



PUBLISHED FOR SISSA BY SPRINGER

RECEIVED: February 28, 2014

ACCEPTED: March 26, 2014

PUBLISHED: April 28, 2014

# Search for direct production of charginos and neutralinos in events with three leptons and missing transverse momentum in $\sqrt{s} = 8$ TeV $pp$ collisions with the ATLAS detector



## The ATLAS collaboration

*E-mail:* [atlas.publications@cern.ch](mailto:atlas.publications@cern.ch)

**ABSTRACT:** A search for the direct production of charginos and neutralinos in final states with three leptons and missing transverse momentum is presented. The analysis is based on  $20.3 \text{ fb}^{-1}$  of  $\sqrt{s} = 8$  TeV proton-proton collision data delivered by the Large Hadron Collider and recorded with the ATLAS detector. Observations are consistent with the Standard Model expectations and limits are set in  $R$ -parity-conserving phenomenological Minimal Supersymmetric Standard Models and in simplified supersymmetric models, significantly extending previous results. For simplified supersymmetric models of direct chargino ( $\tilde{\chi}_1^\pm$ ) and next-to-lightest neutralino ( $\tilde{\chi}_2^0$ ) production with decays to lightest neutralino ( $\tilde{\chi}_1^0$ ) via either all three generations of sleptons, staus only, gauge bosons, or Higgs bosons,  $\tilde{\chi}_1^\pm$  and  $\tilde{\chi}_2^0$  masses are excluded up to 700 GeV, 380 GeV, 345 GeV, or 148 GeV respectively, for a massless  $\tilde{\chi}_1^0$ .

**KEYWORDS:** Hadron-Hadron Scattering

ARXIV EPRINT: [1402.7029](https://arxiv.org/abs/1402.7029)

---

**Contents**

<b>1</b>	<b>Introduction</b>	<b>1</b>
<b>2</b>	<b>SUSY scenarios</b>	<b>2</b>
<b>3</b>	<b>The ATLAS detector</b>	<b>4</b>
<b>4</b>	<b>Monte Carlo simulation</b>	<b>4</b>
<b>5</b>	<b>Event reconstruction</b>	<b>6</b>
<b>6</b>	<b>Event selection</b>	<b>8</b>
<b>7</b>	<b>Standard Model background estimation</b>	<b>10</b>
7.1	Irreducible background processes	10
7.2	Reducible background processes	11
7.3	Systematic uncertainties	12
7.4	Background modelling validation	13
<b>8</b>	<b>Results and interpretations</b>	<b>14</b>
<b>9</b>	<b>Conclusions</b>	<b>21</b>
	<b>The ATLAS collaboration</b>	<b>30</b>

---

**1 Introduction**

Supersymmetry (SUSY) [1–9] proposes the existence of supersymmetric particles, with spin differing by one-half unit with respect to that of their Standard Model (SM) partners. Charginos,  $\tilde{\chi}_{1,2}^{\pm}$ , and neutralinos,  $\tilde{\chi}_{1,2,3,4}^0$ , collectively referred to as electroweakinos, are the ordered mass eigenstates formed from the linear superposition of the SUSY partners of the Higgs and electroweak gauge bosons (higgsinos, winos and binos). Based on naturalness arguments [10, 11], the lightest electroweakinos are expected to have mass of order 100 GeV and be accessible at the Large Hadron Collider (LHC). In the  $R$ -parity-conserving minimal supersymmetric extension of the SM (MSSM) [12–16], SUSY particles are pair-produced and the lightest SUSY particle (LSP), assumed in many models to be the  $\tilde{\chi}_1^0$ , is stable. Charginos and neutralinos can decay into leptonic final states via superpartners of neutrinos ( $\tilde{\nu}$ , sneutrinos) or charged leptons ( $\tilde{\ell}$ , sleptons), or via  $W$ ,  $Z$  or Higgs ( $h$ ) bosons ( $\tilde{\chi}_i^{\pm} \rightarrow \ell^{\pm}\tilde{\nu}, \nu\tilde{\ell}^{\pm}, W^{\pm}\tilde{\chi}_j^0, Z\tilde{\chi}_j^{\pm}, h\tilde{\chi}_j^{\pm}$  and  $\tilde{\chi}_i^0 \rightarrow \nu\tilde{\nu}, \ell^{\pm}\tilde{\ell}^{\mp}, W^{\pm}\tilde{\chi}_j^{\mp}, Z\tilde{\chi}_j^0, h\tilde{\chi}_j^0$  respectively).

This paper presents a search performed with the ATLAS detector for the direct production of charginos and neutralinos decaying to a final state with three charged leptons ( $e$ ,

$\mu$  or  $\tau$ , referred to as leptons in the following) and missing transverse momentum originating from the two undetected LSPs and the neutrinos. The analysis is based on  $20.3 \text{ fb}^{-1}$  of proton-proton collision data recorded by ATLAS at a centre-of-mass energy of  $\sqrt{s} = 8 \text{ TeV}$ . Previous searches for charginos and neutralinos are documented in refs [17–19] by ATLAS, and in ref. [20] by CMS. Similar searches were conducted at the Tevatron [21, 22]. At LEP [23–27], searches for direct chargino production set a model-independent lower limit of 103.5 GeV at 95% confidence level (CL) on the mass of promptly decaying charginos.

## 2 SUSY scenarios

Among the electroweakino pair-production processes leading to three leptons in the final state,  $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$  production has the largest cross-section in most of the MSSM parameter space. Several simplified supersymmetric models (“simplified models” [28]) are considered for the optimisation of the search and interpretation of results. The simplified models target the direct production of  $\tilde{\chi}_1^\pm$  and  $\tilde{\chi}_2^0$ , where the masses and the decay modes of the relevant particles ( $\tilde{\chi}_1^\pm$ ,  $\tilde{\chi}_1^0$ ,  $\tilde{\chi}_2^0$ ,  $\tilde{\nu}$ ,  $\tilde{\ell}_L$ <sup>1</sup>) are the only free parameters. It is assumed that the  $\tilde{\chi}_1^\pm$  and  $\tilde{\chi}_2^0$  consist purely of the wino component and are degenerate in mass, while the  $\tilde{\chi}_1^0$  consists purely of the bino component. Four different scenarios for the decay of the  $\tilde{\chi}_1^\pm$  and  $\tilde{\chi}_2^0$  are considered, where in all cases the decays are prompt,

**$\tilde{\ell}_L$ -mediated:** the  $\tilde{\chi}_1^\pm$  and  $\tilde{\chi}_2^0$  decay with a branching fraction of 1/6 via  $\tilde{e}_L$ ,  $\tilde{\mu}_L$ ,  $\tilde{\tau}_L$ ,  $\tilde{\nu}_e$ ,  $\tilde{\nu}_\mu$ , or  $\tilde{\nu}_\tau$  with masses  $m_{\tilde{\nu}} = m_{\tilde{\ell}_L} = (m_{\tilde{\chi}_1^0} + m_{\tilde{\chi}_1^\pm})/2$ ,

**$\tilde{\tau}_L$ -mediated:** the first- and second-generation sleptons and sneutrinos are assumed to be heavy, so that the  $\tilde{\chi}_1^\pm$  and  $\tilde{\chi}_2^0$  decay with a branching fraction of 1/2 via  $\tilde{\tau}$  or  $\tilde{\nu}_\tau$  with masses  $m_{\tilde{\nu}_\tau} = m_{\tilde{\tau}} = (m_{\tilde{\chi}_1^0} + m_{\tilde{\chi}_2^0})/2$ ,

**$WZ$ -mediated:** all sleptons and sneutrinos are assumed to be heavy, and the  $\tilde{\chi}_1^\pm$  and  $\tilde{\chi}_2^0$  decay via  $W^{(*)}$  and  $Z^{(*)}$  bosons, respectively, with a branching fraction of 100%,

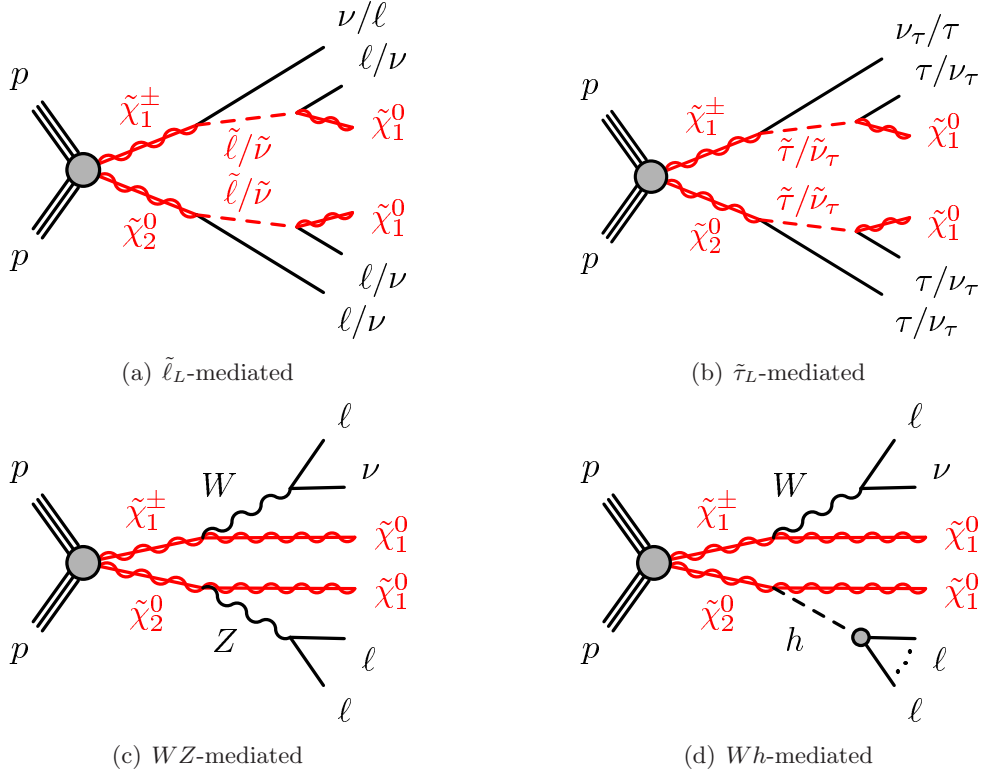
**$Wh$ -mediated:** all sleptons and sneutrinos are assumed to be heavy, and the  $\tilde{\chi}_1^\pm$  and  $\tilde{\chi}_2^0$  decay via  $W$  and lightest Higgs bosons, respectively, with a branching fraction of 100%. The Higgs boson considered is SM-like, with a mass of 125 GeV and is assumed to decay with SM branching ratios.

Diagrams for the considered  $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$  production and decay modes are shown in figure 1.

Results are also interpreted in dedicated phenomenological MSSM (pMSSM) [29] scenarios, which consider all relevant SUSY production processes. In the models considered in this paper, the masses of the coloured sparticles, of the CP-odd Higgs boson, and of the left-handed sleptons are set to high values to allow only the direct production of charginos and neutralinos via  $W/Z$  bosons and their decay via right-handed sleptons, gauge bosons and Higgs bosons. By tuning the mixing in the top-squark sector, the value of the lightest Higgs boson mass is set close to 125 GeV, which is consistent with the mass of the observed Higgs boson [30, 31]. The mass hierarchy, composition and production cross-sections of

---

<sup>1</sup>The sleptons are referred to as left- or right-handed (e.g.  $\tilde{\ell}_L$  or  $\tilde{\ell}_R$ ), depending on the helicity of the fermionic superpartners.



**Figure 1.** The Feynman diagrams for the four simplified models of the direct production of  $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$  studied in this paper. The different decay modes are discussed in the text. The dots in (d) depict possible additional decay products of the lightest Higgs boson decaying via intermediate  $\tau\tau$ ,  $WW$  or  $ZZ$  states.

the electroweakinos are governed by the ratio of the expectation values of the two Higgs doublets  $\tan\beta$ , the gaugino mass parameters  $M_1$  and  $M_2$ , and the higgsino mass parameter  $\mu$ . For the hierarchy  $M_1 < M_2 < \mu$  ( $M_1 < \mu < M_2$ ), the  $\tilde{\chi}_1^0$  is bino-like, the  $\tilde{\chi}_1^\pm$  and  $\tilde{\chi}_2^0$  are wino-like (higgsino-like) and the dominant electroweakino production process leading to a final state with three leptons is  $pp \rightarrow \tilde{\chi}_1^\pm \tilde{\chi}_2^0$  ( $pp \rightarrow \tilde{\chi}_1^\pm \tilde{\chi}_2^0$ ,  $pp \rightarrow \tilde{\chi}_1^\pm \tilde{\chi}_3^0$ ). If  $M_2 < M_1 < \mu$  ( $\mu < M_1 < M_2$ ), the  $\tilde{\chi}_1^0$  ( $\tilde{\chi}_1^0$ ,  $\tilde{\chi}_2^0$ ) and the  $\tilde{\chi}_1^\pm$  are wino-like (higgsino-like) with similar masses and the dominant process leading to a final state with three high transverse momentum leptons is the pair-production of the higgsino-like (wino-like)  $\tilde{\chi}_2^\pm$  and the bino-like  $\tilde{\chi}_2^0$  ( $\tilde{\chi}_3^0$ ).

Finally, the pMSSM scenarios under study are parametrised in the  $\mu$ - $M_2$  plane and are classified based on the masses of the right-handed sleptons into three groups,

**pMSSM  $\tilde{\ell}_R$ :** the right-handed sleptons are degenerate in mass, with mass  $m_{\tilde{\ell}_R} = (m_{\tilde{\chi}_1^0} + m_{\tilde{\chi}_2^0})/2$ . Setting the parameter  $\tan\beta = 6$  yields comparable  $\tilde{\chi}_2^0$  branching ratios into each slepton generation. The  $\tilde{\chi}_1^\pm$  decays predominantly via a  $W$  boson when kinematically allowed and to  $\tilde{\tau}$  otherwise because the sleptons are right-handed. To probe the sensitivity for different  $\tilde{\chi}_1^0$  compositions, three values of  $M_1$  are considered: 100 GeV, 140 GeV and 250 GeV,

**pMSSM  $\tilde{\tau}_R$ :** the selectrons and smuons are heavy and the  $\tilde{\tau}_R$  mass is set to  $m_{\tilde{\tau}_R} = (m_{\tilde{\chi}_1^0} + m_{\tilde{\chi}_2^0})/2$  and  $\tan\beta$  to 50, hence decays via right-handed staus dominate. The parameter  $M_1$  is set to 75 GeV resulting in a bino-like  $\tilde{\chi}_1^0$ ,

**pMSSM no  $\tilde{\ell}$ :** all sleptons are heavy so that decays via  $W$ ,  $Z$  or Higgs bosons dominate. The remaining parameters are  $M_1 = 50$  GeV and  $\tan\beta = 10$ . The Higgs branching fractions are SM-like across much of the parameter space considered. However, the  $h \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0$  branching fraction rises to  $\sim 20\%$  ( $\sim 70\%$ ) when  $\mu$  decreases to 200 (100) GeV, suppressing other decay modes, but this does not affect the mass limits significantly.

### 3 The ATLAS detector

The ATLAS detector [32] is a multi-purpose particle physics detector with forward-backward symmetric cylindrical geometry.<sup>2</sup> The inner tracking detector (ID) covers  $|\eta| < 2.5$  and consists of a silicon pixel detector, a semiconductor microstrip detector, and a transition radiation tracker. The ID is surrounded by a thin superconducting solenoid providing a 2 T axial magnetic field. A high-granularity lead/liquid-argon (LAr) sampling calorimeter measures the energy and the position of electromagnetic showers within  $|\eta| < 3.2$ . Sampling calorimeters with LAr are also used to measure hadronic showers in the end-cap ( $1.5 < |\eta| < 3.2$ ) and forward ( $3.1 < |\eta| < 4.9$ ) regions, while an iron/scintillator tile calorimeter measures hadronic showers in the central region ( $|\eta| < 1.7$ ). The muon spectrometer (MS) surrounds the calorimeters and consists of three large superconducting air-core toroid magnets, each with eight coils, a system of precision tracking chambers ( $|\eta| < 2.7$ ), and fast trigger chambers ( $|\eta| < 2.4$ ). A three-level trigger system [33] selects events to be recorded for offline analysis.

### 4 Monte Carlo simulation

Monte Carlo (MC) generators are used to simulate SM processes and new physics signals relevant to this analysis. The SM processes considered are those that can lead to leptonic signatures. The diboson production processes considered include  $WW$ ,  $WZ$  and  $ZZ$  (where “ $Z$ ” also includes virtual photons), and the  $W\gamma$  and  $Z\gamma$  processes. The triboson processes considered are  $WWW$  and  $ZWW$  (collectively referred to as  $VVV$ ), while samples of SM Higgs boson production via gluon fusion, vector-boson-fusion or in association with  $W/Z$  bosons or  $t\bar{t}$  are also studied. The  $t\bar{t}$ , single top-quark,  $W$ +jets,  $Z$ +jets,  $t\bar{t}W$ ,  $t\bar{t}Z$ ,  $t\bar{t}WW$ , and  $tZ$  processes are also considered, where  $t\bar{t}W$ ,  $t\bar{t}Z$  and  $t\bar{t}WW$  are collectively referred to as  $t\bar{t}V$ . Details of the MC simulation samples used in this paper, as well as the order of cross-section calculations in perturbative QCD used for yield normalisation are shown in table 1.

---

<sup>2</sup>ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the centre of the detector and the  $z$ -axis along the beam pipe. The  $x$ -axis points from the IP to the centre of the LHC ring, and the  $y$ -axis points upward. Cylindrical coordinates  $(r, \phi)$  are used in the transverse plane,  $\phi$  being the azimuthal angle around the  $z$ -axis. The pseudorapidity is defined in terms of the polar angle  $\theta$  as  $\eta = -\ln \tan(\theta/2)$ .

Process	Generator + fragmentation/hadronisation	Cross-section	Tune	PDF set
<b>Dibosons</b>				
$WW, WZ, ZZ$	POWHEG-r2129 [34, 35] + PYTHIA-8.165 [38]	NLO QCD with MCFM-6.2 [39, 40]	AU2 [36]	CT10 [37]
* $WZ, ZZ$	aMC@NLO-2.0.0.beta3 [41] + HERWIG-6.520 [42] (or + PYTHIA-6.426)	NLO QCD with MCFM-6.2	AU2	CT10
$ZZ$ via gluon fusion ( <i>not incl. in POWHEG</i> )	gg2VV [43] + HERWIG-6.520	NLO	AUET2B [44]	CT10
$W\gamma, Z\gamma$	SHERPA-1.4.1 [45]	NLO	(internal)	CT10
<b>Tribosons</b>				
$WWW, ZWW$	MADGRAPH-5.0 [46] + PYTHIA-6.426	NLO [47]	AUET2B	CTEQ6L1 [48]
<b>Higgs</b>				
via gluon fusion	POWHEG-r2092 + PYTHIA-8.165	NNLL QCD, NLO EW [49]	AU2	CT10
via vector-boson-fusion	POWHEG-r2092 + PYTHIA-8.165	NNLO QCD, NLO EW [49]	AU2	CT10
associated $W/Z$ production	PYTHIA-8.165	NNLO QCD, NLO EW [49]	AU2	CTEQ6L1
associated $t\bar{t}$ -production	PYTHIA-8.165	NNLO QCD [49]	AU2	CTEQ6L1
<b>Top+Boson</b>				
$t\bar{t}W, t\bar{t}Z$	ALPGEN-2.14 [50] + HERWIG-6.520	NLO [51, 52]	AUET2B	CTEQ6L1
* $t\bar{t}W, t\bar{t}Z$	MADGRAPH-5.0 + PYTHIA-6.426	NLO	AUET2B	CTEQ6L1
$t\bar{t}WW$	MADGRAPH-5.0 + PYTHIA-6.426	NLO [52]	AUET2B	CTEQ6L1
$tZ$	MADGRAPH-5.0 + PYTHIA-6.426	NLO [53]	AUET2B	CTEQ6L1
$t\bar{t}$	POWHEG-r2129 + PYTHIA-6.426	NNLO+NNLL [54–59]	PERUGIA2011C	CT10
<b>Single top</b>				
$t$ -channel	ACERMC-38 [60] + PYTHIA-6.426	NNLO+NNLL [61]	AUET2B	CTEQ6L1
$s$ -channel, $Wt$	MC@NLO-4.06 [62, 63] + HERWIG-6.520	NNLO+NNLL [64, 65]	AUET2B	CT10
<b><math>W</math>+jets, <math>Z</math>+jets</b>	ALPGEN-2.14 + PYTHIA-6.426 (or + HERWIG-6.520)	DYNNLO-1.1 [66] with MSTW2008 NNLO [67]	PERUGIA2011C	CTEQ6L1

**Table 1.** For the MC samples used in this paper for background estimates, the generator type, the order of cross-section calculations used for yield normalisation, names of parameter tunes used for the underlying event generation and PDF sets.

For all MC samples, the propagation of particles through the ATLAS detector is modelled with GEANT4 [68] using the full ATLAS detector simulation [69], except the  $t\bar{t}$  POWHEG sample, for which a fast simulation using a parametric response of the electromagnetic and hadronic calorimeters is used [70]. The effect of multiple proton-proton collisions from the same or nearby beam bunch crossings (in-time or out-of-time pile-up) is incorporated into the simulation by overlaying additional minimum-bias events generated with PYTHIA onto hard-scatter events. Simulated events are weighted to match the distribution of the number of interactions per bunch crossing observed in data, but are otherwise reconstructed in the same manner as data.

The SUSY signal samples are produced with HERWIG++-2.5.2 [71] using the CTEQ6L1 PDF set. Signal cross-sections are calculated to NLO in the strong coupling constant using PROSPINO2 [72]. They are in agreement with the NLO calculations matched to resummation at next-to-leading logarithmic accuracy (NLO+NLL) within  $\sim 2\%$  [73–75]. The nominal cross-section and the uncertainty are taken from the center and spread, respectively, of the envelope of cross-section predictions using different PDF sets and factorisation and renormalisation scales, as described in ref. [76].

## 5 Event reconstruction

Events recorded during stable data-taking conditions are analysed if the primary vertex has five or more tracks with transverse momentum  $p_T > 400$  MeV associated with it. The primary vertex of an event is identified as the vertex with the highest  $\Sigma p_T^2$  of associated tracks. After the application of beam, detector and data-quality requirements, the total luminosity considered in this analysis corresponds to  $20.3 \text{ fb}^{-1}$ .

Electron candidates must satisfy “medium” identification criteria, following ref. [77] (modified for 2012 data conditions), and are required to have  $|\eta| < 2.47$  and  $p_T > 10$  GeV. Electron  $p_T$  and  $|\eta|$  are determined from the calibrated clustered energy deposits in the electromagnetic calorimeter and the matched ID track, respectively. Muon candidates are reconstructed by combining tracks in the ID and tracks in the MS [78] and are required to have  $|\eta| < 2.5$  and  $p_T > 10$  GeV. Events containing one or more muons that have transverse impact parameter with respect to the primary vertex  $|d_0| > 0.2$  mm or longitudinal impact parameter with respect to the primary vertex  $|z_0| > 1$  mm are rejected to suppress cosmic-ray muon background.

Jets are reconstructed with the anti- $k_t$  algorithm [79] with a radius parameter of  $\Delta R \equiv \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} = 0.4$  using three-dimensional calorimeter energy clusters as input. The clusters are calibrated using the so-called local hadronic calibration, which consists of weighting differently the energy deposits arising from the electromagnetic and hadronic components of the showers [33]. The final jet energy calibration corrects the calorimeter response to the true particle-level jet energy [80, 81], where correction factors are obtained from simulation and then refined and validated using data. Corrections for in-time and out-of-time pile-up are also applied. Jets are required to have  $|\eta| < 2.5$  and  $p_T > 20$  GeV and a “jet vertex fraction” (JVF) larger than 0.5, if  $p_T < 50$  GeV. The JVF is the  $p_T$ -weighted fraction of the tracks in the jet that are associated with the primary vertex. Requiring large JVF values suppresses jets from a different interaction in the same beam bunch crossing. Events containing jets failing to satisfy the quality criteria described in ref. [80] are rejected to suppress events with large calorimeter noise and non-collision backgrounds.

Jets are identified as originating from  $b$ -quarks (referred to as  $b$ -tagged), using a multivariate technique based on quantities related to reconstructed secondary vertices. The chosen working point of the  $b$ -tagging algorithm [82] correctly identifies  $b$ -quark jets in simulated  $t\bar{t}$  samples with an efficiency of 80%, with a light-flavour jet misidentification probability of about 4%.

Hadronically decaying  $\tau$  leptons ( $\tau_{\text{had}}$ ) are reconstructed using jets described above with  $p_T > 10$  GeV and  $|\eta| < 2.47$ . The  $\tau_{\text{had}}$  reconstruction algorithm uses the electromagnetic and hadronic cluster shapes in the calorimeters, as well as information about the tracks within  $\Delta R = 0.2$  of the seed jet. Discriminating track and cluster variables are used within a boosted decision tree algorithm (BDT) to optimise  $\tau_{\text{had}}$  identification. Electrons misidentified as  $\tau_{\text{had}}$  candidates are vetoed using transition radiation and calorimeter information. The  $\tau_{\text{had}}$  candidates are corrected to the  $\tau$  energy scale [83] using an  $\eta$ - and  $p_T$ -dependent calibration. The  $\tau_{\text{had}}$  candidates are required to have one or three associated tracks (prongs) as  $\tau$  leptons predominantly decay to either one or three charged pions,

together with a neutrino and often additional neutral pions. The  $\tau_{\text{had}}$  candidates are also required to have  $p_T > 20$  GeV and have unit total charge.

The missing transverse momentum,  $\vec{p}_T^{\text{miss}}$  (and its magnitude  $E_T^{\text{miss}}$ ), is the negative vector sum of the transverse momenta of all  $p_T > 10$  GeV muons,  $p_T > 10$  GeV electrons,  $p_T > 10$  GeV photons,  $p_T > 20$  GeV jets, and calibrated calorimeter energy clusters with  $|\eta| < 4.9$  not associated with these objects. Hadronically decaying  $\tau$  leptons are included in the  $\vec{p}_T^{\text{miss}}$  calculation as jets. Clusters associated with electrons, photons and jets are calibrated to the scale of the corresponding objects. Calorimeter clusters not associated with these objects are calibrated using both calorimeter and tracker information [84]. For jets, the calibration includes the pile-up correction described above, whilst the jet vertex fraction requirement is not considered when selecting jet candidates.

In this analysis, “tagged” leptons are candidate leptons separated from each other and from jets in the following order:

1. if two electron candidates are reconstructed with  $\Delta R < 0.1$ , the lower energy candidate is discarded to avoid double counting.
2. jets within  $\Delta R = 0.2$  of an electron candidate, and  $\tau_{\text{had}}$  candidates within  $\Delta R = 0.2$  of an electron or muon, are rejected to avoid double counting.
3. electron and muon candidates are rejected if found within  $\Delta R = 0.4$  of a jet to suppress semileptonic decays of  $c$ - and  $b$ -hadrons.
4. to reject bremsstrahlung, close-by electron and muon candidates are both rejected if found within  $\Delta R = 0.01$  (0.05 for close-by muon pairs).
5. jets found within  $\Delta R = 0.2$  of a “signal”  $\tau$  lepton (see below) are rejected, to avoid double counting.

Finally, to suppress low mass resonances, if tagged electrons and muons form a same-flavour opposite-sign (SFOS) pair with  $m_{\text{SFOS}} < 12$  GeV, both leptons in the pair are rejected.

Tagged leptons satisfying additional identification criteria are called “signal” leptons. Signal  $\tau$  leptons must satisfy “medium” identification criteria [85]. Signal electrons (muons) are tagged electrons (muons) for which the scalar sum of the transverse momenta of tracks within a cone of  $\Delta R = 0.3$  around the lepton candidate is less than 16% (12%) of the lepton  $p_T$ . Tracks used for the electron (muon) isolation requirement defined above are those which have  $p_T > 0.4$  (1.0) GeV and  $|z_0| < 2$  mm with respect to the primary vertex of the event. Tracks of the leptons themselves as well as tracks closer in  $z_0$  to another vertex (that is not the primary vertex) are not included. The isolation requirements are imposed to reduce the contributions from semileptonic decays of hadrons. Signal electrons must also satisfy “tight” identification criteria [77] (modified for 2012 data conditions) and the sum of the extra transverse energy deposits in the calorimeter (corrected for pile-up effects) within a cone of  $\Delta R = 0.3$  around the electron candidate must be less than 18% of the electron  $p_T$ . To further suppress electrons and muons originating from secondary vertices, the  $d_0$  normalised to its uncertainty is required to be small, with  $|d_0|/\sigma(d_0) < 5$  (3), and  $|z_0 \sin \theta| < 0.4$  mm (1 mm) for electrons (muons).



Trigger	$p_T$ threshold [GeV]
Single Isolated $e$	25
Single Isolated $\mu$	25
Double $e$	14,14 25,10
Double $\mu$	14,14 18,10
Combined $e\mu$	14( $e$ ),10( $\mu$ ) 18( $\mu$ ),10( $e$ )

**Table 2.** The triggers used in the analysis and the  $p_T$  threshold used, ensuring that the lepton(s) triggering the event are in the plateau region of the trigger efficiency. Muons are triggered within a restricted range of  $|\eta| < 2.4$ .

Signal region	SR0 $\tau$ a	SR0 $\tau$ b	SR1 $\tau$	SR2 $\tau$ a	SR2 $\tau$ b
Flavour/sign	$\ell^+\ell^-\ell, \ell^+\ell^-\ell'$	$\ell^\pm\ell^\pm\ell'^\mp$	$\tau^\pm\ell^\mp\ell'^\mp, \tau^\pm\ell^\mp\ell'^\mp$	$\tau\tau\ell$	$\tau^+\tau^-\ell$
$b$ -tagged jet	veto	veto	veto	veto	veto
$E_T^{\text{miss}}$	binned	$> 50$	$> 50$	$> 50$	$> 60$
Other	$m_{\text{SFOS}}$ binned $m_T$ binned	$p_T^{3\text{rd}\ell} > 20$ $\Delta\phi_{\ell\ell'}^{\text{min}} \leq 1.0$	$p_T^{2\text{nd}\ell} > 30$ $\sum p_T^\ell > 70$ $m_{\ell\tau} < 120$ $m_{ee} Z$ veto	$m_{T2}^{\text{max}} > 100$	$\sum p_T^\tau > 110$ $70 < m_{\tau\tau} < 120$
Target model	$\tilde{\ell}, WZ$ -mediated	$Wh$ -mediated	$Wh$ -mediated	$\tilde{\tau}_L$ -mediated	$Wh$ -mediated

**Table 3.** Summary of the selection requirements for the signal regions. The index of the signal region corresponds to the number of required  $\tau$  leptons. The SR0 $\tau$ a bin definitions are shown in table 4. Energies, momenta and masses are given in units of GeV. The signal models targeted by the selection requirements are also shown.

## 6 Event selection

Events are required to have exactly three tagged leptons, passing signal lepton requirements and separated from each other by  $\Delta R > 0.3$ . At least one electron or muon is required among the three leptons. The signal electrons and muons in the events must have fired at least one of the single- or double-lepton triggers and satisfied the corresponding  $p_T$ -threshold requirements shown in table 2. The  $p_T$  thresholds are chosen such that the overall trigger efficiency with respect to the selected events is in excess of 90%, and is independent of the lepton transverse momenta within uncertainties. The same requirements are applied to the MC-simulated events. Events are further required not to contain any  $b$ -tagged jets to suppress contributions from top-quark production.

In the following, signal electrons and muons are labelled as  $\ell$  or  $\ell'$  where the flavour of  $\ell$  and  $\ell'$  is assumed to be different. Signal  $\tau_{\text{had}}$  are referred to as  $\tau$ . Five main signal regions are defined according to the flavour and charge of the leptons, as shown in table 3, and are labelled by the number of  $\tau$  leptons selected:

**SR0 $\tau$ a** ( $\ell^+\ell^-\ell, \ell^+\ell^-\ell'$ ) — a signal region composed of 20 disjoint bins defined in table 4 is optimised for maximum sensitivity to the  $\tilde{\ell}_L$ -mediated and  $WZ$ -mediated scenarios. SR0 $\tau$ a also offers sensitivity to the  $Wh$ -mediated scenario. This signal region requires a pair of SFOS leptons among the three leptons and has five slices in  $m_{\text{SFOS}}$  (defined as the invariant mass of the SFOS lepton pair closest to the  $Z$  boson mass). Each  $m_{\text{SFOS}}$  slice is further divided into four bins using  $E_{\text{T}}^{\text{miss}}$  and  $m_{\text{T}}$  selections (see table 4), where  $m_{\text{T}}$  is the transverse mass formed using the  $E_{\text{T}}^{\text{miss}}$  and the lepton not forming the SFOS lepton pair with mass closest to the  $Z$  boson mass,  $m_{\text{T}}(\vec{p}_{\text{T}}^{\ell}, \vec{p}_{\text{T}}^{\text{miss}}) = \sqrt{2p_{\text{T}}^{\ell}E_{\text{T}}^{\text{miss}} - 2\vec{p}_{\text{T}}^{\ell} \cdot \vec{p}_{\text{T}}^{\text{miss}}}$ . Events with tripleton mass,  $m_{3\ell}$ , close to the  $Z$  boson mass ( $|m_{3\ell} - m_Z| < 10$  GeV) are vetoed in some bins with low  $E_{\text{T}}^{\text{miss}}$  and low  $m_{\text{T}}$  to suppress contributions from  $Z$  boson decays with converted photons from final-state radiation. The  $WZ$  and  $t\bar{t}$  backgrounds generally dominate the SR0 $\tau$ a bins in varying proportions, with  $WZ$  mainly dominating the bins for which  $m_{\text{SFOS}}$  is in the 81.2–101.2 GeV range.

**SR0 $\tau$ b** ( $\ell^{\pm}\ell^{\pm}\ell'^{\mp}$ ) — optimised for maximum sensitivity to the  $Wh$ -mediated scenario, this signal region vetoes SFOS lepton pairs among the three leptons to effectively suppress the  $WZ$  background. Requirements on  $E_{\text{T}}^{\text{miss}}$ , lepton  $p_{\text{T}}$  and the minimum  $\Delta\phi$  between two opposite-sign (OS) leptons,  $\Delta\phi_{\ell\ell'}^{\text{min}}$ , are used to reduce the backgrounds. The remaining dominant processes are  $t\bar{t}$  and  $VVV$  production.

**SR1 $\tau$**  ( $\tau^{\pm}\ell^{\mp}\ell^{\mp}, \tau^{\pm}\ell^{\mp}\ell'^{\mp}$ ) — a signal region requiring one  $\tau$  and two same sign (SS) electrons or muons ( $e^{\pm}e^{\pm}, e^{\pm}\mu^{\pm}, \mu^{\pm}\mu^{\pm}$ ) is optimised for maximum sensitivity to the  $Wh$ -mediated scenario. To increase the sensitivity to the  $h \rightarrow \tau\tau$  decay,  $m_{\ell\tau}$  is required to be less than 120 GeV, where  $m_{\ell\tau}$  is obtained using the  $\ell$  and  $\tau$  forming the pair closest to the Higgs boson mass of 125 GeV. Electron pairs with mass consistent with a  $Z$  boson ( $m_{ee} = 81.2\text{--}101.2$  GeV) are vetoed to suppress events in which an electron’s charge is assigned the wrong sign. After requirements on lepton  $p_{\text{T}}$ , the diboson and  $t\bar{t}$  processes dominate the background.

**SR2 $\tau$ a** ( $\tau\tau\ell$ ) — this signal region is optimised for maximum sensitivity to the  $\tilde{\tau}_L$ -mediated scenario and also offers some sensitivity to the  $\tilde{\ell}_L$ -mediated scenario. It selects events with high  $E_{\text{T}}^{\text{miss}}$  and high “stransverse mass”  $m_{\text{T}2}^{\text{max}}$  [86, 87]. The stransverse mass is calculated as  $m_{\text{T}2}^{\text{max}} = \min_{\vec{q}_{\text{T}}} [\max(m_{\text{T}}(\vec{p}_{\text{T},1}, \vec{q}_{\text{T}}), m_{\text{T}}(\vec{p}_{\text{T},2}, \vec{p}_{\text{T}}^{\text{miss}} - \vec{q}_{\text{T}}))]$ , where  $\vec{p}_{\text{T},1}$  and  $\vec{p}_{\text{T},2}$  are the transverse momenta of the two leptons yielding the largest stransverse mass, and  $\vec{q}_{\text{T}}$  is a transverse vector that minimises the larger of the two transverse masses  $m_{\text{T}}$ . The dominant background of this signal region is  $t\bar{t}$  production.

**SR2 $\tau$ b** ( $\tau^+\tau^-\ell$ ) — this signal region is optimised for maximum sensitivity to the  $Wh$ -mediated scenario and requires two OS  $\tau$  leptons to target the  $h \rightarrow \tau\tau$  decay. Requirements on the  $p_{\text{T}}^{\tau}$  and  $E_{\text{T}}^{\text{miss}}$  provide background suppression and the  $\tau\tau$  invariant mass  $m_{\tau\tau}$  is required to be consistent with that resulting from a Higgs boson decay (and lower than 125 GeV due to escaping neutrinos). Diboson and  $t\bar{t}$  processes survive the SR2 $\tau$ b selection.

All signal regions are disjoint, with the exception of SR2 $\tau$ a and SR2 $\tau$ b.

SR0 $\tau$ a bin	$m_{\text{SFOS}}$	$m_{\text{T}}$	$E_{\text{T}}^{\text{miss}}$	3 $\ell$ Z veto
1	12–40	0–80	50–90	no
2	12–40	0–80	> 90	no
3	12–40	> 80	50–75	no
4	12–40	> 80	> 75	no
5	40–60	0–80	50–75	yes
6	40–60	0–80	> 75	no
7	40–60	> 80	50–135	no
8	40–60	> 80	> 135	no
9	60–81.2	0–80	50–75	yes
10	60–81.2	> 80	50–75	no
11	60–81.2	0–110	> 75	no
12	60–81.2	> 110	> 75	no
13	81.2–101.2	0–110	50–90	yes
14	81.2–101.2	0–110	> 90	no
15	81.2–101.2	> 110	50–135	no
16	81.2–101.2	> 110	> 135	no
17	> 101.2	0–180	50–210	no
18	> 101.2	> 180	50–210	no
19	> 101.2	0–120	> 210	no
20	> 101.2	> 120	> 210	no

**Table 4.** Summary of the bins in  $m_{\text{SFOS}}$ ,  $m_{\text{T}}$ , and  $E_{\text{T}}^{\text{miss}}$  for SR0 $\tau$ a. All dimensionful values are given in units of GeV.

## 7 Standard Model background estimation

Several SM processes lead to events with three signal leptons. Lepton candidates can be classified into three main types, depending on their origin: “real” leptons are prompt and isolated; “fake” leptons can originate from a misidentified light-flavour quark or gluon jet (referred to as “light flavour”); “non-prompt” leptons can originate from a semileptonic decay of a heavy-flavour quark, or an electron from a photon conversion. The SM background processes are classified into “irreducible” background if they lead to events with three or more real leptons, or into “reducible” background if the event has at least one fake or non-prompt lepton. The predictions for irreducible and reducible backgrounds are tested in validation regions (section 7.4).

### 7.1 Irreducible background processes

Irreducible processes include diboson ( $WZ$  and  $ZZ$ ),  $VVV$ ,  $t\bar{t}V$ ,  $tZ$  and Higgs boson production. The irreducible background contributions are determined using the corresponding MC samples, for which  $b$ -tagged jet selection efficiencies and misidentification probabilities, lepton efficiencies, as well as the energy and momentum measurements of leptons and jets are corrected to account for differences with respect to the data.

## 7.2 Reducible background processes

Reducible processes include single- and pair-production of top quarks,  $WW$  production and single  $W$  or  $Z$  boson produced in association with jets or photons. In signal regions with fewer than two  $\tau$  leptons, the dominant reducible background component is  $t\bar{t}$ , followed by  $Z$ +jets, whereas for signal regions with two  $\tau$  leptons, the dominant component is  $W$ +jets. The reducible background is estimated using a “matrix method” similar to that described in ref. [88] and which was previously used in ref. [17].

In this implementation of the matrix method, the highest- $p_T$  signal electron or muon is taken to be real. Simulation studies show that this is a valid assumption in >95% of three-signal-lepton events. The number of observed events with one or two fake or non-prompt leptons is then extracted from a system of linear equations relating the number of events with two additional signal or tagged leptons to the number of events with two additional candidates that are either real, fake or non-prompt. The coefficients of the linear equations are functions of the real-lepton identification efficiencies and of the fake and non-prompt lepton misidentification probabilities, both defined as a fraction of the corresponding tagged leptons passing the signal lepton requirements.

The real-lepton identification efficiencies are obtained from MC simulation in the signal or validation region under consideration to account for detailed kinematic dependencies and are multiplied by correction factors to account for potential differences with respect to the data. The correction factors are obtained from a control region rich in  $Z \rightarrow e^+e^-$  and  $Z \rightarrow \mu^+\mu^-$  decays and defined with one signal and one tagged lepton, forming a SFOS pair with  $|m_{\text{SFOS}} - m_Z| < 10$  GeV. The real-lepton efficiency correction factors are found to be  $0.998 \pm 0.013$  and  $0.996 \pm 0.001$  for electrons and muons respectively, where the uncertainties are statistical.

The fake and non-prompt lepton misidentification probabilities are calculated as the weighted averages of the corrected, type- and process-dependent, misidentification probabilities defined below according to their relative contributions in a given signal or validation region. The type- and process-dependent misidentification probabilities for each relevant fake and non-prompt lepton type (heavy flavour, light flavour or conversion) and for each reducible background process are obtained using simulated events with one signal and two tagged leptons and parameterised with the lepton  $p_T$  and  $\eta$ . These misidentification probabilities are then corrected using the ratio (“correction factor”) of the misidentification probability in data to that in simulation obtained from dedicated control samples. The correction factors are assumed to be independent of selected regions and any potential composition or kinematic differences. For non-prompt electrons and muons from heavy-flavour quark decays, the correction factor is measured in a  $b\bar{b}$ -dominated control sample. This is defined by selecting events with only one  $b$ -tagged jet (containing a muon candidate) and a tagged lepton, for which the misidentification probability is measured. Contaminating backgrounds leading to the production of real leptons from  $W$  decays include top-quark pair-production and  $W$  bosons produced in association with  $b$ -tagged jets. A requirement that  $E_T^{\text{miss}} < 60$  GeV suppresses both the  $t\bar{t}$  and the  $W$  contamination, and requiring  $m_T < 50$  GeV (constructed using the tagged lepton) further reduces the  $W$  background.

The remaining ( $\sim 1\%$  level) background is subtracted from data using MC predictions. The heavy-flavour correction factor is found to be  $0.74 \pm 0.04$  ( $0.89 \pm 0.03$ ) for electrons (muons), where the uncertainties are statistical.

Fake  $\tau$  leptons predominantly originate from light-flavour quark jets. The corresponding correction factor is measured in a  $W$ +jets-dominated control sample, where events with one signal muon with  $p_T > 25$  GeV and one tagged  $\tau$  are selected. The muon and  $\tau$  must be well separated from all other leptons and jets in the event. To suppress  $Z \rightarrow \tau\tau$  contributions,  $m_T^\mu > 60$  GeV and  $\cos \Delta\phi(\vec{p}_T^{\text{miss}}, \vec{p}_T^\mu) + \cos \Delta\phi(\vec{p}_T^{\text{miss}}, \vec{p}_T^\tau) < -0.15$  are imposed. Finally,  $b$ -tagged jets are vetoed to suppress heavy-flavour contributions. The light-flavour correction factor decreases from 0.9 to 0.6 (1.0 to 0.6) as the  $p_T$  increases from 20 GeV to 150 GeV for one-prong (three-prong)  $\tau$  decays.

The correction factor for the conversion candidates is determined in events with a converted photon radiated from a muon in  $Z \rightarrow \mu\mu$  decays. These are selected by requiring two oppositely charged signal muons and one tagged electron, assumed to originate from the converted photon, such that  $|m_{\mu\mu e} - m_Z| < 10$  GeV. The conversion correction factor for electrons is  $1.14 \pm 0.12$ , where the uncertainty is statistical, and is independent of electron  $p_T$  and  $\eta$ .

### 7.3 Systematic uncertainties

Several sources of systematic uncertainties are considered for the SM background estimates and signal yield predictions. The systematic uncertainties affecting the simulation-based estimates (the yield of the irreducible background, the cross-section-weighted misidentification probabilities, and the signal yield) include the theoretical cross-section uncertainties due to the choice of renormalisation and factorisation scales and PDFs, the acceptance uncertainty due to PDFs, the choice of MC generator, the uncertainty on the luminosity (2.8% [89]), the uncertainty due to the jet energy scale, jet energy resolution, lepton energy scale, lepton energy resolution and lepton identification efficiency, the uncertainty on the  $E_T^{\text{miss}}$  from energy deposits not associated with reconstructed objects, and the uncertainty due to  $b$ -tagging efficiency and mistag probability. The systematic uncertainty associated with the simulation of pile-up is also taken into account. An uncertainty is applied to MC samples to cover differences in efficiency seen between the trigger in data and the MC trigger simulation.

The theoretical cross-section uncertainties for the irreducible backgrounds used in this analysis are 30% for  $t\bar{t}V$  [51, 52], 50% for  $tZ$ , 5% for  $ZZ$ , 7% for  $WZ$  and 100% for the triboson samples. The ATLAS  $WZ$  and  $ZZ$  cross-section measurements [90, 91] are in agreement with the MCFM predictions used here. For the Higgs boson samples, 20% uncertainty is used for  $VH$  and vector-boson-fusion production, while 100% uncertainty is assigned to  $t\bar{t}H$  and Higgs boson production via gluon fusion [49]. The uncertainties on  $tZ$ , tribosons,  $t\bar{t}H$  and Higgs boson production via gluon fusion are assumed to be large to account for uncertainties on the acceptance, while the inclusive cross-sections are known to better precision. The uncertainty on the  $WZ$  and  $ZZ$  acceptance due to the choice of MC generator, parton showering and scales is determined by comparing estimates from

Region name	$N(\ell)$	$N(\tau)$	Flavour/sign	$Z$ boson	$E_T^{\text{miss}}$	$N(b\text{-tagged jets})$	Target process
VR0 $\tau$ noZa	3	0	$\ell^+\ell^-\ell, \ell^+\ell^-\ell'$	$m_{\text{SFOS}} \& m_{3\ell}$ veto	35–50	—	$WZ^*, Z^*Z^*, Z^*+\text{jets}$
VR0 $\tau$ Za	3	0	$\ell^+\ell^-\ell, \ell^+\ell^-\ell'$	request	35–50	—	$WZ, Z+\text{jets}$
VR0 $\tau$ noZb	3	0	$\ell^+\ell^-\ell, \ell^+\ell^-\ell'$	$m_{\text{SFOS}} \& m_{3\ell}$ veto	$> 50$	1	$t\bar{t}$
VR0 $\tau$ Zb	3	0	$\ell^+\ell^-\ell, \ell^+\ell^-\ell'$	request	$> 50$	1	$WZ$
VR0 $\tau$ b	3	0	$\ell^+\ell^-\ell, \ell^+\ell^-\ell'$	binned	binned	1	$WZ, t\bar{t}$
VR1 $\tau$ a	2	1	$\tau^\pm\ell^\mp\ell^\mp, \tau^\pm\ell^\mp\ell'^\mp$	—	35–50	—	$WZ, Z+\text{jets}$
VR1 $\tau$ b	2	1	$\tau^\pm\ell^\mp\ell^\mp, \tau^\pm\ell^\mp\ell'^\mp$	—	$> 50$	1	$t\bar{t}$
VR2 $\tau$ a	1	2	$\tau\tau\ell$	—	35–50	—	$W+\text{jets}, Z+\text{jets}$
VR2 $\tau$ b	1	2	$\tau\tau\ell$	—	$> 50$	1	$t\bar{t}$

**Table 5.** Summary of the selection requirements for the validation regions. Energies, momenta and masses are given in units of GeV.

POWHEG and aMC@NLO, while those for  $t\bar{t}V$  are determined by comparing ALPGEN and MADGRAPH estimates.

The uncertainty on the reducible background includes the MC uncertainty on the weights for the misidentification probabilities from the sources listed in section 7.2 (2–14%) and the uncertainty due to the dependence of the misidentification probability on  $E_T^{\text{miss}}$  (0–7%),  $m_T$  (1–7%),  $m_{\ell\ell}$  (0–18%), SFOS selection/veto (0–5%) and  $\eta$  (1–5%). Also included in the uncertainty on the reducible background is the uncertainty on the correction factors for the misidentification probability, the statistical uncertainty on the data events used to apply the matrix equation and the statistical uncertainty from the misidentification probability measured in simulation.

#### 7.4 Background modelling validation

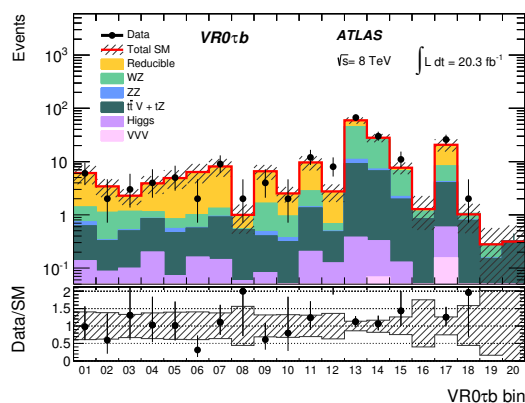
The background predictions are tested in validation regions that are defined to be adjacent to, yet disjoint from, the signal regions. For each  $\tau$  multiplicity considered, validation regions are defined with either low- $E_T^{\text{miss}}$  (“a” regions) or high- $E_T^{\text{miss}} + b$ -tagged jet (“b” regions) to target different background processes. The definition of the regions and the targeted processes are shown in table 5. In the validation region requiring no  $\tau$  leptons, both the  $Z$ -veto and  $Z$ -request regions are tested in the low- $E_T^{\text{miss}}$  and high- $E_T^{\text{miss}} + b$ -tagged jet regions. To validate the binned signal region SR0 $\tau$ a, an orthogonal validation region (VR0 $\tau$ b) is defined with the same binning as shown in table 4 and a  $b$ -tagged jet requirement.

In the validation regions, the observed data count and SM expectations are in good agreement within statistical and systematic uncertainties, as shown in table 6 and figure 2. The  $\text{CL}_b$  value [92], using a profile likelihood ratio as a test statistic [93], verifies the compatibility of the observation with the background prediction. Values of  $\text{CL}_b$  above (below) 0.5 indicate the observed level of agreement above (below) the expected yield. The  $m_T$  distributions in VR0 $\tau$ noZa and VR0 $\tau$ Za along with the  $m_{\ell\tau}$  distribution in VR1 $\tau$ a and  $m_{T2}^{\text{max}}$  distribution in VR2 $\tau$ a are shown in figure 3, while the  $E_T^{\text{miss}}$  distributions in the high- $E_T^{\text{miss}} + b$ -tagged jet validation regions are presented in figure 4.

While the results from the validation regions are not used to derive correction factors for the background, potential signal contamination is assessed. It is found to be at the sub-percent level for most of the SUSY scenarios considered except for some characterised

Sample	VR0 $\tau$ noZa	VR0 $\tau$ Za	VR0 $\tau$ noZb	VR0 $\tau$ Zb	VR1 $\tau$ a	VR1 $\tau$ b	VR2 $\tau$ a	VR2 $\tau$ b
WZ	91 $\pm$ 12	471 $\pm$ 47	10.5 $^{+1.8}_{-2.0}$	58 $\pm$ 7	14.6 $\pm$ 1.9	1.99 $\pm$ 0.35	14.3 $^{+2.4}_{-2.5}$	1.9 $\pm$ 0.4
ZZ	19 $\pm$ 4	48 $\pm$ 7	0.62 $\pm$ 0.12	2.6 $\pm$ 0.4	1.76 $^{+0.29}_{-0.28}$	0.138 $\pm$ 0.028	1.8 $\pm$ 0.4	0.12 $\pm$ 0.04
$t\bar{t}V + tZ$	3.2 $\pm$ 1.0	10.1 $^{+2.3}_{-2.2}$	9.5 $\pm$ 3.1	18 $\pm$ 4	0.9 $\pm$ 0.9	2.8 $\pm$ 1.3	1.0 $\pm$ 0.7	1.7 $\pm$ 0.7
VVV	1.9 $\pm$ 1.9	0.7 $\pm$ 0.7	0.35 $^{+0.36}_{-0.35}$	0.18 $\pm$ 0.18	0.4 $\pm$ 0.4	0.08 $\pm$ 0.08	0.12 $\pm$ 0.12	0.06 $^{+0.07}_{-0.06}$
Higgs	2.7 $\pm$ 1.3	2.7 $\pm$ 1.5	1.5 $\pm$ 1.0	0.71 $\pm$ 0.29	0.57 $\pm$ 0.34	0.5 $\pm$ 0.5	0.6 $\pm$ 0.4	0.5 $\pm$ 0.5
Reducible	73 $^{+20}_{-17}$	261 $\pm$ 70	47 $^{+15}_{-13}$	19 $\pm$ 5	71 $\pm$ 9	22.7 $\pm$ 2.8	630 $^{+9}_{-12}$	162 $^{+6}_{-8}$
Total SM	191 $^{+24}_{-22}$	794 $\pm$ 86	69 $^{+15}_{-14}$	98 $\pm$ 10	89 $^{+10}_{-9}$	28.2 $\pm$ 3.2	648 $^{+10}_{-13}$	166 $^{+6}_{-8}$
Data	228	792	79	110	82	26	656	158
CL <sub>b</sub>	0.90	0.49	0.72	0.79	0.30	0.37	0.61	0.30

**Table 6.** Expected numbers of SM background events and observed numbers of data events in selected validation regions, as defined in table 5. The binned validation region VR0 $\tau$ b is displayed in figure 2. Statistical and systematic uncertainties are included (as described in section 7.3). CL<sub>b</sub> values are given.



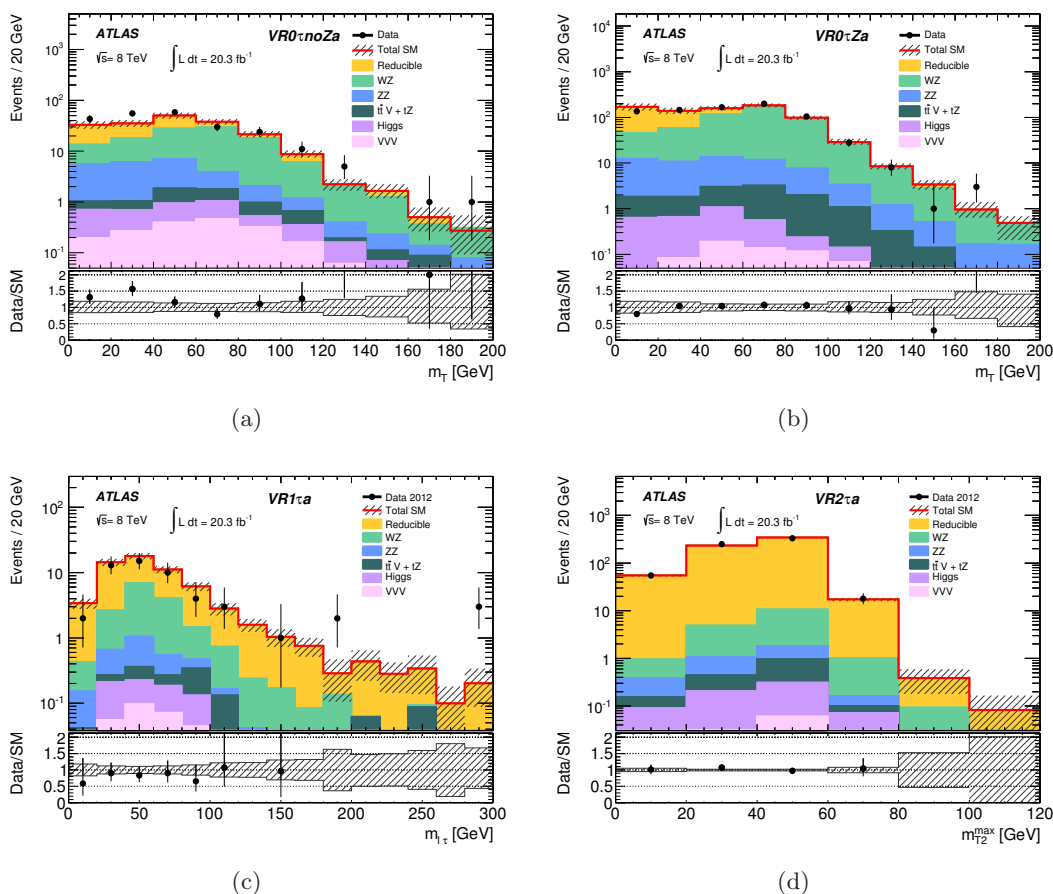
**Figure 2.** Number of expected and observed events in the validation region VR0 $\tau$ b. Also shown are the respective contributions of the various background processes as described in the legend. The uncertainty band includes both the statistical and systematic uncertainties on the SM prediction.

by low chargino mass. These scenarios would, however, lead to a detectable signal in the signal regions.

## 8 Results and interpretations

The observed number of events in each signal region is shown in tables 7 and 8 along with the background expectations and uncertainties. The uncertainties include both the statistical and systematic components described in section 7.3. A summary of the dominant systematic uncertainties in each signal region is given in table 9.

Figure 5 shows the SM expectations and the observations in data in the individual SR0 $\tau$ a bins as well as the distribution of  $E_T^{\text{miss}}$ ,  $m_T$  and  $m_{\text{SFOS}}$  in the combination of all SR0 $\tau$ a regions. For illustration, the distributions are also shown for the  $WZ$ -mediated and  $\tilde{\ell}_L$ -mediated simplified models.

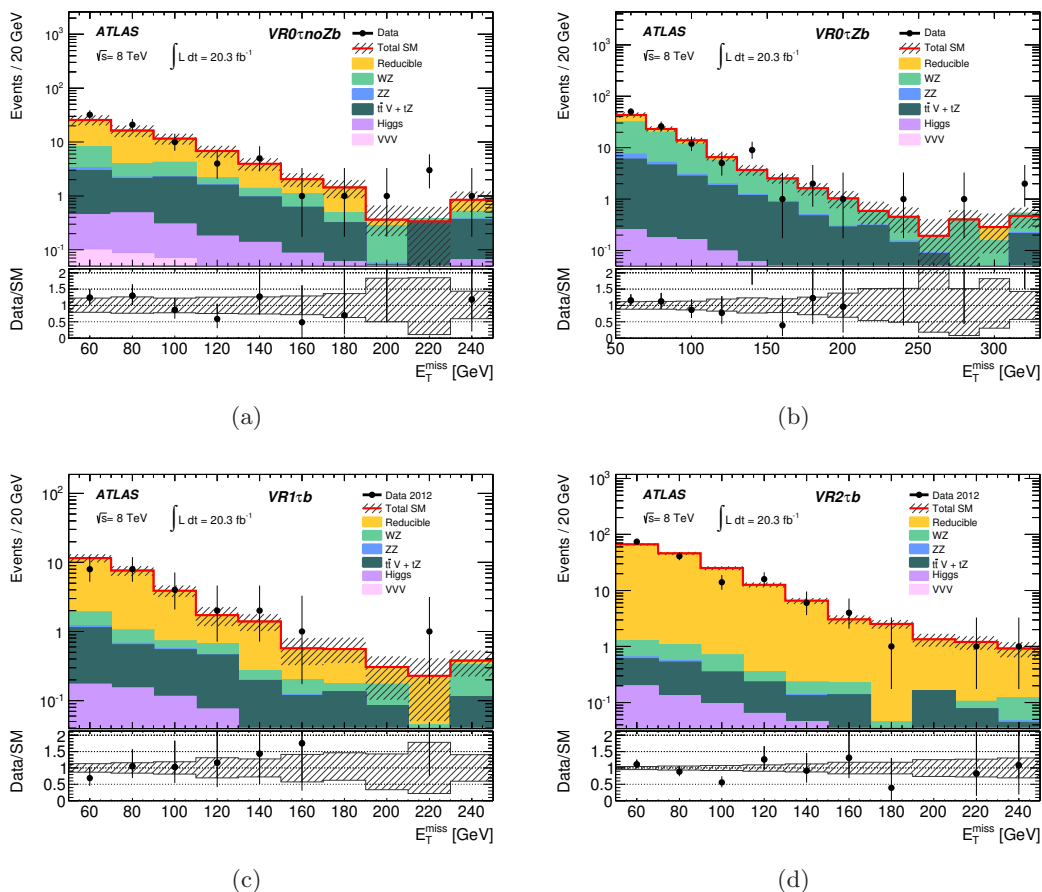


**Figure 3.** For events in the low- $E_T^{\text{miss}}$  validation regions, the  $m_T$  distribution in (a)  $VR0\tau noZa$ , (b)  $VR0\tau Za$ , (c) the  $m_{\ell\tau}$  distribution in  $VR1\tau a$  and (d) the  $m_{T2}^{\text{max}}$  distribution in  $VR2\tau a$ , see text for details. Also shown are the respective contributions of the various background processes as described in the legend. The uncertainty band includes both the statistical and systematic uncertainties on the SM prediction. The last bin in each distribution includes the overflow.

Figure 6 shows the distributions of the quantities  $\Delta\phi_{\ell\ell'}^{\text{min}}$ ,  $E_T^{\text{miss}}$ ,  $m_{T2}^{\text{max}}$  and  $m_{\tau\tau}$  in the  $SR0\tau b$ ,  $SR1\tau$ ,  $SR2\tau a$  and  $SR2\tau b$  regions respectively, prior to the requirements on these variables. Also shown are the distributions of these quantities for signal hypotheses from the  $\tilde{\tau}_L$ -mediated and  $Wh$ -mediated simplified models.

The number of observed events is consistent with the SM expectation in all signal regions, within uncertainties. The one-sided  $p_0$ -value is calculated to quantify the probability of the SM background alone to fluctuate to the observed number of events or higher (shown in table 7 and table 8), and is truncated to 0.5 for  $p_0 > 0.5$ . Upper limits at 95% CL on the expected and observed number of beyond the SM events ( $N_{\text{exp}}^{95}$  and  $N_{\text{obs}}^{95}$ ) for each signal region are calculated using the  $CL_s$  prescription [92] and shown in table 7 and table 8. The profile likelihood ratio is used as a test statistic [93] and sources of systematic uncertainties are treated as nuisance parameters. The  $p_0$  and  $CL_s$  values are calculated using pseudo-experiments.





**Figure 4.** For events in the high- $E_T^{\text{miss}}$  +  $b$ -tagged jet validation regions, the  $E_T^{\text{miss}}$  distribution in (a) VR0 $\tau$ noZb, (b) VR0 $\tau$ Zb, (c) VR1 $\tau$ b and (d) VR2 $\tau$ b. Also shown are the respective contributions of the various background processes as described in the legend. The uncertainty band includes both the statistical and systematic uncertainties on the SM prediction. The last bin in each distribution includes the overflow.

The results obtained are used to derive limits on the simplified and pMSSM models described in section 2. Exclusion limits are calculated by statistically combining results from a number of disjoint signal regions. For the  $\tilde{\ell}_L$ -mediated,  $WZ$ -mediated and  $\tilde{\tau}_L$ -mediated simplified models and for the pMSSM scenarios, SR0 $\tau$ a, SR0 $\tau$ b, SR1 $\tau$  and SR2 $\tau$ a are statistically combined. For the  $Wh$ -mediated simplified model, the statistical combination of SR0 $\tau$ a, SR0 $\tau$ b, SR1 $\tau$  and SR2 $\tau$ b is used. All experimental uncertainties are treated as correlated between regions and processes, with the exception of the experimental uncertainties on the reducible background, which are correlated between regions only. Theoretical uncertainties on the irreducible background and signal are treated as correlated between regions, while statistical uncertainties are treated as uncorrelated between regions and processes. The total systematic uncertainty on all SUSY signal processes is in the 10–20% range, where  $\sim 7\%$  originates from the uncertainty on the signal cross-section. The uncertainty due to changes in signal acceptance from varying the PDFs and the amount of initial-state radiation is found to be negligible compared to the total systematic uncertainty for the

Sample	SR0 $\tau$ a-bin01	SR0 $\tau$ a-bin02	SR0 $\tau$ a-bin03	SR0 $\tau$ a-bin04	SR0 $\tau$ a-bin05	SR0 $\tau$ a-bin06
$WZ$	$13.2^{+3.4}_{-3.2}$	$3.0 \pm 1.4$	$7.8 \pm 1.6$	$4.5^{+1.1}_{-1.0}$	$6.3 \pm 1.6$	$3.7 \pm 1.6$
$ZZ$	$1.4^{+0.6}_{-0.5}$	$0.12 \pm 0.06$	$0.40 \pm 0.14$	$0.20 \pm 0.18$	$1.5 \pm 0.5$	$0.25^{+0.14}_{-0.11}$
$t\bar{t}V + tZ$	$0.14 \pm 0.05$	$0.07 \pm 0.04$	$0.04^{+0.05}_{-0.04}$	$0.14 \pm 0.13$	$0.11 \pm 0.08$	$0.047^{+0.022}_{-0.021}$
$VVV$	$0.33 \pm 0.33$	$0.10 \pm 0.10$	$0.19 \pm 0.19$	$0.6 \pm 0.6$	$0.26^{+0.27}_{-0.26}$	$0.24 \pm 0.24$
Higgs	$0.66 \pm 0.26$	$0.15 \pm 0.08$	$0.64 \pm 0.22$	$0.46^{+0.18}_{-0.17}$	$0.36^{+0.14}_{-0.15}$	$0.33^{+0.13}_{-0.12}$
Reducible	$6.7 \pm 2.4$	$0.8 \pm 0.4$	$1.6^{+0.7}_{-0.6}$	$2.7 \pm 1.0$	$4.3^{+1.6}_{-1.4}$	$2.0 \pm 0.8$
Total SM	$23 \pm 4$	$4.2 \pm 1.5$	$10.6 \pm 1.8$	$8.5^{+1.7}_{-1.6}$	$12.9^{+2.4}_{-2.3}$	$6.6^{+1.9}_{-1.8}$
Data	36	5	9	9	11	13
$p_0$ ( $\sigma$ )	0.02 (2.16)	0.35 (0.38)	0.50	0.40 (0.26)	0.50	0.03 (1.91)
$N_{\text{exp}}^{95}$	$14.1^{+5.6}_{-3.6}$	$6.2^{+2.5}_{-1.7}$	$8.4^{+3.1}_{-2.3}$	$7.7^{+3.1}_{-2.1}$	$9.0^{+3.6}_{-2.5}$	$8.0^{+3.2}_{-1.9}$
$N_{\text{obs}}^{95}$	26.8	6.9	7.3	8.4	7.9	14.4
Sample	SR0 $\tau$ a-bin07	SR0 $\tau$ a-bin08	SR0 $\tau$ a-bin09	SR0 $\tau$ a-bin10	SR0 $\tau$ a-bin11	SR0 $\tau$ a-bin12
$WZ$	$7.6 \pm 1.3$	$0.30^{+0.25}_{-0.24}$	$16.2^{+3.2}_{-3.1}$	$13.1^{+2.5}_{-2.6}$	$19 \pm 4$	$3.7 \pm 1.2$
$ZZ$	$0.55^{+0.16}_{-0.14}$	$0.012^{+0.008}_{-0.007}$	$1.43^{+0.32}_{-0.28}$	$0.60^{+0.12}_{-0.13}$	$0.7 \pm 1.2$	$0.14 \pm 0.09$
$t\bar{t}V + tZ$	$0.04^{+0.15}_{-0.04}$	$0.12^{+0.13}_{-0.12}$	$0.16^{+0.09}_{-0.12}$	$0.12 \pm 0.10$	$0.41^{+0.24}_{-0.22}$	$0.12 \pm 0.11$
$VVV$	$0.9 \pm 0.9$	$0.13^{+0.14}_{-0.13}$	$0.23^{+0.24}_{-0.23}$	$0.4 \pm 0.4$	$0.6 \pm 0.6$	$0.6 \pm 0.6$
Higgs	$0.98^{+0.29}_{-0.30}$	$0.13 \pm 0.06$	$0.32 \pm 0.11$	$0.22^{+0.10}_{-0.11}$	$0.28 \pm 0.12$	$0.12 \pm 0.06$
Reducible	$4.0^{+1.5}_{-1.4}$	$0.40^{+0.27}_{-0.26}$	$4.1^{+1.3}_{-1.2}$	$1.9^{+0.9}_{-0.8}$	$5.7^{+2.1}_{-1.9}$	$0.9^{+0.5}_{-0.4}$
Total SM	$14.1 \pm 2.2$	$1.1 \pm 0.4$	$22.4^{+3.6}_{-3.4}$	$16.4 \pm 2.8$	$27 \pm 5$	$5.5^{+1.5}_{-1.4}$
Data	15	1	28	24	29	8
$p_0$ ( $\sigma$ )	0.37 (0.33)	0.50	0.13 (1.12)	0.07 (1.50)	0.39 (0.28)	0.21 (0.82)
$N_{\text{exp}}^{95}$	$9.6^{+3.9}_{-2.5}$	$3.7^{+1.5}_{-0.9}$	$12.7^{+4.9}_{-3.5}$	$11.3^{+4.5}_{-3.1}$	$13.8^{+5.4}_{-3.7}$	$6.9^{+2.9}_{-1.7}$
$N_{\text{obs}}^{95}$	10.8	3.7	18.0	18.3	15.3	9.2

**Table 7.** Expected numbers of SM background events and observed numbers of data events in the signal regions SR0 $\tau$ a-bin01-bin12 for 20.3 fb<sup>-1</sup>. Statistical and systematic uncertainties are included as described in section 7.3. Also shown are the one-sided  $p_0$ -values and the upper limits at 95% CL on the expected and observed number of beyond-the-SM events ( $N_{\text{exp}}^{95}$  and  $N_{\text{obs}}^{95}$ ) for each signal region, calculated using pseudo-experiments and the CL<sub>s</sub> prescription. For  $p_0$ -values below 0.5, the observed number of standard deviations,  $\sigma$ , is also shown in parentheses.

signal scenarios under consideration. For the exclusion limits, the observed and expected 95% CL limits are calculated using pseudo-experiments for each SUSY model point, taking into account the theoretical and experimental uncertainties on the SM background and the experimental uncertainties on the signal. The impact of the theoretical uncertainties on the signal cross-section is shown for the observed limit and where quoted, limits refer to the  $-1\sigma$  variation on the observed limit.

In the  $\tilde{\ell}_L$ -mediated simplified model,  $\tilde{\chi}_1^\pm$  and  $\tilde{\chi}_2^0$  masses are excluded up to 700 GeV as shown in figure 7(a). The region SR0 $\tau$ a-bin20 offers the best sensitivity to scenarios with high  $\tilde{\chi}_1^\pm$  and  $\tilde{\chi}_2^0$  masses, and the low- $m_{\text{SFOS}}$  SR0 $\tau$ a bins to the small  $m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$  scenarios. In the  $WZ$ -mediated simplified model shown in figure 7(b),  $\tilde{\chi}_1^\pm$  and  $\tilde{\chi}_2^0$  masses are excluded up

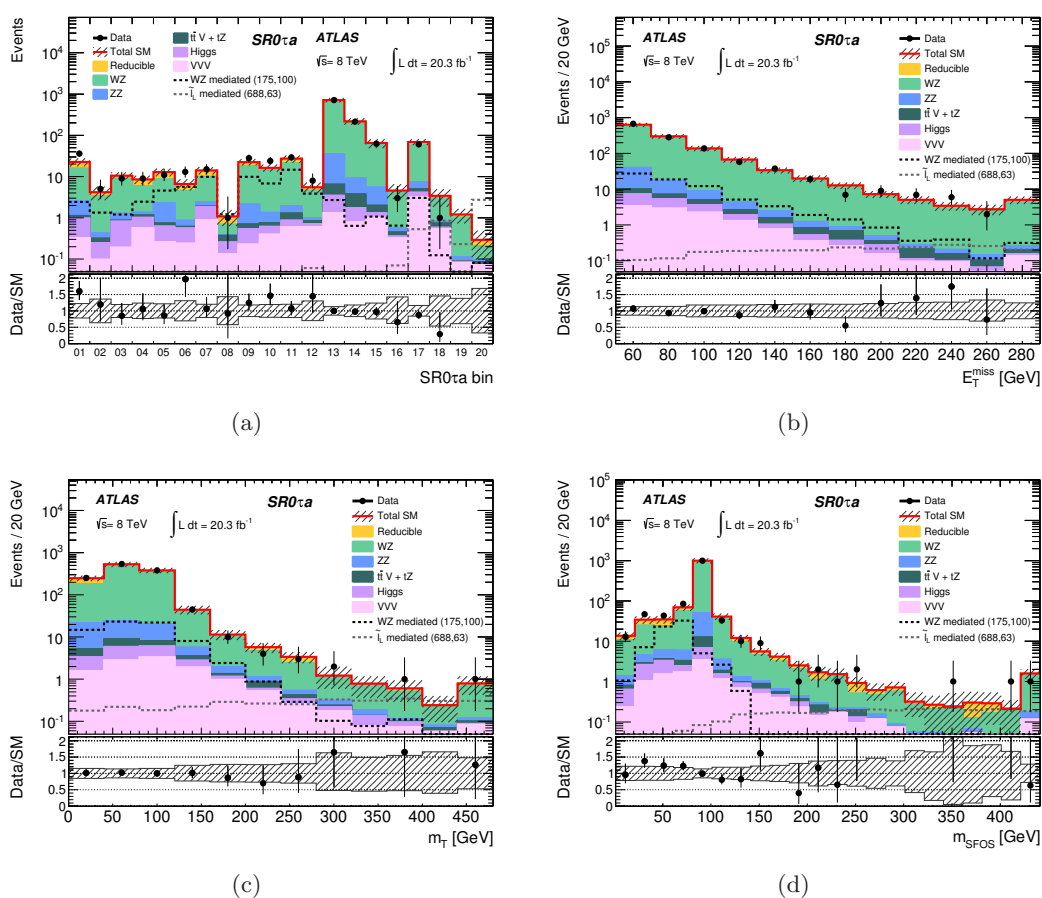
Sample	SR0 $\tau$ a-bin13	SR0 $\tau$ a-bin14	SR0 $\tau$ a-bin15	SR0 $\tau$ a-bin16	SR0 $\tau$ a-bin17	SR0 $\tau$ a-bin18
$WZ$	$613 \pm 65$	$207_{-32}^{+33}$	$58_{-13}^{+12}$	$3.9_{-1.4}^{+1.6}$	$50_{-6}^{+7}$	$2.3 \pm 1.3$
$ZZ$	$29 \pm 4$	$5.5 \pm 1.5$	$3.5_{-1.0}^{+1.1}$	$0.12_{-0.07}^{+0.08}$	$2.4_{-0.6}^{+0.7}$	$0.08 \pm 0.04$
$t\bar{t}V + tZ$	$2.9_{-0.6}^{+0.7}$	$2.0_{-0.6}^{+0.7}$	$0.67_{-0.28}^{+0.29}$	$0.08_{-0.08}^{+0.10}$	$0.8 \pm 0.5$	$0.15_{-0.15}^{+0.16}$
$VVV$	$1.3 \pm 1.3$	$0.8 \pm 0.8$	$1.0 \pm 1.0$	$0.33 \pm 0.33$	$3.2 \pm 3.2$	$0.5 \pm 0.5$
Higgs	$2.2 \pm 0.7$	$0.98 \pm 0.20$	$0.31 \pm 0.11$	$0.033 \pm 0.018$	$0.95 \pm 0.29$	$0.05 \pm 0.04$
Reducible	$68_{-19}^{+21}$	$2.2_{-2.0}^{+1.9}$	$1.2 \pm 0.6$	$0.14_{-0.14}^{+0.25}$	$11.3_{-3.2}^{+3.5}$	$0.27 \pm 0.20$
Total SM	$715 \pm 70$	$219 \pm 33$	$65 \pm 13$	$4.6_{-1.5}^{+1.7}$	$69_{-8}^{+9}$	$3.4 \pm 1.4$
Data	714	214	63	3	60	1
$p_0$ ( $\sigma$ )	0.50	0.50	0.50	0.50	0.50	0.50
$N_{\text{exp}}^{95}$	$133_{-36}^{+46}$	$66_{-18}^{+24}$	$28.6_{-7.2}^{+10.1}$	$5.9_{-1.5}^{+2.6}$	$21.4_{-5.6}^{+8.2}$	$4.8_{-1.1}^{+2.0}$
$N_{\text{obs}}^{95}$	133	65	27.6	5.2	18.8	3.7
Sample	SR0 $\tau$ a-bin19	SR0 $\tau$ a-bin20	SR0 $\tau$ b	SR1 $\tau$	SR2 $\tau$ a	SR2 $\tau$ b
$WZ$	$0.9 \pm 0.4$	$0.12 \pm 0.11$	$0.68 \pm 0.20$	$4.6 \pm 0.6$	$1.51_{-0.33}^{+0.35}$	$2.09_{-0.31}^{+0.30}$
$ZZ$	$0.021 \pm 0.019$	$0.009 \pm 0.009$	$0.028 \pm 0.009$	$0.36 \pm 0.08$	$0.049_{-0.014}^{+0.016}$	$0.135 \pm 0.025$
$t\bar{t}V + tZ$	$0.0023_{-0.0019}^{+0.0032}$	$0.012_{-0.012}^{+0.016}$	$0.17_{-0.17}^{+0.32}$	$0.16_{-0.16}^{+0.18}$	$0.21_{-0.21}^{+0.27}$	$0.023_{-0.018}^{+0.015}$
$VVV$	$0.08 \pm 0.08$	$0.07_{-0.07}^{+0.08}$	$1.0 \pm 1.0$	$0.5 \pm 0.5$	$0.09 \pm 0.09$	$0.031 \pm 0.033$
Higgs	$0.007 \pm 0.006$	$0.0009 \pm 0.0004$	$0.49 \pm 0.17$	$0.28 \pm 0.12$	$0.021 \pm 0.010$	$0.08 \pm 0.04$
Reducible	$0.17_{-0.15}^{+0.16}$	$0.08_{-0.08}^{+0.11}$	$1.5 \pm 0.4$	$4.3 \pm 0.8$	$5.1 \pm 0.7$	$4.9 \pm 0.7$
Total SM	$1.2 \pm 0.4$	$0.29_{-0.17}^{+0.18}$	$3.8 \pm 1.2$	$10.3 \pm 1.2$	$6.9 \pm 0.8$	$7.2_{-0.8}^{+0.7}$
Data	0	0	3	13	6	5
$p_0$ ( $\sigma$ )	0.50	0.50	0.50	0.19 (0.86)	0.50	0.50
$N_{\text{exp}}^{95}$	$3.7_{-0.7}^{+1.4}$	$3.0_{-0.0}^{+0.8}$	$5.6_{-1.4}^{+2.2}$	$8.1_{-2.2}^{+3.2}$	$6.8_{-1.9}^{+2.7}$	$6.7_{-1.8}^{+2.8}$
$N_{\text{obs}}^{95}$	3.0	3.0	5.4	10.9	6.0	5.2

**Table 8.** Expected numbers of SM background events and observed numbers of data events in the signal regions SR0 $\tau$ a-bin13-bin20, SR0 $\tau$ b, SR1 $\tau$ , SR2 $\tau$ a and SR2 $\tau$ b for  $20.3 \text{ fb}^{-1}$ . Statistical and systematic uncertainties are included as described in section 7.3. Also shown are the one-sided  $p_0$ -values and the upper limits at 95% CL on the expected and observed number of beyond-the-SM events ( $N_{\text{exp}}^{95}$  and  $N_{\text{obs}}^{95}$ ) for each signal region, calculated using pseudo-experiments and the  $\text{CL}_s$  prescription. For  $p_0$ -values below 0.5, the observed number of standard deviations,  $\sigma$ , is also shown in parentheses.

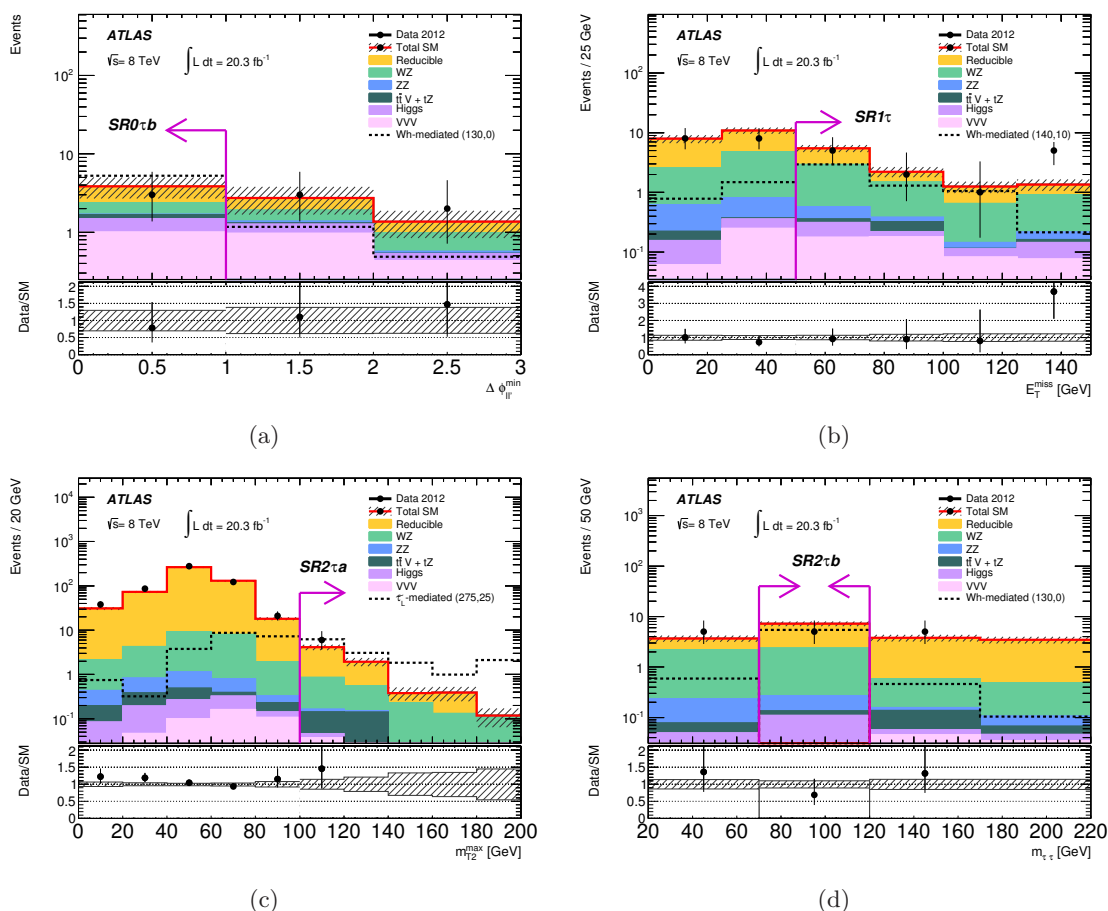
to 345 GeV for massless  $\tilde{\chi}_1^0$ . The region SR0 $\tau$ a-bin16 offers the best sensitivity to scenarios with high  $\tilde{\chi}_1^\pm$  and  $\tilde{\chi}_2^0$  masses, and SR0 $\tau$ a-bin01 to the small  $m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$  scenarios. The results in the signal regions lead to a weaker (stronger) observed exclusion than expected for the compressed (high-mass  $\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$ ) scenarios in both the  $\tilde{\ell}_L$ -mediated and  $WZ$ -mediated simplified models. In the  $WZ$ -mediated simplified model, there is a reduced sensitivity to

	SR0 $\tau$ a	SR0 $\tau$ b	SR1 $\tau$	SR2 $\tau$ a	SR2 $\tau$ b
Cross-section	4–25%	37%	9%	3.1%	3.0%
Generator	3.2–35%	11%	3.1%	6%	< 1%
Statistics on irreducible background	0.8–26%	8%	5%	5%	3.1%
Statistics on reducible background	0.4–29%	14%	8%	13%	12%
Electron misidentification probability	0.3–10%	1.3%	< 1%	–	–
Muon misidentification probability	0.1–24%	2.2%	< 1%	–	–
$\tau$ misidentification probability	–	–	8%	4%	5%

**Table 9.** Summary of the dominant systematic uncertainties in the background estimates for each signal region. Uncertainties are quoted relative to the total expected background. For the 20 bins of the SR0 $\tau$ a the range of the uncertainties is provided.



**Figure 5.** Expected distributions of SM background events and observed data distributions in (a) the binned signal regions SR0 $\tau$ a. The distributions of (b)  $E_T^{\text{miss}}$ , (c)  $m_T$  and (d)  $m_{\text{SFOS}}$  are shown in the summation of all SR0 $\tau$ a regions prior to the requirements on these variables. Also shown are the respective contributions of the various background processes as described in the legend. Both the statistical and systematic uncertainties are shown. The last bin in each distribution includes the overflow. For illustration, the distributions of signal hypotheses are also shown.



**Figure 6.** Expected distributions of SM background events and observed data distributions for (a)  $\Delta\phi_{\ell\ell'}^{\min}$ , (b)  $E_T^{\text{miss}}$ , (c)  $m_{T2}^{\text{max}}$  and (d)  $m_{\tau\tau}$  variables in the SR0 $\tau$ b, SR1 $\tau$ , SR2 $\tau$ a and SR2 $\tau$ b regions respectively, prior to the requirements on these variables. Arrows indicate the limits on the values of the variables used to define the signal regions. Also shown are the respective contributions of the various background processes as described in the legend. Both the statistical and systematic uncertainties are shown. The last bin in each distribution includes the overflow. The plots also show the distribution for signal hypotheses, where the parentheses following the simplified model denote the mass parameters in GeV as  $(m(\tilde{\chi}_1^\pm, \tilde{\chi}_2^0), m(\tilde{\chi}_1^0))$ .

scenarios in the  $m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0} = m_Z$  region as the signal populates regions with high  $WZ$  background. These limits improve those reported by ATLAS in ref. [17] by  $\sim 200$  GeV.

In the  $\tilde{\tau}_L$ -mediated simplified model,  $\tilde{\chi}_1^\pm$  and  $\tilde{\chi}_2^0$  masses are excluded up to 380 GeV for massless  $\tilde{\chi}_1^0$  as shown in figure 7(c). The low  $m_{\text{SFOS}}$  SR0 $\tau$ a bins offer the best sensitivity to the small  $m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$  scenarios, and SR2 $\tau$ a to the high-mass  $\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$  scenarios. The results in the low  $m_{\text{SFOS}}$  SR0 $\tau$ a bins lead to a weaker observed exclusion than expected for the compressed scenarios.

In the  $Wh$ -mediated simplified model shown in figure 7(d),  $\tilde{\chi}_1^\pm$  and  $\tilde{\chi}_2^0$  masses are excluded up to 148 GeV. The regions SR0 $\tau$ a, SR0 $\tau$ b, SR1 $\tau$  and SR2 $\tau$ b offer the best sensitivity in this simplified model when statistically combined. The results in some SR0 $\tau$ a bins and SR1 $\tau$  are responsible for the observed exclusion being slightly weaker than expected.

In the pMSSM scenarios shown in figure 8, for a given value of  $M_1$ , the sensitivity for high values of  $M_2$  and  $\mu$ , and therefore for high values of chargino and heavy neutralino masses, is driven by the decrease of the production cross-section. Due to small  $m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$  or  $m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0}$ , limited sensitivity is found in the regions with  $M_1 \sim M_2 \ll \mu$ , as seen in figures 8(a–d). In the case of the pMSSM  $\tilde{\tau}_R$  scenario, the small mass splittings also reduce the sensitivity in the  $M_1 \sim \mu \ll M_2$  region. In the pMSSM  $\tilde{\ell}_R$  scenario with  $M_1 = 250$  GeV, the  $M_2 \gtrsim 250$  GeV and  $\mu \gtrsim 250$  GeV region is characterised by small  $m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0}$ , and due to the results in SR0 $\tau$ a-bin01 the observed exclusion region is significantly smaller than that expected. For the pMSSM no  $\tilde{\ell}$  scenarios, in the region with  $M_2 \gtrsim 200$  GeV and  $\mu \gtrsim 200$  GeV the decay mode  $\tilde{\chi}_2^0 \rightarrow h\tilde{\chi}_1^0$  is kinematically allowed and reduces the sensitivity.

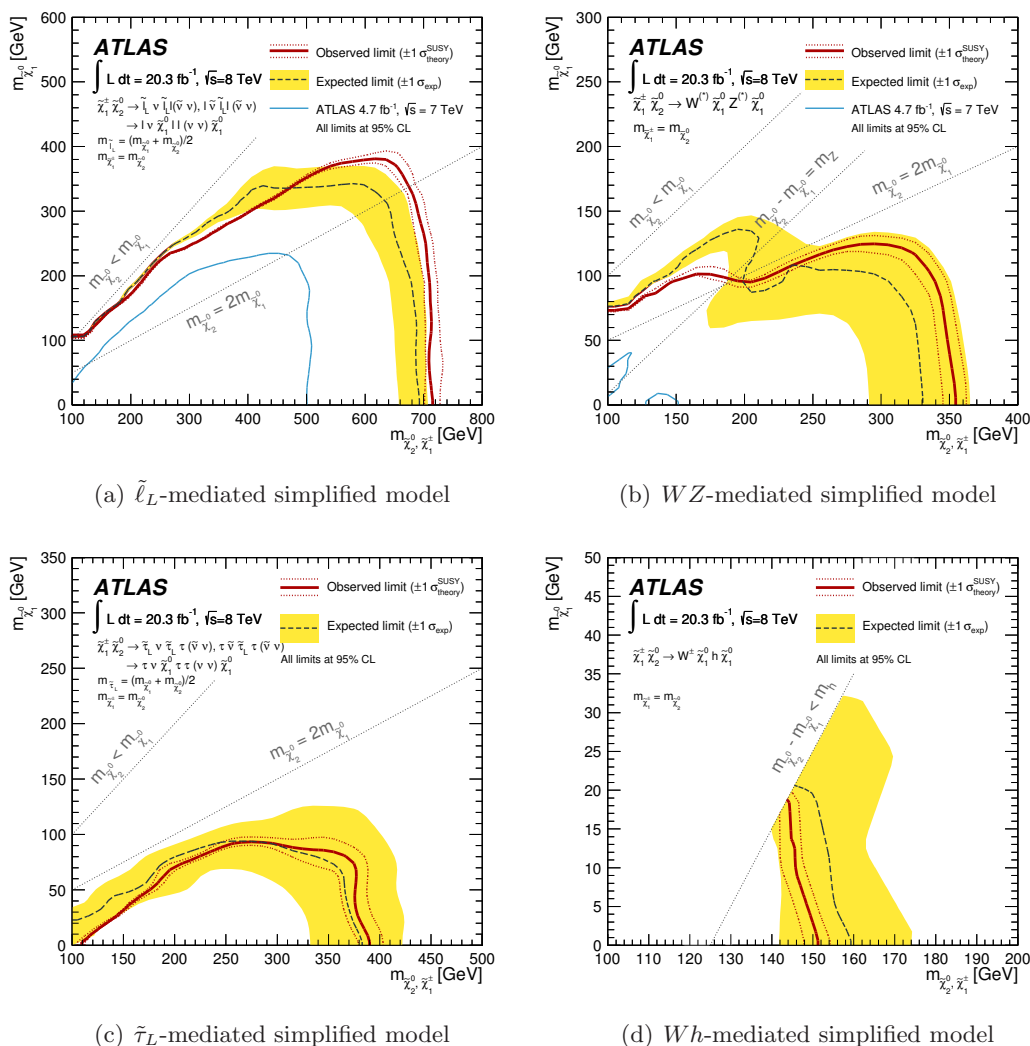
## 9 Conclusions

This paper describes a search for the production of charginos and neutralinos decaying into final states with three leptons ( $e$ ,  $\mu$ ,  $\tau$ ) and missing transverse momentum. The analysis uses  $20.3 \text{ fb}^{-1}$  of  $\sqrt{s} = 8$  TeV proton-proton collision data delivered by the LHC and recorded with the ATLAS detector in 2012. No significant excess of events above SM expectations is found in data. The null result is interpreted in simplified SUSY models and in various pMSSM scenarios. For the simplified SUSY models with intermediate slepton decays, degenerate  $\tilde{\chi}_1^\pm$  and  $\tilde{\chi}_2^0$  masses up to 700 GeV are excluded for large mass differences with the  $\tilde{\chi}_1^0$ , while for the simplified SUSY models with gauge boson decays, the exclusion reaches 345 GeV. These limits improve upon the previous ATLAS results in ref. [17] by  $\sim 200$  GeV. For the simplified SUSY models with intermediate staus, degenerate  $\tilde{\chi}_1^\pm$  and  $\tilde{\chi}_2^0$  masses up to 380 GeV are excluded, while for the simplified SUSY models with intermediate Higgs boson decays, degenerate  $\tilde{\chi}_1^\pm$  and  $\tilde{\chi}_2^0$  masses up to 148 GeV are excluded.

## Acknowledgments

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.

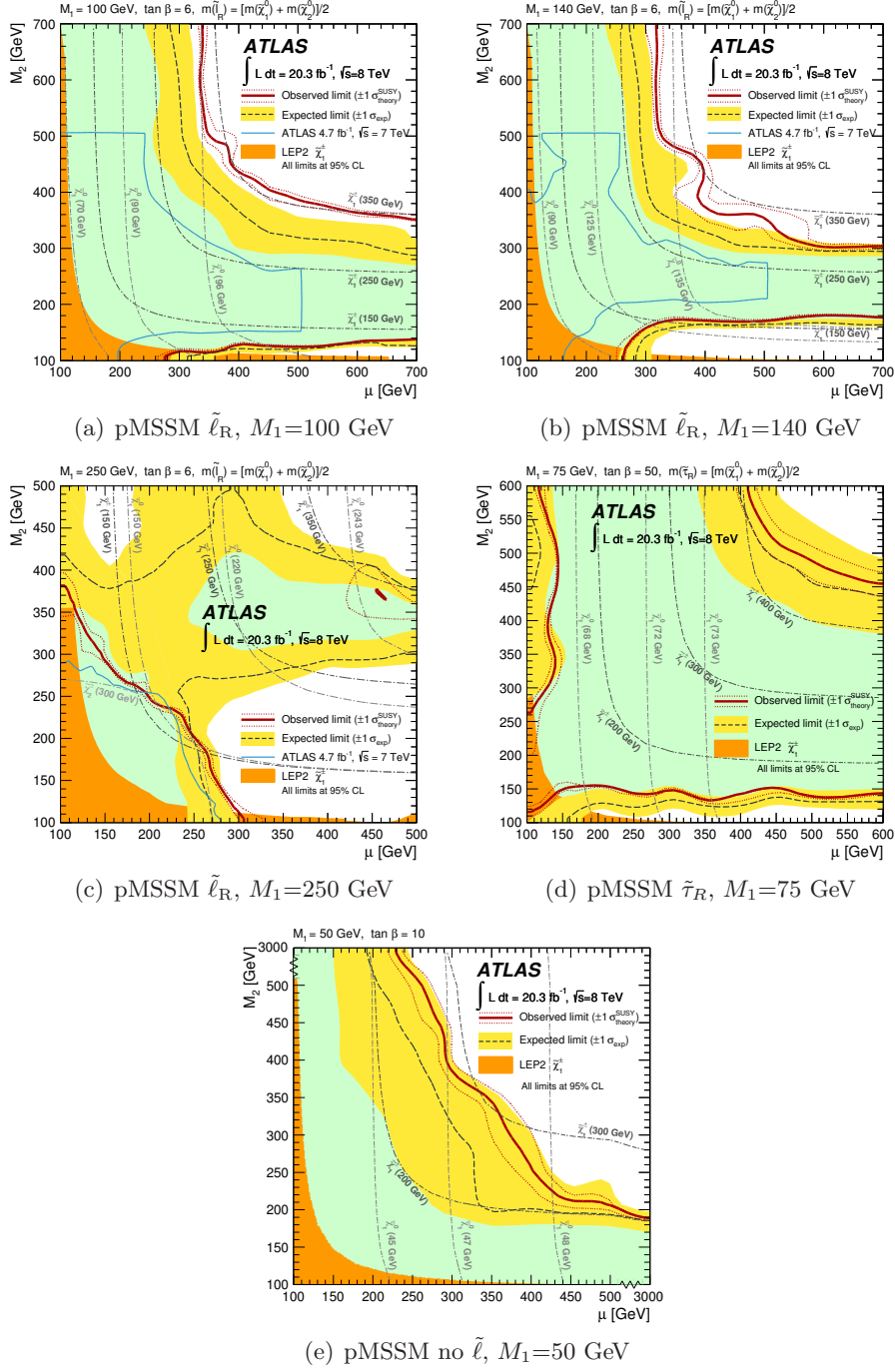
We acknowledge the support of ANPCyT, Argentina; YerPhI, Armenia; ARC, Australia; BMWF and FWF, Austria; ANAS, Azerbaijan; SSTC, Belarus; CNPq and FAPESP, Brazil; NSERC, NRC and CFI, Canada; CERN; CONICYT, Chile; CAS, MOST and NSFC, China; COLCIENCIAS, Colombia; MSMT CR, MPO CR and VSC CR, Czech Republic; DNRF, DNSRC and Lundbeck Foundation, Denmark; EPLANET, ERC and NSRF, European Union; IN2P3-CNRS, CEA-DSM/IRFU, France; GNSF, Georgia; BMBF, DFG, HGF, MPG and AvH Foundation, Germany; GSRT and NSRF, Greece; ISF, MINERVA, GIF, I-CORE and Benoziyo Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; FOM and NWO, Netherlands; BRF and RCN, Norway; MNiSW and NCN, Poland; GRICES and FCT, Portugal; MNE/IFA, Romania; MES of Russia and ROSATOM, Russian Federation; JINR; MSTD, Serbia; MSSR, Slovakia; ARRS and MIZŠ, Slovenia; DST/NRF, South Africa; MINECO, Spain; SRC and Wallenberg Foundation, Sweden; SER, SNSF and Cantons of Bern and Geneva, Switzerland; NSC, Taiwan; TAEK, Turkey;



**Figure 7.** Observed and expected 95% CL exclusion contours for chargino and neutralino production in the (a)  $\tilde{\ell}_L$ -mediated, (b)  $WZ$ -mediated, (c)  $\tilde{\tau}_L$ -mediated and (d)  $Wh$ -mediated simplified models. The band around the expected limit shows the  $\pm 1\sigma$  variations of the expected limit, including all uncertainties except theoretical uncertainties on the signal cross-section. The dotted lines around the observed limit indicate the sensitivity to  $\pm 1\sigma$  variations of these theoretical uncertainties. The blue contours in (a) and (b) correspond to the 7 TeV limits from the ATLAS three-lepton analysis [17]. Linear interpolation is used to account for the discrete nature of the signal grids.

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.



**Figure 8.** Observed and expected 95% CL exclusion contours in the pMSSM model with (a)–(c) sleptons, (d) staus and (e) no sleptons. The band around the expected limit shows the  $\pm 1\sigma$  variations of the expected limit, including all uncertainties except theoretical uncertainties on the signal cross-section. The dotted lines around the observed limit indicate the sensitivity to  $\pm 1\sigma$  variations of these theoretical uncertainties. The area covered by the  $-1\sigma$  expected limit is shown in green. The blue contours in (a)–(c) correspond to the 7 TeV limits from the ATLAS three-lepton analysis [17]. Linear interpolation is used to account for the discrete nature of the signal grids.



**Open Access.** This article is distributed under the terms of the Creative Commons Attribution License ([CC-BY 4.0](https://creativecommons.org/licenses/by/4.0/)), which permits any use, distribution and reproduction in any medium, provided the original author(s) and source are credited.

## References

- [1] H. Miyazawa, *Baryon number changing currents*, *Prog. Theor. Phys.* **36** (1966) 1266.
- [2] P. Ramond, *Dual theory for free fermions*, *Phys. Rev. D* **3** (1971) 2415 [[INSPIRE](#)].
- [3] Y. Golfand and E. Likhtman, *Extension of the algebra of Poincaré group generators and violation of  $p$  invariance*, *JETP Lett.* **13** (1971) 323 [[INSPIRE](#)].
- [4] A. Neveu and J.H. Schwarz, *Factorizable dual model of pions*, *Nucl. Phys. B* **31** (1971) 86 [[INSPIRE](#)].
- [5] A. Neveu and J.H. Schwarz, *Quark model of dual pions*, *Phys. Rev. D* **4** (1971) 1109 [[INSPIRE](#)].
- [6] J.-L. Gervais and B. Sakita, *Field theory interpretation of supergauges in dual models*, *Nucl. Phys. B* **34** (1971) 632 [[INSPIRE](#)].
- [7] D.V. Volkov and V.P. Akulov, *Is the neutrino a goldstone particle?*, *Phys. Lett. B* **46** (1973) 109 [[INSPIRE](#)].
- [8] J. Wess and B. Zumino, *A Lagrangian model invariant under supergauge transformations*, *Phys. Lett. B* **49** (1974) 52 [[INSPIRE](#)].
- [9] J. Wess and B. Zumino, *Supergauge transformations in four-dimensions*, *Nucl. Phys. B* **70** (1974) 39 [[INSPIRE](#)].
- [10] R. Barbieri and G. Giudice, *Upper bounds on supersymmetric particle masses*, *Nucl. Phys. B* **306** (1988) 63 [[INSPIRE](#)].
- [11] B. de Carlos and J.A. Casas, *One loop analysis of the electroweak breaking in supersymmetric models and the fine tuning problem*, *Phys. Lett. B* **309** (1993) 320 [[hep-ph/9303291](#)] [[INSPIRE](#)].
- [12] P. Fayet, *Supersymmetry and weak, electromagnetic and strong interactions*, *Phys. Lett. B* **64** (1976) 159 [[INSPIRE](#)].
- [13] P. Fayet, *Spontaneously broken supersymmetric theories of weak, electromagnetic and strong interactions*, *Phys. Lett. B* **69** (1977) 489 [[INSPIRE](#)].
- [14] G.R. Farrar and P. Fayet, *Phenomenology of the production, decay and detection of new hadronic states associated with supersymmetry*, *Phys. Lett. B* **76** (1978) 575 [[INSPIRE](#)].
- [15] P. Fayet, *Relations between the masses of the superpartners of leptons and quarks, the goldstino couplings and the neutral currents*, *Phys. Lett. B* **84** (1979) 416 [[INSPIRE](#)].
- [16] S. Dimopoulos and H. Georgi, *Softly broken supersymmetry and SU(5)*, *Nucl. Phys. B* **193** (1981) 150 [[INSPIRE](#)].
- [17] ATLAS collaboration, *Search for direct production of charginos and neutralinos in events with three leptons and missing transverse momentum in  $\sqrt{s} = 7$  TeV  $pp$  collisions with the ATLAS detector*, *Phys. Lett. B* **718** (2013) 841 [[arXiv:1208.3144](#)] [[INSPIRE](#)].

- [18] ATLAS collaboration, *Search for direct slepton and gaugino production in final states with two leptons and missing transverse momentum with the ATLAS detector in pp collisions at  $\sqrt{s} = 7$  TeV*, *Phys. Lett. B* **718** (2013) 879 [[arXiv:1208.2884](#)] [[INSPIRE](#)].
- [19] ATLAS collaboration, *Search for supersymmetry in events with three leptons and missing transverse momentum in  $\sqrt{s} = 7$  TeV pp collisions with the ATLAS detector*, *Phys. Rev. Lett.* **108** (2012) 261804 [[arXiv:1204.5638](#)] [[INSPIRE](#)].
- [20] CMS collaboration, *Search for electroweak production of charginos and neutralinos using leptonic final states in pp collisions at  $\sqrt{s} = 7$  TeV*, *JHEP* **11** (2012) 147 [[arXiv:1209.6620](#)] [[INSPIRE](#)].
- [21] D0 collaboration, V. Abazov et al., *Search for associated production of charginos and neutralinos in the trilepton final state using  $2.3\text{fb}^{-1}$  of data*, *Phys. Lett. B* **680** (2009) 34 [[arXiv:0901.0646](#)] [[INSPIRE](#)].
- [22] CDF collaboration, T. Aaltonen et al., *Search for supersymmetry in  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96$  TeV using the trilepton signature of chargino-neutralino production*, *Phys. Rev. Lett.* **101** (2008) 251801 [[arXiv:0808.2446](#)] [[INSPIRE](#)].
- [23] LEPSUSYWG, ALEPH, DELPHI, L3 and OPAL experiments, *Combined LEP Chargino Results, up to 208 GeV for large  $m_0$* , LEPSUSYWG/01-03.1, <http://lepsusy.web.cern.ch/lepsusy/Welcome.html>.
- [24] ALEPH collaboration, A. Heister et al., *Absolute mass lower limit for the lightest neutralino of the MSSM from  $e^+e^-$  data at  $\sqrt{s}^{1/2}$  up to 209 GeV*, *Phys. Lett. B* **583** (2004) 247 [[INSPIRE](#)].
- [25] DELPHI collaboration, J. Abdallah et al., *Searches for supersymmetric particles in  $e^+e^-$  collisions up to 208 GeV and interpretation of the results within the MSSM*, *Eur. Phys. J. C* **31** (2003) 421 [[hep-ex/0311019](#)] [[INSPIRE](#)].
- [26] L3 collaboration, M. Acciarri et al., *Search for charginos and neutralinos in  $e^+e^-$  collisions at  $\sqrt{s} = 189$  GeV*, *Phys. Lett. B* **472** (2000) 420 [[hep-ex/9910007](#)] [[INSPIRE](#)].
- [27] OPAL collaboration, G. Abbiendi et al., *Search for chargino and neutralino production at  $\sqrt{s} = 192$  GeV to 209 GeV at LEP*, *Eur. Phys. J. C* **35** (2004) 1 [[hep-ex/0401026](#)] [[INSPIRE](#)].
- [28] J. Alwall, P. Schuster and N. Toro, *Simplified models for a first characterization of new physics at the LHC*, *Phys. Rev. D* **79** (2009) 075020 [[arXiv:0810.3921](#)] [[INSPIRE](#)].
- [29] MSSM WORKING GROUP collaboration, A. Djouadi et al., *The minimal supersymmetric standard model: group summary report*, [hep-ph/9901246](#) [[INSPIRE](#)].
- [30] ATLAS collaboration, *Observation of a new particle in the search for the standard model Higgs boson with the ATLAS detector at the LHC*, *Phys. Lett. B* **716** (2012) 1 [[arXiv:1207.7214](#)] [[INSPIRE](#)].
- [31] CMS collaboration, *Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC*, *Phys. Lett. B* **716** (2012) 30 [[arXiv:1207.7235](#)] [[INSPIRE](#)].
- [32] ATLAS collaboration, *The ATLAS experiment at the CERN Large Hadron Collider, 2008* *JINST* **3** S08003 [[INSPIRE](#)].
- [33] ATLAS collaboration, *Performance of the ATLAS trigger system in 2010*, *Eur. Phys. J. C* **72** (2012) 1849 [[arXiv:1110.1530](#)] [[INSPIRE](#)].

- [34] P. Nason, *A new method for combining NLO QCD with shower Monte Carlo algorithms*, *JHEP* **11** (2004) 040 [[hep-ph/0409146](#)] [[INSPIRE](#)].
- [35] S. Frixione, P. Nason and C. Oleari, *Matching NLO QCD computations with Parton Shower simulations: the POWHEG method*, *JHEP* **11** (2007) 070 [[arXiv:0709.2092](#)] [[INSPIRE](#)].
- [36] ATLAS collaboration, *Summary of ATLAS PYTHIA 8 tunes*, [ATL-PHYS-PUB-2012-003](#) (2012).
- [37] H.-L. Lai et al., *New parton distributions for collider physics*, *Phys. Rev. D* **82** (2010) 074024 [[arXiv:1007.2241](#)] [[INSPIRE](#)].
- [38] T. Sjöstrand, S. Mrenna and P.Z. Skands, *PYTHIA 6.4 physics and manual*, *JHEP* **05** (2006) 026 [[hep-ph/0603175](#)] [[INSPIRE](#)].
- [39] J.M. Campbell and R.K. Ellis, *An update on vector boson pair production at hadron colliders*, *Phys. Rev. D* **60** (1999) 113006 [[hep-ph/9905386](#)] [[INSPIRE](#)].
- [40] J.M. Campbell, R.K. Ellis and C. Williams, *Vector boson pair production at the LHC*, *JHEP* **07** (2011) 018 [[arXiv:1105.0020](#)] [[INSPIRE](#)].
- [41] S. Frixione and B.R. Webber, *Matching NLO QCD computations and parton shower simulations*, *JHEP* **06** (2002) 029 [[hep-ph/0204244](#)] [[INSPIRE](#)].
- [42] G. Corcella et al., *HERWIG 6: an event generator for hadron emission reactions with interfering gluons (including supersymmetric processes)*, *JHEP* **01** (2001) 010 [[hep-ph/0011363](#)] [[INSPIRE](#)].
- [43] N. Kauer and G. Passarino, *Inadequacy of zero-width approximation for a light Higgs boson signal*, *JHEP* **08** (2012) 116 [[arXiv:1206.4803](#)] [[INSPIRE](#)].
- [44] ATLAS collaboration, *ATLAS tunes of PYTHIA 6 and PYTHIA 8 for MC11*, [ATL-PHYS-PUB-2011-009](#) (2011).
- [45] T. Gleisberg et al., *Event generation with SHERPA 1.1*, *JHEP* **02** (2009) 007 [[arXiv:0811.4622](#)] [[INSPIRE](#)].
- [46] J. Alwall et al., *MadGraph/MadEvent v4: the new web generation*, *JHEP* **09** (2007) 028 [[arXiv:0706.2334](#)] [[INSPIRE](#)].
- [47] F. Campanario, V. Hankele, C. Oleari, S. Prestel and D. Zeppenfeld, *QCD corrections to charged triple vector boson production with leptonic decay*, *Phys. Rev. D* **78** (2008) 094012 [[arXiv:0809.0790](#)] [[INSPIRE](#)].
- [48] J. Pumplin et al., *New generation of parton distributions with uncertainties from global QCD analysis*, *JHEP* **07** (2002) 012 [[hep-ph/0201195](#)] [[INSPIRE](#)].
- [49] S. Dittmaier et al., *Handbook of LHC Higgs cross sections: 2. Differential distributions*, [arXiv:1201.3084](#) [[INSPIRE](#)].
- [50] M.L. Mangano, M. Moretti, F. Piccinini, R. Pittau and A.D. Polosa, *ALPGEN, a generator for hard multiparton processes in hadronic collisions*, *JHEP* **07** (2003) 001 [[hep-ph/0206293](#)] [[INSPIRE](#)].
- [51] A. Kardos, Z. Trócsányi and C. Papadopoulos, *Top quark pair production in association with a Z-boson at NLO accuracy*, *Phys. Rev. D* **85** (2012) 054015 [[arXiv:1111.0610](#)] [[INSPIRE](#)].
- [52] J.M. Campbell and R.K. Ellis,  *$t\bar{t}W^{+-}$  production and decay at NLO*, *JHEP* **07** (2012) 052 [[arXiv:1204.5678](#)] [[INSPIRE](#)].

- [53] J. Campbell, R.K. Ellis and R. Rötsch, *Single top production in association with a Z boson at the LHC*, *Phys. Rev. D* **87** (2013) 114006 [[arXiv:1302.3856](#)] [[INSPIRE](#)].
- [54] M. Cacciari, M. Czakon, M. Mangano, A. Mitov and P. Nason, *Top-pair production at hadron colliders with next-to-next-to-leading logarithmic soft-gluon resummation*, *Phys. Lett. B* **710** (2012) 612 [[arXiv:1111.5869](#)] [[INSPIRE](#)].
- [55] P. Bärnreuther, M. Czakon and A. Mitov, *Percent level precision physics at the Tevatron: first genuine NNLO QCD corrections to  $q\bar{q} \rightarrow t\bar{t} + X$* , *Phys. Rev. Lett.* **109** (2012) 132001 [[arXiv:1204.5201](#)] [[INSPIRE](#)].
- [56] M. Czakon and A. Mitov, *NNLO corrections to top-pair production at hadron colliders: the all-fermionic scattering channels*, *JHEP* **12** (2012) 054 [[arXiv:1207.0236](#)] [[INSPIRE](#)].
- [57] M. Czakon and A. Mitov, *NNLO corrections to top pair production at hadron colliders: the quark-gluon reaction*, *JHEP* **01** (2013) 080 [[arXiv:1210.6832](#)] [[INSPIRE](#)].
- [58] M. Czakon, P. Fiedler and A. Mitov, *Total top-quark pair-production cross section at hadron colliders through  $O(\alpha_s^4)$* , *Phys. Rev. Lett.* **110** (2013) 252004 [[arXiv:1303.6254](#)] [[INSPIRE](#)].
- [59] M. Czakon and A. Mitov, *Top++: a program for the calculation of the top-pair cross-section at hadron colliders*, [arXiv:1112.5675](#) [[INSPIRE](#)].
- [60] B.P. Kersevan and E. Richter-Was, *The Monte Carlo event generator AcerMC versions 2.0 to 3.8 with interfaces to PYTHIA 6.4, HERWIG 6.5 and ARIADNE 4.1*, *Comput. Phys. Commun.* **184** (2013) 919 [[hep-ph/0405247](#)] [[INSPIRE](#)].
- [61] N. Kidonakis, *Next-to-next-to-leading-order collinear and soft gluon corrections for t-channel single top quark production*, *Phys. Rev. D* **83** (2011) 091503 [[arXiv:1103.2792](#)] [[INSPIRE](#)].
- [62] S. Frixione, E. Laenen, P. Motylinski and B.R. Webber, *Single-top production in MC@NLO*, *JHEP* **03** (2006) 092 [[hep-ph/0512250](#)] [[INSPIRE](#)].
- [63] S. Frixione, E. Laenen, P. Motylinski, B.R. Webber and C.D. White, *Single-top hadroproduction in association with a W boson*, *JHEP* **07** (2008) 029 [[arXiv:0805.3067](#)] [[INSPIRE](#)].
- [64] N. Kidonakis, *NNLL resummation for s-channel single top quark production*, *Phys. Rev. D* **81** (2010) 054028 [[arXiv:1001.5034](#)] [[INSPIRE](#)].
- [65] N. Kidonakis, *Two-loop soft anomalous dimensions for single top quark associated production with a  $W^-$  or  $H^-$* , *Phys. Rev. D* **82** (2010) 054018 [[arXiv:1005.4451](#)] [[INSPIRE](#)].
- [66] S. Catani, L. Cieri, G. Ferrera, D. de Florian and M. Grazzini, *Vector boson production at hadron colliders: a fully exclusive QCD calculation at NNLO*, *Phys. Rev. Lett.* **103** (2009) 082001 [[arXiv:0903.2120](#)] [[INSPIRE](#)].
- [67] A. Martin, W. Stirling, R. Thorne and G. Watt, *Parton distributions for the LHC*, *Eur. Phys. J. C* **63** (2009) 189 [[arXiv:0901.0002](#)] [[INSPIRE](#)].
- [68] GEANT4 collaboration, S. Agostinelli et al., *GEANT4 — a simulation toolkit*, *Nucl. Instrum. Meth. A* **506** (2003) 250 [[INSPIRE](#)].
- [69] ATLAS collaboration, *The ATLAS simulation infrastructure*, *Eur. Phys. J. C* **70** (2010) 823 [[arXiv:1005.4568](#)] [[INSPIRE](#)].
- [70] ATLAS collaboration, *The simulation principle and performance of the ATLAS fast calorimeter simulation FastCaloSim*, *ATL-PHYS-PUB-2010-013* (2010).

- [71] M. Bahr et al., *HERWIG++ physics and manual*, *Eur. Phys. J. C* **58** (2008) 639 [[arXiv:0803.0883](#)] [[INSPIRE](#)].
- [72] W. Beenakker, R. Hopker, M. Spira and P. Zerwas, *Squark and gluino production at hadron colliders*, *Nucl. Phys. B* **492** (1997) 51 [[hep-ph/9610490](#)] [[INSPIRE](#)].
- [73] B. Fuks, M. Klasen, D.R. Lamprea and M. Rothering, *Gaugino production in proton-proton collisions at a center-of-mass energy of 8 TeV*, *JHEP* **10** (2012) 081 [[arXiv:1207.2159](#)] [[INSPIRE](#)].
- [74] B. Fuks, M. Klasen, D.R. Lamprea and M. Rothering, *Precision predictions for electroweak superpartner production at hadron colliders with Resummino*, *Eur. Phys. J. C* **73** (2013) 2480 [[arXiv:1304.0790](#)] [[INSPIRE](#)].
- [75] B. Fuks, M. Klasen, D.R. Lamprea and M. Rothering, *Revisiting slepton pair production at the Large Hadron Collider*, *JHEP* **01** (2014) 168 [[arXiv:1310.2621](#)] [[INSPIRE](#)].
- [76] M. Krämer et al., *Supersymmetry production cross sections in pp collisions at  $\sqrt{s} = 7$  TeV*, [arXiv:1206.2892](#) [[INSPIRE](#)].
- [77] ATLAS collaboration, *Electron performance measurements with the ATLAS detector using the 2010 LHC proton-proton collision data*, *Eur. Phys. J. C* **72** (2012) 1909 [[arXiv:1110.3174](#)] [[INSPIRE](#)].
- [78] ATLAS collaboration, *Measurement of the inclusive  $W^\pm$  and  $Z/\gamma$  cross sections in the electron and muon decay channels in pp collisions at  $\sqrt{s} = 7$  TeV with the ATLAS detector*, *Phys. Rev. D* **85** (2012) 072004 [[arXiv:1109.5141](#)] [[INSPIRE](#)].
- [79] M. Cacciari, G.P. Salam and G. Soyez, *The anti- $k_t$  jet clustering algorithm*, *JHEP* **04** (2008) 063 [[arXiv:0802.1189](#)] [[INSPIRE](#)].
- [80] ATLAS collaboration, *Jet energy measurement with the ATLAS detector in proton-proton collisions at  $\sqrt{s} = 7$  TeV*, *Eur. Phys. J. C* **73** (2013) 2304 [[arXiv:1112.6426](#)] [[INSPIRE](#)].
- [81] ATLAS collaboration, *Single hadron response measurement and calorimeter jet energy scale uncertainty with the ATLAS detector at the LHC*, *Eur. Phys. J. C* **73** (2013) 2305 [[arXiv:1203.1302](#)] [[INSPIRE](#)].
- [82] ATLAS collaboration, *Commissioning of the ATLAS high-performance b-tagging algorithms in the 7 TeV collision data*, [ATLAS-CONF-2011-102](#) (2011).
- [83] ATLAS collaboration, *Determination of the  $\tau$  energy scale and the associated systematic uncertainty in proton-proton collisions at  $\sqrt{s} = 8$  TeV with the ATLAS detector at the LHC in 2012*, [ATL-CONF-2013-044](#) (2013).
- [84] ATLAS collaboration, *Performance of missing transverse momentum reconstruction in proton-proton collisions at 7 TeV with ATLAS*, *Eur. Phys. J. C* **72** (2012) 1844 [[arXiv:1108.5602](#)] [[INSPIRE](#)].
- [85] ATLAS collaboration, *Identification of the hadronic decays of  $\tau$  leptons in 2012 data with the ATLAS detector*, [ATL-CONF-2013-064](#) (2013).
- [86] C. Lester and D. Summers, *Measuring masses of semiinvisibly decaying particles pair produced at hadron colliders*, *Phys. Lett. B* **463** (1999) 99 [[hep-ph/9906349](#)] [[INSPIRE](#)].
- [87] A. Barr, C. Lester and P. Stephens,  *$m_{T2}$ : the truth behind the glamour*, *J. Phys. G* **29** (2003) 2343 [[hep-ph/0304226](#)] [[INSPIRE](#)].

- [88] ATLAS collaboration, *Measurement of the top quark-pair production cross section with ATLAS in pp collisions at  $\sqrt{s} = 7$  TeV*, *Eur. Phys. J. C* **71** (2011) 1577 [[arXiv:1012.1792](#)] [[INSPIRE](#)].
- [89] ATLAS collaboration, *Improved luminosity determination in pp collisions at  $\sqrt{s} = 7$  TeV using the ATLAS detector at the LHC*, *Eur. Phys. J. C* **73** (2013) 2518 [[arXiv:1302.4393](#)] [[INSPIRE](#)].
- [90] ATLAS collaboration, *Measurement of WZ production in proton-proton collisions at  $\sqrt{s} = 7$  TeV with the ATLAS detector*, *Eur. Phys. J. C* **72** (2012) 2173 [[arXiv:1208.1390](#)] [[INSPIRE](#)].
- [91] ATLAS collaboration, *Measurement of ZZ production in pp collisions at  $\sqrt{s} = 7$  TeV and limits on anomalous ZZZ and ZZ $\gamma$  couplings with the ATLAS detector*, *JHEP* **03** (2013) 128 [[arXiv:1211.6096](#)] [[INSPIRE](#)].
- [92] A.L. Read, *Presentation of search results: the  $CL(s)$  technique*, *J. Phys. G* **28** (2002) 2693 [[INSPIRE](#)].
- [93] G. Cowan, K. Cranmer, E. Gross and O. Vitells, *Asymptotic formulae for likelihood-based tests of new physics*, *Eur. Phys. J. C* **71** (2011) 1554 [[arXiv:1007.1727](#)] [[INSPIRE](#)].

## The ATLAS collaboration

G. Aad<sup>84</sup>, T. Abajyan<sup>21</sup>, B. Abbott<sup>112</sup>, J. Abdallah<sup>152</sup>, S. Abdel Khalek<sup>116</sup>, O. Abdinov<sup>11</sup>, R. Aben<sup>106</sup>, B. Abi<sup>113</sup>, M. Abolins<sup>89</sup>, O.S. AbouZeid<sup>159</sup>, H. Abramowicz<sup>154</sup>, H. Abreu<sup>137</sup>, Y. Abulaiti<sup>147a,147b</sup>, B.S. Acharya<sup>165a,165b,a</sup>, L. Adamczyk<sup>38a</sup>, D.L. Adams<sup>25</sup>, J. Adelman<sup>177</sup>, S. Adomeit<sup>99</sup>, T. Adye<sup>130</sup>, T. Agatonovic-Jovin<sup>13b</sup>, J.A. Aguilar-Saavedra<sup>125f,125a</sup>, M. Agustoni<sup>17</sup>, S.P. Ahlen<sup>22</sup>, A. Ahmad<sup>149</sup>, F. Ahmadov<sup>64,b</sup>, G. Aielli<sup>134a,134b</sup>, T.P.A. Åkesson<sup>80</sup>, G. Akimoto<sup>156</sup>, A.V. Akimov<sup>95</sup>, J. Albert<sup>170</sup>, S. Albrand<sup>55</sup>, M.J. Alconada Verzini<sup>70</sup>, M. Aleksa<sup>30</sup>, I.N. Aleksandrov<sup>64</sup>, C. Alexa<sup>26a</sup>, G. Alexander<sup>154</sup>, G. Alexandre<sup>49</sup>, T. Alexopoulos<sup>10</sup>, M. Alhroob<sup>165a,165c</sup>, G. Alimonti<sup>90a</sup>, L. Alio<sup>84</sup>, J. Alison<sup>31</sup>, B.M.M. Allbrooke<sup>18</sup>, L.J. Allison<sup>71</sup>, P.P. Allport<sup>73</sup>, S.E. Allwood-Spiers<sup>53</sup>, J. Almond<sup>83</sup>, A. Aloisio<sup>103a,103b</sup>, R. Alon<sup>173</sup>, A. Alonso<sup>36</sup>, F. Alonso<sup>70</sup>, C. Alpigiani<sup>75</sup>, A. Altheimer<sup>35</sup>, B. Alvarez Gonzalez<sup>89</sup>, M.G. Alviggi<sup>103a,103b</sup>, K. Amako<sup>65</sup>, Y. Amaral Coutinho<sup>24a</sup>, C. Amelung<sup>23</sup>, D. Amidei<sup>88</sup>, V.V. Ammosov<sup>129,\*</sup>, S.P. Amor Dos Santos<sup>125a,125c</sup>, A. Amorim<sup>125a,125b</sup>, S. Amoroso<sup>48</sup>, N. Amram<sup>154</sup>, G. Amundsen<sup>23</sup>, C. Anastopoulos<sup>140</sup>, L.S. Ancu<sup>17</sup>, N. Andari<sup>30</sup>, T. Andeen<sup>35</sup>, C.F. Anders<sup>58b</sup>, G. Anders<sup>30</sup>, K.J. Anderson<sup>31</sup>, A. Andreazza<sup>90a,90b</sup>, V. Andrei<sup>58a</sup>, X.S. Anduaga<sup>70</sup>, S. Angelidakis<sup>9</sup>, P. Anger<sup>44</sup>, A. Angerami<sup>35</sup>, F. Anghinolfi<sup>30</sup>, A.V. Anisenkov<sup>108</sup>, N. Anjos<sup>125a</sup>, A. Annovi<sup>47</sup>, A. Antonaki<sup>9</sup>, M. Antonelli<sup>47</sup>, A. Antonov<sup>97</sup>, J. Antos<sup>145b</sup>, F. Anulli<sup>133a</sup>, M. Aoki<sup>65</sup>, L. Aperio Bella<sup>18</sup>, R. Apolle<sup>119,c</sup>, G. Arabidze<sup>89</sup>, I. Aracena<sup>144</sup>, Y. Arai<sup>65</sup>, J.P. Araque<sup>125a</sup>, A.T.H. Arce<sup>45</sup>, J-F. Arguin<sup>94</sup>, S. Argyropoulos<sup>42</sup>, M. Arik<sup>19a</sup>, A.J. Armbruster<sup>30</sup>, O. Arnaez<sup>82</sup>, V. Arnal<sup>81</sup>, O. Arslan<sup>21</sup>, A. Artamonov<sup>96</sup>, G. Artoni<sup>23</sup>, S. Asai<sup>156</sup>, N. Asbah<sup>94</sup>, A. Ashkenazi<sup>154</sup>, S. Ask<sup>28</sup>, B. Åsman<sup>147a,147b</sup>, L. Asquith<sup>6</sup>, K. Assamagan<sup>25</sup>, R. Astalos<sup>145a</sup>, M. Atkinson<sup>166</sup>, N.B. Atlay<sup>142</sup>, B. Auerbach<sup>6</sup>, E. Auge<sup>116</sup>, K. Augsten<sup>127</sup>, M. Aurousseau<sup>146b</sup>, G. Avolio<sup>30</sup>, G. Azuelos<sup>94,d</sup>, Y. Azuma<sup>156</sup>, M.A. Baak<sup>30</sup>, C. Bacci<sup>135a,135b</sup>, H. Bachacou<sup>137</sup>, K. Bachas<sup>155</sup>, M. Backes<sup>30</sup>, M. Backhaus<sup>30</sup>, J. Backus Mayes<sup>144</sup>, E. Badescu<sup>26a</sup>, P. Bagiachi<sup>133a,133b</sup>, P. Bagnaia<sup>133a,133b</sup>, Y. Bai<sup>33a</sup>, D.C. Bailey<sup>159</sup>, T. Bain<sup>35</sup>, J.T. Baines<sup>130</sup>, O.K. Baker<sup>177</sup>, S. Baker<sup>77</sup>, P. Balek<sup>128</sup>, F. Balli<sup>137</sup>, E. Banas<sup>39</sup>, Sw. Banerjee<sup>174</sup>, D. Banfi<sup>30</sup>, A. Bangert<sup>151</sup>, A.A.E. Bannoura<sup>176</sup>, V. Bansal<sup>170</sup>, H.S. Bansil<sup>18</sup>, L. Barak<sup>173</sup>, S.P. Baranov<sup>95</sup>, T. Barber<sup>48</sup>, E.L. Barberio<sup>87</sup>, D. Barberis<sup>50a,50b</sup>, M. Barbero<sup>84</sup>, T. Barillari<sup>100</sup>, M. Barisonzi<sup>176</sup>, T. Barklow<sup>144</sup>, N. Barlow<sup>28</sup>, B.M. Barnett<sup>130</sup>, R.M. Barnett<sup>15</sup>, Z. Barnovska<sup>5</sup>, A. Baroncelli<sup>135a</sup>, G. Barone<sup>49</sup>, A.J. Barr<sup>119</sup>, F. Barreiro<sup>81</sup>, J. Barreiro Guimarães da Costa<sup>57</sup>, R. Bartoldus<sup>144</sup>, A.E. Barton<sup>71</sup>, P. Bartos<sup>145a</sup>, V. Bartsch<sup>150</sup>, A. Bassalat<sup>116</sup>, A. Basye<sup>166</sup>, R.L. Bates<sup>53</sup>, L. Batkova<sup>145a</sup>, J.R. Batley<sup>28</sup>, M. Battistin<sup>30</sup>, F. Bauer<sup>137</sup>, H.S. Bawa<sup>144,e</sup>, T. Beau<sup>79</sup>, P.H. Beauchemin<sup>162</sup>, R. Beccherle<sup>123a,123b</sup>, P. Bechtel<sup>21</sup>, H.P. Beck<sup>17</sup>, K. Becker<sup>176</sup>, S. Becker<sup>99</sup>, M. Beckingham<sup>139</sup>, C. Becot<sup>116</sup>, A.J. Beddall<sup>19c</sup>, A. Beddall<sup>19c</sup>, S. Bedikian<sup>177</sup>, V.A. Bednyakov<sup>64</sup>, C.P. Bee<sup>149</sup>, L.J. Beamster<sup>106</sup>, T.A. Beermann<sup>176</sup>, M. Begel<sup>25</sup>, K. Behr<sup>119</sup>, C. Belanger-Champagne<sup>86</sup>, P.J. Bell<sup>49</sup>, W.H. Bell<sup>49</sup>, G. Bella<sup>154</sup>, L. Bellagamba<sup>20a</sup>, A. Bellerive<sup>29</sup>, M. Bellomo<sup>85</sup>, A. Belloni<sup>57</sup>, O.L. Beloborodova<sup>108,f</sup>, K. Belotskiy<sup>97</sup>, O. Beltramello<sup>30</sup>, O. Benary<sup>154</sup>, D. Benchekroun<sup>136a</sup>, K. Bendtz<sup>147a,147b</sup>, N. Benekos<sup>166</sup>, Y. Benhammou<sup>154</sup>, E. Benhar Nocchioli<sup>49</sup>, J.A. Benitez Garcia<sup>160b</sup>, D.P. Benjamin<sup>45</sup>, J.R. Bensinger<sup>23</sup>, K. Benslama<sup>131</sup>, S. Bentvelsen<sup>106</sup>, D. Berge<sup>106</sup>, E. Bergeaas Kuutmann<sup>16</sup>, N. Berger<sup>5</sup>, F. Berghaus<sup>170</sup>, E. Berglund<sup>106</sup>, J. Beringer<sup>15</sup>, C. Bernard<sup>22</sup>, P. Bernat<sup>77</sup>, C. Bernius<sup>78</sup>, F.U. Bernlochner<sup>170</sup>, T. Berry<sup>76</sup>, P. Berta<sup>128</sup>, C. Bertella<sup>84</sup>, F. Bertolucci<sup>123a,123b</sup>, M.I. Besana<sup>90a</sup>, G.J. Besjes<sup>105</sup>, O. Bessidskaia<sup>147a,147b</sup>, N. Besson<sup>137</sup>, C. Betancourt<sup>48</sup>, S. Bethke<sup>100</sup>, W. Bhimji<sup>46</sup>, R.M. Bianchi<sup>124</sup>, L. Bianchini<sup>23</sup>, M. Bianco<sup>30</sup>, O. Biebel<sup>99</sup>, S.P. Bieniek<sup>77</sup>, K. Bierwagen<sup>54</sup>, J. Biesiada<sup>15</sup>, M. Biglietti<sup>135a</sup>, J. Bilbao De Mendizabal<sup>49</sup>, H. Bilokon<sup>47</sup>, M. Bindi<sup>54</sup>, S. Binet<sup>116</sup>, A. Bingul<sup>19c</sup>, C. Bini<sup>133a,133b</sup>, C.W. Black<sup>151</sup>, J.E. Black<sup>144</sup>, K.M. Black<sup>22</sup>, D. Blackburn<sup>139</sup>, R.E. Blair<sup>6</sup>, J.-B. Blanchard<sup>137</sup>, T. Blazek<sup>145a</sup>, I. Bloch<sup>42</sup>, C. Blocker<sup>23</sup>, W. Blum<sup>82,\*</sup>, U. Blumenschein<sup>54</sup>, G.J. Bobbink<sup>106</sup>, V.S. Bobrovnikov<sup>108</sup>, S.S. Bocchetta<sup>80</sup>, A. Bocchi<sup>45</sup>, C.R. Boddy<sup>119</sup>, M. Boehler<sup>48</sup>, J. Boek<sup>176</sup>, T.T. Boek<sup>176</sup>, J.A. Bogaerts<sup>30</sup>, A.G. Bogdanchikov<sup>108</sup>, A. Bogouch<sup>91,\*</sup>, C. Bohm<sup>147a</sup>, J. Bohm<sup>126</sup>, V. Boisvert<sup>76</sup>, T. Bold<sup>38a</sup>, V. Boldea<sup>26a</sup>, A.S. Boldyrev<sup>98</sup>, N.M. Bolnet<sup>137</sup>, M. Bomben<sup>79</sup>, M. Bona<sup>75</sup>, M. Boonekamp<sup>137</sup>, A. Borisov<sup>129</sup>, G. Borissov<sup>71</sup>, M. Borri<sup>83</sup>, S. Borroni<sup>42</sup>, J. Bortfeldt<sup>99</sup>, V. Bortolotto<sup>135a,135b</sup>, K. Bos<sup>106</sup>, D. Boscherini<sup>20a</sup>, M. Bosman<sup>12</sup>,

H. Boterenbrood<sup>106</sup>, J. Boudreau<sup>124</sup>, J. Bouffard<sup>2</sup>, E.V. Bouhova-Thacker<sup>71</sup>, D. Boumediene<sup>34</sup>,  
 C. Bourdarios<sup>116</sup>, N. Bousson<sup>113</sup>, S. Boutouil<sup>136d</sup>, A. Boveia<sup>31</sup>, J. Boyd<sup>30</sup>, I.R. Boyko<sup>64</sup>,  
 I. Bozovic-Jelisavcic<sup>13b</sup>, J. Bracinik<sup>18</sup>, P. Branchini<sup>135a</sup>, A. Brandt<sup>8</sup>, G. Brandt<sup>15</sup>, O. Brandt<sup>58a</sup>,  
 U. Bratzler<sup>157</sup>, B. Brau<sup>85</sup>, J.E. Brau<sup>115</sup>, H.M. Braun<sup>176,\*</sup>, S.F. Brazzale<sup>165a,165c</sup>, B. Brelier<sup>159</sup>,  
 K. Brendlinger<sup>121</sup>, A.J. Brennan<sup>87</sup>, R. Brenner<sup>167</sup>, S. Bressler<sup>173</sup>, K. Bristow<sup>146c</sup>, T.M. Bristow<sup>46</sup>,  
 D. Britton<sup>53</sup>, F.M. Brochu<sup>28</sup>, I. Brock<sup>21</sup>, R. Brock<sup>89</sup>, C. Bromberg<sup>89</sup>, J. Bronner<sup>100</sup>,  
 G. Brooijmans<sup>35</sup>, T. Brooks<sup>76</sup>, W.K. Brooks<sup>32b</sup>, J. Brosamer<sup>15</sup>, E. Brost<sup>115</sup>, G. Brown<sup>83</sup>,  
 J. Brown<sup>55</sup>, P.A. Bruckman de Renstrom<sup>39</sup>, D. Bruncko<sup>145b</sup>, R. Bruneliere<sup>48</sup>, S. Brunet<sup>60</sup>,  
 A. Bruni<sup>20a</sup>, G. Bruni<sup>20a</sup>, M. Bruschi<sup>20a</sup>, L. Bryngemark<sup>80</sup>, T. Buanes<sup>14</sup>, Q. Buat<sup>143</sup>, F. Bucci<sup>49</sup>,  
 P. Buchholz<sup>142</sup>, R.M. Buckingham<sup>119</sup>, A.G. Buckley<sup>53</sup>, S.I. Buda<sup>26a</sup>, I.A. Budagov<sup>64</sup>,  
 F. Buehrer<sup>48</sup>, L. Bugge<sup>118</sup>, M.K. Bugge<sup>118</sup>, O. Bulekov<sup>97</sup>, A.C. Bundock<sup>73</sup>, H. Burckhart<sup>30</sup>,  
 S. Burdin<sup>73</sup>, B. Burghgrave<sup>107</sup>, S. Burke<sup>130</sup>, I. Burmeister<sup>43</sup>, E. Busato<sup>34</sup>, V. Büscher<sup>82</sup>,  
 P. Bussey<sup>53</sup>, C.P. Buszello<sup>167</sup>, B. Butler<sup>57</sup>, J.M. Butler<sup>22</sup>, A.I. Butt<sup>3</sup>, C.M. Buttar<sup>53</sup>,  
 J.M. Butterworth<sup>77</sup>, P. Butti<sup>106</sup>, W. Buttinger<sup>28</sup>, A. Buzatu<sup>53</sup>, M. Byszewski<sup>10</sup>,  
 S. Cabrera Urbán<sup>168</sup>, D. Caforio<sup>20a,20b</sup>, O. Cakir<sup>4a</sup>, P. Calafiura<sup>15</sup>, G. Calderini<sup>79</sup>, P. Calfayan<sup>99</sup>,  
 R. Calkins<sup>107</sup>, L.P. Caloba<sup>24a</sup>, D. Calvet<sup>34</sup>, S. Calvet<sup>34</sup>, R. Camacho Toro<sup>49</sup>, S. Camarda<sup>42</sup>,  
 D. Cameron<sup>118</sup>, L.M. Caminada<sup>15</sup>, R. Caminal Armadans<sup>12</sup>, S. Campana<sup>30</sup>, M. Campanelli<sup>77</sup>,  
 A. Campoverde<sup>149</sup>, V. Canale<sup>103a,103b</sup>, A. Canepa<sup>160a</sup>, J. Cantero<sup>81</sup>, R. Cantrill<sup>76</sup>, T. Cao<sup>40</sup>,  
 M.D.M. Capeans Garrido<sup>30</sup>, I. Caprini<sup>26a</sup>, M. Caprini<sup>26a</sup>, M. Capua<sup>37a,37b</sup>, R. Caputo<sup>82</sup>,  
 R. Cardarelli<sup>134a</sup>, T. Carli<sup>30</sup>, G. Carlino<sup>103a</sup>, L. Carminati<sup>90a,90b</sup>, S. Caron<sup>105</sup>, E. Carquin<sup>32a</sup>,  
 G.D. Carrillo-Montoya<sup>146c</sup>, A.A. Carter<sup>75</sup>, J.R. Carter<sup>28</sup>, J. Carvalho<sup>125a,125c</sup>, D. Casadei<sup>77</sup>,  
 M.P. Casado<sup>12</sup>, E. Castaneda-Miranda<sup>146b</sup>, A. Castelli<sup>106</sup>, V. Castillo Gimenez<sup>168</sup>,  
 N.F. Castro<sup>125a</sup>, P. Catastini<sup>57</sup>, A. Catinaccio<sup>30</sup>, J.R. Catmore<sup>71</sup>, A. Cattai<sup>30</sup>, G. Cattani<sup>134a,134b</sup>,  
 S. Caughron<sup>89</sup>, V. Cavaliere<sup>166</sup>, D. Cavalli<sup>90a</sup>, M. Cavalli-Sforza<sup>12</sup>, V. Cavasinni<sup>123a,123b</sup>,  
 F. Ceradini<sup>135a,135b</sup>, B. Cerio<sup>45</sup>, K. Cerny<sup>128</sup>, A.S. Cerqueira<sup>24b</sup>, A. Cerri<sup>150</sup>, L. Cerrito<sup>75</sup>,  
 F. Cerutti<sup>15</sup>, M. Cerv<sup>30</sup>, A. Cervelli<sup>17</sup>, S.A. Cetin<sup>19b</sup>, A. Chafaq<sup>136a</sup>, D. Chakraborty<sup>107</sup>,  
 I. Chalupkova<sup>128</sup>, K. Chan<sup>3</sup>, P. Chang<sup>166</sup>, B. Chapleau<sup>86</sup>, J.D. Chapman<sup>28</sup>, D. Charfeddine<sup>116</sup>,  
 D.G. Charlton<sup>18</sup>, C.C. Chau<sup>159</sup>, C.A. Chavez Barajas<sup>150</sup>, S. Cheatham<sup>86</sup>, A. Chegwiddden<sup>89</sup>,  
 S. Chekanov<sup>6</sup>, S.V. Chekulaev<sup>160a</sup>, G.A. Chelkov<sup>64</sup>, M.A. Chelstowska<sup>88</sup>, C. Chen<sup>63</sup>, H. Chen<sup>25</sup>,  
 K. Chen<sup>149</sup>, L. Chen<sup>33d,g</sup>, S. Chen<sup>33c</sup>, X. Chen<sup>146c</sup>, Y. Chen<sup>35</sup>, H.C. Cheng<sup>88</sup>, Y. Cheng<sup>31</sup>,  
 A. Cheplakov<sup>64</sup>, R. Cherkaoui El Moursli<sup>136e</sup>, V. Chernyatin<sup>25,\*</sup>, E. Cheu<sup>7</sup>, L. Chevalier<sup>137</sup>,  
 V. Chiarella<sup>47</sup>, G. Chiefari<sup>103a,103b</sup>, J.T. Childers<sup>6</sup>, A. Chilingarov<sup>71</sup>, G. Chiodini<sup>72a</sup>,  
 A.S. Chisholm<sup>18</sup>, R.T. Chislett<sup>77</sup>, A. Chitan<sup>26a</sup>, M.V. Chizhov<sup>64</sup>, S. Chouridou<sup>9</sup>, B.K.B. Chow<sup>99</sup>,  
 I.A. Christidi<sup>77</sup>, D. Chromek-Burckhart<sup>30</sup>, M.L. Chu<sup>152</sup>, J. Chudoba<sup>126</sup>, L. Chytka<sup>114</sup>,  
 G. Ciapetti<sup>133a,133b</sup>, A.K. Ciftci<sup>4a</sup>, R. Ciftci<sup>4a</sup>, D. Cinca<sup>62</sup>, V. Cindro<sup>74</sup>, A. Ciocio<sup>15</sup>,  
 P. Cirkovic<sup>13b</sup>, Z.H. Citron<sup>173</sup>, M. Citterio<sup>90a</sup>, M. Ciubancan<sup>26a</sup>, A. Clark<sup>49</sup>, P.J. Clark<sup>46</sup>,  
 R.N. Clarke<sup>15</sup>, W. Cleland<sup>124</sup>, J.C. Clemens<sup>84</sup>, B. Clement<sup>55</sup>, C. Clement<sup>147a,147b</sup>, Y. Coadou<sup>84</sup>,  
 M. Cobal<sup>165a,165c</sup>, A. Coccaro<sup>139</sup>, J. Cochran<sup>63</sup>, L. Coffey<sup>23</sup>, J.G. Cogan<sup>144</sup>, J. Coggeshall<sup>166</sup>,  
 B. Cole<sup>35</sup>, S. Cole<sup>107</sup>, A.P. Colijn<sup>106</sup>, C. Collins-Tooth<sup>53</sup>, J. Collot<sup>55</sup>, T. Colombo<sup>58c</sup>, G. Colon<sup>85</sup>,  
 G. Compostella<sup>100</sup>, P. Conde Muño<sup>125a,125b</sup>, E. Coniavitis<sup>167</sup>, M.C. Conidi<sup>12</sup>, S.H. Connell<sup>146b</sup>,  
 I.A. Connelly<sup>76</sup>, S.M. Consonni<sup>90a,90b</sup>, V. Consorti<sup>48</sup>, S. Constantinescu<sup>26a</sup>, C. Conta<sup>120a,120b</sup>,  
 G. Conti<sup>57</sup>, F. Conventi<sup>103a,h</sup>, M. Cooke<sup>15</sup>, B.D. Cooper<sup>77</sup>, A.M. Cooper-Sarkar<sup>119</sup>,  
 N.J. Cooper-Smith<sup>76</sup>, K. Copic<sup>15</sup>, T. Cornelissen<sup>176</sup>, M. Corradi<sup>20a</sup>, F. Corriveau<sup>86,i</sup>,  
 A. Corso-Radu<sup>164</sup>, A. Cortes-Gonzalez<sup>12</sup>, G. Cortiana<sup>100</sup>, G. Costa<sup>90a</sup>, M.J. Costa<sup>168</sup>,  
 D. Costanzo<sup>140</sup>, D. Côté<sup>8</sup>, G. Cottin<sup>28</sup>, G. Cowan<sup>76</sup>, B.E. Cox<sup>83</sup>, K. Cranmer<sup>109</sup>, G. Cree<sup>29</sup>,  
 S. Crépe-Renaudin<sup>55</sup>, F. Crescioli<sup>79</sup>, M. Crispin Ortuzar<sup>119</sup>, M. Cristinziani<sup>21</sup>, G. Crosetti<sup>37a,37b</sup>,  
 C.-M. Cuciuc<sup>26a</sup>, C. Cuenca Almenar<sup>177</sup>, T. Cuhadar Donszelmann<sup>140</sup>, J. Cummings<sup>177</sup>,  
 M. Curatolo<sup>47</sup>, C. Cuthbert<sup>151</sup>, H. Cziri<sup>142</sup>, P. Czodrowski<sup>3</sup>, Z. Czyżczula<sup>177</sup>, S. D'Auria<sup>53</sup>,  
 M. D'Onofrio<sup>73</sup>, M.J. Da Cunha Sargedas De Sousa<sup>125a,125b</sup>, C. Da Via<sup>83</sup>, W. Dabrowski<sup>38a</sup>,  
 A. Dafinca<sup>119</sup>, T. Dai<sup>88</sup>, O. Dale<sup>14</sup>, F. Dallaire<sup>94</sup>, C. Dallapiccola<sup>85</sup>, M. Dam<sup>36</sup>, A.C. Daniells<sup>18</sup>,  
 M. Dano Hoffmann<sup>137</sup>, V. Dao<sup>105</sup>, G. Darbo<sup>50a</sup>, G.L. Darlea<sup>26c</sup>, S. Darmora<sup>8</sup>, J.A. Dassoulas<sup>42</sup>,  
 W. Davey<sup>21</sup>, C. David<sup>170</sup>, T. Davidek<sup>128</sup>, E. Davies<sup>119,c</sup>, M. Davies<sup>94</sup>, O. Davignon<sup>79</sup>,



A.R. Davison<sup>77</sup>, P. Davison<sup>77</sup>, Y. Davygora<sup>58a</sup>, E. Dawe<sup>143</sup>, I. Dawson<sup>140</sup>,  
 R.K. Daya-Ishmukhametova<sup>23</sup>, K. De<sup>8</sup>, R. de Asmundis<sup>103a</sup>, S. De Castro<sup>20a,20b</sup>, S. De Cecco<sup>79</sup>,  
 J. de Graat<sup>99</sup>, N. De Groot<sup>105</sup>, P. de Jong<sup>106</sup>, C. De La Taille<sup>116</sup>, H. De la Torre<sup>81</sup>,  
 F. De Lorenzi<sup>63</sup>, L. De Nooij<sup>106</sup>, D. De Pedis<sup>133a</sup>, A. De Salvo<sup>133a</sup>, U. De Sanctis<sup>165a,165c</sup>,  
 A. De Santo<sup>150</sup>, J.B. De Vivie De Regie<sup>116</sup>, G. De Zorzi<sup>133a,133b</sup>, W.J. Dearnaley<sup>71</sup>, R. Debbes<sup>25</sup>,  
 C. Debenedetti<sup>46</sup>, B. Dechenaux<sup>55</sup>, D.V. Dedovich<sup>64</sup>, J. Degenhardt<sup>121</sup>, I. Deigaard<sup>106</sup>,  
 J. Del Peso<sup>81</sup>, T. Del Prete<sup>123a,123b</sup>, F. Deliot<sup>137</sup>, C.M. Delitzsch<sup>49</sup>, M. Deliyergiyev<sup>74</sup>,  
 A. Dell'Acqua<sup>30</sup>, L. Dell'Asta<sup>22</sup>, M. Dell'Orso<sup>123a,123b</sup>, M. Della Pietra<sup>103a,h</sup>, D. della Volpe<sup>49</sup>,  
 M. Delmastro<sup>5</sup>, P.A. Delsart<sup>55</sup>, C. Deluca<sup>106</sup>, S. Demers<sup>177</sup>, M. Demichev<sup>64</sup>, A. Demilly<sup>79</sup>,  
 S.P. Denisov<sup>129</sup>, D. Derendarz<sup>39</sup>, J.E. Derkaoui<sup>136d</sup>, F. Derue<sup>79</sup>, P. Dervan<sup>73</sup>, K. Desch<sup>21</sup>,  
 C. Deterre<sup>42</sup>, P.O. Deviveiros<sup>106</sup>, A. Dewhurst<sup>130</sup>, S. Dhaliwal<sup>106</sup>, A. Di Ciaccio<sup>134a,134b</sup>,  
 L. Di Ciaccio<sup>5</sup>, A. Di Domenico<sup>133a,133b</sup>, C. Di Donato<sup>103a,103b</sup>, A. Di Girolamo<sup>30</sup>,  
 B. Di Girolamo<sup>30</sup>, A. Di Mattia<sup>153</sup>, B. Di Micco<sup>135a,135b</sup>, R. Di Nardo<sup>47</sup>, A. Di Simone<sup>48</sup>,  
 R. Di Sipio<sup>20a,20b</sup>, D. Di Valentino<sup>29</sup>, M.A. Diaz<sup>32a</sup>, E.B. Diehl<sup>88</sup>, J. Dietrich<sup>42</sup>, T.A. Dietzsch<sup>58a</sup>,  
 S. Diglio<sup>87</sup>, A. Dimitrievska<sup>13a</sup>, J. Dingfelder<sup>21</sup>, C. Dionisi<sup>133a,133b</sup>, P. Dita<sup>26a</sup>, S. Dita<sup>26a</sup>,  
 F. Dittus<sup>30</sup>, F. Djama<sup>84</sup>, T. Djobava<sup>51b</sup>, M.A.B. do Vale<sup>24c</sup>, A. Do Valle Wemans<sup>125a,125g</sup>,  
 T.K.O. Doan<sup>5</sup>, D. Dobos<sup>30</sup>, E. Dobson<sup>77</sup>, C. Doglioni<sup>49</sup>, T. Doherty<sup>53</sup>, T. Dohmae<sup>156</sup>,  
 J. Dolejsi<sup>128</sup>, Z. Dolezal<sup>128</sup>, B.A. Dolgoshein<sup>97,\*</sup>, M. Donadelli<sup>24d</sup>, S. Donati<sup>123a,123b</sup>,  
 P. Dondero<sup>120a,120b</sup>, J. Donini<sup>34</sup>, J. Dopke<sup>30</sup>, A. Doria<sup>103a</sup>, A. Dos Anjos<sup>174</sup>, M.T. Dova<sup>70</sup>,  
 A.T. Doyle<sup>53</sup>, M. Dris<sup>10</sup>, J. Dubbert<sup>88</sup>, S. Dube<sup>15</sup>, E. Dubreuil<sup>34</sup>, E. Duchovni<sup>173</sup>, G. Duckeck<sup>99</sup>,  
 O.A. Ducu<sup>26a</sup>, D. Duda<sup>176</sup>, A. Dudarev<sup>30</sup>, F. Dudziak<sup>63</sup>, L. Duflot<sup>116</sup>, L. Duguid<sup>76</sup>,  
 M. Dührssen<sup>30</sup>, M. Dunford<sup>58a</sup>, H. Duran Yildiz<sup>4a</sup>, M. Düren<sup>52</sup>, A. Durglishvili<sup>51b</sup>,  
 M. Dwuznik<sup>38a</sup>, M. Dyndal<sup>38a</sup>, J. Ebke<sup>99</sup>, W. Edson<sup>2</sup>, N.C. Edwards<sup>46</sup>, W. Ehrenfeld<sup>21</sup>,  
 T. Eifert<sup>144</sup>, G. Eigen<sup>14</sup>, K. Einsweiler<sup>15</sup>, T. Ekelof<sup>167</sup>, M. El Kacimi<sup>136c</sup>, M. Ellert<sup>167</sup>, S. Elles<sup>5</sup>,  
 F. Ellinghaus<sup>82</sup>, N. Ellis<sup>30</sup>, J. Elmsheuser<sup>99</sup>, M. Elsing<sup>30</sup>, D. Emelianov<sup>130</sup>, Y. Enari<sup>156</sup>,  
 O.C. Endner<sup>82</sup>, M. Endo<sup>117</sup>, R. Engelmann<sup>149</sup>, J. Erdmann<sup>177</sup>, A. Ereditato<sup>17</sup>, D. Eriksson<sup>147a</sup>,  
 G. Ernis<sup>176</sup>, J. Ernst<sup>2</sup>, M. Ernst<sup>25</sup>, J. Ernwein<sup>137</sup>, D. Errede<sup>166</sup>, S. Errede<sup>166</sup>, E. Ertel<sup>82</sup>,  
 M. Escalier<sup>116</sup>, H. Esch<sup>43</sup>, C. Escobar<sup>124</sup>, B. Esposito<sup>47</sup>, A.I. Etienne<sup>137</sup>, E. Etzion<sup>154</sup>, H. Evans<sup>60</sup>,  
 L. Fabbri<sup>20a,20b</sup>, G. Facini<sup>30</sup>, R.M. Fakhruddinov<sup>129</sup>, S. Falciano<sup>133a</sup>, Y. Fang<sup>33a</sup>, M. Fanti<sup>90a,90b</sup>,  
 A. Farbin<sup>8</sup>, A. Farilla<sup>135a</sup>, T. Farooque<sup>12</sup>, S. Farrell<sup>164</sup>, S.M. Farrington<sup>171</sup>, P. Farthouat<sup>30</sup>,  
 F. Fassi<sup>168</sup>, P. Fassnacht<sup>30</sup>, D. Fassouliotis<sup>9</sup>, A. Favareto<sup>50a,50b</sup>, L. Fayard<sup>116</sup>, P. Federic<sup>145a</sup>,  
 O.L. Fedin<sup>122</sup>, W. Fedorko<sup>169</sup>, M. Fehling-Kaschek<sup>48</sup>, S. Feigl<sup>30</sup>, L. Felgioni<sup>84</sup>, C. Feng<sup>33d</sup>,  
 E.J. Feng<sup>6</sup>, H. Feng<sup>88</sup>, A.B. Fenyuk<sup>129</sup>, S. Fernandez Perez<sup>30</sup>, S. Ferrag<sup>53</sup>, J. Ferrando<sup>53</sup>,  
 V. Ferrara<sup>42</sup>, A. Ferrari<sup>167</sup>, P. Ferrari<sup>106</sup>, R. Ferrari<sup>120a</sup>, D.E. Ferreira de Lima<sup>53</sup>, A. Ferrer<sup>168</sup>,  
 D. Ferrere<sup>49</sup>, C. Ferretti<sup>88</sup>, A. Ferretto Parodi<sup>50a,50b</sup>, M. Fiascaris<sup>31</sup>, F. Fiedler<sup>82</sup>, A. Filipčić<sup>74</sup>,  
 M. Filipuzzi<sup>42</sup>, F. Filthaut<sup>105</sup>, M. Fincke-Keeler<sup>170</sup>, K.D. Finelli<sup>151</sup>, M.C.N. Fiolhais<sup>125a,125c</sup>,  
 L. Fiorini<sup>168</sup>, A. Firan<sup>40</sup>, J. Fischer<sup>176</sup>, M.J. Fisher<sup>110</sup>, W.C. Fisher<sup>89</sup>, E.A. Fitzgerald<sup>23</sup>,  
 M. Flechl<sup>48</sup>, I. Fleck<sup>142</sup>, P. Fleischmann<sup>175</sup>, S. Fleischmann<sup>176</sup>, G.T. Fletcher<sup>140</sup>, G. Fletcher<sup>75</sup>,  
 T. Flick<sup>176</sup>, A. Floderus<sup>80</sup>, L.R. Flores Castillo<sup>174</sup>, A.C. Florez Bustos<sup>160b</sup>, M.J. Flowerdew<sup>100</sup>,  
 A. Formica<sup>137</sup>, A. Forti<sup>83</sup>, D. Fortin<sup>160a</sup>, D. Fournier<sup>116</sup>, H. Fox<sup>71</sup>, S. Fracchia<sup>12</sup>, P. Francavilla<sup>79</sup>,  
 M. Franchini<sup>20a,20b</sup>, S. Franchino<sup>30</sup>, D. Francis<sup>30</sup>, M. Franklin<sup>57</sup>, S. Franz<sup>61</sup>,  
 M. Fraternali<sup>120a,120b</sup>, S.T. French<sup>28</sup>, C. Friedrich<sup>42</sup>, F. Friedrich<sup>44</sup>, D. Froidevaux<sup>30</sup>, J.A. Frost<sup>28</sup>,  
 C. Fukunaga<sup>157</sup>, E. Fullana Torregrosa<sup>82</sup>, B.G. Fulson<sup>144</sup>, J. Fuster<sup>168</sup>, C. Gabaldon<sup>55</sup>,  
 O. Gabizon<sup>173</sup>, A. Gabrielli<sup>20a,20b</sup>, A. Gabrielli<sup>133a,133b</sup>, S. Gadatsch<sup>106</sup>, S. Gadomski<sup>49</sup>,  
 G. Gagliardi<sup>50a,50b</sup>, P. Gagnon<sup>60</sup>, C. Galea<sup>105</sup>, B. Galhardo<sup>125a,125c</sup>, E.J. Gallas<sup>119</sup>, V. Gallo<sup>17</sup>,  
 B.J. Gallop<sup>130</sup>, P. Gallus<sup>127</sup>, G. Galster<sup>36</sup>, K.K. Gan<sup>110</sup>, R.P. Gandrajula<sup>62</sup>, J. Gao<sup>33b,g</sup>,  
 Y.S. Gao<sup>144,e</sup>, F.M. Garay Walls<sup>46</sup>, F. Garbersson<sup>177</sup>, C. García<sup>168</sup>, J.E. García Navarro<sup>168</sup>,  
 M. Garcia-Sciveres<sup>15</sup>, R.W. Gardner<sup>31</sup>, N. Garelli<sup>144</sup>, V. Garonne<sup>30</sup>, C. Gatti<sup>47</sup>, G. Gaudio<sup>120a</sup>,  
 B. Gaur<sup>142</sup>, L. Gauthier<sup>94</sup>, P. Gauzzi<sup>133a,133b</sup>, I.L. Gavrilenko<sup>95</sup>, C. Gay<sup>169</sup>, G. Gaycken<sup>21</sup>,  
 E.N. Gazis<sup>10</sup>, P. Ge<sup>33d</sup>, Z. Gece<sup>169</sup>, C.N.P. Gee<sup>130</sup>, D.A.A. Geerts<sup>106</sup>, Ch. Geich-Gimbel<sup>21</sup>,  
 K. Gellerstedt<sup>147a,147b</sup>, C. Gemme<sup>50a</sup>, A. Gemmell<sup>53</sup>, M.H. Genest<sup>55</sup>, S. Gentile<sup>133a,133b</sup>,  
 M. George<sup>54</sup>, S. George<sup>76</sup>, D. Gerbaudo<sup>164</sup>, A. Gershon<sup>154</sup>, H. Ghazlane<sup>136b</sup>, N. Ghodbane<sup>34</sup>,

B. Giacobbe<sup>20a</sup>, S. Giagu<sup>133a,133b</sup>, V. Giangiobbe<sup>12</sup>, P. Giannetti<sup>123a,123b</sup>, F. Gianotti<sup>30</sup>,  
 B. Gibbard<sup>25</sup>, S.M. Gibson<sup>76</sup>, M. Gilchriese<sup>15</sup>, T.P.S. Gillam<sup>28</sup>, D. Gillberg<sup>30</sup>, G. Gilles<sup>34</sup>,  
 D.M. Gingrich<sup>3,d</sup>, N. Giokaris<sup>9</sup>, M.P. Giordani<sup>165a,165c</sup>, R. Giordano<sup>103a,103b</sup>, F.M. Giorgi<sup>16</sup>,  
 P.F. Giraud<sup>137</sup>, D. Giugni<sup>90a</sup>, C. Giuliani<sup>48</sup>, M. Giulini<sup>58b</sup>, B.K. Gjelsten<sup>118</sup>, I. Gkialas<sup>155,j</sup>,  
 L.K. Gladilin<sup>98</sup>, C. Glasman<sup>81</sup>, J. Glatzer<sup>30</sup>, P.C.F. Glaysher<sup>46</sup>, A. Glazov<sup>42</sup>, G.L. Glonti<sup>64</sup>,  
 M. Goblirsch-Kolb<sup>100</sup>, J.R. Goddard<sup>75</sup>, J. Godfrey<sup>143</sup>, J. Godlewski<sup>30</sup>, C. Goeringer<sup>82</sup>,  
 S. Goldfarb<sup>88</sup>, T. Golling<sup>177</sup>, D. Golubkov<sup>129</sup>, A. Gomes<sup>125a,125b,125d</sup>, L.S. Gomez Fajardo<sup>42</sup>,  
 R. Gonçalo<sup>125a</sup>, J. Goncalves Pinto Firmino Da Costa<sup>42</sup>, L. Gonella<sup>21</sup>, S. González de la Hoz<sup>168</sup>,  
 G. Gonzalez Parra<sup>12</sup>, M.L. Gonzalez Silva<sup>27</sup>, S. Gonzalez-Sevilla<sup>49</sup>, L. Goossens<sup>30</sup>,  
 P.A. Gorbounov<sup>96</sup>, H.A. Gordon<sup>25</sup>, I. Gorelov<sup>104</sup>, G. Gorfine<sup>176</sup>, B. Gorini<sup>30</sup>, E. Gorini<sup>72a,72b</sup>,  
 A. Gorišek<sup>74</sup>, E. Gornicki<sup>39</sup>, A.T. Goshaw<sup>6</sup>, C. Gössling<sup>43</sup>, M.I. Gostkin<sup>64</sup>, M. Gouighri<sup>136a</sup>,  
 D. Goujdami<sup>136c</sup>, M.P. Goulette<sup>49</sup>, A.G. Goussiou<sup>139</sup>, C. Goy<sup>5</sup>, S. Gozpinar<sup>23</sup>, H.M.X. Grabas<sup>137</sup>,  
 L. Graber<sup>54</sup>, I. Grabowska-Bold<sup>38a</sup>, P. Grafström<sup>20a,20b</sup>, K.-J. Grahm<sup>42</sup>, J. Gramling<sup>49</sup>,  
 E. Gramstad<sup>118</sup>, F. Grancagnolo<sup>72a</sup>, S. Grancagnolo<sup>16</sup>, V. Grassi<sup>149</sup>, V. Gratchev<sup>122</sup>,  
 H.M. Gray<sup>30</sup>, E. Graziani<sup>135a</sup>, O.G. Grebenyuk<sup>122</sup>, Z.D. Greenwood<sup>78,k</sup>, K. Gregersen<sup>36</sup>,  
 I.M. Gregor<sup>42</sup>, P. Grenier<sup>144</sup>, J. Griffiths<sup>8</sup>, N. Grigalashvili<sup>64</sup>, A.A. Grillo<sup>138</sup>, K. Grimm<sup>71</sup>,  
 S. Grinstein<sup>12,l</sup>, Ph. Gris<sup>34</sup>, Y.V. Grishkevich<sup>98</sup>, J.-F. Grivaz<sup>116</sup>, J.P. Grohs<sup>44</sup>, A. Grohsjean<sup>42</sup>,  
 E. Gross<sup>173</sup>, J. Grosse-Knetter<sup>54</sup>, G.C. Grossi<sup>134a,134b</sup>, J. Groth-Jensen<sup>173</sup>, Z.J. Grout<sup>150</sup>,  
 K. Grybel<sup>142</sup>, L. Guan<sup>33b</sup>, F. Guescini<sup>49</sup>, D. Guest<sup>177</sup>, O. Gueta<sup>154</sup>, C. Guicheney<sup>34</sup>,  
 E. Guido<sup>50a,50b</sup>, T. Guillemin<sup>116</sup>, S. Guindon<sup>2</sup>, U. Gul<sup>53</sup>, C. Gumpert<sup>44</sup>, J. Gunther<sup>127</sup>, J. Guo<sup>35</sup>,  
 S. Gupta<sup>119</sup>, P. Gutierrez<sup>112</sup>, N.G. Gutierrez Ortiz<sup>53</sup>, C. Gutsche<sup>77</sup>, N. Guttman<sup>154</sup>,  
 C. Guyot<sup>137</sup>, C. Gwenlan<sup>119</sup>, C.B. Gwilliam<sup>73</sup>, A. Haas<sup>109</sup>, C. Haber<sup>15</sup>, H.K. Hadavand<sup>8</sup>,  
 N. Haddad<sup>136e</sup>, P. Haefner<sup>21</sup>, S. Hageboeck<sup>21</sup>, Z. Hajduk<sup>39</sup>, H. Hakobyan<sup>178</sup>, M. Haleem<sup>42</sup>,  
 D. Hall<sup>119</sup>, G. Halladjian<sup>89</sup>, K. Hamacher<sup>176</sup>, P. Hamal<sup>114</sup>, K. Hamano<sup>87</sup>, M. Hamer<sup>54</sup>,  
 A. Hamilton<sup>146a</sup>, S. Hamilton<sup>162</sup>, P.G. Hamnett<sup>42</sup>, L. Han<sup>33b</sup>, K. Hanagaki<sup>117</sup>, K. Hanawa<sup>156</sup>,  
 M. Hance<sup>15</sup>, P. Hanke<sup>58a</sup>, J.R. Hansen<sup>36</sup>, J.B. Hansen<sup>36</sup>, J.D. Hansen<sup>36</sup>, P.H. Hansen<sup>36</sup>,  
 K. Hara<sup>161</sup>, A.S. Hard<sup>174</sup>, T. Harenberg<sup>176</sup>, S. Harkusha<sup>91</sup>, D. Harper<sup>88</sup>, R.D. Harrington<sup>46</sup>,  
 O.M. Harris<sup>139</sup>, P.F. Harrison<sup>171</sup>, F. Hartjes<sup>106</sup>, S. Hasegawa<sup>102</sup>, Y. Hasegawa<sup>141</sup>, A. Hasib<sup>112</sup>,  
 S. Hassani<sup>137</sup>, S. Haug<sup>17</sup>, M. Hauschild<sup>30</sup>, R. Hauser<sup>89</sup>, M. Havranek<sup>126</sup>, C.M. Hawkes<sup>18</sup>,  
 R.J. Hawking<sup>30</sup>, A.D. Hawkins<sup>80</sup>, T. Hayashi<sup>161</sup>, D. Hayden<sup>89</sup>, C.P. Hays<sup>119</sup>, H.S. Hayward<sup>73</sup>,  
 S.J. Haywood<sup>130</sup>, S.J. Head<sup>18</sup>, T. Heck<sup>82</sup>, V. Hedberg<sup>80</sup>, L. Heelan<sup>8</sup>, S. Heim<sup>121</sup>, T. Heim<sup>176</sup>,  
 B. Heinemann<sup>15</sup>, L. Heinrich<sup>109</sup>, S. Heisterkamp<sup>36</sup>, J. Hejbal<sup>126</sup>, L. Helary<sup>22</sup>, C. Heller<sup>99</sup>,  
 M. Heller<sup>30</sup>, S. Hellman<sup>147a,147b</sup>, D. Hellmich<sup>21</sup>, C. Helsens<sup>30</sup>, J. Henderson<sup>119</sup>,  
 R.C.W. Henderson<sup>71</sup>, C. Hengler<sup>42</sup>, A. Henrichs<sup>177</sup>, A.M. Henriques Correia<sup>30</sup>,  
 S. Henrot-Versille<sup>116</sup>, C. Hensel<sup>54</sup>, G.H. Herbert<sup>16</sup>, Y. Hernández Jiménez<sup>168</sup>,  
 R. Herrberg-Schubert<sup>16</sup>, G. Herten<sup>48</sup>, R. Hertenberger<sup>99</sup>, L. Hervas<sup>30</sup>, G.G. Hesketh<sup>77</sup>,  
 N.P. Hessey<sup>106</sup>, R. Hickling<sup>75</sup>, E. Higón-Rodríguez<sup>168</sup>, J.C. Hill<sup>28</sup>, K.H. Hiller<sup>42</sup>, S. Hillert<sup>21</sup>,  
 S.J. Hillier<sup>18</sup>, I. Hinchliffe<sup>15</sup>, E. Hines<sup>121</sup>, M. Hirose<sup>117</sup>, D. Hirschbuehl<sup>176</sup>, J. Hobbs<sup>149</sup>, N. Hod<sup>106</sup>,  
 M.C. Hodgkinson<sup>140</sup>, P. Hodgson<sup>140</sup>, A. Hoecker<sup>30</sup>, M.R. Hoferkamp<sup>104</sup>, J. Hoffman<sup>40</sup>,  
 D. Hoffmann<sup>84</sup>, J.I. Hofmann<sup>58a</sup>, M. Hohlfeld<sup>82</sup>, T.R. Holmes<sup>15</sup>, T.M. Hong<sup>121</sup>,  
 L. Hooft van Huysduynen<sup>109</sup>, J.-Y. Hostachy<sup>55</sup>, S. Hou<sup>152</sup>, A. Hoummada<sup>136a</sup>, J. Howard<sup>119</sup>,  
 J. Howarth<sup>42</sup>, M. Hrabovsky<sup>114</sup>, I. Hristova<sup>16</sup>, J. Hrivnac<sup>116</sup>, T. Hryn'ova<sup>5</sup>, P.J. Hsu<sup>82</sup>,  
 S.-C. Hsu<sup>139</sup>, D. Hu<sup>35</sup>, X. Hu<sup>25</sup>, Y. Huang<sup>146c</sup>, Z. Hubacek<sup>30</sup>, F. Hubaut<sup>84</sup>, F. Huegging<sup>21</sup>,  
 T.B. Huffman<sup>119</sup>, E.W. Hughes<sup>35</sup>, G. Hughes<sup>71</sup>, M. Huhtinen<sup>30</sup>, T.A. Hülsing<sup>82</sup>, M. Hurwitz<sup>15</sup>,  
 N. Huseynov<sup>64,b</sup>, J. Huston<sup>89</sup>, J. Huth<sup>57</sup>, G. Iacobucci<sup>49</sup>, G. Iakovidis<sup>10</sup>, I. Ibragimov<sup>142</sup>,  
 L. Iconomidou-Fayard<sup>116</sup>, J. Idarraga<sup>116</sup>, E. Ideal<sup>177</sup>, P. Iengo<sup>103a</sup>, O. Igonkina<sup>106</sup>, T. Iizawa<sup>172</sup>,  
 Y. Ikegami<sup>65</sup>, K. Ikematsu<sup>142</sup>, M. Ikeno<sup>65</sup>, D. Iliadis<sup>155</sup>, N. Ilic<sup>159</sup>, Y. Inamaru<sup>66</sup>, T. Ince<sup>100</sup>,  
 P. Ioannou<sup>9</sup>, M. Iodice<sup>135a</sup>, K. Iordanidou<sup>9</sup>, V. Ippolito<sup>57</sup>, A. Irles Quiles<sup>168</sup>, C. Isaksson<sup>167</sup>,  
 M. Ishino<sup>67</sup>, M. Ishitsuka<sup>158</sup>, R. Ishmukhametov<sup>110</sup>, C. Issever<sup>119</sup>, S. Istin<sup>19a</sup>,  
 J.M. Iturbe Ponce<sup>83</sup>, A.V. Ivashin<sup>129</sup>, W. Iwanski<sup>39</sup>, H. Iwasaki<sup>65</sup>, J.M. Izen<sup>41</sup>, V. Izzo<sup>103a</sup>,  
 B. Jackson<sup>121</sup>, J.N. Jackson<sup>73</sup>, M. Jackson<sup>73</sup>, P. Jackson<sup>1</sup>, M.R. Jaekel<sup>30</sup>, V. Jain<sup>2</sup>, K. Jakobs<sup>48</sup>,  
 S. Jakobsen<sup>36</sup>, T. Jakoubek<sup>126</sup>, J. Jakubek<sup>127</sup>, D.O. Jamin<sup>152</sup>, D.K. Jana<sup>78</sup>, E. Jansen<sup>77</sup>,

H. Jansen<sup>30</sup>, J. Janssen<sup>21</sup>, M. Janus<sup>171</sup>, G. Jarlskog<sup>80</sup>, T. Javurek<sup>48</sup>, L. Jeanty<sup>15</sup>, G.-Y. Jeng<sup>151</sup>, D. Jennens<sup>87</sup>, P. Jenni<sup>48,m</sup>, J. Jentzsch<sup>43</sup>, C. Jeske<sup>171</sup>, S. Jézéquel<sup>5</sup>, H. Ji<sup>174</sup>, W. Ji<sup>82</sup>, J. Jia<sup>149</sup>, Y. Jiang<sup>33b</sup>, M. Jimenez Belenguer<sup>42</sup>, S. Jin<sup>33a</sup>, A. Jinaru<sup>26a</sup>, O. Jinnouchi<sup>158</sup>, M.D. Joergensen<sup>36</sup>, K.E. Johansson<sup>147a</sup>, P. Johansson<sup>140</sup>, K.A. Johns<sup>7</sup>, K. Jon-And<sup>147a,147b</sup>, G. Jones<sup>171</sup>, R.W.L. Jones<sup>71</sup>, T.J. Jones<sup>73</sup>, J. Jongmanns<sup>58a</sup>, P.M. Jorge<sup>125a,125b</sup>, K.D. Joshi<sup>83</sup>, J. Jovicevic<sup>148</sup>, X. Ju<sup>174</sup>, C.A. Jung<sup>43</sup>, R.M. Jungst<sup>30</sup>, P. Jussel<sup>61</sup>, A. Juste Rozas<sup>12,l</sup>, M. Kaci<sup>168</sup>, A. Kaczmarek<sup>39</sup>, M. Kado<sup>116</sup>, H. Kagan<sup>110</sup>, M. Kagan<sup>144</sup>, E. Kajomovitz<sup>45</sup>, S. Kama<sup>40</sup>, N. Kanaya<sup>156</sup>, M. Kaneda<sup>30</sup>, S. Kaneti<sup>28</sup>, T. Kanno<sup>158</sup>, V.A. Kantserov<sup>97</sup>, J. Kanzaki<sup>65</sup>, B. Kaplan<sup>109</sup>, A. Kapliy<sup>31</sup>, D. Kar<sup>53</sup>, K. Karakostas<sup>10</sup>, N. Karastathis<sup>10</sup>, M. Karnevskiy<sup>82</sup>, S.N. Karpov<sup>64</sup>, K. Karthik<sup>109</sup>, V. Kartvelishvili<sup>71</sup>, A.N. Karyukhin<sup>129</sup>, L. Kashif<sup>174</sup>, G. Kasieczka<sup>58b</sup>, R.D. Kass<sup>110</sup>, A. Kastanas<sup>14</sup>, Y. Kataoka<sup>156</sup>, A. Katre<sup>49</sup>, J. Katzy<sup>42</sup>, V. Kaushik<sup>7</sup>, K. Kawagoe<sup>69</sup>, T. Kawamoto<sup>156</sup>, G. Kawamura<sup>54</sup>, S. Kazama<sup>156</sup>, V.F. Kazanin<sup>108</sup>, M.Y. Kazarinov<sup>64</sup>, R. Keeler<sup>170</sup>, P.T. Keener<sup>121</sup>, R. Kehoe<sup>40</sup>, M. Keil<sup>54</sup>, J.S. Keller<sup>42</sup>, H. Keoshkerian<sup>5</sup>, O. Kepka<sup>126</sup>, B.P. Kerševan<sup>74</sup>, S. Kersten<sup>176</sup>, K. Kessoku<sup>156</sup>, J. Keung<sup>159</sup>, F. Khalil-zada<sup>11</sup>, H. Khandanyan<sup>147a,147b</sup>, A. Khanov<sup>113</sup>, A. Khodinov<sup>97</sup>, A. Khomich<sup>58a</sup>, T.J. Khoo<sup>28</sup>, G. Khoraiuli<sup>21</sup>, A. Khoroshilov<sup>176</sup>, V. Khovanskiy<sup>96</sup>, E. Khramov<sup>64</sup>, J. Khubua<sup>51b</sup>, H.Y. Kim<sup>8</sup>, H. Kim<sup>147a,147b</sup>, S.H. Kim<sup>161</sup>, N. Kimura<sup>172</sup>, O. Kind<sup>16</sup>, B.T. King<sup>73</sup>, M. King<sup>168</sup>, R.S.B. King<sup>119</sup>, S.B. King<sup>169</sup>, J. Kirk<sup>130</sup>, A.E. Kiryunin<sup>100</sup>, T. Kishimoto<sup>66</sup>, D. Kisielewska<sup>38a</sup>, F. Kiss<sup>48</sup>, T. Kitamura<sup>66</sup>, T. Kittelmann<sup>124</sup>, K. Kiuchi<sup>161</sup>, E. Kladiva<sup>145b</sup>, M. Klein<sup>73</sup>, U. Klein<sup>73</sup>, K. Kleinknecht<sup>82</sup>, P. Klimek<sup>147a,147b</sup>, A. Klimentov<sup>25</sup>, R. Klingenberg<sup>43</sup>, J.A. Klinger<sup>83</sup>, E.B. Klinkby<sup>36</sup>, T. Klioutchnikova<sup>30</sup>, P.F. Klok<sup>105</sup>, E.-E. Kluge<sup>58a</sup>, P. Kluit<sup>106</sup>, S. Kluth<sup>100</sup>, E. Kneringer<sup>61</sup>, E.B.F.G. Knoops<sup>84</sup>, A. Knue<sup>53</sup>, T. Kobayashi<sup>156</sup>, M. Kobel<sup>44</sup>, M. Kocian<sup>144</sup>, P. Kodys<sup>128</sup>, P. Koevesarki<sup>21</sup>, T. Koffas<sup>29</sup>, E. Koffeman<sup>106</sup>, L.A. Kogan<sup>119</sup>, S. Kohlmann<sup>176</sup>, Z. Kohout<sup>127</sup>, T. Kohriki<sup>65</sup>, T. Koi<sup>144</sup>, H. Kolanoski<sup>16</sup>, I. Koletsou<sup>5</sup>, J. Koll<sup>89</sup>, A.A. Komar<sup>95,\*</sup>, Y. Komori<sup>156</sup>, T. Kondo<sup>65</sup>, N. Kondrashova<sup>42</sup>, K. Köneke<sup>48</sup>, A.C. König<sup>105</sup>, S. König<sup>82</sup>, T. Kono<sup>65,n</sup>, R. Konoplich<sup>109,o</sup>, N. Konstantinidis<sup>77</sup>, R. Kopeliansky<sup>153</sup>, S. Koperny<sup>38a</sup>, L. Köpke<sup>82</sup>, A.K. Kopp<sup>48</sup>, K. Korcyl<sup>39</sup>, K. Kordas<sup>155</sup>, A. Korn<sup>77</sup>, A.A. Korol<sup>108</sup>, I. Korolkov<sup>12</sup>, E.V. Korolkova<sup>140</sup>, V.A. Korotkov<sup>129</sup>, O. Kortner<sup>100</sup>, S. Kortner<sup>100</sup>, V.V. Kostyukhin<sup>21</sup>, S. Kotov<sup>100</sup>, V.M. Kotov<sup>64</sup>, A. Kotwal<sup>45</sup>, C. Kourkoumelis<sup>9</sup>, V. Kouskoura<sup>155</sup>, A. Koutsman<sup>160a</sup>, R. Kowalewski<sup>170</sup>, T.Z. Kowalski<sup>38a</sup>, W. Kozanecki<sup>137</sup>, A.S. Kozhin<sup>129</sup>, V. Kral<sup>127</sup>, V.A. Kramarenko<sup>98</sup>, G. Kramberger<sup>74</sup>, D. Krasnopevtsev<sup>97</sup>, M.W. Krasny<sup>79</sup>, A. Krasznahorkay<sup>30</sup>, J.K. Kraus<sup>21</sup>, A. Kravchenko<sup>25</sup>, S. Kreiss<sup>109</sup>, M. Kretz<sup>58c</sup>, J. Kretzschmar<sup>73</sup>, K. Kreutzfeldt<sup>52</sup>, P. Krieger<sup>159</sup>, K. Kroeninger<sup>54</sup>, H. Kroha<sup>100</sup>, J. Kroll<sup>121</sup>, J. Kroseberg<sup>21</sup>, J. Krstic<sup>13a</sup>, U. Kruchonak<sup>64</sup>, H. Krüger<sup>21</sup>, T. Kruker<sup>17</sup>, N. Krumnack<sup>63</sup>, Z.V. Krumshteyn<sup>64</sup>, A. Kruse<sup>174</sup>, M.C. Kruse<sup>45</sup>, M. Kruskal<sup>22</sup>, T. Kubota<sup>87</sup>, S. Kудay<sup>4a</sup>, S. Kuehn<sup>48</sup>, A. Kugel<sup>58c</sup>, A. Kuhl<sup>138</sup>, T. Kuhl<sup>42</sup>, V. Kukhtin<sup>64</sup>, Y. Kulchitsky<sup>91</sup>, S. Kuleshov<sup>32b</sup>, M. Kuna<sup>133a,133b</sup>, J. Kunkle<sup>121</sup>, A. Kupco<sup>126</sup>, H. Kurashige<sup>66</sup>, Y.A. Kurochkin<sup>91</sup>, R. Kurumida<sup>66</sup>, V. Kus<sup>126</sup>, E.S. Kuwertz<sup>148</sup>, M. Kuze<sup>158</sup>, J. Kvita<sup>143</sup>, A. La Rosa<sup>49</sup>, L. La Rotonda<sup>37a,37b</sup>, L. Labarga<sup>81</sup>, C. Lacasta<sup>168</sup>, F. Lacava<sup>133a,133b</sup>, J. Lacey<sup>29</sup>, H. Lacker<sup>16</sup>, D. Lacour<sup>79</sup>, V.R. Lacuesta<sup>168</sup>, E. Ladygin<sup>64</sup>, R. Lafaye<sup>5</sup>, B. Laforge<sup>79</sup>, T. Lagouri<sup>177</sup>, S. Lai<sup>48</sup>, H. Laier<sup>58a</sup>, L. Lambourne<sup>77</sup>, S. Lammers<sup>60</sup>, C.L. Lampen<sup>7</sup>, W. Lampl<sup>7</sup>, E. Lançon<sup>137</sup>, U. Landgraf<sup>48</sup>, M.P.J. Landon<sup>75</sup>, V.S. Lang<sup>58a</sup>, C. Lange<sup>42</sup>, A.J. Lankford<sup>164</sup>, F. Lanni<sup>25</sup>, K. Lantzsck<sup>30</sup>, A. Lanza<sup>120a</sup>, S. Laplace<sup>79</sup>, C. Lapoire<sup>21</sup>, J.F. Laporte<sup>137</sup>, T. Lari<sup>90a</sup>, M. Lassnig<sup>30</sup>, P. Laurelli<sup>47</sup>, V. Lavorini<sup>37a,37b</sup>, W. Lavrijsen<sup>15</sup>, A.T. Law<sup>138</sup>, P. Laycock<sup>73</sup>, B.T. Le<sup>55</sup>, O. Le Dortz<sup>79</sup>, E. Le Guirriec<sup>84</sup>, E. Le Menedeu<sup>12</sup>, T. LeCompte<sup>6</sup>, F. Ledroit-Guillon<sup>55</sup>, C.A. Lee<sup>152</sup>, H. Lee<sup>106</sup>, J.S.H. Lee<sup>117</sup>, S.C. Lee<sup>152</sup>, L. Lee<sup>177</sup>, G. Lefebvre<sup>79</sup>, M. Lefebvre<sup>170</sup>, F. Legger<sup>99</sup>, C. Leggett<sup>15</sup>, A. Lehan<sup>73</sup>, M. Lehmann<sup>21</sup>, G. Lehmann Miotto<sup>30</sup>, X. Lei<sup>7</sup>, A.G. Leister<sup>177</sup>, M.A.L. Leite<sup>24d</sup>, R. Leitner<sup>128</sup>, D. Lellouch<sup>173</sup>, B. Lemmer<sup>54</sup>, K.J.C. Leney<sup>77</sup>, T. Lenz<sup>106</sup>, G. Lenzen<sup>176</sup>, B. Lenzi<sup>30</sup>, R. Leone<sup>7</sup>, K. Leonhardt<sup>44</sup>, S. Leontsinis<sup>10</sup>, C. Leroy<sup>94</sup>, C.G. Lester<sup>28</sup>, C.M. Lester<sup>121</sup>, J. Levêque<sup>5</sup>, D. Levin<sup>88</sup>, L.J. Levinson<sup>173</sup>, M. Levy<sup>18</sup>, A. Lewis<sup>119</sup>, G.H. Lewis<sup>109</sup>, A.M. Leyko<sup>21</sup>, M. Leyton<sup>41</sup>, B. Li<sup>33b,p</sup>, B. Li<sup>84</sup>, H. Li<sup>149</sup>, H.L. Li<sup>31</sup>, S. Li<sup>45</sup>, X. Li<sup>88</sup>, Y. Li<sup>116,q</sup>, Z. Liang<sup>119,r</sup>, H. Liao<sup>34</sup>, B. Liberti<sup>134a</sup>, P. Lichard<sup>30</sup>, K. Lie<sup>166</sup>, J. Liebal<sup>21</sup>, W. Liebig<sup>14</sup>, C. Limbach<sup>21</sup>, A. Limosani<sup>87</sup>,

M. Limper<sup>62</sup>, S.C. Lin<sup>152,s</sup>, F. Linde<sup>106</sup>, B.E. Lindquist<sup>149</sup>, J.T. Linnemann<sup>89</sup>, E. Lipeles<sup>121</sup>,  
 A. Lipniacka<sup>14</sup>, M. Lisovyi<sup>42</sup>, T.M. Liss<sup>166</sup>, D. Lissauer<sup>25</sup>, A. Lister<sup>169</sup>, A.M. Litke<sup>138</sup>, B. Liu<sup>152</sup>,  
 D. Liu<sup>152</sup>, J.B. Liu<sup>33b</sup>, K. Liu<sup>33b,t</sup>, L. Liu<sup>88</sup>, M. Liu<sup>45</sup>, M. Liu<sup>33b</sup>, Y. Liu<sup>33b</sup>, M. Livan<sup>120a,120b</sup>,  
 S.S.A. Livermore<sup>119</sup>, A. Lleres<sup>55</sup>, J. Llorente Merino<sup>81</sup>, S.L. Lloyd<sup>75</sup>, F. Lo Sterzo<sup>152</sup>,  
 E. Lobodzinska<sup>42</sup>, P. Loch<sup>7</sup>, W.S. Lockman<sup>138</sup>, T. Loddenkoetter<sup>21</sup>, F.K. Loebinger<sup>83</sup>,  
 A.E. Loevschall-Jensen<sup>36</sup>, A. Loginov<sup>177</sup>, C.W. Loh<sup>169</sup>, T. Lohse<sup>16</sup>, K. Lohwasser<sup>48</sup>,  
 M. Lokajicek<sup>126</sup>, V.P. Lombardo<sup>5</sup>, J.D. Long<sup>88</sup>, R.E. Long<sup>71</sup>, L. Lopes<sup>125a</sup>, D. Lopez Mateos<sup>57</sup>,  
 B. Lopez Paredes<sup>140</sup>, J. Lorenz<sup>99</sup>, N. Lorenzo Martinez<sup>60</sup>, M. Losada<sup>163</sup>, P. Loscutoff<sup>15</sup>, X. Lou<sup>41</sup>,  
 A. Lounis<sup>116</sup>, J. Love<sup>6</sup>, P.A. Love<sup>71</sup>, A.J. Lowe<sup>144,e</sup>, F. Lu<sup>33a</sup>, H.J. Lubatti<sup>139</sup>, C. Luci<sup>133a,133b</sup>,  
 A. Lucotte<sup>55</sup>, F. Luehring<sup>60</sup>, W. Lukas<sup>61</sup>, L. Luminari<sup>133a</sup>, O. Lundberg<sup>147a,147b</sup>,  
 B. Lund-Jensen<sup>148</sup>, M. Lungwitz<sup>82</sup>, D. Lynn<sup>25</sup>, R. Lysak<sup>126</sup>, E. Lytken<sup>80</sup>, H. Ma<sup>25</sup>, L.L. Ma<sup>33d</sup>,  
 G. Maccarrone<sup>47</sup>, A. Macchiolo<sup>100</sup>, B. Maček<sup>74</sup>, J. Machado Miguens<sup>125a,125b</sup>, D. Macina<sup>30</sup>,  
 D. Madaffari<sup>84</sup>, R. Madar<sup>48</sup>, H.J. Maddocks<sup>71</sup>, W.F. Mader<sup>44</sup>, A. Madsen<sup>167</sup>, M. Maeno<sup>8</sup>,  
 T. Maeno<sup>25</sup>, E. Magradze<sup>54</sup>, K. Mahboubi<sup>48</sup>, J. Mahlstedt<sup>106</sup>, S. Mahmoud<sup>73</sup>, C. Maiani<sup>137</sup>,  
 C. Maidantchik<sup>24a</sup>, A. Maio<sup>125a,125b,125d</sup>, S. Majewski<sup>115</sup>, Y. Makida<sup>65</sup>, N. Makovec<sup>116</sup>,  
 P. Mal<sup>137,u</sup>, B. Malaescu<sup>79</sup>, Pa. Malecki<sup>39</sup>, V.P. Maleev<sup>122</sup>, F. Malek<sup>55</sup>, U. Mallik<sup>62</sup>, D. Malon<sup>6</sup>,  
 C. Malone<sup>144</sup>, S. Maltezos<sup>10</sup>, V.M. Malyshev<sup>108</sup>, S. Malyukov<sup>30</sup>, J. Mamuzic<sup>13b</sup>, B. Mandelli<sup>30</sup>,  
 L. Mandelli<sup>90a</sup>, I. Mandić<sup>74</sup>, R. Mandrysch<sup>62</sup>, J. Maneira<sup>125a,125b</sup>, A. Manfredini<sup>100</sup>,  
 L. Manhaes de Andrade Filho<sup>24b</sup>, J.A. Manjarres Ramos<sup>160b</sup>, A. Mann<sup>99</sup>, P.M. Manning<sup>138</sup>,  
 A. Manousakis-Katsikakis<sup>9</sup>, B. Mansoulie<sup>137</sup>, R. Mantifel<sup>86</sup>, L. Mapelli<sup>30</sup>, L. March<sup>168</sup>,  
 J.F. Marchand<sup>29</sup>, G. Marchiori<sup>79</sup>, M. Marcisovsky<sup>126</sup>, C.P. Marino<sup>170</sup>, C.N. Marques<sup>125a</sup>,  
 F. Marroquin<sup>24a</sup>, S.P. Marsden<sup>83</sup>, Z. Marshall<sup>15</sup>, L.F. Marti<sup>17</sup>, S. Marti-Garcia<sup>168</sup>, B. Martin<sup>30</sup>,  
 B. Martin<sup>89</sup>, J.P. Martin<sup>94</sup>, T.A. Martin<sup>171</sup>, V.J. Martin<sup>46</sup>, B. Martin dit Latour<sup>14</sup>,  
 H. Martinez<sup>137</sup>, M. Martinez<sup>12,l</sup>, S. Martin-Haugh<sup>130</sup>, A.C. Martyniuk<sup>77</sup>, M. Marx<sup>139</sup>,  
 F. Marzano<sup>133a</sup>, A. Marzin<sup>30</sup>, L. Masetti<sup>82</sup>, T. Mashimo<sup>156</sup>, R. Mashinistov<sup>95</sup>, J. Masik<sup>83</sup>,  
 A.L. Maslennikov<sup>108</sup>, I. Massa<sup>20a,20b</sup>, N. Massol<sup>5</sup>, P. Mastrandrea<sup>149</sup>, A. Mastroberardino<sup>37a,37b</sup>,  
 T. Masubuchi<sup>156</sup>, P. Matricon<sup>116</sup>, H. Matsunaga<sup>156</sup>, T. Matsushita<sup>66</sup>, P. Mättig<sup>176</sup>, S. Mättig<sup>42</sup>,  
 J. Mattmann<sup>82</sup>, J. Maurer<sup>26a</sup>, S.J. Maxfield<sup>73</sup>, D.A. Maximov<sup>108,f</sup>, R. Mazini<sup>152</sup>,  
 L. Mazzaferro<sup>134a,134b</sup>, G. Mc Goldrick<sup>159</sup>, S.P. Mc Kee<sup>88</sup>, A. McCarn<sup>88</sup>, R.L. McCarthy<sup>149</sup>,  
 T.G. McCarthy<sup>29</sup>, N.A. McCubbin<sup>130</sup>, K.W. McFarlane<sup>56,\*</sup>, J.A. McFayden<sup>77</sup>, G. Mchedlidze<sup>54</sup>,  
 T. McLaughlan<sup>18</sup>, S.J. McMahon<sup>130</sup>, R.A. McPherson<sup>170,i</sup>, A. Meade<sup>85</sup>, J. Mechnich<sup>106</sup>,  
 M. Medinnis<sup>42</sup>, S. Meehan<sup>31</sup>, R. Meera-Lebbai<sup>112</sup>, S. Mehlhase<sup>36</sup>, A. Mehta<sup>73</sup>, K. Meier<sup>58a</sup>,  
 C. Meineck<sup>99</sup>, B. Meirose<sup>80</sup>, C. Melachrinou<sup>31</sup>, B.R. Mellado Garcia<sup>146c</sup>, F. Meloni<sup>90a,90b</sup>,  
 A. Mengarelli<sup>20a,20b</sup>, S. Menke<sup>100</sup>, E. Meoni<sup>162</sup>, K.M. Mercurio<sup>57</sup>, S. Mergelmeyer<sup>21</sup>, N. Meric<sup>137</sup>,  
 P. Mermod<sup>49</sup>, L. Merola<sup>103a,103b</sup>, C. Meroni<sup>90a</sup>, F.S. Merritt<sup>31</sup>, H. Merritt<sup>110</sup>, A. Messina<sup>30,v</sup>,  
 J. Metcalfe<sup>25</sup>, A.S. Mete<sup>164</sup>, C. Meyer<sup>82</sup>, C. Meyer<sup>31</sup>, J-P. Meyer<sup>137</sup>, J. Meyer<sup>30</sup>,  
 R.P. Middleton<sup>130</sup>, S. Migas<sup>73</sup>, L. Mijović<sup>137</sup>, G. Mikenberg<sup>173</sup>, M. Mikestikova<sup>126</sup>, M. Mikuž<sup>74</sup>,  
 D.W. Miller<sup>31</sup>, C. Mills<sup>46</sup>, A. Milov<sup>173</sup>, D.A. Milstead<sup>147a,147b</sup>, D. Milstein<sup>173</sup>, A.A. Minaenko<sup>129</sup>,  
 M. Miñano Moya<sup>168</sup>, I.A. Minashvili<sup>64</sup>, A.I. Mincer<sup>109</sup>, B. Mindur<sup>38a</sup>, M. Mineev<sup>64</sup>, Y. Ming<sup>174</sup>,  
 L.M. Mir<sup>12</sup>, G. Mirabelli<sup>133a</sup>, T. Mitani<sup>172</sup>, J. Mitrevski<sup>99</sup>, V.A. Mitsou<sup>168</sup>, S. Mitsui<sup>65</sup>,  
 A. Miucci<sup>49</sup>, P.S. Miyagawa<sup>140</sup>, J.U. Mjörnmark<sup>80</sup>, T. Moa<sup>147a,147b</sup>, K. Mochizuki<sup>84</sup>, V. Moeller<sup>28</sup>,  
 S. Mohapatra<sup>35</sup>, W. Mohr<sup>48</sup>, S. Molander<sup>147a,147b</sup>, R. Moles-Valls<sup>168</sup>, K. Mönig<sup>42</sup>, C. Monini<sup>55</sup>,  
 J. Monk<sup>36</sup>, E. Monnier<sup>84</sup>, J. Montejo Berlingen<sup>12</sup>, F. Monticelli<sup>70</sup>, S. Monzani<sup>133a,133b</sup>,  
 R.W. Moore<sup>3</sup>, C. Mora Herrera<sup>49</sup>, A. Moraes<sup>53</sup>, N. Morange<sup>62</sup>, J. Morel<sup>54</sup>, D. Moreno<sup>82</sup>,  
 M. Moreno Llácer<sup>54</sup>, P. Morettini<sup>50a</sup>, M. Morgenstern<sup>44</sup>, M. Morii<sup>57</sup>, S. Moritz<sup>82</sup>, A.K. Morley<sup>148</sup>,  
 G. Mornacchi<sup>30</sup>, J.D. Morris<sup>75</sup>, L. Morvaj<sup>102</sup>, H.G. Moser<sup>100</sup>, M. Mosidze<sup>51b</sup>, J. Moss<sup>110</sup>,  
 R. Mount<sup>144</sup>, E. Mountricha<sup>25</sup>, S.V. Mouraviev<sup>95,\*</sup>, E.J.W. Moyse<sup>85</sup>, S.G. Muanza<sup>84</sup>,  
 R.D. Mudd<sup>18</sup>, F. Mueller<sup>58a</sup>, J. Mueller<sup>124</sup>, K. Mueller<sup>21</sup>, T. Mueller<sup>28</sup>, T. Mueller<sup>82</sup>,  
 D. Muenstermann<sup>49</sup>, Y. Munwes<sup>154</sup>, J.A. Murillo Quijada<sup>18</sup>, W.J. Murray<sup>171,c</sup>, H. Musheghyan<sup>54</sup>,  
 E. Musto<sup>153</sup>, A.G. Myagkov<sup>129,w</sup>, M. Myska<sup>126</sup>, O. Nackenhorst<sup>54</sup>, J. Nadal<sup>54</sup>, K. Nagai<sup>61</sup>,  
 R. Nagai<sup>158</sup>, Y. Nagai<sup>84</sup>, K. Nagano<sup>65</sup>, A. Nagarkar<sup>110</sup>, Y. Nagasaka<sup>59</sup>, M. Nagel<sup>100</sup>, A.M. Nairz<sup>30</sup>,  
 Y. Nakahama<sup>30</sup>, K. Nakamura<sup>65</sup>, T. Nakamura<sup>156</sup>, I. Nakano<sup>111</sup>, H. Namasivayam<sup>41</sup>, G. Nanava<sup>21</sup>,

R. Narayan<sup>58b</sup>, T. Nattermann<sup>21</sup>, T. Naumann<sup>42</sup>, G. Navarro<sup>163</sup>, R. Nayyar<sup>7</sup>, H.A. Neal<sup>88</sup>,  
P.Yu. Nechaeva<sup>95</sup>, T.J. Neep<sup>83</sup>, A. Negri<sup>120a,120b</sup>, G. Negri<sup>30</sup>, M. Negrini<sup>20a</sup>, S. Nektarijevic<sup>49</sup>,  
A. Nelson<sup>164</sup>, T.K. Nelson<sup>144</sup>, S. Nemecek<sup>126</sup>, P. Nemethy<sup>109</sup>, A.A. Nepomuceno<sup>24a</sup>, M. Nessi<sup>30,x</sup>,  
M.S. Neubauer<sup>166</sup>, M. Neumann<sup>176</sup>, R.M. Neves<sup>109</sup>, P. Nevski<sup>25</sup>, F.M. Newcomer<sup>121</sup>,  
P.R. Newman<sup>18</sup>, D.H. Nguyen<sup>6</sup>, R.B. Nickerson<sup>119</sup>, R. Nicolaidou<sup>137</sup>, B. Nicquevert<sup>30</sup>,  
J. Nielsen<sup>138</sup>, N. Nikiforou<sup>35</sup>, A. Nikiforov<sup>16</sup>, V. Nikolaenko<sup>129,w</sup>, I. Nikolic-Audit<sup>79</sup>, K. Nikolics<sup>49</sup>,  
K. Nikolopoulos<sup>18</sup>, P. Nilsson<sup>8</sup>, Y. Ninomiya<sup>156</sup>, A. Nisati<sup>133a</sup>, R. Nisius<sup>100</sup>, T. Nobe<sup>158</sup>,  
L. Nodulman<sup>6</sup>, M. Nomachi<sup>117</sup>, I. Nomidis<sup>155</sup>, S. Norberg<sup>112</sup>, M. Nordberg<sup>30</sup>, J. Novakova<sup>128</sup>,  
S. Nowak<sup>100</sup>, M. Nozaki<sup>65</sup>, L. Nozka<sup>114</sup>, K. Ntekas<sup>10</sup>, G. Nunes Hanninger<sup>87</sup>, T. Nunnemann<sup>99</sup>,  
E. Nurse<sup>77</sup>, F. Nuti<sup>87</sup>, B.J. O'Brien<sup>46</sup>, F. O'grady<sup>7</sup>, D.C. O'Neil<sup>143</sup>, V. O'Shea<sup>53</sup>,  
F.G. Oakham<sup>29,d</sup>, H. Oberlack<sup>100</sup>, T. Obermann<sup>21</sup>, J. Ocariz<sup>79</sup>, A. Ochi<sup>66</sup>, M.I. Ochoa<sup>77</sup>,  
S. Oda<sup>69</sup>, S. Odaka<sup>65</sup>, H. Ogren<sup>60</sup>, A. Oh<sup>83</sup>, S.H. Oh<sup>45</sup>, C.C. Ohm<sup>30</sup>, H. Ohman<sup>167</sup>,  
T. Ohshima<sup>102</sup>, W. Okamura<sup>117</sup>, H. Okawa<sup>25</sup>, Y. Okumura<sup>31</sup>, T. Okuyama<sup>156</sup>, A. Olariu<sup>26a</sup>,  
A.G. Olchevski<sup>64</sup>, S.A. Olivares Pino<sup>46</sup>, D. Oliveira Damazio<sup>25</sup>, E. Oliver Garcia<sup>168</sup>, D. Olivito<sup>121</sup>,  
A. Olszewski<sup>39</sup>, J. Olszowska<sup>39</sup>, A. Onofre<sup>125a,125e</sup>, P.U.E. Onyisi<sup>31,y</sup>, C.J. Oram<sup>160a</sup>,  
M.J. Oreglia<sup>31</sup>, Y. Oren<sup>154</sup>, D. Orestano<sup>135a,135b</sup>, N. Orlando<sup>72a,72b</sup>, C. Oropeza Barrera<sup>53</sup>,  
R.S. Orr<sup>159</sup>, B. Osculati<sup>50a,50b</sup>, R. Ospanov<sup>121</sup>, G. Otero y Garzon<sup>27</sup>, H. Otono<sup>69</sup>, M. Ouchrif<sup>136d</sup>,  
E.A. Ouellette<sup>170</sup>, F. Ould-Saada<sup>118</sup>, A. Ouraou<sup>137</sup>, K.P. Oussoren<sup>106</sup>, Q. Ouyang<sup>33a</sup>,  
A. Ovcharova<sup>15</sup>, M. Owen<sup>83</sup>, V.E. Ozcan<sup>19a</sup>, N. Ozturk<sup>8</sup>, K. Pachal<sup>119</sup>, A. Pacheco Pages<sup>12</sup>,  
C. Padilla Aranda<sup>12</sup>, M. Pagáčová<sup>48</sup>, S. Pagan Griso<sup>15</sup>, E. Paganis<sup>140</sup>, C. Pahl<sup>100</sup>, F. Paige<sup>25</sup>,  
P. Pais<sup>85</sup>, K. Pajchel<sup>118</sup>, G. Palacino<sup>160b</sup>, S. Palestini<sup>30</sup>, D. Pallin<sup>34</sup>, A. Palma<sup>125a,125b</sup>,  
J.D. Palmer<sup>18</sup>, Y.B. Pan<sup>174</sup>, E. Panagiotopoulou<sup>10</sup>, J.G. Panduro Vazquez<sup>76</sup>, P. Pani<sup>106</sup>,  
N. Panikashvili<sup>88</sup>, S. Panitkin<sup>25</sup>, D. Pantea<sup>26a</sup>, L. Paolozzi<sup>134a,134b</sup>, Th.D. Papadopoulou<sup>10</sup>,  
K. Papageorgiou<sup>155,j</sup>, A. Paramonov<sup>6</sup>, D. Paredes Hernandez<sup>34</sup>, M.A. Parker<sup>28</sup>, F. Parodi<sup>50a,50b</sup>,  
J.A. Parsons<sup>35</sup>, U. Parzefall<sup>48</sup>, E. Pasqualucci<sup>133a</sup>, S. Passaggio<sup>50a</sup>, A. Passeri<sup>135a</sup>,  
F. Pastore<sup>135a,135b,\*</sup>, Fr. Pastore<sup>76</sup>, G. Pásztor<sup>49,z</sup>, S. Patariaia<sup>176</sup>, N.D. Patel<sup>151</sup>, J.R. Pater<sup>83</sup>,  
S. Patricelli<sup>103a,103b</sup>, T. Pauly<sup>30</sup>, J. Pearce<sup>170</sup>, M. Pedersen<sup>118</sup>, S. Pedraza Lopez<sup>168</sup>,  
R. Pedro<sup>125a,125b</sup>, S.V. Peleganchuk<sup>108</sup>, D. Pelikan<sup>167</sup>, H. Peng<sup>33b</sup>, B. Penning<sup>31</sup>, J. Penwell<sup>60</sup>,  
D.V. Perepelitsa<sup>25</sup>, E. Perez Codina<sup>160a</sup>, M.T. Pérez García-Estañ<sup>168</sup>, V. Perez Reale<sup>35</sup>,  
L. Perini<sup>90a,90b</sup>, H. Pernegger<sup>30</sup>, R. Perrino<sup>72a</sup>, R. Peschke<sup>42</sup>, V.D. Peshekhonov<sup>64</sup>, K. Peters<sup>30</sup>,  
R.F.Y. Peters<sup>83</sup>, B.A. Petersen<sup>87</sup>, J. Petersen<sup>30</sup>, T.C. Petersen<sup>36</sup>, E. Petit<sup>42</sup>, A. Petridis<sup>147a,147b</sup>,  
C. Petridou<sup>155</sup>, E. Petrolo<sup>133a</sup>, F. Petrucci<sup>135a,135b</sup>, M. Petteni<sup>143</sup>, N.E. Pettersson<sup>158</sup>,  
R. Pezoa<sup>32b</sup>, P.W. Phillips<sup>130</sup>, G. Piacquadio<sup>144</sup>, E. Pianori<sup>171</sup>, A. Picazio<sup>49</sup>, E. Piccaro<sup>75</sup>,  
M. Piccinini<sup>20a,20b</sup>, S.M. Piec<sup>42</sup>, R. Piegai<sup>27</sup>, D.T. Pignotti<sup>110</sup>, J.E. Pilcher<sup>31</sup>, A.D. Pilkington<sup>77</sup>,  
J. Pina<sup>125a,125b,125d</sup>, M. Pinamonti<sup>165a,165c,aa</sup>, A. Pinder<sup>119</sup>, J.L. Pinfold<sup>3</sup>, A. Pingel<sup>36</sup>,  
B. Pinto<sup>125a</sup>, S. Pires<sup>79</sup>, C. Pizio<sup>90a,90b</sup>, M.-A. Pleier<sup>25</sup>, V. Pleskot<sup>128</sup>, E. Plotnikova<sup>64</sup>,  
P. Plucinski<sup>147a,147b</sup>, S. Poddar<sup>58a</sup>, F. Podlyski<sup>34</sup>, R. Poettgen<sup>82</sup>, L. Poggioli<sup>116</sup>, D. Pohl<sup>21</sup>,  
M. Pohl<sup>49</sup>, G. Polesello<sup>120a</sup>, A. Policicchio<sup>37a,37b</sup>, R. Polifka<sup>159</sup>, A. Polini<sup>20a</sup>, C.S. Pollard<sup>45</sup>,  
V. Polychronakos<sup>25</sup>, K. Pommès<sup>30</sup>, L. Pontecorvo<sup>133a</sup>, B.G. Pope<sup>89</sup>, G.A. Popeneciu<sup>26b</sup>,  
D.S. Popovic<sup>13a</sup>, A. Poppleton<sup>30</sup>, X. Portell Bueso<sup>12</sup>, G.E. Pospelov<sup>100</sup>, S. Pospisil<sup>127</sup>,  
K. Potamianos<sup>15</sup>, I.N. Potrap<sup>64</sup>, C.J. Potter<sup>150</sup>, C.T. Potter<sup>115</sup>, G. Poulard<sup>30</sup>, J. Poveda<sup>60</sup>,  
V. Pozdnyakov<sup>64</sup>, R. Prabhu<sup>77</sup>, P. Pralavorio<sup>84</sup>, A. Pranko<sup>15</sup>, S. Prasad<sup>30</sup>, R. Pravahan<sup>8</sup>,  
S. Prell<sup>63</sup>, D. Price<sup>83</sup>, J. Price<sup>73</sup>, L.E. Price<sup>6</sup>, D. Prieur<sup>124</sup>, M. Primavera<sup>72a</sup>, M. Proissl<sup>46</sup>,  
K. Prokofiev<sup>109</sup>, F. Prokoshin<sup>32b</sup>, E. Protopapadaki<sup>137</sup>, S. Protopopescu<sup>25</sup>, J. Proudfoot<sup>6</sup>,  
M. Przybycien<sup>38a</sup>, H. Przysiezniak<sup>5</sup>, E. Ptacek<sup>115</sup>, E. Pueschel<sup>85</sup>, D. Puldon<sup>149</sup>, M. Purohit<sup>25,ab</sup>,  
P. Puzo<sup>116</sup>, Y. Pylypchenko<sup>62</sup>, J. Qian<sup>88</sup>, G. Qin<sup>53</sup>, A. Quadt<sup>54</sup>, D.R. Quarrie<sup>15</sup>,  
W.B. Quayle<sup>165a,165b</sup>, D. Quilty<sup>53</sup>, A. Qureshi<sup>160b</sup>, V. Radeka<sup>25</sup>, V. Radescu<sup>42</sup>,  
S.K. Radhakrishnan<sup>149</sup>, P. Radloff<sup>115</sup>, P. Rados<sup>87</sup>, F. Ragusa<sup>90a,90b</sup>, G. Rahal<sup>179</sup>,  
S. Rajagopalan<sup>25</sup>, M. Rammensee<sup>30</sup>, M. Rammes<sup>142</sup>, A.S. Randle-Conde<sup>40</sup>, C. Rangel-Smith<sup>79</sup>,  
K. Rao<sup>164</sup>, F. Rauscher<sup>99</sup>, T.C. Rave<sup>48</sup>, T. Ravenscroft<sup>53</sup>, M. Raymond<sup>30</sup>, A.L. Read<sup>118</sup>,  
D.M. Rebuzzi<sup>120a,120b</sup>, A. Redelbach<sup>175</sup>, G. Redlinger<sup>25</sup>, R. Reece<sup>138</sup>, K. Reeves<sup>41</sup>, L. Rehnisch<sup>16</sup>,  
A. Reinsch<sup>115</sup>, H. Reisin<sup>27</sup>, M. Relich<sup>164</sup>, C. Rembser<sup>30</sup>, Z.L. Ren<sup>152</sup>, A. Renaud<sup>116</sup>,

M. Rescigno<sup>133a</sup>, S. Resconi<sup>90a</sup>, B. Resende<sup>137</sup>, P. Reznicek<sup>128</sup>, R. Rezvani<sup>94</sup>, R. Richter<sup>100</sup>,  
 M. Ridel<sup>79</sup>, P. Rieck<sup>16</sup>, M. Rijssenbeek<sup>149</sup>, A. Rimoldi<sup>120a,120b</sup>, L. Rinaldi<sup>20a</sup>, E. Ritsch<sup>61</sup>, I. Riu<sup>12</sup>,  
 F. Rizatdinova<sup>113</sup>, E. Rizvi<sup>75</sup>, S.H. Robertson<sup>86,i</sup>, A. Robichaud-Veronneau<sup>119</sup>, D. Robinson<sup>28</sup>,  
 J.E.M. Robinson<sup>83</sup>, A. Robson<sup>53</sup>, C. Roda<sup>123a,123b</sup>, L. Rodrigues<sup>30</sup>, S. Roe<sup>30</sup>, O. Röhne<sup>118</sup>,  
 S. Rolli<sup>162</sup>, A. Romaniouk<sup>97</sup>, M. Romano<sup>20a,20b</sup>, G. Romeo<sup>27</sup>, E. Romero Adam<sup>168</sup>,  
 N. Rompotis<sup>139</sup>, L. Roos<sup>79</sup>, E. Ros<sup>168</sup>, S. Rosati<sup>133a</sup>, K. Rosbach<sup>49</sup>, M. Rose<sup>76</sup>, P.L. Rosendahl<sup>14</sup>,  
 O. Rosenthal<sup>142</sup>, V. Rossetti<sup>147a,147b</sup>, E. Rossi<sup>103a,103b</sup>, L.P. Rossi<sup>50a</sup>, R. Rosten<sup>139</sup>, M. Rotaru<sup>26a</sup>,  
 I. Roth<sup>173</sup>, J. Rothberg<sup>139</sup>, D. Rousseau<sup>116</sup>, C.R. Royon<sup>137</sup>, A. Rozanov<sup>84</sup>, Y. Rozen<sup>153</sup>,  
 X. Ruan<sup>146c</sup>, F. Rubbo<sup>12</sup>, I. Rubinskiy<sup>42</sup>, V.I. Rud<sup>98</sup>, C. Rudolph<sup>44</sup>, M.S. Rudolph<sup>159</sup>, F. Rühr<sup>48</sup>,  
 A. Ruiz-Martinez<sup>63</sup>, Z. Rurikova<sup>48</sup>, N.A. Rusakovich<sup>64</sup>, A. Ruschke<sup>99</sup>, J.P. Rutherford<sup>7</sup>,  
 N. Ruthmann<sup>48</sup>, Y.F. Ryabov<sup>122</sup>, M. Rybar<sup>128</sup>, G. Rybkin<sup>116</sup>, N.C. Ryder<sup>119</sup>, A.F. Saavedra<sup>151</sup>,  
 S. Sacerdoti<sup>27</sup>, A. Saddique<sup>3</sup>, I. Sadeh<sup>154</sup>, H.F.-W. Sadrozinski<sup>138</sup>, R. Sadykov<sup>64</sup>,  
 F. Safai Tehrani<sup>133a</sup>, H. Sakamoto<sup>156</sup>, Y. Sakurai<sup>172</sup>, G. Salamanna<sup>75</sup>, A. Salamon<sup>134a</sup>,  
 M. Saleem<sup>112</sup>, D. Salek<sup>106</sup>, P.H. Sales De Bruin<sup>139</sup>, D. Salihagic<sup>100</sup>, A. Salnikov<sup>144</sup>, J. Salt<sup>168</sup>,  
 B.M. Salvachua Ferrando<sup>6</sup>, D. Salvatore<sup>37a,37b</sup>, F. Salvatore<sup>150</sup>, A. Salvucci<sup>105</sup>, A. Salzburger<sup>30</sup>,  
 D. Sampsonidis<sup>155</sup>, A. Sanchez<sup>103a,103b</sup>, J. Sánchez<sup>168</sup>, V. Sanchez Martinez<sup>168</sup>, H. Sandaker<sup>14</sup>,  
 H.G. Sander<sup>82</sup>, M.P. Sanders<sup>99</sup>, M. Sandhoff<sup>176</sup>, T. Sandoval<sup>28</sup>, C. Sandoval<sup>163</sup>, R. Sandstroem<sup>100</sup>,  
 D.P.C. Sankey<sup>130</sup>, A. Sansoni<sup>47</sup>, C. Santoni<sup>34</sup>, R. Santonico<sup>134a,134b</sup>, H. Santos<sup>125a</sup>,  
 I. Santoyo Castillo<sup>150</sup>, K. Sapp<sup>124</sup>, A. Saponov<sup>64</sup>, J.G. Saraiva<sup>125a,125d</sup>, B. Sarrazin<sup>21</sup>,  
 G. Sartisohn<sup>176</sup>, O. Sasaki<sup>65</sup>, Y. Sasaki<sup>156</sup>, I. Satsounkevitch<sup>91</sup>, G. Sauvage<sup>5,\*</sup>, E. Sauvan<sup>5</sup>,  
 P. Savard<sup>159,d</sup>, D.O. Savu<sup>30</sup>, C. Sawyer<sup>119</sup>, L. Sawyer<sup>78,k</sup>, D.H. Saxon<sup>53</sup>, J. Saxon<sup>121</sup>,  
 C. Sbarra<sup>20a</sup>, A. Sbrizzi<sup>3</sup>, T. Scanlon<sup>30</sup>, D.A. Scannicchio<sup>164</sup>, M. Scarcella<sup>151</sup>, J. Schaarschmidt<sup>173</sup>,  
 P. Schacht<sup>100</sup>, D. Schaefer<sup>121</sup>, R. Schaefer<sup>42</sup>, A. Schaelicke<sup>46</sup>, S. Schaepe<sup>21</sup>, S. Schaezel<sup>58b</sup>,  
 U. Schäfer<sup>82</sup>, A.C. Schaffer<sup>116</sup>, D. Schaile<sup>99</sup>, R.D. Schamberger<sup>149</sup>, V. Scharf<sup>58a</sup>,  
 V.A. Schegelsky<sup>122</sup>, D. Scheirich<sup>128</sup>, M. Schernau<sup>164</sup>, M.I. Scherzer<sup>35</sup>, C. Schiavi<sup>50a,50b</sup>,  
 J. Schieck<sup>99</sup>, C. Schillo<sup>48</sup>, M. Schioppa<sup>37a,37b</sup>, S. Schlenker<sup>30</sup>, E. Schmidt<sup>48</sup>, K. Schmieden<sup>30</sup>,  
 C. Schmitt<sup>82</sup>, C. Schmitt<sup>99</sup>, S. Schmitt<sup>58b</sup>, B. Schneider<sup>17</sup>, Y.J. Schnellbach<sup>73</sup>, U. Schnoor<sup>44</sup>,  
 L. Schoeffel<sup>137</sup>, A. Schoening<sup>58b</sup>, B.D. Schoenrock<sup>89</sup>, A.L.S. Schorlemmer<sup>54</sup>, M. Schott<sup>82</sup>,  
 D. Schouten<sup>160a</sup>, J. Schovancova<sup>25</sup>, M. Schram<sup>86</sup>, S. Schramm<sup>159</sup>, M. Schreyer<sup>175</sup>, C. Schroeder<sup>82</sup>,  
 N. Schuh<sup>82</sup>, M.J. Schultens<sup>21</sup>, H.-C. Schultz-Coulon<sup>58a</sup>, H. Schulz<sup>16</sup>, M. Schumacher<sup>48</sup>,  
 B.A. Schumm<sup>138</sup>, Ph. Schune<sup>137</sup>, A. Schwartzman<sup>144</sup>, Ph. Schwegler<sup>100</sup>, Ph. Schwemling<sup>137</sup>,  
 R. Schwienhorst<sup>89</sup>, J. Schwindling<sup>137</sup>, T. Schwindt<sup>21</sup>, M. Schwoerer<sup>5</sup>, F.G. Sciacca<sup>17</sup>, E. Scifo<sup>116</sup>,  
 G. Sciolla<sup>23</sup>, W.G. Scott<sup>130</sup>, F. Scuri<sup>123a,123b</sup>, F. Scutti<sup>21</sup>, J. Searcy<sup>88</sup>, G. Sedov<sup>42</sup>, E. Sedykh<sup>122</sup>,  
 S.C. Seidel<sup>104</sup>, A. Seiden<sup>138</sup>, F. Seifert<sup>127</sup>, J.M. Seixas<sup>24a</sup>, G. Sekhniaidze<sup>103a</sup>, S.J. Sekula<sup>40</sup>,  
 K.E. Selbach<sup>46</sup>, D.M. Seliverstov<sup>122,\*</sup>, G. Sellers<sup>73</sup>, N. Semprini-Cesari<sup>20a,20b</sup>, C. Serfon<sup>30</sup>,  
 L. Serin<sup>116</sup>, L. Serkin<sup>54</sup>, T. Serre<sup>84</sup>, R. Seuster<sup>160a</sup>, H. Severini<sup>112</sup>, F. Sforza<sup>100</sup>, A. Sfyrlla<sup>30</sup>,  
 E. Shabalina<sup>54</sup>, M. Shamim<sup>115</sup>, L.Y. Shan<sup>33a</sup>, J.T. Shank<sup>22</sup>, Q.T. Shao<sup>87</sup>, M. Shapiro<sup>15</sup>,  
 P.B. Shatalov<sup>96</sup>, K. Shaw<sup>165a,165b</sup>, P. Sherwood<sup>77</sup>, S. Shimizu<sup>66</sup>, C.O. Shimmin<sup>164</sup>,  
 M. Shimojima<sup>101</sup>, T. Shin<sup>56</sup>, M. Shiyakova<sup>64</sup>, A. Shmeleva<sup>95</sup>, M.J. Shochet<sup>31</sup>, D. Short<sup>119</sup>,  
 S. Shrestha<sup>63</sup>, E. Shulga<sup>97</sup>, M.A. Shupe<sup>7</sup>, S. Shushkevich<sup>42</sup>, P. Sicho<sup>126</sup>, D. Sidorov<sup>113</sup>,  
 A. Sidoti<sup>133a</sup>, F. Siegert<sup>44</sup>, Dj. Sijacki<sup>13a</sup>, O. Silbert<sup>173</sup>, J. Silva<sup>125a,125d</sup>, Y. Silver<sup>154</sup>,  
 D. Silverstein<sup>144</sup>, S.B. Silverstein<sup>147a</sup>, V. Simak<sup>127</sup>, O. Simard<sup>5</sup>, Lj. Simic<sup>13a</sup>, S. Simion<sup>116</sup>,  
 E. Simioni<sup>82</sup>, B. Simmons<sup>77</sup>, R. Simoniello<sup>90a,90b</sup>, M. Simonyan<sup>36</sup>, P. Sinervo<sup>159</sup>, N.B. Sinev<sup>115</sup>,  
 V. Sipica<sup>142</sup>, G. Siragusa<sup>175</sup>, A. Sircar<sup>78</sup>, A.N. Sisakyan<sup>64,\*</sup>, S.Yu. Sivoklov<sup>98</sup>, J. Sjölin<sup>147a,147b</sup>,  
 T.B. Sjørnsen<sup>14</sup>, L.A. Skinnari<sup>15</sup>, H.P. Skottowe<sup>57</sup>, K.Yu. Skovpen<sup>108</sup>, P. Skubic<sup>112</sup>, M. Slater<sup>18</sup>,  
 T. Slavicek<sup>127</sup>, K. Sliwa<sup>162</sup>, V. Smakhtin<sup>173</sup>, B.H. Smart<sup>46</sup>, L. Smestad<sup>118</sup>, S.Yu. Smirnov<sup>97</sup>,  
 Y. Smirnov<sup>97</sup>, L.N. Smirnova<sup>98,ac</sup>, O. Smirnova<sup>80</sup>, K.M. Smith<sup>53</sup>, M. Smizanska<sup>71</sup>, K. Smolek<sup>127</sup>,  
 A.A. Snesarev<sup>95</sup>, G. Snidero<sup>75</sup>, J. Snow<sup>112</sup>, S. Snyder<sup>25</sup>, R. Sobie<sup>170,i</sup>, F. Socher<sup>44</sup>, J. Sodomka<sup>127</sup>,  
 A. Soffer<sup>154</sup>, D.A. Soh<sup>152,r</sup>, C.A. Solans<sup>30</sup>, M. Solar<sup>127</sup>, J. Solc<sup>127</sup>, E.Yu. Soldatov<sup>97</sup>,  
 U. Soldevila<sup>168</sup>, E. Solfaroli Camillocci<sup>133a,133b</sup>, A.A. Solodkov<sup>129</sup>, O.V. Solovyanov<sup>129</sup>,  
 V. Solovyev<sup>122</sup>, P. Sommer<sup>48</sup>, H.Y. Song<sup>33b</sup>, N. Soni<sup>1</sup>, A. Sood<sup>15</sup>, V. Sopko<sup>127</sup>, B. Sopko<sup>127</sup>,  
 V. Sorin<sup>12</sup>, M. Sosebee<sup>8</sup>, R. Soualah<sup>165a,165c</sup>, P. Soueid<sup>94</sup>, A.M. Soukharev<sup>108</sup>, D. South<sup>42</sup>,

S. Spagnolo<sup>72a,72b</sup>, F. Spanò<sup>76</sup>, W.R. Spearman<sup>57</sup>, R. Spighi<sup>20a</sup>, G. Spigo<sup>30</sup>, M. Spousta<sup>128</sup>,  
 T. Spreitzer<sup>159</sup>, B. Spurlock<sup>8</sup>, R.D. St. Denis<sup>53</sup>, S. Staerz<sup>44</sup>, J. Stahlman<sup>121</sup>, R. Stamen<sup>58a</sup>,  
 E. Stanecka<sup>39</sup>, R.W. Stanek<sup>6</sup>, C. Stanescu<sup>135a</sup>, M. Stanescu-Bellu<sup>42</sup>, M.M. Stanitzki<sup>42</sup>,  
 S. Stapnes<sup>118</sup>, E.A. Starchenko<sup>129</sup>, J. Stark<sup>55</sup>, P. Staroba<sup>126</sup>, P. Starovoitov<sup>42</sup>, R. Staszewski<sup>39</sup>,  
 P. Stavina<sup>145a,\*</sup>, G. Steele<sup>53</sup>, P. Steinberg<sup>25</sup>, I. Stekl<sup>127</sup>, B. Stelzer<sup>143</sup>, H.J. Stelzer<sup>30</sup>,  
 O. Stelzer-Chilton<sup>160a</sup>, H. Stenzel<sup>52</sup>, S. Stern<sup>100</sup>, G.A. Stewart<sup>53</sup>, J.A. Stillings<sup>21</sup>,  
 M.C. Stockton<sup>86</sup>, M. Stoebe<sup>86</sup>, K. Stoerig<sup>48</sup>, G. Stoicea<sup>26a</sup>, P. Stolte<sup>54</sup>, S. Stonjek<sup>100</sup>,  
 A.R. Stradling<sup>8</sup>, A. Straessner<sup>44</sup>, J. Strandberg<sup>148</sup>, S. Strandberg<sup>147a,147b</sup>, A. Strandlie<sup>118</sup>,  
 E. Strauss<sup>144</sup>, M. Strauss<sup>112</sup>, P. Strizenec<sup>145b</sup>, R. Ströhmer<sup>175</sup>, D.M. Strom<sup>115</sup>, R. Stroynowski<sup>40</sup>,  
 S.A. Stucci<sup>17</sup>, B. Stugu<sup>14</sup>, N.A. Styles<sup>42</sup>, D. Su<sup>144</sup>, J. Su<sup>124</sup>, HS. Subramania<sup>3</sup>, R. Subramaniam<sup>78</sup>,  
 A. Succurro<sup>12</sup>, Y. Sugaya<sup>117</sup>, C. Suhr<sup>107</sup>, M. Suk<sup>127</sup>, V.V. Sulin<sup>95</sup>, S. Sultansoy<sup>4c</sup>, T. Sumida<sup>67</sup>,  
 X. Sun<sup>33a</sup>, J.E. Sundermann<sup>48</sup>, K. Suruliz<sup>140</sup>, G. Susinno<sup>37a,37b</sup>, M.R. Sutton<sup>150</sup>, Y. Suzuki<sup>65</sup>,  
 M. Svatos<sup>126</sup>, S. Swedish<sup>169</sup>, M. Swiatlowski<sup>144</sup>, I. Sykora<sup>145a</sup>, T. Sykora<sup>128</sup>, D. Ta<sup>89</sup>,  
 K. Tackmann<sup>42</sup>, J. Taenzer<sup>159</sup>, A. Taffard<sup>164</sup>, R. Tafirout<sup>160a</sup>, N. Taiblum<sup>154</sup>, Y. Takahashi<sup>102</sup>,  
 H. Takai<sup>25</sup>, R. Takashima<sup>68</sup>, H. Takeda<sup>66</sup>, T. Takeshita<sup>141</sup>, Y. Takubo<sup>65</sup>, M. Talby<sup>84</sup>,  
 A.A. Talyshev<sup>108,f</sup>, J.Y.C. Tam<sup>175</sup>, M.C. Tamsett<sup>78,ad</sup>, K.G. Tan<sup>87</sup>, J. Tanaka<sup>156</sup>, R. Tanaka<sup>116</sup>,  
 S. Tanaka<sup>132</sup>, S. Tanaka<sup>65</sup>, A.J. Tanasijczuk<sup>143</sup>, K. Tani<sup>66</sup>, N. Tannoury<sup>84</sup>, S. Tapprogge<sup>82</sup>,  
 S. Tarem<sup>153</sup>, F. Tarrade<sup>29</sup>, G.F. Tartarelli<sup>90a</sup>, P. Tas<sup>128</sup>, M. Tasevsky<sup>126</sup>, T. Tashiro<sup>67</sup>,  
 E. Tassi<sup>37a,37b</sup>, A. Tavares Delgado<sup>125a,125b</sup>, Y. Tayalati<sup>136d</sup>, C. Taylor<sup>77</sup>, F.E. Taylor<sup>93</sup>,  
 G.N. Taylor<sup>87</sup>, W. Taylor<sup>160b</sup>, F.A. Teischinger<sup>30</sup>, M. Teixeira Dias Castanheira<sup>75</sup>,  
 P. Teixeira-Dias<sup>76</sup>, K.K. Temming<sup>48</sup>, H. Ten Kate<sup>30</sup>, P.K. Teng<sup>152</sup>, S. Terada<sup>65</sup>, K. Terashi<sup>156</sup>,  
 J. Terron<sup>81</sup>, S. Terzo<sup>100</sup>, M. Testa<sup>47</sup>, R.J. Teuscher<sup>159,i</sup>, J. Therhaag<sup>21</sup>, T. Theveneaux-Pelzer<sup>34</sup>,  
 S. Thoma<sup>48</sup>, J.P. Thomas<sup>18</sup>, J. Thomas-Wilsker<sup>76</sup>, E.N. Thompson<sup>35</sup>, P.D. Thompson<sup>18</sup>,  
 P.D. Thompson<sup>159</sup>, A.S. Thompson<sup>53</sup>, L.A. Thomsen<sup>36</sup>, E. Thomson<sup>121</sup>, M. Thomson<sup>28</sup>,  
 W.M. Thong<sup>87</sup>, R.P. Thun<sup>88,\*</sup>, F. Tian<sup>35</sup>, M.J. Tibbetts<sup>15</sup>, V.O. Tikhomirov<sup>95,ae</sup>,  
 Yu.A. Tikhonov<sup>108,f</sup>, S. Timoshenko<sup>97</sup>, E. Tiouchichine<sup>84</sup>, P. Tipton<sup>177</sup>, S. Tisserant<sup>84</sup>,  
 T. Todorov<sup>5</sup>, S. Todorova-Nova<sup>128</sup>, B. Toggerson<sup>164</sup>, J. Tojo<sup>69</sup>, S. Tokár<sup>145a</sup>, K. Tokushuku<sup>65</sup>,  
 K. Tollefson<sup>89</sup>, L. Tomlinson<sup>83</sup>, M. Tomoto<sup>102</sup>, L. Tompkins<sup>31</sup>, K. Toms<sup>104</sup>, N.D. Topilin<sup>64</sup>,  
 E. Torrence<sup>115</sup>, H. Torres<sup>143</sup>, E. Torró Pastor<sup>168</sup>, J. Toth<sup>84,z</sup>, F. Touchard<sup>84</sup>, D.R. Tovey<sup>140</sup>,  
 H.L. Tran<sup>116</sup>, T. Trefzger<sup>175</sup>, L. Tremblet<sup>30</sup>, A. Tricoli<sup>30</sup>, I.M. Trigger<sup>160a</sup>, S. Trincaz-Duvoid<sup>79</sup>,  
 M.F. Tripijana<sup>70</sup>, N. Triplett<sup>25</sup>, W. Trischuk<sup>159</sup>, B. Trocmé<sup>55</sup>, C. Troncon<sup>90a</sup>,  
 M. Trotter-McDonald<sup>143</sup>, M. Trovatelli<sup>135a,135b</sup>, P. True<sup>89</sup>, M. Trzebinski<sup>39</sup>, A. Trzupek<sup>39</sup>,  
 C. Tsarouchas<sup>30</sup>, J.C-L. Tseng<sup>119</sup>, P.V. Tsiarehshka<sup>91</sup>, D. Tsionou<sup>137</sup>, G. Tsipolitis<sup>10</sup>,  
 N. Tsirintanis<sup>9</sup>, S. Tsiskaridze<sup>12</sup>, V. Tsiskaridze<sup>48</sup>, E.G. Tskhadadze<sup>51a</sup>, I.I. Tsukerman<sup>96</sup>,  
 V. Tsulaia<sup>15</sup>, S. Tsuno<sup>65</sup>, D. Tsybychev<sup>149</sup>, A. Tua<sup>140</sup>, A. Tudorache<sup>26a</sup>, V. Tudorache<sup>26a</sup>,  
 A.N. Tuna<sup>121</sup>, S.A. Tupputi<sup>20a,20b</sup>, S. Turchikhin<sup>98,ac</sup>, D. Turecek<sup>127</sup>, I. Turk Cakir<sup>4d</sup>,  
 R. Turra<sup>90a,90b</sup>, P.M. Tuts<sup>35</sup>, A. Tykhonov<sup>74</sup>, M. Tylmad<sup>147a,147b</sup>, M. Tyndel<sup>130</sup>, K. Uchida<sup>21</sup>,  
 I. Ueda<sup>156</sup>, R. Ueno<sup>29</sup>, M. Ughetto<sup>84</sup>, M. Uglan<sup>14</sup>, M. Uhlenbrock<sup>21</sup>, F. Ukegawa<sup>161</sup>, G. Unal<sup>30</sup>,  
 A. Undrus<sup>25</sup>, G. Unel<sup>164</sup>, F.C. Ungaro<sup>48</sup>, Y. Unno<sup>65</sup>, D. Urbaniec<sup>35</sup>, P. Urquijo<sup>21</sup>, G. Usai<sup>8</sup>,  
 A. Usanova<sup>61</sup>, L. Vacavant<sup>84</sup>, V. Vacek<sup>127</sup>, B. Vachon<sup>86</sup>, N. Valencic<sup>106</sup>, S. Valentineti<sup>20a,20b</sup>,  
 A. Valero<sup>168</sup>, L. Valery<sup>34</sup>, S. Valkar<sup>128</sup>, E. Valladolid Gallego<sup>168</sup>, S. Vallecorsa<sup>49</sup>,  
 J.A. Valls Ferrer<sup>168</sup>, R. Van Berg<sup>121</sup>, P.C. Van Der Deijl<sup>106</sup>, R. van der Geer<sup>106</sup>,  
 H. van der Graaf<sup>106</sup>, R. Van Der Leeuw<sup>106</sup>, D. van der Ster<sup>30</sup>, N. van Eldik<sup>30</sup>, P. van Gemmeren<sup>6</sup>,  
 J. Van Nieuwkoop<sup>143</sup>, I. van Vulpen<sup>106</sup>, M.C. van Woerden<sup>30</sup>, M. Vanadia<sup>133a,133b</sup>, W. Vandelli<sup>30</sup>,  
 R. Vanguri<sup>121</sup>, A. Vaniachine<sup>6</sup>, P. Vankov<sup>42</sup>, F. Vannucci<sup>79</sup>, G. Vardanyan<sup>178</sup>, R. Vari<sup>133a</sup>,  
 E.W. Varnes<sup>7</sup>, T. Varol<sup>85</sup>, D. Varouchas<sup>79</sup>, A. Vartapetian<sup>8</sup>, K.E. Varvell<sup>151</sup>,  
 V.I. Vassilakopoulos<sup>56</sup>, F. Vazeille<sup>34</sup>, T. Vazquez Schroeder<sup>54</sup>, J. Veatch<sup>7</sup>, F. Veloso<sup>125a,125c</sup>,  
 S. Veneziano<sup>133a</sup>, A. Ventura<sup>72a,72b</sup>, D. Ventura<sup>85</sup>, M. Venturi<sup>48</sup>, N. Venturi<sup>159</sup>, A. Venturini<sup>23</sup>,  
 V. Vercesi<sup>120a</sup>, M. Verducci<sup>139</sup>, W. Verkerke<sup>106</sup>, J.C. Vermeulen<sup>106</sup>, A. Vest<sup>44</sup>, M.C. Vetterli<sup>143,d</sup>,  
 O. Viazlo<sup>80</sup>, I. Vichou<sup>166</sup>, T. Vickey<sup>146c,af</sup>, O.E. Vickey Boeriu<sup>146c</sup>, G.H.A. Viehhauser<sup>119</sup>,  
 S. Viel<sup>169</sup>, R. Vigne<sup>30</sup>, M. Villa<sup>20a,20b</sup>, M. Villaplana Perez<sup>168</sup>, E. Vilucchi<sup>47</sup>, M.G. Vincker<sup>29</sup>,  
 V.B. Vinogradov<sup>64</sup>, J. Virzi<sup>15</sup>, O. Vitells<sup>173</sup>, I. Vivarelli<sup>150</sup>, F. Vives Vaque<sup>3</sup>, S. Vlachos<sup>10</sup>,

D. Vladoiu<sup>99</sup>, M. Vlasak<sup>127</sup>, A. Vogel<sup>21</sup>, P. Vokac<sup>127</sup>, G. Volpi<sup>47</sup>, M. Volpi<sup>87</sup>,  
H. von der Schmitt<sup>100</sup>, H. von Radziewski<sup>48</sup>, E. von Toerne<sup>21</sup>, V. Vorobel<sup>128</sup>, K. Vorobey<sup>97</sup>,  
M. Vos<sup>168</sup>, R. Voss<sup>30</sup>, J.H. Vosseveld<sup>73</sup>, N. Vranjes<sup>137</sup>, M. Vranjes Milosavljevic<sup>106</sup>, V. Vrba<sup>126</sup>,  
M. Vreeswijk<sup>106</sup>, T. Vu Anh<sup>48</sup>, R. Vuillermet<sup>30</sup>, I. Vukotic<sup>31</sup>, Z. Vykydal<sup>127</sup>, W. Wagner<sup>176</sup>,  
P. Wagner<sup>21</sup>, S. Wahrmund<sup>44</sup>, J. Wakabayashi<sup>102</sup>, J. Walder<sup>71</sup>, R. Walker<sup>99</sup>, W. Walkowiak<sup>142</sup>,  
R. Wall<sup>177</sup>, P. Waller<sup>73</sup>, B. Walsh<sup>177</sup>, C. Wang<sup>152</sup>, C. Wang<sup>45</sup>, F. Wang<sup>174</sup>, H. Wang<sup>15</sup>,  
H. Wang<sup>40</sup>, J. Wang<sup>42</sup>, J. Wang<sup>33a</sup>, K. Wang<sup>86</sup>, R. Wang<sup>104</sup>, S.M. Wang<sup>152</sup>, T. Wang<sup>21</sup>,  
X. Wang<sup>177</sup>, A. Warburton<sup>86</sup>, C.P. Ward<sup>28</sup>, D.R. Wardrope<sup>77</sup>, M. Warsinsky<sup>48</sup>, A. Washbrook<sup>46</sup>,  
C. Wasicki<sup>42</sup>, I. Watanabe<sup>66</sup>, P.M. Watkins<sup>18</sup>, A.T. Watson<sup>18</sup>, I.J. Watson<sup>151</sup>, M.F. Watson<sup>18</sup>,  
G. Watts<sup>139</sup>, S. Watts<sup>83</sup>, B.M. Waugh<sup>77</sup>, S. Webb<sup>83</sup>, M.S. Weber<sup>17</sup>, S.W. Weber<sup>175</sup>,  
J.S. Webster<sup>31</sup>, A.R. Weidberg<sup>119</sup>, P. Weigell<sup>100</sup>, B. Weinert<sup>60</sup>, J. Weingarten<sup>54</sup>, C. Weiser<sup>48</sup>,  
H. Weits<sup>106</sup>, P.S. Wells<sup>30</sup>, T. Wenaus<sup>25</sup>, D. Wendland<sup>16</sup>, Z. Weng<sup>152,r</sup>, T. Wengler<sup>30</sup>, S. Wenig<sup>30</sup>,  
N. Wermes<sup>21</sup>, M. Werner<sup>48</sup>, P. Werner<sup>30</sup>, M. Wessels<sup>58a</sup>, J. Wetter<sup>162</sup>, K. Whalen<sup>29</sup>, A. White<sup>8</sup>,  
M.J. White<sup>1</sup>, R. White<sup>32b</sup>, S. White<sup>123a,123b</sup>, D. Whiteson<sup>164</sup>, D. Wicke<sup>176</sup>, F.J. Wickens<sup>130</sup>,  
W. Wiedenmann<sup>174</sup>, M. Wielers<sup>130</sup>, P. Wienemann<sup>21</sup>, C. Wiglesworth<sup>36</sup>, L.A.M. Wiik-Fuchs<sup>21</sup>,  
P.A. Wijeratne<sup>77</sup>, A. Wildauer<sup>100</sup>, M.A. Wildt<sup>42,ag</sup>, H.G. Wilkens<sup>30</sup>, J.Z. Will<sup>99</sup>,  
H.H. Williams<sup>121</sup>, S. Williams<sup>28</sup>, C. Willis<sup>89</sup>, S. Willocq<sup>85</sup>, J.A. Wilson<sup>18</sup>, A. Wilson<sup>88</sup>,  
I. Wingerter-Seez<sup>5</sup>, S. Winkelmann<sup>48</sup>, F. Winklmeier<sup>115</sup>, M. Wittgen<sup>144</sup>, T. Wittig<sup>43</sup>,  
J. Wittkowski<sup>99</sup>, S.J. Wollstadt<sup>82</sup>, M.W. Wolter<sup>39</sup>, H. Wolters<sup>125a,125c</sup>, B.K. Wosiek<sup>39</sup>,  
J. Wotschack<sup>30</sup>, M.J. Woudstra<sup>83</sup>, K.W. Wozniak<sup>39</sup>, M. Wright<sup>53</sup>, M. Wu<sup>55</sup>, S.L. Wu<sup>174</sup>, X. Wu<sup>49</sup>,  
Y. Wu<sup>88</sup>, E. Wulf<sup>35</sup>, T.R. Wyatt<sup>83</sup>, B.M. Wynne<sup>46</sup>, S. Xella<sup>36</sup>, M. Xiao<sup>137</sup>, D. Xu<sup>33a</sup>, L. Xu<sup>33b,ah</sup>,  
B. Yabsley<sup>151</sup>, S. Yacoob<sup>146b,ai</sup>, M. Yamada<sup>65</sup>, H. Yamaguchi<sup>156</sup>, Y. Yamaguchi<sup>156</sup>,  
A. Yamamoto<sup>65</sup>, K. Yamamoto<sup>63</sup>, S. Yamamoto<sup>156</sup>, T. Yamamura<sup>156</sup>, T. Yamanaka<sup>156</sup>,  
K. Yamauchi<sup>102</sup>, Y. Yamazaki<sup>66</sup>, Z. Yan<sup>22</sup>, H. Yang<sup>33e</sup>, H. Yang<sup>174</sup>, U.K. Yang<sup>83</sup>, Y. Yang<sup>110</sup>,  
S. Yanush<sup>92</sup>, L. Yao<sup>33a</sup>, W.-M. Yao<sup>15</sup>, Y. Yasu<sup>65</sup>, E. Yatsenko<sup>42</sup>, K.H. Yau Wong<sup>21</sup>, J. Ye<sup>40</sup>,  
S. Ye<sup>25</sup>, A.L. Yen<sup>57</sup>, E. Yildirim<sup>42</sup>, M. Yilmaz<sup>4b</sup>, R. Yoosoofmiya<sup>124</sup>, K. Yorita<sup>172</sup>, R. Yoshida<sup>6</sup>,  
K. Yoshihara<sup>156</sup>, C. Young<sup>144</sup>, C.J.S. Young<sup>30</sup>, S. Youssef<sup>22</sup>, D.R. Yu<sup>15</sup>, J. Yu<sup>8</sup>, J.M. Yu<sup>88</sup>,  
J. Yu<sup>113</sup>, L. Yuan<sup>66</sup>, A. Yurkewicz<sup>107</sup>, B. Zabinski<sup>39</sup>, R. Zaidan<sup>62</sup>, A.M. Zaitsev<sup>129,w</sup>,  
A. Zaman<sup>149</sup>, S. Zambito<sup>23</sup>, L. Zanello<sup>133a,133b</sup>, D. Zanzi<sup>100</sup>, A. Zaytsev<sup>25</sup>, C. Zeitnitz<sup>176</sup>,  
M. Zeman<sup>127</sup>, A. Zemla<sup>38a</sup>, K. Zengel<sup>23</sup>, O. Zenin<sup>129</sup>, T. Ženiš<sup>145a</sup>, D. Zerwas<sup>116</sup>,  
G. Zevi della Porta<sup>57</sup>, D. Zhang<sup>88</sup>, F. Zhang<sup>174</sup>, H. Zhang<sup>89</sup>, J. Zhang<sup>6</sup>, L. Zhang<sup>152</sup>, X. Zhang<sup>33d</sup>,  
Z. Zhang<sup>116</sup>, Z. Zhao<sup>33b</sup>, A. Zhemchugov<sup>64</sup>, J. Zhong<sup>119</sup>, B. Zhou<sup>88</sup>, L. Zhou<sup>35</sup>, N. Zhou<sup>164</sup>,  
C.G. Zhu<sup>33d</sup>, H. Zhu<sup>33a</sup>, J. Zhu<sup>88</sup>, Y. Zhu<sup>33b</sup>, X. Zhuang<sup>33a</sup>, A. Zibell<sup>99</sup>, D. Zieminska<sup>60</sup>,  
N.I. Zimine<sup>64</sup>, C. Zimmermann<sup>82</sup>, R. Zimmermann<sup>21</sup>, S. Zimmermann<sup>21</sup>, S. Zimmermann<sup>48</sup>,  
Z. Zinonos<sup>54</sup>, M. Ziolkowski<sup>142</sup>, R. Zitoun<sup>5</sup>, G. Zoernig<sup>174</sup>, A. Zoccoli<sup>20a,20b</sup>, M. zur Nedden<sup>16</sup>,  
G. Zurzolo<sup>103a,103b</sup>, V. Zutshi<sup>107</sup>, L. Zwalinski<sup>30</sup>

<sup>1</sup> Department of Physics, University of Adelaide, Adelaide, Australia  
<sup>2</sup> Physics Department, SUNY Albany, Albany NY, United States of America  
<sup>3</sup> Department of Physics, University of Alberta, Edmonton AB, Canada  
<sup>4</sup> <sup>(a)</sup> Department of Physics, Ankara University, Ankara; <sup>(b)</sup> Department of Physics, Gazi University, Ankara; <sup>(c)</sup> Division of Physics, TOBB University of Economics and Technology, Ankara; <sup>(d)</sup> Turkish Atomic Energy Authority, Ankara, Turkey  
<sup>5</sup> LAPP, CNRS/IN2P3 and Université de Savoie, Annecy-le-Vieux, France  
<sup>6</sup> High Energy Physics Division, Argonne National Laboratory, Argonne IL, United States of America  
<sup>7</sup> Department of Physics, University of Arizona, Tucson AZ, United States of America  
<sup>8</sup> Department of Physics, The University of Texas at Arlington, Arlington TX, United States of America  
<sup>9</sup> Physics Department, University of Athens, Athens, Greece  
<sup>10</sup> Physics Department, National Technical University of Athens, Zografou, Greece  
<sup>11</sup> Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan  
<sup>12</sup> Institut de Física d'Altes Energies and Departament de Física de la Universitat Autònoma de Barcelona, Barcelona, Spain



- 13 <sup>(a)</sup> Institute of Physics, University of Belgrade, Belgrade; <sup>(b)</sup> Vinca Institute of Nuclear Sciences, University of Belgrade, Belgrade, Serbia
- 14 Department for Physics and Technology, University of Bergen, Bergen, Norway
- 15 Physics Division, Lawrence Berkeley National Laboratory and University of California, Berkeley CA, United States of America
- 16 Department of Physics, Humboldt University, Berlin, Germany
- 17 Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern, Switzerland
- 18 School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom
- 19 <sup>(a)</sup> Department of Physics, Bogazici University, Istanbul; <sup>(b)</sup> Department of Physics, Dogus University, Istanbul; <sup>(c)</sup> Department of Physics Engineering, Gaziantep University, Gaziantep, Turkey
- 20 <sup>(a)</sup> INFN Sezione di Bologna; <sup>(b)</sup> Dipartimento di Fisica e Astronomia, Università di Bologna, Bologna, Italy
- 21 Physikalisches Institut, University of Bonn, Bonn, Germany
- 22 Department of Physics, Boston University, Boston MA, United States of America
- 23 Department of Physics, Brandeis University, Waltham MA, United States of America
- 24 <sup>(a)</sup> Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro; <sup>(b)</sup> Federal University of Juiz de Fora (UFJF), Juiz de Fora; <sup>(c)</sup> Federal University of Sao Joao del Rei (UFSJ), Sao Joao del Rei; <sup>(d)</sup> Instituto de Fisica, Universidade de Sao Paulo, Sao Paulo, Brazil
- 25 Physics Department, Brookhaven National Laboratory, Upton NY, United States of America
- 26 <sup>(a)</sup> National Institute of Physics and Nuclear Engineering, Bucharest; <sup>(b)</sup> National Institute for Research and Development of Isotopic and Molecular Technologies, Physics Department, Cluj Napoca; <sup>(c)</sup> University Politehnica Bucharest, Bucharest; <sup>(d)</sup> West University in Timisoara, Timisoara, Romania
- 27 Departamento de Física, Universidad de Buenos Aires, Buenos Aires, Argentina
- 28 Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom
- 29 Department of Physics, Carleton University, Ottawa ON, Canada
- 30 CERN, Geneva, Switzerland
- 31 Enrico Fermi Institute, University of Chicago, Chicago IL, United States of America
- 32 <sup>(a)</sup> Departamento de Física, Pontificia Universidad Católica de Chile, Santiago; <sup>(b)</sup> Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile
- 33 <sup>(a)</sup> Institute of High Energy Physics, Chinese Academy of Sciences, Beijing; <sup>(b)</sup> Department of Modern Physics, University of Science and Technology of China, Anhui; <sup>(c)</sup> Department of Physics, Nanjing University, Jiangsu; <sup>(d)</sup> School of Physics, Shandong University, Shandong; <sup>(e)</sup> Physics Department, Shanghai Jiao Tong University, Shanghai, China
- 34 Laboratoire de Physique Corpusculaire, Clermont Université and Université Blaise Pascal and CNRS/IN2P3, Clermont-Ferrand, France
- 35 Nevis Laboratory, Columbia University, Irvington NY, United States of America
- 36 Niels Bohr Institute, University of Copenhagen, Kobenhavn, Denmark
- 37 <sup>(a)</sup> INFN Gruppo Collegato di Cosenza, Laboratori Nazionali di Frascati; <sup>(b)</sup> Dipartimento di Fisica, Università della Calabria, Rende, Italy
- 38 <sup>(a)</sup> AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, Krakow; <sup>(b)</sup> Marian Smoluchowski Institute of Physics, Jagiellonian University, Krakow, Poland
- 39 The Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, Krakow, Poland
- 40 Physics Department, Southern Methodist University, Dallas TX, United States of America
- 41 Physics Department, University of Texas at Dallas, Richardson TX, United States of America
- 42 DESY, Hamburg and Zeuthen, Germany
- 43 Institut für Experimentelle Physik IV, Technische Universität Dortmund, Dortmund, Germany
- 44 Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden, Germany
- 45 Department of Physics, Duke University, Durham NC, United States of America

- 46 SUPA - School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom  
47 INFN Laboratori Nazionali di Frascati, Frascati, Italy  
48 Fakultät für Mathematik und Physik, Albert-Ludwigs-Universität, Freiburg, Germany  
49 Section de Physique, Université de Genève, Geneva, Switzerland  
50 <sup>(a)</sup> INFN Sezione di Genova; <sup>(b)</sup> Dipartimento di Fisica, Università di Genova, Genova, Italy  
51 <sup>(a)</sup> E. Andronikashvili Institute of Physics, Iv. Javakishvili Tbilisi State University, Tbilisi; <sup>(b)</sup>  
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 <sup>(a)</sup> Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg; <sup>(b)</sup>  
Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg; <sup>(c)</sup> 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 <sup>(a)</sup> INFN Sezione di Lecce; <sup>(b)</sup> 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 Louisiana Tech University, Ruston LA, United States of America  
79 Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and  
CNRS/IN2P3, Paris, France  
80 Fysiska institutionen, Lunds universitet, Lund, Sweden  
81 Departamento de Física Teórica C-15, Universidad Autónoma de Madrid, Madrid, Spain  
82 Institut für Physik, Universität Mainz, Mainz, Germany  
83 School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom  
84 CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France  
85 Department of Physics, University of Massachusetts, Amherst MA, United States of America  
86 Department of Physics, McGill University, Montreal QC, Canada  
87 School of Physics, University of Melbourne, Victoria, Australia  
88 Department of Physics, The University of Michigan, Ann Arbor MI, United States of America  
89 Department of Physics and Astronomy, Michigan State University, East Lansing MI, United States  
of America

- 90 <sup>(a)</sup> INFN Sezione di Milano; <sup>(b)</sup> Dipartimento di Fisica, Università di Milano, Milano, Italy
- 91 B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Republic of Belarus
- 92 National Scientific and Educational Centre for Particle and High Energy Physics, Minsk, Republic of Belarus
- 93 Department of Physics, Massachusetts Institute of Technology, Cambridge MA, United States of America
- 94 Group of Particle Physics, University of Montreal, Montreal QC, Canada
- 95 P.N. Lebedev Institute of Physics, Academy of Sciences, Moscow, Russia
- 96 Institute for Theoretical and Experimental Physics (ITEP), Moscow, Russia
- 97 Moscow Engineering and Physics Institute (MEPhI), Moscow, Russia
- 98 D.V.Skobeltzyn Institute of Nuclear Physics, M.V.Lomonosov Moscow State University, Moscow, Russia
- 99 Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany
- 100 Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany
- 101 Nagasaki Institute of Applied Science, Nagasaki, Japan
- 102 Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya, Japan
- 103 <sup>(a)</sup> INFN Sezione di Napoli; <sup>(b)</sup> Dipartimento di Fisica, Università di Napoli, Napoli, Italy
- 104 Department of Physics and Astronomy, University of New Mexico, Albuquerque NM, United States of America
- 105 Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands
- 106 Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands
- 107 Department of Physics, Northern Illinois University, DeKalb IL, United States of America
- 108 Budker Institute of Nuclear Physics, SB RAS, Novosibirsk, Russia
- 109 Department of Physics, New York University, New York NY, United States of America
- 110 Ohio State University, Columbus OH, United States of America
- 111 Faculty of Science, Okayama University, Okayama, Japan
- 112 Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman OK, United States of America
- 113 Department of Physics, Oklahoma State University, Stillwater OK, United States of America
- 114 Palacký University, RCPTM, Olomouc, Czech Republic
- 115 Center for High Energy Physics, University of Oregon, Eugene OR, United States of America
- 116 LAL, Université Paris-Sud and CNRS/IN2P3, Orsay, France
- 117 Graduate School of Science, Osaka University, Osaka, Japan
- 118 Department of Physics, University of Oslo, Oslo, Norway
- 119 Department of Physics, Oxford University, Oxford, United Kingdom
- 120 <sup>(a)</sup> INFN Sezione di Pavia; <sup>(b)</sup> Dipartimento di Fisica, Università di Pavia, Pavia, Italy
- 121 Department of Physics, University of Pennsylvania, Philadelphia PA, United States of America
- 122 Petersburg Nuclear Physics Institute, Gatchina, Russia
- 123 <sup>(a)</sup> INFN Sezione di Pisa; <sup>(b)</sup> Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy
- 124 Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh PA, United States of America
- 125 <sup>(a)</sup> Laboratório de Instrumentação e Física Experimental de Partículas - LIP, Lisboa; <sup>(b)</sup> Faculdade de Ciências, Universidade de Lisboa, Lisboa; <sup>(c)</sup> Department of Physics, University of Coimbra, Coimbra; <sup>(d)</sup> Centro de Física Nuclear da Universidade de Lisboa, Lisboa; <sup>(e)</sup> Departamento de Física, Universidade do Minho, Braga; <sup>(f)</sup> Departamento de Física Teórica y del Cosmos and CAFPE, Universidad de Granada, Granada (Spain); <sup>(g)</sup> Dep Física and CEFITEC of Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Caparica, Portugal
- 126 Institute of Physics, Academy of Sciences of the Czech Republic, Praha, Czech Republic
- 127 Czech Technical University in Prague, Praha, Czech Republic

- 128 Faculty of Mathematics and Physics, Charles University in Prague, Praha, Czech Republic  
 129 State Research Center Institute for High Energy Physics, Protvino, Russia  
 130 Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom  
 131 Physics Department, University of Regina, Regina SK, Canada  
 132 Ritsumeikan University, Kusatsu, Shiga, Japan  
 133 <sup>(a)</sup> INFN Sezione di Roma; <sup>(b)</sup> Dipartimento di Fisica, Sapienza Università di Roma, Roma, Italy  
 134 <sup>(a)</sup> INFN Sezione di Roma Tor Vergata; <sup>(b)</sup> Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy  
 135 <sup>(a)</sup> INFN Sezione di Roma Tre; <sup>(b)</sup> Dipartimento di Matematica e Fisica, Università Roma Tre, Roma, Italy  
 136 <sup>(a)</sup> Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies - Université Hassan II, Casablanca; <sup>(b)</sup> Centre National de l'Energie des Sciences Techniques Nucleaires, Rabat; <sup>(c)</sup> Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA-Marrakech; <sup>(d)</sup> Faculté des Sciences, Université Mohamed Premier and LPTPM, Oujda; <sup>(e)</sup> Faculté des sciences, Université Mohammed V-Agdal, Rabat, Morocco  
 137 DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l'Univers), CEA Saclay (Commissariat à l'Energie Atomique et aux Energies Alternatives), Gif-sur-Yvette, France  
 138 Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz CA, United States of America  
 139 Department of Physics, University of Washington, Seattle WA, United States of America  
 140 Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom  
 141 Department of Physics, Shinshu University, Nagano, Japan  
 142 Fachbereich Physik, Universität Siegen, Siegen, Germany  
 143 Department of Physics, Simon Fraser University, Burnaby BC, Canada  
 144 SLAC National Accelerator Laboratory, Stanford CA, United States of America  
 145 <sup>(a)</sup> Faculty of Mathematics, Physics & Informatics, Comenius University, Bratislava; <sup>(b)</sup> Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice, Slovak Republic  
 146 <sup>(a)</sup> Department of Physics, University of Cape Town, Cape Town; <sup>(b)</sup> Department of Physics, University of Johannesburg, Johannesburg; <sup>(c)</sup> School of Physics, University of the Witwatersrand, Johannesburg, South Africa  
 147 <sup>(a)</sup> Department of Physics, Stockholm University; <sup>(b)</sup> The Oskar Klein Centre, Stockholm, Sweden  
 148 Physics Department, Royal Institute of Technology, Stockholm, Sweden  
 149 Departments of Physics & Astronomy and Chemistry, Stony Brook University, Stony Brook NY, United States of America  
 150 Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom  
 151 School of Physics, University of Sydney, Sydney, Australia  
 152 Institute of Physics, Academia Sinica, Taipei, Taiwan  
 153 Department of Physics, Technion: Israel Institute of Technology, Haifa, Israel  
 154 Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel  
 155 Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece  
 156 International Center for Elementary Particle Physics and Department of Physics, The University of Tokyo, Tokyo, Japan  
 157 Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo, Japan  
 158 Department of Physics, Tokyo Institute of Technology, Tokyo, Japan  
 159 Department of Physics, University of Toronto, Toronto ON, Canada  
 160 <sup>(a)</sup> TRIUMF, Vancouver BC; <sup>(b)</sup> Department of Physics and Astronomy, York University, Toronto ON, Canada  
 161 Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba, Japan  
 162 Department of Physics and Astronomy, Tufts University, Medford MA, United States of America  
 163 Centro de Investigaciones, Universidad Antonio Narino, Bogota, Colombia

- 164 Department of Physics and Astronomy, University of California Irvine, Irvine CA, United States of America
- 165 <sup>(a)</sup> INFN Gruppo Collegato di Udine, Sezione di Trieste, Udine; <sup>(b)</sup> ICTP, Trieste; <sup>(c)</sup> Dipartimento di Chimica, Fisica e Ambiente, Università di Udine, Udine, Italy
- 166 Department of Physics, University of Illinois, Urbana IL, United States of America
- 167 Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden
- 168 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
- 169 Department of Physics, University of British Columbia, Vancouver BC, Canada
- 170 Department of Physics and Astronomy, University of Victoria, Victoria BC, Canada
- 171 Department of Physics, University of Warwick, Coventry, United Kingdom
- 172 Waseda University, Tokyo, Japan
- 173 Department of Particle Physics, The Weizmann Institute of Science, Rehovot, Israel
- 174 Department of Physics, University of Wisconsin, Madison WI, United States of America
- 175 Fakultät für Physik und Astronomie, Julius-Maximilians-Universität, Würzburg, Germany
- 176 Fachbereich C Physik, Bergische Universität Wuppertal, Wuppertal, Germany
- 177 Department of Physics, Yale University, New Haven CT, United States of America
- 178 Yerevan Physics Institute, Yerevan, Armenia
- 179 Centre de Calcul de l'Institut National de Physique Nucléaire et de Physique des Particules (IN2P3), Villeurbanne, France
- <sup>a</sup> Also at Department of Physics, King's College London, London, United Kingdom
- <sup>b</sup> Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan
- <sup>c</sup> Also at Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom
- <sup>d</sup> Also at TRIUMF, Vancouver BC, Canada
- <sup>e</sup> Also at Department of Physics, California State University, Fresno CA, United States of America
- <sup>f</sup> Also at Novosibirsk State University, Novosibirsk, Russia
- <sup>g</sup> Also at CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France
- <sup>h</sup> Also at Università di Napoli Parthenope, Napoli, Italy
- <sup>i</sup> Also at Institute of Particle Physics (IPP), Canada
- <sup>j</sup> Also at Department of Financial and Management Engineering, University of the Aegean, Chios, Greece
- <sup>k</sup> Also at Louisiana Tech University, Ruston LA, United States of America
- <sup>l</sup> Also at Institutio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona, Spain
- <sup>m</sup> Also at CERN, Geneva, Switzerland
- <sup>n</sup> Also at Ochadai Academic Production, Ochanomizu University, Tokyo, Japan
- <sup>o</sup> Also at Manhattan College, New York NY, United States of America
- <sup>p</sup> Also at Institute of Physics, Academia Sinica, Taipei, Taiwan
- <sup>q</sup> Also at Department of Physics, Nanjing University, Jiangsu, China
- <sup>r</sup> Also at School of Physics and Engineering, Sun Yat-sen University, Guangzhou, China
- <sup>s</sup> Also at Academia Sinica Grid Computing, Institute of Physics, Academia Sinica, Taipei, Taiwan
- <sup>t</sup> Also at Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France
- <sup>u</sup> Also at School of Physical Sciences, National Institute of Science Education and Research, Bhubaneswar, India
- <sup>v</sup> Also at Dipartimento di Fisica, Sapienza Università di Roma, Roma, Italy
- <sup>w</sup> Also at Moscow Institute of Physics and Technology State University, Dolgoprudny, Russia
- <sup>x</sup> Also at Section de Physique, Université de Genève, Geneva, Switzerland
- <sup>y</sup> Also at Department of Physics, The University of Texas at Austin, Austin TX, United States of America
- <sup>z</sup> Also at Institute for Particle and Nuclear Physics, Wigner Research Centre for Physics, Budapest, Hungary

- <sup>aa</sup> Also at International School for Advanced Studies (SISSA), Trieste, Italy
- <sup>ab</sup> Also at Department of Physics and Astronomy, University of South Carolina, Columbia SC, United States of America
- <sup>ac</sup> Also at Faculty of Physics, M.V.Lomonosov Moscow State University, Moscow, Russia
- <sup>ad</sup> Also at Physics Department, Brookhaven National Laboratory, Upton NY, United States of America
- <sup>ae</sup> Also at Moscow Engineering and Physics Institute (MEPhI), Moscow, Russia
- <sup>af</sup> Also at Department of Physics, Oxford University, Oxford, United Kingdom
- <sup>ag</sup> Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany
- <sup>ah</sup> Also at Department of Physics, The University of Michigan, Ann Arbor MI, United States of America
- <sup>ai</sup> Also at Discipline of Physics, University of KwaZulu-Natal, Durban, South Africa
- \* Deceased