EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

CERN-PH-EP-2012-122
Submitted to: European Physical Journal C

A search for $t\bar{t}$ resonances with the ATLAS detector in 2.05 fb^{-1} of proton-proton collisions at $\sqrt{s} = 7$ TeV

The ATLAS Collaboration

Abstract

A search for top quark pair resonances in final states containing at least one electron or muon has been performed with the ATLAS experiment at the CERN Large Hadron Collider. The search uses a data sample corresponding to an integrated luminosity of 2.05 fb^{-1}, which was recorded in 2011 at a proton-proton centre-of-mass energy of 7 TeV. No evidence for a resonance is found and limits are set on the production cross-section times branching ratio to $t\bar{t}$ for narrow and wide resonances. For narrow Z' bosons, the observed 95% Bayesian credibility level limits range from 9.3 pb to 0.95 pb for masses in the range of $m_{Z'} = 500$ GeV to $m_{Z'} = 1300$ GeV. The corresponding excluded mass region for a leptophobic topcolour Z' boson (Kaluza-Klein gluon excitation in the Randall-Sundrum model) is $m_{Z'} < 880$ GeV ($m_{g_{\mathrm{KK}}} <$ 1130 GeV).

Eur. Phys. J. C manuscript No.
(will be inserted by the editor)

A search for $t\bar{t}$ resonances with the ATLAS detector in 2.05 fb^{-1} of proton-proton collisions at $\sqrt{s} = 7$ TeV

The ATLAS Collaboration

[1]CERN, 1211 Geneva 23, Switzerland E-mail: atlas.publications@cern.ch

July 7, 2012

Abstract A search for top quark pair resonances in final states containing at least one electron or muon has been performed with the ATLAS experiment at the CERN Large Hadron Collider. The search uses a data sample corresponding to an integrated luminosity of 2.05 fb^{-1}, which was recorded in 2011 at a proton-proton centre-of-mass energy of 7 TeV. No evidence for a resonance is found and limits are set on the production cross-section times branching ratio to $t\bar{t}$ for narrow and wide resonances. For narrow Z' bosons, the observed 95% Bayesian credibility level limits range from 9.3 pb to 0.95 pb for masses in the range of $m_{Z'} = 500$ GeV to $m_{Z'} = 1300$ GeV. The corresponding excluded mass region for a leptophobic topcolour Z' boson (Kaluza-Klein gluon excitation in the Randall-Sundrum model) is $m_{Z'} < 880$ GeV ($m_{g_{\rm KK}} <$ 1130 GeV).

PACS 12.60.Nz · 14.80.Rt

1 Introduction

The Standard Model of particle physics (SM) is believed to be an effective theory valid up to energies in the TeV range. Since particle masses are central to the breaking of the electroweak symmetry, final states that involve the heaviest of the particles presumed to be elementary, the top quark, offer particular promise in searches for new physics. This Article describes searches for new heavy particles decaying to top quark pairs ($t\bar{t}$) using the ATLAS detector [1] at the CERN Large Hadron Collider (LHC). Multiple final state topologies containing at least one lepton (electron or muon) are considered, in which the lepton is expected to originate from the decay of one of the W bosons produced in the top quark decays. In events with one lepton – the lepton plus jets ($\ell +$jets) channel – the reconstructed $t\bar{t}$ mass spectrum is used to search for a signal. In events with two leptons – the dilepton channel – the effective mass is used. Both variables are defined in Section 8.

The benchmark model used to quantify the experimental sensitivity to narrow resonances is a topcolour Z' boson [2] arising in models of strong electroweak symmetry breaking through top quark condensation [3]. The specific model used is the leptophobic scenario, model IV in Ref. [2] with $f_1 = 1$ and $f_2 = 0$ and a width of 1.2% of the Z' boson mass. The model used for wide resonances is a Kaluza-Klein (KK) gluon $g_{\rm KK}$, which appears in Randall-Sundrum (RS) models in which particles are located in a warped dimension [4–7]. The left-handed (g_L) and right-handed (g_R) couplings to quarks take the conventional RS values [5]: $g_L = g_R = -0.2g_s$ for light quarks including charm, where $g_s = \sqrt{4\pi\alpha_s}$; $g_L = 1.0g_s, g_R = -0.2g_s$ for bottom quarks; and $g_L = 1.0g_s, g_R = 4.0g_s$ for the top quark. In this case, the resonance width is 15.3% of its mass, larger than the detector resolution.

Previous searches for $t\bar{t}$ resonances were most recently carried out by the CDF [8–12] and D0 [13, 14] collaborations at Run II of the Fermilab Tevatron Collider, and by the CMS collaboration [15] at the LHC. No evidence for new particles was uncovered and 95% confidence level limits were set on the mass of a leptophobic topcolour Z' boson [16] at $m_{Z'} > 900$ GeV [11] as well as on the coupling strength of a heavy colour-octet vector particle.

2 The ATLAS detector

The ATLAS detector [1] is designed to measure the properties of particles produced in proton-proton (pp) interactions with excellent precision. Its cylindrical geometry, with axis aligned with the proton beams, is augmented by two endcap sections. This results in almost complete 4π solid angle coverage. The Inner Detector (ID) covers pseudorapidities[1] of $|\eta| < 2.5$ and consists of layers of silicon pixel and strip detectors and a straw-tube transition radiation tracker. It is embedded in the bore of a 2 T superconducting solenoidal magnet to allow precise measurement of charged particle momenta. This system is surrounded by a hermetic calorimeter system consisting of finely segmented sampling calorimeters using lead/liquid-argon for the detection of electromagnetic (EM) showers up to $|\eta| < 3.2$, and copper or tungsten/liquid-argon for hadronic showers for $1.5 < |\eta| < 4.9$. In the central region ($|\eta| < 1.7$), an iron/scintillator hadronic calorimeter is used. Outside the calorimeters, the muon spectrometer incorporates multiple layers of trigger and tracking chambers within an air-core toroidal magnetic field, enabling an independent, precise measurement of muon track momenta.

3 Data sample

The data were collected with the ATLAS detector at the CERN LHC in 2011 using single-lepton triggers with transverse momentum thresholds at 20 GeV or 22 GeV for electrons and 18 GeV for muons. These triggers use similar, but looser selection criteria than the offline reconstruction and reach their efficiency plateaus at 25 GeV (electrons) and 20 GeV (muons).

Only data where all subsystems were operational are used. Applying these requirements to *pp* collision data recorded with stable beam conditions between March and August 2011 at $\sqrt{s} = 7$ TeV results in a data sample of 2.05 ± 0.08 fb^{-1} [17, 18].

4 Simulated samples

The irreducible SM $t\bar{t}$ background is simulated using MC@NLO v3.41 [19, 20] with `CTEQ6.6` [21] parton distribution functions (PDFs), interfaced to HERWIG v6.5 [22] for the parton shower and hadronization steps and JIMMY [23] to model effects due to the underlying event and multiple parton interactions. The top quark mass is set to 172.5 GeV and only events in which at least one of the W bosons decays leptonically are generated. The inclusive cross-section of 165 pb is taken from approximate next-to-next-to-leading-order (NNLO) calculations [24]. Electroweak single top quark production is simulated using the same programs, and cross-sections are based on approximate NNLO calculations: 65 pb (t-channel) [25], 4.6 pb (s-channel) [26] and 15.7 pb (Wt process) [27]. Samples produced with different parameter settings or other Monte Carlo (MC) event generators are used to evaluate the systematic uncertainties due to the top quark mass, modelling of the shape of the $t\bar{t}$ mass distribution (POWHEG [28]), the parton shower model (POWHEG+ HERWIG compared to POWHEG+PYTHIA [29]), and initial- and final-state radiation effects (using ACERMC [30]). These last uncertainties are considered both separately and in a correlated way.

Production of a W or Z boson plus jets with leptonic vector boson decays is simulated with ALPGEN v2.13 [31] and `CTEQ6L1` [32] PDFs in exclusive bins of parton multiplicity for multiplicities lower than five, and inclusively above that. For the Z boson plus jets sample, Z-photon interference is included and events are required to have a dilepton invariant mass in the range $10 < m_{\ell\ell} < 2000$ GeV. The events are processed by HERWIG and JIMMY, and matrix-element–parton-shower matching is performed with the MLM [33] method. The inclusive samples are initially normalized to the NNLO cross-sections [34, 35], and in addition later corrected using data as described in Section 7.2 and Section 7.3.

Diboson samples for the $\ell +$ jets channel are produced using HERWIG v6.5 with JIMMY and `MRST2007LO`* [36] PDFs with JIMMY. A filter requires the presence of one lepton with $p_{\mathrm{T}} > 10$ GeV and pseudorapidity $|\eta| < 2.8$. The cross-sections used for these filtered samples are 11.8 pb for WW production, 3.4 pb for WZ production, and 0.98 pb for ZZ production. These values are multiplied with "K-factors" of 1.52, 1.58 and 1.20, corresponding to the ratio of the next-to-leading-order (NLO) and leading-order (LO) calculations, and obtained using the MCFM [37,38] generator. Additional diboson samples for the dilepton channel are simulated using ALPGEN v2.13 with `CTEQ6L1` PDFs and interfaced with HERWIG and JIMMY.

Signal samples for Z' bosons decaying to $t\bar{t}$ are generated using PYTHIA v6.421 with `CTEQ6L1` PDFs allowing all top quark decay modes. Cross-sections for the Z' boson samples are evaluated with an updated calculation [39] to which a K-factor of 1.3 is applied [40]. Samples of KK gluons are generated with MADGRAPH v4.4.51 [41], and showered with PYTHIA without taking into account interference with SM $t\bar{t}$ production,

---

[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 upward. Cylindrical coordinates (r, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the beam pipe. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln\tan(\theta/2)$.

and the cross-sections are recalculated using PYTHIA v8.1 [42]. In both cases, `CTEQ6L1` PDFs are used. The resulting cross-sections are given in Table 1.

Table 1 Cross-sections times branching ratios for the resonant signal processes obtained using the generator and PDF combinations described in the text. The KK gluon (Z') cross-sections are given at LO (LO × 1.3).

Signal mass [GeV]	$\sigma\times$ BR($Z'/g_{\mathrm{KK}} \to t\bar{t}$) [pb]	
	Topcolour Z'	g_{KK}
500 GeV	19.6	81.2
600 GeV	10.3	39.4
700 GeV	5.6	20.8
800 GeV	3.2	11.6
900 GeV	1.9	6.8
1000 GeV	1.2	4.1
1200 GeV	0.46	1.7
1400 GeV	0.19	0.73
1600 GeV	0.086	0.35
1800 GeV	0.039	0.18
2000 GeV	0.018	0.095

After event generation, all samples are processed by a GEANT4-based [43] simulation of the ATLAS detector [44] and reconstructed using the same software as used for data. All simulated samples include the effects due to multiple pp interactions per bunch-crossing, and events are reweighted so that the data and simulated sample instantaneous luminosity profiles match.

5 Object reconstruction

Electron candidates must have an EM shower shape consistent with expectations based on simulation, test-beam and $Z \to ee$ events in data, and must have a matching track in the ID [45]. They are required to have transverse momentum $p_{\mathrm{T}} > 25$ GeV and $|\eta_{\mathrm{cluster}}| < 2.47$, where η_{cluster} is the pseudorapidity of the calorimeter cluster associated to the candidate. Candidates in the calorimeter transition region at $1.37 < |\eta_{\mathrm{cluster}}| < 1.52$ are excluded.

Muon candidates are reconstructed from track segments in the various layers of the muon chambers, and matched with tracks found in the ID. The final candidates are refitted using the complete track information from both detector systems, and required to satisfy $p_{\mathrm{T}} > 25$ GeV and $|\eta| < 2.5$. Additionally, muons are required to be separated by $\Delta R > 0.4$ from any jet with $p_{\mathrm{T}} > 20$ GeV.

The leptons in each event are required to be isolated [46] to reduce the background due to non-prompt leptons, e.g. from decays of hadrons (including heavy flavour) produced in jets. For electrons, the calorimeter isolation transverse energy in a cone in η-ϕ space of radius $\Delta R = 0.2$ around the electron position[2] is required to be less than 3.5 GeV. The core of the electron energy deposition is excluded and the sum is corrected for transverse shower leakage and pile-up from additional pp collisions. For muons, the calorimeter isolation transverse energy, corrected for muon energy deposition, in a cone of $\Delta R = 0.3$ is required to be less than 4.0 GeV. The scalar sum of track transverse momenta in a cone of $\Delta R = 0.3$ around but excluding the muon track is also required to be less than 4.0 GeV.

Jets are reconstructed with the anti-k_t algorithm [47, 48] with radius parameter $R = 0.4$ from topological clusters [49] of energy deposits in the calorimeters, calibrated at the EM energy scale appropriate for the energy deposited by electrons or photons. These jets are then calibrated to the hadronic energy scale, using a p_{T}- and η-dependent correction factor [49] obtained from simulation, test-beam and collision data. The uncertainty on this correction factor is determined from control samples in data. Jets must have $p_{\mathrm{T}} > 20$ GeV and $|\eta| < 4.5$. If the closest object to an electron candidate is a jet with a separation $\Delta R < 0.2$ the jet is removed in order to avoid double-counting of electrons as jets. While the topological clusters are taken to be massless, jets are composed of many of these, and their spatial distribution within the jet cone leads to an invariant mass [50].

Jets originating from b-quarks are selected by exploiting the long lifetimes of bottom hadrons (about 1.5 ps) leading to typical flight paths before decay of a few millimeters, which are observable in the detector. A multivariate b-tagging algorithm [51] is used in this analysis at an operating point yielding, in simulated $t\bar{t}$ events, an average 60% b-tagging efficiency and a light quark jet rejection factor of 345.

The missing transverse momentum ($E_{\mathrm{T}}^{\mathrm{miss}}$) is constructed [52] from the vector sum of all calorimeter cells contained in topological clusters. Calorimeter cells are associated with a parent physics object in a chosen order: electrons, jets and muons, such that a cell is uniquely associated to a single physics object. Cells belonging to electrons are calibrated at the electron energy scale, but omitting the out-of-cluster correction to avoid double cell-energy counting, while cells belonging to jets are taken at the corrected energy scale used for jets. Finally, the p_{T} of muons passing selection requirements is included, and the contributions from any calorimeter cells associated to the muons are sub-

---

[2] The radius ΔR between the object axis and the edge of the object cone is defined as $\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$.

tracted. The remaining energy clusters not associated to electrons or jets are included at the EM scale.

For all reconstructed objects in simulation, scaling factors are applied to compensate for the difference in reconstruction efficiencies between data and simulation. The uncertainties on these scaling factors are used to determine the corresponding systematic uncertainties.

6 Event selection

After the event has been accepted by the trigger, it is required to have at least one offline-reconstructed primary vertex with at least five tracks with $p_{\mathrm{T}} > 0.4$ GeV, and it is discarded if any jet with $p_{\mathrm{T}} > 20$ GeV is identified as out-of-time activity or calorimeter noise [49].

6.1 $\ell +$ jets channel

The event must contain exactly one isolated lepton, and events where an electron shares an inner detector track with a non-isolated muon, or with a second lepton with $p_{\mathrm{T}} > 15$ GeV, are rejected. The total $t\bar{t}$ event fraction is enhanced by applying the following event-level cuts. In the electron channel, $E_{\mathrm{T}}^{\mathrm{miss}}$ must be larger than 35 GeV and $m_{\mathrm{T}} > 25$ GeV, where m_{T} is the lepton-$E_{\mathrm{T}}^{\mathrm{miss}}$ transverse mass[3]; in the muon channel, $E_{\mathrm{T}}^{\mathrm{miss}} > 20$ GeV and $E_{\mathrm{T}}^{\mathrm{miss}}+m_{\mathrm{T}} > 60$ GeV are required. If one of the jets has mass $m_j > 60$ GeV, the event must contain at least three jets with $p_{\mathrm{T}} > 25$ GeV and $|\eta| < 2.5$; if not, at least four jets satisfying the same p_{T} and η criteria must be present. The leading jet must have $p_{\mathrm{T}} > 60$ GeV, and at least one of the jets must be tagged as a b-jet. The requirement on the number of jets is relaxed when one jet has $m_j > 60$ GeV since for top quarks with significant boost the decay products are collimated, and multiple quarks from top quark or W boson decay can be reconstructed as a single, massive jet. This subsample represents approximately 0.3% of the selected event sample. The total signal acceptance times branching ratio to $t\bar{t}$ is is 7.4% for a topcolour Z' boson of mass $m_{Z'} = 800$ GeV and 7.3% for a KK-gluon of mass $m_{g_{\mathrm{KK}}} = 1300$ GeV.

6.2 Dilepton channel

The event selection follows that used in a recent ATLAS $t\bar{t}$ production cross-section measurement [53]. Candidate events are required to have two isolated leptons of opposite charge and two or more jets with $p_{\mathrm{T}} > 25$ GeV. In order to suppress the Z plus jets background, ee and $\mu\mu$ events are required to have an invariant dilepton mass outside the Z boson mass window, defined as $|m_Z - m_{\ell\ell}| < 10$ GeV, and $E_{\mathrm{T}}^{\mathrm{miss}} > 40$ GeV. An additional cut $m_{\ell\ell} > 10$ GeV is applied to the data in order to conform with the lower $m_{\ell\ell}$ cut-off in the Z plus jets simulation and to reduce backgrounds from meson resonances. In the $e\mu$ channel the non-$t\bar{t}$ background is suppressed by requiring the scalar sum of the transverse momenta of the identified leptons and jets to be larger than 130 GeV. The total signal acceptance times branching ratio to $t\bar{t}$ is 1.3% for a topcolour Z' boson of mass $m_{Z'} = 800$ GeV and 1.5% for a KK-gluon of mass $m_{g_{\mathrm{KK}}} = 1100$ GeV.

7 Data-driven background modelling

For the dominant background sources, $t\bar{t}$ and single top production, W plus jets in the $\ell +$ jets channel and Z plus jets in the dilepton channel, the simulated samples are corrected based on measurements in data. The multijet background is determined directly from data. All other backgrounds are taken without modification from simulation.

7.1 SM $t\bar{t}$ and single top modelling

As discussed in Section 4, the SM $t\bar{t}$ and single top backgrounds are simulated using the MC@NLO generator with `CTEQ6.6` PDFs. To investigate the impact of the choice of PDFs on modelling of this dominant background, the events are re-weighted to `MSTW2008nlo` [54] PDFs and the data are compared to the background expectation for angular variables: jet and lepton rapidities, and azimuthal angles between these objects and $E_{\mathrm{T}}^{\mathrm{miss}}$. Since the use of `MSTW2008nlo` leads to better agreement in these angular variables, samples re-weighted to these PDFs are used in the analysis. Distributions obtained with `CTEQ6.6` PDFs are used to estimate the systematic uncertainty associated with this shape modelling.

7.2 W plus jets corrections

For the $\ell +$ jets channel, the W plus jets background is determined using the ALPGEN samples described in Section 4, with data-driven corrections.

The flavour composition is determined from data based on the tagged fraction of W plus one- and two-jet events [55], and the known b-tagging efficiencies,

---

[3] The transverse mass is defined by the formula $m_{\mathrm{T}} = \sqrt{2p_{\mathrm{T}}^{\ell}E_{\mathrm{T}}^{\mathrm{miss}}(1-\cos\Delta\phi)}$, where p_{T}^{ℓ} is the lepton p_{T} and $\Delta\phi$ is the azimuthal angle between the lepton and $E_{\mathrm{T}}^{\mathrm{miss}}$.

measured using various techniques involving jets containing muons [56]. The MC predictions for different flavour contributions are scaled accordingly, adjusting the “light parton” scale factor to keep the untagged W plus two jets normalization unchanged. The $Wb\bar{b}$ and $Wc\bar{c}$ components are scaled by a factor 1.63, the Wc component by a factor 1.11, and the “light parton” component by a factor 0.83. The flavour composition uncertainty of the W plus jets background is estimated by varying these scaling factors by their uncertainties (13% for $Wb\bar{b}$ and $Wc\bar{c}$, 9% for Wc).

Normalization factors are derived based on the charge asymmetry in W boson production at the LHC [57]:

$$(N_{W^+} + N_{W^-})^{\mathrm{exp}} = \left(\frac{r_{\mathrm{MC}}+1}{r_{\mathrm{MC}}-1}\right)(N_{W^+} - N_{W^-})^{\mathrm{data}}$$

where N_{W^+} and N_{W^-} are the number of events with W^+ and W^- bosons, $r_{\mathrm{MC}} = N_{W^+}/N_{W^-}$, and the superscripts “exp” and “data” denote expected and data events, respectively. The difference $(N_{W^+} - N_{W^-})^{\mathrm{data}}$ and ratio r_{MC} are extracted from data and simulation, respectively, as a function of the number of b-tags and the number of reconstructed jets passing the selection cuts. The background contamination in the W boson samples extracted from data is verified to be charge-symmetric within uncertainties, and cancels in the difference. In the tagged four-jet bin, an overall normalization factor for the simulated samples of 0.91 (0.81) is required in the electron (muon) channel to match the data-driven prediction. The overall normalization uncertainty on the W plus jets background is set at 48%, based on an uncorrelated, 24%–per-jet uncertainty with respect to the inclusive W boson production cross-section [58].

7.3 Z plus jets corrections

Even though the event selection in the dilepton channel includes cuts to reject Z plus jets events, a small fraction of events in the $E_{\mathrm{T}}^{\mathrm{miss}}$ tails and dilepton invariant mass sidebands remain. To estimate this background contribution, the number of Drell-Yan events is measured in a data control sample orthogonal to the signal sample [53]. The control sample consists of events with at least two jets, a dilepton invariant mass inside the Z boson mass window, and $E_{\mathrm{T}}^{\mathrm{miss}} > 40$ GeV.

A small contamination in the control sample from non-Z-boson processes is subtracted from data using simulation. A scale factor is then derived based on ALPGEN Z plus jets samples to extrapolate the data-to-MC differences measured in the control region (CR) into the signal region (SR):

$$N^{\mathrm{SR}}_{Z+\mathrm{jets}} = \frac{(\mathrm{Data}^{\mathrm{CR}} - \mathrm{MC}^{\mathrm{CR}}_{\mathrm{other}})}{\mathrm{MC}^{\mathrm{CR}}_{N_{Z+\mathrm{jets}}}}\mathrm{MC}^{\mathrm{SR}}_{N_{Z+\mathrm{jets}}}$$

where $\mathrm{MC}^{\mathrm{SR/CR}}_{N_{Z+\mathrm{jets}}}$ represents the expected number of events in the signal and control regions, respectively. $\mathrm{MC}^{\mathrm{CR}}_{\mathrm{other}}$ is the number of events from non-Z contamination in the control region. $\mathrm{Data}^{\mathrm{CR}}$ is the observed number of events in the control region. The Z plus jets background normalization prediction from the simulation is thus scaled by the ratio of data to simulated events in the control region. In the $\ell+$jets channel the background from Z plus jets production is small and evaluated directly from the simulation.

7.4 Multijet background estimation

Jets, including those containing a leptonically decaying bottom or charmed hadron, can fake the isolated lepton signature produced by vector boson decays. Multijet events can thus contain objects that pass the lepton selection but are not leptons from vector boson decays, and contribute to the selected events. In the $\ell+$ jets channel, the multijet background expectation and kinematic distributions are determined using the method described below. It models the multijet background with a data-driven template, which is normalized in the multijet-dominated low $E_{\mathrm{T}}^{\mathrm{miss}}$ region. Since the multijet background in the b-tagged samples is dominated by true, non-prompt leptons from heavy flavour quark decays in both electron and muon samples, the template is used for both samples.

Events for the template are selected from a jet-triggered sample where exactly one jet with a high electromagnetic fraction (between 0.8 and 0.95) is present. This jet, which in addition must have at least four tracks to reduce the contribution from photon conversions, is used to model the lepton candidate. Events in which a good electron candidate is present are rejected, yielding a sample highly enriched in multijet background with kinematic characteristics very similar to the multijet events that do pass all the lepton selection cuts.

To determine the normalization of the multijet background, the data-driven multijet template and the simulated $t\bar{t}$, single top, W plus jets and Z plus jets background samples are fitted to the data using the full $E_{\mathrm{T}}^{\mathrm{miss}}$ spectrum, i.e. applying all selections except the $E_{\mathrm{T}}^{\mathrm{miss}}$ cut. Other contributions are negligible after all selection cuts. For MC samples, each bin is allowed to vary according to a Gaussian distribution centred at the bin height, with 10% RMS to account for their own modelling uncertainties. The multijet background and signal $E_{\mathrm{T}}^{\mathrm{miss}}$ spectra are sufficiently different so that fitting the multijet contribution to the full distribution will not mask a potential signal. The multijet template is determined before b-tagging to reduce statistical fluctuations. The kinematic distributions in both tagged and untagged samples have been verified to agree in shape within the available statistics in data.

In the dilepton channel, the small multijet background contribution is estimated from data using the Matrix Method [59], which accounts for small backgrounds with both one (W plus jets background) and two objects (multijet background) mimicking leptons from vector boson decays.

8 Mass reconstruction

8.1 $\ell +$jets channel

To reconstruct the $t\bar{t}$ invariant mass, the neutrino's longitudinal momentum (p_z) is determined by imposing the W boson mass constraint. If the discriminant of the quadratic equation is negative, a situation usually due to $E_{\mathrm{T}}^{\mathrm{miss}}$ resolution effects, the smallest changes to the $E_{\mathrm{T}}^{\mathrm{miss}}$ x and y components that lead to a null discriminant are applied [60], leading to an improved resolution for those two components. If there are two solutions, the smallest p_z solution is chosen.

Different mass reconstruction algorithms are used for the samples with or without a jet with $m_j > 60$ GeV. In the sample without such a jet, the dominant source of long, non-Gaussian tails in the mass resolution is the inclusion of a jet from initial- or final-state radiation in place of one of the jets directly related to a top quark decay product. To reduce this contribution, the four leading jets with $p_{\mathrm{T}} > 20$ GeV and $|\eta| < 2.5$ are considered, and a jet is excluded if its angular distance to the lepton or closest jet satisfies $\Delta R > 2.5 - 0.015 \times (m_j/\text{ GeV})$. If more than one jet satisfies this condition, the jet with the largest ΔR is excluded. If a jet was discarded and more than three jets remain, the procedure is iterated. Then $m_{t\bar{t}}$ is reconstructed from the lepton, $E_{\mathrm{T}}^{\mathrm{miss}}$ and the leading four jets, or three jets if only three remain. The ΔR cut removes jets that are well-separated from the rest of the activity in the event. Furthermore, by requiring only three jets in the mass reconstruction, the method allows one of the jets from top quark decay to be outside the detector acceptance, or merged with another jet.

For events with high $t\bar{t}$ mass, the top quark and W boson momenta can be large enough for some of the decay products to be merged into a single jet, in which case using the four highest p_{T} jets often leads to a significant overestimation of $m_{t\bar{t}}$, causing a substantial contribution to the very high mass tail. To mitigate this, if one of the jets has mass $m_j > 60$ GeV, it is combined with the jet closest to it (in ΔR) with $p_{\mathrm{T}} > 20$ GeV to form the hadronic top quark candidate, and the other top quark is formed by combining the reconstructed leptonic W boson candidate with, among those remaining, the jet with $p_{\mathrm{T}} > 20$ GeV closest to it.

The mass resolution obtained from simulation is shown in Fig. 1 using a few signal masses, and the correlation between true and reconstructed $t\bar{t}$ mass ($m_{t\bar{t}}$) is shown in Fig. 2(a).

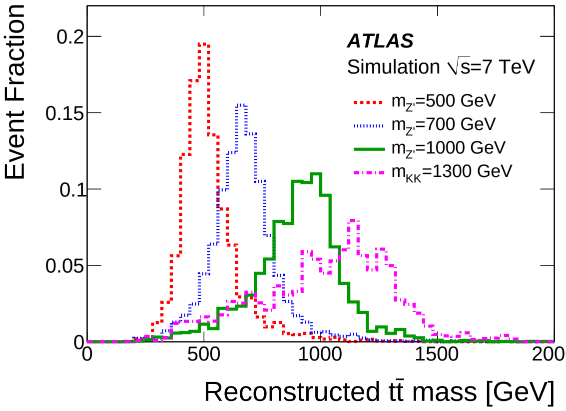


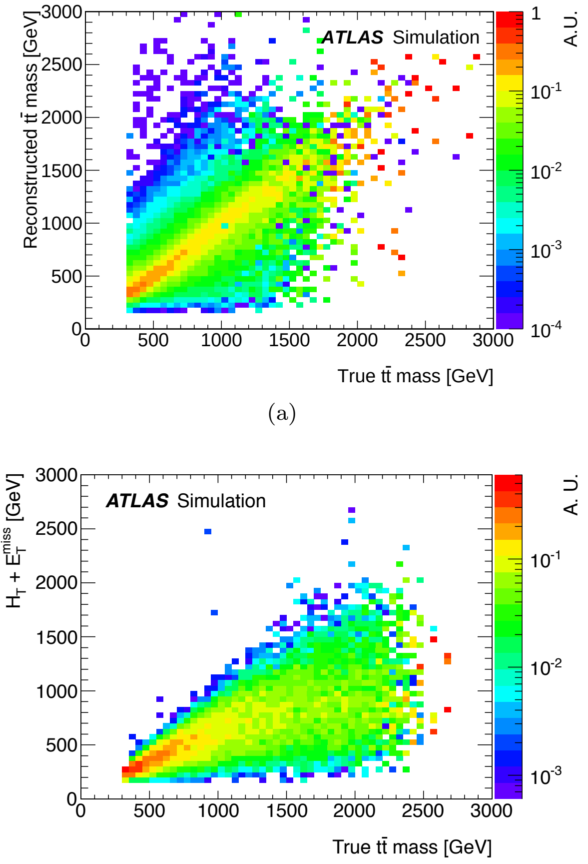
Fig. 1 Reconstructed $t\bar{t}$ pair invariant mass in simulation for four resonance masses: $m_{Z'} = 500$, 700, 1000 and $m_{g_{\mathrm{KK}}} = 1300$ GeV.

8.2 Dilepton channel

The dilepton channel is kinematically underconstrained due to the presence of two undetected neutrinos. The effective mass is correlated with $m_{t\bar{t}}$ and is defined as $H_{\mathrm{T}}+E_{\mathrm{T}}^{\mathrm{miss}}$, where H_{T} is the scalar sum of transverse momenta of the leptons and the two leading jets. The correlation between true $t\bar{t}$ mass and reconstructed $H_{\mathrm{T}}+E_{\mathrm{T}}^{\mathrm{miss}}$ is shown in Fig. 2(b).

9 Systematic uncertainties

Since the search for resonances is done using binned $m_{t\bar{t}}$ and $H_{\mathrm{T}}+E_{\mathrm{T}}^{\mathrm{miss}}$ distributions, two categories of systematic uncertainties are considered: uncertainties in the normalization of the expected event yield, which do not impact the shapes of the different contributions, and uncertainties affecting the shape of the $m_{t\bar{t}}$ or effective mass distributions, which can also impact the event yields.



(a)

(b)

Fig. 2 (a) Reconstructed versus true $t\bar{t}$ pair invariant mass in the ℓ+jets channel and (b) effective mass (H_{T}+$E_{\mathrm{T}}^{\mathrm{miss}}$) versus true $t\bar{t}$ invariant mass in the dilepton channel. The spectrum is normalized to unity for each bin in the true $t\bar{t}$ mass to show the correlation over a large mass range better.

Systematic uncertainties that affect only the normalization of the different backgrounds come from the uncertainty on the integrated luminosity (3.7%); the lepton trigger and reconstruction efficiencies ($\leq$ 1.5%); and background normalizations: $t\bar{t}$ ($^{+7.0}_{-9.6}$% [24]), single top (10%), diboson (5%), W or Z plus jets in the ℓ+jets channel (48%), Z plus jets in the dilepton channel (12%), W plus jets and multijet in the dilepton channel (76%), multijet in the ℓ + jets channel (50%).

The dominant uncertainties that affect both yields and shape in the ℓ+jets channel arise from the b-tagging efficiency [56], with 13% (17%) variation in the background ($m_{Z'}$ = 800 GeV signal) yields, jet energy scale including pile-up effects, 15% (4%) [49], and modelling of initial- and final-state radiation, 7% (6%). The first two have been determined from data by comparing results from different methods and/or data samples, while the last has been estimated from MC simulations in which the relevant parameters were varied [61].

Table 2 Number of expected and observed events for the e and μ+jets channels after applying all selection cuts described in Section 6. The uncertainties given are the normalization uncertainties as described in Section 9. Statistical uncertainties on these numbers are small.

	Electron channel	Muon channel
$t\bar{t}$	7830 ± 750	10000 ± 960
Single top	470 ± 50	570 ± 60
W plus jets	1120 ± 540	1450 ± 700
Z plus jets	85 ± 40	90 ± 45
Diboson	18 ± 1	18 ± 1
Multijet	340 ± 170	470 ± 240
Total expected	9860 ± 940	12600 ± 1210
Data observed	9622	12706
$m_{g_{Z'}}$ = 800 GeV	200	224
$m_{g_{\mathrm{KK}}}$ = 1300 GeV	59	65

The largest shape uncertainties in the dilepton channel arise from the modelling of initial- and final-state radiation, with 1.0% (5.1%) variation in the background ($m_{g_{\mathrm{KK}}}$ = 1000 GeV signal) yields, the jet energy scale 2.5% (3.0%) and PDFs 3.7% (0.6%).

Other uncertainties arising from MC modelling as well as object identification and momentum measurements have smaller impact. These include the following: jet energy resolution and reconstruction efficiency, muon p_{T} resolution, electron energy scale and energy resolution, $E_{\mathrm{T}}^{\mathrm{miss}}$ measurement, $m_{t\bar{t}}$ shape (as evaluated by comparison of POWHEG with MC@NLO), parton shower and fragmentation (PYTHIA versus HERWIG), W plus jets shape (evaluated by varying ALPGEN generation parameters), W plus jets composition (from the uncertainty in Wc and $Wc\bar{c} + Wb\bar{b}$ fractions), mis-modelling of the multijet background shape, as well as potential effects due to mis-modelling of pile-up effects.

10 Comparison of data and background expectation

Tables 2 and 3 compare the predicted and observed event yields after applying the event selection cuts described in Section 6 for the ℓ + jets and dilepton channels, respectively. The reconstructed $m_{t\bar{t}}$ distribution is shown for data and background expectation as well as two signal masses in Fig. 3. Figure 4 shows the H_{T}+$E_{\mathrm{T}}^{\mathrm{miss}}$ distribution for data and SM expectation together with a hypothetical KK-gluon signal with a mass of 1100 GeV for comparison. (The dilepton channel has very limited sensitivity to topcolour Z' bosons.) In both the ℓ + jets and dilepton channels good agreement is found between data and expected background

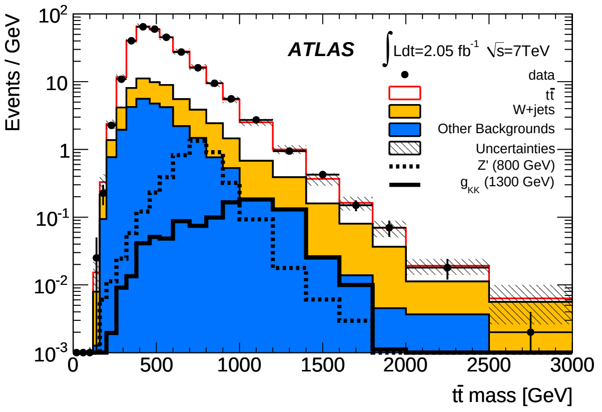


Fig. 3 Reconstructed $t\bar{t}$ mass in the $\ell+$jets channel after all cuts, with the expectation from SM background and two signal masses, a Z' boson with $m_{Z'} = 800$ GeV and a KK gluon with $m_{g_{\rm KK}} = 1300$ GeV. The electron and muon channels have been added together and all events beyond the range of the histogram have been added to the last bin. "Other backgrounds" includes single top, Z plus jets, diboson and multijet production. The hatched area shows the background normalization uncertainties.

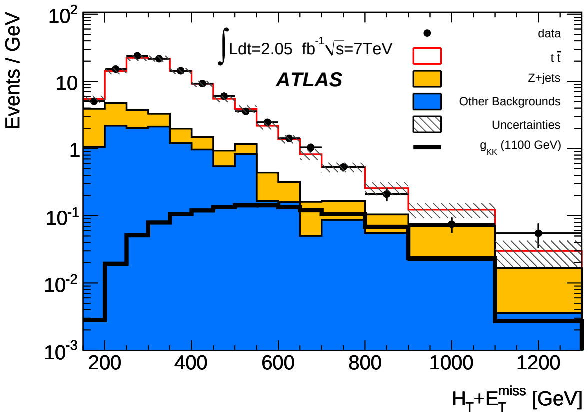


Fig. 4 The $H_{\rm T}+E_{\rm T}^{\rm miss}$ distribution after all selection requirements in the dilepton channel with a KK-gluon signal of mass $m_{g_{\rm KK}}$ =1100 GeV for comparison. "Other backgrounds" includes single top, diboson, W plus jets, and multijet production. The hatched area shows the background normalization uncertainties.

in the event yields as well as the shapes of kinematic distributions.

11 Results

The results of this search are obtained by comparing the $m_{t\bar{t}}$ and $H_{\rm T}+E_{\rm T}^{\rm miss}$ distributions with background-only and signal-plus-background hypotheses. The significance of a potential signal is summarized by a p-value, the probability of observing, in the absence of signal, an excess at least as signal-like as the one observed in data. The outcome of the search is ranked using the BumpHunter [62] algorithm for the $\ell+$jets channel and a likelihood ratio test statistic for the dilepton channel. No significant deviations from SM expectations are observed.

Table 3 Number of expected and observed events in the dilepton channel after applying all selection cuts described in Section 6. The uncertainties shown are all normalization uncertainties as described in Section 9. Statistical uncertainties on these numbers are small.

	Dilepton channel
$t\bar{t}$	4020 $\pm$ 470
Single top	210 $\pm$ 30
Z plus jets	570 $\pm$ 70
Diboson	185 $\pm$ 30
W plus jets and Multijet	190 $\pm$ 145
Total expected	5200 $\pm$ 500
Data observed	5304
$m_{g_{Z'}}$ = 800 GeV	77
$m_{g_{\rm KK}}$ = 1100 GeV	75

Given the absence of a signal, upper limits are set on cross-section times branching ratio ($\sigma\times$ BR) as a function of mass using a Bayesian approach [63]. For the limit setting, the $\ell+$jets channel uses variable-size binning, with bins ranging in size from 40 GeV to 500 GeV bins for narrow resonances, and 80 GeV to 500 GeV for Kaluza-Klein gluons. These values are close to the mass resolution while limiting bin-by-bin statistical fluctuations. Mass values below 500 GeV, i.e. the $t\bar{t}$ threshold region, are not considered. A single bin contains all events with $m_{t\bar{t}} > 2.5$ TeV. In the dilepton channel variable-sized bins are used with bins ranging in size from 50 GeV to 200 GeV to maximize sensitivity while limiting bin-by-bin statistical fluctuations. The last bin contains all events with $H_{\rm T}+E_{\rm T}^{\rm miss} > 1.1$ TeV.

The likelihood function is defined as the product of the Poisson probabilities over all bins of the reconstructed $t\bar{t}$ invariant mass or $H_{\rm T}+E_{\rm T}^{\rm miss}$ distribution in the $\ell+$jets or dilepton channel, respectively. The Poisson probability in each bin is evaluated for the observed number of data events given the background and signal template expectation. The total signal acceptance as a function of mass is propagated into the expectation. To calculate a likelihood for combined channels, the likelihoods of the individual channels are multiplied.

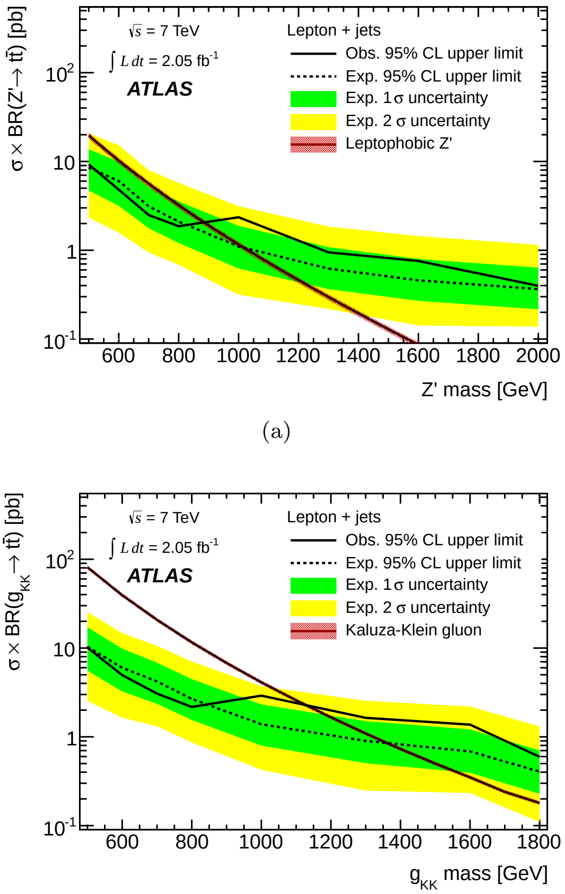
The posterior probability density is calculated using Bayes' theorem, with a flat positive prior in the signal cross-section which is found to be a good approximation of the reference prior [64]. Systematic uncertainties are incorporated using nuisance parameters that smear the parameters of the Poisson probability in each bin. For each systematic uncertainty a Gaussian prior controls the probability for a given deviation of the parameter from the nominal value. The 95% credibility level (CL) upper limit on the signal cross-section times branching ratio is identified with the 95% point of the posterior probability. The expected limits are determined by using the background expectation instead of the data in the limit computation, and the one and two standard-deviation bands around these limits are determined from the distribution of limits in pseudo-experiments.

Systematic uncertainties degrade the expected cross-section limits by a factor ranging from 3.0 at low mass to 1.5 at high mass. Of the 32 systematic uncertainties considered, none contribute individually more than 15% of the degradation.

For the $\ell+$jets channel the 95% CL observed limits on narrow and wide resonances are shown in Fig. 5, together with the predicted cross-section times branching ratio for the models considered and the expected limits. Numerical values are given in Tables 4 and 5. The observed (expected) 95% CL limit on $\sigma\times$ BR$(Z' \to t\bar{t})$ ranges from 9.3 (8.5) pb at $m_{Z'} = 500$ GeV to 0.95 (0.62) pb at $m_{Z'} = 1300$ GeV. The mass range 500 GeV $< m_{Z'} <$ 880 GeV is excluded at 95% CL. The expected mass exclusion is 500 GeV $< m_{Z'} <$ 1010 GeV [4]. The observed (expected) 95% CL limit on $\sigma\times$ BR$(g_{\rm KK} \to t\bar{t})$ ranges from 10.1 (10.3) pb at $m_{g_{\rm KK}} = 500$ GeV to 1.6 (0.9) pb at $m_{g_{\rm KK}} = 1300$ GeV. $g_{\rm KK}$ resonances with mass between 500 GeV and 1130 GeV are excluded at 95% CL, while the expected mass exclusion is 500 GeV $< m_{g_{\rm KK}} <$ 1360 GeV.

For the dilepton channel, the 95% CL limits on the $g_{\rm KK}$ resonance are shown in Fig. 6 with numerical values summarized in Table 5. The observed (expected) 95% CL limit on $\sigma\times$ BR$(g_{\rm KK} \to t\bar{t})$ ranges from 19.6 (17.0) pb at $m_{g_{\rm KK}} = 500$ GeV to 2.3 (2.7) pb at $m_{g_{\rm KK}} = 1300$ GeV. This result excludes $g_{\rm KK}$ resonances with masses between 500 GeV and 1080 GeV at 95% CL while the expected mass exclusion is 500 GeV $< m_{g_{\rm KK}} <$ 1070 GeV. No limit is set on $m_{Z'}$ in the dilepton channel.

Combining the $\ell+$jets and dilepton channels does not lead to a significant improvement in the limits. However, the dilepton channel, with different background composition and systematics, provides an important and largely independent cross-check of the result.



(a)

(b)

Fig. 5 Observed (solid line) and expected (dashed line) 95% CL upper limits on (a) $\sigma\times$ BR$(Z' \to t\bar{t})$ and (b) $\sigma\times$ BR$(g_{\rm KK} \to t\bar{t})$ for the $\ell+$jets channel. The inner and outer bands show the range in which the limit is expected to lie in 68% and 95% of pseudo-experiments, respectively, and the bold lines correspond to the predicted cross-section times branching ratio in the leptophobic topcolour and RS models. The bands around the signal cross-section curves represent the effect of the PDF uncertainty on the prediction.

Table 4 Expected and observed 95% CL upper limits on $\sigma\times$ BR$(Z' \to t\bar{t})$ for the $\ell+$jets channel.

Mass [GeV]	Z' Exp. [pb]	Z' Obs. [pb]
500	8.5	9.3
600	6.0	4.8
700	3.1	2.5
800	2.1	1.9
1000	1.1	2.4
1300	0.62	0.95
1600	0.46	0.76
2000	0.37	0.40

---

[4] For comparison with the Tevatron, the observed (expected) 95% CL exclusion limit is 500 GeV $< m_{Z'} <$ 860 (930) GeV when using the old LO cross-section calculation [2].

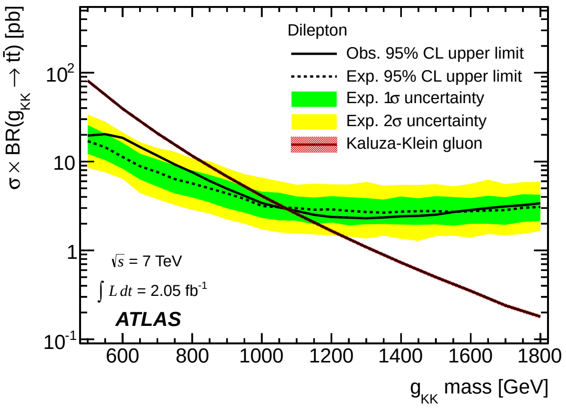


Fig. 6 Observed (solid line) and expected (dashed line) 95% CL upper limits on $\sigma\times$ BR($g_{\mathrm{KK}} \to t\bar{t}$) for the dilepton channel. The inner and outer bands show the range in which the limit is expected to lie in 68% and 95% of pseudo-experiments, respectively, and the bold line corresponds to the predicted cross-section times branching ratio for the RS model. The band around the signal cross-section curve represents the effect of the PDF uncertainty on the prediction.

Table 5 Expected and observed 95% CL upper limits on $\sigma\times$ BR($g_{\mathrm{KK}} \to t\bar{t}$).

$\ell +$ jets channel		
Mass [GeV]	g_{KK} Exp. [pb]	g_{KK} Obs. [pb]
500	10.3	10.1
600	6.0	5.0
700	4.2	3.1
800	2.7	2.2
1000	1.4	2.9
1300	0.90	1.6
1600	0.68	1.4
1800	0.41	0.60
Dilepton channel		
Mass [GeV]	g_{KK} Exp. [pb]	g_{KK} Obs. [pb]
500	17.0	19.6
600	11.3	18.5
700	7.6	11.7
800	5.7	7.6
1000	3.2	3.4
1300	2.7	2.3
1600	2.8	2.9
1800	3.1	3.4

12 Summary

A search for top quark pair resonances in the ℓ+jets and dilepton final states has been performed with the ATLAS experiment at the LHC. The search uses a data sample corresponding to an integrated luminosity of 2.05 fb^{-1}, recorded at a proton-proton centre-of-mass energy of 7 TeV. The data are found to be consistent with Standard Model background expectations. Using the reconstructed $t\bar{t}$ mass ($H_{\mathrm{T}}+E_{\mathrm{T}}^{\mathrm{miss}}$) spectrum in the ℓ+jets (dilepton) channel, limits are set on the production cross-section times branching ratio to $t\bar{t}$ for narrow and wide resonances. In the narrow Z' benchmark model, observed 95% CL limits range from 9.3 pb at $m = 500$ GeV to 0.95 pb at $m = 1300$ GeV, and a leptophobic topcolour Z' boson with 500 GeV $< m_{Z'} <$ 880 GeV is excluded at 95% CL. In the wide resonance benchmark model, Randall-Sundrum Kaluza-Klein gluons are excluded at 95% CL with masses between 500 GeV and 1130 GeV.

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; BMWF, Austria; ANAS, Azerbaijan; SSTC, Belarus; CNPq and FAPESP, Brazil; NSERC, NRC and CFI, Canada; CERN; CONICYT, Chile; CAS, MOST and NSFC, China; COLCIENCIAS, Colombia; MSMT CR, MPO CR and VSC CR, Czech Republic; DNRF, DNSRC and Lundbeck Foundation, Denmark; EPLANET and ERC, European Union; IN2P3-CNRS, CEA-DSM/IRFU, France; GNAS, Georgia; BMBF, DFG, HGF, MPG and AvH Foundation, Germany; GSRT, Greece; ISF, MINERVA, GIF, DIP and Benoziyo Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; FOM and NWO, Netherlands; RCN, Norway; MNiSW, Poland; GRICES and FCT, Portugal; MERYS (MECTS), Romania; MES of Russia and ROSATOM, Russian Federation; JINR; MSTD, Serbia; MSSR, Slovakia; ARRS and MVZT, Slovenia; DST/NRF, South Africa; MICINN, Spain; SRC and Wallenberg Foundation, Sweden; SER, SNSF and Cantons of Bern and Geneva, Switzerland; NSC, Taiwan; TAEK, Turkey; STFC, the Royal Society and Leverhulme Trust, United Kingdom; DOE and NSF, United States of America.

The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN and 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) and in the Tier-2 facilities worldwide.

References

1. ATLAS Collaboration, JINST **3**, S08003 (2008)
2. R. M. Harris, C. T. Hill, S. J. Parke (1999), `hep-ph/9911288`
3. C. T. Hill, Phys. Lett. **B345**, 483 (1995)

4. K. Agashe, A. Belyaev, T. Krupovnickas, et al., Phys. Rev. **D77**, 015003 (2008)
5. B. Lillie, L. Randall, L.-T. Wang, JHEP **09**, 074 (2007)
6. A. Djouadi, G. Moreau, R. K. Singh, Nucl. Phys. **B797**, 1 (2008)
7. B. C. Allanach, F. Mahmoudi, J. P. Skittrall, et al., JHEP **03**, 014 (2010)
8. T. Aaltonen, et al. (CDF), Phys. Rev. Lett. **100**, 231801 (2008)
9. T. Aaltonen, et al. (CDF), Phys. Rev. **D77**, 051102 (2008)
10. T. Aaltonen, et al. (CDF), Phys. Lett. **B691**, 183 (2010)
11. T. Aaltonen, et al. (CDF), Phys.Rev. **D84**, 072004 (2011)
12. T. Aaltonen, et al. (CDF), Phys.Rev. **D84**, 072003 (2011)
13. V. Abazov, et al. (D0), Phys. Lett. **B668**, 98 (2008)
14. V. M. Abazov, et al. (D0), Phys.Rev. **D85**, 051101 (2012)
15. CMS Collaboration (2012), submitted to JHEP, `arXiv:1204.2488`
16. C. T. Hill, S. J. Parke, Phys. Rev. **D49**, 4454 (1994)
17. ATLAS Collaboration, Eur. Phys. J. **C71**, 1630 (2011)
18. ATLAS Collaboration, *Luminosity Determination in pp Collisions at $\sqrt{s}$ = 7 TeV using the ATLAS Detector in 2011*, Tech. Rep. ATLAS-CONF-2011-116
19. S. Frixione, B. R. Webber, JHEP **06**, 029 (2002)
20. S. Frixione, P. Nason, B. R. Webber, JHEP **08**, 007 (2003)
21. P. M. Nadolsky, H.-L. Lai, Q.-H. Cao, et al., Phys. Rev. **D78**, 013004 (2008)
22. G. Corcella, I. Knowles, G. Marchesini, et al., JHEP **0101**, 010 (2001)
23. J. Butterworth, J. R. Forshaw, M. Seymour, Z. Phys. **C72**, 637 (1996)
24. S. Moch, P. Uwer, Phys. Rev. **D78**, 034003 (2008)
25. N. Kidonakis, Phys. Rev. **D83**, 091503 (2011)
26. N. Kidonakis, Phys. Rev. **D81**, 054028 (2010)
27. N. Kidonakis, Phys.Rev. **D82**, 054018 (2010)
28. S. Frixione, P. Nason, C. Oleari, JHEP **0711**, 070 (2007)
29. T. Sjostrand, S. Mrenna, P. Z. Skands, JHEP **0605**, 026 (2006)
30. B. P. Kersevan, E. Richter-Was (2004), `hep-ph/0405247`
31. M. L. Mangano, M. Moretti, F. Piccinini, et al., JHEP **0307**, 001 (2003)
32. J. Pumplin, D. Stump, J. Huston, et al., JHEP **0207**, 012 (2002)
33. S. Hoeche, F. Krauss, N. Lavesson, et al. (2006), `hep-ph/0602031`
34. R. Hamberg, W. van Neerven, T. Matsuura, Nucl. Phys. **B359**, 343 (1991)
35. R. Gavin, Y. Li, F. Petriello, et al. (2012), `arXiv:1201.5896`
36. A. Sherstnev, R. Thorne, Eur. Phys. J. **C55**, 553 (2008)
37. J. Campbell, R. Ellis, *MCFM—Monte Carlo for FeMtobarn processes*, `http://mcfm.fnal.gov`
38. J. M. Campbell, R. Ellis, C. Williams, JHEP **1107**, 018 (2011)
39. R. M. Harris, S. Jain (2011), `arXiv:1112.4928`
40. J. Gao, C. S. Li, B. H. Li, et al., Phys. Rev. **D82**, 014020 (2010)
41. J. Alwall, et al., JHEP **0709**, 028 (2007)
42. T. Sjostrand, S. Mrenna, P. Z. Skands, Comput. Phys. Commun. **178**, 852 (2008)
43. S. Agostinelli, et al. (GEANT4), Nucl. Instrum. Meth. **A506**, 250 (2003)
44. ATLAS Collaboration, Eur. Phys. J. **C70**, 823 (2010)
45. ATLAS Collaboration, Eur. Phys. J. **C72**, 1909 (2012)
46. ATLAS Collaboration, Phys. Lett. **B711**, 244 (2012)
47. M. Cacciari, G. P. Salam, Phys. Lett. **B641**, 57 (2006)
48. M. Cacciari, G. P. Salam, G. Soyez, JHEP **0804**, 063 (2008), http://fastjet.fr/
49. ATLAS Collaboration, Submitted to Eur. Phys. J. (2011), `arXiv:1112.6426`
50. ATLAS Collaboration, Submitted to JHEP (2012), `arXiv:1203.4606`
51. ATLAS Collaboration, *Commissioning of the ATLAS high-performance b-tagging algorithms in the 7 TeV collision data*, Tech. Rep. ATLAS-CONF-2011-102
52. ATLAS Collaboration, Eur. Phys. J. **C72**, 1844 (2012)
53. G. Aad, et al. (ATLAS Collaboration), JHEP **1205**, 059 (2012)
54. A. Martin, W. Stirling, R. Thorne, et al., Eur. Phys. J. **C63**, 189 (2009)
55. ATLAS Collaboration, Phys. Lett. **B707**, 418 (2012)
56. ATLAS Collaboration, *Calibrating the b-Tag Efficiency and Mistag Rate in 35 pb^{-1} of Data with the ATLAS Detector*, Tech. Rep. ATLAS-CONF-2011-089
57. ATLAS Collaboration, Submitted to Eur. Phys. J. C. (2012), `arXiv:1203.4211`
58. J. Alwall, S. Hoche, F. Krauss, et al., Eur. Phys. J. **C53**, 473 (2008)
59. ATLAS Collaboration, Phys.Lett. **B707**, 459 (2012)
60. T. Chwalek, *Ph.D. Thesis*, Tech. Rep. IEKP-KA/2010-5 pp. 81-85, KIT Karlsruhe (2010)
61. ATLAS Collaboration pp. 870–883 (2009), `arXiv:0901.0512`
62. G. Choudalakis (2011), `arXiv:1101.0390`
63. I. Bertram, et al. (D0), *A Recipe for the construction of confidence limits*, Tech. Rep. FERMILAB-TM-2104, Fermilab (2000)
64. D. Casadei, JINST **7**, P01012 (2012)

The ATLAS Collaboration

G. Aad[48], B. Abbott[111], J. Abdallah[11], S. Abdel Khalek[115], A.A. Abdelalim[49], O. Abdinov[10], B. Abi[112], M. Abolins[88], O.S. AbouZeid[158], H. Abramowicz[153], H. Abreu[136], E. Acerbi[89a,89b], B.S. Acharya[164a,164b], L. Adamczyk[37], D.L. Adams[24], T.N. Addy[56], J. Adelman[176], S. Adomeit[98], P. Adragna[75], T. Adye[129], S. Aefsky[22], J.A. Aguilar-Saavedra[124b,a], M. Agustoni[16], M. Aharrouche[81], S.P. Ahlen[21], F. Ahles[48], A. Ahmad[148], M. Ahsan[40], G. Aielli[133a,133b], T. Akdogan[18a], T.P.A. Åkesson[79], G. Akimoto[155], A.V. Akimov [94], M.S. Alam[1], M.A. Alam[76], J. Albert[169], S. Albrand[55], M. Aleksa[29], I.N. Aleksandrov[64], F. Alessandria[89a], C. Alexa[25a], G. Alexander[153], G. Alexandre[49], T. Alexopoulos[9], M. Alhroob[164a,164c], M. Aliev[15], G. Alimonti[89a], J. Alison[120], B.M.M. Allbrooke[17], P.P. Allport[73], S.E. Allwood-Spiers[53], J. Almond[82], A. Aloisio[102a,102b], R. Alon[172], A. Alonso[79], B. Alvarez Gonzalez[88], M.G. Alviggi[102a,102b], K. Amako[65], C. Amelung[22], V.V. Ammosov[128], A. Amorim[124a,b], N. Amram[153], C. Anastopoulos[29], L.S. Ancu[16], N. Andari[115], T. Andeen[34], C.F. Anders[58b], G. Anders[58a], K.J. Anderson[30], A. Andreazza[89a,89b], V. Andrei[58a], X.S. Anduaga[70], P. Anger[43], A. Angerami[34], F. Anghinolfi[29], A. Anisenkov[107], N. Anjos[124a], A. Annovi[47], A. Antonaki[8], M. Antonelli[47], A. Antonov[96], J. Antos[144b], F. Anulli[132a], S. Aoun[83], L. Aperio Bella[4], R. Apolle[118,c], G. Arabidze[88], I. Aracena[143], Y. Arai[65], A.T.H. Arce[44], S. Arfaoui[148], J-F. Arguin[14], E. Arik[18a,*], M. Arik[18a], A.J. Armbruster[87], O. Arnaez[81], V. Arnal[80], C. Arnault[115], A. Artamonov[95], G. Artoni[132a,132b], D. Arutinov[20], S. Asai[155], R. Asfandiyarov[173], S. Ask[27], B. Åsman[146a,146b], L. Asquith[5], K. Assamagan[24], A. Astbury[169], B. Aubert[4], E. Auge[115], K. Augsten[127], M. Aurousseau[145a], G. Avolio[163], R. Avramidou[9], D. Axen[168], G. Azuelos[93,d], Y. Azuma[155], M.A. Baak[29], G. Baccaglioni[89a], C. Bacci[134a,134b], A.M. Bach[14], H. Bachacou[136], K. Bachas[29], M. Backes[49], M. Backhaus[20], E. Badescu[25a], P. Bagnaia[132a,132b], S. Bahinipati[2], Y. Bai[32a], D.C. Bailey[158], T. Bain[158], J.T. Baines[129], O.K. Baker[176], M.D. Baker[24], S. Baker[77], E. Banas[38], P. Banerjee[93], Sw. Banerjee[173], D. Banfi[29], A. Bangert[150], V. Bansal[169], H.S. Bansil[17], L. Barak[172], S.P. Baranov[94], A. Barbaro Galtieri[14], T. Barber[48], E.L. Barberio[86], D. Barberis[50a,50b], M. Barbero[20], D.Y. Bardin[64], T. Barillari[99], M. Barisonzi[175], T. Barklow[143], N. Barlow[27], B.M. Barnett[129], R.M. Barnett[14], A. Baroncelli[134a], G. Barone[49], A.J. Barr[118], F. Barreiro[80], J. Barreiro Guimarães da Costa[57], P. Barrillon[115], R. Bartoldus[143], A.E. Barton[71], V. Bartsch[149], R.L. Bates[53], L. Batkova[144a], J.R. Batley[27], A. Battaglia[16], M. Battistin[29], F. Bauer[136], H.S. Bawa[143,e], S. Beale[98], T. Beau[78], P.H. Beauchemin[161], R. Beccherle[50a], P. Bechtle[20], H.P. Beck[16], A.K. Becker[175], S. Becker[98], M. Beckingham[138], K.H. Becks[175], A.J. Beddall[18c], A. Beddall[18c], S. Bedikian[176], V.A. Bednyakov[64], C.P. Bee[83], M. Begel[24], S. Behar Harpaz[152], M. Beimforde[99], C. Belanger-Champagne[85], P.J. Bell[49], W.H. Bell[49], G. Bella[153], L. Bellagamba[19a], F. Bellina[29], M. Bellomo[29], A. Belloni[57], O. Beloborodova[107,f], K. Belotskiy[96], O. Beltramello[29], O. Benary[153], D. Benchekroun[135a], K. Bendtz[146a,146b], N. Benekos[165], Y. Benhammou[153], E. Benhar Noccioli[49], J.A. Benitez Garcia[159b], D.P. Benjamin[44], M. Benoit[115], J.R. Bensinger[22], K. Benslama[130], S. Bentvelsen[105], D. Berge[29], E. Bergeaas Kuutmann[41], N. Berger[4], F. Berghaus[169], E. Berglund[105], J. Beringer[14], P. Bernat[77], R. Bernhard[48], C. Bernius[24], T. Berry[76], C. Bertella[83], A. Bertin[19a,19b], F. Bertolucci[122a,122b], M.I. Besana[89a,89b], G.J. Besjes[104], N. Besson[136], S. Bethke[99], W. Bhimji[45], R.M. Bianchi[29], M. Bianco[72a,72b], O. Biebel[98], S.P. Bieniek[77], K. Bierwagen[54], J. Biesiada[14], M. Biglietti[134a], H. Bilokon[47], M. Bindi[19a,19b], S. Binet[115], A. Bingul[18c], C. Bini[132a,132b], C. Biscarat[178], U. Bitenc[48], K.M. Black[21], R.E. Blair[5], J.-B. Blanchard[136], G. Blanchot[29], T. Blazek[144a], C. Blocker[22], J. Blocki[38], A. Blondel[49], W. Blum[81], U. Blumenschein[54], G.J. Bobbink[105], V.B. Bobrovnikov[107], S.S. Bocchetta[79], A. Bocci[44], C.R. Boddy[118], M. Boehler[41], J. Boek[175], N. Boelaert[35], J.A. Bogaerts[29], A. Bogdanchikov[107], A. Bogouch[90,*], C. Bohm[146a], J. Bohm[125], V. Boisvert[76], T. Bold[37], V. Boldea[25a], N.M. Bolnet[136], M. Bomben[78], M. Bona[75], M. Boonekamp[136], C.N. Booth[139], S. Bordoni[78], C. Borer[16], A. Borisov[128], G. Borissov[71], I. Borjanovic[12a], M. Borri[82], S. Borroni[87], V. Bortolotto[134a,134b], K. Bos[105], D. Boscherini[19a], M. Bosman[11], H. Boterenbrood[105], D. Botterill[129], J. Bouchami[93], J. Boudreau[123], E.V. Bouhova-Thacker[71], D. Boumediene[33], C. Bourdarios[115], N. Bousson[83], A. Boveia[30], J. Boyd[29], I.R. Boyko[64], I. Bozovic-Jelisavcic[12b], J. Bracinik[17], P. Branchini[134a], A. Brandt[7], G. Brandt[118], O. Brandt[54], U. Bratzler[156], B. Brau[84], J.E. Brau[114], H.M. Braun[175], S.F. Brazzale[164a,164c], B. Brelier[158], J. Bremer[29], K. Brendlinger[120], R. Brenner[166], S. Bressler[172], D. Britton[53], F.M. Brochu[27], I. Brock[20], R. Brock[88], E. Brodet[153], F. Broggi[89a], C. Bromberg[88], J. Bronner[99], G. Brooijmans[34], T. Brooks[76], W.K. Brooks[31b], G. Brown[82], H. Brown[7], P.A. Bruckman de Renstrom[38], D. Bruncko[144b], R. Bruneliere[48], S. Brunet[60], A. Bruni[19a], G. Bruni[19a], M. Bruschi[19a], T. Buanes[13], Q. Buat[55], F. Bucci[49], J. Buchanan[118], P. Buchholz[141], R.M. Buckingham[118], A.G. Buckley[45], S.I. Buda[25a], I.A. Budagov[64],

B. Budick[108], V. Büscher[81], L. Bugge[117], O. Bulekov[96], A.C. Bundock[73], M. Bunse[42], T. Buran[117],
H. Burckhart[29], S. Burdin[73], T. Burgess[13], S. Burke[129], E. Busato[33], P. Bussey[53], C.P. Buszello[166], B. Butler[143],
J.M. Butler[21], C.M. Buttar[53], J.M. Butterworth[77], W. Buttinger[27], S. Cabrera Urbán[167], D. Caforio[19a,19b],
O. Cakir[3a], P. Calafiura[14], G. Calderini[78], P. Calfayan[98], R. Calkins[106], L.P. Caloba[23a], R. Caloi[132a,132b],
D. Calvet[33], S. Calvet[33], R. Camacho Toro[33], P. Camarri[133a,133b], D. Cameron[117], L.M. Caminada[14],
S. Campana[29], M. Campanelli[77], V. Canale[102a,102b], F. Canelli[30,g], A. Canepa[159a], J. Cantero[80], R. Cantrill[76],
L. Capasso[102a,102b], M.D.M. Capeans Garrido[29], I. Caprini[25a], M. Caprini[25a], D. Capriotti[99], M. Capua[36a,36b],
R. Caputo[81], R. Cardarelli[133a], T. Carli[29], G. Carlino[102a], L. Carminati[89a,89b], B. Caron[85], S. Caron[104],
E. Carquin[31b], G.D. Carrillo Montoya[173], A.A. Carter[75], J.R. Carter[27], J. Carvalho[124a,h], D. Casadei[108],
M.P. Casado[11], M. Cascella[122a,122b], C. Caso[50a,50b,*], A.M. Castaneda Hernandez[173,i], E. Castaneda-Miranda[173],
V. Castillo Gimenez[167], N.F. Castro[124a], G. Cataldi[72a], P. Catastini[57], A. Catinaccio[29], J.R. Catmore[29],
A. Cattai[29], G. Cattani[133a,133b], S. Caughron[88], P. Cavalleri[78], D. Cavalli[89a], M. Cavalli-Sforza[11],
V. Cavasinni[122a,122b], F. Ceradini[134a,134b], A.S. Cerqueira[23b], A. Cerri[29], L. Cerrito[75], F. Cerutti[47],
S.A. Cetin[18b], A. Chafaq[135a], D. Chakraborty[106], I. Chalupkova[126], K. Chan[2], B. Chapleau[85], J.D. Chapman[27],
J.W. Chapman[87], E. Chareyre[78], D.G. Charlton[17], V. Chavda[82], C.A. Chavez Barajas[29], S. Cheatham[85],
S. Chekanov[5], S.V. Chekulaev[159a], G.A. Chelkov[64], M.A. Chelstowska[104], C. Chen[63], H. Chen[24], S. Chen[32c],
X. Chen[173], Y. Chen[34], A. Cheplakov[64], R. Cherkaoui El Moursli[135e], V. Chernyatin[24], E. Cheu[6],
S.L. Cheung[158], L. Chevalier[136], G. Chiefari[102a,102b], L. Chikovani[51a], J.T. Childers[29], A. Chilingarov[71],
G. Chiodini[72a], A.S. Chisholm[17], R.T. Chislett[77], A. Chitan[25a], M.V. Chizhov[64], G. Choudalakis[30],
S. Chouridou[137], I.A. Christidi[77], A. Christov[48], D. Chromek-Burckhart[29], M.L. Chu[151], J. Chudoba[125],
G. Ciapetti[132a,132b], A.K. Ciftci[3a], R. Ciftci[3a], D. Cinca[33], V. Cindro[74], C. Ciocca[19a,19b], A. Ciocio[14],
M. Cirilli[87], P. Cirkovic[12b], M. Citterio[89a], M. Ciubancan[25a], A. Clark[49], P.J. Clark[45], R.N. Clarke[14],
W. Cleland[123], J.C. Clemens[83], B. Clement[55], C. Clement[146a,146b], Y. Coadou[83], M. Cobal[164a,164c],
A. Coccaro[138], J. Cochran[63], J.G. Cogan[143], J. Coggeshall[165], E. Cogneras[178], J. Colas[4], A.P. Colijn[105],
N.J. Collins[17], C. Collins-Tooth[53], J. Collot[55], T. Colombo[119a,119b], G. Colon[84], P. Conde Muiño[124a],
E. Coniavitis[118], M.C. Conidi[11], S.M. Consonni[89a,89b], V. Consorti[48], S. Constantinescu[25a], C. Conta[119a,119b],
G. Conti[57], F. Conventi[102a,j], M. Cooke[14], B.D. Cooper[77], A.M. Cooper-Sarkar[118], K. Copic[14],
T. Cornelissen[175], M. Corradi[19a], F. Corriveau[85,k], A. Cortes-Gonzalez[165], G. Cortiana[99], G. Costa[89a],
M.J. Costa[167], D. Costanzo[139], T. Costin[30], D. Côté[29], L. Courneyea[169], G. Cowan[76], C. Cowden[27], B.E. Cox[82],
K. Cranmer[108], F. Crescioli[122a,122b], M. Cristinziani[20], G. Crosetti[36a,36b], R. Crupi[72a,72b], S. Crépé-Renaudin[55],
C.-M. Cuciuc[25a], C. Cuenca Almenar[176], T. Cuhadar Donszelmann[139], M. Curatolo[47], C.J. Curtis[17],
C. Cuthbert[150], P. Cwetanski[60], H. Czirr[141], P. Czodrowski[43], Z. Czyczula[176], S. D'Auria[53], M. D'Onofrio[73],
A. D'Orazio[132a,132b], M.J. Da Cunha Sargedas De Sousa[124a], C. Da Via[82], W. Dabrowski[37], A. Dafinca[118],
T. Dai[87], C. Dallapiccola[84], M. Dam[35], M. Dameri[50a,50b], D.S. Damiani[137], H.O. Danielsson[29], V. Dao[49],
G. Darbo[50a], G.L. Darlea[25b], W. Davey[20], T. Davidek[126], N. Davidson[86], R. Davidson[71], E. Davies[118,c],
M. Davies[93], A.R. Davison[77], Y. Davygora[58a], E. Dawe[142], I. Dawson[139], R.K. Daya-Ishmukhametova[22], K. De[7],
R. de Asmundis[102a], S. De Castro[19a,19b], S. De Cecco[78], J. de Graat[98], N. De Groot[104], P. de Jong[105],
C. De La Taille[115], H. De la Torre[80], F. De Lorenzi[63], L. de Mora[71], L. De Nooij[105], D. De Pedis[132a],
A. De Salvo[132a], U. De Sanctis[164a,164c], A. De Santo[149], J.B. De Vivie De Regie[115], G. De Zorzi[132a,132b],
W.J. Dearnaley[71], R. Debbe[24], C. Debenedetti[45], B. Dechenaux[55], D.V. Dedovich[64], J. Degenhardt[120],
C. Del Papa[164a,164c], J. Del Peso[80], T. Del Prete[122a,122b], T. Delemontex[55], M. Deliyergiyev[74], A. Dell'Acqua[29],
L. Dell'Asta[21], M. Della Pietra[102a,j], D. della Volpe[102a,102b], M. Delmastro[4], P.A. Delsart[55], C. Deluca[105],
S. Demers[176], M. Demichev[64], B. Demirkoz[11,l], J. Deng[163], S.P. Denisov[128], D. Derendarz[38], J.E. Derkaoui[135d],
F. Derue[78], P. Dervan[73], K. Desch[20], E. Devetak[148], P.O. Deviveiros[105], A. Dewhurst[129], B. DeWilde[148],
S. Dhaliwal[158], R. Dhullipudi[24,m], A. Di Ciaccio[133a,133b], L. Di Ciaccio[4], A. Di Girolamo[29], B. Di Girolamo[29],
S. Di Luise[134a,134b], A. Di Mattia[173], B. Di Micco[29], R. Di Nardo[47], A. Di Simone[133a,133b], R. Di Sipio[19a,19b],
M.A. Diaz[31a], E.B. Diehl[87], J. Dietrich[41], T.A. Dietzsch[58a], S. Diglio[86], K. Dindar Yagci[39], J. Dingfelder[20],
F. Dinut[25a], C. Dionisi[132a,132b], P. Dita[25a], S. Dita[25a], F. Dittus[29], F. Djama[83], T. Djobava[51b],
M.A.B. do Vale[23c], A. Do Valle Wemans[124a,n], T.K.O. Doan[4], M. Dobbs[85], R. Dobinson [29,*], D. Dobos[29],
E. Dobson[29,o], J. Dodd[34], C. Doglioni[49], T. Doherty[53], Y. Doi[65,*], J. Dolejsi[126], I. Dolenc[74], Z. Dolezal[126],
B.A. Dolgoshein[96,*], T. Dohmae[155], M. Donadelli[23d], J. Donini[33], J. Dopke[29], A. Doria[102a], A. Dos Anjos[173],
A. Dotti[122a,122b], M.T. Dova[70], A.D. Doxiadis[105], A.T. Doyle[53], M. Dris[9], J. Dubbert[99], S. Dube[14],
E. Duchovni[172], G. Duckeck[98], A. Dudarev[29], F. Dudziak[63], M. Dührssen [29], I.P. Duerdoth[82], L. Duflot[115],

M-A. Dufour[85], M. Dunford[29], H. Duran Yildiz[3a], R. Duxfield[139], M. Dwuznik[37], F. Dydak [29], M. Düren[52], J. Ebke[98], S. Eckweiler[81], K. Edmonds[81], C.A. Edwards[76], N.C. Edwards[53], W. Ehrenfeld[41], T. Eifert[143], G. Eigen[13], K. Einsweiler[14], E. Eisenhandler[75], T. Ekelof[166], M. El Kacimi[135c], M. Ellert[166], S. Elles[4], F. Ellinghaus[81], K. Ellis[75], N. Ellis[29], J. Elmsheuser[98], M. Elsing[29], D. Emeliyanov[129], R. Engelmann[148], A. Engl[98], B. Epp[61], A. Eppig[87], J. Erdmann[54], A. Ereditato[16], D. Eriksson[146a], J. Ernst[1], M. Ernst[24], J. Ernwein[136], D. Errede[165], S. Errede[165], E. Ertel[81], M. Escalier[115], H. Esch[42], C. Escobar[123], X. Espinal Curull[11], B. Esposito[47], F. Etienne[83], A.I. Etienvre[136], E. Etzion[153], D. Evangelakou[54], H. Evans[60], L. Fabbri[19a,19b], C. Fabre[29], R.M. Fakhrutdinov[128], S. Falciano[132a], Y. Fang[173], M. Fanti[89a,89b], A. Farbin[7], A. Farilla[134a], J. Farley[148], T. Farooque[158], S. Farrell[163], S.M. Farrington[118], P. Farthouat[29], P. Fassnacht[29], D. Fassouliotis[8], B. Fatholahzadeh[158], A. Favareto[89a,89b], L. Fayard[115], S. Fazio[36a,36b], R. Febbraro[33], P. Federic[144a], O.L. Fedin[121], W. Fedorko[88], M. Fehling-Kaschek[48], L. Feligioni[83], D. Fellmann[5], C. Feng[32d], E.J. Feng[5], A.B. Fenyuk[128], J. Ferencei[144b], W. Fernando[5], S. Ferrag[53], J. Ferrando[53], V. Ferrara[41], A. Ferrari[166], P. Ferrari[105], R. Ferrari[119a], D.E. Ferreira de Lima[53], A. Ferrer[167], D. Ferrere[49], C. Ferretti[87], A. Ferretto Parodi[50a,50b], M. Fiascaris[30], F. Fiedler[81], A. Filipčič[74], F. Filthaut[104], M. Fincke-Keeler[169], M.C.N. Fiolhais[124a,h], L. Fiorini[167], A. Firan[39], G. Fischer[41], M.J. Fisher[109], M. Flechl[48], I. Fleck[141], J. Fleckner[81], P. Fleischmann[174], S. Fleischmann[175], T. Flick[175], A. Floderus[79], L.R. Flores Castillo[173], M.J. Flowerdew[99], T. Fonseca Martin[16], A. Formica[136], A. Forti[82], D. Fortin[159a], D. Fournier[115], H. Fox[71], P. Francavilla[11], S. Franchino[119a,119b], D. Francis[29], T. Frank[172], S. Franz[29], M. Fraternali[119a,119b], S. Fratina[120], S.T. French[27], C. Friedrich[41], F. Friedrich [43], R. Froeschl[29], D. Froidevaux[29], J.A. Frost[27], C. Fukunaga[156], E. Fullana Torregrosa[29], B.G. Fulsom[143], J. Fuster[167], C. Gabaldon[29], O. Gabizon[172], T. Gadfort[24], S. Gadomski[49], G. Gagliardi[50a,50b], P. Gagnon[60], C. Galea[98], E.J. Gallas[118], V. Gallo[16], B.J. Gallop[129], P. Gallus[125], K.K. Gan[109], Y.S. Gao[143,e], A. Gaponenko[14], F. Garberson[176], M. Garcia-Sciveres[14], C. García[167], J.E. García Navarro[167], R.W. Gardner[30], N. Garelli[29], H. Garitaonandia[105], V. Garonne[29], J. Garvey[17], C. Gatti[47], G. Gaudio[119a], B. Gaur[141], L. Gauthier[136], P. Gauzzi[132a,132b], I.L. Gavrilenko[94], C. Gay[168], G. Gaycken[20], E.N. Gazis[9], P. Ge[32d], Z. Gecse[168], C.N.P. Gee[129], D.A.A. Geerts[105], Ch. Geich-Gimbel[20], K. Gellerstedt[146a,146b], C. Gemme[50a], A. Gemmell[53], M.H. Genest[55], S. Gentile[132a,132b], M. George[54], S. George[76], P. Gerlach[175], A. Gershon[153], C. Geweniger[58a], H. Ghazlane[135b], N. Ghodbane[33], B. Giacobbe[19a], S. Giagu[132a,132b], V. Giakoumopoulou[8], V. Giangiobbe[11], F. Gianotti[29], B. Gibbard[24], A. Gibson[158], S.M. Gibson[29], D. Gillberg[28], A.R. Gillman[129], D.M. Gingrich[2,d], J. Ginzburg[153], N. Giokaris[8], M.P. Giordani[164c], R. Giordano[102a,102b], F.M. Giorgi[15], P. Giovannini[99], P.F. Giraud[136], D. Giugni[89a], M. Giunta[93], P. Giusti[19a], B.K. Gjelsten[117], L.K. Gladilin[97], C. Glasman[80], J. Glatzer[48], A. Glazov[41], K.W. Glitza[175], G.L. Glonti[64], J.R. Goddard[75], J. Godfrey[142], J. Godlewski[29], M. Goebel[41], T. Göpfert[43], C. Goeringer[81], C. Gössling[42], S. Goldfarb[87], T. Golling[176], A. Gomes[124a,b], L.S. Gomez Fajardo[41], R. Gonçalo[76], J. Goncalves Pinto Firmino Da Costa[41], L. Gonella[20], S. Gonzalez[173], S. González de la Hoz[167], G. Gonzalez Parra[11], M.L. Gonzalez Silva[26], S. Gonzalez-Sevilla[49], J.J. Goodson[148], L. Goossens[29], P.A. Gorbounov[95], H.A. Gordon[24], I. Gorelov[103], G. Gorfine[175], B. Gorini[29], E. Gorini[72a,72b], A. Gorišek[74], E. Gornicki[38], B. Gosdzik[41], A.T. Goshaw[5], M. Gosselink[105], M.I. Gostkin[64], I. Gough Eschrich[163], M. Gouighri[135a], D. Goujdami[135c], M.P. Goulette[49], A.G. Goussiou[138], C. Goy[4], S. Gozpinar[22], I. Grabowska-Bold[37], P. Grafström[19a,19b], K-J. Grahn[41], F. Grancagnolo[72a], S. Grancagnolo[15], V. Grassi[148], V. Gratchev[121], N. Grau[34], H.M. Gray[29], J.A. Gray[148], E. Graziani[134a], O.G. Grebenyuk[121], T. Greenshaw[73], Z.D. Greenwood[24,m], K. Gregersen[35], I.M. Gregor[41], P. Grenier[143], J. Griffiths[138], N. Grigalashvili[64], A.A. Grillo[137], S. Grinstein[11], Y.V. Grishkevich[97], J.-F. Grivaz[115], E. Gross[172], J. Grosse-Knetter[54], J. Groth-Jensen[172], K. Grybel[141], D. Guest[176], C. Guicheney[33], A. Guida[72a,72b], S. Guindon[54], U. Gul[53], H. Guler[85,p], J. Gunther[125], B. Guo[158], J. Guo[34], P. Gutierrez[111], N. Guttman[153], O. Gutzwiller[173], C. Guyot[136], C. Gwenlan[118], C.B. Gwilliam[73], A. Haas[143], S. Haas[29], C. Haber[14], H.K. Hadavand[39], D.R. Hadley[17], P. Haefner[20], F. Hahn[29], S. Haider[29], Z. Hajduk[38], H. Hakobyan[177], D. Hall[118], J. Haller[54], K. Hamacher[175], P. Hamal[113], M. Hamer[54], A. Hamilton[145b,q], S. Hamilton[161], L. Han[32b], K. Hanagaki[116], K. Hanawa[160], M. Hance[14], C. Handel[81], P. Hanke[58a], J.R. Hansen[35], J.B. Hansen[35], J.D. Hansen[35], P.H. Hansen[35], P. Hansson[143], K. Hara[160], G.A. Hare[137], T. Harenberg[175], S. Harkusha[90], D. Harper[87], R.D. Harrington[45], O.M. Harris[138], J. Hartert[48], F. Hartjes[105], T. Haruyama[65], A. Harvey[56], S. Hasegawa[101], Y. Hasegawa[140], S. Hassani[136], S. Haug[16], M. Hauschild[29], R. Hauser[88], M. Havranek[20], C.M. Hawkes[17], R.J. Hawkings[29], A.D. Hawkins[79], D. Hawkins[163], T. Hayakawa[66], T. Hayashi[160], D. Hayden[76], C.P. Hays[118], H.S. Hayward[73], S.J. Haywood[129], M. He[32d], S.J. Head[17], V. Hedberg[79], L. Heelan[7], S. Heim[88], B. Heinemann[14],

S. Heisterkamp[35], L. Helary[21], C. Heller[98], M. Heller[29], S. Hellman[146a,146b], D. Hellmich[20], C. Helsens[11],
R.C.W. Henderson[71], M. Henke[58a], A. Henrichs[54], A.M. Henriques Correia[29], S. Henrot-Versille[115], C. Hensel[54],
T. Henß[175], C.M. Hernandez[7], Y. Hernández Jiménez[167], R. Herrberg[15], G. Herten[48], R. Hertenberger[98],
L. Hervas[29], G.G. Hesketh[77], N.P. Hessey[105], E. Higón-Rodriguez[167], J.C. Hill[27], K.H. Hiller[41], S. Hillert[20],
S.J. Hillier[17], I. Hinchliffe[14], E. Hines[120], M. Hirose[116], F. Hirsch[42], D. Hirschbuehl[175], J. Hobbs[148], N. Hod[153],
M.C. Hodgkinson[139], P. Hodgson[139], A. Hoecker[29], M.R. Hoeferkamp[103], J. Hoffman[39], D. Hoffmann[83],
M. Hohlfeld[81], M. Holder[141], S.O. Holmgren[146a], T. Holy[127], J.L. Holzbauer[88], T.M. Hong[120],
L. Hooft van Huysduynen[108], C. Horn[143], S. Horner[48], J-Y. Hostachy[55], S. Hou[151], A. Hoummada[135a],
J. Howard[118], J. Howarth[82], I. Hristova [15], J. Hrivnac[115], T. Hryn'ova[4], P.J. Hsu[81], S.-C. Hsu[14], Z. Hubacek[127],
F. Hubaut[83], F. Huegging[20], A. Huettmann[41], T.B. Huffman[118], E.W. Hughes[34], G. Hughes[71], M. Huhtinen[29],
M. Hurwitz[14], U. Husemann[41], N. Huseynov[64,r], J. Huston[88], J. Huth[57], G. Iacobucci[49], G. Iakovidis[9],
M. Ibbotson[82], I. Ibragimov[141], L. Iconomidou-Fayard[115], J. Idarraga[115], P. Iengo[102a], O. Igonkina[105],
Y. Ikegami[65], M. Ikeno[65], D. Iliadis[154], N. Ilic[158], T. Ince[20], J. Inigo-Golfin[29], P. Ioannou[8], M. Iodice[134a],
K. Iordanidou[8], V. Ippolito[132a,132b], A. Irles Quiles[167], C. Isaksson[166], M. Ishino[67], M. Ishitsuka[157],
R. Ishmukhametov[39], C. Issever[118], S. Istin[18a], A.V. Ivashin[128], W. Iwanski[38], H. Iwasaki[65], J.M. Izen[40],
V. Izzo[102a], B. Jackson[120], J.N. Jackson[73], P. Jackson[143], M.R. Jaekel[29], V. Jain[60], K. Jakobs[48], S. Jakobsen[35],
T. Jakoubek[125], J. Jakubek[127], D.K. Jana[111], E. Jansen[77], H. Jansen[29], A. Jantsch[99], M. Janus[48], G. Jarlskog[79],
L. Jeanty[57], I. Jen-La Plante[30], P. Jenni[29], A. Jeremie[4], P. Jež[35], S. Jézéquel[4], M.K. Jha[19a], H. Ji[173], W. Ji[81],
J. Jia[148], Y. Jiang[32b], M. Jimenez Belenguer[41], S. Jin[32a], O. Jinnouchi[157], M.D. Joergensen[35], D. Joffe[39],
M. Johansen[146a,146b], K.E. Johansson[146a], P. Johansson[139], S. Johnert[41], K.A. Johns[6], K. Jon-And[146a,146b],
G. Jones[170], R.W.L. Jones[71], T.J. Jones[73], C. Joram[29], P.M. Jorge[124a], K.D. Joshi[82], J. Jovicevic[147], T. Jovin[12b],
X. Ju[173], C.A. Jung[42], R.M. Jungst[29], V. Juranek[125], P. Jussel[61], A. Juste Rozas[11], S. Kabana[16], M. Kaci[167],
A. Kaczmarska[38], P. Kadlecik[35], M. Kado[115], H. Kagan[109], M. Kagan[57], E. Kajomovitz[152], S. Kalinin[175],
L.V. Kalinovskaya[64], S. Kama[39], N. Kanaya[155], M. Kaneda[29], S. Kaneti[27], T. Kanno[157], V.A. Kantserov[96],
J. Kanzaki[65], B. Kaplan[176], A. Kapliy[30], J. Kaplon[29], D. Kar[53], M. Karagounis[20], K. Karakostas[9],
M. Karnevskiy[41], V. Kartvelishvili[71], A.N. Karyukhin[128], L. Kashif[173], G. Kasieczka[58b], R.D. Kass[109],
A. Kastanas[13], M. Kataoka[4], Y. Kataoka[155], E. Katsoufis[9], J. Katzy[41], V. Kaushik[6], K. Kawagoe[69],
T. Kawamoto[155], G. Kawamura[81], M.S. Kayl[105], V.A. Kazanin[107], M.Y. Kazarinov[64], R. Keeler[169], R. Kehoe[39],
M. Keil[54], G.D. Kekelidze[64], J.S. Keller[138], M. Kenyon[53], O. Kepka[125], N. Kerschen[29], B.P. Kerševan[74],
S. Kersten[175], K. Kessoku[155], J. Keung[158], F. Khalil-zada[10], H. Khandanyan[165], A. Khanov[112], D. Kharchenko[64],
A. Khodinov[96], A. Khomich[58a], T.J. Khoo[27], G. Khoriauli[20], A. Khoroshilov[175], V. Khovanskiy[95],
E. Khramov[64], J. Khubua[51b], H. Kim[146a,146b], S.H. Kim[160], N. Kimura[171], O. Kind[15], B.T. King[73], M. King[66],
R.S.B. King[118], J. Kirk[129], A.E. Kiryunin[99], T. Kishimoto[66], D. Kisielewska[37], T. Kittelmann[123], E. Kladiva[144b],
M. Klein[73], U. Klein[73], K. Kleinknecht[81], M. Klemetti[85], A. Klier[172], P. Klimek[146a,146b], A. Klimentov[24],
R. Klingenberg[42], J.A. Klinger[82], E.B. Klinkby[35], T. Klioutchnikova[29], P.F. Klok[104], S. Klous[105], E.-E. Kluge[58a],
T. Kluge[73], P. Kluit[105], S. Kluth[99], N.S. Knecht[158], E. Kneringer[61], E.B.F.G. Knoops[83], A. Knue[54], B.R. Ko[44],
T. Kobayashi[155], M. Kobel[43], M. Kocian[143], P. Kodys[126], K. Köneke[29], A.C. König[104], S. Koenig[81], L. Köpke[81],
F. Koetsveld[104], P. Koevesarki[20], T. Koffas[28], E. Koffeman[105], L.A. Kogan[118], S. Kohlmann[175], F. Kohn[54],
Z. Kohout[127], T. Kohriki[65], T. Koi[143], G.M. Kolachev[107], H. Kolanoski[15], V. Kolesnikov[64], I. Koletsou[89a],
J. Koll[88], M. Kollefrath[48], A.A. Komar[94], Y. Komori[155], T. Kondo[65], T. Kono[41,s], A.I. Kononov[48],
R. Konoplich[108,t], N. Konstantinidis[77], S. Koperny[37], K. Korcyl[38], K. Kordas[154], A. Korn[118], A. Korol[107],
I. Korolkov[11], E.V. Korolkova[139], V.A. Korotkov[128], O. Kortner[99], S. Kortner[99], V.V. Kostyukhin[20], S. Kotov[99],
V.M. Kotov[64], A. Kotwal[44], C. Kourkoumelis[8], V. Kouskoura[154], A. Koutsman[159a], R. Kowalewski[169],
T.Z. Kowalski[37], W. Kozanecki[136], A.S. Kozhin[128], V. Kral[127], V.A. Kramarenko[97], G. Kramberger[74],
M.W. Krasny[78], A. Krasznahorkay[108], J. Kraus[88], J.K. Kraus[20], S. Kreiss[108], F. Krejci[127], J. Kretzschmar[73],
N. Krieger[54], P. Krieger[158], K. Kroeninger[54], H. Kroha[99], J. Kroll[120], J. Kroseberg[20], J. Krstic[12a],
U. Kruchonak[64], H. Krüger[20], T. Kruker[16], N. Krumnack[63], Z.V. Krumshteyn[64], A. Kruth[20], T. Kubota[86],
S. Kuday[3a], S. Kuehn[48], A. Kugel[58c], T. Kuhl[41], D. Kuhn[61], V. Kukhtin[64], Y. Kulchitsky[90], S. Kuleshov[31b],
C. Kummer[98], M. Kuna[78], J. Kunkle[120], A. Kupco[125], H. Kurashige[66], M. Kurata[160], Y.A. Kurochkin[90],
V. Kus[125], E.S. Kuwertz[147], M. Kuze[157], J. Kvita[142], R. Kwee[15], A. La Rosa[49], L. La Rotonda[36a,36b],
L. Labarga[80], J. Labbe[4], S. Lablak[135a], C. Lacasta[167], F. Lacava[132a,132b], H. Lacker[15], D. Lacour[78],
V.R. Lacuesta[167], E. Ladygin[64], R. Lafaye[4], B. Laforge[78], T. Lagouri[80], S. Lai[48], E. Laisne[55], M. Lamanna[29],
L. Lambourne[77], C.L. Lampen[6], W. Lampl[6], E. Lancon[136], U. Landgraf[48], M.P.J. Landon[75], J.L. Lane[82],

V.S. Lang[58a], C. Lange[41], A.J. Lankford[163], F. Lanni[24], K. Lantzsch[175], S. Laplace[78], C. Lapoire[20], J.F. Laporte[136], T. Lari[89a], A. Larner[118], M. Lassnig[29], P. Laurelli[47], V. Lavorini[36a,36b], W. Lavrijsen[14], P. Laycock[73], O. Le Dortz[78], E. Le Guirriec[83], C. Le Maner[158], E. Le Menedeu[11], T. LeCompte[5], F. Ledroit-Guillon[55], H. Lee[105], J.S.H. Lee[116], S.C. Lee[151], L. Lee[176], M. Lefebvre[169], M. Legendre[136], F. Legger[98], C. Leggett[14], M. Lehmacher[20], G. Lehmann Miotto[29], X. Lei[6], M.A.L. Leite[23d], R. Leitner[126], D. Lellouch[172], B. Lemmer[54], V. Lendermann[58a], K.J.C. Leney[145b], T. Lenz[105], G. Lenzen[175], B. Lenzi[29], K. Leonhardt[43], S. Leontsinis[9], F. Lepold[58a], C. Leroy[93], J-R. Lessard[169], C.G. Lester[27], C.M. Lester[120], J. Levêque[4], D. Levin[87], L.J. Levinson[172], A. Lewis[118], G.H. Lewis[108], A.M. Leyko[20], M. Leyton[15], B. Li[83], H. Li[173,u], S. Li[32b,v], X. Li[87], Z. Liang[118,w], H. Liao[33], B. Liberti[133a], P. Lichard[29], M. Lichtnecker[98], K. Lie[165], W. Liebig[13], C. Limbach[20], A. Limosani[86], M. Limper[62], S.C. Lin[151,x], F. Linde[105], J.T. Linnemann[88], E. Lipeles[120], A. Lipniacka[13], T.M. Liss[165], D. Lissauer[24], A. Lister[49], A.M. Litke[137], C. Liu[28], D. Liu[151], H. Liu[87], J.B. Liu[87], L. Liu[87], M. Liu[32b], Y. Liu[32b], M. Livan[119a,119b], S.S.A. Livermore[118], A. Lleres[55], J. Llorente Merino[80], S.L. Lloyd[75], E. Lobodzinska[41], P. Loch[6], W.S. Lockman[137], T. Loddenkoetter[20], F.K. Loebinger[82], A. Loginov[176], C.W. Loh[168], T. Lohse[15], K. Lohwasser[48], M. Lokajicek[125], V.P. Lombardo[4], R.E. Long[71], L. Lopes[124a], D. Lopez Mateos[57], J. Lorenz[98], N. Lorenzo Martinez[115], M. Losada[162], P. Loscutoff[14], F. Lo Sterzo[132a,132b], M.J. Losty[159a], X. Lou[40], A. Lounis[115], K.F. Loureiro[162], J. Love[21], P.A. Love[71], A.J. Lowe[143,e], F. Lu[32a], H.J. Lubatti[138], C. Luci[132a,132b], A. Lucotte[55], A. Ludwig[43], D. Ludwig[41], I. Ludwig[48], J. Ludwig[48], F. Luehring[60], G. Luijckx[105], W. Lukas[61], D. Lumb[48], L. Luminari[132a], E. Lund[117], B. Lund-Jensen[147], B. Lundberg[79], J. Lundberg[146a,146b], O. Lundberg[146a,146b], J. Lundquist[35], M. Lungwitz[81], D. Lynn[24], E. Lytken[79], H. Ma[24], L.L. Ma[173], G. Maccarrone[47], A. Macchiolo[99], B. Maček[74], J. Machado Miguens[124a], R. Mackeprang[35], R.J. Madaras[14], W.F. Mader[43], R. Maenner[58c], T. Maeno[24], P. Mättig[175], S. Mättig[41], L. Magnoni[29], E. Magradze[54], K. Mahboubi[48], S. Mahmoud[73], G. Mahout[17], C. Maiani[136], C. Maidantchik[23a], A. Maio[124a,b], S. Majewski[24], Y. Makida[65], N. Makovec[115], P. Mal[136], B. Malaescu[29], Pa. Malecki[38], P. Malecki[38], V.P. Maleev[121], F. Malek[55], U. Mallik[62], D. Malon[5], C. Malone[143], S. Maltezos[9], V. Malyshev[107], S. Malyukov[29], R. Mameghani[98], J. Mamuzic[12b], A. Manabe[65], L. Mandelli[89a], I. Mandić[74], R. Mandrysch[15], J. Maneira[124a], P.S. Mangeard[88], L. Manhaes de Andrade Filho[23a], A. Mann[54], P.M. Manning[137], A. Manousakis-Katsikakis[8], B. Mansoulie[136], A. Mapelli[29], L. Mapelli[29], L. March [80], J.F. Marchand[28], F. Marchese[133a,133b], G. Marchiori[78], M. Marcisovsky[125], C.P. Marino[169], F. Marroquim[23a], Z. Marshall[29], F.K. Martens[158], L.F. Marti[16], S. Marti-Garcia[167], B. Martin[29], B. Martin[88], J.P. Martin[93], T.A. Martin[17], V.J. Martin[45], B. Martin dit Latour[49], S. Martin-Haugh[149], M. Martinez[11], V. Martinez Outschoorn[57], A.C. Martyniuk[169], M. Marx[82], F. Marzano[132a], A. Marzin[111], L. Masetti[81], T. Mashimo[155], R. Mashinistov[94], J. Masik[82], A.L. Maslennikov[107], I. Massa[19a,19b], G. Massaro[105], N. Massol[4], A. Mastroberardino[36a,36b], T. Masubuchi[155], P. Matricon[115], H. Matsunaga[155], T. Matsushita[66], C. Mattravers[118,c], J. Maurer[83], S.J. Maxfield[73], A. Mayne[139], R. Mazini[151], M. Mazur[20], L. Mazzaferro[133a,133b], M. Mazzanti[89a], S.P. Mc Kee[87], A. McCarn[165], R.L. McCarthy[148], T.G. McCarthy[28], N.A. McCubbin[129], K.W. McFarlane[56], J.A. Mcfayden[139], H. McGlone[53], G. Mchedlidze[51b], T. Mclaughlan[17], S.J. McMahon[129], R.A. McPherson[169,k], A. Meade[84], J. Mechnich[105], M. Mechtel[175], M. Medinnis[41], R. Meera-Lebbai[111], T. Meguro[116], R. Mehdiyev[93], S. Mehlhase[35], A. Mehta[73], K. Meier[58a], B. Meirose[79], C. Melachrinos[30], B.R. Mellado Garcia[173], F. Meloni[89a,89b], L. Mendoza Navas[162], Z. Meng[151,u], A. Mengarelli[19a,19b], S. Menke[99], E. Meoni[161], K.M. Mercurio[57], P. Mermod[49], L. Merola[102a,102b], C. Meroni[89a], F.S. Merritt[30], H. Merritt[109], A. Messina[29,y], J. Metcalfe[103], A.S. Mete[163], C. Meyer[81], C. Meyer[30], J-P. Meyer[136], J. Meyer[174], J. Meyer[54], T.C. Meyer[29], W.T. Meyer[63], J. Miao[32d], S. Michal[29], L. Micu[25a], R.P. Middleton[129], S. Migas[73], L. Mijović[136], G. Mikenberg[172], M. Mikestikova[125], M. Mikuž[74], D.W. Miller[30], R.J. Miller[88], W.J. Mills[168], C. Mills[57], A. Milov[172], D.A. Milstead[146a,146b], D. Milstein[172], A.A. Minaenko[128], M. Miñano Moya[167], I.A. Minashvili[64], A.I. Mincer[108], B. Mindur[37], M. Mineev[64], Y. Ming[173], L.M. Mir[11], G. Mirabelli[132a], J. Mitrevski[137], V.A. Mitsou[167], S. Mitsui[65], P.S. Miyagawa[139], J.U. Mjörnmark[79], T. Moa[146a,146b], V. Moeller[27], K. Mönig[41], N. Möser[20], S. Mohapatra[148], W. Mohr[48], R. Moles-Valls[167], J. Monk[77], E. Monnier[83], J. Montejo Berlingen[11], S. Montesano[89a,89b], F. Monticelli[70], S. Monzani[19a,19b], R.W. Moore[2], G.F. Moorhead[86], C. Mora Herrera[49], A. Moraes[53], N. Morange[136], J. Morel[54], G. Morello[36a,36b], D. Moreno[81], M. Moreno Llácer[167], P. Morettini[50a], M. Morgenstern[43], M. Morii[57], A.K. Morley[29], G. Mornacchi[29], J.D. Morris[75], L. Morvaj[101], H.G. Moser[99], M. Mosidze[51b], J. Moss[109], R. Mount[143], E. Mountricha[9,z], S.V. Mouraviev[94], E.J.W. Moyse[84], F. Mueller[58a], J. Mueller[123], K. Mueller[20], T.A. Müller[98], T. Mueller[81], D. Muenstermann[29], Y. Munwes[153], W.J. Murray[129], I. Mussche[105], E. Musto[102a,102b], A.G. Myagkov[128], M. Myska[125], J. Nadal[11], K. Nagai[160], K. Nagano[65],

A. Nagarkar[109], Y. Nagasaka[59], M. Nagel[99], A.M. Nairz[29], Y. Nakahama[29], K. Nakamura[155], T. Nakamura[155], I. Nakano[110], G. Nanava[20], A. Napier[161], R. Narayan[58b], M. Nash[77,c], T. Nattermann[20], T. Naumann[41], G. Navarro[162], H.A. Neal[87], P.Yu. Nechaeva[94], T.J. Neep[82], A. Negri[119a,119b], G. Negri[29], S. Nektarijevic[49], A. Nelson[163], T.K. Nelson[143], S. Nemecek[125], P. Nemethy[108], A.A. Nepomuceno[23a], M. Nessi[29,aa], M.S. Neubauer[165], A. Neusiedl[81], R.M. Neves[108], P. Nevski[24], P.R. Newman[17], V. Nguyen Thi Hong[136], R.B. Nickerson[118], R. Nicolaidou[136], B. Nicquevert[29], F. Niedercorn[115], J. Nielsen[137], N. Nikiforou[34], A. Nikiforov[15], V. Nikolaenko[128], I. Nikolic-Audit[78], K. Nikolics[49], K. Nikolopoulos[24], H. Nilsen[48], P. Nilsson[7], Y. Ninomiya [155], A. Nisati[132a], R. Nisius[99], T. Nobe[157], L. Nodulman[5], M. Nomachi[116], I. Nomidis[154], M. Nordberg[29], P.R. Norton[129], J. Novakova[126], M. Nozaki[65], L. Nozka[113], I.M. Nugent[159a], A.-E. Nuncio-Quiroz[20], G. Nunes Hanninger[86], T. Nunnemann[98], E. Nurse[77], B.J. O'Brien[45], S.W. O'Neale[17,*], D.C. O'Neil[142], V. O'Shea[53], L.B. Oakes[98], F.G. Oakham[28,d], H. Oberlack[99], J. Ocariz[78], A. Ochi[66], S. Oda[69], S. Odaka[65], J. Odier[83], H. Ogren[60], A. Oh[82], S.H. Oh[44], C.C. Ohm[146a,146b], T. Ohshima[101], H. Okawa[163], Y. Okumura[30], T. Okuyama[155], A. Olariu[25a], A.G. Olchevski[64], S.A. Olivares Pino[31a], M. Oliveira[124a,h], D. Oliveira Damazio[24], E. Oliver Garcia[167], D. Olivito[120], A. Olszewski[38], J. Olszowska[38], A. Onofre[124a,ab], P.U.E. Onyisi[30], C.J. Oram[159a], M.J. Oreglia[30], Y. Oren[153], D. Orestano[134a,134b], N. Orlando[72a,72b], I. Orlov[107], C. Oropeza Barrera[53], R.S. Orr[158], B. Osculati[50a,50b], R. Ospanov[120], C. Osuna[11], G. Otero y Garzon[26], J.P. Ottersbach[105], M. Ouchrif[135d], E.A. Ouellette[169], F. Ould-Saada[117], A. Ouraou[136], Q. Ouyang[32a], A. Ovcharova[14], M. Owen[82], S. Owen[139], V.E. Ozcan[18a], N. Ozturk[7], A. Pacheco Pages[11], C. Padilla Aranda[11], S. Pagan Griso[14], E. Paganis[139], F. Paige[24], P. Pais[84], K. Pajchel[117], G. Palacino[159b], C.P. Paleari[6], S. Palestini[29], D. Pallin[33], A. Palma[124a], J.D. Palmer[17], Y.B. Pan[173], E. Panagiotopoulou[9], P. Pani[105], N. Panikashvili[87], S. Panitkin[24], D. Pantea[25a], A. Papadelis[146a], Th.D. Papadopoulou[9], A. Paramonov[5], D. Paredes Hernandez[33], W. Park[24,ac], M.A. Parker[27], F. Parodi[50a,50b], J.A. Parsons[34], U. Parzefall[48], S. Pashapour[54], E. Pasqualucci[132a], S. Passaggio[50a], A. Passeri[134a], F. Pastore[134a,134b], Fr. Pastore[76], G. Pásztor [49,ad], S. Pataraia[175], N. Patel[150], J.R. Pater[82], S. Patricelli[102a,102b], T. Pauly[29], M. Pecsy[144a], M.I. Pedraza Morales[173], S.V. Peleganchuk[107], D. Pelikan[166], H. Peng[32b], B. Penning[30], A. Penson[34], J. Penwell[60], M. Perantoni[23a], K. Perez[34,ae], T. Perez Cavalcanti[41], E. Perez Codina[159a], M.T. Pérez García-Estañ[167], V. Perez Reale[34], L. Perini[89a,89b], H. Pernegger[29], R. Perrino[72a], P. Perrodo[4], V.D. Peshekhonov[64], K. Peters[29], B.A. Petersen[29], J. Petersen[29], T.C. Petersen[35], E. Petit[4], A. Petridis[154], C. Petridou[154], E. Petrolo[132a], F. Petrucci[134a,134b], D. Petschull[41], M. Petteni[142], R. Pezoa[31b], A. Phan[86], P.W. Phillips[129], G. Piacquadio[29], A. Picazio[49], E. Piccaro[75], M. Piccinini[19a,19b], S.M. Piec[41], R. Piegaia[26], D.T. Pignotti[109], J.E. Pilcher[30], A.D. Pilkington[82], J. Pina[124a,b], M. Pinamonti[164a,164c], A. Pinder[118], J.L. Pinfold[2], B. Pinto[124a], C. Pizio[89a,89b], M. Plamondon[169], M.-A. Pleier[24], E. Plotnikova[64], A. Poblaguev[24], S. Poddar[58a], F. Podlyski[33], L. Poggioli[115], T. Poghosyan[20], M. Pohl[49], G. Polesello[119a], A. Policicchio[36a,36b], A. Polini[19a], J. Poll[75], C.S. Pollard[44], V. Polychronakos[24], D. Pomeroy[22], K. Pommès[29], L. Pontecorvo[132a], B.G. Pope[88], G.A. Popeneciu[25a], D.S. Popovic[12a], A. Poppleton[29], X. Portell Bueso[29], G.E. Pospelov[99], S. Pospisil[127], I.N. Potrap[99], C.J. Potter[149], C.T. Potter[114], G. Poulard[29], J. Poveda[60], V. Pozdnyakov[64], R. Prabhu[77], P. Pralavorio[83], A. Pranko[14], S. Prasad[29], R. Pravahan[24], S. Prell[63], K. Pretzl[16], D. Price[60], J. Price[73], L.E. Price[5], D. Prieur[123], M. Primavera[72a], K. Prokofiev[108], F. Prokoshin[31b], S. Protopopescu[24], J. Proudfoot[5], X. Prudent[43], M. Przybycien[37], H. Przysiezniak[4], S. Psoroulas[20], E. Ptacek[114], E. Pueschel[84], J. Purdham[87], M. Purohit[24,ac], P. Puzo[115], Y. Pylypchenko[62], J. Qian[87], A. Quadt[54], D.R. Quarrie[14], W.B. Quayle[173], F. Quinonez[31a], M. Raas[104], V. Radescu[41], P. Radloff[114], T. Rador[18a], F. Ragusa[89a,89b], G. Rahal[178], A.M. Rahimi[109], D. Rahm[24], S. Rajagopalan[24], M. Rammensee[48], M. Rammes[141], A.S. Randle-Conde[39], K. Randrianarivony[28], F. Rauscher[98], T.C. Rave[48], M. Raymond[29], A.L. Read[117], D.M. Rebuzzi[119a,119b], A. Redelbach[174], G. Redlinger[24], R. Reece[120], K. Reeves[40], E. Reinherz-Aronis[153], A. Reinsch[114], I. Reisinger[42], C. Rembser[29], Z.L. Ren[151], A. Renaud[115], M. Rescigno[132a], S. Resconi[89a], B. Resende[136], P. Reznicek[98], R. Rezvani[158], R. Richter[99], E. Richter-Was[4,af], M. Ridel[78], M. Rijpstra[105], M. Rijssenbeek[148], A. Rimoldi[119a,119b], L. Rinaldi[19a], R.R. Rios[39], I. Riu[11], G. Rivoltella[89a,89b], F. Rizatdinova[112], E. Rizvi[75], S.H. Robertson[85,k], A. Robichaud-Veronneau[118], D. Robinson[27], J.E.M. Robinson[77], A. Robson[53], J.G. Rocha de Lima[106], C. Roda[122a,122b], D. Roda Dos Santos[29], A. Roe[54], S. Roe[29], O. Røhne[117], S. Rolli[161], A. Romaniouk[96], M. Romano[19a,19b], G. Romeo[26], E. Romero Adam[167], L. Roos[78], E. Ros[167], S. Rosati[132a], K. Rosbach[49], A. Rose[149], M. Rose[76], G.A. Rosenbaum[158], E.I. Rosenberg[63], P.L. Rosendahl[13], O. Rosenthal[141], L. Rosselet[49], V. Rossetti[11], E. Rossi[132a,132b], L.P. Rossi[50a], M. Rotaru[25a], I. Roth[172], J. Rothberg[138], D. Rousseau[115], C.R. Royon[136], A. Rozanov[83], Y. Rozen[152], X. Ruan[32a,ag],

F. Rubbo[11], I. Rubinskiy[41], B. Ruckert[98], N. Ruckstuhl[105], V.I. Rud[97], C. Rudolph[43], G. Rudolph[61], F. Rühr[6], A. Ruiz-Martinez[63], L. Rumyantsev[64], Z. Rurikova[48], N.A. Rusakovich[64], J.P. Rutherfoord[6], C. Ruwiedel[14], P. Ruzicka[125], Y.F. Ryabov[121], P. Ryan[88], M. Rybar[126], G. Rybkin[115], N.C. Ryder[118], A.F. Saavedra[150], I. Sadeh[153], H.F-W. Sadrozinski[137], R. Sadykov[64], F. Safai Tehrani[132a], H. Sakamoto[155], G. Salamanna[75], A. Salamon[133a], M. Saleem[111], D. Salek[29], D. Salihagic[99], A. Salnikov[143], J. Salt[167], B.M. Salvachua Ferrando[5], D. Salvatore[36a,36b], F. Salvatore[149], A. Salvucci[104], A. Salzburger[29], D. Sampsonidis[154], B.H. Samset[117], A. Sanchez[102a,102b], V. Sanchez Martinez[167], H. Sandaker[13], H.G. Sander[81], M.P. Sanders[98], M. Sandhoff[175], T. Sandoval[27], C. Sandoval [162], R. Sandstroem[99], D.P.C. Sankey[129], A. Sansoni[47], C. Santamarina Rios[85], C. Santoni[33], R. Santonico[133a,133b], H. Santos[124a], J.G. Saraiva[124a], T. Sarangi[173], E. Sarkisyan-Grinbaum[7], F. Sarri[122a,122b], G. Sartisohn[175], O. Sasaki[65], N. Sasao[67], I. Satsounkevitch[90], G. Sauvage[4], E. Sauvan[4], J.B. Sauvan[115], P. Savard[158,d], V. Savinov[123], D.O. Savu[29], L. Sawyer[24,m], D.H. Saxon[53], J. Saxon[120], C. Sbarra[19a], A. Sbrizzi[19a,19b], O. Scallon[93], D.A. Scannicchio[163], M. Scarcella[150], J. Schaarschmidt[115], P. Schacht[99], D. Schaefer[120], U. Schäfer[81], S. Schaepe[20], S. Schaetzel[58b], A.C. Schaffer[115], D. Schaile[98], R.D. Schamberger[148], A.G. Schamov[107], V. Scharf[58a], V.A. Schegelsky[121], D. Scheirich[87], M. Schernau[163], M.I. Scherzer[34], C. Schiavi[50a,50b], J. Schieck[98], M. Schioppa[36a,36b], S. Schlenker[29], E. Schmidt[48], K. Schmieden[20], C. Schmitt[81], S. Schmitt[58b], M. Schmitz[20], B. Schneider[16], U. Schnoor[43], A. Schöning[58b], A.L.S. Schorlemmer[54], M. Schott[29], D. Schouten[159a], J. Schovancova[125], M. Schram[85], C. Schroeder[81], N. Schroer[58c], M.J. Schultens[20], J. Schultes[175], H.-C. Schultz-Coulon[58a], H. Schulz[15], M. Schumacher[48], B.A. Schumm[137], Ph. Schune[136], C. Schwanenberger[82], A. Schwartzman[143], Ph. Schwemling[78], R. Schwienhorst[88], R. Schwierz[43], J. Schwindling[136], T. Schwindt[20], M. Schwoerer[4], G. Sciolla[22], W.G. Scott[129], J. Searcy[114], G. Sedov[41], E. Sedykh[121], S.C. Seidel[103], A. Seiden[137], F. Seifert[43], J.M. Seixas[23a], G. Sekhniaidze[102a], S.J. Sekula[39], K.E. Selbach[45], D.M. Seliverstov[121], B. Sellden[146a], G. Sellers[73], M. Seman[144b], N. Semprini-Cesari[19a,19b], C. Serfon[98], L. Serin[115], L. Serkin[54], R. Seuster[99], H. Severini[111], A. Sfyrla[29], E. Shabalina[54], M. Shamim[114], L.Y. Shan[32a], J.T. Shank[21], Q.T. Shao[86], M. Shapiro[14], P.B. Shatalov[95], K. Shaw[164a,164c], D. Sherman[176], P. Sherwood[77], A. Shibata[108], S. Shimizu[29], M. Shimojima[100], T. Shin[56], M. Shiyakova[64], A. Shmeleva[94], M.J. Shochet[30], D. Short[118], S. Shrestha[63], E. Shulga[96], M.A. Shupe[6], P. Sicho[125], A. Sidoti[132a], F. Siegert[48], Dj. Sijacki[12a], O. Silbert[172], J. Silva[124a], Y. Silver[153], D. Silverstein[143], S.B. Silverstein[146a], V. Simak[127], O. Simard[136], Lj. Simic[12a], S. Simion[115], E. Simioni[81], B. Simmons[77], R. Simoniello[89a,89b], M. Simonyan[35], P. Sinervo[158], N.B. Sinev[114], V. Sipica[141], G. Siragusa[174], A. Sircar[24], A.N. Sisakyan[64], S.Yu. Sivoklokov[97], J. Sjölin[146a,146b], T.B. Sjursen[13], L.A. Skinnari[14], H.P. Skottowe[57], K. Skovpen[107], P. Skubic[111], M. Slater[17], T. Slavicek[127], K. Sliwa[161], V. Smakhtin[172], B.H. Smart[45], S.Yu. Smirnov[96], Y. Smirnov[96], L.N. Smirnova[97], O. Smirnova[79], B.C. Smith[57], D. Smith[143], K.M. Smith[53], M. Smizanska[71], K. Smolek[127], A.A. Snesarev[94], S.W. Snow[82], J. Snow[111], S. Snyder[24], R. Sobie[169,k], J. Sodomka[127], A. Soffer[153], C.A. Solans[167], M. Solar[127], J. Solc[127], E.Yu. Soldatov[96], U. Soldevila[167], E. Solfaroli Camillocci[132a,132b], A.A. Solodkov[128], O.V. Solovyanov[128], N. Soni[2], V. Sopko[127], B. Sopko[127], M. Sosebee[7], R. Soualah[164a,164c], A. Soukharev[107], S. Spagnolo[72a,72b], F. Spanò[76], R. Spighi[19a], G. Spigo[29], F. Spila[132a,132b], R. Spiwoks[29], M. Spousta[126], T. Spreitzer[158], B. Spurlock[7], R.D. St. Denis[53], J. Stahlman[120], R. Stamen[58a], E. Stanecka[38], R.W. Stanek[5], C. Stanescu[134a], M. Stanescu-Bellu[41], S. Stapnes[117], E.A. Starchenko[128], J. Stark[55], P. Staroba[125], P. Starovoitov[41], R. Staszewski[38], A. Staude[98], P. Stavina[144a], G. Steele[53], P. Steinbach[43], P. Steinberg[24], I. Stekl[127], B. Stelzer[142], H.J. Stelzer[88], O. Stelzer-Chilton[159a], H. Stenzel[52], S. Stern[99], G.A. Stewart[29], J.A. Stillings[20], M.C. Stockton[85], K. Stoerig[48], G. Stoicea[25a], S. Stonjek[99], P. Strachota[126], A.R. Stradling[7], A. Straessner[43], J. Strandberg[147], S. Strandberg[146a,146b], A. Strandlie[117], M. Strang[109], E. Strauss[143], M. Strauss[111], P. Strizenec[144b], R. Ströhmer[174], D.M. Strom[114], J.A. Strong[76,*], R. Stroynowski[39], J. Strube[129], B. Stugu[13], I. Stumer[24,*], J. Stupak[148], P. Sturm[175], N.A. Styles[41], D.A. Soh[151,w], D. Su[143], HS. Subramania[2], A. Succurro[11], Y. Sugaya[116], C. Suhr[106], M. Suk[126], V.V. Sulin[94], S. Sultansoy[3d], T. Sumida[67], X. Sun[55], J.E. Sundermann[48], K. Suruliz[139], G. Susinno[36a,36b], M.R. Sutton[149], Y. Suzuki[65], Y. Suzuki[66], M. Svatos[125], S. Swedish[168], I. Sykora[144a], T. Sykora[126], J. Sánchez[167], D. Ta[105], K. Tackmann[41], A. Taffard[163], R. Tafirout[159a], N. Taiblum[153], Y. Takahashi[101], H. Takai[24], R. Takashima[68], H. Takeda[66], T. Takeshita[140], Y. Takubo[65], M. Talby[83], A. Talyshev[107,f], M.C. Tamsett[24], J. Tanaka[155], R. Tanaka[115], S. Tanaka[131], S. Tanaka[65], A.J. Tanasijczuk[142], K. Tani[66], N. Tannoury[83], S. Tapprogge[81], D. Tardif[158], S. Tarem[152], F. Tarrade[28], G.F. Tartarelli[89a], P. Tas[126], M. Tasevsky[125], E. Tassi[36a,36b], M. Tatarkhanov[14], Y. Tayalati[135d], C. Taylor[77], F.E. Taylor[92], G.N. Taylor[86], W. Taylor[159b], M. Teinturier[115], M. Teixeira Dias Castanheira[75], P. Teixeira-Dias[76], K.K. Temming[48], H. Ten Kate[29], P.K. Teng[151], S. Terada[65], K. Terashi[155], J. Terron[80],

M. Testa[47], R.J. Teuscher[158,k], J. Therhaag[20], T. Theveneaux-Pelzer[78], S. Thoma[48], J.P. Thomas[17], E.N. Thompson[34], P.D. Thompson[17], P.D. Thompson[158], A.S. Thompson[53], L.A. Thomsen[35], E. Thomson[120], M. Thomson[27], R.P. Thun[87], F. Tian[34], M.J. Tibbetts[14], T. Tic[125], V.O. Tikhomirov[94], Y.A. Tikhonov[107,f], S. Timoshenko[96], P. Tipton[176], F.J. Tique Aires Viegas[29], S. Tisserant[83], T. Todorov[4], S. Todorova-Nova[161], B. Toggerson[163], J. Tojo[69], S. Tokár[144a], K. Tokushuku[65], K. Tollefson[88], M. Tomoto[101], L. Tompkins[30], K. Toms[103], A. Tonoyan[13], C. Topfel[16], N.D. Topilin[64], I. Torchiani[29], E. Torrence[114], H. Torres[78], E. Torró Pastor[167], J. Toth[83,ad], F. Touchard[83], D.R. Tovey[139], T. Trefzger[174], L. Tremblet[29], A. Tricoli[29], I.M. Trigger[159a], S. Trincaz-Duvoid[78], M.F. Tripiana[70], W. Trischuk[158], B. Trocmé[55], C. Troncon[89a], M. Trottier-McDonald[142], M. Trzebinski[38], A. Trzupek[38], C. Tsarouchas[29], J.C-L. Tseng[118], M. Tsiakiris[105], P.V. Tsiareshka[90], D. Tsionou[4,ah], G. Tsipolitis[9], V. Tsiskaridze[48], E.G. Tskhadadze[51a], I.I. Tsukerman[95], V. Tsulaia[14], J.-W. Tsung[20], S. Tsuno[65], D. Tsybychev[148], A. Tua[139], A. Tudorache[25a], V. Tudorache[25a], J.M. Tuggle[30], M. Turala[38], D. Turecek[127], I. Turk Cakir[3e], E. Turlay[105], R. Turra[89a,89b], P.M. Tuts[34], A. Tykhonov[74], M. Tylmad[146a,146b], M. Tyndel[129], G. Tzanakos[8], K. Uchida[20], I. Ueda[155], R. Ueno[28], M. Ugland[13], M. Uhlenbrock[20], M. Uhrmacher[54], F. Ukegawa[160], G. Unal[29], A. Undrus[24], G. Unel[163], Y. Unno[65], D. Urbaniec[34], G. Usai[7], M. Uslenghi[119a,119b], L. Vacavant[83], V. Vacek[127], B. Vachon[85], S. Vahsen[14], J. Valenta[125], P. Valente[132a], S. Valentinetti[19a,19b], A. Valero[167], S. Valkar[126], E. Valladolid Gallego[167], S. Vallecorsa[152], J.A. Valls Ferrer[167], H. van der Graaf[105], E. van der Kraaij[105], R. Van Der Leeuw[105], E. van der Poel[105], D. van der Ster[29], N. van Eldik[29], P. van Gemmeren[5], I. van Vulpen[105], M. Vanadia[99], W. Vandelli[29], A. Vaniachine[5], P. Vankov[41], F. Vannucci[78], R. Vari[132a], T. Varol[84], D. Varouchas[14], A. Vartapetian[7], K.E. Varvell[150], V.I. Vassilakopoulos[56], F. Vazeille[33], T. Vazquez Schroeder[54], G. Vegni[89a,89b], J.J. Veillet[115], F. Veloso[124a], R. Veness[29], S. Veneziano[132a], A. Ventura[72a,72b], D. Ventura[84], M. Venturi[48], N. Venturi[158], V. Vercesi[119a], M. Verducci[138], W. Verkerke[105], J.C. Vermeulen[105], A. Vest[43], M.C. Vetterli[142,d], I. Vichou[165], T. Vickey[145b,ai], O.E. Vickey Boeriu[145b], G.H.A. Viehhauser[118], S. Viel[168], M. Villa[19a,19b], M. Villaplana Perez[167], E. Vilucchi[47], M.G. Vincter[28], E. Vinek[29], V.B. Vinogradov[64], M. Virchaux[136,*], J. Virzi[14], O. Vitells[172], M. Viti[41], I. Vivarelli[48], F. Vives Vaque[2], S. Vlachos[9], D. Vladoiu[98], M. Vlasak[127], A. Vogel[20], P. Vokac[127], G. Volpi[47], M. Volpi[86], G. Volpini[89a], H. von der Schmitt[99], J. von Loeben[99], H. von Radziewski[48], E. von Toerne[20], V. Vorobel[126], V. Vorwerk[11], M. Vos[167], R. Voss[29], T.T. Voss[175], J.H. Vossebeld[73], N. Vranjes[136], M. Vranjes Milosavljevic[105], V. Vrba[125], M. Vreeswijk[105], T. Vu Anh[48], R. Vuillermet[29], I. Vukotic[115], W. Wagner[175], P. Wagner[120], H. Wahlen[175], S. Wahrmund[43], J. Wakabayashi[101], S. Walch[87], J. Walder[71], R. Walker[98], W. Walkowiak[141], R. Wall[176], P. Waller[73], C. Wang[44], H. Wang[173], H. Wang[32b,aj], J. Wang[151], J. Wang[55], R. Wang[103], S.M. Wang[151], T. Wang[20], A. Warburton[85], C.P. Ward[27], M. Warsinsky[48], A. Washbrook[45], C. Wasicki[41], P.M. Watkins[17], A.T. Watson[17], I.J. Watson[150], M.F. Watson[17], G. Watts[138], S. Watts[82], A.T. Waugh[150], B.M. Waugh[77], M. Weber[129], M.S. Weber[16], P. Weber[54], A.R. Weidberg[118], P. Weigell[99], J. Weingarten[54], C. Weiser[48], H. Wellenstein[22], P.S. Wells[29], T. Wenaus[24], D. Wendland[15], Z. Weng[151,w], T. Wengler[29], S. Wenig[29], N. Wermes[20], M. Werner[48], P. Werner[29], M. Werth[163], M. Wessels[58a], J. Wetter[161], C. Weydert[55], K. Whalen[28], S.J. Wheeler-Ellis[163], A. White[7], M.J. White[86], S. White[122a,122b], S.R. Whitehead[118], D. Whiteson[163], D. Whittington[60], F. Wicek[115], D. Wicke[175], F.J. Wickens[129], W. Wiedenmann[173], M. Wielers[129], P. Wienemann[20], C. Wiglesworth[75], L.A.M. Wiik-Fuchs[48], P.A. Wijeratne[77], A. Wildauer[167], M.A. Wildt[41,s], I. Wilhelm[126], H.G. Wilkens[29], J.Z. Will[98], E. Williams[34], H.H. Williams[120], W. Willis[34], S. Willocq[84], J.A. Wilson[17], M.G. Wilson[143], A. Wilson[87], I. Wingerter-Seez[4], S. Winkelmann[48], F. Winklmeier[29], M. Wittgen[143], S.J. Wollstadt[81], M.W. Wolter[38], H. Wolters[124a,h], W.C. Wong[40], G. Wooden[87], B.K. Wosiek[38], J. Wotschack[29], M.J. Woudstra[82], K.W. Wozniak[38], K. Wraight[53], C. Wright[53], M. Wright[53], B. Wrona[73], S.L. Wu[173], X. Wu[49], Y. Wu[32b,ak], E. Wulf[34], B.M. Wynne[45], S. Xella[35], M. Xiao[136], S. Xie[48], C. Xu[32b,z], D. Xu[139], B. Yabsley[150], S. Yacoob[145b], M. Yamada[65], H. Yamaguchi[155], A. Yamamoto[65], K. Yamamoto[63], S. Yamamoto[155], T. Yamamura[155], T. Yamanaka[155], J. Yamaoka[44], T. Yamazaki[155], Y. Yamazaki[66], Z. Yan[21], H. Yang[87], U.K. Yang[82], Y. Yang[60], Z. Yang[146a,146b], S. Yanush[91], L. Yao[32a], Y. Yao[14], Y. Yasu[65], G.V. Ybeles Smit[130], J. Ye[39], S. Ye[24], M. Yilmaz[3c], R. Yoosoofmiya[123], K. Yorita[171], R. Yoshida[5], C. Young[143], C.J. Young[118], S. Youssef[21], D. Yu[24], J. Yu[7], J. Yu[112], L. Yuan[66], A. Yurkewicz[106], B. Zabinski[38], R. Zaidan[62], A.M. Zaitsev[128], Z. Zajacova[29], L. Zanello[132a,132b], A. Zaytsev[107], C. Zeitnitz[175], M. Zeman[125], A. Zemla[38], C. Zendler[20], O. Zenin[128], T. Ženiš[144a], Z. Zinonos[122a,122b], S. Zenz[14], D. Zerwas[115], G. Zevi della Porta[57], Z. Zhan[32d], D. Zhang[32b,aj], H. Zhang[88], J. Zhang[5], X. Zhang[32d], Z. Zhang[115], L. Zhao[108], T. Zhao[138], Z. Zhao[32b], A. Zhemchugov[64], J. Zhong[118], B. Zhou[87], N. Zhou[163], Y. Zhou[151], C.G. Zhu[32d], H. Zhu[41], J. Zhu[87], Y. Zhu[32b], X. Zhuang[98], V. Zhuravlov[99], D. Zieminska[60], N.I. Zimin[64], R. Zimmermann[20], S. Zimmermann[20], S. Zimmermann[48], M. Ziolkowski[141], R. Zitoun[4], L. Živković[34], V.V. Zmouchko[128,*], G. Zobernig[173], A. Zoccoli[19a,19b], M. zur Nedden[15], V. Zutshi[106], L. Zwalinski[29].

[1] University at Albany, Albany NY, United States of America
[2] Department of Physics, University of Alberta, Edmonton AB, Canada
[3] (a)Department of Physics, Ankara University, Ankara; (b)Department of Physics, Dumlupinar University, Kutahya; (c)Department of Physics, Gazi University, Ankara; (d)Division of Physics, TOBB University of Economics and Technology, Ankara; (e)Turkish Atomic Energy Authority, Ankara, Turkey
[4] LAPP, CNRS/IN2P3 and Université de Savoie, Annecy-le-Vieux, France
[5] High Energy Physics Division, Argonne National Laboratory, Argonne IL, United States of America
[6] Department of Physics, University of Arizona, Tucson AZ, United States of America
[7] Department of Physics, The University of Texas at Arlington, Arlington TX, United States of America
[8] Physics Department, University of Athens, Athens, Greece
[9] Physics Department, National Technical University of Athens, Zografou, Greece
[10] Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan
[11] Institut de Física d'Altes Energies and Departament de Física de la Universitat Autònoma de Barcelona and ICREA, Barcelona, Spain
[12] (a)Institute of Physics, University of Belgrade, Belgrade; (b)Vinca Institute of Nuclear Sciences, University of Belgrade, Belgrade, Serbia
[13] Department for Physics and Technology, University of Bergen, Bergen, Norway
[14] Physics Division, Lawrence Berkeley National Laboratory and University of California, Berkeley CA, United States of America
[15] Department of Physics, Humboldt University, Berlin, Germany
[16] Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern, Switzerland
[17] School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom
[18] (a)Department of Physics, Bogazici University, Istanbul; (b)Division of Physics, Dogus University, Istanbul; (c)Department of Physics Engineering, Gaziantep University, Gaziantep; (d)Department of Physics, Istanbul Technical University, Istanbul, Turkey
[19] (a)INFN Sezione di Bologna; (b)Dipartimento di Fisica, Università di Bologna, Bologna, Italy
[20] Physikalisches Institut, University of Bonn, Bonn, Germany
[21] Department of Physics, Boston University, Boston MA, United States of America
[22] Department of Physics, Brandeis University, Waltham MA, United States of America
[23] (a)Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro; (b)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
[24] Physics Department, Brookhaven National Laboratory, Upton NY, United States of America
[25] (a)National Institute of Physics and Nuclear Engineering, Bucharest; (b)University Politehnica Bucharest, Bucharest; (c)West University in Timisoara, Timisoara, Romania
[26] Departamento de Física, Universidad de Buenos Aires, Buenos Aires, Argentina
[27] Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom
[28] Department of Physics, Carleton University, Ottawa ON, Canada
[29] CERN, Geneva, Switzerland
[30] Enrico Fermi Institute, University of Chicago, Chicago IL, United States of America
[31] (a)Departamento de Física, Pontificia Universidad Católica de Chile, Santiago; (b)Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile
[32] (a)Institute of High Energy Physics, Chinese Academy of Sciences, Beijing; (b)Department of Modern Physics, University of Science and Technology of China, Anhui; (c)Department of Physics, Nanjing University, Jiangsu; (d)School of Physics, Shandong University, Shandong, China
[33] Laboratoire de Physique Corpusculaire, Clermont Université and Université Blaise Pascal and CNRS/IN2P3, Aubiere Cedex, France
[34] Nevis Laboratory, Columbia University, Irvington NY, United States of America

[35] Niels Bohr Institute, University of Copenhagen, Kobenhavn, Denmark
[36] [(a)]INFN Gruppo Collegato di Cosenza; [(b)]Dipartimento di Fisica, Università della Calabria, Arcavata di Rende, Italy
[37] AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, Krakow, Poland
[38] The Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, Krakow, Poland
[39] Physics Department, Southern Methodist University, Dallas TX, United States of America
[40] Physics Department, University of Texas at Dallas, Richardson TX, United States of America
[41] DESY, Hamburg and Zeuthen, Germany
[42] Institut für Experimentelle Physik IV, Technische Universität Dortmund, Dortmund, Germany
[43] Institut für Kern- und Teilchenphysik, Technical University Dresden, Dresden, Germany
[44] Department of Physics, Duke University, Durham NC, United States of America
[45] SUPA - School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom
[46] Fachhochschule Wiener Neustadt, Johannes Gutenbergstrasse 3 2700 Wiener Neustadt, Austria
[47] INFN Laboratori Nazionali di Frascati, Frascati, Italy
[48] Fakultät für Mathematik und Physik, Albert-Ludwigs-Universität, Freiburg i.Br., Germany
[49] Section de Physique, Université de Genève, Geneva, Switzerland
[50] [(a)]INFN Sezione di Genova; [(b)]Dipartimento di Fisica, Università di Genova, Genova, Italy
[51] [(a)]E.Andronikashvili Institute of Physics, Tbilisi State University, Tbilisi; [(b)]High Energy Physics Institute, Tbilisi State University, Tbilisi, Georgia
[52] II Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen, Germany
[53] SUPA - School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom
[54] II Physikalisches Institut, Georg-August-Universität, Göttingen, Germany
[55] Laboratoire de Physique Subatomique et de Cosmologie, Université Joseph Fourier and CNRS/IN2P3 and Institut National Polytechnique de Grenoble, Grenoble, France
[56] Department of Physics, Hampton University, Hampton VA, United States of America
[57] Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge MA, United States of America
[58] [(a)]Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg; [(b)]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg; [(c)]ZITI Institut für technische Informatik, Ruprecht-Karls-Universität Heidelberg, Mannheim, Germany
[59] Faculty of Applied Information Science, Hiroshima Institute of Technology, Hiroshima, Japan
[60] Department of Physics, Indiana University, Bloomington IN, United States of America
[61] Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck, Austria
[62] University of Iowa, Iowa City IA, United States of America
[63] Department of Physics and Astronomy, Iowa State University, Ames IA, United States of America
[64] Joint Institute for Nuclear Research, JINR Dubna, Dubna, Russia
[65] KEK, High Energy Accelerator Research Organization, Tsukuba, Japan
[66] Graduate School of Science, Kobe University, Kobe, Japan
[67] Faculty of Science, Kyoto University, Kyoto, Japan
[68] Kyoto University of Education, Kyoto, Japan
[69] Department of Physics, Kyushu University, Fukuoka, Japan
[70] Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina
[71] Physics Department, Lancaster University, Lancaster, United Kingdom
[72] [(a)]INFN Sezione di Lecce; [(b)]Dipartimento di Matematica e Fisica, Università del Salento, Lecce, Italy
[73] Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom
[74] Department of Physics, Jožef Stefan Institute and University of Ljubljana, Ljubljana, Slovenia
[75] School of Physics and Astronomy, Queen Mary University of London, London, United Kingdom
[76] Department of Physics, Royal Holloway University of London, Surrey, United Kingdom
[77] Department of Physics and Astronomy, University College London, London, United Kingdom
[78] Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France
[79] Fysiska institutionen, Lunds universitet, Lund, Sweden
[80] Departamento de Fisica Teorica C-15, Universidad Autonoma de Madrid, Madrid, Spain

[81] Institut für Physik, Universität Mainz, Mainz, Germany
[82] School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom
[83] CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France
[84] Department of Physics, University of Massachusetts, Amherst MA, United States of America
[85] Department of Physics, McGill University, Montreal QC, Canada
[86] School of Physics, University of Melbourne, Victoria, Australia
[87] Department of Physics, The University of Michigan, Ann Arbor MI, United States of America
[88] Department of Physics and Astronomy, Michigan State University, East Lansing MI, United States of America
[89] (a)INFN Sezione di Milano; (b)Dipartimento di Fisica, Università di Milano, Milano, Italy
[90] B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Republic of Belarus
[91] National Scientific and Educational Centre for Particle and High Energy Physics, Minsk, Republic of Belarus
[92] Department of Physics, Massachusetts Institute of Technology, Cambridge MA, United States of America
[93] Group of Particle Physics, University of Montreal, Montreal QC, Canada
[94] P.N. Lebedev Institute of Physics, Academy of Sciences, Moscow, Russia
[95] Institute for Theoretical and Experimental Physics (ITEP), Moscow, Russia
[96] Moscow Engineering and Physics Institute (MEPhI), Moscow, Russia
[97] Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
[98] Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany
[99] Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany
[100] Nagasaki Institute of Applied Science, Nagasaki, Japan
[101] Graduate School of Science, Nagoya University, Nagoya, Japan
[102] (a)INFN Sezione di Napoli; (b)Dipartimento di Scienze Fisiche, Università di Napoli, Napoli, Italy
[103] Department of Physics and Astronomy, University of New Mexico, Albuquerque NM, United States of America
[104] Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands
[105] Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands
[106] Department of Physics, Northern Illinois University, DeKalb IL, United States of America
[107] Budker Institute of Nuclear Physics, SB RAS, Novosibirsk, Russia
[108] Department of Physics, New York University, New York NY, United States of America
[109] Ohio State University, Columbus OH, United States of America
[110] Faculty of Science, Okayama University, Okayama, Japan
[111] Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman OK, United States of America
[112] Department of Physics, Oklahoma State University, Stillwater OK, United States of America
[113] Palacký University, RCPTM, Olomouc, Czech Republic
[114] Center for High Energy Physics, University of Oregon, Eugene OR, United States of America
[115] LAL, Université Paris-Sud and CNRS/IN2P3, Orsay, France
[116] Graduate School of Science, Osaka University, Osaka, Japan
[117] Department of Physics, University of Oslo, Oslo, Norway
[118] Department of Physics, Oxford University, Oxford, United Kingdom
[119] (a)INFN Sezione di Pavia; (b)Dipartimento di Fisica, Università di Pavia, Pavia, Italy
[120] Department of Physics, University of Pennsylvania, Philadelphia PA, United States of America
[121] Petersburg Nuclear Physics Institute, Gatchina, Russia
[122] (a)INFN Sezione di Pisa; (b)Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy
[123] Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh PA, United States of America
[124] (a)Laboratorio de Instrumentacao e Fisica Experimental de Particulas - LIP, Lisboa, Portugal; (b)Departamento de Fisica Teorica y del Cosmos and CAFPE, Universidad de Granada, Granada, Spain
[125] Institute of Physics, Academy of Sciences of the Czech Republic, Praha, Czech Republic
[126] Faculty of Mathematics and Physics, Charles University in Prague, Praha, Czech Republic
[127] Czech Technical University in Prague, Praha, Czech Republic
[128] State Research Center Institute for High Energy Physics, Protvino, Russia
[129] Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom

[130] Physics Department, University of Regina, Regina SK, Canada
[131] Ritsumeikan University, Kusatsu, Shiga, Japan
[132] (a)INFN Sezione di Roma I; (b)Dipartimento di Fisica, Università La Sapienza, Roma, Italy
[133] (a)INFN Sezione di Roma Tor Vergata; (b)Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy
[134] (a)INFN Sezione di Roma Tre; (b)Dipartimento di Fisica, Università Roma Tre, Roma, Italy
[135] (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-Agdal, Rabat, Morocco
[136] DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l'Univers), CEA Saclay (Commissariat a l'Energie Atomique), Gif-sur-Yvette, France
[137] Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz CA, United States of America
[138] Department of Physics, University of Washington, Seattle WA, United States of America
[139] Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom
[140] Department of Physics, Shinshu University, Nagano, Japan
[141] Fachbereich Physik, Universität Siegen, Siegen, Germany
[142] Department of Physics, Simon Fraser University, Burnaby BC, Canada
[143] SLAC National Accelerator Laboratory, Stanford CA, United States of America
[144] (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
[145] (a)Department of Physics, University of Johannesburg, Johannesburg; (b)School of Physics, University of the Witwatersrand, Johannesburg, South Africa
[146] (a)Department of Physics, Stockholm University; (b)The Oskar Klein Centre, Stockholm, Sweden
[147] Physics Department, Royal Institute of Technology, Stockholm, Sweden
[148] Departments of Physics & Astronomy and Chemistry, Stony Brook University, Stony Brook NY, United States of America
[149] Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom
[150] School of Physics, University of Sydney, Sydney, Australia
[151] Institute of Physics, Academia Sinica, Taipei, Taiwan
[152] Department of Physics, Technion: Israel Institute of Technology, Haifa, Israel
[153] Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel
[154] Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece
[155] International Center for Elementary Particle Physics and Department of Physics, The University of Tokyo, Tokyo, Japan
[156] Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo, Japan
[157] Department of Physics, Tokyo Institute of Technology, Tokyo, Japan
[158] Department of Physics, University of Toronto, Toronto ON, Canada
[159] (a)TRIUMF, Vancouver BC; (b)Department of Physics and Astronomy, York University, Toronto ON, Canada
[160] Institute of Pure and Applied Sciences, University of Tsukuba,1-1-1 Tennodai,Tsukuba, Ibaraki 305-8571, Japan
[161] Science and Technology Center, Tufts University, Medford MA, United States of America
[162] Centro de Investigaciones, Universidad Antonio Narino, Bogota, Colombia
[163] Department of Physics and Astronomy, University of California Irvine, Irvine CA, United States of America
[164] (a)INFN Gruppo Collegato di Udine; (b)ICTP, Trieste; (c)Dipartimento di Chimica, Fisica e Ambiente, Università di Udine, Udine, Italy
[165] Department of Physics, University of Illinois, Urbana IL, United States of America
[166] Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden
[167] Instituto de Física Corpuscular (IFIC) and Departamento de Física Atómica, Molecular y Nuclear and Departamento de Ingeniería Electrónica and Instituto de Microelectrónica de Barcelona (IMB-CNM), University of Valencia and CSIC, Valencia, Spain

[168] Department of Physics, University of British Columbia, Vancouver BC, Canada
[169] Department of Physics and Astronomy, University of Victoria, Victoria BC, Canada
[170] Department of Physics, University of Warwick, Coventry, United Kingdom
[171] Waseda University, Tokyo, Japan
[172] Department of Particle Physics, The Weizmann Institute of Science, Rehovot, Israel
[173] Department of Physics, University of Wisconsin, Madison WI, United States of America
[174] Fakultät für Physik und Astronomie, Julius-Maximilians-Universität, Würzburg, Germany
[175] Fachbereich C Physik, Bergische Universität Wuppertal, Wuppertal, Germany
[176] Department of Physics, Yale University, New Haven CT, United States of America
[177] Yerevan Physics Institute, Yerevan, Armenia
[178] Domaine scientifique de la Doua, Centre de Calcul CNRS/IN2P3, Villeurbanne Cedex, France
[a] Also at Laboratorio de Instrumentacao e Fisica Experimental de Particulas - LIP, Lisboa, Portugal
[b] Also at Faculdade de Ciencias and CFNUL, Universidade de Lisboa, Lisboa, Portugal
[c] Also at Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom
[d] Also at TRIUMF, Vancouver BC, Canada
[e] Also at Department of Physics, California State University, Fresno CA, United States of America
[f] Also at Novosibirsk State University, Novosibirsk, Russia
[g] Also at Fermilab, Batavia IL, United States of America
[h] Also at Department of Physics, University of Coimbra, Coimbra, Portugal
[i] Also at Department of Physics, UASLP, San Luis Potosi, Mexico
[j] Also at Università di Napoli Parthenope, Napoli, Italy
[k] Also at Institute of Particle Physics (IPP), Canada
[l] Also at Department of Physics, Middle East Technical University, Ankara, Turkey
[m] Also at Louisiana Tech University, Ruston LA, United States of America
[n] Also at Dep Fisica and CEFITEC of Faculdade de Ciencias e Tecnologia, Universidade Nova de Lisboa, Caparica, Portugal
[o] Also at Department of Physics and Astronomy, University College London, London, United Kingdom
[p] Also at Group of Particle Physics, University of Montreal, Montreal QC, Canada
[q] Also at Department of Physics, University of Cape Town, Cape Town, South Africa
[r] Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan
[s] Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany
[t] Also at Manhattan College, New York NY, United States of America
[u] Also at School of Physics, Shandong University, Shandong, China
[v] Also at CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France
[w] Also at School of Physics and Engineering, Sun Yat-sen University, Guanzhou, China
[x] Also at Academia Sinica Grid Computing, Institute of Physics, Academia Sinica, Taipei, Taiwan
[y] Also at Dipartimento di Fisica, Università La Sapienza, Roma, Italy
[z] Also at DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l'Univers), CEA Saclay (Commissariat a l'Energie Atomique), Gif-sur-Yvette, France
[aa] Also at Section de Physique, Université de Genève, Geneva, Switzerland
[ab] Also at Departamento de Fisica, Universidade de Minho, Braga, Portugal
[ac] Also at Department of Physics and Astronomy, University of South Carolina, Columbia SC, United States of America
[ad] Also at Institute for Particle and Nuclear Physics, Wigner Research Centre for Physics, Budapest, Hungary
[ae] Also at California Institute of Technology, Pasadena CA, United States of America
[af] Also at Institute of Physics, Jagiellonian University, Krakow, Poland
[ag] Also at LAL, Université Paris-Sud and CNRS/IN2P3, Orsay, France
[ah] Also at Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom
[ai] Also at Department of Physics, Oxford University, Oxford, United Kingdom
[aj] Also at Institute of Physics, Academia Sinica, Taipei, Taiwan
[ak] Also at Department of Physics, The University of Michigan, Ann Arbor MI, United States of America
* Deceased