



# Search for long-lived, multi-charged particles in $pp$ collisions at $\sqrt{s} = 7$ TeV using the ATLAS detector<sup>☆</sup>

ATLAS Collaboration<sup>\*</sup>

## ARTICLE INFO

### Article history:

Received 22 January 2013  
 Received in revised form 3 April 2013  
 Accepted 19 April 2013  
 Available online 24 April 2013  
 Editor: H. Weerts

### Keywords:

High-energy collider experiment  
 Long-lived particle  
 Highly ionising  
 New physics  
 Multiple electric charges

## ABSTRACT

A search for highly ionising, penetrating particles with electric charges from  $|q| = 2e$  to  $6e$  is performed using the ATLAS detector at the CERN Large Hadron Collider. Proton–proton collision data taken at  $\sqrt{s} = 7$  TeV during the 2011 running period, corresponding to an integrated luminosity of  $4.4 \text{ fb}^{-1}$ , are analysed. No signal candidates are observed, and 95% confidence level cross-section upper limits are interpreted as mass-exclusion lower limits for a simplified Drell–Yan production model. In this model, masses are excluded from 50 GeV up to 430, 480, 490, 470 and 420 GeV for charges  $2e$ ,  $3e$ ,  $4e$ ,  $5e$  and  $6e$ , respectively.

© 2013 CERN. Published by Elsevier B.V. Open access under [CC BY-NC-ND license](#).

## 1. Introduction

Numerous theories of physics beyond the Standard Model (SM) predict long-lived<sup>1</sup> exotic objects producing anomalous ionisation. These include magnetic monopoles [1], dyons [2], long-lived micro black holes in models of low-scale gravity [3] and  $Q$ -balls [4], which are non-topological solitons predicted by minimal supersymmetric generalisations of the SM. No such particles have so far been observed in cosmic-ray and collider searches [1,5–7], including several recent searches at the Large Hadron Collider (LHC) [8–13]. The high centre-of-mass energy of the LHC makes a new energy regime accessible, and searching for multi-charged particles with electric charges  $2e \leq |q| \leq 6e$  complements the searches for singly charged particles [10] and for particles with charges beyond  $6e$  [8].

The existence of long-lived particles with an electric charge  $|q| > e$  could have implications for the formation of composite dark matter [14]. Two extensions of the SM in which heavy stable multi-charged particles are predicted are the AC model [15] and the walking technicolour model [16–18]. The AC model is based on the approach of almost-commutative geometry [19] which extends the fermion content of the SM by two heavy particles with

opposite electric charges,  $\pm q$ . The minimal walking technicolour model predicts the existence of three particle pairs, with electric charges given in general by  $q + e$ ,  $q$ , and  $q - e$ , which would behave like leptons in the detector. In both of these models,  $|q|$  may be larger than  $e$ .

This Letter describes a search for multi-charged particles in  $\sqrt{s} = 7$  TeV  $pp$  collisions using data collected in 2011 by the ATLAS detector at the CERN LHC. The data sample corresponds to an integrated luminosity of  $4.4 \text{ fb}^{-1}$ . Multi-charged particles will be highly ionising, and thus leave an abnormally large specific ionisation signal,  $dE/dx$ . In this Letter, a search for such particles traversing the ATLAS detector leaving a track in the inner tracking detector, and producing a signal in the muon spectrometer, is reported. A SM-like coupling proportional to the electric charge is assumed as the production model of the multi-charged particles. Therefore, the main production mode is Drell–Yan (DY) with no weak coupling. Multi-charged particles can also be pair-produced from radiated photons resulting in a larger production cross section, and in some cases non-perturbative effects [20] can also enhance the production rate. In the derivation of limits, neither enhancement is included in the calculation resulting in conservative limits in these scenarios.

## 2. ATLAS detector

The ATLAS detector [21] covers nearly the entire solid angle around the collision point. It consists of an inner tracking detector (ID) comprising a silicon pixel detector (pixel), a silicon microstrip

<sup>\*</sup> E-mail address: [atlas.publications@cern.ch](mailto:atlas.publications@cern.ch).

<sup>1</sup> The term long-lived in this paper refers to a particle that does not decay within the ATLAS detector.

detector (SCT) and a Transition Radiation Tracker (TRT). Apart from being a straw-based tracking detector, the TRT (covering  $|\eta| < 2.0$ )<sup>2</sup> also provides particle identification via transition radiation and ionisation energy-loss measurements [22]. The ID is surrounded by a thin superconducting solenoid providing a 2 T axial magnetic field, and by high-granularity liquid-argon (LAr) sampling electromagnetic calorimeters. An iron-scintillator tile calorimeter provides hadronic energy measurements in the central rapidity region. The endcap and forward regions are instrumented with LAr calorimeters for both electromagnetic and hadronic energy measurements. The calorimeter system is surrounded by a muon spectrometer (MS) incorporating three superconducting toroid magnet assemblies. The MS is a combination of several sub-detectors used to measure muons that traverse the ATLAS calorimeters. The Resistive Plate Chambers (RPC) in the barrel region ( $|\eta| < 1.05$ ) and the Thin Gap Chambers (TGC) in the endcap region ( $1.05 < |\eta| < 2.4$ ) provide signals for the trigger for charged particles reaching the MS. Monitored Drift Tube (MDT) chambers measure the momentum and track positions of muons with very high precision.

### 3. Simulated samples

Benchmark samples of simulated events with multi-charged particles are produced for masses of 50, 100, 200, 300, 400, 500 and 600 GeV, with charges<sup>3</sup>  $2e$ ,  $3e$ ,  $4e$ ,  $5e$  and  $6e$ . Pairs of long-lived multi-charged particles are simulated using MADGRAPH5 [23] via the DY process to model the kinematic distributions. The DY production model also determines the cross section used for limit setting. Typical values for the cross sections of simulated multi-charge pair-production range from tens of pb for a mass of 50 GeV down to a few fb at a mass of 600 GeV. Events are generated using the CTEQ6L1 [24] parton distribution functions, and PYTHIA version 6.425 [25] is used for hadronisation and underlying-event generation. A GEANT4 simulation [26,27] is used to model the response of the ATLAS detector, and the samples are reconstructed and analysed in the same way as the data. The production cross sections are estimated using MADGRAPH5 and are cross-checked with CALCHEP 3.4 [28]. Each simulated event is overlaid with additional collision events (“pile-up”) in order to reproduce the observed distribution of the number of proton–proton collisions per bunch crossing. In 2011 data the average number of interactions per bunch crossing was typically between 5 and 20. These samples are used to determine the detection efficiency, the resolution on the quantities used in the event selection and the associated systematic uncertainties for multi-charged particles. While the background estimation is data-driven, muons from  $Z \rightarrow \mu\mu$  simulated samples are used to calibrate the selection variables. These samples are generated in PYTHIA and passed through the GEANT4 simulation of the ATLAS detector.

### 4. Ionisation estimators

The specific energy loss,  $dE/dx$ , is described by the Bethe–Bloch formula [29]. The energy loss depends quadratically on the particle charge,  $q$ , so that particles with higher charges have a significantly higher energy loss.

<sup>2</sup> The ATLAS coordinate system is right-handed with the pseudorapidity,  $\eta$ , defined as  $\eta = -\ln[\tan(\theta/2)]$ , where the polar angle  $\theta$  is measured with respect to the LHC beamline. The azimuthal angle,  $\phi$ , is measured with respect to the  $x$ -axis, which points towards the centre of the LHC ring. The  $z$ -axis is parallel to the anti-clockwise beam viewed from above. Transverse momentum and energy are defined as  $p_T = p \sin \theta$  and  $E_T = E \sin \theta$ , respectively.

<sup>3</sup> Wherever a charge is quoted for the exotic particles, the charge conjugate state is also implied.

#### 4.1. MDT $dE/dx$

Each drift tube of the MDT system provides a signal proportional to the charge from ionisation, which is used to estimate  $dE/dx$ . A truncated mean of  $dE/dx$ , where the maximum value is removed, is used as the overall MDT  $dE/dx$  estimator. As each track crosses more than 20 drift tubes, the MDT  $dE/dx$  provides a good estimate of ionisation losses.

#### 4.2. TRT $dE/dx$

Energy deposits in a TRT straw greater than 200 eV (low-threshold hits) are used for tracking, while those that exceed 6 keV (high-threshold hits) occur due to the passage of highly ionising particles or due to transition radiation emitted by highly relativistic electrons when they cross radiator material between the straws. The estimated  $dE/dx$  value for each hit is derived from the time the signal remains above the low threshold. The TRT  $dE/dx$  is the truncated mean of the  $dE/dx$  estimates, where the highest estimate is removed. On average, a track in the TRT contains 32 hits. Additionally, the ratio of the number of high-threshold (HT) hits to the total number of TRT hits on a given track  $f^{\text{HT}}$  provides a second estimator of high ionisation.

#### 4.3. Pixel $dE/dx$

The pixel detector measures the charge from ionisation in each pixel. The  $dE/dx$  from the pixel detector is calculated from the truncated mean of measurements from several clusters of pixels [30]. Particles with charges higher than  $2e$  deposit energies which easily exceed the dynamic range of the pixel detector readout. Therefore, the electronic signal is saturated and pixel information will not be read out leading to an unreliable  $dE/dx$  measurement for such particles.

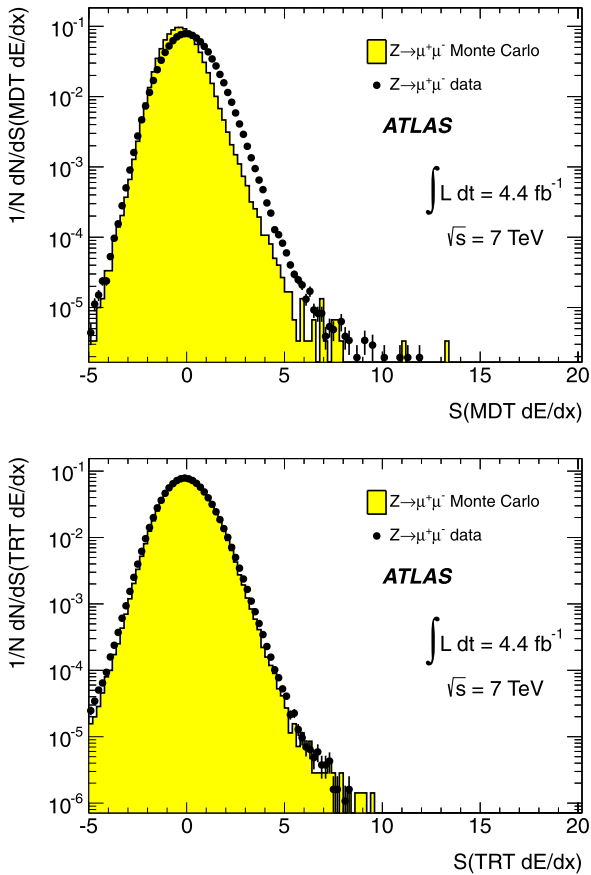
#### 4.4. $dE/dx$ significance

The significance of each  $dE/dx$  variable is defined as the difference between the observed  $dE/dx$  of the track and that expected for muons, measured in units of the uncertainty of the measurement:

$$S(dE/dx) = \frac{dE/dx_{\text{track}} - \langle dE/dx_{\mu} \rangle}{\sigma(dE/dx_{\mu})}. \quad (1)$$

Here  $dE/dx_{\text{track}}$  represents the estimated  $dE/dx$  of the track, and  $\langle dE/dx_{\mu} \rangle$  and  $\sigma(dE/dx_{\mu})$ , respectively, are the mean and the width of the  $dE/dx$  distribution for muons in data.

To obtain expected  $dE/dx$  values and their resolution for the different detector components (MDT, TRT, Pixel), the  $dE/dx$  variables are calibrated with muons from  $Z \rightarrow \mu\mu$  events in data and simulation. Muons for this calibration are selected by requiring a track reconstructed in the MS matched to a good quality track in the ID with  $p_T > 20$  GeV and  $|\eta| < 2.4$ . Each muon is further required to belong to an oppositely charged pair with dimuon mass between 81 GeV and 101 GeV. Fig. 1 shows the comparison between these muons in data and simulation for the MDT and TRT  $dE/dx$  significance. While the TRT distribution shows good agreement except in the tails, a discrepancy between simulation and data is observed for the MDT significance. This discrepancy has a small effect on the limit setting, and the effect is included in the systematic uncertainties. Fig. 2 shows the distributions of the MDT and TRT  $dE/dx$  significance for simulated muons from  $Z \rightarrow \mu\mu$  production compared to those of multi-charged particles for different charges ( $2e$ ,  $4e$  and  $6e$ ) and for a mass of 200 GeV. For the multi-charge particle search, the  $S(\text{MDT } dE/dx)$  and  $S(\text{TRT } dE/dx)$



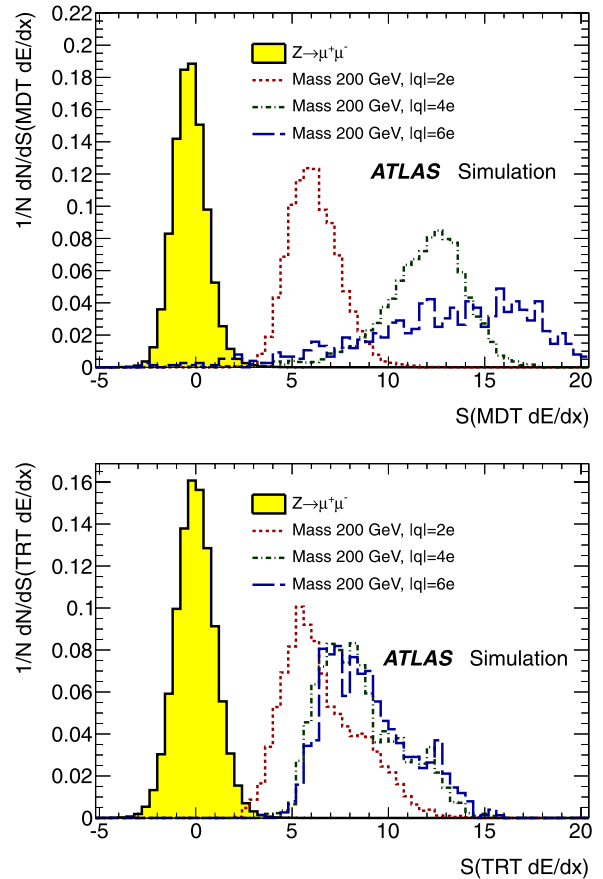
**Fig. 1.** Comparison of normalised distributions of the  $S(\text{MDT } dE/dx)$  (top) and  $S(\text{TRT } dE/dx)$  (bottom) for muons from  $Z \rightarrow \mu\mu$  events in data and simulation.

variables are required to exceed threshold values. These thresholds are established from the separation of the  $dE/dx$  significance distributions between muons and  $|q| = 2e$  signal particles. The  $dE/dx$  significance distributions for higher charge values,  $|q| > 2e$ , are further separated from muons, as seen for simulated events in Fig. 2. The detailed response for these higher charge particles may not be perfectly modelled by the simulation due to saturation effects. However, their  $dE/dx$  response will certainly be higher than that of  $|q| = 2e$  particles, and thus their detailed response has no significance for the analysis. The separation power of the pixel  $dE/dx$  significance is shown in Fig. 3 for a  $2e$  charge at  $m = 200, 400$  and  $600$  GeV. The behaviour of the  $dE/dx$  significance distributions is found to be as expected with respect to  $p_T$ ,  $\eta$ , and  $\phi$ . For simulated multi-charged particles the  $dE/dx$  significances strongly depend on the particle's charge and weakly on the particle's mass.

## 5. Event and candidate selection

Multi-charged candidates are sought for among those particles traversing the entire ATLAS detector, thus being initially selected as muons. Candidates are selected by analysing the specific ionisation losses in the different detectors. The search is based on a cut-and-count method, described in Section 6, where the signal region is defined by high  $dE/dx$  significances of the track measured by the TRT and MDT detectors.

Track reconstruction assumes particles with charge  $\pm 1e$ , whereas particles with higher charges bend more in the magnetic field. Therefore, the effective cut on the momentum of the multi-charged particle imposed by the trigger and selection is a factor



**Fig. 2.** Normalised distributions of  $S(\text{MDT } dE/dx)$  (top) and  $S(\text{TRT } dE/dx)$  (bottom) for simulated muons and multi-charged particles. Distributions are shown for the signal samples for  $|q| = 2e, 4e$  and  $6e$ , for a mass of  $200$  GeV.

of  $|q|/e$  higher than the cut on the muon candidate. In the following, we will refer to  $p_T$  as the reconstructed transverse momentum assuming charge  $|q| = 1e$ .

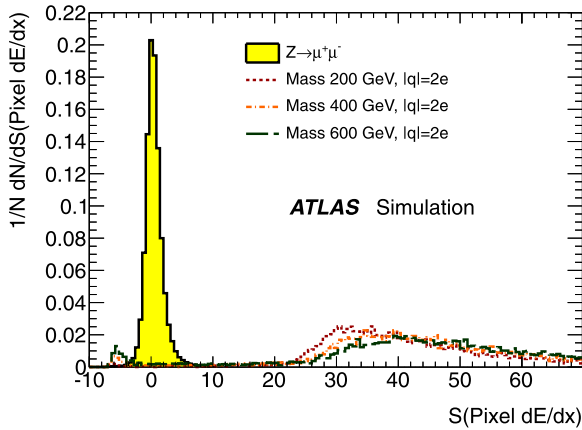
### 5.1. Trigger and event selection

Events collected with a single-muon trigger [31] with a transverse momentum threshold of  $p_T = 18$  GeV are considered. In simulated events the trigger efficiency from the RPC is corrected as a function of a particle's  $\eta$  and  $\beta$ , where  $\beta$  is the ratio of the particle's velocity to the speed of light. Events are further required<sup>4</sup> to contain either at least one muon with  $p_T > 75$  GeV or at least two muons with  $p_T > 15$  GeV.

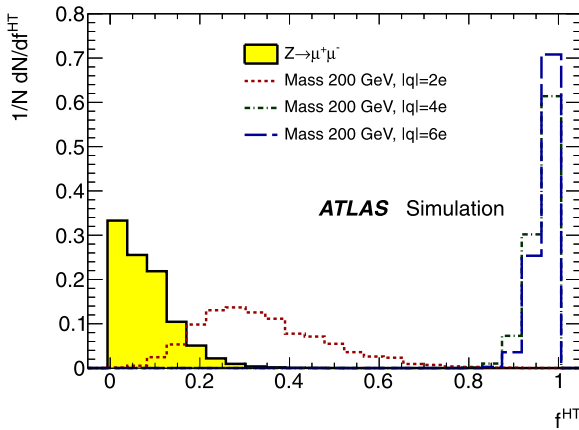
### 5.2. Candidate selection

Candidate particles are tracks reconstructed in the MS which are required to be matched to the object passing the muon trigger, and to originate within tolerances from the primary interaction point. They must also be within the acceptance region  $|\eta| < 2.0$ , have a  $p_T > 20$  GeV, and leave a high-quality track in the ID. However, because of potential pixel readout saturation, there is no requirement that a candidate particle has pixel information. The  $p_T$  measured by the muon system is smaller than the  $p_T$

<sup>4</sup> Information on the MDT  $dE/dx$  is not available in the standard ATLAS data stream. Hence, this analysis is based on a special stream which includes this information. The  $p_T$  requirements on muons given here are imposed for the preparation of this stream and are not optimised for the current analysis.



**Fig. 3.** Normalised distribution of  $S(\text{pixel } dE/dx)$  for simulated muons and multi-charged particles. Distributions are shown for the signal sample for  $|q| = 2e$ , for masses of 200, 400 and 600 GeV. The structure at a significance of  $-5$  is from pixel readout saturation.

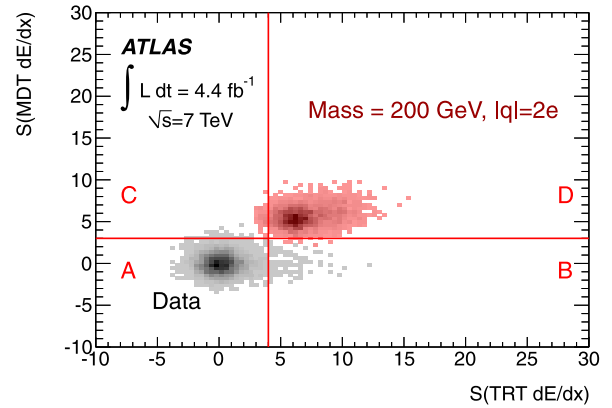


**Fig. 4.** Normalised distribution of  $f^{\text{HT}}$  for simulated muons and multi-charged particles. Distributions are shown for the signal samples for  $|q| = 2e, 4e,$  and  $6e$  for a mass of 200 GeV.

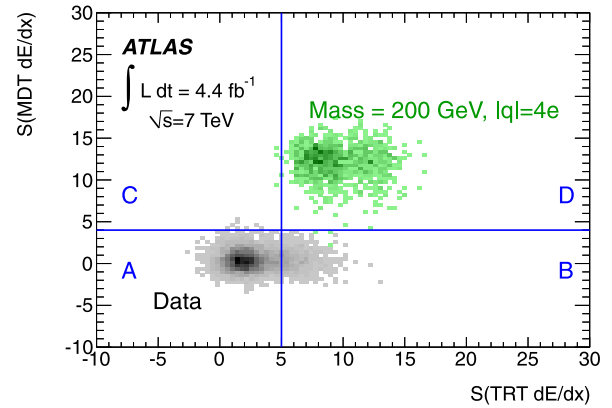
measured in the ID due to energy loss in the calorimeters, and the  $p_T$  in the ID is used for candidate selection. In the track candidate selection, the measurement of the ionisation energy loss in the calorimeter system was not used. However, the calorimeter energy loss was validated for use as an independent cross-check in case of an observation of candidates above the expected background.

An initial preselection of highly ionising candidates is based on the pixel  $dE/dx$  significance and the TRT high-threshold fraction  $f^{\text{HT}}$ . As seen in Fig. 3, the pixel  $dE/dx$  significance is a powerful discriminator for particles with  $|q| = 2e$ . The signal region is defined by candidates with a significance greater than 10. For higher values of  $|q|$ , the pixel readout saturates and the  $dE/dx$  signal is no longer reliable. Therefore, to search for particles with  $|q| > 2e$ , the TRT  $f^{\text{HT}}$  (see Fig. 4) is used as a discriminating variable instead. The signal region is defined by requiring the  $f^{\text{HT}}$  to be above 0.4. This preselection using the pixel  $dE/dx$  or the  $f^{\text{HT}}$  reduces the background contribution by almost three orders of magnitude for both  $|q| = 2e$  and  $|q| > 2e$ .

In the final step of the search, the MDT  $dE/dx$  significance,  $S(\text{MDT } dE/dx)$ , and the TRT  $dE/dx$  significance,  $S(\text{TRT } dE/dx)$ , are used as discriminating variables to separate the signal and background. These variables are shown for real data and simulated signal events in Fig. 5 (Fig. 6) for candidates preselected as  $|q| = 2e$  ( $|q| > 2e$ ). Only the signal sample for a mass of 200 GeV is shown



**Fig. 5.** The plane of TRT and MDT  $dE/dx$  significances after the  $|q| = 2e$  selection. The distributions of the 2011 data and the signal sample (here for a mass of 200 GeV) are shown. The regions labelled A, B and C are control regions used to estimate the background expected in the signal region D.



**Fig. 6.** The plane of TRT and MDT  $dE/dx$  significances after the  $|q| > 2e$  selection. The distributions of the 2011 data and the signal sample (here for a mass of 200 GeV and  $|q| = 4e$ ) are shown. The regions labelled A, B and C are control regions used to estimate the background expected in the signal region D.

**Table 1**

The final signal regions for the two preselections.

	$S(\text{MDT } dE/dx)$	$S(\text{TRT } dE/dx)$
$ q  = 2e$	$> 3$	$> 4$
$ q  > 2e$	$> 4$	$> 5$

as there is very little change in the selection variables for different masses. As seen, the detector signatures are different for the two preselected samples, and thus the final signal regions are chosen differently. They are defined in Table 1. The selection was optimised using only simulated samples and data control samples without examining the signal region in the data.

## 6. Background estimation

The background contribution to the signal region is estimated using an ABCD method. In this method, the regions A, B, C and D are defined by dividing the plane of the uncorrelated TRT and MDT  $dE/dx$  significances using the final selection cuts, as seen in Figs. 5 and 6. The region D is defined as the signal region, with regions A, B and C as control regions for the background. The expected number of candidates from background in the region D,  $N_{\text{data}}^{\text{D}}$ , is estimated from the numbers of observed data candidates in regions A, B and C ( $N_{\text{data}}^{\text{A,B,C}}$ ):

**Table 2**

The observed candidate yields in data for an integrated luminosity of  $4.4 \text{ fb}^{-1}$ . The last column shows the expected background in the signal region D with statistical uncertainty.

	A	B	C	D	D <sub>exp.</sub>
$ q  = 2e$	8543	92	38	0	$0.41 \pm 0.08$
$ q  > 2e$	4940	754	9	0	$1.37 \pm 0.46$

**Table 3**

The efficiencies to select a signal candidate (in %) for the DY production model.

Mass [GeV]	Efficiencies [%]				
	$ q  = 2e$	$ q  = 3e$	$ q  = 4e$	$ q  = 5e$	$ q  = 6e$
50	4.3	2.0	0.3	0.03	0.003
100	8.6	5.5	2.3	0.4	0.07
200	12.6	9.2	4.6	1.8	0.5
300	12.6	9.9	5.8	2.5	0.8
400	10.9	9.0	5.6	2.9	1.0
500	9.9	8.5	5.3	2.9	1.3
600	7.8	6.8	4.6	2.3	1.1

$$N_{\text{data}}^D = \frac{N_{\text{data}}^B \times N_{\text{data}}^C}{N_{\text{data}}^A} \quad (2)$$

Table 2 gives the number of candidates in A, B and C, as well as the observed number of candidates in the signal region D after the final selection. These results are compared to the expected number of background candidates of  $0.41 \pm 0.08$  for the  $|q| = 2e$  selection and  $1.37 \pm 0.46$  for the  $|q| > 2e$  selection. The uncertainties are statistical. The systematic uncertainty on the background estimation is discussed in Section 8.1.

## 7. Signal selection efficiency

The signal cross section is given by

$$\sigma = \frac{N_{\text{data}}^{\text{rec}}}{2 \times \mathcal{L} \times \epsilon} \quad (3)$$

where  $\mathcal{L}$  is the integrated luminosity of the analysed data,  $N_{\text{data}}^{\text{rec}}$  the number of candidate particles in data above the expected background and the factor of 2 is the number of particles per event in the DY model. The efficiency  $\epsilon$  includes trigger, reconstruction and selection efficiencies. The efficiency is the number of all multi-charged particles that satisfy the selection criteria divided by the number of all simulated multi-charged particles.

The efficiency to find a multi-charged particle is given in Table 3 for each signal sample. Several factors contribute to the overall low efficiency and its dependencies on mass and charge. The  $|\eta| < 2.0$  selection and the requirement to reach the MS with a  $\beta$  which fits the timing window for the trigger are the primary causes of the reduction in efficiency. For the simulated signal samples, this timing requirement generally implies a momentum requirement stricter than the explicit  $p_T$  selection. The implied selection can be as high as approximately  $p_T/q > 120 \text{ GeV}$ . The charge dependence of the efficiency results from higher ionisation and the higher effective single-muon  $p_T$  selection, which are augmented by the factors  $q^2$  and  $q$ , respectively. The mass dependence has two competing factors: at low mass there are more candidates above  $|\eta| = 2.0$ , while at high mass the  $\beta$  spectrum is softer.

## 8. Systematic uncertainties

The systematic uncertainties on the background estimate and on the signal efficiency are determined by varying the selection cuts within the uncertainty on each selection variable.

### 8.1. Background estimation uncertainty

The background estimate in the signal region, D, relies on the fact that the  $S(\text{TRT } dE/dx)$  and the  $S(\text{MDT } dE/dx)$  are uncorrelated. To estimate potential influences of signal contamination close to the region boundaries and remaining correlations in the tails of the distributions, the ABCD regions are varied. For this estimate, the signal region D is maintained, but regions A, B and C are redefined by excluding the region close to the default cut from the background estimation. This ensures a higher background purity. This test is performed for many different definitions of the control regions and leads to an uncertainty of 5% on the estimated background contribution in the signal region.

### 8.2. Trigger efficiency uncertainty

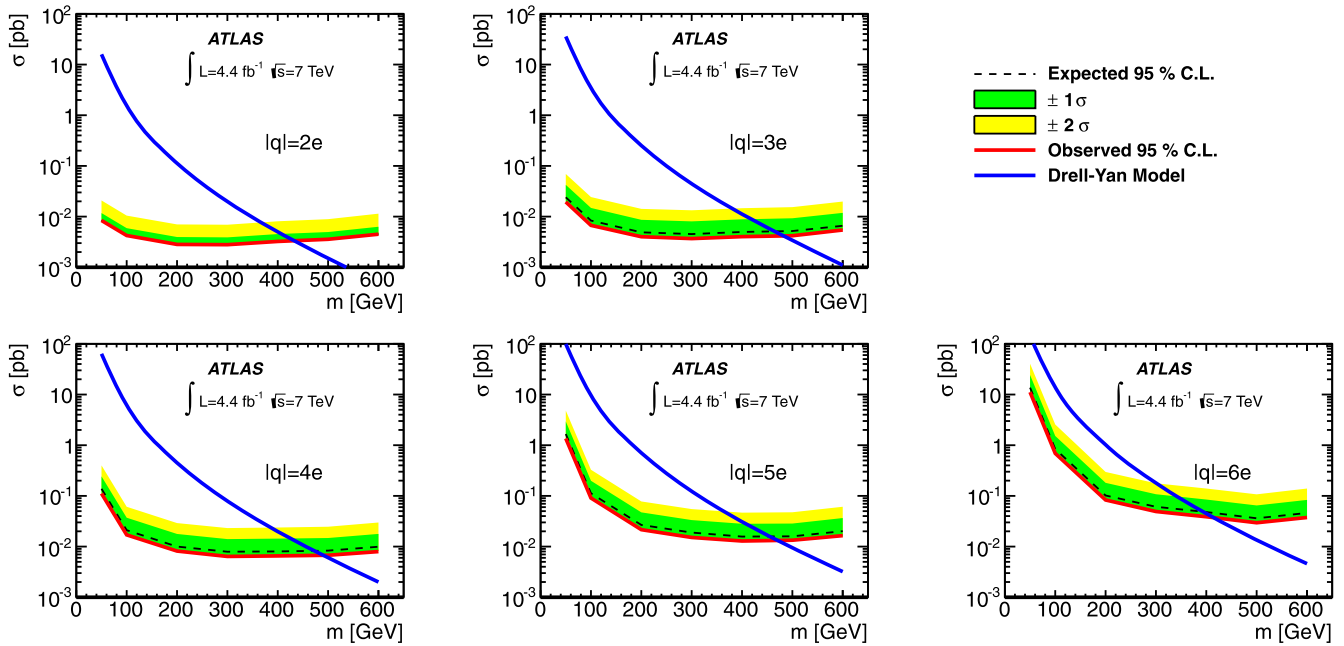
The uncertainty on the trigger efficiency has two sources: the standard uncertainty on the trigger efficiency of 1% as determined by ATLAS muon performance studies [31] and a  $\beta$ -dependent trigger uncertainty. The size of the  $\beta$ -dependent part is dominated by the uncertainty on the timing correction of the RPC trigger efficiency (trigger for  $|\eta| < 1.05$ ). This correction is varied by  $\pm 50\%$  to account for the large dependence of the efficiency on the trigger timing. The relative difference of the trigger efficiencies between the nominal and the varied correction depends on the mass and charge of the benchmark samples, and ranges from less than 1% for  $|q| = 6e$ ,  $m = 50 \text{ GeV}$  to 24% for  $|q| = 5e$ ,  $m = 600 \text{ GeV}$ . The timing in the TGC (trigger for  $|\eta| \geq 1.05$ ) for data and simulation is in good agreement, and the systematic uncertainty for the TGC timing correction is negligible. The systematic uncertainty on whether a candidate particle would reach the MS in the timing window for the trigger selection also depends on the simulation of energy losses in the calorimeters and the material description of the detector. In a study using muons from  $Z \rightarrow \mu\mu$  events in data and simulation, the energy-loss difference between data and simulation is less than 5%. A cross-check that varies the amount of material by  $\pm 10\%$  has a negligible effect on the total systematic uncertainty.

### 8.3. Uncertainties due to selection

The uncertainties on the selection efficiency arise from the uncertainties on each selection variable used. The following variations of the nominal cuts are studied:  $p_T$  by  $\pm 3\%$ ,  $S(\text{pixel } dE/dx)$  by  $\pm 5\%$ , TRT HT fraction by  $\pm 20\%$ ,  $S(\text{TRT } dE/dx)$  by  $\pm 5\%$  and  $S(\text{MDT } dE/dx)$  by  $-5\%$  and  $+50\%$ . For the  $p_T$  cut this corresponds to the resolution of the track  $p_T$  measurements. The variation of 20% of the TRT HT fraction arises from the pile-up dependence of this variable. For the pixel and the TRT  $dE/dx$  significances, 5% corresponds to the observed agreement of the mean and width of these distributions in the  $Z \rightarrow \mu\mu$  events in data and simulation. This is also applied to the lower variation of  $S(\text{MDT } dE/dx)$ . Here, a relative shift between simulation and data is observed. The magnitude and direction of this shift suggest a variation of  $S(\text{MDT } dE/dx)$  by 50% in the positive direction. While this would have been important for a potential signal interpretation, it has only a small effect on the limit setting. For all other variables the variations have no observable effect in any of the signal samples. The total systematic uncertainties on the efficiency arising from these cut variations range up to 2.1%.

### 8.4. Summary of systematic uncertainties

In Table 4 the quadratic sums of all the systematic uncertainties considered above are summarised for the different signal



**Fig. 7.** Upper limits on the production cross section of multi-charged highly ionising particles from pair-production as a function of particle mass. The dotted line shows the expected limit with the  $\pm 1\sigma$  and  $\pm 2\sigma$  uncertainty bands. The observed limit is compared with the predicted rapidly falling cross section from the DY model. The plots are shown separately for charges from  $|q|=2e$  to  $|q|=6e$ . In the  $|q|=2e$  case, the observed limit lies on top of the expected limit.

**Table 4**

Summary of relative systematic uncertainties on the expected number of candidates derived from the uncertainties on the background estimation, trigger efficiency, Monte Carlo statistics and due to selection cuts.

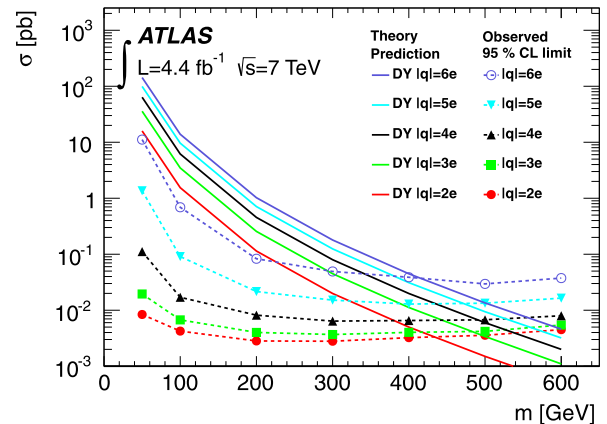
Mass [GeV]	Quadratic sum of systematic uncertainties [%]				
	$ q =2e$	$ q =3e$	$ q =4e$	$ q =5e$	$ q =6e$
50	8	6	6	10	19
100	10	9	7	12	28
200	13	12	10	9	12
300	14	15	15	12	11
400	17	17	18	18	13
500	18	18	19	21	18
600	22	22	23	25	24

samples. The two main uncertainties are the uncertainty on the trigger efficiency and the uncertainty due to the small number of Monte Carlo events. The latter makes a significant contribution for some of the high-charge and low-mass samples. The 50 GeV samples were produced with a selection at the generator level requiring  $p_T/q > 15$  GeV in order to decrease the statistical uncertainty. The systematic uncertainties vary between 6% and 28% in total.

The uncertainty on the integrated luminosity is estimated to be 3.9% from Van der Meer scans [32,33] and is not included in Table 4.

## 9. Results

No signal candidates are found for either the  $|q|=2e$  or the  $|q| > 2e$  selected sample. The results are consistent with the expectation of  $0.41 \pm 0.08 \pm 0.02$  and  $1.37 \pm 0.46 \pm 0.07$  background candidates, respectively. From these numbers the expected and observed limits are computed using pseudo-experiments. For the total cross-section limit, the systematic uncertainties on efficiency and the luminosity are taken into account in the pseudo-experiments. For every benchmark point, 100 000 pseudo-experiments are used. The measurement excludes DY model pair-production over wide ranges of tested masses. Fig. 7 shows the



**Fig. 8.** Observed 95% CL cross-section upper limits and theoretical cross sections as functions of the multi-charged particle mass.

observed 95% confidence level cross-section limits as a function of mass for the five different charges. Due to the low number of expected events, the dominant uncertainty arises from Poisson statistics as reflected in the asymmetric uncertainty bands. The limits range from around  $10^{-2}$  pb for the lower charges to  $10^{-1}$  pb for  $|q|=6e$ . In addition to the expected and observed limits the predicted cross section is shown for the simplified Drell-Yan model. For the given model the cross-section limits can be transformed into mass-exclusion lower limits from 50 GeV to 430, 480, 490, 470 and 420 GeV for charges  $|q|=2e, 3e, 4e, 5e$  and  $6e$ , respectively. Fig. 8 summarises the observed limits.

## 10. Summary

A search for long-lived, multi-charged particles has been performed using an integrated luminosity of  $4.4 \text{ fb}^{-1}$  of  $pp$  collisions recorded by the ATLAS detector at the LHC. No candidates are found in the 2011 data set, consistent with the background expectation. The results presented here are the first mass limits from

ATLAS for charges of  $2e$  to  $6e$ , filling the missing range of charges between the searches for slow singly charged long-lived particles [10] and searches for particles with charges from  $6e$  to  $17e$  [8].

### Acknowledgements

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

We acknowledge the support of ANPCyT, Argentina; YerPhI, Armenia; ARC, Australia; BMWF 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, DIP and Benoziyo Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; FOM and NWO, Netherlands; BRF and RCN, Norway; MNiSW, Poland; GRICES and FCT, Portugal; MERYS (MECTS), Romania; MES of Russia and ROSATOM, Russian Federation; JINR; MSTB, Serbia; MSSR, Slovakia; ARRS and MVZT, Slovenia; DST/NRF, South Africa; MICINN, Spain; SRC and Wallenberg Foundation, Sweden; SER, SNSF and Cantons of Bern and Geneva, Switzerland; NSC, Taiwan; TAEK, Turkey; STFC, the Royal Society and Leverhulme Trust, United Kingdom; DOE and NSF, United States of America.

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

### Open access

This article is published Open Access at [sciencedirect.com](http://sciencedirect.com). It is distributed under the terms of the Creative Commons Attribution License 3.0, which permits unrestricted use, distribution, and reproduction in any medium, provided the original authors and source are credited.

### References

- [1] M. Fairbairn, et al., Phys. Rep. 438 (2007) 1, arXiv:hep-ph/0611040.
- [2] J. Schwinger, Phys. Rev. 144 (1966) 1087.

### ATLAS Collaboration

G. Aad<sup>48</sup>, T. Abajyan<sup>21</sup>, B. Abbott<sup>111</sup>, J. Abdallah<sup>12</sup>, S. Abdel Khalek<sup>115</sup>, A.A. Abdelalim<sup>49</sup>, O. Abidinov<sup>11</sup>, R. Aben<sup>105</sup>, B. Abi<sup>112</sup>, M. Abolins<sup>88</sup>, O.S. AbouZeid<sup>158</sup>, H. Abramowicz<sup>153</sup>, H. Abreu<sup>136</sup>, B.S. Acharya<sup>164a,164b,a</sup>, L. Adamczyk<sup>38</sup>, D.L. Adams<sup>25</sup>, T.N. Addy<sup>56</sup>, J. Adelman<sup>176</sup>, S. Adomeit<sup>98</sup>, P. Adragna<sup>75</sup>, T. Adye<sup>129</sup>, S. Aefsky<sup>23</sup>, J.A. Aguilar-Saavedra<sup>124b,b</sup>, M. Agustoni<sup>17</sup>, M. Aharrouche<sup>81</sup>, S.P. Ahlen<sup>22</sup>, F. Ahles<sup>48</sup>, A. Ahmad<sup>148</sup>, M. Ahsan<sup>41</sup>, G. Aielli<sup>133a,133b</sup>, T.P.A. Åkesson<sup>79</sup>, G. Akimoto<sup>155</sup>, A.V. Akimov<sup>94</sup>, M.A. Alam<sup>76</sup>, J. Albert<sup>169</sup>, S. Albrand<sup>55</sup>, M. Aleksa<sup>30</sup>, I.N. Aleksandrov<sup>64</sup>, F. Alessandria<sup>89a</sup>, C. Alexa<sup>26a</sup>, G. Alexander<sup>153</sup>, G. Alexandre<sup>49</sup>, T. Alexopoulos<sup>10</sup>, M. Alhroob<sup>164a,164c</sup>, M. Aliev<sup>16</sup>, G. Alimonti<sup>89a</sup>, J. Alison<sup>120</sup>, B.M.M. Allbrooke<sup>18</sup>, P.P. Allport<sup>73</sup>, S.E. Allwood-Spiers<sup>53</sup>, J. Almond<sup>82</sup>, A. Aloisio<sup>102a,102b</sup>, R. Alon<sup>172</sup>, A. Alonso<sup>36</sup>, F. Alonso<sup>70</sup>, A. Altheimer<sup>35</sup>, B. Alvarez Gonzalez<sup>88</sup>, M.G. Alviggi<sup>102a,102b</sup>, K. Amako<sup>65</sup>, C. Amelung<sup>23</sup>, V.V. Ammosov<sup>128,\*</sup>, S.P. Amor Dos Santos<sup>124a</sup>, A. Amorim<sup>124a,c</sup>, N. Amram<sup>153</sup>, C. Anastopoulos<sup>30</sup>, L.S. Ancu<sup>17</sup>, N. Andari<sup>115</sup>, T. Andeen<sup>35</sup>, C.F. Anders<sup>58b</sup>, G. Anders<sup>58a</sup>, K.J. Anderson<sup>31</sup>, A. Andreazza<sup>89a,89b</sup>, V. Andrei<sup>58a</sup>,

- [3] S. Dimopoulos, G.L. Landsberg, Phys. Rev. Lett. 87 (2001) 161602, arXiv:hep-ph/0106295.
- [4] A. Kusenko, M.E. Shaposhnikov, Phys. Lett. B 418 (1998) 46, arXiv:hep-ph/9709492.
- [5] SLIM Collaboration, S. Cecchini, et al., Eur. Phys. J. C 57 (2008) 525, arXiv:0805.1797 [hep-ex].
- [6] DO Collaboration, V.M. Abazov, et al., Phys. Rev. Lett. 102 (2009) 161802, arXiv:0809.4472 [hep-ex].
- [7] CDF Collaboration, T. Aaltonen, et al., Phys. Rev. Lett. 103 (2009) 021802, arXiv:0902.1266 [hep-ex].
- [8] ATLAS Collaboration, Phys. Lett. B 698 (2011) 353, arXiv:1102.0459 [hep-ex].
- [9] ATLAS Collaboration, Phys. Lett. B 701 (2011) 1, arXiv:1103.1984 [hep-ex].
- [10] ATLAS Collaboration, Searches for heavy long-lived sleptons and R-hadrons with the ATLAS detector in pp collisions at  $\sqrt{s} = 7$  TeV, CERN-PH-EP-2012-236, arXiv:1211.1597 [hep-ex].
- [11] CMS Collaboration, JHEP 1103 (2011) 024, arXiv:1101.1645 [hep-ex].
- [12] CMS Collaboration, Phys. Lett. B 713 (2012) 408, arXiv:1205.0272 [hep-ex].
- [13] ATLAS Collaboration, Phys. Rev. Lett. 109 (2012) 261803, arXiv:1207.6411 [hep-ex].
- [14] M.Y. Khlopov, Mod. Phys. Lett. A 26 (2011) 2823, arXiv:1111.2838 [astro-ph.CO].
- [15] C.A. Stephan, J. Phys. A 39 (2006) 9657, arXiv:hep-th/0509213.
- [16] F. Sannino, K. Tuominen, Phys. Rev. D 71 (2005) 051901, arXiv:hep-ph/0405209.
- [17] S.B. Gudnason, C. Kouvaris, F. Sannino, Phys. Rev. D 73 (2006) 115003, arXiv:hep-ph/0603014.
- [18] R. Foadi, M.T. Frandsen, T.A. Rytto, F. Sannino, Phys. Rev. D 76 (2007) 055005, arXiv:0706.1696 [hep-ph].
- [19] A. Connes, Noncommutative Geometry, Academic Press, London, San Diego, 1994.
- [20] A. Sakharov, Sov. Phys. Usp 34 (1991) 375, Zh. Eksp. Teor. Fiz. 18 (1948) 631.
- [21] ATLAS Collaboration, JINST 3 (2008) S08003.
- [22] ATLAS Collaboration, Particle identification performance of the ATLAS transition radiation tracker, ATLAS-CONF-2011-128, <http://cdsweb.cern.ch/record/1383793>.
- [23] J. Alwall, M. Herquet, F. Maltoni, O. Mattelaer, T. Stelzer, JHEP 1106 (2011) 128, arXiv:1106.0522 [hep-ph].
- [24] J. Pumplin, D. Stump, J. Huston, H. Lai, P.M. Nadolsky, W. Tung, JHEP 0207 (2002) 012, arXiv:hep-ph/0201195.
- [25] T. Sjostrand, S. Mrenna, P. Skands, JHEP 0605 (2006) 026, arXiv:hep-ph/0603175.
- [26] GEANT4 Collaboration, S. Agostinelli, et al., Nucl. Instrum. Meth. A 506 (2003) 250.
- [27] ATLAS Collaboration, Eur. Phys. J. C 70 (2010) 823, arXiv:1005.4568 [physics.ins-det].
- [28] A. Belyaev, N.D. Christensen, A. Pukhov, CalcHEP 3.4 for collider physics within and beyond the Standard Model, arXiv:1207.6082 [hep-ph].
- [29] H. Bethe, Ann. Phys. 5 (1930) 325.
- [30] ATLAS Collaboration,  $dE/dx$  measurement in the ATLAS pixel detector and its use for particle identification, ATLAS-CONF-2011-16, <http://cdsweb.cern.ch/record/1336519>.
- [31] ATLAS Collaboration, Performance of the ATLAS muon trigger in 2011, ATLAS-CONF-2012-099, <http://cdsweb.cern.ch/record/1462601>.
- [32] ATLAS Collaboration, Eur. Phys. J. C 71 (2011) 1630, arXiv:1101.2185 [hep-ex].
- [33] ATLAS Collaboration, Luminosity determination in pp collisions at  $\sqrt{s} = 7$  TeV using the ATLAS detector in 2011, ATLAS-CONF-2011-116, <http://cdsweb.cern.ch/record/1376384>.

M-L. Andrieux<sup>55</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. Anisenkov<sup>107</sup>, N. Anjos<sup>124a</sup>, A. Annovi<sup>47</sup>, A. Antonaki<sup>9</sup>, M. Antonelli<sup>47</sup>, A. Antonov<sup>96</sup>, J. Antos<sup>144b</sup>,  
 F. Anulli<sup>132a</sup>, M. Aoki<sup>101</sup>, S. Aoun<sup>83</sup>, L. Aperio Bella<sup>5</sup>, R. Apolle<sup>118,d</sup>, G. Arabidze<sup>88</sup>, I. Aracena<sup>143</sup>,  
 Y. Arai<sup>65</sup>, A.T.H. Arce<sup>45</sup>, S. Arfaoui<sup>148</sup>, J-F. Arguin<sup>93</sup>, S. Argyropoulos<sup>42</sup>, E. Arik<sup>19a,\*</sup>, M. Arik<sup>19a</sup>,  
 A.J. Armbruster<sup>87</sup>, O. Arnaez<sup>81</sup>, V. Arnal<sup>80</sup>, A. Artamonov<sup>95</sup>, G. Artoni<sup>132a,132b</sup>, D. Arutinov<sup>21</sup>, S. Asai<sup>155</sup>,  
 S. Ask<sup>28</sup>, B. Åsman<sup>146a,146b</sup>, D. Asner<sup>29</sup>, L. Asquith<sup>6</sup>, K. Assamagan<sup>25,e</sup>, A. Astbury<sup>169</sup>, M. Atkinson<sup>165</sup>,  
 B. Aubert<sup>5</sup>, E. Auge<sup>115</sup>, K. Augsten<sup>126</sup>, M. Auresseau<sup>145a</sup>, G. Avolio<sup>30</sup>, D. Axen<sup>168</sup>, G. Azuelos<sup>93,f</sup>,  
 Y. Azuma<sup>155</sup>, M.A. Baak<sup>30</sup>, G. Baccaglioni<sup>89a</sup>, C. Bacci<sup>134a,134b</sup>, A.M. Bach<sup>15</sup>, H. Bachacou<sup>136</sup>,  
 K. Bachas<sup>154</sup>, M. Backes<sup>49</sup>, M. Backhaus<sup>21</sup>, J. Backus Mayes<sup>143</sup>, E. Badescu<sup>26a</sup>, P. Bagnaia<sup>132a,132b</sup>,  
 S. Bahinipati<sup>3</sup>, Y. Bai<sup>33a</sup>, D.C. Bailey<sup>158</sup>, T. Bain<sup>35</sup>, J.T. Baines<sup>129</sup>, O.K. Baker<sup>176</sup>, M.D. Baker<sup>25</sup>, S. Baker<sup>77</sup>,  
 P. Balek<sup>127</sup>, E. Banas<sup>39</sup>, P. Banerjee<sup>93</sup>, Sw. Banerjee<sup>173</sup>, D. Banfi<sup>30</sup>, A. Bangert<sup>150</sup>, V. Bansal<sup>169</sup>,  
 H.S. Bansil<sup>18</sup>, L. Barak<sup>172</sup>, S.P. Baranov<sup>94</sup>, A. Barbaro Galtieri<sup>15</sup>, T. Barber<sup>48</sup>, E.L. Barberio<sup>86</sup>,  
 D. Barberis<sup>50a,50b</sup>, M. Barbero<sup>21</sup>, D.Y. Bardin<sup>64</sup>, T. Barillari<sup>99</sup>, M. Barisonzi<sup>175</sup>, T. Barklow<sup>143</sup>,  
 N. Barlow<sup>28</sup>, B.M. Barnett<sup>129</sup>, R.M. Barnett<sup>15</sup>, A. Baroncelli<sup>134a</sup>, G. Barone<sup>49</sup>, A.J. Barr<sup>118</sup>, F. Barreiro<sup>80</sup>,  
 J. Barreiro Guimarães da Costa<sup>57</sup>, R. Bartoldus<sup>143</sup>, A.E. Barton<sup>71</sup>, V. Bartsch<sup>149</sup>, A. Basye<sup>165</sup>, R.L. Bates<sup>53</sup>,  
 L. Batkova<sup>144a</sup>, J.R. Batley<sup>28</sup>, A. Battaglia<sup>17</sup>, M. Battistin<sup>30</sup>, F. Bauer<sup>136</sup>, H.S. Bawa<sup>143,g</sup>, S. Beale<sup>98</sup>,  
 T. Beau<sup>78</sup>, P.H. Beauchemin<sup>161</sup>, R. Beccherle<sup>50a</sup>, P. Bechtel<sup>21</sup>, H.P. Beck<sup>17</sup>, K. Becker<sup>175</sup>, S. Becker<sup>98</sup>,  
 M. Beckingham<sup>138</sup>, K.H. Becks<sup>175</sup>, A.J. Beddall<sup>19c</sup>, A. Beddall<sup>19c</sup>, S. Bedikian<sup>176</sup>, V.A. Bednyakov<sup>64</sup>,  
 C.P. Bee<sup>83</sup>, L.J. Beemster<sup>105</sup>, M. Begel<sup>25</sup>, S. Behar Harpaz<sup>152</sup>, P.K. Behera<sup>62</sup>, M. Beimforde<sup>99</sup>,  
 C. Belanger-Champagne<sup>85</sup>, P.J. Bell<sup>49</sup>, W.H. Bell<sup>49</sup>, G. Bella<sup>153</sup>, L. Bellagamba<sup>20a</sup>, M. Bellomo<sup>30</sup>,  
 A. Belloni<sup>57</sup>, O. Beloborodova<sup>107,h</sup>, K. Belotskiy<sup>96</sup>, O. Beltramello<sup>30</sup>, O. Benary<sup>153</sup>, D. Benchekroun<sup>135a</sup>,  
 K. Bendtz<sup>146a,146b</sup>, N. Benekos<sup>165</sup>, Y. Benhammou<sup>153</sup>, E. Benhar Noccioli<sup>49</sup>, J.A. Benitez Garcia<sup>159b</sup>,  
 D.P. Benjamin<sup>45</sup>, M. Benoit<sup>115</sup>, J.R. Bensinger<sup>23</sup>, K. Benslama<sup>130</sup>, S. Bentvelsen<sup>105</sup>, D. Berge<sup>30</sup>,  
 E. Bergeaas Kuutmann<sup>42</sup>, N. Berger<sup>5</sup>, F. Berghaus<sup>169</sup>, E. Berglund<sup>105</sup>, J. Beringer<sup>15</sup>, P. Bernat<sup>77</sup>,  
 R. Bernhard<sup>48</sup>, C. Bernius<sup>25</sup>, T. Berry<sup>76</sup>, C. Bertella<sup>83</sup>, A. Bertin<sup>20a,20b</sup>, F. Bertolucci<sup>122a,122b</sup>,  
 M.I. Besana<sup>89a,89b</sup>, G.J. Besjes<sup>104</sup>, N. Besson<sup>136</sup>, S. Bethke<sup>99</sup>, W. Bhimji<sup>46</sup>, R.M. Bianchi<sup>30</sup>, L. Bianchini<sup>23</sup>,  
 M. Bianco<sup>72a,72b</sup>, O. Biebel<sup>98</sup>, S.P. Bieniek<sup>77</sup>, K. Bierwagen<sup>54</sup>, J. Biesiada<sup>15</sup>, M. Biglietti<sup>134a</sup>, H. Bilokon<sup>47</sup>,  
 M. Bindi<sup>20a,20b</sup>, S. Binet<sup>115</sup>, A. Bingul<sup>19c</sup>, C. Bini<sup>132a,132b</sup>, C. Biscarat<sup>178</sup>, B. Bittner<sup>99</sup>, C.W. Black<sup>150</sup>,  
 K.M. Black<sup>22</sup>, R.E. Blair<sup>6</sup>, J.-B. Blanchard<sup>136</sup>, T. Blazek<sup>144a</sup>, I. Bloch<sup>42</sup>, C. Blocker<sup>23</sup>, J. Blocki<sup>39</sup>,  
 A. Blondel<sup>49</sup>, W. Blum<sup>81</sup>, U. Blumenschein<sup>54</sup>, G.J. Bobbink<sup>105</sup>, V.S. Bobrovnikov<sup>107</sup>, S.S. Bocchetta<sup>79</sup>,  
 A. Bocci<sup>45</sup>, C.R. Boddy<sup>118</sup>, M. Boehler<sup>48</sup>, J. Boek<sup>175</sup>, T.T. Boek<sup>175</sup>, N. Boelaert<sup>36</sup>, J.A. Bogaerts<sup>30</sup>,  
 A. Bogdanchikov<sup>107</sup>, A. Bogouch<sup>90,\*</sup>, C. Bohm<sup>146a</sup>, J. Bohm<sup>125</sup>, V. Boisvert<sup>76</sup>, T. Bold<sup>38</sup>, V. Boldea<sup>26a</sup>,  
 N.M. Bolnet<sup>136</sup>, M. Bomben<sup>78</sup>, M. Bona<sup>75</sup>, M. Boonekamp<sup>136</sup>, S. Bordini<sup>78</sup>, C. Borer<sup>17</sup>, A. Borisov<sup>128</sup>,  
 G. Borissov<sup>71</sup>, I. Borjanovic<sup>13a</sup>, M. Borri<sup>82</sup>, S. Borroni<sup>87</sup>, J. Bortfeldt<sup>98</sup>, V. Bortolotto<sup>134a,134b</sup>, K. Bos<sup>105</sup>,  
 D. Boscherini<sup>20a</sup>, M. Bosman<sup>12</sup>, H. Boterenbrood<sup>105</sup>, J. Bouchami<sup>93</sup>, J. Boudreau<sup>123</sup>,  
 E.V. Bouhova-Thacker<sup>71</sup>, D. Boumediene<sup>34</sup>, C. Bourdarios<sup>115</sup>, N. Bousson<sup>83</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>134a</sup>, A. Brandt<sup>8</sup>, G. Brandt<sup>118</sup>,  
 O. Brandt<sup>54</sup>, U. Bratzler<sup>156</sup>, B. Brau<sup>84</sup>, J.E. Brau<sup>114</sup>, H.M. Braun<sup>175,\*</sup>, S.F. Brazzale<sup>164a,164c</sup>, B. Brelier<sup>158</sup>,  
 J. Bremer<sup>30</sup>, K. Brendlinger<sup>120</sup>, R. Brenner<sup>166</sup>, S. Bressler<sup>172</sup>, D. Britton<sup>53</sup>, F.M. Brochu<sup>28</sup>, I. Brock<sup>21</sup>,  
 R. Brock<sup>88</sup>, F. Broggi<sup>89a</sup>, C. Bromberg<sup>88</sup>, J. Bronner<sup>99</sup>, G. Brooijmans<sup>35</sup>, T. Brooks<sup>76</sup>, W.K. Brooks<sup>32b</sup>,  
 G. Brown<sup>82</sup>, P.A. Bruckman de Renstrom<sup>39</sup>, D. Bruncko<sup>144b</sup>, R. Brunelieire<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>79</sup>, T. Buanes<sup>14</sup>, Q. Buat<sup>55</sup>, F. Bucci<sup>49</sup>, J. Buchanan<sup>118</sup>,  
 P. Buchholz<sup>141</sup>, R.M. Buckingham<sup>118</sup>, A.G. Buckley<sup>46</sup>, S.I. Buda<sup>26a</sup>, I.A. Budagov<sup>64</sup>, B. Budick<sup>108</sup>,  
 L. Bugge<sup>117</sup>, O. Bulekov<sup>96</sup>, A.C. Bundock<sup>73</sup>, M. Bunse<sup>43</sup>, T. Buran<sup>117</sup>, H. Burckhart<sup>30</sup>, S. Burdin<sup>73</sup>,  
 T. Burgess<sup>14</sup>, S. Burke<sup>129</sup>, E. Busato<sup>34</sup>, V. Büscher<sup>81</sup>, P. Bussey<sup>53</sup>, C.P. Buszello<sup>166</sup>, B. Butler<sup>143</sup>,  
 J.M. Butler<sup>22</sup>, C.M. Buttar<sup>53</sup>, J.M. Butterworth<sup>77</sup>, W. Buttinger<sup>28</sup>, M. Byszewski<sup>30</sup>, S. Cabrera Urbán<sup>167</sup>,  
 D. Caforio<sup>20a,20b</sup>, O. Cakir<sup>4a</sup>, P. Calafiura<sup>15</sup>, G. Calderini<sup>78</sup>, P. Calfayan<sup>98</sup>, R. Calkins<sup>106</sup>, L.P. Caloba<sup>24a</sup>,  
 R. Caloi<sup>132a,132b</sup>, D. Calvet<sup>34</sup>, S. Calvet<sup>34</sup>, R. Camacho Toro<sup>34</sup>, P. Camarri<sup>133a,133b</sup>, D. Cameron<sup>117</sup>,  
 L.M. Caminada<sup>15</sup>, R. Caminal Armadans<sup>12</sup>, S. Campana<sup>30</sup>, M. Campanelli<sup>77</sup>, V. Canale<sup>102a,102b</sup>,  
 F. Canelli<sup>31</sup>, A. Canepa<sup>159a</sup>, J. Cantero<sup>80</sup>, R. Cantrill<sup>76</sup>, L. Capasso<sup>102a,102b</sup>, M.D.M. Capeans Garrido<sup>30</sup>,  
 I. Caprini<sup>26a</sup>, M. Caprini<sup>26a</sup>, D. Capriotti<sup>99</sup>, M. Capua<sup>37a,37b</sup>, R. Caputo<sup>81</sup>, R. Cardarelli<sup>133a</sup>, T. Carli<sup>30</sup>,  
 G. Carlino<sup>102a</sup>, L. Carminati<sup>89a,89b</sup>, B. Caron<sup>85</sup>, S. Caron<sup>104</sup>, E. Carquin<sup>32b</sup>, G.D. Carrillo-Montoya<sup>145b</sup>,



A.A. Carter<sup>75</sup>, J.R. Carter<sup>28</sup>, J. Carvalho<sup>124a,i</sup>, D. Casadei<sup>108</sup>, M.P. Casado<sup>12</sup>, M. Cascella<sup>122a,122b</sup>,  
 C. Caso<sup>50a,50b,\*</sup>, A.M. Castaneda Hernandez<sup>173,j</sup>, E. Castaneda-Miranda<sup>173</sup>, V. Castillo Gimenez<sup>167</sup>,  
 N.F. Castro<sup>124a</sup>, G. Cataldi<sup>72a</sup>, P. Catastini<sup>57</sup>, A. Catinaccio<sup>30</sup>, J.R. Catmore<sup>30</sup>, A. Cattai<sup>30</sup>,  
 G. Cattani<sup>133a,133b</sup>, S. Caughron<sup>88</sup>, V. Cavaliere<sup>165</sup>, P. Cavalleri<sup>78</sup>, D. Cavalli<sup>89a</sup>, M. Cavalli-Sforza<sup>12</sup>,  
 V. Cavasinni<sup>122a,122b</sup>, F. Ceradini<sup>134a,134b</sup>, A.S. Cerqueira<sup>24b</sup>, A. Cerri<sup>15</sup>, L. Cerrito<sup>75</sup>, F. Cerutti<sup>15</sup>,  
 S.A. Cetin<sup>19b</sup>, A. Chafaq<sup>135a</sup>, D. Chakraborty<sup>106</sup>, I. Chalupkova<sup>127</sup>, K. Chan<sup>3</sup>, P. Chang<sup>165</sup>, B. Chapleau<sup>85</sup>,  
 J.D. Chapman<sup>28</sup>, J.W. Chapman<sup>87</sup>, D.G. Charlton<sup>18</sup>, V. Chavda<sup>82</sup>, C.A. Chavez Barajas<sup>30</sup>, S. Cheatham<sup>85</sup>,  
 S. Chekanov<sup>6</sup>, S.V. Chekulaev<sup>159a</sup>, G.A. Chelkov<sup>64</sup>, M.A. Chelstowska<sup>104</sup>, C. Chen<sup>63</sup>, H. Chen<sup>25</sup>,  
 S. Chen<sup>33c</sup>, X. Chen<sup>173</sup>, Y. Chen<sup>35</sup>, Y. Cheng<sup>31</sup>, A. Cheplakov<sup>64</sup>, R. Cherkaoui El Moursli<sup>135e</sup>,  
 V. Chernyatin<sup>25</sup>, E. Cheu<sup>7</sup>, S.L. Cheung<sup>158</sup>, L. Chevalier<sup>136</sup>, G. Chiefari<sup>102a,102b</sup>, L. Chikovani<sup>51a,\*</sup>,  
 J.T. Childers<sup>30</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>, G. Choudalakis<sup>31</sup>, S. Chouridou<sup>137</sup>, I.A. Christidi<sup>77</sup>, A. Christov<sup>48</sup>,  
 D. Chromek-Burckhart<sup>30</sup>, M.L. Chu<sup>151</sup>, J. Chudoba<sup>125</sup>, G. Ciapetti<sup>132a,132b</sup>, A.K. Ciftci<sup>4a</sup>, R. Ciftci<sup>4a</sup>,  
 D. Cinca<sup>34</sup>, V. Cindro<sup>74</sup>, A. Ciocio<sup>15</sup>, M. Cirilli<sup>87</sup>, P. Cirkovic<sup>13b</sup>, Z.H. Citron<sup>172</sup>, M. Citterio<sup>89a</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>123</sup>, J.C. Clemens<sup>83</sup>, B. Clement<sup>55</sup>,  
 C. Clement<sup>146a,146b</sup>, Y. Coadou<sup>83</sup>, M. Cobal<sup>164a,164c</sup>, A. Coccaro<sup>138</sup>, J. Cochran<sup>63</sup>, L. Coffey<sup>23</sup>,  
 J.G. Cogan<sup>143</sup>, J. Coggeshall<sup>165</sup>, J. Colas<sup>5</sup>, S. Cole<sup>106</sup>, A.P. Colijn<sup>105</sup>, N.J. Collins<sup>18</sup>, C. Collins-Tooth<sup>53</sup>,  
 J. Collot<sup>55</sup>, T. Colombo<sup>119a,119b</sup>, G. Colon<sup>84</sup>, G. Compostella<sup>99</sup>, P. Conde Muiño<sup>124a</sup>, E. Coniavitis<sup>166</sup>,  
 M.C. Conidi<sup>12</sup>, S.M. Consonni<sup>89a,89b</sup>, V. Consorti<sup>48</sup>, S. Constantinescu<sup>26a</sup>, C. Conta<sup>119a,119b</sup>, G. Conti<sup>57</sup>,  
 F. Conventi<sup>102a,k</sup>, M. Cooke<sup>15</sup>, B.D. Cooper<sup>77</sup>, A.M. Cooper-Sarkar<sup>118</sup>, K. Copic<sup>15</sup>, T. Cornelissen<sup>175</sup>,  
 M. Corradi<sup>20a</sup>, F. Corriveau<sup>85,l</sup>, A. Cortes-Gonzalez<sup>165</sup>, G. Cortiana<sup>99</sup>, G. Costa<sup>89a</sup>, M.J. Costa<sup>167</sup>,  
 D. Costanzo<sup>139</sup>, D. Côté<sup>30</sup>, L. Courneyea<sup>169</sup>, G. Cowan<sup>76</sup>, B.E. Cox<sup>82</sup>, K. Cranmer<sup>108</sup>,  
 S. Crépe-Renaudin<sup>55</sup>, F. Crescioli<sup>78</sup>, M. Cristinziani<sup>21</sup>, G. Crosetti<sup>37a,37b</sup>, C.-M. Cuciuc<sup>26a</sup>,  
 C. Cuenca Almenar<sup>176</sup>, T. Cuhadar Donszelmann<sup>139</sup>, J. Cummings<sup>176</sup>, M. Curatolo<sup>47</sup>, C.J. Curtis<sup>18</sup>,  
 C. Cuthbert<sup>150</sup>, P. Cwetanski<sup>60</sup>, H. Czirr<sup>141</sup>, P. Czodrowski<sup>44</sup>, Z. Czyczula<sup>176</sup>, S. D'Auria<sup>53</sup>,  
 M. D'Onofrio<sup>73</sup>, A. D'Orazio<sup>132a,132b</sup>, M.J. Da Cunha Sargedas De Sousa<sup>124a</sup>, C. Da Via<sup>82</sup>,  
 W. Dabrowski<sup>38</sup>, A. Dafinca<sup>118</sup>, T. Dai<sup>87</sup>, F. Dallaire<sup>93</sup>, C. Dallapiccola<sup>84</sup>, M. Dam<sup>36</sup>, M. Dameri<sup>50a,50b</sup>,  
 D.S. Damiani<sup>137</sup>, H.O. Danielsson<sup>30</sup>, V. Dao<sup>49</sup>, G. Darbo<sup>50a</sup>, G.L. Darlea<sup>26b</sup>, J.A. Dassoulas<sup>42</sup>, W. Davey<sup>21</sup>,  
 T. Davidek<sup>127</sup>, N. Davidson<sup>86</sup>, R. Davidson<sup>71</sup>, E. Davies<sup>118,d</sup>, M. Davies<sup>93</sup>, O. Davignon<sup>78</sup>, A.R. Davison<sup>77</sup>,  
 Y. Davygora<sup>58a</sup>, E. Dawe<sup>142</sup>, I. Dawson<sup>139</sup>, R.K. Daya-Ishmukhametova<sup>23</sup>, K. De<sup>8</sup>, R. de Asmundis<sup>102a</sup>,  
 S. De Castro<sup>20a,20b</sup>, S. De Cecco<sup>78</sup>, J. de Graat<sup>98</sup>, N. De Groot<sup>104</sup>, P. de Jong<sup>105</sup>, C. De La Taille<sup>115</sup>,  
 H. De la Torre<sup>80</sup>, F. De Lorenzi<sup>63</sup>, L. de Mora<sup>71</sup>, L. De Nooij<sup>105</sup>, D. De Pedis<sup>132a</sup>, A. De Salvo<sup>132a</sup>,  
 U. De Sanctis<sup>164a,164c</sup>, A. De Santo<sup>149</sup>, J.B. De Vivie De Regie<sup>115</sup>, G. De Zorzi<sup>132a,132b</sup>, W.J. Dearnaley<sup>71</sup>,  
 R. Debbe<sup>25</sup>, C. Debenedetti<sup>46</sup>, B. Dechenaux<sup>55</sup>, D.V. Dedovich<sup>64</sup>, J. Degenhardt<sup>120</sup>, J. Del Peso<sup>80</sup>,  
 T. Del Prete<sup>122a,122b</sup>, T. Delemontex<sup>55</sup>, M. Deliyergiyev<sup>74</sup>, A. Dell'Acqua<sup>30</sup>, L. Dell'Asta<sup>22</sup>,  
 M. Della Pietra<sup>102a,k</sup>, D. della Volpe<sup>102a,102b</sup>, M. Delmastro<sup>5</sup>, P.A. Delsart<sup>55</sup>, C. Deluca<sup>105</sup>, S. Demers<sup>176</sup>,  
 M. Demichev<sup>64</sup>, B. Demirkoz<sup>12,m</sup>, S.P. Denisov<sup>128</sup>, D. Derendarz<sup>39</sup>, J.E. Derkaoui<sup>135d</sup>, F. Derue<sup>78</sup>,  
 P. Dervan<sup>73</sup>, K. Desch<sup>21</sup>, E. Devetak<sup>148</sup>, P.O. Deviveiros<sup>105</sup>, A. Dewhurst<sup>129</sup>, B. DeWilde<sup>148</sup>,  
 S. Dhaliwal<sup>105</sup>, R. Dhullipudi<sup>25,n</sup>, A. Di Ciaccio<sup>133a,133b</sup>, L. Di Ciaccio<sup>5</sup>, C. Di Donato<sup>102a,102b</sup>,  
 A. Di Girolamo<sup>30</sup>, B. Di Girolamo<sup>30</sup>, S. Di Luise<sup>134a,134b</sup>, A. Di Mattia<sup>152</sup>, B. Di Micco<sup>30</sup>, R. Di Nardo<sup>47</sup>,  
 A. Di Simone<sup>133a,133b</sup>, R. Di Sipio<sup>20a,20b</sup>, M.A. Diaz<sup>32a</sup>, E.B. Diehl<sup>87</sup>, J. Dietrich<sup>42</sup>, T.A. Dietzsch<sup>58a</sup>,  
 S. Diglio<sup>86</sup>, K. Dindar Yagci<sup>40</sup>, J. Dingfelder<sup>21</sup>, F. Dinut<sup>26a</sup>, C. Dionisi<sup>132a,132b</sup>, P. Dita<sup>26a</sup>, S. Dita<sup>26a</sup>,  
 F. Dittus<sup>30</sup>, F. Djama<sup>83</sup>, T. Djobava<sup>51b</sup>, M.A.B. do Vale<sup>24c</sup>, A. Do Valle Wemans<sup>124a,o</sup>, T.K.O. Doan<sup>5</sup>,  
 M. Dobbs<sup>85</sup>, D. Dobos<sup>30</sup>, E. Dobson<sup>30,p</sup>, J. Dodd<sup>35</sup>, C. Doglioni<sup>49</sup>, T. Doherty<sup>53</sup>, T. Dohmae<sup>155</sup>, Y. Doi<sup>65,\*</sup>,  
 J. Dolejsi<sup>127</sup>, Z. Dolezal<sup>127</sup>, B.A. Dolgoshein<sup>96,\*</sup>, M. Donadelli<sup>24d</sup>, J. Donini<sup>34</sup>, J. Dopke<sup>30</sup>, A. Doria<sup>102a</sup>,  
 A. Dos Anjos<sup>173</sup>, A. Dotti<sup>122a,122b</sup>, M.T. Dova<sup>70</sup>, A.D. Doxiadis<sup>105</sup>, A.T. Doyle<sup>53</sup>, N. Dressnandt<sup>120</sup>,  
 M. Dris<sup>10</sup>, J. Dubbert<sup>99</sup>, S. Dube<sup>15</sup>, E. Duchovni<sup>172</sup>, G. Duckeck<sup>98</sup>, D. Duda<sup>175</sup>, A. Dudarev<sup>30</sup>,  
 F. Dudziak<sup>63</sup>, I.P. Duerdoth<sup>82</sup>, L. Dufлот<sup>115</sup>, M-A. Dufour<sup>85</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>, R. Duxfield<sup>139</sup>, M. Dwuznik<sup>38</sup>, W.L. Ebenstein<sup>45</sup>, J. Ebke<sup>98</sup>,  
 S. Eckweiler<sup>81</sup>, K. Edmonds<sup>81</sup>, W. Edson<sup>2</sup>, C.A. Edwards<sup>76</sup>, N.C. Edwards<sup>53</sup>, W. Ehrenfeld<sup>42</sup>, T. Eifert<sup>143</sup>,  
 G. Eigen<sup>14</sup>, K. Einsweiler<sup>15</sup>, E. Eisenhandler<sup>75</sup>, T. Ekelof<sup>166</sup>, M. El Kacimi<sup>135c</sup>, M. Ellert<sup>166</sup>, S. Elles<sup>5</sup>,  
 F. Ellinghaus<sup>81</sup>, K. Ellis<sup>75</sup>, N. Ellis<sup>30</sup>, J. Elmsheuser<sup>98</sup>, M. Elsing<sup>30</sup>, D. Emelianov<sup>129</sup>, R. Engelmann<sup>148</sup>,

A. Engl<sup>98</sup>, B. Epp<sup>61</sup>, J. Erdmann<sup>176</sup>, A. Ereditato<sup>17</sup>, D. Eriksson<sup>146a</sup>, J. Ernst<sup>2</sup>, M. Ernst<sup>25</sup>, J. Ernwein<sup>136</sup>,  
 D. Errede<sup>165</sup>, S. Errede<sup>165</sup>, E. Ertel<sup>81</sup>, M. Escalier<sup>115</sup>, H. Esch<sup>43</sup>, C. Escobar<sup>123</sup>, X. Espinal Curull<sup>12</sup>,  
 B. Esposito<sup>47</sup>, F. Etienne<sup>83</sup>, A.I. Etievre<sup>136</sup>, E. Etzion<sup>153</sup>, D. Evangelakou<sup>54</sup>, H. Evans<sup>60</sup>, L. Fabbri<sup>20a,20b</sup>,  
 C. Fabre<sup>30</sup>, R.M. Fakhruddinov<sup>128</sup>, S. Falciano<sup>132a</sup>, Y. Fang<sup>33a</sup>, M. Fanti<sup>89a,89b</sup>, A. Farbin<sup>8</sup>, A. Farilla<sup>134a</sup>,  
 J. Farley<sup>148</sup>, T. Farooque<sup>158</sup>, S. Farrell<sup>163</sup>, S.M. Farrington<sup>170</sup>, P. Farthouat<sup>30</sup>, F. Fassi<sup>167</sup>, P. Fassnacht<sup>30</sup>,  
 D. Fassouliotis<sup>9</sup>, B. Fatholahzadeh<sup>158</sup>, A. Favareto<sup>89a,89b</sup>, L. Fayard<sup>115</sup>, P. Federic<sup>144a</sup>, O.L. Fedin<sup>121</sup>,  
 W. Fedorko<sup>88</sup>, M. Fehling-Kaschek<sup>48</sup>, L. Feligioni<sup>83</sup>, C. Feng<sup>33d</sup>, E.J. Feng<sup>6</sup>, A.B. Fenyuk<sup>128</sup>,  
 J. Ferencei<sup>144b</sup>, W. Fernando<sup>6</sup>, S. Ferrag<sup>53</sup>, J. Ferrando<sup>53</sup>, V. Ferrara<sup>42</sup>, A. Ferrari<sup>166</sup>, P. Ferrari<sup>105</sup>,  
 R. Ferrari<sup>119a</sup>, D.E. Ferreira de Lima<sup>53</sup>, A. Ferrer<sup>167</sup>, D. Ferrere<sup>49</sup>, C. Ferretti<sup>87</sup>, A. Ferretto Parodi<sup>50a,50b</sup>,  
 M. Fiascaris<sup>31</sup>, F. Fiedler<sup>81</sup>, A. Filipčič<sup>74</sup>, F. Filthaut<sup>104</sup>, M. Fincke-Keeler<sup>169</sup>, M.C.N. Fiolhais<sup>124a,i</sup>,  
 L. Fiorini<sup>167</sup>, A. Firan<sup>40</sup>, G. Fischer<sup>42</sup>, M.J. Fisher<sup>109</sup>, M. Flechl<sup>48</sup>, I. Fleck<sup>141</sup>, J. Fleckner<sup>81</sup>,  
 P. Fleischmann<sup>174</sup>, S. Fleischmann<sup>175</sup>, T. Flick<sup>175</sup>, A. Floderus<sup>79</sup>, L.R. Flores Castillo<sup>173</sup>,  
 A.C. Florez Bustos<sup>159b</sup>, M.J. Flowerdew<sup>99</sup>, T. Fonseca Martin<sup>17</sup>, A. Formica<sup>136</sup>, A. Forti<sup>82</sup>, D. Fortin<sup>159a</sup>,  
 D. Fournier<sup>115</sup>, A.J. Fowler<sup>45</sup>, H. Fox<sup>71</sup>, P. Francavilla<sup>12</sup>, M. Franchini<sup>20a,20b</sup>, S. Franchino<sup>119a,119b</sup>,  
 D. Francis<sup>30</sup>, T. Frank<sup>172</sup>, M. Franklin<sup>57</sup>, S. Franz<sup>30</sup>, M. Fraternali<sup>119a,119b</sup>, S. Fratina<sup>120</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>156</sup>, E. Fullana Torregrosa<sup>127</sup>,  
 B.G. Fulson<sup>143</sup>, J. Fuster<sup>167</sup>, C. Gabaldon<sup>30</sup>, O. Gabizon<sup>172</sup>, T. Gadfort<sup>25</sup>, S. Gadomski<sup>49</sup>,  
 G. Gagliardi<sup>50a,50b</sup>, P. Gagnon<sup>60</sup>, C. Galea<sup>98</sup>, B. Galhardo<sup>124a</sup>, E.J. Gallas<sup>118</sup>, V. Gallo<sup>17</sup>, B.J. Gallop<sup>129</sup>,  
 P. Gallus<sup>125</sup>, K.K. Gan<sup>109</sup>, Y.S. Gao<sup>143,g</sup>, A. Gaponenko<sup>15</sup>, F. Garberon<sup>176</sup>, C. García<sup>167</sup>,  
 J.E. García Navarro<sup>167</sup>, M. Garcia-Sciveres<sup>15</sup>, R.W. Gardner<sup>31</sup>, N. Garelli<sup>30</sup>, V. Garonne<sup>30</sup>, C. Gatti<sup>47</sup>,  
 G. Gaudio<sup>119a</sup>, B. Gaur<sup>141</sup>, L. Gauthier<sup>136</sup>, P. Gauzzi<sup>132a,132b</sup>, I.L. Gavrilenko<sup>94</sup>, C. Gay<sup>168</sup>, G. Gaycken<sup>21</sup>,  
 E.N. Gazis<sup>10</sup>, P. Ge<sup>33d,q</sup>, Z. Gecse<sup>168</sup>, C.N.P. Gee<sup>129</sup>, D.A.A. Geerts<sup>105</sup>, Ch. Geich-Gimbel<sup>21</sup>,  
 K. Gellerstedt<sup>146a,146b</sup>, C. Gemme<sup>50a</sup>, A. Gemmell<sup>53</sup>, M.H. Genest<sup>55</sup>, S. Gentile<sup>132a,132b</sup>, M. George<sup>54</sup>,  
 S. George<sup>76</sup>, D. Gerbaudo<sup>12</sup>, P. Gerlach<sup>175</sup>, A. Gershon<sup>153</sup>, C. Geweniger<sup>58a</sup>, H. Ghazlane<sup>135b</sup>,  
 N. Ghodbane<sup>34</sup>, B. Giacobbe<sup>20a</sup>, S. Giagu<sup>132a,132b</sup>, V. Giangiobbe<sup>12</sup>, F. Gianotti<sup>30</sup>, B. Gibbard<sup>25</sup>,  
 A. Gibson<sup>158</sup>, S.M. Gibson<sup>30</sup>, M. Gilchriese<sup>15</sup>, D. Gillberg<sup>29</sup>, A.R. Gillman<sup>129</sup>, D.M. Gingrich<sup>3,f</sup>,  
 J. Ginzburg<sup>153</sup>, N. Giokaris<sup>9</sup>, M.P. Giordani<sup>164c</sup>, R. Giordano<sup>102a,102b</sup>, F.M. Giorgi<sup>16</sup>, P. Giovannini<sup>99</sup>,  
 P.F. Giraud<sup>136</sup>, D. Giugni<sup>89a</sup>, M. Giunta<sup>93</sup>, B.K. Gjelsten<sup>117</sup>, L.K. Gladilin<sup>97</sup>, C. Glasman<sup>80</sup>, J. Glatzer<sup>21</sup>,  
 A. Glazov<sup>42</sup>, K.W. Glitza<sup>175</sup>, G.L. Glonti<sup>64</sup>, J.R. Goddard<sup>75</sup>, J. Godfrey<sup>142</sup>, J. Godlewski<sup>30</sup>, M. Goebel<sup>42</sup>,  
 C. Goeringer<sup>81</sup>, S. Goldfarb<sup>87</sup>, T. Golling<sup>176</sup>, D. Golubkov<sup>128</sup>, A. Gomes<sup>124a,c</sup>, L.S. Gomez Fajardo<sup>42</sup>,  
 R. Gonçalo<sup>76</sup>, J. Goncalves Pinto Firmino Da Costa<sup>42</sup>, L. Gonella<sup>21</sup>, S. González de la Hoz<sup>167</sup>,  
 G. Gonzalez Parra<sup>12</sup>, M.L. Gonzalez Silva<sup>27</sup>, S. Gonzalez-Sevilla<sup>49</sup>, J.J. Goodson<sup>148</sup>, L. Goossens<sup>30</sup>,  
 T. Göpfert<sup>44</sup>, P.A. Gorbounov<sup>95</sup>, H.A. Gordon<sup>25</sup>, I. Gorelov<sup>103</sup>, G. Gorfine<sup>175</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>, M. Gosselink<sup>105</sup>, C. Gössling<sup>43</sup>, M.I. Gostkin<sup>64</sup>,  
 I. Gough Eschrich<sup>163</sup>, M. Gouighri<sup>135a</sup>, D. Goujdami<sup>135c</sup>, M.P. Goulette<sup>49</sup>, A.G. Goussiou<sup>138</sup>, C. Goy<sup>5</sup>,  
 S. Gozpinar<sup>23</sup>, I. Grabowska-Bold<sup>38</sup>, P. Grafström<sup>20a,20b</sup>, K.-J. Grahn<sup>42</sup>, E. Gramstad<sup>117</sup>,  
 F. Grancagnolo<sup>72a</sup>, S. Grancagnolo<sup>16</sup>, V. Grassi<sup>148</sup>, V. Gratchev<sup>121</sup>, N. Grau<sup>35</sup>, H.M. Gray<sup>30</sup>, J.A. Gray<sup>148</sup>,  
 E. Graziani<sup>134a</sup>, O.G. Grebenyuk<sup>121</sup>, T. Greenshaw<sup>73</sup>, Z.D. Greenwood<sup>25,n</sup>, K. Gregersen<sup>36</sup>, I.M. Gregor<sup>42</sup>,  
 P. Grenier<sup>143</sup>, J. Griffiths<sup>8</sup>, N. Grigalashvili<sup>64</sup>, A.A. Grillo<sup>137</sup>, S. Grinstein<sup>12</sup>, Ph. Gris<sup>34</sup>,  
 Y.V. Grishkevich<sup>97</sup>, J.-F. Grivaz<sup>115</sup>, A. Grohsjean<sup>42</sup>, E. Gross<sup>172</sup>, J. Grosse-Knetter<sup>54</sup>, J. Groth-Jensen<sup>172</sup>,  
 K. Grybel<sup>141</sup>, D. Guest<sup>176</sup>, C. Guichenev<sup>34</sup>, E. Guido<sup>50a,50b</sup>, S. Guindon<sup>54</sup>, U. Gul<sup>53</sup>, J. Gunther<sup>125</sup>,  
 B. Guo<sup>158</sup>, J. Guo<sup>35</sup>, P. Gutierrez<sup>111</sup>, N. Guttman<sup>153</sup>, O. Gutzwiller<sup>173</sup>, C. Guyot<sup>136</sup>, C. Gwenlan<sup>118</sup>,  
 C.B. Gwilliam<sup>73</sup>, A. Haas<sup>108</sup>, S. Haas<sup>30</sup>, C. Haber<sup>15</sup>, H.K. Hadavand<sup>8</sup>, D.R. Hadley<sup>18</sup>, P. Haefner<sup>21</sup>,  
 F. Hahn<sup>30</sup>, Z. Hajduk<sup>39</sup>, H. Hakobyan<sup>177</sup>, D. Hall<sup>118</sup>, K. Hamacher<sup>175</sup>, P. Hamal<sup>113</sup>, K. Hamano<sup>86</sup>,  
 M. Hamer<sup>54</sup>, A. Hamilton<sup>145b,r</sup>, S. Hamilton<sup>161</sup>, L. Han<sup>33b</sup>, K. Hanagaki<sup>116</sup>, K. Hanawa<sup>160</sup>, M. Hance<sup>15</sup>,  
 C. Handel<sup>81</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>, P. Hansson<sup>143</sup>,  
 K. Hara<sup>160</sup>, T. Harenberg<sup>175</sup>, S. Harkusha<sup>90</sup>, D. Harper<sup>87</sup>, R.D. Harrington<sup>46</sup>, O.M. Harris<sup>138</sup>, J. Hartert<sup>48</sup>,  
 F. Hartjes<sup>105</sup>, T. Haruyama<sup>65</sup>, A. Harvey<sup>56</sup>, S. Hasegawa<sup>101</sup>, Y. Hasegawa<sup>140</sup>, S. Hassani<sup>136</sup>, S. Haug<sup>17</sup>,  
 M. Hauschild<sup>30</sup>, R. Hauser<sup>88</sup>, M. Havranek<sup>21</sup>, C.M. Hawkes<sup>18</sup>, R.J. Hawkins<sup>30</sup>, A.D. Hawkins<sup>79</sup>,  
 T. Hayakawa<sup>66</sup>, T. Hayashi<sup>160</sup>, D. Hayden<sup>76</sup>, C.P. Hays<sup>118</sup>, H.S. Hayward<sup>73</sup>, S.J. Haywood<sup>129</sup>, S.J. Head<sup>18</sup>,  
 V. Hedberg<sup>79</sup>, L. Heelan<sup>8</sup>, S. Heim<sup>120</sup>, B. Heinemann<sup>15</sup>, S. Heisterkamp<sup>36</sup>, L. Helary<sup>22</sup>, C. Heller<sup>98</sup>,  
 M. Heller<sup>30</sup>, S. Hellman<sup>146a,146b</sup>, D. Hellmich<sup>21</sup>, C. Helsens<sup>12</sup>, R.C.W. Henderson<sup>71</sup>, M. Henke<sup>58a</sup>,

A. Henrichs<sup>176</sup>, A.M. Henriques Correia<sup>30</sup>, S. Henrot-Versille<sup>115</sup>, C. Hensel<sup>54</sup>, C.M. Hernandez<sup>8</sup>,  
 Y. Hernández Jiménez<sup>167</sup>, R. Herrberg<sup>16</sup>, G. Herten<sup>48</sup>, R. Hertenberger<sup>98</sup>, L. Hervas<sup>30</sup>, G.G. Hesketh<sup>77</sup>,  
 N.P. Hessey<sup>105</sup>, E. Higón-Rodríguez<sup>167</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>120</sup>, M. Hirose<sup>116</sup>, F. Hirsch<sup>43</sup>, D. Hirschbuehl<sup>175</sup>, J. Hobbs<sup>148</sup>, N. Hod<sup>153</sup>, M.C. Hodgkinson<sup>139</sup>,  
 P. Hodgson<sup>139</sup>, A. Hoecker<sup>30</sup>, M.R. Hoferkamp<sup>103</sup>, J. Hoffman<sup>40</sup>, D. Hoffmann<sup>83</sup>, M. Hohlfield<sup>81</sup>,  
 M. Holder<sup>141</sup>, S.O. Holmgren<sup>146a</sup>, T. Holy<sup>126</sup>, J.L. Holzbauer<sup>88</sup>, T.M. Hong<sup>120</sup>,  
 L. Hooft van Huysduynen<sup>108</sup>, S. Horner<sup>48</sup>, J.-Y. Hostachy<sup>55</sup>, S. Hou<sup>151</sup>, A. Hoummada<sup>135a</sup>, J. Howard<sup>118</sup>,  
 J. Howarth<sup>82</sup>, I. Hristova<sup>16</sup>, J. Hrivnac<sup>115</sup>, T. Hryn'ova<sup>5</sup>, P.J. Hsu<sup>81</sup>, S.-C. Hsu<sup>138</sup>, D. Hu<sup>35</sup>, Z. Hubacek<sup>30</sup>,  
 F. Hubaut<sup>83</sup>, F. Huegging<sup>21</sup>, A. Huettmann<sup>42</sup>, T.B. Huffman<sup>118</sup>, E.W. Hughes<sup>35</sup>, G. Hughes<sup>71</sup>,  
 M. Huhtinen<sup>30</sup>, M. Hurwitz<sup>15</sup>, N. Huseynov<sup>64,s</sup>, J. Huston<sup>88</sup>, J. Huth<sup>57</sup>, G. Iacobucci<sup>49</sup>, G. Iakovidis<sup>10</sup>,  
 M. Ibbotson<sup>82</sup>, I. Ibragimov<sup>141</sup>, L. Iconomidou-Fayard<sup>115</sup>, J. Idarraga<sup>115</sup>, P. Iengo<sup>102a</sup>, O. Igonkina<sup>105</sup>,  
 Y. Ikegami<sup>65</sup>, M. Ikeno<sup>65</sup>, D. Iliadis<sup>154</sup>, N. Ilic<sup>158</sup>, T. Ince<sup>99</sup>, P. Ioannou<sup>9</sup>, M. Iodice<sup>134a</sup>, K. Iordanidou<sup>9</sup>,  
 V. Ippolito<sup>132a,132b</sup>, A. Irlles Quiles<sup>167</sup>, C. Isaksson<sup>166</sup>, M. Ishino<sup>67</sup>, M. Ishitsuka<sup>157</sup>,  
 R. Ishmukhametov<sup>109</sup>, C. Issever<sup>118</sup>, S. Istin<sup>19a</sup>, A.V. Ivashin<sup>128</sup>, W. Iwanski<sup>39</sup>, H. Iwasaki<sup>65</sup>, J.M. Izen<sup>41</sup>,  
 V. Izzo<sup>102a</sup>, B. Jackson<sup>120</sup>, J.N. 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>125</sup>, J. Jakubek<sup>126</sup>, D.O. Jamin<sup>151</sup>, D.K. Jana<sup>111</sup>, E. Jansen<sup>77</sup>, H. Jansen<sup>30</sup>, J. Janssen<sup>21</sup>,  
 A. Jantsch<sup>99</sup>, M. Janus<sup>48</sup>, R.C. Jared<sup>173</sup>, G. Jarlskog<sup>79</sup>, L. Jeanty<sup>57</sup>, G.-Y. Jeng<sup>150</sup>, I. Jen-La Plante<sup>31</sup>,  
 D. Jennens<sup>86</sup>, P. Jenni<sup>30</sup>, P. Jež<sup>36</sup>, S. Jézéquel<sup>5</sup>, M.K. Jha<sup>20a</sup>, H. Ji<sup>173</sup>, W. Ji<sup>81</sup>, J. Jia<sup>148</sup>, Y. Jiang<sup>33b</sup>,  
 M. Jimenez Belenguer<sup>42</sup>, S. Jin<sup>33a</sup>, O. Jinnouchi<sup>157</sup>, M.D. Joergensen<sup>36</sup>, D. Joffe<sup>40</sup>, M. Johansen<sup>146a,146b</sup>,  
 K.E. Johansson<sup>146a</sup>, P. Johansson<sup>139</sup>, S. Johnert<sup>42</sup>, K.A. Johns<sup>7</sup>, K. Jon-And<sup>146a,146b</sup>, G. Jones<sup>170</sup>,  
 R.W.L. Jones<sup>71</sup>, T.J. Jones<sup>73</sup>, C. Joram<sup>30</sup>, P.M. Jorge<sup>124a</sup>, K.D. Joshi<sup>82</sup>, J. Jovicevic<sup>147</sup>, T. Jovin<sup>13b</sup>, X. Ju<sup>173</sup>,  
 C.A. Jung<sup>43</sup>, R.M. Jungst<sup>30</sup>, V. Juranek<sup>125</sup>, P. Jussel<sup>61</sup>, A. Juste Rozas<sup>12</sup>, S. Kabana<sup>17</sup>, M. Kaci<sup>167</sup>,  
 A. Kaczmarska<sup>39</sup>, P. Kadlecik<sup>36</sup>, M. Kado<sup>115</sup>, H. Kagan<sup>109</sup>, M. Kagan<sup>57</sup>, E. Kajomovitz<sup>152</sup>, S. Kalinin<sup>175</sup>,  
 L.V. Kalinovskaya<sup>64</sup>, S. Kama<sup>40</sup>, N. Kanaya<sup>155</sup>, M. Kaneda<sup>30</sup>, S. Kaneti<sup>28</sup>, T. Kanno<sup>157</sup>, V.A. Kantserov<sup>96</sup>,  
 J. Kanzaki<sup>65</sup>, B. Kaplan<sup>108</sup>, A. Kapliy<sup>31</sup>, D. Kar<sup>53</sup>, M. Karagounis<sup>21</sup>, K. Karakostas<sup>10</sup>, M. Karnevskiy<sup>58b</sup>,  
 V. Kartvelishvili<sup>71</sup>, A.N. Karyukhin<sup>128</sup>, L. Kashif<sup>173</sup>, G. Kasieczka<sup>58b</sup>, R.D. Kass<sup>109</sup>, A. Kastanas<sup>14</sup>,  
 Y. Kataoka<sup>155</sup>, J. Katzy<sup>42</sup>, V. Kaushik<sup>7</sup>, K. Kawagoe<sup>69</sup>, T. Kawamoto<sup>155</sup>, G. Kawamura<sup>81</sup>, M.S. Kayl<sup>105</sup>,  
 S. Kazama<sup>155</sup>, V.F. Kazanin<sup>107</sup>, M.Y. Kazarinov<sup>64</sup>, R. Keeler<sup>169</sup>, P.T. Keener<sup>120</sup>, R. Kehoe<sup>40</sup>, M. Keil<sup>54</sup>,  
 G.D. Kekelidze<sup>64</sup>, J.S. Keller<sup>138</sup>, M. Kenyon<sup>53</sup>, O. Kepka<sup>125</sup>, N. Kerschen<sup>30</sup>, B.P. Kerševan<sup>74</sup>, S. Kersten<sup>175</sup>,  
 K. Kessoku<sup>155</sup>, J. Keung<sup>158</sup>, F. Khalil-zada<sup>11</sup>, H. Khandanyan<sup>146a,146b</sup>, A. Khanov<sup>112</sup>, D. Kharchenko<sup>64</sup>,  
 A. Khodinov<sup>96</sup>, A. Khomich<sup>58a</sup>, T.J. Khoo<sup>28</sup>, G. Khorauli<sup>21</sup>, A. Khoroshilov<sup>175</sup>, V. Khovanskiy<sup>95</sup>,  
 E. Khramov<sup>64</sup>, J. Khubua<sup>51b</sup>, H. Kim<sup>146a,146b</sup>, S.H. Kim<sup>160</sup>, N. Kimura<sup>171</sup>, O. Kind<sup>16</sup>, B.T. King<sup>73</sup>,  
 M. King<sup>66</sup>, R.S.B. King<sup>118</sup>, J. Kirk<sup>129</sup>, A.E. Kiryunin<sup>99</sup>, T. Kishimoto<sup>66</sup>, D. Kisiielewska<sup>38</sup>, T. Kitamura<sup>66</sup>,  
 T. Kittelmann<sup>123</sup>, K. Kiuchi<sup>160</sup>, E. Kladiva<sup>144b</sup>, M. Klein<sup>73</sup>, U. Klein<sup>73</sup>, K. Kleinknecht<sup>81</sup>, M. Klemetti<sup>85</sup>,  
 A. Klier<sup>172</sup>, P. Klimek<sup>146a,146b</sup>, A. Klimentov<sup>25</sup>, R. Klingenberg<sup>43</sup>, J.A. Klinger<sup>82</sup>, E.B. Klinkby<sup>36</sup>,  
 T. Klioutchnikova<sup>30</sup>, P.F. Klok<sup>104</sup>, S. Klous<sup>105</sup>, E.-E. Kluge<sup>58a</sup>, T. Kluge<sup>73</sup>, P. Kluit<sup>105</sup>, S. Kluth<sup>99</sup>,  
 E. Kneringer<sup>61</sup>, E.B.F.G. Knoop<sup>83</sup>, A. Knue<sup>54</sup>, B.R. Ko<sup>45</sup>, T. Kobayashi<sup>155</sup>, M. Kobel<sup>44</sup>, M. Kocian<sup>143</sup>,  
 P. Kodys<sup>127</sup>, S. Koenig<sup>81</sup>, F. Koetsveld<sup>104</sup>, P. Koevesarki<sup>21</sup>, T. Koffas<sup>29</sup>, E. Koffeman<sup>105</sup>, L.A. Kogan<sup>118</sup>,  
 S. Kohlmann<sup>175</sup>, F. Kohn<sup>54</sup>, Z. Kohout<sup>126</sup>, T. Kohriki<sup>65</sup>, T. Koi<sup>143</sup>, G.M. Kolachev<sup>107,\*</sup>, H. Kolanoski<sup>16</sup>,  
 V. Kolesnikov<sup>64</sup>, I. Koletsou<sup>89a</sup>, J. Koll<sup>88</sup>, A.A. Komar<sup>94</sup>, Y. Komori<sup>155</sup>, T. Kondo<sup>65</sup>, K. Köneke<sup>30</sup>,  
 A.C. König<sup>104</sup>, T. Kono<sup>42,t</sup>, A.I. Kononov<sup>48</sup>, R. Konoplich<sup>108,u</sup>, N. Konstantinidis<sup>77</sup>, R. Kopeliansky<sup>152</sup>,  
 S. Koperny<sup>38</sup>, L. Köpke<sup>81</sup>, K. Korcyl<sup>39</sup>, K. Kordas<sup>154</sup>, A. Korn<sup>118</sup>, A. Korol<sup>107</sup>, I. Korolkov<sup>12</sup>,  
 E.V. Korolkova<sup>139</sup>, V.A. Korotkov<sup>128</sup>, O. Kortner<sup>99</sup>, S. Kortner<sup>99</sup>, V.V. Kostyukhin<sup>21</sup>, S. Kotov<sup>99</sup>,  
 V.M. Kotov<sup>64</sup>, A. Kotwal<sup>45</sup>, C. Kourkoumelis<sup>9</sup>, V. Kouskoura<sup>154</sup>, A. Koutsman<sup>159a</sup>, R. Kowalewski<sup>169</sup>,  
 T.Z. Kowalski<sup>38</sup>, W. Kozanecki<sup>136</sup>, A.S. Kozhin<sup>128</sup>, V. Kral<sup>126</sup>, V.A. Kramarenko<sup>97</sup>, G. Kramberger<sup>74</sup>,  
 M.W. Krasny<sup>78</sup>, A. Krasznahorkay<sup>108</sup>, J.K. Kraus<sup>21</sup>, A. Kravchenko<sup>25</sup>, S. Kreiss<sup>108</sup>, F. Krejci<sup>126</sup>,  
 J. Kretzschmar<sup>73</sup>, K. Kreutzfeldt<sup>52</sup>, N. Krieger<sup>54</sup>, P. Krieger<sup>158</sup>, K. Kroeninger<sup>54</sup>, H. Kroha<sup>99</sup>, J. Kroll<sup>120</sup>,  
 J. Kröseberg<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>, M.K. Kruse<sup>45</sup>, T. Kubota<sup>86</sup>, S. Kудay<sup>4a</sup>, S. Kuehn<sup>48</sup>, A. Kugel<sup>58c</sup>, T. Kuhl<sup>42</sup>,  
 D. Kuhn<sup>61</sup>, V. Kukhtin<sup>64</sup>, Y. Kulchitsky<sup>90</sup>, S. Kuleshov<sup>32b</sup>, C. Kummer<sup>98</sup>, M. Kuna<sup>78</sup>, J. Kunkle<sup>120</sup>,  
 A. Kupco<sup>125</sup>, H. Kurashige<sup>66</sup>, M. Kurata<sup>160</sup>, Y.A. Kurochkin<sup>90</sup>, V. Kus<sup>125</sup>, E.S. Kuwertz<sup>147</sup>, M. Kuze<sup>157</sup>,  
 J. Kvita<sup>142</sup>, R. Kwee<sup>16</sup>, A. La Rosa<sup>49</sup>, L. La Rotonda<sup>37a,37b</sup>, L. Labarga<sup>80</sup>, S. Lablak<sup>135a</sup>, C. Lacasta<sup>167</sup>,

F. Lacava<sup>132a,132b</sup>, J. Lacey<sup>29</sup>, H. Lacker<sup>16</sup>, D. Lacour<sup>78</sup>, V.R. Lacuesta<sup>167</sup>, E. Ladygin<sup>64</sup>, R. Lafaye<sup>5</sup>, B. Laforge<sup>78</sup>, T. Lagouri<sup>176</sup>, S. Lai<sup>48</sup>, E. Laisne<sup>55</sup>, L. Lambourne<sup>77</sup>, C.L. Lampen<sup>7</sup>, W. Lampl<sup>7</sup>, E. Lançon<sup>136</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>163</sup>, F. Lanni<sup>25</sup>, K. Lantsch<sup>30</sup>, A. Lanza<sup>119a</sup>, S. Laplace<sup>78</sup>, C. Lapoire<sup>21</sup>, J.F. Laporte<sup>136</sup>, T. Lari<sup>89a</sup>, A. Larner<sup>118</sup>, M. Lassnig<sup>30</sup>, P. Laurelli<sup>47</sup>, V. Lavorini<sup>37a,37b</sup>, W. Lavrijsen<sup>15</sup>, P. Laycock<sup>73</sup>, O. Le Dortz<sup>78</sup>, E. Le Guirriec<sup>83</sup>, E. Le Menedeu<sup>12</sup>, T. LeCompte<sup>6</sup>, F. Ledroit-Guillon<sup>55</sup>, H. Lee<sup>105</sup>, J.S.H. Lee<sup>116</sup>, S.C. Lee<sup>151</sup>, L. Lee<sup>176</sup>, M. Lefebvre<sup>169</sup>, M. Legendre<sup>136</sup>, F. Legger<sup>98</sup>, C. Leggett<sup>15</sup>, M. Lehmacher<sup>21</sup>, G. Lehmann Miotto<sup>30</sup>, A.G. Leister<sup>176</sup>, M.A.L. Leite<sup>24d</sup>, R. Leitner<sup>127</sup>, D. Lellouch<sup>172</sup>, B. Lemmer<sup>54</sup>, V. Lendermann<sup>58a</sup>, K.J.C. Leney<sup>145b</sup>, T. Lenz<sup>105</sup>, G. Lenzen<sup>175</sup>, B. Lenzi<sup>30</sup>, K. Leonhardt<sup>44</sup>, S. Leontsinis<sup>10</sup>, F. Lepold<sup>58a</sup>, C. Leroy<sup>93</sup>, J.-R. Lessard<sup>169</sup>, C.G. Lester<sup>28</sup>, C.M. Lester<sup>120</sup>, J. Levêque<sup>5</sup>, D. Levin<sup>87</sup>, L.J. Levinson<sup>172</sup>, A. Lewis<sup>118</sup>, G.H. Lewis<sup>108</sup>, A.M. Leyko<sup>21</sup>, M. Leyton<sup>16</sup>, B. Li<sup>33b</sup>, B. Li<sup>83</sup>, H. Li<sup>148</sup>, H.L. Li<sup>31</sup>, S. Li<sup>33b,v</sup>, X. Li<sup>87</sup>, Z. Liang<sup>118,w</sup>, H. Liao<sup>34</sup>, B. Liberti<sup>133a</sup>, P. Lichard<sup>30</sup>, M. Lichtnecker<sup>98</sup>, K. Lie<sup>165</sup>, W. Liebig<sup>14</sup>, C. Limbach<sup>21</sup>, A. Limosani<sup>86</sup>, M. Limper<sup>62</sup>, S.C. Lin<sup>151,x</sup>, F. Linde<sup>105</sup>, J.T. Linnemann<sup>88</sup>, E. Lipeles<sup>120</sup>, A. Lipniacka<sup>14</sup>, T.M. Liss<sup>165</sup>, D. Lissauer<sup>25</sup>, A. Lister<sup>49</sup>, A.M. Litke<sup>137</sup>, C. Liu<sup>29</sup>, D. Liu<sup>151</sup>, J.B. Liu<sup>87</sup>, L. Liu<sup>87</sup>, M. Liu<sup>33b</sup>, Y. Liu<sup>33b</sup>, M. Livan<sup>119a,119b</sup>, S.S.A. Livermore<sup>118</sup>, A. Lleres<sup>55</sup>, J. Llorente Merino<sup>80</sup>, S.L. Lloyd<sup>75</sup>, F. Lo Sterzo<sup>132a,132b</sup>, E. Lobodzinska<sup>42</sup>, P. Loch<sup>7</sup>, W.S. Lockman<sup>137</sup>, T. Loddenkoetter<sup>21</sup>, F.K. Loebinger<sup>82</sup>, A.E. Loevschall-Jensen<sup>36</sup>, A. Loginov<sup>176</sup>, C.W. Loh<sup>168</sup>, T. Lohse<sup>16</sup>, K. Lohwasser<sup>48</sup>, M. Lokajicek<sup>125</sup>, V.P. Lombardo<sup>5</sup>, R.E. Long<sup>71</sup>, L. Lopes<sup>124a</sup>, D. Lopez Mateos<sup>57</sup>, J. Lorenz<sup>98</sup>, N. Lorenzo Martinez<sup>115</sup>, M. Losada<sup>162</sup>, P. Loscutoff<sup>15</sup>, M.J. Losty<sup>159a,\*</sup>, X. Lou<sup>41</sup>, A. Lounis<sup>115</sup>, K.F. Loureiro<sup>162</sup>, J. Love<sup>6</sup>, P.A. Love<sup>71</sup>, A.J. Lowe<sup>143,g</sup>, F. Lu<sup>33a</sup>, H.J. Lubatti<sup>138</sup>, C. Luci<sup>132a,132b</sup>, A. Lucotte<sup>55</sup>, D. Ludwig<sup>42</sup>, I. Ludwig<sup>48</sup>, J. Ludwig<sup>48</sup>, F. Luehring<sup>60</sup>, G. Luijckx<sup>105</sup>, W. Lukas<sup>61</sup>, L. Luminari<sup>132a</sup>, E. Lund<sup>117</sup>, B. Lundberg<sup>79</sup>, J. Lundberg<sup>146a,146b</sup>, O. Lundberg<sup>146a,146b</sup>, B. Lund-Jensen<sup>147</sup>, J. Lundquist<sup>36</sup>, M. Lungwitz<sup>81</sup>, D. Lynn<sup>25</sup>, E. Lytken<sup>79</sup>, H. Ma<sup>25</sup>, L.L. Ma<sup>173</sup>, G. Maccarrone<sup>47</sup>, A. Macchiolo<sup>99</sup>, B. Maček<sup>74</sup>, J. Machado Miguens<sup>124a</sup>, D. Macina<sup>30</sup>, R. Mackeprang<sup>36</sup>, R.J. Madaras<sup>15</sup>, H.J. Maddocks<sup>71</sup>, W.F. Mader<sup>44</sup>, R. Maenner<sup>58c</sup>, M. Maeno<sup>5</sup>, T. Maeno<sup>25</sup>, L. Magnoni<sup>163</sup>, E. Magradze<sup>54</sup>, K. Mahboubi<sup>48</sup>, J. Mahlstedt<sup>105</sup>, S. Mahmoud<sup>73</sup>, G. Mahout<sup>18</sup>, C. Maiani<sup>136</sup>, C. Maidantchik<sup>24a</sup>, A. Maio<sup>124a,c</sup>, S. Majewski<sup>25</sup>, Y. Makida<sup>65</sup>, N. Makovec<sup>115</sup>, P. Mal<sup>136</sup>, B. Malaescu<sup>30</sup>, Pa. Malecki<sup>39</sup>, P. Malecki<sup>39</sup>, V.P. Maleev<sup>121</sup>, F. Malek<sup>55</sup>, U. Mallik<sup>62</sup>, D. Malon<sup>6</sup>, C. Malone<sup>143</sup>, S. Maltezos<sup>10</sup>, V. Malyshev<sup>107</sup>, S. Malyukov<sup>30</sup>, J. Mamuzic<sup>13b</sup>, A. Manabe<sup>65</sup>, L. Mandelli<sup>89a</sup>, I. Mandić<sup>74</sup>, R. Mandrysch<sup>62</sup>, J. Maneira<sup>124a</sup>, A. Manfredini<sup>99</sup>, L. Manhaes de Andrade Filho<sup>24b</sup>, J.A. Manjarres Ramos<sup>136</sup>, A. Mann<sup>98</sup>, P.M. Manning<sup>137</sup>, A. Manousakis-Katsikakis<sup>9</sup>, B. Mansoulie<sup>136</sup>, R. Mantifel<sup>85</sup>, A. Mapelli<sup>30</sup>, L. Mapelli<sup>30</sup>, L. March<sup>167</sup>, J.F. Marchand<sup>29</sup>, F. Marchese<sup>133a,133b</sup>, G. Marchiori<sup>78</sup>, M. Marcisovsky<sup>125</sup>, C.P. Marino<sup>169</sup>, F. Marroquim<sup>24a</sup>, Z. Marshall<sup>30</sup>, L.F. Marti<sup>17</sup>, S. Marti-Garcia<sup>167</sup>, B. Martin<sup>30</sup>, B. Martin<sup>88</sup>, J.P. Martin<sup>93</sup>, T.A. Martin<sup>18</sup>, V.J. Martin<sup>46</sup>, B. Martin dit Latour<sup>49</sup>, H. Martinez<sup>136</sup>, M. Martinez<sup>12</sup>, V. Martinez Outschoorn<sup>57</sup>, S. Martin-Haugh<sup>149</sup>, A.C. Martyniuk<sup>169</sup>, M. Marx<sup>82</sup>, F. Marzano<sup>132a</sup>, A. Marzin<sup>111</sup>, L. Masetti<sup>81</sup>, T. Mashimo<sup>155</sup>, R. Mashinistov<sup>94</sup>, J. Masik<sup>82</sup>, A.L. Maslennikov<sup>107</sup>, I. Massa<sup>20a,20b</sup>, G. Massaro<sup>105</sup>, N. Massol<sup>5</sup>, P. Mastrandrea<sup>148</sup>, A. Mastroberardino<sup>37a,37b</sup>, T. Masubuchi<sup>155</sup>, H. Matsunaga<sup>155</sup>, T. Matsushita<sup>66</sup>, P. Mättig<sup>175</sup>, S. Mättig<sup>42</sup>, C. Mattravers<sup>118,d</sup>, J. Maurer<sup>83</sup>, S.J. Maxfield<sup>73</sup>, D.A. Maximov<sup>107,h</sup>, A. Mayne<sup>139</sup>, R. Mazini<sup>151</sup>, M. Mazur<sup>21</sup>, L. Mazzaferro<sup>133a,133b</sup>, M. Mazzanti<sup>89a</sup>, J. Mc Donald<sup>85</sup>, S.P. Mc Kee<sup>87</sup>, A. McCarn<sup>165</sup>, R.L. McCarthy<sup>148</sup>, T.G. McCarthy<sup>29</sup>, N.A. McCubbin<sup>129</sup>, K.W. McFarlane<sup>56,\*</sup>, J.A. McFayden<sup>139</sup>, G. Mchedlidze<sup>51b</sup>, T. McLaughlan<sup>18</sup>, S.J. McMahon<sup>129</sup>, R.A. McPherson<sup>169,i</sup>, A. Meade<sup>84</sup>, J. Mechnich<sup>105</sup>, M. Mechtel<sup>175</sup>, M. Medinnis<sup>42</sup>, S. Meehan<sup>31</sup>, R. Meera-Lebbai<sup>111</sup>, T. Meguro<sup>116</sup>, S. Mehlhase<sup>36</sup>, A. Mehta<sup>73</sup>, K. Meier<sup>58a</sup>, B. Meirose<sup>79</sup>, C. Melachrinou<sup>31</sup>, B.R. Mellado Garcia<sup>173</sup>, F. Meloni<sup>89a,89b</sup>, L. Mendoza Navas<sup>162</sup>, Z. Meng<sup>151,y</sup>, A. Mengarelli<sup>20a,20b</sup>, S. Menke<sup>99</sup>, E. Meoni<sup>161</sup>, K.M. Mercurio<sup>57</sup>, P. Mermod<sup>49</sup>, L. Merola<sup>102a,102b</sup>, C. Meroni<sup>89a</sup>, F.S. Merritt<sup>31</sup>, H. Merritt<sup>109</sup>, A. Messina<sup>30,z</sup>, J. Metcalfe<sup>25</sup>, A.S. Mete<sup>163</sup>, C. Meyer<sup>81</sup>, C. Meyer<sup>31</sup>, J.-P. Meyer<sup>136</sup>, J. Meyer<sup>174</sup>, J. Meyer<sup>54</sup>, S. Michal<sup>30</sup>, L. Micu<sup>26a</sup>, R.P. Middleton<sup>129</sup>, S. Migas<sup>73</sup>, L. Mijović<sup>136</sup>, G. Mikenberg<sup>172</sup>, M. Mikestikova<sup>125</sup>, M. Mikuž<sup>74</sup>, D.W. Miller<sup>31</sup>, R.J. Miller<sup>88</sup>, W.J. Mills<sup>168</sup>, C. Mills<sup>57</sup>, A. Milov<sup>172</sup>, D.A. Milstead<sup>146a,146b</sup>, D. Milstein<sup>172</sup>, A.A. Minaenko<sup>128</sup>, M. Miñano Moya<sup>167</sup>, I.A. Minashvili<sup>64</sup>, A.I. Mincer<sup>108</sup>, B. Mindur<sup>38</sup>, M. Mineev<sup>64</sup>, Y. Ming<sup>173</sup>, L.M. Mir<sup>12</sup>, G. Mirabelli<sup>132a</sup>, J. Mitrevski<sup>137</sup>, V.A. Mitsou<sup>167</sup>, S. Mitsui<sup>65</sup>, P.S. Miyagawa<sup>139</sup>, J.U. Mjörnmark<sup>79</sup>, T. Moa<sup>146a,146b</sup>,

V. Moeller<sup>28</sup>, S. Mohapatra<sup>148</sup>, W. Mohr<sup>48</sup>, R. Moles-Valls<sup>167</sup>, A. Molfetas<sup>30</sup>, K. Mönig<sup>42</sup>, J. Monk<sup>77</sup>, E. Monnier<sup>83</sup>, J. Montejo Berlingen<sup>12</sup>, F. Monticelli<sup>70</sup>, S. Monzani<sup>20a,20b</sup>, R.W. Moore<sup>3</sup>, G.F. Moorhead<sup>86</sup>, C. Mora Herrera<sup>49</sup>, A. Moraes<sup>53</sup>, N. Morange<sup>136</sup>, J. Morel<sup>54</sup>, G. Morello<sup>37a,37b</sup>, D. Moreno<sup>81</sup>, M. Moreno Llácer<sup>167</sup>, P. Morettini<sup>50a</sup>, M. Morgenstern<sup>44</sup>, M. Morii<sup>57</sup>, A.K. Morley<sup>30</sup>, G. Mornacchi<sup>30</sup>, J.D. Morris<sup>75</sup>, L. Morvaj<sup>101</sup>, N. Möser<sup>21</sup>, H.G. Moser<sup>99</sup>, M. Mosidze<sup>51b</sup>, J. Moss<sup>109</sup>, R. Mount<sup>143</sup>, E. Mountricha<sup>10,aa</sup>, S.V. Mouraviev<sup>94,\*</sup>, E.J.W. Moyse<sup>84</sup>, F. Mueller<sup>58a</sup>, J. Mueller<sup>123</sup>, K. Mueller<sup>21</sup>, T. Mueller<sup>81</sup>, D. Muenstermann<sup>30</sup>, T.A. Müller<sup>98</sup>, Y. Munwes<sup>153</sup>, W.J. Murray<sup>129</sup>, I. Mussche<sup>105</sup>, E. Musto<sup>152</sup>, A.G. Myagkov<sup>128</sup>, M. Myska<sup>125</sup>, O. Nackenhorst<sup>54</sup>, J. Nadal<sup>12</sup>, K. Nagai<sup>160</sup>, R. Nagai<sup>157</sup>, K. Nagano<sup>65</sup>, A. Nagarkar<sup>109</sup>, Y. Nagasaka<sup>59</sup>, M. Nagel<sup>99</sup>, A.M. Nairz<sup>30</sup>, Y. Nakahama<sup>30</sup>, K. Nakamura<sup>155</sup>, T. Nakamura<sup>155</sup>, I. Nakano<sup>110</sup>, G. Nanava<sup>21</sup>, A. Napier<sup>161</sup>, R. Narayan<sup>58b</sup>, M. Nash<sup>77,d</sup>, T. Nattermann<sup>21</sup>, T. Naumann<sup>42</sup>, G. Navarro<sup>162</sup>, H.A. Neal<sup>87</sup>, P.Yu. Nechaeva<sup>94</sup>, T.J. Neep<sup>82</sup>, A. Negri<sup>119a,119b</sup>, G. Negri<sup>30</sup>, M. Negrini<sup>20a</sup>, S. Nektarijevic<sup>49</sup>, A. Nelson<sup>163</sup>, T.K. Nelson<sup>143</sup>, S. Nemecek<sup>125</sup>, P. Nemethy<sup>108</sup>, A.A. Nepomuceno<sup>24a</sup>, M. Nessi<sup>30,ab</sup>, M.S. Neubauer<sup>165</sup>, M. Neumann<sup>175</sup>, A. Neusiedl<sup>81</sup>, R.M. Neves<sup>108</sup>, P. Nevski<sup>25</sup>, F.M. Newcomer<sup>120</sup>, P.R. Newman<sup>18</sup>, V. Nguyen Thi Hong<sup>136</sup>, R.B. Nickerson<sup>118</sup>, R. Nicolaidou<sup>136</sup>, B. Nicquevert<sup>30</sup>, F. Niedercorn<sup>115</sup>, J. Nielsen<sup>137</sup>, N. Nikiforou<sup>35</sup>, A. Nikiforov<sup>16</sup>, V. Nikolaenko<sup>128</sup>, I. Nikolic-Audit<sup>78</sup>, K. Nikolics<sup>49</sup>, K. Nikolopoulos<sup>18</sup>, H. Nilsen<sup>48</sup>, P. Nilsson<sup>8</sup>, Y. Ninomiya<sup>155</sup>, A. Nisati<sup>132a</sup>, R. Nisius<sup>99</sup>, T. Nobe<sup>157</sup>, L. Nodulman<sup>6</sup>, M. Nomachi<sup>116</sup>, I. Nomidis<sup>154</sup>, S. Norberg<sup>111</sup>, M. Nordberg<sup>30</sup>, J. Novakova<sup>127</sup>, M. Nozaki<sup>65</sup>, L. Nozka<sup>113</sup>, I.M. Nugent<sup>159a</sup>, A.-E. Nuncio-Quiroz<sup>21</sup>, G. Nunes Hanninger<sup>86</sup>, T. Nunnemann<sup>98</sup>, E. Nurse<sup>77</sup>, B.J. O'Brien<sup>46</sup>, D.C. O'Neil<sup>142</sup>, V. O'Shea<sup>53</sup>, L.B. Oakes<sup>98</sup>, F.G. Oakham<sup>29,f</sup>, H. Oberlack<sup>99</sup>, J. Ocariz<sup>78</sup>, A. Ochi<sup>66</sup>, S. Oda<sup>69</sup>, S. Odaka<sup>65</sup>, J. Odier<sup>83</sup>, H. Ogren<sup>60</sup>, A. Oh<sup>82</sup>, S.H. Oh<sup>45</sup>, C.C. Ohm<sup>30</sup>, T. Ohshima<sup>101</sup>, W. Okamura<sup>116</sup>, H. Okawa<sup>25</sup>, Y. Okumura<sup>31</sup>, T. Okuyama<sup>155</sup>, A. Olariu<sup>26a</sup>, A.G. Olchevski<sup>64</sup>, S.A. Olivares Pino<sup>32a</sup>, M. Oliveira<sup>124a,i</sup>, D. Oliveira Damazio<sup>25</sup>, E. Oliver Garcia<sup>167</sup>, D. Olivito<sup>120</sup>, A. Olszewski<sup>39</sup>, J. Olszowska<sup>39</sup>, A. Onofre<sup>124a,ac</sup>, P.U.E. Onyisi<sup>31,ad</sup>, C.J. Oram<sup>159a</sup>, M.J. Oreglia<sup>31</sup>, Y. Oren<sup>153</sup>, D. Orestano<sup>134a,134b</sup>, N. Orlando<sup>72a,72b</sup>, I. Orlov<sup>107</sup>, C. Oropeza Barrera<sup>53</sup>, R.S. Orr<sup>158</sup>, B. Osculati<sup>50a,50b</sup>, R. Ospanov<sup>120</sup>, C. Osuna<sup>12</sup>, G. Otero y Garzon<sup>27</sup>, J.P. Ottersbach<sup>105</sup>, M. Ouchrif<sup>135d</sup>, E.A. Ouellette<sup>169</sup>, F. Ould-Saada<sup>117</sup>, A. Ouraou<sup>136</sup>, Q. Ouyang<sup>33a</sup>, A. Ovcharova<sup>15</sup>, M. Owen<sup>82</sup>, S. Owen<sup>139</sup>, V.E. Ozcan<sup>19a</sup>, N. Ozturk<sup>8</sup>, A. Pacheco Pages<sup>12</sup>, C. Padilla Aranda<sup>12</sup>, S. Pagan Griso<sup>15</sup>, E. Paganis<sup>139</sup>, C. Pahl<sup>99</sup>, F. Paige<sup>25</sup>, P. Pais<sup>84</sup>, K. Pajchel<sup>117</sup>, G. Palacino<sup>159b</sup>, C.P. Paleari<sup>7</sup>, S. Palestini<sup>30</sup>, D. Pallin<sup>34</sup>, A. Palma<sup>124a</sup>, J.D. Palmer<sup>18</sup>, Y.B. Pan<sup>173</sup>, E. Panagiotopoulou<sup>10</sup>, J.G. Panduro Vazquez<sup>76</sup>, P. Pani<sup>105</sup>, N. Panikashvili<sup>87</sup>, S. Panitkin<sup>25</sup>, D. Pantea<sup>26a</sup>, A. Papadelis<sup>146a</sup>, Th.D. Papadopoulou<sup>10</sup>, A. Paramonov<sup>6</sup>, D. Paredes Hernandez<sup>34</sup>, W. Park<sup>25,ae</sup>, M.A. Parker<sup>28</sup>, F. Parodi<sup>50a,50b</sup>, J.A. Parsons<sup>35</sup>, U. Parzefall<sup>48</sup>, S. Pashapour<sup>54</sup>, E. Pasqualucci<sup>132a</sup>, S. Passaggio<sup>50a</sup>, A. Passeri<sup>134a</sup>, F. Pastore<sup>134a,134b,\*</sup>, Fr. Pastore<sup>76</sup>, G. Pásztor<sup>49,af</sup>, S. Patariaia<sup>175</sup>, N.D. Patel<sup>150</sup>, J.R. Pater<sup>82</sup>, S. Patricelli<sup>102a,102b</sup>, T. Pauly<sup>30</sup>, M. Pecsny<sup>144a</sup>, S. Pedraza Lopez<sup>167</sup>, M.I. Pedraza Morales<sup>173</sup>, S.V. Peleganchuk<sup>107</sup>, D. Pelikan<sup>166</sup>, H. Peng<sup>33b</sup>, B. Penning<sup>31</sup>, A. Penson<sup>35</sup>, J. Penwell<sup>60</sup>, M. Perantoni<sup>24a</sup>, K. Perez<sup>35,ag</sup>, T. Perez Cavalcanti<sup>42</sup>, E. Perez Codina<sup>159a</sup>, M.T. Pérez García-Estañ<sup>167</sup>, V. Perez Reale<sup>35</sup>, L. Perini<sup>89a,89b</sup>, H. Pernegger<sup>30</sup>, R. Perrino<sup>72a</sup>, P. Perrodo<sup>5</sup>, V.D. Peshekhonov<sup>64</sup>, K. Peters<sup>30</sup>, B.A. Petersen<sup>30</sup>, J. Petersen<sup>30</sup>, T.C. Petersen<sup>36</sup>, E. Petit<sup>5</sup>, A. Petridis<sup>154</sup>, C. Petridou<sup>154</sup>, E. Petrolo<sup>132a</sup>, F. Petrucci<sup>134a,134b</sup>, D. Petschull<sup>42</sup>, M. Petteni<sup>142</sup>, R. Pezoa<sup>32b</sup>, A. Phan<sup>86</sup>, P.W. Phillips<sup>129</sup>, G. Piacquadio<sup>30</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>109</sup>, J.E. Pilcher<sup>31</sup>, A.D. Pilkington<sup>82</sup>, J. Pina<sup>124a,c</sup>, M. Pinamonti<sup>164a,164c,ah</sup>, A. Pinder<sup>118</sup>, J.L. Pinfold<sup>3</sup>, A. Pingel<sup>36</sup>, B. Pinto<sup>124a</sup>, C. Pizio<sup>89a,89b</sup>, M.-A. Pleier<sup>25</sup>, E. Plotnikova<sup>64</sup>, A. Poblaguev<sup>25</sup>, S. Poddar<sup>58a</sup>, F. Podlyski<sup>34</sup>, L. Poggioli<sup>115</sup>, D. Pohl<sup>21</sup>, M. Pohl<sup>49</sup>, G. Polesello<sup>119a</sup>, A. Policicchio<sup>37a,37b</sup>, A. Polini<sup>20a</sup>, J. Poll<sup>75</sup>, V. Polychronakos<sup>25</sup>, D. Pomeroy<sup>23</sup>, K. Pommès<sup>30</sup>, L. Pontecorvo<sup>132a</sup>, B.G. Pope<sup>88</sup>, G.A. Popeneciu<sup>26a</sup>, D.S. Popovic<sup>13a</sup>, A. Poppleton<sup>30</sup>, X. Portell Bueso<sup>30</sup>, G.E. Pospelov<sup>99</sup>, S. Pospisil<sup>126</sup>, I.N. Potrap<sup>99</sup>, C.J. Potter<sup>149</sup>, C.T. Potter<sup>114</sup>, G. Poulard<sup>30</sup>, J. Poveda<sup>60</sup>, V. Pozdnyakov<sup>64</sup>, R. Prabhu<sup>77</sup>, P. Pralavorio<sup>83</sup>, A. Pranko<sup>15</sup>, S. Prasad<sup>30</sup>, R. Pravahan<sup>25</sup>, S. Prell<sup>63</sup>, K. Pretzl<sup>17</sup>, D. Price<sup>60</sup>, J. Price<sup>73</sup>, L.E. Price<sup>6</sup>, D. Prieur<sup>123</sup>, M. Primavera<sup>72a</sup>, K. Prokofiev<sup>108</sup>, F. Prokoshin<sup>32b</sup>, S. Protopopescu<sup>25</sup>, J. Proudfoot<sup>6</sup>, X. Prudent<sup>44</sup>, M. Przybycien<sup>38</sup>, H. Przysiezniak<sup>5</sup>, S. Psoroulas<sup>21</sup>, E. Ptacek<sup>114</sup>, E. Pueschel<sup>84</sup>, D. Puldon<sup>148</sup>, J. Purdham<sup>87</sup>, M. Purohit<sup>25,ae</sup>, P. Puzo<sup>115</sup>, Y. Pylypchenko<sup>62</sup>, J. Qian<sup>87</sup>, A. Quadt<sup>54</sup>, D.R. Quarrie<sup>15</sup>, W.B. Quayle<sup>173</sup>, M. Raas<sup>104</sup>, V. Radeka<sup>25</sup>, V. Radescu<sup>42</sup>, P. Radloff<sup>114</sup>, F. Ragusa<sup>89a,89b</sup>,

G. Rahal<sup>178</sup>, A.M. Rahimi<sup>109</sup>, D. Rahm<sup>25</sup>, S. Rajagopalan<sup>25</sup>, M. Rammensee<sup>48</sup>, M. Rammes<sup>141</sup>, A.S. Randle-Conde<sup>40</sup>, K. Randrianarivony<sup>29</sup>, K. Rao<sup>163</sup>, F. Rauscher<sup>98</sup>, T.C. Rave<sup>48</sup>, M. Raymond<sup>30</sup>, A.L. Read<sup>117</sup>, D.M. Rebuffi<sup>119a,119b</sup>, A. Redelbach<sup>174</sup>, G. Redlinger<sup>25</sup>, R. Reece<sup>120</sup>, K. Reeves<sup>41</sup>, A. Reinsch<sup>114</sup>, I. Reisinger<sup>43</sup>, C. Rembser<sup>30</sup>, Z.L. Ren<sup>151</sup>, A. Renaud<sup>115</sup>, M. Rescigno<sup>132a</sup>, S. Resconi<sup>89a</sup>, B. Resende<sup>136</sup>, P. Reznicek<sup>98</sup>, R. Rezvani<sup>158</sup>, R. Richter<sup>99</sup>, E. Richter-Was<sup>5</sup>, M. Ridel<sup>78</sup>, M. Rijpstra<sup>105</sup>, M. Rijssenbeek<sup>148</sup>, A. Rimoldi<sup>119a,119b</sup>, L. Rinaldi<sup>20a</sup>, R.R. Rios<sup>40</sup>, I. Riu<sup>12</sup>, G. Rivoltella<sup>89a,89b</sup>, F. Rizatdinova<sup>112</sup>, E. Rizvi<sup>75</sup>, S.H. Robertson<sup>85,l</sup>, A. Robichaud-Veronneau<sup>118</sup>, D. Robinson<sup>28</sup>, J.E.M. Robinson<sup>82</sup>, A. Robson<sup>53</sup>, J.G. Rocha de Lima<sup>106</sup>, C. Roda<sup>122a,122b</sup>, D. Roda Dos Santos<sup>30</sup>, A. Roe<sup>54</sup>, S. Roe<sup>30</sup>, O. Røhne<sup>117</sup>, S. Rolli<sup>161</sup>, A. Romaniouk<sup>96</sup>, M. Romano<sup>20a,20b</sup>, G. Romeo<sup>27</sup>, E. Romero Adam<sup>167</sup>, N. Rompotis<sup>138</sup>, L. Roos<sup>78</sup>, E. Ros<sup>167</sup>, S. Rosati<sup>132a</sup>, K. Rosbach<sup>49</sup>, A. Rose<sup>149</sup>, M. Rose<sup>76</sup>, G.A. Rosenbaum<sup>158</sup>, P.L. Rosendahl<sup>14</sup>, O. Rosenthal<sup>141</sup>, L. Rosselet<sup>49</sup>, V. Rossetti<sup>12</sup>, E. Rossi<sup>132a,132b</sup>, L.P. Rossi<sup>50a</sup>, M. Rotaru<sup>26a</sup>, I. Roth<sup>172</sup>, J. Rothberg<sup>138</sup>, D. Rousseau<sup>115</sup>, C.R. Royon<sup>136</sup>, A. Rozanov<sup>83</sup>, Y. Rozen<sup>152</sup>, X. Ruan<sup>33a,ai</sup>, F. Rubbo<sup>12</sup>, I. Rubinskiy<sup>42</sup>, N. Ruckstuhl<sup>105</sup>, V.I. Rud<sup>97</sup>, C. Rudolph<sup>44</sup>, G. Rudolph<sup>61</sup>, F. Rühr<sup>7</sup>, A. Ruiz-Martinez<sup>63</sup>, L. Rumyantsev<sup>64</sup>, Z. Rurikova<sup>48</sup>, N.A. Rusakovich<sup>64</sup>, A. Ruschke<sup>98</sup>, J.P. Rutherford<sup>7</sup>, N. Ruthmann<sup>48</sup>, P. Ruzicka<sup>125</sup>, Y.F. Ryabov<sup>121</sup>, M. Rybar<sup>127</sup>, G. Rybkin<sup>115</sup>, N.C. Ryder<sup>118</sup>, A.F. Saavedra<sup>150</sup>, I. Sadeh<sup>153</sup>, H.F-W. Sadrozinski<sup>137</sup>, R. Sadykov<sup>64</sup>, F. Safai Tehrani<sup>132a</sup>, H. Sakamoto<sup>155</sup>, G. Salamanna<sup>75</sup>, A. Salamon<sup>133a</sup>, M. Saleem<sup>111</sup>, D. Salek<sup>30</sup>, D. Salihagic<sup>99</sup>, A. Salnikov<sup>143</sup>, J. Salt<sup>167</sup>, B.M. Salvachua Ferrando<sup>6</sup>, D. Salvatore<sup>37a,37b</sup>, F. Salvatore<sup>149</sup>, A. Salvucci<sup>104</sup>, A. Salzburger<sup>30</sup>, D. Sampsonidis<sup>154</sup>, B.H. Samset<sup>117</sup>, A. Sanchez<sup>102a,102b</sup>, J. Sánchez<sup>167</sup>, V. Sanchez Martinez<sup>167</sup>, H. Sandaker<sup>14</sup>, H.G. Sander<sup>81</sup>, M.P. Sanders<sup>98</sup>, M. Sandhoff<sup>175</sup>, T. Sandoval<sup>28</sup>, C. Sandoval<sup>162</sup>, R. Sandstroem<sup>99</sup>, D.P.C. Sankey<sup>129</sup>, A. Sansoni<sup>47</sup>, C. Santamarina Rios<sup>85</sup>, C. Santoni<sup>34</sup>, R. Santonico<sup>133a,133b</sup>, H. Santos<sup>124a</sup>, I. Santoyo Castillo<sup>149</sup>, J.G. Saraiva<sup>124a</sup>, T. Sarangi<sup>173</sup>, E. Sarkisyan-Grinbaum<sup>8</sup>, B. Sarrazin<sup>21</sup>, F. Sarri<sup>122a,122b</sup>, G. Sartisohn<sup>175</sup>, O. Sasaki<sup>65</sup>, Y. Sasaki<sup>155</sup>, N. Sasao<sup>67</sup>, I. Satsounkevitch<sup>90</sup>, G. Sauvage<sup>5,\*</sup>, E. Sauvan<sup>5</sup>, J.B. Sauvan<sup>115</sup>, P. Savard<sup>158,f</sup>, V. Savinov<sup>123</sup>, D.O. Savu<sup>30</sup>, L. Sawyer<sup>25,n</sup>, D.H. Saxon<sup>53</sup>, J. Saxon<sup>120</sup>, C. Sbarra<sup>20a</sup>, A. Sbrizzi<sup>20a,20b</sup>, D.A. Scannicchio<sup>163</sup>, M. Scarcella<sup>150</sup>, J. Schaarschmidt<sup>115</sup>, P. Schacht<sup>99</sup>, D. Schaefer<sup>120</sup>, A. Schaelicke<sup>46</sup>, S. Schaepe<sup>21</sup>, S. Schaezel<sup>58b</sup>, U. Schäfer<sup>81</sup>, A.C. Schaffer<sup>115</sup>, D. Schaile<sup>98</sup>, R.D. Schamberger<sup>148</sup>, A.G. Schamov<sup>107</sup>, V. Scharf<sup>58a</sup>, V.A. Schegelsky<sup>121</sup>, D. Scheirich<sup>87</sup>, M. Schernau<sup>163</sup>, M.I. Scherzer<sup>35</sup>, C. Schiavi<sup>50a,50b</sup>, J. Schieck<sup>98</sup>, M. Schioppa<sup>37a,37b</sup>, S. Schlenker<sup>30</sup>, E. Schmidt<sup>48</sup>, K. Schmieden<sup>21</sup>, C. Schmitt<sup>81</sup>, S. Schmitt<sup>58b</sup>, B. Schneider<sup>17</sup>, U. Schnoor<sup>44</sup>, L. Schoeffel<sup>136</sup>, A. Schoening<sup>58b</sup>, A.L.S. Schorlemmer<sup>54</sup>, M. Schott<sup>81</sup>, D. Schouten<sup>159a</sup>, J. Schovancova<sup>125</sup>, M. Schram<sup>85</sup>, C. Schroeder<sup>81</sup>, N. Schroer<sup>58c</sup>, M.J. Schultens<sup>21</sup>, J. Schultes<sup>175</sup>, H.-C. Schultz-Coulon<sup>58a</sup>, H. Schulz<sup>16</sup>, M. Schumacher<sup>48</sup>, B.A. Schumm<sup>137</sup>, Ph. Schune<sup>136</sup>, A. Schwartzman<sup>143</sup>, Ph. Schwegler<sup>99</sup>, Ph. Schwemling<sup>78</sup>, R. Schwienhorst<sup>88</sup>, R. Schwierz<sup>44</sup>, J. Schwindling<sup>136</sup>, T. Schwindt<sup>21</sup>, M. Schwoerer<sup>5</sup>, F.G. Sciacca<sup>17</sup>, G. Sciolla<sup>23</sup>, W.G. Scott<sup>129</sup>, J. Searcy<sup>114</sup>, G. Sedov<sup>42</sup>, E. Sedykh<sup>121</sup>, S.C. Seidel<sup>103</sup>, A. Seiden<sup>137</sup>, F. Seifert<sup>44</sup>, J.M. Seixas<sup>24a</sup>, G. Sekhniaidze<sup>102a</sup>, S.J. Sekula<sup>40</sup>, K.E. Selbach<sup>46</sup>, D.M. Seliverstov<sup>121</sup>, B. Sellden<sup>146a</sup>, G. Sellers<sup>73</sup>, M. Seman<sup>144b</sup>, N. Semprini-Cesari<sup>20a,20b</sup>, C. Serfon<sup>98</sup>, L. Serin<sup>115</sup>, L. Serkin<sup>54</sup>, R. Seuster<sup>159a</sup>, H. Severini<sup>111</sup>, A. Sfyrla<sup>30</sup>, E. Shabalina<sup>54</sup>, M. Shamim<sup>114</sup>, L.Y. Shan<sup>33a</sup>, J.T. Shank<sup>22</sup>, Q.T. Shao<sup>86</sup>, M. Shapiro<sup>15</sup>, P.B. Shatalov<sup>95</sup>, K. Shaw<sup>164a,164c</sup>, D. Sherman<sup>176</sup>, P. Sherwood<sup>77</sup>, S. Shimizu<sup>101</sup>, M. Shimojima<sup>100</sup>, T. Shin<sup>56</sup>, M. Shiyakova<sup>64</sup>, A. Shmeleva<sup>94</sup>, M.J. Shochet<sup>31</sup>, D. Short<sup>118</sup>, S. Shrestha<sup>63</sup>, E. Shulga<sup>96</sup>, M.A. Shupe<sup>7</sup>, P. Sicho<sup>125</sup>, A. Sidoti<sup>132a</sup>, F. Siegert<sup>48</sup>, Dj. Sijacki<sup>13a</sup>, O. Silbert<sup>172</sup>, J. Silva<sup>124a</sup>, Y. Silver<sup>153</sup>, D. Silverstein<sup>143</sup>, S.B. Silverstein<sup>146a</sup>, V. Simak<sup>126</sup>, O. Simard<sup>136</sup>, Lj. Simic<sup>13a</sup>, S. Simion<sup>115</sup>, E. Simioni<sup>81</sup>, B. Simmons<sup>77</sup>, R. Simoniello<sup>89a,89b</sup>, M. Simonyan<sup>36</sup>, P. Sinervo<sup>158</sup>, N.B. Sinev<sup>114</sup>, V. Sipica<sup>141</sup>, G. Siragusa<sup>174</sup>, A. Sircar<sup>25</sup>, A.N. Sisakyan<sup>64,\*</sup>, S.Yu. Sivoklov<sup>97</sup>, J. Sjölín<sup>146a,146b</sup>, T.B. Sjurson<sup>14</sup>, L.A. Skinnari<sup>15</sup>, H.P. Skottowe<sup>57</sup>, K. Skovpen<sup>107</sup>, P. Skubic<sup>111</sup>, M. Slater<sup>18</sup>, T. Slavicek<sup>126</sup>, K. Sliwa<sup>161</sup>, V. Smakhtin<sup>172</sup>, B.H. Smart<sup>46</sup>, L. Smestad<sup>117</sup>, S.Yu. Smirnov<sup>96</sup>, Y. Smirnov<sup>96</sup>, L.N. Smirnova<sup>97,qj</sup>, O. Smirnova<sup>79</sup>, B.C. Smith<sup>57</sup>, D. Smith<sup>143</sup>, K.M. Smith<sup>53</sup>, M. Smizanska<sup>71</sup>, K. Smolek<sup>126</sup>, A.A. Snesarev<sup>94</sup>, S.W. Snow<sup>82</sup>, J. Snow<sup>111</sup>, S. Snyder<sup>25</sup>, R. Sobie<sup>169,l</sup>, J. Sodomka<sup>126</sup>, A. Soffer<sup>153</sup>, D.A. Soh<sup>151,w</sup>, C.A. Solans<sup>167</sup>, M. Solar<sup>126</sup>, J. Solc<sup>126</sup>, E.Yu. Soldatov<sup>96</sup>, U. Soldevila<sup>167</sup>, E. Solfaroli Camillocci<sup>132a,132b</sup>, A.A. Solodkov<sup>128</sup>, O.V. Solovyanov<sup>128</sup>, V. Solovyev<sup>121</sup>, N. Soni<sup>1</sup>, A. Sood<sup>15</sup>, V. Sopko<sup>126</sup>, B. Sopko<sup>126</sup>, M. Sosebee<sup>8</sup>, R. Soualah<sup>164a,164c</sup>, P. Soueid<sup>93</sup>, A. Soukharev<sup>107</sup>, S. Spagnolo<sup>72a,72b</sup>, F. Spanò<sup>76</sup>, R. Spighi<sup>20a</sup>, G. Spigo<sup>30</sup>, R. Spiwoks<sup>30</sup>,

M. Spousta<sup>127,ak</sup>, T. Spreitzer<sup>158</sup>, B. Spurlock<sup>8</sup>, R.D. St. Denis<sup>53</sup>, J. Stahlman<sup>120</sup>, R. Stamen<sup>58a</sup>,  
 E. Stanecka<sup>39</sup>, R.W. Stanek<sup>6</sup>, C. Stanescu<sup>134a</sup>, M. Stanescu-Bellu<sup>42</sup>, M.M. Stanitzki<sup>42</sup>, S. Stapnes<sup>117</sup>,  
 E.A. Starchenko<sup>128</sup>, J. Stark<sup>55</sup>, P. Staroba<sup>125</sup>, P. Starovoitov<sup>42</sup>, R. Staszewski<sup>39</sup>, A. Staude<sup>98</sup>,  
 P. Stavina<sup>144a,\*</sup>, G. Steele<sup>53</sup>, P. Steinbach<sup>44</sup>, P. Steinberg<sup>25</sup>, I. Stekl<sup>126</sup>, B. Stelzer<sup>142</sup>, H.J. Stelzer<sup>88</sup>,  
 O. Stelzer-Chilton<sup>159a</sup>, H. Stenzel<sup>52</sup>, S. Stern<sup>99</sup>, G.A. Stewart<sup>30</sup>, J.A. Stillings<sup>21</sup>, M.C. Stockton<sup>85</sup>,  
 K. Stoerig<sup>48</sup>, G. Stoicea<sup>26a</sup>, S. Stonjek<sup>99</sup>, P. Strachota<sup>127</sup>, A.R. Stradling<sup>8</sup>, A. Straessner<sup>44</sup>,  
 J. Strandberg<sup>147</sup>, S. Strandberg<sup>146a,146b</sup>, A. Strandlie<sup>117</sup>, M. Strang<sup>109</sup>, E. Strauss<sup>143</sup>, M. Strauss<sup>111</sup>,  
 P. Strizenec<sup>144b</sup>, R. Ströhmer<sup>174</sup>, D.M. Strom<sup>114</sup>, J.A. Strong<sup>76,\*</sup>, R. Stroynowski<sup>40</sup>, B. Stugu<sup>14</sup>,  
 I. Stumer<sup>25,\*</sup>, J. Stupak<sup>148</sup>, P. Sturm<sup>175</sup>, N.A. Styles<sup>42</sup>, D. Su<sup>143</sup>, H.S. Subramania<sup>3</sup>, R. Subramaniam<sup>25</sup>,  
 A. Succurro<sup>12</sup>, Y. Sugaya<sup>116</sup>, C. Suhr<sup>106</sup>, M. Suk<sup>127</sup>, V.V. Sulin<sup>94</sup>, S. Sultansoy<sup>4d</sup>, T. Sumida<sup>67</sup>, X. Sun<sup>55</sup>,  
 J.E. Sundermann<sup>48</sup>, K. Suruliz<sup>139</sup>, G. Susinno<sup>37a,37b</sup>, M.R. Sutton<sup>149</sup>, Y. Suzuki<sup>65</sup>, Y. Suzuki<sup>66</sup>,  
 M. Svatos<sup>125</sup>, S. Swedish<sup>168</sup>, I. Sykora<sup>144a</sup>, T. Sykora<sup>127</sup>, D. Ta<sup>105</sup>, K. Tackmann<sup>42</sup>, A. Taffard<sup>163</sup>,  
 R. Tahirout<sup>159a</sup>, N. Taiblum<sup>153</sup>, Y. Takahashi<sup>101</sup>, H. Takai<sup>25</sup>, R. Takashima<sup>68</sup>, H. Takeda<sup>66</sup>, T. Takeshita<sup>140</sup>,  
 Y. Takubo<sup>65</sup>, M. Talby<sup>83</sup>, A. Talyshev<sup>107,h</sup>, M.C. Tamsett<sup>25</sup>, K.G. Tan<sup>86</sup>, J. Tanaka<sup>155</sup>, R. Tanaka<sup>115</sup>,  
 S. Tanaka<sup>131</sup>, S. Tanaka<sup>65</sup>, A.J. Tanasijczuk<sup>142</sup>, K. Tani<sup>66</sup>, N. Tannoury<sup>83</sup>, S. Tapprogge<sup>81</sup>, D. Tardif<sup>158</sup>,  
 S. Tarem<sup>152</sup>, F. Tarrade<sup>29</sup>, G.F. Tartarelli<sup>89a</sup>, P. Tas<sup>127</sup>, M. Tasevsky<sup>125</sup>, E. Tassi<sup>37a,37b</sup>, Y. Tayalati<sup>135d</sup>,  
 C. Taylor<sup>77</sup>, F.E. Taylor<sup>92</sup>, G.N. Taylor<sup>86</sup>, W. Taylor<sup>159b</sup>, M. Teinturier<sup>115</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>151</sup>,  
 S. Terada<sup>65</sup>, K. Terashi<sup>155</sup>, J. Terron<sup>80</sup>, M. Testa<sup>47</sup>, R.J. Teuscher<sup>158,l</sup>, J. Therhaag<sup>21</sup>,  
 T. Theveneaux-Pelzer<sup>78</sup>, S. Thoma<sup>48</sup>, J.P. Thomas<sup>18</sup>, E.N. Thompson<sup>35</sup>, P.D. Thompson<sup>18</sup>,  
 P.D. Thompson<sup>158</sup>, A.S. Thompson<sup>53</sup>, L.A. Thomsen<sup>36</sup>, E. Thomson<sup>120</sup>, M. Thomson<sup>28</sup>, W.M. Thong<sup>86</sup>,  
 R.P. Thun<sup>87</sup>, F. Tian<sup>35</sup>, M.J. Tibbetts<sup>15</sup>, T. Tic<sup>125</sup>, V.O. Tikhomirov<sup>94</sup>, Y.A. Tikhonov<sup>107,h</sup>, S. Timoshenko<sup>96</sup>,  
 E. Tiouchichine<sup>83</sup>, P. Tipton<sup>176</sup>, S. Tisserant<sup>83</sup>, T. Todorov<sup>5</sup>, S. Todorova-Nova<sup>161</sup>, B. Toggerson<sup>163</sup>,  
 J. Tojo<sup>69</sup>, S. Tokár<sup>144a</sup>, K. Tokushuku<sup>65</sup>, K. Tollefson<sup>88</sup>, M. Tomoto<sup>101</sup>, L. Tompkins<sup>31</sup>, K. Toms<sup>103</sup>,  
 A. Tonoyan<sup>14</sup>, C. Topfel<sup>17</sup>, N.D. Topilin<sup>64</sup>, E. Torrence<sup>114</sup>, H. Torres<sup>78</sup>, E. Torró Pastor<sup>167</sup>, J. Toth<sup>83,af</sup>,  
 F. Touchard<sup>83</sup>, D.R. Tovey<sup>139</sup>, T. Trefzger<sup>174</sup>, L. Tremblet<sup>30</sup>, A. Tricoli<sup>30</sup>, I.M. Trigger<sup>159a</sup>,  
 S. Trincaz-Duvoid<sup>78</sup>, M.F. Tripiana<sup>70</sup>, N. Triplett<sup>25</sup>, W. Trischuk<sup>158</sup>, B. Trocmé<sup>55</sup>, C. Troncon<sup>89a</sup>,  
 M. Trottier-McDonald<sup>142</sup>, P. True<sup>88</sup>, M. Trzebinski<sup>39</sup>, A. Trzupek<sup>39</sup>, C. Tsarouchas<sup>30</sup>, J.C.-L. Tseng<sup>118</sup>,  
 M. Tsiakiris<sup>105</sup>, P.V. Tsiarehka<sup>90</sup>, D. Tsionou<sup>5,al</sup>, G. Tsipolitis<sup>10</sup>, S. Tsiskaridze<sup>12</sup>, V. Tsiskaridze<sup>48</sup>,  
 E.G. Tskhadadze<sup>51a</sup>, I.I. Tsukerman<sup>95</sup>, V. Tsulaia<sup>15</sup>, J.-W. Tsung<sup>21</sup>, S. Tsuno<sup>65</sup>, D. Tsybychev<sup>148</sup>,  
 A. Tua<sup>139</sup>, A. Tudorache<sup>26a</sup>, V. Tudorache<sup>26a</sup>, J.M. Tuggle<sup>31</sup>, M. Turala<sup>39</sup>, D. Turecek<sup>126</sup>, I. Turk Cakir<sup>4e</sup>,  
 E. Turlay<sup>105</sup>, R. Turra<sup>89a,89b</sup>, P.M. Tuts<sup>35</sup>, A. Tykhonov<sup>74</sup>, M. Tylmad<sup>146a,146b</sup>, M. Tyndel<sup>129</sup>,  
 G. Tzanakos<sup>9</sup>, K. Uchida<sup>21</sup>, I. Ueda<sup>155</sup>, R. Ueno<sup>29</sup>, M. Ughetto<sup>83</sup>, M. Ugland<sup>14</sup>, M. Uhlenbrock<sup>21</sup>,  
 M. Uhrmacher<sup>54</sup>, F. Ukegawa<sup>160</sup>, G. Unal<sup>30</sup>, A. Undrus<sup>25</sup>, G. Unel<sup>163</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>, M. Uslenghi<sup>119a,119b</sup>, L. Vacavant<sup>83</sup>, V. Vacek<sup>126</sup>, B. Vachon<sup>85</sup>,  
 S. Vahsen<sup>15</sup>, S. Valentinetti<sup>20a,20b</sup>, A. Valero<sup>167</sup>, S. Valkar<sup>127</sup>, E. Valladolid Gallego<sup>167</sup>, S. Vallecorsa<sup>152</sup>,  
 J.A. Valls Ferrer<sup>167</sup>, R. Van Berg<sup>120</sup>, P.C. Van Der Deijl<sup>105</sup>, R. van der Geer<sup>105</sup>, H. van der Graaf<sup>105</sup>,  
 R. Van Der Leeuw<sup>105</sup>, E. van der Poel<sup>105</sup>, D. van der Ster<sup>30</sup>, N. van Eldik<sup>30</sup>, P. van Gemmeren<sup>6</sup>,  
 J. Van Nieuwkoop<sup>142</sup>, I. van Vulpen<sup>105</sup>, M. Vanadia<sup>99</sup>, W. Vandelli<sup>30</sup>, A. Vaniachine<sup>6</sup>, P. Vankov<sup>42</sup>,  
 F. Vannucci<sup>78</sup>, R. Vari<sup>132a</sup>, E.W. Varnes<sup>7</sup>, T. Varol<sup>84</sup>, D. Varouchas<sup>15</sup>, A. Vartapetian<sup>8</sup>, K.E. Varvell<sup>150</sup>,  
 V.I. Vassilikopoulos<sup>56</sup>, F. Vazeille<sup>34</sup>, T. Vazquez Schroeder<sup>54</sup>, G. Vegni<sup>89a,89b</sup>, J.J. Veillet<sup>115</sup>,  
 F. Veloso<sup>124a</sup>, R. Veness<sup>30</sup>, S. Veneziano<sup>132a</sup>, A. Ventura<sup>72a,72b</sup>, D. Ventura<sup>84</sup>, M. Venturi<sup>48</sup>,  
 N. Venturi<sup>158</sup>, V. Vercesi<sup>119a</sup>, M. Verducci<sup>138</sup>, W. Verkerke<sup>105</sup>, J.C. Vermeulen<sup>105</sup>, A. Vest<sup>44</sup>,  
 M.C. Vetterli<sup>142,f</sup>, I. Vichou<sup>165</sup>, T. Vickey<sup>145b,am</sup>, O.E. Vickey Boeriu<sup>145b</sup>, G.H.A. Viehhauser<sup>118</sup>, S. Viel<sup>168</sup>,  
 M. Villa<sup>20a,20b</sup>, M. Villaplana Perez<sup>167</sup>, E. Vilucchi<sup>47</sup>, M.G. Vincter<sup>29</sup>, E. Vinek<sup>30</sup>, V.B. Vinogradov<sup>64</sup>,  
 M. Virchaux<sup>136,\*</sup>, J. Virzi<sup>15</sup>, O. Vitells<sup>172</sup>, M. Viti<sup>42</sup>, I. Vivarelli<sup>48</sup>, F. Vives Vaque<sup>3</sup>, S. Vlachos<sup>10</sup>,  
 D. Vladoiu<sup>98</sup>, M. Vlasak<sup>126</sup>, A. Vogel<sup>21</sup>, P. Vokac<sup>126</sup>, G. Volpi<sup>47</sup>, M. Volpi<sup>86</sup>, G. Volpini<sup>89a</sup>,  
 H. von der Schmitt<sup>99</sup>, H. von Radziewski<sup>48</sup>, E. von Toerne<sup>21</sup>, V. Vorobel<sup>127</sup>, V. Vorwerk<sup>12</sup>, M. Vos<sup>167</sup>,  
 R. Voss<sup>30</sup>, J.H. Vossebeld<sup>73</sup>, N. Vranjes<sup>136</sup>, M. Vranjes Milosavljevic<sup>105</sup>, V. Vrba<sup>125</sup>, M. Vreeswijk<sup>105</sup>,  
 T. Vu Anh<sup>48</sup>, R. Vuillermet<sup>30</sup>, I. Vukotic<sup>31</sup>, W. Wagner<sup>175</sup>, P. Wagner<sup>21</sup>, H. Wahlen<sup>175</sup>, S. Wahrenmund<sup>44</sup>,  
 J. Wakabayashi<sup>101</sup>, S. Walch<sup>87</sup>, J. Walder<sup>71</sup>, R. Walker<sup>98</sup>, W. Walkowiak<sup>141</sup>, R. Wall<sup>176</sup>, P. Waller<sup>73</sup>,  
 B. Walsh<sup>176</sup>, C. Wang<sup>45</sup>, H. Wang<sup>173</sup>, H. Wang<sup>40</sup>, J. Wang<sup>151</sup>, J. Wang<sup>33a</sup>, R. Wang<sup>103</sup>, S.M. Wang<sup>151</sup>,

T. Wang<sup>21</sup>, A. Warburton<sup>85</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>150</sup>, M.F. Watson<sup>18</sup>, G. Watts<sup>138</sup>,  
 S. Watts<sup>82</sup>, A.T. Waugh<sup>150</sup>, B.M. Waugh<sup>77</sup>, M.S. Weber<sup>17</sup>, J.S. Webster<sup>31</sup>, A.R. Weidberg<sup>118</sup>, P. Weigell<sup>99</sup>,  
 J. Weingarten<sup>54</sup>, C. Weiser<sup>48</sup>, P.S. Wells<sup>30</sup>, T. Wenaus<sup>25</sup>, D. Wendland<sup>16</sup>, Z. Weng<sup>151,w</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. Werth<sup>163</sup>, M. Wessels<sup>58a</sup>, J. Wetter<sup>161</sup>,  
 C. Weydert<sup>55</sup>, K. Whalen<sup>29</sup>, A. White<sup>8</sup>, M.J. White<sup>86</sup>, S. White<sup>122a,122b</sup>, S.R. Whitehead<sup>118</sup>,  
 D. Whiteson<sup>163</sup>, D. Whittington<sup>60</sup>, D. Wicke<sup>175</sup>, F.J. Wickens<sup>129</sup>, W. Wiedenmann<sup>173</sup>, M. Wielers<sup>129</sup>,  
 P. Wienemann<sup>21</sup>, C. Wiglesworth<sup>75</sup>, L.A.M. Wiik-Fuchs<sup>21</sup>, P.A. Wijeratne<sup>77</sup>, A. Wildauer<sup>99</sup>,  
 M.A. Wildt<sup>42,t</sup>, I. Wilhelm<sup>127</sup>, H.G. Wilkens<sup>30</sup>, J.Z. Will<sup>98</sup>, E. Williams<sup>35</sup>, H.H. Williams<sup>120</sup>,  
 S. Williams<sup>28</sup>, W. Willis<sup>35</sup>, S. Willocq<sup>84</sup>, J.A. Wilson<sup>18</sup>, M.G. Wilson<sup>143</sup>, A. Wilson<sup>87</sup>, I. Wingerter-Seez<sup>5</sup>,  
 S. Winkelmann<sup>48</sup>, F. Winklmeier<sup>30</sup>, M. Wittgen<sup>143</sup>, S.J. Wollstadt<sup>81</sup>, M.W. Wolter<sup>39</sup>, H. Wolters<sup>124a,i</sup>,  
 W.C. Wong<sup>41</sup>, G. Wooden<sup>87</sup>, B.K. Wosiek<sup>39</sup>, J. Wotschack<sup>30</sup>, M.J. Woudstra<sup>82</sup>, K.W. Wozniak<sup>39</sup>,  
 K. Wraight<sup>53</sup>, M. Wright<sup>53</sup>, B. Wrona<sup>73</sup>, S.L. Wu<sup>173</sup>, X. Wu<sup>49</sup>, Y. Wu<sup>33b,an</sup>, E. Wulf<sup>35</sup>, B.M. Wynne<sup>46</sup>,  
 S. Xella<sup>36</sup>, M. Xiao<sup>136</sup>, S. Xie<sup>48</sup>, C. Xu<sup>33b,aa</sup>, D. Xu<sup>33a</sup>, L. Xu<sup>33b</sup>, B. Yabsley<sup>150</sup>, S. Yacoob<sup>145a,ao</sup>,  
 M. Yamada<sup>65</sup>, H. Yamaguchi<sup>155</sup>, A. Yamamoto<sup>65</sup>, K. Yamamoto<sup>63</sup>, S. Yamamoto<sup>155</sup>, T. Yamamura<sup>155</sup>,  
 T. Yamanaka<sup>155</sup>, T. Yamazaki<sup>155</sup>, Y. Yamazaki<sup>66</sup>, Z. Yan<sup>22</sup>, H. Yang<sup>87</sup>, U.K. Yang<sup>82</sup>, Y. Yang<sup>109</sup>,  
 Z. Yang<sup>146a,146b</sup>, S. Yanush<sup>91</sup>, L. Yao<sup>33a</sup>, Y. Yasu<sup>65</sup>, E. Yatsenko<sup>42</sup>, J. Ye<sup>40</sup>, S. Ye<sup>25</sup>, A.L. Yen<sup>57</sup>,  
 M. Yilmaz<sup>4c</sup>, R. Yoosoofmiya<sup>123</sup>, K. Yorita<sup>171</sup>, R. Yoshida<sup>6</sup>, K. Yoshihara<sup>155</sup>, C. Young<sup>143</sup>, C.J.S. Young<sup>118</sup>,  
 S. Youssef<sup>22</sup>, D. Yu<sup>25</sup>, D.R. Yu<sup>15</sup>, J. Yu<sup>8</sup>, J. Yu<sup>112</sup>, L. Yuan<sup>66</sup>, A. Yurkewicz<sup>106</sup>, B. Zabinski<sup>39</sup>, R. Zaidan<sup>62</sup>,  
 A.M. Zaitsev<sup>128</sup>, L. Zanello<sup>132a,132b</sup>, D. Zanzi<sup>99</sup>, A. Zaytsev<sup>25</sup>, C. Zeitnitz<sup>175</sup>, M. Zeman<sup>126</sup>, A. Zemla<sup>39</sup>,  
 O. Zenin<sup>128</sup>, T. Ženiš<sup>144a</sup>, D. Zerwas<sup>115</sup>, G. Zevi della Porta<sup>57</sup>, D. Zhang<sup>87</sup>, H. Zhang<sup>88</sup>, J. Zhang<sup>6</sup>,  
 X. Zhang<sup>33d</sup>, Z. Zhang<sup>115</sup>, L. Zhao<sup>108</sup>, Z. Zhao<sup>33b</sup>, A. Zhemchugov<sup>64</sup>, J. Zhong<sup>118</sup>, B. Zhou<sup>87</sup>, N. Zhou<sup>163</sup>,  
 Y. Zhou<sup>151</sup>, C.G. Zhu<sup>33d</sup>, H. Zhu<sup>42</sup>, J. Zhu<sup>87</sup>, Y. Zhu<sup>33b</sup>, X. Zhuang<sup>98</sup>, V. Zhuravlov<sup>99</sup>, A. Zibell<sup>98</sup>,  
 D. Zieminska<sup>60</sup>, N.I. Zimin<sup>64</sup>, R. Zimmermann<sup>21</sup>, S. Zimmermann<sup>21</sup>, S. Zimmermann<sup>48</sup>,  
 Z. Zinonos<sup>122a,122b</sup>, M. Ziolkowski<sup>141</sup>, R. Zitoun<sup>5</sup>, L. Živković<sup>35</sup>, V.V. Zmouchko<sup>128,\*</sup>, G. Zoernig<sup>173</sup>,  
 A. Zoccoli<sup>20a,20b</sup>, M. zur Nedden<sup>16</sup>, V. Zutshi<sup>106</sup>, L. Zwalinski<sup>30</sup>

<sup>1</sup> School of Chemistry and Physics, University of Adelaide, Adelaide, Australia

<sup>2</sup> Physics Department, SUNY Albany, Albany NY, United States

<sup>3</sup> Department of Physics, University of Alberta, Edmonton AB, Canada

<sup>4</sup> (a) Department of Physics, Ankara University, Ankara; (b) Department of Physics, Dumlupinar University, Kutahya; (c) Department of Physics, Gazi University, Ankara;

(d) Division of Physics, TOBB University of Economics and Technology, Ankara; (e) Turkish Atomic Energy Authority, Ankara, Turkey

<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

<sup>7</sup> Department of Physics, University of Arizona, Tucson AZ, United States

<sup>8</sup> Department of Physics, The University of Texas at Arlington, Arlington TX, United States

<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 and ICREA, Barcelona, Spain

<sup>13</sup> (a) Institute of Physics, University of Belgrade, Belgrade; (b) Vinca Institute of Nuclear Sciences, University of Belgrade, Belgrade, Serbia

<sup>14</sup> Department for Physics and Technology, University of Bergen, Bergen, Norway

<sup>15</sup> Physics Division, Lawrence Berkeley National Laboratory and University of California, Berkeley CA, United States

<sup>16</sup> Department of Physics, Humboldt University, Berlin, Germany

<sup>17</sup> Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern, Switzerland

<sup>18</sup> School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom

<sup>19</sup> (a) Department of Physics, Bogazici University, Istanbul; (b) Division of Physics, Dogus University, Istanbul; (c) Department of Physics Engineering, Gaziantep University, Gaziantep;

(d) Department of Physics, Istanbul Technical University, Istanbul, Turkey

<sup>20</sup> (a) INFN Sezione di Bologna; (b) Dipartimento di Fisica, Università di Bologna, Bologna, Italy

<sup>21</sup> Physikalisches Institut, University of Bonn, Bonn, Germany

<sup>22</sup> Department of Physics, Boston University, Boston MA, United States

<sup>23</sup> Department of Physics, Brandeis University, Waltham MA, United States

<sup>24</sup> (a) Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro; (b) Federal University of Juiz de Fora (UFJF), Juiz de Fora; (c) Federal University of Sao Joao del Rei (UFSJ),

Sao Joao del Rei; (d) Instituto de Física, Universidade de Sao Paulo, Sao Paulo, Brazil

<sup>25</sup> Physics Department, Brookhaven National Laboratory, Upton NY, United States

<sup>26</sup> (a) National Institute of Physics and Nuclear Engineering, Bucharest; (b) University Politehnica Bucharest, Bucharest; (c) West University in Timisoara, Timisoara, Romania

<sup>27</sup> Departamento de Física, Universidad de Buenos Aires, Buenos Aires, Argentina

<sup>28</sup> Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom

<sup>29</sup> Department of Physics, Carleton University, Ottawa ON, Canada

<sup>30</sup> CERN, Geneva, Switzerland

<sup>31</sup> Enrico Fermi Institute, University of Chicago, Chicago IL, United States

<sup>32</sup> (a) Departamento de Física, Pontificia Universidad Católica de Chile, Santiago; (b) Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile

<sup>33</sup> (a) Institute of High Energy Physics, Chinese Academy of Sciences, Beijing; (b) Department of Modern Physics, University of Science and Technology of China, Anhui;

(c) Department of Physics, Nanjing University, Jiangsu; (d) School of Physics, Shandong University, Shandong; (e) Physics Department, Shanghai Jiao Tong University, Shanghai, China

<sup>34</sup> Laboratoire de Physique Corpusculaire, Clermont Université and Université Blaise Pascal and CNRS/IN2P3, Clermont-Ferrand, France

<sup>35</sup> Nevis Laboratory, Columbia University, Irvington NY, United States



- 36 Niels Bohr Institute, University of Copenhagen, Kobenhavn, Denmark
- 37 <sup>(a)</sup> INFN Gruppo Collegato di Cosenza; <sup>(b)</sup> Dipartimento di Fisica, Università della Calabria, Rende, Italy
- 38 AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, 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
- 41 Physics Department, University of Texas at Dallas, Richardson TX, United States
- 42 DESY, Hamburg and Zeuthen, Germany
- 43 Institut für Experimentelle Physik IV, Technische Universität Dortmund, Dortmund, Germany
- 44 Institut für Kern- und Teilchenphysik, Technical University Dresden, Dresden, Germany
- 45 Department of Physics, Duke University, Durham NC, United States
- 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. Javakhishvili Tbilisi State University, Tbilisi; <sup>(b)</sup> High Energy Physics Institute, Tbilisi State University, Tbilisi, Georgia
- 52 Il Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen, Germany
- 53 SUPA – School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom
- 54 Il 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
- 57 Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge MA, United States
- 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
- 61 Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck, Austria
- 62 University of Iowa, Iowa City IA, United States
- 63 Department of Physics and Astronomy, Iowa State University, Ames IA, United States
- 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 Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France
- 79 Fysiska institutionen, Lunds universitet, Lund, Sweden
- 80 Departamento de Física Teórica C-15, Universidad Autónoma de Madrid, Madrid, Spain
- 81 Institut für Physik, Universität Mainz, Mainz, Germany
- 82 School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom
- 83 CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France
- 84 Department of Physics, University of Massachusetts, Amherst MA, United States
- 85 Department of Physics, McGill University, Montreal QC, Canada
- 86 School of Physics, University of Melbourne, Victoria, Australia
- 87 Department of Physics, The University of Michigan, Ann Arbor MI, United States
- 88 Department of Physics and Astronomy, Michigan State University, East Lansing MI, United States
- 89 <sup>(a)</sup> INFN Sezione di Milano; <sup>(b)</sup> Dipartimento di Fisica, Università di Milano, Milano, Italy
- 90 B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Belarus
- 91 National Scientific and Educational Centre for Particle and High Energy Physics, Minsk, Belarus
- 92 Department of Physics, Massachusetts Institute of Technology, Cambridge MA, United States
- 93 Group of Particle Physics, University of Montreal, Montreal QC, Canada
- 94 P.N. Lebedev Institute of Physics, Academy of Sciences, Moscow, Russia
- 95 Institute for Theoretical and Experimental Physics (ITEP), Moscow, Russia
- 96 Moscow Engineering and Physics Institute (MEPhI), Moscow, Russia
- 97 D.V. Skobel'syn Institute of Nuclear Physics, M.V. Lomonosov Moscow State University, Moscow, Russia
- 98 Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany
- 99 Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany
- 100 Nagasaki Institute of Applied Science, Nagasaki, Japan
- 101 Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya, Japan
- 102 <sup>(a)</sup> INFN Sezione di Napoli; <sup>(b)</sup> Dipartimento di Scienze Fisiche, Università di Napoli, Napoli, Italy
- 103 Department of Physics and Astronomy, University of New Mexico, Albuquerque NM, United States
- 104 Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands
- 105 Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands
- 106 Department of Physics, Northern Illinois University, DeKalb IL, United States
- 107 Budker Institute of Nuclear Physics, SB RAS, Novosibirsk, Russia
- 108 Department of Physics, New York University, New York NY, United States
- 109 Ohio State University, Columbus OH, United States
- 110 Faculty of Science, Okayama University, Okayama, Japan
- 111 Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman OK, United States
- 112 Department of Physics, Oklahoma State University, Stillwater OK, United States
- 113 Palacký University, RCPTM, Olomouc, Czech Republic

- <sup>114</sup> Center for High Energy Physics, University of Oregon, Eugene OR, United States  
<sup>115</sup> LAL, Université Paris-Sud and CNRS/IN2P3, Orsay, France  
<sup>116</sup> Graduate School of Science, Osaka University, Osaka, Japan  
<sup>117</sup> Department of Physics, University of Oslo, Oslo, Norway  
<sup>118</sup> Department of Physics, Oxford University, Oxford, United Kingdom  
<sup>119</sup> <sup>(a)</sup> INFN Sezione di Pavia; <sup>(b)</sup> Dipartimento di Fisica, Università di Pavia, Pavia, Italy  
<sup>120</sup> Department of Physics, University of Pennsylvania, Philadelphia PA, United States  
<sup>121</sup> Petersburg Nuclear Physics Institute, Gatchina, Russia  
<sup>122</sup> <sup>(a)</sup> INFN Sezione di Pisa; <sup>(b)</sup> Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy  
<sup>123</sup> Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh PA, United States  
<sup>124</sup> <sup>(a)</sup> Laboratório de Instrumentação e Física Experimental de Partículas — LIP, Lisboa, Portugal; <sup>(b)</sup> Departamento de Física Teórica y del Cosmos and CAFPE, Universidad de Granada, Granada, Spain  
<sup>125</sup> Institute of Physics, Academy of Sciences of the Czech Republic, Praha, Czech Republic  
<sup>126</sup> Czech Technical University in Prague, Praha, Czech Republic  
<sup>127</sup> Faculty of Mathematics and Physics, Charles University in Prague, Praha, Czech Republic  
<sup>128</sup> State Research Center Institute for High Energy Physics, Protvino, Russia  
<sup>129</sup> Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom  
<sup>130</sup> Physics Department, University of Regina, Regina SK, Canada  
<sup>131</sup> Ritsumeikan University, Kusatsu, Shiga, Japan  
<sup>132</sup> <sup>(a)</sup> INFN Sezione di Roma I; <sup>(b)</sup> Dipartimento di Fisica, Università La Sapienza, Roma, Italy  
<sup>133</sup> <sup>(a)</sup> INFN Sezione di Roma Tor Vergata; <sup>(b)</sup> Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy  
<sup>134</sup> <sup>(a)</sup> INFN Sezione di Roma Tre; <sup>(b)</sup> Dipartimento di Matematica e Fisica, Università Roma Tre, Roma, Italy  
<sup>135</sup> <sup>(a)</sup> Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies and 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  
<sup>136</sup> 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  
<sup>137</sup> Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz CA, United States  
<sup>138</sup> Department of Physics, University of Washington, Seattle WA, United States  
<sup>139</sup> Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom  
<sup>140</sup> Department of Physics, Shinshu University, Nagano, Japan  
<sup>141</sup> Fachbereich Physik, Universität Siegen, Siegen, Germany  
<sup>142</sup> Department of Physics, Simon Fraser University, Burnaby BC, Canada  
<sup>143</sup> SLAC National Accelerator Laboratory, Stanford CA, United States  
<sup>144</sup> <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  
<sup>145</sup> <sup>(a)</sup> Department of Physics, University of Johannesburg, Johannesburg; <sup>(b)</sup> School of Physics, University of the Witwatersrand, Johannesburg, South Africa  
<sup>146</sup> <sup>(a)</sup> Department of Physics, Stockholm University; <sup>(b)</sup> The Oskar Klein Centre, Stockholm, Sweden  
<sup>147</sup> Physics Department, Royal Institute of Technology, Stockholm, Sweden  
<sup>148</sup> Departments of Physics & Astronomy and Chemistry, Stony Brook University, Stony Brook NY, United States  
<sup>149</sup> Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom  
<sup>150</sup> School of Physics, University of Sydney, Sydney, Australia  
<sup>151</sup> Institute of Physics, Academia Sinica, Taipei, Taiwan  
<sup>152</sup> Department of Physics, Technion: Israel Institute of Technology, Haifa, Israel  
<sup>153</sup> Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel  
<sup>154</sup> Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece  
<sup>155</sup> International Center for Elementary Particle Physics and Department of Physics, The University of Tokyo, Tokyo, Japan  
<sup>156</sup> Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo, Japan  
<sup>157</sup> Department of Physics, Tokyo Institute of Technology, Tokyo, Japan  
<sup>158</sup> Department of Physics, University of Toronto, Toronto ON, Canada  
<sup>159</sup> <sup>(a)</sup> TRIUMF, Vancouver BC; <sup>(b)</sup> Department of Physics and Astronomy, York University, Toronto ON, Canada  
<sup>160</sup> Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba, Japan  
<sup>161</sup> Department of Physics and Astronomy, Tufts University, Medford MA, United States  
<sup>162</sup> Centro de Investigaciones, Universidad Antonio Narino, Bogota, Colombia  
<sup>163</sup> Department of Physics and Astronomy, University of California Irvine, Irvine CA, United States  
<sup>164</sup> <sup>(a)</sup> INFN Gruppo Collegato di Udine; <sup>(b)</sup> ICTP, Trieste; <sup>(c)</sup> Dipartimento di Chimica, Fisica e Ambiente, Università di Udine, Udine, Italy  
<sup>165</sup> Department of Physics, University of Illinois, Urbana IL, United States  
<sup>166</sup> Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden  
<sup>167</sup> 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  
<sup>168</sup> Department of Physics, University of British Columbia, Vancouver BC, Canada  
<sup>169</sup> Department of Physics and Astronomy, University of Victoria, Victoria BC, Canada  
<sup>170</sup> Department of Physics, University of Warwick, Coventry, United Kingdom  
<sup>171</sup> Waseda University, Tokyo, Japan  
<sup>172</sup> Department of Particle Physics, The Weizmann Institute of Science, Rehovot, Israel  
<sup>173</sup> Department of Physics, University of Wisconsin, Madison WI, United States  
<sup>174</sup> Fakultät für Physik und Astronomie, Julius-Maximilians-Universität, Würzburg, Germany  
<sup>175</sup> Fachbereich C Physik, Bergische Universität Wuppertal, Wuppertal, Germany  
<sup>176</sup> Department of Physics, Yale University, New Haven CT, United States  
<sup>177</sup> Yerevan Physics Institute, Yerevan, Armenia  
<sup>178</sup> 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 Laboratório de Instrumentação e Física Experimental de Partículas — LIP, Lisboa, Portugal.

<sup>c</sup> Also at Faculdade de Ciências and CFNUL, Universidade de Lisboa, Lisboa, Portugal.

<sup>d</sup> Also at Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom.

<sup>e</sup> Also at Department of Physics, University of Johannesburg, Johannesburg, South Africa.

<sup>f</sup> Also at TRIUMF, Vancouver BC, Canada.

<sup>g</sup> Also at Department of Physics, California State University, Fresno CA, United States.

- <sup>h</sup> Also at Novosibirsk State University, Novosibirsk, Russia.
- <sup>i</sup> Also at Department of Physics, University of Coimbra, Coimbra, Portugal.
- <sup>j</sup> Also at Department of Physics, UASLP, San Luis Potosi, Mexico.
- <sup>k</sup> Also at Università di Napoli Parthenope, Napoli, Italy.
- <sup>l</sup> Also at Institute of Particle Physics (IPP), Canada.
- <sup>m</sup> Also at Department of Physics, Middle East Technical University, Ankara, Turkey.
- <sup>n</sup> Also at Louisiana Tech University, Ruston LA, United States.
- <sup>o</sup> Also at Departamento de Física and CEFITEC of Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Caparica, Portugal.
- <sup>p</sup> Also at Department of Physics and Astronomy, University College London, London, United Kingdom.
- <sup>q</sup> Also at Department of Physics and Astronomy, Michigan State University, East Lansing MI, United States.
- <sup>r</sup> Also at Department of Physics, University of Cape Town, Cape Town, South Africa.
- <sup>s</sup> Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan.
- <sup>t</sup> Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany.
- <sup>u</sup> Also at Manhattan College, New York NY, United States.
- <sup>v</sup> Also at CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France.
- <sup>w</sup> Also at School of Physics and Engineering, Sun Yat-sen University, Guanzhou, China.
- <sup>x</sup> Also at Academia Sinica Grid Computing, Institute of Physics, Academia Sinica, Taipei, Taiwan.
- <sup>y</sup> Also at School of Physics, Shandong University, Shandong, China.
- <sup>z</sup> Also at Dipartimento di Fisica, Università La Sapienza, Roma, Italy.
- <sup>aa</sup> Also at 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.
- <sup>ab</sup> Also at Section de Physique, Université de Genève, Geneva, Switzerland.
- <sup>ac</sup> Also at Departamento de Física, Universidade de Minho, Braga, Portugal.
- <sup>ad</sup> Also at Department of Physics, The University of Texas at Austin, Austin TX, United States.
- <sup>ae</sup> Also at Department of Physics and Astronomy, University of South Carolina, Columbia SC, United States.
- <sup>af</sup> Also at Institute for Particle and Nuclear Physics, Wigner Research Centre for Physics, Budapest, Hungary.
- <sup>ag</sup> Also at California Institute of Technology, Pasadena CA, United States.
- <sup>ah</sup> Also at International School for Advanced Studies (SISSA), Trieste, Italy.
- <sup>ai</sup> Also at LAL, Université Paris-Sud and CNRS/IN2P3, Orsay, France.
- <sup>aj</sup> Also at Faculty of Physics, M.V. Lomonosov Moscow State University, Moscow, Russia.
- <sup>ak</sup> Also at Nevis Laboratory, Columbia University, Irvington NY, United States.
- <sup>al</sup> Also at Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom.
- <sup>am</sup> Also at Department of Physics, Oxford University, Oxford, United Kingdom.
- <sup>an</sup> Also at Department of Physics, The University of Michigan, Ann Arbor MI, United States.
- <sup>ao</sup> Also at Discipline of Physics, University of KwaZulu-Natal, Durban, South Africa.
- \* Deceased.