arXiv:1808.09054v1 [hep-ex] 27 Aug 2018

EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

Submitted to: Phys. Lett. B.

CERN-EP-2018-212
29th August 2018

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

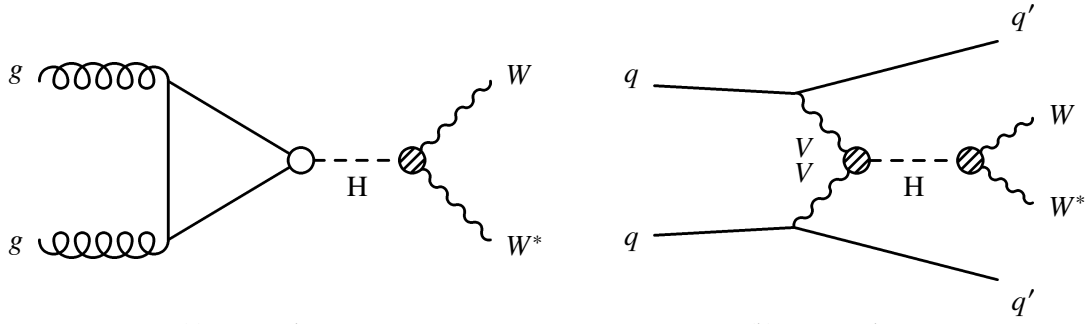
The ATLAS Collaboration

Higgs boson production cross-sections in proton–proton collisions are measured in the $H \to WW^* \to e\nu\mu\nu$ 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 $H \to WW^*$ branching fraction times the gluon–gluon fusion and vector-boson fusion cross-sections are measured to be $12.6^{+1.0}_{-1.0}(\text{stat.})^{+1.9}_{-1.8}(\text{syst.})$ pb and $0.50^{+0.24}_{-0.23}(\text{stat.}) \pm 0.18(\text{syst.})$ pb, respectively, in agreement with the Standard Model predictions.

© 2018 CERN for the benefit of the ATLAS Collaboration.
Reproduction of this article or parts of it is allowed as specified in the CC-BY-4.0 license.

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 $H \to WW^* \to e\nu\mu\nu$ using 36.1 fb^{-1} of proton–proton collisions at a centre-of-mass energy of 13 TeV recorded by the ATLAS detector. The 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 $H \to WW^*$ 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 Figure 1.



(a) ggF production (b) VBF production

Figure 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.

2 ATLAS detector

ATLAS is a particle detector designed to achieve a nearly full coverage in solid angle[1] [5, 6]. It consists of an inner tracking detector surrounded by a thin superconducting solenoid, electromagnetic 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 ($3.2 > |\eta|$), copper absorber for the hadronic endcap calorimeter ($3.2 > |\eta| > 1.5$), 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 $|\eta| < 2.7$,

[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, $\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2}$, is also used to define cone sizes. Transverse momentum and energy are defined as $p_{\mathrm{T}} = p\sin\theta$ and $E_{\mathrm{T}} = E\sin\theta$, respectively.

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 $gg \to H$ observables by reweighting the Higgs boson rapidity spectrum in Hj-MiNLO [10] to that of HNNLO [11]. The transverse momentum spectrum of the Higgs boson 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] 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 [17–19]. The corresponding SM branching fraction $\mathcal{B}_{H\to WW^*}$ is calculated using HDecay [20] to be 0.214 [21]. The $H\to WW^*\to \ell\nu\ell\nu$ decay, where $\ell = e$ or μ, always includes the small contribution from $W \to \tau\nu \to \ell\nu\nu\nu$ decays. Other production and decay modes of the Higgs boson are either fixed to SM predictions (VH production and $H\to\tau\tau$ 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 [22–26]. The NLO QCD and EW calculations are used with approximate NNLO QCD corrections for the VBF production cross-section [22, 27–29].

The WW background was generated separately for the $qq \to WW$ and $gg \to WW$ production mechanisms. The $qq \to WW$ production process was generated using Sherpa 2.2.2 [30, 31] interfaced with the NNPDF3.0 NNLO PDF set [32] and Sherpa parton shower, hadronisation and underlying event simulation (UEPS) model [33, 34]. 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 $gg \to WW$ process was simulated by Sherpa 2.1.1 with zero or one additional jet [35]. The sample is normalised to the NLO $gg \to WW$ cross-section [36].

While NNLO cross-sections are available for diboson production processes [37–39], the Sherpa MEPS@NLO prescription [34] 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 [40] simulation of the ATLAS detector [41] 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 [42] and the MSTW2008LO PDF set [43]. 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.

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 [44, 45])	PDF4LHC15 NNLO [9]	Pythia 8 [14] (Herwig 7 [46])	N^{3}LO QCD + NLO EW [22–26]
VBF H	Powheg-Box v2 (MG5_aMC@NLO)	PDF4LHC15 NLO	Pythia 8 (Herwig 7)	NNLO QCD + NLO EW [22, 27–29]
VH	Powheg-Box v2 [47]	PDF4LHC15 NLO	Pythia 8	NNLO QCD + NLO EW[48–50]
$qq \to WW$	Sherpa 2.2.2 [30, 31] (Powheg-Box v2, MG5_aMC@NLO)	NNPDF3.0NNLO [32]	Sherpa 2.2.2 [33, 34] (Herwig++ [46])	NLO [35]
$gg \to WW$	Sherpa 2.1.1 [35]	CT10 [51]	Sherpa 2.1	NLO [36]
$WZ/V\gamma^*/ZZ$	Sherpa 2.1	CT10	Sherpa 2.1	NLO [35]
$V\gamma$	Sherpa 2.2.2 (MG5_aMC@NLO)	NNPDF3.0NNLO	Sherpa 2.2.2 (CSS variation [33, 52])	NLO [35]
$t\bar{t}$	Powheg-Box v2 [53] (Sherpa 2.2.1)	NNPDF3.0NLO	Pythia 8 (Herwig 7)	NNLO+NNLL [54]
Wt	Powheg-Box v1 [55] (MG5_aMC@NLO)	CT10 [51]	Pythia 6.428 [56] (Herwig++)	NLO [55]
Z/γ^*	Sherpa 2.2.1	NNPDF3.0NNLO	Sherpa 2.2.1	NNLO [57, 58]

4 Event selection and categorisations

Events are triggered using single-lepton triggers and a dilepton e–μ trigger. The transverse momentum threshold ranges between 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–μ 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 [59, 60]. 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 [61] 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 [61, 62] are applied. The electron identification criteria applied provide an efficiency in the range 88–94% depending on electron p_{T} and η. For the muon, 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 $p_{\mathrm{T}} > 22$ GeV and the subleading lepton with $p_{\mathrm{T}} > 15$ GeV. At least one of the leptons must correspond to a lepton that triggered the recording of the event. When the e–μ 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_t algorithm [63] 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 [64].

Jets are required to have $p_{\mathrm{T}} > 20$ GeV and $|\eta| < 4.5$. A multivariate selection that reduces contamination from pile-up [65] is applied to jets with $p_{\mathrm{T}} < 60$ GeV and $|\eta| < 2.4$, utilising calorimeter and tracking information to separate hard-scatter jets from pile-up jets. For jets with $p_{\mathrm{T}} < 50$ GeV and $|\eta| > 2.5$, jet shapes and topological jet correlations in pile-up interactions are exploited to reduce contamination. Jets with $p_{\mathrm{T}} > 20$ 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 [66]. 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 removed if they are within $\Delta R = \min(0.4, 0.04 + 10\ \mathrm{GeV}/p_{\mathrm{T}}$ of the axis of any surviving jet. The missing transverse momentum $\boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}}$ (with magnitude $E_{\mathrm{T}}^{\mathrm{miss}}$) 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 [67]. A second definition of missing transverse momentum (in this case denoted $p_{\mathrm{T}}^{\mathrm{miss}}$) uses the tracks associated with the jets instead of the calorimeter-measured jets. It was found during the optimisation that $p_{\mathrm{T}}^{\mathrm{miss}}$ performs better in terms of background rejection [67].
Events are classified into one of three categories based on the number of jets with $p_{\mathrm{T}} > 30$ GeV: events with zero jets and events with exactly one jet target the ggF production mode ($N_{\mathrm{jet}} = 0$ and $N_{\mathrm{jet}} = 1$ ggF categories), and events with at least two jets target the VBF production mode ($N_{\mathrm{jet}} \geq 2$ VBF category). Figure 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

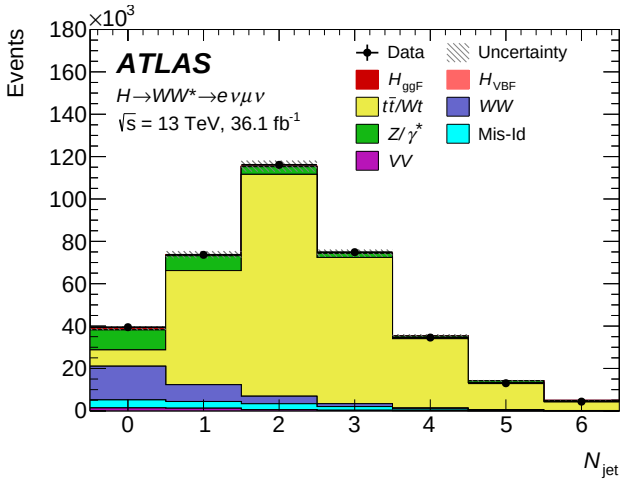


Figure 2: Jet multiplicity distribution after applying the preselection criteria. The shaded band represents the systematic uncertainty and accounts for experimental uncertainties only.

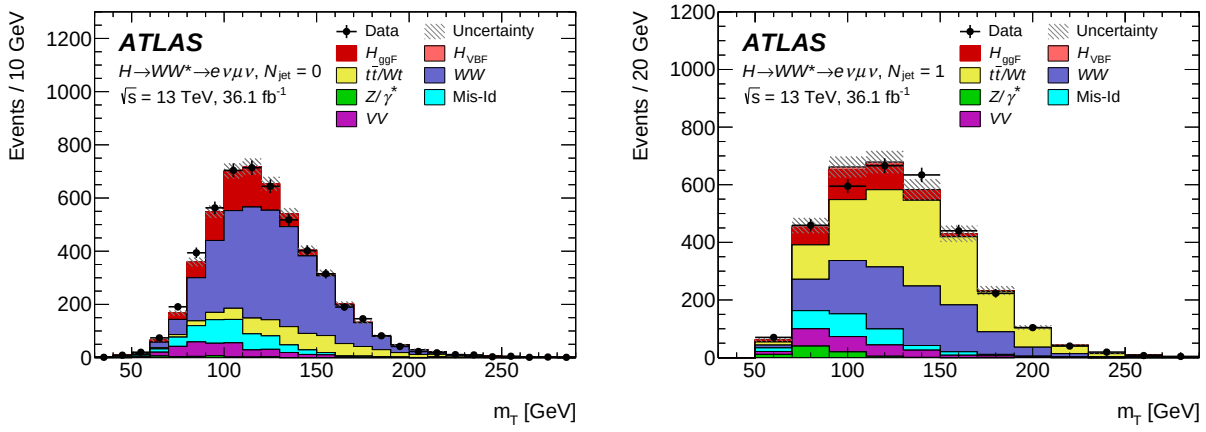
production, events containing b-jets with $p_{\mathrm{T}} > 20$ GeV ($N_{b\text{-jet},(p_{\mathrm{T}}>20\ \mathrm{GeV})}$) are vetoed. The full event selection is summarised in Table 2, where $\Delta\phi(\ell\ell, E_{\mathrm{T}}^{\mathrm{miss}})$ is defined as the azimuthal angle between $\boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}}$ and the dilepton system, $p_{\mathrm{T}}^{\ell\ell}$ is the transverse momentum of the dilepton system, $m_{\ell\ell}$ is the invariant mass of the two leptons, $\Delta\phi_{\ell\ell}$ is the azimuthal angle between the two leptons, and max $\left(m_{\mathrm{T}}^{\ell}\right)$ is the larger of

$m_{\mathrm{T}}^{\ell_i} = \sqrt{2\, p_{\mathrm{T}}^{\ell_i} \cdot E_{\mathrm{T}}^{\mathrm{miss}} \cdot \left(1 - \cos\Delta\phi\left(\ell_i, E_{\mathrm{T}}^{\mathrm{miss}}\right)\right)}$, 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 $p_{\mathrm{T}} > 20$ GeV in the rapidity gap between the two leading jets. In the $N_{\mathrm{jet}} = 1$ and $N_{\mathrm{jet}} \geq 2$ categories, the invariant mass of the τ-lepton pair ($m_{\tau\tau}$), calculated using the collinear approximation [68], is used to veto background from $Z \to \tau\tau$ production. Signal regions (SRs) are defined in each N_{jet} category after applying all selection criteria.

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

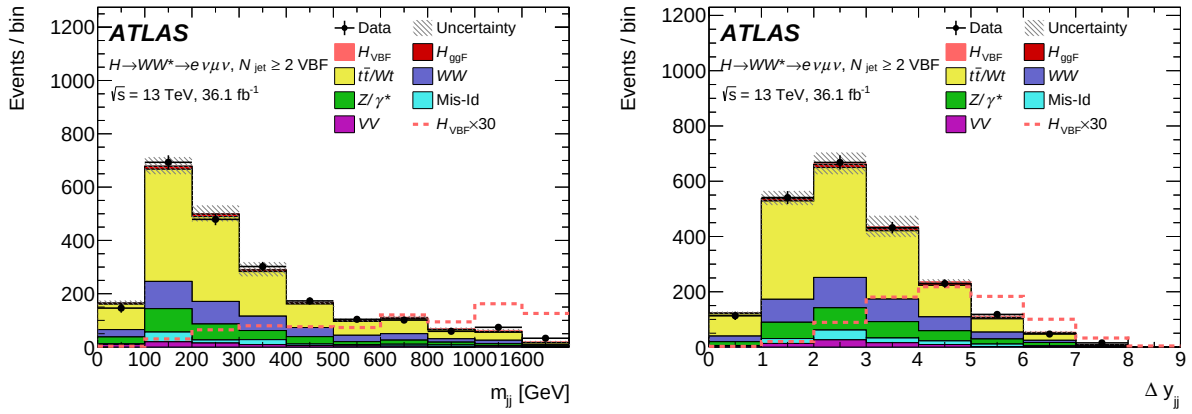
Category	$N_{\mathrm{jet},(p_{\mathrm{T}}>30\ \mathrm{GeV})} = 0$ ggF	$N_{\mathrm{jet},(p_{\mathrm{T}}>30\ \mathrm{GeV})} = 1$ ggF	$N_{\mathrm{jet},(p_{\mathrm{T}}>30\ \mathrm{GeV})} \geq 2$ VBF
Preselection	Two isolated, different-flavour leptons ($\ell = e, \mu$) with opposite charge $p_{\mathrm{T}}^{\mathrm{lead}}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

For both the $N_{\mathrm{jet}} = 0$ and $N_{\mathrm{jet}} = 1$ 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 $p_{\mathrm{T}}^{\mathrm{sublead}} < 20$ GeV and $p_{\mathrm{T}}^{\mathrm{sublead}} \geq 20$ 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 transverse mass, defined as $m_{\mathrm{T}} = \sqrt{\left(E_{\mathrm{T}}^{\ell\ell} + E_{\mathrm{T}}^{\mathrm{miss}}\right)^2 - \left|\mathbf{p}_{\mathrm{T}}^{\ell\ell} + \boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}}\right|^2}$ where $E_{\mathrm{T}}^{\ell\ell} = \sqrt{|\mathbf{p}_{\mathrm{T}}^{\ell\ell}|^2 + m_{\ell\ell}^2}$ and $\mathbf{p}_{\mathrm{T}}^{\ell\ell}$ 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 $N_{\mathrm{jet}} = 0$ and six bins for the $N_{\mathrm{jet}} = 1$ 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 $N_{\mathrm{jet}} = 0$ and $N_{\mathrm{jet}} = 1$ SRs are shown in Figure 3. All figures in this Letter, except Figure 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 $N_{\mathrm{jet}} \geq 2$ VBF selection, a boosted decision tree (BDT) [69] 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 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 $C_\ell = |2\eta_\ell - \sum \eta_j|/\Delta\eta_{jj}$), which quantifies the positions of the leptons relative to the leading jets in pseudorapidity [70], the sum of the invariant masses of all four possible lepton–jet pairs ($\sum_{\ell,j} m_{\ell j}$), and the total transverse momentum ($p_{\mathrm{T}}^{\mathrm{tot}}$), 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 Figure 4 after applying all selections. The BDT score reflects the compatibility of an event with the 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



(a) (b)

Figure 3: Post-fit m_{T} distributions with the signal and the background predictions in the (a) $N_{\mathrm{jet}} = 0$ and (b) $N_{\mathrm{jet}} = 1$ signal regions. The hatched band shows the total uncertainty of the signal and background predictions.



(a) (b)

Figure 4: Post-fit m_{jj} (a) and Δy_{jj} (b) distributions with signal and background predictions in the $N_{\mathrm{jet}} \geq 2$ 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 predictions.

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 Figure 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 $Z \to \tau\tau$,

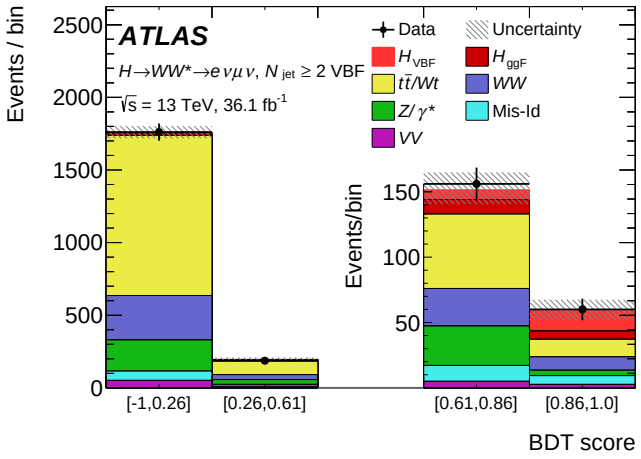


Figure 5: Post-fit BDT score distribution with the signal and the background predictions in the VBF signal region. The hatched band shows the total uncertainty of the signal and background predictions.

hereafter denoted Z/γ^*) production. Other background 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

Table 3: Event selection criteria used to define the control regions. Every control region selection starts from the selection labelled "Preselection" in Table 2. $N_{b\text{-jet},(20\text{ GeV}<p_{\text{T}}<30\text{ GeV})}$ represents the number of b-jets with 20 GeV $< p_{\text{T}} <$ 30 GeV.

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

(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. Figure 6 presents the post-fit m_{T} distributions in the $N_{\text{jet}} = 0$ and $N_{\text{jet}} = 1$ CRs.

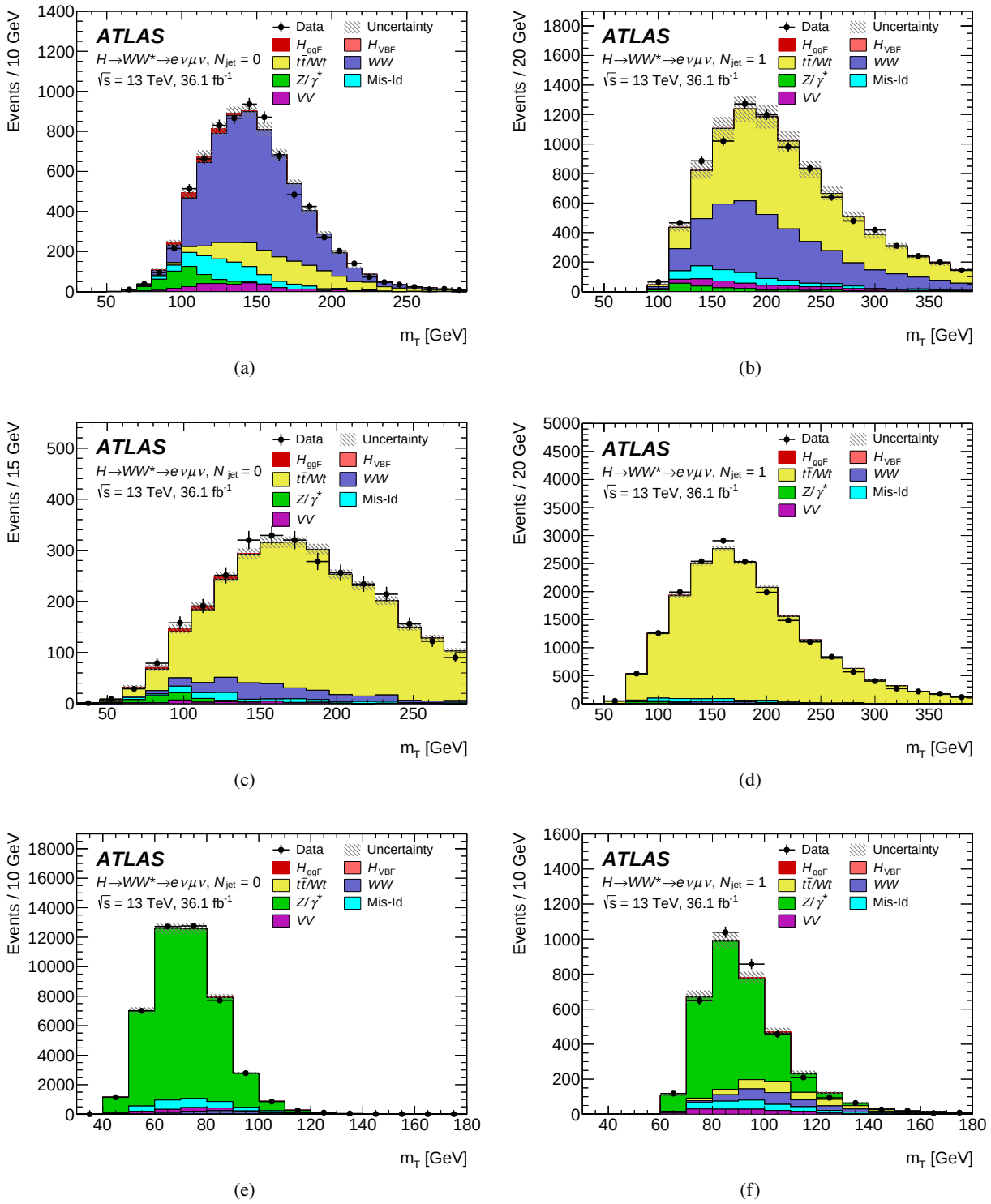


Figure 6: Post-fit m_{T} distributions with signal and background expectations in the $N_{\mathrm{jet}} = 0$ and $N_{\mathrm{jet}} = 1$ control regions for the WW (a,b), $t\bar{t}/Wt$ (c,d), and Z/γ^* (e,f) processes. The hatched band shows the total uncertainty of the signal and background predictions.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

In Figure 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

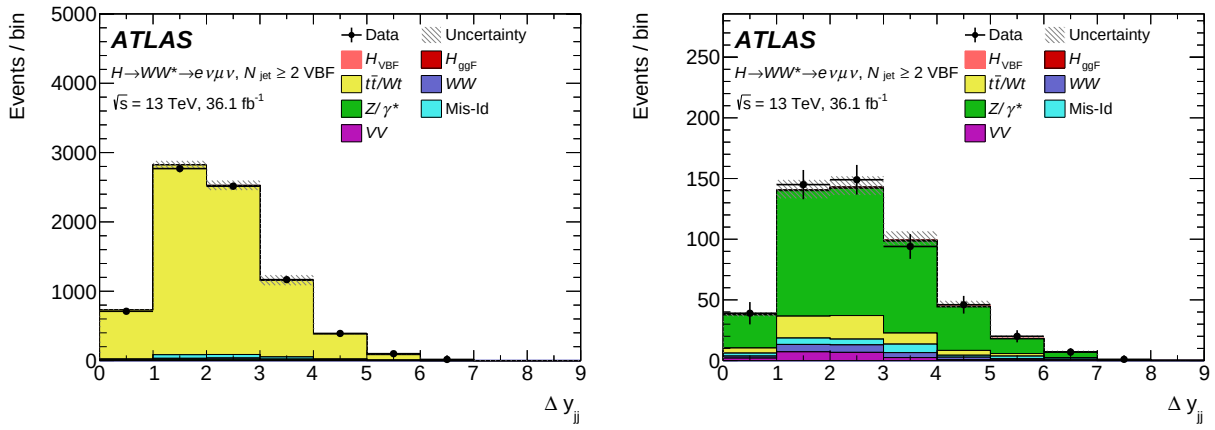


Figure 7: Post-fit Δy_{jj} distribution with signal and background predictions in the (a) $t\bar{t}/Wt$ and (b) Z/γ^* control regions in the $N_{\text{jet}} \geq 2$ VBF analysis category. The hatched band shows the total uncertainty of the signal and background predictions. Some contributions are too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

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 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 events 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 $p_{\text{T}} < 25$ GeV and $p_{\text{T}} > 25$ 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 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

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^*
$N_{\text{jet},(p_{\text{T}}>30\text{ GeV})} = 0$ ggF	1.09 ± 0.09	0.94 ± 0.16	0.87 ± 0.05
$N_{\text{jet},(p_{\text{T}}>30\text{ GeV})} = 1$ ggF	0.97 ± 0.22	0.98 ± 0.07	0.99 ± 0.12
$N_{\text{jet},(p_{\text{T}}>30\text{ GeV})} \geq 2$ VBF	–	1.02 ± 0.01	0.97 ± 0.07

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 [71], and the b-tagging efficiency [72]. Other sources of uncertainty are lepton energy (momentum) scale and resolution, identification and isolation criteria [60, 61, 73], missing transverse momentum measurement [74], modelling of pile-up, and luminosity measurement [75]. 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 individual 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. Figure 8 shows the combined m_{T} distribution for $N_{\mathrm{jet}} \leq 1$. The bottom panel of Figure 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-sections times branching fractions, $\sigma_{\mathrm{ggF}} \cdot \mathcal{B}_{H\to WW^*}$ and $\sigma_{\mathrm{VBF}} \cdot \mathcal{B}_{H\to WW^*}$, are simultaneously determined to be:

$$\begin{aligned}
\sigma_{\mathrm{ggF}} \cdot \mathcal{B}_{H\to WW^*} &= 12.6 \pm 1.0(\mathrm{stat.}) \pm 1.1(\mathrm{theo\ syst.})^{+1.6}_{-1.5}(\mathrm{exp\ syst.})\ \mathrm{pb} = 12.6^{+2.3}_{-2.1}\ \mathrm{pb} \\
\sigma_{\mathrm{VBF}} \cdot \mathcal{B}_{H\to WW^*} &= 0.50^{+0.24}_{-0.23}(\mathrm{stat.}) \pm 0.11(\mathrm{theo\ syst.}) \pm 0.13(\mathrm{exp\ syst.})\ \mathrm{pb} = 0.50^{+0.30}_{-0.29}\ \mathrm{pb}.
\end{aligned}$$

The predicted cross-section times branching fraction values are 10.4 ± 0.6 pb and 0.81 ± 0.02 pb for ggF and VBF [21], respectively. The 68% and 95% confidence level two-dimensional contours of $\sigma_{\mathrm{ggF}} \cdot \mathcal{B}_{H\to WW^*}$ and $\sigma_{\mathrm{VBF}} \cdot \mathcal{B}_{H\to WW^*}$ are shown in Figure 9 and are consistent with the SM predictions.

Table 5: Post-fit MC and data yields in 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}	680 ± 110	300 ± 50	45 ± 18	6.4 ± 2.3
H_{VBF}	7 ± 1	30 ± 2	28 ± 16	15.9 ± 4.1
WW	2960 ± 200	1020 ± 210	370 ± 60	10.2 ± 3.2
VV	320 ± 30	200 ± 30	70 ± 12	2.6 ± 1.6
$t\bar{t}/Wt$	580 ± 130	1400 ± 180	1270 ± 80	13.4 ± 3.7
Mis-Id	470 ± 80	250 ± 50	96 ± 30	6.7 ± 2.7
Z/γ^*	27 ± 10	76 ± 22	280 ± 40	4.2 ± 2.1
Total	5060 ± 70	3290 ± 50	2143 ± 48	59.7 ± 7.8
Observed	5089	3264	2164	60

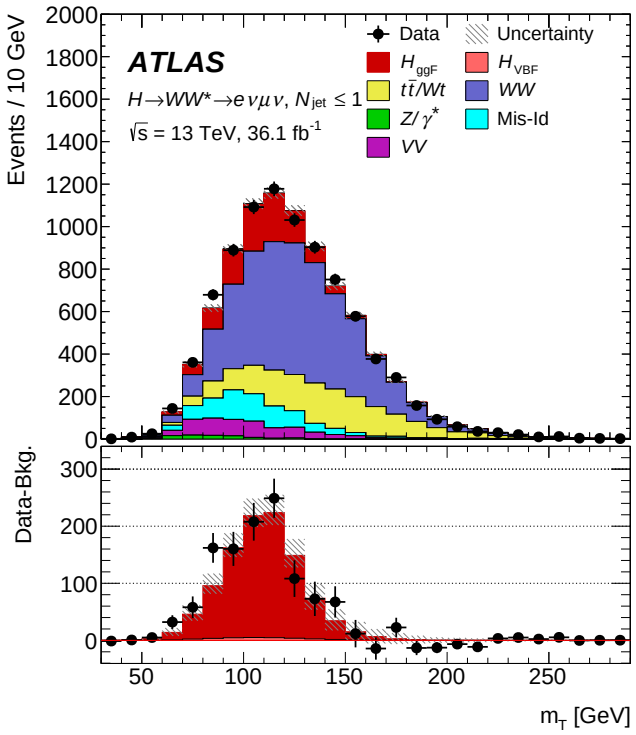


Figure 8: Post-fit combined transverse mass distribution for $N_{\text{jet}} \leq 1$. The bottom panel shows the difference between the data and the estimated background compared to the distribution for a SM Higgs boson with $m_H = 125$ GeV. The signal and the background contributions are fitted to the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

The signal strength parameter μ is defined as the ratio of the measured signal yield to that predicted by the SM. The measured signal strengths for the ggF and VBF production modes in the $H \to WW^*$ decay

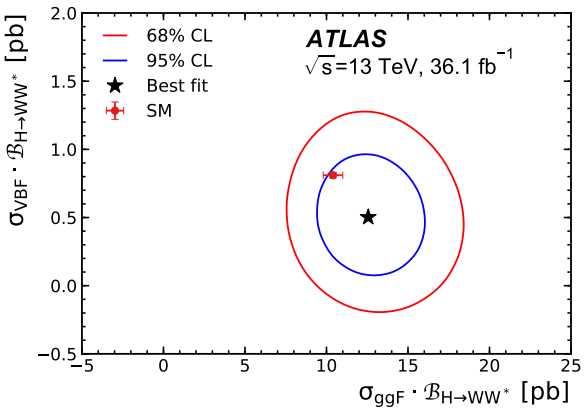


Figure 9: 68% and 95% confidence level two-dimensional likelihood contours of $\sigma_{\mathrm{ggF}} \cdot \mathcal{B}_{H\to WW^*}$ vs. $\sigma_{\mathrm{VBF}} \cdot \mathcal{B}_{H\to WW^*}$, compared to the Standard Model prediction shown by the red marker.

channel are simultaneously determined to be

$$\begin{aligned} \mu_{\mathrm{ggF}} &= 1.21 \pm 0.10(\mathrm{stat.})^{+0.13}_{-0.12}(\mathrm{theo\ syst.}) \pm 0.15(\mathrm{exp\ syst.}) = 1.21^{+0.22}_{-0.21} \\ \mu_{\mathrm{VBF}} &= 0.62^{+0.30}_{-0.28}(\mathrm{stat.}) \pm 0.13(\mathrm{theo\ syst.}) \pm 0.16(\mathrm{exp\ syst.}) = 0.62^{+0.37}_{-0.36}. \end{aligned}$$

Table 6 shows the relative impact of the main uncertainties on the measured values for $\sigma_{\mathrm{ggF}} \cdot \mathcal{B}_{H\to WW^*}$

Table 6: Breakdown of the main contributions to the total uncertainty in $\sigma_{\mathrm{ggF}} \cdot \mathcal{B}_{H\to WW^*}$ and $\sigma_{\mathrm{VBF}} \cdot \mathcal{B}_{H\to WW^*}$. 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	$\Delta\sigma_{\mathrm{ggF}} \cdot \mathcal{B}_{H\to WW^*}$ [%]	$\Delta\sigma_{\mathrm{VBF}} \cdot \mathcal{B}_{H\to WW^*}$ [%]
Data statistics	8	46
CR statistics	8	9
MC statistics	5	23
Theoretical uncertainties	8	21
ggF signal	5	15
VBF signal	<1	5
WW	5	12
Top-quark	4	4
Experimental uncertainties	9	8
b-tagging	5	6
Modelling of pile-up	5	2
Jet	3	4
Electron	3	<1
Misidentified leptons	5	9
Luminosity	2	3
TOTAL	17	59

and $\sigma_{\mathrm{VBF}} \cdot \mathcal{B}_{H\to WW^*}$. The theory uncertainties in the non-resonant WW background produce one of the largest uncertainties, of the order of 5%, in the measured ggF cross-section. The uncertainty in the ratio of $gg \to WW$ to $qq \to WW$ comes from the limited NLO accuracy of the $gg \to WW$ production cross-section [36]. The resulting uncertainty in the cross-section when using acceptance criteria similar to those in this analysis was evaluated in Ref. [76] for $N_{\mathrm{jet}} = 0$ and for $N_{\mathrm{jet}} = 1$. In the $N_{\mathrm{jet}} \geq 2$ VBF SR, the 12% uncertainty in the WW background originates from the matching and UEPS modelling of

$qq \to WW$. The amount of ggF contamination in the VBF region is subject to QCD scale uncertainties and this produces an uncertainty of about 15% 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 23%.
The observed (expected) ggF and VBF signals have significances of 6.3 (5.2) and 1.9 (2.7) 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 $H \to WW^*$ 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 $H \to WW^*$ branching ratio are measured to be $12.6 \pm 1.0(\text{stat.})^{+1.9}_{-1.8}(\text{syst.})$ pb and $0.50^{+0.24}_{-0.23}(\text{stat.}) \pm 0.18(\text{syst.})$ pb, respectively, in agreement with the Standard Model predictions.

9 Acknowledgements

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

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

The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN, the ATLAS Tier-1 facilities at TRIUMF (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN-CNAF (Italy), NL-T1 (Netherlands), PIC (Spain), ASGC (Taiwan), RAL (UK) and BNL (USA), the Tier-2 facilities worldwide and large non-WLCG resource providers. Major contributors of computing resources are listed in Ref. [77].

References

[1] ATLAS Collaboration,
Observation and measurement of Higgs boson decays to WW^* 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*,
JHEP **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*, (2018), arXiv: 1806.05246 [hep-ex].

[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*,
JHEP **08** (2016) 045, arXiv: 1606.02266 [hep-ex].

[5] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*,
JINST **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,
URL: 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 and G. Zanderighi, *NNLOPS simulation of Higgs boson production*,
JHEP **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*, JHEP **07** (2012) 092, arXiv: 1202.5475 [hep-ph].

[11] S. Catani and 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 and 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 and D. Tommasini,
Transverse-momentum resummation: Higgs boson production at the Tevatron and the LHC,
JHEP **11** (2011) 064, arXiv: 1109.2109 [hep-ph].

[14] T. Sjostrand, S. Mrenna and 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*, JHEP **09** (2014) 145,
arXiv: 1406.3660 [hep-ex].

[16] P. Nason and C. Oleari,
NLO Higgs boson production via vector-boson fusion matched with shower in POWHEG,
JHEP **02** (2010) 037, arXiv: 0911.5299 [hep-ph].

[17] 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].

[18] ATLAS Collaboration, *Measurement of the Higgs boson mass in the $H \to ZZ^* \to 4\ell$ and $H \to \gamma\gamma$ channels with $\sqrt{s}$ = 13 TeV pp collisions using the ATLAS detector*, (2018),
arXiv: 1806.00242 [hep-ex].

[19] CMS Collaboration, *Measurements of properties of the Higgs boson decaying into the four-lepton final state in pp collisions at $\sqrt{s}$ = 13 TeV*, JHEP **11** (2017) 047, arXiv: 1706.09936 [hep-ex].

[20] A. Djouadi, J. Kalinowski and M. Spira, *HDECAY: a program for Higgs boson decays in the Standard Model and its supersymmetric extension*,
Computer Physics Communications **108** (1998) 56, ISSN: 0010-4655,
URL: http://www.sciencedirect.com/science/article/pii/S0010465597001239.

[21] LHC Higgs Cross Section Working Group,
Handbook of LHC Higgs Cross Sections: 4. Deciphering the Nature of the Higgs Sector, (2016),
arXiv: 1610.07922 [hep-ph].

[22] 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,
URL: https://cds.cern.ch/record/1559921.

[23] C. Anastasiou, C. Duhr, F. Dulat, F. Herzog and B. Mistlberger,
Higgs Boson Gluon-Fusion Production in QCD at Three Loops,
Phys. Rev. Lett. **114** (2015) 212001, arXiv: 1503.06056 [hep-ph].

[24] C. Anastasiou et al.,
High precision determination of the gluon fusion Higgs boson cross-section at the LHC,
JHEP **05** (2016) 058, arXiv: 1602.00695 [hep-ph].

[25] S. Actis, G. Passarino, C. Sturm and S. Uccirati,
NLO electroweak corrections to Higgs boson production at hadron colliders,
Phys. Lett. B **670** (2008) 12, arXiv: 0809.1301 [hep-ph].

[26] C. Anastasiou, R. Boughezal and F. Petriello,
Mixed QCD-electroweak corrections to Higgs boson production in gluon fusion,
JHEP **04** (2009) 003, arXiv: 0811.3458 [hep-ph].

[27] M. Ciccolini, A. Denner and 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].

[28] M. Ciccolini, A. Denner and S. Dittmaier,
Electroweak and QCD corrections to Higgs production via vector-boson fusion at the LHC,
Phys. Rev. D **77** (2008) 013002, arXiv: 0710.4749 [hep-ph].

[29] P. Bolzoni, F. Maltoni, S.-O. Moch and 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].

[30] T. Gleisberg et al., *Event generation with SHERPA 1.1*, JHEP **02** (2009) 007, arXiv: 0811.4622 [hep-ph].

[31] T. Gleisberg and S. Höche, *Comix, a new matrix element generator*, JHEP **12** (2008) 039, arXiv: 0808.3674 [hep-ph].

[32] R. D. Ball et al., *Parton distributions for the LHC Run II*, JHEP **04** (2015) 040, arXiv: 1410.8849 [hep-ph].

[33] S. Schumann and F. Krauss, *A Parton shower algorithm based on Catani-Seymour dipole factorisation*, JHEP **03** (2008) 038, arXiv: 0709.1027 [hep-ph].

[34] S. Höche, F. Krauss, M. Schönherr and F. Siegert, *QCD matrix elements + parton showers: The NLO case*, JHEP **04** (2013) 027, arXiv: 1207.5030 [hep-ph].

[35] F. Cascioli et al., *Precise Higgs-background predictions: merging NLO QCD and squared quark-loop corrections to four-lepton + 0,1 jet production*, JHEP **01** (2014) 046, arXiv: 1309.0500 [hep-ph].

[36] F. Caola, K. Melnikov, R. Röntsch and L. Tancredi, *QCD corrections to W^+W^- production through gluon fusion*, Phys. Lett. B **754** (2016) 275, arXiv: 1511.08617 [hep-ph].

[37] M. Grazzini, S. Kallweit, S. Pozzorini, D. Rathlev and M. Wiesemann, *W^+W^- production at the LHC: fiducial cross sections and distributions in NNLO QCD*, JHEP **08** (2016) 140, arXiv: 1605.02716 [hep-ph].

[38] M. Grazzini, S. Kallweit, D. Rathlev and M. Wiesemann, *$W^\pm Z$ production at the LHC: fiducial cross sections and distributions in NNLO QCD*, JHEP **05** (2017) 139, arXiv: 1703.09065 [hep-ph].

[39] F. Cascioli et al., *ZZ production at hadron colliders in NNLO QCD*, Phys. Lett. B **735** (2014) 311, arXiv: 1405.2219 [hep-ph].

[40] S. Agostinelli et al., *GEANT4: a simulation toolkit*, Nucl. Instrum. Meth. A **506** (2003) 250.

[41] ATLAS Collaboration, *The ATLAS Simulation Infrastructure*, Eur. Phys. J. C **70** (2010) 823, arXiv: 1005.4568 [physics.ins-det].

[42] ATLAS Collaboration, *Summary of ATLAS Pythia 8 tunes*, ATL-PHYS-PUB-2012-003, 2012, URL: https://cds.cern.ch/record/1474107.

[43] A. D. Martin, W. J. Stirling, R. S. Thorne and G. Watt, *Parton distributions for the LHC*, Eur. Phys. J. C **63** (2009) 189, arXiv: 0901.0002 [hep-ph].

[44] J. Alwall et al., *The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations*, JHEP **07** (2014) 079, arXiv: 1405.0301 [hep-ph].

[45] R. Frederix and S. Frixione, *Merging meets matching in MC@NLO*, JHEP **12** (2012) 061, arXiv: 1209.6215 [hep-ph].

[46] J. Bellm et al., *Herwig 7.0/Herwig++ 3.0 release note*, Eur. Phys. J. C **76** (2016) 196, arXiv: 1512.01178 [hep-ph].

[47] G. Luisoni, P. Nason, C. Oleari and F. Tramontano, *$HW^{\pm}/HZ + 0$ and 1 jet at NLO with the POWHEG BOX interfaced to GoSam and their merging within MiNLO*, JHEP **10** (2013) 083, arXiv: 1306.2542 [hep-ph].

[48] T. Han and S. Willenbrock, *QCD correction to the $pp \to WH$ and ZH total cross sections*, Phys. Lett. B **273** (1991) 167, ISSN: 0370-2693, URL: http://www.sciencedirect.com/science/article/pii/0370269391905728.

[49] O. Brein, A. Djouadi and R. Harlander, *NNLO QCD corrections to the Higgs-strahlung processes at hadron colliders*, Phys. Lett. B **579** (2004) 149, arXiv: hep-ph/0307206 [hep-ph].

[50] M. Ciccolini, S. Dittmaier and 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].

[51] H.-L. Lai et al., *New parton distributions for collider physics*, Phys. Rev. D **82** (2010) 074024, arXiv: 1007.2241 [hep-ph].

[52] S. Höche, S. Schumann and F. Siegert, *Hard photon production and matrix-element parton-shower merging*, Phys. Rev. D **81** (2010) 034026, arXiv: 0912.3501 [hep-ph].

[53] S. Frixione, P. Nason and G. Ridolfi, *A positive-weight next-to-leading-order Monte Carlo for heavy flavour hadroproduction*, JHEP **09** (2007) 126, arXiv: 0707.3088 [hep-ph].

[54] M. Czakon, P. Fiedler and 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].

[55] 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].

[56] T. Sjöstrand, S. Mrenna and P. Z. Skands, *PYTHIA 6.4 physics and manual*, JHEP **05** (2006) 026, arXiv: hep-ph/0603175 [hep-ph].

[57] K. Melnikov and 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].

[58] C. Anastasiou, L. J. Dixon, K. Melnikov and 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].

[59] 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].

[60] ATLAS Collaboration, *Electron efficiency measurements with the ATLAS detector using the 2015 LHC proton–proton collision data*, ATLAS-CONF-2016-024, 2016, URL: https://cds.cern.ch/record/2157687.

[61] 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].

[62] ATLAS Collaboration,
Electron identification measurements in ATLAS using $\sqrt{s}$ = 13 TeV data with 50 ns bunch spacing,
ATL-PHYS-PUB-2015-041, 2015, URL: https://cds.cern.ch/record/2048202.

[63] M. Cacciari, G. P. Salam and G. Soyez, *The anti-k_t jet clustering algorithm*, JHEP **04** (2008) 063,
arXiv: 0802.1189 [hep-ph].

[64] 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].

[65] ATLAS Collaboration,
Identification and rejection of pile-up jets at high pseudorapidity with the ATLAS detector,
Eur. Phys. J. C **77** (2017) 580, [Erratum: Eur. Phys. J. C 77 (2017) 712],
arXiv: 1705.02211 [hep-ex].

[66] ATLAS Collaboration,
Measurements of b-jet tagging efficiency with the ATLAS detector using $t\bar{t}$ events at $\sqrt{s}$ = 13 TeV,
(2018), arXiv: 1805.01845 [hep-ex].

[67] ATLAS Collaboration, *Performance of missing transverse momentum reconstruction with the ATLAS detector using proton-proton collisions at $\sqrt{s}$ = 13 TeV*, (2018),
arXiv: 1802.08168 [hep-ex].

[68] T. Plehn, D. L. Rainwater and D. Zeppenfeld,
A method for identifying $H \to \tau^+\tau^- \to e^\pm\mu^\mp\, p_T$ at the CERN LHC,
Phys. Rev. D **61** (2000) 093005, arXiv: hep-ph/9911385 [hep-ph].

[69] J. H. Friedman, *Greedy function approximation: A gradient boosting machine.*,
Ann. Statist. **29** (2001) 1189.

[70] V. Barger, R. Phillips and D. Zeppenfeld,
Minijet veto: a tool for the heavy Higgs search at the LHC, Phys, Lett. **B346** (1995) 106,
ISSN: 0370-2693,
URL: http://www.sciencedirect.com/science/article/pii/0370269395000089.

[71] ATLAS Collaboration, *Jet Calibration and Systematic Uncertainties for Jets Reconstructed in the ATLAS Detector at $\sqrt{s}$ = 13 TeV*, ATL-PHYS-PUB-2015-015, 2015,
URL: https://cds.cern.ch/record/2037613.

[72] ATLAS Collaboration, *Optimisation of the ATLAS b-tagging performance for the 2016 LHC Run*,
ATL-PHYS-PUB-2016-012, 2016, URL: https://cds.cern.ch/record/2160731.

[73] 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, 2016,
URL: https://cds.cern.ch/record/2203514.

[74] ATLAS Collaboration, *Performance of missing transverse momentum reconstruction with the ATLAS detector in the first proton–proton collisions at $\sqrt{s}$ = 13 TeV*, ATL-PHYS-PUB-2015-027,
2015, URL: https://cds.cern.ch/record/2037904.

[75] 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].

[76] T. Melia, K. Melnikov, R. Rontsch, M. Schulze and G. Zanderighi,
Gluon fusion contribution to W^+W^- + jet production, JHEP **08** (2012) 115,
arXiv: 1205.6987 [hep-ph].

[77] ATLAS Collaboration, *ATLAS Computing Acknowledgements*, ATL-GEN-PUB-2016-002,
URL: https://cds.cern.ch/record/2202407.

The ATLAS Collaboration

M. Aaboud[34d], G. Aad[99], B. Abbott[124], O. Abdinov[13,*], B. Abeloos[128], D.K. Abhayasinghe[91], S.H. Abidi[164], O.S. AbouZeid[39], N.L. Abraham[153], H. Abramowicz[158], H. Abreu[157], Y. Abulaiti[6], B.S. Acharya[64a,64b,n], S. Adachi[160], L. Adam[97], L. Adamczyk[81a], J. Adelman[119], M. Adersberger[112], A. Adiguzel[12c,ag], T. Adye[141], A.A. Affolder[143], Y. Afik[157], C. Agheorghiesei[27c], J.A. Aguilar-Saavedra[136f,136a], F. Ahmadov[77,ae], G. Aielli[71a,71b], S. Akatsuka[83], T.P.A. Åkesson[94], E. Akilli[52], A.V. Akimov[108], G.L. Alberghi[23b,23a], J. Albert[173], P. Albicocco[49], M.J. Alconada Verzini[86], S. Alderweireldt[117], M. Aleksa[35], I.N. Aleksandrov[77], C. Alexa[27b], T. Alexopoulos[10], M. Alhroob[124], B. Ali[138], G. Alimonti[66a], J. Alison[36], S.P. Alkire[145], C. Allaire[128], B.M.M. Allbrooke[153], B.W. Allen[127], P.P. Allport[21], A. Aloisio[67a,67b], A. Alonso[39], F. Alonso[86], C. Alpigiani[145], A.A. Alshehri[55], M.I. Alstaty[99], B. Alvarez Gonzalez[35], D. Álvarez Piqueras[171], M.G. Alviggi[67a,67b], B.T. Amadio[18], Y. Amaral Coutinho[78b], A. Ambler[101], L. Ambroz[131], C. Amelung[26], D. Amidei[103], 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. Azuelos[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. Bauce[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. Bechtle[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. Benchekroun[34a], M. Bender[112], N. Benekos[10], Y. Benhammou[158], E. Benhar Noccioli[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. Bocci[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. Cameron[130], R. Caminal Armadans[100], C. Camincher[35], S. Campana[35], M. Campanelli[92], A. Camplani[39], A. Campoverde[148], V. Canale[67a,67b], M. Cano Bret[58c], J. Cantero[125], T. Cao[158], Y. Cao[170], M.D.M. Capeans Garrido[35], I. Caprini[27b], M. Caprini[27b], M. Capua[40b,40a], R.M. Carbone[38], R. Cardarelli[71a], F.C. Cardillo[146], I. Carli[139], T. Carli[35], G. Carlino[67a], B.T. Carlson[135], L. Carminati[66a,66b], R.M.D. Carney[43a,43b], S. Caron[117], E. Carquin[144b], S. Carrá[66a,66b], G.D. Carrillo-Montoya[35], D. Casadei[32b], M.P. Casado[14,f], A.F. Casha[164], D.W. Casper[168], R. Castelijn[118], F.L. Castillo[171], V. Castillo Gimenez[171], N.F. Castro[136a,136e], A. Catinaccio[35], J.R. Catmore[130], A. Cattai[35], J. Caudron[24], V. Cavaliere[29], E. Cavallaro[14], D. Cavalli[66a], M. Cavalli-Sforza[14], V. Cavasinni[69a,69b], E. Celebi[12b], F. Ceradini[72a,72b], L. Cerda Alberich[171], A.S. Cerqueira[78a], A. Cerri[153], L. Cerrito[71a,71b], F. Cerutti[18], A. Cervelli[23b,23a], S.A. Cetin[12b], A. Chafaq[34a], D Chakraborty[119], S.K. Chan[57], W.S. Chan[118], Y.L. Chan[61a], J.D. Chapman[31], B. Chargeishvili[156b], D.G. Charlton[21], C.C. Chau[33], C.A. Chavez Barajas[153], S. Che[122], A. Chegwidden[104], S. Chekanov[6], S.V. Chekulaev[165a], G.A. Chelkov[77,aq], M.A. Chelstowska[35], C. Chen[58a], C.H. Chen[76], H. Chen[29], J. Chen[58a], J. Chen[38], S. Chen[133], S.J. Chen[15c], X. Chen[15b,ap], Y. Chen[80], Y-H. Chen[44], H.C. Cheng[103], H.J. Cheng[15d], A. Cheplakov[77], E. Cheremushkina[140], R. Cherkaoui El Moursli[34e], E. Cheu[7], K. Cheung[62], L. Chevalier[142], V. Chiarella[49], G. Chiarelli[69a], G. Chiodini[65a], A.S. Chisholm[35,21], A. Chitan[27b], I. Chiu[160], Y.H. Chiu[173], M.V. Chizhov[77], K. Choi[63], A.R. Chomont[128], S. Chouridou[159], Y.S. Chow[118], V. Christodoulou[92], M.C. Chu[61a], J. Chudoba[137], A.J. Chuinard[101], J.J. Chwastowski[82], L. Chytka[126], D. Cinca[45], V. Cindro[89], I.A. Cioară[24], A. Ciocio[18], F. Cirotto[67a,67b], Z.H. Citron[177], M. Citterio[66a], A. Clark[52], M.R. Clark[38], P.J. Clark[48], C. Clement[43a,43b], Y. Coadou[99], M. Cobal[64a,64c], A. Coccaro[53b,53a], J. Cochran[76], H. Cohen[158], A.E.C. Coimbra[177], L. Colasurdo[117], B. Cole[38], A.P. Colijn[118], J. Collot[56], P. Conde Muiño[136a,136b], E. Coniavitis[50], S.H. Connell[32b], I.A. Connelly[98], S. Constantinescu[27b], F. Conventi[67a,as], A.M. Cooper-Sarkar[131], F. Cormier[172], K.J.R. Cormier[164], L.D. Corpe[92], M. Corradi[70a,70b], E.E. Corrigan[94], F. Corriveau[101,ac], A. Cortes-Gonzalez[35], M.J. Costa[171], F. Costanza[5], D. Costanzo[146], G. Cottin[31], G. Cowan[91], B.E. Cox[98], J. Crane[98], K. Cranmer[121], S.J. Crawley[55], R.A. Creager[133], G. Cree[33], S. Crépé-Renaudin[56], F. Crescioli[132],

M. Cristinziani[24], V. Croft[121], G. Crosetti[40b,40a], A. Cueto[96], T. Cuhadar Donszelmann[146], A.R. Cukierman[150], S. Czekierda[82], P. Czodrowski[35], M.J. Da Cunha Sargedas De Sousa[58b,136b], C. Da Via[98], W. Dabrowski[81a], T. Dado[28a,x], S. Dahbi[34e], T. Dai[103], F. Dallaire[107], C. Dallapiccola[100], M. Dam[39], G. D'amen[23b,23a], J. Damp[97], J.R. Dandoy[133], M.F. Daneri[30], N.P. Dang[178,j], N.D Dann[98], M. Danninger[172], V. Dao[35], G. Darbo[53b], S. Darmora[8], O. Dartsi[5], A. Dattagupta[127], T. Daubney[44], S. D'Auria[55], W. Davey[24], C. David[44], T. Davidek[139], D.R. Davis[47], E. Dawe[102], I. Dawson[146], K. De[8], R. De Asmundis[67a], A. De Benedetti[124], M. De Beurs[118], S. De Castro[23b,23a], S. De Cecco[70a,70b], N. De Groot[117], P. de Jong[118], H. De la Torre[104], F. De Lorenzi[76], 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 Santo[153], K. De Vasconcelos Corga[99], J.B. De Vivie De Regie[128], C. Debenedetti[143], D.V. Dedovich[77], N. Dehghanian[3], M. Del Gaudio[40b,40a], J. Del Peso[96], Y. Delabat Diaz[44], D. Delgove[128], F. Deliot[142], C.M. Delitzsch[7], M. Della Pietra[67a,67b], D. Della Volpe[52], A. Dell'Acqua[35], L. Dell'Asta[25], M. Delmastro[5], C. Delporte[128], P.A. Delsart[56], D.A. DeMarco[164], S. Demers[180], M. Demichev[77], S.P. Denisov[140], D. Denysiuk[118], L. D'Eramo[132], D. Derendarz[82], J.E. Derkaoui[34d], F. Derue[132], P. Dervan[88], K. Desch[24], C. Deterre[44], K. Dette[164], M.R. Devesa[30], P.O. Deviveiros[35], A. Dewhurst[141], S. Dhaliwal[26], F.A. Di Bello[52], A. Di Ciaccio[71a,71b], L. Di Ciaccio[5], W.K. Di Clemente[133], C. Di Donato[67a,67b], A. Di Girolamo[35], B. Di Micco[72a,72b], R. Di Nardo[100], K.F. Di Petrillo[57], R. Di Sipio[164], D. Di Valentino[33], C. Diaconu[99], M. Diamond[164], F.A. Dias[39], T. Dias Do Vale[136a], M.A. Diaz[144a], J. Dickinson[18], E.B. Diehl[103], J. Dietrich[19], S. Díez Cornell[44], A. Dimitrievska[18], J. Dingfelder[24], F. Dittus[35], F. Djama[99], T. Djobava[156b], J.I. Djuvsland[59a], M.A.B. Do Vale[78c], M. Dobre[27b], D. Dodsworth[26], C. Doglioni[94], J. Dolejsi[139], Z. Dolezal[139], M. Donadelli[78d], J. Donini[37], A. D'onofrio[90], M. D'Onofrio[88], J. Dopke[141], A. Doria[67a], M.T. Dova[86], A.T. Doyle[55], E. Drechsler[51], E. Dreyer[149], T. Dreyer[51], D. Du[58b], Y. Du[58b], F. Dubinin[108], M. Dubovsky[28a], A. Dubreuil[52], E. Duchovni[177], G. Duckeck[112], A. Ducourthial[132], O.A. Ducu[107,w], D. Duda[113], A. Dudarev[35], A.C. Dudder[97], E.M. Duffield[18], L. Duflot[128], M. Dührssen[35], C. Dülsen[179], M. Dumancic[177], A.E. Dumitriu[27b,d], A.K. Duncan[55], M. Dunford[59a], A. Duperrin[99], H. Duran Yildiz[4a], M. Düren[54], A. Durglishvili[156b], D. Duschinger[46], B. Dutta[44], D. Duvnjak[1], M. Dyndal[44], S. Dysch[98], B.S. Dziedzic[82], C. Eckardt[44], K.M. Ecker[113], R.C. Edgar[103], T. Eifert[35], G. Eigen[17], K. Einsweiler[18], 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. Emeliyanov[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. Etienvre[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. Fakhrutdinov[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. Faucci 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. Giuli[131], M. Giulini[59b], S. Gkaitatzis[159], I. Gkialas[9,i], E.L. Gkougkousis[14], P. Gkountoumis[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. Gonçalo[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. Guillemin[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. Hadef[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. Hawkings[35], D. Hayden[104], C. Hayes[152], C.P. Hays[131], J.M. Hays[90], H.S. Hayward[88], S.J. Haywood[141], M.P. Heath[48], V. Hedberg[94], L. Heelan[8], S. Heer[24], K.K. Heidegger[50], J. Heilman[33], S. Heim[44], T. Heim[18], B. Heinemann[44,am], J.J. Heinrich[112], L. Heinrich[121], C. Heinz[54], J. Hejbal[137], L. Helary[35], A. Held[172], S. Hellesund[130], S. Hellman[43a,43b], C. Helsens[35], R.C.W. Henderson[87], Y. Heng[178], S. Henkelmann[172], A.M. Henriques Correia[35], G.H. Herbert[19], H. Herde[26], V. Herget[174], Y. Hernández Jiménez[32c], H. Herr[97], M.G. Herrmann[112], G. Herten[50], R. Hertenberger[112], L. Hervas[35], T.C. Herwig[133], G.G. Hesketh[92], N.P. Hessey[165a], J.W. Hetherly[41], S. Higashino[79], E. Higón-Rodriguez[171], K. Hildebrand[36], E. Hill[173], J.C. Hill[31], K.K. Hill[29], K.H. Hiller[44], S.J. Hillier[21], M. Hils[46], I. Hinchliffe[18], M. Hirose[129], D. Hirschbuehl[179], B. Hiti[89], O. Hladik[137], D.R. Hlaluku[32c], X. Hoad[48], J. Hobbs[152], N. Hod[165a], M.C. Hodgkinson[146], A. Hoecker[35], M.R. Hoeferkamp[116], F. Hoenig[112], D. Hohn[24], D. Hohov[128], T.R. Holmes[36], M. Holzbock[112], M. Homann[45], S. Honda[166], T. Honda[79], T.M. Hong[135], A. Hönle[113], B.H. Hooberman[170], W.H. Hopkins[127], Y. Horii[115], P. Horn[46], A.J. Horton[149], L.A. Horyn[36], J-Y. Hostachy[56], A. Hostiuc[145], S. Hou[155], A. Hoummada[34a], J. Howarth[98], J. Hoya[86], M. Hrabovsky[126],

I. Hristova[19], J. Hrivnac[128], A. Hrynevich[106], T. Hryn'ova[5], H. Hsu[62], P.J. Hsu[62], S.-C. Hsu[145], Q. Hu[29], S. Hu[58c], Y. Huang[15a], Z. Hubacek[138], F. Hubaut[99], M. Huebner[24], F. Huegging[24], T.B. Huffman[131], E.W. Hughes[38], M. Huhtinen[35], R.F.H. Hunter[33], P. Huo[152], A.M. Hupe[33], N. Huseynov[77,ae], J. Huston[104], J. Huth[57], R. Hyneman[103], G. Iacobucci[52], G. Iakovidis[29], I. Ibragimov[148], L. Iconomidou-Fayard[128], Z. Idrissi[34e], P. Iengo[35], R. Ignazzi[39], O. Igonkina[118,aa], R. Iguchi[160], T. Iizawa[52], Y. Ikegami[79], M. Ikeno[79], D. Iliadis[159], N. Ilic[150], F. Iltzsche[46], G. Introzzi[68a,68b], M. Iodice[72a], K. Iordanidou[38], V. Ippolito[70a,70b], M.F. Isacson[169], N. Ishijima[129], M. Ishino[160], M. Ishitsuka[162], W. Islam[125], C. Issever[131], S. Istin[157], F. Ito[166], J.M. Iturbe Ponce[61a], R. Iuppa[73a,73b], A. Ivina[177], H. Iwasaki[79], J.M. Izen[42], V. Izzo[67a], P. Jacka[137], P. Jackson[1], R.M. Jacobs[24], B.P. Jaeger[149], V. Jain[2], G. Jäkel[179], K.B. Jakobi[97], K. Jakobs[50], S. Jakobsen[74], T. Jakoubek[137], D.O. Jamin[125], D.K. Jana[93], R. Jansky[52], J. Janssen[24], M. Janus[51], P.A. Janus[81a], G. Jarlskog[94], N. Javadov[77,ae], T. Javůrek[35], M. Javurkova[50], F. Jeanneau[142], L. Jeanty[18], J. Jejelava[156a,af], A. Jelinskas[175], P. Jenni[50,c], J. Jeong[44], N. Jeong[44], S. Jézéquel[5], H. Ji[178], J. Jia[152], H. Jiang[76], Y. Jiang[58a], Z. Jiang[150,p], S. Jiggins[50], F.A. Jimenez Morales[37], J. Jimenez Pena[171], S. Jin[15c], A. Jinaru[27b], O. Jinnouchi[162], H. Jivan[32c], P. Johansson[146], K.A. Johns[7], C.A. Johnson[63], W.J. Johnson[145], K. Jon-And[43a,43b], R.W.L. Jones[87], S.D. Jones[153], S. Jones[7], T.J. Jones[88], J. Jongmanns[59a], P.M. Jorge[136a,136b], J. Jovicevic[165a], X. Ju[18], J.J. Junggeburth[113], A. Juste Rozas[14,y], A. Kaczmarska[82], M. Kado[128], H. Kagan[122], M. Kagan[150], T. Kaji[176], E. Kajomovitz[157], C.W. Kalderon[94], A. Kaluza[97], S. Kama[41], A. Kamenshchikov[140], L. Kanjir[89], Y. Kano[160], V.A. Kantserov[110], J. Kanzaki[79], B. Kaplan[121], L.S. Kaplan[178], D. Kar[32c], M.J. Kareem[165b], E. Karentzos[10], S.N. Karpov[77], Z.M. Karpova[77], V. Kartvelishvili[87], A.N. Karyukhin[140], L. Kashif[178], R.D. Kass[122], A. Kastanas[43a,43b], Y. Kataoka[160], C. Kato[58d,58c], J. Katzy[44], K. Kawade[80], K. Kawagoe[85], T. Kawamoto[160], G. Kawamura[51], E.F. Kay[88], V.F. Kazanin[120b,120a], R. Keeler[173], R. Kehoe[41], J.S. Keller[33], E. Kellermann[94], J.J. Kempster[21], J. Kendrick[21], O. Kepka[137], S. Kersten[179], B.P. Kerševan[89], R.A. Keyes[101], M. Khader[170], F. Khalil-Zada[13], A. Khanov[125], A.G. Kharlamov[120b,120a], T. Kharlamova[120b,120a], E.E. Khoda[172], A. Khodinov[163], T.J. Khoo[52], E. Khramov[77], J. Khubua[156b], S. Kido[80], M. Kiehn[52], C.R. Kilby[91], Y.K. Kim[36], N. Kimura[64a,64c], O.M. Kind[19], B.T. King[88], D. Kirchmeier[46], J. Kirk[141], A.E. Kiryunin[113], T. Kishimoto[160], D. Kisielewska[81a], V. Kitali[44], O. Kivernyk[5], E. Kladiva[28b], T. Klapdor-Kleingrothaus[50], M.H. Klein[103], M. Klein[88], U. Klein[88], K. Kleinknecht[97], P. Klimek[119], A. Klimentov[29], R. Klingenberg[45,*], T. Klingl[24], T. Klioutchnikova[35], F.F. Klitzner[112], P. Kluit[118], S. Kluth[113], E. Kneringer[74], E.B.F.G. Knoops[99], A. Knue[50], A. Kobayashi[160], D. Kobayashi[85], T. Kobayashi[160], M. Kobel[46], M. Kocian[150], P. Kodys[139], P.T. Koenig[24], T. Koffas[33], E. Koffeman[118], N.M. Köhler[113], T. Koi[150], M. Kolb[59b], I. Koletsou[5], T. Kondo[79], N. Kondrashova[58c], K. Köneke[50], A.C. König[117], T. Kono[79], R. Konoplich[121,aj], V. Konstantinides[92], N. Konstantinidis[92], B. Konya[94], R. Kopeliansky[63], S. Koperny[81a], K. Korcyl[82], K. Kordas[159], G. Koren[158], A. Korn[92], I. Korolkov[14], E.V. Korolkova[146], N. Korotkova[111], O. Kortner[113], S. Kortner[113], T. Kosek[139], V.V. Kostyukhin[24], A. Kotwal[47], A. Koulouris[10], A. Kourkoumeli-Charalampidi[68a,68b], C. Kourkoumelis[9], E. Kourlitis[146], V. Kouskoura[29], A.B. Kowalewska[82], R. Kowalewski[173], T.Z. Kowalski[81a], C. Kozakai[160], W. Kozanecki[142], A.S. Kozhin[140], V.A. Kramarenko[111], G. Kramberger[89], D. Krasnopevtsev[58a], M.W. Krasny[132], A. Krasznahorkay[35], D. Krauss[113], J.A. Kremer[81a], J. Kretzschmar[88], P. Krieger[164], K. Krizka[18], K. Kroeninger[45], H. Kroha[113], J. Kroll[137], J. Kroll[133], J. Krstic[16], U. Kruchonak[77], H. Krüger[24], N. Krumnack[76], M.C. Kruse[47], T. Kubota[102], S. Kuday[4b], J.T. Kuechler[179], S. Kuehn[35], A. Kugel[59a], F. Kuger[174], T. Kuhl[44], V. Kukhtin[77], R. Kukla[99], Y. Kulchitsky[105], S. Kuleshov[144b], Y.P. Kulinich[170], M. Kuna[56], T. Kunigo[83], A. Kupco[137], T. Kupfer[45], O. Kuprash[158], H. Kurashige[80], L.L. Kurchaninov[165a], Y.A. Kurochkin[105], M.G. Kurth[15d], E.S. Kuwertz[35], M. Kuze[162], J. Kvita[126], T. Kwan[101], A. La Rosa[113], J.L. La Rosa Navarro[78d], L. La Rotonda[40b,40a], F. La Ruffa[40b,40a], C. Lacasta[171], F. Lacava[70a,70b], J. Lacey[44], D.P.J. Lack[98], H. Lacker[19], D. Lacour[132], E. Ladygin[77],

R. Lafaye[5], B. Laforge[132], T. Lagouri[32c], S. Lai[51], S. Lammers[63], W. Lampl[7], E. Lançon[29], U. Landgraf[50], M.P.J. Landon[90], M.C. Lanfermann[52], V.S. Lang[44], J.C. Lange[14], R.J. Langenberg[35], A.J. Lankford[168], F. Lanni[29], K. Lantzsch[24], A. Lanza[68a], A. Lapertosa[53b,53a], S. Laplace[132], J.F. Laporte[142], T. Lari[66a], F. Lasagni Manghi[23b,23a], M. Lassnig[35], T.S. Lau[61a], A. Laudrain[128], M. Lavorgna[67a,67b], A.T. Law[143], M. Lazzaroni[66a,66b], B. Le[102], O. Le Dortz[132], E. Le Guirriec[99], E.P. Le Quilleuc[142], M. LeBlanc[7], T. LeCompte[6], F. Ledroit-Guillon[56], C.A. Lee[29], G.R. Lee[144a], L. Lee[57], S.C. Lee[155], B. Lefebvre[101], M. Lefebvre[173], F. Legger[112], C. Leggett[18], K. Lehmann[149], N. Lehmann[179], G. Lehmann Miotto[35], W.A. Leight[44], A. Leisos[159,v], M.A.L. Leite[78d], R. Leitner[139], D. Lellouch[177], B. Lemmer[51], K.J.C. Leney[92], T. Lenz[24], B. Lenzi[35], R. Leone[7], S. Leone[69a], C. Leonidopoulos[48], G. Lerner[153], C. Leroy[107], R. Les[164], A.A.J. Lesage[142], C.G. Lester[31], M. Levchenko[134], J. Levêque[5], D. Levin[103], L.J. Levinson[177], D. Lewis[90], B. Li[103], 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. Li[148], Z. Liang[15a], B. Liberti[71a], A. Liblong[164], K. Lie[61c], S. Liem[118], A. Limosani[154], C.Y. Lin[31], K. Lin[104], T.H. Lin[97], R.A. Linck[63], J.H. Lindon[21], B.E. Lindquist[152], A.L. Lionti[52], E. Lipeles[133], A. Lipniacka[17], M. Lisovyi[59b], T.M. Liss[170,ao], A. Lister[172], A.M. Litke[143], J.D. Little[8], B. Liu[76], B.L Liu[6], H.B. Liu[29], H. Liu[103], J.B. Liu[58a], J.K.K. Liu[131], K. Liu[132], M. Liu[58a], P. Liu[18], Y. Liu[15a], Y.L. Liu[58a], Y.W. Liu[58a], M. Livan[68a,68b], A. Lleres[56], J. Llorente Merino[15a], S.L. Lloyd[90], C.Y. Lo[61b], Y. Lo[62], F. Lo Sterzo[41], E.M. Lobodzinska[44], P. Loch[7], A. Loesle[50], T. Lohse[19], K. Lohwasser[146], M. Lokajicek[137], B.A. Long[25], J.D. Long[170], R.E. Long[87], L. Longo[65a,65b], K.A. Looper[122], J.A. Lopez[144b], I. Lopez Paz[14], A. Lopez Solis[146], J. Lorenz[112], N. Lorenzo Martinez[5], M. Losada[22], P.J. Lösel[112], X. Lou[44], X. Lou[15a], A. Lounis[128], J. Love[6], P.A. Love[87], J.J. Lozano Bahilo[171], H. Lu[61a], M. Lu[58a], N. Lu[103], Y.J. Lu[62], H.J. Lubatti[145], C. Luci[70a,70b], A. Lucotte[56], C. Luedtke[50], F. Luehring[63], I. Luise[132], L. Luminari[70a], B. Lund-Jensen[151], M.S. Lutz[100], P.M. Luzi[132], D. Lynn[29], R. Lysak[137], E. Lytken[94], F. Lyu[15a], V. Lyubushkin[77], H. Ma[29], L.L. Ma[58b], Y. Ma[58b], G. Maccarrone[49], A. Macchiolo[113], C.M. Macdonald[146], J. Machado Miguens[133,136b], D. Madaffari[171], R. Madar[37], W.F. Mader[46], A. Madsen[44], N. Madysa[46], J. Maeda[80], K. Maekawa[160], S. Maeland[17], T. Maeno[29], A.S. Maevskiy[111], V. Magerl[50], C. Maidantchik[78b], T. Maier[112], A. Maio[136a,136b,136d], O. Majersky[28a], S. Majewski[127], Y. Makida[79], N. Makovec[128], B. Malaescu[132], Pa. Malecki[82], V.P. Maleev[134], F. Malek[56], U. Mallik[75], D. Malon[6], C. Malone[31], S. Maltezos[10], S. Malyukov[35], J. Mamuzic[171], G. Mancini[49], I. Mandić[89], J. Maneira[136a], L. Manhaes de Andrade Filho[78a], J. Manjarres Ramos[46], K.H. Mankinen[94], A. Mann[112], A. Manousos[74], B. Mansoulie[142], J.D. Mansour[15a], M. Mantoani[51], S. Manzoni[66a,66b], A. Marantis[159], G. Marceca[30], L. March[52], L. Marchese[131], G. Marchiori[132], M. Marcisovsky[137], C.A. Marin Tobon[35], M. Marjanovic[37], D.E. Marley[103], F. Marroquim[78b], Z. Marshall[18], M.U.F Martensson[169], S. Marti-Garcia[171], C.B. Martin[122], T.A. Martin[175], V.J. Martin[48], B. Martin dit Latour[17], M. Martinez[14,y], V.I. Martinez Outschoorn[100], S. Martin-Haugh[141], V.S. Martoiu[27b], A.C. Martyniuk[92], A. Marzin[35], L. Masetti[97], T. Mashimo[160], R. Mashinistov[108], J. Masik[98], A.L. Maslennikov[120b,120a], L.H. Mason[102], L. Massa[71a,71b], P. Massarotti[67a,67b], P. Mastrandrea[5], A. Mastroberardino[40b,40a], T. Masubuchi[160], P. Mättig[179], J. Maurer[27b], B. Maček[89], S.J. Maxfield[88], D.A. Maximov[120b,120a], R. Mazini[155], I. Maznas[159], S.M. Mazza[143], N.C. Mc Fadden[116], G. Mc Goldrick[164], S.P. Mc Kee[103], A. McCarn[103], T.G. McCarthy[113], L.I. McClymont[92], E.F. McDonald[102], J.A. Mcfayden[35], G. Mchedlidze[51], M.A. McKay[41], K.D. McLean[173], S.J. McMahon[141], P.C. McNamara[102], C.J. McNicol[175], R.A. McPherson[173,ac], J.E. Mdhluli[32c], Z.A. Meadows[100], S. Meehan[145], T.M. Megy[50], S. Mehlhase[112], A. Mehta[88], T. Meideck[56], B. Meirose[42], D. Melini[171,g], B.R. Mellado Garcia[32c], J.D. Mellenthin[51], M. Melo[28a], F. Meloni[44], A. Melzer[24], S.B. Menary[98], E.D. Mendes Gouveia[136a], L. Meng[88], X.T. Meng[103], A. Mengarelli[23b,23a], S. Menke[113], E. Meoni[40b,40a], S. Mergelmeyer[19], C. Merlassino[20], P. Mermod[52], L. Merola[67a,67b], C. Meroni[66a], F.S. Merritt[36], A. Messina[70a,70b], J. Metcalfe[6], A.S. Mete[168], C. Meyer[133], J. Meyer[157], J-P. Meyer[142], H. Meyer Zu Theenhausen[59a],

F. Miano[153], R.P. Middleton[141], L. Mijović[48], G. Mikenberg[177], M. Mikestikova[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. Panagoulias[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. Pataraia[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. Potrap[77], C.J. Potter[31], H. Potti[11], T. Poulsen[94], J. Poveda[35], T.D. Powell[146], M.E. Pozo Astigarraga[35], P. Pralavorio[99], S. Prell[76], D. Price[98], M. Primavera[65a], S. Prince[101], N. Proklova[110], K. Prokofiev[61c], F. Prokoshin[144b], S. Protopopescu[29], J. Proudfoot[6], M. Przybycien[81a], A. Puri[170], P. Puzo[128], J. Qian[103], Y. Qin[98], A. Quadt[51], M. Queitsch-Maitland[44], A. Qureshi[1], P. Rados[102], F. Ragusa[66a,66b], G. Rahal[95], J.A. Raine[52], S. Rajagopalan[29], A. Ramirez Morales[90], T. Rashid[128], S. Raspopov[5], M.G. Ratti[66a,66b], D.M. Rauch[44], F. Rauscher[112], S. Rave[97], B. Ravina[146], I. Ravinovich[177], J.H. Rawling[98], M. Raymond[35], A.L. Read[130], N.P. Readioff[56], M. Reale[65a,65b], D.M. Rebuzzi[68a,68b], A. Redelbach[174], G. Redlinger[29], R. Reece[143], R.G. Reed[32c], K. Reeves[42], L. Rehnisch[19], J. Reichert[133], D. Reikher[158], A. Reiss[97], C. Rembser[35], H. Ren[15d], M. Rescigno[70a], S. Resconi[66a], E.D. Resseguie[133], S. Rettie[172], E. Reynolds[21], O.L. Rezanova[120b,120a], P. Reznicek[139], E. Ricci[73a,73b], R. Richter[113], S. Richter[44], E. Richter-Was[81b], O. Ricken[24], M. Ridel[132], P. Rieck[113], C.J. Riegel[179], O. Rifki[44], M. Rijssenbeek[152], A. Rimoldi[68a,68b], M. Rimoldi[20], L. Rinaldi[23b], G. Ripellino[151], B. Ristić[87], E. Ritsch[35], I. Riu[14], J.C. Rivera Vergara[144a], F. Rizatdinova[125], E. Rizvi[90], C. Rizzi[14], R.T. Roberts[98], S.H. Robertson[101,ac], D. Robinson[31], J.E.M. Robinson[44], A. Robson[55], E. Rocco[97], C. Roda[69a,69b], Y. Rodina[99], S. Rodriguez Bosca[171], A. Rodriguez Perez[14], D. Rodriguez Rodriguez[171], A.M. Rodríguez Vera[165b], S. Roe[35], C.S. Rogan[57], O. Røhne[130], R. Röhrig[113], C.P.A. Roland[63], J. Roloff[57], A. Romaniouk[110], M. Romano[23b,23a], N. Rompotis[88], M. Ronzani[121], L. Roos[132], S. Rosati[70a], K. Rosbach[50], P. Rose[143], N-A. Rosien[51], B.J. Rosser[133], E. Rossi[44], E. Rossi[72a,72b], E. Rossi[67a,67b], L.P. Rossi[53b], L. Rossini[66a,66b], J.H.N. Rosten[31], R. Rosten[14], M. Rotaru[27b], J. Rothberg[145], D. Rousseau[128], D. Roy[32c], A. Rozanov[99], Y. Rozen[157], X. Ruan[32c], F. Rubbo[150], F. Rühr[50], A. Ruiz-Martinez[171], Z. Rurikova[50], N.A. Rusakovich[77], H.L. Russell[101], J.P. Rutherfoord[7], E.M. Rüttinger[44,k], Y.F. Ryabov[134], M. Rybar[170], G. Rybkin[128], S. Ryu[6], A. Ryzhov[140], G.F. Rzehorz[51], P. Sabatini[51], G. Sabato[118], S. Sacerdoti[128], H.F-W. Sadrozinski[143], R. Sadykov[77], F. Safai Tehrani[70a], P. Saha[119], M. Sahinsoy[59a], A. Sahu[179], M. Saimpert[44], M. Saito[160], T. Saito[160], H. Sakamoto[160], A. Sakharov[121,aj], D. Salamani[52], G. Salamanna[72a,72b], J.E. Salazar Loyola[144b], D. Salek[118], P.H. Sales De Bruin[169], D. Salihagic[113], A. Salnikov[150], J. Salt[171], D. Salvatore[40b,40a], F. Salvatore[153], A. Salvucci[61a,61b,61c], A. Salzburger[35], J. Samarati[35], D. Sammel[50], D. Sampsonidis[159], D. Sampsonidou[159], J. Sánchez[171], A. Sanchez Pineda[64a,64c], H. Sandaker[130], C.O. Sander[44], M. Sandhoff[179], C. Sandoval[22], D.P.C. Sankey[141], M. Sannino[53b,53a], Y. Sano[115], A. Sansoni[49], C. Santoni[37], H. Santos[136a], I. Santoyo Castillo[153], A. Santra[171], A. Sapronov[77], J.G. Saraiva[136a,136d], O. Sasaki[79], K. Sato[166], E. Sauvan[5], P. Savard[164,ar], N. Savic[113], R. Sawada[160], C. Sawyer[141], L. Sawyer[93,ai], C. Sbarra[23b], A. Sbrizzi[23b,23a], T. Scanlon[92], J. Schaarschmidt[145], P. Schacht[113], B.M. Schachtner[112], D. Schaefer[36], L. Schaefer[133], J. Schaeffer[97], S. Schaepe[35], U. Schäfer[97], A.C. Schaffer[128], D. Schaile[112], R.D. Schamberger[152], N. Scharmberg[98], V.A. Schegelsky[134], D. Scheirich[139], F. Schenck[19], M. Schernau[168], C. Schiavi[53b,53a], S. Schier[143], L.K. Schildgen[24], Z.M. Schillaci[26], E.J. Schioppa[35], M. Schioppa[40b,40a], K.E. Schleicher[50], S. Schlenker[35], K.R. Schmidt-Sommerfeld[113], K. Schmieden[35], C. Schmitt[97], S. Schmitt[44], S. Schmitz[97], J.C. Schmoeckel[44], U. Schnoor[50], L. Schoeffel[142], A. Schoening[59b], E. Schopf[131], M. Schott[97], J.F.P. Schouwenberg[117], J. Schovancova[35], S. Schramm[52], A. Schulte[97], H-C. Schultz-Coulon[59a], M. Schumacher[50], B.A. Schumm[143], Ph. Schune[142], A. Schwartzman[150], T.A. Schwarz[103], Ph. Schwemling[142], R. Schwienhorst[104], A. Sciandra[24], G. Sciolla[26], M. Scornajenghi[40b,40a], F. Scuri[69a], F. Scutti[102], L.M. Scyboz[113], J. Searcy[103], C.D. Sebastiani[70a,70b], P. Seema[19], S.C. Seidel[116],

A. Seiden[143], T. Seiss[36], J.M. Seixas[78b], G. Sekhniaidze[67a], K. Sekhon[103], S.J. Sekula[41], N. Semprini-Cesari[23b,23a], S. Sen[47], S. Senkin[37], C. Serfon[130], L. Serin[128], L. Serkin[64a,64b], M. Sessa[58a], H. Severini[124], F. Sforza[167], A. Sfyrla[52], E. Shabalina[51], J.D. Shahinian[143], N.W. Shaikh[43a,43b], L.Y. Shan[15a], R. Shang[170], J.T. Shank[25], M. Shapiro[18], A.S. Sharma[1], A. Sharma[131], P.B. Shatalov[109], K. Shaw[153], S.M. Shaw[98], A. Shcherbakova[134], Y. Shen[124], N. Sherafati[33], A.D. Sherman[25], P. Sherwood[92], L. Shi[155,an], S. Shimizu[79], C.O. Shimmin[180], M. Shimojima[114], I.P.J. Shipsey[131], S. Shirabe[85], M. Shiyakova[77], J. Shlomi[177], A. Shmeleva[108], D. Shoaleh Saadi[107], M.J. Shochet[36], S. Shojaii[102], D.R. Shope[124], S. Shrestha[122], E. Shulga[110], P. Sicho[137], A.M. Sickles[170], P.E. Sidebo[151], E. Sideras Haddad[32c], O. Sidiropoulou[35], A. Sidoti[23b,23a], F. Siegert[46], Dj. Sijacki[16], J. Silva[136a], M. Silva Jr.[178], M.V. Silva Oliveira[78a], S.B. Silverstein[43a], L. Simic[77], S. Simion[128], E. Simioni[97], M. Simon[97], R. Simoniello[97], P. Sinervo[164], N.B. Sinev[127], M. Sioli[23b,23a], G. Siragusa[174], I. Siral[103], 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. Tafirout[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. Ucchielli[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. Vigani[131], M. Villa[23b,23a], M. Villaplana Perez[66a,66b], E. Vilucchi[49], M.G. Vincter[33], V.B. Vinogradov[77], A. Vishwakarma[44], C. Vittori[23b,23a], I. Vivarelli[153], S. Vlachos[10], M. Vogel[179], P. Vokac[138], G. Volpi[14], S.E. von Buddenbrock[32c], E. Von Toerne[24], V. Vorobel[139], K. Vorobev[110], M. Vos[171], J.H. Vossebeld[88], N. Vranjes[16], M. Vranjes Milosavljevic[16], V. Vrba[138], M. Vreeswijk[118], T. Šfiligoj[89], R. Vuillermet[35], I. Vukotic[36], T. Ženiš[28a], L. Živković[16], P. Wagner[24], W. Wagner[179], J. Wagner-Kuhr[112], H. Wahlberg[86], S. Wahrmund[46], K. Wakamiya[80], V.M. Walbrecht[113], J. Walder[87], R. Walker[112], S.D. Walker[91], W. Walkowiak[148], V. Wallangen[43a,43b], A.M. Wang[57], C. Wang[58b,d], F. Wang[178], H. Wang[18], H. Wang[3], J. Wang[154], J. Wang[59b], P. Wang[41], Q. Wang[124], R.-J. Wang[132], R. Wang[58a], R. Wang[6], S.M. Wang[155], W.T. Wang[58a], W. Wang[15c,ad], W.X. Wang[58a,ad], Y. Wang[58a], Z. Wang[58c], C. Wanotayaroj[44], A. Warburton[101], C.P. Ward[31], D.R. Wardrope[92], A. Washbrook[48], P.M. Watkins[21], A.T. Watson[21], M.F. Watson[21], G. Watts[145], S. Watts[98], B.M. Waugh[92], A.F. Webb[11], S. Webb[97], C. Weber[180], M.S. Weber[20], S.A. Weber[33], S.M. Weber[59a], A.R. Weidberg[131], B. Weinert[63], J. Weingarten[51], M. Weirich[97], C. Weiser[50], P.S. Wells[35], T. Wenaus[29], T. Wengler[35], S. Wenig[35], N. Wermes[24], M.D. Werner[76], P. Werner[35], M. Wessels[59a], T.D. Weston[20], K. Whalen[127], N.L. Whallon[145], A.M. Wharton[87], A.S. White[103], A. White[8], M.J. White[1], R. White[144b], D. Whiteson[168], B.W. Whitmore[87], F.J. Wickens[141], W. Wiedenmann[178], M. Wielers[141], C. Wiglesworth[39], L.A.M. Wiik-Fuchs[50], F. Wilk[98], H.G. Wilkens[35], L.J. Wilkins[91], H.H. Williams[133], S. Williams[31], C. Willis[104], S. Willocq[100], J.A. Wilson[21], I. Wingerter-Seez[5], E. Winkels[153], F. Winklmeier[127], O.J. Winston[153], B.T. Winter[24], M. Wittgen[150], M. Wobisch[93], A. Wolf[97], T.M.H. Wolf[118], R. Wolff[99], M.W. Wolter[82], H. Wolters[136a,136c], V.W.S. Wong[172], N.L. Woods[143], S.D. Worm[21], B.K. Wosiek[82], K.W. Woźniak[82], K. Wraight[55], M. Wu[36], S.L. Wu[178], X. Wu[52], Y. Wu[58a], T.R. Wyatt[98], B.M. Wynne[48], S. Xella[39], Z. Xi[103], L. Xia[175], D. Xu[15a], H. Xu[58a], L. Xu[29], T. Xu[142], W. Xu[103], B. Yabsley[154], S. Yacoob[32a], K. Yajima[129], D.P. Yallup[92], D. Yamaguchi[162], Y. Yamaguchi[162], A. Yamamoto[79], T. Yamanaka[160], F. Yamane[80], M. Yamatani[160], T. Yamazaki[160], Y. Yamazaki[80], Z. Yan[25], H.J. Yang[58c,58d], H.T. Yang[18], S. Yang[75], Y. Yang[160], Z. Yang[17], W-M. Yao[18], Y.C. Yap[44], Y. Yasu[79], E. Yatsenko[58c,58d], J. Ye[41], S. Ye[29], I. Yeletskikh[77], E. Yigitbasi[25], E. Yildirim[97], K. Yorita[176], K. Yoshihara[133], C.J.S. Young[35], C. Young[150], J. Yu[8], J. Yu[76], X. Yue[59a], S.P.Y. Yuen[24], B. Zabinski[82], G. Zacharis[10], E. Zaffaroni[52], R. Zaidan[14], A.M. Zaitsev[140,ak], T. Zakareishvili[156b], N. Zakharchuk[33], J. Zalieckas[17], S. Zambito[57], D. Zanzi[35], D.R. Zaripovas[55], S.V. Zeißner[45], C. Zeitnitz[179], G. Zemaityte[131], J.C. Zeng[170], Q. Zeng[150], O. Zenin[140], D. Zerwas[128], M. Zgubič[131], D.F. Zhang[58b], D. Zhang[103], F. Zhang[178], G. Zhang[58a], H. Zhang[15c], J. Zhang[6], L. Zhang[15c], L. Zhang[58a], M. Zhang[170],

P. Zhang[15c], R. Zhang[58a], R. Zhang[24], X. Zhang[58b], Y. Zhang[15d], Z. Zhang[128], X. Zhao[41], Y. Zhao[58b,128,ah], Z. Zhao[58a], A. Zhemchugov[77], Z. Zheng[103], D. Zhong[170], B. Zhou[103], C. Zhou[178], L. Zhou[41], M.S. Zhou[15d], M. Zhou[152], N. Zhou[58c], Y. Zhou[7], C.G. Zhu[58b], H.L. Zhu[58a], H. Zhu[15a], J. Zhu[103], Y. Zhu[58a], X. Zhuang[15a], K. Zhukov[108], V. Zhulanov[120b,120a], A. Zibell[174], D. Zieminska[63], N.I. Zimine[77], S. Zimmermann[50], Z. Zinonos[113], M. Zinser[97], M. Ziolkowski[148], G. Zobernig[178], A. Zoccoli[23b,23a], K. Zoch[51], T.G. Zorbas[146], R. Zou[36], M. Zur Nedden[19], L. Zwalinski[35].

[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 Investigaciónes, 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 (CNESTEN), Rabat;(c)Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA-Marrakech;(d)Faculté des Sciences, Université Mohamed Premier and LPTPM, Oujda;(e)Faculté des sciences, Université Mohammed V, Rabat; Morocco.
[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 Teorica 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. Skobeltsyn 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 Teorica y del Cosmos, Universidad de Granada, Granada (Spain);[(g)]Dep Física and CEFITEC of Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Caparica; Portugal.
[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. Javakhishvili 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 Fisica de la Universitat Autonoma de Barcelona, Barcelona; Spain.
[g] Also at Departamento de Física Teorica 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 Institucio 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 Universita di Napoli Parthenope, Napoli; Italy.
[*] Deceased