



Letter

Observation of VVZ production at $\sqrt{s} = 13$ TeV with the ATLAS detectorThe ATLAS Collaboration ^{*}

ARTICLE INFO

Editor: M. Doser

Dataset link: <https://hepdata.cedar.ac.uk>

ABSTRACT

A search for the production of three massive vector bosons, VVZ ($V = W, Z$), in proton–proton collisions at $\sqrt{s} = 13$ TeV is performed using data with an integrated luminosity of 140 fb^{-1} recorded by the ATLAS detector at the Large Hadron Collider. Events produced in the leptonic final states $WWZ \rightarrow \ell\nu\ell\nu\ell$ ($\ell = e, \mu$), $WZZ \rightarrow \ell\nu\ell\ell\ell$, $ZZZ \rightarrow \ell\ell\ell\ell\ell$, and the semileptonic final states $WWZ \rightarrow qq\ell\nu\ell$ and $WZZ \rightarrow \ell\nu qq\ell$, are analysed. The measured cross section for the $pp \rightarrow VVZ$ process is $660^{+93}_{-90}(\text{stat.})^{+88}_{-81}(\text{syst.}) \text{ fb}$, and the observed (expected) significance is 6.4 (4.7) standard deviations, representing the observation of VVZ production. In addition, the measured cross section for the $pp \rightarrow WWZ$ process is $442 \pm 94(\text{stat.})^{+60}_{-52}(\text{syst.}) \text{ fb}$, and the observed (expected) significance is 4.4 (3.6) standard deviations, representing evidence of WWZ production. The measured cross sections are consistent with the Standard Model predictions. Constraints on physics beyond the Standard Model are also derived in the effective field theory framework by setting limits on Wilson coefficients for dimension-8 operators describing anomalous quartic gauge boson couplings.

1. Introduction

In the Standard Model (SM), the non-Abelian structure of the electroweak sector predicts the self-interaction of vector bosons leading to vertices with three or four vector bosons. Studying processes containing vertices with four vector bosons is a sensitive test of the SM as deviations from the SM expectation would be hints of new physics at higher energy scales [1–4]. Four vector boson vertices can be probed in vector boson scattering processes [5,6] or in three boson final states.

The production of three massive vector bosons in proton–proton (pp) collisions at the Large Hadron Collider (LHC) [7] was studied using data collected at a centre-of-mass energy of $\sqrt{s} = 13$ TeV by both the ATLAS [8] and CMS [9] experiments. ATLAS has provided evidence for the production of WWW and WVZ ($V = W, Z$) using data with an integrated luminosity of 79.8 fb^{-1} [10], and later observed WWW production using 139 fb^{-1} of data [11]. Meanwhile, CMS has observed the combined production of VVV ($WWW + WWZ + WZZ + ZZZ$) based on 137 fb^{-1} of data [12]. This article reports on a search for the production of three massive vector bosons of which at least one is a Z boson, i.e. WWZ , WZZ , and ZZZ , using 140 fb^{-1} of data.

The production of three massive vector bosons can occur via diagrams containing mono to quartic boson interaction vertices, and via the Higgsstrahlung process. Representative Feynman diagrams are shown in Fig. 1.

Three distinct search channels based on the number of leptons in the final state are used, targeting different tri-boson final states, namely 3ℓ

for WWZ and WZZ , 4ℓ for WWZ , and at least 5ℓ for WZZ and ZZZ processes, with $\ell = e, \mu$. The sets of selection criteria for the different search channels are designed to avoid overlap between the channels. The dominant background processes are WZ production for the 3ℓ channel, and WZ and ZZ production for the 4ℓ and 5ℓ channels. To enhance the sensitivity, the signal regions for the 3ℓ and 4ℓ channels are further split into sub-categories. Boosted decision tree (BDT) discriminants are trained individually for each channel to enhance the separation between signal and background events. These channels are then combined with a binned maximum-likelihood fit of the BDT discriminants, yielding a combined signal strength parameter μ for VVZ production with μ defined as the ratio of the measured tri-boson production cross section to its SM prediction. The signal strength is also determined separately for WWZ and WZZ production. Additionally, the signal strength for on-shell VVZ production is extracted by treating the Higgsstrahlung contribution as background. Finally, limits on effective field theory (EFT) parameters describing the four-vector-boson interaction vertex are derived with discriminants optimised to enhance the sensitivity to EFT contributions to the SM processes.

2. The ATLAS detector, data and simulation samples

The ATLAS detector at the LHC is a multipurpose particle detector with a forward–backward symmetric cylindrical geometry and a near 4π coverage in solid angle.¹ It consists of an inner tracking detector (ID) surrounded by a thin superconducting solenoid providing a

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

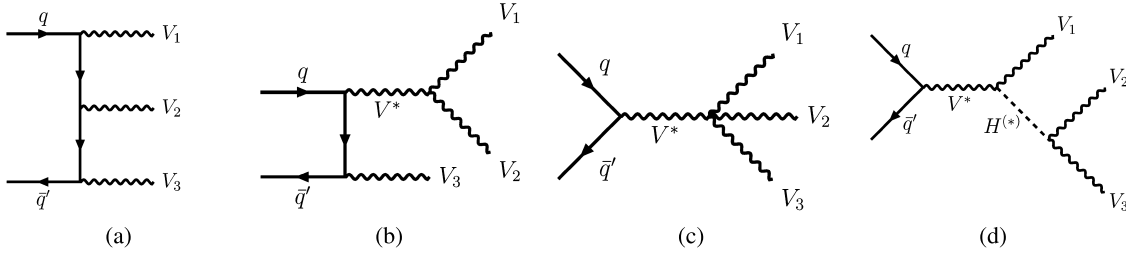


Fig. 1. Representative Feynman diagrams for the production of three massive vector bosons, including diagrams with (a) mono boson vertices, diagrams sensitive to (b) triple and (c) quartic gauge boson couplings, and (d) the Higgsstrahlung process, where $H^{(*)}$ denotes an on-shell or off-shell Higgs boson.

2 T axial magnetic field, electromagnetic (EM) and hadron calorimeters, and a muon spectrometer (MS). The inner tracking detector covers the pseudorapidity range of $|\eta| < 2.5$. It consists of silicon pixel, silicon microstrip, and transition radiation tracking detectors. Lead/liquid-argon (LAr) sampling calorimeters provide EM energy measurements with high granularity. A steel/scintillator-tile hadron calorimeter covers the central pseudorapidity range $|\eta| < 1.7$. The endcap and forward regions are instrumented with LAr calorimeters for both the EM and hadronic energy measurements up to $|\eta| = 4.9$. The muon spectrometer surrounds the calorimeters and is based on three large superconducting air-core toroidal magnets with eight coils each. The field integral of the toroids ranges between 2.0 and 6.0 Tm across most of the detector. The muon spectrometer includes a system of precision tracking chambers and fast detectors for triggering. A two-level trigger system [13] is used to select interesting events. The first-level trigger is implemented in hardware and uses a subset of the detector information to accept events at a rate below 100 kHz. This is followed by a software-based trigger that reduces the accepted event rate to 1 kHz on average, depending on the data-taking conditions. An extensive software suite [14] is used in data simulation, in the reconstruction and analysis of real and simulated data, in detector operations, and in the trigger and data acquisition systems of the experiment.

The data used in the analysis were collected between 2015 and 2018 in pp collisions at $\sqrt{s} = 13$ TeV. Only events recorded with a fully operational detector and stable beams are included resulting in a total integrated luminosity of 140 fb^{-1} [15]. Candidate events are selected by single or multiple lepton (e or μ) triggers with transverse momentum thresholds varying depending on the lepton flavour, isolation requirements, and run period. Due to the presence of at least three leptons in the final state and the requirement of at least one lepton with $p_T > 27 \text{ GeV}$ in the event selection, the lepton triggers are fully efficient for the tri-boson signals in the signal regions defined in Section 3.2.

Signal and background processes were simulated with a range of Monte Carlo (MC) event generators and the ATLAS detector response [16] was modelled with GEANT4 [17]. The effect of multiple pp interactions in the same and neighbouring bunch crossings (pile-up) was included by overlaying minimum-bias events simulated with PYTHIA8.186 [18] using the A3 [19] set of tuned MC parameters and the NNPDF2.3LO [20] parton distribution function (PDF) set, on each generated event in all samples. Tri-boson signal and WWW background events [21] with three on-mass-shell vector bosons including processes involving an off-shell Higgs boson mediator were simulated using SHERPA2.2.2 [22] with the NNPDF3.0NNLO [23] PDF. Off-mass-shell

tri-boson final states with an on-shell Higgs boson mediator, i.e. $WH \rightarrow WVV^*$ and $ZH \rightarrow ZVV^*$, were generated using POWHEG BOX2 [24–29] interfaced to PYTHIA8.186 and EVTGEN1.6.0 [30]. All tri-boson processes were generated at next-to-leading-order (NLO) quantum chromodynamics (QCD) accuracy [31–34]. The expected cross section (VH included) is 329 fb for WWZ , 93.1 fb for WZZ , and 34.0 fb for ZZZ . The total theory uncertainty in the signal cross sections is about 10% and was evaluated by varying parameters in the simulation related to the renormalisation and factorisation scales, parton shower and PDF sets. For the interpretation within the EFT approach (described in Section 5), samples of WWZ and WZZ production with non-zero Wilson coefficients for the $M2$, $M3$, $M4$ and $M5$ operators in the Ebsi model [35] were generated at leading-order (LO) with MADGRAPH2.7.3 [36] using the NNPDF3.0NNLO PDF set and interfaced to PYTHIA8.245 [37] and the A14 [38] tune. The EFT interpretation does not include the 5ℓ channel, so the ZZZ samples are not included as their impact is negligible in the 3ℓ and 4ℓ channels.

Diboson (WW , WZ , ZZ , $W\gamma$, and $Z\gamma$) processes [21] were modelled using SHERPA2.2.12 with the NNPDF3.0NNLO PDF set. Single boson (W/Z +jets) [39] production and electroweak production of $W^\pm W^\pm + 2$ jets, $WZ + 2$ jets, and $ZZ + 2$ jets, were modelled using SHERPA2.2.11 and SHERPA2.2.2, respectively.

Top-quark pair events ($t\bar{t}$) were simulated using POWHEG BOX2 [40] interfaced to PYTHIA8.230 and EVTGEN1.6.0. The NNPDF3.0NNLO PDF set was used for the matrix-element calculation, while the NNPDF2.3LO PDF set was used for the showering with the A14 tune. Production processes of a top-quark pair in association with a vector boson ($t\bar{t}Z$ and $t\bar{t}W$) were modelled at NLO with MADGRAPH2.2.3 with the NNPDF3.0NNLO PDF set and interfaced to PYTHIA8.210 using the A14 tune and EVTGEN1.2.0 for heavy flavour decays. The $t\bar{t}H$ production was generated at LO in QCD with POWHEG BOX2 interface to PYTHIA8.210 and EVTGEN1.6.0. Other background processes containing top quarks were generated with MADGRAPH5_AMC@NLO [41] interfaced to PYTHIA8.230, at LO ($t\bar{t}\gamma$, tZ , $t\bar{t}WW$, $t\bar{t}WZ$, and $t\bar{t}t\bar{t}$) or with POWHEG BOX2 [42] interfaced to PYTHIA8.212 and EVTGEN1.6.0 (tWZ).

3. Object definitions, event selection and background estimation

3.1. Object definitions and preselection criteria

At the trigger level, candidate events are selected using all combinations of unprescaled single lepton, dilepton, tri-lepton, and four-lepton triggers [43,44]. Triggers requiring a mixture of lepton flavours (for example, dilepton triggers with an electron and a muon at the trigger level) are also used. These triggers require leptons to satisfy certain p_T threshold, identification, and isolation criteria. The combined trigger efficiency is fully efficient for tri-boson events in the fiducial regions. The candidate events are required to contain one reconstructed primary vertex [45]. If more than one reconstructed vertex is found, the vertex with the largest p_T^2 sum of associated ID tracks is considered as the primary vertex.

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 upwards. Polar 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 $\eta = -\ln \tan(\theta/2)$. Transverse momentum (p_T) is defined relative to the beam axis and is calculated as $p_T = p \sin \theta$ where p is the momentum. Transverse energy (E_T) is calculated as $E_T = E \sin \theta$ where E is the energy. Angular distance is measured in units of $\Delta R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$.

Table 1

Summary of the object selection and event preselection criteria used in the analysis.

Object selection criteria	
Electron	Passes the “Loose” quality requirement and have at least one hit in the innermost pixel layer $ d_0 /\sigma_{d_0} < 5$, $ z_0 \times \sin \theta < 0.5$ mm $p_T > 7$ GeV, $ \eta < 2.47$
Muon	Passes the “Loose” quality requirement $ d_0 /\sigma_{d_0} < 3$, $ z_0 \times \sin \theta < 0.5$ mm $p_T > 5$ GeV ($p_T > 15$ GeV for calorimeter-tagged muons), $ \eta < 2.7$
Jet	Passes the JVT requirement, $p_T > 20$ GeV, $ \eta < 4.5$
Event preselection criteria	
Trigger	Single lepton, dilepton, tri-lepton, or quad-lepton triggers
Number of charged leptons	≥ 3
Z boson invariant mass	$ m_{\ell\ell} - m_Z < 40$ GeV

Electrons are reconstructed from energy clusters in the EM calorimeter matched to ID tracks and are identified using a likelihood discriminant constructed with information about the shape of the EM showers in the calorimeter, the track properties, and the quality of the track-to-cluster matching for the candidate [46]. Electrons must satisfy the “Loose” requirement based on the electron likelihood discriminant and have at least one hit in the innermost pixel layer. Electrons are required to have $p_T > 7$ GeV and $|\eta| < 2.47$. Electron candidates reconstructed within the transition region between the barrel and endcap calorimeters, $1.37 < |\eta| < 1.52$, are also kept.

Muons are reconstructed in multiple ways based on information from the ID, the MS, and the calorimeters [47]. In the range of the ID coverage, the muon reconstruction is primarily performed by a global fit of fully reconstructed tracks in the ID and the MS (referred to as “combined muons”). In the central region ($|\eta| < 0.1$) of the detector where the MS lacks in coverage, muons can also be identified by matching a fully reconstructed ID track to either an MS track segment (referred to as “segment-tagged muons”) or a calorimetric energy deposit consistent with that of a minimum-ionising particle (referred to as “calorimeter-tagged muons”). For the last two cases, the muon momentum is determined by the ID track alone. In the forward MS region ($2.5 < |\eta| < 2.7$), MS tracks with hits in the three MS layers are accepted (referred to as “standalone muons”). Muons are required to satisfy the “Loose” identification requirement described in Ref. [47] and to have $|\eta| < 2.7$ and $p_T > 5$ GeV for all types except for the calorimeter-tagged type where the requirement is increased to $p_T > 15$ GeV.

Both electrons and muons are required to be consistent with originating from the primary vertex by imposing requirements on the transverse impact parameter, d_0 , its uncertainty, σ_{d_0} , the longitudinal impact parameter, z_0 , and the polar angle θ . These requirements are $|d_0|/\sigma_{d_0} < 5$ and $|z_0 \times \sin \theta| < 0.5$ mm for electrons, and $|d_0|/\sigma_{d_0} < 3$ and $|z_0 \times \sin \theta| < 0.5$ mm for muons. The leptons selected with these criteria are classified as baseline leptons.

Jets are reconstructed from particle-flow objects using the anti- k_t algorithm [48,49] with a radius parameter of 0.4. The particle-flow algorithm combines information about ID tracks and energy deposits in the calorimeters to form the input for jet reconstruction [50]. Jets are selected by requiring $p_T > 20$ GeV and $|\eta| < 4.5$. To suppress jets arising from pile-up, a jet-vertex-tagging (JVT) technique [51] using a multivariate likelihood is applied to jets with $p_T < 60$ GeV and $|\eta| < 2.4$, ensuring that the selected jets are matched to the primary vertex.

Jets containing b -hadrons are identified (b -tagged) using the DL1r b -tagging algorithm [52] based on a deep neural network that combines information from displaced tracks and reconstructed secondary and tertiary vertices inside jets. A jet with $|\eta| < 2.5$ is b -tagged if the response value of the DL1r algorithm exceeds a predefined threshold. The operating point defined with an efficiency of 77% for b -jets measured in simulated $t\bar{t}$ events is used.

The missing transverse momentum, whose magnitude is denoted E_T^{miss} , is defined as the negative vector sum of the p_T of all reconstructed

and calibrated physics objects in the event [53]. This sum includes a term to account for the energy from low-momentum particles that are not associated with a reconstructed lepton or jet.

The object reconstruction and identification algorithms do not always result in unambiguous identifications of physics objects. An overlap removal procedure is applied to the leptons and jets in the following order. Calorimeter-tagged muons sharing a track with any electrons are removed. Electrons sharing an ID track with muons are removed. Any jet within $\Delta R < 0.2$ of an electron is removed and electrons within $\Delta R < 0.4$ of any remaining jets are removed. Jets with less than three associated tracks and within $\Delta R < 0.2$ of a muon are removed, and muons within $\Delta R < 0.4$ of any of the remaining jets are removed.

The preselected events are required to have at least three charged leptons satisfying the baseline lepton selection criteria. In addition, at least one same-flavour opposite-sign charge (SFOS) lepton pair that is consistent with the Z boson pole mass ($m_Z = 91.188$ GeV) within 40 GeV is required. Table 1 shows all preselection criteria used.

3.2. Event selection criteria

The 3ℓ channel requires exactly three charged leptons and at least one reconstructed jet in the final state. All SFOS dilepton pairs should have an invariant mass $m_{\ell\ell} > 12$ GeV. Events are required to have at least one SFOS lepton pair that is consistent with m_Z within 20 GeV. This pair is considered to be the Z boson candidate. If more than one pair can be formed, the pair whose invariant mass is closest to m_Z is taken as the Z boson candidate. These two leptons are assigned to the Z boson decay (labelled Z -leptons). The remaining third lepton is assigned to the W boson decay (labelled W -lepton). To reduce instrumental backgrounds, events with both Z -electrons falling into the calorimeter transition region $1.37 < |\eta| < 1.52$ are rejected. In addition, events with the third electron falling into the calorimeter transition region are rejected.

All three leptons are required to have $p_T > 15$ GeV and at least one must have $p_T > 27$ GeV. The electrons must satisfy the “Loose” isolation requirement based on prompt tracks within a shrinking cone around the electron track as p_T increases and calorimeter energy depositions within $\Delta R = 0.2$ of the electron. Similarly, the muons are required to satisfy the “Loose” isolation requirement based on prompt tracks and calorimeter energy depositions [47]. Backgrounds originating from misidentified leptons are suppressed by requiring the W -lepton to satisfy more stringent selection criteria. The W -lepton must satisfy the “Tight” quality requirement for electrons based on the likelihood discriminant [54] and the “Tight” quality requirement for muons [47]. Both W -leptons must satisfy the “Tight” isolation working point based on a multivariate discriminant used to reject non-prompt leptons from heavy-flavour decays [55]. At least one jet with $p_T > 20$ GeV and $|\eta| < 2.5$ is required to be present in the final state. Events with at least one b -jet are rejected.

To gain sensitivity, the 3ℓ channel makes use of events containing four leptons that satisfy the 3ℓ channel selection shown in Table 2, but fail to satisfy the 4ℓ channel selection criteria shown in Table 3. These

Table 2Overview of the criteria used to select inclusive 3ℓ events and the three 3ℓ SRs.

Inclusive 3ℓ event selection			
Satisfy preselection criteria	✓		
Lepton	$p_{\text{T}} > 15$ GeV and at least one lepton with $p_{\text{T}} > 27$ GeV		
Lepton from the Z decays	“Loose” isolation requirement based on tracker and calorimeter measurements		
Lepton from the W decays	“Tight” identification and “Tight” isolation		
Invariant mass of any SFOS dilepton pairs	> 12 GeV		
Invariant mass of the Z boson	$ m_{\ell\ell} - m_Z < 20$ GeV		
Number of leptons	$= 3$		
Number of b -jets	$= 0$		
3ℓ signal regions			
	3ℓ -1j	3ℓ -2j-inV	3ℓ -2j-outV
Satisfy inclusive 3ℓ selection criteria	✓	✓	✓
BDT score > 0.42	✓	✓	✓
Number of jets	$= 1$	≥ 2	≥ 2
m_{jj}	–	> 60 GeV and < 110 GeV	< 60 GeV or > 110 GeV

Table 3Overview of the criteria used to select inclusive 4ℓ events and the three 4ℓ SRs.

Inclusive 4ℓ event selection			
Satisfy preselection criteria	✓		
Lepton	Exactly four leptons with $p_T > 30, 15, 8, 6$ GeV		
Lepton from the Z decays	“Loose” isolation requirement based on tracker and calorimeter measurements		
Leptons from the W decays	“Medium” identification and “Tight” isolation		
Invariant mass of any SFOS dilepton pairs	> 12 GeV		
Invariant mass of the Z boson	$ m_{\ell\ell} - m_Z < 20$ GeV		
Minimum angular distance between any lepton pairs	> 0.1		
E_T^{miss}	> 10 GeV		
Number of b -jets	$= 0$		
4ℓ signal regions			
	4ℓ -DF	4ℓ -SF-inZ	4ℓ -SF-outZ
Satisfy inclusive 4ℓ selection criteria	✓	✓	✓
Flavour for lepton from the W decays	$e\mu$	same-flavour	same-flavour
$m_{\ell\ell}$ for the two W -leptons	–	$ m_{\ell\ell} - m_Z < 20$ GeV	$ m_{\ell\ell} - m_Z > 20$ GeV

4ℓ events are required to contain only one lepton pair with $|m_{\ell\ell} - m_Z| < 20$ GeV. One of the other two leptons is required to satisfy the 3ℓ quality requirements for a W -lepton, while the other lepton is required to fail this requirement. This increases the signal yield by 2% and the estimated background by 1.5%.

Three signal regions (SRs) are defined according to the number of jets and the invariant mass of the two leading jets in the event: the 3ℓ -1j SR is defined by requiring events with exactly one reconstructed jet; the requirements of at least two jets with the invariant mass of the two leading jets, m_{jj} , lying within a window close to the W or Z boson pole mass, i.e. $60 < m_{jj} < 110$ GeV, defines the 3ℓ -2j-inV SR; the remaining events compose the 3ℓ -2j-outV SR. With these selection criteria applied, the signal-to-background ratio is close to 1% for the 3ℓ -1j channel, 5% for the 3ℓ -2j-inV channel, and 3% for the 3ℓ -2j-outV channel. To reduce the WZ +jets background, each event is required to have a BDT score (described in Section 4) that is larger than 0.42. Table 2 summarises all selection criteria used and the definitions of these three SRs.

The 4ℓ channel requires exactly four leptons in the event. The SFOS lepton pair with its invariant mass, $m_{\ell\ell}$, closest to m_Z is identified as the Z boson candidate and must fulfil $|m_{\ell\ell} - m_Z| < 20$ GeV. The remaining two leptons are assigned as leptons from W decays and must satisfy the “Tight” isolation and “Medium” quality requirements. All SFOS lepton pairs must have an invariant mass of $m_{\ell\ell} > 12$ GeV. The set of four leptons is required to satisfy the ordered p_T thresholds of 30, 15, 8, and 6 GeV. The angular distance between any two leptons is required to be $\Delta R > 0.1$. Furthermore, each event must have $E_T^{\text{miss}} > 10$ GeV and no jets reconstructed as b -tagged jets. Events that satisfy the selection are categorised into three SRs depending on the flavours of the two W -leptons. Those events where the two leptons have different flavour compose the 4ℓ -DF SR and events with two same-flavour leptons

are split into two SRs based on their invariant mass: events satisfying $|m_{\ell\ell} - m_Z| < 20$ GeV define the 4ℓ -SF-inZ SR, while the remaining events compose the 4ℓ -SF-outZ SR. Table 3 summarises the selection criteria and the definitions of these three SRs.

The 5ℓ channel requires at least five leptons with at least two SFOS pairs in the event. The two SFOS lepton pairs with their invariant mass closest to m_Z are identified as Z boson candidates and must fulfil $|m_{\ell\ell} - m_Z| < 20$ GeV. The remaining lepton is assigned as a lepton from another Z/W boson decay and no additional quality requirements or isolation requirements are applied. Events with at least one b -jet are rejected. Table 4 summarises the selection criteria.

To further increase the separation between the signal and background events in the SRs, seven BDT discriminants are trained using the XGBoost package [56]² and are applied separately to each of the seven SRs. The majority of the input variables are kinematic features of the events. For the 3ℓ channel, the BDT is trained with 17 variables for 3ℓ -1j, 20 variables for 3ℓ -2j-inV, and 24 variables for 3ℓ -2j-outV, with some of these variables overlapping between the channels. For the 4ℓ channel, the same 23 variables are used as inputs for the BDT training for 4ℓ -DF, 4ℓ -SF-inZ, and 4ℓ -SF-outZ. For the 5ℓ channel, the BDT is trained with 11 variables. All backgrounds except fake backgrounds (due to non-prompt leptons from hadron decay or jets misidentified as leptons) are included in the BDT training. Since XGBoost cannot handle negative-weight events, the absolute value of each event weight is used. A five-fold training and cross-validation procedure is used to produce the final discriminant for each SR, and each of the five models is trained

² Julia packages (UnROOT.jl [57] and XGBoost.jl) were used for the 4ℓ channel.

Table 4Overview of the criteria used to select inclusive 5ℓ events, which form the 5ℓ SR.

Inclusive 5ℓ event selection (5ℓ SR)	
Satisfy preselection criteria	✓
Leptons	At least five leptons “Loose” isolation requirement based on tracker and calorimeter measurements
Z boson candidates	At least two SFOS pairs with $ m_{\ell\ell} - m_Z < 20$ GeV
Z boson invariant mass	$ m_{\ell\ell} - m_Z < 20$ GeV
Number of b -jets	$= 0$

on 80% of the expected signal and background events. Each of the five trained BDTs is applied to the remaining 20% of the total events. The final BDT score is obtained by averaging the outputs of the five trained BDTs and is used to generate the BDT distribution for the fit.

3.3. Background estimation

The SM background processes can be divided into two categories: processes with three, four, or at least five prompt leptons in the final state, and fake background processes. Depending on the source, the background is estimated in data or simulation, as described below, or a combination of both.

The dominant background source in the 3ℓ channel is from WZ +jets production, followed in importance by ZZ +jets production. The WZ +jets process contributes 83% of the expected background in the 3ℓ -1j SR, 79% in the 3ℓ -2j-inV SR, and 81% in the 3ℓ -2j-outV SR. The ZZ +jets process contributes 11% of the expected background in the 3ℓ -1j SR, 10% in the 3ℓ -2j-inV SR, and 7% in the 3ℓ -2j-outV SR. Due to the presence of three isolated leptons in the final states, the fake background contribution from the Z +jets process is $< 3\%$. As a result, all backgrounds are estimated with MC simulated events.

The dominant background sources in the 4ℓ channel are from ZZ +jets and fake background processes. The ZZ +jets process contributes 50% of the expected background in the 4ℓ -DF SR, 98% of the events in the 4ℓ -SF-inZ SR, and 93% in the 4ℓ -SF-outZ SR. The fake background mainly originates from the WZ +jets and Z +jets processes where one or two jets are identified as isolated leptons. The contribution from $t\bar{t}$ production is found to be negligible due to the b -jet veto requirement. The fake background contributes 17% of the expected background in the 4ℓ -DF SR, 1% in the 4ℓ -SF-inZ SR, and 3% in the 4ℓ -SF-outZ SR. The $t\bar{t}Z$ process also contributes 21% of the expected background in the 4ℓ -DF SR. Due to its contribution to the most sensitive 4ℓ -DF SR, the fake background is estimated by using a data-driven method as described in Ref. [58], while all other backgrounds are estimated with MC simulations.

The dominant backgrounds in the 5ℓ channel originate from fake background processes such as ZZ +jets and $t\bar{t}Z$ production. The ZZ +jets process contributes 95% of the expected background in the SR, while the $t\bar{t}Z$ process contributes 2.5%. These backgrounds have one or two jets misidentified as isolated leptons and are estimated by using a combination of data-driven and simulation-based techniques.

Five control regions (CRs) are defined to check the background modelling in different channels: WZ +jets (3ℓ channel), ZZ +jets (4ℓ channel), Z +jets (3ℓ channel), and two $t\bar{t}Z$ CRs (one for the 3ℓ channel and the other for the 4ℓ channel). The two $t\bar{t}Z$ CRs are orthogonal to each other due to the requirement on the number of leptons in the event.

The WZ +jets CR is defined with the same set of selection criteria as used for the inclusive 3ℓ SRs except for a requirement that the BDT score (described in Section 4), be less than 0.42. The purity of WZ events in this CR is $\sim 76\%$. The ZZ +jets CR has the same selection criteria as used in the 4ℓ -SF-inZ SR except the E_T^{miss} requirement is reversed to have $E_T^{\text{miss}} < 10$ GeV. The purity of ZZ events in this CR is $\sim 99\%$. In addition, the two 3ℓ SRs (3ℓ -1j and 3ℓ -2j-inV) and the two 4ℓ SRs (4ℓ -SF-inZ and 4ℓ -SF-outZ) with significant contributions from the WZ +jets and ZZ +jets processes, help constrain the estimates for these two background processes.

The Z +jets CR has the same selection criteria as used in the 3ℓ -1j SR except the W -lepton is required to have $8 < p_T < 15$ GeV, the invariant mass of the three charged leptons is required to be below 150 GeV, and there is exactly one jet reconstructed in the event and this jet is not tagged as a b -jet. The purity of Z +jets events in this CR is $\sim 72\%$.

The $t\bar{t}Z$ CR in the 3ℓ channel is defined in the same way as the signal region, with the exception that at least four jets are required, of which at least two are b -tagged. The purity of $t\bar{t}Z$ events in this CR is $\sim 66\%$. The $t\bar{t}Z$ CR in the 4ℓ channel is defined in the same way as the 4ℓ -SF-inZ SR, with the exception that at least one b -jet be present in the event. The purity of $t\bar{t}Z$ in this CR is $\sim 74\%$.

The data-driven method used to estimate the fake background in the 4ℓ and 5ℓ channels defines lepton-like jets by requiring the leptons to meet a looser selection criterion but fail to meet the signal-lepton requirement. Compared with the signal leptons, muon-like jets have to satisfy the “Loose” quality requirement and electron-like jets have to satisfy the “Loose” quality requirement based on the electron likelihood discriminant and have at least one hit in the innermost pixel layer for the 4ℓ channel, while both muon-like and electron-like jets are required to satisfy a looser quality requirement for the 5ℓ channel. In addition, $|d_0|/\sigma_{d_0}$ is required to be less than 10 and no requirements are applied on the isolation variables for both muon-like and electron-like jets. Events containing up to two lepton-like jets are weighted by a “fake factor” to predict the non-prompt lepton background contribution, selected from data for the 4ℓ channel and from MC simulation for the 5ℓ channel. The fake factor is the ratio of the number of non-prompt leptons satisfying the signal lepton criteria over the number satisfying the lepton-like jet criteria. Its value is derived from data samples enriched in Z +jets and $t\bar{t}$ production. For the 4ℓ channel, the dominant fake background originates from the WZ +jets process where most jets are light-flavour jets. For the 5ℓ channel, the dominant fake background originates from both ZZ +jets and $t\bar{t}Z$ processes where jets are a mixture of light-flavour and heavy-flavour jets. The fake factor measured in the Z +jets sample is thus used for the fake background estimate for the 4ℓ channel, while the fake factors measured in the Z +jets and $t\bar{t}$ samples are combined according to the light-flavour to heavy-flavour background ratio expected in the SR for the 5ℓ channel.

The normalisations of simulated WZ +jets, ZZ +jets, Z +jets, and $t\bar{t}Z$ backgrounds are determined from data in the likelihood fits of SRs and CRs described in Section 4.

4. Signal extraction and combination

The 3ℓ , 4ℓ , and 5ℓ regions are combined using the profile likelihood method based on a simultaneous fit to distributions in the SRs and CRs. Seven SRs defined in Section 3.2 and five CRs defined in Section 3.3 are used in the fit. The distributions used in the fit are the seven BDT distributions for the seven SRs and the jet multiplicity distributions in the WZ +jets and ZZ +jets CRs. The number of selected events in the Z +jets CR, the $t\bar{t}Z$ CR in the 3ℓ channel, and the $t\bar{t}Z$ CR in the 4ℓ channel are each included as a single bin in the fit.

For the signal BDT distributions, a total of 58 bins are used: 10 bins for each SR of the 3ℓ channels, 10 bins collectively for the 4ℓ -DF channels, eight bins each for the 4ℓ -SF-inZ and 4ℓ -SF-outZ channels, and two bins for the 5ℓ channel. For the CR distributions, a total of nine bins are used: three bins each for the WZ (1, 2, or ≥ 3 jets) and ZZ

Table 5

Data and post-fit predicted yields for all SRs. Uncertainties in the predictions include both statistical and systematic uncertainties added in quadrature; correlations among systematic uncertainties are taken into account in the calculation of the total uncertainties.

Signal region	3 ℓ -1j	3 ℓ -2j-inV	3 ℓ -2j-outV	4 ℓ -DF	4 ℓ -SF-inZ	4 ℓ -SF-outZ	5 ℓ
VVZ	104 $\pm$ 17	99 $\pm$ 15	173 $\pm$ 27	26.7 $\pm$ 4.6	18.6 $\pm$ 2.1	26.8 $\pm$ 4.0	3.9 $\pm$ 0.6
WZ +jets	4271 $\pm$ 91	932 $\pm$ 26	2656 $\pm$ 81	—	—	—	—
ZZ +jets	547 $\pm$ 46	113 $\pm$ 14	239 $\pm$ 27	19.7 $\pm$ 1.2	1447 $\pm$ 35	383.2 $\pm$ 9.9	—
Z +jets	130 $\pm$ 43	35 $\pm$ 12	59 $\pm$ 18	—	—	—	—
$i\bar{i}Z$	8.2 $\pm$ 1.0	35.5 $\pm$ 3.1	92.5 $\pm$ 7.0	8.3 $\pm$ 0.9	1.8 $\pm$ 0.2	7.0 $\pm$ 0.7	—
Fake	—	—	—	6.5 $\pm$ 2.0	14.5 $\pm$ 8.5	11.6 $\pm$ 4.2	4.9 $\pm$ 0.6
Others	219 $\pm$ 12	65.1 $\pm$ 5.5	221 $\pm$ 12	4.5 $\pm$ 0.4	12.2 $\pm$ 0.4	10.7 $\pm$ 0.4	—
Total expected	5280 $\pm$ 68	1278 $\pm$ 28	3440 $\pm$ 54	65.8 $\pm$ 5.1	1494 $\pm$ 34	439 $\pm$ 10	8.9 $\pm$ 0.9
Data	5273	1280	3423	65	1513	429	13

(0, 1, or ≥ 2 jets) CRs, and one bin each for the Z +jets CR, the $i\bar{i}Z$ CR in the 3 ℓ channel, and the $i\bar{i}Z$ CR in the 4 ℓ channel. In total, 67 bins are used in the combined fit.

A binned likelihood function [59] is constructed as a product of Poisson probability terms over all bins considered. This likelihood function depends on the signal-strength parameter μ , a multiplicative factor that scales the expected number of signal events, and θ , a set of nuisance parameters that encode the effect of systematic uncertainties in the signal and background expectations [58]. The nuisance parameters are implemented in the likelihood function as Gaussian, log-normal or Poisson constraints, depending on their origin. Correlations of systematic uncertainties arising from common sources are maintained across processes and channels.

The fit includes nine unconstrained parameters that scale the number of events for a particular process predicted by MC simulation: the signal strength μ , three scale factors ($\mu_{WZ+1\text{ jets}}$, $\mu_{WZ+2\text{ jet}}$, and $\mu_{WZ+\geq 3\text{ jets}}$) for WZ + 1 jets, WZ + 2 jet, and WZ + ≥ 3 jets, three scale factors ($\mu_{ZZ+0\text{ jets}}$, $\mu_{ZZ+1\text{ jet}}$, and $\mu_{ZZ+\geq 2\text{ jets}}$) for ZZ + 0 jets, ZZ + 1 jet, and ZZ + ≥ 2 jets, one scale factor ($\mu_{Z+\text{jets}}$) for the Z +jets process, and one scale factor ($\mu_{i\bar{i}Z}$) for the $i\bar{i}Z$ process. For the combined fit, the same value for $\mu = \mu_{VVZ}$ is assumed for the WWZ , WZZ and ZZZ processes. The ratio of on-shell VVZ production to $VH \rightarrow VWW^*/VZZ^*$ production is determined from MC simulation and is allowed to vary within the theoretical uncertainties of the two processes.

Experimental uncertainties are related to the lepton trigger, reconstruction and identification efficiencies [54,60], lepton isolation criteria [55], lepton energy (momentum) scale and resolution [60,61], jet energy scale and resolution [62], jet vertex tagging [51], b -tagging [63–65], modelling of pile-up and missing transverse momentum [53], and integrated luminosity [15,66]. Nuisance parameters related to these uncertainties are treated as correlated between all channels.

For each of the background processes evaluated using simulation, a nuisance parameter representing its normalisation uncertainty is included. For dominant backgrounds from the WZ +jets and ZZ +jets processes, the simultaneous fit model has the power to constrain their normalisations at the $\sim 5\%$ level.

Uncertainties in data-driven background evaluations mainly come from statistical and systematic uncertainties in the lepton fake factor measurement. Additional uncertainties come from the statistical uncertainties of the subsamples used to extrapolate the background evaluations to the SRs. Nuisance parameters are treated as correlated for backgrounds evaluated using the same method and from the same sources of systematic uncertainty.

Shape-only variations of the signal and simulation-based background distributions due to QCD renormalisation and factorisation scales, PDF, and parton-shower matching scales are considered in the simultaneous fit. The corresponding nuisance parameters for the signal distributions are treated as correlated between the WWZ , WZZ and ZZZ channels.

Table 5 shows the post-fit background, signal, and observed yields for all SRs. The three most sensitive channels are 3 ℓ -2j-outV, 4 ℓ -DF, and 5 ℓ . The fitted scale factors for various background processes are: $\mu_{WZ+1\text{ jets}} = 1.03 \pm 0.11$, $\mu_{WZ+2\text{ jet}} = 0.95 \pm 0.16$, $\mu_{WZ+\geq 3\text{ jets}} = 0.95 \pm 0.26$, $\mu_{ZZ+0\text{ jets}} = 1.03 \pm 0.10$, $\mu_{ZZ+1\text{ jet}} = 0.99 \pm 0.13$, $\mu_{ZZ+\geq 2\text{ jets}} = 0.84 \pm 0.24$, $\mu_{Z+\text{jets}} = 0.83 \pm 0.10$, and $\mu_{i\bar{i}Z} = 1.31 \pm 0.17$. Contributions from SM processes producing the same detector signature as events in these SRs besides those listed are combined into “Others”. The uncertainties shown include both statistical and systematic uncertainties. Data and predictions agree within uncertainties in all channels. The contribution of the VH process to the VVZ yield depends on the decay channel and ranges between 3% (for 4 ℓ -SF-inZ) and 50% (for 3 ℓ -1j) in the seven SRs.

Fig. 2 shows the comparison of the observed number of events to the predicted yields after fitting for both SRs and CRs. Fig. 3 shows the comparison of the BDT distribution between data and predictions for all seven SRs. The two variables with the highest discriminating power are: H_T^{tot} (scalar sum of the p_T of leptons and jets) and the second leading jet p_T for the 3 ℓ -2j-outV channel, the invariant mass of the second Z -lepton pair and the jet multiplicity for the 4 ℓ -DF channel, and the E_T^{miss} significance and the W -lepton p_T for the 5 ℓ channel.

Additional fits are performed separately to determine the signal strength of the WWZ process (μ_{WWZ}) and the WZZ process (μ_{WZZ}). Due to limited statistics, there are no specific SRs defined for ZZZ production, and thus no separate fit is performed to determine the signal strength of the ZZZ process. For these fits the other signal strength is fixed to its SM expectation.

The measured signal strengths combined with the SM predicted cross sections are used to derive the measured cross sections of various processes. The combined observed (expected) signal strength for the VVZ process is $\mu_{VVZ} = 1.43 \pm 0.20$ (stat.) $^{+0.21}_{-0.19}$ (syst.) (1.00 $^{+0.27}_{-0.25}$). The measured cross section is found to be 660 $^{+93}_{-90}$ (stat.) $^{+88}_{-81}$ (syst.) fb and the observed (expected) significance corresponds to 6.4 (4.7) σ , marking the observation of VVZ production. The observed (expected) significance of WWZ production is 4.4 (3.6) σ , representing the evidence of this process at the LHC. Table 6 shows the measured signal strengths, cross sections and observed (expected) sensitivities for the VVZ , WWZ , and WZZ processes. The systematic uncertainties in the measured signal strengths are dominated by QCD scale uncertainties in the signal processes, uncertainties in reconstructed jet energy scale, resolution and b -tagging, and limited MC statistics of the signal samples.

If VH production is considered as part of the background, the combined observed cross section is found to be $\sigma(pp \rightarrow VVZ) = 382^{+65}_{-63}$ (stat.) $^{+57}_{-60}$ (syst.) fb with an observed signal strength of 1.59 $^{+0.24}_{-0.29}$ (stat.) $^{+0.30}_{-0.25}$ (syst.). The observed (expected) significance corresponds to 5.5 (3.7) σ . The ratio of on-shell VVZ production to $VH \rightarrow VWW^*/VZZ^*$ production is determined from MC simulation and is allowed to vary within the theoretical uncertainties of the two processes.

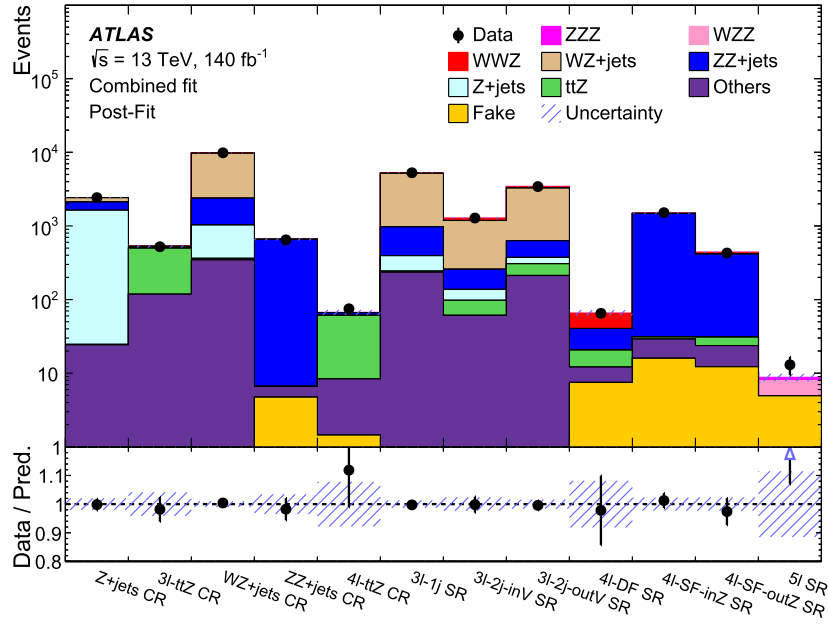


Fig. 2. Comparison of the observed numbers of events to the predicted yields after fitting for all SRs and CRs. The bottom panel shows the ratio of the data and SM predictions. The uncertainty band includes both statistical and systematic uncertainties obtained by the fit.

Table 6

Measured signal strengths and inclusive cross sections and observed (expected) sensitivities for WWZ , WZZ , and VVZ production. The uncertainties listed are statistical and systematic.

Process	Signal strength	Cross section (fb)	Observed (expected) sensitivity
VVZ	$1.43 \pm 0.20(\text{stat.})^{+0.21}_{-0.19}(\text{syst.})$	$660^{+93}_{-90}(\text{stat.})^{+88}_{-81}(\text{syst.})$	6.4 (4.7) σ
WWZ	$1.33 \pm 0.28(\text{stat.})^{+0.21}_{-0.17}(\text{syst.})$	$442 \pm 94(\text{stat.})^{+60}_{-52}(\text{syst.})$	4.4 (3.6) σ
WZZ	$2.13^{+1.18}_{-0.96}(\text{stat.})^{+0.76}_{-0.41}(\text{syst.})$	$200^{+111}_{-91}(\text{stat.})^{+65}_{-37}(\text{syst.})$	2.8 (1.6) σ

Table 7

The observed (expected) non-unitarised limits on Wilson coefficients for the 3ℓ and 4ℓ channels separately, and the combined limits.

Observed (expected) 95% CL limits on Wilson coefficients (TeV^{-4})			
Coefficient	3ℓ	4ℓ	Combination
f_{M2}/Λ^4	$[-15, 15]$ ($[-17, 17]$)	$[-23, 23]$ ($[-18, 18]$)	$[-15, 15]$ ($[-14, 14]$)
f_{M3}/Λ^4	$[-25, 25]$ ($[-29, 30]$)	$[-39, 40]$ ($[-31, 31]$)	$[-26, 26]$ ($[-25, 25]$)
f_{M4}/Λ^4	$[-13, 14]$ ($[-16, 16]$)	$[-17, 17]$ ($[-16, 16]$)	$[-11, 11]$ ($[-13, 13]$)
f_{M5}/Λ^4	$[-11, 11]$ ($[-13, 13]$)	$[-12, 12]$ ($[-13, 13]$)	$[-8.5, 8.7]$ ($[-10, 10]$)

Table 8

The observed and expected unitarised limits on Wilson coefficients for the combination of the 3ℓ and 4ℓ channels on dimension 8 operator Wilson coefficients, together with the energy scale at which the unitarity bound is crossed.

Coefficient	Expected limit [TeV^{-4}]	Exp. $\sqrt{\hat{s}_c}$ [TeV]	Observed limit [TeV^{-4}]	Obs. $\sqrt{\hat{s}_c}$ [TeV]
f_{M2}/Λ^4	$[-18, 17]$	1.2	$[-19, 19]$	1.2
f_{M3}/Λ^4	$[-28, 29]$	1.5	$[-28, 29]$	1.5
f_{M4}/Λ^4	$[-14, 14]$	1.6	$[-12, 12]$	1.7
f_{M5}/Λ^4	$[-11, 11]$	2.1	$[-9.1, 9.3]$	2.2

5. EFT analysis

The production of three massive vector bosons allows to study the quartic vector boson vertex. The EFT approach was chosen to constrain physics beyond the SM at higher mass scales. The EFT extends the SM Lagrangian with additional terms of higher dimensions,

$$\mathcal{L}_{SMEFT} = \mathcal{L}_{SM} + \mathcal{L}^{(5)} + \mathcal{L}^{(6)} + \mathcal{L}^{(7)} + \dots,$$

$$\text{where } \mathcal{L}^{(d)} = \sum_{i=1}^{n_d} \frac{f_i^{(d)}}{\Lambda^{d-4}} \mathcal{O}_i^{(d)} \quad \text{for } d > 4, \quad (1)$$

with f_i the Wilson coefficient, d the dimension of the operator, Λ an arbitrary energy scale set to 1 TeV, and $\mathcal{O}_i$ the EFT operator extending the SM. The Eboli parameterisation [35] is used, where the lowest dimension operators acting on the quartic gauge boson vertex are of dimension 8 with the assumption of a light Higgs boson and thus a linear realisation of the $SU(2)_L \otimes U(1)_Y$ symmetry breaking [35]. The Wil-

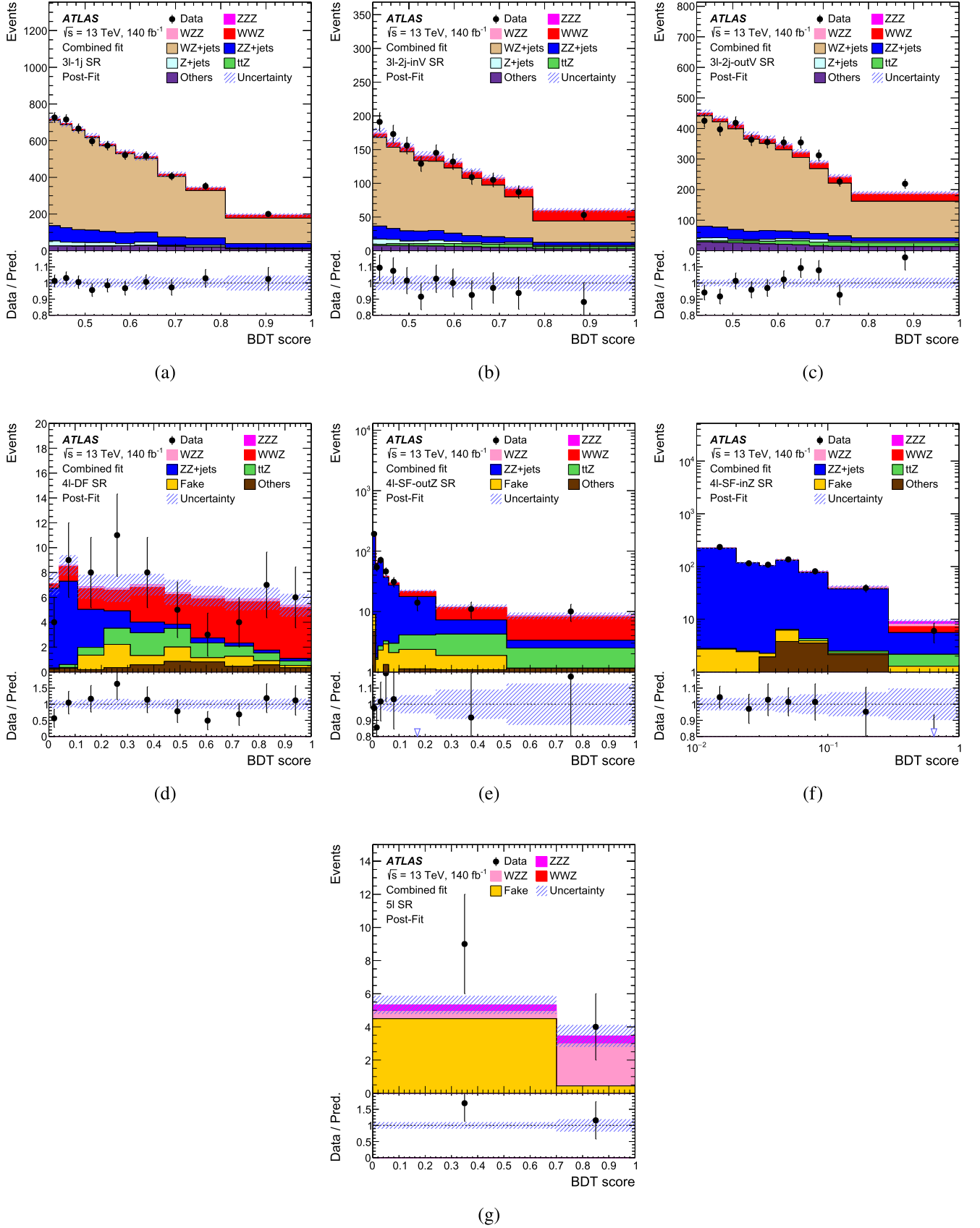


Fig. 3. Comparison of the BDT distribution between data and predictions for the (a) $3\ell-1j$, (b) $3\ell-2j\text{-inV}$, (c) $3\ell-2j\text{-outV}$, (d) $4\ell\text{-DF}$, (e) $4\ell\text{-SF-outZ}$, (f) $4\ell\text{-SF-inZ}$, and (g) 5ℓ SRs. The bottom panel shows the ratio of the data and SM predictions. The uncertainty band includes both statistical and systematic uncertainties obtained by the fit.

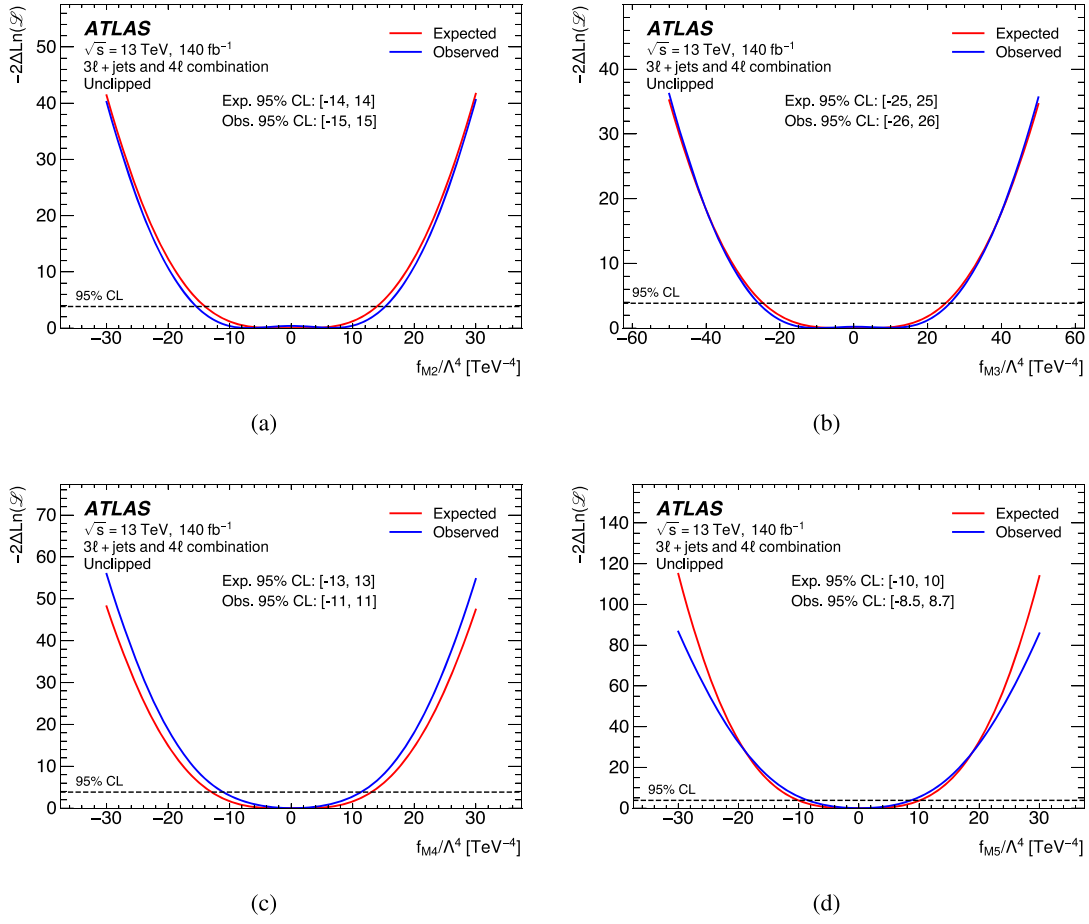


Fig. 4. The combined 3ℓ +jets and 4ℓ channel log-likelihood curves for the Wilson coefficients (a) f_{M2} , (b) f_{M3} , (c) f_{M4} , and (d) f_{M5} . Expected and observed log-likelihood curves are shown, no unitarisation is applied.

son coefficients of the most sensitive operators to massive tri-boson final states are f_{M2} , f_{M3} , f_{M4} , and f_{M5} . One dimensional limits are derived by allowing only one coefficient to vary from zero and setting constraints using multivariate techniques, combining the 3ℓ and 4ℓ channels in a simultaneous fit. To account for QCD NLO corrections a k -factor is applied to the EFT MC samples. To increase the sensitivity to EFT effects, a BDT is trained on events with contributions from all EFT operators under consideration. The training is repeated for each signal region in the 3ℓ and 4ℓ channels, following the same approach as described in Section 3.2.

The EFT expectation is parameterised as

$$N_{b,H}(\mathbf{f}, \theta) = \sum_p \sum_d N_b^{pd, \text{SM}}(\theta) \left(1 + \sum_i A_{bi}^{pd} f_i + \sum_i B_{bi}^{pd} f_i^2 + \sum_{i < j} C_{bij}^{pd} f_i f_j \right) + N_b^{\text{bkg, SM}}(\theta), \quad (2)$$

with expected number of events, $N_{b,H}$ for a bin b with Wilson coefficients $\mathbf{f}$, and the nuisance parameters θ . The expected number of SM events in tri-boson process p and decay channel d is $N_b^{pd, \text{SM}}(\theta)$, with expected number of background events $N_b^{\text{bkg, SM}}(\theta)$. The EFT contributions are modelled with A_{bi}^{pd} , B_{bi}^{pd} and C_{bij}^{pd} [67]. The likelihood is constructed as

$$L(N | \mathbf{f}, \theta) = \prod_b \left(\frac{N_b^{N_b} e^{-N_b}}{N_b!} \right) \times \prod_{i=1}^{n_{\text{sys}}} \xi_i(\theta_i), \quad (3)$$

with N signal events per bin over a total number of bins n_{bins} and ξ_i the constraints on each nuisance parameter, n_{sys} , to account for the experimental systematic uncertainties. The one dimensional 95% confidence level (CL) limits on the Wilson coefficients f_i are then extracted using a profile likelihood ratio test allowing only the coefficient under consideration to vary while setting the other coefficients to zero. The expected and observed 95% CL limits for the 3ℓ and 4ℓ channel separately and combined, including statistical and systematic uncertainties, are shown in Table 7. The combined log-likelihood curves for the Wilson coefficients f_{M2} , f_{M3} , f_{M4} , and f_{M5} are shown in Fig. 4.

The unitarity bounds of the Wilson coefficients were estimated by adapting the existing calculation for dimension-8 operators in two-to-two scattering process into vector boson scattering processes [68] and setting the parton centre-of-mass energy $\sqrt{s}$ to the maximum of the three diboson invariant mass combinations $m_{\text{max}}(V_i V_j)$. The limits are then derived as a function of the clipping parameter $\sqrt{s_c}$, where the EFT contribution in events with $m_{\text{max}}(V_i V_j) > \sqrt{s_c}$ is set to zero. The clipping scans [69] for the Wilson coefficients f_{M2} , f_{M3} , f_{M4} , and f_{M5} are shown in Fig. 5 together with the unitarity limits. The most constraining limit respecting unitarity is found at the intersection of the calculated limit with the unitarity bound, and listed for all operators in Table 8. These constraints are comparable to published limits derived in the $W\gamma jj$ final state [70,71].

6. Conclusions

A search for the joint production of three massive vector bosons (WWZ , WZZ , and ZZZ) is presented using 140 fb^{-1} of data at $\sqrt{s} = 13 \text{ TeV}$ collected by the ATLAS detector at the LHC. Events with

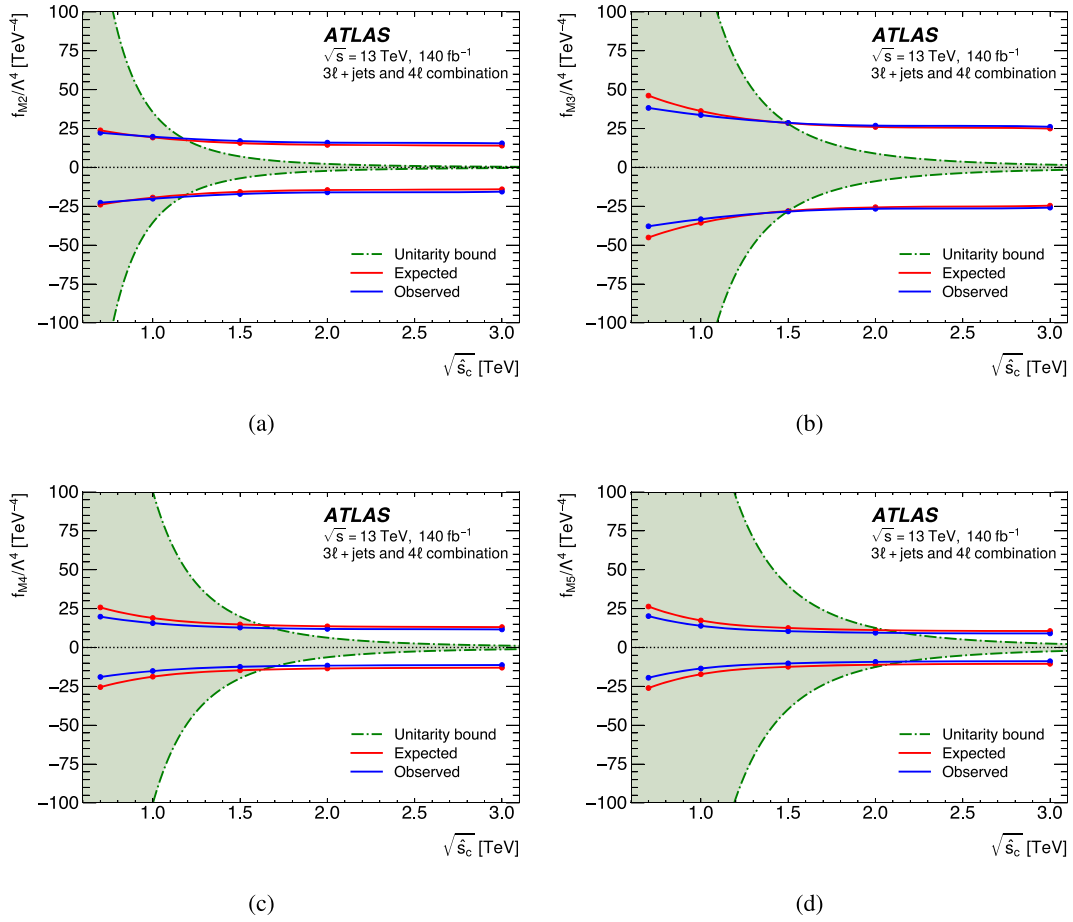


Fig. 5. The clipping scans for the Wilson coefficients (a) f_{M2} , (b) f_{M3} , (c) f_{M4} , and (d) f_{M5} are shown together with the unitarity limits as a function of the clipping parameter $\sqrt{s_c}$, where the EFT contribution in events with $m_{\max}(V_i V_j) > \sqrt{s_c}$ is set to zero.

three, four, or five or more reconstructed electrons and muons are analysed. The measured cross section for the $pp \rightarrow VVZ$ process is $660^{+93}_{-90}(\text{stat.})^{+88}_{-81}(\text{syst.})$ fb, and the observed (expected) significance is 6.4 (4.7) standard deviations, representing the first observation of VVZ production. In addition, the measured cross section for the $pp \rightarrow WWZ$ process is $442 \pm 94(\text{stat.})^{+60}_{-52}(\text{syst.})$ fb, and the observed (expected) significance is 4.4 (3.6) standard deviations, representing evidence of WWZ production. The measured cross sections are consistent with the SM predictions. Constraints on physics beyond the SM are also derived in the EFT framework by setting limits on Wilson coefficients for dimension-8 operators describing anomalous quartic gauge boson couplings. The constraints are comparable to published limits in the $W\gamma jj$ final state.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

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

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

wide and large non-WLCG resource providers. Major contributors of computing resources are listed in Ref. [72].

We gratefully acknowledge the support of ANPCyT, Argentina; YerPhI, Armenia; ARC, Australia; BMWFW and FWF, Austria; ANAS, Azerbaijan; CNPq and FAPESP, Brazil; NSERC, NRC and CFI, Canada; CERN; ANID, Chile; CAS, MOST and NSFC, China; Minciencias, Colombia; MEYS CR, Czech Republic; DNRf and DNSRC, Denmark; IN2P3-CNRS and CEA-DRF/IRFU, France; SRNSFG, Georgia; BMBF, HGF and MPG, Germany; GSRI, Greece; RGC and Hong Kong SAR, China; ICHEP and Academy of Sciences and Humanities, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; NWO, Netherlands; RCN, Norway; MNiSW, Poland; FCT, Portugal; MNE/IFA, Romania; MSTDI, Serbia; MSSR, Slovakia; ARIS and MVZI, Slovenia; DSI/NRF, South Africa; MICIU/AEI, Spain; SRC and Wallenberg Foundation, Sweden; SERI, SNSF and Cantons of Bern and Geneva, Switzerland; NSTC, Taipei; TENMAK, Türkiye; STFC/UKRI, United Kingdom; DOE and NSF, United States of America.

Individual groups and members have received support from BCKDF, CANARIE, CRC and DRAC, Canada; CERN-CZ, FORTE and PRIMUS, Czech Republic; COST, ERC, ERDF, Horizon 2020, ICSC-NextGenerationEU and Marie Skłodowska-Curie Actions, European Union; Investissements d'Avenir Labex, Investissements d'Avenir IDEX and ANR, France; DFG and AvH Foundation, Germany; Herakleitos, Thales and Aristeia programmes co-financed by EU-ESF and the Greek NSRF, Greece; BSF-NSF and MINERVA, Israel; NCN and NAWA, Poland; La Caixa Banking Foundation, CERCA Programme Generalitat de Catalunya and PROMETEO and GenT Programmes Generalitat Valenciana, Spain; Göran Gustafssons Stiftelse, Sweden; The Royal Society and Leverhulme Trust, United Kingdom.

In addition, individual members wish to acknowledge support from Armenia: Yerevan Physics Institute (FAPERJ); CERN: European Organization for Nuclear Research (CERN DOCT); Chile: Agencia Nacional de Investigación y Desarrollo (FONDECYT 1230812, FONDECYT 1230987, FONDECYT 1240864); China: Chinese Ministry of Science and Technology (MOST-2023YFA1605700, MOST-2023YFA1609300), National Natural Science Foundation of China (NSFC - 12175119, NSFC 12275265, NSFC-12075060); Czech Republic: Czech Science Foundation (GACR - 24-11373S), Ministry of Education Youth and Sports (ERC-CZ-LL2327, FORTE CZ.02.01.01/00/22_008/0004632), PRIMUS Research Programme (PRIMUS/21/SCI/017); EU: H2020 European Research Council (ERC - 101002463); European Union: European Research Council (ERC - 948254, ERC 101089007, ERC, BARD, 101116429), Horizon 2020 Framework Programme (MUCCA - CHIST-ERA-19-XAI-00), European Union, Future Artificial Intelligence Research (FAIR-NextGenerationEU PE00000013), Italian Center for High Performance Computing, Big Data and Quantum Computing (ICSC, NextGenerationEU); France: Agence Nationale de la Recherche (ANR-20-CE31-0013, ANR-21-CE31-0013, ANR-21-CE31-0022, ANR-22-EDIR-0002); Germany: Baden-Württemberg Stiftung (BW Stiftung-Postdoc Eliteprogramme), Deutsche Forschungsgemeinschaft (DFG - 469666862, DFG - CR 312/5-2); Italy: Istituto Nazionale di Fisica Nucleare (ICSC, NextGenerationEU), Ministero dell'Università e della Ricerca (NextGenEU PRIN20223N7F8K M4C2.1.1); Japan: Japan Society for the Promotion of Science (JSPS KAKENHI JP22H01227, JSPS KAKENHI JP22H04944, JSPS KAKENHI JP22KK0227, JSPS KAKENHI JP23KK0245); Norway: Research Council of Norway (RCN-314472); Poland: Ministry of Science and Higher Education (IDUB AGH, POB8, D4 no 9722), Polish National Agency for Academic Exchange (PPN/PPO/2020/1/00002/U/00001), Polish National Science Centre (NCN 2021/42/E/ST2/00350, NCN OPUS 2023/51/B/ST2/02507, NCN OPUS nr 2022/47/B/ST2/03059, NCN UMO-2019/34/E/ST2/00393, UMO-2020/37/B/ST2/01043, UMO-2021/40/C/ST2/00187, UMO-2022/47/O/ST2/00148, UMO-2023/49/B/ST2/04085, UMO-2023/51/B/ST2/00920); Portugal: Foundation for Science and Technology (FCT); Spain: Generalitat Valenciana (Artemisa, FEDER, IDIFEDER/2018/048), Ministry of Science and Innovation (MCIN & NextGenEU PCI2022-135018-2, MICIN & FEDER PID2021-125273NB, RYC2019-028510-I, RYC2020-030254-I, RYC2021-031273-I, RYC2022-038164-I); Sweden: Carl Trygger Foundation (Carl Trygger Foundation CTS 22:2312), Swedish Research Council (Swedish Research Council 2023-04654, VR 2018-00482, VR 2021-03651, VR 2022-03845, VR 2022-04683, VR 2023-03403), Knut and Alice Wallenberg Foundation (KAW 2018.0458, KAW 2019.0447, KAW 2022.0358); Switzerland: Swiss National Science Foundation (SNSF - PCEFP2_194658); United Kingdom: Leverhulme Trust (Leverhulme Trust RPG-2020-004), Royal Society (NIF-R1-231091); United States of America: U.S. Department of Energy (ECA DE-AC02-76SF00515), Neubauer Family Foundation.

Data availability

The data for this manuscript are not available. The values in the plots and tables associated to this article are stored in HEPDATA (<https://hepdata.cedar.ac.uk>).

References

- [1] A.S. Belyaev, et al., Strongly interacting vector bosons at the CERN LHC: quartic anomalous couplings, *Phys. Rev. D* 59 (1999) 015022, arXiv:hep-ph/9805229.
- [2] C. Du, et al., Discovering new gauge bosons of electroweak symmetry breaking at LHC-8, *Phys. Rev. D* 86 (2012) 095011, arXiv:1206.6022 [hep-ph].
- [3] S. Fichtel, G. von Gersdorff, Anomalous gauge couplings from composite Higgs and warped extra dimensions, *J. High Energy Phys.* 03 (2014) 102, arXiv:1311.6815 [hep-ph].
- [4] G.F. Giudice, C. Grojean, A. Pomarol, R. Rattazzi, The strongly-interacting light Higgs, *J. High Energy Phys.* 06 (2007) 045, arXiv:hep-ph/0703164.
- [5] ATLAS Collaboration, Observation of electroweak production of a same-sign W boson pair in association with two jets in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, *Phys. Rev. Lett.* 123 (2019) 161801, arXiv:1906.03203 [hep-ex].
- [6] CMS Collaboration, Measurements of production cross sections of WZ and same-sign WW boson pairs in association with two jets in proton-proton collisions at $\sqrt{s} = 13$ TeV, *Phys. Lett. B* 809 (2020) 135710, arXiv:2005.01173 [hep-ex].
- [7] L. Evans, P. Bryant, LHC machine, *J. Instrum.* 3 (2008) S08001.
- [8] ATLAS Collaboration, The ATLAS experiment at the CERN Large Hadron Collider, *J. Instrum.* 3 (2008) S08003.
- [9] CMS Collaboration, The CMS experiment at the CERN LHC, *J. Instrum.* 3 (2008) S08004.
- [10] ATLAS Collaboration, Evidence for the production of three massive vector bosons with the ATLAS detector, *Phys. Lett. B* 798 (2019) 134913, arXiv:1903.10415 [hep-ex].
- [11] ATLAS Collaboration, Observation of WWW production in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, *Phys. Rev. Lett.* 129 (2022) 061803, arXiv:2201.13045 [hep-ex].
- [12] CMS Collaboration, Observation of the production of three massive gauge bosons at $\sqrt{s} = 13$ TeV, *Phys. Rev. Lett.* 125 (2020) 151802, arXiv:2006.11191 [hep-ex].
- [13] ATLAS Collaboration, Performance of the ATLAS trigger system in 2015, *Eur. Phys. J. C* 77 (2017) 317, arXiv:1611.09661 [hep-ex].
- [14] ATLAS Collaboration, Software and computing for run 3 of the ATLAS experiment at the LHC, arXiv:2404.06335 [hep-ex], 2024.
- [15] ATLAS Collaboration, Luminosity determination in pp collisions at $\sqrt{s} = 13$ TeV using the ATLAS detector at the LHC, *Eur. Phys. J. C* 83 (2023) 982, arXiv:2212.09379 [hep-ex].
- [16] ATLAS Collaboration, The ATLAS simulation infrastructure, *Eur. Phys. J. C* 70 (2010) 823, arXiv:1005.4568 [physics.ins-det].
- [17] S. Agostinelli, et al., Geant4 – a simulation toolkit, *Nucl. Instrum. Methods A* 506 (2003) 250.
- [18] T. Sjöstrand, S. Mrenna, P. Skands, A brief introduction to Pythia 8.1, *Comput. Phys. Commun.* 178 (2008) 852, arXiv:0710.3820 [hep-ph].
- [19] ATLAS Collaboration, The Pythia 8 A3 tune description of ATLAS minimum bias and inelastic measurements incorporating the Donnachie-Landshoff diffractive model, ATL-PHYS-PUB-2016-017, <https://cds.cern.ch/record/2206965>, 2016.
- [20] NNPDF Collaboration, R.D. Ball, et al., Parton distributions with LHC data, *Nucl. Phys. B* 867 (2013) 244, arXiv:1207.1303 [hep-ph].
- [21] ATLAS Collaboration, Multi-boson simulation for 13 TeV ATLAS analyses, ATL-PHYS-PUB-2017-005, <https://cds.cern.ch/record/2261933>, 2017.
- [22] E. Bothmann, et al., Event generation with Sherpa 2.2, *SciPost Phys.* 7 (2019) 034, arXiv:1905.09127 [hep-ph].
- [23] NNPDF Collaboration, R.D. Ball, et al., Parton distributions for the LHC run II, *J. High Energy Phys.* 04 (2015) 040, arXiv:1410.8849 [hep-ph].
- [24] S. Alioli, P. Nason, C. Oleari, E. Re, A general framework for implementing NLO calculations in shower Monte Carlo programs: the POWHEG BOX, *J. High Energy Phys.* 06 (2010) 043, arXiv:1002.2581 [hep-ph].
- [25] P. Nason, A new method for combining NLO QCD with shower Monte Carlo algorithms, *J. High Energy Phys.* 11 (2004) 040, arXiv:hep-ph/0409146.
- [26] S. Frixione, P. Nason, C. Oleari, Matching NLO QCD computations with parton shower simulations: the POWHEG method, *J. High Energy Phys.* 11 (2007) 070, arXiv:0709.2092 [hep-ph].
- [27] G. Cullen, et al., Automated one-loop calculations with GoSam, *Eur. Phys. J. C* 72 (2012) 1889, arXiv:1111.2034 [hep-ph].
- [28] K. Hamilton, P. Nason, G. Zanderighi, MINLO: multi-scale improved NLO, *J. High Energy Phys.* 10 (2012) 155, arXiv:1206.3572 [hep-ph].
- [29] G. Luisoni, P. Nason, C. Oleari, F. Tramontano, $HW^\pm/HZ + 0$ and 1 jet at NLO with the POWHEG BOX interfaced to GoSam and their merging within MINLO, *J. High Energy Phys.* 10 (2013) 083, arXiv:1306.2542 [hep-ph].
- [30] D.J. Lange, The EvtGen particle decay simulation package, *Nucl. Instrum. Methods A* 462 (2001) 152.
- [31] A. Lazopoulos, M.C. Melnikov, F. Petriello, QCD corrections to triboson production, *Phys. Rev. D* 76 (2007) 014001, arXiv:hep-ph/0703273.
- [32] T. Binoth, G. Ossola, C.G. Papadopoulos, R. Pittau, NLO QCD corrections to tri-boson production, *J. High Energy Phys.* 06 (2008) 082, arXiv:0804.0350 [hep-ph].
- [33] V. Hankele, D. Zeppenfeld, QCD corrections to hadronic WWZ production with leptonic decays, *Phys. Lett. B* 661 (2008) 103, arXiv:0712.3544 [hep-ph].
- [34] F. Campanario, V. Hankele, C. Oleari, S. Prestel, D. Zeppenfeld, QCD corrections to charged triple vector boson production with leptonic decay, *Phys. Rev. D* 78 (2008) 094012, arXiv:0809.0790 [hep-ph].
- [35] O.J.P. Éboli, M.C. Gonzalez-Garcia, J.K. Mizukoshi, $pp \rightarrow jj e^\pm \mu^\pm \nu \nu$ and $jj e^\pm \mu^\pm \nu \nu$ at $\mathcal{O}(\alpha_{\text{em}}^6)$ and $\mathcal{O}(\alpha_{\text{em}}^4 \alpha_s^2)$ for the study of the quartic electroweak gauge boson vertex at CERN LHC, *Phys. Rev. D* 74 (2006) 073005.
- [36] J. Alwall, et al., The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations, *J. High Energy Phys.* 07 (2014) 079, arXiv:1405.0301 [hep-ph].
- [37] T. Sjöstrand, et al., An introduction to Pythia 8.2, *Comput. Phys. Commun.* 191 (2015) 159, arXiv:1410.3012 [hep-ph].
- [38] ATLAS Collaboration, ATLAS Pythia 8 tunes to 7 TeV data, ATL-PHYS-PUB-2014-021, <https://cds.cern.ch/record/1966419>, 2014.
- [39] ATLAS Collaboration, Monte Carlo generators for the production of a W or Z/γ^* boson in association with jets at ATLAS in run 2, ATL-PHYS-PUB-2016-003, <https://cds.cern.ch/record/2120133>, 2016.

- [40] S. Frixione, G. Ridolfi, P. Nason, A positive-weight next-to-leading-order Monte Carlo for heavy flavour hadroproduction, *J. High Energy Phys.* 09 (2007) 126, arXiv:0707.3088 [hep-ph].
- [41] J. Alwall, et al., The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations, *J. High Energy Phys.* 07 (2014) 079, arXiv:1405.0301 [hep-ph].
- [42] E. Re, Single-top W -channel production matched with parton showers using the POWHEG method, *Eur. Phys. J. C* 71 (2011) 1547, arXiv:1009.2450 [hep-ph].
- [43] ATLAS Collaboration, Performance of the ATLAS muon triggers in run 2, *J. Instrum.* 15 (2020) P09015, arXiv:2004.13447 [physics.ins-det].
- [44] ATLAS Collaboration, Performance of electron and photon triggers in ATLAS during LHC run 2, *Eur. Phys. J. C* 80 (2020) 47, arXiv:1909.00761 [hep-ex].
- [45] ATLAS Collaboration, Reconstruction of primary vertices at the ATLAS experiment in run 1 proton–proton collisions at the LHC, *Eur. Phys. J. C* 77 (2017) 332, arXiv:1611.10235 [physics.ins-det].
- [46] ATLAS Collaboration, Electron and photon performance measurements with the ATLAS detector using the 2015–2017 LHC proton–proton collision data, *J. Instrum.* 14 (2019) P12006, arXiv:1908.00005 [hep-ex].
- [47] ATLAS Collaboration, Muon reconstruction and identification efficiency in ATLAS using the full run 2 pp collision data set at $\sqrt{s} = 13 \text{ TeV}$, *Eur. Phys. J. C* 81 (2021) 578, arXiv:2012.00578 [hep-ex].
- [48] M. Cacciari, G.P. Salam, G. Soyez, The anti- k_t jet clustering algorithm, *J. High Energy Phys.* 04 (2008) 063, arXiv:0802.1189 [hep-ph].
- [49] M. Cacciari, G.P. Salam, G. Soyez, FastJet user manual, *Eur. Phys. J. C* 72 (2012) 1896, arXiv:1111.6097 [hep-ph].
- [50] ATLAS Collaboration, Jet reconstruction and performance using particle flow with the ATLAS detector, *Eur. Phys. J. C* 77 (2017) 466, arXiv:1703.10485 [hep-ex].
- [51] ATLAS Collaboration, Performance of pile-up mitigation techniques for jets in pp collisions at $\sqrt{s} = 8 \text{ TeV}$ using the ATLAS detector, *Eur. Phys. J. C* 76 (2016) 581, arXiv:1510.03823 [hep-ex].
- [52] ATLAS Collaboration, ATLAS flavour-tagging algorithms for the LHC run 2 pp collision dataset, *Eur. Phys. J. C* 83 (2023) 681, arXiv:2211.16345 [physics.data-an].
- [53] ATLAS Collaboration, The performance of missing transverse momentum reconstruction and its significance with the ATLAS detector using 140 fb^{-1} of $\sqrt{s} = 13 \text{ TeV}$ pp collisions, arXiv:2402.05858 [hep-ex], 2024.
- [54] ATLAS Collaboration, Electron reconstruction and identification in the ATLAS experiment using the 2015 and 2016 LHC proton–proton collision data at $\sqrt{s} = 13 \text{ TeV}$, *Eur. Phys. J. C* 79 (2019) 639, arXiv:1902.04655 [physics.ins-det].
- [55] ATLAS Collaboration, Evidence for the associated production of the Higgs boson and a top quark pair with the ATLAS detector, *Phys. Rev. D* 97 (2018) 072003, arXiv:1712.08891 [hep-ex].
- [56] T. Chen, C. Guestrin, XGBoost: a scalable tree boosting system, arXiv:1603.02754 [cs.LG], 2016.
- [57] T. Gál, J. Ling, N. Amin, UnROOT: an I/O library for the CERN ROOT file format written in Julia, *J. Open Source Softw.* 7 (2022) 4452.
- [58] ATLAS Collaboration, Measurement of $W^\pm W^\pm$ vector-boson scattering and limits on anomalous quartic gauge couplings with the ATLAS detector, *Phys. Rev. D* 96 (2017) 012007, arXiv:1611.02428 [hep-ex].
- [59] K. Cranmer, G. Lewis, L. Moneta, A. Shibata, W. Verkerke, HistFactory: A tool for creating statistical models for use with RooFit and RooStats, CERN-OPEN-2012-016, 2012.
- [60] ATLAS Collaboration, Muon reconstruction performance of the ATLAS detector in proton–proton collision data at $\sqrt{s} = 13 \text{ TeV}$, *Eur. Phys. J. C* 76 (2016) 292, arXiv:1603.05598 [hep-ex].
- [61] ATLAS Collaboration, Electron and photon energy calibration with the ATLAS detector using LHC run 2 data, *J. Instrum.* 19 (2024) P02009, arXiv:2309.05471 [hep-ex].
- [62] ATLAS Collaboration, Jet energy scale and resolution measured in proton–proton collisions at $\sqrt{s} = 13 \text{ TeV}$ with the ATLAS detector, *Eur. Phys. J. C* 81 (2021) 689, arXiv:2007.02645 [hep-ex].
- [63] ATLAS Collaboration, ATLAS b -jet identification performance and efficiency measurement with $t\bar{t}$ events in pp collisions at $\sqrt{s} = 13 \text{ TeV}$, *Eur. Phys. J. C* 79 (2019) 970, arXiv:1907.05120 [hep-ex].
- [64] ATLAS Collaboration, Measurement of the c -jet mistagging efficiency in $t\bar{t}$ events using pp collision data at $\sqrt{s} = 13 \text{ TeV}$ collected with the ATLAS detector, *Eur. Phys. J. C* 82 (2022) 95, arXiv:2109.10627 [hep-ex].
- [65] ATLAS Collaboration, Calibration of the light-flavour jet mistagging efficiency of the b -tagging algorithms with Z +jets events using 139 fb^{-1} of ATLAS proton–proton collision data at $\sqrt{s} = 13 \text{ TeV}$, *Eur. Phys. J. C* 83 (2023) 728, arXiv:2301.06319 [hep-ex].
- [66] G. Avoni, et al., The new LUCID-2 detector for luminosity measurement and monitoring in ATLAS, *J. Instrum.* 13 (2018) P07017.
- [67] ATLAS Collaboration, Combined effective field theory interpretation of Higgs boson and weak boson production and decay with ATLAS data and electroweak precision observables, ATL-PHYS-PUB-2022-037, <https://cds.cern.ch/record/2816369>, 2022.
- [68] E. d. S. Almeida, O.J.P. Éboli, M.C. Gonzalez-Garcia, Unitarity constraints on anomalous quartic couplings, *Phys. Rev. D* 101 (2020) 113003, arXiv:2004.05174 [hep-ph].
- [69] M. Szleper, et al., EFT validity issues in vector boson scattering processes, PoS LHCP2020 (2020) 023.
- [70] ATLAS Collaboration, Fiducial and differential cross-section measurements of electroweak $W\gamma jj$ production in pp collisions at $\sqrt{s} = 13 \text{ TeV}$ with the ATLAS detector, *Eur. Phys. J. C* 84 (2024) 1064, arXiv:2403.02809 [hep-ex].
- [71] CMS Collaboration, Measurement of the electroweak production of $W\gamma$ in association with two jets in proton–proton collisions at $\sqrt{s} = 13 \text{ TeV}$, *Phys. Rev. D* 108 (2023) 032017, arXiv:2212.12592 [hep-ex].
- [72] ATLAS Collaboration, ATLAS computing acknowledgements, ATL-SOFT-PUB-2025-001, <https://cds.cern.ch/record/2922210>, 2025.

The ATLAS Collaboration

G. Aad^{105, }, E. Aakvaag^{17, }, B. Abbott^{124, }, S. Abdelhameed^{120a, }, K. Abeling^{56, }, N.J. Abicht^{50, }, S.H. Abidi^{30, }, M. Aboeela^{46, }, A. Aboulhorma^{36e, }, H. Abramowicz^{158, }, Y. Abulaiti^{121, }, B.S. Acharya^{70a,70b, }, A. Ackermann^{64a, }, C. Adam Bourdarios^{4, }, L. Adamczyk^{87a, }, S.V. Addepalli^{150, }, M.J. Addison^{104, }, J. Adelman^{119, }, A. Adiguzel^{22c, }, T. Adye^{138, }, A.A. Affolder^{140, }, Y. Afik^{41, }, M.N. Agaras^{13, }, A. Aggarwal^{103, }, C. Agheorghiesei^{28c, }, F. Ahmadov^{40, }, S. Ahuja^{98, }, X. Ai^{144b, }, G. Aielli^{77a,77b, }, A. Aikot^{170, }, M. Ait Tamliah^{36e, }, B. Aitbenchikh^{36a, }, M. Akbiyik^{103, }, T.P.A. Åkesson^{101, }, A.V. Akimov^{152, }, D. Akiyama^{175, }, N.N. Akolkar^{25, }, S. Aktas^{22a, }, G.L. Alberghi^{24b, }, J. Albert^{172, }, P. Albicocco^{54, }, G.L. Albouy^{61, }, S. Alderweireldt^{53, }, Z.L. Alegria^{125, }, M. Aleksa^{37, }, I.N. Aleksandrov^{40, }, C. Alexa^{28b, }, T. Alexopoulos^{10, }, F. Alfonsi^{24b, }, M. Algren^{57, }, M. Alhroob^{174, }, B. Ali^{136, }, H.M.J. Ali^{94, }, S. Ali^{32, }, S.W. Alibocus^{95, }, M. Aliev^{34c, }, G. Alimonti^{72a, }, W. Alkakhri^{56, }, C. Allaire^{67, }, B.M.M. Allbrooke^{153, }, J.S. Allen^{104, }, J.F. Allen^{53, }, P.P. Allport^{21, }, A. Aloisio^{73a,73b, }, F. Alonso^{93, }, C. Alpigiani^{143, }, Z.M.K. Alsolami^{94, }, A. Alvarez Fernandez^{103, }, M. Alves Cardoso^{57, }, M.G. Alviggi^{73a,73b, }, M. Aly^{104, }, Y. Amaral Coutinho^{84b, }, A. Ambler^{107, }, C. Amelung^{37, }, M. Amerl^{104, }, C.G. Ames^{112, }, D. Amidei^{109, }, B. Amini^{55, }, K. Amirie^{162, }, A. Amirkhanov^{40, }, S.P. Amor Dos Santos^{134a, }, K.R. Amos^{170, }, D. Amperiadou^{159, }, S. An^{85, }, V. Ananiev^{129, }, C. Anastopoulos^{146, }, T. Andeen^{11, }, J.K. Anders^{95, }, A.C. Anderson^{60, }, A. Andreazza^{72a,72b, }, S. Angelidakis^{9, }, A. Angerami^{43, }, A.V. Anisenkov^{40, }, A. Annovi^{75a, }, C. Antel^{57, },

E. Antipov ^{152, [id](#)}, M. Antonelli ^{54, [id](#)}, F. Anulli ^{76a, [id](#)}, M. Aoki ^{85, [id](#)}, T. Aoki ^{160, [id](#)}, M.A. Aparo ^{153, [id](#)},
L. Aperio Bella ^{49, [id](#)}, C. Appelt ^{158, [id](#)}, A. Apyan ^{27, [id](#)}, S.J. Arbiol Val ^{88, [id](#)}, C. Arcangeletti ^{54, [id](#)}, A.T.H. Arce ^{52, [id](#)},
J-F. Arguin ^{111, [id](#)}, S. Argyropoulos ^{159, [id](#)}, J.-H. Arling ^{49, [id](#)}, O. Arnaez ^{4, [id](#)}, H. Arnold ^{152, [id](#)}, G. Artoni ^{76a,76b, [id](#)},
H. Asada ^{114, [id](#)}, K. Asai ^{122, [id](#)}, S. Asai ^{160, [id](#)}, N.A. Asbah ^{37, [id](#)}, R.A. Ashby Pickering ^{174, [id](#)}, A.M. Aslam ^{98, [id](#)},
K. Assamagan ^{30, [id](#)}, R. Astalos ^{29a, [id](#)}, K.S.V. Astrand ^{101, [id](#)}, S. Atashi ^{166, [id](#)}, R.J. Atkin ^{34a, [id](#)}, H. Atmani ^{36f},
P.A. Atlasiddha ^{132, [id](#)}, K. Augsten ^{136, [id](#)}, A.D. Aurion ^{42, [id](#)}, V.A. Austrup ^{104, [id](#)}, G. Avolio ^{37, [id](#)}, K. Axiotis ^{57, [id](#)},
G. Azuelos ^{111, [id](#)}, D. Babal ^{29b, [id](#)}, H. Bachacou ^{139, [id](#)}, K. Bachas ^{159, [id](#)}, A. Bachi ^{35, [id](#)}, E. Bachmann ^{51, [id](#)},
M.J. Backes ^{64a, [id](#)}, A. Badea ^{41, [id](#)}, T.M. Baer ^{109, [id](#)}, P. Bagnaia ^{76a,76b, [id](#)}, M. Bahmani ^{19, [id](#)}, D. Bahner ^{55, [id](#)},
K. Bai ^{127, [id](#)}, J.T. Baines ^{138, [id](#)}, L. Baines ^{97, [id](#)}, O.K. Baker ^{179, [id](#)}, E. Bakos ^{16, [id](#)}, D. Bakshi Gupta ^{8, [id](#)},
L.E. Balabram Filho ^{84b, [id](#)}, V. Balakrishnan ^{124, [id](#)}, R. Balasubramanian ^{4, [id](#)}, E.M. Baldin ^{39, [id](#)}, P. Balek ^{87a, [id](#)},
E. Ballabene ^{24b,24a, [id](#)}, F. Balli ^{139, [id](#)}, L.M. Baltes ^{64a, [id](#)}, W.K. Balunas ^{33, [id](#)}, J. Balz ^{103, [id](#)}, I. Bamwidhi ^{120b, [id](#)},
E. Banas ^{88, [id](#)}, M. Bandieramonte ^{133, [id](#)}, A. Bandyopadhyay ^{25, [id](#)}, S. Bansal ^{25, [id](#)}, L. Barak ^{158, [id](#)}, M. Barakat ^{49, [id](#)},
E.L. Barberio ^{108, [id](#)}, D. Barberis ^{58b,58a, [id](#)}, M. Barbero ^{105, [id](#)}, M.Z. Barel ^{118, [id](#)}, T. Barillari ^{113, [id](#)}, M-S. Barisits ^{37, [id](#)},
T. Barklow ^{150, [id](#)}, P. Baron ^{126, [id](#)}, D.A. Baron Moreno ^{104, [id](#)}, A. Baroncelli ^{63, [id](#)}, A.J. Barr ^{130, [id](#)}, J.D. Barr ^{99, [id](#)},
F. Barreiro ^{102, [id](#)}, J. Barreiro Guimarães da Costa ^{14, [id](#)}, M.G. Barros Teixeira ^{134a, [id](#)}, S. Barsov ^{39, [id](#)},
F. Bartels ^{64a, [id](#)}, R. Bartoldus ^{150, [id](#)}, A.E. Barton ^{94, [id](#)}, P. Bartos ^{29a, [id](#)}, A. Basan ^{103, [id](#)}, M. Baselga ^{50, [id](#)},
S. Bashiri ⁸⁸, A. Bassalat ^{67, [id](#)}, M.J. Basso ^{163a, [id](#)}, S. Bataju ^{46, [id](#)}, R. Bate ^{171, [id](#)}, R.L. Bates ^{60, [id](#)}, S. Batlamous ¹⁰²,
M. Battaglia ^{140, [id](#)}, D. Battulga ^{19, [id](#)}, M. Baue ^{76a,76b, [id](#)}, M. Bauer ^{80, [id](#)}, P. Bauer ^{25, [id](#)}, L.T. Bayer ^{49, [id](#)},
L.T. Bazzano Hurrell ^{31, [id](#)}, J.B. Beacham ^{113, [id](#)}, T. Beau ^{131, [id](#)}, J.Y. Beauchamp ^{93, [id](#)}, P.H. Beauchemin ^{165, [id](#)},
P. Bechtle ^{25, [id](#)}, H.P. Beck ^{20, [id](#)}, K. Becker ^{174, [id](#)}, A.J. Beddall ^{83, [id](#)}, V.A. Bednyakov ^{40, [id](#)}, C.P. Bee ^{152, [id](#)},
L.J. Beemster ^{16, [id](#)}, M. Begalli ^{84d, [id](#)}, M. Begel ^{30, [id](#)}, J.K. Behr ^{49, [id](#)}, J.F. Beirer ^{37, [id](#)}, F. Beisiegel ^{25, [id](#)},
M. Belfkir ^{120b, [id](#)}, G. Bella ^{158, [id](#)}, L. Bellagamba ^{24b, [id](#)}, A. Bellerive ^{35, [id](#)}, P. Bellos ^{21, [id](#)}, K. Beloborodov ^{39, [id](#)},
D. Bencheikroun ^{36a, [id](#)}, F. Bendebe ^{36a, [id](#)}, Y. Benhammou ^{158, [id](#)}, K.C. Benkendorfer ^{62, [id](#)}, L. Beresford ^{49, [id](#)},
M. Beretta ^{54, [id](#)}, E. Bergeas Kuutmann ^{168, [id](#)}, N. Berger ^{4, [id](#)}, B. Bergmann ^{136, [id](#)}, J. Beringer ^{18a, [id](#)},
G. Bernardi ^{5, [id](#)}, C. Bernius ^{150, [id](#)}, F.U. Bernlochner ^{25, [id](#)}, F. Bernon ^{37, [id](#)}, A. Berrocal Guardia ^{13, [id](#)}, T. Berry ^{98, [id](#)},
P. Berta ^{137, [id](#)}, A. Berthold ^{51, [id](#)}, R. Bertrand ^{105, [id](#)}, S. Bethke ^{113, [id](#)}, A. Betti ^{76a,76b, [id](#)}, A.J. Bevan ^{97, [id](#)},
L. Bezio ^{57, [id](#)}, N.K. Bhalla ^{55, [id](#)}, S. Bharthuar ^{113, [id](#)}, S. Bhatta ^{152, [id](#)}, D.S. Bhattacharya ^{173, [id](#)}, P. Bhattarai ^{150, [id](#)},
Z.M. Bhatti ^{121, [id](#)}, K.D. Bhide ^{55, [id](#)}, V.S. Bhopatkar ^{125, [id](#)}, R.M. Bianchi ^{133, [id](#)}, G. Bianco ^{24b,24a, [id](#)}, O. Biebel ^{112, [id](#)},
M. Biglietti ^{78a, [id](#)}, C.S. Billingsley ⁴⁶, Y. Bimgdi ^{36f, [id](#)}, M. Bindi ^{56, [id](#)}, A. Bingham ^{178, [id](#)}, A. Bingul ^{22b, [id](#)},
C. Bini ^{76a,76b, [id](#)}, G.A. Bird ^{33, [id](#)}, M. Birman ^{176, [id](#)}, M. Biros ^{137, [id](#)}, S. Biryukov ^{153, [id](#)}, T. Bisanz ^{50, [id](#)},
E. Bisceglie ^{24b,24a, [id](#)}, J.P. Biswal ^{138, [id](#)}, D. Biswas ^{148, [id](#)}, I. Bloch ^{49, [id](#)}, A. Blue ^{60, [id](#)}, U. Blumenschein ^{97, [id](#)},
J. Blumenthal ^{103, [id](#)}, V.S. Bobrovnikov ^{40, [id](#)}, M. Boehler ^{55, [id](#)}, B. Boehm ^{173, [id](#)}, D. Bogavac ^{37, [id](#)},
A.G. Bogdanchikov ^{39, [id](#)}, L.S. Boggia ^{131, [id](#)}, V. Boisvert ^{98, [id](#)}, P. Bokan ^{37, [id](#)}, T. Bold ^{87a, [id](#)}, M. Bomben ^{5, [id](#)},
M. Bona ^{97, [id](#)}, M. Boonekamp ^{139, [id](#)}, A.G. Borbély ^{60, [id](#)}, I.S. Bordulev ^{39, [id](#)}, G. Borissov ^{94, [id](#)}, D. Bortoletto ^{130, [id](#)},
D. Boscherini ^{24b, [id](#)}, M. Bosman ^{13, [id](#)}, K. Bouaouda ^{36a, [id](#)}, N. Bouchhar ^{170, [id](#)}, L. Boudet ^{4, [id](#)}, J. Boudreau ^{133, [id](#)},
E.V. Bouhova-Thacker ^{94, [id](#)}, D. Boumediene ^{42, [id](#)}, R. Bouquet ^{58b,58a, [id](#)}, A. Boveia ^{123, [id](#)}, J. Boyd ^{37, [id](#)},
D. Boye ^{30, [id](#)}, I.R. Boyko ^{40, [id](#)}, L. Bozianu ^{57, [id](#)}, J. Bracinik ^{21, [id](#)}, N. Brahimi ^{4, [id](#)}, G. Brandt ^{178, [id](#)}, O. Brandt ^{33, [id](#)},
B. Brau ^{106, [id](#)}, J.E. Brau ^{127, [id](#)}, R. Brenner ^{176, [id](#)}, L. Brenner ^{118, [id](#)}, R. Brenner ^{168, [id](#)}, S. Bressler ^{176, [id](#)},
G. Brianti ^{79a,79b, [id](#)}, D. Britton ^{60, [id](#)}, D. Britzger ^{113, [id](#)}, I. Brock ^{25, [id](#)}, R. Brock ^{110, [id](#)}, G. Brooijmans ^{43, [id](#)},
A.J. Brooks ⁶⁹, E.M. Brooks ^{163b, [id](#)}, E. Brost ^{30, [id](#)}, L.M. Brown ^{172,163a, [id](#)}, L.E. Bruce ^{62, [id](#)}, T.L. Bruckler ^{130, [id](#)},
P.A. Bruckman de Renstrom ^{88, [id](#)}, B. Brüers ^{49, [id](#)}, A. Bruni ^{24b, [id](#)}, G. Bruni ^{24b, [id](#)}, D. Brunner ^{48a,48b, [id](#)},
M. Bruschi ^{24b, [id](#)}, N. Bruscino ^{76a,76b, [id](#)}, T. Buanes ^{17, [id](#)}, Q. Buat ^{143, [id](#)}, D. Buchin ^{113, [id](#)}, A.G. Buckley ^{60, [id](#)},

O. Bulekov^{39, [id](#)}, B.A. Bullard^{150, [id](#)}, S. Burdin^{95, [id](#)}, C.D. Burgard^{50, [id](#)}, A.M. Burger^{37, [id](#)}, B. Burghgrave^{8, [id](#)}, O. Burlayenko^{55, [id](#)}, J. Burleson^{169, [id](#)}, J.T.P. Burr^{33, [id](#)}, J.C. Burzynski^{149, [id](#)}, E.L. Busch^{43, [id](#)}, V. Büscher^{103, [id](#)}, P.J. Bussey^{60, [id](#)}, J.M. Butler^{26, [id](#)}, C.M. Buttar^{60, [id](#)}, J.M. Butterworth^{99, [id](#)}, W. Buttinger^{138, [id](#)}, C.J. Buxo Vazquez^{110, [id](#)}, A.R. Buzykaev^{40, [id](#)}, S. Cabrera Urbán^{170, [id](#)}, L. Cadamuro^{67, [id](#)}, D. Caforio^{59, [id](#)}, H. Cai^{133, [id](#)}, Y. Cai^{24b,115c,24a, [id](#)}, Y. Cai^{115a, [id](#)}, V.M.M. Cairo^{37, [id](#)}, O. Cakir^{3a, [id](#)}, N. Calace^{37, [id](#)}, P. Calafiura^{18a, [id](#)}, G. Calderini^{131, [id](#)}, P. Calfayan^{35, [id](#)}, G. Callea^{60, [id](#)}, L.P. Caloba^{84b, [id](#)}, D. Calvet^{42, [id](#)}, S. Calvet^{42, [id](#)}, R. Camacho Toro^{131, [id](#)}, S. Camarda^{37, [id](#)}, D. Camarero Munoz^{27, [id](#)}, P. Camarri^{77a,77b, [id](#)}, M.T. Camerlingo^{73a,73b, [id](#)}, D. Cameron^{37, [id](#)}, C. Camincher^{172, [id](#)}, M. Campanelli^{99, [id](#)}, A. Camplani^{44, [id](#)}, V. Canale^{73a,73b, [id](#)}, A.C. Canbay^{3a, [id](#)}, E. Canonero^{98, [id](#)}, J. Cantero^{170, [id](#)}, Y. Cao^{169, [id](#)}, F. Capocasa^{27, [id](#)}, M. Capua^{45b,45a, [id](#)}, A. Carbone^{72a,72b, [id](#)}, R. Cardarelli^{77a, [id](#)}, J.C.J. Cardenas^{8, [id](#)}, M.P. Cardiff^{27, [id](#)}, G. Carducci^{45b,45a, [id](#)}, T. Carli^{37, [id](#)}, G. Carlino^{73a, [id](#)}, J.I. Carlotto^{13, [id](#)}, B.T. Carlson^{133, [id](#)}, E.M. Carlson^{172, [id](#)}, J. Carmignani^{95, [id](#)}, L. Carminati^{72a,72b, [id](#)}, A. Carnelli^{4, [id](#)}, M. Carnesale^{37, [id](#)}, S. Caron^{117, [id](#)}, E. Carquin^{141f, [id](#)}, I.B. Carr^{108, [id](#)}, S. Carrá^{72a, [id](#)}, G. Carratta^{24b,24a, [id](#)}, A.M. Carroll^{127, [id](#)}, M.P. Casado^{13, [id](#)}, M. Caspar^{49, [id](#)}, F.L. Castillo^{4, [id](#)}, L. Castillo Garcia^{13, [id](#)}, V. Castillo Gimenez^{170, [id](#)}, N.F. Castro^{134a,134e, [id](#)}, A. Catinaccio^{37, [id](#)}, J.R. Catmore^{129, [id](#)}, T. Cavaliere^{4, [id](#)}, V. Cavaliere^{30, [id](#)}, L.J. Caviedes Betancourt^{23b, [id](#)}, Y.C. Cekmecelioglu^{49, [id](#)}, E. Celebi^{83, [id](#)}, S. Cella^{37, [id](#)}, V. Cepaitis^{57, [id](#)}, K. Cerny^{126, [id](#)}, A.S. Cerqueira^{84a, [id](#)}, A. Cerri^{75a,75b, [id](#)}, L. Cerrito^{77a,77b, [id](#)}, F. Cerutti^{18a, [id](#)}, B. Cervato^{72a,72b, [id](#)}, A. Cervelli^{24b, [id](#)}, G. Cesarini^{54, [id](#)}, S.A. Cetin^{83, [id](#)}, P.M. Chabrilat^{131, [id](#)}, J. Chan^{18a, [id](#)}, W.Y. Chan^{160, [id](#)}, J.D. Chapman^{33, [id](#)}, E. Chapon^{139, [id](#)}, B. Chargeishvili^{156b, [id](#)}, D.G. Charlton^{21, [id](#)}, C. Chauhan^{137, [id](#)}, Y. Che^{115a, [id](#)}, S. Chekanov^{6, [id](#)}, S.V. Chekulaev^{163a, [id](#)}, G.A. Chelkov^{40, [id](#)}, B. Chen^{158, [id](#)}, B. Chen^{172, [id](#)}, H. Chen^{115a, [id](#)}, H. Chen^{30, [id](#)}, J. Chen^{145a, [id](#)}, J. Chen^{149, [id](#)}, M. Chen^{130, [id](#)}, S. Chen^{90, [id](#)}, S.J. Chen^{115a, [id](#)}, X. Chen^{145a, [id](#)}, X. Chen^{15, [id](#)}, C.L. Cheng^{177, [id](#)}, H.C. Cheng^{65a, [id](#)}, S. Cheong^{150, [id](#)}, A. Cheplakov^{40, [id](#)}, E. Cheremushkina^{49, [id](#)}, E. Cherepanova^{118, [id](#)}, R. Cherkaoui El Moursli^{36e, [id](#)}, E. Cheu^{7, [id](#)}, K. Cheung^{66, [id](#)}, L. Chevalier^{139, [id](#)}, V. Chiarella^{54, [id](#)}, G. Chiarelli^{75a, [id](#)}, N. Chiedde^{105, [id](#)}, G. Chiodini^{71a, [id](#)}, A.S. Chisholm^{21, [id](#)}, A. Chitan^{28b, [id](#)}, M. Chitishvili^{170, [id](#)}, M.V. Chizhov^{40, [id](#)}, K. Choi^{11, [id](#)}, Y. Chou^{143, [id](#)}, E.Y.S. Chow^{117, [id](#)}, K.L. Chu^{176, [id](#)}, M.C. Chu^{65a, [id](#)}, X. Chu^{14,115c, [id](#)}, Z. Chubinidze^{54, [id](#)}, J. Chudoba^{135, [id](#)}, J.J. Chwastowski^{88, [id](#)}, D. Cieri^{113, [id](#)}, K.M. Ciesla^{87a, [id](#)}, V. Cindro^{96, [id](#)}, A. Ciochio^{18a, [id](#)}, F. Ciotto^{73a,73b, [id](#)}, Z.H. Citron^{176, [id](#)}, M. Citterio^{72a, [id](#)}, D.A. Ciubotaru^{28b, [id](#)}, A. Clark^{57, [id](#)}, P.J. Clark^{53, [id](#)}, N. Clarke Hall^{99, [id](#)}, C. Clarry^{162, [id](#)}, S.E. Clawson^{49, [id](#)}, C. Clement^{48a,48b, [id](#)}, Y. Coadou^{105, [id](#)}, M. Cobal^{70a,70c, [id](#)}, A. Cocco^{58b, [id](#)}, R.F. Coelho Barrue^{134a, [id](#)}, R. Coelho Lopes De Sa^{106, [id](#)}, S. Coelli^{72a, [id](#)}, L.S. Colangeli^{162, [id](#)}, B. Cole^{43, [id](#)}, P. Collado Soto^{102, [id](#)}, J. Collot^{61, [id](#)}, P. Conde Muiño^{134a,134g, [id](#)}, M.P. Connell^{34c, [id](#)}, S.H. Connell^{34c, [id](#)}, E.I. Conroy^{130, [id](#)}, F. Conventi^{73a, [id](#)}, H.G. Cooke^{21, [id](#)}, A.M. Cooper-Sarkar^{130, [id](#)}, F.A. Corchia^{24b,24a, [id](#)}, A. Cordeiro Oudot Choi^{131, [id](#)}, L.D. Corpe^{42, [id](#)}, M. Corradi^{76a,76b, [id](#)}, F. Corriveau^{107, [id](#)}, A. Cortes-Gonzalez^{19, [id](#)}, M.J. Costa^{170, [id](#)}, F. Costanza^{4, [id](#)}, D. Costanzo^{146, [id](#)}, B.M. Cote^{123, [id](#)}, J. Couthures^{4, [id](#)}, G. Cowan^{98, [id](#)}, K. Cranmer^{177, [id](#)}, L. Cremer^{50, [id](#)}, D. Cremonini^{24b,24a, [id](#)}, S. Crépe-Renaudin^{61, [id](#)}, F. Crescioli^{131, [id](#)}, M. Cristinziani^{148, [id](#)}, M. Cristoforetti^{79a,79b, [id](#)}, V. Croft^{118, [id](#)}, J.E. Crosby^{125, [id](#)}, G. Crosetti^{45b,45a, [id](#)}, A. Cueto^{102, [id](#)}, H. Cui^{99, [id](#)}, Z. Cui^{7, [id](#)}, W.R. Cunningham^{60, [id](#)}, F. Curcio^{170, [id](#)}, J.R. Curran^{53, [id](#)}, P. Czodrowski^{37, [id](#)}, M.J. Da Cunha Sargedas De Sousa^{58b,58a, [id](#)}, J.V. Da Fonseca Pinto^{84b, [id](#)}, C. Da Via^{104, [id](#)}, W. Dabrowski^{87a, [id](#)}, T. Dado^{37, [id](#)}, S. Dahbi^{155, [id](#)}, T. Dai^{109, [id](#)}, D. Dal Santo^{20, [id](#)}, C. Dallapiccola^{106, [id](#)}, M. Dam^{44, [id](#)}, G. D'amen^{30, [id](#)}, V. D'Amico^{112, [id](#)}, J. Damp^{103, [id](#)}, J.R. Dandoy^{35, [id](#)}, D. Dannheim^{37, [id](#)}, M. Danninger^{149, [id](#)}, V. Dao^{152, [id](#)}, G. Darbo^{58b, [id](#)}, S.J. Das^{30, [id](#)}, F. Dattola^{49, [id](#)}, S. D'Auria^{72a,72b, [id](#)}, A. D'Avanzo^{73a,73b, [id](#)}, T. Davidek^{137, [id](#)}, I. Dawson^{97, [id](#)}, H.A. Day-hall^{136, [id](#)}, K. De^{8, [id](#)}, C. De Almeida Rossi^{162, [id](#)}, R. De Asmundis^{73a, [id](#)}, N. De Biase^{49, [id](#)}, S. De Castro^{24b,24a, [id](#)}, N. De Groot^{117, [id](#)},

P. de Jong ^{118, [ib](#)}, H. De la Torre ^{119, [ib](#)}, A. De Maria ^{115a, [ib](#)}, A. De Salvo ^{76a, [ib](#)}, U. De Sanctis ^{77a,77b, [ib](#)},
F. De Santis ^{71a,71b, [ib](#)}, A. De Santo ^{153, [ib](#)}, J.B. De Vivie De Regie ^{61, [ib](#)}, J. Debevc ^{96, [ib](#)}, D.V. Dedovich ⁴⁰,
J. Degens ^{95, [ib](#)}, A.M. Deiana ^{46, [ib](#)}, J. Del Peso ^{102, [ib](#)}, L. Delagrangé ^{131, [ib](#)}, F. Deliot ^{139, [ib](#)}, C.M. Delitzsch ^{50, [ib](#)},
M. Della Pietra ^{73a,73b, [ib](#)}, D. Della Volpe ^{57, [ib](#)}, A. Dell'Acqua ^{37, [ib](#)}, L. Dell'Asta ^{72a,72b, [ib](#)}, M. Delmastro ^{4, [ib](#)},
C.C. Delogu ^{103, [ib](#)}, P.A. Delsart ^{61, [ib](#)}, S. Demers ^{179, [ib](#)}, M. Demichev ^{40, [ib](#)}, S.P. Denisov ^{39, [ib](#)}, H. Denizli ^{22a, [ib](#), [i](#)},
L. D'Eramo ^{42, [ib](#)}, D. Derendarz ^{88, [ib](#)}, F. Derue ^{131, [ib](#)}, P. Dervan ^{95, [ib](#)}, K. Desch ^{25, [ib](#)}, C. Deutsch ^{25, [ib](#)},
F.A. Di Bello ^{58b,58a, [ib](#)}, A. Di Ciaccio ^{77a,77b, [ib](#)}, L. Di Ciaccio ^{4, [ib](#)}, A. Di Domenico ^{76a,76b, [ib](#)}, C. Di Donato ^{73a,73b, [ib](#)},
A. Di Girolamo ^{37, [ib](#)}, G. Di Gregorio ^{37, [ib](#)}, A. Di Luca ^{79a,79b, [ib](#)}, B. Di Micco ^{78a,78b, [ib](#)}, R. Di Nardo ^{78a,78b, [ib](#)},
K.F. Di Petrillo ^{41, [ib](#)}, M. Diamantopoulou ^{35, [ib](#)}, F.A. Dias ^{118, [ib](#)}, T. Dias Do Vale ^{149, [ib](#)}, M.A. Diaz ^{141a,141b, [ib](#)},
A.R. Didenko ^{40, [ib](#)}, M. Didenko ^{170, [ib](#)}, E.B. Diehl ^{109, [ib](#)}, S. Díez Cornell ^{49, [ib](#)}, C. Díez Pardo ^{148, [ib](#)},
C. Dimitriadis ^{151, [ib](#)}, A. Dimitrievska ^{21, [ib](#)}, A. Dimri ^{152, [ib](#)}, J. Dingfelder ^{25, [ib](#)}, T. Dingley ^{130, [ib](#)}, I-M. Dinu ^{28b, [ib](#)},
S.J. Dittmeier ^{64b, [ib](#)}, F. Dittus ^{37, [ib](#)}, M. Divisek ^{137, [ib](#)}, B. Dixit ^{95, [ib](#)}, F. Djama ^{105, [ib](#)}, T. Djobava ^{156b, [ib](#)},
C. Doglioni ^{104,101, [ib](#)}, A. Dohnalova ^{29a, [ib](#)}, Z. Dolezal ^{137, [ib](#)}, K. Domijan ^{87a, [ib](#)}, K.M. Dona ^{41, [ib](#)}, M. Donadelli ^{84d, [ib](#)},
B. Dong ^{110, [ib](#)}, J. Donini ^{42, [ib](#)}, A. D'Onofrio ^{73a,73b, [ib](#)}, M. D'Onofrio ^{95, [ib](#)}, J. Dopke ^{138, [ib](#)}, A. Doria ^{73a, [ib](#)},
N. Dos Santos Fernandes ^{134a, [ib](#)}, P. Dougan ^{104, [ib](#)}, M.T. Dova ^{93, [ib](#)}, A.T. Doyle ^{60, [ib](#)}, M.A. Draguet ^{130, [ib](#)},
M.P. Drescher ^{56, [ib](#)}, E. Dreyer ^{176, [ib](#)}, I. Drivas-koulouris ^{10, [ib](#)}, M. Drnevich ^{121, [ib](#)}, M. Drozdova ^{57, [ib](#)}, D. Du ^{63, [ib](#)},
T.A. du Pree ^{118, [ib](#)}, F. Dubinin ^{40, [ib](#)}, M. Dubovsky ^{29a, [ib](#)}, E. Duchovni ^{176, [ib](#)}, G. Duckeck ^{112, [ib](#)}, P.K. Duckett ⁹⁹,
O.A. Ducu ^{28b, [ib](#)}, D. Duda ^{53, [ib](#)}, A. Dudarev ^{37, [ib](#)}, E.R. Duden ^{27, [ib](#)}, M. D'uffizi ^{104, [ib](#)}, L. Duflot ^{67, [ib](#)},
M. Dührssen ^{37, [ib](#)}, I. Duminica ^{28g, [ib](#)}, A.E. Dumitriu ^{28b, [ib](#)}, M. Dunford ^{64a, [ib](#)}, S. Dungs ^{50, [ib](#)}, K. Dunne ^{48a,48b, [ib](#)},
A. Duperrin ^{105, [ib](#)}, H. Duran Yildiz ^{3a, [ib](#)}, M. Düren ^{59, [ib](#)}, A. Durglishvili ^{156b, [ib](#)}, D. Duvnjak ^{35, [ib](#)}, B.L. Dwyer ^{119, [ib](#)},
G.I. Dyckes ^{18a, [ib](#)}, M. Dyndal ^{87a, [ib](#)}, B.S. Dziedzic ^{37, [ib](#)}, Z.O. Earnshaw ^{153, [ib](#)}, G.H. Eberwein ^{130, [ib](#)},
B. Eckerova ^{29a, [ib](#)}, S. Eggebrecht ^{56, [ib](#)}, E. Egidio Purcino De Souza ^{84e, [ib](#)}, G. Eigen ^{17, [ib](#)}, K. Einsweiler ^{18a, [ib](#)},
T. Ekelof ^{168, [ib](#)}, P.A. Ekman ^{101, [ib](#)}, S. El Farkh ^{36b, [ib](#)}, Y. El Ghazali ^{63, [ib](#)}, H. El Jarrari ^{37, [ib](#)}, A. El Moussaouy ^{36a, [ib](#)},
V. Ellajosyula ^{168, [ib](#)}, M. Ellert ^{168, [ib](#)}, F. Ellinghaus ^{178, [ib](#)}, N. Ellis ^{37, [ib](#)}, J. Elmsheuser ^{30, [ib](#)}, M. Elsayy ^{120a, [ib](#)},
M. Elsing ^{37, [ib](#)}, D. Emelianov ^{138, [ib](#)}, Y. Enari ^{85, [ib](#)}, I. Ene ^{18a, [ib](#)}, S. Epari ^{13, [ib](#)}, D. Ernani Martins Neto ^{88, [ib](#)},
M. Errenst ^{178, [ib](#)}, M. Escalier ^{67, [ib](#)}, C. Escobar ^{170, [ib](#)}, E. Etzion ^{158, [ib](#)}, G. Evans ^{134a,134b, [ib](#)}, H. Evans ^{69, [ib](#)},
L.S. Evans ^{98, [ib](#)}, A. Ezhilov ^{39, [ib](#)}, S. Ezzarqtouni ^{36a, [ib](#)}, F. Fabbri ^{24b,24a, [ib](#)}, L. Fabbri ^{24b,24a, [ib](#)}, G. Facini ^{99, [ib](#)},
V. Fadeyev ^{140, [ib](#)}, R.M. Fakhrutdinov ^{39, [ib](#)}, D. Fakoudis ^{103, [ib](#)}, S. Falciano ^{76a, [ib](#)}, L.F. Falda Ulhoa Coelho ^{134a, [ib](#)},
F. Fallavollita ^{113, [ib](#)}, G. Falsetti ^{45b,45a, [ib](#)}, J. Faltova ^{137, [ib](#)}, C. Fan ^{169, [ib](#)}, K.Y. Fan ^{65b, [ib](#)}, Y. Fan ^{14, [ib](#)},
Y. Fang ^{14,115c, [ib](#)}, M. Fanti ^{72a,72b, [ib](#)}, M. Faraj ^{70a,70b, [ib](#)}, Z. Farazpay ^{100, [ib](#)}, A. Farbin ^{8, [ib](#)}, A. Farilla ^{78a, [ib](#)},
T. Farooque ^{110, [ib](#)}, J.N. Farr ^{179, [ib](#)}, S.M. Farrington ^{138,53, [ib](#)}, F. Fassi ^{36c, [ib](#)}, D. Fassouliotis ^{9, [ib](#)}, L. Fayard ^{67, [ib](#)},
P. Federic ^{137, [ib](#)}, P. Federicova ^{135, [ib](#)}, O.L. Fedin ^{39, [ib](#), [a](#)}, M. Feickert ^{177, [ib](#)}, L. Feligioni ^{105, [ib](#)}, D.E. Fellers ^{18a, [ib](#)},
C. Feng ^{144a, [ib](#)}, Z. Feng ^{118, [ib](#)}, M.J. Fenton ^{166, [ib](#)}, L. Ferencz ^{49, [ib](#)}, P. Fernandez Martinez ^{68, [ib](#)},
M.J.V. Fernoux ^{105, [ib](#)}, J. Ferrando ^{94, [ib](#)}, A. Ferrari ^{168, [ib](#)}, P. Ferrari ^{118,117, [ib](#)}, R. Ferrari ^{74a, [ib](#)}, D. Ferrere ^{57, [ib](#)},
C. Ferretti ^{109, [ib](#)}, M.P. Fewell ^{1, [ib](#)}, D. Fiacco ^{76a,76b, [ib](#)}, F. Fiedler ^{103, [ib](#)}, P. Fiedler ^{136, [ib](#)}, S. Filimonov ^{39, [ib](#)},
A. Filipčič ^{96, [ib](#)}, E.K. Filmer ^{163a, [ib](#)}, F. Filthaut ^{117, [ib](#)}, M.C.N. Fiolhais ^{134a,134c, [ib](#), [c](#)}, L. Fiorini ^{170, [ib](#)},
W.C. Fisher ^{110, [ib](#)}, T. Fitschen ^{104, [ib](#)}, P.M. Fitzhugh ¹³⁹, I. Fleck ^{148, [ib](#)}, P. Fleischmann ^{109, [ib](#)}, T. Flick ^{178, [ib](#)},
M. Flores ^{34d, [ib](#), [af](#)}, L.R. Flores Castillo ^{65a, [ib](#)}, L. Flores Sanz De Acedo ^{37, [ib](#)}, F.M. Follega ^{79a,79b, [ib](#)}, N. Fomin ^{33, [ib](#)},
J.H. Foo ^{162, [ib](#)}, A. Formica ^{139, [ib](#)}, A.C. Forti ^{104, [ib](#)}, E. Fortin ^{37, [ib](#)}, A.W. Fortman ^{18a, [ib](#)}, L. Fountas ^{9, [ib](#), [j](#)},
D. Fournier ^{67, [ib](#)}, H. Fox ^{94, [ib](#)}, P. Francavilla ^{75a,75b, [ib](#)}, S. Francescato ^{62, [ib](#)}, S. Franchellucci ^{57, [ib](#)},
M. Franchini ^{24b,24a, [ib](#)}, S. Franchino ^{64a, [ib](#)}, D. Francis ³⁷, L. Franco ^{117, [ib](#)}, V. Franco Lima ^{37, [ib](#)}, L. Franconi ^{49, [ib](#)},
M. Franklin ^{62, [ib](#)}, G. Frattari ^{27, [ib](#)}, Y.Y. Frid ^{158, [ib](#)}, J. Friend ^{60, [ib](#)}, N. Fritzsche ^{37, [ib](#)}, A. Froch ^{57, [ib](#)},

D. Froidevaux^{37, [ib](#)}, J.A. Frost^{130, [ib](#)}, Y. Fu^{110, [ib](#)}, S. Fuenzalida Garrido^{141f, [ib](#)}, M. Fujimoto^{105, [ib](#)}, K.Y. Fung^{65a, [ib](#)}, E. Furtado De Simas Filho^{84e, [ib](#)}, M. Furukawa^{160, [ib](#)}, J. Fuster^{170, [ib](#)}, A. Gaa^{56, [ib](#)}, A. Gabrielli^{24b,24a, [ib](#)}, A. Gabrielli^{162, [ib](#)}, P. Gadow^{37, [ib](#)}, G. Gagliardi^{58b,58a, [ib](#)}, L.G. Gagnon^{18a, [ib](#)}, S. Gaid^{89b, [ib](#)}, S. Galantzan^{158, [ib](#)}, J. Gallagher^{1, [ib](#)}, E.J. Gallas^{130, [ib](#)}, A.L. Gallen^{168, [ib](#)}, B.J. Gallop^{138, [ib](#)}, K.K. Gan^{123, [ib](#)}, S. Ganguly^{160, [ib](#)}, Y. Gao^{53, [ib](#)}, A. Garabaglu^{143, [ib](#)}, F.M. Garay Walls^{141a,141b, [ib](#)}, B. Garcia³⁰, C. García^{170, [ib](#)}, A. Garcia Alonso^{118, [ib](#)}, A.G. Garcia Caffaro^{179, [ib](#)}, J.E. García Navarro^{170, [ib](#)}, M. Garcia-Sciveres^{18a, [ib](#)}, G.L. Gardner^{132, [ib](#)}, R.W. Gardner^{41, [ib](#)}, N. Garelli^{165, [ib](#)}, R.B. Garg^{150, [ib](#)}, J.M. Gargan^{53, [ib](#)}, C.A. Garner¹⁶², C.M. Garvey^{34a, [ib](#)}, V.K. Gassmann¹⁶⁵, G. Gaudio^{74a, [ib](#)}, V. Gautam¹³, P. Gauzzi^{76a,76b, [ib](#)}, J. Gavranovic^{96, [ib](#)}, I.L. Gavrilenko^{134a, [ib](#)}, A. Gavrilyuk^{39, [ib](#)}, C. Gay^{171, [ib](#)}, G. Gaycken^{127, [ib](#)}, E.N. Gazis^{10, [ib](#)}, A. Gekow¹²³, C. Gemme^{58b, [ib](#)}, M.H. Genest^{61, [ib](#)}, A.D. Gentry^{116, [ib](#)}, S. George^{98, [ib](#)}, W.F. George^{21, [ib](#)}, T. Geralis^{47, [ib](#)}, A.A. Gerwin^{124, [ib](#)}, P. Gessinger-Befurt^{37, [ib](#)}, M.E. Geyik^{178, [ib](#)}, M. Ghani^{174, [ib](#)}, K. Ghorbanian^{97, [ib](#)}, A. Ghosal^{148, [ib](#)}, A. Ghosh^{166, [ib](#)}, A. Ghosh^{7, [ib](#)}, B. Giacobbe^{24b, [ib](#)}, S. Giagu^{76a,76b, [ib](#)}, T. Giani^{118, [ib](#)}, A. Giannini^{63, [ib](#)}, S.M. Gibson^{98, [ib](#)}, M. Gignac^{140, [ib](#)}, D.T. Gil^{87b, [ib](#)}, A.K. Gilbert^{87a, [ib](#)}, B.J. Gilbert^{43, [ib](#)}, D. Gillberg^{35, [ib](#)}, G. Gilles^{118, [ib](#)}, L. Ginabat^{131, [ib](#)}, D.M. Gingrich^{2, [ib](#), [ai](#)}, M.P. Giordani^{70a,70c, [ib](#)}, P.F. Giraud^{139, [ib](#)}, G. Giugliarelli^{70a,70c, [ib](#)}, D. Giugni^{72a, [ib](#)}, F. Giuli^{77a,77b, [ib](#)}, I. Gkialas^{9, [ib](#), [j](#)}, L.K. Gladilin^{39, [ib](#)}, C. Glasman^{102, [ib](#)}, G. Glemža^{49, [ib](#)}, M. Glisic¹²⁷, I. Gnesi^{45b, [ib](#)}, Y. Go^{30, [ib](#)}, M. Goblirsch-Kolb^{37, [ib](#)}, B. Gocke^{50, [ib](#)}, D. Godin¹¹¹, B. Gokturk^{22a, [ib](#)}, S. Goldfarb^{108, [ib](#)}, T. Golling^{57, [ib](#)}, M.G.D. Gololo^{34c, [ib](#)}, D. Golubkov^{39, [ib](#)}, J.P. Gombas^{110, [ib](#)}, A. Gomes^{134a,134b, [ib](#)}, G. Gomes Da Silva^{148, [ib](#)}, A.J. Gomez Delegido^{170, [ib](#)}, R. Gonçalo^{134a, [ib](#)}, L. Gonella^{21, [ib](#)}, A. Gongadze^{156c, [ib](#)}, F. Gonnella^{21, [ib](#)}, J.L. Gonski^{150, [ib](#)}, R.Y. González Andana^{53, [ib](#)}, S. González de la Hoz^{170, [ib](#)}, R. Gonzalez Lopez^{95, [ib](#)}, C. Gonzalez Renteria^{18a, [ib](#)}, M.V. Gonzalez Rodrigues^{49, [ib](#)}, R. Gonzalez Suarez^{168, [ib](#)}, S. Gonzalez-Sevilla^{57, [ib](#)}, L. Goossens^{37, [ib](#)}, B. Gorini^{37, [ib](#)}, E. Gorini^{71a,71b, [ib](#)}, A. Gorišek^{96, [ib](#)}, T.C. Gosart^{132, [ib](#)}, A.T. Goshaw^{52, [ib](#)}, M.I. Gostkin^{40, [ib](#)}, S. Goswami^{125, [ib](#)}, C.A. Gottardo^{37, [ib](#)}, S.A. Gotz^{112, [ib](#)}, M. Goughri^{36b, [ib](#)}, A.G. Goussiou^{143, [ib](#)}, N. Govender^{34c, [ib](#)}, R.P. Grabarczyk^{130, [ib](#)}, I. Grabowska-Bold^{87a, [ib](#)}, K. Graham^{35, [ib](#)}, E. Gramstad^{129, [ib](#)}, S. Grancagnolo^{71a,71b, [ib](#)}, C.M. Grant^{1,139}, P.M. Gravila^{28f, [ib](#)}, F.G. Gravili^{71a,71b, [ib](#)}, H.M. Gray^{18a, [ib](#)}, M. Greco^{113, [ib](#)}, M.J. Green^{1, [ib](#)}, C. Greife^{25, [ib](#)}, A.S. Grefsrud^{17, [ib](#)}, I.M. Gregor^{49, [ib](#)}, K.T. Greif^{166, [ib](#)}, P. Grenier^{150, [ib](#)}, S.G. Grewe¹¹³, A.A. Grillo^{140, [ib](#)}, K. Grimm^{32, [ib](#)}, S. Grinstein^{13, [ib](#), [x](#)}, J.-F. Grivaz^{67, [ib](#)}, E. Gross^{176, [ib](#)}, J. Grosse-Knetter^{56, [ib](#)}, L. Guan^{109, [ib](#)}, G. Guerrieri^{37, [ib](#)}, R. Gugel^{103, [ib](#)}, J.A.M. Guhit^{109, [ib](#)}, A. Guida^{19, [ib](#)}, E. Guillon^{174, [ib](#)}, S. Guindon^{37, [ib](#)}, F. Guo^{14,115c, [ib](#)}, J. Guo^{145a, [ib](#)}, L. Guo^{49, [ib](#)}, L. Guo^{115b, [ib](#), [v](#)}, Y. Guo^{109, [ib](#)}, A. Gupta^{50, [ib](#)}, R. Gupta^{133, [ib](#)}, S. Gurbuz^{25, [ib](#)}, S.S. Gurdasani^{49, [ib](#)}, G. Gustavino^{76a,76b, [ib](#)}, P. Gutierrez^{124, [ib](#)}, L.F. Gutierrez Zagazeta^{132, [ib](#)}, M. Gutsche^{51, [ib](#)}, C. Gutschow^{99, [ib](#)}, C. Gwenlan^{130, [ib](#)}, C.B. Gwilliam^{95, [ib](#)}, E.S. Haaland^{129, [ib](#)}, A. Haas^{121, [ib](#)}, M. Habedank^{60, [ib](#)}, C. Haber^{18a, [ib](#)}, H.K. Hadavand^{8, [ib](#)}, A. Haddad^{42, [ib](#)}, A. Hadeef^{51, [ib](#)}, A.I. Hagan^{94, [ib](#)}, J.J. Hahn^{148, [ib](#)}, E.H. Haines^{99, [ib](#)}, M. Haleem^{173, [ib](#)}, J. Haley^{125, [ib](#)}, G.D. Hallewell^{105, [ib](#)}, L. Halser^{20, [ib](#)}, K. Hamano^{172, [ib](#)}, M. Hamer^{25, [ib](#)}, S.E.D. Hammoud^{67, [ib](#)}, E.J. Hampshire^{98, [ib](#)}, J. Han^{144a, [ib](#)}, L. Han^{115a, [ib](#)}, L. Han^{63, [ib](#)}, S. Han^{18a, [ib](#)}, K. Hanagaki^{85, [ib](#)}, M. Hance^{140, [ib](#)}, D.A. Hangal^{43, [ib](#)}, H. Hanif^{149, [ib](#)}, M.D. Hank^{132, [ib](#)}, J.B. Hansen^{44, [ib](#)}, P.H. Hansen^{44, [ib](#)}, D. Harada^{57, [ib](#)}, T. Harenberg^{178, [ib](#)}, S. Harkusha^{180, [ib](#)}, M.L. Harris^{106, [ib](#)}, Y.T. Harris^{25, [ib](#)}, J. Harrison^{13, [ib](#)}, N.M. Harrison^{123, [ib](#)}, P.F. Harrison¹⁷⁴, N.M. Hartman^{113, [ib](#)}, N.M. Hartmann^{112, [ib](#)}, R.Z. Hasan^{98,138, [ib](#)}, Y. Hasegawa^{147, [ib](#)}, F. Haslbeck^{130, [ib](#)}, S. Hassan^{17, [ib](#)}, R. Hauser^{110, [ib](#)}, C.M. Hawkes^{21, [ib](#)}, R.J. Hawkings^{37, [ib](#)}, Y. Hayashi^{160, [ib](#)}, D. Hayden^{110, [ib](#)}, C. Hayes^{109, [ib](#)}, R.L. Hayes^{118, [ib](#)}, C.P. Hays^{130, [ib](#)}, J.M. Hays^{97, [ib](#)}, H.S. Hayward^{95, [ib](#)}, F. He^{63, [ib](#)}, M. He^{14,115c, [ib](#)}, Y. He^{49, [ib](#)}, Y. He^{99, [ib](#)}, N.B. Heatley^{97, [ib](#)}, V. Hedberg^{101, [ib](#)}, A.L. Heggelund^{129, [ib](#)}, C. Heidegger^{55, [ib](#)}, K.K. Heidegger^{55, [ib](#)}, J. Heilman^{35, [ib](#)}, S. Heim^{49, [ib](#)}, T. Heim^{18a, [ib](#)}, J.G. Heinlein^{132, [ib](#)}, J.J. Heinrich^{127, [ib](#)}, L. Heinrich^{113, [ib](#), [ag](#)}, J. Hejbal^{135, [ib](#)}, A. Held^{177, [ib](#)},

S. Hellesund ^{17, [ib](#)}, C.M. Helling ^{171, [ib](#)}, S. Hellman ^{48a,48b, [ib](#)}, L. Henkelmann ^{33, [ib](#)}, A.M. Henriques Correia ³⁷,
H. Herde ^{101, [ib](#)}, Y. Hernández Jiménez ^{152, [ib](#)}, L.M. Herrmann ^{25, [ib](#)}, T. Herrmann ^{51, [ib](#)}, G. Herten ^{55, [ib](#)},
R. Hertenberger ^{112, [ib](#)}, L. Hervas ^{37, [ib](#)}, M.E. Hespings ^{103, [ib](#)}, N.P. Hessey ^{163a, [ib](#)}, J. Hessler ^{113, [ib](#)}, M. Hidaoui ^{36b, [ib](#)},
N. Hidic ^{137, [ib](#)}, E. Hill ^{162, [ib](#)}, S.J. Hillier ^{21, [ib](#)}, J.R. Hinds ^{110, [ib](#)}, F. Hinterkeuser ^{25, [ib](#)}, M. Hirose ^{128, [ib](#)},
S. Hirose ^{164, [ib](#)}, D. Hirschbuehl ^{178, [ib](#)}, T.G. Hitchings ^{104, [ib](#)}, B. Hiti ^{96, [ib](#)}, J. Hobbs ^{152, [ib](#)}, R. Hobincu ^{28e, [ib](#)},
N. Hod ^{176, [ib](#)}, M.C. Hodgkinson ^{146, [ib](#)}, B.H. Hodgkinson ^{130, [ib](#)}, A. Hoecker ^{37, [ib](#)}, D.D. Hofer ^{109, [ib](#)}, J. Hofer ^{170, [ib](#)},
M. Holzbock ^{37, [ib](#)}, L.B.A.H. Hommels ^{33, [ib](#)}, B.P. Honan ^{104, [ib](#)}, J.J. Hong ^{69, [ib](#)}, J. Hong ^{145a, [ib](#)}, T.M. Hong ^{133, [ib](#)},
B.H. Hooberman ^{169, [ib](#)}, W.H. Hopkins ^{6, [ib](#)}, M.C. Hoppesch ^{169, [ib](#)}, Y. Horii ^{114, [ib](#)}, M.E. Horstmann ^{113, [ib](#)},
S. Hou ^{155, [ib](#)}, M.R. Housenga ^{169, [ib](#)}, A.S. Howard ^{96, [ib](#)}, J. Howarth ^{60, [ib](#)}, J. Hoya ^{6, [ib](#)}, M. Hrabovsky ^{126, [ib](#)},
T. Hryn'ova ^{4, [ib](#)}, P.J. Hsu ^{66, [ib](#)}, S.-C. Hsu ^{143, [ib](#)}, T. Hsu ^{67, [ib](#)}, M. Hu ^{18a, [ib](#)}, Q. Hu ^{63, [ib](#)}, S. Huang ^{33, [ib](#)},
X. Huang ^{14,115c, [ib](#)}, Y. Huang ^{137, [ib](#)}, Y. Huang ^{115b, [ib](#)}, Y. Huang ^{103, [ib](#)}, Y. Huang ^{14, [ib](#)}, Z. Huang ^{104, [ib](#)},
Z. Hubacek ^{136, [ib](#)}, M. Huebner ^{25, [ib](#)}, F. Huegging ^{25, [ib](#)}, T.B. Huffman ^{130, [ib](#)}, M. Hufnagel Maranha De Faria ^{84a, [ib](#)},
C.A. Hugli ^{49, [ib](#)}, M. Huhtinen ^{37, [ib](#)}, S.K. Huiberts ^{17, [ib](#)}, R. Hulsken ^{107, [ib](#)}, C.E. Hultquist ^{18a, [ib](#)}, N. Huseynov ^{12, [ib](#)},
J. Huston ^{110, [ib](#)}, J. Huth ^{62, [ib](#)}, R. Hyneman ^{7, [ib](#)}, G. Iacobucci ^{57, [ib](#)}, G. Iakovidis ^{30, [ib](#)}, L. Iconomidou-Fayard ^{67, [ib](#)},
J.P. Iddon ^{37, [ib](#)}, P. Iengo ^{73a,73b, [ib](#)}, R. Iguchi ^{160, [ib](#)}, Y. Iiyama ^{160, [ib](#)}, T. Iizawa ^{130, [ib](#)}, Y. Ikegami ^{85, [ib](#)},
D. Iliadis ^{159, [ib](#)}, N. Ilic ^{162, [ib](#)}, H. Imam ^{84c, [ib](#)}, G. Inacio Goncalves ^{84d, [ib](#)}, S.A. Infante Cabanas ^{141c, [ib](#)},
T. Ingebrechtsen Carlson ^{48a,48b, [ib](#)}, J.M. Inglis ^{97, [ib](#)}, G. Introzzi ^{74a,74b, [ib](#)}, M. Iodice ^{78a, [ib](#)}, V. Ippolito ^{76a,76b, [ib](#)},
R.K. Irwin ^{95, [ib](#)}, M. Ishino ^{160, [ib](#)}, W. Islam ^{177, [ib](#)}, C. Issever ^{19, [ib](#)}, S. Istin ^{22a, [ib](#)},^{an}, H. Ito ^{175, [ib](#)}, R. Iuppa ^{79a,79b, [ib](#)},
A. Ivina ^{176, [ib](#)}, V. Izzo ^{73a, [ib](#)}, P. Jacka ^{135, [ib](#)}, P. Jackson ^{1, [ib](#)}, P. Jain ^{49, [ib](#)}, K. Jakobs ^{55, [ib](#)}, T. Jakoubek ^{176, [ib](#)},
J. Jamieson ^{60, [ib](#)}, W. Jang ^{160, [ib](#)}, S. Jankovych ^{137, [ib](#)}, M. Javurkova ^{106, [ib](#)}, P. Jawahar ^{104, [ib](#)}, L. Jeanty ^{127, [ib](#)},
J. Jejelava ^{156a, [ib](#)},^{ae}, P. Jenni ^{55, [ib](#)},^f, C.E. Jessiman ^{35, [ib](#)}, C. Jia ^{144a, [ib](#)}, H. Jia ^{171, [ib](#)}, J. Jia ^{152, [ib](#)}, X. Jia ^{14,115c, [ib](#)},
Z. Jia ^{115a, [ib](#)}, C. Jiang ^{53, [ib](#)}, Q. Jiang ^{65b, [ib](#)}, S. Jiggins ^{49, [ib](#)}, J. Jimenez Pena ^{13, [ib](#)}, S. Jin ^{115a, [ib](#)}, A. Jinaru ^{28b, [ib](#)},
O. Jinnouchi ^{142, [ib](#)}, P. Johansson ^{146, [ib](#)}, K.A. Johns ^{7, [ib](#)}, J.W. Johnson ^{140, [ib](#)}, F.A. Jolly ^{49, [ib](#)}, D.M. Jones ^{153, [ib](#)},
E. Jones ^{49, [ib](#)}, K.S. Jones ⁸, P. Jones ^{33, [ib](#)}, R.W.L. Jones ^{94, [ib](#)}, T.J. Jones ^{95, [ib](#)}, H.L. Joos ^{56,37, [ib](#)}, R. Joshi ^{123, [ib](#)},
J. Jovicevic ^{16, [ib](#)}, X. Ju ^{18a, [ib](#)}, J.J. Junggeburth ^{37, [ib](#)}, T. Junkermann ^{64a, [ib](#)}, A. Juste Rozas ^{13, [ib](#)},^x, M.K. Juzek ^{88, [ib](#)},
S. Kabana ^{141e, [ib](#)}, A. Kaczmarska ^{88, [ib](#)}, M. Kado ^{113, [ib](#)}, H. Kagan ^{123, [ib](#)}, M. Kagan ^{150, [ib](#)}, A. Kahn ^{132, [ib](#)},
C. Kahra ^{103, [ib](#)}, T. Kaji ^{160, [ib](#)}, E. Kajomovitz ^{157, [ib](#)}, N. Kakati ^{176, [ib](#)}, I. Kalaitzidou ^{55, [ib](#)}, N.J. Kang ^{140, [ib](#)},
D. Kar ^{34g, [ib](#)}, K. Karava ^{130, [ib](#)}, E. Karentzos ^{25, [ib](#)}, O. Karkout ^{118, [ib](#)}, S.N. Karpov ^{40, [ib](#)}, Z.M. Karpova ^{40, [ib](#)},
V. Kartvelishvili ^{94, [ib](#)}, A.N. Karyukhin ^{39, [ib](#)}, E. Kasimi ^{159, [ib](#)}, J. Katzy ^{49, [ib](#)}, S. Kaur ^{35, [ib](#)}, K. Kawade ^{147, [ib](#)},
M.P. Kawale ^{124, [ib](#)}, C. Kawamoto ^{90, [ib](#)}, T. Kawamoto ^{63, [ib](#)}, E.F. Kay ^{37, [ib](#)}, F.I. Kaya ^{165, [ib](#)}, S. Kazakos ^{110, [ib](#)},
V.F. Kazanin ^{39, [ib](#)}, Y. Ke ^{152, [ib](#)}, J.M. Keaveney ^{34a, [ib](#)}, R. Keeler ^{172, [ib](#)}, G.V. Kehris ^{62, [ib](#)}, J.S. Keller ^{35, [ib](#)},
J.J. Kempster ^{153, [ib](#)}, O. Kepka ^{135, [ib](#)}, J. Kerr ^{163b, [ib](#)}, B.P. Kerridge ^{138, [ib](#)}, B.P. Kerševan ^{96, [ib](#)}, L. Keszeghova ^{29a, [ib](#)},
R.A. Khan ^{133, [ib](#)}, A. Khanov ^{125, [ib](#)}, A.G. Kharlamov ^{39, [ib](#)}, T. Kharlamova ^{39, [ib](#)}, E.E. Khoda ^{143, [ib](#)},
M. Kholodenko ^{134a, [ib](#)}, T.J. Khoo ^{19, [ib](#)}, G. Khorauli ^{173, [ib](#)}, J. Khubua ^{156b, [ib](#)},^{*}, Y.A.R. Khwaira ^{131, [ib](#)},
B. Kibirige ^{34g}, D. Kim ^{6, [ib](#)}, D.W. Kim ^{48a,48b, [ib](#)}, Y.K. Kim ^{41, [ib](#)}, N. Kimura ^{99, [ib](#)}, M.K. Kingston ^{56, [ib](#)},
A. Kirchhoff ^{56, [ib](#)}, C. Kirfel ^{25, [ib](#)}, F. Kirfel ^{25, [ib](#)}, J. Kirk ^{138, [ib](#)}, A.E. Kiryunin ^{113, [ib](#)}, S. Kita ^{164, [ib](#)}, C. Kitsaki ^{10, [ib](#)},
O. Kivernyk ^{25, [ib](#)}, M. Klassen ^{165, [ib](#)}, C. Klein ^{35, [ib](#)}, L. Klein ^{173, [ib](#)}, M.H. Klein ^{46, [ib](#)}, S.B. Klein ^{57, [ib](#)}, U. Klein ^{95, [ib](#)},
A. Klimentov ^{30, [ib](#)}, T. Klioutchnikova ^{37, [ib](#)}, P. Kluit ^{118, [ib](#)}, S. Kluth ^{113, [ib](#)}, E. Kneringer ^{80, [ib](#)}, T.M. Knight ^{162, [ib](#)},
A. Knue ^{50, [ib](#)}, M. Kobel ^{51, [ib](#)}, D. Kobylanskii ^{176, [ib](#)}, S.F. Koch ^{130, [ib](#)}, M. Kocian ^{150, [ib](#)}, P. Kodyš ^{137, [ib](#)},
D.M. Koeck ^{127, [ib](#)}, P.T. Koenig ^{25, [ib](#)}, T. Koffas ^{35, [ib](#)}, O. Kolay ^{51, [ib](#)}, I. Koletsou ^{4, [ib](#)}, T. Komarek ^{88, [ib](#)},
K. Köneke ^{56, [ib](#)}, A.X.Y. Kong ^{1, [ib](#)}, T. Kono ^{122, [ib](#)}, N. Konstantinidis ^{99, [ib](#)}, P. Kontaxakis ^{57, [ib](#)}, B. Konya ^{101, [ib](#)},
R. Kopeliansky ^{43, [ib](#)}, S. Koperny ^{87a, [ib](#)}, K. Korcyl ^{88, [ib](#)}, K. Kordas ^{159, [ib](#)},^e, A. Korn ^{99, [ib](#)}, S. Korn ^{56, [ib](#)},

I. Korolkov ^{13, [ib](#)}, N. Korotkova ^{39, [ib](#)}, B. Kortman ^{118, [ib](#)}, O. Kortner ^{113, [ib](#)}, S. Kortner ^{113, [ib](#)}, W.H. Kostecka ^{119, [ib](#)}, V.V. Kostyukhin ^{148, [ib](#)}, A. Kotskechagia ^{37, [ib](#)}, A. Kotwal ^{52, [ib](#)}, A. Koulouris ^{37, [ib](#)}, A. Kourkouveli-Charalampidi ^{74a,74b, [ib](#)}, C. Kourkouvelis ^{9, [ib](#)}, E. Kourlitis ^{113, [ib](#)}, O. Kovanda ^{127, [ib](#)}, R. Kowalewski ^{172, [ib](#)}, W. Kozanecki ^{127, [ib](#)}, A.S. Kozhin ^{39, [ib](#)}, V.A. Kramarenko ^{39, [ib](#)}, G. Kramberger ^{96, [ib](#)}, P. Kramer ^{25, [ib](#)}, M.W. Krasny ^{131, [ib](#)}, A. Krasznahorkay ^{106, [ib](#)}, A.C. Kraus ^{119, [ib](#)}, J.W. Kraus ^{178, [ib](#)}, J.A. Kremer ^{49, [ib](#)}, N.B. Krengel ^{148, [ib](#)}, T. Kresse ^{51, [ib](#)}, L. Kretschmann ^{178, [ib](#)}, J. Kretschmar ^{95, [ib](#)}, K. Kreul ^{19, [ib](#)}, P. Krieger ^{162, [ib](#)}, K. Krizka ^{21, [ib](#)}, K. Kroeninger ^{50, [ib](#)}, H. Kroha ^{113, [ib](#)}, J. Kroll ^{135, [ib](#)}, J. Kroll ^{132, [ib](#)}, K.S. Krowpman ^{110, [ib](#)}, U. Kruchonak ^{40, [ib](#)}, H. Krüger ^{25, [ib](#)}, N. Krumnack ⁸², M.C. Kruse ^{52, [ib](#)}, O. Kuchinskaia ^{39, [ib](#)}, S. Kuday ^{3a, [ib](#)}, S. Kuehn ^{37, [ib](#)}, R. Kuesters ^{55, [ib](#)}, T. Kuhl ^{49, [ib](#)}, V. Kukhtin ^{40, [ib](#)}, Y. Kulchitsky ^{40, [ib](#)}, S. Kuleshov ^{141d,141b, [ib](#)}, M. Kumar ^{34g, [ib](#)}, N. Kumari ^{49, [ib](#)}, P. Kumari ^{163b, [ib](#)}, A. Kupco ^{135, [ib](#)}, T. Kupfer ⁵⁰, A. Kupich ^{39, [ib](#)}, O. Kuprash ^{55, [ib](#)}, H. Kurashige ^{86, [ib](#)}, L.L. Kurchaninov ^{163a, [ib](#)}, O. Kurdysh ^{4, [ib](#)}, Y.A. Kurochkin ^{38, [ib](#)}, A. Kurova ^{39, [ib](#)}, M. Kuze ^{142, [ib](#)}, A.K. Kvam ^{106, [ib](#)}, J. Kvita ^{126, [ib](#)}, N.G. Kyriacou ^{109, [ib](#)}, L.A.O. Laatu ^{105, [ib](#)}, C. Lacasta ^{170, [ib](#)}, F. Lacava ^{76a,76b, [ib](#)}, H. Lacker ^{19, [ib](#)}, D. Lacour ^{131, [ib](#)}, N.N. Lad ^{99, [ib](#)}, E. Ladygin ^{40, [ib](#)}, A. Lafarge ^{42, [ib](#)}, B. Laforge ^{131, [ib](#)}, T. Lagouri ^{179, [ib](#)}, F.Z. Lahbabi ^{36a, [ib](#)}, S. Lai ^{56, [ib](#)}, J.E. Lambert ^{172, [ib](#)}, S. Lammers ^{69, [ib](#)}, W. Lampl ^{7, [ib](#)}, C. Lampoudis ^{159, [ib](#)}, G. Lamprinouidis ^{103, [ib](#)}, A.N. Lancaster ^{119, [ib](#)}, E. Lançon ^{30, [ib](#)}, U. Landgraf ^{55, [ib](#)}, M.P.J. Landon ^{97, [ib](#)}, V.S. Lang ^{55, [ib](#)}, O.K.B. Langrekken ^{129, [ib](#)}, A.J. Lankford ^{166, [ib](#)}, F. Lanni ^{37, [ib](#)}, K. Lantzsche ^{25, [ib](#)}, A. Lanza ^{74a, [ib](#)}, M. Lanza Berrocal ^{170, [ib](#)}, J.F. Laporte ^{139, [ib](#)}, T. Lari ^{72a, [ib](#)}, D. Larsen ^{17, [ib](#)}, F. Lasagni Manghi ^{24b, [ib](#)}, M. Lassnig ^{37, [ib](#)}, V. Latonova ^{135, [ib](#)}, S.D. Lawlor ^{146, [ib](#)}, Z. Lawrence ^{104, [ib](#)}, R. Lazaridou ¹⁷⁴, M. Lazzaroni ^{72a,72b, [ib](#)}, H.D.M. Le ^{110, [ib](#)}, E.M. Le Boulicaut ^{179, [ib](#)}, L.T. Le Pottier ^{18a, [ib](#)}, B. Leban ^{24b,24a, [ib](#)}, M. LeBlanc ^{104, [ib](#)}, F. Ledroit-Guillon ^{61, [ib](#)}, S.C. Lee ^{155, [ib](#)}, T.F. Lee ^{95, [ib](#)}, L.L. Leeuw ^{34c, [ib](#)}, M. Lefebvre ^{172, [ib](#)}, C. Leggett ^{18a, [ib](#)}, G. Lehmann Miotto ^{37, [ib](#)}, M. Leigh ^{57, [ib](#)}, W.A. Leight ^{106, [ib](#)}, W. Leinonen ^{117, [ib](#)}, A. Leisos ^{159, [ib](#)}, M.A.L. Leite ^{84c, [ib](#)}, C.E. Leitgeb ^{19, [ib](#)}, R. Leitner ^{137, [ib](#)}, K.J.C. Leney ^{46, [ib](#)}, T. Lenz ^{25, [ib](#)}, S. Leone ^{75a, [ib](#)}, C. Leonidopoulos ^{53, [ib](#)}, A. Leopold ^{151, [ib](#)}, J.H. Lepage Bourbonnais ^{35, [ib](#)}, R. Les ^{110, [ib](#)}, C.G. Lester ^{33, [ib](#)}, M. Levchenko ^{39, [ib](#)}, J. Levêque ^{4, [ib](#)}, L.J. Levinson ^{176, [ib](#)}, G. Levirini ^{24b,24a, [ib](#)}, M.P. Lewicki ^{88, [ib](#)}, C. Lewis ^{143, [ib](#)}, D.J. Lewis ^{4, [ib](#)}, L. Lewitt ^{146, [ib](#)}, A. Li ^{30, [ib](#)}, B. Li ^{144a, [ib](#)}, C. Li ¹⁰⁹, C-Q. Li ^{113, [ib](#)}, H. Li ^{63, [ib](#)}, H. Li ^{144a, [ib](#)}, H. Li ^{104, [ib](#)}, H. Li ^{15, [ib](#)}, H. Li ⁶³, H. Li ^{144a, [ib](#)}, J. Li ^{145a, [ib](#)}, K. Li ^{14, [ib](#)}, L. Li ^{145a, [ib](#)}, R. Li ^{179, [ib](#)}, S. Li ^{14,115c, [ib](#)}, S. Li ^{145b,145a, [ib](#)}, T. Li ^{5, [ib](#)}, X. Li ^{107, [ib](#)}, Z. Li ^{160, [ib](#)}, Z. Li ^{14,115c, [ib](#)}, Z. Li ^{63, [ib](#)}, S. Liang ^{14,115c, [ib](#)}, Z. Liang ^{14, [ib](#)}, M. Liberatore ^{139, [ib](#)}, B. Liberti ^{77a, [ib](#)}, K. Lie ^{65c, [ib](#)}, J. Lieber Marin ^{84c, [ib](#)}, H. Lien ^{69, [ib](#)}, H. Lin ^{109, [ib](#)}, L. Linden ^{112, [ib](#)}, R.E. Lindley ^{7, [ib](#)}, J.H. Lindon ^{2, [ib](#)}, J. Ling ^{62, [ib](#)}, E. Lipeles ^{132, [ib](#)}, A. Lipniacka ^{17, [ib](#)}, A. Lister ^{171, [ib](#)}, J.D. Little ^{69, [ib](#)}, B. Liu ^{14, [ib](#)}, B.X. Liu ^{115b, [ib](#)}, D. Liu ^{145b,145a, [ib](#)}, E.H.L. Liu ^{21, [ib](#)}, J.K.K. Liu ^{33, [ib](#)}, K. Liu ^{145b, [ib](#)}, K. Liu ^{145b,145a, [ib](#)}, M. Liu ^{63, [ib](#)}, M.Y. Liu ^{63, [ib](#)}, P. Liu ^{14, [ib](#)}, Q. Liu ^{145b,143,145a, [ib](#)}, X. Liu ^{63, [ib](#)}, X. Liu ^{144a, [ib](#)}, Y. Liu ^{115b,115c, [ib](#)}, Y.L. Liu ^{144a, [ib](#)}, Y.W. Liu ^{63, [ib](#)}, S.L. Lloyd ^{97, [ib](#)}, E.M. Lobodzinska ^{49, [ib](#)}, P. Loch ^{7, [ib](#)}, E. Lodhi ^{162, [ib](#)}, T. Lohse ^{19, [ib](#)}, K. Lohwasser ^{146, [ib](#)}, E. Loiacono ^{49, [ib](#)}, J.D. Lomas ^{21, [ib](#)}, J.D. Long ^{43, [ib](#)}, I. Longarini ^{166, [ib](#)}, R. Longo ^{169, [ib](#)}, A. Lopez Solis ^{49, [ib](#)}, N.A. Lopez-canelas ^{7, [ib](#)}, N. Lorenzo Martinez ^{4, [ib](#)}, A.M. Lory ^{112, [ib](#)}, M. Losada ^{120a, [ib](#)}, G. Löschcke Centeno ^{153, [ib](#)}, O. Loseva ^{39, [ib](#)}, X. Lou ^{48a,48b, [ib](#)}, X. Lou ^{14,115c, [ib](#)}, A. Lounis ^{67, [ib](#)}, P.A. Love ^{94, [ib](#)}, G. Lu ^{14,115c, [ib](#)}, M. Lu ^{67, [ib](#)}, S. Lu ^{132, [ib](#)}, Y.J. Lu ^{155, [ib](#)}, H.J. Lubatti ^{143, [ib](#)}, C. Luci ^{76a,76b, [ib](#)}, F.L. Lucio Alves ^{115a, [ib](#)}, F. Luehring ^{69, [ib](#)}, B.S. Lunday ^{132, [ib](#)}, O. Lundberg ^{151, [ib](#)}, B. Lund-Jensen ^{151, [ib](#)}, N.A. Luongo ^{6, [ib](#)}, M.S. Lutz ^{37, [ib](#)}, A.B. Lux ^{26, [ib](#)}, D. Lynn ^{30, [ib](#)}, R. Lysak ^{135, [ib](#)}, V. Lysenko ^{136, [ib](#)}, E. Lytken ^{101, [ib](#)}, V. Lyubushkin ^{40, [ib](#)}, T. Lyubushkina ^{40, [ib](#)}, M.M. Lyukova ^{152, [ib](#)}, M. Firdaus M. Soberi ^{53, [ib](#)}, H. Ma ^{30, [ib](#)}, K. Ma ^{63, [ib](#)}, L.L. Ma ^{144a, [ib](#)}, W. Ma ^{63, [ib](#)}, Y. Ma ^{125, [ib](#)}, J.C. MacDonald ^{103, [ib](#)}, P.C. Machado De Abreu Farias ^{84e, [ib](#)}, R. Madar ^{42, [ib](#)}, T. Madula ^{99, [ib](#)}, J. Maeda ^{86, [ib](#)}, T. Maeno ^{30, [ib](#)}, P.T. Mafa ^{34c, [ib](#)}, H. Maguire ^{146, [ib](#)}, V. Maiboroda ^{67, [ib](#)}, A. Maio ^{134a,134b,134d, [ib](#)}, K. Maj ^{87a, [ib](#)}, O. Majersky ^{49, [ib](#)}, S. Majewski ^{127, [ib](#)}, R. Makhmanazarov ^{39, [ib](#)},

N. Makovec^{67, [id](#)}, V. Maksimovic^{16, [id](#)}, B. Malaescu^{131, [id](#)}, Pa. Malecki^{88, [id](#)}, V.P. Maleev^{39, [id](#)}, F. Malek^{61, [id](#), [p](#)}, M. Mali^{96, [id](#)}, D. Malito^{98, [id](#)}, U. Mallik^{81, [id](#), [*](#)}, S. Maltezos¹⁰, S. Malyukov⁴⁰, J. Mamuzic^{13, [id](#)}, G. Mancini^{54, [id](#)}, M.N. Mancini^{27, [id](#)}, G. Manco^{74a,74b, [id](#)}, J.P. Mandalia^{97, [id](#)}, S.S. Mandarray^{153, [id](#)}, I. Mandić^{96, [id](#)}, L. Manhaes de Andrade Filho^{84a, [id](#)}, I.M. Maniatis^{176, [id](#)}, J. Manjarres Ramos^{92, [id](#)}, D.C. Mankad^{176, [id](#)}, A. Mann^{112, [id](#)}, S. Manzoni^{37, [id](#)}, L. Mao^{145a, [id](#)}, X. Mapekula^{34c, [id](#)}, A. Marantis^{159, [id](#), [u](#)}, G. Marchiori^{5, [id](#)}, M. Marcisovsky^{135, [id](#)}, C. Marcon^{72a, [id](#)}, M. Marinescu^{21, [id](#)}, S. Marium^{49, [id](#)}, M. Marjanovic^{124, [id](#)}, A. Markhoos^{55, [id](#)}, M. Markovitch^{67, [id](#)}, M.K. Maroun^{106, [id](#)}, E.J. Marshall^{94, [id](#)}, Z. Marshall^{18a, [id](#)}, S. Marti-Garcia^{170, [id](#)}, J. Martin^{99, [id](#)}, T.A. Martin^{138, [id](#)}, V.J. Martin^{53, [id](#)}, B. Martin dit Latour^{17, [id](#)}, L. Martinelli^{76a,76b, [id](#)}, M. Martinez^{13, [id](#), [x](#)}, P. Martinez Agullo^{170, [id](#)}, V.I. Martinez Outschoorn^{106, [id](#)}, P. Martinez Suarez^{13, [id](#)}, S. Martin-Haugh^{138, [id](#)}, G. Martinovicova^{137, [id](#)}, V.S. Martoiu^{28b, [id](#)}, A.C. Martyniuk^{99, [id](#)}, A. Marzin^{37, [id](#)}, D. Mascione^{79a,79b, [id](#)}, L. Masetti^{103, [id](#)}, J. Masik^{104, [id](#)}, A.L. Maslennikov^{40, [id](#)}, S.L. Mason^{43, [id](#)}, P. Massarotti^{73a,73b, [id](#)}, P. Mastrandrea^{75a,75b, [id](#)}, A. Mastroberardino^{45b,45a, [id](#)}, T. Masubuchi^{128, [id](#)}, T.T. Mathew^{127, [id](#)}, J. Matousek^{137, [id](#)}, D.M. Mattern^{50, [id](#)}, J. Maurer^{28b, [id](#)}, T. Maurin^{60, [id](#)}, A.J. Maury^{67, [id](#)}, B. Maček^{96, [id](#)}, D.A. Maximov^{39, [id](#)}, A.E. May^{104, [id](#)}, E. Mayer^{42, [id](#)}, R. Mazini^{34g, [id](#)}, I. Maznas^{119, [id](#)}, M. Mazza^{110, [id](#)}, S.M. Mazza^{140, [id](#)}, E. Mazzeo^{72a,72b, [id](#)}, J.P. Mc Gowan^{172, [id](#)}, S.P. Mc Kee^{109, [id](#)}, C.A. Mc Lean^{6, [id](#)}, C.C. McCracken^{171, [id](#)}, E.F. McDonald^{108, [id](#)}, A.E. McDougall^{118, [id](#)}, L.F. Mcelhinney^{94, [id](#)}, J.A. Mcfayden^{153, [id](#)}, R.P. McGovern^{132, [id](#)}, R.P. McKenzie^{34g, [id](#)}, T.C. McLachlan^{49, [id](#)}, D.J. McLaughlin^{99, [id](#)}, S.J. McMahon^{138, [id](#)}, C.M. Mcpartland^{95, [id](#)}, R.A. McPherson^{172, [id](#), [ab](#)}, S. Mehlhase^{112, [id](#)}, A. Mehta^{95, [id](#)}, D. Melini^{170, [id](#)}, B.R. Mellado Garcia^{34g, [id](#)}, A.H. Melo^{56, [id](#)}, F. Meloni^{49, [id](#)}, A.M. Mendes Jacques Da Costa^{104, [id](#)}, H.Y. Meng^{162, [id](#)}, L. Meng^{94, [id](#)}, S. Menke^{113, [id](#)}, M. Mentink^{37, [id](#)}, E. Meoni^{45b,45a, [id](#)}, G. Mercado^{119, [id](#)}, S. Merianos^{159, [id](#)}, C. Merlassino^{70a,70c, [id](#)}, C. Meroni^{72a,72b, [id](#)}, J. Metcalfe^{6, [id](#)}, A.S. Mete^{6, [id](#)}, E. Meuser^{103, [id](#)}, C. Meyer^{69, [id](#)}, J.-P. Meyer^{139, [id](#)}, R.P. Middleton^{138, [id](#)}, L. Mijović^{53, [id](#)}, G. Mikenberg^{176, [id](#)}, M. Mikestikova^{135, [id](#)}, M. Mikuž^{96, [id](#)}, H. Mildner^{103, [id](#)}, A. Milic^{37, [id](#)}, D.W. Miller^{41, [id](#)}, E.H. Miller^{150, [id](#)}, L.S. Miller^{35, [id](#)}, A. Milov^{176, [id](#)}, D.A. Milstead^{48a,48b}, T. Min^{115a}, A.A. Minaenko^{39, [id](#)}, I.A. Minashvili^{156b, [id](#)}, A.I. Mincer^{121, [id](#)}, B. Mindur^{87a, [id](#)}, M. Mineev^{40, [id](#)}, Y. Mino^{90, [id](#)}, L.M. Mir^{13, [id](#)}, M. Miralles Lopez^{60, [id](#)}, M. Mironova^{18a, [id](#)}, M.C. Missio^{117, [id](#)}, A. Mitra^{174, [id](#)}, V.A. Mitsou^{170, [id](#)}, Y. Mitsumori^{114, [id](#)}, O. Miu^{162, [id](#)}, P.S. Miyagawa^{97, [id](#)}, T. Mkrtchyan^{64a, [id](#)}, M. Mlinarevic^{99, [id](#)}, T. Mlinarevic^{99, [id](#)}, M. Mlynarikova^{37, [id](#)}, S. Mobius^{20, [id](#)}, P. Mogg^{112, [id](#)}, M.H. Mohamed Farook^{116, [id](#)}, A.F. Mohammed^{14,115c, [id](#)}, S. Mohapatra^{43, [id](#)}, S. Mohiuddin^{125, [id](#)}, G. Mokgatitswane^{34g, [id](#)}, L. Moleri^{176, [id](#)}, B. Mondal^{148, [id](#)}, S. Mondal^{136, [id](#)}, K. Mönig^{49, [id](#)}, E. Monnier^{105, [id](#)}, L. Monsonis Romero¹⁷⁰, J. Montejo Berlingen^{13, [id](#)}, A. Montella^{48a,48b, [id](#)}, M. Montella^{123, [id](#)}, F. Montereali^{78a,78b, [id](#)}, F. Monticelli^{93, [id](#)}, S. Monzani^{70a,70c, [id](#)}, A. Moranco Tarda^{44, [id](#)}, N. Morange^{67, [id](#)}, A.L. Moreira De Carvalho^{49, [id](#)}, M. Moreno Llácer^{170, [id](#)}, C. Moreno Martinez^{57, [id](#)}, J.M. Moreno Perez^{23b}, P. Morettini^{58b, [id](#)}, S. Morgenstern^{37, [id](#)}, M. Morii^{62, [id](#)}, M. Morinaga^{160, [id](#)}, M. Moritsu^{91, [id](#)}, F. Morodei^{76a,76b, [id](#)}, P. Moschovakos^{37, [id](#)}, B. Moser^{130, [id](#)}, M. Mosidze^{156b, [id](#)}, T. Moskalets^{46, [id](#)}, P. Moskvitina^{117, [id](#)}, J. Moss^{32, [id](#), [m](#)}, P. Moszkowicz^{87a, [id](#)}, A. Moussa^{36d, [id](#)}, Y. Moyal^{176, [id](#)}, E.J.W. Moyse^{106, [id](#)}, O. Mtintsilana^{34g, [id](#)}, S. Muanza^{105, [id](#)}, J. Mueller^{133, [id](#)}, R. Müller^{37, [id](#)}, G.A. Mullier^{168, [id](#)}, A.J. Mullin³³, J.J. Mullin⁵², A.E. Mulski^{62, [id](#)}, D.P. Mungo^{162, [id](#)}, D. Munoz Perez^{170, [id](#)}, F.J. Munoz Sanchez^{104, [id](#)}, M. Murin^{104, [id](#)}, W.J. Murray^{174,138, [id](#)}, M. Muškinja^{96, [id](#)}, C. Mwewa^{30, [id](#)}, A.G. Myagkov^{39, [id](#), [a](#)}, A.J. Myers^{8, [id](#)}, G. Myers^{109, [id](#)}, M. Myska^{136, [id](#)}, B.P. Nachman^{18a, [id](#)}, K. Nagai^{130, [id](#)}, K. Nagano^{85, [id](#)}, R. Nagasaka¹⁶⁰, J.L. Nagle^{30, [id](#), [ak](#)}, E. Nagy^{105, [id](#)}, A.M. Nairz^{37, [id](#)}, Y. Nakahama^{85, [id](#)}, K. Nakamura^{85, [id](#)}, K. Nakkalil^{5, [id](#)}, H. Nanjo^{128, [id](#)}, E.A. Narayanan^{46, [id](#)}, Y. Narukawa^{160, [id](#)}, I. Naryshkin^{39, [id](#)}, L. Nasella^{72a,72b, [id](#)}, S. Nasri^{120b, [id](#)}, C. Nass^{25, [id](#)}, G. Navarro^{23a, [id](#)}, J. Navarro-Gonzalez^{170, [id](#)}, A. Nayaz^{19, [id](#)}, P.Y. Nechaeva^{39, [id](#)}, S. Nechaeva^{24b,24a, [id](#)}, F. Nechansky^{135, [id](#)},

L. Nedic ^{130, [ib](#)}, T.J. Neep ^{21, [ib](#)}, A. Negri ^{74a,74b, [ib](#)}, M. Negrini ^{24b, [ib](#)}, C. Nellist ^{118, [ib](#)}, C. Nelson ^{107, [ib](#)},
 K. Nelson ^{109, [ib](#)}, S. Nemecek ^{135, [ib](#)}, M. Nessi ^{37, [ib](#), [h](#)}, M.S. Neubauer ^{169, [ib](#)}, F. Neuhaus ^{103, [ib](#)}, J. Newell ^{95, [ib](#)},
 P.R. Newman ^{21, [ib](#)}, Y.W.Y. Ng ^{169, [ib](#)}, B. Ngair ^{120a, [ib](#)}, H.D.N. Nguyen ^{111, [ib](#)}, R.B. Nickerson ^{130, [ib](#)},
 R. Nicolaidou ^{139, [ib](#)}, J. Nielsen ^{140, [ib](#)}, M. Niemeyer ^{56, [ib](#)}, J. Niermann ^{37, [ib](#)}, N. Nikiforou ^{37, [ib](#)},
 V. Nikolaenko ^{39, [ib](#), [a](#)}, I. Nikolic-Audit ^{131, [ib](#)}, P. Nilsson ^{30, [ib](#)}, I. Ninca ^{49, [ib](#)}, G. Ninio ^{158, [ib](#)}, A. Nisati ^{76a, [ib](#)},
 N. Nishu ^{2, [ib](#)}, R. Nisius ^{113, [ib](#)}, N. Nitika ^{70a,70c, [ib](#)}, J-E. Nitschke ^{51, [ib](#)}, E.K. Nkadimeng ^{34g, [ib](#)}, T. Nobe ^{160, [ib](#)},
 T. Nommensen ^{154, [ib](#)}, M.B. Norfolk ^{146, [ib](#)}, B.J. Norman ^{35, [ib](#)}, M. Noury ^{36a, [ib](#)}, J. Novak ^{96, [ib](#)}, T. Novak ^{96, [ib](#)},
 R. Novotny ^{116, [ib](#)}, L. Nozka ^{126, [ib](#)}, K. Ntekas ^{166, [ib](#)}, N.M.J. Nunes De Moura Junior ^{84b, [ib](#)}, J. Ocariz ^{131, [ib](#)},
 A. Ochi ^{86, [ib](#)}, I. Ochoa ^{134a, [ib](#)}, S. Oerdek ^{49, [ib](#), [y](#)}, J.T. Offermann ^{41, [ib](#)}, A. Ogrodnik ^{137, [ib](#)}, A. Oh ^{104, [ib](#)},
 C.C. Ohm ^{151, [ib](#)}, H. Oide ^{85, [ib](#)}, R. Oishi ^{160, [ib](#)}, M.L. Ojeda ^{37, [ib](#)}, Y. Okumura ^{160, [ib](#)}, L.F. Oleiro Seabra ^{134a, [ib](#)},
 I. Oleksiyuk ^{57, [ib](#)}, S.A. Olivares Pino ^{141d, [ib](#)}, G. Oliveira Correa ^{13, [ib](#)}, D. Oliveira Damazio ^{30, [ib](#)}, J.L. Oliver ^{166, [ib](#)},
 Ö.O. Öncel ^{55, [ib](#)}, A.P. O'Neill ^{20, [ib](#)}, A. Onofre ^{134a,134c, [ib](#)}, P.U.E. Onyisi ^{11, [ib](#)}, M.J. Oreglia ^{41, [ib](#)},
 D. Orestano ^{78a,78b, [ib](#)}, R.S. Orr ^{162, [ib](#)}, L.M. Osojnak ^{132, [ib](#)}, Y. Osumi ^{114, [ib](#)}, G. Otero y Garzon ^{31, [ib](#)}, H. Otono ^{91, [ib](#)},
 G.J. Ottino ^{18a, [ib](#)}, M. Ouchrif ^{36d, [ib](#)}, F. Ould-Saada ^{129, [ib](#)}, T. Ovsianikova ^{143, [ib](#)}, M. Owen ^{60, [ib](#)}, R.E. Owen ^{138, [ib](#)},
 V.E. Ozcan ^{22a, [ib](#)}, F. Ozturk ^{88, [ib](#)}, N. Ozturk ^{8, [ib](#)}, S. Ozturk ^{83, [ib](#)}, H.A. Pacey ^{130, [ib](#)}, K. Pachal ^{163a, [ib](#)},
 A. Pacheco Pages ^{13, [ib](#)}, C. Padilla Aranda ^{13, [ib](#)}, G. Padovano ^{76a,76b, [ib](#)}, S. Pagan Griso ^{18a, [ib](#)}, G. Palacino ^{69, [ib](#)},
 A. Palazzo ^{71a,71b, [ib](#)}, J. Pampel ^{25, [ib](#)}, J. Pan ^{179, [ib](#)}, T. Pan ^{65a, [ib](#)}, D.K. Panchal ^{11, [ib](#)}, C.E. Pandini ^{118, [ib](#)},
 J.G. Panduro Vazquez ^{138, [ib](#)}, H.D. Pandya ^{1, [ib](#)}, H. Pang ^{139, [ib](#)}, P. Pani ^{49, [ib](#)}, G. Panizzo ^{70a,70c, [ib](#)}, L. Panwar ^{131, [ib](#)},
 L. Paolozzi ^{57, [ib](#)}, S. Parajuli ^{169, [ib](#)}, A. Paramonov ^{6, [ib](#)}, C. Paraskevopoulos ^{54, [ib](#)}, D. Paredes Hernandez ^{65b, [ib](#)},
 A. Pareti ^{74a,74b, [ib](#)}, K.R. Park ^{43, [ib](#)}, T.H. Park ^{113, [ib](#)}, F. Parodi ^{58b,58a, [ib](#)}, J.A. Parsons ^{43, [ib](#)}, U. Parzefall ^{55, [ib](#)},
 B. Pascual Dias ^{42, [ib](#)}, L. Pascual Dominguez ^{102, [ib](#)}, E. Pasqualucci ^{76a, [ib](#)}, S. Passaggio ^{58b, [ib](#)}, F. Pastore ^{98, [ib](#)},
 P. Patel ^{88, [ib](#)}, U.M. Patel ^{52, [ib](#)}, J.R. Pater ^{104, [ib](#)}, T. Pauly ^{37, [ib](#)}, F. Pauwels ^{137, [ib](#)}, C.I. Pazos ^{165, [ib](#)},
 M. Pedersen ^{129, [ib](#)}, R. Pedro ^{134a, [ib](#)}, S.V. Peleganchuk ^{39, [ib](#)}, O. Penc ^{37, [ib](#)}, E.A. Pender ^{53, [ib](#)}, S. Peng ^{15, [ib](#)},
 G.D. Penn ^{179, [ib](#)}, K.E. Pensi ^{112, [ib](#)}, M. Penzin ^{39, [ib](#)}, B.S. Peralva ^{84d, [ib](#)}, A.P. Pereira Peixoto ^{143, [ib](#)},
 L. Pereira Sanchez ^{150, [ib](#)}, D.V. Perepelitsa ^{30, [ib](#), [ak](#)}, G. Perera ^{106, [ib](#)}, E. Perez Codina ^{163a, [ib](#)}, M. Perganti ^{10, [ib](#)},
 H. Pernegger ^{37, [ib](#)}, S. Perrella ^{76a,76b, [ib](#)}, O. Perrin ^{42, [ib](#)}, K. Peters ^{49, [ib](#)}, R.F.Y. Peters ^{104, [ib](#)}, B.A. Petersen ^{37, [ib](#)},
 T.C. Petersen ^{44, [ib](#)}, E. Petit ^{105, [ib](#)}, V. Petousis ^{136, [ib](#)}, A.R. Petri ^{72a,72b, [ib](#)}, C. Petridou ^{159, [ib](#), [e](#)}, T. Petru ^{137, [ib](#)},
 A. Petrukhin ^{148, [ib](#)}, M. Pettee ^{18a, [ib](#)}, A. Petukhov ^{83, [ib](#)}, K. Petukhova ^{37, [ib](#)}, R. Pezoa ^{141f, [ib](#)}, L. Pezzotti ^{24b,24a, [ib](#)},
 G. Pezzullo ^{179, [ib](#)}, L. Pfaffenbichler ^{37, [ib](#)}, A.J. Pfleger ^{37, [ib](#)}, T.M. Pham ^{177, [ib](#)}, T. Pham ^{108, [ib](#)}, P.W. Phillips ^{138, [ib](#)},
 G. Piacquadio ^{152, [ib](#)}, E. Pianori ^{18a, [ib](#)}, F. Piazza ^{127, [ib](#)}, R. Piegaia ^{31, [ib](#)}, D. Pietreanu ^{28b, [ib](#)}, A.D. Pilkington ^{104, [ib](#)},
 M. Pinamonti ^{70a,70c, [ib](#)}, J.L. Pinfold ^{2, [ib](#)}, B.C. Pinheiro Pereira ^{134a, [ib](#)}, J. Pinol Bel ^{13, [ib](#)},
 A.E. Pinto Pinoargote ^{131, [ib](#)}, L. Pintucci ^{70a,70c, [ib](#)}, K.M. Piper ^{153, [ib](#)}, A. Pirttikoski ^{57, [ib](#)}, D.A. Pizzi ^{35, [ib](#)},
 L. Pizzimento ^{65b, [ib](#)}, M.-A. Pleier ^{30, [ib](#)}, V. Pleskot ^{137, [ib](#)}, E. Plotnikova ^{40, [ib](#)}, G. Poddar ^{97, [ib](#)}, R. Poettgen ^{101, [ib](#)},
 L. Poggioli ^{131, [ib](#)}, S. Polacek ^{137, [ib](#)}, G. Polesello ^{74a, [ib](#)}, A. Poley ^{149,163a, [ib](#)}, A. Polini ^{24b, [ib](#)}, C.S. Pollard ^{174, [ib](#)},
 Z.B. Pollock ^{123, [ib](#)}, E. Pompa Pacchi ^{124, [ib](#)}, N.I. Pond ^{99, [ib](#)}, D. Ponomarenko ^{69, [ib](#)}, L. Pontecorvo ^{37, [ib](#)},
 S. Popa ^{28a, [ib](#)}, G.A. Popeneciu ^{28d, [ib](#)}, A. Poreba ^{37, [ib](#)}, D.M. Portillo Quintero ^{163a, [ib](#)}, S. Pospisil ^{136, [ib](#)},
 M.A. Postill ^{146, [ib](#)}, P. Postolache ^{28c, [ib](#)}, K. Potamianos ^{174, [ib](#)}, P.A. Potepa ^{87a, [ib](#)}, I.N. Potrap ^{40, [ib](#)}, C.J. Potter ^{33, [ib](#)},
 H. Potti ^{154, [ib](#)}, J. Poveda ^{170, [ib](#)}, M.E. Pozo Astigarraga ^{37, [ib](#)}, A. Prades Ibanez ^{77a,77b, [ib](#)}, J. Pretel ^{172, [ib](#)},
 D. Price ^{104, [ib](#)}, M. Primavera ^{71a, [ib](#)}, L. Primomo ^{70a,70c, [ib](#)}, M.A. Principe Martin ^{102, [ib](#)}, R. Privara ^{126, [ib](#)},
 T. Procter ^{60, [ib](#)}, M.L. Proffitt ^{143, [ib](#)}, N. Proklova ^{132, [ib](#)}, K. Prokofiev ^{65c, [ib](#)}, G. Proto ^{113, [ib](#)}, J. Proudfoot ^{6, [ib](#)},
 M. Przybycien ^{87a, [ib](#)}, W.W. Przygoda ^{87b, [ib](#)}, A. Psallidas ^{47, [ib](#)}, J.E. Puddefoot ^{146, [ib](#)}, D. Pudzha ^{55, [ib](#)},
 D. Pyatiizbyantseva ^{117, [ib](#)}, J. Qian ^{109, [ib](#)}, R. Qian ^{110, [ib](#)}, D. Qichen ^{104, [ib](#)}, Y. Qin ^{13, [ib](#)}, T. Qiu ^{53, [ib](#)}, A. Quadt ^{56, [ib](#)},

M. Queitsch-Maitland ^{104, [id](#)}, G. Quetant ^{57, [id](#)}, R.P. Quinn ^{171, [id](#)}, G. Rabanal Bolanos ^{62, [id](#)}, D. Rafanoharana ^{55, [id](#)}, F. Raffaelli ^{77a,77b, [id](#)}, F. Ragusa ^{72a,72b, [id](#)}, J.L. Rainbolt ^{41, [id](#)}, J.A. Raine ^{57, [id](#)}, S. Rajagopalan ^{30, [id](#)}, E. Ramakoti ^{39, [id](#)}, L. Rambelli ^{58b,58a, [id](#)}, I.A. Ramirez-Berend ^{35, [id](#)}, K. Ran ^{49,115c, [id](#)}, D.S. Rankin ^{132, [id](#)}, N.P. Rapheeha ^{34g, [id](#)}, H. Rasheed ^{28b, [id](#)}, V. Raskina ^{131, [id](#)}, D.F. Rassloff ^{64a, [id](#)}, A. Rastogi ^{18a, [id](#)}, S. Rave ^{103, [id](#)}, S. Ravera ^{58b,58a, [id](#)}, B. Ravina ^{37, [id](#)}, I. Ravinovitch ^{176, [id](#)}, M. Raymond ^{37, [id](#)}, A.L. Read ^{129, [id](#)}, N.P. Readioff ^{146, [id](#)}, D.M. Rebuzzi ^{74a,74b, [id](#)}, A.S. Reed ^{113, [id](#)}, K. Reeves ^{27, [id](#)}, J.A. Reidelsturz ^{178, [id](#)}, D. Reikher ^{127, [id](#)}, A. Rej ^{50, [id](#)}, C. Rembser ^{37, [id](#)}, H. Ren ^{63, [id](#)}, M. Renda ^{28b, [id](#)}, F. Renner ^{49, [id](#)}, A.G. Rennie ^{166, [id](#)}, A.L. Rescia ^{49, [id](#)}, S. Resconi ^{72a, [id](#)}, M. Ressegotti ^{58b,58a, [id](#)}, S. Rettie ^{37, [id](#)}, W.F. Rettie ^{35, [id](#)}, J.G. Reyes Rivera ^{110, [id](#)}, E. Reynolds ^{18a, [id](#)}, O.L. Rezanova ^{40, [id](#)}, P. Reznicek ^{137, [id](#)}, H. Riani ^{36d, [id](#)}, N. Ribaric ^{52, [id](#)}, E. Ricci ^{79a,79b, [id](#)}, R. Richter ^{113, [id](#)}, S. Richter ^{48a,48b, [id](#)}, E. Richter-Was ^{87b, [id](#)}, M. Ridel ^{131, [id](#)}, S. Ridouani ^{36d, [id](#)}, P. Rieck ^{121, [id](#)}, P. Riedler ^{37, [id](#)}, E.M. Riefel ^{48a,48b, [id](#)}, J.O. Rieger ^{118, [id](#)}, M. Rijssenbeek ^{152, [id](#)}, M. Rimoldi ^{37, [id](#)}, L. Rinaldi ^{24b,24a, [id](#)}, P. Rincke ^{56, [id](#)}, G. Ripellino ^{168, [id](#)}, I. Riu ^{13, [id](#)}, J.C. Rivera Vergara ^{172, [id](#)}, F. Rizatdinova ^{125, [id](#)}, E. Rizvi ^{97, [id](#)}, B.R. Roberts ^{18a, [id](#)}, S.S. Roberts ^{140, [id](#)}, D. Robinson ^{33, [id](#)}, M. Robles Manzano ^{103, [id](#)}, A. Robson ^{60, [id](#)}, A. Rocchi ^{77a,77b, [id](#)}, C. Roda ^{75a,75b, [id](#)}, S. Rodriguez Bosca ^{37, [id](#)}, Y. Rodriguez Garcia ^{23a, [id](#)}, A.M. Rodríguez Vera ^{119, [id](#)}, S. Roe ^{37, [id](#)}, J.T. Roemer ^{37, [id](#)}, O. Røhne ^{129, [id](#)}, R.A. Rojas ^{37, [id](#)}, C.P.A. Roland ^{131, [id](#)}, J. Roloff ^{30, [id](#)}, A. Romanouk ^{80, [id](#)}, E. Romano ^{74a,74b, [id](#)}, M. Romano ^{24b, [id](#)}, A.C. Romero Hernandez ^{169, [id](#)}, N. Rompotis ^{95, [id](#)}, L. Roos ^{131, [id](#)}, S. Rosati ^{76a, [id](#)}, B.J. Rosser ^{41, [id](#)}, E. Rossi ^{130, [id](#)}, E. Rossi ^{73a,73b, [id](#)}, L.P. Rossi ^{62, [id](#)}, L. Rossini ^{55, [id](#)}, R. Rosten ^{123, [id](#)}, M. Rotaru ^{28b, [id](#)}, B. Rottler ^{55, [id](#)}, D. Rousseau ^{67, [id](#)}, D. Rousso ^{49, [id](#)}, S. Roy-Garand ^{162, [id](#)}, A. Rozanov ^{105, [id](#)}, Z.M.A. Rozario ^{60, [id](#)}, Y. Rozen ^{157, [id](#)}, A. Rubio Jimenez ^{170, [id](#)}, V.H. Ruelas Rivera ^{19, [id](#)}, T.A. Ruggeri ^{1, [id](#)}, A. Ruggiero ^{130, [id](#)}, A. Ruiz-Martinez ^{170, [id](#)}, A. Rummler ^{37, [id](#)}, Z. Rurikova ^{55, [id](#)}, N.A. Rusakovich ^{40, [id](#)}, H.L. Russell ^{172, [id](#)}, G. Russo ^{76a,76b, [id](#)}, J.P. Rutherford ^{7, [id](#)}, S. Rutherford Colmenares ^{33, [id](#)}, M. Rybar ^{137, [id](#)}, P. Rybczynski ^{87a, [id](#)}, E.B. Rye ^{129, [id](#)}, A. Ryzhov ^{46, [id](#)}, J.A. Sabater Iglesias ^{57, [id](#)}, H.F.W. Sadrozinski ^{140, [id](#)}, F. Safai Tehrani ^{76a, [id](#)}, S. Saha ^{1, [id](#)}, M. Sahinsoy ^{83, [id](#)}, A. Saibel ^{170, [id](#)}, B.T. Saifuddin ^{124, [id](#)}, M. Saimpert ^{139, [id](#)}, M. Saito ^{160, [id](#)}, T. Saito ^{160, [id](#)}, A. Sala ^{72a,72b, [id](#)}, D. Salamani ^{37, [id](#)}, A. Salnikov ^{150, [id](#)}, J. Salt ^{170, [id](#)}, A. Salvador Salas ^{158, [id](#)}, D. Salvatore ^{45b,45a, [id](#)}, F. Salvatore ^{153, [id](#)}, A. Salzburger ^{37, [id](#)}, D. Sammel ^{55, [id](#)}, E. Sampson ^{94, [id](#)}, D. Sampsonidis ^{159, [id](#)}, D. Sampsonidou ^{127, [id](#)}, J. Sánchez ^{170, [id](#)}, V. Sanchez Sebastian ^{170, [id](#)}, H. Sandaker ^{129, [id](#)}, C.O. Sander ^{49, [id](#)}, J.A. Sandesara ^{106, [id](#)}, M. Sandhoff ^{178, [id](#)}, C. Sandoval ^{23b, [id](#)}, L. Sanfilippo ^{64a, [id](#)}, D.P.C. Sankey ^{138, [id](#)}, T. Sano ^{90, [id](#)}, A. Sansoni ^{54, [id](#)}, L. Santi ^{37, [id](#)}, C. Santoni ^{42, [id](#)}, H. Santos ^{134a,134b, [id](#)}, A. Santra ^{176, [id](#)}, E. Sanzani ^{24b,24a, [id](#)}, K.A. Saoucha ^{89b, [id](#)}, J.G. Saraiva ^{134a,134d, [id](#)}, J. Sardain ^{7, [id](#)}, O. Sasaki ^{85, [id](#)}, K. Sato ^{164, [id](#)}, C. Sauer ^{37, [id](#)}, E. Sauvan ^{4, [id](#)}, P. Savard ^{162, [id](#)}, R. Sawada ^{160, [id](#)}, C. Sawyer ^{138, [id](#)}, L. Sawyer ^{100, [id](#)}, C. Sbarra ^{24b, [id](#)}, A. Sbrizzi ^{24b,24a, [id](#)}, T. Scanlon ^{99, [id](#)}, J. Schaarschmidt ^{143, [id](#)}, U. Schäfer ^{103, [id](#)}, A.C. Schaffer ^{67,46, [id](#)}, D. Schaile ^{112, [id](#)}, R.D. Schamberger ^{152, [id](#)}, C. Scharf ^{19, [id](#)}, M.M. Schefer ^{20, [id](#)}, V.A. Schegelsky ^{39, [id](#)}, D. Scheirich ^{137, [id](#)}, M. Schernau ^{141e, [id](#)}, C. Scheulen ^{57, [id](#)}, C. Schiavi ^{58b,58a, [id](#)}, M. Schioppa ^{45b,45a, [id](#)}, B. Schlag ^{150, [id](#)}, S. Schlenker ^{37, [id](#)}, J. Schmeing ^{178, [id](#)}, M.A. Schmidt ^{178, [id](#)}, K. Schmieden ^{103, [id](#)}, C. Schmitt ^{103, [id](#)}, N. Schmitt ^{103, [id](#)}, S. Schmitt ^{49, [id](#)}, L. Schoeffel ^{139, [id](#)}, A. Schoening ^{64b, [id](#)}, P.G. Scholer ^{35, [id](#)}, E. Schopf ^{148, [id](#)}, M. Schott ^{25, [id](#)}, S. Schramm ^{57, [id](#)}, T. Schroer ^{57, [id](#)}, H-C. Schultz-Coulon ^{64a, [id](#)}, M. Schumacher ^{55, [id](#)}, B.A. Schumm ^{140, [id](#)}, Ph. Schune ^{139, [id](#)}, H.R. Schwartz ^{140, [id](#)}, A. Schwartzman ^{150, [id](#)}, T.A. Schwarz ^{109, [id](#)}, Ph. Schwemling ^{139, [id](#)}, R. Schwienhorst ^{110, [id](#)}, F.G. Sciacca ^{20, [id](#)}, A. Sciandra ^{30, [id](#)}, G. Sciolla ^{27, [id](#)}, F. Scuri ^{75a, [id](#)}, C.D. Sebastiani ^{37, [id](#)}, K. Sedlaczek ^{119, [id](#)}, S.C. Seidel ^{116, [id](#)}, A. Seiden ^{140, [id](#)}, B.D. Seidlitz ^{43, [id](#)}, C. Seitz ^{49, [id](#)}, J.M. Seixas ^{84b, [id](#)}, G. Sekhniaidze ^{73a, [id](#)}, L. Selem ^{61, [id](#)}, N. Semprini-Cesari ^{24b,24a, [id](#)}, A. Semushin ^{180,39, [id](#)}, D. Sengupta ^{57, [id](#)}, V. Senthilkumar ^{170, [id](#)}, L. Serin ^{67, [id](#)}, M. Sessa ^{77a,77b, [id](#)}, H. Severini ^{124, [id](#)}, F. Sforza ^{58b,58a, [id](#)}, A. Sfyrla ^{57, [id](#)}, Q. Sha ^{14, [id](#)}, E. Shabalina ^{56, [id](#)}, H. Shaddix ^{119, [id](#)}, A.H. Shah ^{33, [id](#)}, R. Shaheen ^{151, [id](#)},

J.D. Shahinian^{132, [id](#)}, D. Shaked Renous^{176, [id](#)}, M. Shamim^{37, [id](#)}, L.Y. Shan^{14, [id](#)}, M. Shapiro^{18a, [id](#)}, A. Sharma^{37, [id](#)}, A.S. Sharma^{171, [id](#)}, P. Sharma^{30, [id](#)}, P.B. Shatalov^{39, [id](#)}, K. Shaw^{153, [id](#)}, S.M. Shaw^{104, [id](#)}, Q. Shen^{145a, [id](#)}, D.J. Sheppard^{149, [id](#)}, P. Sherwood^{99, [id](#)}, L. Shi^{99, [id](#)}, X. Shi^{14, [id](#)}, S. Shimizu^{85, [id](#)}, C.O. Shimmin^{179, [id](#)}, I.P.J. Shipsey^{130, [id](#)},*, S. Shirabe^{91, [id](#)}, M. Shiyakova^{40, [id](#)},^z, M.J. Shochet^{41, [id](#)}, D.R. Shope^{129, [id](#)}, B. Shrestha^{124, [id](#)}, S. Shrestha^{123, [id](#)},^{am}, I. Shreyber^{39, [id](#)}, M.J. Shroff^{172, [id](#)}, P. Sicho^{135, [id](#)}, A.M. Sickles^{169, [id](#)}, E. Sideras Haddad^{34g, 167, [id](#)}, A.C. Sidley^{118, [id](#)}, A. Sidoti^{24b, [id](#)}, F. Siegert^{51, [id](#)}, Dj. Sijacki^{16, [id](#)}, F. Sili^{93, [id](#)}, J.M. Silva^{53, [id](#)}, I. Silva Ferreira^{84b, [id](#)}, M.V. Silva Oliveira^{30, [id](#)}, S.B. Silverstein^{48a, [id](#)}, S. Simion⁶⁷, R. Simoniello^{37, [id](#)}, E.L. Simpson^{104, [id](#)}, H. Simpson^{153, [id](#)}, L.R. Simpson^{109, [id](#)}, S. Simsek^{83, [id](#)}, S. Sindhu^{56, [id](#)}, P. Sinervo^{162, [id](#)}, S.N. Singh^{27, [id](#)}, S. Singh^{30, [id](#)}, S. Sinha^{49, [id](#)}, S. Sinha^{104, [id](#)}, M. Sioli^{24b, 24a, [id](#)}, K. Sioulas^{9, [id](#)}, I. Siral^{37, [id](#)}, E. Sitnikova^{49, [id](#)}, J. Sjölin^{48a, 48b, [id](#)}, A. Skaf^{56, [id](#)}, E. Skorda^{21, [id](#)}, P. Skubic^{124, [id](#)}, M. Slawinska^{88, [id](#)}, I. Slazyk^{17, [id](#)}, V. Smakhtin¹⁷⁶, B.H. Smart^{138, [id](#)}, S.Yu. Smirnov^{141b, [id](#)}, Y. Smirnov^{83, [id](#)}, L.N. Smirnova^{39, [id](#)},^a, O. Smirnova^{101, [id](#)}, A.C. Smith^{43, [id](#)}, D.R. Smith¹⁶⁶, E.A. Smith^{41, [id](#)}, J.L. Smith^{104, [id](#)}, M.B. Smith^{35, [id](#)}, R. Smith¹⁵⁰, H. Smitmanns^{103, [id](#)}, M. Smizanska^{94, [id](#)}, K. Smolek^{136, [id](#)}, A.A. Snesev^{40, [id](#)}, H.L. Snoek^{118, [id](#)}, S. Snyder^{30, [id](#)}, R. Sobie^{172, [id](#)},^{ab}, A. Soffer^{158, [id](#)}, C.A. Solans Sanchez^{37, [id](#)}, E.Yu. Soldatov^{40, [id](#)}, U. Soldevila^{170, [id](#)}, A.A. Solodkov^{34g, [id](#)}, S. Solomon^{27, [id](#)}, A. Soloshenko^{40, [id](#)}, K. Solovieva^{55, [id](#)}, O.V. Solovyanov^{42, [id](#)}, P. Sommer^{51, [id](#)}, A. Sonay^{13, [id](#)}, W.Y. Song^{163b, [id](#)}, A. Sopczak^{136, [id](#)}, A.L. Soppio^{53, [id](#)}, F. Sopkova^{29b, [id](#)}, J.D. Sorenson^{116, [id](#)}, I.R. Sotarriva Alvarez^{142, [id](#)}, V. Sothilingam^{64a}, O.J. Soto Sandoval^{141c, 141b, [id](#)}, S. Sottocornola^{69, [id](#)}, R. Soualah^{89a, [id](#)}, Z. Soumami^{36e, [id](#)}, D. South^{49, [id](#)}, N. Soybelman^{176, [id](#)}, S. Spagnolo^{71a, 71b, [id](#)}, M. Spalla^{113, [id](#)}, D. Sperlich^{55, [id](#)}, B. Spisso^{73a, 73b, [id](#)}, D.P. Spiteri^{60, [id](#)}, M. Spousta^{137, [id](#)}, E.J. Staats^{35, [id](#)}, R. Stamen^{64a, [id](#)}, E. Stanecka^{88, [id](#)}, W. Stanek-Maslouska^{49, [id](#)}, M.V. Stange^{51, [id](#)}, B. Stanislaus^{18a, [id](#)}, M.M. Stanitzki^{49, [id](#)}, B. Stapf^{49, [id](#)}, E.A. Starchenko^{39, [id](#)}, G.H. Stark^{140, [id](#)}, J. Stark^{92, [id](#)}, P. Staroba^{135, [id](#)}, P. Starovoitov^{89b, [id](#)}, R. Staszewski^{88, [id](#)}, G. Stavropoulos^{47, [id](#)}, A. Stefl^{37, [id](#)}, P. Steinberg^{30, [id](#)}, B. Stelzer^{149, 163a, [id](#)}, H.J. Stelzer^{133, [id](#)}, O. Stelzer-Chilton^{163a, [id](#)}, H. Stenzel^{59, [id](#)}, T.J. Stevenson^{153, [id](#)}, G.A. Stewart^{37, [id](#)}, J.R. Stewart^{125, [id](#)}, M.C. Stockton^{37, [id](#)}, G. Stoicea^{28b, [id](#)}, M. Stolarski^{134a, [id](#)}, S. Stonjek^{113, [id](#)}, A. Straessner^{51, [id](#)}, J. Strandberg^{151, [id](#)}, S. Strandberg^{48a, 48b, [id](#)}, M. Stratmann^{178, [id](#)}, M. Strauss^{124, [id](#)}, T. Strebler^{105, [id](#)}, P. Strizenec^{29b, [id](#)}, R. Ströhmer^{173, [id](#)}, D.M. Strom^{127, [id](#)}, R. Stroynowski^{46, [id](#)}, A. Strubig^{48a, 48b, [id](#)}, S.A. Stucci^{30, [id](#)}, B. Stugu^{17, [id](#)}, J. Stupak^{124, [id](#)}, N.A. Styles^{49, [id](#)}, D. Su^{150, [id](#)}, S. Su^{63, [id](#)}, W. Su^{145b, [id](#)}, X. Su^{63, [id](#)}, D. Suchy^{29a, [id](#)}, K. Sugizaki^{132, [id](#)}, V.V. Sulin^{39, [id](#)}, M.J. Sullivan^{95, [id](#)}, D.M.S. Sultan^{130, [id](#)}, L. Sultanaliyeva^{39, [id](#)}, S. Sultansoy^{3b, [id](#)}, S. Sun^{177, [id](#)}, W. Sun^{14, [id](#)}, O. Sunneborn Gudnadottir^{168, [id](#)}, N. Sur^{105, [id](#)}, M.R. Sutton^{153, [id](#)}, H. Suzuki^{164, [id](#)}, M. Svatos^{135, [id](#)}, P.N. Swallow^{33, [id](#)}, M. Swiatkowski^{163a, [id](#)}, T. Swirski^{173, [id](#)}, I. Sykora^{29a, [id](#)}, M. Sykora^{137, [id](#)}, T. Sykora^{137, [id](#)}, D. Ta^{103, [id](#)}, K. Tackmann^{49, [id](#)},^y, A. Taffard^{166, [id](#)}, R. Tafirot^{163a, [id](#)}, J.S. Tafoya Vargas^{67, [id](#)}, Y. Takubo^{85, [id](#)}, M. Talby^{105, [id](#)}, A.A. Talyshev^{39, [id](#)}, K.C. Tam^{65b, [id](#)}, N.M. Tamir^{158, [id](#)}, A. Tanaka^{160, [id](#)}, J. Tanaka^{160, [id](#)}, R. Tanaka^{67, [id](#)}, M. Tanasini^{152, [id](#)}, Z. Tao^{171, [id](#)}, S. Tapia Araya^{141f, [id](#)}, S. Tapprogge^{103, [id](#)}, A. Tarek Abouelfadl Mohamed^{110, [id](#)}, S. Tarem^{157, [id](#)}, K. Tariq^{14, [id](#)}, G. Tarna^{28b, [id](#)}, G.F. Tartarelli^{72a, [id](#)}, M.J. Tartarin^{92, [id](#)}, P. Tas^{137, [id](#)}, M. Tasevsky^{135, [id](#)}, E. Tassi^{45b, 45a, [id](#)}, A.C. Tate^{169, [id](#)}, G. Tateno^{160, [id](#)}, Y. Tayalati^{36e, [id](#)},^{aa}, G.N. Taylor^{108, [id](#)}, W. Taylor^{163b, [id](#)}, A.S. Tegetmeier^{92, [id](#)}, P. Teixeira-Dias^{98, [id](#)}, J.J. Teoh^{162, [id](#)}, K. Terashi^{160, [id](#)}, J. Terron^{102, [id](#)}, S. Terzo^{13, [id](#)}, M. Testa^{54, [id](#)}, R.J. Teuscher^{162, [id](#)},^{ab}, A. Thaler^{80, [id](#)}, O. Theiner^{57, [id](#)}, T. Theveneaux-Pelzer^{105, [id](#)}, O. Thielmann^{178, [id](#)}, D.W. Thomas⁹⁸, J.P. Thomas^{21, [id](#)}, E.A. Thompson^{18a, [id](#)}, P.D. Thompson^{21, [id](#)}, E. Thomson^{132, [id](#)}, R.E. Thornberry^{46, [id](#)}, C. Tian^{63, [id](#)}, Y. Tian^{57, [id](#)}, V. Tikhomirov^{83, [id](#)}, Yu.A. Tikhonov^{39, [id](#)}, S. Timoshenko³⁹, D. Timoshyn^{137, [id](#)}, E.X.L. Ting^{1, [id](#)}, P. Tipton^{179, [id](#)}, A. Tishelman-Charny^{30, [id](#)}, S.H. Tlou^{34g, [id](#)}, K. Todome^{142, [id](#)},

S. Todorova-Nova ^{137, [id](#)}, S. Todt ⁵¹, L. Toffolin ^{70a,70c, [id](#)}, M. Togawa ^{85, [id](#)}, J. Tojo ^{91, [id](#)}, S. Tokár ^{29a, [id](#)},
O. Toldaiev ^{69, [id](#)}, G. Tolkachev ^{105, [id](#)}, M. Tomoto ^{85,114, [id](#)}, L. Tompkins ^{150, [id](#), [o](#)}, E. Torrence ^{127, [id](#)}, H. Torres ^{92, [id](#)},
E. Torró Pastor ^{170, [id](#)}, M. Toscani ^{31, [id](#)}, C. Toscirì ^{41, [id](#)}, M. Tost ^{11, [id](#)}, D.R. Tovey ^{146, [id](#)}, T. Trefzger ^{173, [id](#)},
P.M. Tricarico ^{13, [id](#)}, A. Tricoli ^{30, [id](#)}, I.M. Trigger ^{163a, [id](#)}, S. Trincaz-Duvold ^{131, [id](#)}, D.A. Trischuk ^{27, [id](#)},
A. Tropina ⁴⁰, L. Truong ^{34c, [id](#)}, M. Trzebinski ^{88, [id](#)}, A. Trzupek ^{88, [id](#)}, F. Tsai ^{152, [id](#)}, M. Tsai ^{109, [id](#)}, A. Tsiamis ^{159, [id](#)},
P.V. Tsiarashka ⁴⁰, S. Tsigaridas ^{163a, [id](#)}, A. Tsirigotis ^{159, [id](#), [u](#)}, V. Tsiskaridze ^{162, [id](#)}, E.G. Tskhadadze ^{156a, [id](#)},
M. Tsopoulou ^{159, [id](#)}, Y. Tsujikawa ^{90, [id](#)}, I.I. Tsukerman ^{39, [id](#)}, V. Tsulaia ^{18a, [id](#)}, S. Tsuno ^{85, [id](#)}, K. Tsurì ^{122, [id](#)},
D. Tsybychev ^{152, [id](#)}, Y. Tu ^{65b, [id](#)}, A. Tudorache ^{28b, [id](#)}, V. Tudorache ^{28b, [id](#)}, S. Turchikhin ^{58b,58a, [id](#)},
I. Turk Cakir ^{3a, [id](#)}, R. Turra ^{72a, [id](#)}, T. Turtuvshin ^{40, [id](#), [ac](#)}, P.M. Tuts ^{43, [id](#)}, S. Tzamarias ^{159, [id](#), [e](#)}, E. Tzovara ^{103, [id](#)},
F. Ukegawa ^{164, [id](#)}, P.A. Ulloa Poblete ^{141c,141b, [id](#)}, E.N. Umaka ^{30, [id](#)}, G. Unal ^{37, [id](#)}, A. Undrus ^{30, [id](#)}, G. Unel ^{166, [id](#)},
J. Urban ^{29b, [id](#)}, P. Urrejola ^{141a, [id](#)}, G. Usai ^{8, [id](#)}, R. Ushioda ^{161, [id](#)}, M. Usman ^{111, [id](#)}, F. Ustuner ^{53, [id](#)}, Z. Uysal ^{83, [id](#)},
V. Vacek ^{136, [id](#)}, B. Vachon ^{107, [id](#)}, T. Vafeiadis ^{37, [id](#)}, A. Vaitkus ^{99, [id](#)}, C. Valderanis ^{112, [id](#)},
E. Valdes Santurio ^{48a,48b, [id](#)}, M. Valente ^{163a, [id](#)}, S. Valentinetti ^{24b,24a, [id](#)}, A. Valero ^{170, [id](#)}, E. Valiente Moreno ^{170, [id](#)},
A. Vallier ^{92, [id](#)}, J.A. Valls Ferrer ^{170, [id](#)}, D.R. Van Arneman ^{118, [id](#)}, T.R. Van Daalen ^{143, [id](#)}, A. Van Der Graaf ^{50, [id](#)},
H.Z. Van Der Schyf ^{34g, [id](#)}, P. Van Gemmeren ^{6, [id](#)}, M. Van Rijnbach ^{37, [id](#)}, S. Van Stroud ^{99, [id](#)}, I. Van Vulpen ^{118, [id](#)},
P. Vana ^{137, [id](#)}, M. Vanadia ^{77a,77b, [id](#)}, U.M. Vande Voorde ^{151, [id](#)}, W. Vandelli ^{37, [id](#)}, E.R. Vandewall ^{125, [id](#)},
D. Vannicola ^{158, [id](#)}, L. Vannoli ^{54, [id](#)}, R. Vari ^{76a, [id](#)}, E.W. Varnes ^{7, [id](#)}, C. Varni ^{18b, [id](#)}, D. Varouchas ^{67, [id](#)},
L. Varriale ^{170, [id](#)}, K.E. Varvell ^{154, [id](#)}, M.E. Vasile ^{28b, [id](#)}, L. Vaslin ⁸⁵, A. Vasyukov ^{40, [id](#)}, L.M. Vaughan ^{125, [id](#)},
R. Vavricka ¹³⁷, T. Vazquez Schroeder ^{13, [id](#)}, J. Veatch ^{32, [id](#)}, V. Vecchio ^{104, [id](#)}, M.J. Veen ^{106, [id](#)}, I. Veliscek ^{30, [id](#)},
L.M. Veloce ^{162, [id](#)}, F. Veloso ^{134a,134c, [id](#)}, S. Veneziano ^{76a, [id](#)}, A. Ventura ^{71a,71b, [id](#)}, S. Ventura Gonzalez ^{139, [id](#)},
A. Verbytskyi ^{113, [id](#)}, M. Verducci ^{75a,75b, [id](#)}, C. Vergis ^{97, [id](#)}, M. Verissimo De Araujo ^{84b, [id](#)}, W. Verkerke ^{118, [id](#)},
J.C. Vermeulen ^{118, [id](#)}, C. Vernieri ^{150, [id](#)}, M. Vessella ^{166, [id](#)}, M.C. Vetterli ^{149, [id](#), [ai](#)}, A. Vgenopoulos ^{103, [id](#)},
N. Viaux Maira ^{141f, [id](#)}, T. Vickey ^{146, [id](#)}, O.E. Vickey Boeriu ^{146, [id](#)}, G.H.A. Viehhauser ^{130, [id](#)}, L. Vignani ^{64b, [id](#)},
M. Vigl ^{113, [id](#)}, M. Villa ^{24b,24a, [id](#)}, M. Villaplana Perez ^{170, [id](#)}, E.M. Villhauer ⁵³, E. Vilucchi ^{54, [id](#)}, M.G. Vincker ^{35, [id](#)},
A. Visibile ¹¹⁸, C. Vittori ^{37, [id](#)}, I. Vivarelli ^{24b,24a, [id](#)}, E. Voevodina ^{113, [id](#)}, F. Vogel ^{112, [id](#)}, J.C. Voigt ^{51, [id](#)},
P. Vokac ^{136, [id](#)}, Yu. Volkotrub ^{87b, [id](#)}, E. Von Toerne ^{25, [id](#)}, B. Vormwald ^{37, [id](#)}, K. Vorobev ^{39, [id](#)}, M. Vos ^{170, [id](#)},
K. Voss ^{148, [id](#)}, M. Vozak ^{37, [id](#)}, L. Vozdecky ^{124, [id](#)}, N. Vranjes ^{16, [id](#)}, M. Vranjes Milosavljevic ^{16, [id](#)},
M. Vreeswijk ^{118, [id](#)}, N.K. Vu ^{145b,145a, [id](#)}, R. Vuillermet ^{37, [id](#)}, O. Vujanovic ^{103, [id](#)}, I. Vukotic ^{41, [id](#)}, I.K. Vyas ^{35, [id](#)},
S. Wada ^{164, [id](#)}, C. Wagner ¹⁵⁰, J.M. Wagner ^{18a, [id](#)}, W. Wagner ^{178, [id](#)}, S. Wahdan ^{178, [id](#)}, H. Wahlberg ^{93, [id](#)},
C.H. Waits ^{124, [id](#)}, J. Walder ^{138, [id](#)}, R. Walker ^{112, [id](#)}, W. Walkowiak ^{148, [id](#)}, A. Wall ^{132, [id](#)}, E.J. Wallin ^{101, [id](#)},
T. Wamorkar ^{18a, [id](#)}, A.Z. Wang ^{140, [id](#)}, C. Wang ^{103, [id](#)}, C. Wang ^{11, [id](#)}, H. Wang ^{18a, [id](#)}, J. Wang ^{65c, [id](#)}, P. Wang ^{104, [id](#)},
P. Wang ^{99, [id](#)}, R. Wang ^{62, [id](#)}, R. Wang ^{6, [id](#)}, S.M. Wang ^{155, [id](#)}, S. Wang ^{14, [id](#)}, T. Wang ^{63, [id](#)}, T. Wang ^{63, [id](#)},
W.T. Wang ^{81, [id](#)}, W. Wang ^{14, [id](#)}, X. Wang ^{169, [id](#)}, X. Wang ^{145a, [id](#)}, X. Wang ^{49, [id](#)}, Y. Wang ^{115a, [id](#)}, Y. Wang ^{63, [id](#)},
Z. Wang ^{109, [id](#)}, Z. Wang ^{145b,52,145a, [id](#)}, Z. Wang ^{109, [id](#)}, C. Wanotayaroj ^{85, [id](#)}, A. Warburton ^{107, [id](#)}, R.J. Ward ^{21, [id](#)},
A.L. Warnerbring ^{148, [id](#)}, N. Warrack ^{60, [id](#)}, S. Waterhouse ^{98, [id](#)}, A.T. Watson ^{21, [id](#)}, H. Watson ^{53, [id](#)},
M.F. Watson ^{21, [id](#)}, E. Watton ^{60, [id](#)}, G. Watts ^{143, [id](#)}, B.M. Waugh ^{99, [id](#)}, J.M. Webb ^{55, [id](#)}, C. Weber ^{30, [id](#)},
H.A. Weber ^{19, [id](#)}, M.S. Weber ^{20, [id](#)}, S.M. Weber ^{64a, [id](#)}, C. Wei ^{63, [id](#)}, Y. Wei ^{55, [id](#)}, A.R. Weidberg ^{130, [id](#)},
E.J. Weik ^{121, [id](#)}, J. Weingarten ^{50, [id](#)}, C. Weiser ^{55, [id](#)}, C.J. Wells ^{49, [id](#)}, T. Wenaus ^{30, [id](#)}, B. Wendland ^{50, [id](#)},
T. Wengler ^{37, [id](#)}, N.S. Wenke ¹¹³, N. Wermes ^{25, [id](#)}, M. Wessels ^{64a, [id](#)}, A.M. Wharton ^{94, [id](#)}, A.S. White ^{62, [id](#)},
A. White ^{8, [id](#)}, M.J. White ^{1, [id](#)}, D. Whiteson ^{166, [id](#)}, L. Wickremasinghe ^{128, [id](#)}, W. Wiedenmann ^{177, [id](#)},
M. Wielers ^{138, [id](#)}, C. Wiglesworth ^{44, [id](#)}, D.J. Wilbern ¹²⁴, H.G. Wilkens ^{37, [id](#)}, J.J.H. Wilkinson ^{33, [id](#)},
D.M. Williams ^{43, [id](#)}, H.H. Williams ¹³², S. Williams ^{33, [id](#)}, S. Willocq ^{106, [id](#)}, B.J. Wilson ^{104, [id](#)}, D.J. Wilson ^{104, [id](#)},

P.J. Windischhofer^{41, [id](#)}, F.I. Winkel^{31, [id](#)}, F. Winklmeier^{127, [id](#)}, B.T. Winter^{55, [id](#)}, M. Wittgen¹⁵⁰,
M. Wobisch^{100, [id](#)}, T. Wojtkowski⁶¹, Z. Wolffs^{118, [id](#)}, J. Wollrath³⁷, M.W. Wolter^{88, [id](#)}, H. Wolters^{134a,134c, [id](#)},
M.C. Wong¹⁴⁰, E.L. Woodward^{43, [id](#)}, S.D. Worm^{49, [id](#)}, B.K. Wosiek^{88, [id](#)}, K.W. Woźniak^{88, [id](#)}, S. Wozniowski^{56, [id](#)},
K. Wraight^{60, [id](#)}, C. Wu^{21, [id](#)}, M. Wu^{115b, [id](#)}, M. Wu^{117, [id](#)}, S.L. Wu^{177, [id](#)}, S. Wu^{14, [id](#)}, X. Wu^{57, [id](#)}, X. Wu^{63, [id](#)},
Y. Wu^{63, [id](#)}, Z. Wu^{4, [id](#)}, J. Wuerzinger^{113, [id](#), [ag](#)}, T.R. Wyatt^{104, [id](#)}, B.M. Wynne^{53, [id](#)}, S. Xella^{44, [id](#)}, L. Xia^{115a, [id](#)},
M. Xia^{15, [id](#)}, M. Xie^{63, [id](#)}, A. Xiong^{127, [id](#)}, J. Xiong^{18a, [id](#)}, D. Xu^{14, [id](#)}, H. Xu^{63, [id](#)}, L. Xu^{63, [id](#)}, R. Xu^{132, [id](#)},
T. Xu^{109, [id](#)}, Y. Xu^{143, [id](#)}, Z. Xu^{53, [id](#)}, Z. Xu^{115a}, B. Yabsley^{154, [id](#)}, S. Yacoub^{34a, [id](#)}, Y. Yamaguchi^{85, [id](#)},
E. Yamashita^{160, [id](#)}, H. Yamauchi^{164, [id](#)}, T. Yamazaki^{18a, [id](#)}, Y. Yamazaki^{86, [id](#)}, S. Yan^{60, [id](#)}, Z. Yan^{106, [id](#)},
H.J. Yang^{145a,145b, [id](#)}, H.T. Yang^{63, [id](#)}, S. Yang^{63, [id](#)}, T. Yang^{65c, [id](#)}, X. Yang^{37, [id](#)}, X. Yang^{14, [id](#)}, Y. Yang^{160, [id](#)},
Y. Yang⁶³, W.-M. Yao^{18a, [id](#)}, C.L. Yardley^{153, [id](#)}, H. Ye^{56, [id](#)}, J. Ye^{14, [id](#)}, S. Ye^{30, [id](#)}, X. Ye^{63, [id](#)}, Y. Yeh^{99, [id](#)},
I. Yeletsikh^{40, [id](#)}, B. Yeo^{18b, [id](#)}, M.R. Yexley^{99, [id](#)}, T.P. Yildirim^{130, [id](#)}, P. Yin^{43, [id](#)}, K. Yorita^{175, [id](#)},
S. Younas^{28b, [id](#)}, C.J.S. Young^{37, [id](#)}, C. Young^{150, [id](#)}, N.D. Young¹²⁷, Y. Yu^{63, [id](#)}, J. Yuan^{14,115c, [id](#)}, M. Yuan^{109, [id](#)},
R. Yuan^{145b,145a, [id](#)}, L. Yue^{99, [id](#)}, M. Zaazoua^{63, [id](#)}, B. Zabinski^{88, [id](#)}, I. Zahir^{36a, [id](#)}, Z.K. Zak^{88, [id](#)},
T. Zakareishvili^{170, [id](#)}, S. Zambito^{57, [id](#)}, J.A. Zamora Saa^{141d,141b, [id](#)}, J. Zang^{160, [id](#)}, D. Zanzi^{55, [id](#)},
R. Zanzottera^{72a,72b, [id](#)}, O. Zaplatilek^{136, [id](#)}, C. Zeitnitz^{178, [id](#)}, H. Zeng^{14, [id](#)}, J.C. Zeng^{169, [id](#)}, D.T. Zenger Jr^{27, [id](#)},
O. Zenin^{39, [id](#)}, T. Ženiš^{29a, [id](#)}, S. Zenz^{97, [id](#)}, S. Zerradi^{36a, [id](#)}, D. Zerwas^{67, [id](#)}, M. Zhai^{14,115c, [id](#)}, D.F. Zhang^{146, [id](#)},
J. Zhang^{144a, [id](#)}, J. Zhang^{6, [id](#)}, K. Zhang^{14,115c, [id](#)}, L. Zhang^{63, [id](#)}, L. Zhang^{115a, [id](#)}, P. Zhang^{14,115c, [id](#)},
R. Zhang^{177, [id](#)}, S. Zhang^{92, [id](#)}, T. Zhang^{160, [id](#)}, X. Zhang^{145a, [id](#)}, Y. Zhang^{143, [id](#)}, Y. Zhang^{99, [id](#)}, Y. Zhang^{63, [id](#)},
Y. Zhang^{115a, [id](#)}, Z. Zhang^{18a, [id](#)}, Z. Zhang^{144a, [id](#)}, Z. Zhang^{67, [id](#)}, H. Zhao^{143, [id](#)}, T. Zhao^{144a, [id](#)}, Y. Zhao^{35, [id](#)},
Z. Zhao^{63, [id](#)}, Z. Zhao^{63, [id](#)}, A. Zhemchugov^{40, [id](#)}, J. Zheng^{115a, [id](#)}, K. Zheng^{169, [id](#)}, X. Zheng^{63, [id](#)}, Z. Zheng^{150, [id](#)},
D. Zhong^{169, [id](#)}, B. Zhou^{109, [id](#)}, H. Zhou^{7, [id](#)}, N. Zhou^{145a, [id](#)}, Y. Zhou^{15, [id](#)}, Y. Zhou^{115a, [id](#)}, Y. Zhou⁷,
C.G. Zhu^{144a, [id](#)}, J. Zhu^{109, [id](#)}, X. Zhu^{145b}, Y. Zhu^{145a, [id](#)}, Y. Zhu^{63, [id](#)}, X. Zhuang^{14, [id](#)}, K. Zhukov^{69, [id](#)},
N.I. Zimine^{40, [id](#)}, J. Zinsser^{64b, [id](#)}, M. Ziolkowski^{148, [id](#)}, L. Živković^{16, [id](#)}, A. Zoccoli^{24b,24a, [id](#)}, K. Zoch^{62, [id](#)},
T.G. Zorbas^{146, [id](#)}, O. Zormpa^{47, [id](#)}, W. Zou^{43, [id](#)}, L. Zwalinski^{37, [id](#)}

¹ Department of Physics, University of Adelaide, Adelaide; Australia² Department of Physics, University of Alberta, Edmonton AB; Canada³ (a) Department of Physics, Ankara University, Ankara; (b) Division of Physics, TOBB University of Economics and Technology, Ankara; Türkiye⁴ LAPP, Université Savoie Mont Blanc, CNRS/IN2P3, Annecy; France⁵ APC, Université Paris Cité, CNRS/IN2P3, Paris; France⁶ High Energy Physics Division, Argonne National Laboratory, Argonne IL; United States of America⁷ Department of Physics, University of Arizona, Tucson AZ; United States of America⁸ Department of Physics, University of Texas at Arlington, Arlington TX; United States of America⁹ Physics Department, National and Kapodistrian University of Athens, Athens; Greece¹⁰ Physics Department, National Technical University of Athens, Zografou; Greece¹¹ Department of Physics, University of Texas at Austin, Austin TX; United States of America¹² Institute of Physics, Azerbaijan Academy of Sciences, Baku; Azerbaijan¹³ Institut de Física d'Altes Energies (IFAE), Barcelona Institute of Science and Technology, Barcelona; Spain¹⁴ Institute of High Energy Physics, Chinese Academy of Sciences, Beijing; China¹⁵ Physics Department, Tsinghua University, Beijing; China¹⁶ Institute of Physics, University of Belgrade, Belgrade; Serbia¹⁷ Department for Physics and Technology, University of Bergen, Bergen; Norway¹⁸ (a) Physics Division, Lawrence Berkeley National Laboratory, Berkeley CA; (b) University of California, Berkeley CA; United States of America¹⁹ Institut für Physik, Humboldt Universität zu Berlin, Berlin; Germany²⁰ Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern; Switzerland²¹ School of Physics and Astronomy, University of Birmingham, Birmingham; United Kingdom²² (a) Department of Physics, Bogazici University, Istanbul; (b) Department of Physics Engineering, Gaziantep University, Gaziantep; (c) Department of Physics, Istanbul University, Istanbul; Türkiye²³ (a) Facultad de Ciencias y Centro de Investigaciones, Universidad Antonio Nariño, Bogotá; (b) Departamento de Física, Universidad Nacional de Colombia, Bogotá; Colombia²⁴ (a) Dipartimento di Fisica e Astronomia A. Righi, Università di Bologna, Bologna; (b) INFN Sezione di Bologna; Italy²⁵ Physikalisches Institut, Universität Bonn, Bonn; Germany²⁶ Department of Physics, Boston University, Boston MA; United States of America²⁷ Department of Physics, Brandeis University, Waltham MA; United States of America²⁸ (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) National University of Science and Technology Politehnica, Bucharest; (f) West University in Timisoara, Timisoara; (g) Faculty of Physics, University of Bucharest, Bucharest; Romania²⁹ (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 Republic³⁰ Physics Department, Brookhaven National Laboratory, Upton NY; United States of America³¹ Universidad de Buenos Aires, Facultad de Ciencias Exactas y Naturales, Departamento de Física, y CONICET, Instituto de Física de Buenos Aires (IFIBA), Buenos Aires; Argentina

- ³² California State University, CA; United States of America
- ³³ Cavendish Laboratory, University of Cambridge, Cambridge; United Kingdom
- ³⁴ ^(a) Department of Physics, University of Cape Town, Cape Town; ^(b) iThemba Labs, Western Cape; ^(c) Department of Mechanical Engineering Science, University of Johannesburg, Johannesburg;
- ^(d) National Institute of Physics, University of the Philippines Diliman (Philippines); ^(e) University of South Africa, Department of Physics, Pretoria; ^(f) University of Zululand, KwaDlangezwa;
- ^(g) School of Physics, University of the Witwatersrand, Johannesburg; South Africa
- ³⁵ Department of Physics, Carleton University, Ottawa ON; Canada
- ³⁶ ^(a) Faculté des Sciences Ain Chock, Université Hassan II de Casablanca; ^(b) Faculté des Sciences, Université Ibn-Tofail, Kénitra; ^(c) Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA-Marrakech; ^(d) LPMR, Faculté des Sciences, Université Mohamed Premier, Oujda; ^(e) Faculté des sciences, Université Mohammed V, Rabat; ^(f) Institute of Applied Physics, Mohammed VI Polytechnic University, Ben Guerir; Morocco
- ³⁷ CERN, Geneva; Switzerland
- ³⁸ Affiliated with an institute formerly covered by a cooperation agreement with CERN
- ³⁹ Affiliated with an institute covered by a cooperation agreement with CERN
- ⁴⁰ Affiliated with an international laboratory covered by a cooperation agreement with CERN
- ⁴¹ Enrico Fermi Institute, University of Chicago, Chicago IL; United States of America
- ⁴² LPC, Université Clermont Auvergne, CNRS/IN2P3, Clermont-Ferrand; France
- ⁴³ Nevis Laboratory, Columbia University, Irvington NY; United States of America
- ⁴⁴ Niels Bohr Institute, University of Copenhagen, Copenhagen; Denmark
- ⁴⁵ ^(a) Dipartimento di Fisica, Università della Calabria, Rende; ^(b) INFN Gruppo Collegato di Cosenza, Laboratori Nazionali di Frascati; Italy
- ⁴⁶ Physics Department, Southern Methodist University, Dallas TX; United States of America
- ⁴⁷ National Centre for Scientific Research “Demokritos”, Agia Paraskevi; Greece
- ⁴⁸ ^(a) Department of Physics, Stockholm University; ^(b) Oskar Klein Centre, Stockholm; Sweden
- ⁴⁹ Deutsches Elektronen-Synchrotron DESY, Hamburg and Zeuthen; Germany
- ⁵⁰ Fakultät Physik, Technische Universität Dortmund, Dortmund; Germany
- ⁵¹ Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden; Germany
- ⁵² Department of Physics, Duke University, Durham NC; United States of America
- ⁵³ SUPA - School of Physics and Astronomy, University of Edinburgh, Edinburgh; United Kingdom
- ⁵⁴ INFN e Laboratori Nazionali di Frascati, Frascati; Italy
- ⁵⁵ Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg; Germany
- ⁵⁶ II. Physikalisches Institut, Georg-August-Universität Göttingen, Göttingen; Germany
- ⁵⁷ Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève; Switzerland
- ⁵⁸ ^(a) Dipartimento di Fisica, Università di Genova, Genova; ^(b) INFN Sezione di Genova; Italy
- ⁵⁹ II. Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen; Germany
- ⁶⁰ SUPA - School of Physics and Astronomy, University of Glasgow, Glasgow; United Kingdom
- ⁶¹ LPSC, Université Grenoble Alpes, CNRS/IN2P3, Grenoble INP, Grenoble; France
- ⁶² Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge MA; United States of America
- ⁶³ Department of Modern Physics and State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei; China
- ⁶⁴ ^(a) Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg; ^(b) Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg; Germany
- ⁶⁵ ^(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
- ⁶⁶ Department of Physics, National Tsing Hua University, Hsinchu; Taiwan
- ⁶⁷ IJCLab, Université Paris-Saclay, CNRS/IN2P3, 91405, Orsay; France
- ⁶⁸ Centro Nacional de Microelectrónica (IMB-CNM-CSIC), Barcelona; Spain
- ⁶⁹ Department of Physics, Indiana University, Bloomington IN; United States of America
- ⁷⁰ ^(a) INFN Gruppo Collegato di Udine, Sezione di Trieste, Udine; ^(b) ICTP, Trieste; ^(c) Dipartimento Politecnico di Ingegneria e Architettura, Università di Udine, Udine; Italy
- ⁷¹ ^(a) INFN Sezione di Lecce; ^(b) Dipartimento di Matematica e Fisica, Università del Salento, Lecce; Italy
- ⁷² ^(a) INFN Sezione di Milano; ^(b) Dipartimento di Fisica, Università di Milano, Milano; Italy
- ⁷³ ^(a) INFN Sezione di Napoli; ^(b) Dipartimento di Fisica, Università di Napoli, Napoli; Italy
- ⁷⁴ ^(a) INFN Sezione di Pavia; ^(b) Dipartimento di Fisica, Università di Pavia, Pavia; Italy
- ⁷⁵ ^(a) INFN Sezione di Pisa; ^(b) Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa; Italy
- ⁷⁶ ^(a) INFN Sezione di Roma; ^(b) Dipartimento di Fisica, Sapienza Università di Roma, Roma; Italy
- ⁷⁷ ^(a) INFN Sezione di Roma Tor Vergata; ^(b) Dipartimento di Fisica, Università di Roma Tor Vergata, Roma; Italy
- ⁷⁸ ^(a) INFN Sezione di Roma Tre; ^(b) Dipartimento di Matematica e Fisica, Università Roma Tre, Roma; Italy
- ⁷⁹ ^(a) INFN-TIFPA; ^(b) Università degli Studi di Trento, Trento; Italy
- ⁸⁰ Universität Innsbruck, Department of Astro and Particle Physics, Innsbruck; Austria
- ⁸¹ University of Iowa, Iowa City IA; United States of America
- ⁸² Department of Physics and Astronomy, Iowa State University, Ames IA; United States of America
- ⁸³ Istinye University, Sariyer, Istanbul; Türkiye
- ⁸⁴ ^(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) Instituto de Física, Universidade de São Paulo, São Paulo; ^(d) Rio de Janeiro State University, Rio de Janeiro; ^(e) Federal University of Bahia, Bahia; Brazil
- ⁸⁵ KEK, High Energy Accelerator Research Organization, Tsukuba; Japan
- ⁸⁶ Graduate School of Science, Kobe University, Kobe; Japan
- ⁸⁷ ^(a) AGH University of Krakow, Faculty of Physics and Applied Computer Science, Krakow; ^(b) Marian Smoluchowski Institute of Physics, Jagiellonian University, Krakow; Poland
- ⁸⁸ Institute of Nuclear Physics Polish Academy of Sciences, Krakow; Poland
- ⁸⁹ ^(a) Khalifa University of Science and Technology, Abu Dhabi; ^(b) University of Sharjah, Sharjah; United Arab Emirates
- ⁹⁰ Faculty of Science, Kyoto University, Kyoto; Japan
- ⁹¹ Research Center for Advanced Particle Physics and Department of Physics, Kyushu University, Fukuoka; Japan
- ⁹² L2IT, Université de Toulouse, CNRS/IN2P3, UPS, Toulouse; France
- ⁹³ Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata; Argentina
- ⁹⁴ Physics Department, Lancaster University, Lancaster; United Kingdom
- ⁹⁵ Oliver Lodge Laboratory, University of Liverpool, Liverpool; United Kingdom
- ⁹⁶ Department of Experimental Particle Physics, Jožef Stefan Institute and Department of Physics, University of Ljubljana, Ljubljana; Slovenia
- ⁹⁷ Department of Physics and Astronomy, Queen Mary University of London, London; United Kingdom
- ⁹⁸ Department of Physics, Royal Holloway University of London, Egham; United Kingdom
- ⁹⁹ Department of Physics and Astronomy, University College London, London; United Kingdom
- ¹⁰⁰ Louisiana Tech University, Ruston LA; United States of America
- ¹⁰¹ Fysiska institutionen, Lunds universitet, Lund; Sweden
- ¹⁰² Departamento de Física Teórica C-15 and CIAFF, Universidad Autónoma de Madrid, Madrid; Spain
- ¹⁰³ Institut für Physik, Universität Mainz, Mainz; Germany
- ¹⁰⁴ School of Physics and Astronomy, University of Manchester, Manchester; United Kingdom
- ¹⁰⁵ CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille; France

- ¹⁰⁶ Department of Physics, University of Massachusetts, Amherst MA; United States of America
- ¹⁰⁷ Department of Physics, McGill University, Montreal QC; Canada
- ¹⁰⁸ School of Physics, University of Melbourne, Victoria; Australia
- ¹⁰⁹ Department of Physics, University of Michigan, Ann Arbor MI; United States of America
- ¹¹⁰ Department of Physics and Astronomy, Michigan State University, East Lansing MI; United States of America
- ¹¹¹ Group of Particle Physics, University of Montreal, Montreal QC; Canada
- ¹¹² Fakultät für Physik, Ludwig-Maximilians-Universität München, München; Germany
- ¹¹³ Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München; Germany
- ¹¹⁴ Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya; Japan
- ¹¹⁵ ^(a) Department of Physics, Nanjing University, Nanjing; ^(b) School of Science, Shenzhen Campus of Sun Yat-sen University; ^(c) University of Chinese Academy of Science (UCAS), Beijing; China
- 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/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) New York University Abu Dhabi, Abu Dhabi; ^(b) United Arab Emirates University, Al Ain; United Arab Emirates
- ¹²¹ Department of Physics, New York University, New York NY; United States of America
- ¹²² Ochanomizu University, Otsuka, Bunkyo-ku, Tokyo; Japan
- ¹²³ Ohio State University, Columbus OH; United States of America
- 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, Joint Laboratory of Optics, Olomouc; Czech Republic
- ¹²⁷ Institute for Fundamental Science, University of Oregon, Eugene, OR; United States of America
- ¹²⁸ Graduate School of Science, University of Osaka, Osaka; Japan
- ¹²⁹ Department of Physics, University of Oslo, Oslo; Norway
- ¹³⁰ Department of Physics, Oxford University, Oxford; United Kingdom
- ¹³¹ LPNHE, Sorbonne Université, Université Paris Cité, CNRS/IN2P3, Paris; France
- ¹³² Department of Physics, University of Pennsylvania, Philadelphia PA; United States of America
- ¹³³ Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh PA; United States of America
- ¹³⁴ ^(a) Laboratório de Instrumentação e Física Experimental de Partículas - LIP, Lisboa; ^(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, Escola de Ciências, Universidade do Minho, Braga; ^(f) Departamento de Física Teórica y del Cosmos, Universidad de Granada, Granada (Spain); ^(g) Departamento de Física, Instituto Superior Técnico, Universidade de Lisboa, Lisboa; Portugal
- ¹³⁵ Institute of Physics of the Czech Academy of Sciences, Prague; Czech Republic
- ¹³⁶ Czech Technical University in Prague, Prague; Czech Republic
- ¹³⁷ Charles University, Faculty of Mathematics and Physics, Prague; Czech Republic
- ¹³⁸ Particle Physics Department, Rutherford Appleton Laboratory, Didcot; United Kingdom
- ¹³⁹ IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette; France
- ¹⁴⁰ Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz CA; United States of America
- ¹⁴¹ ^(a) Departamento de Física, Pontificia Universidad Católica de Chile, Santiago; ^(b) Millennium Institute for Subatomic physics at high energy frontier (SAPHIR), Santiago; ^(c) Instituto de Investigación Multidisciplinario en Ciencia y Tecnología, y Departamento de Física, Universidad de La Serena; ^(d) Universidad Andres Bello, Department of Physics, Santiago; ^(e) Instituto de Alta Investigación, Universidad de Tarapacá, Arica; ^(f) Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso; Chile
- ¹⁴² Department of Physics, Institute of Science, Tokyo; Japan
- ¹⁴³ Department of Physics, University of Washington, Seattle WA; United States of America
- ¹⁴⁴ ^(a) Institute of Frontier and Interdisciplinary Science and Key Laboratory of Particle Physics and Particle Irradiation (MOE), Shandong University, Qingdao; ^(b) School of Physics, Zhengzhou University; China
- ¹⁴⁵ ^(a) State Key Laboratory of Dark Matter Physics, School of Physics and Astronomy, Shanghai Jiao Tong University, Key Laboratory for Particle Astrophysics and Cosmology (MOE), SKLPPC, Shanghai; ^(b) State Key Laboratory of Dark Matter Physics, Tsung-Dao Lee Institute, Shanghai Jiao Tong University, Shanghai; China
- 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 Department of Physics, Royal Institute of Technology, Stockholm; Sweden
- ¹⁵² Departments of Physics and Astronomy, Stony Brook University, Stony Brook NY; United States of America
- ¹⁵³ Department of Physics and Astronomy, University of Sussex, Brighton; United Kingdom
- ¹⁵⁴ School of Physics, University of Sydney, Sydney; Australia
- ¹⁵⁵ Institute of Physics, Academia Sinica, Taipei; Taiwan
- ¹⁵⁶ ^(a) E. Andronikashvili Institute of Physics, Iv. Javakishvili Tbilisi State University, Tbilisi; ^(b) High Energy Physics Institute, Tbilisi State University, Tbilisi; ^(c) University of Georgia, 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, University of Toronto, Toronto ON; Canada
- ¹⁶³ ^(a) TRIUMF, Vancouver BC; ^(b) Department of Physics and Astronomy, York University, Toronto ON; Canada
- ¹⁶⁴ Division of Physics and Tomonaga Center for the History of the Universe, Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba; Japan
- ¹⁶⁵ Department of Physics and Astronomy, Tufts University, Medford MA; United States of America
- ¹⁶⁶ Department of Physics and Astronomy, University of California Irvine, Irvine CA; United States of America
- ¹⁶⁷ University of West Attica, Athens; Greece
- ¹⁶⁸ Department of Physics and Astronomy, University of Uppsala, Uppsala; Sweden
- ¹⁶⁹ Department of Physics, University of Illinois, Urbana IL; United States of America
- ¹⁷⁰ Instituto de Física Corpuscular (IFIC), Centro Mixto Universidad de Valencia - CSIC, Valencia; Spain
- ¹⁷¹ Department of Physics, University of British Columbia, Vancouver BC; Canada
- ¹⁷² Department of Physics and Astronomy, University of Victoria, Victoria BC; Canada
- ¹⁷³ Fakultät für Physik und Astronomie, Julius-Maximilians-Universität Würzburg, Würzburg; Germany
- ¹⁷⁴ Department of Physics, University of Warwick, Coventry; United Kingdom
- ¹⁷⁵ Waseda University, Tokyo; Japan
- ¹⁷⁶ Department of Particle Physics and Astrophysics, Weizmann Institute of Science, Rehovot; Israel
- ¹⁷⁷ Department of Physics, University of Wisconsin, Madison WI; United States of America
- ¹⁷⁸ Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal; Germany

¹⁷⁹ Department of Physics, Yale University, New Haven CT; United States of America

¹⁸⁰ Yerevan Physics Institute, Yerevan; Armenia

- ^a Also Affiliated with an institute covered by a cooperation agreement with CERN.
- ^b Also at An-Najah National University, Nablus; Palestine.
- ^c Also at Borough of Manhattan Community College, City University of New York, New York NY; United States of America.
- ^d Also at Center for High Energy Physics, Peking University; China.
- ^e Also at Center for Interdisciplinary Research and Innovation (CIRI-AUTH), Thessaloniki; Greece.
- ^f Also at CERN, Geneva; Switzerland.
- ^g Also at CMD-AC UNEC Research Center, Azerbaijan State University of Economics (UNEC); Azerbaijan.
- ^h Also at Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève; Switzerland.
- ⁱ Also at Departament de Física de la Universitat Autònoma de Barcelona, Barcelona; Spain.
- ^j Also at Department of Financial and Management Engineering, University of the Aegean, Chios; Greece.
- ^k Also at Department of Mathematical Sciences, University of South Africa, Johannesburg; South Africa.
- ^l Also at Department of Physics, Bolu Abant İzzet Baysal University, Bolu; Türkiye.
- ^m Also at Department of Physics, California State University, Sacramento; United States of America.
- ⁿ Also at Department of Physics, King's College London, London; United Kingdom.
- ^o Also at Department of Physics, Stanford University, Stanford CA; United States of America.
- ^p Also at Department of Physics, Stellenbosch University; South Africa.
- ^q Also at Department of Physics, University of Fribourg, Fribourg; Switzerland.
- ^r Also at Department of Physics, University of Thessaly; Greece.
- ^s Also at Department of Physics, Westmont College, Santa Barbara; United States of America.
- ^t Also at Faculty of Physics, Sofia University, 'St. Kliment Ohridski', Sofia; Bulgaria.
- ^u Also at Hellenic Open University, Patras; Greece.
- ^v Also at Henan University; China.
- ^w Also at Imam Mohammad Ibn Saud Islamic University; Saudi Arabia.
- ^x Also at Institutio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona; Spain.
- ^y Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg; Germany.
- ^z Also at Institute for Nuclear Research and Nuclear Energy (INRNE) of the Bulgarian Academy of Sciences, Sofia; Bulgaria.
- ^{aa} Also at Institute of Applied Physics, Mohammed VI Polytechnic University, Ben Guerir; Morocco.
- ^{ab} Also at Institute of Particle Physics (IPP); Canada.
- ^{ac} Also at Institute of Physics and Technology, Mongolian Academy of Sciences, Ulaanbaatar; Mongolia.
- ^{ad} Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku; Azerbaijan.
- ^{ae} Also at Institute of Theoretical Physics, Ilia State University, Tbilisi; Georgia.
- ^{af} Also at National Institute of Physics, University of the Philippines Diliman (Philippines); Philippines.
- ^{ag} Also at Technical University of Munich, Munich; Germany.
- ^{ah} Also at The Collaborative Innovation Center of Quantum Matter (CICQM), Beijing; China.
- ^{ai} Also at TRIUMF, Vancouver BC; Canada.
- ^{aj} Also at Università di Napoli Parthenope, Napoli; Italy.
- ^{ak} Also at University of Colorado Boulder, Department of Physics, Colorado; United States of America.
- ^{al} Also at University of the Western Cape; South Africa.
- ^{am} Also at Washington College, Chestertown, MD; United States of America.
- ^{an} Also at Yeditepe University, Physics Department, Istanbul; Türkiye.
- * Deceased.