EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

CERN-PH-EP-2012-102
Submitted to: Physics Letters B

Measurement of the top quark pair production cross section with ATLAS in pp collisions at $\sqrt{s} = 7$ TeV using final states with an electron or a muon and a hadronically decaying τ lepton

The ATLAS Collaboration

Abstract

A measurement of the cross section of top quark pair production in proton–proton collisions recorded with the ATLAS detector at the LHC at a centre-of-mass energy of 7 TeV is reported. The data sample used corresponds to an integrated luminosity of 2.05 fb^{-1}. Events with an isolated electron or muon and a τ lepton decaying hadronically are used. In addition, a large missing transverse momentum and two or more energetic jets are required. At least one of the jets must be identified as originating from a b quark. The measured cross section, $\sigma_{t\bar{t}} = 186 \pm 13$ (stat.) ± 20 (syst.) ± 7(lumi.) pb, is in good agreement with the Standard Model prediction.

Measurement of the top quark pair cross section with ATLAS in pp collisions at $\sqrt{s} = 7$ TeV using final states with an electron or a muon and a hadronically decaying τ lepton

The ATLAS Collaboration

Abstract

A measurement of the cross section of top quark pair production in proton−proton collisions recorded with the ATLAS detector at the LHC at a centre-of-mass energy of 7 TeV is reported. The data sample used corresponds to an integrated luminosity of 2.05 fb^{-1}. Events with an isolated electron or muon and a τ lepton decaying hadronically are used. In addition, a large missing transverse momentum and two or more energetic jets are required. At least one of the jets must be identified as originating from a b quark. The measured cross section, $\sigma_{t\bar{t}} = 186 \pm 13$ (stat.) $\pm$ 20 (syst.) $\pm$ 7(lumi.) pb, is in good agreement with the Standard Model prediction.

Keywords: top-quark physics, cross section, lepton+τ

1. Introduction

Measuring the top quark pair ($t\bar{t}$) production cross section ($\sigma_{t\bar{t}}$) in different decay channels is of interest because it can open a window to physics beyond the Standard Model (SM). In the SM, the top quark decays with a branching ratio close to 100% into a W boson and a b quark, and $t\bar{t}$ pairs are identified by either the hadronic or leptonic decays of the W bosons and the presence of additional jets. ATLAS has previously used the single-lepton channel [1], and the dilepton channels including only electrons and muons [2] to perform cross-section measurements.

The large cross section for $t\bar{t}$ production at the LHC provides an opportunity to measure $\sigma_{t\bar{t}}$ using final states with an electron or a muon and a τ lepton with high precision. The $\sigma_{t\bar{t}}$ in this channel has been measured at the Tevatron with 25% precision [6] and recently by the CMS Collaboration at the LHC with 18% precision [7]. A deviation from $\sigma_{t\bar{t}}$ measured in other channels would be an indication of non-Standard Model decays of the top quark, such as a decay to a charged Higgs (H^+) and a b quark with H^+ decaying to a τ lepton and a τ neutrino, or contributions from non-Standard Model processes [3, 4, 5]. ATLAS has set upper limits on the branching ratio of top quark decays to an H^+ bosons decaying to a τ lepton and a neutrino [8].

This analysis uses 2.05 fb^{-1} of data collected by ATLAS at the LHC from pp collisions at a centre-of-mass energy of 7 TeV between March and August 2011. After application of kinematic selection criteria that require one top quark to decay via $W \to \ell\nu$ (where ℓ is either a muon or an electron) and identification of a jet as originating from a b quark (b-tag), the dominant background to the $t\bar{t} \to \ell + \tau + X$ channels with the τ lepton decaying hadronically is the $t\bar{t} \to \ell$ + jets channel in which a jet is misidentified as a hadronic τ lepton decay. Therefore, τ lepton identification (τ ID) is critical for separating signal and background. The τ ID methodology employed in this analysis exploits a multivariate technique to build a discriminant [9]. A boosted decision tree (BDT) algorithm is used [10]. The number of τ leptons in a sample is extracted by fitting the distributions of BDT outputs to background and signal templates. The results are checked using an alternative method, referred to as the "matrix method", based on a cut on the BDT output.

2. ATLAS Detector

The ATLAS detector [11] at the LHC covers nearly the entire solid angle around the collision point.[1] It consists of an inner tracking detector surrounded by a thin superconducting solenoid, electromagnetic (EM) and hadronic calorimeters, and an external muon spectrometer incorporating three large superconducting toroid magnet assemblies. The inner tracking detector provides tracking information in a pseudorapidity range $|\eta| < 2.5$. The liquid-argon (LAr) EM sampling calorimeters cover a range of $|\eta| < 3.2$ with fine granularity. An iron–scintillator tile calorimeter provides hadronic energy measurements in the central rapidity range ($|\eta| < 1.7$). The endcap and forward regions are instrumented with LAr calorimeters for both EM and hadronic energy measurements covering $|\eta| < 4.9$. The muon spectrometer provides precise tracking information in a range of $|\eta| < 2.7$.

[1] 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. The x-axis points to the centre of the LHC ring, and the y-axis points upwards. The azimuthal angle ϕ is measured around the beam axis and the polar angle θ is the angle from the beam axis. The pseudorapidity is defined as $\eta = -\ln[\tan(\theta/2)]$. The distance ΔR in $\eta - \phi$ space is defined as $\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$.

ATLAS uses a three-level trigger system to select events. The level-1 trigger is implemented in hardware using a subset of detector information to reduce the event rate below 75 kHz. This is followed by two software based-trigger levels, level-2 and the event filter, which together reduce the event rate to about 300 Hz recorded for analysis.

3. Simulated Event Samples

Monte Carlo (MC) simulation samples are used to optimise selection procedures, to calculate the signal acceptance and to evaluate contributions from some background processes.

For the $t\bar{t}$ and single top-quark final states, the next-to-leading-order (NLO) generator MC@NLO [12] is used with a top-quark mass of 172.5 GeV and with the NLO parton distribution function (PDF) set CTEQ6.6 [13]. The "diagram removal scheme" is used to remove overlaps between the single top-quark and the $t\bar{t}$ final states. The $t\bar{t}$ cross section is normalised to the prediction of HATHOR (164^{+11}_{-16} pb) [14], which employs an approximate next-to-next-to-leading-order (NNLO) perturbative QCD calculation.

For the background channels, MC samples of W/Z, single top-quark events and diboson WW, WZ, and ZZ events (all in association with jets) are used. W+jets events and Z/γ^{*}+jets events (with dilepton invariant mass $m_{\ell^+\ell^-} > 40$ GeV) are generated by the ALPGEN generator [15] with up to five outgoing partons from the hard scattering process, in addition to the vector bosons.[2] The MLM matching scheme of the ALPGEN generator is used to remove overlaps between matrix-element and parton-shower products. Parton evolution and hadronisation is handled by HERWIG [16], as is the generation of diboson events. The leading-order PDF set CTEQ6L is used for all backgrounds described above.

All samples that use HERWIG for parton shower evolution and hadronisation rely on JIMMY [17] for the underlying event model. The τ-lepton decays are handled by TAUOLA [18]. The effect of multiple pp interactions per bunch crossing ("pile-up") is modelled by overlaying simulated minimum bias events over the original hard-scattering event [19]. MC events are then reweighted so that the distribution of interactions per crossing in the MC simulation matches that observed in data. The average number of pile-up events in the sample is 6.3. After event generation, all samples are processed with the GEANT4 [20] simulation of the ATLAS detector, the trigger simulation and are then subject to the same reconstruction algorithms as the data [21].

4. Data and Event Selection

The event selection uses the same object definition as in the $t\bar{t}$ cross-section measurement in the dilepton channel [2] with the exception of a τ candidate instead of a second electron or muon candidate and some minor adjustments. The electrons must be isolated and have $E_T > 25$ GeV and $|\eta_{\mathrm{cluster}}| < 2.47$, excluding the barrel-endcap transition region ($1.37 < |\eta_{\mathrm{cluster}}| < 1.52$), where E_T is the transverse energy and η_{cluster} is the pseudorapidity of the calorimeter energy cluster associated with the candidate.The electron is defined as isolated if the E_T deposited in the calorimeter and not associated with the electron in a cone in η-ϕ space of radius $\Delta R = 0.2$ is less than 4 GeV. The muons must also be isolated and have $p_T > 20$ GeV and $|\eta| < 2.5$. For isolated muons, both the corresponding E_T and the analogous track isolation transverse momentum (p_T) must be less than 4 GeV in a cone of $\Delta R = 0.3$. The track isolation p_T is calculated from the sum of the track transverse momenta for tracks with $p_T > 1$ GeV around the muon. Jets are reconstructed with the anti-k_t algorithm [22] with a radius parameter $R = 0.4$, starting from energy deposits (clusters) in the calorimeter reconstructed using the scale established for electromagnetic objects. These jets are then calibrated to the hadronic energy scale using p_T- and η-dependent correction factors obtained from simulation [25]. The jet candidates are required to have $p_T > 25$ GeV and $|\eta| < 2.5$. Jets identified as originating from a b quark (b-tag) by a vertex tagging algorithm are those that pass a decay length significance cut corresponding to an efficiency of 70% for b-quark jets from $t\bar{t}$ events and a 1% efficiency for light-quark and gluon jets [2, 26].

The missing transverse momentum is constructed from the vector sum of all calorimeter cells with $|\eta| < 4.5$, projected onto the transverse plane. Its magnitude is denoted E_T^{miss}. The hadronic energy scale is used for the energies of cells associated with jets; τ candidates are treated as jets. Contributions from cells associated with electrons employ the electromagnetic energy calibration. Contributions from the p_T of muon tracks are included, removing the contributions of any calorimeter cells associated with the muon.

4.1. τ Reconstruction and Identification

The reconstruction and identification of hadronically decaying τ leptons proceeds as follows:

1. the τ candidate reconstruction starts by considering each jet as a τ candidate;
2. energy clusters in the calorimeter associated with the τ candidate are used to calculate kinematic quantities (such as E_T) and the associated tracks are found;
3. identification variables are calculated from the tracking and calorimeter information;
4. these variables are combined into multivariate discriminants and the outputs of the discriminants are used to separate jets and electrons misidentified as τ leptons decaying hadronically from τ leptons.

Details are given in Ref. 9. In this analysis the outputs of BDT discriminants are used.

Reconstructed τ candidates are required to have $20\,\mathrm{GeV} < E_T < 100\,\mathrm{GeV}$. They must also have $|\eta| < 2.3$, and one, two or three associated tracks. A track is associated with the τ candidate if it has $p_T > 1$ GeV and is inside a cone of $\Delta R < 0.4$ around the jet axis. The associated track with highest p_T must

[2]The fraction of events with $m_{\ell^+\ell^-} < 40$ GeV is estimated to be less than 0.2% of the total after all selections.

have $p_T > 4$ GeV. The charge is given by the sum of the charges of the associated tracks, and is required to be non-zero. The probability of misidentifying the τ lepton charge sign is about 1%. The charge misidentification rate for muons and electrons is negligible.

If the τ candidate overlaps with a muon ($p_T > 4$ GeV, no isolation required) or an electron candidate within $\Delta R(\ell, \tau) < 0.4$, the τ candidate is removed. To remove electrons misidentified as τ leptons, an additional criterion is used that relies on a BDT trained to separate τ leptons and electrons (BDT$_e$) using seven variables shown to be well modelled by comparing $Z \to e^+e^-$ and $Z \to \tau^+\tau^-$ events in data and in MC simulation. The variables were chosen after ranking a large set by their effectiveness.[3] The most effective variables for BDT$_e$ are E/p, the EM fraction (the ratio of the τ candidate energy measured in the EM calorimeter to the total τ candidate energy measured in the calorimeter), and the cluster-based shower width. The BDT output tends to be near 1 (0) if the τ candidate is a τ lepton (electron). The τ candidate is required to satisfy BDT$_e > 0.51$; 85% of reconstructed τ leptons decaying hadronically satisfy that requirement as measured in $Z \to \tau^+\tau^-$ events. The additional rejection for electrons is a factor of 60.

The majority of objects reconstructed as τ candidates in a multi-jet environment are jets misidentified as τ leptons (fake τ). Another BDT (BDT$_j$) based on eight variables is used to separate τ leptons in τ candidates with one track (denoted τ_1) from such jets. For candidates with more than one track (denoted τ_3) BDT$_j$ includes ten variables. The most effective variables for BDT$_j$ are calorimeter and track isolation, cluster-based jet mass, and the fraction of energy within $\Delta R = 0.1$ of the jet axis. The BDT$_j$ distributions are fit with templates for background and signal to extract the number of τ leptons in the sample. Details are given in Section 6. The fake τ background in the τ_3 sample is significantly higher than in the τ_1 sample, leading to very different BDT$_j$ distributions. Hence independent measurements are carried out for τ_1 and τ_3 candidate events and the results are combined at the end. If there is a τ_1 and a τ_3 candidate in the event, the τ_1 candidate is kept as the probability that the τ_1 is a τ lepton is much higher. If there are two τ_1 or τ_3 candidates, both are kept.

4.2. Event Selection

For this analysis, events are selected using a single-muon trigger with a p_T threshold of 18 GeV or a single-electron trigger with a p_T threshold of 20 GeV, rising to 22 GeV during periods of high instantaneous luminosity. The offline requirements are based on data quality criteria and optimised using Monte Carlo simulation:

- a primary vertex with at least five tracks, each with $p_T >$ 400 MeV, associated with it;
- one and only one isolated high-p_T muon and no identified electrons for the $\mu+\tau$ channel, or one and only one isolated electron and no isolated muons for the $e + \tau$ channel;
- at least one τ candidate (as defined in Section 4.1);
- at least two jets not overlapping with a τ candidate, i.e. $\Delta R(\tau, \text{jet}) > 0.4$;
- $E_T^{\text{miss}} > 30$ GeV to reduce the multi-jet background, and the scalar sum of the p_T of the leptons (including τ), jets, and E_T^{miss} must be greater then 200 GeV, to reduce the W+jets background.

The $\ell + \tau$ samples are divided into events with no jets identified as a b-quark jet (0 b-tag control sample) and those with at least one such jet (≥ 1 b-tag $t\bar{t}$ sample). The 0 b-tag sample is used to estimate the background in the ≥ 1 b-tag $t\bar{t}$ sample. Each sample is split into two, one with the τ candidate and ℓ having the opposite sign charge (OS), and the other one with τ and ℓ having the same sign charge (SS). While the τ candidates in the SS samples are almost all fake τ leptons, the OS samples have a mixture of τ leptons and fake τ leptons. The numbers of observed and expected events in the above samples are shown in Table 1. All processes contribute more events to OS than SS because of the correlation between a leading-quark charge and the lepton charge, except for the multi-jet channel contribution which has equal number of OS and SS events within the uncertainties. The ℓ+jets entry includes the contribution from events with τ leptons when the τ candidate is actually a fake τ. The τ entries require the reconstructed τ candidate be matched to a generated τ lepton. The matching criterion is $\Delta R < 0.1$ between the τ candidate and the observable component of the generated τ lepton.

To estimate the multi-jet background from data, an event selection identical to the $\mu+\tau$ ($e+\tau$) event selection except for an inverted muon (electron) isolation cut is used to obtain a multi-jet template for the shape of the transverse mass, m_T.[4] The normalization of each selected data sample is obtained by fitting the m_T distribution of the selected data samples with the multi-jet template and the sum of non-multi-jet processes predicted by MC, allowing the amount of both to float. The uncertainty on the multi-jet background is estimated to be 30%. However, because of the subtraction method discussed in Section 5, the multi-jet background plays no role in the cross-section measurement. There are small differences between the total number of events predicted and observed which motivate using data as much as possible to estimate the background.

As one can see from Table 1, the τ leptons are almost all in the OS sample and come mainly from two sources: $Z \to \tau^+\tau^-$, which is the dominant source in the sample with 0 b-tag, and $t\bar{t} \to \ell + \tau + X$ which is the dominant source in the sample ≥ 1 b-tag. The sources of fake τ leptons are also quite distinct between the 0 b-tag and the ≥ 1 b-tag samples: the first is mainly W/Z+jets with small contributions from other channels, the second is mainly $t\bar{t}$.

[3] The effectiveness is quantified by quadratically summing over the change in the purity between the mother and daughter leaves for every node in which the given variable is used in a decision tree.

[4] $m_T = \sqrt{(E_T^\ell + E_T^{\text{miss}})^2 - (p_x^\ell + E_x^{\text{miss}})^2 - (p_y^\ell + E_y^{\text{miss}})^2}$.

Table 1: Number of $\ell+\tau$ candidates for Monte Carlo samples and data. $t\bar{t}(\ell+e)$ are $t\bar{t}$ events with one identified lepton and an electron reconstructed as a τ candidate. $t\bar{t}(\ell+\text{jets})$ are $t\bar{t}$ events with one identified lepton and a jet reconstructed as a τ candidate. ℓ+jets are events with one identified lepton and a jet reconstructed as a τ candidates from sources other than $t\bar{t}$ and multi-jets. Sources contributing to jet fakes are W+jets, Z+jets, single top-quark and diboson events. $Wt(\ell+\tau)$ is $W+t$ production with one W decaying to ℓ and another to τ. Excepting multi-jets the uncertainties are statistical only. MC samples are normalized to the data integrated luminosity

$\mu+\tau$	τ_1				τ_3			
	0 b-tag		≥ 1 b-tag		0 b-tag		≥ 1 b-tag	
	OS	SS	OS	SS	OS	SS	OS	SS
$t\bar{t}(\mu+\tau)$	60 ± 2	< 1	390 ± 4	2 ± 1	17 ± 1	1 ± 1	118 ± 3	2 ± 1
$t\bar{t}(\mu+e)$	3 ± 1	< 1	12 ± 1	1 ± 1	1 ± 1	< 1	3 ± 1	< 1
$t\bar{t}(\mu+\text{jets})$	308 ± 4	163 ± 3	1528 ± 9	660 ± 6	685 ± 6	443 ± 5	3484 ± 13	2000 ± 10
μ+jets	5010 ± 70	3020 ± 60	496 ± 17	297 ± 13	12230 ± 120	8670 ± 90	1293 ± 28	928 ± 24
Multi−jets	470 ± 140	540 ± 160	117 ± 35	150 ± 40	990 ± 300	1120 ± 340	460 ± 140	400 ± 120
$Wt(\mu+\tau)$	7 ± 1	< 1	18 ± 1	1 ± 1	2 ± 1	< 1	5 ± 1	< 1
$Z\to\tau\tau$	301 ± 13	2 ± 1	16 ± 3	< 1	75 ± 7	1 ± 1	3 ± 2	< 1
Total	6160 ± 160	3730 ± 170	2580 ± 40	1110 ± 40	14000 ± 320	10230 ± 350	5370 ± 140	3330 ± 120
Data	5450	3700	2472	1332	13322	10193	5703	3683

$e+\tau$	τ_1				τ_3			
	0 b-tag		≥ 1 b-tag		0 b-tag		≥ 1 b-tag	
	OS	SS	OS	SS	OS	SS	OS	SS
$t\bar{t}(e+\tau)$	54 ± 7	1 ± 1	342 ± 19	3 ± 2	15 ± 4	< 1	103 ± 10	2 ± 1
$t\bar{t}(e+e)$	2 ± 1	< 1	11 ± 3	1± 1	< 1	< 1	2 ± 1	< 1
$t\bar{t}(e+\text{jets})$	273 ± 17	146 ± 12	1340 ± 40	599 ± 25	633 ± 25	399 ± 20	3090 ± 60	1780 ± 40
e+jets	3950 ± 60	2590 ± 50	380 ± 20	256 ± 16	10140 ± 100	7530 ± 90	1120 ± 33	841 ± 29
Multi−jets	600 ± 180	620 ± 190	170 ± 50	140 ± 40	2000 ± 600	2000 ±600	690 ± 210	610 ± 180
$Z\to ee$	92 ± 10	3 ± 2	9 ± 3	< 1	11 ± 3	2 ± 1	< 1	< 1
$Wt(e+\tau)$	7 ± 3	< 1	17 ± 4	< 1	1 ± 1	< 1	5 ± 2	< 1
$Z\to\tau\tau$	217 ± 15	2 ± 1	15 ± 4	< 1	60 ± 7	1 ± 1	3 ± 2	< 1
Total	5190 ± 190	3360 ± 200	2280 ± 70	990 ± 50	12900 ± 600	9900 ± 600	5020 ± 220	3230 ± 180
Data	5111	3462	2277	1107	12102	9635	5033	3192

5. Background Models

The jet origin can strongly influence the τ-lepton fake probability. Due to their narrow shower width and lower track multiplicity, light-quark jets have a higher probability of faking a τ lepton than other jet types. Thus the BDT_j distributions have a strong dependence on the jet type. It is therefore crucial to build a background model which properly reflects the jet composition in order to correctly estimate the fake τ contamination in the signal region. Deriving this background model from control regions in data rather than MC simulation is preferable in order to avoid systematic effects related to jet composition in the MC models.

The gluon component of the fake τ leptons is charge symmetric; therefore it is expected to have the same shape in SS events as in OS events and should contribute the same number of fake τ leptons in each sample. The contribution of fake τ leptons from gluons can be removed by subtracting the distribution of any quantity for SS events from the corresponding distribution for OS events. The multi-jet background also cancels, as can be seen in Table 1. The resulting distributions are labeled OS-SS. Similarly, since each sample is expected to have an almost equal contribution from b-jets and $\bar{b}$-jets, the small b-jet component should also be removed by OS-SS (asymmetric single b production is negligible compared to $b\bar{b}$ production). The only jet types remaining in the OS-SS distributions are light-quark jets. MC studies indicate that the BDT_j distributions of c-quark jets misidentified as τ leptons are not noticeably different from those of light-quark jets.

One can construct a background BDT_j distribution from the 0 b-tag data sample by subtracting the expected amount of true τ signal. The signal is mainly from $Z\to\tau^+\tau^-$ and can be reliably predicted from MC. A control sample dominated by W+jets events is considered as a check. The latter sample is selected by requiring events with a muon and a τ candidate, no additional jets, $E_{\text{T}}^{\text{miss}} > 30$ GeV and 40 GeV $< m_{\text{T}} <$ 100 GeV. According to MC simulation, in W+jets events where exactly one jet is required, 90% of the fake τ leptons are from light-quark jets and 10% from gluons. This sample is labeled $W+1$ jet.

The BDT_j background shapes for the OS-SS 0 b-tag and ≥ 1 b-tag data samples are not identical to the $W+1$ jet distributions for two reasons: (1) the shape depends on the jet multiplicity, (2) different OS/SS ratios are observed in the samples. The dependence on the OS/SS ratio comes from the differences in jet fragmentation for a leading particle with the opposite charge and the same charge as the initial quark. MC studies of the ratio of OS-SS BDT_j background distributions derived from $W+1$ jet and ≥ 1 b-tag show that significant corrections are needed (30% for $\text{BDT}_j > 0.8$, a region dominated by the true τ signal). For the 0 b-tag sample the corresponding corrections are much smaller (5% in the same region). Both the 0 b-tag and the W + 1 jet data samples are used to obtain statistically independent estimates of the background in the $\geq$ 1 b-tag sample.

Two different approaches are used for constructing backgrounds in the $\geq$ 1 b-tag data sample. One, used by the fit method (Section 6), is to reweight the BDT$_j$ distribution of the background bin-by-bin using the MC-based ratio of the $\geq$ 1 b-tag background to the background model. In this case the 0 b-tag sample is preferred as it requires smaller corrections derived from MC simulation; the W + 1 jet is used as a cross check. The other approach is to split the background into bins of some variable within which the shapes of BDT$_j$ distributions of the background model are close to those from the $\geq$ 1 b-tag background. This approach, used in the Matrix Method cross check (Section 6.1), avoids using MC corrections, but assumes the data and MC simulation behave similarly as function of the binning variable.

6. Fits to BDT$_j$ Distributions

The contribution from $t\bar{t} \to \ell+\tau+X$ signal is derived from the $\geq$ 1 b-tag data sample by a χ^2 fit to the OS−SS BDT$_j$ distribution with a background template and a signal template. The parameters of the fit are the amount of background and the amount of signal. The shapes of the templates are fixed.

Two background templates corrected by MC, as discussed in Section 5, are used: one derived from 0 b-tag data, the other from the W + 1 jet data sample. The signal BDT$_j$ templates for 0 b-tag and $\geq$ 1 b-tag are derived from τ leptons in $t\bar{t}$ and $Z \to \tau^+\tau^-$ MC simulation. Contributions to the BDT$_j$ distributions from electrons passing the BDT$_e$ cut cannot be distinguished from τ leptons so they are treated as part of the signal.

The uncertainty on the background templates is determined by the numbers of data and MC simulated events. The signal template for the 0 b-tag control sample also has non-negligible statistical uncertainty (2% for τ_1, 5% for τ_3) because of the low acceptance.

The fitting procedure was tested extensively with MC simulation before applying it to data. In the fits to the $\geq$ 1 b-tag data, applying MC corrections to the 0 b-tag background template increases the statistical uncertainty but raises the measured cross section by only 1%.

Figure 1 shows the BDT$_j$ (OS-SS) distributions of ℓ+τ events with 0 b-tag and the 0 b-tag background template after subtracting the expected number of τ leptons and applying the MC corrections. The τ signal is mostly $Z \to \tau^+\tau^-$ events with a small contamination of electrons faking τ leptons (from $t\bar{t} \to \ell+e+X$ and $Z \to e^+e^-$) and a small contribution from $t\bar{t} \to \ell+\tau+X$. The uncertainty on the background template includes the statistical uncertainty of the correction, the statistical uncertainty from MC and the 0 b-tag data uncertainty.

Figure 2 shows the result of the fit to the $\geq$ 1 b-tag samples. The τ lepton signal is mostly $t\bar{t} \to \ell+\tau+X$ with a small contamination of misidentified electrons (estimated by applying fake probabilities derived from data), and small contributions from $Z \to \tau^+\tau^-$ events and single top-quark events (estimated from MC simulation). These contributions are subtracted from the number of signal events before calculating the cross section. The fit results using the background templates derived from 0 b-tag data and W + 1 jet data are shown in Table 2. The results are consistent with each other within the statistical uncertainties of the background templates. The BDT$_j$ distributions for τ_1 and τ_3 are fitted separately. The combined $\ell+\tau_i$ results are obtained by fitting the sum of the distributions. After adding $\ell + \tau_1$ and $\ell + \tau_3$ signals obtained from a χ^2 fit to the combined $e + \tau$ and $\mu+\tau$ distributions and subtracting the small contributions to the signal from $Z \to \tau^+\tau^-$, $Z \to e^+e^-$ and $t\bar{t} \to e + \ell$ (given in Table 1) the results are 840 $\pm$ 70 (243 $\pm$ 60) $t\bar{t} \to \ell + \tau_1(\tau_3) + X$ events. The uncertainty is from the fit only and does not include systematic uncertainties. The results are in good agreement with the 780 $\pm$ 50 (243 $\pm$ 60) events obtained with the W + 1 jet background template and consistent with the number expected from MC simulation, 726 $\pm$ 19 (217 $\pm$ 10). Note that the fit uncertainty is dominated by the uncertainty on the background template, thus the statistical uncertainties of the results with the two different background templates are not strongly correlated.

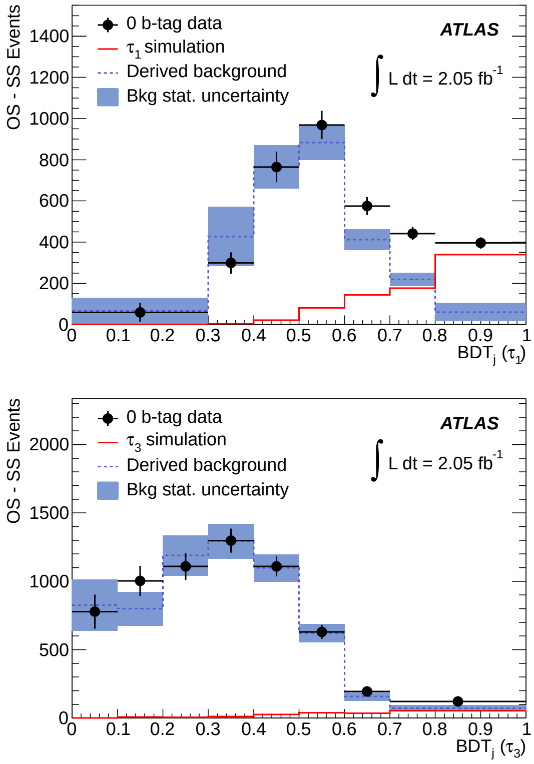

Figure 1: BDT$_j$ (OS-SS) distributions of $\ell + \tau$ (e and μ combined) events in the 0 b-tag data (black points). The expected contributions from τ and e are shown as a solid red line. The derived background templates are shown as dashed histogram with shaded/blue statistical uncertainty bands. The shapes of these background templates are used for the fits to the $\geq$ 1 b-tag distributions after applying MC corrections. Top is for τ_1, bottom for τ_3.

Figure 3 shows the OS-SS distribution of the number of jets for $\geq$ 1 b-tag events adding all channels for two BDT$_j$ regions: BDT$_j$ < 0.7, which is dominated by $t\bar{t} \to \ell$ + jets, and BDT$_j$ >

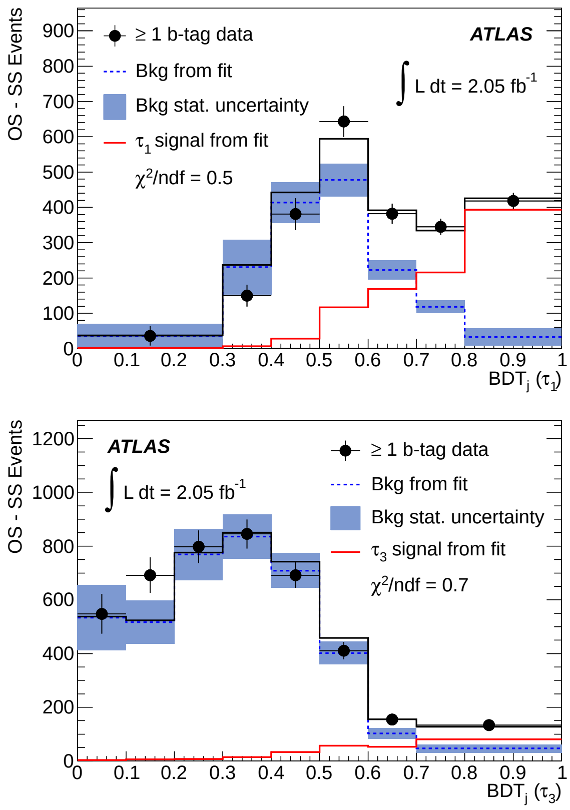

Figure 2: BDT$_j$ (OS-SS) distributions of $\ell + \tau$ in the ≥ 1 b-tag sample. The normalisation of each template is derived from a fit to the data. The fitted contributions are shown as the light/red (signal), dashed/blue (background derived from 0 b-tag after applying MC corrections) and dark/black (total) lines. Shaded/blue bands are the statistical uncertainty of the background template.

Table 2: Results of template fits to $\mu + \tau$, $e + \tau$ and the combined BDT$_j$ distributions. The combined results are obtained by fitting the sum of the $\mu + \tau$ and $e + \tau$ BDT$_j$ distributions. The first column gives the channel and the second the τ type. The third column shows the extracted signal (sum of τ leptons and electrons misidentified as τ leptons) with the background template derived from 0 b-tag data distributions. The fourth column shows the extracted signal with the background template derived from W + 1 jet. The uncertainties are from the uncertainties in the fit parameters and do not include the systematic uncertainties. The MC columns give the expected τ signal and the expected number of $t\bar{t} \to l + \tau$ events after subtracting the contribution from non-$t\bar{t}$ events to the signal, assuming the theoretical $t\bar{t}$ cross section (164 pb).

		Background template		MC	
		0 b-tag	W + 1 jet	Signal	$t\bar{t}$
$\mu + \tau$	τ_1	490 ± 40	456 ± 32	432	388
	τ_3	135 ± 33	130 ± 50	126	116
$e + \tau$	τ_1	440 ± 50	430 ± 50	388	338
	τ_3	116 ± 32	120 ± 28	114	101
Combined	τ_1	930 ± 70	860 ± 50	820	726
	τ_3	260 ± 60	260 ± 40	239	217

0.7, in which the largest contribution is from $t\bar{t} \to \ell + \tau + X$. As expected, the multiplicity of jets peaks at four when BDT$_j$ < 0.7 and three when BDT$_j$ > 0.7 (the τ is counted as a jet).

Figure 4 shows the invariant mass of a selected jet with the τ candidate for BDT$_j$ < 0.7 and BDT$_j$ > 0.7 for events with a τ candidate and three or more jets. The selected jet is the highest p_T untagged jet in events with more than one b-tag and the second highest p_T untagged jet in events with one b-tag. The distribution shows clearly the presence of a W decaying to two jets in the BDT$_j$ < 0.7 region dominated by $t\bar{t} \to \ell$ + jets. The mass distribution in the BDT$_j$ > 0.7 signal region is significantly broader as expected for $t\bar{t} \to \ell + \tau + X$. The signal and background shown in these figures are based on the fit using the 0 b-tag background template.

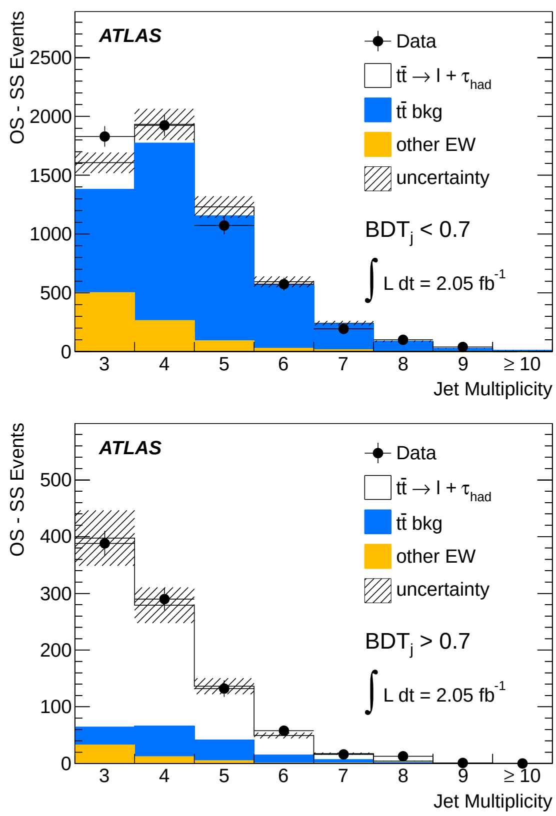

Figure 3: OS-SS number of jets distributions for events with at least one b-tag. The $\mu + \tau$ and $e + \tau$ channels have been summed together. The solid circles indicate data and the histograms indicate the expected signal and backgrounds. The normalisation of the expected signal and the backgrounds are based on the fit result. The uncertainty includes statistical and systematic contributions. The fraction of each background is estimated from MC. Top is for BDT$_j$ < 0.7, bottom for BDT$_j$ > 0.7.

6.1. Check with Matrix Method

From Figures 3 and 4 one can see that a BDT$_j$ > 0.7 requirement separates well a region dominated by $t\bar{t} \to \ell$+jets from a region dominated by $t\bar{t} \to \ell + \tau + X$. One can extract the signal from the same OS-SS ≥ 1 b-tag sample used by the fit method via a matrix method. All τ candidates are labeled "loose", and τ candidates with BDT$_j$ > 0.7 are labeled "tight". The probability that the loose τ candidates are also tight τ candidates, for

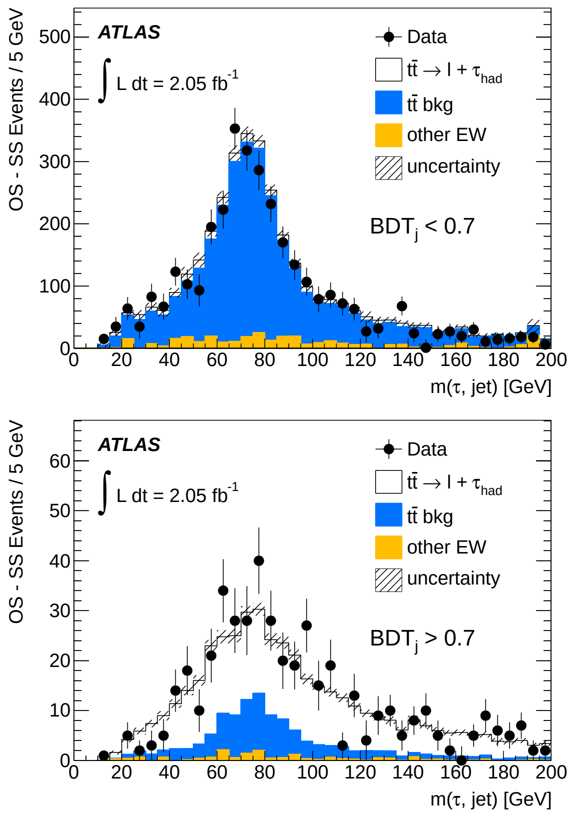

Figure 4: OS-SS invariant mass of jet and τ candidate for events with at least one b-tag. The jet is the highest p_T untagged jet in events with more than one b-tag and the second highest p_T untagged jet in events with one b-tag. The $\mu+\tau$ and $e+\tau$ channels have been summed together. The solid circles indicate data and the histograms indicate the expected signal and backgrounds. The normalisation of the expected signal and the backgrounds are based on the fit result. The uncertainty includes statistical and systematic contributions. The fraction of each background is estimated from MC. Top is for $\mathrm{BDT}_j < 0.7$, bottom for $\mathrm{BDT}_j > 0.7$.

both τ leptons and fake τ leptons, is defined as

$$\epsilon_{\mathrm{real}} = \frac{N^{\mathrm{tight}}_{\mathrm{real}}}{N^{\mathrm{loose}}_{\mathrm{real}}} \qquad \epsilon_{\mathrm{fake}} = \frac{N^{\mathrm{tight}}_{\mathrm{fake}}}{N^{\mathrm{loose}}_{\mathrm{fake}}}$$

where the "real" subscript denotes τ lepton, the "fake" subscript denotes fake τ and N is the number of τ candidates. The number of "tight" τ leptons is then given by

$$N^{\mathrm{tight}}_{\mathrm{real}} = N^{\mathrm{tight}}_{\mathrm{data}} - \frac{\epsilon_{\mathrm{fake}}}{\epsilon_{\mathrm{real}} - \epsilon_{\mathrm{fake}}}(N^{\mathrm{loose}}_{\mathrm{data}} \cdot \epsilon_{\mathrm{real}} - N^{\mathrm{tight}}_{\mathrm{data}}).$$

The value of ϵ_{fake} is measured utilizing the OS-SS BDT_j distributions from the background control samples; ϵ_{real} is derived from MC and was tested using $Z \to \tau^+\tau^-$ events. This method uses the binning approach described in Section 5 to estimate the background. Values of ϵ_{fake} and ϵ_{real} are measured separately for three EM-fraction bins. The EM-fraction, the ratio of the energy measured in the EM calorimeter to the total τ candidate energy measured in the calorimeter, is an effective variable for splitting the data into regions where the shapes of MC OS-SS BDT_j distributions for the W+1 jet background template and

Table 3: Number of signal events obtained with the matrix method for $\mu+\tau$, $e+\tau$ and the combined channels. The first column gives the channel and the second the τ type. The third column shows the extracted signal with the background template derived from 0 b-tag data distributions. The fourth column shows the extracted signal with the background template derived from $W+1$ jet. In order to compare the matrix method results to the fit results the number of signal events shown is $\sum N^{\mathrm{real}}_{\mathrm{tight}}/\bar{\epsilon}_{\mathrm{real}}$ where $\bar{\epsilon}_{\mathrm{real}}$ is the ϵ_{real} averaged over the three EM-fraction bins. The uncertainties are statistical only.

		Background template	
		0 b-tag	$W+1$ jet
$\mu+\tau$	τ_1	460 ± 50	440 ± 50
	τ_3	130 ± 40	105 ± 35
$e+\tau$	τ_1	420 ± 60	350 ± 50
	τ_3	140 ± 40	160 ± 40
Combined	τ_1	880 ± 70	800 ± 70
	τ_3	270 ± 60	260 ± 60

the ≥ 1 b-tag background are similar. Table 3 shows the number of signal events obtained with the matrix method using the background derived from the 0 b-tag data sample and from the $W+1$ jet data sample. The numbers in each pair are in good agreement and consistent with the numbers obtained by fitting the OS-SS BDT_j distributions.

6.2. Systematic Uncertainty

Several experimental and theoretical sources of systematic uncertainty are considered. Lepton trigger, reconstruction and selection efficiencies are assessed by comparing the $Z \to \ell^+\ell^-$ events selected with the same object criteria as used for the $t\bar{t}$ analyses in data and MC.

Scale factors are applied to MC samples when calculating acceptances to account for any differences between predicted and observed efficiencies. The scale factors are evaluated by comparing the observed efficiencies with those determined with simulated Z boson events. Systematic uncertainties on these scale factors are evaluated by varying the selection of events used in the efficiency measurements and by checking the stability of the measurements over the course of data taking.

The modeling of the lepton momentum scale and resolution is studied using reconstructed invariant mass distributions of $Z \to \ell^+\ell^-$ candidate events and used to adjust the simulation accordingly [23, 24].

The jet energy scale (JES) and its uncertainty are derived by combining information from test-beam data, LHC collision data and simulation [25]. For jets within the acceptance, the JES uncertainty varies in the range 4–8% as a function of jet p_{T} and η. Comparing MC and data the estimated systematic uncertainties are 10% and 1–2% for the jet energy resolution (JER) and the efficiency, respectively. The uncertainty on the efficiency of the b-tagging algorithm has been estimated to be 6% for b-quark jets, based on b-tagging calibration studies [26].

The uncertainty in the kinematic distributions of the $t\bar{t}$ signal events gives rise to systematic uncertainties in the signal acceptance, with contributions from the choice of generator, the modeling of initial- and final-state radiation (ISR/FSR) and the choice of the PDF set. The generator uncertainty is evaluated by comparing the MC@NLO predictions with those of POWHEG [27, 28, 29] interfaced to either HERWIG or PYTHIA. The uncertainty due to ISR/FSR is evaluated using the AcerMC generator [30] interfaced to the PYTHIA shower model, and by varying the parameters controlling ISR and FSR in a range consistent with experimental data [21]. Finally, the PDF uncertainty is evaluated using a range of current PDF sets [31, 32, 33]. The dominant uncertainty in this category of systematic uncertainties is the modelling of ISR/FSR.

The τ ID uncertainty is derived from a template fit to a $Z \to \tau^+\tau^-$ data sample selected with the same μ and τ candidate requirements as the sample for this analysis, but with fewer than two jets and $m_T < 20$ GeV to remove W+jets events. The fit relies on the $W+1$ jet data sample for a background template and $Z \to \tau^+\tau^-$ MC events for a signal template. The uncertainty includes the statistical uncertainty of the data samples, the uncertainty in the Z/γ^* cross section measured by ATLAS [34] (excluding luminosity uncertainty) and jet energy scale uncertainty. It also includes the uncertainty on the number of misidentified electrons (< 0.5%, determined from $Z \to e^+e^-$ data).

Table 4: Relative systematic uncertainties, in %, for the cross-section measurement. The first column gives the source of systematic uncertainty, ID/Trigger stands for the combined uncertainty of lepton identification and lepton trigger. The τ ID uncertainty includes electrons misidentified as τ leptons. The second and third collumms give the channel.

Source	$\mu+\tau$	$e+\tau$
μ (ID/Trigger)	−1.1 /+1.5	–
e (ID/Trigger)	–	±2.9
JES	−2.0/+2.2	−1.9 /+2.8
JER	±1.0	±1.2
ISR/FSR	±4.8	±3.5
Generator	±0.7	±0.7
PDF	±2.0	±2.1
b-tag	−7.7/+9.0	−7.5/+8.9
τ_1 ID	−3.0/+3.2	−2.7/+3.0
τ_3 ID	−3.1/+3.4	−2.9/+3.2

The effect of these variations on the final result is evaluated by varying each source of systematic uncertainty by $\pm 1\sigma$, applying the selection cuts and recalculating the cross section.

The uncertainties obtained for the fit method using the 0 b-tag background template are shown in Table 4. The systematic uncertainties for the matrix method are very similar. The uncertainty on the measured integrated luminosity is 3.7% [35].

7. Measuring the $t\bar{t}$ Cross Section

The cross section is derived from the number of observed OS-SS signal events in the ≥ 1 b-tag data sample assuming the only top quark decay mode is $t \to Wb$, and subtracting from that number the small contribution from $t\bar{t} \to e + \ell$ (from electrons faking τ leptons) and τ leptons from $Z \to \tau^+\tau^-$ (Table 1).

Table 5: Measured cross section from the τ_1 and τ_3 samples, as well as the combination (τ_1+τ_3) for each channel separately. The uncertainty in the integrated luminosity (3.7%) is not included.

	$\mu+\tau$
τ_1	189 ± 16 (stat.) ± 20 (syst.) pb
τ_3	180 ± 40 (stat.) ± 21 (syst.) pb
τ_1+τ_3	186 ± 15 (stat.) ± 20 (syst.) pb
	$e+\tau$
τ_1	190 ± 20 (stat.) ± 20 (syst.) pb
τ_3	170 ± 50 (stat.) ± 21 (syst.) pb
τ_1+τ_3	187 ± 18 (stat.) ± 20 (syst.) pb

The systematic uncertainties are estimated as the quadratic sum of all uncertainties given in Table 4, which includes the uncertainty from the subtraction.

The results are given separately for τ_1 and τ_3 and then combined (weighted by their statistical uncertainty and assuming all systematic uncertainties other than from τ ID are fully correlated). The results using the 0 b-tag background template are shown in Table 5.

The results for the $\mu+\tau$ and $e+\tau$ channels are combined taking into account the correlated uncertainties using the BLUE (Best Linear Unbiased Estimator) technique [36]. Combining them does not improve the systematic uncertainty as the systematic uncertainties are almost 100% correlated.

The results for each lepton type are:

$$\mu+\tau: \quad \sigma_{t\bar{t}} = 186 \pm 15\,(\text{stat.}) \pm 20\,(\text{syst.}) \pm 7\,(\text{lumi.})\ \text{pb},$$

$$e+\tau: \quad \sigma_{t\bar{t}} = 187 \pm 18\,(\text{stat.}) \pm 20\,(\text{syst.}) \pm 7\,(\text{lumi.})\ \text{pb},$$

Combining both channels one obtains:

$$\sigma_{t\bar{t}} = 186 \pm 13\,(\text{stat.}) \pm 20\,(\text{syst.}) \pm 7\,(\text{lumi.})\ \text{pb}$$

To check the fit measurements, the cross sections can be calculated using the matrix method and the results obtained with the $W+1$ jet background to minimize the correlation with the fit results. The combination of the matrix method and the fit results with the BLUE method show they are compatible at the 45% and 10% confidence level for $\mu+\tau$ and $e+\tau$, respectively.

8. Conclusions

The cross section for $t\bar{t}$ production in pp collisions at 7 TeV has been measured in the $\mu+\tau$ and the $e+\tau$ channels in which the τ decays hadronically. The number of τ leptons in these channels has been extracted using multivariate discriminators to separate τ leptons from electrons and jets misidentified as hadronically decaying τ leptons. These numbers were obtained by fitting the discriminator outputs and checked with a matrix method. Combining the measurements from $\mu+\tau$ and $e+\tau$ events, the cross section is measured to be

$$\sigma_{t\bar{t}} = 186 \pm 13\,(\text{stat.}) \pm 20\,(\text{syst.}) \pm 7\,(\text{lumi.})\ \text{pb},$$

in good agreement with the cross section measured by ATLAS in other channels [1, 2], with the cross-section measurement by the CMS Collaboration [7, 37] and with the SM prediction, 164^{+11}_{-16} pb [14].

9. Acknowledgements

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

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

The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN and the ATLAS Tier-1 facilities at TRIUMF (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN-CNAF (Italy), NL-T1 (Netherlands), PIC (Spain), ASGC (Taiwan), RAL (UK) and BNL (USA) and in the Tier-2 facilities worldwide.

References

[1] ATLAS Collaboration, *Measurement of the top quark production cross section with ATLAS in the single lepton channel*, Phys. Lett. B711 (2012) 244-263.

[2] ATLAS Collaboration, *Measurement of the cross section for top-quark pair production in pp collisions at* $\sqrt{s}$ = 7 *TeV with the ATLAS detector using final states with two high-*p_{T} *leptons*, arXiv:1202.4892 (submitted to JHEP).

[3] G.L. Kane, C. Kolda, L. Roszkowski, J.D. Wells, *Study of constrained minimal supersymmetry*, Phys. Rev. D 49, (1994) 6173.

[4] T. Han and M.B. Magro, *Top-quark decay via R-parity violating interactions at the Tevatron*, Phys. Lett. B476, (2000) 79.

[5] C. Yue, H. Zong, and L. Liu, *Non Universal Gauge Bosons Z' and Rare Top Decays*, Mod. Phys. Lett. A 18, (2003) 2187.

[6] DØ Collaboration, *Combination of* $t\bar{t}$ *cross section measurements and constraints on the mass of the top quark and its decays into charged Higgs bosons*, Phys. Rev. D 80 (2009) 071102(R).

[7] CMS Collaboration, *Measurement of the* $t\bar{t}$ *cross section in pp collisions at* $\sqrt{s}$ = 7 TeV *in dilepton final states containing a* τ, arXiv:1203.6810, submitted to Phys. Rev. D.

[8] ATLAS Collaboration, *Search for charged Higgs bosons decaying via* H^{+} *in top quark pair events using pp collision data at* $\sqrt{s}$ = 7 TeV *with the ATLAS detector*, arXiv:1204.2760 [hep-ex], submitted to JHEP.

[9] ATLAS Collaboration, *Performance of the Reconstruction and Identification of Hadronic Tau Decays with the ATLAS Detector*, ATLAS-CONF-2011-152.

[10] Y. Freund and R.E. Schapire, in Machine Learning: Proceedings of the Thirteenth International Conference, edited by L. Saitta (Morgan Kaufmann, San Francisco,1996) p. 148; B.P. Roe, H.-J. Yang, J. Zhu, Y. Liu, I. Stancu, and G. McGregor, Nucl. Instrum. and Meth. Phys. Res., *Boosted decision trees as an alternative to artificial neural networks for particle identification*, Sect. A 543, (2005) 577.

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

[12] S. Frixione and B.R. Webber, *Matching NLO QCD computations and parton shower simulations*, JHEP 06 (2002) 029;
S. Frixione, P. Nason and B.R. Webber, *Matching NLO QCD and parton showers in heavy flavour production*, JHEP 08 (2003) 007;
S. Frixione, E. Laenen and P. Motylinski, *Single-top production in MC@NLO*, JHEP 03 (2006) 092.

[13] P.M. Nadolsky et al., *Implications of CTEQ global analysis for collider observables*, Phys. Rev. D 78 (2008) 013004.

[14] M. Aliev et al. *-HATHOR- HAdronic Top and Heavy quarks crOss section calculatoR*, Comput. Phys. Commun. 182 (2011) 1034.

[15] M.L. Mangano, M. Moretti, H. Lai, P. Nadolsky, and A.D. Polosa, *ALPGEN, a generator for hard multiparton processes in hadronic collisions*, JHEP 07 (2003) 001.

[16] G. Corcella et al., *HERWIG 6.5: an event generator for Hadron Emission Reactions With Interfering Gluons (including supersymmetric processes)*, JHEP 01 (2001) 010; G. Corcella et al., HERWIG 6.5 release notes, arXiv:hep-ph/0210213.

[17] J. Butterworth, J.R. Forshaw, and M.H. Seymour, *Multiparton interactions in photoproduction at HERA*, Zeit. f. Phys. C72 (1996) 637.

[18] N.Davidson et al., *Universal Interface of TAUOLA Technical and Physics Documentation*, arXiv:1002.0543.

[19] ATLAS Collaboration, *ATLAS tunes of PYTHIA 6 and PYTHIA 8 for MC11*, ATL-PHYS-PUB-2011-009.

[20] GEANT4 Collaboration, S. Agostinelli et al., *A simulation toolkit*, Nucl. Instrum. and Meth. A506 (2003) 250.

[21] ATLAS Collaboration, *The ATLAS Simulation Infrastructure*, Eur. Phys. J. C70 (2010) 823-874.

[22] M. Cacciari, G. P. Salam, and G. Soyez. *The anti-*k_t *clustering algorithm*, JHEP 0804 (2008) 063.

[23] ATLAS Collaboration, *Electron performance measurements with the ATLAS detector using the 2010 LHC proton-proton collision data*, Eur. Phys. J. C72 (2012) 1909.

[24] ATLAS Collaboration, *Muon reconstruction efficiency in reprocessed 2010 LHC proton-proton collision data recorded with the ATLAS Detector*, ATLAS-CONF-2011-063.

[25] ATLAS Collaboration, *Jet energy measurement with the ATLAS detector in proton-proton collisions at* $\sqrt{s}$ = 7 *TeV*, arXiv:1112.6426

[26] ATLAS Collaboration, *Commisioning of the ATLAS high-performance b-tagging algorithms in the 7 TeV collision data*, ATL-CONF-2011-102.

[27] P. Nason, *A new method for combining NLO QCD with shower Monte Carlo algorithms*, JHEP 11 (2007) 070.

[28] S. Frixione, P. Nason, and C. Oleari, *Matching NLO QCD computations with parton shower simulations: the Powheg method*, JHEP 11 (2007) 040.

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

[30] B.P. Kersevan and E.Richter-Was, *The Monte Carlo event generator AcerMC version 2.0 with interfaces to PYTHIA 6.2 and HERWIG 6.5*, arXiv:hep-ph/0405247.

[31] J. Pumpli, D. Stump, J. Huston, H. Lai, P. Nadolsky, and W. Tung, *New generation of parton distributions with uncertainties from global QCD analysis*, JHEP 07 (2002) 012.

[32] A.D Martin, R.G. Roberts, W.J. Stirling and R.S. Thorne, *Parton distributions: a new global anslyis*, Eur. Phys. J. C4 (1998) 463; *Parton distributions and the LHC: W and Z production*, Eur. Phys. J. C14 (2000) 133.

[33] CTEQ Collaboration, H. Lai et al. *Global QCD analysis of parton structure of the nucleon: CTEQ5 parton distributions*, Eur. Phys. J. C12 (2000) 375.

[34] ATLAS Collaboration, *Measurement of the inclusive $W^{\pm}$ and $Z/\gamma*$ cross sections in the e and μ decay channels in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector*,Phys. Rev. D85 (2012) 041805.

[35] ATLAS Collaboration, *Luminosity Determination in pp collisions at* $\sqrt{s} = 7$ TeV *using the ATLAS Detector in 2011*, ATLAS-CONF-2011-016 (2011).

[36] L. Lyons, D. Gibaut and P. Clifford, *How to combine correlated estimates of a single physical quantity*, Nucl. Instrum. and Meth. A270 (1988) 110.

[37] CMS Collaboration, *Measurement of the $t\bar{t}$ Production Cross Section in pp Collisions at $\sqrt{s}$ =7 TeV in Lepton+Jets Events Using b-quark Jet Identification*, Phys. Rev. D84 (2011) 092004.

The ATLAS Collaboration

G. Aad[48], B. Abbott[111], J. Abdallah[11], S. Abdel Khalek[115], A.A. Abdelalim[49], O. Abdinov[10], B. Abi[112], M. Abolins[88], O.S. AbouZeid[158], H. Abramowicz[153], H. Abreu[136], E. Acerbi[89a,89b], B.S. Acharya[164a,164b], L. Adamczyk[37], D.L. Adams[24], T.N. Addy[56], J. Adelman[176], S. Adomeit[98], P. Adragna[75], T. Adye[129], S. Aefsky[22], J.A. Aguilar-Saavedra[124b,a], M. Aharrouche[81], S.P. Ahlen[21], F. Ahles[48], A. Ahmad[148], M. Ahsan[40], G. Aielli[133a,133b], T. Akdogan[18a], T.P.A. Åkesson[79], G. Akimoto[155], A.V. Akimov [94], A. Akiyama[66], M.S. Alam[1], M.A. Alam[76], J. Albert[169], S. Albrand[55], M. Aleksa[29], I.N. Aleksandrov[64], F. Alessandria[89a], C. Alexa[25a], G. Alexander[153], G. Alexandre[49], T. Alexopoulos[9], M. Alhroob[164a,164c], M. Aliev[15], G. Alimonti[89a], J. Alison[120], B.M.M. Allbrooke[17], P.P. Allport[73], S.E. Allwood-Spiers[53], J. Almond[82], A. Aloisio[102a,102b], R. Alon[172], A. Alonso[79], B. Alvarez Gonzalez[88], M.G. Alviggi[102a,102b], K. Amako[65], C. Amelung[22], V.V. Ammosov[128], A. Amorim[124a,b], G. Amorós[167], N. Amram[153], C. Anastopoulos[29], L.S. Ancu[16], N. Andari[115], T. Andeen[34], C.F. Anders[58b], G. Anders[58a], K.J. Anderson[30], A. Andreazza[89a,89b], V. Andrei[58a], X.S. Anduaga[70], P. Anger[43], A. Angerami[34], F. Anghinolfi[29], A. Anisenkov[107], N. Anjos[124a], A. Annovi[47], A. Antonaki[8], M. Antonelli[47], A. Antonov[96], J. Antos[144b], F. Anulli[132a], S. Aoun[83], L. Aperio Bella[4], R. Apolle[118,c], G. Arabidze[88], I. Aracena[143], Y. Arai[65], A.T.H. Arce[44], S. Arfaoui[148], J-F. Arguin[14], E. Arik[18a,*], M. Arik[18a], A.J. Armbruster[87], O. Arnaez[81], V. Arnal[80], C. Arnault[115], A. Artamonov[95], G. Artoni[132a,132b], D. Arutinov[20], S. Asai[155], R. Asfandiyarov[173], S. Ask[27], B. Åsman[146a,146b], L. Asquith[5], K. Assamagan[24], A. Astbury[169], B. Aubert[4], E. Auge[115], K. Augsten[127], M. Aurousseau[145a], G. Avolio[163], R. Avramidou[9], D. Axen[168], G. Azuelos[93,d], Y. Azuma[155], M.A. Baak[29], G. Baccaglioni[89a], C. Bacci[134a,134b], A.M. Bach[14], H. Bachacou[136], K. Bachas[29], M. Backes[49], M. Backhaus[20], E. Badescu[25a], P. Bagnaia[132a,132b], S. Bahinipati[2], Y. Bai[32a], D.C. Bailey[158], T. Bain[158], J.T. Baines[129], O.K. Baker[176], M.D. Baker[24], S. Baker[77], E. Banas[38], P. Banerjee[93], Sw. Banerjee[173], D. Banfi[29], A. Bangert[150], V. Bansal[169], H.S. Bansil[17], L. Barak[172], S.P. Baranov[94], A. Barbaro Galtieri[14], T. Barber[48], E.L. Barberio[86], D. Barberis[50a,50b], M. Barbero[20], D.Y. Bardin[64], T. Barillari[99], M. Barisonzi[175], T. Barklow[143], N. Barlow[27], B.M. Barnett[129], R.M. Barnett[14], A. Baroncelli[134a], G. Barone[49], A.J. Barr[118], F. Barreiro[80], J. Barreiro Guimarães da Costa[57], P. Barrillon[115], R. Bartoldus[143], A.E. Barton[71], V. Bartsch[149], R.L. Bates[53], L. Batkova[144a], J.R. Batley[27], A. Battaglia[16], M. Battistin[29], F. Bauer[136], H.S. Bawa[143,e], S. Beale[98], T. Beau[78], P.H. Beauchemin[161], R. Beccherle[50a], P. Bechtle[20], H.P. Beck[16], A.K. Becker[175], S. Becker[98], M. Beckingham[138], K.H. Becks[175], A.J. Beddall[18c], A. Beddall[18c], S. Bedikian[176], V.A. Bednyakov[64], C.P. Bee[83], M. Begel[24], S. Behar Harpaz[152], P.K. Behera[62], M. Beimforde[99], C. Belanger-Champagne[85], P.J. Bell[49], W.H. Bell[49], G. Bella[153], L. Bellagamba[19a], F. Bellina[29], M. Bellomo[29], A. Belloni[57], O. Beloborodova[107,f], K. Belotskiy[96], O. Beltramello[29], O. Benary[153], D. Benchekroun[135a], K. Bendtz[146a,146b], N. Benekos[165], Y. Benhammou[153], E. Benhar Noccioli[49], J.A. Benitez Garcia[159b], D.P. Benjamin[44], M. Benoit[115], J.R. Bensinger[22], K. Benslama[130], S. Bentvelsen[105], D. Berge[29], E. Bergeaas Kuutmann[41], N. Berger[4], F. Berghaus[169], E. Berglund[105], J. Beringer[14], P. Bernat[77], R. Bernhard[48], C. Bernius[24], T. Berry[76], C. Bertella[83], A. Bertin[19a,19b], F. Bertolucci[122a,122b], M.I. Besana[89a,89b], N. Besson[136], S. Bethke[99], W. Bhimji[45], R.M. Bianchi[29], M. Bianco[72a,72b], O. Biebel[98], S.P. Bieniek[77], K. Bierwagen[54], J. Biesiada[14], M. Biglietti[134a], H. Bilokon[47], M. Bindi[19a,19b], S. Binet[115], A. Bingul[18c], C. Bini[132a,132b], C. Biscarat[178], U. Bitenc[48], K.M. Black[21], R.E. Blair[5], J.-B. Blanchard[136], G. Blanchot[29], T. Blazek[144a], C. Blocker[22], J. Blocki[38], A. Blondel[49], W. Blum[81], U. Blumenschein[54], G.J. Bobbink[105], V.B. Bobrovnikov[107], S.S. Bocchetta[79], A. Bocci[44], C.R. Boddy[118], M. Boehler[41], J. Boek[175], N. Boelaert[35], J.A. Bogaerts[29], A. Bogdanchikov[107], A. Bogouch[90,*], C. Bohm[146a], J. Bohm[125], V. Boisvert[76], T. Bold[37], V. Boldea[25a], N.M. Bolnet[136], M. Bomben[78], M. Bona[75], M. Bondioli[163], M. Boonekamp[136], C.N. Booth[139], S. Bordoni[78], C. Borer[16], A. Borisov[128], G. Borissov[71], I. Borjanovic[12a], M. Borri[82], S. Borroni[87], V. Bortolotto[134a,134b], K. Bos[105], D. Boscherini[19a], M. Bosman[11], H. Boterenbrood[105], D. Botterill[129], J. Bouchami[93], J. Boudreau[123], E.V. Bouhova-Thacker[71], D. Boumediene[33], C. Bourdarios[115], N. Bousson[83], A. Boveia[30], J. Boyd[29], I.R. Boyko[64], N.I. Bozhko[128], I. Bozovic-Jelisavcic[12b], J. Bracinik[17], P. Branchini[134a], A. Brandt[7], G. Brandt[118], O. Brandt[54], U. Bratzler[156], B. Brau[84], J.E. Brau[114], H.M. Braun[175], B. Brelier[158], J. Bremer[29], K. Brendlinger[120], R. Brenner[166], S. Bressler[172], D. Britton[53], F.M. Brochu[27], I. Brock[20], R. Brock[88], E. Brodet[153], F. Broggi[89a], C. Bromberg[88], J. Bronner[99], G. Brooijmans[34], W.K. Brooks[31b], G. Brown[82], H. Brown[7], P.A. Bruckman de Renstrom[38], D. Bruncko[144b], R. Bruneliere[48], S. Brunet[60], A. Bruni[19a], G. Bruni[19a], M. Bruschi[19a], T. Buanes[13], Q. Buat[55], F. Bucci[49], J. Buchanan[118], P. Buchholz[141], R.M. Buckingham[118], A.G. Buckley[45], S.I. Buda[25a], I.A. Budagov[64], B. Budick[108], V. Büscher[81], L. Bugge[117], O. Bulekov[96], A.C. Bundock[73], M. Bunse[42], T. Buran[117], H. Burckhart[29], S. Burdin[73], T. Burgess[13], S. Burke[129], E. Busato[33], P. Bussey[53], C.P. Buszello[166], B. Butler[143], J.M. Butler[21], C.M. Buttar[53], J.M. Butterworth[77], W. Buttinger[27], S. Cabrera Urbán[167], D. Caforio[19a,19b], O. Cakir[3a], P. Calafiura[14], G. Calderini[78], P. Calfayan[98], R. Calkins[106], L.P. Caloba[23a], R. Caloi[132a,132b], D. Calvet[33], S. Calvet[33], R. Camacho Toro[33], P. Camarri[133a,133b], D. Cameron[117], L.M. Caminada[14], S. Campana[29], M. Campanelli[77], V. Canale[102a,102b], F. Canelli[30,g], A. Canepa[159a], J. Cantero[80], R. Cantrill[76], L. Capasso[102a,102b], M.D.M. Capeans Garrido[29], I. Caprini[25a], M. Caprini[25a], D. Capriotti[99], M. Capua[36a,36b], R. Caputo[81], R. Cardarelli[133a], T. Carli[29], G. Carlino[102a], L. Carminati[89a,89b], B. Caron[85], S. Caron[104], E. Carquin[31b], G.D. Carrillo Montoya[173], A.A. Carter[75], J.R. Carter[27], J. Carvalho[124a,h], D. Casadei[108], M.P. Casado[11], M. Cascella[122a,122b], C. Caso[50a,50b,*], A.M. Castaneda Hernandez[173], E. Castaneda-Miranda[173], V. Castillo Gimenez[167], N.F. Castro[124a], G. Cataldi[72a], P. Catastini[57], A. Catinaccio[29], J.R. Catmore[29], A. Cattai[29], G. Cattani[133a,133b], S. Caughron[88], D. Cauz[164a,164c], P. Cavalleri[78], D. Cavalli[89a], M. Cavalli-Sforza[11], V. Cavasinni[122a,122b], F. Ceradini[134a,134b], A.S. Cerqueira[23b], A. Cerri[29], L. Cerrito[75], F. Cerutti[47], S.A. Cetin[18b], A. Chafaq[135a], D. Chakraborty[106], I. Chalupkova[126], K. Chan[2], B. Chapleau[85], J.D. Chapman[27], J.W. Chapman[87], E. Chareyre[78], D.G. Charlton[17], V. Chavda[82], C.A. Chavez Barajas[29], S. Cheatham[85], S. Chekanov[5], S.V. Chekulaev[159a], G.A. Chelkov[64], M.A. Chelstowska[104], C. Chen[63], H. Chen[24], S. Chen[32c], X. Chen[173], A. Cheplakov[64], R. Cherkaoui El Moursli[135e], V. Chernyatin[24], E. Cheu[6], S.L. Cheung[158], L. Chevalier[136], G. Chiefari[102a,102b], L. Chikovani[51a], J.T. Childers[29], A. Chilingarov[71], G. Chiodini[72a], A.S. Chisholm[17], R.T. Chislett[77], M.V. Chizhov[64], G. Choudalakis[30], S. Chouridou[137], I.A. Christidi[77], A. Christov[48], D. Chromek-Burckhart[29], M.L. Chu[151], J. Chudoba[125], G. Ciapetti[132a,132b], A.K. Ciftci[3a], R. Ciftci[3a], D. Cinca[33], V. Cindro[74], C. Ciocca[19a,19b], A. Ciocio[14], M. Cirilli[87], M. Citterio[89a], M. Ciubancan[25a], A. Clark[49], P.J. Clark[45], W. Cleland[123], J.C. Clemens[83], B. Clement[55], C. Clement[146a,146b], Y. Coadou[83], M. Cobal[164a,164c], A. Coccaro[138], J. Cochran[63], P. Coe[118], J.G. Cogan[143], J. Coggeshall[165], E. Cogneras[178], J. Colas[4], A.P. Colijn[105], N.J. Collins[17], C. Collins-Tooth[53], J. Collot[55], T. Colombo[119a,119b], G. Colon[84], P. Conde Muiño[124a], E. Coniavitis[118], M.C. Conidi[11], S.M. Consonni[89a,89b], V. Consorti[48], S. Constantinescu[25a], C. Conta[119a,119b], G. Conti[57], F. Conventi[102a,i], M. Cooke[14], B.D. Cooper[77], A.M. Cooper-Sarkar[118], K. Copic[14], T. Cornelissen[175], M. Corradi[19a], F. Corriveau[85,j], A. Cortes-Gonzalez[165], G. Cortiana[99], G. Costa[89a], M.J. Costa[167], D. Costanzo[139], T. Costin[30], D. Côté[29], L. Courneyea[169], G. Cowan[76], C. Cowden[27], B.E. Cox[82], K. Cranmer[108], F. Crescioli[122a,122b], M. Cristinziani[20], G. Crosetti[36a,36b], R. Crupi[72a,72b], S. Crépé-Renaudin[55], C.-M. Cuciuc[25a], C. Cuenca Almenar[176], T. Cuhadar Donszelmann[139], M. Curatolo[47], C.J. Curtis[17], C. Cuthbert[150], P. Cwetanski[60], H. Czirr[141], P. Czodrowski[43], Z. Czyczula[176], S. D'Auria[53], M. D'Onofrio[73], A. D'Orazio[132a,132b], C. Da Via[82], W. Dabrowski[37], A. Dafinca[118], T. Dai[87], C. Dallapiccola[84], M. Dam[35], M. Dameri[50a,50b], D.S. Damiani[137], H.O. Danielsson[29], V. Dao[49], G. Darbo[50a], G.L. Darlea[25b], W. Davey[20], T. Davidek[126], N. Davidson[86], R. Davidson[71], E. Davies[118,c], M. Davies[93], A.R. Davison[77], Y. Davygora[58a], E. Dawe[142], I. Dawson[139], R.K. Daya-Ishmukhametova[22], K. De[7], R. de Asmundis[102a], S. De Castro[19a,19b], S. De Cecco[78], J. de Graat[98], N. De Groot[104], P. de Jong[105], C. De La Taille[115], H. De la Torre[80], F. De Lorenzi[63], B. De Lotto[164a,164c], L. de Mora[71], L. De Nooij[105], D. De Pedis[132a], A. De Salvo[132a], U. De Sanctis[164a,164c], A. De Santo[149], J.B. De Vivie De Regie[115], G. De Zorzi[132a,132b], W.J. Dearnaley[71], R. Debbe[24], C. Debenedetti[45], B. Dechenaux[55], D.V. Dedovich[64], J. Degenhardt[120], C. Del Papa[164a,164c], J. Del Peso[80], T. Del Prete[122a,122b], T. Delemontex[55], M. Deliyergiyev[74], A. Dell'Acqua[29], L. Dell'Asta[21], M. Della Pietra[102a,i], D. della Volpe[102a,102b], M. Delmastro[4], P.A. Delsart[55], C. Deluca[105], S. Demers[176], M. Demichev[64], B. Demirkoz[11,k], J. Deng[163], S.P. Denisov[128], D. Derendarz[38], J.E. Derkaoui[135d], F. Derue[78], P. Dervan[73], K. Desch[20], E. Devetak[148], P.O. Deviveiros[105], A. Dewhurst[129], B. DeWilde[148], S. Dhaliwal[158], R. Dhullipudi[24,l], A. Di Ciaccio[133a,133b], L. Di Ciaccio[4], A. Di Girolamo[29], B. Di Girolamo[29], S. Di Luise[134a,134b], A. Di Mattia[173], B. Di Micco[29], R. Di Nardo[47], A. Di Simone[133a,133b], R. Di Sipio[19a,19b], M.A. Diaz[31a], E.B. Diehl[87], J. Dietrich[41], T.A. Dietzsch[58a], S. Diglio[86], K. Dindar Yagci[39], J. Dingfelder[20], C. Dionisi[132a,132b], P. Dita[25a], S. Dita[25a], F. Dittus[29], F. Djama[83], T. Djobava[51b], M.A.B. do Vale[23c], A. Do Valle Wemans[124a], T.K.O. Doan[4], M. Dobbs[85], R. Dobinson [29,*], D. Dobos[29], E. Dobson[29,m], J. Dodd[34], C. Doglioni[49], T. Doherty[53], Y. Doi[65,*], J. Dolejsi[126], I. Dolenc[74], Z. Dolezal[126], B.A. Dolgoshein[96,*], T. Dohmae[155], M. Donadelli[23d], M. Donega[120], J. Donini[33], J. Dopke[29], A. Doria[102a], A. Dos Anjos[173], A. Dotti[122a,122b], M.T. Dova[70], A.D. Doxiadis[105], A.T. Doyle[53], M. Dris[9], J. Dubbert[99], S. Dube[14], E. Duchovni[172], G. Duckeck[98], A. Dudarev[29], F. Dudziak[63], M. Dührssen [29], I.P. Duerdoth[82], L. Duflot[115], M-A. Dufour[85], M. Dunford[29], H. Duran Yildiz[3a], R. Duxfield[139], M. Dwuznik[37], F. Dydak [29], M. Düren[52], J. Ebke[98], S. Eckweiler[81], K. Edmonds[81], C.A. Edwards[76], N.C. Edwards[53], W. Ehrenfeld[41], T. Eifert[143], G. Eigen[13], K. Einsweiler[14], E. Eisenhandler[75], T. Ekelof[166], M. El Kacimi[135c], M. Ellert[166], S. Elles[4], F. Ellinghaus[81], K. Ellis[75], N. Ellis[29], J. Elmsheuser[98], M. Elsing[29], D. Emeliyanov[129], R. Engelmann[148], A. Engl[98], B. Epp[61], A. Eppig[87], J. Erdmann[54], A. Ereditato[16], D. Eriksson[146a], J. Ernst[1], M. Ernst[24], J. Ernwein[136], D. Errede[165], S. Errede[165], E. Ertel[81], M. Escalier[115], C. Escobar[123], X. Espinal Curull[11], B. Esposito[47], F. Etienne[83], A.I. Etienvre[136], E. Etzion[153], D. Evangelakou[54], H. Evans[60], L. Fabbri[19a,19b], C. Fabre[29], R.M. Fakhrutdinov[128], S. Falciano[132a], Y. Fang[173], M. Fanti[89a,89b], A. Farbin[7], A. Farilla[134a], J. Farley[148], T. Farooque[158], S. Farrell[163], S.M. Farrington[118], P. Farthouat[29], P. Fassnacht[29], D. Fassouliotis[8], B. Fatholahzadeh[158], A. Favareto[89a,89b], L. Fayard[115], S. Fazio[36a,36b], R. Febbraro[33], P. Federic[144a], O.L. Fedin[121], W. Fedorko[88], M. Fehling-Kaschek[48], L. Feligioni[83], D. Fellmann[5], C. Feng[32d], E.J. Feng[30], A.B. Fenyuk[128], J. Ferencei[144b], W. Fernando[5], S. Ferrag[53], J. Ferrando[53], V. Ferrara[41], A. Ferrari[166], P. Ferrari[105], R. Ferrari[119a], D.E. Ferreira de Lima[53], A. Ferrer[167], D. Ferrere[49], C. Ferretti[87], A. Ferretto Parodi[50a,50b], M. Fiascaris[30], F. Fiedler[81], A. Filipčič[74], F. Filthaut[104], M. Fincke-Keeler[169], M.C.N. Fiolhais[124a,h], L. Fiorini[167], A. Firan[39], G. Fischer[41], M.J. Fisher[109], M. Flechl[48], I. Fleck[141], J. Fleckner[81], P. Fleischmann[174], S. Fleischmann[175], T. Flick[175], A. Floderus[79], L.R. Flores Castillo[173], M.J. Flowerdew[99], T. Fonseca Martin[16], D.A. Forbush[138], A. Formica[136], A. Forti[82], D. Fortin[159a], D. Fournier[115], H. Fox[71], P. Francavilla[11], S. Franchino[119a,119b], D. Francis[29], T. Frank[172], M. Franklin[57], S. Franz[29], M. Fraternali[119a,119b], S. Fratina[120], S.T. French[27], C. Friedrich[41], F. Friedrich [43], R. Froeschl[29], D. Froidevaux[29], J.A. Frost[27], C. Fukunaga[156], E. Fullana Torregrosa[29], B.G. Fulsom[143], J. Fuster[167], C. Gabaldon[29], O. Gabizon[172], T. Gadfort[24], S. Gadomski[49], G. Gagliardi[50a,50b], P. Gagnon[60], C. Galea[98], E.J. Gallas[118], V. Gallo[16], B.J. Gallop[129], P. Gallus[125], K.K. Gan[109], Y.S. Gao[143,e], A. Gaponenko[14], F. Garberson[176], M. Garcia-Sciveres[14], C. García[167], J.E. García Navarro[167], R.W. Gardner[30], N. Garelli[29], H. Garitaonandia[105], V. Garonne[29], J. Garvey[17], C. Gatti[47], G. Gaudio[119a], B. Gaur[141], L. Gauthier[136], P. Gauzzi[132a,132b], I.L. Gavrilenko[94], C. Gay[168], G. Gaycken[20], E.N. Gazis[9], P. Ge[32d], Z. Gecse[168], C.N.P. Gee[129], D.A.A. Geerts[105], Ch. Geich-Gimbel[20], K. Gellerstedt[146a,146b], C. Gemme[50a], A. Gemmell[53], M.H. Genest[55], S. Gentile[132a,132b], M. George[54], S. George[76], P. Gerlach[175], A. Gershon[153], C. Geweniger[58a], H. Ghazlane[135b], N. Ghodbane[33], B. Giacobbe[19a], S. Giagu[132a,132b], V. Giakoumopoulou[8], V. Giangiobbe[11], F. Gianotti[29], B. Gibbard[24], A. Gibson[158], S.M. Gibson[29], D. Gillberg[28], A.R. Gillman[129], D.M. Gingrich[2,d], J. Ginzburg[153], N. Giokaris[8], M.P. Giordani[164c], R. Giordano[102a,102b], F.M. Giorgi[15],

P. Giovannini[99], P.F. Giraud[136], D. Giugni[89a], M. Giunta[93], P. Giusti[19a], B.K. Gjelsten[117], L.K. Gladilin[97], C. Glasman[80], J. Glatzer[48], A. Glazov[41], K.W. Glitza[175], G.L. Glonti[64], J.R. Goddard[75], J. Godfrey[142], J. Godlewski[29], M. Goebel[41], T. Göpfert[43], C. Goeringer[81], C. Gössling[42], S. Goldfarb[87], T. Golling[176], A. Gomes[124a,b], L.S. Gomez Fajardo[41], R. Gonçalo[76], J. Goncalves Pinto Firmino Da Costa[41], L. Gonella[20], S. Gonzalez[173], S. González de la Hoz[167], G. Gonzalez Parra[11], M.L. Gonzalez Silva[26], S. Gonzalez-Sevilla[49], J.J. Goodson[148], L. Goossens[29], P.A. Gorbounov[95], H.A. Gordon[24], I. Gorelov[103], G. Gorfine[175], B. Gorini[29], E. Gorini[72a,72b], A. Gorišek[74], E. Gornicki[38], B. Gosdzik[41], A.T. Goshaw[5], M. Gosselink[105], M.I. Gostkin[64], I. Gough Eschrich[163], M. Gouighri[135a], D. Goujdami[135c], M.P. Goulette[49], A.G. Goussiou[138], C. Goy[4], S. Gozpinar[22], I. Grabowska-Bold[37], P. Grafström[29], K-J. Grahn[41], F. Grancagnolo[72a], S. Grancagnolo[15], V. Grassi[148], V. Gratchev[121], N. Grau[34], H.M. Gray[29], J.A. Gray[148], E. Graziani[134a], O.G. Grebenyuk[121], T. Greenshaw[73], Z.D. Greenwood[24,l], K. Gregersen[35], I.M. Gregor[41], P. Grenier[143], J. Griffiths[138], N. Grigalashvili[64], A.A. Grillo[137], S. Grinstein[11], Y.V. Grishkevich[97], J.-F. Grivaz[115], E. Gross[172], J. Grosse-Knetter[54], J. Groth-Jensen[172], K. Grybel[141], D. Guest[176], C. Guicheney[33], A. Guida[72a,72b], S. Guindon[54], H. Guler[85,n], J. Gunther[125], B. Guo[158], J. Guo[34], V.N. Gushchin[128], P. Gutierrez[111], N. Guttman[153], O. Gutzwiller[173], C. Guyot[136], C. Gwenlan[118], C.B. Gwilliam[73], A. Haas[143], S. Haas[29], C. Haber[14], H.K. Hadavand[39], D.R. Hadley[17], P. Haefner[99], F. Hahn[29], S. Haider[29], Z. Hajduk[38], H. Hakobyan[177], D. Hall[118], J. Haller[54], K. Hamacher[175], P. Hamal[113], M. Hamer[54], A. Hamilton[145b,o], S. Hamilton[161], L. Han[32b], K. Hanagaki[116], K. Hanawa[160], M. Hance[14], C. Handel[81], P. Hanke[58a], J.R. Hansen[35], J.B. Hansen[35], J.D. Hansen[35], P.H. Hansen[35], P. Hansson[143], K. Hara[160], G.A. Hare[137], T. Harenberg[175], S. Harkusha[90], D. Harper[87], R.D. Harrington[45], O.M. Harris[138], K. Harrison[17], J. Hartert[48], F. Hartjes[105], T. Haruyama[65], A. Harvey[56], S. Hasegawa[101], Y. Hasegawa[140], S. Hassani[136], S. Haug[16], M. Hauschild[29], R. Hauser[88], M. Havranek[20], C.M. Hawkes[17], R.J. Hawkings[29], A.D. Hawkins[79], D. Hawkins[163], T. Hayakawa[66], T. Hayashi[160], D. Hayden[76], C.P. Hays[118], H.S. Hayward[73], S.J. Haywood[129], M. He[32d], S.J. Head[17], V. Hedberg[79], L. Heelan[7], S. Heim[88], B. Heinemann[14], S. Heisterkamp[35], L. Helary[4], C. Heller[98], M. Heller[29], S. Hellman[146a,146b], D. Hellmich[20], C. Helsens[11], R.C.W. Henderson[71], M. Henke[58a], A. Henrichs[54], A.M. Henriques Correia[29], S. Henrot-Versille[115], F. Henry-Couannier[83], C. Hensel[54], T. Henß[175], C.M. Hernandez[7], Y. Hernández Jiménez[167], R. Herrberg[15], G. Herten[48], R. Hertenberger[98], L. Hervas[29], G.G. Hesketh[77], N.P. Hessey[105], E. Higón-Rodriguez[167], J.C. Hill[27], K.H. Hiller[41], S. Hillert[20], S.J. Hillier[17], I. Hinchliffe[14], E. Hines[120], M. Hirose[116], F. Hirsch[42], D. Hirschbuehl[175], J. Hobbs[148], N. Hod[153], M.C. Hodgkinson[139], P. Hodgson[139], A. Hoecker[29], M.R. Hoeferkamp[103], J. Hoffman[39], D. Hoffmann[83], M. Hohlfeld[81], M. Holder[141], S.O. Holmgren[146a], T. Holy[127], J.L. Holzbauer[88], T.M. Hong[120], L. Hooft van Huysduynen[108], C. Horn[143], S. Horner[48], J-Y. Hostachy[55], S. Hou[151], A. Hoummada[135a], J. Howard[118], J. Howarth[82], I. Hristova [15], J. Hrivnac[115], I. Hruska[125], T. Hryn'ova[4], P.J. Hsu[81], S.-C. Hsu[14], Z. Hubacek[127], F. Hubaut[83], F. Huegging[20], A. Huettmann[41], T.B. Huffman[118], E.W. Hughes[34], G. Hughes[71], M. Huhtinen[29], M. Hurwitz[14], U. Husemann[41], N. Huseynov[64,p], J. Huston[88], J. Huth[57], G. Iacobucci[49], G. Iakovidis[9], M. Ibbotson[82], I. Ibragimov[141], L. Iconomidou-Fayard[115], J. Idarraga[115], P. Iengo[102a], O. Igonkina[105], Y. Ikegami[65], M. Ikeno[65], D. Iliadis[154], N. Ilic[158], M. Imori[155], T. Ince[20], J. Inigo-Golfin[29], P. Ioannou[8], M. Iodice[134a], K. Iordanidou[8], V. Ippolito[132a,132b], A. Irles Quiles[167], C. Isaksson[166], A. Ishikawa[66], M. Ishino[67], R. Ishmukhametov[39], C. Issever[118], S. Istin[18a], A.V. Ivashin[128], W. Iwanski[38], H. Iwasaki[65], J.M. Izen[40], V. Izzo[102a], B. Jackson[120], J.N. Jackson[73], P. Jackson[143], M.R. Jaekel[29], V. Jain[60], K. Jakobs[48], S. Jakobsen[35], T. Jakoubek[125], J. Jakubek[127], D.K. Jana[111], E. Jansen[77], H. Jansen[29], A. Jantsch[99], M. Janus[48], G. Jarlskog[79], L. Jeanty[57], I. Jen-La Plante[30], P. Jenni[29], A. Jeremie[4], P. Jež[35], S. Jézéquel[4], M.K. Jha[19a], H. Ji[173], W. Ji[81], J. Jia[148], Y. Jiang[32b], M. Jimenez Belenguer[41], S. Jin[32a], O. Jinnouchi[157], M.D. Joergensen[35], D. Joffe[39], L.G. Johansen[13], M. Johansen[146a,146b], K.E. Johansson[146a], P. Johansson[139], S. Johnert[41], K.A. Johns[6], K. Jon-And[146a,146b], G. Jones[170], R.W.L. Jones[71], T.J. Jones[73], C. Joram[29], P.M. Jorge[124a], K.D. Joshi[82], J. Jovicevic[147], T. Jovin[12b], X. Ju[173], C.A. Jung[42], R.M. Jungst[29], V. Juranek[125], P. Jussel[61], A. Juste Rozas[11], S. Kabana[16], M. Kaci[167], A. Kaczmarska[38], P. Kadlecik[35], M. Kado[115], H. Kagan[109], M. Kagan[57], E. Kajomovitz[152], S. Kalinin[175], L.V. Kalinovskaya[64], S. Kama[39], N. Kanaya[155], M. Kaneda[29], S. Kaneti[27], T. Kanno[157], V.A. Kantserov[96], J. Kanzaki[65], B. Kaplan[176], A. Kapliy[30], J. Kaplon[29], D. Kar[53], M. Karagounis[20], M. Karnevskiy[41], V. Kartvelishvili[71], A.N. Karyukhin[128], L. Kashif[173], G. Kasieczka[58b], R.D. Kass[109], A. Kastanas[13], M. Kataoka[4], Y. Kataoka[155], E. Katsoufis[9], J. Katzy[41], V. Kaushik[6], K. Kawagoe[69], T. Kawamoto[155], G. Kawamura[81], M.S. Kayl[105], V.A. Kazanin[107], M.Y. Kazarinov[64], R. Keeler[169], R. Kehoe[39], M. Keil[54], G.D. Kekelidze[64], J.S. Keller[138], J. Kennedy[98], M. Kenyon[53], O. Kepka[125], N. Kerschen[29], B.P. Kerševan[74], S. Kersten[175], K. Kessoku[155], J. Keung[158], F. Khalil-zada[10], H. Khandanyan[165], A. Khanov[112], D. Kharchenko[64], A. Khodinov[96], A. Khomich[58a], T.J. Khoo[27], G. Khoriauli[20], A. Khoroshilov[175], V. Khovanskiy[95], E. Khramov[64], J. Khubua[51b], H. Kim[146a,146b], M.S. Kim[2], S.H. Kim[160], N. Kimura[171], O. Kind[15], B.T. King[73], M. King[66], R.S.B. King[118], J. Kirk[129], A.E. Kiryunin[99], T. Kishimoto[66], D. Kisielewska[37], T. Kittelmann[123], A.M. Kiver[128], E. Kladiva[144b], M. Klein[73], U. Klein[73], K. Kleinknecht[81], M. Klemetti[85], A. Klier[172], P. Klimek[146a,146b], A. Klimentov[24], R. Klingenberg[42], J.A. Klinger[82], E.B. Klinkby[35], T. Klioutchnikova[29], P.F. Klok[104], S. Klous[105], E.-E. Kluge[58a], T. Kluge[73], P. Kluit[105], S. Kluth[99], N.S. Knecht[158], E. Kneringer[61], E.B.F.G. Knoops[83], A. Knue[54], B.R. Ko[44], T. Kobayashi[155], M. Kobel[43], M. Kocian[143], P. Kodys[126], K. Köneke[29], A.C. König[104], S. Koenig[81], L. Köpke[81], F. Koetsveld[104], P. Koevesarki[20], T. Koffas[28], E. Koffeman[105], L.A. Kogan[118], S. Kohlmann[175], F. Kohn[54], Z. Kohout[127], T. Kohriki[65], T. Koi[143], G.M. Kolachev[107], H. Kolanoski[15], V. Kolesnikov[64], I. Koletsou[89a], J. Koll[88], M. Kollefrath[48], A.A. Komar[94], Y. Komori[155], T. Kondo[65], T. Kono[41,q], A.I. Kononov[48], R. Konoplich[108,r], N. Konstantinidis[77], A. Kootz[175], S. Koperny[37], K. Korcyl[38], K. Kordas[154], A. Korn[118], A. Korol[107], I. Korolkov[11], E.V. Korolkova[139], V.A. Korotkov[128],

O. Kortner[99], S. Kortner[99], V.V. Kostyukhin[20], S. Kotov[99], V.M. Kotov[64], A. Kotwal[44], C. Kourkoumelis[8], V. Kouskoura[154], A. Koutsman[159a], R. Kowalewski[169], T.Z. Kowalski[37], W. Kozanecki[136], A.S. Kozhin[128], V. Kral[127], V.A. Kramarenko[97], G. Kramberger[74], M.W. Krasny[78], A. Krasznahorkay[108], J. Kraus[88], J.K. Kraus[20], F. Krejci[127], J. Kretzschmar[73], N. Krieger[54], P. Krieger[158], K. Kroeninger[54], H. Kroha[99], J. Kroll[120], J. Kroseberg[20], J. Krstic[12a], U. Kruchonak[64], H. Krüger[20], T. Kruker[16], N. Krumnack[63], Z.V. Krumshteyn[64], A. Kruth[20], T. Kubota[86], S. Kuday[3a], S. Kuehn[48], A. Kugel[58c], T. Kuhl[41], D. Kuhn[61], V. Kukhtin[64], Y. Kulchitsky[90], S. Kuleshov[31b], C. Kummer[98], M. Kuna[78], J. Kunkle[120], A. Kupco[125], H. Kurashige[66], M. Kurata[160], Y.A. Kurochkin[90], V. Kus[125], E.S. Kuwertz[147], M. Kuze[157], J. Kvita[142], R. Kwee[15], A. La Rosa[49], L. La Rotonda[36a,36b], L. Labarga[80], J. Labbe[4], S. Lablak[135a], C. Lacasta[167], F. Lacava[132a,132b], H. Lacker[15], D. Lacour[78], V.R. Lacuesta[167], E. Ladygin[64], R. Lafaye[4], B. Laforge[78], T. Lagouri[80], S. Lai[48], E. Laisne[55], M. Lamanna[29], L. Lambourne[77], C.L. Lampen[6], W. Lampl[6], E. Lancon[136], U. Landgraf[48], M.P.J. Landon[75], J.L. Lane[82], C. Lange[41], A.J. Lankford[163], F. Lanni[24], K. Lantzsch[175], S. Laplace[78], C. Lapoire[20], J.F. Laporte[136], T. Lari[89a], A. Larner[118], M. Lassnig[29], P. Laurelli[47], V. Lavorini[36a,36b], W. Lavrijsen[14], P. Laycock[73], O. Le Dortz[78], E. Le Guirriec[83], C. Le Maner[158], E. Le Menedeu[11], T. LeCompte[5], F. Ledroit-Guillon[55], H. Lee[105], J.S.H. Lee[116], S.C. Lee[151], L. Lee[176], M. Lefebvre[169], M. Legendre[136], B.C. LeGeyt[120], F. Legger[98], C. Leggett[14], M. Lehmacher[20], G. Lehmann Miotto[29], X. Lei[6], M.A.L. Leite[23d], R. Leitner[126], D. Lellouch[172], B. Lemmer[54], V. Lendermann[58a], K.J.C. Leney[145b], T. Lenz[105], G. Lenzen[175], B. Lenzi[29], K. Leonhardt[43], S. Leontsinis[9], F. Lepold[58a], C. Leroy[93], J-R. Lessard[169], C.G. Lester[27], C.M. Lester[120], J. Levêque[4], D. Levin[87], L.J. Levinson[172], A. Lewis[118], G.H. Lewis[108], A.M. Leyko[20], M. Leyton[15], B. Li[83], H. Li[173,s], S. Li[32b,t], X. Li[87], Z. Liang[118,u], H. Liao[33], B. Liberti[133a], P. Lichard[29], M. Lichtnecker[98], K. Lie[165], W. Liebig[13], C. Limbach[20], A. Limosani[86], M. Limper[62], S.C. Lin[151,v], F. Linde[105], J.T. Linnemann[88], E. Lipeles[120], A. Lipniacka[13], T.M. Liss[165], D. Lissauer[24], A. Lister[49], A.M. Litke[137], C. Liu[28], D. Liu[151], H. Liu[87], J.B. Liu[87], M. Liu[32b], Y. Liu[32b], M. Livan[119a,119b], S.S.A. Livermore[118], A. Lleres[55], J. Llorente Merino[80], S.L. Lloyd[75], E. Lobodzinska[41], P. Loch[6], W.S. Lockman[137], T. Loddenkoetter[20], F.K. Loebinger[82], A. Loginov[176], C.W. Loh[168], T. Lohse[15], K. Lohwasser[48], M. Lokajicek[125], V.P. Lombardo[4], R.E. Long[71], L. Lopes[124a], D. Lopez Mateos[57], J. Lorenz[98], N. Lorenzo Martinez[115], M. Losada[162], P. Loscutoff[14], F. Lo Sterzo[132a,132b], M.J. Losty[159a], X. Lou[40], A. Lounis[115], K.F. Loureiro[162], J. Love[21], P.A. Love[71], A.J. Lowe[143,e], F. Lu[32a], H.J. Lubatti[138], C. Luci[132a,132b], A. Lucotte[55], A. Ludwig[43], D. Ludwig[41], I. Ludwig[48], J. Ludwig[48], F. Luehring[60], G. Luijckx[105], W. Lukas[61], D. Lumb[48], L. Luminari[132a], E. Lund[117], B. Lund-Jensen[147], B. Lundberg[79], J. Lundberg[146a,146b], J. Lundquist[35], M. Lungwitz[81], D. Lynn[24], E. Lytken[79], H. Ma[24], L.L. Ma[173], J.A. Macana Goia[93], G. Maccarrone[47], A. Macchiolo[99], B. Maček[74], J. Machado Miguens[124a], R. Mackeprang[35], R.J. Madaras[14], W.F. Mader[43], R. Maenner[58c], T. Maeno[24], P. Mättig[175], S. Mättig[41], L. Magnoni[29], E. Magradze[54], K. Mahboubi[48], S. Mahmoud[73], G. Mahout[17], C. Maiani[136], C. Maidantchik[23a], A. Maio[124a,b], S. Majewski[24], Y. Makida[65], N. Makovec[115], P. Mal[136], B. Malaescu[29], Pa. Malecki[38], P. Malecki[38], V.P. Maleev[121], F. Malek[55], U. Mallik[62], D. Malon[5], C. Malone[143], S. Maltezos[9], V. Malyshev[107], S. Malyukov[29], R. Mameghani[98], J. Mamuzic[12b], A. Manabe[65], L. Mandelli[89a], I. Mandić[74], R. Mandrysch[15], J. Maneira[124a], P.S. Mangeard[88], L. Manhaes de Andrade Filho[23a], A. Mann[54], P.M. Manning[137], A. Manousakis-Katsikakis[8], B. Mansoulie[136], A. Mapelli[29], L. Mapelli[29], L. March [80], J.F. Marchand[28], F. Marchese[133a,133b], G. Marchiori[78], M. Marcisovsky[125], C.P. Marino[169], F. Marroquim[23a], Z. Marshall[29], F.K. Martens[158], S. Marti-Garcia[167], B. Martin[29], B. Martin[88], J.P. Martin[93], T.A. Martin[17], V.J. Martin[45], B. Martin dit Latour[49], S. Martin-Haugh[149], M. Martinez[11], V. Martinez Outschoorn[57], A.C. Martyniuk[169], M. Marx[82], F. Marzano[132a], A. Marzin[111], L. Masetti[81], T. Mashimo[155], R. Mashinistov[94], J. Masik[82], A.L. Maslennikov[107], I. Massa[19a,19b], G. Massaro[105], N. Massol[4], A. Mastroberardino[36a,36b], T. Masubuchi[155], P. Matricon[115], H. Matsunaga[155], T. Matsushita[66], C. Mattravers[118,c], J. Maurer[83], S.J. Maxfield[73], A. Mayne[139], R. Mazini[151], M. Mazur[20], L. Mazzaferro[133a,133b], M. Mazzanti[89a], S.P. Mc Kee[87], A. McCarn[165], R.L. McCarthy[148], T.G. McCarthy[28], N.A. McCubbin[129], K.W. McFarlane[56], J.A. Mcfayden[139], H. McGlone[53], G. Mchedlidze[51b], T. Mclaughlan[17], S.J. McMahon[129], R.A. McPherson[169,j], A. Meade[84], J. Mechnich[105], M. Mechtel[175], M. Medinnis[41], R. Meera-Lebbai[111], T. Meguro[116], S. Mehlhase[35], A. Mehta[73], K. Meier[58a], B. Meirose[79], C. Melachrinos[30], B.R. Mellado Garcia[173], F. Meloni[89a,89b], L. Mendoza Navas[162], Z. Meng[151,s], A. Mengarelli[19a,19b], S. Menke[99], E. Meoni[11], K.M. Mercurio[57], P. Mermod[49], L. Merola[102a,102b], C. Meroni[89a], F.S. Merritt[30], H. Merritt[109], A. Messina[29,w], J. Metcalfe[103], A.S. Mete[163], C. Meyer[81], C. Meyer[30], J-P. Meyer[136], J. Meyer[174], J. Meyer[54], T.C. Meyer[29], W.T. Meyer[63], J. Miao[32d], S. Michal[29], L. Micu[25a], R.P. Middleton[129], S. Migas[73], L. Mijović[41], G. Mikenberg[172], M. Mikestikova[125], M. Mikuž[74], D.W. Miller[30], R.J. Miller[88], W.J. Mills[168], C. Mills[57], A. Milov[172], D.A. Milstead[146a,146b], D. Milstein[172], A.A. Minaenko[128], M. Miñano Moya[167], I.A. Minashvili[64], A.I. Mincer[108], B. Mindur[37], M. Mineev[64], Y. Ming[173], L.M. Mir[11], G. Mirabelli[132a], J. Mitrevski[137], V.A. Mitsou[167], S. Mitsui[65], P.S. Miyagawa[139], K. Miyazaki[66], J.U. Mjörnmark[79], T. Moa[146a,146b], P. Mockett[138], S. Moed[57], V. Moeller[27], K. Mönig[41], N. Möser[20], S. Mohapatra[148], W. Mohr[48], R. Moles-Valls[167], J. Molina-Perez[29], J. Monk[77], E. Monnier[83], S. Montesano[89a,89b], F. Monticelli[70], S. Monzani[19a,19b], R.W. Moore[2], G.F. Moorhead[86], C. Mora Herrera[49], A. Moraes[53], N. Morange[136], J. Morel[54], G. Morello[36a,36b], D. Moreno[81], M. Moreno Llácer[167], P. Morettini[50a], M. Morgenstern[43], M. Morii[57], J. Morin[75], A.K. Morley[29], G. Mornacchi[29], J.D. Morris[75], L. Morvaj[101], H.G. Moser[99], M. Mosidze[51b], J. Moss[109], R. Mount[143], E. Mountricha[9,x], S.V. Mouraviev[94], E.J.W. Moyse[84], F. Mueller[58a], J. Mueller[123], K. Mueller[20], T.A. Müller[98], T. Mueller[81], D. Muenstermann[29], Y. Munwes[153], W.J. Murray[129], I. Mussche[105], E. Musto[102a,102b], A.G. Myagkov[128], M. Myska[125], J. Nadal[11], K. Nagai[160], K. Nagano[65], A. Nagarkar[109], Y. Nagasaka[59], M. Nagel[99], A.M. Nairz[29], Y. Nakahama[29], K. Nakamura[155], T. Nakamura[155], I. Nakano[110], G. Nanava[20], A. Napier[161], R. Narayan[58b], M. Nash[77,c], T. Nattermann[20], T. Naumann[41], G. Navarro[162], H.A. Neal[87], P.Yu. Nechaeva[94], T.J. Neep[82],

A. Negri[119a,119b], G. Negri[29], S. Nektarijevic[49], A. Nelson[163], T.K. Nelson[143], S. Nemecek[125], P. Nemethy[108], A.A. Nepomuceno[23a], M. Nessi[29,y], M.S. Neubauer[165], A. Neusiedl[81], R.M. Neves[108], P. Nevski[24], P.R. Newman[17], V. Nguyen Thi Hong[136], R.B. Nickerson[118], R. Nicolaidou[136], B. Nicquevert[29], F. Niedercorn[115], J. Nielsen[137], N. Nikiforou[34], A. Nikiforov[15], V. Nikolaenko[128], I. Nikolic-Audit[78], K. Nikolics[49], K. Nikolopoulos[24], H. Nilsen[48], P. Nilsson[7], Y. Ninomiya [155], A. Nisati[132a], T. Nishiyama[66], R. Nisius[99], L. Nodulman[5], M. Nomachi[116], I. Nomidis[154], M. Nordberg[29], P.R. Norton[129], J. Novakova[126], M. Nozaki[65], L. Nozka[113], I.M. Nugent[159a], A.-E. Nuncio-Quiroz[20], G. Nunes Hanninger[86], T. Nunnemann[98], E. Nurse[77], B.J. O'Brien[45], S.W. O'Neale[17,*], D.C. O'Neil[142], V. O'Shea[53], L.B. Oakes[98], F.G. Oakham[28,d], H. Oberlack[99], J. Ocariz[78], A. Ochi[66], S. Oda[69], S. Odaka[65], J. Odier[83], H. Ogren[60], A. Oh[82], S.H. Oh[44], C.C. Ohm[146a,146b], T. Ohshima[101], S. Okada[66], H. Okawa[163], Y. Okumura[101], T. Okuyama[155], A. Olariu[25a], A.G. Olchevski[64], S.A. Olivares Pino[31a], M. Oliveira[124a,h], D. Oliveira Damazio[24], E. Oliver Garcia[167], D. Olivito[120], A. Olszewski[38], J. Olszowska[38], A. Onofre[124a,z], P.U.E. Onyisi[30], C.J. Oram[159a], M.J. Oreglia[30], Y. Oren[153], D. Orestano[134a,134b], N. Orlando[72a,72b], I. Orlov[107], C. Oropeza Barrera[53], R.S. Orr[158], B. Osculati[50a,50b], R. Ospanov[120], C. Osuna[11], G. Otero y Garzon[26], J.P. Ottersbach[105], M. Ouchrif[135d], E.A. Ouellette[169], F. Ould-Saada[117], A. Ouraou[136], Q. Ouyang[32a], A. Ovcharova[14], M. Owen[82], S. Owen[139], V.E. Ozcan[18a], N. Ozturk[7], A. Pacheco Pages[11], C. Padilla Aranda[11], S. Pagan Griso[14], E. Paganis[139], F. Paige[24], P. Pais[84], K. Pajchel[117], G. Palacino[159b], C.P. Paleari[6], S. Palestini[29], D. Pallin[33], A. Palma[124a], J.D. Palmer[17], Y.B. Pan[173], E. Panagiotopoulou[9], P. Pani[105], N. Panikashvili[87], S. Panitkin[24], D. Pantea[25a], A. Papadelis[146a], Th.D. Papadopoulou[9], A. Paramonov[5], D. Paredes Hernandez[33], W. Park[24,aa], M.A. Parker[27], F. Parodi[50a,50b], J.A. Parsons[34], U. Parzefall[48], S. Pashapour[54], E. Pasqualucci[132a], S. Passaggio[50a], A. Passeri[134a], F. Pastore[134a,134b], Fr. Pastore[76], G. Pásztor [49,ab], S. Pataraia[175], N. Patel[150], J.R. Pater[82], S. Patricelli[102a,102b], T. Pauly[29], M. Pecsy[144a], M.I. Pedraza Morales[173], S.V. Peleganchuk[107], D. Pelikan[166], H. Peng[32b], B. Penning[30], A. Penson[34], J. Penwell[60], M. Perantoni[23a], K. Perez[34,ac], T. Perez Cavalcanti[41], E. Perez Codina[159a], M.T. Pérez García-Estañ[167], V. Perez Reale[34], L. Perini[89a,89b], H. Pernegger[29], R. Perrino[72a], P. Perrodo[4], S. Persembe[3a], V.D. Peshekhonov[64], K. Peters[29], B.A. Petersen[29], J. Petersen[29], T.C. Petersen[35], E. Petit[4], A. Petridis[154], C. Petridou[154], E. Petrolo[132a], F. Petrucci[134a,134b], D. Petschull[41], M. Petteni[142], R. Pezoa[31b], A. Phan[86], P.W. Phillips[129], G. Piacquadio[29], A. Picazio[49], E. Piccaro[75], M. Piccinini[19a,19b], S.M. Piec[41], R. Piegaia[26], D.T. Pignotti[109], J.E. Pilcher[30], A.D. Pilkington[82], J. Pina[124a,b], M. Pinamonti[164a,164c], A. Pinder[118], J.L. Pinfold[2], B. Pinto[124a], C. Pizio[89a,89b], M. Plamondon[169], M.-A. Pleier[24], E. Plotnikova[64], A. Poblaguev[24], S. Poddar[58a], F. Podlyski[33], L. Poggioli[115], T. Poghosyan[20], M. Pohl[49], F. Polci[55], G. Polesello[119a], A. Policicchio[36a,36b], A. Polini[19a], J. Poll[75], V. Polychronakos[24], D.M. Pomarede[136], D. Pomeroy[22], K. Pommès[29], L. Pontecorvo[132a], B.G. Pope[88], G.A. Popeneciu[25a], D.S. Popovic[12a], A. Poppleton[29], X. Portell Bueso[29], G.E. Pospelov[99], S. Pospisil[127], I.N. Potrap[99], C.J. Potter[149], C.T. Potter[114], G. Poulard[29], J. Poveda[173], V. Pozdnyakov[64], R. Prabhu[77], P. Pralavorio[83], A. Pranko[14], S. Prasad[29], R. Pravahan[24], S. Prell[63], K. Pretzl[16], D. Price[60], J. Price[73], L.E. Price[5], D. Prieur[123], M. Primavera[72a], K. Prokofiev[108], F. Prokoshin[31b], S. Protopopescu[24], J. Proudfoot[5], X. Prudent[43], M. Przybycien[37], H. Przysiezniak[4], S. Psoroulas[20], E. Ptacek[114], E. Pueschel[84], J. Purdham[87], M. Purohit[24,aa], P. Puzo[115], Y. Pylypchenko[62], J. Qian[87], A. Quadt[54], D.R. Quarrie[14], W.B. Quayle[173], F. Quinonez[31a], M. Raas[104], V. Radescu[41], P. Radloff[114], T. Rador[18a], F. Ragusa[89a,89b], G. Rahal[178], A.M. Rahimi[109], D. Rahm[24], S. Rajagopalan[24], M. Rammensee[48], M. Rammes[141], A.S. Randle-Conde[39], K. Randrianarivony[28], F. Rauscher[98], T.C. Rave[48], M. Raymond[29], A.L. Read[117], D.M. Rebuzzi[119a,119b], A. Redelbach[174], G. Redlinger[24], R. Reece[120], K. Reeves[40], E. Reinherz-Aronis[153], A. Reinsch[114], I. Reisinger[42], C. Rembser[29], Z.L. Ren[151], A. Renaud[115], M. Rescigno[132a], S. Resconi[89a], B. Resende[136], P. Reznicek[98], R. Rezvani[158], R. Richter[99], E. Richter-Was[4,ad], M. Ridel[78], M. Rijpstra[105], M. Rijssenbeek[148], A. Rimoldi[119a,119b], L. Rinaldi[19a], R.R. Rios[39], I. Riu[11], G. Rivoltella[89a,89b], F. Rizatdinova[112], E. Rizvi[75], S.H. Robertson[85,j], A. Robichaud-Veronneau[118], D. Robinson[27], J.E.M. Robinson[77], A. Robson[53], J.G. Rocha de Lima[106], C. Roda[122a,122b], D. Roda Dos Santos[29], D. Rodriguez[162], A. Roe[54], S. Roe[29], O. Røhne[117], S. Rolli[161], A. Romaniouk[96], M. Romano[19a,19b], G. Romeo[26], E. Romero Adam[167], L. Roos[78], E. Ros[167], S. Rosati[132a], K. Rosbach[49], A. Rose[149], M. Rose[76], G.A. Rosenbaum[158], E.I. Rosenberg[63], P.L. Rosendahl[13], O. Rosenthal[141], L. Rosselet[49], V. Rossetti[11], E. Rossi[132a,132b], L.P. Rossi[50a], M. Rotaru[25a], I. Roth[172], J. Rothberg[138], D. Rousseau[115], C.R. Royon[136], A. Rozanov[83], Y. Rozen[152], X. Ruan[32a,ae], F. Rubbo[11], I. Rubinskiy[41], B. Ruckert[98], N. Ruckstuhl[105], V.I. Rud[97], C. Rudolph[43], G. Rudolph[61], F. Rühr[6], F. Ruggieri[134a,134b], A. Ruiz-Martinez[63], L. Rumyantsev[64], K. Runge[48], Z. Rurikova[48], N.A. Rusakovich[64], J.P. Rutherfoord[6], C. Ruwiedel[14], P. Ruzicka[125], Y.F. Ryabov[121], P. Ryan[88], M. Rybar[126], G. Rybkin[115], N.C. Ryder[118], A.F. Saavedra[150], I. Sadeh[153], H.F-W. Sadrozinski[137], R. Sadykov[64], F. Safai Tehrani[132a], H. Sakamoto[155], G. Salamanna[75], A. Salamon[133a], M. Saleem[111], D. Salek[29], D. Salihagic[99], A. Salnikov[143], J. Salt[167], B.M. Salvachua Ferrando[5], D. Salvatore[36a,36b], F. Salvatore[149], A. Salvucci[104], A. Salzburger[29], D. Sampsonidis[154], B.H. Samset[117], A. Sanchez[102a,102b], V. Sanchez Martinez[167], H. Sandaker[13], H.G. Sander[81], M.P. Sanders[98], M. Sandhoff[175], T. Sandoval[27], C. Sandoval [162], R. Sandstroem[99], D.P.C. Sankey[129], A. Sansoni[47], C. Santamarina Rios[85], C. Santoni[33], R. Santonico[133a,133b], H. Santos[124a], J.G. Saraiva[124a], T. Sarangi[173], E. Sarkisyan-Grinbaum[7], F. Sarri[122a,122b], G. Sartisohn[175], O. Sasaki[65], N. Sasao[67], I. Satsounkevitch[90], G. Sauvage[4], E. Sauvan[4], J.B. Sauvan[115], P. Savard[158,d], V. Savinov[123], D.O. Savu[29], L. Sawyer[24,l], D.H. Saxon[53], J. Saxon[120], C. Sbarra[19a], A. Sbrizzi[19a,19b], O. Scallon[93], D.A. Scannicchio[163], M. Scarcella[150], J. Schaarschmidt[115], P. Schacht[99], D. Schaefer[120], U. Schäfer[81], S. Schaepe[20], S. Schaetzel[58b], A.C. Schaffer[115], D. Schaile[98], R.D. Schamberger[148], A.G. Schamov[107], V. Scharf[58a], V.A. Schegelsky[121], D. Scheirich[87], M. Schernau[163], M.I. Scherzer[34], C. Schiavi[50a,50b], J. Schieck[98], M. Schioppa[36a,36b], S. Schlenker[29], E. Schmidt[48], K. Schmieden[20], C. Schmitt[81], S. Schmitt[58b], M. Schmitz[20], B. Schneider[16], U. Schnoor[43], A. Schöning[58b], M. Schott[29], D. Schouten[159a], J. Schovancova[125], M. Schram[85],

C. Schroeder[81], N. Schroer[58c], M.J. Schultens[20], J. Schultes[175], H.-C. Schultz-Coulon[58a], H. Schulz[15], J.W. Schumacher[20], M. Schumacher[48], B.A. Schumm[137], Ph. Schune[136], C. Schwanenberger[82], A. Schwartzman[143], Ph. Schwemling[78], R. Schwienhorst[88], R. Schwierz[43], J. Schwindling[136], T. Schwindt[20], M. Schwoerer[4], G. Sciolla[22], W.G. Scott[129], J. Searcy[114], G. Sedov[41], E. Sedykh[121], S.C. Seidel[103], A. Seiden[137], F. Seifert[43], J.M. Seixas[23a], G. Sekhniaidze[102a], S.J. Sekula[39], K.E. Selbach[45], D.M. Seliverstov[121], B. Sellden[146a], G. Sellers[73], M. Seman[144b], N. Semprini-Cesari[19a,19b], C. Serfon[98], L. Serin[115], L. Serkin[54], R. Seuster[99], H. Severini[111], A. Sfyrla[29], E. Shabalina[54], M. Shamim[114], L.Y. Shan[32a], J.T. Shank[21], Q.T. Shao[86], M. Shapiro[14], P.B. Shatalov[95], K. Shaw[164a,164c], D. Sherman[176], P. Sherwood[77], A. Shibata[108], H. Shichi[101], S. Shimizu[29], M. Shimojima[100], T. Shin[56], M. Shiyakova[64], A. Shmeleva[94], M.J. Shochet[30], D. Short[118], S. Shrestha[63], E. Shulga[96], M.A. Shupe[6], P. Sicho[125], A. Sidoti[132a], F. Siegert[48], Dj. Sijacki[12a], O. Silbert[172], J. Silva[124a], Y. Silver[153], D. Silverstein[143], S.B. Silverstein[146a], V. Simak[127], O. Simard[136], Lj. Simic[12a], S. Simion[115], B. Simmons[77], R. Simoniello[89a,89b], M. Simonyan[35], P. Sinervo[158], N.B. Sinev[114], V. Sipica[141], G. Siragusa[174], A. Sircar[24], A.N. Sisakyan[64], S.Yu. Sivoklokov[97], J. Sjölin[146a,146b], T.B. Sjursen[13], L.A. Skinnari[14], H.P. Skottowe[57], K. Skovpen[107], P. Skubic[111], M. Slater[17], T. Slavicek[127], K. Sliwa[161], V. Smakhtin[172], B.H. Smart[45], S.Yu. Smirnov[96], Y. Smirnov[96], L.N. Smirnova[97], O. Smirnova[79], B.C. Smith[57], D. Smith[143], K.M. Smith[53], M. Smizanska[71], K. Smolek[127], A.A. Snesarev[94], S.W. Snow[82], J. Snow[111], S. Snyder[24], R. Sobie[169,j], J. Sodomka[127], A. Soffer[153], C.A. Solans[167], M. Solar[127], J. Solc[127], E. Soldatov[96], U. Soldevila[167], E. Solfaroli Camillocci[132a,132b], A.A. Solodkov[128], O.V. Solovyanov[128], N. Soni[2], V. Sopko[127], B. Sopko[127], M. Sosebee[7], R. Soualah[164a,164c], A. Soukharev[107], S. Spagnolo[72a,72b], F. Spanò[76], R. Spighi[19a], G. Spigo[29], F. Spila[132a,132b], R. Spiwoks[29], M. Spousta[126], T. Spreitzer[158], B. Spurlock[7], R.D. St. Denis[53], J. Stahlman[120], R. Stamen[58a], E. Stanecka[38], R.W. Stanek[5], C. Stanescu[134a], M. Stanescu-Bellu[41], S. Stapnes[117], E.A. Starchenko[128], J. Stark[55], P. Staroba[125], P. Starovoitov[41], A. Staude[98], P. Stavina[144a], G. Steele[53], P. Steinbach[43], P. Steinberg[24], I. Stekl[127], B. Stelzer[142], H.J. Stelzer[88], O. Stelzer-Chilton[159a], H. Stenzel[52], S. Stern[99], G.A. Stewart[29], J.A. Stillings[20], M.C. Stockton[85], K. Stoerig[48], G. Stoicea[25a], S. Stonjek[99], P. Strachota[126], A.R. Stradling[7], A. Straessner[43], J. Strandberg[147], S. Strandberg[146a,146b], A. Strandlie[117], M. Strang[109], E. Strauss[143], M. Strauss[111], P. Strizenec[144b], R. Ströhmer[174], D.M. Strom[114], J.A. Strong[76,*], R. Stroynowski[39], J. Strube[129], B. Stugu[13], I. Stumer[24,*], J. Stupak[148], P. Sturm[175], N.A. Styles[41], D.A. Soh[151,u], D. Su[143], HS. Subramania[2], A. Succurro[11], Y. Sugaya[116], C. Suhr[106], K. Suita[66], M. Suk[126], V.V. Sulin[94], S. Sultansoy[3d], T. Sumida[67], X. Sun[55], J.E. Sundermann[48], K. Suruliz[139], G. Susinno[36a,36b], M.R. Sutton[149], Y. Suzuki[65], Y. Suzuki[66], M. Svatos[125], S. Swedish[168], I. Sykora[144a], T. Sykora[126], J. Sánchez[167], D. Ta[105], K. Tackmann[41], A. Taffard[163], R. Tafirout[159a], N. Taiblum[153], Y. Takahashi[101], H. Takai[24], R. Takashima[68], H. Takeda[66], T. Takeshita[140], Y. Takubo[65], M. Talby[83], A. Talyshev[107,f], M.C. Tamsett[24], J. Tanaka[155], R. Tanaka[115], S. Tanaka[131], S. Tanaka[65], A.J. Tanasijczuk[142], K. Tani[66], N. Tannoury[83], S. Tapprogge[81], D. Tardif[158], S. Tarem[152], F. Tarrade[28], G.F. Tartarelli[89a], P. Tas[126], M. Tasevsky[125], E. Tassi[36a,36b], M. Tatarkhanov[14], Y. Tayalati[135d], C. Taylor[77], F.E. Taylor[92], G.N. Taylor[86], W. Taylor[159b], M. Teinturier[115], M. Teixeira Dias Castanheira[75], P. Teixeira-Dias[76], K.K. Temming[48], H. Ten Kate[29], P.K. Teng[151], S. Terada[65], K. Terashi[155], J. Terron[80], M. Testa[47], R.J. Teuscher[158,j], J. Therhaag[20], T. Theveneaux-Pelzer[78], M. Thioye[176], S. Thoma[48], J.P. Thomas[17], E.N. Thompson[34], P.D. Thompson[17], P.D. Thompson[158], A.S. Thompson[53], L.A. Thomsen[35], E. Thomson[120], M. Thomson[27], R.P. Thun[87], F. Tian[34], M.J. Tibbetts[14], T. Tic[125], V.O. Tikhomirov[94], Y.A. Tikhonov[107,f], S. Timoshenko[96], P. Tipton[176], F.J. Tique Aires Viegas[29], S. Tisserant[83], T. Todorov[4], S. Todorova-Nova[161], B. Toggerson[163], J. Tojo[69], S. Tokár[144a], K. Tokunaga[66], K. Tokushuku[65], K. Tollefson[88], M. Tomoto[101], L. Tompkins[30], K. Toms[103], A. Tonoyan[13], C. Topfel[16], N.D. Topilin[64], I. Torchiani[29], E. Torrence[114], H. Torres[78], E. Torró Pastor[167], J. Toth[83,ab], F. Touchard[83], D.R. Tovey[139], T. Trefzger[174], L. Tremblet[29], A. Tricoli[29], I.M. Trigger[159a], S. Trincaz-Duvoid[78], M.F. Tripiana[70], W. Trischuk[158], B. Trocmé[55], C. Troncon[89a], M. Trottier-McDonald[142], M. Trzebinski[38], A. Trzupek[38], C. Tsarouchas[29], J.C-L. Tseng[118], M. Tsiakiris[105], P.V. Tsiareshka[90], D. Tsionou[4,af], G. Tsipolitis[9], V. Tsiskaridze[48], E.G. Tskhadadze[51a], I.I. Tsukerman[95], V. Tsulaia[14], J.-W. Tsung[20], S. Tsuno[65], D. Tsybychev[148], A. Tua[139], A. Tudorache[25a], V. Tudorache[25a], J.M. Tuggle[30], M. Turala[38], D. Turecek[127], I. Turk Cakir[3e], E. Turlay[105], R. Turra[89a,89b], P.M. Tuts[34], A. Tykhonov[74], M. Tylmad[146a,146b], M. Tyndel[129], G. Tzanakos[8], K. Uchida[20], I. Ueda[155], R. Ueno[28], M. Ugland[13], M. Uhlenbrock[20], M. Uhrmacher[54], F. Ukegawa[160], G. Unal[29], A. Undrus[24], G. Unel[163], Y. Unno[65], D. Urbaniec[34], G. Usai[7], M. Uslenghi[119a,119b], L. Vacavant[83], V. Vacek[127], B. Vachon[85], S. Vahsen[14], J. Valenta[125], P. Valente[132a], S. Valentinetti[19a,19b], S. Valkar[126], E. Valladolid Gallego[167], S. Vallecorsa[152], J.A. Valls Ferrer[167], H. van der Graaf[105], E. van der Kraaij[105], R. Van Der Leeuw[105], E. van der Poel[105], D. van der Ster[29], N. van Eldik[84], P. van Gemmeren[5], I. van Vulpen[105], M. Vanadia[99], W. Vandelli[29], A. Vaniachine[5], P. Vankov[41], F. Vannucci[78], R. Vari[132a], T. Varol[84], D. Varouchas[14], A. Vartapetian[7], K.E. Varvell[150], V.I. Vassilakopoulos[56], F. Vazeille[33], T. Vazquez Schroeder[54], G. Vegni[89a,89b], J.J. Veillet[115], F. Veloso[124a], R. Veness[29], S. Veneziano[132a], A. Ventura[72a,72b], D. Ventura[84], M. Venturi[48], N. Venturi[158], V. Vercesi[119a], M. Verducci[138], W. Verkerke[105], J.C. Vermeulen[105], A. Vest[43], M.C. Vetterli[142,d], I. Vichou[165], T. Vickey[145b,ag], O.E. Vickey Boeriu[145b], G.H.A. Viehhauser[118], S. Viel[168], M. Villa[19a,19b], M. Villaplana Perez[167], E. Vilucchi[47], M.G. Vincter[28], E. Vinek[29], V.B. Vinogradov[64], M. Virchaux[136,*], J. Virzi[14], O. Vitells[172], M. Viti[41], I. Vivarelli[48], F. Vives Vaque[2], S. Vlachos[9], D. Vladoiu[98], M. Vlasak[127], A. Vogel[20], P. Vokac[127], G. Volpi[47], M. Volpi[86], G. Volpini[89a], H. von der Schmitt[99], J. von Loeben[99], H. von Radziewski[48], E. von Toerne[20], V. Vorobel[126], V. Vorwerk[11], M. Vos[167], R. Voss[29], T.T. Voss[175], J.H. Vossebeld[73], N. Vranjes[136], M. Vranjes Milosavljevic[105], V. Vrba[125], M. Vreeswijk[105], T. Vu Anh[48], R. Vuillermet[29], I. Vukotic[115], W. Wagner[175], P. Wagner[120], H. Wahlen[175], S. Wahrmund[43], J. Wakabayashi[101], S. Walch[87], J. Walder[71], R. Walker[98], W. Walkowiak[141], R. Wall[176], P. Waller[73], C. Wang[44], H. Wang[173], H. Wang[32b,ah],

J. Wang[151], J. Wang[55], J.C. Wang[138], R. Wang[103], S.M. Wang[151], T. Wang[20], A. Warburton[85], C.P. Ward[27], M. Warsinsky[48], A. Washbrook[45], C. Wasicki[41], P.M. Watkins[17], A.T. Watson[17], I.J. Watson[150], M.F. Watson[17], G. Watts[138], S. Watts[82], A.T. Waugh[150], B.M. Waugh[77], M. Weber[129], M.S. Weber[16], P. Weber[54], A.R. Weidberg[118], P. Weigell[99], J. Weingarten[54], C. Weiser[48], H. Wellenstein[22], P.S. Wells[29], T. Wenaus[24], D. Wendland[15], Z. Weng[151,u], T. Wengler[29], S. Wenig[29], N. Wermes[20], M. Werner[48], P. Werner[29], M. Werth[163], M. Wessels[58a], J. Wetter[161], C. Weydert[55], K. Whalen[28], S.J. Wheeler-Ellis[163], A. White[7], M.J. White[86], S. White[122a,122b], S.R. Whitehead[118], D. Whiteson[163], D. Whittington[60], F. Wicek[115], D. Wicke[175], F.J. Wickens[129], W. Wiedenmann[173], M. Wielers[129], P. Wienemann[20], C. Wiglesworth[75], L.A.M. Wiik-Fuchs[48], P.A. Wijeratne[77], A. Wildauer[167], M.A. Wildt[41,q], I. Wilhelm[126], H.G. Wilkens[29], J.Z. Will[98], E. Williams[34], H.H. Williams[120], W. Willis[34], S. Willocq[84], J.A. Wilson[17], M.G. Wilson[143], A. Wilson[87], I. Wingerter-Seez[4], S. Winkelmann[48], F. Winklmeier[29], M. Wittgen[143], M.W. Wolter[38], H. Wolters[124a,h], W.C. Wong[40], G. Wooden[87], B.K. Wosiek[38], J. Wotschack[29], M.J. Woudstra[84], K.W. Wozniak[38], K. Wraight[53], C. Wright[53], M. Wright[53], B. Wrona[73], S.L. Wu[173], X. Wu[49], Y. Wu[32b,ai], E. Wulf[34], B.M. Wynne[45], S. Xella[35], M. Xiao[136], S. Xie[48], C. Xu[32b,x], D. Xu[139], B. Yabsley[150], S. Yacoob[145b], M. Yamada[65], H. Yamaguchi[155], A. Yamamoto[65], K. Yamamoto[63], S. Yamamoto[155], T. Yamamura[155], T. Yamanaka[155], J. Yamaoka[44], T. Yamazaki[155], Y. Yamazaki[66], Z. Yan[21], H. Yang[87], U.K. Yang[82], Y. Yang[60], Z. Yang[146a,146b], S. Yanush[91], L. Yao[32a], Y. Yao[14], Y. Yasu[65], G.V. Ybeles Smit[130], J. Ye[39], S. Ye[24], M. Yilmaz[3c], R. Yoosoofmiya[123], K. Yorita[171], R. Yoshida[5], C. Young[143], C.J. Young[118], S. Youssef[21], D. Yu[24], J. Yu[7], J. Yu[112], L. Yuan[66], A. Yurkewicz[106], B. Zabinski[38], R. Zaidan[62], A.M. Zaitsev[128], Z. Zajacova[29], L. Zanello[132a,132b], A. Zaytsev[107], C. Zeitnitz[175], M. Zeller[176], M. Zeman[125], A. Zemla[38], C. Zendler[20], O. Zenin[128], T. Ženiš[144a], Z. Zinonos[122a,122b], S. Zenz[14], D. Zerwas[115], G. Zevi della Porta[57], Z. Zhan[32d], D. Zhang[32b,ah], H. Zhang[88], J. Zhang[5], X. Zhang[32d], Z. Zhang[115], L. Zhao[108], T. Zhao[138], Z. Zhao[32b], A. Zhemchugov[64], J. Zhong[118], B. Zhou[87], N. Zhou[163], Y. Zhou[151], C.G. Zhu[32d], H. Zhu[41], J. Zhu[87], Y. Zhu[32b], X. Zhuang[98], V. Zhuravlov[99], D. Zieminska[60], R. Zimmermann[20], S. Zimmermann[20], S. Zimmermann[48], M. Ziolkowski[141], R. Zitoun[4], L. Živković[34], V.V. Zmouchko[128,*], G. Zobernig[173], A. Zoccoli[19a,19b], M. zur Nedden[15], V. Zutshi[106], L. Zwalinski[29].

[1] University at Albany, Albany NY, United States of America
[2] Department of Physics, University of Alberta, Edmonton AB, Canada
[3] [(a)]Department of Physics, Ankara University, Ankara; [(b)]Department of Physics, Dumlupinar University, Kutahya; [(c)]Department of Physics, Gazi University, Ankara; [(d)]Division of Physics, TOBB University of Economics and Technology, Ankara; [(e)]Turkish Atomic Energy Authority, Ankara, Turkey
[4] LAPP, CNRS/IN2P3 and Université de Savoie, Annecy-le-Vieux, France
[5] High Energy Physics Division, Argonne National Laboratory, Argonne IL, United States of America
[6] Department of Physics, University of Arizona, Tucson AZ, United States of America
[7] Department of Physics, The University of Texas at Arlington, Arlington TX, United States of America
[8] Physics Department, University of Athens, Athens, Greece
[9] Physics Department, National Technical University of Athens, Zografou, Greece
[10] Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan
[11] Institut de Física d'Altes Energies and Departament de Física de la Universitat Autònoma de Barcelona and ICREA, Barcelona, Spain
[12] [(a)]Institute of Physics, University of Belgrade, Belgrade; [(b)]Vinca Institute of Nuclear Sciences, University of Belgrade, Belgrade, Serbia
[13] Department for Physics and Technology, University of Bergen, Bergen, Norway
[14] Physics Division, Lawrence Berkeley National Laboratory and University of California, Berkeley CA, United States of America
[15] Department of Physics, Humboldt University, Berlin, Germany
[16] Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern, Switzerland
[17] School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom
[18] [(a)]Department of Physics, Bogazici University, Istanbul; [(b)]Division of Physics, Dogus University, Istanbul; [(c)]Department of Physics Engineering, Gaziantep University, Gaziantep; [(d)]Department of Physics, Istanbul Technical University, Istanbul, Turkey
[19] [(a)]INFN Sezione di Bologna; [(b)]Dipartimento di Fisica, Università di Bologna, Bologna, Italy
[20] Physikalisches Institut, University of Bonn, Bonn, Germany
[21] Department of Physics, Boston University, Boston MA, United States of America
[22] Department of Physics, Brandeis University, Waltham MA, United States of America
[23] [(a)]Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro; [(b)]Federal University of Juiz de Fora (UFJF), Juiz de Fora; [(c)]Federal University of Sao Joao del Rei (UFSJ), Sao Joao del Rei; [(d)]Instituto de Fisica, Universidade de Sao Paulo, Sao Paulo, Brazil
[24] Physics Department, Brookhaven National Laboratory, Upton NY, United States of America
[25] [(a)]National Institute of Physics and Nuclear Engineering, Bucharest; [(b)]University Politehnica Bucharest, Bucharest; [(c)]West University in Timisoara, Timisoara, Romania
[26] Departamento de Física, Universidad de Buenos Aires, Buenos Aires, Argentina

[27] Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom
[28] Department of Physics, Carleton University, Ottawa ON, Canada
[29] CERN, Geneva, Switzerland
[30] Enrico Fermi Institute, University of Chicago, Chicago IL, United States of America
[31] [(a)]Departamento de 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] Department of Physics, Kyushu University, Fukuoka, Japan
[70] Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina
[71] Physics Department, Lancaster University, Lancaster, United Kingdom
[72] [(a)]INFN Sezione di Lecce; [(b)]Dipartimento di Matematica e Fisica, Università del Salento, Lecce, Italy
[73] Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom
[74] Department of Physics, Jožef Stefan Institute and University of Ljubljana, Ljubljana, Slovenia
[75] School of Physics and Astronomy, Queen Mary University of London, London, United Kingdom

[76] Department of Physics, Royal Holloway University of London, Surrey, United Kingdom
[77] Department of Physics and Astronomy, University College London, London, United Kingdom
[78] Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France
[79] Fysiska institutionen, Lunds universitet, Lund, Sweden
[80] Departamento de Fisica Teorica C-15, Universidad Autonoma de Madrid, Madrid, Spain
[81] Institut für Physik, Universität Mainz, Mainz, Germany
[82] School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom
[83] CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France
[84] Department of Physics, University of Massachusetts, Amherst MA, United States of America
[85] Department of Physics, McGill University, Montreal QC, Canada
[86] School of Physics, University of Melbourne, Victoria, Australia
[87] Department of Physics, The University of Michigan, Ann Arbor MI, United States of America
[88] Department of Physics and Astronomy, Michigan State University, East Lansing MI, United States of America
[89] [(a)]INFN Sezione di Milano; [(b)]Dipartimento di Fisica, Università di Milano, Milano, Italy
[90] B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Republic of Belarus
[91] National Scientific and Educational Centre for Particle and High Energy Physics, Minsk, Republic of Belarus
[92] Department of Physics, Massachusetts Institute of Technology, Cambridge MA, United States of America
[93] Group of Particle Physics, University of Montreal, Montreal QC, Canada
[94] P.N. Lebedev Institute of Physics, Academy of Sciences, Moscow, Russia
[95] Institute for Theoretical and Experimental Physics (ITEP), Moscow, Russia
[96] Moscow Engineering and Physics Institute (MEPhI), Moscow, Russia
[97] Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
[98] Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany
[99] Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany
[100] Nagasaki Institute of Applied Science, Nagasaki, Japan
[101] Graduate School of Science, Nagoya University, Nagoya, Japan
[102] [(a)]INFN Sezione di Napoli; [(b)]Dipartimento di Scienze Fisiche, Università di Napoli, Napoli, Italy
[103] Department of Physics and Astronomy, University of New Mexico, Albuquerque NM, United States of America
[104] Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands
[105] Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands
[106] Department of Physics, Northern Illinois University, DeKalb IL, United States of America
[107] Budker Institute of Nuclear Physics, SB RAS, Novosibirsk, Russia
[108] Department of Physics, New York University, New York NY, United States of America
[109] Ohio State University, Columbus OH, United States of America
[110] Faculty of Science, Okayama University, Okayama, Japan
[111] Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman OK, United States of America
[112] Department of Physics, Oklahoma State University, Stillwater OK, United States of America
[113] Palacký University, RCPTM, Olomouc, Czech Republic
[114] Center for High Energy Physics, University of Oregon, Eugene OR, United States of America
[115] LAL, Univ. Paris-Sud and CNRS/IN2P3, Orsay, France
[116] Graduate School of Science, Osaka University, Osaka, Japan
[117] Department of Physics, University of Oslo, Oslo, Norway
[118] Department of Physics, Oxford University, Oxford, United Kingdom
[119] [(a)]INFN Sezione di Pavia; [(b)]Dipartimento di Fisica, Università di Pavia, Pavia, Italy
[120] Department of Physics, University of Pennsylvania, Philadelphia PA, United States of America
[121] Petersburg Nuclear Physics Institute, Gatchina, Russia
[122] [(a)]INFN Sezione di Pisa; [(b)]Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy
[123] Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh PA, United States of America
[124] [(a)]Laboratorio de Instrumentacao e Fisica Experimental de Particulas - LIP, Lisboa, Portugal; [(b)]Departamento de Fisica Teorica y del Cosmos and CAFPE, Universidad de Granada, Granada, Spain
[125] Institute of Physics, Academy of Sciences of the Czech Republic, Praha, Czech Republic
[126] Faculty of Mathematics and Physics, Charles University in Prague, Praha, Czech Republic
[127] Czech Technical University in Prague, Praha, Czech Republic
[128] State Research Center Institute for High Energy Physics, Protvino, Russia
[129] Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom
[130] Physics Department, University of Regina, Regina SK, Canada
[131] Ritsumeikan University, Kusatsu, Shiga, Japan

[132] [(a)]INFN Sezione di Roma I; [(b)]Dipartimento di Fisica, Università La Sapienza, Roma, Italy
[133] [(a)]INFN Sezione di Roma Tor Vergata; [(b)]Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy
[134] [(a)]INFN Sezione di Roma Tre; [(b)]Dipartimento di Fisica, Università Roma Tre, Roma, Italy
[135] [(a)]Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies - Université Hassan II, Casablanca; [(b)]Centre National de l'Energie des Sciences Techniques Nucleaires, Rabat; [(c)]Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA-Marrakech; [(d)]Faculté des Sciences, Université Mohamed Premier and LPTPM, Oujda; [(e)]Faculty of sciences, Mohammed V-Agdal University, Rabat, Morocco
[136] DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l'Univers), CEA Saclay (Commissariat a l'Energie Atomique), Gif-sur-Yvette, France
[137] Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz CA, United States of America
[138] Department of Physics, University of Washington, Seattle WA, United States of America
[139] Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom
[140] Department of Physics, Shinshu University, Nagano, Japan
[141] Fachbereich Physik, Universität Siegen, Siegen, Germany
[142] Department of Physics, Simon Fraser University, Burnaby BC, Canada
[143] SLAC National Accelerator Laboratory, Stanford CA, United States of America
[144] [(a)]Faculty of Mathematics, Physics & Informatics, Comenius University, Bratislava; [(b)]Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice, Slovak Republic
[145] [(a)]Department of Physics, University of Johannesburg, Johannesburg; [(b)]School of Physics, University of the Witwatersrand, Johannesburg, South Africa
[146] [(a)]Department of Physics, Stockholm University; [(b)]The Oskar Klein Centre, Stockholm, Sweden
[147] Physics Department, Royal Institute of Technology, Stockholm, Sweden
[148] Departments of Physics & Astronomy and Chemistry, Stony Brook University, Stony Brook NY, United States of America
[149] Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom
[150] School of Physics, University of Sydney, Sydney, Australia
[151] Institute of Physics, Academia Sinica, Taipei, Taiwan
[152] Department of Physics, Technion: Israel Inst. of Technology, Haifa, Israel
[153] Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel
[154] Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece
[155] International Center for Elementary Particle Physics and Department of Physics, The University of Tokyo, Tokyo, Japan
[156] Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo, Japan
[157] Department of Physics, Tokyo Institute of Technology, Tokyo, Japan
[158] Department of Physics, University of Toronto, Toronto ON, Canada
[159] [(a)]TRIUMF, Vancouver BC; [(b)]Department of Physics and Astronomy, York University, Toronto ON, Canada
[160] Institute of Pure and Applied Sciences, University of Tsukuba,1-1-1 Tennodai,Tsukuba, Ibaraki 305-8571, Japan
[161] Science and Technology Center, Tufts University, Medford MA, United States of America
[162] Centro de Investigaciones, Universidad Antonio Narino, Bogota, Colombia
[163] Department of Physics and Astronomy, University of California Irvine, Irvine CA, United States of America
[164] [(a)]INFN Gruppo Collegato di Udine; [(b)]ICTP, Trieste; [(c)]Dipartimento di Chimica, Fisica e Ambiente, Università di Udine, Udine, Italy
[165] Department of Physics, University of Illinois, Urbana IL, United States of America
[166] Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden
[167] Instituto de Física Corpuscular (IFIC) and Departamento de Física Atómica, Molecular y Nuclear and Departamento de Ingeniería Electrónica and Instituto de Microelectrónica de Barcelona (IMB-CNM), University of Valencia and CSIC, Valencia, Spain
[168] Department of Physics, University of British Columbia, Vancouver BC, Canada
[169] Department of Physics and Astronomy, University of Victoria, Victoria BC, Canada
[170] Department of Physics, University of Warwick, Coventry, United Kingdom
[171] Waseda University, Tokyo, Japan
[172] Department of Particle Physics, The Weizmann Institute of Science, Rehovot, Israel
[173] Department of Physics, University of Wisconsin, Madison WI, United States of America
[174] Fakultät für Physik und Astronomie, Julius-Maximilians-Universität, Würzburg, Germany
[175] Fachbereich C Physik, Bergische Universität Wuppertal, Wuppertal, Germany
[176] Department of Physics, Yale University, New Haven CT, United States of America
[177] Yerevan Physics Institute, Yerevan, Armenia
[178] Domaine scientifique de la Doua, Centre de Calcul CNRS/IN2P3, Villeurbanne Cedex, France
[a] Also at Laboratorio de Instrumentacao e Fisica Experimental de Particulas - LIP, Lisboa, Portugal

[b] Also at Faculdade de Ciencias and CFNUL, Universidade de Lisboa, Lisboa, Portugal
[c] Also at Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom
[d] Also at TRIUMF, Vancouver BC, Canada
[e] Also at Department of Physics, California State University, Fresno CA, United States of America
[f] Also at Novosibirsk State University, Novosibirsk, Russia
[g] Also at Fermilab, Batavia IL, United States of America
[h] Also at Department of Physics, University of Coimbra, Coimbra, Portugal
[i] Also at 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 Dipartimento di Fisica, Università La Sapienza, Roma, Italy
[x] 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
[y] Also at Section de Physique, Université de Genève, Geneva, Switzerland
[z] Also at Departamento de Fisica, Universidade de Minho, Braga, Portugal
[aa] Also at Department of Physics and Astronomy, University of South Carolina, Columbia SC, United States of America
[ab] Also at Institute for Particle and Nuclear Physics, Wigner Research Centre for Physics, Budapest, Hungary
[ac] Also at California Institute of Technology, Pasadena CA, United States of America
[ad] Also at Institute of Physics, Jagiellonian University, Krakow, Poland
[ae] Also at LAL, Univ. Paris-Sud and CNRS/IN2P3, Orsay, France
[af] Also at Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom
[ag] Also at Department of Physics, Oxford University, Oxford, United Kingdom
[ah] Also at Institute of Physics, Academia Sinica, Taipei, Taiwan
[ai] Also at Department of Physics, The University of Michigan, Ann Arbor MI, United States of America
[*] Deceased