Article:

ATLAS Collaboration, . (2018) Search for resonant WZ production in the fully leptonic final state in proton–proton collisions at √s =13 TeV with the ATLAS detector. Physics Letters B, 787. pp. 68-88. ISSN 0370-2693

https://doi.org/10.1016/j.physletb.2018.10.021

Physics Letters B 787 (2018) 68–88

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Search for resonant WZ production in the fully leptonic final state in proton–proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

The ATLAS Collaboration *

A R T I C L E   I N F O

Article history:
Received 5 June 2018
Received in revised form 9 October 2018
Accepted 11 October 2018
Available online 18 October 2018
Editor: M. Doser

A B S T R A C T

A search for a heavy resonance decaying into WZ in the fully leptonic channel (electrons and muons) is performed. It is based on proton–proton collision data collected by the ATLAS experiment at the Large Hadron Collider at a centre-of-mass energy of 13 TeV, corresponding to an integrated luminosity of 36.1 fb^{-1}. No significant excess is observed over the Standard Model predictions and limits are set on the production cross section times branching ratio of a heavy vector particle produced either in quark–antiquark fusion or through vector-boson fusion. Constraints are also obtained on the mass and couplings of a singly charged Higgs boson, in the Georgi–Machacek model, produced through vector-boson fusion.

1. Introduction

Searches for diboson resonances provide an essential test of theories of electroweak symmetry breaking beyond the Standard Model (BSM). Vector resonances are predicted in various BSM scenarios, such as in extended gauge models [1,2], Little Higgs models [3], Composite Higgs models and walking technicolor [4–6], unitarized Electroweak Chiral Lagrangian models [7], as well as in theories with extra dimensions [8–10]. In addition, new scalar diboson resonances result from models with an extended Higgs sector [11,12]. This Letter reports on a search for a WZ resonance in the fully leptonic decay channel $\ell\nu\ \ell\ell$ ($\ell = e$ or μ), produced either by quark–antiquark ($q\bar{q}$) fusion or by vector-boson fusion (VBF). The proton–proton collision data were collected by the ATLAS detector [13] at the Large Hadron Collider (LHC) at a centre-of-mass energy $\sqrt{s} = 13$ TeV.

Parameterized Lagrangians [14–16] incorporating a heavy vector triplet (HVT) permit the interpretation of searches for vector resonances in a generic way. Here, the simplified phenomenological Lagrangian of Ref. [15] is used. The coupling of the new heavy vector resonance, V, to the Higgs boson and the Standard Model (SM) gauge bosons is parameterized by $g_V c_H$ and to the fermions via the combination $(g^2/g_V)c_F$, where g is the SM SU(2) gauge coupling. The parameter g_V represents the typical strength of the vector-boson interaction, while the parameters c_H and c_F are expected to be of the order of unity in most models. The vector-boson scattering process, $pp \to Vjj \to WZjj$, is only sensitive to the gauge boson coupling and, in this case, the benchmark model used to interpret the results assumes no coupling of the heavy vector resonance to fermions.

The Georgi–Machacek model (GM) [17,18] is used as a benchmark for a singly charged scalar resonance. The model extends the Higgs sector by including one real and one complex triplet, while preserving custodial symmetry, ensuring that the parameter $\rho = M_W^2/(M_Z^2 \cos^2\theta_W) = 1$ at tree level. It is less experimentally constrained [19,20] than other models with higher isospin representations, such as Little Higgs models or Left–Right symmetric models [21]. A parameter $\sin\theta_H$, representing the mixing of the vacuum expectation values, determines the contribution of the triplets to the masses of the W and Z bosons. The ten physical scalar states are organized into different custodial multiplets: a fiveplet ($H_5^{++}, H_5^{+}, H_5^{0}, H_5^{-}, H_5^{--}$) which is fermiophobic but couples to WZ, a triplet, and two singlets, one of which is identified as the 125 GeV SM Higgs boson. Assuming that the triplet states are heavier than the fiveplet scalars, H_5 can only be produced by vector-boson fusion and the cross section is proportional to $\sin^2\theta_H$. The singly charged members of this fiveplet are the object of the present search in the VBF channel. For both models the intrinsic width of the resonance is below 4%, which is lower than the experimental resolution in nearly all the parameter space explored in the present analysis.

The VBF process ($pp \to WZjj$) is characterized by the presence of two jets with a large rapidity gap resulting from quarks from which a vector boson has been radiated. The absence of this topology is interpreted as $q\bar{q}$ production, collectively referred to here as $q\bar{q}$. The spectrum of the reconstructed invariant mass of the WZ resonance candidates is examined for localized excesses over the expected SM background. Results are provided for the VBF and $q\bar{q}$

---

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

https://doi.org/10.1016/j.physletb.2018.10.021

categories separately, neglecting possible signal leakage between them.

Early results from the Tevatron [22,23] have put limits on the mass of a W' boson of an extended gauge model [2] in the WZ channel between 180 GeV and 690 GeV. The present analysis extends the search for resonant WZ production beyond that in Run 1 pp collision data at $\sqrt{s} = 8$ TeV performed by the ATLAS [24] and CMS [25] collaborations. Each collaboration has combined results [26–28] from searches for heavy VV and VH resonances ($V = W$ or Z) based on Run 1 data and on partial Run 2 data at $\sqrt{s} = 13$ TeV in the fully hadronic ($qqqq$), semileptonic ($\ell\nu qq$, $\ell\ell qq$, $\nu\nu qq$), and fully leptonic ($\ell\ell\ell\ell$, $\ell\nu\ell\ell$, $\ell\ell\nu\nu$) final states. More recent results from VV and VH resonance searches with data at $\sqrt{s} = 13$ TeV have been reported in Refs. [29–38]. The various decay channels generally differ in sensitivity in different mass regions. The fully leptonic channel, in spite of a lower branching ratio, is expected to be particularly sensitive to low-mass resonances as it has lower backgrounds. A recent search [39] by the CMS Collaboration for a charged Higgs boson produced by vector-boson fusion and decaying into WZ in the fully leptonic mode, using 15.2 fb^{-1} of data collected at $\sqrt{s} = 13$ TeV, has yielded limits on the coupling parameter of the GM model, as a function of mass. Limits on the GM model have also been set, based on analyses of same-charge WW production by CMS [40] and opposite-charge WW production by ATLAS [41], using data at $\sqrt{s} = 13$ TeV with an integrated luminosity of 36.1 fb^{-1}.

2. ATLAS detector

The ATLAS detector at the LHC has a cylindrical geometry with a near 4π coverage in solid angle.[1] The inner detector (ID), consisting of silicon pixel, silicon microstrip and transition radiation detectors, is surrounded by a thin superconducting solenoid providing a 2 T axial magnetic field. It allows precise reconstruction of tracks from charged particles and measurement of their momenta up to a pseudorapidity of $|\eta| = 2.5$. High-granularity lead/liquid-argon (LAr) sampling electromagnetic and steel/scintillator-tile hadron calorimeters, at larger radius, provide energy measurements in the central pseudorapidity range $|\eta| < 1.7$. In the end-cap and forward regions, LAr calorimeters for both the EM and hadronic energy measurements extend the region of angular acceptance up to $|\eta| = 4.9$. Outside the calorimeters, the muon spectrometer incorporates multiple layers of trigger and tracking chambers in a magnetic field produced by a system of superconducting toroid magnets, enabling an independent precise measurement of muon track momenta for $|\eta| < 2.7$. The ATLAS trigger system consists of a hardware-based level-1 trigger followed by a software-based high-level trigger [42].

3. Data and Monte Carlo samples

The data used in this analysis were collected during 2015 and 2016 with the ATLAS detector in pp collisions at a centre-of-mass energy of 13 TeV at the LHC. The minimum bunch crossing interval is 25 ns, with a mean number of 23 additional interactions per bunch crossing. The events are required to have passed combinations of single-electron or single-muon triggers. The transverse momentum threshold of the leptons in 2015 is 24 GeV for electrons and 20 GeV for muons satisfying a loose isolation requirement based only on ID track information. Due to the higher instantaneous luminosity in 2016 the trigger threshold was increased to 26 GeV for both electrons and muons and tighter isolation requirements were applied. Additional electron and muon triggers that do not include any isolation requirements with transverse momentum thresholds of $p_{\mathrm{T}} = 60$ GeV and 50 GeV, and a single-electron trigger requiring $p_{\mathrm{T}} > 120$ GeV with less restrictive electron identification criteria are used to increase the selection efficiency which reaches close to 100%. Events are accepted only if quality criteria for detector and data conditions are satisfied. With these conditions, the available datasets correspond to an integrated luminosity of 36.1 fb^{-1}.

Samples of simulated data were produced by Monte Carlo (MC) generators with the detector response obtained from the GEANT4 toolkit [43,44]. For some samples, the calorimeter response is obtained from a fast parameterized simulation [45], instead of GEANT4. Additional simulated inelastic pp collisions, generated with PYTHIA 8.186 [46] with the A2 set of tuned parameters [47] and the MSTW2008LO [48] parton distribution function (PDF), were overlaid in order to model both the in- and out-of-time effects from additional pp collisions (pile-up) in the same and neighbouring bunch crossings. The mean number of pile-up events in the MC samples was set to reflect the conditions in the data.

For the HVT interpretation, $W' \to WZ$ samples were generated. Two benchmark models, provided in Ref. [15], are used. In Model A, weakly coupled vector resonances arise from an extension of the SM gauge group [49] with an additional SU(2) symmetry group and the branching fractions to fermions and gauge bosons are comparable. In Model B, the heavy vector triplet is produced in a strongly coupled scenario, as in a Composite Higgs model [50] and fermionic couplings are suppressed. The parameter g_V was set to 1 for Model A and to 3 for Model B. For both models, the parameter c_F is assumed to be the same for all types of fermions. Simulated signal samples for the HVT benchmark Model A were generated for masses of vector resonances ranging from 250 GeV to 3 TeV with MADGRAPH_AMC@NLO 2.2.2 [51], using the model file provided by the authors in Ref. [52] with the NNPDF23LO [53] PDF set. They are hadronized with PYTHIA 8.186. For interpretation in terms of Model B, the Model A cross sections are simply scaled. This is justified since the width remains well below the experimental resolution and the angular distributions are the same for both models.

For the VBF production channel, HVT samples were generated with $g_V = 1$ for masses ranging from 250 GeV to 2 TeV. The coupling parameter c_H was set to 1 and all other couplings of the heavy triplet, including c_F, were set to 0 in order to maximize the VBF contribution. A dijet invariant mass of at least 150 GeV was required during event generation.

For the GM signal samples, $pp \to H_5^{\pm} jj \to W^{\pm}Zjj$ were produced with MADGRAPH_AMC@NLO 2.2.2 for the mass range 200 to 900 GeV in the H_5-plane defined in [54], compatible with present limits [20,55], using GMCALC [56] and with $\sin\theta_H = 0.5$. They were produced at leading order, but normalized to next-to-leading order according to Ref. [11], where the cross sections and widths, which scale as $\sin^2\theta_H$, are also given. For these samples, a minimum p_{T} of 15 GeV (10 GeV) for the jets (leptons) was required during event generation and the pseudorapidity must be in the range $|\eta| < 5$ for jets and $|\eta| < 2.7$ for leptons.

The background sources in this analysis include processes with two or more electroweak gauge bosons, namely VV and VVV as well as processes with top quarks, such as $t\bar{t}$, $t\bar{t}V$, single top and tZ, and processes with gauge bosons produced in association with jets or photons ($Z + j$ and $Z\gamma$). MC simulation is used to estimate

---

[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. Cylindrical coordinates (r, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the z-axis. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln\tan(\theta/2)$. Angular distance is measured in units of $\Delta R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$.

the contribution from background processes with three or more prompt leptons while data-driven techniques are used for the case of background processes with at least one misidentified or non-prompt lepton. Simulated events are used for cross checks and to assess the systematic uncertainties in these backgrounds.

The dominant WZ SM background process of order $(\alpha^2\alpha_s^2)$ involving colour-exchange diagrams, here referred to as QCD WZ, was modelled using Sherpa 2.2.2 [57] at next-to-leading order (NLO), and includes hard-scattering, parton shower, hadronization and the underlying events. Up to three additional partons generated at tree level were merged with the parton shower. In order to estimate an uncertainty due to the parton shower modelling, two alternative WZ samples were produced using Powheg-Box v2 [58] interfaced with Pythia 8.186 and Herwig++ [59], respectively. A sample of the purely electroweak process $WZjj \to \ell\nu\ \ell\ell\ jj$ (labelled $WZjj$) with a matrix-element b-quark veto (at zero order in α_s) was generated separately with Sherpa 2.2.2. Contributions from $WZjb \to \ell\nu\ \ell\ell\ bj$ (labelled $WZbj$) are included in the tZ sample described below. To estimate an uncertainty due to the parton shower modelling an alternative Madgraph+Pythia 8 sample was produced. This Madgraph sample includes b-quarks in the initial state and was split to provide a sample without (with) a b-quark in the final state to model the $WZjj$ ($tZ + WZbj$) background.

Samples of $q\bar{q} \to ZZ \to 4\ell$ or $q\bar{q} \to ZZ \to \ell\ell\ \nu\nu$ were generated by Powheg-Box v2 at NLO, interfaced to Pythia 8.186 and normalized to NNLO by K-factors evaluated in Ref. [60]. The $gg \to ZZ$ and tribosons were generated with Sherpa 2.1.1. The $t\bar{t}V$ and tZ processes were generated at LO using Madgraph_aMC@NLO, interfaced with Pythia 8.186 ($t\bar{t}V$) and Pythia 6.428 (tZ). The $t\bar{t}V$ samples were normalized to NLO predictions [11].

Finally samples of SM backgrounds with at least one misidentified or non-prompt lepton, including $Z\gamma$, $W\gamma$, Drell–Yan $Z \to \ell\ell$, $W \to \ell\nu$ as well as top-pair and single-top were generated to assist in the fake/non-prompt lepton background estimate. Events with $Z\gamma$ and $W\gamma$ in the final state were generated with Sherpa 2.1.1. Drell–Yan $Z \to \ell\ell$, $W \to \ell\nu$ as well as top-pair and single-top production channels were generated with Powheg-Box v2 and hadronized with Pythia. To avoid double counting the $Z\gamma$ events, Z events produced by the Drell–Yan process with a photon from final-state radiation with $p_\mathrm{T} > 10$ GeV were removed. The parton shower for processes with top quarks was modelled with Pythia 6.428. Madgraph_aMC@NLO and Pythia 8.186 were used for background processes involving a pair of top quarks accompanied by a W boson or by a pair of charged leptons. The Z and single-top cross sections were normalized to NNLO by K-factors evaluated in Ref. [60,61].

SM backgrounds with Higgs bosons ($H, t\bar{t}H, VH$) contribute less than 0.1% of the total background because of the low cross section and the requirement of a well reconstructed Z boson decaying leptonically. These backgrounds are neglected.

4. Reconstructed objects

Events are required to have at least one primary vertex with at least two associated tracks, each with transverse momentum $p_\mathrm{T} > 0.4$ GeV. If there is more than one vertex reconstructed in the event, the one with the largest track $\sum p_\mathrm{T}^2$ is chosen as the hard-scatter primary vertex and is subsequently used for the reconstruction of electrons, muons, jets and missing transverse momentum.

Electron candidates are reconstructed from energy deposits in the EM calorimeter which are matched to a well-reconstructed ID track originating from the primary vertex. The electron identification is based on a likelihood evaluated from a multivariate discriminant. They are categorized as satisfying the *medium* or the *tight* reconstruction quality requirements, as defined in Ref. [62]. Only electrons with transverse energy $E_\mathrm{T} > 25$ GeV in the pseudorapidity range $|\eta| < 2.47$ are considered in this analysis. The candidate electrons are required to pass an isolation condition: an upper value of the scalar sum of the transverse momentum of the tracks with $p_\mathrm{T} > 0.4$ GeV in a cone of size $\Delta R = \min(0.2, 10\ \mathrm{GeV}/E_\mathrm{T})$ around the electron, excluding the track of the electron itself, is chosen such that the efficiency is constant at 99% for electrons in $Z \to ee$ events. For *tight* electrons, an isolation requirement is imposed, based on calorimeter as well as track variables, which varies as a function of transverse energy and yields an efficiency between 95% and 99% for electrons with p_T in the range 25–60 GeV. For a pair of electrons sharing the same ID-track, the electron with higher cluster E_T is kept.

Muons are reconstructed by combining tracks from the inner detector with tracks from the muon spectrometer. They are required to satisfy *medium* or *tight* quality requirements, as defined in Ref. [63]. Only muons with $p_\mathrm{T} > 25$ GeV and $|\eta| < 2.7$ are considered in this analysis. Isolation requirements are also applied to all muons, based on the ratio $p_\mathrm{T}^\mathrm{varcone}/p_\mathrm{T}^\mu$, where $p_\mathrm{T}^\mathrm{varcone}$ is the scalar sum of the transverse momenta of the tracks with $p_\mathrm{T} > 1$ GeV in a cone of size $\Delta R = \min(10\ \mathrm{GeV}/p_\mathrm{T}^\mu, 0.3)$ around the muon, excluding the muon track itself. This isolation gives 99% efficiency, independently of η or p_T^μ, in $Z \to \mu\mu$ samples.

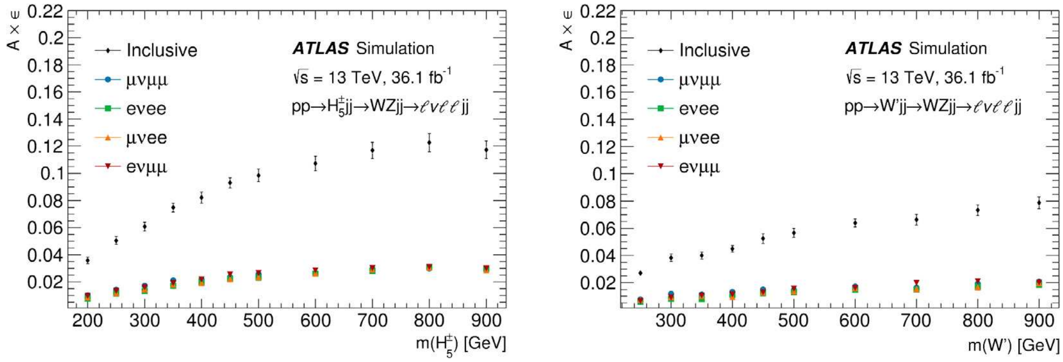
Electron and muon candidates are required to originate from the primary vertex. Thus, the significance of the track's transverse impact parameter calculated relative to the beam line, $|d_0/\sigma_{d_0}|$, must be less than three for muons and less than five for electrons, and the longitudinal impact parameter, z_0 (the difference between the value of z of the point on the track at which d_0 is defined and the longitudinal position of the primary vertex), is required to satisfy $|z_0 \cdot \sin(\theta)| < 0.5$ mm.

Jets are reconstructed from clusters of energy deposition in the calorimeter [64] using the anti-k_t algorithm [65] with a radius parameter $R = 0.4$. Events with jets arising from detector noise or other non-collision sources are discarded [66]. This search considers jets with $p_\mathrm{T} > 30$ GeV in the range $|\eta| < 4.5$. Furthermore, to mitigate the pile-up contamination, a jet vertex tagger [67], based on information about tracks associated with the primary vertex and pile-up vertices, is applied to jets with $p_\mathrm{T} < 60$ GeV and $|\eta| < 2.4$. The selected working point provides at least 92% efficiency. The energy of each jet is calibrated and corrected for detector effects using a combination of simulated events and in situ methods in 13 TeV data [68].

As lepton and jet candidates can be reconstructed from the same detector information, a procedure to resolve overlap ambiguities is applied. If an electron and a muon share the same ID track, the muon is selected. Reconstructed jets which overlap with electrons or muons in a cone of size $\Delta R = 0.2$ are removed.

Jets containing b-hadrons are identified as *b-jets* by the MV2c10 b-tagging algorithm [69], which uses information such as track impact-parameter significances and positions of explicitly reconstructed secondary decay vertices. A working point corresponding to 85% b-tagging efficiency on a sample of $t\bar{t}$ events is chosen [70], with a light-flavour jet rejection factor of about 34 and a c-jet rejection of about 3. Correction factors are applied to the simulated event samples to compensate for differences between data and simulation in the b-tagging efficiency for b-jets, c-jets and light-flavour jets.

The missing transverse momentum, $\vec{p}_\mathrm{T}^\mathrm{\,miss}$, and its magnitude $E_\mathrm{T}^\mathrm{miss}$, are calculated from the imbalance in the sum of visible transverse momenta of reconstructed physics objects: electrons, muons and jets, as well as a “soft” term reconstructed from tracks



(a) (b)

Fig. 1. The signal selection acceptance times efficiency (A×ϵ), defined as the ratio of the number of MC signal events in the VBF category to the number of generated signal events, is presented as a function of the resonance mass. Fig. 1(a) corresponds to the GM Model $H_5^{\pm}$ while Fig. 1(b) corresponds to the HVT models. The A×ϵ is shown for each decay channel and the sum of all lepton flavour combinations (inclusive). The error bars shown in each figure represent the total statistical and systematic uncertainties.

compatible with the primary vertex and not associated with any of those objects [71,72].

5. Event selection

Preselection criteria are first applied to all the event samples. The presence of three prompt leptons is required, two of which will be associated with the Z boson, and are required to satisfy the *medium* quality requirement (Section 4). The Z boson candidate is reconstructed from the two leptons of same flavour and opposite charge, whose invariant mass is closest to the on-shell mass m_Z, and in the range $|m_{\ell\ell} - m_Z| < 20$ GeV. The third lepton, associated with the W boson decay, is required to satisfy the *tight* quality criteria to enhance the background rejection. To ensure that the trigger efficiency is well determined, at least one of the candidate leptons is required to have $p_{\mathrm{T}} > 27$ GeV.

To suppress background processes with at least four prompt leptons, events with a fourth lepton candidate satisfying looser selection criteria are rejected. For this looser selection, the requirement on the minimum p_{T} of the leptons is lowered to $p_{\mathrm{T}} > 7$ GeV and *medium* identification requirements are used for both the electrons and muons.

Since there is a neutrino in the signal events, $E_{\mathrm{T}}^{\mathrm{miss}} > 25$ GeV is also required. The third lepton and the missing transverse momentum are assumed to result from the W boson decay. The longitudinal momentum p_z^{ν} of the neutrino is calculated by requiring that the invariant mass of the lepton–neutrino system be equal to the W mass. The solution results in a quadratic equation which leads to two possible solutions. If they are real, the one with the smaller $|p_z^{\nu}|$ is chosen since it was found to provide a better agreement with the truth. Otherwise, the real part is chosen. The invariant mass, m_{WZ}, of the WZ resonance candidate is then reconstructed using the chosen solution for p_z^{ν} along with the four-momenta of the three charged leptons.

The selected events are then separated into two categories targeting different production mechanisms: VBF and $q\bar{q}$. The VBF category contains events with two or more jets with $p_{\mathrm{T}} > 30$ GeV which fail the b-tagging requirements described in Section 4. The dijet pair defined by the two highest-p_{T} jets in the event must also have large η separation ($|\Delta\eta_{jj}| > 3.5$) and an invariant m_{jj} above 500 GeV. If more than two jets are found in an event, the two highest-p_{T} jets are considered. By imposing a b-jet veto, backgrounds containing one or more top quarks, including $t\bar{t}$, $t\bar{t}+W/Z$, and tZ are suppressed.

The net acceptance times efficiency (A×ϵ) of the selection, relative to signal events generated for $H_5^{\pm}$ and HVT models in the VBF category is shown in Fig. 1. The generation of the GM Model $H_5^{\pm}$ events had the following requirements: p_{T} (jets) > 15 GeV, p_{T} (leptons) > 10 GeV, $|\eta|$(jets) < 5 and $|\eta|$(leptons) < 2.7. Decays of W bosons into all lepton flavours, and of Z bosons into e^+e^- and $\mu^+\mu^-$, were simulated. The $Z \to \tau^+\tau^-$ decays give a negligible contribution and were not included in the simulation, but the A×ϵ shown was scaled to include all decays. For the HVT VBF samples, $m_{jj} > 150$ GeV was required at generator level. Decays of W and Z bosons into all flavours of leptons were included. For HVT and $H_5^{\pm}$ the A×ϵ falls in the range 2–8% and 3–12% respectively for resonance masses ranging between 200 and 900 GeV, the difference being due, with approximately equal importance, to the generator level selection and to the different angular distributions of the final products.

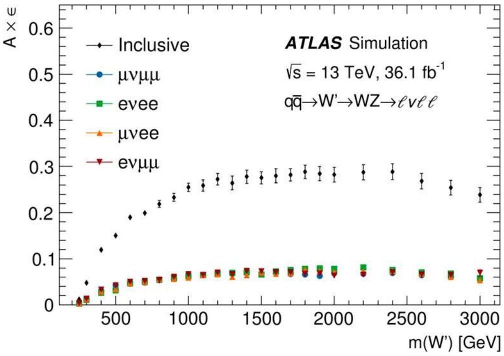
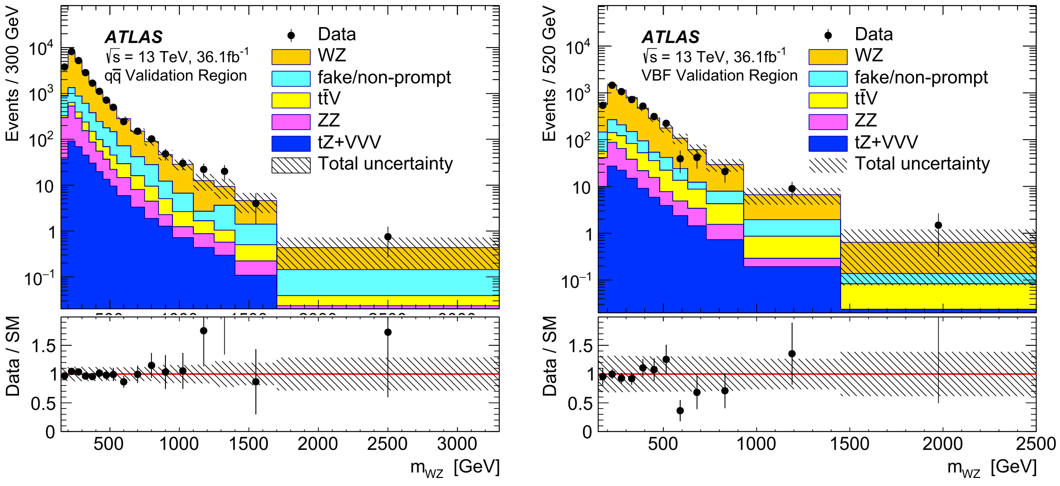


Fig. 2. The signal selection acceptance times efficiency (A×ϵ), defined as the ratio of the number of MC signal events in the $q\bar{q}$ category to the number of generated signal events, as a function of the HVT resonance mass. The error bars represent the total statistical and systematic uncertainties.

The remaining events are assigned to the $q\bar{q}$ category signal region. For this category, the W and Z bosons from a resonance produced in the s-channel with m_{WZ} larger than 250 GeV are expected to have transverse momenta close to 50% of its mass. The requirements $p_{\mathrm{T}}^{W}/m_{WZ} > 0.35$ and $p_{\mathrm{T}}^{Z}/m_{WZ} > 0.35$ enhance the sensitivity to the signal. The overall selection efficiency relative to generated event increases from about 15% to 25% for resonances masses ranging from 500 GeV to 3 TeV as illustrated in Fig. 2. Decays of W and Z bosons into all flavours of leptons are included at event generation. The A×ϵ values decrease for resonance masses above approximately 2 TeV due to the collinearity of electrons from the $Z \to ee$ decays which spoils the isolation.



(a) (b)

Fig. 3. Observed and expected distributions of the WZ invariant mass in (a) the $q\bar{q}$ validation region and (b) the VBF validation region. The points correspond to the data and the histograms to the expectations for the different SM processes. The uncertainty in the total background prediction, shown as bands, combines statistical, theory and systematic contributions. The bin sizes were chosen to reflect the resolution of a reconstructed signal, and the width of the previous to last bin is used to scale the bin contents. The last bin contains the overflow.

6. Background estimation

The dominant background in the resonance search is the SM production of WZ. Its normalization and shape are estimated from MC and validated in dedicated validation regions by comparing the data and MC distributions. Events in the validation regions are selected in exactly the same way as those in their corresponding signal categories except for the following requirements. The VBF WZ validation region is defined by inverting the requirements on the dijet variables: $100 < m_{jj} < 500$ GeV and $|\Delta\eta_{jj}| < 3.5$. The WZ $q\bar{q}$ validation region requires the events to have $p_{\mathrm{T}}^{Z}/m_{WZ} < 0.35$ or $p_{\mathrm{T}}^{W}/m_{WZ} < 0.35$. These validation regions are dominated by the WZ contribution, with a purity higher than 80%. For the benchmark models with parameters given in Section 3, the signal contamination in the $q\bar{q}$ (VBF) validation region is below 5% (1%). The reconstructed m_{WZ} mass in the validation regions is shown in Fig. 3, where good agreement of data with the background prediction is observed.

Events from Z+jets, $Z\gamma$, $W\gamma$, $t\bar{t}$, single top or WW where jets or photons were misidentified as leptons (here called *fake/non-prompt* leptons), can also satisfy the selection criteria. The distribution shapes and number of fake/non-prompt lepton events are estimated for both the $q\bar{q}$ and VBF categories by a data-driven method using a global matrix which exploits differences in object characteristics between real and fake/non-prompt leptons on a statistical basis. Details of the method, here referred to as "Matrix Method", can be found in Ref. [73].

Other backgrounds include $t\bar{t}V$, ZZ, tZ, $WZbj$ and triple boson production. They are estimated by Monte Carlo simulation (Section 3). The tZ, $WZbj$ and VVV backgrounds are added as a single contribution, here called $tZ+VVV$.

7. Systematic uncertainties

Systematic uncertainties result from the theoretical modelling of backgrounds and from object and event reconstruction.

The uncertainty in the normalization of the Sherpa samples of SM WZ background is evaluated by taking into account the variations obtained with different PDF sets [74]. The nominal set NNPDF30nloas0118 is compared with other samples generated with the CT14nnlo and MMHT2014nlo68cl PDF sets and the uncertainty is evaluated from the maximum differences. It is estimated to be below 6% in all mass bins for both the VBF and $q\bar{q}$ categories. The uncertainty associated with the choice of renormalization and factorization scales, μ_{R} and μ_{F}, is taken as the maximum downward and upward variation when the scales are varied independently by factors of 1/2 and 2. While these uncertainties can in principle affect the shape of the m_{WZ} distribution, in practice the shape differences do not have a strong impact on the sensitivity of the search. The uncertainties are therefore treated as normalization uncertainties, taken to be 20% and 40% respectively. Shape systematic uncertainties associated with showering and hadronization of the QCD WZ are evaluated by comparing the Powheg-Box v2 samples interfaced with Pythia 8.186 and Herwig. For the electroweak WZ process the Sherpa 2.2.2 and Madgraph+Pythia 8 predictions are compared. This uncertainty band ranges from 10% to 30% for both categories.

The uncertainties assigned to the cross sections of the other background sources consist of a contribution from PDF uncertainties and from QCD scale uncertainties. They are estimated to be 10% for ZZ, 13% for ttV, 20% for VVV and 15% for tZ.

The theoretical uncertainties in the cross section and acceptance of the simulated signal samples are evaluated in a similar way to the background. The PDF errors are taken from the NNPDF LO PDF error set, and the NNPDF set is also compared with the CTEQ6L1 and MSTW2008lo68cl sets. The different predictions from these PDF sets are taken as an extra contribution to the overall uncertainty. For both the $q\bar{q}$ and VBF categories, the uncertainties are typically below 5%. This procedure was followed for each mass point and a generator-level event selection was chosen to closely mimic the one used in the reconstruction-level analysis. Scale and PDF uncertainties are not correlated between signal and background.

An uncertainty due to the reconstruction efficiency, momentum scales and resolution of electrons and muons is evaluated by varying correction factors applied to the MC samples [63,75] within appropriate limits.

The jet energy scale and resolution uncertainties [66] are also taken into account as they affect the shape and normalization of the background distributions. The uncertainty due to b-tagging [76] is also included.

Missing transverse momentum is calculated using the preselected leptons, jets and other reconstructed objects. The uncertainties in the reconstruction of those objects are then used to evaluate

Table 1
Impact of the dominant sources of relative uncertainties on the 95% CL upper limits of the signal-strength parameter (μ) for a hypothetical HVT signal of mass $m(W') = 800$ GeV in the $q\bar{q}$ category and a GM signal of mass $m(H_5^\pm) = 450$ GeV in the VBF category. The effect of the statistical uncertainty on the signal and background samples is also shown. Sources of systematic uncertainty with an impact of less than 2% in both categories are not shown.

Source	$\Delta\mu/\mu$ [%]	
	$q\bar{q}$ category	VBF category
	$m(W') = 800$ GeV	$m(H_5^\pm) = 450$ GeV
WZ background modelling: scale, PDF	5	11
WZ background modelling: parton shower	10	6
MC statistical uncertainty	7	8
Electron identification	4	2
Muon identification	3	3
Jet uncertainty	1	8
Missing transverse momentum	2	1
Fake/non-prompt	1	5
Total systematic uncertainty	17	21
Statistical uncertainty	53	52

the uncertainty in $E_{\mathrm{T}}^{\mathrm{miss}}$ reconstruction. Those due to the p_{T} scale and resolution of the soft term are also considered [71,72].

An uncertainty in the prediction of the fake/non-prompt background is also taken into account as it affects the shape and normalization of the background distributions. The total uncertainty is about 20% (27%) for the $q\bar{q}$ (VBF) category. It is slightly larger for the VBF category because of the higher statistical uncertainty derived from the Matrix Method (Section 6).

The uncertainty in the integrated luminosity is 2.1%. It is derived, following a methodology similar to the one detailed in Ref. [77], from a calibration of the luminosity scale using x–y beam-separation scans performed in August 2015 and May 2016.

8. Results

The WZ invariant mass distribution, m_{WZ}, obtained as the sum of all four lepton-flavor permutations, is used as the discriminating variable, with bin widths comparable to the expected resolution of a narrow resonant signal. A binned likelihood function, constructed from the Poisson probability of the sum, in each bin, of the contributions of the background and of a hypothetical signal of strength μ relative to the benchmark model, is used to set limits on the presence of a signal. The fit is performed in the signal region for the $q\bar{q}$ and VBF categories separately. The systematic uncertainties described above (Section 7) enter as nuisance parameters with Gaussian or log-normal prior distributions, in convolution with the nominal background distribution.

The effects of systematic uncertainties are studied for hypothesized signals using the signal-strength parameter μ. The list of leading sources of uncertainty in the 95% confidence level (CL) upper limit on the μ value is given in Table 1 together with their relative importance ($\Delta\mu/\mu$). The values are quoted separately for a hypothetical HVT signal of mass $m(W') = 800$ GeV in the $q\bar{q}$ category and a GM signal of mass $m(H_5^\pm) = 450$ GeV in the VBF category. Apart from the statistical uncertainties in the data, the uncertainty with the largest impact on the sensitivity of the searches is related to the WZ background modelling.

The numbers of background events are extracted through a background-only fit of the data in each category. Background contributions from prompt leptons, including their shapes, are taken from MC simulations. In the case of non-prompt leptons the background shapes are taken from the Matrix Method. In the fit, the normalisation of all backgrounds are allowed to vary within their uncertainties. The post-fit background yields are summarized in Table 2 for the $q\bar{q}$ and VBF categories. The fit constrains the SM WZ background estimate to the observed data, which reduces the total background uncertainty, pulling the modelling uncertainties by less than one standard deviation from their pre-fit values. None of the nuisance parameters are significantly pulled or constrained relative to their pre-fit values in the background-only fit.

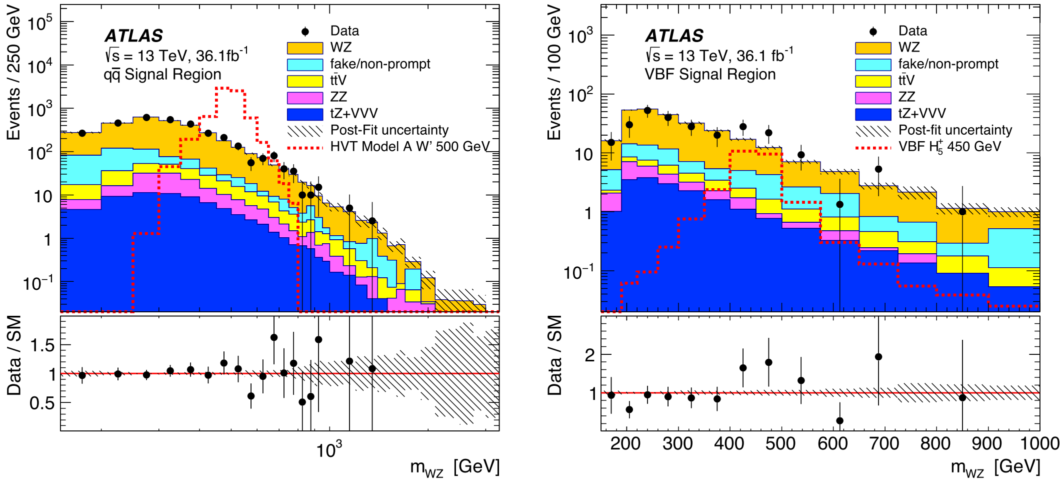
Table 2
Expected and observed yields in the $q\bar{q}$ and VBF signal regions. Yields and uncertainties are evaluated after a background-only fit to the data in the $q\bar{q}$ or VBF signal regions after applying all selection criteria. The uncertainty in the total background estimate is smaller than the sum in quadrature of the individual background contributions due to anti-correlations between the estimates of different background sources.

	$q\bar{q}$ signal region	VBF signal region
WZ	521 ± 29	87 ± 12
Fake/non-prompt	64 ± 13	15 ± 4
$t\bar{t}V$	29 ± 4	4.9 ± 0.8
ZZ	18.9 ± 2.0	4.4 ± 1.0
$tZ + VVV$	14.1 ± 2.9	8.1 ± 1.8
Total background	647 ± 25	120 ± 11
Observed	650	114

Fig. 4 shows the post-fit m_{WZ} distribution for the $q\bar{q}$ and VBF categories. The largest difference between the observed data and the SM background prediction is in the VBF category. A local excess of events at a resonance mass of around 450 GeV can be seen in Fig. 4(b). The local significances for signals of $H_5^\pm$ and of a heavy vector W' are 2.9 and 3.1 standard deviations, respectively. The respective global significances calculated using the Look Elsewhere method as in Ref. [78] and evaluated up to a mass of 900 GeV, are 1.6 and 1.9 standard deviations. In the $q\bar{q}$ category the largest difference between the observed data and the SM background prediction is located around a mass of 700 GeV with a local significance of 1.2 standard deviations.

Upper limits are set on the product of the production cross section of new resonances and their decay branching ratio into WZ. Exclusion intervals are derived using the CL$_s$ method [79] in the asymptotic approximation [80]. For masses higher than 900 (700) GeV in $q\bar{q}$ (VBF) category, the small number of expected events makes the asymptotic approximation imprecise and the limits are calculated using pseudo-experiments. The limit set on the signal strength μ is then translated into a limit on the signal cross section times branching ratio, $\sigma \times \mathcal{B}(W' \to WZ)$, using the theoretical cross section and branching ratio for the given signal model.

Fig. 5 presents the observed and expected limits on $\sigma \times \mathcal{B}(W' \to WZ)$ at 95% CL for the HVT model in the $q\bar{q}$ category. Masses below 2260 GeV can be excluded for Model A and



(a) (b)

Fig. 4. Observed and expected distributions of the WZ invariant mass (a) in the $q\bar{q}$ and (b) in the VBF categories after applying all selection criteria. Signal predictions are overlaid, normalized to the predicted cross sections. The uncertainty in the total background prediction, shown as shaded bands, combines statistical, theory and systematic contributions. The lower panel show the ratios of the observed data to the background predictions.

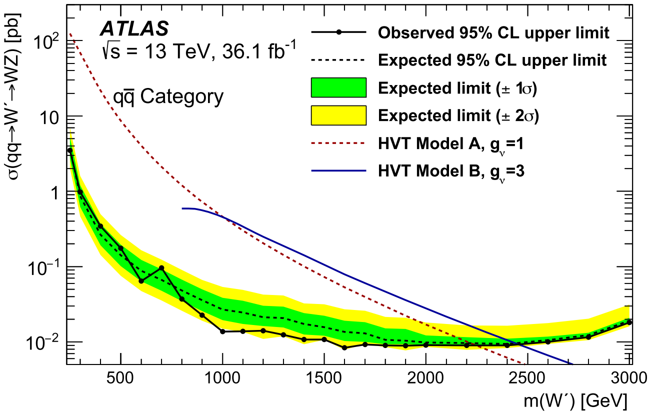


Fig. 5. Observed and expected 95% CL upper limits on $\sigma \times \mathcal{B}(W' \to W^{\pm}Z)$ for the $q\bar{q}$ production of a W' boson in the HVT models as a function of its mass. The theoretical predictions for HVT Models A with $g_V = 1$ and B with $g_V = 3$ are also shown.

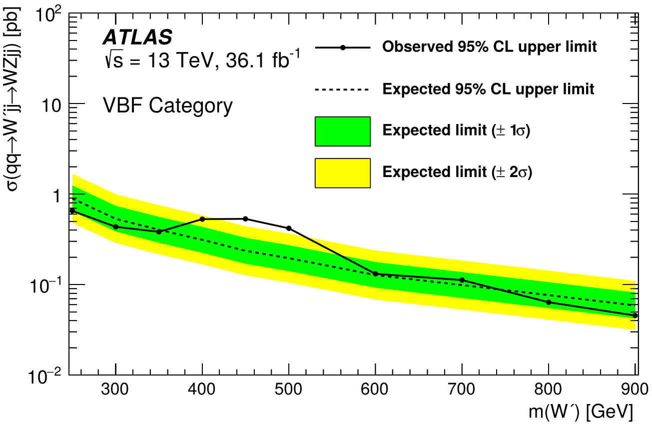


Fig. 6. Observed and expected 95% CL upper limits on $\sigma \times \mathcal{B}(W' \to W^{\pm}Z)$ for the VBF production of a W' boson in the HVT Model, with parameter $c_F = 0$, as a function of its mass.

2460 GeV for Model B. For resonance masses above 2 TeV the exclusion limits become worse due to the acceptance losses at high mass. For the VBF process, the limit on $\sigma \times \mathcal{B}(W' \to WZ)$ is shown in Fig. 6.

Observed and expected exclusion limits at 95% CL on $\sigma \times \mathcal{B}(H_5^{\pm} \to W^{\pm}Z)$ and on the mixing parameter $\sin\theta_H$ of the GM Model are shown in Fig. 7 as a function of $m_{H_5^{\pm}}$. The intrinsic width of the scalar resonance, for $\sin\theta_H = 0.5$, is narrower than the detector resolution in the mass region explored. The shaded regions show the parameter space for which the $H_5^{\pm}$ width exceeds 5% and 10% of $m_{H_5^{\pm}}$.

9. Conclusion

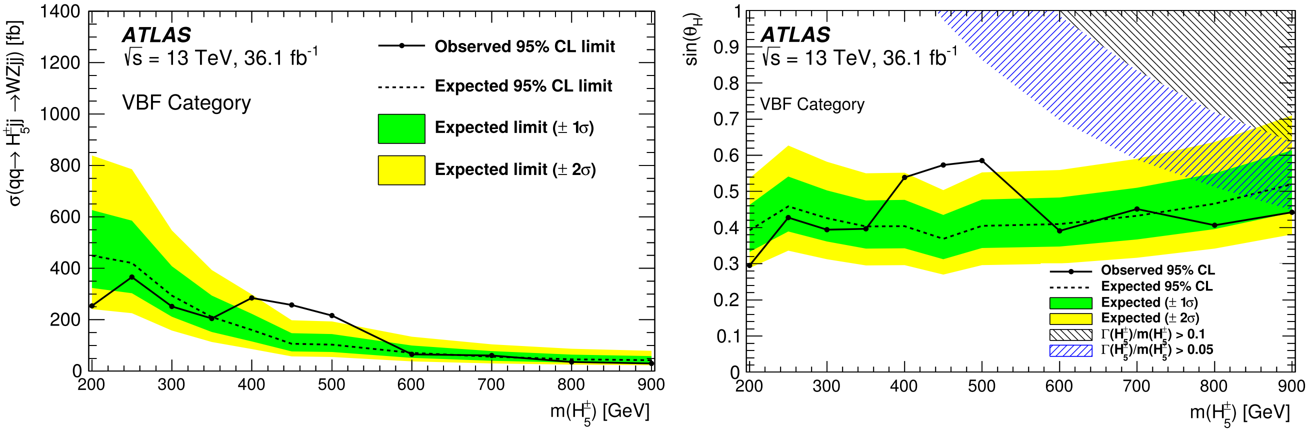
A search is performed for resonant WZ production in fully leptonic final states (electrons and muons) using 36.1 fb^{-1} of $\sqrt{s} = 13$ TeV pp data collected by the ATLAS experiment at the LHC during the 2015 and 2016 run periods. Two different production modes are considered using quark–antiquark annihilation and vector-boson fusion.

The data in the $q\bar{q}$ fusion category are found to be consistent with Standard Model predictions. The results are used to derive upper limits at 95% CL on the cross section times branching ratio of the phenomenological Heavy Vector Triplet benchmark Model A (Model B) with coupling constant $g_V = 1$ ($g_V = 3$) as a function of the resonance mass, with no evidence of heavy resonance production for masses below 2260 (2460) GeV.

In the case of the VBF production processes, limits on the production cross section times branching ratio are obtained as a function of the mass of a charged member of a heavy vector triplet or of the fiveplet scalar in the Georgi–Machacek model. The results show a local excess of events over the Standard Model expectations at a resonance mass of around 450 GeV. The local significances for signals of $H_5^{\pm}$ and of a heavy vector W' boson are 2.9 and 3.1 standard deviations respectively. The respective global significances calculated considering the Look Elsewhere effect are 1.6 and 1.9 standard deviations respectively.

Acknowledgements

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



(a) (b)

Fig. 7. Observed and expected 95% CL upper limits on (a) $\sigma \times \mathcal{B}(H_5^\pm \to W^\pm Z)$ and (b) the parameter $\sin\theta_H$ of the GM Model as a function of $m_{H_5^\pm}$. The shaded region shows where the theoretical intrinsic width of the resonance would be larger than 5% or 10% of the mass.

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

The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN, the ATLAS Tier-1 facilities at TRIUMF (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN-CNAF (Italy), NL-T1 (Netherlands), PIC (Spain), ASGC (Taiwan), RAL (UK) and BNL (USA), the Tier-2 facilities worldwide and large non-WLCG resource providers. Major contributors of computing resources are listed in Ref. [81].

References

[1] P. Langacker, R.W. Robinett, J.L. Rosner, New heavy gauge bosons in pp and pp collisions, Phys. Rev. D 30 (1984) 1470.

[2] G. Altarelli, B. Mele, M. Ruiz-Altaba, Searching for new heavy vector bosons in $p\bar{p}$ colliders, Z. Phys. C 45 (1989) 109.

[3] N. Arkani-Hamed, A.G. Cohen, E. Katz, A.E. Nelson, The littlest Higgs, J. High Energy Phys. 07 (2002) 034, arXiv:hep-ph/0206021 [hep-ph].

[4] K. Agashe, R. Contino, A. Pomarol, The minimal composite Higgs model, Nucl. Phys. B 719 (2005) 165, arXiv:hep-ph/0412089 [hep-ph].

[5] G. Giudice, C. Grojean, A. Pomarol, R. Rattazzi, The strongly-interacting light Higgs, J. High Energy Phys. 06 (2007) 045, arXiv:hep-ph/0703164 [hep-ph].

[6] R. Foadi, M.T. Frandsen, T.A. Ryttov, F. Sannino, Minimal walking technicolor: set up for collider physics, Phys. Rev. D 76 (2007) 055005, arXiv:0706.1696 [hep-ph].

[7] R.L. Delgado, et al., Production of vector resonances at the LHC via WZ-scattering: a unitarized EChL analysis, J. High Energy Phys. 11 (2017) 098, arXiv:1707.04580 [hep-ph].

[8] L. Randall, R. Sundrum, A large mass hierarchy from a small extra dimension, Phys. Rev. Lett. 83 (1999) 3370, arXiv:hep-ph/9905221.

[9] H. Davoudiasl, J.L. Hewett, T.G. Rizzo, Bulk gauge fields in the Randall–Sundrum model, Phys. Lett. B 473 (2000) 43, arXiv:hep-ph/9911262.

[10] C. Csaki, C. Grojean, H. Murayama, L. Pilo, J. Terning, Gauge theories on an interval: unitarity without a Higgs, Phys. Rev. D 69 (2004) 055006, arXiv:hep-ph/0305237 [hep-ph].

[11] D. de Florian, et al., Handbook of LHC Higgs cross sections: 4. Deciphering the nature of the Higgs sector, arXiv:1610.07922 [hep-ph], 2016.

[12] I.P. Ivanov, Building and testing models with extended Higgs sectors, Prog. Part. Nucl. Phys. 95 (2017) 160, arXiv:1702.03776 [hep-ph].

[13] ATLAS Collaboration, The ATLAS experiment at the CERN large hadron collider, J. Instrum. 3 (2008) S08003.

[14] J. de Blas, J.M. Lizana, M. Perez-Victoria, Combining searches of Z' and W' bosons, J. High Energy Phys. 01 (2013) 166, arXiv:1211.2229 [hep-ph].

[15] D. Pappadopulo, A. Thamm, R. Torre, A. Wulzer, Heavy vector triplets: bridging theory and data, J. High Energy Phys. 09 (2014) 060, arXiv:1402.4431 [hep-ph].

[16] D. Greco, D. Liu, Hunting composite vector resonances at the LHC: naturalness facing data, J. High Energy Phys. 12 (2014) 126, arXiv:1410.2883 [hep-ph].

[17] H. Georgi, M. Machacek, Doubly charged Higgs bosons, Nucl. Phys. B 262 (1985) 463.

[18] M.S. Chanowitz, M. Golden, Higgs boson triplets with $M(W) = M(Z)\cos\theta_W$, Phys. Lett. B 165 (1985) 105.

[19] S. Godfrey, K. Moats, Exploring Higgs triplet models via vector boson scattering at the LHC, Phys. Rev. D 81 (2010) 075026, arXiv:1003.3033 [hep-ph].

[20] K. Hartling, K. Kumar, H.E. Logan, Indirect constraints on the Georgi–Machacek model and implications for Higgs boson couplings, Phys. Rev. D 91 (2015) 015013, arXiv:1410.5538 [hep-ph].

[21] R.N. Mohapatra, J.C. Pati, Left–right gauge symmetry and an "isoconjugate" model of CP violation, Phys. Rev. D 11 (1975) 566.

[22] D0 Collaboration, Search for resonant WW and WZ production in $p\bar{p}$ collisions at ?s = 1.96 TeV, Phys. Rev. Lett. 107 (2011) 011801, arXiv:1011.6278 [hep-ex].

[23] CDF Collaboration, Search for new heavy particles decaying to $ZZ \to \ell\ell\ell\ell$, $\ell\ell jj$ in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV, Phys. Rev. D 83 (2011) 112008, arXiv:1102.4566 [hep-ex].

[24] ATLAS Collaboration, Search for WZ resonances in the fully leptonic channel using pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector, Phys. Lett. B 737 (2014) 223, arXiv:1406.4456 [hep-ex].

[25] CMS Collaboration, Search for new resonances decaying via WZ to leptons in proton–proton collisions at $\sqrt{s} = 8$ TeV, Phys. Lett. B 740 (2015) 83, arXiv:1407.3476 [hep-ex].

[26] ATLAS Collaboration, Combination of searches for WW, WZ, and ZZ resonances in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector, Phys. Lett. B 755 (2016) 285, arXiv:1512.05099 [hep-ex].

[27] ATLAS Collaboration, Searches for heavy diboson resonances in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, J. High Energy Phys. 09 (2016) 173, arXiv:1606.04833 [hep-ex].

[28] CMS Collaboration, Combination of searches for heavy resonances decaying to WW, WZ, ZZ, WH, and ZH boson pairs in proton–proton collisions at $\sqrt{s} =$ 8 and 13 TeV, Phys. Lett. B 774 (2017) 533, arXiv:1705.09171 [hep-ex].

[29] ATLAS Collaboration, Search for WW/WZ resonance production in $\ell\nu qq$ final states in pp collisions at $\sqrt{s} =$ 13 TeV with the ATLAS detector, arXiv:1710.07235 [hep-ex], 2017.

[30] ATLAS Collaboration, Searches for heavy ZZ and ZW resonances in the $\ell\ell qq$ and $\nu\nu qq$ final states in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, arXiv:1708.09638 [hep-ex], 2017.

[31] ATLAS Collaboration, Search for diboson resonances with boson-tagged jets in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, Phys. Lett. B 777 (2018) 91, arXiv:1708.04445 [hep-ex].

[32] ATLAS Collaboration, Search for heavy resonances decaying to a W or Z boson and a Higgs boson in the $q\bar{q}^{(\prime)}b\bar{b}$ final state in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, Phys. Lett. B 774 (2017) 494, arXiv:1707.06958 [hep-ex].

[33] ATLAS Collaboration, Search for new resonances decaying to a W or Z boson and a Higgs boson in the $\ell^+\ell^-b\bar{b}$, $\ell\nu b\bar{b}$, and $\nu\bar{\nu}b\bar{b}$ channels with pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, Phys. Lett. B 765 (2017) 32, arXiv:1607.05621 [hep-ex].

[34] CMS Collaboration, Search for heavy resonances that decay into a vector boson and a Higgs boson in hadronic final states at $\sqrt{s} = 13$ TeV, Eur. Phys. J. C 77 (2017) 636, arXiv:1707.01303 [hep-ex].

[35] CMS Collaboration, Search for massive resonances decaying into WW, WZ, ZZ, qW, and qZ with dijet final states at $\sqrt{s} = 13$ TeV, Phys. Rev. D 97 (2018) 072006, arXiv:1708.05379 [hep-ex].

[36] CMS Collaboration, Search for a new heavy resonance decaying into a Z boson and a Z or W boson in $2\ell 2$q final states at $\sqrt{s} =$ 13 TeV, arXiv:1803.10093 [hep-ex], 2018.

[37] CMS Collaboration, Search for a heavy resonance decaying into a Z boson and a vector boson in the $\nu\bar{\nu}\mathrm{q}\bar{\mathrm{q}}$ final state, J. High Energy Phys. 07 (2018) 075, arXiv:1803.03838 [hep-ex].

[38] CMS Collaboration, Search for a heavy resonance decaying to a pair of vector bosons in the lepton plus merged jet final state at $\sqrt{s} = 13$ TeV, J. High Energy Phys. 05 (2018) 088, arXiv:1802.09407 [hep-ex].

[39] CMS Collaboration, Search for charged Higgs bosons produced via vector boson fusion and decaying into a pair of W and Z bosons using pp collisions at $\sqrt{s} = 13$ TeV, Phys. Rev. Lett. 119 (2017) 141802, arXiv:1705.02942 [hep-ex].

[40] CMS Collaboration, Observation of electroweak production of same-sign W boson pairs in the two jet and two same-sign lepton final state in proton–proton collisions at $\sqrt{s} =$ 13 TeV, Phys. Rev. Lett. 120 (2018) 081801, arXiv:1709.05822 [hep-ex].

[41] ATLAS Collaboration, Search for heavy resonances decaying into WW in the $e\nu\mu\nu$ final state in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, Eur. Phys. J. C 78 (2018) 24, arXiv:1710.01123 [hep-ex].

[42] ATLAS Collaboration, Performance of the ATLAS trigger system in 2015, Eur. Phys. J. C 77 (2017) 317, arXiv:1611.09661 [hep-ex].

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

[44] ATLAS Collaboration, The ATLAS simulation infrastructure, Eur. Phys. J. C 70 (2010) 823, arXiv:1005.4568 [hep-ex].

[45] ATLAS Collaboration, The simulation principle and performance of the ATLAS fast calorimeter simulation FastCaloSim, ATL-PHYS-PUB-2010-013, https://cds.cern.ch/record/1300517, 2010.

[46] T. Sjostrand, S. Mrenna, P.Z. Skands, A brief introduction to PYTHIA 8.1, Comput. Phys. Commun. 178 (2008) 852, arXiv:0710.3820 [hep-ph].

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

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

[49] V.D. Barger, W.-Y. Keung, E. Ma, A gauge model with light W and Z bosons, Phys. Rev. D 22 (1980) 727.

[50] R. Contino, D. Marzocca, D. Pappadopulo, R. Rattazzi, On the effect of resonances in composite Higgs phenomenology, J. High Energy Phys. 10 (2011) 081, arXiv:1109.1570 [hep-ph].

[51] 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].

[52] D. Pappadopulo, A. Thamm, R. Torre, A. Wulzer, Heavy vector triplets, http://rtorre.web.cern.ch/rtorre/Riccardotorre/vector_triplet_t.html, 2014.

[53] R.D. Ball, et al., Parton distributions with LHC data, Nucl. Phys. B 867 (2013) 244, arXiv:1207.1303 [hep-ph].

[54] C. Degrande, K. Hartling, H.E. Logan, A.D. Peterson, M. Zaro, Automatic predictions in the Georgi–Machacek model at next-to-leading order accuracy, Phys. Rev. D 93 (2016) 035004, arXiv:1512.01243 [hep-ph].

[55] M. Zaro, H. Logan, Recommendations for the interpretation of LHC searches for H_5^0, $H_5^\pm$, and $H_5^{\pm\pm}$ in vector boson fusion with decays to vector boson pairs, https://cds.cern.ch/record/2002500, 2015.

[56] K. Hartling, K. Kumar, H.E. Logan, GMCALC: a calculator for the Georgi–Machacek model, arXiv:1412.7387 [hep-ph], 2014.

[57] T. Gleisberg, et al., Event generation with SHERPA 1.1, J. High Energy Phys. 02 (2009) 007, arXiv:0811.4622 [hep-ph].

[58] 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].

[59] M. Bahr, et al., Herwig++ physics and manual, Eur. Phys. J. C 58 (2008) 639, arXiv:0803.0883 [hep-ph].

[60] M. Brucherseifer, F. Caola, K. Melnikov, On the NNLO QCD corrections to single-top production at the LHC, Phys. Lett. B 736 (2014) 58, arXiv:1404.7116 [hep-ph].

[61] C. Anastasiou, L.J. Dixon, K. Melnikov, F. Petriello, High precision QCD at hadron colliders: electroweak gauge boson rapidity distributions at NNLO, Phys. Rev. D 69 (2004) 094008, arXiv:hep-ph/0312266 [hep-ph].

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

[63] ATLAS Collaboration, Muon reconstruction performance of the ATLAS detector in proton–proton collision data at $\sqrt{s} = 13$ TeV, Eur. Phys. J. C 76 (2016) 292, arXiv:1603.05598 [hep-ex].

[64] ATLAS Collaboration, Jet energy scale and its systematic uncertainty in proton–proton collisions at $\sqrt{s} = 7$ TeV with ATLAS 2011 data, ATLAS-CONF-2013-004, https://cds.cern.ch/record/1509552, 2013.

[65] 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].

[66] ATLAS Collaboration, Jet energy measurement with the ATLAS detector in proton–proton collisions at $\sqrt{s} = 7$ TeV, Eur. Phys. J. C 73 (2013) 2304, arXiv:1112.6426 [hep-ex].

[67] ATLAS Collaboration, Performance of pile-up mitigation techniques for jets in pp collisions at $\sqrt{s} = 8$ TeV using the ATLAS detector, Eur. Phys. J. C 76 (2016) 581, arXiv:1510.03823 [hep-ex].

[68] ATLAS Collaboration, Jet calibration and systematic uncertainties for jets reconstructed in the ATLAS detector at $\sqrt{s} = 13$ TeV, ATL-PHYS-PUB-2015-015, https://cds.cern.ch/record/2037613, 2015.

[69] ATLAS Collaboration, Performance of b-jet identification in the ATLAS experiment, J. Instrum. 11 (2016) P04008, arXiv:1512.01094 [hep-ex].

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

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

[72] ATLAS Collaboration, Expected performance of missing transverse momentum reconstruction for the ATLAS detector at $\sqrt{s} = 13$ TeV, ATL-PHYS-PUB-2015-023, https://cds.cern.ch/record/2037700, 2015.

[73] ATLAS Collaboration, Measurements of $W^\pm Z$ production cross sections in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector and limits on anomalous gauge boson self-couplings, Phys. Rev. D 93 (2016) 092004, arXiv:1603.02151 [hep-ex].

[74] A. Buckley, et al., LHAPDF6: parton density access in the LHC precision era, Eur. Phys. J. C 75 (2015) 132, arXiv:1412.7420 [hep-ph].

[75] ATLAS Collaboration, Electron efficiency measurements with the ATLAS detector using 2012 LHC proton–proton collision data, Eur. Phys. J. C 77 (2017) 195, arXiv:1612.01456 [hep-ex].

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

[77] ATLAS Collaboration, Luminosity determination in pp collisions at $\sqrt{s} = 8$ TeV using the ATLAS detector at the LHC, Eur. Phys. J. C 76 (2016) 653, arXiv:1608.03953 [hep-ex].

[78] ATLAS Collaboration, Procedure for the LHC Higgs boson search combination in summer 2011, ATL-PHYS-PUB-2011-011, https://cds.cern.ch/record/1375842, 2011.

[79] A.L. Read, Presentation of search results: the CL$_s$ technique, J. Phys. G 28 (2002) 2693.

[80] G. Cowan, K. Cranmer, E. Gross, O. Vitells, Asymptotic formulae for likelihood-based tests of new physics, Eur. Phys. J. C 71 (2011) 1554, arXiv:1007.1727 [physics.data-an];
G. Cowan, K. Cranmer, E. Gross, O. Vitells, Eur. Phys. J. C 73 (2012) 2501, Erratum.

[81] ATLAS Collaboration, ATLAS computing acknowledgements 2016–2017, ATL-GEN-PUB-2016-002, https://cds.cern.ch/record/2202407, 2016.

The ATLAS Collaboration

M. Aaboud[34d], G. Aad[99], B. Abbott[124], O. Abdinov[13,aw], B. Abeloos[128], D.K. Abhayasinghe[91], S.H. Abidi[165], O.S. AbouZeid[143], N.L. Abraham[153], H. Abramowicz[159], H. Abreu[158], Y. Abulaiti[6], B.S. Acharya[64a,64b,o], S. Adachi[161], L. Adamczyk[81a], J. Adelman[119], M. Adersberger[112], A. Adiguzel[12c,ah], T. Adye[141], A.A. Affolder[143], Y. Afik[158], C. Agheorghiesei[27c], J.A. Aguilar-Saavedra[136f,136a], F. Ahmadov[77,af], G. Aielli[71a,71b], S. Akatsuka[83], T.P.A. Åkesson[94], E. Akilli[52], A.V. Akimov[108], G.L. Alberghi[23b,23a], J. Albert[174], P. Albicocco[49], M.J. Alconada Verzini[86], S. Alderweireldt[117], M. Aleksa[35], I.N. Aleksandrov[77], C. Alexa[27b], G. Alexander[159], T. Alexopoulos[10], M. Alhroob[124], B. Ali[138], G. Alimonti[66a], J. Alison[36], S.P. Alkire[145], C. Allaire[128], B.M.M. Allbrooke[153], B.W. Allen[127], P.P. Allport[21], A. Aloisio[67a,67b], A. Alonso[39], F. Alonso[86], C. Alpigiani[145], A.A. Alshehri[55], M.I. Alstaty[99], B. Alvarez Gonzalez[35], D. Álvarez Piqueras[172], M.G. Alviggi[67a,67b], B.T. Amadio[18], Y. Amaral Coutinho[78b], L. Ambroz[131], C. Amelung[26], D. Amidei[103], S.P. Amor Dos Santos[136a,136c], S. Amoroso[35], C.S. Amrouche[52], C. Anastopoulos[146], L.S. Ancu[52], N. Andari[21], T. Andeen[11], C.F. Anders[59b], J.K. Anders[20], K.J. Anderson[36], A. Andreazza[66a,66b], V. Andrei[59a], S. Angelidakis[37], I. Angelozzi[118], A. Angerami[38], A.V. Anisenkov[120b,120a], A. Annovi[69a], C. Antel[59a], M.T. Anthony[146], M. Antonelli[49], D.J.A. Antrim[169], F. Anulli[70a], M. Aoki[79], L. Aperio Bella[35], G. Arabidze[104], Y. Arai[79], J.P. Araque[136a], V. Araujo Ferraz[78b], R. Araujo Pereira[78b], A.T.H. Arce[47], R.E. Ardell[91], F.A. Arduh[86], J-F. Arguin[107], S. Argyropoulos[75], A.J. Armbruster[35], L.J. Armitage[90], A Armstrong[169], O. Arnaez[165], H. Arnold[118], M. Arratia[31], O. Arslan[24], A. Artamonov[109,aw], G. Artoni[131], S. Artz[97], S. Asai[161], N. Asbah[44], A. Ashkenazi[159], E.M. Asimakopoulou[170], L. Asquith[153], K. Assamagan[29], R. Astalos[28a], R.J. Atkin[32a], M. Atkinson[171], N.B. Atlay[148], K. Augsten[138], G. Avolio[35], R. Avramidou[58a], B. Axen[18], M.K. Ayoub[15a], G. Azuelos[107,au], A.E. Baas[59a], M.J. Baca[21], H. Bachacou[142], K. Bachas[65a,65b], M. Backes[131], P. Bagnaia[70a,70b], M. Bahmani[82], H. Bahrasemani[149], A.J. Bailey[172], J.T. Baines[141], M. Bajic[39], O.K. Baker[181], P.J. Bakker[118], D. Bakshi Gupta[93], E.M. Baldin[120b,120a], P. Balek[178], F. Balli[142], W.K. Balunas[133], E. Banas[82], A. Bandyopadhyay[24], S. Banerjee[179,k], A.A.E. Bannoura[180], L. Barak[159], W.M. Barbe[37], E.L. Barberio[102], D. Barberis[53b,53a], M. Barbero[99], T. Barillari[113], M-S. Barisits[35], J. Barkeloo[127], T. Barklow[150], N. Barlow[31], R. Barnea[158], S.L. Barnes[58c], B.M. Barnett[141], R.M. Barnett[18], Z. Barnovska-Blenessy[58a], A. Baroncelli[72a], G. Barone[26], A.J. Barr[131], L. Barranco Navarro[172], F. Barreiro[96], J. Barreiro Guimarães da Costa[15a], R. Bartoldus[150], A.E. Barton[87], P. Bartos[28a], A. Basalaev[134], A. Bassalat[128], R.L. Bates[55], S.J. Batista[165], S. Batlamous[34e], J.R. Batley[31], M. Battaglia[143], M. Bauce[70a,70b], F. Bauer[142], K.T. Bauer[169], H.S. Bawa[150,m], J.B. Beacham[122], M.D. Beattie[87], T. Beau[132], P.H. Beauchemin[168], P. Bechtle[24], H.C. Beck[51], H.P. Beck[20,r], K. Becker[50], M. Becker[97], C. Becot[121], A. Beddall[12d], A.J. Beddall[12a], V.A. Bednyakov[77], M. Bedognetti[118], C.P. Bee[152], T.A. Beermann[35], M. Begalli[78b], M. Begel[29], A. Behera[152], J.K. Behr[44], A.S. Bell[92], G. Bella[159], L. Bellagamba[23b], A. Bellerive[33], M. Bellomo[158], K. Belotskiy[110], N.L. Belyaev[110], O. Benary[159,aw], D. Benchekroun[34a], M. Bender[112], N. Benekos[10], Y. Benhammou[159], E. Benhar Noccioli[181], J. Benitez[75], D.P. Benjamin[47], M. Benoit[52], J.R. Bensinger[26], S. Bentvelsen[118], L. Beresford[131], M. Beretta[49], D. Berge[44], E. Bergeaas Kuutmann[170], N. Berger[5], L.J. Bergsten[26], J. Beringer[18], S. Berlendis[56], N.R. Bernard[100], G. Bernardi[132], C. Bernius[150], F.U. Bernlochner[24], T. Berry[91], P. Berta[97], C. Bertella[15a], G. Bertoli[43a,43b], I.A. Bertram[87], G.J. Besjes[39], O. Bessidskaia Bylund[43a,43b], M. Bessner[44], N. Besson[142], A. Bethani[98], S. Bethke[113], A. Betti[24], A.J. Bevan[90], J. Beyer[113], R.M.B. Bianchi[135], O. Biebel[112], D. Biedermann[19], R. Bielski[98], K. Bierwagen[97], N.V. Biesuz[69a,69b], M. Biglietti[72a], T.R.V. Billoud[107], M. Bindi[51], A. Bingul[12d], C. Bini[70a,70b], S. Biondi[23b,23a], T. Bisanz[51], J.P. Biswal[159], C. Bittrich[46], D.M. Bjergaard[47], J.E. Black[150], K.M. Black[25], R.E. Blair[6], T. Blazek[28a], I. Bloch[44], C. Blocker[26], A. Blue[55], U. Blumenschein[90], Dr. Blunier[144a], G.J. Bobbink[118], V.S. Bobrovnikov[120b,120a], S.S. Bocchetta[94], A. Bocci[47], D. Boerner[180], D. Bogavac[112], A.G. Bogdanchikov[120b,120a], C. Bohm[43a], V. Boisvert[91], P. Bokan[170,y], T. Bold[81a], A.S. Boldyrev[111], A.E. Bolz[59b], M. Bomben[132], M. Bona[90], J.S. Bonilla[127], M. Boonekamp[142], A. Borisov[140], G. Borissov[87], J. Bortfeldt[35], D. Bortoletto[131], V. Bortolotto[71a,61b,61c,71b], D. Boscherini[23b], M. Bosman[14], J.D. Bossio Sola[30], J. Boudreau[135], E.V. Bouhova-Thacker[87], D. Boumediene[37], C. Bourdarios[128], S.K. Boutle[55], A. Boveia[122], J. Boyd[35], I.R. Boyko[77], A.J. Bozson[91], J. Bracinik[21], N. Brahimi[99], A. Brandt[8], G. Brandt[180], O. Brandt[59a], F. Braren[44], U. Bratzler[162], B. Brau[100], J.E. Brau[127], W.D. Breaden Madden[55], K. Brendlinger[44], A.J. Brennan[102], L. Brenner[44], R. Brenner[170], S. Bressler[178], B. Brickwedde[97], D.L. Briglin[21], D. Britton[55], D. Britzger[59b], I. Brock[24], R. Brock[104], G. Brooijmans[38], T. Brooks[91], W.K. Brooks[144b], E. Brost[119], J.H Broughton[21], P.A. Bruckman de Renstrom[82], D. Bruncko[28b], A. Bruni[23b], G. Bruni[23b], L.S. Bruni[118], S. Bruno[71a,71b], B.H. Brunt[31], M. Bruschi[23b], N. Bruscino[135], P. Bryant[36], L. Bryngemark[44], T. Buanes[17], Q. Buat[35], P. Buchholz[148], A.G. Buckley[55], I.A. Budagov[77], F. Buehrer[50], M.K. Bugge[130], O. Bulekov[110], D. Bullock[8], T.J. Burch[119], S. Burdin[88], C.D. Burgard[118], A.M. Burger[5], B. Burghgrave[119], K. Burka[82], S. Burke[141], I. Burmeister[45], J.T.P. Burr[131], D. Büscher[50], V. Büscher[97], E. Buschmann[51], P. Bussey[55], J.M. Butler[25], C.M. Buttar[55], J.M. Butterworth[92], P. Butti[35], W. Buttinger[35], A. Buzatu[155], A.R. Buzykaev[120b,120a], G. Cabras[23b,23a], S. Cabrera Urbán[172], D. Caforio[138], H. Cai[171], V.M.M. Cairo[2], O. Cakir[4a], N. Calace[52], P. Calafiura[18], A. Calandri[99], G. Calderini[132], P. Calfayan[63], G. Callea[40b,40a], L.P. Caloba[78b], S. Calvente Lopez[96], D. Calvet[37], S. Calvet[37], T.P. Calvet[152], M. Calvetti[69a,69b], R. Camacho Toro[132], S. Camarda[35], P. Camarri[71a,71b], D. Cameron[130], R. Caminal Armadans[100], C. Camincher[35], S. Campana[35], M. Campanelli[92], A. Camplani[66a,66b], A. Campoverde[148], V. Canale[67a,67b], M. Cano Bret[58c], J. Cantero[125], T. Cao[159], Y. Cao[171], M.D.M. Capeans Garrido[35], I. Caprini[27b], M. Caprini[27b], M. Capua[40b,40a], R.M. Carbone[38], R. Cardarelli[71a], F.C. Cardillo[50], I. Carli[139], T. Carli[35], G. Carlino[67a], B.T. Carlson[135], L. Carminati[66a,66b], R.M.D. Carney[43a,43b], S. Caron[117], E. Carquin[144b], S. Carrá[66a,66b], G.D. Carrillo-Montoya[35], D. Casadei[32b], M.P. Casado[14,g], A.F. Casha[165], M. Casolino[14], D.W. Casper[169], R. Castelijn[118], F.L. Castillo[172], V. Castillo Gimenez[172], N.F. Castro[136a,136e], A. Catinaccio[35], J.R. Catmore[130], A. Cattai[35], J. Caudron[24], V. Cavaliere[29], E. Cavallaro[14], D. Cavalli[66a], M. Cavalli-Sforza[14], V. Cavasinni[69a,69b], E. Celebi[12b], F. Ceradini[72a,72b], L. Cerda Alberich[172], A.S. Cerqueira[78a], A. Cerri[153], L. Cerrito[71a,71b], F. Cerutti[18], A. Cervelli[23b,23a], S.A. Cetin[12b], A. Chafaq[34a], D Chakraborty[119], S.K. Chan[57], W.S. Chan[118], Y.L. Chan[61a], P. Chang[171], J.D. Chapman[31], D.G. Charlton[21], C.C. Chau[33], C.A. Chavez Barajas[153], S. Che[122], A. Chegwidden[104], S. Chekanov[6], S.V. Chekulaev[166a], G.A. Chelkov[77,at], M.A. Chelstowska[35], C. Chen[58a], C.H. Chen[76], H. Chen[29], J. Chen[58a], J. Chen[38], S. Chen[133], S.J. Chen[15c], X. Chen[15b,as], Y. Chen[80], Y-H. Chen[44], H.C. Cheng[103], H.J. Cheng[15d], A. Cheplakov[77], E. Cheremushkina[140], R. Cherkaoui El Moursli[34e], E. Cheu[7], K. Cheung[62], L. Chevalier[142], V. Chiarella[49], G. Chiarelli[69a], G. Chiodini[65a], A.S. Chisholm[35], A. Chitan[27b], I. Chiu[161], Y.H. Chiu[174], M.V. Chizhov[77], K. Choi[63], A.R. Chomont[128], S. Chouridou[160], Y.S. Chow[118], V. Christodoulou[92], M.C. Chu[61a], J. Chudoba[137], A.J. Chuinard[101], J.J. Chwastowski[82], L. Chytka[126], D. Cinca[45], V. Cindro[89], I.A. Cioară[24], A. Ciocio[18], F. Cirotto[67a,67b], Z.H. Citron[178], M. Citterio[66a], A. Clark[52], M.R. Clark[38], P.J. Clark[48], C. Clement[43a,43b], Y. Coadou[99], M. Cobal[64a,64c], A. Coccaro[53b,53a], J. Cochran[76], A.E.C. Coimbra[178], L. Colasurdo[117], B. Cole[38], A.P. Colijn[118], J. Collot[56], P. Conde Muiño[136a,136b], E. Coniavitis[50], S.H. Connell[32b], I.A. Connelly[98], S. Constantinescu[27b], F. Conventi[67a,av], A.M. Cooper-Sarkar[131], F. Cormier[173], K.J.R. Cormier[165], M. Corradi[70a,70b], E.E. Corrigan[94], F. Corriveau[101,ad], A. Cortes-Gonzalez[35], M.J. Costa[172], D. Costanzo[146], G. Cottin[31], G. Cowan[91], B.E. Cox[98], J. Crane[98], K. Cranmer[121], S.J. Crawley[55], R.A. Creager[133], G. Cree[33], S. Crépé-Renaudin[56], F. Crescioli[132], M. Cristinziani[24], V. Croft[121], G. Crosetti[40b,40a], A. Cueto[96], T. Cuhadar Donszelmann[146], A.R. Cukierman[150], M. Curatolo[49], J. Cúth[97], S. Czekierda[82], P. Czodrowski[35], M.J. Da Cunha Sargedas De Sousa[58b,136b], C. Da Via[98], W. Dabrowski[81a], T. Dado[28a,y], S. Dahbi[34e], T. Dai[103], F. Dallaire[107], C. Dallapiccola[100], M. Dam[39], G. D'amen[23b,23a], J.R. Dandoy[133], M.F. Daneri[30], N.P. Dang[179,k], N.D Dann[98], M. Danninger[173], V. Dao[35], G. Darbo[53b], S. Darmora[8], O. Dartsi[5], A. Dattagupta[127], T. Daubney[44], S. D'Auria[55], W. Davey[24], C. David[44], T. Davidek[139], D.R. Davis[47], E. Dawe[102], I. Dawson[146], K. De[8], R. De Asmundis[67a], A. De Benedetti[124], S. De Castro[23b,23a], S. De Cecco[70a,70b], N. De Groot[117], P. de Jong[118], H. De la Torre[104], F. De Lorenzi[76], A. De Maria[51,t], D. De Pedis[70a], A. De Salvo[70a], U. De Sanctis[71a,71b], A. De Santo[153], K. De Vasconcelos Corga[99], J.B. De Vivie De Regie[128], C. Debenedetti[143], D.V. Dedovich[77], N. Dehghanian[3], M. Del Gaudio[40b,40a], J. Del Peso[96], D. Delgove[128], F. Deliot[142], C.M. Delitzsch[7], M. Della Pietra[67a,67b], D. Della Volpe[52], A. Dell'Acqua[35], L. Dell'Asta[25], M. Delmastro[5], C. Delporte[128], P.A. Delsart[56], D.A. DeMarco[165], S. Demers[181], M. Demichev[77], S.P. Denisov[140], D. Denysiuk[118], L. D'Eramo[132], D. Derendarz[82], J.E. Derkaoui[34d], F. Derue[132], P. Dervan[88], K. Desch[24], C. Deterre[44], K. Dette[165], M.R. Devesa[30], P.O. Deviveiros[35], A. Dewhurst[141], S. Dhaliwal[26], F.A. Di Bello[52], A. Di Ciaccio[71a,71b], L. Di Ciaccio[5], W.K. Di Clemente[133], C. Di Donato[67a,67b], A. Di Girolamo[35],

B. Di Micco[72a,72b], R. Di Nardo[35], K.F. Di Petrillo[57], A. Di Simone[50], R. Di Sipio[165], D. Di Valentino[33],
C. Diaconu[99], M. Diamond[165], F.A. Dias[39], T. Dias Do Vale[136a], M.A. Diaz[144a], J. Dickinson[18],
E.B. Diehl[103], J. Dietrich[19], S. Díez Cornell[44], A. Dimitrievska[18], J. Dingfelder[24], F. Dittus[35], F. Djama[99],
T. Djobava[157b], J.I. Djuvsland[59a], M.A.B. Do Vale[78c], M. Dobre[27b], D. Dodsworth[26], C. Doglioni[94],
J. Dolejsi[139], Z. Dolezal[139], M. Donadelli[78d], J. Donini[37], A. D'onofrio[90], M. D'Onofrio[88], J. Dopke[141],
A. Doria[67a], M.T. Dova[86], A.T. Doyle[55], E. Drechsler[51], E. Dreyer[149], T. Dreyer[51], M. Dris[10], Y. Du[58b],
J. Duarte-Campderros[159], F. Dubinin[108], A. Dubreuil[52], E. Duchovni[178], G. Duckeck[112],
A. Ducourthial[132], O.A. Ducu[107,x], D. Duda[113], A. Dudarev[35], A.C. Dudder[97], E.M. Duffield[18],
L. Duflot[128], M. Dührssen[35], C. Dülsen[180], M. Dumancic[178], A.E. Dumitriu[27b,e], A.K. Duncan[55],
M. Dunford[59a], A. Duperrin[99], H. Duran Yildiz[4a], M. Düren[54], A. Durglishvili[157b], D. Duschinger[46],
B. Dutta[44], D. Duvnjak[1], M. Dyndal[44], B.S. Dziedzic[82], C. Eckardt[44], K.M. Ecker[113], R.C. Edgar[103],
T. Eifert[35], G. Eigen[17], K. Einsweiler[18], T. Ekelof[170], M. El Kacimi[34c], R. El Kosseifi[99], V. Ellajosyula[99],
M. Ellert[170], F. Ellinghaus[180], A.A. Elliot[90], N. Ellis[35], J. Elmsheuser[29], M. Elsing[35], D. Emeliyanov[141],
Y. Enari[161], J.S. Ennis[176], M.B. Epland[47], J. Erdmann[45], A. Ereditato[20], S. Errede[171], M. Escalier[128],
C. Escobar[172], B. Esposito[49], O. Estrada Pastor[172], A.I. Etienvre[142], E. Etzion[159], H. Evans[63],
A. Ezhilov[134], M. Ezzi[34e], F. Fabbri[55], L. Fabbri[23b,23a], V. Fabiani[117], G. Facini[92],
R.M. Faisca Rodrigues Pereira[136a], R.M. Fakhrutdinov[140], S. Falciano[70a], P.J. Falke[5], S. Falke[5],
J. Faltova[139], Y. Fang[15a], M. Fanti[66a,66b], A. Farbin[8], A. Farilla[72a], E.M. Farina[68a,68b], T. Farooque[104],
S. Farrell[18], S.M. Farrington[176], P. Farthouat[35], F. Fassi[34e], P. Fassnacht[35], D. Fassouliotis[9],
M. Faucci Giannelli[48], A. Favareto[53b,53a], W.J. Fawcett[52], L. Fayard[128], O.L. Fedin[134,q], W. Fedorko[173],
M. Feickert[41], S. Feigl[130], L. Feligioni[99], C. Feng[58b], E.J. Feng[35], M. Feng[47], M.J. Fenton[55],
A.B. Fenyuk[140], L. Feremenga[8], J. Ferrando[44], A. Ferrari[170], P. Ferrari[118], R. Ferrari[68a],
D.E. Ferreira de Lima[59b], A. Ferrer[172], D. Ferrere[52], C. Ferretti[103], F. Fiedler[97], A. Filipčič[89],
F. Filthaut[117], M. Fincke-Keeler[174], K.D. Finelli[25], M.C.N. Fiolhais[136a,136c,b], L. Fiorini[172], C. Fischer[14],
W.C. Fisher[104], N. Flaschel[44], I. Fleck[148], P. Fleischmann[103], R.R.M. Fletcher[133], T. Flick[180],
B.M. Flierl[112], L.M. Flores[133], L.R. Flores Castillo[61a], N. Fomin[17], G.T. Forcolin[98], A. Formica[142],
F.A. Förster[14], A.C. Forti[98], A.G. Foster[21], D. Fournier[128], H. Fox[87], S. Fracchia[146], P. Francavilla[69a,69b],
M. Franchini[23b,23a], S. Franchino[59a], D. Francis[35], L. Franconi[130], M. Franklin[57], M. Frate[169],
M. Fraternali[68a,68b], D. Freeborn[92], S.M. Fressard-Batraneanu[35], B. Freund[107], W.S. Freund[78b],
D. Froidevaux[35], J.A. Frost[131], C. Fukunaga[162], T. Fusayasu[114], J. Fuster[172], O. Gabizon[158],
A. Gabrielli[23b,23a], A. Gabrielli[18], G.P. Gach[81a], S. Gadatsch[52], P. Gadow[113], G. Gagliardi[53b,53a],
L.G. Gagnon[107], C. Galea[27b], B. Galhardo[136a,136c], E.J. Gallas[131], B.J. Gallop[141], P. Gallus[138], G. Galster[39],
R. Gamboa Goni[90], K.K. Gan[122], S. Ganguly[178], Y. Gao[88], Y.S. Gao[150,m], C. García[172],
J.E. García Navarro[172], J.A. García Pascual[15a], M. Garcia-Sciveres[18], R.W. Gardner[36], N. Garelli[150],
V. Garonne[130], K. Gasnikova[44], A. Gaudiello[53b,53a], G. Gaudio[68a], I.L. Gavrilenko[108], A. Gavrilyuk[109],
C. Gay[173], G. Gaycken[24], E.N. Gazis[10], C.N.P. Gee[141], J. Geisen[51], M. Geisen[97], M.P. Geisler[59a],
K. Gellerstedt[43a,43b], C. Gemme[53b], M.H. Genest[56], C. Geng[103], S. Gentile[70a,70b], C. Gentsos[160],
S. George[91], D. Gerbaudo[14], G. Gessner[45], S. Ghasemi[148], M. Ghneimat[24], B. Giacobbe[23b],
S. Giagu[70a,70b], N. Giangiacomi[23b,23a], P. Giannetti[69a], S.M. Gibson[91], M. Gignac[143], D. Gillberg[33],
G. Gilles[180], D.M. Gingrich[3,au], M.P. Giordani[64a,64c], F.M. Giorgi[23b], P.F. Giraud[142], P. Giromini[57],
G. Giugliarelli[64a,64c], D. Giugni[66a], F. Giuli[131], M. Giulini[59b], S. Gkaitatzis[160], I. Gkialas[9,j],
E.L. Gkougkousis[14], P. Gkountoumis[10], L.K. Gladilin[111], C. Glasman[96], J. Glatzer[14], P.C.F. Glaysher[44],
A. Glazov[44], M. Goblirsch-Kolb[26], J. Godlewski[82], S. Goldfarb[102], T. Golling[52], D. Golubkov[140],
A. Gomes[136a,136b,136d], R. Goncalves Gama[78a], R. Gonçalo[136a], G. Gonella[50], L. Gonella[21],
A. Gongadze[77], F. Gonnella[21], J.L. Gonski[57], S. González de la Hoz[172], S. Gonzalez-Sevilla[52],
L. Goossens[35], P.A. Gorbounov[109], H.A. Gordon[29], B. Gorini[35], E. Gorini[65a,65b], A. Gorišek[89],
A.T. Goshaw[47], C. Gössling[45], M.I. Gostkin[77], C.A. Gottardo[24], C.R. Goudet[128], D. Goujdami[34c],
A.G. Goussiou[145], N. Govender[32b,c], C. Goy[5], E. Gozani[158], I. Grabowska-Bold[81a], P.O.J. Gradin[170],
E.C. Graham[88], J. Gramling[169], E. Gramstad[130], S. Grancagnolo[19], V. Gratchev[134], P.M. Gravila[27f],
C. Gray[55], H.M. Gray[18], Z.D. Greenwood[93,aj], C. Grefe[24], K. Gregersen[92], I.M. Gregor[44], P. Grenier[150],
K. Grevtsov[44], J. Griffiths[8], A.A. Grillo[143], K. Grimm[150], S. Grinstein[14,z], Ph. Gris[37], J.-F. Grivaz[128],
S. Groh[97], E. Gross[178], J. Grosse-Knetter[51], G.C. Grossi[93], Z.J. Grout[92], C. Grud[103], A. Grummer[116],

L. Guan[103], W. Guan[179], J. Guenther[35], A. Guerguichon[128], F. Guescini[166a], D. Guest[169], R. Gugel[50], B. Gui[122], T. Guillemin[5], S. Guindon[35], U. Gul[55], C. Gumpert[35], J. Guo[58c], W. Guo[103], Y. Guo[58a,s], Z. Guo[99], R. Gupta[41], S. Gurbuz[12c], G. Gustavino[124], B.J. Gutelman[158], P. Gutierrez[124], C. Gutschow[92], C. Guyot[142], M.P. Guzik[81a], C. Gwenlan[131], C.B. Gwilliam[88], A. Haas[121], C. Haber[18], H.K. Hadavand[8], N. Haddad[34e], A. Hadef[58a], S. Hageböck[24], M. Hagihara[167], H. Hakobyan[182,aw], M. Haleem[175], J. Haley[125], G. Halladjian[104], G.D. Hallewell[99], K. Hamacher[180], P. Hamal[126], K. Hamano[174], A. Hamilton[32a], G.N. Hamity[146], K. Han[58a,ai], L. Han[58a], S. Han[15d], K. Hanagaki[79,v], M. Hance[143], D.M. Handl[112], B. Haney[133], R. Hankache[132], P. Hanke[59a], E. Hansen[94], J.B. Hansen[39], J.D. Hansen[39], M.C. Hansen[24], P.H. Hansen[39], K. Hara[167], A.S. Hard[179], T. Harenberg[180], S. Harkusha[105], P.F. Harrison[176], N.M. Hartmann[112], Y. Hasegawa[147], A. Hasib[48], S. Hassani[142], S. Haug[20], R. Hauser[104], L. Hauswald[46], L.B. Havener[38], M. Havranek[138], C.M. Hawkes[21], R.J. Hawkings[35], D. Hayden[104], C. Hayes[152], C.P. Hays[131], J.M. Hays[90], H.S. Hayward[88], S.J. Haywood[141], M.P. Heath[48], V. Hedberg[94], L. Heelan[8], S. Heer[24], K.K. Heidegger[50], J. Heilman[33], S. Heim[44], T. Heim[18], B. Heinemann[44,ap], J.J. Heinrich[112], L. Heinrich[121], C. Heinz[54], J. Hejbal[137], L. Helary[35], A. Held[173], S. Hellesund[130], S. Hellman[43a,43b], C. Helsens[35], R.C.W. Henderson[87], Y. Heng[179], S. Henkelmann[173], A.M. Henriques Correia[35], G.H. Herbert[19], H. Herde[26], V. Herget[175], Y. Hernández Jiménez[32c], H. Herr[97], G. Herten[50], R. Hertenberger[112], L. Hervas[35], T.C. Herwig[133], G.G. Hesketh[92], N.P. Hessey[166a], J.W. Hetherly[41], S. Higashino[79], E. Higón-Rodriguez[172], K. Hildebrand[36], E. Hill[174], J.C. Hill[31], K.K. Hill[29], K.H. Hiller[44], S.J. Hillier[21], M. Hils[46], I. Hinchliffe[18], M. Hirose[129], D. Hirschbuehl[180], B. Hiti[89], O. Hladik[137], D.R. Hlaluku[32c], X. Hoad[48], J. Hobbs[152], N. Hod[166a], M.C. Hodgkinson[146], A. Hoecker[35], M.R. Hoeferkamp[116], F. Hoenig[112], D. Hohn[24], D. Hohov[128], T.R. Holmes[36], M. Holzbock[112], M. Homann[45], S. Honda[167], T. Honda[79], T.M. Hong[135], A. Hönle[113], B.H. Hooberman[171], W.H. Hopkins[127], Y. Horii[115], P. Horn[46], A.J. Horton[149], L.A. Horyn[36], J-Y. Hostachy[56], A. Hostiuc[145], S. Hou[155], A. Hoummada[34a], J. Howarth[98], J. Hoya[86], M. Hrabovsky[126], J. Hrdinka[35], I. Hristova[19], J. Hrivnac[128], A. Hrynevich[106], T. Hryn'ova[5], P.J. Hsu[62], S.-C. Hsu[145], Q. Hu[29], S. Hu[58c], Y. Huang[15a], Z. Hubacek[138], F. Hubaut[99], M. Huebner[24], F. Huegging[24], T.B. Huffman[131], E.W. Hughes[38], M. Huhtinen[35], R.F.H. Hunter[33], P. Huo[152], A.M. Hupe[33], N. Huseynov[77,af], J. Huston[104], J. Huth[57], R. Hyneman[103], G. Iacobucci[52], G. Iakovidis[29], I. Ibragimov[148], L. Iconomidou-Fayard[128], Z. Idrissi[34e], P. Iengo[35], R. Ignazzi[39], O. Igonkina[118,ab], R. Iguchi[161], T. Iizawa[177], Y. Ikegami[79], M. Ikeno[79], D. Iliadis[160], N. Ilic[150], F. Iltzsche[46], G. Introzzi[68a,68b], M. Iodice[72a], K. Iordanidou[38], V. Ippolito[70a,70b], M.F. Isacson[170], N. Ishijima[129], M. Ishino[161], M. Ishitsuka[163], C. Issever[131], S. Istin[12c,an], F. Ito[167], J.M. Iturbe Ponce[61a], R. Iuppa[73a,73b], A. Ivina[178], H. Iwasaki[79], J.M. Izen[42], V. Izzo[67a], S. Jabbar[3], P. Jacka[137], P. Jackson[1], R.M. Jacobs[24], V. Jain[2], G. Jäkel[180], K.B. Jakobi[97], K. Jakobs[50], S. Jakobsen[74], T. Jakoubek[137], D.O. Jamin[125], D.K. Jana[93], R. Jansky[52], J. Janssen[24], M. Janus[51], P.A. Janus[81a], G. Jarlskog[94], N. Javadov[77,af], T. Javůrek[50], M. Javurkova[50], F. Jeanneau[142], L. Jeanty[18], J. Jejelava[157a,ag], A. Jelinskas[176], P. Jenni[50,d], J. Jeong[44], C. Jeske[176], S. Jézéquel[5], H. Ji[179], J. Jia[152], H. Jiang[76], Y. Jiang[58a], Z. Jiang[150], S. Jiggins[50], F.A. Jimenez Morales[37], J. Jimenez Pena[172], S. Jin[15c], A. Jinaru[27b], O. Jinnouchi[163], H. Jivan[32c], P. Johansson[146], K.A. Johns[7], C.A. Johnson[63], W.J. Johnson[145], K. Jon-And[43a,43b], R.W.L. Jones[87], S.D. Jones[153], S. Jones[7], T.J. Jones[88], J. Jongmanns[59a], P.M. Jorge[136a,136b], J. Jovicevic[166a], X. Ju[179], J.J. Junggeburth[113], A. Juste Rozas[14,z], A. Kaczmarska[82], M. Kado[128], H. Kagan[122], M. Kagan[150], T. Kaji[177], E. Kajomovitz[158], C.W. Kalderon[94], A. Kaluza[97], S. Kama[41], A. Kamenshchikov[140], L. Kanjir[89], Y. Kano[161], V.A. Kantserov[110], J. Kanzaki[79], B. Kaplan[121], L.S. Kaplan[179], D. Kar[32c], M.J. Kareem[166b], E. Karentzos[10], S.N. Karpov[77], Z.M. Karpova[77], V. Kartvelishvili[87], A.N. Karyukhin[140], K. Kasahara[167], L. Kashif[179], R.D. Kass[122], A. Kastanas[151], Y. Kataoka[161], C. Kato[161], J. Katzy[44], K. Kawade[80], K. Kawagoe[85], T. Kawamoto[161], G. Kawamura[51], E.F. Kay[88], V.F. Kazanin[120b,120a], R. Keeler[174], R. Kehoe[41], J.S. Keller[33], E. Kellermann[94], J.J. Kempster[21], J. Kendrick[21], O. Kepka[137], S. Kersten[180], B.P. Kerševan[89], R.A. Keyes[101], M. Khader[171], F. Khalil-Zada[13], A. Khanov[125], A.G. Kharlamov[120b,120a], T. Kharlamova[120b,120a], A. Khodinov[164], T.J. Khoo[52], E. Khramov[77], J. Khubua[157b], S. Kido[80], M. Kiehn[52], C.R. Kilby[91], S.H. Kim[167], Y.K. Kim[36], N. Kimura[64a,64c], O.M. Kind[19], B.T. King[88], D. Kirchmeier[46], J. Kirk[141], A.E. Kiryunin[113], T. Kishimoto[161], D. Kisielewska[81a], V. Kitali[44], O. Kivernyk[5], E. Kladiva[28b], T. Klapdor-Kleingrothaus[50], M.H. Klein[103], M. Klein[88], U. Klein[88], K. Kleinknecht[97], P. Klimek[119],

A. Klimentov[29], R. Klingenberg[45,aw], T. Klingl[24], T. Klioutchnikova[35], F.F. Klitzner[112], P. Kluit[118],
S. Kluth[113], E. Kneringer[74], E.B.F.G. Knoops[99], A. Knue[50], A. Kobayashi[161], D. Kobayashi[85],
T. Kobayashi[161], M. Kobel[46], M. Kocian[150], P. Kodys[139], T. Koffas[33], E. Koffeman[118], N.M. Köhler[113],
T. Koi[150], M. Kolb[59b], I. Koletsou[5], T. Kondo[79], N. Kondrashova[58c], K. Köneke[50], A.C. König[117],
T. Kono[79], R. Konoplich[121,ak], N. Konstantinidis[92], B. Konya[94], R. Kopeliansky[63], S. Koperny[81a],
K. Korcyl[82], K. Kordas[160], A. Korn[92], I. Korolkov[14], E.V. Korolkova[146], O. Kortner[113], S. Kortner[113],
T. Kosek[139], V.V. Kostyukhin[24], A. Kotwal[47], A. Koulouris[10], A. Kourkoumeli-Charalampidi[68a,68b],
C. Kourkoumelis[9], E. Kourlitis[146], V. Kouskoura[29], A.B. Kowalewska[82], R. Kowalewski[174],
T.Z. Kowalski[81a], C. Kozakai[161], W. Kozanecki[142], A.S. Kozhin[140], V.A. Kramarenko[111], G. Kramberger[89],
D. Krasnopevtsev[110], M.W. Krasny[132], A. Krasznahorkay[35], D. Krauss[113], J.A. Kremer[81a],
J. Kretzschmar[88], P. Krieger[165], K. Krizka[18], K. Kroeninger[45], H. Kroha[113], J. Kroll[137], J. Kroll[133],
J. Krstic[16], U. Kruchonak[77], H. Krüger[24], N. Krumnack[76], M.C. Kruse[47], T. Kubota[102], S. Kuday[4b],
J.T. Kuechler[180], S. Kuehn[35], A. Kugel[59a], F. Kuger[175], T. Kuhl[44], V. Kukhtin[77], R. Kukla[99],
Y. Kulchitsky[105], S. Kuleshov[144b], Y.P. Kulinich[171], M. Kuna[56], T. Kunigo[83], A. Kupco[137], T. Kupfer[45],
O. Kuprash[159], H. Kurashige[80], L.L. Kurchaninov[166a], Y.A. Kurochkin[105], M.G. Kurth[15d], E.S. Kuwertz[174],
M. Kuze[163], J. Kvita[126], T. Kwan[174], A. La Rosa[113], J.L. La Rosa Navarro[78d], L. La Rotonda[40b,40a],
F. La Ruffa[40b,40a], C. Lacasta[172], F. Lacava[70a,70b], J. Lacey[44], D.P.J. Lack[98], H. Lacker[19], D. Lacour[132],
E. Ladygin[77], R. Lafaye[5], B. Laforge[132], T. Lagouri[32c], S. Lai[51], S. Lammers[63], W. Lampl[7], E. Lançon[29],
U. Landgraf[50], M.P.J. Landon[90], M.C. Lanfermann[52], V.S. Lang[44], J.C. Lange[14], R.J. Langenberg[35],
A.J. Lankford[169], F. Lanni[29], K. Lantzsch[24], A. Lanza[68a], A. Lapertosa[53b,53a], S. Laplace[132], J.F. Laporte[142],
T. Lari[66a], F. Lasagni Manghi[23b,23a], M. Lassnig[35], T.S. Lau[61a], A. Laudrain[128], A.T. Law[143], P. Laycock[88],
M. Lazzaroni[66a,66b], B. Le[102], O. Le Dortz[132], E. Le Guirriec[99], E.P. Le Quilleuc[142], M. LeBlanc[7],
T. LeCompte[6], F. Ledroit-Guillon[56], C.A. Lee[29], G.R. Lee[144a], L. Lee[57], S.C. Lee[155], B. Lefebvre[101],
M. Lefebvre[174], F. Legger[112], C. Leggett[18], G. Lehmann Miotto[35], W.A. Leight[44], A. Leisos[160,w],
M.A.L. Leite[78d], R. Leitner[139], D. Lellouch[178], B. Lemmer[51], K.J.C. Leney[92], T. Lenz[24], B. Lenzi[35],
R. Leone[7], S. Leone[69a], C. Leonidopoulos[48], G. Lerner[153], C. Leroy[107], R. Les[165], A.A.J. Lesage[142],
C.G. Lester[31], M. Levchenko[134], J. Levêque[5], D. Levin[103], L.J. Levinson[178], D. Lewis[90], B. Li[103],
C-Q. Li[58a], H. Li[58b], L. Li[58c], Q. Li[15d], Q.Y. Li[58a], S. Li[58d,58c], X. Li[58c], Y. Li[148], Z. Liang[15a], B. Liberti[71a],
A. Liblong[165], K. Lie[61c], S. Liem[118], A. Limosani[154], C.Y. Lin[31], K. Lin[104], S.C. Lin[156], T.H. Lin[97],
R.A. Linck[63], B.E. Lindquist[152], A.L. Lionti[52], E. Lipeles[133], A. Lipniacka[17], M. Lisovyi[59b], T.M. Liss[171,ar],
A. Lister[173], A.M. Litke[143], J.D. Little[8], B. Liu[76], B.L Liu[6], H.B. Liu[29], H. Liu[103], J.B. Liu[58a], J.K.K. Liu[131],
K. Liu[132], M. Liu[58a], P. Liu[18], Y.L. Liu[58a], Y.W. Liu[58a], M. Livan[68a,68b], A. Lleres[56], J. Llorente Merino[15a],
S.L. Lloyd[90], C.Y. Lo[61b], F. Lo Sterzo[41], E.M. Lobodzinska[44], P. Loch[7], F.K. Loebinger[98], A. Loesle[50],
K.M. Loew[26], T. Lohse[19], K. Lohwasser[146], M. Lokajicek[137], B.A. Long[25], J.D. Long[171], R.E. Long[87],
L. Longo[65a,65b], K.A. Looper[122], J.A. Lopez[144b], I. Lopez Paz[14], A. Lopez Solis[132], J. Lorenz[112],
N. Lorenzo Martinez[5], M. Losada[22], P.J. Lösel[112], X. Lou[44], X. Lou[15a], A. Lounis[128], J. Love[6], P.A. Love[87],
J.J. Lozano Bahilo[172], H. Lu[61a], M. Lu[58a], N. Lu[103], Y.J. Lu[62], H.J. Lubatti[145], C. Luci[70a,70b], A. Lucotte[56],
C. Luedtke[50], F. Luehring[63], I. Luise[132], W. Lukas[74], L. Luminari[70a], B. Lund-Jensen[151], M.S. Lutz[100],
P.M. Luzi[132], D. Lynn[29], R. Lysak[137], E. Lytken[94], F. Lyu[15a], V. Lyubushkin[77], H. Ma[29], L.L. Ma[58b],
Y. Ma[58b], G. Maccarrone[49], A. Macchiolo[113], C.M. Macdonald[146], J. Machado Miguens[133,136b],
D. Madaffari[172], R. Madar[37], W.F. Mader[46], A. Madsen[44], N. Madysa[46], J. Maeda[80], S. Maeland[17],
T. Maeno[29], A.S. Maevskiy[111], V. Magerl[50], C. Maidantchik[78b], T. Maier[112], A. Maio[136a,136b,136d],
O. Majersky[28a], S. Majewski[127], Y. Makida[79], N. Makovec[128], B. Malaescu[132], Pa. Malecki[82],
V.P. Maleev[134], F. Malek[56], U. Mallik[75], D. Malon[6], C. Malone[31], S. Maltezos[10], S. Malyukov[35],
J. Mamuzic[172], G. Mancini[49], I. Mandić[89], J. Maneira[136a], L. Manhaes de Andrade Filho[78a],
J. Manjarres Ramos[46], K.H. Mankinen[94], A. Mann[112], A. Manousos[74], B. Mansoulie[142], J.D. Mansour[15a],
M. Mantoani[51], S. Manzoni[66a,66b], G. Marceca[30], L. March[52], L. Marchese[131], G. Marchiori[132],
M. Marcisovsky[137], C.A. Marin Tobon[35], M. Marjanovic[37], D.E. Marley[103], F. Marroquim[78b],
Z. Marshall[18], M.U.F Martensson[170], S. Marti-Garcia[172], C.B. Martin[122], T.A. Martin[176], V.J. Martin[48],
B. Martin dit Latour[17], M. Martinez[14,z], V.I. Martinez Outschoorn[100], S. Martin-Haugh[141],
V.S. Martoiu[27b], A.C. Martyniuk[92], A. Marzin[35], L. Masetti[97], T. Mashimo[161], R. Mashinistov[108],
J. Masik[98], A.L. Maslennikov[120b,120a], L.H. Mason[102], L. Massa[71a,71b], P. Mastrandrea[5],

A. Mastroberardino [40b,40a], T. Masubuchi [161], P. Mättig [180], J. Maurer [27b], B. Maček [89], S.J. Maxfield [88], D.A. Maximov [120b,120a], R. Mazini [155], I. Maznas [160], S.M. Mazza [143], N.C. Mc Fadden [116], G. Mc Goldrick [165], S.P. Mc Kee [103], A. McCarn [103], T.G. McCarthy [113], L.I. McClymont [92], E.F. McDonald [102], J.A. Mcfayden [35], G. Mchedlidze [51], M.A. McKay [41], K.D. McLean [174], S.J. McMahon [141], P.C. McNamara [102], C.J. McNicol [176], R.A. McPherson [174,ad], J.E. Mdhluli [32c], Z.A. Meadows [100], S. Meehan [145], T. Megy [50], S. Mehlhase [112], A. Mehta [88], T. Meideck [56], B. Meirose [42], D. Melini [172,h], B.R. Mellado Garcia [32c], J.D. Mellenthin [51], M. Melo [28a], F. Meloni [20], A. Melzer [24], S.B. Menary [98], L. Meng [88], X.T. Meng [103], A. Mengarelli [23b,23a], S. Menke [113], E. Meoni [40b,40a], S. Mergelmeyer [19], C. Merlassino [20], P. Mermod [52], L. Merola [67a,67b], C. Meroni [66a], F.S. Merritt [36], A. Messina [70a,70b], J. Metcalfe [6], A.S. Mete [169], C. Meyer [133], J. Meyer [158], J-P. Meyer [142], H. Meyer Zu Theenhausen [59a], F. Miano [153], R.P. Middleton [141], L. Mijović [48], G. Mikenberg [178], M. Mikestikova [137], M. Mikuž [89], M. Milesi [102], A. Milic [165], D.A. Millar [90], D.W. Miller [36], A. Milov [178], D.A. Milstead [43a,43b], A.A. Minaenko [140], I.A. Minashvili [157b], A.I. Mincer [121], B. Mindur [81a], M. Mineev [77], Y. Minegishi [161], Y. Ming [179], L.M. Mir [14], A. Mirto [65a,65b], K.P. Mistry [133], T. Mitani [177], J. Mitrevski [112], V.A. Mitsou [172], A. Miucci [20], P.S. Miyagawa [146], A. Mizukami [79], J.U. Mjörnmark [94], T. Mkrtchyan [182], M. Mlynarikova [139], T. Moa [43a,43b], K. Mochizuki [107], P. Mogg [50], S. Mohapatra [38], S. Molander [43a,43b], R. Moles-Valls [24], M.C. Mondragon [104], K. Mönig [44], J. Monk [39], E. Monnier [99], A. Montalbano [149], J. Montejo Berlingen [35], F. Monticelli [86], S. Monzani [66a], R.W. Moore [3], N. Morange [128], D. Moreno [22], M. Moreno Llácer [35], P. Morettini [53b], M. Morgenstern [118], S. Morgenstern [35], D. Mori [149], T. Mori [161], M. Morii [57], M. Morinaga [177], V. Morisbak [130], A.K. Morley [35], G. Mornacchi [35], J.D. Morris [90], L. Morvaj [152], P. Moschovakos [10], M. Mosidze [157b], H.J. Moss [146], J. Moss [150,n], K. Motohashi [163], R. Mount [150], E. Mountricha [29], E.J.W. Moyse [100], S. Muanza [99], F. Mueller [113], J. Mueller [135], R.S.P. Mueller [112], D. Muenstermann [87], P. Mullen [55], G.A. Mullier [20], F.J. Munoz Sanchez [98], P. Murin [28b], W.J. Murray [176,141], A. Murrone [66a,66b], M. Muškinja [89], C. Mwewa [32a], A.G. Myagkov [140,al], J. Myers [127], M. Myska [138], B.P. Nachman [18], O. Nackenhorst [45], K. Nagai [131], R. Nagai [79,ao], K. Nagano [79], Y. Nagasaka [60], K. Nagata [167], M. Nagel [50], E. Nagy [99], A.M. Nairz [35], Y. Nakahama [115], K. Nakamura [79], T. Nakamura [161], I. Nakano [123], H. Nanjo [129], F. Napolitano [59a], R.F. Naranjo Garcia [44], R. Narayan [11], D.I. Narrias Villar [59a], I. Naryshkin [134], T. Naumann [44], G. Navarro [22], R. Nayyar [7], H.A. Neal [103], P.Y. Nechaeva [108], T.J. Neep [142], A. Negri [68a,68b], M. Negrini [23b], S. Nektarijevic [117], C. Nellist [51], M.E. Nelson [131], S. Nemecek [137], P. Nemethy [121], M. Nessi [35,f], M.S. Neubauer [171], M. Neumann [180], P.R. Newman [21], T.Y. Ng [61c], Y.S. Ng [19], H.D.N. Nguyen [99], T. Nguyen Manh [107], E. Nibigira [37], R.B. Nickerson [131], R. Nicolaidou [142], J. Nielsen [143], N. Nikiforou [11], V. Nikolaenko [140,al], I. Nikolic-Audit [132], K. Nikolopoulos [21], P. Nilsson [29], Y. Ninomiya [79], A. Nisati [70a], N. Nishu [58c], R. Nisius [113], I. Nitsche [45], T. Nitta [177], T. Nobe [161], Y. Noguchi [83], M. Nomachi [129], I. Nomidis [33], M.A. Nomura [29], T. Nooney [90], M. Nordberg [35], N. Norjoharuddeen [131], T. Novak [89], O. Novgorodova [46], R. Novotny [138], M. Nozaki [79], L. Nozka [126], K. Ntekas [169], E. Nurse [92], F. Nuti [102], F.G. Oakham [33,au], H. Oberlack [113], T. Obermann [24], J. Ocariz [132], A. Ochi [80], I. Ochoa [38], J.P. Ochoa-Ricoux [144a], K. O'Connor [26], S. Oda [85], S. Odaka [79], A. Oh [98], S.H. Oh [47], C.C. Ohm [151], H. Oide [53b,53a], H. Okawa [167], Y. Okazaki [83], Y. Okumura [161], T. Okuyama [79], A. Olariu [27b], L.F. Oleiro Seabra [136a], S.A. Olivares Pino [144a], D. Oliveira Damazio [29], J.L. Oliver [1], M.J.R. Olsson [36], A. Olszewski [82], J. Olszowska [82], D.C. O'Neil [149], A. Onofre [136a,136e], K. Onogi [115], P.U.E. Onyisi [11], H. Oppen [130], M.J. Oreglia [36], Y. Oren [159], D. Orestano [72a,72b], E.C. Orgill [98], N. Orlando [61b], A.A. O'Rourke [44], R.S. Orr [165], B. Osculati [53b,53a,aw], V. O'Shea [55], R. Ospanov [58a], G. Otero y Garzon [30], H. Otono [85], M. Ouchrif [34d], F. Ould-Saada [130], A. Ouraou [142], Q. Ouyang [15a], M. Owen [55], R.E. Owen [21], V.E. Ozcan [12c], N. Ozturk [8], J. Pacalt [126], H.A. Pacey [31], K. Pachal [149], A. Pacheco Pages [14], L. Pacheco Rodriguez [142], C. Padilla Aranda [14], S. Pagan Griso [18], M. Paganini [181], G. Palacino [63], S. Palazzo [40b,40a], S. Palestini [35], M. Palka [81b], D. Pallin [37], I. Panagoulias [10], C.E. Pandini [35], J.G. Panduro Vazquez [91], P. Pani [35], G. Panizzo [64a,64c], L. Paolozzi [52], T.D. Papadopoulou [10], K. Papageorgiou [9,j], A. Paramonov [6], D. Paredes Hernandez [61b], B. Parida [58c], A.J. Parker [87], K.A. Parker [44], M.A. Parker [31], F. Parodi [53b,53a], J.A. Parsons [38], U. Parzefall [50], V.R. Pascuzzi [165], J.M.P. Pasner [143], E. Pasqualucci [70a], S. Passaggio [53b], F. Pastore [91], P. Pasuwan [43a,43b], S. Pataraia [97], J.R. Pater [98], A. Pathak [179,k], T. Pauly [35], B. Pearson [113], M. Pedersen [130], L. Pedraza Diaz [117], S. Pedraza Lopez [172], R. Pedro [136a,136b], S.V. Peleganchuk [120b,120a], O. Penc [137], C. Peng [15d], H. Peng [58a], B.S. Peralva [78a], M.M. Perego [142], A.P. Pereira Peixoto [136a], D.V. Perepelitsa [29], F. Peri [19], L. Perini [66a,66b], H. Pernegger [35], S. Perrella [67a,67b], V.D. Peshekhonov [77,aw],

K. Peters[44], R.F.Y. Peters[98], B.A. Petersen[35], T.C. Petersen[39], E. Petit[56], A. Petridis[1], C. Petridou[160], P. Petroff[128], E. Petrolo[70a], M. Petrov[131], F. Petrucci[72a,72b], M. Pettee[181], N.E. Pettersson[100], A. Peyaud[142], R. Pezoa[144b], T. Pham[102], F.H. Phillips[104], P.W. Phillips[141], G. Piacquadio[152], E. Pianori[18], A. Picazio[100], M.A. Pickering[131], R. Piegaia[30], J.E. Pilcher[36], A.D. Pilkington[98], M. Pinamonti[71a,71b], J.L. Pinfold[3], M. Pitt[178], M-A. Pleier[29], V. Pleskot[139], E. Plotnikova[77], D. Pluth[76], P. Podberezko[120b,120a], R. Poettgen[94], R. Poggi[68a,68b], L. Poggioli[128], I. Pogrebnyak[104], D. Pohl[24], I. Pokharel[51], G. Polesello[68a], A. Poley[44], A. Policicchio[40b,40a], R. Polifka[35], A. Polini[23b], C.S. Pollard[44], V. Polychronakos[29], D. Ponomarenko[110], L. Pontecorvo[70a], G.A. Popeneciu[27d], D.M. Portillo Quintero[132], S. Pospisil[138], K. Potamianos[44], I.N. Potrap[77], C.J. Potter[31], H. Potti[11], T. Poulsen[94], J. Poveda[35], T.D. Powell[146], M.E. Pozo Astigarraga[35], P. Pralavorio[99], S. Prell[76], D. Price[98], M. Primavera[65a], S. Prince[101], N. Proklova[110], K. Prokofiev[61c], F. Prokoshin[144b], S. Protopopescu[29], J. Proudfoot[6], M. Przybycien[81a], A. Puri[171], P. Puzo[128], J. Qian[103], Y. Qin[98], A. Quadt[51], M. Queitsch-Maitland[44], A. Qureshi[1], P. Rados[102], F. Ragusa[66a,66b], G. Rahal[95], J.A. Raine[98], S. Rajagopalan[29], A. Ramirez Morales[90], T. Rashid[128], S. Raspopov[5], M.G. Ratti[66a,66b], D.M. Rauch[44], F. Rauscher[112], S. Rave[97], B. Ravina[146], I. Ravinovich[178], J.H. Rawling[98], M. Raymond[35], A.L. Read[130], N.P. Readioff[56], M. Reale[65a,65b], D.M. Rebuzzi[68a,68b], A. Redelbach[175], G. Redlinger[29], R. Reece[143], R.G. Reed[32c], K. Reeves[42], L. Rehnisch[19], J. Reichert[133], A. Reiss[97], C. Rembser[35], H. Ren[15d], M. Rescigno[70a], S. Resconi[66a], E.D. Resseguie[133], S. Rettie[173], E. Reynolds[21], O.L. Rezanova[120b,120a], P. Reznicek[139], R. Richter[113], S. Richter[92], E. Richter-Was[81b], O. Ricken[24], M. Ridel[132], P. Rieck[113], C.J. Riegel[180], O. Rifki[44], M. Rijssenbeek[152], A. Rimoldi[68a,68b], M. Rimoldi[20], L. Rinaldi[23b], G. Ripellino[151], B. Ristić[87], E. Ritsch[35], I. Riu[14], J.C. Rivera Vergara[144a], F. Rizatdinova[125], E. Rizvi[90], C. Rizzi[14], R.T. Roberts[98], S.H. Robertson[101,ad], A. Robichaud-Veronneau[101], D. Robinson[31], J.E.M. Robinson[44], A. Robson[55], E. Rocco[97], C. Roda[69a,69b], Y. Rodina[99], S. Rodriguez Bosca[172], A. Rodriguez Perez[14], D. Rodriguez Rodriguez[172], A.M. Rodríguez Vera[166b], S. Roe[35], C.S. Rogan[57], O. Røhne[130], R. Röhrig[113], C.P.A. Roland[63], J. Roloff[57], A. Romaniouk[110], M. Romano[23b,23a], N. Rompotis[88], M. Ronzani[121], L. Roos[132], S. Rosati[70a], K. Rosbach[50], P. Rose[143], N-A. Rosien[51], E. Rossi[67a,67b], L.P. Rossi[53b], L. Rossini[66a,66b], J.H.N. Rosten[31], R. Rosten[145], M. Rotaru[27b], J. Rothberg[145], D. Rousseau[128], D. Roy[32c], A. Rozanov[99], Y. Rozen[158], X. Ruan[32c], F. Rubbo[150], F. Rühr[50], A. Ruiz-Martinez[33], Z. Rurikova[50], N.A. Rusakovich[77], H.L. Russell[101], J.P. Rutherfoord[7], N. Ruthmann[35], E.M. Rüttinger[44,l], Y.F. Ryabov[134], M. Rybar[171], G. Rybkin[128], S. Ryu[6], A. Ryzhov[140], G.F. Rzehorz[51], P. Sabatini[51], G. Sabato[118], S. Sacerdoti[128], H.F-W. Sadrozinski[143], R. Sadykov[77], F. Safai Tehrani[70a], P. Saha[119], M. Sahinsoy[59a], A. Sahu[180], M. Saimpert[44], M. Saito[161], T. Saito[161], H. Sakamoto[161], A. Sakharov[121,ak], D. Salamani[52], G. Salamanna[72a,72b], J.E. Salazar Loyola[144b], D. Salek[118], P.H. Sales De Bruin[170], D. Salihagic[113], A. Salnikov[150], J. Salt[172], D. Salvatore[40b,40a], F. Salvatore[153], A. Salvucci[61a,61b,61c], A. Salzburger[35], D. Sammel[50], D. Sampsonidis[160], D. Sampsonidou[160], J. Sánchez[172], A. Sanchez Pineda[64a,64c], H. Sandaker[130], C.O. Sander[44], M. Sandhoff[180], C. Sandoval[22], D.P.C. Sankey[141], M. Sannino[53b,53a], Y. Sano[115], A. Sansoni[49], C. Santoni[37], H. Santos[136a], I. Santoyo Castillo[153], A. Sapronov[77], J.G. Saraiva[136a,136d], O. Sasaki[79], K. Sato[167], E. Sauvan[5], P. Savard[165,au], N. Savic[113], R. Sawada[161], C. Sawyer[141], L. Sawyer[93,aj], C. Sbarra[23b], A. Sbrizzi[23b,23a], T. Scanlon[92], D.A. Scannicchio[169], J. Schaarschmidt[145], P. Schacht[113], B.M. Schachtner[112], D. Schaefer[36], L. Schaefer[133], J. Schaeffer[97], S. Schaepe[35], U. Schäfer[97], A.C. Schaffer[128], D. Schaile[112], R.D. Schamberger[152], N. Scharmberg[98], V.A. Schegelsky[134], D. Scheirich[139], F. Schenck[19], M. Schernau[169], C. Schiavi[53b,53a], S. Schier[143], L.K. Schildgen[24], Z.M. Schillaci[26], E.J. Schioppa[35], M. Schioppa[40b,40a], K.E. Schleicher[50], S. Schlenker[35], K.R. Schmidt-Sommerfeld[113], K. Schmieden[35], C. Schmitt[97], S. Schmitt[44], S. Schmitz[97], U. Schnoor[50], L. Schoeffel[142], A. Schoening[59b], E. Schopf[24], M. Schott[97], J.F.P. Schouwenberg[117], J. Schovancova[35], S. Schramm[52], N. Schuh[97], A. Schulte[97], H-C. Schultz-Coulon[59a], M. Schumacher[50], B.A. Schumm[143], Ph. Schune[142], A. Schwartzman[150], T.A. Schwarz[103], H. Schweiger[98], Ph. Schwemling[142], R. Schwienhorst[104], A. Sciandra[24], G. Sciolla[26], M. Scornajenghi[40b,40a], F. Scuri[69a], F. Scutti[102], L.M. Scyboz[113], J. Searcy[103], C.D. Sebastiani[70a,70b], P. Seema[24], S.C. Seidel[116], A. Seiden[143], T. Seiss[36], J.M. Seixas[78b], G. Sekhniaidze[67a], K. Sekhon[103], S.J. Sekula[41], N. Semprini-Cesari[23b,23a], S. Sen[47], S. Senkin[37], C. Serfon[130], L. Serin[128], L. Serkin[64a,64b], M. Sessa[72a,72b], H. Severini[124], F. Sforza[168], A. Sfyrla[52], E. Shabalina[51], J.D. Shahinian[143], N.W. Shaikh[43a,43b], L.Y. Shan[15a], R. Shang[171], J.T. Shank[25],

M. Shapiro[18], A.S. Sharma[1], A. Sharma[131], P.B. Shatalov[109], K. Shaw[64a,64b], S.M. Shaw[98],
A. Shcherbakova[134], C.Y. Shehu[153], Y. Shen[124], N. Sherafati[33], A.D. Sherman[25], P. Sherwood[92],
L. Shi[155,aq], S. Shimizu[80], C.O. Shimmin[181], M. Shimojima[114], I.P.J. Shipsey[131], S. Shirabe[85],
M. Shiyakova[77], J. Shlomi[178], A. Shmeleva[108], D. Shoaleh Saadi[107], M.J. Shochet[36], S. Shojaii[102],
D.R. Shope[124], S. Shrestha[122], E. Shulga[110], P. Sicho[137], A.M. Sickles[171], P.E. Sidebo[151],
E. Sideras Haddad[32c], O. Sidiropoulou[175], A. Sidoti[23b,23a], F. Siegert[46], Dj. Sijacki[16], J. Silva[136a], M. Silva
Jr.[179], S.B. Silverstein[43a], L. Simic[77], S. Simion[128], E. Simioni[97], M. Simon[97], P. Sinervo[165],
N.B. Sinev[127], M. Sioli[23b,23a], G. Siragusa[175], I. Siral[103], S.Yu. Sivoklokov[111], J. Sjölin[43a,43b],
M.B. Skinner[87], P. Skubic[124], M. Slater[21], T. Slavicek[138], M. Slawinska[82], K. Sliwa[168], R. Slovak[139],
V. Smakhtin[178], B.H. Smart[5], J. Smiesko[28a], N. Smirnov[110], S.Yu. Smirnov[110], Y. Smirnov[110],
L.N. Smirnova[111], O. Smirnova[94], J.W. Smith[51], M.N.K. Smith[38], R.W. Smith[38], M. Smizanska[87],
K. Smolek[138], A.A. Snesarev[108], I.M. Snyder[127], S. Snyder[29], R. Sobie[174,ad], A.M. Soffa[169], A. Soffer[159],
A. Søgaard[48], D.A. Soh[155], G. Sokhrannyi[89], C.A. Solans Sanchez[35], M. Solar[138], E.Yu. Soldatov[110],
U. Soldevila[172], A.A. Solodkov[140], A. Soloshenko[77], O.V. Solovyanov[140], V. Solovyev[134], P. Sommer[146],
H. Son[168], W. Song[141], A. Sopczak[138], F. Sopkova[28b], D. Sosa[59b], C.L. Sotiropoulou[69a,69b],
S. Sottocornola[68a,68b], R. Soualah[64a,64c,i], A.M. Soukharev[120b,120a], D. South[44], B.C. Sowden[91],
S. Spagnolo[65a,65b], M. Spalla[113], M. Spangenberg[176], F. Spanò[91], D. Sperlich[19], F. Spettel[113],
T.M. Spieker[59a], R. Spighi[23b], G. Spigo[35], L.A. Spiller[102], M. Spousta[139], A. Stabile[66a,66b], R. Stamen[59a],
S. Stamm[19], E. Stanecka[82], R.W. Stanek[6], C. Stanescu[72a], M.M. Stanitzki[44], B. Stapf[118], S. Stapnes[130],
E.A. Starchenko[140], G.H. Stark[36], J. Stark[56], S.H Stark[39], P. Staroba[137], P. Starovoitov[59a], S. Stärz[35],
R. Staszewski[82], M. Stegler[44], P. Steinberg[29], B. Stelzer[149], H.J. Stelzer[35], O. Stelzer-Chilton[166a],
H. Stenzel[54], T.J. Stevenson[90], G.A. Stewart[55], M.C. Stockton[127], G. Stoicea[27b], P. Stolte[51], S. Stonjek[113],
A. Straessner[46], J. Strandberg[151], S. Strandberg[43a,43b], M. Strauss[124], P. Strizenec[28b], R. Ströhmer[175],
D.M. Strom[127], R. Stroynowski[41], A. Strubig[48], S.A. Stucci[29], B. Stugu[17], J. Stupak[124], N.A. Styles[44],
D. Su[150], J. Su[135], S. Suchek[59a], Y. Sugaya[129], M. Suk[138], V.V. Sulin[108], D.M.S. Sultan[52], S. Sultansoy[4c],
T. Sumida[83], S. Sun[103], X. Sun[3], K. Suruliz[153], C.J.E. Suster[154], M.R. Sutton[153], S. Suzuki[79],
M. Svatos[137], M. Swiatlowski[36], S.P. Swift[2], A. Sydorenko[97], I. Sykora[28a], T. Sykora[139], D. Ta[97],
K. Tackmann[44,aa], J. Taenzer[159], A. Taffard[169], R. Tafirout[166a], E. Tahirovic[90], N. Taiblum[159], H. Takai[29],
R. Takashima[84], E.H. Takasugi[113], K. Takeda[80], T. Takeshita[147], Y. Takubo[79], M. Talby[99],
A.A. Talyshev[120b,120a], J. Tanaka[161], M. Tanaka[163], R. Tanaka[128], R. Tanioka[80], B.B. Tannenwald[122],
S. Tapia Araya[144b], S. Tapprogge[97], A. Tarek Abouelfadl Mohamed[132], S. Tarem[158], G. Tarna[27b,e],
G.F. Tartarelli[66a], P. Tas[139], M. Tasevsky[137], T. Tashiro[83], E. Tassi[40b,40a], A. Tavares Delgado[136a,136b],
Y. Tayalati[34e], A.C. Taylor[116], A.J. Taylor[48], G.N. Taylor[102], P.T.E. Taylor[102], W. Taylor[166b], A.S. Tee[87],
P. Teixeira-Dias[91], D. Temple[149], H. Ten Kate[35], P.K. Teng[155], J.J. Teoh[129], F. Tepel[180], S. Terada[79],
K. Terashi[161], J. Terron[96], S. Terzo[14], M. Testa[49], R.J. Teuscher[165,ad], S.J. Thais[181],
T. Theveneaux-Pelzer[44], F. Thiele[39], J.P. Thomas[21], A.S. Thompson[55], P.D. Thompson[21], L.A. Thomsen[181],
E. Thomson[133], Y. Tian[38], R.E. Ticse Torres[51], V.O. Tikhomirov[108,am], Yu.A. Tikhonov[120b,120a],
S. Timoshenko[110], P. Tipton[181], S. Tisserant[99], K. Todome[163], S. Todorova-Nova[5], S. Todt[46], J. Tojo[85],
S. Tokár[28a], K. Tokushuku[79], E. Tolley[122], M. Tomoto[115], L. Tompkins[150], K. Toms[116], B. Tong[57],
P. Tornambe[50], E. Torrence[127], H. Torres[46], E. Torró Pastor[145], C. Tosciri[131], J. Toth[99,ac], F. Touchard[99],
D.R. Tovey[146], C.J. Treado[121], T. Trefzger[175], F. Tresoldi[153], A. Tricoli[29], I.M. Trigger[166a],
S. Trincaz-Duvoid[132], M.F. Tripiana[14], W. Trischuk[165], B. Trocmé[56], A. Trofymov[128], C. Troncon[66a],
M. Trovatelli[174], F. Trovato[153], L. Truong[32b], M. Trzebinski[82], A. Trzupek[82], F. Tsai[44], J.C-L. Tseng[131],
P.V. Tsiareshka[105], N. Tsirintanis[9], V. Tsiskaridze[152], E.G. Tskhadadze[157a], I.I. Tsukerman[109],
V. Tsulaia[18], S. Tsuno[79], D. Tsybychev[152], Y. Tu[61b], A. Tudorache[27b], V. Tudorache[27b], T.T. Tulbure[27a],
A.N. Tuna[57], S. Turchikhin[77], D. Turgeman[178], I. Turk Cakir[4b,u], R. Turra[66a], P.M. Tuts[38], E. Tzovara[97],
G. Ucchielli[23b,23a], I. Ueda[79], M. Ughetto[43a,43b], F. Ukegawa[167], G. Unal[35], A. Undrus[29], G. Unel[169],
F.C. Ungaro[102], Y. Unno[79], K. Uno[161], J. Urban[28b], P. Urquijo[102], P. Urrejola[97], G. Usai[8], J. Usui[79],
L. Vacavant[99], V. Vacek[138], B. Vachon[101], K.O.H. Vadla[130], A. Vaidya[92], C. Valderanis[112],
E. Valdes Santurio[43a,43b], M. Valente[52], S. Valentinetti[23b,23a], A. Valero[172], L. Valéry[44], R.A. Vallance[21],
A. Vallier[5], J.A. Valls Ferrer[172], T.R. Van Daalen[14], W. Van Den Wollenberg[118], H. Van der Graaf[118],
P. Van Gemmeren[6], J. Van Nieuwkoop[149], I. Van Vulpen[118], M.C. van Woerden[118], M. Vanadia[71a,71b],

W. Vandelli[35], A. Vaniachine[164], P. Vankov[118], R. Vari[70a], E.W. Varnes[7], C. Varni[53b,53a], T. Varol[41], D. Varouchas[128], A. Vartapetian[8], K.E. Varvell[154], G.A. Vasquez[144b], J.G. Vasquez[181], F. Vazeille[37], D. Vazquez Furelos[14], T. Vazquez Schroeder[101], J. Veatch[51], V. Vecchio[72a,72b], L.M. Veloce[165], F. Veloso[136a,136c], S. Veneziano[70a], A. Ventura[65a,65b], M. Venturi[174], N. Venturi[35], V. Vercesi[68a], M. Verducci[72a,72b], C.M. Vergel Infante[76], W. Verkerke[118], A.T. Vermeulen[118], J.C. Vermeulen[118], M.C. Vetterli[149,au], N. Viaux Maira[144b], O. Viazlo[94], I. Vichou[171,aw], T. Vickey[146], O.E. Vickey Boeriu[146], G.H.A. Viehhauser[131], S. Viel[18], L. Vigani[131], M. Villa[23b,23a], M. Villaplana Perez[66a,66b], E. Vilucchi[49], M.G. Vincter[33], V.B. Vinogradov[77], A. Vishwakarma[44], C. Vittori[23b,23a], I. Vivarelli[153], S. Vlachos[10], M. Vogel[180], P. Vokac[138], G. Volpi[14], S.E. von Buddenbrock[32c], E. Von Toerne[24], V. Vorobel[139], K. Vorobev[110], M. Vos[172], J.H. Vossebeld[88], N. Vranjes[16], M. Vranjes Milosavljevic[16], V. Vrba[138], M. Vreeswijk[118], T. Šfiligoj[89], R. Vuillermet[35], I. Vukotic[36], T. Ženiš[28a], L. Živković[16], P. Wagner[24], W. Wagner[180], J. Wagner-Kuhr[112], H. Wahlberg[86], S. Wahrmund[46], K. Wakamiya[80], J. Walder[87], R. Walker[112], W. Walkowiak[148], V. Wallangen[43a,43b], A.M. Wang[57], C. Wang[58b,e], F. Wang[179], H. Wang[18], H. Wang[3], J. Wang[154], J. Wang[59b], P. Wang[41], Q. Wang[124], R.-J. Wang[132], R. Wang[58a], R. Wang[6], S.M. Wang[155], W. Wang[155,p], W.X. Wang[58a,ae], Y. Wang[58a], Z. Wang[58c], C. Wanotayaroj[44], A. Warburton[101], C.P. Ward[31], D.R. Wardrope[92], A. Washbrook[48], P.M. Watkins[21], A.T. Watson[21], M.F. Watson[21], G. Watts[145], S. Watts[98], B.M. Waugh[92], A.F. Webb[11], S. Webb[97], C. Weber[181], M.S. Weber[20], S.A. Weber[33], S.M. Weber[59a], J.S. Webster[6], A.R. Weidberg[131], B. Weinert[63], J. Weingarten[51], M. Weirich[97], C. Weiser[50], P.S. Wells[35], T. Wenaus[29], T. Wengler[35], S. Wenig[35], N. Wermes[24], M.D. Werner[76], P. Werner[35], M. Wessels[59a], T.D. Weston[20], K. Whalen[127], N.L. Whallon[145], A.M. Wharton[87], A.S. White[103], A. White[8], M.J. White[1], R. White[144b], D. Whiteson[169], B.W. Whitmore[87], F.J. Wickens[141], W. Wiedenmann[179], M. Wielers[141], C. Wiglesworth[39], L.A.M. Wiik-Fuchs[50], A. Wildauer[113], F. Wilk[98], H.G. Wilkens[35], H.H. Williams[133], S. Williams[31], C. Willis[104], S. Willocq[100], J.A. Wilson[21], I. Wingerter-Seez[5], E. Winkels[153], F. Winklmeier[127], O.J. Winston[153], B.T. Winter[24], M. Wittgen[150], M. Wobisch[93], A. Wolf[97], T.M.H. Wolf[118], R. Wolff[99], M.W. Wolter[82], H. Wolters[136a,136c], V.W.S. Wong[173], N.L. Woods[143], S.D. Worm[21], B.K. Wosiek[82], K.W. Woźniak[82], K. Wraight[55], M. Wu[36], S.L. Wu[179], X. Wu[52], Y. Wu[58a], T.R. Wyatt[98], B.M. Wynne[48], S. Xella[39], Z. Xi[103], L. Xia[176], D. Xu[15a], H. Xu[58a], L. Xu[29], T. Xu[142], W. Xu[103], B. Yabsley[154], S. Yacoob[32a], K. Yajima[129], D.P. Yallup[92], D. Yamaguchi[163], Y. Yamaguchi[163], A. Yamamoto[79], T. Yamanaka[161], F. Yamane[80], M. Yamatani[161], T. Yamazaki[161], Y. Yamazaki[80], Z. Yan[25], H.J. Yang[58c,58d], H.T. Yang[18], S. Yang[75], Y. Yang[161], Y. Yang[155], Z. Yang[17], W-M. Yao[18], Y.C. Yap[44], Y. Yasu[79], E. Yatsenko[5], J. Ye[41], S. Ye[29], I. Yeletskikh[77], E. Yigitbasi[25], E. Yildirim[97], K. Yorita[177], K. Yoshihara[133], C.J.S. Young[35], C. Young[150], J. Yu[8], J. Yu[76], X. Yue[59a], S.P.Y. Yuen[24], I. Yusuff[31,a], B. Zabinski[82], G. Zacharis[10], E. Zaffaroni[52], R. Zaidan[14], A.M. Zaitsev[140,al], N. Zakharchuk[44], J. Zalieckas[17], S. Zambito[57], D. Zanzi[35], D.R. Zaripovas[55], C. Zeitnitz[180], G. Zemaityte[131], J.C. Zeng[171], Q. Zeng[150], O. Zenin[140], D. Zerwas[128], M. Zgubič[131], D.F. Zhang[58b], D. Zhang[103], F. Zhang[179], G. Zhang[58a,ae], H. Zhang[15c], J. Zhang[6], L. Zhang[50], L. Zhang[58a], M. Zhang[171], P. Zhang[15c], R. Zhang[58a,e], R. Zhang[24], X. Zhang[58b], Y. Zhang[15d], Z. Zhang[128], X. Zhao[41], Y. Zhao[58b,128,ai], Z. Zhao[58a], A. Zhemchugov[77], B. Zhou[103], C. Zhou[179], L. Zhou[41], M.S. Zhou[15d], M. Zhou[152], N. Zhou[58c], Y. Zhou[7], C.G. Zhu[58b], H.L. Zhu[58a], H. Zhu[15a], J. Zhu[103], Y. Zhu[58a], X. Zhuang[15a], K. Zhukov[108], V. Zhulanov[120b,120a], A. Zibell[175], D. Zieminska[63], N.I. Zimine[77], S. Zimmermann[50], Z. Zinonos[113], M. Zinser[97], M. Ziolkowski[148], G. Zobernig[179], A. Zoccoli[23b,23a], K. Zoch[51], T.G. Zorbas[146], R. Zou[36], M. Zur Nedden[19], L. Zwalinski[35]

[1] *Department of Physics, University of Adelaide, Adelaide, Australia*
[2] *Physics Department, SUNY Albany, Albany, NY, United States of America*
[3] *Department of Physics, University of Alberta, Edmonton, AB, Canada*
[4] (a) *Department of Physics, Ankara University, Ankara;* (b) *Istanbul Aydin University, Istanbul;* (c) *Division of Physics, TOBB University of Economics and Technology, Ankara, Turkey*
[5] *LAPP, Université Grenoble Alpes, Université Savoie Mont Blanc, CNRS/IN2P3, Annecy, France*
[6] *High Energy Physics Division, Argonne National Laboratory, Argonne, IL, United States of America*
[7] *Department of Physics, University of Arizona, Tucson, AZ, United States of America*
[8] *Department of Physics, University of Texas at Arlington, Arlington, TX, United States of America*
[9] *Physics Department, National and Kapodistrian University of Athens, Athens, Greece*
[10] *Physics Department, National Technical University of Athens, Zografou, Greece*
[11] *Department of Physics, University of Texas at Austin, Austin, TX, United States of America*
[12] (a) *Bahcesehir University, Faculty of Engineering and Natural Sciences, Istanbul;* (b) *Istanbul Bilgi University, Faculty of Engineering and Natural Sciences, Istanbul;* (c) *Department of Physics, Bogazici University, Istanbul;* (d) *Department of Physics Engineering, Gaziantep University, Gaziantep, Turkey*

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

[81] (a) *AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, Krakow;* (b) *Marian Smoluchowski Institute of Physics, Jagiellonian University, Krakow, Poland*
[82] *Institute of Nuclear Physics Polish Academy of Sciences, Krakow, Poland*
[83] *Faculty of Science, Kyoto University, Kyoto, Japan*
[84] *Kyoto University of Education, Kyoto, Japan*
[85] *Research Center for Advanced Particle Physics and Department of Physics, Kyushu University, Fukuoka, Japan*
[86] *Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina*
[87] *Physics Department, Lancaster University, Lancaster, United Kingdom*
[88] *Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom*
[89] *Department of Experimental Particle Physics, Jožef Stefan Institute and Department of Physics, University of Ljubljana, Ljubljana, Slovenia*
[90] *School of Physics and Astronomy, Queen Mary University of London, London, United Kingdom*
[91] *Department of Physics, Royal Holloway University of London, Egham, United Kingdom*
[92] *Department of Physics and Astronomy, University College London, London, United Kingdom*
[93] *Louisiana Tech University, Ruston, LA, United States of America*
[94] *Fysiska institutionen, Lunds universitet, Lund, Sweden*
[95] *Centre de Calcul de l'Institut National de Physique Nucléaire et de Physique des Particules (IN2P3), Villeurbanne, France*
[96] *Departamento de Física Teorica C-15 and CIAFF, Universidad Autónoma de Madrid, Madrid, Spain*
[97] *Institut für Physik, Universität Mainz, Mainz, Germany*
[98] *School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom*
[99] *CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille, France*
[100] *Department of Physics, University of Massachusetts, Amherst, MA, United States of America*
[101] *Department of Physics, McGill University, Montreal, QC, Canada*
[102] *School of Physics, University of Melbourne, Victoria, Australia*
[103] *Department of Physics, University of Michigan, Ann Arbor, MI, United States of America*
[104] *Department of Physics and Astronomy, Michigan State University, East Lansing, MI, United States of America*
[105] *B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Belarus*
[106] *Research Institute for Nuclear Problems of Byelorussian State University, Minsk, Belarus*
[107] *Group of Particle Physics, University of Montreal, Montreal, QC, Canada*
[108] *P.N. Lebedev Physical Institute of the Russian Academy of Sciences, Moscow, Russia*
[109] *Institute for Theoretical and Experimental Physics (ITEP), Moscow, Russia*
[110] *National Research Nuclear University MEPhI, Moscow, Russia*
[111] *D.V. Skobeltsyn Institute of Nuclear Physics, M.V. Lomonosov Moscow State University, Moscow, Russia*
[112] *Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany*
[113] *Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany*
[114] *Nagasaki Institute of Applied Science, Nagasaki, Japan*
[115] *Graduate School of Science and Kobayashi–Maskawa Institute, Nagoya University, Nagoya, Japan*
[116] *Department of Physics and Astronomy, University of New Mexico, Albuquerque, NM, United States of America*
[117] *Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands*
[118] *Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands*
[119] *Department of Physics, Northern Illinois University, DeKalb, IL, United States of America*
[120] (a) *Budker Institute of Nuclear Physics, SB RAS, Novosibirsk;* (b) *Novosibirsk State University Novosibirsk, Russia*
[121] *Department of Physics, New York University, New York, NY, United States of America*
[122] *Ohio State University, Columbus, OH, United States of America*
[123] *Faculty of Science, Okayama University, Okayama, Japan*
[124] *Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman, OK, United States of America*
[125] *Department of Physics, Oklahoma State University, Stillwater, OK, United States of America*
[126] *Palacký University, RCPTM, Joint Laboratory of Optics, Olomouc, Czech Republic*
[127] *Center for High Energy Physics, University of Oregon, Eugene, OR, United States of America*
[128] *LAL, Université Paris-Sud, CNRS/IN2P3, Université Paris-Saclay, Orsay, France*
[129] *Graduate School of Science, Osaka University, Osaka, Japan*
[130] *Department of Physics, University of Oslo, Oslo, Norway*
[131] *Department of Physics, Oxford University, Oxford, United Kingdom*
[132] *LPNHE, Sorbonne Université, Paris Diderot Sorbonne Paris Cité, CNRS/IN2P3, Paris, France*
[133] *Department of Physics, University of Pennsylvania, Philadelphia, PA, United States of America*
[134] *Konstantinov Nuclear Physics Institute of National Research Centre "Kurchatov Institute", PNPI, St. Petersburg, Russia*
[135] *Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, PA, United States of America*
[136] (a) *Laboratório de Instrumentação e Física Experimental de Partículas – LIP;* (b) *Departamento de Física, Faculdade de Ciências, Universidade de Lisboa, Lisboa;* (c) *Departamento de Física, Universidade de Coimbra, Coimbra;* (d) *Centro de Física Nuclear da Universidade de Lisboa, Lisboa;* (e) *Departamento de Física, Universidade do Minho, Braga;* (f) *Departamento de Física Teorica y del Cosmos, Universidad de Granada, Granada (Spain);* (g) *Dep Física and CEFITEC of Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Caparica, Portugal*
[137] *Institute of Physics, Academy of Sciences of the Czech Republic, Prague, Czech Republic*
[138] *Czech Technical University in Prague, Prague, Czech Republic*
[139] *Charles University, Faculty of Mathematics and Physics, Prague, Czech Republic*
[140] *State Research Center Institute for High Energy Physics, NRC KI, Protvino, Russia*
[141] *Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom*
[142] *IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France*
[143] *Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz, CA, United States of America*
[144] (a) *Departamento de Física, Pontificia Universidad Católica de Chile, Santiago;* (b) *Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile*
[145] *Department of Physics, University of Washington, Seattle, WA, United States of America*
[146] *Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom*
[147] *Department of Physics, Shinshu University, Nagano, Japan*
[148] *Department Physik, Universität Siegen, Siegen, Germany*
[149] *Department of Physics, Simon Fraser University, Burnaby, BC, Canada*
[150] *SLAC National Accelerator Laboratory, Stanford, CA, United States of America*
[151] *Physics Department, Royal Institute of Technology, Stockholm, Sweden*
[152] *Departments of Physics and Astronomy, Stony Brook University, Stony Brook, NY, United States of America*
[153] *Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom*
[154] *School of Physics, University of Sydney, Sydney, Australia*
[155] *Institute of Physics, Academia Sinica, Taipei, Taiwan*
[156] *Academia Sinica Grid Computing, Institute of Physics, Academia Sinica, Taipei, Taiwan*

[157] [(a)] *E. Andronikashvili Institute of Physics, Iv. Javakhishvili Tbilisi State University, Tbilisi;* [(b)] *High Energy Physics Institute, Tbilisi State University, Tbilisi, Georgia*
[158] *Department of Physics, Technion, Israel Institute of Technology, Haifa, Israel*
[159] *Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel*
[160] *Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece*
[161] *International Center for Elementary Particle Physics and Department of Physics, University of Tokyo, Tokyo, Japan*
[162] *Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo, Japan*
[163] *Department of Physics, Tokyo Institute of Technology, Tokyo, Japan*
[164] *Tomsk State University, Tomsk, Russia*
[165] *Department of Physics, University of Toronto, Toronto, ON, Canada*
[166] [(a)] *TRIUMF, Vancouver, BC;* [(b)] *Department of Physics and Astronomy, York University, Toronto, ON, Canada*
[167] *Division of Physics and Tomonaga Center for the History of the Universe, Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba, Japan*
[168] *Department of Physics and Astronomy, Tufts University, Medford, MA, United States of America*
[169] *Department of Physics and Astronomy, University of California Irvine, Irvine, CA, United States of America*
[170] *Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden*
[171] *Department of Physics, University of Illinois, Urbana, IL, United States of America*
[172] *Instituto de Física Corpuscular (IFIC), Centro Mixto Universidad de Valencia – CSIC, Valencia, Spain*
[173] *Department of Physics, University of British Columbia, Vancouver, BC, Canada*
[174] *Department of Physics and Astronomy, University of Victoria, Victoria, BC, Canada*
[175] *Fakultät für Physik und Astronomie, Julius-Maximilians-Universität Würzburg, Würzburg, Germany*
[176] *Department of Physics, University of Warwick, Coventry, United Kingdom*
[177] *Waseda University, Tokyo, Japan*
[178] *Department of Particle Physics, Weizmann Institute of Science, Rehovot, Israel*
[179] *Department of Physics, University of Wisconsin, Madison, WI, United States of America*
[180] *Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal, Germany*
[181] *Department of Physics, Yale University, New Haven, CT, United States of America*
[182] *Yerevan Physics Institute, Yerevan, Armenia*

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