EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)



Phys. Lett. B 783 (2018) 392

DOI: 10.1016/j.physletb.2018.07.006



2nd August 2018

Search for a heavy Higgs boson decaying into a Z boson and another heavy Higgs boson in the $\ell\ell bb$ final state in pp collisions at $\sqrt{s} = 13$ TeV with the **ATLAS** detector

The ATLAS Collaboration

A search for a heavy neutral Higgs boson, A, decaying into a Z boson and another heavy Higgs boson, H, is performed using a data sample corresponding to an integrated luminosity of 36.1 fb⁻¹ from proton–proton collisions at $\sqrt{s} = 13$ TeV recorded in 2015 and 2016 by the ATLAS detector at the Large Hadron Collider. The search considers the Z boson decaying to electrons or muons and the H boson into a pair of b-quarks. No evidence for the production of an A boson is found. Considering each production process separately, the 95% confidencelevel upper limits on the $pp \to A \to ZH$ production cross-section times the branching ratio $H \rightarrow bb$ are in the range of 14–830 fb for the gluon–gluon fusion process and 26–570 fb for the b-associated process for the mass ranges 130-700 GeV of the H boson and 230-800 GeV of the A boson. The results are interpreted in the context of two-Higgs-doublet models.

1 Introduction

After the discovery of a Higgs boson at the Large Hadron Collider (LHC) [1, 2], one of the most important remaining questions is whether the recently discovered particle is part of an extended scalar sector or not. Additional Higgs bosons appear in all models with an extended scalar sector, such as the two-Higgs-doublet model (2HDM) [3, 4]. Such extensions are motivated by, and included in, several new physics scenarios, such as supersymmetry [5], dark matter [6] and axion [7] models, electroweak baryogenesis [8] and neutrino mass models [9].

The addition of a second Higgs doublet leads to five Higgs bosons after electroweak symmetry breaking. The phenomenology of such a model is very rich and depends on many parameters, such as the ratio of the vacuum expectation values of the two Higgs doublets $(\tan \beta)$, and the Yukawa couplings of the scalar sector [4]. When CP conservation is assumed, the model contains two CP-even Higgs bosons, h and H with $m_H > m_h$, one CP-odd, A, and two charged scalars, H^{\pm} . There have been many searches for the heavy neutral Higgs bosons of the 2HDM at the LHC, including $H \to WW/ZZ$ [10–13], $A/H \to \tau\tau/bb$ [14–16], $A \to Zh$ [17, 18] and $H \to hh$ [19, 20]. For the interpretation of these searches it is usually assumed that the heavy Higgs bosons, H and H are degenerate in mass, i.e. H and H are degenerate in H are degenerate in H and H are degenerate in H and H are degenerate in H are degenerate in H and H are degenerated in H and H are degenerated in H and H are degenerated in H are degenerated in H are degenerated in H and H are degenerated in H are degenerated in H and H are degenerated in H are degenerated in H are degenerated in H

This assumption of mass degeneracy is relaxed in this Letter by assuming $m_A > m_H$. Such a case is motivated by electroweak baryogenesis scenarios in the context of the 2HDM [21–24]. For 2HDM electroweak baryogenesis to occur, the requirement $m_A > m_H$ is favoured [21] for a strong first-order phase transition to take place in the early universe. The A boson mass is also bounded from above to be less than approximately 800 GeV, whereas the lighter CP-even Higgs boson, h, is required to have properties similar to those of a Standard Model (SM) Higgs boson and is assumed to be the Higgs boson with mass of 125 GeV that was discovered at the LHC [21]. Under such conditions and for large parts of the 2HDM parameter space, the CP-odd Higgs boson, A, decays into ZH [21, 25]. The production of the A boson in the relevant 2HDM parameter space proceeds mainly through gluon–gluon fusion and b-associated production at the LHC.

This search for $A \to ZH$ decays uses proton–proton collision data at $\sqrt{s} = 13$ TeV corresponding to an integrated luminosity of 36.1 fb⁻¹ recorded by the ATLAS detector at the LHC. The search considers only $Z \to \ell\ell$, where $\ell = e, \mu$, to take advantage of the clean leptonic final state, and $H \to bb$, because of its large branching ratio. This final state allows full reconstruction of the A boson's decay kinematics. The reconstruction of the A boson's invariant mass uses the assumed value of the mass of the H boson to improve its resolution. The final state is also categorised by the presence of two or three b-tagged jets to take advantage of the b-associated production mechanism. The CMS Collaboration has published a similar search at $\sqrt{s} = 8$ TeV [26]. This Letter reports the result of a search at $\sqrt{s} = 13$ TeV, which extends the previous search by considering explicitly the gluon–gluon fusion and b-associated production processes as well as both narrow and wide widths of the A boson.

2 ATLAS detector

The ATLAS detector is a general-purpose particle detector, described in detail in Ref. [27]. It includes an inner detector surrounded by a 2 T superconducting solenoid, electromagnetic and hadronic calorimeters and a muon spectrometer with a toroidal magnetic field. The inner detector consists of a high-granularity silicon pixel detector, including the insertable B-layer [28] installed in 2014, a silicon microstrip detector,

and a straw-tube tracker. It provides precision tracking of charged particles with pseudorapidity $|\eta| < 2.5.^1$ The calorimeter system covers the pseudorapidity range $|\eta| < 4.9$. It is composed of sampling calorimeters with either liquid argon or scintillator tiles as the active medium. The muon spectrometer provides muon identification and measurement for $|\eta| < 2.7$. A two-level trigger system [29] is employed to select events for offline analysis, which reduced the average recorded collision rate to about 1 kHz.

3 Data and simulation

The data used in this search were collected during 2015 and 2016 from $\sqrt{s} = 13 \,\text{TeV}$ proton–proton collisions and correspond to an integrated luminosity of 36.1 fb⁻¹, which includes only data-taking periods where all relevant detector subsystems were operational. The data sample was collected using a set of single-muon and single-electron triggers. The lowest- p_T trigger thresholds depend on the data-taking period and are in the range of 20–26 GeV for the single-muon triggers and 24–26 GeV for the single-electron triggers.

Simulated signal events with *A* bosons produced by gluon–gluon fusion were generated at leading order with MadGraph5_aMC@NLO 2.3.3 [30, 31] using Pythia 8.210 [32] with a set of tuned parameters called the A14 tune [33] for parton showering. For the generation of *A* bosons produced in association with *b*-quarks, MadGraph5_aMC@NLO 2.1.2 [31, 34, 35] was used following Ref. [36] together with Pythia 8.212 and the A14 tune for parton showering. The gluon–gluon fusion production used NNPDF2.3LO [37] as the parton distribution functions (PDF), while the *b*-associated production used CT10nlo_nf4 [38]. The signal samples were generated for *A* bosons with masses in the range of 230–800 GeV and widths up to 20% of the mass and for narrow-width *H* bosons with masses in the range of 130–700 GeV.

Background events from the production of *W* and *Z* bosons in association with jets were simulated with Sherpa 2.2.1 [39] using the NNPDF3.0NNLO PDF set [40]. Top-quark-pair production was simulated with Powheg-Box v2 [41–43] and the CT10nlo PDF set [38], while the electroweak single-top-quark production was simulated with Powheg-Box v1 and the fixed four-flavour PDF set CT10nlo_f4 [38]. The parton shower was performed with Pythia 6.428 [44] using the Perugia 2012 set of tuned parameters [45]. The production of top-quark pairs in association with a vector boson was simulated using Madgraph5_aMC@NLO 2.2.3 and the NNPDF3.0NLO PDF set, whereas Pythia 8.186 was used for the parton shower with the A14 tune. Production of *WW*, *ZZ* and *WZ* pairs was simulated using Sherpa 2.2.1 and the NNPDF3.0NNLO PDF set. Finally, SM Higgs boson production in association with a *Z* boson was generated with Powheg-Box v2 and the NNPDF3.0NLO PDF set, whereas the parton shower was performed with Pythia 8.186 using the AZNLO tune [46].

The modelling of bottom- and charm-hadron decays was performed with the EvtGen v1.2.0 package [47] for all samples apart from those simulated with Sherpa. The simulated events were overlaid with inelastic proton-proton collisions to account for the effect of multiple interactions occurring in the same and neighbouring bunch crossings ('pile-up'). These events were generated using Pythia 8 with the A2

ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the centre of the detector and the *z*-axis along the beam pipe. The *x*-axis points from the IP to the centre of the LHC ring, and the *y*-axis points upward. Cylindrical coordinates (r,ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the beam pipe. The pseudorapidity is defined in terms of the polar angle, θ , as $\eta = -\ln\tan(\theta/2)$. Transverse momenta are computed from the three-momenta, \vec{p} , as $p_T = |\vec{p}| \sin \theta$.

tune [48] and the MSTW2008LO PDF set [49]. The events were reweighted so that the distribution of the average number of interactions per bunch crossing agreed with the data.

All generated background samples were passed through the Geant4-based [50] detector simulation [51] of the ATLAS detector. The ATLFAST2 simulation [51] was used for the signal samples to allow for the generation of many different A and B boson masses. The simulated events were reconstructed in the same way as the data.

4 Object reconstruction

Electrons are reconstructed from energy clusters in the electromagnetic calorimeter that are matched to tracks in the inner detector [52]. Electrons are required to have $|\eta| < 2.47$ and $p_T > 7$ GeV. To distinguish electrons from jets, isolation and quality requirements are applied [53]. The isolation requirements (the 'LooseTrackOnly' working point) are defined by the p_T of tracks within cones around the electron with a size that decreases as a function of the transverse energy. The quality requirements (the 'Loose' working point) refer to both the inner detector track and the calorimeter shower shape. The efficiency for an electron to be reconstructed and meet these criteria is about 85% for electron $p_T > 7$ GeV and increases to about 90% for $p_T > 27$ GeV.

Muons are reconstructed by matching tracks reconstructed in the inner detector to tracks or track segments in the muon spectrometer [54]. Muons used for this search must have $|\eta| < 2.5$ and $p_T > 7$ GeV, and are required to satisfy 'LooseTrackOnly' isolation requirements, similar to those used for electrons, as well as inner detector and muon spectrometer track 'Loose' quality criteria, corresponding to an efficiency of about 97%.

Jets are reconstructed using the anti- k_t algorithm [55, 56] with radius parameter R=0.4 from clusters of energy deposits in the calorimeter system [57]. Candidate jets are required to have $p_T>20$ GeV ($p_T>30$ GeV) for $|\eta|<2.5$ ($2.5<|\eta|<4.5$). Low- p_T jets from pile-up are rejected by a multivariate algorithm that uses properties of the reconstructed tracks in the event [58].

Jets containing b-hadrons are selected using a multivariate tagging algorithm (b-tagging) [59, 60]. The energy of the tagged jet (b-jet) is corrected for the average energy loss from semileptonic decays of b-hadrons and out-of-jet-cone tracks with large impact parameters [61]. The b-tagging efficiency for the jet p_T range used in this analysis is between 65% and 75%. Applying the b-tagging algorithm reduces the number of light-flavour (c-quark) jets by a factor of 250–550 (10–20), depending on the jet kinematics.

When electrons, muons and jets are spatially close, these algorithms can lead to ambiguous identifications. An overlap removal procedure [61] is therefore applied to uniquely identify these objects.

The missing transverse momentum, $E_{\rm T}^{\rm miss}$, is computed using reconstructed and calibrated leptons, photons and jets [62]. Tracks from the primary vertex² which are not associated with any identified lepton or jet are also taken into account in the $E_{\rm T}^{\rm miss}$ reconstruction [63].

² The primary vertex is taken to be the reconstructed vertex with the highest Σp_T^2 of the associated tracks.

5 Event selection

The decay $A \to ZH \to \ell\ell bb$ features a pair of oppositely charged, same flavour leptons and two b-jets. Three resonances can be formed by combining the selected objects: the Z boson $(\ell\ell)$, the H boson (bb) and the A boson $(\ell\ell bb)$. Moreover, additional b-jets may be present if the A boson is produced via the b-associated production mechanism. These features are used to define the event selection as summarised in Table 1.

The events recorded by the single-muon and the single-electron triggers are required to contain exactly two muons or two electrons, respectively. At least one of the leptons must have $p_T > 27$ GeV. Only events that contain a primary vertex with at least two associated tracks with $p_T > 400$ MeV [64] are considered. In the case of muons, they are required to have opposite electric charges. No such requirement is applied to electrons due to their non-negligible charge misidentification rates resulting from conversions of bremsstrahlung photons. The invariant mass of the lepton pair, $m_{\ell\ell}$, must be in the range of 80–100 GeV to be compatible with the mass of the Z boson.

The $H \to bb$ decay is reconstructed by requiring at least two b-jets with the highest- p_T one having $p_T > 45$ GeV. When more than two b-jets are present, the two highest- p_T b-jets are considered to be from the H decay. Requiring b-jets increases the fraction of top-quark background in the signal region, including top-quark pair and single-top-quark production. This is reduced by requiring $E_T^{\rm miss}/\sqrt{H_T} < 3.5$ GeV^{1/2}, where H_T is the scalar sum of the p_T of all jets and leptons in the event. In addition, a requirement that reduces the Z+jets background is also applied: $\sqrt{\sum p_T^2}/m_{\ell\ell bb} > 0.4$, where $m_{\ell\ell bb}$ is the four-body invariant mass of the two-lepton, two-b-jet system assigned to the A boson and the summation is performed over the p_T of these objects.

Subsequently, two categories are defined: the $n_b = 2$ category, which contains events with exactly two b-jets, and the $n_b \geq 3$ category, which contains events with three or more b-jets. For the gluon–gluon fusion production, 94%–97% of the events passing the above selection fall into the $n_b = 2$ category, depending on the assumed m_A and m_H . However for the b-associated production, 27%–36% fall into the $n_b \geq 3$ category. The remaining b-associated produced signal events are categorised as $n_b = 2$ events, even though more than two b-jets are expected, due to the relatively soft p_T spectrum of the associated b-jets and the geometric acceptance of the tracker.

Finally, the invariant mass of the two leading b-jets, m_{bb} , must be compatible with the assumed H boson mass by satisfying the requirement of $0.85 \cdot m_H - 20$ GeV $< m_{bb} < m_H + 20$ GeV for the $n_b = 2$ category, and $0.85 \cdot m_H - 25$ GeV $< m_{bb} < m_H + 50$ GeV for the $n_b \ge 3$ category. The wider window for $n_b \ge 3$ is motivated by a slightly degraded resolution due to potential b-jet mis-assignments (see later). The overall signal efficiency of the $n_b = 2$ category after this requirement is 5%–11% (3%–7%) for gluon–gluon fusion (b-associated production), depending on the m_A and m_H values. Similarly, the efficiency of the $n_b \ge 3$ category is 2%–4% for the b-associated production. The signal region selection is summarised in Table 1.

The $m_{\ell\ell bb}$ distribution after the m_{bb} requirement is used to discriminate between signal and background. To improve the $m_{\ell\ell bb}$ resolution, the bb system's four-momentum components are scaled to match the assumed H boson mass and the $\ell\ell$ system's four-momentum components are scaled to match the Z boson mass. This procedure, performed after the event selection, improves the $m_{\ell\ell bb}$ resolution by a factor of two without significantly distorting the background distributions, resulting in an A boson mass resolution of 0.3%-4%.

Table 1: Summary of the event selection for signal and control regions.

Single-electron or single-muon trigger

Exactly 2 leptons (e or μ) ($p_T > 7$ GeV) with the leading one having $p_T > 27$ GeV Opposite electric charge for $\mu\mu$ or $e\mu$ pairs; 80 GeV $< m_{\ell\ell}$, $m_{e\mu} < 100$ GeV, $\ell = e$, μ At least 2 b-jets ($p_T > 20$ GeV) with one of them having $p_T > 45$ GeV

$$E_{\rm T}^{\rm miss}/\sqrt{H_{\rm T}} < 3.5 \; {\rm GeV}^{1/2}, \; \sqrt{\Sigma p_{\rm T}^2}/m_{\ell\ell bb} > 0.4$$

	$n_b = 2$ category	$n_b \ge 3$ category		
	Exactly 2 b-tagged jets	At least 3 b-tagged jets		
Signal region	<i>ee</i> or $\mu\mu$ pair 0.85 · m_H – 20 GeV < m_{bb} < m_H + 20 GeV	<i>ee</i> or $\mu\mu$ pair 0.85 · m_H -25 GeV < m_{bb} < m_H +50 GeV		
Top control region	$e\mu$ pair $0.85 \cdot m_H - 20 \text{ GeV} < m_{bb} < m_H + 20 \text{ GeV}$	$e\mu$ pair $0.85 \cdot m_H - 25 \text{ GeV} < m_{bb} < m_H + 50 \text{ GeV}$		
Z+jets control region	<i>ee</i> or $\mu\mu$ pair $m_{bb} < 0.85 \cdot m_H - 20 \text{ GeV}$ or $m_{bb} > m_H + 20 \text{ GeV}$	<i>ee</i> or $\mu\mu$ pair $m_{bb} < 0.85 \cdot m_H - 25 \text{ GeV}$ or $m_{bb} > m_H + 50 \text{ GeV}$		

The dominant backgrounds after these selections are from Z+jets and top-quark production. For topquark-pair production, a very pure (> 99% of predicted events) control region is used to determine the normalisation of the background, whereas its shape in the signal region is taken from the simulation. This control region is defined by keeping the same selection as discussed previously, apart from an opposite-flavour lepton criterion, i.e., an opposite-charge $e\mu$ pair is required instead of an ee or $\mu\mu$ pair (see also Table 1). The shape of the Z+jets background distribution is obtained from simulation and the normalisation is extracted from data together with the signal (see also Section 7). This procedure is possible because of the very different shapes of the $m_{\ell\ell bb}$ distributions from signal and Z+jets events. The normalisation of the Z+jets production is further constrained by a control region defined by inverting the m_{bb} window criterion for each H boson mass hypothesis (see also Table 1). The control regions are distinct for the $n_b = 2$ and the $n_b \ge 3$ categories, since the accuracy of the background simulation depends on the number of b-jets present in the event. Backgrounds from diboson, single top, and Higgs boson production, as well as top-quark-pair production in association with a vector boson, give a typical contribution of $\sim 5\%$ to the total background. Their shapes are taken from simulation, whereas they are normalised using precise inclusive cross-sections calculated from theory. The diboson samples are normalised using next-to-next-to-leading-order (NNLO) cross-sections [65–68]. Single-top-quark production and top-quark-pair production in association with vector bosons are normalised to next-toleading-order (NLO) cross-sections from Refs. [69–71] and Ref. [31], respectively. The normalisation of the Higgs boson production in association with a vector boson follows the recommendations of Ref. [36] using NNLO QCD and NLO electroweak corrections.

6 Signal modelling

The good $m_{\ell\ell bb}$ mass resolution together with the fact that theory models often predict A bosons with large widths inflates the number of signal mass and width hypotheses that need to be considered. For this reason, the $m_{\ell\ell bb}$ distributions are taken from simulation of a limited number of (m_A, m_H) mass points and an interpolation using analytical functions is employed for the rest.

The $m_{\ell\ell bb}$ distributions for A bosons produced by gluon—gluon fusion and with negligible widths compared with the experimental resolution are found to be adequately described by the ExpGaussExp (EGE) function [72]:

$$f_{\text{EGE}}(m; a, \sigma, k_L, k_H) = \begin{cases} e^{\frac{1}{2}k_L^2 + k_L\left(\frac{m-a}{\sigma}\right)} \\ e^{-\frac{1}{2}\left(\frac{m-a}{\sigma}\right)^2} \end{cases} \text{ for } \begin{cases} \frac{m-a}{\sigma} \le -k_L \\ -k_L < \frac{m-a}{\sigma} \le k_H \end{cases}$$
$$\frac{e^{\frac{1}{2}k_H^2 - k_H\left(\frac{m-a}{\sigma}\right)}}{e^{\frac{1}{2}k_H^2 - k_H\left(\frac{m-a}{\sigma}\right)}} \end{cases}$$

On the other hand, $m_{\ell\ell bb}$ distributions for A bosons from b-associated production, also with negligible widths compared with the experimental resolution, are better described by a double-Gaussian Crystal Ball (DSCB) function [73]:

$$f_{\text{DSCB}}(m;a,\sigma,k_L,k_H,n_1,n_2) \ = \ \begin{cases} g(m;a,-\sigma,k_L,n_1) \cdot \mathrm{e}^{-\frac{1}{2}k_L^2} \\ \mathrm{e}^{-\frac{1}{2}\left(\frac{m-a}{\sigma}\right)^2} \\ g(m;a,\sigma,k_H,n_2) \cdot \mathrm{e}^{\frac{1}{2}k_H^2} \end{cases} \qquad \text{for} \ \begin{cases} \frac{m-a}{\sigma} \leq -k_L \\ -k_L < \frac{m-a}{\sigma} \leq k_H \\ \frac{m-a}{\sigma} > k_H \end{cases}$$

where $g(m; a, \sigma, k, n) = [(|k|/n)(n/|k| - |k| + (m-a)/\sigma)]^{-n}$. Both functions consist of a Gaussian core with mean a and variance σ^2 , whereas the rest of the parameters (k_L, k_H, n_1, n_2) describe the tails. The DSCB function describes better than the EGEE function the slightly longer tails of the mass distribution of the b-associated production compared to gluon–gluon fusion. This is due to the few cases in which the b-quark produced in association with the Higgs boson is taken to be one of the b-quarks from the Higgs

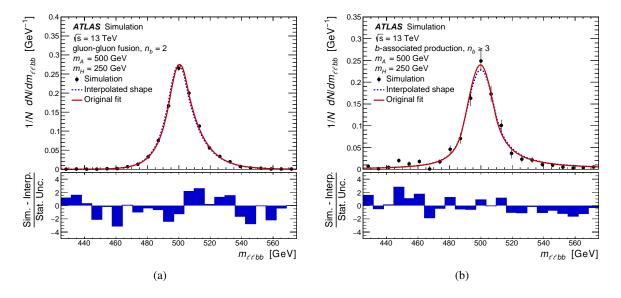


Figure 1: Simulated signal $m_{\ell\ell bb}$ distributions (closed circles) assuming $m_A = 500$ GeV and $m_H = 250$ GeV for the following cases: (a) the gluon–gluon fusion in the $n_b = 2$ category and (b) b-associated production in the $n_b \geq 3$ category. Signal parameterisations are overlaid for comparison. The solid curves are from parameter values obtained directly from the fits to the simulated distributions, whereas the dashed curves use the interpolated parameter values. The differences between the simulation and the interpolated shape divided by the statistical uncertainties of the simulation are shown in the bottom panels. The distributions for the $n_b = 2$ category of the b-associated production are similar to the $n_b \geq 3$ shape shown.

boson decay. The values of the function parameters are extracted from unbinned maximum-likelihood fits to the simulated $m_{\ell\ell bb}$ distributions. The core mean, a, is parameterised using a linear function of m_A . The core width, σ , is observed to monotonically increase with $\Delta m \equiv m_A - m_H$ and is parameterised with a third-degree polynomial. The rest of the parameters are largely constant and are fixed to their average values from the fits, with the exception of mass points with $\Delta m = 100$ GeV. The distributions at mass points with $\Delta m = 100$ GeV correspond to the smallest mass splitting considered in this search and are close to the kinematic cutoff. Their non-core parameters are fixed to the average fit values obtained from signal samples with this mass splitting only. As an example of the performance of this procedure, Figure 1 shows a comparison for the $(m_A, m_H) = (500, 250)$ GeV mass point between the simulated distributions and the parametric functions described previously. The cores of the $m_{\ell\ell bb}$ distributions are well-parameterised by the chosen functional forms. The small differences seen in the tails of some distributions between the functional forms and the simulations have only negligible effects on the final results, and moreover they are included as a source of systematic uncertainty.

The previously described parameterisation applies to signal samples generated with narrow-width A bosons. In some regions of 2HDM parameter space relevant to this analysis, the A boson's width is significant compared with the detector resolution while the H boson's width remains negligible. In order to model the $m_{\ell\ell bb}$ shape of A bosons with large natural widths, a modified Breit–Wigner distribution³ is convolved with the EGE and DSCB functions. The procedure is validated by comparing the results of the convolution with those of the simulated samples of A bosons with large natural widths. Widths of up to 20% of the A boson mass are considered. An example of signal distributions with large natural widths is shown in Figure 2 for the same signal points used in Figure 1.

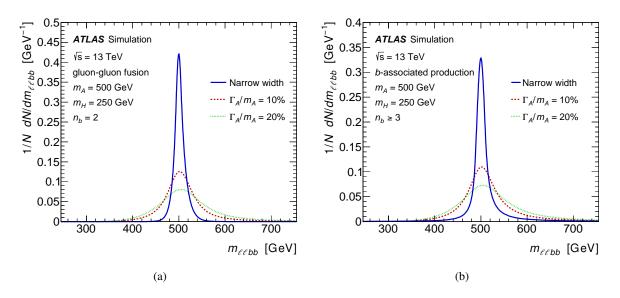


Figure 2: The interpolated signal $m_{\ell\ell bb}$ distribution shapes assuming $m_A = 500$ GeV and $m_H = 250$ GeV and various A boson widths for the following cases: (a) gluon–gluon fusion in the $n_b = 2$ category and (b) b-associated production in the $n_b \geq 3$ category. The distributions for the $n_b = 2$ category of the b-associated production are similar to the $n_b \geq 3$ shape shown.

Finally, the signal efficiencies for the interpolated mass points are obtained through separate two-

³ The modification is the multiplication of the Breit–Wigner distribution with a log-normal distribution to account for the distortion due to the event selection.

7 Fit model and systematic uncertainties

The $m_{\ell\ell bb}$ distribution is expected to exhibit a resonant structure if signal events are present, while background events result in a smooth shape. Therefore $m_{\ell\ell bb}$ is chosen as the final signal and background discriminating variable. The shape differences in the $m_{\ell\ell bb}$ distribution between the signal and background contributions are exploited through binned maximum-likelihood fits of the signal-plus-background hypotheses to extract potential signal contributions. The fits are based on the statistical framework described in Refs. [75–77]. For a given mass hypothesis of (m_A, m_H) , the likelihood is constructed as the product of Poisson statistics in $m_{\ell\ell bb}$ bins:

$$L(\mu, \vec{\alpha}, \vec{\theta} | m_A, m_H) = \prod_{i=\text{bins}} \text{Poisson}\left(N_i | \left(\mu \times S_i(m_A, m_H, \vec{\theta}) + B_i(\vec{\alpha}, \vec{\theta})\right)\right) \cdot G(\vec{\theta}).$$

Here N_i is the number of observed events and $S_i(m_A, m_H, \vec{\theta})$ and $B_i(\vec{\alpha}, \vec{\theta})$ are the expected number of signal and estimated background events in bin i. The vector $\vec{\alpha}$ represents free background normalisation scale factors (described later) and vector $\vec{\theta}$ denotes all non-explicitly listed parameters of the likelihood function such as nuisance parameters associated with systematic uncertainties. The function $G(\vec{\theta})$ represents constraints on $\vec{\theta}$. The parameter of interest, μ , is a multiplicative factor to the expected signal rate and is called the signal-strength parameter. The $m_{\ell\ell bb}$ bin widths are chosen according to the expected detector resolution and taking into account the statistical uncertainty related to the number of background Monte Carlo events. The bin centres are adjusted such that at least 68% of the test signal is contained in one bin. Only the $n_b = 2$ category is considered for the gluon–gluon fusion production while both the $n_b = 2$ and $n_b \geq 3$ categories are included in the likelihood calculation for the b-associated production.

For each bin, S_i is calculated from the total integrated luminosity, the theoretical cross-section for the signal and its selection efficiency. The sum of all background contributions in the bin, B_i , is estimated from simulation. However, the $t\bar{t}$ and Z+jets control regions are included in the likelihood calculation as one bin each, to help constrain their respective contributions in the signal regions. This is achieved by introducing two free normalisation scale factors, represented by $\vec{\alpha}$, for each category for the two most relevant background contributions: one for $t\bar{t}$ and the other for the heavy-flavour component (Z+h.f.) of the Z+jets contribution. These scale factors are applied to their respective contributions estimated from the simulations and their values are determined from the fit. Typical values of scale factors are close to unity. Taking (m_A , m_H) = (700, 200) GeV as an example, the Z+h.f. scale factor is 1.12 \pm 0.09 for the n_b = 2 category and 1.1 \pm 0.2 for the n_b \geq 3 category. Similarly, the $t\bar{t}$ scale factors are 0.96 \pm 0.06 and 1.2 \pm 0.2 for the two corresponding categories.

Systematic uncertainties are incorporated in the likelihood as nuisance parameters with either Gaussian or log-normal constraint terms. They include both the experimental and theoretical sources of uncertainty. Experimental uncertainties comprise those in the luminosity measurement, trigger, object identification, energy/momentum scale and resolution as well as underlying event and pile-up modelling. These uncertainties, discussed in Refs. [10, 61], impact the simulations of signal and background processes. Theoretical uncertainties include both the signal and background modelling. For the signal modelling, uncertainties due to the factorisation and renormalisation scale choice, the initial- and final-state radiation treatment and the PDF choice are considered. Additional systematic uncertainties are assigned to cover the differences in signal efficiencies and $m_{\ell\ell bb}$ parameter values between the interpolations and

the simulations. For the background modelling, the most important sources of systematic uncertainty are from the modelling of the m_{bb} and the $p_{\rm T}^{\ell\ell}$ distributions of Z+jets. They are taken to be the difference between the data and simulation of the selected samples before the event categorisation and the m_{bb} requirement. The samples are dominated by the Z+jets contribution, and any potential signal contamination is expected to be negligible. For other background processes, they are obtained by varying the factorisation and renormalisation scales, the amount of initial- and final-state radiation, and the choices of PDF parameterisations.

The effect of these systematic uncertainties on the search is studied using the signal-strength parameter μ for hypothesised signal production. Uncertainties having the largest impact depend on the choice of (m_A, m_H) signal point. Table 2 shows the relative uncertainties in the best-fit μ value from the leading sources of systematic uncertainty for two example mass points of both gluon–gluon fusion and b-associated production of a narrow-width A boson. The leading sources of systematic uncertainty are similar for other mass points studied and for larger A boson widths. For all cases, the limited size of the simulated samples has the largest impact on the search sensitivity among all the sources of systematic uncertainty. While systematic uncertainties and the statistical uncertainty of the data have comparable impact at low masses, the search sensitivity is mostly determined at high masses by the limited size of the data sample.

Table 2: The effect of the most important sources of uncertainty on the signal-strength parameter at two example mass points of $(m_A, m_H) = (230, 130)$ GeV and $(m_A, m_H) = (700, 200)$ GeV for both the gluon–gluon fusion and b-associated production of a narrow-width A boson. The signal cross-sections are taken to be the expected median upper limits (see Section 8). JES and JER stand for jet energy scale and jet energy resolution, 'Sim. stat.' for simulation statistics, and 'Bkg. model.' for the background modelling.

Gluon-gluon fusion production				b-associated production			
(230, 130) GeV		(700, 200) GeV		(230, 130) GeV		(700, 200) GeV	
Source	$\Delta\mu/\mu$ [%]	Source	$\Delta\mu/\mu$ [%]	Source	$\Delta\mu/\mu$ [%]	Source	$\Delta\mu/\mu$ [%]
Data stat.	32	Data stat.	49	Data stat.	35	Data stat.	46
Total syst.	36	Total syst.	22	Total syst.	38	Total syst.	26
Sim. stat.	22	Sim. stat.	10	Sim. stat.	26	Sim. stat.	12
Bkg. model.	16	Bkg. model.	10	b-tagging	14	Bkg. model.	11
JES/JER	12	Theory	9.1	JES/JER	11	b-tagging	10
b-tagging	9.9	b-tagging	8.5	Bkg. model.	9.8	Theory	6.8
Theory	7.5	Leptons	4.2	Theory	7.0	JES/JER	6.2

8 Results

The $m_{\ell\ell bb}$ distributions from different m_{bb} mass windows are scanned for potential excesses beyond the background expectations through signal-plus-background fits. The scan is performed in steps of 10 GeV for both the m_A range 230–800 GeV and the m_H range 130–700 GeV, such that $m_A - m_H \ge 100$ GeV. The step sizes are chosen to be compatible with the detector resolution for $m_{\ell\ell bb}$ and m_{bb} .

Figure 3 shows the $m_{\ell\ell bb}$ distributions in the $n_b = 2$ and $n_b \ge 3$ categories for the m_{bb} window defined for $m_H = 200$ GeV. The m_{bb} distributions before any m_{bb} window cut are also shown in this figure. The $m_{\ell\ell bb}$ distributions for two other m_{bb} windows, defined for $m_H = 300$ GeV and $m_H = 500$ GeV are shown in Figure 4. In all cases, the data are found to be well described by the background model. The most significant excess for the gluon–gluon fusion production signal assumption is at the $(m_A, m_H) = (750, 610)$ GeV signal point, for which the local (global) significance [78] is 3.5 (2.0) standard deviations. For the *b*-associated

production, the most significant excess is at the $(m_A, m_H) = (510, 130)$ GeV signal point, for which the local (global) significance is 3.0 (1.2) standard deviations. The significances are calculated for each production process separately ignoring the contribution from the other.

In the absence of a statistically significant excess, constraints on the production of $A \to ZH$ followed by the $H \to bb$ decay are derived. The method of Ref. [79] is used to calculate 95% confidence level (CL) upper bounds on the product of cross-section and decay branching ratios, $\sigma \times \mathcal{B}(A \to ZH) \times \mathcal{B}(H \to bb)$, using the asymptotic approximation [77]. The upper limits are shown in Figure 5 for a narrow-width A boson produced via gluon–gluon fusion and b-associated production. As for the significance calculations above, these limits are derived separately for each production process. For the gluon–gluon fusion limits, only the $n_b = 2$ category is used. For the b-associated production, both the $n_b = 2$ and $n_b \geq 3$ categories are used. The upper limit for gluon–gluon fusion varies from 14 fb for the $(m_A, m_H) = (800, 140)$ GeV signal point to 830 fb for the $(m_A, m_H) = (240, 130)$ GeV signal points. For the b-associated production the upper limits vary from 26 fb for the $(m_A, m_H) = (780, 680)$ GeV signal point to 830 fb for the $(m_A, m_H) = (240, 130)$ GeV signal point with expected limits of 46 fb and 360 fb, respectively.

The results of the search are interpreted in the context of the 2HDM. For this interpretation, several assumptions are made to reduce the number of free parameters in the model. The charged Higgs boson is assumed to have the same mass as the A boson. The 2HDM parameter m_{12}^2 is fixed to $m_A^2 \tan \beta/(1+\tan^2 \beta)$. The lightest Higgs boson of the model, h, is assumed to have a mass of 125 GeV and its couplings are set to be the same as those of the SM Higgs boson, by choosing $\cos(\beta - \alpha) = 0$. The widths of the A and A bosons are taken from the predictions of the 2HDM. The cross-sections for A boson production in the 2HDM are calculated using up to NNLO QCD corrections for gluon–gluon fusion and b-associated production in the five-flavour scheme as implemented in SusHi [80–83]. For b-associated production a cross-section in the four-flavour scheme is also calculated as described in Refs. [84, 85] and the results are combined with the five-flavour scheme calculation following Ref. [86]. The Higgs boson widths and branching ratios are calculated using 2HDMC [87]. The procedure for the calculation of the cross-sections and branching ratios, as well as for the choice of 2HDM parameters, follows Ref. [36].

Since both gluon–gluon fusion and b-associated production are expected, a new signal model weighted by the predicted cross sections of the two processes is built for every point tested in the 2HDM parameter space. Upper limits on $\sigma \times \mathcal{B}(A \to ZH) \times \mathcal{B}(H \to bb)$ with σ here including contributions from both processes are recalculated and compared with the 2HDM predictions to derive the limits in the 2HDM parameter space. Figure 6 shows the observed and expected limits for Type I, Type II, 'lepton specific' and 'flipped' 2HDMs in the (m_A, m_H) plane for various $\tan \beta$ values. Type-II and flipped show similar constraints because in these models the Yukawa couplings are the same for all fermions apart from leptons. The same holds when comparing Type-I and lepton-specific 2HDM, where the main reason for the difference in sensitivity is the increased significance of the $H \to \tau\tau$ decay in the lepton-specific model. The gluon–gluon fusion production cross section decreases with increasing $\tan \beta$, which explains the loss of sensitivity in Type-I and lepton specific for large $\tan \beta$ values. In the case of Type-II and flipped, at large $\tan \beta$ values it is the b-associated production that dominates instead of the gluon–gluon fusion in this region. For instance the exclusion can reach up to $m_H \approx 400$ GeV at lower tan β (less than 10) and $m_H \approx 600$ GeV at higher tan β (more than 20). At low tan β values the Higgs boson branching fraction to $t\bar{t}$ becomes sizable, and this is what limits the sensitivity to below $m_H \approx 350$ GeV in all models examined here.

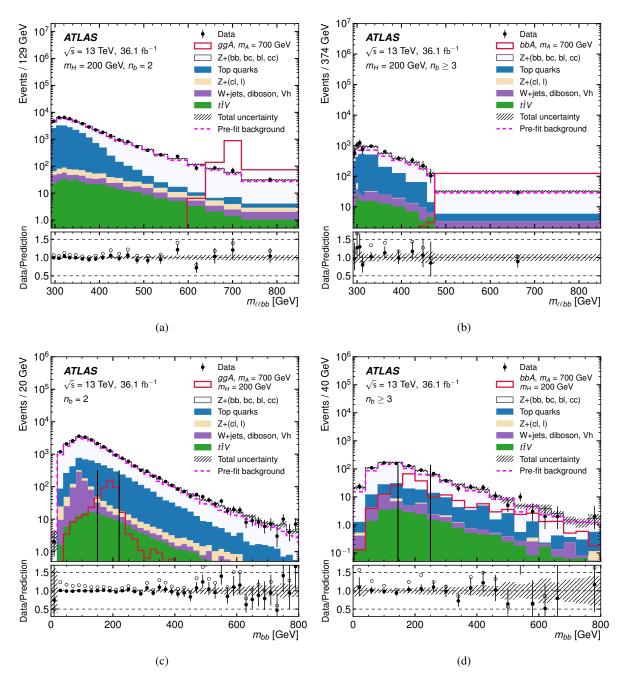


Figure 3: The $m_{\ell\ell bb}$ mass distribution for the m_{bb} window defined for $m_H=200$ GeV for (a) the $n_b=2$ and (b) the $n_b\geq 3$ category. The m_{bb} distribution before any m_{bb} window cuts is shown in (c) and (d) for the $n_b=2$ and the $n_b\geq 3$ categories, respectively. Signal distributions for $m_A=700$ GeV, $m_H=200$ GeV are also shown for gluon–gluon fusion production in (a, c) and b-associated production in (b, d) assuming production cross-sections times the branching ratios $\mathcal{B}(A\to ZH)$ and $\mathcal{B}(H\to bb)$ of 1 pb. The solid dots in the lower panels represent the ratio of the data to the post-fit background prediction, while the open circles are the ratio of the data to the pre-fit background prediction. In the m_{bb} distributions in (c, d) the m_{bb} window boundaries are also shown as vertical solid lines. The window efficiencies for the signals shown on the plots are about $(77.4\pm1.0)\%$ for (c) and $(58.3\pm2.6)\%$ for (d). The $m_{\ell\ell bb}$ distributions in (a) and (b) use variable bin widths. The last bin is used as a reference for normalisation, and its width is noted in the y-axis label. In this case, the content displayed in a bin is the number of events shown in that bin multiplied by the ratio of widths of the last bin relative to the bin shown.

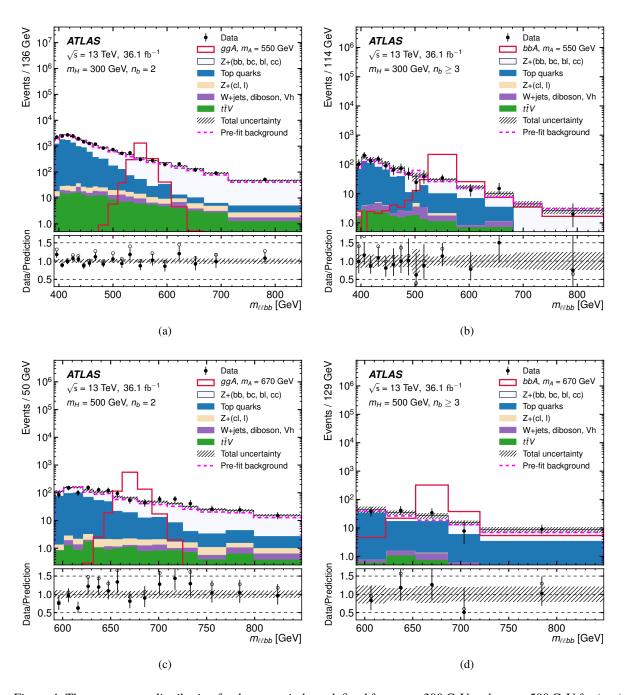


Figure 4: The $m_{\ell\ell bb}$ mass distribution for the m_{bb} windows defined for $m_H=300$ GeV and $m_H=500$ GeV for (a, c) the $n_b=2$ and (b, d) the $n_b\geq 3$ category, respectively. Signal distributions are also shown for gluon–gluon fusion production in (a, c) and b-associated production in (b, d) assuming production cross-sections times the branching ratios $\mathcal{B}(A\to ZH)$ and $\mathcal{B}(H\to bb)$ of 1 pb. The same conventions as in Figure 3 are used.

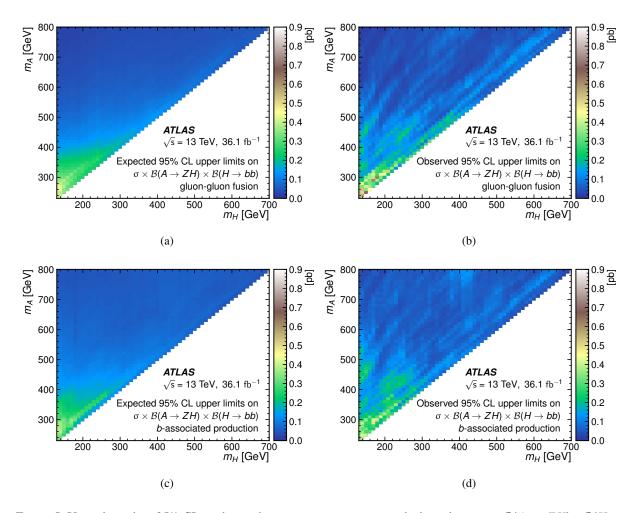


Figure 5: Upper bounds at 95% CL on the production cross-section times the branching ratio $\mathcal{B}(A \to ZH) \times \mathcal{B}(H \to bb)$ in pb for (a, b) gluon–gluon fusion and (c, d) *b*-associated production. The expected upper limits are shown in (a) and (c) and the observed upper limits are shown in (b) and (d).

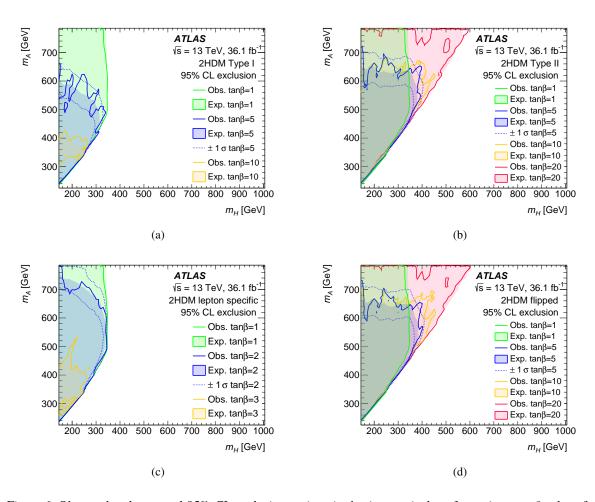


Figure 6: Observed and expected 95% CL exclusion regions in the (m_A, m_H) plane for various $\tan \beta$ values for (a) Type I, (b) Type II, (c) lepton specific and (d) flipped 2HDM.

9 Conclusion

Data recorded by the ATLAS experiment at the LHC, corresponding to an integrated luminosity of $36.1~{\rm fb^{-1}}$ from proton–proton collisions at a centre-of-mass energy 13 TeV, are used to search for a heavy Higgs boson, A, decaying into ZH, where H denotes a heavy Higgs boson with mass $m_H > 125~{\rm GeV}$. The A boson is assumed to be produced via either gluon–gluon fusion or b-associated production. No significant deviation from the SM background predictions are observed in the $ZH \to \ell\ell\ell bb$ final state that is considered in this search. Considering each production process separately, upper limits are set at the 95% confidence level for $\sigma \times \mathcal{B}(A \to ZH) \times \mathcal{B}(H \to bb)$ of 14–830 fb for gluon–gluon fusion and 26–570 fb for b-associated production of a narrow A boson for the mass ranges 130–700 GeV of the H boson and 230–800 GeV of the A boson. Taking into account both production processes, this search tightens the constraints on the 2HDM in the case of large mass splittings between its heavier neutral Higgs bosons.

Acknowledgements

We thank CERN for the very successful operation of the LHC, as well as the support staff from our institutions without whom ATLAS could not be operated efficiently.

We acknowledge the support of ANPCyT, Argentina; YerPhI, Armenia; ARC, Australia; BMWFW and FWF, Austria; ANAS, Azerbaijan; SSTC, Belarus; CNPq and FAPESP, Brazil; NSERC, NRC and CFI, Canada; CERN; CONICYT, Chile; CAS, MOST and NSFC, China; COLCIENCIAS, Colombia; MSMT CR, MPO CR and VSC CR, Czech Republic; DNRF and DNSRC, Denmark; IN2P3-CNRS, CEA-DRF/IRFU, France; SRNSFG, Georgia; BMBF, HGF, and MPG, Germany; GSRT, Greece; RGC, Hong Kong SAR, China; ISF, I-CORE and Benoziyo Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; NWO, Netherlands; RCN, Norway; MNiSW and NCN, Poland; FCT, Portugal; MNE/IFA, Romania; MES of Russia and NRC KI, Russian Federation; JINR; MESTD, Serbia; MSSR, Slovakia; ARRS and MIZŠ, Slovenia; DST/NRF, South Africa; MINECO, Spain; SRC and Wallenberg Foundation, Sweden; SERI, SNSF and Cantons of Bern and Geneva, Switzerland; MOST, Taiwan; TAEK, Turkey; STFC, United Kingdom; DOE and NSF, United States of America. In addition, individual groups and members have received support from BCKDF, the Canada Council, CANARIE, CRC, Compute Canada, FQRNT, and the Ontario Innovation Trust, Canada; EPLANET, ERC, ERDF, FP7, Horizon 2020 and Marie Skłodowska-Curie Actions, European Union; Investissements d'Avenir Labex and Idex, ANR, Région Auvergne and Fondation Partager le Savoir, France; DFG and AvH Foundation, Germany; Herakleitos, Thales and Aristeia programmes co-financed by EU-ESF and the Greek NSRF; BSF, GIF and Minerva, Israel; BRF, Norway; CERCA Programme Generalitat de Catalunya, Generalitat Valenciana, Spain; the Royal Society and Leverhulme Trust, United Kingdom.

The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN, the ATLAS Tier-1 facilities at TRIUMF (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN-CNAF (Italy), NL-T1 (Netherlands), PIC (Spain), ASGC (Taiwan), RAL (UK) and BNL (USA), the Tier-2 facilities worldwide and large non-WLCG resource providers. Major contributors of computing resources are listed in Ref. [88].

References

- [1] ATLAS Collaboration, Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC, Phys. Lett. B **716** (2012) 1, arXiv: 1207.7214 [hep-ex].
- [2] CMS Collaboration,

 Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC,

 Phys. Lett. B **716** (2012) 30, arXiv: 1207.7235 [hep-ex].
- [3] T. D. Lee, A theory of spontaneous T violation, Phys. Rev. D 8 (1973) 1226.
- [4] G. Branco, P. Ferreira, L. Lavoura, M. Rebelo, M. Sher, et al., Theory and phenomenology of two-Higgs-doublet models, Phys. Rept. **516** (2012) 1, arXiv: 1106.0034 [hep-ph].
- [5] A. Djouadi, *The Anatomy of electro-weak symmetry breaking. Tome II: The Higgs bosons in the minimal supersymmetric model*, Phys. Rept. **459** (2008) 1, arXiv: hep-ph/0503173.
- [6] J. Abdallah et al., *Simplified models for dark matter dearches at the LHC*, Phys. Dark Univ. **9-10** (2015) 8, arXiv: 1506.03116 [hep-ph].
- [7] J. E. Kim and G. Carosi, *Axions and the strong CP problem*, Rev. Mod. Phys. **82** (2010) 557, arXiv: 0807.3125 [hep-ph].
- [8] A. G. Cohen, D. B. Kaplan, and A. E. Nelson, *Progress in electroweak baryogenesis*, Ann. Rev. Nucl. Part. Sci. **43** (1993) 27, arXiv: hep-ph/9302210.
- [9] S. F. King, Neutrino mass models, Rept. Prog. Phys. 67 (2004) 107, arXiv: hep-ph/0310204.
- [10] ATLAS Collaboration, Searches for heavy ZZ and ZW resonances in the $\ell\ell qq$ and vvqq final states in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, JHEP **03** (2018) 009, arXiv: 1708.09638 [hep-ex].
- [11] ATLAS Collaboration, Search for WW/WZ resonance production in ℓvqq final states in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, (2017), arXiv: 1710.07235 [hep-ex].
- [12] CMS Collaboration, Search for massive resonances decaying into WW, WZ or ZZ bosons in proton–proton collisions at $\sqrt{s} = 13$ TeV, JHEP **03** (2017) 162, arXiv: 1612.09159 [hep-ex].
- [13] CMS Collaboration, Combination of searches for heavy resonances decaying to WW, WZ, ZZ, WH, and ZH boson pairs in proton–proton collisions at $\sqrt{s} = 8$ TeV and 13 TeV, Phys. Lett. B **774** (2017) 533, arXiv: 1705.09171 [hep-ex].
- [14] ATLAS Collaboration, Search for additional heavy neutral Higgs and gauge bosons in the ditau final state produced in 36 fb⁻¹ of pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, JHEP **01** (2018) 055, arXiv: 1709.07242 [hep-ex].
- [15] CMS Collaboration, Search for beyond the standard model Higgs bosons decaying into a $b\bar{b}$ pair in pp collisions at $\sqrt{s} = 13$ TeV, CERN-EP-2018-124 (2018), arXiv: 1805.12191 [hep-ex].
- [16] CMS Collaboration, Search for additional neutral MSSM Higgs bosons in the $\tau\tau$ final state in proton-proton collisions at $\sqrt{s} = 13$ TeV, CERN-EP-2018-026 (2018), arXiv: 1803.06553 [hep-ex].

- [17] ATLAS Collaboration, Search for heavy resonances decaying into a W or Z boson and a Higgs boson in final states with leptons and b-jets in 36 fb⁻¹ of $\sqrt{s} = 13$ TeV pp collisions with the ATLAS detector, (2017), arXiv: 1712.06518 [hep-ex].
- [18] CMS Collaboration, Search for heavy resonances decaying into a vector boson and a Higgs boson in final states with charged leptons, neutrinos, and b quarks, Phys. Lett. B **768** (2017) 137, arXiv: 1610.08066 [hep-ex].
- [19] ATLAS Collaboration, *Searches for Higgs boson pair production in the* $hh \rightarrow bb\tau\tau$, $\gamma\gamma WW^*$, $\gamma\gamma bb$, bbbb channels with the ATLAS detector, Phys. Rev. D **92** (2015) 092004, arXiv: 1509.04670 [hep-ex].
- [20] CMS Collaboration, Search for resonant and nonresonant Higgs boson pair production in the $b\bar{b}\ell\nu\ell\nu$ final state in proton-proton collisions at $\sqrt{s} = 13$ TeV, JHEP **01** (2018) 054, arXiv: 1708.04188 [hep-ex].
- [21] G. C. Dorsch, S. J. Huber, K. Mimasu, and J. M. No, *Echoes of the Electroweak Phase Transition:* Discovering a second Higgs doublet through $A_0 \rightarrow ZH_0$, Phys. Rev. Lett. **113** (2014) 211802, arXiv: 1405.5537 [hep-ph].
- [22] N. Turok and J. Zadrozny, *Electroweak baryogenesis in the two doublet model*, Nucl. Phys. B **358** (1991) 471.
- [23] L. Fromme, S. J. Huber, and M. Seniuch, *Baryogenesis in the two-Higgs doublet model*, JHEP 11 (2006) 038, arXiv: hep-ph/0605242.
- [24] P. Basler, M. Krause, M. Muhlleitner, J. Wittbrodt, and A. Wlotzka, Strong First Order Electroweak Phase Transition in the CP-Conserving 2HDM Revisited, JHEP 02 (2017) 121, arXiv: 1612.04086 [hep-ph].
- [25] B. Coleppa, F. Kling, and S. Su, *Exotic decays of a heavy neutral Higgs through HZ/AZ channel*, JHEP **09** (2014) 161, arXiv: 1404.1922 [hep-ph].
- [26] CMS Collaboration,

 Search for neutral resonances decaying into a Z boson and a pair of b jets or τ leptons,

 Phys. Lett. B **759** (2016) 369, arXiv: 1603.02991 [hep-ex].
- [27] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, JINST **3** (2008) S08003.
- [28] ATLAS Collaboration, ATLAS Insertable B-Layer Technical Design Report, CERN-LHCC-2010-013, ATLAS-TDR-19 (2010), URL: https://cds.cern.ch/record/1291633, ATLAS Insertable B-Layer Technical Design Report Addendum, (ATLAS-TDR-19-ADD-1), URL: https://cds.cern.ch/record/1451888.
- [29] ATLAS Collaboration, *Performance of the ATLAS Trigger System in 2015*, Eur. Phys. J. C **77** (2017) 317, arXiv: 1611.09661 [hep-ex].
- [30] J. Alwall, M. Herquet, F. Maltoni, O. Mattelaer, and T. Stelzer, *MadGraph 5 : going beyond*, JHEP **06** (2011) 128, arXiv: 1106.0522 [hep-ph].
- [31] J. Alwall et al., *The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations*, JHEP **07** (2014) 079, arXiv: 1405.0301 [hep-ph].

- [32] T. Sjöstrand, S. Mrenna, and P. Z. Skands, *A brief introduction to PYTHIA 8.1*, Comput. Phys. Commun. **178** (2008) 852, arXiv: 0710.3820 [hep-ph].
- [33] ATLAS Collaboration, *ATLAS Pythia 8 tunes to 7 TeV data*, ATL-PHYS-PUB-2014-021, 2014, url: https://cds.cern.ch/record/1966419.
- [34] S. Frixione and B. R. Webber, *Matching NLO QCD computations and parton shower simulations*, JHEP **06** (2002) 029, arXiv: hep-ph/0204244.
- [35] M. Wiesemann et al., *Higgs production in association with bottom quarks*, JHEP **02** (2015) 132, arXiv: 1409.5301 [hep-ph].
- [36] D. de Florian et al., Handbook of LHC Higgs Cross Sections: 4. Deciphering the Nature of the Higgs Sector, (2016), arXiv: 1610.07922 [hep-ph].
- [37] R. D. Ball et al., *Parton distributions with LHC data*, Nucl. Phys. B **867** (2013) 244, arXiv: 1207.1303 [hep-ph].
- [38] H.-L. Lai et al., *New parton distributions for collider physics*, Phys. Rev. D **82** (2010) 074024, arXiv: 1007.2241 [hep-ph].
- [39] T. Gleisberg et al., *Event generation with SHERPA 1.1*, JHEP **02** (2009) 007, arXiv: **0811.4622** [hep-ph].
- [40] R. D. Ball et al., *Parton distributions for the LHC Run II*, JHEP **04** (2015) 040, arXiv: 1410.8849 [hep-ph].
- [41] P. Nason, A New method for combining NLO QCD with shower Monte Carlo algorithms, JHEP 11 (2004) 040, arXiv: hep-ph/0409146.
- [42] S. Frixione, P. Nason, and C. Oleari, *Matching NLO QCD computations with Parton Shower simulations: the POWHEG method*,

 JHEP 11 (2007) 070, arXiv: 0709.2092 [hep-ph].
- [43] S. Alioli, P. Nason, C. Oleari, and E. Re, *A general framework for implementing NLO calculations in shower Monte Carlo programs: the POWHEG BOX*, JHEP **06** (2010) 043, arXiv: 1002.2581 [hep-ph].
- [44] T. Sjöstrand, S. Mrenna, and P. Z. Skands, *PYTHIA 6.4 Physics and Manual*, JHEP **05** (2006) 026, arXiv: hep-ph/0603175.
- [45] P. Z. Skands, *Tuning Monte Carlo Generators: The Perugia Tunes*, Phys. Rev. D **82** (2010) 074018, arXiv: 1005.3457 [hep-ph].
- [46] ATLAS Collaboration, *Measurement of the Z/\gamma^* boson transverse momentum distribution in pp collisions at \sqrt{s} = 7 TeV with the ATLAS detector, JHEP 09 (2014) 145, arXiv: 1406.3660 [hep-ex].*
- [47] D. J. Lange, *The EvtGen particle decay simulation package*, Nucl. Instrum. Meth. A **462** (2001) 152.
- [48] ATLAS Collaboration, *Summary of ATLAS Pythia 8 tunes*, ATL-PHYS-PUB-2012-003 (2012), url: https://cds.cern.ch/record/1474107.
- [49] A. D. Martin, W. J. Stirling, R. S. Thorne, and G. Watt, *Parton distributions for the LHC*, Eur. Phys. J. C **63** (2009) 189, arXiv: 0901.0002 [hep-ph].
- [50] S. Agostinelli et al., GEANT4: A simulation toolkit, Nucl. Instrum. Meth. A 506 (2003) 250.

- [51] ATLAS Collaboration, *The ATLAS Simulation Infrastructure*, Eur. Phys. J. C **70** (2010) 823, arXiv: 1005.4568 [hep-ex].
- [52] ATLAS Collaboration, *Electron and photon energy calibration with the ATLAS detector using LHC Run 1 data*, Eur. Phys. J. C **74** (2014) 3071, arXiv: 1407.5063 [hep-ex].
- [53] ATLAS Collaboration, Electron efficiency measurements with the ATLAS detector using the 2015 LHC proton-proton collision data, ATLAS-CONF-2016-024, 2016, URL: https://cds.cern.ch/record/2157687.
- [54] ATLAS Collaboration, Muon reconstruction performance of the ATLAS detector in proton–proton collision data at $\sqrt{s} = 13$ TeV, Eur. Phys. J. C **76** (2016) 292, arXiv: 1603.05598 [hep-ex].
- [55] M. Cacciari, G. P. Salam, and G. Soyez, *The Anti-k(t) jet clustering algorithm*, JHEP **04** (2008) 063, arXiv: **0802.1189** [hep-ph].
- [56] M. Cacciari, G. P. Salam, and G. Soyez, *FastJet user manual*, Eur. Phys. J. C **72** (2012) 1896, arXiv: 1111.6097 [hep-ph].
- [57] ATLAS Collaboration,

 Topological cell clustering in the ATLAS calorimeters and its performance in LHC Run 1,

 Eur. Phys. J. C 77 (2017) 490, arXiv: 1603.02934 [hep-ex].
- [58] ATLAS Collaboration, *Performance of pile-up mitigation techniques for jets in pp collisions at* $\sqrt{s} = 8$ *TeV using the ATLAS detector*, Eur. Phys. J. C **76** (2016) 581, arXiv: 1510.03823 [hep-ex].
- [59] ATLAS Collaboration, *Performance of b-Jet Identification in the ATLAS Experiment*, JINST **11** (2016) P04008, arXiv: 1512.01094 [hep-ex].
- [60] ATLAS Collaboration, *Optimisation of the ATLAS b-tagging performance for the 2016 LHC Run*, ATL-PHYS-PUB-2016-012, 2016, url: https://cds.cern.ch/record/2160731.
- [61] ATLAS Collaboration, *Evidence for the H* \rightarrow *bb decay with the ATLAS detector*, JHEP **12** (2017) 024, arXiv: 1708.03299 [hep-ex].
- [62] ATLAS Collaboration, Performance of missing transverse momentum reconstruction with the ATLAS detector in the first proton–proton collisions at $\sqrt{s} = 13$ TeV, ATL-PHYS-PUB-2015-027, 2015, URL: https://cds.cern.ch/record/2037904.
- [63] ATLAS Collaboration, *Performance of algorithms that reconstruct missing transverse momentum* in $\sqrt{s} = 8$ TeV proton–proton collisions in the ATLAS detector, Eur. Phys. J. C **77** (2017) 241, arXiv: 1609.09324 [hep-ex].
- [64] ATLAS Collaboration, Reconstruction of primary vertices at the ATLAS experiment in Run 1 proton–proton collisions at the LHC, Eur. Phys. J. C 77 (2017) 332, arXiv: 1611.10235 [hep-ex].
- [65] T. Gehrmann et al., W⁺W⁻ Production at hadron colliders in next to next to leading order QCD, Phys. Rev. Lett. **113** (2014) 212001, arXiv: 1408.5243 [hep-ph].
- [66] M. Grazzini, S. Kallweit, D. Rathlev, and M. Wiesemann, W[±]Z production at hadron colliders in NNLO QCD, Phys. Lett. B 761 (2016) 179, arXiv: 1604.08576 [hep-ph].

- [67] M. Grazzini, S. Kallweit, and D. Rathlev, ZZ production at the LHC: fiducial cross sections and distributions in NNLO QCD, Phys. Lett. B **750** (2015) 407, arXiv: 1507.06257 [hep-ph].
- [68] F. Cascioli et al., ZZ production at hadron colliders in NNLO QCD, Phys. Lett. B **735** (2014) 311, arXiv: 1405.2219 [hep-ph].
- [69] N. Kidonakis, *NNLL resummation for s-channel single top quark production*, Phys. Rev. D **81** (2010) 054028, arXiv: 1001.5034 [hep-ph].
- [70] N. Kidonakis, *Next-to-next-to-leading-order collinear and soft gluon corrections for t-channel single top quark production*, Phys. Rev. D **83** (2011) 091503, arXiv: 1103.2792 [hep-ph].
- [71] N. Kidonakis,

 Two-loop soft anomalous dimensions for single top quark associated production with a W- or H-,

 Phys. Rev. D 82 (2010) 054018, arXiv: 1005.4451 [hep-ph].
- [72] S. Das, A simple alternative to the Crystal Ball function, (2016), arXiv: 1603.08591 [hep-ex].
- [73] M. Oreglia, A Study of the Reactions $\psi' \to \gamma \gamma \psi$, SLAC-R-0236 (1980), URL: http://www.slac.stanford.edu/cgi-wrap/getdoc/slac-r-236.pdf.
- [74] J. Duchon, *Interpolation des fonctions de deux variables suivant le principe de la flexion des plaques minces*, fre, ESAIM: Mathematical Modelling and Numerical Analysis Modélisation Mathématique et Analyse Numérique **10** (1976) 5, URL: https://eudml.org/doc/193284.
- [75] L. Moneta et al., *The RooStats Project*, PoS **ACAT2010** (2010) 057, arXiv: 1009.1003 [physics.data-an].
- [76] W. Verkerke and D. Kirkby, *The RooFit toolkit for data modeling*, 2003, arXiv: physics/0306116 [physics.data-an].
- [77] G. Cowan, K. Cranmer, E. Gross, and O. Vitells,

 Asymptotic formulae for likelihood-based tests of new physics, Eur. Phys. J. C 71 (2011) 1554,

 arXiv: 1007.1727 [physics.data-an], Erratum: Eur. Phys. J. C 73 (2013) 2501.
- [78] O. Vitells and E. Gross, *Estimating the significance of a signal in a multi-dimensional search*, Astropart. Phys. **35** (2011) 230, arXiv: 1105.4355 [astro-ph.IM].
- [79] A. L. Read, *Presentation of search results: The CLs technique*, Journal of Physics G: Nuclear and Particle Physics **28** (2002) 2693.
- [80] R. V. Harlander, S. Liebler, and H. Mantler, *SusHi: A program for the calculation of Higgs production in gluon fusion and bottom-quark annihilation in the Standard Model and the MSSM*, Comput. Phys. Commun. **184** (2013) 1605, arXiv: 1212.3249 [hep-ph].
- [81] R. Harlander and P. Kant,

 Higgs production and decay: Analytic results at next-to-leading order QCD, JHEP 12 (2005) 015,

 arXiv: hep-ph/0509189.
- [82] R. V. Harlander and W. B. Kilgore, Higgs boson production in bottom quark fusion at next-to-next-to leading order, Phys. Rev. D **68** (2003) 013001, arXiv: hep-ph/0304035.
- [83] R. V. Harlander and W. B. Kilgore,

 Next-to-next-to-leading order Higgs production at hadron colliders,
 Phys. Rev. Lett. 88 (2002) 201801, arXiv: hep-ph/0201206.

- [84] S. Dawson, C. B. Jackson, L. Reina, and D. Wackeroth, Exclusive Higgs boson production with bottom quarks at hadron colliders, Phys. Rev. D **69** (2004) 074027, arXiv: hep-ph/0311067.
- [85] S. Dittmaier, M. Kramer 1, and M. Spira,

 Higgs radiation off bottom quarks at the Tevatron and the CERN LHC,

 Phys. Rev. D 70 (2004) 074010, arXiv: hep-ph/0309204.
- [86] R. Harlander, M. Kramer, and M. Schumacher, *Bottom-quark associated Higgs-boson production: reconciling the four- and five-flavour scheme approach*, (2011), arXiv: 1112.3478 [hep-ph].
- [87] D. Eriksson, J. Rathsman, and O. Stal,
 2HDMC: Two-Higgs-doublet model calculator physics and manual,
 Comput. Phys. Commun. 181 (2010) 189, arXiv: 0902.0851 [hep-ph].
- [88] ATLAS Collaboration, ATLAS Computing Acknowledgements 2016–2017, ATL-GEN-PUB-2016-002, URL: https://cds.cern.ch/record/2202407.

The ATLAS Collaboration

```
M. Aaboud<sup>34d</sup>, G. Aad<sup>99</sup>, B. Abbott<sup>124</sup>, O. Abdinov<sup>13,*</sup>, B. Abeloos<sup>128</sup>, S.H. Abidi<sup>165</sup>, O.S. AbouZeid<sup>143</sup>,
N.L. Abraham<sup>153</sup>, H. Abramowicz<sup>159</sup>, H. Abreu<sup>158</sup>, Y. Abulaiti<sup>6</sup>, B.S. Acharya<sup>64a,64b,o</sup>, S. Adachi<sup>161</sup>,
L. Adamczyk<sup>81a</sup>, J. Adelman<sup>119</sup>, M. Adersberger<sup>112</sup>, T. Adye<sup>141</sup>, A.A. Affolder<sup>143</sup>, Y. Afik<sup>158</sup>,
C. Agheorghiesei<sup>27c</sup>, J.A. Aguilar-Saavedra<sup>136f,136a</sup>, F. Ahmadov<sup>77,ah</sup>, G. Aielli<sup>71a,71b</sup>, S. Akatsuka<sup>83</sup>,
T.P.A. Åkesson<sup>94</sup>, E. Akilli<sup>52</sup>, A.V. Akimov<sup>108</sup>, G.L. Alberghi<sup>23b,23a</sup>, J. Albert<sup>174</sup>, P. Albicocco<sup>49</sup>,
M.J. Alconada Verzini<sup>86</sup>, S. Alderweireldt<sup>117</sup>, M. Aleksa<sup>35</sup>, I.N. Aleksandrov<sup>77</sup>, C. Alexa<sup>27b</sup>.
G. Alexander<sup>159</sup>, T. Alexopoulos<sup>10</sup>, M. Alhroob<sup>124</sup>, B. Ali<sup>138</sup>, G. Alimonti<sup>66a</sup>, J. Alison<sup>36</sup>, S.P. Alkire<sup>145</sup>.
C. Allaire<sup>128</sup>, B.M.M. Allbrooke<sup>153</sup>, B.W. Allen<sup>127</sup>, P.P. Allport<sup>21</sup>, A. Aloisio<sup>67a,67b</sup>, A. Alonso<sup>39</sup>,
F. Alonso<sup>86</sup>, C. Alpigiani<sup>145</sup>, A.A. Alshehri<sup>55</sup>, M.I. Alstaty<sup>99</sup>, B. Alvarez Gonzalez<sup>35</sup>,
D. Álvarez Piqueras<sup>172</sup>, M.G. Alviggi<sup>67a,67b</sup>, B.T. Amadio<sup>18</sup>, Y. Amaral Coutinho<sup>78b</sup>, L. Ambroz<sup>131</sup>,
C. Amelung<sup>26</sup>, D. Amidei<sup>103</sup>, S.P. Amor Dos Santos<sup>136a,136c</sup>, S. Amoroso<sup>35</sup>, C.S. Amrouche<sup>52</sup>,
C. Anastopoulos<sup>146</sup>, L.S. Ancu<sup>52</sup>, N. Andari<sup>21</sup>, T. Andeen<sup>11</sup>, C.F. Anders<sup>59b</sup>, J.K. Anders<sup>20</sup>,
K.J. Anderson<sup>36</sup>, A. Andreazza<sup>66a,66b</sup>, V. Andrei<sup>59a</sup>, S. Angelidakis<sup>37</sup>, I. Angelozzi<sup>118</sup>, A. Angerami<sup>38</sup>,
A.V. Anisenkov<sup>120b,120a</sup>, A. Annovi<sup>69a</sup>, C. Antel<sup>59a</sup>, M.T. Anthony<sup>146</sup>, M. Antonelli<sup>49</sup>, D.J.A. Antrim<sup>169</sup>,
F. Anulli<sup>70a</sup>, M. Aoki<sup>79</sup>, L. Aperio Bella<sup>35</sup>, G. Arabidze<sup>104</sup>, Y. Arai<sup>79</sup>, J.P. Araque<sup>136a</sup>,
V. Araujo Ferraz<sup>78b</sup>, R. Araujo Pereira<sup>78b</sup>, A.T.H. Arce<sup>47</sup>, R.E. Ardell<sup>91</sup>, F.A. Arduh<sup>86</sup>, J-F. Arguin<sup>107</sup>,
S. Argyropoulos<sup>75</sup>, A.J. Armbruster<sup>35</sup>, L.J. Armitage<sup>90</sup>, O. Arnaez<sup>165</sup>, H. Arnold<sup>118</sup>, M. Arratia<sup>31</sup>,
O. Arslan<sup>24</sup>, A. Artamonov<sup>109,*</sup>, G. Artoni<sup>131</sup>, S. Artz<sup>97</sup>, S. Asai<sup>161</sup>, N. Asbah<sup>44</sup>, A. Ashkenazi<sup>159</sup>,
E.M. Asimakopoulou<sup>170</sup>, L. Asquith<sup>153</sup>, K. Assamagan<sup>29</sup>, R. Astalos<sup>28a</sup>, R.J. Atkin<sup>32a</sup>, M. Atkinson<sup>171</sup>, N.B. Atlay<sup>148</sup>, K. Augsten<sup>138</sup>, G. Avolio<sup>35</sup>, R. Avramidou<sup>58a</sup>, B. Axen<sup>18</sup>, M.K. Ayoub<sup>15a</sup>,
G. Azuelos<sup>107,av</sup>, A.E. Baas<sup>59a</sup>, M.J. Baca<sup>21</sup>, H. Bachacou<sup>142</sup>, K. Bachas<sup>65a,65b</sup>, M. Backes<sup>131</sup>,
P. Bagnaia<sup>70a,70b</sup>, M. Bahmani<sup>82</sup>, H. Bahrasemani<sup>149</sup>, A.J. Bailey<sup>172</sup>, J.T. Baines<sup>141</sup>, M. Bajic<sup>39</sup>,
O.K. Baker<sup>181</sup>, P.J. Bakker<sup>118</sup>, D. Bakshi Gupta<sup>93</sup>, E.M. Baldin<sup>120b,120a</sup>, P. Balek<sup>178</sup>, F. Balli<sup>142</sup>,
W.K. Balunas<sup>133</sup>, E. Banas<sup>82</sup>, A. Bandyopadhyay<sup>24</sup>, S. Banerjee<sup>179,k</sup>, A.A.E. Bannoura<sup>180</sup>, L. Barak<sup>159</sup>, W.M. Barbe<sup>37</sup>, E.L. Barberio<sup>102</sup>, D. Barberis<sup>53b,53a</sup>, M. Barbero<sup>99</sup>, T. Barillari<sup>113</sup>, M-S. Barisits<sup>35</sup>,
J. Barkeloo<sup>127</sup>, T. Barklow<sup>150</sup>, N. Barlow<sup>31</sup>, R. Barnea<sup>158</sup>, S.L. Barnes<sup>58c</sup>, B.M. Barnett<sup>141</sup>,
R.M. Barnett<sup>18</sup>, Z. Barnovska-Blenessy<sup>58a</sup>, A. Baroncelli<sup>72a</sup>, G. Barone<sup>26</sup>, A.J. Barr<sup>131</sup>,
L. Barranco Navarro<sup>172</sup>, F. Barreiro<sup>96</sup>, J. Barreiro Guimarães da Costa<sup>15a</sup>, R. Bartoldus<sup>150</sup>,
A.E. Barton<sup>87</sup>, P. Bartos<sup>28a</sup>, A. Basalaev<sup>134</sup>, A. Bassalat<sup>128</sup>, R.L. Bates<sup>55</sup>, S.J. Batista<sup>165</sup>,
S. Batlamous<sup>34e</sup>, J.R. Batley<sup>31</sup>, M. Battaglia<sup>143</sup>, M. Bauce<sup>70a,70b</sup>, F. Bauer<sup>142</sup>, K.T. Bauer<sup>169</sup>,
H.S. Bawa<sup>150,m</sup>, J.B. Beacham<sup>122</sup>, M.D. Beattie<sup>87</sup>, T. Beau<sup>132</sup>, P.H. Beauchemin<sup>168</sup>, P. Bechtle<sup>24</sup>,
H.C. Beck<sup>51</sup>, H.P. Beck<sup>20,8</sup>, K. Becker<sup>50</sup>, M. Becker<sup>97</sup>, C. Becot<sup>121</sup>, A. Beddall<sup>12d</sup>, A.J. Beddall<sup>12a</sup>,
V.A. Bednyakov<sup>77</sup>, M. Bedognetti<sup>118</sup>, C.P. Bee<sup>152</sup>, T.A. Beermann<sup>35</sup>, M. Begalli<sup>78b</sup>, M. Begel<sup>29</sup>, A. Behera<sup>152</sup>, J.K. Behr<sup>44</sup>, A.S. Bell<sup>92</sup>, G. Bella<sup>159</sup>, L. Bellagamba<sup>23b</sup>, A. Bellerive<sup>33</sup>, M. Bellomo<sup>158</sup>,
K. Belotskiy<sup>110</sup>, N.L. Belyaev<sup>110</sup>, O. Benary<sup>159,*</sup>, D. Benchekroun<sup>34a</sup>, M. Bender<sup>112</sup>, N. Benekos<sup>10</sup>,
Y. Benhammou<sup>159</sup>, E. Benhar Noccioli<sup>181</sup>, J. Benitez<sup>75</sup>, D.P. Benjamin<sup>47</sup>, M. Benoit<sup>52</sup>, J.R. Bensinger<sup>26</sup>,
S. Bentvelsen<sup>118</sup>, L. Beresford<sup>131</sup>, M. Beretta<sup>49</sup>, D. Berge<sup>44</sup>, E. Bergeaas Kuutmann<sup>170</sup>, N. Berger<sup>5</sup>,
L.J. Bergsten<sup>26</sup>, J. Beringer<sup>18</sup>, S. Berlendis<sup>56</sup>, N.R. Bernard<sup>100</sup>, G. Bernardi<sup>132</sup>, C. Bernius<sup>150</sup>, F.U. Bernlochner<sup>24</sup>, T. Berry<sup>91</sup>, P. Berta<sup>97</sup>, C. Bertella<sup>15a</sup>, G. Bertoli<sup>43a,43b</sup>, I.A. Bertram<sup>87</sup>,
C. Bertsche<sup>44</sup>, G.J. Besjes<sup>39</sup>, O. Bessidskaia Bylund<sup>43a,43b</sup>, M. Bessner<sup>44</sup>, N. Besson<sup>142</sup>, A. Bethani<sup>98</sup>,
S. Bethke<sup>113</sup>, A. Betti<sup>24</sup>, A.J. Bevan<sup>90</sup>, J. Beyer<sup>113</sup>, R.M. Bianchi<sup>135</sup>, O. Biebel<sup>112</sup>, D. Biedermann<sup>19</sup>,
R. Bielski<sup>98</sup>, K. Bierwagen<sup>97</sup>, N.V. Biesuz<sup>69a,69b</sup>, M. Biglietti<sup>72a</sup>, T.R.V. Billoud<sup>107</sup>, M. Bindi<sup>51</sup>,
A. Bingul<sup>12d</sup>, C. Bini<sup>70a,70b</sup>, S. Biondi<sup>23b,23a</sup>, T. Bisanz<sup>51</sup>, C. Bittrich<sup>46</sup>, D.M. Bjergaard<sup>47</sup>, J.E. Black<sup>150</sup>,
K.M. Black<sup>25</sup>, R.E. Blair<sup>6</sup>, T. Blazek<sup>28a</sup>, I. Bloch<sup>44</sup>, C. Blocker<sup>26</sup>, A. Blue<sup>55</sup>, U. Blumenschein<sup>90</sup>,
```

```
Dr. Blunier<sup>144a</sup>, G.J. Bobbink<sup>118</sup>, V.S. Bobrovnikov<sup>120b,120a</sup>, S.S. Bocchetta<sup>94</sup>, A. Bocci<sup>47</sup>, C. Bock<sup>112</sup>,
D. Boerner<sup>180</sup>, D. Bogavac<sup>112</sup>, A.G. Bogdanchikov<sup>120b,120a</sup>, C. Bohm<sup>43a</sup>, V. Boisvert<sup>91</sup>, P. Bokan<sup>170,z</sup>,
T. Bold<sup>81a</sup>, A.S. Boldyrev<sup>111</sup>, A.E. Bolz<sup>59b</sup>, M. Bomben<sup>132</sup>, M. Bona<sup>90</sup>, J.S. Bonilla<sup>127</sup>,
M. Boonekamp<sup>142</sup>, A. Borisov<sup>140</sup>, G. Borissov<sup>87</sup>, J. Bortfeldt<sup>35</sup>, D. Bortoletto<sup>131</sup>,
V. Bortolotto<sup>71a,61b,61c,71b</sup>, D. Boscherini<sup>23b</sup>, M. Bosman<sup>14</sup>, J.D. Bossio Sola<sup>30</sup>, J. Boudreau<sup>135</sup>,
E.V. Bouhova-Thacker<sup>87</sup>, D. Boumediene<sup>37</sup>, C. Bourdarios<sup>128</sup>, S.K. Boutle<sup>55</sup>, A. Boveia<sup>122</sup>, J. Boyd<sup>35</sup>,
I.R. Boyko<sup>77</sup>, A.J. Bozson<sup>91</sup>, J. Bracinik<sup>21</sup>, N. Brahimi<sup>99</sup>, A. Brandt<sup>8</sup>, G. Brandt<sup>180</sup>, O. Brandt<sup>59a</sup>,
F. Braren<sup>44</sup>, U. Bratzler<sup>162</sup>, B. Brau<sup>100</sup>, J.E. Brau<sup>127</sup>, W.D. Breaden Madden<sup>55</sup>, K. Brendlinger<sup>44</sup>,
A.J. Brennan<sup>102</sup>, L. Brenner<sup>44</sup>, R. Brenner<sup>170</sup>, S. Bressler<sup>178</sup>, B. Brickwedde<sup>97</sup>, D.L. Briglin<sup>21</sup>,
T.M. Bristow<sup>48</sup>, D. Britton<sup>55</sup>, D. Britzger<sup>59b</sup>, I. Brock<sup>24</sup>, R. Brock<sup>104</sup>, G. Brooijmans<sup>38</sup>, T. Brooks<sup>91</sup>,
W.K. Brooks<sup>144b</sup>, E. Brost<sup>119</sup>, J.H Broughton<sup>21</sup>, P.A. Bruckman de Renstrom<sup>82</sup>, D. Bruncko<sup>28b</sup>,
A. Bruni<sup>23b</sup>, G. Bruni<sup>23b</sup>, L.S. Bruni<sup>118</sup>, S. Bruno<sup>71a,71b</sup>, B.H. Brunt<sup>31</sup>, M. Bruschi<sup>23b</sup>, N. Bruscino<sup>135</sup>,
P. Bryant<sup>36</sup>, L. Bryngemark<sup>44</sup>, T. Buanes<sup>17</sup>, Q. Buat<sup>35</sup>, P. Buchholz<sup>148</sup>, A.G. Buckley<sup>55</sup>, I.A. Budagov<sup>77</sup>,
F. Buehrer<sup>50</sup>, M.K. Bugge<sup>130</sup>, O. Bulekov<sup>110</sup>, D. Bullock<sup>8</sup>, T.J. Burch<sup>119</sup>, S. Burdin<sup>88</sup>, C.D. Burgard<sup>118</sup>, A.M. Burger<sup>5</sup>, B. Burghgrave<sup>119</sup>, K. Burka<sup>82</sup>, S. Burke<sup>141</sup>, I. Burmeister<sup>45</sup>, J.T.P. Burr<sup>131</sup>, D. Büscher<sup>50</sup>,
V. Büscher<sup>97</sup>, E. Buschmann<sup>51</sup>, P. Bussey<sup>55</sup>, J.M. Butler<sup>25</sup>, C.M. Buttar<sup>55</sup>, J.M. Butterworth<sup>92</sup>, P. Butti<sup>35</sup>,
W. Buttinger<sup>35</sup>, A. Buzatu<sup>155</sup>, A.R. Buzykaev<sup>120b,120a</sup>, G. Cabras<sup>23b,23a</sup>, S. Cabrera Urbán<sup>172</sup>,
D. Caforio<sup>138</sup>, H. Cai<sup>171</sup>, V.M.M. Cairo<sup>2</sup>, O. Cakir<sup>4a</sup>, N. Calace<sup>52</sup>, P. Calafiura<sup>18</sup>, A. Calandri<sup>99</sup>,
G. Calderini<sup>132</sup>, P. Calfayan<sup>63</sup>, G. Callea<sup>40b,40a</sup>, L.P. Caloba<sup>78b</sup>, S. Calvente Lopez<sup>96</sup>, D. Calvet<sup>37</sup>,
S. Calvet<sup>37</sup>, T.P. Calvet<sup>152</sup>, M. Calvetti<sup>69a,69b</sup>, R. Camacho Toro<sup>36</sup>, S. Camarda<sup>35</sup>, P. Camarri<sup>71a,71b</sup>,
D. Cameron<sup>130</sup>, R. Caminal Armadans<sup>100</sup>, C. Camincher<sup>56</sup>, S. Campana<sup>35</sup>, M. Campanelli<sup>92</sup>,
A. Camplani<sup>66a,66b</sup>, A. Campoverde<sup>148</sup>, V. Canale<sup>67a,67b</sup>, M. Cano Bret<sup>58c</sup>, J. Cantero<sup>125</sup>, T. Cao<sup>159</sup>,
Y. Cao<sup>171</sup>, M.D.M. Capeans Garrido<sup>35</sup>, I. Caprini<sup>27b</sup>, M. Caprini<sup>27b</sup>, M. Capua<sup>40b,40a</sup>, R.M. Carbone<sup>38</sup>,
R. Cardarelli<sup>71a</sup>, F.C. Cardillo<sup>50</sup>, I. Carli<sup>139</sup>, T. Carli<sup>35</sup>, G. Carlino<sup>67a</sup>, B.T. Carlson<sup>135</sup>,
L. Carminati<sup>66a,66b</sup>, R.M.D. Carney<sup>43a,43b</sup>, S. Caron<sup>117</sup>, E. Carquin<sup>144b</sup>, S. Carrá<sup>66a,66b</sup>,
G.D. Carrillo-Montova<sup>35</sup>, D. Casadei<sup>32b</sup>, M.P. Casado<sup>14,g</sup>, A.F. Casha<sup>165</sup>, M. Casolino<sup>14</sup>,
D.W. Casper<sup>169</sup>, R. Castelijn<sup>118</sup>, V. Castillo Gimenez<sup>172</sup>, N.F. Castro<sup>136a,136e</sup>, A. Catinaccio<sup>35</sup>,
J.R. Catmore<sup>130</sup>, A. Cattai<sup>35</sup>, J. Caudron<sup>24</sup>, V. Cavaliere<sup>29</sup>, E. Cavallaro<sup>14</sup>, D. Cavalli<sup>66a</sup>,
M. Cavalli-Sforza<sup>14</sup>, V. Cavasinni<sup>69a,69b</sup>, E. Celebi<sup>12b</sup>, F. Ceradini<sup>72a,72b</sup>, L. Cerda Alberich<sup>172</sup>,
A.S. Cerqueira<sup>78a</sup>, A. Cerri<sup>153</sup>, L. Cerrito<sup>71a,71b</sup>, F. Cerutti<sup>18</sup>, A. Cervelli<sup>23b,23a</sup>, S.A. Cetin<sup>12b</sup>,
A. Chafaq<sup>34a</sup>, D Chakraborty<sup>119</sup>, S.K. Chan<sup>57</sup>, W.S. Chan<sup>118</sup>, W.Y. Chan<sup>88</sup>, Y.L. Chan<sup>61a</sup>, P. Chang<sup>171</sup>,
J.D. Chapman<sup>31</sup>, D.G. Charlton<sup>21</sup>, C.C. Chau<sup>33</sup>, C.A. Chavez Barajas<sup>153</sup>, S. Che<sup>122</sup>, A. Chegwidden<sup>104</sup>,
S. Chekanov<sup>6</sup>, S.V. Chekulaev<sup>166a</sup>, G.A. Chelkov<sup>77,au</sup>, M.A. Chelstowska<sup>35</sup>, C. Chen<sup>58a</sup>, C.H. Chen<sup>76</sup>,
H. Chen<sup>29</sup>, J. Chen<sup>58a</sup>, J. Chen<sup>38</sup>, S. Chen<sup>133</sup>, S.J. Chen<sup>15c</sup>, X. Chen<sup>15b,at</sup>, Y. Chen<sup>80</sup>, Y-H. Chen<sup>44</sup>,
H.C. Cheng<sup>103</sup>, H.J. Cheng<sup>15d</sup>, A. Cheplakov<sup>77</sup>, E. Cheremushkina<sup>140</sup>, R. Cherkaoui El Moursli<sup>34e</sup>,
E. Cheu<sup>7</sup>, K. Cheung<sup>62</sup>, L. Chevalier<sup>142</sup>, V. Chiarella<sup>49</sup>, G. Chiarelli<sup>69a</sup>, G. Chiodini<sup>65a</sup>, A.S. Chisholm<sup>35</sup>,
A. Chitan<sup>27b</sup>, I. Chiu<sup>161</sup>, Y.H. Chiu<sup>174</sup>, M.V. Chizhov<sup>77</sup>, K. Choi<sup>63</sup>, A.R. Chomont<sup>128</sup>, S. Chouridou<sup>160</sup>,
Y.S. Chow<sup>118</sup>, V. Christodoulou<sup>92</sup>, M.C. Chu<sup>61a</sup>, J. Chudoba<sup>137</sup>, A.J. Chuinard<sup>101</sup>, J.J. Chwastowski<sup>82</sup>,
L. Chytka<sup>126</sup>, D. Cinca<sup>45</sup>, V. Cindro<sup>89</sup>, I.A. Cioară<sup>24</sup>, A. Ciocio<sup>18</sup>, F. Cirotto<sup>67a,67b</sup>, Z.H. Citron<sup>178</sup>,
M. Citterio<sup>66a</sup>, A. Clark<sup>52</sup>, M.R. Clark<sup>38</sup>, P.J. Clark<sup>48</sup>, R.N. Clarke<sup>18</sup>, C. Clement<sup>43a,43b</sup>, Y. Coadou<sup>99</sup>
M. Cobal<sup>64a,64c</sup>, A. Coccaro<sup>53b,53a</sup>, J. Cochran<sup>76</sup>, L. Colasurdo<sup>117</sup>, B. Cole<sup>38</sup>, A.P. Colijn<sup>118</sup>, J. Collot<sup>56</sup>,
P. Conde Muiño<sup>136a,136b</sup>, E. Coniavitis<sup>50</sup>, S.H. Connell<sup>32b</sup>, I.A. Connelly<sup>98</sup>, S. Constantinescu<sup>27b</sup>,
F. Conventi<sup>67a,aw</sup>, A.M. Cooper-Sarkar<sup>131</sup>, F. Cormier<sup>173</sup>, K.J.R. Cormier<sup>165</sup>, M. Corradi<sup>70a,70b</sup>,
E.E. Corrigan<sup>94</sup>, F. Corriveau<sup>101,af</sup>, A. Cortes-Gonzalez<sup>35</sup>, M.J. Costa<sup>172</sup>, D. Costanzo<sup>146</sup>, G. Cottin<sup>31</sup>,
G. Cowan<sup>91</sup>, B.E. Cox<sup>98</sup>, J. Crane<sup>98</sup>, K. Cranmer<sup>121</sup>, S.J. Crawley<sup>55</sup>, R.A. Creager<sup>133</sup>, G. Cree<sup>33</sup>,
S. Crépé-Renaudin<sup>56</sup>, F. Crescioli<sup>132</sup>, M. Cristinziani<sup>24</sup>, V. Croft<sup>121</sup>, G. Crosetti<sup>40b,40a</sup>, A. Cueto<sup>96</sup>,
T. Cuhadar Donszelmann<sup>146</sup>, A.R. Cukierman<sup>150</sup>, M. Curatolo<sup>49</sup>, J. Cúth<sup>97</sup>, S. Czekierda<sup>82</sup>,
```

```
P. Czodrowski<sup>35</sup>, M.J. Da Cunha Sargedas De Sousa<sup>58b,136b</sup>, C. Da Via<sup>98</sup>, W. Dabrowski<sup>81a</sup>, T. Dado<sup>28a,z</sup>,
S. Dahbi<sup>34e</sup>, T. Dai<sup>103</sup>, O. Dale<sup>17</sup>, F. Dallaire<sup>107</sup>, C. Dallapiccola<sup>100</sup>, M. Dam<sup>39</sup>, G. D'amen<sup>23b,23a</sup>,
J.R. Dandoy<sup>133</sup>, M.F. Daneri<sup>30</sup>, N.P. Dang<sup>179,k</sup>, N.D Dann<sup>98</sup>, M. Danninger<sup>173</sup>, V. Dao<sup>35</sup>, G. Darbo<sup>53b</sup>,
S. Darmora<sup>8</sup>, O. Dartsi<sup>5</sup>, A. Dattagupta<sup>127</sup>, T. Daubney<sup>44</sup>, S. D'Auria<sup>55</sup>, W. Davey<sup>24</sup>, C. David<sup>44</sup>, T. Davidek<sup>139</sup>, D.R. Davis<sup>47</sup>, E. Dawe<sup>102</sup>, I. Dawson<sup>146</sup>, K. De<sup>8</sup>, R. De Asmundis<sup>67a</sup>, A. De Benedetti<sup>124</sup>,
S. De Castro<sup>23b,23a</sup>, S. De Cecco<sup>132</sup>, N. De Groot<sup>117</sup>, P. de Jong<sup>118</sup>, H. De la Torre<sup>104</sup>, F. De Lorenzi<sup>76</sup>,
A. De Maria<sup>51,u</sup>, D. De Pedis<sup>70a</sup>, A. De Salvo<sup>70a</sup>, U. De Sanctis<sup>71a,71b</sup>, A. De Santo<sup>153</sup>,
K. De Vasconcelos Corga<sup>99</sup>, J.B. De Vivie De Regie<sup>128</sup>, C. Debenedetti<sup>143</sup>, D.V. Dedovich<sup>77</sup>,
N. Dehghanian<sup>3</sup>, M. Del Gaudio<sup>40b,40a</sup>, J. Del Peso<sup>96</sup>, D. Delgove<sup>128</sup>, F. Deliot<sup>142</sup>, C.M. Delitzsch<sup>7</sup>,
M. Della Pietra<sup>67a,67b</sup>, D. Della Volpe<sup>52</sup>, A. Dell'Acqua<sup>35</sup>, L. Dell'Asta<sup>25</sup>, M. Delmastro<sup>5</sup>, C. Delporte<sup>128</sup>,
P.A. Delsart<sup>56</sup>, D.A. DeMarco<sup>165</sup>, S. Demers<sup>181</sup>, M. Demichev<sup>77</sup>, S.P. Denisov<sup>140</sup>, D. Denysiuk<sup>118</sup>,
L. D'Eramo<sup>132</sup>, D. Derendarz<sup>82</sup>, J.E. Derkaoui<sup>34d</sup>, F. Derue<sup>132</sup>, P. Dervan<sup>88</sup>, K. Desch<sup>24</sup>, C. Deterre<sup>44</sup>,
K. Dette<sup>165</sup>, M.R. Devesa<sup>30</sup>, P.O. Deviveiros<sup>35</sup>, A. Dewhurst<sup>141</sup>, S. Dhaliwal<sup>26</sup>, F.A. Di Bello<sup>52</sup>,
A. Di Ciaccio<sup>71a,71b</sup>, L. Di Ciaccio<sup>5</sup>, W.K. Di Clemente<sup>133</sup>, C. Di Donato<sup>67a,67b</sup>, A. Di Girolamo<sup>35</sup>,
B. Di Micco<sup>72a,72b</sup>, R. Di Nardo<sup>35</sup>, K.F. Di Petrillo<sup>57</sup>, A. Di Simone<sup>50</sup>, R. Di Sipio<sup>165</sup>, D. Di Valentino<sup>33</sup>,
C. Diaconu<sup>99</sup>, M. Diamond<sup>165</sup>, F.A. Dias<sup>39</sup>, T. Dias Do Vale<sup>136a</sup>, M.A. Diaz<sup>144a</sup>, J. Dickinson<sup>18</sup>,
E.B. Diehl<sup>103</sup>, J. Dietrich<sup>19</sup>, S. Díez Cornell<sup>44</sup>, A. Dimitrievska<sup>18</sup>, J. Dingfelder<sup>24</sup>, F. Dittus<sup>35</sup>,
F. Djama<sup>99</sup>, T. Djobava<sup>157b</sup>, J.I. Djuvsland<sup>59a</sup>, M.A.B. Do Vale<sup>78c</sup>, M. Dobre<sup>27b</sup>, D. Dodsworth<sup>26</sup>,
C. Doglioni<sup>94</sup>, J. Dolejsi<sup>139</sup>, Z. Dolezal<sup>139</sup>, M. Donadelli<sup>78d</sup>, J. Donini<sup>37</sup>, M. D'Onofrio<sup>88</sup>, J. Dopke<sup>141</sup>,
A. Doria<sup>67a</sup>, M.T. Dova<sup>86</sup>, A.T. Doyle<sup>55</sup>, E. Drechsler<sup>51</sup>, E. Dreyer<sup>149</sup>, T. Dreyer<sup>51</sup>, M. Dris<sup>10</sup>, Y. Du<sup>58b</sup>,
J. Duarte-Campderros<sup>159</sup>, F. Dubinin<sup>108</sup>, A. Dubreuil<sup>52</sup>, E. Duchovni<sup>178</sup>, G. Duckeck<sup>112</sup>,
A. Ducourthial<sup>132</sup>, O.A. Ducu<sup>107,y</sup>, D. Duda<sup>118</sup>, A. Dudarev<sup>35</sup>, A.C. Dudder<sup>97</sup>, E.M. Duffield<sup>18</sup>,
L. Duflot<sup>128</sup>, M. Dührssen<sup>35</sup>, C. Dülsen<sup>180</sup>, M. Dumancic<sup>178</sup>, A.E. Dumitriu<sup>27b,e</sup>, A.K. Duncan<sup>55</sup>,
M. Dunford<sup>59a</sup>, A. Duperrin<sup>99</sup>, H. Duran Yildiz<sup>4a</sup>, M. Düren<sup>54</sup>, A. Durglishvili<sup>157b</sup>, D. Duschinger<sup>46</sup>,
B. Dutta<sup>44</sup>, D. Duvnjak<sup>1</sup>, M. Dyndal<sup>44</sup>, B.S. Dziedzic<sup>82</sup>, C. Eckardt<sup>44</sup>, K.M. Ecker<sup>113</sup>, R.C. Edgar<sup>103</sup>,
T. Eifert<sup>35</sup>, G. Eigen<sup>17</sup>, K. Einsweiler<sup>18</sup>, T. Ekelof<sup>170</sup>, M. El Kacimi<sup>34c</sup>, R. El Kosseifi<sup>99</sup>, V. Ellajosyula<sup>99</sup>, M. Ellert<sup>170</sup>, F. Ellinghaus<sup>180</sup>, A.A. Elliot<sup>174</sup>, N. Ellis<sup>35</sup>, J. Elmsheuser<sup>29</sup>, M. Elsing<sup>35</sup>, D. Emeliyanov<sup>141</sup>,
Y. Enari<sup>161</sup>, J.S. Ennis<sup>176</sup>, M.B. Epland<sup>47</sup>, J. Erdmann<sup>45</sup>, A. Ereditato<sup>20</sup>, S. Errede<sup>171</sup>, M. Escalier<sup>128</sup>,
C. Escobar<sup>172</sup>, B. Esposito<sup>49</sup>, O. Estrada Pastor<sup>172</sup>, A.I. Etienvre<sup>142</sup>, E. Etzion<sup>159</sup>, H. Evans<sup>63</sup>,
A. Ezhilov<sup>134</sup>, M. Ezzi<sup>34e</sup>, F. Fabbri<sup>23b,23a</sup>, L. Fabbri<sup>23b,23a</sup>, V. Fabiani<sup>117</sup>, G. Facini<sup>92</sup>,
R.M. Fakhrutdinov<sup>140</sup>, S. Falciano<sup>70a</sup>, P.J. Falke<sup>5</sup>, S. Falke<sup>5</sup>, J. Faltova<sup>139</sup>, Y. Fang<sup>15a</sup>, M. Fanti<sup>66a,66b</sup>,
A. Farbin<sup>8</sup>, A. Farilla<sup>72a</sup>, E.M. Farina<sup>68a,68b</sup>, T. Farooque<sup>104</sup>, S. Farrell<sup>18</sup>, S.M. Farrington<sup>176</sup>, P. Farthouat<sup>35</sup>, F. Fassi<sup>34e</sup>, P. Fassnacht<sup>35</sup>, D. Fassouliotis<sup>9</sup>, M. Faucci Giannelli<sup>48</sup>, A. Favareto<sup>53b,53a</sup>, W.J. Fawcett<sup>52</sup>, L. Fayard<sup>128</sup>, O.L. Fedin<sup>134,q</sup>, W. Fedorko<sup>173</sup>, M. Feickert<sup>41</sup>, S. Feigl<sup>130</sup>, L. Feligioni<sup>99</sup>,
C. Feng<sup>58b</sup>, E.J. Feng<sup>35</sup>, M. Feng<sup>47</sup>, M.J. Fenton<sup>55</sup>, A.B. Fenyuk<sup>140</sup>, L. Feremenga<sup>8</sup>, J. Ferrando<sup>44</sup>,
A. Ferrari<sup>170</sup>, P. Ferrari<sup>118</sup>, R. Ferrari<sup>68a</sup>, D.E. Ferreira de Lima<sup>59b</sup>, A. Ferrer<sup>172</sup>, D. Ferrere<sup>52</sup>,
C. Ferretti<sup>103</sup>, F. Fiedler<sup>97</sup>, A. Filipčič<sup>89</sup>, F. Filthaut<sup>117</sup>, M. Fincke-Keeler<sup>174</sup>, K.D. Finelli<sup>25</sup>,
M.C.N. Fiolhais 136a,136c,b, L. Fiorini 172, C. Fischer 14, J. Fischer 180, W.C. Fisher 104, N. Flaschel 44,
I. Fleck<sup>148</sup>, P. Fleischmann<sup>103</sup>, R.R.M. Fletcher<sup>133</sup>, T. Flick<sup>180</sup>, B.M. Flierl<sup>112</sup>, L.M. Flores<sup>133</sup>,
L.R. Flores Castillo<sup>61a</sup>, N. Fomin<sup>17</sup>, G.T. Forcolin<sup>98</sup>, A. Formica<sup>142</sup>, F.A. Förster<sup>14</sup>, A.C. Forti<sup>98</sup>,
A.G. Foster<sup>21</sup>, D. Fournier<sup>128</sup>, H. Fox<sup>87</sup>, S. Fracchia<sup>146</sup>, P. Francavilla<sup>69a,69b</sup>, M. Franchini<sup>23b,23a</sup>,
S. Franchino<sup>59a</sup>, D. Francis<sup>35</sup>, L. Franconi<sup>130</sup>, M. Franklin<sup>57</sup>, M. Frate<sup>169</sup>, M. Fraternali<sup>68a,68b</sup>,
D. Freeborn<sup>92</sup>, S.M. Fressard-Batraneanu<sup>35</sup>, B. Freund<sup>107</sup>, W.S. Freund<sup>78b</sup>, D. Froidevaux<sup>35</sup>,
J.A. Frost<sup>131</sup>, C. Fukunaga<sup>162</sup>, T. Fusayasu<sup>114</sup>, J. Fuster<sup>172</sup>, O. Gabizon<sup>158</sup>, A. Gabrielli<sup>23b,23a</sup>,
A. Gabrielli^{18}, G.P. Gach^{81a}, S. Gadatsch^{52}, S. Gadomski^{52}, P. Gadow^{113}, G. Gagliardi^{53b,53a}, L.G. Gagnon^{107}, C. Galea^{27b}, B. Galhardo^{136a,136c}, E.J. Gallas^{131}, B.J. Gallop^{141}, P. Gallus^{138},
G. Galster<sup>39</sup>, R. Gamboa Goni<sup>90</sup>, K.K. Gan<sup>122</sup>, S. Ganguly<sup>178</sup>, Y. Gao<sup>88</sup>, Y.S. Gao<sup>150,m</sup>, C. García<sup>172</sup>,
```

```
J.E. García Navarro<sup>172</sup>, J.A. García Pascual<sup>15a</sup>, M. Garcia-Sciveres<sup>18</sup>, R.W. Gardner<sup>36</sup>, N. Garelli<sup>150</sup>,
V. Garonne<sup>130</sup>, K. Gasnikova<sup>44</sup>, A. Gaudiello<sup>53b,53a</sup>, G. Gaudio<sup>68a</sup>, I.L. Gavrilenko<sup>108</sup>, A. Gavrilyuk<sup>109</sup>,
C. Gay<sup>173</sup>, G. Gaycken<sup>24</sup>, E.N. Gazis<sup>10</sup>, C.N.P. Gee<sup>141</sup>, J. Geisen<sup>51</sup>, M. Geisen<sup>97</sup>, M.P. Geisler<sup>59a</sup>,
K. Gellerstedt<sup>43a,43b</sup>, C. Gemme<sup>53b</sup>, M.H. Genest<sup>56</sup>, C. Geng<sup>103</sup>, S. Gentile<sup>70a,70b</sup>, C. Gentsos<sup>160</sup>,
S. George<sup>91</sup>, D. Gerbaudo<sup>14</sup>, G. Gessner<sup>45</sup>, S. Ghasemi<sup>148</sup>, M. Ghneimat<sup>24</sup>, B. Giacobbe<sup>23b</sup>,
S. Giagu<sup>70a,70b</sup>, N. Giangiacomi<sup>23b,23a</sup>, P. Giannetti<sup>69a</sup>, S.M. Gibson<sup>91</sup>, M. Gignac<sup>143</sup>, D. Gillberg<sup>33</sup>,
G. Gilles<sup>180</sup>, D.M. Gingrich<sup>3,av</sup>, M.P. Giordani<sup>64a,64c</sup>, F.M. Giorgi<sup>23b</sup>, P.F. Giraud<sup>142</sup>, P. Giromini<sup>57</sup>,
G. Giugliarelli<sup>64a,64c</sup>, D. Giugni<sup>66a</sup>, F. Giuli<sup>131</sup>, M. Giulini<sup>59b</sup>, S. Gkaitatzis<sup>160</sup>, I. Gkialas<sup>9,j</sup>,
E.L. Gkougkousis<sup>14</sup>, P. Gkountoumis<sup>10</sup>, L.K. Gladilin<sup>111</sup>, C. Glasman<sup>96</sup>, J. Glatzer<sup>14</sup>, P.C.F. Glaysher<sup>44</sup>,
A. Glazov<sup>44</sup>, M. Goblirsch-Kolb<sup>26</sup>, J. Godlewski<sup>82</sup>, S. Goldfarb<sup>102</sup>, T. Golling<sup>52</sup>, D. Golubkov<sup>140</sup>,
A. Gomes<sup>136a,136b,136d</sup>, R. Goncalves Gama<sup>78a</sup>, R. Gonçalo<sup>136a</sup>, G. Gonella<sup>50</sup>, L. Gonella<sup>21</sup>,
A. Gongadze<sup>77</sup>, F. Gonnella<sup>21</sup>, J.L. Gonski<sup>57</sup>, S. González de la Hoz<sup>172</sup>, S. Gonzalez-Sevilla<sup>52</sup>,
L. Goossens<sup>35</sup>, P.A. Gorbounov<sup>109</sup>, H.A. Gordon<sup>29</sup>, B. Gorini<sup>35</sup>, E. Gorini<sup>65a,65b</sup>, A. Gorišek<sup>89</sup>,
A.T. Goshaw<sup>47</sup>, C. Gössling<sup>45</sup>, M.I. Gostkin<sup>77</sup>, C.A. Gottardo<sup>24</sup>, C.R. Goudet<sup>128</sup>, D. Goujdami<sup>34c</sup>,
A.G. Goussiou<sup>145</sup>, N. Govender<sup>32b,c</sup>, C. Goy<sup>5</sup>, E. Gozani<sup>158</sup>, I. Grabowska-Bold<sup>81a</sup>, P.O.J. Gradin<sup>170</sup>,
E.C. Graham<sup>88</sup>, J. Gramling<sup>169</sup>, E. Gramstad<sup>130</sup>, S. Grancagnolo<sup>19</sup>, V. Gratchev<sup>134</sup>, P.M. Gravila<sup>27f</sup>,
C. Gray<sup>55</sup>, H.M. Gray<sup>18</sup>, Z.D. Greenwood<sup>93,ak</sup>, C. Grefe<sup>24</sup>, K. Gregersen<sup>92</sup>, I.M. Gregor<sup>44</sup>, P. Grenier<sup>150</sup>,
K. Grevtsov<sup>44</sup>, J. Griffiths<sup>8</sup>, A.A. Grillo<sup>143</sup>, K. Grimm<sup>150</sup>, S. Grinstein<sup>14,aa</sup>, Ph. Gris<sup>37</sup>, J.-F. Grivaz<sup>128</sup>,
S. Groh<sup>97</sup>, E. Gross<sup>178</sup>, J. Grosse-Knetter<sup>51</sup>, G.C. Grossi<sup>93</sup>, Z.J. Grout<sup>92</sup>, A. Grummer<sup>116</sup>, L. Guan<sup>103</sup>,
W. Guan<sup>179</sup>, J. Guenther<sup>35</sup>, A. Guerguichon<sup>128</sup>, F. Guescini<sup>166a</sup>, D. Guest<sup>169</sup>, O. Gueta<sup>159</sup>, R. Gugel<sup>50</sup>,
B. Gui<sup>122</sup>, T. Guillemin<sup>5</sup>, S. Guindon<sup>35</sup>, U. Gul<sup>55</sup>, C. Gumpert<sup>35</sup>, J. Guo<sup>58c</sup>, W. Guo<sup>103</sup>, Y. Guo<sup>58a,t</sup>,
Z. Guo<sup>99</sup>, R. Gupta<sup>41</sup>, S. Gurbuz<sup>12c</sup>, G. Gustavino<sup>124</sup>, B.J. Gutelman<sup>158</sup>, P. Gutierrez<sup>124</sup>,
N.G. Gutierrez Ortiz<sup>92</sup>, C. Gutschow<sup>92</sup>, C. Guyot<sup>142</sup>, M.P. Guzik<sup>81a</sup>, C. Gwenlan<sup>131</sup>, C.B. Gwilliam<sup>88</sup>,
A. Haas<sup>121</sup>, C. Haber<sup>18</sup>, H.K. Hadavand<sup>8</sup>, N. Haddad<sup>34e</sup>, A. Hadef<sup>99</sup>, S. Hageböck<sup>24</sup>, M. Hagihara<sup>167</sup>,
H. Hakobyan<sup>182,*</sup>, M. Haleem<sup>175</sup>, J. Haley<sup>125</sup>, G. Halladjian<sup>104</sup>, G.D. Hallewell<sup>99</sup>, K. Hamacher<sup>180</sup>,
P. Hamal<sup>126</sup>, K. Hamano<sup>174</sup>, A. Hamilton<sup>32a</sup>, G.N. Hamity<sup>146</sup>, K. Han<sup>58a</sup>, J. Han<sup>58a</sup>, S. Han<sup>15d</sup>,
K. Hanagaki<sup>79,w</sup>, M. Hance<sup>143</sup>, D.M. Handl<sup>112</sup>, B. Haney<sup>133</sup>, R. Hankache<sup>132</sup>, P. Hanke<sup>59a</sup>, E. Hansen<sup>94</sup>,
J.B. Hansen<sup>39</sup>, J.D. Hansen<sup>39</sup>, M.C. Hansen<sup>24</sup>, P.H. Hansen<sup>39</sup>, K. Hara<sup>167</sup>, A.S. Hard<sup>179</sup>,
T. Harenberg<sup>180</sup>, S. Harkusha<sup>105</sup>, P.F. Harrison<sup>176</sup>, N.M. Hartmann<sup>112</sup>, Y. Hasegawa<sup>147</sup>, A. Hasib<sup>48</sup>,
S. Hassani<sup>142</sup>, S. Haug<sup>20</sup>, R. Hauser<sup>104</sup>, L. Hauswald<sup>46</sup>, L.B. Havener<sup>38</sup>, M. Havranek<sup>138</sup>,
C.M. Hawkes<sup>21</sup>, R.J. Hawkings<sup>35</sup>, D. Hayden<sup>104</sup>, C. Hayes<sup>152</sup>, C.P. Hays<sup>131</sup>, J.M. Hays<sup>90</sup>,
H.S. Hayward<sup>88</sup>, S.J. Haywood<sup>141</sup>, M.P. Heath<sup>48</sup>, V. Hedberg<sup>94</sup>, L. Heelan<sup>8</sup>, S. Heer<sup>24</sup>,
K.K. Heidegger<sup>50</sup>, S. Heim<sup>44</sup>, T. Heim<sup>18</sup>, B. Heinemann<sup>44,aq</sup>, J.J. Heinrich<sup>112</sup>, L. Heinrich<sup>121</sup>, C. Heinz<sup>54</sup>, J. Hejbal<sup>137</sup>, L. Helary<sup>35</sup>, A. Held<sup>173</sup>, S. Hellesund<sup>130</sup>, S. Hellman<sup>43a,43b</sup>, C. Helsens<sup>35</sup>,
R.C.W. Henderson<sup>87</sup>, Y. Heng<sup>179</sup>, S. Henkelmann<sup>173</sup>, A.M. Henriques Correia<sup>35</sup>, G.H. Herbert<sup>19</sup>,
H. Herde<sup>26</sup>, V. Herget<sup>175</sup>, Y. Hernández Jiménez<sup>32c</sup>, H. Herr<sup>97</sup>, G. Herten<sup>50</sup>, R. Hertenberger<sup>112</sup>,
L. Hervas<sup>35</sup>, T.C. Herwig<sup>133</sup>, G.G. Hesketh<sup>92</sup>, N.P. Hessey<sup>166a</sup>, J.W. Hetherly<sup>41</sup>, S. Higashino<sup>79</sup>,
E. Higón-Rodriguez<sup>172</sup>, K. Hildebrand<sup>36</sup>, E. Hill<sup>174</sup>, J.C. Hill<sup>31</sup>, K.H. Hiller<sup>44</sup>, S.J. Hillier<sup>21</sup>, M. Hils<sup>46</sup>,
I. Hinchliffe<sup>18</sup>, M. Hirose<sup>129</sup>, D. Hirschbuehl<sup>180</sup>, B. Hiti<sup>89</sup>, O. Hladik<sup>137</sup>, D.R. Hlaluku<sup>32c</sup>, X. Hoad<sup>48</sup>,
J. Hobbs<sup>152</sup>, N. Hod<sup>166a</sup>, M.C. Hodgkinson<sup>146</sup>, A. Hoecker<sup>35</sup>, M.R. Hoeferkamp<sup>116</sup>, F. Hoenig<sup>112</sup>,
D. Hohn<sup>24</sup>, D. Hohov<sup>128</sup>, T.R. Holmes<sup>36</sup>, M. Holzbock<sup>112</sup>, M. Homann<sup>45</sup>, S. Honda<sup>167</sup>, T. Honda<sup>79</sup>,
T.M. Hong<sup>135</sup>, B.H. Hooberman<sup>171</sup>, W.H. Hopkins<sup>127</sup>, Y. Horii<sup>115</sup>, P. Horn<sup>46</sup>, A.J. Horton<sup>149</sup>,
L.A. Horyn<sup>36</sup>, J-Y. Hostachy<sup>56</sup>, A. Hostiuc<sup>145</sup>, S. Hou<sup>155</sup>, A. Hoummada<sup>34a</sup>, J. Howarth<sup>98</sup>, J. Hoya<sup>86</sup>,
M. Hrabovsky<sup>126</sup>, J. Hrdinka<sup>35</sup>, I. Hristova<sup>19</sup>, J. Hrivnac<sup>128</sup>, A. Hrynevich<sup>106</sup>, T. Hryn'ova<sup>5</sup>, P.J. Hsu<sup>62</sup>,
S.-C. Hsu<sup>145</sup>, Q. Hu<sup>29</sup>, S. Hu<sup>58c</sup>, Y. Huang<sup>15a</sup>, Z. Hubacek<sup>138</sup>, F. Hubaut<sup>99</sup>, M. Huebner<sup>24</sup>,
F. Huegging<sup>24</sup>, T.B. Huffman<sup>131</sup>, E.W. Hughes<sup>38</sup>, M. Huhtinen<sup>35</sup>, R.F.H. Hunter<sup>33</sup>, P. Huo<sup>152</sup>,
A.M. Hupe<sup>33</sup>, N. Huseynov<sup>77,ah</sup>, J. Huston<sup>104</sup>, J. Huth<sup>57</sup>, R. Hyneman<sup>103</sup>, G. Iacobucci<sup>52</sup>, G. Iakovidis<sup>29</sup>,
```

```
I. Ibragimov<sup>148</sup>, L. Iconomidou-Fayard<sup>128</sup>, Z. Idrissi<sup>34e</sup>, P. Iengo<sup>35</sup>, R. Ignazzi<sup>39</sup>, O. Igonkina<sup>118,ad</sup>,
R. Iguchi<sup>161</sup>, T. Iizawa<sup>177</sup>, Y. Ikegami<sup>79</sup>, M. Ikeno<sup>79</sup>, D. Iliadis<sup>160</sup>, N. Ilic<sup>150</sup>, F. Iltzsche<sup>46</sup>,
G. Introzzi<sup>68a,68b</sup>, M. Iodice<sup>72a</sup>, K. Iordanidou<sup>38</sup>, V. Ippolito<sup>70a,70b</sup>, M.F. Isacson<sup>170</sup>, N. Ishijima<sup>129</sup>,
M. Ishino<sup>161</sup>, M. Ishitsuka<sup>163</sup>, C. Issever<sup>131</sup>, S. Istin<sup>12c,ao</sup>, F. Ito<sup>167</sup>, J.M. Iturbe Ponce<sup>61a</sup>, R. Iuppa<sup>73a,73b</sup>,
A. Ivina<sup>178</sup>, H. Iwasaki<sup>79</sup>, J.M. Izen<sup>42</sup>, V. Izzo<sup>67a</sup>, S. Jabbar<sup>3</sup>, P. Jacka<sup>137</sup>, P. Jackson<sup>1</sup>, R.M. Jacobs<sup>24</sup>,
V. Jain<sup>2</sup>, G. Jäkel<sup>180</sup>, K.B. Jakobi<sup>97</sup>, K. Jakobs<sup>50</sup>, S. Jakobsen<sup>74</sup>, T. Jakoubek<sup>137</sup>, D.O. Jamin<sup>125</sup>,
D.K. Jana<sup>93</sup>, R. Jansky<sup>52</sup>, J. Janssen<sup>24</sup>, M. Janus<sup>51</sup>, P.A. Janus<sup>81a</sup>, G. Jarlskog<sup>94</sup>, N. Javadov<sup>77,ah</sup>,
T. Javůrek<sup>50</sup>, M. Javurkova<sup>50</sup>, F. Jeanneau<sup>142</sup>, L. Jeanty<sup>18</sup>, J. Jejelava<sup>157a,ai</sup>, A. Jelinskas<sup>176</sup>, P. Jenni<sup>50,d</sup>,
J. Jeong<sup>44</sup>, C. Jeske<sup>176</sup>, S. Jézéquel<sup>5</sup>, H. Ji<sup>179</sup>, J. Jia<sup>152</sup>, H. Jiang<sup>76</sup>, Y. Jiang<sup>58a</sup>, Z. Jiang<sup>150,r</sup>, S. Jiggins<sup>50</sup>, F.A. Jimenez Morales<sup>37</sup>, J. Jimenez Pena<sup>172</sup>, S. Jin<sup>15c</sup>, A. Jinaru<sup>27b</sup>, O. Jinnouchi<sup>163</sup>, H. Jivan<sup>32c</sup>,
P. Johansson<sup>146</sup>, K.A. Johns<sup>7</sup>, C.A. Johnson<sup>63</sup>, W.J. Johnson<sup>145</sup>, K. Jon-And<sup>43a,43b</sup>, R.W.L. Jones<sup>87</sup>
S.D. Jones<sup>153</sup>, S. Jones<sup>7</sup>, T.J. Jones<sup>88</sup>, J. Jongmanns<sup>59a</sup>, P.M. Jorge<sup>136a,136b</sup>, J. Jovicevic<sup>166a</sup>, X. Ju<sup>179</sup>,
J.J. Junggeburth<sup>113</sup>, A. Juste Rozas<sup>14,aa</sup>, A. Kaczmarska<sup>82</sup>, M. Kado<sup>128</sup>, H. Kagan<sup>122</sup>, M. Kagan<sup>150</sup>, T. Kaji<sup>177</sup>, E. Kajomovitz<sup>158</sup>, C.W. Kalderon<sup>94</sup>, A. Kaluza<sup>97</sup>, S. Kama<sup>41</sup>, A. Kamenshchikov<sup>140</sup>,
L. Kanjir<sup>89</sup>, Y. Kano<sup>161</sup>, V.A. Kantserov<sup>110</sup>, J. Kanzaki<sup>79</sup>, B. Kaplan<sup>121</sup>, L.S. Kaplan<sup>179</sup>, D. Kar<sup>32c</sup>,
M.J. Kareem<sup>166b</sup>, E. Karentzos<sup>10</sup>, S.N. Karpov<sup>77</sup>, Z.M. Karpova<sup>77</sup>, V. Kartvelishvili<sup>87</sup>,
A.N. Karyukhin<sup>140</sup>, K. Kasahara<sup>167</sup>, L. Kashif<sup>179</sup>, R.D. Kass<sup>122</sup>, A. Kastanas<sup>151</sup>, Y. Kataoka<sup>161</sup>,
C. Kato<sup>161</sup>, A. Katre<sup>52</sup>, J. Katzy<sup>44</sup>, K. Kawade<sup>80</sup>, K. Kawagoe<sup>85</sup>, T. Kawamoto<sup>161</sup>, G. Kawamura<sup>51</sup>,
E.F. Kay<sup>88</sup>, V.F. Kazanin<sup>120b,120a</sup>, R. Keeler<sup>174</sup>, R. Kehoe<sup>41</sup>, J.S. Keller<sup>33</sup>, E. Kellermann<sup>94</sup>,
J.J. Kempster<sup>21</sup>, J. Kendrick<sup>21</sup>, O. Kepka<sup>137</sup>, S. Kersten<sup>180</sup>, B.P. Kerševan<sup>89</sup>, R.A. Keyes<sup>101</sup>,
M. Khader<sup>171</sup>, F. Khalil-Zada<sup>13</sup>, A. Khanov<sup>125</sup>, A.G. Kharlamov<sup>120b,120a</sup>, T. Kharlamova<sup>120b,120a</sup>,
A. Khodinov<sup>164</sup>, T.J. Khoo<sup>52</sup>, V. Khovanskiy<sup>109,*</sup>, E. Khramov<sup>77</sup>, J. Khubua<sup>157b</sup>, S. Kido<sup>80</sup>, M. Kiehn<sup>52</sup>,
C.R. Kilby<sup>91</sup>, H.Y. Kim<sup>8</sup>, S.H. Kim<sup>167</sup>, Y.K. Kim<sup>36</sup>, N. Kimura<sup>64a,64c</sup>, O.M. Kind<sup>19</sup>, B.T. King<sup>88</sup>,
D. Kirchmeier<sup>46</sup>, J. Kirk<sup>141</sup>, A.E. Kiryunin<sup>113</sup>, T. Kishimoto<sup>161</sup>, D. Kisielewska<sup>81a</sup>, V. Kitali<sup>44</sup>,
O. Kivernyk<sup>5</sup>, E. Kladiva<sup>28b</sup>, T. Klapdor-Kleingrothaus<sup>50</sup>, M.H. Klein<sup>103</sup>, M. Klein<sup>88</sup>, U. Klein<sup>88</sup>,
K. Kleinknecht<sup>97</sup>, P. Klimek<sup>119</sup>, A. Klimentov<sup>29</sup>, R. Klingenberg<sup>45,*</sup>, T. Klingl<sup>24</sup>, T. Klioutchnikova<sup>35</sup>,
F.F. Klitzner<sup>112</sup>, P. Kluit<sup>118</sup>, S. Kluth<sup>113</sup>, E. Kneringer<sup>74</sup>, E.B.F.G. Knoops<sup>99</sup>, A. Knue<sup>50</sup>,
A. Kobayashi<sup>161</sup>, D. Kobayashi<sup>85</sup>, T. Kobayashi<sup>161</sup>, M. Kobel<sup>46</sup>, M. Kocian<sup>150</sup>, P. Kodys<sup>139</sup>, T. Koffas<sup>33</sup>,
E. Koffeman<sup>118</sup>, N.M. Köhler<sup>113</sup>, T. Koi<sup>150</sup>, M. Kolb<sup>59b</sup>, I. Koletsou<sup>5</sup>, T. Kondo<sup>79</sup>, N. Kondrashova<sup>58c</sup>,
K. Köneke<sup>50</sup>, A.C. König<sup>117</sup>, T. Kono<sup>79,ap</sup>, R. Konoplich<sup>121,al</sup>, N. Konstantinidis<sup>92</sup>, B. Konya<sup>94</sup>,
R. Kopeliansky<sup>63</sup>, S. Koperny<sup>81a</sup>, K. Korcyl<sup>82</sup>, K. Kordas<sup>160</sup>, A. Korn<sup>92</sup>, I. Korolkov<sup>14</sup>,
E.V. Korolkova<sup>146</sup>, O. Kortner<sup>113</sup>, S. Kortner<sup>113</sup>, T. Kosek<sup>139</sup>, V.V. Kostyukhin<sup>24</sup>, A. Kotwal<sup>47</sup>,
A. Koulouris<sup>10</sup>, A. Kourkoumeli-Charalampidi<sup>68a,68b</sup>, C. Kourkoumelis<sup>9</sup>, E. Kourlitis<sup>146</sup>,
V. Kouskoura<sup>29</sup>, A.B. Kowalewska<sup>82</sup>, R. Kowalewski<sup>174</sup>, T.Z. Kowalski<sup>81a</sup>, C. Kozakai<sup>161</sup>,
W. Kozanecki<sup>142</sup>, A.S. Kozhin<sup>140</sup>, V.A. Kramarenko<sup>111</sup>, G. Kramberger<sup>89</sup>, D. Krasnopevtsev<sup>110</sup>,
M.W. Krasny<sup>132</sup>, A. Krasznahorkay<sup>35</sup>, D. Krauss<sup>113</sup>, J.A. Kremer<sup>81a</sup>, J. Kretzschmar<sup>88</sup>, K. Kreutzfeldt<sup>54</sup>,
P. Krieger<sup>165</sup>, K. Krizka<sup>18</sup>, K. Kroeninger<sup>45</sup>, H. Kroha<sup>113</sup>, J. Kroll<sup>137</sup>, J. Kroll<sup>133</sup>, J. Kroseberg<sup>24</sup>,
J. Krstic<sup>16</sup>, U. Kruchonak<sup>77</sup>, H. Krüger<sup>24</sup>, N. Krumnack<sup>76</sup>, M.C. Kruse<sup>47</sup>, T. Kubota<sup>102</sup>, S. Kuday<sup>4b</sup>,
J.T. Kuechler<sup>180</sup>, S. Kuehn<sup>35</sup>, A. Kugel<sup>59a</sup>, F. Kuger<sup>175</sup>, T. Kuhl<sup>44</sup>, V. Kukhtin<sup>77</sup>, R. Kukla<sup>99</sup>,
Y. Kulchitsky<sup>105</sup>, S. Kuleshov<sup>144b</sup>, Y.P. Kulinich<sup>171</sup>, M. Kuna<sup>56</sup>, T. Kunigo<sup>83</sup>, A. Kupco<sup>137</sup>, T. Kupfer<sup>45</sup>,
O. Kuprash<sup>159</sup>, H. Kurashige<sup>80</sup>, L.L. Kurchaninov<sup>166a</sup>, Y.A. Kurochkin<sup>105</sup>, M.G. Kurth<sup>15d</sup>,
E.S. Kuwertz<sup>174</sup>, M. Kuze<sup>163</sup>, J. Kvita<sup>126</sup>, T. Kwan<sup>174</sup>, A. La Rosa<sup>113</sup>, J.L. La Rosa Navarro<sup>78d</sup>,
L. La Rotonda<sup>40b,40a</sup>, F. La Ruffa<sup>40b,40a</sup>, C. Lacasta<sup>172</sup>, F. Lacava<sup>70a,70b</sup>, J. Lacey<sup>44</sup>, D.P.J. Lack<sup>98</sup>,
H. Lacker<sup>19</sup>, D. Lacour<sup>132</sup>, E. Ladygin<sup>77</sup>, R. Lafaye<sup>5</sup>, B. Laforge<sup>132</sup>, S. Lai<sup>51</sup>, S. Lammers<sup>63</sup>, W. Lampl<sup>7</sup>,
E. Lançon<sup>29</sup>, U. Landgraf<sup>50</sup>, M.P.J. Landon<sup>90</sup>, M.C. Lanfermann<sup>52</sup>, V.S. Lang<sup>44</sup>, J.C. Lange<sup>14</sup>,
R.J. Langenberg<sup>35</sup>, A.J. Lankford<sup>169</sup>, F. Lanni<sup>29</sup>, K. Lantzsch<sup>24</sup>, A. Lanza<sup>68a</sup>, A. Lapertosa<sup>53b,53a</sup>,
S. Laplace<sup>132</sup>, J.F. Laporte<sup>142</sup>, T. Lari<sup>66a</sup>, F. Lasagni Manghi<sup>23b,23a</sup>, M. Lassnig<sup>35</sup>, T.S. Lau<sup>61a</sup>,
```

```
A. Laudrain<sup>128</sup>, A.T. Law<sup>143</sup>, P. Laycock<sup>88</sup>, M. Lazzaroni<sup>66a,66b</sup>, B. Le<sup>102</sup>, O. Le Dortz<sup>132</sup>,
E. Le Guirriec<sup>99</sup>, E.P. Le Quilleuc<sup>142</sup>, M. LeBlanc<sup>7</sup>, T. LeCompte<sup>6</sup>, F. Ledroit-Guillon<sup>56</sup>, C.A. Lee<sup>29</sup>, G.R. Lee<sup>144a</sup>, L. Lee<sup>57</sup>, S.C. Lee<sup>155</sup>, B. Lefebvre<sup>101</sup>, M. Lefebvre<sup>174</sup>, F. Legger<sup>112</sup>, C. Leggett<sup>18</sup>,
G. Lehmann Miotto<sup>35</sup>, W.A. Leight<sup>44</sup>, A. Leisos<sup>160,x</sup>, M.A.L. Leite<sup>78d</sup>, R. Leitner<sup>139</sup>, D. Lellouch<sup>178</sup>,
B. Lemmer<sup>51</sup>, K.J.C. Leney<sup>92</sup>, T. Lenz<sup>24</sup>, B. Lenzi<sup>35</sup>, R. Leone<sup>7</sup>, S. Leone<sup>69a</sup>, C. Leonidopoulos<sup>48</sup>,
G. Lerner<sup>153</sup>, C. Leroy<sup>107</sup>, R. Les<sup>165</sup>, A.A.J. Lesage<sup>142</sup>, C.G. Lester<sup>31</sup>, M. Levchenko<sup>134</sup>, J. Levêque<sup>5</sup>,
D. Levin<sup>103</sup>, L.J. Levinson<sup>178</sup>, M. Levy<sup>21</sup>, D. Lewis<sup>90</sup>, B. Li<sup>58a,t</sup>, C-Q. Li<sup>58a</sup>, H. Li<sup>58b</sup>, L. Li<sup>58c</sup>, Q. Li<sup>15d</sup>,
Q.Y. Li<sup>58a</sup>, S. Li<sup>58d,58c</sup>, X. Li<sup>58c</sup>, Y. Li<sup>148</sup>, Z. Liang<sup>15a</sup>, B. Liberti<sup>71a</sup>, A. Liblong<sup>165</sup>, K. Lie<sup>61c</sup>, S. Liem<sup>118</sup>,
A. Limosani<sup>154</sup>, C.Y. Lin<sup>31</sup>, K. Lin<sup>104</sup>, S.C. Lin<sup>156</sup>, T.H. Lin<sup>97</sup>, R.A. Linck<sup>63</sup>, B.E. Lindquist<sup>152</sup>,
A.L. Lionti<sup>52</sup>, E. Lipeles<sup>133</sup>, A. Lipniacka<sup>17</sup>, M. Lisovyi<sup>59b</sup>, T.M. Liss<sup>171</sup>, as, A. Lister<sup>173</sup>, A.M. Litke<sup>143</sup>,
J.D. Little<sup>8</sup>, B. Liu<sup>76</sup>, B.L Liu<sup>6</sup>, H.B. Liu<sup>29</sup>, H. Liu<sup>103</sup>, J.B. Liu<sup>58a</sup>, J.K.K. Liu<sup>131</sup>, K. Liu<sup>132</sup>, M. Liu<sup>58a</sup>, P. Liu<sup>18</sup>, Y.L. Liu<sup>58a</sup>, Y.W. Liu<sup>58a</sup>, M. Livan<sup>68a,68b</sup>, A. Lleres<sup>56</sup>, J. Llorente Merino<sup>15a</sup>, S.L. Lloyd<sup>90</sup>,
C.Y. Lo<sup>61b</sup>, F. Lo Sterzo<sup>41</sup>, E.M. Lobodzinska<sup>44</sup>, P. Loch<sup>7</sup>, F.K. Loebinger<sup>98</sup>, A. Loesle<sup>50</sup>, K.M. Loew<sup>26</sup>,
T. Lohse<sup>19</sup>, K. Lohwasser<sup>146</sup>, M. Lokajicek<sup>137</sup>, B.A. Long<sup>25</sup>, J.D. Long<sup>171</sup>, R.E. Long<sup>87</sup>, L. Longo<sup>65a,65b</sup>,
K.A. Looper<sup>122</sup>, J.A. Lopez<sup>144b</sup>, I. Lopez Paz<sup>14</sup>, A. Lopez Solis<sup>132</sup>, J. Lorenz<sup>112</sup>, N. Lorenzo Martinez<sup>5</sup>,
M. Losada<sup>22</sup>, P.J. Lösel<sup>112</sup>, X. Lou<sup>44</sup>, X. Lou<sup>15a</sup>, A. Lounis<sup>128</sup>, J. Love<sup>6</sup>, P.A. Love<sup>87</sup>,
J.J. Lozano Bahilo<sup>172</sup>, H. Lu<sup>61a</sup>, N. Lu<sup>103</sup>, Y.J. Lu<sup>62</sup>, H.J. Lubatti<sup>145</sup>, C. Luci<sup>70a,70b</sup>, A. Lucotte<sup>56</sup>,
C. Luedtke<sup>50</sup>, F. Luehring<sup>63</sup>, I. Luise<sup>132</sup>, W. Lukas<sup>74</sup>, L. Luminari<sup>70a</sup>, B. Lund-Jensen<sup>151</sup>, M.S. Lutz<sup>100</sup>,
P.M. Luzi<sup>132</sup>, D. Lynn<sup>29</sup>, R. Lysak<sup>137</sup>, E. Lytken<sup>94</sup>, F. Lyu<sup>15a</sup>, V. Lyubushkin<sup>77</sup>, H. Ma<sup>29</sup>, L.L. Ma<sup>58b</sup>,
Y. Ma<sup>58b</sup>, G. Maccarrone<sup>49</sup>, A. Macchiolo<sup>113</sup>, C.M. Macdonald<sup>146</sup>, J. Machado Miguens<sup>133,136b</sup>,
D. Madaffari<sup>172</sup>, R. Madar<sup>37</sup>, W.F. Mader<sup>46</sup>, A. Madsen<sup>44</sup>, N. Madysa<sup>46</sup>, J. Maeda<sup>80</sup>, S. Maeland<sup>17</sup>,
T. Maeno<sup>29</sup>, A.S. Maevskiy<sup>111</sup>, V. Magerl<sup>50</sup>, C. Maidantchik<sup>78b</sup>, T. Maier<sup>112</sup>, A. Maio<sup>136a,136b,136d</sup>,
O.\ Majersky^{28a},\ S.\ Majewski^{127},\ Y.\ Makida^{79},\ N.\ Makovec^{128},\ B.\ Malaescu^{132},\ Pa.\ Malecki^{82},
V.P. Maleev<sup>134</sup>, F. Malek<sup>56</sup>, U. Mallik<sup>75</sup>, D. Malon<sup>6</sup>, C. Malone<sup>31</sup>, S. Maltezos<sup>10</sup>, S. Malyukov<sup>35</sup>,
J. Mamuzic<sup>172</sup>, G. Mancini<sup>49</sup>, I. Mandić<sup>89</sup>, J. Maneira<sup>136a</sup>, L. Manhaes de Andrade Filho<sup>78a</sup>,
J. Manjarres Ramos<sup>46</sup>, K.H. Mankinen<sup>94</sup>, A. Mann<sup>112</sup>, A. Manousos<sup>74</sup>, B. Mansoulie<sup>142</sup>,
J.D. Mansour<sup>15a</sup>, R. Mantifel<sup>101</sup>, M. Mantoani<sup>51</sup>, S. Manzoni<sup>66a,66b</sup>, G. Marceca<sup>30</sup>, L. March<sup>52</sup>,
L. Marchese<sup>131</sup>, G. Marchiori<sup>132</sup>, M. Marcisovsky<sup>137</sup>, C.A. Marin Tobon<sup>35</sup>, M. Marjanovic<sup>37</sup>,
D.E. Marley<sup>103</sup>, F. Marroquim<sup>78b</sup>, Z. Marshall<sup>18</sup>, M.U.F Martensson<sup>170</sup>, S. Marti-Garcia<sup>172</sup>,
C.B. Martin<sup>122</sup>, T.A. Martin<sup>176</sup>, V.J. Martin<sup>48</sup>, B. Martin dit Latour<sup>17</sup>, M. Martinez<sup>14,aa</sup>,
V.I. Martinez Outschoorn<sup>100</sup>, S. Martin-Haugh<sup>141</sup>, V.S. Martoiu<sup>27b</sup>, A.C. Martyniuk<sup>92</sup>, A. Marzin<sup>35</sup>,
L. Masetti<sup>97</sup>, T. Mashimo<sup>161</sup>, R. Mashinistov<sup>108</sup>, J. Masik<sup>98</sup>, A.L. Maslennikov<sup>120b,120a</sup>, L.H. Mason<sup>102</sup>,
L. Massa<sup>71a,71b</sup>, P. Mastrandrea<sup>5</sup>, A. Mastroberardino<sup>40b,40a</sup>, T. Masubuchi<sup>161</sup>, P. Mättig<sup>180</sup>, J. Maurer<sup>27b</sup>, B. Maček<sup>89</sup>, S.J. Maxfield<sup>88</sup>, D.A. Maximov<sup>120b,120a</sup>, R. Mazini<sup>155</sup>, I. Maznas<sup>160</sup>, S.M. Mazza<sup>143</sup>,
N.C. Mc Fadden<sup>116</sup>, G. Mc Goldrick<sup>165</sup>, S.P. Mc Kee<sup>103</sup>, A. McCarn<sup>103</sup>, T.G. McCarthy<sup>113</sup>,
L.I. McClymont<sup>92</sup>, E.F. McDonald<sup>102</sup>, J.A. Mcfayden<sup>35</sup>, G. Mchedlidze<sup>51</sup>, M.A. McKay<sup>41</sup>,
K.D. McLean<sup>174</sup>, S.J. McMahon<sup>141</sup>, P.C. McNamara<sup>102</sup>, C.J. McNicol<sup>176</sup>, R.A. McPherson<sup>174</sup>, af,
J.E. Mdhluli<sup>32c</sup>, Z.A. Meadows<sup>100</sup>, S. Meehan<sup>145</sup>, T.M. Megy<sup>50</sup>, S. Mehlhase<sup>112</sup>, A. Mehta<sup>88</sup>,
T. Meideck<sup>56</sup>, B. Meirose<sup>42</sup>, D. Melini<sup>172,h</sup>, B.R. Mellado Garcia<sup>32c</sup>, J.D. Mellenthin<sup>51</sup>, M. Melo<sup>28a</sup>,
F. Meloni<sup>20</sup>, A. Melzer<sup>24</sup>, S.B. Menary<sup>98</sup>, L. Meng<sup>88</sup>, X.T. Meng<sup>103</sup>, A. Mengarelli<sup>23b,23a</sup>, S. Menke<sup>113</sup>, E. Meoni<sup>40b,40a</sup>, S. Mergelmeyer<sup>19</sup>, C. Merlassino<sup>20</sup>, P. Mermod<sup>52</sup>, L. Merola<sup>67a,67b</sup>, C. Meroni<sup>66a</sup>,
F.S. Merritt<sup>36</sup>, A. Messina<sup>70a,70b</sup>, J. Metcalfe<sup>6</sup>, A.S. Mete<sup>169</sup>, C. Meyer<sup>133</sup>, J. Meyer<sup>158</sup>, J-P. Meyer<sup>142</sup>,
H. Meyer Zu Theenhausen<sup>59a</sup>, F. Miano<sup>153</sup>, R.P. Middleton<sup>141</sup>, L. Mijović<sup>48</sup>, G. Mikenberg<sup>178</sup>,
M. Mikestikova<sup>137</sup>, M. Mikuž<sup>89</sup>, M. Milesi<sup>102</sup>, A. Milic<sup>165</sup>, D.A. Millar<sup>90</sup>, D.W. Miller<sup>36</sup>, A. Milov<sup>178</sup>, D.A. Milstead<sup>43a,43b</sup>, A.A. Minaenko<sup>140</sup>, I.A. Minashvili<sup>157b</sup>, A.I. Mincer<sup>121</sup>, B. Mindur<sup>81a</sup>, M. Mineev<sup>77</sup>, Y. Minegishi<sup>161</sup>, Y. Ming<sup>179</sup>, L.M. Mir<sup>14</sup>, A. Mirto<sup>65a,65b</sup>, K.P. Mistry<sup>133</sup>, T. Mitani<sup>177</sup>,
J. Mitrevski<sup>112</sup>, V.A. Mitsou<sup>172</sup>, A. Miucci<sup>20</sup>, P.S. Miyagawa<sup>146</sup>, A. Mizukami<sup>79</sup>, J.U. Mjörnmark<sup>94</sup>.
```

```
T. Mkrtchyan<sup>182</sup>, M. Mlynarikova<sup>139</sup>, T. Moa<sup>43a,43b</sup>, K. Mochizuki<sup>107</sup>, P. Mogg<sup>50</sup>, S. Mohapatra<sup>38</sup>,
S. Molander<sup>43a,43b</sup>, R. Moles-Valls<sup>24</sup>, M.C. Mondragon<sup>104</sup>, K. Mönig<sup>44</sup>, J. Monk<sup>39</sup>, E. Monnier<sup>99</sup>,
A. Montalbano<sup>149</sup>, J. Montejo Berlingen<sup>35</sup>, F. Monticelli<sup>86</sup>, S. Monzani<sup>66a</sup>, R.W. Moore<sup>3</sup>,
N. Morange<sup>128</sup>, D. Moreno<sup>22</sup>, M. Moreno Llácer<sup>35</sup>, P. Morettini<sup>53b</sup>, M. Morgenstern<sup>118</sup>, S. Morgenstern<sup>35</sup>, D. Mori<sup>149</sup>, T. Mori<sup>161</sup>, M. Morii<sup>57</sup>, M. Morinaga<sup>177</sup>, V. Morisbak<sup>130</sup>, A.K. Morley<sup>35</sup>,
G. Mornacchi<sup>35</sup>, J.D. Morris<sup>90</sup>, L. Morvaj<sup>152</sup>, P. Moschovakos<sup>10</sup>, M. Mosidze<sup>157b</sup>, H.J. Moss<sup>146</sup>,
J. Moss<sup>150,n</sup>, K. Motohashi<sup>163</sup>, R. Mount<sup>150</sup>, E. Mountricha<sup>29</sup>, E.J.W. Moyse<sup>100</sup>, S. Muanza<sup>99</sup>,
F. Mueller<sup>113</sup>, J. Mueller<sup>135</sup>, R.S.P. Mueller<sup>112</sup>, D. Muenstermann<sup>87</sup>, P. Mullen<sup>55</sup>, G.A. Mullier<sup>20</sup>,
F.J. Munoz Sanchez<sup>98</sup>, P. Murin<sup>28b</sup>, W.J. Murray<sup>176,141</sup>, A. Murrone<sup>66a,66b</sup>, M. Muškinja<sup>89</sup>,
C. Mwewa<sup>32a</sup>, A.G. Myagkov<sup>140,am</sup>, J. Myers<sup>127</sup>, M. Myska<sup>138</sup>, B.P. Nachman<sup>18</sup>, O. Nackenhorst<sup>45</sup>,
K. Nagai<sup>131</sup>, R. Nagai<sup>79,ap</sup>, K. Nagano<sup>79</sup>, Y. Nagasaka<sup>60</sup>, K. Nagata<sup>167</sup>, M. Nagel<sup>50</sup>, E. Nagy<sup>99</sup>,
A.M. Nairz<sup>35</sup>, Y. Nakahama<sup>115</sup>, K. Nakamura<sup>79</sup>, T. Nakamura<sup>161</sup>, I. Nakano<sup>123</sup>, F. Napolitano<sup>59a</sup>,
R.F. Naranjo Garcia<sup>44</sup>, R. Narayan<sup>11</sup>, D.I. Narrias Villar<sup>59a</sup>, I. Naryshkin<sup>134</sup>, T. Naumann<sup>44</sup>,
G. Navarro<sup>22</sup>, R. Nayyar<sup>7</sup>, H.A. Neal<sup>103</sup>, P.Y. Nechaeva<sup>108</sup>, T.J. Neep<sup>142</sup>, A. Negrii<sup>68a,68b</sup>, M. Negrini<sup>23b</sup>,
S. Nektarijevic<sup>117</sup>, C. Nellist<sup>51</sup>, M.E. Nelson<sup>131</sup>, S. Nemecek<sup>137</sup>, P. Nemethy<sup>121</sup>, M. Nessi<sup>35,f</sup>,
M.S. Neubauer<sup>171</sup>, M. Neumann<sup>180</sup>, P.R. Newman<sup>21</sup>, T.Y. Ng<sup>61c</sup>, Y.S. Ng<sup>19</sup>, H.D.N. Nguyen<sup>99</sup>,
T. Nguyen Manh<sup>107</sup>, E. Nibigira<sup>37</sup>, R.B. Nickerson<sup>131</sup>, R. Nicolaidou<sup>142</sup>, J. Nielsen<sup>143</sup>, N. Nikiforou<sup>11</sup>,
V. Nikolaenko<sup>140,am</sup>, I. Nikolic-Audit<sup>132</sup>, K. Nikolopoulos<sup>21</sup>, P. Nilsson<sup>29</sup>, Y. Ninomiya<sup>79</sup>, A. Nisati<sup>70a</sup>,
N. Nishu<sup>58c</sup>, R. Nisius<sup>113</sup>, I. Nitsche<sup>45</sup>, T. Nitta<sup>177</sup>, T. Nobe<sup>161</sup>, Y. Noguchi<sup>83</sup>, M. Nomachi<sup>129</sup>,
I. Nomidis<sup>33</sup>, M.A. Nomura<sup>29</sup>, T. Nooney<sup>90</sup>, M. Nordberg<sup>35</sup>, N. Norjoharuddeen<sup>131</sup>, T. Novak<sup>89</sup>
O. Novgorodova<sup>46</sup>, R. Novotny<sup>138</sup>, M. Nozaki<sup>79</sup>, L. Nozka<sup>126</sup>, K. Ntekas<sup>169</sup>, E. Nurse<sup>92</sup>, F. Nuti<sup>102</sup>,
F.G. Oakham<sup>33,av</sup>, H. Oberlack<sup>113</sup>, T. Obermann<sup>24</sup>, J. Ocariz<sup>132</sup>, A. Ochi<sup>80</sup>, I. Ochoa<sup>38</sup>,
J.P. Ochoa-Ricoux<sup>144a</sup>, K. O'Connor<sup>26</sup>, S. Oda<sup>85</sup>, S. Odaka<sup>79</sup>, A. Oh<sup>98</sup>, S.H. Oh<sup>47</sup>, C.C. Ohm<sup>151</sup>,
H. Ohman<sup>170</sup>, H. Oide<sup>53b,53a</sup>, H. Okawa<sup>167</sup>, Y. Okazaki<sup>83</sup>, Y. Okumura<sup>161</sup>, T. Okuyama<sup>79</sup>, A. Olariu<sup>27b</sup>,
L.F. Oleiro Seabra<sup>136a</sup>, S.A. Olivares Pino<sup>144a</sup>, D. Oliveira Damazio<sup>29</sup>, J.L. Oliver<sup>1</sup>, M.J.R. Olsson<sup>36</sup>,
A. Olszewski<sup>82</sup>, J. Olszowska<sup>82</sup>, D.C. O'Neil<sup>149</sup>, A. Onofre<sup>136a,136e</sup>, K. Onogi<sup>115</sup>, P.U.E. Onyisi<sup>11</sup>,
H. Oppen<sup>130</sup>, M.J. Oreglia<sup>36</sup>, Y. Oren<sup>159</sup>, D. Orestano<sup>72a,72b</sup>, E.C. Orgill<sup>98</sup>, N. Orlando<sup>61b</sup>,
A.A. O'Rourke<sup>44</sup>, R.S. Orr<sup>165</sup>, B. Osculati<sup>53b,53a,*</sup>, V. O'Shea<sup>55</sup>, R. Ospanov<sup>58a</sup>, G. Otero y Garzon<sup>30</sup>,
H. Otono<sup>85</sup>, M. Ouchrif<sup>34d</sup>, F. Ould-Saada<sup>130</sup>, A. Ouraou<sup>142</sup>, K.P. Oussoren<sup>118</sup>, Q. Ouyang<sup>15a</sup>,
M. Owen<sup>55</sup>, R.E. Owen<sup>21</sup>, V.E. Ozcan<sup>12c</sup>, N. Ozturk<sup>8</sup>, K. Pachal<sup>149</sup>, A. Pacheco Pages<sup>14</sup>,
L. Pacheco Rodriguez<sup>142</sup>, C. Padilla Aranda<sup>14</sup>, S. Pagan Griso<sup>18</sup>, M. Paganini<sup>181</sup>, G. Palacino<sup>63</sup>,
S. Palazzo<sup>40b,40a</sup>, S. Palestini<sup>35</sup>, M. Palka<sup>81b</sup>, D. Pallin<sup>37</sup>, I. Panagoulias<sup>10</sup>, C.E. Pandini<sup>52</sup>,
J.G. Panduro Vazquez<sup>91</sup>, P. Pani<sup>35</sup>, L. Paolozzi<sup>52</sup>, T.D. Papadopoulou<sup>10</sup>, K. Papageorgiou<sup>9,j</sup>,
A. Paramonov<sup>6</sup>, D. Paredes Hernandez<sup>61b</sup>, B. Parida<sup>58c</sup>, A.J. Parker<sup>87</sup>, K.A. Parker<sup>44</sup>, M.A. Parker<sup>31</sup>,
F. Parodi<sup>53b,53a</sup>, J.A. Parsons<sup>38</sup>, U. Parzefall<sup>50</sup>, V.R. Pascuzzi<sup>165</sup>, J.M.P. Pasner<sup>143</sup>, E. Pasqualucci<sup>70a</sup>,
S. Passaggio<sup>53b</sup>, F. Pastore<sup>91</sup>, P. Pasuwan<sup>43a,43b</sup>, S. Pataraia<sup>97</sup>, J.R. Pater<sup>98</sup>, A. Pathak<sup>179,k</sup>, T. Pauly<sup>35</sup>,
B. Pearson<sup>113</sup>, S. Pedraza Lopez<sup>172</sup>, R. Pedro<sup>136a,136b</sup>, S.V. Peleganchuk<sup>120b,120a</sup>, O. Penc<sup>137</sup>, C. Peng<sup>15d</sup>,
H. Peng<sup>58a</sup>, J. Penwell<sup>63</sup>, B.S. Peralva<sup>78a</sup>, M.M. Perego<sup>142</sup>, A.P. Pereira Peixoto<sup>136a</sup>, D.V. Perepelitsa<sup>29</sup>,
F. Peri<sup>19</sup>, L. Perini<sup>66a,66b</sup>, H. Pernegger<sup>35</sup>, S. Perrella<sup>67a,67b</sup>, V.D. Peshekhonov<sup>77,*</sup>, K. Peters<sup>44</sup>,
R.F.Y. Peters<sup>98</sup>, B.A. Petersen<sup>35</sup>, T.C. Petersen<sup>39</sup>, E. Petit<sup>56</sup>, A. Petridis<sup>1</sup>, C. Petridou<sup>160</sup>, P. Petroff<sup>128</sup>,
E. Petrolo<sup>70a</sup>, M. Petrov<sup>131</sup>, F. Petrucci<sup>72a,72b</sup>, N.E. Pettersson<sup>100</sup>, A. Peyaud<sup>142</sup>, R. Pezoa<sup>144b</sup>, T. Pham<sup>102</sup>,
F.H. Phillips<sup>104</sup>, P.W. Phillips<sup>141</sup>, G. Piacquadio<sup>152</sup>, E. Pianori<sup>176</sup>, A. Picazio<sup>100</sup>, M.A. Pickering<sup>131</sup>,
R. Piegaia<sup>30</sup>, J.E. Pilcher<sup>36</sup>, A.D. Pilkington<sup>98</sup>, M. Pinamonti<sup>71a,71b</sup>, J.L. Pinfold<sup>3</sup>, M. Pitt<sup>178</sup>,
M-A. Pleier<sup>29</sup>, V. Pleskot<sup>139</sup>, E. Plotnikova<sup>77</sup>, D. Pluth<sup>76</sup>, P. Podberezko<sup>120b,120a</sup>, R. Poettgen<sup>94</sup>,
R. Poggi<sup>68a,68b</sup>, L. Poggioli<sup>128</sup>, I. Pogrebnyak<sup>104</sup>, D. Pohl<sup>24</sup>, I. Pokharel<sup>51</sup>, G. Polesello<sup>68a</sup>, A. Poley<sup>44</sup>,
A. Policicchio<sup>40b,40a</sup>, R. Polifka<sup>35</sup>, A. Polini<sup>23b</sup>, C.S. Pollard<sup>44</sup>, V. Polychronakos<sup>29</sup>, D. Ponomarenko<sup>110</sup>,
L. Pontecorvo<sup>70a</sup>, G.A. Popeneciu<sup>27d</sup>, D.M. Portillo Quintero<sup>132</sup>, S. Pospisil<sup>138</sup>, K. Potamianos<sup>44</sup>,
```

```
I.N. Potrap<sup>77</sup>, C.J. Potter<sup>31</sup>, H. Potti<sup>11</sup>, T. Poulsen<sup>94</sup>, J. Poveda<sup>35</sup>, M.E. Pozo Astigarraga<sup>35</sup>,
P. Pralavorio<sup>99</sup>, S. Prell<sup>76</sup>, D. Price<sup>98</sup>, M. Primavera<sup>65a</sup>, S. Prince<sup>101</sup>, N. Proklova<sup>110</sup>, K. Prokofiev<sup>61c</sup>,
F. Prokoshin<sup>144b</sup>, S. Protopopescu<sup>29</sup>, J. Proudfoot<sup>6</sup>, M. Przybycien<sup>81a</sup>, A. Puri<sup>171</sup>, P. Puzo<sup>128</sup>, J. Qian<sup>103</sup>,
Y. Qin<sup>98</sup>, A. Quadt<sup>51</sup>, M. Queitsch-Maitland<sup>44</sup>, A. Qureshi<sup>1</sup>, S.K. Radhakrishnan<sup>152</sup>, P. Rados<sup>102</sup>,
F. Ragusa<sup>66a,66b</sup>, G. Rahal<sup>95</sup>, J.A. Raine<sup>98</sup>, S. Rajagopalan<sup>29</sup>, T. Rashid<sup>128</sup>, S. Raspopov<sup>5</sup>,
M.G. Ratti<sup>66a,66b</sup>, D.M. Rauch<sup>44</sup>, F. Rauscher<sup>112</sup>, S. Rave<sup>97</sup>, B. Ravina<sup>146</sup>, I. Ravinovich<sup>178</sup>,
J.H. Rawling<sup>98</sup>, M. Raymond<sup>35</sup>, A.L. Read<sup>130</sup>, N.P. Readioff<sup>56</sup>, M. Reale<sup>65a,65b</sup>, D.M. Rebuzzi<sup>68a,68b</sup>,
A. Redelbach<sup>175</sup>, G. Redlinger<sup>29</sup>, R. Reece<sup>143</sup>, R.G. Reed<sup>32c</sup>, K. Reeves<sup>42</sup>, L. Rehnisch<sup>19</sup>, J. Reichert<sup>133</sup>,
A. Reiss<sup>97</sup>, C. Rembser<sup>35</sup>, H. Ren<sup>15d</sup>, M. Rescigno<sup>70a</sup>, S. Resconi<sup>66a</sup>, E.D. Resseguie<sup>133</sup>, S. Rettie<sup>173</sup>,
E. Reynolds<sup>21</sup>, O.L. Rezanova<sup>120b,120a</sup>, P. Reznicek<sup>139</sup>, R. Richter<sup>113</sup>, S. Richter<sup>92</sup>, E. Richter-Was<sup>81b</sup>,
O. Ricken<sup>24</sup>, M. Ridel<sup>132</sup>, P. Rieck<sup>113</sup>, C.J. Riegel<sup>180</sup>, O. Rifki<sup>44</sup>, M. Rijssenbeek<sup>152</sup>, A. Rimoldi<sup>68a,68b</sup>,
M. Rimoldi<sup>20</sup>, L. Rinaldi<sup>23b</sup>, G. Ripellino<sup>151</sup>, B. Ristić<sup>35</sup>, E. Ritsch<sup>35</sup>, I. Riu<sup>14</sup>, J.C. Rivera Vergara<sup>144a</sup>,
F. Rizatdinova<sup>125</sup>, E. Rizvi<sup>90</sup>, C. Rizzi<sup>14</sup>, R.T. Roberts<sup>98</sup>, S.H. Robertson<sup>101,af</sup>,
A. Robichaud-Veronneau<sup>101</sup>, D. Robinson<sup>31</sup>, J.E.M. Robinson<sup>44</sup>, A. Robson<sup>55</sup>, E. Rocco<sup>97</sup>,
C. Roda<sup>69a,69b</sup>, Y. Rodina<sup>99,ab</sup>, S. Rodriguez Bosca<sup>172</sup>, A. Rodriguez Perez<sup>14</sup>, D. Rodriguez Rodriguez<sup>172</sup>,
A.M. Rodríguez Vera<sup>166b</sup>, S. Roe<sup>35</sup>, C.S. Rogan<sup>57</sup>, O. Røhne<sup>130</sup>, R. Röhrig<sup>113</sup>, C.P.A. Roland<sup>63</sup>,
J. Roloff<sup>57</sup>, A. Romaniouk<sup>110</sup>, M. Romano<sup>23b,23a</sup>, E. Romero Adam<sup>172</sup>, N. Rompotis<sup>88</sup>, M. Ronzani<sup>121</sup>,
L. Roos<sup>132</sup>, S. Rosati<sup>70a</sup>, K. Rosbach<sup>50</sup>, P. Rose<sup>143</sup>, N-A. Rosien<sup>51</sup>, E. Rossi<sup>67a,67b</sup>, L.P. Rossi<sup>53b</sup>,
L. Rossini<sup>66a,66b</sup>, J.H.N. Rosten<sup>31</sup>, R. Rosten<sup>145</sup>, M. Rotaru<sup>27b</sup>, J. Rothberg<sup>145</sup>, D. Rousseau<sup>128</sup>,
D. Roy<sup>32c</sup>, A. Rozanov<sup>99</sup>, Y. Rozen<sup>158</sup>, X. Ruan<sup>32c</sup>, F. Rubbo<sup>150</sup>, F. Rühr<sup>50</sup>, A. Ruiz-Martinez<sup>33</sup>,
Z.\ Rurikova^{50},\ N.A.\ Rusakovich^{77},\ H.L.\ Russell^{101},\ J.P.\ Rutherfoord^7,\ N.\ Ruthmann^{35},
E.M. Rüttinger<sup>44,l</sup>, Y.F. Ryabov<sup>134</sup>, M. Rybar<sup>171</sup>, G. Rybkin<sup>128</sup>, S. Ryu<sup>6</sup>, A. Ryzhov<sup>140</sup>, G.F. Rzehorz<sup>51</sup>,
P. Sabatini<sup>51</sup>, G. Sabato<sup>118</sup>, S. Sacerdoti<sup>128</sup>, H.F-W. Sadrozinski<sup>143</sup>, R. Sadykov<sup>77</sup>, F. Safai Tehrani<sup>70a</sup>,
P. Saha<sup>119</sup>, M. Sahinsoy<sup>59a</sup>, M. Saimpert<sup>44</sup>, M. Saito<sup>161</sup>, T. Saito<sup>161</sup>, H. Sakamoto<sup>161</sup>, A. Sakharov<sup>121,al</sup>,
D. Salamani<sup>52</sup>, G. Salamanna<sup>72a,72b</sup>, J.E. Salazar Loyola<sup>144b</sup>, D. Salek<sup>118</sup>, P.H. Sales De Bruin<sup>170</sup>,
D. Salihagic<sup>113</sup>, A. Salnikov<sup>150</sup>, J. Salt<sup>172</sup>, D. Salvatore<sup>40b,40a</sup>, F. Salvatore<sup>153</sup>, A. Salvucci<sup>61a,61b,61c</sup>,
A. Salzburger<sup>35</sup>, D. Sammel<sup>50</sup>, D. Sampsonidis<sup>160</sup>, D. Sampsonidou<sup>160</sup>, J. Sánchez<sup>172</sup>,
A. Sanchez Pineda<sup>64a,64c</sup>, H. Sandaker<sup>130</sup>, C.O. Sander<sup>44</sup>, M. Sandhoff<sup>180</sup>, C. Sandoval<sup>22</sup>,
D.P.C. Sankey<sup>141</sup>, M. Sannino<sup>53b,53a</sup>, Y. Sano<sup>115</sup>, A. Sansoni<sup>49</sup>, C. Santoni<sup>37</sup>, H. Santos<sup>136a</sup>,
I. Santoyo Castillo<sup>153</sup>, A. Sapronov<sup>77</sup>, J.G. Saraiva<sup>136a,136d</sup>, O. Sasaki<sup>79</sup>, K. Sato<sup>167</sup>, E. Sauvan<sup>5</sup>,
P. Savard<sup>165,av</sup>, N. Savic<sup>113</sup>, R. Sawada<sup>161</sup>, C. Sawyer<sup>141</sup>, L. Sawyer<sup>93,ak</sup>, C. Sbarra<sup>23b</sup>, A. Sbrizzi<sup>23b,23a</sup>,
T. Scanlon<sup>92</sup>, D.A. Scannicchio<sup>169</sup>, J. Schaarschmidt<sup>145</sup>, P. Schacht<sup>113</sup>, B.M. Schachtner<sup>112</sup>,
D. Schaefer<sup>36</sup>, L. Schaefer<sup>133</sup>, J. Schaeffer<sup>97</sup>, S. Schaepe<sup>35</sup>, U. Schäfer<sup>97</sup>, A.C. Schaffer<sup>128</sup>, D. Schaile<sup>112</sup>,
R.D. Schamberger<sup>152</sup>, N. Scharmberg<sup>98</sup>, V.A. Schegelsky<sup>134</sup>, D. Scheirich<sup>139</sup>, F. Schenck<sup>19</sup>,
M. Schernau<sup>169</sup>, C. Schiavi<sup>53b,53a</sup>, S. Schier<sup>143</sup>, L.K. Schildgen<sup>24</sup>, Z.M. Schillaci<sup>26</sup>, E.J. Schioppa<sup>35</sup>,
M. Schioppa<sup>40b,40a</sup>, K.E. Schleicher<sup>50</sup>, S. Schlenker<sup>35</sup>, K.R. Schmidt-Sommerfeld<sup>113</sup>, K. Schmieden<sup>35</sup>,
C. Schmitt<sup>97</sup>, S. Schmitt<sup>44</sup>, S. Schmitz<sup>97</sup>, U. Schnoor<sup>50</sup>, L. Schoeffel<sup>142</sup>, A. Schoening<sup>59b</sup>, E. Schopf<sup>24</sup>,
M. Schott<sup>97</sup>, J.F.P. Schouwenberg<sup>117</sup>, J. Schovancova<sup>35</sup>, S. Schramm<sup>52</sup>, N. Schuh<sup>97</sup>, A. Schulte<sup>97</sup>,
H-C. Schultz-Coulon<sup>59a</sup>, M. Schumacher<sup>50</sup>, B.A. Schumm<sup>143</sup>, Ph. Schune<sup>142</sup>, A. Schwartzman<sup>150</sup>,
T.A. Schwarz<sup>103</sup>, H. Schweiger<sup>98</sup>, Ph. Schwemling<sup>142</sup>, R. Schwienhorst<sup>104</sup>, A. Sciandra<sup>24</sup>, G. Sciolla<sup>26</sup>,
M. Scornajenghi<sup>40b,40a</sup>, F. Scuri<sup>69a</sup>, F. Scutti<sup>102</sup>, L.M. Scyboz<sup>113</sup>, J. Searcy<sup>103</sup>, C.D. Sebastiani<sup>70a,70b</sup>,
P. Seema<sup>24</sup>, S.C. Seidel<sup>116</sup>, A. Seiden<sup>143</sup>, J.M. Seixas<sup>78b</sup>, G. Sekhniaidze<sup>67a</sup>, K. Sekhon<sup>103</sup>, S.J. Sekula<sup>41</sup>,
N. Semprini-Cesari<sup>23b,23a</sup>, S. Senkin<sup>37</sup>, C. Serfon<sup>130</sup>, L. Serin<sup>128</sup>, L. Serkin<sup>64a,64b</sup>, M. Sessa<sup>72a,72b</sup>,
H. Severini<sup>124</sup>, F. Sforza<sup>168</sup>, A. Sfyrla<sup>52</sup>, E. Shabalina<sup>51</sup>, J.D. Shahinian<sup>143</sup>, N.W. Shaikh<sup>43a,43b</sup>,
L.Y. Shan<sup>15a</sup>, R. Shang<sup>171</sup>, J.T. Shank<sup>25</sup>, M. Shapiro<sup>18</sup>, A.S. Sharma<sup>1</sup>, A. Sharma<sup>131</sup>, P.B. Shatalov<sup>109</sup>,
K. Shaw<sup>64a,64b</sup>, S.M. Shaw<sup>98</sup>, A. Shcherbakova<sup>134</sup>, C.Y. Shehu<sup>153</sup>, Y. Shen<sup>124</sup>, N. Sherafati<sup>33</sup>,
A.D. Sherman<sup>25</sup>, P. Sherwood<sup>92</sup>, L. Shi<sup>155,ar</sup>, S. Shimizu<sup>80</sup>, C.O. Shimmin<sup>181</sup>, M. Shimojima<sup>114</sup>,
```

```
I.P.J. Shipsey<sup>131</sup>, S. Shirabe<sup>85</sup>, M. Shiyakova<sup>77</sup>, J. Shlomi<sup>178</sup>, A. Shmeleva<sup>108</sup>, D. Shoaleh Saadi<sup>107</sup>,
M.J. Shochet<sup>36</sup>, S. Shojaii<sup>102</sup>, D.R. Shope<sup>124</sup>, S. Shrestha<sup>122</sup>, E. Shulga<sup>110</sup>, P. Sicho<sup>137</sup>, A.M. Sickles<sup>171</sup>,
P.E. Sidebo<sup>151</sup>, E. Sideras Haddad<sup>32c</sup>, O. Sidiropoulou<sup>175</sup>, A. Sidoti<sup>23b,23a</sup>, F. Siegert<sup>46</sup>, Dj. Sijacki<sup>16</sup>,
J. Silva<sup>136a</sup>, M. Silva Jr.<sup>179</sup>, S.B. Silverstein<sup>43a</sup>, L. Simic<sup>77</sup>, S. Simion<sup>128</sup>, E. Simioni<sup>97</sup>, B. Simmons<sup>92</sup>,
M. Simon<sup>97</sup>, P. Sinervo<sup>165</sup>, N.B. Sinev<sup>127</sup>, M. Sioli<sup>23b,23a</sup>, G. Siragusa<sup>175</sup>, I. Siral<sup>103</sup>,
S.Yu. Sivoklokov<sup>111</sup>, J. Sjölin<sup>43a,43b</sup>, M.B. Skinner<sup>87</sup>, P. Skubic<sup>124</sup>, M. Slater<sup>21</sup>, T. Slavicek<sup>138</sup>,
M. Slawinska<sup>82</sup>, K. Sliwa<sup>168</sup>, R. Slovak<sup>139</sup>, V. Smakhtin<sup>178</sup>, B.H. Smart<sup>5</sup>, J. Smiesko<sup>28a</sup>, N. Smirnov<sup>110</sup>,
S.Yu. Smirnov<sup>110</sup>, Y. Smirnov<sup>110</sup>, L.N. Smirnova<sup>111</sup>, O. Smirnova<sup>94</sup>, J.W. Smith<sup>51</sup>, M.N.K. Smith<sup>38</sup>,
R.W. Smith<sup>38</sup>, M. Smizanska<sup>87</sup>, K. Smolek<sup>138</sup>, A.A. Snesarev<sup>108</sup>, I.M. Snyder<sup>127</sup>, S. Snyder<sup>29</sup>, R. Sobie<sup>174</sup>, F. Socher<sup>46</sup>, A.M. Soffa<sup>169</sup>, A. Soffer<sup>159</sup>, A. Søgaard<sup>48</sup>, D.A. Soh<sup>155</sup>, G. Sokhrannyi<sup>89</sup>,
C.A. Solans Sanchez<sup>35</sup>, M. Solar<sup>138</sup>, E.Yu. Soldatov<sup>110</sup>, U. Soldevila<sup>172</sup>, A.A. Solodkov<sup>140</sup>,
A. Soloshenko<sup>77</sup>, O.V. Solovyanov<sup>140</sup>, V. Solovyev<sup>134</sup>, P. Sommer<sup>146</sup>, H. Son<sup>168</sup>, W. Song<sup>141</sup>,
A. Sopczak<sup>138</sup>, F. Sopkova<sup>28b</sup>, D. Sosa<sup>59b</sup>, C.L. Sotiropoulou<sup>69a,69b</sup>, S. Sottocornola<sup>68a,68b</sup>,
R. Soualah<sup>64a,64c,i</sup>, A.M. Soukharev<sup>120b,120a</sup>, D. South<sup>44</sup>, B.C. Sowden<sup>91</sup>, S. Spagnolo<sup>65a,65b</sup>,
M. Spalla<sup>113</sup>, M. Spangenberg<sup>176</sup>, F. Spanò<sup>91</sup>, D. Sperlich<sup>19</sup>, F. Spettel<sup>113</sup>, T.M. Spieker<sup>59a</sup>, R. Spighi<sup>23b</sup>,
G. Spigo<sup>35</sup>, L.A. Spiller<sup>102</sup>, M. Spousta<sup>139</sup>, A. Stabile<sup>66a,66b</sup>, R. Stamen<sup>59a</sup>, S. Stamm<sup>19</sup>, E. Stanecka<sup>82</sup>,
R.W. Stanek<sup>6</sup>, C. Stanescu<sup>72a</sup>, M.M. Stanitzki<sup>44</sup>, B. Stapf<sup>118</sup>, S. Stapnes<sup>130</sup>, E.A. Starchenko<sup>140</sup>,
G.H. Stark<sup>36</sup>, J. Stark<sup>56</sup>, S.H Stark<sup>39</sup>, P. Staroba<sup>137</sup>, P. Starovoitov<sup>59a</sup>, S. Stärz<sup>35</sup>, R. Staszewski<sup>82</sup>,
M. Stegler<sup>44</sup>, P. Steinberg<sup>29</sup>, B. Stelzer<sup>149</sup>, H.J. Stelzer<sup>35</sup>, O. Stelzer-Chilton<sup>166a</sup>, H. Stenzel<sup>54</sup>,
T.J. Stevenson<sup>90</sup>, G.A. Stewart<sup>55</sup>, M.C. Stockton<sup>127</sup>, G. Stoicea<sup>27b</sup>, P. Stolte<sup>51</sup>, S. Stonjek<sup>113</sup>,
A. Straessner<sup>46</sup>, J. Strandberg<sup>151</sup>, S. Strandberg<sup>43a,43b</sup>, M. Strauss<sup>124</sup>, P. Strizenec<sup>28b</sup>, R. Ströhmer<sup>175</sup>,
D.M. Strom<sup>127</sup>, R. Stroynowski<sup>41</sup>, A. Strubig<sup>48</sup>, S.A. Stucci<sup>29</sup>, B. Stugu<sup>17</sup>, J. Stupak<sup>124</sup>, N.A. Styles<sup>44</sup>,
D. Su<sup>150</sup>, J. Su<sup>135</sup>, S. Suchek<sup>59a</sup>, Y. Sugaya<sup>129</sup>, M. Suk<sup>138</sup>, V.V. Sulin<sup>108</sup>, D.M.S. Sultan<sup>52</sup>, S. Sultansoy<sup>4c</sup>,
T. Sumida<sup>83</sup>, S. Sun<sup>103</sup>, X. Sun<sup>3</sup>, K. Suruliz<sup>153</sup>, C.J.E. Suster<sup>154</sup>, M.R. Sutton<sup>153</sup>, S. Suzuki<sup>79</sup>,
M. Svatos<sup>137</sup>, M. Swiatlowski<sup>36</sup>, S.P. Swift<sup>2</sup>, A. Sydorenko<sup>97</sup>, I. Sykora<sup>28a</sup>, T. Sykora<sup>139</sup>, D. Ta<sup>97</sup>,
K. Tackmann<sup>44,ac</sup>, J. Taenzer<sup>159</sup>, A. Taffard<sup>169</sup>, R. Tafirout<sup>166a</sup>, E. Tahirovic<sup>90</sup>, N. Taiblum<sup>159</sup>, H. Takai<sup>29</sup>,
R. Takashima<sup>84</sup>, E.H. Takasugi<sup>113</sup>, K. Takeda<sup>80</sup>, T. Takeshita<sup>147</sup>, Y. Takubo<sup>79</sup>, M. Talby<sup>99</sup>,
A.A. Talyshev<sup>120b,120a</sup>, J. Tanaka<sup>161</sup>, M. Tanaka<sup>163</sup>, R. Tanaka<sup>128</sup>, R. Tanioka<sup>80</sup>, B.B. Tannenwald<sup>122</sup>,
S. Tapia Araya<sup>144b</sup>, S. Tapprogge<sup>97</sup>, A. Tarek Abouelfadl Mohamed<sup>132</sup>, S. Tarem<sup>158</sup>, G. Tarna<sup>27b,e</sup>,
G.F. Tartarelli<sup>66a</sup>, P. Tas<sup>139</sup>, M. Tasevsky<sup>137</sup>, T. Tashiro<sup>83</sup>, E. Tassi<sup>40b,40a</sup>, A. Tavares Delgado<sup>136a,136b</sup>,
Y. Tayalati<sup>34e</sup>, A.C. Taylor<sup>116</sup>, A.J. Taylor<sup>48</sup>, G.N. Taylor<sup>102</sup>, P.T.E. Taylor<sup>102</sup>, W. Taylor<sup>166b</sup>, A.S. Tee<sup>87</sup>,
P. Teixeira-Dias<sup>91</sup>, D. Temple<sup>149</sup>, H. Ten Kate<sup>35</sup>, P.K. Teng<sup>155</sup>, J.J. Teoh<sup>129</sup>, F. Tepel<sup>180</sup>, S. Terada<sup>79</sup>,
K. Terashi<sup>161</sup>, J. Terron<sup>96</sup>, S. Terzo<sup>14</sup>, M. Testa<sup>49</sup>, R.J. Teuscher<sup>165,af</sup>, S.J. Thais<sup>181</sup>, T. Theveneaux-Pelzer<sup>44</sup>, F. Thiele<sup>39</sup>, J.P. Thomas<sup>21</sup>, A.S. Thompson<sup>55</sup>, P.D. Thompson<sup>21</sup>,
L.A. Thomsen<sup>181</sup>, E. Thomson<sup>133</sup>, Y. Tian<sup>38</sup>, R.E. Ticse Torres<sup>51</sup>, V.O. Tikhomirov<sup>108,an</sup>,
Yu.A. Tikhonov<sup>120b,120a</sup>, S. Timoshenko<sup>110</sup>, P. Tipton<sup>181</sup>, S. Tisserant<sup>99</sup>, K. Todome<sup>163</sup>,
S. Todorova-Nova<sup>5</sup>, S. Todt<sup>46</sup>, J. Tojo<sup>85</sup>, S. Tokár<sup>28a</sup>, K. Tokushuku<sup>79</sup>, E. Tolley<sup>122</sup>, M. Tomoto<sup>115</sup>,
L. Tompkins<sup>150,r</sup>, K. Toms<sup>116</sup>, B. Tong<sup>57</sup>, P. Tornambe<sup>50</sup>, E. Torrence<sup>127</sup>, H. Torres<sup>46</sup>, E. Torró Pastor<sup>145</sup>,
C. Tosciri<sup>131</sup>, J. Toth<sup>99,ae</sup>, F. Touchard<sup>99</sup>, D.R. Tovey<sup>146</sup>, C.J. Treado<sup>121</sup>, T. Trefzger<sup>175</sup>, F. Tresoldi<sup>153</sup>,
A. Tricoli<sup>29</sup>, I.M. Trigger<sup>166a</sup>, S. Trincaz-Duvoid<sup>132</sup>, M.F. Tripiana<sup>14</sup>, W. Trischuk<sup>165</sup>, B. Trocmé<sup>56</sup>,
A. Trofymov<sup>44</sup>, C. Troncon<sup>66a</sup>, M. Trovatelli<sup>174</sup>, F. Trovato<sup>153</sup>, L. Truong<sup>32b</sup>, M. Trzebinski<sup>82</sup>,
A. Trzupek<sup>82</sup>, F. Tsai<sup>44</sup>, K.W. Tsang<sup>61a</sup>, J.C-L. Tseng<sup>131</sup>, P.V. Tsiareshka<sup>105</sup>, N. Tsirintanis<sup>9</sup>,
S. Tsiskaridze<sup>14</sup>, V. Tsiskaridze<sup>152</sup>, E.G. Tskhadadze<sup>157a</sup>, I.I. Tsukerman<sup>109</sup>, V. Tsulaia<sup>18</sup>, S. Tsuno<sup>79</sup>,
D. Tsybychev<sup>152</sup>, Y. Tu<sup>61b</sup>, A. Tudorache<sup>27b</sup>, V. Tudorache<sup>27b</sup>, T.T. Tulbure<sup>27a</sup>, A.N. Tuna<sup>57</sup>,
S. Turchikhin<sup>77</sup>, D. Turgeman<sup>178</sup>, I. Turk Cakir<sup>4b,v</sup>, R. Turra<sup>66a</sup>, P.M. Tuts<sup>38</sup>, G. Ucchielli<sup>23b,23a</sup>,
I. Ueda<sup>79</sup>, M. Ughetto<sup>43a,43b</sup>, F. Ukegawa<sup>167</sup>, G. Unal<sup>35</sup>, A. Undrus<sup>29</sup>, G. Unel<sup>169</sup>, F.C. Ungaro<sup>102</sup>,
Y. Unno<sup>79</sup>, K. Uno<sup>161</sup>, J. Urban<sup>28b</sup>, P. Urquijo<sup>102</sup>, P. Urrejola<sup>97</sup>, G. Usai<sup>8</sup>, J. Usui<sup>79</sup>, L. Vacavant<sup>99</sup>,
```

```
V. Vacek<sup>138</sup>, B. Vachon<sup>101</sup>, K.O.H. Vadla<sup>130</sup>, A. Vaidya<sup>92</sup>, C. Valderanis<sup>112</sup>, E. Valdes Santurio<sup>43a,43b</sup>,
M. Valente<sup>52</sup>, S. Valentinetti<sup>23b,23a</sup>, A. Valero<sup>172</sup>, L. Valéry<sup>44</sup>, R.A. Vallance<sup>21</sup>, A. Vallier<sup>5</sup>,
J.A. Valls Ferrer<sup>172</sup>, T.R. Van Daalen<sup>14</sup>, W. Van Den Wollenberg<sup>118</sup>, H. Van der Graaf<sup>118</sup>,
P. Van Gemmeren<sup>6</sup>, J. Van Nieuwkoop<sup>149</sup>, I. Van Vulpen<sup>118</sup>, M.C. van Woerden<sup>118</sup>, M. Vanadia<sup>71a,71b</sup>,
W. Vandelli<sup>35</sup>, A. Vaniachine<sup>164</sup>, P. Vankov<sup>118</sup>, R. Vari<sup>70a</sup>, E.W. Varnes<sup>7</sup>, C. Varni<sup>53b,53a</sup>, T. Varol<sup>41</sup>,
D. Varouchas<sup>128</sup>, A. Vartapetian<sup>8</sup>, K.E. Varvell<sup>154</sup>, G.A. Vasquez<sup>144b</sup>, J.G. Vasquez<sup>181</sup>, F. Vazeille<sup>37</sup>,
D. Vazquez Furelos<sup>14</sup>, T. Vazquez Schroeder<sup>101</sup>, J. Veatch<sup>51</sup>, V. Vecchio<sup>72a,72b</sup>, L.M. Veloce<sup>165</sup>,
F. Veloso<sup>136a,136c</sup>, S. Veneziano<sup>70a</sup>, A. Ventura<sup>65a,65b</sup>, M. Venturi<sup>174</sup>, N. Venturi<sup>35</sup>, V. Vercesi<sup>68a</sup>,
M. Verducci<sup>72a,72b</sup>, W. Verkerke<sup>118</sup>, A.T. Vermeulen<sup>118</sup>, J.C. Vermeulen<sup>118</sup>, M.C. Vetterli<sup>149,av</sup>,
N. Viaux Maira<sup>144b</sup>, O. Viazlo<sup>94</sup>, I. Vichou<sup>171,*</sup>, T. Vickey<sup>146</sup>, O.E. Vickey Boeriu<sup>146</sup>,
G.H.A. Viehhauser<sup>131</sup>, S. Viel<sup>18</sup>, L. Vigani<sup>131</sup>, M. Villa<sup>23b,23a</sup>, M. Villaplana Perez<sup>66a,66b</sup>, E. Vilucchi<sup>49</sup>,
M.G. Vincter<sup>33</sup>, V.B. Vinogradov<sup>77</sup>, A. Vishwakarma<sup>44</sup>, C. Vittori<sup>23b,23a</sup>, I. Vivarelli<sup>153</sup>, S. Vlachos<sup>10</sup>,
M. Vogel<sup>180</sup>, P. Vokac<sup>138</sup>, G. Volpi<sup>14</sup>, S.E. von Buddenbrock<sup>32c</sup>, E. Von Toerne<sup>24</sup>, V. Vorobel<sup>139</sup>,
K. Vorobev<sup>110</sup>, M. Vos<sup>172</sup>, J.H. Vossebeld<sup>88</sup>, N. Vranjes<sup>16</sup>, M. Vranjes Milosavljevic<sup>16</sup>, V. Vrba<sup>138</sup>,
M. Vreeswijk<sup>118</sup>, T. Šfiligoj<sup>89</sup>, R. Vuillermet<sup>35</sup>, I. Vukotic<sup>36</sup>, T. Ženiš<sup>28a</sup>, L. Živković<sup>16</sup>, P. Wagner<sup>24</sup>,
W. Wagner<sup>180</sup>, J. Wagner-Kuhr<sup>112</sup>, H. Wahlberg<sup>86</sup>, S. Wahrmund<sup>46</sup>, K. Wakamiya<sup>80</sup>, J. Walder<sup>87</sup>,
R. Walker<sup>112</sup>, W. Walkowiak<sup>148</sup>, V. Wallangen<sup>43a,43b</sup>, A.M. Wang<sup>57</sup>, C. Wang<sup>58b,e</sup>, F. Wang<sup>179</sup>,
H. Wang<sup>18</sup>, H. Wang<sup>3</sup>, J. Wang<sup>154</sup>, J. Wang<sup>59b</sup>, P. Wang<sup>41</sup>, Q. Wang<sup>124</sup>, R.-J. Wang<sup>132</sup>, R. Wang<sup>58a</sup>, R. Wang<sup>6</sup>, S.M. Wang<sup>155</sup>, T. Wang<sup>38</sup>, W. Wang<sup>155,p</sup>, W.X. Wang<sup>58a,ag</sup>, Y. Wang<sup>58a</sup>, Z. Wang<sup>58c</sup>,
C. Wanotayaroj<sup>44</sup>, A. Warburton<sup>101</sup>, C.P. Ward<sup>31</sup>, D.R. Wardrope<sup>92</sup>, A. Washbrook<sup>48</sup>, P.M. Watkins<sup>21</sup>,
A.T. Watson<sup>21</sup>, M.F. Watson<sup>21</sup>, G. Watts<sup>145</sup>, S. Watts<sup>98</sup>, B.M. Waugh<sup>92</sup>, A.F. Webb<sup>11</sup>, S. Webb<sup>97</sup>,
C. Weber<sup>181</sup>, M.S. Weber<sup>20</sup>, S.A. Weber<sup>33</sup>, S.M. Weber<sup>59a</sup>, J.S. Webster<sup>6</sup>, A.R. Weidberg<sup>131</sup>,
B. Weinert<sup>63</sup>, J. Weingarten<sup>51</sup>, M. Weirich<sup>97</sup>, C. Weiser<sup>50</sup>, P.S. Wells<sup>35</sup>, T. Wenaus<sup>29</sup>, T. Wengler<sup>35</sup>,
S. Wenig<sup>35</sup>, N. Wermes<sup>24</sup>, M.D. Werner<sup>76</sup>, P. Werner<sup>35</sup>, M. Wessels<sup>59a</sup>, T.D. Weston<sup>20</sup>, K. Whalen<sup>127</sup>,
N.L. Whallon<sup>145</sup>, A.M. Wharton<sup>87</sup>, A.S. White<sup>103</sup>, A. White<sup>8</sup>, M.J. White<sup>1</sup>, R. White<sup>144b</sup>,
D. Whiteson<sup>169</sup>, B.W. Whitmore<sup>87</sup>, F.J. Wickens<sup>141</sup>, W. Wiedenmann<sup>179</sup>, M. Wielers<sup>141</sup>,
C. Wiglesworth<sup>39</sup>, L.A.M. Wiik-Fuchs<sup>50</sup>, A. Wildauer<sup>113</sup>, F. Wilk<sup>98</sup>, H.G. Wilkens<sup>35</sup>, H.H. Williams<sup>133</sup>,
S. Williams<sup>31</sup>, C. Willis<sup>104</sup>, S. Willocq<sup>100</sup>, J.A. Wilson<sup>21</sup>, I. Wingerter-Seez<sup>5</sup>, E. Winkels<sup>153</sup>,
F. Winklmeier<sup>127</sup>, O.J. Winston<sup>153</sup>, B.T. Winter<sup>24</sup>, M. Wittgen<sup>150</sup>, M. Wobisch<sup>93</sup>, A. Wolf<sup>97</sup>,
T.M.H. Wolf<sup>118</sup>, R. Wolff<sup>99</sup>, M.W. Wolter<sup>82</sup>, H. Wolters<sup>136a,136c</sup>, V.W.S. Wong<sup>173</sup>, N.L. Woods<sup>143</sup>,
S.D. Worm<sup>21</sup>, B.K. Wosiek<sup>82</sup>, K.W. Woźniak<sup>82</sup>, K. Wraight<sup>55</sup>, M. Wu<sup>36</sup>, S.L. Wu<sup>179</sup>, X. Wu<sup>52</sup>, Y. Wu<sup>58a</sup>,
T.R. Wyatt<sup>98</sup>, B.M. Wynne<sup>48</sup>, S. Xella<sup>39</sup>, Z. Xi<sup>103</sup>, L. Xia<sup>15b</sup>, D. Xu<sup>15a</sup>, H. Xu<sup>58a</sup>, L. Xu<sup>29</sup>, T. Xu<sup>142</sup>,
W. Xu<sup>103</sup>, B. Yabsley<sup>154</sup>, S. Yacoob<sup>32a</sup>, K. Yajima<sup>129</sup>, D.P. Yallup<sup>92</sup>, D. Yamaguchi<sup>163</sup>, Y. Yamaguchi<sup>163</sup>, A. Yamamoto<sup>79</sup>, T. Yamanaka<sup>161</sup>, F. Yamane<sup>80</sup>, M. Yamatani<sup>161</sup>, T. Yamazaki<sup>161</sup>, Y. Yamazaki<sup>80</sup>,
Z. Yan<sup>25</sup>, H.J. Yang<sup>58c,58d</sup>, H.T. Yang<sup>18</sup>, S. Yang<sup>75</sup>, Y. Yang<sup>161</sup>, Y. Yang<sup>155</sup>, Z. Yang<sup>17</sup>, W-M. Yao<sup>18</sup>,
Y.C. Yap<sup>44</sup>, Y. Yasu<sup>79</sup>, E. Yatsenko<sup>5</sup>, K.H. Yau Wong<sup>24</sup>, J. Ye<sup>41</sup>, S. Ye<sup>29</sup>, I. Yeletskikh<sup>77</sup>, E. Yigitbasi<sup>25</sup>,
E. Yildirim<sup>97</sup>, K. Yorita<sup>177</sup>, K. Yoshihara<sup>133</sup>, C.J.S. Young<sup>35</sup>, C. Young<sup>150</sup>, J. Yu<sup>8</sup>, J. Yu<sup>76</sup>, X. Yue<sup>59a</sup>,
S.P.Y. Yuen<sup>24</sup>, I. Yusuff<sup>31,a</sup>, B. Zabinski<sup>82</sup>, G. Zacharis<sup>10</sup>, R. Zaidan<sup>14</sup>, A.M. Zaitsev<sup>140,am</sup>,
N. Zakharchuk<sup>44</sup>, J. Zalieckas<sup>17</sup>, S. Zambito<sup>57</sup>, D. Zanzi<sup>35</sup>, C. Zeitnitz<sup>180</sup>, G. Zemaityte<sup>131</sup>, J.C. Zeng<sup>171</sup>,
Q. Zeng<sup>150</sup>, O. Zenin<sup>140</sup>, D. Zerwas<sup>128</sup>, M. Zgubič<sup>131</sup>, D.F. Zhang<sup>58b</sup>, D. Zhang<sup>103</sup>, F. Zhang<sup>179</sup>,
G. Zhang<sup>58a,ag</sup>, H. Zhang<sup>15c</sup>, J. Zhang<sup>6</sup>, L. Zhang<sup>50</sup>, L. Zhang<sup>58a</sup>, M. Zhang<sup>171</sup>, P. Zhang<sup>15c</sup>,
R. Zhang<sup>58a,e</sup>, R. Zhang<sup>24</sup>, X. Zhang<sup>58b</sup>, Y. Zhang<sup>15d</sup>, Z. Zhang<sup>128</sup>, X. Zhao<sup>41</sup>, Y. Zhao<sup>58b,128,aj</sup>,
Z. Zhao<sup>58a</sup>, A. Zhemchugov<sup>77</sup>, B. Zhou<sup>103</sup>, C. Zhou<sup>179</sup>, L. Zhou<sup>41</sup>, M.S. Zhou<sup>15d</sup>, M. Zhou<sup>152</sup>,
N. Zhou<sup>58c</sup>, Y. Zhou<sup>7</sup>, C.G. Zhu<sup>58b</sup>, H.L. Zhu<sup>58a</sup>, H. Zhu<sup>15a</sup>, J. Zhu<sup>103</sup>, Y. Zhu<sup>58a</sup>, X. Zhuang<sup>15a</sup>,
K. Zhukov<sup>108</sup>, V. Zhulanov<sup>120b,120a</sup>, A. Zibell<sup>175</sup>, D. Zieminska<sup>63</sup>, N.I. Zimine<sup>77</sup>, S. Zimmermann<sup>50</sup>,
Z. Zinonos<sup>113</sup>, M. Zinser<sup>97</sup>, M. Ziolkowski<sup>148</sup>, G. Zobernig<sup>179</sup>, A. Zoccoli<sup>23b,23a</sup>, K. Zoch<sup>51</sup>,
T.G. Zorbas<sup>146</sup>, R. Zou<sup>36</sup>, M. Zur Nedden<sup>19</sup>, L. Zwalinski<sup>35</sup>.
```

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

Engineering Science, University of Johannesburg, Johannesburg; (c) School of Physics, University of the Witwatersrand, Johannesburg; South Africa.

- ³³Department of Physics, Carleton University, Ottawa ON; Canada.
- ^{34(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 (CNESTEN), 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, Rabat; Morocco.
- ³⁵CERN, Geneva; Switzerland.
- ³⁶Enrico Fermi Institute, University of Chicago, Chicago IL; United States of America.
- ³⁷LPC, Université Clermont Auvergne, CNRS/IN2P3, Clermont-Ferrand; France.
- ³⁸Nevis Laboratory, Columbia University, Irvington NY; United States of America.
- ³⁹Niels Bohr Institute, University of Copenhagen, Copenhagen; Denmark.
- $^{40(a)}$ Dipartimento di Fisica, Università della Calabria, Rende; $^{(b)}$ INFN Gruppo Collegato di Cosenza, Laboratori Nazionali di Frascati; Italy.
- ⁴¹Physics Department, Southern Methodist University, Dallas TX; United States of America.
- ⁴²Physics Department, University of Texas at Dallas, Richardson TX; United States of America.
- ^{43(a)}Department of Physics, Stockholm University; ^(b)Oskar Klein Centre, Stockholm; Sweden.
- ⁴⁴Deutsches Elektronen-Synchrotron DESY, Hamburg and Zeuthen; Germany.
- ⁴⁵Lehrstuhl für Experimentelle Physik IV, Technische Universität Dortmund, Dortmund; Germany.
- ⁴⁶Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden; Germany.
- ⁴⁷Department of Physics, Duke University, Durham NC; United States of America.
- ⁴⁸SUPA School of Physics and Astronomy, University of Edinburgh, Edinburgh; United Kingdom.
- ⁴⁹INFN e Laboratori Nazionali di Frascati, Frascati; Italy.
- ⁵⁰Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg; Germany.
- ⁵¹II. Physikalisches Institut, Georg-August-Universität Göttingen, Göttingen; Germany.
- ⁵²Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève; Switzerland.
- ^{53(a)}Dipartimento di Fisica, Università di Genova, Genova; (b) INFN Sezione di Genova; Italy.
- ⁵⁴II. Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen; Germany.
- ⁵⁵SUPA School of Physics and Astronomy, University of Glasgow, Glasgow; United Kingdom.
- ⁵⁶LPSC, Université Grenoble Alpes, CNRS/IN2P3, Grenoble INP, Grenoble; France.
- ⁵⁷Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge MA; United States of America.
- ^{58(a)}Department of Modern Physics and State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei; (b) Institute of Frontier and Interdisciplinary Science and Key Laboratory of Particle Physics and Particle Irradiation (MOE), Shandong University, Qingdao; (c) School of Physics and Astronomy, Shanghai Jiao Tong University, KLPPAC-MoE, SKLPPC, Shanghai; (d) Tsung-Dao Lee Institute, Shanghai; China.
- ^{59(a)}Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg; ^(b)Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg; Germany.
- ⁶⁰Faculty of Applied Information Science, Hiroshima Institute of Technology, Hiroshima; Japan.
- ^{61(a)}Department of Physics, Chinese University of Hong Kong, Shatin, N.T., Hong Kong; ^(b)Department of Physics, University of Hong Kong, Hong Kong; ^(c)Department of Physics and Institute for Advanced Study, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong; China.
- ⁶²Department of Physics, National Tsing Hua University, Hsinchu; Taiwan.
- ⁶³Department of Physics, Indiana University, Bloomington IN; United States of America.

- $^{64(a)}$ INFN Gruppo Collegato di Udine, Sezione di Trieste, Udine; $^{(b)}$ ICTP, Trieste; $^{(c)}$ Dipartimento di Chimica, Fisica e Ambiente, Università di Udine, Udine; Italy.
- ^{65(a)}INFN Sezione di Lecce; ^(b)Dipartimento di Matematica e Fisica, Università del Salento, Lecce; Italy.
- ^{66(a)}INFN Sezione di Milano; ^(b)Dipartimento di Fisica, Università di Milano, Milano; Italy.
- ^{67(a)}INFN Sezione di Napoli; ^(b)Dipartimento di Fisica, Università di Napoli, Napoli; Italy.
- ^{68(a)}INFN Sezione di Pavia; ^(b)Dipartimento di Fisica, Università di Pavia, Pavia; Italy.
- $^{69(a)}$ INFN Sezione di Pisa; $^{(b)}$ Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa; Italy.
- ^{70(a)}INFN Sezione di Roma; ^(b)Dipartimento di Fisica, Sapienza Università di Roma, Roma; Italy.
- $^{71(a)} \rm INFN$ Sezione di Roma Tor Vergata; $^{(b)} \rm Dipartimento$ di Fisica, Università di Roma Tor Vergata, Roma; Italy.
- $^{72(a)}$ INFN Sezione di Roma Tre; $^{(b)}$ Dipartimento di Matematica e Fisica, Università Roma Tre, Roma; Italy.
- ^{73(a)}INFN-TIFPA; ^(b)Università degli Studi di Trento, Trento; Italy.
- ⁷⁴Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck; Austria.
- ⁷⁵University of Iowa, Iowa City IA; United States of America.
- ⁷⁶Department of Physics and Astronomy, Iowa State University, Ames IA; United States of America.
- ⁷⁷Joint Institute for Nuclear Research, Dubna; Russia.
- ^{78(a)}Departamento de Engenharia Elétrica, Universidade Federal de Juiz de Fora (UFJF), Juiz de Fora; (b) Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro; (c) Universidade Federal de São João del Rei (UFSJ), São João del Rei; (d) Instituto de Física, Universidade de São Paulo, São Paulo; Brazil.
- ⁷⁹KEK, High Energy Accelerator Research Organization, Tsukuba; Japan.
- ⁸⁰Graduate School of Science, Kobe University, Kobe; Japan.
- $^{81(a)}$ AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, Krakow; $^{(b)}$ Marian Smoluchowski Institute of Physics, Jagiellonian University, Krakow; Poland.
- ⁸²Institute of Nuclear Physics Polish Academy of Sciences, Krakow; Poland.
- ⁸³Faculty of Science, Kyoto University, Kyoto; Japan.
- ⁸⁴Kyoto University of Education, Kyoto; Japan.
- ⁸⁵Research Center for Advanced Particle Physics and Department of Physics, Kyushu University, Fukuoka; Japan.
- ⁸⁶Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata; Argentina.
- ⁸⁷Physics Department, Lancaster University, Lancaster; United Kingdom.
- ⁸⁸Oliver Lodge Laboratory, University of Liverpool, Liverpool; United Kingdom.
- ⁸⁹Department of Experimental Particle Physics, Jožef Stefan Institute and Department of Physics, University of Ljubljana, Ljubljana; Slovenia.
- ⁹⁰School of Physics and Astronomy, Queen Mary University of London, London; United Kingdom.
- ⁹¹Department of Physics, Royal Holloway University of London, Egham; United Kingdom.
- ⁹²Department of Physics and Astronomy, University College London, London; United Kingdom.
- ⁹³Louisiana Tech University, Ruston LA; United States of America.
- ⁹⁴Fysiska institutionen, Lunds universitet, Lund; Sweden.
- ⁹⁵Centre de Calcul de l'Institut National de Physique Nucléaire et de Physique des Particules (IN2P3), Villeurbanne; France.
- ⁹⁶Departamento de Física Teorica C-15 and CIAFF, Universidad Autónoma de Madrid, Madrid; Spain.
- ⁹⁷Institut für Physik, Universität Mainz, Mainz; Germany.
- ⁹⁸School of Physics and Astronomy, University of Manchester, Manchester; United Kingdom.
- ⁹⁹CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille; France.
- ¹⁰⁰Department of Physics, University of Massachusetts, Amherst MA; United States of America.

- ¹⁰¹Department of Physics, McGill University, Montreal QC; Canada.
- ¹⁰²School of Physics, University of Melbourne, Victoria; Australia.
- ¹⁰³Department of Physics, University of Michigan, Ann Arbor MI; United States of America.
- ¹⁰⁴Department of Physics and Astronomy, Michigan State University, East Lansing MI; United States of America.
- ¹⁰⁵B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk; Belarus.
- ¹⁰⁶Research Institute for Nuclear Problems of Byelorussian State University, Minsk; Belarus.
- ¹⁰⁷Group of Particle Physics, University of Montreal, Montreal QC; Canada.
- ¹⁰⁸P.N. Lebedev Physical Institute of the Russian Academy of Sciences, Moscow; Russia.
- ¹⁰⁹Institute for Theoretical and Experimental Physics (ITEP), Moscow; Russia.
- ¹¹⁰National Research Nuclear University MEPhI, Moscow; Russia.
- ¹¹¹D.V. Skobeltsyn Institute of Nuclear Physics, M.V. Lomonosov Moscow State University, Moscow; Russia.
- ¹¹²Fakultät für Physik, Ludwig-Maximilians-Universität München, München; Germany.
- ¹¹³Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München; Germany.
- ¹¹⁴Nagasaki Institute of Applied Science, Nagasaki; Japan.
- ¹¹⁵Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya; Japan.
- ¹¹⁶Department of Physics and Astronomy, University of New Mexico, Albuquerque NM; United States of America.
- ¹¹⁷Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen; Netherlands.
- ¹¹⁸Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam; Netherlands.
- ¹¹⁹Department of Physics, Northern Illinois University, DeKalb IL; United States of America.
- ^{120(a)}Budker Institute of Nuclear Physics, SB RAS, Novosibirsk; ^(b)Novosibirsk State University Novosibirsk; Russia.
- ¹²¹Department of Physics, New York University, New York NY; United States of America.
- ¹²²Ohio State University, Columbus OH; United States of America.
- ¹²³Faculty of Science, Okayama University, Okayama; Japan.
- ¹²⁴Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman OK; United States of America.
- ¹²⁵Department of Physics, Oklahoma State University, Stillwater OK; United States of America.
- ¹²⁶Palacký University, RCPTM, Joint Laboratory of Optics, Olomouc; Czech Republic.
- ¹²⁷Center for High Energy Physics, University of Oregon, Eugene OR; United States of America.
- ¹²⁸LAL, Université Paris-Sud, CNRS/IN2P3, Université Paris-Saclay, Orsay; France.
- ¹²⁹Graduate School of Science, Osaka University, Osaka; Japan.
- ¹³⁰Department of Physics, University of Oslo, Oslo; Norway.
- ¹³¹Department of Physics, Oxford University, Oxford; United Kingdom.
- ¹³²LPNHE, Sorbonne Université, Paris Diderot Sorbonne Paris Cité, CNRS/IN2P3, Paris; France.
- ¹³³Department of Physics, University of Pennsylvania, Philadelphia PA; United States of America.
- ¹³⁴Konstantinov Nuclear Physics Institute of National Research Centre "Kurchatov Institute", PNPI, St. Petersburg; Russia.
- ¹³⁵Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh PA; United States of America.
- ^{136(a)}Laboratório de Instrumentação e Física Experimental de Partículas LIP; (b) Departamento de Física, Faculdade de Ciências, Universidade de Lisboa, Lisboa; (c) Departamento de Física, Universidade de Coimbra, Coimbra; (d) Centro de Física Nuclear da Universidade de Lisboa, Lisboa; (e) Departamento

- de Física, Universidade do Minho, Braga; $^{(f)}$ Departamento de Física Teorica y del Cosmos, Universidad de Granada, Granada (Spain); $^{(g)}$ Dep Física and CEFITEC of Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Caparica; Portugal.
- ¹³⁷Institute of Physics, Academy of Sciences of the Czech Republic, Prague; Czech Republic.
- ¹³⁸Czech Technical University in Prague, Prague; Czech Republic.
- ¹³⁹Charles University, Faculty of Mathematics and Physics, Prague; Czech Republic.
- ¹⁴⁰State Research Center Institute for High Energy Physics, NRC KI, Protvino; Russia.
- ¹⁴¹Particle Physics Department, Rutherford Appleton Laboratory, Didcot; United Kingdom.
- ¹⁴²IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette; France.
- ¹⁴³Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz CA; United States of America.
- ¹⁴⁴(a) Departamento de Física, Pontificia Universidad Católica de Chile, Santiago; (b) Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso; Chile.
- ¹⁴⁵Department of Physics, University of Washington, Seattle WA; United States of America.
- ¹⁴⁶Department of Physics and Astronomy, University of Sheffield, Sheffield; United Kingdom.
- ¹⁴⁷Department of Physics, Shinshu University, Nagano; Japan.
- ¹⁴⁸Department Physik, Universität Siegen, Siegen; Germany.
- ¹⁴⁹Department of Physics, Simon Fraser University, Burnaby BC; Canada.
- ¹⁵⁰SLAC National Accelerator Laboratory, Stanford CA; United States of America.
- ¹⁵¹Physics Department, Royal Institute of Technology, Stockholm; Sweden.
- ¹⁵²Departments of Physics and Astronomy, Stony Brook University, Stony Brook NY; United States of America.
- ¹⁵³Department of Physics and Astronomy, University of Sussex, Brighton; United Kingdom.
- ¹⁵⁴School of Physics, University of Sydney, Sydney; Australia.
- ¹⁵⁵Institute of Physics, Academia Sinica, Taipei; Taiwan.
- ¹⁵⁶Academia Sinica Grid Computing, Institute of Physics, Academia Sinica, Taipei; Taiwan.
- ^{157(a)}E. Andronikashvili Institute of Physics, Iv. Javakhishvili Tbilisi State University, Tbilisi; ^(b)High Energy Physics Institute, Tbilisi State University, Tbilisi; Georgia.
- ¹⁵⁸Department of Physics, Technion, Israel Institute of Technology, Haifa; Israel.
- ¹⁵⁹Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv; Israel.
- ¹⁶⁰Department of Physics, Aristotle University of Thessaloniki, Thessaloniki; Greece.
- ¹⁶¹International Center for Elementary Particle Physics and Department of Physics, University of Tokyo, Tokyo; Japan.
- ¹⁶²Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo; Japan.
- ¹⁶³Department of Physics, Tokyo Institute of Technology, Tokyo; Japan.
- ¹⁶⁴Tomsk State University, Tomsk; Russia.
- ¹⁶⁵Department of Physics, University of Toronto, Toronto ON; Canada.
- ^{166(a)}TRIUMF, Vancouver BC; ^(b)Department of Physics and Astronomy, York University, Toronto ON; Canada.
- ¹⁶⁷Division of Physics and Tomonaga Center for the History of the Universe, Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba; Japan.
- ¹⁶⁸Department of Physics and Astronomy, Tufts University, Medford MA; United States of America.
- ¹⁶⁹Department of Physics and Astronomy, University of California Irvine, Irvine CA; United States of America
- ¹⁷⁰Department of Physics and Astronomy, University of Uppsala, Uppsala; Sweden.
- ¹⁷¹Department of Physics, University of Illinois, Urbana IL; United States of America.
- ¹⁷²Instituto de Física Corpuscular (IFIC), Centro Mixto Universidad de Valencia CSIC, Valencia; Spain.

- ¹⁷³Department of Physics, University of British Columbia, Vancouver BC; Canada.
- ¹⁷⁴Department of Physics and Astronomy, University of Victoria, Victoria BC; Canada.
- ¹⁷⁵Fakultät für Physik und Astronomie, Julius-Maximilians-Universität Würzburg, Würzburg; Germany.
- ¹⁷⁶Department of Physics, University of Warwick, Coventry; United Kingdom.
- ¹⁷⁷Waseda University, Tokyo; Japan.
- ¹⁷⁸Department of Particle Physics, Weizmann Institute of Science, Rehovot; Israel.
- ¹⁷⁹Department of Physics, University of Wisconsin, Madison WI; United States of America.
- ¹⁸⁰Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal; Germany.
- ¹⁸¹Department of Physics, Yale University, New Haven CT; United States of America.
- ¹⁸²Yerevan Physics Institute, Yerevan; Armenia.
- ^a Also at Department of Physics, University of Malaya, Kuala Lumpur; Malaysia.
- ^b Also at Borough of Manhattan Community College, City University of New York, NY; United States of America.
- ^c Also at Centre for High Performance Computing, CSIR Campus, Rosebank, Cape Town; South Africa.
- ^d Also at CERN, Geneva; Switzerland.
- ^e Also at CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille; France.
- f Also at Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève; Switzerland.
- ^g Also at Departament de Fisica de la Universitat Autonoma de Barcelona, Barcelona; Spain.
- ^h Also at Departamento de Física Teorica y del Cosmos, Universidad de Granada, Granada (Spain); Spain.
- ⁱ Also at Department of Applied Physics and Astronomy, University of Sharjah, Sharjah; United Arab Emirates.
- ^j Also at Department of Financial and Management Engineering, University of the Aegean, Chios; Greece
- ^k Also at Department of Physics and Astronomy, University of Louisville, Louisville, KY; United States of America.
- ¹ Also at Department of Physics and Astronomy, University of Sheffield, Sheffield; United Kingdom.
- ^m Also at Department of Physics, California State University, Fresno CA; United States of America.
- ⁿ Also at Department of Physics, California State University, Sacramento CA; United States of America.
- ^o Also at Department of Physics, King's College London, London; United Kingdom.
- ^p Also at Department of Physics, Nanjing University, Nanjing; China.
- ^q Also at Department of Physics, St. Petersburg State Polytechnical University, St. Petersburg; Russia.
- ^r Also at Department of Physics, Stanford University; United States of America.
- ^s Also at Department of Physics, University of Fribourg, Fribourg; Switzerland.
- ^t Also at Department of Physics, University of Michigan, Ann Arbor MI; United States of America.
- ^u Also at Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa; Italy.
- $^{\nu}$ Also at Giresun University, Faculty of Engineering, Giresun; Turkey.
- ^w Also at Graduate School of Science, Osaka University, Osaka; Japan.
- ^x Also at Hellenic Open University, Patras; Greece.
- ^y Also at Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest; Romania.
- ^z Also at II. Physikalisches Institut, Georg-August-Universität Göttingen, Göttingen; Germany.
- aa Also at Institucio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona; Spain.
- ab Also at Institut de Física d'Altes Energies (IFAE), Barcelona Institute of Science and Technology, Barcelona; Spain.
- ac Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg; Germany.

- ad Also at Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen; Netherlands.
- ae Also at Institute for Particle and Nuclear Physics, Wigner Research Centre for Physics, Budapest; Hungary.
- af Also at Institute of Particle Physics (IPP); Canada.
- ag Also at Institute of Physics, Academia Sinica, Taipei; Taiwan.
- ah Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku; Azerbaijan.
- ai Also at Institute of Theoretical Physics, Ilia State University, Tbilisi; Georgia.
- aj Also at LAL, Université Paris-Sud, CNRS/IN2P3, Université Paris-Saclay, Orsay; France.
- ak Also at Louisiana Tech University, Ruston LA; United States of America.
- al Also at Manhattan College, New York NY; United States of America.
- am Also at Moscow Institute of Physics and Technology State University, Dolgoprudny; Russia.
- an Also at National Research Nuclear University MEPhI, Moscow; Russia.
- ao Also at Near East University, Nicosia, North Cyprus, Mersin; Turkey.
- ^{ap} Also at Ochadai Academic Production, Ochanomizu University, Tokyo; Japan.
- aq Also at Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg; Germany.
- ar Also at School of Physics, Sun Yat-sen University, Guangzhou; China.
- as Also at The City College of New York, New York NY; United States of America.
- at Also at The Collaborative Innovation Center of Quantum Matter (CICQM), Beijing; China.
- ^{au} Also at Tomsk State University, Tomsk, and Moscow Institute of Physics and Technology State University, Dolgoprudny; Russia.
- av Also at TRIUMF, Vancouver BC; Canada.
- aw Also at Universita di Napoli Parthenope, Napoli; Italy.
- * Deceased