EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

Phys. Lett. B 855 (2024) 138764
DOI: 10.1016/j.physletb.2024.138764

CERN-EP-2023-235
26th August 2024

Measurement of ZZ production cross-sections in the four-lepton final state in pp collisions at $\sqrt{s} = 13.6$ TeV with the ATLAS experiment

The ATLAS Collaboration

This paper reports cross-section measurements of ZZ production in pp collisions at $\sqrt{s}$ = 13.6 TeV at the Large Hadron Collider. The data were collected by the ATLAS detector in 2022, and correspond to an integrated luminosity of 29 fb^{-1}. Events in the $ZZ \to 4\ell$ ($\ell = e$, μ) final states are selected and used to measure the inclusive and differential cross-sections in a fiducial region defined close to the analysis selections. The inclusive cross-section is further extrapolated to the total phase space with a requirement of $66 < m_Z < 116$ GeV for both Z bosons, yielding 16.8 ± 1.1 pb. The results are well described by the Standard Model predictions.

1 Introduction

The study of the production of pairs of massive electroweak gauge bosons ('dibosons') has an important place in the physics programme at the Large Hadron Collider (LHC). Among all the contributing Feynman diagrams, those containing triple-gauge-boson couplings (TGCs) or involving the Higgs boson are particularly interesting, due to their direct connections with two fundamental features of the Standard Model (SM) electroweak (EW) theory, namely the non-Abelian gauge group structure and spontaneous EW symmetry breaking. Moreover, diboson production is a key process used to directly search for new phenomena beyond the SM (BSM). The diboson studies can be traced back to experiments at LEP [1] and Tevatron [2, 3]; the LHC extends the precision measurements to unprecedented energy scales, owing to the high centre-of-mass energy and the large integrated luminosity.

The production of two on-shell Z bosons is the rarest diboson process, but still attractive because of the high signal-to-background ratio for the fully leptonic decay channels. The ZZ process is a key channel to search for anomalous neutral TGCs (aTGCs) [4] and to study off-shell production of the Higgs boson [5]. Various measurements of ZZ production have been performed by the ATLAS and CMS collaborations using data taken at $\sqrt{s}$ = 5.02, 7, 8, and 13 TeV [6–15]. Two complementary final states originating from the decays of the Z boson pair are utilised in those measurements, one with four charged leptons ($ZZ \rightarrow 4\ell$), and the other with two charged leptons and two neutrinos ($ZZ \rightarrow 2\ell 2\nu$), where ℓ refers to e or μ. The smallest relative error in the measured inclusive cross-section was achieved with 13 TeV data, and is 5% [14] and 7% [15] for the $ZZ \rightarrow 4\ell$ and $ZZ \rightarrow 2\ell 2\nu$ channels, respectively. Differential measurements have been performed on kinematic variables sensitive to aTGCs and off-shell Higgs boson production. These measurements also cast light on calculations of higher-order quantum chromodynamics (QCD) and EW corrections. Two key variables commonly considered for the $ZZ \rightarrow 4\ell$ channels are the invariant mass and the transverse momentum of the four-lepton system, $m_{4\ell}$ and $p_{\mathrm{T}}^{4\ell}$, respectively, that are studied here.

This paper reports a first measurement of ZZ production in pp collisions at $\sqrt{s}$ = 13.6 TeV, which extends the test of the SM for this rare process to a new pp centre-of-mass energy. The $ZZ \rightarrow 4\ell$ channel, where ℓ can be an electron or a muon, is utilised in this measurement, and a signal region is defined by selecting four high-p_{T}, isolated leptons, with a fiducial region defined close to the detector-level selections. The cross-section for $ZZ \rightarrow 4\ell$ production is measured in the fiducial region, and extrapolated to the total ZZ production cross-section satisfying $66 < m_Z < 116$ GeV. Finally, the differential measurements are presented.

2 The ATLAS detector

The ATLAS detector [16, 17] at the LHC is a multipurpose particle detector with a forward–backward symmetric cylindrical geometry and a near 4π coverage in solid angle.[1] It consists of an inner tracking detector surrounded by a thin superconducting solenoid providing a 2 T axial magnetic field, electromagnetic and hadron calorimeters, and a muon spectrometer. The inner tracking detector covers the pseudorapidity range of $|\eta| < 2.5$. It consists of silicon pixel, silicon microstrip, and transition radiation tracking detectors. Lead/liquid-argon (LAr) sampling calorimeters provide electromagnetic (EM) energy measurements with

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

high granularity. A steel/scintillator-tile hadron calorimeter covers the central pseudorapidity range of $|\eta| < 1.7$. The endcap and forward regions are instrumented with LAr calorimeters for both the EM and hadronic energy measurements up to $|\eta| = 4.9$. The muon spectrometer surrounds the calorimeters and is based on three large superconducting air-core toroidal magnets with eight coils each. The field integral of the toroids ranges between 2.0 and 6.0 T m across most of the detector. The muon spectrometer includes a system of precision tracking chambers and fast detectors for triggering. A two-level trigger system is used to select events. The first-level trigger is implemented in hardware and uses a subset of the detector information to accept events at a rate below 100 kHz. This is followed by a software-based trigger that reduces the accepted event rate to 3 kHz on average, depending on the data-taking conditions. An extensive software suite [18] is used in data simulation, in the reconstruction and analysis of real and simulated data, in detector operations, and in the trigger and data acquisition systems of the experiment.

3 Data and simulation

This measurement uses the pp collision data recorded by the ATLAS detector in 2022, the first year of the Run 3 data taking period. The data sample corresponds to an integrated luminosity of 29 fb^{-1}, with an uncertainty of 2.2% [19]. The mean number of interactions per bunch crossing, known as pile-up, averaged over all colliding bunch pairs is about 40. Events are required to have fired at least one single-lepton trigger [20, 21]. For the main triggers, the transverse momentum (p_{T}) thresholds are 26 and 24 GeV for electrons and muons, respectively. The combined trigger efficiency is above 99% for events satisfying the signal selections given in Section 4.

Simulated data samples from Monte Carlo (MC) generators are used to estimate detector effects, and to provide theoretical predictions for comparison with the measured results. The MC samples employed are summarised in the following. The next-to-next-to-leading-order (NNLO) parton distribution function (PDF) set of NNPDF3.0 [22] was used in the matrix-element (ME) calculation for all processes.

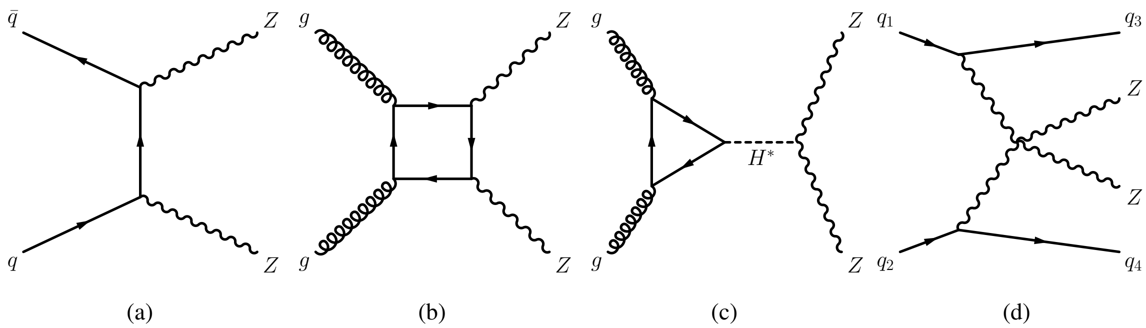


Figure 1: Examples of leading-order SM Feynman diagrams for different classes of ZZ production in proton–proton collisions: (a) $q\bar{q} \to ZZ$, (b) $gg \to ZZ$, (c) $gg \to (H^* \to)ZZ$ and (d) electroweak $qq \to ZZ + 2j$.

The dominant contribution to ZZ production, the $q\bar{q}$-initiated process ($q\bar{q} \to ZZ$), was generated with Sherpa 2.2.12 [23–25], with ME calculation accuracy at next-to-leading order (NLO) in the strong coupling α_s for final states with up to one additional parton, and at leading-order (LO) accuracy for up to three additional partons. The ME calculations utilised OpenLoops [25] for the virtual QCD corrections, and were merged with the Sherpa parton shower (PS) using the ME+PS@NLO prescription [26]. The

$q\bar{q} \to ZZ$ contribution also includes $qg \to ZZq$ production processes. Sherpa 2.2.12 provides higher-order NLO EW corrections as alternative internal weights [27]. The predicted cross-section in the fiducial region for this measurement, defined in Section 4, is reduced by 12% when adopting the alternative weights, which then lies below other theoretical predictions [28, 29] by approximately 10%. Therefore the NLO EW weights are not used to estimate detector effects, and are only shown when comparing the measured data with predictions.

The loop-induced gluon-initiated signal ($gg \to ZZ$) was simulated with Sherpa 2.2.12 at LO precision with up to one extra parton, with the same PS modelling as described above. The $gg \to ZZ$ sample includes the box-diagram $gg \to ZZ$ process and the off-shell Higgs production with $H^* \to ZZ$ decays. The predicted cross-section of $gg \to ZZ$ is scaled by a K-factor of 1.7 to account approximately for the higher-order QCD corrections. The K-factor was calculated for massless quark loops [30, 31] in the heavy top-quark approximation [32]. A relative uncertainty of 60% was assessed from QCD scale variations [33].

EW production of ZZ in association with two jets (EW $qq \to ZZ + 2j$) was modelled with Powheg Box v2 [34–39] at LO in the EW coupling, corresponding to α^4, and at NLO in α_s. The generator was interfaced to Pythia 8.3 [40] for PS and hadronisation.

These three sets of processes with the subsequent $ZZ \to 4\ell$ decays provide the signal in this measurement. Figure 1 shows representative Feynman diagrams for the respective contributions to ZZ production.

Additional samples were generated to estimate the background contribution in the selected phase space. Irreducible backgrounds arise from $t\bar{t}Z$ and tri-boson (VVV) production, where $V = W, Z$, both modelled with Sherpa 2.2.12, requiring at least four charged leptons in the final state. Backgrounds with non-prompt leptons (Section 5) arise primarily from Z boson production with associated jets (Z+jets), production of WZ and $t\bar{t}$. Production of Z+jets was simulated using Sherpa 2.2.12 with up to two partons at NLO and four partons at LO in α_s. The WZ process was simulated using Sherpa 2.2.12, with a similar configuration as for the $q\bar{q} \to ZZ$ signal. Events from $t\bar{t}$ production were generated with Powheg Box v2 +Pythia 8.3 at NLO in α_s.

A full simulation of detector effects using Geant4 [41, 42] was applied to all these samples, along with dedicated calibrations and corrections to physics objects to match the performance of real data.

4 Object and phase space definitions

To account for the performance of the ATLAS detector and the $ZZ \to 4\ell$ final-state signature, the candidate events must satisfy requirements on data-taking quality, triggers (Section 3), physics objects and reconstructed boson candidates, to improve the signal purity by suppressing the backgrounds. The data quality requirements are imposed to reject running periods in which detector subsystems were not operating robustly. All candidate events have at least one primary vertex [43] with at least two associated inner tracking detector tracks. The object and event selections, which are described below, are similar to those defined for previous ATLAS measurements [14, 44].

Electrons are reconstructed from energy deposited in the electromagnetic calorimeter matched to tracks in the inner tracking detector. Electrons are required to have $p_{\mathrm{T}} > 7$ GeV and $|\eta| < 2.47$. Candidates within the transition region between barrel and endcap calorimeters ($1.37 < |\eta| < 1.52$) are excluded. In addition, to distinguish real, isolated electrons from other objects, 'LooseAndBLayer' likelihood identification and 'Loose' isolation selections [45, 46], both optimised for Run 3 analysis conditions, must be satisfied.

Muons are reconstructed [47] primarily by matching the tracks in the muon spectrometer and inner tracker. Because of the limited geometrical coverage of the muon spectrometer at the centre of the detector ($|\eta| < 0.1$), a fully reconstructed inner detector track is also matched to a muon spectrometer track segment or a calorimeter energy deposition (calorimeter-tagged muons) for muon identification. Muon candidates are required to have $p_{\mathrm{T}} > 5$ GeV and $|\eta| < 2.5$. The p_{T} threshold is increased to 15 GeV for calorimeter-tagged muons. Candidates are required to further satisfy the 'Loose' identification and 'PflowLoose' isolation [47, 48] quality requirements.

To select lepton candidates originating from the primary vertex, a requirement is placed on the longitudinal impact parameter, z_0, multiplied by the sine of the track polar angle θ with $|z_0 \times \sin\theta| < 0.5$ mm. A requirement is also placed on the significance of the transverse impact parameter d_0 with $|d_0|/\sigma_{d_0} < 5(3)$ for electrons (muons).

Events with at least two individual pairs of same-flavour-opposite-charge (SFOC) leptons are selected. The two highest-p_{T} leptons are required to have $p_{\mathrm{T}} > 27$ GeV and 10 GeV, respectively. Any SFOC pair must have an invariant mass greater than 5 GeV, removing low-mass resonance contributions. Any lepton in the final state must be separated from other leptons with the requirement of $\Delta R(\ell_i, \ell_j) > 0.05$. In each event with at least four leptons, the quadruplet of leptons is formed from two separate SFOC pairs. The SFOC pair with mass closest to the Z mass [49] is called the leading pair $(\ell\ell, 1)$. Then the subleading pair $(\ell\ell, 2)$ is formed from the remaining leptons, with mass next closest to the Z mass. In addition, the two SFOC lepton pairs are required to satisfy $66 < m_{\ell\ell,1}, m_{\ell\ell,2} < 116$ GeV. The invariant mass of the four leptons in the two pairs is required to be $m_{4\ell} > 180$ GeV, motivated to select only on-shell ZZ events. Candidate events selected with these criteria enter into the signal region (SR) for this measurement.

The fiducial phase space is defined with a set of criteria very close to that of the detector-level SR criteria. This strategy helps to reduce the amount of phase-space extrapolation in the fiducial measurements and therefore reduces the theoretical uncertainties of the results. The criteria are applied to 'particle-level' physics objects, which are reconstructed from stable final-state particles, before their interactions with the detector. For electrons, QED final-state radiation is partly recovered by adding to the lepton four-momentum the four-momenta of surrounding photons not originating from hadrons within an angular distance $\Delta R < 0.1$ (dressed leptons), while the bare leptons defined after QED radiation are considered for muons. The different choices are to best mimic the corresponding object reconstruction at the detector level.

The total lepton phase space is defined for both individual SFOC pairs having $66 < m_{\ell\ell} < 116$ GeV, and any SFOC lepton pair in the decay final state must satisfy the requirement of $m_{ij} > 5$ GeV, where m_Z and m_{ij} are calculated with the leptons defined at Born level, i.e. before any QED final-state radiation. Table 1 summarises the total and fiducial phase-space definitions. The cross-section in the total phase space is calculated by correcting for the branching fraction for $ZZ \to 4\ell$ decays, thus maintaining the invariant mass selections on Z and ZZ systems.

5 Background estimation

The background contamination in the SR is expected to be less than 5% of the total yield with the majority being from reducible backgrounds. The irreducible backgrounds consist almost entirely of $t\bar{t}Z$ and triboson production. They are evaluated using MC simulation, as discussed in Section 3. The uncertainties in these backgrounds, experimental and theoretical, are discussed in Section 6. The final states with τ-leptons from Z decays contribute at the per-mille level and are neglected.

Table 1: Definition of the fiducial and total lepton phase-space regions.

	Fiducial phase space	**Total lepton phase space**
Muon selection	Bare, $p_{\mathrm{T}} > 5$ GeV , $\|\eta\| < 2.5$	Born
Electron selection	Dressed, $p_{\mathrm{T}} > 7$ GeV , $\|\eta\| < 2.47$	Born
Four-lepton signature	≥ 2 SFOC pairs	≥ 2 SFOC pairs
Lepton kinematics	$p_{\mathrm{T}} > 27/10$ GeV	
Lepton separation	$\Delta R(\ell_i, \ell_j) > 0.05$	
Low-mass $\ell^+\ell^-$ veto	$m_{ij} > 5$ GeV	$m_{ij} > 5$ GeV
Z mass window	$66 < m_{\ell\ell,1}, m_{\ell\ell,2} < 116$ GeV	$66 < m_{\ell\ell,1}, m_{\ell\ell,2} < 116$ GeV
ZZ on-shell	$m_{4l} > 180$ GeV	

A prompt lepton refers to a final-state lepton that does not originate from the decay of a hadron or τ-lepton. Events with two or three prompt leptons can satisfy the SR criteria, if associated non-prompt leptons, jets or photons are mis-identified as signal leptons (fake leptons), leading to a reducible fake background. Most reducible background arises from fake leptons in Z+jets and $t\bar{t}$ events. Fake contributions from events with fewer than two prompt leptons are negligible and neglected.

Modelling of such background using purely MC predictions is unreliable and therefore a fake-factor (FF) technique that estimates the background with real data is used. The FF is calculated in a region dominated by single Z production, with events that always have a selected SFOC lepton pair, with an invariant mass satisfying $66 < m_{\ell\ell} < 116$ GeV. The signal trigger and data-quality selections are applied. Any extra lepton in this region is considered to be fake after subtracting other prompt contributions from WZ and ZZ production estimated from simulation. The FF is then calculated as the ratio of the number of leptons satisfying the standard lepton selection to the number satisfying the same selection except failing to meet the isolation or transverse impact parameter requirements (fake-enriched selection). A 'Loose' likelihood identification [46] is additionally required in the fake-enriched selection for electrons, to suppress the overwhelming photon contributions. The fake factors are obtained in bins of p_{T} and η, separately for electrons and muons.

An application region is defined using all the SR criteria, except that one or two leptons are required to satisfy the fake-enriched selection instead of the standard lepton selection. The number of reducible background events in the SR is calculated by applying the FFs to fake-enriched events in the application region, after subtracting the contribution from ZZ production, following the methodology described in Ref. [14]. The inclusive yield is reported in Table 2 and the relative uncertainty is assessed to be 30%, as discussed in Section 6.

The shape of the reducible background is obtained by applying the FF method in each kinematic bin and it is subject to large statistical uncertainties due to the limited sample size in data in the application region. To reduce these statistical fluctuations, a smoothing procedure based on a variable-span smoothing technique [50] is utilised. The smoothed fake distribution and uncertainty are estimated with 50 000 MC sets generated using random values taken from a Gaussian distribution for each bin before smoothing. Then the smoothing is performed on all the sets. The mean value and standard deviation of the sets in each bin are taken as the nominal value and uncertainty of the smoothed fake background. In addition, to evaluate the uncertainty from the choice of smoothing technique, Lowess smoothing [51] is used as an alternative. The smoothing procedure significantly reduces the bin-by-bin fluctuations and improves the background predictions for the differential cross-section measurements.

6 Systematic uncertainties

The systematic uncertainties can be categorised into experimental and theoretical uncertainties. The uncertainties in the overall cross-section measurements from the sources listed in Table 3 are given there.

Experimental uncertainties address the imprecision in luminosity determination and modelling of detector effects. In addition, a MC statistical uncertainty arises from the limited size of the simulated samples. The integrated luminosity impacts both the signal and background expected yields. The uncertainty is 2.2% [19]. The pile-up modelling uncertainty is assessed by varying by ±4% the value of the visible inelastic cross-section that reweights the pile-up distribution in the simulation to that observed in the data [52].

Uncertainties in the lepton-energy calibration, and in the efficiency of lepton reconstruction, identification, isolation and trigger, influence the expected yields and distributions, and also the migration matrices and acceptance and correction factors in the cross-section measurements, defined below. The estimates are based on studies of the detector performance using Run 2 and Run 3 data [45, 47, 53].

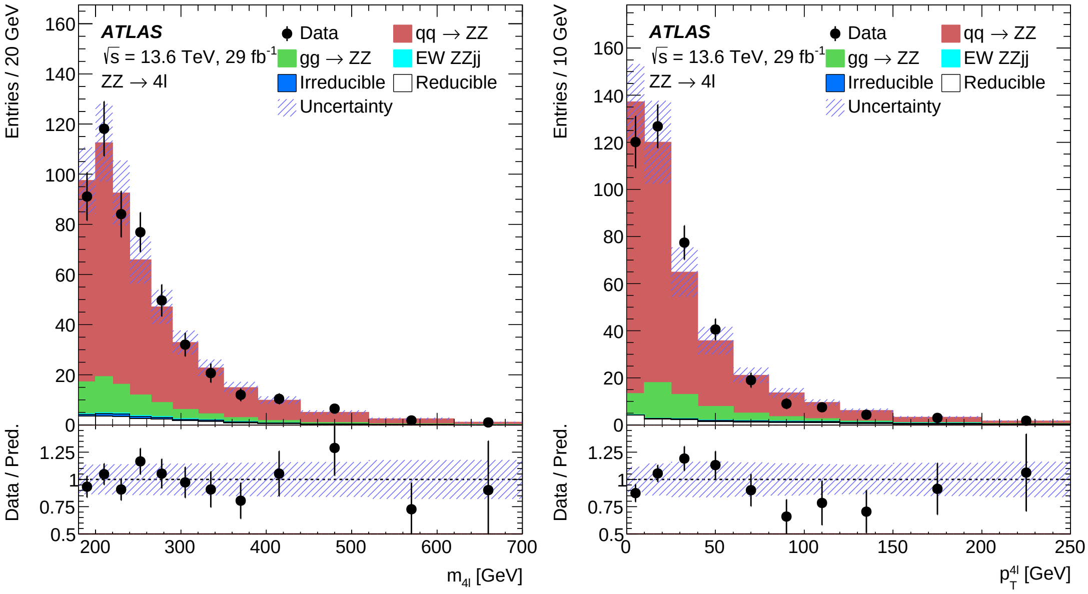
Several sources of uncertainty affect the estimate of the reducible backgrounds, coming from the limited number of data events in the application region, the uncertainty in the subtracted prompt-lepton contributions in that region, and additional uncertainties in the FF estimates [14]. The contribution from the production of VVV and $t\bar{t}Z$ processes to the SR is relatively small, and constant relative uncertainties of 10% and 15% are assigned to them, respectively, to account for the total systematic uncertainty covering experimental and theoretical sources.

The theoretical uncertainties in modelling the $q\bar{q} \to ZZ$ process are considered for sources including PDF sets, higher-order QCD corrections and parton shower models. The PDF uncertainty is estimated by using 100 eigenvector variations of the NNPDF3.0 set, as suggested in Ref. [22]. In addition, the nominal prediction is compared with another prediction employing an alternative PDF set, the NLO CT18 [54], to evaluate the uncertainty due to the choice of PDF set. The higher-order QCD uncertainties are evaluated by varying the default choice of renormalisation and factorisation scales independently by factors of two, removing combinations where the variations differ by a factor of four. The largest deviations are taken as the uncertainty. The impact of parton shower uncertainties are calculated following the recommendation of the Sherpa [26] authors.

For the $gg \to ZZ$ process, a conservative QCD correction uncertainty of 60% is assigned [30, 33], thus the other sources of theoretical uncertainties are not added, as they are assumed to be small compared to the QCD uncertainty. For the EW $qq \to ZZ + 2j$ process, a constant theoretical uncertainty of 20% is assigned [55].

7 Results

The observed data yield and the estimated signal and background contributions in the SR are listed in Table 2, while Figure 2 gives the detector-level distributions for $m_{4\ell}$ and $p_{\mathrm{T}}^{4\ell}$. Good agreement is found between the observations and predictions. Using these samples, the measurements of the inclusive and differential cross-sections are presented in this section.



(a) (b)

Figure 2: Kinematic distributions for (a) $m_{4\ell}$ and (b) $p_{\mathrm{T}}^{4\ell}$ in the signal region. Data are compared with the predictions with all uncertainties included. The lower panels show the ratios of the data to the predictions.

Table 2: Observed and predicted detector level yields in the signal region, corresponding to the integrated luminosity of 29 fb^{-1}. All systematic uncertainties described in Section 6 are included.

Process	$q\bar{q} \to ZZ$	$gg \to ZZ$	EW $qq \to ZZ + 2j$	$t\bar{t}Z$	VVV	Reducible	Total	Data
Yield	515 ± 50	74 ± 44	4.7 ± 1.0	5.5 ± 0.8	2.1 ± 0.2	25.4 ± 8.1	626 ± 88	625

7.1 Measurement of inclusive cross-sections

The inclusive cross-section in the fiducial region is calculated as:

$$\sigma_{\mathrm{fid}} = \frac{N_{\mathrm{obs}} - N_{\mathrm{bkg}}}{L \times C_{ZZ}},$$

where N_{obs} and N_{bkg} denote the data yield and the expected background contribution in the SR, respectively. The integrated luminosity of 29 fb^{-1} is denoted by L, while C_{ZZ} is the correction factor to account for reconstruction inefficiencies and resolution effects.

The C_{ZZ} factor is computed as the ratio of the number of simulated detector-level signal events passing the SR criteria to the number of particle-level events satisfying the fiducial selection. The value of C_{ZZ} is determined to be 0.555 ± 0.022, where the uncertainty includes all sources discussed, and is dominated by the uncertainties from electron identification and muon isolation. The theoretical uncertainties have little impact on C_{ZZ} compared to that on the overall normalisation, as they cancel out in the ratio. The fiducial cross-section is measured to be:

$$\sigma_{\mathrm{fid}} = 36.7 \pm 1.6(\mathrm{stat}) \pm 1.5(\mathrm{syst}) \pm 0.8(\mathrm{lumi})\ \mathrm{fb}.$$

The measurement precision is 6.3%, with a breakdown into categories shown in Table 3. The statistical uncertainty of the data is at the same level as the total systematic uncertainty. As described in Section 6, the theoretical uncertainty consists of uncertainties from the PDF sets, QCD corrections and parton showering of the signal processes. The uncertainty due to the background estimate contains all sources of uncertainties in the evaluation of reducible and irreducible backgrounds.

Table 3: Breakdown of relative uncertainty in the measured fiducial cross-section σ_{fid}.

Source	Relative uncertainty(%)
Data statistical uncertainty	4.2
MC statistical uncertainty	0.3
Luminosity	2.2
Pile-up	0.3
Lepton momentum	0.2
Lepton efficiency	3.7
Background	1.6
Theoretical uncertainty	1.0
Total	6.3

The fiducial cross-section is extrapolated to the total phase space, by dividing it by the acceptance factor (A_{ZZ}) and the branching fraction for $ZZ \rightarrow 4\ell$ decays with $\ell = e, \mu$. The A_{ZZ} factor is the ratio of the cross-section in the fiducial region to that in the total lepton phase space, calculated from theoretical predictions at particle level. In this measurement, the A_{ZZ} factor is determined by the MATRIX programme [29]. MATRIX predicts the cross-section for $ZZ \rightarrow 4\ell$ processes at fixed order, with next-to-next-to-leading-order QCD and NLO EW accuracy for the $q\bar{q} \rightarrow ZZ$ process, and with NLO QCD accuracy for the $gg \rightarrow ZZ$ process. The NNPDF3.0 PDF set is utilised in the MATRIX calculation. The relative PDF uncertainty from Sherpa is applied to the MATRIX prediction because MATRIX does not support the calculation of PDF variations. The value of A_{ZZ} is 0.482 ± 0.003, with the uncertainty coming from the PDF set and the QCD scale. The value of A_{ZZ} is alternatively derived from the signal samples; a good agreement is found with that from MATRIX. The total cross-section is:

$$\sigma_{\text{total}} = 16.8 \pm 0.7(\text{stat}) \pm 0.7(\text{syst}) \pm 0.4(\text{lumi}) \text{ pb}.$$

The relative uncertainty is 6.5%.

The measured inclusive cross-sections in the fiducial and total phase spaces are presented in Table 4, and compared with predictions. The prediction from MC simulation includes $q\bar{q} \rightarrow ZZ$, $gg \rightarrow ZZ$, and EW $qq \rightarrow ZZ + 2j$ processes, with the accuracy described in Section 3. The uncertainty in the predicted cross-section from MC simulation includes the theoretical uncertainty sources described in Section 6, and is dominated by the QCD-correction error from the K-factor for $gg \rightarrow ZZ$. The MATRIX prediction includes the QCD scale variation, and the PDF uncertainty from Sherpa. The measured cross-sections are well described by the predictions.

Table 4: The measured inclusive cross-sections compared with the predictions from MC simulation and from the MATRIX calculation at fixed order. Both the fiducial and total phase space results are included. In all predictions, EW $qq \to ZZ + 2j$ is modelled by POWHEG Box v2.

	Measurement	MC prediction	MATRIX + EW $ZZjj$
Fiducial	$36.7 \pm 1.6(\text{stat}) \pm 1.5(\text{syst}) \pm 0.8(\text{lumi})$ fb	$36.8\ ^{+4.3}_{-3.5}$ fb	36.5 ± 0.7 fb
Total	$16.8 \pm 0.7(\text{stat}) \pm 0.7(\text{syst}) \pm 0.4(\text{lumi})$ pb	$17.0\ ^{+1.9}_{-1.4}$ pb	16.7 ± 0.5 pb

7.2 Measurement of differential cross-sections

The differential cross-section is measured by subtracting the expected background from observed data events in each bin of the studied observable in the fiducial phase space, and unfolding to correct for the detector effects, including efficiency, resolution and acceptance. Moreover, events falling outside the fiducial region might still satisfy the detector-level selection criteria because of resolution effects; the corresponding fraction are subtracted in this measurement. All these effects can be accounted for with a response matrix, the element M_{dp} of which is defined as the probability that an event in particle-level bin p is reconstructed at detector-level in bin d. The diagonal elements denote the fraction of events in a detector-level bin that originate from the same bin at particle-level, which defines the unfolding purity.

The unfolding is performed by calculating the response matrix using the signal samples, and applying it to the distribution of the measured observable at detector-level. To reduce the statistical uncertainty while constraining the regularisation bias, an iterative unfolding method based on Bayes' theorem [56], with the particle-level distribution from MC as a prior, is used. The number of iterations for the Bayesian unfolding is chosen to be two for both $m_{4\ell}$ and $p_{\text{T}}^{4\ell}$. The nominal response matrix, corrections and priors are all derived from simulation. The unfolding purity is globally greater than 80%.

The statistical uncertainty in the unfolded distributions is estimated with 1000 MC sets generated from the observed distributions (pseudodata), using Poisson random values for each bin. The root mean square of the deviation of the resulting unfolded spectrum of the pseudodata sets, from the actual unfolded data, is considered as the statistical uncertainty in each bin. The uncertainty due to any inherent bias in the unfolding method and the residual mis-modelling in simulation is evaluated with a procedure described in Ref. [57]. The simulations are reweighted by a polynomial function to match the observed data when unfolded with the nominal response matrix. After unfolding, the differences between the reweighted MC distribution and the measured data distribution define the unfolding bias uncertainty in each bin, which remains globally below 1%, owing to the high resolution of the measured observable. The experimental and theoretical uncertainties discussed in Section 6 are estimated separately for signal and background. For the signal process, each uncertainty variation leads to a modification of the response matrix and therefore results in a difference in the unfolded distribution. The background uncertainties impact the data subtraction before unfolding.

Figure 3 presents the measured differential cross-sections for $m_{4\ell}$ and $p_{\text{T}}^{4\ell}$. The unfolded distributions are compared with the SM predictions, accounting for production of $q\bar{q} \to ZZ$, $gg \to ZZ$, and EW $qq \to ZZ + 2j$. The EW $qq \to ZZ + 2j$ contribution is included in the $q\bar{q} \to ZZ$ category in the figure. The results agree well within the total statistical and systematic uncertainty in most of the bins. For the $m_{4\ell}$ distribution, the two predictions, both with and without EW corrections, describe the data adequately, while for the $p_{\text{T}}^{4\ell}$ distribution, SHERPA gives a better description of the low-$p_{\text{T}}^{4\ell}$ region, due to its merging and matching of multiple partons in the predictions. The impact of the NLO EW correction is generally not large compared to the precision of the measurements, but for MATRIX the description with the correction included is slightly better than without. In the case of SHERPA, the predictions without NLO EW corrections are slightly better than those including them, correlated with the reduced cross-section estimate discussed in Section 3.

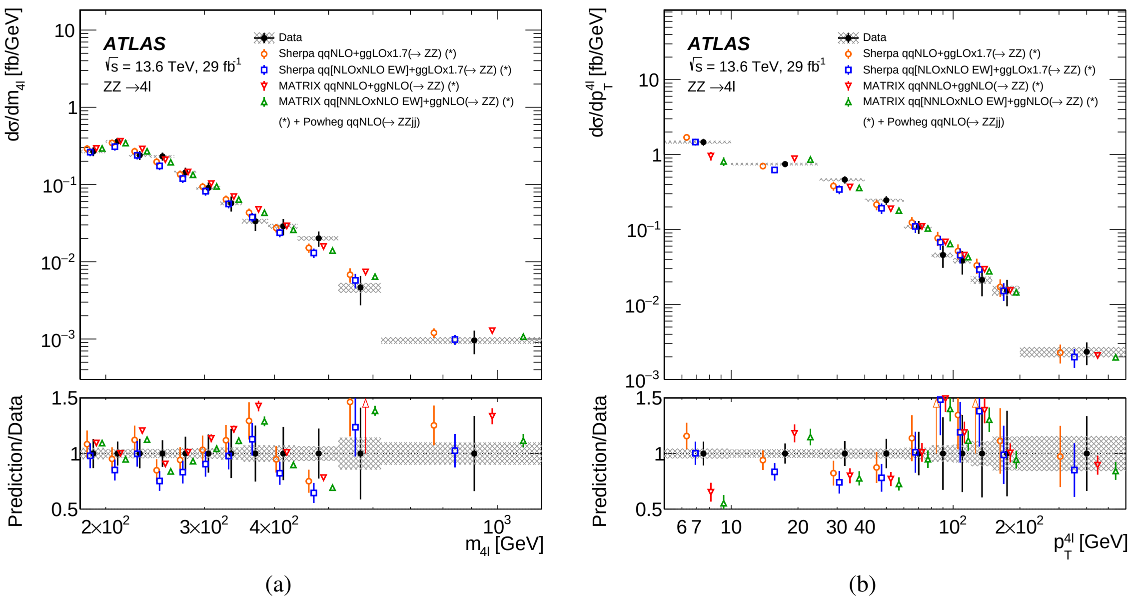


Figure 3: The measured differential cross-sections (filled points) are compared with the predictions, in each of the (a) $m_{4\ell}$ and (b) $p_{\mathrm{T}}^{4\ell}$ bins. The error bars on the measurement points give the total uncertainty and the hatched band gives the systematic uncertainty. The upwards arrows in the ratio panels indicate that the cross-section of the corresponding prediction is more than 1.5 times the data in that bin. In all predictions, EW $qq \to ZZ + 2j$ is modelled by POWHEG BOX v2. SHERPA models $q\bar{q} \to ZZ$ at NLO QCD and LO EW accuracy, and provides NLO EW corrections as alternative internal weights. The SHERPA $q\bar{q} \to ZZ$ predictions using nominal and alternative weights are shown respectively as 'qqNLO' and 'qq[NLO × NLO EW]'. The $gg \to ZZ$ process predicted by SHERPA is at LO QCD accuracy, and scaled to NLO QCD using a K-factor of 1.7. The error bands on the SHERPA predictions show the theoretical uncertainties in the signal process, where QCD, PDF and parton shower uncertainties are considered. MATRIX calculates $q\bar{q} \to ZZ$ at NNLO QCD, and at up to NLO EW accuracy. MATRIX calculates $gg \to ZZ$ at NLO QCD accuracy. Only the QCD scale uncertainty is considered in the MATRIX predictions. The lower panels show the ratios of the SM predictions to the measured data.

8 Conclusion

This paper presents cross-section measurements of ZZ production in the 4ℓ final state, based on 29 fb^{-1} of data collected by the ATLAS detector at the LHC in pp collisions at $\sqrt{s}$ = 13.6 TeV. The inclusive cross-sections within both a fiducial and the total phase-space regions are measured. Differential measurements of $m_{4\ell}$ and $p_{\mathrm{T}}^{4\ell}$ are also presented. The results are well described by the predictions, both from state-of-the-art MC simulation and from fixed-order calculations with accuracy up to NNLO QCD + NLO EW. These results are the first step in the programme of diboson production measurements at the new centre-of-mass energy of 13.6 TeV.

Acknowledgements

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

The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN, the ATLAS Tier-1 facilities at TRIUMF/SFU (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN-CNAF (Italy), NL-T1 (Netherlands), PIC (Spain), RAL (UK) and BNL (USA), the Tier-2 facilities worldwide and large non-WLCG resource providers. Major contributors of computing resources are listed in Ref. [58].

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

Individual groups and members have received support from BCKDF, CANARIE, CRC and DRAC, Canada; CERN-CZ, PRIMUS 21/SCI/017 and UNCE SCI/013, Czech Republic; COST, ERC, ERDF, Horizon 2020, ICSC-NextGenerationEU and Marie Skłodowska-Curie Actions, European Union; Investissements d'Avenir Labex, Investissements d'Avenir Idex and ANR, France; DFG and AvH Foundation, Germany; Herakleitos, Thales and Aristeia programmes co-financed by EU-ESF and the Greek NSRF, Greece; BSF-NSF and MINERVA, Israel; Norwegian Financial Mechanism 2014-2021, Norway; NCN and NAWA, Poland; La Caixa Banking Foundation, CERCA Programme Generalitat de Catalunya and PROMETEO and GenT Programmes Generalitat Valenciana, Spain; Göran Gustafssons Stiftelse, Sweden; The Royal Society and Leverhulme Trust, United Kingdom.

In addition, individual members wish to acknowledge support from Chile: Agencia Nacional de Investigación y Desarrollo (FONDECYT 1190886, FONDECYT 1210400, FONDECYT 1230812, FONDECYT 1230987); China: National Natural Science Foundation of China (NSFC - 12175119, NSFC 12275265, NSFC-12075060); Czech Republic: PRIMUS Research Programme (PRIMUS/21/SCI/017); EU: H2020 European Research Council (ERC - 101002463); European Union: European Research Council (ERC - 948254), Horizon 2020 Framework Programme (MUCCA - CHIST-ERA-19-XAI-00), European Union, Future Artificial Intelligence Research (FAIR-NextGenerationEU PE00000013), Italian Center for High Performance Computing, Big Data and Quantum Computing (ICSC, NextGenerationEU), Marie Sklodowska-Curie Actions (EU H2020 MSC IF GRANT NO 101033496); France: Agence Nationale de la Recherche (ANR-20-CE31-0013, ANR-21-CE31-0013, ANR-21-CE31-0022, ANR-22-EDIR-0002), Investissements d'Avenir Idex (ANR-11-LABX-0012), Investissements d'Avenir Labex (ANR-11-LABX-0012); Germany: Baden-Württemberg Stiftung (BW Stiftung-Postdoc Eliteprogramme), Deutsche Forschungsgemeinschaft (DFG - 469666862, DFG - CR 312/5-1); Italy: Istituto Nazionale di Fisica Nucleare (FELLINI G.A. n. 754496, ICSC, NextGenerationEU); Japan: Japan Society for the Promotion of Science (JSPS KAKENHI JP21H05085, JSPS KAKENHI JP22H01227, JSPS KAKENHI JP22H04944, JSPS KAKENHI JP22KK0227); Netherlands: Netherlands Organisation for Scientific Research (NWO Veni

2020 - VI.Veni.202.179); Norway: Research Council of Norway (RCN-314472); Poland: Polish National Agency for Academic Exchange (PPN/PPO/2020/1/00002/U/00001), Polish National Science Centre (NCN 2021/42/E/ST2/00350, NCN OPUS nr 2022/47/B/ST2/03059, NCN UMO-2019/34/E/ST2/00393, UMO-2020/37/B/ST2/01043, UMO-2021/40/C/ST2/00187); Slovenia: Slovenian Research Agency (ARIS grant J1-3010); Spain: BBVA Foundation (LEO22-1-603), Generalitat Valenciana (Artemisa, FEDER, IDIFEDER/2018/048), La Caixa Banking Foundation (LCF/BQ/PI20/11760025), Ministry of Science and Innovation (MCIN & NextGenEU PCI2022-135018-2, MICIN & FEDER PID2021-125273NB, RYC2019-028510-I, RYC2020-030254-I, RYC2021-031273-I, RYC2022-038164-I), PROMETEO and GenT Programmes Generalitat Valenciana (CIDEGENT/2019/023, CIDEGENT/2019/027); Sweden: Swedish Research Council (VR 2018-00482, VR 2022-03845, VR 2022-04683, VR grant 2021-03651), Knut and Alice Wallenberg Foundation (KAW 2017.0100, KAW 2018.0157, KAW 2018.0458, KAW 2019.0447); Switzerland: Swiss National Science Foundation (SNSF - PCEFP2_194658); United Kingdom: Leverhulme Trust (Leverhulme Trust RPG-2020-004); United States of America: U.S. Department of Energy (ECA DE-AC02-76SF00515), Neubauer Family Foundation.

References

[1] The ALEPH Collaboration, The DELPHI Collaboration, The L3 Collaboration, The OPAL Collaboration, The LEP Electroweak Working Group, *Electroweak measurements in electron–positron collisions at W-boson-pair energies at LEP*, Phys. Rep. **532** (2013) 119, URL: https://doi.org/10.1016%2Fj.physrep.2013.07.004.

[2] D0 Collaboration, *Measurement of the ZZ Production Cross Section and Search for the Standard Model Higgs Boson in the Four Lepton Final State in $p\bar{p}$ Collisions*, Phys. Rev. D **88** (2013) 032008, arXiv: 1304.5422 [hep-ex].

[3] CDF Collaboration, *Measurement of the ZZ production cross section using the full CDF II data set*, Phys. Rev. D **89** (2014) 112001, arXiv: 1403.2300 [hep-ex].

[4] U. Baur and D. L. Rainwater, *Probing neutral gauge boson selfinteractions in ZZ production at hadron colliders*, Phys. Rev. D **62** (2000) 113011, arXiv: hep-ph/0008063.

[5] D. Goncalves, T. Han and S. Mukhopadhyay, *Off-Shell Higgs Probe of Naturalness*, Phys. Rev. Lett. **120** (2018) 111801, [Erratum: Phys.Rev.Lett. 121, 079902 (2018)], arXiv: 1710.02149 [hep-ph].

[6] CMS Collaboration, *Measurements of the Electroweak Diboson Production Cross Sections in Proton-Proton Collisions at* $\sqrt{s} = 5.02$ TeV *Using Leptonic Decays*, Phys. Rev. Lett. **127** (19 2021) 191801, arXiv: 2107.01137 [hep-ex].

[7] ATLAS Collaboration, *Measurement of ZZ production in pp collisions at $\sqrt{s} = 7$ TeV and limits on anomalous ZZZ and ZZγ couplings with the ATLAS detector*, JHEP **03** (2013) 128, arXiv: 1211.6096 [hep-ex].

[8] ATLAS Collaboration, *Measurement of the ZZ production cross section in proton-proton collisions at $\sqrt{s} = 8$ TeV using the $ZZ \to \ell^-\ell^+\ell'^-\ell'^+$ and $ZZ \to \ell^-\ell^+\nu\bar{\nu}$ channels with the ATLAS detector*, JHEP **01** (2017) 099, arXiv: 1610.07585 [hep-ex].

[9] CMS Collaboration, *Measurement of the ZZ production cross section and search for anomalous couplings in $2\ell2\ell'$ final states in pp collisions at $\sqrt{s} = 7$ TeV*, JHEP **01** (2013) 063, arXiv: 1211.4890 [hep-ex].

[10] CMS Collaboration, *Measurements of the ZZ production cross sections in the $2\ell 2\nu$ channel in proton–proton collisions at $\sqrt{s} = 7$ and 8 TeV and combined constraints on triple gauge couplings*, Eur. Phys. J. C **75** (2015) 511, arXiv: 1503.05467 [hep-ex].

[11] CMS Collaboration, *Measurement of the $pp \to ZZ$ production cross section and constraints on anomalous triple gauge couplings in four-lepton final states at $\sqrt{s} = 8$ TeV*, Phys. Lett. B **740** (2015) 250, arXiv: 1406.0113 [hep-ex].

[12] CMS Collaboration, *Measurements of $pp \to ZZ$ production cross sections and constraints on anomalous triple gauge couplings at $\sqrt{s} = 13$ TeV*, Eur. Phys. J. C **81** (2021) 200, arXiv: 2009.01186 [hep-ex].

[13] CMS Collaboration, *Measurement of the ZZ production cross section and $Z \to \ell^+\ell^-\ell'^+\ell'^-$ branching fraction in pp collisions at $\sqrt{s} = 13$ TeV*, Phys. Lett. B **763** (2016) 280, arXiv: 1607.08834 [hep-ex].

[14] ATLAS Collaboration, *$ZZ \to \ell^+\ell^-\ell'^+\ell'^-$ cross-section measurements and search for anomalous triple gauge couplings in 13 TeV pp collisions with the ATLAS detector*, Phys. Rev. D **97** (2018) 032005, arXiv: 1709.07703 [hep-ex].

[15] ATLAS Collaboration, *Measurement of ZZ production in the $\ell\ell\nu\nu$ final state with the ATLAS detector in pp collisions at $\sqrt{s} = 13$ TeV*, JHEP **10** (2019) 127, arXiv: 1905.07163 [hep-ex].

[16] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, JINST **3** (2008) S08003.

[17] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider: A Description of the Detector Configuration for Run 3*, (2023), arXiv: 2305.16623 [physics.ins-det].

[18] ATLAS Collaboration, *The ATLAS Collaboration Software and Firmware*, ATL-SOFT-PUB-2021-001, 2021, URL: https://cds.cern.ch/record/2767187.

[19] ATLAS Collaboration, *Preliminary analysis of the luminosity calibration of the ATLAS 13.6 TeV data recorded in 2022*, ATL-DAPR-PUB-2023-001, 2023, URL: https://cds.cern.ch/record/2853525.

[20] ATLAS Collaboration, *Performance of the ATLAS muon triggers in Run 2*, JINST **15** (2020) P09015, arXiv: 2004.13447 [physics.ins-det].

[21] ATLAS Collaboration, *Performance of electron and photon triggers in ATLAS during LHC Run 2*, Eur. Phys. J. C **80** (2020) 47, arXiv: 1909.00761 [hep-ex].

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

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

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

[25] F. Cascioli, P. Maierhöfer and S. Pozzorini, *Scattering Amplitudes with Open Loops*, Phys. Rev. Lett. **108** (2012) 111601, arXiv: 1111.5206 [hep-ph].

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

[27] B. Biedermann et al., *Automation of NLO QCD and EW corrections with Sherpa and Recola*, Eur. Phys. J. C **77** (2017) 492, arXiv: 1704.05783 [hep-ph].

[28] B. Biedermann, A. Denner, S. Dittmaier, L. Hofer and B. Jager, *Next-to-leading-order electroweak corrections to the production of four charged leptons at the LHC*, JHEP **01** (2017) 033, arXiv: 1611.05338 [hep-ph].

[29] M. Grazzini, S. Kallweit and D. Rathlev, *ZZ production at the LHC: fiducial cross sections and distributions in NNLO QCD*, Phys. Lett. B **750** (2015) 407, arXiv: 1507.06257 [hep-ph].

[30] F. Caola, K. Melnikov, R. Röntsch and L. Tancredi, *QCD corrections to ZZ production in gluon fusion at the LHC*, Phys. Rev. D **92** (9 2015) 094028, URL: https://link.aps.org/doi/10.1103/PhysRevD.92.094028.

[31] J. M. Campbell, R. K. Ellis, M. Czakon and S. Kirchner, *Two loop correction to interference in $gg \to ZZ$*, JHEP **2016** (2016), URL: https://doi.org/10.1007%2Fjhep08%282016%29011.

[32] K. Melnikov and M. Dowling, *Production of two Z-bosons in gluon fusion in the heavy top quark approximation*, Phys. Lett. B **744** (2015) 43, ISSN: 0370-2693, URL: https://www.sciencedirect.com/science/article/pii/S0370269315001938.

[33] ATLAS Collaboration, *Search for heavy resonances decaying into a pair of Z bosons in the $\ell^+\ell^-\ell'^+\ell'^-$ and $\ell^+\ell^-\nu\bar{\nu}$ final states using 139 fb^{-1} of proton–proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector*, Eur. Phys. J. C **81** (2021) 332, arXiv: 2009.14791 [hep-ex].

[34] K. Hamilton, P. Nason, E. Re and G. Zanderighi, *NNLOPS simulation of Higgs boson production*, JHEP **10** (2013) 222, arXiv: 1309.0017 [hep-ph].

[35] K. Hamilton, P. Nason and G. Zanderighi, *Finite quark-mass effects in the NNLOPS POWHEG+MiNLO Higgs generator*, JHEP **05** (2015) 140, arXiv: 1501.04637 [hep-ph].

[36] S. Alioli, P. Nason, C. Oleari and E. Re, *A general framework for implementing NLO calculations in shower Monte Carlo programs: the POWHEG BOX*, JHEP **06** (2010) 043, arXiv: 1002.2581 [hep-ph].

[37] P. Nason, *A new method for combining NLO QCD with shower Monte Carlo algorithms*, JHEP **11** (2004) 040, arXiv: hep-ph/0409146.

[38] S. Frixione, P. Nason and C. Oleari, *Matching NLO QCD computations with parton shower simulations: the POWHEG method*, JHEP **11** (2007) 070, arXiv: 0709.2092 [hep-ph].

[39] B. Jäger, A. Karlberg and G. Zanderighi, *Electroweak $ZZjj$ production in the Standard Model and beyond in the POWHEG-BOX V2*, JHEP **03** (2014) 141, arXiv: 1312.3252 [hep-ph].

[40] C. Bierlich et al., *A comprehensive guide to the physics and usage of PYTHIA 8.3*, (2022), arXiv: 2203.11601 [hep-ph].

[41] S. Agostinelli et al., *Geant4 – a simulation toolkit*, Nucl. Instrum. Meth. A **506** (2003) 250.

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

[43] ATLAS Collaboration, *Development of ATLAS Primary Vertex Reconstruction for LHC Run 3*, ATL-PHYS-PUB-2019-015, 2019, URL: https://cds.cern.ch/record/2670380.

[44] ATLAS Collaboration, *Measurements of differential cross-sections in four-lepton events in 13 TeV proton-proton collisions with the ATLAS detector*, JHEP **07** (2021) 005, arXiv: 2103.01918 [hep-ex].

[45] ATLAS Collaboration, *Electron and photon performance measurements with the ATLAS detector using the 2015–2017 LHC proton–proton collision data*, JINST **14** (2019) P12006, arXiv: 1908.00005 [hep-ex].

[46] ATLAS Collaboration, *Electron reconstruction and identification in the ATLAS experiment using the 2015 and 2016 LHC proton-proton collision data at $\sqrt{s}$ = 13 TeV*, Eur. Phys. J. C **79** (2019) 639, arXiv: 1902.04655 [physics.ins-det].

[47] 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].

[48] ATLAS Collaboration, *Muon reconstruction and identification efficiency in ATLAS using the full Run 2 pp collision data set at $\sqrt{s} = 13$ TeV*, Eur. Phys. J. C **81** (2021) 578, arXiv: 2012.00578 [hep-ex].

[49] The ALEPH Collaboration, the DELPHI Collaboration, the L3 Collaboration, the OPAL Collaboration, the SLD Collaboration, the LEP Electroweak Working Group, the SLD electroweak, heavy flavour groups, *Precision electroweak measurements on the Z resonance*, Phys. Rep. **427** (2006) 257, arXiv: hep-ex/0509008.

[50] J. H. Friedman, *A variable span smoother*, tech. rep., SLAC, 1984, URL: https://cds.cern.ch/record/155846.

[51] W. S. Cleveland, *LOWESS: A Program for Smoothing Scatterplots by Robust Locally Weighted Regression*, The American Statistician **35** (1981) 54, ISSN: 00031305.

[52] ATLAS Collaboration, *Measurement of the Inelastic Proton–Proton Cross Section at $\sqrt{s} = 13$ TeV with the ATLAS Detector at the LHC*, Phys. Rev. Lett. **117** (2016) 182002, arXiv: 1606.02625 [hep-ex].

[53] ATLAS Collaboration, *Electron and photon energy calibration with the ATLAS detector using 2015–2016 LHC proton–proton collision data*, JINST **14** (2019) P03017, arXiv: 1812.03848 [hep-ex].

[54] T.-J. Hou et al., *New CTEQ global analysis of quantum chromodynamics with high-precision data from the LHC*, Phys. Rev. D **103** (2021) 014013, arXiv: 1912.10053 [hep-ph].

[55] ATLAS Collaboration, *Observation of electroweak production of two jets and a Z-boson pair*, Nature Phys. **19** (2023) 237, arXiv: 2004.10612 [hep-ex].

[56] G. D'Agostini, *A multidimensional unfolding method based on Bayes' theorem*, Nucl. Instrum. Meth. A **362** (1995) 487.

[57] B. Malaescu, *An iterative, dynamically stabilized method of data unfolding*, 2009, arXiv: 0907.3791 [physics.data-an].

[58] ATLAS Collaboration, *ATLAS Computing Acknowledgements*, ATL-SOFT-PUB-2023-001, 2023, URL: https://cds.cern.ch/record/2869272.

The ATLAS Collaboration

G. Aad[102], B. Abbott[120], K. Abeling[55], N.J. Abicht[49], S.H. Abidi[29], A. Aboulhorma[35e], H. Abramowicz[151], H. Abreu[150], Y. Abulaiti[117], B.S. Acharya[69a,69b,m], C. Adam Bourdarios[4], L. Adamczyk[86a], S.V. Addepalli[26], M.J. Addison[101], J. Adelman[115], A. Adiguzel[21c], T. Adye[134], A.A. Affolder[136], Y. Afik[39], M.N. Agaras[13], J. Agarwala[73a,73b], A. Aggarwal[100], C. Agheorghiesei[27c], A. Ahmad[36], F. Ahmadov[38,aa], W.S. Ahmed[104], S. Ahuja[95], X. Ai[62e], G. Aielli[76a,76b], A. Aikot[163], M. Ait Tamlihat[35e], B. Aitbenchikh[35a], I. Aizenberg[169], M. Akbiyik[100], T.P.A. Åkesson[98], A.V. Akimov[37], D. Akiyama[168], N.N. Akolkar[24], S. Aktas[21a], K. Al Khoury[41], G.L. Alberghi[23b], J. Albert[165], P. Albicocco[53], G.L. Albouy[60], S. Alderweireldt[52], Z.L. Alegria[121], M. Aleksa[36], I.N. Aleksandrov[38], C. Alexa[27b], T. Alexopoulos[10], F. Alfonsi[23b], M. Algren[56], M. Alhroob[120], B. Ali[132], H.M.J. Ali[91], S. Ali[148], S.W. Alibocus[92], M. Aliev[145], G. Alimonti[71a], W. Alkakhi[55], C. Allaire[66], B.M.M. Allbrooke[146], J.F. Allen[52], C.A. Allendes Flores[137f], P.P. Allport[20], A. Aloisio[72a,72b], F. Alonso[90], C. Alpigiani[138], M. Alvarez Estevez[99], A. Alvarez Fernandez[100], M. Alves Cardoso[56], M.G. Alviggi[72a,72b], M. Aly[101], Y. Amaral Coutinho[83b], A. Ambler[104], C. Amelung[36], M. Amerl[101], C.G. Ames[109], D. Amidei[106], S.P. Amor Dos Santos[130a], K.R. Amos[163], V. Ananiev[125], C. Anastopoulos[139], T. Andeen[11], J.K. Anders[36], S.Y. Andrean[47a,47b], A. Andreazza[71a,71b], S. Angelidakis[9], A. Angerami[41,ad], A.V. Anisenkov[37], A. Annovi[74a], C. Antel[56], M.T. Anthony[139], E. Antipov[145], M. Antonelli[53], F. Anulli[75a], M. Aoki[84], T. Aoki[153], J.A. Aparisi Pozo[163], M.A. Aparo[146], L. Aperio Bella[48], C. Appelt[18], A. Apyan[26], N. Aranzabal[36], S.J. Arbiol Val[87], C. Arcangeletti[53], A.T.H. Arce[51], E. Arena[92], J-F. Arguin[108], S. Argyropoulos[54], J.-H. Arling[48], O. Arnaez[4], H. Arnold[114], G. Artoni[75a,75b], H. Asada[111], K. Asai[118], S. Asai[153], N.A. Asbah[61], J. Assahsah[35d], K. Assamagan[29], R. Astalos[28a], S. Atashi[159], R.J. Atkin[33a], M. Atkinson[162], H. Atmani[35f], P.A. Atmasiddha[128], K. Augsten[132], S. Auricchio[72a,72b], A.D. Auriol[20], V.A. Austrup[101], G. Avolio[36], K. Axiotis[56], G. Azuelos[108,ah], D. Babal[28b], H. Bachacou[135], K. Bachas[152,q], A. Bachiu[34], F. Backman[47a,47b], A. Badea[61], T.M. Baer[106], P. Bagnaia[75a,75b], M. Bahmani[18], D. Bahner[54], A.J. Bailey[163], V.R. Bailey[162], J.T. Baines[134], L. Baines[94], O.K. Baker[172], E. Bakos[15], D. Bakshi Gupta[8], V. Balakrishnan[120], R. Balasubramanian[114], E.M. Baldin[37], P. Balek[86a], E. Ballabene[23b,23a], F. Balli[135], L.M. Baltes[63a], W.K. Balunas[32], J. Balz[100], E. Banas[87], M. Bandieramonte[129], A. Bandyopadhyay[24], S. Bansal[24], L. Barak[151], M. Barakat[48], E.L. Barberio[105], D. Barberis[57b,57a], M. Barbero[102], M.Z. Barel[114], K.N. Barends[33a], T. Barillari[110], M-S. Barisits[36], T. Barklow[143], P. Baron[122], D.A. Baron Moreno[101], A. Baroncelli[62a], G. Barone[29], A.J. Barr[126], J.D. Barr[96], L. Barranco Navarro[47a,47b], F. Barreiro[99], J. Barreiro Guimarães da Costa[14a], U. Barron[151], M.G. Barros Teixeira[130a], S. Barsov[37], F. Bartels[63a], R. Bartoldus[143], A.E. Barton[91], P. Bartos[28a], A. Basan[100], M. Baselga[49], A. Bassalat[66,b], M.J. Basso[156a], C.R. Basson[101], R.L. Bates[59], S. Batlamous[35e], J.R. Batley[32], B. Batool[141], M. Battaglia[136], D. Battulga[18], M. Bauce[75a,75b], M. Bauer[36], P. Bauer[24], L.T. Bazzano Hurrell[30], J.B. Beacham[51], T. Beau[127], J.Y. Beaucamp[90], P.H. Beauchemin[158], P. Bechtle[24], H.P. Beck[19,p], K. Becker[167], A.J. Beddall[82], V.A. Bednyakov[38], C.P. Bee[145], L.J. Beemster[15], T.A. Beermann[36], M. Begalli[83d], M. Begel[29], A. Behera[145], J.K. Behr[48], J.F. Beirer[36], F. Beisiegel[24], M. Belfkir[116b], G. Bella[151], L. Bellagamba[23b], A. Bellerive[34], P. Bellos[20], K. Beloborodov[37], D. Benchekroun[35a], F. Bendebba[35a], Y. Benhammou[151], M. Benoit[29], J.R. Bensinger [26], S. Bentvelsen [114], L. Beresford [48], M. Beretta [53], E. Bergeaas Kuutmann [161], N. Berger [4], B. Bergmann [132], J. Beringer [17a], G. Bernardi [5], C. Bernius [143], F.U. Bernlochner [24], F. Bernon [36,102], A. Berrocal Guardia [13], T. Berry [95], P. Berta [133], A. Berthold [50], I.A. Bertram [91], S. Bethke [110], A. Betti [75a,75b], A.J. Bevan [94], N.K. Bhalla [54], M. Bhamjee [33c], S. Bhatta [145], D.S. Bhattacharya [166], P. Bhattarai [143], V.S. Bhopatkar [121], R. Bi[29,ak], R.M. Bianchi [129], G. Bianco [23b,23a], O. Biebel [109], R. Bielski [123], M. Biglietti [77a], M. Bindi [55], A. Bingul [21b], C. Bini [75a,75b], A. Biondini [92], C.J. Birch-sykes [101], G.A. Bird [20,134], M. Birman [169], M. Biros [133], S. Biryukov [146], T. Bisanz [49], E. Bisceglie [43b,43a], J.P. Biswal [134], D. Biswas [141], A. Bitadze [101], K. Bjørke [125], I. Bloch [48], A. Blue [59], U. Blumenschein [94], J. Blumenthal [100], G.J. Bobbink [114], V.S. Bobrovnikov [37], M. Boehler [54], B. Boehm [166], D. Bogavac [36], A.G. Bogdanchikov [37], C. Bohm [47a], V. Boisvert [95], P. Bokan [48], T. Bold [86a], M. Bomben [5], M. Bona [94], M. Boonekamp [135], C.D. Booth [95], A.G. Borbély [59], I.S. Bordulev [37], H.M. Borecka-Bielska [108], G. Borissov [91], D. Bortoletto [126], D. Boscherini [23b], M. Bosman [13], J.D. Bossio Sola [36], K. Bouaouda [35a], N. Bouchhar [163], J. Boudreau [129], E.V. Bouhova-Thacker [91], D. Boumediene [40], R. Bouquet [165], A. Boveia [119], J. Boyd [36], D. Boye [29], I.R. Boyko [38], J. Bracinik [20], N. Brahimi [62d], G. Brandt [171], O. Brandt [32], F. Braren [48], B. Brau [103], J.E. Brau [123], R. Brener [169], L. Brenner [114], R. Brenner [161], S. Bressler [169], D. Britton [59], D. Britzger [110], I. Brock [24], R. Brock [107], G. Brooijmans [41], W.K. Brooks [137f], E. Brost [29], L.M. Brown [165], L.E. Bruce [61], T.L. Bruckler [126], P.A. Bruckman de Renstrom [87], B. Brüers [48], A. Bruni [23b], G. Bruni [23b], M. Bruschi [23b], N. Bruscino [75a,75b], T. Buanes [16], Q. Buat [138], D. Buchin [110], A.G. Buckley [59], O. Bulekov [37], B.A. Bullard [143], S. Burdin [92], C.D. Burgard [49], A.M. Burger [40], B. Burghgrave [8], O. Burlayenko [54], J.T.P. Burr [32], C.D. Burton [11], J.C. Burzynski [142], E.L. Busch [41], V. Büscher [100], P.J. Bussey [59], J.M. Butler [25], C.M. Buttar [59], J.M. Butterworth [96], W. Buttinger [134], C.J. Buxo Vazquez [107], A.R. Buzykaev [37], S. Cabrera Urbán [163], L. Cadamuro [66], D. Caforio [58], H. Cai [129], Y. Cai [14a,14e], Y. Cai [14c], V.M.M. Cairo [36], O. Cakir [3a], N. Calace [36], P. Calafiura [17a], G. Calderini [127], P. Calfayan [68], G. Callea [59], L.P. Caloba[83b], D. Calvet [40], S. Calvet [40], M. Calvetti [74a,74b], R. Camacho Toro [127], S. Camarda [36], D. Camarero Munoz [26], P. Camarri [76a,76b], M.T. Camerlingo [72a,72b], D. Cameron [36], C. Camincher [165], M. Campanelli [96], A. Camplani [42], V. Canale [72a,72b], A. Canesse [104], J. Cantero [163], Y. Cao [162], F. Capocasa [26], M. Capua [43b,43a], A. Carbone [71a,71b], R. Cardarelli [76a], J.C.J. Cardenas [8], F. Cardillo [163], G. Carducci [43b,43a], T. Carli [36], G. Carlino [72a], J.I. Carlotto [13], B.T. Carlson [129,r], E.M. Carlson [165,156a], L. Carminati [71a,71b], A. Carnelli [135], M. Carnesale [75a,75b], S. Caron [113], E. Carquin [137f], S. Carrá [71a], G. Carratta [23b,23a], F. Carrio Argos [33g], J.W.S. Carter [155], T.M. Carter [52], M.P. Casado [13,i], M. Caspar [48], F.L. Castillo [4], L. Castillo Garcia [13], V. Castillo Gimenez [163], N.F. Castro [130a,130e], A. Catinaccio [36], J.R. Catmore [125], V. Cavaliere [29], N. Cavalli [23b,23a], V. Cavasinni [74a,74b], Y.C. Cekmecelioglu [48], E. Celebi [21a], F. Celli [126], M.S. Centonze [70a,70b], V. Cepaitis [56], K. Cerny [122], A.S. Cerqueira [83a], A. Cerri [146], L. Cerrito [76a,76b], F. Cerutti [17a], B. Cervato [141], A. Cervelli [23b], G. Cesarini [53], S.A. Cetin [82], D. Chakraborty [115], J. Chan [170], W.Y. Chan [153], J.D. Chapman [32], E. Chapon [135], B. Chargeishvili [149b], D.G. Charlton [20], M. Chatterjee [19], C. Chauhan [133], S. Chekanov [6], S.V. Chekulaev [156a], G.A. Chelkov [38,a], A. Chen [106], B. Chen [151], B. Chen [165], H. Chen [14c], H. Chen [29], J. Chen [62c], J. Chen [142], M. Chen [126], S. Chen [153], S.J. Chen [14c], X. Chen [62c,135], X. Chen [14b,ag], Y. Chen [62a], C.L. Cheng [170], H.C. Cheng [64a], S. Cheong [143], A. Cheplakov [38], E. Cheremushkina [48], E. Cherepanova [114], R. Cherkaoui El Moursli [35e], E. Cheu [7], K. Cheung [65], L. Chevalier [135], V. Chiarella [53], G. Chiarelli [74a], N. Chiedde [102], G. Chiodini [70a], A.S. Chisholm [20], A. Chitan [27b],

M. Chitishvili [163], M.V. Chizhov [38,s], K. Choi [11], A.R. Chomont [75a,75b], Y. Chou [103], E.Y.S. Chow [113], T. Chowdhury [33g], K.L. Chu [169], M.C. Chu [64a], X. Chu [14a,14e], J. Chudoba [131], J.J. Chwastowski [87], D. Cieri [110], K.M. Ciesla [86a], V. Cindro [93], A. Ciocio [17a], F. Cirotto [72a,72b], Z.H. Citron [169,k], M. Citterio [71a], D.A. Ciubotaru[27b], A. Clark [56], P.J. Clark [52], C. Clarry [155], J.M. Clavijo Columbie [48], S.E. Clawson [48], C. Clement [47a,47b], J. Clercx [48], Y. Coadou [102], M. Cobal [69a,69c], A. Coccaro [57b], R.F. Coelho Barrue [130a], R. Coelho Lopes De Sa [103], S. Coelli [71a], A.E.C. Coimbra [71a,71b], B. Cole [41], J. Collot [60], P. Conde Muiño [130a,130g], M.P. Connell [33c], S.H. Connell [33c], I.A. Connelly [59], E.I. Conroy [126], F. Conventi [72a,ai], H.G. Cooke [20], A.M. Cooper-Sarkar [126], A. Cordeiro Oudot Choi [127], L.D. Corpe [40], M. Corradi [75a,75b], F. Corriveau [104,y], A. Cortes-Gonzalez [18], M.J. Costa [163], F. Costanza [4], D. Costanzo [139], B.M. Cote [119], G. Cowan [95], K. Cranmer [170], D. Cremonini [23b,23a], S. Crépé-Renaudin [60], F. Crescioli [127], M. Cristinziani [141], M. Cristoforetti [78a,78b], V. Croft [114], J.E. Crosby [121], G. Crosetti [43b,43a], A. Cueto [99], T. Cuhadar Donszelmann [159], H. Cui [14a,14e], Z. Cui [7], W.R. Cunningham [59], F. Curcio [43b,43a], P. Czodrowski [36], M.M. Czurylo [63b], M.J. Da Cunha Sargedas De Sousa [57b,57a], J.V. Da Fonseca Pinto [83b], C. Da Via [101], W. Dabrowski [86a], T. Dado [49], S. Dahbi [33g], T. Dai [106], D. Dal Santo [19], C. Dallapiccola [103], M. Dam [42], G. D'amen [29], V. D'Amico [109], J. Damp [100], J.R. Dandoy [34], M. Danninger [142], V. Dao [36], G. Darbo [57b], S. Darmora [6], S.J. Das [29,ak], S. D'Auria [71a,71b], C. David [156b], T. Davidek [133], B. Davis-Purcell [34], I. Dawson [94], H.A. Day-hall [132], K. De [8], R. De Asmundis [72a], N. De Biase [48], S. De Castro [23b,23a], N. De Groot [113], P. de Jong [114], H. De la Torre [115], A. De Maria [14c], A. De Salvo [75a], U. De Sanctis [76a,76b], F. De Santis [70a,70b], A. De Santo [146], J.B. De Vivie De Regie [60], D.V. Dedovich[38], J. Degens [114], A.M. Deiana [44], F. Del Corso [23b,23a], J. Del Peso [99], F. Del Rio [63a], L. Delagrange [127], F. Deliot [135], C.M. Delitzsch [49], M. Della Pietra [72a,72b], D. Della Volpe [56], A. Dell'Acqua [36], L. Dell'Asta [71a,71b], M. Delmastro [4], P.A. Delsart [60], S. Demers [172], M. Demichev [38], S.P. Denisov [37], L. D'Eramo [40], D. Derendarz [87], F. Derue [127], P. Dervan [92], K. Desch [24], C. Deutsch [24], F.A. Di Bello [57b,57a], A. Di Ciaccio [76a,76b], L. Di Ciaccio [4], A. Di Domenico [75a,75b], C. Di Donato [72a,72b], A. Di Girolamo [36], G. Di Gregorio [36], A. Di Luca [78a,78b], B. Di Micco [77a,77b], R. Di Nardo [77a,77b], C. Diaconu [102], M. Diamantopoulou [34], F.A. Dias [114], T. Dias Do Vale [142], M.A. Diaz [137a,137b], F.G. Diaz Capriles [24], M. Didenko [163], E.B. Diehl [106], L. Diehl [54], S. Díez Cornell [48], C. Diez Pardos [141], C. Dimitriadi [161,24], A. Dimitrievska [17a], J. Dingfelder [24], I-M. Dinu [27b], S.J. Dittmeier [63b], F. Dittus [36], F. Djama [102], T. Djobava [149b], C. Doglioni [101,98], A. Dohnalova [28a], J. Dolejsi [133], Z. Dolezal [133], K.M. Dona [39], M. Donadelli [83c], B. Dong [107], J. Donini [40], A. D'Onofrio [72a,72b], M. D'Onofrio [92], J. Dopke [134], A. Doria [72a], N. Dos Santos Fernandes [130a], P. Dougan [101], M.T. Dova [90], A.T. Doyle [59], M.A. Draguet [126], E. Dreyer [169], I. Drivas-koulouris [10], M. Drnevich [117], A.S. Drobac [158], M. Drozdova [56], D. Du [62a], T.A. du Pree [114], F. Dubinin [37], M. Dubovsky [28a], E. Duchovni [169], G. Duckeck [109], O.A. Ducu [27b], D. Duda [52], A. Dudarev [36], E.R. Duden [26], M. D'uffizi [101], L. Duflot [66], M. Dührssen [36], A.E. Dumitriu [27b], M. Dunford [63a], S. Dungs [49], K. Dunne [47a,47b], A. Duperrin [102], H. Duran Yildiz [3a], M. Düren [58], A. Durglishvili [149b], B.L. Dwyer [115], G.I. Dyckes [17a], M. Dyndal [86a], B.S. Dziedzic [87], Z.O. Earnshaw [146], G.H. Eberwein [126], B. Eckerova [28a], S. Eggebrecht [55], E. Egidio Purcino De Souza [127], L.F. Ehrke [56], G. Eigen [16], K. Einsweiler [17a], T. Ekelof [161], P.A. Ekman [98], S. El Farkh [35b], Y. El Ghazali [35b], H. El Jarrari [36], A. El Moussaouy [108], V. Ellajosyula [161], M. Ellert [161], F. Ellinghaus [171], N. Ellis [36], J. Elmsheuser [29], M. Elsing [36], D. Emeliyanov [134], Y. Enari [153], I. Ene [17a], S. Epari [13], P.A. Erland [87], M. Errenst [171], M. Escalier [66], C. Escobar [163], E. Etzion [151],

G. Evans [130a], H. Evans [68], L.S. Evans [95], M.O. Evans [146], A. Ezhilov [37], S. Ezzarqtouni [35a], F. Fabbri [59], L. Fabbri [23b,23a], G. Facini [96], V. Fadeyev [136], R.M. Fakhrutdinov [37], D. Fakoudis [100], S. Falciano [75a], L.F. Falda Ulhoa Coelho [36], P.J. Falke [24], J. Faltova [133], C. Fan [162], Y. Fan [14a], Y. Fang [14a,14e], M. Fanti [71a,71b], M. Faraj [69a,69b], Z. Farazpay [97], A. Farbin [8], A. Farilla [77a], T. Farooque [107], S.M. Farrington [52], F. Fassi [35e], D. Fassouliotis [9], M. Faucci Giannelli [76a,76b], W.J. Fawcett [32], L. Fayard [66], P. Federic [133], P. Federicova [131], O.L. Fedin [37,a], G. Fedotov [37], M. Feickert [170], L. Feligioni [102], D.E. Fellers [123], C. Feng [62b], M. Feng [14b], Z. Feng [114], M.J. Fenton [159], A.B. Fenyuk [37], L. Ferencz [48], R.A.M. Ferguson [91], S.I. Fernandez Luengo [137f], P. Fernandez Martinez [13], M.J.V. Fernoux [102], J. Ferrando [91], A. Ferrari [161], P. Ferrari [114,113], R. Ferrari [73a], D. Ferrere [56], C. Ferretti [106], F. Fiedler [100], P. Fiedler [132], A. Filipčič [93], E.K. Filmer [1], F. Filthaut [113], M.C.N. Fiolhais [130a,130c,c], L. Fiorini [163], W.C. Fisher [107], T. Fitschen [101], P.M. Fitzhugh [135], I. Fleck [141], P. Fleischmann [106], T. Flick [171], M. Flores [33d,ae], L.R. Flores Castillo [64a], L. Flores Sanz De Acedo [36], F.M. Follega [78a,78b], N. Fomin [16], J.H. Foo [155], B.C. Forland [68], A. Formica [135], A.C. Forti [101], E. Fortin [36], A.W. Fortman [61], M.G. Foti [17a], L. Fountas [9,j], D. Fournier [66], H. Fox [91], P. Francavilla [74a,74b], S. Francescato [61], S. Franchellucci [56], M. Franchini [23b,23a], S. Franchino [63a], D. Francis [36], L. Franco [113], V. Franco Lima [36], L. Franconi [48], M. Franklin [61], G. Frattari [26], A.C. Freegard [94], W.S. Freund [83b], Y.Y. Frid [151], J. Friend [59], N. Fritzsche [50], A. Froch [54], D. Froidevaux [36], J.A. Frost [126], Y. Fu [62a], S. Fuenzalida Garrido [137f], M. Fujimoto [102], K.Y. Fung [64a], E. Furtado De Simas Filho [83b], M. Furukawa [153], J. Fuster [163], A. Gabrielli [23b,23a], A. Gabrielli [155], P. Gadow [36], G. Gagliardi [57b,57a], L.G. Gagnon [17a], E.J. Gallas [126], B.J. Gallop [134], K.K. Gan [119], S. Ganguly [153], Y. Gao [52], F.M. Garay Walls [137a,137b], B. Garcia [29], C. García [163], A. Garcia Alonso [114], A.G. Garcia Caffaro [172], J.E. García Navarro [163], M. Garcia-Sciveres [17a], G.L. Gardner [128], R.W. Gardner [39], N. Garelli [158], D. Garg [80], R.B. Garg [143,n], J.M. Gargan [52], C.A. Garner [155], C.M. Garvey [33a], P. Gaspar [83b], V.K. Gassmann [158], G. Gaudio [73a], V. Gautam [13], P. Gauzzi [75a,75b], I.L. Gavrilenko [37], A. Gavrilyuk [37], C. Gay [164], G. Gaycken [48], E.N. Gazis [10], A.A. Geanta [27b], C.M. Gee [136], A. Gekow [119], C. Gemme [57b], M.H. Genest [60], S. Gentile [75a,75b], A.D. Gentry [112], S. George [95], W.F. George [20], T. Geralis [46], P. Gessinger-Befurt [36], M.E. Geyik [171], M. Ghani [167], M. Ghneimat [141], K. Ghorbanian [94], A. Ghosal [141], A. Ghosh [159], A. Ghosh [7], B. Giacobbe [23b], S. Giagu [75a,75b], T. Giani [114], P. Giannetti [74a], A. Giannini [62a], S.M. Gibson [95], M. Gignac [136], D.T. Gil [86b], A.K. Gilbert [86a], B.J. Gilbert [41], D. Gillberg [34], G. Gilles [114], N.E.K. Gillwald [48], L. Ginabat [127], D.M. Gingrich [2,ah], M.P. Giordani [69a,69c], P.F. Giraud [135], G. Giugliarelli [69a,69c], D. Giugni [71a], F. Giuli [36], I. Gkialas [9,j], L.K. Gladilin [37], C. Glasman [99], G.R. Gledhill [123], G. Glemža [48], M. Glisic [123], I. Gnesi [43b,f], Y. Go [29,ak], M. Goblirsch-Kolb [36], B. Gocke [49], D. Godin [108], B. Gokturk [21a], S. Goldfarb [105], T. Golling [56], M.G.D. Gololo [33g], D. Golubkov [37], J.P. Gombas [107], A. Gomes [130a,130b], G. Gomes Da Silva [141], A.J. Gomez Delegido [163], R. Gonçalo [130a,130c], G. Gonella [123], L. Gonella [20], A. Gongadze [149c], F. Gonnella [20], J.L. Gonski [41], R.Y. González Andana [52], S. González de la Hoz [163], R. Gonzalez Lopez [92], C. Gonzalez Renteria [17a], M.V. Gonzalez Rodrigues [48], R. Gonzalez Suarez [161], S. Gonzalez-Sevilla [56], G.R. Gonzalvo Rodriguez [163], L. Goossens [36], B. Gorini [36], E. Gorini [70a,70b], A. Gorišek [93], T.C. Gosart [128], A.T. Goshaw [51], M.I. Gostkin [38], S. Goswami [121], C.A. Gottardo [36], S.A. Gotz [109], M. Gouighri [35b], V. Goumarre [48], A.G. Goussiou [138], N. Govender [33c], I. Grabowska-Bold [86a], K. Graham [34], E. Gramstad [125], S. Grancagnolo [70a,70b], M. Grandi [146], C.M. Grant [1,135], P.M. Gravila [27f], F.G. Gravili [70a,70b], H.M. Gray [17a], M. Greco [70a,70b], C. Grefe [24], I.M. Gregor [48], P. Grenier [143], S.G. Grewe [110], C. Grieco [13], A.A. Grillo [136], K. Grimm [31], S. Grinstein [13,u], J.-F. Grivaz [66], E. Gross [169],

J. Grosse-Knetter[55], C. Grud[106], J.C. Grundy[126], L. Guan[106], W. Guan[29], C. Gubbels[164], J.G.R. Guerrero Rojas[163], G. Guerrieri[69a,69c], F. Guescini[110], R. Gugel[100], J.A.M. Guhit[106], A. Guida[18], E. Guilloton[167,134], S. Guindon[36], F. Guo[14a,14e], J. Guo[62c], L. Guo[48], Y. Guo[106], R. Gupta[48], R. Gupta[129], S. Gurbuz[24], S.S. Gurdasani[54], G. Gustavino[36], M. Guth[56], P. Gutierrez[120], L.F. Gutierrez Zagazeta[128], M. Gutsche[50], C. Gutschow[96], C. Gwenlan[126], C.B. Gwilliam[92], E.S. Haaland[125], A. Haas[117], M. Habedank[48], C. Haber[17a], H.K. Hadavand[8], A. Hadef[50], S. Hadzic[110], A.I. Hagan[91], J.J. Hahn[141], E.H. Haines[96], M. Haleem[166], J. Haley[121], J.J. Hall[139], G.D. Hallewell[102], L. Halser[19], K. Hamano[165], M. Hamer[24], G.N. Hamity[52], E.J. Hampshire[95], J. Han[62b], K. Han[62a], L. Han[14c], L. Han[62a], S. Han[17a], Y.F. Han[155], K. Hanagaki[84], M. Hance[136], D.A. Hangal[41,ad], H. Hanif[142], M.D. Hank[128], J.B. Hansen[42], J.D. Hansen[42], P.H. Hansen[42], K. Hara[157], D. Harada[56], T. Harenberg[171], S. Harkusha[37], M.L. Harris[103], Y.T. Harris[126], J. Harrison[13], N.M. Harrison[119], P.F. Harrison[167], N.M. Hartman[110], N.M. Hartmann[109], Y. Hasegawa[140], R. Hauser[107], C.M. Hawkes[20], R.J. Hawkings[36], Y. Hayashi[153], S. Hayashida[111], D. Hayden[107], C. Hayes[106], R.L. Hayes[114], C.P. Hays[126], J.M. Hays[94], H.S. Hayward[92], F. He[62a], M. He[14a,14e], Y. He[154], Y. He[48], N.B. Heatley[94], V. Hedberg[98], A.L. Heggelund[125], N.D. Hehir[94,*], C. Heidegger[54], K.K. Heidegger[54], W.D. Heidorn[81], J. Heilman[34], S. Heim[48], T. Heim[17a], J.G. Heinlein[128], J.J. Heinrich[123], L. Heinrich[110,af], J. Hejbal[131], L. Helary[48], A. Held[170], S. Hellesund[16], C.M. Helling[164], S. Hellman[47a,47b], R.C.W. Henderson[91], L. Henkelmann[32], A.M. Henriques Correia[36], H. Herde[98], Y. Hernández Jiménez[145], L.M. Herrmann[24], T. Herrmann[50], G. Herten[54], R. Hertenberger[109], L. Hervas[36], M.E. Hesping[100], N.P. Hessey[156a], H. Hibi[85], E. Hill[155], S.J. Hillier[20], J.R. Hinds[107], F. Hinterkeuser[24], M. Hirose[124], S. Hirose[157], D. Hirschbuehl[171], T.G. Hitchings[101], B. Hiti[93], J. Hobbs[145], R. Hobincu[27e], N. Hod[169], M.C. Hodgkinson[139], B.H. Hodkinson[32], A. Hoecker[36], D.D. Hofer[106], J. Hofer[48], T. Holm[24], M. Holzbock[110], L.B.A.H. Hommels[32], B.P. Honan[101], J. Hong[62c], T.M. Hong[129], B.H. Hooberman[162], W.H. Hopkins[6], Y. Horii[111], S. Hou[148], A.S. Howard[93], J. Howarth[59], J. Hoya[6], M. Hrabovsky[122], A. Hrynevich[48], T. Hryn'ova[4], P.J. Hsu[65], S.-C. Hsu[138], Q. Hu[62a], Y.F. Hu[14a,14e], S. Huang[64b], X. Huang[14c], X. Huang[14a,14e], Y. Huang[139], Y. Huang[14a], Z. Huang[101], Z. Hubacek[132], M. Huebner[24], F. Huegging[24], T.B. Huffman[126], C.A. Hugli[48], M. Huhtinen[36], S.K. Huiberts[16], R. Hulsken[104], N. Huseynov[12], J. Huston[107], J. Huth[61], R. Hyneman[143], G. Iacobucci[56], G. Iakovidis[29], I. Ibragimov[141], L. Iconomidou-Fayard[66], P. Iengo[72a,72b], R. Iguchi[153], T. Iizawa[126], Y. Ikegami[84], N. Ilic[155], H. Imam[35a], M. Ince Lezki[56], T. Ingebretsen Carlson[47a,47b], G. Introzzi[73a,73b], M. Iodice[77a], V. Ippolito[75a,75b], R.K. Irwin[92], M. Ishino[153], W. Islam[170], C. Issever[18,48], S. Istin[21a,am], H. Ito[168], J.M. Iturbe Ponce[64a], R. Iuppa[78a,78b], A. Ivina[169], J.M. Izen[45], V. Izzo[72a], P. Jacka[131,132], P. Jackson[1], R.M. Jacobs[48], B.P. Jaeger[142], C.S. Jagfeld[109], G. Jain[156a], P. Jain[54], K. Jakobs[54], T. Jakoubek[169], J. Jamieson[59], K.W. Janas[86a], M. Javurkova[103], F. Jeanneau[135], L. Jeanty[123], J. Jejelava[149a,ab], P. Jenni[54,g], C.E. Jessiman[34], S. Jézéquel[4], C. Jia[62b], J. Jia[145], X. Jia[61], X. Jia[14a,14e], Z. Jia[14c], S. Jiggins[48], J. Jimenez Pena[13], S. Jin[14c], A. Jinaru[27b], O. Jinnouchi[154], P. Johansson[139], K.A. Johns[7], J.W. Johnson[136], D.M. Jones[32], E. Jones[48], P. Jones[32], R.W.L. Jones[91], T.J. Jones[92], H.L. Joos[55,36], R. Joshi[119], J. Jovicevic[15], X. Ju[17a], J.J. Junggeburth[103], T. Junkermann[63a], A. Juste Rozas[13,u], M.K. Juzek[87], S. Kabana[137e], A. Kaczmarska[87], M. Kado[110], H. Kagan[119], M. Kagan[143], A. Kahn[41], A. Kahn[128], C. Kahra[100], T. Kaji[153], E. Kajomovitz[150], N. Kakati[169], I. Kalaitzidou[54], C.W. Kalderon[29], A. Kamenshchikov[155], N.J. Kang[136], D. Kar[33g], K. Karava[126], M.J. Kareem[156b], E. Karentzos[54], I. Karkanias[152],

O. Karkout [114], S.N. Karpov [38], Z.M. Karpova [38], V. Kartvelishvili [91], A.N. Karyukhin [37], E. Kasimi [152], J. Katzy [48], S. Kaur [34], K. Kawade [140], M.P. Kawale [120], C. Kawamoto [88], T. Kawamoto [62a], E.F. Kay [36], F.I. Kaya [158], S. Kazakos [107], V.F. Kazanin [37], Y. Ke [145], J.M. Keaveney [33a], R. Keeler [165], G.V. Kehris [61], J.S. Keller [34], A.S. Kelly[96], J.J. Kempster [146], K.E. Kennedy [41], P.D. Kennedy [100], O. Kepka [131], B.P. Kerridge [167], S. Kersten [171], B.P. Kerševan [93], S. Keshri [66], L. Keszeghova [28a], S. Ketabchi Haghighat [155], R.A. Khan [129], A. Khanov [121], A.G. Kharlamov [37], T. Kharlamova [37], E.E. Khoda [138], M. Kholodenko [37], T.J. Khoo [18], G. Khoriauli [166], J. Khubua [149b,*], Y.A.R. Khwaira [66], A. Kilgallon [123], D.W. Kim [47a,47b], Y.K. Kim [39], N. Kimura [96], M.K. Kingston [55], A. Kirchhoff [55], C. Kirfel [24], F. Kirfel [24], J. Kirk [134], A.E. Kiryunin [110], C. Kitsaki [10], O. Kivernyk [24], M. Klassen [63a], C. Klein [34], L. Klein [166], M.H. Klein [44], M. Klein [92], S.B. Klein [56], U. Klein [92], P. Klimek [36], A. Klimentov [29], T. Klioutchnikova [36], P. Kluit [114], S. Kluth [110], E. Kneringer [79], T.M. Knight [155], A. Knue [49], R. Kobayashi [88], D. Kobylianskii [169], S.F. Koch [126], M. Kocian [143], P. Kodyš [133], D.M. Koeck [123], P.T. Koenig [24], T. Koffas [34], O. Kolay [50], I. Koletsou [4], T. Komarek [122], K. Köneke [54], A.X.Y. Kong [1], T. Kono [118], N. Konstantinidis [96], P. Kontaxakis [56], B. Konya [98], R. Kopeliansky [68], S. Koperny [86a], K. Korcyl [87], K. Kordas [152,e], A. Korn [96], S. Korn [55], I. Korolkov [13], N. Korotkova [37], B. Kortman [114], O. Kortner [110], S. Kortner [110], W.H. Kostecka [115], V.V. Kostyukhin [141], A. Kotsokechagia [135], A. Kotwal [51], A. Koulouris [36], A. Kourkoumeli-Charalampidi [73a,73b], C. Kourkoumelis [9], E. Kourlitis [110,af], O. Kovanda [146], R. Kowalewski [165], W. Kozanecki [135], A.S. Kozhin [37], V.A. Kramarenko [37], G. Kramberger [93], P. Kramer [100], M.W. Krasny [127], A. Krasznahorkay [36], J.W. Kraus [171], J.A. Kremer [48], T. Kresse [50], J. Kretzschmar [92], K. Kreul [18], P. Krieger [155], S. Krishnamurthy [103], M. Krivos [133], K. Krizka [20], K. Kroeninger [49], H. Kroha [110], J. Kroll [131], J. Kroll [128], K.S. Krowpman [107], U. Kruchonak [38], H. Krüger [24], N. Krumnack[81], M.C. Kruse [51], O. Kuchinskaia [37], S. Kuday [3a], S. Kuehn [36], R. Kuesters [54], T. Kuhl [48], V. Kukhtin [38], Y. Kulchitsky [37,a], S. Kuleshov [137d,137b], M. Kumar [33g], N. Kumari [48], P. Kumari [156b], A. Kupco [131], T. Kupfer[49], A. Kupich [37], O. Kuprash [54], H. Kurashige [85], L.L. Kurchaninov [156a], O. Kurdysh [66], Y.A. Kurochkin [37], A. Kurova [37], M. Kuze [154], A.K. Kvam [103], J. Kvita [122], T. Kwan [104], N.G. Kyriacou [106], L.A.O. Laatu [102], C. Lacasta [163], F. Lacava [75a,75b], H. Lacker [18], D. Lacour [127], N.N. Lad [96], E. Ladygin [38], B. Laforge [127], T. Lagouri [137e], F.Z. Lahbabi [35a], S. Lai [55], I.K. Lakomiec [86a], N. Lalloue [60], J.E. Lambert [165], S. Lammers [68], W. Lampl [7], C. Lampoudis [152,e], A.N. Lancaster [115], E. Lançon [29], U. Landgraf [54], M.P.J. Landon [94], V.S. Lang [54], R.J. Langenberg [103], O.K.B. Langrekken [125], A.J. Lankford [159], F. Lanni [36], K. Lantzsch [24], A. Lanza [73a], A. Lapertosa [57b,57a], J.F. Laporte [135], T. Lari [71a], F. Lasagni Manghi [23b], M. Lassnig [36], V. Latonova [131], A. Laudrain [100], A. Laurier [150], S.D. Lawlor [139], Z. Lawrence [101], R. Lazaridou[167], M. Lazzaroni [71a,71b], B. Le[101], E.M. Le Boulicaut [51], B. Leban [93], A. Lebedev [81], M. LeBlanc [101], T. LeCompte [6], F. Ledroit-Guillon [60], A.C.A. Lee[96], S.C. Lee [148], S. Lee [47a,47b], T.F. Lee [92], L.L. Leeuw [33c], H.P. Lefebvre [95], M. Lefebvre [165], C. Leggett [17a], G. Lehmann Miotto [36], M. Leigh [56], W.A. Leight [103], W. Leinonen [113], A. Leisos [152,t], M.A.L. Leite [83c], C.E. Leitgeb [48], R. Leitner [133], K.J.C. Leney [44], T. Lenz [24], S. Leone [74a], C. Leonidopoulos [52], A. Leopold [144], C. Leroy [108], R. Les [107], C.G. Lester [32], M. Levchenko [37], J. Levêque [4], D. Levin [106], L.J. Levinson [169], M.P. Lewicki [87], D.J. Lewis [4], A. Li [5], B. Li [62b], C. Li[62a], C-Q. Li [110], H. Li [62a], H. Li [62b], H. Li [14c], H. Li [14b], H. Li [62b], J. Li [62c], K. Li [138], L. Li [62c], M. Li [14a,14e], Q.Y. Li [62a], S. Li [14a,14e], S. Li [62d,62c,d], T. Li [5], X. Li [104], Z. Li [126], Z. Li [104], Z. Li [14a,14e], S. Liang [14a,14e], Z. Liang [14a], M. Liberatore [135], B. Liberti [76a], K. Lie [64c], J. Lieber Marin [83b], H. Lien [68], K. Lin [107], R.E. Lindley [7], J.H. Lindon [2], E. Lipeles [128],

A. Lipniacka [16], A. Lister [164], J.D. Little [4], B. Liu [14a], B.X. Liu [142], D. Liu [62d,62c], J.B. Liu [62a], J.K.K. Liu [32], K. Liu [62d,62c], M. Liu [62a], M.Y. Liu [62a], P. Liu [14a], Q. Liu [62d,138,62c], X. Liu [62a], X. Liu [62b], Y. Liu [14d,14e], Y.L. Liu [62b], Y.W. Liu [62a], J. Llorente Merino [142], S.L. Lloyd [94], E.M. Lobodzinska [48], P. Loch [7], T. Lohse [18], K. Lohwasser [139], E. Loiacono [48], M. Lokajicek [131,*], J.D. Lomas [20], J.D. Long [162], I. Longarini [159], L. Longo [70a,70b], R. Longo [162], I. Lopez Paz [67], A. Lopez Solis [48], N. Lorenzo Martinez [4], A.M. Lory [109], G. Löschcke Centeno [146], O. Loseva [37], X. Lou [47a,47b], X. Lou [14a,14e], A. Lounis [66], J. Love [6], P.A. Love [91], G. Lu [14a,14e], M. Lu [80], S. Lu [128], Y.J. Lu [65], H.J. Lubatti [138], C. Luci [75a,75b], F.L. Lucio Alves [14c], A. Lucotte [60], F. Luehring [68], I. Luise [145], O. Lukianchuk [66], O. Lundberg [144], B. Lund-Jensen [144,*], N.A. Luongo [6], M.S. Lutz [151], A.B. Lux [25], D. Lynn [29], H. Lyons[92], R. Lysak [131], E. Lytken [98], V. Lyubushkin [38], T. Lyubushkina [38], M.M. Lyukova [145], H. Ma [29], K. Ma [62a], L.L. Ma [62b], W. Ma [62a], Y. Ma [121], D.M. Mac Donell [165], G. Maccarrone [53], J.C. MacDonald [100], P.C. Machado De Abreu Farias [83b], R. Madar [40], W.F. Mader [50], T. Madula [96], J. Maeda [85], T. Maeno [29], H. Maguire [139], V. Maiboroda [135], A. Maio [130a,130b,130d], K. Maj [86a], O. Majersky [48], S. Majewski [123], N. Makovec [66], V. Maksimovic [15], B. Malaescu [127], Pa. Malecki [87], V.P. Maleev [37], F. Malek [60,o], M. Mali [93], D. Malito [95], U. Mallik [80,*], S. Maltezos[10], S. Malyukov[38], J. Mamuzic [13], G. Mancini [53], G. Manco [73a,73b], J.P. Mandalia [94], I. Mandić [93], L. Manhaes de Andrade Filho [83a], I.M. Maniatis [169], J. Manjarres Ramos [102,ac], D.C. Mankad [169], A. Mann [109], B. Mansoulie [135], S. Manzoni [36], L. Mao [62c], X. Mapekula [33c], A. Marantis [152,t], G. Marchiori [5], M. Marcisovsky [131], C. Marcon [71a], M. Marinescu [20], S. Marium [48], M. Marjanovic [120], E.J. Marshall [91], Z. Marshall [17a], S. Marti-Garcia [163], T.A. Martin [167], V.J. Martin [52], B. Martin dit Latour [16], L. Martinelli [75a,75b], M. Martinez [13,u], P. Martinez Agullo [163], V.I. Martinez Outschoorn [103], P. Martinez Suarez [13], S. Martin-Haugh [134], V.S. Martoiu [27b], A.C. Martyniuk [96], A. Marzin [36], D. Mascione [78a,78b], L. Masetti [100], T. Mashimo [153], J. Masik [101], A.L. Maslennikov [37], P. Massarotti [72a,72b], P. Mastrandrea [74a,74b], A. Mastroberardino [43b,43a], T. Masubuchi [153], T. Mathisen [161], J. Matousek [133], N. Matsuzawa[153], J. Maurer [27b], B. Maček [93], D.A. Maximov [37], R. Mazini [148], I. Maznas [152], M. Mazza [107], S.M. Mazza [136], E. Mazzeo [71a,71b], C. Mc Ginn [29], J.P. Mc Gowan [104], S.P. Mc Kee [106], C.C. McCracken [164], E.F. McDonald [105], A.E. McDougall [114], J.A. Mcfayden [146], R.P. McGovern [128], G. Mchedlidze [149b], R.P. Mckenzie [33g], T.C. Mclachlan [48], D.J. Mclaughlin [96], S.J. McMahon [134], C.M. Mcpartland [92], R.A. McPherson [165,y], S. Mehlhase [109], A. Mehta [92], D. Melini [150], B.R. Mellado Garcia [33g], A.H. Melo [55], F. Meloni [48], A.M. Mendes Jacques Da Costa [101], H.Y. Meng [155], L. Meng [91], S. Menke [110], M. Mentink [36], E. Meoni [43b,43a], G. Mercado [115], C. Merlassino [69a,69c], L. Merola [72a,72b], C. Meroni [71a,71b], J. Metcalfe [6], A.S. Mete [6], C. Meyer [68], J-P. Meyer [135], R.P. Middleton [134], L. Mijović [52], G. Mikenberg [169], M. Mikestikova [131], M. Mikuž [93], H. Mildner [100], A. Milic [36], C.D. Milke [44], D.W. Miller [39], E.H. Miller [143], L.S. Miller [34], A. Milov [169], D.A. Milstead[47a,47b], T. Min[14c], A.A. Minaenko [37], I.A. Minashvili [149b], L. Mince [59], A.I. Mincer [117], B. Mindur [86a], M. Mineev [38], Y. Mino [88], L.M. Mir [13], M. Miralles Lopez [163], M. Mironova [17a], A. Mishima[153], M.C. Missio [113], A. Mitra [167], V.A. Mitsou [163], Y. Mitsumori [111], O. Miu [155], P.S. Miyagawa [94], T. Mkrtchyan [63a], M. Mlinarevic [96], T. Mlinarevic [96], M. Mlynarikova [36], S. Mobius [19], P. Moder [48], P. Mogg [109], M.H. Mohamed Farook [112], A.F. Mohammed [14a,14e], S. Mohapatra [41], G. Mokgatitswane [33g], L. Moleri [169], B. Mondal [141], S. Mondal [132], K. Mönig [48], E. Monnier [102], L. Monsonis Romero[163], J. Montejo Berlingen [13], M. Montella [119], F. Montereali [77a,77b], F. Monticelli [90], S. Monzani [69a,69c], N. Morange [66], A.L. Moreira De Carvalho [130a], M. Moreno Llácer [163], C. Moreno Martinez [56], P. Morettini [57b],

S. Morgenstern [36], M. Morii [61], M. Morinaga [153], A.K. Morley [36], F. Morodei [75a,75b],
L. Morvaj [36], P. Moschovakos [36], B. Moser [36], M. Mosidze [149b], T. Moskalets [54],
P. Moskvitina [113], J. Moss [31,l], E.J.W. Moyse [103], O. Mtintsilana [33g], S. Muanza [102],
J. Mueller [129], D. Muenstermann [91], R. Müller [19], G.A. Mullier [161], A.J. Mullin[32], J.J. Mullin[128],
D.P. Mungo [155], D. Munoz Perez [163], F.J. Munoz Sanchez [101], M. Murin [101], W.J. Murray [167,134],
A. Murrone [71a,71b], M. Muškinja [17a], C. Mwewa [29], A.G. Myagkov [37,a], A.J. Myers [8],
G. Myers [68], M. Myska [132], B.P. Nachman [17a], O. Nackenhorst [49], A. Nag [50], K. Nagai [126],
K. Nagano [84], J.L. Nagle [29,ak], E. Nagy [102], A.M. Nairz [36], Y. Nakahama [84], K. Nakamura [84],
K. Nakkalil [5], H. Nanjo [124], R. Narayan [44], E.A. Narayanan [112], I. Naryshkin [37], M. Naseri [34],
S. Nasri [116b], C. Nass [24], G. Navarro [22a], J. Navarro-Gonzalez [163], R. Nayak [151], A. Nayaz [18],
P.Y. Nechaeva [37], F. Nechansky [48], L. Nedic [126], T.J. Neep [20], A. Negri [73a,73b], M. Negrini [23b],
C. Nellist [114], C. Nelson [104], K. Nelson [106], S. Nemecek [131], M. Nessi [36,h], M.S. Neubauer [162],
F. Neuhaus [100], J. Neundorf [48], R. Newhouse [164], P.R. Newman [20], C.W. Ng [129], Y.W.Y. Ng [48],
B. Ngair [116a], H.D.N. Nguyen [108], R.B. Nickerson [126], R. Nicolaidou [135], J. Nielsen [136],
M. Niemeyer [55], J. Niermann [55,36], N. Nikiforou [36], V. Nikolaenko [37,a], I. Nikolic-Audit [127],
K. Nikolopoulos [20], P. Nilsson [29], I. Ninca [48], H.R. Nindhito [56], G. Ninio [151], A. Nisati [75a],
N. Nishu [2], R. Nisius [110], J-E. Nitschke [50], E.K. Nkadimeng [33g], T. Nobe [153], D.L. Noel [32],
T. Nommensen [147], M.B. Norfolk [139], R.R.B. Norisam [96], B.J. Norman [34], M. Noury [35a],
J. Novak [93], T. Novak [48], L. Novotny [132], R. Novotny [112], L. Nozka [122], K. Ntekas [159],
N.M.J. Nunes De Moura Junior [83b], E. Nurse[96], J. Ocariz [127], A. Ochi [85], I. Ochoa [130a],
S. Oerdek [48,v], J.T. Offermann [39], A. Ogrodnik [133], A. Oh [101], C.C. Ohm [144], H. Oide [84],
R. Oishi [153], M.L. Ojeda [48], Y. Okumura [153], L.F. Oleiro Seabra [130a], S.A. Olivares Pino [137d],
D. Oliveira Damazio [29], D. Oliveira Goncalves [83a], J.L. Oliver [159], Ö.O. Öncel [54], A.P. O'Neill [19],
A. Onofre [130a,130e], P.U.E. Onyisi [11], M.J. Oreglia [39], G.E. Orellana [90], D. Orestano [77a,77b],
N. Orlando [13], R.S. Orr [155], V. O'Shea [59], L.M. Osojnak [128], R. Ospanov [62a],
G. Otero y Garzon [30], H. Otono [89], P.S. Ott [63a], G.J. Ottino [17a], M. Ouchrif [35d], J. Ouellette [29],
F. Ould-Saada [125], M. Owen [59], R.E. Owen [134], K.Y. Oyulmaz [21a], V.E. Ozcan [21a], F. Ozturk [87],
N. Ozturk [8], S. Ozturk [82], H.A. Pacey [126], A. Pacheco Pages [13], C. Padilla Aranda [13],
G. Padovano [75a,75b], S. Pagan Griso [17a], G. Palacino [68], A. Palazzo [70a,70b], J. Pan [172], T. Pan [64a],
D.K. Panchal [11], C.E. Pandini [114], J.G. Panduro Vazquez [95], H.D. Pandya [1], H. Pang [14b],
P. Pani [48], G. Panizzo [69a,69c], L. Paolozzi [56], C. Papadatos [108], S. Parajuli [162], A. Paramonov [6],
C. Paraskevopoulos [10], D. Paredes Hernandez [64b], K.R. Park [41], T.H. Park [155], M.A. Parker [32],
F. Parodi [57b,57a], E.W. Parrish [115], V.A. Parrish [52], J.A. Parsons [41], U. Parzefall [54],
B. Pascual Dias [108], L. Pascual Dominguez [151], E. Pasqualucci [75a], S. Passaggio [57b], F. Pastore [95],
P. Pasuwan [47a,47b], P. Patel [87], U.M. Patel [51], J.R. Pater [101], T. Pauly [36], J. Pearkes [143],
M. Pedersen [125], R. Pedro [130a], S.V. Peleganchuk [37], O. Penc [36], E.A. Pender [52],
K.E. Penski [109], M. Penzin [37], B.S. Peralva [83d], A.P. Pereira Peixoto [60], L. Pereira Sanchez [47a,47b],
D.V. Perepelitsa [29,ak], E. Perez Codina [156a], M. Perganti [10], L. Perini [71a,71b,*], H. Pernegger [36],
O. Perrin [40], K. Peters [48], R.F.Y. Peters [101], B.A. Petersen [36], T.C. Petersen [42], E. Petit [102],
V. Petousis [132], C. Petridou [152,e], A. Petrukhin [141], M. Pettee [17a], N.E. Pettersson [36],
A. Petukhov [37], K. Petukhova [133], R. Pezoa [137f], L. Pezzotti [36], G. Pezzullo [172], T.M. Pham [170],
T. Pham [105], P.W. Phillips [134], G. Piacquadio [145], E. Pianori [17a], F. Piazza [123], R. Piegaia [30],
D. Pietreanu [27b], A.D. Pilkington [101], M. Pinamonti [69a,69c], J.L. Pinfold [2],
B.C. Pinheiro Pereira [130a], A.E. Pinto Pinoargote [100,135], L. Pintucci [69a,69c], K.M. Piper [146],
A. Pirttikoski [56], D.A. Pizzi [34], L. Pizzimento [64b], A. Pizzini [114], M.-A. Pleier [29], V. Plesanovs[54],
V. Pleskot [133], E. Plotnikova[38], G. Poddar [4], R. Poettgen [98], L. Poggioli [127], I. Pokharel [55],
S. Polacek [133], G. Polesello [73a], A. Poley [142,156a], R. Polifka [132], A. Polini [23b], C.S. Pollard [167],

Z.B. Pollock[119], V. Polychronakos[29], E. Pompa Pacchi[75a,75b], D. Ponomarenko[113], L. Pontecorvo[36], S. Popa[27a], G.A. Popeneciu[27d], A. Poreba[36], D.M. Portillo Quintero[156a], S. Pospisil[132], M.A. Postill[139], P. Postolache[27c], K. Potamianos[167], P.A. Potepa[86a], I.N. Potrap[38], C.J. Potter[32], H. Potti[1], T. Poulsen[48], J. Poveda[163], M.E. Pozo Astigarraga[36], A. Prades Ibanez[163], J. Pretel[54], D. Price[101], M. Primavera[70a], M.A. Principe Martin[99], R. Privara[122], T. Procter[59], M.L. Proffitt[138], N. Proklova[128], K. Prokofiev[64c], G. Proto[110], S. Protopopescu[29], J. Proudfoot[6], M. Przybycien[86a], W.W. Przygoda[86b], A. Psallidas[46], J.E. Puddefoot[139], D. Pudzha[37], D. Pyatiizbyantseva[37], J. Qian[106], D. Qichen[101], Y. Qin[101], T. Qiu[52], A. Quadt[55], M. Queitsch-Maitland[101], G. Quetant[56], R.P. Quinn[164], G. Rabanal Bolanos[61], D. Rafanoharana[54], F. Ragusa[71a,71b], J.L. Rainbolt[39], J.A. Raine[56], S. Rajagopalan[29], E. Ramakoti[37], I.A. Ramirez-Berend[34], K. Ran[48,14e], N.P. Rapheeha[33g], H. Rasheed[27b], V. Raskina[127], D.F. Rassloff[63a], A. Rastogi[17a], S. Rave[100], B. Ravina[55], I. Ravinovich[169], M. Raymond[36], A.L. Read[125], N.P. Readioff[139], D.M. Rebuzzi[73a,73b], G. Redlinger[29], A.S. Reed[110], K. Reeves[26], J.A. Reidelsturz[171], D. Reikher[151], A. Rej[49], C. Rembser[36], A. Renardi[48], M. Renda[27b], M.B. Rendel[110], F. Renner[48], A.G. Rennie[159], A.L. Rescia[48], S. Resconi[71a], M. Ressegotti[57b,57a], S. Rettie[36], J.G. Reyes Rivera[107], E. Reynolds[17a], O.L. Rezanova[37], P. Reznicek[133], N. Ribaric[91], E. Ricci[78a,78b], R. Richter[110], S. Richter[47a,47b], E. Richter-Was[86b], M. Ridel[127], S. Ridouani[35d], P. Rieck[117], P. Riedler[36], E.M. Riefel[47a,47b], J.O. Rieger[114], M. Rijssenbeek[145], A. Rimoldi[73a,73b], M. Rimoldi[36], L. Rinaldi[23b,23a], T.T. Rinn[29], M.P. Rinnagel[109], G. Ripellino[161], I. Riu[13], P. Rivadeneira[48], J.C. Rivera Vergara[165], F. Rizatdinova[121], E. Rizvi[94], B.A. Roberts[167], B.R. Roberts[17a], S.H. Robertson[104,y], D. Robinson[32], C.M. Robles Gajardo[137f], M. Robles Manzano[100], A. Robson[59], A. Rocchi[76a,76b], C. Roda[74a,74b], S. Rodriguez Bosca[63a], Y. Rodriguez Garcia[22a], A. Rodriguez Rodriguez[54], A.M. Rodríguez Vera[156b], S. Roe[36], J.T. Roemer[159], A.R. Roepe-Gier[136], J. Roggel[171], O. Røhne[125], R.A. Rojas[103], C.P.A. Roland[127], J. Roloff[29], A. Romaniouk[37], E. Romano[73a,73b], M. Romano[23b], A.C. Romero Hernandez[162], N. Rompotis[92], L. Roos[127], S. Rosati[75a], B.J. Rosser[39], E. Rossi[126], E. Rossi[72a,72b], L.P. Rossi[57b], L. Rossini[54], R. Rosten[119], M. Rotaru[27b], B. Rottler[54], C. Rougier[102,ac], D. Rousseau[66], D. Rousso[32], A. Roy[162], S. Roy-Garand[155], A. Rozanov[102], Z.M.A. Rozario[59], Y. Rozen[150], X. Ruan[33g], A. Rubio Jimenez[163], A.J. Ruby[92], V.H. Ruelas Rivera[18], T.A. Ruggeri[1], A. Ruggiero[126], A. Ruiz-Martinez[163], A. Rummler[36], Z. Rurikova[54], N.A. Rusakovich[38], H.L. Russell[165], G. Russo[75a,75b], J.P. Rutherfoord[7], S. Rutherford Colmenares[32], K. Rybacki[91], M. Rybar[133], E.B. Rye[125], A. Ryzhov[44], J.A. Sabater Iglesias[56], P. Sabatini[163], H.F-W. Sadrozinski[136], F. Safai Tehrani[75a], B. Safarzadeh Samani[134], M. Safdari[143], S. Saha[165], M. Sahinsoy[110], A. Saibel[163], M. Saimpert[135], M. Saito[153], T. Saito[153], D. Salamani[36], A. Salnikov[143], J. Salt[163], A. Salvador Salas[151], D. Salvatore[43b,43a], F. Salvatore[146], A. Salzburger[36], D. Sammel[54], D. Sampsonidis[152,e], D. Sampsonidou[123], J. Sánchez[163], A. Sanchez Pineda[4], V. Sanchez Sebastian[163], H. Sandaker[125], C.O. Sander[48], J.A. Sandesara[103], M. Sandhoff[171], C. Sandoval[22b], D.P.C. Sankey[134], T. Sano[88], A. Sansoni[53], L. Santi[75a,75b], C. Santoni[40], H. Santos[130a,130b], A. Santra[169], K.A. Saoucha[160], J.G. Saraiva[130a,130d], J. Sardain[7], O. Sasaki[84], K. Sato[157], C. Sauer[63b], F. Sauerburger[54], E. Sauvan[4], P. Savard[155,ah], R. Sawada[153], C. Sawyer[134], L. Sawyer[97], I. Sayago Galvan[163], C. Sbarra[23b], A. Sbrizzi[23b,23a], T. Scanlon[96], J. Schaarschmidt[138], U. Schäfer[100], A.C. Schaffer[66,44], D. Schaile[109], R.D. Schamberger[145], C. Scharf[18], M.M. Schefer[19], V.A. Schegelsky[37], D. Scheirich[133], F. Schenck[18], M. Schernau[159], C. Scheulen[55], C. Schiavi[57b,57a], E.J. Schioppa[70a,70b], M. Schioppa[43b,43a], B. Schlag[143,n], K.E. Schleicher[54], S. Schlenker[36], J. Schmeing[171], M.A. Schmidt[171], K. Schmieden[100], C. Schmitt[100], N. Schmitt[100], S. Schmitt[48], L. Schoeffel[135], A. Schoening[63b], P.G. Scholer[54], E. Schopf[126], M. Schott[100], J. Schovancova[36], S. Schramm[56], F. Schroeder[171], T. Schroer[56], H-C. Schultz-Coulon[63a], M. Schumacher[54], B.A. Schumm[136], Ph. Schune[135], A.J. Schuy[138], H.R. Schwartz[136], A. Schwartzman[143], T.A. Schwarz[106], Ph. Schwemling[135], R. Schwienhorst[107], A. Sciandra[136], G. Sciolla[26], F. Scuri[74a], C.D. Sebastiani[92], K. Sedlaczek[115], P. Seema[18], S.C. Seidel[112], A. Seiden[136], B.D. Seidlitz[41], C. Seitz[48], J.M. Seixas[83b], G. Sekhniaidze[72a], L. Selem[60], N. Semprini-Cesari[23b,23a], D. Sengupta[56], V. Senthilkumar[163], L. Serin[66], L. Serkin[69a,69b], M. Sessa[76a,76b], H. Severini[120], F. Sforza[57b,57a], A. Sfyrla[56], E. Shabalina[55], R. Shaheen[144], J.D. Shahinian[128], D. Shaked Renous[169], L.Y. Shan[14a], M. Shapiro[17a], A. Sharma[36], A.S. Sharma[164], P. Sharma[80], S. Sharma[48], P.B. Shatalov[37], K. Shaw[146], S.M. Shaw[101], A. Shcherbakova[37], Q. Shen[62c,5], D.J. Sheppard[142], P. Sherwood[96], L. Shi[96], X. Shi[14a], C.O. Shimmin[172], J.D. Shinner[95], I.P.J. Shipsey[126], S. Shirabe[56,h], M. Shiyakova[38,w], J. Shlomi[169], M.J. Shochet[39], J. Shojaii[105], D.R. Shope[125], B. Shrestha[120], S. Shrestha[119,al], E.M. Shrif[33g], M.J. Shroff[165], P. Sicho[131], A.M. Sickles[162], E. Sideras Haddad[33g], A. Sidoti[23b], F. Siegert[50], Dj. Sijacki[15], F. Sili[90], J.M. Silva[20], M.V. Silva Oliveira[29], S.B. Silverstein[47a], S. Simion[66], R. Simoniello[36], E.L. Simpson[59], H. Simpson[146], L.R. Simpson[106], N.D. Simpson[98], S. Simsek[82], S. Sindhu[55], P. Sinervo[155], S. Singh[155], S. Sinha[48], S. Sinha[101], M. Sioli[23b,23a], I. Siral[36], E. Sitnikova[48], S.Yu. Sivoklokov[37,*], J. Sjölin[47a,47b], A. Skaf[55], E. Skorda[20], P. Skubic[120], M. Slawinska[87], V. Smakhtin[169], B.H. Smart[134], S.Yu. Smirnov[37], Y. Smirnov[37], L.N. Smirnova[37,a], O. Smirnova[98], A.C. Smith[41], E.A. Smith[39], H.A. Smith[126], J.L. Smith[92], R. Smith[143], M. Smizanska[91], K. Smolek[132], A.A. Snesarev[37], S.R. Snider[155], H.L. Snoek[114], S. Snyder[29], R. Sobie[165,y], A. Soffer[151], C.A. Solans Sanchez[36], E.Yu. Soldatov[37], U. Soldevila[163], A.A. Solodkov[37], S. Solomon[26], A. Soloshenko[38], K. Solovieva[54], O.V. Solovyanov[40], V. Solovyev[37], P. Sommer[36], A. Sonay[13], W.Y. Song[156b], J.M. Sonneveld[114], A. Sopczak[132], A.L. Sopio[96], F. Sopkova[28b], J.D. Sorenson[112], I.R. Sotarriva Alvarez[154], V. Sothilingam[63a], O.J. Soto Sandoval[137c,137b], S. Sottocornola[68], R. Soualah[160], Z. Soumaimi[35e], D. South[48], N. Soybelman[169], S. Spagnolo[70a,70b], M. Spalla[110], D. Sperlich[54], G. Spigo[36], S. Spinali[91], D.P. Spiteri[59], M. Spousta[133], E.J. Staats[34], A. Stabile[71a,71b], R. Stamen[63a], A. Stampekis[20], M. Standke[24], E. Stanecka[87], M.V. Stange[50], B. Stanislaus[17a], M.M. Stanitzki[48], B. Stapf[48], E.A. Starchenko[37], G.H. Stark[136], J. Stark[102,ac], P. Staroba[131], P. Starovoitov[63a], S. Stärz[104], R. Staszewski[87], G. Stavropoulos[46], J. Steentoft[161], P. Steinberg[29], B. Stelzer[142,156a], H.J. Stelzer[129], O. Stelzer-Chilton[156a], H. Stenzel[58], T.J. Stevenson[146], G.A. Stewart[36], J.R. Stewart[121], M.C. Stockton[36], G. Stoicea[27b], M. Stolarski[130a], S. Stonjek[110], A. Straessner[50], J. Strandberg[144], S. Strandberg[47a,47b], M. Stratmann[171], M. Strauss[120], T. Strebler[102], P. Strizenec[28b], R. Ströhmer[166], D.M. Strom[123], R. Stroynowski[44], A. Strubig[47a,47b], S.A. Stucci[29], B. Stugu[16], J. Stupak[120], N.A. Styles[48], D. Su[143], S. Su[62a], W. Su[62d], X. Su[62a,66], K. Sugizaki[153], V.V. Sulin[37], M.J. Sullivan[92], D.M.S. Sultan[78a,78b], L. Sultanaliyeva[37], S. Sultansoy[3b], T. Sumida[88], S. Sun[106], S. Sun[170], O. Sunneborn Gudnadottir[161], N. Sur[102], M.R. Sutton[146], H. Suzuki[157], M. Svatos[131], M. Swiatlowski[156a], T. Swirski[166], I. Sykora[28a], M. Sykora[133], T. Sykora[133], D. Ta[100], K. Tackmann[48,v], A. Taffard[159], R. Tafirout[156a], J.S. Tafoya Vargas[66], E.P. Takeva[52], Y. Takubo[84], M. Talby[102], A.A. Talyshev[37], K.C. Tam[64b], N.M. Tamir[151], A. Tanaka[153], J. Tanaka[153], R. Tanaka[66], M. Tanasini[57b,57a], Z. Tao[164], S. Tapia Araya[137f], S. Tapprogge[100], A. Tarek Abouelfadl Mohamed[107], S. Tarem[150], K. Tariq[14a], G. Tarna[102,27b], G.F. Tartarelli[71a], P. Tas[133], M. Tasevsky[131], E. Tassi[43b,43a], A.C. Tate[162], G. Tateno[153],

Y. Tayalati[35e,x], G.N. Taylor[105], W. Taylor[156b], A.S. Tee[170], R. Teixeira De Lima[143], P. Teixeira-Dias[95], J.J. Teoh[155], K. Terashi[153], J. Terron[99], S. Terzo[13], M. Testa[53], R.J. Teuscher[155,y], A. Thaler[79], O. Theiner[56], N. Themistokleous[52], T. Theveneaux-Pelzer[102], O. Thielmann[171], D.W. Thomas[95], J.P. Thomas[20], E.A. Thompson[17a], P.D. Thompson[20], E. Thomson[128], Y. Tian[55], V. Tikhomirov[37,a], Yu.A. Tikhonov[37], S. Timoshenko[37], D. Timoshyn[133], E.X.L. Ting[1], P. Tipton[172], S.H. Tlou[33g], A. Tnourji[40], K. Todome[154], S. Todorova-Nova[133], S. Todt[50], M. Togawa[84], J. Tojo[89], S. Tokár[28a], K. Tokushuku[84], O. Toldaiev[68], R. Tombs[32], M. Tomoto[84,111], L. Tompkins[143,n], K.W. Topolnicki[86b], E. Torrence[123], H. Torres[102,ac], E. Torró Pastor[163], M. Toscani[30], C. Tosciri[39], M. Tost[11], D.R. Tovey[139], A. Traeet[16], I.S. Trandafir[27b], T. Trefzger[166], A. Tricoli[29], I.M. Trigger[156a], S. Trincaz-Duvoid[127], D.A. Trischuk[26], B. Trocmé[60], C. Troncon[71a], L. Truong[33c], M. Trzebinski[87], A. Trzupek[87], F. Tsai[145], M. Tsai[106], A. Tsiamis[152,e], P.V. Tsiareshka[37], S. Tsigaridas[156a], A. Tsirigotis[152,t], V. Tsiskaridze[155], E.G. Tskhadadze[149a], M. Tsopoulou[152,e], Y. Tsujikawa[88], I.I. Tsukerman[37], V. Tsulaia[17a], S. Tsuno[84], K. Tsuri[118], D. Tsybychev[145], Y. Tu[64b], A. Tudorache[27b], V. Tudorache[27b], A.N. Tuna[61], S. Turchikhin[57b,57a], I. Turk Cakir[3a], R. Turra[71a], T. Turtuvshin[38,z], P.M. Tuts[41], S. Tzamarias[152,e], P. Tzanis[10], E. Tzovara[100], F. Ukegawa[157], P.A. Ulloa Poblete[137c,137b], E.N. Umaka[29], G. Unal[36], M. Unal[11], A. Undrus[29], G. Unel[159], J. Urban[28b], P. Urquijo[105], P. Urrejola[137a], G. Usai[8], R. Ushioda[154], M. Usman[108], Z. Uysal[82], V. Vacek[132], B. Vachon[104], K.O.H. Vadla[125], T. Vafeiadis[36], A. Vaitkus[96], C. Valderanis[109], E. Valdes Santurio[47a,47b], M. Valente[156a], S. Valentinetti[23b,23a], A. Valero[163], E. Valiente Moreno[163], A. Vallier[102,ac], J.A. Valls Ferrer[163], D.R. Van Arneman[114], T.R. Van Daalen[138], A. Van Der Graaf[49], P. Van Gemmeren[6], M. Van Rijnbach[125,36], S. Van Stroud[96], I. Van Vulpen[114], M. Vanadia[76a,76b], W. Vandelli[36], M. Vandenbroucke[135], E.R. Vandewall[121], D. Vannicola[151], L. Vannoli[57b,57a], R. Vari[75a], E.W. Varnes[7], C. Varni[17b], T. Varol[148], D. Varouchas[66], L. Varriale[163], K.E. Varvell[147], M.E. Vasile[27b], L. Vaslin[84], G.A. Vasquez[165], A. Vasyukov[38], F. Vazeille[40], T. Vazquez Schroeder[36], J. Veatch[31], V. Vecchio[101], M.J. Veen[103], I. Veliscek[126], L.M. Veloce[155], F. Veloso[130a,130c], S. Veneziano[75a], A. Ventura[70a,70b], S. Ventura Gonzalez[135], A. Verbytskyi[110], M. Verducci[74a,74b], C. Vergis[24], M. Verissimo De Araujo[83b], W. Verkerke[114], J.C. Vermeulen[114], C. Vernieri[143], M. Vessella[103], M.C. Vetterli[142,ah], A. Vgenopoulos[152,e], N. Viaux Maira[137f], T. Vickey[139], O.E. Vickey Boeriu[139], G.H.A. Viehhauser[126], L. Vigani[63b], M. Villa[23b,23a], M. Villaplana Perez[163], E.M. Villhauer[52], E. Vilucchi[53], M.G. Vincter[34], G.S. Virdee[20], A. Vishwakarma[52], A. Visibile[114], C. Vittori[36], I. Vivarelli[146], E. Voevodina[110], F. Vogel[109], J.C. Voigt[50], P. Vokac[132], Yu. Volkotrub[86a], J. Von Ahnen[48], E. Von Toerne[24], B. Vormwald[36], V. Vorobel[133], K. Vorobev[37], M. Vos[163], K. Voss[141], J.H. Vossebeld[92], M. Vozak[114], L. Vozdecky[94], N. Vranjes[15], M. Vranjes Milosavljevic[15], M. Vreeswijk[114], N.K. Vu[62d,62c], R. Vuillermet[36], O. Vujinovic[100], I. Vukotic[39], S. Wada[157], C. Wagner[103], J.M. Wagner[17a], W. Wagner[171], S. Wahdan[171], H. Wahlberg[90], M. Wakida[111], J. Walder[134], R. Walker[109], W. Walkowiak[141], A. Wall[128], T. Wamorkar[6], A.Z. Wang[136], C. Wang[100], C. Wang[62c], H. Wang[17a], J. Wang[64a], R.-J. Wang[100], R. Wang[61], R. Wang[6], S.M. Wang[148], S. Wang[62b], T. Wang[62a], W.T. Wang[80], W. Wang[14a], X. Wang[14c], X. Wang[162], X. Wang[62c], Y. Wang[62d], Y. Wang[14c], Z. Wang[106], Z. Wang[62d,51,62c], Z. Wang[106], A. Warburton[104], R.J. Ward[20], N. Warrack[59], A.T. Watson[20], H. Watson[59], M.F. Watson[20], E. Watton[59,134], G. Watts[138], B.M. Waugh[96], C. Weber[29], H.A. Weber[18], M.S. Weber[19], S.M. Weber[63a], C. Wei[62a], Y. Wei[126], A.R. Weidberg[126], E.J. Weik[117], J. Weingarten[49], M. Weirich[100], C. Weiser[54], C.J. Wells[48], T. Wenaus[29],

B. Wendland [49], T. Wengler [36], N.S. Wenke[110], N. Wermes [24], M. Wessels [63a], A.M. Wharton [91], A.S. White [61], A. White [8], M.J. White [1], D. Whiteson [159], L. Wickremasinghe [124], W. Wiedenmann [170], M. Wielers [134], C. Wiglesworth [42], D.J. Wilbern[120], H.G. Wilkens [36], D.M. Williams [41], H.H. Williams[128], S. Williams [32], S. Willocq [103], B.J. Wilson [101], P.J. Windischhofer [39], F.I. Winkel [30], F. Winklmeier [123], B.T. Winter [54], J.K. Winter [101], M. Wittgen[143], M. Wobisch [97], Z. Wolffs [114], J. Wollrath[159], M.W. Wolter [87], H. Wolters [130a,130c], A.F. Wongel [48], E.L. Woodward [41], S.D. Worm [48], B.K. Wosiek [87], K.W. Woźniak [87], S. Wozniewski [55], K. Wraight [59], C. Wu [20], J. Wu [14a,14e], M. Wu [64a], M. Wu [113], S.L. Wu [170], X. Wu [56], X. Wu [62a], Y. Wu [62a], Z. Wu [135], J. Wuerzinger [110,af], T.R. Wyatt [101], B.M. Wynne [52], S. Xella [42], L. Xia [14c], M. Xia [14b], J. Xiang [64c], M. Xie [62a], X. Xie [62a], S. Xin [14a,14e], A. Xiong [123], J. Xiong [17a], D. Xu [14a], H. Xu [62a], L. Xu [62a], R. Xu [128], T. Xu [106], Y. Xu [14b], Z. Xu [52], Z. Xu[14c], B. Yabsley [147], S. Yacoob [33a], Y. Yamaguchi [154], E. Yamashita [153], H. Yamauchi [157], T. Yamazaki [17a], Y. Yamazaki [85], J. Yan[62c], S. Yan [126], Z. Yan [25], H.J. Yang [62c,62d], H.T. Yang [62a], S. Yang [62a], T. Yang [64c], X. Yang [36], X. Yang [14a], Y. Yang [44], Y. Yang[62a], Z. Yang [62a], W-M. Yao [17a], Y.C. Yap [48], H. Ye [14c], H. Ye [55], J. Ye [14a], S. Ye [29], X. Ye [62a], Y. Yeh [96], I. Yeletskikh [38], B. Yeo [17b], M.R. Yexley [96], P. Yin [41], K. Yorita [168], S. Younas [27b], C.J.S. Young [36], C. Young [143], C. Yu [14a,14e,aj], Y. Yu [62a], M. Yuan [106], R. Yuan [62b], L. Yue [96], M. Zaazoua [62a], B. Zabinski [87], E. Zaid[52], Z.K. Zak [87], T. Zakareishvili [149b], N. Zakharchuk [34], S. Zambito [56], J.A. Zamora Saa [137d,137b], J. Zang [153], D. Zanzi [54], O. Zaplatilek [132], C. Zeitnitz [171], H. Zeng [14a], J.C. Zeng [162], D.T. Zenger Jr [26], O. Zenin [37], T. Ženiš [28a], S. Zenz [94], S. Zerradi [35a], D. Zerwas [66], M. Zhai [14a,14e], B. Zhang [14c], D.F. Zhang [139], J. Zhang [62b], J. Zhang [6], K. Zhang [14a,14e], L. Zhang [14c], P. Zhang [14a,14e], R. Zhang [170], S. Zhang [106], S. Zhang [44], T. Zhang [153], X. Zhang [62c], X. Zhang [62b], Y. Zhang [62c,5], Y. Zhang [96], Y. Zhang [14c], Z. Zhang [17a], Z. Zhang [62b], Z. Zhang [66], H. Zhao [138], T. Zhao [62b], Y. Zhao [136], Z. Zhao [62a], A. Zhemchugov [38], J. Zheng [14c], K. Zheng [162], X. Zheng [62a], Z. Zheng [143], D. Zhong [162], B. Zhou [106], H. Zhou [7], N. Zhou [62c], Y. Zhou [14c], Y. Zhou[7], C.G. Zhu [62b], J. Zhu [106], Y. Zhu [62c], Y. Zhu [62a], X. Zhuang [14a], K. Zhukov [37], V. Zhulanov [37], N.I. Zimine [38], J. Zinsser [63b], M. Ziolkowski [141], L. Živković [15], A. Zoccoli [23b,23a], K. Zoch [61], T.G. Zorbas [139], O. Zormpa [46], W. Zou [41], L. Zwalinski [36].

[1]Department of Physics, University of Adelaide, Adelaide; Australia.
[2]Department of Physics, University of Alberta, Edmonton AB; Canada.
[3(a)]Department of Physics, Ankara University, Ankara;[(b)]Division of Physics, TOBB University of Economics and Technology, Ankara; Türkiye.
[4]LAPP, Université Savoie Mont Blanc, CNRS/IN2P3, Annecy; France.
[5]APC, Université Paris Cité, CNRS/IN2P3, Paris; 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]Institute of Physics, Azerbaijan Academy of Sciences, Baku; Azerbaijan.
[13]Institut de Física d'Altes Energies (IFAE), Barcelona Institute of Science and Technology, Barcelona; Spain.
[14(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)]School of Science, Shenzhen Campus of Sun Yat-sen University;[(e)]University of Chinese Academy of Science (UCAS), Beijing; China.
[15]Institute of Physics, University of Belgrade, Belgrade; Serbia.
[16]Department for Physics and Technology, University of Bergen, Bergen; Norway.
[17(a)]Physics Division, Lawrence Berkeley National Laboratory, Berkeley CA;[(b)]University of California, Berkeley CA; United States of America.
[18]Institut für Physik, Humboldt Universität zu Berlin, Berlin; Germany.
[19]Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern; Switzerland.
[20]School of Physics and Astronomy, University of Birmingham, Birmingham; United Kingdom.
[21(a)]Department of Physics, Bogazici University, Istanbul;[(b)]Department of Physics Engineering, Gaziantep University, Gaziantep;[(c)]Department of Physics, Istanbul University, Istanbul; Türkiye.
[22(a)]Facultad de Ciencias y Centro de Investigaciónes, Universidad Antonio Nariño, Bogotá;[(b)]Departamento de Física, Universidad Nacional de Colombia, Bogotá; Colombia.
[23(a)]Dipartimento di Fisica e Astronomia A. Righi, 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)]National University of Science and Technology Politechnica, Bucharest;[(f)]West University in Timisoara, Timisoara;[(g)]Faculty of Physics, University of Bucharest, Bucharest; 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]Universidad de Buenos Aires, Facultad de Ciencias Exactas y Naturales, Departamento de Física, y CONICET, Instituto de Física de Buenos Aires (IFIBA), Buenos Aires; Argentina.
[31]California State University, CA; United States of America.
[32]Cavendish Laboratory, University of Cambridge, Cambridge; United Kingdom.
[33(a)]Department of Physics, University of Cape Town, Cape Town;[(b)]iThemba Labs, Western Cape;[(c)]Department of Mechanical Engineering Science, University of Johannesburg, Johannesburg;[(d)]National Institute of Physics, University of the Philippines Diliman (Philippines);[(e)]University of South Africa, Department of Physics, Pretoria;[(f)]University of Zululand, KwaDlangezwa;[(g)]School of Physics, University of the Witwatersrand, Johannesburg; South Africa.
[34]Department of Physics, Carleton University, Ottawa ON; Canada.
[35(a)]Faculté des Sciences Ain Chock, Université Hassan II de Casablanca;[(b)]Faculté des Sciences, Université Ibn-Tofail, Kénitra;[(c)]Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA-Marrakech;[(d)]LPMR, Faculté des Sciences, Université Mohamed Premier, Oujda;[(e)]Faculté des sciences, Université Mohammed V, Rabat;[(f)]Institute of Applied Physics, Mohammed VI Polytechnic University, Ben Guerir; Morocco.
[36]CERN, Geneva; Switzerland.
[37]Affiliated with an institute covered by a cooperation agreement with CERN.
[38]Affiliated with an international laboratory covered by a cooperation agreement with CERN.

[39]Enrico Fermi Institute, University of Chicago, Chicago IL; United States of America.
[40]LPC, Université Clermont Auvergne, CNRS/IN2P3, Clermont-Ferrand; France.
[41]Nevis Laboratory, Columbia University, Irvington NY; United States of America.
[42]Niels Bohr Institute, University of Copenhagen, Copenhagen; Denmark.
[43][(a)]Dipartimento di Fisica, Università della Calabria, Rende;[(b)]INFN Gruppo Collegato di Cosenza, Laboratori Nazionali di Frascati; Italy.
[44]Physics Department, Southern Methodist University, Dallas TX; United States of America.
[45]Physics Department, University of Texas at Dallas, Richardson TX; United States of America.
[46]National Centre for Scientific Research "Demokritos", Agia Paraskevi; Greece.
[47][(a)]Department of Physics, Stockholm University;[(b)]Oskar Klein Centre, Stockholm; Sweden.
[48]Deutsches Elektronen-Synchrotron DESY, Hamburg and Zeuthen; Germany.
[49]Fakultät Physik , Technische Universität Dortmund, Dortmund; Germany.
[50]Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden; Germany.
[51]Department of Physics, Duke University, Durham NC; United States of America.
[52]SUPA - School of Physics and Astronomy, University of Edinburgh, Edinburgh; United Kingdom.
[53]INFN e Laboratori Nazionali di Frascati, Frascati; Italy.
[54]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg; Germany.
[55]II. Physikalisches Institut, Georg-August-Universität Göttingen, Göttingen; Germany.
[56]Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève; Switzerland.
[57][(a)]Dipartimento di Fisica, Università di Genova, Genova;[(b)]INFN Sezione di Genova; Italy.
[58]II. Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen; Germany.
[59]SUPA - School of Physics and Astronomy, University of Glasgow, Glasgow; United Kingdom.
[60]LPSC, Université Grenoble Alpes, CNRS/IN2P3, Grenoble INP, Grenoble; France.
[61]Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge MA; United States of America.
[62][(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, Key Laboratory for Particle Astrophysics and Cosmology (MOE), SKLPPC, Shanghai;[(d)]Tsung-Dao Lee Institute, Shanghai;[(e)]School of Physics and Microelectronics, Zhengzhou University; China.
[63][(a)]Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg;[(b)]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg; Germany.
[64][(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.
[65]Department of Physics, National Tsing Hua University, Hsinchu; Taiwan.
[66]IJCLab, Université Paris-Saclay, CNRS/IN2P3, 91405, Orsay; France.
[67]Centro Nacional de Microelectrónica (IMB-CNM-CSIC), Barcelona; Spain.
[68]Department of Physics, Indiana University, Bloomington IN; United States of America.
[69][(a)]INFN Gruppo Collegato di Udine, Sezione di Trieste, Udine;[(b)]ICTP, Trieste;[(c)]Dipartimento Politecnico di Ingegneria e Architettura, Università di Udine, Udine; Italy.
[70][(a)]INFN Sezione di Lecce;[(b)]Dipartimento di Matematica e Fisica, Università del Salento, Lecce; Italy.
[71][(a)]INFN Sezione di Milano;[(b)]Dipartimento di Fisica, Università di Milano, Milano; Italy.
[72][(a)]INFN Sezione di Napoli;[(b)]Dipartimento di Fisica, Università di Napoli, Napoli; Italy.
[73][(a)]INFN Sezione di Pavia;[(b)]Dipartimento di Fisica, Università di Pavia, Pavia; Italy.
[74][(a)]INFN Sezione di Pisa;[(b)]Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa; Italy.

[75(a)]INFN Sezione di Roma;[(b)]Dipartimento di Fisica, Sapienza Università di Roma, Roma; Italy.
[76(a)]INFN Sezione di Roma Tor Vergata;[(b)]Dipartimento di Fisica, Università di Roma Tor Vergata, Roma; Italy.
[77(a)]INFN Sezione di Roma Tre;[(b)]Dipartimento di Matematica e Fisica, Università Roma Tre, Roma; Italy.
[78(a)]INFN-TIFPA;[(b)]Università degli Studi di Trento, Trento; Italy.
[79]Universität Innsbruck, Department of Astro and Particle Physics, Innsbruck; Austria.
[80]University of Iowa, Iowa City IA; United States of America.
[81]Department of Physics and Astronomy, Iowa State University, Ames IA; United States of America.
[82]Istinye University, Sariyer, Istanbul; Türkiye.
[83(a)]Departamento de Engenharia Elétrica, Universidade Federal de Juiz de Fora (UFJF), Juiz de Fora;[(b)]Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro;[(c)]Instituto de Física, Universidade de São Paulo, São Paulo;[(d)]Rio de Janeiro State University, Rio de Janeiro; Brazil.
[84]KEK, High Energy Accelerator Research Organization, Tsukuba; Japan.
[85]Graduate School of Science, Kobe University, Kobe; Japan.
[86(a)]AGH University of Krakow, Faculty of Physics and Applied Computer Science, Krakow;[(b)]Marian Smoluchowski Institute of Physics, Jagiellonian University, Krakow; Poland.
[87]Institute of Nuclear Physics Polish Academy of Sciences, Krakow; Poland.
[88]Faculty of Science, Kyoto University, Kyoto; Japan.
[89]Research Center for Advanced Particle Physics and Department of Physics, Kyushu University, Fukuoka ; Japan.
[90]Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata; Argentina.
[91]Physics Department, Lancaster University, Lancaster; United Kingdom.
[92]Oliver Lodge Laboratory, University of Liverpool, Liverpool; United Kingdom.
[93]Department of Experimental Particle Physics, Jožef Stefan Institute and Department of Physics, University of Ljubljana, Ljubljana; Slovenia.
[94]School of Physics and Astronomy, Queen Mary University of London, London; United Kingdom.
[95]Department of Physics, Royal Holloway University of London, Egham; United Kingdom.
[96]Department of Physics and Astronomy, University College London, London; United Kingdom.
[97]Louisiana Tech University, Ruston LA; United States of America.
[98]Fysiska institutionen, Lunds universitet, Lund; Sweden.
[99]Departamento de Física Teorica C-15 and CIAFF, Universidad Autónoma de Madrid, Madrid; Spain.
[100]Institut für Physik, Universität Mainz, Mainz; Germany.
[101]School of Physics and Astronomy, University of Manchester, Manchester; United Kingdom.
[102]CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille; France.
[103]Department of Physics, University of Massachusetts, Amherst MA; United States of America.
[104]Department of Physics, McGill University, Montreal QC; Canada.
[105]School of Physics, University of Melbourne, Victoria; Australia.
[106]Department of Physics, University of Michigan, Ann Arbor MI; United States of America.
[107]Department of Physics and Astronomy, Michigan State University, East Lansing MI; United States of America.
[108]Group of Particle Physics, University of Montreal, Montreal QC; Canada.
[109]Fakultät für Physik, Ludwig-Maximilians-Universität München, München; Germany.
[110]Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München; Germany.
[111]Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya; Japan.
[112]Department of Physics and Astronomy, University of New Mexico, Albuquerque NM; United States of America.

[113]Institute for Mathematics, Astrophysics and Particle Physics, Radboud University/Nikhef, Nijmegen; Netherlands.
[114]Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam; Netherlands.
[115]Department of Physics, Northern Illinois University, DeKalb IL; United States of America.
[116](a)New York University Abu Dhabi, Abu Dhabi;(b)United Arab Emirates University, Al Ain; United Arab Emirates.
[117]Department of Physics, New York University, New York NY; United States of America.
[118]Ochanomizu University, Otsuka, Bunkyo-ku, Tokyo; Japan.
[119]Ohio State University, Columbus OH; United States of America.
[120]Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman OK; United States of America.
[121]Department of Physics, Oklahoma State University, Stillwater OK; United States of America.
[122]Palacký University, Joint Laboratory of Optics, Olomouc; Czech Republic.
[123]Institute for Fundamental Science, University of Oregon, Eugene, OR; United States of America.
[124]Graduate School of Science, Osaka University, Osaka; Japan.
[125]Department of Physics, University of Oslo, Oslo; Norway.
[126]Department of Physics, Oxford University, Oxford; United Kingdom.
[127]LPNHE, Sorbonne Université, Université Paris Cité, CNRS/IN2P3, Paris; France.
[128]Department of Physics, University of Pennsylvania, Philadelphia PA; United States of America.
[129]Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh PA; United States of America.
[130](a)Laboratório de Instrumentação e Física Experimental de Partículas - LIP, Lisboa;(b)Departamento de Física, Faculdade de Ciências, Universidade de Lisboa, Lisboa;(c)Departamento de Física, Universidade de Coimbra, Coimbra;(d)Centro de Física Nuclear da Universidade de Lisboa, Lisboa;(e)Departamento de Física, Universidade do Minho, Braga;(f)Departamento de Física Teórica y del Cosmos, Universidad de Granada, Granada (Spain);(g)Departamento de Física, Instituto Superior Técnico, Universidade de Lisboa, Lisboa; Portugal.
[131]Institute of Physics of the Czech Academy of Sciences, Prague; Czech Republic.
[132]Czech Technical University in Prague, Prague; Czech Republic.
[133]Charles University, Faculty of Mathematics and Physics, Prague; Czech Republic.
[134]Particle Physics Department, Rutherford Appleton Laboratory, Didcot; United Kingdom.
[135]IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette; France.
[136]Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz CA; United States of America.
[137](a)Departamento de Física, Pontificia Universidad Católica de Chile, Santiago;(b)Millennium Institute for Subatomic physics at high energy frontier (SAPHIR), Santiago;(c)Instituto de Investigación Multidisciplinario en Ciencia y Tecnología, y Departamento de Física, Universidad de La Serena;(d)Universidad Andres Bello, Department of Physics, Santiago;(e)Instituto de Alta Investigación, Universidad de Tarapacá, Arica;(f)Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso; Chile.
[138]Department of Physics, University of Washington, Seattle WA; United States of America.
[139]Department of Physics and Astronomy, University of Sheffield, Sheffield; United Kingdom.
[140]Department of Physics, Shinshu University, Nagano; Japan.
[141]Department Physik, Universität Siegen, Siegen; Germany.
[142]Department of Physics, Simon Fraser University, Burnaby BC; Canada.
[143]SLAC National Accelerator Laboratory, Stanford CA; United States of America.

[144]Department of Physics, Royal Institute of Technology, Stockholm; Sweden.
[145]Departments of Physics and Astronomy, Stony Brook University, Stony Brook NY; United States of America.
[146]Department of Physics and Astronomy, University of Sussex, Brighton; United Kingdom.
[147]School of Physics, University of Sydney, Sydney; Australia.
[148]Institute of Physics, Academia Sinica, Taipei; Taiwan.
[149] [(a)]E. Andronikashvili Institute of Physics, Iv. Javakhishvili Tbilisi State University, Tbilisi;[(b)]High Energy Physics Institute, Tbilisi State University, Tbilisi;[(c)]University of Georgia, Tbilisi; Georgia.
[150]Department of Physics, Technion, Israel Institute of Technology, Haifa; Israel.
[151]Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv; Israel.
[152]Department of Physics, Aristotle University of Thessaloniki, Thessaloniki; Greece.
[153]International Center for Elementary Particle Physics and Department of Physics, University of Tokyo, Tokyo; Japan.
[154]Department of Physics, Tokyo Institute of Technology, Tokyo; Japan.
[155]Department of Physics, University of Toronto, Toronto ON; Canada.
[156] [(a)]TRIUMF, Vancouver BC;[(b)]Department of Physics and Astronomy, York University, Toronto ON; Canada.
[157]Division of Physics and Tomonaga Center for the History of the Universe, Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba; Japan.
[158]Department of Physics and Astronomy, Tufts University, Medford MA; United States of America.
[159]Department of Physics and Astronomy, University of California Irvine, Irvine CA; United States of America.
[160]University of Sharjah, Sharjah; United Arab Emirates.
[161]Department of Physics and Astronomy, University of Uppsala, Uppsala; Sweden.
[162]Department of Physics, University of Illinois, Urbana IL; United States of America.
[163]Instituto de Física Corpuscular (IFIC), Centro Mixto Universidad de Valencia - CSIC, Valencia; Spain.
[164]Department of Physics, University of British Columbia, Vancouver BC; Canada.
[165]Department of Physics and Astronomy, University of Victoria, Victoria BC; Canada.
[166]Fakultät für Physik und Astronomie, Julius-Maximilians-Universität Würzburg, Würzburg; Germany.
[167]Department of Physics, University of Warwick, Coventry; United Kingdom.
[168]Waseda University, Tokyo; Japan.
[169]Department of Particle Physics and Astrophysics, Weizmann Institute of Science, Rehovot; Israel.
[170]Department of Physics, University of Wisconsin, Madison WI; United States of America.
[171]Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal; Germany.
[172]Department of Physics, Yale University, New Haven CT; United States of America.
[a] Also Affiliated with an institute covered by a cooperation agreement with CERN.
[b] Also at An-Najah National University, Nablus; Palestine.
[c] Also at Borough of Manhattan Community College, City University of New York, New York NY; United States of America.
[d] Also at Center for High Energy Physics, Peking University; China.
[e] Also at Center for Interdisciplinary Research and Innovation (CIRI-AUTH), Thessaloniki; Greece.
[f] Also at Centro Studi e Ricerche Enrico Fermi; Italy.
[g] Also at CERN, Geneva; Switzerland.
[h] Also at Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève; Switzerland.
[i] Also at Departament de Fisica de la Universitat Autonoma de Barcelona, Barcelona; Spain.

[j] Also at Department of Financial and Management Engineering, University of the Aegean, Chios; Greece.
[k] Also at Department of Physics, Ben Gurion University of the Negev, Beer Sheva; Israel.
[l] Also at Department of Physics, California State University, Sacramento; United States of America.
[m] Also at Department of Physics, King's College London, London; United Kingdom.
[n] Also at Department of Physics, Stanford University, Stanford CA; United States of America.
[o] Also at Department of Physics, Stellenbosch University; South Africa.
[p] Also at Department of Physics, University of Fribourg, Fribourg; Switzerland.
[q] Also at Department of Physics, University of Thessaly; Greece.
[r] Also at Department of Physics, Westmont College, Santa Barbara; United States of America.
[s] Also at Faculty of Physics, Sofia University, 'St. Kliment Ohridski', Sofia; Bulgaria.
[t] Also at Hellenic Open University, Patras; Greece.
[u] Also at Institucio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona; Spain.
[v] Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg; Germany.
[w] Also at Institute for Nuclear Research and Nuclear Energy (INRNE) of the Bulgarian Academy of Sciences, Sofia; Bulgaria.
[x] Also at Institute of Applied Physics, Mohammed VI Polytechnic University, Ben Guerir; Morocco.
[y] Also at Institute of Particle Physics (IPP); Canada.
[z] Also at Institute of Physics and Technology, Mongolian Academy of Sciences, Ulaanbaatar; Mongolia.
[aa] Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku; Azerbaijan.
[ab] Also at Institute of Theoretical Physics, Ilia State University, Tbilisi; Georgia.
[ac] Also at L2IT, Université de Toulouse, CNRS/IN2P3, UPS, Toulouse; France.
[ad] Also at Lawrence Livermore National Laboratory, Livermore; United States of America.
[ae] Also at National Institute of Physics, University of the Philippines Diliman (Philippines); Philippines.
[af] Also at Technical University of Munich, Munich; Germany.
[ag] Also at The Collaborative Innovation Center of Quantum Matter (CICQM), Beijing; China.
[ah] Also at TRIUMF, Vancouver BC; Canada.
[ai] Also at Università di Napoli Parthenope, Napoli; Italy.
[aj] Also at University of Chinese Academy of Sciences (UCAS), Beijing; China.
[ak] Also at University of Colorado Boulder, Department of Physics, Colorado; United States of America.
[al] Also at Washington College, Chestertown, MD; United States of America.
[am] Also at Yeditepe University, Physics Department, Istanbul; Türkiye.
[*] Deceased