



Measurements of gluon–gluon fusion and vector-boson fusion Higgs boson production cross-sections in the $H \rightarrow WW^* \rightarrow e\nu\mu\nu$ decay channel in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

The ATLAS Collaboration*



ARTICLE INFO

Article history:

Received 28 August 2018
 Received in revised form 15 November 2018
 Accepted 18 November 2018
 Available online 2 January 2019
 Editor: W.-D. Schlatter

ABSTRACT

Higgs boson production cross-sections in proton–proton collisions are measured in the $H \rightarrow WW^* \rightarrow e\nu\mu\nu$ decay channel. The proton–proton collision data were produced at the Large Hadron Collider at a centre-of-mass energy of 13 TeV and recorded by the ATLAS detector in 2015 and 2016, corresponding to an integrated luminosity of 36.1 fb^{-1} . The product of the $H \rightarrow WW^*$ branching fraction times the gluon–gluon fusion and vector-boson fusion cross-sections are measured to be $11.4^{+1.2}_{-1.1}(\text{stat.})^{+1.8}_{-1.7}(\text{syst.}) \text{ pb}$ and $0.50^{+0.24}_{-0.22}(\text{stat.}) \pm 0.17(\text{syst.}) \text{ pb}$, respectively, in agreement with Standard Model predictions.

© 2019 The Author. Published by Elsevier B.V. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>). Funded by SCOAP³.

1. Introduction

This Letter presents a measurement of the inclusive Higgs boson production cross-sections via gluon–gluon fusion (ggF) and vector-boson fusion (VBF) through the decay $H \rightarrow WW^* \rightarrow e\nu\mu\nu$ using 36.1 fb^{-1} of proton–proton collisions at a centre-of-mass energy of 13 TeV recorded by the ATLAS detector. Higgs boson couplings have been studied in this channel with Run-1 data by the ATLAS [1] and CMS [2] experiments and recently with Run-2 data by the CMS experiment [3]. The $H \rightarrow WW^*$ decay channel has the second-largest branching fraction and allowed the most precise Higgs boson cross-section measurements in Run-1 [4]. The measured cross-section of the ggF production process probes the Higgs boson couplings to gluons and heavy quarks, while the VBF process directly probes the couplings to W and Z bosons. The leading-order diagrams for the ggF and VBF production processes are depicted in Fig. 1.

2. ATLAS detector

ATLAS is a particle detector designed to achieve a nearly full coverage in solid angle¹ [5,6]. It consists of an inner tracking detector surrounded by a thin superconducting solenoid, electro-

magnetic and hadronic calorimeters, and a muon spectrometer incorporating three large superconducting air-core toroidal magnets. The inner tracking detector (ID) is located in a 2 T magnetic field and is designed to measure charged-particle trajectories up to a pseudorapidity of $|\eta| = 2.5$. Surrounding the ID are electromagnetic and hadronic calorimeters, which use liquid argon (LAr) and lead absorber for the electromagnetic central and endcap calorimeters ($|\eta| < 3.2$), copper absorber for the hadronic endcap calorimeter ($1.5 < |\eta| < 3.2$), and scintillator-tile active material with steel absorber for the central ($|\eta| < 1.7$) hadronic calorimeter. The solid angle coverage is extended to $|\eta| = 4.9$ with forward copper/LAr and tungsten/LAr calorimeter modules. The muon spectrometer comprises separate trigger chambers within the range $|\eta| < 2.4$ and high-precision tracking chambers within the range $|\eta| < 2.7$, measuring the deflection of muons in a magnetic field generated by the three superconducting toroidal magnets. A two-level trigger system is used to select events [7].

3. Signal and background Monte Carlo predictions

Higgs boson production via ggF was simulated at next-to-next-to-leading-order (NNLO) accuracy in QCD using the POWHEG-Box v2 NNLOPS program [8], with the PDF4LHC15 NNLO set of parton distribution functions (PDF) [9]. The simulation achieves NNLO accuracy for arbitrary inclusive $gg \rightarrow H$ observables by reweighting the Higgs boson rapidity spectrum in HJ-MiNLO [10] to that of HNNLO [11]. The transverse momentum spectrum of the Higgs bo-

¹ $\sqrt{\Delta\phi^2 + \Delta\eta^2}$, is also used to define cone sizes. Transverse momentum and energy are defined as $p_T = p \sin\theta$ and $E_T = E \sin\theta$, respectively.

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

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

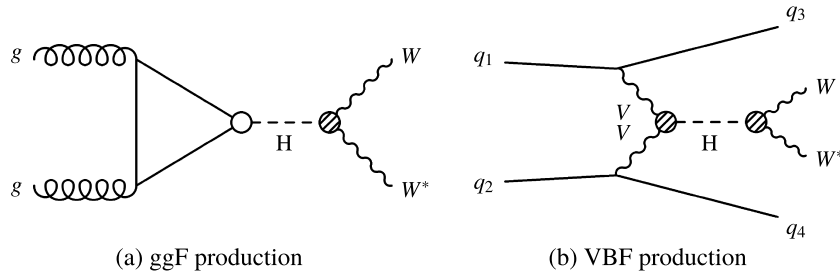


Fig. 1. Diagrams for the leading production modes (ggF and VBF), where the VVH and qqH coupling vertices are marked with shaded and empty circles, respectively. The V represents a W or Z vector boson.

Table 1

Overview of simulation tools used to generate signal and background processes, and to model the UEPS. The PDF sets are also summarised. Alternative event generators and configurations used to estimate systematic uncertainties are shown in parentheses.

Process	Matrix element (alternative)	PDF set	UEPS model (alternative model)	Prediction order for total cross-section
ggF H	PowHEG-Box v2 NNLOPS [8,10,16] (MG5_AMC@NLO [47,48])	PDF4LHC15 NNLO [9]	PyTHIA 8 [14]	N^3 LO QCD + NLO EW [24–28]
VBF H	PowHEG-Box v2	PDF4LHC15 NLO	(Herwig 7 [49]) PyTHIA 8 (Herwig 7)	NNLO QCD + NLO EW [24,29–31]
VH	PowHEG-Box v2 [50]	PDF4LHC15 NLO	PyTHIA 8	NNLO QCD + NLO EW [51–53]
$qq \rightarrow WW$	SHERPA 2.2.2 [32,33] (PowHEG-Box v2, MG5_AMC@NLO)	NNPDF3.0NNLO [34]	SHERPA 2.2.2 [35,36] (Herwig++ [49])	NLO [37]
$gg \rightarrow WW$	SHERPA 2.1.1 [37]	CT10 [54]	SHERPA 2.1	NLO [38]
$WZ/V\gamma^*/ZZ$	SHERPA 2.1	CT10	SHERPA 2.1	NLO [37]
$V\gamma$	SHERPA 2.2.2 (MG5_AMC@NLO)	NNPDF3.0NNLO	SHERPA 2.2.2 (CSS variation [35,55])	NLO [37]
$t\bar{t}$	PowHEG-Box v2 [56] (SHERPA 2.2.1)	NNPDF3.0NLO	PyTHIA 8 (Herwig 7)	NNLO + NNLL [57]
Wt	PowHEG-Box v1 [58] (MG5_AMC@NLO)	CT10 [54]	PyTHIA 6.428 [59] (Herwig++)	NLO [58]
Z/γ^*	SHERPA 2.2.1	NNPDF3.0NNLO	SHERPA 2.2.1	NNLO [60,61]

son obtained with this sample was found to be compatible within uncertainties with the resummed NNLO+NNLL HRes2.3 calculation [12,13]. The parton-level events produced by the PowHEG-Box v2 NNLOPS program were passed to PyTHIA 8 [14] to provide parton showering, hadronisation and the underlying event, using the AZNLO set of data-tuned parameters [15].

Higgs boson production via VBF was simulated at next-to-leading-order (NLO) accuracy in QCD using PowHEG-Box v2 [8, 10,16,17] with the PDF4LHC15 NLO PDF set [9]. The parton-level events were passed to PyTHIA 8 [14] with the same parameters as for ggF.

The mass of the Higgs boson was set to 125 GeV, compatible with the experimental measurement [18–20]. The corresponding Standard Model (SM) branching fraction $\mathcal{B}_{H \rightarrow WW^*}$ is calculated using HDecay v6.50 [21,22] to be 0.214 [23]. The $H \rightarrow WW^* \rightarrow \ell\nu\ell\nu$ decay, where $\ell = e$ or μ , always includes the small contribution from $W \rightarrow \tau\nu \rightarrow \ell\nu\nu\nu$ decays. Other production and decay modes of the Higgs boson are either fixed to SM predictions (VH production and $H \rightarrow \tau\tau$ decay) or neglected ($t\bar{t}H$ and $b\bar{b}H$ associated production).

The ggF production cross-section was calculated with next-to-next-to-next-to-leading-order accuracy in QCD and includes NLO electroweak (EW) corrections [24–28]. The NLO QCD and EW calculations are used with approximate NNLO QCD corrections for the VBF production cross-section [24,29–31].

The WW background was generated separately for the $qq \rightarrow WW$ and $gg \rightarrow WW$ production mechanisms. The $qq \rightarrow WW$ production process was generated using SHERPA 2.2.2 [32,33] interfaced with the NNPDF3.0 NNLO PDF set [34] and the SHERPA parton shower, hadronisation and underlying event simulation (UEPS) model [35,36]. The matrix elements were calculated for up to one

additional parton at NLO and up to three additional partons at LO precision. The loop-induced $gg \rightarrow WW$ process was simulated by SHERPA 2.1.1 with zero or one additional jet [37]. The sample is normalised to the NLO $gg \rightarrow WW$ cross-section [38]. Interferences with direct WW production have a negligible impact after event selection cuts have been applied and are, therefore, not considered in this analysis [39].

While NNLO cross-sections are available for diboson production processes [40–42], the SHERPA MEPS@NLO prescription [36] is used in this analysis. This procedure already captures the majority of the NNLO shape corrections.

The MC generators, PDFs, and programmes used for the UEPS are summarised in Table 1. The order of the perturbative prediction for each sample is also reported.

The generated events were passed through a GEANT 4 [43] simulation of the ATLAS detector [44] and reconstructed with the same analysis software as used for the data. Additional proton–proton interactions (pile-up) are included in the simulation for all generated events such that the distributions of the average number of interactions per bunch crossing reproduces that observed in the data. The inelastic proton–proton collisions were produced using PyTHIA 8 with the A2 set of data-tuned parameters [45] and the MSTW2008LO PDF set [46]. Correction factors are applied to account for small differences observed between data and simulation in electrons, muons, and jets identification efficiencies and energy/momentum scales and resolutions.

4. Event selection and categorisations

Events are triggered using single-lepton triggers and a dilepton $e-\mu$ trigger. The transverse momentum threshold ranges be-

Table 2

Event selection criteria used to define the signal regions in the $H \rightarrow WW^* \rightarrow e\nu\mu\nu$ analysis. For the $N_{\text{jet}} \geq 2$ VBF signal region, the input variables used for the boosted decision tree (BDT) training are also reported.

Category	$N_{\text{jet}, (p_T > 30 \text{ GeV})} = 0$ ggF	$N_{\text{jet}, (p_T > 30 \text{ GeV})} = 1$ ggF	$N_{\text{jet}, (p_T > 30 \text{ GeV})} \geq 2$ VBF
Preselection	Two isolated, different-flavour leptons ($\ell = e, \mu$) with opposite charge $p_T^{\text{lead}} > 22 \text{ GeV}, p_T^{\text{sublead}} > 15 \text{ GeV}$ $m_{\ell\ell} > 10 \text{ GeV}$ $p_T^{\text{miss}} > 20 \text{ GeV}$		
Background rejection	$\Delta\phi(\ell\ell, E_T^{\text{miss}}) > \pi/2$ $p_T^{\ell\ell} > 30 \text{ GeV}$	$N_{b\text{-jet}, (p_T > 20 \text{ GeV})} = 0$ $\max(m_{\tau\tau}^{\ell}) > 50 \text{ GeV}$ $m_{\tau\tau} < m_Z - 25 \text{ GeV}$	
$H \rightarrow WW^* \rightarrow e\nu\mu\nu$ topology	$m_{\ell\ell} < 55 \text{ GeV}$ $\Delta\phi_{\ell\ell} < 1.8$	central jet veto outside lepton veto	
Discriminant variable BDT input variables	$m_{\tau\tau}$ BDT $m_{jj}, \Delta y_{jj}, m_{\ell\ell}, \Delta\phi_{\ell\ell}, m_{\tau\tau}, \sum_{\ell} C_{\ell}, \sum_{\ell, j} m_{\ell j}, p_T^{\text{tot}}$		

tween 24 GeV and 26 GeV for single-electron triggers and between 20 GeV and 26 GeV for single-muon triggers, depending on the run period [7]. The $e\text{-}\mu$ trigger requires a minimum p_T threshold of 17 GeV for electrons and 14 GeV for muons.

Electron candidates are reconstructed from energy clusters in the electromagnetic calorimeter with an associated well-reconstructed track [62,63]. Electrons are required to satisfy $|\eta| < 2.47$, excluding the transition region between the barrel and endcap calorimeters, $1.37 < |\eta| < 1.52$. Muon candidates are selected from tracks reconstructed in the ID matched to tracks reconstructed in the muon spectrometer [64] and are required to satisfy $|\eta| < 2.5$. To reject particles misidentified as leptons, several identification requirements as well as calorimeter and track isolation criteria [64, 65] are applied. The electron identification criteria applied provide an efficiency in the range 88–94% depending on electron p_T and η . For muons, high efficiency, close to 95%, is observed over the full instrumented η range. The final lepton-selection criteria require two different-flavour opposite-sign leptons, the higher- p_T (leading) lepton with $p_T > 22 \text{ GeV}$ and the subleading lepton with $p_T > 15 \text{ GeV}$. At least one of the leptons must correspond to a lepton that triggered the recording of the event. When the $e\text{-}\mu$ trigger is solely responsible for the recording of the event, each lepton must be matched to one of the trigger objects. The trigger matching requires the offline p_T of the matching object to be higher than the trigger level threshold by at least 1 GeV. Jets are reconstructed using the anti- k_r algorithm [66] with a radius parameter $R = 0.4$. The four-momenta of jets are corrected for the non-compensating response of calorimeter, signal losses due to noise threshold effects, energy lost in non-instrumented regions, and contributions from pile-up [67]. Jets are required to have $p_T > 20 \text{ GeV}$ and $|\eta| < 4.5$. A multivariate selection that reduces contamination from pile-up [68] is applied to jets with $p_T < 60 \text{ GeV}$ and $|\eta| < 2.4$, utilising calorimeter and tracking information to separate hard-scatter jets from pile-up jets. For jets with $p_T < 50 \text{ GeV}$ and $|\eta| > 2.5$, jet shapes and topological jet correlations in pile-up interactions are exploited to reduce contamination. Jets with $p_T > 20 \text{ GeV}$ and $|\eta| < 2.5$ containing b -hadrons (b -jets) are identified using a multivariate technique having as input the track impact parameters and information from secondary vertices. The adopted working point provides a nominal 3% light-flavour (u -, d -, s -quark and gluon) misidentification rate and a 32% c -jet misidentification rate with an average 85% b -jet tagging efficiency, as estimated from simulated $t\bar{t}$ events [69]. Ambiguities from overlapping reconstructed jet and lepton candidates are resolved as follows. If a reconstructed muon shares an ID track with a reconstructed electron, the electron is removed. Reconstructed jets geometrically overlapping in a cone of radius $\Delta R = 0.2$ with electrons or muons are also removed. Electrons and muons, with transverse momentum p_T , are

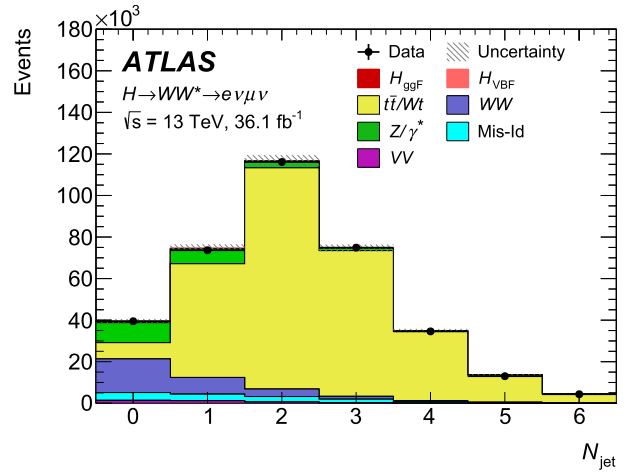


Fig. 2. Jet multiplicity distribution after applying the preselection criteria. The shaded band represents the systematic uncertainty and accounts for experimental uncertainties only.

removed if they are within $\Delta R = \min(0.4, 0.04 + 10 \text{ GeV}/p_T)$ of the axis of any surviving jet. The missing transverse momentum E_T^{miss} (with magnitude E_T^{miss}) is defined as the negative vector sum of the p_T of all the selected leptons and jets, and including reconstructed tracks not associated with these objects, and consistent with originating from the primary pp collision [70]. A second definition of missing transverse momentum (in this case denoted p_T^{miss}) uses the tracks associated with the jets instead of the calorimeter-measured jets. It was found during the optimisation that p_T^{miss} performs better in terms of background rejection [70].

Events are classified into one of three categories based on the number of jets with $p_T > 30 \text{ GeV}$: events with zero jets and events with exactly one jet target the ggF production mode ($N_{\text{jet}} = 0$ and $N_{\text{jet}} = 1$ ggF categories), and events with at least two jets target the VBF production mode ($N_{\text{jet}} \geq 2$ VBF category). Fig. 2 shows the jet multiplicity distribution after applying the preselection criteria defined in Table 2. The different background compositions as a function of jet multiplicity motivate the division of the data sample into the various N_{jet} categories and the definition of a signal region in each jet multiplicity bin. Details of the background estimation are provided in Section 5. To reject background from top-quark production, events containing b -jets with $p_T > 20 \text{ GeV}$ ($N_{b\text{-jet}, (p_T > 20 \text{ GeV})}$) are vetoed. The full event selection is summarised in Table 2, where $\Delta\phi(\ell\ell, E_T^{\text{miss}})$ is defined as the azimuthal angle between E_T^{miss} and the dilepton system, $p_T^{\ell\ell}$ is the transverse momentum of the dilepton system, $m_{\ell\ell}$ is

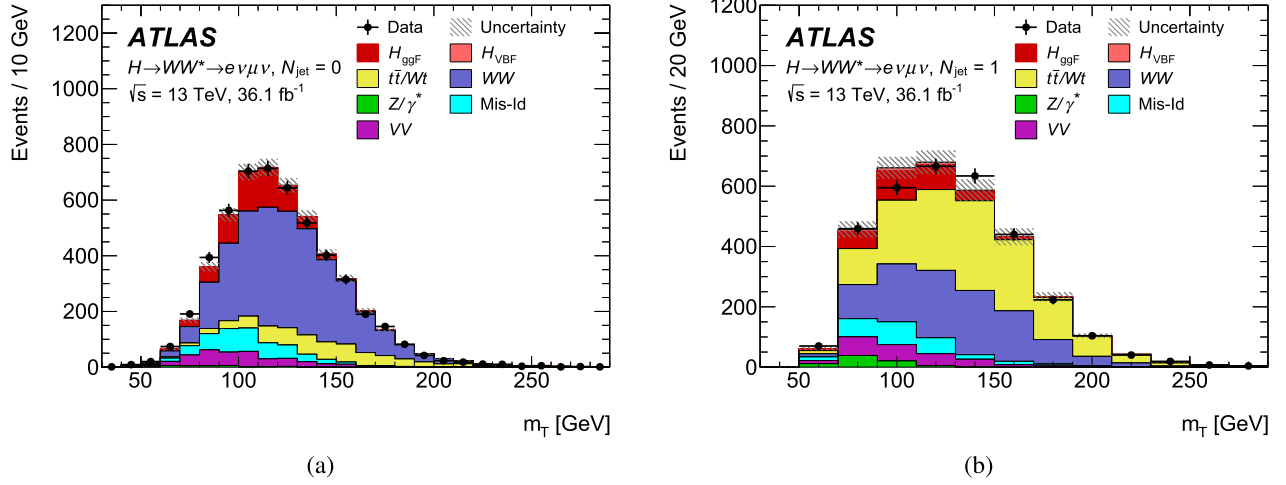


Fig. 3. Post-fit m_T distributions with the signal and the background modelled contributions in the (a) $N_{\text{jet}}=0$ and (b) $N_{\text{jet}}=1$ signal regions. The hatched band shows the total uncertainty of the signal and background modelled contributions.

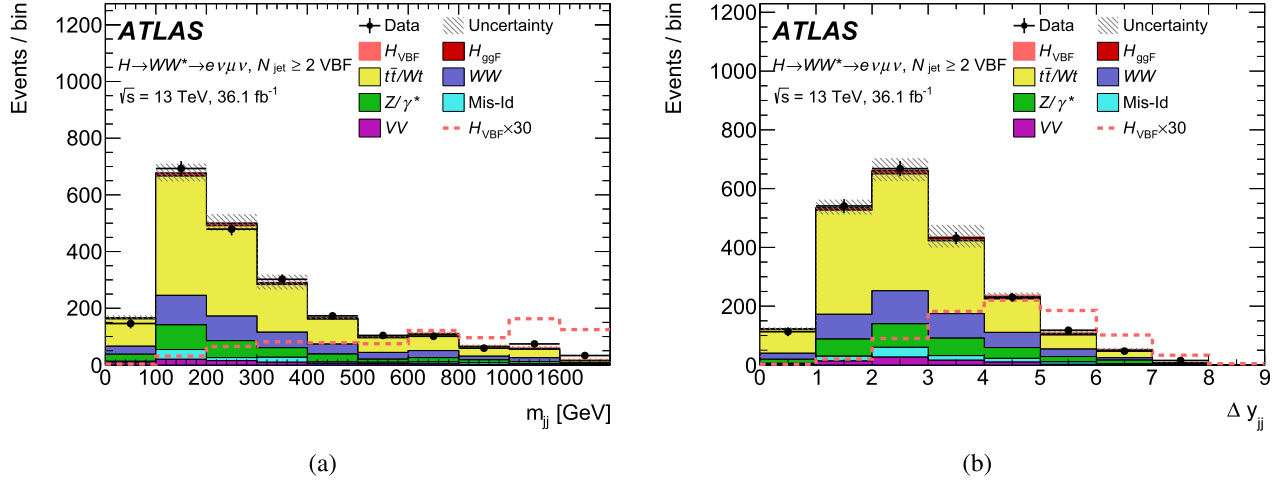


Fig. 4. Post-fit m_{jj} (a) and Δy_{jj} (b) distributions with signal and background modelled contributions in the $N_{\text{jet}} \geq 2$ VBF signal region. The dashed line shows the VBF signal scaled by a factor of 30. The hatched band shows the total uncertainty of the signal and background modelled contributions.

Table 3

Event selection criteria used to define the control regions. Every control region selection starts from the selection labelled “Preselection” in Table 2. $N_{b\text{-jet},(20 \text{ GeV} < p_T < 30 \text{ GeV})}$ represents the number of b -jets with $20 \text{ GeV} < p_T < 30 \text{ GeV}$.

CR	$N_{\text{jet},(p_T > 30 \text{ GeV})} = 0$ ggF	$N_{\text{jet},(p_T > 30 \text{ GeV})} = 1$ ggF	$N_{\text{jet},(p_T > 30 \text{ GeV})} \geq 2$ VBF
WW	$55 < m_{\ell\ell} < 110 \text{ GeV}$ $\Delta\phi_{\ell\ell} < 2.6$ $N_{b\text{-jet},(p_T > 20 \text{ GeV})} = 0$	$m_{\ell\ell} > 80 \text{ GeV}$ $ m_{\tau\tau} - m_Z > 25 \text{ GeV}$ $\max(m_T^\ell) > 50 \text{ GeV}$	
$t\bar{t}/Wt$	$N_{b\text{-jet},(20 \text{ GeV} < p_T < 30 \text{ GeV})} > 0$ $\Delta\phi(\ell\ell, E_T^{\text{miss}}) > \pi/2$ $p_T^{\ell\ell} > 30 \text{ GeV}$ $\Delta\phi_{\ell\ell} < 2.8$	$N_{b\text{-jet},(p_T > 30 \text{ GeV})} = 1$ $N_{b\text{-jet},(20 \text{ GeV} < p_T < 30 \text{ GeV})} = 0$ $\max(m_T^\ell) > 50 \text{ GeV}$ $m_{\tau\tau} < m_Z - 25 \text{ GeV}$	$N_{b\text{-jet},(p_T > 20 \text{ GeV})} = 1$ central jet veto outside lepton veto
Z/γ^*	no p_T^{miss} requirement $\Delta\phi_{\ell\ell} > 2.8$	$N_{b\text{-jet},(p_T > 20 \text{ GeV})} = 0$ $m_{\ell\ell} < 80 \text{ GeV}$ $\max(m_T^\ell) > 50 \text{ GeV}$ $m_{\tau\tau} > m_Z - 25 \text{ GeV}$	central jet veto outside lepton veto $ m_{\tau\tau} - m_Z \leq 25 \text{ GeV}$

the invariant mass of the two leptons, $\Delta\phi_{\ell\ell}$ is the azimuthal angle between the two leptons, and $\max(m_T^\ell)$ is the larger of

$$m_T^\ell = \sqrt{2 p_T^\ell \cdot E_T^{\text{miss}} \cdot (1 - \cos \Delta\phi(\ell_i, E_T^{\text{miss}}))},$$

where ℓ_i can be either the leading or the subleading lepton. The “outside lepton veto” requires the two leptons to reside within the rapidity gap spanned by the two leading jets, and the “central jet veto” rejects events with additional jets with $p_T > 20$ GeV in the rapidity gap between the two leading jets. In the $N_{\text{jet}}=1$ and $N_{\text{jet}} \geq 2$ categories, the invariant mass of the τ -lepton pair ($m_{\tau\tau}$), calculated using the collinear approximation [71], is used to veto background from $Z \rightarrow \tau\tau$ production. Signal regions (SRs) are defined in each N_{jet} category after applying all selection criteria. For both the $N_{\text{jet}}=0$ and $N_{\text{jet}}=1$ ggF SRs, eight regions, later used for the fit, are defined by subdividing in $m_{\ell\ell}$ at $m_{\ell\ell} < 30$ GeV and $m_{\ell\ell} \geq 30$ GeV, in p_T of the subleading lepton at $p_T^{\text{sublead}} < 20$ GeV and $p_T^{\text{sublead}} \geq 20$ GeV, and by the flavour of the subleading lepton. For the categories with zero jets and with exactly one jet, the discriminating variable between signal and SM background processes is the dilepton

$$\text{transverse mass, defined as } m_T = \sqrt{(E_T^{\ell\ell} + E_T^{\text{miss}})^2 - |\mathbf{p}_T^{\ell\ell} + \mathbf{E}_T^{\text{miss}}|^2}$$

where $E_T^{\ell\ell} = \sqrt{|\mathbf{p}_T^{\ell\ell}|^2 + m_{\ell\ell}^2}$ and $\mathbf{p}_T^{\ell\ell}$ is the vector sum of the lepton transverse momenta. The discriminating variable m_T is used in the ggF SRs, with eight bins for the $N_{\text{jet}}=0$ and six bins for the $N_{\text{jet}}=1$ regions. The bin boundaries are chosen such that approximately the same number of signal events is expected in each bin. The m_T distributions for the $N_{\text{jet}}=0$ and $N_{\text{jet}}=1$ SRs are shown in Fig. 3. All figures in this Letter, except Fig. 2, use signal and background normalisations as fitted by the final statistical analysis of all signal and control regions, including pulls of statistical and systematic uncertainty parameters (post-fit). For the $N_{\text{jet}} \geq 2$ VBF selection, a boosted decision tree (BDT) [72] is used to enhance discrimination power between the VBF signal and backgrounds, including the ggF process. Kinematic variables of the two leading jets (j) and the two leading leptons (ℓ) are used as inputs to the BDT: the invariant masses (m_{jj} , $m_{\ell\ell}$), the difference between the two jet rapidities (Δy_{jj}), and the difference between the azimuthal angles of the two leptons ($\Delta\phi_{\ell\ell}$). Other variables used in the BDT training are: m_T , the lepton η -centrality ($\sum_\ell C_\ell$, where $C_\ell = |2\eta_\ell - \sum_j \eta_j| / \Delta\eta_{jj}$), which quantifies the positions of the leptons relative to the leading jets in pseudorapidity [73], the sum of the invariant masses of all four possible lepton–jet pairs ($\sum_{\ell,j} m_{\ell j}$), and the total transverse momentum (p_T^{tot}), which is defined as the magnitude of the vectorial sum of all selected objects. The observables providing the best discrimination between signal and background are m_{jj} and Δy_{jj} , and are shown in Fig. 4 after applying all selections. The BDT score reflects the compatibility of an event with VBF-like kinematics. Signal-like events would tend to have high BDT score, while background-like events tend to have low BDT score. The signal purity, therefore, increases at high values of BDT score. The BDT score is used as the discriminating variable in the statistical analysis with four bins. The bin boundaries are chosen to maximise the expected sensitivity for the VBF production mode, resulting in smaller bin widths for larger values of the BDT score. In the highest-score BDT bin, the expected signal-to-background ratio of the VBF signal is approximately 0.6. The BDT distribution for the VBF-enriched region is presented in Fig. 5.

5. Background estimation

The background contamination in the SRs originates from various processes: non-resonant WW , top-quark pair ($t\bar{t}$) and single-top-quark (Wt), diboson (WZ , ZZ , $W\gamma$ and $W\gamma^*$) and Drell–Yan (mainly $Z \rightarrow \tau\tau$, hereafter denoted Z/γ^*) production. Other back-

Table 4

Post-fit normalisation factors which scale the corresponding estimated yields in the signal region; the dash indicates where MC-based normalisation is used. The errors include the statistical and systematic uncertainties.

Category	WW	$t\bar{t}/Wt$	Z/γ^*
$N_{\text{jet},(p_T > 30 \text{ GeV})} = 0$ ggF	1.06 ± 0.09	0.99 ± 0.17	0.84 ± 0.04
$N_{\text{jet},(p_T > 30 \text{ GeV})} = 1$ ggF	0.97 ± 0.17	0.98 ± 0.08	0.90 ± 0.12
$N_{\text{jet},(p_T > 30 \text{ GeV})} \geq 2$ VBF	–	1.01 ± 0.01	0.93 ± 0.07

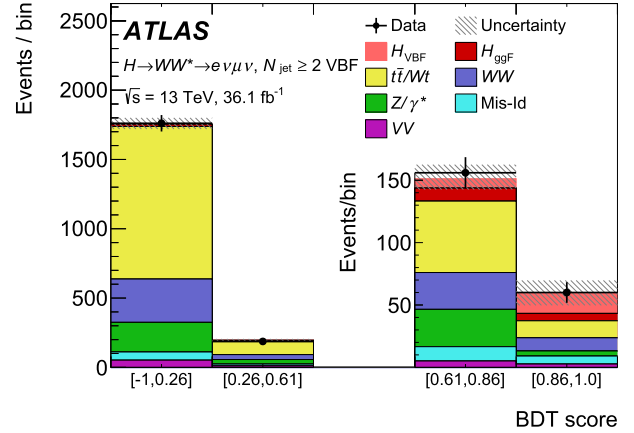
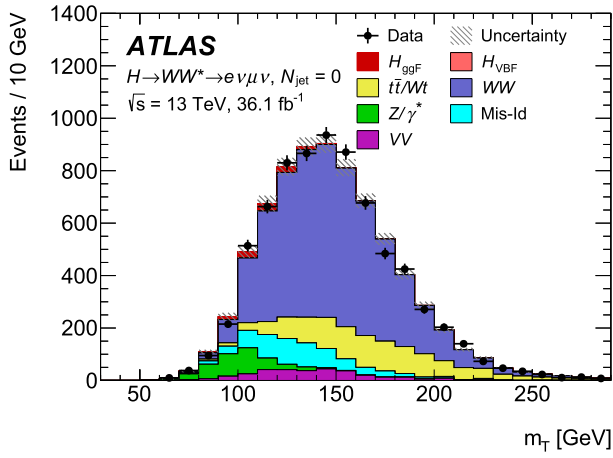


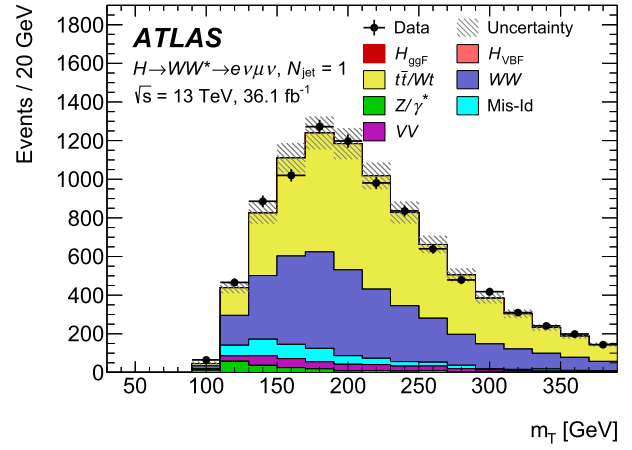
Fig. 5. Post-fit BDT score distribution with the signal and the background modelled contributions in the VBF signal region. The hatched band shows the total uncertainty of the signal and background modelled contributions.

ground contributions arise from W + jets and multi-jet production with misidentified leptons, which are either non-prompt leptons from decays of heavy-flavour hadrons or jets faking prompt leptons. Dedicated regions in data, identified hereafter as control regions (CRs), are used to normalise the predictions of some of the background processes. CRs are defined for the main background processes: WW (only for $N_{\text{jet}} \leq 1$ final states), $t\bar{t}/Wt$, and Z/γ^* . Table 3 summarises the event selection for all CRs. For the $N_{\text{jet}}=0$ and $N_{\text{jet}}=1$ WW CRs, $m_{\ell\ell}$ selections orthogonal to those of the SRs are applied. For the $t\bar{t}/Wt$ CRs, the b -veto is replaced with a b -tag requirement. For the $N_{\text{jet}}=1$ and $N_{\text{jet}} \geq 2$ VBF Z/γ^* CRs, the $m_{\tau\tau}$ selection is inverted, while for the $N_{\text{jet}}=0$ Z/γ^* CR the $\Delta\phi_{\ell\ell}$ selection criterion is inverted. Fig. 6 presents the post-fit m_T distributions in the $N_{\text{jet}}=0$ and $N_{\text{jet}}=1$ CRs.

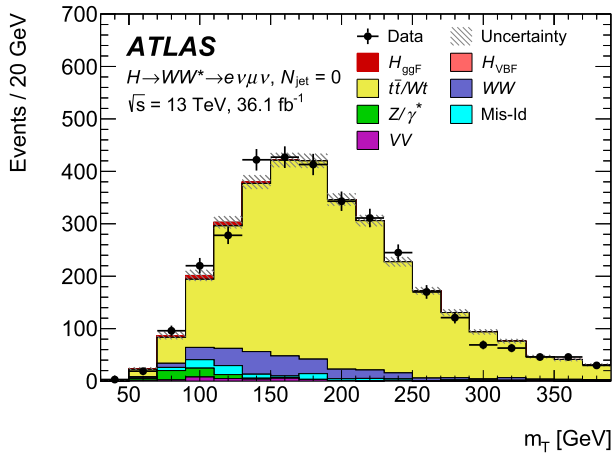
In Fig. 7, the post-fit Δy_{jj} distributions in the $N_{\text{jet}} \geq 2$ VBF CRs are shown. Data and simulation are in agreement within uncertainties for all the relevant distributions in the different CRs. The background contributions with misidentified leptons are estimated using a data-driven technique. A control sample where one of the two lepton candidates fails to meet the nominal identification and isolation criteria but satisfies looser identification criteria, referred to as an anti-identified lepton, is used. The contribution of this background in the SRs and CRs is then obtained by scaling the number of data events, after the subtraction of processes with two prompt leptons, in the control samples by an extrapolation factor. The latter is measured in a Z +jets-enriched data sample, where the Z boson decays to a pair of electrons or muons, and the misidentified lepton candidate recoils against the Z boson. The extrapolation factor is defined as the ratio of the numbers of identified and anti-identified leptons, and is measured in bins of p_T and η . Furthermore, a sample composition correction factor is applied separately in $p_T < 25$ GeV and $p_T > 25$ GeV bins, and is defined in each bin as the ratio of the extrapolation factors measured in W +jets and Z +jets MC simulation. The total uncertainty of the background with misidentified leptons includes uncertainties due to the difference in sample composition between the



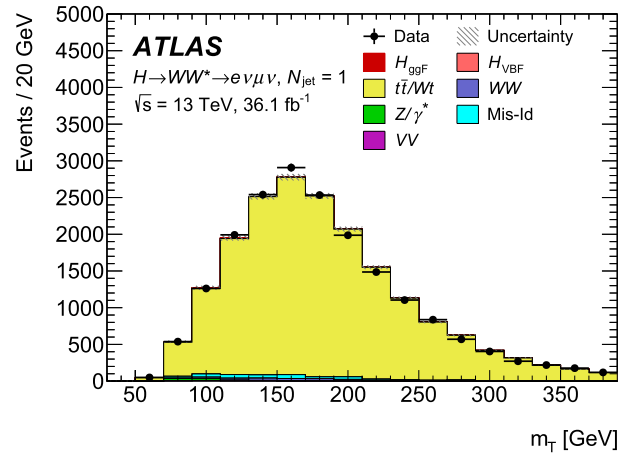
(a)



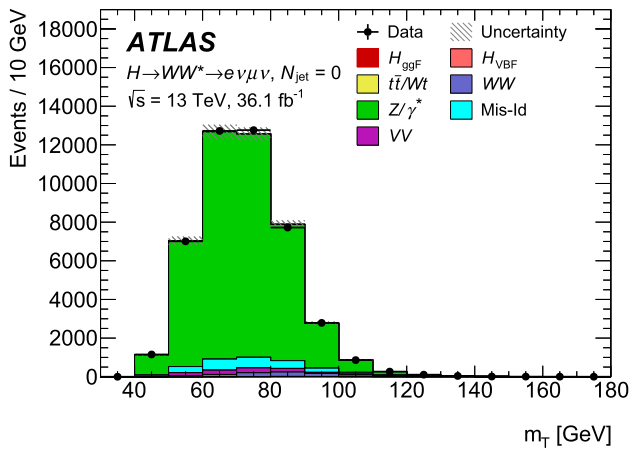
(b)



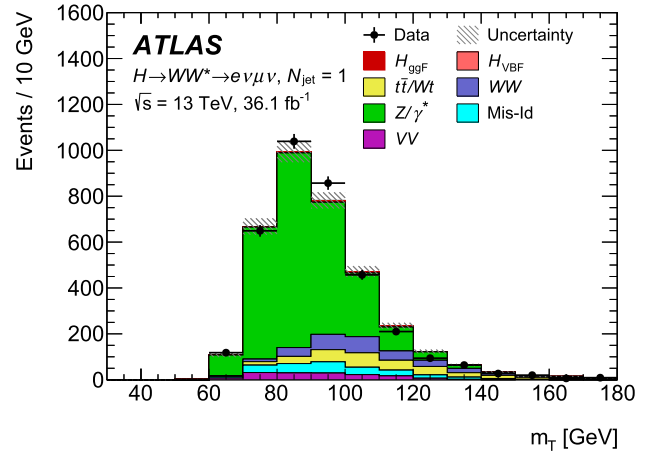
(c)



(d)



(e)



(f)

Fig. 6. Post-fit m_T distributions with signal and background modelled contributions in the $N_{\text{jet}}=0$ and $N_{\text{jet}}=1$ control regions for the W (a, b), $t\bar{t}/Wt$ (c, d), and Z/γ^* (e, f) processes. The hatched band shows the total uncertainty of the signal and background modelled contributions. Some contributions are too small to be visible.

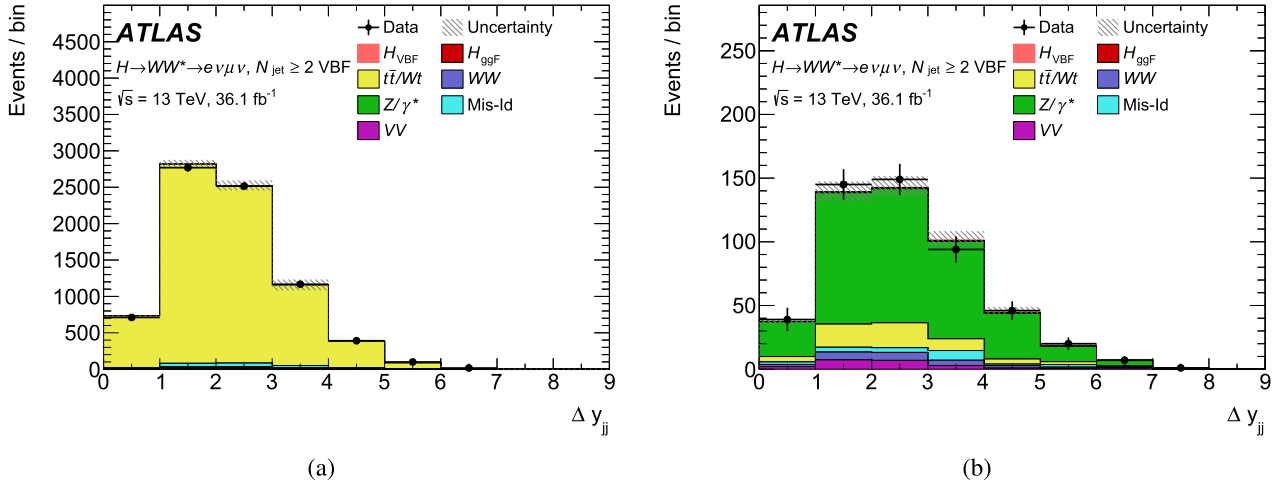


Fig. 7. Post-fit Δy_{jj} distribution with signal and background modelled contributions in the (a) $t\bar{t}/Wt$ and (b) Z/γ^* control regions in the $N_{\text{jet}} \geq 2$ VBF analysis category. The hatched band shows the total uncertainty of the signal and background modelled contributions. Some contributions are too small to be visible.

W +jets and Z +jets control samples determined with MC simulation, the statistical uncertainty of the Z +jets control sample, and the subtraction of other processes. In the VBF regions, the background estimation is corrected for the contamination from events with two misidentified leptons, whose origin is largely multi-jet events. This contribution is negligible in other regions. Details of this method can be found in Ref. [1].

The post-fit background normalisation factors are summarised in Table 4. The Z/γ^* normalisation factors are affected by residual misalignments in the inner detector which distort the measurements of the track parameters for particles originating from secondary vertices e.g. leptons from τ decays.

6. Systematic uncertainties

The sources of uncertainty can be classified into two categories: experimental and theoretical. The dominant experimental uncertainties are the jet energy scale and resolution [74], and the b -tagging efficiency [75]. Other sources of uncertainty are lepton energy (momentum) scale and resolution, identification and isolation [63,64,76], missing transverse momentum measurement [77], modelling of pile-up, and luminosity measurement [78]. The luminosity uncertainty is only applied to the Higgs boson signal and to background processes that are normalised to theoretical predictions. For the main processes, the theoretical uncertainties are assessed by a comparison between nominal and alternative event generators and UEPS models, as indicated in Table 1. For the prediction of WZ , ZZ , $V\gamma^*$, and $V\gamma$ production (VV), variations of the matching scale are considered instead of an alternative generator. In addition, the effects of QCD factorisation and renormalisation scale variations and PDF model uncertainties are evaluated.

7. Signal region yields and results

The ggF and VBF cross-sections are obtained from a simultaneous statistical analysis of the data samples in all SRs and CRs by maximising a likelihood function in a fit using scaling parameters multiplying the predicted total production cross-section of each signal process and applying the profile likelihood method. The CRs are used to determine the normalisation of the corresponding backgrounds. The systematic uncertainties enter the fit as nuisance parameters in the likelihood function.

Table 5 shows the post-fit yields for all of the three SRs. Yields in the highest-score VBF BDT bin are also given. The uncertainties in the total yields are smaller than those of some of the individ-

Table 5
Post-fit MC and data yields in the ggF and VBF SRs. Yields in the highest-score VBF BDT bin are also presented. The quoted uncertainties include the theoretical and experimental systematic sources and those due to sample statistics. The sum of all the contributions may differ from the total value due to rounding. Moreover, the total uncertainty differs from the sum in quadrature of the single-process uncertainties due to the correlations.

Process	$N_{\text{jet}} = 0$ ggF	$N_{\text{jet}} = 1$ ggF	$N_{\text{jet}} \geq 2$ VBF	
			Inclusive	BDT: [0.86, 1.0]
H_{ggF}	639 ± 110	285 ± 51	42 ± 16	6 ± 3
H_{VBF}	7 ± 1	31 ± 2	28 ± 16	16 ± 6
WW	3016 ± 203	1053 ± 206	400 ± 60	11 ± 2
VV	333 ± 38	208 ± 32	70 ± 12	3 ± 1
$t\bar{t}/Wt$	588 ± 130	1397 ± 179	1270 ± 80	14 ± 2
Mis-Id	447 ± 77	234 ± 49	90 ± 30	6 ± 2
Z/γ^*	27 ± 11	76 ± 24	280 ± 40	4 ± 1
Total	5067 ± 80	3296 ± 61	2170 ± 50	60 ± 10
Observed	5089	3264	2164	60

ual background processes. This effect is due to correlations among different data regions, background processes, and nuisance parameters. The correlations are imposed by the fit as it constrains the total yield to match the data. For example, for the b -tagging efficiency, which is the main source of uncertainty in the $t\bar{t}/Wt$ yields in the SRs as well as in WW CRs, the combination of these two regions in the statistical analysis leads to an anti-correlation between the SR yields of the WW and $t\bar{t}/Wt$ backgrounds. Changes in the b -tagging efficiency simultaneously increase/decrease the yields of $t\bar{t}/Wt$ and WW backgrounds, resulting in a small uncertainty in the combined yields of the processes but large uncertainties in the individual components.

Fig. 8 shows the combined m_T distribution for $N_{\text{jet}} \leq 1$. The bottom panel of Fig. 8 shows the difference between the data and the total estimated background compared to the m_T distribution of a SM Higgs boson with $m_H = 125$ GeV. The total signal observed (see Table 5) of about 1000 events is in agreement, in both shape and rate, with the expected SM signal. The cross-section times branching fractions, $\sigma_{\text{ggF}} \cdot \mathcal{B}_{H \rightarrow WW^*}$ and $\sigma_{\text{VBF}} \cdot \mathcal{B}_{H \rightarrow WW^*}$, are simultaneously determined to be:

$$\begin{aligned} \sigma_{\text{ggF}} \cdot \mathcal{B}_{H \rightarrow WW^*} &= 11.4_{-1.1}^{+1.2} (\text{stat.})_{-1.1}^{+1.2} (\text{theo syst.})_{-1.3}^{+1.4} (\text{exp syst.}) \text{ pb} \\ &= 11.4_{-2.1}^{+2.2} \text{ pb} \end{aligned}$$

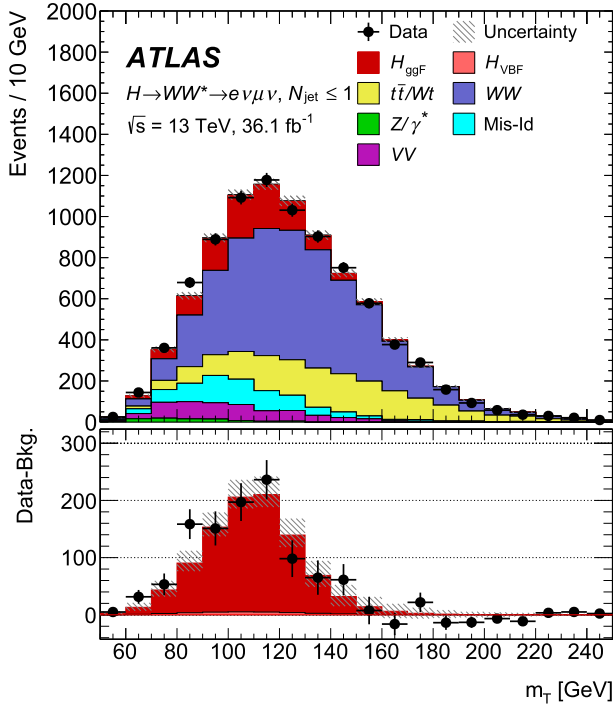


Fig. 8. Post-fit combined transverse mass distribution for $N_{\text{jet}} \leq 1$. The bottom panel shows the difference between the data and the estimated background compared to the distribution for a SM Higgs boson with $m_H = 125$ GeV. The signal and the background modelled contributions are fitted to the data with a floating signal strength. The hatched band shows the total uncertainty of the signal and background modelled contributions. The H_{VBF} contribution is too small to be visible.

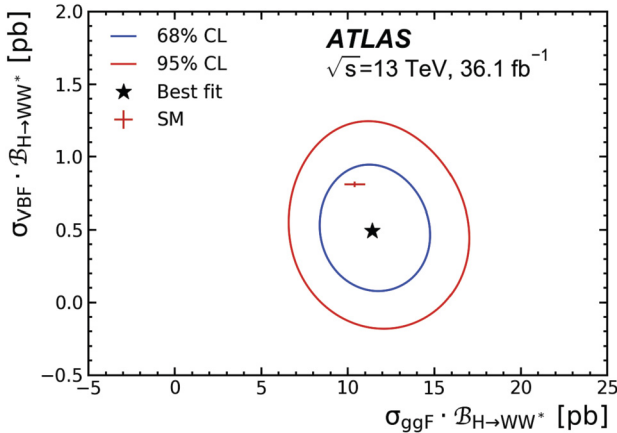


Fig. 9. 68% and 95% confidence level two-dimensional likelihood contours of $\sigma_{\text{ggF}} \cdot \mathcal{B}_{H \rightarrow WW^*}$ vs. $\sigma_{\text{VBF}} \cdot \mathcal{B}_{H \rightarrow WW^*}$, compared to the SM prediction shown by the red marker. The error bars on the SM prediction represent the ggF and VBF theory uncertainty [23], respectively.

$$\begin{aligned} \sigma_{\text{VBF}} \cdot \mathcal{B}_{H \rightarrow WW^*} &= 0.50_{-0.22}^{+0.24}(\text{stat.}) \pm 0.10(\text{theo syst.})_{-0.13}^{+0.12}(\text{exp syst.}) \text{ pb} \\ &= 0.50_{-0.28}^{+0.29} \text{ pb.} \end{aligned}$$

The predicted cross-section times branching fraction values are 10.4 ± 0.6 pb and 0.81 ± 0.02 pb for ggF and VBF [23], respectively. The 68% and 95% confidence level two-dimensional contours of $\sigma_{\text{ggF}} \cdot \mathcal{B}_{H \rightarrow WW^*}$ and $\sigma_{\text{VBF}} \cdot \mathcal{B}_{H \rightarrow WW^*}$ are shown in Fig. 9 and are consistent with the SM predictions.

The signal strength parameter μ is defined as the ratio of the measured signal yield to that predicted by the SM. The measured

Table 6

Breakdown of the main contributions to the total uncertainty in $\sigma_{\text{ggF}} \cdot \mathcal{B}_{H \rightarrow WW^*}$ and $\sigma_{\text{VBF}} \cdot \mathcal{B}_{H \rightarrow WW^*}$. The individual sources of systematic uncertainties are grouped together. The sum in quadrature of the individual components differs from the total uncertainty due to correlations between the components.

Source	$\Delta\sigma_{\text{ggF}} \cdot \mathcal{B}_{H \rightarrow WW^*}$ [%]	$\Delta\sigma_{\text{VBF}} \cdot \mathcal{B}_{H \rightarrow WW^*}$ [%]
Data statistics	10	46
CR statistics	7	9
MC statistics	6	21
Theoretical uncertainties	10	19
ggF signal	5	13
VBF signal	<1	4
WW	6	12
Top-quark	5	5
Experimental uncertainties	8	9
b-tagging	4	6
Modelling of pile-up	5	2
Jet	2	2
Lepton	3	<1
Misidentified leptons	6	9
Luminosity	3	3
TOTAL	18	57

signal strengths for the ggF and VBF production modes in the $H \rightarrow WW^*$ decay channel are simultaneously determined to be

$$\begin{aligned} \mu_{\text{ggF}} &= 1.10_{-0.09}^{+0.10}(\text{stat.})_{-0.11}^{+0.13}(\text{theo syst.})_{-0.13}^{+0.14}(\text{exp syst.}) \\ &= 1.10_{-0.20}^{+0.21} \\ \mu_{\text{VBF}} &= 0.62_{-0.27}^{+0.29}(\text{stat.})_{-0.13}^{+0.12}(\text{theo syst.}) \pm 0.15(\text{exp syst.}) \\ &= 0.62_{-0.35}^{+0.36}. \end{aligned}$$

Table 6 shows the relative impact of the main uncertainties on the measured values for $\sigma_{\text{ggF}} \cdot \mathcal{B}_{H \rightarrow WW^*}$ and $\sigma_{\text{VBF}} \cdot \mathcal{B}_{H \rightarrow WW^*}$. The theory uncertainties in the non-resonant WW background produce one of the largest uncertainties, of the order of 6%, in the measured ggF cross-section. The uncertainty in the ratio of $gg \rightarrow WW$ to $qq \rightarrow WW$ comes from the limited NLO accuracy of the $gg \rightarrow WW$ production cross-section [38]. The resulting uncertainty in the cross-section when using acceptance criteria similar to those in this analysis was evaluated in Ref. [79] for $N_{\text{jet}}=0$ and for $N_{\text{jet}} \geq 2$ VBF SR, the 12% uncertainty in the WW background originates from the matching and UEPS modelling of $qq \rightarrow WW$. The amount of ggF contamination in the VBF region is subject to QCD scale uncertainties and this produces an uncertainty of about 13% in the measured VBF cross-section. The statistical uncertainty of the MC simulation has a relatively large impact, especially for the VBF cross-section measurement, where it contributes 21%.

The observed (expected) ggF and VBF signals have significances of 6.0 (5.3) and 1.8 (2.6) standard deviations, respectively.

8. Conclusions

Measurements of the inclusive cross-section of Higgs boson production via the gluon-gluon fusion (ggF) and vector-boson fusion (VBF) modes in the $H \rightarrow WW^*$ decay channel are presented. They are based on 36.1 fb^{-1} of $\sqrt{s} = 13$ TeV proton-proton collisions recorded by the ATLAS detector at the LHC in 2015–2016. The ggF and VBF cross-sections times the $H \rightarrow WW^*$ branching ratio are measured to be $11.4_{-1.1}^{+1.2}(\text{stat.})_{-1.7}^{+1.8}(\text{syst.})$ pb and $0.50_{-0.22}^{+0.24}(\text{stat.}) \pm 0.17(\text{syst.})$ pb, respectively, in agreement with SM prediction.

Acknowledgements

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

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

The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN, the ATLAS Tier-1 facilities at TRIUMF (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN-CNAF (Italy), NL-T1 (Netherlands), PIC (Spain), ASGC (Taiwan), RAL (UK) and BNL (USA), the Tier-2 facilities worldwide and large non-WLCG resource providers. Major contributors of computing resources are listed in Ref. [80].

References

- [1] ATLAS Collaboration, Observation and measurement of Higgs boson decays to $W W^*$ with the ATLAS detector, *Phys. Rev. D* 92 (2015) 012006, arXiv:1412.2641 [hep-ex].
- [2] CMS Collaboration, Observation of a new boson with mass near 125 GeV in pp collisions at $\sqrt{s} = 7$ and 8 TeV, *J. High Energy Phys.* 06 (2013) 081, arXiv:1303.4571 [hep-ex].
- [3] CMS Collaboration, Measurements of properties of the Higgs boson decaying to a W boson pair in pp collisions at $\sqrt{s} = 13$ TeV, arXiv:1806.05246 [hep-ex], 2018.
- [4] ATLAS and CMS Collaborations, Measurements of the Higgs boson production and decay rates and constraints on its couplings from a combined ATLAS and CMS analysis of the LHC pp collision data at $\sqrt{s} = 7$ and 8 TeV, *J. High Energy Phys.* 08 (2016) 045, arXiv:1606.02266 [hep-ex].
- [5] ATLAS Collaboration, The ATLAS experiment at the CERN Large Hadron Collider, *J. Instrum.* 3 (2008) S08003.
- [6] ATLAS Collaboration, ATLAS Insertable B-Layer Technical Design Report Addendum, tech. rep. CERN-LHCC-2012-009, ATLAS-TDR-19-ADD-1, Addendum to CERN-LHCC-2010-013, ATLAS-TDR-019, 2012, <https://cds.cern.ch/record/1451888>.
- [7] ATLAS Collaboration, Performance of the ATLAS trigger system in 2015, *Eur. Phys. J. C* 77 (2017) 317, arXiv:1611.09661 [hep-ex].
- [8] K. Hamilton, P. Nason, E. Re, G. Zanderighi, NNLO simulation of Higgs boson production, *J. High Energy Phys.* 10 (2013) 222, arXiv:1309.0017 [hep-ph].
- [9] J. Butterworth, et al., PDF4LHC recommendations for LHC Run II, *J. Phys. G* 43 (2016) 023001, arXiv:1510.03865 [hep-ph].
- [10] J.M. Campbell, et al., NLO Higgs boson production plus one and two jets using the POWHEG BOX, MadGraph4 and MCFM, *J. High Energy Phys.* 07 (2012) 092, arXiv:1202.5475 [hep-ph].
- [11] S. Catani, M. Grazzini, Next-to-next-to-leading-order subtraction formalism in hadron collisions and its application to Higgs-boson production at the Large Hadron Collider, *Phys. Rev. Lett.* 98 (2007) 222002, arXiv:hep-ph/0703012 [hep-ph].
- [12] G. Bozzi, S. Catani, D. de Florian, M. Grazzini, Transverse-momentum resummation and the spectrum of the Higgs boson at the LHC, *Nucl. Phys. B* 737 (2006) 73, arXiv:hep-ph/0508068 [hep-ph].
- [13] D. de Florian, G. Ferrera, M. Grazzini, D. Tommasini, Transverse-momentum resummation: Higgs boson production at the Tevatron and the LHC, *J. High Energy Phys.* 11 (2011) 064, arXiv:1109.2109 [hep-ph].
- [14] T. Sjöstrand, S. Mrenna, P.Z. Skands, A brief introduction to PYTHIA 8.1, *Comput. Phys. Commun.* 178 (2008) 852, arXiv:0710.3820 [hep-ph].
- [15] ATLAS Collaboration, Measurement of the Z/γ^* boson transverse momentum distribution in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector, *J. High Energy Phys.* 09 (2014) 145, arXiv:1406.3660 [hep-ex].
- [16] P. Nason, C. Oleari, NLO Higgs boson production via vector-boson fusion matched with shower in POWHEG, *J. High Energy Phys.* 02 (2010) 037, arXiv:0911.5299 [hep-ph].
- [17] K. Hamilton, P. Nason, G. Zanderighi, Finite quark-mass effects in the NNLO POWHEG+MiNLO Higgs generator, *J. High Energy Phys.* 05 (2015) 140, arXiv:1501.04637 [hep-ph].
- [18] ATLAS and CMS Collaborations, Combined measurement of the Higgs boson mass in pp collisions at $\sqrt{s} = 7$ and 8 TeV with the ATLAS and CMS experiments, *Phys. Rev. Lett.* 114 (2015) 191803, arXiv:1503.07589 [hep-ex].
- [19] ATLAS Collaboration, Measurement of the Higgs boson mass in the $H \rightarrow ZZ^* \rightarrow 4\ell$ and $H \rightarrow \gamma\gamma$ channels with $\sqrt{s} = 13$ TeV pp collisions using the ATLAS detector, arXiv:1806.00242 [hep-ex], 2018.
- [20] CMS Collaboration, Measurements of properties of the Higgs boson decaying into the four-lepton final state in pp collisions at $\sqrt{s} = 13$ TeV, *J. High Energy Phys.* 11 (2017) 047, arXiv:1706.09936 [hep-ex].
- [21] A. Djouadi, J. Kalinowski, M. Spira, HDECAY: a program for Higgs boson decays in the Standard Model and its supersymmetric extension, *Comput. Phys. Commun.* (ISSN 0010-4655) 108 (1998) 56, <http://www.sciencedirect.com/science/article/pii/S0010465597001239>.
- [22] A. Djouadi, J. Kalinowski, M. Muehlleitner, M. Spira, HDECAY: twenty+ years after, arXiv:1801.09506 [hep-ph], 2018.
- [23] LHC Higgs Cross Section Working Group, Handbook of LHC Higgs cross sections: 4. Deciphering the nature of the Higgs sector, arXiv:1610.07922 [hep-ph], 2016.
- [24] LHC Higgs Cross Section Working Group, Handbook of LHC Higgs Cross Sections: 3. Higgs Properties: Report of the LHC Higgs Cross Section Working Group, tech. rep. CERN-2013-004, CERN-2013-004, 2013, <https://cds.cern.ch/record/1559921>.
- [25] C. Anastasiou, C. Duhr, F. Dulat, F. Herzog, B. Mistlberger, Higgs boson gluon-fusion production in QCD at three loops, *Phys. Rev. Lett.* 114 (2015) 212001, arXiv:1503.06056 [hep-ph].
- [26] C. Anastasiou, et al., High precision determination of the gluon fusion Higgs boson cross-section at the LHC, *J. High Energy Phys.* 05 (2016) 058, arXiv:1602.00695 [hep-ph].
- [27] S. Actis, G. Passarino, C. Sturm, S. Uccirati, NLO electroweak corrections to Higgs boson production at hadron colliders, *Phys. Lett. B* 670 (2008) 12, arXiv:0809.1301 [hep-ph].
- [28] C. Anastasiou, R. Boughezal, F. Petriello, Mixed QCD-electroweak corrections to Higgs boson production in gluon fusion, *J. High Energy Phys.* 04 (2009) 003, arXiv:0811.3458 [hep-ph].
- [29] M. Ciccolini, A. Denner, S. Dittmaier, Strong and electroweak corrections to the production of Higgs boson + 2 jets via weak interactions at the LHC, *Phys. Rev. Lett.* 99 (2007) 161803, arXiv:0707.0381 [hep-ph].
- [30] M. Ciccolini, A. Denner, S. Dittmaier, Electroweak and QCD corrections to Higgs production via vector-boson fusion at the LHC, *Phys. Rev. D* 77 (2008) 013002, arXiv:0710.4749 [hep-ph].
- [31] P. Bolzoni, F. Maltoni, S.-O. Moch, M. Zaro, Higgs boson production via vector-boson fusion at next-to-next-to-leading order in QCD, *Phys. Rev. Lett.* 105 (2010) 011801, arXiv:1003.4451 [hep-ph].
- [32] T. Gleisberg, et al., Event generation with SHERPA 1.1, *J. High Energy Phys.* 02 (2009) 007, arXiv:0811.4622 [hep-ph].
- [33] T. Gleisberg, S. Höche, Comix, a new matrix element generator, *J. High Energy Phys.* 12 (2008) 039, arXiv:0808.3674 [hep-ph].
- [34] R.D. Ball, et al., Parton distributions for the LHC Run II, *J. High Energy Phys.* 04 (2015) 040, arXiv:1410.8849 [hep-ph].
- [35] S. Schumann, F. Krauss, A Parton shower algorithm based on Catani-Seymour dipole factorisation, *J. High Energy Phys.* 03 (2008) 038, arXiv:0709.1027 [hep-ph].
- [36] S. Höche, F. Krauss, M. Schönherr, F. Siegert, QCD matrix elements + parton showers: the NLO case, *J. High Energy Phys.* 04 (2013) 027, arXiv:1207.5030 [hep-ph].
- [37] F. Cascioli, et al., Precise Higgs-background predictions: merging NLO QCD and squared quark-loop corrections to four-lepton $+0,1$ jet production, *J. High Energy Phys.* 01 (2014) 046, arXiv:1309.0500 [hep-ph].
- [38] F. Caola, K. Melnikov, R. Röntsch, L. Tancredi, QCD corrections to W^+W^- production through gluon fusion, *Phys. Lett. B* 754 (2016) 275, arXiv:1511.08617 [hep-ph].

- [39] J.M. Campbell, R.K. Ellis, C. Williams, Gluon–gluon contributions to W^+W^- production and Higgs interference effects, *J. High Energy Phys.* 10 (2011) 005, arXiv:1107.5569 [hep-ph].
- [40] M. Grazzini, S. Kallweit, S. Pozzorini, D. Rathlev, M. Wiesemann, W^+W^- production at the LHC: fiducial cross sections and distributions in NNLO QCD, *J. High Energy Phys.* 08 (2016) 140, arXiv:1605.02716 [hep-ph].
- [41] M. Grazzini, S. Kallweit, D. Rathlev, M. Wiesemann, $W^\pm Z$ production at the LHC: fiducial cross sections and distributions in NNLO QCD, *J. High Energy Phys.* 05 (2017) 139, arXiv:1703.09065 [hep-ph].
- [42] F. Cascioli, et al., ZZ production at hadron colliders in NNLO QCD, *Phys. Lett. B* 735 (2014) 311, arXiv:1405.2219 [hep-ph].
- [43] S. Agostinelli, et al., GEANT4: a simulation toolkit, *Nucl. Instrum. Methods A* 506 (2003) 250.
- [44] ATLAS Collaboration, The ATLAS simulation infrastructure, *Eur. Phys. J. C* 70 (2010) 823, arXiv:1005.4568 [physics.ins-det].
- [45] ATLAS Collaboration, Summary of ATLAS Pythia 8 tunes, ATL-PHYS-PUB-2012-003, <https://cds.cern.ch/record/1474107>, 2012.
- [46] A.D. Martin, W.J. Stirling, R.S. Thorne, G. Watt, Parton distributions for the LHC, *Eur. Phys. J. C* 63 (2009) 189, arXiv:0901.0002 [hep-ph].
- [47] J. Alwall, et al., The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations, *J. High Energy Phys.* 07 (2014) 079, arXiv:1405.0301 [hep-ph].
- [48] R. Frederix, S. Frixione, Merging meets matching in MC@NLO, *J. High Energy Phys.* 12 (2012) 061, arXiv:1209.6215 [hep-ph].
- [49] J. Bellm, et al., Herwig 7.0/Herwig++ 3.0 release note, *Eur. Phys. J. C* 76 (2016) 196, arXiv:1512.01178 [hep-ph].
- [50] G. Luisoni, P. Nason, C. Oleari, F. Tramontano, $HW^\pm/HZ + 0$ and 1 jet at NLO with the POWHEG BOX interfaced to GoSam and their merging within MiNLO, *J. High Energy Phys.* 10 (2013) 083, arXiv:1306.2542 [hep-ph].
- [51] T. Han, S. Willenbrock, QCD correction to the $pp \rightarrow WH$ and ZH total cross sections, *Phys. Lett. B* (ISSN 0370-2693) 273 (1991) 167, <http://www.sciencedirect.com/science/article/pii/0370269391905728>.
- [52] O. Brein, A. Djouadi, R. Harlander, NNLO QCD corrections to the Higgsstrahlung processes at hadron colliders, *Phys. Lett. B* 579 (2004) 149, arXiv:hep-ph/0307206 [hep-ph].
- [53] M. Ciccolini, S. Dittmaier, M. Krmer, Electroweak radiative corrections to associated WH and ZH production at hadron colliders, *Phys. Rev. D* 68 (2003) 073003, arXiv:hep-ph/0306234 [hep-ph].
- [54] H.-L. Lai, et al., New parton distributions for collider physics, *Phys. Rev. D* 82 (2010) 074024, arXiv:1007.2241 [hep-ph].
- [55] S. Höche, S. Schumann, F. Siegert, Hard photon production and matrix-element parton-shower merging, *Phys. Rev. D* 81 (2010) 034026, arXiv:0912.3501 [hep-ph].
- [56] S. Frixione, P. Nason, G. Ridolfi, A positive-weight next-to-leading-order Monte Carlo for heavy flavour hadroproduction, *J. High Energy Phys.* 09 (2007) 126, arXiv:0707.3088 [hep-ph].
- [57] M. Czakon, P. Fiedler, A. Mitov, Total top-quark pair-production cross section at hadron colliders through $O(\alpha_s^4)$, *Phys. Rev. Lett.* 110 (2013) 252004, arXiv:1303.6254 [hep-ph].
- [58] E. Re, Single-top Wt -channel production matched with parton showers using the POWHEG method, *Eur. Phys. J. C* 71 (2011) 1547, arXiv:1009.2450 [hep-ph].
- [59] T. Sjöstrand, S. Mrenna, P.Z. Skands, PYTHIA 6.4 physics and manual, *J. High Energy Phys.* 05 (2006) 026, arXiv:hep-ph/0603175 [hep-ph].
- [60] K. Melnikov, F. Petriello, Electroweak gauge boson production at hadron colliders through $O(\alpha_s^2)$, *Phys. Rev. D* 74 (2006) 114017, arXiv:hep-ph/0609070 [hep-ph].
- [61] C. Anastasiou, L.J. Dixon, K. Melnikov, F. Petriello, High precision QCD at hadron colliders: electroweak gauge boson rapidity distributions at NNLO, *Phys. Rev. D* 69 (2004) 094008, arXiv:hep-ph/0312266 [hep-ph].
- [62] ATLAS Collaboration, Electron efficiency measurements with the ATLAS detector using 2012 LHC proton–proton collision data, *Eur. Phys. J. C* 77 (2017) 195, arXiv:1612.01456 [hep-ex].
- [63] ATLAS Collaboration, Electron efficiency measurements with the ATLAS detector using the 2015 LHC proton–proton collision data, ATL-CONF-2016-024, <https://cds.cern.ch/record/2157687>, 2016.
- [64] ATLAS Collaboration, Muon reconstruction performance of the ATLAS detector in proton–proton collision data at $\sqrt{s} = 13$ TeV, *Eur. Phys. J. C* 76 (2016) 292, arXiv:1603.05598 [hep-ex].
- [65] ATLAS Collaboration, Electron identification measurements in ATLAS using $\sqrt{s} = 13$ TeV data with 50 ns bunch spacing, ATL-PHYS-PUB-2015-041, <https://cds.cern.ch/record/2048202>, 2015.
- [66] M. Cacciari, G.P. Salam, G. Soyez, The anti- k_t jet clustering algorithm, *J. High Energy Phys.* 04 (2008) 063, arXiv:0802.1189 [hep-ph].
- [67] ATLAS Collaboration, Jet energy scale measurements and their systematic uncertainties in proton–proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, *Phys. Rev. D* 96 (2017) 072002, arXiv:1703.09665 [hep-ex].
- [68] ATLAS Collaboration, Identification and rejection of pile-up jets at high pseudo-rapidity with the ATLAS detector, *Eur. Phys. J. C* 77 (2017) 580; Erratum: *Eur. Phys. J. C* 77 (2017) 712, arXiv:1705.02211 [hep-ex].
- [69] ATLAS Collaboration, Measurements of b -jet tagging efficiency with the ATLAS detector using $t\bar{t}$ events at $\sqrt{s} = 13$ TeV, arXiv:1805.01845 [hep-ex], 2018.
- [70] ATLAS Collaboration, Performance of missing transverse momentum reconstruction with the ATLAS detector using proton–proton collisions at $\sqrt{s} = 13$ TeV, arXiv:1802.08168 [hep-ex], 2018.
- [71] T. Plehn, D.L. Rainwater, D. Zeppenfeld, A method for identifying $H \rightarrow \tau^+ \tau^- \rightarrow e^\pm \mu^\mp p_T$ at the CERN LHC, *Phys. Rev. D* 61 (2000) 093005, arXiv:hep-ph/9911385 [hep-ph].
- [72] J.H. Friedman, Greedy function approximation: a gradient boosting machine, *Ann. Stat.* 29 (2001) 1189.
- [73] V. Barger, R. Phillips, D. Zeppenfeld, Minijet veto: a tool for the heavy Higgs search at the LHC, *Phys. Lett. B* (ISSN 0370-2693) 346 (1995) 106, <http://www.sciencedirect.com/science/article/pii/0370269395000089>.
- [74] ATLAS Collaboration, Jet calibration and systematic uncertainties for jets reconstructed in the ATLAS detector at $\sqrt{s} = 13$ TeV, ATL-PHYS-PUB-2015-015, <https://cds.cern.ch/record/2037613>, 2015.
- [75] ATLAS Collaboration, Optimisation of the ATLAS b -tagging performance for the 2016 LHC Run, ATL-PHYS-PUB-2016-012, <https://cds.cern.ch/record/2160731>, 2016.
- [76] ATLAS Collaboration, Electron and photon energy calibration with the ATLAS detector using data collected in 2015 at $\sqrt{s} = 13$ TeV, ATL-PHYS-PUB-2016-015, <https://cds.cern.ch/record/2203514>, 2016.
- [77] ATLAS Collaboration, Performance of missing transverse momentum reconstruction with the ATLAS detector in the first proton–proton collisions at $\sqrt{s} = 13$ TeV, ATL-PHYS-PUB-2015-027, <https://cds.cern.ch/record/2037904>, 2015.
- [78] ATLAS Collaboration, Luminosity determination in pp collisions at $\sqrt{s} = 8$ TeV using the ATLAS detector at the LHC, *Eur. Phys. J. C* 76 (2016) 653, arXiv:1608.03953 [hep-ex].
- [79] T. Melia, K. Melnikov, R. Rontsch, M. Schulze, G. Zanderighi, Gluon fusion contribution to $W^+W^- + \text{jet}$ production, *J. High Energy Phys.* 08 (2012) 115, arXiv:1205.6987 [hep-ph].
- [80] ATLAS Collaboration, ATLAS computing acknowledgements, ATL-GEN-PUB-2016-002, <https://cds.cern.ch/record/2202407>.

The ATLAS Collaboration

M. Aaboud^{34d}, G. Aad⁹⁹, B. Abbott¹²⁴, O. Abdinov^{13,*}, B. Abeloos¹²⁸, D.K. Abhayasinghe⁹¹, S.H. Abidi¹⁶⁴, O.S. AbouZeid³⁹, N.L. Abraham¹⁵³, H. Abramowicz¹⁵⁸, H. Abreu¹⁵⁷, Y. Abulaiti⁶, B.S. Acharya^{64a,64b,n}, S. Adachi¹⁶⁰, L. Adam⁹⁷, L. Adamczyk^{81a}, J. Adelman¹¹⁹, M. Adersberger¹¹², A. Adiguzel^{12c,ag}, T. Adye¹⁴¹, A.A. Affolder¹⁴³, Y. Afik¹⁵⁷, C. Agheorghiesei^{27c}, J.A. Aguilar-Saavedra^{136f,136a}, F. Ahmadov^{77,ae}, G. Aielli^{71a,71b}, S. Akatsuka⁸³, T.P.A. Åkesson⁹⁴, E. Akilli⁵², A.V. Akimov¹⁰⁸, G.L. Alberghi^{23b,23a}, J. Albert¹⁷³, P. Albicocco⁴⁹, M.J. Alconada Verzini⁸⁶, S. Alderweireldt¹¹⁷, M. Aleksa³⁵, I.N. Aleksandrov⁷⁷, C. Alexa^{27b}, T. Alexopoulos¹⁰, M. Alhroob¹²⁴, B. Ali¹³⁸, G. Alimonti^{66a}, J. Alison³⁶, S.P. Alkire¹⁴⁵, C. Allaire¹²⁸, B.M.M. Allbrooke¹⁵³, B.W. Allen¹²⁷, P.P. Allport²¹, A. Aloisio^{67a,67b}, A. Alonso³⁹, F. Alonso⁸⁶, C. Alpigiani¹⁴⁵, A.A. Alshehri⁵⁵, M.I. Alstady⁹⁹, B. Alvarez Gonzalez³⁵, D. Álvarez Piqueras¹⁷¹, M.G. Alviggi^{67a,67b}, B.T. Amadio¹⁸, Y. Amaral Coutinho^{78b}, A. Ambler¹⁰¹, L. Ambroz¹³¹, C. Amelung²⁶, D. Amidei¹⁰³,

S.P. Amor Dos Santos ^{136a,136c}, S. Amoroso ⁴⁴, C.S. Amrouche ⁵², C. Anastopoulos ¹⁴⁶, L.S. Ancu ⁵², N. Andari ¹⁴², T. Andeen ¹¹, C.F. Anders ^{59b}, J.K. Anders ²⁰, K.J. Anderson ³⁶, A. Andreazza ^{66a,66b}, V. Andrei ^{59a}, C.R. Anelli ¹⁷³, S. Angelidakis ³⁷, I. Angelozzi ¹¹⁸, A. Angerami ³⁸, A.V. Anisenkov ^{120b,120a}, A. Annovi ^{69a}, C. Antel ^{59a}, M.T. Anthony ¹⁴⁶, M. Antonelli ⁴⁹, D.J.A. Antrim ¹⁶⁸, F. Anulli ^{70a}, M. Aoki ⁷⁹, J.A. Aparisi Pozo ¹⁷¹, L. Aperio Bella ³⁵, G. Arabidze ¹⁰⁴, J.P. Araque ^{136a}, V. Araujo Ferraz ^{78b}, R. Araujo Pereira ^{78b}, A.T.H. Arce ⁴⁷, R.E. Ardell ⁹¹, F.A. Arduh ⁸⁶, J-F. Arguin ¹⁰⁷, S. Argyropoulos ⁷⁵, A.J. Armbruster ³⁵, L.J. Armitage ⁹⁰, A. Armstrong ¹⁶⁸, O. Arnaez ¹⁶⁴, H. Arnold ¹¹⁸, M. Arratia ³¹, O. Arslan ²⁴, A. Artamonov ^{109,*}, G. Artoni ¹³¹, S. Artz ⁹⁷, S. Asai ¹⁶⁰, N. Asbah ⁵⁷, E.M. Asimakopoulou ¹⁶⁹, L. Asquith ¹⁵³, K. Assamagan ²⁹, R. Astalos ^{28a}, R.J. Atkin ^{32a}, M. Atkinson ¹⁷⁰, N.B. Atlay ¹⁴⁸, K. Augsten ¹³⁸, G. Avolio ³⁵, R. Avramidou ^{58a}, M.K. Ayoub ^{15a}, G. Azeulos ^{107,ar}, A.E. Baas ^{59a}, M.J. Baca ²¹, H. Bachacou ¹⁴², K. Bachas ^{65a,65b}, M. Backes ¹³¹, P. Bagnaia ^{70a,70b}, M. Bahmani ⁸², H. Bahrasemani ¹⁴⁹, A.J. Bailey ¹⁷¹, J.T. Baines ¹⁴¹, M. Bajic ³⁹, C. Bakalis ¹⁰, O.K. Baker ¹⁸⁰, P.J. Bakker ¹¹⁸, D. Bakshi Gupta ⁹³, S. Balaji ¹⁵⁴, E.M. Baldin ^{120b,120a}, P. Balek ¹⁷⁷, F. Balli ¹⁴², W.K. Balunas ¹³³, J. Balz ⁹⁷, E. Banas ⁸², A. Bandyopadhyay ²⁴, S. Banerjee ^{178,j}, A.A.E. Bannoura ¹⁷⁹, L. Barak ¹⁵⁸, W.M. Barbe ³⁷, E.L. Barberio ¹⁰², D. Barberis ^{53b,53a}, M. Barbero ⁹⁹, T. Barillari ¹¹³, M-S. Barisits ³⁵, J. Barkeloo ¹²⁷, T. Barklow ¹⁵⁰, R. Barnea ¹⁵⁷, S.L. Barnes ^{58c}, B.M. Barnett ¹⁴¹, R.M. Barnett ¹⁸, Z. Barnovska-Blenessy ^{58a}, A. Baroncelli ^{72a}, G. Barone ²⁶, A.J. Barr ¹³¹, L. Barranco Navarro ¹⁷¹, F. Barreiro ⁹⁶, J. Barreiro Guimarães da Costa ^{15a}, R. Bartoldus ¹⁵⁰, A.E. Barton ⁸⁷, P. Bartos ^{28a}, A. Basalaev ¹³⁴, A. Bassalat ¹²⁸, R.L. Bates ⁵⁵, S.J. Batista ¹⁶⁴, S. Batlamous ^{34e}, J.R. Batley ³¹, M. Battaglia ¹⁴³, M. Baucé ^{70a,70b}, F. Bauer ¹⁴², K.T. Bauer ¹⁶⁸, H.S. Bawa ^{150,l}, J.B. Beacham ¹²², T. Beau ¹³², P.H. Beauchemin ¹⁶⁷, P. Bechtel ²⁴, H.C. Beck ⁵¹, H.P. Beck ^{20,q}, K. Becker ⁵⁰, M. Becker ⁹⁷, C. Becot ⁴⁴, A. Beddall ^{12d}, A.J. Beddall ^{12a}, V.A. Bednyakov ⁷⁷, M. Bedognetti ¹¹⁸, C.P. Bee ¹⁵², T.A. Beermann ³⁵, M. Begalli ^{78b}, M. Begel ²⁹, A. Behera ¹⁵², J.K. Behr ⁴⁴, A.S. Bell ⁹², G. Bella ¹⁵⁸, L. Bellagamba ^{23b}, A. Bellerive ³³, M. Bellomo ¹⁵⁷, P. Bellos ⁹, K. Belotskiy ¹¹⁰, N.L. Belyaev ¹¹⁰, O. Benary ^{158,*}, D. Bencheikroun ^{34a}, M. Bender ¹¹², N. Benekos ¹⁰, Y. Benhammou ¹⁵⁸, E. Benhar Nocchioli ¹⁸⁰, J. Benitez ⁷⁵, D.P. Benjamin ⁴⁷, M. Benoit ⁵², J.R. Bensinger ²⁶, S. Bentvelsen ¹¹⁸, L. Beresford ¹³¹, M. Beretta ⁴⁹, D. Berge ⁴⁴, E. Bergeaas Kuutmann ¹⁶⁹, N. Berger ⁵, L.J. Bergsten ²⁶, J. Beringer ¹⁸, S. Berlendis ⁷, N.R. Bernard ¹⁰⁰, G. Bernardi ¹³², C. Bernius ¹⁵⁰, F.U. Bernlochner ²⁴, T. Berry ⁹¹, P. Berta ⁹⁷, C. Bertella ^{15a}, G. Bertoli ^{43a,43b}, I.A. Bertram ⁸⁷, G.J. Besjes ³⁹, O. Bessidskaia Bylund ¹⁷⁹, M. Bessner ⁴⁴, N. Besson ¹⁴², A. Bethani ⁹⁸, S. Bethke ¹¹³, A. Betti ²⁴, A.J. Bevan ⁹⁰, J. Beyer ¹¹³, R.M.B. Bianchi ¹³⁵, O. Biebel ¹¹², D. Biedermann ¹⁹, R. Bielski ³⁵, K. Bierwagen ⁹⁷, N.V. Biesuz ^{69a,69b}, M. Biglietti ^{72a}, T.R.V. Billoud ¹⁰⁷, M. Bindi ⁵¹, A. Bingul ^{12d}, C. Bini ^{70a,70b}, S. Biondi ^{23b,23a}, M. Birman ¹⁷⁷, T. Bisanz ⁵¹, J.P. Biswal ¹⁵⁸, C. Bittrich ⁴⁶, D.M. Bjergaard ⁴⁷, J.E. Black ¹⁵⁰, K.M. Black ²⁵, T. Blazek ^{28a}, I. Bloch ⁴⁴, C. Blocker ²⁶, A. Blue ⁵⁵, U. Blumenschein ⁹⁰, Dr. Blunier ^{144a}, G.J. Bobbink ¹¹⁸, V.S. Bobrovnikov ^{120b,120a}, S.S. Bocchetta ⁹⁴, A. Bocchi ⁴⁷, D. Boerner ¹⁷⁹, D. Bogavac ¹¹², A.G. Bogdanchikov ^{120b,120a}, C. Bohm ^{43a}, V. Boisvert ⁹¹, P. Bokan ^{169,x}, T. Bold ^{81a}, A.S. Boldyrev ¹¹¹, A.E. Bolz ^{59b}, M. Bomben ¹³², M. Bona ⁹⁰, J.S. Bonilla ¹²⁷, M. Boonekamp ¹⁴², A. Borisov ¹⁴⁰, G. Borissov ⁸⁷, J. Bortfeldt ³⁵, D. Bortoletto ¹³¹, V. Bortolotto ^{71a,71b}, D. Boscherini ^{23b}, M. Bosman ¹⁴, J.D. Bossio Sola ³⁰, K. Bouaouda ^{34a}, J. Boudreau ¹³⁵, E.V. Bouhova-Thacker ⁸⁷, D. Boumediene ³⁷, C. Bourdarios ¹²⁸, S.K. Boutle ⁵⁵, A. Boveia ¹²², J. Boyd ³⁵, D. Boye ^{32b}, I.R. Boyko ⁷⁷, A.J. Bozson ⁹¹, J. Bracinik ²¹, N. Brahimi ⁹⁹, A. Brandt ⁸, G. Brandt ¹⁷⁹, O. Brandt ^{59a}, F. Braren ⁴⁴, U. Bratzler ¹⁶¹, B. Brau ¹⁰⁰, J.E. Brau ¹²⁷, W.D. Breaden Madden ⁵⁵, K. Brendlinger ⁴⁴, L. Brenner ⁴⁴, R. Brenner ¹⁶⁹, S. Bressler ¹⁷⁷, B. Brickwedde ⁹⁷, D.L. Briglin ²¹, D. Britton ⁵⁵, D. Britzger ^{59b}, I. Brock ²⁴, R. Brock ¹⁰⁴, G. Brooijmans ³⁸, T. Brooks ⁹¹, W.K. Brooks ^{144b}, E. Brost ¹¹⁹, J.H. Broughton ²¹, P.A. Bruckman de Renstrom ⁸², D. Bruncko ^{28b}, A. Bruni ^{23b}, G. Bruni ^{23b}, L.S. Bruni ¹¹⁸, S. Bruno ^{71a,71b}, B.H. Brunt ³¹, M. Bruschi ^{23b}, N. Bruscino ¹³⁵, P. Bryant ³⁶, L. Bryngemark ⁴⁴, T. Buanes ¹⁷, Q. Buat ³⁵, P. Buchholz ¹⁴⁸, A.G. Buckley ⁵⁵, I.A. Budagov ⁷⁷, F. Buehrer ⁵⁰, M.K. Bugge ¹³⁰, O. Bulekov ¹¹⁰, D. Bullock ⁸, T.J. Burch ¹¹⁹, S. Burdin ⁸⁸, C.D. Burgard ¹¹⁸, A.M. Burger ⁵, B. Burghgrave ¹¹⁹, K. Burka ⁸², S. Burke ¹⁴¹, I. Burmeister ⁴⁵, J.T.P. Burr ¹³¹, V. Büscher ⁹⁷, E. Buschmann ⁵¹, P. Bussey ⁵⁵, J.M. Butler ²⁵, C.M. Buttar ⁵⁵, J.M. Butterworth ⁹², P. Butti ³⁵, W. Buttinger ³⁵, A. Buzatu ¹⁵⁵, A.R. Buzykaev ^{120b,120a}, G. Cabras ^{23b,23a}, S. Cabrera Urbán ¹⁷¹, D. Caforio ¹³⁸, H. Cai ¹⁷⁰, V.M.M. Cairo ², O. Cakir ^{4a}, N. Calace ⁵², P. Calafiura ¹⁸, A. Calandri ⁹⁹, G. Calderini ¹³², P. Calfayan ⁶³, G. Callea ^{40b,40a}, L.P. Caloba ^{78b}, S. Calvente Lopez ⁹⁶, D. Calvet ³⁷, S. Calvet ³⁷, T.P. Calvet ¹⁵², M. Calvetti ^{69a,69b}, R. Camacho Toro ¹³², S. Camarda ³⁵, P. Camarri ^{71a,71b},

D. Cameron¹³⁰, R. Caminal Armadans¹⁰⁰, C. Camincher³⁵, S. Campana³⁵, M. Campanelli⁹²,
A. Camplani³⁹, A. Campoverde¹⁴⁸, V. Canale^{67a,67b}, M. Cano Bret^{58c}, J. Cantero¹²⁵, T. Cao¹⁵⁸, Y. Cao¹⁷⁰,
M.D.M. Capeans Garrido³⁵, I. Caprini^{27b}, M. Caprini^{27b}, M. Capua^{40b,40a}, R.M. Carbone³⁸,
R. Cardarelli^{71a}, F.C. Cardillo¹⁴⁶, I. Carli¹³⁹, T. Carli³⁵, G. Carlino^{67a}, B.T. Carlson¹³⁵, L. Carminati^{66a,66b},
R.M.D. Carney^{43a,43b}, S. Caron¹¹⁷, E. Carquin^{144b}, S. Carrá^{66a,66b}, G.D. Carrillo-Montoya³⁵, D. Casadei^{32b},
M.P. Casado^{14,f}, A.F. Casha¹⁶⁴, D.W. Casper¹⁶⁸, R. Castelijin¹¹⁸, F.L. Castillo¹⁷¹, V. Castillo Gimenez¹⁷¹,
N.F. Castro^{136a,136e}, A. Catinaccio³⁵, J.R. Catmore¹³⁰, A. Cattai³⁵, J. Caudron²⁴, V. Cavaliere²⁹,
E. Cavallaro¹⁴, D. Cavalli^{66a}, M. Cavalli-Sforza¹⁴, V. Cavasinni^{69a,69b}, E. Celebi^{12b}, F. Ceradini^{72a,72b},
L. Cerda Alberich¹⁷¹, A.S. Cerqueira^{78a}, A. Cerri¹⁵³, L. Cerrito^{71a,71b}, F. Cerutti¹⁸, A. Cervelli^{23b,23a},
S.A. Cetin^{12b}, A. Chafaq^{34a}, D. Chakraborty¹¹⁹, S.K. Chan⁵⁷, W.S. Chan¹¹⁸, Y.L. Chan^{61a}, J.D. Chapman³¹,
B. Chargeishvili^{156b}, D.G. Charlton²¹, C.C. Chau³³, C.A. Chavez Barajas¹⁵³, S. Che¹²², A. Chegwidan¹⁰⁴,
S. Chekanov⁶, S.V. Chekulaev^{165a}, G.A. Chelkov^{77,aq}, M.A. Chelstowska³⁵, C. Chen^{58a}, C.H. Chen⁷⁶,
H. Chen²⁹, J. Chen^{58a}, J. Chen³⁸, S. Chen¹³³, S.J. Chen^{15c}, X. Chen^{15b,ap}, Y. Chen⁸⁰, Y-H. Chen⁴⁴,
H.C. Cheng¹⁰³, H.J. Cheng^{15d}, A. Cheplakov⁷⁷, E. Cheremushkina¹⁴⁰, R. Cherkaoui El Moursli^{34e},
E. Cheu⁷, K. Cheung⁶², L. Chevalier¹⁴², V. Chiarella⁴⁹, G. Chiarelli^{69a}, G. Chiodini^{65a}, A.S. Chisholm^{35,21},
A. Chitan^{27b}, I. Chiu¹⁶⁰, Y.H. Chiu¹⁷³, M.V. Chizhov⁷⁷, K. Choi⁶³, A.R. Chomont¹²⁸, S. Chouridou¹⁵⁹,
Y.S. Chow¹¹⁸, V. Christodoulou⁹², M.C. Chu^{61a}, J. Chudoba¹³⁷, A.J. Chuinard¹⁰¹, J.J. Chwastowski⁸²,
L. Chytka¹²⁶, D. Cinca⁴⁵, V. Cindro⁸⁹, I.A. Cioară²⁴, A. Ciocio¹⁸, F. Ciotto^{67a,67b}, Z.H. Citron¹⁷⁷,
M. Citterio^{66a}, A. Clark⁵², M.R. Clark³⁸, P.J. Clark⁴⁸, C. Clement^{43a,43b}, Y. Coadou⁹⁹, M. Cobal^{64a,64c},
A. Coccaro^{53b,53a}, J. Cochran⁷⁶, H. Cohen¹⁵⁸, A.E.C. Coimbra¹⁷⁷, L. Colasurdo¹¹⁷, B. Cole³⁸,
A.P. Colijn¹¹⁸, J. Collot⁵⁶, P. Conde Muiño^{136a,136b}, E. Coniavitis⁵⁰, S.H. Connell^{32b}, I.A. Connelly⁹⁸,
S. Constantinescu^{27b}, F. Conventi^{67a,as}, A.M. Cooper-Sarkar¹³¹, F. Cormier¹⁷², K.J.R. Cormier¹⁶⁴,
L.D. Corpe⁹², M. Corradi^{70a,70b}, E.E. Corrigan⁹⁴, F. Corriveau^{101,ac}, A. Cortes-Gonzalez³⁵, M.J. Costa¹⁷¹,
F. Costanza⁵, D. Costanzo¹⁴⁶, G. Cottin³¹, G. Cowan⁹¹, B.E. Cox⁹⁸, J. Crane⁹⁸, K. Cranmer¹²¹,
S.J. Crawley⁵⁵, R.A. Creager¹³³, G. Cree³³, S. Crépé-Renaudin⁵⁶, F. Crescioli¹³², M. Cristinziani²⁴,
V. Croft¹²¹, G. Crosetti^{40b,40a}, A. Cueto⁹⁶, T. Cuhadar Donszelmann¹⁴⁶, A.R. Cukierman¹⁵⁰,
S. Czekierda⁸², P. Czodrowski³⁵, M.J. Da Cunha Sargedas De Sousa^{58b,136b}, C. Da Via⁹⁸,
W. Dabrowski^{81a}, T. Dado^{28a,x}, S. Dahbi^{34e}, T. Dai¹⁰³, F. Dallaire¹⁰⁷, C. Dallapiccola¹⁰⁰, M. Dam³⁹,
G. D'amen^{23b,23a}, J. Damp⁹⁷, J.R. Dandoy¹³³, M.F. Daneri³⁰, N.P. Dang^{178,j}, N.D. Dann⁹⁸,
M. Danninger¹⁷², V. Dao³⁵, G. Darbo^{53b}, S. Darmora⁸, O. Dartsis⁵, A. Dattagupta¹²⁷, T. Daubney⁴⁴,
S. D'Auria⁵⁵, W. Davey²⁴, C. David⁴⁴, T. Davidek¹³⁹, D.R. Davis⁴⁷, E. Dawe¹⁰², I. Dawson¹⁴⁶, K. De⁸,
R. De Asmundis^{67a}, A. De Benedetti¹²⁴, M. De Beurs¹¹⁸, S. De Castro^{23b,23a}, S. De Cecco^{70a,70b},
N. De Groot¹¹⁷, P. de Jong¹¹⁸, H. De la Torre¹⁰⁴, F. De Lorenzi⁷⁶, A. De Maria^{51,s}, D. De Pedis^{70a},
A. De Salvo^{70a}, U. De Sanctis^{71a,71b}, M. De Santis^{71a,71b}, A. De Santo¹⁵³, K. De Vasconcelos Corga⁹⁹,
J.B. De Vivie De Regie¹²⁸, C. Debenedetti¹⁴³, D.V. Dedovich⁷⁷, N. Dehghanian³, M. Del Gaudio^{40b,40a},
J. Del Peso⁹⁶, Y. Delabat Diaz⁴⁴, D. Delgove¹²⁸, F. Deliot¹⁴², C.M. Delitzsch⁷, M. Della Pietra^{67a,67b},
D. Della Volpe⁵², A. Dell'Acqua³⁵, L. Dell'Asta²⁵, M. Delmastro⁵, C. Delporte¹²⁸, P.A. Delsart⁵⁶,
D.A. DeMarco¹⁶⁴, S. Demers¹⁸⁰, M. Demichev⁷⁷, S.P. Denisov¹⁴⁰, D. Denysiuk¹¹⁸, L. D'Eramo¹³²,
D. Derendarz⁸², J.E. Derkaoui^{34d}, F. Derue¹³², P. Dervan⁸⁸, K. Desch²⁴, C. Deterre⁴⁴, K. Dette¹⁶⁴,
M.R. Devesa³⁰, P.O. Deviveiros³⁵, A. Dewhurst¹⁴¹, S. Dhaliwal²⁶, F.A. Di Bello⁵², A. Di Ciaccio^{71a,71b},
L. Di Ciaccio⁵, W.K. Di Clemente¹³³, C. Di Donato^{67a,67b}, A. Di Girolamo³⁵, B. Di Micco^{72a,72b},
R. Di Nardo¹⁰⁰, K.F. Di Petrillo⁵⁷, R. Di Sipio¹⁶⁴, D. Di Valentino³³, C. Diaconu⁹⁹, M. Diamond¹⁶⁴,
F.A. Dias³⁹, T. Dias Do Vale^{136a}, M.A. Diaz^{144a}, J. Dickinson¹⁸, E.B. Diehl¹⁰³, J. Dietrich¹⁹,
S. Díez Cornell⁴⁴, A. Dimitrievska¹⁸, J. Dingfelder²⁴, F. Dittus³⁵, F. Djama⁹⁹, T. Djobava^{156b},
J.I. Djuvsland^{59a}, M.A.B. Do Vale^{78c}, M. Dobre^{27b}, D. Dodsworth²⁶, C. Doglioni⁹⁴, J. Dolejsi¹³⁹,
Z. Dolezal¹³⁹, M. Donadelli^{78d}, J. Donini³⁷, A. D'onofrio⁹⁰, M. D'Onofrio⁸⁸, J. Dopke¹⁴¹, A. Doria^{67a},
M.T. Dova⁸⁶, A.T. Doyle⁵⁵, E. Drechsler⁵¹, E. Dreyer¹⁴⁹, T. Dreyer⁵¹, D. Du^{58b}, Y. Du^{58b}, F. Dubinin¹⁰⁸,
M. Dubovsky^{28a}, A. Dubreuil⁵², E. Duchovni¹⁷⁷, G. Duckeck¹¹², A. Ducourthial¹³², O.A. Ducu^{107,w},
D. Duda¹¹³, A. Dudarev³⁵, A.C. Dudder⁹⁷, E.M. Duffield¹⁸, L. Duflot¹²⁸, M. Dührssen³⁵, C. Dülsen¹⁷⁹,
M. Dumancic¹⁷⁷, A.E. Dumitriu^{27b,d}, A.K. Duncan⁵⁵, M. Dunford^{59a}, A. Duperrin⁹⁹, H. Duran Yildiz^{4a},
M. Düren⁵⁴, A. Durglishvili^{156b}, D. Duschinger⁴⁶, B. Dutta⁴⁴, D. Duvnjak¹, M. Dyndal⁴⁴, S. Dysch⁹⁸,
B.S. Dziedzic⁸², C. Eckardt⁴⁴, K.M. Ecker¹¹³, R.C. Edgar¹⁰³, T. Eifert³⁵, G. Eigen¹⁷, K. Einsweiler¹⁸,

T. Ekelof ¹⁶⁹, M. El Kacimi ^{34c}, R. El Kosseifi ⁹⁹, V. Ellajosyula ⁹⁹, M. Ellert ¹⁶⁹, F. Ellinghaus ¹⁷⁹, A.A. Elliot ⁹⁰, N. Ellis ³⁵, J. Elmsheuser ²⁹, M. Elsing ³⁵, D. Emelianov ¹⁴¹, Y. Enari ¹⁶⁰, J.S. Ennis ¹⁷⁵, M.B. Epland ⁴⁷, J. Erdmann ⁴⁵, A. Ereditato ²⁰, S. Errede ¹⁷⁰, M. Escalier ¹²⁸, C. Escobar ¹⁷¹, O. Estrada Pastor ¹⁷¹, A.I. Etienne ¹⁴², E. Etzion ¹⁵⁸, H. Evans ⁶³, A. Ezhilov ¹³⁴, M. Ezzi ^{34e}, F. Fabbri ⁵⁵, L. Fabbri ^{23b,23a}, V. Fabiani ¹¹⁷, G. Facini ⁹², R.M. Faisca Rodrigues Pereira ^{136a}, R.M. Fakhruddinov ¹⁴⁰, S. Falciano ^{70a}, P.J. Falke ⁵, S. Falke ⁵, J. Faltova ¹³⁹, Y. Fang ^{15a}, M. Fanti ^{66a,66b}, A. Farbin ⁸, A. Farilla ^{72a}, E.M. Farina ^{68a,68b}, T. Farooque ¹⁰⁴, S. Farrell ¹⁸, S.M. Farrington ¹⁷⁵, P. Farthouat ³⁵, F. Fassi ^{34e}, P. Fassnacht ³⁵, D. Fassouliotis ⁹, M. Fauci Giannelli ⁴⁸, A. Favareto ^{53b,53a}, W.J. Fawcett ³¹, L. Fayard ¹²⁸, O.L. Fedin ^{134,o}, W. Fedorko ¹⁷², M. Feickert ⁴¹, S. Feigl ¹³⁰, L. Feligioni ⁹⁹, C. Feng ^{58b}, E.J. Feng ³⁵, M. Feng ⁴⁷, M.J. Fenton ⁵⁵, A.B. Fenyuk ¹⁴⁰, L. Feremenga ⁸, J. Ferrando ⁴⁴, A. Ferrari ¹⁶⁹, P. Ferrari ¹¹⁸, R. Ferrari ^{68a}, D.E. Ferreira de Lima ^{59b}, A. Ferrer ¹⁷¹, D. Ferrere ⁵², C. Ferretti ¹⁰³, F. Fiedler ⁹⁷, A. Filipčič ⁸⁹, F. Filthaut ¹¹⁷, K.D. Finelli ²⁵, M.C.N. Fiolhais ^{136a,136c,a}, L. Fiorini ¹⁷¹, C. Fischer ¹⁴, W.C. Fisher ¹⁰⁴, N. Flaschel ⁴⁴, I. Fleck ¹⁴⁸, P. Fleischmann ¹⁰³, R.R.M. Fletcher ¹³³, T. Flick ¹⁷⁹, B.M. Flierl ¹¹², L.M. Flores ¹³³, L.R. Flores Castillo ^{61a}, F.M. Follega ^{73a,73b}, N. Fomin ¹⁷, G.T. Forcolin ^{73a,73b}, A. Formica ¹⁴², F.A. Förster ¹⁴, A.C. Forti ⁹⁸, A.G. Foster ²¹, D. Fournier ¹²⁸, H. Fox ⁸⁷, S. Fracchia ¹⁴⁶, P. Francavilla ^{69a,69b}, M. Franchini ^{23b,23a}, S. Franchino ^{59a}, D. Francis ³⁵, L. Franconi ¹³⁰, M. Franklin ⁵⁷, M. Frate ¹⁶⁸, M. Fraternali ^{68a,68b}, A.N. Fray ⁹⁰, D. Freeborn ⁹², S.M. Fressard-Batraneanu ³⁵, B. Freund ¹⁰⁷, W.S. Freund ^{78b}, E.M. Freundlich ⁴⁵, D.C. Frizzell ¹²⁴, D. Froidevaux ³⁵, J.A. Frost ¹³¹, C. Fukunaga ¹⁶¹, E. Fullana Torregrosa ¹⁷¹, T. Fusayasu ¹¹⁴, J. Fuster ¹⁷¹, O. Gabizon ¹⁵⁷, A. Gabrielli ^{23b,23a}, A. Gabrielli ¹⁸, G.P. Gach ^{81a}, S. Gadatsch ⁵², P. Gadow ¹¹³, G. Gagliardi ^{53b,53a}, L.G. Gagnon ¹⁰⁷, C. Galea ^{27b}, B. Galhardo ^{136a,136c}, E.J. Gallas ¹³¹, B.J. Gallop ¹⁴¹, P. Gallus ¹³⁸, G. Galster ³⁹, R. Gamboa Goni ⁹⁰, K.K. Gan ¹²², S. Ganguly ¹⁷⁷, J. Gao ^{58a}, Y. Gao ⁸⁸, Y.S. Gao ^{150,l}, C. García ¹⁷¹, J.E. García Navarro ¹⁷¹, J.A. García Pascual ^{15a}, M. Garcia-Sciveres ¹⁸, R.W. Gardner ³⁶, N. Garelli ¹⁵⁰, V. Garonne ¹³⁰, K. Gasnikova ⁴⁴, A. Gaudiello ^{53b,53a}, G. Gaudio ^{68a}, I.L. Gavrilenko ¹⁰⁸, A. Gavrilyuk ¹⁰⁹, C. Gay ¹⁷², G. Gaycken ²⁴, E.N. Gazis ¹⁰, C.N.P. Gee ¹⁴¹, J. Geisen ⁵¹, M. Geisen ⁹⁷, M.P. Geisler ^{59a}, K. Gellerstedt ^{43a,43b}, C. Gemme ^{53b}, M.H. Genest ⁵⁶, C. Geng ¹⁰³, S. Gentile ^{70a,70b}, S. George ⁹¹, D. Gerbaudo ¹⁴, G. Gessner ⁴⁵, S. Ghasemi ¹⁴⁸, M. Ghasemi Bostanabad ¹⁷³, M. Ghneimat ²⁴, B. Giacobbe ^{23b}, S. Giagu ^{70a,70b}, N. Giangiacomi ^{23b,23a}, P. Giannetti ^{69a}, A. Giannini ^{67a,67b}, S.M. Gibson ⁹¹, M. Gignac ¹⁴³, D. Gillberg ³³, G. Gilles ¹⁷⁹, D.M. Gingrich ^{3,ar}, M.P. Giordani ^{64a,64c}, F.M. Giorgi ^{23b}, P.F. Giraud ¹⁴², P. Giromini ⁵⁷, G. Giugliarelli ^{64a,64c}, D. Giugni ^{66a}, F. Giulini ¹³¹, M. Giulini ^{59b}, S. Gkaitatzis ¹⁵⁹, I. Gkialas ^{9,i}, E.L. Gkoukousis ¹⁴, P. Gkoutoumis ¹⁰, L.K. Gladilin ¹¹¹, C. Glasman ⁹⁶, J. Glatzer ¹⁴, P.C.F. Glaysher ⁴⁴, A. Glazov ⁴⁴, M. Goblirsch-Kolb ²⁶, J. Godlewski ⁸², S. Goldfarb ¹⁰², T. Golling ⁵², D. Golubkov ¹⁴⁰, A. Gomes ^{136a,136b,136d}, R. Goncalves Gama ^{78a}, R. Gonçalves ^{136a}, G. Gonella ⁵⁰, L. Gonella ²¹, A. Gongadze ⁷⁷, F. Gonnella ²¹, J.L. Gonski ⁵⁷, S. González de la Hoz ¹⁷¹, S. Gonzalez-Sevilla ⁵², L. Goossens ³⁵, P.A. Gorbounov ¹⁰⁹, H.A. Gordon ²⁹, B. Gorini ³⁵, E. Gorini ^{65a,65b}, A. Gorišek ⁸⁹, A.T. Goshaw ⁴⁷, C. Gössling ⁴⁵, M.I. Gostkin ⁷⁷, C.A. Gottardo ²⁴, C.R. Goudet ¹²⁸, D. Goujdami ^{34c}, A.G. Goussiou ¹⁴⁵, N. Govender ^{32b,b}, C. Goy ⁵, E. Gozani ¹⁵⁷, I. Grabowska-Bold ^{81a}, P.O.J. Gradin ¹⁶⁹, E.C. Graham ⁸⁸, J. Gramling ¹⁶⁸, E. Gramstad ¹³⁰, S. Grancagnolo ¹⁹, V. Gratchev ¹³⁴, P.M. Gravila ^{27f}, F.G. Gravili ^{65a,65b}, C. Gray ⁵⁵, H.M. Gray ¹⁸, Z.D. Greenwood ^{93,ai}, C. Grefe ²⁴, K. Gregersen ⁹⁴, I.M. Gregor ⁴⁴, P. Grenier ¹⁵⁰, K. Grevtsov ⁴⁴, N.A. Grieser ¹²⁴, J. Griffiths ⁸, A.A. Grillo ¹⁴³, K. Grimm ¹⁵⁰, S. Grinstein ^{14,y}, Ph. Gris ³⁷, J.-F. Grivaz ¹²⁸, S. Groh ⁹⁷, E. Gross ¹⁷⁷, J. Grosse-Knetter ⁵¹, G.C. Grossi ⁹³, Z.J. Grout ⁹², C. Grud ¹⁰³, A. Grummer ¹¹⁶, L. Guan ¹⁰³, W. Guan ¹⁷⁸, J. Guenther ³⁵, A. Guerguichon ¹²⁸, F. Guescini ^{165a}, D. Guest ¹⁶⁸, R. Gugel ⁵⁰, B. Gui ¹²², T. Guillemain ⁵, S. Guindon ³⁵, U. Gul ⁵⁵, C. Gumpert ³⁵, J. Guo ^{58c}, W. Guo ¹⁰³, Y. Guo ^{58a,r}, Z. Guo ⁹⁹, R. Gupta ⁴¹, S. Gurbuz ^{12c}, G. Gustavino ¹²⁴, B.J. Gutelman ¹⁵⁷, P. Gutierrez ¹²⁴, C. Gutschow ⁹², C. Guyot ¹⁴², M.P. Guzik ^{81a}, C. Gwenlan ¹³¹, C.B. Gwilliam ⁸⁸, A. Haas ¹²¹, C. Haber ¹⁸, H.K. Hadavand ⁸, N. Haddad ^{34e}, A. Hadeef ^{58a}, S. Hageböck ²⁴, M. Hagihara ¹⁶⁶, H. Hakobyan ^{181,*}, M. Haleem ¹⁷⁴, J. Haley ¹²⁵, G. Halladjian ¹⁰⁴, G.D. Hallewell ⁹⁹, K. Hamacher ¹⁷⁹, P. Hamal ¹²⁶, K. Hamano ¹⁷³, A. Hamilton ^{32a}, G.N. Hamity ¹⁴⁶, K. Han ^{58a,ah}, L. Han ^{58a}, S. Han ^{15d}, K. Hanagaki ^{79,u}, M. Hance ¹⁴³, D.M. Handl ¹¹², B. Haney ¹³³, R. Hankache ¹³², P. Hanke ^{59a}, E. Hansen ⁹⁴, J.B. Hansen ³⁹, J.D. Hansen ³⁹, M.C. Hansen ²⁴, P.H. Hansen ³⁹, K. Hara ¹⁶⁶, A.S. Hard ¹⁷⁸, T. Harenberg ¹⁷⁹, S. Harkusha ¹⁰⁵, P.F. Harrison ¹⁷⁵, N.M. Hartmann ¹¹², Y. Hasegawa ¹⁴⁷, A. Hasib ⁴⁸, S. Hassani ¹⁴², S. Haug ²⁰, R. Hauser ¹⁰⁴, L. Hauswald ⁴⁶, L.B. Havener ³⁸, M. Havranek ¹³⁸, C.M. Hawkes ²¹,

R.J. Hawkings³⁵, D. Hayden¹⁰⁴, C. Hayes¹⁵², C.P. Hays¹³¹, J.M. Hays⁹⁰, H.S. Hayward⁸⁸, S.J. Haywood¹⁴¹, M.P. Heath⁴⁸, V. Hedberg⁹⁴, L. Heelan⁸, S. Heer²⁴, K.K. Heidegger⁵⁰, J. Heilman³³, S. Heim⁴⁴, T. Heim¹⁸, B. Heinemann^{44,am}, J.J. Heinrich¹¹², L. Heinrich¹²¹, C. Heinz⁵⁴, J. Hejbal¹³⁷, L. Helary³⁵, A. Held¹⁷², S. Hellesund¹³⁰, S. Hellman^{43a,43b}, C. Helsens³⁵, R.C.W. Henderson⁸⁷, Y. Heng¹⁷⁸, S. Henkelmann¹⁷², A.M. Henriques Correia³⁵, G.H. Herbert¹⁹, H. Herde²⁶, V. Herget¹⁷⁴, Y. Hernández Jiménez^{32c}, H. Herr⁹⁷, M.G. Herrmann¹¹², G. Herten⁵⁰, R. Hertenberger¹¹², L. Hervas³⁵, T.C. Herwig¹³³, G.G. Hesketh⁹², N.P. Hessey^{165a}, J.W. Hetherly⁴¹, S. Higashino⁷⁹, E. Higón-Rodríguez¹⁷¹, K. Hildebrand³⁶, E. Hill¹⁷³, J.C. Hill³¹, K.K. Hill²⁹, K.H. Hiller⁴⁴, S.J. Hillier²¹, M. Hils⁴⁶, I. Hinchliffe¹⁸, M. Hirose¹²⁹, D. Hirschbuehl¹⁷⁹, B. Hiti⁸⁹, O. Hladik¹³⁷, D.R. Hlaluku^{32c}, X. Hoad⁴⁸, J. Hobbs¹⁵², N. Hod^{165a}, M.C. Hodgkinson¹⁴⁶, A. Hoecker³⁵, M.R. Hoferkamp¹¹⁶, F. Hoenic¹¹², D. Hohn²⁴, D. Hohov¹²⁸, T.R. Holmes³⁶, M. Holzbock¹¹², M. Homann⁴⁵, S. Honda¹⁶⁶, T. Honda⁷⁹, T.M. Hong¹³⁵, A. Hönle¹¹³, B.H. Hooberman¹⁷⁰, W.H. Hopkins¹²⁷, Y. Horii¹¹⁵, P. Horn⁴⁶, A.J. Horton¹⁴⁹, L.A. Horyn³⁶, J.-Y. Hostachy⁵⁶, A. Hostiuc¹⁴⁵, S. Hou¹⁵⁵, A. Hoummada^{34a}, J. Howarth⁹⁸, J. Hoya⁸⁶, M. Hrabovsky¹²⁶, I. Hristova¹⁹, J. Hrivnac¹²⁸, A. Hrynevich¹⁰⁶, T. Hryn'ova⁵, H. Hsu⁶², P.J. Hsu⁶², S.-C. Hsu¹⁴⁵, Q. Hu²⁹, S. Hu^{58c}, Y. Huang^{15a}, Z. Hubacek¹³⁸, F. Hubaut⁹⁹, M. Huebner²⁴, F. Huegging²⁴, T.B. Huffman¹³¹, E.W. Hughes³⁸, M. Huhtinen³⁵, R.F.H. Hunter³³, P. Huo¹⁵², A.M. Hupe³³, N. Huseynov^{77,ae}, J. Huston¹⁰⁴, J. Huth⁵⁷, R. Hyneman¹⁰³, G. Iacobucci⁵², G. Iakovidis²⁹, I. Ibragimov¹⁴⁸, L. Iconomidou-Fayard¹²⁸, Z. Idrissi^{34e}, P. Iengo³⁵, R. Ignazzi³⁹, O. Igonkina^{118,aa}, R. Iguchi¹⁶⁰, T. Iizawa⁵², Y. Ikegami⁷⁹, M. Ikeno⁷⁹, D. Iliadis¹⁵⁹, N. Ilic¹⁵⁰, F. Iltzsche⁴⁶, G. Introzzi^{68a,68b}, M. Iodice^{72a}, K. Iordanidou³⁸, V. Ippolito^{70a,70b}, M.F. Isacson¹⁶⁹, N. Ishijima¹²⁹, M. Ishino¹⁶⁰, M. Ishitsuka¹⁶², W. Islam¹²⁵, C. Issever¹³¹, S. Istin¹⁵⁷, F. Ito¹⁶⁶, J.M. Iturbe Ponce^{61a}, R. Iuppa^{73a,73b}, A. Ivina¹⁷⁷, H. Iwasaki⁷⁹, J.M. Izen⁴², V. Izzo^{67a}, P. Jacka¹³⁷, P. Jackson¹, R.M. Jacobs²⁴, B.P. Jaeger¹⁴⁹, V. Jain², G. Jäkel¹⁷⁹, K.B. Jakobi⁹⁷, K. Jakobs⁵⁰, S. Jakobsen⁷⁴, T. Jakoubek¹³⁷, D.O. Jamin¹²⁵, D.K. Jana⁹³, R. Jansky⁵², J. Janssen²⁴, M. Janus⁵¹, P.A. Janus^{81a}, G. Jarlskog⁹⁴, N. Javadov^{77,ae}, T. Javůrek³⁵, M. Javurkova⁵⁰, F. Jeanneau¹⁴², L. Jeanty¹⁸, J. Jejelava^{156a,af}, A. Jelinskas¹⁷⁵, P. Jenni^{50,c}, J. Jeong⁴⁴, N. Jeong⁴⁴, S. Jézéquel⁵, H. Ji¹⁷⁸, J. Jia¹⁵², H. Jiang⁷⁶, Y. Jiang^{58a}, Z. Jiang^{150,p}, S. Jiggins⁵⁰, F.A. Jimenez Morales³⁷, J. Jimenez Pena¹⁷¹, S. Jin^{15c}, A. Jinaru^{27b}, O. Jinnouchi¹⁶², H. Jivan^{32c}, P. Johansson¹⁴⁶, K.A. Johns⁷, C.A. Johnson⁶³, W.J. Johnson¹⁴⁵, K. Jon-And^{43a,43b}, R.W.L. Jones⁸⁷, S.D. Jones¹⁵³, S. Jones⁷, T.J. Jones⁸⁸, J. Jongmanns^{59a}, P.M. Jorge^{136a,136b}, J. Jovicevic^{165a}, X. Ju¹⁸, J.J. Junggeburth¹¹³, A. Juste Rozas^{14,y}, A. Kaczmarska⁸², M. Kado¹²⁸, H. Kagan¹²², M. Kagan¹⁵⁰, T. Kaji¹⁷⁶, E. Kajomovitz¹⁵⁷, C.W. Kalderon⁹⁴, A. Kaluza⁹⁷, S. Kama⁴¹, A. Kamenshchikov¹⁴⁰, L. Kanjir⁸⁹, Y. Kano¹⁶⁰, V.A. Kantserov¹¹⁰, J. Kanzaki⁷⁹, B. Kaplan¹²¹, L.S. Kaplan¹⁷⁸, D. Kar^{32c}, M.J. Kareem^{165b}, E. Karentzos¹⁰, S.N. Karpov⁷⁷, Z.M. Karpova⁷⁷, V. Kartvelishvili⁸⁷, A.N. Karyukhin¹⁴⁰, L. Kashif¹⁷⁸, R.D. Kass¹²², A. Kastanas^{43a,43b}, Y. Kataoka¹⁶⁰, C. Kato^{58d,58c}, J. Katzy⁴⁴, K. Kawade⁸⁰, K. Kawagoe⁸⁵, T. Kawamoto¹⁶⁰, G. Kawamura⁵¹, E.F. Kay⁸⁸, V.F. Kazanin^{120b,120a}, R. Keeler¹⁷³, R. Kehoe⁴¹, J.S. Keller³³, E. Kellermann⁹⁴, J.J. Kempster²¹, J. Kendrick²¹, O. Kepka¹³⁷, S. Kersten¹⁷⁹, B.P. Kerševan⁸⁹, R.A. Keyes¹⁰¹, M. Khader¹⁷⁰, F. Khalil-Zada¹³, A. Khanov¹²⁵, A.G. Kharlamov^{120b,120a}, T. Kharlamova^{120b,120a}, E.E. Khoda¹⁷², A. Khodinov¹⁶³, T.J. Khoo⁵², E. Khramov⁷⁷, J. Khubua^{156b}, S. Kido⁸⁰, M. Kiehn⁵², C.R. Kilby⁹¹, Y.K. Kim³⁶, N. Kimura^{64a,64c}, O.M. Kind¹⁹, B.T. King⁸⁸, D. Kirchmeier⁴⁶, J. Kirk¹⁴¹, A.E. Kiryunin¹¹³, T. Kishimoto¹⁶⁰, D. Kisielewska^{81a}, V. Kitali⁴⁴, O. Kivernyk⁵, E. Kladiva^{28b}, T. Klapdor-Kleingrothaus⁵⁰, M.H. Klein¹⁰³, M. Klein⁸⁸, U. Klein⁸⁸, K. Kleinknecht⁹⁷, P. Klimek¹¹⁹, A. Klimentov²⁹, R. Klingenberg^{45,*}, T. Klingl²⁴, T. Klioutchnikova³⁵, F.F. Klitzner¹¹², P. Kluit¹¹⁸, S. Kluth¹¹³, E. Kneringer⁷⁴, E.B.F.G. Knoop⁹⁹, A. Knue⁵⁰, A. Kobayashi¹⁶⁰, D. Kobayashi⁸⁵, T. Kobayashi¹⁶⁰, M. Kobel⁴⁶, M. Kocian¹⁵⁰, P. Kodys¹³⁹, P.T. Koenig²⁴, T. Koffas³³, E. Koffeman¹¹⁸, N.M. Köhler¹¹³, T. Koi¹⁵⁰, M. Kolb^{59b}, I. Koletsou⁵, T. Kondo⁷⁹, N. Kondrashova^{58c}, K. Köneke⁵⁰, A.C. König¹¹⁷, T. Kono⁷⁹, R. Konoplich^{121,aj}, V. Konstantinides⁹², N. Konstantinidis⁹², B. Konya⁹⁴, R. Kopeliansky⁶³, S. Koperny^{81a}, K. Korcyl⁸², K. Kordas¹⁵⁹, G. Koren¹⁵⁸, A. Korn⁹², I. Korolkov¹⁴, E.V. Korolkova¹⁴⁶, N. Korotkova¹¹¹, O. Kortner¹¹³, S. Kortner¹¹³, T. Kosek¹³⁹, V.V. Kostyukhin²⁴, A. Kotwal⁴⁷, A. Koulouris¹⁰, A. Kourkoumeli-Charalampidi^{68a,68b}, C. Kourkoumelis⁹, E. Kourlitis¹⁴⁶, V. Kouskoura²⁹, A.B. Kowalewska⁸², R. Kowalewski¹⁷³, T.Z. Kowalski^{81a}, C. Kozakai¹⁶⁰, W. Kozanecki¹⁴², A.S. Kozhin¹⁴⁰, V.A. Kramarenko¹¹¹, G. Kramberger⁸⁹, D. Krasnopevtsev^{58a}, M.W. Krasny¹³², A. Krasznahorkay³⁵, D. Krauss¹¹³, J.A. Kremer^{81a}, J. Kretschmar⁸⁸, P. Krieger¹⁶⁴, K. Krizka¹⁸, K. Kroeninger⁴⁵, H. Kroha¹¹³

J. Kroll¹³⁷, J. Kroll¹³³, J. Krstic¹⁶, U. Kruchonak⁷⁷, H. Krüger²⁴, N. Krumnack⁷⁶, M.C. Kruse⁴⁷,
 T. Kubota¹⁰², S. Kuday^{4b}, J.T. Kuechler¹⁷⁹, S. Kuehn³⁵, A. Kugel^{59a}, F. Kuger¹⁷⁴, T. Kuhl⁴⁴, V. Kukhtin⁷⁷,
 R. Kukla⁹⁹, Y. Kulchitsky¹⁰⁵, S. Kuleshov^{144b}, Y.P. Kulinich¹⁷⁰, M. Kuna⁵⁶, T. Kunigo⁸³, A. Kupco¹³⁷,
 T. Kupfer⁴⁵, O. Kuprash¹⁵⁸, H. Kurashige⁸⁰, L.L. Kurchaninov^{165a}, Y.A. Kurochkin¹⁰⁵, M.G. Kurth^{15d},
 E.S. Kuwertz³⁵, M. Kuze¹⁶², J. Kvita¹²⁶, T. Kwan¹⁰¹, A. La Rosa¹¹³, J.L. La Rosa Navarro^{78d},
 L. La Rotonda^{40b,40a}, F. La Ruffa^{40b,40a}, C. Lacasta¹⁷¹, F. Lacava^{70a,70b}, J. Lacey⁴⁴, D.P.J. Lack⁹⁸,
 H. Lacker¹⁹, D. Lacour¹³², E. Ladygin⁷⁷, R. Lafaye⁵, B. Laforge¹³², T. Lagouri^{32c}, S. Lai⁵¹, S. Lammers⁶³,
 W. Lampl⁷, E. Lançon²⁹, U. Landgraf⁵⁰, M.P.J. Landon⁹⁰, M.C. Lanfermann⁵², V.S. Lang⁴⁴, J.C. Lange¹⁴,
 R.J. Langenberg³⁵, A.J. Lankford¹⁶⁸, F. Lanni²⁹, K. Lantzsch²⁴, A. Lanza^{68a}, A. Lapertosa^{53b,53a},
 S. Laplace¹³², J.F. Laporte¹⁴², T. Lari^{66a}, F. Lasagni Manghi^{23b,23a}, M. Lassnig³⁵, T.S. Lau^{61a},
 A. Laudrain¹²⁸, M. Lavorgna^{67a,67b}, A.T. Law¹⁴³, M. Lazzaroni^{66a,66b}, B. Le¹⁰², O. Le Dortz¹³²,
 E. Le Guirriec⁹⁹, E.P. Le Quilleuc¹⁴², M. LeBlanc⁷, T. LeCompte⁶, F. Ledroit-Guillon⁵⁶, C.A. Lee²⁹,
 G.R. Lee^{144a}, L. Lee⁵⁷, S.C. Lee¹⁵⁵, B. Lefebvre¹⁰¹, M. Lefebvre¹⁷³, F. Legger¹¹², C. Leggett¹⁸,
 K. Lehmann¹⁴⁹, N. Lehmann¹⁷⁹, G. Lehmann Miotto³⁵, W.A. Leight⁴⁴, A. Leisos^{159,v}, M.A.L. Leite^{78d},
 R. Leitner¹³⁹, D. Lellouch¹⁷⁷, B. Lemmer⁵¹, K.J.C. Leney⁹², T. Lenz²⁴, B. Lenzi³⁵, R. Leone⁷, S. Leone^{69a},
 C. Leonidopoulos⁴⁸, G. Lerner¹⁵³, C. Leroy¹⁰⁷, R. Les¹⁶⁴, A.A.J. Lesage¹⁴², C.G. Lester³¹,
 M. Levchenko¹³⁴, J. Levêque⁵, D. Levin¹⁰³, L.J. Levinson¹⁷⁷, D. Lewis⁹⁰, B. Li¹⁰³, C-Q. Li^{58a}, H. Li^{58b},
 L. Li^{58c}, M. Li^{15a}, Q. Li^{15d}, Q.Y. Li^{58a}, S. Li^{58d,58c}, X. Li^{58c}, Y. Li¹⁴⁸, Z. Liang^{15a}, B. Liberti^{71a},
 A. Liblong¹⁶⁴, K. Lie^{61c}, S. Liem¹¹⁸, A. Limosani¹⁵⁴, C.Y. Lin³¹, K. Lin¹⁰⁴, T.H. Lin⁹⁷, R.A. Linck⁶³,
 J.H. Lindon²¹, B.E. Lindquist¹⁵², A.L. Lioni⁵², E. Lipeles¹³³, A. Lipniacka¹⁷, M. Lisovsky^{59b}, T.M. Liss^{170,ao},
 A. Lister¹⁷², A.M. Litke¹⁴³, J.D. Little⁸, B. Liu⁷⁶, B.L. Liu⁶, H.B. Liu²⁹, H. Liu¹⁰³, J.B. Liu^{58a}, J.K.K. Liu¹³¹,
 K. Liu¹³², M. Liu^{58a}, P. Liu¹⁸, Y. Liu^{15a}, Y.L. Liu^{58a}, Y.W. Liu^{58a}, M. Livan^{68a,68b}, A. Lleres⁵⁶,
 J. Llorente Merino^{15a}, S.L. Lloyd⁹⁰, C.Y. Lo^{61b}, Y. Lo⁶², F. Lo Sterzo⁴¹, E.M. Lobodzinska⁴⁴, P. Loch⁷,
 A. Loesle⁵⁰, T. Lohse¹⁹, K. Lohwasser¹⁴⁶, M. Lokajicek¹³⁷, B.A. Long²⁵, J.D. Long¹⁷⁰, R.E. Long⁸⁷,
 L. Longo^{65a,65b}, K.A. Looper¹²², J.A. Lopez^{144b}, I. Lopez Paz¹⁴, A. Lopez Solis¹⁴⁶, J. Lorenz¹¹²,
 N. Lorenzo Martinez⁵, M. Losada²², P.J. Lösel¹¹², X. Lou⁴⁴, X. Lou^{15a}, A. Lounis¹²⁸, J. Love⁶, P.A. Love⁸⁷,
 J.J. Lozano Bahilo¹⁷¹, H. Lu^{61a}, M. Lu^{58a}, N. Lu¹⁰³, Y.J. Lu⁶², H.J. Lubatti¹⁴⁵, C. Luci^{70a,70b}, A. Lucotte⁵⁶,
 C. Luedtke⁵⁰, F. Luehring⁶³, I. Luise¹³², L. Luminari^{70a}, B. Lund-Jensen¹⁵¹, M.S. Lutz¹⁰⁰, P.M. Luzi¹³²,
 D. Lynn²⁹, R. Lysak¹³⁷, E. Lytken⁹⁴, F. Lyu^{15a}, V. Lyubushkin⁷⁷, H. Ma²⁹, L.L. Ma^{58b}, Y. Ma^{58b},
 G. Maccarrone⁴⁹, A. Macchiolo¹¹³, C.M. Macdonald¹⁴⁶, J. Machado Miguens^{133,136b}, D. Madaffari¹⁷¹,
 R. Madar³⁷, W.F. Mader⁴⁶, A. Madsen⁴⁴, N. Madysa⁴⁶, J. Maeda⁸⁰, K. Maekawa¹⁶⁰, S. Maeland¹⁷,
 T. Maeno²⁹, A.S. Maevskiy¹¹¹, V. Magerl⁵⁰, C. Maidantchik^{78b}, T. Maier¹¹², A. Maio^{136a,136b,136d},
 O. Majersky^{28a}, S. Majewski¹²⁷, Y. Makida⁷⁹, N. Makovec¹²⁸, B. Malaescu¹³², Pa. Malecki⁸²,
 V.P. Maleev¹³⁴, F. Malek⁵⁶, U. Mallik⁷⁵, D. Malon⁶, C. Malone³¹, S. Maltezos¹⁰, S. Malyukov³⁵,
 J. Mamuzic¹⁷¹, G. Mancini⁴⁹, I. Mandić⁸⁹, J. Maneira^{136a}, L. Manhaes de Andrade Filho^{78a},
 J. Manjarres Ramos⁴⁶, K.H. Mankinen⁹⁴, A. Mann¹¹², A. Manouos⁷⁴, B. Mansoulie¹⁴², J.D. Mansour^{15a},
 M. Mantoani⁵¹, S. Manzoni^{66a,66b}, A. Marantis¹⁵⁹, G. Marceca³⁰, L. March⁵², L. Marchese¹³¹,
 G. Marchiori¹³², M. Marcisovsky¹³⁷, C.A. Marin Tobon³⁵, M. Marjanovic³⁷, D.E. Marley¹⁰³,
 F. Marroquim^{78b}, Z. Marshall¹⁸, M.U.F. Martensson¹⁶⁹, S. Marti-Garcia¹⁷¹, C.B. Martin¹²², T.A. Martin¹⁷⁵,
 V.J. Martin⁴⁸, B. Martin dit Latour¹⁷, M. Martinez^{14,y}, V.I. Martinez Outschoorn¹⁰⁰, S. Martin-Haugh¹⁴¹,
 V.S. Martoiu^{27b}, A.C. Martyniuk⁹², A. Marzin³⁵, L. Masetti⁹⁷, T. Mashimo¹⁶⁰, R. Mashinistov¹⁰⁸,
 J. Masik⁹⁸, A.L. Maslennikov^{120b,120a}, L.H. Mason¹⁰², L. Massa^{71a,71b}, P. Massarotti^{67a,67b},
 P. Mastrandrea⁵, A. Mastroberardino^{40b,40a}, T. Masubuchi¹⁶⁰, P. Mättig¹⁷⁹, J. Maurer^{27b}, B. Maček⁸⁹,
 S.J. Maxfield⁸⁸, D.A. Maximov^{120b,120a}, R. Mazini¹⁵⁵, I. Maznas¹⁵⁹, S.M. Mazza¹⁴³, N.C. Mc Fadden¹¹⁶,
 G. Mc Goldrick¹⁶⁴, S.P. Mc Kee¹⁰³, A. McCarn¹⁰³, T.G. McCarthy¹¹³, L.I. McClymont⁹², E.F. McDonald¹⁰²,
 J.A. Mcfayden³⁵, G. Mchedlidze⁵¹, M.A. McKay⁴¹, K.D. McLean¹⁷³, S.J. McMahon¹⁴¹, P.C. McNamara¹⁰²,
 C.J. McNicol¹⁷⁵, R.A. McPherson^{173,ac}, J.E. Mdhlluli^{32c}, Z.A. Meadows¹⁰⁰, S. Meehan¹⁴⁵, T.M. Megy⁵⁰,
 S. Mehlhase¹¹², A. Mehta⁸⁸, T. Meideck⁵⁶, B. Meirose⁴², D. Melini^{171,g}, B.R. Mellado Garcia^{32c},
 J.D. Mellenthin⁵¹, M. Melo^{28a}, F. Meloni⁴⁴, A. Melzer²⁴, S.B. Menary⁹⁸, E.D. Mendes Gouveia^{136a},
 L. Meng⁸⁸, X.T. Meng¹⁰³, A. Mengarelli^{23b,23a}, S. Menke¹¹³, E. Meoni^{40b,40a}, S. Mergelmeyer¹⁹,
 C. Merlassino²⁰, P. Mermod⁵², L. Merola^{67a,67b}, C. Meroni^{66a}, F.S. Merritt³⁶, A. Messina^{70a,70b},
 J. Metcalfe⁶, A.S. Mete¹⁶⁸, C. Meyer¹³³, J. Meyer¹⁵⁷, J-P. Meyer¹⁴², H. Meyer Zu Theenhausen^{59a},

F. Miano ¹⁵³, R.P. Middleton ¹⁴¹, L. Mijović ⁴⁸, G. Mikenberg ¹⁷⁷, M. Mikesikova ¹³⁷, M. Mikuž ⁸⁹, M. Milesi ¹⁰², A. Milic ¹⁶⁴, D.A. Millar ⁹⁰, D.W. Miller ³⁶, A. Milov ¹⁷⁷, D.A. Milstead ^{43a,43b}, A.A. Minaenko ¹⁴⁰, M. Miñano Moya ¹⁷¹, I.A. Minashvili ^{156b}, A.I. Mincer ¹²¹, B. Mindur ^{81a}, M. Mineev ⁷⁷, Y. Minegishi ¹⁶⁰, Y. Ming ¹⁷⁸, L.M. Mir ¹⁴, A. Mirto ^{65a,65b}, K.P. Mistry ¹³³, T. Mitani ¹⁷⁶, J. Mitrevski ¹¹², V.A. Mitsou ¹⁷¹, A. Miucci ²⁰, P.S. Miyagawa ¹⁴⁶, A. Mizukami ⁷⁹, J.U. Mjörnmark ⁹⁴, T. Mkrtchyan ¹⁸¹, M. Mlynarikova ¹³⁹, T. Moa ^{43a,43b}, K. Mochizuki ¹⁰⁷, P. Mogg ⁵⁰, S. Mohapatra ³⁸, S. Molander ^{43a,43b}, R. Moles-Valls ²⁴, M.C. Mondragon ¹⁰⁴, K. Mönig ⁴⁴, J. Monk ³⁹, E. Monnier ⁹⁹, A. Montalbano ¹⁴⁹, J. Montejo Berlingen ³⁵, F. Monticelli ⁸⁶, S. Monzani ^{66a}, N. Morange ¹²⁸, D. Moreno ²², M. Moreno Llácer ³⁵, P. Morettini ^{53b}, M. Morgenstern ¹¹⁸, S. Morgenstern ⁴⁶, D. Mori ¹⁴⁹, M. Morii ⁵⁷, M. Morinaga ¹⁷⁶, V. Morisbak ¹³⁰, A.K. Morley ³⁵, G. Mornacchi ³⁵, A.P. Morris ⁹², J.D. Morris ⁹⁰, L. Morvaj ¹⁵², P. Moschovakos ¹⁰, M. Mosidze ^{156b}, H.J. Moss ¹⁴⁶, J. Moss ^{150,m}, K. Motohashi ¹⁶², R. Mount ¹⁵⁰, E. Mountricha ³⁵, E.J.W. Moyse ¹⁰⁰, S. Muanza ⁹⁹, F. Mueller ¹¹³, J. Mueller ¹³⁵, R.S.P. Mueller ¹¹², D. Muenstermann ⁸⁷, G.A. Mullier ²⁰, F.J. Munoz Sanchez ⁹⁸, P. Murin ^{28b}, W.J. Murray ^{175,141}, A. Murrone ^{66a,66b}, M. Muškinja ⁸⁹, C. Mwewa ^{32a}, A.G. Myagkov ^{140,ak}, J. Myers ¹²⁷, M. Myska ¹³⁸, B.P. Nachman ¹⁸, O. Nackenhorst ⁴⁵, K. Nagai ¹³¹, K. Nagano ⁷⁹, Y. Nagasaka ⁶⁰, M. Nagel ⁵⁰, E. Nagy ⁹⁹, A.M. Nairz ³⁵, Y. Nakahama ¹¹⁵, K. Nakamura ⁷⁹, T. Nakamura ¹⁶⁰, I. Nakano ¹²³, H. Nanjo ¹²⁹, F. Napolitano ^{59a}, R.F. Naranjo Garcia ⁴⁴, R. Narayan ¹¹, D.I. Narrias Villar ^{59a}, I. Naryshkin ¹³⁴, T. Naumann ⁴⁴, G. Navarro ²², R. Nayyar ⁷, H.A. Neal ¹⁰³, P.Y. Nechaeva ¹⁰⁸, T.J. Neep ¹⁴², A. Negri ^{68a,68b}, M. Negrini ^{23b}, S. Nektarijevic ¹¹⁷, C. Nellist ⁵¹, M.E. Nelson ¹³¹, S. Nemecek ¹³⁷, P. Nemethy ¹²¹, M. Nessi ^{35,e}, M.S. Neubauer ¹⁷⁰, M. Neumann ¹⁷⁹, P.R. Newman ²¹, T.Y. Ng ^{61c}, Y.S. Ng ¹⁹, H.D.N. Nguyen ⁹⁹, T. Nguyen Manh ¹⁰⁷, E. Nibigira ³⁷, R.B. Nickerson ¹³¹, R. Nicolaidou ¹⁴², J. Nielsen ¹⁴³, N. Nikiforou ¹¹, V. Nikolaenko ^{140,ak}, I. Nikolic-Audit ¹³², K. Nikolopoulos ²¹, P. Nilsson ²⁹, Y. Ninomiya ⁷⁹, A. Nisati ^{70a}, N. Nishu ^{58c}, R. Nisius ¹¹³, I. Nitsche ⁴⁵, T. Nitta ¹⁷⁶, T. Nobe ¹⁶⁰, Y. Noguchi ⁸³, M. Nomachi ¹²⁹, I. Nomidis ¹³², M.A. Nomura ²⁹, T. Nooney ⁹⁰, M. Nordberg ³⁵, N. Norjoharuddeen ¹³¹, T. Novak ⁸⁹, O. Novgorodova ⁴⁶, R. Novotny ¹³⁸, L. Nozka ¹²⁶, K. Ntekas ¹⁶⁸, E. Nurse ⁹², F. Nuti ¹⁰², F.G. Oakham ^{33,ar}, H. Oberlack ¹¹³, T. Obermann ²⁴, J. Ocariz ¹³², A. Ochi ⁸⁰, I. Ochoa ³⁸, J.P. Ochoa-Ricoux ^{144a}, K. O'Connor ²⁶, S. Oda ⁸⁵, S. Odaka ⁷⁹, S. Oerdek ⁵¹, A. Oh ⁹⁸, S.H. Oh ⁴⁷, C.C. Ohm ¹⁵¹, H. Oide ^{53b,53a}, M.L. Ojeda ¹⁶⁴, H. Okawa ¹⁶⁶, Y. Okazaki ⁸³, Y. Okumura ¹⁶⁰, T. Okuyama ⁷⁹, A. Olariu ^{27b}, L.F. Oleiro Seabra ^{136a}, S.A. Olivares Pino ^{144a}, D. Oliveira Damazio ²⁹, J.L. Oliver ¹, M.J.R. Olsson ³⁶, A. Olszewski ⁸², J. Olszowska ⁸², D.C. O'Neil ¹⁴⁹, A. Onofre ^{136a,136e}, K. Onogi ¹¹⁵, P.U.E. Onyisi ¹¹, H. Oppen ¹³⁰, M.J. Oreglia ³⁶, G.E. Orellana ⁸⁶, Y. Oren ¹⁵⁸, D. Orestano ^{72a,72b}, E.C. Orgill ⁹⁸, N. Orlando ^{61b}, A.A. O'Rourke ⁴⁴, R.S. Orr ¹⁶⁴, B. Osculati ^{53b,53a,*}, V. O'Shea ⁵⁵, R. Ospanov ^{58a}, G. Otero y Garzon ³⁰, H. Otono ⁸⁵, M. Ouchrif ^{34d}, F. Ould-Saada ¹³⁰, A. Ouraou ¹⁴², Q. Ouyang ^{15a}, M. Owen ⁵⁵, R.E. Owen ²¹, V.E. Ozcan ^{12c}, N. Ozturk ⁸, J. Pacalt ¹²⁶, H.A. Pacey ³¹, K. Pachal ¹⁴⁹, A. Pacheco Pages ¹⁴, L. Pacheco Rodriguez ¹⁴², C. Padilla Aranda ¹⁴, S. Pagan Griso ¹⁸, M. Paganini ¹⁸⁰, G. Palacino ⁶³, S. Palazzo ^{40b,40a}, S. Palestini ³⁵, M. Palka ^{81b}, D. Pallin ³⁷, I. Panagoulas ¹⁰, C.E. Pandini ³⁵, J.G. Panduro Vazquez ⁹¹, P. Pani ³⁵, G. Panizzo ^{64a,64c}, L. Paolozzi ⁵², T.D. Papadopoulou ¹⁰, K. Papageorgiou ^{9,i}, A. Paramonov ⁶, D. Paredes Hernandez ^{61b}, S.R. Paredes Saenz ¹³¹, B. Parida ¹⁶³, A.J. Parker ⁸⁷, K.A. Parker ⁴⁴, M.A. Parker ³¹, F. Parodi ^{53b,53a}, J.A. Parsons ³⁸, U. Parzefall ⁵⁰, V.R. Pascuzzi ¹⁶⁴, J.M.P. Pasner ¹⁴³, E. Pasqualucci ^{70a}, S. Passaggio ^{53b}, F. Pastore ⁹¹, P. Pasuwan ^{43a,43b}, S. Patarai ⁹⁷, J.R. Pater ⁹⁸, A. Pathak ^{178,j}, T. Pauly ³⁵, B. Pearson ¹¹³, M. Pedersen ¹³⁰, L. Pedraza Diaz ¹¹⁷, R. Pedro ^{136a,136b}, S.V. Peleganchuk ^{120b,120a}, O. Penc ¹³⁷, C. Peng ^{15d}, H. Peng ^{58a}, B.S. Peralva ^{78a}, M.M. Perego ¹⁴², A.P. Pereira Peixoto ^{136a}, D.V. Perepelitsa ²⁹, F. Peri ¹⁹, L. Perini ^{66a,66b}, H. Pernegger ³⁵, S. Perrella ^{67a,67b}, V.D. Peshekhonov ^{77,*}, K. Peters ⁴⁴, R.F.Y. Peters ⁹⁸, B.A. Petersen ³⁵, T.C. Petersen ³⁹, E. Petit ⁵⁶, A. Petridis ¹, C. Petridou ¹⁵⁹, P. Petroff ¹²⁸, M. Petrov ¹³¹, F. Petrucci ^{72a,72b}, M. Pettee ¹⁸⁰, N.E. Pettersson ¹⁰⁰, A. Peyaud ¹⁴², R. Pezoa ^{144b}, T. Pham ¹⁰², F.H. Phillips ¹⁰⁴, P.W. Phillips ¹⁴¹, M.W. Phipps ¹⁷⁰, G. Piacquadio ¹⁵², E. Pianori ¹⁸, A. Picazio ¹⁰⁰, M.A. Pickering ¹³¹, R.H. Pickles ⁹⁸, R. Piegaia ³⁰, J.E. Pilcher ³⁶, A.D. Pilkington ⁹⁸, M. Pinamonti ^{71a,71b}, J.L. Pinfold ³, M. Pitt ¹⁷⁷, M-A. Pleier ²⁹, V. Pleskot ¹³⁹, E. Plotnikova ⁷⁷, D. Pluth ⁷⁶, P. Podberezko ^{120b,120a}, R. Poettgen ⁹⁴, R. Poggi ⁵², L. Poggioli ¹²⁸, I. Pogrebnyak ¹⁰⁴, D. Pohl ²⁴, I. Pokharel ⁵¹, G. Polesello ^{68a}, A. Poley ¹⁸, A. Policicchio ^{70a,70b}, R. Polifka ³⁵, A. Polini ^{23b}, C.S. Pollard ⁴⁴, V. Polychronakos ²⁹, D. Ponomarenko ¹¹⁰, L. Pontecorvo ^{70a}, G.A. Popeneciu ^{27d}, D.M. Portillo Quintero ¹³², S. Pospisil ¹³⁸, K. Potamianos ⁴⁴,

I.N. Potrap⁷⁷, C.J. Potter³¹, H. Potti¹¹, T. Poulsen⁹⁴, J. Poveda³⁵, T.D. Powell¹⁴⁶, M.E. Pozo Astigarraga³⁵, P. Pralavorio⁹⁹, S. Prell⁷⁶, D. Price⁹⁸, M. Primavera^{65a}, S. Prince¹⁰¹, N. Proklova¹¹⁰, K. Prokofiev^{61c}, F. Prokoshin^{144b}, S. Protopopescu²⁹, J. Proudfoot⁶, M. Przybycien^{81a}, A. Puri¹⁷⁰, P. Puzo¹²⁸, J. Qian¹⁰³, Y. Qin⁹⁸, A. Quadt⁵¹, M. Queitsch-Maitland⁴⁴, A. Qureshi¹, P. Rados¹⁰², F. Ragusa^{66a,66b}, G. Rahal⁹⁵, J.A. Raine⁵², S. Rajagopalan²⁹, A. Ramirez Morales⁹⁰, T. Rashid¹²⁸, S. Raspopov⁵, M.G. Ratti^{66a,66b}, D.M. Rauch⁴⁴, F. Rauscher¹¹², S. Rave⁹⁷, B. Ravina¹⁴⁶, I. Ravinovich¹⁷⁷, J.H. Rawling⁹⁸, M. Raymond³⁵, A.L. Read¹³⁰, N.P. Readioff⁵⁶, M. Reale^{65a,65b}, D.M. Rebuszi^{68a,68b}, A. Redelbach¹⁷⁴, G. Redlinger²⁹, R. Reece¹⁴³, R.G. Reed^{32c}, K. Reeves⁴², L. Rehnisch¹⁹, J. Reichert¹³³, D. Reikher¹⁵⁸, A. Reiss⁹⁷, C. Rembser³⁵, H. Ren^{15d}, M. Rescigno^{70a}, S. Resconi^{66a}, E.D. Resseguie¹³³, S. Rettie¹⁷², E. Reynolds²¹, O.L. Rezanova^{120b,120a}, P. Reznicek¹³⁹, E. Ricci^{73a,73b}, R. Richter¹¹³, S. Richter⁴⁴, E. Richter-Was^{81b}, O. Ricken²⁴, M. Ridel¹³², P. Rieck¹¹³, C.J. Riegel¹⁷⁹, O. Rifki⁴⁴, M. Rijssenbeek¹⁵², A. Rimoldi^{68a,68b}, M. Rimoldi²⁰, L. Rinaldi^{23b}, G. Ripellino¹⁵¹, B. Ristić⁸⁷, E. Ritsch³⁵, I. Riu¹⁴, J.C. Rivera Vergara^{144a}, F. Rizatdinova¹²⁵, E. Rizvi⁹⁰, C. Rizzi¹⁴, R.T. Roberts⁹⁸, S.H. Robertson^{101.ac}, D. Robinson³¹, J.E.M. Robinson⁴⁴, A. Robson⁵⁵, E. Rocco⁹⁷, C. Roda^{69a,69b}, Y. Rodina⁹⁹, S. Rodriguez Bosca¹⁷¹, A. Rodriguez Perez¹⁴, D. Rodriguez Rodriguez¹⁷¹, A.M. Rodríguez Vera^{165b}, S. Roe³⁵, C.S. Rogan⁵⁷, O. Røhne¹³⁰, R. Röhrig¹¹³, C.P.A. Roland⁶³, J. Roloff⁵⁷, A. Romaniouk¹¹⁰, M. Romano^{23b,23a}, N. Rompotis⁸⁸, M. Ronzani¹²¹, L. Roos¹³², S. Rosati^{70a}, K. Rosbach⁵⁰, P. Rose¹⁴³, N-A. Rosien⁵¹, B.J. Rosser¹³³, E. Rossi⁴⁴, E. Rossi^{72a,72b}, E. Rossi^{67a,67b}, L.P. Rossi^{53b}, L. Rossini^{66a,66b}, J.H.N. Rosten³¹, R. Rosten¹⁴, M. Rotaru^{27b}, J. Rothberg¹⁴⁵, D. Rousseau¹²⁸, D. Roy^{32c}, A. Rozanov⁹⁹, Y. Rozen¹⁵⁷, X. Ruan^{32c}, F. Rubbo¹⁵⁰, F. Rühr⁵⁰, A. Ruiz-Martinez¹⁷¹, Z. Rurikova⁵⁰, N.A. Rusakovich⁷⁷, H.L. Russell¹⁰¹, J.P. Rutherford⁷, E.M. Rüttinger^{44.k}, Y.F. Ryabov¹³⁴, M. Rybar¹⁷⁰, G. Rybkin¹²⁸, S. Ryu⁶, A. Ryzhov¹⁴⁰, G.F. Rzehorz⁵¹, P. Sabatini⁵¹, G. Sabato¹¹⁸, S. Sacerdoti¹²⁸, H.F-W. Sadrozinski¹⁴³, R. Sadykov⁷⁷, F. Safai Tehrani^{70a}, P. Saha¹¹⁹, M. Sahinsoy^{59a}, A. Sahu¹⁷⁹, M. Saimpert⁴⁴, M. Saito¹⁶⁰, T. Saito¹⁶⁰, H. Sakamoto¹⁶⁰, A. Sakharov^{121.aj}, D. Salamani⁵², G. Salamanna^{72a,72b}, J.E. Salazar Loyola^{144b}, D. Salek¹¹⁸, P.H. Sales De Bruin¹⁶⁹, D. Salihagic¹¹³, A. Salnikov¹⁵⁰, J. Salt¹⁷¹, D. Salvatore^{40b,40a}, F. Salvatore¹⁵³, A. Salvucci^{61a,61b,61c}, A. Salzburger³⁵, J. Samarati³⁵, D. Sammel⁵⁰, D. Sampsonidis¹⁵⁹, D. Sampsonidou¹⁵⁹, J. Sánchez¹⁷¹, A. Sanchez Pineda^{64a,64c}, H. Sandaker¹³⁰, C.O. Sander⁴⁴, M. Sandhoff¹⁷⁹, C. Sandoval²², D.P.C. Sankey¹⁴¹, M. Sannino^{53b,53a}, Y. Sano¹¹⁵, A. Sansoni⁴⁹, C. Santoni³⁷, H. Santos^{136a}, I. Santoyo Castillo¹⁵³, A. Santra¹⁷¹, A. Saprionov⁷⁷, J.G. Saraiva^{136a,136d}, O. Sasaki⁷⁹, K. Sato¹⁶⁶, E. Sauvan⁵, P. Savard^{164.ar}, N. Savic¹¹³, R. Sawada¹⁶⁰, C. Sawyer¹⁴¹, L. Sawyer^{93.ai}, C. Sbarra^{23b}, A. Sbrizzi^{23b,23a}, T. Scanlon⁹², J. Schaarschmidt¹⁴⁵, P. Schacht¹¹³, B.M. Schachtner¹¹², D. Schaefer³⁶, L. Schaefer¹³³, J. Schaeffer⁹⁷, S. Schaepe³⁵, U. Schäfer⁹⁷, A.C. Schaffer¹²⁸, D. Schaile¹¹², R.D. Schamberger¹⁵², N. Scharmberg⁹⁸, V.A. Schegelsky¹³⁴, D. Scheirich¹³⁹, F. Schenck¹⁹, M. Schernau¹⁶⁸, C. Schiavi^{53b,53a}, S. Schier¹⁴³, L.K. Schildgen²⁴, Z.M. Schillaci²⁶, E.J. Schioppa³⁵, M. Schioppa^{40b,40a}, K.E. Schleicher⁵⁰, S. Schlenker³⁵, K.R. Schmidt-Sommerfeld¹¹³, K. Schmieden³⁵, C. Schmitt⁹⁷, S. Schmitt⁴⁴, S. Schmitz⁹⁷, J.C. Schmoeckel⁴⁴, U. Schnoor⁵⁰, L. Schoeffel¹⁴², A. Schoening^{59b}, E. Schopf¹³¹, M. Schott⁹⁷, J.F.P. Schouwenberg¹¹⁷, J. Schovancova³⁵, S. Schramm⁵², A. Schulte⁹⁷, H-C. Schultz-Coulon^{59a}, M. Schumacher⁵⁰, B.A. Schumm¹⁴³, Ph. Schune¹⁴², A. Schwartzman¹⁵⁰, T.A. Schwarz¹⁰³, Ph. Schwemling¹⁴², R. Schwiendorst¹⁰⁴, A. Sciandra²⁴, G. Sciolla²⁶, M. Scornajenghi^{40b,40a}, F. Scuri^{69a}, F. Scutti¹⁰², L.M. Scyboz¹¹³, J. Searcy¹⁰³, C.D. Sebastiani^{70a,70b}, P. Seema¹⁹, S.C. Seidel¹¹⁶, A. Seiden¹⁴³, T. Seiss³⁶, J.M. Seixas^{78b}, G. Sekhniaidze^{67a}, K. Sekhon¹⁰³, S.J. Sekula⁴¹, N. Semprini-Cesari^{23b,23a}, S. Sen⁴⁷, S. Senkin³⁷, C. Serfon¹³⁰, L. Serin¹²⁸, L. Serkin^{64a,64b}, M. Sessa^{58a}, H. Severini¹²⁴, F. Sforza¹⁶⁷, A. Sfyrly⁵², E. Shabalina⁵¹, J.D. Shahinian¹⁴³, N.W. Shaikh^{43a,43b}, L.Y. Shan^{15a}, R. Shang¹⁷⁰, J.T. Shank²⁵, M. Shapiro¹⁸, A.S. Sharma¹, A. Sharma¹³¹, P.B. Shatalov¹⁰⁹, K. Shaw¹⁵³, S.M. Shaw⁹⁸, A. Shcherbakova¹³⁴, Y. Shen¹²⁴, N. Sherafati³³, A.D. Sherman²⁵, P. Sherwood⁹², L. Shi^{155.an}, S. Shimizu⁷⁹, C.O. Shimmin¹⁸⁰, M. Shimojima¹¹⁴, I.P.J. Shipsey¹³¹, S. Shirabe⁸⁵, M. Shiyakova⁷⁷, J. Shlomi¹⁷⁷, A. Shmeleva¹⁰⁸, D. Shoaleh Saadi¹⁰⁷, M.J. Shochet³⁶, S. Shojaii¹⁰², D.R. Shope¹²⁴, S. Shrestha¹²², E. Shulga¹¹⁰, P. Sicho¹³⁷, A.M. Sickles¹⁷⁰, P.E. Sidebo¹⁵¹, E. Sideras Haddad^{32c}, O. Sidiropoulou³⁵, A. Sidoti^{23b,23a}, F. Siegert⁴⁶, Dj. Sijacki¹⁶, J. Silva^{136a}, M. Silva Jr.¹⁷⁸, M.V. Silva Oliveira^{78a}, S.B. Silverstein^{43a}, L. Simic⁷⁷, S. Simion¹²⁸, E. Simioni⁹⁷, M. Simon⁹⁷, R. Simoniello⁹⁷, P. Sinervo¹⁶⁴, N.B. Sinev¹²⁷, M. Sioli^{23b,23a}, G. Siragusa¹⁷⁴, I. Siral¹⁰³,

S.Yu. Sivoklokov ¹¹¹, J. Sjölin ^{43a,43b}, P. Skubic ¹²⁴, M. Slater ²¹, T. Slavicek ¹³⁸, M. Slawinska ⁸², K. Sliwa ¹⁶⁷, R. Slovak ¹³⁹, V. Smakhtin ¹⁷⁷, B.H. Smart ⁵, J. Smiesko ^{28a}, N. Smirnov ¹¹⁰, S.Yu. Smirnov ¹¹⁰, Y. Smirnov ¹¹⁰, L.N. Smirnova ¹¹¹, O. Smirnova ⁹⁴, J.W. Smith ⁵¹, M.N.K. Smith ³⁸, M. Smizanska ⁸⁷, K. Smolek ¹³⁸, A. Smykiewicz ⁸², A.A. Snesarev ¹⁰⁸, I.M. Snyder ¹²⁷, S. Snyder ²⁹, R. Sobie ^{173.ac}, A.M. Soffa ¹⁶⁸, A. Soffer ¹⁵⁸, A. Søgaard ⁴⁸, D.A. Soh ¹⁵⁵, G. Sokhrannyi ⁸⁹, C.A. Solans Sanchez ³⁵, M. Solar ¹³⁸, E.Yu. Soldatov ¹¹⁰, U. Soldevila ¹⁷¹, A.A. Solodkov ¹⁴⁰, A. Soloshenko ⁷⁷, O.V. Solovyanov ¹⁴⁰, V. Solovyev ¹³⁴, P. Sommer ¹⁴⁶, H. Son ¹⁶⁷, W. Song ¹⁴¹, W.Y. Song ^{165b}, A. Sopczak ¹³⁸, F. Sopkova ^{28b}, C.L. Sotiropoulou ^{69a,69b}, S. Sottocornola ^{68a,68b}, R. Soualah ^{64a,64c,h}, A.M. Soukharev ^{120b,120a}, D. South ⁴⁴, B.C. Sowden ⁹¹, S. Spagnolo ^{65a,65b}, M. Spalla ¹¹³, M. Spangenberg ¹⁷⁵, F. Spanò ⁹¹, D. Sperlich ¹⁹, F. Spettel ¹¹³, T.M. Spieker ^{59a}, R. Spighi ^{23b}, G. Spigo ³⁵, L.A. Spiller ¹⁰², D.P. Spiteri ⁵⁵, M. Spousta ¹³⁹, A. Stabile ^{66a,66b}, R. Stamen ^{59a}, S. Stamm ¹⁹, E. Stanecka ⁸², R.W. Stanek ⁶, C. Stanescu ^{72a}, B. Stanislaus ¹³¹, M.M. Stanitzki ⁴⁴, B. Stapf ¹¹⁸, S. Stapnes ¹³⁰, E.A. Starchenko ¹⁴⁰, G.H. Stark ³⁶, J. Stark ⁵⁶, S.H. Stark ³⁹, P. Staroba ¹³⁷, P. Starovoitov ^{59a}, S. Stärz ³⁵, R. Staszewski ⁸², M. Stegler ⁴⁴, P. Steinberg ²⁹, B. Stelzer ¹⁴⁹, H.J. Stelzer ³⁵, O. Stelzer-Chilton ^{165a}, H. Stenzel ⁵⁴, T.J. Stevenson ⁹⁰, G.A. Stewart ⁵⁵, M.C. Stockton ¹²⁷, G. Stoicea ^{27b}, P. Stolte ⁵¹, S. Stonjek ¹¹³, A. Straessner ⁴⁶, J. Strandberg ¹⁵¹, S. Strandberg ^{43a,43b}, M. Strauss ¹²⁴, P. Strizenec ^{28b}, R. Ströhmer ¹⁷⁴, D.M. Strom ¹²⁷, R. Stroynowski ⁴¹, A. Strubig ⁴⁸, S.A. Stucci ²⁹, B. Stugu ¹⁷, J. Stupak ¹²⁴, N.A. Styles ⁴⁴, D. Su ¹⁵⁰, J. Su ¹³⁵, S. Suchek ^{59a}, Y. Sugaya ¹²⁹, M. Suk ¹³⁸, V.V. Sulin ¹⁰⁸, M.J. Sullivan ⁸⁸, D.M.S. Sultan ⁵², S. Sultansoy ^{4c}, T. Sumida ⁸³, S. Sun ¹⁰³, X. Sun ³, K. Suruliz ¹⁵³, C.J.E. Suster ¹⁵⁴, M.R. Sutton ¹⁵³, S. Suzuki ⁷⁹, M. Svatos ¹³⁷, M. Swiatlowski ³⁶, S.P. Swift ², A. Sydorenko ⁹⁷, I. Sykora ^{28a}, T. Sykora ¹³⁹, D. Ta ⁹⁷, K. Tackmann ^{44,z}, J. Taenzer ¹⁵⁸, A. Taffard ¹⁶⁸, R. Tafiout ^{165a}, E. Tahirovic ⁹⁰, N. Taiblum ¹⁵⁸, H. Takai ²⁹, R. Takashima ⁸⁴, E.H. Takasugi ¹¹³, K. Takeda ⁸⁰, T. Takeshita ¹⁴⁷, Y. Takubo ⁷⁹, M. Talby ⁹⁹, A.A. Talyshev ^{120b,120a}, J. Tanaka ¹⁶⁰, M. Tanaka ¹⁶², R. Tanaka ¹²⁸, B.B. Tannenwald ¹²², S. Tapia Araya ^{144b}, S. Tapprogge ⁹⁷, A. Tarek Abouelfadl Mohamed ¹³², S. Tarem ¹⁵⁷, G. Tarna ^{27b,d}, G.F. Tartarelli ^{66a}, P. Tas ¹³⁹, M. Tasevsky ¹³⁷, T. Tashiro ⁸³, E. Tassi ^{40b,40a}, A. Tavares Delgado ^{136a,136b}, Y. Tayalati ^{34e}, A.C. Taylor ¹¹⁶, A.J. Taylor ⁴⁸, G.N. Taylor ¹⁰², P.T.E. Taylor ¹⁰², W. Taylor ^{165b}, A.S. Tee ⁸⁷, P. Teixeira-Dias ⁹¹, H. Ten Kate ³⁵, P.K. Teng ¹⁵⁵, J.J. Teoh ¹¹⁸, S. Terada ⁷⁹, K. Terashi ¹⁶⁰, J. Terron ⁹⁶, S. Terzo ¹⁴, M. Testa ⁴⁹, R.J. Teuscher ^{164.ac}, S.J. Thais ¹⁸⁰, T. Theveneaux-Pelzer ⁴⁴, F. Thiele ³⁹, D.W. Thomas ⁹¹, J.P. Thomas ²¹, A.S. Thompson ⁵⁵, P.D. Thompson ²¹, L.A. Thomsen ¹⁸⁰, E. Thomson ¹³³, Y. Tian ³⁸, R.E. Ticse Torres ⁵¹, V.O. Tikhomirov ^{108.al}, Yu.A. Tikhonov ^{120b,120a}, S. Timoshenko ¹¹⁰, P. Tipton ¹⁸⁰, S. Tisserant ⁹⁹, K. Todome ¹⁶², S. Todorova-Nova ⁵, S. Todt ⁴⁶, J. Tojo ⁸⁵, S. Tokár ^{28a}, K. Tokushuku ⁷⁹, E. Tolley ¹²², K.G. Tomiwa ^{32c}, M. Tomoto ¹¹⁵, L. Tompkins ^{150.p}, K. Toms ¹¹⁶, B. Tong ⁵⁷, P. Tornambe ⁵⁰, E. Torrence ¹²⁷, H. Torres ⁴⁶, E. Torró Pastor ¹⁴⁵, C. Tosciri ¹³¹, J. Toth ^{99.ab}, F. Touchard ⁹⁹, D.R. Tovey ¹⁴⁶, C.J. Treado ¹²¹, T. Trefzger ¹⁷⁴, F. Tresoldi ¹⁵³, A. Tricoli ²⁹, I.M. Trigger ^{165a}, S. Trincaz-Duvoid ¹³², M.F. Tripiana ¹⁴, W. Trischuk ¹⁶⁴, B. Trocmé ⁵⁶, A. Trofymov ¹²⁸, C. Troncon ^{66a}, M. Trovatelli ¹⁷³, F. Trovato ¹⁵³, L. Truong ^{32b}, M. Trzebinski ⁸², A. Trzupek ⁸², F. Tsai ⁴⁴, M. Tsai ⁶², J.C.-L. Tseng ¹³¹, P.V. Tsiareshka ¹⁰⁵, A. Tsirigotis ¹⁵⁹, N. Tsirintanis ⁹, V. Tsiskaridze ¹⁵², E.G. Tskhadadze ^{156a}, I.I. Tsukerman ¹⁰⁹, V. Tsulaia ¹⁸, S. Tsuno ⁷⁹, D. Tsybychev ^{152,163}, Y. Tu ^{61b}, A. Tudorache ^{27b}, V. Tudorache ^{27b}, T.T. Tulbure ^{27a}, A.N. Tuna ⁵⁷, S. Turchikhin ⁷⁷, D. Turgeman ¹⁷⁷, I. Turk Cakir ^{4b.t}, R. Turra ^{66a}, P.M. Tuts ³⁸, E. Tzovara ⁹⁷, G. Uccielli ^{23b,23a}, I. Ueda ⁷⁹, M. Ughetto ^{43a,43b}, F. Ukegawa ¹⁶⁶, G. Unal ³⁵, A. Undrus ²⁹, G. Unel ¹⁶⁸, F.C. Ungaro ¹⁰², Y. Unno ⁷⁹, K. Uno ¹⁶⁰, J. Urban ^{28b}, P. Urquijo ¹⁰², P. Urrejola ⁹⁷, G. Usai ⁸, J. Usui ⁷⁹, L. Vacavant ⁹⁹, V. Vacek ¹³⁸, B. Vachon ¹⁰¹, K.O.H. Vadla ¹³⁰, A. Vaidya ⁹², C. Valderanis ¹¹², E. Valdes Santurio ^{43a,43b}, M. Valente ⁵², S. Valentinetti ^{23b,23a}, A. Valero ¹⁷¹, L. Valéry ⁴⁴, R.A. Vallance ²¹, A. Vallier ⁵, J.A. Valls Ferrer ¹⁷¹, T.R. Van Daalen ¹⁴, H. Van der Graaf ¹¹⁸, P. Van Gemmeren ⁶, J. Van Nieuwkoop ¹⁴⁹, I. Van Vulpen ¹¹⁸, M. Vanadia ^{71a,71b}, W. Vandelli ³⁵, A. Vaniachine ¹⁶³, P. Vankov ¹¹⁸, R. Vari ^{70a}, E.W. Varnes ⁷, C. Varni ^{53b,53a}, T. Varol ⁴¹, D. Varouchas ¹²⁸, K.E. Varvell ¹⁵⁴, G.A. Vasquez ^{144b}, J.G. Vasquez ¹⁸⁰, F. Vazeille ³⁷, D. Vazquez Furelos ¹⁴, T. Vazquez Schroeder ¹⁰¹, J. Veatch ⁵¹, V. Vecchio ^{72a,72b}, L.M. Veloce ¹⁶⁴, F. Veloso ^{136a,136c}, S. Veneziano ^{70a}, A. Ventura ^{65a,65b}, M. Venturi ¹⁷³, N. Venturi ³⁵, V. Vercesi ^{68a}, M. Verducci ^{72a,72b}, C.M. Vergel Infante ⁷⁶, C. Vergis ²⁴, W. Verkerke ¹¹⁸, A.T. Vermeulen ¹¹⁸, J.C. Vermeulen ¹¹⁸, M.C. Vetterli ^{149.ar}, N. Viaux Maira ^{144b}, M. Vicente Barreto Pinto ⁵², I. Vichou ^{170,*}, T. Vickey ¹⁴⁶, O.E. Vickey Boeriu ¹⁴⁶, G.H.A. Viehhauser ¹³¹, S. Viel ¹⁸, L. Viganì ¹³¹, M. Villa ^{23b,23a}, M. Villaplana Perez ^{66a,66b}, E. Vilucchi ⁴⁹, M.G. Vincter ³³,

V.B. Vinogradov⁷⁷, A. Vishwakarma⁴⁴, C. Vittori^{23b,23a}, I. Vivarelli¹⁵³, S. Vlachos¹⁰, M. Vogel¹⁷⁹, P. Vokac¹³⁸, G. Volpi¹⁴, S.E. von Buddenbrock^{32c}, E. Von Toerne²⁴, V. Vorobel¹³⁹, K. Vorobev¹¹⁰, M. Vos¹⁷¹, J.H. Vosseveld⁸⁸, N. Vranjes¹⁶, M. Vranjes Milosavljevic¹⁶, V. Vrba¹³⁸, M. Vreeswijk¹¹⁸, T. Šfiligoj⁸⁹, R. Vuillermet³⁵, I. Vukotic³⁶, T. Ženiš^{28a}, L. Živković¹⁶, P. Wagner²⁴, W. Wagner¹⁷⁹, J. Wagner-Kuhr¹¹², H. Wahlberg⁸⁶, S. Wahrenmund⁴⁶, K. Wakamiya⁸⁰, V.M. Walbrecht¹¹³, J. Walder⁸⁷, R. Walker¹¹², S.D. Walker⁹¹, W. Walkowiak¹⁴⁸, V. Wallangen^{43a,43b}, A.M. Wang⁵⁷, C. Wang^{58b,d}, F. Wang¹⁷⁸, H. Wang¹⁸, H. Wang³, J. Wang¹⁵⁴, J. Wang^{59b}, P. Wang⁴¹, Q. Wang¹²⁴, R.-J. Wang¹³², R. Wang^{58a}, R. Wang⁶, S.M. Wang¹⁵⁵, W.T. Wang^{58a}, W. Wang^{15c,ad}, W.X. Wang^{58a,ad}, Y. Wang^{58a}, Z. Wang^{58c}, C. Wanotayaroj⁴⁴, A. Warburton¹⁰¹, C.P. Ward³¹, D.R. Wardrope⁹², A. Washbrook⁴⁸, P.M. Watkins²¹, A.T. Watson²¹, M.F. Watson²¹, G. Watts¹⁴⁵, S. Watts⁹⁸, B.M. Waugh⁹², A.F. Webb¹¹, S. Webb⁹⁷, C. Weber¹⁸⁰, M.S. Weber²⁰, S.A. Weber³³, S.M. Weber^{59a}, A.R. Weidberg¹³¹, B. Weinert⁶³, J. Weingarten⁵¹, M. Weirich⁹⁷, C. Weiser⁵⁰, P.S. Wells³⁵, T. Wenaus²⁹, T. Wengler³⁵, S. Wenig³⁵, N. Wermes²⁴, M.D. Werner⁷⁶, P. Werner³⁵, M. Wessels^{59a}, T.D. Weston²⁰, K. Whalen¹²⁷, N.L. Whallon¹⁴⁵, A.M. Wharton⁸⁷, A.S. White¹⁰³, A. White⁸, M.J. White¹, R. White^{144b}, D. Whiteson¹⁶⁸, B.W. Whitmore⁸⁷, F.J. Wickens¹⁴¹, W. Wiedenmann¹⁷⁸, M. Wielers¹⁴¹, C. Wiglesworth³⁹, L.A.M. Wiik-Fuchs⁵⁰, F. Wilk⁹⁸, H.G. Wilkens³⁵, L.J. Wilkins⁹¹, H.H. Williams¹³³, S. Williams³¹, C. Willis¹⁰⁴, S. Willocq¹⁰⁰, J.A. Wilson²¹, I. Wingerter-Seez⁵, E. Winkels¹⁵³, F. Winklmeier¹²⁷, O.J. Winston¹⁵³, B.T. Winter²⁴, M. Wittgen¹⁵⁰, M. Wobisch⁹³, A. Wolf⁹⁷, T.M.H. Wolf¹¹⁸, R. Wolff⁹⁹, M.W. Wolter⁸², H. Wolters^{136a,136c}, V.W.S. Wong¹⁷², N.L. Woods¹⁴³, S.D. Worm²¹, B.K. Wosiek⁸², K.W. Woźniak⁸², K. Wraight⁵⁵, M. Wu³⁶, S.L. Wu¹⁷⁸, X. Wu⁵², Y. Wu^{58a}, T.R. Wyatt⁹⁸, B.M. Wynne⁴⁸, S. Xella³⁹, Z. Xi¹⁰³, L. Xia¹⁷⁵, D. Xu^{15a}, H. Xu^{58a}, L. Xu²⁹, T. Xu¹⁴², W. Xu¹⁰³, B. Yabsley¹⁵⁴, S. Yacoob^{32a}, K. Yajima¹²⁹, D.P. Yallup⁹², D. Yamaguchi¹⁶², Y. Yamaguchi¹⁶², A. Yamamoto⁷⁹, T. Yamanaka¹⁶⁰, F. Yamane⁸⁰, M. Yamatani¹⁶⁰, T. Yamazaki¹⁶⁰, Y. Yamazaki⁸⁰, Z. Yan²⁵, H.J. Yang^{58c,58d}, H.T. Yang¹⁸, S. Yang⁷⁵, Y. Yang¹⁶⁰, Z. Yang¹⁷, W.-M. Yao¹⁸, Y.C. Yap⁴⁴, Y. Yasu⁷⁹, E. Yatsenko^{58c,58d}, J. Ye⁴¹, S. Ye²⁹, I. Yeletsikh⁷⁷, E. Yigitbasi²⁵, E. Yildirim⁹⁷, K. Yorita¹⁷⁶, K. Yoshihara¹³³, C.J.S. Young³⁵, C. Young¹⁵⁰, J. Yu⁸, J. Yu⁷⁶, X. Yue^{59a}, S.P.Y. Yuen²⁴, B. Zabinski⁸², G. Zacharis¹⁰, E. Zaffaroni⁵², R. Zaidan¹⁴, A.M. Zaitsev^{140,ak}, T. Zakareishvili^{156b}, N. Zakharchuk³³, J. Zalieckas¹⁷, S. Zambito⁵⁷, D. Zanzi³⁵, D.R. Zariповas⁵⁵, S.V. Zeiřner⁴⁵, C. Zeitnitz¹⁷⁹, G. Zemaityte¹³¹, J.C. Zeng¹⁷⁰, Q. Zeng¹⁵⁰, O. Zenin¹⁴⁰, D. Zerwas¹²⁸, M. Zgubić¹³¹, D.F. Zhang^{58b}, D. Zhang¹⁰³, F. Zhang¹⁷⁸, G. Zhang^{58a}, H. Zhang^{15c}, J. Zhang⁶, L. Zhang^{15c}, L. Zhang^{58a}, M. Zhang¹⁷⁰, P. Zhang^{15c}, R. Zhang^{58a}, R. Zhang²⁴, X. Zhang^{58b}, Y. Zhang^{15d}, Z. Zhang¹²⁸, X. Zhao⁴¹, Y. Zhao^{58b,128,ah}, Z. Zhao^{58a}, A. Zhemchugov⁷⁷, Z. Zheng¹⁰³, D. Zhong¹⁷⁰, B. Zhou¹⁰³, C. Zhou¹⁷⁸, L. Zhou⁴¹, M.S. Zhou^{15d}, M. Zhou¹⁵², N. Zhou^{58c}, Y. Zhou⁷, C.G. Zhu^{58b}, H.L. Zhu^{58a}, H. Zhu^{15a}, J. Zhu¹⁰³, Y. Zhu^{58a}, X. Zhuang^{15a}, K. Zhukov¹⁰⁸, V. Zhulanov^{120b,120a}, A. Zibell¹⁷⁴, D. Zieminska⁶³, N.I. Zimine⁷⁷, S. Zimmermann⁵⁰, Z. Zinonos¹¹³, M. Zinser⁹⁷, M. Ziolkowski¹⁴⁸, G. Zobernig¹⁷⁸, A. Zoccoli^{23b,23a}, K. Zoch⁵¹, T.G. Zorbas¹⁴⁶, R. Zou³⁶, M. Zur Nedden¹⁹, L. Zwalinski³⁵

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

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

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

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

⁵ LAPP, Université Grenoble Alpes, Université Savoie Mont Blanc, CNRS/IN2P3, Annecy, France

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

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

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

⁹ Physics Department, National and Kapodistrian University of Athens, Athens, Greece

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

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

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

¹³ Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan

¹⁴ Institut de Física d'Altes Energies (IFAE), Barcelona Institute of Science and Technology, Barcelona, Spain

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

(d) University of Chinese Academy of Science (UCAS), Beijing, China

¹⁶ Institute of Physics, University of Belgrade, Belgrade, Serbia

¹⁷ Department for Physics and Technology, University of Bergen, Bergen, Norway

¹⁸ Physics Division, Lawrence Berkeley National Laboratory and University of California, Berkeley CA, United States of America

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

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

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

²² Centro de Investigaciones, Universidad Antonio Nariño, Bogota, Colombia

- 23 ^(a) Dipartimento di Fisica e Astronomia, Università di Bologna, Bologna; ^(b) INFN Sezione di Bologna, Italy
- 24 Physikalisches Institut, Universität Bonn, Bonn, Germany
- 25 Department of Physics, Boston University, Boston MA, United States of America
- 26 Department of Physics, Brandeis University, Waltham MA, United States of America
- 27 ^(a) Transilvania University of Brasov, Brasov; ^(b) Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest; ^(c) Department of Physics, Alexandru Ioan Cuza University of Iasi, Iasi; ^(d) National Institute for Research and Development of Isotopic and Molecular Technologies, Physics Department, Cluj-Napoca; ^(e) University Politehnica Bucharest, Bucharest; ^(f) West University in Timisoara, Timisoara, Romania
- 28 ^(a) Faculty of Mathematics, Physics and Informatics, Comenius University, Bratislava; ^(b) Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice, Slovak Republic
- 29 Physics Department, Brookhaven National Laboratory, Upton NY, United States of America
- 30 Departamento de Física, Universidad de Buenos Aires, Buenos Aires, Argentina
- 31 Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom
- 32 ^(a) Department of Physics, University of Cape Town, Cape Town; ^(b) Department of Mechanical Engineering Science, University of Johannesburg, Johannesburg; ^(c) School of Physics, University of the Witwatersrand, Johannesburg, South Africa
- 33 Department of Physics, Carleton University, Ottawa ON, Canada
- 34 ^(a) Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies – Université Hassan II, Casablanca; ^(b) Centre National de l’Energie des Sciences Techniques Nucleaires (CNSTEN), Rabat; ^(c) Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA-Marrakech; ^(d) Faculté des Sciences, Université Mohamed Premier and LPTPM, Oujda; ^(e) Faculté des sciences, Université Mohammed V, Rabat, Morocco
- 35 CERN, Geneva, Switzerland
- 36 Enrico Fermi Institute, University of Chicago, Chicago IL, United States of America
- 37 LPC, Université Clermont Auvergne, CNRS/IN2P3, Clermont-Ferrand, France
- 38 Nevis Laboratory, Columbia University, Irvington NY, United States of America
- 39 Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark
- 40 ^(a) Dipartimento di Fisica, Università della Calabria, Rende; ^(b) INFN Gruppo Collegato di Cosenza, Laboratori Nazionali di Frascati, Italy
- 41 Physics Department, Southern Methodist University, Dallas TX, United States of America
- 42 Physics Department, University of Texas at Dallas, Richardson TX, United States of America
- 43 ^(a) Department of Physics, Stockholm University; ^(b) Oskar Klein Centre, Stockholm, Sweden
- 44 Deutsches Elektronen-Synchrotron DESY, Hamburg and Zeuthen, Germany
- 45 Lehrstuhl für Experimentelle Physik IV, Technische Universität Dortmund, Dortmund, Germany
- 46 Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden, Germany
- 47 Department of Physics, Duke University, Durham NC, United States of America
- 48 SUPA – School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom
- 49 INFN e Laboratori Nazionali di Frascati, Frascati, Italy
- 50 Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany
- 51 II. Physikalisches Institut, Georg-August-Universität Göttingen, Göttingen, Germany
- 52 Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève, Switzerland
- 53 ^(a) Dipartimento di Fisica, Università di Genova, Genova; ^(b) INFN Sezione di Genova, Italy
- 54 II. Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen, Germany
- 55 SUPA – School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom
- 56 LPSC, Université Grenoble Alpes, CNRS/IN2P3, Grenoble INP, Grenoble, France
- 57 Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge MA, United States of America
- 58 ^(a) Department of Modern Physics and State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei; ^(b) Institute of Frontier and Interdisciplinary Science and Key Laboratory of Particle Physics and Particle Irradiation (MOE), Shandong University, Qingdao; ^(c) School of Physics and Astronomy, Shanghai Jiao Tong University, KLPPAC-MoE, SKLPPC, Shanghai; ^(d) Tsung-Dao Lee Institute, Shanghai, China
- 59 ^(a) Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg; ^(b) Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany
- 60 Faculty of Applied Information Science, Hiroshima Institute of Technology, Hiroshima, Japan
- 61 ^(a) Department of Physics, Chinese University of Hong Kong, Shatin, N.T., Hong Kong; ^(b) Department of Physics, University of Hong Kong, Hong Kong; ^(c) Department of Physics and Institute for Advanced Study, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China
- 62 Department of Physics, National Tsing Hua University, Hsinchu, Taiwan
- 63 Department of Physics, Indiana University, Bloomington IN, United States of America
- 64 ^(a) INFN Gruppo Collegato di Udine, Sezione di Trieste, Udine; ^(b) ICTP, Trieste; ^(c) Dipartimento di Chimica, Fisica e Ambiente, Università di Udine, Udine, Italy
- 65 ^(a) INFN Sezione di Lecce; ^(b) Dipartimento di Matematica e Fisica, Università del Salento, Lecce, Italy
- 66 ^(a) INFN Sezione di Milano; ^(b) Dipartimento di Fisica, Università di Milano, Milano, Italy
- 67 ^(a) INFN Sezione di Napoli; ^(b) Dipartimento di Fisica, Università di Napoli, Napoli, Italy
- 68 ^(a) INFN Sezione di Pavia; ^(b) Dipartimento di Fisica, Università di Pavia, Pavia, Italy
- 69 ^(a) INFN Sezione di Pisa; ^(b) Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy
- 70 ^(a) INFN Sezione di Roma; ^(b) Dipartimento di Fisica, Sapienza Università di Roma, Roma, Italy
- 71 ^(a) INFN Sezione di Roma Tor Vergata; ^(b) Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy
- 72 ^(a) INFN Sezione di Roma Tre; ^(b) Dipartimento di Matematica e Fisica, Università Roma Tre, Roma, Italy
- 73 ^(a) INFN-TIFPA; ^(b) Università degli Studi di Trento, Trento, Italy
- 74 Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck, Austria
- 75 University of Iowa, Iowa City IA, United States of America
- 76 Department of Physics and Astronomy, Iowa State University, Ames IA, United States of America
- 77 Joint Institute for Nuclear Research, Dubna, Russia
- 78 ^(a) Departamento de Engenharia Elétrica, Universidade Federal de Juiz de Fora (UFJF), Juiz de Fora; ^(b) Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro; ^(c) Universidade Federal de São João del Rei (UFSJ), São João del Rei; ^(d) Instituto de Física, Universidade de São Paulo, São Paulo, Brazil
- 79 KEK, High Energy Accelerator Research Organization, Tsukuba, Japan
- 80 Graduate School of Science, Kobe University, Kobe, Japan
- 81 ^(a) AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, Krakow; ^(b) Marian Smoluchowski Institute of Physics, Jagiellonian University, Krakow, Poland
- 82 Institute of Nuclear Physics Polish Academy of Sciences, Krakow, Poland
- 83 Faculty of Science, Kyoto University, Kyoto, Japan
- 84 Kyoto University of Education, Kyoto, Japan
- 85 Research Center for Advanced Particle Physics and Department of Physics, Kyushu University, Fukuoka, Japan
- 86 Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina
- 87 Physics Department, Lancaster University, Lancaster, United Kingdom
- 88 Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom
- 89 Department of Experimental Particle Physics, Jožef Stefan Institute and Department of Physics, University of Ljubljana, Ljubljana, Slovenia
- 90 School of Physics and Astronomy, Queen Mary University of London, London, United Kingdom

- ⁹¹ Department of Physics, Royal Holloway University of London, Egham, United Kingdom
- ⁹² Department of Physics and Astronomy, University College London, London, United Kingdom
- ⁹³ Louisiana Tech University, Ruston LA, United States of America
- ⁹⁴ Fysiska institutionen, Lunds universitet, Lund, Sweden
- ⁹⁵ Centre de Calcul de l'Institut National de Physique Nucléaire et de Physique des Particules (IN2P3), Villeurbanne, France
- ⁹⁶ Departamento de Física Teórica C-15 and CIAFF, Universidad Autónoma de Madrid, Madrid, Spain
- ⁹⁷ Institut für Physik, Universität Mainz, Mainz, Germany
- ⁹⁸ School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom
- ⁹⁹ CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille, France
- ¹⁰⁰ Department of Physics, University of Massachusetts, Amherst MA, United States of America
- ¹⁰¹ Department of Physics, McGill University, Montreal QC, Canada
- ¹⁰² School of Physics, University of Melbourne, Victoria, Australia
- ¹⁰³ Department of Physics, University of Michigan, Ann Arbor MI, United States of America
- ¹⁰⁴ Department of Physics and Astronomy, Michigan State University, East Lansing MI, United States of America
- ¹⁰⁵ B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Belarus
- ¹⁰⁶ Research Institute for Nuclear Problems of Byelorussian State University, Minsk, Belarus
- ¹⁰⁷ Group of Particle Physics, University of Montreal, Montreal QC, Canada
- ¹⁰⁸ P.N. Lebedev Physical Institute of the Russian Academy of Sciences, Moscow, Russia
- ¹⁰⁹ Institute for Theoretical and Experimental Physics (ITEP), Moscow, Russia
- ¹¹⁰ National Research Nuclear University MEPhI, Moscow, Russia
- ¹¹¹ D.V. Skobel'syn Institute of Nuclear Physics, M.V. Lomonosov Moscow State University, Moscow, Russia
- ¹¹² Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany
- ¹¹³ Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany
- ¹¹⁴ Nagasaki Institute of Applied Science, Nagasaki, Japan
- ¹¹⁵ Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya, Japan
- ¹¹⁶ Department of Physics and Astronomy, University of New Mexico, Albuquerque NM, United States of America
- ¹¹⁷ Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands
- ¹¹⁸ Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands
- ¹¹⁹ Department of Physics, Northern Illinois University, DeKalb IL, United States of America
- ¹²⁰ ^(a) Budker Institute of Nuclear Physics, SB RAS, Novosibirsk; ^(b) Novosibirsk State University Novosibirsk, Russia
- ¹²¹ Department of Physics, New York University, New York NY, United States of America
- ¹²² Ohio State University, Columbus OH, United States of America
- ¹²³ Faculty of Science, Okayama University, Okayama, Japan
- ¹²⁴ Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman OK, United States of America
- ¹²⁵ Department of Physics, Oklahoma State University, Stillwater OK, United States of America
- ¹²⁶ Palacký University, RCPTM, Joint Laboratory of Optics, Olomouc, Czech Republic
- ¹²⁷ Center for High Energy Physics, University of Oregon, Eugene OR, United States of America
- ¹²⁸ LAL, Université Paris-Sud, CNRS/IN2P3, Université Paris-Saclay, Orsay, France
- ¹²⁹ Graduate School of Science, Osaka University, Osaka, Japan
- ¹³⁰ Department of Physics, University of Oslo, Oslo, Norway
- ¹³¹ Department of Physics, Oxford University, Oxford, United Kingdom
- ¹³² LPNHE, Sorbonne Université, Paris Diderot Sorbonne Paris Cité, CNRS/IN2P3, Paris, France
- ¹³³ Department of Physics, University of Pennsylvania, Philadelphia PA, United States of America
- ¹³⁴ Konstantinov Nuclear Physics Institute of National Research Centre "Kurchatov Institute", PNPI, St. Petersburg, Russia
- ¹³⁵ Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh PA, United States of America
- ¹³⁶ ^(a) Laboratório de Instrumentação e Física Experimental de Partículas – LIP; ^(b) Departamento de Física, Faculdade de Ciências, Universidade de Lisboa, Lisboa; ^(c) Departamento de Física, Universidade de Coimbra, Coimbra; ^(d) Centro de Física Nuclear da Universidade de Lisboa, Lisboa; ^(e) Departamento de Física, Universidade do Minho, Braga; ^(f) Departamento de Física Teórica y del Cosmos, Universidad de Granada, Granada (Spain); ^(g) Dep Física and CEFITEC of Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Caparica, Portugal
- ¹³⁷ Institute of Physics, Academy of Sciences of the Czech Republic, Prague, Czech Republic
- ¹³⁸ Czech Technical University in Prague, Prague, Czech Republic
- ¹³⁹ Charles University, Faculty of Mathematics and Physics, Prague, Czech Republic
- ¹⁴⁰ State Research Center Institute for High Energy Physics, NRC KI, Protvino, Russia
- ¹⁴¹ Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom
- ¹⁴² IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France
- ¹⁴³ Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz CA, United States of America
- ¹⁴⁴ ^(a) Departamento de Física, Pontificia Universidad Católica de Chile, Santiago; ^(b) Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile
- ¹⁴⁵ Department of Physics, University of Washington, Seattle WA, United States of America
- ¹⁴⁶ Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom
- ¹⁴⁷ Department of Physics, Shinshu University, Nagano, Japan
- ¹⁴⁸ Department Physik, Universität Siegen, Siegen, Germany
- ¹⁴⁹ Department of Physics, Simon Fraser University, Burnaby BC, Canada
- ¹⁵⁰ SLAC National Accelerator Laboratory, Stanford CA, United States of America
- ¹⁵¹ Physics Department, Royal Institute of Technology, Stockholm, Sweden
- ¹⁵² Departments of Physics and Astronomy, Stony Brook University, Stony Brook NY, United States of America
- ¹⁵³ Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom
- ¹⁵⁴ School of Physics, University of Sydney, Sydney, Australia
- ¹⁵⁵ Institute of Physics, Academia Sinica, Taipei, Taiwan
- ¹⁵⁶ ^(a) E. Andronikashvili Institute of Physics, Iv. Javakishvili Tbilisi State University, Tbilisi; ^(b) High Energy Physics Institute, Tbilisi State University, Tbilisi, Georgia
- ¹⁵⁷ Department of Physics, Technion, Israel Institute of Technology, Haifa, Israel
- ¹⁵⁸ Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel
- ¹⁵⁹ Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece
- ¹⁶⁰ International Center for Elementary Particle Physics and Department of Physics, University of Tokyo, Tokyo, Japan
- ¹⁶¹ Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo, Japan
- ¹⁶² Department of Physics, Tokyo Institute of Technology, Tokyo, Japan
- ¹⁶³ Tomsk State University, Tomsk, Russia
- ¹⁶⁴ Department of Physics, University of Toronto, Toronto ON, Canada
- ¹⁶⁵ ^(a) TRIUMF, Vancouver BC; ^(b) Department of Physics and Astronomy, York University, Toronto ON, Canada
- ¹⁶⁶ Division of Physics and Tomonaga Center for the History of the Universe, Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba, Japan
- ¹⁶⁷ Department of Physics and Astronomy, Tufts University, Medford MA, United States of America

- ¹⁶⁸ Department of Physics and Astronomy, University of California Irvine, Irvine CA, United States of America
¹⁶⁹ Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden
¹⁷⁰ Department of Physics, University of Illinois, Urbana IL, United States of America
¹⁷¹ Instituto de Física Corpuscular (IFIC), Centro Mixto Universidad de Valencia – CSIC, Valencia, Spain
¹⁷² Department of Physics, University of British Columbia, Vancouver BC, Canada
¹⁷³ Department of Physics and Astronomy, University of Victoria, Victoria BC, Canada
¹⁷⁴ Fakultät für Physik und Astronomie, Julius-Maximilians-Universität Würzburg, Würzburg, Germany
¹⁷⁵ Department of Physics, University of Warwick, Coventry, United Kingdom
¹⁷⁶ Waseda University, Tokyo, Japan
¹⁷⁷ Department of Particle Physics, Weizmann Institute of Science, Rehovot, Israel
¹⁷⁸ Department of Physics, University of Wisconsin, Madison WI, United States of America
¹⁷⁹ Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal, Germany
¹⁸⁰ Department of Physics, Yale University, New Haven CT, United States of America
¹⁸¹ Yerevan Physics Institute, Yerevan, Armenia

- ^a Also at Borough of Manhattan Community College, City University of New York, NY; United States of America.
^b Also at Centre for High Performance Computing, CSIR Campus, Rosebank, Cape Town; South Africa.
^c Also at CERN, Geneva; Switzerland.
^d Also at CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille; France.
^e Also at Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève; Switzerland.
^f Also at Departament de Física de la Universitat Autònoma de Barcelona, Barcelona; Spain.
^g Also at Departamento de Física Teórica y del Cosmos, Universidad de Granada, Granada (Spain); Spain.
^h Also at Department of Applied Physics and Astronomy, University of Sharjah, Sharjah; United Arab Emirates.
ⁱ Also at Department of Financial and Management Engineering, University of the Aegean, Chios; Greece.
^j Also at Department of Physics and Astronomy, University of Louisville, Louisville, KY; United States of America.
^k Also at Department of Physics and Astronomy, University of Sheffield, Sheffield; United Kingdom.
^l Also at Department of Physics, California State University, Fresno CA; United States of America.
^m Also at Department of Physics, California State University, Sacramento CA; United States of America.
ⁿ Also at Department of Physics, King's College London, London; United Kingdom.
^o Also at Department of Physics, St. Petersburg State Polytechnical University, St. Petersburg; Russia.
^p Also at Department of Physics, Stanford University; United States of America.
^q Also at Department of Physics, University of Fribourg, Fribourg; Switzerland.
^r Also at Department of Physics, University of Michigan, Ann Arbor MI; United States of America.
^s Also at Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa; Italy.
^t Also at Giresun University, Faculty of Engineering, Giresun; Turkey.
^u Also at Graduate School of Science, Osaka University, Osaka; Japan.
^v Also at Hellenic Open University, Patras; Greece.
^w Also at Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest; Romania.
^x Also at II. Physikalisches Institut, Georg-August-Universität Göttingen, Göttingen; Germany.
^y Also at Institutio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona; Spain.
^z Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg; Germany.
^{aa} Also at Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen; Netherlands.
^{ab} Also at Institute for Particle and Nuclear Physics, Wigner Research Centre for Physics, Budapest; Hungary.
^{ac} Also at Institute of Particle Physics (IPP); Canada.
^{ad} Also at Institute of Physics, Academia Sinica, Taipei; Taiwan.
^{ae} Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku; Azerbaijan.
^{af} Also at Institute of Theoretical Physics, Ilia State University, Tbilisi; Georgia.
^{ag} Also at Istanbul University, Dept. of Physics, Istanbul; Turkey.
^{ah} Also at LAL, Université Paris-Sud, CNRS/IN2P3, Université Paris-Saclay, Orsay; France.
^{ai} Also at Louisiana Tech University, Ruston LA; United States of America.
^{aj} Also at Manhattan College, New York NY; United States of America.
^{ak} Also at Moscow Institute of Physics and Technology State University, Dolgoprudny; Russia.
^{al} Also at National Research Nuclear University MEPhI, Moscow; Russia.
^{am} Also at Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg; Germany.
^{an} Also at School of Physics, Sun Yat-sen University, Guangzhou; China.
^{ao} Also at The City College of New York, New York NY; United States of America.
^{ap} Also at The Collaborative Innovation Center of Quantum Matter (CICQM), Beijing; China.
^{aq} Also at Tomsk State University, Tomsk, and Moscow Institute of Physics and Technology State University, Dolgoprudny; Russia.
^{ar} Also at TRIUMF, Vancouver BC; Canada.
^{as} Also at Università di Napoli Parthenope, Napoli; Italy.
^{*} Deceased.