Physics Letters B 780 (2018) 557–577

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Measurement of the production cross-section of a single top quark in association with a Z boson in proton–proton collisions at 13 TeV with the ATLAS detector

The ATLAS Collaboration ⋆

ARTICLE INFO

Article history:
Received 10 October 2017
Received in revised form 27 February 2018
Accepted 10 March 2018
Available online 14 March 2018
Editor: M. Doser

ABSTRACT

The production of a top quark in association with a Z boson is investigated. The proton–proton collision data collected by the ATLAS experiment at the LHC in 2015 and 2016 at a centre-of-mass energy of $\sqrt{s} = 13$ TeV are used, corresponding to an integrated luminosity of 36.1 fb^{-1}. Events containing three identified leptons (electrons and/or muons) and two jets, one of which is identified as a b-quark jet are selected. The major backgrounds are diboson, $t\bar{t}$ and $Z+$jets production. A neural network is used to improve the background rejection and extract the signal. The resulting significance is 4.2σ in the data and the expected significance is 5.4σ. The measured cross-section for tZq production is $600 \pm 170\,(\text{stat.}) \pm 140\,(\text{syst.})$ fb.

1. Introduction

At hadron colliders, the top quark is typically produced in $t\bar{t}$ pairs through the strong interaction or as a single top or antitop quark through the electroweak interaction. The top quark was first observed via $t\bar{t}$ production at the Tevatron [1,2]. This was followed by the observation of single top-quark production [3–5] in the t- and s-channels, also at the Tevatron. The associated tW production was first observed in 8 TeV proton–proton collisions at the Large Hadron Collider (LHC) [6,7]. These single-top-quark channels allow a direct determination of the dominant tWb vertex and of the magnitude of the CKM matrix element $|V_{tb}|$ [8] using their measured cross-sections.

With increasing energy and integrated luminosity, the ability to study rare Standard Model (SM) phenomena becomes possible. In the case of single top-quark production, examples include $pp \to tZq$ [9] and $pp \to tH$ [10]. The $pp \to tZq$ process involves WWZ and tZ couplings and has not been observed so far [11]. Fig. 1 shows typical lowest-order Feynman diagrams for the process. This channel probes two SM couplings in a single process, whereas the similar final state $t\bar{t}Z$ only probes the tZ coupling. The $t\bar{t}Z$ process has been measured by the ATLAS [12,13] and CMS [14] collaborations. In addition, the production of $pp \to tZq$ is a SM background to the tH final state [10].

This Letter presents evidence of the production of a single top quark in association with a Z boson in the t-channel process $pp \to tZq$, where the Z boson decays into electrons or muons and the W boson from the top quark decays leptonically.

2. ATLAS detector

The ATLAS experiment [15] at the LHC is a multi-purpose particle detector with a forward–backward symmetric cylindrical geometry and a near 4π coverage in solid angle.[1] It consists of an inner detector (ID) surrounded by a thin superconducting solenoid providing a 2 T axial magnetic field, electromagnetic and hadron calorimeters, and a muon spectrometer. The inner detector covers the pseudorapidity range $|\eta| < 2.5$. It consists of silicon pixel, silicon micro-strip and transition radiation tracking detectors. The innermost pixel layer, the insertable B-layer, was added between Run 1 and Run 2 of the LHC, at a radius of 33 mm around a new, thinner, beam pipe [16]. Lead/liquid-argon (LAr) sampling calorimeters provide electromagnetic (EM) energy measurements with high granularity. A hadron (steel/scintillator-tile) calorimeter covers the central pseudorapidity range ($|\eta| < 1.7$). The end-cap and forward regions are instrumented with LAr calorimeters for both the EM and hadronic energy measurements up to $|\eta| = 4.9$.

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

[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 $\eta = -\ln\tan(\theta/2)$. Distances in the η–ϕ plane are measured in units of $\Delta R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$.

https://doi.org/10.1016/j.physletb.2018.03.023

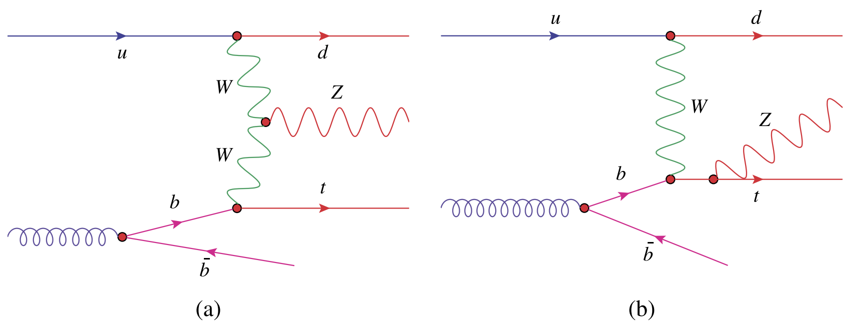

Fig. 1. Example Feynman diagrams of the lowest-order amplitudes for the tZq process. In the four-flavour scheme, the b-quark originates from gluon splitting. The largest contributing amplitude to the cross-section where the Z boson is coupled to the W boson is shown in (a) while (b) shows one of the four diagrams with radiation off a fermion.

The muon spectrometer surrounds the calorimeters and is based on three large air-core toroidal superconducting 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 reduce the accepted rate to at most 100 kHz. This is followed by a software-based trigger level that reduces the accepted event rate to 1 kHz on average.

3. Data and simulation samples

The pp collision data sample used in this measurement was collected with the ATLAS detector at the LHC during the 2015 and 2016 data-taking periods, corresponding to integrated luminosities of 3.3 fb^{-1} and 32.8 fb^{-1}, respectively, for a total of 36.1 fb^{-1}, after requiring that the detector is fully operational. Events are considered if they were accepted by at least one of the single-muon or single-electron triggers [17,18]. The electron triggers select a cluster in the calorimeter matched to a track. Electrons must then satisfy identification criteria based on a multivariate technique using a likelihood discriminant. In 2015, electrons had to satisfy a 'medium' identification requirement and have a transverse energy of $E_{\text{T}} > 24$ GeV. In 2016, electrons had to satisfy a 'tight' identification together with an isolation criterion and have $E_{\text{T}} > 26$ GeV. To avoid efficiency loss due to isolation at high E_{T}, an additional trigger was used, selecting 'medium' electrons with $E_{\text{T}} > 60$ GeV. Muons are triggered on by matching tracks reconstructed in the muon spectrometer and in the inner detector. In 2015, muons had to satisfy a 'loose' isolation requirement and have a transverse momentum of $p_{\text{T}} > 20$ GeV. In 2016, the isolation criteria were tightened and the threshold increased to $p_{\text{T}} = 26$ GeV. In both years, another muon trigger without any isolation requirement was used, selecting muons with $p_{\text{T}} > 50$ GeV.

In order to evaluate the effects of the detector resolution and acceptance on signal and background and to estimate the SM background, a full GEANT4-based detector simulation was used [19,20]. Event generators were used to estimate the expected signal and background contributions and their uncertainties. The top-quark mass in the event generators described below was set to 172.5 GeV. Multiple inelastic pp collisions (referred to as pile-up) are simulated with PYTHIA 8.186 [21], and are overlaid on each Monte Carlo (MC) event. Weights are assigned to the simulated events such that the distribution of the number of pile-up interactions in the simulation matches the corresponding distribution in the data. All simulation samples are processed through the same reconstruction algorithms as the data.

Monte Carlo tZq signal samples were generated at leading order (LO) in QCD using MG5_aMC@NLO 2.2.1 [22] in the four-flavour scheme, treating the b-quark as massive, with the CTEQ6L1 [23] LO parton distribution functions (PDFs). The Z boson was simulated to be on-shell and off-shell Z/γ^* contributions and their interference are not taken into account. Following the discussion in Ref. [24], the renormalisation and factorisation scales (μ_{r} and μ_{f}) used in MG5_aMC@NLO are set to $\mu_{\text{r}} = \mu_{\text{f}} = 4\sqrt{m_b^2 + p_{\text{T},b}^2}$, where the b-quark is the external one produced from gluon splitting in the event. This choice is motivated by the total scale dependence being dominated by this external b-quark, shown in Fig. 1. The parton shower and the hadronisation of signal events were simulated with PYTHIA 6 [25] using the Perugia2012 set of tuned parameters [26]. The tZq total cross-section, calculated at next-to-leading order (NLO) using MG5_aMC@NLO 2.3.3 with the NNPDF3.0_nlo_as_0118 [27] PDF, is 800 fb, with an uncertainty of $^{+6.1}_{-7.4}$%. The uncertainty is computed by varying the renormalisation and factorisation scales by a factor of two and by a factor of 0.5.

A comparison of the event kinematics before parton showering between the LO MG5_aMC@NLO 2.2.1 sample and a sample generated using NLO MG5_aMC@NLO 2.3.3 showed agreement within 10%, justifying the use of a LO sample for the detector simulation.

Monte Carlo simulated events are used to estimate the SM background that can produce three leptons and at least two jets in the final state. In $t\bar{t}$ production, if both W bosons decay into leptons (referred to as 'prompt') and either a b- or c-hadron decays into a lepton (referred to as 'non-prompt') that is isolated, the final state can mimic the tZq final state. The nominal $t\bar{t}$ simulated sample was generated at NLO with the POWHEG-BOX [28–30] event generator using the CT10 PDFs [31]. The cut-off parameter, h_{damp}, for the first emission of gluons was set to the top-quark mass. The events were then processed using PYTHIA 6 to perform the fragmentation and hadronisation, and to generate the underlying event.

Events from the associated production of a $t\bar{t}$ pair and a boson ($W/Z/H$) provide additional modes for the production of leptons in the final state. For $t\bar{t} + W$ the MC simulated events were generated using MG5_aMC@NLO 2.2.2 [22], while the $t\bar{t} + H$ and $t\bar{t} + Z$ MC simulated events were generated using MG5_aMC@NLO 2.2.3. The generated events were then processed with PYTHIA 8 [21] to perform the fragmentation and hadronisation, and to generate the underlying event, using the NNPDF2.3LO PDF set and the A14 tune [32].

Processes that include the production of WW, WZ and ZZ events were simulated using SHERPA 2.1.1 at LO with up to three additional partons and the CT10 PDF set. In the trilepton topology, the diboson background consists mainly of WZ events, while the contribution to the background from WW final states, corresponding to the case where a jet is misidentified as a lepton, is negligible. The ZZ background gives a small contribution of 9% of all diboson events. The gluon-induced diboson production, which amounts to about 10% of the quark-induced diboson production, is therefore negligible in the tZq signal region, and is not included in the diboson samples. In order to estimate the systematic uncertainty, additional diboson samples were simulated using the POWHEG-Box generator in combination with PYTHIA 8 and the CTEQ6L1 PDF sets.

Of the aforementioned single-top-quark production channels, only the tW channel contributes to the trilepton final state. This sample was produced using the NLO POWHEG-Box event generator with the CT10 PDF set. The events were then processed with PYTHIA 6 to perform the fragmentation and hadronisation, and produce the underlying event. A sample of tWZ events was produced using the MG5_aMC@NLO 2.2.3 generator and showered with PYTHIA 8, using the NNPDF3.0_NLO PDF set and the A14 tune.

4. Object reconstruction

The reconstruction of the basic physics objects used in this analysis is described in the following. The primary vertex is chosen as the proton–proton vertex candidate with the highest sum of the squared transverse momenta of all associated tracks with $p_{\mathrm{T}} > 400$ MeV.

Electron candidates are reconstructed from energy deposits in the electromagnetic calorimeter that match a reconstructed track [33–36]. The clusters are required to be within $|\eta| < 2.47$ excluding the transition region between the barrel and end-cap calorimeters at $1.37 < |\eta| < 1.52$. Electron candidates must also satisfy a transverse energy requirement of $E_{\mathrm{T}} > 15$ GeV. A likelihood-based discriminant is constructed from a set of variables that enhance the electron selection, while rejecting photon conversions and hadrons misidentified as electrons [34]. An $|\eta|$- and p_{T}-dependent selection on the likelihood discriminant is applied, such that it has an 80% efficiency when used to identify electrons from the Z-boson decay. This working point corresponds to an approximate rejection factor against jets of 700 at a p_{T} of 40 GeV. Electrons are further required to be isolated using criteria based on ID tracks and topological clusters in the calorimeter, with an isolation efficiency of 90(99)% for $p_{\mathrm{T}} = 25(60)$ GeV. Correction factors are applied to simulated electrons to take into account the small differences in reconstruction, identification and isolation efficiencies between data and MC simulation.

Muon candidates are required to have $|\eta|<2.5$ and $p_{\mathrm{T}}>15$ GeV, and are reconstructed by combining a reconstructed track from the inner detector with one from the muon spectrometer [37]. To reject misidentified muon candidates, primarily from pion and kaon decays, several quality requirements are imposed on the muon candidate. An isolation requirement based on ID tracks and topological clusters in the calorimeter is imposed, and results in an isolation efficiency of 90(99)% for $p_{\mathrm{T}} = 25(60)$ GeV. The overall efficiency obtained for muons from W-boson decays in simulated $pp \to t\bar{t}$ events is 96% and the rejection factor for non-prompt muons with $p_{\mathrm{T}} > 20$ GeV is approximately 600. As for electrons, correction factors are applied to muons to account for the small differences between data and simulation.

Jets are reconstructed from topological clusters using the anti-k_t algorithm [38,39] with the radius parameter set to $R = 0.4$. They are reconstructed for $p_{\mathrm{T}} > 30$ GeV in the region with $|\eta| < 4.5$. To account for inhomogeneities and the non-compensating response of the calorimeter, the reconstructed jet energies are corrected using p_{T}- and η-dependent factors that are derived in MC simulation and validated in data. Any remaining differences in the jet energy scale are corrected using *in situ* techniques, where a well-defined reference object is momentum-balanced with a jet [40]. To suppress pile-up, a discriminant called the jet-vertex-tagger (JVT) is constructed using a two-dimensional likelihood method [41]. For jets with $p_{\mathrm{T}} < 60$ GeV and $|\eta| < 2.4$ a JVT requirement corresponding to a 92% efficiency, while rejecting 98% of jets from pile-up and noise, is imposed.

To identify jets containing a b-hadron (b-tagging), a multivariate algorithm is employed [42]. This algorithm uses the impact parameter and reconstructed secondary vertex information of the tracks contained in the jet as input for a neural network. Due to its use of the inner detectors, the reconstruction of b-jets is done in the region with $|\eta| < 2.5$. Jets initiated by b-quarks are selected by setting the algorithm's output threshold such that a 77% b-jet selection efficiency is achieved in simulated $t\bar{t}$ events. With this setting, the misidentification rate for jets initiated by light-flavour quarks or gluons is 1%, while it is 17% for jets initiated by c-quarks [43]. Correction factors are derived and applied to correct for the small differences in b-quark selection efficiency between data and MC simulation [42].

The missing transverse momentum, with magnitude $E_{\mathrm{T}}^{\mathrm{miss}}$, is calculated as the negative of the vector sum of the transverse momenta of all reconstructed objects, $p_{\mathrm{T}}^{\mathrm{miss}}$. In addition to the identified jets, electrons and muons, a track-based 'soft' term is included in the $p_{\mathrm{T}}^{\mathrm{miss}}$ calculation, by considering tracks associated with the primary vertex in the event but not with an identified jet, electron, or muon [44,45].

To avoid cases where the detector response to a single physical object is reconstructed as two separate final-state objects, several steps are followed to remove such overlaps, following Ref. [46].

5. Signal, control and validation regions

The reconstructed tZq final state consists of three charged leptons (electron and/or muon), a b-tagged jet, an additional jet and $E_{\mathrm{T}}^{\mathrm{miss}}$. Reconstructing the Z boson and the top quark is important in order to identify specific features that help to separate the signal from the background. For example, the Z-boson mass distributions can contribute to the reduction of top-quark backgrounds, as these do not include a Z boson in the final state, while the untagged-jet pseudorapidity distribution differs in shape between tZq signal events and diboson and $t\bar{t}Z$ events, which constitute some of the largest backgrounds.

The signal region (SR) definition reflects the tZq final state by selecting only events that have exactly three charged leptons, one b-tagged jet and one additional jet, referred to as the untagged jet as no b-tagging requirement is applied. In order to better separate the tZq signal from background, additional requirements are imposed on the properties of the selected objects. The three leptons are sorted by their p_{T}, irrespective of flavour, and required to have transverse momenta of at least 28, 25 and 15 GeV, respectively. Both jets are required to have $p_{\mathrm{T}} > 30$ GeV.

An opposite-sign, same-flavour (OSSF) lepton pair is required in order to reconstruct the Z boson. In the μee and $e\mu\mu$ channels, the pair is uniquely identified. For the eee and $\mu\mu\mu$ events, both possible combinations are considered and the pair that has the invariant mass closest to the Z-boson mass is chosen. The W boson is reconstructed from the remaining lepton and the missing transverse momentum, using as constraint the W-boson mass to evaluate the z component of the neutrino momentum.[2] The top quark is reconstructed from the reconstructed W boson and the b-tagged jet.

To suppress background sources that do not contain a Z boson, the invariant mass of the leptons is required to be between 81 and 101 GeV. Because a W boson is expected in the final state,

[2] In case of an imaginary solution, the $p_{\mathrm{T}}^{\mathrm{miss}}$ value is varied until one real solution is found.

Table 1
Overview of the requirements applied for selecting events in the signal, validation and control regions.

Common Selections			
Exactly 3 leptons with $\lvert\eta\rvert < 2.5$ and $p_T > 15$ GeV			
$p_T(\ell_1) > 28$ GeV, $p_T(\ell_2) > 25$ GeV, $p_T(\ell_3) > 15$ GeV			
p_T(jet) > 30 GeV			
$m_T(\ell_W, \nu) > 20$ GeV			
SR	Diboson VR / CR	$t\bar{t}$ VR	$t\bar{t}$ CR
≥1 OSSF pair	≥1 OSSF pair	≥1 OSSF pair	≥1 OSDF pair
$\lvert m_{\ell\ell} - m_Z\rvert < 10$ GeV	$\lvert m_{\ell\ell} - m_Z\rvert < 10$ GeV	$\lvert m_{\ell\ell} - m_Z\rvert > 10$ GeV	No OSSF pair
2 jets, $\lvert\eta\rvert < 4.5$	1 jet, $\lvert\eta\rvert < 4.5$	2 jets, $\lvert\eta\rvert < 4.5$	2 jets, $\lvert\eta\rvert < 4.5$
1 b-jet, $\lvert\eta\rvert < 2.5$	–	1 b-jet, $\lvert\eta\rvert < 2.5$	1 b-jet, $\lvert\eta\rvert < 2.5$
–	VR/CR: $m_T(\ell_W, \nu) > 20/60$ GeV	–	–

the reconstructed transverse mass[3] of the W-boson candidate is required to satisfy $m_T(\ell, \nu) > 20$ GeV.

The selection criteria that define the SR are summarised in Table 1. In total, 141 events are selected using these criteria. The criteria are modified to define validation regions, which are used to check the modelling of the main background contributions. Two validation regions (VR) are defined as follows: the diboson VR uses the same event selection as the SR, except that only one jet is required in the event and no b-tagging requirement is applied. The $t\bar{t}$ VR also uses the same selection as the SR, except that the invariant mass of the OSSF pair must be outside the Z-mass window ($m_{\ell\ell} < 81$ GeV or $m_{\ell\ell} > 101$ GeV). In addition, two control regions (CR) are defined, from which the normalisations of the diboson and the $t\bar{t}$ background sources are computed, as explained in Section 6. The diboson CR is defined in the same way as the diboson VR, except with a tighter requirement on $m_T(\ell_W, \nu)$. The $t\bar{t}$ CR instead has the same selection as the SR but it requires an opposite-sign, different-flavour (OSDF) lepton pair and rejects events with an OSSF pair.

6. Background estimation

Different SM processes are considered as background sources for this analysis. These are either processes such as diboson or $t\bar{t}V + t\bar{t}H$ production, in which three or more prompt leptons are produced, or processes with only two prompt leptons in the final state (such as Z + jets and $t\bar{t}$ production) and one additional non-prompt or 'fake' lepton that meets the selection criteria. Such non-prompt or fake leptons can originate from decays of bottom or charm hadrons, a jet that is misidentified as an electron, leptons from kaon or pion decays, or electrons from photon conversions.

The dominant source of background originates from diboson production. This consists mainly of WZ events with a small fraction of ZZ events in which the fourth lepton is missed (roughly 9% of the total number of diboson events). Studies in the diboson VR indicated that the number of events predicted by the Sherpa MC samples is lower than the number observed. The kinematic distributions are otherwise well described. Hence, the total number of diboson events predicted by the Sherpa samples is scaled by a factor of 1.47, leading to an expected number of diboson events in the SR of 53. The scale factor is derived from the diboson CR, defined in Section 5, by computing the data-to-MC ratio for events that satisfy the condition $m_T(W) > 60$ GeV. This selection is applied in order to reduce the Z + jets contamination and ensure a diboson-dominated region. The uncertainty in the scale factor is estimated by varying the requirement for the $m_T(W)$ selection. An additional uncertainty in the diboson estimate is assigned by evaluating the difference in the number of events in the signal region when using the default Sherpa samples and a set of Powheg samples. This results in an estimated uncertainty of 30%, also taking into account the extrapolation of the scale factor from the CR to the SR.

The main sources of non-prompt or fake-lepton background for this analysis are $t\bar{t}$ and Z + jets events. These two contributions are evaluated separately. This choice is motivated by MC generator-level studies showing that although very similar in origin, the source of the non-prompt or fake lepton is usually different for processes involving top quarks compared to Z + jets events. For $t\bar{t}$ events, in most cases, it is the softer of the two leptons assigned to the reconstructed Z boson, while for Z + jets events it is the lepton not assigned to the Z boson.

In order to take into account a possible difference between data and MC simulation for $t\bar{t}$ events, the number of events containing a non-prompt or fake lepton in the MC simulation is scaled by a data/MC factor that is derived in the $t\bar{t}$ CR defined in Section 5. This $t\bar{t}$ control region and the signal region have very similar non-prompt lepton compositions. Requiring a pair of opposite-sign, different-flavour leptons, and rejecting events with an OSSF pair, ensures that there is no contamination from Z + jets events and from the SR. Different electron–muon invariant mass windows around the Z mass, with widths ranging from 20 GeV to 60 GeV, were investigated and the average of the obtained factors is used for scaling the $t\bar{t}$ background in the signal region. The total uncertainty in the scaling factor is calculated taking into account this variation and the statistical uncertainty of the sample. This leads to a data/MC scale factor of 1.21 ± 0.51. Deriving separate factors depending on the fake lepton's flavour or on the lepton p_T was also investigated. All approaches are consistent with each other within the assigned uncertainties. The expected number of $t\bar{t}$ events in the SR is 18 ± 9. According to the MC prediction, the tW contribution is found to be less than one event.

A data-driven technique called the fake-factor method is used to estimate the Z + jets background contribution. A region defined by selecting events with $m_T(W) < 20$ GeV is used for deriving the fake factors. Since it is observed that the number of non-prompt or fake electrons and muons can be very different, the estimation is done separately for the electron and muon channel. Fake factors are defined as the ratio of data events that have three isolated leptons to events in which one of the leptons fails the isolation requirement. They are derived in bins of the p_T of the lepton not associated with the Z boson. According to MC simulation, this lepton is in over 95% of the cases the non-prompt or fake lepton. These factors are then applied to events passing the signal region selection (including a $m_T(W) > 20$ GeV cut) that have one of the three leptons failing the isolation requirement. Contamination from other background sources, which is about 50% and mainly coming from $t\bar{t}$, is taken into account and subtracted before making the

[3] The transverse mass is calculated using the momentum of the lepton associated with the W boson, p_T^{miss} and the azimuthal angular difference between the two: $m_T\left(\ell, p_T^{miss}\right) = \sqrt{2p_T(\ell)E_T^{miss}\left[1 - \cos\Delta\phi\left(\ell, p_T^{miss}\right)\right]}$.

final $Z +$ jets estimate. The expected number of $Z +$ jets events in the SR is 37. Different sources of uncertainty are investigated, including consistency checks of the fake-factor method using MC $Z +$ jets samples, the effect of changing the diboson scale factor and the statistical uncertainties in the estimated and observed number of events. All these amount to a total uncertainty of 40%.

The expected $t\bar{t}V$, $t\bar{t}H$ and tWZ contributions are evaluated from the MC samples normalised to their predicted NLO cross-sections [22]. The $t\bar{t}V + t\bar{t}H$ contribution is approximately 10% of the total background estimate, while tWZ events amount to 3%. The expected number of $t\bar{t}V + t\bar{t}H + tWZ$ events is 20 ± 3. The uncertainty in the predictions is taken to be 13% [22].

7. Multivariate analysis

A multivariate analysis is used to separate the signal from the large number of background events. The neural-network package NeuroBayes [47,48] is used, which combines a three-layer feed-forward neural network with a complex robust preprocessing. Several variables are combined into one discriminant, then mapped onto the interval [0, 1], such that background-like events have an output value, O_{NN}, closer to 0 and signal-like events have an output closer to 1. All background processes are considered in the training except $t\bar{t}$ production, due to the very small number of available MC events that meet the selection criteria. Only variables that provide separation power and are well modelled are taken into account in the final neural network (NN). For the NN training, the ten variables with the highest separation power are used. These variables are explained in the order of their importance in Table 2. They include simple variables, such as the p_{T} and η of jets and of the lepton not associated with the Z boson. Information about the reconstructed W boson, Z boson and top quark, such as their p_{T} as well as their masses, is also used. In addition, the ΔR between the untagged jet and the Z boson is employed as an input.

Table 2
Variables used as input to the neural network, ordered by their separation power.

Variable	Definition
$\lvert\eta(\mathrm{j})\rvert$	Absolute value of untagged jet η
$p_{\mathrm{T}}(\mathrm{j})$	Untagged jet p_{T}
m_t	Reconstructed top-quark mass
$p_{\mathrm{T}}(\ell^W)$	p_{T} of the lepton from the W-boson decay
$\Delta R(\mathrm{j}, Z)$	ΔR between the untagged jet and the Z boson
$m_{\mathrm{T}}(\ell, E_{\mathrm{T}}^{\mathrm{miss}})$	Transverse mass of W boson
$p_{\mathrm{T}}(t)$	Reconstructed top-quark p_{T}
$p_{\mathrm{T}}(b)$	Tagged jet p_{T}
$p_{\mathrm{T}}(Z)$	p_{T} of the reconstructed Z boson
$\lvert\eta(\ell^W)\rvert$	Absolute value of η of the lepton coming from the W-boson decay

The modelling of the input variables is checked both in the validation regions defined in Table 1 and in the signal region. The distributions of some input variables in the signal region are shown in Fig. 2, normalised to the expected number of events, including the scale factors determined in Section 6. Good agreement between data and the prediction is observed.

The output of the NN is checked in the validation regions, shown in Fig. 3. Good agreement between the expected and ob-

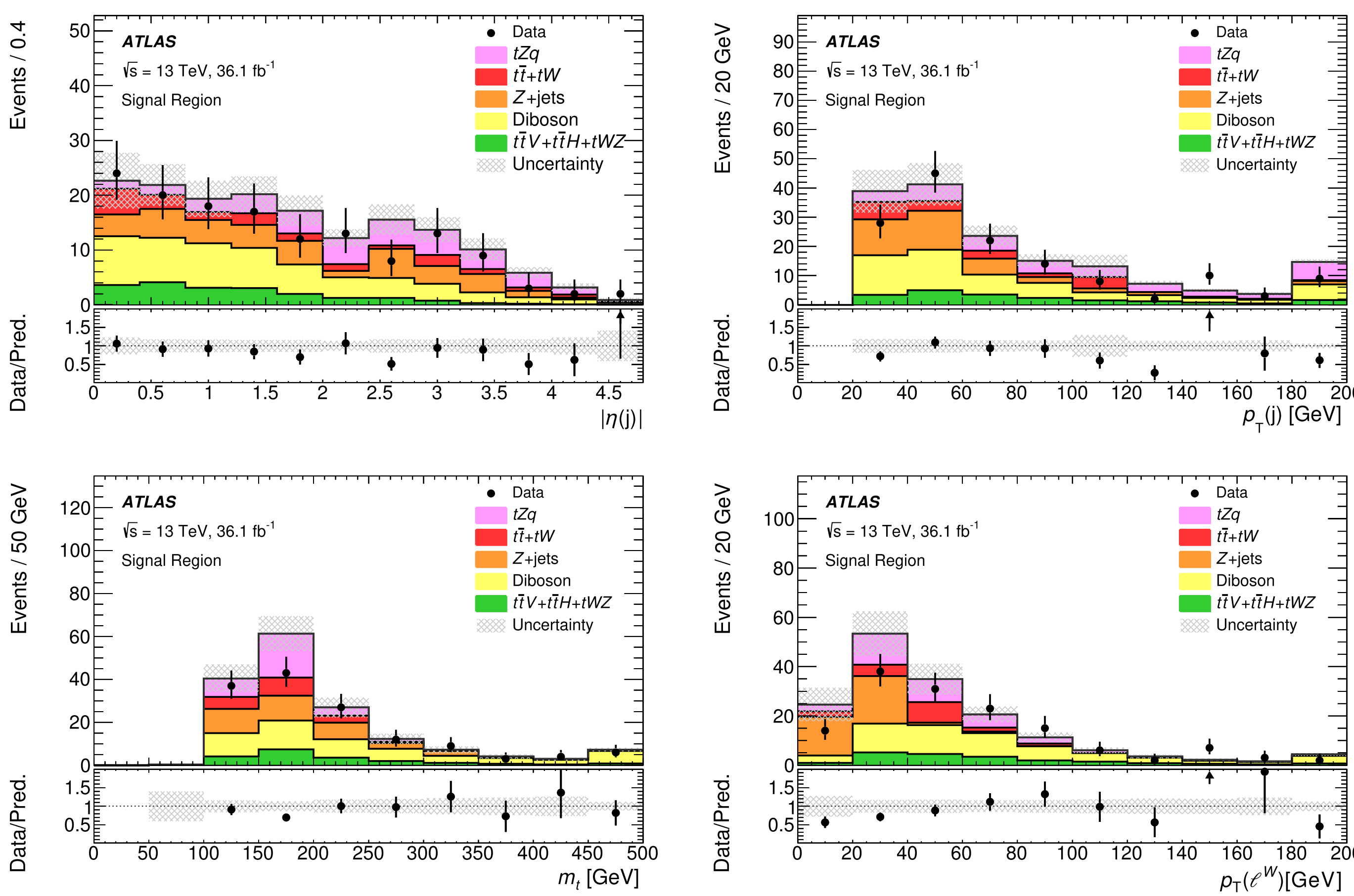

Fig. 2. Comparison of the data and the signal + background model for the neural-network training variables with the highest separation power. Signal and backgrounds are normalised to the expected number of events. The $Z +$ jets background is estimated using a data-driven technique. The uncertainty band includes the statistical uncertainty and the uncertainties in the backgrounds derived in Section 6. The rightmost bin includes overflow events.

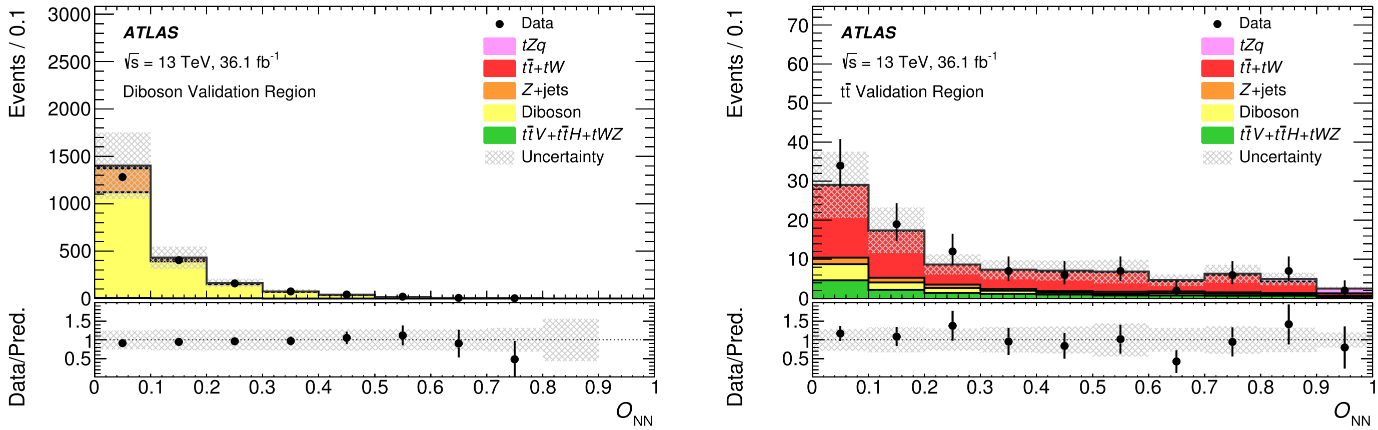

Fig. 3. Neural-network output distribution of the events in the diboson (left) and $t\bar{t}$ (right) validation regions. Signal and backgrounds are normalised to the expected number of events. The $Z+$jets background is estimated using a data-driven technique. The uncertainty band includes the statistical uncertainty and the uncertainties in the backgrounds derived in Section 6.

served numbers of events and in the shape of the NN output distribution are seen, demonstrating reliable background modelling. NeuroBayes includes extensive protection against overtraining and several further checks confirm that it functions well.

8. Systematic uncertainties

Systematic uncertainties in the normalisation of the individual backgrounds and in the signal acceptance, as well as uncertainties in the shape of the NN distributions, are taken into account when determining the tZq cross-section. For uncertainties where variations as a function of the NN distribution are consistent with being due to statistical fluctuations, only the normalisation difference is taken into account. The uncertainties are split into the following categories:

Reconstruction efficiency and calibration uncertainties Systematic uncertainties affecting the reconstruction and energy calibration of jets, electrons and muons are propagated through the analysis. The dominant sources of uncertainty for this measurement are the jet energy scale (JES) calibration, including the modelling of pile-up, and the b-jet tagging efficiencies.

The uncertainties due to lepton reconstruction, identification, isolation requirements and trigger efficiencies are estimated using tag-and-probe methods in $Z \to \ell\ell$ events. Correction factors are derived to match the simulation to observed distributions in collision data and associated uncertainties are estimated. Uncertainties in the lepton momentum scale and resolution are also assessed using $Z \to \ell\ell$ events [34,37,49].

Several components of the JES uncertainty are considered [40,50]. Uncertainties derived from different dijet-p_{T}-balance measurements as well as uncertainties associated with other in situ calibration techniques are considered. Furthermore, the presence of nearby jets and the modelling of pile-up affect the jet calibration. The uncertainty in the flavour composition covers effects due to the difference in quark–gluon composition between the jets used in the calibration and the jets used in this analysis. Also an uncertainty due to the different calorimeter responses to light-quark and gluon jets is taken into account. Finally, the JES uncertainty is estimated for b-jets by varying the modelling of b-quark fragmentation. The uncertainty in the jet energy resolution (JER) and the one associated with the JVT requirement are also considered [51]. The jet-related uncertainties with the highest impact on the final result are the JER and the flavour composition.

The impact of a possible miscalibration on the soft-track component of $E_{\mathrm{T}}^{\mathrm{miss}}$ is derived from data–MC comparisons of the p_{T} balance between the hard and soft $E_{\mathrm{T}}^{\mathrm{miss}}$ components [45]. The uncertainty associated with the leptons and jets is propagated from the corresponding uncertainties in the energy/momentum scales and resolutions, and it is classified together with the uncertainty associated with the corresponding objects.

Since the analysis makes use of b-tagging, the uncertainties in the b-tagging efficiency and the mistag rate are taken into account. These uncertainties were determined using $\sqrt{s} = 8$ TeV data as described in Ref. [52] for b-jets and Ref. [53] for light jets, with additional uncertainties to account for the presence of the newly added inner layer of the pixel detector and the extrapolation to $\sqrt{s} = 13$ TeV.

Signal PDF and radiation The systematic effects due to uncertainties in the parton distribution functions are taken into account for the signal. As it was generated at LO, the uncertainty is evaluated using the 30 eigenvectors of the NNPDF3.0_lo_as_0118 [27] PDF set, in the four-flavour scheme. The events are reweighted according to each of the PDF uncertainty eigenvectors. As a cross-check, the PDF uncertainty is also evaluated following the updated PDF4LHC recommendation [54] by using the PDF4LHC15 NLO PDF set. This has a smaller effect; hence the uncertainty from the LO PDF set is used.

Variations of the amount of additional radiation are studied by changing the hard-scatter scales and the scales in the parton shower simultaneously in the tZq sample. A variation of the factorisation and renormalisation scale by a factor of two is combined with the Perugia2012 set of tuned parameters with lower radiation (P2012radLo) than the nominal set; while a variation of both scales by a factor of 0.5 is combined with the Perugia2012 set of tuned parameters with higher radiation (P2012radHi).

Luminosity The uncertainty in the combined 2015 + 2016 integrated luminosity is 2.1%. It is derived, following a methodology similar to that detailed in Ref. [55], from a calibration of the luminosity scale using x–y beam-separation scans performed in August 2015 and May 2016.

The effects of the above uncertainties on the number of signal events are summarised in Table 3. This does not include the impact of the background uncertainties.

Background The uncertainties in the normalisation of the various background processes use the uncertainty estimated in Section 6. For the $t\bar{t}$ sample, the systematic effects due to uncertainties in the scale and the amount of radiation are included.

Table 3
Breakdown of the impact of the systematic uncertainties on the number of tZq signal events in order of decreasing effect. Details of the systematic uncertainties are provided in the text. MC statistics refers to the effect of the limited size of the MC samples used.

Source	Uncertainty [%]
tZq radiation	±10.8
Jets	±4.6
b-tagging	±2.9
MC statistics	±2.8
tZq PDF	±2.2
Luminosity	±2.1
Leptons	±2.1
$E_{\mathrm{T}}^{\mathrm{miss}}$	±0.3

9. Results

Using the 141 selected events, a maximum-likelihood fit is performed to extract the tZq signal strength, μ, defined as the ratio of the measured signal yield to the NLO Standard Model prediction. The statistical analysis of the data employs a binned likelihood function $\mathcal{L}(\mu, \vec{\theta})$, constructed as the product of Poisson probability terms, to estimate μ [56]. The likelihood is maximised on the NN output distribution in the signal region. The background normalisations are allowed to vary within the uncertainties given in Section 6.

The impact of systematic uncertainties on the expected numbers of signal and background events is described by nuisance parameters, $\vec{\theta}$, which are each parameterised by a Gaussian or log-normal constraint for each bin of the NN output distribution. If the variation of the uncertainty in each bin is consistent with being due to statistical fluctuations, only the overall change in normalisation is included as a nuisance parameter. The uncertainties are set to be symmetric in the fit, using the average of the variations up and down. The expected numbers of signal and background events in each bin are functions of $\vec{\theta}$. The test statistic, q_{μ}, is constructed according to the profile likelihood ratio: $q_{\mu} = -2\ln[\mathcal{L}(\mu, \hat{\hat{\vec{\theta}}})/\mathcal{L}(\hat{\mu}, \hat{\vec{\theta}})]$, where $\hat{\mu}$ and $\hat{\vec{\theta}}$ are the parameters that maximise the likelihood, and $\hat{\hat{\vec{\theta}}}$ are the nuisance parameter values that maximise the likelihood for a given μ. This test statistic is used to determine a probability for accepting the background-only hypothesis for the observed data.

Fig. 4 shows the NN discriminant in the signal region with background normalisations, signal normalisation and nuisance parameters adjusted by the profile likelihood fit.

The results for the numbers of fitted signal and background events are summarised in Table 4. The table also shows the result of a fit to the Asimov dataset [56]. The total uncertainty in the number of fitted events includes the effect of correlations, which are large among the background sources, as the O_{NN} distributions have a similar shape. The strongest correlation is found to be between the diboson and the $Z+$jets contributions and it is about -0.5 for both the Asimov dataset and the data.

After performing the binned maximum-likelihood fit and estimating the total uncertainty, the fitted value for μ is $0.75 \pm 0.21\,(\text{stat.}) \pm 0.17\,(\text{syst.}) \pm 0.05\,(\text{th.})$. The quoted theory (th.) uncertainty in μ includes the tZq NLO cross-section uncertainty given in Section 3. This is not taken into account when evaluating the cross-section. The statistical uncertainty in the cross-section is determined by performing a fit to the data, including only the statistical uncertainties. The total systematic uncertainty is determined by subtracting this value in quadrature from the total uncertainty. The cross-section for tZq production is measured to be $600 \pm 170\,(\text{stat.}) \pm 140\,(\text{syst.})$ fb, assuming a top-quark mass of $m_t = 172.5$ GeV.

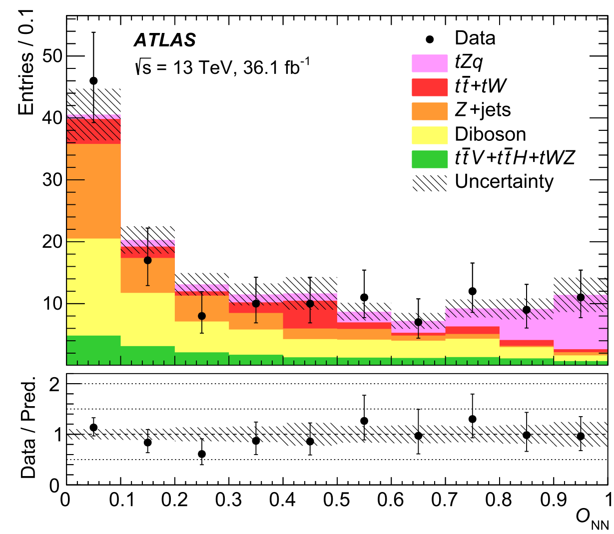

Fig. 4. Post-fit neural-network output distributions in the signal region. Signal and backgrounds are normalised to the expected number of events after the fit. The uncertainty band includes both the statistical and systematic uncertainties as obtained by the fit.

Table 4
Fitted yields in the signal region for the Asimov dataset and the data. The fitted numbers of events contain the statistical plus systematic uncertainties.

Channel	Number of events	
	Asimov dataset	Data
tZq	35 ± 9	26 ± 8
$t\bar{t}+tW$	28 ± 7	17 ± 7
$Z+$jets	37 ± 11	34 ± 11
Diboson	53 ± 13	48 ± 12
$t\bar{t}V+t\bar{t}H+tWZ$	20 ± 3	18 ± 3
Total	163 ± 12	143 ± 11

The probability p_0 of obtaining a result at least as signal-like as observed in the data if no signal were present is calculated using the test statistic $q_{\mu=0}$ in the asymptotic approximation [56]. The observed p_0 value is 1.3×10^{-5}. The resulting significance is 4.2σ, to be compared with the expected significance of 5.4σ.

10. Conclusion

The cross-section for tZq production has been measured using 36.1 fb^{-1} of proton–proton collision data collected by the ATLAS experiment at the LHC in 2015 and 2016 at a centre-of-mass energy of $\sqrt{s} = 13$ TeV. Evidence for the signal is obtained with a measured (expected) significance of 4.2σ (5.4σ). The measured cross-section is $600 \pm 170\,(\text{stat.}) \pm 140\,(\text{syst.})$ fb. This result is in agreement with the predicted SM tZq cross-section, calculated at NLO to be 800 fb with a scale uncertainty of $^{+6.1}_{-7.4}$%.

Acknowledgements

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

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

The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN, the ATLAS Tier-1 facilities at TRIUMF (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN–CNAF (Italy), NL-T1 (Netherlands), PIC (Spain), ASGC (Taiwan), RAL (UK) and BNL (USA), the Tier-2 facilities worldwide and large non-WLCG resource providers. Major contributors of computing resources are listed in Ref. [57].

References

[1] CDF Collaboration, F. Abe, et al., Observation of top quark production in $\bar{p}p$ collisions, Phys. Rev. Lett. 74 (1995) 2626, arXiv:hep-ex/9503002.
[2] DO Collaboration, S. Abachi, et al., Observation of the top quark, Phys. Rev. Lett. 74 (1995) 2632, arXiv:hep-ex/9503003.
[3] DO Collaboration, V.M. Abazov, et al., Observation of single top quark production, Phys. Rev. Lett. 103 (2009) 092001, arXiv:0903.0850 [hep-ex].
[4] CDF Collaboration, T. Aaltonen, et al., First observation of electroweak single top quark production, Phys. Rev. Lett. 103 (2009) 092002, arXiv:0903.0885 [hep-ex].
[5] CDF and D0 Collaborations, T. Aaltonen, et al., Observation of s-channel production of single top quarks at the Tevatron, Phys. Rev. Lett. 112 (2014) 231803, arXiv:1402.5126 [hep-ex].
[6] ATLAS Collaboration, Measurement of the production cross-section of a single top quark in association with a W boson at 8 TeV with the ATLAS experiment, J. High Energy Phys. 01 (2016) 064, arXiv:1510.03752 [hep-ex].
[7] CMS Collaboration, Observation of the associated production of a single top quark and a W boson in pp collisions at $\sqrt{s} = 8$ TeV, Phys. Rev. Lett. 112 (2014) 231802, arXiv:1401.2942 [hep-ex].
[8] C. Patrignani, et al., Review of particle physics, Chin. Phys. C 40 (2016) 100001.
[9] J. Campbell, R.K. Ellis, R. Rontsch, Single top production in association with a Z boson at the LHC, Phys. Rev. D 87 (2013) 114006, arXiv:1302.3856 [hep-ph].
[10] J. Chang, K. Cheung, J.S. Lee, C.-T. Lu, Probing the top-Yukawa coupling in associated Higgs production with a single top quark, J. High Energy Phys. 05 (2014) 062, arXiv:1403.2053 [hep-ph].
[11] CMS Collaboration, Search for associated production of a Z boson with a single top quark and for tZ flavour-changing interactions in pp collisions at $\sqrt{s} = 8$ TeV, J. High Energy Phys. 07 (2017) 003, arXiv:1702.01404 [hep-ex].
[12] ATLAS Collaboration, Measurement of the $t\bar{t}W$ and $t\bar{t}Z$ production cross sections in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector, J. High Energy Phys. 11 (2015) 172, arXiv:1509.05276 [hep-ex].
[13] ATLAS Collaboration, Measurement of the $t\bar{t}Z$ and $t\bar{t}W$ production cross sections in multilepton final states using 3.2 fb^{-1} of pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, Eur. Phys. J. C 77 (2017) 40, arXiv:1609.01599 [hep-ex].
[14] CMS Collaboration, Observation of top quark pairs produced in association with a vector boson in pp collisions at $\sqrt{s} = 8$ TeV, J. High Energy Phys. 01 (2016) 096, arXiv:1510.01131 [hep-ex].
[15] ATLAS Collaboration, The ATLAS experiment at the CERN large hadron collider, J. Instrum. 3 (2008), S08003.
[16] ATLAS Collaboration, Early inner detector tracking performance in the 2015 data at $\sqrt{s} = 13$ TeV, ATL-PHYS-PUB-2015-051, https://cds.cern.ch/record/2110140, 2015.
[17] ATLAS Collaboration, Trigger menu in 2016, ATL-DAQ-PUB-2017-001, https://cds.cern.ch/record/2242069, 2017.
[18] ATLAS Collaboration, Performance of the ATLAS trigger system in 2015, Eur. Phys. J. C 77 (2017) 317, arXiv:1611.09661 [hep-ex].
[19] S. Agostinelli, et al., GEANT4 – a simulation toolkit, Nucl. Instrum. Methods A 506 (2003) 250.
[20] ATLAS Collaboration, The ATLAS simulation infrastructure, Eur. Phys. J. C 70 (2010) 823, arXiv:1005.4568 [hep-ex].
[21] T. Sjöstrand, S. Mrenna, P.Z. Skands, A brief introduction to PYTHIA 8.1, Comput. Phys. Commun. 178 (2008) 852, arXiv:0710.3820 [hep-ph].
[22] J. Alwall, et al., The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations, J. High Energy Phys. 07 (2014) 079, arXiv:1405.0301 [hep-ph].
[23] J. Pumplin, et al., New generation of parton distributions with uncertainties from global QCD analysis, J. High Energy Phys. 07 (2002) 012, arXiv:hep-ph/0201195.
[24] R. Frederix, E. Re, P. Torrielli, Single-top t-channel hadroproduction in the four-flavour scheme with POWHEG and aMC@NLO, J. High Energy Phys. 09 (2012) 130, arXiv:1207.5391 [hep-ph].
[25] T. Sjostrand, S. Mrenna, P.Z. Skands, PYTHIA 6.4 physics and manual, J. High Energy Phys. 05 (2006) 026, arXiv:hep-ph/0603175.
[26] P.Z. Skands, Tuning Monte Carlo generators: the Perugia tunes, Phys. Rev. D 82 (2010) 074018, arXiv:1005.3457 [hep-ph].
[27] R.D. Ball, et al., Parton distributions for the LHC run II, J. High Energy Phys. 04 (2015) 40, arXiv:1410.8849 [hep-ph].
[28] 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.
[29] 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].
[30] 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].
[31] H.-L. Lai, et al., New parton distributions for collider physics, Phys. Rev. D 82 (2010) 074024, arXiv:1007.2241 [hep-ph].
[32] ATLAS Collaboration, ATLAS Pythia 8 tunes to 7 TeV data, ATL-PHYS-PUB-2014-021, https://cds.cern.ch/record/1966419, 2014.
[33] ATLAS Collaboration, Electron reconstruction and identification efficiency measurements with the ATLAS detector using the 2011 LHC proton–proton collision data, Eur. Phys. J. C 74 (2014) 2941, arXiv:1404.2240 [hep-ex].
[34] ATLAS Collaboration, Electron identification measurements in ATLAS using $\sqrt{s} = 13$ TeV data with 50 ns bunch spacing, ATL-PHYS-PUB-2015-041, https://cds.cern.ch/record/2048202, 2015.
[35] ATLAS Collaboration, Electron and photon energy calibration with the ATLAS detector using data collected in 2015 at $\sqrt{s} = 13$ TeV, ATL-PHYS-PUB-2016-015, https://cds.cern.ch/record/2203514, 2016.
[36] ATLAS Collaboration, Electron efficiency measurements with the ATLAS detector using the 2015 LHC proton–proton collision data, ATLAS-CONF-2016-024, https://cds.cern.ch/record/2157687, 2016.
[37] 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].
[38] M. Cacciari, G.P. Salam, Dispelling the N^3 myth for the k_t jet-finder, Phys. Lett. B 641 (2006) 57, arXiv:hep-ph/0512210.
[39] M. Cacciari, G.P. Salam, G. Soyez, The anti-k_t jet clustering algorithm, J. High Energy Phys. 04 (2008) 063, arXiv:0802.1189.
[40] ATLAS Collaboration, Jet energy measurement and its systematic uncertainty in proton–proton collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector, Eur. Phys. J. C 75 (2015) 17, arXiv:1406.0076 [hep-ex].
[41] 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].
[42] ATLAS Collaboration, Performance of b-jet identification in the ATLAS experiment, J. Instrum. 11 (2016) P04008, arXiv:1512.01094 [hep-ex].
[43] ATLAS Collaboration, Optimisation of the ATLAS b-tagging performance for the 2016 LHC Run, ATL-PHYS-PUB-2016-012, https://cds.cern.ch/record/2160731, 2016.
[44] ATLAS Collaboration, Performance of algorithms that reconstruct missing transverse momentum in $\sqrt{s} = 8$ TeV proton–proton collisions in the ATLAS detector, Eur. Phys. J. C 77 (2017) 241, arXiv:1609.09324 [hep-ex].
[45] ATLAS Collaboration, Performance of missing transverse momentum reconstruction with the ATLAS detector in the first proton–proton collisions at $\sqrt{s} = 13$ TeV, ATL-PHYS-PUB-2015-027, https://cds.cern.ch/record/2037904, 2015.

[46] ATLAS Collaboration, Measurement of the cross-section for producing a W boson in association with a single top quark in pp collisions at $\sqrt{s} = 13$ TeV with ATLAS, J. High Energy Phys. 01 (2018) 063, arXiv:1612.07231 [hep-ex].

[47] M. Feindt, A neural Bayesian estimator for conditional probability densities, arXiv:physics/0402093, 2004.

[48] M. Feindt, U. Kerzel, The NeuroBayes neural network package, Nucl. Instrum. Methods A 559 (2006) 190.

[49] ATLAS Collaboration, Electron and photon energy calibration with the ATLAS detector using LHC Run 1 data, Eur. Phys. J. C 74 (2014) 3071, arXiv:1407.5063 [hep-ex].

[50] 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.

[51] ATLAS Collaboration, Jet energy resolution in proton–proton collisions at $\sqrt{s} = 7$ TeV recorded in 2010 with the ATLAS detector, Eur. Phys. J. C 73 (2013) 2306, arXiv:1210.6210 [hep-ex].

[52] ATLAS Collaboration, Calibration of b-tagging using dileptonic top pair events in a combinatorial likelihood approach with the ATLAS experiment, ATLAS-CONF-2014-004, https://cds.cern.ch/record/1664335, 2014.

[53] ATLAS Collaboration, Calibration of the performance of b-tagging for c and light-flavour jets in the 2012 ATLAS data, ATLAS-CONF-2014-046, https://cds.cern.ch/record/1741020, 2014.

[54] J. Butterworth, et al., PDF4LHC recommendations for LHC Run II, J. Phys. G 43 (2016) 023001, arXiv:1510.03865 [hep-ph].

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

[56] G. Cowan, K. Cranmer, E. Gross, O. Vitells, Asymptotic formulae for likelihood-based tests of new physics, Eur. Phys. J. C 71 (2011) 1554, arXiv:1007.1727 [physics.data-an], Erratum: Eur. Phys. J. C 73 (2013) 2501.

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

The ATLAS Collaboration

M. Aaboud [137d], G. Aad [88], B. Abbott [115], O. Abdinov [12,∗], B. Abeloos [119], S.H. Abidi [161], O.S. AbouZeid [139], N.L. Abraham [151], H. Abramowicz [155], H. Abreu [154], R. Abreu [118], Y. Abulaiti [148a,148b], B.S. Acharya [167a,167b,a], S. Adachi [157], L. Adamczyk [41a], J. Adelman [110], M. Adersberger [102], T. Adye [133], A.A. Affolder [139], Y. Afik [154], T. Agatonovic-Jovin [14], C. Agheorghiesei [28c], J.A. Aguilar-Saavedra [128a,128f], S.P. Ahlen [24], F. Ahmadov [68,b], G. Aielli [135a,135b], S. Akatsuka [71], H. Akerstedt [148a,148b], T.P.A. Åkesson [84], E. Akilli [52], A.V. Akimov [98], G.L. Alberghi [22a,22b], J. Albert [172], P. Albicocco [50], M.J. Alconada Verzini [74], S.C. Alderweireldt [108], M. Aleksa [32], I.N. Aleksandrov [68], C. Alexa [28b], G. Alexander [155], T. Alexopoulos [10], M. Alhroob [115], B. Ali [130], M. Aliev [76a,76b], G. Alimonti [94a], J. Alison [33], S.P. Alkire [38], B.M.M. Allbrooke [151], B.W. Allen [118], P.P. Allport [19], A. Aloisio [106a,106b], A. Alonso [39], F. Alonso [74], C. Alpigiani [140], A.A. Alshehri [56], M.I. Alstaty [88], B. Alvarez Gonzalez [32], D. Álvarez Piqueras [170], M.G. Alviggi [106a,106b], B.T. Amadio [16], Y. Amaral Coutinho [26a], C. Amelung [25], D. Amidei [92], S.P. Amor Dos Santos [128a,128c], S. Amoroso [32], G. Amundsen [25], C. Anastopoulos [141], L.S. Ancu [52], N. Andari [19], T. Andeen [11], C.F. Anders [60b], J.K. Anders [77], K.J. Anderson [33], A. Andreazza [94a,94b], V. Andrei [60a], S. Angelidakis [37], I. Angelozzi [109], A. Angerami [38], A.V. Anisenkov [111,c], N. Anjos [13], A. Annovi [126a,126b], C. Antel [60a], M. Antonelli [50], A. Antonov [100,∗], D.J. Antrim [166], F. Anulli [134a], M. Aoki [69], L. Aperio Bella [32], G. Arabidze [93], Y. Arai [69], J.P. Araque [128a], V. Araujo Ferraz [26a], A.T.H. Arce [48], R.E. Ardell [80], F.A. Arduh [74], J-F. Arguin [97], S. Argyropoulos [66], M. Arik [20a], A.J. Armbruster [32], L.J. Armitage [79], O. Arnaez [161], H. Arnold [51], M. Arratia [30], O. Arslan [23], A. Artamonov [99,∗], G. Artoni [122], S. Artz [86], S. Asai [157], N. Asbah [45], A. Ashkenazi [155], L. Asquith [151], K. Assamagan [27], R. Astalos [146a], M. Atkinson [169], N.B. Atlay [143], K. Augsten [130], G. Avolio [32], B. Axen [16], M.K. Ayoub [35a], G. Azuelos [97,d], A.E. Baas [60a], M.J. Baca [19], H. Bachacou [138], K. Bachas [76a,76b], M. Backes [122], P. Bagnaia [134a,134b], M. Bahmani [42], H. Bahrasemani [144], J.T. Baines [133], M. Bajic [39], O.K. Baker [179], P.J. Bakker [109], E.M. Baldin [111,c], P. Balek [175], F. Balli [138], W.K. Balunas [124], E. Banas [42], A. Bandyopadhyay [23], Sw. Banerjee [176,e], A.A.E. Bannoura [178], L. Barak [155], E.L. Barberio [91], D. Barberis [53a,53b], M. Barbero [88], T. Barillari [103], M-S Barisits [32], J.T. Barkeloo [118], T. Barklow [145], N. Barlow [30], S.L. Barnes [36c], B.M. Barnett [133], R.M. Barnett [16], Z. Barnovska-Blenessy [36a], A. Baroncelli [136a], G. Barone [25], A.J. Barr [122], L. Barranco Navarro [170], F. Barreiro [85], J. Barreiro Guimarães da Costa [35a], R. Bartoldus [145], A.E. Barton [75], P. Bartos [146a], A. Basalaev [125], A. Bassalat [119,f], R.L. Bates [56], S.J. Batista [161], J.R. Batley [30], M. Battaglia [139], M. Bauce [134a,134b], F. Bauer [138], H.S. Bawa [145,g], J.B. Beacham [113], M.D. Beattie [75], T. Beau [83], P.H. Beauchemin [165], P. Bechtle [23], H.P. Beck [18,h], H.C. Beck [57], K. Becker [122], M. Becker [86], C. Becot [112], A.J. Beddall [20e], A. Beddall [20b], V.A. Bednyakov [68], M. Bedognetti [109], C.P. Bee [150], T.A. Beermann [32], M. Begalli [26a], M. Begel [27], J.K. Behr [45], A.S. Bell [81], G. Bella [155], L. Bellagamba [22a], A. Bellerive [31], M. Bellomo [154], K. Belotskiy [100], O. Beltramello [32], N.L. Belyaev [100], O. Benary [155,∗], D. Benchekroun [137a], M. Bender [102], N. Benekos [10], Y. Benhammou [155], E. Benhar Noccioli [179], J. Benitez [66], D.P. Benjamin [48], M. Benoit [52], J.R. Bensinger [25], S. Bentvelsen [109], L. Beresford [122], M. Beretta [50], D. Berge [109], E. Bergeaas Kuutmann [168], N. Berger [5], L.J. Bergsten [25], J. Beringer [16], S. Berlendis [58], N.R. Bernard [89], G. Bernardi [83], C. Bernius [145], F.U. Bernlochner [23], T. Berry [80], P. Berta [86], C. Bertella [35a], G. Bertoli [148a,148b], I.A. Bertram [75], C. Bertsche [45], G.J. Besjes [39], O. Bessidskaia Bylund [148a,148b], M. Bessner [45], N. Besson [138], A. Bethani [87], S. Bethke [103], A. Betti [23], A.J. Bevan [79], J. Beyer [103], R.M. Bianchi [127], O. Biebel [102], D. Biedermann [17],

R. Bielski [87], K. Bierwagen [86], N.V. Biesuz [126a,126b], M. Biglietti [136a], T.R.V. Billoud [97], H. Bilokon [50], M. Bindi [57], A. Bingul [20b], C. Bini [134a,134b], S. Biondi [22a,22b], T. Bisanz [57], C. Bittrich [47], D.M. Bjergaard [48], J.E. Black [145], K.M. Black [24], R.E. Blair [6], T. Blazek [146a], I. Bloch [45], C. Blocker [25], A. Blue [56], U. Blumenschein [79], S. Blunier [34a], G.J. Bobbink [109], V.S. Bobrovnikov [111,c], S.S. Bocchetta [84], A. Bocci [48], C. Bock [102], M. Boehler [51], D. Boerner [178], D. Bogavac [102], A.G. Bogdanchikov [111], C. Bohm [148a], V. Boisvert [80], P. Bokan [168,i], T. Bold [41a], A.S. Boldyrev [101], A.E. Bolz [60b], M. Bomben [83], M. Bona [79], M. Boonekamp [138], A. Borisov [132], G. Borissov [75], J. Bortfeldt [32], D. Bortoletto [122], V. Bortolotto [62a], D. Boscherini [22a], M. Bosman [13], J.D. Bossio Sola [29], J. Boudreau [127], E.V. Bouhova-Thacker [75], D. Boumediene [37], C. Bourdarios [119], S.K. Boutle [56], A. Boveia [113], J. Boyd [32], I.R. Boyko [68], A.J. Bozson [80], J. Bracinik [19], A. Brandt [8], G. Brandt [57], O. Brandt [60a], F. Braren [45], U. Bratzler [158], B. Brau [89], J.E. Brau [118], W.D. Breaden Madden [56], K. Brendlinger [45], A.J. Brennan [91], L. Brenner [109], R. Brenner [168], S. Bressler [175], D.L. Briglin [19], T.M. Bristow [49], D. Britton [56], D. Britzger [45], F.M. Brochu [30], I. Brock [23], R. Brock [93], G. Brooijmans [38], T. Brooks [80], W.K. Brooks [34b], J. Brosamer [16], E. Brost [110], J.H Broughton [19], P.A. Bruckman de Renstrom [42], D. Bruncko [146b], A. Bruni [22a], G. Bruni [22a], L.S. Bruni [109], S. Bruno [135a,135b], BH Brunt [30], M. Bruschi [22a], N. Bruscino [127], P. Bryant [33], L. Bryngemark [45], T. Buanes [15], Q. Buat [144], P. Buchholz [143], A.G. Buckley [56], I.A. Budagov [68], F. Buehrer [51], M.K. Bugge [121], O. Bulekov [100], D. Bullock [8], T.J. Burch [110], S. Burdin [77], C.D. Burgard [109], A.M. Burger [5], B. Burghgrave [110], K. Burka [42], S. Burke [133], I. Burmeister [46], J.T.P. Burr [122], D. Büscher [51], V. Büscher [86], P. Bussey [56], J.M. Butler [24], C.M. Buttar [56], J.M. Butterworth [81], P. Butti [32], W. Buttinger [27], A. Buzatu [153], A.R. Buzykaev [111,c], S. Cabrera Urbán [170], D. Caforio [130], H. Cai [169], V.M. Cairo [40a,40b], O. Cakir [4a], N. Calace [52], P. Calafiura [16], A. Calandri [88], G. Calderini [83], P. Calfayan [64], G. Callea [40a,40b], L.P. Caloba [26a], S. Calvente Lopez [85], D. Calvet [37], S. Calvet [37], T.P. Calvet [88], R. Camacho Toro [33], S. Camarda [32], P. Camarri [135a,135b], D. Cameron [121], R. Caminal Armadans [169], C. Camincher [58], S. Campana [32], M. Campanelli [81], A. Camplani [94a,94b], A. Campoverde [143], V. Canale [106a,106b], M. Cano Bret [36c], J. Cantero [116], T. Cao [155], M.D.M. Capeans Garrido [32], I. Caprini [28b], M. Caprini [28b], M. Capua [40a,40b], R.M. Carbone [38], R. Cardarelli [135a], F. Cardillo [51], I. Carli [131], T. Carli [32], G. Carlino [106a], B.T. Carlson [127], L. Carminati [94a,94b], R.M.D. Carney [148a,148b], S. Caron [108], E. Carquin [34b], S. Carrá [94a,94b], G.D. Carrillo-Montoya [32], D. Casadei [19], M.P. Casado [13,j], A.F. Casha [161], M. Casolino [13], D.W. Casper [166], R. Castelijn [109], V. Castillo Gimenez [170], N.F. Castro [128a,k], A. Catinaccio [32], J.R. Catmore [121], A. Cattai [32], J. Caudron [23], V. Cavaliere [169], E. Cavallaro [13], D. Cavalli [94a], M. Cavalli-Sforza [13], V. Cavasinni [126a,126b], E. Celebi [20d], F. Ceradini [136a,136b], L. Cerda Alberich [170], A.S. Cerqueira [26b], A. Cerri [151], L. Cerrito [135a,135b], F. Cerutti [16], A. Cervelli [22a,22b], S.A. Cetin [20d], A. Chafaq [137a], D. Chakraborty [110], S.K. Chan [59], W.S. Chan [109], Y.L. Chan [62a], P. Chang [169], J.D. Chapman [30], D.G. Charlton [19], C.C. Chau [31], C.A. Chavez Barajas [151], S. Che [113], S. Cheatham [167a,167c], A. Chegwidden [93], S. Chekanov [6], S.V. Chekulaev [163a], G.A. Chelkov [68,l], M.A. Chelstowska [32], C. Chen [36a], C. Chen [67], H. Chen [27], J. Chen [36a], S. Chen [35b], S. Chen [157], X. Chen [35c,m], Y. Chen [70], H.C. Cheng [92], H.J. Cheng [35a,35d], A. Cheplakov [68], E. Cheremushkina [132], R. Cherkaoui El Moursli [137e], E. Cheu [7], K. Cheung [63], L. Chevalier [138], V. Chiarella [50], G. Chiarelli [126a,126b], G. Chiodini [76a], A.S. Chisholm [32], A. Chitan [28b], Y.H. Chiu [172], M.V. Chizhov [68], K. Choi [64], A.R. Chomont [37], S. Chouridou [156], Y.S. Chow [62a], V. Christodoulou [81], M.C. Chu [62a], J. Chudoba [129], A.J. Chuinard [90], J.J. Chwastowski [42], L. Chytka [117], A.K. Ciftci [4a], D. Cinca [46], V. Cindro [78], I.A. Cioara [23], A. Ciocio [16], F. Cirotto [106a,106b], Z.H. Citron [175], M. Citterio [94a], M. Ciubancan [28b], A. Clark [52], B.L. Clark [59], M.R. Clark [38], P.J. Clark [49], R.N. Clarke [16], C. Clement [148a,148b], Y. Coadou [88], M. Cobal [167a,167c], A. Coccaro [52], J. Cochran [67], L. Colasurdo [108], B. Cole [38], A.P. Colijn [109], J. Collot [58], T. Colombo [166], P. Conde Muiño [128a,128b], E. Coniavitis [51], S.H. Connell [147b], I.A. Connelly [87], S. Constantinescu [28b], G. Conti [32], F. Conventi [106a,n], M. Cooke [16], A.M. Cooper-Sarkar [122], F. Cormier [171], K.J.R. Cormier [161], M. Corradi [134a,134b], F. Corriveau [90,o], A. Cortes-Gonzalez [32], G. Costa [94a], M.J. Costa [170], D. Costanzo [141], G. Cottin [30], G. Cowan [80], B.E. Cox [87], K. Cranmer [112], S.J. Crawley [56], R.A. Creager [124], G. Cree [31], S. Crépé-Renaudin [58], F. Crescioli [83], W.A. Cribbs [148a,148b], M. Cristinziani [23], V. Croft [112], G. Crosetti [40a,40b], A. Cueto [85], T. Cuhadar Donszelmann [141], A.R. Cukierman [145], J. Cummings [179], M. Curatolo [50], J. Cúth [86], S. Czekierda [42], P. Czodrowski [32], G. D'amen [22a,22b], S. D'Auria [56], L. D'eramo [83], M. D'Onofrio [77], M.J. Da Cunha Sargedas De Sousa [128a,128b], C. Da Via [87], W. Dabrowski [41a], T. Dado [146a], T. Dai [92], O. Dale [15], F. Dallaire [97], C. Dallapiccola [89], M. Dam [39], J.R. Dandoy [124], M.F. Daneri [29], N.P. Dang [176], A.C. Daniells [19], N.S. Dann [87], M. Danninger [171], M. Dano Hoffmann [138], V. Dao [150], G. Darbo [53a], S. Darmora [8], J. Dassoulas [3], A. Dattagupta [118], T. Daubney [45], W. Davey [23], C. David [45], T. Davidek [131], D.R. Davis [48], P. Davison [81], E. Dawe [91], I. Dawson [141], K. De [8], R. de Asmundis [106a], A. De Benedetti [115], S. De Castro [22a,22b], S. De Cecco [83], N. De Groot [108], P. de Jong [109], H. De la Torre [93], F. De Lorenzi [67], A. De Maria [57], D. De Pedis [134a], A. De Salvo [134a], U. De Sanctis [135a,135b], A. De Santo [151], K. De Vasconcelos Corga [88], J.B. De Vivie De Regie [119], R. Debbe [27], C. Debenedetti [139], D.V. Dedovich [68], N. Dehghanian [3], I. Deigaard [109], M. Del Gaudio [40a,40b], J. Del Peso [85], D. Delgove [119], F. Deliot [138], C.M. Delitzsch [7], A. Dell'Acqua [32], L. Dell'Asta [24], M. Dell'Orso [126a,126b], M. Della Pietra [106a,106b], D. della Volpe [52], M. Delmastro [5], C. Delporte [119], P.A. Delsart [58], D.A. DeMarco [161], S. Demers [179], M. Demichev [68], A. Demilly [83], S.P. Denisov [132], D. Denysiuk [138], D. Derendarz [42], J.E. Derkaoui [137d], F. Derue [83], P. Dervan [77], K. Desch [23], C. Deterre [45], K. Dette [161], M.R. Devesa [29], P.O. Deviveiros [32], A. Dewhurst [133], S. Dhaliwal [25], F.A. Di Bello [52], A. Di Ciaccio [135a,135b], L. Di Ciaccio [5], W.K. Di Clemente [124], C. Di Donato [106a,106b], A. Di Girolamo [32], B. Di Girolamo [32], B. Di Micco [136a,136b], R. Di Nardo [32], K.F. Di Petrillo [59], A. Di Simone [51], R. Di Sipio [161], D. Di Valentino [31], C. Diaconu [88], M. Diamond [161], F.A. Dias [39], M.A. Diaz [34a], E.B. Diehl [92], J. Dietrich [17], S. Díez Cornell [45], A. Dimitrievska [14], J. Dingfelder [23], P. Dita [28b], S. Dita [28b], F. Dittus [32], F. Djama [88], T. Djobava [54b], J.I. Djuvsland [60a], M.A.B. do Vale [26c], D. Dobos [32], M. Dobre [28b], D. Dodsworth [25], C. Doglioni [84], J. Dolejsi [131], Z. Dolezal [131], M. Donadelli [26d], S. Donati [126a,126b], P. Dondero [123a,123b], J. Donini [37], J. Dopke [133], A. Doria [106a], M.T. Dova [74], A.T. Doyle [56], E. Drechsler [57], M. Dris [10], Y. Du [36b], J. Duarte-Campderros [155], F. Dubinin [98], A. Dubreuil [52], E. Duchovni [175], G. Duckeck [102], A. Ducourthial [83], O.A. Ducu [97,p], D. Duda [109], A. Dudarev [32], A.Chr. Dudder [86], E.M. Duffield [16], L. Duflot [119], M. Dührssen [32], C. Dulsen [178], M. Dumancic [175], A.E. Dumitriu [28b], A.K. Duncan [56], M. Dunford [60a], A. Duperrin [88], H. Duran Yildiz [4a], M. Düren [55], A. Durglishvili [54b], D. Duschinger [47], B. Dutta [45], D. Duvnjak [1], M. Dyndal [45], B.S. Dziedzic [42], C. Eckardt [45], K.M. Ecker [103], R.C. Edgar [92], T. Eifert [32], G. Eigen [15], K. Einsweiler [16], T. Ekelof [168], M. El Kacimi [137c], R. El Kosseifi [88], V. Ellajosyula [88], M. Ellert [168], S. Elles [5], F. Ellinghaus [178], A.A. Elliot [172], N. Ellis [32], J. Elmsheuser [27], M. Elsing [32], D. Emeliyanov [133], Y. Enari [157], J.S. Ennis [173], M.B. Epland [48], J. Erdmann [46], A. Ereditato [18], M. Ernst [27], S. Errede [169], M. Escalier [119], C. Escobar [170], B. Esposito [50], O. Estrada Pastor [170], A.I. Etienvre [138], E. Etzion [155], H. Evans [64], A. Ezhilov [125], M. Ezzi [137e], F. Fabbri [22a,22b], L. Fabbri [22a,22b], V. Fabiani [108], G. Facini [81], R.M. Fakhrutdinov [132], S. Falciano [134a], R.J. Falla [81], J. Faltova [32], Y. Fang [35a], M. Fanti [94a,94b], A. Farbin [8], A. Farilla [136a], C. Farina [127], E.M. Farina [123a,123b], T. Farooque [93], S. Farrell [16], S.M. Farrington [173], P. Farthouat [32], F. Fassi [137e], P. Fassnacht [32], D. Fassouliotis [9], M. Faucci Giannelli [49], A. Favareto [53a,53b], W.J. Fawcett [122], L. Fayard [119], O.L. Fedin [125,q], W. Fedorko [171], S. Feigl [121], L. Feligioni [88], C. Feng [36b], E.J. Feng [32], M.J. Fenton [56], A.B. Fenyuk [132], L. Feremenga [8], P. Fernandez Martinez [170], J. Ferrando [45], A. Ferrari [168], P. Ferrari [109], R. Ferrari [123a], D.E. Ferreira de Lima [60b], A. Ferrer [170], D. Ferrere [52], C. Ferretti [92], F. Fiedler [86], A. Filipčič [78], M. Filipuzzi [45], F. Filthaut [108], M. Fincke-Keeler [172], K.D. Finelli [24], M.C.N. Fiolhais [128a,128c,r], L. Fiorini [170], A. Fischer [2], C. Fischer [13], J. Fischer [178], W.C. Fisher [93], N. Flaschel [45], I. Fleck [143], P. Fleischmann [92], R.R.M. Fletcher [124], T. Flick [178], B.M. Flierl [102], L.R. Flores Castillo [62a], M.J. Flowerdew [103], G.T. Forcolin [87], A. Formica [138], F.A. Förster [13], A. Forti [87], A.G. Foster [19], D. Fournier [119], H. Fox [75], S. Fracchia [141], P. Francavilla [126a,126b], M. Franchini [22a,22b], S. Franchino [60a], D. Francis [32], L. Franconi [121], M. Franklin [59], M. Frate [166], M. Fraternali [123a,123b], D. Freeborn [81], S.M. Fressard-Batraneanu [32], B. Freund [97], D. Froidevaux [32], J.A. Frost [122], C. Fukunaga [158], T. Fusayasu [104], J. Fuster [170], O. Gabizon [154], A. Gabrielli [22a,22b], A. Gabrielli [16], G.P. Gach [41a], S. Gadatsch [32], S. Gadomski [80], G. Gagliardi [53a,53b], L.G. Gagnon [97], C. Galea [108], B. Galhardo [128a,128c], E.J. Gallas [122], B.J. Gallop [133], P. Gallus [130], G. Galster [39], K.K. Gan [113], S. Ganguly [37], Y. Gao [77], Y.S. Gao [145,g], F.M. Garay Walls [34a], C. García [170], J.E. García Navarro [170], J.A. García Pascual [35a], M. Garcia-Sciveres [16], R.W. Gardner [33], N. Garelli [145], V. Garonne [121], A. Gascon Bravo [45], K. Gasnikova [45], C. Gatti [50], A. Gaudiello [53a,53b], G. Gaudio [123a], I.L. Gavrilenko [98], C. Gay [171], G. Gaycken [23], E.N. Gazis [10], C.N.P. Gee [133], J. Geisen [57], M. Geisen [86], M.P. Geisler [60a], K. Gellerstedt [148a,148b], C. Gemme [53a], M.H. Genest [58], C. Geng [92], S. Gentile [134a,134b], C. Gentsos [156], S. George [80], D. Gerbaudo [13], G. Geßner [46], S. Ghasemi [143], M. Ghneimat [23], B. Giacobbe [22a], S. Giagu [134a,134b], N. Giangiacomi [22a,22b], P. Giannetti [126a,126b], S.M. Gibson [80], M. Gignac [171], M. Gilchriese [16], D. Gillberg [31], G. Gilles [178], D.M. Gingrich [3,d], M.P. Giordani [167a,167c], F.M. Giorgi [22a], P.F. Giraud [138], P. Giromini [59], G. Giugliarelli [167a,167c], D. Giugni [94a], F. Giuli [122], C. Giuliani [103], M. Giulini [60b], B.K. Gjelsten [121], S. Gkaitatzis [156], I. Gkialas [9,s], E.L. Gkougkousis [13], P. Gkountoumis [10], L.K. Gladilin [101], C. Glasman [85], J. Glatzer [13], P.C.F. Glaysher [45], A. Glazov [45], M. Goblirsch-Kolb [25], J. Godlewski [42], S. Goldfarb [91], T. Golling [52], D. Golubkov [132], A. Gomes [128a,128b,128d], R. Gonçalo [128a], R. Goncalves Gama [26a], J. Goncalves Pinto Firmino Da Costa [138], G. Gonella [51], L. Gonella [19], A. Gongadze [68], J.L. Gonski [59], S. González de la Hoz [170], S. Gonzalez-Sevilla [52], L. Goossens [32], P.A. Gorbounov [99], H.A. Gordon [27], I. Gorelov [107], B. Gorini [32], E. Gorini [76a,76b], A. Gorišek [78], A.T. Goshaw [48], C. Gössling [46], M.I. Gostkin [68], C.A. Gottardo [23], C.R. Goudet [119], D. Goujdami [137c], A.G. Goussiou [140], N. Govender [147b,t], E. Gozani [154], I. Grabowska-Bold [41a], P.O.J. Gradin [168], J. Gramling [166], E. Gramstad [121], S. Grancagnolo [17], V. Gratchev [125], P.M. Gravila [28f], C. Gray [56], H.M. Gray [16], Z.D. Greenwood [82,u], C. Grefe [23], K. Gregersen [81], I.M. Gregor [45], P. Grenier [145], K. Grevtsov [5], J. Griffiths [8], A.A. Grillo [139], K. Grimm [75], S. Grinstein [13,v], Ph. Gris [37], J.-F. Grivaz [119], S. Groh [86], E. Gross [175], J. Grosse-Knetter [57], G.C. Grossi [82], Z.J. Grout [81], A. Grummer [107], L. Guan [92], W. Guan [176], J. Guenther [32], F. Guescini [163a], D. Guest [166], O. Gueta [155], B. Gui [113], E. Guido [53a,53b], T. Guillemin [5], S. Guindon [32], U. Gul [56], C. Gumpert [32], J. Guo [36c], W. Guo [92], Y. Guo [36a,w], R. Gupta [43], S. Gurbuz [20a], G. Gustavino [115], B.J. Gutelman [154], P. Gutierrez [115], N.G. Gutierrez Ortiz [81], C. Gutschow [81], C. Guyot [138], M.P. Guzik [41a], C. Gwenlan [122], C.B. Gwilliam [77], A. Haas [112], C. Haber [16], H.K. Hadavand [8], N. Haddad [137e], A. Hadef [88], S. Hageböck [23], M. Hagihara [164], H. Hakobyan [180,*], M. Haleem [45], J. Haley [116], G. Halladjian [93], G.D. Hallewell [88], K. Hamacher [178], P. Hamal [117], K. Hamano [172], A. Hamilton [147a], G.N. Hamity [141], P.G. Hamnett [45], L. Han [36a], S. Han [35a,35d], K. Hanagaki [69,x], K. Hanawa [157], M. Hance [139], D.M. Handl [102], B. Haney [124], P. Hanke [60a], J.B. Hansen [39], J.D. Hansen [39], M.C. Hansen [23], P.H. Hansen [39], K. Hara [164], A.S. Hard [176], T. Harenberg [178], F. Hariri [119], S. Harkusha [95], P.F. Harrison [173], N.M. Hartmann [102], Y. Hasegawa [142], A. Hasib [49], S. Hassani [138], S. Haug [18], R. Hauser [93], L. Hauswald [47], L.B. Havener [38], M. Havranek [130], C.M. Hawkes [19], R.J. Hawkings [32], D. Hayakawa [159], D. Hayden [93], C.P. Hays [122], J.M. Hays [79], H.S. Hayward [77], S.J. Haywood [133], S.J. Head [19], T. Heck [86], V. Hedberg [84], L. Heelan [8], S. Heer [23], K.K. Heidegger [51], S. Heim [45], T. Heim [16], B. Heinemann [45,y], J.J. Heinrich [102], L. Heinrich [112], C. Heinz [55], J. Hejbal [129], L. Helary [32], A. Held [171], S. Hellman [148a,148b], C. Helsens [32], R.C.W. Henderson [75], Y. Heng [176], S. Henkelmann [171], A.M. Henriques Correia [32], S. Henrot-Versille [119], G.H. Herbert [17], H. Herde [25], V. Herget [177], Y. Hernández Jiménez [147c], H. Herr [86], G. Herten [51], R. Hertenberger [102], L. Hervas [32], T.C. Herwig [124], G.G. Hesketh [81], N.P. Hessey [163a], J.W. Hetherly [43], S. Higashino [69], E. Higón-Rodriguez [170], K. Hildebrand [33], E. Hill [172], J.C. Hill [30], K.H. Hiller [45], S.J. Hillier [19], M. Hils [47], I. Hinchliffe [16], M. Hirose [51], D. Hirschbuehl [178], B. Hiti [78], O. Hladik [129], D.R. Hlaluku [147c], X. Hoad [49], J. Hobbs [150], N. Hod [163a], M.C. Hodgkinson [141], P. Hodgson [141], A. Hoecker [32], M.R. Hoeferkamp [107], F. Hoenig [102], D. Hohn [23], T.R. Holmes [33], M. Homann [46], S. Honda [164], T. Honda [69], T.M. Hong [127], B.H. Hooberman [169], W.H. Hopkins [118], Y. Horii [105], A.J. Horton [144], J-Y. Hostachy [58], A. Hostiuc [140], S. Hou [153], A. Hoummada [137a], J. Howarth [87], J. Hoya [74], M. Hrabovsky [117], J. Hrdinka [32], I. Hristova [17], J. Hrivnac [119], T. Hryn'ova [5], A. Hrynevich [96], P.J. Hsu [63], S.-C. Hsu [140], Q. Hu [27], S. Hu [36c], Y. Huang [35a], Z. Hubacek [130], F. Hubaut [88], F. Huegging [23], T.B. Huffman [122], E.W. Hughes [38], M. Huhtinen [32], R.F.H. Hunter [31], P. Huo [150], N. Huseynov [68,b], J. Huston [93], J. Huth [59], R. Hyneman [92], G. Iacobucci [52], G. Iakovidis [27], I. Ibragimov [143], L. Iconomidou-Fayard [119], Z. Idrissi [137e], P. Iengo [32], O. Igonkina [109,z], T. Iizawa [174], Y. Ikegami [69], M. Ikeno [69], Y. Ilchenko [11,aa], D. Iliadis [156], N. Ilic [145], F. Iltzsche [47], G. Introzzi [123a,123b], P. Ioannou [9,*], M. Iodice [136a], K. Iordanidou [38], V. Ippolito [59], M.F. Isacson [168], N. Ishijima [120], M. Ishino [157], M. Ishitsuka [159], C. Issever [122], S. Istin [20a], F. Ito [164], J.M. Iturbe Ponce [62a], R. Iuppa [162a,162b], H. Iwasaki [69], J.M. Izen [44], V. Izzo [106a], S. Jabbar [3], P. Jackson [1], R.M. Jacobs [23], V. Jain [2], K.B. Jakobi [86], K. Jakobs [51], S. Jakobsen [65], T. Jakoubek [129], D.O. Jamin [116], D.K. Jana [82], R. Jansky [52], J. Janssen [23], M. Janus [57], P.A. Janus [41a], G. Jarlskog [84], N. Javadov [68,b], T. Javůrek [51], M. Javurkova [51], F. Jeanneau [138], L. Jeanty [16], J. Jejelava [54a,ab], A. Jelinskas [173], P. Jenni [51,ac], C. Jeske [173], S. Jézéquel [5], H. Ji [176], J. Jia [150], H. Jiang [67], Y. Jiang [36a], Z. Jiang [145], S. Jiggins [81], J. Jimenez Pena [170], S. Jin [35b], A. Jinaru [28b], O. Jinnouchi [159], H. Jivan [147c], P. Johansson [141], K.A. Johns [7], C.A. Johnson [64], W.J. Johnson [140], K. Jon-And [148a,148b], R.W.L. Jones [75], S.D. Jones [151], S. Jones [7], T.J. Jones [77], J. Jongmanns [60a], P.M. Jorge [128a,128b], J. Jovicevic [163a], X. Ju [176], A. Juste Rozas [13,v], M.K. Köhler [175], A. Kaczmarska [42], M. Kado [119], H. Kagan [113], M. Kagan [145], S.J. Kahn [88], T. Kaji [174], E. Kajomovitz [154], C.W. Kalderon [84], A. Kaluza [86], S. Kama [43], A. Kamenshchikov [132], N. Kanaya [157], L. Kanjir [78], V.A. Kantserov [100], J. Kanzaki [69], B. Kaplan [112], L.S. Kaplan [176], D. Kar [147c], K. Karakostas [10], N. Karastathis [10], M.J. Kareem [163b], E. Karentzos [10], S.N. Karpov [68], Z.M. Karpova [68], K. Karthik [112], V. Kartvelishvili [75], A.N. Karyukhin [132], K. Kasahara [164], L. Kashif [176], R.D. Kass [113], A. Kastanas [149], Y. Kataoka [157], C. Kato [157], A. Katre [52], J. Katzy [45], K. Kawade [70], K. Kawagoe [73], T. Kawamoto [157], G. Kawamura [57], E.F. Kay [77], V.F. Kazanin [111,c], R. Keeler [172], R. Kehoe [43], J.S. Keller [31], E. Kellermann [84], J.J. Kempster [80], J Kendrick [19], H. Keoshkerian [161], O. Kepka [129], B.P. Kerševan [78], S. Kersten [178], R.A. Keyes [90], M. Khader [169], F. Khalil-zada [12], A. Khanov [116], A.G. Kharlamov [111,c], T. Kharlamova [111,c], A. Khodinov [160], T.J. Khoo [52], V. Khovanskiy [99,*], E. Khramov [68], J. Khubua [54b,ad], S. Kido [70], C.R. Kilby [80], H.Y. Kim [8], S.H. Kim [164], Y.K. Kim [33], N. Kimura [156], O.M. Kind [17], B.T. King [77], D. Kirchmeier [47], J. Kirk [133], A.E. Kiryunin [103], T. Kishimoto [157], D. Kisielewska [41a], V. Kitali [45], O. Kivernyk [5], E. Kladiva [146b], T. Klapdor-Kleingrothaus [51], M.H. Klein [92], M. Klein [77], U. Klein [77], K. Kleinknecht [86], P. Klimek [110], A. Klimentov [27], R. Klingenberg [46,*], T. Klingl [23], T. Klioutchnikova [32], F.F. Klitzner [102], E.-E. Kluge [60a], P. Kluit [109], S. Kluth [103], E. Kneringer [65], E.B.F.G. Knoops [88], A. Knue [103], A. Kobayashi [157], D. Kobayashi [73], T. Kobayashi [157], M. Kobel [47], M. Kocian [145], P. Kodys [131], T. Koffas [31], E. Koffeman [109], N.M. Köhler [103], T. Koi [145], M. Kolb [60b], I. Koletsou [5], T. Kondo [69], N. Kondrashova [36c], K. Köneke [51], A.C. König [108], T. Kono [69,ae], R. Konoplich [112,af], N. Konstantinidis [81], B. Konya [84], R. Kopeliansky [64], S. Koperny [41a], A.K. Kopp [51], K. Korcyl [42], K. Kordas [156], A. Korn [81], A.A. Korol [111,c], I. Korolkov [13], E.V. Korolkova [141], O. Kortner [103], S. Kortner [103], T. Kosek [131], V.V. Kostyukhin [23], A. Kotwal [48], A. Koulouris [10], A. Kourkoumeli-Charalampidi [123a,123b], C. Kourkoumelis [9], E. Kourlitis [141], V. Kouskoura [27], A.B. Kowalewska [42], R. Kowalewski [172], T.Z. Kowalski [41a], C. Kozakai [157], W. Kozanecki [138], A.S. Kozhin [132], V.A. Kramarenko [101], G. Kramberger [78], D. Krasnopevtsev [100], M.W. Krasny [83], A. Krasznahorkay [32], D. Krauss [103], J.A. Kremer [41a], J. Kretzschmar [77], K. Kreutzfeldt [55], P. Krieger [161], K. Krizka [16], K. Kroeninger [46], H. Kroha [103], J. Kroll [129], J. Kroll [124], J. Kroseberg [23], J. Krstic [14], U. Kruchonak [68], H. Krüger [23], N. Krumnack [67], M.C. Kruse [48], T. Kubota [91], H. Kucuk [81], S. Kuday [4b], J.T. Kuechler [178], S. Kuehn [32], A. Kugel [60a], F. Kuger [177], T. Kuhl [45], V. Kukhtin [68], R. Kukla [88], Y. Kulchitsky [95], S. Kuleshov [34b], Y.P. Kulinich [169], M. Kuna [134a,134b], T. Kunigo [71], A. Kupco [129], T. Kupfer [46], O. Kuprash [155], H. Kurashige [70], L.L. Kurchaninov [163a], Y.A. Kurochkin [95], M.G. Kurth [35a,35d], E.S. Kuwertz [172], M. Kuze [159], J. Kvita [117], T. Kwan [172], D. Kyriazopoulos [141], A. La Rosa [103], J.L. La Rosa Navarro [26d], L. La Rotonda [40a,40b], F. La Ruffa [40a,40b], C. Lacasta [170], F. Lacava [134a,134b], J. Lacey [45], D.P.J. Lack [87], H. Lacker [17], D. Lacour [83], E. Ladygin [68], R. Lafaye [5], B. Laforge [83], T. Lagouri [179], S. Lai [57], S. Lammers [64], W. Lampl [7], E. Lançon [27], U. Landgraf [51], M.P.J. Landon [79], M.C. Lanfermann [52], V.S. Lang [45], J.C. Lange [13], R.J. Langenberg [32], A.J. Lankford [166], F. Lanni [27], K. Lantzsch [23], A. Lanza [123a], A. Lapertosa [53a,53b], S. Laplace [83], J.F. Laporte [138], T. Lari [94a], F. Lasagni Manghi [22a,22b], M. Lassnig [32], T.S. Lau [62a], P. Laurelli [50], W. Lavrijsen [16], A.T. Law [139], P. Laycock [77], T. Lazovich [59], M. Lazzaroni [94a,94b], B. Le [91], O. Le Dortz [83], E. Le Guirriec [88], E.P. Le Quilleuc [138], M. LeBlanc [172], T. LeCompte [6], F. Ledroit-Guillon [58], C.A. Lee [27], G.R. Lee [34a], S.C. Lee [153], L. Lee [59], B. Lefebvre [90], G. Lefebvre [83], M. Lefebvre [172], F. Legger [102], C. Leggett [16], G. Lehmann Miotto [32], X. Lei [7], W.A. Leight [45], M.A.L. Leite [26d], R. Leitner [131], D. Lellouch [175], B. Lemmer [57], K.J.C. Leney [81], T. Lenz [23], B. Lenzi [32], R. Leone [7], S. Leone [126a,126b], C. Leonidopoulos [49], G. Lerner [151], C. Leroy [97], R. Les [161], A.A.J. Lesage [138], C.G. Lester [30], M. Levchenko [125], J. Levêque [5], D. Levin [92], L.J. Levinson [175], M. Levy [19], D. Lewis [79], B. Li [36a,w], Changqiao Li [36a], H. Li [150], L. Li [36c], Q. Li [35a,35d], Q. Li [36a], S. Li [48], X. Li [36c], Y. Li [143], Z. Liang [35a], B. Liberti [135a], A. Liblong [161], K. Lie [62c], J. Liebal [23], W. Liebig [15], A. Limosani [152], C.Y. Lin [30], K. Lin [93], S.C. Lin [182], T.H. Lin [86], R.A. Linck [64], B.E. Lindquist [150], A.E. Lionti [52], E. Lipeles [124], A. Lipniacka [15], M. Lisovyi [60b], T.M. Liss [169,ag], A. Lister [171], A.M. Litke [139], B. Liu [67], H. Liu [92], H. Liu [27], J.K.K. Liu [122], J. Liu [36b], J.B. Liu [36a], K. Liu [88], L. Liu [169], M. Liu [36a], Y.L. Liu [36a], Y. Liu [36a], M. Livan [123a,123b], A. Lleres [58], J. Llorente Merino [35a], S.L. Lloyd [79], C.Y. Lo [62b], F. Lo Sterzo [43], E.M. Lobodzinska [45], P. Loch [7], F.K. Loebinger [87], A. Loesle [51], K.M. Loew [25], T. Lohse [17], K. Lohwasser [141], M. Lokajicek [129], B.A. Long [24], J.D. Long [169], R.E. Long [75], L. Longo [76a,76b], K.A. Looper [113], J.A. Lopez [34b], I. Lopez Paz [13], A. Lopez Solis [83], J. Lorenz [102], N. Lorenzo Martinez [5], M. Losada [21], P.J. Lösel [102], X. Lou [35a], A. Lounis [119], J. Love [6], P.A. Love [75], H. Lu [62a], N. Lu [92], Y.J. Lu [63], H.J. Lubatti [140], C. Luci [134a,134b], A. Lucotte [58], C. Luedtke [51], F. Luehring [64], W. Lukas [65], L. Luminari [134a], O. Lundberg [148a,148b], B. Lund-Jensen [149], M.S. Lutz [89], P.M. Luzi [83], D. Lynn [27], R. Lysak [129], E. Lytken [84], F. Lyu [35a], V. Lyubushkin [68], H. Ma [27], L.L. Ma [36b], Y. Ma [36b], G. Maccarrone [50], A. Macchiolo [103], C.M. Macdonald [141], B. Maček [78], J. Machado Miguens [124,128b], D. Madaffari [170], R. Madar [37], W.F. Mader [47], A. Madsen [45], N. Madysa [47], J. Maeda [70], S. Maeland [15], T. Maeno [27], A.S. Maevskiy [101], V. Magerl [51], C. Maiani [119], C. Maidantchik [26a], T. Maier [102], A. Maio [128a,128b,128d], O. Majersky [146a], S. Majewski [118], Y. Makida [69], N. Makovec [119], B. Malaescu [83], Pa. Malecki [42], V.P. Maleev [125], F. Malek [58], U. Mallik [66], D. Malon [6], C. Malone [30], S. Maltezos [10], S. Malyukov [32], J. Mamuzic [170], G. Mancini [50], I. Mandić [78], J. Maneira [128a,128b], L. Manhaes de Andrade Filho [26b], J. Manjarres Ramos [47], K.H. Mankinen [84], A. Mann [102], A. Manousos [32], B. Mansoulie [138], J.D. Mansour [35a], R. Mantifel [90], M. Mantoani [57], S. Manzoni [94a,94b], L. Mapelli [32], G. Marceca [29], L. March [52], L. Marchese [122], G. Marchiori [83], M. Marcisovsky [129], C.A. Marin Tobon [32], M. Marjanovic [37], D.E. Marley [92], F. Marroquim [26a], S.P. Marsden [87], Z. Marshall [16], M.U.F Martensson [168], S. Marti-Garcia [170], C.B. Martin [113], T.A. Martin [173], V.J. Martin [49], B. Martin dit Latour [15], M. Martinez [13,v], V.I. Martinez Outschoorn [169], S. Martin-Haugh [133], V.S. Martoiu [28b], A.C. Martyniuk [81], A. Marzin [32], L. Masetti [86], T. Mashimo [157], R. Mashinistov [98], J. Masik [87], A.L. Maslennikov [111,c], L.H. Mason [91], L. Massa [135a,135b], P. Mastrandrea [5], A. Mastroberardino [40a,40b], T. Masubuchi [157], P. Mättig [178], J. Maurer [28b], S.J. Maxfield [77], D.A. Maximov [111,c], R. Mazini [153], I. Maznas [156], S.M. Mazza [94a,94b], N.C. Mc Fadden [107], G. Mc Goldrick [161], S.P. Mc Kee [92], A. McCarn [92], R.L. McCarthy [150], T.G. McCarthy [103], L.I. McClymont [81], E.F. McDonald [91], J.A. Mcfayden [32], G. Mchedlidze [57], S.J. McMahon [133], P.C. McNamara [91], C.J. McNicol [173], R.A. McPherson [172,o], S. Meehan [140], T.J. Megy [51], S. Mehlhase [102], A. Mehta [77], T. Meideck [58], K. Meier [60a], B. Meirose [44], D. Melini [170,ah], B.R. Mellado Garcia [147c], J.D. Mellenthin [57], M. Melo [146a], F. Meloni [18], A. Melzer [23], S.B. Menary [87], L. Meng [77], X.T. Meng [92], A. Mengarelli [22a,22b], S. Menke [103], E. Meoni [40a,40b], S. Mergelmeyer [17], C. Merlassino [18], P. Mermod [52], L. Merola [106a,106b], C. Meroni [94a], F.S. Merritt [33], A. Messina [134a,134b], J. Metcalfe [6], A.S. Mete [166], C. Meyer [124], J-P. Meyer [138], J. Meyer [109], H. Meyer Zu Theenhausen [60a], F. Miano [151], R.P. Middleton [133], S. Miglioranzi [53a,53b], L. Mijović [49], G. Mikenberg [175], M. Mikestikova [129], M. Mikuž [78], M. Milesi [91], A. Milic [161], D.A. Millar [79], D.W. Miller [33], C. Mills [49], A. Milov [175], D.A. Milstead [148a,148b], A.A. Minaenko [132], Y. Minami [157], I.A. Minashvili [54b], A.I. Mincer [112], B. Mindur [41a], M. Mineev [68], Y. Minegishi [157], Y. Ming [176], L.M. Mir [13], A. Mirto [76a,76b], K.P. Mistry [124], T. Mitani [174], J. Mitrevski [102], V.A. Mitsou [170], A. Miucci [18], P.S. Miyagawa [141], A. Mizukami [69], J.U. Mjörnmark [84], T. Mkrtchyan [180], M. Mlynarikova [131], T. Moa [148a,148b], K. Mochizuki [97], P. Mogg [51], S. Mohapatra [38], S. Molander [148a,148b], R. Moles-Valls [23], M.C. Mondragon [93], K. Mönig [45], J. Monk [39], E. Monnier [88], A. Montalbano [150], J. Montejo Berlingen [32], F. Monticelli [74], S. Monzani [94a,94b], R.W. Moore [3], N. Morange [119], D. Moreno [21], M. Moreno Llácer [32], P. Morettini [53a], S. Morgenstern [32], D. Mori [144], T. Mori [157], M. Morii [59], M. Morinaga [174], V. Morisbak [121], A.K. Morley [32], G. Mornacchi [32], J.D. Morris [79], L. Morvaj [150], P. Moschovakos [10], M. Mosidze [54b], H.J. Moss [141], J. Moss [145,ai], K. Motohashi [159], R. Mount [145], E. Mountricha [27], E.J.W. Moyse [89], S. Muanza [88], F. Mueller [103], J. Mueller [127], R.S.P. Mueller [102], D. Muenstermann [75], P. Mullen [56], G.A. Mullier [18], F.J. Munoz Sanchez [87], W.J. Murray [173,133], H. Musheghyan [32], M. Muškinja [78], A.G. Myagkov [132,aj], M. Myska [130], B.P. Nachman [16], O. Nackenhorst [52], K. Nagai [122], R. Nagai [69,ae], K. Nagano [69], Y. Nagasaka [61], K. Nagata [164], M. Nagel [51], E. Nagy [88], A.M. Nairz [32], Y. Nakahama [105], K. Nakamura [69], T. Nakamura [157], I. Nakano [114], R.F. Naranjo Garcia [45], R. Narayan [11], D.I. Narrias Villar [60a], I. Naryshkin [125], T. Naumann [45], G. Navarro [21], R. Nayyar [7], H.A. Neal [92], P.Yu. Nechaeva [98], T.J. Neep [138], A. Negri [123a,123b], M. Negrini [22a], S. Nektarijevic [108], C. Nellist [57], A. Nelson [166], M.E. Nelson [122], S. Nemecek [129], P. Nemethy [112], M. Nessi [32,ak], M.S. Neubauer [169], M. Neumann [178], P.R. Newman [19], T.Y. Ng [62c], Y.S. Ng [17], T. Nguyen Manh [97], R.B. Nickerson [122], R. Nicolaidou [138], J. Nielsen [139], N. Nikiforou [11], V. Nikolaenko [132,aj], I. Nikolic-Audit [83], K. Nikolopoulos [19], P. Nilsson [27], Y. Ninomiya [69], A. Nisati [134a], N. Nishu [36c], R. Nisius [103], I. Nitsche [46], T. Nitta [174], T. Nobe [157], Y. Noguchi [71], M. Nomachi [120], I. Nomidis [31], M.A. Nomura [27], T. Nooney [79], M. Nordberg [32], N. Norjoharuddeen [122], O. Novgorodova [47], M. Nozaki [69], L. Nozka [117], K. Ntekas [166], E. Nurse [81], F. Nuti [91], K. O'connor [25], D.C. O'Neil [144], A.A. O'Rourke [45], V. O'Shea [56], F.G. Oakham [31,d], H. Oberlack [103], T. Obermann [23], J. Ocariz [83], A. Ochi [70], I. Ochoa [38], J.P. Ochoa-Ricoux [34a], S. Oda [73], S. Odaka [69], A. Oh [87], S.H. Oh [48], C.C. Ohm [149], H. Ohman [168], H. Oide [53a,53b], H. Okawa [164], Y. Okumura [157], T. Okuyama [69], A. Olariu [28b], L.F. Oleiro Seabra [128a], S.A. Olivares Pino [34a], D. Oliveira Damazio [27], M.J.R. Olsson [33], A. Olszewski [42], J. Olszowska [42], A. Onofre [128a,128e], K. Onogi [105], P.U.E. Onyisi [11,aa], H. Oppen [121], M.J. Oreglia [33], Y. Oren [155], D. Orestano [136a,136b], N. Orlando [62b], R.S. Orr [161], B. Osculati [53a,53b,*], R. Ospanov [36a], G. Otero y Garzon [29], H. Otono [73], M. Ouchrif [137d], F. Ould-Saada [121], A. Ouraou [138], K.P. Oussoren [109], Q. Ouyang [35a], M. Owen [56], R.E. Owen [19], V.E. Ozcan [20a], N. Ozturk [8], K. Pachal [144], A. Pacheco Pages [13], L. Pacheco Rodriguez [138], C. Padilla Aranda [13], S. Pagan Griso [16], M. Paganini [179], F. Paige [27], G. Palacino [64], S. Palazzo [40a,40b], S. Palestini [32], M. Palka [41b], D. Pallin [37], E.St. Panagiotopoulou [10], I. Panagoulias [10], C.E. Pandini [52], J.G. Panduro Vazquez [80], P. Pani [32], S. Panitkin [27], D. Pantea [28b], L. Paolozzi [52], Th.D. Papadopoulou [10], K. Papageorgiou [9,s], A. Paramonov [6], D. Paredes Hernandez [179], A.J. Parker [75], M.A. Parker [30], K.A. Parker [45], F. Parodi [53a,53b], J.A. Parsons [38], U. Parzefall [51], V.R. Pascuzzi [161], J.M. Pasner [139], E. Pasqualucci [134a], S. Passaggio [53a], Fr. Pastore [80], S. Pataraia [86], J.R. Pater [87], T. Pauly [32], B. Pearson [103], S. Pedraza Lopez [170], R. Pedro [128a,128b], S.V. Peleganchuk [111,c], O. Penc [129], C. Peng [35a,35d], H. Peng [36a], J. Penwell [64], B.S. Peralva [26b], M.M. Perego [138], D.V. Perepelitsa [27], F. Peri [17], L. Perini [94a,94b], H. Pernegger [32], S. Perrella [106a,106b], R. Peschke [45], V.D. Peshekhonov [68,*], K. Peters [45], R.F.Y. Peters [87], B.A. Petersen [32], T.C. Petersen [39], E. Petit [58], A. Petridis [1], C. Petridou [156], P. Petroff [119], E. Petrolo [134a], M. Petrov [122], F. Petrucci [136a,136b], N.E. Pettersson [89], A. Peyaud [138], R. Pezoa [34b], F.H. Phillips [93], P.W. Phillips [133], G. Piacquadio [150], E. Pianori [173], A. Picazio [89], M.A. Pickering [122], R. Piegaia [29], J.E. Pilcher [33], A.D. Pilkington [87], M. Pinamonti [135a,135b], J.L. Pinfold [3], H. Pirumov [45], M. Pitt [175], L. Plazak [146a], M.-A. Pleier [27], V. Pleskot [86], E. Plotnikova [68], D. Pluth [67], P. Podberezko [111], R. Poettgen [84], R. Poggi [123a,123b], L. Poggioli [119], I. Pogrebnyak [93], D. Pohl [23], I. Pokharel [57], G. Polesello [123a], A. Poley [45], A. Policicchio [40a,40b], R. Polifka [32], A. Polini [22a], C.S. Pollard [56], V. Polychronakos [27], K. Pommès [32], D. Ponomarenko [100], L. Pontecorvo [134a], G.A. Popeneciu [28d], D.M. Portillo Quintero [83], S. Pospisil [130], K. Potamianos [45], I.N. Potrap [68], C.J. Potter [30], H. Potti [11], T. Poulsen [84], J. Poveda [32], M.E. Pozo Astigarraga [32], P. Pralavorio [88], A. Pranko [16], S. Prell [67], D. Price [87], M. Primavera [76a], S. Prince [90], N. Proklova [100], K. Prokofiev [62c], F. Prokoshin [34b], S. Protopopescu [27], J. Proudfoot [6], M. Przybycien [41a], A. Puri [169], P. Puzo [119], J. Qian [92], G. Qin [56], Y. Qin [87], A. Quadt [57], M. Queitsch-Maitland [45], D. Quilty [56], S. Raddum [121], V. Radeka [27], V. Radescu [122], S.K. Radhakrishnan [150], P. Radloff [118], P. Rados [91], F. Ragusa [94a,94b], G. Rahal [181], J.A. Raine [87], S. Rajagopalan [27], C. Rangel-Smith [168], T. Rashid [119], S. Raspopov [5], M.G. Ratti [94a,94b], D.M. Rauch [45], F. Rauscher [102], S. Rave [86], I. Ravinovich [175], J.H. Rawling [87], M. Raymond [32], A.L. Read [121], N.P. Readioff [58], M. Reale [76a,76b], D.M. Rebuzzi [123a,123b], A. Redelbach [177], G. Redlinger [27], R. Reece [139], R.G. Reed [147c], K. Reeves [44], L. Rehnisch [17], J. Reichert [124], A. Reiss [86], C. Rembser [32], H. Ren [35a,35d], M. Rescigno [134a], S. Resconi [94a], E.D. Resseguie [124], S. Rettie [171], E. Reynolds [19], O.L. Rezanova [111,c], P. Reznicek [131], R. Rezvani [97], R. Richter [103], S. Richter [81], E. Richter-Was [41b], O. Ricken [23], M. Ridel [83], P. Rieck [103], C.J. Riegel [178], J. Rieger [57], O. Rifki [115], M. Rijssenbeek [150], A. Rimoldi [123a,123b], M. Rimoldi [18], L. Rinaldi [22a], G. Ripellino [149], B. Ristić [32], E. Ritsch [32], I. Riu [13], F. Rizatdinova [116], E. Rizvi [79], C. Rizzi [13], R.T. Roberts [87], S.H. Robertson [90,o], A. Robichaud-Veronneau [90], D. Robinson [30], J.E.M. Robinson [45], A. Robson [56], E. Rocco [86], C. Roda [126a,126b], Y. Rodina [88,al], S. Rodriguez Bosca [170], A. Rodriguez Perez [13], D. Rodriguez Rodriguez [170], S. Roe [32], C.S. Rogan [59], O. Røhne [121], J. Roloff [59], A. Romaniouk [100], M. Romano [22a,22b], S.M. Romano Saez [37], E. Romero Adam [170], N. Rompotis [77], M. Ronzani [51], L. Roos [83], S. Rosati [134a], K. Rosbach [51], P. Rose [139], N.-A. Rosien [57], E. Rossi [106a,106b], L.P. Rossi [53a], J.H.N. Rosten [30], R. Rosten [140], M. Rotaru [28b], J. Rothberg [140], D. Rousseau [119], A. Rozanov [88], Y. Rozen [154], X. Ruan [147c], F. Rubbo [145], E.M. Ruettinger [45], F. Rühr [51], A. Ruiz-Martinez [31], Z. Rurikova [51], N.A. Rusakovich [68], H.L. Russell [90], J.P. Rutherfoord [7], N. Ruthmann [32], Y.F. Ryabov [125], M. Rybar [169], G. Rybkin [119], S. Ryu [6], A. Ryzhov [132], G.F. Rzehorz [57], A.F. Saavedra [152], G. Sabato [109], S. Sacerdoti [29], H.F-W. Sadrozinski [139], R. Sadykov [68], F. Safai Tehrani [134a], P. Saha [110], M. Sahinsoy [60a], M. Saimpert [45], M. Saito [157], T. Saito [157], H. Sakamoto [157], Y. Sakurai [174], G. Salamanna [136a,136b], J.E. Salazar Loyola [34b], D. Salek [109], P.H. Sales De Bruin [168], D. Salihagic [103], A. Salnikov [145], J. Salt [170], D. Salvatore [40a,40b], F. Salvatore [151], A. Salvucci [62a,62b,62c], A. Salzburger [32], D. Sammel [51], D. Sampsonidis [156], D. Sampsonidou [156], J. Sánchez [170], V. Sanchez Martinez [170], A. Sanchez Pineda [167a,167c], H. Sandaker [121], R.L. Sandbach [79], C.O. Sander [45], M. Sandhoff [178], C. Sandoval [21], D.P.C. Sankey [133], M. Sannino [53a,53b], Y. Sano [105], A. Sansoni [50], C. Santoni [37], H. Santos [128a], I. Santoyo Castillo [151], A. Sapronov [68], J.G. Saraiva [128a,128d], B. Sarrazin [23], O. Sasaki [69], K. Sato [164], E. Sauvan [5], G. Savage [80], P. Savard [161,d], N. Savic [103], C. Sawyer [133],

L. Sawyer [82,u], J. Saxon [33], C. Sbarra [22a], A. Sbrizzi [22a,22b], T. Scanlon [81], D.A. Scannicchio [166], J. Schaarschmidt [140], P. Schacht [103], B.M. Schachtner [102], D. Schaefer [33], L. Schaefer [124], R. Schaefer [45], J. Schaeffer [86], S. Schaepe [32], S. Schaetzel [60b], U. Schäfer [86], A.C. Schaffer [119], D. Schaile [102], R.D. Schamberger [150], V.A. Schegelsky [125], D. Scheirich [131], M. Schernau [166], C. Schiavi [53a,53b], S. Schier [139], L.K. Schildgen [23], C. Schillo [51], M. Schioppa [40a,40b], S. Schlenker [32], K.R. Schmidt-Sommerfeld [103], K. Schmieden [32], C. Schmitt [86], S. Schmitt [45], S. Schmitz [86], U. Schnoor [51], L. Schoeffel [138], A. Schoening [60b], B.D. Schoenrock [93], E. Schopf [23], M. Schott [86], J.F.P. Schouwenberg [108], J. Schovancova [32], S. Schramm [52], N. Schuh [86], A. Schulte [86], M.J. Schultens [23], H.-C. Schultz-Coulon [60a], H. Schulz [17], M. Schumacher [51], B.A. Schumm [139], Ph. Schune [138], A. Schwartzman [145], T.A. Schwarz [92], H. Schweiger [87], Ph. Schwemling [138], R. Schwienhorst [93], J. Schwindling [138], A. Sciandra [23], G. Sciolla [25], M. Scornajenghi [40a,40b], F. Scuri [126a,126b], F. Scutti [91], J. Searcy [92], P. Seema [23], S.C. Seidel [107], A. Seiden [139], J.M. Seixas [26a], G. Sekhniaidze [106a], K. Sekhon [92], S.J. Sekula [43], N. Semprini-Cesari [22a,22b], S. Senkin [37], C. Serfon [121], L. Serin [119], L. Serkin [167a,167b], M. Sessa [136a,136b], R. Seuster [172], H. Severini [115], T. Sfiligoj [78], F. Sforza [165], A. Sfyrla [52], E. Shabalina [57], N.W. Shaikh [148a,148b], L.Y. Shan [35a], R. Shang [169], J.T. Shank [24], M. Shapiro [16], P.B. Shatalov [99], K. Shaw [167a,167b], S.M. Shaw [87], A. Shcherbakova [148a,148b], C.Y. Shehu [151], Y. Shen [115], N. Sherafati [31], A.D. Sherman [24], P. Sherwood [81], L. Shi [153,am], S. Shimizu [70], C.O. Shimmin [179], M. Shimojima [104], I.P.J. Shipsey [122], S. Shirabe [73], M. Shiyakova [68,an], J. Shlomi [175], A. Shmeleva [98], D. Shoaleh Saadi [97], M.J. Shochet [33], S. Shojaii [94a,94b], D.R. Shope [115], S. Shrestha [113], E. Shulga [100], M.A. Shupe [7], P. Sicho [129], A.M. Sickles [169], P.E. Sidebo [149], E. Sideras Haddad [147c], O. Sidiropoulou [177], A. Sidoti [22a,22b], F. Siegert [47], Dj. Sijacki [14], J. Silva [128a,128d], S.B. Silverstein [148a], V. Simak [130], L. Simic [68], S. Simion [119], E. Simioni [86], B. Simmons [81], M. Simon [86], P. Sinervo [161], N.B. Sinev [118], M. Sioli [22a,22b], G. Siragusa [177], I. Siral [92], S.Yu. Sivoklokov [101], J. Sjölin [148a,148b], M.B. Skinner [75], P. Skubic [115], M. Slater [19], T. Slavicek [130], M. Slawinska [42], K. Sliwa [165], R. Slovak [131], V. Smakhtin [175], B.H. Smart [5], J. Smiesko [146a], N. Smirnov [100], S.Yu. Smirnov [100], Y. Smirnov [100], L.N. Smirnova [101,ao], O. Smirnova [84], J.W. Smith [57], M.N.K. Smith [38], R.W. Smith [38], M. Smizanska [75], K. Smolek [130], A.A. Snesarev [98], I.M. Snyder [118], S. Snyder [27], R. Sobie [172,o], F. Socher [47], A. Soffer [155], A. Søgaard [49], D.A. Soh [153], G. Sokhrannyi [78], C.A. Solans Sanchez [32], M. Solar [130], E.Yu. Soldatov [100], U. Soldevila [170], A.A. Solodkov [132], A. Soloshenko [68], O.V. Solovyanov [132], V. Solovyev [125], P. Sommer [141], H. Son [165], A. Sopczak [130], D. Sosa [60b], C.L. Sotiropoulou [126a,126b], S. Sottocornola [123a,123b], R. Soualah [167a,167c], A.M. Soukharev [111,c], D. South [45], B.C. Sowden [80], S. Spagnolo [76a,76b], M. Spalla [126a,126b], M. Spangenberg [173], F. Spanò [80], D. Sperlich [17], F. Spettel [103], T.M. Spieker [60a], R. Spighi [22a], G. Spigo [32], L.A. Spiller [91], M. Spousta [131], R.D. St. Denis [56,*], A. Stabile [94a], R. Stamen [60a], S. Stamm [17], E. Stanecka [42], R.W. Stanek [6], C. Stanescu [136a], M.M. Stanitzki [45], B.S. Stapf [109], S. Stapnes [121], E.A. Starchenko [132], G.H. Stark [33], J. Stark [58], S.H Stark [39], P. Staroba [129], P. Starovoitov [60a], S. Stärz [32], R. Staszewski [42], M. Stegler [45], P. Steinberg [27], B. Stelzer [144], H.J. Stelzer [32], O. Stelzer-Chilton [163a], H. Stenzel [55], T.J. Stevenson [79], G.A. Stewart [56], M.C. Stockton [118], M. Stoebe [90], G. Stoicea [28b], P. Stolte [57], S. Stonjek [103], A.R. Stradling [8], A. Straessner [47], M.E. Stramaglia [18], J. Strandberg [149], S. Strandberg [148a,148b], M. Strauss [115], P. Strizenec [146b], R. Ströhmer [177], D.M. Strom [118], R. Stroynowski [43], A. Strubig [49], S.A. Stucci [27], B. Stugu [15], N.A. Styles [45], D. Su [145], J. Su [127], S. Suchek [60a], Y. Sugaya [120], M. Suk [130], V.V. Sulin [98], DMS Sultan [162a,162b], S. Sultansoy [4c], T. Sumida [71], S. Sun [59], X. Sun [3], K. Suruliz [151], C.J.E. Suster [152], M.R. Sutton [151], S. Suzuki [69], M. Svatos [129], M. Swiatlowski [33], S.P. Swift [2], I. Sykora [146a], T. Sykora [131], D. Ta [51], K. Tackmann [45], J. Taenzer [155], A. Taffard [166], R. Tafirout [163a], E. Tahirovic [79], N. Taiblum [155], H. Takai [27], R. Takashima [72], E.H. Takasugi [103], K. Takeda [70], T. Takeshita [142], Y. Takubo [69], M. Talby [88], A.A. Talyshev [111,c], J. Tanaka [157], M. Tanaka [159], R. Tanaka [119], S. Tanaka [69], R. Tanioka [70], B.B. Tannenwald [113], S. Tapia Araya [34b], S. Tapprogge [86], S. Tarem [154], G.F. Tartarelli [94a], P. Tas [131], M. Tasevsky [129], T. Tashiro [71], E. Tassi [40a,40b], A. Tavares Delgado [128a,128b], Y. Tayalati [137e], A.C. Taylor [107], A.J. Taylor [49], G.N. Taylor [91], P.T.E. Taylor [91], W. Taylor [163b], P. Teixeira-Dias [80], D. Temple [144], H. Ten Kate [32], P.K. Teng [153], J.J. Teoh [120], F. Tepel [178], S. Terada [69], K. Terashi [157], J. Terron [85], S. Terzo [13], M. Testa [50], R.J. Teuscher [161,o], S.J. Thais [179], T. Theveneaux-Pelzer [88], F. Thiele [39], J.P. Thomas [19], J. Thomas-Wilsker [80], P.D. Thompson [19], A.S. Thompson [56], L.A. Thomsen [179], E. Thomson [124], Y. Tian [38], M.J. Tibbetts [16], R.E. Ticse Torres [57], V.O. Tikhomirov [98,ap], Yu.A. Tikhonov [111,c], S. Timoshenko [100], P. Tipton [179], S. Tisserant [88], K. Todome [159], S. Todorova-Nova [5], S. Todt [47], J. Tojo [73], S. Tokár [146a], K. Tokushuku [69], E. Tolley [113], L. Tomlinson [87], M. Tomoto [105], L. Tompkins [145,aq], K. Toms [107],

B. Tong [59], P. Tornambe [51], E. Torrence [118], H. Torres [47], E. Torró Pastor [140], J. Toth [88,ar], F. Touchard [88], D.R. Tovey [141], C.J. Treado [112], T. Trefzger [177], F. Tresoldi [151], A. Tricoli [27], I.M. Trigger [163a], S. Trincaz-Duvoid [83], M.F. Tripiana [13], W. Trischuk [161], B. Trocmé [58], A. Trofymov [45], C. Troncon [94a], M. Trottier-McDonald [16], M. Trovatelli [172], L. Truong [147b], M. Trzebinski [42], A. Trzupek [42], K.W. Tsang [62a], J.C-L. Tseng [122], P.V. Tsiareshka [95], N. Tsirintanis [9], S. Tsiskaridze [13], V. Tsiskaridze [51], E.G. Tskhadadze [54a], I.I. Tsukerman [99], V. Tsulaia [16], S. Tsuno [69], D. Tsybychev [150], Y. Tu [62b], A. Tudorache [28b], V. Tudorache [28b], T.T. Tulbure [28a], A.N. Tuna [59], S. Turchikhin [68], D. Turgeman [175], I. Turk Cakir [4b,as], R. Turra [94a], P.M. Tuts [38], G. Ucchielli [22a,22b], I. Ueda [69], M. Ughetto [148a,148b], F. Ukegawa [164], G. Unal [32], A. Undrus [27], G. Unel [166], F.C. Ungaro [91], Y. Unno [69], K. Uno [157], C. Unverdorben [102], J. Urban [146b], P. Urquijo [91], P. Urrejola [86], G. Usai [8], J. Usui [69], L. Vacavant [88], V. Vacek [130], B. Vachon [90], K.O.H. Vadla [121], A. Vaidya [81], C. Valderanis [102], E. Valdes Santurio [148a,148b], M. Valente [52], S. Valentinetti [22a,22b], A. Valero [170], L. Valéry [13], S. Valkar [131], A. Vallier [5], J.A. Valls Ferrer [170], W. Van Den Wollenberg [109], H. van der Graaf [109], P. van Gemmeren [6], J. Van Nieuwkoop [144], I. van Vulpen [109], M.C. van Woerden [109], M. Vanadia [135a,135b], W. Vandelli [32], A. Vaniachine [160], P. Vankov [109], G. Vardanyan [180], R. Vari [134a], E.W. Varnes [7], C. Varni [53a,53b], T. Varol [43], D. Varouchas [119], A. Vartapetian [8], K.E. Varvell [152], J.G. Vasquez [179], G.A. Vasquez [34b], F. Vazeille [37], D. Vazquez Furelos [13], T. Vazquez Schroeder [90], J. Veatch [57], V. Veeraraghavan [7], L.M. Veloce [161], F. Veloso [128a,128c], S. Veneziano [134a], A. Ventura [76a,76b], M. Venturi [172], N. Venturi [32], A. Venturini [25], V. Vercesi [123a], M. Verducci [136a,136b], W. Verkerke [109], A.T. Vermeulen [109], J.C. Vermeulen [109], M.C. Vetterli [144,d], N. Viaux Maira [34b], O. Viazlo [84], I. Vichou [169,*], T. Vickey [141], O.E. Vickey Boeriu [141], G.H.A. Viehhauser [122], S. Viel [16], L. Vigani [122], M. Villa [22a,22b], M. Villaplana Perez [94a,94b], E. Vilucchi [50], M.G. Vincter [31], V.B. Vinogradov [68], A. Vishwakarma [45], C. Vittori [22a,22b], I. Vivarelli [151], S. Vlachos [10], M. Vogel [178], P. Vokac [130], G. Volpi [13], H. von der Schmitt [103], E. von Toerne [23], V. Vorobel [131], K. Vorobev [100], M. Vos [170], R. Voss [32], J.H. Vossebeld [77], N. Vranjes [14], M. Vranjes Milosavljevic [14], V. Vrba [130], M. Vreeswijk [109], R. Vuillermet [32], I. Vukotic [33], P. Wagner [23], W. Wagner [178], J. Wagner-Kuhr [102], H. Wahlberg [74], S. Wahrmund [47], K. Wakamiya [70], J. Walder [75], R. Walker [102], W. Walkowiak [143], V. Wallangen [148a,148b], C. Wang [35b], C. Wang [36b,at], F. Wang [176], H. Wang [16], H. Wang [3], J. Wang [45], J. Wang [152], Q. Wang [115], R.-J. Wang [83], R. Wang [6], S.M. Wang [153], T. Wang [38], W. Wang [153,au], W. Wang [36a,av], Z. Wang [36c], C. Wanotayaroj [45], A. Warburton [90], C.P. Ward [30], D.R. Wardrope [81], A. Washbrook [49], P.M. Watkins [19], A.T. Watson [19], M.F. Watson [19], G. Watts [140], S. Watts [87], B.M. Waugh [81], A.F. Webb [11], S. Webb [86], M.S. Weber [18], S.M. Weber [60a], S.W. Weber [177], S.A. Weber [31], J.S. Webster [6], A.R. Weidberg [122], B. Weinert [64], J. Weingarten [57], M. Weirich [86], C. Weiser [51], H. Weits [109], P.S. Wells [32], T. Wenaus [27], T. Wengler [32], S. Wenig [32], N. Wermes [23], M.D. Werner [67], P. Werner [32], M. Wessels [60a], T.D. Weston [18], K. Whalen [118], N.L. Whallon [140], A.M. Wharton [75], A.S. White [92], A. White [8], M.J. White [1], R. White [34b], D. Whiteson [166], B.W. Whitmore [75], F.J. Wickens [133], W. Wiedenmann [176], M. Wielers [133], C. Wiglesworth [39], L.A.M. Wiik-Fuchs [51], A. Wildauer [103], F. Wilk [87], H.G. Wilkens [32], H.H. Williams [124], S. Williams [109], C. Willis [93], S. Willocq [89], J.A. Wilson [19], I. Wingerter-Seez [5], E. Winkels [151], F. Winklmeier [118], O.J. Winston [151], B.T. Winter [23], M. Wittgen [145], M. Wobisch [82,u], A. Wolf [86], T.M.H. Wolf [109], R. Wolff [88], M.W. Wolter [42], H. Wolters [128a,128c], V.W.S. Wong [171], N.L. Woods [139], S.D. Worm [19], B.K. Wosiek [42], J. Wotschack [32], K.W. Wozniak [42], M. Wu [33], S.L. Wu [176], X. Wu [52], Y. Wu [92], T.R. Wyatt [87], B.M. Wynne [49], S. Xella [39], Z. Xi [92], L. Xia [35c], D. Xu [35a], L. Xu [27], T. Xu [138], W. Xu [92], B. Yabsley [152], S. Yacoob [147a], D. Yamaguchi [159], Y. Yamaguchi [159], A. Yamamoto [69], S. Yamamoto [157], T. Yamanaka [157], F. Yamane [70], M. Yamatani [157], T. Yamazaki [157], Y. Yamazaki [70], Z. Yan [24], H. Yang [36c], H. Yang [16], Y. Yang [153], Z. Yang [15], W-M. Yao [16], Y.C. Yap [45], Y. Yasu [69], E. Yatsenko [5], K.H. Yau Wong [23], J. Ye [43], S. Ye [27], I. Yeletskikh [68], E. Yigitbasi [24], E. Yildirim [86], K. Yorita [174], K. Yoshihara [124], C. Young [145], C.J.S. Young [32], J. Yu [8], J. Yu [67], S.P.Y. Yuen [23], I. Yusuff [30,aw], B. Zabinski [42], G. Zacharis [10], R. Zaidan [13], A.M. Zaitsev [132,aj], N. Zakharchuk [45], J. Zalieckas [15], A. Zaman [150], S. Zambito [59], D. Zanzi [91], C. Zeitnitz [178], G. Zemaityte [122], A. Zemla [41a], J.C. Zeng [169], Q. Zeng [145], O. Zenin [132], T. Ženiš [146a], D. Zerwas [119], D. Zhang [36b], D. Zhang [92], F. Zhang [176], G. Zhang [36a,av], H. Zhang [119], J. Zhang [6], L. Zhang [51], L. Zhang [36a], M. Zhang [169], P. Zhang [35b], R. Zhang [23], R. Zhang [36a,at], X. Zhang [36b], Y. Zhang [35a,35d], Z. Zhang [119], X. Zhao [43], Y. Zhao [36b,ax], Z. Zhao [36a], A. Zhemchugov [68], B. Zhou [92], C. Zhou [176], L. Zhou [43], M. Zhou [35a,35d], M. Zhou [150], N. Zhou [36c], Y. Zhou [7], C.G. Zhu [36b], H. Zhu [35a], J. Zhu [92], Y. Zhu [36a], X. Zhuang [35a], K. Zhukov [98], A. Zibell [177], D. Zieminska [64], N.I. Zimine [68], C. Zimmermann [86], S. Zimmermann [51], Z. Zinonos [103], M. Zinser [86], M. Ziolkowski [143], L. Živković [14], G. Zobernig [176], A. Zoccoli [22a,22b], R. Zou [33], M. zur Nedden [17], L. Zwalinski [32]

[1] *Department of Physics, University of Adelaide, Adelaide, Australia*
[2] *Physics Department, SUNY Albany, Albany NY, United States*
[3] *Department of Physics, University of Alberta, Edmonton AB, Canada*
[4] [(a)] *Department of Physics, Ankara University, Ankara;* [(b)] *Istanbul Aydin University, Istanbul;* [(c)] *Division of Physics, TOBB University of Economics and Technology, Ankara, Turkey*
[5] *LAPP, CNRS/IN2P3 and Université Savoie Mont Blanc, Annecy-le-Vieux, France*
[6] *High Energy Physics Division, Argonne National Laboratory, Argonne IL, United States*
[7] *Department of Physics, University of Arizona, Tucson AZ, United States*
[8] *Department of Physics, The University of Texas at Arlington, Arlington TX, United States*
[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, The University of Texas at Austin, Austin TX, United States*
[12] *Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan*
[13] *Institut de Física d'Altes Energies (IFAE), The Barcelona Institute of Science and Technology, Barcelona, Spain*
[14] *Institute of Physics, University of Belgrade, Belgrade, Serbia*
[15] *Department for Physics and Technology, University of Bergen, Bergen, Norway*
[16] *Physics Division, Lawrence Berkeley National Laboratory and University of California, Berkeley CA, United States*
[17] *Department of Physics, Humboldt University, Berlin, Germany*
[18] *Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern, Switzerland*
[19] *School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom*
[20] [(a)] *Department of Physics, Bogazici University, Istanbul;* [(b)] *Department of Physics Engineering, Gaziantep University, Gaziantep;* [(d)] *Istanbul Bilgi University, Faculty of Engineering and Natural Sciences, Istanbul;* [(e)] *Bahcesehir University, Faculty of Engineering and Natural Sciences, Istanbul, Turkey*
[21] *Centro de Investigaciones, Universidad Antonio Narino, Bogota, Colombia*
[22] [(a)] *INFN Sezione di Bologna;* [(b)] *Dipartimento di Fisica e Astronomia, Università di Bologna, Bologna, Italy*
[23] *Physikalisches Institut, University of Bonn, Bonn, Germany*
[24] *Department of Physics, Boston University, Boston MA, United States*
[25] *Department of Physics, Brandeis University, Waltham MA, United States*
[26] [(a)] *Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro;* [(b)] *Electrical Circuits Department, Federal University of Juiz de Fora (UFJF), Juiz de Fora;* [(c)] *Federal University of Sao Joao del Rei (UFSJ), Sao Joao del Rei;* [(d)] *Instituto de Fisica, Universidade de Sao Paulo, Sao Paulo, Brazil*
[27] *Physics Department, Brookhaven National Laboratory, Upton NY, United States*
[28] [(a)] *Transilvania University of Brasov, Brasov;* [(b)] *Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest;* [(c)] *Department of Physics, Alexandru Ioan Cuza University of Iasi, Iasi;* [(d)] *National Institute for Research and Development of Isotopic and Molecular Technologies, Physics Department, Cluj Napoca;* [(e)] *University Politehnica Bucharest, Bucharest;* [(f)] *West University in Timisoara, Timisoara, Romania*
[29] *Departamento de Física, Universidad de Buenos Aires, Buenos Aires, Argentina*
[30] *Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom*
[31] *Department of Physics, Carleton University, Ottawa ON, Canada*
[32] *CERN, Geneva, Switzerland*
[33] *Enrico Fermi Institute, University of Chicago, Chicago IL, United States*
[34] [(a)] *Departamento de Física, Pontificia Universidad Católica de Chile, Santiago;* [(b)] *Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile*
[35] [(a)] *Institute of High Energy Physics, Chinese Academy of Sciences, Beijing;* [(b)] *Department of Physics, Nanjing University, Jiangsu;* [(c)] *Physics Department, Tsinghua University, Beijing 100084;* [(d)] *University of Chinese Academy of Science (UCAS), Beijing, China*
[36] [(a)] *Department of Modern Physics and State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Anhui;* [(b)] *School of Physics, Shandong University, Shandong;* [(c)] *Department of Physics and Astronomy, Key Laboratory for Particle Physics, Astrophysics and Cosmology, Ministry of Education; Shanghai Key Laboratory for Particle Physics and Cosmology, Shanghai Jiao Tong University, Shanghai (also at PKU-CHEP), China*
[37] *Université Clermont Auvergne, CNRS/IN2P3, LPC, Clermont-Ferrand, France*
[38] *Nevis Laboratory, Columbia University, Irvington NY, United States*
[39] *Niels Bohr Institute, University of Copenhagen, Kobenhavn, Denmark*
[40] [(a)] *INFN Gruppo Collegato di Cosenza, Laboratori Nazionali di Frascati;* [(b)] *Dipartimento di Fisica, Università della Calabria, Rende, Italy*
[41] [(a)] *AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, Krakow;* [(b)] *Marian Smoluchowski Institute of Physics, Jagiellonian University, Krakow, Poland*
[42] *Institute of Nuclear Physics Polish Academy of Sciences, Krakow, Poland*
[43] *Physics Department, Southern Methodist University, Dallas TX, United States*
[44] *Physics Department, University of Texas at Dallas, Richardson TX, United States*
[45] *DESY, Hamburg and Zeuthen, Germany*
[46] *Lehrstuhl für Experimentelle Physik IV, Technische Universität Dortmund, Dortmund, Germany*
[47] *Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden, Germany*
[48] *Department of Physics, Duke University, Durham NC, United States*
[49] *SUPA - School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom*
[50] *INFN e Laboratori Nazionali di Frascati, Frascati, Italy*
[51] *Fakultät für Mathematik und Physik, Albert-Ludwigs-Universität, Freiburg, Germany*
[52] *Departement de Physique Nucleaire et Corpusculaire, Université de Genève, Geneva, Switzerland*
[53] [(a)] *INFN Sezione di Genova;* [(b)] *Dipartimento di Fisica, Università di Genova, Genova, Italy*
[54] [(a)] *E. Andronikashvili Institute of Physics, Iv. Javakhishvili Tbilisi State University, Tbilisi;* [(b)] *High Energy Physics Institute, Tbilisi State University, Tbilisi, Georgia*
[55] *II Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen, Germany*
[56] *SUPA - School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom*
[57] *II Physikalisches Institut, Georg-August-Universität, Göttingen, Germany*
[58] *Laboratoire de Physique Subatomique et de Cosmologie, Université Grenoble-Alpes, CNRS/IN2P3, Grenoble, France*
[59] *Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge MA, United States*
[60] [(a)] *Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg;* [(b)] *Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany*
[61] *Faculty of Applied Information Science, Hiroshima Institute of Technology, Hiroshima, Japan*
[62] [(a)] *Department of Physics, The Chinese University of Hong Kong, Shatin, N.T., Hong Kong;* [(b)] *Department of Physics, The University of Hong Kong, Hong Kong;* [(c)] *Department of Physics and Institute for Advanced Study, The Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China*
[63] *Department of Physics, National Tsing Hua University, Taiwan*
[64] *Department of Physics, Indiana University, Bloomington IN, United States*
[65] *Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck, Austria*
[66] *University of Iowa, Iowa City IA, United States*

[67] Department of Physics and Astronomy, Iowa State University, Ames IA, United States
[68] Joint Institute for Nuclear Research, JINR Dubna, Dubna, Russia
[69] KEK, High Energy Accelerator Research Organization, Tsukuba, Japan
[70] Graduate School of Science, Kobe University, Kobe, Japan
[71] Faculty of Science, Kyoto University, Kyoto, Japan
[72] Kyoto University of Education, Kyoto, Japan
[73] Research Center for Advanced Particle Physics and Department of Physics, Kyushu University, Fukuoka, Japan
[74] Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina
[75] Physics Department, Lancaster University, Lancaster, United Kingdom
[76] [(a)] INFN Sezione di Lecce; [(b)] Dipartimento di Matematica e Fisica, Università del Salento, Lecce, Italy
[77] Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom
[78] Department of Experimental Particle Physics, Jožef Stefan Institute and Department of Physics, University of Ljubljana, Ljubljana, Slovenia
[79] School of Physics and Astronomy, Queen Mary University of London, London, United Kingdom
[80] Department of Physics, Royal Holloway University of London, Surrey, United Kingdom
[81] Department of Physics and Astronomy, University College London, London, United Kingdom
[82] Louisiana Tech University, Ruston LA, United States
[83] Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France
[84] Fysiska institutionen, Lunds universitet, Lund, Sweden
[85] Departamento de Fisica Teorica C-15, Universidad Autonoma de Madrid, Madrid, Spain
[86] Institut für Physik, Universität Mainz, Mainz, Germany
[87] School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom
[88] CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France
[89] Department of Physics, University of Massachusetts, Amherst MA, United States
[90] Department of Physics, McGill University, Montreal QC, Canada
[91] School of Physics, University of Melbourne, Victoria, Australia
[92] Department of Physics, The University of Michigan, Ann Arbor MI, United States
[93] Department of Physics and Astronomy, Michigan State University, East Lansing MI, United States
[94] [(a)] INFN Sezione di Milano; [(b)] Dipartimento di Fisica, Università di Milano, Milano, Italy
[95] B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Belarus
[96] Research Institute for Nuclear Problems of Byelorussian State University, Minsk, Belarus
[97] Group of Particle Physics, University of Montreal, Montreal QC, Canada
[98] P.N. Lebedev Physical Institute of the Russian Academy of Sciences, Moscow, Russia
[99] Institute for Theoretical and Experimental Physics (ITEP), Moscow, Russia
[100] National Research Nuclear University MEPhI, Moscow, Russia
[101] D.V. Skobeltsyn Institute of Nuclear Physics M.V. Lomonosov Moscow State University, Moscow, Russia
[102] Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany
[103] Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany
[104] Nagasaki Institute of Applied Science, Nagasaki, Japan
[105] Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya, Japan
[106] [(a)] INFN Sezione di Napoli; [(b)] Dipartimento di Fisica, Università di Napoli, Napoli, Italy
[107] Department of Physics and Astronomy, University of New Mexico, Albuquerque NM, United States
[108] Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands
[109] Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands
[110] Department of Physics, Northern Illinois University, DeKalb IL, United States
[111] Budker Institute of Nuclear Physics, SB RAS, Novosibirsk, Russia
[112] Department of Physics, New York University, New York NY, United States
[113] Ohio State University, Columbus OH, United States
[114] Faculty of Science, Okayama University, Okayama, Japan
[115] Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman OK, United States
[116] Department of Physics, Oklahoma State University, Stillwater OK, United States
[117] Palacký University, RCPTM, Olomouc, Czech Republic
[118] Center for High Energy Physics, University of Oregon, Eugene OR, United States
[119] LAL, Univ. Paris-Sud, CNRS/IN2P3, Université Paris-Saclay, Orsay, France
[120] Graduate School of Science, Osaka University, Osaka, Japan
[121] Department of Physics, University of Oslo, Oslo, Norway
[122] Department of Physics, Oxford University, Oxford, United Kingdom
[123] [(a)] INFN Sezione di Pavia; [(b)] Dipartimento di Fisica, Università di Pavia, Pavia, Italy
[124] Department of Physics, University of Pennsylvania, Philadelphia PA, United States
[125] National Research Centre "Kurchatov Institute", B.P.Konstantinov Petersburg Nuclear Physics Institute, St. Petersburg, Russia
[126] [(a)] INFN Sezione di Pisa; [(b)] Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy
[127] Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh PA, United States
[128] [(a)] Laboratório de Instrumentação e Física Experimental de Partículas - LIP, Lisboa; [(b)] Faculdade de Ciências, Universidade de Lisboa, Lisboa; [(c)] Department of Physics, University of Coimbra, Coimbra; [(d)] Centro de Física Nuclear da Universidade de Lisboa, Lisboa; [(e)] Departamento de Fisica, Universidade do Minho, Braga; [(f)] Departamento de Fisica Teorica y del Cosmos, Universidad de Granada, Granada; [(g)] Dep Fisica and CEFITEC of Faculdade de Ciencias e Tecnologia, Universidade Nova de Lisboa, Caparica, Portugal
[129] Institute of Physics, Academy of Sciences of the Czech Republic, Praha, Czech Republic
[130] Czech Technical University in Prague, Praha, Czech Republic
[131] Charles University, Faculty of Mathematics and Physics, Prague, Czech Republic
[132] State Research Center, Institute for High Energy Physics (Protvino), NRC KI, Russia
[133] Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom
[134] [(a)] INFN Sezione di Roma; [(b)] Dipartimento di Fisica, Sapienza Università di Roma, Roma, Italy
[135] [(a)] INFN Sezione di Roma Tor Vergata; [(b)] Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy
[136] [(a)] INFN Sezione di Roma Tre; [(b)] Dipartimento di Matematica e Fisica, Università Roma Tre, Roma, Italy
[137] [(a)] Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies - Université Hassan II, Casablanca; [(b)] Centre National de l'Energie des Sciences Techniques Nucleaires, Rabat; [(c)] Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA-Marrakech; [(d)] Faculté des Sciences, Université Mohamed Premier and LPTPM, Oujda; [(e)] Faculté des sciences, Université Mohammed V, Rabat, Morocco
[138] DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l'Univers), CEA Saclay (Commissariat à l'Energie Atomique et aux Energies Alternatives), Gif-sur-Yvette, France
[139] Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz CA, United States
[140] Department of Physics, University of Washington, Seattle WA, United States
[141] Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom

[142] *Department of Physics, Shinshu University, Nagano, Japan*
[143] *Department Physik, Universität Siegen, Siegen, Germany*
[144] *Department of Physics, Simon Fraser University, Burnaby BC, Canada*
[145] *SLAC National Accelerator Laboratory, Stanford CA, United States*
[146] [(a)] *Faculty of Mathematics, Physics & Informatics, Comenius University, Bratislava;* [(b)] *Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice, Slovak Republic*
[147] [(a)] *Department of Physics, University of Cape Town, Cape Town;* [(b)] *Department of Physics, University of Johannesburg, Johannesburg;* [(c)] *School of Physics, University of the Witwatersrand, Johannesburg, South Africa*
[148] [(a)] *Department of Physics, Stockholm University;* [(b)] *The Oskar Klein Centre, Stockholm, Sweden*
[149] *Physics Department, Royal Institute of Technology, Stockholm, Sweden*
[150] *Departments of Physics & Astronomy and Chemistry, Stony Brook University, Stony Brook NY, United States*
[151] *Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom*
[152] *School of Physics, University of Sydney, Sydney, Australia*
[153] *Institute of Physics, Academia Sinica, Taipei, Taiwan*
[154] *Department of Physics, Technion: Israel Institute of Technology, Haifa, Israel*
[155] *Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel*
[156] *Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece*
[157] *International Center for Elementary Particle Physics and Department of Physics, The University of Tokyo, Tokyo, Japan*
[158] *Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo, Japan*
[159] *Department of Physics, Tokyo Institute of Technology, Tokyo, Japan*
[160] *Tomsk State University, Tomsk, Russia*
[161] *Department of Physics, University of Toronto, Toronto ON, Canada*
[162] [(a)] *INFN-TIFPA;* [(b)] *University of Trento, Trento, Italy*
[163] [(a)] *TRIUMF, Vancouver BC;* [(b)] *Department of Physics and Astronomy, York University, Toronto ON, Canada*
[164] *Faculty of Pure and Applied Sciences, and Center for Integrated Research in Fundamental Science and Engineering, University of Tsukuba, Tsukuba, Japan*
[165] *Department of Physics and Astronomy, Tufts University, Medford MA, United States*
[166] *Department of Physics and Astronomy, University of California Irvine, Irvine CA, United States*
[167] [(a)] *INFN Gruppo Collegato di Udine, Sezione di Trieste, Udine;* [(b)] *ICTP, Trieste;* [(c)] *Dipartimento di Chimica, Fisica e Ambiente, Università di Udine, Udine, Italy*
[168] *Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden*
[169] *Department of Physics, University of Illinois, Urbana IL, United States*
[170] *Instituto de Fisica Corpuscular (IFIC), Centro Mixto Universidad de Valencia - CSIC, Spain*
[171] *Department of Physics, University of British Columbia, Vancouver BC, Canada*
[172] *Department of Physics and Astronomy, University of Victoria, Victoria BC, Canada*
[173] *Department of Physics, University of Warwick, Coventry, United Kingdom*
[174] *Waseda University, Tokyo, Japan*
[175] *Department of Particle Physics, The Weizmann Institute of Science, Rehovot, Israel*
[176] *Department of Physics, University of Wisconsin, Madison WI, United States*
[177] *Fakultät für Physik und Astronomie, Julius-Maximilians-Universität, Würzburg, Germany*
[178] *Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal, Germany*
[179] *Department of Physics, Yale University, New Haven CT, United States*
[180] *Yerevan Physics Institute, Yerevan, Armenia*
[181] *Centre de Calcul de l'Institut National de Physique Nucléaire et de Physique des Particules (IN2P3), Villeurbanne, France*
[182] *Academia Sinica Grid Computing, Institute of Physics, Academia Sinica, Taipei, Taiwan*

[a] Also at Department of Physics, King's College London, London, United Kingdom.
[b] Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan.
[c] Also at Novosibirsk State University, Novosibirsk, Russia.
[d] Also at TRIUMF, Vancouver BC, Canada.
[e] Also at Department of Physics & Astronomy, University of Louisville, Louisville, KY, United States of America.
[f] Also at Physics Department, An-Najah National University, Nablus, Palestine.
[g] Also at Department of Physics, California State University, Fresno CA, United States of America.
[h] Also at Department of Physics, University of Fribourg, Fribourg, Switzerland.
[i] Also at II Physikalisches Institut, Georg-August-Universität, Göttingen, Germany.
[j] Also at Departament de Fisica de la Universitat Autonoma de Barcelona, Barcelona, Spain.
[k] Also at Departamento de Fisica e Astronomia, Faculdade de Ciencias, Universidade do Porto, Portugal.
[l] Also at Tomsk State University, Tomsk, and Moscow Institute of Physics and Technology State University, Dolgoprudny, Russia.
[m] Also at The Collaborative Innovation Center of Quantum Matter (CICQM), Beijing, China.
[n] Also at Universita di Napoli Parthenope, Napoli, Italy.
[o] Also at Institute of Particle Physics (IPP), Canada.
[p] Also at Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest, Romania.
[q] Also at Department of Physics, St. Petersburg State Polytechnical University, St. Petersburg, Russia.
[r] Also at Borough of Manhattan Community College, City University of New York, New York City, United States of America.
[s] Also at Department of Financial and Management Engineering, University of the Aegean, Chios, Greece.
[t] Also at Centre for High Performance Computing, CSIR Campus, Rosebank, Cape Town, South Africa.
[u] Also at Louisiana Tech University, Ruston LA, United States of America.
[v] Also at Institucio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona, Spain.
[w] Also at Department of Physics, The University of Michigan, Ann Arbor MI, United States of America.
[x] Also at Graduate School of Science, Osaka University, Osaka, Japan.
[y] Also at Fakultät für Mathematik und Physik, Albert-Ludwigs-Universität, Freiburg, Germany.
[z] Also at Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands.
[aa] Also at Department of Physics, The University of Texas at Austin, Austin TX, United States of America.
[ab] Also at Institute of Theoretical Physics, Ilia State University, Tbilisi, Georgia.
[ac] Also at CERN, Geneva, Switzerland.
[ad] Also at Georgian Technical University (GTU), Tbilisi, Georgia.
[ae] Also at Ochadai Academic Production, Ochanomizu University, Tokyo, Japan.
[af] Also at Manhattan College, New York NY, United States of America.
[ag] Also at The City College of New York, New York NY, United States of America.

[ah] Also at Departamento de Fisica Teorica y del Cosmos, Universidad de Granada, Granada, Portugal.
[ai] Also at Department of Physics, California State University, Sacramento CA, United States of America.
[aj] Also at Moscow Institute of Physics and Technology State University, Dolgoprudny, Russia.
[ak] Also at Departement de Physique Nucleaire et Corpusculaire, Université de Genève, Geneva, Switzerland.
[al] Also at Institut de Física d'Altes Energies (IFAE), The Barcelona Institute of Science and Technology, Barcelona, Spain.
[am] Also at School of Physics, Sun Yat-sen University, Guangzhou, China.
[an] Also at Institute for Nuclear Research and Nuclear Energy (INRNE) of the Bulgarian Academy of Sciences, Sofia, Bulgaria.
[ao] Also at Faculty of Physics, M.V.Lomonosov Moscow State University, Moscow, Russia.
[ap] Also at National Research Nuclear University MEPhI, Moscow, Russia.
[aq] Also at Department of Physics, Stanford University, Stanford CA, United States of America.
[ar] Also at Institute for Particle and Nuclear Physics, Wigner Research Centre for Physics, Budapest, Hungary.
[as] Also at Giresun University, Faculty of Engineering, Turkey.
[at] Also at CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France.
[au] Also at Department of Physics, Nanjing University, Jiangsu, China.
[av] Also at Institute of Physics, Academia Sinica, Taipei, Taiwan.
[aw] Also at University of Malaya, Department of Physics, Kuala Lumpur, Malaysia.
[ax] Also at LAL, Univ. Paris-Sud, CNRS/IN2P3, Université Paris-Saclay, Orsay, France.
[*] Deceased.