to the jet multiplicity distribution; the result is consistent with the primary estimate.

The W + jet process contributes to the selected sample when one or more hadrons in the jet decay to, or are misidentified as, a charged lepton. Jets reconstructed as electrons or muons predominantly arise from misidentification or heavy-flavour quark decays, respectively. This background is estimated with a pass-to-fail ratio f_e (f_μ), defined as the ratio of the number of electron (muon) candidates passing the electron (muon) identification cri-

teria to the number of candidates failing the criteria. These ratios are measured in data samples dominated by hadronic jets collected with a trigger requiring an electromagnetic cluster or a muon candidate. All candidates are required to pass a loose set of selection criteria, including an isolation requirement. The measured f_e and f_μ are then applied as multiplicative factors to events satisfying all WW selection cuts except with one lepton failing the identification criteria but passing the looser criteria.

The above procedure measures f_e and f_μ ratios averaged over misidentified jets and heavy-flavour quark decays in jet-dominated samples. If, for example, the ratio f_e differs for these two contributions, the W + jet prediction could be biased. To address this issue, two sets of loose criteria are applied to electron candidates, one based on the track and the shower profile and expected to enhance the misidentification fraction, and the other based on the isolation and expected to enhance the heavy flavour fraction. The f_e ratio is measured for these criteria separately in events where there is an additional b -jet and events where there is no such jet. From the combination of measurements, the heavy-flavour and misidentification contributions are separated; the resulting W + jet background is consistent with that obtained using the inclusive f_e for the misidentification and heavy-flavour components. A similar separation is not performed for f_μ , since heavy-flavour decays dominate the contribution of background muons from the W + jet process.

The systematic uncertainty on the W + jet prediction is dominated by a 30% variation of the ratios f_e and f_μ with the jet p_T threshold. This variation is sensitive to the relative fraction of quarks and gluons in the samples used to measure f_e and f_μ , and thus encompasses potential differences in f_e and f_μ ratios between these samples and those used to estimate the W + jet background.

Several alternative methods are used to check the W + jet prediction and give consistent results. The first method applies the measured f_e and f_μ ratios to an inclusive W + jets data sample, and then determines the fraction of expected events with no additional jets using W + jets Monte Carlo events with two identified leptons. The second method defines different sets of “loose” lepton criteria and independently measures efficiencies for lepton identification and rates for misidentified or decaying hadrons to pass the standard identification criteria. Background from dijet production is estimated with this method and is found to be small; it is implicitly included in the primary estimate.

Monte Carlo estimates of the $W\gamma$, WZ , and ZZ backgrounds are obtained using a combination of ALPGEN and PYTHIA (for $W\gamma$) and HERWIG [19] with JIMMY [20] (for the others), normalized to the next-to-leading order (NLO) cross sections calculated with MCFM [21]. The $\mathcal{O}(10\%)$ systematic uncertainty on these backgrounds is dominated by the uncertainty on the jet energy scale.

5. WW acceptance modeling

The WW total cross section measurement requires the knowledge of the A_{WW} and C_{WW} factors given in Eq. (1). The acceptance factor A_{WW} is defined as the ratio of generated WW events in the fiducial phase space to those in the total phase space. The correction factor C_{WW} is defined as the ratio of measured events to generator-level events in the fiducial phase space. The value of this ratio is determined primarily by lepton trigger and identification efficiencies, with a small contribution from differences in generated and measured phase space due to detector resolutions. The fiducial phase space is defined at generator level as:

- Muon $p_T > 20$ GeV and $|\eta| < 2.4$ ($p_T > 25$ GeV for at least one muon in the $\mu\nu\mu\nu$ channel);

Table 2
The total WW acceptance $A_{WW} \times C_{WW}$ in the individual decay channels, and the expected number of SM WW events (N_{WW}) for an integrated luminosity of 1.02 fb^{-1} .

	$e\nu\mu\nu$ selection		$e\nu e\nu$ selection		$\mu\nu\mu\nu$ selection	
	$WW \rightarrow e\nu\mu\nu$	$WW \rightarrow l\nu\tau\nu$	$WW \rightarrow e\nu e\nu$	$WW \rightarrow e\nu\tau\nu$	$WW \rightarrow \mu\nu\mu\nu$	$WW \rightarrow \mu\nu\tau\nu$
$A_{WW} \times C_{WW}$	10.8%	3.0%	4.4%	1.1%	7.6%	1.6%
N_{WW}	114.9	12.0	23.4	2.3	40.3	3.3

Table 3

Relative uncertainties, in percent, on the estimate of the product $A_{WW} \times C_{WW}$ for the individual WW decay channels. The uncertainty on A_{WW} (C_{WW}) receives contributions from the last three (first six) sources.

Source of uncertainty	Relative uncertainty (%)		
	$e\nu\mu\nu$ selection	$e\nu e\nu$ selection	$\mu\nu\mu\nu$ selection
Trigger efficiency	1.0	1.0	1.0
Lepton efficiency	2.3	4.1	1.8
Lepton p_T scale and resolution	0.4	1.0	0.1
E_T^{miss} modeling	0.6	1.0	2.2
Jet energy scale and resolution	1.1	1.1	1.1
Lepton acceptance	2.0	2.1	1.6
Jet veto acceptance	5.0	5.0	5.0
PDFs	1.4	1.2	1.2
Total	6.2	7.2	6.2

- Electron $p_T > 20 \text{ GeV}$ and either $|\eta| < 1.37$ or $1.52 < |\eta| < 2.47$ ($p_T > 25 \text{ GeV}$ in the $e\nu\mu\nu$ channel and for at least one electron in the $e\nu e\nu$ channel);
- No anti- k_t jet ($R = 0.4$) with $p_T > 25 \text{ GeV}$, $|\eta| < 4.5$, and $\Delta R(e, \text{jet}) > 0.3$;
- No anti- k_t jet with $p_T > 20 \text{ GeV}$, $|\eta| < 2.5$, $\Delta R(e, \text{jet}) > 0.3$, and $\Delta R(b, \text{jet}) < 0.3$, where the b -quark has $p_T > 5 \text{ GeV}$;
- Neutrino $|\sum \vec{p}_T|$ or $|\sum \vec{p}_T| \times \sin \Delta\phi$ (for $\Delta\phi < \pi/2$) $> 45, 40, 25 \text{ GeV}$ in the $\mu\nu\mu\nu, e\nu e\nu$ and $e\nu\mu\nu$ channels, respectively ($\Delta\phi$ is the azimuthal angle between the neutrino $\sum \vec{p}_T$ and the nearest charged lepton);
- $m_{\ell\ell} > 15$ (10) GeV in the $\mu\nu\mu\nu$ and $e\nu e\nu$ channels ($e\nu\mu\nu$ channel);
- $|m_{\ell\ell} - m_Z| > 15 \text{ GeV}$ in the $\mu\nu\mu\nu$ and $e\nu e\nu$ channels,

where m_Z is the Z boson mass. To reduce the dependence on the model of QED final-state radiation, the electron and muon p_T include contributions from photons within $\Delta R = 0.1$ of the lepton direction.

Estimates of A_{WW} and C_{WW} are based on samples of $q\bar{q} \rightarrow WW$ and $gg \rightarrow WW$ events generated with MC@NLO and $gg2WW$ [22], respectively. Initial parton momenta are modeled with CTEQ 6.6 [23] parton distribution functions (PDFs). The underlying event and parton showering are modeled with JIMMY, and hadronization and tau-lepton decays with HERWIG. Data-based corrections measured with W and Z boson data are applied to reduce uncertainties, as described below. Because the corrections are applied to WW MC samples, residual uncertainties on the fiducial cross section measurement are based on the kinematics of SM WW production.

The combined factor $A_{WW} \times C_{WW}$ is estimated separately for each leptonic decay channel, including decays to tau leptons (Table 2). Tau-lepton decays to hadrons are not included in the denominator for the acceptances in the table. The impact of pile-up is modeled by adding PYTHIA-generated low- Q^2 events to the WW MC according to the distribution of the number of additional collisions in the same bunch crossing in the data. Effects on detector response from nearby bunches are also modeled using this distribution.

A correction to the $q\bar{q} \rightarrow WW$ MC modeling of the jet veto is derived using Z -boson data. The fraction of Z -boson events with

no additional jets is compared between data and MC@NLO simulated samples. The ratio of this fraction in data to the fraction in the MC is applied as a multiplicative correction factor of 0.963 to the WW MC. The correction reduces the uncertainties due to jet energy scale and resolution to 1.1%. A theoretical uncertainty of 5.0% on the jet veto acceptance contributes the largest uncertainty to A_{WW} , as shown in Table 3.

Contributions to E_T^{miss} include energy from the interacting protons' remnants (the underlying event), and from pile-up. The dominant uncertainty arises from the detector response to the underlying event, and is evaluated by varying the individual calorimeter cell energy deposits in the MC [24]. To determine the uncertainty due to additional pp interactions in the same bunch crossing as the hard-scattering process, the event \vec{p}_T measured with the calorimeter is compared between data and MC in $Z \rightarrow \mu\mu$ events. The mean $|\vec{p}_T|$ as a function of the number of reconstructed vertices agrees to within 3% between data and MC, yielding a negligible uncertainty on the WW acceptance. The effect of collisions from other bunch crossings is studied by splitting Z -boson samples in data and MC according to the bunch position in the LHC train, and by smearing E_T^{miss} in the simulation samples to match the acceptance of a given E_T^{miss} cut in the data samples. The resulting uncertainty on the WW acceptance is small.

The efficiencies for triggering, reconstructing, and identifying charged leptons are measured as a function of lepton p_T and η using Z boson events and (for electrons) W boson events [1]. Corrections to the MC derived from these data are within 1% of unity for trigger and muon identification efficiencies and deviate from unity by up to 11% at low p_T for the electron identification efficiency. Uncertainties on the corrections are largely due to the limited number of events available for the measurements and, in case of electron identification, from the estimate of the jet background contamination.

Finally, there are small uncertainties on the WW production model. Uncertainties on PDFs are determined using the CTEQ eigenvectors and the acceptance differences between the CTEQ 6.6 and MSTW 2008 PDF sets [25]. The impact of unmodeled higher order contributions is estimated by varying the renormalization and factorization scales coherently by factors of 2 and 1/2.

The total acceptance uncertainty on the three channels combined is 6.2%.

Table 4

The measured total ($\sigma(pp \rightarrow WW)$) and fiducial (σ_{fid}) cross sections and the components used in the calculations, as well as the SM predictions for the fiducial cross sections ($\sigma_{\text{fid}}^{\text{SM}}$). The first uncertainty is statistical and the second systematic. The 3.7% relative uncertainty on the integrated luminosity is the third uncertainty on the measured cross sections. The uncertainties on $\sigma_{\text{fid}}^{\text{SM}}$ are highly correlated between the channels.

	$e\nu\mu\nu$ selection	$e\nu\nu$ selection	$\mu\nu\mu\nu$ selection
Data	202	59	64
Background	$40.0 \pm 3.3 \pm 3.6$	$21.7 \pm 2.8 \pm 1.8$	$21.8 \pm 2.8 \pm 2.1$
C_{WW}	$0.541 \pm 0.005 \pm 0.022$	$0.396 \pm 0.005 \pm 0.019$	$0.721 \pm 0.005 \pm 0.025$
A_{WW}	$0.161 \pm 0.001 \pm 0.008$	$0.089 \pm 0.001 \pm 0.005$	$0.082 \pm 0.001 \pm 0.004$
$A_{WW} \times C_{WW}$	$0.087 \pm 0.001 \pm 0.005$	$0.035 \pm 0.001 \pm 0.003$	$0.059 \pm 0.001 \pm 0.004$
$\sigma(pp \rightarrow WW)$ [pb]	$56.3 \pm 4.9 \pm 3.9 \pm 2.1$	$64.1 \pm 13.0 \pm 7.4 \pm 2.4$	$43.2 \pm 8.1 \pm 4.5 \pm 1.6$
σ_{fid} [fb]	$294 \pm 26 \pm 15 \pm 11$	$92.0 \pm 18.9 \pm 9.4 \pm 3.4$	$57.2 \pm 10.8 \pm 5.2 \pm 2.1$
$\sigma_{\text{fid}}^{\text{SM}}$ [fb]	230 ± 19	63.4 ± 5.3	59.0 ± 4.7

6. Cross section results

The WW cross section is measured in the fiducial phase space and extrapolated to the total phase space. The total cross section is defined in Eq. (1), while the fiducial cross section is

$$\sigma_{\text{fid}} = \frac{N_{\text{data}} - N_{\text{bg}}}{\mathcal{L}C_{WW}}. \quad (2)$$

Uncertainties on the fiducial cross section measurement result from modeling lepton and jet efficiency, energy scale and resolution, and $E_{\text{T}}^{\text{miss}}$ (the first five rows of Table 3). Small uncertainties of 1.4% ($\mu\nu\mu\nu$ and $e\nu\nu$ channels) and 0.5% ($e\nu\mu\nu$ channel) arise from the impact of QCD renormalization and factorization scale variations on lepton momenta (included in the sixth row of Table 3). Table 4 shows C_{WW} and the other components of the cross section measurements for each channel. The measurements are performed by minimizing a likelihood fit to the observed data with respect to the WW and background predictions for the three channels combined. The measured cross sections are consistent with the SM predictions, differing by $+1.7\sigma$ ($e\nu\mu\nu$ channel), $+1.3\sigma$ ($e\nu\nu$ channel) and -0.1σ ($\mu\nu\mu\nu$ channel). Contributions from a hypothetical SM Higgs boson would be small: 2.9, 0.9, and 1.8 events in the $e\nu\mu\nu$, $e\nu\nu$ and $\mu\nu\mu\nu$ channels, respectively, for a Higgs boson mass of 125 GeV.

The A_{WW} uncertainty comes from PDFs and scale variations affecting the lepton and jet veto acceptances (the last three rows of Table 3). The combined $A_{WW} \times C_{WW}$ and the total measured cross section in each channel are shown in Table 4. The contribution of leptons from tau decays is included. The channels are combined by maximizing a log likelihood, yielding

$$\begin{aligned} \sigma(pp \rightarrow WW) \\ = 54.4 \pm 4.0 \text{ (stat.)} \pm 3.9 \text{ (syst.)} \pm 2.0 \text{ (lumi.) pb,} \end{aligned}$$

to be compared with the NLO SM prediction of $\sigma(pp \rightarrow WW) = 44.4 \pm 2.8$ pb [16,22]. Fig. 2 shows the following distributions for data and MC: $E_{\text{T}}^{\text{miss}}$, transverse mass, the azimuthal angle between the charged leptons [$\Delta\phi(l, l)$], and the invariant mass of the charged leptons [$m_{\ell\ell}$]. The transverse mass is $m_{\text{T}}(\ell E_{\text{T}}^{\text{miss}}) = \sqrt{(p_{\text{T}}^1 + p_{\text{T}}^2 + E_{\text{T}}^{\text{miss}})^2 - \sum (p_i^1 + p_i^2 + E_i^{\text{miss}})^2}$, where the sum runs over the x and y coordinates and l_1 and l_2 refer to the two charged leptons.

7. Anomalous triple-gauge couplings

The s -channel production of WW events occurs via the triple-gauge couplings $WW\gamma$ and WWZ . Contributions to these couplings from new physics processes at a high energy scale would affect the measured cross section, particularly at high momentum

transfer [26]. Below the energy scale of these new physics processes, an effective Lagrangian can be used to describe the effect of non-SM processes on the WWV ($V = \gamma, Z$) couplings. Assuming the dominant non-SM contributions conserve C and P , the general Lagrangian for WWV couplings is

$$\begin{aligned} \mathcal{L}_{WWV}/g_{WWV} = & ig_1^V (W_{\mu\nu}^\dagger W^{\mu\nu} V^\nu - W_\mu^\dagger V_\nu W^{\mu\nu}) \\ & + i\kappa_V W_\mu^\dagger W_\nu V^{\mu\nu} + \frac{i\lambda_V}{m_W^2} W_{\lambda\mu}^\dagger W_\nu^\mu V^{\nu\lambda}, \quad (3) \end{aligned}$$

where $g_{WW\gamma} = -e$, $g_{WWZ} = -e \cot\theta_W$, $V_{\mu\nu} = \partial_\mu V_\nu - \partial_\nu V_\mu$ and $W_{\mu\nu} = \partial_\mu W_\nu - \partial_\nu W_\mu$. The SM couplings are $g_1^V = \kappa_V = 1$ and $\lambda_V = 0$. Individually, non-zero couplings lead to divergent cross sections at high \sqrt{s} , and non-SM values of the g_1^V or κ_V couplings break the gauge cancellation of processes at high momentum transfer. To regulate this behavior, a suppression factor depending on a scale Λ with the general form

$$\lambda(\hat{s}) = \frac{\lambda}{(1 + \hat{s}/\Lambda^2)^2} \quad (4)$$

is defined for λ , $\Delta g_1 \equiv g_1 - 1$ and $\Delta\kappa \equiv \kappa - 1$. Here, λ is the coupling value at low energy and $\sqrt{\hat{s}}$ is the invariant mass of the WW pair. The g_1^V coupling is fixed to its SM value by electromagnetic gauge invariance.

To reduce the number of WWV coupling parameters, three specific scenarios are considered. The first is the ‘‘LEP scenario’’ [27,28], where anomalous couplings arise from dimension-6 operators and electroweak symmetry breaking occurs via a light SM Higgs boson. This leads to the relations

$$\Delta\kappa_\gamma = -\frac{\cos^2\theta_W}{\sin^2\theta_W} (\Delta\kappa_Z - \Delta g_1^Z) \quad \text{and} \quad \lambda_\gamma = \lambda_Z, \quad (5)$$

leaving three free parameters (Δg_1^Z , $\Delta\kappa_Z$, λ_Z). The parameter space can be further reduced by requiring equal couplings of the $SU(2)$ and $U(1)$ gauge bosons to the Higgs boson in the dimension-6 operators. This adds the constraint $\Delta g_1^Z = \Delta\kappa_\gamma / (2\cos^2\theta_W)$ and is referred to as the ‘‘HISZ scenario’’ [27]. The third ‘‘Equal Coupling scenario’’ assumes common couplings for the WWZ and $WW\gamma$ vertices ($\Delta\kappa_Z = \Delta\kappa_\gamma$, $\lambda_Z = \lambda_\gamma$, $\Delta g_1^Z = \Delta g_1^V = 0$).

The differential cross section as a function of the invariant mass of the WW pair is the most direct probe of anomalous couplings, particularly at high invariant mass. The mass cannot be fully reconstructed but is correlated with the momentum of the individual leptons. The p_{T} distribution of the highest- p_{T} charged lepton is therefore a sensitive probe of anomalous TGCs and is used in a binned likelihood fit to extract the values of the anomalous couplings preferred by the data (Fig. 3). The dependence of the distribution on specific anomalous couplings is modeled by reweighting the mc@NLO SM WW MC to the predictions of the BHO generator

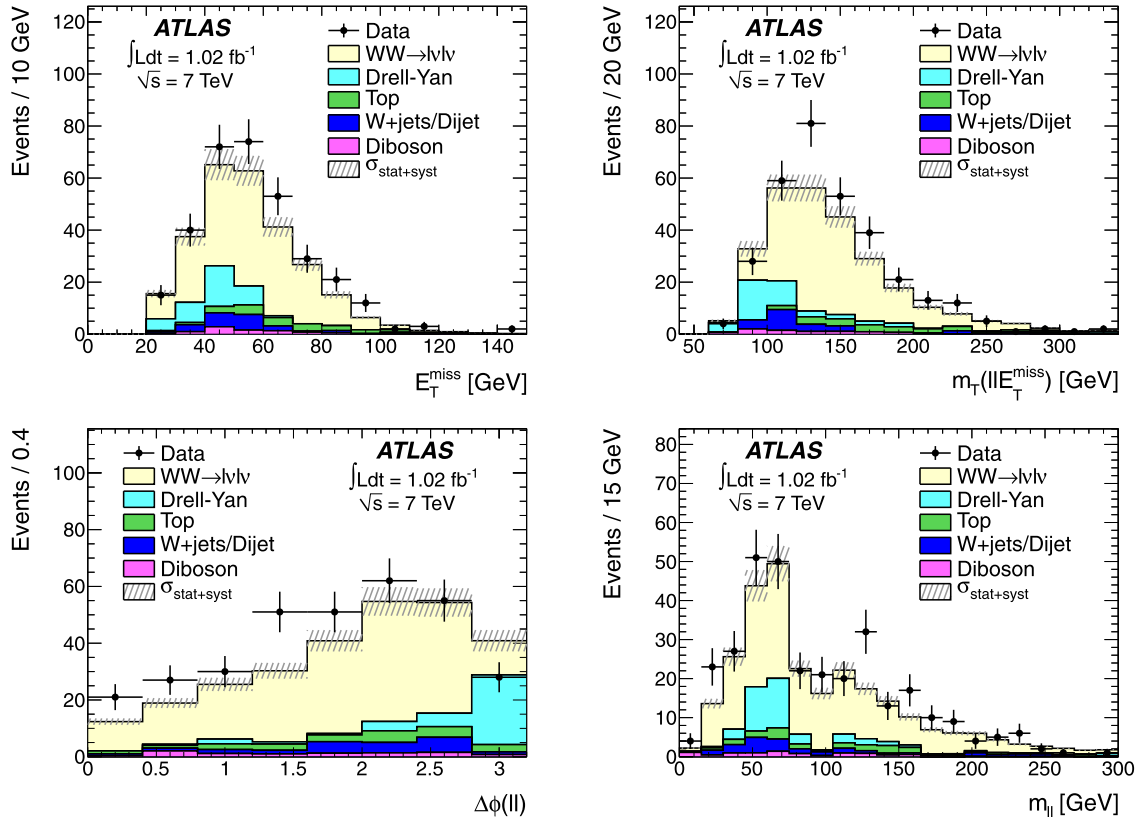


Fig. 2. The E_T^{miss} (top left), m_T (top right), $\Delta\phi(l, l)$ (bottom left) and $m_{\ell\ell}$ (bottom right) distributions for the combined dilepton channels after all selection requirements. The data (dots) are compared to the expectation from WW and the backgrounds (histograms). The W + jet and dijet backgrounds are estimated using data. The hashed region shows the $\pm 1\sigma$ uncertainty band on the expectation.

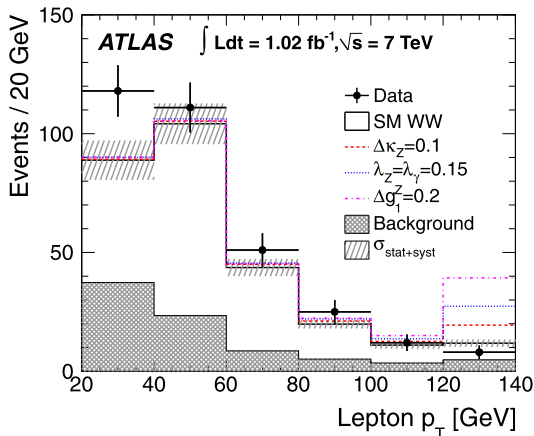


Fig. 3. The p_T distribution of the highest- p_T charged lepton in WW final states. Shown are the data (dots), the background (shaded histogram), SM WW plus background (solid histogram), and the following WW anomalous couplings added to the background: $\Delta\kappa_Z = 0.1$ (dashed histogram), $\lambda_Z = \lambda_\gamma = 0.15$ (dotted histogram), and $\Delta g_1^Z = 0.2$ (dash-dotted histogram). The last bin corresponds to $p_T > 120$ GeV.

[29] at the matrix-element level. Fig. 3 demonstrates the sensitivity to anomalous TGCs at high lepton p_T ; the coupling measurement is negligibly affected by the excess in the data at low p_T . The fiducial cross section is measured in the last bin of Fig. 3. The result $\sigma_{\text{fid}}(p_T \geq 120 \text{ GeV}) = 5.6_{-4.4}^{+5.4}$ (stat.) ± 2.9 (syst.) ± 0.2 (lumi.) fb is consistent with the SM WW prediction of $\sigma_{\text{fid}}(p_T \geq 120 \text{ GeV}) = 12.2 \pm 1.0$ fb.

Table 5 and Fig. 4 show the results of the coupling fits to one and two parameters respectively in the LEP scenario, with the

Table 5

95% CL limits on anomalous TGCs in the LEP scenario assuming the other couplings not fixed in the scenario are set to their SM values.

Λ	Δg_1^Z	$\Delta\kappa_Z$	λ_Z
3 TeV	[−0.064, 0.096]	[−0.100, 0.067]	[−0.090, 0.086]
∞	[−0.052, 0.082]	[−0.071, 0.071]	[−0.079, 0.077]

other parameter(s) fixed by Eq. (5) or set to the SM value(s). One-dimensional limits on λ_Z in the HISZ and Equal Coupling scenarios are the same as in the LEP scenario. In the HISZ scenario, the 95% CL limits on $\Delta\kappa_Z$ are [−0.049, 0.072] and [−0.037, 0.069] for $\Lambda = 3$ TeV and $\Lambda = \infty$, respectively. The corresponding limits in the Equal Coupling scenario are [−0.089, 0.096] and [−0.065, 0.102], respectively.

The anomalous coupling limits in the LEP scenario are compared with limits obtained from CMS, CDF, D0 and the combined LEP results in Fig. 5. The sensitivity of this result is significantly greater than that of the Tevatron due to the higher center-of-mass energy and higher WW production cross section. It is also comparable to the combined results from LEP, which include data from four detectors and all WW decay channels.

8. Summary

Using 1.02 fb^{-1} of $\sqrt{s} = 7$ TeV pp data, the $pp \rightarrow WW$ cross section has been measured with the ATLAS detector in the fully leptonic decay channel. The measured total cross section of 54.4 ± 5.9 pb is consistent with the SM prediction of 44.4 ± 2.8 pb and is the most precise measurement to date. In addition, the first measurement of the WW cross section in a fiducial phase space region

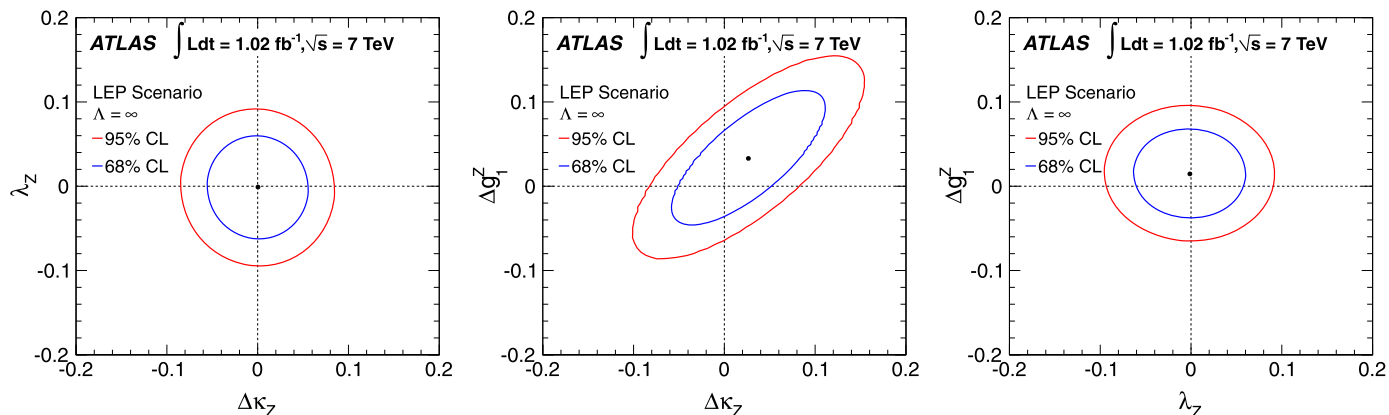


Fig. 4. Two-dimensional fits to the anomalous couplings in the LEP scenario: $\Delta\kappa_Z$ vs. λ_Z (left), $\Delta\kappa_Z$ vs. Δg_1^Z (middle), and λ_Z vs. Δg_1^Z (right). The inner (outer) ellipse encloses the 68% (95%) CL allowed region.

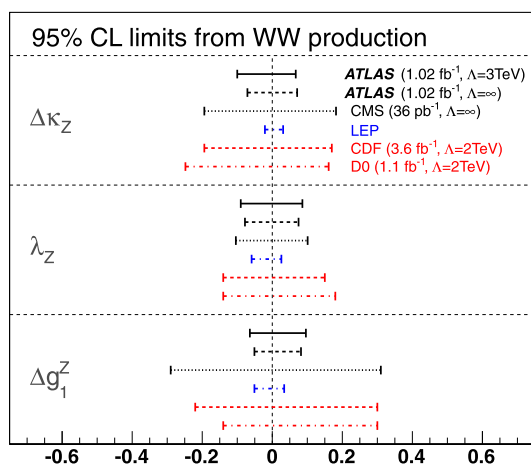


Fig. 5. Anomalous TGC limits from ATLAS, D0 and LEP (based on the LEP scenario) and CDF and CMS (based on the HISZ scenario), as obtained from WW production measurements.

has been presented. Limits on anomalous couplings have been derived in three scenarios using the p_T distribution of the leading charged lepton. No significant deviation is observed with respect to the SM prediction. These limits are competitive with previous results and are sensitive to a higher mass scale for new physical processes.

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; BMWF, Austria; ANAS, Azerbaijan; SSTC, Belarus; CNPq and FAPESP, Brazil; NSERC, NRC and CFI, Canada; CERN; CONICYT, Chile; CAS, MOST and NSFC, China; COLCIENCIAS, Colombia; MSMT CR, MPO CR and VSC CR, Czech Republic; DNRF, DNSRC and Lundbeck Foundation, Denmark; EPLANET and ERC, European Union; IN2P3-CNRS, CEA-DSM/IRFU, France; GNAS, Georgia; BMBF, DFG, HGF, MPG and AvH Foundation, Germany; GSRT, Greece; ISF, MINERVA, GIF, DIP and Benoziyo Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; FOM and NWO, Netherlands; RCN, Norway; MNiSW, Poland; GRICES and FCT, Portugal; MERYs (MECTS), Romania; MES of Russia and ROSATOM, Russian Federation; JINR; MSTB, Serbia; MSSR, Slovakia; ARRS and

MVZT, Slovenia; DST/NRF, South Africa; MICINN, Spain; SRC and Wallenberg Foundation, Sweden; SER, SNSF and Cantons of Bern and Geneva, Switzerland; NSC, Taiwan; TAEK, Turkey; STFC, the Royal Society and Leverhulme Trust, United Kingdom; DOE and NSF, United States of America.

The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN and 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) and in the Tier-2 facilities worldwide.

Open access

This article is published Open Access at scimedirect.com. It is distributed under the terms of the Creative Commons Attribution License 3.0, which permits unrestricted use, distribution, and reproduction in any medium, provided the original authors and source are credited.

References

- [1] ATLAS Collaboration, Phys. Rev. D 85 (2012) 072004, <http://dx.doi.org/10.1103/PhysRevD.85.072004>.
- [2] CMS Collaboration, Phys. Lett. B 699 (2011) 25.
- [3] ATLAS Collaboration, Phys. Rev. Lett. 107 (2011) 041802.
- [4] T. Aaltonen, et al., CDF Collaboration, Phys. Rev. Lett. 104 (2010) 201801; V. Abazov, et al., D0 Collaboration, Phys. Rev. Lett. 103 (2009) 191801; V. Abazov, et al., D0 Collaboration, Phys. Rev. D 80 (2009) 053012.
- [5] S. Schael, et al., ALEPH Collaboration, Phys. Lett. B 614 (2005) 7; G. Abbiendi, et al., OPAL Collaboration, Eur. Phys. J. C 33 (2004) 463; P. Achard, et al., L3 Collaboration, Phys. Lett. B 586 (2004) 151.
- [6] ATLAS Collaboration, JINST 3 (2008) S08003.
- [7] ATLAS Collaboration, Eur. Phys. J. C 71 (2011) 1630; ATLAS Collaboration, Luminosity determination in pp collisions at $\sqrt{s} = 7$ TeV using the ATLAS detector in 2011, ATLAS-CONF-2011-116, 2011.
- [8] ATLAS Collaboration, Eur. Phys. J. C 72 (2012) 1909.
- [9] ATLAS Collaboration, Phys. Lett. B 707 (2012) 438.
- [10] M. Cacciari, G.P. Salam, G. Soyez, JHEP 0804 (2008) 063.
- [11] ATLAS Collaboration, Commissioning of the ATLAS high-performance b -tagging algorithms in the 7 TeV collision data, ATLAS-CONF-2011-152, 2011.
- [12] S. Agostinelli, et al., Nucl. Inst. Meth. A 506 (2003) 250.
- [13] ATLAS Collaboration, Eur. Phys. J. C 70 (2010) 787.
- [14] M.L. Mangano, et al., JHEP 0307 (2003) 001.
- [15] T. Sjöstrand, S. Mrenna, P. Skands, JHEP 0605 (2006) 026.
- [16] S. Frixione, B.R. Webber, JHEP 0206 (2002) 029.
- [17] B.P. Kersevan, E. Richter-Was, The Monte Carlo event generator AcerMC 2.0 with interfaces to PYTHIA 6.2 and HERWIG 6.5, arXiv:hep-ph/0405247, 2004.
- [18] B. Mellado, X. Ruan, Z. Zhang, Phys. Rev. D 84 (2011) 096005.
- [19] J. Pumplin, et al., JHEP 0207 (2002) 012.
- [20] G. Corcella, et al., JHEP 0101 (2001) 010.

- [21] J.M. Campbell, R.K. Ellis, D.J. Rainwater, Phys. Rev. D 68 (2003) 094021.
 [22] T. Binoth, M. Ciccolini, N. Kauer, M. Krämer, JHEP 0612 (2006) 046.
 [23] P.M. Nadolsky, et al., Phys. Rev. D 78 (2008) 013004.
 [24] ATLAS Collaboration, Eur. Phys. J. C 72 (2012) 1844.
 [25] A.D. Martin, W.J. Stirling, R.S. Thorne, G. Watt, Eur. Phys. J. C 63 (2009) 189.
 [26] K. Hagiwara, R.D. Peccei, D. Zeppenfeld, K. Hikasa, Nucl. Phys. B 282 (1987) 253.
 [27] K. Hagiwara, S. Ishihara, R. Szalapski, D. Zeppenfeld, Phys. Lett. B 283 (1992) 353;
 K. Hagiwara, S. Ishihara, R. Szalapski, D. Zeppenfeld, Phys. Rev. D 48 (1993) 2182.
 [28] G. Gounaris, et al., Triple gauge boson couplings, arXiv:hep-ph/9601233v1, 1996.
 [29] U. Baur, T. Han, J. Ohnemus, Phys. Rev. D 53 (1996) 1098.

ATLAS Collaboration

G. Aad⁴⁸, B. Abbott¹¹¹, J. Abdallah¹¹, S. Abdel Khalek¹¹⁵, A.A. Abdelalim⁴⁹, A. Abdesselam¹¹⁸, O. Abidinov¹⁰, B. Abi¹¹², M. Abolins⁸⁸, O.S. AbouZeid¹⁵⁸, H. Abramowicz¹⁵³, H. Abreu¹³⁶, E. Acerbi^{89a,89b}, B.S. Acharya^{164a,164b}, L. Adamczyk³⁷, D.L. Adams²⁴, T.N. Addy⁵⁶, J. Adelman¹⁷⁶, M. Aderholz⁹⁹, S. Adomeit⁹⁸, P. Adragna⁷⁵, T. Adye¹²⁹, S. Aefsky²², J.A. Aguilar-Saavedra^{124b,a}, M. Aharrouche⁸¹, S.P. Ahlen²¹, F. Ahles⁴⁸, A. Ahmad¹⁴⁸, M. Ahsan⁴⁰, G. Aielli^{133a,133b}, T. Akdogan^{18a}, T.P.A. Åkesson⁷⁹, G. Akimoto¹⁵⁵, A.V. Akimov⁹⁴, A. Akiyama⁶⁶, M.S. Alam¹, M.A. Alam⁷⁶, J. Albert¹⁶⁹, S. Albrand⁵⁵, M. Aleksa²⁹, I.N. Aleksandrov⁶⁴, F. Alessandria^{89a}, C. Alexa^{25a}, G. Alexander¹⁵³, G. Alexandre⁴⁹, T. Alexopoulos⁹, M. Alhroob^{164a,164c}, M. Aliev¹⁵, G. Alimonti^{89a}, J. Alison¹²⁰, M. Aliyev¹⁰, B.M.M. Allbrooke¹⁷, P.P. Allport⁷³, S.E. Allwood-Spiers⁵³, J. Almond⁸², A. Aloisio^{102a,102b}, R. Alon¹⁷², A. Alonso⁷⁹, B. Alvarez Gonzalez⁸⁸, M.G. Alviggi^{102a,102b}, K. Amako⁶⁵, P. Amaral²⁹, C. Amelung²², V.V. Ammosov¹²⁸, A. Amorim^{124a,b}, G. Amorós¹⁶⁷, N. Amram¹⁵³, C. Anastopoulos²⁹, L.S. Ancu¹⁶, N. Andari¹¹⁵, T. Andeen³⁴, C.F. Anders²⁰, G. Anders^{58a}, K.J. Anderson³⁰, A. Andreazza^{89a,89b}, V. Andrei^{58a}, M.-L. Andrieux⁵⁵, X.S. Anduaga⁷⁰, A. Angerami³⁴, F. Anghinolfi²⁹, A. Anisenkov¹⁰⁷, N. Anjos^{124a}, A. Annovi⁴⁷, A. Antonaki⁸, M. Antonelli⁴⁷, A. Antonov⁹⁶, J. Antos^{144b}, F. Anulli^{132a}, S. Aoun⁸³, L. Aperio Bella⁴, R. Apolle^{118,c}, G. Arabidze⁸⁸, I. Aracena¹⁴³, Y. Arai⁶⁵, A.T.H. Arce⁴⁴, S. Arfaoui¹⁴⁸, J.-F. Arguin¹⁴, E. Arik^{18a,*}, M. Arik^{18a}, A.J. Armbruster⁸⁷, O. Arnaez⁸¹, V. Arnal⁸⁰, C. Arnault¹¹⁵, A. Artamonov⁹⁵, G. Artoni^{132a,132b}, D. Arutinov²⁰, S. Asai¹⁵⁵, R. Asfandiyarov¹⁷³, S. Ask²⁷, B. Åsman^{146a,146b}, L. Asquith⁵, K. Assamagan²⁴, A. Astbury¹⁶⁹, B. Aubert⁴, E. Auge¹¹⁵, K. Augsten¹²⁷, M. Aurousseau^{145a}, G. Avolio¹⁶³, R. Avramidou⁹, D. Axen¹⁶⁸, C. Ay⁵⁴, G. Azuelos^{93,d}, Y. Azuma¹⁵⁵, M.A. Baak²⁹, G. Baccaglioni^{89a}, C. Bacci^{134a,134b}, A.M. Bach¹⁴, H. Bachacou¹³⁶, K. Bachas²⁹, M. Backes⁴⁹, M. Backhaus²⁰, E. Badescu^{25a}, P. Bagnaia^{132a,132b}, S. Bahinipati², Y. Bai^{32a}, D.C. Bailey¹⁵⁸, T. Bain¹⁵⁸, J.T. Baines¹²⁹, O.K. Baker¹⁷⁶, M.D. Baker²⁴, S. Baker⁷⁷, E. Banas³⁸, P. Banerjee⁹³, Sw. Banerjee¹⁷³, D. Banfi²⁹, A. Bangert¹⁵⁰, V. Bansal¹⁶⁹, H.S. Bansil¹⁷, L. Barak¹⁷², S.P. Baranov⁹⁴, A. Barashkou⁶⁴, A. Barbaro Galtieri¹⁴, T. Barber⁴⁸, E.L. Barberio⁸⁶, D. Barberis^{50a,50b}, M. Barbero²⁰, D.Y. Bardin⁶⁴, T. Barillari⁹⁹, M. Barisonzi¹⁷⁵, T. Barklow¹⁴³, N. Barlow²⁷, B.M. Barnett¹²⁹, R.M. Barnett¹⁴, A. Baroncelli^{134a}, G. Barone⁴⁹, A.J. Barr¹¹⁸, F. Barreiro⁸⁰, J. Barreiro Guimarães da Costa⁵⁷, P. Barrillon¹¹⁵, R. Bartoldus¹⁴³, A.E. Barton⁷¹, V. Bartsch¹⁴⁹, R.L. Bates⁵³, L. Batkova^{144a}, J.R. Batley²⁷, A. Battaglia¹⁶, M. Battistin²⁹, F. Bauer¹³⁶, H.S. Bawa^{143,e}, S. Beale⁹⁸, T. Beau⁷⁸, P.H. Beauchemin¹⁶¹, R. Beccherle^{50a}, P. Bechtel²⁰, H.P. Beck¹⁶, S. Becker⁹⁸, M. Beckingham¹³⁸, K.H. Becks¹⁷⁵, A.J. Beddall^{18c}, A. Beddall^{18c}, S. Bedikian¹⁷⁶, V.A. Bednyakov⁶⁴, C.P. Bee⁸³, M. Begel²⁴, S. Behar Harpaz¹⁵², P.K. Behera⁶², M. Beimforde⁹⁹, C. Belanger-Champagne⁸⁵, P.J. Bell⁴⁹, W.H. Bell⁴⁹, G. Bella¹⁵³, L. Bellagamba^{19a}, F. Bellina²⁹, M. Bellomo²⁹, A. Belloni⁵⁷, O. Beloborodova^{107,f}, K. Belotskiy⁹⁶, O. Beltramello²⁹, O. Benary¹⁵³, D. Bencheikroun^{135a}, M. Bendel⁸¹, K. Bendtz^{146a,146b}, N. Benekos¹⁶⁵, Y. Benhammou¹⁵³, E. Benhar Nocchioli⁴⁹, J.A. Benitez Garcia^{159b}, D.P. Benjamin⁴⁴, M. Benoit¹¹⁵, J.R. Bensinger²², K. Benslama¹³⁰, S. Bentvelsen¹⁰⁵, D. Berge²⁹, E. Bergeaas Kuutmann⁴¹, N. Berger⁴, F. Berghaus¹⁶⁹, E. Berglund¹⁰⁵, J. Beringer¹⁴, P. Bernat⁷⁷, R. Bernhard⁴⁸, C. Bernius²⁴, T. Berry⁷⁶, C. Bertella⁸³, A. Bertin^{19a,19b}, F. Bertinelli²⁹, F. Bertolucci^{122a,122b}, M.I. Besana^{89a,89b}, N. Besson¹³⁶, S. Bethke⁹⁹, W. Bhimji⁴⁵, R.M. Bianchi²⁹, M. Bianco^{72a,72b}, O. Biebel⁹⁸, S.P. Bieniek⁷⁷, K. Bierwagen⁵⁴, J. Biesiada¹⁴, M. Biglietti^{134a}, H. Bilokon⁴⁷, M. Bindi^{19a,19b}, S. Binet¹¹⁵, A. Bingul^{18c}, C. Bini^{132a,132b}, C. Biscarat¹⁷⁸, U. Bitenc⁴⁸, K.M. Black²¹, R.E. Blair⁵, J.-B. Blanchard¹³⁶, G. Blanchot²⁹, T. Blazek^{144a}, C. Blocker²², J. Blocki³⁸, A. Blondel⁴⁹, W. Blum⁸¹, U. Blumenschein⁵⁴, G.J. Bobbink¹⁰⁵, V.B. Bobrovnikov¹⁰⁷, S.S. Bocchetta⁷⁹, A. Bocchi⁴⁴, C.R. Boddy¹¹⁸, M. Boehler⁴¹, J. Boek¹⁷⁵, N. Boelaert³⁵, J.A. Bogaerts²⁹, A. Bogdanchikov¹⁰⁷, A. Bogouch^{90,*}, C. Bohm^{146a}, J. Bohm¹²⁵, V. Boisvert⁷⁶, T. Bold³⁷, V. Boldea^{25a}, N.M. Bolnet¹³⁶, M. Bomben⁷⁸, M. Bona⁷⁵, V.G. Bondarenko⁹⁶, M. Bondioli¹⁶³, M. Boonekamp¹³⁶,

C.N. Booth¹³⁹, S. Bordini⁷⁸, C. Borer¹⁶, A. Borisov¹²⁸, G. Borissov⁷¹, I. Borjanovic^{12a}, M. Borri⁸²,
 S. Borroni⁸⁷, V. Bortolotto^{134a,134b}, K. Bos¹⁰⁵, D. Boscherini^{19a}, M. Bosman¹¹, H. Boterenbrood¹⁰⁵,
 D. Botterill¹²⁹, J. Bouchami⁹³, J. Boudreau¹²³, E.V. Bouhova-Thacker⁷¹, D. Boumediene³³,
 C. Bourdarios¹¹⁵, N. Bousson⁸³, A. Boveia³⁰, J. Boyd²⁹, I.R. Boyko⁶⁴, N.I. Bozhko¹²⁸,
 I. Bozovic-Jelisavcic^{12b}, J. Bracinik¹⁷, A. Braem²⁹, P. Branchini^{134a}, G.W. Brandenburg⁵⁷, A. Brandt⁷,
 G. Brandt¹¹⁸, O. Brandt⁵⁴, U. Bratzler¹⁵⁶, B. Brau⁸⁴, J.E. Brau¹¹⁴, H.M. Braun¹⁷⁵, B. Brelief¹⁵⁸,
 J. Bremer²⁹, K. Brendlinger¹²⁰, R. Brenner¹⁶⁶, S. Bressler¹⁷², D. Britton⁵³, F.M. Brochu²⁷, I. Brock²⁰,
 R. Brock⁸⁸, T.J. Brodbeck⁷¹, E. Brodet¹⁵³, F. Broggi^{89a}, C. Bromberg⁸⁸, J. Bronner⁹⁹, G. Brooijmans³⁴,
 W.K. Brooks^{31b}, G. Brown⁸², H. Brown⁷, P.A. Bruckman de Renstrom³⁸, D. Bruncko^{144b}, R. Bruneliere⁴⁸,
 S. Brunet⁶⁰, A. Bruni^{19a}, G. Bruni^{19a}, M. Bruschi^{19a}, T. Buanes¹³, Q. Buat⁵⁵, F. Bucci⁴⁹, J. Buchanan¹¹⁸,
 N.J. Buchanan², P. Buchholz¹⁴¹, R.M. Buckingham¹¹⁸, A.G. Buckley⁴⁵, S.I. Buda^{25a}, I.A. Budagov⁶⁴,
 B. Budick¹⁰⁸, V. Büscher⁸¹, L. Bugge¹¹⁷, O. Bulekov⁹⁶, A.C. Bundock⁷³, M. Bunse⁴², T. Buran¹¹⁷,
 H. Burckhart²⁹, S. Burdin⁷³, T. Burgess¹³, S. Burke¹²⁹, E. Busato³³, P. Bussey⁵³, C.P. Buszello¹⁶⁶,
 F. Butin²⁹, B. Butler¹⁴³, J.M. Butler²¹, C.M. Buttar⁵³, J.M. Butterworth⁷⁷, W. Buttinger²⁷,
 S. Cabrera Urbán¹⁶⁷, D. Caforio^{19a,19b}, O. Cakir^{3a}, P. Calafiura¹⁴, G. Calderini⁷⁸, P. Calfayan⁹⁸,
 R. Calkins¹⁰⁶, L.P. Caloba^{23a}, R. Caloi^{132a,132b}, D. Calvet³³, S. Calvet³³, R. Camacho Toro³³,
 P. Camarri^{133a,133b}, M. Cambiaghi^{119a,119b}, D. Cameron¹¹⁷, L.M. Caminada¹⁴, S. Campana²⁹,
 M. Campanelli⁷⁷, V. Canale^{102a,102b}, F. Canelli^{30,g}, A. Canepa^{159a}, J. Cantero⁸⁰, L. Capasso^{102a,102b},
 M.D.M. Capeans Garrido²⁹, I. Caprini^{25a}, M. Caprini^{25a}, D. Capriotti⁹⁹, M. Capua^{36a,36b}, R. Caputo⁸¹,
 R. Cardarelli^{133a}, T. Carli²⁹, G. Carlino^{102a}, L. Carminati^{89a,89b}, B. Caron⁸⁵, S. Caron¹⁰⁴, E. Carquin^{31b},
 G.D. Carrillo Montoya¹⁷³, A.A. Carter⁷⁵, J.R. Carter²⁷, J. Carvalho^{124a,h}, D. Casadei¹⁰⁸, M.P. Casado¹¹,
 M. Cascella^{122a,122b}, C. Caso^{50a,50b,*}, A.M. Castaneda Hernandez¹⁷³, E. Castaneda-Miranda¹⁷³,
 V. Castillo Gimenez¹⁶⁷, N.F. Castro^{124a}, G. Cataldi^{72a}, A. Catinaccio²⁹, J.R. Catmore²⁹, A. Cattai²⁹,
 G. Cattani^{133a,133b}, S. Caughron⁸⁸, D. Cauz^{164a,164c}, P. Cavalleri⁷⁸, D. Cavalli^{89a}, M. Cavalli-Sforza¹¹,
 V. Cavasinni^{122a,122b}, F. Ceradini^{134a,134b}, A.S. Cerqueira^{23b}, A. Cerri²⁹, L. Cerrito⁷⁵, F. Cerutti⁴⁷,
 S.A. Cetin^{18b}, F. Cevenini^{102a,102b}, A. Chafaq^{135a}, D. Chakraborty¹⁰⁶, I. Chalupkova¹²⁶, K. Chan²,
 B. Chapleau⁸⁵, J.D. Chapman²⁷, J.W. Chapman⁸⁷, E. Chareyre⁷⁸, D.G. Charlton¹⁷, V. Chavda⁸²,
 C.A. Chavez Barajas²⁹, S. Cheatham⁸⁵, S. Chekanov⁵, S.V. Chekulaev^{159a}, G.A. Chelkov⁶⁴,
 M.A. Chelstowska¹⁰⁴, C. Chen⁶³, H. Chen²⁴, S. Chen^{32c}, T. Chen^{32c}, X. Chen¹⁷³, S. Cheng^{32a},
 A. Cheplakov⁶⁴, V.F. Chepurinov⁶⁴, R. Cherkaoui El Moursli^{135e}, V. Chernyatin²⁴, E. Cheu⁶,
 S.L. Cheung¹⁵⁸, L. Chevalier¹³⁶, G. Chiefari^{102a,102b}, L. Chikovani^{51a}, J.T. Childers²⁹, A. Chilingarov⁷¹,
 G. Chiodini^{72a}, A.S. Chisholm¹⁷, R.T. Chislett⁷⁷, M.V. Chizhov⁶⁴, G. Choudalakis³⁰, S. Chouridou¹³⁷,
 I.A. Christidi⁷⁷, A. Christov⁴⁸, D. Chromek-Burckhart²⁹, M.L. Chu¹⁵¹, J. Chudoba¹²⁵, G. Ciapetti^{132a,132b},
 A.K. Ciftci^{3a}, R. Ciftci^{3a}, D. Cinca³³, V. Cindro⁷⁴, C. Ciocca^{19a}, A. Ciocio¹⁴, M. Cirilli⁸⁷, M. Citterio^{89a},
 M. Ciubancan^{25a}, A. Clark⁴⁹, P.J. Clark⁴⁵, W. Cleland¹²³, J.C. Clemens⁸³, B. Clement⁵⁵,
 C. Clement^{146a,146b}, R.W. Clift¹²⁹, Y. Coadou⁸³, M. Cobal^{164a,164c}, A. Coccaro¹³⁸, J. Cochran⁶³, P. Coe¹¹⁸,
 J.G. Cogan¹⁴³, J. Coggeshall¹⁶⁵, E. Cogneras¹⁷⁸, J. Colas⁴, A.P. Colijn¹⁰⁵, N.J. Collins¹⁷, C. Collins-Tooth⁵³,
 J. Collot⁵⁵, G. Colon⁸⁴, P. Conde Muiño^{124a}, E. Coniavitis¹¹⁸, M.C. Conidi¹¹, M. Consonni¹⁰⁴,
 S.M. Consonni^{89a,89b}, V. Consorti⁴⁸, S. Constantinescu^{25a}, C. Conta^{119a,119b}, G. Conti⁵⁷, F. Conventi^{102a,i},
 J. Cook²⁹, M. Cooke¹⁴, B.D. Cooper⁷⁷, A.M. Cooper-Sarkar¹¹⁸, K. Copic¹⁴, T. Cornelissen¹⁷⁵,
 M. Corradi^{19a}, F. Corriveau^{85,j}, A. Cortes-Gonzalez¹⁶⁵, G. Cortiana⁹⁹, G. Costa^{89a}, M.J. Costa¹⁶⁷,
 D. Costanzo¹³⁹, T. Costin³⁰, D. Côté²⁹, L. Courneyea¹⁶⁹, G. Cowan⁷⁶, C. Cowden²⁷, B.E. Cox⁸²,
 K. Cranmer¹⁰⁸, F. Crescioli^{122a,122b}, M. Cristinziani²⁰, G. Crosetti^{36a,36b}, R. Crupi^{72a,72b},
 S. Crépe-Renaudin⁵⁵, C.-M. Cuciuc^{25a}, C. Cuenca Almenar¹⁷⁶, T. Cuhadar Donszelmann¹³⁹,
 M. Curatolo⁴⁷, C.J. Curtis¹⁷, C. Cuthbert¹⁵⁰, P. Cwetanski⁶⁰, H. Czirr¹⁴¹, P. Czodrowski⁴³, Z. Czyczula¹⁷⁶,
 S. D'Auria⁵³, M. D'Onofrio⁷³, A. D'Orazio^{132a,132b}, P.V.M. Da Silva^{23a}, C. Da Via⁸², W. Dabrowski³⁷,
 A. Dainca¹¹⁸, T. Dai⁸⁷, C. Dallapiccola⁸⁴, M. Dam³⁵, M. Dameri^{50a,50b}, D.S. Damiani¹³⁷,
 H.O. Danielsson²⁹, D. Dannheim⁹⁹, V. Dao⁴⁹, G. Darbo^{50a}, G.L. Darlea^{25b}, W. Davey²⁰, T. Davidek¹²⁶,
 N. Davidson⁸⁶, R. Davidson⁷¹, E. Davies^{118,c}, M. Davies⁹³, A.R. Davison⁷⁷, Y. Davygora^{58a}, E. Dawe¹⁴²,
 I. Dawson¹³⁹, J.W. Dawson^{5,*}, R.K. Daya-Ishmukhametova²², K. De⁷, R. de Asmundis^{102a},
 S. De Castro^{19a,19b}, P.E. De Castro Faria Salgado²⁴, S. De Cecco⁷⁸, J. de Graat⁹⁸, N. De Groot¹⁰⁴,
 P. de Jong¹⁰⁵, C. De La Taille¹¹⁵, H. De la Torre⁸⁰, B. De Lotto^{164a,164c}, L. de Mora⁷¹, L. De Nooij¹⁰⁵,

D. De Pedis^{132a}, A. De Salvo^{132a}, U. De Sanctis^{164a,164c}, A. De Santo¹⁴⁹, J.B. De Vivie De Regie¹¹⁵,
 G. De Zorzi^{132a,132b}, S. Dean⁷⁷, W.J. Dearnaley⁷¹, R. Debbe²⁴, C. Debenedetti⁴⁵, B. Dechenaux⁵⁵,
 D.V. Dedovich⁶⁴, J. Degenhardt¹²⁰, C. Del Papa^{164a,164c}, J. Del Peso⁸⁰, T. Del Prete^{122a,122b},
 T. Delemontex⁵⁵, M. Deliyergiyev⁷⁴, A. Dell'Acqua²⁹, L. Dell'Asta²¹, M. Della Pietra^{102a,i},
 D. della Volpe^{102a,102b}, M. Delmastro⁴, N. Delruelle²⁹, P.A. Delsart⁵⁵, C. Deluca¹⁴⁸, S. Demers¹⁷⁶,
 M. Demichev⁶⁴, B. Demirkoz^{11,k}, J. Deng¹⁶³, S.P. Denisov¹²⁸, D. Derendarz³⁸, J.E. Derkaoui^{135d},
 F. Derue⁷⁸, P. Dervan⁷³, K. Desch²⁰, E. Devetak¹⁴⁸, P.O. Deviveiros¹⁰⁵, A. Dewhurst¹²⁹, B. DeWilde¹⁴⁸,
 S. Dhaliwal¹⁵⁸, R. Dhullipudi^{24,l}, A. Di Ciaccio^{133a,133b}, L. Di Ciaccio⁴, A. Di Girolamo²⁹,
 B. Di Girolamo²⁹, S. Di Luise^{134a,134b}, A. Di Mattia¹⁷³, B. Di Micco²⁹, R. Di Nardo⁴⁷,
 A. Di Simone^{133a,133b}, R. Di Sipio^{19a,19b}, M.A. Diaz^{31a}, F. Diblen^{18c}, E.B. Diehl⁸⁷, J. Dietrich⁴¹,
 T.A. Dietzsch^{58a}, S. Diglio⁸⁶, K. Dindar Yagci³⁹, J. Dingfelder²⁰, C. Dionisi^{132a,132b}, P. Dita^{25a}, S. Dita^{25a},
 F. Dittus²⁹, F. Djama⁸³, T. Djobava^{51b}, M.A.B. do Vale^{23c}, A. Do Valle Wemans^{124a}, T.K.O. Doan⁴,
 M. Dobbs⁸⁵, R. Dobinson^{29,*}, D. Dobos²⁹, E. Dobson^{29,m}, J. Dodd³⁴, C. Doglioni⁴⁹, T. Doherty⁵³,
 Y. Doi^{65,*}, J. Dolejsi¹²⁶, I. Dolenc⁷⁴, Z. Dolezal¹²⁶, B.A. Dolgoshein^{96,*}, T. Dohmae¹⁵⁵, M. Donadelli^{23d},
 M. Donega¹²⁰, J. Donini³³, J. Dopke²⁹, A. Doria^{102a}, A. Dos Anjos¹⁷³, M. Dosil¹¹, A. Dotti^{122a,122b},
 M.T. Dova⁷⁰, A.D. Doxiadis¹⁰⁵, A.T. Doyle⁵³, Z. Drasal¹²⁶, J. Drees¹⁷⁵, N. Dressnandt¹²⁰,
 H. Drevermann²⁹, C. Driouichi³⁵, M. Dris⁹, J. Dubbert⁹⁹, S. Dube¹⁴, E. Duchovni¹⁷², G. Duckeck⁹⁸,
 A. Dudarev²⁹, F. Dudziak⁶³, M. Dührssen²⁹, I.P. Duerdoth⁸², L. Duflot¹¹⁵, M.-A. Dufour⁸⁵, M. Dunford²⁹,
 H. Duran Yildiz^{3a}, R. Duxfield¹³⁹, M. Dwuznik³⁷, F. Dydak²⁹, M. Düren⁵², W.L. Ebenstein⁴⁴, J. Ebke⁹⁸,
 S. Eckweiler⁸¹, K. Edmonds⁸¹, C.A. Edwards⁷⁶, N.C. Edwards⁵³, W. Ehrenfeld⁴¹, T. Ehrich⁹⁹, T. Eifert¹⁴³,
 G. Eigen¹³, K. Einsweiler¹⁴, E. Eisenhandler⁷⁵, T. Ekelof¹⁶⁶, M. El Kacimi^{135c}, M. Ellert¹⁶⁶, S. Elles⁴,
 F. Ellinghaus⁸¹, K. Ellis⁷⁵, N. Ellis²⁹, J. Elmsheuser⁹⁸, M. Elsing²⁹, D. Emeliyanov¹²⁹, R. Engelmann¹⁴⁸,
 A. Engl⁹⁸, B. Epp⁶¹, A. Eppig⁸⁷, J. Erdmann⁵⁴, A. Ereditato¹⁶, D. Eriksson^{146a}, J. Ernst¹, M. Ernst²⁴,
 J. Ernwein¹³⁶, D. Errede¹⁶⁵, S. Errede¹⁶⁵, E. Ertel⁸¹, M. Escalier¹¹⁵, C. Escobar¹²³, X. Espinal Curull¹¹,
 B. Esposito⁴⁷, F. Etienne⁸³, A.I. Etievre¹³⁶, E. Etzion¹⁵³, D. Evangelakou⁵⁴, H. Evans⁶⁰, L. Fabbri^{19a,19b},
 C. Fabre²⁹, R.M. Fakhruddinov¹²⁸, S. Falciano^{132a}, Y. Fang¹⁷³, M. Fanti^{89a,89b}, A. Farbin⁷, A. Farilla^{134a},
 J. Farley¹⁴⁸, T. Farooque¹⁵⁸, S. Farrell¹⁶³, S.M. Farrington¹¹⁸, P. Farthouat²⁹, P. Fassnacht²⁹,
 D. Fassouliotis⁸, B. Fatholahzadeh¹⁵⁸, A. Favareto^{89a,89b}, L. Fayard¹¹⁵, S. Fazio^{36a,36b}, R. Febbraro³³,
 P. Federic^{144a}, O.L. Fedin¹²¹, W. Fedorko⁸⁸, M. Fehling-Kaschek⁴⁸, L. Felgioni⁸³, D. Fellmann⁵,
 C. Feng^{32d}, E.J. Feng³⁰, A.B. Fenyuk¹²⁸, J. Ferencei^{144b}, J. Ferland⁹³, W. Fernando¹⁰⁹, S. Ferrag⁵³,
 J. Ferrando⁵³, V. Ferrara⁴¹, A. Ferrari¹⁶⁶, P. Ferrari¹⁰⁵, R. Ferrari^{119a}, D.E. Ferreira de Lima⁵³,
 A. Ferrer¹⁶⁷, M.L. Ferrer⁴⁷, D. Ferrere⁴⁹, C. Ferretti⁸⁷, A. Ferretto Parodi^{50a,50b}, M. Fiascaris³⁰,
 F. Fiedler⁸¹, A. Filipčič⁷⁴, A. Filippas⁹, F. Filthaut¹⁰⁴, M. Fincke-Keeler¹⁶⁹, M.C.N. Fiolhais^{124a,h},
 L. Fiorini¹⁶⁷, A. Firan³⁹, G. Fischer⁴¹, P. Fischer²⁰, M.J. Fisher¹⁰⁹, M. Flechl⁴⁸, I. Fleck¹⁴¹, J. Fleckner⁸¹,
 P. Fleischmann¹⁷⁴, S. Fleischmann¹⁷⁵, T. Flick¹⁷⁵, A. Floderus⁷⁹, L.R. Flores Castillo¹⁷³,
 M.J. Flowerdew⁹⁹, M. Fokitis⁹, T. Fonseca Martin¹⁶, D.A. Forbush¹³⁸, A. Formica¹³⁶, A. Forti⁸²,
 D. Fortin^{159a}, J.M. Foster⁸², D. Fournier¹¹⁵, A. Foussat²⁹, A.J. Fowler⁴⁴, K. Fowler¹³⁷, H. Fox⁷¹,
 P. Francavilla¹¹, S. Franchino^{119a,119b}, D. Francis²⁹, T. Frank¹⁷², M. Franklin⁵⁷, S. Franz²⁹,
 M. Fraternali^{119a,119b}, S. Fratina¹²⁰, S.T. French²⁷, C. Friedrich⁴¹, F. Friedrich⁴³, R. Froeschl²⁹,
 D. Froidevaux²⁹, J.A. Frost²⁷, C. Fukunaga¹⁵⁶, E. Fullana Torregrosa²⁹, B.G. Fulsom¹⁴³, J. Fuster¹⁶⁷,
 C. Gabaldon²⁹, O. Gabizon¹⁷², T. Gadfort²⁴, S. Gadomski⁴⁹, G. Gagliardi^{50a,50b}, P. Gagnon⁶⁰, C. Galea⁹⁸,
 E.J. Gallas¹¹⁸, V. Gallo¹⁶, B.J. Gallop¹²⁹, P. Gallus¹²⁵, K.K. Gan¹⁰⁹, Y.S. Gao^{143,e}, V.A. Gapienko¹²⁸,
 A. Gaponenko¹⁴, F. Garbersson¹⁷⁶, M. Garcia-Sciveres¹⁴, C. García¹⁶⁷, J.E. García Navarro¹⁶⁷,
 R.W. Gardner³⁰, N. Garelli²⁹, H. Garitaonandia¹⁰⁵, V. Garonne²⁹, J. Garvey¹⁷, C. Gatti⁴⁷, G. Gaudio^{119a},
 B. Gaur¹⁴¹, L. Gauthier¹³⁶, P. Gauzzi^{132a,132b}, I.L. Gavrilenko⁹⁴, C. Gay¹⁶⁸, G. Gaycken²⁰, J.-C. Gayde²⁹,
 E.N. Gazis⁹, P. Ge^{32d}, Z. Gecse¹⁶⁸, C.N.P. Gee¹²⁹, D.A.A. Geerts¹⁰⁵, Ch. Geich-Gimbel²⁰,
 K. Gellerstedt^{146a,146b}, C. Gemme^{50a}, A. Gemmell⁵³, M.H. Genest⁵⁵, S. Gentile^{132a,132b}, M. George⁵⁴,
 S. George⁷⁶, P. Gerlach¹⁷⁵, A. Gershon¹⁵³, C. Geweniger^{58a}, H. Ghazlane^{135b}, N. Ghodbane³³,
 B. Giacobbe^{19a}, S. Giagu^{132a,132b}, V. Giakoumopoulou⁸, V. Giangiobbe¹¹, F. Gianotti²⁹, B. Gibbard²⁴,
 A. Gibson¹⁵⁸, S.M. Gibson²⁹, L.M. Gilbert¹¹⁸, V. Gilewsky⁹¹, D. Gillberg²⁸, A.R. Gillman¹²⁹,
 D.M. Gingrich^{2,d}, J. Ginzburg¹⁵³, N. Giokaris⁸, M.P. Giordani^{164c}, R. Giordano^{102a,102b}, F.M. Giorgi¹⁵,
 P. Giovannini⁹⁹, P.F. Giraud¹³⁶, D. Giugni^{89a}, M. Giunta⁹³, P. Giusti^{19a}, B.K. Gjelsten¹¹⁷, L.K. Gladilin⁹⁷,

C. Glasman⁸⁰, J. Glatzer⁴⁸, A. Glazov⁴¹, K.W. Glitza¹⁷⁵, G.L. Glonti⁶⁴, J.R. Goddard⁷⁵, J. Godfrey¹⁴²,
 J. Godlewski²⁹, M. Goebel⁴¹, T. Göpfert⁴³, C. Goeringer⁸¹, C. Gössling⁴², T. Göttfert⁹⁹, S. Goldfarb⁸⁷,
 T. Golling¹⁷⁶, A. Gomes^{124a,b}, L.S. Gomez Fajardo⁴¹, R. Gonçalves⁷⁶,
 J. Goncalves Pinto Firmino Da Costa⁴¹, L. Gonella²⁰, A. Gonidec²⁹, S. Gonzalez¹⁷³,
 S. González de la Hoz¹⁶⁷, G. Gonzalez Parra¹¹, M.L. Gonzalez Silva²⁶, S. Gonzalez-Sevilla⁴⁹,
 J.J. Goodson¹⁴⁸, L. Goossens²⁹, P.A. Gorbounov⁹⁵, H.A. Gordon²⁴, I. Gorelov¹⁰³, G. Gorfine¹⁷⁵,
 B. Gorini²⁹, E. Gorini^{72a,72b}, A. Gorišek⁷⁴, E. Gornicki³⁸, V.N. Goryachev¹²⁸, B. Gosdzik⁴¹, A.T. Goshaw⁵,
 M. Gosselink¹⁰⁵, M.I. Gostkin⁶⁴, I. Gough Eschrich¹⁶³, M. Gouighri^{135a}, D. Goujdami^{135c},
 M.P. Goulette⁴⁹, A.G. Goussiou¹³⁸, C. Goy⁴, S. Gozpinar²², I. Grabowska-Bold³⁷, P. Grafström²⁹,
 K.-J. Grahm⁴¹, F. Grancagnolo^{72a}, S. Grancagnolo¹⁵, V. Grassi¹⁴⁸, V. Gratchev¹²¹, N. Grau³⁴, H.M. Gray²⁹,
 J.A. Gray¹⁴⁸, E. Graziani^{134a}, O.G. Grebenyuk¹²¹, T. Greenshaw⁷³, Z.D. Greenwood^{24,1}, K. Gregersen³⁵,
 I.M. Gregor⁴¹, P. Grenier¹⁴³, J. Griffiths¹³⁸, N. Grigalashvili⁶⁴, A.A. Grillo¹³⁷, S. Grinstein¹¹,
 Y.V. Grishkevich⁹⁷, J.-F. Grivaz¹¹⁵, E. Gross¹⁷², J. Grosse-Knetter⁵⁴, J. Groth-Jensen¹⁷², K. Grybel¹⁴¹,
 V.J. Guarino⁵, D. Guest¹⁷⁶, C. Guicheney³³, A. Guida^{72a,72b}, S. Guindon⁵⁴, H. Guler^{85,n}, J. Gunther¹²⁵,
 B. Guo¹⁵⁸, J. Guo³⁴, A. Gupta³⁰, Y. Gusakov⁶⁴, V.N. Gushchin¹²⁸, P. Gutierrez¹¹¹, N. Guttman¹⁵³,
 O. Gutzwiller¹⁷³, C. Guyot¹³⁶, C. Gwenlan¹¹⁸, C.B. Gwilliam⁷³, A. Haas¹⁴³, S. Haas²⁹, C. Haber¹⁴,
 H.K. Hadavand³⁹, D.R. Hadley¹⁷, P. Haefner⁹⁹, F. Hahn²⁹, S. Haider²⁹, Z. Hajduk³⁸, H. Hakobyan¹⁷⁷,
 D. Hall¹¹⁸, J. Haller⁵⁴, K. Hamacher¹⁷⁵, P. Hamal¹¹³, M. Hamer⁵⁴, A. Hamilton^{145b,o}, S. Hamilton¹⁶¹,
 H. Han^{32a}, L. Han^{32b}, K. Hanagaki¹¹⁶, K. Hanawa¹⁶⁰, M. Hance¹⁴, C. Handel⁸¹, P. Hanke^{58a},
 J.R. Hansen³⁵, J.B. Hansen³⁵, J.D. Hansen³⁵, P.H. Hansen³⁵, P. Hansson¹⁴³, K. Hara¹⁶⁰, G.A. Hare¹³⁷,
 T. Harenberg¹⁷⁵, S. Harkusha⁹⁰, D. Harper⁸⁷, R.D. Harrington⁴⁵, O.M. Harris¹³⁸, K. Harrison¹⁷,
 J. Hartert⁴⁸, F. Hartjes¹⁰⁵, T. Haruyama⁶⁵, A. Harvey⁵⁶, S. Hasegawa¹⁰¹, Y. Hasegawa¹⁴⁰, S. Hassani¹³⁶,
 M. Hatch²⁹, D. Hauff⁹⁹, S. Haug¹⁶, M. Hauschild²⁹, R. Hauser⁸⁸, M. Havranek²⁰, B.M. Hawes¹¹⁸,
 C.M. Hawkes¹⁷, R.J. Hawkins²⁹, A.D. Hawkins⁷⁹, D. Hawkins¹⁶³, T. Hayakawa⁶⁶, T. Hayashi¹⁶⁰,
 D. Hayden⁷⁶, C.P. Hays¹¹⁸, H.S. Hayward⁷³, S.J. Haywood¹²⁹, E. Hazen²¹, M. He^{32d}, S.J. Head¹⁷,
 V. Hedberg⁷⁹, L. Heelan⁷, S. Heim⁸⁸, B. Heinemann¹⁴, S. Heisterkamp³⁵, L. Helary⁴, C. Heller⁹⁸,
 M. Heller²⁹, S. Hellman^{146a,146b}, D. Hellmich²⁰, C. Helsens¹¹, R.C.W. Henderson⁷¹, M. Henke^{58a},
 A. Henrichs⁵⁴, A.M. Henriques Correia²⁹, S. Henrot-Versille¹¹⁵, F. Henry-Couannier⁸³, C. Hensel⁵⁴,
 T. Henß¹⁷⁵, C.M. Hernandez⁷, Y. Hernández Jiménez¹⁶⁷, R. Herrberg¹⁵, G. Herten⁴⁸, R. Hertenberger⁹⁸,
 L. Hervas²⁹, G.G. Hesketh⁷⁷, N.P. Hessey¹⁰⁵, E. Higón-Rodríguez¹⁶⁷, D. Hill^{5,*}, J.C. Hill²⁷, N. Hill⁵,
 K.H. Hiller⁴¹, S. Hillert²⁰, S.J. Hillier¹⁷, I. Hinchliffe¹⁴, E. Hines¹²⁰, M. Hirose¹¹⁶, F. Hirsch⁴²,
 D. Hirschbuehl¹⁷⁵, J. Hobbs¹⁴⁸, N. Hod¹⁵³, M.C. Hodgkinson¹³⁹, P. Hodgson¹³⁹, A. Hoecker²⁹,
 M.R. Hoferkamp¹⁰³, J. Hoffman³⁹, D. Hoffmann⁸³, M. Hohlfeld⁸¹, M. Holder¹⁴¹, S.O. Holmgren^{146a},
 T. Holy¹²⁷, J.L. Holzbauer⁸⁸, Y. Homma⁶⁶, T.M. Hong¹²⁰, L. Hooft van Huysduynen¹⁰⁸,
 T. Horazdovsky¹²⁷, C. Horn¹⁴³, S. Horner⁴⁸, J.-Y. Hostachy⁵⁵, S. Hou¹⁵¹, M.A. Houlden⁷³,
 A. Hoummada^{135a}, J. Howarth⁸², D.F. Howell¹¹⁸, I. Hristova¹⁵, J. Hrivnac¹¹⁵, I. Hruska¹²⁵, T. Hryn'ova⁴,
 P.J. Hsu⁸¹, S.-C. Hsu¹⁴, G.S. Huang¹¹¹, Z. Hubacek¹²⁷, F. Hubaut⁸³, F. Huegging²⁰, A. Huettmann⁴¹,
 T.B. Huffman¹¹⁸, E.W. Hughes³⁴, G. Hughes⁷¹, R.E. Hughes-Jones⁸², M. Huhtinen²⁹, P. Hurst⁵⁷,
 M. Hurwitz¹⁴, U. Husemann⁴¹, N. Huseynov^{64,p}, J. Huston⁸⁸, J. Huth⁵⁷, G. Iacobucci⁴⁹, G. Iakovidis⁹,
 M. Ibbotson⁸², I. Ibragimov¹⁴¹, R. Ichimiya⁶⁶, L. Iconomidou-Fayard¹¹⁵, J. Idarraga¹¹⁵, P. Iengo^{102a},
 O. Igonkina¹⁰⁵, Y. Ikegami⁶⁵, M. Ikeno⁶⁵, Y. Ilchenko³⁹, D. Iliadis¹⁵⁴, N. Ilic¹⁵⁸, M. Imori¹⁵⁵, T. Ince²⁰,
 J. Inigo-Golfín²⁹, P. Ioannou⁸, M. Iodice^{134a}, K. Iordanidou⁸, V. Ippolito^{132a,132b}, A. Irlés Quiles¹⁶⁷,
 C. Isaksson¹⁶⁶, A. Ishikawa⁶⁶, M. Ishino⁶⁷, R. Ishmukhametov³⁹, C. Issever¹¹⁸, S. Istin^{18a},
 A.V. Ivashin¹²⁸, W. Iwanski³⁸, H. Iwasaki⁶⁵, J.M. Izen⁴⁰, V. Izzo^{102a}, B. Jackson¹²⁰, J.N. Jackson⁷³,
 P. Jackson¹⁴³, M.R. Jaekel²⁹, V. Jain⁶⁰, K. Jakobs⁴⁸, S. Jakobsen³⁵, J. Jakubek¹²⁷, D.K. Jana¹¹¹,
 E. Jansen⁷⁷, H. Jansen²⁹, A. Jantsch⁹⁹, M. Janus⁴⁸, G. Jarlskog⁷⁹, L. Jeanty⁵⁷, K. Jelen³⁷,
 I. Jen-La Plante³⁰, P. Jenni²⁹, A. Jeremie⁴, P. Jež³⁵, S. Jézéquel⁴, M.K. Jha^{19a}, H. Ji¹⁷³, W. Ji⁸¹, J. Jia¹⁴⁸,
 Y. Jiang^{32b}, M. Jimenez Belenguer⁴¹, G. Jin^{32b}, S. Jin^{32a}, O. Jinnouchi¹⁵⁷, M.D. Joergensen³⁵, D. Joffe³⁹,
 L.G. Johansen¹³, M. Johansen^{146a,146b}, K.E. Johansson^{146a}, P. Johansson¹³⁹, S. Johnert⁴¹, K.A. Johns⁶,
 K. Jon-And^{146a,146b}, G. Jones¹¹⁸, R.W.L. Jones⁷¹, T.W. Jones⁷⁷, T.J. Jones⁷³, O. Jonsson²⁹, C. Joram²⁹,
 P.M. Jorge^{124a}, J. Joseph¹⁴, K.D. Joshi⁸², J. Jovicevic¹⁴⁷, T. Jovin^{12b}, X. Ju¹⁷³, C.A. Jung⁴², R.M. Jungst²⁹,
 V. Juranek¹²⁵, P. Jussel⁶¹, A. Juste Rozas¹¹, V.V. Kabachenko¹²⁸, S. Kabana¹⁶, M. Kaci¹⁶⁷,

A. Kaczmarska³⁸, P. Kadlecik³⁵, M. Kado¹¹⁵, H. Kagan¹⁰⁹, M. Kagan⁵⁷, S. Kaiser⁹⁹, E. Kajomovitz¹⁵²,
 S. Kalinin¹⁷⁵, L.V. Kalinovskaya⁶⁴, S. Kama³⁹, N. Kanaya¹⁵⁵, M. Kaneda²⁹, S. Kaneti²⁷, T. Kanno¹⁵⁷,
 V.A. Kantserov⁹⁶, J. Kanzaki⁶⁵, B. Kaplan¹⁷⁶, A. Kapliy³⁰, J. Kaplon²⁹, D. Kar⁵³, M. Karagounis²⁰,
 M. Karagoz¹¹⁸, M. Karnevskiy⁴¹, V. Kartvelishvili⁷¹, A.N. Karyukhin¹²⁸, L. Kashif¹⁷³, G. Kasieczka^{58b},
 R.D. Kass¹⁰⁹, A. Kastanas¹³, M. Kataoka⁴, Y. Kataoka¹⁵⁵, E. Katsoufis⁹, J. Katzy⁴¹, V. Kaushik⁶,
 K. Kawagoe⁶⁹, T. Kawamoto¹⁵⁵, G. Kawamura⁸¹, M.S. Kayl¹⁰⁵, V.A. Kazanin¹⁰⁷, M.Y. Kazarinov⁶⁴,
 R. Keeler¹⁶⁹, R. Kehoe³⁹, M. Keil⁵⁴, G.D. Kekelidze⁶⁴, J.S. Keller¹³⁸, J. Kennedy⁹⁸, M. Kenyon⁵³,
 O. Kepka¹²⁵, N. Kerschen²⁹, B.P. Kerševan⁷⁴, S. Kersten¹⁷⁵, K. Kessoku¹⁵⁵, J. Keung¹⁵⁸, F. Khalil-zada¹⁰,
 H. Khandanyan¹⁶⁵, A. Khanov¹¹², D. Kharchenko⁶⁴, A. Khodinov⁹⁶, A.G. Kholodenko¹²⁸, A. Khomich^{58a},
 T.J. Khoo²⁷, G. Khorauli²⁰, A. Khoroshilov¹⁷⁵, N. Khovanskiy⁶⁴, V. Khovanskiy⁹⁵, E. Khrarov⁶⁴,
 J. Khubua^{51b}, H. Kim^{146a,146b}, M.S. Kim², S.H. Kim¹⁶⁰, N. Kimura¹⁷¹, O. Kind¹⁵, B.T. King⁷³, M. King⁶⁶,
 R.S.B. King¹¹⁸, J. Kirk¹²⁹, L.E. Kirsch²², A.E. Kiryunin⁹⁹, T. Kishimoto⁶⁶, D. Kisielewska³⁷,
 T. Kittelmann¹²³, A.M. Kiver¹²⁸, E. Kladiva^{144b}, M. Klein⁷³, U. Klein⁷³, K. Kleinknecht⁸¹, M. Klemetti⁸⁵,
 A. Klier¹⁷², P. Klimek^{146a,146b}, A. Klimentov²⁴, R. Klingenberg⁴², J.A. Klinger⁸², E.B. Klinkby³⁵,
 T. Klioutchnikova²⁹, P.F. Klok¹⁰⁴, S. Klous¹⁰⁵, E.-E. Kluge^{58a}, T. Kluge⁷³, P. Kluit¹⁰⁵, S. Kluth⁹⁹,
 N.S. Knecht¹⁵⁸, E. Kneringer⁶¹, J. Knobloch²⁹, E.B.F.G. Knoops⁸³, A. Knue⁵⁴, B.R. Ko⁴⁴, T. Kobayashi¹⁵⁵,
 M. Kobel⁴³, M. Kocian¹⁴³, P. Kodys¹²⁶, K. Köneke²⁹, A.C. König¹⁰⁴, S. Koenig⁸¹, L. Köpke⁸¹,
 F. Koetsveld¹⁰⁴, P. Koevesarki²⁰, T. Koffas²⁸, E. Koffeman¹⁰⁵, L.A. Kogan¹¹⁸, S. Kohlmann¹⁷⁵, F. Kohn⁵⁴,
 Z. Kohout¹²⁷, T. Kohriki⁶⁵, T. Koi¹⁴³, T. Kokott²⁰, G.M. Kolachev¹⁰⁷, H. Kolanoski¹⁵, V. Kolesnikov⁶⁴,
 I. Koletsou^{89a}, J. Koll⁸⁸, M. Kollefrath⁴⁸, S.D. Kolya⁸², A.A. Komar⁹⁴, Y. Komori¹⁵⁵, T. Kondo⁶⁵,
 T. Kono^{41,q}, A.I. Kononov⁴⁸, R. Konoplich^{108,r}, N. Konstantinidis⁷⁷, A. Kootz¹⁷⁵, S. Koperny³⁷,
 K. Korcyl³⁸, K. Kordas¹⁵⁴, V. Koreshev¹²⁸, A. Korn¹¹⁸, A. Korol¹⁰⁷, I. Korolkov¹¹, E.V. Korolkova¹³⁹,
 V.A. Korotkov¹²⁸, O. Kortner⁹⁹, S. Kortner⁹⁹, V.V. Kostyukhin²⁰, M.J. Kotamäki²⁹, S. Kotov⁹⁹,
 V.M. Kotov⁶⁴, A. Kotwal⁴⁴, C. Kourkoumelis⁸, V. Kouskoura¹⁵⁴, A. Koutsman^{159a}, R. Kowalewski¹⁶⁹,
 T.Z. Kowalski³⁷, W. Kozanecki¹³⁶, A.S. Kozhin¹²⁸, V. Kral¹²⁷, V.A. Kramarenko⁹⁷, G. Kramerberger⁷⁴,
 M.W. Krasny⁷⁸, A. Krasznahorkay¹⁰⁸, J. Kraus⁸⁸, J.K. Kraus²⁰, F. Krejci¹²⁷, J. Kretschmar⁷³,
 N. Krieger⁵⁴, P. Krieger¹⁵⁸, K. Kroeninger⁵⁴, H. Kroha⁹⁹, J. Kroll¹²⁰, J. Kroseberg²⁰, J. Krstic^{12a},
 U. Kruchonak⁶⁴, H. Krüger²⁰, T. Kruker¹⁶, N. Krumnack⁶³, Z.V. Krumshteyn⁶⁴, A. Kruth²⁰, T. Kubota⁸⁶,
 S. Kuday^{3a}, S. Kuehn⁴⁸, A. Kugel^{58c}, T. Kuhl⁴¹, D. Kuhn⁶¹, V. Kukhtin⁶⁴, Y. Kulchitsky⁹⁰, S. Kuleshov^{31b},
 C. Kummer⁹⁸, M. Kuna⁷⁸, N. Kundu¹¹⁸, J. Kunkle¹²⁰, A. Kupco¹²⁵, H. Kurashige⁶⁶, M. Kurata¹⁶⁰,
 Y.A. Kurochkin⁹⁰, V. Kus¹²⁵, E.S. Kuwertz¹⁴⁷, M. Kuze¹⁵⁷, J. Kvita¹⁴², R. Kwee¹⁵, A. La Rosa⁴⁹,
 L. La Rotonda^{36a,36b}, L. Labarga⁸⁰, J. Labbe⁴, S. Lablak^{135a}, C. Lacasta¹⁶⁷, F. Lacava^{132a,132b}, H. Lacker¹⁵,
 D. Lacour⁷⁸, V.R. Lacuesta¹⁶⁷, E. Ladygin⁶⁴, R. Lafaye⁴, B. Laforge⁷⁸, T. Lagouri⁸⁰, S. Lai⁴⁸, E. Laisne⁵⁵,
 M. Lamanna²⁹, L. Lambourne⁷⁷, C.L. Lampen⁶, W. Lampl⁶, E. Lancon¹³⁶, U. Landgraf⁴⁸, M.P.J. Landon⁷⁵,
 J.L. Lane⁸², C. Lange⁴¹, A.J. Lankford¹⁶³, F. Lanni²⁴, K. Lantzsch¹⁷⁵, S. Laplace⁷⁸, C. Lapoire²⁰,
 J.F. Laporte¹³⁶, T. Lari^{89a}, A.V. Larionov¹²⁸, A. Larner¹¹⁸, C. Lasseur²⁹, M. Lassnig²⁹, P. Laurelli⁴⁷,
 V. Lavorini^{36a,36b}, W. Lavrijsen¹⁴, P. Laycock⁷³, A.B. Lazarev⁶⁴, O. Le Dortz⁷⁸, E. Le Guirriec⁸³,
 C. Le Maner¹⁵⁸, E. Le Menedeu¹¹, C. Lebel⁹³, T. LeCompte⁵, F. Ledroit-Guillon⁵⁵, H. Lee¹⁰⁵,
 J.S.H. Lee¹¹⁶, S.C. Lee¹⁵¹, L. Lee¹⁷⁶, M. Lefebvre¹⁶⁹, M. Legendre¹³⁶, A. Leger⁴⁹, B.C. LeGeyt¹²⁰,
 F. Legger⁹⁸, C. Leggett¹⁴, M. Lehmacher²⁰, G. Lehmann Miotto²⁹, X. Lei⁶, M.A.L. Leite^{23d}, R. Leitner¹²⁶,
 D. Lellouch¹⁷², M. Leltchouk³⁴, B. Lemmer⁵⁴, V. Lendermann^{58a}, K.J.C. Leney^{145b}, T. Lenz¹⁰⁵,
 G. Lenzen¹⁷⁵, B. Lenzi²⁹, K. Leonhardt⁴³, S. Leontsinis⁹, F. Lepold^{58a}, C. Leroy⁹³, J.-R. Lessard¹⁶⁹,
 J. Lesser^{146a}, C.G. Lester²⁷, C.M. Lester¹²⁰, J. Levêque⁴, D. Levin⁸⁷, L.J. Levinson¹⁷², M.S. Levitski¹²⁸,
 A. Lewis¹¹⁸, G.H. Lewis¹⁰⁸, A.M. Leyko²⁰, M. Leyton¹⁵, B. Li⁸³, H. Li^{173,s}, S. Li^{32b,t}, X. Li⁸⁷, Z. Liang^{118,u},
 H. Liao³³, B. Liberti^{133a}, P. Lichard²⁹, M. Lichtnecker⁹⁸, K. Lie¹⁶⁵, W. Liebig¹³, C. Limbach²⁰,
 A. Limosani⁸⁶, M. Limper⁶², S.C. Lin^{151,v}, F. Linde¹⁰⁵, J.T. Linnemann⁸⁸, E. Lipeles¹²⁰, L. Lipinsky¹²⁵,
 A. Lipniacka¹³, T.M. Liss¹⁶⁵, D. Lissauer²⁴, A. Lister⁴⁹, A.M. Litke¹³⁷, C. Liu²⁸, D. Liu¹⁵¹, H. Liu⁸⁷,
 J.B. Liu⁸⁷, M. Liu^{32b}, Y. Liu^{32b}, M. Livan^{119a,119b}, S.S.A. Livermore¹¹⁸, A. Lleres⁵⁵, J. Llorente Merino⁸⁰,
 S.L. Lloyd⁷⁵, E. Lobodzinska⁴¹, P. Loch⁶, W.S. Lockman¹³⁷, T. Loddenkoetter²⁰, F.K. Loebinger⁸²,
 A. Loginov¹⁷⁶, C.W. Loh¹⁶⁸, T. Lohse¹⁵, K. Lohwasser⁴⁸, M. Lokajicek¹²⁵, J. Loken¹¹⁸, V.P. Lombardo⁴,
 R.E. Long⁷¹, L. Lopes^{124a}, D. Lopez Mateos⁵⁷, J. Lorenz⁹⁸, N. Lorenzo Martinez¹¹⁵, M. Losada¹⁶²,
 P. Loscutoff¹⁴, F. Lo Sterzo^{132a,132b}, M.J. Losty^{159a}, X. Lou⁴⁰, A. Lounis¹¹⁵, K.F. Loureiro¹⁶², J. Love²¹,

P.A. Love⁷¹, A.J. Lowe^{143,e}, F. Lu^{32a}, H.J. Lubatti¹³⁸, C. Luci^{132a,132b}, A. Lucotte⁵⁵, A. Ludwig⁴³,
 D. Ludwig⁴¹, I. Ludwig⁴⁸, J. Ludwig⁴⁸, F. Luehring⁶⁰, G. Luijkx¹⁰⁵, W. Lukas⁶¹, D. Lumb⁴⁸,
 L. Luminari^{132a}, E. Lund¹¹⁷, B. Lund-Jensen¹⁴⁷, B. Lundberg⁷⁹, J. Lundberg^{146a,146b}, J. Lundquist³⁵,
 M. Lungwitz⁸¹, G. Lutz⁹⁹, D. Lynn²⁴, J. Lys¹⁴, E. Lytken⁷⁹, H. Ma²⁴, L.L. Ma¹⁷³, J.A. Macana Goia⁹³,
 G. Maccarrone⁴⁷, A. Macchiolo⁹⁹, B. Maček⁷⁴, J. Machado Miguens^{124a}, R. Mackeprang³⁵,
 R.J. Madaras¹⁴, W.F. Mader⁴³, R. Maenner^{58c}, T. Maeno²⁴, P. Mättig¹⁷⁵, S. Mättig⁴¹, L. Magnoni²⁹,
 E. Magradze⁵⁴, Y. Mahalalel¹⁵³, K. Mahboubi⁴⁸, S. Mahmoud⁷³, G. Mahout¹⁷, C. Maiani^{132a,132b},
 C. Maidantchik^{23a}, A. Maio^{124a,b}, S. Majewski²⁴, Y. Makida⁶⁵, N. Makovec¹¹⁵, P. Mal¹³⁶, B. Malaescu²⁹,
 Pa. Malecki³⁸, P. Malecki³⁸, V.P. Maleev¹²¹, F. Malek⁵⁵, U. Mallik⁶², D. Malon⁵, C. Malone¹⁴³,
 S. Maltezos⁹, V. Malyshev¹⁰⁷, S. Malyukov²⁹, R. Mameghani⁹⁸, J. Mamuzic^{12b}, A. Manabe⁶⁵,
 L. Mandelli^{89a}, I. Mandić⁷⁴, R. Mandrysch¹⁵, J. Maneira^{124a}, P.S. Mangedard⁸⁸,
 L. Manhaes de Andrade Filho^{23a}, I.D. Manjavidze⁶⁴, A. Mann⁵⁴, P.M. Manning¹³⁷,
 A. Manousakis-Katsikakis⁸, B. Mansoulie¹³⁶, A. Manz⁹⁹, A. Mapelli²⁹, L. Mapelli²⁹, L. March⁸⁰,
 J.F. Marchand²⁸, F. Marchese^{133a,133b}, G. Marchiori⁷⁸, M. Marcisovsky¹²⁵, C.P. Marino¹⁶⁹,
 F. Marroquim^{23a}, R. Marshall⁸², Z. Marshall²⁹, F.K. Martens¹⁵⁸, S. Marti-Garcia¹⁶⁷, A.J. Martin¹⁷⁶,
 B. Martin²⁹, B. Martin⁸⁸, F.F. Martin¹²⁰, J.P. Martin⁹³, Ph. Martin⁵⁵, T.A. Martin¹⁷, V.J. Martin⁴⁵,
 B. Martin dit Latour⁴⁹, S. Martin-Haugh¹⁴⁹, M. Martinez¹¹, V. Martinez Outschoorn⁵⁷,
 A.C. Martyniuk¹⁶⁹, M. Marx⁸², F. Marzano^{132a}, A. Marzin¹¹¹, L. Masetti⁸¹, T. Mashimo¹⁵⁵,
 R. Mashinistov⁹⁴, J. Masik⁸², A.L. Maslennikov¹⁰⁷, I. Massa^{19a,19b}, G. Massaro¹⁰⁵, N. Massol⁴,
 P. Mastrandrea^{132a,132b}, A. Mastroberardino^{36a,36b}, T. Masubuchi¹⁵⁵, P. Matricon¹¹⁵, H. Matsumoto¹⁵⁵,
 H. Matsunaga¹⁵⁵, T. Matsushita⁶⁶, C. Mattraversi^{118,c}, J.M. Maugain²⁹, J. Maurer⁸³, S.J. Maxfield⁷³,
 D.A. Maximov^{107,f}, E.N. May⁵, A. Mayne¹³⁹, R. Mazini¹⁵¹, M. Mazur²⁰, L. Mazzaferro^{133a,133b},
 M. Mazzanti^{89a}, S.P. Mc Kee⁸⁷, A. McCarn¹⁶⁵, R.L. McCarthy¹⁴⁸, T.G. McCarthy²⁸, N.A. McCubbin¹²⁹,
 K.W. McFarlane⁵⁶, J.A. McFayden¹³⁹, H. McGlone⁵³, G. Mchedlidze^{51b}, R.A. McLaren²⁹, T. McLaughlan¹⁷,
 S.J. McMahon¹²⁹, R.A. McPherson^{169,j}, A. Meade⁸⁴, J. Mechnich¹⁰⁵, M. Mechtel¹⁷⁵, M. Medinnis⁴¹,
 R. Meera-Lebbai¹¹¹, T. Meguro¹¹⁶, R. Mehdiyev⁹³, S. Mehlhase³⁵, A. Mehta⁷³, K. Meier^{58a},
 B. Meirose⁷⁹, C. Melachrinou³⁰, B.R. Mellado Garcia¹⁷³, F. Meloni^{89a,89b}, L. Mendoza Navas¹⁶²,
 Z. Meng^{151,s}, A. Mengarelli^{19a,19b}, S. Menke⁹⁹, C. Menot²⁹, E. Meoni¹¹, K.M. Mercurio⁵⁷, P. Mermod⁴⁹,
 L. Merola^{102a,102b}, C. Meroni^{89a}, F.S. Merritt³⁰, H. Merritt¹⁰⁹, A. Messina²⁹, J. Metcalfe¹⁰³, A.S. Mete⁶³,
 C. Meyer⁸¹, C. Meyer³⁰, J.-P. Meyer¹³⁶, J. Meyer¹⁷⁴, J. Meyer⁵⁴, T.C. Meyer²⁹, W.T. Meyer⁶³, J. Miao^{32d},
 S. Michal²⁹, L. Micu^{25a}, R.P. Middleton¹²⁹, S. Migas⁷³, L. Mijović⁴¹, G. Mikenberg¹⁷², M. Mikesikova¹²⁵,
 M. Mikuž⁷⁴, D.W. Miller³⁰, R.J. Miller⁸⁸, W.J. Mills¹⁶⁸, C. Mills⁵⁷, A. Milov¹⁷², D.A. Milstead^{146a,146b},
 D. Milstein¹⁷², A.A. Minaenko¹²⁸, M. Miñano Moya¹⁶⁷, I.A. Minashvili⁶⁴, A.I. Mincer¹⁰⁸, B. Mindur³⁷,
 M. Mineev⁶⁴, Y. Ming¹⁷³, L.M. Mir¹¹, G. Mirabelli^{132a}, L. Miralles Verge¹¹, A. Misiejuk⁷⁶,
 J. Mitrevski¹³⁷, G.Y. Mitrofanov¹²⁸, V.A. Mitsou¹⁶⁷, S. Mitsui⁶⁵, P.S. Miyagawa¹³⁹, K. Miyazaki⁶⁶,
 J.U. Mjörnmark⁷⁹, T. Moa^{146a,146b}, P. Mockett¹³⁸, S. Moed⁵⁷, V. Moeller²⁷, K. Mönig⁴¹, N. Möser²⁰,
 S. Mohapatra¹⁴⁸, W. Mohr⁴⁸, S. Mohrdieck-Möck⁹⁹, R. Moles-Valls¹⁶⁷, J. Molina-Perez²⁹, J. Monk⁷⁷,
 E. Monnier⁸³, S. Montesano^{89a,89b}, F. Monticelli⁷⁰, S. Monzani^{19a,19b}, R.W. Moore², G.F. Moorhead⁸⁶,
 C. Mora Herrera⁴⁹, A. Moraes⁵³, N. Morange¹³⁶, J. Morel⁵⁴, G. Morello^{36a,36b}, D. Moreno⁸¹,
 M. Moreno Llácer¹⁶⁷, P. Morettini^{50a}, M. Morgenstern⁴³, M. Morii⁵⁷, J. Morin⁷⁵, A.K. Morley²⁹,
 G. Mornacchi²⁹, S.V. Morozov⁹⁶, J.D. Morris⁷⁵, L. Morvaj¹⁰¹, H.G. Moser⁹⁹, M. Mosidze^{51b}, J. Moss¹⁰⁹,
 R. Mount¹⁴³, E. Mountricha^{9,w}, S.V. Mouraviev⁹⁴, E.J.W. Moyses⁸⁴, M. Mudrinic^{12b}, F. Mueller^{58a},
 J. Mueller¹²³, K. Mueller²⁰, T.A. Müller⁹⁸, T. Mueller⁸¹, D. Muenstermann²⁹, Y. Munwes¹⁵³,
 W.J. Murray¹²⁹, I. Mussche¹⁰⁵, E. Musto^{102a,102b}, A.G. Myagkov¹²⁸, M. Myska¹²⁵, J. Nadal¹¹,
 K. Nagai¹⁶⁰, K. Nagano⁶⁵, A. Nagarkar¹⁰⁹, Y. Nagasaka⁵⁹, M. Nagel⁹⁹, A.M. Nairz²⁹, Y. Nakahama²⁹,
 K. Nakamura¹⁵⁵, T. Nakamura¹⁵⁵, I. Nakano¹¹⁰, G. Nanava²⁰, A. Napier¹⁶¹, R. Narayan^{58b}, M. Nash^{77,c},
 N.R. Nation²¹, T. Nattermann²⁰, T. Naumann⁴¹, G. Navarro¹⁶², H.A. Neal⁸⁷, E. Nebot⁸⁰,
 P.Yu. Nechaeva⁹⁴, T.J. Neep⁸², A. Negri^{119a,119b}, G. Negri²⁹, S. Nektarijevic⁴⁹, A. Nelson¹⁶³,
 T.K. Nelson¹⁴³, S. Nemecek¹²⁵, P. Nemethy¹⁰⁸, A.A. Nepomuceno^{23a}, M. Nessi^{29,x}, M.S. Neubauer¹⁶⁵,
 A. Neusiedl⁸¹, R.M. Neves¹⁰⁸, P. Nevski²⁴, P.R. Newman¹⁷, V. Nguyen Thi Hong¹³⁶, R.B. Nickerson¹¹⁸,
 R. Nicolaidou¹³⁶, L. Nicolas¹³⁹, B. Nicquevert²⁹, F. Niedercorn¹¹⁵, J. Nielsen¹³⁷, T. Niinikoski²⁹,
 N. Nikiforou³⁴, A. Nikiforov¹⁵, V. Nikolaenko¹²⁸, K. Nikolaev⁶⁴, I. Nikolic-Audit⁷⁸, K. Nikolics⁴⁹,

K. Nikolopoulos²⁴, H. Nilsen⁴⁸, P. Nilsson⁷, Y. Ninomiya¹⁵⁵, A. Nisati^{132a}, T. Nishiyama⁶⁶, R. Nisius⁹⁹,
 L. Nodulman⁵, M. Nomachi¹¹⁶, I. Nomidis¹⁵⁴, M. Nordberg²⁹, P.R. Norton¹²⁹, J. Novakova¹²⁶,
 M. Nozaki⁶⁵, L. Nozka¹¹³, I.M. Nugent^{159a}, A.-E. Nuncio-Quiroz²⁰, G. Nunes Hanninger⁸⁶,
 T. Nunnemann⁹⁸, E. Nurse⁷⁷, B.J. O'Brien⁴⁵, S.W. O'Neale^{17,*}, D.C. O'Neil¹⁴², V. O'Shea⁵³, L.B. Oakes⁹⁸,
 F.G. Oakham^{28,d}, H. Oberlack⁹⁹, J. Ocariz⁷⁸, A. Ochi⁶⁶, S. Oda¹⁵⁵, S. Odaka⁶⁵, J. Odier⁸³, H. Ogren⁶⁰,
 A. Oh⁸², S.H. Oh⁴⁴, C.C. Ohm^{146a,146b}, T. Ohshima¹⁰¹, H. Ohshita¹⁴⁰, S. Okada⁶⁶, H. Okawa¹⁶³,
 Y. Okumura¹⁰¹, T. Okuyama¹⁵⁵, A. Olariu^{25a}, M. Olcese^{50a}, A.G. Olchevski⁶⁴, S.A. Olivares Pino^{31a},
 M. Oliveira^{124a,h}, D. Oliveira Damazio²⁴, E. Oliver Garcia¹⁶⁷, D. Olivito¹²⁰, A. Olszewski³⁸,
 J. Olszowska³⁸, C. Omachi⁶⁶, A. Onofre^{124a,y}, P.U.E. Onyisi³⁰, C.J. Oram^{159a}, M.J. Oreglia³⁰, Y. Oren¹⁵³,
 D. Orestano^{134a,134b}, N. Orlando^{72a,72b}, I. Orlov¹⁰⁷, C. Oropeza Barrera⁵³, R.S. Orr¹⁵⁸, B. Osculati^{50a,50b},
 R. Ospanov¹²⁰, C. Osuna¹¹, G. Otero y Garzon²⁶, J.P. Ottersbach¹⁰⁵, M. Ouchrif^{135d}, E.A. Ouellette¹⁶⁹,
 F. Ould-Saada¹¹⁷, A. Ouraou¹³⁶, Q. Ouyang^{32a}, A. Ovcharova¹⁴, M. Owen⁸², S. Owen¹³⁹, V.E. Ozcan^{18a},
 N. Ozturk⁷, A. Pacheco Pages¹¹, C. Padilla Aranda¹¹, S. Pagan Griso¹⁴, E. Paganis¹³⁹, F. Paige²⁴,
 P. Pais⁸⁴, K. Pajchel¹¹⁷, G. Palacino^{159b}, C.P. Paleari⁶, S. Palestini²⁹, D. Pallin³³, A. Palma^{124a},
 J.D. Palmer¹⁷, Y.B. Pan¹⁷³, E. Panagiotopoulou⁹, B. Panes^{31a}, N. Panikashvili⁸⁷, S. Panitkin²⁴,
 D. Pantea^{25a}, M. Panuskova¹²⁵, V. Paolone¹²³, A. Papadelis^{146a}, Th.D. Papadopoulou⁹, A. Paramonov⁵,
 D. Paredes Hernandez³³, W. Park^{24,z}, M.A. Parker²⁷, F. Parodi^{50a,50b}, J.A. Parsons³⁴, U. Parzefall⁴⁸,
 S. Pashapour⁵⁴, E. Pasqualucci^{132a}, S. Passaggio^{50a}, A. Passeri^{134a}, F. Pastore^{134a,134b}, Fr. Pastore⁷⁶,
 G. Pásztor^{49,aa}, S. Pataraja¹⁷⁵, N. Patel¹⁵⁰, J.R. Pater⁸², S. Patricelli^{102a,102b}, T. Pauly²⁹, M. Pecsny^{144a},
 M.I. Pedraza Morales¹⁷³, S.V. Peleganchuk¹⁰⁷, D. Pelikan¹⁶⁶, H. Peng^{32b}, B. Penning³⁰, A. Penson³⁴,
 J. Penwell⁶⁰, M. Perantoni^{23a}, K. Perez^{34,ab}, T. Perez Cavalcanti⁴¹, E. Perez Codina^{159a},
 M.T. Pérez García-Estañ¹⁶⁷, V. Perez Reale³⁴, L. Perini^{89a,89b}, H. Pernegger²⁹, R. Perrino^{72a}, P. Perrodo⁴,
 S. Persema^{3a}, V.D. Peshekhonov⁶⁴, K. Peters²⁹, B.A. Petersen²⁹, J. Petersen²⁹, T.C. Petersen³⁵, E. Petit⁴,
 A. Petridis¹⁵⁴, C. Petridou¹⁵⁴, E. Petrolo^{132a}, F. Petrucci^{134a,134b}, D. Petschull⁴¹, M. Petteni¹⁴²,
 R. Pezoa^{31b}, A. Phan⁸⁶, P.W. Phillips¹²⁹, G. Piacquadio²⁹, A. Picazio⁴⁹, E. Piccaro⁷⁵, M. Piccinini^{19a,19b},
 S.M. Piec⁴¹, R. Piegaia²⁶, D.T. Pignotti¹⁰⁹, J.E. Pilcher³⁰, A.D. Pilkington⁸², J. Pina^{124a,b},
 M. Pinamonti^{164a,164c}, A. Pinder¹¹⁸, J.L. Pinfold², J. Ping^{32c}, B. Pinto^{124a}, O. Pirotte²⁹, C. Pizio^{89a,89b},
 R. Placakyte⁴¹, M. Plamondon¹⁶⁹, M.-A. Pleier²⁴, A.V. Pleskach¹²⁸, E. Plotnikova⁶⁴, A. Poblaguev²⁴,
 S. Poddar^{58a}, F. Podlyski³³, L. Poggioli¹¹⁵, T. Poghosyan²⁰, M. Pohl⁴⁹, F. Polci⁵⁵, G. Polesello^{119a},
 A. Policicchio^{36a,36b}, A. Polini^{19a}, J. Poll⁷⁵, V. Polychronakos²⁴, D.M. Pomarede¹³⁶, D. Pomeroy²²,
 K. Pommès²⁹, L. Pontecorvo^{132a}, B.G. Pope⁸⁸, G.A. Popeneciu^{25a}, D.S. Popovic^{12a}, A. Poppleton²⁹,
 X. Portell Bueso²⁹, C. Posch²¹, G.E. Pospelov⁹⁹, S. Pospisil¹²⁷, I.N. Potrap⁹⁹, C.J. Potter¹⁴⁹, C.T. Potter¹¹⁴,
 G. Poulard²⁹, J. Poveda¹⁷³, V. Pozdnyakov⁶⁴, R. Prabhu⁷⁷, P. Pralavorio⁸³, A. Pranko¹⁴, S. Prasad²⁹,
 R. Pravahan²⁴, S. Prell⁶³, K. Pretzl¹⁶, L. Pribyl²⁹, D. Price⁶⁰, J. Price⁷³, L.E. Price⁵, M.J. Price²⁹,
 D. Prieur¹²³, M. Primavera^{72a}, K. Prokofiev¹⁰⁸, F. Prokoshin^{31b}, S. Protopopescu²⁴, J. Proudfoot⁵,
 X. Prudent⁴³, M. Przybycien³⁷, H. Przysieznik⁴, S. Psoroulas²⁰, E. Ptacek¹¹⁴, E. Pueschel⁸⁴,
 J. Purdham⁸⁷, M. Purohit^{24,z}, P. Puzo¹¹⁵, Y. Pylypchenko⁶², J. Qian⁸⁷, Z. Qian⁸³, Z. Qin⁴¹, A. Quadt⁵⁴,
 D.R. Quarrie¹⁴, W.B. Quayle¹⁷³, F. Quinonez^{31a}, M. Raas¹⁰⁴, V. Radescu⁴¹, B. Radics²⁰, P. Radloff¹¹⁴,
 T. Rador^{18a}, F. Ragusa^{89a,89b}, G. Rahal¹⁷⁸, A.M. Rahimi¹⁰⁹, D. Rahm²⁴, S. Rajagopalan²⁴,
 M. Rammensee⁴⁸, M. Rammes¹⁴¹, A.S. Randle-Conde³⁹, K. Randrianarivony²⁸, P.N. Ratoff⁷¹,
 F. Rauscher⁹⁸, T.C. Rave⁴⁸, M. Raymond²⁹, A.L. Read¹¹⁷, D.M. Rebuzzi^{119a,119b}, A. Redelbach¹⁷⁴,
 G. Redlinger²⁴, R. Reece¹²⁰, K. Reeves⁴⁰, A. Reichold¹⁰⁵, E. Reinherz-Aronis¹⁵³, A. Reinsch¹¹⁴,
 I. Reisinger⁴², C. Rembser²⁹, Z.L. Ren¹⁵¹, A. Renaud¹¹⁵, M. Rescigno^{132a}, S. Resconi^{89a}, B. Resende¹³⁶,
 P. Reznicek⁹⁸, R. Rezvani¹⁵⁸, A. Richards⁷⁷, R. Richter⁹⁹, E. Richter-Was^{4,ac}, M. Ridel⁷⁸, M. Rijpstra¹⁰⁵,
 M. Rijssenbeek¹⁴⁸, A. Rimoldi^{119a,119b}, L. Rinaldi^{19a}, R.R. Rios³⁹, I. Riu¹¹, G. Rivoltella^{89a,89b},
 F. Rizatdinova¹¹², E. Rizvi⁷⁵, S.H. Robertson^{85,j}, A. Robichaud-Veronneau¹¹⁸, D. Robinson²⁷,
 J.E.M. Robinson⁷⁷, A. Robson⁵³, J.G. Rocha de Lima¹⁰⁶, C. Roda^{122a,122b}, D. Roda Dos Santos²⁹,
 D. Rodriguez¹⁶², A. Roe⁵⁴, S. Roe²⁹, O. Røhne¹¹⁷, V. Rojo¹, S. Rolli¹⁶¹, A. Romaniouk⁹⁶,
 M. Romano^{19a,19b}, V.M. Romanov⁶⁴, G. Romeo²⁶, E. Romero Adam¹⁶⁷, L. Roos⁷⁸, E. Ros¹⁶⁷,
 S. Rosati^{132a}, K. Rosbach⁴⁹, A. Rose¹⁴⁹, M. Rose⁷⁶, G.A. Rosenbaum¹⁵⁸, E.I. Rosenberg⁶³,
 P.L. Rosendahl¹³, O. Rosenthal¹⁴¹, L. Rosselet⁴⁹, V. Rossetti¹¹, E. Rossi^{132a,132b}, L.P. Rossi^{50a},
 M. Rotaru^{25a}, I. Roth¹⁷², J. Rothberg¹³⁸, D. Rousseau¹¹⁵, C.R. Royon¹³⁶, A. Rozanov⁸³, Y. Rozen¹⁵²,

X. Ruan^{32a,ad}, F. Rubbo¹¹, I. Rubinskiy⁴¹, B. Ruckert⁹⁸, N. Ruckstuhl¹⁰⁵, V.I. Rud⁹⁷, C. Rudolph⁴³, G. Rudolph⁶¹, F. Rühr⁶, F. Ruggieri^{134a,134b}, A. Ruiz-Martinez⁶³, V. Rumiantsev^{91,*}, L. Romyantsev⁶⁴, K. Runge⁴⁸, Z. Rurikova⁴⁸, N.A. Rusakovich⁶⁴, J.P. Rutherford⁶, C. Ruwiedel¹⁴, P. Ruzicka¹²⁵, Y.F. Ryabov¹²¹, V. Ryadovikov¹²⁸, P. Ryan⁸⁸, M. Rybar¹²⁶, G. Rybkin¹¹⁵, N.C. Ryder¹¹⁸, S. Rzaeva¹⁰, A.F. Saavedra¹⁵⁰, I. Sadeh¹⁵³, H.F.-W. Sadrozinski¹³⁷, R. Sadykov⁶⁴, F. Safai Tehrani^{132a}, H. Sakamoto¹⁵⁵, G. Salamanna⁷⁵, A. Salamon^{133a}, M. Saleem¹¹¹, D. Salek²⁹, D. Salihagic⁹⁹, A. Salnikov¹⁴³, J. Salt¹⁶⁷, B.M. Salvachua Ferrando⁵, D. Salvatore^{36a,36b}, F. Salvatore¹⁴⁹, A. Salvucci¹⁰⁴, A. Salzburger²⁹, D. Sampsonidis¹⁵⁴, B.H. Samset¹¹⁷, A. Sanchez^{102a,102b}, V. Sanchez Martinez¹⁶⁷, H. Sandaker¹³, H.G. Sander⁸¹, M.P. Sanders⁹⁸, M. Sandhoff¹⁷⁵, T. Sandoval²⁷, C. Sandoval¹⁶², R. Sandstroem⁹⁹, S. Sandvoss¹⁷⁵, D.P.C. Sankey¹²⁹, A. Sansoni⁴⁷, C. Santamarina Rios⁸⁵, C. Santoni³³, R. Santonico^{133a,133b}, H. Santos^{124a}, J.G. Saraiva^{124a}, T. Sarangi¹⁷³, E. Sarkisyan-Grinbaum⁷, F. Sarri^{122a,122b}, G. Sartisohn¹⁷⁵, O. Sasaki⁶⁵, N. Sasao⁶⁷, I. Satsounkevitch⁹⁰, G. Sauvage⁴, E. Sauvan⁴, J.B. Sauvan¹¹⁵, P. Savard^{158,d}, V. Savinov¹²³, D.O. Savu²⁹, L. Sawyer^{24,l}, D.H. Saxon⁵³, J. Saxon¹²⁰, L.P. SAYS³³, C. Sbarra^{19a}, A. Sbrizzi^{19a,19b}, O. Scallion⁹³, D.A. Scannicchio¹⁶³, M. Scarcella¹⁵⁰, J. Schaarschmidt¹¹⁵, P. Schacht⁹⁹, D. Schaefer¹²⁰, U. Schäfer⁸¹, S. Schaepe²⁰, S. Schaezel^{58b}, A.C. Schaffer¹¹⁵, D. Schaile⁹⁸, R.D. Schamberger¹⁴⁸, A.G. Schamov¹⁰⁷, V. Scharf^{58a}, V.A. Schegelsky¹²¹, D. Scheirich⁸⁷, M. Schernau¹⁶³, M.I. Scherzer³⁴, C. Schiavi^{50a,50b}, J. Schieck⁹⁸, M. Schioppa^{36a,36b}, S. Schlenker²⁹, J.L. Schlereth⁵, E. Schmidt⁴⁸, K. Schmieden²⁰, C. Schmitt⁸¹, S. Schmitt^{58b}, M. Schmitz²⁰, A. Schöning^{58b}, M. Schott²⁹, D. Schouten^{159a}, J. Schovancova¹²⁵, M. Schram⁸⁵, C. Schroeder⁸¹, N. Schroer^{58c}, G. Schuler²⁹, M.J. Schultens²⁰, J. Schultes¹⁷⁵, H.-C. Schultz-Coulon^{58a}, H. Schulz¹⁵, J.W. Schumacher²⁰, M. Schumacher⁴⁸, B.A. Schumm¹³⁷, Ph. Schune¹³⁶, C. Schwanenberger⁸², A. Schwartzman¹⁴³, Ph. Schwemling⁷⁸, R. Schwiendhorst⁸⁸, R. Schwierz⁴³, J. Schwindling¹³⁶, T. Schwindt²⁰, M. Schwoerer⁴, G. Sciolla²², W.G. Scott¹²⁹, J. Searcy¹¹⁴, G. Sedov⁴¹, E. Sedykh¹²¹, E. Segura¹¹, S.C. Seidel¹⁰³, A. Seiden¹³⁷, F. Seifert⁴³, J.M. Seixas^{23a}, G. Sekhniadze^{102a}, S.J. Sekula³⁹, K.E. Selbach⁴⁵, D.M. Seliverstov¹²¹, B. Sellden^{146a}, G. Sellers⁷³, M. Seman^{144b}, N. Semprini-Cesari^{19a,19b}, C. Serfon⁹⁸, L. Serin¹¹⁵, L. Serkin⁵⁴, R. Seuster⁹⁹, H. Severini¹¹¹, M.E. Sevir⁸⁶, A. Sfyrla²⁹, E. Shabalina⁵⁴, M. Shamim¹¹⁴, L.Y. Shan^{32a}, J.T. Shank²¹, Q.T. Shao⁸⁶, M. Shapiro¹⁴, P.B. Shatalov⁹⁵, L. Shaver⁶, K. Shaw^{164a,164c}, D. Sherman¹⁷⁶, P. Sherwood⁷⁷, A. Shibata¹⁰⁸, H. Shichi¹⁰¹, S. Shimizu²⁹, M. Shimojima¹⁰⁰, T. Shin⁵⁶, M. Shiyakova⁶⁴, A. Shmeleva⁹⁴, M.J. Shochet³⁰, D. Short¹¹⁸, S. Shrestha⁶³, E. Shulga⁹⁶, M.A. Shupe⁶, P. Sicho¹²⁵, A. Sidoti^{132a}, F. Siegert⁴⁸, Dj. Sijacki^{12a}, O. Silbert¹⁷², J. Silva^{124a}, Y. Silver¹⁵³, D. Silverstein¹⁴³, S.B. Silverstein^{146a}, V. Simak¹²⁷, O. Simard¹³⁶, Lj. Simic^{12a}, S. Simion¹¹⁵, B. Simmons⁷⁷, R. Simoniello^{89a,89b}, M. Simonyan³⁵, P. Sinervo¹⁵⁸, N.B. Sinev¹¹⁴, V. Sipica¹⁴¹, G. Siragusa¹⁷⁴, A. Sircar²⁴, A.N. Sisakyan⁶⁴, S.Yu. Sivoklokov⁹⁷, J. Sjölin^{146a,146b}, T.B. Sjurson¹³, L.A. Skinnari¹⁴, H.P. Skottowe⁵⁷, K. Skovpen¹⁰⁷, P. Skubic¹¹¹, N. Skvorodnev²², M. Slater¹⁷, T. Slavicek¹²⁷, K. Sliwa¹⁶¹, J. Sloper²⁹, V. Smakhtin¹⁷², B.H. Smart⁴⁵, S.Yu. Smirnov⁹⁶, Y. Smirnov⁹⁶, L.N. Smirnova⁹⁷, O. Smirnova⁷⁹, B.C. Smith⁵⁷, D. Smith¹⁴³, K.M. Smith⁵³, M. Smizanska⁷¹, K. Smolek¹²⁷, A.A. Snesarev⁹⁴, S.W. Snow⁸², J. Snow¹¹¹, S. Snyder²⁴, M. Soares^{124a}, R. Sobie^{169,j}, J. Sodomka¹²⁷, A. Soffer¹⁵³, C.A. Solans¹⁶⁷, M. Solar¹²⁷, J. Solc¹²⁷, E. Soldatov⁹⁶, U. Soldevila¹⁶⁷, E. Solfaroli Camillocci^{132a,132b}, A.A. Solodkov¹²⁸, O.V. Solovyanov¹²⁸, N. Soni², V. Sopko¹²⁷, B. Sopko¹²⁷, M. Sosebee⁷, R. Soualah^{164a,164c}, A. Soukharev¹⁰⁷, S. Spagnolo^{72a,72b}, F. Spanò⁷⁶, R. Spighi^{19a}, G. Spigo²⁹, F. Spila^{132a,132b}, R. Spiwoks²⁹, M. Spousta¹²⁶, T. Spreitzer¹⁵⁸, B. Spurlock⁷, R.D. St. Denis⁵³, J. Stahlman¹²⁰, R. Stamen^{58a}, E. Stanecka³⁸, R.W. Stanek⁵, C. Stanescu^{134a}, M. Stanescu-Bellu⁴¹, S. Stapnes¹¹⁷, E.A. Starchenko¹²⁸, J. Stark⁵⁵, P. Staroba¹²⁵, P. Starovoitov⁴¹, A. Staude⁹⁸, P. Stavina^{144a}, G. Steele⁵³, P. Steinbach⁴³, P. Steinberg²⁴, I. Stekl¹²⁷, B. Stelzer¹⁴², H.J. Stelzer⁸⁸, O. Stelzer-Chilton^{159a}, H. Stenzel⁵², S. Stern⁹⁹, K. Stevenson⁷⁵, G.A. Stewart²⁹, J.A. Stillings²⁰, M.C. Stockton⁸⁵, K. Stoerig⁴⁸, G. Stoicea^{25a}, S. Stonjek⁹⁹, P. Strachota¹²⁶, A.R. Stradling⁷, A. Straessner⁴³, J. Strandberg¹⁴⁷, S. Strandberg^{146a,146b}, A. Strandlie¹¹⁷, M. Strang¹⁰⁹, E. Strauss¹⁴³, M. Strauss¹¹¹, P. Strizenecek^{144b}, R. Ströhmer¹⁷⁴, D.M. Strom¹¹⁴, J.A. Strong^{76,*}, R. Stroynowski³⁹, J. Strube¹²⁹, B. Stugu¹³, I. Stumer^{24,*}, J. Stupak¹⁴⁸, P. Sturm¹⁷⁵, N.A. Styles⁴¹, D.A. Soh^{151,u}, D. Su¹⁴³, H.S. Subramania², A. Succurro¹¹, Y. Sugaya¹¹⁶, T. Sugimoto¹⁰¹, C. Suhr¹⁰⁶, K. Suita⁶⁶, M. Suk¹²⁶, V.V. Sulin⁹⁴, S. Sultansoy^{3d}, T. Sumida⁶⁷, X. Sun⁵⁵, J.E. Sundermann⁴⁸, K. Suruliz¹³⁹, S. Sushkov¹¹, G. Susinno^{36a,36b}, M.R. Sutton¹⁴⁹, Y. Suzuki⁶⁵, Y. Suzuki⁶⁶, M. Svatos¹²⁵,

Yu.M. Sviridov¹²⁸, S. Swedish¹⁶⁸, I. Sykora^{144a}, T. Sykora¹²⁶, B. Szeless²⁹, J. Sánchez¹⁶⁷, D. Ta¹⁰⁵,
 K. Tackmann⁴¹, A. Taffard¹⁶³, R. Tafirout^{159a}, N. Taiblum¹⁵³, Y. Takahashi¹⁰¹, H. Takai²⁴,
 R. Takashima⁶⁸, H. Takeda⁶⁶, T. Takeshita¹⁴⁰, Y. Takubo⁶⁵, M. Talby⁸³, A. Talyshev^{107,f}, M.C. Tamssett²⁴,
 J. Tanaka¹⁵⁵, R. Tanaka¹¹⁵, S. Tanaka¹³¹, S. Tanaka⁶⁵, Y. Tanaka¹⁰⁰, A.J. Tanasijczuk¹⁴², K. Tani⁶⁶,
 N. Tannoury⁸³, G.P. Tappern²⁹, S. Tapprogge⁸¹, D. Tardif¹⁵⁸, S. Tarem¹⁵², F. Tarrade²⁸, G.F. Tartarelli^{89a},
 P. Tas¹²⁶, M. Tasevsky¹²⁵, E. Tassi^{36a,36b}, M. Tatarkhanov¹⁴, Y. Tayalati^{135d}, C. Taylor⁷⁷, F.E. Taylor⁹²,
 G.N. Taylor⁸⁶, W. Taylor^{159b}, M. Teinturier¹¹⁵, M. Teixeira Dias Castanheira⁷⁵, P. Teixeira-Dias⁷⁶,
 K.K. Temming⁴⁸, H. Ten Kate²⁹, P.K. Teng¹⁵¹, S. Terada⁶⁵, K. Terashi¹⁵⁵, J. Terron⁸⁰, M. Testa⁴⁷,
 R.J. Teuscher^{158,j}, J. Thadome¹⁷⁵, J. Therhaag²⁰, T. Theveneaux-Pelzer⁷⁸, M. Thioye¹⁷⁶, S. Thoma⁴⁸,
 J.P. Thomas¹⁷, E.N. Thompson³⁴, P.D. Thompson¹⁷, P.D. Thompson¹⁵⁸, A.S. Thompson⁵³,
 L.A. Thomsen³⁵, E. Thomson¹²⁰, M. Thomson²⁷, R.P. Thun⁸⁷, F. Tian³⁴, M.J. Tibbetts¹⁴, T. Tic¹²⁵,
 V.O. Tikhomirov⁹⁴, Y.A. Tikhonov^{107,f}, S. Timoshenko⁹⁶, P. Tipton¹⁷⁶, F.J. Tique Aires Viegas²⁹,
 S. Tisserant⁸³, B. Toczec³⁷, T. Todorov⁴, S. Todorova-Nova¹⁶¹, B. Toggerson¹⁶³, J. Tojo⁶⁹, S. Tokár^{144a},
 K. Tokunaga⁶⁶, K. Tokushuku⁶⁵, K. Tollefson⁸⁸, M. Tomoto¹⁰¹, L. Tompkins³⁰, K. Toms¹⁰³, G. Tong^{32a},
 A. Tonoyan¹³, C. Topfel¹⁶, N.D. Topilin⁶⁴, I. Torchiani²⁹, E. Torrence¹¹⁴, H. Torres⁷⁸, E. Torró Pastor¹⁶⁷,
 J. Toth^{83,aa}, F. Touchard⁸³, D.R. Tovey¹³⁹, T. Trefzger¹⁷⁴, L. Tremblet²⁹, A. Tricoli²⁹, I.M. Trigger^{159a},
 S. Trincaz-Duvoid⁷⁸, T.N. Trinh⁷⁸, M.F. Tripiana⁷⁰, W. Trischuk¹⁵⁸, A. Trivedi^{24,z}, B. Trocmé⁵⁵,
 C. Troncon^{89a}, M. Trottier-McDonald¹⁴², M. Trzebinski³⁸, A. Trzupek³⁸, C. Tsarouchas²⁹, J.C.-L. Tseng¹¹⁸,
 M. Tsiakiris¹⁰⁵, P.V. Tsiareshka⁹⁰, D. Tsionou^{4,ae}, G. Tsiopolitis⁹, V. Tsiskaridze⁴⁸, E.G. Tskhadadze^{51a},
 I.I. Tsukerman⁹⁵, V. Tsulaia¹⁴, J.-W. Tsung²⁰, S. Tsuno⁶⁵, D. Tsybychev¹⁴⁸, A. Tua¹³⁹, A. Tudorache^{25a},
 V. Tudorache^{25a}, J.M. Tuggle³⁰, M. Turala³⁸, D. Turecek¹²⁷, I. Turk Cakir^{3e}, E. Turlay¹⁰⁵, R. Turra^{89a,89b},
 P.M. Tuts³⁴, A. Tykhonov⁷⁴, M. Tylmad^{146a,146b}, M. Tyndel¹²⁹, G. Tzanakos⁸, K. Uchida²⁰, I. Ueda¹⁵⁵,
 R. Ueno²⁸, M. Uglan¹³, M. Uhlenbrock²⁰, M. Uhrmacher⁵⁴, F. Ukegawa¹⁶⁰, G. Unal²⁹,
 D.G. Underwood⁵, A. Undrus²⁴, G. Unel¹⁶³, Y. Unno⁶⁵, D. Urbaniec³⁴, G. Usai⁷, M. Uslenghi^{119a,119b},
 L. Vacavant⁸³, V. Vacek¹²⁷, B. Vachon⁸⁵, S. Vahsen¹⁴, J. Valenta¹²⁵, P. Valente^{132a}, S. Valentinetti^{19a,19b},
 S. Valkar¹²⁶, E. Valladolid Gallego¹⁶⁷, S. Vallecorsa¹⁵², J.A. Valls Ferrer¹⁶⁷, H. van der Graaf¹⁰⁵,
 E. van der Kraaij¹⁰⁵, R. Van Der Leeuw¹⁰⁵, E. van der Poel¹⁰⁵, D. van der Ster²⁹, N. van Eldik⁸⁴,
 P. van Gemmeren⁵, Z. van Kesteren¹⁰⁵, I. van Vulpen¹⁰⁵, M. Vanadia⁹⁹, W. Vandelli²⁹, G. Vandoni²⁹,
 A. Vaniachine⁵, P. Vankov⁴¹, F. Vannucci⁷⁸, F. Varela Rodriguez²⁹, R. Vari^{132a}, E.W. Varnes⁶, T. Varol⁸⁴,
 D. Varouchas¹⁴, A. Vartapetian⁷, K.E. Varvell¹⁵⁰, V.I. Vassilakopoulos⁵⁶, F. Vazeille³³,
 T. Vazquez Schroeder⁵⁴, G. Vegni^{89a,89b}, J.J. Veillet¹¹⁵, C. Vellidis⁸, F. Veloso^{124a}, R. Veness²⁹,
 S. Veneziano^{132a}, A. Ventura^{72a,72b}, D. Ventura¹³⁸, M. Venturi⁴⁸, N. Venturi¹⁵⁸, V. Vercesi^{119a},
 M. Verducci¹³⁸, W. Verkerke¹⁰⁵, J.C. Vermeulen¹⁰⁵, A. Vest⁴³, M.C. Vetterli^{142,d}, I. Vichou¹⁶⁵,
 T. Vickey^{145b,af}, O.E. Vickey Boeriu^{145b}, G.H.A. Viehhauser¹¹⁸, S. Viel¹⁶⁸, M. Villa^{19a,19b},
 M. Villaplana Perez¹⁶⁷, E. Vilucchi⁴⁷, M.G. Vincter²⁸, E. Vinek²⁹, V.B. Vinogradov⁶⁴, M. Virchaux^{136,*},
 J. Virzi¹⁴, O. Vitells¹⁷², M. Viti⁴¹, I. Vivarelli⁴⁸, F. Vives Vaque², S. Vlachos⁹, D. Vladoiu⁹⁸, M. Vlasak¹²⁷,
 N. Vlasov²⁰, A. Vogel²⁰, P. Vokac¹²⁷, G. Volpi⁴⁷, M. Volpi⁸⁶, G. Volpini^{89a}, H. von der Schmitt⁹⁹,
 J. von Loeben⁹⁹, H. von Radziewski⁴⁸, E. von Toerne²⁰, V. Vorobel¹²⁶, A.P. Vorobiev¹²⁸, V. Vorwerk¹¹,
 M. Vos¹⁶⁷, R. Voss²⁹, T.T. Voss¹⁷⁵, J.H. Vosseveld⁷³, N. Vranjes¹³⁶, M. Vranjes Milosavljevic¹⁰⁵,
 V. Vrba¹²⁵, M. Vreeswijk¹⁰⁵, T. Vu Anh⁴⁸, R. Vuillermet²⁹, I. Vukotic¹¹⁵, W. Wagner¹⁷⁵, P. Wagner¹²⁰,
 H. Wahlen¹⁷⁵, J. Wakabayashi¹⁰¹, S. Walch⁸⁷, J. Walder⁷¹, R. Walker⁹⁸, W. Walkowiak¹⁴¹, R. Wall¹⁷⁶,
 P. Waller⁷³, C. Wang⁴⁴, H. Wang¹⁷³, H. Wang^{32b,ag}, J. Wang¹⁵¹, J. Wang⁵⁵, J.C. Wang¹³⁸, R. Wang¹⁰³,
 S.M. Wang¹⁵¹, T. Wang²⁰, A. Warburton⁸⁵, C.P. Ward²⁷, M. Warsinsky⁴⁸, A. Washbrook⁴⁵, C. Wasicki⁴¹,
 P.M. Watkins¹⁷, A.T. Watson¹⁷, I.J. Watson¹⁵⁰, M.F. Watson¹⁷, G. Watts¹³⁸, S. Watts⁸², A.T. Waugh¹⁵⁰,
 B.M. Waugh⁷⁷, M. Weber¹²⁹, M.S. Weber¹⁶, P. Weber⁵⁴, A.R. Weidberg¹¹⁸, P. Weigell⁹⁹,
 J. Weingarten⁵⁴, C. Weiser⁴⁸, H. Wellenstein²², P.S. Wells²⁹, T. Wenaus²⁴, D. Wendland¹⁵,
 S. Wendler¹²³, Z. Weng^{151,u}, T. Wengler²⁹, S. Wenig²⁹, N. Vermes²⁰, M. Werner⁴⁸, P. Werner²⁹,
 M. Werth¹⁶³, M. Wessels^{58a}, J. Wetter¹⁶¹, C. Weydert⁵⁵, K. Whalen²⁸, S.J. Wheeler-Ellis¹⁶³,
 S.P. Whitaker²¹, A. White⁷, M.J. White⁸⁶, S. White^{122a,122b}, S.R. Whitehead¹¹⁸, D. Whiteson¹⁶³,
 D. Whittington⁶⁰, F. Wicek¹¹⁵, D. Wicke¹⁷⁵, F.J. Wickens¹²⁹, W. Wiedenmann¹⁷³, M. Wielers¹²⁹,
 P. Wienemann²⁰, C. Wiglesworth⁷⁵, L.A.M. Wiik-Fuchs⁴⁸, P.A. Wijeratne⁷⁷, A. Wildauer¹⁶⁷,
 M.A. Wildt^{41,q}, I. Wilhelm¹²⁶, H.G. Wilkens²⁹, J.Z. Will⁹⁸, E. Williams³⁴, H.H. Williams¹²⁰, W. Willis³⁴,

S. Willocq⁸⁴, J.A. Wilson¹⁷, M.G. Wilson¹⁴³, A. Wilson⁸⁷, I. Wingerter-Seez⁴, S. Winkelmann⁴⁸, F. Winklmeier²⁹, M. Wittgen¹⁴³, M.W. Wolter³⁸, H. Wolters^{124a,h}, W.C. Wong⁴⁰, G. Wooden⁸⁷, B.K. Wosiek³⁸, J. Wotschack²⁹, M.J. Woudstra⁸⁴, K.W. Wozniak³⁸, K. Wraight⁵³, C. Wright⁵³, M. Wright⁵³, B. Wrona⁷³, S.L. Wu¹⁷³, X. Wu⁴⁹, Y. Wu^{32b,ah}, E. Wulf³⁴, R. Wunstorff⁴², B.M. Wynne⁴⁵, S. Xella³⁵, M. Xiao¹³⁶, S. Xie⁴⁸, Y. Xie^{32a}, C. Xu^{32b,w}, D. Xu¹³⁹, G. Xu^{32a}, B. Yabsley¹⁵⁰, S. Yacoob^{145b}, M. Yamada⁶⁵, H. Yamaguchi¹⁵⁵, A. Yamamoto⁶⁵, K. Yamamoto⁶³, S. Yamamoto¹⁵⁵, T. Yamamura¹⁵⁵, T. Yamanaka¹⁵⁵, J. Yamaoka⁴⁴, T. Yamazaki¹⁵⁵, Y. Yamazaki⁶⁶, Z. Yan²¹, H. Yang⁸⁷, U.K. Yang⁸², Y. Yang⁶⁰, Y. Yang^{32a}, Z. Yang^{146a,146b}, S. Yanush⁹¹, Y. Yao¹⁴, Y. Yasu⁶⁵, G.V. Ybeles Smit¹³⁰, J. Ye³⁹, S. Ye²⁴, M. Yilmaz^{3c}, R. Yoosofmiya¹²³, K. Yorita¹⁷¹, R. Yoshida⁵, C. Young¹⁴³, C.J. Young¹¹⁸, S. Youssef²¹, D. Yu²⁴, J. Yu⁷, J. Yu¹¹², L. Yuan⁶⁶, A. Yurkewicz¹⁰⁶, B. Zabinski³⁸, V.G. Zaets¹²⁸, R. Zaidan⁶², A.M. Zaitsev¹²⁸, Z. Zajacova²⁹, L. Zanello^{132a,132b}, A. Zaytsev¹⁰⁷, C. Zeitnitz¹⁷⁵, M. Zeller¹⁷⁶, M. Zeman¹²⁵, A. Zemla³⁸, C. Zendler²⁰, O. Zenin¹²⁸, T. Ženiš^{144a}, Z. Zinonos^{122a,122b}, S. Zenz¹⁴, D. Zerwas¹¹⁵, G. Zevi della Porta⁵⁷, Z. Zhan^{32d}, D. Zhang^{32b,ag}, H. Zhang⁸⁸, J. Zhang⁵, X. Zhang^{32d}, Z. Zhang¹¹⁵, L. Zhao¹⁰⁸, T. Zhao¹³⁸, Z. Zhao^{32b}, A. Zhemchugov⁶⁴, S. Zheng^{32a}, J. Zhong¹¹⁸, B. Zhou⁸⁷, N. Zhou¹⁶³, Y. Zhou¹⁵¹, C.G. Zhu^{32d}, H. Zhu⁴¹, J. Zhu⁸⁷, Y. Zhu^{32b}, X. Zhuang⁹⁸, V. Zhuravlov⁹⁹, D. Zieminska⁶⁰, R. Zimmermann²⁰, S. Zimmermann²⁰, S. Zimmermann⁴⁸, M. Ziolkowski¹⁴¹, R. Zitoun⁴, L. Živković³⁴, V.V. Zmouchko^{128,*}, G. Zobernig¹⁷³, A. Zoccoli^{19a,19b}, A. Zsenei²⁹, M. zur Nedden¹⁵, V. Zutshi¹⁰⁶, L. Zwalinski²⁹

¹ University at Albany, Albany, NY, United States

² Department of Physics, University of Alberta, Edmonton, AB, Canada

³ (a) Department of Physics, Ankara University, Ankara; (b) Department of Physics, Dumlupinar University, Kutahya; (c) Department of Physics, Gazi University, Ankara; (d) Division of Physics, TOBB University of Economics and Technology, Ankara; (e) Turkish Atomic Energy Authority, Ankara, Turkey

⁴ LAPP, CNRS/IN2P3 and Université de Savoie, Annecy-le-Vieux, France

⁵ High Energy Physics Division, Argonne National Laboratory, Argonne, IL, United States

⁶ Department of Physics, University of Arizona, Tucson, AZ, United States

⁷ Department of Physics, The University of Texas at Arlington, Arlington, TX, United States

⁸ Physics Department, University of Athens, Athens, Greece

⁹ Physics Department, National Technical University of Athens, Zografou, Greece

¹⁰ Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan

¹¹ Institut de Física d'Altes Energies and Departament de Física de la Universitat Autònoma de Barcelona and ICREA, Barcelona, Spain

¹² (a) Institute of Physics, University of Belgrade, Belgrade; (b) Vinca Institute of Nuclear Sciences, University of Belgrade, Belgrade, Serbia

¹³ Department for Physics and Technology, University of Bergen, Bergen, Norway

¹⁴ Physics Division, Lawrence Berkeley National Laboratory and University of California, Berkeley, CA, United States

¹⁵ Department of Physics, Humboldt University, Berlin, Germany

¹⁶ Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern, Switzerland

¹⁷ School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom

¹⁸ (a) Department of Physics, Bogazici University, Istanbul; (b) Division of Physics, Dogus University, Istanbul; (c) Department of Physics Engineering, Gaziantep University, Gaziantep;

(d) Department of Physics, Istanbul Technical University, Istanbul, Turkey

¹⁹ (a) INFN Sezione di Bologna; (b) Dipartimento di Fisica, Università di Bologna, Bologna, Italy

²⁰ Physikalisches Institut, University of Bonn, Bonn, Germany

²¹ Department of Physics, Boston University, Boston, MA, United States

²² Department of Physics, Brandeis University, Waltham, MA, United States

²³ (a) Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro; (b) Federal University of Juiz de Fora (UFJF), Juiz de Fora; (c) Federal University of Sao Joao del Rei (UFSJ), Sao Joao del Rei; (d) Instituto de Física, Universidade de Sao Paulo, Sao Paulo, Brazil

²⁴ Physics Department, Brookhaven National Laboratory, Upton, NY, United States

²⁵ (a) National Institute of Physics and Nuclear Engineering, Bucharest; (b) University Politehnica Bucharest, Bucharest; (c) West University in Timisoara, Timisoara, Romania

²⁶ Departamento de Física, Universidad de Buenos Aires, Buenos Aires, Argentina

²⁷ Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom

²⁸ Department of Physics, Carleton University, Ottawa, ON, Canada

²⁹ CERN, Geneva, Switzerland

³⁰ Enrico Fermi Institute, University of Chicago, Chicago, IL, United States

³¹ (a) Departamento de Física, Pontificia Universidad Católica de Chile, Santiago; (b) Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile

³² (a) Institute of High Energy Physics, Chinese Academy of Sciences, Beijing; (b) Department of Modern Physics, University of Science and Technology of China, Anhui; (c) Department of Physics, Nanjing University, Jiangsu; (d) School of Physics, Shandong University, Shandong, China

³³ Laboratoire de Physique Corpusculaire, Clermont Université and Université Blaise Pascal and CNRS/IN2P3, Aubiere Cedex, France

³⁴ Nevis Laboratory, Columbia University, Irvington, NY, United States

³⁵ Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark

³⁶ (a) INFN Gruppo Collegato di Cosenza; (b) Dipartimento di Fisica, Università della Calabria, Arcavacata di Rende, Italy

³⁷ AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, Krakow, Poland

³⁸ The Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, Krakow, Poland

³⁹ Physics Department, Southern Methodist University, Dallas, TX, United States

⁴⁰ Physics Department, University of Texas at Dallas, Richardson, TX, United States

⁴¹ DESY, Hamburg and Zeuthen, Germany

⁴² Institut für Experimentelle Physik IV, Technische Universität Dortmund, Dortmund, Germany

⁴³ Institut für Kern- und Teilchenphysik, Technical University Dresden, Dresden, Germany

⁴⁴ Department of Physics, Duke University, Durham, NC, United States

⁴⁵ SUPA – School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom

⁴⁶ Fachhochschule Wiener Neustadt, Johannes Gutenbergstrasse 3, 2700 Wiener Neustadt, Austria

⁴⁷ INFN Laboratori Nazionali di Frascati, Frascati, Italy

- 48 Fakultät für Mathematik und Physik, Albert-Ludwigs-Universität, Freiburg i.Br., Germany
- 49 Section de Physique, Université de Genève, Geneva, Switzerland
- 50 ^(a) INFN Sezione di Genova; ^(b) Dipartimento di Fisica, Università di Genova, Genova, Italy
- 51 ^(a) E. Andronikashvili Institute of Physics, Tbilisi State University, Tbilisi; ^(b) High Energy Physics Institute, Tbilisi State University, Tbilisi, Georgia
- 52 II Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen, Germany
- 53 SUPA – School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom
- 54 II Physikalisches Institut, Georg-August-Universität, Göttingen, Germany
- 55 Laboratoire de Physique Subatomique et de Cosmologie, Université Joseph Fourier and CNRS/IN2P3 and Institut National Polytechnique de Grenoble, Grenoble, France
- 56 Department of Physics, Hampton University, Hampton, VA, United States
- 57 Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge, MA, United States
- 58 ^(a) Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg; ^(b) Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg; ^(c) ZITI Institut für technische Informatik, Ruprecht-Karls-Universität Heidelberg, Mannheim, Germany
- 59 Faculty of Applied Information Science, Hiroshima Institute of Technology, Hiroshima, Japan
- 60 Department of Physics, Indiana University, Bloomington, IN, United States
- 61 Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck, Austria
- 62 University of Iowa, Iowa City, IA, United States
- 63 Department of Physics and Astronomy, Iowa State University, Ames, IA, United States
- 64 Joint Institute for Nuclear Research, JINR Dubna, Dubna, Russia
- 65 KEK, High Energy Accelerator Research Organization, Tsukuba, Japan
- 66 Graduate School of Science, Kobe University, Kobe, Japan
- 67 Faculty of Science, Kyoto University, Kyoto, Japan
- 68 Kyoto University of Education, Kyoto, Japan
- 69 Department of Physics, Kyushu University, Fukuoka, Japan
- 70 Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina
- 71 Physics Department, Lancaster University, Lancaster, United Kingdom
- 72 ^(a) INFN Sezione di Lecce; ^(b) Dipartimento di Fisica, Università del Salento, Lecce, Italy
- 73 Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom
- 74 Department of Physics, Jozef Stefan Institute and University of Ljubljana, Ljubljana, Slovenia
- 75 School of Physics and Astronomy, Queen Mary University of London, London, United Kingdom
- 76 Department of Physics, Royal Holloway University of London, Surrey, United Kingdom
- 77 Department of Physics and Astronomy, University College London, London, United Kingdom
- 78 Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France
- 79 Fysiska institutionen, Lunds universitet, Lund, Sweden
- 80 Departamento de Física Teórica C-15, Universidad Autónoma de Madrid, Madrid, Spain
- 81 Institut für Physik, Universität Mainz, Mainz, Germany
- 82 School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom
- 83 CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France
- 84 Department of Physics, University of Massachusetts, Amherst, MA, United States
- 85 Department of Physics, McGill University, Montreal, QC, Canada
- 86 School of Physics, University of Melbourne, Victoria, Australia
- 87 Department of Physics, The University of Michigan, Ann Arbor, MI, United States
- 88 Department of Physics and Astronomy, Michigan State University, East Lansing, MI, United States
- 89 ^(a) INFN Sezione di Milano; ^(b) Dipartimento di Fisica, Università di Milano, Milano, Italy
- 90 B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Belarus
- 91 National Scientific and Educational Centre for Particle and High Energy Physics, Minsk, Belarus
- 92 Department of Physics, Massachusetts Institute of Technology, Cambridge, MA, United States
- 93 Group of Particle Physics, University of Montreal, Montreal, QC, Canada
- 94 P.N. Lebedev Institute of Physics, Academy of Sciences, Moscow, Russia
- 95 Institute for Theoretical and Experimental Physics (ITEP), Moscow, Russia
- 96 Moscow Engineering and Physics Institute (MEPhI), Moscow, Russia
- 97 Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
- 98 Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany
- 99 Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany
- 100 Nagasaki Institute of Applied Science, Nagasaki, Japan
- 101 Graduate School of Science, Nagoya University, Nagoya, Japan
- 102 ^(a) INFN Sezione di Napoli; ^(b) Dipartimento di Scienze Fisiche, Università di Napoli, Napoli, Italy
- 103 Department of Physics and Astronomy, University of New Mexico, Albuquerque, NM, United States
- 104 Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands
- 105 Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands
- 106 Department of Physics, Northern Illinois University, DeKalb, IL, United States
- 107 Budker Institute of Nuclear Physics, SB RAS, Novosibirsk, Russia
- 108 Department of Physics, New York University, New York, NY, United States
- 109 Ohio State University, Columbus, OH, United States
- 110 Faculty of Science, Okayama University, Okayama, Japan
- 111 Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman, OK, United States
- 112 Department of Physics, Oklahoma State University, Stillwater, OK, United States
- 113 Palacký University, RCPTM, Olomouc, Czech Republic
- 114 Center for High Energy Physics, University of Oregon, Eugene, OR, United States
- 115 LAL, Univ. Paris-Sud and CNRS/IN2P3, Orsay, France
- 116 Graduate School of Science, Osaka University, Osaka, Japan
- 117 Department of Physics, University of Oslo, Oslo, Norway
- 118 Department of Physics, Oxford University, Oxford, United Kingdom
- 119 ^(a) INFN Sezione di Pavia; ^(b) Dipartimento di Fisica, Università di Pavia, Pavia, Italy
- 120 Department of Physics, University of Pennsylvania, Philadelphia, PA, United States
- 121 Petersburg Nuclear Physics Institute, Gatchina, Russia
- 122 ^(a) INFN Sezione di Pisa; ^(b) Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy
- 123 Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, PA, United States
- 124 ^(a) Laboratório de Instrumentação e Física Experimental de Partículas – LIP, Lisboa, Portugal; ^(b) Departamento de Física Teórica y del Cosmos and CAFPE, Universidad de Granada, Granada, Spain

- 125 Institute of Physics, Academy of Sciences of the Czech Republic, Praha, Czech Republic
 126 Faculty of Mathematics and Physics, Charles University in Prague, Praha, Czech Republic
 127 Czech Technical University in Prague, Praha, Czech Republic
 128 State Research Center Institute for High Energy Physics, Protvino, Russia
 129 Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom
 130 Physics Department, University of Regina, Regina, SK, Canada
 131 Ritsumeikan University, Kusatsu, Shiga, Japan
 132 ^(a) INFN Sezione di Roma I; ^(b) Dipartimento di Fisica, Università La Sapienza, Roma, Italy
 133 ^(a) INFN Sezione di Roma Tor Vergata; ^(b) Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy
 134 ^(a) INFN Sezione di Roma Tre; ^(b) Dipartimento di Fisica, Università Roma Tre, Roma, Italy
 135 ^(a) Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies – Université Hassan II, Casablanca; ^(b) Centre National de l'Energie des Sciences Techniques Nucleaires, Rabat; ^(c) Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA – Marrakech; ^(d) Faculté des Sciences, Université Mohamed Premier and LPTPM, Oujda; ^(e) Faculté des Sciences, Université Mohammed V – Agdal, Rabat, Morocco
 136 DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l'Univers), CEA Saclay (Commissariat a l'Energie Atomique), Gif-sur-Yvette, France
 137 Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz, CA, United States
 138 Department of Physics, University of Washington, Seattle, WA, United States
 139 Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom
 140 Department of Physics, Shinshu University, Nagano, Japan
 141 Fachbereich Physik, Universität Siegen, Siegen, Germany
 142 Department of Physics, Simon Fraser University, Burnaby, BC, Canada
 143 SLAC National Accelerator Laboratory, Stanford, CA, United States
 144 ^(a) Faculty of Mathematics, Physics & Informatics, Comenius University, Bratislava; ^(b) Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice, Slovak Republic
 145 ^(a) Department of Physics, University of Johannesburg, Johannesburg; ^(b) School of Physics, University of the Witwatersrand, Johannesburg, South Africa
 146 ^(a) Department of Physics, Stockholm University; ^(b) The Oskar Klein Centre, Stockholm, Sweden
 147 Physics Department, Royal Institute of Technology, Stockholm, Sweden
 148 Departments of Physics & Astronomy and Chemistry, Stony Brook University, Stony Brook, NY, United States
 149 Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom
 150 School of Physics, University of Sydney, Sydney, Australia
 151 Institute of Physics, Academia Sinica, Taipei, Taiwan
 152 Department of Physics, Technion: Israel Inst. of Technology, Haifa, Israel
 153 Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel
 154 Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece
 155 International Center for Elementary Particle Physics and Department of Physics, The University of Tokyo, Tokyo, Japan
 156 Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo, Japan
 157 Department of Physics, Tokyo Institute of Technology, Tokyo, Japan
 158 Department of Physics, University of Toronto, Toronto, ON, Canada
 159 ^(a) TRIUMF, Vancouver BC; ^(b) Department of Physics and Astronomy, York University, Toronto ON, Canada
 160 Institute of Pure and Applied Sciences, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki 305-8571, Japan
 161 Science and Technology Center, Tufts University, Medford, MA, United States
 162 Centro de Investigaciones, Universidad Antonio Narino, Bogota, Colombia
 163 Department of Physics and Astronomy, University of California Irvine, Irvine, CA, United States
 164 ^(a) INFN Gruppo Collegato di Udine; ^(b) ICTP, Trieste; ^(c) Dipartimento di Chimica, Fisica e Ambiente, Università di Udine, Udine, Italy
 165 Department of Physics, University of Illinois, Urbana, IL, United States
 166 Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden
 167 Instituto de Física Corpuscular (IFIC) and Departamento de Física Atómica, Molecular y Nuclear and Departamento de Ingeniería Electrónica and Instituto de Microelectrónica de Barcelona (IMB-CNM), University of Valencia and CSIC, Valencia, Spain
 168 Department of Physics, University of British Columbia, Vancouver, BC, Canada
 169 Department of Physics and Astronomy, University of Victoria, Victoria, BC, Canada
 170 Department of Physics, University of Warwick, Coventry, United Kingdom
 171 Waseda University, Tokyo, Japan
 172 Department of Particle Physics, The Weizmann Institute of Science, Rehovot, Israel
 173 Department of Physics, University of Wisconsin, Madison, WI, United States
 174 Fakultät für Physik und Astronomie, Julius-Maximilians-Universität, Würzburg, Germany
 175 Fachbereich C Physik, Bergische Universität Wuppertal, Wuppertal, Germany
 176 Department of Physics, Yale University, New Haven, CT, United States
 177 Yerevan Physics Institute, Yerevan, Armenia
 178 Domaine scientifique de la Doua, Centre de Calcul CNRS/IN2P3, Villeurbanne Cedex, France

^a Also at Laboratório de Instrumentação e Física Experimental de Partículas – LIP, Lisboa, Portugal.

^b Also at Faculdade de Ciências and CFNUL, Universidade de Lisboa, Lisboa, Portugal.

^c Also at Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom.

^d Also at TRIUMF, Vancouver, BC, Canada.

^e Also at Department of Physics, California State University, Fresno, CA, United States.

^f Also at Novosibirsk State University, Novosibirsk, Russia.

^g Also at Fermilab, Batavia, IL, United States.

^h Also at Department of Physics, University of Coimbra, Coimbra, Portugal.

ⁱ Also at Università di Napoli Parthenope, Napoli, Italy.

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

^k Also at Department of Physics, Middle East Technical University, Ankara, Turkey.

^l Also at Louisiana Tech University, Ruston, LA, United States.

^m Also at Department of Physics and Astronomy, University College London, London, United Kingdom.

ⁿ Also at Group of Particle Physics, University of Montreal, Montreal, QC, Canada.

^o Also at Department of Physics, University of Cape Town, Cape Town, South Africa.

^p Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan.

^q Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany.

^r Also at Manhattan College, New York, NY, United States.

^s Also at School of Physics, Shandong University, Shandong, China.

^t Also at CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France.

^u Also at School of Physics and Engineering, Sun Yat-sen University, Guanzhou, China.

^v Also at Academia Sinica Grid Computing, Institute of Physics, Academia Sinica, Taipei, Taiwan.

^w Also at DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l'Univers), CEA Saclay (Commissariat à l'Energie Atomique), Gif-sur-Yvette, France.

^x Also at Section de Physique, Université de Genève, Geneva, Switzerland.

^y Also at Departamento de Física, Universidade de Minho, Braga, Portugal.

^z Also at Department of Physics and Astronomy, University of South Carolina, Columbia, SC, United States.

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

^{ab} Also at California Institute of Technology, Pasadena, CA, United States.

^{ac} Also at Institute of Physics, Jagiellonian University, Krakow, Poland.

^{ad} Also at LAL, Univ. Paris-Sud and CNRS/IN2P3, Orsay, France.

^{ae} Also at Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom.

^{af} Also at Department of Physics, Oxford University, Oxford, United Kingdom.

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

^{ah} Also at Department of Physics, The University of Michigan, Ann Arbor, MI, United States.

* Deceased.