



Search for the Standard Model Higgs boson produced in association with a vector boson and decaying to a b -quark pair with the ATLAS detector[☆]

ATLAS Collaboration^{*}

ARTICLE INFO

Article history:

Received 1 July 2012

Received in revised form 14 September 2012

Accepted 23 October 2012

Available online 26 October 2012

Editor: H. Weerts

Keywords:

Standard Model Higgs boson

ATLAS

LHC

ABSTRACT

This Letter presents the results of a direct search with the ATLAS detector at the LHC for a Standard Model Higgs boson of mass $110 \leq m_H \leq 130$ GeV produced in association with a W or Z boson and decaying to $b\bar{b}$. Three decay channels are considered: $ZH \rightarrow \ell^+ \ell^- b\bar{b}$, $WH \rightarrow \ell \nu b\bar{b}$ and $ZH \rightarrow \nu \bar{\nu} b\bar{b}$, where ℓ corresponds to an electron or a muon. No evidence for Higgs boson production is observed in a dataset of 7 TeV pp collisions corresponding to 4.7 fb^{-1} of integrated luminosity collected by ATLAS in 2011. Exclusion limits on Higgs boson production, at the 95% confidence level, of 2.5 to 5.5 times the Standard Model cross section are obtained in the mass range 110–130 GeV. The expected exclusion limits range between 2.5 and 4.9 for the same mass interval.

© 2012 CERN. Published by Elsevier B.V. Open access under CC BY license.

1. Introduction

The search for the Standard Model (SM) Higgs boson [1–3] is one of the most important endeavours of the Large Hadron Collider (LHC). The $H \rightarrow b\bar{b}$ decay corresponds to the highest branching ratio for a low-mass Higgs boson in the SM. Observing this decay would provide direct sensitivity to the Higgs boson coupling to fermions. The results of searches in various channels using data corresponding to an integrated luminosity of up to 4.9 fb^{-1} have been reported recently by both the ATLAS and CMS collaborations [4,5]. The Higgs boson has been excluded at the 95% confidence level (CL) below 114.4 GeV by the LEP experiments [6], in the regions 100–106 GeV and 147–179 GeV at the Tevatron $p\bar{p}$ collider [7], and in the regions 112.9–115.5 GeV and 127–600 GeV by the LHC experiments [4,5]. This Letter reports on a search for the SM Higgs boson performed for the $H \rightarrow b\bar{b}$ decay mode, over the mass range 110–130 GeV where this decay mode dominates.

Due to the large backgrounds present in the dominant production process $gg \rightarrow H \rightarrow b\bar{b}$, the analysis reported here is restricted to Higgs boson production in association with a vector boson, WH and ZH [8–12], where the vector boson provides an additional final state signature, allowing for significant background suppression. An additional handle against the backgrounds is provided by exploiting the better signal-over-background level of the kinematic regions where the weak bosons have high transverse momenta [13]. These channels are also important contributors to Higgs boson searches at CMS [14] and the Tevatron [7].

This Letter presents searches in the $ZH \rightarrow \ell^+ \ell^- b\bar{b}$, $WH \rightarrow \ell \nu b\bar{b}$ and $ZH \rightarrow \nu \bar{\nu} b\bar{b}$ channels, where ℓ is either an electron or a muon, including electrons and muons from tau lepton decays. The data used were recorded by the ATLAS experiment during the 2011 LHC run at a centre-of-mass energy of $\sqrt{s} = 7$ TeV and correspond to integrated luminosities of 4.6 to 4.7 fb^{-1} [15,16], depending on the analysis channel. The leptonic decay modes of the weak bosons are selected to suppress backgrounds containing only jets in the final state. In the $ZH \rightarrow \nu \bar{\nu} b\bar{b}$ channel, the multijet background is suppressed by requiring a large missing transverse energy.

2. The ATLAS detector

The ATLAS detector [17] consists of four main subsystems. An inner tracking detector is immersed in the 2 T magnetic field produced by a superconducting solenoid. Charged particle position and momentum measurements are made by silicon detectors in the pseudorapidity¹ range $|\eta| < 2.5$ and by a straw tube tracker in the range $|\eta| < 2.0$. Calorimeters cover $|\eta| < 4.9$ with a variety of detector technologies. The liquid-argon electromagnetic calorimeter is divided into barrel ($|\eta| < 1.475$) and end-cap ($1.375 < |\eta| < 3.2$) sections. The hadronic calorimeters (using

¹ ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the centre of the detector and the z -axis coinciding with the axis of the beam pipe. The x -axis points from the IP to the centre of the LHC ring, and the y -axis points upward. Cylindrical coordinates (r, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the beam pipe. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln \tan(\theta/2)$. For the purpose of the fiducial selection, this is calculated relative to the geometric centre of the detector; otherwise, it is relative to the reconstructed primary vertex of each event.

[☆] © CERN for the benefit of the ATLAS Collaboration.

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

liquid argon or scintillating tiles as active materials) surround the electromagnetic calorimeter and cover $|\eta| < 4.9$. The muon spectrometer measures the deflection of muon tracks in the field of three large air-core toroidal magnets, each containing eight superconducting coils. It is instrumented with separate trigger chambers (covering $|\eta| < 2.4$) and high-precision tracking chambers (covering $|\eta| < 2.7$).

3. Data and Monte Carlo samples

The collision data used in this analysis are selected such that all elements of the ATLAS detector were delivering high-quality data. In the $ZH \rightarrow \ell^+ \ell^- b\bar{b}$ and the $WH \rightarrow \ell\nu b\bar{b}$ analyses, events were primarily collected using single-lepton triggers with a transverse momentum (p_T) threshold of 20 GeV for electrons, which was raised to 22 GeV as the instantaneous luminosity increased, and 18 GeV for muons. In the $ZH \rightarrow \ell^+ \ell^- b\bar{b}$ analysis, these triggers were supplemented with a di-electron trigger with a threshold of 12 GeV. The lepton trigger efficiency is measured using a sample of $Z \rightarrow \ell^+ \ell^-$ events. The resulting efficiencies, relative to the offline selection, are close to 100% for $ZH \rightarrow e^+ e^- b\bar{b}$ and $WH \rightarrow e\nu b\bar{b}$. The efficiencies are around 95% for the $ZH \rightarrow \mu^+ \mu^- b\bar{b}$ channel and 90% for the $WH \rightarrow \mu\nu b\bar{b}$ channel, due to the lower angular coverage of the muon trigger chambers with respect to the precision tracking chambers. The missing transverse energy (E_T^{miss}) trigger used for the $ZH \rightarrow \nu\bar{\nu} b\bar{b}$ channel has a threshold of 70 GeV and an efficiency above 50% for E_T^{miss} above 120 GeV. This efficiency exceeds 99% for E_T^{miss} above 170 GeV. The efficiency curve is measured in a sample of $W \rightarrow \mu\nu + \text{jet}$ events collected using muon triggers, which do not rely on the presence of E_T^{miss} . The Monte Carlo (MC) simulation predicts the trigger efficiency to be 5% higher than that observed in collision data for 120 GeV $\leq E_T^{\text{miss}} < 160$ GeV and agrees for $E_T^{\text{miss}} \geq 160$ GeV. A correction factor of 0.95 ± 0.01 is therefore applied to the MC in the lower E_T^{miss} region, and no trigger efficiency correction is applied elsewhere.

Due to practical constraints, several MC generators were used to simulate signal and background processes. The WH and ZH signal processes are modelled using MC events produced by the PYTHIA [18] event generator, interfaced with the MRST modified leading-order (LO*) [19] parton distribution functions (PDFs), using the AUET2B tune [20] for the parton shower, hadronization and multiple parton interactions. The total cross sections for these channels, as well as their corresponding uncertainties, are taken from the LHC Higgs Cross Section Working Group report [21]. Differential next-to-leading order (NLO) electroweak corrections as a function of the W or Z transverse momentum have also been applied [22,12]. The Higgs boson decay branching ratios are calculated with HDECAY [23].

The background processes are modelled with several different event generators. The POWHEG [24–26] generator, in combination with MSTW 2008 NLO PDFs [27] and interfaced with the PYTHIA program for the parton shower and hadronization, is used to simulate $W + \geq 1b$ jet events. The SHERPA generator [28] is used to simulate $Z + \geq 1b$ jet and $Z + \geq 1c$ jet events. The ALPGEN generator [29] interfaced with the HERWIG program [30] is used to simulate $W + \geq 1c$ jet, $W + \geq 1$ light jet (i.e. not a c or b jet) and $Z + \geq 1$ light jet events. The above background simulations include γ^* production and Z/γ^* interference where appropriate. The MC@NLO generator [31], using CT10 NLO PDFs [32] and interfaced to HERWIG, is used for the production of top-quarks (single-top and top-quark pair production). The HERWIG generator, is used to simulate the diboson (ZZ , WZ and WW) samples. The HERWIG generator uses the AUET2 tune [33] for the parton shower

and hadronization model, relies on MRST LO* PDFs (except for top production) and is in all cases interfaced to JIMMY [34] for the modelling of multiple parton interactions. The diboson cross sections normalized to NLO QCD computations [35,36]. MC samples are passed through the full ATLAS detector simulation [37] based on the GEANT4 [38] program.

4. Reconstruction and identification of physics objects

Events are required to have at least one reconstructed primary vertex with three or more associated tracks with $p_T > 0.4$ GeV in the inner detector. If more than one vertex is reconstructed, the primary vertex is chosen as the one with the highest sum of the squares of the transverse momenta of all its associated tracks.

Electron candidates are reconstructed from energy clusters in the electromagnetic calorimeter and are required to pass identification criteria based on the shower shape. Central electrons must have a matching track in the inner detector that is consistent with originating from the primary vertex and requirements are placed on track quality and track-cluster matching [39]. Further track and cluster related identification criteria are applied to electron candidates in order to reduce background from jets being misidentified as electrons. The criteria are tighter for W decays, where the background is larger. Muons are found offline by searching for tracks reconstructed in the muon spectrometer with $|\eta| < 2.7$.

The charged leptons that are used to reconstruct the vector boson candidate are required to satisfy $p_T > 20$ GeV in the $ZH \rightarrow \ell^+ \ell^- b\bar{b}$ channel, while this cut is increased to $p_T > 25$ GeV in the $WH \rightarrow \ell\nu b\bar{b}$ channel in order to be above the trigger threshold, and maintain a high trigger efficiency. In both cases, the leptons must be central ($|\eta| < 2.47$ for electrons and $|\eta| < 2.5$ for muons) and have a matching track in the inner detector (with a coverage up to $|\eta| < 2.5$) that is consistent with originating from the primary vertex.

In order to suppress background from semileptonic heavy-flavour hadron decays, the leptons are required to be isolated. In the $ZH \rightarrow \ell^+ \ell^- b\bar{b}$ and $WH \rightarrow \ell\nu b\bar{b}$ channels the sum of the transverse momenta of all charged tracks (other than those of the charged leptons) reconstructed in the inner detector within a cone of $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} < 0.2$ from each charged lepton is required to be less than 10% of the transverse momentum of the lepton itself. In the $WH \rightarrow \ell\nu b\bar{b}$ channel, the isolation requirement is strengthened by requiring in addition that the sum of all transverse energy deposits in the calorimeter within a cone of $\Delta R < 0.3$ from the charged lepton be less than 14% of the transverse energy of the lepton itself.

In order to suppress the top-quark background in the $ZH \rightarrow \nu\bar{\nu} b\bar{b}$ channel, events containing electrons with $|\eta| < 2.47$ and $p_T > 10$ GeV, or muons with $|\eta| < 2.7$ and $p_T > 10$ GeV are removed. Similar requirements are applied on any additional lepton reconstructed in the $WH \rightarrow \ell\nu b\bar{b}$ channel, but the minimum lepton p_T is increased to 20 GeV if the additional lepton has the same charge as, or a different flavour than the signal lepton. Events with forward electrons [39] ($2.47 < |\eta| < 4.5$) with $p_T > 20$ GeV are also removed in the $WH \rightarrow \ell\nu b\bar{b}$ channel.

Jets are reconstructed from energy clusters in the calorimeter using the anti- k_r algorithm [40] with a radius parameter of 0.4. Jet energies are calibrated using p_T - and η -dependent correction factors based on MC simulation and validated with data [41]. A further correction is applied when calculating the di-jet invariant mass, as described in Section 5 below. The contribution from jets originating from other collisions in the same bunch crossing is reduced by requiring that at least 75% of the summed transverse momentum of inner detector tracks (with $p_T > 0.4$ GeV) associated with the jet are compatible with originating from the

primary vertex. Furthermore, a jet is required to have no identified electron within $\Delta R \leq 0.4$. Only jets with $p_T > 25$ GeV and within the acceptance of the inner detector ($|\eta| < 2.5$) are used to reconstruct Higgs boson candidates. Events containing additional jets are rejected in the $WH \rightarrow \ell\nu b\bar{b}$ analysis, to suppress backgrounds characterized by additional hadronic activity. To do this, jets are counted using the following criteria: $p_T > 20$ GeV and $|\eta| < 4.5$.

Jets which originate from b quarks can be distinguished from other jets by the relatively long lifetime of hadrons containing b quarks. Such jets are primarily identified (“ b -tagged”) by reconstructing one or more secondary decay vertices from tracks within the jet, using either an inclusive vertex reconstruction algorithm or a cascade $b \rightarrow c$ -hadron decay chain vertex fit, or by combining the distances of closest approach to the primary event vertex (impact parameters) of tracks in the jet [42–45]. The information from the vertex and impact parameter based algorithms is combined into a single discriminant w by using an artificial neural network, which is trained based on a set of samples of simulated events, such that a jet with higher w is more likely to be a b jet. A selection cut on w is applied, resulting in an efficiency of about 70% for identifying true b jets, of about 20% for c jets and about 0.8% for light jets, as evaluated in simulated $t\bar{t}$ events. The b -tagging efficiency and rejection factors in the simulation are corrected to the respective measurements in data by the use of appropriate scale factors. These correspond to corrections of around 5 to 15% for b jets, 20% for c jets, and around 50% for light jets.

The E_T^{miss} magnitude and direction are measured from the vector sum of the transverse momentum vectors associated with clusters of energy reconstructed in the calorimeters with $|\eta| < 4.9$ [46]. A correction is applied to the energy of those clusters that are associated with a reconstructed physical object (jet, electron, τ -lepton, photon). Reconstructed muons are also included in the sum, and any calorimeter energy deposits associated with them are excluded. To supplement the calorimeter-based definition of E_T^{miss} in the $ZH \rightarrow \nu\bar{\nu}b\bar{b}$ channel, the track-based missing transverse momentum, p_T^{miss} , is calculated from the vector sum of the transverse momenta of inner detector tracks associated with the primary vertex [47].

5. Event selection

Events in the $ZH \rightarrow \ell^+\ell^-b\bar{b}$ channel are required to contain exactly two same-flavour leptons. The two leptons must be oppositely charged in the case of muons. This is not required for electrons since energy losses from showering in material in the inner detector lead to a higher charge misidentification probability. The invariant mass of the lepton pair must be in the range $83 \text{ GeV} < m_{\ell\ell} < 99 \text{ GeV}$. A requirement of $E_T^{\text{miss}} < 50 \text{ GeV}$ reduces the background from top-quark production.

Events in the $WH \rightarrow \ell\nu b\bar{b}$ channel are required to contain a single charged lepton and $E_T^{\text{miss}} > 25 \text{ GeV}$. A requirement on the transverse mass² of $m_T > 40 \text{ GeV}$ is imposed to suppress the multijet background.

The $ZH \rightarrow \nu\bar{\nu}b\bar{b}$ selection requires $E_T^{\text{miss}} > 120 \text{ GeV}$. Requirements of $p_T^{\text{miss}} > 30 \text{ GeV}$ and on the difference in azimuthal angle between the directions of E_T^{miss} and p_T^{miss} , $\Delta\phi(E_T^{\text{miss}}, p_T^{\text{miss}}) < \pi/2$, are imposed to suppress events with poorly measured E_T^{miss} . These help to suppress the multijet background, which is dominated by

one or more jets being mismeasured by the calorimeter. A cut on the difference in azimuthal angle between E_T^{miss} and the nearest jet $\min(\Delta\phi(E_T^{\text{miss}}, \text{jet})) > 1.8$ is applied to further reduce the multijet background.

The transverse momentum of the vector boson, p_T^V , is reconstructed from the two leptons in the $ZH \rightarrow \ell^+\ell^-b\bar{b}$ channel, from the lepton and E_T^{miss} in the $WH \rightarrow \ell\nu b\bar{b}$ channel and from E_T^{miss} in the $ZH \rightarrow \nu\bar{\nu}b\bar{b}$ channel.

Events in all channels are required to contain exactly two b -tagged jets, of which one must have $p_T > 45 \text{ GeV}$ and the other $p_T > 25 \text{ GeV}$. If p_T^V is less than 200 GeV the two b -tagged jets are required to have a separation of $\Delta R > 0.7$, to reduce $W + \text{jet}$ and $Z + \text{jet}$ backgrounds. Additionally, in the $ZH \rightarrow \nu\bar{\nu}b\bar{b}$ channel a cut on the separation between the two jets of $\Delta R < 2.0$ ($\Delta R < 1.7$) for $p_T^V < 160 \text{ GeV}$ ($p_T^V > 160 \text{ GeV}$) is applied to reduce the multijet background. Events in the $ZH \rightarrow \ell^+\ell^-b\bar{b}$ channel may contain additional non- b -tagged jets, while in the $WH \rightarrow \ell\nu b\bar{b}$ and $ZH \rightarrow \nu\bar{\nu}b\bar{b}$ channels, events with additional jets are rejected to further suppress top-quark background. In the $WH \rightarrow \ell\nu b\bar{b}$ analysis, where the top-quark background is dominant, events containing additional jets with $|\eta| < 4.5$ and $p_T > 20 \text{ GeV}$ are rejected, while in the $ZH \rightarrow \nu\bar{\nu}b\bar{b}$ channel the selection is restricted to jets with $|\eta| < 2.5$ and $p_T \geq 25 \text{ GeV}$.

In the $ZH \rightarrow \nu\bar{\nu}b\bar{b}$ analysis, further cuts are applied on the azimuthal angle between E_T^{miss} and the reconstructed transverse momentum of the $b\bar{b}$ system, $\Delta\phi(b\bar{b}, E_T^{\text{miss}})$, to further reject multijet background. The $ZH \rightarrow \nu\bar{\nu}b\bar{b}$ signal, where the Higgs and Z bosons recoil against each other, is characterized by large values of this angle. The cuts of $\Delta\phi(b\bar{b}, E_T^{\text{miss}}) > 2.7$ for $120 < p_T^V < 160 \text{ GeV}$ and $\Delta\phi(b\bar{b}, E_T^{\text{miss}}) > 2.9$ for $p_T^V \geq 160 \text{ GeV}$ were established from MC-based optimization studies.

A search for $H \rightarrow b\bar{b}$ decays is performed by looking for an excess of events above the background expectation in the invariant mass distribution of the b -jet pair ($m_{b\bar{b}}$). The value of the reconstructed $m_{b\bar{b}}$ is scaled by a factor of 1.05, obtained from MC-based studies, to account on average for e.g. losses due to soft muons and neutrinos from b and c hadron decays. To increase the sensitivity of the search, this distribution is examined in bins of p_T^V . As the expected signal is characterized by a relatively hard p_T^V spectrum, the signal to background ratio increases with p_T^V . The $ZH \rightarrow \ell^+\ell^-b\bar{b}$ and $WH \rightarrow \ell\nu b\bar{b}$ channels are examined in four bins of the transverse momentum of the reconstructed W or Z boson, given by: $p_T^V < 50 \text{ GeV}$, $50 \leq p_T^V < 100 \text{ GeV}$, $100 \leq p_T^V < 200 \text{ GeV}$ and $p_T^V \geq 200 \text{ GeV}$. In the $ZH \rightarrow \nu\bar{\nu}b\bar{b}$ search three bins are defined: $120 < p_T^V < 160 \text{ GeV}$, $160 \leq p_T^V < 200 \text{ GeV}$ and $p_T^V \geq 200 \text{ GeV}$. The expected signal to background ratios for a Higgs boson signal with $m_H = 120 \text{ GeV}$ vary from about 1% in the lowest p_T^V bins to about 10–15% in the highest p_T^V bins. For this Higgs boson mass, 5.0% and 2.4% of the $ZH \rightarrow \ell^+\ell^-b\bar{b}$ and $WH \rightarrow \ell\nu b\bar{b}$ events are expected to pass the respective analysis selections, with negligible contributions from other final states. On the other hand, the $ZH \rightarrow \nu\bar{\nu}b\bar{b}$ analysis has a non-negligible contribution from $WH \rightarrow \ell\nu b\bar{b}$: 2.1% of the $ZH \rightarrow \nu\bar{\nu}b\bar{b}$ signal and 0.2% of the $WH \rightarrow \ell\nu b\bar{b}$ signal are expected to pass the analysis selection.

6. Background estimation

Backgrounds are estimated using a combination of data-driven and MC-based techniques. Significant sources of background include top, $W + \text{jet}$, $Z + \text{jet}$, diboson and multijet production. The dominant background in the $ZH \rightarrow \ell^+\ell^-b\bar{b}$ channel is $Z + \text{jet}$ production. In the $WH \rightarrow \ell\nu b\bar{b}$ channel both the top-quark and

² The transverse mass (m_T) is defined from the transverse momenta and the azimuthal angles of the charged lepton (p_T^ℓ and ϕ^ℓ) and neutrino (p_T^ν and ϕ^ν): $m_T = \sqrt{2p_T^\ell p_T^\nu (1 - \cos(\phi^\ell - \phi^\nu))}$, where $p_T^\nu = E_T^{\text{miss}}$.

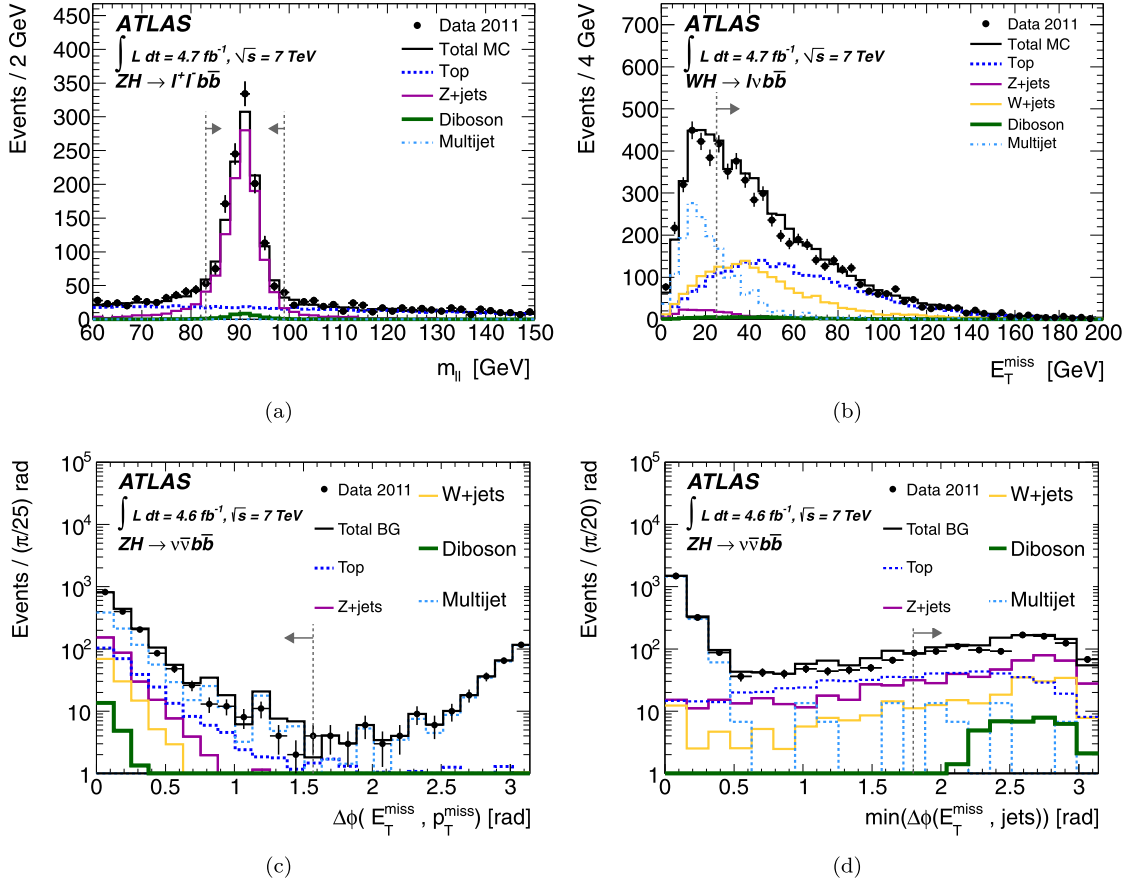


Fig. 1. (a) The dilepton invariant mass distribution in the $ZH \rightarrow \ell^+\ell^-b\bar{b}$ channel, (b) the missing transverse energy without the m_T requirement in the $WH \rightarrow \ell\nu b\bar{b}$ channel, (c) the azimuthal angle separation between E_T^{miss} and p_T^{miss} and (d) the minimum azimuthal separation between E_T^{miss} and any jet in the $ZH \rightarrow \nu\bar{\nu}b\bar{b}$ channel. All distributions are shown for events containing two b -tagged jets. The various Monte Carlo background distributions are normalized to data sidebands and control distributions and the multijet background is entirely estimated from data as described in the text. The vertical dashed lines correspond to the values of the cuts applied in each analysis, and the horizontal arrows indicate the events selected by each cut.

W + jet production are important. In the $ZH \rightarrow \nu\bar{\nu}b\bar{b}$ channel, there is a significant contribution from top, W + jet, Z + jet and diboson production. Multijet production is a negligible background, except for the $WH \rightarrow \ell\nu b\bar{b}$ channel.

The flavour composition of the W + jet and Z + jet backgrounds is determined partially from data.

The shapes of the $m_{b\bar{b}}$ distribution of the top, W + jet and Z + jet backgrounds are taken from MC simulation, with the respective normalizations being determined from data. The ratio of single-top to top-pair production is taken from NLO QCD computations [48].

The flavour composition of the W + jet and Z + jet samples is determined using templates produced from three exclusive MC samples containing at least one true b jet, at least one true c jet, or only light jets. The relative normalizations of the three components are adjusted by fitting the distribution of the b -tagging discriminating variable w found in MC simulation to the distribution found in control data samples dominated by W + jet and Z + jet events. For the Z + jet sample this is a Z reconstructed from 2 electrons or muons and 2 jets. The W + jet sample is a W and 2 jets with an additional cut on the invariant mass of the 2 jets of less than 80 GeV to reduce top background. Once the relative normalizations of the flavour components have been fixed, the overall normalizations are determined from data in a separate step.

Sidebands in the $m_{b\bar{b}}$ distribution, defined by selecting events with $m_{b\bar{b}} < 80$ GeV or $150 \text{ GeV} < m_{b\bar{b}} < 250$ GeV along with the standard event selection, are used to normalize the Z + jet, W + jet and top backgrounds.

In addition, two control regions which are dominated by top-quark production are used to further constrain the normalization of the top background. The ZH top control region selects events from the sidebands of the Z boson mass peak: $m_{\ell\ell} \in [60 \text{ GeV}, 76 \text{ GeV}] \cup [106 \text{ GeV}, 150 \text{ GeV}]$ with $E_T^{\text{miss}} > 50$ GeV, while the WH top control region selects W + 3 jet events with two b -tagged jets.

The normalizations of the Z + jet, W + jet and top-quark backgrounds are determined in the $ZH \rightarrow \ell^+\ell^-b\bar{b}$ or $WH \rightarrow \ell\nu b\bar{b}$ channels, by simultaneous fits to the sidebands of the $m_{b\bar{b}}$ distributions, and either the ZH or WH top control regions defined above. In the WH sideband fit, the normalizations of the top-quark, the W + 2 jet and the W + 3 jet distributions are varied. In the ZH sideband fit, the normalizations of the top-quark and Z + jet backgrounds are left floating. The normalizations of the remaining sub-leading backgrounds are left fixed in the fit at their expectation values from Monte Carlo predictions, except for multijet production which is estimated from data. The relative data to MC normalization factors for top-quark background agree with unity to within 20% in both the $ZH \rightarrow \ell^+\ell^-b\bar{b}$ or $WH \rightarrow \ell\nu b\bar{b}$ sideband fits. The normalization of the top-quark background in the $ZH \rightarrow \ell^+\ell^-b\bar{b}$ signal region is based on the ZH sideband and control region fit result. The normalization of the top-quark background in the $WH \rightarrow \ell\nu b\bar{b}$ and $ZH \rightarrow \nu\bar{\nu}b\bar{b}$ signal regions is based on the WH sideband and control region fit result. Monte Carlo simulation is used to estimate the shape of the Z + jet (W + jet) background, while its normalization is determined in the

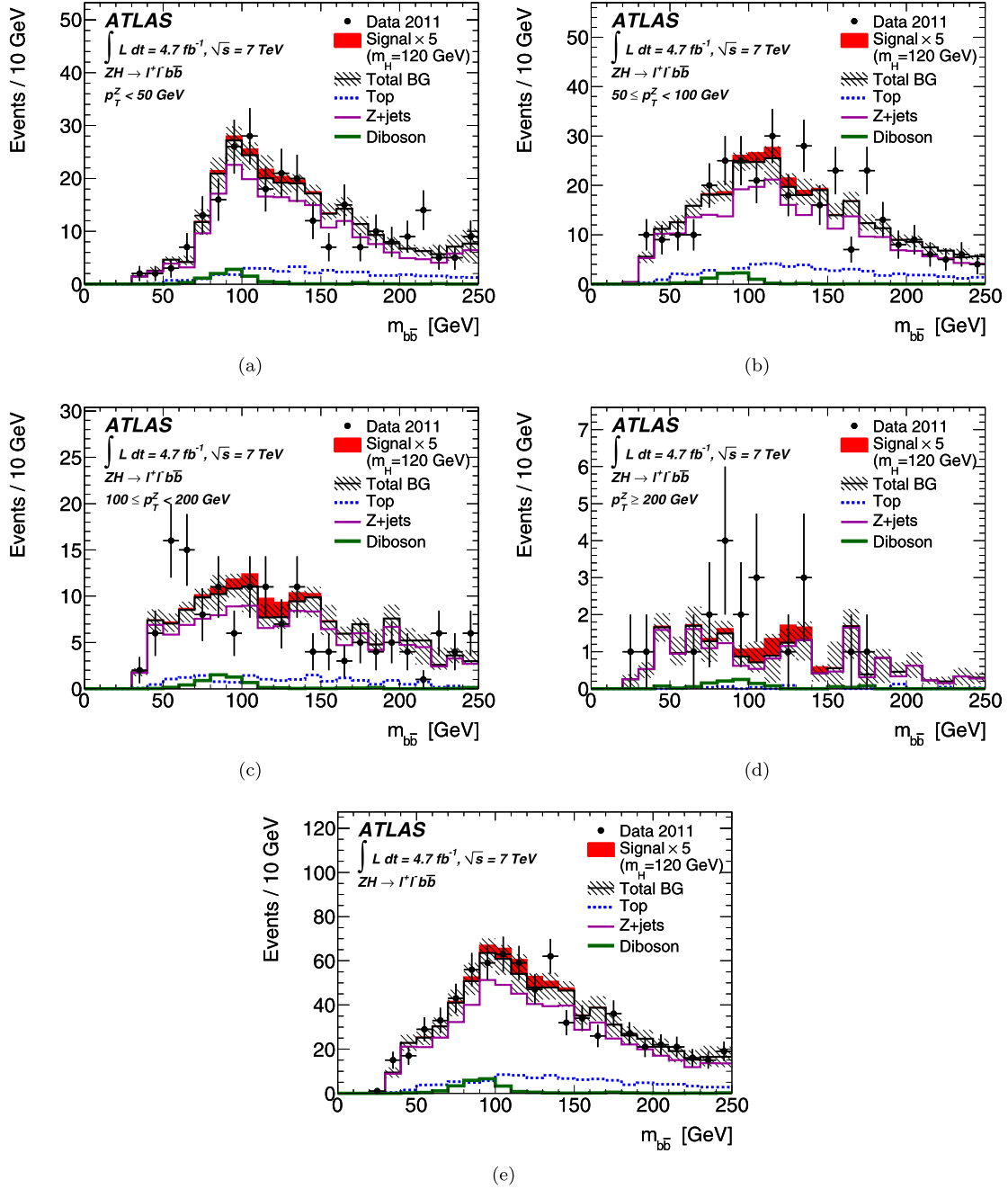


Fig. 2. The invariant mass $m_{b\bar{b}}$ for $ZH \rightarrow \ell^+\ell^-b\bar{b}$ shown for the different p_T^Z bins: (a) $0 < p_T^Z < 50$ GeV, (b) $50 \leq p_T^Z < 100$ GeV, (c) $100 \leq p_T^Z < 200$ GeV, (d) $p_T^Z \geq 200$ GeV and (e) for the combination of all p_T^Z bins. The signal distributions are shown for $m_H = 120$ GeV and are enhanced by a factor of five for visibility. The shaded area indicates the total uncertainty on the background prediction. For better visibility, the signal histogram is stacked onto the total background, unlike the various background components which are simply overlaid in the distribution.

$ZH \rightarrow \ell^+\ell^-b\bar{b}$ ($WH \rightarrow \ell\nu b\bar{b}$) sidebands to the signal regions of all three channels. The MC to data normalization factors for W + jet and Z + jet range from 0.8 to 2.4 depending on jet flavour and multiplicity. The normalization factors are applied to the MC in several additional control samples with selections to enhance the Z , W or top-quark contributions. After these corrections are applied, good agreement is found with the data in both shape and normalization within the statistical and systematic uncertainties.

The backgrounds from multijet events are estimated entirely from collision data. For the $ZH \rightarrow \ell^+\ell^-b\bar{b}$ channel, the multijet background normalization is determined from the sidebands of the $m_{\ell\ell}$ distribution in events containing at least two jets, and is found

to contribute less than 1% and is therefore neglected. Multijet E_T^{miss} templates for the $WH \rightarrow \ell\nu b\bar{b}$ channel are obtained by selecting events with lepton candidates failing the charged lepton analysis selection, but satisfying looser lepton selections. The normalization is determined by fitting these templates to the E_T^{miss} distribution. A 30% uncertainty is determined from a comparison between the normalized templates and the data in a multijet-dominated control region, defined by requiring $E_T^{\text{miss}} < 25$ GeV and $m_T < 40$ GeV.

In the $ZH \rightarrow \nu\bar{\nu}b\bar{b}$ channel, the multijet background is estimated using three control regions defined using two variables, $\Delta\phi(E_T^{\text{miss}}, p_T^{\text{miss}})$ and $\min(\Delta\phi(E_T^{\text{miss}}, \text{jets}))$, which showed no appreciable correlation. The ratio of events with $\Delta\phi(E_T^{\text{miss}}, \text{jet}) > 1.8$

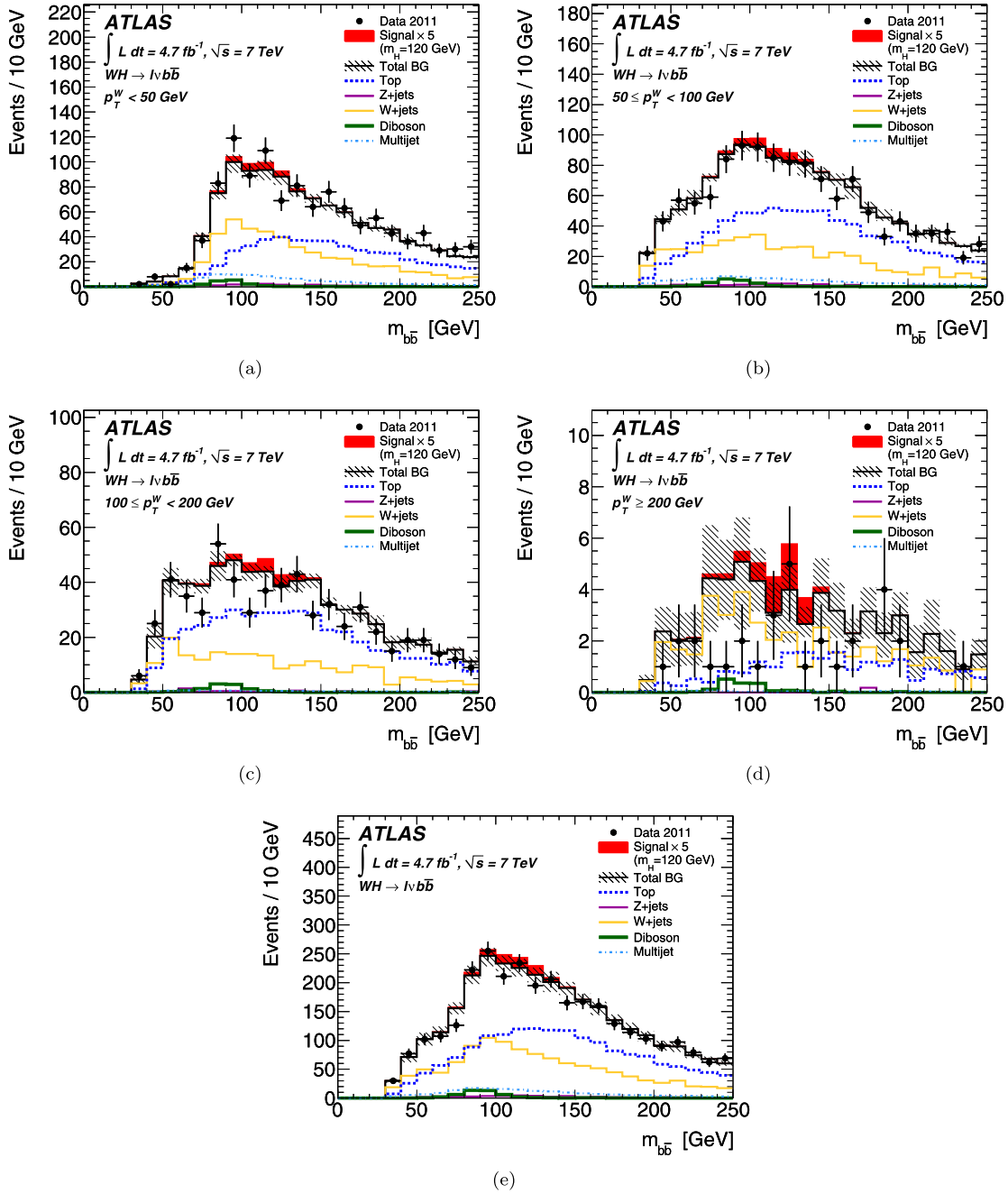


Fig. 3. The invariant mass $m_{b\bar{b}}$ for $WH \rightarrow \ell\nu b\bar{b}$ shown for the different p_T^W bins: (a) $0 < p_T^W < 50$ GeV, (b) $50 \leq p_T^W < 100$ GeV, (c) $100 \leq p_T^W < 200$ GeV, (d) $p_T^W \geq 200$ GeV and (e) for the combination of all p_T^W bins. The signal distributions are shown for $m_H = 120$ GeV and are enhanced by a factor of five for visibility. The shaded area indicates the total uncertainty on the background prediction. For better visibility, the signal histogram is stacked onto the total background, unlike the various background components which are simply overlaid in the distribution.

to those with $\min(\Delta\phi(E_T^{\text{miss}}, \text{jet})) < 1.8$ is determined for events with $\Delta\phi(E_T^{\text{miss}}, p_T^{\text{miss}}) > \pi/2$. This ratio is then applied to events with $\Delta\phi(E_T^{\text{miss}}, p_T^{\text{miss}}) < \pi/2$ to estimate the multijet contamination in the signal region. Upper estimates of the multijet contamination in the signal region are found to be 0.85, 0.04 and 0.26 events for $120 < p_T^V < 160$ GeV, $160 \leq p_T^V < 200$ GeV and $p_T^V \geq 200$ GeV, respectively. The accuracy of the estimate is limited by the number of events in the control regions.

The distribution of $m_{\ell\ell}$ in the $ZH \rightarrow \ell^+\ell^-b\bar{b}$ channel is shown in Fig. 1(a) after all analysis requirements have been applied (except for the di-lepton mass cut), including the requirement of two b -tagged jets. The signal region is seen to be dominated

by $Z + \text{jet}$ with smaller contributions from top-quark and diboson production. The E_T^{miss} distribution in the $WH \rightarrow \ell\nu b\bar{b}$ channel is shown in Fig. 1(b) after all requirements, except for the m_T and E_T^{miss} cuts. The signal region is seen to have large contributions from top-quark production and $W + \text{jet}$, with smaller contributions from the multijet background, $Z + \text{jet}$ and diboson production. Figs. 1(c) and 1(d) show the $\Delta\phi(E_T^{\text{miss}}, p_T^{\text{miss}})$ and $\min(\Delta\phi(E_T^{\text{miss}}, \text{jet}))$ distributions for the $ZH \rightarrow \nu\bar{\nu}b\bar{b}$ channel, after all requirements except for those applied to these variables. The multijet background shape in Fig. 1(c) is obtained from data events with $\min(\Delta\phi(E_T^{\text{miss}}, \text{jet})) < 0.4$, after subtracting the remaining backgrounds, and normalized to the data in the region

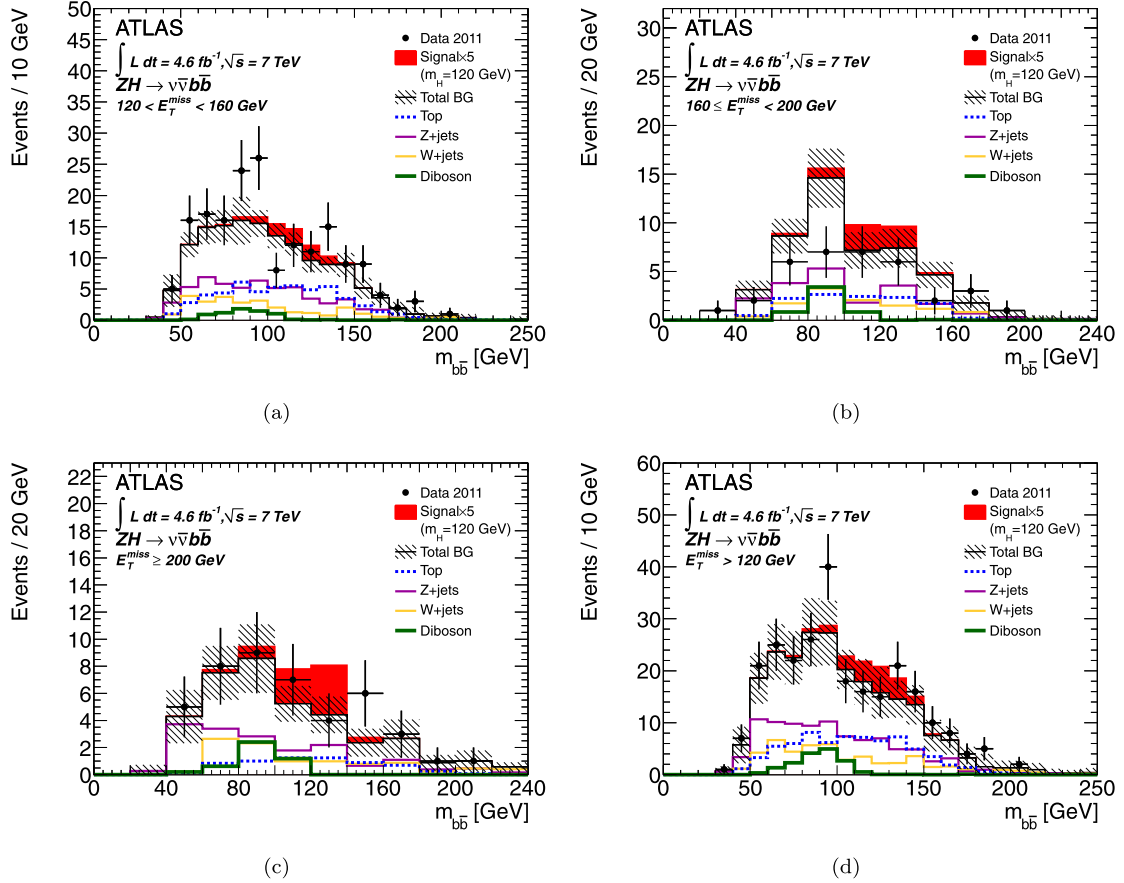


Fig. 4. The invariant mass m_{bb} for $ZH \rightarrow \nu\bar{\nu}b\bar{b}$ shown for the different p_T^Z bins: (a) $120 < p_T^Z < 160$ GeV, (b) $160 \leq p_T^Z < 200$ GeV, (c) $p_T^Z \geq 200$ GeV and (d) for the combination of all p_T^Z bins. The signal distributions are shown for $m_H = 120$ GeV and are enhanced by a factor of five for visibility. The shaded area indicates the total uncertainty on the background prediction. For better visibility, the signal histogram is stacked onto the total background, unlike the various background components which are simply overlaid in the distribution.

defined by $\Delta\phi(E_T^{\text{miss}}, p_T^{\text{miss}}) > \pi/2$. In Fig. 1(d), the multijet shape is obtained from events with $\Delta\phi(E_T^{\text{miss}}, p_T^{\text{miss}}) > \pi/2$ and normalized to data events with $\min(\Delta\phi(E_T^{\text{miss}}, \text{jet})) < 0.4$.

It can be seen that the requirements on these variables effectively reduce the multijet background. The signal region has large contributions from Z +jet and top, with smaller contributions from the W +jet, diboson production and multijet backgrounds. For all distributions, the data are reasonably well described by MC simulation and the multijet background, which was determined from data.

7. Systematic uncertainties

The sources of systematic uncertainty considered are those affecting the various efficiencies (reconstruction, identification, selection), as well as the momentum or energy of physics objects, the normalization and shape of the m_{bb} distribution of the signal and background processes, and the integrated luminosity. Among these, the leading instrumental uncertainties for all channels are related to the uncertainty on the b -tagging efficiency, which varies between 5% and 19% depending on the b -tagged jet p_T [44], and the jet energy scale (JES) for b -tagged jets which varies between 3% and 14% depending on the jet p_T and η [49]. The p_T dependence of the b -tagging efficiency has been considered, based on the full covariance matrix of the measured b -tagging efficiency in jet p_T intervals [44]. The uncertainty on the flavour composition of the Z +jet and W +jet background is estimated by varying the

relative fraction of Z +c-jets and W +c-jets derived from the fit described in Section 6 by 30%.

The uncertainties on the SM Higgs boson inclusive cross sections are evaluated by varying the factorization and renormalization scales, and by taking into account the uncertainties on the PDFs, on the strong coupling constant and on the $H \rightarrow b\bar{b}$ branching fraction. These uncertainties are estimated to be $\approx 4\%$ for both WH and ZH production and are treated according to the recommendations given in Refs. [21,50,51]. Additional uncertainties are considered, as a function of the transverse momentum of the W and Z bosons, which range from $\approx 4\%$ to $\approx 8\%$, depending on channel and on the p_T^W or p_T^Z interval. These correspond to the difference between the inclusive and differential electroweak corrections [22,12], and to differences in acceptance between the PYTHIA and POWHEG+HERWIG generators. The latter arise mainly from the perturbative QCD model uncertainty caused by rejecting events with three or more jets in the $WH \rightarrow \ell\nu b\bar{b}$ and $ZH \rightarrow \nu\bar{\nu}b\bar{b}$ analyses.

The uncertainties on the normalizations of the Z +jet, W +jet and top-quark backgrounds are taken from the statistical uncertainties on the fits to control regions and m_{bb} sidebands (see Section 6) and from variations of the nominal fit result induced by the remaining sources of systematic uncertainty. The resulting normalization uncertainties are applied to the $ZH \rightarrow \nu\bar{\nu}b\bar{b}$ channel. A correlation between the normalizations of the W +jet and top-quark backgrounds is introduced by the simultaneous fit to the m_{bb} sidebands and the WH top control region in the $WH \rightarrow \ell\nu b\bar{b}$ channel. This correlation is taken into account when transferring

Table 1
Number of data, simulated signal, and estimated background events in each bin of p_T^V for the $WH \rightarrow \ell\nu b\bar{b}$, $ZH \rightarrow \ell^+\ell^-b\bar{b}$ and $ZH \rightarrow \nu\bar{\nu}b\bar{b}$ channels. The signal corresponds to a Higgs boson mass of $m_H = 120$ GeV. The number of events is shown for the full signal region ($m_{b\bar{b}} \in [80 \text{ GeV}, 150 \text{ GeV}]$). Background sources found to be negligible are signalled with “–”. Relative systematic uncertainties on the hypothesized signal and estimated total background are shown.

bin	$ZH \rightarrow \ell^+\ell^-b\bar{b}$				$WH \rightarrow \ell\nu b\bar{b}$				$ZH \rightarrow \nu\bar{\nu}b\bar{b}$		
	p_T^V [GeV]				p_T^V [GeV]				p_T^V [GeV]		
	0–50	50–100	100–200	>200	0–50	50–100	100–200	>200	120–160	160–200	>200
Number of events for $80 < m_{b\bar{b}} < 150$ GeV											
Signal	1.3 ± 0.1	1.8 ± 0.2	1.6 ± 0.2	0.4 ± 0.1	5.0 ± 0.6	5.1 ± 0.6	3.7 ± 0.4	1.2 ± 0.2	2.0 ± 0.2	1.2 ± 0.1	1.5 ± 0.2
Top	17.4	24.1	7.3	0.2	229.9	342.7	201.3	8.2	35.2	8.3	4.1
W + jets	–	–	–	–	285.9	193.6	85.8	17.5	13.2	7.8	4.8
Z + jets	123.2	119.9	55.9	6.1	11.1	10.5	2.8	0.0	31.5	11.9	7.1
Diboson	7.2	5.6	3.6	0.7	12.6	11.9	7.8	1.4	4.6	4.3	3.6
Multijet	–	–	–	–	55.5	38.2	3.6	0.2	–	–	–
Total BG	148 ± 10	150 ± 6	67 ± 4	6.9 ± 1.2	596 ± 23	598 ± 16	302 ± 10	27 ± 5	85 ± 8	32 ± 3	20 ± 3
Data	141	163	61	13	614	588	271	15	105	22	25
Components of the relative systematic uncertainties of the background [%]											
b -tag eff	1.4	1.0	0.3	4.8	0.9	1.3	0.9	7.2	4.1	4.2	5.5
BG norm	3.6	3.4	3.6	3.8	2.7	1.8	1.8	4.5	2.7	2.2	3.2
Jets/ E_T^{miss}	2.1	1.2	2.7	5.1	1.5	1.4	2.1	9.5	7.7	8.2	12.1
Leptons	0.2	0.3	1.1	3.4	0.1	0.2	0.2	1.7	0.0	0.0	0.0
Luminosity	0.2	0.1	0.2	0.4	0.1	0.1	0.1	0.2	0.2	0.5	0.7
Pileup	0.9	1.6	0.5	1.3	0.1	0.2	0.8	0.5	1.6	2.5	3.0
Theory	5.2	1.3	4.7	14.9	2.2	0.3	1.6	14.8	2.9	4.0	7.7
Total BG	6.9	4.3	6.6	17.3	3.9	2.7	3.4	19.6	9.7	10.6	16.0
Components of the relative systematic uncertainties of the signal [%]											
b -tag eff	6.4	6.4	7.0	13.7	6.4	6.4	7.0	12.1	7.1	8.2	9.2
Jets/ E_T^{miss}	4.9	3.2	3.5	5.5	5.8	4.6	3.7	3.3	7.3	5.1	6.3
Leptons	0.9	1.2	1.7	2.6	3.0	3.0	3.0	3.2	0.0	0.0	0.0
Luminosity	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9
Pileup	0.5	1.1	1.8	2.2	1.2	0.3	0.3	1.6	0.2	0.2	0.0
Theory	4.6	3.6	3.3	5.3	4.4	4.7	5.0	8.0	3.3	3.3	5.6
Total signal	10.1	9.1	9.6	16.5	11.4	10.8	11.0	16.0	11.8	11.4	13.4

Table 2
The observed and expected 95% CL exclusion limits on the Higgs boson cross section for each channel, expressed in multiples of the SM cross section as a function of the hypothesized Higgs boson mass. The last two columns show the combined exclusion limits for the three channels.

Mass [GeV]	$ZH \rightarrow \ell^+\ell^-b\bar{b}$		$WH \rightarrow \ell\nu b\bar{b}$		$ZH \rightarrow \nu\bar{\nu}b\bar{b}$		Combined	
	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.
110	7.7	6.0	3.3	4.2	3.7	4.0	2.5	2.5
115	7.7	6.2	4.0	4.9	3.6	4.2	2.6	2.7
120	10.4	8.0	4.9	5.9	4.8	5.0	3.4	3.3
125	11.6	9.1	5.5	7.5	7.3	6.0	4.6	4.0
130	14.4	11.6	5.9	9.2	10.3	7.6	5.5	4.9

to the $ZH \rightarrow \nu\bar{\nu}b\bar{b}$ channel the uncertainties on the normalization of these backgrounds.

The background normalization corrections are determined in an inclusive way, using all selected events in the $ZH \rightarrow \ell^+\ell^-b\bar{b}$ and $WH \rightarrow \ell\nu b\bar{b}$ channels, and the shape of the $m_{b\bar{b}}$ and p_T^V distributions are in each case taken from the MC simulation. Therefore, a possible mismodelling of the underlying $m_{b\bar{b}}$ and p_T^V distributions, as predicted by the MC generators, is also considered. An uncertainty due to the shape of the p_T^Z distribution for the Z + jet background in the $ZH \rightarrow \ell^+\ell^-b\bar{b}$ channel is estimated by finding variations of the MC p_T^Z distribution in the $m_{b\bar{b}}$ sidebands which cover any differences between MC simulation and data. The $m_{b\bar{b}}$ distribution of simulated Z + jet events is then reweighted according to these variations, to estimate the effect on the final results. An uncertainty due to the modelling of W + jet in the $WH \rightarrow \ell\nu b\bar{b}$ channel is estimated by reweighting the p_T^W and $m_{b\bar{b}}$ distributions of simulated W + jet events by variations motivated by a comparison of different theoretical models (POWHEG + PYTHIA, POWHEG + HERWIG, aMC@NLO + HERWIG [52] and ALPGEN + HERWIG). Theoretical uncertainties of 11% and 15%

are applied to the normalization of the diboson samples and the single-top sample, respectively. The normalization uncertainty for the multijet background is taken to be 30% for $WH \rightarrow \ell\nu b\bar{b}$, as described in Section 6. For $ZH \rightarrow \ell^+\ell^-b\bar{b}$ and $ZH \rightarrow \nu\bar{\nu}b\bar{b}$ this background is found to be negligible. The uncertainty in the integrated luminosity has been estimated to be 3.9% [15,16]. This uncertainty is applied only to the simulated signal and to the diboson background, which are not normalized to the data. Where it is applied, this systematic uncertainty is assumed to be correlated among the different samples.

8. Results

The analysis is performed for five Higgs boson mass hypotheses between 110 GeV and 130 GeV and the signal hypothesis is tested based on a fit to the invariant mass distribution of the b -jet pair, $m_{b\bar{b}}$, in the signal region ($80 < m_{b\bar{b}} < 150$ GeV). The $m_{b\bar{b}}$ distribution is shown in Figs. 2–4 for each channel, separately for different ranges of p_T^V . The data distributions are overlaid with the expectations from the MC simulation and data-driven backgrounds.

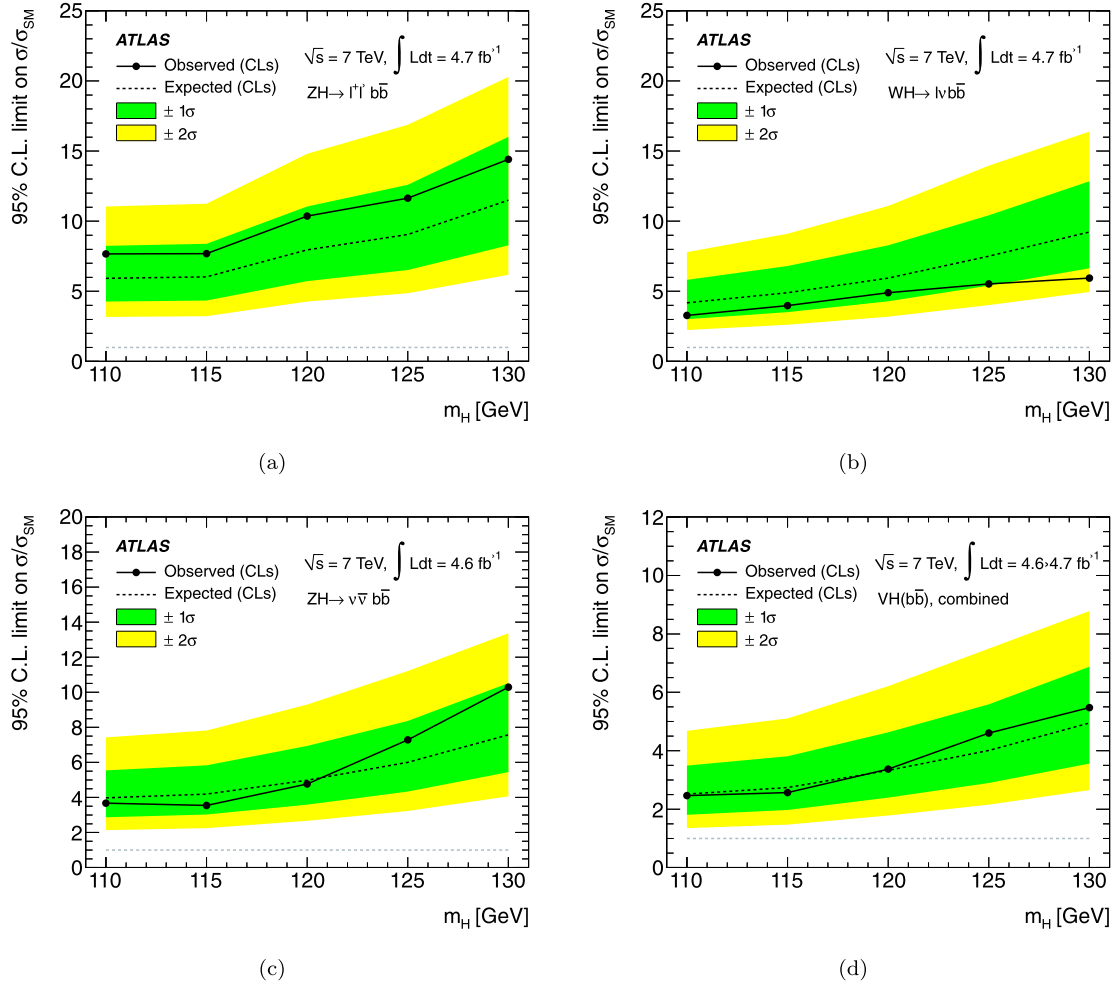


Fig. 5. Expected (dashed) and observed (solid line) exclusion limits for (a) the $ZH \rightarrow \ell^+\ell^-b\bar{b}$, (b) $WH \rightarrow \ell\nu b\bar{b}$ and (c) $ZH \rightarrow \nu\bar{\nu}b\bar{b}$ channels expressed as the ratio to the SM Higgs boson cross section, using the profile-likelihood method with CL_s . The dark (green in the web version) and light (yellow in the web version) areas represent the $\pm 1\sigma$ and $\pm 2\sigma$ ranges of the expectation in the absence of a signal. (d) shows the 95% CL exclusion limits obtained from the combination of the three channels.

Within the experimental uncertainty, the data show no excess over the background expectation. The signal shape is dominated by the experimental resolution on the jet energy measurement. The $m_{b\bar{b}}$ resolution for signal events is about 16 GeV on average.

The number of events in the signal region selected in data is shown in Table 1 for each channel. The expected number of signal events for $m_H = 120$ GeV is also shown, along with the corresponding estimated number of background events. Also shown are the relative systematic uncertainties on the signal and total background yields arising from the following sources: b -tagging efficiency and mis-tag rate, background normalization, jet and E_T^{miss} uncertainties, lepton reconstruction and identification, integrated luminosity, overlaid collision events (pileup), and uncertainties on the MC predictions (theory). Uncertainties on the shape of the $m_{b\bar{b}}$ distribution are also taken into account in the fit.

For each Higgs boson mass hypothesis, a one-sided upper limit is placed on the ratio of the Higgs boson production cross section to its SM value, $\mu = \sigma/\sigma_{\text{SM}}$, at the 95% CL. The exclusion limits are derived from the CL_s [53] treatment of the p -values computed with the profile likelihood ratio test statistic [54], as implemented in the RooStats program [55], using the binned distribution of $m_{b\bar{b}}$. The systematic uncertainties are treated by making the expected $m_{b\bar{b}}$ templates and sample normalizations dependent on additional fit parameters (“nuisance parameters”), one for each systematic uncertainty, which are then constrained with Gaussian

terms within their expected uncertainties. The dependence of the $m_{b\bar{b}}$ shapes on the nuisance parameters is described with bin-by-bin linear interpolation between the corresponding $+1\sigma$ or -1σ variations and the nominal case.

The resulting exclusion limits are listed in Table 2 for each channel and for the statistical combination of the three channels. They are also plotted in Fig. 5. The limits are expressed as the multiple of the SM Higgs boson production cross section which is excluded at 95% CL for each value of the Higgs boson mass. The observed upper limits range between 7.7 and 14.4 for the $ZH \rightarrow \ell^+\ell^-b\bar{b}$ channel, between 3.3 and 5.9 for the $WH \rightarrow \ell\nu b\bar{b}$ channel and between 3.7 and 10.3 for the $ZH \rightarrow \nu\bar{\nu}b\bar{b}$ channel, depending on the Higgs boson mass. The combined exclusion limit for the three channels together ranges from 2.5 to 5.5 times the SM cross section, depending on the Higgs boson mass. The limits include systematic uncertainties, the largest of which arise from the top, Z + jet, and W + jet background estimates, the b -tagging efficiency, and the jet energy scale. The systematic uncertainties weaken the limits by 25–40% depending on the search channel.

9. Summary

This Letter presents the results of a direct search by ATLAS for the SM Higgs boson produced in association with a W or Z boson. The following decay channels are considered: $ZH \rightarrow \ell^+\ell^-b\bar{b}$,

$WH \rightarrow \ell\nu b\bar{b}$ and $ZH \rightarrow \nu\bar{\nu}b\bar{b}$, where ℓ corresponds to an electron or a muon. The mass range $110 < m_H < 130$ GeV is examined for five Higgs boson mass hypotheses separated by 5 GeV steps. The three channels use datasets corresponding to $4.6\text{--}4.7 \text{ fb}^{-1}$ of pp collisions at $\sqrt{s} = 7$ TeV. No significant excess of events above the estimated backgrounds is observed. Upper limits on Higgs boson production, at the 95% CL, of 2.5 to 5.5 times the SM cross section are obtained in the mass range 110–130 GeV. The expected exclusion limits range between 2.5 and 4.9 for the same mass interval.

Acknowledgements

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

We acknowledge the support of ANPCyT, Argentina; YerPhI, Armenia; ARC, Australia; BMWF, Austria; ANAS, Azerbaijan; SSTC, Belarus; CNPq and FAPESP, Brazil; NSERC, NRC and CFI, Canada; CERN; CONICYT, Chile; CAS, MOST and NSFC, China; COLCIENCIAS, Colombia; MSMT CR, MPO CR and VSC CR, Czech Republic; DNRF, DNSRC and Lundbeck Foundation, Denmark; EPLANET and ERC, European Union; IN2P3-CNRS, CEA-DSM/IRFU, France; GNAS, Georgia; BMBF, DFG, HGF, MPG and AvH Foundation, Germany; GSRT, Greece; ISF, MINERVA, GIF, DIP and Benoziyo Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; FOM and NWO, Netherlands; RCN, Norway; MNiSW, Poland; GRICES and FCT, Portugal; MERYS (MECTS), Romania; MES of Russia and ROSATOM, Russian Federation; JINR; MSTB, Serbia; MSSR, Slovakia; ARRS and MVZT, Slovenia; DST/NRF, South Africa; MICINN, Spain; SRC and Wallenberg Foundation, Sweden; SER, SNSF and Cantons of Bern and Geneva, Switzerland; NSC, Taiwan; TAEK, Turkey; STFC, the Royal Society and Leverhulme Trust, United Kingdom; DOE and NSF, United States.

The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN and the ATLAS Tier-1 facilities at TRIUMF (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN-CNAF (Italy), NL-T1 (Netherlands), PIC (Spain), ASGC (Taiwan), RAL (UK) and BNL (USA) and in the Tier-2 facilities worldwide.

Open access

This article is published Open Access at [sciencedirect.com](http://www.sciencedirect.com). It is distributed under the terms of the Creative Commons Attribution License 3.0, which permits unrestricted use, distribution, and reproduction in any medium, provided the original authors and source are credited.

References

- [1] F. Englert, R. Brout, Phys. Rev. Lett. 13 (1964) 321, <http://dx.doi.org/10.1103/PhysRevLett.13.321>.
- [2] P.W. Higgs, Phys. Rev. Lett. 13 (1964) 508, <http://dx.doi.org/10.1103/PhysRevLett.13.508>.
- [3] G. Guralnik, C. Hagen, T. Kibble, Phys. Rev. Lett. 13 (1964) 585, <http://dx.doi.org/10.1103/PhysRevLett.13.585>.
- [4] ATLAS Collaboration, Phys. Lett. B 710 (2012) 49, arXiv:1202.1408, <http://dx.doi.org/10.1016/j.physletb.2012.02.044>.
- [5] CMS Collaboration, Phys. Lett. B 710 (2012) 26, arXiv:1202.1488, <http://dx.doi.org/10.1016/j.physletb.2012.02.064>.
- [6] L.E.P. Working, Phys. Lett. B 565 (2003) 61, arXiv:hep-ex/0306033, [http://dx.doi.org/10.1016/S0370-2693\(03\)00614-2](http://dx.doi.org/10.1016/S0370-2693(03)00614-2).
- [7] Tevatron New Phenomena, Higgs Working Group, Combined CDF and D0 search for Standard Model Higgs boson production with up to 10.0 fb^{-1} of data, arXiv:1203.3774.
- [8] T. Han, S. Willenbrock, Phys. Lett. B 273 (1991) 167, [http://dx.doi.org/10.1016/0370-2693\(91\)90572-8](http://dx.doi.org/10.1016/0370-2693(91)90572-8).

- [9] O. Brein, A. Djouadi, R. Harlander, Phys. Lett. B 579 (2004) 149.
- [10] M.L. Ciccolini, S. Dittmaier, M. Krämer, Phys. Rev. D 68 (2003) 073003.
- [11] A. Denner, et al., Electroweak corrections to Higgs-strahlung off W/Z bosons at the Tevatron and the LHC with HAWK, arXiv:1112.5142.
- [12] G. Ferrera, M. Grazzini, F. Tramontano, Phys. Rev. Lett. 107 (2011) 152003, arXiv:1107.1164, <http://dx.doi.org/10.1103/PhysRevLett.107.152003>.
- [13] J.M. Butterworth, A.R. Davison, M. Rubin, G.P. Salam, Phys. Rev. Lett. 100 (2008) 242001, arXiv:0802.2470, <http://dx.doi.org/10.1103/PhysRevLett.100.242001>.
- [14] CMS Collaboration, Phys. Lett. B 710 (2012) 284, arXiv:1202.4195, <http://dx.doi.org/10.1016/j.physletb.2012.02.085>.
- [15] ATLAS Collaboration, Eur. Phys. J. C 71 (2011) 1630, arXiv:1101.2185 [hep-ex].
- [16] ATLAS Collaboration, Luminosity determination in pp collisions at $\sqrt{s} = 7$ TeV using the ATLAS detector in 2011, ATLAS-CONF-2011-116.
- [17] ATLAS Collaboration, JINST 3 (2008) S08003.
- [18] T. Sjostrand, S. Mrenna, P.Z. Skands, JHEP 0605 (2006) 026, arXiv:hep-ph/0603175, <http://dx.doi.org/10.1088/1126-6708/2006/05/026>.
- [19] A. Sherstnev, R. Thorne, Eur. Phys. J. C 55 (2008) 553, arXiv:0711.2473, <http://dx.doi.org/10.1140/epjc/s10052-008-0610-x>.
- [20] ATLAS Collaboration, ATLAS tunes of PYTHIA6 and Pythia8 for MC11, ATLAS-PHYS-PUB-2011-009, <http://cdsweb.cern.ch/record/1363300>.
- [21] S. Dittmaier, C. Mariotti, G. Passarino, R. Tanaka (Eds.), LHC Higgs Cross Section Working Group, Handbook of LHC Higgs cross sections: 1. Inclusive observables, CERN-2011-002, arXiv:1101.0593.
- [22] S. Dittmaier, S. Dittmaier, C. Mariotti, G. Passarino, R. Tanaka, et al., Handbook of LHC Higgs Cross Sections: 2. Differential Distributions. Report of the LHC Higgs Cross Section Working Group, arXiv:1201.3084.
- [23] A. Djouadi, J. Kalinowski, M. Spira, Comput. Phys. Commun. 108 (1998) 56.
- [24] S. Alioli, et al., JHEP 0904 (2009) 002, arXiv:0812.0578.
- [25] P. Nason, C. Oleari, JHEP 1002 (2010) 037, arXiv:0911.5299.
- [26] C. Oleari, L. Reina, JHEP 1108 (2011) 061, arXiv:1105.4488, [http://dx.doi.org/10.1007/JHEP11\(2011\)040](http://dx.doi.org/10.1007/JHEP11(2011)040), [http://dx.doi.org/10.1007/JHEP08\(2011\)061](http://dx.doi.org/10.1007/JHEP08(2011)061).
- [27] A.D. Martin, et al., Eur. Phys. J. C 63 (2009) 189, arXiv:0901.0002, <http://dx.doi.org/10.1140/epjc/s10052-009-1072-5>.
- [28] T. Gleisberg, et al., JHEP 0902 (2009) 007, arXiv:0811.4622, <http://dx.doi.org/10.1088/1126-6708/2009/02/007>.
- [29] M.L. Mangano, et al., JHEP 0307 (2003) 001.
- [30] G. Corcella, et al., JHEP 0101 (2001) 010, <http://dx.doi.org/10.1088/1126-6708/2001/01/010>.
- [31] S. Frixione, B.R. Webber, JHEP 0206 (2002) 029, arXiv:hep-ph/0204244.
- [32] H.-L. Lai, M. Guzzi, J. Huston, Z. Li, P.M. Nadolsky, et al., Phys. Rev. D 82 (2010) 074024, arXiv:1007.2241, <http://dx.doi.org/10.1103/PhysRevD.82.074024>.
- [33] ATLAS Collaboration, New ATLAS event generator tunes to 2010 data, Tech. Rep. ATLAS-PHYS-PUB-2011-008, CERN, Geneva, 2011, <https://cdsweb.cern.ch/record/1345343>.
- [34] J.M. Butterworth, J.R. Forshaw, M.H. Seymour, Z. Phys. C 72 (1996) 637, arXiv:hep-ph/9601371, <http://dx.doi.org/10.1007/s002880050286>.
- [35] J.M. Campbell, R.K. Ellis, Phys. Rev. D 60 (1999) 113006, arXiv:hep-ph/9905386, <http://dx.doi.org/10.1103/PhysRevD.60.113006>.
- [36] T. Binoth, M. Ciccolini, N. Kauer, M. Krämer, JHEP 0612 (2006) 046, arXiv:hep-ph/0611170v1.
- [37] ATLAS Collaboration, Eur. Phys. J. C 70 (2010) 823, arXiv:1005.4568, <http://dx.doi.org/10.1140/epjc/s10052-010-1429-9>.
- [38] S. Agostinelli, et al., Nucl. Instrum. Meth. A 506 (2003) 250, [http://dx.doi.org/10.1016/S0168-9002\(03\)01368-8](http://dx.doi.org/10.1016/S0168-9002(03)01368-8).
- [39] ATLAS Collaboration, Eur. Phys. J. C 72 (2012) 1909, arXiv:1110.3174v2, <http://dx.doi.org/10.1140/epjc/s10052-012-1909-1>.
- [40] M. Cacciari, G.P. Salam, G. Soyez, JHEP 0804 (2008) 063, arXiv:0802.1189, <http://dx.doi.org/10.1088/1126-6708/2008/04/063>.
- [41] ATLAS Collaboration, Eur. Phys. J. C, submitted for publication, arXiv:1112.6426.
- [42] ATLAS Collaboration, b-jet tagging calibration on c-jets containing d^* mesons, ATLAS-CONF-2012-039, <https://cdsweb.cern.ch/record/1435193>.
- [43] ATLAS Collaboration, Measurement of the mistag rate with 5 fb^{-1} of data collected by the ATLAS detector, ATLAS-CONF-2012-040, <https://cdsweb.cern.ch/record/1435194>.
- [44] ATLAS Collaboration, Measurement of the b-tag efficiency in a sample of jets containing muons with 5 fb^{-1} of data from the ATLAS detector, ATLAS-CONF-2012-043, <https://cdsweb.cern.ch/record/1435197>.
- [45] G. Aad, et al., Expected performance of the ATLAS experiment – detector, trigger and physics, arXiv:0901.0512.
- [46] ATLAS Collaboration, Eur. Phys. J. C 72 (2012) 1844, arXiv:1108.5602.
- [47] ATLAS Collaboration, Measurement of the missing transverse momentum based on tracks in proton–proton collisions at $\sqrt{s} = 900$ GeV centre-of-mass energy with the ATLAS detector, ATLAS-CONF-2010-020, <https://cdsweb.cern.ch/record/1277652>.
- [48] M. Aliiev, et al., Comput. Phys. Commun. 182 (2011) 1034, arXiv:1007.1327.
- [49] ATLAS Collaboration, Update on the jet energy scale systematic uncertainty for jets produced in proton–proton collisions at $\sqrt{s} = 7$ TeV measured with the ATLAS detector, ATLAS-CONF-2011-007, <https://cdsweb.cern.ch/record/1330713>.

- [50] M. Botje, J. Butterworth, A. Cooper-Sarkar, A. de Roeck, J. Feltesse, et al., The PDF4LHC working group interim recommendations, arXiv:1101.0538.
- [51] R.D. Ball, et al., Nucl. Phys. B 849 (2011) 296, arXiv:1101.1300, <http://dx.doi.org/10.1016/j.nuclphysb.2011.03.021>.
- [52] R. Frederix, S. Frixione, V. Hirschi, F. Maltoni, R. Pittau, et al., JHEP 1109 (2011) 061, arXiv:1106.6019, [http://dx.doi.org/10.1007/JHEP09\(2011\)061](http://dx.doi.org/10.1007/JHEP09(2011)061).
- [53] A.L. Read, J. Phys. G 28 (2002) 2693.
- [54] G. Cowan, K. Cranmer, E. Gross, O. Vitells, Eur. Phys. J. C 71 (2011) 1554, arXiv:1007.1727v2, <http://dx.doi.org/10.1140/epjc/s10052-011-1554-0>.
- [55] L. Moneta, et al., in: Proceedings of the 13th International Workshop on Advanced Computing and Analysis Techniques in Physics Research, ACAT2010, in: Proceedings of Science, 2010, arXiv:1009.1003.

ATLAS Collaboration

G. Aad⁴⁸, B. Abbott¹¹¹, J. Abdallah¹¹, S. Abdel Khalek¹¹⁵, A.A. Abdelalim⁴⁹, O. Abdinov¹⁰, B. Abi¹¹², M. Abolins⁸⁸, O.S. AbouZeid¹⁵⁸, H. Abramowicz¹⁵³, H. Abreu¹³⁶, E. Acerbi^{89a,89b}, B.S. Acharya^{164a,164b}, L. Adamczyk³⁷, D.L. Adams²⁴, T.N. Addy⁵⁶, J. Adelman¹⁷⁶, S. Adomeit⁹⁸, P. Adragna⁷⁵, T. Adye¹²⁹, S. Aefsky²², J.A. Aguilar-Saavedra^{124b,a}, M. Agustoni¹⁶, M. Aharrouche⁸¹, S.P. Ahlen²¹, F. Ahles⁴⁸, A. Ahmad¹⁴⁸, M. Ahsan⁴⁰, G. Aielli^{133a,133b}, T. Akdogan^{18a}, T.P.A. Åkesson⁷⁹, G. Akimoto¹⁵⁵, A.V. Akimov⁹⁴, M.S. Alam¹, M.A. Alam⁷⁶, J. Albert¹⁶⁹, S. Albrand⁵⁵, M. Aleksa²⁹, I.N. Aleksandrov⁶⁴, F. Alessandria^{89a}, C. Alexa^{25a}, G. Alexander¹⁵³, G. Alexandre⁴⁹, T. Alexopoulos⁹, M. Alhroob^{164a,164c}, M. Aliev¹⁵, G. Alimonti^{89a}, J. Alison¹²⁰, B.M.M. Allbrooke¹⁷, P.P. Allport⁷³, S.E. Allwood-Spiers⁵³, J. Almond⁸², A. Aloisio^{102a,102b}, R. Alon¹⁷², A. Alonso⁷⁹, F. Alonso⁷⁰, B. Alvarez Gonzalez⁸⁸, M.G. Alviggi^{102a,102b}, K. Amako⁶⁵, C. Amelung²², V.V. Ammosov^{128,*}, A. Amorim^{124a,b}, N. Amram¹⁵³, C. Anastopoulos²⁹, L.S. Ancu¹⁶, N. Andari¹¹⁵, T. Andeen³⁴, C.F. Anders^{58b}, G. Anders^{58a}, K.J. Anderson³⁰, A. Andreazza^{89a,89b}, V. Andrei^{58a}, X.S. Anduaga⁷⁰, P. Anger⁴³, A. Angerami³⁴, F. Anghinolfi²⁹, A. Anisenkov¹⁰⁷, N. Anjos^{124a}, A. Annovi⁴⁷, A. Antonaki⁸, M. Antonelli⁴⁷, A. Antonov⁹⁶, J. Antos^{144b}, F. Anulli^{132a}, S. Aoun⁸³, L. Aperio Bella⁴, R. Apolle^{118,c}, G. Arabidze⁸⁸, I. Aracena¹⁴³, Y. Arai⁶⁵, A.T.H. Arce⁴⁴, S. Arfaoui¹⁴⁸, J.-F. Arguin¹⁴, E. Arik^{18a,*}, M. Arik^{18a}, A.J. Armbruster⁸⁷, O. Arnaez⁸¹, V. Arnal⁸⁰, C. Arnault¹¹⁵, A. Artamonov⁹⁵, G. Artoni^{132a,132b}, D. Arutinov²⁰, S. Asai¹⁵⁵, R. Asfandiyarov¹⁷³, S. Ask²⁷, B. Åsman^{146a,146b}, L. Asquith⁵, K. Assamagan²⁴, A. Astbury¹⁶⁹, B. Aubert⁴, E. Auge¹¹⁵, K. Augsten¹²⁷, M. Aourousseau^{145a}, G. Avolio¹⁶³, R. Avramidou⁹, D. Axen¹⁶⁸, G. Azuelos^{93,d}, Y. Azuma¹⁵⁵, M.A. Baak²⁹, G. Baccaglioni^{89a}, C. Bacci^{134a,134b}, A.M. Bach¹⁴, H. Bachacou¹³⁶, K. Bachas²⁹, M. Backes⁴⁹, M. Backhaus²⁰, E. Badescu^{25a}, P. Bagnaia^{132a,132b}, S. Bahinipati², Y. Bai^{32a}, D.C. Bailey¹⁵⁸, T. Bain¹⁵⁸, J.T. Baines¹²⁹, O.K. Baker¹⁷⁶, M.D. Baker²⁴, S. Baker⁷⁷, E. Banas³⁸, P. Banerjee⁹³, Sw. Banerjee¹⁷³, D. Banfi²⁹, A. Bangert¹⁵⁰, V. Bansal¹⁶⁹, H.S. Bansil¹⁷, L. Barak¹⁷², S.P. Baranov⁹⁴, A. Barbaro Galtieri¹⁴, T. Barber⁴⁸, E.L. Barberio⁸⁶, D. Barberis^{50a,50b}, M. Barbero²⁰, D.Y. Bardin⁶⁴, T. Barillari⁹⁹, M. Barisonzi¹⁷⁵, T. Barklow¹⁴³, N. Barlow²⁷, B.M. Barnett¹²⁹, R.M. Barnett¹⁴, A. Baroncelli^{134a}, G. Barone⁴⁹, A.J. Barr¹¹⁸, F. Barreiro⁸⁰, J. Barreiro Guimarães da Costa⁵⁷, P. Barrillon¹¹⁵, R. Bartoldus¹⁴³, A.E. Barton⁷¹, V. Bartsch¹⁴⁹, R.L. Bates⁵³, L. Batkova^{144a}, J.R. Batley²⁷, A. Battaglia¹⁶, M. Battistin²⁹, F. Bauer¹³⁶, H.S. Bawa^{143,e}, S. Beale⁹⁸, T. Beau⁷⁸, P.H. Beauchemin¹⁶¹, R. Beccherle^{50a}, P. Bechtel²⁰, H.P. Beck¹⁶, A.K. Becker¹⁷⁵, S. Becker⁹⁸, M. Beckingham¹³⁸, K.H. Becks¹⁷⁵, A.J. Beddall^{18c}, A. Beddall^{18c}, S. Bedikian¹⁷⁶, V.A. Bednyakov⁶⁴, C.P. Bee⁸³, M. Begel²⁴, S. Behar Harpaz¹⁵², M. Beimforde⁹⁹, C. Belanger-Champagne⁸⁵, P.J. Bell⁴⁹, W.H. Bell⁴⁹, G. Bella¹⁵³, L. Bellagamba^{19a}, F. Bellina²⁹, M. Bellomo²⁹, A. Belloni⁵⁷, O. Beloborodova^{107,f}, K. Belotskiy⁹⁶, O. Beltramello²⁹, O. Benary¹⁵³, D. Benchekroun^{135a}, K. Bendtz^{146a,146b}, N. Benekos¹⁶⁵, Y. Benhammou¹⁵³, E. Benhar Nocchioli⁴⁹, J.A. Benitez Garcia^{159b}, D.P. Benjamin⁴⁴, M. Benoit¹¹⁵, J.R. Bensinger²², K. Benslama¹³⁰, S. Bentvelsen¹⁰⁵, D. Berge²⁹, E. Bergeas Kuutmann⁴¹, N. Berger⁴, F. Berghaus¹⁶⁹, E. Berglund¹⁰⁵, J. Beringer¹⁴, P. Bernat⁷⁷, R. Bernhard⁴⁸, C. Bernius²⁴, T. Berry⁷⁶, C. Bertella⁸³, A. Bertin^{19a,19b}, F. Bertolucci^{122a,122b}, M.I. Besana^{89a,89b}, G.J. Besjes¹⁰⁴, N. Besson¹³⁶, S. Bethke⁹⁹, W. Bhimji⁴⁵, R.M. Bianchi²⁹, M. Bianco^{72a,72b}, O. Biebel⁹⁸, S.P. Bieniek⁷⁷, K. Bierwagen⁵⁴, J. Biesiada¹⁴, M. Biglietti^{134a}, H. Bilokon⁴⁷, M. Bindi^{19a,19b}, S. Binet¹¹⁵, A. Bingul^{18c}, C. Bini^{132a,132b}, C. Biscarat¹⁷⁸, U. Bitenc⁴⁸, K.M. Black²¹, R.E. Blair⁵, J.-B. Blanchard¹³⁶, G. Blanchot²⁹, T. Blazek^{144a}, C. Blocker²², J. Blocki³⁸, A. Blondel⁴⁹, W. Blum⁸¹, U. Blumenschein⁵⁴, G.J. Bobbink¹⁰⁵, V.B. Bobrovnikov¹⁰⁷, S.S. Bocchetta⁷⁹, A. Bocci⁴⁴, C.R. Boddy¹¹⁸, M. Boehler⁴¹, J. Boek¹⁷⁵, N. Boelaert³⁵, J.A. Bogaerts²⁹, A. Bogdanchikov¹⁰⁷, A. Bogouch^{90,*}, C. Bohm^{146a}, J. Bohm¹²⁵, V. Boisvert⁷⁶, T. Bold³⁷, V. Boldea^{25a}, N.M. Bolnet¹³⁶, M. Bomben⁷⁸, M. Bona⁷⁵, M. Boonekamp¹³⁶, C.N. Booth¹³⁹, S. Bordon⁷⁸, C. Borer¹⁶, A. Borisov¹²⁸, G. Borissov⁷¹, I. Borjanovic^{12a}, M. Borri⁸², S. Borroni⁸⁷, V. Bortolotto^{134a,134b}, K. Bos¹⁰⁵,

D. Boscherini^{19a}, M. Bosman¹¹, H. Boterenbrood¹⁰⁵, D. Botterill¹²⁹, J. Bouchami⁹³, J. Boudreau¹²³,
 E.V. Bouhova-Thacker⁷¹, D. Boumediene³³, C. Bourdarios¹¹⁵, N. Bousson⁸³, A. Boveia³⁰, J. Boyd²⁹,
 I.R. Boyko⁶⁴, I. Bozovic-Jelisavcic^{12b}, J. Bracinik¹⁷, P. Branchini^{134a}, A. Brandt⁷, G. Brandt¹¹⁸,
 O. Brandt⁵⁴, U. Bratzler¹⁵⁶, B. Brau⁸⁴, J.E. Brau¹¹⁴, H.M. Braun^{175,*}, S.F. Brazzale^{164a,164c}, B. Brelrier¹⁵⁸,
 J. Bremer²⁹, K. Brendlinger¹²⁰, R. Brenner¹⁶⁶, S. Bressler¹⁷², D. Britton⁵³, F.M. Brochu²⁷, I. Brock²⁰,
 R. Brock⁸⁸, E. Brodet¹⁵³, F. Broggi^{89a}, C. Bromberg⁸⁸, J. Bronner⁹⁹, G. Brooijmans³⁴, T. Brooks⁷⁶,
 W.K. Brooks^{31b}, G. Brown⁸², H. Brown⁷, P.A. Bruckman de Renstrom³⁸, D. Bruncko^{144b}, R. Bruneliere⁴⁸,
 S. Brunet⁶⁰, A. Bruni^{19a}, G. Bruni^{19a}, M. Bruschi^{19a}, T. Buanes¹³, Q. Buat⁵⁵, F. Bucci⁴⁹, J. Buchanan¹¹⁸,
 P. Buchholz¹⁴¹, R.M. Buckingham¹¹⁸, A.G. Buckley⁴⁵, S.I. Buda^{25a}, I.A. Budagov⁶⁴, B. Budick¹⁰⁸,
 V. Büscher⁸¹, L. Bugge¹¹⁷, O. Bulekov⁹⁶, A.C. Bundock⁷³, M. Bunse⁴², T. Buran¹¹⁷, H. Burckhart²⁹,
 S. Burdin⁷³, T. Burgess¹³, S. Burke¹²⁹, E. Busato³³, P. Bussey⁵³, C.P. Buszello¹⁶⁶, B. Butler¹⁴³,
 J.M. Butler²¹, C.M. Buttar⁵³, J.M. Butterworth⁷⁷, W. Buttinger²⁷, S. Cabrera Urbán¹⁶⁷, D. Caforio^{19a,19b},
 O. Cakir^{3a}, P. Calafiura¹⁴, G. Calderini⁷⁸, P. Calfayan⁹⁸, R. Calkins¹⁰⁶, L.P. Caloba^{23a}, R. Caloi^{132a,132b},
 D. Calvet³³, S. Calvet³³, R. Camacho Toro³³, P. Camarri^{133a,133b}, D. Cameron¹¹⁷, L.M. Caminada¹⁴,
 S. Campana²⁹, M. Campanelli⁷⁷, V. Canale^{102a,102b}, F. Canelli^{30,g}, A. Canepa^{159a}, J. Cantero⁸⁰,
 R. Cantrill⁷⁶, L. Capasso^{102a,102b}, M.D.M. Capeans Garrido²⁹, I. Caprini^{25a}, M. Caprini^{25a}, D. Capriotti⁹⁹,
 M. Capua^{36a,36b}, R. Caputo⁸¹, R. Cardarelli^{133a}, T. Carli²⁹, G. Carlino^{102a}, L. Carminati^{89a,89b}, B. Caron⁸⁵,
 S. Caron¹⁰⁴, E. Carquin^{31b}, G.D. Carrillo Montoya¹⁷³, A.A. Carter⁷⁵, J.R. Carter²⁷, J. Carvalho^{124a,h},
 D. Casadei¹⁰⁸, M.P. Casado¹¹, M. Cascella^{122a,122b}, C. Caso^{50a,50b,*}, A.M. Castaneda Hernandez^{173,i},
 E. Castaneda-Miranda¹⁷³, V. Castillo Gimenez¹⁶⁷, N.F. Castro^{124a}, G. Cataldi^{72a}, P. Catastini⁵⁷,
 A. Catinaccio²⁹, J.R. Catmore²⁹, A. Cattai²⁹, G. Cattani^{133a,133b}, S. Caughron⁸⁸, P. Cavalleri⁷⁸,
 D. Cavalli^{89a}, M. Cavalli-Sforza¹¹, V. Cavasinni^{122a,122b}, F. Ceradini^{134a,134b}, A.S. Cerqueira^{23b}, A. Cerri²⁹,
 L. Cerrito⁷⁵, F. Cerutti⁴⁷, S.A. Cetin^{18b}, A. Chafaq^{135a}, D. Chakraborty¹⁰⁶, I. Chalupkova¹²⁶, K. Chan²,
 B. Chapleau⁸⁵, J.D. Chapman²⁷, J.W. Chapman⁸⁷, E. Chareyre⁷⁸, D.G. Charlton¹⁷, V. Chavda⁸²,
 C.A. Chavez Barajas²⁹, S. Cheatham⁸⁵, S. Chekanov⁵, S.V. Chekulaev^{159a}, G.A. Chelkov⁶⁴,
 M.A. Chelstowska¹⁰⁴, C. Chen⁶³, H. Chen²⁴, S. Chen^{32c}, X. Chen¹⁷³, Y. Chen³⁴, A. Cheplakov⁶⁴,
 R. Cherkaoui El Moursli^{135e}, V. Chernyatin²⁴, E. Cheu⁶, S.L. Cheung¹⁵⁸, L. Chevalier¹³⁶,
 G. Chiefari^{102a,102b}, L. Chikovani^{51a,*}, J.T. Childers²⁹, A. Chilingarov⁷¹, G. Chiodini^{72a}, A.S. Chisholm¹⁷,
 R.T. Chislett⁷⁷, A. Chitan^{25a}, M.V. Chizhov⁶⁴, G. Choudalakis³⁰, S. Chouridou¹³⁷, I.A. Christidi⁷⁷,
 A. Christov⁴⁸, D. Chromek-Burckhart²⁹, M.L. Chu¹⁵¹, J. Chudoba¹²⁵, G. Ciapetti^{132a,132b}, A.K. Ciftci^{3a},
 R. Ciftci^{3a}, D. Cinca³³, V. Cindro⁷⁴, C. Ciocca^{19a,19b}, A. Ciocio¹⁴, M. Cirilli⁸⁷, P. Cirkovic^{12b},
 M. Citterio^{89a}, M. Ciubancan^{25a}, A. Clark⁴⁹, P.J. Clark⁴⁵, R.N. Clarke¹⁴, W. Cleland¹²³, J.C. Clemens⁸³,
 B. Clement⁵⁵, C. Clement^{146a,146b}, Y. Coadou⁸³, M. Cobal^{164a,164c}, A. Coccaro¹³⁸, J. Cochran⁶³,
 J.G. Cogan¹⁴³, J. Coggeshall¹⁶⁵, E. Cogneras¹⁷⁸, J. Colas⁴, A.P. Colijn¹⁰⁵, N.J. Collins¹⁷, C. Collins-Tooth⁵³,
 J. Collot⁵⁵, T. Colombo^{119a,119b}, G. Colon⁸⁴, P. Conde Muiño^{124a}, E. Coniavitis¹¹⁸, M.C. Conidi¹¹,
 S.M. Consonni^{89a,89b}, V. Consorti⁴⁸, S. Constantinescu^{25a}, C. Conta^{119a,119b}, G. Conti⁵⁷, F. Conventi^{102a,j},
 M. Cooke¹⁴, B.D. Cooper⁷⁷, A.M. Cooper-Sarkar¹¹⁸, K. Copic¹⁴, T. Cornelissen¹⁷⁵, M. Corradi^{19a},
 F. Corriveau^{85,k}, A. Cortes-Gonzalez¹⁶⁵, G. Cortiana⁹⁹, G. Costa^{89a}, M.J. Costa¹⁶⁷, D. Costanzo¹³⁹,
 T. Costin³⁰, D. Côté²⁹, L. Courneyea¹⁶⁹, G. Cowan⁷⁶, C. Cowden²⁷, B.E. Cox⁸², K. Cranmer¹⁰⁸,
 F. Crescioli^{122a,122b}, M. Cristinziani²⁰, G. Crosetti^{36a,36b}, R. Crupi^{72a,72b}, S. Crépe-Renaudin⁵⁵,
 C.-M. Cuciuc^{25a}, C. Cuenca Almenar¹⁷⁶, T. Cuhadar Donszelmann¹³⁹, M. Curatolo⁴⁷, C.J. Curtis¹⁷,
 C. Cuthbert¹⁵⁰, P. Cwetanski⁶⁰, H. Czirr¹⁴¹, P. Czodrowski⁴³, Z. Czynzula¹⁷⁶, S. D'Auria⁵³,
 M. D'Onofrio⁷³, A. D'Orazio^{132a,132b}, M.J. Da Cunha Sargedas De Sousa^{124a}, C. Da Via⁸²,
 W. Dabrowski³⁷, A. Dafinca¹¹⁸, T. Dai⁸⁷, C. Dallapiccola⁸⁴, M. Dam³⁵, M. Dameri^{50a,50b},
 D.S. Damiani¹³⁷, H.O. Danielsson²⁹, V. Dao⁴⁹, G. Darbo^{50a}, G.L. Darlea^{25b}, W. Davey²⁰, T. Davidek¹²⁶,
 N. Davidson⁸⁶, R. Davidson⁷¹, E. Davies^{118,c}, M. Davies⁹³, A.R. Davison⁷⁷, Y. Davygora^{58a}, E. Dawe¹⁴²,
 I. Dawson¹³⁹, R.K. Daya-Ishmukhametova²², K. De⁷, R. de Asmundis^{102a}, S. De Castro^{19a,19b},
 S. De Cecco⁷⁸, J. de Graat⁹⁸, N. De Groot¹⁰⁴, P. de Jong¹⁰⁵, C. De La Taille¹¹⁵, H. De la Torre⁸⁰,
 F. De Lorenzi⁶³, L. de Mora⁷¹, L. De Nooij¹⁰⁵, D. De Pedis^{132a}, A. De Salvo^{132a}, U. De Sanctis^{164a,164c},
 A. De Santo¹⁴⁹, J.B. De Vivie De Regie¹¹⁵, G. De Zorzi^{132a,132b}, W.J. Dearnaley⁷¹, R. Debbé²⁴,
 C. Debenedetti⁴⁵, B. Dechenaux⁵⁵, D.V. Dedovich⁶⁴, J. Degenhardt¹²⁰, C. Del Papa^{164a,164c}, J. Del Peso⁸⁰,
 T. Del Prete^{122a,122b}, T. Delemontex⁵⁵, M. Deliyergiyev⁷⁴, A. Dell'Acqua²⁹, L. Dell'Asta²¹,

M. Della Pietra ^{102a,j}, D. della Volpe ^{102a,102b}, M. Delmastro ⁴, P.A. Delsart ⁵⁵, C. Deluca ¹⁰⁵, S. Demers ¹⁷⁶,
 M. Demichev ⁶⁴, B. Demirköz ^{11,l}, J. Deng ¹⁶³, S.P. Denisov ¹²⁸, D. Derendarz ³⁸, J.E. Derkaoui ^{135d},
 F. Derue ⁷⁸, P. Dervan ⁷³, K. Desch ²⁰, E. Devetak ¹⁴⁸, P.O. Deviveiros ¹⁰⁵, A. Dewhurst ¹²⁹, B. DeWilde ¹⁴⁸,
 S. Dhaliwal ¹⁵⁸, R. Dhullipudi ^{24,m}, A. Di Ciaccio ^{133a,133b}, L. Di Ciaccio ⁴, A. Di Girolamo ²⁹,
 B. Di Girolamo ²⁹, S. Di Luise ^{134a,134b}, A. Di Mattia ¹⁷³, B. Di Micco ²⁹, R. Di Nardo ⁴⁷,
 A. Di Simone ^{133a,133b}, R. Di Sipio ^{19a,19b}, M.A. Diaz ^{31a}, E.B. Diehl ⁸⁷, J. Dietrich ⁴¹, T.A. Dietzsch ^{58a},
 S. Diglio ⁸⁶, K. Dindar Yagci ³⁹, J. Dingfelder ²⁰, F. Dinut ^{25a}, C. Dionisi ^{132a,132b}, P. Dita ^{25a}, S. Dita ^{25a},
 F. Dittus ²⁹, F. Djama ⁸³, T. Djobava ^{51b}, M.A.B. do Vale ^{23c}, A. Do Valle Wemans ^{124a,n}, T.K.O. Doan ⁴,
 M. Dobbs ⁸⁵, R. Dobinson ^{29,*}, D. Dobos ²⁹, E. Dobson ^{29,o}, J. Dodd ³⁴, C. Doglioni ⁴⁹, T. Doherty ⁵³,
 Y. Doi ^{65,*}, J. Dolejsi ¹²⁶, I. Dolenc ⁷⁴, Z. Dolezal ¹²⁶, B.A. Dolgoshein ^{96,*}, T. Dohmae ¹⁵⁵, M. Donadelli ^{23d},
 J. Donini ³³, J. Dopke ²⁹, A. Doria ^{102a}, A. Dos Anjos ¹⁷³, A. Dotti ^{122a,122b}, M.T. Dova ⁷⁰, A.D. Doxiadis ¹⁰⁵,
 A.T. Doyle ⁵³, M. Dris ⁹, J. Dubbert ⁹⁹, S. Dube ¹⁴, E. Duchovni ¹⁷², G. Duckeck ⁹⁸, A. Dudarev ²⁹,
 F. Dudziak ⁶³, M. Dührssen ²⁹, I.P. Duerdoth ⁸², L. Duflot ¹¹⁵, M.-A. Dufour ⁸⁵, M. Dunford ²⁹,
 H. Duran Yildiz ^{3a}, R. Duxfield ¹³⁹, M. Dwuznik ³⁷, F. Dydak ²⁹, M. Düren ⁵², J. Ebke ⁹⁸, S. Eckweiler ⁸¹,
 K. Edmonds ⁸¹, W. Edson ¹, C.A. Edwards ⁷⁶, N.C. Edwards ⁵³, W. Ehrenfeld ⁴¹, T. Eifert ¹⁴³, G. Eigen ¹³,
 K. Einsweiler ¹⁴, E. Eisenhandler ⁷⁵, T. Ekelof ¹⁶⁶, M. El Kacimi ^{135c}, M. Ellert ¹⁶⁶, S. Elles ⁴, F. Ellinghaus ⁸¹,
 K. Ellis ⁷⁵, N. Ellis ²⁹, J. Elmsheuser ⁹⁸, M. Elsing ²⁹, D. Emeliyanov ¹²⁹, R. Engelmann ¹⁴⁸, A. Engl ⁹⁸,
 B. Epp ⁶¹, J. Erdmann ⁵⁴, A. Ereditato ¹⁶, D. Eriksson ^{146a}, J. Ernst ¹, M. Ernst ²⁴, J. Ernwein ¹³⁶,
 D. Errede ¹⁶⁵, S. Errede ¹⁶⁵, E. Ertel ⁸¹, M. Escalier ¹¹⁵, H. Esch ⁴², C. Escobar ¹²³, X. Espinal Curull ¹¹,
 B. Esposito ⁴⁷, F. Etienne ⁸³, A.I. Etienvre ¹³⁶, E. Etzion ¹⁵³, D. Evangelakou ⁵⁴, H. Evans ⁶⁰, L. Fabbri ^{19a,19b},
 C. Fabre ²⁹, R.M. Fakhruddinov ¹²⁸, S. Falciano ^{132a}, Y. Fang ¹⁷³, M. Fanti ^{89a,89b}, A. Farbin ⁷, A. Farilla ^{134a},
 J. Farley ¹⁴⁸, T. Farooque ¹⁵⁸, S. Farrell ¹⁶³, S.M. Farrington ¹¹⁸, P. Farthouat ²⁹, P. Fassnacht ²⁹,
 D. Fassouliotis ⁸, B. Fatholahzadeh ¹⁵⁸, A. Favareto ^{89a,89b}, L. Fayard ¹¹⁵, S. Fazio ^{36a,36b}, R. Febbraro ³³,
 P. Federic ^{144a}, O.L. Fedin ¹²¹, W. Fedorko ⁸⁸, M. Fehling-Kaschek ⁴⁸, L. Feligioni ⁸³, D. Fellmann ⁵,
 C. Feng ^{32d}, E.J. Feng ⁵, A.B. Fenyuk ¹²⁸, J. Ferencei ^{144b}, W. Fernando ⁵, S. Ferrag ⁵³, J. Ferrando ⁵³,
 V. Ferrara ⁴¹, A. Ferrari ¹⁶⁶, P. Ferrari ¹⁰⁵, R. Ferrari ^{119a}, D.E. Ferreira de Lima ⁵³, A. Ferrer ¹⁶⁷,
 D. Ferrere ⁴⁹, C. Ferretti ⁸⁷, A. Ferretto Parodi ^{50a,50b}, M. Fiascaris ³⁰, F. Fiedler ⁸¹, A. Filipčić ⁷⁴,
 F. Filthaut ¹⁰⁴, M. Fincke-Keeler ¹⁶⁹, M.C.N. Fiolhais ^{124a,h}, L. Fiorini ¹⁶⁷, A. Firan ³⁹, G. Fischer ⁴¹,
 M.J. Fisher ¹⁰⁹, M. Flechl ⁴⁸, I. Fleck ¹⁴¹, J. Fleckner ⁸¹, P. Fleischmann ¹⁷⁴, S. Fleischmann ¹⁷⁵, T. Flick ¹⁷⁵,
 A. Floderus ⁷⁹, L.R. Flores Castillo ¹⁷³, M.J. Flowerdew ⁹⁹, T. Fonseca Martin ¹⁶, A. Formica ¹³⁶, A. Forti ⁸²,
 D. Fortin ^{159a}, D. Fournier ¹¹⁵, H. Fox ⁷¹, P. Francavilla ¹¹, M. Franchini ^{19a,19b}, S. Franchino ^{119a,119b},
 D. Francis ²⁹, T. Frank ¹⁷², S. Franz ²⁹, M. Fraternali ^{119a,119b}, S. Fratina ¹²⁰, S.T. French ²⁷, C. Friedrich ⁴¹,
 F. Friedrich ⁴³, R. Froeschl ²⁹, D. Froidevaux ²⁹, J.A. Frost ²⁷, C. Fukunaga ¹⁵⁶, E. Fullana Torregrosa ²⁹,
 B.G. Fulsom ¹⁴³, J. Fuster ¹⁶⁷, C. Gabaldon ²⁹, O. Gabizon ¹⁷², T. Gadfort ²⁴, S. Gadomski ⁴⁹,
 G. Gagliardi ^{50a,50b}, P. Gagnon ⁶⁰, C. Galea ⁹⁸, E.J. Gallas ¹¹⁸, V. Gallo ¹⁶, B.J. Gallop ¹²⁹, P. Gallus ¹²⁵,
 K.K. Gan ¹⁰⁹, Y.S. Gao ^{143,e}, A. Gaponenko ¹⁴, F. Garbersson ¹⁷⁶, M. Garcia-Sciveres ¹⁴, C. García ¹⁶⁷,
 J.E. García Navarro ¹⁶⁷, R.W. Gardner ³⁰, N. Garelli ²⁹, H. Garitaonandia ¹⁰⁵, V. Garonne ²⁹, J. Garvey ¹⁷,
 C. Gatti ⁴⁷, G. Gaudio ^{119a}, B. Gaur ¹⁴¹, L. Gauthier ¹³⁶, P. Gauzzi ^{132a,132b}, I.L. Gavrilenko ⁹⁴, C. Gay ¹⁶⁸,
 G. Gaycken ²⁰, E.N. Gazis ⁹, P. Ge ^{32d}, Z. Gecse ¹⁶⁸, C.N.P. Gee ¹²⁹, D.A.A. Geerts ¹⁰⁵, Ch. Geich-Gimbel ²⁰,
 K. Gellerstedt ^{146a,146b}, C. Gemme ^{50a}, A. Gemmell ⁵³, M.H. Genest ⁵⁵, S. Gentile ^{132a,132b}, M. George ⁵⁴,
 S. George ⁷⁶, P. Gerlach ¹⁷⁵, A. Gershon ¹⁵³, C. Geweniger ^{58a}, H. Ghazlane ^{135b}, N. Ghodbane ³³,
 B. Giacobbe ^{19a}, S. Giagu ^{132a,132b}, V. Giakoumopoulou ⁸, V. Giangiobbe ¹¹, F. Gianotti ²⁹, B. Gibbard ²⁴,
 A. Gibson ¹⁵⁸, S.M. Gibson ²⁹, D. Gillberg ²⁸, A.R. Gillman ¹²⁹, D.M. Gingrich ^{2,d}, J. Ginzburg ¹⁵³,
 N. Giokaris ⁸, M.P. Giordani ^{164c}, R. Giordano ^{102a,102b}, F.M. Giorgi ¹⁵, P. Giovannini ⁹⁹, P.F. Giraud ¹³⁶,
 D. Giugni ^{89a}, M. Giunta ⁹³, P. Giusti ^{19a}, B.K. Gjelsten ¹¹⁷, L.K. Gladilin ⁹⁷, C. Glasman ⁸⁰, J. Glatzer ⁴⁸,
 A. Glazov ⁴¹, K.W. Glitza ¹⁷⁵, G.L. Glonti ⁶⁴, J.R. Goddard ⁷⁵, J. Godfrey ¹⁴², J. Godlewski ²⁹, M. Goebel ⁴¹,
 T. Göpfert ⁴³, C. Goeringer ⁸¹, C. Gössling ⁴², S. Goldfarb ⁸⁷, T. Golling ¹⁷⁶, A. Gomes ^{124a,b},
 L.S. Gomez Fajardo ⁴¹, R. Gonçalves ⁷⁶, J. Goncalves Pinto Firmino Da Costa ⁴¹, L. Gonella ²⁰, S. Gonzalez ¹⁷³,
 S. González de la Hoz ¹⁶⁷, G. Gonzalez Parra ¹¹, M.L. Gonzalez Silva ²⁶, S. Gonzalez-Sevilla ⁴⁹,
 J.J. Goodson ¹⁴⁸, L. Goossens ²⁹, P.A. Gorbounov ⁹⁵, H.A. Gordon ²⁴, I. Gorelov ¹⁰³, G. Gorfine ¹⁷⁵,
 B. Gorini ²⁹, E. Gorini ^{72a,72b}, A. Gorišek ⁷⁴, E. Gornicki ³⁸, B. Gosdzik ⁴¹, A.T. Goshaw ⁵, M. Gosselink ¹⁰⁵,
 M.I. Gostkin ⁶⁴, I. Gough Eschrich ¹⁶³, M. Gouighri ^{135a}, D. Goujdami ^{135c}, M.P. Goulette ⁴⁹,

A.G. Goussiou¹³⁸, C. Goy⁴, S. Gozpinar²², I. Grabowska-Bold³⁷, P. Grafström^{19a,19b}, K.-J. Grahn⁴¹,
 F. Grancagnolo^{72a}, S. Grancagnolo¹⁵, V. Grassi¹⁴⁸, V. Gratchev¹²¹, N. Grau³⁴, H.M. Gray²⁹, J.A. Gray¹⁴⁸,
 E. Graziani^{134a}, O.G. Grebenyuk¹²¹, T. Greenshaw⁷³, Z.D. Greenwood^{24,m}, K. Gregersen³⁵, I.M. Gregor⁴¹,
 P. Grenier¹⁴³, J. Griffiths¹³⁸, N. Grigalashvili⁶⁴, A.A. Grillo¹³⁷, S. Grinstein¹¹, Y.V. Grishkevich⁹⁷,
 J.-F. Grivaz¹¹⁵, E. Gross¹⁷², J. Grosse-Knetter⁵⁴, J. Groth-Jensen¹⁷², K. Grybel¹⁴¹, D. Guest¹⁷⁶,
 C. Guicheney³³, A. Guida^{72a,72b}, S. Guindon⁵⁴, U. Gul⁵³, H. Guler^{85,p}, J. Gunther¹²⁵, B. Guo¹⁵⁸,
 J. Guo³⁴, P. Gutierrez¹¹¹, N. Guttman¹⁵³, O. Gutzwiller¹⁷³, C. Guyot¹³⁶, C. Gwenlan¹¹⁸, C.B. Gwilliam⁷³,
 A. Haas¹⁴³, S. Haas²⁹, C. Haber¹⁴, H.K. Hadavand³⁹, D.R. Hadley¹⁷, P. Haefner²⁰, F. Hahn²⁹, S. Haider²⁹,
 Z. Hajduk³⁸, H. Hakobyan¹⁷⁷, D. Hall¹¹⁸, J. Haller⁵⁴, K. Hamacher¹⁷⁵, P. Hamal¹¹³, M. Hamer⁵⁴,
 A. Hamilton^{145b,q}, S. Hamilton¹⁶¹, L. Han^{32b}, K. Hanagaki¹¹⁶, K. Hanawa¹⁶⁰, M. Hance¹⁴, C. Handel⁸¹,
 P. Hanke^{58a}, J.R. Hansen³⁵, J.B. Hansen³⁵, J.D. Hansen³⁵, P.H. Hansen³⁵, P. Hansson¹⁴³, K. Hara¹⁶⁰,
 G.A. Hare¹³⁷, T. Harenberg¹⁷⁵, S. Harkusha⁹⁰, D. Harper⁸⁷, R.D. Harrington⁴⁵, O.M. Harris¹³⁸,
 J. Hartert⁴⁸, F. Hartjes¹⁰⁵, T. Haruyama⁶⁵, A. Harvey⁵⁶, S. Hasegawa¹⁰¹, Y. Hasegawa¹⁴⁰, S. Hassani¹³⁶,
 S. Haug¹⁶, M. Hauschild²⁹, R. Hauser⁸⁸, M. Havranek²⁰, C.M. Hawkes¹⁷, R.J. Hawkins²⁹,
 A.D. Hawkins⁷⁹, D. Hawkins¹⁶³, T. Hayakawa⁶⁶, T. Hayashi¹⁶⁰, D. Hayden⁷⁶, C.P. Hays¹¹⁸,
 H.S. Hayward⁷³, S.J. Haywood¹²⁹, M. He^{32d}, S.J. Head¹⁷, V. Hedberg⁷⁹, L. Heelan⁷, S. Heim⁸⁸,
 B. Heinemann¹⁴, S. Heisterkamp³⁵, L. Helary²¹, C. Heller⁹⁸, M. Heller²⁹, S. Hellman^{146a,146b},
 D. Hellmich²⁰, C. Hensens¹¹, R.C.W. Henderson⁷¹, M. Henke^{58a}, A. Henrichs⁵⁴,
 A.M. Henriques Correia²⁹, S. Henrot-Versille¹¹⁵, C. Hensel⁵⁴, T. Henß¹⁷⁵, C.M. Hernandez⁷,
 Y. Hernández Jiménez¹⁶⁷, R. Herrberg¹⁵, G. Herten⁴⁸, R. Hertenberger⁹⁸, L. Hervas²⁹, G.G. Hesketh⁷⁷,
 N.P. Hessey¹⁰⁵, E. Higón-Rodríguez¹⁶⁷, J.C. Hill²⁷, K.H. Hiller⁴¹, S. Hillert²⁰, S.J. Hillier¹⁷, I. Hinchliffe¹⁴,
 E. Hines¹²⁰, M. Hirose¹¹⁶, F. Hirsch⁴², D. Hirschebuehl¹⁷⁵, J. Hobbs¹⁴⁸, N. Hod¹⁵³, M.C. Hodgkinson¹³⁹,
 P. Hodgson¹³⁹, A. Hoecker²⁹, M.R. Hoferkamp¹⁰³, J. Hoffman³⁹, D. Hoffmann⁸³, M. Hohlfeld⁸¹,
 M. Holder¹⁴¹, S.O. Holmgren^{146a}, T. Holy¹²⁷, J.L. Holzbauer⁸⁸, T.M. Hong¹²⁰,
 L. Hooft van Huysduynen¹⁰⁸, C. Horn¹⁴³, S. Horner⁴⁸, J.-Y. Hostachy⁵⁵, S. Hou¹⁵¹, A. Hoummada^{135a},
 J. Howard¹¹⁸, J. Howarth⁸², I. Hristova¹⁵, J. Hrivnac¹¹⁵, T. Hryn'ova⁴, P.J. Hsu⁸¹, S.-C. Hsu¹⁴,
 Z. Hubacek¹²⁷, F. Hubaut⁸³, F. Huegging²⁰, A. Huettmann⁴¹, T.B. Huffman¹¹⁸, E.W. Hughes³⁴,
 G. Hughes⁷¹, M. Huhtinen²⁹, M. Hurwitz¹⁴, U. Husemann⁴¹, N. Huseynov^{64,r}, J. Huston⁸⁸, J. Huth⁵⁷,
 G. Iacobucci⁴⁹, G. Iakovidis⁹, M. Ibbotson⁸², I. Ibragimov¹⁴¹, L. Iconomidou-Fayard¹¹⁵, J. Idarraga¹¹⁵,
 P. Iengo^{102a}, O. Igonkina¹⁰⁵, Y. Ikegami⁶⁵, M. Ikeno⁶⁵, D. Iliadis¹⁵⁴, N. Ilic¹⁵⁸, T. Ince²⁰,
 J. Inigo-Golfín²⁹, P. Ioannou⁸, M. Iodice^{134a}, K. Iordanidou⁸, V. Ippolito^{132a,132b}, A. Irlés Quiles¹⁶⁷,
 C. Isaksson¹⁶⁶, M. Ishino⁶⁷, M. Ishitsuka¹⁵⁷, R. Ishmukhametov³⁹, C. Issever¹¹⁸, S. Istin^{18a},
 A.V. Ivashin¹²⁸, W. Iwanski³⁸, H. Iwasaki⁶⁵, J.M. Izen⁴⁰, V. Izzo^{102a}, B. Jackson¹²⁰, J.N. Jackson⁷³,
 M. Jackson⁷³, P. Jackson¹⁴³, M.R. Jaekel²⁹, V. Jain⁶⁰, K. Jakobs⁴⁸, S. Jakobsen³⁵, T. Jakoubek¹²⁵,
 J. Jakubek¹²⁷, D.O. Jamin¹⁵¹, D.K. Jana¹¹¹, E. Jansen⁷⁷, H. Jansen²⁹, A. Jantsch⁹⁹, M. Janus⁴⁸,
 G. Jarlskog⁷⁹, L. Jeanty⁵⁷, I. Jen-La Plante³⁰, P. Jenni²⁹, A. Jeremie⁴, P. Jež³⁵, S. Jézéquel⁴, M.K. Jha^{19a},
 H. Ji¹⁷³, W. Ji⁸¹, J. Jia¹⁴⁸, Y. Jiang^{32b}, M. Jimenez Belenguer⁴¹, S. Jin^{32a}, O. Jinnouchi¹⁵⁷,
 M.D. Joergensen³⁵, D. Joffe³⁹, M. Johansen^{146a,146b}, K.E. Johansson^{146a}, P. Johansson¹³⁹, S. Johnert⁴¹,
 K.A. Johns⁶, K. Jon-And^{146a,146b}, G. Jones¹⁷⁰, R.W.L. Jones⁷¹, T.J. Jones⁷³, C. Joram²⁹, P.M. Jorge^{124a},
 K.D. Joshi⁸², J. Jovicevic¹⁴⁷, T. Jovin^{12b}, X. Ju¹⁷³, C.A. Jung⁴², R.M. Jungst²⁹, V. Juranek¹²⁵, P. Jussel⁶¹,
 A. Juste Rozas¹¹, S. Kabana¹⁶, M. Kaci¹⁶⁷, A. Kaczmarska³⁸, P. Kadlecik³⁵, M. Kado¹¹⁵, H. Kagan¹⁰⁹,
 M. Kagan⁵⁷, E. Kajomovitz¹⁵², S. Kalinin¹⁷⁵, L.V. Kalinovskaya⁶⁴, S. Kama³⁹, N. Kanaya¹⁵⁵, M. Kaneda²⁹,
 S. Kaneti²⁷, T. Kanno¹⁵⁷, V.A. Kantserov⁹⁶, J. Kanzaki⁶⁵, B. Kaplan¹⁷⁶, A. Kapliy³⁰, J. Kaplon²⁹, D. Kar⁵³,
 M. Karagounis²⁰, K. Karakostas⁹, M. Karnevskiy⁴¹, V. Kartvelishvili⁷¹, A.N. Karyukhin¹²⁸, L. Kashif¹⁷³,
 G. Kasieczka^{58b}, R.D. Kass¹⁰⁹, A. Kastanas¹³, M. Kataoka⁴, Y. Kataoka¹⁵⁵, E. Katsoufis⁹, J. Katzy⁴¹,
 V. Kaushik⁶, K. Kawagoe⁶⁹, T. Kawamoto¹⁵⁵, G. Kawamura⁸¹, M.S. Kayl¹⁰⁵, V.A. Kazanin¹⁰⁷,
 M.Y. Kazarinov⁶⁴, R. Keeler¹⁶⁹, R. Kehoe³⁹, M. Keil⁵⁴, G.D. Kekelidze⁶⁴, J.S. Keller¹³⁸, M. Kenyon⁵³,
 O. Kepka¹²⁵, N. Kerschen²⁹, B.P. Kerševan⁷⁴, S. Kersten¹⁷⁵, K. Kessoku¹⁵⁵, J. Keung¹⁵⁸, F. Khalil-zada¹⁰,
 H. Khandanyan¹⁶⁵, A. Khanov¹¹², D. Kharchenko⁶⁴, A. Khodinov⁹⁶, A. Khomich^{58a}, T.J. Khoo²⁷,
 G. Khoraiuli²⁰, A. Khoroshilov¹⁷⁵, V. Khovanskiy⁹⁵, E. Khramov⁶⁴, J. Khubua^{51b}, H. Kim^{146a,146b},
 S.H. Kim¹⁶⁰, N. Kimura¹⁷¹, O. Kind¹⁵, B.T. King⁷³, M. King⁶⁶, R.S.B. King¹¹⁸, J. Kirk¹²⁹, A.E. Kiryunin⁹⁹,
 T. Kishimoto⁶⁶, D. Kisielewska³⁷, T. Kittelmann¹²³, E. Kladiva^{144b}, M. Klein⁷³, U. Klein⁷³,

K. Kleinknecht⁸¹, M. Klemetti⁸⁵, A. Klier¹⁷², P. Klimek^{146a,146b}, A. Klimentov²⁴, R. Klingenberg⁴²,
 J.A. Klinger⁸², E.B. Klinkby³⁵, T. Klioutchnikova²⁹, P.F. Klok¹⁰⁴, S. Klous¹⁰⁵, E.-E. Kluge^{58a}, T. Kluge⁷³,
 P. Kluit¹⁰⁵, S. Kluth⁹⁹, N.S. Knecht¹⁵⁸, E. Kneringer⁶¹, E.B.F.G. Knoops⁸³, A. Knue⁵⁴, B.R. Ko⁴⁴,
 T. Kobayashi¹⁵⁵, M. Kobel⁴³, M. Kocian¹⁴³, P. Kodys¹²⁶, K. Köneke²⁹, A.C. König¹⁰⁴, S. Koenig⁸¹,
 L. Köpke⁸¹, F. Koetsveld¹⁰⁴, P. Koevesarki²⁰, T. Koffas²⁸, E. Koffeman¹⁰⁵, L.A. Kogan¹¹⁸, S. Kohlmann¹⁷⁵,
 F. Kohn⁵⁴, Z. Kohout¹²⁷, T. Kohriki⁶⁵, T. Koi¹⁴³, G.M. Kolachev^{107,*}, H. Kolanoski¹⁵, V. Kolesnikov⁶⁴,
 I. Koletsou^{89a}, J. Koll⁸⁸, M. Kollefrath⁴⁸, A.A. Komar⁹⁴, Y. Komori¹⁵⁵, T. Kondo⁶⁵, T. Kono^{41,s},
 A.I. Kononov⁴⁸, R. Konoplich^{108,t}, N. Konstantinidis⁷⁷, S. Koperny³⁷, K. Korcyl³⁸, K. Kordas¹⁵⁴,
 A. Korn¹¹⁸, A. Korol¹⁰⁷, I. Korolkov¹¹, E.V. Korolkova¹³⁹, V.A. Korotkov¹²⁸, O. Kortner⁹⁹, S. Kortner⁹⁹,
 V.V. Kostyukhin²⁰, S. Kotov⁹⁹, V.M. Kotov⁶⁴, A. Kotwal⁴⁴, C. Kourkoumelis⁸, V. Kouskoura¹⁵⁴,
 A. Koutsman^{159a}, R. Kowalewski¹⁶⁹, T.Z. Kowalski³⁷, W. Kozanecki¹³⁶, A.S. Kozhin¹²⁸, V. Kral¹²⁷,
 V.A. Kramarenko⁹⁷, G. Kramberger⁷⁴, M.W. Krasny⁷⁸, A. Krasznahorkay¹⁰⁸, J. Kraus⁸⁸, J.K. Kraus²⁰,
 S. Kreiss¹⁰⁸, F. Krejci¹²⁷, J. Kretzschmar⁷³, N. Krieger⁵⁴, P. Krieger¹⁵⁸, K. Kroeninger⁵⁴, H. Kroha⁹⁹,
 J. Kroll¹²⁰, J. Kroseberg²⁰, J. Krstic^{12a}, U. Kruchonak⁶⁴, H. Krüger²⁰, T. Kruker¹⁶, N. Krumnack⁶³,
 Z.V. Krumshteyn⁶⁴, A. Kruth²⁰, T. Kubota⁸⁶, S. Kuday^{3a}, S. Kuehn⁴⁸, A. Kugel^{58c}, T. Kuhl⁴¹, D. Kuhn⁶¹,
 V. Kukhtin⁶⁴, Y. Kulchitsky⁹⁰, S. Kuleshov^{31b}, C. Kummer⁹⁸, M. Kuna⁷⁸, J. Kunkle¹²⁰, A. Kupco¹²⁵,
 H. Kurashige⁶⁶, M. Kurata¹⁶⁰, Y.A. Kurochkin⁹⁰, V. Kus¹²⁵, E.S. Kuwertz¹⁴⁷, M. Kuze¹⁵⁷, J. Kvita¹⁴²,
 R. Kwee¹⁵, A. La Rosa⁴⁹, L. La Rotonda^{36a,36b}, L. Labarga⁸⁰, J. Labbe⁴, S. Lablak^{135a}, C. Lacasta¹⁶⁷,
 F. Lacava^{132a,132b}, H. Lacker¹⁵, D. Lacour⁷⁸, V.R. Lacuesta¹⁶⁷, E. Ladygin⁶⁴, R. Lafaye⁴, B. Laforge⁷⁸,
 T. Lagouri⁸⁰, S. Lai⁴⁸, E. Laisne⁵⁵, M. Lamanna²⁹, L. Lambourne⁷⁷, C.L. Lampen⁶, W. Lampl⁶,
 E. Lancon¹³⁶, U. Landgraf⁴⁸, M.P.J. Landon⁷⁵, J.L. Lane⁸², V.S. Lang^{58a}, C. Lange⁴¹, A.J. Lankford¹⁶³,
 F. Lanni²⁴, K. Lantzsch¹⁷⁵, S. Laplace⁷⁸, C. Lapoire²⁰, J.F. Laporte¹³⁶, T. Lari^{89a}, A. Larner¹¹⁸,
 M. Lassnig²⁹, P. Laurelli⁴⁷, V. Lavorini^{36a,36b}, W. Lavrijsen¹⁴, P. Laycock⁷³, O. Le Dortz⁷⁸,
 E. Le Guirriec⁸³, C. Le Maner¹⁵⁸, E. Le Menedeu¹¹, T. LeCompte⁵, F. Ledroit-Guillon⁵⁵, H. Lee¹⁰⁵,
 J.S.H. Lee¹¹⁶, S.C. Lee¹⁵¹, L. Lee¹⁷⁶, M. Lefebvre¹⁶⁹, M. Legendre¹³⁶, F. Legger⁹⁸, C. Leggett¹⁴,
 M. Lehmacher²⁰, G. Lehmann Miotto²⁹, X. Lei⁶, M.A.L. Leite^{23d}, R. Leitner¹²⁶, D. Lellouch¹⁷²,
 B. Lemmer⁵⁴, V. Lendermann^{58a}, K.J.C. Leney^{145b}, T. Lenz¹⁰⁵, G. Lenzen¹⁷⁵, B. Lenzi²⁹, K. Leonhardt⁴³,
 S. Leontsinis⁹, F. Lepold^{58a}, C. Leroy⁹³, J.-R. Lessard¹⁶⁹, C.G. Lester²⁷, C.M. Lester¹²⁰, J. Levêque⁴,
 D. Levin⁸⁷, L.J. Levinson¹⁷², A. Lewis¹¹⁸, G.H. Lewis¹⁰⁸, A.M. Leyko²⁰, M. Leyton¹⁵, B. Li⁸³, H. Li^{173,u},
 S. Li^{32b,v}, X. Li⁸⁷, Z. Liang^{118,w}, H. Liao³³, B. Liberti^{133a}, P. Lichard²⁹, M. Lichtnecker⁹⁸, K. Lie¹⁶⁵,
 W. Liebig¹³, C. Limbach²⁰, A. Limosani⁸⁶, M. Limper⁶², S.C. Lin^{151,x}, F. Linde¹⁰⁵, J.T. Linnemann⁸⁸,
 E. Lipeles¹²⁰, A. Lipniacka¹³, T.M. Liss¹⁶⁵, D. Lissauer²⁴, A. Lister⁴⁹, A.M. Litke¹³⁷, C. Liu²⁸, D. Liu¹⁵¹,
 H. Liu⁸⁷, J.B. Liu⁸⁷, L. Liu⁸⁷, M. Liu^{32b}, Y. Liu^{32b}, M. Livan^{119a,119b}, S.S.A. Livermore¹¹⁸, A. Lleres⁵⁵,
 J. Llorente Merino⁸⁰, S.L. Lloyd⁷⁵, E. Lobodzinska⁴¹, P. Loch⁶, W.S. Lockman¹³⁷, T. Loddenkoetter²⁰,
 F.K. Loebinger⁸², A. Loginov¹⁷⁶, C.W. Loh¹⁶⁸, T. Lohse¹⁵, K. Lohwasser⁴⁸, M. Lokajicek¹²⁵,
 V.P. Lombardo⁴, R.E. Long⁷¹, L. Lopes^{124a}, D. Lopez Mateos⁵⁷, J. Lorenz⁹⁸, N. Lorenzo Martinez¹¹⁵,
 M. Losada¹⁶², P. Loscutoff¹⁴, F. Lo Sterzo^{132a,132b}, M.J. Losty^{159a}, X. Lou⁴⁰, A. Lounis¹¹⁵, K.F. Loureiro¹⁶²,
 J. Love²¹, P.A. Love⁷¹, A.J. Lowe^{143,e}, F. Lu^{32a}, H.J. Lubatti¹³⁸, C. Luci^{132a,132b}, A. Lucotte⁵⁵, A. Ludwig⁴³,
 D. Ludwig⁴¹, I. Ludwig⁴⁸, J. Ludwig⁴⁸, F. Luehring⁶⁰, G. Luijckx¹⁰⁵, W. Lukas⁶¹, D. Lumb⁴⁸,
 L. Luminari^{132a}, E. Lund¹¹⁷, B. Lund-Jensen¹⁴⁷, B. Lundberg⁷⁹, J. Lundberg^{146a,146b},
 O. Lundberg^{146a,146b}, J. Lundquist³⁵, M. Lungwitz⁸¹, D. Lynn²⁴, E. Lytken⁷⁹, H. Ma²⁴, L.L. Ma¹⁷³,
 G. Maccarrone⁴⁷, A. Macchiolo⁹⁹, B. Maček⁷⁴, J. Machado Miguens^{124a}, R. Mackeprang³⁵,
 R.J. Madaras¹⁴, W.F. Mader⁴³, R. Maenner^{58c}, T. Maeno²⁴, P. Mättig¹⁷⁵, S. Mättig⁴¹, L. Magnoni²⁹,
 E. Magradze⁵⁴, K. Mahboubi⁴⁸, S. Mahmoud⁷³, G. Mahout¹⁷, C. Maiani¹³⁶, C. Maidantchik^{23a},
 A. Maio^{124a,b}, S. Majewski²⁴, Y. Makida⁶⁵, N. Makovec¹¹⁵, P. Mal¹³⁶, B. Malaescu²⁹, Pa. Malecki³⁸,
 P. Malecki³⁸, V.P. Maleev¹²¹, F. Malek⁵⁵, U. Mallik⁶², D. Malon⁵, C. Malone¹⁴³, S. Maltezos⁹,
 V. Malyshev¹⁰⁷, S. Malyukov²⁹, R. Mameghani⁹⁸, J. Mamuzic^{12b}, A. Manabe⁶⁵, L. Mandelli^{89a},
 I. Mandić⁷⁴, R. Mandrysch¹⁵, J. Maneira^{124a}, P.S. Mangeard⁸⁸, L. Manhaes de Andrade Filho^{23a},
 A. Mann⁵⁴, P.M. Manning¹³⁷, A. Manousakis-Katsikakis⁸, B. Mansoulie¹³⁶, A. Mapelli²⁹, L. Mapelli²⁹,
 L. March⁸⁰, J.F. Marchand²⁸, F. Marchese^{133a,133b}, G. Marchiori⁷⁸, M. Marcisovsky¹²⁵, C.P. Marino¹⁶⁹,
 F. Marroquim^{23a}, Z. Marshall²⁹, F.K. Martens¹⁵⁸, L.F. Marti¹⁶, S. Marti-Garcia¹⁶⁷, B. Martin²⁹,
 B. Martin⁸⁸, J.P. Martin⁹³, T.A. Martin¹⁷, V.J. Martin⁴⁵, B. Martin dit Latour⁴⁹, S. Martin-Haugh¹⁴⁹,

M. Martinez¹¹, V. Martinez Outschoorn⁵⁷, A.C. Martyniuk¹⁶⁹, M. Marx⁸², F. Marzano^{132a}, A. Marzin¹¹¹,
 L. Masetti⁸¹, T. Mashimo¹⁵⁵, R. Mashinistov⁹⁴, J. Masik⁸², A.L. Maslennikov¹⁰⁷, I. Massa^{19a,19b},
 G. Massaro¹⁰⁵, N. Massol⁴, A. Mastroberardino^{36a,36b}, T. Masubuchi¹⁵⁵, P. Matricon¹¹⁵,
 H. Matsunaga¹⁵⁵, T. Matsushita⁶⁶, C. Mattravers^{118.c}, J. Maurer⁸³, S.J. Maxfield⁷³, A. Mayne¹³⁹,
 R. Mazini¹⁵¹, M. Mazur²⁰, L. Mazzaferro^{133a,133b}, M. Mazzanti^{89a}, S.P. Mc Kee⁸⁷, A. McCarn¹⁶⁵,
 R.L. McCarthy¹⁴⁸, T.G. McCarthy²⁸, N.A. McCubbin¹²⁹, K.W. McFarlane^{56,*}, J.A. MCFayden¹³⁹,
 H. McGlone⁵³, G. Mchedlidze^{51b}, T. Mclaughlan¹⁷, S.J. McMahon¹²⁹, R.A. McPherson^{169,k}, A. Meade⁸⁴,
 J. Mechnich¹⁰⁵, M. Mechtel¹⁷⁵, M. Medinnis⁴¹, R. Meera-Lebbai¹¹¹, T. Meguro¹¹⁶, R. Mehdiev⁹³,
 S. Mehlhase³⁵, A. Mehta⁷³, K. Meier^{58a}, B. Meirose⁷⁹, C. Melachrinos³⁰, B.R. Mellado Garcia¹⁷³,
 F. Meloni^{89a,89b}, L. Mendoza Navas¹⁶², Z. Meng^{151,u}, A. Mengarelli^{19a,19b}, S. Menke⁹⁹, E. Meoni¹⁶¹,
 K.M. Mercurio⁵⁷, P. Mermod⁴⁹, L. Merola^{102a,102b}, C. Meroni^{89a}, F.S. Merritt³⁰, H. Merritt¹⁰⁹,
 A. Messina^{29,y}, J. Metcalfe¹⁰³, A.S. Mete¹⁶³, C. Meyer⁸¹, C. Meyer³⁰, J.-P. Meyer¹³⁶, J. Meyer¹⁷⁴,
 J. Meyer⁵⁴, T.C. Meyer²⁹, W.T. Meyer⁶³, J. Miao^{32d}, S. Michal²⁹, L. Micu^{25a}, R.P. Middleton¹²⁹,
 S. Migas⁷³, L. Mijović¹³⁶, G. Mikenberg¹⁷², M. Mikestikova¹²⁵, M. Mikuž⁷⁴, D.W. Miller³⁰, R.J. Miller⁸⁸,
 W.J. Mills¹⁶⁸, C. Mills⁵⁷, A. Milov¹⁷², D.A. Milstead^{146a,146b}, D. Milstein¹⁷², A.A. Minaenko¹²⁸,
 M. Miñano Moya¹⁶⁷, I.A. Minashvili⁶⁴, A.I. Mincer¹⁰⁸, B. Mindur³⁷, M. Mineev⁶⁴, Y. Ming¹⁷³,
 L.M. Mir¹¹, G. Mirabelli^{132a}, J. Mitrevski¹³⁷, V.A. Mitsou¹⁶⁷, S. Mitsui⁶⁵, P.S. Miyagawa¹³⁹,
 J.U. Mjörnmark⁷⁹, T. Moa^{146a,146b}, V. Moeller²⁷, K. Mönig⁴¹, N. Möser²⁰, S. Mohapatra¹⁴⁸, W. Mohr⁴⁸,
 R. Moles-Valls¹⁶⁷, J. Monk⁷⁷, E. Monnier⁸³, J. Montejo Berlingen¹¹, S. Montesano^{89a,89b}, F. Monticelli⁷⁰,
 S. Monzani^{19a,19b}, R.W. Moore², G.F. Moorhead⁸⁶, C. Mora Herrera⁴⁹, A. Moraes⁵³, N. Morange¹³⁶,
 J. Morel⁵⁴, G. Morello^{36a,36b}, D. Moreno⁸¹, M. Moreno Llácer¹⁶⁷, P. Morettini^{50a}, M. Morgenstern⁴³,
 M. Morii⁵⁷, A.K. Morley²⁹, G. Mornacchi²⁹, J.D. Morris⁷⁵, L. Morvaj¹⁰¹, H.G. Moser⁹⁹, M. Mosidze^{51b},
 J. Moss¹⁰⁹, R. Mount¹⁴³, E. Mountricha^{9,z}, S.V. Mouraviev^{94,*}, E.J.W. Moyse⁸⁴, F. Mueller^{58a},
 J. Mueller¹²³, K. Mueller²⁰, T.A. Müller⁹⁸, T. Mueller⁸¹, D. Muenstermann²⁹, Y. Munwes¹⁵³,
 W.J. Murray¹²⁹, I. Mussche¹⁰⁵, E. Musto^{102a,102b}, A.G. Myagkov¹²⁸, M. Myska¹²⁵, J. Nadal¹¹, K. Nagai¹⁶⁰,
 K. Nagano⁶⁵, A. Nagarkar¹⁰⁹, Y. Nagasaka⁵⁹, M. Nagel⁹⁹, A.M. Nairz²⁹, Y. Nakahama²⁹, K. Nakamura¹⁵⁵,
 T. Nakamura¹⁵⁵, I. Nakano¹¹⁰, G. Nanava²⁰, A. Napier¹⁶¹, R. Narayan^{58b}, M. Nash^{77,c}, T. Nattermann²⁰,
 T. Naumann⁴¹, G. Navarro¹⁶², H.A. Neal⁸⁷, P.Yu. Nechaeva⁹⁴, T.J. Neep⁸², A. Negri^{119a,119b}, G. Negri²⁹,
 S. Nektarijevic⁴⁹, A. Nelson¹⁶³, T.K. Nelson¹⁴³, S. Nemecek¹²⁵, P. Nemethy¹⁰⁸, A.A. Nepomuceno^{23a},
 M. Nessi^{29,aa}, M.S. Neubauer¹⁶⁵, A. Neusiedl⁸¹, R.M. Neves¹⁰⁸, P. Nevski²⁴, P.R. Newman¹⁷,
 V. Nguyen Thi Hong¹³⁶, R.B. Nickerson¹¹⁸, R. Nicolaidou¹³⁶, B. Nicquevert²⁹, F. Niedercorn¹¹⁵,
 J. Nielsen¹³⁷, N. Nikiforou³⁴, A. Nikiforov¹⁵, V. Nikolaenko¹²⁸, I. Nikolic-Audit⁷⁸, K. Nikolics⁴⁹,
 K. Nikolopoulos²⁴, H. Nilsen⁴⁸, P. Nilsson⁷, Y. Ninomiya¹⁵⁵, A. Nisati^{132a}, R. Nisius⁹⁹, T. Nobe¹⁵⁷,
 L. Nodulman⁵, M. Nomachi¹¹⁶, I. Nomidis¹⁵⁴, M. Nordberg²⁹, P.R. Norton¹²⁹, J. Novakova¹²⁶,
 M. Nozaki⁶⁵, L. Nozka¹¹³, I.M. Nugent^{159a}, A.-E. Nuncio-Quiroz²⁰, G. Nunes Hanninger⁸⁶,
 T. Nunnemann⁹⁸, E. Nurse⁷⁷, B.J. O'Brien⁴⁵, S.W. O'Neale^{17,*}, D.C. O'Neil¹⁴², V. O'Shea⁵³, L.B. Oakes⁹⁸,
 F.G. Oakham^{28,d}, H. Oberlack⁹⁹, J. Ocariz⁷⁸, A. Ochi⁶⁶, S. Oda⁶⁹, S. Odaka⁶⁵, J. Odier⁸³, H. Ogren⁶⁰,
 A. Oh⁸², S.H. Oh⁴⁴, C.C. Ohm^{146a,146b}, T. Ohshima¹⁰¹, H. Okawa¹⁶³, Y. Okumura³⁰, T. Okuyama¹⁵⁵,
 A. Olariu^{25a}, A.G. Olchevski⁶⁴, S.A. Olivares Pino^{31a}, M. Oliveira^{124a,h}, D. Oliveira Damazio²⁴,
 E. Oliver Garcia¹⁶⁷, D. Olivito¹²⁰, A. Olszewski³⁸, J. Olszowska³⁸, A. Onofre^{124a,ab}, P.U.E. Onyisi³⁰,
 C.J. Oram^{159a}, M.J. Oreglia³⁰, Y. Oren¹⁵³, D. Orestano^{134a,134b}, N. Orlando^{72a,72b}, I. Orlov¹⁰⁷,
 C. Oropeza Barrera⁵³, R.S. Orr¹⁵⁸, B. Osculati^{50a,50b}, R. Ospanov¹²⁰, C. Osuna¹¹, G. Otero y Garzon²⁶,
 J.P. Ottersbach¹⁰⁵, M. Ouchrif^{135d}, E.A. Ouellette¹⁶⁹, F. Ould-Saada¹¹⁷, A. Ouraou¹³⁶, Q. Ouyang^{32a},
 A. Ovcharova¹⁴, M. Owen⁸², S. Owen¹³⁹, V.E. Ozcan^{18a}, N. Ozturk⁷, A. Pacheco Pages¹¹,
 C. Padilla Aranda¹¹, S. Pagan Griso¹⁴, E. Paganis¹³⁹, F. Paige²⁴, P. Pais⁸⁴, K. Pajchel¹¹⁷, G. Palacino^{159b},
 C.P. Paleari⁶, S. Palestini²⁹, D. Pallin³³, A. Palma^{124a}, J.D. Palmer¹⁷, Y.B. Pan¹⁷³, E. Panagiotopoulou⁹,
 P. Pani¹⁰⁵, N. Panikashvili⁸⁷, S. Panitkin²⁴, D. Pantea^{25a}, A. Papadelis^{146a}, Th.D. Papadopoulou⁹,
 A. Paramonov⁵, D. Paredes Hernandez³³, W. Park^{24,ac}, M.A. Parker²⁷, F. Parodi^{50a,50b}, J.A. Parsons³⁴,
 U. Parzefall⁴⁸, S. Pashapour⁵⁴, E. Pasqualucci^{132a}, S. Passaggio^{50a}, A. Passeri^{134a}, F. Pastore^{134a,134b,*},
 Fr. Pastore⁷⁶, G. Pásztor^{49,ad}, S. Pataraiia¹⁷⁵, N. Patel¹⁵⁰, J.R. Pater⁸², S. Patricelli^{102a,102b}, T. Pauly²⁹,
 M. Pecsý^{144a}, M.I. Pedraza Morales¹⁷³, S.V. Peleganchuk¹⁰⁷, D. Pelikan¹⁶⁶, H. Peng^{32b}, B. Penning³⁰,
 A. Pensón³⁴, J. Penwell⁶⁰, M. Perantoni^{23a}, K. Perez^{34,ae}, T. Perez Cavalcanti⁴¹, E. Perez Codina^{159a},

M.T. Pérez García-Estañ ¹⁶⁷, V. Perez Reale ³⁴, L. Perini ^{89a,89b}, H. Pernegger ²⁹, R. Perrino ^{72a}, P. Perrodo ⁴, V.D. Peshekhonov ⁶⁴, K. Peters ²⁹, B.A. Petersen ²⁹, J. Petersen ²⁹, T.C. Petersen ³⁵, E. Petit ⁴, A. Petridis ¹⁵⁴, C. Petridou ¹⁵⁴, E. Petrolo ^{132a}, F. Petrucci ^{134a,134b}, D. Petschull ⁴¹, M. Petteni ¹⁴², R. Pezoa ^{31b}, A. Phan ⁸⁶, P.W. Phillips ¹²⁹, G. Piacquadio ²⁹, A. Picazio ⁴⁹, E. Piccaro ⁷⁵, M. Piccinini ^{19a,19b}, S.M. Piec ⁴¹, R. Piegai ²⁶, D.T. Pignotti ¹⁰⁹, J.E. Pilcher ³⁰, A.D. Pilkington ⁸², J. Pina ^{124a,b}, M. Pinamonti ^{164a,164c}, A. Pinder ¹¹⁸, J.L. Pinfold ², B. Pinto ^{124a}, C. Pizio ^{89a,89b}, M. Plamondon ¹⁶⁹, M.-A. Pleier ²⁴, E. Plotnikova ⁶⁴, A. Poblaguev ²⁴, S. Poddar ^{58a}, F. Podlyski ³³, L. Poggioli ¹¹⁵, T. Poghosyan ²⁰, M. Pohl ⁴⁹, G. Polesello ^{119a}, A. Policicchio ^{36a,36b}, A. Polini ^{19a}, J. Poll ⁷⁵, V. Polychronakos ²⁴, D. Pomeroy ²², K. Pommès ²⁹, L. Pontecorvo ^{132a}, B.G. Pope ⁸⁸, G.A. Popeneciu ^{25a}, D.S. Popovic ^{12a}, A. Poppleton ²⁹, X. Portell Bueso ²⁹, G.E. Pospelov ⁹⁹, S. Pospisil ¹²⁷, I.N. Potrap ⁹⁹, C.J. Potter ¹⁴⁹, C.T. Potter ¹¹⁴, G. Poulard ²⁹, J. Poveda ⁶⁰, V. Pozdnyakov ⁶⁴, R. Prabhu ⁷⁷, P. Pralavorio ⁸³, A. Pranko ¹⁴, S. Prasad ²⁹, R. Pravahan ²⁴, S. Prell ⁶³, K. Pretzl ¹⁶, D. Price ⁶⁰, J. Price ⁷³, L.E. Price ⁵, D. Prieur ¹²³, M. Primavera ^{72a}, K. Prokofiev ¹⁰⁸, F. Prokoshin ^{31b}, S. Protopopescu ²⁴, J. Proudfoot ⁵, X. Prudent ⁴³, M. Przybycien ³⁷, H. Przysiezniak ⁴, S. Psoroulas ²⁰, E. Ptacek ¹¹⁴, E. Pueschel ⁸⁴, J. Purdham ⁸⁷, M. Purohit ^{24,ac}, P. Puzo ¹¹⁵, Y. Pylypchenko ⁶², J. Qian ⁸⁷, A. Quadt ⁵⁴, D.R. Quarrie ¹⁴, W.B. Quayle ¹⁷³, F. Quinonez ^{31a}, M. Raas ¹⁰⁴, V. Radescu ⁴¹, P. Radloff ¹¹⁴, T. Rador ^{18a}, F. Ragusa ^{89a,89b}, G. Rahal ¹⁷⁸, A.M. Rahimi ¹⁰⁹, D. Rahm ²⁴, S. Rajagopalan ²⁴, M. Rammensee ⁴⁸, M. Rammes ¹⁴¹, A.S. Randle-Conde ³⁹, K. Randrianarivony ²⁸, F. Rauscher ⁹⁸, T.C. Rave ⁴⁸, M. Raymond ²⁹, A.L. Read ¹¹⁷, D.M. Rebuffi ^{119a,119b}, A. Redelbach ¹⁷⁴, G. Redlinger ²⁴, R. Reece ¹²⁰, K. Reeves ⁴⁰, E. Reinherz-Aronis ¹⁵³, A. Reinsch ¹¹⁴, I. Reisinger ⁴², C. Rembser ²⁹, Z.L. Ren ¹⁵¹, A. Renaud ¹¹⁵, M. Rescigno ^{132a}, S. Resconi ^{89a}, B. Resende ¹³⁶, P. Reznicek ⁹⁸, R. Rezvani ¹⁵⁸, R. Richter ⁹⁹, E. Richter-Was ^{4,af}, M. Ridel ⁷⁸, M. Rijpstra ¹⁰⁵, M. Rijssenbeek ¹⁴⁸, A. Rimoldi ^{119a,119b}, L. Rinaldi ^{19a}, R.R. Rios ³⁹, I. Riu ¹¹, G. Rivoltella ^{89a,89b}, F. Rizatdinova ¹¹², E. Rizvi ⁷⁵, S.H. Robertson ^{85,k}, A. Robichaud-Veronneau ¹¹⁸, D. Robinson ²⁷, J.E.M. Robinson ⁷⁷, A. Robson ⁵³, J.G. Rocha de Lima ¹⁰⁶, C. Roda ^{122a,122b}, D. Roda Dos Santos ²⁹, A. Roe ⁵⁴, S. Roe ²⁹, O. Røhne ¹¹⁷, S. Rolli ¹⁶¹, A. Romaniouk ⁹⁶, M. Romano ^{19a,19b}, G. Romeo ²⁶, E. Romero Adam ¹⁶⁷, L. Roos ⁷⁸, E. Ros ¹⁶⁷, S. Rosati ^{132a}, K. Rosbach ⁴⁹, A. Rose ¹⁴⁹, M. Rose ⁷⁶, G.A. Rosenbaum ¹⁵⁸, E.I. Rosenberg ⁶³, P.L. Rosendahl ¹³, O. Rosenthal ¹⁴¹, L. Rossetti ⁴⁹, V. Rossetti ¹¹, E. Rossi ^{132a,132b}, L.P. Rossi ^{50a}, M. Rotaru ^{25a}, I. Roth ¹⁷², J. Rothberg ¹³⁸, D. Rousseau ¹¹⁵, C.R. Royon ¹³⁶, A. Rozanov ⁸³, Y. Rozen ¹⁵², X. Ruan ^{32a,ag}, F. Rubbo ¹¹, I. Rubinskiy ⁴¹, B. Ruckert ⁹⁸, N. Ruckstuhl ¹⁰⁵, V.I. Rud ⁹⁷, C. Rudolph ⁴³, G. Rudolph ⁶¹, F. Rühr ⁶, A. Ruiz-Martinez ⁶³, L. Rumyantsev ⁶⁴, Z. Rurikova ⁴⁸, N.A. Rusakovich ⁶⁴, J.P. Rutherford ⁶, C. Ruwiedel ^{14,*}, P. Ruzicka ¹²⁵, Y.F. Ryabov ¹²¹, P. Ryan ⁸⁸, M. Rybar ¹²⁶, G. Rybkin ¹¹⁵, N.C. Ryder ¹¹⁸, A.F. Saavedra ¹⁵⁰, I. Sadeh ¹⁵³, H.F.-W. Sadrozinski ¹³⁷, R. Sadykov ⁶⁴, F. Safai Tehrani ^{132a}, H. Sakamoto ¹⁵⁵, G. Salamanna ⁷⁵, A. Salamon ^{133a}, M. Saleem ¹¹¹, D. Salek ²⁹, D. Salihagic ⁹⁹, A. Salnikov ¹⁴³, J. Salt ¹⁶⁷, B.M. Salvachua Ferrando ⁵, D. Salvatore ^{36a,36b}, F. Salvatore ¹⁴⁹, A. Salvucci ¹⁰⁴, A. Salzburger ²⁹, D. Sampsonidis ¹⁵⁴, B.H. Samset ¹¹⁷, A. Sanchez ^{102a,102b}, V. Sanchez Martinez ¹⁶⁷, H. Sandaker ¹³, H.G. Sander ⁸¹, M.P. Sanders ⁹⁸, M. Sandhoff ¹⁷⁵, T. Sandoval ²⁷, C. Sandoval ¹⁶², R. Sandstroem ⁹⁹, D.P.C. Sankey ¹²⁹, A. Sansoni ⁴⁷, C. Santamarina Rios ⁸⁵, C. Santoni ³³, R. Santonico ^{133a,133b}, H. Santos ^{124a}, J.G. Saraiva ^{124a}, T. Sarangi ¹⁷³, E. Sarkisyan-Grinbaum ⁷, F. Sarri ^{122a,122b}, G. Sartisohn ¹⁷⁵, O. Sasaki ⁶⁵, N. Sasao ⁶⁷, I. Satsounkevitch ⁹⁰, G. Sauvage ^{4,*}, E. Sauvan ⁴, J.B. Sauvan ¹¹⁵, P. Savard ^{158,d}, V. Savinov ¹²³, D.O. Savu ²⁹, L. Sawyer ^{24,m}, D.H. Saxon ⁵³, J. Saxon ¹²⁰, C. Sbarra ^{19a}, A. Sbrizzi ^{19a,19b}, O. Scallon ⁹³, D.A. Scannicchio ¹⁶³, M. Scarcella ¹⁵⁰, J. Schaarschmidt ¹¹⁵, P. Schacht ⁹⁹, D. Schaefer ¹²⁰, U. Schäfer ⁸¹, S. Schaepe ²⁰, S. Schaezel ^{58b}, A.C. Schaffer ¹¹⁵, D. Schaile ⁹⁸, R.D. Schamberger ¹⁴⁸, A.G. Schamov ¹⁰⁷, V. Scharf ^{58a}, V.A. Schegelsky ¹²¹, D. Scheirich ⁸⁷, M. Schernau ¹⁶³, M.I. Scherzer ³⁴, C. Schiavi ^{50a,50b}, J. Schieck ⁹⁸, M. Schioppa ^{36a,36b}, S. Schlenker ²⁹, E. Schmidt ⁴⁸, K. Schmieden ²⁰, C. Schmitt ⁸¹, S. Schmitt ^{58b}, M. Schmitz ²⁰, B. Schneider ¹⁶, U. Schnoor ⁴³, A. Schoening ^{58b}, A.L.S. Schorlemmer ⁵⁴, M. Schott ²⁹, D. Schouten ^{159a}, J. Schovancova ¹²⁵, M. Schram ⁸⁵, C. Schroeder ⁸¹, N. Schroer ^{58c}, M.J. Schultens ²⁰, J. Schultes ¹⁷⁵, H.-C. Schultz-Coulon ^{58a}, H. Schulz ¹⁵, M. Schumacher ⁴⁸, B.A. Schumm ¹³⁷, Ph. Schune ¹³⁶, C. Schwanenberger ⁸², A. Schwartzman ¹⁴³, Ph. Schwemling ⁷⁸, R. Schwienhorst ⁸⁸, R. Schwierz ⁴³, J. Schwindling ¹³⁶, T. Schwindt ²⁰, M. Schwoerer ⁴, G. Sciolla ²², W.G. Scott ¹²⁹, J. Searcy ¹¹⁴, G. Sedov ⁴¹, E. Sedykh ¹²¹, S.C. Seidel ¹⁰³, A. Seiden ¹³⁷, F. Seifert ⁴³, J.M. Seixas ^{23a}, G. Sekhniaidze ^{102a}, S.J. Sekula ³⁹, K.E. Selbach ⁴⁵, D.M. Seliverstov ¹²¹, B. Sellden ^{146a}, G. Sellers ⁷³, M. Seman ^{144b}, N. Semprini-Cesari ^{19a,19b}, C. Serfon ⁹⁸, L. Serin ¹¹⁵, L. Serkin ⁵⁴, R. Seuster ⁹⁹,

H. Severini¹¹¹, A. Sfyrla²⁹, E. Shabalina⁵⁴, M. Shamim¹¹⁴, L.Y. Shan^{32a}, J.T. Shank²¹, Q.T. Shao⁸⁶, M. Shapiro¹⁴, P.B. Shatalov⁹⁵, K. Shaw^{164a,164c}, D. Sherman¹⁷⁶, P. Sherwood⁷⁷, A. Shibata¹⁰⁸, S. Shimizu²⁹, M. Shimojima¹⁰⁰, T. Shin⁵⁶, M. Shiyakova⁶⁴, A. Shmeleva⁹⁴, M.J. Shochet³⁰, D. Short¹¹⁸, S. Shrestha⁶³, E. Shulga⁹⁶, M.A. Shupe⁶, P. Sicho¹²⁵, A. Sidoti^{132a}, F. Siegert⁴⁸, Dj. Sijacki^{12a}, O. Silbert¹⁷², J. Silva^{124a}, Y. Silver¹⁵³, D. Silverstein¹⁴³, S.B. Silverstein^{146a}, V. Simak¹²⁷, O. Simard¹³⁶, Lj. Simic^{12a}, S. Simion¹¹⁵, E. Simioni⁸¹, B. Simmons⁷⁷, R. Simoniello^{89a,89b}, M. Simonyan³⁵, P. Sinervo¹⁵⁸, N.B. Sinev¹¹⁴, V. Sipica¹⁴¹, G. Siragusa¹⁷⁴, A. Sircar²⁴, A.N. Sisakyan^{64,*}, S.Yu. Sivoklov⁹⁷, J. Sjölin^{146a,146b}, T.B. Sjursen¹³, L.A. Skinnari¹⁴, H.P. Skottowe⁵⁷, K. Skovpen¹⁰⁷, P. Skubic¹¹¹, M. Slater¹⁷, T. Slavicek¹²⁷, K. Sliwa¹⁶¹, V. Smakhtin¹⁷², B.H. Smart⁴⁵, S.Yu. Smirnov⁹⁶, Y. Smirnov⁹⁶, L.N. Smirnova⁹⁷, O. Smirnova⁷⁹, B.C. Smith⁵⁷, D. Smith¹⁴³, K.M. Smith⁵³, M. Smizanska⁷¹, K. Smolek¹²⁷, A.A. Snesev⁹⁴, S.W. Snow⁸², J. Snow¹¹¹, S. Snyder²⁴, R. Sobie^{169,k}, J. Sodomka¹²⁷, A. Soffer¹⁵³, C.A. Solans¹⁶⁷, M. Solar¹²⁷, J. Solc¹²⁷, E.Yu. Soldatov⁹⁶, U. Soldevila¹⁶⁷, E. Solfaroli Camillocci^{132a,132b}, A.A. Solodkov¹²⁸, O.V. Solovyanov¹²⁸, N. Soni⁸⁶, V. Sopko¹²⁷, B. Sopko¹²⁷, M. Sosebee⁷, R. Soualah^{164a,164c}, A. Soukharev¹⁰⁷, S. Spagnolo^{72a,72b}, F. Spanò⁷⁶, R. Spighi^{19a}, G. Spigo²⁹, F. Spila^{132a,132b}, R. Spiwoks²⁹, M. Spousta^{126,ah}, T. Spreitzer¹⁵⁸, B. Spurlock⁷, R.D. St. Denis⁵³, J. Stahlman¹²⁰, R. Stamen^{58a}, E. Stanecka³⁸, R.W. Stanek⁵, C. Stanescu^{134a}, M. Stanescu-Bellu⁴¹, S. Stapnes¹¹⁷, E.A. Starchenko¹²⁸, J. Stark⁵⁵, P. Staroba¹²⁵, P. Starovoitov⁴¹, R. Staszewski³⁸, A. Staude⁹⁸, P. Stavina^{144a,*}, G. Steele⁵³, P. Steinbach⁴³, P. Steinberg²⁴, I. Stekl¹²⁷, B. Stelzer¹⁴², H.J. Stelzer⁸⁸, O. Stelzer-Chilton^{159a}, H. Stenzel⁵², S. Stern⁹⁹, G.A. Stewart²⁹, J.A. Stillings²⁰, M.C. Stockton⁸⁵, K. Stoerig⁴⁸, G. Stoicea^{25a}, S. Stonjek⁹⁹, P. Strachota¹²⁶, A.R. Stradling⁷, A. Straessner⁴³, J. Strandberg¹⁴⁷, S. Strandberg^{146a,146b}, A. Strandlie¹¹⁷, M. Strang¹⁰⁹, E. Strauss¹⁴³, M. Strauss¹¹¹, P. Strizenc^{144b}, R. Ströhmer¹⁷⁴, D.M. Strom¹¹⁴, J.A. Strong^{76,*}, R. Stroynowski³⁹, J. Strube¹²⁹, B. Stugu¹³, I. Stumer^{24,*}, J. Stupak¹⁴⁸, P. Sturm¹⁷⁵, N.A. Styles⁴¹, D.A. Soh^{151,w}, D. Su¹⁴³, H.S. Subramania², A. Succurro¹¹, Y. Sugaya¹¹⁶, C. Suhr¹⁰⁶, M. Suk¹²⁶, V.V. Sulin⁹⁴, S. Sultansoy^{3d}, T. Sumida⁶⁷, X. Sun⁵⁵, J.E. Sundermann⁴⁸, K. Suruliz¹³⁹, G. Susinno^{36a,36b}, M.R. Sutton¹⁴⁹, Y. Suzuki⁶⁵, Y. Suzuki⁶⁶, M. Svatos¹²⁵, S. Swedish¹⁶⁸, I. Sykora^{144a}, T. Sykora¹²⁶, J. Sánchez¹⁶⁷, D. Ta¹⁰⁵, K. Tackmann⁴¹, A. Taffard¹⁶³, R. Tahirout^{159a}, N. Taiblum¹⁵³, Y. Takahashi¹⁰¹, H. Takai²⁴, R. Takashima⁶⁸, H. Takeda⁶⁶, T. Takeshita¹⁴⁰, Y. Takubo⁶⁵, M. Talby⁸³, A. Talyshev^{107,f}, M.C. Tamsett²⁴, J. Tanaka¹⁵⁵, R. Tanaka¹¹⁵, S. Tanaka¹³¹, S. Tanaka⁶⁵, A.J. Tanasijczuk¹⁴², K. Tani⁶⁶, N. Tannoury⁸³, S. Tapprogge⁸¹, D. Tardif¹⁵⁸, S. Tarem¹⁵², F. Tarrade²⁸, G.F. Tartarelli^{89a}, P. Tas¹²⁶, M. Tasevsky¹²⁵, E. Tassi^{36a,36b}, M. Tatarkhanov¹⁴, Y. Tayalati^{135d}, C. Taylor⁷⁷, F.E. Taylor⁹², G.N. Taylor⁸⁶, W. Taylor^{159b}, M. Teinturier¹¹⁵, M. Teixeira Dias Castanheira⁷⁵, P. Teixeira-Dias⁷⁶, K.K. Temming⁴⁸, H. Ten Kate²⁹, P.K. Teng¹⁵¹, S. Terada⁶⁵, K. Terashi¹⁵⁵, J. Terron⁸⁰, M. Testa⁴⁷, R.J. Teuscher^{158,k}, J. Therhaag²⁰, T. Theveneaux-Pelzer⁷⁸, S. Thoma⁴⁸, J.P. Thomas¹⁷, E.N. Thompson³⁴, P.D. Thompson¹⁷, P.D. Thompson¹⁵⁸, A.S. Thompson⁵³, L.A. Thomsen³⁵, E. Thomson¹²⁰, M. Thomson²⁷, R.P. Thun⁸⁷, F. Tian³⁴, M.J. Tibbetts¹⁴, T. Tic¹²⁵, V.O. Tikhomirov⁹⁴, Y.A. Tikhonov^{107,f}, S. Timoshenko⁹⁶, P. Tipton¹⁷⁶, F.J. Tique Aires Viegas²⁹, S. Tisserant⁸³, T. Todorov⁴, S. Todorova-Nova¹⁶¹, B. Toggerson¹⁶³, J. Tojo⁶⁹, S. Tokár^{144a}, K. Tokushuku⁶⁵, K. Tollefson⁸⁸, M. Tomoto¹⁰¹, L. Tompkins³⁰, K. Toms¹⁰³, A. Tonoyan¹³, C. Topfel¹⁶, N.D. Topilin⁶⁴, I. Torchiani²⁹, E. Torrence¹¹⁴, H. Torres⁷⁸, E. Torrò Pastor¹⁶⁷, J. Toth^{83,ad}, F. Touchard⁸³, D.R. Tovey¹³⁹, T. Trefzger¹⁷⁴, L. Tremblet²⁹, A. Tricoli²⁹, I.M. Trigger^{159a}, S. Trincaz-Duvoid⁷⁸, M.F. Tripiana⁷⁰, W. Trischuk¹⁵⁸, B. Trocme⁵⁵, C. Troncon^{89a}, M. Trottier-McDonald¹⁴², M. Trzebinski³⁸, A. Trzupek³⁸, C. Tsarouchas²⁹, J.C-L. Tseng¹¹⁸, M. Tsiakiris¹⁰⁵, P.V. Tsiarehka⁹⁰, D. Tsiouou^{4,ai}, G. Tsipolitis⁹, S. Tsiskaridze¹¹, V. Tsiskaridze⁴⁸, E.G. Tskhadadze^{51a}, I.I. Tsukerman⁹⁵, V. Tsulaia¹⁴, J.-W. Tsung²⁰, S. Tsuno⁶⁵, D. Tsybychev¹⁴⁸, A. Tua¹³⁹, A. Tudorache^{25a}, V. Tudorache^{25a}, J.M. Tuggle³⁰, M. Turala³⁸, D. Turecek¹²⁷, I. Turk Cakir^{3e}, E. Turlay¹⁰⁵, R. Turra^{89a,89b}, P.M. Tuts³⁴, A. Tykhonov⁷⁴, M. Tylmad^{146a,146b}, M. Tyndel¹²⁹, G. Tzanakos⁸, K. Uchida²⁰, I. Ueda¹⁵⁵, R. Ueno²⁸, M. Uglan¹³, M. Uhlenbrock²⁰, M. Uhrmacher⁵⁴, F. Ukegawa¹⁶⁰, G. Unal²⁹, A. Undrus²⁴, G. Unel¹⁶³, Y. Unno⁶⁵, D. Urbaniec³⁴, G. Usai⁷, M. Uslenghi^{119a,119b}, L. Vacavant⁸³, V. Vacek¹²⁷, B. Vachon⁸⁵, S. Vahsen¹⁴, J. Valenta¹²⁵, P. Valente^{132a}, S. Valentinetti^{19a,19b}, A. Valero¹⁶⁷, S. Valkar¹²⁶, E. Valladolid Gallego¹⁶⁷, S. Vallecorsa¹⁵², J.A. Valls Ferrer¹⁶⁷, H. van der Graaf¹⁰⁵, E. van der Kraaij¹⁰⁵, R. Van Der Leeuw¹⁰⁵, E. van der Poel¹⁰⁵, D. van der Ster²⁹, N. van Eldik²⁹, P. van Gemmeren⁵, I. van Vulpen¹⁰⁵, M. Vanadia⁹⁹, W. Vandelli²⁹, A. Vaniachine⁵, P. Vankov⁴¹, F. Vannucci⁷⁸, R. Vari^{132a},

T. Varol⁸⁴, D. Varouchas¹⁴, A. Vartapetian⁷, K.E. Varvell¹⁵⁰, V.I. Vassilakopoulos⁵⁶, F. Vazeille³³, T. Vazquez Schroeder⁵⁴, G. Vegni^{89a,89b}, J.J. Veillet¹¹⁵, F. Veloso^{124a}, R. Veness²⁹, S. Veneziano^{132a}, A. Ventura^{72a,72b}, D. Ventura⁸⁴, M. Venturi⁴⁸, N. Venturi¹⁵⁸, V. Vercesi^{119a}, M. Verducci¹³⁸, W. Verkerke¹⁰⁵, J.C. Vermeulen¹⁰⁵, A. Vest⁴³, M.C. Vetterli^{142,d}, I. Vichou¹⁶⁵, T. Vickey^{145b,aj}, O.E. Vickey Boeriu^{145b}, G.H.A. Viehhauser¹¹⁸, S. Viel¹⁶⁸, M. Villa^{19a,19b}, M. Villaplana Perez¹⁶⁷, E. Vilucchi⁴⁷, M.G. Vincter²⁸, E. Vinek²⁹, V.B. Vinogradov⁶⁴, M. Virchaux^{136,*}, J. Virzi¹⁴, O. Vitells¹⁷², M. Viti⁴¹, I. Vivarelli⁴⁸, F. Vives Vaque², S. Vlachos⁹, D. Vladoiu⁹⁸, M. Vlasak¹²⁷, A. Vogel²⁰, P. Vokac¹²⁷, G. Volpi⁴⁷, M. Volpi⁸⁶, G. Volpini^{89a}, H. von der Schmitt⁹⁹, J. von Loeben⁹⁹, H. von Radziewski⁴⁸, E. von Toerne²⁰, V. Vorobel¹²⁶, V. Vorwerk¹¹, M. Vos¹⁶⁷, R. Voss²⁹, T.T. Voss¹⁷⁵, J.H. Vosseveld⁷³, N. Vranjes¹³⁶, M. Vranjes Milosavljevic¹⁰⁵, V. Vrba¹²⁵, M. Vreeswijk¹⁰⁵, T. Vu Anh⁴⁸, R. Vuillermet²⁹, I. Vukotic¹¹⁵, W. Wagner¹⁷⁵, P. Wagner¹²⁰, H. Wahlen¹⁷⁵, S. Wahrmund⁴³, J. Wakabayashi¹⁰¹, S. Walch⁸⁷, J. Walder⁷¹, R. Walker⁹⁸, W. Walkowiak¹⁴¹, R. Wall¹⁷⁶, P. Waller⁷³, C. Wang⁴⁴, H. Wang¹⁷³, H. Wang^{32b,ak}, J. Wang¹⁵¹, J. Wang⁵⁵, R. Wang¹⁰³, S.M. Wang¹⁵¹, T. Wang²⁰, A. Warburton⁸⁵, C.P. Ward²⁷, M. Warsinsky⁴⁸, A. Washbrook⁴⁵, C. Wasicki⁴¹, P.M. Watkins¹⁷, A.T. Watson¹⁷, I.J. Watson¹⁵⁰, M.F. Watson¹⁷, G. Watts¹³⁸, S. Watts⁸², A.T. Waugh¹⁵⁰, B.M. Waugh⁷⁷, M. Weber¹²⁹, M.S. Weber¹⁶, P. Weber⁵⁴, A.R. Weidberg¹¹⁸, P. Weigell⁹⁹, J. Weingarten⁵⁴, C. Weiser⁴⁸, H. Wellenstein²², P.S. Wells²⁹, T. Wenaus²⁴, D. Wendland¹⁵, Z. Weng^{151,w}, T. Wengler²⁹, S. Wenig²⁹, N. Wermes²⁰, M. Werner⁴⁸, P. Werner²⁹, M. Werth¹⁶³, M. Wessels^{58a}, J. Wetter¹⁶¹, C. Weydert⁵⁵, K. Whalen²⁸, S.J. Wheeler-Ellis¹⁶³, A. White⁷, M.J. White⁸⁶, S. White^{122a,122b}, S.R. Whitehead¹¹⁸, D. Whiteson¹⁶³, D. Whittington⁶⁰, F. Wicek¹¹⁵, D. Wicke¹⁷⁵, F.J. Wickens¹²⁹, W. Wiedenmann¹⁷³, M. Wielers¹²⁹, P. Wienemann²⁰, C. Wiglesworth⁷⁵, L.A.M. Wiik-Fuchs⁴⁸, P.A. Wijeratne⁷⁷, A. Wildauer¹⁶⁷, M.A. Wildt^{41,s}, I. Wilhelm¹²⁶, H.G. Wilkens²⁹, J.Z. Will⁹⁸, E. Williams³⁴, H.H. Williams¹²⁰, W. Willis³⁴, S. Willocq⁸⁴, J.A. Wilson¹⁷, M.G. Wilson¹⁴³, A. Wilson⁸⁷, I. Wingerter-Seez⁴, S. Winkelmann⁴⁸, F. Winklmeier²⁹, M. Wittgen¹⁴³, S.J. Wollstadt⁸¹, M.W. Wolter³⁸, H. Wolters^{124a,h}, W.C. Wong⁴⁰, G. Wooden⁸⁷, B.K. Wosiek³⁸, J. Wotschack²⁹, M.J. Woudstra⁸², K.W. Wozniak³⁸, K. Wraight⁵³, C. Wright⁵³, M. Wright⁵³, B. Wrona⁷³, S.L. Wu¹⁷³, X. Wu⁴⁹, Y. Wu^{32b,al}, E. Wulf³⁴, B.M. Wynne⁴⁵, S. Xella³⁵, M. Xiao¹³⁶, S. Xie⁴⁸, C. Xu^{32b,z}, D. Xu¹³⁹, B. Yabsley¹⁵⁰, S. Yacoob^{145b}, M. Yamada⁶⁵, H. Yamaguchi¹⁵⁵, A. Yamamoto⁶⁵, K. Yamamoto⁶³, S. Yamamoto¹⁵⁵, T. Yamamura¹⁵⁵, T. Yamanaka¹⁵⁵, J. Yamaoka⁴⁴, T. Yamazaki¹⁵⁵, Y. Yamazaki⁶⁶, Z. Yan²¹, H. Yang⁸⁷, U.K. Yang⁸², Y. Yang⁶⁰, Z. Yang^{146a,146b}, S. Yanush⁹¹, L. Yao^{32a}, Y. Yao¹⁴, Y. Yasu⁶⁵, G.V. Ybeles Smit¹³⁰, J. Ye³⁹, S. Ye²⁴, M. Yilmaz^{3c}, R. Yoosoofmiya¹²³, K. Yorita¹⁷¹, R. Yoshida⁵, C. Young¹⁴³, C.J. Young¹¹⁸, S. Youssef²¹, D. Yu²⁴, J. Yu⁷, J. Yu¹¹², L. Yuan⁶⁶, A. Yurkewicz¹⁰⁶, B. Zabinski³⁸, R. Zaidan⁶², A.M. Zaitsev¹²⁸, Z. Zajacova²⁹, L. Zanello^{132a,132b}, A. Zaytsev¹⁰⁷, C. Zeitnitz¹⁷⁵, M. Zeman¹²⁵, A. Zemla³⁸, C. Zendler²⁰, O. Zenin¹²⁸, T. Ženiš^{144a}, Z. Zinonos^{122a,122b}, S. Zenz¹⁴, D. Zerwas¹¹⁵, G. Zevi della Porta⁵⁷, Z. Zhan^{32d}, D. Zhang^{32b,ak}, H. Zhang⁸⁸, J. Zhang⁵, X. Zhang^{32d}, Z. Zhang¹¹⁵, L. Zhao¹⁰⁸, T. Zhao¹³⁸, Z. Zhao^{32b}, A. Zhemchugov⁶⁴, J. Zhong¹¹⁸, B. Zhou⁸⁷, N. Zhou¹⁶³, Y. Zhou¹⁵¹, C.G. Zhu^{32d}, H. Zhu⁴¹, J. Zhu⁸⁷, Y. Zhu^{32b}, X. Zhuang⁹⁸, V. Zhuravlov⁹⁹, D. Zieminska⁶⁰, N.I. Zimin⁶⁴, R. Zimmermann²⁰, S. Zimmermann²⁰, S. Zimmermann⁴⁸, M. Ziolkowski¹⁴¹, R. Zitoun⁴, L. Živković³⁴, V.V. Zmouchko^{128,*}, G. Zobernig¹⁷³, A. Zoccoli^{19a,19b}, M. zur Nedden¹⁵, V. Zutshi¹⁰⁶, L. Zwalinski²⁹

¹ Physics Department, SUNY Albany, Albany, NY, United States

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

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

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

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

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

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

⁸ Physics Department, University of Athens, Athens, Greece

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

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

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

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

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

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

¹⁵ Department of Physics, Humboldt University, Berlin, Germany

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

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

- 18 ^(a) Department of Physics, Bogazici University, Istanbul; ^(b) Division of Physics, Dogus University, Istanbul; ^(c) Department of Physics Engineering, Gaziantep University, Gaziantep;
- 19 ^(a) INFN Sezione di Bologna; ^(b) Dipartimento di Fisica, Università di Bologna, Bologna, Italy
- 20 Physikalisches Institut, University of Bonn, Bonn, Germany
- 21 Department of Physics, Boston University, Boston, MA, United States
- 22 Department of Physics, Brandeis University, Waltham, MA, United States
- 23 ^(a) Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro; ^(b) Federal University of Juiz de Fora (UFJF), Juiz de Fora; ^(c) Federal University of Sao Joao del Rei (UFSJ), Sao Joao del Rei; ^(d) Instituto de Fisica, Universidade de Sao Paulo, Sao Paulo, Brazil
- 24 Physics Department, Brookhaven National Laboratory, Upton, NY, United States
- 25 ^(a) National Institute of Physics and Nuclear Engineering, Bucharest; ^(b) University Politehnica Bucharest, Bucharest; ^(c) West University in Timisoara, Timisoara, Romania
- 26 Departamento de Fisica, Universidad de Buenos Aires, Buenos Aires, Argentina
- 27 Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom
- 28 Department of Physics, Carleton University, Ottawa, ON, Canada
- 29 CERN, Geneva, Switzerland
- 30 Enrico Fermi Institute, University of Chicago, Chicago, IL, United States
- 31 ^(a) Departamento de Fisica, Pontificia Universidad Católica de Chile, Santiago; ^(b) Departamento de Fisica, Universidad Técnica Federico Santa María, Valparaíso, Chile
- 32 ^(a) Institute of High Energy Physics, Chinese Academy of Sciences, Beijing; ^(b) Department of Modern Physics, University of Science and Technology of China, Anhui; ^(c) Department of Physics, Nanjing University, Jiangsu; ^(d) School of Physics, Shandong University, Shandong, China
- 33 Laboratoire de Physique Corpusculaire, Clermont Université and Université Blaise Pascal and CNRS/IN2P3, Aubiere Cedex, France
- 34 Nevis Laboratory, Columbia University, Irvington, NY, United States
- 35 Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark
- 36 ^(a) INFN Gruppo Collegato di Cosenza; ^(b) Dipartimento di Fisica, Università della Calabria, Arcavacata di Rende, Italy
- 37 AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, Krakow, Poland
- 38 The Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, Krakow, Poland
- 39 Physics Department, Southern Methodist University, Dallas, TX, United States
- 40 Physics Department, University of Texas at Dallas, Richardson, TX, United States
- 41 DESY, Hamburg and Zeuthen, Germany
- 42 Institut für Experimentelle Physik IV, Technische Universität Dortmund, Dortmund, Germany
- 43 Institut für Kern- und Teilchenphysik, Technical University Dresden, Dresden, Germany
- 44 Department of Physics, Duke University, Durham NC, United States
- 45 SUPA - School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom
- 46 Fachhochschule Wiener Neustadt, Johannes Gutenbergstrasse 32700 Wiener Neustadt, Austria
- 47 INFN Laboratori Nazionali di Frascati, Frascati, Italy
- 48 Fakultät für Mathematik und Physik, Albert-Ludwigs-Universität, Freiburg i.Br., Germany
- 49 Section de Physique, Université de Genève, Geneva, Switzerland
- 50 ^(a) INFN Sezione di Genova; ^(b) Dipartimento di Fisica, Università di Genova, Genova, Italy
- 51 ^(a) E. Andronikashvili Institute of Physics, Tbilisi State University, Tbilisi; ^(b) High Energy Physics Institute, Tbilisi State University, Tbilisi, Georgia
- 52 II Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen, Germany
- 53 SUPA - School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom
- 54 II Physikalisches Institut, Georg-August-Universität, Göttingen, Germany
- 55 Laboratoire de Physique Subatomique et de Cosmologie, Université Joseph Fourier and CNRS/IN2P3 and Institut National Polytechnique de Grenoble, Grenoble, France
- 56 Department of Physics, Hampton University, Hampton, VA, United States
- 57 Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge, MA, United States
- 58 ^(a) Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg; ^(b) Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg; ^(c) ZITI Institut für technische Informatik, Ruprecht-Karls-Universität Heidelberg, Mannheim, Germany
- 59 Faculty of Applied Information Science, Hiroshima Institute of Technology, Hiroshima, Japan
- 60 Department of Physics, Indiana University, Bloomington, IN, United States
- 61 Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck, Austria
- 62 University of Iowa, Iowa City, IA, United States
- 63 Department of Physics and Astronomy, Iowa State University, Ames, IA, United States
- 64 Joint Institute for Nuclear Research, JINR Dubna, Dubna, Russia
- 65 KEK, High Energy Accelerator Research Organization, Tsukuba, Japan
- 66 Graduate School of Science, Kobe University, Kobe, Japan
- 67 Faculty of Science, Kyoto University, Kyoto, Japan
- 68 Kyoto University of Education, Kyoto, Japan
- 69 Department of Physics, Kyushu University, Fukuoka, Japan
- 70 Instituto de Fisica La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina
- 71 Physics Department, Lancaster University, Lancaster, United Kingdom
- 72 ^(a) INFN Sezione di Lecce; ^(b) Dipartimento di Matematica e Fisica, Università del Salento, Lecce, Italy
- 73 Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom
- 74 Department of Physics, Jozef Stefan Institute and University of Ljubljana, Ljubljana, Slovenia
- 75 School of Physics and Astronomy, Queen Mary University of London, London, United Kingdom
- 76 Department of Physics, Royal Holloway University of London, Surrey, United Kingdom
- 77 Department of Physics and Astronomy, University College London, London, United Kingdom
- 78 Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France
- 79 Fysiska institutionen, Lunds universitet, Lund, Sweden
- 80 Departamento de Fisica Teorica C-15, Universidad Autonoma de Madrid, Madrid, Spain
- 81 Institut für Physik, Universität Mainz, Mainz, Germany
- 82 School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom
- 83 CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France
- 84 Department of Physics, University of Massachusetts, Amherst, MA, United States
- 85 Department of Physics, McGill University, Montreal, QC, Canada
- 86 School of Physics, University of Melbourne, Victoria, Australia
- 87 Department of Physics, The University of Michigan, Ann Arbor, MI, United States
- 88 Department of Physics and Astronomy, Michigan State University, East Lansing, MI, United States
- 89 ^(a) INFN Sezione di Milano; ^(b) Dipartimento di Fisica, Università di Milano, Milano, Italy
- 90 B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Belarus
- 91 National Scientific and Educational Centre for Particle and High Energy Physics, Minsk, Belarus
- 92 Department of Physics, Massachusetts Institute of Technology, Cambridge, MA, United States

- ⁹³ Group of Particle Physics, University of Montreal, Montreal, QC, Canada
- ⁹⁴ P.N. Lebedev Institute of Physics, Academy of Sciences, Moscow, Russia
- ⁹⁵ Institute for Theoretical and Experimental Physics (ITEP), Moscow, Russia
- ⁹⁶ Moscow Engineering and Physics Institute (MEPhI), Moscow, Russia
- ⁹⁷ Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
- ⁹⁸ Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany
- ⁹⁹ Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany
- ¹⁰⁰ Nagasaki Institute of Applied Science, Nagasaki, Japan
- ¹⁰¹ Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya, Japan
- ¹⁰² ^(a) INFN Sezione di Napoli; ^(b) Dipartimento di Scienze Fisiche, Università di Napoli, Napoli, Italy
- ¹⁰³ Department of Physics and Astronomy, University of New Mexico, Albuquerque, NM, United States
- ¹⁰⁴ Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands
- ¹⁰⁵ Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands
- ¹⁰⁶ Department of Physics, Northern Illinois University, DeKalb, IL, United States
- ¹⁰⁷ Budker Institute of Nuclear Physics, SB RAS, Novosibirsk, Russia
- ¹⁰⁸ Department of Physics, New York University, New York, NY, United States
- ¹⁰⁹ Ohio State University, Columbus, OH, United States
- ¹¹⁰ Faculty of Science, Okayama University, Okayama, Japan
- ¹¹¹ Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman, OK, United States
- ¹¹² Department of Physics, Oklahoma State University, Stillwater, OK, United States
- ¹¹³ Palacký University, RCPTM, Olomouc, Czech Republic
- ¹¹⁴ Center for High Energy Physics, University of Oregon, Eugene, OR, United States
- ¹¹⁵ LAL, Université Paris-Sud and CNRS/IN2P3, Orsay, France
- ¹¹⁶ Graduate School of Science, Osaka University, Osaka, Japan
- ¹¹⁷ Department of Physics, University of Oslo, Oslo, Norway
- ¹¹⁸ Department of Physics, Oxford University, Oxford, United Kingdom
- ¹¹⁹ ^(a) INFN Sezione di Pavia; ^(b) Dipartimento di Fisica, Università di Pavia, Pavia, Italy
- ¹²⁰ Department of Physics, University of Pennsylvania, Philadelphia, PA, United States
- ¹²¹ Petersburg Nuclear Physics Institute, Gatchina, Russia
- ¹²² ^(a) INFN Sezione di Pisa; ^(b) Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy
- ¹²³ Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, PA, United States
- ¹²⁴ ^(a) Laboratório de Instrumentação e Física Experimental de Partículas – LIP, Lisboa, Portugal; ^(b) Departamento de Física Teórica y del Cosmos and CAFPE, Universidad de Granada, Granada, Spain
- ¹²⁵ Institute of Physics, Academy of Sciences of the Czech Republic, Praha, Czech Republic
- ¹²⁶ Faculty of Mathematics and Physics, Charles University in Prague, Praha, Czech Republic
- ¹²⁷ Czech Technical University in Prague, Praha, Czech Republic
- ¹²⁸ State Research Center Institute for High Energy Physics, Protvino, Russia
- ¹²⁹ Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom
- ¹³⁰ Physics Department, University of Regina, Regina, SK, Canada
- ¹³¹ Ritsumeikan University, Kusatsu, Shiga, Japan
- ¹³² ^(a) INFN Sezione di Roma I; ^(b) Dipartimento di Fisica, Università La Sapienza, Roma, Italy
- ¹³³ ^(a) INFN Sezione di Roma Tor Vergata; ^(b) Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy
- ¹³⁴ ^(a) INFN Sezione di Roma Tre; ^(b) Dipartimento di Fisica, Università Roma Tre, Roma, Italy
- ¹³⁵ ^(a) Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies, Université Hassan II, Casablanca; ^(b) Centre National de l'Energie des Sciences Techniques Nucleaires, Rabat; ^(c) Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA, Marrakech; ^(d) Faculté des Sciences, Université Mohamed Premier and LPTPM, Oujda; ^(e) Faculté des sciences, Université Mohammed V, Agdal, Rabat, Morocco
- ¹³⁶ DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l'Univers), CEA Saclay (Commissariat à l'Energie Atomique), Gif-sur-Yvette, France
- ¹³⁷ Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz, CA, United States
- ¹³⁸ Department of Physics, University of Washington, Seattle, WA, United States
- ¹³⁹ Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom
- ¹⁴⁰ Department of Physics, Shinshu University, Nagano, Japan
- ¹⁴¹ Fachbereich Physik, Universität Siegen, Siegen, Germany
- ¹⁴² Department of Physics, Simon Fraser University, Burnaby, BC, Canada
- ¹⁴³ SLAC National Accelerator Laboratory, Stanford, CA, United States
- ¹⁴⁴ ^(a) Faculty of Mathematics, Physics & Informatics, Comenius University, Bratislava; ^(b) Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice, Slovak Republic
- ¹⁴⁵ ^(a) Department of Physics, University of Johannesburg, Johannesburg; ^(b) School of Physics, University of the Witwatersrand, Johannesburg, South Africa
- ¹⁴⁶ ^(a) Department of Physics, Stockholm University; ^(b) The Oskar Klein Centre, Stockholm, Sweden
- ¹⁴⁷ Physics Department, Royal Institute of Technology, Stockholm, Sweden
- ¹⁴⁸ Departments of Physics & Astronomy and Chemistry, Stony Brook University, Stony Brook, NY, United States
- ¹⁴⁹ Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom
- ¹⁵⁰ School of Physics, University of Sydney, Sydney, Australia
- ¹⁵¹ Institute of Physics, Academia Sinica, Taipei, Taiwan
- ¹⁵² Department of Physics, Technion: Israel Institute of Technology, Haifa, Israel
- ¹⁵³ Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel
- ¹⁵⁴ Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece
- ¹⁵⁵ International Center for Elementary Particle Physics and Department of Physics, The University of Tokyo, Tokyo, Japan
- ¹⁵⁶ Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo, Japan
- ¹⁵⁷ Department of Physics, Tokyo Institute of Technology, Tokyo, Japan
- ¹⁵⁸ Department of Physics, University of Toronto, Toronto, ON, Canada
- ¹⁵⁹ ^(a) TRIUMF, Vancouver, BC; ^(b) Department of Physics and Astronomy, York University, Toronto, ON, Canada
- ¹⁶⁰ Institute of Pure and Applied Sciences, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki 305-8571, Japan
- ¹⁶¹ Science and Technology Center, Tufts University, Medford, MA, United States
- ¹⁶² Centro de Investigaciones, Universidad Antonio Narino, Bogota, Colombia
- ¹⁶³ Department of Physics and Astronomy, University of California Irvine, Irvine, CA, United States
- ¹⁶⁴ ^(a) INFN Gruppo Collegato di Udine; ^(b) ICTP, Trieste; ^(c) Dipartimento di Chimica, Fisica e Ambiente, Università di Udine, Udine, Italy
- ¹⁶⁵ Department of Physics, University of Illinois, Urbana, IL, United States
- ¹⁶⁶ Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden

¹⁶⁷ Instituto de Física Corpuscular (IFIC) and Departamento de Física Atómica, Molecular y Nuclear and Departamento de Ingeniería Electrónica and Instituto de Microelectrónica de Barcelona (IMB-CNM), University of Valencia and CSIC, Valencia, Spain

¹⁶⁸ Department of Physics, University of British Columbia, Vancouver, BC, Canada

¹⁶⁹ Department of Physics and Astronomy, University of Victoria, Victoria, BC, Canada

¹⁷⁰ Department of Physics, University of Warwick, Coventry, United Kingdom

¹⁷¹ Waseda University, Tokyo, Japan

¹⁷² Department of Particle Physics, The Weizmann Institute of Science, Rehovot, Israel

¹⁷³ Department of Physics, University of Wisconsin, Madison, WI, United States

¹⁷⁴ Fakultät für Physik und Astronomie, Julius-Maximilians-Universität, Würzburg, Germany

¹⁷⁵ Fachbereich C Physik, Bergische Universität Wuppertal, Wuppertal, Germany

¹⁷⁶ Department of Physics, Yale University, New Haven, CT, United States

¹⁷⁷ Yerevan Physics Institute, Yerevan, Armenia

¹⁷⁸ Domaine scientifique de la Doua, Centre de Calcul CNRS/IN2P3, Villeurbanne Cedex, France

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

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

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

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

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

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

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

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

ⁱ Also at Department of Physics, UASLP, San Luis Potosí, Mexico.

^j Also at Università di Napoli Parthenope, Napoli, Italy.

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

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

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

ⁿ Also at Dep Física and CEFITEC of Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Caparica, Portugal.

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

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

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

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

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

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

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

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

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

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

^y Also at Dipartimento di Fisica, Università La Sapienza, Roma, Italy.

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

^{aa} Also at Section de Physique, Université de Genève, Geneva, Switzerland.

^{ab} Also at Departamento de Física, Universidade de Minho, Braga, Portugal.

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

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

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

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

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

^{ah} Also at Nevis Laboratory, Columbia University, Irvington, NY, United States.

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

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

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

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

* Deceased.