Phys. Lett. B 848 (2024) 138376

Contents lists available at ScienceDirect

Physics Letters B

journal homepage: www.elsevier.com/locate/physletb

Letter

Measurement of the $t\bar{t}$ cross section and its ratio to the Z production cross section using pp collisions at $\sqrt{s} = 13.6$ TeV with the ATLAS detector

The ATLAS Collaboration *

ARTICLE INFO

Editor: M. Doser

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

ABSTRACT

The inclusive top-quark-pair production cross section $\sigma_{t\bar{t}}$ and its ratio to the Z-boson production cross section have been measured in proton–proton collisions at $\sqrt{s} = 13.6$ TeV, using 29 fb^{-1} of data collected in 2022 with the ATLAS experiment at the Large Hadron Collider. Using events with an opposite-charge electron-muon pair and b-tagged jets, and assuming Standard Model decays, the top-quark-pair production cross section is measured to be $\sigma_{t\bar{t}} = 850 \pm 3(\text{stat.}) \pm 18(\text{syst.}) \pm 20(\text{lumi.})$ pb. The ratio of the $t\bar{t}$ and the Z-boson production cross sections is also measured, where the Z-boson contribution is determined for inclusive e^+e^- and $\mu^+\mu^-$ events in a fiducial phase space. The relative uncertainty on the ratio is reduced compared to the $t\bar{t}$ cross section, thanks to the cancellation of several systematic uncertainties. The result for the ratio, $R_{t\bar{t}/Z} = 1.145 \pm 0.003(\text{stat.}) \pm 0.021(\text{syst.}) \pm 0.002(\text{lumi.})$ is consistent with the Standard Model prediction using the PDF4LHC21 PDF set.

Contents

1. Introduction

Measurements of the top-quark production cross section in hadron-hadron collisions at the LHC provide essential tests of Quantum Chromodynamics (QCD) and parton distributions functions (PDFs). This quantity has been measured by ATLAS [1–4] and CMS [5–9] at energies between 5 and 13 TeV, and by LHCb [10,11] at energies between 7 and 13 TeV, with percent-level precision. Theory calculations with similar precision are available [12–17] and are found to be in good agreement with the measurements.

In the ratio of the $t\bar{t}$ to the Z-boson production cross section, several experimental uncertainties cancel, so that it can be obtained very precisely. Since $t\bar{t}$ production proceeds preferentially via a gluon-gluon initial state while Z-boson production is dominated by $q\bar{q}$, the ratio of these cross sections at a given centre-of-mass energy has a significant sensitivity to the gluon-to-quark PDF ratio [18,19]. ATLAS published such ratios at various centre-of-mass energies in Ref. [20]. Predictions for the Z-boson production cross section are available at NNLO QCD plus next-to-leading-order (NLO) electroweak (EW) accuracy [21–25].

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

https://doi.org/10.1016/j.physletb.2023.138376
Received 21 August 2023; Received in revised form 22 October 2023; Accepted 1 December 2023

Available online 7 December 2023

The analysis uses proton–proton collision data delivered by the LHC at CERN in 2022 at a new centre-of-mass energy of $\sqrt{s} = 13.6$ TeV and recorded with the ATLAS detector, representing an integrated luminosity of 29 fb^{-1}. Due to the steep rise of the PDFs towards lower Bjorken-x, a 12% increase of the $t\bar{t}$ cross section at 13.6 TeV is expected with respect to 13 TeV, which should be visible already with the present precision on the detector calibration.

This letter reports the measurement of the $t\bar{t}$ cross section in the full phase-space and of the ratio of the $t\bar{t}$ and Z-boson cross sections. The CMS experiment has published a measurement of the $t\bar{t}$ cross section at $\sqrt{s} = 13.6$ TeV [26] using an integrated luminosity of 1.21 fb^{-1}, without including the ratio to the Z-boson cross section.

2. Analysis strategy

Top-quark pair production is analysed in the channel in which one top-quark decays into an electron, a neutrino and a b-quark, and the other top-quark into a muon, a neutrino and a b-quark. For Z-bosons, decays to a pair of electrons or muons are considered. Three channels are thus defined using electrons and muons of opposite electric charge: ee, $\mu\mu$ and $e\mu$.

In the $e\mu$ channel, the presence of additional b-tagged jets is required. The analysis uses the method already employed in Ref. [2,27], where the numbers of events with one and two b-tagged jets are counted separately, allowing the $t\bar{t}$ cross section to be extracted together with the efficiency to identify a b-tagged jet. Opposite-sign electron-muon pairs are selected and the numbers of events that have one b-tagged jet (N_1) and two b-tagged jets (N_2) are counted. The event yields are given by

$$N_1 = L\sigma_{t\bar{t}}\epsilon_{e\mu}2\epsilon_b\left(1 - C_b\epsilon_b\right) + N_1^{\mathrm{bkg}}, \tag{1}$$

$$N_2 = L\sigma_{t\bar{t}}\epsilon_{e\mu}C_b\epsilon_b^2 + N_2^{\mathrm{bkg}}, \tag{2}$$

where L is the integrated luminosity, $\sigma_{t\bar{t}}$ is the measured $t\bar{t}$ cross section, ϵ_b is the combined probability to reconstruct and b-tag a b-jet after the selection, and $\epsilon_{e\mu}$ is the efficiency for a $t\bar{t}$ event to pass the opposite-sign $e\mu$ selection. The tagging correlation coefficient $C_b = \epsilon_{bb}/\epsilon_b^2$, where ϵ_{bb} represents the probability to reconstruct and tag both b-jets, may deviate slightly from unity due to kinematic correlations of the b-jets produced in a $t\bar{t}$ event and is estimated from simulation. The nominal value for C_b is found to be 1.0068.

For the same-flavour channels (ee, $\mu\mu$), the reconstructed invariant mass of the lepton pair, $m_{\ell\ell}$, is required to be $66 < m_{\ell\ell} < 116$ GeV. These channels are then used to extract the cross section for Z-boson production

$$N_{ee} = L\sigma_Z\epsilon_{ee} + N_{ee}^{\mathrm{bkg}}, \tag{3}$$

$$N_{\mu\mu} = L\sigma_Z\epsilon_{\mu\mu} + N_{\mu\mu}^{\mathrm{bkg}}, \tag{4}$$

where N_{ee} ($N_{\mu\mu}$) is the selected number of events passing the ee ($\mu\mu$) selection. Parameters ϵ_{ee} and $\epsilon_{\mu\mu}$ are the efficiencies for a Z-boson event to pass the opposite-sign ee and $\mu\mu$ selection, respectively.

The fiducial phase-space for Z-boson production is defined by the transverse momentum of the leptons $p_{\mathrm{T}} > 27$ GeV, the absolute value of the leptons' pseudorapidity $|\eta| < 2.5$ and the invariant mass of $66 < m_{\ell\ell} < 116$ GeV for $\ell = e, \mu$.[1] Within this phase space, an almost pure Z-boson contribution is obtained, with about 99.5% of events in the simulation originating from Z-boson production.

The total $t\bar{t}$ production cross section and the ratio of the cross sections, $R_{t\bar{t}/Z}$, are measured in a common fit to the same- and different-flavour channels, using a binned profile-likelihood technique. To understand the cancellation of uncertainties in the cross section ratio, the fiducial Z-boson production cross section $\sigma^{\mathrm{fid.}}_{Z\to\ell\ell}$ is measured in a separate fit using same-flavour dilepton events only, within the same phase space as used for the ratio measurement.

3. ATLAS detector

The ATLAS experiment [28,29] at the LHC is a multipurpose particle detector with a forward–backward symmetric cylindrical geometry and a near 4π coverage in solid angle. It consists of an inner tracking detector (ID) surrounded by a thin superconducting solenoid providing a 2 T axial magnetic field, electromagnetic and hadron calorimeters, and a muon spectrometer (MS). The inner tracking detector covers the pseudorapidity range $|\eta| < 2.5$. It consists of silicon pixel, silicon microstrip, and transition radiation tracking detectors. Lead/liquid-argon (LAr) sampling calorimeters provide electromagnetic (EM) energy measurements with high granularity. A steel/scintillator-tile hadron calorimeter covers the central pseudorapidity range ($|\eta| < 1.7$). The endcap and forward regions are instrumented with LAr calorimeters for both the EM and hadronic energy measurements up to $|\eta| = 4.9$. The muon spectrometer surrounds the calorimeters and is based on three large superconducting air-core toroidal magnets with eight coils each. The field integral of the toroids ranges between 2.0 and 6.0 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 [30] 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.

4. Data and MC samples

The analysis is performed using the data collected between August and October 2022 with the ATLAS detector, in pp collisions at $\sqrt{s} = 13.6$ TeV. After applying data-quality requirements [31], the data sample corresponds to an integrated luminosity of 29 fb^{-1}. The average number of inelastic pp collisions in the dataset is about 42. MC simulated samples are used in the analysis to optimise the event selection, estimate the selection efficiencies and correlation for the efficiencies of identifying and reconstructing two b-tagged jets, represented by the C_b parameter, and predict contributions from various background processes. If not stated otherwise, a top-quark mass of $m_t = 172.5$ GeV is used, in the MC simulated samples and cross-section calculations.

The production of $t\bar{t}$ events was simulated using the POWHEG BOX v2 [32–35] generator at next-to-leading-order (NLO) with the NNPDF3.0NLO [36] PDF set and the h_{damp} parameter set to $1.5\,m_t$ [37].[2] The events were interfaced to PYTHIA 8.307 [38] to model the parton shower, hadronisation, and underlying event, with parameters set according to the A14 tune [39] and using the NNPDF2.3LO set of PDFs [40]. The decays of bottom and charm hadrons were performed with EVTGEN 2.1.1 [41]. The $t\bar{t}$ sample was normalised to the cross-section prediction at next-to-next-to-leading-order (NNLO) in QCD including the resummation of next-to-next-to-leading-logarithm (NNLL)

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

[2] The h_{damp} parameter is a resummation damping factor and one of the parameters that controls the matching of POWHEG matrix elements to the parton shower and thus effectively regulates the high-p_{T} radiation against which the $t\bar{t}$ system recoils.

soft-gluon terms calculated using Top++ 2.0 [12–17,42]. For proton–proton collisions at a centre-of-mass energy of $\sqrt{s} = 13.6$ TeV, this cross-section corresponds to $\sigma(t\bar{t})_{\text{NNLO+NNLL}} = 924^{+32}_{-40}$ pb, including all $t\bar{t}$ decay channels, using the PDF4LHC21 PDF set [43]. The uncertainty includes variations in the renormalisation and factorisation scale, α_s and PDFs. For the nominal prediction, the renormalisation and factorisation scales were set equal to the top-quark mass, and the strong coupling constant was set to $\alpha_s(m_Z) = 0.118$. Samples of $t\bar{t}$ and tW events with a different top-quark mass have been simulated to estimate the variation of the reconstruction efficiency as a function of this mass.

Events of $Z/\gamma^* \to \ell^+\ell^-$ production were simulated with the Sherpa 2.2.12 [44] generator using NLO matrix elements (ME) for up to two partons, and up to five partons at leading-order (LO) calculated with the Comix [45] and OpenLoops [46–48] libraries. They were matched with the Sherpa parton shower [49] using the MEPS@NLO prescription [50–53] using the set of tuned parameters developed by the Sherpa authors. The NNPDF3.0nnlo set of PDFs was used. Decays of $Z/\gamma^* \to e^+e^-$, $Z/\gamma^* \to \mu^+\mu^-$ and $Z/\gamma^* \to \tau^+\tau^-$ were simulated. The inclusive cross sections of the MC samples are normalised to NNLO in QCD and NLO in EW predictions, calculated using the MATRIX [54] program with the PDF4LHC21 PDF set. In both the MC generator requirement and in the MATRIX calculation, leptons before QED radiation are used. In the fiducial phase-space defined with lepton $p_T > 27$ GeV, $|\eta| < 2.5$ and $66 < m_{\ell\ell} < 116$ GeV, the predicted cross-section at NNLO in QCD and NLO in EW is $\sigma(Z)^{\text{fid.}} = 746 \pm 0.7(\text{integration})^{+3}_{-5}(\text{scale}) \pm 21(\text{PDF})$ pb for the Z-boson decaying into a single lepton flavour and leptons before QED radiation.[3]

For the calculation of the $t\bar{t}$ to the Z-boson production cross-section ratio, several PDF sets are considered: PDF4LHC21, CT18 [55], CT18A [55], MSHT20 [56], NNPDF4.0 [57], ABMP16 [58] and ATLASpdf21 [59]. The uncertainties from the QCD scale variations are assumed to be uncorrelated between the processes, while the PDF variations are fully correlated in the calculation of the uncertainty. The QCD scale uncertainty is evaluated by restricting the variations of the renormalisation and factorisation scales, where μ_r and μ_f are independently varied by a factor of two while meeting the requirement that they never differ from each other by more than a factor of two. The predicted central values for the ratios for the different PDF sets vary between about 1.13 for the ABMP16 and 1.27 for the CT18 PDF set. The uncertainties on the predictions range from about 4.5% up to 9%.

The associated production of single top quarks with W bosons (tW) was modelled with the Powheg Box v2 generator at NLO in QCD using the five-flavour scheme and the NNPDF3.0nlo set of PDFs [36]. The diagram-removal scheme [60] was used to remove interference and overlap with $t\bar{t}$ production. The events were interfaced to Pythia 8.307 using the A14 tune and the NNPDF2.3lo set of PDFs. The inclusive cross-section was corrected to the theory prediction calculated at approximate N^{3}LO in QCD using the PDF4LHC21 PDF set [61]. The cross-section corresponds to $\sigma(tW)_{\text{aN}^3\text{LO}} = 87.9^{+2.0}_{-1.9}(\text{scale}) \pm 2.4(\text{PDF})$ pb.

Single-top-quark t-channel production was modelled with the Powheg Box v2 generator at NLO in QCD using the four-flavour scheme and the corresponding NNPDF3.0nlo set of PDFs. The events were interfaced with Pythia 8.307 using the A14 tune and the NNPDF2.3lo set of PDFs. Single-top-quark s-channel production was modelled using the Powheg Box v2 [33–35,62] generator at NLO in QCD in the five-flavour scheme with the NNPDF3.0nlo [36] PDF set. The events were interfaced with Pythia 8.307 using the A14 tune [39] and the NNPDF2.3lo PDF set. However, t-channel and s-channel productions contribute only via fake and non-prompt leptons.

The production of W+jets was simulated with the Sherpa 2.2.12 generator with the same settings as the Z-boson sample. The events were normalised to NNLO in QCD with NLO EW corrections calculated using the MATRIX software with the PDF4LHC21 PDF set.

Samples of diboson final states (VV) were simulated with the Sherpa 2.2.12 generator, including off-shell effects and Higgs boson contributions where appropriate. Fully-leptonic final states and semileptonic final states, where one boson decays leptonically and the other hadronically, were generated using matrix elements at NLO accuracy in QCD for up to one additional parton and at LO accuracy for up to three additional parton emissions.

Samples of associated production of top-quark pairs with a Z-boson or a W-boson are simulated using the Sherpa 2.2.12 generator. Events with at least two leptons in the final state are considered.

The effect of multiple interactions in the same and neighbouring bunch crossings (pile-up) was modelled by overlaying [63] the original hard-scattering event with simulated inelastic pp events generated by EPOS 2.0.1.4 [64,65] and Pythia 8.307. The events generated with EPOS used the EPOS LHC tune, while the Pythia 8 events used the NNPDF2.3 LO set of PDFs and parameter values set according to the A3 tune [66]. Pythia simulates events that contain at least one high transverse momentum (p_T) jet, isolated photon or lepton from the decay of b-hadrons, while EPOS simulates all remaining events in the sample. The events are generated independently and a filter is applied to EPOS generated events to veto the events simulated by Pythia. The simulation has been reweighted to match the distribution of the number of primary vertices seen in data.

After the event generation, the ATLAS detector response is simulated by the toolkit Geant4 [67] with the full simulation of the ATLAS detector [68]. The simulated samples are processed with the same software framework as the real data.

5. Object definitions and event selection

Events are selected if they include at least one lepton that is matched to a lepton identified by a single-lepton trigger. The lowest p_T threshold in the single-lepton triggers is 26 GeV for electrons and 24 GeV for muons. Events are also required to have at least one reconstructed collision vertex with two or more associated tracks with p_T greater than 500 MeV. The vertex with the highest $\sum p_T^2$ of the associated tracks is taken as the primary vertex.

Electron candidates are reconstructed from clusters of energy deposits in the electromagnetic calorimeter which are matched to particle tracks inside the ID. The candidates need to pass the *Tight* likelihood-based identification criteria [69]. Furthermore, they should pass the kinematic requirements $p_T > 27$ GeV and $|\eta| < 2.47$, with the transition region between the barrel and the endcap calorimeters at $1.37 < |\eta| < 1.52$ excluded. Additionally, electron candidates need to fulfil impact parameter selection criteria: $|z_0 \sin\theta| < 0.5$ mm and $|d_0/\sigma(d_0)| < 5$.[4]

Muon candidates are reconstructed from tracks from the MS matched to tracks from the ID. The candidates are required to pass *Medium* identification criteria [70] as well as $p_T > 27$ GeV and $|\eta| < 2.5$. Additionally, muon candidates need to pass the selection of $|z_0 \sin\theta| < 0.5$ mm and $|d_0/\sigma(d_0)| < 3$.

To suppress non-prompt electrons or muons, isolation criteria are imposed. The isolation is imposed by requiring the energy deposited in the calorimeter in a cone $\Delta R < 0.2$ around the object, divided by the object p_T, to be smaller than 0.15 and the momentum, reconstructed by the ID, in a cone $\Delta R < 0.3$ around the object, divided by the object p_T, to be smaller than 0.04.

Dedicated scale factors (SFs) are used to correct the identification, reconstruction, isolation and trigger efficiencies to match the efficiencies in data. For electrons, the identification SFs are calculated by

[3] The integration uncertainty represents the uncertainty due to the finite number of points used in the MC integration of the phase-space integrals.

[4] d_0 is the distance of closest approach of the track to the primary vertex point, in the r—ϕ projection and $|z_0|$ is the z-coordinate of the track at the point of closest approach to the global z-axis.

reconstructing Run 2 data using the same software as used for Run 3 and following the methodology described in Refs. [69,71]. The nominal reconstruction and isolation SFs are assumed to be one, with the differences observed between data and MC efficiencies being covered by the uncertainties in the SFs. For muons, the reconstruction, identification, isolation and track-to-vertex-association (*i.e.* impact parameter requirements) efficiency SFs have been measured using the Run 3 data, using the methodology described in Ref. [72]. The electron (muon) momentum is corrected using calibrations obtained from Run 2 (Run 3) with conservative uncertainties. Trigger SFs for both electron and muon triggers are measured in Run 3 in various data-taking periods and are applied to the simulation reflecting the relative luminosity of the individual periods.

Jets are reconstructed using a Particle Flow algorithm [73] that exploits both the calorimeter and ID information. The anti-k_t [74] jet algorithm is used with radius parameter $R = 0.4$ implemented in the FastJet [75] software. The calibration of jets uses simulation, representing the Run 3 conditions, to correct the jet-energy scale in both simulation and data. Furthermore, the jet-energy scale in data is corrected using the *in-situ* calibration measured in Run 2 [76]. Any residual difference between Run 2 and Run 3 conditions after applying the calibration is considered as a systematic uncertainty estimated from the simulation. After the calibration, jet candidates are required to have $p_{\mathrm{T}} > 30$ GeV and $|\eta| < 2.5$. To suppress jets originating from pile-up, jets need to pass a neural-network-based Jet Vertex Tagger (NNJVT) discriminant for jets with p_{T} below 60 GeV. This is a successor of the Jet Vertex Tagger [77].

Jets containing b-hadrons are identified (b-tagged) using the DL1d algorithm. The DL1d tagger uses a similar architecture as its predecessor DL1r, described in Ref. [78], but employs DeepSets [79] instead of a recurrent neural network for the processing of the track impact parameters. The DL1d algorithm returns the probability of a jet being light-flavour, c-jet and b-jet, which is then combined into a single discriminant. The jets are considered as b-tagged if the value of the discriminant passes the requirement corresponding to a 77% efficiency for tagging a true b-jet. The charm-jet (light-flavour-jet) rejection factor for jets with $p_{\mathrm{T}} > 20$ GeV is about 6 (260) in $t\bar{t}$ events. Dedicated SFs are applied to the simulation to correct for the efficiency of tagging a true b-jet as a function of jet p_{T}. No SFs are applied for the mis-tagging of c and light-flavour jets, but their uncertainty is still considered. To remove the ambiguity when one physical object is reconstructed as multiple objects, the overlap-removal algorithm used in Ref. [80] is employed.

Selected events are required to have exactly two leptons (electrons or muons) of opposite electric charge. In the same-flavour channels, events are required to have $66 < m_{\ell\ell} < 116$ GeV. No dilepton mass criteria are imposed on the $e\mu$ channel, but the events are required to have one or two b-tagged jets, as described in Section 2.

Hadrons mis-identified as electrons as well as electrons from photon conversions and leptons from heavy flavour decays can be identified as prompt leptons. These contributions are collectively referred to as fake or non-prompt leptons. To estimate the contribution of fake or non-prompt leptons, for each simulated event, the MC particle-level information is checked to determine if the event that passed the selection contains a fake lepton or non-prompt lepton. Based on this particle-level information, the events are split into real and fake or non-prompt lepton contributions. The events classified as containing at least one fake or non-prompt lepton are combined into a single distribution, representing the estimate of this lepton contribution in data. In the $e\mu$ channel, the expected contribution from the events with fake or non-prompt leptons accounts for about 1% of all events, while in the same-flavour channels the contribution is below 0.1% in both channels.

Fig. 1(a) compares the multiplicity of b-tagged jets for data and prediction in the inclusive $e\mu$ channel. The distribution of the leading lepton p_{T} in the $e\mu$ channel with at least one b-tagged jet, which is dominated by $t\bar{t}$ production, is shown in Fig. 1(b). Figs. 1(c) and (d) compare the data and prediction for the leading lepton p_{T} distribution in the ee channel and $\mu\mu$ channel, respectively, dominated by Z-boson production. Figs. 1(e) and (f) show the comparison of data and prediction for the invariant mass of the dilepton system in the ee and $\mu\mu$ channel, respectively. The observed p_{T} distribution of the selected leptons with the highest p_{T} in an event is harder than expected in the same-flavour channels and softer in the $e\mu$ channel. However, in both cases the data agree with the prediction within the uncertainties indicated by the hashed band for the low-p_{T} regions that are relevant for this measurement as the lepton uncertainties impact the fitted cross section only via acceptance.

Table 1 shows the predicted and measured event yields in the different dilepton categories. The $e\mu$ inclusive region is only used in the simulation to calculate C_b.

6. Systematic uncertainties

The uncertainty in the integrated luminosity for data recorded in 2022 is 2.2% [81], following the methodology discussed in Ref. [82], using the LUCID-2 detector [83] for the primary luminosity measurements, complemented by measurements using the inner detector and calorimeters. The uncertainty is dominated by effects from horizontal-vertical correlations, known as non-factorisation, in the bunch-density distributions during the beam-separation scans used to determine the absolute luminosity scale, as well as by uncertainties in transferring this calibration from the data-taking conditions of the absolute luminosity calibration to the conditions of routine physics data-taking. Various beam-, calibration-method-, consistency-, reproducibility- and stability-related effects provide smaller contributions to the overall uncertainty. The uncertainty in the pile-up modelling is estimated by varying the average number of interactions per bunch-crossing by 4% in the simulation.

For the electron energy corrections, uncertainties obtained from the Run 2 calibrations using $Z \rightarrow ee$, as described in Ref. [69], are increased, covering the differences in the reconstruction between Run 2 and Run 3 of the LHC as estimated from the simulation. The uncertainty in the muon momentum correction is estimated by separately varying the ID and MS components as estimated from $Z \rightarrow \mu\mu$ events, similarly to Ref. [70]. The uncertainties in the corrections are split into several components both for electrons and muons.

The uncertainties in the electron identification SFs are computed comparing simulation between Run 2 and Run 3. It was checked that the SFs in Run 3 are within the estimated uncertainties in Run 2. The uncertainties on the muon SFs have been calculated using the methods described in Ref. [72]. The trigger efficiencies with their uncertainties are measured using the Run 3 data. Most events can be triggered by either lepton, reducing the systematic uncertainty from the modelling of the trigger efficiencies.

The lepton efficiencies (trigger, identification, reconstruction and isolation) are generally the dominant detector uncertainties on the measurements. They depend on the lepton p_{T}, η and ϕ. In the calculation of the uncertainty in $R_{t\bar{t}/Z}$, the nuisance parameters (NPs) corresponding to each systematic uncertainty for the detector related uncertainties are taken to be fully correlated between the $t\bar{t}$ and Z-boson processes. Correlating or treating the lepton isolation uncertainties separately between the $t\bar{t}$ and Z-boson processes has no significant impact on the central value nor the total uncertainty in the $R_{t\bar{t}/Z}$ fit.

The uncertainties in the jet-energy scale (JES) [84] and jet-energy resolution (JER) [85] are considered, as estimated in Run 2. Additionally, dedicated uncertainties due to the differences in reconstruction between Run 2 and Run 3 are considered; these are estimated from simulation. A 10% uncertainty per b-tagged jet is considered for events in the $e\mu$ channel to cover the discrepancies between data and simulation for the NNJVT discriminant. The uncertainty is not applied to simulated $t\bar{t}$ events, as the jet reconstruction and tagging probability is eventually determined in data as the ϵ_b parameter.

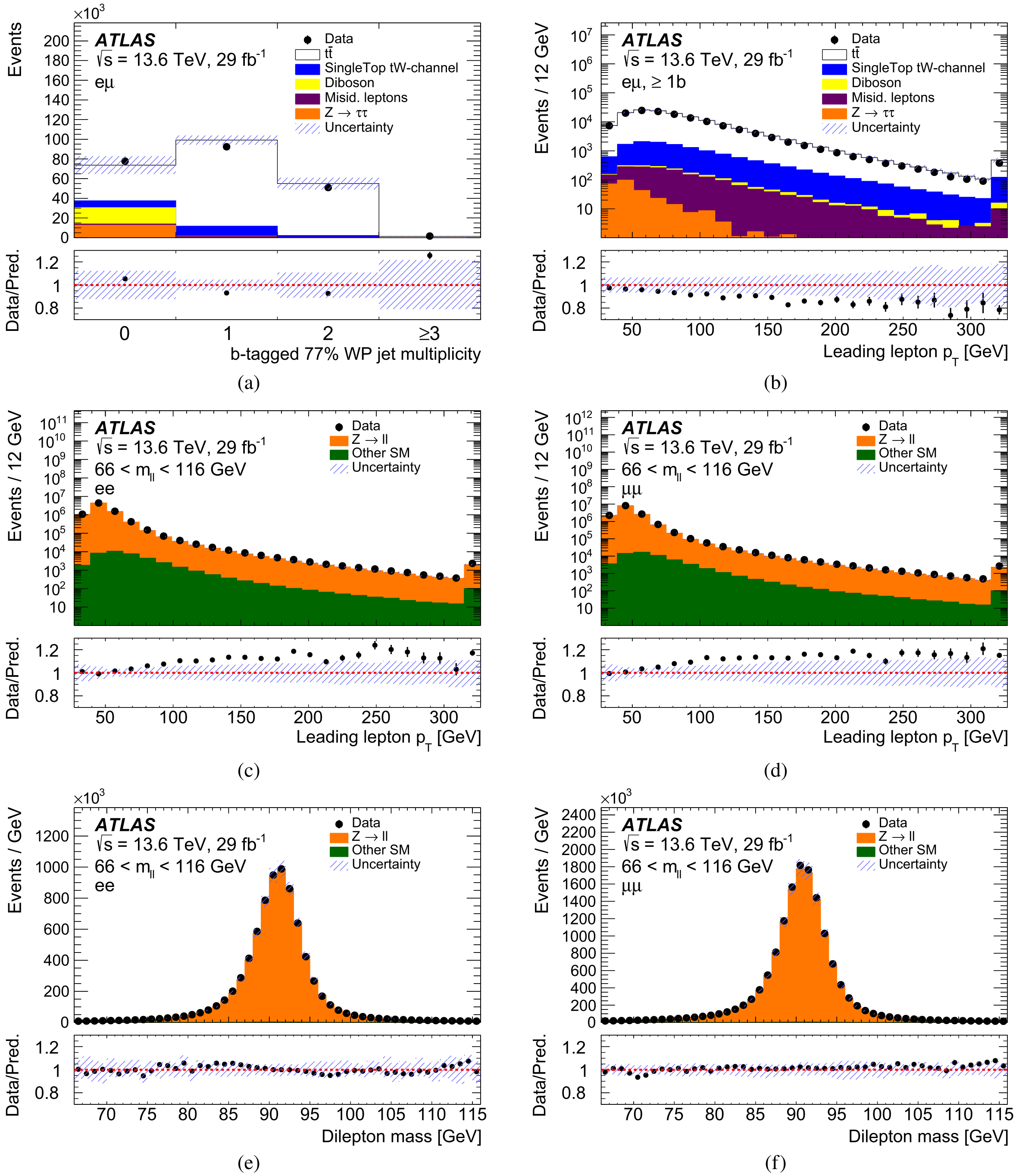

Fig. 1. Comparison of observed data and predictions for (a) the distribution of the number of b-tagged jets in the inclusive $e\mu$ channel, (b) the p_T of the leading lepton in the $e\mu$ channel with at least one b-tagged jet, (c) the leading lepton p_T in the ee channel, (d) the leading lepton p_T in the $\mu\mu$ channel, the invariant mass of the dilepton system in (e) the ee channel and (f) the $\mu\mu$ channel. The expected yields are calculated by normalising the MC prediction to the product of integrated luminosity and predicted cross section for each process. The "Other SM" represents all non-Z-boson SM processes merged into a single distribution. The "Misid. leptons" label represents fake or non-prompt leptons. The hashed band represents the total uncertainty. The bottom panel shows the ratio of data to the prediction. The rightmost bins contain the overflow events.

The b-tagging efficiencies for the tW process and other backgrounds are estimated from the simulation. The uncertainty in the b-jet efficiency, binned in jet p_T, is estimated using dilepton $t\bar{t}$ events, employing a simplified version of the method described in Ref. [86]. Separate, p_T-independent uncertainties are assigned to the charm- and light-flavours for the efficiency of (mis-)tagging. These are 20% for the c-mis-tag efficiency and 40% for the light-flavour-mis-tag efficiency. The uncertainties cover the differences in the modelling of the discriminant between data and simulation in $t\bar{t}$ lepton+jets events for the charm mis-tag rate and in events with a Z-boson and at least one jet for the light-flavour mis-tag rate.

The impact of using a different parton shower and hadronisation model is evaluated by comparing the nominal $t\bar{t}$ sample with another sample produced by interfacing the POWHEG BOX v2 [32–35] generator using the NNPDF3.0NLO [36] PDF set with HERWIG 7.2.3 [87–89]. Uncertainties due to the modelling of the $t\bar{t}$ signal are estimated considering independent variations of the renormalisation and factorisation scales in the ME of the nominal $t\bar{t}$ sample by factors of 0.5 and 2, excluding variations that differ by a factor of four, but normalising the signal

Table 1
Predicted and observed event yields in the different dilepton regions after event selection. Systematic uncertainties, representing all considered sources, are shown for the predicted yields.

Process	Region				
	$e\mu$ inclusive	$e\mu$ 1 b	$e\mu$ 2 b	ee	$\mu\mu$
$t\bar{t}$	$177\,000 \pm 5\,000$	$87\,400 \pm 2\,600$	$52\,700 \pm 1\,600$	$22\,300 \pm 1\,200$	$33\,500 \pm 1\,900$
$Z \to ll$	$13\,100 \pm 600$	270 ± 70	14.2 ± 3.0	$7\,7490\,000 \pm 230\,000$	$14\,100\,000 \pm 400\,000$
SingleTop tW-channel	$19\,000 \pm 9\,000$	$10\,200 \pm 700$	$1\,720 \pm 290$	$2\,250 \pm 120$	$3\,410 \pm 200$
Diboson	$17\,000 \pm 8\,000$	230 ± 120	5.3 ± 3.0	$9\,000 \pm 5\,000$	$18\,000 \pm 9\,000$
$t\bar{t}V$	220 ± 110	100 ± 50	69 ± 35	240 ± 120	250 ± 130
Fake/non-prompt leptons	$2\,800 \pm 1\,400$	$1\,100 \pm 500$	500 ± 500	$6\,000 \pm 6\,000$	$6\,000 \pm 6\,000$
Total prediction	$229\,000 \pm 14\,000$	$99\,200 \pm 3\,000$	$55\,000 \pm 1\,700$	$7\,780\,000 \pm 230\,000$	$14\,100\,000 \pm 400\,000$
Data	222 711	92 385	50 956	7 812 978	14 242 875

to the nominal cross section. Additionally, variations of the renormalisation and factorisation scales are considered for the parton shower simulation affecting the initial- and final-state radiation, where the former is represented by the variation of the Var3c parameter of the A14 tune [90]. The uncertainty due to the choice of the $h_{\rm damp}$ parameter is estimated by increasing it by a factor of two. To account for the uncertainty due to the top-quark $p_{\rm T}$ distribution mismodelling [27], the nominal $t\bar{t}$ sample is compared with the same sample reweighted to match the top-quark $p_{\rm T}$ distribution computed at NNLO in QCD precision using the MATRIX program.

Several sources of systematic uncertainties in the modelling of the Z-boson events are considered. Independent renormalisation and factorisation scale variations in the ME as well as the simultaneous variations of the ME and the parton shower by a factor of 0.5 and 2, excluding variations that differ by a factor of four, are tested. The variation with the maximum impact on the yields is symmetrised and used to estimate the uncertainty in the analysis. This variation originates from the simultaneous variation of the renormalisation and factorisation scale by a factor of 0.5 in the ME and the parton shower. For all modelling uncertainties in the Z-boson production, the systematic variation is rescaled to have the same cross section in the fiducial phase-space.

A normalisation uncertainty of 3.5% is assigned to the tW process, reflecting the theoretical uncertainty in the cross section. Similarly to $t\bar{t}$ uncertainties, scale variations in the ME, Var3c and for the final-state radiation of the parton shower are considered for the single-top quark processes. Furthermore, an uncertainty due to the interference between the tW and $t\bar{t}$ processes is obtained by comparing the diagram-removal scheme with the diagram-subtraction scheme [60]. Scale variations between the $t\bar{t}$ and tW production processes are assumed to be uncorrelated, but this assumption is found to have no significant impact on the total expected uncertainty.

The PDF uncertainty for $t\bar{t}$ and Z modelling is estimated by considering the internal variations of the PDF4LHC21 PDF set [43]. This uncertainty is correlated between processes. Only the acceptance effects are considered for the PDF and the modelling uncertainties.

A normalisation uncertainty of 50 (100)% is assigned for the fake and non-prompt lepton background in the $e\mu$ channel for events with 1 (2) b-tagged jets as estimated from the simulation, similarly to Ref. [91]. An uncertainty of 100% is assigned on the normalisation of the fake and non-prompt lepton background in the $Z \to ee$ and $Z \to \mu\mu$ events. A 50% uncertainty is considered for the normalisation of the diboson processes and processes with associated production of the top-quark pairs with a Z-boson or a W-boson. These normalisation uncertainties have no significant impact on the total uncertainty of the measurement.

7. Results

Fig. 2 shows the distributions used in the fit to extract the $t\bar{t}$ cross section and the ratio of the cross sections. A profile-likelihood fit is used to extract $\sigma_{t\bar{t}}$ and $R_{t\bar{t}/Z}$ together with the b-tagging efficiency ϵ_b. The results of the fit are:

$$\sigma_{t\bar{t}} = 850 \pm 3(\text{stat.}) \pm 18(\text{syst.}) \pm 20(\text{lumi.})\ \text{pb},$$

$$R_{t\bar{t}/Z} = 1.145 \pm 0.003(\text{stat.}) \pm 0.021(\text{syst.}) \pm 0.002(\text{lumi.}),$$

$$\epsilon_b = 0.544 \pm 0.001(\text{stat.}) \pm 0.004(\text{syst.}) \pm 0.001(\text{lumi.}),$$

where the Z-boson cross section in $R_{t\bar{t}/Z}$ is measured in a fiducial phase-space defined by lepton $p_{\rm T} > 27$ GeV, lepton $|\eta| < 2.5$ and an invariant mass of $66 < m_{\ell\ell} < 116$ GeV for $\ell = e, \mu$.

This procedure takes into account all correlations among systematic uncertainties in the $t\bar{t}$ and Z-boson cross section measurements. The obtained values for the parameters $\sigma_{t\bar{t}}$ and $R_{t\bar{t}/Z}$have a positive correlation of about 0.6. The result for $\sigma_{t\bar{t}}$ is reported for a fixed top quark mass of $m_t = 172.5$ GeV, and depends on the assumed value according to $(1/\sigma_{t\bar{t}})\mathrm{d}\sigma_{t\bar{t}}/\mathrm{d}m_t = -0.36\%/\text{GeV}$, as estimated from a variation of the top-quark mass in the $t\bar{t}$ and tW samples to 171.5 GeV and 173.5 GeV.

The predicted values for the $t\bar{t}$ cross section and the ratio $R_{t\bar{t}/Z}$ extrapolated to the full phase assuming a top-quark mass of 172.5 GeV and using the PDF4LHC21 PDF set are:

$$\sigma_{t\bar{t}}^{\text{theory}} = 924^{+32}_{-40}\ (\text{scale} + \text{PDF} + \alpha_s)\ \text{pb},$$

$$R_{t\bar{t}/Z}^{\text{theory}} = 1.238^{+0.063}_{-0.071}\ (\text{scale} + \text{PDF} + \alpha_s).$$

The ϵ_b value in the $t\bar{t}$ simulation is 0.5431 ± 0.0003 (MC stat.), compatible within the per mille uncertainty with the fitted value. No significant pulls or constrains of the NPs are present, with the exception of a NP for the uncertainty in the isolation of muons, that is constrained to about 75% of its pre-fit uncertainty. The low constraining power in the fit is due to the presence of three unconstrained parameters in the likelihood.

Fig. 3 shows the measured $t\bar{t}$ cross section as a function of the centre-of-mass energy compared to the theory prediction using the PDF4LHC21 PDF set. The 13.6 TeV measurement is slightly lower than the prediction but compatible within 1.5 standard deviations, when adding the downward uncertainty on the prediction and upward measurement uncertainties in quadrature. In Fig. 4, the ratio of the $t\bar{t}$ and Z-boson production cross sections is compared to the prediction for several PDF sets. The measured ratio is compatible with the SM prediction based on the PDF4LHC21 set at 1.3 standard deviations assuming a top-quark mass of 172.5 GeV.

To understand the cancellation of the systematic uncertainties, the Z-boson cross section has been obtained from a fit to same-flavour events only. The result of the fit is:

$$\sigma_{Z\to\ell\ell}^{\text{fid.}} = 744 \pm 11\ (\text{stat.} + \text{syst.}) \pm 16\ (\text{lumi.})\ \text{pb},$$

using the same fiducial phase-space as was used for $R_{t\bar{t}/Z}$. The statistical uncertainty is negligible compared to the systematic uncertainty.

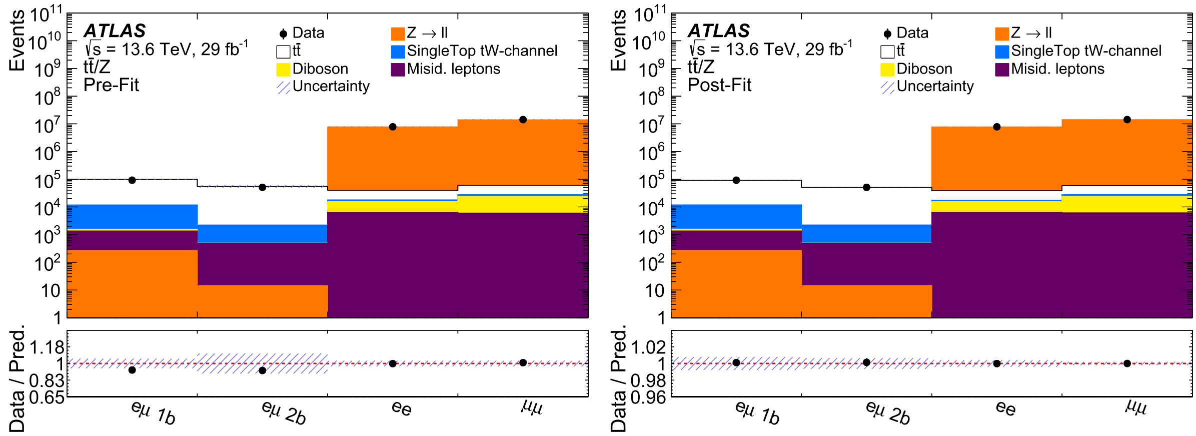

Fig. 2. Comparison of data and prediction for the event yields before (left) and after the fit (right) in the regions used in the $t\bar{t}$ fit. The bottom panel shows the ratio of data over the prediction. The hashed bands represent the total uncertainty. Correlations of the NPs as obtained from the fit are used to build the uncertainty band in the post-fit distribution. The error bars on the data points are smaller than the displayed points.

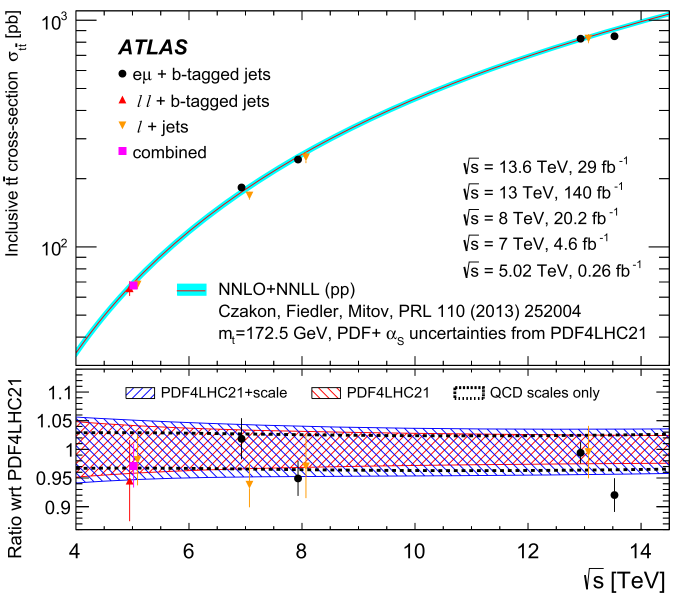

Fig. 3. Comparison of the measured $t\bar{t}$ cross sections at various centre-of-mass energies and the theory predictions using the PDF4LHC21 PDF set. Measurements using the $e\mu$ final state ($e\mu$ + b-tagged jets); ee, $\mu\mu$ and $e\mu$ final states (ll + b-tagged jets); single lepton final states (l + jets); as well as combinations of final states (combined) are compared. The bottom panel shows the ratio of the measured values and three predictions that either contain only the uncertainties originating from the QCD scale variations (black), only the variations in the PDF uncertainties (red) or the total uncertainty in the prediction (blue).

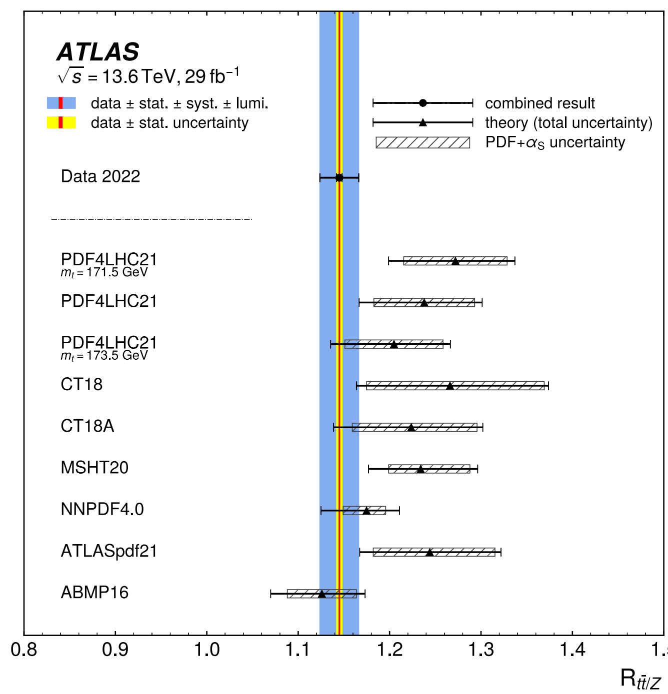

Fig. 4. Ratio of the $t\bar{t}$ to the Z-boson cross section compared to the predictions for several sets of parton distribution functions. The total cross section for $t\bar{t}$ production and the fiducial cross section for Z-boson production are used. If not explicitly mentioned, a top-quark mass of 172.5 GeV is assumed. The hatched box represents the PDF+α_s component of the uncertainty on the prediction. For the PDF4LHC21 PDF set, predictions for different assumptions about the top-quark mass are also displayed.

In the Z-boson cross section fit, a supplementary normalisation uncertainty of 5.1% is applied on the $t\bar{t}$ sample, according to the theoretical uncertainty on the predicted cross section value. The only pull and constraint on nuisance parameters can come from the requirement that the $Z \to ee$ and $Z \to \mu\mu$ cross sections are equal. Since these two cross section measurements agree to better than 0.5 standard deviations, no pulls are observed.

The theory prediction for the fiducial $Z \to \ell\ell$ cross section is

$$\sigma^{\text{fid.,theory}}_{Z\to\ell\ell} = 746^{+21}_{-22}\ (\text{scale} + \text{PDF} + \alpha_s)\ \text{pb},$$

agreeing with the measurement within 1 standard deviation. Table 2 shows the impact of the systematic uncertainties grouped by their origin. The largest source of systematic uncertainty in the individual cross sections originates from the uncertainty in the luminosity estimation, followed by electron and muon reconstruction. For the $t\bar{t}$ cross section, the uncertainty in the parton shower and hadronisation modelling also has a significant impact on the precision. For the cross section ratio, several sources of the systematic uncertainties partially cancel out. The dominant uncertainty for the cross section ratio originates from $t\bar{t}$ modelling, as it does not cancel out. Other significant uncertainties on the ratio include uncertainty in the trigger efficiencies and lepton reconstruction efficiencies. The trigger efficiency uncertainty does not fully cancel out as there are different η and p_T distributions in $t\bar{t}$ and Z-boson events, and different combinations of triggers employed.

The simulated distribution of the p_T of the dilepton pair is known to not be accurately modelled by the MC simulation [92]. As a cross check, the simulated distribution of the p_T of the dilepton pair has been reweighted to match the data in ee and $\mu\mu$ events, assuming that only

Table 2
Observed impact of the different sources of uncertainty on the $t\bar{t}$ and Z-boson cross sections and their ratio R, grouped by category. The $t\bar{t}$ cross section and R are obtained in a simultaneous fit to the four regions shown in Fig. 2, while the Z-boson cross section is obtained from a fit to same-flavour events only. The impact of each category is obtained by repeating the fit after having fixed the set of nuisance parameters corresponding to that category, and subtracting that uncertainty in quadrature from the uncertainty found in the full fit. The statistical uncertainty is obtained by repeating the fit after having fixed all nuisance parameters to their fitted values. Only the acceptance effects are considered for the PDF and the modelling uncertainties.

	Category	Uncertainty [%]		
		$\sigma_{t\bar{t}}$	$\sigma^{\text{fid.}}_{Z\to\ell\ell}$	$R_{t\bar{t}/Z}$
$t\bar{t}$	$t\bar{t}$ parton shower/hadronisation	0.9	< 0.2	0.9
	$t\bar{t}$ scale variations	0.4	< 0.2	0.4
	$t\bar{t}$ normalisation	-	< 0.2	-
	Top quark p_{T} reweighting	0.6	< 0.2	0.6
Z	Z scale variations	< 0.2	0.4	0.3
Bkg.	Single top modelling	0.6	< 0.2	0.6
	Diboson modelling	< 0.2	< 0.2	0.2
	$t\bar{t}V$ modelling	< 0.2	< 0.2	< 0.2
	Fake and non-prompt leptons	0.6	< 0.2	0.6
Lept.	Electron reconstruction	1.2	1.0	0.4
	Muon reconstruction	1.4	1.4	0.3
	Lepton trigger	0.4	0.4	0.4
Jets/tagging	Jet reconstruction	0.4	-	0.4
	Flavour tagging	0.4	-	0.3
	PDFs	0.5	< 0.2	0.5
	Pileup	0.7	0.8	< 0.2
	Luminosity	2.3	2.2	0.3
	Systematic uncertainty	3.2	2.8	1.8
	Statistical uncertainty	0.3	0.02	0.3
	Total uncertainty	3.2	2.8	1.9

Z-boson events contribute. After the reweighting, the impact on the total predicted yields was found to be below 0.13%, thus negligible.

8. Conclusions

The first ATLAS measurements of the inclusive $t\bar{t}$ production cross section and the ratio of the $t\bar{t}$ to the Z-boson cross section at the new LHC centre-of-mass energy of 13.6 TeV are presented, using 29 fb^{-1} of data collected in 2022. The $t\bar{t}$ cross section is measured to be $\sigma_{t\bar{t}} = 850 \pm 3(\text{stat.}) \pm 18(\text{syst.}) \pm 20(\text{lumi.})$ pb. The measured value for the ratio is $R_{t\bar{t}/Z} = 1.145 \pm 0.003(\text{stat.}) \pm 0.021(\text{syst.}) \pm 0.002(\text{lumi.})$. Both measurements agree with the Standard Model predictions of $924^{+32}_{-40}(\text{scale}+\text{PDF}+\alpha_{\text{s}})$ pb for the $t\bar{t}$ cross section and of $R^{\text{theory}}_{t\bar{t}/Z} = 1.238^{+0.063}_{-0.071}(\text{scale}+\text{PDF}+\alpha_{\text{s}})$ for the ratio, using the PDF4LHC21 PDF set. The absolute cross section measurement is limited by the uncertainty in the luminosity measurement as well as the lepton efficiency uncertainties. In the ratio of the $t\bar{t}$ and Z cross sections, however, the luminosity uncertainty and lepton uncertainties cancel out to a large extent resulting in the total uncertainty of about 1.9%. A top-quark mass of 172.5 GeV is assumed for the prediction and for the simulation used to correct data. The dependence on the Monte Carlo top-quark mass parameter on the cross section is provided.

Declaration of competing interest

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

Data availability

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

Acknowledgements

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

We acknowledge the support of ANPCyT, Argentina; YerPhI, Armenia; ARC, Australia; BMWFW and FWF, Austria; ANAS, Azerbaijan; 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; ARRS and MIZŠ, Slovenia; DSI/NRF, South Africa; MICINN, Spain; SRC and Wallenberg Foundation, Sweden; SERI, SNSF and Cantons of Bern and Geneva, Switzerland; MOST, Taiwan; TENMAK, Türkiye; STFC, United Kingdom; DOE and NSF, United States of America. In addition, individual groups and members have received support from BCKDF, Canarie, Compute Canada and CRC, Canada; 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 Stiftelser, Sweden; The Royal Society and Leverhulme Trust, United Kingdom.

The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN, the ATLAS Tier-1 facilities at TRIUMF (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN-CNAF (Italy), NL-T1 (Netherlands), PIC (Spain), ASGC (Taiwan), RAL (UK) and BNL (USA), the Tier-2 facilities worldwide and large non-WLCG resource providers. Major contributors of computing resources are listed in Ref. [93].

References

[1] ATLAS Collaboration, Measurement of the $t\bar{t}$ production cross-section in pp collisions at $\sqrt{s} = 5.02$ TeV with the ATLAS detector, J. High Energy Phys. 06 (2023) 138, arXiv:2207.01354 [hep-ex].

[2] ATLAS Collaboration, Measurement of the $t\bar{t}$ production cross-section using $e\mu$ events with b-tagged jets in pp collisions at $\sqrt{s} = 7$ and 8 TeV with the ATLAS detector, Eur. Phys. J. C 74 (2014) 3109, arXiv:1406.5375 [hep-ex], Addendum: Eur. Phys. J. C 76 (2016) 642.

[3] ATLAS Collaboration, Measurement of the top quark pair production cross-section with ATLAS in the single lepton channel, Phys. Lett. B 711 (2012) 244, arXiv:1201.1889 [hep-ex].

[4] ATLAS Collaboration, Inclusive and differential cross-sections for dilepton $t\bar{t}$ production measured in $\sqrt{s} = 13$ TeV pp collisions with the ATLAS detector, J. High Energy Phys. 07 (2023) 141, arXiv:2303.15340 [hep-ex].

[5] CMS Collaboration, Measurement of the inclusive $t\bar{t}$ cross section in pp collisions at $\sqrt{s} = 5.02$ TeV using final states with at least one charged lepton, J. High Energy Phys. 03 (2018) 115, arXiv:1711.03143 [hep-ex].

[6] CMS Collaboration, Measurement of the $t\bar{t}$ production cross section in the $e\mu$ channel in proton–proton collisions at $\sqrt{s} = 7$ and 8 TeV, J. High Energy Phys. 08 (2016) 029, arXiv:1603.02303 [hep-ex].

[7] CMS Collaboration, Measurements of the $t\bar{t}$ production cross section in lepton+jets final states in pp collisions at 8 TeV and ratio of 8 to 7 TeV cross sections, Eur. Phys. J. C 77 (2017) 15, arXiv:1602.09024 [hep-ex].

[8] CMS Collaboration, Measurement of the $t\bar{t}$ production cross section in pp collisions at $\sqrt{s} = 7$ TeV with lepton+jets final states, Phys. Lett. B 720 (2013) 83, arXiv:1212.6682 [hep-ex].
[9] CMS Collaboration, Measurement of the top quark pair production cross section in proton–proton collisions at $\sqrt{s} = 13$ TeV, Phys. Rev. Lett. 116 (2016) 052002, arXiv:1510.05302 [hep-ex].
[10] LHCb Collaboration, First observation of top quark production in the forward region, Phys. Rev. Lett. 115 (2015) 112001, arXiv:1506.00903 [hep-ex].
[11] LHCb Collaboration, Measurement of forward top pair production in the dilepton channel in pp collisions at $\sqrt{s} = 13$ TeV, J. High Energy Phys. 08 (2018) 174, arXiv:1803.05188 [hep-ex].
[12] M. Cacciari, M. Czakon, M. Mangano, A. Mitov, P. Nason, Top-pair production at hadron colliders with next-to-next-to-leading logarithmic soft-gluon resummation, Phys. Lett. B 710 (2012) 612, arXiv:1111.5869 [hep-ph].
[13] P. Bärnreuther, M. Czakon, A. Mitov, Percent-level-precision physics at the tevatron: next-to-next-to-leading order QCD corrections to $q\bar{q} \to t\bar{t} + X$, Phys. Rev. Lett. 109 (2012) 132001, arXiv:1204.5201 [hep-ph].
[14] M. Czakon, A. Mitov, NNLO corrections to top-pair production at hadron colliders: the all-fermionic scattering channels, J. High Energy Phys. 12 (2012) 054, arXiv:1207.0236 [hep-ph].
[15] M. Czakon, A. Mitov, NNLO corrections to top pair production at hadron colliders: the quark-gluon reaction, J. High Energy Phys. 01 (2013) 080, arXiv:1210.6832 [hep-ph].
[16] M. Czakon, P. Fiedler, A. Mitov, Total top-quark pair production cross section at hadron colliders through O(α_S^4), Phys. Rev. Lett. 110 (2013) 252004, arXiv:1303.6254 [hep-ph].
[17] S. Catani, et al., Top-quark pair hadroproduction at next-to-next-to-leading order in QCD, Phys. Rev. D 99 (2019) 051501, arXiv:1901.04005 [hep-ph].
[18] J. Rojo, et al., The PDF4LHC report on PDFs and LHC data: results from Run I and preparation for Run II, J. Phys. G 42 (2015) 103103, arXiv:1507.00556 [hep-ph].
[19] M.L. Mangano, J. Rojo, Cross Section Ratios between different CM energies at the LHC: opportunities for precision measurements and BSM sensitivity, J. High Energy Phys. 08 (2012) 010, arXiv:1206.3557 [hep-ph].
[20] ATLAS Collaboration, Measurements of top-quark pair to Z-boson cross-section ratios at $\sqrt{s} = 13, 8, 7$ TeV with the ATLAS detector, J. High Energy Phys. 02 (2017) 117, arXiv:1612.03636 [hep-ex].
[21] C. Anastasiou, L. Dixon, K. Melnikov, F. Petriello, High-precision QCD at hadron colliders: electroweak gauge boson rapidity distributions at next-to-next-to leading order, Phys. Rev. D 69 (2004) 094008, arXiv:hep-ph/0312266.
[22] S. Catani, M. Grazzini, Next-to-next-to-leading-order subtraction formalism in hadron collisions and its application to Higgs-boson production at the large hadron collider, Phys. Rev. Lett. 98 (2007) 222002, arXiv:hep-ph/0703012 [hep-ph].
[23] S. Catani, L. Cieri, G. Ferrera, D. de Florian, M. Grazzini, Vector boson production at hadron colliders: a fully exclusive QCD calculation at next-to-next-to-leading order, Phys. Rev. Lett. 103 (2009) 082001, arXiv:0903.2120 [hep-ph].
[24] R. Gavin, Y. Li, F. Petriello, S. Quackenbush, FEWZ 2.0: a code for hadronic Z production at next-to-next-to-leading order, arXiv:1011.3540 [hep-ph], 2010.
[25] Y. Li, F. Petriello, Combining QCD and electroweak corrections to dilepton production in the framework of the FEWZ simulation code, Phys. Rev. D 86 (2012) 094034, arXiv:1208.5967 [hep-ph].
[26] CMS Collaboration, First measurement of the top quark pair production cross section in proton-proton collisions at $\sqrt{s} = 13.6$ TeV, arXiv:2303.10680 [hep-ex], 2023.
[27] ATLAS Collaboration, Measurement of the $t\bar{t}$ production cross-section and lepton differential distributions in $e\mu$ dilepton events from pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, Eur. Phys. J. C 80 (2020) 528, arXiv:1910.08819 [hep-ex].
[28] ATLAS Collaboration, The ATLAS experiment at the CERN large hadron collider, J. Instrum. 3 (2008) S08003.
[29] ATLAS Collaboration, The ATLAS experiment at the CERN large hadron collider: a description of the detector configuration for Run 3, arXiv:2305.16623 [physics.ins-det], 2023.
[30] ATLAS Collaboration, The ATLAS collaboration software and firmware, ATL-SOFT-PUB-2021-001, https://cds.cern.ch/record/2767187, 2021.
[31] ATLAS Collaboration, ATLAS data quality operations and performance for 2015–2018 data-taking, J. Instrum. 15 (2020) P04003, arXiv:1911.04632 [physics.ins-det].
[32] S. Frixione, G. Ridolfi, P. Nason, A positive-weight next-to-leading-order Monte Carlo for heavy flavour hadroproduction, J. High Energy Phys. 09 (2007) 126, arXiv:0707.3088 [hep-ph].
[33] P. Nason, A new method for combining NLO QCD with shower Monte Carlo algorithms, J. High Energy Phys. 11 (2004) 040, arXiv:hep-ph/0409146.
[34] S. Frixione, P. Nason, C. Oleari, Matching NLO QCD computations with parton shower simulations: the POWHEG method, J. High Energy Phys. 11 (2007) 070, arXiv:0709.2092 [hep-ph].
[35] S. Alioli, P. Nason, C. Oleari, E. Re, A general framework for implementing NLO calculations in shower Monte Carlo programs: the POWHEG BOX, J. High Energy Phys. 06 (2010) 043, arXiv:1002.2581 [hep-ph].
[36] The NNPDF Collaboration, R.D. Ball, et al., Parton distributions for the LHC run II, J. High Energy Phys. 04 (2015) 040, arXiv:1410.8849 [hep-ph].
[37] ATLAS Collaboration, Studies on top-quark Monte Carlo modelling for Top2016, ATL-PHYS-PUB-2016-020, https://cds.cern.ch/record/2216168, 2016.
[38] C. Bierlich, et al., A comprehensive guide to the physics and usage of PYTHIA 8.3, SciPost Phys. Codebases (2022), arXiv:2203.11601 [hep-ph].
[39] ATLAS Collaboration, ATLAS Pythia 8 tunes to 7 *TeV* data, ATL-PHYS-PUB-2014-021, https://cds.cern.ch/record/1966419, 2014.
[40] NNPDF Collaboration, R.D. Ball, et al., Parton distributions with LHC data, Nucl. Phys. B 867 (2013) 244, arXiv:1207.1303 [hep-ph].
[41] D.J. Lange, The EvtGen particle decay simulation package, Nucl. Instrum. Methods Phys. Res., Sect. A 462 (2001) 152.
[42] M. Czakon, A. Mitov, Top++: a program for the calculation of the top-pair cross-section at hadron colliders, Comput. Phys. Commun. 185 (2014) 2930, arXiv:1112.5675 [hep-ph].
[43] R.D. Ball, et al., The PDF4LHC21 combination of global PDF fits for the LHC Run III, J. Phys. G 49 (2022) 080501, arXiv:2203.05506 [hep-ph].
[44] E. Bothmann, et al., Event generation with Sherpa 2.2, SciPost Phys. 7 (2019) 034, arXiv:1905.09127 [hep-ph].
[45] T. Gleisberg, S. Höche, Comix, a new matrix element generator, J. High Energy Phys. 12 (2008) 039, arXiv:0808.3674 [hep-ph].
[46] F. Buccioni, et al., OpenLoops 2, Eur. Phys. J. C 79 (2019) 866, arXiv:1907.13071 [hep-ph].
[47] F. Cascioli, P. Maierhöfer, S. Pozzorini, Scattering amplitudes with open loops, Phys. Rev. Lett. 108 (2012) 111601, arXiv:1111.5206 [hep-ph].
[48] A. Denner, S. Dittmaier, L. Hofer, Collier: a fortran-based complex one-loop library in extended regularizations, Comput. Phys. Commun. 212 (2017) 220, arXiv:1604.06792 [hep-ph].
[49] S. Schumann, F. Krauss, A parton shower algorithm based on Catani–Seymour dipole factorisation, J. High Energy Phys. 03 (2008) 038, arXiv:0709.1027 [hep-ph].
[50] S. Höche, F. Krauss, M. Schönherr, F. Siegert, A critical appraisal of NLO+PS matching methods, J. High Energy Phys. 09 (2012) 049, arXiv:1111.1220 [hep-ph].
[51] S. Höche, F. Krauss, M. Schönherr, F. Siegert, QCD matrix elements + parton showers. The NLO case, J. High Energy Phys. 04 (2013) 027, arXiv:1207.5030 [hep-ph].
[52] S. Catani, F. Krauss, B.R. Webber, R. Kuhn, QCD matrix elements + parton showers, J. High Energy Phys. 11 (2001) 063, arXiv:hep-ph/0109231.
[53] S. Höche, F. Krauss, S. Schumann, F. Siegert, QCD matrix elements and truncated showers, J. High Energy Phys. 05 (2009) 053, arXiv:0903.1219 [hep-ph].
[54] M. Grazzini, S. Kallweit, M. Wiesemann, Fully differential NNLO computations with MATRIX, Eur. Phys. J. C 78 (2018) 537, arXiv:1711.06631 [hep-ph].
[55] 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].
[56] S. Bailey, T. Cridge, L.A. Harland-Lang, A.D. Martin, R.S. Thorne, Parton distributions from LHC, HERA, tevatron and fixed target data: MSHT20 PDFs, Eur. Phys. J. C 81 (2021) 341, arXiv:2012.04684 [hep-ph].
[57] R.D. Ball, et al., The path to proton structure at 1% accuracy, Eur. Phys. J. C 82 (2022) 428, arXiv:2109.02653 [hep-ph].
[58] S. Alekhin, J. Blümlein, S. Moch, R. Placakyte, Parton distribution functions, α_s, and heavy-quark masses for LHC Run II, Phys. Rev. D 96 (2017) 014011, arXiv:1701.05838 [hep-ph].
[59] ATLAS Collaboration, Determination of the parton distribution functions of the proton using diverse ATLAS data from pp collisions at $\sqrt{s} = 7, 8$ and 13 TeV, Eur. Phys. J. C 82 (2021) 438, arXiv:2112.11266 [hep-ex].
[60] S. Frixione, E. Laenen, P. Motylinski, C. White, B.R. Webber, Single-top hadroproduction in association with a W boson, J. High Energy Phys. 07 (2008) 029, arXiv:0805.3067 [hep-ph].
[61] N. Kidonakis, N. Yamanaka, Higher-order corrections for tW production at high-energy hadron colliders, J. High Energy Phys. 05 (2021) 278, arXiv:2102.11300 [hep-ph].
[62] S. Alioli, P. Nason, C. Oleari, E. Re, NLO single-top production matched with shower in POWHEG: s- and t-channel contributions, J. High Energy Phys. 09 (2009) 111, arXiv:0907.4076 [hep-ph], Erratum: J. High Energy Phys. 02 (2010) 011.
[63] ATLAS Collaboration, Emulating the impact of additional proton–proton interactions in the ATLAS simulation by pre-sampling sets of inelastic Monte Carlo events, Comput. Softw. Big Sci. 6 (2021) 3, arXiv:2102.09495 [hep-ex].
[64] S. Porteboeuf, T. Pierog, K. Werner, Producing Hard Processes Regarding the Complete Event: The EPOS Event Generator, Gioi Publishers, 2010, p. 135, arXiv:1006.2967 [hep-ph].
[65] T. Pierog, I. Karpenko, J.M. Katzy, E. Yatsenko, K. Werner, EPOS LHC: test of collective hadronization with data measured at the CERN Large Hadron Collider, Phys. Rev. C 92 (2015) 034906, arXiv:1306.0121 [hep-ph].
[66] ATLAS Collaboration, The Pythia 8 A3 tune description of ATLAS minimum bias and inelastic measurements incorporating the Donnachie–Landshoff diffractive model, ATL-PHYS-PUB-2016-017, https://cds.cern.ch/record/2206965, 2016.
[67] S. Agostinelli, et al., Geant4 – a simulation toolkit, Nucl. Instrum. Methods Phys. Res., Sect. A 506 (2003) 250.
[68] ATLAS Collaboration, The ATLAS simulation infrastructure, Eur. Phys. J. C 70 (2010) 823, arXiv:1005.4568 [physics.ins-det].
[69] ATLAS Collaboration, Electron and photon performance measurements with the ATLAS detector using the 2015–2017 LHC proton–proton collision data, J. Instrum. 14 (2019) P12006, arXiv:1908.00005 [hep-ex].
[70] 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].

[71] 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].

[72] 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].

[73] ATLAS Collaboration, Jet reconstruction and performance using particle flow with the ATLAS Detector, Eur. Phys. J. C 77 (2017) 466, arXiv:1703.10485 [hep-ex].

[74] M. Cacciari, G.P. Salam, G. Soyez, The anti-k_t jet clustering algorithm, J. High Energy Phys. 04 (2008) 063, arXiv:0802.1189 [hep-ph].

[75] M. Cacciari, G.P. Salam, G. Soyez, FastJet user manual, Eur. Phys. J. C 72 (2012) 1896, arXiv:1111.6097 [hep-ph].

[76] ATLAS Collaboration, Jet energy scale and resolution measured in proton–proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, Eur. Phys. J. C 81 (2020) 689, arXiv:2007.02645 [hep-ex].

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

[78] ATLAS Collaboration, ATLAS flavour-tagging algorithms for the LHC Run 2 pp collision dataset, Eur. Phys. J. C 83 (2022) 681, arXiv:2211.16345 [physics.data-an].

[79] ATLAS Collaboration, Deep sets based neural networks for impact parameter flavour tagging in ATLAS, ATL-PHYS-PUB-2020-014, https://cds.cern.ch/record/2718948, 2020.

[80] ATLAS Collaboration, Measurements of top-quark pair differential cross-sections in the lepton+jets channel in pp collisions at $\sqrt{s} = 13$ TeV using the ATLAS detector, J. High Energy Phys. 11 (2017) 191, arXiv:1708.00727 [hep-ex].

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

[82] ATLAS Collaboration, Luminosity determination in pp collisions at $\sqrt{s} = 13$ TeV using the ATLAS detector at the LHC, arXiv:2212.09379 [hep-ex], 2022.

[83] G. Avoni, et al., The new LUCID-2 detector for luminosity measurement and monitoring in ATLAS, J. Instrum. 13 (2018) P07017.

[84] ATLAS Collaboration, Jet energy scale measurements and their systematic uncertainties in proton–proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, Phys. Rev. D 96 (2017) 072002, arXiv:1703.09665 [hep-ex].

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

[86] ATLAS Collaboration, ATLAS b-jet identification performance and efficiency measurement with $t\bar{t}$ events in pp collisions at $\sqrt{s} = 13$ TeV, Eur. Phys. J. C 79 (2019) 970, arXiv:1907.05120 [hep-ex].

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

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

[89] J. Bellm, et al., Herwig 7.2 release note, Eur. Phys. J. C 80 (2020) 452, arXiv:1912.06509 [hep-ph].

[90] ATLAS Collaboration, Studies on top-quark Monte Carlo modelling with Sherpa and MG5_aMC@NLO, ATL-PHYS-PUB-2017-007, https://cds.cern.ch/record/2261938, 2017.

[91] ATLAS Collaboration, Measurement of the $t\bar{t}$ production cross-section using $e\mu$ events with b-tagged jets in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, Phys. Lett. B 761 (2016) 136, arXiv:1606.02699 [hep-ex], Erratum: Phys. Lett. B 772 (2017) 879.

[92] ATLAS Collaboration, Modelling and computational improvements to the simulation of single vector-boson plus jet processes for the ATLAS experiment, J. High Energy Phys. 08 (2021) 089, arXiv:2112.09588 [hep-ex].

[93] ATLAS Collaboration, ATLAS computing acknowledgements, ATL-SOFT-PUB-2023-001, https://cds.cern.ch/record/2869272, 2023.

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,q], 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[36], M.N. Agaras[13], J. Agarwala[73a,73b], A. Aggarwal[100], C. Agheorghiesei[27c], A. Ahmad[36], F. Ahmadov[38,ak], W.S. Ahmed[104], S. Ahuja[95], X. Ai[62a], 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,ao], 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[160], 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,av], D. Babal[28b], H. Bachacou[135], K. Bachas[152,w],

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,af], 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], F. Becherer [54], P. Bechtle [24], H.P. Beck [19,u], 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 [159], 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,ay], 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,as], 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], G. Brooijmans [41], W.K. Brooks [137f], E. Brost [29], L.M. Brown [165,n], 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], T.P. Calvet [102], 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,h], 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,x], 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,71b], G. Carratta [23b,23a], F. Carrio Argos [33g], J.W.S. Carter [155], T.M. Carter [52], M.P. Casado [13,k], 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,au], 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], 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,o], 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,aw], 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,ai], 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 [160], 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.F. Daneri [30], M. Danninger [142], V. Dao [36], G. Darbo [57b], S. Darmora [6], S.J. Das [29,ay], 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], J.I. Djuvsland [16], 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], C. Dülsen [171], 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,ab], 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], J. Erdmann [49], 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 [160], 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 [48], 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,d], 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,ap], 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,l], 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,ay], 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,t], 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 [160], 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,av], M.P. Giordani [69a,69c], P.F. Giraud [135], G. Giugliarelli [69a,69c], D. Giugni [71a], F. Giuli [36], I. Gkialas [9,l], L.K. Gladilin [37], C. Glasman [99], G.R. Gledhill [123], G. Glemža [48], M. Glisic [123], I. Gnesi [43b,g], Y. Go [29,ay], 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], S. Gonzalez Fernandez [13], 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,ad], 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,ao], H. Hanif [142], M.D. Hank [128], R. Hankache [101], 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,at], 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,m], 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,r], 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,ba], 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,al], P. Jenni [54,i], 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,v], T. Junkermann [63a], A. Juste Rozas [13,ad], 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], M. Khandoga [127], 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 [106], 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,f], G. Koren [151], 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,at], 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], 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,n], S. Lammers[68], W. Lampl[7], C. Lampoudis[152,f], 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[160], 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,ar], 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,ac], 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,e], T. Li[5,c], X. Li[104], Z. Li[126], Z. Li[104], Z. Li[14a,14e], S. Liang[14a,14e], Z. Liang[14a], M. Liberatore[135,am], 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[160], L. Longo[70a,70b], R. Longo[162], I. Lopez Paz[67], A. Lopez Solis[48], N. Lorenzo Martinez[4], A.M. Lory[109], 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], M. Mali [93], D. Malito [95,s], 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,an], D.C. Mankad [169], A. Mann [109], B. Mansoulie [135], S. Manzoni [36], L. Mao [62c], X. Mapekula [33c], A. Marantis [152,ac], G. Marchiori [5], M. Marcisovsky [131], C. Marcon [71a,71b], 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,ad], 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], L. Massa [23b], P. Massarotti [72a,72b], P. Mastrandrea [74a,74b], A. Mastroberardino [43b,43a], T. Masubuchi [153], T. Mathisen [161], J. Matousek [133], N. Matsuzawa [153], D.M. Mattern [49], 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,ai], 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], G. Merz [106], 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], 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], G. Monig [146], 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,p], 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,ay], 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 [159], 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,j], 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 [35e], 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 [160], N.M.J. Nunes De Moura Junior [83b], E. Nurse [96], J. Ocariz [127], A. Ochi [85], I. Ochoa [130a], S. Oerdek [48,y], J.T. Offermann [39], A. Ogrodnik [133], A. Oh [101], C.C. Ohm [144], H. Oide [84], R. Oishi [153], M.L. Ojeda [48], M.W. O'Keefe [92], Y. Okumura [153], L.F. Oleiro Seabra [130a], S.A. Olivares Pino [137d], D. Oliveira Damazio [29], D. Oliveira Goncalves [83a], J.L. Oliver [160], 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], S. Palestini [36], 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 [44], 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,ay], 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,f], 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], 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,aa], D. Reikher[151], A. Rej[49,z], C. Rembser[36], A. Renardi[48], M. Renda[27b], M.B. Rendel[110], F. Renner[48], A.G. Rennie[160], 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,ai], 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[160], 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,an], 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,f], 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], S.N. Santpur[17a], A. Santra[169], K.A. Saoucha[116b], 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,av], 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], P. Schacht[110], 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[160], C. Scheulen[55], C. Schiavi[57b,57a], E.J. Schioppa[70a,70b], M. Schioppa[43b,43a], B. Schlag[143,t], 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], S.J. Sekula[44], 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,j], M. Shiyakova [38,ag], J. Shlomi [169], M.J. Shochet [39], J. Shojaii [105], D.R. Shope [125], B. Shrestha [120], S. Shrestha [119,az], 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,aq], P. Skubic [120], M. Slawinska [87], V. Smakhtin [169], B.H. Smart [134], J. Smiesko [36], 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,ai], 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], I.R. Sotarriva Alvarez [154], V. Sothilingam [63a], O.J. Soto Sandoval [137c,137b], S. Sottocornola [68], R. Soualah [116b], 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,an], D.M. Starko [156b], 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,ae], A. Taffard [160], 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,ah], 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,ai], 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,t], K.W. Topolnicki [86b], E. Torrence [123], H. Torres [102,an], 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,f], P.V. Tsiareshka [37], S. Tsigaridas [156a], A. Tsirigotis [152,ac], V. Tsiskaridze [155], E.G. Tskhadadze [149a], M. Tsopoulou [152,f], 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,aj], P.M. Tuts [41], S. Tzamarias [152,f], 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 [160], J. Urban [28b], P. Urquijo [105], P. Urrejola [137a], G. Usai [8], R. Ushioda [154], M. Usman [108], Z. Uysal [21b], 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,an], 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,av], A. Vgenopoulos [152,f], 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], 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 [160], L. Wickremasinghe [124], W. Wiedenmann [170], C. Wiel [50], 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 [160], 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], Y. Wu [62a], Z. Wu [135], J. Wuerzinger [110,at], 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.K. 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,ax], 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 [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 [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)] *University Politehnica Bucharest, 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, Réseau Universitaire de Physique des Hautes Energies - Université Hassan II, 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)] University of Sharjah, Sharjah; 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] United Arab Emirates University, Al Ain; United Arab Emirates
[160] Department of Physics and Astronomy, University of California Irvine, Irvine CA; United States of America
[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 APC, Université Paris Cité, CNRS/IN2P3, Paris; France.
[d] Also at Borough of Manhattan Community College, City University of New York, New York NY; United States of America.
[e] Also at Center for High Energy Physics, Peking University; China.
[f] Also at Center for Interdisciplinary Research and Innovation (CIRI-AUTH), Thessaloniki; Greece.
[g] Also at Centro Studi e Ricerche Enrico Fermi; Italy.
[h] Also at CERN Tier-0; Switzerland.
[i] Also at CERN, Geneva; Switzerland.
[j] Also at Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève; Switzerland.
[k] Also at Departament de Fisica de la Universitat Autonoma de Barcelona, Barcelona; Spain.
[l] Also at Department of Financial and Management Engineering, University of the Aegean, Chios; Greece.
[m] Also at Department of Physics and Astronomy, University of Sheffield, Sheffield; United Kingdom.
[n] Also at Department of Physics and Astronomy, University of Victoria, Victoria BC; Canada.
[o] Also at Department of Physics, Ben Gurion University of the Negev, Beer Sheva; Israel.
[p] Also at Department of Physics, California State University, Sacramento; United States of America.
[q] Also at Department of Physics, King's College London, London; United Kingdom.
[r] Also at Department of Physics, Oxford University, Oxford; United Kingdom.
[s] Also at Department of Physics, Royal Holloway University of London, Egham; United Kingdom.
[t] Also at Department of Physics, Stanford University, Stanford CA; United States of America.
[u] Also at Department of Physics, University of Fribourg, Fribourg; Switzerland.
[v] Also at Department of Physics, University of Massachusetts, Amherst MA; United States of America.
[w] Also at Department of Physics, University of Thessaly; Greece.
[x] Also at Department of Physics, Westmont College, Santa Barbara; United States of America.
[y] Also at Deutsches Elektronen-Synchrotron DESY, Hamburg and Zeuthen; Germany.
[z] Also at Fakultät Physik, Technische Universität Dortmund, Dortmund; Germany.
[aa] Also at Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal; Germany.
[ab] Also at Group of Particle Physics, University of Montreal, Montreal QC; Canada.
[ac] Also at Hellenic Open University, Patras; Greece.
[ad] Also at Institucio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona; Spain.
[ae] Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg; Germany.
[af] Also at Institut für Physik, Universität Mainz, Mainz; Germany.
[ag] Also at Institute for Nuclear Research and Nuclear Energy (INRNE) of the Bulgarian Academy of Sciences, Sofia; Bulgaria.
[ah] Also at Institute of Applied Physics, Mohammed VI Polytechnic University, Ben Guerir; Morocco.
[ai] Also at Institute of Particle Physics (IPP); Canada.
[aj] Also at Institute of Physics and Technology, Ulaanbaatar; Mongolia.
[ak] Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku; Azerbaijan.
[al] Also at Institute of Theoretical Physics, Ilia State University, Tbilisi; Georgia.
[am] Also at IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette; France.
[an] Also at L2IT, Université de Toulouse, CNRS/IN2P3, UPS, Toulouse; France.
[ao] Also at Lawrence Livermore National Laboratory, Livermore; United States of America.
[ap] Also at National Institute of Physics, University of the Philippines Diliman (Philippines); Philippines.
[aq] Also at School of Physics and Astronomy, University of Birmingham, Birmingham; United Kingdom.
[ar] Also at School of Physics and Astronomy, University of Manchester, Manchester; United Kingdom.
[as] Also at SUPA - School of Physics and Astronomy, University of Glasgow, Glasgow; United Kingdom.
[at] Also at Technical University of Munich, Munich; Germany.
[au] Also at The Collaborative Innovation Center of Quantum Matter (CICQM), Beijing; China.
[av] Also at TRIUMF, Vancouver BC; Canada.
[aw] Also at Università di Napoli Parthenope, Napoli; Italy.
[ax] Also at University of Chinese Academy of Sciences (UCAS), Beijing; China.
[ay] Also at University of Colorado Boulder, Department of Physics, Colorado; United States of America.
[az] Also at Washington College, Chestertown, MD; United States of America.
[ba] Also at Yeditepe University, Physics Department, Istanbul; Türkiye.
[*] Deceased.