

Search for the Standard Model Higgs boson produced by vector-boson fusion and decaying to bottom quarks in $\sqrt{s} = 8$ TeV pp collisions with the ATLAS detector



The ATLAS collaboration

E-mail: atlas.publications@cern.ch

ABSTRACT: A search with the ATLAS detector is presented for the Standard Model Higgs boson produced by vector-boson fusion and decaying to a pair of bottom quarks, using 20.2fb^{-1} of LHC proton-proton collision data at $\sqrt{s} = 8$ TeV. The signal is searched for as a resonance in the invariant mass distribution of a pair of jets containing b -hadrons in vector-boson-fusion candidate events. The yield is measured to be -0.8 ± 2.3 times the Standard Model cross-section for a Higgs boson mass of 125 GeV. The upper limit on the cross-section times the branching ratio is found to be 4.4 times the Standard Model cross-section at the 95% confidence level, consistent with the expected limit value of 5.4 (5.7) in the background-only (Standard Model production) hypothesis.

KEYWORDS: Hadron-Hadron scattering (experiments), Higgs physics, proton-proton scattering

ARXIV EPRINT: [1606.02181](https://arxiv.org/abs/1606.02181)

Contents

1	Introduction	1
2	The ATLAS detector	3
3	Data and simulation samples	3
4	Object reconstruction	4
5	Event pre-selection	5
6	Multivariate analysis	5
7	Invariant mass spectrum of the two b-jets	6
8	Sources of systematic uncertainty	9
8.1	Experimental uncertainties	10
8.2	Modelling uncertainties on the m_{bb} shape of the non-resonant background	10
8.3	Theoretical uncertainties	10
9	Statistical procedure and results	11
10	Cut-based analysis	13
11	Summary	15
	The ATLAS collaboration	20

1 Introduction

Since the ATLAS and CMS collaborations reported the observation [1, 2] of a new particle with a mass of about 125 GeV and with properties consistent with those expected for the Higgs boson in the Standard Model (SM) [3–5], more precise measurements have strengthened the hypothesis that the new particle is indeed the Higgs boson [6–9]. These measurements were performed primarily in the bosonic decay modes of the new particle: $H \rightarrow \gamma\gamma, ZZ, W^+W^-$. It is essential to study whether it also directly decays into fermions as predicted by the SM. Recently CMS and ATLAS reported evidence for the $H \rightarrow \tau^+\tau^-$ decay mode at a significance level of 3.4 and 4.5 standard deviations, respectively [10–12], and the combination of these results qualifies as an observation [13]. However, the $H \rightarrow b\bar{b}$ decay mode has not yet been observed [14–19], and the only direct evidence of its existence so far has been obtained by the CDF and D0 collaborations [14] at the Tevatron collider.

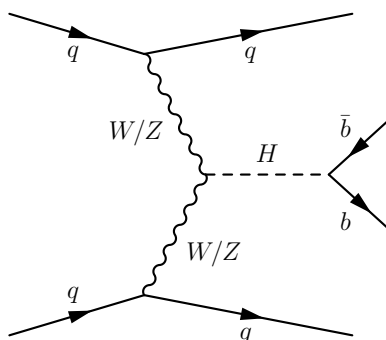


Figure 1. An example Feynman diagram illustrating vector-boson-fusion production of the Higgs boson and its decay to a $b\bar{b}$ pair.

The production processes of Higgs bosons at the LHC include gluon fusion ($gg \rightarrow H$, denoted ggF), vector-boson fusion ($qq \rightarrow qqH$, denoted VBF), Higgs-strahlung ($q\bar{q}' \rightarrow WH, ZH$, denoted WH/ZH or jointly VH), and production in association with a top-quark pair ($gg \rightarrow t\bar{t}H$, denoted $t\bar{t}H$). While an inclusive observation of the SM Higgs boson decaying to a $b\bar{b}$ pair is difficult in hadron collisions because of the overwhelming background from multijet production, the VH , VBF, and $t\bar{t}H$ processes offer viable options for the observation of the $b\bar{b}$ decay channel. As reported in refs. [15–19], the leptonic decays of vector bosons, the kinematic properties of the production process, and the identification of top quarks are used to reduce the background for VH , VBF, and $t\bar{t}H$, respectively.

This article presents a search for VBF production of the SM Higgs boson in the $b\bar{b}$ decay mode (VBF signal or VBF Higgs hereafter) using data recorded with the ATLAS detector in proton-proton collisions at a centre-of-mass energy $\sqrt{s} = 8$ TeV. The signal is searched for as a resonance in the invariant mass distribution (m_{bb}) of a pair of jets containing b -hadrons (b -jets) in vector-boson-fusion candidates. Events are selected by requiring four energetic jets generated from the $qqH \rightarrow qq\bar{b}b$ process as illustrated in figure 1: two light-quark jets (VBF jets) at a small angle with respect to the beam line and two b -jets from the Higgs boson decay in more central regions. Higgs bosons are colour singlets with no colour line to the bottom quarks; thus little QCD radiation and hadronic activity is expected between the two VBF jets, creating a rapidity gap between them. This feature is used to distinguish signal events from multijet events, which form the dominant background with a non-resonant contribution to the m_{bb} distribution. Another relevant background source arises from the decay of a Z boson to $b\bar{b}$ in association with two jets ($Z \rightarrow b\bar{b}$ or Z hereafter). This results in a resonant contribution to the m_{bb} distribution.

To improve the sensitivity, a multivariate analysis (MVA) is used to exploit the topology of the VBF Higgs final state. An alternative analysis is performed using kinematic cuts and the m_{bb} distribution. The selected sample contains a minor contribution from Higgs boson events produced via the ggF process in association with two jets. These events exhibit an m_{bb} distribution similar to that of VBF Higgs events, and are treated as signal in this analysis. The possible contribution of VH production to the signal was also studied but found to be negligible compared to VBF and ggF Higgs production for this analysis.

2 The ATLAS detector

The ATLAS experiment uses a multi-purpose particle detector [20] with a forward-backward symmetric cylindrical geometry and a near 4π coverage in solid angle.¹ It consists of an inner tracking detector (ID) surrounded by a thin superconducting solenoid providing a 2 T magnetic field, electromagnetic and hadronic calorimeters, and a muon spectrometer (MS). The ID consists of silicon pixel and microstrip tracking detectors covering the pseudorapidity range $|\eta| < 2.5$, and a transition radiation detector in the region $|\eta| < 2.0$. Lead/liquid-argon (LAr) sampling calorimeters in the region $|\eta| < 3.2$ provide electromagnetic energy measurements with high granularity. A hadron (steel/scintillator-tile) calorimeter covers the range $|\eta| < 1.7$. The end-cap and forward regions are instrumented with LAr calorimeters for both the electromagnetic and hadronic energy measurements up to $|\eta| = 4.9$. The MS surrounds the calorimeters and is based on three large air-core toroid superconducting magnets with eight coils each. It includes a system of tracking chambers covering $|\eta| < 2.7$ and fast detectors for triggering in the range $|\eta| < 2.4$. The ATLAS trigger system [21] consists of three levels: the first (L1) is a hardware-based system, and the second and third levels are software-based systems which are collectively referred to as the high-level trigger (HLT).

3 Data and simulation samples

The data used in this analysis were collected by the ATLAS experiment at a centre-of-mass energy of 8 TeV during 2012, and correspond to an integrated luminosity of 20.2 fb^{-1} recorded in stable beam conditions and with all relevant sub-detectors providing high-quality data.

Events are primarily selected by a trigger requiring four jets with transverse momentum $p_T > 15 \text{ GeV}$ at L1 and $p_T > 35 \text{ GeV}$ in the HLT, two of which must be identified as b -jets by a dedicated HLT b -tagging algorithm (HLT b -jets). This trigger was available during the entire 2012 data-taking period. Two triggers designed to enhance the acceptance for VBF $H \rightarrow b\bar{b}$ events (VBF Higgs triggers) were added during the 2012 data-taking period. They require either three L1 jets with $p_T > 15 \text{ GeV}$ where one jet is in the forward region ($|\eta| > 3.2$), or two L1 jets in the forward region with $p_T > 15 \text{ GeV}$. These criteria are completed by the requirement of at least one HLT b -jet with $p_T > 35 \text{ GeV}$. The VBF Higgs triggers were used for a data sample corresponding to an integrated luminosity of 4.4 fb^{-1} , resulting in an approximately 25% increase of the signal acceptance.

VBF and ggF Higgs boson signal events and Z boson background events are modelled by Monte Carlo (MC) simulations. The signal samples with a Higgs boson mass of 125 GeV are generated by POWHEG [22–24], which calculates the VBF and ggF Higgs production processes up to next-to-leading order (NLO) in α_S . Samples of Z boson + jets events

¹ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the centre of the detector and the z -axis along the beam pipe. The x -axis points from the IP to the centre of the LHC ring, and the y -axis points upwards. Cylindrical coordinates (r, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the z -axis. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln \tan(\theta/2)$. Angular distance is measured in units of $\Delta R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$.

are generated using MADGRAPH5 [25], where the associated jets are produced via strong or electroweak (EW) processes including VBF, and the matrix elements are calculated for up to and including three partons at leading order. For all simulated samples, the NLO CT10 parton distribution functions (PDF) [26] are used. The parton shower and the hadronisation are modelled by PYTHIA8 [27], with the AU2 set of tuned parameters [28, 29] for the underlying event.

The VBF Higgs predictions are normalised to a cross-section calculation that includes full NLO QCD and EW corrections and approximate next-to-next-to-leading-order (NNLO) QCD corrections [30]. The NLO EW corrections also affect the p_T shape of the Higgs boson [31]. The p_T shape is reweighted, based on the shape difference between HAWK calculations without and with NLO EW corrections included [32, 33].

The overall normalisation of the ggF process is taken from a calculation at NNLO in QCD that includes soft-gluon resummation up to next-to-next-to-leading logarithmic terms (NNLL) [30]. Corrections to the shape of the generated p_T distribution of Higgs bosons are applied to match the distribution from the NNLO calculation with the NNLL corrections provided by the HRES program [34, 35]. In this calculation, the effects of finite masses of the top and bottom quarks are included and dynamic renormalisation and factorisation scales are used. A reweighting is derived such that the inclusive Higgs p_T spectrum matches the HRES prediction, and the Higgs p_T spectrum of events with at least two jets matches the MINLO HJJ [36] prediction, the most recent calculation in this phase space.

The ATLAS simulation [37] of the detector is used for all MC events based on the GEANT4 program [38] except for the response of the calorimeters, for which a parameterised simulation [39] is used. All simulated events are generated with a range of minimum-bias interactions overlaid on the hard-scattering interaction to account for multiple pp interactions that occur in the same or neighbouring bunch crossings (pile-up). The simulated events are processed with the same reconstruction algorithms as the data. Corrections are applied to the simulated samples to account for differences between data and simulation in the trigger and reconstruction efficiencies and in pile-up contributions.

4 Object reconstruction

Charged-particle tracks are reconstructed with a p_T threshold of 400 MeV. Event vertices are formed from these tracks and are required to have at least three tracks. The primary vertex is chosen as the vertex with the largest Σp_T^2 of the associated tracks.

Jets are reconstructed from topological clusters of energy deposits, after noise suppression, in the calorimeters [40] using the anti- k_t algorithm [41] with a radius parameter $R = 0.4$. Jet energies are corrected for the contribution of pile-up interactions using a jet-area-based technique [42], and calibrated using p_T - and η -dependent correction factors determined from MC simulations and in-situ data measurements of Z +jet, γ +jet and multi-jet events [43, 44]. To suppress jets from pile-up interactions, which are mainly at low p_T , a jet vertex tagger [45], based on tracking and vertexing information, is applied to jets with $p_T < 50$ GeV and $|\eta| < 2.4$.

Process	Cross-section \times BR [pb]	Acceptance
VBF $H \rightarrow b\bar{b}$	0.9	6.9×10^{-3}
ggF $H \rightarrow b\bar{b}$	11.1	4.2×10^{-4}
$Z \rightarrow b\bar{b} + 1, 2, \text{ or } 3 \text{ partons}$	5.9×10^2	3.1×10^{-4}

Table 1. Cross-sections times branching ratios (BRs) used for the VBF and ggF $H \rightarrow b\bar{b}$ and $Z \rightarrow b\bar{b}$ MC generation, and acceptances of the pre-selection criteria for simulated samples.

The b -jets are identified (b -tagged) by exploiting the relatively long lifetime and large mass of b -hadrons. The b -tagging methods are based on the presence of tracks with a large impact parameter with respect to the primary vertex, and secondary decay vertices. This information is combined into a single neural-network discriminant [46]. This analysis uses a b -tagging criterion that, in simulated $t\bar{t}$ events, provides an average efficiency of 70% for b -jets and a c -jet (light-jet) mis-tag rate less than 20% (1%).

5 Event pre-selection

Events with exactly four jets, each with $p_T > 50$ GeV and $|\eta| < 4.5$, are retained. The four jets are ordered in η such that $\eta_1 < \eta_2 < \eta_3 < \eta_4$. The jets associated with η_1 and η_4 are labelled as VBF jets (or $J1$ and $J2$). The other two jets associated with η_2 and η_3 (Higgs jets or $b1$ and $b2$) are required to be within the tracker acceptance ($|\eta| < 2.5$), and to be identified as b -jets. The two Higgs jets must be matched to the HLT b -jets for events satisfying the primary trigger; for events satisfying the VBF Higgs triggers, one of the two Higgs jets is required to be matched to an HLT b -jet. The 50 GeV cut on jet p_T shapes the m_{bb} distribution for non-resonant backgrounds, creating a peak near 130 GeV, which makes the extraction of a signal difficult. This shaping is removed by requiring the p_T of the $b\bar{b}$ system to exceed 100 GeV. Table 1 summarises the acceptances of these pre-selection criteria, for the VBF and ggF Higgs MC events [30, 47] and the Z MC events.

For the pre-selected events, corrections are applied to improve the b -jet energy measurements. If muons with $p_T > 4$ GeV and $|\eta| < 2.5$ are found within a b -jet, the four-momentum of the muon closest to the jet axis is added to that of the jet (after correcting for the expected energy deposited by the muon in the calorimeter material). Such muons are reconstructed by combining measurements from the ID and MS systems, and are required to satisfy tight muon identification quality criteria [48]. In addition, a p_T -dependent correction of up to 5% is applied to account for biases in the response due to resolution effects. This correction is determined from simulated WH/ZH events following ref. [15].

6 Multivariate analysis

A Boosted Decision Tree [49, 50] (BDT) method, as implemented in the Toolkit for Multivariate Data Analysis package [51], is used to exploit the characteristics of VBF production. The BDT is trained to discriminate between VBF Higgs signal events and non-resonant

background events modelled using the data in the sideband regions of the m_{bb} distribution ($70 < m_{bb} < 90$ GeV and $150 < m_{bb} < 190$ GeV).

The input variables of the BDT are chosen to exploit the difference in topologies between signal events and background events while keeping them as uncorrelated as possible with m_{bb} , to ensure that the sideband regions provide a good description of the non-resonant background in the signal region. In order of decreasing discrimination power, which is determined by removing variables one by one from the analysis, the variables are: the jet widths of VBF jets having $|\eta| < 2.1$ (the jet width is defined as the p_T -weighted angular distance of the jet constituents from the jet axis, and is set to zero if $|\eta| > 2.1$), which differs on average for quark and gluon jets; the scalar sum of the p_T of additional jets with $p_T > 20$ GeV in the region $|\eta| < 2.5$, Σp_T^{jets} ; the invariant mass of the two VBF jets, m_{JJ} ; the η separation between the two VBF jets, $\Delta\eta_{JJ}$; the maximum $|\eta|$ of the two VBF jets, $\max(|\eta_{J1}|, |\eta_{J2}|)$; the separation between the $|\eta|$ average of the VBF jets and that of the Higgs jets, $(|\eta_{J1}| + |\eta_{J2}|)/2 - (|\eta_{b1}| + |\eta_{b2}|)/2$; and the cosine of the polar angle of the cross product of the VBF jets momenta, $\cos\theta$, which is sensitive to the production mechanism.

Figures 2 and 3 show the distributions of the BDT input variables in the data and the simulated samples for the VBF $H \rightarrow b\bar{b}$, ggF $H \rightarrow b\bar{b}$, and $Z \rightarrow b\bar{b}$ events that satisfy the pre-selection criteria. The BDT responses to the pre-selected data and simulated events are compared in figure 4. As expected, the BDT response to the VBF Higgs signal sample is significantly different from its response to the data, which are primarily multijet events, and also from its response to the Z and ggF Higgs samples.

7 Invariant mass spectrum of the two b -jets

The signal is estimated using a fit to the m_{bb} distribution in the range $70 < m_{bb} < 300$ GeV. The contributions to the distribution include $H \rightarrow b\bar{b}$ events, from either VBF or ggF production; $Z \rightarrow b\bar{b}$ events produced in association with jets; and non-resonant processes such as multijet, $t\bar{t}$, single top, and W +jets production. In order to better exploit the MVA discrimination power, the fit is performed simultaneously in four categories based on the BDT output. The boundaries of the four categories, shown in table 2, were optimised by minimising the relative statistical uncertainties, $\sqrt{N_{\text{sig}} + N_{\text{bg}}}/N_{\text{sig}}$, where N_{sig} and N_{bg} are the expected numbers of signal and background events, respectively. Table 2 shows, for each category, the total number of events observed in the data and the number of Higgs events expected from the VBF and ggF production processes, along with the number of Z events expected in the entire mass range. The categories in table 2 are listed in order of increasing sensitivity.

The shapes of the m_{bb} distributions for Higgs and Z boson events are taken from simulation. Their shapes in the four categories are found to be comparable; therefore the inclusive shapes are used. The m_{bb} shapes for VBF and ggF Higgs boson events are similar, as expected. In order to minimise the effects of the limited MC sample size, the resulting m_{bb} histograms for Higgs and Z events are smoothed using the 353QH algorithm [52]. The m_{bb} distributions used in the fit are shown in figure 5. The Higgs yield is left free to vary. The Z yield is constrained to the SM prediction within its theoretical uncertainty (see section 8.3).

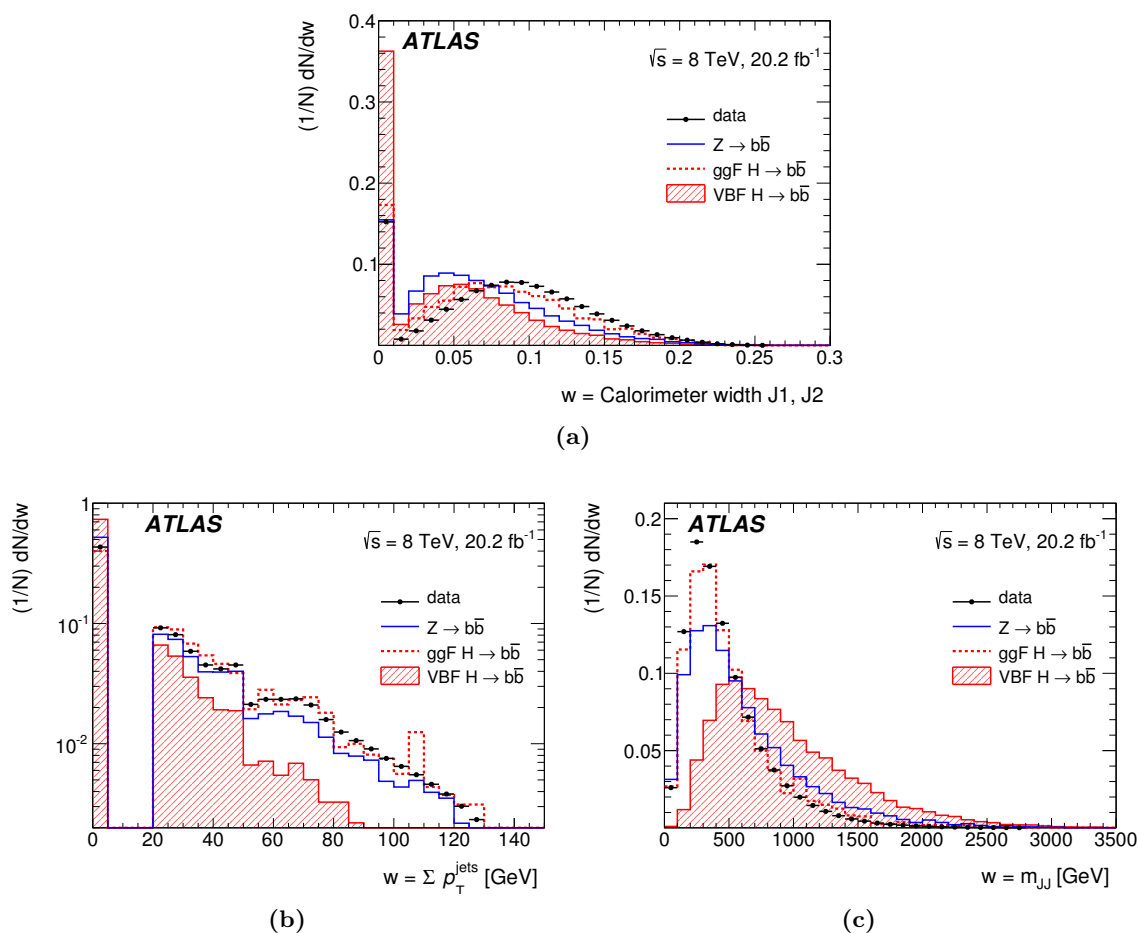


Figure 2. Distributions of the BDT input variables from the data (points) and the simulated samples for VBF $H \rightarrow b\bar{b}$ events (shaded histograms), ggF $H \rightarrow b\bar{b}$ events (open dashed histograms) and $Z \rightarrow b\bar{b}$ events (open solid histograms). The pre-selection criteria are applied to these samples. The variables are: (a) the jet widths for the VBF jets having $|\eta| < 2.1$ (the jet width is set at zero if $|\eta| > 2.1$); (b) the scalar sum of the p_T of additional jets with $p_T > 20$ GeV in the region $|\eta| < 2.5$, Σp_T^{jets} (the peak at zero represents events without additional jets); and (c) the invariant mass of the two VBF jets, m_{JJ} .

Process	Pre-selection	Category I (-0.08 to 0.01)	Category II (0.01 to 0.06)	Category III (0.06 to 0.09)	Category IV (> 0.09)
VBF $H \rightarrow b\bar{b}$	130	39	33	23	19
ggF $H \rightarrow b\bar{b}$	94	31	8.5	3.8	1.6
$Z \rightarrow b\bar{b}$	3700	1100	350	97	49
Data	554302	176073	46912	15015	6493

Table 2. Expected numbers of events for VBF and ggF $H \rightarrow b\bar{b}$ and $Z \rightarrow b\bar{b}$ processes, and the observed numbers of events in data with $70 < m_{bb} < 300$ GeV, after the pre-selection criteria are applied, in the four categories of the BDT response. The categories are listed in order of increasing sensitivity. The values in the parentheses represent the boundaries of each BDT category.

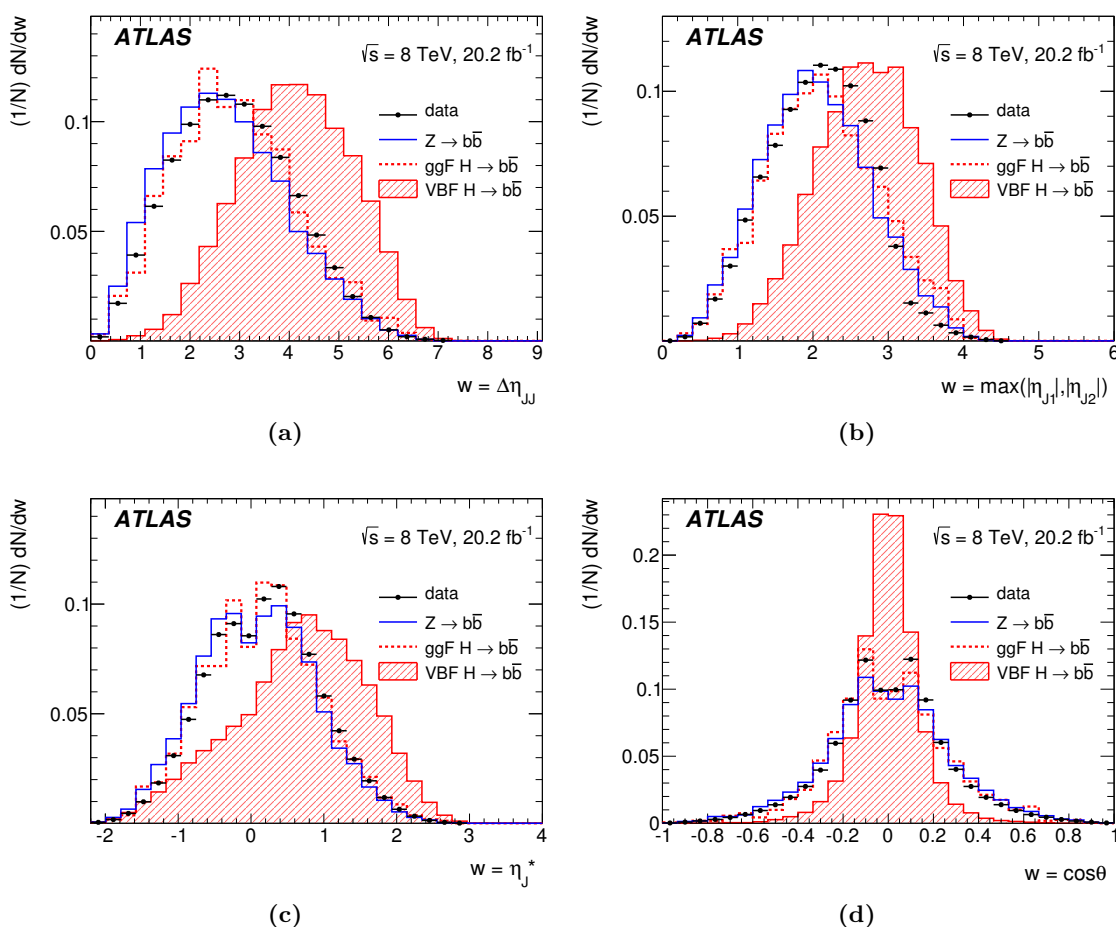


Figure 3. Distributions of the BDT input variables from the data (points) and the simulated samples for VBF $H \rightarrow b\bar{b}$ events (shaded histograms), ggF $H \rightarrow b\bar{b}$ events (open dashed histograms) and $Z \rightarrow b\bar{b}$ events (open solid histograms). The pre-selection criteria are applied to these samples. The variables are: (a) the η separation between the two VBF jets, $\Delta\eta_{JJ}$; (b) the maximum $|\eta|$ of the two VBF jets, $\max(|\eta_{J1}|, |\eta_{J2}|)$; (c) the separation between the $|\eta|$ average of the VBF jets and that of the Higgs jets, $\eta_J^* = (|\eta_{J1}| + |\eta_{J2}|)/2 - (|\eta_{b1}| + |\eta_{b2}|)/2$; and (d) the cosine of the polar angle of the cross product of the VBF jets momenta, $\cos\theta$.

A data-driven method is used to model the m_{bb} distribution of the non-resonant background. Data in the sidebands of the m_{bb} distribution are fit simultaneously to a function which is then interpolated to the signal region. The analytic forms considered are Bernstein polynomials [53], combinations of exponential functions, and combinations of Bernstein polynomials and exponential functions with various numbers of coefficients, and functions with a χ^2 probability greater than 0.05, that do not introduce a bias, are selected. For each form, the minimum number of coefficients is determined by performing an F-test, and the corresponding function is chosen as a candidate function. The fitted signal strength is measured for each candidate function using toy samples. The function giving the smallest bias is used as the nominal distribution. The function giving the second smallest bias is

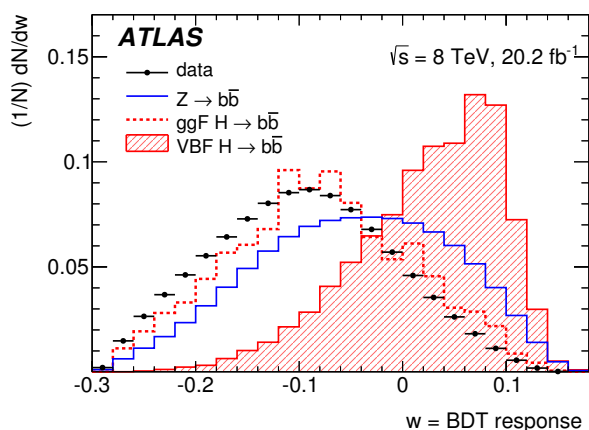


Figure 4. Distributions of the BDT response to the data (points) and to the simulated samples for VBF $H \rightarrow b\bar{b}$ events (shaded histogram), ggF $H \rightarrow b\bar{b}$ events (open dashed histogram) and $Z \rightarrow b\bar{b}$ events (open solid histogram). The pre-selection criteria are applied to these samples.

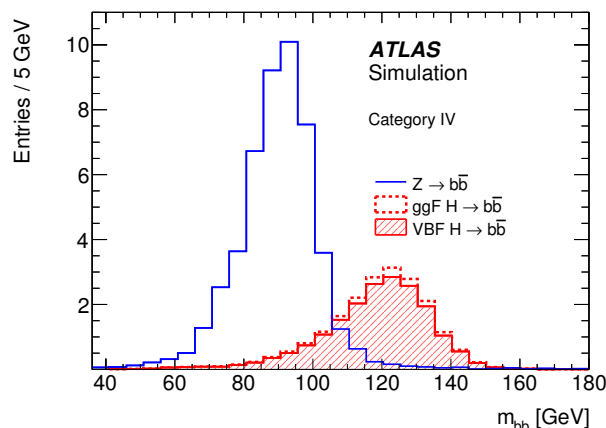


Figure 5. Simulated invariant mass distributions of two b -jets from decays of Higgs bosons, summed for VBF (shaded histogram) and ggF (open dashed histogram) production, as well as from decays of Z bosons (open solid histogram), normalised to the expected contributions in category IV, which gives the highest sensitivity.

taken as an alternative distribution, and is used to estimate the systematic uncertainty due to the choice of analytic function. The shapes of the m_{bb} distributions are observed to be different in the four categories. Bernstein polynomials of different degrees, fourth-order in category I and third-order in the higher-sensitivity categories, are found to best describe the m_{bb} shape of the non-resonant background. The nominal and alternative functions are summarised in table 3.

8 Sources of systematic uncertainty

This section discusses sources of systematic uncertainty: experimental uncertainties, uncertainties on the modelling of the non-resonant background, and theoretical uncertainties

	category I	category II	category III	category IV
Nominal	4 th Pol.	3 rd Pol.	3 rd Pol.	3 rd Pol.
Alternative	2 nd Pol. \times exponential	3 exponentials	2 exponentials	exponential

Table 3. Nominal and alternative functions describing the non-resonant background in the four BDT categories. The fourth-, third-, and second-order Bernstein polynomials are referred to as 4th Pol., 3rd Pol., and 2nd Pol.

on the Higgs and Z processes. The uncertainties can affect the normalisation and the kinematic distributions individually or both together.

8.1 Experimental uncertainties

The dominant experimental uncertainties on the Higgs signal yield arise from the statistical uncertainty due to the finite size of the MC samples, the jet energy scale uncertainty, and the b -jet triggering and tagging, contributing 15%, 10–20%, and 10% respectively, to the total uncertainty on the Higgs yield. Limited MC sizes affect the normalisation via the acceptance of the signal events and the shape of the signal m_{bb} distribution. Several sources contribute to the uncertainty on the jet energy scale [44]. They include the in situ jet calibration, pile-up-dependent corrections and the flavour composition of jets in different event classes. The shape of the m_{bb} distribution for the Higgs signal and the Z background is affected by the jet energy scale uncertainty. Moreover, the change in the jet energy modifies the value of the BDT output and can cause migration of events between BDT categories. The b -jet trigger and tagging efficiencies are another source of systematic uncertainty, contributing 10% to the total uncertainty. They are calibrated using multijet events containing a muon and $t\bar{t}$ events, respectively [54]. The uncertainty on the jet energy resolution contributes about 4%. The uncertainty on the integrated luminosity, 1.9% [55], is included, but is negligible compared to the other uncertainties mentioned above.

8.2 Modelling uncertainties on the m_{bb} shape of the non-resonant background

The uncertainties on the shape of the m_{bb} distribution for the non-resonant background is the largest source of systematic uncertainty, contributing about 80% to the total uncertainty on the Higgs yield. The dominant contributions to this source come from the limited number of events in the m_{bb} sidebands of the data used for the fit to the nominal function, and from the choice of the function. For the latter, an alternative function is chosen for each BDT region, as described in section 7 and listed in table 3. Pseudo-data are generated using the nominal functions and are fit simultaneously in the four BDT categories with nominal and alternative functions. The bin-by-bin differences in the background yield predicted by the two alternative descriptions are used to estimate, by means of an eigenvector decomposition, the corresponding systematic uncertainties.

8.3 Theoretical uncertainties

The uncertainties on the MC modelling of the Higgs signal events contribute about 10% to the total uncertainty on the Higgs yield. The sources for these uncertainties are higher order

QCD corrections, the modelling of the underlying event and the parton shower, the PDFs, and the $H \rightarrow b\bar{b}$ branching ratio. An uncertainty on higher order QCD corrections for the cross-sections and acceptances is estimated by varying the factorisation and renormalisation scales, μ_F and μ_R , independently by a factor of two around the nominal values [31] with the constraint $0.5 \leq \mu_F/\mu_R \leq 2$. Higher order corrections to the p_T spectrum of the Higgs boson (described in section 3) are an additional source of the modelling uncertainties. This uncertainty is estimated by comparing the results between LO and NLO calculations for VBF production and by varying the factorisation and renormalisation scales for ggF production. Uncertainties related to the simulation of the underlying event and the parton shower are estimated by comparing distributions obtained using POWHEG+PYTHIA8 and POWHEG+HERWIG [56]. The uncertainties on the acceptance due to uncertainties in the PDFs are estimated by studying the change in the acceptance when different PDF sets such as MSTW2008NLO [57] and NNPDF2.3 [58] are used or the CT10 PDF set parameters are varied within their uncertainties. The largest variation in acceptance is taken as a systematic uncertainty. The uncertainty on the $H \rightarrow b\bar{b}$ branching ratio, 3.2% [47], is also accounted for.

The uncertainty on higher order QCD corrections to the $Z \rightarrow b\bar{b}$ yield is estimated by varying the factorisation and renormalisation scales around the nominal value in the manner described above. It is found to be about 40-50%, depending on the BDT category, out of which about 25% is correlated. These correlated and uncorrelated uncertainties are used to constrain the Z yield in the fit. This process results in about 20-25% to the total uncertainty on the Higgs yield.

9 Statistical procedure and results

A statistical fitting procedure based on the RooStats framework [59, 60] is used to estimate the Higgs signal strength, μ , from the data, where μ is the ratio of the measured signal yield to the SM prediction. A binned likelihood function is constructed as the product of Poisson-probability terms of the bins in the m_{bb} distributions, and of the four different BDT categories.

The impact of systematic uncertainties on the signal and background expectations, presented in section 8, is described by a vector of nuisance parameters (NPs), $\vec{\theta}$. The expected numbers of signal and background events in each bin and category are functions of $\vec{\theta}$. For each NP with an a priori constraint, the prior is taken into account as a Gaussian constraint in the likelihood. The NPs associated with uncertainties in the shape and normalisation of the non-resonant background events, which do not have priors, are determined from the data.

The test statistic q_μ is constructed according to the profile-likelihood ratio:

$$q_\mu = 2 \ln(\mathcal{L}(\mu, \vec{\theta}_\mu) / \mathcal{L}(\hat{\mu}, \vec{\theta})), \quad (9.1)$$

where $\hat{\mu}$ and $\vec{\theta}$ are the parameters that maximise the likelihood, and $\vec{\theta}_\mu$ are the nuisance parameter values that maximise the likelihood for a given μ . This test statistic is used

Source of uncertainty		Uncertainty on μ	
		MVA	Cut-based
Experimental uncertainties	Detector-related	+0.2/−0.3	+1.6/−1.2
	MC statistics	±0.4	±0.1
Theoretical uncertainties	MC signal modelling	±0.1	±1.3
	Z yield	+0.6/−0.5	±1.4
Non-resonant background modelling	Choice of function	±1.0	±1.0
	Sideband statistics	±1.7	±3.7
Statistical uncertainties		±1.3	
Total		±2.3	+4.6/−4.4

Table 4. Summary of uncertainties on the Higgs signal strength for the MVA analysis, and for the cut-based analysis. They are estimated at the central values of the signal strength, $\mu = -0.8$ and -5.2 for the MVA and cut-based analyses, respectively. The two systematic uncertainties accounting for non-resonant background modelling are strongly correlated. Their combined value for the MVA analysis is 1.8.

both to measure the compatibility of the background-only model with the data, and to determine exclusion intervals using the CL_S method [61, 62].

The robustness of the fit is validated by generating pseudo-data and estimating the number of signal events for various values of μ . The results of the fit in the four categories are shown in figure 6. The Z yield is constrained to the SM prediction within its theoretical uncertainty, using four independent constraints in the four BDT regions (uncorrelated terms) and a common constraint (correlated term) as described in section 8.3. The ratios of Z yields to the SM predictions (μ_Z) are found to be compatible in all of the four BDT regions. Combined over the four categories, the fit further constrains μ_Z to 0.7 ± 0.2 .

The combined Higgs signal strength is -0.8 ± 2.3 , where the uncertainty includes both the statistical (± 1.3) and systematic ($+1.8/-1.9$) components. The breakdown of the systematic uncertainty on the estimated signal strength is given in table 4. The correlation coefficient between the combined μ and the combined μ_Z is found to be 0.22. In the absence of a signal, the limit on the Higgs signal strength at 95% confidence level (CL) is expected to be 5.4. When Standard Model production is assumed, the expected limit is found to be 5.7. The observed limit is 4.4.

The compatibility between the measured Z yield and its SM prediction is alternatively tested by removing its a priori constraint from the fit. In this case a value of $\mu_Z = 0.3 \pm 0.3$ is extracted from the fit, to be compared to the theory prediction of 1.0 ± 0.4 . The absence of the Z constraint modifies the combined Higgs signal strength slightly, to -0.5 ± 2.3 .

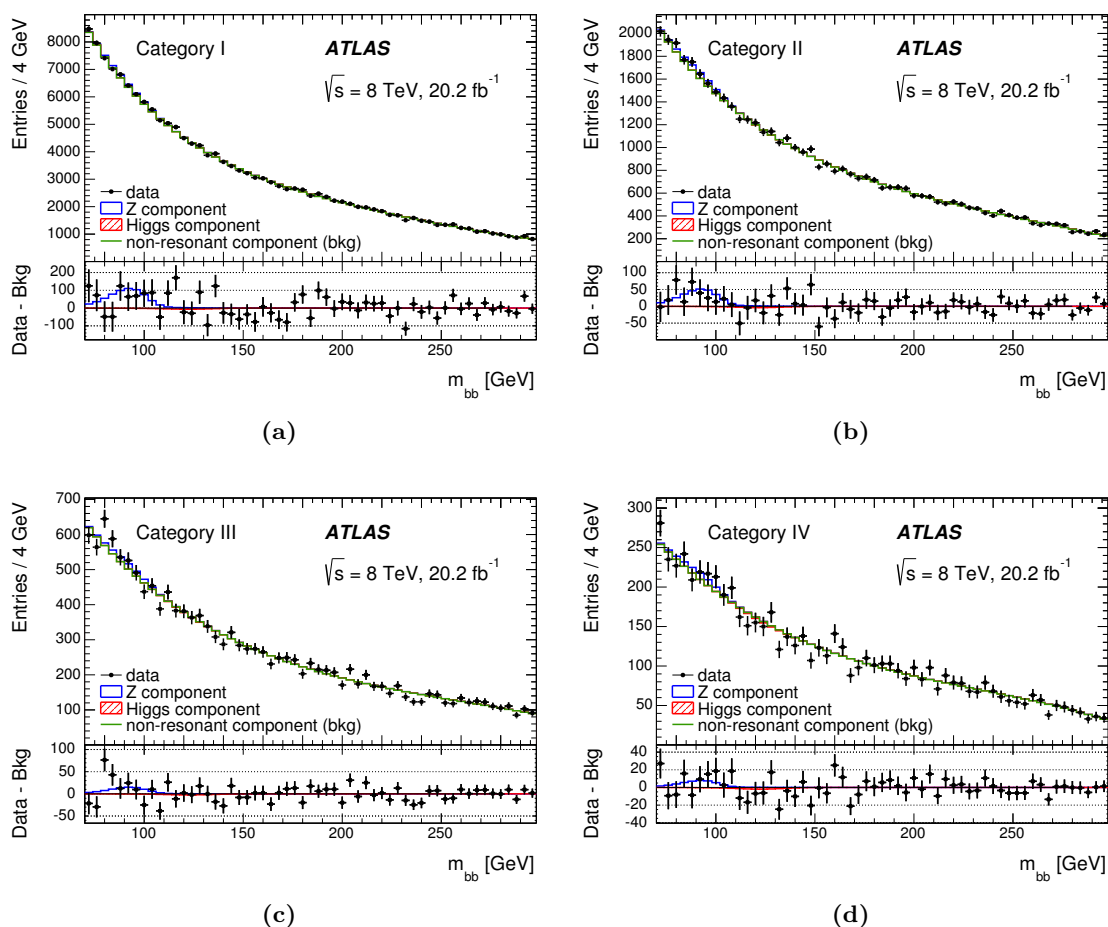


Figure 6. Results of the profile-likelihood fit to the m_{bb} distributions in the four BDT categories. The points represent the data, and the histograms represent the non-resonant background, Z , and Higgs contributions. In the lower panels, the data after subtraction of the non-resonant background (points) are compared with the fit to the Z (open histogram) and Higgs (shaded histogram) contributions.

10 Cut-based analysis

An alternative analysis is performed based on kinematic cuts. While the MVA performs a simultaneous fit to the m_{bb} distributions of the four samples categorised by the BDT response, the cut-based analysis performs a fit to one m_{bb} distribution of the entire sample in the mass range between 70 GeV and 300 GeV. Events are required to satisfy kinematic criteria featuring the VBF Higgs final state. Events must not have any additional jet with $p_T > 25$ GeV and $|\eta| < 2.4$, and must satisfy $|\Delta\eta_{JJ}| > 3.0$ and $m_{JJ} > 650$ GeV. Figure 7 shows the m_{bb} distribution of 32906 events in the data that satisfy the selection criteria. The number of signal events in the data is expected to be 68.8, with about 15% coming from ggF production. This can be compared to 158.9 events in the MVA, as obtained by summing the corresponding numbers in table 2 over the four categories, where about 28% comes from ggF production.

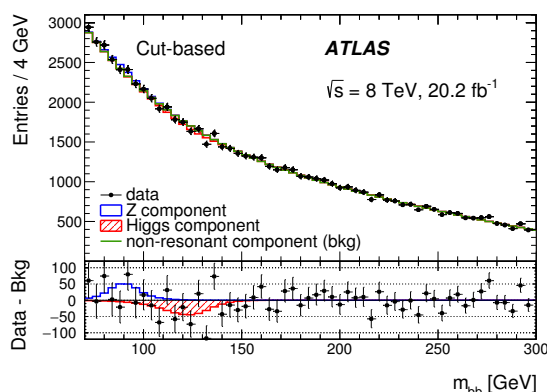


Figure 7. Distribution of m_{bb} for events selected in the cut-based analysis. The points represent the data, and the histograms represent the non-resonant background, Z , and Higgs contributions. In the lower panel, the data after subtraction of the non-resonant background (points) are compared with the fit to the Z (open histogram) and Higgs (shaded histogram) contributions. The Higgs yield extracted from the fit is consistent with zero.

The cut-based analysis uses an unbinned maximum likelihood fit. The resonance shapes of the m_{bb} distributions for the Higgs and Z events are determined by a fit to a Bukin function [63] using MC events. The analytic functions describing the non-resonant background are studied by using events that satisfy the pre-selection criteria described in section 5. A fourth-order polynomial is chosen as the nominal function and a fifth-order polynomial is chosen as the alternative function.

The Higgs yield is left free to vary, but the Z yield is fixed to its SM prediction. The robustness of the fit is validated by generating pseudo-data and constructing pulls of the estimated number of Higgs events for various values of μ . The fit results are presented in figure 7. The Higgs signal strength is measured to be $\mu = -5.2 \pm 3.7(\text{stat.})_{-2.5}^{+2.7}(\text{syst.})$, where the statistical uncertainty includes the statistical uncertainty on the non-resonant background modelling (see table 4). The sources of systematic uncertainty are the same as those for the MVA analysis as described in section 8 and are summarised in table 4. The uncertainties on μ are estimated as the changes in μ when the sources are varied within their uncertainties. Higher-order corrections to the Z samples and to the signal samples, the choice of function describing the non-resonant background, and the jet energy scale are the dominant sources of systematic uncertainty, each contributing about 40–50% to the total systematic uncertainty on the Higgs signal strength. The magnitudes of experimental and theoretical uncertainties are scaled with the central value of μ , as illustrated in table 4 except for the case of the MC statistical uncertainty. This is due to the fact that the MVA divides the MC samples into four categories, and uses the signal m_{bb} distribution directly in the fit as a template while the cut-based analysis uses an interpolated function. The upper limit on the strength is found to be 5.4 at the 95% CL, which can be compared to the expected limit values of 8.5 in the background-only hypothesis and 9.5 if Standard Model production is assumed. These results are consistent with those of the MVA. As expected, the cut-based analysis is less sensitive than the MVA.

11 Summary

A search for the Standard Model Higgs boson produced by vector-boson fusion and decaying into a pair of bottom quarks is presented. The dataset analysed corresponds to an integrated luminosity of 20.2 fb^{-1} from pp collisions at $\sqrt{s} = 8 \text{ TeV}$, recorded by the ATLAS experiment during Run 1 of the LHC. Events are selected using the distinct final state of the VBF $H \rightarrow b\bar{b}$ signal, which is the presence of four energetic jets: two b -jets from the Higgs boson decay in the central region of the detector and two jets in the forward/backward region. To improve the sensitivity, a multivariate analysis is used, exploiting the topology of the VBF Higgs final state and the properties of jets. The signal yield is estimated by performing a fit to the invariant mass distribution of the two b -jets in the range $70 < m_{bb} < 300 \text{ GeV}$ and assuming a Higgs boson mass of 125 GeV . The ratio of the Higgs signal yield to the SM prediction is measured to be $\mu = -0.8 \pm 1.3(\text{stat.})_{-1.9}^{+1.8}(\text{syst.}) = -0.8 \pm 2.3$. The upper limit on μ is observed to be $\mu = 4.4$ at the 95% CL, which should be compared to the expected limits of 5.4 in the background-only hypothesis and 5.7 if Standard Model production is assumed. An alternative analysis is performed using kinematic selection criteria and provides consistent results: $\mu = -5.2_{-4.4}^{+4.6}$ and a 95% CL upper limit of 5.4.

Acknowledgments

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

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

Generalitat de Catalunya, Generalitat Valenciana, Spain; the Royal Society and Leverhulme Trust, United Kingdom.

The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN, the ATLAS Tier-1 facilities at TRIUMF (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN-CNAF (Italy), NL-T1 (Netherlands), PIC (Spain), ASGC (Taiwan), RAL (U.K.) and BNL (U.S.A.), the Tier-2 facilities worldwide and large non-WLCG resource providers. Major contributors of computing resources are listed in ref. [64].

Open Access. This article is distributed under the terms of the Creative Commons Attribution License ([CC-BY 4.0](https://creativecommons.org/licenses/by/4.0/)), which permits any use, distribution and reproduction in any medium, provided the original author(s) and source are credited.

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](https://arxiv.org/abs/1207.7214)] [[INSPIRE](#)].
- [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](https://arxiv.org/abs/1207.7235)] [[INSPIRE](#)].
- [3] F. Englert and R. Brout, *Broken symmetry and the mass of gauge vector mesons*, *Phys. Rev. Lett.* **13** (1964) 321 [[INSPIRE](#)].
- [4] P.W. Higgs, *Broken symmetries and the masses of gauge bosons*, *Phys. Rev. Lett.* **13** (1964) 508 [[INSPIRE](#)].
- [5] P.W. Higgs, *Broken symmetries, massless particles and gauge fields*, *Phys. Lett.* **12** (1964) 132 [[INSPIRE](#)].
- [6] ATLAS collaboration, *Measurements of Higgs boson production and couplings in diboson final states with the ATLAS detector at the LHC*, *Phys. Lett. B* **726** (2013) 88 [*Erratum ibid.* **B 734** (2014) 406] [[arXiv:1307.1427](https://arxiv.org/abs/1307.1427)] [[INSPIRE](#)].
- [7] ATLAS collaboration, *Evidence for the spin-0 nature of the Higgs boson using ATLAS data*, *Phys. Lett. B* **726** (2013) 120 [[arXiv:1307.1432](https://arxiv.org/abs/1307.1432)] [[INSPIRE](#)].
- [8] CMS collaboration, *Precise determination of the mass of the Higgs boson and tests of compatibility of its couplings with the Standard Model predictions using proton collisions at 7 and 8 TeV*, *Eur. Phys. J. C* **75** (2015) 212 [[arXiv:1412.8662](https://arxiv.org/abs/1412.8662)] [[INSPIRE](#)].
- [9] CMS collaboration, *Constraints on the spin-parity and anomalous HVV couplings of the Higgs boson in proton collisions at 7 and 8 TeV*, *Phys. Rev. D* **92** (2015) 012004 [[arXiv:1411.3441](https://arxiv.org/abs/1411.3441)] [[INSPIRE](#)].
- [10] CMS collaboration, *Evidence for the 125 GeV Higgs boson decaying to a pair of τ leptons*, *JHEP* **05** (2014) 104 [[arXiv:1401.5041](https://arxiv.org/abs/1401.5041)] [[INSPIRE](#)].
- [11] CMS collaboration, *Evidence for the direct decay of the 125 GeV Higgs boson to fermions*, *Nature Phys.* **10** (2014) 557 [[arXiv:1401.6527](https://arxiv.org/abs/1401.6527)] [[INSPIRE](#)].
- [12] ATLAS collaboration, *Evidence for the Higgs-boson Yukawa coupling to tau leptons with the ATLAS detector*, *JHEP* **04** (2015) 117 [[arXiv:1501.04943](https://arxiv.org/abs/1501.04943)] [[INSPIRE](#)].

- [13] ATLAS and CMS collaborations, *Measurements of the Higgs boson production and decay rates and constraints on its couplings from a combined ATLAS and CMS analysis of the LHC pp collision data at $\sqrt{s} = 7$ and 8 TeV*, [ATLAS-CONF-2015-044](#), CERN, Geneva Switzerland (2015) [[CMS-PAS-HIG-15-002](#)] [[INSPIRE](#)].
- [14] CDF and D0 collaborations, T. Aaltonen et al., *Evidence for a particle produced in association with weak bosons and decaying to a bottom-antibottom quark pair in Higgs boson searches at the Tevatron*, *Phys. Rev. Lett.* **109** (2012) 071804 [[arXiv:1207.6436](#)] [[INSPIRE](#)].
- [15] ATLAS collaboration, *Search for the $b\bar{b}$ decay of the Standard Model Higgs boson in associated (W/Z)H production with the ATLAS detector*, *JHEP* **01** (2015) 069 [[arXiv:1409.6212](#)] [[INSPIRE](#)].
- [16] CMS collaboration, *Search for the Standard Model Higgs boson produced in association with a W or a Z boson and decaying to bottom quarks*, *Phys. Rev. D* **89** (2014) 012003 [[arXiv:1310.3687](#)] [[INSPIRE](#)].
- [17] CMS collaboration, *Search for the Standard Model Higgs boson produced through vector boson fusion and decaying to $b\bar{b}$* , *Phys. Rev. D* **92** (2015) 032008 [[arXiv:1506.01010](#)] [[INSPIRE](#)].
- [18] CMS collaboration, *Search for the associated production of the Higgs boson with a top-quark pair*, *JHEP* **09** (2014) 087 [Erratum *ibid.* **10** (2014) 106] [[arXiv:1408.1682](#)] [[INSPIRE](#)].
- [19] ATLAS collaboration, *Search for the Standard Model Higgs boson produced in association with top quarks and decaying into $b\bar{b}$ in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector*, *Eur. Phys. J. C* **75** (2015) 349 [[arXiv:1503.05066](#)] [[INSPIRE](#)].
- [20] ATLAS collaboration, *The ATLAS experiment at the CERN Large Hadron Collider*, **2008 JINST** **3** S08003 [[INSPIRE](#)].
- [21] ATLAS collaboration, *Performance of the ATLAS trigger system in 2010*, *Eur. Phys. J. C* **72** (2012) 1849 [[arXiv:1110.1530](#)] [[INSPIRE](#)].
- [22] P. Nason, *A new method for combining NLO QCD with shower Monte Carlo algorithms*, *JHEP* **11** (2004) 040 [[hep-ph/0409146](#)] [[INSPIRE](#)].
- [23] 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](#)] [[INSPIRE](#)].
- [24] 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](#)] [[INSPIRE](#)].
- [25] J. Alwall, R. Frederix, S. Frixione, V. Hirschi, F. Maltoni, O. Mattelaer 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](#)] [[INSPIRE](#)].
- [26] H.-L. Lai, M. Guzzi, J. Huston, Z. Li, P.M. Nadolsky, J. Pumplin et al., *New parton distributions for collider physics*, *Phys. Rev. D* **82** (2010) 074024 [[arXiv:1007.2241](#)] [[INSPIRE](#)].
- [27] T. Sjöstrand, S. Mrenna and P.Z. Skands, *A brief introduction to PYTHIA 8.1*, *Comput. Phys. Commun.* **178** (2008) 852 [[arXiv:0710.3820](#)] [[INSPIRE](#)].
- [28] ATLAS collaboration, *ATLAS tunes of PYTHIA 6 and PYTHIA 8 for MC11*, [ATL-PHYS-PUB-2011-009](#), CERN, Geneva Switzerland (2011).

- [29] ATLAS collaboration, *New ATLAS event generator tunes to 2010 data*, [ATL-PHYS-PUB-2011-008](#), CERN, Geneva Switzerland (2011).
- [30] LHC HIGGS CROSS SECTION WORKING GROUP collaboration, J.R. Andersen et al., *Handbook of LHC Higgs cross sections: 3. Higgs properties*, [arXiv:1307.1347](#) [INSPIRE].
- [31] S. Dittmaier et al., *Handbook of LHC Higgs cross sections: 2. Differential distributions*, [arXiv:1201.3084](#) [INSPIRE].
- [32] M. Ciccolini, A. Denner and S. Dittmaier, *Strong and electroweak NLO corrections to Higgs-boson production in vector-boson fusion at the LHC*, *Nucl. Phys. Proc. Suppl.* **183** (2008) 103 [[arXiv:0806.3624](#)] [INSPIRE].
- [33] M. Ciccolini, A. Denner and S. Dittmaier, *Electroweak and QCD corrections to Higgs production via vector-boson fusion at the LHC*, *Phys. Rev. D* **77** (2008) 013002 [[arXiv:0710.4749](#)] [INSPIRE].
- [34] D. de Florian, G. Ferrera, M. Grazzini and D. Tommasini, *Higgs boson production at the LHC: transverse momentum resummation effects in the $H \rightarrow \gamma\gamma$, $H \rightarrow WW \rightarrow \ell\nu\ell\nu$ and $H \rightarrow ZZ \rightarrow 4\ell$ decay modes*, *JHEP* **06** (2012) 132 [[arXiv:1203.6321](#)] [INSPIRE].
- [35] M. Grazzini and H. Sargsyan, *Heavy-quark mass effects in Higgs boson production at the LHC*, *JHEP* **09** (2013) 129 [[arXiv:1306.4581](#)] [INSPIRE].
- [36] J.M. Campbell, R.K. Ellis and G. Zanderighi, *Next-to-leading order Higgs + 2 jet production via gluon fusion*, *JHEP* **10** (2006) 028 [[hep-ph/0608194](#)] [INSPIRE].
- [37] ATLAS collaboration, *The ATLAS simulation infrastructure*, *Eur. Phys. J. C* **70** (2010) 823 [[arXiv:1005.4568](#)] [INSPIRE].
- [38] GEANT4 collaboration, S. Agostinelli et al., *GEANT4: a simulation toolkit*, *Nucl. Instrum. Meth. A* **506** (2003) 250 [INSPIRE].
- [39] ATLAS collaboration, *The simulation principle and performance of the ATLAS fast calorimeter simulation FastCaloSim*, [ATL-PHYS-PUB-2010-013](#), CERN, Geneva Switzerland (2010).
- [40] ATLAS collaboration, *Topological cell clustering in the ATLAS calorimeters and its performance in LHC Run 1*, [arXiv:1603.02934](#) [INSPIRE].
- [41] M. Cacciari, G.P. Salam and G. Soyez, *The anti- k_t jet clustering algorithm*, *JHEP* **04** (2008) 063 [[arXiv:0802.1189](#)] [INSPIRE].
- [42] M. Cacciari and G.P. Salam, *Pileup subtraction using jet areas*, *Phys. Lett. B* **659** (2008) 119 [[arXiv:0707.1378](#)] [INSPIRE].
- [43] ATLAS collaboration, *Jet energy measurement with the ATLAS detector in proton-proton collisions at $\sqrt{s} = 7$ TeV*, *Eur. Phys. J. C* **73** (2013) 2304 [[arXiv:1112.6426](#)] [INSPIRE].
- [44] ATLAS collaboration, *Jet energy measurement and its systematic uncertainty in proton-proton collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector*, *Eur. Phys. J. C* **75** (2015) 17 [[arXiv:1406.0076](#)] [INSPIRE].
- [45] ATLAS collaboration, *Tagging and suppression of pileup jets with the ATLAS detector*, [ATLAS-CONF-2014-018](#), CERN, Geneva Switzerland (2014).
- [46] ATLAS collaboration, *Performance of b-jet identification in the ATLAS experiment*, 2016 *JINST* **11** P04008 [[arXiv:1512.01094](#)] [INSPIRE].
- [47] A. Djouadi, J. Kalinowski and M. Spira, *HDECAY: a program for Higgs boson decays in the Standard Model and its supersymmetric extension*, *Comput. Phys. Commun.* **108** (1998) 56 [[hep-ph/9704448](#)] [INSPIRE].

- [48] ATLAS collaboration, *Measurement of the muon reconstruction performance of the ATLAS detector using 2011 and 2012 LHC proton-proton collision data*, *Eur. Phys. J. C* **74** (2014) 3130 [[arXiv:1407.3935](#)] [[INSPIRE](#)].
- [49] L. Breiman, J. Friedman, R.A. Olshen and C.J. Stone, *Classification and regression trees*, Chapman and Hall/CRC, U.K. and U.S.A. (1984) [[INSPIRE](#)].
- [50] Y. Freund and R.E. Schapire, *Experiments with a new boosting algorithm*, in *Machine Learning, Proceedings of the Thirteenth International Conference (ICML)*, Morgan Kaufmann, U.S.A. (1996).
- [51] A. Hocker et al., *TMVA — toolkit for multivariate data analysis*, *PoS(ACAT)040* [[physics/0703039](#)] [[INSPIRE](#)].
- [52] J.H. Friedman, *Data analysis techniques for high energy particle physics*, SLAC-0176, (1974) [[INSPIRE](#)].
- [53] B. Bernstein, *Démonstration du théorème de Weierstrass fondée sur le calcul des probabilités* (in French), *Comm. Soc. Math. Kharkov* **13** (1912) 1.
- [54] ATLAS collaboration, *Calibration of b-tagging using dileptonic top pair events in a combinatorial likelihood approach with the ATLAS experiment*, *ATLAS-CONF-2014-004*, CERN, Geneva Switzerland (2014).
- [55] ATLAS collaboration, *Luminosity determination in pp collisions at $\sqrt{s} = 8$ TeV using the ATLAS detector at the LHC*, [arXiv:1608.03953](#) [[INSPIRE](#)].
- [56] G. Corcella, I.G. Knowles, G. Marchesini, S. Moretti, K. Odagiri, P. Richardson et al., *HERWIG 6: an event generator for hadron emission reactions with interfering gluons (including supersymmetric processes)*, *JHEP* **01** (2001) 010 [[hep-ph/0011363](#)] [[INSPIRE](#)].
- [57] A. Sherstnev and R.S. Thorne, *Parton distributions for LO generators*, *Eur. Phys. J. C* **55** (2008) 553 [[arXiv:0711.2473](#)] [[INSPIRE](#)].
- [58] R.D. Ball et al., *Parton distributions with LHC data*, *Nucl. Phys. B* **867** (2013) 244 [[arXiv:1207.1303](#)] [[INSPIRE](#)].
- [59] L. Moneta, K. Belasco, K.S. Cranmer, S. Kreiss, A. Lazzaro, D. Piparo et al., *The RooStats project*, *PoS(ACAT2010)057* [[arXiv:1009.1003](#)] [[INSPIRE](#)].
- [60] W. Verkerke and D.P. Kirkby, *The RooFit toolkit for data modeling*, in *Statistical problems in particle physics, astrophysics and cosmology. Proceedings, Conference, PHYSTAT05*, Oxford U.K. September 12–15 2005 [*eConf C 0303241* (2003) MOLT007] [[physics/0306116](#)] [[INSPIRE](#)].
- [61] A.L. Read, *Presentation of search results: the CL_s technique*, *J. Phys. G* **28** (2002) 2693 [[INSPIRE](#)].
- [62] 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 [*Erratum ibid. C 73* (2013) 2501] [[arXiv:1007.1727](#)] [[INSPIRE](#)].
- [63] A.D. Bukin, *Fitting function for asymmetric peaks*, [arXiv:0711.4449](#).
- [64] ATLAS collaboration, *ATLAS computing acknowledgements 2016–2017*, *ATL-GEN-PUB-2016-002*, CERN, Geneva Switzerland (2016).

The ATLAS collaboration

M. Aaboud^{136d}, G. Aad⁸⁷, B. Abbott¹¹⁴, J. Abdallah⁶⁵, O. Abdinov¹², B. Abeloos¹¹⁸,
R. Aben¹⁰⁸, O.S. AbouZeid¹³⁸, N.L. Abraham¹⁵⁰, H. Abramowicz¹⁵⁴, H. Abreu¹⁵³, R. Abreu¹¹⁷,
Y. Abulaiti^{147a,147b}, B.S. Acharya^{164a,164b,a}, L. Adamczyk^{40a}, D.L. Adams²⁷, J. Adelman¹⁰⁹,
S. Adomeit¹⁰¹, T. Adye¹³², A.A. Affolder⁷⁶, T. Agatonovic-Jovin¹⁴, J. Agricola⁵⁶,
J.A. Aguilar-Saavedra^{127a,127f}, S.P. Ahlen²⁴, F. Ahmadov^{67,b}, G. Aielli^{134a,134b},
H. Akerstedt^{147a,147b}, T.P.A. Åkesson⁸³, A.V. Akimov⁹⁷, G.L. Alberghi^{22a,22b}, J. Albert¹⁶⁹,
S. Albrand⁵⁷, M.J. Alconada Verzini⁷³, M. Aleksa³², I.N. Aleksandrov⁶⁷, C. Alexa^{28b},
G. Alexander¹⁵⁴, T. Alexopoulos¹⁰, M. Alhroob¹¹⁴, M. Aliev^{75a,75b}, G. Alimonti^{93a}, J. Alison³³,
S.P. Alkire³⁷, B.M.M. Allbrooke¹⁵⁰, B.W. Allen¹¹⁷, P.P. Allport¹⁹, A. Aloisio^{105a,105b}, A. Alonso³⁸,
F. Alonso⁷³, C. Alpigiani¹³⁹, M. Alstaty⁸⁷, B. Alvarez Gonzalez³², D. Álvarez Piqueras¹⁶⁷,
M.G. Alvigi^{105a,105b}, B.T. Amadio¹⁶, K. Amako⁶⁸, Y. Amaral Coutinho^{26a}, C. Amelung²⁵,
D. Amidei⁹¹, S.P. Amor Dos Santos^{127a,127c}, A. Amorim^{127a,127b}, S. Amoroso³², G. Amundsen²⁵,
C. Anastopoulos¹⁴⁰, L.S. Ancu⁵¹, N. Andari¹⁰⁹, T. Andeen¹¹, C.F. Anders^{60b}, G. Anders³²,
J.K. Anders⁷⁶, K.J. Anderson³³, A. Andreazza^{93a,93b}, V. Andrei^{60a}, S. Angelidakis⁹,
I. Angelozzi¹⁰⁸, P. Anger⁴⁶, A. Angerami³⁷, F. Anghinolfi³², A.V. Anisenkov^{110,c}, N. Anjos¹³,
A. Annovi^{125a,125b}, M. Antonelli⁴⁹, A. Antonov⁹⁹, F. Anulli^{133a}, M. Aoki⁶⁸, L. Aperio Bella¹⁹,
G. Arabidze⁹², Y. Arai⁶⁸, J.P. Araque^{127a}, A.T.H. Arce⁴⁷, F.A. Arduh⁷³, J-F. Arguin⁹⁶,
S. Argyropoulos⁶⁵, M. Arik^{20a}, A.J. Armbruster¹⁴⁴, L.J. Armitage⁷⁸, O. Arnaez³², H. Arnold⁵⁰,
M. Arratia³⁰, O. Arslan²³, A. Artamonov⁹⁸, G. Artoni¹²¹, S. Artz⁸⁵, S. Asai¹⁵⁶, N. Asbah⁴⁴,
A. Ashkenazi¹⁵⁴, B. Åsman^{147a,147b}, L. Asquith¹⁵⁰, K. Assamagan²⁷, R. Astalos^{145a},
M. Atkinson¹⁶⁶, N.B. Atlay¹⁴², K. Augsten¹²⁹, G. Avolio³², B. Axen¹⁶, M.K. Ayoub¹¹⁸,
G. Azuelos^{96,d}, M.A. Baak³², A.E. Baas^{60a}, M.J. Baca¹⁹, H. Bachacou¹³⁷, K. Bachas^{75a,75b},
M. Backes³², M. Backhaus³², P. Bagiachi^{133a,133b}, P. Bagnaia^{133a,133b}, Y. Bai^{35a}, J.T. Baines¹³²,
O.K. Baker¹⁷⁶, E.M. Baldin^{110,c}, P. Balek¹³⁰, T. Balestri¹⁴⁹, F. Balli¹³⁷, W.K. Balunas¹²³,
E. Banas⁴¹, Sw. Banerjee^{173,e}, A.A.E. Bannoura¹⁷⁵, L. Barak³², E.L. Barberio⁹⁰,
D. Barberis^{52a,52b}, M. Barbero⁸⁷, T. Barillari¹⁰², T. Barklow¹⁴⁴, N. Barlow³⁰, S.L. Barnes⁸⁶,
B.M. Barnett¹³², R.M. Barnett¹⁶, Z. Barnovska⁵, A. Baroncelli^{135a}, G. Barone²⁵, A.J. Barr¹²¹,
L. Barranco Navarro¹⁶⁷, F. Barreiro⁸⁴, J. Barreiro Guimarães da Costa^{35a}, R. Bartoldus¹⁴⁴,
A.E. Barton⁷⁴, P. Bartos^{145a}, A. Basalae¹²⁴, A. Bassalat¹¹⁸, R.L. Bates⁵⁵, S.J. Batista¹⁵⁹,
J.R. Batley³⁰, M. Battaglia¹³⁸, M. Bauge^{133a,133b}, F. Bauer¹³⁷, H.S. Bawa^{144,f}, J.B. Beacham¹¹²,
M.D. Beattie⁷⁴, T. Beau⁸², P.H. Beauchemin¹⁶², P. Bechtel²³, H.P. Beck^{18,g}, K. Becker¹²¹,
M. Becker⁸⁵, M. Beckingham¹⁷⁰, C. Becot¹¹¹, A.J. Beddall^{20e}, A. Beddall^{20b}, V.A. Bednyakov⁶⁷,
M. Bedognetti¹⁰⁸, C.P. Bee¹⁴⁹, L.J. Beemster¹⁰⁸, T.A. Beermann³², M. Begel²⁷, J.K. Behr⁴⁴,
C. Belanger-Champagne⁸⁹, A.S. Bell⁸⁰, G. Bella¹⁵⁴, L. Bellagamba^{22a}, A. Bellerive³¹,
M. Bellomo⁸⁸, K. Belotskiy⁹⁹, O. Beltramello³², N.L. Belyaev⁹⁹, O. Benary¹⁵⁴,
D. Bencheikroun^{136a}, M. Bender¹⁰¹, K. Bendtz^{147a,147b}, N. Benekos¹⁰, Y. Benhammou¹⁵⁴,
E. Benhar Nocchioli¹⁷⁶, J. Benitez⁶⁵, D.P. Benjamin⁴⁷, J.R. Bensinger²⁵, S. Bentvelsen¹⁰⁸,
L. Beresford¹²¹, M. Beretta⁴⁹, D. Berge¹⁰⁸, E. Bergeaas Kuutmann¹⁶⁵, N. Berger⁵, J. Beringer¹⁶,
S. Berlendis⁵⁷, N.R. Bernard⁸⁸, C. Bernius¹¹¹, F.U. Bernlochner²³, T. Berry⁷⁹, P. Berta¹³⁰,
C. Bertella⁸⁵, G. Bertoli^{147a,147b}, F. Bertolucci^{125a,125b}, I.A. Bertram⁷⁴, C. Bertsche⁴⁴,
D. Bertsche¹¹⁴, G.J. Besjes³⁸, O. Bessidskaia Bylund^{147a,147b}, M. Bessner⁴⁴, N. Besson¹³⁷,
C. Betancourt⁵⁰, S. Bethke¹⁰², A.J. Bevan⁷⁸, W. Bhimji¹⁶, R.M. Bianchi¹²⁶, L. Bianchini²⁵,
M. Bianco³², O. Biebel¹⁰¹, D. Biedermann¹⁷, R. Bielski⁸⁶, N.V. Biesuz^{125a,125b}, M. Biglietti^{135a},
J. Bilbao De Mendizabal⁵¹, H. Bilokon⁴⁹, M. Bindi⁵⁶, S. Binet¹¹⁸, A. Bingul^{20b}, C. Bini^{133a,133b},
S. Biondi^{22a,22b}, D.M. Bjergaard⁴⁷, C.W. Black¹⁵¹, J.E. Black¹⁴⁴, K.M. Black²⁴, D. Blackburn¹³⁹,
R.E. Blair⁶, J.-B. Blanchard¹³⁷, J.E. Blanco⁷⁹, T. Blazek^{145a}, I. Bloch⁴⁴, C. Blocker²⁵,

W. Blum^{85,*}, U. Blumenschein⁵⁶, S. Blunier^{34a}, G.J. Bobbink¹⁰⁸, V.S. Bobrovnikov^{110,c},
 S.S. Bocchetta⁸³, A. Bocci⁴⁷, C. Bock¹⁰¹, M. Boehler⁵⁰, D. Boerner¹⁷⁵, J.A. Bogaerts³²,
 D. Bogavac¹⁴, A.G. Bogdanchikov¹¹⁰, C. Boehm^{147a}, V. Boisvert⁷⁹, P. Bokan¹⁴, T. Bold^{40a},
 A.S. Boldyrev^{164a,164c}, M. Bomben⁸², M. Bona⁷⁸, M. Boonekamp¹³⁷, A. Borisov¹³¹, G. Borissov⁷⁴,
 J. Bortfeldt¹⁰¹, D. Bortoletto¹²¹, V. Bortolotto^{62a,62b,62c}, K. Bos¹⁰⁸, D. Boscherini^{22a},
 M. Bosman¹³, J.D. Bossio Sola²⁹, J. Boudreau¹²⁶, J. Bouffard², E.V. Bouhova-Thacker⁷⁴,
 D. Boumediene³⁶, C. Bourdarios¹¹⁸, S.K. Boutle⁵⁵, A. Boveia³², J. Boyd³², I.R. Boyko⁶⁷,
 J. Bracinik¹⁹, A. Brandt⁸, G. Brandt⁵⁶, O. Brandt^{60a}, U. Bratzler¹⁵⁷, B. Brau⁸⁸, J.E. Brau¹¹⁷,
 H.M. Braun^{175,*}, W.D. Breaden Madden⁵⁵, K. Brendlinger¹²³, A.J. Brennan⁹⁰, L. Brenner¹⁰⁸,
 R. Brenner¹⁶⁵, S. Bressler¹⁷², T.M. Bristow⁴⁸, D. Britton⁵⁵, D. Britzger⁴⁴, F.M. Brochu³⁰,
 I. Brock²³, R. Brock⁹², G. Brooijmans³⁷, T. Brooks⁷⁹, W.K. Brooks^{34b}, J. Brosamer¹⁶,
 E. Brost¹¹⁷, J.H. Broughton¹⁹, P.A. Bruckman de Renstrom⁴¹, D. Bruncko^{145b}, R. Bruneliere⁵⁰,
 A. Bruni^{22a}, G. Bruni^{22a}, B.H. Brunt³⁰, M. Bruschi^{22a}, N. Bruscinio²³, P. Bryant³³,
 L. Bryngemark⁸³, T. Buanes¹⁵, Q. Buat¹⁴³, P. Buchholz¹⁴², A.G. Buckley⁵⁵, I.A. Budagov⁶⁷,
 F. Buehrer⁵⁰, M.K. Bugge¹²⁰, O. Bulekov⁹⁹, D. Bullock⁸, H. Burckhart³², S. Burdin⁷⁶,
 C.D. Burgard⁵⁰, B. Burghgrave¹⁰⁹, K. Burka⁴¹, S. Burke¹³², I. Burmeister⁴⁵, E. Busato³⁶,
 D. Büscher⁵⁰, V. Büscher⁸⁵, P. Bussey⁵⁵, J.M. Butler²⁴, C.M. Buttar⁵⁵, J.M. Butterworth⁸⁰,
 P. Butti¹⁰⁸, W. Buttinger²⁷, A. Buzatu⁵⁵, A.R. Buzykaev^{110,c}, S. Cabrera Urbán¹⁶⁷,
 D. Caforio¹²⁹, V.M. Cairo^{39a,39b}, O. Cakir^{4a}, N. Calace⁵¹, P. Calafiura¹⁶, A. Calandri⁸⁷,
 G. Calderini⁸², P. Calfayan¹⁰¹, L.P. Caloba^{26a}, D. Calvet³⁶, S. Calvet³⁶, T.P. Calvet⁸⁷,
 R. Camacho Toro³³, S. Camarda³², P. Camarri^{134a,134b}, D. Cameron¹²⁰,
 R. Caminal Armadans¹⁶⁶, C. Camincher⁵⁷, S. Campana³², M. Campanelli⁸⁰, A. Camplani^{93a,93b},
 A. Campoverde¹⁴⁹, V. Canale^{105a,105b}, A. Canepa^{160a}, M. Cano Bret^{35e}, J. Cantero¹¹⁵,
 R. Cantrill^{127a}, T. Cao⁴², M.D.M. Capeans Garrido³², I. Caprini^{28b}, M. Caprini^{28b},
 M. Capua^{39a,39b}, R. Caputo⁸⁵, R.M. Carbone³⁷, R. Cardarelli^{134a}, F. Cardillo⁵⁰, I. Carli¹³⁰,
 T. Carli³², G. Carlino^{105a}, L. Carminati^{93a,93b}, S. Caron¹⁰⁷, E. Carquin^{34b},
 G.D. Carrillo-Montoya³², J.R. Carter³⁰, J. Carvalho^{127a,127c}, D. Casadei¹⁹, M.P. Casado^{13,h},
 M. Casolino¹³, D.W. Casper¹⁶³, E. Castaneda-Miranda^{146a}, R. Castelijns¹⁰⁸, A. Castelli¹⁰⁸,
 V. Castillo Gimenez¹⁶⁷, N.F. Castro^{127a,i}, A. Catinaccio³², J.R. Catmore¹²⁰, A. Cattai³²,
 J. Caudron⁸⁵, V. Cavaliere¹⁶⁶, E. Cavallaro¹³, D. Cavalli^{93a}, M. Cavalli-Sforza¹³,
 V. Cavasinni^{125a,125b}, F. Ceradini^{135a,135b}, L. Cerda Alberich¹⁶⁷, B.C. Cerio⁴⁷, A.S. Cerqueira^{26b},
 A. Cerri¹⁵⁰, L. Cerrito⁷⁸, F. Cerutti¹⁶, M. Cerv³², A. Cervelli¹⁸, S.A. Cetin^{20d}, A. Chafaq^{136a},
 D. Chakraborty¹⁰⁹, S.K. Chan⁵⁹, Y.L. Chan^{62a}, P. Chang¹⁶⁶, J.D. Chapman³⁰, D.G. Charlton¹⁹,
 A. Chatterjee⁵¹, C.C. Chau¹⁵⁹, C.A. Chavez Barajas¹⁵⁰, S. Che¹¹², S. Cheatham⁷⁴,
 A. Chegwiddden⁹², S. Chekanov⁶, S.V. Chekulaev^{160a}, G.A. Chelkov^{67,j}, M.A. Chelstowska⁹¹,
 C. Chen⁶⁶, H. Chen²⁷, K. Chen¹⁴⁹, S. Chen^{35c}, S. Chen¹⁵⁶, X. Chen^{35f}, Y. Chen⁶⁹, H.C. Cheng⁹¹,
 H.J. Cheng^{35a}, Y. Cheng³³, A. Cheplakov⁶⁷, E. Cheremushkina¹³¹, R. Cherkaoui El Moursli^{136e},
 V. Chernyatin^{27,*}, E. Cheu⁷, L. Chevalier¹³⁷, V. Chiarella⁴⁹, G. Chiarelli^{125a,125b}, G. Chiodini^{75a},
 A.S. Chisholm¹⁹, A. Chitan^{28b}, M.V. Chizhov⁶⁷, K. Choi⁶³, A.R. Chomont³⁶, S. Chouridou⁹,
 B.K.B. Chow¹⁰¹, V. Christodoulou⁸⁰, D. Chromek-Burckhart³², J. Chudoba¹²⁸, A.J. Chuinard⁸⁹,
 J.J. Chwastowski⁴¹, L. Chytka¹¹⁶, G. Ciapetti^{133a,133b}, A.K. Ciftci^{4a}, D. Cinca⁵⁵, V. Cindro⁷⁷,
 I.A. Cioara²³, A. Ciocio¹⁶, F. Ciotto^{105a,105b}, Z.H. Citron¹⁷², M. Citterio^{93a}, M. Ciubancan^{28b},
 A. Clark⁵¹, B.L. Clark⁵⁹, M.R. Clark³⁷, P.J. Clark⁴⁸, R.N. Clarke¹⁶, C. Clement^{147a,147b},
 Y. Coadou⁸⁷, M. Cokal^{164a,164c}, A. Coccaro⁵¹, J. Cochran⁶⁶, L. Coffey²⁵, L. Colasurdo¹⁰⁷,
 B. Cole³⁷, A.P. Colijn¹⁰⁸, J. Collot⁵⁷, T. Colombo³², G. Compostella¹⁰², P. Conde Muiño^{127a,127b},
 E. Coniavitis⁵⁰, S.H. Connell^{146b}, I.A. Connelly⁷⁹, V. Consorti⁵⁰, S. Constantinescu^{28b},
 G. Conti³², F. Conventi^{105a,k}, M. Cooke¹⁶, B.D. Cooper⁸⁰, A.M. Cooper-Sarkar¹²¹,
 K.J.R. Cormier¹⁵⁹, T. Cornelissen¹⁷⁵, M. Corradi^{133a,133b}, F. Corriveau^{89,l}, A. Corso-Radu¹⁶³,

A. Cortes-Gonzalez¹³, G. Cortiana¹⁰², G. Costa^{93a}, M.J. Costa¹⁶⁷, D. Costanzo¹⁴⁰, G. Cottin³⁰,
 G. Cowan⁷⁹, B.E. Cox⁸⁶, K. Cranmer¹¹¹, S.J. Crawley⁵⁵, G. Cree³¹, S. Crépé-Renaudin⁵⁷,
 F. Crescioli⁸², W.A. Cribbs^{147a,147b}, M. Crispin Ortuzar¹²¹, M. Cristinziani²³, V. Croft¹⁰⁷,
 G. Crosetti^{39a,39b}, T. Cuhadar Donszelmann¹⁴⁰, J. Cummings¹⁷⁶, M. Curatolo⁴⁹, J. Cúth⁸⁵,
 C. Cuthbert¹⁵¹, H. Czirr¹⁴², P. Czodrowski³, G. D'amen^{22a,22b}, S. D'Auria⁵⁵, M. D'Onofrio⁷⁶,
 M.J. Da Cunha Sargedas De Sousa^{127a,127b}, C. Da Via⁸⁶, W. Dabrowski^{40a}, T. Dado^{145a},
 T. Dai⁹¹, O. Dale¹⁵, F. Dallaire⁹⁶, C. Dallapiccola⁸⁸, M. Dam³⁸, J.R. Dandoy³³, N.P. Dang⁵⁰,
 A.C. Daniells¹⁹, N.S. Dann⁸⁶, M. Danninger¹⁶⁸, M. Dano Hoffmann¹³⁷, V. Dao⁵⁰, G. Darbo^{52a},
 S. Darmora⁸, J. Dassoulas³, A. Dattagupta⁶³, W. Davey²³, C. David¹⁶⁹, T. Davidek¹³⁰,
 M. Davies¹⁵⁴, P. Davison⁸⁰, E. Dawe⁹⁰, I. Dawson¹⁴⁰, R.K. Daya-Ishmukhametova⁸⁸, K. De⁸,
 R. de Asmundis^{105a}, A. De Benedetti¹¹⁴, S. De Castro^{22a,22b}, S. De Cecco⁸², N. De Groot¹⁰⁷,
 P. de Jong¹⁰⁸, H. De la Torre⁸⁴, F. De Lorenzi⁶⁶, A. De Maria⁵⁶, D. De Pedis^{133a}, A. De Salvo^{133a},
 U. De Sanctis¹⁵⁰, A. De Santo¹⁵⁰, J.B. De Vivie De Regie¹¹⁸, W.J. Dearnaley⁷⁴, R. Debbe²⁷,
 C. Debenedetti¹³⁸, D.V. Dedovich⁶⁷, N. Dehghanian³, I. Deigaard¹⁰⁸, M. Del Gaudio^{39a,39b},
 J. Del Peso⁸⁴, T. Del Prete^{125a,125b}, D. Delgove¹¹⁸, F. Deliot¹³⁷, C.M. Delitzsch⁵¹,
 M. Deliyergiyev⁷⁷, A. Dell'Acqua³², L. Dell'Asta²⁴, M. Dell'Orso^{125a,125b}, M. Della Pietra^{105a,k},
 D. della Volpe⁵¹, M. Delmastro⁵, P.A. Delsart⁵⁷, C. Deluca¹⁰⁸, D.A. DeMarco¹⁵⁹, S. Demers¹⁷⁶,
 M. Demichev⁶⁷, A. Demilly⁸², S.P. Denisov¹³¹, D. Denysiuk¹³⁷, D. Derendarz⁴¹, J.E. Derkaoui^{136d},
 F. Derue⁸², P. Dervan⁷⁶, K. Desch²³, C. Deterre⁴⁴, K. Dette⁴⁵, P.O. Deviveiros³², A. Dewhurst¹³²,
 S. Dhaliwal²⁵, A. Di Ciaccio^{134a,134b}, L. Di Ciaccio⁵, W.K. Di Clemente¹²³, C. Di Donato^{133a,133b},
 A. Di Girolamo³², B. Di Girolamo³², B. Di Micco^{135a,135b}, R. Di Nardo³², A. Di Simone⁵⁰,
 R. Di Sipio¹⁵⁹, D. Di Valentino³¹, C. Diaconu⁸⁷, M. Diamond¹⁵⁹, F.A. Dias⁴⁸, M.A. Diaz^{34a},
 E.B. Diehl⁹¹, J. Dietrich¹⁷, S. Diglio⁸⁷, A. Dimitrievska¹⁴, J. Dingfelder²³, P. Dita^{28b}, S. Dita^{28b},
 F. Dittus³², F. Djama⁸⁷, T. Djobava^{53b}, J.I. Djuvsland^{60a}, M.A.B. do Vale^{26c}, D. Dobos³²,
 M. Dobre^{28b}, C. Doglioni⁸³, T. Dohmae¹⁵⁶, J. Dolejsi¹³⁰, Z. Dolezal¹³⁰, B.A. Dolgoshein^{99,*},
 M. Donadelli^{26d}, S. Donati^{125a,125b}, P. Dondero^{122a,122b}, J. Donini³⁶, J. Dopke¹³², A. Doria^{105a},
 M.T. Dova⁷³, A.T. Doyle⁵⁵, E. Drechsler⁵⁶, M. Dris¹⁰, Y. Du^{35d}, J. Duarte-Campderros¹⁵⁴,
 E. Duchovni¹⁷², G. Duckeck¹⁰¹, O.A. Ducu^{96,m}, D. Duda¹⁰⁸, A. Dudarev³², E.M. Duffield¹⁶,
 L. Dufflot¹¹⁸, L. Duguid⁷⁹, M. Dührssen³², M. Dumancic¹⁷², M. Dunford^{60a}, H. Duran Yildiz^{4a},
 M. Düren⁵⁴, A. Durglishvili^{53b}, D. Duschinger⁴⁶, B. Dutta⁴⁴, M. Dyndal⁴⁴, C. Eckardt⁴⁴,
 K.M. Ecker¹⁰², R.C. Edgar⁹¹, N.C. Edwards⁴⁸, T. Eifert³², G. Eigen¹⁵, K. Einsweiler¹⁶,
 T. Ekelof¹⁶⁵, M. El Kacimi^{136c}, V. Ellajosyula⁸⁷, M. Ellert¹⁶⁵, S. Elles⁵, F. Ellinghaus¹⁷⁵,
 A.A. Elliot¹⁶⁹, N. Ellis³², J. Elmsheuser²⁷, M. Elsing³², D. Emeliyanov¹³², Y. Enari¹⁵⁶,
 O.C. Endner⁸⁵, M. Endo¹¹⁹, J.S. Ennis¹⁷⁰, J. Erdmann⁴⁵, A. Ereditato¹⁸, G. Ernis¹⁷⁵, J. Ernst²,
 M. Ernst²⁷, S. Errede¹⁶⁶, E. Ertel⁸⁵, M. Escalier¹¹⁸, H. Esch⁴⁵, C. Escobar¹²⁶, B. Esposito⁴⁹,
 A.I. Etiennevire¹³⁷, E. Etzion¹⁵⁴, H. Evans⁶³, A. Ezhilov¹²⁴, F. Fabbri^{22a,22b}, L. Fabbri^{22a,22b},
 G. Facini³³, R.M. Fakhrutdinov¹³¹, S. Falciano^{133a}, R.J. Falla⁸⁰, J. Faltova¹³⁰, Y. Fang^{35a},
 M. Fantì^{93a,93b}, A. Farbin⁸, A. Farilla^{135a}, C. Farina¹²⁶, T. Farooque¹³, S. Farrell¹⁶,
 S.M. Farrington¹⁷⁰, P. Farthouat³², F. Fassi^{136e}, P. Fassnacht³², D. Fassouliotis⁹,
 M. Fauci Giannelli⁷⁹, A. Favareto^{52a,52b}, W.J. Fawcett¹²¹, L. Fayard¹¹⁸, O.L. Fedin^{124,n},
 W. Fedorko¹⁶⁸, S. Feigl¹²⁰, L. Feligioni⁸⁷, C. Feng^{35d}, E.J. Feng³², H. Feng⁹¹, A.B. Fenyuk¹³¹,
 L. Feremenga⁸, P. Fernandez Martinez¹⁶⁷, S. Fernandez Perez¹³, J. Ferrando⁵⁵, A. Ferrari¹⁶⁵,
 P. Ferrari¹⁰⁸, R. Ferrari^{122a}, D.E. Ferreira de Lima^{60b}, A. Ferrer¹⁶⁷, D. Ferrere⁵¹, C. Ferretti⁹¹,
 A. Ferretto Parodi^{52a,52b}, F. Fiedler⁸⁵, A. Filipčić⁷⁷, M. Filipuzzi⁴⁴, F. Filthaut¹⁰⁷,
 M. Fincke-Keeler¹⁶⁹, K.D. Finelli¹⁵¹, M.C.N. Fiolhais^{127a,127c}, L. Fiorini¹⁶⁷, A. Firan⁴²,
 A. Fischer², C. Fischer¹³, J. Fischer¹⁷⁵, W.C. Fisher⁹², N. Flaschel⁴⁴, I. Fleck¹⁴²,
 P. Fleischmann⁹¹, G.T. Fletcher¹⁴⁰, R.R.M. Fletcher¹²³, T. Flick¹⁷⁵, A. Floderus⁸³,
 L.R. Flores Castillo^{62a}, M.J. Flowerdew¹⁰², G.T. Forcolin⁸⁶, A. Formica¹³⁷, A. Forti⁸⁶,

A.G. Foster¹⁹, D. Fournier¹¹⁸, H. Fox⁷⁴, S. Fracchia¹³, P. Francavilla⁸², M. Franchini^{22a,22b},
 D. Francis³², L. Franconi¹²⁰, M. Franklin⁵⁹, M. Frate¹⁶³, M. Fraternali^{122a,122b}, D. Freeborn⁸⁰,
 S.M. Fressard-Batranceanu³², F. Friedrich⁴⁶, D. Froidevaux³², J.A. Frost¹²¹, C. Fukunaga¹⁵⁷,
 E. Fullana Torregrosa⁸⁵, T. Fusayasu¹⁰³, J. Fuster¹⁶⁷, C. Gabaldon⁵⁷, O. Gabizon¹⁷⁵,
 A. Gabrielli^{22a,22b}, A. Gabrielli¹⁶, G.P. Gach^{40a}, S. Gadatsch³², S. Gadomski⁵¹,
 G. Gagliardi^{52a,52b}, L.G. Gagnon⁹⁶, P. Gagnon⁶³, C. Galea¹⁰⁷, B. Galhardo^{127a,127c},
 E.J. Gallas¹²¹, B.J. Gallop¹³², P. Gallus¹²⁹, G. Galster³⁸, K.K. Gan¹¹², J. Gao^{35b,87}, Y. Gao⁴⁸,
 Y.S. Gao^{144,f}, F.M. Garay Walls⁴⁸, C. García¹⁶⁷, J.E. García Navarro¹⁶⁷, M. Garcia-Sciveres¹⁶,
 R.W. Gardner³³, N. Garelli¹⁴⁴, V. Garonne¹²⁰, A. Gascon Bravo⁴⁴, C. Gatti⁴⁹,
 A. Gaudiello^{52a,52b}, G. Gaudio^{122a}, B. Gaur¹⁴², L. Gauthier⁹⁶, I.L. Gavrilenko⁹⁷, C. Gay¹⁶⁸,
 G. Gaycken²³, E.N. Gazis¹⁰, Z. Gecse¹⁶⁸, C.N.P. Gee¹³², Ch. Geich-Gimbel²³, M. Geisen⁸⁵,
 M.P. Geisler^{60a}, C. Gemme^{52a}, M.H. Genest⁵⁷, C. Geng^{35b,o}, S. Gentile^{133a,133b}, S. George⁷⁹,
 D. Gerbaudo¹³, A. Gershon¹⁵⁴, S. Ghasemi¹⁴², H. Ghazlane^{136b}, M. Ghneimat²³, B. Giacobbe^{22a},
 S. Giagu^{133a,133b}, P. Giannetti^{125a,125b}, B. Gibbard²⁷, S.M. Gibson⁷⁹, M. Gignac¹⁶⁸,
 M. Gilchriese¹⁶, T.P.S. Gillam³⁰, D. Gillberg³¹, G. Gilles¹⁷⁵, D.M. Gingrich^{3,d}, N. Giokaris⁹,
 M.P. Giordani^{164a,164c}, F.M. Giorgi^{22a}, F.M. Giorgi¹⁷, P.F. Giraud¹³⁷, P. Giromini⁵⁹,
 D. Giugni^{93a}, F. Giuli¹²¹, C. Giuliani¹⁰², M. Giulini^{60b}, B.K. Gjelsten¹²⁰, S. Gkaitatzis¹⁵⁵,
 I. Gkialas¹⁵⁵, E.L. Gkoukousis¹¹⁸, L.K. Gladilin¹⁰⁰, C. Glasman⁸⁴, J. Glatzer³²,
 P.C.F. Glaysher⁴⁸, A. Glazov⁴⁴, M. Goblirsch-Kolb¹⁰², J. Godlewski⁴¹, S. Goldfarb⁹¹,
 T. Golling⁵¹, D. Golubkov¹³¹, A. Gomes^{127a,127b,127d}, R. Gonçalo^{127a},
 J. Goncalves Pinto Firmino Da Costa¹³⁷, L. Gonella¹⁹, A. Gongadze⁶⁷, S. González de la Hoz¹⁶⁷,
 G. Gonzalez Parra¹³, S. Gonzalez-Sevilla⁵¹, L. Goossens³², P.A. Gorbounov⁹⁸, H.A. Gordon²⁷,
 I. Gorelov¹⁰⁶, B. Gorini³², E. Gorini^{75a,75b}, A. Gorišek⁷⁷, E. Gornicki⁴¹, A.T. Goshaw⁴⁷,
 C. Gössling⁴⁵, M.I. Gostkin⁶⁷, C.R. Goudet¹¹⁸, D. Goujdami^{136c}, A.G. Goussiou¹³⁹,
 N. Govender^{146b,p}, E. Gozani¹⁵³, L. Graber⁵⁶, I. Grabowska-Bold^{40a}, P.O.J. Gradin⁵⁷,
 P. Grafström^{22a,22b}, J. Gramling⁵¹, E. Gramstad¹²⁰, S. Grancagnolo¹⁷, V. Gratchev¹²⁴,
 P.M. Gravila^{28e}, H.M. Gray³², E. Graziani^{135a}, Z.D. Greenwood^{81,q}, C. Grefe²³, K. Gregersen⁸⁰,
 I.M. Gregor⁴⁴, P. Grenier¹⁴⁴, K. Grevtsov⁵, J. Griffiths⁸, A.A. Grillo¹³⁸, K. Grimm⁷⁴,
 S. Grinstein^{13,r}, Ph. Gris³⁶, J.-F. Grivaz¹¹⁸, S. Groh⁸⁵, J.P. Grohs⁴⁶, E. Gross¹⁷²,
 J. Grosse-Knetter⁵⁶, G.C. Grossi⁸¹, Z.J. Grout¹⁵⁰, L. Guan⁹¹, W. Guan¹⁷³, J. Guenther¹²⁹,
 F. Guescini⁵¹, D. Guest¹⁶³, O. Gueta¹⁵⁴, E. Guido^{52a,52b}, T. Guillemain⁵, S. Guindon², U. Gul⁵⁵,
 C. Gumpert³², J. Guo^{35e}, Y. Guo^{35b,o}, S. Gupta¹²¹, G. Gustavino^{133a,133b}, P. Gutierrez¹¹⁴,
 N.G. Gutierrez Ortiz⁸⁰, C. Gutsche⁴⁶, C. Guyot¹³⁷, C. Gwenlan¹²¹, C.B. Gwilliam⁷⁶,
 A. Haas¹¹¹, C. Haber¹⁶, H.K. Hadavand⁸, N. Haddad^{136e}, A. Hadeef⁸⁷, P. Haefner²³,
 S. Hageböck²³, Z. Hajduk⁴¹, H. Hakobyan^{177,*}, M. Haleem⁴⁴, J. Haley¹¹⁵, G. Halladjian⁹²,
 G.D. Hallowell⁸⁷, K. Hamacher¹⁷⁵, P. Hamal¹¹⁶, K. Hamano¹⁶⁹, A. Hamilton^{146a}, G.N. Hamity¹⁴⁰,
 P.G. Hamnett⁴⁴, L. Han^{35b}, K. Hanagaki^{68,s}, K. Hanawa¹⁵⁶, M. Hance¹³⁸, B. Haney¹²³,
 P. Hanke^{60a}, R. Hanna¹³⁷, J.B. Hansen³⁸, J.D. Hansen³⁸, M.C. Hansen²³, P.H. Hansen³⁸,
 K. Hara¹⁶¹, A.S. Hard¹⁷³, T. Harenberg¹⁷⁵, F. Hariri¹¹⁸, S. Harkusha⁹⁴, R.D. Harrington⁴⁸,
 P.F. Harrison¹⁷⁰, F. Hartjes¹⁰⁸, N.M. Hartmann¹⁰¹, M. Hasegawa⁶⁹, Y. Hasegawa¹⁴¹, A. Hasib¹¹⁴,
 S. Hassani¹³⁷, S. Haug¹⁸, R. Hauser⁹², L. Hauswald⁴⁶, M. Havranek¹²⁸, C.M. Hawkes¹⁹,
 R.J. Hawkins³², D. Hayden⁹², C.P. Hays¹²¹, J.M. Hays⁷⁸, H.S. Hayward⁷⁶, S.J. Haywood¹³²,
 S.J. Head¹⁹, T. Heck⁸⁵, V. Hedberg⁸³, L. Heelan⁸, S. Heim¹²³, T. Heim¹⁶, B. Heinemann¹⁶,
 J.J. Heinrich¹⁰¹, L. Heinrich¹¹¹, C. Heinz⁵⁴, J. Hejbal¹²⁸, L. Helary²⁴, S. Hellman^{147a,147b},
 C. Helsen³², J. Henderson¹²¹, R.C.W. Henderson⁷⁴, Y. Heng¹⁷³, S. Henkelmann¹⁶⁸,
 A.M. Henriques Correia³², S. Henrot-Versille¹¹⁸, G.H. Herbert¹⁷, Y. Hernández Jiménez¹⁶⁷,
 G. Herten⁵⁰, R. Hertenberger¹⁰¹, L. Hervas³², G.G. Hesketh⁸⁰, N.P. Hessey¹⁰⁸, J.W. Hetherly⁴²,
 R. Hickling⁷⁸, E. Higón-Rodriguez¹⁶⁷, E. Hill¹⁶⁹, J.C. Hill³⁰, K.H. Hiller⁴⁴, S.J. Hillier¹⁹,

I. Hinchliffe¹⁶, E. Hines¹²³, R.R. Hinman¹⁶, M. Hirose¹⁵⁸, D. Hirschbuehl¹⁷⁵, J. Hobbs¹⁴⁹,
 N. Hod^{160a}, M.C. Hodgkinson¹⁴⁰, P. Hodgson¹⁴⁰, A. Hoecker³², M.R. Hoferkamp¹⁰⁶,
 F. Hoenig¹⁰¹, D. Hohn²³, T.R. Holmes¹⁶, M. Homann⁴⁵, T.M. Hong¹²⁶, B.H. Hooberman¹⁶⁶,
 W.H. Hopkins¹¹⁷, Y. Horii¹⁰⁴, A.J. Horton¹⁴³, J.-Y. Hostachy⁵⁷, S. Hou¹⁵², A. Hoummada^{136a},
 J. Howarth⁴⁴, M. Hrabovsky¹¹⁶, I. Hristova¹⁷, J. Hrivnac¹¹⁸, T. Hryn'ova⁵, A. Hrynevich⁹⁵,
 C. Hsu^{146c}, P.J. Hsu^{152,t}, S.-C. Hsu¹³⁹, D. Hu³⁷, Q. Hu^{35b}, Y. Huang⁴⁴, Z. Hubacek¹²⁹,
 F. Hubaut⁸⁷, F. Huegging²³, T.B. Huffman¹²¹, E.W. Hughes³⁷, G. Hughes⁷⁴, M. Huhtinen³²,
 T.A. Hülsing⁸⁵, P. Huo¹⁴⁹, N. Huseynov^{67,b}, J. Huston⁹², J. Huth⁵⁹, G. Iacobucci⁵¹,
 G. Iakovidis²⁷, I. Ibragimov¹⁴², L. Iconomidou-Fayard¹¹⁸, E. Ideal¹⁷⁶, Z. Idrissi^{136e}, P. Iengo³²,
 O. Igonkina^{108,u}, T. Iizawa¹⁷¹, Y. Ikegami⁶⁸, M. Ikeno⁶⁸, Y. Ilchenko^{11,v}, D. Iliadis¹⁵⁵, N. Ilic¹⁴⁴,
 T. Ince¹⁰², G. Introzzi^{122a,122b}, P. Ioannou^{9,*}, M. Iodice^{135a}, K. Iordanidou³⁷, V. Ippolito⁵⁹,
 M. Ishino⁷⁰, M. Ishitsuka¹⁵⁸, R. Ishmukhametov¹¹², C. Issever¹²¹, S. Istin^{20a}, F. Ito¹⁶¹,
 J.M. Iturbe Ponce⁸⁶, R. Iuppa^{134a,134b}, W. Iwanski⁴¹, H. Iwasaki⁶⁸, J.M. Izen⁴³, V. Izzo^{105a},
 S. Jabbar³, B. Jackson¹²³, M. Jackson⁷⁶, P. Jackson¹, V. Jain², K.B. Jakobi⁸⁵, K. Jakobs⁵⁰,
 S. Jakobsen³², T. Jakoubek¹²⁸, D.O. Jamin¹¹⁵, D.K. Jana⁸¹, E. Jansen⁸⁰, R. Jansky⁶⁴,
 J. Janssen²³, M. Janus⁵⁶, G. Jarlskog⁸³, N. Javadov^{67,b}, T. Javůrek⁵⁰, F. Jeanneau¹³⁷,
 L. Jeanty¹⁶, J. Jejelava^{53a,w}, G.-Y. Jeng¹⁵¹, D. Jennens⁹⁰, P. Jenni^{50,x}, J. Jentzsch⁴⁵, C. Jeske¹⁷⁰,
 S. Jézéquel⁵, H. Ji¹⁷³, J. Jia¹⁴⁹, H. Jiang⁶⁶, Y. Jiang^{35b}, S. Jiggins⁸⁰, J. Jimenez Pena¹⁶⁷,
 S. Jin^{35a}, A. Jinaru^{28b}, O. Jinnouchi¹⁵⁸, P. Johansson¹⁴⁰, K.A. Johns⁷, W.J. Johnson¹³⁹,
 K. Jon-And^{147a,147b}, G. Jones¹⁷⁰, R.W.L. Jones⁷⁴, S. Jones⁷, T.J. Jones⁷⁶, J. Jongmanns^{60a},
 P.M. Jorge^{127a,127b}, J. Jovicevic^{160a}, X. Ju¹⁷³, A. Juste Rozas^{13,r}, M.K. Köhler¹⁷²,
 A. Kaczmarek⁴¹, M. Kado¹¹⁸, H. Kagan¹¹², M. Kagan¹⁴⁴, S.J. Kahn⁸⁷, E. Kajomovitz⁴⁷,
 C.W. Kalderon¹²¹, A. Kaluza⁸⁵, S. Kama⁴², A. Kamenshchikov¹³¹, N. Kanaya¹⁵⁶, S. Kaneti³⁰,
 L. Kanjir⁷⁷, V.A. Kantserov⁹⁹, J. Kanzaki⁶⁸, B. Kaplan¹¹¹, L.S. Kaplan¹⁷³, A. Kapliy³³,
 D. Kar^{146c}, K. Karakostas¹⁰, A. Karamaoun³, N. Karastathis¹⁰, M.J. Kareem⁵⁶, E. Karentzos¹⁰,
 M. Karnevskiy⁸⁵, S.N. Karpov⁶⁷, Z.M. Karpova⁶⁷, K. Karthik¹¹¹, V. Kartvelishvili⁷⁴,
 A.N. Karyukhin¹³¹, K. Kasahara¹⁶¹, L. Kashif¹⁷³, R.D. Kass¹¹², A. Kastanas¹⁵, Y. Kataoka¹⁵⁶,
 C. Kato¹⁵⁶, A. Katre⁵¹, J. Katzy⁴⁴, K. Kawagoe⁷², T. Kawamoto¹⁵⁶, G. Kawamura⁵⁶,
 S. Kazama¹⁵⁶, V.F. Kazanin^{110,c}, R. Keeler¹⁶⁹, R. Kehoe⁴², J.S. Keller⁴⁴, J.J. Kempster⁷⁹,
 K. Kentaro¹⁰⁴, H. Keoshkerian¹⁵⁹, O. Kepka¹²⁸, B.P. Kerševan⁷⁷, S. Kersten¹⁷⁵, R.A. Keyes⁸⁹,
 F. Khalil-zada¹², A. Khanov¹¹⁵, A.G. Kharlamov^{110,c}, T.J. Khoo⁵¹, V. Khovanskiy⁹⁸,
 E. Khramov⁶⁷, J. Khubua^{53b,y}, S. Kido⁶⁹, H.Y. Kim⁸, S.H. Kim¹⁶¹, Y.K. Kim³³, N. Kimura¹⁵⁵,
 O.M. Kind¹⁷, B.T. King⁷⁶, M. King¹⁶⁷, S.B. King¹⁶⁸, J. Kirk¹³², A.E. Kiryunin¹⁰²,
 T. Kishimoto⁶⁹, D. Kisielewska^{40a}, F. Kiss⁵⁰, K. Kiuchi¹⁶¹, O. Kivernyk¹³⁷, E. Kladiva^{145b},
 M.H. Klein³⁷, M. Klein⁷⁶, U. Klein⁷⁶, K. Kleinknecht⁸⁵, P. Klimek^{147a,147b}, A. Klimentov²⁷,
 R. Klingenberg⁴⁵, J.A. Klinger¹⁴⁰, T. Klioutchnikova³², E.-E. Kluge^{60a}, P. Kluit¹⁰⁸, S. Kluth¹⁰²,
 J. Knapik⁴¹, E. Kneringer⁶⁴, E.B.F.G. Knoops⁸⁷, A. Knue⁵⁵, A. Kobayashi¹⁵⁶, D. Kobayashi¹⁵⁸,
 T. Kobayashi¹⁵⁶, M. Kobel⁴⁶, M. Kocian¹⁴⁴, P. Kodys¹³⁰, T. Koffas³¹, E. Koffeman¹⁰⁸, T. Koi¹⁴⁴,
 H. Kolanoski¹⁷, M. Kolb^{60b}, I. Koletsou⁵, A.A. Komar^{97,*}, Y. Komori¹⁵⁶, T. Kondo⁶⁸,
 N. Kondrashova⁴⁴, K. Köneke⁵⁰, A.C. König¹⁰⁷, T. Kono^{68,z}, R. Konoplich^{111,aa},
 N. Konstantinidis⁸⁰, R. Kopeliansky⁶³, S. Koperny^{40a}, L. Köpke⁸⁵, A.K. Kopp⁵⁰, K. Korcyl⁴¹,
 K. Kordas¹⁵⁵, A. Korn⁸⁰, A.A. Korol^{110,c}, I. Korolkov¹³, E.V. Korolkova¹⁴⁰, O. Kortner¹⁰²,
 S. Kortner¹⁰², T. Kosek¹³⁰, V.V. Kostyukhin²³, A. Kotwal⁴⁷, A. Kourkoumeli-Charalampidi¹⁵⁵,
 C. Kourkoumelis⁹, V. Kouskoura²⁷, A.B. Kowalewska⁴¹, R. Kowalewski¹⁶⁹, T.Z. Kowalski^{40a},
 C. Kozakai¹⁵⁶, W. Kozanecki¹³⁷, A.S. Kozhin¹³¹, V.A. Kramarenko¹⁰⁰, G. Kramberger⁷⁷,
 D. Krasnopevtsev⁹⁹, M.W. Krasny⁸², A. Krasznahorkay³², J.K. Kraus²³, A. Kravchenko²⁷,
 M. Kretz^{60c}, J. Kretzschmar⁷⁶, K. Kreutzfeldt⁵⁴, P. Krieger¹⁵⁹, K. Krizka³³, K. Kroeninger⁴⁵,
 H. Kroha¹⁰², J. Kroll¹²³, J. Kröseberg²³, J. Krstic¹⁴, U. Kruchonak⁶⁷, H. Krüger²³,

N. Krumnack⁶⁶, A. Kruse¹⁷³, M.C. Kruse⁴⁷, M. Kruskal²⁴, T. Kubota⁹⁰, H. Kucuk⁸⁰, S. Kuday^{4b}, J.T. Kuechler¹⁷⁵, S. Kuehn⁵⁰, A. Kugel^{60c}, F. Kuger¹⁷⁴, A. Kuhl¹³⁸, T. Kuhl⁴⁴, V. Kukhtin⁶⁷, R. Kukla¹³⁷, Y. Kulchitsky⁹⁴, S. Kuleshov^{34b}, M. Kuna^{133a,133b}, T. Kunigo⁷⁰, A. Kupco¹²⁸, H. Kurashige⁶⁹, Y.A. Kurochkin⁹⁴, V. Kus¹²⁸, E.S. Kuwertz¹⁶⁹, M. Kuze¹⁵⁸, J. Kvita¹¹⁶, T. Kwan¹⁶⁹, D. Kyriazopoulos¹⁴⁰, A. La Rosa¹⁰², J.L. La Rosa Navarro^{26d}, L. La Rotonda^{39a,39b}, C. Lacasta¹⁶⁷, F. Lacava^{133a,133b}, J. Lacey³¹, H. Lacker¹⁷, D. Lacour⁸², V.R. Lacuesta¹⁶⁷, E. Ladygin⁶⁷, R. Lafaye⁵, B. Laforge⁸², T. Lagouri¹⁷⁶, S. Lai⁵⁶, S. Lammers⁶³, W. Lampl⁷, E. Lançon¹³⁷, U. Landgraf⁵⁰, M.P.J. Landon⁷⁸, V.S. Lang^{60a}, J.C. Lange¹³, A.J. Lankford¹⁶³, F. Lanni²⁷, K. Lantzscht²³, A. Lanza^{122a}, S. Laplace⁸², C. Lapoire³², J.F. Laporte¹³⁷, T. Lari^{93a}, F. Lasagni Manghi^{22a,22b}, M. Lassnig³², P. Laurelli⁴⁹, W. Lavrijsen¹⁶, A.T. Law¹³⁸, P. Laycock⁷⁶, T. Lazovich⁵⁹, M. Lazzaroni^{93a,93b}, B. Le⁹⁰, O. Le Dortz⁸², E. Le Guirriec⁸⁷, E.P. Le Quilleuc¹³⁷, M. LeBlanc¹⁶⁹, T. LeCompte⁶, F. Ledroit-Guillon⁵⁷, C.A. Lee²⁷, S.C. Lee¹⁵², L. Lee¹, G. Lefebvre⁸², M. Lefebvre¹⁶⁹, F. Legger¹⁰¹, C. Leggett¹⁶, A. Lehan⁷⁶, G. Lehmann Miotto³², X. Lei⁷, W.A. Leight³¹, A. Leisos^{155,ab}, A.G. Leister¹⁷⁶, M.A.L. Leite^{26d}, R. Leitner¹³⁰, D. Lellouch¹⁷², B. Lemmer⁵⁶, K.J.C. Leney⁸⁰, T. Lenz²³, B. Lenzi³², R. Leone⁷, S. Leone^{125a,125b}, C. Leonidopoulos⁴⁸, S. Leontsinis¹⁰, G. Lerner¹⁵⁰, C. Leroy⁹⁶, A.A.J. Lesage¹³⁷, C.G. Lester³⁰, M. Levchenko¹²⁴, J. Levêque⁵, D. Levin⁹¹, L.J. Levinson¹⁷², M. Levy¹⁹, D. Lewis⁷⁸, A.M. Leyko²³, M. Leyton⁴³, B. Li^{35b,o}, H. Li¹⁴⁹, H.L. Li³³, L. Li⁴⁷, L. Li^{35e}, Q. Li^{35a}, S. Li⁴⁷, X. Li⁸⁶, Y. Li¹⁴², Z. Liang^{35a}, B. Liberti^{134a}, A. Liblong¹⁵⁹, P. Lichard³², K. Lie¹⁶⁶, J. Liebal²³, W. Liebig¹⁵, A. Limosani¹⁵¹, S.C. Lin^{152,ac}, T.H. Lin⁸⁵, B.E. Lindquist¹⁴⁹, A.E. Lioni⁵¹, E. Lipeles¹²³, A. Lipniacka¹⁵, M. Lisovyi^{60b}, T.M. Liss¹⁶⁶, A. Lister¹⁶⁸, A.M. Litke¹³⁸, B. Liu^{152,ad}, D. Liu¹⁵², H. Liu⁹¹, H. Liu²⁷, J. Liu⁸⁷, J.B. Liu^{35b}, K. Liu⁸⁷, L. Liu¹⁶⁶, M. Liu⁴⁷, M. Liu^{35b}, Y.L. Liu^{35b}, Y. Liu^{35b}, M. Livan^{122a,122b}, A. Lleres⁵⁷, J. Llorente Merino^{35a}, S.L. Lloyd⁷⁸, F. Lo Sterzo¹⁵², E. Lobodzinska⁴⁴, P. Loch⁷, W.S. Lockman¹³⁸, F.K. Loebinger⁸⁶, A.E. Loevschall-Jensen³⁸, K.M. Loew²⁵, A. Loginov¹⁷⁶, T. Lohse¹⁷, K. Lohwasser⁴⁴, M. Lokajicek¹²⁸, B.A. Long²⁴, J.D. Long¹⁶⁶, R.E. Long⁷⁴, L. Longo^{75a,75b}, K.A. Looper¹¹², L. Lopes^{127a}, D. Lopez Mateos⁵⁹, B. Lopez Paredes¹⁴⁰, I. Lopez Paz¹³, A. Lopez Solis⁸², J. Lorenz¹⁰¹, N. Lorenzo Martinez⁶³, M. Losada²¹, P.J. Lösel¹⁰¹, X. Lou^{35a}, A. Lounis¹¹⁸, J. Love⁶, P.A. Love⁷⁴, H. Lu^{62a}, N. Lu⁹¹, H.J. Lubatti¹³⁹, C. Luci^{133a,133b}, A. Lucotte⁵⁷, C. Luedtke⁵⁰, F. Luehring⁶³, W. Lukas⁶⁴, L. Luminari^{133a}, O. Lundberg^{147a,147b}, B. Lund-Jensen¹⁴⁸, P.M. Luzzi⁸², D. Lynn²⁷, R. Lysak¹²⁸, E. Lytken⁸³, V. Lyubushkin⁶⁷, H. Ma²⁷, L.L. Ma^{35d}, Y. Ma^{35d}, G. Maccarrone⁴⁹, A. Macchiolo¹⁰², C.M. Macdonald¹⁴⁰, B. Maček⁷⁷, J. Machado Miguens^{123,127b}, D. Madaffari⁸⁷, R. Madar³⁶, H.J. Maddocks¹⁶⁵, W.F. Mader⁴⁶, A. Madsen⁴⁴, J. Maeda⁶⁹, S. Maeland¹⁵, T. Maeno²⁷, A. Maevskiy¹⁰⁰, E. Magradze⁵⁶, J. Mahlstedt¹⁰⁸, C. Maiani¹¹⁸, C. Maidantchik^{26a}, A.A. Maier¹⁰², T. Maier¹⁰¹, A. Maio^{127a,127b,127d}, S. Majewski¹¹⁷, Y. Makida⁶⁸, N. Makovec¹¹⁸, B. Malaescu⁸², Pa. Malecki⁴¹, V.P. Maleev¹²⁴, F. Malek⁵⁷, U. Mallik⁶⁵, D. Malon⁶, C. Malone¹⁴⁴, S. Maltezos¹⁰, S. Malukov³², J. Mamuzic¹⁶⁷, G. Mancini⁴⁹, B. Mandelli³², L. Mandelli^{93a}, I. Mandić⁷⁷, J. Maneira^{127a,127b}, L. Manhaes de Andrade Filho^{26b}, J. Manjarres Ramos^{160b}, A. Mann¹⁰¹, A. Manousos³², B. Mansoulie¹³⁷, J.D. Mansour^{35a}, R. Mantifel⁸⁹, M. Mantoani⁵⁶, S. Manzoni^{93a,93b}, L. Mapelli³², G. Marceca²⁹, L. March⁵¹, G. Marchiori⁸², M. Marcisovsky¹²⁸, M. Marjanovic¹⁴, D.E. Marley⁹¹, F. Marroquim^{26a}, S.P. Marsden⁸⁶, Z. Marshall¹⁶, S. Marti-Garcia¹⁶⁷, B. Martin⁹², T.A. Martin¹⁷⁰, V.J. Martin⁴⁸, B. Martin dit Latour¹⁵, M. Martinez^{13,r}, S. Martin-Haugh¹³², V.S. Martoiu^{28b}, A.C. Martyniuk⁸⁰, M. Marx¹³⁹, A. Marzin³², L. Masetti⁸⁵, T. Mashimo¹⁵⁶, R. Mashinistov⁹⁷, J. Masik⁸⁶, A.L. Maslennikov^{110,c}, I. Massa^{22a,22b}, L. Massa^{22a,22b}, P. Mastrandrea⁵, A. Mastroberardino^{39a,39b}, T. Masubuchi¹⁵⁶, P. Mättig¹⁷⁵, J. Mattmann⁸⁵, J. Maurer^{28b}, S.J. Maxfield⁷⁶, D.A. Maximov^{110,c}, R. Mazini¹⁵², S.M. Mazza^{93a,93b}, N.C. Mc Fadden¹⁰⁶, G. Mc Goldrick¹⁵⁹, S.P. Mc Kee⁹¹, A. McCarn⁹¹, R.L. McCarthy¹⁴⁹, T.G. McCarthy³¹, L.I. McClymont⁸⁰, E.F. McDonald⁹⁰, K.W. McFarlane^{58,*},

J.A. McFayden⁸⁰, G. Mchedlidze⁵⁶, S.J. McMahon¹³², R.A. McPherson^{169,l}, M. Medinnis⁴⁴,
 S. Meehan¹³⁹, S. Mehlhase¹⁰¹, A. Mehta⁷⁶, K. Meier^{60a}, C. Meineck¹⁰¹, B. Meirose⁴³,
 D. Melini¹⁶⁷, B.R. Mellado Garcia^{146c}, M. Melo^{145a}, F. Meloni¹⁸, A. Mengarelli^{22a,22b},
 S. Menke¹⁰², E. Meoni¹⁶², S. Mergelmeyer¹⁷, P. Mermod⁵¹, L. Merola^{105a,105b}, C. Meroni^{93a},
 F.S. Merritt³³, A. Messina^{133a,133b}, J. Metcalfe⁶, A.S. Mete¹⁶³, C. Meyer⁸⁵, C. Meyer¹²³,
 J.-P. Meyer¹³⁷, J. Meyer¹⁰⁸, H. Meyer Zu Theenhausen^{60a}, F. Miano¹⁵⁰, R.P. Middleton¹³²,
 S. Miglioranza^{52a,52b}, L. Mijović²³, G. Mikenberg¹⁷², M. Mikestikova¹²⁸, M. Mikuš⁷⁷, M. Milesi⁹⁰,
 A. Milic⁶⁴, D.W. Miller³³, C. Mills⁴⁸, A. Milov¹⁷², D.A. Milstead^{147a,147b}, A.A. Minaenko¹³¹,
 Y. Minami¹⁵⁶, I.A. Minashvili⁶⁷, A.I. Mincer¹¹¹, B. Mindur^{40a}, M. Mineev⁶⁷, Y. Ming¹⁷³,
 L.M. Mir¹³, K.P. Mistry¹²³, T. Mitani¹⁷¹, J. Mitrevski¹⁰¹, V.A. Mitsou¹⁶⁷, A. Miucci⁵¹,
 P.S. Miyagawa¹⁴⁰, J.U. Mjörnmark⁸³, T. Moa^{147a,147b}, K. Mochizuki⁹⁶, S. Mohapatra³⁷,
 S. Molander^{147a,147b}, R. Moles-Valls²³, R. Monden⁷⁰, M.C. Mondragon⁹², K. Mönig⁴⁴, J. Monk³⁸,
 E. Monnier⁸⁷, A. Montalbano¹⁴⁹, J. Montejo Berlingen³², F. Monticelli⁷³, S. Monzani^{93a,93b},
 R.W. Moore³, N. Morange¹¹⁸, D. Moreno²¹, M. Moreno Llácer⁵⁶, P. Morettini^{52a}, D. Mori¹⁴³,
 T. Mori¹⁵⁶, M. Morii⁵⁹, M. Morinaga¹⁵⁶, V. Morisbak¹²⁰, S. Moritz⁸⁵, A.K. Morley¹⁵¹,
 G. Mornacchi³², J.D. Morris⁷⁸, S.S. Mortensen³⁸, L. Morvaj¹⁴⁹, M. Mosidze^{53b}, J. Moss¹⁴⁴,
 K. Motohashi¹⁵⁸, R. Mount¹⁴⁴, E. Mountricha²⁷, S.V. Mouraviev^{97,*}, E.J.W. Moyses⁸⁸,
 S. Muanza⁸⁷, R.D. Mudd¹⁹, F. Mueller¹⁰², J. Mueller¹²⁶, R.S.P. Mueller¹⁰¹, T. Mueller³⁰,
 D. Muenstermann⁷⁴, P. Mullen⁵⁵, G.A. Mullier¹⁸, F.J. Munoz Sanchez⁸⁶, J.A. Murillo Quijada¹⁹,
 W.J. Murray^{170,132}, H. Musheghyan⁵⁶, M. Muškinja⁷⁷, A.G. Myagkov^{131,ae}, M. Myska¹²⁹,
 B.P. Nachman¹⁴⁴, O. Nackenhorst⁵¹, K. Nagai¹²¹, R. Nagai^{68,z}, K. Nagano⁶⁸, Y. Nagasaka⁶¹,
 K. Nagata¹⁶¹, M. Nagel⁵⁰, E. Nagy⁸⁷, A.M. Nairz³², Y. Nakahama³², K. Nakamura⁶⁸,
 T. Nakamura¹⁵⁶, I. Nakano¹¹³, H. Namasivayam⁴³, R.F. Naranjo Garcia⁴⁴, R. Narayan¹¹,
 D.I. Narrias Villar^{60a}, I. Naryshkin¹²⁴, T. Naumann⁴⁴, G. Navarro²¹, R. Nayyar⁷, H.A. Neal⁹¹,
 P.Yu. Nechaeva⁹⁷, T.J. Neep⁸⁶, P.D. Nef¹⁴⁴, A. Negri^{122a,122b}, M. Negrini^{22a}, S. Nektarijevic¹⁰⁷,
 C. Nellist¹¹⁸, A. Nelson¹⁶³, S. Nemecek¹²⁸, P. Nemethy¹¹¹, A.A. Nepomuceno^{26a}, M. Nessi^{32,af},
 M.S. Neubauer¹⁶⁶, M. Neumann¹⁷⁵, R.M. Neves¹¹¹, P. Nevski²⁷, P.R. Newman¹⁹, D.H. Nguyen⁶,
 T. Nguyen Manh⁹⁶, R.B. Nickerson¹²¹, R. Nicolaidou¹³⁷, J. Nielsen¹³⁸, A. Nikiforov¹⁷,
 V. Nikolaenko^{131,ae}, I. Nikolic-Audit⁸², K. Nikolopoulos¹⁹, J.K. Nilsen¹²⁰, P. Nilsson²⁷,
 Y. Ninomiya¹⁵⁶, A. Nisati^{133a}, R. Nisius¹⁰², T. Nobe¹⁵⁶, L. Nodulman⁶, M. Nomachi¹¹⁹,
 I. Nomidis³¹, T. Nooney⁷⁸, S. Norberg¹¹⁴, M. Nordberg³², N. Norjoharuddeen¹²¹,
 O. Novgorodova⁴⁶, S. Nowak¹⁰², M. Nozaki⁶⁸, L. Nozka¹¹⁶, K. Ntekas¹⁰, E. Nurse⁸⁰, F. Nuti⁹⁰,
 F. O'grady⁷, D.C. O'Neil¹⁴³, A.A. O'Rourke⁴⁴, V. O'Shea⁵⁵, F.G. Oakham^{31,d}, H. Oberlack¹⁰²,
 T. Obermann²³, J. Ocariz⁸², A. Ochi⁶⁹, I. Ochoa³⁷, J.P. Ochoa-Ricoux^{34a}, S. Oda⁷², S. Odaka⁶⁸,
 H. Ogren⁶³, A. Oh⁸⁶, S.H. Oh⁴⁷, C.C. Ohm¹⁶, H. Ohman¹⁶⁵, H. Oide³², H. Okawa¹⁶¹,
 Y. Okumura³³, T. Okuyama⁶⁸, A. Olariu^{28b}, L.F. Oleiro Seabra^{127a}, S.A. Olivares Pino⁴⁸,
 D. Oliveira Damazio²⁷, A. Olszewski⁴¹, J. Olszowska⁴¹, A. Onofre^{127a,127e}, K. Onogi¹⁰⁴,
 P.U.E. Onyisi^{11,v}, M.J. Oreglia³³, Y. Oren¹⁵⁴, D. Orestano^{135a,135b}, N. Orlando^{62b}, R.S. Orr¹⁵⁹,
 B. Osculati^{52a,52b}, R. Ospanov⁸⁶, G. Otero y Garzon²⁹, H. Otono⁷², M. Ouchrif^{136d},
 F. Ould-Saada¹²⁰, A. Ouraou¹³⁷, K.P. Oussoren¹⁰⁸, Q. Ouyang^{35a}, M. Owen⁵⁵, R.E. Owen¹⁹,
 V.E. Ozcan^{20a}, N. Ozturk⁸, K. Pachal¹⁴³, A. Pacheco Pages¹³, C. Padilla Aranda¹³,
 M. Pagáčová⁵⁰, S. Pagan Griso¹⁶, F. Paige²⁷, P. Pais⁸⁸, K. Pajchel¹²⁰, G. Palacino^{160b},
 S. Palestini³², M. Palka^{40b}, D. Pallin³⁶, A. Palma^{127a,127b}, E.St. Panagiotopoulou¹⁰,
 C.E. Pandini⁸², J.G. Panduro Vazquez⁷⁹, P. Pani^{147a,147b}, S. Panitkin²⁷, D. Pantea^{28b},
 L. Paolozzi⁵¹, Th.D. Papadopoulou¹⁰, K. Papageorgiou¹⁵⁵, A. Paramonov⁶,
 D. Paredes Hernandez¹⁷⁶, A.J. Parker⁷⁴, M.A. Parker³⁰, K.A. Parker¹⁴⁰, F. Parodi^{52a,52b},
 J.A. Parsons³⁷, U. Parzefall⁵⁰, V.R. Pascuzzi¹⁵⁹, E. Pasqualucci^{133a}, S. Passaggio^{52a},
 Fr. Pastore⁷⁹, G. Pásztor^{31,ag}, S. Pataraiia¹⁷⁵, J.R. Pater⁸⁶, T. Pauly³², J. Pearce¹⁶⁹,

B. Pearson¹¹⁴, L.E. Pedersen³⁸, M. Pedersen¹²⁰, S. Pedraza Lopez¹⁶⁷, R. Pedro^{127a,127b},
 S.V. Peleganchuk^{110,c}, D. Pelikan¹⁶⁵, O. Penc¹²⁸, C. Peng^{35a}, H. Peng^{35b}, J. Penwell⁶³,
 B.S. Peralva^{26b}, M.M. Perego¹³⁷, D.V. Perepelitsa²⁷, E. Perez Codina^{160a}, L. Perini^{93a,93b},
 H. Pernegger³², S. Perrella^{105a,105b}, R. Peschke⁴⁴, V.D. Peshekhonov⁶⁷, K. Peters⁴⁴,
 R.F.Y. Peters⁸⁶, B.A. Petersen³², T.C. Petersen³⁸, E. Petit⁵⁷, A. Petridis¹, C. Petridou¹⁵⁵,
 P. Petroff¹¹⁸, E. Petrolo^{133a}, M. Petrov¹²¹, F. Petrucci^{135a,135b}, N.E. Pettersson⁸⁸, A. Peyaud¹³⁷,
 R. Pezoa^{34b}, P.W. Phillips¹³², G. Piacquadio¹⁴⁴, E. Pianori¹⁷⁰, A. Picazio⁸⁸, E. Piccaro⁷⁸,
 M. Piccinini^{22a,22b}, M.A. Pickering¹²¹, R. Piegai²⁹, J.E. Pilcher³³, A.D. Pilkington⁸⁶,
 A.W.J. Pin⁸⁶, M. Pinamonti^{164a,164c,ah}, J.L. Pinfeld³, A. Pingel³⁸, S. Pires⁸², H. Pirumov⁴⁴,
 M. Pitt¹⁷², L. Plazak^{145a}, M.-A. Pleier²⁷, V. Pleskot⁸⁵, E. Plotnikova⁶⁷, P. Plucinski⁹², D. Pluth⁶⁶,
 R. Poettgen^{147a,147b}, L. Poggioli¹¹⁸, D. Pohl²³, G. Polesello^{122a}, A. Poley⁴⁴, A. Policicchio^{39a,39b},
 R. Polifka¹⁵⁹, A. Polini^{22a}, C.S. Pollard⁵⁵, V. Polychronakos²⁷, K. Pommès³², L. Pontecorvo^{133a},
 B.G. Pope⁹², G.A. Popeneciu^{28c}, D.S. Popovic¹⁴, A. Poppleton³², S. Pospisil¹²⁹, K. Potamianos¹⁶,
 I.N. Potrap⁶⁷, C.J. Potter³⁰, C.T. Potter¹¹⁷, G. Poulard³², J. Poveda³², V. Pozdnyakov⁶⁷,
 M.E. Pozo Astigarraga³², P. Pralavorio⁸⁷, A. Pranko¹⁶, S. Prell⁶⁶, D. Price⁸⁶, L.E. Price⁶,
 M. Primavera^{75a}, S. Prince⁸⁹, M. Proissl⁴⁸, K. Prokofiev^{62c}, F. Prokoshin^{34b}, S. Protopopescu²⁷,
 J. Proudfoot⁶, M. Przybycien^{40a}, D. Puddu^{135a,135b}, D. Puldon¹⁴⁹, M. Purohit^{27,ai}, P. Puzo¹¹⁸,
 J. Qian⁹¹, G. Qin⁵⁵, Y. Qin⁸⁶, A. Quadt⁵⁶, W.B. Quayle^{164a,164b}, M. Queitsch-Maitland⁸⁶,
 D. Quilty⁵⁵, S. Raddum¹²⁰, V. Radeka²⁷, V. Radescu^{60b}, S.K. Radhakrishnan¹⁴⁹, P. Radloff¹¹⁷,
 P. Rados⁹⁰, F. Ragusa^{93a,93b}, G. Rahal¹⁷⁸, J.A. Raine⁸⁶, S. Rajagopalan²⁷, M. Rammensee³²,
 C. Rangel-Smith¹⁶⁵, M.G. Ratti^{93a,93b}, F. Rauscher¹⁰¹, S. Rave⁸⁵, T. Ravenscroft⁵⁵,
 I. Ravinovich¹⁷², M. Raymond³², A.L. Read¹²⁰, N.P. Readioff⁷⁶, M. Reale^{75a,75b},
 D.M. Rebuzzi^{122a,122b}, A. Redelbach¹⁷⁴, G. Redlinger²⁷, R. Reece¹³⁸, K. Reeves⁴³, L. Rehnisch¹⁷,
 J. Reichert¹²³, H. Reisin²⁹, C. Rembser³², H. Ren^{35a}, M. Rescigno^{133a}, S. Resconi^{93a},
 O.L. Rezanova^{110,c}, P. Reznicek¹³⁰, R. Rezvani⁹⁶, R. Richter¹⁰², S. Richter⁸⁰, E. Richter-Was^{40b},
 O. Ricken²³, M. Ridel⁸², P. Rieck¹⁷, C.J. Riegel¹⁷⁵, J. Rieger⁵⁶, O. Rifki¹¹⁴, M. Rijssenbeek¹⁴⁹,
 A. Rimoldi^{122a,122b}, M. Rimoldi¹⁸, L. Rinaldi^{22a}, B. Ristic⁵¹, E. Ritsch³², I. Riu¹³,
 F. Rizatdinova¹¹⁵, E. Rizvi⁷⁸, C. Rizzi¹³, S.H. Robertson^{89,l}, A. Robichaud-Veronneau⁸⁹,
 D. Robinson³⁰, J.E.M. Robinson⁴⁴, A. Robson⁵⁵, C. Roda^{125a,125b}, Y. Rodina⁸⁷,
 A. Rodriguez Perez¹³, D. Rodriguez Rodriguez¹⁶⁷, S. Roe³², C.S. Rogan⁵⁹, O. Røhne¹²⁰,
 A. Romaniouk⁹⁹, M. Romano^{22a,22b}, S.M. Romano Saez³⁶, E. Romero Adam¹⁶⁷, N. Rompotis¹³⁹,
 M. Ronzani⁵⁰, L. Roos⁸², E. Ros¹⁶⁷, S. Rosati^{133a}, K. Rosbach⁵⁰, P. Rose¹³⁸, O. Rosenthal¹⁴²,
 N.-A. Rosien⁵⁶, V. Rossetti^{147a,147b}, E. Rossi^{105a,105b}, L.P. Rossi^{52a}, J.H.N. Rosten³⁰,
 R. Rosten¹³⁹, M. Rotaru^{28b}, I. Roth¹⁷², J. Rothberg¹³⁹, D. Rousseau¹¹⁸, C.R. Royon¹³⁷,
 A. Rozanov⁸⁷, Y. Rozen¹⁵³, X. Ruan^{146c}, F. Rubbo¹⁴⁴, M.S. Rudolph¹⁵⁹, F. Rühr⁵⁰,
 A. Ruiz-Martinez³¹, Z. Rurikova⁵⁰, N.A. Rusakovich⁶⁷, A. Ruschke¹⁰¹, H.L. Russell¹³⁹,
 J.P. Rutherford⁷, N. Ruthmann³², Y.F. Ryabov¹²⁴, M. Rybar¹⁶⁶, G. Rybkin¹¹⁸, S. Ryu⁶,
 A. Ryzhov¹³¹, G.F. Rzehorz⁵⁶, A.F. Saavedra¹⁵¹, G. Sabato¹⁰⁸, S. Sacerdoti²⁹,
 H.F.-W. Sadrozinski¹³⁸, R. Sadykov⁶⁷, F. Safai Tehrani^{133a}, P. Saha¹⁰⁹, M. Sahinsoy^{60a},
 M. Saimpert¹³⁷, T. Saito¹⁵⁶, H. Sakamoto¹⁵⁶, Y. Sakurai¹⁷¹, G. Salamanna^{135a,135b},
 A. Salamon^{134a,134b}, J.E. Salazar Loyola^{34b}, D. Salek¹⁰⁸, P.H. Sales De Bruin¹³⁹, D. Salihagic¹⁰²,
 A. Salnikov¹⁴⁴, J. Salt¹⁶⁷, D. Salvatore^{39a,39b}, F. Salvatore¹⁵⁰, A. Salvucci^{62a}, A. Salzburger³²,
 D. Sammel⁵⁰, D. Sampsonidis¹⁵⁵, A. Sanchez^{105a,105b}, J. Sánchez¹⁶⁷, V. Sanchez Martinez¹⁶⁷,
 H. Sandaker¹²⁰, R.L. Sandbach⁷⁸, H.G. Sander⁸⁵, M. Sandhoff¹⁷⁵, C. Sandoval²¹,
 R. Sandstroem¹⁰², D.P.C. Sankey¹³², M. Sannino^{52a,52b}, A. Sansoni⁴⁹, C. Santoni³⁶,
 R. Santonic^{134a,134b}, H. Santos^{127a}, I. Santoyo Castillo¹⁵⁰, K. Sapp¹²⁶, A. Saponov⁶⁷,
 J.G. Saraiva^{127a,127d}, B. Sarrazin²³, O. Sasaki⁶⁸, Y. Sasaki¹⁵⁶, K. Sato¹⁶¹, G. Sauvage^{5,*},
 E. Sauvan⁵, G. Savage⁷⁹, P. Savard^{159,d}, C. Sawyer¹³², L. Sawyer^{81,q}, J. Saxon³³, C. Sbarra^{22a},

A. Sbrizzi^{22a,22b}, T. Scanlon⁸⁰, D.A. Scannicchio¹⁶³, M. Scarcella¹⁵¹, V. Scarfone^{39a,39b},
 J. Schaarschmidt¹⁷², P. Schacht¹⁰², B.M. Schachtner¹⁰¹, D. Schaefer³², R. Schaefer⁴⁴,
 J. Schaeffer⁸⁵, S. Schaepe²³, S. Schaetzel^{60b}, U. Schäfer⁸⁵, A.C. Schaffer¹¹⁸, D. Schaile¹⁰¹,
 R.D. Schamberger¹⁴⁹, V. Scharf^{60a}, V.A. Schegelsky¹²⁴, D. Scheirich¹³⁰, M. Schernau¹⁶³,
 C. Schiavi^{52a,52b}, S. Schier¹³⁸, C. Schillo⁵⁰, M. Schioppa^{39a,39b}, S. Schlenker³²,
 K.R. Schmidt-Sommerfeld¹⁰², K. Schmieden³², C. Schmitt⁸⁵, S. Schmitt⁴⁴, S. Schmitz⁸⁵,
 B. Schneider^{160a}, U. Schnoor⁵⁰, L. Schoeffel¹³⁷, A. Schoening^{60b}, B.D. Schoenrock⁹², E. Schopf²³,
 M. Schott⁸⁵, J. Schovancova⁸, S. Schramm⁵¹, M. Schreyer¹⁷⁴, N. Schuh⁸⁵, M.J. Schultens²³,
 H.-C. Schultz-Coulon^{60a}, H. Schulz¹⁷, M. Schumacher⁵⁰, B.A. Schumm¹³⁸, Ph. Schune¹³⁷,
 A. Schwartzman¹⁴⁴, T.A. Schwarz⁹¹, Ph. Schwegler¹⁰², H. Schweiger⁸⁶, Ph. Schwemling¹³⁷,
 R. Schwienhorst⁹², J. Schwindling¹³⁷, T. Schwindt²³, G. Sciolla²⁵, F. Scuri^{125a,125b}, F. Scutti⁹⁰,
 J. Searcy⁹¹, P. Seema²³, S.C. Seidel¹⁰⁶, A. Seiden¹³⁸, F. Seifert¹²⁹, J.M. Seixas^{26a},
 G. Sekhniaidze^{105a}, K. Sekhon⁹¹, S.J. Sekula⁴², D.M. Seliverstov^{124,*}, N. Semprini-Cesari^{22a,22b},
 C. Serfon¹²⁰, L. Serin¹¹⁸, L. Serkin^{164a,164b}, M. Sessa^{135a,135b}, R. Seuster¹⁶⁹, H. Severini¹¹⁴,
 T. Sfiligoj⁷⁷, F. Sforza³², A. Sfyrta⁵¹, E. Shabalina⁵⁶, N.W. Shaikh^{147a,147b}, L.Y. Shan^{35a},
 R. Shang¹⁶⁶, J.T. Shank²⁴, M. Shapiro¹⁶, P.B. Shatalov⁹⁸, K. Shaw^{164a,164b}, S.M. Shaw⁸⁶,
 A. Shcherbakova^{147a,147b}, C.Y. Shehu¹⁵⁰, P. Sherwood⁸⁰, L. Shi^{152,aj}, S. Shimizu⁶⁹,
 C.O. Shimmmin¹⁶³, M. Shimojima¹⁰³, M. Shiyakova^{67,ak}, A. Shmeleva⁹⁷, D. Shoaleh Saadi⁹⁶,
 M.J. Shochet³³, S. Shojaii^{93a,93b}, S. Shrestha¹¹², E. Shulga⁹⁹, M.A. Shupe⁷, P. Sicho¹²⁸,
 A.M. Sickles¹⁶⁶, P.E. Sidebo¹⁴⁸, O. Sidiropoulou¹⁷⁴, D. Sidorov¹¹⁵, A. Sidoti^{22a,22b}, F. Siegert⁴⁶,
 Dj. Sijacki¹⁴, J. Silva^{127a,127d}, S.B. Silverstein^{147a}, V. Simak¹²⁹, O. Simard⁵, Lj. Simic¹⁴,
 S. Simion¹¹⁸, E. Simioni⁸⁵, B. Simmons⁸⁰, D. Simon³⁶, M. Simon⁸⁵, P. Sinervo¹⁵⁹, N.B. Sinev¹¹⁷,
 M. Sioli^{22a,22b}, G. Siragusa¹⁷⁴, S.Yu. Sivoklov¹⁰⁰, J. Sjölin^{147a,147b}, T.B. Sjursen¹⁵,
 M.B. Skinner⁷⁴, H.P. Skottowe⁵⁹, P. Skubic¹¹⁴, M. Slater¹⁹, T. Slavicek¹²⁹, M. Slawinska¹⁰⁸,
 K. Sliwa¹⁶², R. Slovak¹³⁰, V. Smakhtin¹⁷², B.H. Smart⁵, L. Smestad¹⁵, J. Smiesko^{145a},
 S.Yu. Smirnov⁹⁹, Y. Smirnov⁹⁹, L.N. Smirnova^{100,al}, O. Smirnova⁸³, M.N.K. Smith³⁷,
 R.W. Smith³⁷, M. Smizanska⁷⁴, K. Smolek¹²⁹, A.A. Snesarev⁹⁷, S. Snyder²⁷, R. Sobie^{169,l},
 F. Socher⁴⁶, A. Soffer¹⁵⁴, D.A. Soh¹⁵², G. Sokhrannyi⁷⁷, C.A. Solans Sanchez³², M. Solar¹²⁹,
 E.Yu. Soldatov⁹⁹, U. Soldevila¹⁶⁷, A.A. Solodkov¹³¹, A. Soloshenko⁶⁷, O.V. Solovyanov¹³¹,
 V. Solovyev¹²⁴, P. Sommer⁵⁰, H. Son¹⁶², H.Y. Song^{35b,am}, A. Sood¹⁶, A. Sopczak¹²⁹, V. Sopko¹²⁹,
 V. Sorin¹³, D. Sosa^{60b}, C.L. Sotiropoulou^{125a,125b}, R. Soualah^{164a,164c}, A.M. Soukharev^{110,c},
 D. South⁴⁴, B.C. Sowden⁷⁹, S. Spagnolo^{75a,75b}, M. Spalla^{125a,125b}, M. Spangenberg¹⁷⁰,
 F. Spano⁷⁹, D. Sperlich¹⁷, F. Spettel¹⁰², R. Spighi^{22a}, G. Spigo³², L.A. Spiller⁹⁰, M. Spousta¹³⁰,
 R.D. St. Denis^{55,*}, A. Stabile^{93a}, R. Stamen^{60a}, S. Stamm¹⁷, E. Stanecka⁴¹, R.W. Stanek⁶,
 C. Stanescu^{135a}, M. Stanescu-Bellu⁴⁴, M.M. Stanitzki⁴⁴, S. Stapnes¹²⁰, E.A. Starchenko¹³¹,
 G.H. Stark³³, J. Stark⁵⁷, P. Staroba¹²⁸, P. Starovoitov^{60a}, S. Stärz³², R. Staszewski⁴¹,
 P. Steinberg²⁷, B. Stelzer¹⁴³, H.J. Stelzer³², O. Stelzer-Chilton^{160a}, H. Stenzel⁵⁴, G.A. Stewart⁵⁵,
 J.A. Stillings²³, M.C. Stockton⁸⁹, M. Stoebe⁸⁹, G. Stoicea^{28b}, P. Stolte⁵⁶, S. Stonjek¹⁰²,
 A.R. Stradling⁸, A. Straessner⁴⁶, M.E. Stramaglia¹⁸, J. Strandberg¹⁴⁸, S. Strandberg^{147a,147b},
 A. Strandlie¹²⁰, M. Strauss¹¹⁴, P. Striznec^{145b}, R. Ströhmer¹⁷⁴, D.M. Strom¹¹⁷,
 R. Stroynowski⁴², A. Strubig¹⁰⁷, S.A. Stucci¹⁸, B. Stugu¹⁵, N.A. Styles⁴⁴, D. Su¹⁴⁴, J. Su¹²⁶,
 R. Subramaniam⁸¹, S. Suchek^{60a}, Y. Sugaya¹¹⁹, M. Suk¹²⁹, V.V. Sulin⁹⁷, S. Sultansoy^{4c},
 T. Sumida⁷⁰, S. Sun⁵⁹, X. Sun^{35a}, J.E. Sundermann⁵⁰, K. Suruliz¹⁵⁰, G. Susinno^{39a,39b},
 M.R. Sutton¹⁵⁰, S. Suzuki⁶⁸, M. Svatos¹²⁸, M. Swiatlowski³³, I. Sykora^{145a}, T. Sykora¹³⁰, D. Ta⁵⁰,
 C. Taccini^{135a,135b}, K. Tackmann⁴⁴, J. Taenzer¹⁵⁹, A. Taffard¹⁶³, R. Tafirout^{160a}, N. Taiblum¹⁵⁴,
 H. Takai²⁷, R. Takashima⁷¹, T. Takeshita¹⁴¹, Y. Takubo⁶⁸, M. Talby⁸⁷, A.A. Talyshev^{110,c},
 K.G. Tan⁹⁰, J. Tanaka¹⁵⁶, R. Tanaka¹¹⁸, S. Tanaka⁶⁸, B.B. Tannenwald¹¹², S. Tapia Araya^{34b},
 S. Tapprogge⁸⁵, S. Tarem¹⁵³, G.F. Tartarelli^{93a}, P. Tas¹³⁰, M. Tasevsky¹²⁸, T. Tashiro⁷⁰,

E. Tassi^{39a,39b}, A. Tavares Delgado^{127a,127b}, Y. Tayalati^{136d}, A.C. Taylor¹⁰⁶, G.N. Taylor⁹⁰,
 P.T.E. Taylor⁹⁰, W. Taylor^{160b}, F.A. Teischinger³², P. Teixeira-Dias⁷⁹, K.K. Temming⁵⁰,
 D. Temple¹⁴³, H. Ten Kate³², P.K. Teng¹⁵², J.J. Teoh¹¹⁹, F. Tepel¹⁷⁵, S. Terada⁶⁸, K. Terashi¹⁵⁶,
 J. Terron⁸⁴, S. Terzo¹⁰², M. Testa⁴⁹, R.J. Teuscher^{159,l}, T. Theveneaux-Pelzer⁸⁷, J.P. Thomas¹⁹,
 J. Thomas-Wilsker⁷⁹, E.N. Thompson³⁷, P.D. Thompson¹⁹, A.S. Thompson⁵⁵, L.A. Thomsen¹⁷⁶,
 E. Thomson¹²³, M. Thomson³⁰, M.J. Tibbetts¹⁶, R.E. Ticse Torres⁸⁷, V.O. Tikhomirov^{97,an},
 Yu.A. Tikhonov^{110,c}, S. Timoshenko⁹⁹, P. Tipton¹⁷⁶, S. Tisserant⁸⁷, K. Todome¹⁵⁸,
 T. Todorov^{5,*}, S. Todorova-Nova¹³⁰, J. Tojo⁷², S. Tokár^{145a}, K. Tokushuku⁶⁸, E. Tolley⁵⁹,
 L. Tomlinson⁸⁶, M. Tomoto¹⁰⁴, L. Tompkins^{144,ao}, K. Toms¹⁰⁶, B. Tong⁵⁹, E. Torrence¹¹⁷,
 H. Torres¹⁴³, E. Torró Pastor¹³⁹, J. Toth^{87,ap}, F. Touchard⁸⁷, D.R. Tovey¹⁴⁰, T. Trefzger¹⁷⁴,
 A. Tricoli²⁷, I.M. Trigger^{160a}, S. Trincaz-Duvoid⁸², M.F. Tripiana¹³, W. Trischuk¹⁵⁹, B. Trocmé⁵⁷,
 A. Trofymov⁴⁴, C. Troncon^{93a}, M. Trottier-McDonald¹⁶, M. Trovatelli¹⁶⁹, L. Truong^{164a,164c},
 M. Trzebinski⁴¹, A. Trzupek⁴¹, J.C-L. Tseng¹²¹, P.V. Tsiarshka⁹⁴, G. Tsipolitis¹⁰,
 N. Tsirintanis⁹, S. Tsiskaridze¹³, V. Tsiskaridze⁵⁰, E.G. Tskhadadze^{53a}, K.M. Tsui^{62a},
 I.I. Tsukerman⁹⁸, V. Tsulaia¹⁶, S. Tsuno⁶⁸, D. Tsybychev¹⁴⁹, A. Tudorache^{28b}, V. Tudorache^{28b},
 A.N. Tuna⁵⁹, S.A. Tuppuri^{22a,22b}, S. Turchikhin^{100,al}, D. Turecek¹²⁹, D. Turgeman¹⁷²,
 R. Turra^{93a,93b}, A.J. Turvey⁴², P.M. Tuts³⁷, M. Tyndel¹³², G. Uccielli^{22a,22b}, I. Ueda¹⁵⁶,
 R. Ueno³¹, M. Ughetto^{147a,147b}, F. Ukegawa¹⁶¹, G. Unal³², A. Undrus²⁷, G. Unel¹⁶³,
 F.C. Ungaro⁹⁰, Y. Unno⁶⁸, C. Unverdorben¹⁰¹, J. Urban^{145b}, P. Urquijo⁹⁰, P. Urrejola⁸⁵,
 G. Usai⁸, A. Usanova⁶⁴, L. Vacavant⁸⁷, V. Vacek¹²⁹, B. Vachon⁸⁹, C. Valderanis¹⁰¹,
 E. Valdes Santurio^{147a,147b}, N. Valencic¹⁰⁸, S. Valentineti^{22a,22b}, A. Valero¹⁶⁷, L. Valery¹³,
 S. Valkar¹³⁰, S. Vallecorsa⁵¹, J.A. Valls Ferrer¹⁶⁷, W. Van Den Wollenberg¹⁰⁸,
 P.C. Van Der Deijl¹⁰⁸, R. van der Geer¹⁰⁸, H. van der Graaf¹⁰⁸, N. van Eldik¹⁵³,
 P. van Gemmeren⁶, J. Van Nieuwkoop¹⁴³, I. van Vulpen¹⁰⁸, M.C. van Woerden³²,
 M. Vanadia^{133a,133b}, W. Vandelli³², R. Vanguri¹²³, A. Vaniachine⁶, P. Vankov¹⁰⁸,
 G. Vardanyan¹⁷⁷, R. Vari^{133a}, E.W. Varnes⁷, C. Varni^{52a,52b}, T. Varol⁴², D. Varouchas⁸²,
 A. Vartapetian⁸, K.E. Varvell¹⁵¹, J.G. Vasquez¹⁷⁶, F. Vazeille³⁶, T. Vazquez Schroeder⁸⁹,
 J. Veatch⁵⁶, L.M. Veloce¹⁵⁹, F. Veloso^{127a,127c}, S. Veneziano^{133a}, A. Ventura^{75a,75b}, M. Venturi¹⁶⁹,
 N. Venturi¹⁵⁹, A. Venturini²⁵, V. Vercesi^{122a}, M. Verducci^{133a,133b}, W. Verkerke¹⁰⁸,
 J.C. Vermeulen¹⁰⁸, A. Vest^{46,aq}, M.C. Vetterli^{143,d}, O. Viazlo⁸³, I. Vichou¹⁶⁶, T. Vickey¹⁴⁰,
 O.E. Vickey Boeriu¹⁴⁰, G.H.A. Viehhauser¹²¹, S. Viel¹⁶, L. Vignani¹²¹, R. Vigne⁶⁴, M. Villa^{22a,22b},
 M. Villaplana Perez^{93a,93b}, E. Vilucchi⁴⁹, M.G. Vincter³¹, V.B. Vinogradov⁶⁷, C. Vittori^{22a,22b},
 I. Vivarelli¹⁵⁰, S. Vlachos¹⁰, M. Vlasak¹²⁹, M. Vogel¹⁷⁵, P. Vokac¹²⁹, G. Volpi^{125a,125b}, M. Volpi⁹⁰,
 H. von der Schmitt¹⁰², E. von Toerne²³, V. Vorobel¹³⁰, K. Vorobev⁹⁹, M. Vos¹⁶⁷, R. Voss³²,
 J.H. Vossebeld⁷⁶, N. Vranjes¹⁴, M. Vranjes Milosavljevic¹⁴, V. Vrba¹²⁸, M. Vreeswijk¹⁰⁸,
 R. Vuillermet³², I. Vukotic³³, Z. Vykydal¹²⁹, P. Wagner²³, W. Wagner¹⁷⁵, H. Wahlberg⁷³,
 S. Wahrmund⁴⁶, J. Wakabayashi¹⁰⁴, J. Walder⁷⁴, R. Walker¹⁰¹, W. Walkowiak¹⁴²,
 V. Wallangen^{147a,147b}, C. Wang^{35c}, C. Wang^{35d,87}, F. Wang¹⁷³, H. Wang¹⁶, H. Wang⁴²,
 J. Wang⁴⁴, J. Wang¹⁵¹, K. Wang⁸⁹, R. Wang⁶, S.M. Wang¹⁵², T. Wang²³, T. Wang³⁷,
 W. Wang^{35b}, X. Wang¹⁷⁶, C. Wanotayaroj¹¹⁷, A. Warburton⁸⁹, C.P. Ward³⁰, D.R. Wardrope⁸⁰,
 A. Washbrook⁴⁸, P.M. Watkins¹⁹, A.T. Watson¹⁹, M.F. Watson¹⁹, G. Watts¹³⁹, S. Watts⁸⁶,
 B.M. Waugh⁸⁰, S. Webb⁸⁵, M.S. Weber¹⁸, S.W. Weber¹⁷⁴, J.S. Webster⁶, A.R. Weidberg¹²¹,
 B. Weinert⁶³, J. Weingarten⁵⁶, C. Weiser⁵⁰, H. Weits¹⁰⁸, P.S. Wells³², T. Wenaus²⁷, T. Wengler³²,
 S. Wenig³², N. Wermes²³, M. Werner⁵⁰, P. Werner³², M. Wessels^{60a}, J. Wetter¹⁶², K. Whalen¹¹⁷,
 N.L. Whallon¹³⁹, A.M. Wharton⁷⁴, A. White⁸, M.J. White¹, R. White^{34b}, D. Whiteson¹⁶³,
 F.J. Wickens¹³², W. Wiedenmann¹⁷³, M. Wielers¹³², P. Wienemann²³, C. Wiglesworth³⁸,
 L.A.M. Wiik-Fuchs²³, A. Wildauer¹⁰², F. Wilk⁸⁶, H.G. Wilkens³², H.H. Williams¹²³,
 S. Williams¹⁰⁸, C. Willis⁹², S. Willocq⁸⁸, J.A. Wilson¹⁹, I. Wingarter-Seez⁵, F. Winklmeier¹¹⁷,

O.J. Winston¹⁵⁰, B.T. Winter²³, M. Wittgen¹⁴⁴, J. Wittkowski¹⁰¹, S.J. Wollstadt⁸⁵, M.W. Wolter⁴¹, H. Wolters^{127a,127c}, B.K. Wosiek⁴¹, J. Wotschack³², M.J. Woudstra⁸⁶, K.W. Wozniak⁴¹, M. Wu⁵⁷, M. Wu³³, S.L. Wu¹⁷³, X. Wu⁵¹, Y. Wu⁹¹, T.R. Wyatt⁸⁶, B.M. Wynne⁴⁸, S. Xella³⁸, D. Xu^{35a}, L. Xu²⁷, B. Yabsley¹⁵¹, S. Yacoob^{146a}, R. Yakabe⁶⁹, D. Yamaguchi¹⁵⁸, Y. Yamaguchi¹¹⁹, A. Yamamoto⁶⁸, S. Yamamoto¹⁵⁶, T. Yamanaka¹⁵⁶, K. Yamauchi¹⁰⁴, Y. Yamazaki⁶⁹, Z. Yan²⁴, H. Yang^{35e}, H. Yang¹⁷³, Y. Yang¹⁵², Z. Yang¹⁵, W.-M. Yao¹⁶, Y.C. Yap⁸², Y. Yasu⁶⁸, E. Yatsenko⁵, K.H. Yau Wong²³, J. Ye⁴², S. Ye²⁷, I. Yeletsikh⁶⁷, A.L. Yen⁵⁹, E. Yildirim⁸⁵, K. Yorita¹⁷¹, R. Yoshida⁶, K. Yoshihara¹²³, C. Young¹⁴⁴, C.J.S. Young³², S. Youssef²⁴, D.R. Yu¹⁶, J. Yu⁸, J.M. Yu⁹¹, J. Yu⁶⁶, L. Yuan⁶⁹, S.P.Y. Yuen²³, I. Yusuf^{30,ar}, B. Zabinski⁴¹, R. Zaidan^{35d}, A.M. Zaitsev^{131,ae}, N. Zakharuk⁴⁴, J. Zalieckas¹⁵, A. Zaman¹⁴⁹, S. Zambito⁵⁹, L. Zanello^{133a,133b}, D. Zanzi⁹⁰, C. Zeitnitz¹⁷⁵, M. Zeman¹²⁹, A. Zemla^{40a}, J.C. Zeng¹⁶⁶, Q. Zeng¹⁴⁴, K. Zengel²⁵, O. Zenin¹³¹, T. Ženiš^{145a}, D. Zerwas¹¹⁸, D. Zhang⁹¹, F. Zhang¹⁷³, G. Zhang^{35b,am}, H. Zhang^{35c}, J. Zhang⁶, L. Zhang⁵⁰, R. Zhang²³, R. Zhang^{35b,as}, X. Zhang^{35d}, Z. Zhang¹¹⁸, X. Zhao⁴², Y. Zhao^{35d}, Z. Zhao^{35b}, A. Zhemchugov⁶⁷, J. Zhong¹²¹, B. Zhou⁹¹, C. Zhou⁴⁷, L. Zhou³⁷, L. Zhou⁴², M. Zhou¹⁴⁹, N. Zhou^{35f}, C.G. Zhu^{35d}, H. Zhu^{35a}, J. Zhu⁹¹, Y. Zhu^{35b}, X. Zhuang^{35a}, K. Zhukov⁹⁷, A. Zibell¹⁷⁴, D. Ziemska⁶³, N.I. Zimine⁶⁷, C. Zimmermann⁸⁵, S. Zimmermann⁵⁰, Z. Zinonos⁵⁶, M. Zinser⁸⁵, M. Ziolkowski¹⁴², L. Živković¹⁴, G. Zobernig¹⁷³, A. Zoccoli^{22a,22b}, M. zur Nedden¹⁷, G. Zurzolo^{105a,105b} and L. Zwalinski³²

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

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

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

⁴ ^(a) Department of Physics, Ankara University, Ankara; ^(b) Istanbul Aydin University, Istanbul; ^(c) Division of Physics, TOBB University of Economics and Technology, Ankara, Turkey

⁵ LAPP, CNRS/IN2P3 and Université Savoie Mont Blanc, Annecy-le-Vieux, France

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

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

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

⁹ Physics Department, University of Athens, Athens, Greece

¹⁰ Physics Department, National Technical University of Athens, Zografou, Greece

¹¹ Department of Physics, The University of Texas at Austin, Austin TX, United States of America

¹² Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan

¹³ Institut de Física d'Altes Energies (IFAE), The Barcelona Institute of Science and Technology, Barcelona, Spain, Spain

¹⁴ Institute of Physics, University of Belgrade, Belgrade, Serbia

¹⁵ Department for Physics and Technology, University of Bergen, Bergen, Norway

¹⁶ Physics Division, Lawrence Berkeley National Laboratory and University of California, Berkeley CA, United States of America

¹⁷ Department of Physics, Humboldt University, Berlin, Germany

¹⁸ Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern, Switzerland

¹⁹ School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom

²⁰ ^(a) Department of Physics, Bogazici University, Istanbul; ^(b) Department of Physics Engineering, Gaziantep University, Gaziantep; ^(d) Istanbul Bilgi University, Faculty of Engineering and Natural Sciences, Istanbul, Turkey; ^(e) Bahcesehir University, Faculty of Engineering and Natural Sciences, Istanbul, Turkey, Turkey

²¹ Centro de Investigaciones, Universidad Antonio Narino, Bogota, Colombia

²² ^(a) INFN Sezione di Bologna; ^(b) Dipartimento di Fisica e Astronomia, Università di Bologna, Bologna, Italy

- ²³ *Physikalisches Institut, University of Bonn, Bonn, Germany*
- ²⁴ *Department of Physics, Boston University, Boston MA, United States of America*
- ²⁵ *Department of Physics, Brandeis University, Waltham MA, United States of America*
- ²⁶ ^(a) *Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro;* ^(b) *Electrical Circuits Department, Federal University of Juiz de Fora (UFJF), Juiz de Fora;* ^(c) *Federal University of Sao Joao del Rei (UFSJ), Sao Joao del Rei;* ^(d) *Instituto de Física, Universidade de Sao Paulo, Sao Paulo, Brazil*
- ²⁷ *Physics Department, Brookhaven National Laboratory, Upton NY, United States of America*
- ²⁸ ^(a) *Transilvania University of Brasov, Brasov, Romania;* ^(b) *National Institute of Physics and Nuclear Engineering, Bucharest;* ^(c) *National Institute for Research and Development of Isotopic and Molecular Technologies, Physics Department, Cluj Napoca;* ^(d) *University Politehnica Bucharest, Bucharest;* ^(e) *West University in Timisoara, Timisoara, Romania*
- ²⁹ *Departamento de Física, Universidad de Buenos Aires, Buenos Aires, Argentina*
- ³⁰ *Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom*
- ³¹ *Department of Physics, Carleton University, Ottawa ON, Canada*
- ³² *CERN, Geneva, Switzerland*
- ³³ *Enrico Fermi Institute, University of Chicago, Chicago IL, United States of America*
- ³⁴ ^(a) *Departamento de Física, Pontificia Universidad Católica de Chile, Santiago;* ^(b) *Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile*
- ³⁵ ^(a) *Institute of High Energy Physics, Chinese Academy of Sciences, Beijing;* ^(b) *Department of Modern Physics, University of Science and Technology of China, Anhui;* ^(c) *Department of Physics, Nanjing University, Jiangsu;* ^(d) *School of Physics, Shandong University, Shandong;* ^(e) *Department of Physics and Astronomy, Shanghai Key Laboratory for Particle Physics and Cosmology, Shanghai Jiao Tong University, Shanghai; (also affiliated with PKU-CHEP);* ^(f) *Physics Department, Tsinghua University, Beijing 100084, China*
- ³⁶ *Laboratoire de Physique Corpusculaire, Clermont Université and Université Blaise Pascal and CNRS/IN2P3, Clermont-Ferrand, France*
- ³⁷ *Nevis Laboratory, Columbia University, Irvington NY, United States of America*
- ³⁸ *Niels Bohr Institute, University of Copenhagen, Kobenhavn, Denmark*
- ³⁹ ^(a) *INFN Gruppo Collegato di Cosenza, Laboratori Nazionali di Frascati;* ^(b) *Dipartimento di Fisica, Università della Calabria, Rende, Italy*
- ⁴⁰ ^(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*
- ⁴¹ *Institute of Nuclear Physics Polish Academy of Sciences, Krakow, Poland*
- ⁴² *Physics Department, Southern Methodist University, Dallas TX, United States of America*
- ⁴³ *Physics Department, University of Texas at Dallas, Richardson TX, United States of America*
- ⁴⁴ *DESY, Hamburg and Zeuthen, Germany*
- ⁴⁵ *Institut für Experimentelle Physik IV, Technische Universität Dortmund, Dortmund, Germany*
- ⁴⁶ *Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden, Germany*
- ⁴⁷ *Department of Physics, Duke University, Durham NC, United States of America*
- ⁴⁸ *SUPA - School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom*
- ⁴⁹ *INFN Laboratori Nazionali di Frascati, Frascati, Italy*
- ⁵⁰ *Fakultät für Mathematik und Physik, Albert-Ludwigs-Universität, Freiburg, Germany*
- ⁵¹ *Section de Physique, Université de Genève, Geneva, Switzerland*
- ⁵² ^(a) *INFN Sezione di Genova;* ^(b) *Dipartimento di Fisica, Università di Genova, Genova, Italy*
- ⁵³ ^(a) *E. Andronikashvili Institute of Physics, Iv. Javakishvili Tbilisi State University, Tbilisi;* ^(b) *High Energy Physics Institute, Tbilisi State University, Tbilisi, Georgia*
- ⁵⁴ *II Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen, Germany*
- ⁵⁵ *SUPA - School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom*
- ⁵⁶ *II Physikalisches Institut, Georg-August-Universität, Göttingen, Germany*
- ⁵⁷ *Laboratoire de Physique Subatomique et de Cosmologie, Université Grenoble-Alpes, CNRS/IN2P3, Grenoble, France*

- 58 *Department of Physics, Hampton University, Hampton VA, United States of America*
- 59 *Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge MA, United States of America*
- 60 ^(a) *Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg;* ^(b) *Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg;* ^(c) *ZITI Institut für technische Informatik, Ruprecht-Karls-Universität Heidelberg, Mannheim, Germany*
- 61 *Faculty of Applied Information Science, Hiroshima Institute of Technology, Hiroshima, Japan*
- 62 ^(a) *Department of Physics, The Chinese University of Hong Kong, Shatin, N.T., Hong Kong;* ^(b) *Department of Physics, The University of Hong Kong, Hong Kong;* ^(c) *Department of Physics, The Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China*
- 63 *Department of Physics, Indiana University, Bloomington IN, United States of America*
- 64 *Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck, Austria*
- 65 *University of Iowa, Iowa City IA, United States of America*
- 66 *Department of Physics and Astronomy, Iowa State University, Ames IA, United States of America*
- 67 *Joint Institute for Nuclear Research, JINR Dubna, Dubna, Russia*
- 68 *KEK, High Energy Accelerator Research Organization, Tsukuba, Japan*
- 69 *Graduate School of Science, Kobe University, Kobe, Japan*
- 70 *Faculty of Science, Kyoto University, Kyoto, Japan*
- 71 *Kyoto University of Education, Kyoto, Japan*
- 72 *Department of Physics, Kyushu University, Fukuoka, Japan*
- 73 *Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina*
- 74 *Physics Department, Lancaster University, Lancaster, United Kingdom*
- 75 ^(a) *INFN Sezione di Lecce;* ^(b) *Dipartimento di Matematica e Fisica, Università del Salento, Lecce, Italy*
- 76 *Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom*
- 77 *Department of Physics, Jožef Stefan Institute and University of Ljubljana, Ljubljana, Slovenia*
- 78 *School of Physics and Astronomy, Queen Mary University of London, London, United Kingdom*
- 79 *Department of Physics, Royal Holloway University of London, Surrey, United Kingdom*
- 80 *Department of Physics and Astronomy, University College London, London, United Kingdom*
- 81 *Louisiana Tech University, Ruston LA, United States of America*
- 82 *Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France*
- 83 *Fysiska institutionen, Lunds universitet, Lund, Sweden*
- 84 *Departamento de Física Teórica C-15, Universidad Autónoma de Madrid, Madrid, Spain*
- 85 *Institut für Physik, Universität Mainz, Mainz, Germany*
- 86 *School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom*
- 87 *CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France*
- 88 *Department of Physics, University of Massachusetts, Amherst MA, United States of America*
- 89 *Department of Physics, McGill University, Montreal QC, Canada*
- 90 *School of Physics, University of Melbourne, Victoria, Australia*
- 91 *Department of Physics, The University of Michigan, Ann Arbor MI, United States of America*
- 92 *Department of Physics and Astronomy, Michigan State University, East Lansing MI, United States of America*
- 93 ^(a) *INFN Sezione di Milano;* ^(b) *Dipartimento di Fisica, Università di Milano, Milano, Italy*
- 94 *B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Republic of Belarus*
- 95 *National Scientific and Educational Centre for Particle and High Energy Physics, Minsk, Republic of Belarus*
- 96 *Group of Particle Physics, University of Montreal, Montreal QC, Canada*
- 97 *P.N. Lebedev Physical Institute of the Russian Academy of Sciences, Moscow, Russia*
- 98 *Institute for Theoretical and Experimental Physics (ITEP), Moscow, Russia*
- 99 *National Research Nuclear University MEPhI, Moscow, Russia*

- 100 *D.V. Skobeltsyn Institute of Nuclear Physics, M.V. Lomonosov Moscow State University, Moscow, Russia*
- 101 *Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany*
- 102 *Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany*
- 103 *Nagasaki Institute of Applied Science, Nagasaki, Japan*
- 104 *Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya, Japan*
- 105 ^(a) *INFN Sezione di Napoli;* ^(b) *Dipartimento di Fisica, Università di Napoli, Napoli, Italy*
- 106 *Department of Physics and Astronomy, University of New Mexico, Albuquerque NM, United States of America*
- 107 *Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands*
- 108 *Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands*
- 109 *Department of Physics, Northern Illinois University, DeKalb IL, United States of America*
- 110 *Budker Institute of Nuclear Physics, SB RAS, Novosibirsk, Russia*
- 111 *Department of Physics, New York University, New York NY, United States of America*
- 112 *Ohio State University, Columbus OH, United States of America*
- 113 *Faculty of Science, Okayama University, Okayama, Japan*
- 114 *Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman OK, United States of America*
- 115 *Department of Physics, Oklahoma State University, Stillwater OK, United States of America*
- 116 *Palacký University, RCPTM, Olomouc, Czech Republic*
- 117 *Center for High Energy Physics, University of Oregon, Eugene OR, United States of America*
- 118 *LAL, Univ. Paris-Sud, CNRS/IN2P3, Université Paris-Saclay, Orsay, France*
- 119 *Graduate School of Science, Osaka University, Osaka, Japan*
- 120 *Department of Physics, University of Oslo, Oslo, Norway*
- 121 *Department of Physics, Oxford University, Oxford, United Kingdom*
- 122 ^(a) *INFN Sezione di Pavia;* ^(b) *Dipartimento di Fisica, Università di Pavia, Pavia, Italy*
- 123 *Department of Physics, University of Pennsylvania, Philadelphia PA, United States of America*
- 124 *National Research Centre “Kurchatov Institute” B.P.Konstantinov Petersburg Nuclear Physics Institute, St. Petersburg, Russia*
- 125 ^(a) *INFN Sezione di Pisa;* ^(b) *Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy*
- 126 *Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh PA, United States of America*
- 127 ^(a) *Laboratório de Instrumentação e Física Experimental de Partículas - LIP, Lisboa;* ^(b) *Faculdade de Ciências, Universidade de Lisboa, Lisboa;* ^(c) *Department of Physics, University of Coimbra, Coimbra;* ^(d) *Centro de Física Nuclear da Universidade de Lisboa, Lisboa;* ^(e) *Departamento de Física, Universidade do Minho, Braga;* ^(f) *Departamento de Física Teórica y del Cosmos and CAFPE, Universidad de Granada, Granada (Spain);* ^(g) *Dep Física and CEFITEC of Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Caparica, Portugal*
- 128 *Institute of Physics, Academy of Sciences of the Czech Republic, Praha, Czech Republic*
- 129 *Czech Technical University in Prague, Praha, Czech Republic*
- 130 *Faculty of Mathematics and Physics, Charles University in Prague, Praha, Czech Republic*
- 131 *State Research Center Institute for High Energy Physics (Protvino), NRC KI, Russia*
- 132 *Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom*
- 133 ^(a) *INFN Sezione di Roma;* ^(b) *Dipartimento di Fisica, Sapienza Università di Roma, Roma, Italy*
- 134 ^(a) *INFN Sezione di Roma Tor Vergata;* ^(b) *Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy*
- 135 ^(a) *INFN Sezione di Roma Tre;* ^(b) *Dipartimento di Matematica e Fisica, Università Roma Tre, Roma, Italy*
- 136 ^(a) *Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies - Université Hassan II, Casablanca;* ^(b) *Centre National de l’Energie des Sciences Techniques*

- Nucleaires, Rabat; ^(c) *Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA-Marrakech;*
^(d) *Faculté des Sciences, Université Mohamed Premier and LPTPM, Oujda;* ^(e) *Faculté des sciences, Université Mohammed V, Rabat, Morocco*
- 137 *DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l'Univers), CEA Saclay (Commissariat à l'Energie Atomique et aux Energies Alternatives), Gif-sur-Yvette, France*
- 138 *Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz CA, United States of America*
- 139 *Department of Physics, University of Washington, Seattle WA, United States of America*
- 140 *Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom*
- 141 *Department of Physics, Shinshu University, Nagano, Japan*
- 142 *Fachbereich Physik, Universität Siegen, Siegen, Germany*
- 143 *Department of Physics, Simon Fraser University, Burnaby BC, Canada*
- 144 *SLAC National Accelerator Laboratory, Stanford CA, United States of America*
- 145 ^(a) *Faculty of Mathematics, Physics & Informatics, Comenius University, Bratislava;* ^(b) *Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice, Slovak Republic*
- 146 ^(a) *Department of Physics, University of Cape Town, Cape Town;* ^(b) *Department of Physics, University of Johannesburg, Johannesburg;* ^(c) *School of Physics, University of the Witwatersrand, Johannesburg, South Africa*
- 147 ^(a) *Department of Physics, Stockholm University;* ^(b) *The Oskar Klein Centre, Stockholm, Sweden*
- 148 *Physics Department, Royal Institute of Technology, Stockholm, Sweden*
- 149 *Departments of Physics & Astronomy and Chemistry, Stony Brook University, Stony Brook NY, United States of America*
- 150 *Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom*
- 151 *School of Physics, University of Sydney, Sydney, Australia*
- 152 *Institute of Physics, Academia Sinica, Taipei, Taiwan*
- 153 *Department of Physics, Technion: Israel Institute of Technology, Haifa, Israel*
- 154 *Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel*
- 155 *Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece*
- 156 *International Center for Elementary Particle Physics and Department of Physics, The University of Tokyo, Tokyo, Japan*
- 157 *Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo, Japan*
- 158 *Department of Physics, Tokyo Institute of Technology, Tokyo, Japan*
- 159 *Department of Physics, University of Toronto, Toronto ON, Canada*
- 160 ^(a) *TRIUMF, Vancouver BC;* ^(b) *Department of Physics and Astronomy, York University, Toronto ON, Canada*
- 161 *Faculty of Pure and Applied Sciences, and Center for Integrated Research in Fundamental Science and Engineering, University of Tsukuba, Tsukuba, Japan*
- 162 *Department of Physics and Astronomy, Tufts University, Medford MA, United States of America*
- 163 *Department of Physics and Astronomy, University of California Irvine, Irvine CA, United States of America*
- 164 ^(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*
- 165 *Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden*
- 166 *Department of Physics, University of Illinois, Urbana IL, United States of America*
- 167 *Instituto de Física Corpuscular (IFIC) and Departamento de Física Atómica, Molecular y Nuclear and Departamento de Ingeniería Electrónica and Instituto de Microelectrónica de Barcelona (IMB-CNM), University of Valencia and CSIC, Valencia, Spain*
- 168 *Department of Physics, University of British Columbia, Vancouver BC, Canada*
- 169 *Department of Physics and Astronomy, University of Victoria, Victoria BC, Canada*
- 170 *Department of Physics, University of Warwick, Coventry, United Kingdom*

- 171 *Waseda University, Tokyo, Japan*
- 172 *Department of Particle Physics, The Weizmann Institute of Science, Rehovot, Israel*
- 173 *Department of Physics, University of Wisconsin, Madison WI, United States of America*
- 174 *Fakultät für Physik und Astronomie, Julius-Maximilians-Universität, Würzburg, Germany*
- 175 *Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal, Germany*
- 176 *Department of Physics, Yale University, New Haven CT, United States of America*
- 177 *Yerevan Physics Institute, Yerevan, Armenia*
- 178 *Centre de Calcul de l'Institut National de Physique Nucléaire et de Physique des Particules (IN2P3), Villeurbanne, France*
- ^a *Also at Department of Physics, King's College London, London, United Kingdom*
- ^b *Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan*
- ^c *Also at Novosibirsk State University, Novosibirsk, Russia*
- ^d *Also at TRIUMF, Vancouver BC, Canada*
- ^e *Also at Department of Physics & Astronomy, University of Louisville, Louisville, KY, United States of America*
- ^f *Also at Department of Physics, California State University, Fresno CA, United States of America*
- ^g *Also at Department of Physics, University of Fribourg, Fribourg, Switzerland*
- ^h *Also at Departament de Física de la Universitat Autònoma de Barcelona, Barcelona, Spain*
- ⁱ *Also at Departamento de Física e Astronomia, Faculdade de Ciências, Universidade do Porto, Portugal*
- ^j *Also at Tomsk State University, Tomsk, Russia*
- ^k *Also at Università di Napoli Parthenope, Napoli, Italy*
- ^l *Also at Institute of Particle Physics (IPP), Canada*
- ^m *Also at National Institute of Physics and Nuclear Engineering, Bucharest, Romania*
- ⁿ *Also at Department of Physics, St. Petersburg State Polytechnical University, St. Petersburg, Russia*
- ^o *Also at Department of Physics, The University of Michigan, Ann Arbor MI, United States of America*
- ^p *Also at Centre for High Performance Computing, CSIR Campus, Rosebank, Cape Town, South Africa*
- ^q *Also at Louisiana Tech University, Ruston LA, United States of America*
- ^r *Also at Institutio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona, Spain*
- ^s *Also at Graduate School of Science, Osaka University, Osaka, Japan*
- ^t *Also at Department of Physics, National Tsing Hua University, Taiwan*
- ^u *Also at Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands*
- ^v *Also at Department of Physics, The University of Texas at Austin, Austin TX, United States of America*
- ^w *Also at Institute of Theoretical Physics, Iliia State University, Tbilisi, Georgia*
- ^x *Also at CERN, Geneva, Switzerland*
- ^y *Also at Georgian Technical University (GTU), Tbilisi, Georgia*
- ^z *Also at O Chadai Academic Production, Ochanomizu University, Tokyo, Japan*
- ^{aa} *Also at Manhattan College, New York NY, United States of America*
- ^{ab} *Also at Hellenic Open University, Patras, Greece*
- ^{ac} *Also at Academia Sinica Grid Computing, Institute of Physics, Academia Sinica, Taipei, Taiwan*
- ^{ad} *Also at School of Physics, Shandong University, Shandong, China*
- ^{ae} *Also at Moscow Institute of Physics and Technology State University, Dolgoprudny, Russia*
- ^{af} *Also at Section de Physique, Université de Genève, Geneva, Switzerland*
- ^{ag} *Also at Eotvos Lorand University, Budapest, Hungary*
- ^{ah} *Also at International School for Advanced Studies (SISSA), Trieste, Italy*

- ^{ai} Also at Department of Physics and Astronomy, University of South Carolina, Columbia SC, United States of America
- ^{aj} Also at School of Physics and Engineering, Sun Yat-sen University, Guangzhou, China
- ^{ak} Also at Institute for Nuclear Research and Nuclear Energy (INRNE) of the Bulgarian Academy of Sciences, Sofia, Bulgaria
- ^{al} Also at Faculty of Physics, M.V.Lomonosov Moscow State University, Moscow, Russia
- ^{am} Also at Institute of Physics, Academia Sinica, Taipei, Taiwan
- ^{an} Also at National Research Nuclear University MEPhI, Moscow, Russia
- ^{ao} Also at Department of Physics, Stanford University, Stanford CA, United States of America
- ^{ap} Also at Institute for Particle and Nuclear Physics, Wigner Research Centre for Physics, Budapest, Hungary
- ^{aq} Also at Flensburg University of Applied Sciences, Flensburg, Germany
- ^{ar} Also at University of Malaya, Department of Physics, Kuala Lumpur, Malaysia
- ^{as} Also at CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France
- * Deceased