EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

CERN-PH-EP-2012-046
Submitted to: Physics Letters B

Search for TeV-scale Gravity Signatures in Final States with Leptons and Jets with the ATLAS Detector at $\sqrt{s}$ = 7 TeV

The ATLAS Collaboration

Abstract

The production of events with multiple high transverse momentum particles including charged leptons and jets is measured, using 1.04 fb^{-1} of proton-proton collision data recorded by the ATLAS detector during the first half of 2011 at $\sqrt{s} = 7$ TeV. No excess beyond Standard Model expectations is observed, and upper limits on the fiducial cross sections for non-Standard Model production of these final states are set. Using models for string ball and black hole production and decay, exclusion contours are determined as a function of mass threshold and the fundamental gravity scale.

Search for TeV-scale gravity signatures in final states with leptons and jets with the ATLAS detector at $\sqrt{s} = 7$ TeV

The ATLAS Collaboration

Abstract

The production of events with multiple high transverse momentum particles including charged leptons and jets is measured, using 1.04 fb^{-1} of proton-proton collision data recorded by the ATLAS detector during the first half of 2011 at $\sqrt{s} = 7$ TeV. No excess beyond Standard Model expectations is observed, and upper limits on the fiducial cross sections for non-Standard Model production of these final states are set. Using models for string ball and black hole production and decay, exclusion contours are determined as a function of mass threshold and the fundamental gravity scale.

1. Introduction

Models proposing extra spatial dimensions address the mass hierarchy problem, the origin of the sixteen orders of magnitude separation between the electroweak and Planck scales. These allow the gravitational field to propagate into the $(n + 4)$ dimensions, where n is the number of extra spatial dimensions, while Standard Model (SM) fields are constrained to lie in our four-dimensional brane. Consequently, the resulting Planck scale in $(n + 4)$ dimensions, M_{D}, is greatly diminished compared to the four-dimensional analogue, M_{Pl}, and should be near the other fundamental scale, the electroweak scale, if the hierarchy problem is to be addressed. Such low-scale gravity models allow the existence of gravitational states such as black holes and, within the context of weakly-coupled string theory, string balls, that could be produced with appreciable cross sections at the Large Hadron Collider (LHC).

Two such extra-dimensional scenarios are the Randall-Sundrum models [1] and the large, flat extra-dimensional ADD models [2, 3]. In the large extra dimension scenario, there are a number $n > 1$ of additional flat extra dimensions, and M_{D} is determined by the volume and shape of the extra dimensions. Within the context of this model, experimental lower limits on the value of M_{D} have been obtained from experiments at LEP [4] and the Tevatron [5, 6], as well as at ATLAS [7, 8] and CMS [9], by searching for production of the heavy Kaluza-Klein gravitons associated with the extra dimensions. The most stringent limits [7] come from the LHC analyses that search for non-interacting gravitons recoiling against a single jet (monojet and large missing transverse energy), and range from $M_{\mathrm{D}} > 2.0$ TeV, for $n = 6$, to $M_{\mathrm{D}} > 3.2$ TeV, for $n = 2$. Due to the greatly enhanced strength of gravitational interactions at short distances, or high energies, the formation of gravitational states such as black holes or string balls at the LHC is another signature of extra dimensional models.

Large extra dimensions can be embedded into weakly-coupled string theory [10, 11]. In these models, black holes end their Hawking evaporation phase when their mass reaches a critical value $M_{\mathrm{S}}/g_{\mathrm{S}}^2$, also known as the correspondence point, where M_{S} and g_{S} are the string scale and coupling constant, respectively. At this point they transform into high-entropy string states – string balls – which, in turn, continue to decay thermally.

The semi-classical approximations used in the modelling of black hole production are valid only for partonic centre-of-mass energies well above M_{D}, motivating the use of a minimal threshold M_{TH} to remove contributions where the modelling is not reliable. The resulting black hole mass distribution ranges from this threshold up to $\sqrt{s}$. The precise mass value above which the production of such high multiplicity states is feasible is uncertain. A conservative interpretation [12, 13] is that $M_{\mathrm{TH}} > 3M_{\mathrm{S}}$ for string balls and $M_{\mathrm{TH}} > 5M_{\mathrm{D}}$ for black holes.

Thermal radiation is thought to be emitted by black holes due to quantum effects [14]. A black hole, in $(n+4)$ dimensions, of given mass and angular momentum is characterised by a Hawking temperature, which is higher for a lighter, or more strongly rotating, black hole. Grey-body factors modify the spectrum of emitted particles from that of a perfect thermal black body [15], by quantifying the transmission probability through the curved space-time outside the horizon; these emissivities depend upon particle spin, n and the properties of the black hole. All Standard Model particles are emitted.

As the black hole mass approaches the Planck scale and few further emissions are expected, quantum effects become important and classical evaporation is no longer a suitable description. The remaining black hole remnant is decayed to a small number of SM particles[1].

[1] This paper considers both high multiplicity, generated by the BlackMax burst model or the Charybdis variable multiplicity decay with a four-body average, and low multiplicity decays to two bodies.

Were black hole states[2] to be produced at the LHC, they would decay to final states with a relatively high multiplicity of high-p_{T} particles, most commonly jets. While the multiplicity is generally high, the exact spectrum is rather model dependent: for example, the inclusion of black hole rotation leads to a somewhat lower multiplicity of higher energy emissions [16]. One of the few more robust predictions of these models is the expectation that particles are produced approximately according to their degrees of freedom, (with some modification by the relative emissivities). This is the "democratic" or "universal" coupling of gravity. Thus, the probability for the production of a leptonic final state varies primarily with the emission multiplicity, which depends upon model parameters and the remnant state treatment. Nonetheless, this multiplicity dependence is much reduced compared to using the multiplicity directly, for even low multiplicity decays will frequently contain a lepton. Hence, these models predict the existence of at least one high-p_{T} lepton[3] in a significant fraction ($\sim 15-50$ %) of final states for black holes or string balls with M_{D} and M_{TH} values in the range accessible to LHC experiments and not already excluded. The largest theoretical uncertainties in the modelling of these states are the limited knowledge of gravitational radiation and the resultant cross section during the formation phase, and the uncertainties of the decay process as the black hole mass approaches M_D, especially the treatment of the remnant state.

Searches for these gravitational states have previously been performed by investigating final states with multiple high-p_{T} objects [17], high-p_{T} jets only, and in dimuon events [8]. This analysis searches for an excess of multi-object events produced at high $\sum p_{\mathrm{T}}$, defined as the scalar sum of p_{T} of the reconstructed objects selected (hadronic jets, electrons and muons). Only events containing at least one isolated electron or muon are selected. While jets should dominate the decays of black holes, the rate for lepton production is anticipated to be sizable, as noted above. Additionally, the requirement of a high-p_{T} lepton significantly reduces the dominant multi-jet background, whilst maintaining a high efficiency for black hole events.

This search considers final states with three or more selected objects (leptons or jets), and consequently is not sensitive to two-body final states, as predicted in so-called quantum black hole states [18]. Results for two-body final states can be found in Ref. [19].

2. The ATLAS Detector

The ATLAS detector [20] is a multipurpose particle physics apparatus with a forward-backward symmetric cylindrical geometry and nearly 4π coverage in solid angle[4]. The layout of the detector is dominated by four superconducting magnet systems, which comprise a thin solenoid surrounding inner tracking detectors and three large toroids, each consisting of eight coils. The inner detector consists of a silicon pixel detector, a silicon microstrip detector (SCT) and a transition radiation tracker (TRT). In the pseudorapidity region $|\eta| < 3.2$, high-granularity liquid-argon (LAr) electromagnetic (EM) sampling calorimeters are used. An iron-scintillator tile calorimeter provides coverage for hadronic showers over $|\eta| < 1.7$. The end-cap and forward regions, spanning $1.5 < |\eta| < 4.9$, are instrumented with LAr calorimetry for both EM and hadronic measurements. The muon spectrometer surrounds these, and comprises a system of precision tracking chambers, and detectors for triggering.

3. Trigger and Data Selection

The data used in this analysis were recorded between March and July in 2011, with the LHC operating at a centre-of-mass energy of 7 TeV. The integrated luminosity is 1.04 fb^{-1}, with an uncertainty of 3.7% [21, 22].

Events are required to pass either a single electron or a single muon trigger, for the electron and muon channels, respectively. The electron (muon) trigger threshold lies at transverse energy, $E_{\mathrm{T}} = 20$ GeV ($p_{\mathrm{T}} = 18$ GeV). The trigger efficiencies reach the plateau region for lepton transverse momenta values substantially below the minimum analysis threshold of 40 GeV, with typical trigger efficiencies for leptons selected for offline analysis of: 96% for electrons [23], 75% for muons with $|\eta| < 1.05$ and 88% for muons with $1.05 < |\eta| < 2.0$ [24].

4. Monte Carlo Simulation

Monte Carlo (MC) simulated event samples are used to develop and validate the analysis procedure, to help estimate the SM backgrounds in the signal region and to investigate specific signal models. Jets produced via QCD processes are generated with Pythia [25], using the MRST2007LO* modified leading-order parton distribution functions (PDF) [26], which are used with all leading-order (LO) Monte Carlo generators. The production of top quark pairs and of single top quarks is simulated with MC@NLO [27] (with a top quark mass of 172.5 GeV) and the next-to-leading order (NLO) PDF set CTEQ6.6 [28], which is used with all NLO MC generators. Samples of W and Z/γ^* Monte Carlo events with accompanying jets are produced with Alpgen [29], using the CTEQ6L1

[2]In this Letter, all references to black holes also apply to string balls, unless otherwise stated.

[3]Throughout this Letter "lepton" denotes electrons and muons only.

[4] ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point in the centre of the detector and the z-axis along the beam pipe. Cylindrical coordinates (r, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the beam pipe. The pseudorapidity η is defined in terms of the polar angle θ by $\eta = -\ln\tan(\theta/2)$.

PDFs [30], and events generated with SHERPA [31] are used to assess the systematic uncertainty associated with the choice of MC generator. Diboson (WW, WZ, ZZ) production is simulated with HERWIG [32]. Fragmentation and hadronisation for the ALPGEN and MC@NLO samples are performed with HERWIG, using JIMMY [33] for the underlying event. All MC samples are produced using a specific ATLAS parameter tune [34] and the ATLAS full GEANT4 [35] detector simulation [36]. The MC samples are produced with a simulation of multiple interactions per LHC bunch crossing (pile-up). Different pile-up conditions as a function of the LHC instantaneous luminosity are taken into account by reweighting MC events according to the number of interactions observed in the data, which has a mean of about six.

Signal samples are generated with the CHARYBDIS [16] and BLACKMAX [37, 38] generators. The shower evolution and hadronisation uses PYTHIA, with the CTEQ6.6 PDF sets using the black hole mass as the QCD scale. No radiation losses in the formation phase are modelled. The CHARYBDIS samples are generated with both low and high multiplicity remnants, whilst the BLACKMAX samples use the final burst remnant model, which gives high multiplicity remnant states [37]. The high multiplicity options of both generators produce concordant distributions. Samples are generated for both rotating and non-rotating black holes for six extra dimensions. Focus is placed on models with six extra dimensions due to the less stringent limits on M_{D}. String ball samples are produced with CHARYBDIS for both rotating and non-rotating cases, for six extra dimensions, and a string coupling, g_{S}, of 0.4. For each benchmark model, samples are generated with M_{D} (M_{S} for string ball models) varying from 0.5–2.5 TeV and M_{TH} from 3–5 TeV.

5. Object Reconstruction

Electrons are reconstructed from clusters in the electromagnetic calorimeter matched to a track in the inner detector [23]. A set of electron identification criteria based on the calorimeter shower shape, track quality and track matching with the calorimeter cluster are described in Ref. [39] and are referred to as "loose", "medium" and "tight". Electrons are required to have $p_{\mathrm{T}} > 40$ GeV, $|\eta| < 2.47$ and to pass the "medium" electron definition. Electron candidates are required to be isolated: the sum of the transverse energy deposited within a cone of size $\Delta R < 0.2$ around the electron candidate (corrected for transverse shower leakage and pile-up from additional pp collisions) is required to be less than 10% of the electron p_{T}. Electrons with a distance to the closest jet of $0.2 < \Delta R < 0.4$ are discarded, where $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$.

Muon candidates are selected from a combined track in the muon spectrometer and in the inner detector. Muons are required to have $p_{\mathrm{T}} > 40$ GeV. Muon candidates are required to have an associated inner detector track with sufficient hits in the pixel, SCT and TRT detectors to ensure a good measurement. Additional requirements are made on the muon system hits in order to guarantee the best possible resolution at high p_{T}: muon candidates must have hits in at least three precision layers and no hits in detector regions with more limited alignment precision. These requirements effectively restrict the muon acceptance to the barrel region ($|\eta| < 1.0$) and a portion of the end-cap region ($1.3 < |\eta| < 2.0$) [40]. Muons with a distance to the closest jet of $\Delta R < 0.4$ are discarded. In order to reject muons resulting from cosmic rays, requirements are placed on the distance of each muon track from a reconstructed primary vertex (PV): $|z_0| < 1$ mm and $|d_0| < 0.2$ mm, where z_0 and d_0 are the impact parameters of each muon in the longitudinal and transverse planes, respectively. Muons must be isolated: the p_{T} sum of tracks within a cone of $\Delta R < 0.3$ around the muon candidate is required to be less than 5% of the muon p_{T}.

Jets are reconstructed using the anti-k_t jet clustering algorithm [41] with a distance parameter R of 0.4. The inputs to the jet algorithm are clusters seeded from calorimeter cells with energy deposits significantly above the measured noise [42]. Jets are corrected for effects from calorimeter non-compensation and inhomogeneities through the use of p_{T}- and η-dependent calibration factors based on Monte Carlo corrections validated with test-beam and collision data [43]. This calibration corresponds to the scale that would be obtained applying the jet algorithm to stable particles at the primary collision vertex. Selected jets are required to have $p_{\mathrm{T}} > 40$ GeV and $|\eta| < 2.8$. Events with jets failing jet quality criteria against noise and non-collision backgrounds are rejected [44]. Jets within a distance $\Delta R < 0.2$ of a selected electron are also rejected.

6. Event Selection

Events are required to have a reconstructed primary vertex associated with at least five tracks. During the data-taking period considered, a readout failure in the LAr barrel calorimeter resulted in a small "dead" region, in which up to 30% of the incident jet energy may be lost. Should any of the four leading jets with $p_{\mathrm{T}} > 40$ GeV fall into this region, the event is vetoed. This is applied consistently to all data and Monte Carlo events, and results in a loss of signal efficiency of $\sim 15 - 20\%$ for the models considered. Additionally, electrons incident on this region are discarded. Selected events contain at least one high-p_{T} (> 40 GeV) isolated lepton. Two statistically independent samples are defined by separating events for which the leading lepton (that of highest p_{T}) is an electron (muon) into an electron (muon) channel sample.

High multiplicity final states of interest can be separated from Standard Model background events using the

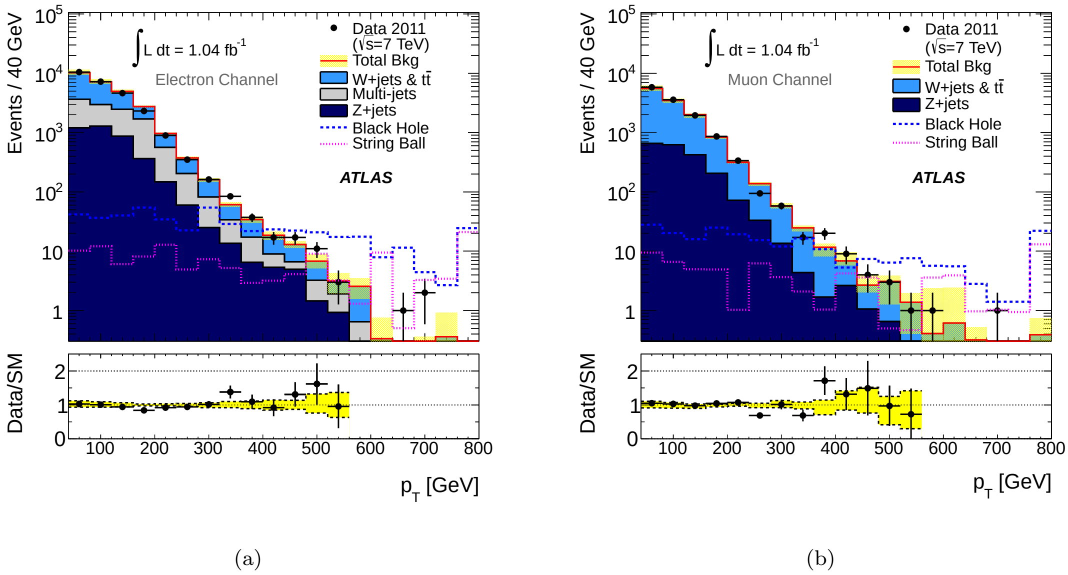


Figure 1: The transverse momentum distributions of the highest momentum lepton, after event preselection, in electron (a) and muon (b) channels. The Monte Carlo distributions are rescaled to be in agreement with data in selected control regions. The lower panels show the ratio of the data to the expected background (points) and the uncertainty (shaded band). The shaded band in each panel indicates the total uncertainty on the expectation from the finite size of event samples, jet and lepton energy scales and resolutions. Two representative signal distributions are overlaid for comparison purposes. The signal labelled "Black Hole" is a non-rotating black hole sample with $n = 6$, $M_{\mathrm{D}} = 0.8$ TeV and $M_{\mathrm{TH}} = 4$ TeV. The signal labelled "String Ball" is a rotating string ball sample with $n = 6$, $M_{\mathrm{D}} = 1.26$ TeV, $M_{\mathrm{S}} = 1$ TeV and $M_{\mathrm{TH}} = 3$ TeV. Both signal samples were generated with the CHARYBDIS generator. The final histogram bin shows the integral of all events with $p_{\mathrm{T}} \geq 760$ GeV.

quantity:

$$\sum p_{\mathrm{T}} = \sum_{i=\mathrm{objects}} p_{\mathrm{T},i} \,, \qquad (1)$$

which is the scalar sum of the transverse momenta of the selected final state reconstructed objects (leptons and jets), described in Section 5. The signal, containing multiple high-p_{T} leptons and jets, manifests itself at high $\sum p_{\mathrm{T}}$.

The missing transverse momentum $E_{\mathrm{T}}^{\mathrm{miss}}$ is defined as the opposite of the vectorial p_{T} sum of reconstructed objects in the event, comprising selected leptons, jets with $p_{\mathrm{T}} > 20$ GeV, any additional identified non-isolated muons, and calorimeter clusters not belonging to any of the aforementioned object types. Although $E_{\mathrm{T}}^{\mathrm{miss}}$ is not considered as an object in this analysis, it is used in the definitions of regions for background estimation.

Preselection requirements are used to select a sample of events with similar kinematics and composition to the signal regions for this search, described later in this Section, but with lower p_{T} thresholds for selected objects. Events are required to have at least three selected objects passing the 40 GeV p_{T} threshold, with at least one lepton, and have a moderate requirement of $\sum p_{\mathrm{T}} > 300$ GeV. Additionally, the electron channel requires the leading electron to pass the "tight" selection. Figure 1 shows the transverse momentum of the leading lepton after event preselection for electron and muon channels, where the background distributions have been normalised to be in agreement with data in selected control regions, as described in Section 7.

For the signal region, the $\sum p_{\mathrm{T}}$, lepton and jet p_{T} requirements are raised further. Events are required to contain at least three reconstructed objects with $p_{\mathrm{T}} > 100$ GeV, at least one of which must be a lepton. These events are required to have a minimum $\sum p_{\mathrm{T}}$ of 700 GeV. To determine limits on the cross section for the signal production of these final states, this threshold is varied between 700 and 1500 GeV. In making exclusion contours in the M_{D}-M_{TH} plane, using the benchmark models described in Section 4, a single signal region is used, defined by a $\sum p_{\mathrm{T}} > 1500$ GeV requirement.

7. Background Estimation

The backgrounds are estimated using a combination of data-driven and MC-based techniques. The dominant Standard Model sources of background are: W+jets, Z/γ^*+jets, $t\bar{t}$ and other non-$t\bar{t}$ multi-jet processes, subsequently referred to as multi-jet events. In W+jets, Z/γ^*+jets and $t\bar{t}$ processes, events are produced with real leptons, and associated additional high-p_{T} jets. In multi-jet events, reconstructed high-p_{T} leptons are present either due to the production of a real lepton within a jet, via semileptonic quark decays (dominantly heavy flavour decays), or due to a jet being misreconstructed from calorimeter clusters as a high-p_{T} electron. These are denoted as fake leptons while those originating from τ-leptons or heavy gauge bosons are referred to as prompt leptons.

The contribution to the muon channel signal region from multi-jets is predicted to be negligible by MC simulations, cross-checked with data using a non-isolated muon sample with the yield extrapolated to the signal region criteria. The multi-jet contribution to the electron channel is estimated using a data-driven matrix method, described in detail in Ref. [45]. Using the signal region definition, a multi-jet enhanced region is defined by loosening the electron identification criterion used in the event selection from "tight" to "medium".

The numbers of data events in this looser electron sample which pass ($N_{\rm pass}$) and fail ($N_{\rm fail}$) the final, tighter lepton selection criteria are counted. $N_{\rm prompt}$ and $N_{\rm fake}$ are defined as the numbers of events for which the electrons are prompt and fake, respectively. The following relationships hold:

$$N_{\rm pass} = \epsilon_{\rm prompt} N_{\rm prompt} + \epsilon_{\rm fake} N_{\rm fake}, \quad (2)$$

$$N_{\rm fail} = (1 - \epsilon_{\rm prompt}) N_{\rm prompt} + (1 - \epsilon_{\rm fake}) N_{\rm fake}. \quad (3)$$

Simultaneous solution of these two equations gives a prediction for the number of events in data in the signal region which are events with fake leptons:

$$N^{\rm pass}_{\rm fake} = \epsilon_{\rm fake} N_{\rm fake} = \frac{N_{\rm fail} - (1/\epsilon_{\rm prompt} - 1) N_{\rm pass}}{1/\epsilon_{\rm fake} - 1/\epsilon_{\rm prompt}} \ . \quad (4)$$

The efficiency $\epsilon_{\rm fake}$ is determined from a multi-jet dominated data control region defined by $300 < \sum p_{\rm T} < 700$ GeV and $E_{\rm T}^{\rm miss} < 15$ GeV, in which events must have at least three reconstructed objects passing preselection criteria, in the electron channel. This region is also considered with the electron criterion loosened to "medium". The efficiency for identifying fakes as prompt electrons is measured as the fraction of these events which also pass the tighter electron identification requirement. The MC simulations are used to correct the efficiency for the small fraction ($< 10\%$) of prompt leptons. No dependence on lepton $p_{\rm T}$, $\sum p_{\rm T}$ or the choice of maximum $E_{\rm T}^{\rm miss}$ used to define the control region is observed.

The efficiency $\epsilon_{\rm prompt}$ is evaluated in a second control region, again containing at least three preselected objects, but with at least two opposite-sign electrons satisfying $80 < m_{\ell\ell} < 100$ GeV, where $m_{\ell\ell}$ denotes the dilepton invariant mass. The efficiency for identifying prompt electrons is obtained through the ratio of "medium-medium" to "medium-tight" events in this high purity control region.

The numbers of Z/γ^*+jets events in the signal region for each channel are estimated by measuring the ratio of the number of events in data to that in MC simulation in a control region with: two opposite-sign leptons (two electrons or two muons) with $80 < m_{\ell\ell} < 100$ GeV, at least three preselected objects and $300 < \sum p_{\rm T} < 700$ GeV. This ratio is a scaling factor that is then used to rescale the pure MC prediction (normalised to the next-to-next-to-leading order (NNLO) cross section) in the signal region. The factors derived agree with unity to within the experimental uncertainty.

The numbers of W+jets and $t\bar{t}$ events in the signal region is estimated in a similar fashion, by defining a control region containing events with: exactly one electron (or muon, separately), with $40 < m_{\rm T} < 100$ GeV, where $m_{\rm T}$ is the transverse mass, calculated from the lepton transverse momentum vector, $\vec{p}_{\rm T}^{\,\ell}$, and the missing transverse momentum vector, $\vec{p}_{\rm T}^{\rm \,miss}$:

$$m_{\rm T} = \sqrt{2 \cdot p_{\rm T}^{\ell} \cdot E_{\rm T}^{\rm miss} \cdot (1 - \cos(\Delta\phi(\vec{p}_{\rm T}^{\,\ell}, \vec{p}_{\rm T}^{\rm \,miss})))} \ , \quad (5)$$

with $30 < E_{\rm T}^{\rm miss} < 60$ GeV, at least three preselected objects and $300 < \sum p_{\rm T} < 700$ GeV. Due to their similar behaviour in $\sum p_{\rm T}$, W+jets and $t\bar{t}$ events are treated as a single background; a scaling factor is derived and used to rescale the pure MC prediction (normalised to the NNLO cross section) in the signal region. The factors derived are consistent with unity to within the experimental uncertainty.

8. Systematic Uncertainties

In this analysis, the dominant sources of systematic uncertainty on the estimated background event rates are: choice of the control regions used to derive the background estimates (for the multi-jet and Z+jets backgrounds), MC modelling uncertainties assessed using alternative samples produced with different generators (for the Z+jets, W+jets and $t\bar{t}$ backgrounds) and the jet energy scale (JES). Other uncertainties include those on the jet energy resolution (JER), lepton reconstruction and identification, PDF uncertainties, the finite size of event samples in the control regions and the uncertainties in the effects of initial and final-state radiation. For the Z+jets, W+jets and $t\bar{t}$ backgrounds the use of a control region in data to renormalise the MC predictions, as described in Section 7, mitigates the effects of most of the systematic uncertainties, which act primarily to vary the overall magnitude of the predicted backgrounds, rather than their shapes. For the background estimates of Z+jets, W+jets and $t\bar{t}$ processes, the dominant uncertainties are those associated with the extrapolation of the background shape to the signal region, followed by the jet energy scale. The sizes of the systematic uncertainties described above vary, depending on the channel and on the $\sum p_{\rm T}$ range of the signal region, but are typically $15-20\%$, except for the highest $\sum p_{\rm T}$ bins in which the MC event samples are smaller leading to larger statistical fluctuations. These are summarised in Tables 1 and 2.

The JES and JER uncertainties are applied to Monte Carlo simulated jets, and are propagated throughout the analysis to assess their effect. The JES uncertainties applied were measured using the complete 2010 dataset and

$\sum p_T$ (GeV)	Multi-jets	W+jets/$t\bar{t}$	Z+jets	Total SM	Data
> 700	$137 \pm 10 \pm 45$	$371 \pm 10 \pm 77$	$119 \pm 4 \pm 22$	$627 \pm 15 \pm 92$	586
> 800	$75 \pm 7 \pm 25$	$210 \pm 6 \pm 42$	$74 \pm 4 \pm 13$	$358 \pm 10 \pm 51$	348
> 900	$42 \pm 5 \pm 14$	$122 \pm 5 \pm 28$	$46.9 \pm 2.8 \pm 8.6$	$210 \pm 8 \pm 33$	196
> 1000	$24.6 \pm 4.2 \pm 8.0$	$73 \pm 3 \pm 17$	$22.2 \pm 1.8 \pm 4.5$	$119 \pm 5 \pm 20$	113
> 1200	$8.1 \pm 2.5 \pm 2.7$	$28.5 \pm 1.8 \pm 7.6$	$9.1 \pm 1.0 \pm 1.9$	$45.7 \pm 3.2 \pm 8.3$	41
> 1500	$1.3 \pm 1.1 \pm 0.4$	$6.3 \pm 0.8 \pm 2.5$	$2.6 \pm 0.5 \pm 0.5$	$10.2 \pm 1.4 \pm 2.6$	8

Table 1: Background estimation summary as a function of $\sum p_T$ in the electron channel, using the methods described in the main body of this Letter, compared to data. The first quoted errors are statistical, the second systematic. All other backgrounds considered (WW, ZZ and WZ) are estimated to have negligible contributions.

$\sum p_T$ (GeV)	W+jets/$t\bar{t}$	Z+jets	Total SM	Data
> 700	$236 \pm 7 \pm 43$	$49 \pm 3 \pm 11$	$285 \pm 8 \pm 44$	241
> 800	$129 \pm 4 \pm 25$	$32.0 \pm 2.4 \pm 7.5$	$161 \pm 5 \pm 26$	145
> 900	$71 \pm 3 \pm 16$	$19.5 \pm 1.7 \pm 5.0$	$91 \pm 3 \pm 16$	78
> 1000	$38.9 \pm 2.3 \pm 8.3$	$13.1 \pm 1.3 \pm 3.1$	$52.0 \pm 2.6 \pm 8.9$	46
> 1200	$9.9 \pm 1.2 \pm 3.6$	$4.0 \pm 0.6 \pm 1.2$	$14.0 \pm 1.3 \pm 3.8$	15
> 1500	$2.2 \pm 0.5 \pm 1.1$	$0.6 \pm 0.2 \pm 0.4$	$2.8 \pm 0.5 \pm 1.1$	2

Table 2: Background estimation summary as a function of $\sum p_T$ in the muon channel, using the methods described in the main body of this Letter, compared to data. The first quoted errors are statistical, the second systematic. All other backgrounds considered (WW, ZZ, WZ and multi-jet processes) are estimated to have negligible contributions.

the techniques described in Ref. [44]. The JER measured with 2010 data [44] is applied to all Monte Carlo simulated jets, with the difference between the nominal and recalibrated values taken as the systematic uncertainty. Additional contributions are added to both of these uncertainties to account for the effect of high luminosity pile-up in the 2011 run. The effect of pile-up on other analysis-level distributions was investigated and found to be negligible, as expected from the high-p_T objects populating the signal region.

9. Results and Interpretation

The observed and predicted event yields, following the estimations described in Section 7, are given in Tables 1 and 2, as a function of minimum $\sum p_T$. The distribution of $\sum p_T$ is shown in Figure 2, along with the distribution of the highest-p_T lepton or jet.

The SM background estimates are in good agreement with the observed data, for all choices of $\sum p_T$ threshold. No excess is observed beyond the Standard Model expectation; p-values for the background-only hypothesis in the signal regions are in the range 0.43 – 0.47. Therefore, model-independent exclusion limits are determined on the fiducial cross section for non-SM production of these final states, $\sigma(pp \to \ell X)$, as a function of minimum $\sum p_T$.

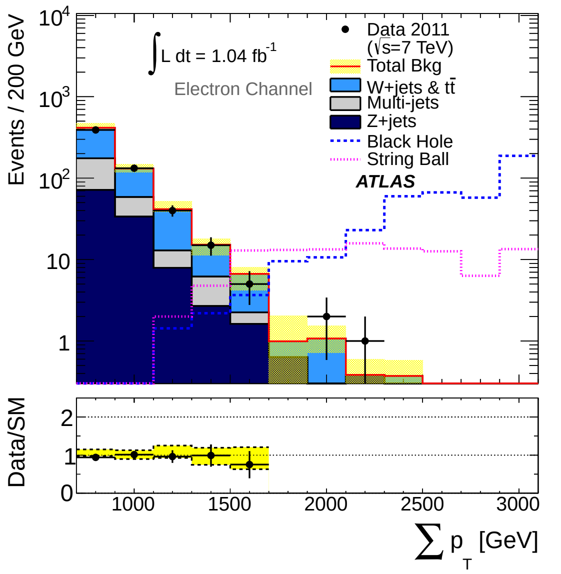
The translation from an upper limit on the number of events to a fiducial cross section requires knowledge of the mapping (or, equivalently, the selection efficiency), ϵ_{fid}, from the true signal production in the fiducial region to that reconstructed. The true fiducial region for the electron (muon) channel is defined from simulated events with final states that pass the following requirements at generator level: the leading lepton is a prompt electron (muon)[5] within the experimental acceptance described in Section 5, with $p_T > 100$ GeV and separated from jets with $p_T > 20$ GeV by ΔR(lepton,jet)> 0.4; at least two additional jets or isolated leptons with $p_T > 100$ GeV are present and $\sum p_T$ is above the respective signal region threshold. Jets are defined using the anti-k_t algorithm with $R = 0.4$ on stable particles.

For the models considered, ϵ_{fid} varies, and averages 63% for the electron channel, and 44% for the muon channel. The full range of ϵ_{fid} is 57–67% for the electron channel and 39–50% for the muon channel.

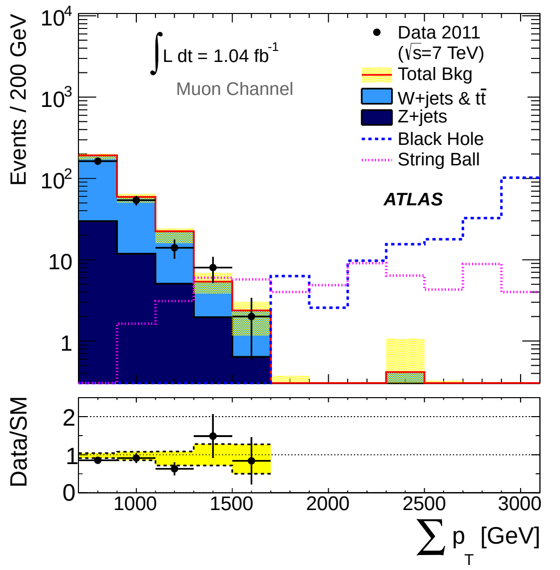
Under the assumption of equal *a priori* signal model production of electrons and muons, a combined limit can also be calculated: this is a limit on the fiducial cross section for all final states with at least one lepton (e or μ), for which ϵ_{fid} averages 57%, with a range from 50–61%.

For the derivation of the upper limits on the fiducial cross section, the lowest observed efficiency for each channel is used, for all signal regions. The corresponding observed and expected upper limits on the fiducial cross-section $\sigma(pp \to \ell X)$ at 95% confidence level are displayed in Figure 3 and Table 3. These exclusion regions are obtained using the CL_s prescription [46]. For $\sum p_T >$ 1.5 TeV, the observed (expected) 95% C.L. upper limit on the non-Standard Model fiducial cross section is 16.7 fb

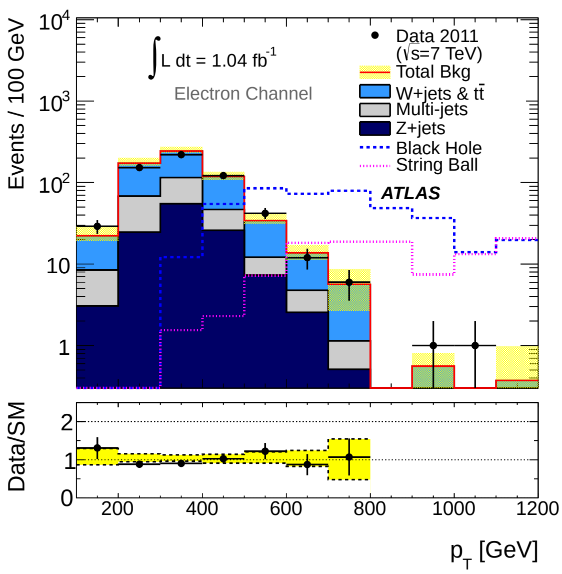
[5]Electrons (muons) originating from τ-leptons, heavy gauge bosons or directly from the black hole are considered to be prompt.



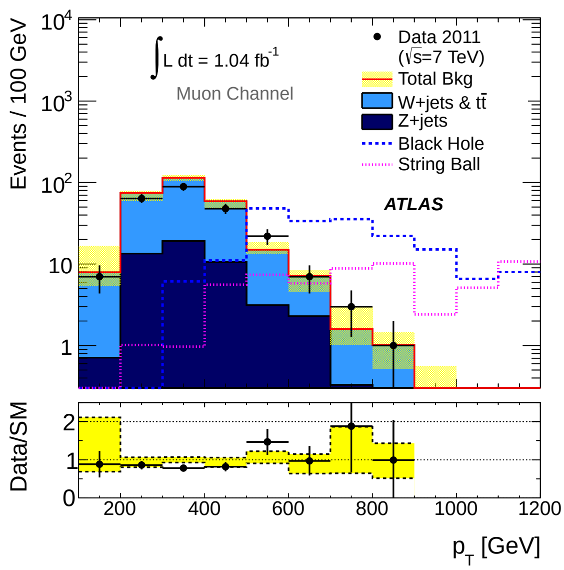
(a)



(b)



(c)



(d)

Figure 2: The distributions of $\sum p_{\mathrm{T}}$ (a), (b) and leading object p_{T} (c), (d) for the signal region in the electron (left) and muon (right) channels. The background processes are shown according to their data-derived estimates. The lower panels show the ratio of the data to the expected background (points) and the uncertainty (shaded band). The shaded band in each panel indicates the uncertainty on the expectation from the finite size of event samples, jet and lepton energy scales and resolutions. Two representative signal distributions are overlaid for comparison purposes. The signal labelled "Black Hole" is a non-rotating black hole sample with $n = 6$, $M_{\mathrm{D}} = 0.8$ TeV and $M_{\mathrm{TH}} = 4$ TeV. The signal labelled "String Ball" is a rotating string ball sample with $n = 6$, $M_{\mathrm{D}} = 1.26$ TeV, $M_{\mathrm{S}} = 1$ TeV and $M_{\mathrm{TH}} = 3$ TeV. The final histogram bin shows the integral of all events with $\sum p_{\mathrm{T}} \geq 2900$ GeV (a), (b) or $p_{\mathrm{T}} \geq 1100$ GeV (c), (d).

(20.4 fb) for final states containing at least one electron or muon.

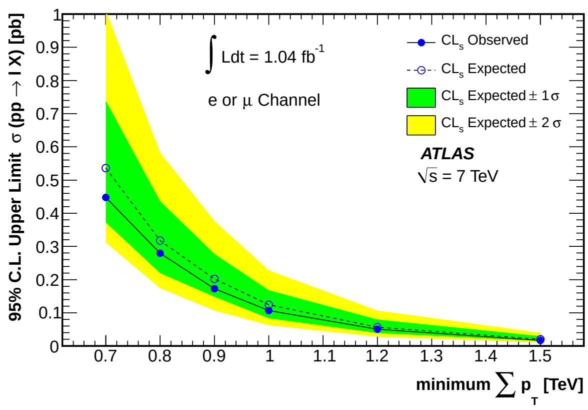


Figure 3: Upper limits on the fiducial cross sections $\sigma\,(pp \to \ell X)$ for the production of final states with at least three objects passing a 100 GeV $p_{\rm T}$ requirement including at least one isolated lepton, and $\sum p_{\rm T}$ above threshold, for all final states with at least one electron or muon. The observed and expected 95% C.L. limits according to the CL$_{\rm s}$ prescription are shown, as well as the 1σ and 2σ bounds on the expected limit.

$\sum p_{\rm T}$ (GeV)	$\sigma\,(pp \to \ell X)$ 95% C.L. Upper Limit (fb) Observed (Expected)		
	Electron Channel	Muon Channel	Channels Combined
> 700	282 (323)	166 (233)	448 (536)
> 800	179 (186)	117 (145)	279 (317)
> 900	108 (125)	72.6 (92.8)	173 (202)
> 1000	70.9 (78.5)	48.2 (58.2)	107 (124)
> 1200	33.5 (38.0)	31.0 (28.5)	51.0 (56.8)
> 1500	12.8 (15.4)	11.0 (12.3)	16.7 (20.4)

Table 3: The observed and expected 95% C.L. upper limits on the fiducial cross sections $\sigma\,(pp \to \ell X)$ for the production of final states with at least three objects passing a 100 GeV $p_{\rm T}$ requirement including at least one isolated lepton, and $\sum p_{\rm T}$ above threshold, for muon and electron channels separately, and for their combination (where $l = e$ or μ). The CL$_{\rm s}$ method is used to obtain the limits.

The expected and observed limits in the muon channel are slightly more stringent, due to the lower level of the SM background, in spite of the smaller efficiency and acceptance for the signal.

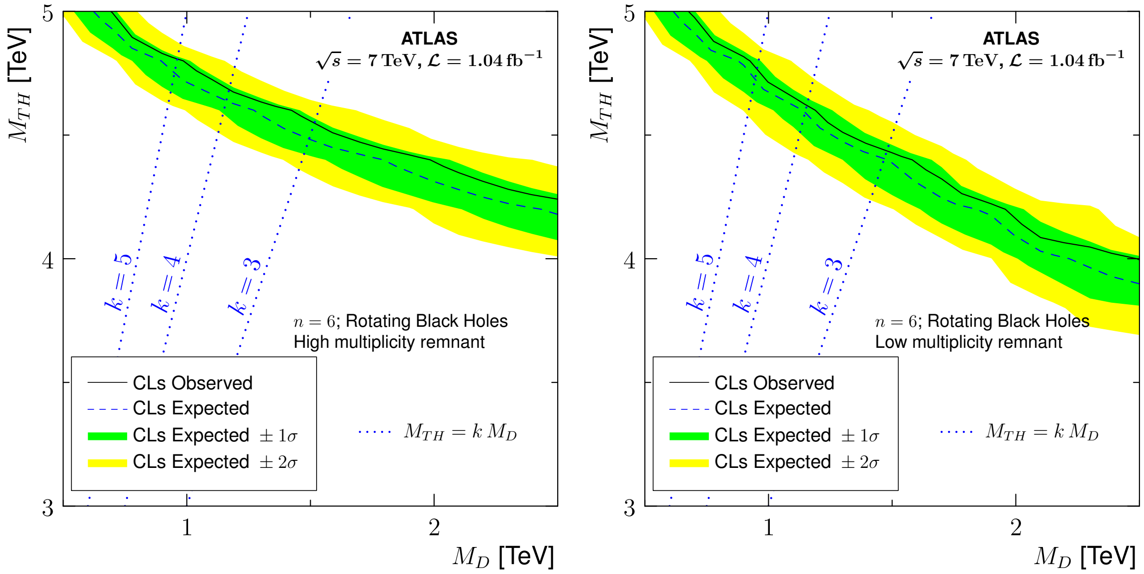
For the models considered, the total signal acceptance is highly model-dependent, driven primarily by the fraction of events containing a lepton in the final states, and averages about 10% and 5% for the (mutually exclusive) electron and muon channels respectively. It is lowest for the low multiplicity, low mass states (small values of $M_{\rm TH}/M_{\rm D}$, or $M_{\rm TH}$ and $M_{\rm D}$) that are theoretically or experimentally disfavoured.

The observed number of data events in the signal region (for $\sum p_{\rm T} > 1500$ GeV) along with the background expectations are used to obtain exclusion contours in the plane of $M_{\rm D}$ and $M_{\rm TH}$ for several benchmark-model gravitational states. No theoretical uncertainty on signal prediction is assessed; that is, the exclusion limits are set for the exact benchmark models as implemented in the BlackMax and Charybdis generators. In deriving the exclusion contours, the uncertainty in the integrated luminosity and the statistical and experimental systematic uncertainties in the signal acceptances are included, and are found to be less than 10% in total. Some of the theoretical uncertainties, such as the effects of black hole rotation, or spin, are discussed in Section 1. One of the more significant theoretical uncertainties is that associated with the decay of the state as its mass approaches $M_{\rm D}$. A common prescription is to end thermal emissions at a mass close to $M_{\rm D}$, at which point the state decays immediately to a remnant state, the multiplicity of which is uncertain. The efficiency of the event selection for searches for strong gravitational states could differ significantly according to the remnant model choice, particularly for samples in which a limited number of Hawking emissions are anticipated, motivating the consideration of multiple remnant models. The requirement of only three high-$p_{\rm T}$ objects for this analysis mitigates the dependence of the selection efficiency, and resulting cross section limits, on the modelling of the remnant decays.

The 95% exclusion contours in the $M_{\rm D}$-$M_{\rm TH}$ plane ($M_{\rm S}$-$M_{\rm TH}$ plane for string balls) for different models are obtained using the CL$_{\rm s}$ prescription. Figure 4 shows exclusion contours for rotating black hole benchmark models with high- and low-multiplicity remnant decays. Their comparison allows an assessment of the effect of this modelling uncertainty on the analysis, which is inevitably greatest in the regime of low $M_{\rm TH}/M_{\rm D}$. Limits for rotating and non-rotating string ball models are shown in Figure 5. The behaviour of the contours observed at high values of $M_{\rm TH}/M_{\rm S}$ are due to a step decrease in the gradient of the string ball cross section, $d\sigma_{\rm SB}/dM_{\rm S}$ above a value of $M_{\rm TH} = M_{\rm S}/g_S^2$. The string ball models illustrated were simulated using a high-multiplicity remnant model.

10. Summary

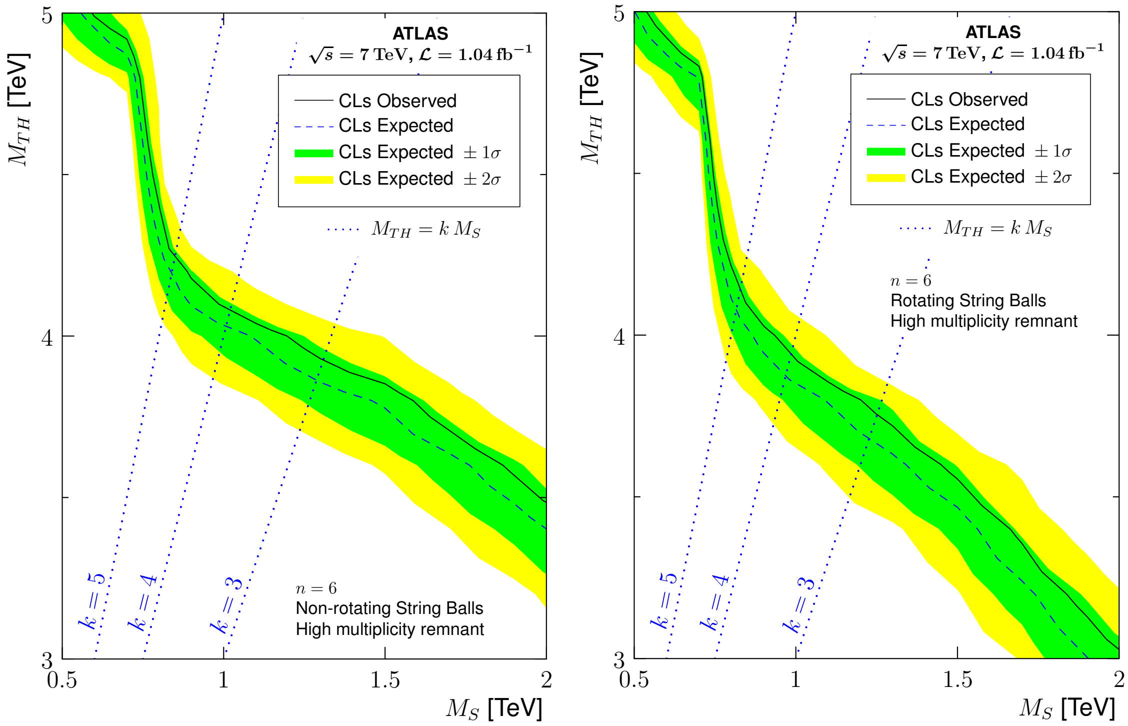
A search for microscopic black holes and string ball states in ATLAS using a total integrated luminosity of 1.04 fb^{-1} was presented. The search has considered final states with three or more high transverse momentum objects, at least one of which was required to be a lepton (electron or muon). No deviation from the Standard Model was observed in either the electron or the muon channels. Consequently, limits are set on TeV-scale gravity models, interpreted in a two-dimensional parameter grid of benchmark models in the $M_{\rm D}$-$M_{\rm TH}$ plane. Upper limits, at 95% C.L., are set on the fiducial cross-sections for new physics production of high-$\sum p_{\rm T}$ multi-object final states containing a high-$p_{\rm T}$ (> 100 GeV) isolated lepton



(a)

(b)

Figure 4: The exclusion limit in the M_{TH}-M_{D} plane, with electron and muon channels combined, for rotating black hole models with six extra dimensions. The black hole decays result in a high-multiplicity remnant state generated with BLACKMAX (a), and a low-multiplicity remnant state generated by CHARYBDIS (b). The solid (dashed) line shows the observed (expected) 95% C.L. limits, with the dark and light bands illustrating the expected 1σ and 2σ variations of the expected limits. The dotted lines indicate constant $k = M_{\mathrm{TH}}/M_{\mathrm{D}}$.



(a)

(b)

Figure 5: The exclusion limit in the M_{TH}-M_{S} plane, with electron and muon channels combined, for non-rotating (a) and rotating (b) string balls with six extra dimensions. The solid (dashed) line shows the observed (expected) 95% C.L. limits, with the dark and light bands the expected 1σ and 2σ variations of the expected limits. The dotted lines indicate constant $k = M_{\mathrm{TH}}/M_{\mathrm{S}}$. All samples were produced with the CHARYBDIS generator, using a high multiplicity remnant state.

within the experimental acceptance. For final states with $\sum p_{\mathrm{T}} > 1.5$ TeV, a limit of 16.7 fb is set.

11. 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] L. Randall and R. Sundrum, Phys. Rev. Lett. **83** (1999) 3370.
[2] N. Arkani-Hamed, S. Dimopoulos, and G. R. Dvali, Phys. Lett. B **429** (1998) 263.
[3] I. Antoniadis, N. Arkani-Hamed, S. Dimopoulos, and G. R. Dvali, Phys. Lett. B **436** (1998) 257.
[4] LEP Exotica Working Group, LEP Exotica WG 2004-03; ALEPH Collaboration, Eur. Phys. J. C **28** (2003) 1; DELPHI Collaboration, Eur. Phys. J. C **38** (2005) 395; L3 Collaboration, Phys. Lett. B **587** (2004) 16; OPAL Collaboration, Eur. Phys. J. C **18** (2000) 253.
[5] CDF Collaboration, Phys. Rev. Lett. **101** (2008) 181602.
[6] D0 Collaboration, Phys. Rev. Lett. **101** (2008) 011601.
[7] ATLAS Collaboration, Phys. Lett. B **705** (2011) 294.
[8] ATLAS Collaboration, Phys. Lett. B **709** (2012) 322.
[9] CMS Collaboration, Phys. Rev. Lett. **107** (2011) 201804.
[10] S. Dimopoulos and R. Emparan, Phys. Lett. B **526** (2002) 393.
[11] D. M. Gingrich and K. Martell, Phys. Rev. D. **78** (2008) 115009.
[12] L. A. Anchordoqui, J. L. Feng, H. Goldberg, and A. D. Shapere, Phys. Rev. D **65** (2002) 124027.
[13] D. M. Gingrich, Int. J. Mod. Phys. A **21** (2006) 6653.
[14] S. Hawking, Commun. Math. Phys. **43** (1975) 199.
[15] D. N. Page, Phys. Rev. D **13** (1976) 198.
[16] J. A. Frost et al., JHEP **10** (2009) 014.
[17] CMS Collaboration, Phys. Lett. B **697** (2011) 434.
[18] P. Meade and L. Randall, JHEP **05** (2008) 003.
[19] ATLAS Collaboration, New J. Phys. **13** (2011) 053044.
[20] ATLAS Collaboration, JINST **3** (2008) S08003.
[21] ATLAS Collaboration, ATLAS-CONF-2011-116, http://cdsweb.cern.ch/record/1376384/.
[22] ATLAS Collaboration, Eur. Phys. J. **C 71** (2011) 1630.
[23] ATLAS Collaboration, arXiv:1110.3174 (2011) [hep-ex], accepted by Eur. Phys. J. C.
[24] ATLAS Collaboration, ATLAS-CONF-2010-095, http://cdsweb.cern.ch/record/1299573/.
[25] T. Sjostrand, S. Mrenna, and P. Z. Skands, JHEP **05** (2006) 026.
[26] A. Sherstnev and R. S. Thorne, Eur. Phys. J. C **55** (2008) 553.
[27] S. Frixione and B. R. Webber, JHEP **06** (2002) 029; S. Frixione, P. Nason and B. R. Webber, JHEP **08** (2003) 007; S. Frixione, E. Laenen and P. Motylinski, JHEP **03** (2006) 092.
[28] P. M. Nadolsky et al., Phys. Rev. D **78** (2008) 013004.
[29] M. L. Mangano, M. Moretti, F. Piccinini, R. Pittau, and A. D. Polosa, JHEP **07** (2003) 001.
[30] J. Pumplin et al., JHEP **07** (2002) 012.
[31] T. Gleisberg et al., JHEP **02** (2004) 056.
[32] G. Corcella et al., JHEP **0101** (2001) 010.
[33] J. Butterworth, J. Forshaw, and M. Seymour, Z. Phys. C **72** (1996) 637.
[34] ATLAS Collaboration, ATL-PHYS-PUB-2011-008 .
[35] S. Agostinelli et al., Nucl. Instr. and Meth. A **506** (2003) 250.
[36] ATLAS Collaboration, Eur. Phys. J. C **70** (2010) 823.
[37] D.-C. Dai, G. Starkman, D. Stojkovic, C. Issever, E. Rizvi, and J. Tseng, Phys. Rev. D **77** (2008) 076007.
[38] D.-C. Dai, C. Issever, E. Rizvi, G. Starkman, D. Stojkovic, and J. Tseng. arXiv:0902.3577 [hep-ph].
[39] ATLAS Collaboration, JHEP **12** (2010) 060.
[40] ATLAS Collaboration, Phys. Lett. B **705** (2011) 28.
[41] M. Cacciari, G. P. Salam, and G. Soyez, JHEP **04** (2008) 063.
[42] ATLAS Collaboration, ATL-LARG-PUB-2008-002 .
[43] ATLAS Collaboration, ATLAS-CONF-2011-032, http://cdsweb.cern.ch/record/1337782/.
[44] ATLAS Collaboration. arXiv:1112.6426 (2011) [hep-ex], submitted to Eur. Phys. J. C.
[45] ATLAS Collaboration, Eur. Phys. J. C **71** (2011) 1.
[46] A. L. Read, J. Phys. G **28** (2002) 2693.

The ATLAS Collaboration

G. Aad[48], B. Abbott[110], J. Abdallah[11], A.A. Abdelalim[49], A. Abdesselam[117], O. Abdinov[10], B. Abi[111], M. Abolins[87], O.S. AbouZeid[157], H. Abramowicz[152], H. Abreu[114], E. Acerbi[88a,88b], B.S. Acharya[163a,163b], L. Adamczyk[37], D.L. Adams[24], T.N. Addy[56], J. Adelman[174], M. Aderholz[98], S. Adomeit[97], P. Adragna[74], T. Adye[128], S. Aefsky[22], J.A. Aguilar-Saavedra[123b,a], M. Aharrouche[80], S.P. Ahlen[21], F. Ahles[48], A. Ahmad[147], M. Ahsan[40], G. Aielli[132a,132b], T. Akdogan[18a], T.P.A. Åkesson[78], G. Akimoto[154], A.V. Akimov [93], A. Akiyama[66], M.S. Alam[1], M.A. Alam[75], J. Albert[168], S. Albrand[55], M. Aleksa[29], I.N. Aleksandrov[64], F. Alessandria[88a], C. Alexa[25a], G. Alexander[152], G. Alexandre[49], T. Alexopoulos[9], M. Alhroob[20], M. Aliev[15], G. Alimonti[88a], J. Alison[119], M. Aliyev[10], B.M.M. Allbrooke[17], P.P. Allport[72], S.E. Allwood-Spiers[53], J. Almond[81], A. Aloisio[101a,101b], R. Alon[170], A. Alonso[78], B. Alvarez Gonzalez[87], M.G. Alviggi[101a,101b], K. Amako[65], P. Amaral[29], C. Amelung[22], V.V. Ammosov[127], A. Amorim[123a,b], G. Amorós[166], N. Amram[152], C. Anastopoulos[29], L.S. Ancu[16], N. Andari[114], T. Andeen[34], C.F. Anders[20], G. Anders[58a], K.J. Anderson[30], A. Andreazza[88a,88b], V. Andrei[58a], M-L. Andrieux[55], X.S. Anduaga[69], A. Angerami[34], F. Anghinolfi[29], A. Anisenkov[106], N. Anjos[123a], A. Annovi[47], A. Antonaki[8], M. Antonelli[47], A. Antonov[95], J. Antos[143b], F. Anulli[131a], S. Aoun[82], L. Aperio Bella[4], R. Apolle[117,c], G. Arabidze[87], I. Aracena[142], Y. Arai[65], A.T.H. Arce[44], S. Arfaoui[147], J-F. Arguin[14], E. Arik[18a,*], M. Arik[18a], A.J. Armbruster[86], O. Arnaez[80], C. Arnault[114], A. Artamonov[94], G. Artoni[131a,131b], D. Arutinov[20], S. Asai[154], R. Asfandiyarov[171], S. Ask[27], B. Åsman[145a,145b], L. Asquith[5], K. Assamagan[24], A. Astbury[168], A. Astvatsatourov[52], B. Aubert[4], E. Auge[114], K. Augsten[126], M. Aurousseau[144a], G. Avolio[162], R. Avramidou[9], D. Axen[167], C. Ay[54], G. Azuelos[92,d], Y. Azuma[154], M.A. Baak[29], G. Baccaglioni[88a], C. Bacci[133a,133b], A.M. Bach[14], H. Bachacou[135], K. Bachas[29], M. Backes[49], M. Backhaus[20], E. Badescu[25a], P. Bagnaia[131a,131b], S. Bahinipati[2], Y. Bai[32a], D.C. Bailey[157], T. Bain[157], J.T. Baines[128], O.K. Baker[174], M.D. Baker[24], S. Baker[76], E. Banas[38], P. Banerjee[92], Sw. Banerjee[171], D. Banfi[29], A. Bangert[149], V. Bansal[168], H.S. Bansil[17], L. Barak[170], S.P. Baranov[93], A. Barashkou[64], A. Barbaro Galtieri[14], T. Barber[48], E.L. Barberio[85], D. Barberis[50a,50b], M. Barbero[20], D.Y. Bardin[64], T. Barillari[98], M. Barisonzi[173], T. Barklow[142], N. Barlow[27], B.M. Barnett[128], R.M. Barnett[14], A. Baroncelli[133a], G. Barone[49], A.J. Barr[117], F. Barreiro[79], J. Barreiro Guimarães da Costa[57], P. Barrillon[114], R. Bartoldus[142], A.E. Barton[70], V. Bartsch[148], R.L. Bates[53], L. Batkova[143a], J.R. Batley[27], A. Battaglia[16], M. Battistin[29], F. Bauer[135], H.S. Bawa[142,e], S. Beale[97], T. Beau[77], P.H. Beauchemin[160], R. Beccherle[50a], P. Bechtle[20], H.P. Beck[16], S. Becker[97], M. Beckingham[137], K.H. Becks[173], A.J. Beddall[18c], A. Beddall[18c], S. Bedikian[174], V.A. Bednyakov[64], C.P. Bee[82], M. Begel[24], S. Behar Harpaz[151], P.K. Behera[62], M. Beimforde[98], C. Belanger-Champagne[84], P.J. Bell[49], W.H. Bell[49], G. Bella[152], L. Bellagamba[19a], F. Bellina[29], M. Bellomo[29], A. Belloni[57], O. Beloborodova[106,f], K. Belotskiy[95], O. Beltramello[29], S. Ben Ami[151], O. Benary[152], D. Benchekroun[134a], C. Benchouk[82], M. Bendel[80], N. Benekos[164], Y. Benhammou[152], E. Benhar Noccioli[49], J.A. Benitez Garcia[158b], D.P. Benjamin[44], M. Benoit[114], J.R. Bensinger[22], K. Benslama[129], S. Bentvelsen[104], D. Berge[29], E. Bergeaas Kuutmann[41], N. Berger[4], F. Berghaus[168], E. Berglund[104], J. Beringer[14], P. Bernat[76], R. Bernhard[48], C. Bernius[24], T. Berry[75], C. Bertella[82], A. Bertin[19a,19b], F. Bertinelli[29], F. Bertolucci[121a,121b], M.I. Besana[88a,88b], N. Besson[135], S. Bethke[98], W. Bhimji[45], R.M. Bianchi[29], M. Bianco[71a,71b], O. Biebel[97], S.P. Bieniek[76], K. Bierwagen[54], J. Biesiada[14], M. Biglietti[133a], H. Bilokon[47], M. Bindi[19a,19b], S. Binet[114], A. Bingul[18c], C. Bini[131a,131b], C. Biscarat[176], U. Bitenc[48], K.M. Black[21], R.E. Blair[5], J.-B. Blanchard[135], G. Blanchot[29], T. Blazek[143a], C. Blocker[22], J. Blocki[38], A. Blondel[49], W. Blum[80], U. Blumenschein[54], G.J. Bobbink[104], V.B. Bobrovnikov[106], S.S. Bocchetta[78], A. Bocci[44], C.R. Boddy[117], M. Boehler[41], J. Boek[173], N. Boelaert[35], J.A. Bogaerts[29], A. Bogdanchikov[106], A. Bogouch[89,*], C. Bohm[145a], V. Boisvert[75], T. Bold[37], V. Boldea[25a], N.M. Bolnet[135], M. Bona[74], V.G. Bondarenko[95], M. Bondioli[162], M. Boonekamp[135], C.N. Booth[138], S. Bordoni[77], C. Borer[16], A. Borisov[127], G. Borissov[70], I. Borjanovic[12a], M. Borri[81], S. Borroni[86], V. Bortolotto[133a,133b], K. Bos[104], D. Boscherini[19a], M. Bosman[11], H. Boterenbrood[104], D. Botterill[128], J. Bouchami[92], J. Boudreau[122], E.V. Bouhova-Thacker[70], D. Boumediene[33], C. Bourdarios[114], N. Bousson[82], A. Boveia[30], J. Boyd[29], I.R. Boyko[64], N.I. Bozhko[127], I. Bozovic-Jelisavcic[12b], J. Bracinik[17], A. Braem[29], P. Branchini[133a], G.W. Brandenburg[57], A. Brandt[7], G. Brandt[117], O. Brandt[54], U. Bratzler[155], B. Brau[83], J.E. Brau[113], H.M. Braun[173], B. Brelier[157], J. Bremer[29], R. Brenner[165], S. Bressler[170], D. Britton[53], F.M. Brochu[27], I. Brock[20], R. Brock[87], T.J. Brodbeck[70], E. Brodet[152], F. Broggi[88a], C. Bromberg[87], J. Bronner[98], G. Brooijmans[34], W.K. Brooks[31b], G. Brown[81], H. Brown[7], P.A. Bruckman de Renstrom[38], D. Bruncko[143b], 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[117], N.J. Buchanan[2], P. Buchholz[140], R.M. Buckingham[117], A.G. Buckley[45], S.I. Buda[25a], I.A. Budagov[64], B. Budick[107], V. Büscher[80], L. Bugge[116], O. Bulekov[95], M. Bunse[42], T. Buran[116], H. Burckhart[29], S. Burdin[72], T. Burgess[13], S. Burke[128], E. Busato[33], P. Bussey[53], C.P. Buszello[165], F. Butin[29], B. Butler[142], J.M. Butler[21], C.M. Buttar[53], J.M. Butterworth[76], W. Buttinger[27], S. Cabrera Urbán[166], D. Caforio[19a,19b], O. Cakir[3a], P. Calafiura[14], G. Calderini[77], P. Calfayan[97], R. Calkins[105], L.P. Caloba[23a], R. Caloi[131a,131b], D. Calvet[33], S. Calvet[33], R. Camacho Toro[33], P. Camarri[132a,132b], M. Cambiaghi[118a,118b], D. Cameron[116], L.M. Caminada[14], S. Campana[29], M. Campanelli[76], V. Canale[101a,101b], F. Canelli[30,g], A. Canepa[158a],

J. Cantero[79], L. Capasso[101a,101b], M.D.M. Capeans Garrido[29], I. Caprini[25a], M. Caprini[25a], D. Capriotti[98], M. Capua[36a,36b], R. Caputo[80], C. Caramarcu[24], R. Cardarelli[132a], T. Carli[29], G. Carlino[101a], L. Carminati[88a,88b], B. Caron[84], S. Caron[103], G.D. Carrillo Montoya[171], A.A. Carter[74], J.R. Carter[27], J. Carvalho[123a,h], D. Casadei[107], M.P. Casado[11], M. Cascella[121a,121b], C. Caso[50a,50b,*], A.M. Castaneda Hernandez[171], E. Castaneda-Miranda[171], V. Castillo Gimenez[166], N.F. Castro[123a], G. Cataldi[71a], F. Cataneo[29], A. Catinaccio[29], J.R. Catmore[29], A. Cattai[29], G. Cattani[132a,132b], S. Caughron[87], D. Cauz[163a,163c], P. Cavalleri[77], D. Cavalli[88a], M. Cavalli-Sforza[11], V. Cavasinni[121a,121b], F. Ceradini[133a,133b], A.S. Cerqueira[23b], A. Cerri[29], L. Cerrito[74], F. Cerutti[47], S.A. Cetin[18b], F. Cevenini[101a,101b], A. Chafaq[134a], D. Chakraborty[105], K. Chan[2], B. Chapleau[84], J.D. Chapman[27], J.W. Chapman[86], E. Chareyre[77], D.G. Charlton[17], V. Chavda[81], C.A. Chavez Barajas[29], S. Cheatham[84], S. Chekanov[5], S.V. Chekulaev[158a], G.A. Chelkov[64], M.A. Chelstowska[103], C. Chen[63], H. Chen[24], S. Chen[32c], T. Chen[32c], X. Chen[171], S. Cheng[32a], A. Cheplakov[64], V.F. Chepurnov[64], R. Cherkaoui El Moursli[134e], V. Chernyatin[24], E. Cheu[6], S.L. Cheung[157], L. Chevalier[135], G. Chiefari[101a,101b], L. Chikovani[51a], J.T. Childers[29], A. Chilingarov[70], G. Chiodini[71a], A.S. Chisholm[17], M.V. Chizhov[64], G. Choudalakis[30], S. Chouridou[136], I.A. Christidi[76], A. Christov[48], D. Chromek-Burckhart[29], M.L. Chu[150], J. Chudoba[124], G. Ciapetti[131a,131b], K. Ciba[37], A.K. Ciftci[3a], R. Ciftci[3a], D. Cinca[33], V. Cindro[73], M.D. Ciobotaru[162], C. Ciocca[19a], A. Ciocio[14], M. Cirilli[86], M. Citterio[88a], M. Ciubancan[25a], A. Clark[49], P.J. Clark[45], W. Cleland[122], J.C. Clemens[82], B. Clement[55], C. Clement[145a,145b], R.W. Clifft[128], Y. Coadou[82], M. Cobal[163a,163c], A. Coccaro[171], J. Cochran[63], P. Coe[117], J.G. Cogan[142], J. Coggeshall[164], E. Cogneras[176], J. Colas[4], A.P. Colijn[104], N.J. Collins[17], C. Collins-Tooth[53], J. Collot[55], G. Colon[83], P. Conde Muiño[123a], E. Coniavitis[117], M.C. Conidi[11], M. Consonni[103], V. Consorti[48], S. Constantinescu[25a], C. Conta[118a,118b], F. Conventi[101a,i], J. Cook[29], M. Cooke[14], B.D. Cooper[76], A.M. Cooper-Sarkar[117], K. Copic[14], T. Cornelissen[173], M. Corradi[19a], F. Corriveau[84,j], A. Cortes-Gonzalez[164], G. Cortiana[98], G. Costa[88a], M.J. Costa[166], D. Costanzo[138], T. Costin[30], D. Côté[29], R. Coura Torres[23a], L. Courneyea[168], G. Cowan[75], C. Cowden[27], B.E. Cox[81], K. Cranmer[107], F. Crescioli[121a,121b], M. Cristinziani[20], G. Crosetti[36a,36b], R. Crupi[71a,71b], S. Crépé-Renaudin[55], C.-M. Cuciuc[25a], C. Cuenca Almenar[174], T. Cuhadar Donszelmann[138], M. Curatolo[47], C.J. Curtis[17], C. Cuthbert[149], P. Cwetanski[60], H. Czirr[140], P. Czodrowski[43], Z. Czyczula[174], S. D'Auria[53], M. D'Onofrio[72], A. D'Orazio[131a,131b], P.V.M. Da Silva[23a], C. Da Via[81], W. Dabrowski[37], T. Dai[86], C. Dallapiccola[83], M. Dam[35], M. Dameri[50a,50b], D.S. Damiani[136], H.O. Danielsson[29], D. Dannheim[98], V. Dao[49], G. Darbo[50a], G.L. Darlea[25b], W. Davey[20], T. Davidek[125], N. Davidson[85], R. Davidson[70], E. Davies[117,c], M. Davies[92], A.R. Davison[76], Y. Davygora[58a], E. Dawe[141], I. Dawson[138], J.W. Dawson[5,*], R.K. Daya-Ishmukhametova[22], K. De[7], R. de Asmundis[101a], S. De Castro[19a,19b], P.E. De Castro Faria Salgado[24], S. De Cecco[77], J. de Graat[97], N. De Groot[103], P. de Jong[104], C. De La Taille[114], H. De la Torre[79], B. De Lotto[163a,163c], L. de Mora[70], L. De Nooij[104], D. De Pedis[131a], A. De Salvo[131a], U. De Sanctis[163a,163c], A. De Santo[148], J.B. De Vivie De Regie[114], S. Dean[76], W.J. Dearnaley[70], R. Debbe[24], C. Debenedetti[45], D.V. Dedovich[64], J. Degenhardt[119], M. Dehchar[117], C. Del Papa[163a,163c], J. Del Peso[79], T. Del Prete[121a,121b], T. Delemontex[55], M. Deliyergiyev[73], A. Dell'Acqua[29], L. Dell'Asta[21], M. Della Pietra[101a,i], D. della Volpe[101a,101b], M. Delmastro[4], N. Delruelle[29], P.A. Delsart[55], C. Deluca[147], S. Demers[174], M. Demichev[64], B. Demirkoz[11,k], J. Deng[162], S.P. Denisov[127], D. Derendarz[38], J.E. Derkaoui[134d], F. Derue[77], P. Dervan[72], K. Desch[20], E. Devetak[147], P.O. Deviveiros[104], A. Dewhurst[128], B. DeWilde[147], S. Dhaliwal[157], R. Dhullipudi[24,l], A. Di Ciaccio[132a,132b], L. Di Ciaccio[4], A. Di Girolamo[29], B. Di Girolamo[29], S. Di Luise[133a,133b], A. Di Mattia[171], B. Di Micco[29], R. Di Nardo[47], A. Di Simone[132a,132b], R. Di Sipio[19a,19b], M.A. Diaz[31a], F. Diblen[18c], E.B. Diehl[86], J. Dietrich[41], T.A. Dietzsch[58a], S. Diglio[85], K. Dindar Yagci[39], J. Dingfelder[20], C. Dionisi[131a,131b], P. Dita[25a], S. Dita[25a], F. Dittus[29], F. Djama[82], T. Djobava[51b], M.A.B. do Vale[23c], A. Do Valle Wemans[123a], T.K.O. Doan[4], M. Dobbs[84], R. Dobinson [29,*], D. Dobos[29], E. Dobson[29,m], J. Dodd[34], C. Doglioni[49], T. Doherty[53], Y. Doi[65,*], J. Dolejsi[125], I. Dolenc[73], Z. Dolezal[125], B.A. Dolgoshein[95,*], T. Dohmae[154], M. Donadelli[23d], M. Donega[119], J. Donini[33], J. Dopke[29], A. Doria[101a], A. Dos Anjos[171], M. Dosil[11], A. Dotti[121a,121b], M.T. Dova[69], J.D. Dowell[17], A.D. Doxiadis[104], A.T. Doyle[53], Z. Drasal[125], J. Drees[173], N. Dressnandt[119], H. Drevermann[29], C. Driouichi[35], M. Dris[9], J. Dubbert[98], S. Dube[14], E. Duchovni[170], G. Duckeck[97], A. Dudarev[29], F. Dudziak[63], M. Dührssen [29], I.P. Duerdoth[81], L. Duflot[114], M-A. Dufour[84], M. Dunford[29], H. Duran Yildiz[3a], R. Duxfield[138], M. Dwuznik[37], F. Dydak [29], M. Düren[52], W.L. Ebenstein[44], J. Ebke[97], S. Eckweiler[80], K. Edmonds[80], C.A. Edwards[75], N.C. Edwards[53], W. Ehrenfeld[41], T. Ehrich[98], T. Eifert[142], G. Eigen[13], K. Einsweiler[14], E. Eisenhandler[74], T. Ekelof[165], M. El Kacimi[134c], M. Ellert[165], S. Elles[4], F. Ellinghaus[80], K. Ellis[74], N. Ellis[29], J. Elmsheuser[97], M. Elsing[29], D. Emeliyanov[128], R. Engelmann[147], A. Engl[97], B. Epp[61], A. Eppig[86], J. Erdmann[54], A. Ereditato[16], D. Eriksson[145a], J. Ernst[1], M. Ernst[24], J. Ernwein[135], D. Errede[164], S. Errede[164], E. Ertel[80], M. Escalier[114], C. Escobar[122], X. Espinal Curull[11], B. Esposito[47], F. Etienne[82], A.I. Etienvre[135], E. Etzion[152], D. Evangelakou[54], H. Evans[60], L. Fabbri[19a,19b], C. Fabre[29], R.M. Fakhrutdinov[127], S. Falciano[131a], Y. Fang[171], M. Fanti[88a,88b], A. Farbin[7], A. Farilla[133a], J. Farley[147], T. Farooque[157], S.M. Farrington[117], P. Farthouat[29], P. Fassnacht[29], D. Fassouliotis[8], B. Fatholahzadeh[157], A. Favareto[88a,88b], L. Fayard[114], S. Fazio[36a,36b], R. Febbraro[33], P. Federic[143a], O.L. Fedin[120], W. Fedorko[87], M. Fehling-Kaschek[48], L. Feligioni[82], D. Fellmann[5], C. Feng[32d], E.J. Feng[30], A.B. Fenyuk[127], J. Ferencei[143b], J. Ferland[92], W. Fernando[108], S. Ferrag[53], J. Ferrando[53], V. Ferrara[41], A. Ferrari[165], P. Ferrari[104], R. Ferrari[118a], D.E. Ferreira de Lima[53], A. Ferrer[166], M.L. Ferrer[47], D. Ferrere[49], C. Ferretti[86], A. Ferretto Parodi[50a,50b], M. Fiascaris[30], F. Fiedler[80], A. Filipčič[73], A. Filippas[9], F. Filthaut[103], M. Fincke-Keeler[168], M.C.N. Fiolhais[123a,h], L. Fiorini[166], A. Firan[39], G. Fischer[41], P. Fischer [20], M.J. Fisher[108], M. Flechl[48], I. Fleck[140], J. Fleckner[80], P. Fleischmann[172], S. Fleischmann[173], T. Flick[173], A. Floderus[78], L.R. Flores Castillo[171], M.J. Flowerdew[98], M. Fokitis[9], T. Fonseca Martin[16], D.A. Forbush[137], A. Formica[135], A. Forti[81], D. Fortin[158a], J.M. Foster[81], D. Fournier[114], A. Foussat[29], A.J. Fowler[44], K. Fowler[136], H. Fox[70], P. Francavilla[11], S. Franchino[118a,118b], D. Francis[29], T. Frank[170], M. Franklin[57], S. Franz[29], M. Fraternali[118a,118b], S. Fratina[119], S.T. French[27], F. Friedrich [43], R. Froeschl[29], D. Froidevaux[29], J.A. Frost[27], C. Fukunaga[155], E. Fullana Torregrosa[29], J. Fuster[166], C. Gabaldon[29], O. Gabizon[170], T. Gadfort[24], S. Gadomski[49], G. Gagliardi[50a,50b], P. Gagnon[60], C. Galea[97], E.J. Gallas[117], V. Gallo[16], B.J. Gallop[128], P. Gallus[124], K.K. Gan[108], Y.S. Gao[142,e], V.A. Gapienko[127], A. Gaponenko[14], F. Garberson[174], M. Garcia-Sciveres[14], C. García[166], J.E. García Navarro[166], R.W. Gardner[30], N. Garelli[29], H. Garitaonandia[104], V. Garonne[29], J. Garvey[17], C. Gatti[47], G. Gaudio[118a], B. Gaur[140], L. Gauthier[135], I.L. Gavrilenko[93], C. Gay[167], G. Gaycken[20], J-C. Gayde[29], E.N. Gazis[9], P. Ge[32d], C.N.P. Gee[128], D.A.A. Geerts[104], Ch. Geich-Gimbel[20], K. Gellerstedt[145a,145b], C. Gemme[50a], A. Gemmell[53], M.H. Genest[55], S. Gentile[131a,131b], M. George[54], S. George[75], P. Gerlach[173], A. Gershon[152], C. Geweniger[58a], H. Ghazlane[134b], N. Ghodbane[33], B. Giacobbe[19a], S. Giagu[131a,131b], V. Giakoumopoulou[8], V. Giangiobbe[11], F. Gianotti[29], B. Gibbard[24], A. Gibson[157], S.M. Gibson[29], L.M. Gilbert[117], V. Gilewsky[90], D. Gillberg[28], A.R. Gillman[128], D.M. Gingrich[2,d], J. Ginzburg[152], N. Giokaris[8], M.P. Giordani[163c], R. Giordano[101a,101b], F.M. Giorgi[15], P. Giovannini[98], P.F. Giraud[135], D. Giugni[88a], M. Giunta[92], P. Giusti[19a], B.K. Gjelsten[116], L.K. Gladilin[96], C. Glasman[79], J. Glatzer[48], A. Glazov[41], K.W. Glitza[173], G.L. Glonti[64], J.R. Goddard[74], J. Godfrey[141], J. Godlewski[29], M. Goebel[41], T. Göpfert[43], C. Goeringer[80], C. Gössling[42], T. Göttfert[98], S. Goldfarb[86], T. Golling[174], A. Gomes[123a,b], L.S. Gomez Fajardo[41], R. Gonçalo[75], J. Goncalves Pinto Firmino Da Costa[41], L. Gonella[20], A. Gonidec[29], S. Gonzalez[171], S. González de la Hoz[166], G. Gonzalez Parra[11], M.L. Gonzalez Silva[26], S. Gonzalez-Sevilla[49], J.J. Goodson[147], L. Goossens[29], P.A. Gorbounov[94], H.A. Gordon[24], I. Gorelov[102], G. Gorfine[173], B. Gorini[29], E. Gorini[71a,71b], A. Gorišek[73], E. Gornicki[38], S.A. Gorokhov[127], V.N. Goryachev[127], B. Gosdzik[41], M. Gosselink[104], M.I. Gostkin[64], I. Gough Eschrich[162], M. Gouighri[134a], D. Goujdami[134c], M.P. Goulette[49], A.G. Goussiou[137], C. Goy[4], S. Gozpinar[22], I. Grabowska-Bold[37], P. Grafström[29], K-J. Grahn[41], F. Grancagnolo[71a], S. Grancagnolo[15], V. Grassi[147], V. Gratchev[120], N. Grau[34], H.M. Gray[29], J.A. Gray[147], E. Graziani[133a], O.G. Grebenyuk[120], T. Greenshaw[72], Z.D. Greenwood[24,l], K. Gregersen[35], I.M. Gregor[41], P. Grenier[142], J. Griffiths[137], N. Grigalashvili[64], A.A. Grillo[136], S. Grinstein[11], Y.V. Grishkevich[96], J.-F. Grivaz[114], M. Groh[98], E. Gross[170], J. Grosse-Knetter[54], J. Groth-Jensen[170], K. Grybel[140], V.J. Guarino[5], D. Guest[174], C. Guicheney[33], A. Guida[71a,71b], S. Guindon[54], H. Guler[84,n], J. Gunther[124], B. Guo[157], J. Guo[34], A. Gupta[30], Y. Gusakov[64], V.N. Gushchin[127], P. Gutierrez[110], N. Guttman[152], O. Gutzwiller[171], C. Guyot[135], C. Gwenlan[117], C.B. Gwilliam[72], A. Haas[142], S. Haas[29], C. Haber[14], H.K. Hadavand[39], D.R. Hadley[17], P. Haefner[98], F. Hahn[29], S. Haider[29], Z. Hajduk[38], H. Hakobyan[175], D. Hall[117], J. Haller[54], K. Hamacher[173], P. Hamal[112], M. Hamer[54], A. Hamilton[144b,o], S. Hamilton[160], H. Han[32a], L. Han[32b], K. Hanagaki[115], K. Hanawa[159], M. Hance[14], C. Handel[80], P. Hanke[58a], J.R. Hansen[35], J.B. Hansen[35], J.D. Hansen[35], P.H. Hansen[35], P. Hansson[142], K. Hara[159], G.A. Hare[136], T. Harenberg[173], S. Harkusha[89], D. Harper[86], R.D. Harrington[45], O.M. Harris[137], K. Harrison[17], J. Hartert[48], F. Hartjes[104], T. Haruyama[65], A. Harvey[56], S. Hasegawa[100], Y. Hasegawa[139], S. Hassani[135], M. Hatch[29], D. Hauff[98], S. Haug[16], M. Hauschild[29], R. Hauser[87], M. Havranek[20], B.M. Hawes[117], C.M. Hawkes[17], R.J. Hawkings[29], A.D. Hawkins[78], D. Hawkins[162], T. Hayakawa[66], T. Hayashi[159], D. Hayden[75], H.S. Hayward[72], S.J. Haywood[128], E. Hazen[21], M. He[32d], S.J. Head[17], V. Hedberg[78], L. Heelan[7], S. Heim[87], B. Heinemann[14], S. Heisterkamp[35], L. Helary[4], C. Heller[97], M. Heller[29], S. Hellman[145a,145b], D. Hellmich[20], C. Helsens[11], R.C.W. Henderson[70], M. Henke[58a], A. Henrichs[54], A.M. Henriques Correia[29], S. Henrot-Versille[114], F. Henry-Couannier[82], C. Hensel[54], T. Henß[173], C.M. Hernandez[7], Y. Hernández Jiménez[166], R. Herrberg[15], A.D. Hershenhorn[151], G. Herten[48], R. Hertenberger[97], L. Hervas[29], G.G. Hesketh[76], N.P. Hessey[104], E. Higón-Rodriguez[166], D. Hill[5,*], J.C. Hill[27], N. Hill[5], K.H. Hiller[41], S. Hillert[20], S.J. Hillier[17], I. Hinchliffe[14], E. Hines[119], M. Hirose[115], F. Hirsch[42], D. Hirschbuehl[173], J. Hobbs[147], N. Hod[152], M.C. Hodgkinson[138], P. Hodgson[138], A. Hoecker[29], M.R. Hoeferkamp[102], J. Hoffman[39], D. Hoffmann[82], M. Hohlfeld[80], M. Holder[140], S.O. Holmgren[145a], T. Holy[126], J.L. Holzbauer[87], Y. Homma[66], T.M. Hong[119], L. Hooft van Huysduynen[107], T. Horazdovsky[126], C. Horn[142], S. Horner[48], J-Y. Hostachy[55], S. Hou[150], M.A. Houlden[72], A. Hoummada[134a], J. Howarth[81], D.F. Howell[117], I. Hristova [15], J. Hrivnac[114], I. Hruska[124], T. Hryn'ova[4], P.J. Hsu[80], S.-C. Hsu[14], G.S. Huang[110], Z. Hubacek[126], F. Hubaut[82], F. Huegging[20], A. Huettmann[41], T.B. Huffman[117], E.W. Hughes[34], G. Hughes[70], R.E. Hughes-Jones[81], M. Huhtinen[29], P. Hurst[57], M. Hurwitz[14], U. Husemann[41], N. Huseynov[64,p], J. Huston[87], J. Huth[57], G. Iacobucci[49], G. Iakovidis[9], M. Ibbotson[81], I. Ibragimov[140], R. Ichimiya[66], L. Iconomidou-Fayard[114], J. Idarraga[114], P. Iengo[101a], O. Igonkina[104], Y. Ikegami[65], M. Ikeno[65], Y. Ilchenko[39], D. Iliadis[153], N. Ilic[157], M. Imori[154], T. Ince[20], J. Inigo-Golfin[29], P. Ioannou[8], M. Iodice[133a], V. Ippolito[131a,131b], A. Irles Quiles[166], C. Isaksson[165], A. Ishikawa[66], M. Ishino[67], R. Ishmukhametov[39],

C. Issever[117], S. Istin[18a], A.V. Ivashin[127], W. Iwanski[38], H. Iwasaki[65], J.M. Izen[40], V. Izzo[101a], B. Jackson[119], J.N. Jackson[72], P. Jackson[142], M.R. Jaekel[29], V. Jain[60], K. Jakobs[48], S. Jakobsen[35], J. Jakubek[126], D.K. Jana[110], E. Jankowski[157], E. Jansen[76], H. Jansen[29], A. Jantsch[98], M. Janus[20], G. Jarlskog[78], L. Jeanty[57], K. Jelen[37], I. Jen-La Plante[30], P. Jenni[29], A. Jeremie[4], P. Jež[35], S. Jézéquel[4], M.K. Jha[19a], H. Ji[171], W. Ji[80], J. Jia[147], Y. Jiang[32b], M. Jimenez Belenguer[41], G. Jin[32b], S. Jin[32a], O. Jinnouchi[156], M.D. Joergensen[35], D. Joffe[39], L.G. Johansen[13], M. Johansen[145a,145b], K.E. Johansson[145a], P. Johansson[138], S. Johnert[41], K.A. Johns[6], K. Jon-And[145a,145b], G. Jones[117], R.W.L. Jones[70], T.W. Jones[76], T.J. Jones[72], O. Jonsson[29], C. Joram[29], P.M. Jorge[123a], J. Joseph[14], J. Jovicevic[146], T. Jovin[12b], X. Ju[171], C.A. Jung[42], R.M. Jungst[29], V. Juranek[124], P. Jussel[61], A. Juste Rozas[11], V.V. Kabachenko[127], S. Kabana[16], M. Kaci[166], A. Kaczmarska[38], P. Kadlecik[35], M. Kado[114], H. Kagan[108], M. Kagan[57], S. Kaiser[98], E. Kajomovitz[151], S. Kalinin[173], L.V. Kalinovskaya[64], S. Kama[39], N. Kanaya[154], M. Kaneda[29], S. Kaneti[27], T. Kanno[156], V.A. Kantserov[95], J. Kanzaki[65], B. Kaplan[174], A. Kapliy[30], J. Kaplon[29], D. Kar[43], M. Karagounis[20], M. Karagoz[117], M. Karnevskiy[41], K. Karr[5], V. Kartvelishvili[70], A.N. Karyukhin[127], L. Kashif[171], G. Kasieczka[58b], R.D. Kass[108], A. Kastanas[13], M. Kataoka[4], Y. Kataoka[154], E. Katsoufis[9], J. Katzy[41], V. Kaushik[6], K. Kawagoe[66], T. Kawamoto[154], G. Kawamura[80], M.S. Kayl[104], V.A. Kazanin[106], M.Y. Kazarinov[64], R. Keeler[168], R. Kehoe[39], M. Keil[54], G.D. Kekelidze[64], J. Kennedy[97], C.J. Kenney[142], M. Kenyon[53], O. Kepka[124], N. Kerschen[29], B.P. Kerševan[73], S. Kersten[173], K. Kessoku[154], J. Keung[157], F. Khalil-zada[10], H. Khandanyan[164], A. Khanov[111], D. Kharchenko[64], A. Khodinov[95], A.G. Kholodenko[127], A. Khomich[58a], T.J. Khoo[27], G. Khoriauli[20], A. Khoroshilov[173], N. Khovanskiy[64], V. Khovanskiy[94], E. Khramov[64], J. Khubua[51b], H. Kim[145a,145b], M.S. Kim[2], S.H. Kim[159], N. Kimura[169], O. Kind[15], B.T. King[72], M. King[66], R.S.B. King[117], J. Kirk[128], L.E. Kirsch[22], A.E. Kiryunin[98], T. Kishimoto[66], D. Kisielewska[37], T. Kittelmann[122], A.M. Kiver[127], E. Kladiva[143b], J. Klaiber-Lodewigs[42], M. Klein[72], U. Klein[72], K. Kleinknecht[80], M. Klemetti[84], A. Klier[170], P. Klimek[145a,145b], A. Klimentov[24], R. Klingenberg[42], J.A. Klinger[81], E.B. Klinkby[35], T. Klioutchnikova[29], P.F. Klok[103], S. Klous[104], E.-E. Kluge[58a], T. Kluge[72], P. Kluit[104], S. Kluth[98], N.S. Knecht[157], E. Kneringer[61], J. Knobloch[29], E.B.F.G. Knoops[82], A. Knue[54], B.R. Ko[44], T. Kobayashi[154], M. Kobel[43], M. Kocian[142], P. Kodys[125], K. Köneke[29], A.C. König[103], S. Koenig[80], L. Köpke[80], F. Koetsveld[103], P. Koevesarki[20], T. Koffas[28], E. Koffeman[104], L.A. Kogan[117], F. Kohn[54], Z. Kohout[126], T. Kohriki[65], T. Koi[142], T. Kokott[20], G.M. Kolachev[106], H. Kolanoski[15], V. Kolesnikov[64], I. Koletsou[88a], J. Koll[87], M. Kollefrath[48], S.D. Kolya[81], A.A. Komar[93], Y. Komori[154], T. Kondo[65], T. Kono[41,q], A.I. Kononov[48], R. Konoplich[107,r], N. Konstantinidis[76], A. Kootz[173], S. Koperny[37], K. Korcyl[38], K. Kordas[153], V. Koreshev[127], A. Korn[117], A. Korol[106], I. Korolkov[11], E.V. Korolkova[138], V.A. Korotkov[127], O. Kortner[98], S. Kortner[98], V.V. Kostyukhin[20], M.J. Kotamäki[29], S. Kotov[98], V.M. Kotov[64], A. Kotwal[44], C. Kourkoumelis[8], V. Kouskoura[153], A. Koutsman[158a], R. Kowalewski[168], T.Z. Kowalski[37], W. Kozanecki[135], A.S. Kozhin[127], V. Kral[126], V.A. Kramarenko[96], G. Kramberger[73], M.W. Krasny[77], A. Krasznahorkay[107], J. Kraus[87], J.K. Kraus[20], A. Kreisel[152], F. Krejci[126], J. Kretzschmar[72], N. Krieger[54], P. Krieger[157], K. Kroeninger[54], H. Kroha[98], J. Kroll[119], 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[85], S. Kuday[3a], S. Kuehn[48], A. Kugel[58c], T. Kuhl[41], D. Kuhn[61], V. Kukhtin[64], Y. Kulchitsky[89], S. Kuleshov[31b], C. Kummer[97], M. Kuna[77], N. Kundu[117], J. Kunkle[119], A. Kupco[124], H. Kurashige[66], M. Kurata[159], Y.A. Kurochkin[89], V. Kus[124], E.S. Kuwertz[146], M. Kuze[156], J. Kvita[141], R. Kwee[15], A. La Rosa[49], L. La Rotonda[36a,36b], L. Labarga[79], J. Labbe[4], S. Lablak[134a], C. Lacasta[166], F. Lacava[131a,131b], H. Lacker[15], D. Lacour[77], V.R. Lacuesta[166], E. Ladygin[64], R. Lafaye[4], B. Laforge[77], T. Lagouri[79], S. Lai[48], E. Laisne[55], M. Lamanna[29], C.L. Lampen[6], W. Lampl[6], E. Lancon[135], U. Landgraf[48], M.P.J. Landon[74], J.L. Lane[81], C. Lange[41], A.J. Lankford[162], F. Lanni[24], K. Lantzsch[173], S. Laplace[77], C. Lapoire[20], J.F. Laporte[135], T. Lari[88a], A.V. Larionov [127], A. Larner[117], C. Lasseur[29], M. Lassnig[29], P. Laurelli[47], V. Lavorini[36a,36b], W. Lavrijsen[14], P. Laycock[72], A.B. Lazarev[64], O. Le Dortz[77], E. Le Guirriec[82], C. Le Maner[157], E. Le Menedeu[9], C. Lebel[92], T. LeCompte[5], F. Ledroit-Guillon[55], H. Lee[104], J.S.H. Lee[115], S.C. Lee[150], L. Lee[174], M. Lefebvre[168], M. Legendre[135], A. Leger[49], B.C. LeGeyt[119], F. Legger[97], C. Leggett[14], M. Lehmacher[20], G. Lehmann Miotto[29], X. Lei[6], M.A.L. Leite[23d], R. Leitner[125], D. Lellouch[170], M. Leltchouk[34], B. Lemmer[54], V. Lendermann[58a], K.J.C. Leney[144b], T. Lenz[104], G. Lenzen[173], B. Lenzi[29], K. Leonhardt[43], S. Leontsinis[9], C. Leroy[92], J-R. Lessard[168], J. Lesser[145a], C.G. Lester[27], A. Leung Fook Cheong[171], J. Levêque[4], D. Levin[86], L.J. Levinson[170], M.S. Levitski[127], A. Lewis[117], G.H. Lewis[107], A.M. Leyko[20], M. Leyton[15], B. Li[82], H. Li[171,s], S. Li[32b,t], X. Li[86], Z. Liang[117,u], H. Liao[33], B. Liberti[132a], P. Lichard[29], M. Lichtnecker[97], K. Lie[164], W. Liebig[13], R. Lifshitz[151], C. Limbach[20], A. Limosani[85], M. Limper[62], S.C. Lin[150,v], F. Linde[104], J.T. Linnemann[87], E. Lipeles[119], L. Lipinsky[124], A. Lipniacka[13], T.M. Liss[164], D. Lissauer[24], A. Lister[49], A.M. Litke[136], C. Liu[28], D. Liu[150], H. Liu[86], J.B. Liu[86], M. Liu[32b], Y. Liu[32b], M. Livan[118a,118b], S.S.A. Livermore[117], A. Lleres[55], J. Llorente Merino[79], S.L. Lloyd[74], E. Lobodzinska[41], P. Loch[6], W.S. Lockman[136], T. Loddenkoetter[20], F.K. Loebinger[81], A. Loginov[174], C.W. Loh[167], T. Lohse[15], K. Lohwasser[48], M. Lokajicek[124], J. Loken [117], V.P. Lombardo[4], R.E. Long[70], L. Lopes[123a], D. Lopez Mateos[57], J. Lorenz[97], N. Lorenzo Martinez[114], M. Losada[161], P. Loscutoff[14], F. Lo Sterzo[131a,131b], M.J. Losty[158a], X. Lou[40], A. Lounis[114], K.F. Loureiro[161], J. Love[21], P.A. Love[70], A.J. Lowe[142,e], F. Lu[32a], H.J. Lubatti[137], C. Luci[131a,131b], A. Lucotte[55],

A. Ludwig[43], D. Ludwig[41], I. Ludwig[48], J. Ludwig[48], F. Luehring[60], G. Luijckx[104], D. Lumb[48], L. Luminari[131a], E. Lund[116], B. Lund-Jensen[146], B. Lundberg[78], J. Lundberg[145a,145b], J. Lundquist[35], M. Lungwitz[80], G. Lutz[98], D. Lynn[24], J. Lys[14], E. Lytken[78], H. Ma[24], L.L. Ma[171], J.A. Macana Goia[92], G. Maccarrone[47], A. Macchiolo[98], B. Maček[73], J. Machado Miguens[123a], R. Mackeprang[35], R.J. Madaras[14], W.F. Mader[43], R. Maenner[58c], T. Maeno[24], P. Mättig[173], S. Mättig[41], L. Magnoni[29], E. Magradze[54], Y. Mahalalel[152], K. Mahboubi[48], G. Mahout[17], C. Maiani[131a,131b], C. Maidantchik[23a], A. Maio[123a,b], S. Majewski[24], Y. Makida[65], N. Makovec[114], P. Mal[135], B. Malaescu[29], Pa. Malecki[38], P. Malecki[38], V.P. Maleev[120], F. Malek[55], U. Mallik[62], D. Malon[5], C. Malone[142], S. Maltezos[9], V. Malyshev[106], S. Malyukov[29], R. Mameghani[97], J. Mamuzic[12b], A. Manabe[65], L. Mandelli[88a], I. Mandić[73], R. Mandrysch[15], J. Maneira[123a], P.S. Mangeard[87], L. Manhaes de Andrade Filho[23a], I.D. Manjavidze[64], A. Mann[54], P.M. Manning[136], A. Manousakis-Katsikakis[8], B. Mansoulie[135], A. Manz[98], A. Mapelli[29], L. Mapelli[29], L. March [79], J.F. Marchand[28], F. Marchese[132a,132b], G. Marchiori[77], M. Marcisovsky[124], A. Marin[21,*], C.P. Marino[168], F. Marroquim[23a], R. Marshall[81], Z. Marshall[29], F.K. Martens[157], S. Marti-Garcia[166], A.J. Martin[174], B. Martin[29], B. Martin[87], F.F. Martin[119], J.P. Martin[92], Ph. Martin[55], T.A. Martin[17], V.J. Martin[45], B. Martin dit Latour[49], S. Martin-Haugh[148], M. Martinez[11], V. Martinez Outschoorn[57], A.C. Martyniuk[168], M. Marx[81], F. Marzano[131a], A. Marzin[110], L. Masetti[80], T. Mashimo[154], R. Mashinistov[93], J. Masik[81], A.L. Maslennikov[106], I. Massa[19a,19b], G. Massaro[104], N. Massol[4], P. Mastrandrea[131a,131b], A. Mastroberardino[36a,36b], T. Masubuchi[154], M. Mathes[20], P. Matricon[114], H. Matsumoto[154], H. Matsunaga[154], T. Matsushita[66], C. Mattravers[117,c], J.M. Maugain[29], J. Maurer[82], S.J. Maxfield[72], D.A. Maximov[106,f], E.N. May[5], A. Mayne[138], R. Mazini[150], M. Mazur[20], M. Mazzanti[88a], E. Mazzoni[121a,121b], S.P. Mc Kee[86], A. McCarn[164], R.L. McCarthy[147], T.G. McCarthy[28], N.A. McCubbin[128], K.W. McFarlane[56], J.A. Mcfayden[138], H. McGlone[53], G. Mchedlidze[51b], R.A. McLaren[29], T. Mclaughlan[17], S.J. McMahon[128], R.A. McPherson[168,j], A. Meade[83], J. Mechnich[104], M. Mechtel[173], M. Medinnis[41], R. Meera-Lebbai[110], T. Meguro[115], R. Mehdiyev[92], S. Mehlhase[35], A. Mehta[72], K. Meier[58a], B. Meirose[78], C. Melachrinos[30], B.R. Mellado Garcia[171], L. Mendoza Navas[161], Z. Meng[150,s], A. Mengarelli[19a,19b], S. Menke[98], C. Menot[29], E. Meoni[11], K.M. Mercurio[57], P. Mermod[49], L. Merola[101a,101b], C. Meroni[88a], F.S. Merritt[30], H. Merritt[108], A. Messina[29], J. Metcalfe[102], A.S. Mete[63], C. Meyer[80], C. Meyer[30], J-P. Meyer[135], J. Meyer[172], J. Meyer[54], T.C. Meyer[29], W.T. Meyer[63], J. Miao[32d], S. Michal[29], L. Micu[25a], R.P. Middleton[128], S. Migas[72], L. Mijović[41], G. Mikenberg[170], M. Mikestikova[124], M. Mikuž[73], D.W. Miller[30], R.J. Miller[87], W.J. Mills[167], C. Mills[57], A. Milov[170], D.A. Milstead[145a,145b], D. Milstein[170], A.A. Minaenko[127], M. Miñano Moya[166], I.A. Minashvili[64], A.I. Mincer[107], B. Mindur[37], M. Mineev[64], Y. Ming[171], L.M. Mir[11], G. Mirabelli[131a], L. Miralles Verge[11], A. Misiejuk[75], J. Mitrevski[136], G.Y. Mitrofanov[127], V.A. Mitsou[166], S. Mitsui[65], P.S. Miyagawa[138], K. Miyazaki[66], J.U. Mjörnmark[78], T. Moa[145a,145b], P. Mockett[137], S. Moed[57], V. Moeller[27], K. Mönig[41], N. Möser[20], S. Mohapatra[147], W. Mohr[48], S. Mohrdieck-Möck[98], A.M. Moisseev[127,*], R. Moles-Valls[166], J. Molina-Perez[29], J. Monk[76], E. Monnier[82], S. Montesano[88a,88b], F. Monticelli[69], S. Monzani[19a,19b], R.W. Moore[2], G.F. Moorhead[85], C. Mora Herrera[49], A. Moraes[53], N. Morange[135], J. Morel[54], G. Morello[36a,36b], D. Moreno[80], M. Moreno Llácer[166], P. Morettini[50a], M. Morgenstern[43], M. Morii[57], J. Morin[74], A.K. Morley[29], G. Mornacchi[29], S.V. Morozov[95], J.D. Morris[74], L. Morvaj[100], H.G. Moser[98], M. Mosidze[51b], J. Moss[108], R. Mount[142], E. Mountricha[9,w], S.V. Mouraviev[93], E.J.W. Moyse[83], M. Mudrinic[12b], F. Mueller[58a], J. Mueller[122], K. Mueller[20], T.A. Müller[97], T. Mueller[80], D. Muenstermann[29], A. Muir[167], Y. Munwes[152], W.J. Murray[128], I. Mussche[104], E. Musto[101a,101b], A.G. Myagkov[127], M. Myska[124], J. Nadal[11], K. Nagai[159], K. Nagano[65], A. Nagarkar[108], Y. Nagasaka[59], M. Nagel[98], A.M. Nairz[29], Y. Nakahama[29], K. Nakamura[154], T. Nakamura[154], I. Nakano[109], G. Nanava[20], A. Napier[160], R. Narayan[58b], M. Nash[76,c], N.R. Nation[21], T. Nattermann[20], T. Naumann[41], G. Navarro[161], H.A. Neal[86], E. Nebot[79], P.Yu. Nechaeva[93], T.J. Neep[81], A. Negri[118a,118b], G. Negri[29], S. Nektarijevic[49], A. Nelson[162], S. Nelson[142], T.K. Nelson[142], S. Nemecek[124], P. Nemethy[107], A.A. Nepomuceno[23a], M. Nessi[29,x], M.S. Neubauer[164], A. Neusiedl[80], R.M. Neves[107], P. Nevski[24], P.R. Newman[17], V. Nguyen Thi Hong[135], R.B. Nickerson[117], R. Nicolaidou[135], L. Nicolas[138], B. Nicquevert[29], F. Niedercorn[114], J. Nielsen[136], T. Niinikoski[29], N. Nikiforou[34], A. Nikiforov[15], V. Nikolaenko[127], K. Nikolaev[64], I. Nikolic-Audit[77], K. Nikolics[49], K. Nikolopoulos[24], H. Nilsen[48], P. Nilsson[7], Y. Ninomiya [154], A. Nisati[131a], T. Nishiyama[66], R. Nisius[98], L. Nodulman[5], M. Nomachi[115], I. Nomidis[153], M. Nordberg[29], B. Nordkvist[145a,145b], P.R. Norton[128], J. Novakova[125], M. Nozaki[65], L. Nozka[112], I.M. Nugent[158a], A.-E. Nuncio-Quiroz[20], G. Nunes Hanninger[85], T. Nunnemann[97], E. Nurse[76], B.J. O'Brien[45], S.W. O'Neale[17,*], D.C. O'Neil[141], V. O'Shea[53], L.B. Oakes[97], F.G. Oakham[28,d], H. Oberlack[98], J. Ocariz[77], A. Ochi[66], S. Oda[154], S. Odaka[65], J. Odier[82], H. Ogren[60], A. Oh[81], S.H. Oh[44], C.C. Ohm[145a,145b], T. Ohshima[100], H. Ohshita[139], T. Ohsugi[177] S. Okada[66], H. Okawa[162], Y. Okumura[100], T. Okuyama[154], A. Olariu[25a], M. Olcese[50a], A.G. Olchevski[64], S.A. Olivares Pino[31a], M. Oliveira[123a,h], D. Oliveira Damazio[24], E. Oliver Garcia[166], D. Olivito[119], A. Olszewski[38], J. Olszowska[38], C. Omachi[66], A. Onofre[123a,y], P.U.E. Onyisi[30], C.J. Oram[158a], M.J. Oreglia[30], Y. Oren[152], D. Orestano[133a,133b], I. Orlov[106], C. Oropeza Barrera[53], R.S. Orr[157], B. Osculati[50a,50b], R. Ospanov[119], C. Osuna[11], G. Otero y Garzon[26], J.P. Ottersbach[104], M. Ouchrif[134d], E.A. Ouellette[168], F. Ould-Saada[116], A. Ouraou[135], Q. Ouyang[32a], A. Ovcharova[14], M. Owen[81], S. Owen[138], V.E. Ozcan[18a], N. Ozturk[7], A. Pacheco Pages[11],

C. Padilla Aranda[11], S. Pagan Griso[14], E. Paganis[138], F. Paige[24], P. Pais[83], K. Pajchel[116], G. Palacino[158b], C.P. Paleari[6], S. Palestini[29], D. Pallin[33], A. Palma[123a], J.D. Palmer[17], Y.B. Pan[171], E. Panagiotopoulou[9], B. Panes[31a], N. Panikashvili[86], S. Panitkin[24], D. Pantea[25a], M. Panuskova[124], V. Paolone[122], A. Papadelis[145a], Th.D. Papadopoulou[9], A. Paramonov[5], D. Paredes Hernandez[33], W. Park[24,z], M.A. Parker[27], F. Parodi[50a,50b], J.A. Parsons[34], U. Parzefall[48], E. Pasqualucci[131a], S. Passaggio[50a], A. Passeri[133a], F. Pastore[133a,133b], Fr. Pastore[75], G. Pásztor [49,aa], S. Pataraia[173], N. Patel[149], J.R. Pater[81], S. Patricelli[101a,101b], T. Pauly[29], M. Pecsy[143a], M.I. Pedraza Morales[171], S.V. Peleganchuk[106], H. Peng[32b], R. Pengo[29], B. Penning[30], A. Penson[34], J. Penwell[60], M. Perantoni[23a], K. Perez[34,ab], T. Perez Cavalcanti[41], E. Perez Codina[11], M.T. Pérez García-Estañ[166], V. Perez Reale[34], L. Perini[88a,88b], H. Pernegger[29], R. Perrino[71a], P. Perrodo[4], S. Persembe[3a], A. Perus[114], V.D. Peshekhonov[64], K. Peters[29], B.A. Petersen[29], J. Petersen[29], T.C. Petersen[35], E. Petit[4], A. Petridis[153], C. Petridou[153], E. Petrolo[131a], F. Petrucci[133a,133b], D. Petschull[41], M. Petteni[141], R. Pezoa[31b], A. Phan[85], P.W. Phillips[128], G. Piacquadio[29], E. Piccaro[74], M. Piccinini[19a,19b], S.M. Piec[41], R. Piegaia[26], D.T. Pignotti[108], J.E. Pilcher[30], A.D. Pilkington[81], J. Pina[123a,b], M. Pinamonti[163a,163c], A. Pinder[117], J.L. Pinfold[2], J. Ping[32c], B. Pinto[123a], O. Pirotte[29], C. Pizio[88a,88b], M. Plamondon[168], M.-A. Pleier[24], A.V. Pleskach[127], A. Poblaguev[24], S. Poddar[58a], F. Podlyski[33], L. Poggioli[114], T. Poghosyan[20], M. Pohl[49], F. Polci[55], G. Polesello[118a], A. Policicchio[36a,36b], A. Polini[19a], J. Poll[74], V. Polychronakos[24], D.M. Pomarede[135], D. Pomeroy[22], K. Pommès[29], L. Pontecorvo[131a], B.G. Pope[87], G.A. Popeneciu[25a], D.S. Popovic[12a], A. Poppleton[29], X. Portell Bueso[29], C. Posch[21], G.E. Pospelov[98], S. Pospisil[126], I.N. Potrap[98], C.J. Potter[148], C.T. Potter[113], G. Poulard[29], J. Poveda[171], V. Pozdnyakov[64], R. Prabhu[76], P. Pralavorio[82], A. Pranko[14], S. Prasad[57], R. Pravahan[7], S. Prell[63], K. Pretzl[16], L. Pribyl[29], D. Price[60], J. Price[72], L.E. Price[5], M.J. Price[29], D. Prieur[122], M. Primavera[71a], K. Prokofiev[107], F. Prokoshin[31b], S. Protopopescu[24], J. Proudfoot[5], X. Prudent[43], M. Przybycien[37], H. Przysiezniak[4], S. Psoroulas[20], E. Ptacek[113], E. Pueschel[83], J. Purdham[86], M. Purohit[24,z], P. Puzo[114], Y. Pylypchenko[62], J. Qian[86], Z. Qian[82], Z. Qin[41], A. Quadt[54], D.R. Quarrie[14], W.B. Quayle[171], F. Quinonez[31a], M. Raas[103], V. Radescu[58b], B. Radics[20], P. Radloff[113], T. Rador[18a], F. Ragusa[88a,88b], G. Rahal[176], A.M. Rahimi[108], D. Rahm[24], S. Rajagopalan[24], M. Rammensee[48], M. Rammes[140], A.S. Randle-Conde[39], K. Randrianarivony[28], P.N. Ratoff[70], F. Rauscher[97], T.C. Rave[48], M. Raymond[29], A.L. Read[116], D.M. Rebuzzi[118a,118b], A. Redelbach[172], G. Redlinger[24], R. Reece[119], K. Reeves[40], A. Reichold[104], E. Reinherz-Aronis[152], A. Reinsch[113], I. Reisinger[42], C. Rembser[29], Z.L. Ren[150], A. Renaud[114], P. Renkel[39], M. Rescigno[131a], S. Resconi[88a], B. Resende[135], P. Reznicek[97], R. Rezvani[157], A. Richards[76], R. Richter[98], E. Richter-Was[4,ac], M. Ridel[77], M. Rijpstra[104], M. Rijssenbeek[147], A. Rimoldi[118a,118b], L. Rinaldi[19a], R.R. Rios[39], I. Riu[11], G. Rivoltella[88a,88b], F. Rizatdinova[111], E. Rizvi[74], S.H. Robertson[84,j], A. Robichaud-Veronneau[117], D. Robinson[27], J.E.M. Robinson[76], M. Robinson[113], A. Robson[53], J.G. Rocha de Lima[105], C. Roda[121a,121b], D. Roda Dos Santos[29], D. Rodriguez[161], A. Roe[54], S. Roe[29], O. Røhne[116], V. Rojo[1], S. Rolli[160], A. Romaniouk[95], M. Romano[19a,19b], V.M. Romanov[64], G. Romeo[26], E. Romero Adam[166], L. Roos[77], E. Ros[166], S. Rosati[131a], K. Rosbach[49], A. Rose[148], M. Rose[75], G.A. Rosenbaum[157], E.I. Rosenberg[63], P.L. Rosendahl[13], O. Rosenthal[140], L. Rosselet[49], V. Rossetti[11], E. Rossi[131a,131b], L.P. Rossi[50a], M. Rotaru[25a], I. Roth[170], J. Rothberg[137], D. Rousseau[114], C.R. Royon[135], A. Rozanov[82], Y. Rozen[151], X. Ruan[32a,ad], I. Rubinskiy[41], B. Ruckert[97], N. Ruckstuhl[104], V.I. Rud[96], C. Rudolph[43], G. Rudolph[61], F. Rühr[6], F. Ruggieri[133a,133b], A. Ruiz-Martinez[63], V. Rumiantsev[90,*], L. Rumyantsev[64], K. Runge[48], Z. Rurikova[48], N.A. Rusakovich[64], D.R. Rust[60], J.P. Rutherfoord[6], C. Ruwiedel[14], P. Ruzicka[124], Y.F. Ryabov[120], V. Ryadovikov[127], P. Ryan[87], M. Rybar[125], G. Rybkin[114], N.C. Ryder[117], S. Rzaeva[10], A.F. Saavedra[149], I. Sadeh[152], H.F-W. Sadrozinski[136], R. Sadykov[64], F. Safai Tehrani[131a], H. Sakamoto[154], G. Salamanna[74], A. Salamon[132a], M. Saleem[110], D. Salihagic[98], A. Salnikov[142], J. Salt[166], B.M. Salvachua Ferrando[5], D. Salvatore[36a,36b], F. Salvatore[148], A. Salvucci[103], A. Salzburger[29], D. Sampsonidis[153], B.H. Samset[116], A. Sanchez[101a,101b], V. Sanchez Martinez[166], H. Sandaker[13], H.G. Sander[80], M.P. Sanders[97], M. Sandhoff[173], T. Sandoval[27], C. Sandoval [161], R. Sandstroem[98], S. Sandvoss[173], D.P.C. Sankey[128], A. Sansoni[47], C. Santamarina Rios[84], C. Santoni[33], R. Santonico[132a,132b], H. Santos[123a], J.G. Saraiva[123a], T. Sarangi[171], E. Sarkisyan-Grinbaum[7], F. Sarri[121a,121b], G. Sartisohn[173], O. Sasaki[65], N. Sasao[67], I. Satsounkevitch[89], G. Sauvage[4], E. Sauvan[4], J.B. Sauvan[114], P. Savard[157,d], V. Savinov[122], D.O. Savu[29], L. Sawyer[24,l], D.H. Saxon[53], L.P. Says[33], C. Sbarra[19a], A. Sbrizzi[19a,19b], O. Scallon[92], D.A. Scannicchio[162], M. Scarcella[149], J. Schaarschmidt[114], P. Schacht[98], U. Schäfer[80], S. Schaepe[20], S. Schaetzel[58b], A.C. Schaffer[114], D. Schaile[97], R.D. Schamberger[147], A.G. Schamov[106], V. Scharf[58a], V.A. Schegelsky[120], D. Scheirich[86], M. Schernau[162], M.I. Scherzer[34], C. Schiavi[50a,50b], J. Schieck[97], M. Schioppa[36a,36b], S. Schlenker[29], J.L. Schlereth[5], E. Schmidt[48], K. Schmieden[20], C. Schmitt[80], S. Schmitt[58b], M. Schmitz[20], A. Schöning[58b], M. Schott[29], D. Schouten[158a], J. Schovancova[124], M. Schram[84], C. Schroeder[80], N. Schroer[58c], S. Schuh[29], G. Schuler[29], M.J. Schultens[20], J. Schultes[173], H.-C. Schultz-Coulon[58a], H. Schulz[15], J.W. Schumacher[20], M. Schumacher[48], B.A. Schumm[136], Ph. Schune[135], C. Schwanenberger[81], A. Schwartzman[142], Ph. Schwemling[77], R. Schwienhorst[87], R. Schwierz[43], J. Schwindling[135], T. Schwindt[20], M. Schwoerer[4], W.G. Scott[128], J. Searcy[113], G. Sedov[41], E. Sedykh[120], E. Segura[11], S.C. Seidel[102], A. Seiden[136], F. Seifert[43], J.M. Seixas[23a], G. Sekhniaidze[101a], K.E. Selbach[45], D.M. Seliverstov[120], B. Sellden[145a], G. Sellers[72], M. Seman[143b],

N. Semprini-Cesari[19a,19b], C. Serfon[97], L. Serin[114], L. Serkin[54], R. Seuster[98], H. Severini[110], M.E. Sevior[85], A. Sfyrla[29], E. Shabalina[54], M. Shamim[113], L.Y. Shan[32a], J.T. Shank[21], Q.T. Shao[85], M. Shapiro[14], P.B. Shatalov[94], L. Shaver[6], K. Shaw[163a,163c], D. Sherman[174], P. Sherwood[76], A. Shibata[107], H. Shichi[100], S. Shimizu[29], M. Shimojima[99], T. Shin[56], M. Shiyakova[64], A. Shmeleva[93], M.J. Shochet[30], D. Short[117], S. Shrestha[63], E. Shulga[95], M.A. Shupe[6], P. Sicho[124], A. Sidoti[131a], F. Siegert[48], Dj. Sijacki[12a], O. Silbert[170], J. Silva[123a,b], Y. Silver[152], D. Silverstein[142], S.B. Silverstein[145a], V. Simak[126], O. Simard[135], Lj. Simic[12a], S. Simion[114], B. Simmons[76], M. Simonyan[35], P. Sinervo[157], N.B. Sinev[113], V. Sipica[140], G. Siragusa[172], A. Sircar[24], A.N. Sisakyan[64], S.Yu. Sivoklokov[96], J. Sjölin[145a,145b], T.B. Sjursen[13], L.A. Skinnari[14], H.P. Skottowe[57], K. Skovpen[106], P. Skubic[110], N. Skvorodnev[22], M. Slater[17], T. Slavicek[126], K. Sliwa[160], J. Sloper[29], V. Smakhtin[170], B.H. Smart[45], S.Yu. Smirnov[95], Y. Smirnov[95], L.N. Smirnova[96], O. Smirnova[78], B.C. Smith[57], D. Smith[142], K.M. Smith[53], M. Smizanska[70], K. Smolek[126], A.A. Snesarev[93], S.W. Snow[81], J. Snow[110], J. Snuverink[104], S. Snyder[24], M. Soares[123a], R. Sobie[168,j], J. Sodomka[126], A. Soffer[152], C.A. Solans[166], M. Solar[126], J. Solc[126], E. Soldatov[95], U. Soldevila[166], E. Solfaroli Camillocci[131a,131b], A.A. Solodkov[127], O.V. Solovyanov[127], N. Soni[2], V. Sopko[126], B. Sopko[126], M. Sosebee[7], R. Soualah[163a,163c], A. Soukharev[106], S. Spagnolo[71a,71b], F. Spanò[75], R. Spighi[19a], G. Spigo[29], F. Spila[131a,131b], R. Spiwoks[29], M. Spousta[125], T. Spreitzer[157], B. Spurlock[7], R.D. St. Denis[53], J. Stahlman[119], R. Stamen[58a], E. Stanecka[38], R.W. Stanek[5], C. Stanescu[133a], S. Stapnes[116], E.A. Starchenko[127], J. Stark[55], P. Staroba[124], P. Starovoitov[90], A. Staude[97], P. Stavina[143a], G. Stavropoulos[14], G. Steele[53], P. Steinbach[43], P. Steinberg[24], I. Stekl[126], B. Stelzer[141], H.J. Stelzer[87], O. Stelzer-Chilton[158a], H. Stenzel[52], S. Stern[98], K. Stevenson[74], G.A. Stewart[29], J.A. Stillings[20], M.C. Stockton[84], K. Stoerig[48], G. Stoicea[25a], S. Stonjek[98], P. Strachota[125], A.R. Stradling[7], A. Straessner[43], J. Strandberg[146], S. Strandberg[145a,145b], A. Strandlie[116], M. Strang[108], E. Strauss[142], M. Strauss[110], P. Strizenec[143b], R. Ströhmer[172], D.M. Strom[113], J.A. Strong[75,*], R. Stroynowski[39], J. Strube[128], B. Stugu[13], I. Stumer[24,*], J. Stupak[147], P. Sturm[173], N.A. Styles[41], D.A. Soh[150,u], D. Su[142], HS. Subramania[2], A. Succurro[11], Y. Sugaya[115], T. Sugimoto[100], C. Suhr[105], K. Suita[66], M. Suk[125], V.V. Sulin[93], S. Sultansoy[3d], T. Sumida[67], X. Sun[55], J.E. Sundermann[48], K. Suruliz[138], S. Sushkov[11], G. Susinno[36a,36b], M.R. Sutton[148], Y. Suzuki[65], Y. Suzuki[66], M. Svatos[124], Yu.M. Sviridov[127], S. Swedish[167], I. Sykora[143a], T. Sykora[125], B. Szeless[29], J. Sánchez[166], D. Ta[104], K. Tackmann[41], A. Taffard[162], R. Tafirout[158a], N. Taiblum[152], Y. Takahashi[100], H. Takai[24], R. Takashima[68], H. Takeda[66], T. Takeshita[139], Y. Takubo[65], M. Talby[82], A. Talyshev[106,f], M.C. Tamsett[24], J. Tanaka[154], R. Tanaka[114], S. Tanaka[130], S. Tanaka[65], Y. Tanaka[99], A.J. Tanasijczuk[141], K. Tani[66], N. Tannoury[82], G.P. Tappern[29], S. Tapprogge[80], D. Tardif[157], S. Tarem[151], F. Tarrade[28], G.F. Tartarelli[88a], P. Tas[125], M. Tasevsky[124], E. Tassi[36a,36b], M. Tatarkhanov[14], Y. Tayalati[134d], C. Taylor[76], F.E. Taylor[91], G.N. Taylor[85], W. Taylor[158b], M. Teinturier[114], M. Teixeira Dias Castanheira[74], P. Teixeira-Dias[75], K.K. Temming[48], H. Ten Kate[29], P.K. Teng[150], S. Terada[65], K. Terashi[154], J. Terron[79], M. Testa[47], R.J. Teuscher[157,j], J. Thadome[173], J. Therhaag[20], T. Theveneaux-Pelzer[77], M. Thioye[174], S. Thoma[48], J.P. Thomas[17], E.N. Thompson[34], P.D. Thompson[17], P.D. Thompson[157], A.S. Thompson[53], L.A. Thomsen[35], E. Thomson[119], M. Thomson[27], R.P. Thun[86], F. Tian[34], M.J. Tibbetts[14], T. Tic[124], V.O. Tikhomirov[93], Y.A. Tikhonov[106,f], S Timoshenko[95], P. Tipton[174], F.J. Tique Aires Viegas[29], S. Tisserant[82], B. Toczek[37], T. Todorov[4], S. Todorova-Nova[160], B. Toggerson[162], J. Tojo[65], S. Tokár[143a], K. Tokunaga[66], K. Tokushuku[65], K. Tollefson[87], M. Tomoto[100], L. Tompkins[30], K. Toms[102], G. Tong[32a], A. Tonoyan[13], C. Topfel[16], N.D. Topilin[64], I. Torchiani[29], E. Torrence[113], H. Torres[77], E. Torró Pastor[166], J. Toth[82,aa], F. Touchard[82], D.R. Tovey[138], T. Trefzger[172], L. Tremblet[29], A. Tricoli[29], I.M. Trigger[158a], S. Trincaz-Duvoid[77], T.N. Trinh[77], M.F. Tripiana[69], W. Trischuk[157], A. Trivedi[24,z], B. Trocmé[55], C. Troncon[88a], M. Trottier-McDonald[141], M. Trzebinski[38], A. Trzupek[38], C. Tsarouchas[29], J.C-L. Tseng[117], M. Tsiakiris[104], P.V. Tsiareshka[89], D. Tsionou[4,ae], G. Tsipolitis[9], V. Tsiskaridze[48], E.G. Tskhadadze[51a], I.I. Tsukerman[94], V. Tsulaia[14], J.-W. Tsung[20], S. Tsuno[65], D. Tsybychev[147], A. Tua[138], A. Tudorache[25a], V. Tudorache[25a], J.M. Tuggle[30], M. Turala[38], D. Turecek[126], I. Turk Cakir[3e], E. Turlay[104], R. Turra[88a,88b], P.M. Tuts[34], A. Tykhonov[73], M. Tylmad[145a,145b], M. Tyndel[128], G. Tzanakos[8], K. Uchida[20], I. Ueda[154], R. Ueno[28], M. Ugland[13], M. Uhlenbrock[20], M. Uhrmacher[54], F. Ukegawa[159], G. Unal[29], D.G. Underwood[5], A. Undrus[24], G. Unel[162], Y. Unno[65], D. Urbaniec[34], G. Usai[7], M. Uslenghi[118a,118b], L. Vacavant[82], V. Vacek[126], B. Vachon[84], S. Vahsen[14], J. Valenta[124], P. Valente[131a], S. Valentinetti[19a,19b], S. Valkar[125], E. Valladolid Gallego[166], S. Vallecorsa[151], J.A. Valls Ferrer[166], H. van der Graaf[104], E. van der Kraaij[104], R. Van Der Leeuw[104], E. van der Poel[104], D. van der Ster[29], N. van Eldik[83], P. van Gemmeren[5], Z. van Kesteren[104], I. van Vulpen[104], M. Vanadia[98], W. Vandelli[29], G. Vandoni[29], A. Vaniachine[5], P. Vankov[41], F. Vannucci[77], F. Varela Rodriguez[29], R. Vari[131a], E.W. Varnes[6], D. Varouchas[14], A. Vartapetian[7], K.E. Varvell[149], V.I. Vassilakopoulos[56], F. Vazeille[33], G. Vegni[88a,88b], J.J. Veillet[114], C. Vellidis[8], F. Veloso[123a], R. Veness[29], S. Veneziano[131a], A. Ventura[71a,71b], D. Ventura[137], M. Venturi[48], N. Venturi[157], V. Vercesi[118a], M. Verducci[137], W. Verkerke[104], J.C. Vermeulen[104], A. Vest[43], M.C. Vetterli[141,d], I. Vichou[164], T. Vickey[144b,af], O.E. Vickey Boeriu[144b], G.H.A. Viehhauser[117], S. Viel[167], M. Villa[19a,19b], M. Villaplana Perez[166], E. Vilucchi[47], M.G. Vincter[28], E. Vinek[29], V.B. Vinogradov[64], M. Virchaux[135,*], J. Virzi[14], O. Vitells[170], M. Viti[41], I. Vivarelli[48], F. Vives Vaque[2], S. Vlachos[9], D. Vladoiu[97], M. Vlasak[126], N. Vlasov[20], A. Vogel[20], P. Vokac[126], G. Volpi[47],

M. Volpi[85], G. Volpini[88a], H. von der Schmitt[98], J. von Loeben[98], H. von Radziewski[48], E. von Toerne[20], V. Vorobel[125], A.P. Vorobiev[127], V. Vorwerk[11], M. Vos[166], R. Voss[29], T.T. Voss[173], J.H. Vossebeld[72], N. Vranjes[135], M. Vranjes Milosavljevic[104], V. Vrba[124], M. Vreeswijk[104], T. Vu Anh[48], R. Vuillermet[29], I. Vukotic[114], W. Wagner[173], P. Wagner[119], H. Wahlen[173], J. Wakabayashi[100], J. Walbersloh[42], S. Walch[86], J. Walder[70], R. Walker[97], W. Walkowiak[140], R. Wall[174], P. Waller[72], C. Wang[44], H. Wang[171], H. Wang[32b,ag], J. Wang[150], J. Wang[55], J.C. Wang[137], R. Wang[102], S.M. Wang[150], A. Warburton[84], C.P. Ward[27], M. Warsinsky[48], P.M. Watkins[17], A.T. Watson[17], I.J. Watson[149], M.F. Watson[17], G. Watts[137], S. Watts[81], A.T. Waugh[149], B.M. Waugh[76], M. Weber[128], M.S. Weber[16], P. Weber[54], A.R. Weidberg[117], P. Weigell[98], J. Weingarten[54], C. Weiser[48], H. Wellenstein[22], P.S. Wells[29], M. Wen[47], T. Wenaus[24], D. Wendland[15], S. Wendler[122], Z. Weng[150,u], T. Wengler[29], S. Wenig[29], N. Wermes[20], M. Werner[48], P. Werner[29], M. Werth[162], M. Wessels[58a], C. Weydert[55], K. Whalen[28], S.J. Wheeler-Ellis[162], S.P. Whitaker[21], A. White[7], M.J. White[85], S.R. Whitehead[117], D. Whiteson[162], D. Whittington[60], F. Wicek[114], D. Wicke[173], F.J. Wickens[128], W. Wiedenmann[171], M. Wielers[128], P. Wienemann[20], C. Wiglesworth[74], L.A.M. Wiik-Fuchs[48], P.A. Wijeratne[76], A. Wildauer[166], M.A. Wildt[41,q], I. Wilhelm[125], H.G. Wilkens[29], J.Z. Will[97], E. Williams[34], H.H. Williams[119], W. Willis[34], S. Willocq[83], J.A. Wilson[17], M.G. Wilson[142], A. Wilson[86], I. Wingerter-Seez[4], S. Winkelmann[48], F. Winklmeier[29], M. Wittgen[142], M.W. Wolter[38], H. Wolters[123a,h], W.C. Wong[40], G. Wooden[86], B.K. Wosiek[38], J. Wotschack[29], M.J. Woudstra[83], K.W. Wozniak[38], K. Wraight[53], C. Wright[53], M. Wright[53], B. Wrona[72], S.L. Wu[171], X. Wu[49], Y. Wu[32b,ah], E. Wulf[34], R. Wunstorf[42], B.M. Wynne[45], S. Xella[35], M. Xiao[135], S. Xie[48], Y. Xie[32a], C. Xu[32b,w], D. Xu[138], G. Xu[32a], B. Yabsley[149], S. Yacoob[144b], M. Yamada[65], H. Yamaguchi[154], A. Yamamoto[65], K. Yamamoto[63], S. Yamamoto[154], T. Yamamura[154], T. Yamanaka[154], J. Yamaoka[44], T. Yamazaki[154], Y. Yamazaki[66], Z. Yan[21], H. Yang[86], U.K. Yang[81], Y. Yang[60], Y. Yang[32a], Z. Yang[145a,145b], S. Yanush[90], Y. Yao[14], Y. Yasu[65], G.V. Ybeles Smit[129], J. Ye[39], S. Ye[24], M. Yilmaz[3c], R. Yoosoofmiya[122], K. Yorita[169], R. Yoshida[5], C. Young[142], S. Youssef[21], D. Yu[24], J. Yu[7], J. Yu[111], L. Yuan[32a,ai], A. Yurkewicz[105], B. Zabinski[38], V.G. Zaets [127], R. Zaidan[62], A.M. Zaitsev[127], Z. Zajacova[29], L. Zanello[131a,131b], P. Zarzhitsky[39], A. Zaytsev[106], C. Zeitnitz[173], M. Zeller[174], M. Zeman[124], A. Zemla[38], C. Zendler[20], O. Zenin[127], T. Ženiš[143a], Z. Zinonos[121a,121b], S. Zenz[14], D. Zerwas[114], G. Zevi della Porta[57], Z. Zhan[32d], D. Zhang[32b,ag], H. Zhang[87], J. Zhang[5], X. Zhang[32d], Z. Zhang[114], L. Zhao[107], T. Zhao[137], Z. Zhao[32b], A. Zhemchugov[64], S. Zheng[32a], J. Zhong[117], B. Zhou[86], N. Zhou[162], Y. Zhou[150], C.G. Zhu[32d], H. Zhu[41], J. Zhu[86], Y. Zhu[32b], X. Zhuang[97], V. Zhuravlov[98], D. Zieminska[60], R. Zimmermann[20], S. Zimmermann[20], S. Zimmermann[48], M. Ziolkowski[140], R. Zitoun[4], L. Živković[34], V.V. Zmouchko[127,*], G. Zobernig[171], A. Zoccoli[19a,19b], Y. Zolnierowski[4], A. Zsenei[29], M. zur Nedden[15], V. Zutshi[105], 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 Fisica, 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] Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina
[70] Physics Department, Lancaster University, Lancaster, United Kingdom
[71] [(a)]INFN Sezione di Lecce; [(b)]Dipartimento di Fisica, Università del Salento, Lecce, Italy
[72] Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom
[73] Department of Physics, Jožef Stefan Institute and University of Ljubljana, Ljubljana, Slovenia
[74] School of Physics and Astronomy, Queen Mary University of London, London, United Kingdom
[75] Department of Physics, Royal Holloway University of London, Surrey, United Kingdom
[76] Department of Physics and Astronomy, University College London, London, United Kingdom
[77] Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France
[78] Fysiska institutionen, Lunds universitet, Lund, Sweden
[79] Departamento de Fisica Teorica C-15, Universidad Autonoma de Madrid, Madrid, Spain
[80] Institut für Physik, Universität Mainz, Mainz, Germany
[81] School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom
[82] CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France
[83] Department of Physics, University of Massachusetts, Amherst MA, United States of America
[84] Department of Physics, McGill University, Montreal QC, Canada
[85] School of Physics, University of Melbourne, Victoria, Australia
[86] Department of Physics, The University of Michigan, Ann Arbor MI, United States of America
[87] Department of Physics and Astronomy, Michigan State University, East Lansing MI, United States of America
[88] [(a)]INFN Sezione di Milano; [(b)]Dipartimento di Fisica, Università di Milano, Milano, Italy
[89] B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Republic of Belarus
[90] National Scientific and Educational Centre for Particle and High Energy Physics, Minsk, Republic of Belarus
[91] Department of Physics, Massachusetts Institute of Technology, Cambridge MA, United States of America
[92] Group of Particle Physics, University of Montreal, Montreal QC, Canada
[93] P.N. Lebedev Institute of Physics, Academy of Sciences, Moscow, Russia
[94] Institute for Theoretical and Experimental Physics (ITEP), Moscow, Russia
[95] Moscow Engineering and Physics Institute (MEPhI), Moscow, Russia
[96] Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
[97] Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany
[98] Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany
[99] Nagasaki Institute of Applied Science, Nagasaki, Japan
[100] Graduate School of Science, Nagoya University, Nagoya, Japan
[101] [(a)]INFN Sezione di Napoli; [(b)]Dipartimento di Scienze Fisiche, Università di Napoli, Napoli, Italy
[102] Department of Physics and Astronomy, University of New Mexico, Albuquerque NM, United States of America
[103] Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands
[104] Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands
[105] Department of Physics, Northern Illinois University, DeKalb IL, United States of America
[106] Budker Institute of Nuclear Physics, SB RAS, Novosibirsk, Russia
[107] Department of Physics, New York University, New York NY, United States of America
[108] Ohio State University, Columbus OH, United States of America
[109] Faculty of Science, Okayama University, Okayama, Japan
[110] Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman OK, United States of America
[111] Department of Physics, Oklahoma State University, Stillwater OK, United States of America
[112] Palacký University, RCPTM, Olomouc, Czech Republic
[113] Center for High Energy Physics, University of Oregon, Eugene OR, United States of America
[114] LAL, Univ. Paris-Sud and CNRS/IN2P3, Orsay, France
[115] Graduate School of Science, Osaka University, Osaka, Japan
[116] Department of Physics, University of Oslo, Oslo, Norway
[117] Department of Physics, Oxford University, Oxford, United Kingdom
[118] [(a)]INFN Sezione di Pavia; [(b)]Dipartimento di Fisica, Università di Pavia, Pavia, Italy

[119] Department of Physics, University of Pennsylvania, Philadelphia PA, United States of America
[120] Petersburg Nuclear Physics Institute, Gatchina, Russia
[121] [(a)]INFN Sezione di Pisa; [(b)]Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy
[122] Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh PA, United States of America
[123] [(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
[124] Institute of Physics, Academy of Sciences of the Czech Republic, Praha, Czech Republic
[125] Faculty of Mathematics and Physics, Charles University in Prague, Praha, Czech Republic
[126] Czech Technical University in Prague, Praha, Czech Republic
[127] State Research Center Institute for High Energy Physics, Protvino, Russia
[128] Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom
[129] Physics Department, University of Regina, Regina SK, Canada
[130] Ritsumeikan University, Kusatsu, Shiga, Japan
[131] [(a)]INFN Sezione di Roma I; [(b)]Dipartimento di Fisica, Università La Sapienza, Roma, Italy
[132] [(a)]INFN Sezione di Roma Tor Vergata; [(b)]Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy
[133] [(a)]INFN Sezione di Roma Tre; [(b)]Dipartimento di Fisica, Università Roma Tre, Roma, Italy
[134] [(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
[135] DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l'Univers), CEA Saclay (Commissariat a l'Energie Atomique), Gif-sur-Yvette, France
[136] Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz CA, United States of America
[137] Department of Physics, University of Washington, Seattle WA, United States of America
[138] Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom
[139] Department of Physics, Shinshu University, Nagano, Japan
[140] Fachbereich Physik, Universität Siegen, Siegen, Germany
[141] Department of Physics, Simon Fraser University, Burnaby BC, Canada
[142] SLAC National Accelerator Laboratory, Stanford CA, United States of America
[143] [(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
[144] [(a)]Department of Physics, University of Johannesburg, Johannesburg; [(b)]School of Physics, University of the Witwatersrand, Johannesburg, South Africa
[145] [(a)]Department of Physics, Stockholm University; [(b)]The Oskar Klein Centre, Stockholm, Sweden
[146] Physics Department, Royal Institute of Technology, Stockholm, Sweden
[147] Departments of Physics & Astronomy and Chemistry, Stony Brook University, Stony Brook NY, United States of America
[148] Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom
[149] School of Physics, University of Sydney, Sydney, Australia
[150] Institute of Physics, Academia Sinica, Taipei, Taiwan
[151] Department of Physics, Technion: Israel Inst. of Technology, Haifa, Israel
[152] Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel
[153] Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece
[154] International Center for Elementary Particle Physics and Department of Physics, The University of Tokyo, Tokyo, Japan
[155] Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo, Japan
[156] Department of Physics, Tokyo Institute of Technology, Tokyo, Japan
[157] Department of Physics, University of Toronto, Toronto ON, Canada
[158] [(a)]TRIUMF, Vancouver BC; [(b)]Department of Physics and Astronomy, York University, Toronto ON, Canada
[159] Institute of Pure and Applied Sciences, University of Tsukuba,1-1-1 Tennodai,Tsukuba, Ibaraki 305-8571, Japan
[160] Science and Technology Center, Tufts University, Medford MA, United States of America
[161] Centro de Investigaciones, Universidad Antonio Narino, Bogota, Colombia
[162] Department of Physics and Astronomy, University of California Irvine, Irvine CA, United States of America
[163] [(a)]INFN Gruppo Collegato di Udine; [(b)]ICTP, Trieste; [(c)]Dipartimento di Chimica, Fisica e Ambiente, Università di Udine, Udine, Italy
[164] Department of Physics, University of Illinois, Urbana IL, United States of America

[165] Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden
[166] 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
[167] Department of Physics, University of British Columbia, Vancouver BC, Canada
[168] Department of Physics and Astronomy, University of Victoria, Victoria BC, Canada
[169] Waseda University, Tokyo, Japan
[170] Department of Particle Physics, The Weizmann Institute of Science, Rehovot, Israel
[171] Department of Physics, University of Wisconsin, Madison WI, United States of America
[172] Fakultät für Physik und Astronomie, Julius-Maximilians-Universität, Würzburg, Germany
[173] Fachbereich C Physik, Bergische Universität Wuppertal, Wuppertal, Germany
[174] Department of Physics, Yale University, New Haven CT, United States of America
[175] Yerevan Physics Institute, Yerevan, Armenia
[176] Domaine scientifique de la Doua, Centre de Calcul CNRS/IN2P3, Villeurbanne Cedex, France
[177] Faculty of Science, Hiroshima University, Hiroshima, Japan
[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 Università di Napoli Parthenope, Napoli, Italy
[j] Also at Institute of Particle Physics (IPP), Canada
[k] Also at Department of Physics, Middle East Technical University, Ankara, Turkey
[l] Also at Louisiana Tech University, Ruston LA, United States of America
[m] Also at Department of Physics and Astronomy, University College London, London, United Kingdom
[n] Also at Group of Particle Physics, University of Montreal, Montreal QC, Canada
[o] Also at Department of Physics, University of Cape Town, Cape Town, South Africa
[p] Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan
[q] Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany
[r] Also at Manhattan College, New York NY, United States of America
[s] Also at School of Physics, Shandong University, Shandong, China
[t] Also at CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France
[u] Also at School of Physics and Engineering, Sun Yat-sen University, Guanzhou, China
[v] Also at Academia Sinica Grid Computing, Institute of Physics, Academia Sinica, Taipei, Taiwan
[w] 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
[x] Also at Section de Physique, Université de Genève, Geneva, Switzerland
[y] Also at Departamento de Fisica, Universidade de Minho, Braga, Portugal
[z] Also at Department of Physics and Astronomy, University of South Carolina, Columbia SC, United States of America
[aa] Also at Institute for Particle and Nuclear Physics, Wigner Research Centre for Physics, Budapest, Hungary
[ab] Also at California Institute of Technology, Pasadena CA, United States of America
[ac] Also at Institute of Physics, Jagiellonian University, Krakow, Poland
[ad] Also at LAL, Univ. Paris-Sud and CNRS/IN2P3, Orsay, France
[ae] Also at Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom
[af] Also at Department of Physics, Oxford University, Oxford, United Kingdom
[ag] Also at Institute of Physics, Academia Sinica, Taipei, Taiwan
[ah] Also at Department of Physics, The University of Michigan, Ann Arbor MI, United States of America
[ai] Also at Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France
* Deceased