



Article scientifique

Article

2011

Published version

Open Access

This is the published version of the publication, made available in accordance with the publisher's policy.

Search for massive long-lived highly ionising particles with the ATLAS detector at the LHC

Collaborators: Abdelalim Aly, Ahmed Aly; Alexandre, Gauthier; Backes, Moritz; Bell, Paul; Bell, William; Berglund, Frida Elina; Blondel, Alain; Bucci, Francesca; Clark, Allan Geoffrey; Dao, Valerio; Efthymiopoulos, Ilias; Ferrere, Didier; Gadomski, Szymon **[and 21 more]**

How to cite

ATLAS Collaboration. Search for massive long-lived highly ionising particles with the ATLAS detector at the LHC. In: Physics letters. B, 2011, vol. 698, n° 5, p. 353–370. doi: 10.1016/j.physletb.2011.03.033

This publication URL: <https://archive-ouverte.unige.ch/unige:41425>

Publication DOI: [10.1016/j.physletb.2011.03.033](https://doi.org/10.1016/j.physletb.2011.03.033)



Search for massive long-lived highly ionising particles with the ATLAS detector at the LHC [☆]

ATLAS Collaboration ^{*}

ARTICLE INFO

Article history:

Received 2 February 2011
 Received in revised form 16 March 2011
 Accepted 16 March 2011
 Available online 23 March 2011
 Editor: M. Cvetič

Keywords:

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

ABSTRACT

A search is made for massive highly ionising particles with lifetimes in excess of 100 ns, with the ATLAS experiment at the Large Hadron Collider, using 3.1 pb^{-1} of pp collision data taken at $\sqrt{s} = 7 \text{ TeV}$. The signature of energy loss in the ATLAS inner detector and electromagnetic calorimeter is used. No such particles are found and limits on the production cross section for electric charges $6e \leq |q| \leq 17e$ and masses $200 \text{ GeV} \leq m \leq 1000 \text{ GeV}$ are set in the range 1–12 pb for different hypotheses on the production mechanism.

© 2011 CERN. Published by Elsevier B.V. All rights reserved.

1. Introduction

The observation of a massive long-lived highly ionising particle (HIP) possessing a large electric charge $|q| \gg e$, where e is the elementary charge, would represent striking evidence for physics beyond the Standard Model. Examples of putative particles which can give rise to HIP signatures include Q-balls [1], stable micro black-hole remnants [2], magnetic monopoles [3] and dyons [4]. Searches for HIPs are made in cosmic rays [5] and at colliders [3]; recent collider searches were performed at LEP [6–8] and the Tevatron [9–12]. Cross sections and event topologies associated with HIP production cannot be reliably predicted due to the fact that the coupling between a HIP and the photon is so strong that perturbative calculations are not possible. Therefore, search results at colliders are usually quoted as cross section limits in a range of charge and mass for given kinematics [3]. Also, for the same reason, limits obtained at different collision energies or for different types of collisions cannot be directly compared; rather, they are complementary.

HIP searches are part of a program of searches at the CERN Large Hadron Collider (LHC) which explore the multi-TeV energy regime. Further motivation is provided by the gauge hierarchy problem, to which proposed solutions typically postulate the existence of hitherto unobserved particles with TeV-scale masses. HIPs at the LHC can be sought at the dedicated MoEDAL plastic-track experiment [13] or, as in this work, via their active detection at a multipurpose detector.

Due to their assumed large mass (hundreds of GeV), HIPs are characterised by their non-relativistic speed. The expected large amounts of energy loss per unit length (dE/dx) through ionisation (no bremsstrahlung) are mainly due to the high particle charge, but also due to the low speed. The ATLAS detector is well suited to detect HIPs. A HIP with sufficient kinetic energy would leave a track in the inner detector tracking system of ATLAS and lose its energy on its way to and through the electromagnetic calorimeter, giving rise to an electron-like signature. The presence of a HIP can be inferred from measurements of the proportion of high-ionisation hits in the inner detector. In addition, assuming isolation, the lateral extent of the energy deposition in the calorimeter is a sensitive discriminant between HIPs and Standard Model particles.

The ranges of HIP charge, mass and lifetime for which unambiguous conclusions can be drawn are determined by the chosen trigger and event selections. The choice of an electromagnetic trigger limits the phase space to HIPs which stop in the electromagnetic calorimeter of ATLAS. The search is optimised for data collected at relatively low instantaneous luminosities (up to $10^{31} \text{ cm}^{-2} \text{ s}^{-1}$), for which a low (10 GeV) trigger transverse energy threshold is available. In the barrel region of the calorimeter, this gives access to energy depositions corresponding to HIPs with electric charges down to $6e$. Standard electron reconstruction algorithms are used, which implies that tracks which bend like electrically charged particles are sought. Particles with magnetic charge, or electric charge above $17e$, are not addressed here due to the bending along the beam axis in the case of a monopole, and due to effects from delta electrons and electron recombination in the active detector at the corresponding values of energy loss ($dE/dx > 2 \cdot 10^3 \text{ MeV/cm}$). For such types of HIPs, more detailed studies are needed to assess and minimise the impact of these

[☆] © CERN, for the benefit of the ATLAS Collaboration.

^{*} E-mail address: atlas.publications@cern.ch.

effects on the selection efficiency. The 1000 GeV upper bound in mass sensitivity is determined by trigger timing constraints, as a significantly heavier HIP (with charge $17e$ or lower) would be delayed by more than 12 ns with respect to $\beta = 1$ when it stops in the electromagnetic calorimeter (this corresponds to $\beta < 0.3$), and would thus risk being triggered in the next proton bunch crossing. The search is sensitive to HIP lifetimes larger than 100 ns since a particle which decays much earlier in the calorimeter (even after stopping) would spoil the signature of a narrow energy deposition.

2. The ATLAS detector

The ATLAS detector [14] is a multipurpose particle physics apparatus with a forward–backward symmetric cylindrical geometry and near 4π coverage in solid angle.¹ A thin superconducting solenoid magnet surrounding the inner part of the ATLAS detector produces a field of approximately 2 T along the beam axis.

Inner detector (ID) tracking is performed by silicon-based detectors and an outer tracker using straw tubes with particle identification capabilities based on transition radiation (Transition Radiation Tracker, TRT). The TRT is divided into barrel (covering the pseudorapidity range $|\eta| < 1.0$) and endcap ($0.8 < |\eta| < 2.0$) components. A track gives a typical number of straw hits of 36. At the front-end electronics of the TRT, discriminators are used to compare the signal against low and high thresholds. While the TRT has two hit threshold levels, there is no upper limit to the amount of ionisation in a straw which will lead to a signal [15], guaranteeing that highly ionising particles would not escape detection in the TRT. Rather, they would produce a large number of high-threshold (HT) hits along their trajectories. The amount of ionisation in a straw tube needed for a TRT HT hit is roughly equivalent to three times that expected from a minimum ionising particle.

Liquid-argon sampling electromagnetic (EM) calorimeters, which comprise accordion-shaped electrodes and lead absorbers, surround the ID. The EM calorimeter barrel ($|\eta| < 1.475$) is used in this search. It is segmented transversely and divided in three layers in depth, denoted first, second, and third layer, respectively. In front of the accordion calorimeter a thin presampler layer is used to correct for fluctuations of energy loss. The typical cell granularity ($\Delta\eta \times \Delta\phi$) of the EM barrel is 0.003×0.1 in the first layer and 0.025×0.025 in the second layer. The signal expected for a HIP in the considered charge range lies in a region in time and energy where the electronic response in EM calorimeter cells is well understood and does not saturate. The robustness of the EM calorimeter energy reconstruction has been studied in detail and pulse shape predictions are consistent with the measured signals [16].

The stopping power of a HIP in the ATLAS detector depends on its charge, mass and energy, as well as the material budget along its path. Details of the latter are given in Ref. [17] in terms of number of radiation lengths X_0 , as a function of depth and pseudorapidity. The integrated radiation length between the interaction point and the exit of the TRT is $0.5 X_0$ at $\eta = 0$ and $1.5 X_0$ at $|\eta| = 1.3$. The additional amount of material before the first layer of the EM calorimeter is $2.0 X_0$ at $\eta = 0$ and $3.5 X_0$ at $|\eta| = 1.3$. The thicknesses of the first, second and third EM layers are $4.5 X_0$, $16.5 X_0$ and $1.5 X_0$ at $\eta = 0$ and $3 X_0$, $20 X_0$ and $5 X_0$ at $|\eta| = 1.3$, respectively.

¹ ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the centre of the detector and the z -axis coinciding with the axis of the beam pipe. The x -axis points from the IP to the centre of the LHC ring, and the y axis points upward. Cylindrical coordinates (r, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the beam pipe. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln \tan(\theta/2)$.

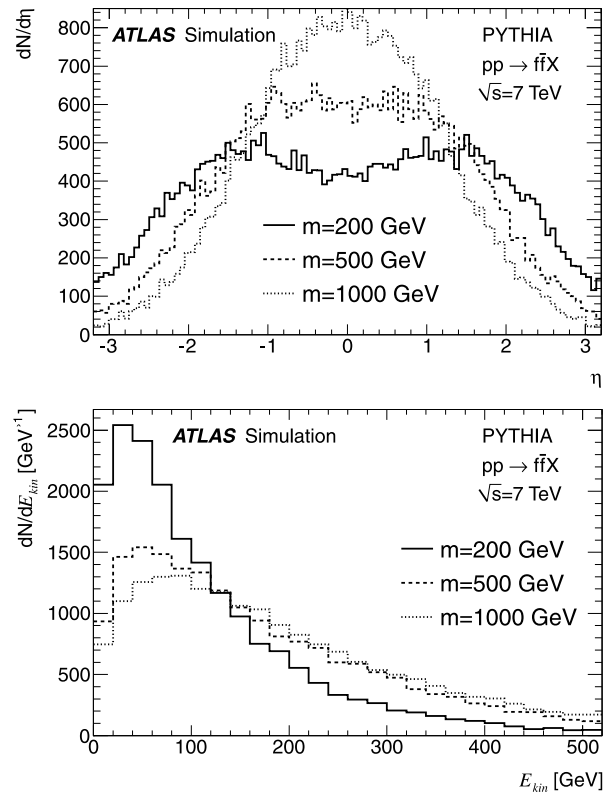


Fig. 1. Distributions of pseudorapidity η (top) and kinetic energy E_{kin} (bottom) at origin for heavy fermions produced with the Drell–Yan process. The latter is given with a requirement of $|\eta| < 1.35$. The distributions for the three different masses are normalised to the same number of entries.

3. Simulated event samples

Signal events are generated with the PYTHIA Monte Carlo (MC) event generator [18] according to the fermion pair production process: $p + p \rightarrow f + \bar{f} + X$. Ref. [19] is used for the parton distributions of the proton. Direct pair production implies that the HIPs are not part of a jet and thus isolated. A Drell–Yan-like production mechanism, modified to take into account the mass of the HIP [20], is used to model the kinematic properties of the HIPs. Generated η distributions, as well as kinetic energy (E_{kin}) spectra in the central region ($|\eta| < 1.35$), are shown in Fig. 1 for the three mass points considered in this search.

An ATLAS detector simulation [21] based on GEANT-4 [22] is used, where the particle interactions include secondary ionisation by delta electrons in addition to the standard ionisation process based on the Bethe–Bloch formula. A correction for electron–ion recombination effects in the EM calorimeter (Birks’ correction) is applied, with typical visible energy fractions between 0.2 and 0.5 for the signal particles considered. Effects of delays are simulated, except for the ability to trigger slow-moving particles within the proton bunch crossing time, which is considered separately as a systematic uncertainty (see Section 6). Samples of approximately 20 000 events are produced for HIPs with masses of 200, 500 and 1000 GeV. For each mass point, HIPs with charges $6e$, $10e$ and $17e$ are simulated.

A data-driven method is used in this work to estimate backgrounds surviving the final selections (see Section 4.2). However, in order to demonstrate that the distributions of the relevant observables are understood, a sample of simulated background events is used. The background sample, generated with PYTHIA [18] and labeled “Standard Model”, consists mostly of QCD events in which

the hard subprocess is a strong 2-to-2 process with a matrix element transverse momentum cut-off of 15 GeV, but also includes contributions from heavy quark and vector boson production. A true transverse energy larger than 17 GeV in a typical first level trigger tower is also required. This sample contains $4 \cdot 10^7$ events and corresponds roughly to an integrated luminosity of 0.8 pb^{-1} .

4. Trigger and event selection

The collected data sample corresponds to an integrated luminosity of $3.1 \pm 0.3 \text{ pb}^{-1}$, using a first level trigger based on energy deposits in the calorimeters. At the first level of the trigger, so-called trigger towers with dimension $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ are defined. In each trigger tower the cells of the electromagnetic or hadronic calorimeter are summed. EM clusters with fixed size $\Delta\eta \times \Delta\phi = 0.2 \times 0.2$ are sought and are retained if the total transverse energy (E_T) in an adjacent pair of their four trigger towers is above 5 GeV. Further electron-like higher level trigger requirements are imposed on the candidate, including $E_T > 10$ GeV, a matching to a track in the ID and a veto on hadronic leakage [23]. The efficiency of this trigger for the data under consideration is measured to be $(94.0 \pm 1.5)\%$ for electrons with $E_T > 15$ GeV and is well described by the simulation. The simulation predicts that a highly charged particle which stops in the EM barrel would be triggered with a similar efficiency or higher.

Offline electron candidates have cluster sizes of $\Delta\eta \times \Delta\phi = 0.075 \times 0.175$ in the EM barrel, with a matched track in a window of $\Delta\eta \times \Delta\phi = 0.05 \times 0.1$ amongst reconstructed tracks with transverse momentum larger than 0.5 GeV. Identification requirements corresponding to “medium” electrons [24], implying track and shower shape quality cuts, are applied to the candidates. These cuts filter out backgrounds but have a negligible impact on the signal, for which the cluster width is much narrower than for typical electrons. The cluster energy is estimated correcting for the energy deposited outside the active calorimeter regions, assuming an EM shower.

Further offline selections on the cluster transverse energy ($E_T > 15$ GeV) and pseudorapidity ($|\eta| < 1.35$) are imposed. The E_T selection guarantees that the trigger efficiency is higher than 94% for the objects under study. The restriction of $|\eta| < 1.35$ excludes the transition region between the EM calorimeter barrel and endcap, reducing the probability for backgrounds to fake a narrow energy deposition.

4.1. Selection cuts

A loose selection based on TRT and EM calorimeter information is also imposed on the candidates to ensure that the quality of the track and cluster associated to the electron-like object is good enough to ensure the robustness of the HIP selection variables, and to provide a data sample with which to estimate the background rate. Only candidates with more than 10 TRT hits are retained. In addition to the $E_T > 15$ GeV cut for the EM cluster associated with the candidate, a significant fraction of the total cluster energy is required to be contained in six calorimeter cells among the first and second EM layers. This is done by requiring the summed energy in the three most energetic cells in each of the first and second layers to be greater than 2 and 4 GeV, respectively. Following these selections, 137 503 candidates remain in the data.

Two sets of observables are used in the final selection. The ID-based observable is the fraction, f_{HT} , of TRT hits on the track which pass the high threshold. The calorimeter-based discriminants are the fractions of energies outside of the three most energetic cells associated to a selected EM cluster, in the first and second EM calorimeter layers: w_1 and w_2 .

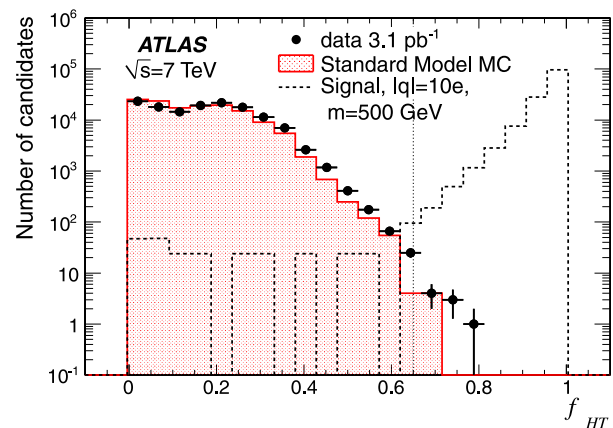


Fig. 2. Distribution of the fraction of TRT high-threshold hits for candidates satisfying the loose selection. Data (dots) are compared with area-normalised signal ($|q| = 10e$ and $m = 500$ GeV, dashed line) and Standard Model background (shaded area) simulations. The dotted line shows the selection cut value.

The f_{HT} distribution for loosely selected candidates is shown in Fig. 2. The data extend up to $f_{HT} = 0.8$. The prediction of the signal simulation for a HIP of mass 500 GeV and charge 10e is also shown. It peaks at $f_{HT} \sim 1$ and has a small tail extending into the Standard Model region.

The distributions of w_1 and w_2 also provide good discrimination between signal and background, as shown in Fig. 3. For a signal, energy is deposited only in the few cells along the particle trajectory (as opposed to backgrounds which induce showers in the EM calorimeter) and the distributions peak around zero for both variables. The shapes of the measured distributions are well described by the background simulation. A faint double-peak structure is visible in data and in background simulations for the f_{HT} , w_1 and w_2 distributions in Figs. 2 and 3, where the main peak (closest to the signal) corresponds to electrons and the secondary peak corresponds to hadrons which fake the electron identification signature.

Finally, the following HIP selection is made: $f_{HT} > 0.65$, $w_1 < 0.20$ and $w_2 < 0.15$. For signal particles, these cuts reject only candidates in the tails of the distributions, and varying them has a minor impact on the efficiency; this feature is common to all considered charge and mass points. The cut values were chosen to yield a very small ($\ll 1$ event) expected background (see Section 4.2) while retaining a high ($\sim 96\%$) efficiency for the signal. No candidates in data or in simulated Standard Model events pass this selection.

4.2. Data-driven background estimation

A data-driven method is used to quantify the expected background yield after the HIP selection. Potential backgrounds consist mainly of electrons. For Standard Model candidates, the ID and calorimeter observables are correlated in a way that further suppresses the backgrounds (see Fig. 4). The background estimation assumes that f_{HT} is uncorrelated with w_1 and w_2 and is thus conservative.

The yield of particle candidates passing the loose selection $N_{loose} = 137\,503$ can be divided into the following: N_0 , N_1 , $N_{f_{HT}}$, and N_w , which represent the number of candidates which satisfy both of the selections, neither of the selections, only the f_{HT} selection, and only the w_1 and w_2 selections taken together, respectively. Even in the presence of a signal, N_1 , $N_{f_{HT}}$ and N_w would be dominantly composed of background events. The probability of a background candidate passing the TRT requirement is

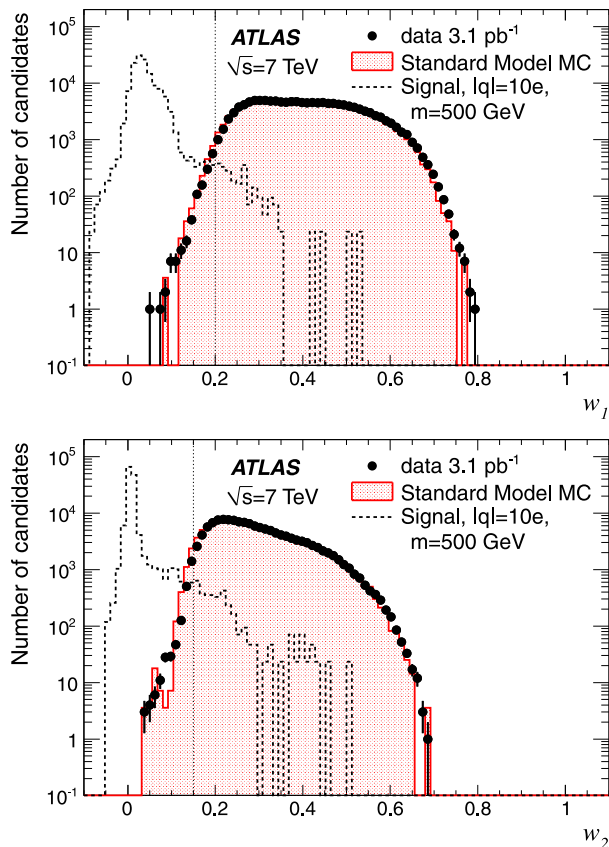


Fig. 3. Distributions of w_1 and w_2 following the loose selection. Data (dots) are compared with area-normalised signal ($|q| = 10e$ and $m = 500$ GeV, dashed lines) and Standard Model background (shaded area) simulations. Negative values are caused by pedestal fluctuations. Dotted lines show the selection cut values.

then $P_{f_{HT}} = \frac{N_{f_{HT}}}{(N_1 + N_{f_{HT}})}$ and the probability to pass the calorimeter requirements is $P_w = \frac{N_w}{(N_1 + N_w)}$, leading to an expectation of the number of background candidates entering the signal region: $N_{bg} = N_{loose} P_{f_{HT}} P_w$. The data sample yields $N_0 = 0$, $N_1 = 137342$, $N_{f_{HT}} = 18$ and $N_w = 143$, leading to $P_{f_{HT}} = (1.3 \pm 0.3) \cdot 10^{-4}$ and $P_w = (1.0 \pm 0.1) \cdot 10^{-3}$. The expected number of background candidates surviving the selection, and thereby the expected number of background events, is thus $N_{bg} = 0.019 \pm 0.005$. The quoted uncertainty is statistical.

5. Signal selection efficiency

5.1. Efficiencies in acceptance kinematic regions

The probability to retain a signal event can be factorised in two parts: acceptance (probability for a HIP in a region where the detector is sensitive) and efficiency (probability for this HIP to pass the selection cuts). The acceptance is defined here as the probability that at least one signal particle will be in the range $|\eta| < 1.35$ and stop in the second or third layer of the EM calorimeter. If this condition is satisfied, the simulation predicts a high probability to trigger on, reconstruct and select the event. This corresponds to the dark region in Fig. 5, which shows the predicted selection efficiency mapped as a function of the initial HIP pseudorapidity and kinetic energy, in the case of $|q| = 10e$ and $m = 500$ GeV. Such acceptance kinematic regions can be parametrised with three values defining three corners of a parallelogram. These parameters are summarised in Table 1. For HIPs produced inside such regions, the

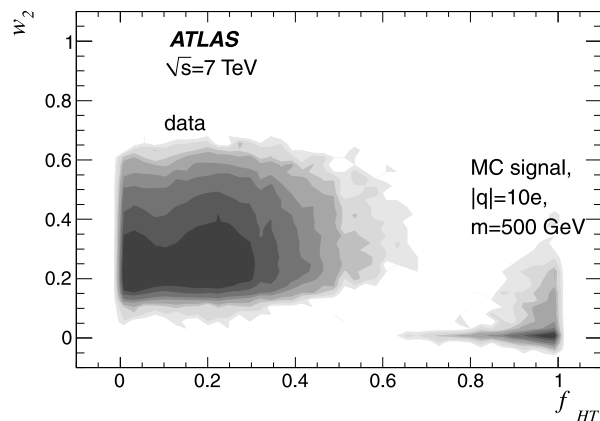


Fig. 4. Contours of w_2 versus f_{HT} distributions following loose selection, showing the density of entries on a log scale. Data and signal Monte Carlo ($|q| = 10e$ and $m = 500$ GeV) are shown, and no candidates in the data appear near the signal region. The correlation factor between w_2 and f_{HT} in the data is positive (coefficient 0.15); the same trend is also true for the correlation between w_1 and f_{HT} (coefficient 0.18).

Table 1

Kinetic energies (in GeV) defining the acceptance kinematic ranges for HIPs with the masses and electric charges considered in this search. The three columns correspond to the lower left, lower right, and upper left corners of parallelograms in the $(|\eta|, E_{kin})$ plane.

$ q $	m [GeV]	$E_{kin}^{min}(\eta = 0)$	$E_{kin}^{min}(\eta = 1.35)$	$E_{kin}^{max}(\eta = 0)$
6e	200	40	50	50
6e	500	50	70	70
6e	1000	60	130	80
10e	200	50	80	90
10e	500	80	110	130
10e	1000	110	150	180
17e	200	100	150	190
17e	500	150	190	260
17e	1000	190	240	350

Table 2

Expected fractions of HIP candidates passing the final selection, assuming they are isolated and produced inside the acceptance regions defined by the values in Table 1. Uncertainties due to MC statistics are quoted; other systematic uncertainties are discussed in Section 6.

m [GeV]	$ q = 6e$	$ q = 10e$	$ q = 17e$
200	0.822 ± 0.026	0.820 ± 0.015	0.484 ± 0.012
500	0.868 ± 0.021	0.856 ± 0.014	0.617 ± 0.011
1000	0.558 ± 0.019	0.858 ± 0.012	0.700 ± 0.012

candidate selection efficiency is flat within 10% and takes values between 0.5 and 0.9 depending on the charge and mass (see Table 2). For $|q| = 17e$, the main source of inefficiency is the requirement on the number of TRT HT hits, which contributes up to 20% signal loss. This is largely due to the presence of track segments from delta electrons, which have a non-negligible probability to be chosen by the standard electron track matching algorithm. For low charges, inefficiencies are dominated by the cluster E_T cut, typically accounting for $\sim 6\%$ loss. Other contributions, like trigger, electron reconstruction, and electron identification, can each cause 1–6% additional inefficiency.

5.2. Efficiencies for Drell–Yan kinematics

The estimated fractions of signal events where at least one candidate passes the final selection, assuming they are produced

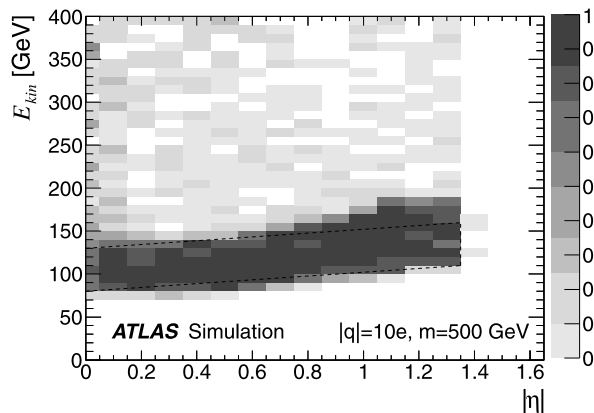


Fig. 5. Probability to pass all selection criteria as a function of pseudorapidity and kinetic energy at origin, for a HIP with charge 10e and mass 500 GeV. The dark region corresponds to the kinetic range where the particle stops in or near the second layer of the EM calorimeter barrel and is parametrised with three energy values (dashed parallelogram, see Table 1).

Table 3

Expected fractions of signal events passing the final selection, assuming Drell–Yan kinematics. Uncertainties due to MC statistics are quoted; other systematic uncertainties are discussed in Section 6.

m [GeV]	$ q = 6e$	$ q = 10e$	$ q = 17e$
200	0.102 ± 0.002	0.175 ± 0.003	0.112 ± 0.002
500	0.150 ± 0.003	0.236 ± 0.003	0.193 ± 0.003
1000	0.133 ± 0.002	0.299 ± 0.004	0.237 ± 0.004

with Drell–Yan kinematics, are shown in Table 3 for the values of charge and mass considered in this search. The dominant source of loss (70–85% loss) is from the kinematic acceptance, i.e., the production of HIPs with $|\eta| > 1.35$, as well as their stopping before they reach the second layer of the EM calorimeter, or after they reach the first layer of the hadronic calorimeter. The relative contributions from these various types of acceptance loss depend on mass and charge, as well as the kinematics of the assumed production model. The Drell–Yan production model implies that the fraction of HIPs produced in the acceptance region of pseudorapidity $|\eta| < 1.35$ is larger with increasing mass (see Fig. 1). Also, with the assumed energy spectra (bottom plot in Fig. 1), the acceptance is highest for intermediate charges ($|q| = 10e$), since HIPs with low charges tend to punch through the EM calorimeter and HIPs with high charges tend to stop before reaching it.

6. Systematic uncertainties

The major sources of systematic uncertainties affecting the efficiency estimation are summarised below. These mainly concern possible imperfections in the description of HIPs in the detector by the simulation.

- The recombination of electrons and ions in the sampling region of the EM calorimeter affects the measured current and thus the total visible energy. Recombination effects become larger with increasing dE/dx . In the ATLAS simulation, this is parametrised by Birks' law [25]. To estimate the uncertainty associated with the approximate modeling of recombination effects, predictions from the ATLAS implementation of Birks' correction [26] are compared to existing data of heavy ions punching through a layer of liquid argon [27–29]. In the range $2 \cdot 10^2 \text{ MeV/cm} < dE/dx < 2 \cdot 10^3 \text{ MeV/cm}$, which corresponds to typical HIP energy losses in the EM calorimeter for the

Table 4

Relative systematic uncertainties in efficiency, combining in quadrature all the effects described in the text.

m [GeV]	$ q = 6e$	$ q = 10e$	$ q = 17e$
200	25%	11%	9%
500	17%	10%	9%
1000	28%	10%	9%

charges and masses under consideration, the uncertainty in the simulated visible energy fraction is $\pm 15\%$. This introduces between 4% and 23% uncertainty in the signal selection efficiency. The impact is largest for charge 6e, for which a lower visible energy would be more likely to push the candidate below the 15 GeV cluster E_T threshold.

- The fraction of HIPs which stop in the detector prior to reaching the EM calorimeter is affected by the assumed amount of material in the GEANT-4 simulation. Varying the material density within the assumed uncertainty range ($\pm \sim 10\%$ [30]), independently in the ID and EM calorimeter volumes, leads to a 6% uncertainty in signal acceptance.
- The modeling of inactive or inefficient EM calorimeter regions in the simulation results in a 2% uncertainty in the signal efficiency.
- Cross-talk effects between EM calorimeter cells affect the w_1 and w_2 variables and this may not be accurately described by the simulation for large energy depositions per cell. The resulting uncertainty in signal efficiency is 2%.
- Secondary ionisation by delta electrons affects the track reconstruction and the calorimeter energy output. The amount of delta electrons in ATLAS detectors as described in GEANT-4 depends on the cutoff parameter (the radius beyond which delta electrons are considered separate from the mother particle). Varying this parameter results in a 3% uncertainty in the signal efficiency.
- For clusters delayed by more than 10 ns with respect to the expected arrival time of a highly relativistic particle, which corresponds to $\beta < 0.37$, there is a significant chance that the event is triggered in the next bunch crossing by the first level EM trigger. In most of the mass and charge range considered in this search, more than 99% of the particles which are energetic enough to reach the EM calorimeter and pass the event selection are in the high-efficiency range $\beta > 0.4$. The only exception is $|q| = 6e$ and $m = 1000$ GeV, for which the β distribution after selection peaks between 0.32 and 0.47. The trigger efficiency loss is corrected for, resulting in an additional 25% uncertainty for this particular case.
- Uncertainties in the choice of parametrisation for the parton density functions (pdfs) of the proton have an impact on the event kinematics. To test this effect, events were generated (see Section 3) with 7 different pdfs from various sources [19, 31–34]. Assuming that acceptance variations due to the choice of pdf are Gaussian, the resulting relative uncertainty in the acceptance is 3%.
- The relative uncertainty in efficiency due to MC statistics is of the order of 2%.

Other effects, like event pile-up and electron pick-up by positively charged particles, have been investigated and found to be negligible. Efficiency systematics are dominated by Birks' correction. The relative uncertainties in the signal selection efficiencies (Tables 2 and 3), obtained by adding all effects in quadrature, are shown in Table 4.

The systematic uncertainty in the absolute integrated luminosity is 11% [35].

Table 5

Inclusive HIP cross section upper limits (in pb) at 95% confidence level for isolated long-lived massive particles with high electric charges produced in regions of pseudorapidity and kinetic energy as defined in Table 1. Efficiencies in Table 2 and uncertainties in Table 4 were used in the cross section limit calculation.

m [GeV]	$ q = 6e$	$ q = 10e$	$ q = 17e$
200	1.4	1.2	2.1
500	1.2	1.2	1.6
1000	2.2	1.2	1.5

Table 6

Pair production cross section upper limits (in pb) at 95% confidence level for long-lived massive particles with high electric charges, assuming a Drell–Yan mechanism. Efficiencies in Table 3 and uncertainties in Table 4 were used in the cross section limit calculation.

m [GeV]	$ q = 6e$	$ q = 10e$	$ q = 17e$
200	11.5	5.9	9.1
500	7.2	4.3	5.3
1000	9.3	3.4	4.3

7. Upper limit on the cross section

A very low ($\ll 1$ event) background yield is expected and no events are observed to pass the selection. Knowing the integrated luminosity (3.1 pb^{-1}) and the selection efficiency for various model assumptions (Tables 2 and 3), cross section limits are obtained. This is done using a Bayesian statistical approach with a uniform prior for the signal and the standard assumption that the uncertainties in integrated luminosity (11%) and efficiency (Table 4) are Gaussian and independent. The limits are presented in Table 5 (for a particle produced in the acceptance kinematic region defined by Table 1) and in Table 6 (assuming Drell–Yan kinematics).

These limits can be approximately interpolated to intermediate values of mass and charge. Also, the limits quoted in Table 5 can be used to extract cross section limits for any given model of kinematics by correcting for the acceptance (fraction of events with at least one generated HIP in the ranges defined by Table 1): such a procedure yields conservative limits thanks to the fact that candidates beyond the sharp edges of the acceptance regions defined in Table 1 can also be accepted.

8. Summary

A search has been made for HIPs with lifetimes in excess of 100 ns produced in the ATLAS detector at the LHC using 3.1 pb^{-1} of pp collisions at $\sqrt{s} = 7$ TeV. The signature of high ionisation in an inner detector track matched to a narrow calorimeter cluster has been used. Upper cross section limits between 1.2 pb and 11.5 pb have been extracted for HIPs with electric charges between $6e$ and $17e$ and masses between 200 GeV and 1000 GeV, under two kinematics assumptions: a generic isolated HIP in a fiducial range of pseudorapidity and kinetic energy, or a Drell–Yan fermion pair production mechanism. HIP mass ranges above 800 GeV [11] are probed for the first time at a particle collider. These limits are the first constraints obtained on long-lived highly charged particle production at LHC collision energies.

ATLAS Collaboration

G. Aad⁴⁸, B. Abbott¹¹¹, J. Abdallah¹¹, A.A. Abdelalim⁴⁹, A. Abdesselam¹¹⁸, O. Abidinov¹⁰, B. Abi¹¹², M. Abolins⁸⁸, H. Abramowicz¹⁵³, H. Abreu¹¹⁵, E. Acerbi^{89a,89b}, B.S. Acharya^{164a,164b}, D.L. Adams²⁴, T.N. Addy⁵⁶, J. Adelman¹⁷⁵, M. Aderholz⁹⁹, S. Adomeit⁹⁸, P. Adragna⁷⁵, T. Adye¹²⁹, S. Aefsky²², J.A. Aguilar-Saavedra^{124b,a}, M. Aharrouche⁸¹, S.P. Ahlen²¹, F. Ahles⁴⁸, A. Ahmad¹⁴⁸, M. Ahsan⁴⁰,

Open access

This article is published Open Access at 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] A. Kusenko, M.E. Shaposhnikov, Phys. Lett. B 418 (1998) 46, arXiv:hep-ph/9709492.
- [2] B. Koch, M. Bleicher, H. Stoecker, J. Phys. G 34 (2007) 535, arXiv:hep-ph/0702187v2.
- [3] M. Fairbairn, et al., Phys. Rep. 438 (2007) 1, arXiv:hep-ph/0611040.
- [4] J.S. Schwinger, Phys. Rev. 144 (1966) 1087.
- [5] SLIM Collaboration, Eur. Phys. J. C 57 (2008) 525, arXiv:0805.1797 [hep-ex].
- [6] K. Kinoshita, et al., Phys. Rev. D 46 (1992) 881.
- [7] J.L. Pinfold, et al., Phys. Lett. B 316 (1993) 407.
- [8] OPAL Collaboration, Phys. Lett. B 663 (2008) 37, arXiv:0707.0404v1 [hep-ex].
- [9] P.B. Price, G.-X. Ren, K. Kinoshita, Phys. Rev. Lett. 59 (1987) 2523.
- [10] P.B. Price, G.-R. Jing, K. Kinoshita, Phys. Rev. Lett. 65 (1990) 149.
- [11] M. Bertani, et al., Europhys. Lett. 12 (1990) 613.
- [12] C.D.F. Collaboration, Phys. Rev. Lett. 96 (2006) 201801, arXiv:hep-ex/0509015v1.
- [13] Moedal Collaboration, J. Pinfold, et al., Technical Design Report of the Moedal Experiment, CERN-LHCC-2009-006; MOEDAL-TDR-001, <http://cdsweb.cern.ch/record/1181486>, 2009.
- [14] ATLAS Collaboration, G. Aad, et al., JINST 3 (2008) S08003.
- [15] G. Abat, et al., JINST 3 (2008) P06007.
- [16] ATLAS Collaboration, Eur. Phys. J. C 70 (2010) 723, arXiv:0912.2642v4 [physics.ins-det].
- [17] ATLAS Collaboration, JINST 3 (2008) S08003.
- [18] T. Sjostrand, S. Mrenna, P. Skands, JHEP 0605 (2006) 026, arXiv:hep-ph/0603175.
- [19] A. Sherstnev, R.S. Thorne, Eur. Phys. J. C 55 (2008) 553, arXiv:0711.2473 [hep-ph].
- [20] G.R. Kalbfleisch, W. Luo, K.A. Milton, E.H. Smith, M.G. Strauss, Phys. Rev. D 69 (2004) 052002, arXiv:hep-ex/0306045.
- [21] ATLAS Collaboration, Eur. Phys. J. C 70 (2010) 823, arXiv:1005.4568v1 [physics.ins-det].
- [22] GEANT4 Collaboration, S. Agostinelli, et al., Nucl. Instrum. Methods A 506 (2003) 250.
- [23] ATLAS Collaboration, Performance of the electron and photon trigger in p – p collisions at $\sqrt{s} = 900$ GeV, ATLAS-CONF-2010-022, <http://cdsweb.cern.ch/record/1277654>, 2010.
- [24] ATLAS Collaboration, JHEP 1012 (2010) 1, arXiv:1010.2130v1 [hep-ex].
- [25] J. Birks, Phys. Rev. 86 (1952) 569.
- [26] ATLAS Collaboration, Response and shower topology of 2 to 180 GeV pions measured with the ATLAS barrel calorimeter at the CERN test-beam and comparison to Monte Carlo simulations, ATL-CAL-PUB-2010-001, <http://cdsweb.cern.ch/record/1263861>, 2010.
- [27] T. Doke, et al., Nucl. Instrum. Methods A 235 (1985) 136.
- [28] E. Shibamura, et al., Nucl. Instrum. Methods A 260 (1987) 437.
- [29] H.J. Crawford, et al., Nucl. Instrum. Methods A 256 (1987) 47.
- [30] ATLAS Collaboration, Phys. Lett. B 688 (2010) 21, arXiv:1003.3124v2 [hep-ex].
- [31] M. Gluck, E. Reya, A. Vogt, Z. Phys. C 67 (1995) 433.
- [32] CTEQ Collaboration, H.L. Lai, et al., Eur. Phys. J. C 12 (2000) 375, arXiv:hep-ph/9903282.
- [33] J. Pumplin, et al., JHEP 0207 (2002) 012, arXiv:hep-ph/0201195.
- [34] A.D. Martin, W.J. Stirling, R.S. Thorne, G. Watt, Eur. Phys. J. C 63 (2009) 189, arXiv:0901.0002 [hep-ph].
- [35] ATLAS Collaboration, Luminosity determination in pp collisions at $\sqrt{s} = 7$ TeV using the ATLAS detector at the LHC, arXiv:1101.2185v1 [hep-ex], Eur. Phys. J. C (2011), in press.

G. Aielli ^{133a,133b}, T. Akdogan ^{18a}, T.P.A. Åkesson ⁷⁹, G. Akimoto ¹⁵⁵, A.V. Akimov ⁹⁴, M.S. Alam ¹, M.A. Alam ⁷⁶, S. Albrand ⁵⁵, M. Aleksa ²⁹, I.N. Aleksandrov ⁶⁵, M. Aleppo ^{89a,89b}, F. Alessandria ^{89a}, C. Alexa ^{25a}, G. Alexander ¹⁵³, G. Alexandre ⁴⁹, T. Alexopoulos ⁹, M. Alhroob ²⁰, M. Aliev ¹⁵, G. Alimonti ^{89a}, J. Alison ¹²⁰, M. Aliyev ¹⁰, P.P. Allport ⁷³, S.E. Allwood-Spiers ⁵³, J. Almond ⁸², A. Aloisio ^{102a,102b}, R. Alon ¹⁷¹, A. Alonso ⁷⁹, M.G. Alviggi ^{102a,102b}, K. Amako ⁶⁶, P. Amaral ²⁹, C. Amelung ²², V.V. Ammosov ¹²⁸, A. Amorim ^{124a,b}, G. Amorós ¹⁶⁷, N. Amram ¹⁵³, C. Anastopoulos ¹³⁹, T. Andeen ³⁴, C.F. Anders ²⁰, K.J. Anderson ³⁰, A. Andreazza ^{89a,89b}, V. Andrei ^{58a}, M.-L. Andrieux ⁵⁵, X.S. Anduaga ⁷⁰, A. Angerami ³⁴, F. Anghinolfi ²⁹, N. Anjos ^{124a}, A. Annovi ⁴⁷, A. Antonaki ⁸, M. Antonelli ⁴⁷, S. Antonelli ^{19a,19b}, J. Antos ^{144b}, F. Anulli ^{132a}, S. Aoun ⁸³, L. Aperio Bella ⁴, R. Apolle ¹¹⁸, G. Arabidze ⁸⁸, I. Aracena ¹⁴³, Y. Arai ⁶⁶, A.T.H. Arce ⁴⁴, J.P. Archambault ²⁸, S. Arfaoui ^{29,c}, J.-F. Arguin ¹⁴, E. Arik ^{18a,*}, M. Arik ^{18a}, A.J. Armbruster ⁸⁷, S.R. Armstrong ²⁴, O. Arnaez ⁸¹, C. Arnault ¹¹⁵, A. Artamonov ⁹⁵, G. Artoni ^{132a,132b}, D. Arutinov ²⁰, S. Asai ¹⁵⁵, R. Asfandiyarov ¹⁷², S. Ask ²⁷, B. Åsman ^{146a,146b}, L. Asquith ⁵, K. Assamagan ²⁴, A. Astbury ¹⁶⁹, A. Astvatsatourov ⁵², G. Atoian ¹⁷⁵, B. Aubert ⁴, B. Auerbach ¹⁷⁵, E. Auge ¹¹⁵, K. Augsten ¹²⁷, M. Aurousseau ⁴, N. Austin ⁷³, R. Avramidou ⁹, D. Axen ¹⁶⁸, C. Ay ⁵⁴, G. Azuelos ^{93,d}, Y. Azuma ¹⁵⁵, M.A. Baak ²⁹, G. Baccaglioni ^{89a}, C. Bacci ^{134a,134b}, A.M. Bach ¹⁴, H. Bachacou ¹³⁶, K. Bachas ²⁹, G. Bachy ²⁹, M. Backes ⁴⁹, M. Backhaus ²⁰, E. Badescu ^{25a}, P. Bagnaia ^{132a,132b}, S. Bahinipati ², Y. Bai ^{32a}, D.C. Bailey ¹⁵⁸, T. Bain ¹⁵⁸, J.T. Baines ¹²⁹, O.K. Baker ¹⁷⁵, M.D. Baker ²⁴, S. Baker ⁷⁷, F. Baltasar Dos Santos Pedrosa ²⁹, E. Banas ³⁸, P. Banerjee ⁹³, Sw. Banerjee ¹⁶⁹, D. Banfi ²⁹, A. Bangert ¹³⁷, V. Bansal ¹⁶⁹, H.S. Bansil ¹⁷, L. Barak ¹⁷¹, S.P. Baranov ⁹⁴, A. Barashkou ⁶⁵, A. Barbaro Galtieri ¹⁴, T. Barber ²⁷, E.L. Barberio ⁸⁶, D. Barberis ^{50a,50b}, M. Barbero ²⁰, D.Y. Bardin ⁶⁵, T. Barillari ⁹⁹, M. Barisonzi ¹⁷⁴, T. Barklow ¹⁴³, N. Barlow ²⁷, B.M. Barnett ¹²⁹, R.M. Barnett ¹⁴, A. Baroncelli ^{134a}, A.J. Barr ¹¹⁸, F. Barreiro ⁸⁰, J. Barreiro Guimarães da Costa ⁵⁷, P. Barrillon ¹¹⁵, R. Bartoldus ¹⁴³, A.E. Barton ⁷¹, D. Bartsch ²⁰, R.L. Bates ⁵³, L. Batkova ^{144a}, J.R. Batley ²⁷, A. Battaglia ¹⁶, M. Battistin ²⁹, G. Battistoni ^{89a}, F. Bauer ¹³⁶, H.S. Bawa ¹⁴³, B. Beare ¹⁵⁸, T. Beau ⁷⁸, P.H. Beauchemin ¹¹⁸, R. Beccherle ^{50a}, P. Bechtel ⁴¹, H.P. Beck ¹⁶, M. Beckingham ⁴⁸, K.H. Becks ¹⁷⁴, A.J. Beddall ^{18c}, A. Beddall ^{18c}, V.A. Bednyakov ⁶⁵, C. Bee ⁸³, M. Begel ²⁴, S. Behar Harpaz ¹⁵², P.K. Behera ⁶³, M. Beimforde ⁹⁹, C. Belanger-Champagne ¹⁶⁶, P.J. Bell ⁴⁹, W.H. Bell ⁴⁹, G. Bella ¹⁵³, L. Bellagamba ^{19a}, F. Bellina ²⁹, G. Bellomo ^{89a,89b}, M. Bellomo ^{119a}, A. Belloni ⁵⁷, K. Belotskiy ⁹⁶, O. Beltramello ²⁹, S. Ben Ami ¹⁵², O. Benary ¹⁵³, D. Benchekroun ^{135a}, C. Benchouk ⁸³, M. Bendel ⁸¹, B.H. Benedict ¹⁶³, N. Benekos ¹⁶⁵, Y. Benhammou ¹⁵³, D.P. Benjamin ⁴⁴, M. Benoit ¹¹⁵, J.R. Bensinger ²², K. Benslama ¹³⁰, S. Bentvelsen ¹⁰⁵, D. Berge ²⁹, E. Bergeaas Kuutmann ⁴¹, N. Berger ⁴, F. Berghaus ¹⁶⁹, E. Berglund ⁴⁹, J. Beringer ¹⁴, K. Bernardet ⁸³, P. Bernat ¹¹⁵, R. Bernhard ⁴⁸, C. Bernius ²⁴, T. Berry ⁷⁶, A. Bertin ^{19a,19b}, F. Bertinelli ²⁹, F. Bertolucci ^{122a,122b}, M.I. Besana ^{89a,89b}, N. Besson ¹³⁶, S. Bethke ⁹⁹, W. Bhimji ⁴⁵, R.M. Bianchi ²⁹, M. Bianco ^{72a,72b}, O. Biebel ⁹⁸, J. Biesiada ¹⁴, M. Biglietti ^{132a,132b}, H. Bilokon ⁴⁷, M. Bindi ^{19a,19b}, A. Bingul ^{18c}, C. Bini ^{132a,132b}, C. Biscarat ¹⁷⁷, U. Bitenc ⁴⁸, K.M. Black ²¹, R.E. Blair ⁵, J.-B. Blanchard ¹¹⁵, G. Blanchot ²⁹, C. Blocker ²², J. Blocki ³⁸, A. Blondel ⁴⁹, W. Blum ⁸¹, U. Blumenschein ⁵⁴, G.J. Bobbink ¹⁰⁵, V.B. Bobrovnikov ¹⁰⁷, A. Bocci ⁴⁴, R. Bock ²⁹, C.R. Boddy ¹¹⁸, M. Boehler ⁴¹, J. Boek ¹⁷⁴, N. Boelaert ³⁵, S. Böser ⁷⁷, J.A. Bogaerts ²⁹, A. Bogdanchikov ¹⁰⁷, A. Bogouch ^{90,*}, C. Böhm ^{146a}, V. Boisvert ⁷⁶, T. Bold ^{163,e}, V. Boldea ^{25a}, M. Bona ⁷⁵, M. Boonekamp ¹³⁶, G. Boorman ⁷⁶, C.N. Booth ¹³⁹, P. Booth ¹³⁹, S. Bordini ⁷⁸, C. Borer ¹⁶, A. Borisov ¹²⁸, G. Borissov ⁷¹, I. Borjanovic ^{12a}, S. Borroni ^{132a,132b}, K. Bos ¹⁰⁵, D. Boscherini ^{19a}, M. Bosman ¹¹, H. Boterenbrood ¹⁰⁵, D. Botterill ¹²⁹, J. Bouchami ⁹³, J. Boudreau ¹²³, E.V. Bouhova-Thacker ⁷¹, C. Boulahouache ¹²³, C. Bourdarios ¹¹⁵, N. Bousson ⁸³, A. Boveia ³⁰, J. Boyd ²⁹, I.R. Boyko ⁶⁵, N.I. Bozhko ¹²⁸, I. Bozovic-Jelisavcic ^{12b}, J. Bracinik ¹⁷, A. Braem ²⁹, E. Brambilla ^{72a,72b}, P. Branchini ^{134a}, G.W. Brandenburg ⁵⁷, A. Brandt ⁷, G. Brandt ⁴¹, O. Brandt ⁵⁴, U. Bratzler ¹⁵⁶, B. Brau ⁸⁴, J.E. Brau ¹¹⁴, H.M. Braun ¹⁷⁴, B. Brelier ¹⁵⁸, J. Bremer ²⁹, R. Brenner ¹⁶⁶, S. Bressler ¹⁵², D. Breton ¹¹⁵, N.D. Brett ¹¹⁸, P.G. Bright-Thomas ¹⁷, D. Britton ⁵³, F.M. Brochu ²⁷, I. Brock ²⁰, R. Brock ⁸⁸, T.J. Brodbeck ⁷¹, E. Brodet ¹⁵³, F. Broggi ^{89a}, C. Bromberg ⁸⁸, G. Brooijmans ³⁴, W.K. Brooks ^{31b}, G. Brown ⁸², E. Brubaker ³⁰, P.A. Bruckman de Renstrom ³⁸, D. Bruncko ^{144b}, R. Bruneliere ⁴⁸, S. Brunet ⁶¹, A. Bruni ^{19a}, G. Bruni ^{19a}, M. Bruschi ^{19a}, T. Buanes ¹³, F. Bucci ⁴⁹, J. Buchanan ¹¹⁸, N.J. Buchanan ², P. Buchholz ¹⁴¹, R.M. Buckingham ¹¹⁸, A.G. Buckley ⁴⁵, S.I. Buda ^{25a}, I.A. Budagov ⁶⁵, B. Budick ¹⁰⁸, V. Büscher ⁸¹, L. Bugge ¹¹⁷, D. Buirra-Clark ¹¹⁸, E.J. Buis ¹⁰⁵, O. Bulekov ⁹⁶, M. Bunse ⁴², T. Buran ¹¹⁷, H. Burckhart ²⁹, S. Burdin ⁷³, T. Burgess ¹³, S. Burke ¹²⁹, E. Busato ³³, P. Bussey ⁵³, C.P. Buszello ¹⁶⁶,

F. Butin²⁹, B. Butler¹⁴³, J.M. Butler²¹, C.M. Buttar⁵³, J.M. Butterworth⁷⁷, W. Buttinger²⁷, T. Byatt⁷⁷, S. Cabrera Urbán¹⁶⁷, M. Caccia^{89a,89b}, D. Caforio^{19a,19b}, O. Cakir^{3a}, P. Calafiura¹⁴, G. Calderini⁷⁸, P. Calfayan⁹⁸, R. Calkins¹⁰⁶, L.P. Caloba^{23a}, R. Caloi^{132a,132b}, D. Calvet³³, S. Calvet³³, R. Camacho Toro³³, A. Camard⁷⁸, P. Camarri^{133a,133b}, M. Cambiaghi^{119a,119b}, D. Cameron¹¹⁷, J. Cammin²⁰, S. Campana²⁹, M. Campanelli⁷⁷, V. Canale^{102a,102b}, F. Canelli³⁰, A. Canepa^{159a}, J. Cantero⁸⁰, L. Capasso^{102a,102b}, M.D.M. Capeans Garrido²⁹, I. Caprini^{25a}, M. Caprini^{25a}, D. Capriotti⁹⁹, M. Capua^{36a,36b}, R. Caputo¹⁴⁸, C. Caramarcu^{25a}, R. Cardarelli^{133a}, T. Carli²⁹, G. Carlino^{102a}, L. Carminati^{89a,89b}, B. Caron^{159a}, S. Caron⁴⁸, C. Carpentieri⁴⁸, G.D. Carrillo Montoya¹⁷², S. Carron Montero¹⁵⁸, A.A. Carter⁷⁵, J.R. Carter²⁷, J. Carvalho^{124a,f}, D. Casadei¹⁰⁸, M.P. Casado¹¹, M. Cascella^{122a,122b}, C. Caso^{50a,50b,*}, A.M. Castaneda Hernandez¹⁷², E. Castaneda-Miranda¹⁷², V. Castillo Gimenez¹⁶⁷, N.F. Castro^{124b,a}, G. Cataldi^{72a}, F. Cataneo²⁹, A. Catinaccio²⁹, J.R. Catmore⁷¹, A. Cattai²⁹, G. Cattani^{133a,133b}, S. Caughron⁸⁸, D. Cauz^{164a,164c}, A. Cavallari^{132a,132b}, P. Cavalleri⁷⁸, D. Cavalli^{89a}, M. Cavalli-Sforza¹¹, V. Cavasinni^{122a,122b}, A. Cazzato^{72a,72b}, F. Ceradini^{134a,134b}, A.S. Cerqueira^{23a}, A. Cerri²⁹, L. Cerrito⁷⁵, F. Cerutti⁴⁷, S.A. Cetin^{18b}, F. Cevenini^{102a,102b}, A. Chafaq^{135a}, D. Chakraborty¹⁰⁶, K. Chan², B. Chapleau⁸⁵, J.D. Chapman²⁷, J.W. Chapman⁸⁷, E. Chareyre⁷⁸, D.G. Charlton¹⁷, V. Chavda⁸², S. Cheatham⁷¹, S. Chekanov⁵, S.V. Chekulaev^{159a}, G.A. Chelkov⁶⁵, H. Chen²⁴, L. Chen², S. Chen^{32c}, T. Chen^{32c}, X. Chen¹⁷², S. Cheng^{32a}, A. Cheplakov⁶⁵, V.F. Chepurinov⁶⁵, R. Cherkaoui El Moursli^{135d}, V. Chernyatin²⁴, E. Cheu⁶, S.L. Cheung¹⁵⁸, L. Chevalier¹³⁶, F. Chevallier¹³⁶, G. Chiefari^{102a,102b}, L. Chikovani⁵¹, J.T. Childers^{58a}, A. Chilingarov⁷¹, G. Chiodini^{72a}, M.V. Chizhov⁶⁵, G. Choudalakis³⁰, S. Chouridou¹³⁷, I.A. Christidi⁷⁷, A. Christov⁴⁸, D. Chromek-Burckhart²⁹, M.L. Chu¹⁵¹, J. Chudoba¹²⁵, G. Ciapetti^{132a,132b}, A.K. Ciftci^{3a}, R. Ciftci^{3a}, D. Cinca³³, V. Cindro⁷⁴, M.D. Ciobotaru¹⁶³, C. Ciocca^{19a,19b}, A. Ciochio¹⁴, M. Cirilli⁸⁷, M. Ciubancan^{25a}, A. Clark⁴⁹, P.J. Clark⁴⁵, W. Cleland¹²³, J.C. Clemens⁸³, B. Clement⁵⁵, C. Clement^{146a,146b}, R.W. Clift¹²⁹, Y. Coadou⁸³, M. Cobal^{164a,164c}, A. Coccaro^{50a,50b}, J. Cochran⁶⁴, P. Coe¹¹⁸, J.G. Cogan¹⁴³, J. Coggeshall¹⁶⁵, E. Cogneras¹⁷⁷, C.D. Cojocar²⁸, J. Colas⁴, A.P. Colijn¹⁰⁵, C. Collard¹¹⁵, N.J. Collins¹⁷, C. Collins-Tooth⁵³, J. Collot⁵⁵, G. Colon⁸⁴, R. Coluccia^{72a,72b}, G. Comune⁸⁸, P. Conde Muiño^{124a}, E. Coniavitis¹¹⁸, M.C. Conidi¹¹, M. Consonni¹⁰⁴, S. Constantinescu^{25a}, C. Conta^{119a,119b}, F. Conventi^{102a,g}, J. Cook²⁹, M. Cooke¹⁴, B.D. Cooper⁷⁵, A.M. Cooper-Sarkar¹¹⁸, N.J. Cooper-Smith⁷⁶, K. Copic³⁴, T. Cornelissen^{50a,50b}, M. Corradi^{19a}, F. Corriveau^{85,h}, A. Cortes-Gonzalez¹⁶⁵, G. Cortiana⁹⁹, G. Costa^{89a}, M.J. Costa¹⁶⁷, D. Costanzo¹³⁹, T. Costin³⁰, D. Côté²⁹, R. Coura Torres^{23a}, L. Courneyea¹⁶⁹, G. Cowan⁷⁶, C. Cowden²⁷, B.E. Cox⁸², K. Cranmer¹⁰⁸, M. Cristinziani²⁰, G. Crosetti^{36a,36b}, R. Crupi^{72a,72b}, S. Crépe-Renaudin⁵⁵, C. Cuenca Almenar¹⁷⁵, T. Cuhadar Donszelmann¹³⁹, S. Cuneo^{50a,50b}, M. Curatolo⁴⁷, C.J. Curtis¹⁷, P. Cwetanski⁶¹, H. Czirr¹⁴¹, Z. Czynzula¹¹⁷, S. D'Auria⁵³, M. D'Onofrio⁷³, A. D'Orazio^{132a,132b}, A. Da Rocha Gesualdi Mello^{23a}, P.V.M. Da Silva^{23a}, C. Da Via⁸², W. Dabrowski³⁷, A. Dahlhoff⁴⁸, T. Dai⁸⁷, C. Dallapiccola⁸⁴, S.J. Dallison^{129,*}, M. Dam³⁵, M. Dameri^{50a,50b}, D.S. Damiani¹³⁷, H.O. Danielsson²⁹, R. Dankers¹⁰⁵, D. Dannheim⁹⁹, V. Dao⁴⁹, G. Darbo^{50a}, G.L. Darlea^{25b}, C. Daum¹⁰⁵, J.P. Dauvergne²⁹, W. Davey⁸⁶, T. Davidek¹²⁶, N. Davidson⁸⁶, R. Davidson⁷¹, M. Davies⁹³, A.R. Davison⁷⁷, E. Dawe¹⁴², I. Dawson¹³⁹, J.W. Dawson^{5,*}, R.K. Daya³⁹, K. De⁷, R. de Asmundis^{102a}, S. De Castro^{19a,19b}, P.E. De Castro Faria Salgado²⁴, S. De Cecco⁷⁸, J. de Graat⁹⁸, N. De Groot¹⁰⁴, P. de Jong¹⁰⁵, C. De La Taille¹¹⁵, B. De Lotto^{164a,164c}, L. De Mora⁷¹, L. De Nooij¹⁰⁵, M. De Oliveira Branco²⁹, D. De Pedis^{132a}, P. de Saintignon⁵⁵, A. De Salvo^{132a}, U. De Sanctis^{164a,164c}, A. De Santo¹⁴⁹, J.B. De Vivie De Regie¹¹⁵, S. Dean⁷⁷, G. Dedes⁹⁹, D.V. Dedovich⁶⁵, J. Degenhardt¹²⁰, M. Dehchar¹¹⁸, M. Deile⁹⁸, C. Del Papa^{164a,164c}, J. Del Peso⁸⁰, T. Del Prete^{122a,122b}, A. Dell'Acqua²⁹, L. Dell'Asta^{89a,89b}, M. Della Pietra^{102a,g}, D. della Volpe^{102a,102b}, M. Delmastro²⁹, P. Delpierre⁸³, N. Delruelle²⁹, P.A. Delsart⁵⁵, C. Deluca¹⁴⁸, S. Demers¹⁷⁵, M. Demichev⁶⁵, B. Demirköz¹¹, J. Deng¹⁶³, S.P. Denisov¹²⁸, C. Dennis¹¹⁸, D. Derendarz³⁸, J.E. Derkaoui^{135c}, F. Derue⁷⁸, P. Dervan⁷³, K. Desch²⁰, E. Devetak¹⁴⁸, P.O. Deviveiros¹⁵⁸, A. Dewhurst¹²⁹, B. DeWilde¹⁴⁸, S. Dhaliwal¹⁵⁸, R. Dhullipudi^{24,i}, A. Di Ciaccio^{133a,133b}, L. Di Ciaccio⁴, A. Di Girolamo²⁹, B. Di Girolamo²⁹, S. Di Luise^{134a,134b}, A. Di Mattia⁸⁸, B. Di Micco^{134a,134b}, R. Di Nardo^{133a,133b}, A. Di Simone^{133a,133b}, R. Di Sipio^{19a,19b}, M.A. Diaz^{31a}, F. Diblen^{18c}, E.B. Diehl⁸⁷, H. Dietl⁹⁹, J. Dietrich⁴⁸, T.A. Dietzsch^{58a}, S. Diglio¹¹⁵, K. Dindar Yagci³⁹, J. Dingfelder²⁰, C. Dionisi^{132a,132b}, P. Dita^{25a}, S. Dita^{25a}, F. Dittus²⁹, F. Djama⁸³, R. Djilkibaev¹⁰⁸, T. Djobava⁵¹, M.A.B. do Vale^{23a}, A. Do Valle Wemans^{124a}, T.K.O. Doan⁴, M. Dobbs⁸⁵,

R. Dobinson^{29,*}, D. Dobos⁴², E. Dobson²⁹, M. Dobson¹⁶³, J. Dodd³⁴, O.B. Dogan^{18a,*}, C. Doglioni¹¹⁸, T. Doherty⁵³, Y. Doi^{66,*}, J. Dolejsi¹²⁶, I. Dolenc⁷⁴, Z. Dolezal¹²⁶, B.A. Dolgoshein^{96,*}, T. Dohmae¹⁵⁵, M. Donadelli^{23b}, M. Donega¹²⁰, J. Donini⁵⁵, J. Dopke¹⁷⁴, A. Doria^{102a}, A. Dos Anjos¹⁷², M. Dosil¹¹, A. Dotti^{122a,122b}, M.T. Dova⁷⁰, J.D. Dowell¹⁷, A.D. Doxiadis¹⁰⁵, A.T. Doyle⁵³, Z. Drasal¹²⁶, J. Drees¹⁷⁴, N. Dressnandt¹²⁰, H. Drevermann²⁹, C. Driouchi³⁵, M. Dris⁹, J.G. Drohan⁷⁷, J. Dubbert⁹⁹, T. Dubbs¹³⁷, S. Dube¹⁴, E. Duchovni¹⁷¹, G. Duckeck⁹⁸, A. Dudarev²⁹, F. Dudziak¹¹⁵, M. Dührssen²⁹, I.P. Duerdoth⁸², L. Duflot¹¹⁵, M.-A. Dufour⁸⁵, M. Dunford²⁹, H. Duran Yildiz^{3b}, R. Duxfield¹³⁹, M. Dwuznik³⁷, F. Dydak²⁹, D. Dzahini⁵⁵, M. Düren⁵², J. Ebke⁹⁸, S. Eckert⁴⁸, S. Eckweiler⁸¹, K. Edmonds⁸¹, C.A. Edwards⁷⁶, I. Efthymiopoulos⁴⁹, W. Ehrenfeld⁴¹, T. Ehrich⁹⁹, T. Eifert²⁹, G. Eigen¹³, K. Einsweiler¹⁴, E. Eisenhandler⁷⁵, T. Ekelof¹⁶⁶, M. El Kacimi⁴, M. Ellert¹⁶⁶, S. Elles⁴, F. Ellinghaus⁸¹, K. Ellis⁷⁵, N. Ellis²⁹, J. Elmsheuser⁹⁸, M. Elsing²⁹, R. Ely¹⁴, D. Emeliyanov¹²⁹, R. Engelmann¹⁴⁸, A. Engl⁹⁸, B. Epp⁶², A. Eppig⁸⁷, J. Erdmann⁵⁴, A. Ereditato¹⁶, D. Eriksson^{146a}, J. Ernst¹, M. Ernst²⁴, J. Ernwein¹³⁶, D. Errede¹⁶⁵, S. Errede¹⁶⁵, E. Ertel⁸¹, M. Escalier¹¹⁵, C. Escobar¹⁶⁷, X. Espinal Curull¹¹, B. Esposito⁴⁷, F. Etienne⁸³, A.I. Etievre¹³⁶, E. Etzion¹⁵³, D. Evangelakou⁵⁴, H. Evans⁶¹, L. Fabbri^{19a,19b}, C. Fabre²⁹, K. Facius³⁵, R.M. Fakhruddinov¹²⁸, S. Falciano^{132a}, A.C. Falou¹¹⁵, Y. Fang¹⁷², M. Fanti^{89a,89b}, A. Farbin⁷, A. Farilla^{134a}, J. Farley¹⁴⁸, T. Farooque¹⁵⁸, S.M. Farrington¹¹⁸, P. Farthouat²⁹, D. Fasching¹⁷², P. Fassnacht²⁹, D. Fassouliotis⁸, B. Fatholahzadeh¹⁵⁸, A. Favareto^{89a,89b}, L. Fayard¹¹⁵, S. Fazio^{36a,36b}, R. Febbraro³³, P. Federic^{144a}, O.L. Fedin¹²¹, I. Fedorko²⁹, W. Fedorko⁸⁸, M. Fehling-Kaschek⁴⁸, L. Feligioni⁸³, D. Fellmann⁵, C.U. Felzmann⁸⁶, C. Feng^{32d}, E.J. Feng³⁰, A.B. Fenyuk¹²⁸, J. Ferencei^{144b}, J. Ferland⁹³, B. Fernandes^{124a,j}, W. Fernando¹⁰⁹, S. Ferrag⁵³, J. Ferrando¹¹⁸, V. Ferrara⁴¹, A. Ferrari¹⁶⁶, P. Ferrari¹⁰⁵, R. Ferrari^{119a}, A. Ferrer¹⁶⁷, M.L. Ferrer⁴⁷, D. Ferrere⁴⁹, C. Ferretti⁸⁷, A. Ferretto Parodi^{50a,50b}, M. Fiascaris³⁰, F. Fiedler⁸¹, A. Filipčič⁷⁴, A. Filippas⁹, F. Filthaut¹⁰⁴, M. Fincke-Keeler¹⁶⁹, M.C.N. Fiolhais^{124a,f}, L. Fiorini¹¹, A. Firan³⁹, G. Fischer⁴¹, P. Fischer²⁰, M.J. Fisher¹⁰⁹, S.M. Fisher¹²⁹, J. Flammer²⁹, M. Flechl⁴⁸, I. Fleck¹⁴¹, J. Fleckner⁸¹, P. Fleischmann¹⁷³, S. Fleischmann¹⁷⁴, T. Flick¹⁷⁴, L.R. Flores Castillo¹⁷², M.J. Flowerdew⁹⁹, F. Föhlich^{58a}, M. Fokitis⁹, T. Fonseca Martin¹⁶, D.A. Forbush¹³⁸, A. Formica¹³⁶, A. Forti⁸², D. Fortin^{159a}, J.M. Foster⁸², D. Fournier¹¹⁵, A. Foussat²⁹, A.J. Fowler⁴⁴, K. Fowler¹³⁷, H. Fox⁷¹, P. Francavilla^{122a,122b}, S. Franchino^{119a,119b}, D. Francis²⁹, T. Frank¹⁷¹, M. Franklin⁵⁷, S. Franz²⁹, M. Fraternali^{119a,119b}, S. Fratina¹²⁰, S.T. French²⁷, R. Froeschl²⁹, D. Froidevaux²⁹, J.A. Frost²⁷, C. Fukunaga¹⁵⁶, E. Fullana Torregrosa²⁹, J. Fuster¹⁶⁷, C. Gabaldon²⁹, O. Gabizon¹⁷¹, T. Gadfort²⁴, S. Gadomski⁴⁹, G. Gagliardi^{50a,50b}, P. Gagnon⁶¹, C. Galea⁹⁸, E.J. Gallas¹¹⁸, M.V. Gallas²⁹, V. Gallo¹⁶, B.J. Gallop¹²⁹, P. Gallus¹²⁵, E. Galyaev⁴⁰, K.K. Gan¹⁰⁹, Y.S. Gao^{143,k}, V.A. Gapienko¹²⁸, A. Gaponenko¹⁴, F. Garberon¹⁷⁵, M. Garcia-Sciveres¹⁴, C. García¹⁶⁷, J.E. García Navarro⁴⁹, R.W. Gardner³⁰, N. Garelli²⁹, H. Garitaonandia¹⁰⁵, V. Garonne²⁹, J. Garvey¹⁷, C. Gatti⁴⁷, G. Gaudio^{119a}, O. Gaumer⁴⁹, B. Gaur¹⁴¹, L. Gauthier¹³⁶, I.L. Gavrilenko⁹⁴, C. Gay¹⁶⁸, G. Gaycken²⁰, J.-C. Gayde²⁹, E.N. Gazis⁹, P. Ge^{32d}, C.N.P. Gee¹²⁹, Ch. Geich-Gimbel²⁰, K. Gellerstedt^{146a,146b}, C. Gemme^{50a}, A. Gemmell⁵³, M.H. Genest⁹⁸, S. Gentile^{132a,132b}, F. Georgatos⁹, S. George⁷⁶, P. Gerlach¹⁷⁴, A. Gershon¹⁵³, C. Geweniger^{58a}, H. Ghazlane^{135d}, P. Ghez⁴, N. Ghodbane³³, B. Giacobbe^{19a}, S. Giagu^{132a,132b}, V. Giakoumopoulou⁸, V. Giangiobbe^{122a,122b}, F. Gianotti²⁹, B. Gibbard²⁴, A. Gibson¹⁵⁸, S.M. Gibson²⁹, G.F. Gieraltowski⁵, L.M. Gilbert¹¹⁸, M. Gilchriese¹⁴, V. Gilevsky⁹¹, D. Gillberg²⁸, A.R. Gillman¹²⁹, D.M. Gingrich^{2,d}, J. Ginzburg¹⁵³, N. Giokaris⁸, R. Giordano^{102a,102b}, F.M. Giorgi¹⁵, P. Giovannini⁹⁹, P.F. Giraud¹³⁶, D. Giugni^{89a}, P. Giusti^{19a}, B.K. Gjelsten¹¹⁷, L.K. Gladilin⁹⁷, C. Glasman⁸⁰, J. Glatzer⁴⁸, A. Glazov⁴¹, K.W. Glitza¹⁷⁴, G.L. Glonti⁶⁵, J. Godfrey¹⁴², J. Godlewski²⁹, M. Goebel⁴¹, T. Göpfert⁴³, C. Goeringer⁸¹, C. Gössling⁴², T. Göttfert⁹⁹, S. Goldfarb⁸⁷, D. Goldin³⁹, T. Golling¹⁷⁵, N.P. Gollub²⁹, S.N. Golovnia¹²⁸, A. Gomes^{124a,l}, L.S. Gomez Fajardo⁴¹, R. Gonçalves⁷⁶, L. Gonella²⁰, A. Gonidec²⁹, S. Gonzalez¹⁷², S. González de la Hoz¹⁶⁷, M.L. Gonzalez Silva²⁶, S. Gonzalez-Sevilla⁴⁹, J.J. Goodson¹⁴⁸, L. Goossens²⁹, P.A. Gorbounov⁹⁵, H.A. Gordon²⁴, I. Gorelov¹⁰³, G. Gorfine¹⁷⁴, B. Gorini²⁹, E. Gorini^{72a,72b}, A. Gorišek⁷⁴, E. Gornicki³⁸, S.A. Gorokhov¹²⁸, V.N. Goryachev¹²⁸, B. Gosdzik⁴¹, M. Gosselink¹⁰⁵, M.I. Gostkin⁶⁵, M. Gouanère⁴, I. Gough Eschrich¹⁶³, M. Gouighri^{135a}, D. Goujdami^{135a}, M.P. Goulette⁴⁹, A.G. Goussiou¹³⁸, C. Goy⁴, I. Grabowska-Bold^{163,e}, V. Grabski¹⁷⁶, P. Grafström²⁹, C. Grah¹⁷⁴, K.-J. Grah¹⁴⁷, F. Grancagnolo^{72a}, S. Grancagnolo¹⁵, V. Grassi¹⁴⁸, V. Gratchev¹²¹, N. Grau³⁴, H.M. Gray^{34,m}, J.A. Gray¹⁴⁸, E. Graziani^{134a}, O.G. Grebenyuk¹²¹, D. Greenfield¹²⁹, T. Greenshaw⁷³,

Z.D. Greenwood^{24,i}, I.M. Gregor⁴¹, P. Grenier¹⁴³, E. Griesmayer⁴⁶, J. Griffiths¹³⁸, N. Grigalashvili⁶⁵, A.A. Grillo¹³⁷, K. Grimm¹⁴⁸, S. Grinstein¹¹, P.L.Y. Gris³³, Y.V. Grishkevich⁹⁷, J.-F. Grivaz¹¹⁵, J. Grognez²⁹, M. Groh⁹⁹, E. Gross¹⁷¹, J. Grosse-Knetter⁵⁴, J. Groth-Jensen⁷⁹, M. Gruwe²⁹, K. Grybel¹⁴¹, V.J. Guarino⁵, C. Guicheney³³, A. Guida^{72a,72b}, T. Guillemin⁴, S. Guindon⁵⁴, H. Guler^{85,n}, J. Gunther¹²⁵, B. Guo¹⁵⁸, J. Guo³⁴, A. Gupta³⁰, Y. Gusakov⁶⁵, V.N. Gushchin¹²⁸, A. Gutierrez⁹³, P. Gutierrez¹¹¹, N. Guttman¹⁵³, O. Gutzwiller¹⁷², C. Guyot¹³⁶, C. Gwenlan¹¹⁸, C.B. Gwilliam⁷³, A. Haas¹⁴³, S. Haas²⁹, C. Haber¹⁴, R. Hackenburg²⁴, H.K. Hadavand³⁹, D.R. Hadley¹⁷, P. Haefner⁹⁹, F. Hahn²⁹, S. Haider²⁹, Z. Hajduk³⁸, H. Hakobyan¹⁷⁶, J. Haller⁵⁴, K. Hamacher¹⁷⁴, A. Hamilton⁴⁹, S. Hamilton¹⁶¹, H. Han^{32a}, L. Han^{32b}, K. Hanagaki¹¹⁶, M. Hance¹²⁰, C. Handel⁸¹, P. Hanke^{58a}, C.J. Hansen¹⁶⁶, J.R. Hansen³⁵, J.B. Hansen³⁵, J.D. Hansen³⁵, P.H. Hansen³⁵, P. Hansson¹⁴³, K. Hara¹⁶⁰, G.A. Hare¹³⁷, T. Harenberg¹⁷⁴, D. Harper⁸⁷, R.D. Harrington²¹, O.M. Harris¹³⁸, K. Harrison¹⁷, J. Hartert⁴⁸, F. Hartjes¹⁰⁵, T. Haruyama⁶⁶, A. Harvey⁵⁶, S. Hasegawa¹⁰¹, Y. Hasegawa¹⁴⁰, S. Hassani¹³⁶, M. Hatch²⁹, D. Hauff⁹⁹, S. Haug¹⁶, M. Hauschild²⁹, R. Hauser⁸⁸, M. Havranek¹²⁵, B.M. Hawes¹¹⁸, C.M. Hawkes¹⁷, R.J. Hawkins²⁹, D. Hawkins¹⁶³, T. Hayakawa⁶⁷, D. Hayden⁷⁶, H.S. Hayward⁷³, S.J. Haywood¹²⁹, E. Hazen²¹, M. He^{32d}, S.J. Head¹⁷, V. Hedberg⁷⁹, L. Heelan²⁸, S. Heim⁸⁸, B. Heinemann¹⁴, S. Heisterkamp³⁵, L. Helary⁴, M. Heldmann⁴⁸, M. Heller¹¹⁵, S. Hellman^{146a,146b}, C. Hensens¹¹, R.C.W. Henderson⁷¹, M. Henke^{58a}, A. Henrichs⁵⁴, A.M. Henriques Correia²⁹, S. Henrot-Versille¹¹⁵, F. Henry-Couannier⁸³, C. Hensel⁵⁴, T. Henß¹⁷⁴, Y. Hernández Jiménez¹⁶⁷, R. Herrberg¹⁵, A.D. Hershenhorn¹⁵², G. Herten⁴⁸, R. Hertenberger⁹⁸, L. Hervas²⁹, N.P. Hessey¹⁰⁵, A. Hidvegi^{146a}, E. Higón-Rodríguez¹⁶⁷, D. Hill^{5,*}, J.C. Hill²⁷, N. Hill⁵, K.H. Hiller⁴¹, S. Hillert²⁰, S.J. Hillier¹⁷, I. Hinchliffe¹⁴, E. Hines¹²⁰, M. Hirose¹¹⁶, F. Hirsch⁴², D. Hirschbuehl¹⁷⁴, J. Hobbs¹⁴⁸, N. Hod¹⁵³, M.C. Hodgkinson¹³⁹, P. Hodgson¹³⁹, A. Hoecker²⁹, M.R. Hoferkamp¹⁰³, J. Hoffman³⁹, D. Hoffmann⁸³, M. Hohlfeld⁸¹, M. Holder¹⁴¹, A. Holmes¹¹⁸, S.O. Holmgren^{146a}, T. Holy¹²⁷, J.L. Holzbauer⁸⁸, R.J. Homer¹⁷, Y. Homma⁶⁷, L. Hooft van Huysduynen¹⁰⁸, T. Horazdovsky¹²⁷, C. Horn¹⁴³, S. Horner⁴⁸, K. Horton¹¹⁸, J.-Y. Hostachy⁵⁵, T. Hott⁹⁹, S. Hou¹⁵¹, M.A. Houlden⁷³, A. Hoummada^{135a}, J. Howarth⁸², D.F. Howell¹¹⁸, I. Hristova⁴¹, J. Hrivnac¹¹⁵, I. Hruska¹²⁵, T. Hryn'ova⁴, P.J. Hsu¹⁷⁵, S.-C. Hsu¹⁴, G.S. Huang¹¹¹, Z. Hubacek¹²⁷, F. Hubaut⁸³, F. Huegging²⁰, T.B. Huffman¹¹⁸, E.W. Hughes³⁴, G. Hughes⁷¹, R.E. Hughes-Jones⁸², M. Huhtinen²⁹, P. Hurst⁵⁷, M. Hurwitz¹⁴, U. Husemann⁴¹, N. Huseynov^{65,o}, J. Huston⁸⁸, J. Huth⁵⁷, G. Iacobucci^{102a}, G. Iakovidis⁹, M. Ibbotson⁸², I. Ibragimov¹⁴¹, R. Ichimiya⁶⁷, L. Iconomidou-Fayard¹¹⁵, J. Idarraga¹¹⁵, M. Idzik³⁷, P. Iengo⁴, O. Igonkina¹⁰⁵, Y. Ikegami⁶⁶, M. Ikeno⁶⁶, Y. Ilchenko³⁹, D. Iliadis¹⁵⁴, D. Imbault⁷⁸, M. Imhaeuser¹⁷⁴, M. Imori¹⁵⁵, T. Ince²⁰, J. Inigo-Golfín²⁹, P. Ioannou⁸, M. Iodice^{134a}, G. Ionescu⁴, A. Irles Quiles¹⁶⁷, K. Ishii⁶⁶, A. Ishikawa⁶⁷, M. Ishino⁶⁶, R. Ishmukhametov³⁹, T. Isobe¹⁵⁵, C. Issever¹¹⁸, S. Istin^{18a}, Y. Itoh¹⁰¹, A.V. Ivashin¹²⁸, W. Iwanski³⁸, H. Iwasaki⁶⁶, J.M. Izen⁴⁰, V. Izzo^{102a}, B. Jackson¹²⁰, J.N. Jackson⁷³, P. Jackson¹⁴³, M.R. Jaekel²⁹, V. Jain⁶¹, K. Jakobs⁴⁸, S. Jakobsen³⁵, J. Jakubek¹²⁷, D.K. Jana¹¹¹, E. Jankowski¹⁵⁸, E. Jansen⁷⁷, A. Jantsch⁹⁹, M. Janus²⁰, G. Jarlskog⁷⁹, L. Jeanty⁵⁷, K. Jelen³⁷, I. Jen-La Plante³⁰, P. Jenni²⁹, A. Jeremie⁴, P. Jež³⁵, S. Jézéquel⁴, H. Ji¹⁷², W. Ji⁸¹, J. Jia¹⁴⁸, Y. Jiang^{32b}, M. Jimenez Belenguer²⁹, G. Jin^{32b}, S. Jin^{32a}, O. Jinnouchi¹⁵⁷, M.D. Joergensen³⁵, D. Joffe³⁹, L.G. Johansen¹³, M. Johansen^{146a,146b}, K.E. Johansson^{146a}, P. Johansson¹³⁹, S. Johnert⁴¹, K.A. Johns⁶, K. Jon-And^{146a,146b}, G. Jones⁸², R.W.L. Jones⁷¹, T.W. Jones⁷⁷, T.J. Jones⁷³, O. Jonsson²⁹, C. Joram²⁹, P.M. Jorge^{124a,b}, J. Joseph¹⁴, X. Ju¹³⁰, V. Juranek¹²⁵, P. Jussel⁶², V.V. Kabachenko¹²⁸, S. Kabana¹⁶, M. Kaci¹⁶⁷, A. Kaczmarska³⁸, P. Kadlecik³⁵, M. Kado¹¹⁵, H. Kagan¹⁰⁹, M. Kagan⁵⁷, S. Kaiser⁹⁹, E. Kajomovitz¹⁵², S. Kalinin¹⁷⁴, L.V. Kalinovskaya⁶⁵, S. Kama³⁹, N. Kanaya¹⁵⁵, M. Kaneda¹⁵⁵, T. Kanno¹⁵⁷, V.A. Kantserov⁹⁶, J. Kanzaki⁶⁶, B. Kaplan¹⁷⁵, A. Kapliy³⁰, J. Kaplon²⁹, D. Kar⁴³, M. Karagoz¹¹⁸, M. Karnevskiy⁴¹, K. Karr⁵, V. Kartvelishvili⁷¹, A.N. Karyukhin¹²⁸, L. Kashif⁵⁷, A. Kasmi³⁹, R.D. Kass¹⁰⁹, A. Kastanas¹³, M. Kataoka⁴, Y. Kataoka¹⁵⁵, E. Katsoufis⁹, J. Katzy⁴¹, V. Kaushik⁶, K. Kawagoe⁶⁷, T. Kawamoto¹⁵⁵, G. Kawamura⁸¹, M.S. Kayl¹⁰⁵, V.A. Kazanin¹⁰⁷, M.Y. Kazarinov⁶⁵, S.I. Kazi⁸⁶, J.R. Keates⁸², R. Keeler¹⁶⁹, R. Kehoe³⁹, M. Keil⁵⁴, G.D. Kekelidze⁶⁵, M. Kelly⁸², J. Kennedy⁹⁸, C.J. Kenney¹⁴³, M. Kenyon⁵³, O. Kepka¹²⁵, N. Kerschen²⁹, B.P. Kerševan⁷⁴, S. Kersten¹⁷⁴, K. Kessoku¹⁵⁵, C. Ketterer⁴⁸, M. Khakzad²⁸, F. Khalil-zada¹⁰, H. Khandanyan¹⁶⁵, A. Khanov¹¹², D. Kharchenko⁶⁵, A. Khodinov¹⁴⁸, A.G. Kholodenko¹²⁸, A. Khomich^{58a}, T.J. Khoo²⁷, G. Khorauli²⁰, N. Khovanskiy⁶⁵, V. Khovanskiy⁹⁵, E. Khramov⁶⁵, J. Khubua⁵¹, G. Kilvington⁷⁶,

H. Kim⁷, M.S. Kim², P.C. Kim¹⁴³, S.H. Kim¹⁶⁰, N. Kimura¹⁷⁰, O. Kind¹⁵, B.T. King⁷³, M. King⁶⁷, R.S.B. King¹¹⁸, J. Kirk¹²⁹, G.P. Kirsch¹¹⁸, L.E. Kirsch²², A.E. Kiryunin⁹⁹, D. Kisielewska³⁷, T. Kittelmann¹²³, A.M. Kiver¹²⁸, H. Kiyamura⁶⁷, E. Kladiva^{144b}, J. Klaiber-Lodewigs⁴², M. Klein⁷³, U. Klein⁷³, K. Kleinknecht⁸¹, M. Klemetti⁸⁵, A. Klier¹⁷¹, A. Klimentov²⁴, R. Klingenberg⁴², E.B. Klinkby³⁵, T. Klioutchnikova²⁹, P.F. Klok¹⁰⁴, S. Klous¹⁰⁵, E.-E. Kluge^{58a}, T. Kluge⁷³, P. Kluit¹⁰⁵, S. Kluth⁹⁹, E. Kneringer⁶², J. Knobloch²⁹, A. Knue⁵⁴, B.R. Ko⁴⁴, T. Kobayashi¹⁵⁵, M. Kobel⁴³, B. Koblitz²⁹, M. Kocian¹⁴³, A. Kocnar¹¹³, P. Kodys¹²⁶, K. Köneke²⁹, A.C. König¹⁰⁴, S. Koenig⁸¹, S. König⁴⁸, L. Köpke⁸¹, F. Koetsveld¹⁰⁴, P. Koevesarki²⁰, T. Koffas²⁹, E. Koffeman¹⁰⁵, F. Kohn⁵⁴, Z. Kohout¹²⁷, T. Kohriki⁶⁶, T. Koi¹⁴³, T. Kokott²⁰, G.M. Kolachev¹⁰⁷, H. Kolanoski¹⁵, V. Kolesnikov⁶⁵, I. Koletsou^{89a}, J. Koll⁸⁸, D. Kollar²⁹, M. Kollefrath⁴⁸, S.D. Kolya⁸², A.A. Komar⁹⁴, J.R. Komaragiri¹⁴², T. Kondo⁶⁶, T. Kono^{41,p}, A.I. Kononov⁴⁸, R. Konoplich^{108,q}, N. Konstantinidis⁷⁷, A. Kootz¹⁷⁴, S. Koperny³⁷, S.V. Kopikov¹²⁸, K. Korcyl³⁸, K. Kordas¹⁵⁴, V. Koreshev¹²⁸, A. Korn¹⁴, A. Korol¹⁰⁷, I. Korolkov¹¹, E.V. Korolkova¹³⁹, V.A. Korotkov¹²⁸, O. Kortner⁹⁹, S. Kortner⁹⁹, V.V. Kostyukhin²⁰, M.J. Kotamäki²⁹, S. Kotov⁹⁹, V.M. Kotov⁶⁵, C. Kourkoumelis⁸, V. Kouskoura¹⁵⁴, A. Koutsman¹⁰⁵, R. Kowalewski¹⁶⁹, T.Z. Kowalski³⁷, W. Kozanecki¹³⁶, A.S. Kozhin¹²⁸, V. Kral¹²⁷, V.A. Kramarenko⁹⁷, G. Kramberger⁷⁴, O. Krasel⁴², M.W. Krasny⁷⁸, A. Krasznahorkay¹⁰⁸, J. Kraus⁸⁸, A. Kreisel¹⁵³, F. Krejci¹²⁷, J. Kretschmar⁷³, N. Krieger⁵⁴, P. Krieger¹⁵⁸, K. Kroeninger⁵⁴, H. Kroha⁹⁹, J. Kroll¹²⁰, J. Kroseberg²⁰, J. Krstic^{12a}, U. Kruchonak⁶⁵, H. Krüger²⁰, Z.V. Krumshteyn⁶⁵, A. Kruth²⁰, T. Kubota¹⁵⁵, S. Kuehn⁴⁸, A. Kugel^{58c}, T. Kuhl¹⁷⁴, D. Kuhn⁶², V. Kukhtin⁶⁵, Y. Kulchitsky⁹⁰, S. Kuleshov^{31b}, C. Kummer⁹⁸, M. Kuna⁸³, N. Kundu¹¹⁸, J. Kunkle¹²⁰, A. Kupco¹²⁵, H. Kurashige⁶⁷, M. Kurata¹⁶⁰, Y.A. Kurochkin⁹⁰, V. Kus¹²⁵, W. Kuykendall¹³⁸, M. Kuze¹⁵⁷, P. Kuzhir⁹¹, O. Kvasnicka¹²⁵, R. Kwee¹⁵, A. La Rosa²⁹, L. La Rotonda^{36a,36b}, L. Labarga⁸⁰, J. Labbe⁴, C. Lacasta¹⁶⁷, F. Lacava^{132a,132b}, H. Lacker¹⁵, D. Lacour⁷⁸, V.R. Lacuesta¹⁶⁷, E. Ladygin⁶⁵, R. Lafaye⁴, B. Laforge⁷⁸, T. Lagouri⁸⁰, S. Lai⁴⁸, E. Laisne⁵⁵, M. Lamanna²⁹, C.L. Lampen⁶, W. Lampl⁶, E. Lancon¹³⁶, U. Landgraf⁴⁸, M.P.J. Landon⁷⁵, H. Landsman¹⁵², J.L. Lane⁸², C. Lange⁴¹, A.J. Lankford¹⁶³, F. Lanni²⁴, K. Lantzsck²⁹, V.V. Lapin^{128,*}, S. Laplace⁷⁸, C. Lapoire²⁰, J.F. Laporte¹³⁶, T. Lari^{89a}, A.V. Larionov¹²⁸, A. Larner¹¹⁸, C. Lasseur²⁹, M. Lassnig²⁹, W. Lau¹¹⁸, P. Laurelli⁴⁷, A. Lavorato¹¹⁸, W. Lavrijsen¹⁴, P. Laycock⁷³, A.B. Lazarev⁶⁵, A. Lazzaro^{89a,89b}, O. Le Dortz⁷⁸, E. Le Guirriec⁸³, C. Le Maner¹⁵⁸, E. Le Menedeu¹³⁶, M. Leahu²⁹, A. Lebedev⁶⁴, C. Lebel⁹³, T. LeCompte⁵, F. Ledroit-Guillon⁵⁵, H. Lee¹⁰⁵, J.S.H. Lee¹⁵⁰, S.C. Lee¹⁵¹, L. Lee¹⁷⁵, M. Lefebvre¹⁶⁹, M. Legendre¹³⁶, A. Leger⁴⁹, B.C. LeGeyt¹²⁰, F. Legger⁹⁸, C. Leggett¹⁴, M. Lehmacher²⁰, G. Lehmann Miotto²⁹, M. Lehto¹³⁹, X. Lei⁶, M.A.L. Leite^{23b}, R. Leitner¹²⁶, D. Lellouch¹⁷¹, J. Lellouch⁷⁸, M. Leltchouk³⁴, V. Lendermann^{58a}, K.J.C. Leney^{145b}, T. Lenz¹⁷⁴, G. Lenzen¹⁷⁴, B. Lenzi¹³⁶, K. Leonhardt⁴³, S. Leontsinis⁹, C. Leroy⁹³, J.-R. Lessard¹⁶⁹, J. Lesser^{146a}, C.G. Lester²⁷, A. Leung Fook Cheong¹⁷², J. Levêque⁸³, D. Levin⁸⁷, L.J. Levinson¹⁷¹, M.S. Levitski¹²⁸, M. Lewandowska²¹, G.H. Lewis¹⁰⁸, M. Leyton¹⁵, B. Li⁸³, H. Li¹⁷², S. Li^{32b}, X. Li⁸⁷, Z. Liang³⁹, Z. Liang^{118,r}, B. Liberti^{133a}, P. Lichard²⁹, M. Lichtnecker⁹⁸, K. Lie¹⁶⁵, W. Liebig¹³, R. Lifshitz¹⁵², J.N. Lilley¹⁷, A. Limosani⁸⁶, M. Limper⁶³, S.C. Lin^{151,s}, F. Linde¹⁰⁵, J.T. Linnemann⁸⁸, E. Lipeles¹²⁰, L. Lipinsky¹²⁵, A. Lipniacka¹³, T.M. Liss¹⁶⁵, A. Lister⁴⁹, A.M. Litke¹³⁷, C. Liu²⁸, D. Liu^{151,t}, H. Liu⁸⁷, J.B. Liu⁸⁷, M. Liu^{32b}, S. Liu², Y. Liu^{32b}, M. Livan^{119a,119b}, S.S.A. Livermore¹¹⁸, A. Lleres⁵⁵, S.L. Lloyd⁷⁵, E. Lobodzinska⁴¹, P. Loch⁶, W.S. Lockman¹³⁷, S. Lockwitz¹⁷⁵, T. Loddenkoetter²⁰, F.K. Loebinger⁸², A. Loginov¹⁷⁵, C.W. Loh¹⁶⁸, T. Lohse¹⁵, K. Lohwasser⁴⁸, M. Lokajicek¹²⁵, J. Loken¹¹⁸, V.P. Lombardo^{89a}, R.E. Long⁷¹, L. Lopes^{124a,b}, D. Lopez Mateos^{34,m}, M. Losada¹⁶², P. Loscutoff¹⁴, F. Lo Sterzo^{132a,132b}, M.J. Losty^{159a}, X. Lou⁴⁰, A. Lounis¹¹⁵, K.F. Loureiro¹⁶², J. Love²¹, P.A. Love⁷¹, A.J. Lowe¹⁴³, F. Lu^{32a}, J. Lu², L. Lu³⁹, H.J. Lubatti¹³⁸, C. Luci^{132a,132b}, A. Lucotte⁵⁵, A. Ludwig⁴³, D. Ludwig⁴¹, I. Ludwig⁴⁸, J. Ludwig⁴⁸, F. Luehring⁶¹, G. Luijckx¹⁰⁵, D. Lumb⁴⁸, L. Luminari^{132a}, E. Lund¹¹⁷, B. Lund-Jensen¹⁴⁷, B. Lundberg⁷⁹, J. Lundberg^{146a,146b}, J. Lundquist³⁵, M. Lungwitz⁸¹, A. Lupi^{122a,122b}, G. Lutz⁹⁹, D. Lynn²⁴, J. Lys¹⁴, E. Lytken⁷⁹, H. Ma²⁴, L.L. Ma¹⁷², J.A. Macana Goia⁹³, G. Maccarrone⁴⁷, A. Macchiolo⁹⁹, B. Maček⁷⁴, J. Machado Miguens^{124a,b}, D. Macina⁴⁹, R. Mackeprang³⁵, R.J. Madaras¹⁴, W.F. Mader⁴³, R. Maenner^{58c}, T. Maeno²⁴, P. Mättig¹⁷⁴, S. Mättig⁴¹, P.J. Magalhaes Martins^{124a,f}, L. Magnoni²⁹, E. Magradze⁵¹, C.A. Magrath¹⁰⁴, Y. Mahalalel¹⁵³, K. Mahboubi⁴⁸, G. Mahout¹⁷, C. Maiani^{132a,132b}, C. Maidantchik^{23a}, A. Maio^{124a,l}, S. Majewski²⁴, Y. Makida⁶⁶, N. Makovec¹¹⁵, P. Mal⁶, Pa. Malecki³⁸, P. Malecki³⁸, V.P. Maleev¹²¹, F. Malek⁵⁵, U. Mallik⁶³, D. Malon⁵, S. Maltezos⁹,

V. Malyshev¹⁰⁷, S. Malyukov⁶⁵, R. Mameghani⁹⁸, J. Mamuzic^{12b}, A. Manabe⁶⁶, L. Mandelli^{89a}, I. Mandić⁷⁴, R. Mandrysch¹⁵, J. Maneira^{124a}, P.S. Mangedard⁸⁸, I.D. Manjavidze⁶⁵, A. Mann⁵⁴, P.M. Manning¹³⁷, A. Manousakis-Katsikakis⁸, B. Mansoulie¹³⁶, A. Manz⁹⁹, A. Mapelli²⁹, L. Mapelli²⁹, L. March⁸⁰, J.F. Marchand²⁹, F. Marchese^{133a,133b}, M. Marchesotti²⁹, G. Marchiori⁷⁸, M. Marcisovsky¹²⁵, A. Marin^{21,*}, C.P. Marino⁶¹, F. Marroquim^{23a}, R. Marshall⁸², Z. Marshall^{34,m}, F.K. Martens¹⁵⁸, S. Marti-Garcia¹⁶⁷, A.J. Martin¹⁷⁵, B. Martin²⁹, B. Martin⁸⁸, F.F. Martin¹²⁰, J.P. Martin⁹³, Ph. Martin⁵⁵, T.A. Martin¹⁷, B. Martin dit Latour⁴⁹, M. Martinez¹¹, V. Martinez Outschoorn⁵⁷, A.C. Martyniuk⁸², M. Marx⁸², F. Marzano^{132a}, A. Marzin¹¹¹, L. Masetti⁸¹, T. Mashimo¹⁵⁵, R. Mashinistov⁹⁴, J. Masik⁸², A.L. Maslennikov¹⁰⁷, M. Maß⁴², I. Massa^{19a,19b}, G. Massaro¹⁰⁵, N. Massol⁴, A. Mastroberardino^{36a,36b}, T. Masubuchi¹⁵⁵, M. Mathes²⁰, P. Matricon¹¹⁵, H. Matsumoto¹⁵⁵, H. Matsunaga¹⁵⁵, T. Matsushita⁶⁷, C. Mattravers^{118,u}, J.M. Maugain²⁹, S.J. Maxfield⁷³, E.N. May⁵, A. Mayne¹³⁹, R. Mazini¹⁵¹, M. Mazur²⁰, M. Mazzanti^{89a}, E. Mazzoni^{122a,122b}, S.P. Mc Kee⁸⁷, A. McCarn¹⁶⁵, R.L. McCarthy¹⁴⁸, T.G. McCarthy²⁸, N.A. McCubbin¹²⁹, K.W. McFarlane⁵⁶, J.A. McFayden¹³⁹, H. McGlone⁵³, G. Mchedlidze⁵¹, R.A. McLaren²⁹, T. McLaughlan¹⁷, S.J. McMahon¹²⁹, T.J. McMahon¹⁷, R.A. McPherson^{169,h}, A. Meade⁸⁴, J. Mechnich¹⁰⁵, M. Mechtel¹⁷⁴, M. Medinnis⁴¹, R. Meera-Lebbai¹¹¹, T. Meguro¹¹⁶, R. Mehdiyev⁹³, S. Mehlhase⁴¹, A. Mehta⁷³, K. Meier^{58a}, J. Meinhardt⁴⁸, B. Meirose⁷⁹, C. Melachrinou³⁰, B.R. Mellado Garcia¹⁷², L. Mendoza Navas¹⁶², Z. Meng^{151,t}, A. Mengarelli^{19a,19b}, S. Menke⁹⁹, C. Menot²⁹, E. Meoni¹¹, D. Merkl⁹⁸, P. Mermod¹¹⁸, L. Merola^{102a,102b}, C. Meroni^{89a}, F.S. Merritt³⁰, A. Messina²⁹, J. Metcalfe¹⁰³, A.S. Mete⁶⁴, S. Meuser²⁰, C. Meyer⁸¹, J.-P. Meyer¹³⁶, J. Meyer¹⁷³, J. Meyer⁵⁴, T.C. Meyer²⁹, W.T. Meyer⁶⁴, J. Miao^{32d}, S. Michal²⁹, L. Micu^{25a}, R.P. Middleton¹²⁹, P. Miele²⁹, S. Migas⁷³, L. Mijović⁴¹, G. Mikenberg¹⁷¹, M. Mikesikova¹²⁵, B. Mikulec⁴⁹, M. Mikuž⁷⁴, D.W. Miller¹⁴³, R.J. Miller⁸⁸, W.J. Mills¹⁶⁸, C. Mills⁵⁷, A. Milov¹⁷¹, D.A. Milstead^{146a,146b}, D. Milstein¹⁷¹, A.A. Minaenko¹²⁸, M. Miñano¹⁶⁷, I.A. Minashvili⁶⁵, A.I. Mincer¹⁰⁸, B. Mindur³⁷, M. Mineev⁶⁵, Y. Ming¹³⁰, L.M. Mir¹¹, G. Mirabelli^{132a}, L. Miralles Verge¹¹, A. Misiejuk⁷⁶, A. Mitra¹¹⁸, J. Mitrevski¹³⁷, G.Y. Mitrofanov¹²⁸, V.A. Mitsou¹⁶⁷, S. Mitsui⁶⁶, P.S. Miyagawa⁸², K. Miyazaki⁶⁷, J.U. Mjörnmark⁷⁹, T. Moa^{146a,146b}, P. Mockett¹³⁸, S. Moed⁵⁷, V. Moeller²⁷, K. Mönig⁴¹, N. Möser²⁰, S. Mohapatra¹⁴⁸, B. Mohn¹³, W. Mohr⁴⁸, S. Mohr dieck-Möck⁹⁹, A.M. Moiseev^{128,*}, R. Moles-Valls¹⁶⁷, J. Molina-Perez²⁹, L. Moneta⁴⁹, J. Monk⁷⁷, E. Monnier⁸³, S. Montesano^{89a,89b}, F. Monticelli⁷⁰, S. Monzani^{19a,19b}, R.W. Moore², G.F. Moorhead⁸⁶, C. Mora Herrera⁴⁹, A. Moraes⁵³, A. Morais^{124a,b}, N. Morange¹³⁶, J. Morel⁵⁴, G. Morello^{36a,36b}, D. Moreno⁸¹, M. Moreno Llacer¹⁶⁷, P. Morettini^{50a}, M. Morii⁵⁷, J. Morin⁷⁵, Y. Morita⁶⁶, A.K. Morley²⁹, G. Mornacchi²⁹, M.-C. Morone⁴⁹, J.D. Morris⁷⁵, H.G. Moser⁹⁹, M. Mosidze⁵¹, J. Moss¹⁰⁹, R. Mount¹⁴³, E. Mountricha⁹, S.V. Mouraviev⁹⁴, E.J.W. Moyse⁸⁴, M. Mudrinic^{12b}, F. Mueller^{58a}, J. Mueller¹²³, K. Mueller²⁰, T.A. Müller⁹⁸, D. Muenstermann⁴², A. Muijs¹⁰⁵, A. Muir¹⁶⁸, Y. Munwes¹⁵³, K. Murakami⁶⁶, W.J. Murray¹²⁹, I. Mussche¹⁰⁵, E. Musto^{102a,102b}, A.G. Myagkov¹²⁸, M. Myska¹²⁵, J. Nadal¹¹, K. Nagai¹⁶⁰, K. Nagano⁶⁶, Y. Nagasaka⁶⁰, A.M. Nairz²⁹, Y. Nakahama¹¹⁵, K. Nakamura¹⁵⁵, I. Nakano¹¹⁰, G. Nanava²⁰, A. Napier¹⁶¹, M. Nash^{77,u}, N.R. Nation²¹, T. Nattermann²⁰, T. Naumann⁴¹, G. Navarro¹⁶², H.A. Neal⁸⁷, E. Nebot⁸⁰, P.Yu. Nechaeva⁹⁴, A. Negri^{119a,119b}, G. Negri²⁹, S. Nektarijevic⁴⁹, A. Nelson⁶⁴, S. Nelson¹⁴³, T.K. Nelson¹⁴³, S. Nemecek¹²⁵, P. Nemethy¹⁰⁸, A.A. Nepomuceno^{23a}, M. Nessi²⁹, S.Y. Nesterov¹²¹, M.S. Neubauer¹⁶⁵, A. Neusiedl⁸¹, R.M. Neves¹⁰⁸, P. Nevski²⁴, P.R. Newman¹⁷, R.B. Nickerson¹¹⁸, R. Nicolaidou¹³⁶, L. Nicolas¹³⁹, B. Nicquevert²⁹, F. Niedercorn¹¹⁵, J. Nielsen¹³⁷, T. Niinikoski²⁹, A. Nikiforov¹⁵, V. Nikolaenko¹²⁸, K. Nikolaev⁶⁵, I. Nikolic-Audit⁷⁸, K. Nikolopoulos²⁴, H. Nilsen⁴⁸, P. Nilsson⁷, Y. Ninomiya¹⁵⁵, A. Nisati^{132a}, T. Nishiyama⁶⁷, R. Nisius⁹⁹, L. Nodulman⁵, M. Nomachi¹¹⁶, I. Nomidis¹⁵⁴, H. Nomoto¹⁵⁵, M. Nordberg²⁹, B. Nordkvist^{146a,146b}, P.R. Norton¹²⁹, J. Novakova¹²⁶, M. Nozaki⁶⁶, M. Nožička⁴¹, I.M. Nugent^{159a}, A.-E. Nuncio-Quiroz²⁰, G. Nunes Hanninger²⁰, T. Nunnemann⁹⁸, E. Nurse⁷⁷, T. Nyman²⁹, B.J. O'Brien⁴⁵, S.W. O'Neale^{17,*}, D.C. O'Neil¹⁴², V. O'Shea⁵³, F.G. Oakham^{28,d}, H. Oberlack⁹⁹, J. Ocariz⁷⁸, A. Ochi⁶⁷, S. Oda¹⁵⁵, S. Odaka⁶⁶, J. Odier⁸³, G.A. Odino^{50a,50b}, H. Ogren⁶¹, A. Oh⁸², S.H. Oh⁴⁴, C.C. Ohm^{146a,146b}, T. Ohshima¹⁰¹, H. Ohshita¹⁴⁰, T.K. Ohsaka⁶⁶, T. Ohsugi⁵⁹, S. Okada⁶⁷, H. Okawa¹⁶³, Y. Okumura¹⁰¹, T. Okuyama¹⁵⁵, M. Olcese^{50a}, A.G. Olchevski⁶⁵, M. Oliveira^{124a,f}, D. Oliveira Damazio²⁴, E. Oliver Garcia¹⁶⁷, D. Olivito¹²⁰, A. Olszewski³⁸, J. Olszowska³⁸, C. Omachi⁶⁷, A. Onofre^{124a,v}, P.U.E. Onyisi³⁰, C.J. Oram^{159a}, G. Ordóñez¹⁰⁴, M.J. Oreglia³⁰, F. Orellana⁴⁹, Y. Oren¹⁵³, D. Orestano^{134a,134b}, I. Orlov¹⁰⁷, C. Oropeza Barrera⁵³, R.S. Orr¹⁵⁸, E.O. Ortega¹³⁰, B. Osculati^{50a,50b},

R. Ospanov¹²⁰, C. Osuna¹¹, G. Otero y Garzon²⁶, J.P. Ottersbach¹⁰⁵, M. Ouchrif^{135c}, F. Ould-Saada¹¹⁷, A. Ouraou¹³⁶, Q. Ouyang^{32a}, M. Owen⁸², S. Owen¹³⁹, A. Oyarzun^{31b}, O.K. Øye¹³, V.E. Ozcan⁷⁷, N. Ozturk⁷, A. Pacheco Pages¹¹, C. Padilla Aranda¹¹, E. Paganis¹³⁹, F. Paige²⁴, K. Pajchel¹¹⁷, S. Palestini²⁹, D. Pallin³³, A. Palma^{124a,b}, J.D. Palmer¹⁷, Y.B. Pan¹⁷², E. Panagiotopoulou⁹, B. Panes^{31a}, N. Panikashvili⁸⁷, S. Panitkin²⁴, D. Pantea^{25a}, M. Panuskova¹²⁵, V. Paolone¹²³, A. Paoloni^{133a,133b}, A. Papadelis^{146a}, Th.D. Papadopoulou⁹, A. Paramonov⁵, W. Park^{24,w}, M.A. Parker²⁷, F. Parodi^{50a,50b}, J.A. Parsons³⁴, U. Parzefall⁴⁸, E. Pasqualucci^{132a}, A. Passeri^{134a}, F. Pastore^{134a,134b}, Fr. Pastore²⁹, G. Pásztor^{49,x}, S. Pataraiia¹⁷², N. Patel¹⁵⁰, J.R. Pater⁸², S. Patricelli^{102a,102b}, T. Pauly²⁹, M. Pecsny^{144a}, M.I. Pedraza Morales¹⁷², S.V. Peleganchuk¹⁰⁷, H. Peng¹⁷², R. Pengo²⁹, A. Penson³⁴, J. Penwell⁶¹, M. Perantoni^{23a}, K. Perez^{34,m}, T. Perez Cavalcanti⁴¹, E. Perez Codina¹¹, M.T. Pérez García-Estañ¹⁶⁷, V. Perez Reale³⁴, I. Peric²⁰, L. Perini^{89a,89b}, H. Pernegger²⁹, R. Perrino^{72a}, P. Perrodo⁴, S. Perseme^{3a}, A. Perus¹¹⁵, V.D. Peshekhonov⁶⁵, O. Peters¹⁰⁵, B.A. Petersen²⁹, J. Petersen²⁹, T.C. Petersen³⁵, E. Petit⁸³, A. Petridis¹⁵⁴, C. Petridou¹⁵⁴, E. Petrolo^{132a}, F. Petrucci^{134a,134b}, D. Petschull⁴¹, M. Petteni¹⁴², R. Pezoa^{31b}, A. Phan⁸⁶, A.W. Phillips²⁷, P.W. Phillips¹²⁹, G. Piacquadio²⁹, E. Piccaro⁷⁵, M. Piccinini^{19a,19b}, A. Pickford⁵³, S.M. Piec⁴¹, R. Piegaiia²⁶, J.E. Pilcher³⁰, A.D. Pilkington⁸², J. Pina^{124a,l}, M. Pinamonti^{164a,164c}, A. Pinder¹¹⁸, J.L. Pinfold², J. Ping^{32c}, B. Pinto^{124a,b}, O. Pirotte²⁹, C. Pizio^{89a,89b}, R. Placakyte⁴¹, M. Plamondon¹⁶⁹, W.G. Plano⁸², M.-A. Pleier²⁴, A.V. Pleskach¹²⁸, A. Poblaguev²⁴, S. Poddar^{58a}, F. Podlyski³³, L. Poggioli¹¹⁵, T. Poghosyan²⁰, M. Pohl⁴⁹, F. Polci⁵⁵, G. Polesello^{119a}, A. Policicchio¹³⁸, A. Polini^{19a}, J. Poll⁷⁵, V. Polychronakos²⁴, D.M. Pomarede¹³⁶, D. Pomeroy²², K. Pommès²⁹, L. Pontecorvo^{132a}, B.G. Pope⁸⁸, G.A. Popeneciu^{25a}, D.S. Popovic^{12a}, A. Poppleton²⁹, X. Portell Bueso⁴⁸, R. Porter¹⁶³, C. Posch²¹, G.E. Pospelov⁹⁹, S. Pospisil¹²⁷, I.N. Potrap⁹⁹, C.J. Potter¹⁴⁹, C.T. Potter⁸⁵, G. Poulard²⁹, J. Poveda¹⁷², R. Prabhu⁷⁷, P. Pralavorio⁸³, S. Prasad⁵⁷, R. Pravahan⁷, S. Prell⁶⁴, K. Pretzl¹⁶, L. Pribyl²⁹, D. Price⁶¹, L.E. Price⁵, M.J. Price²⁹, P.M. Prichard⁷³, D. Prieur¹²³, M. Primavera^{72a}, K. Prokofiev¹⁰⁸, F. Prokoshin^{31b}, S. Protopopescu²⁴, J. Proudfoot⁵, X. Prudent⁴³, H. Przysiezniak⁴, S. Psoroulas²⁰, E. Ptacek¹¹⁴, J. Purdham⁸⁷, M. Purohit^{24,w}, P. Puzo¹¹⁵, Y. Pylypchenko¹¹⁷, J. Qian⁸⁷, Z. Qian⁸³, Z. Qin⁴¹, A. Quadt⁵⁴, D.R. Quarrie¹⁴, W.B. Quayle¹⁷², F. Quinonez^{31a}, M. Raas¹⁰⁴, V. Radescu^{58b}, B. Radics²⁰, T. Rador^{18a}, F. Ragusa^{89a,89b}, G. Rahal¹⁷⁷, A.M. Rahimi¹⁰⁹, S. Rajagopalan²⁴, S. Rajek⁴², M. Rammensee⁴⁸, M. Rammes¹⁴¹, M. Ramstedt^{146a,146b}, K. Randrianarivony²⁸, P.N. Ratoff⁷¹, F. Rauscher⁹⁸, E. Rauter⁹⁹, M. Raymond²⁹, A.L. Read¹¹⁷, D.M. Rebuffi^{119a,119b}, A. Redelbach¹⁷³, G. Redlinger²⁴, R. Reece¹²⁰, K. Reeves⁴⁰, A. Reichold¹⁰⁵, E. Reinherz-Aronis¹⁵³, A. Reinsch¹¹⁴, I. Reisinger⁴², D. Reljic^{12a}, C. Rembser²⁹, Z.L. Ren¹⁵¹, A. Renaud¹¹⁵, P. Renkel³⁹, B. Rensch³⁵, M. Rescigno^{132a}, S. Resconi^{89a}, B. Resende¹³⁶, P. Reznicek⁹⁸, R. Rezvani¹⁵⁸, A. Richards⁷⁷, R. Richter⁹⁹, E. Richter-Was^{38,y}, M. Ridel⁷⁸, S. Rieke⁸¹, M. Rijpstra¹⁰⁵, M. Rijssenbeek¹⁴⁸, A. Rimoldi^{119a,119b}, L. Rinaldi^{19a}, R.R. Rios³⁹, I. Riu¹¹, G. Rivoltella^{89a,89b}, F. Rizatdinova¹¹², E. Rizvi⁷⁵, S.H. Robertson^{85,h}, A. Robichaud-Veronneau⁴⁹, D. Robinson²⁷, J.E.M. Robinson⁷⁷, M. Robinson¹¹⁴, A. Robson⁵³, J.G. Rocha de Lima¹⁰⁶, C. Roda^{122a,122b}, D. Roda Dos Santos²⁹, S. Rodier⁸⁰, D. Rodriguez¹⁶², Y. Rodriguez Garcia¹⁵, A. Roe⁵⁴, S. Roe²⁹, O. Røhne¹¹⁷, V. Rojo¹, S. Rolli¹⁶¹, A. Romaniouk⁹⁶, V.M. Romanov⁶⁵, G. Romeo²⁶, D. Romero Maltrana^{31a}, L. Roos⁷⁸, E. Ros¹⁶⁷, S. Rosati¹³⁸, M. Rose⁷⁶, G.A. Rosenbaum¹⁵⁸, E.I. Rosenberg⁶⁴, P.L. Rosendahl¹³, L. Rosselet⁴⁹, V. Rossetti¹¹, E. Rossi^{102a,102b}, L.P. Rossi^{50a}, L. Rossi^{89a,89b}, M. Rotaru^{25a}, I. Roth¹⁷¹, J. Rothberg¹³⁸, I. Rottländer²⁰, D. Rousseau¹¹⁵, C.R. Royon¹³⁶, A. Rozanov⁸³, Y. Rozen¹⁵², X. Ruan¹¹⁵, I. Rubinskiy⁴¹, B. Ruckert⁹⁸, N. Ruckstuhl¹⁰⁵, V.I. Rud⁹⁷, G. Rudolph⁶², F. Rühr⁶, A. Ruiz-Martinez⁶⁴, E. Rulikowska-Zarebska³⁷, V. Rumiantsev^{91,*}, L. Romyantsev⁶⁵, K. Runge⁴⁸, O. Runolfsson²⁰, Z. Rurikova⁴⁸, N.A. Rusakovich⁶⁵, D.R. Rust⁶¹, J.P. Rutherford⁶, C. Ruwiedel¹⁴, P. Ruzicka¹²⁵, Y.F. Ryabov¹²¹, V. Ryadovikov¹²⁸, P. Ryan⁸⁸, M. Rybar¹²⁶, G. Rybkin¹¹⁵, N.C. Ryder¹¹⁸, S. Rzaeva¹⁰, A.F. Saavedra¹⁵⁰, I. Sadeh¹⁵³, H.F.-W. Sadrozinski¹³⁷, R. Sadykov⁶⁵, F. Safai Tehrani^{132a,132b}, H. Sakamoto¹⁵⁵, G. Salamanna¹⁰⁵, A. Salamon^{133a}, M. Saleem¹¹¹, D. Salihagic⁹⁹, A. Salnikov¹⁴³, J. Salt¹⁶⁷, B.M. Salvachua Ferrando⁵, D. Salvatore^{36a,36b}, F. Salvatore¹⁴⁹, A. Salzburger²⁹, D. Sampsonidis¹⁵⁴, B.H. Samset¹¹⁷, H. Sandaker¹³, H.G. Sander⁸¹, M.P. Sanders⁹⁸, M. Sandhoff¹⁷⁴, P. Sandhu¹⁵⁸, T. Sandoval²⁷, R. Sandstroem¹⁰⁵, S. Sandvoss¹⁷⁴, D.P.C. Sankey¹²⁹, A. Sansoni⁴⁷, C. Santamarina Rios⁸⁵, C. Santoni³³,

R. Santonico^{133a,133b}, H. Santos^{124a}, J.G. Saraiva^{124a,l}, T. Sarangi¹⁷², E. Sarkisyan-Grinbaum⁷, F. Sarri^{122a,122b}, G. Sartisohn¹⁷⁴, O. Sasaki⁶⁶, T. Sasaki⁶⁶, N. Sasao⁶⁸, I. Satsounkevitch⁹⁰, G. Sauvage⁴, J.B. Sauvan¹¹⁵, P. Savard^{158,d}, V. Savinov¹²³, D.O. Savu²⁹, P. Savva⁹, L. Sawyer^{24,i}, D.H. Saxon⁵³, L.P. Says³³, C. Sbarra^{19a,19b}, A. Sbrizzi^{19a,19b}, O. Scallan⁹³, D.A. Scannicchio¹⁶³, J. Schaarschmidt¹¹⁵, P. Schacht⁹⁹, U. Schäfer⁸¹, S. Schaezel^{58b}, A.C. Schaffer¹¹⁵, D. Schaile⁹⁸, R.D. Schamberger¹⁴⁸, A.G. Schamov¹⁰⁷, V. Scharf^{58a}, V.A. Schegelsky¹²¹, D. Scheirich⁸⁷, M.I. Scherzer¹⁴, C. Schiavi^{50a,50b}, J. Schieck⁹⁸, M. Schioppa^{36a,36b}, S. Schlenker²⁹, J.L. Schlereth⁵, E. Schmidt⁴⁸, M.P. Schmidt^{175,*}, K. Schmieden²⁰, C. Schmitt⁸¹, M. Schmitz²⁰, A. Schöning^{58b}, M. Schott²⁹, D. Schouten¹⁴², J. Schovancova¹²⁵, M. Schram⁸⁵, C. Schroeder⁸¹, N. Schroer^{58c}, S. Schuh²⁹, G. Schuler²⁹, J. Schultes¹⁷⁴, H.-C. Schultz-Coulon^{58a}, H. Schulz¹⁵, J.W. Schumacher²⁰, M. Schumacher⁴⁸, B.A. Schumm¹³⁷, Ph. Schune¹³⁶, C. Schwanenberger⁸², A. Schwartzman¹⁴³, Ph. Schwemling⁷⁸, R. Schwienhorst⁸⁸, R. Schwierz⁴³, J. Schwindling¹³⁶, W.G. Scott¹²⁹, J. Searcy¹¹⁴, E. Sedykh¹²¹, E. Segura¹¹, S.C. Seidel¹⁰³, A. Seiden¹³⁷, F. Seifert⁴³, J.M. Seixas^{23a}, G. Sekhniadze^{102a}, D.M. Seliverstov¹²¹, B. Sellden^{146a}, G. Sellers⁷³, M. Seman^{144b}, N. Semprini-Cesari^{19a,19b}, C. Serfon⁹⁸, L. Serin¹¹⁵, R. Seuster⁹⁹, H. Severini¹¹¹, M.E. Sevier⁸⁶, A. Sfyrla²⁹, E. Shabalina⁵⁴, M. Shamim¹¹⁴, L.Y. Shan^{32a}, J.T. Shank²¹, Q.T. Shao⁸⁶, M. Shapiro¹⁴, P.B. Shatalov⁹⁵, L. Shaver⁶, C. Shaw⁵³, K. Shaw^{164a,164c}, D. Sherman¹⁷⁵, P. Sherwood⁷⁷, A. Shibata¹⁰⁸, S. Shimizu²⁹, M. Shimojima¹⁰⁰, T. Shin⁵⁶, A. Shmeleva⁹⁴, M.J. Shochet³⁰, D. Short¹¹⁸, M.A. Shupe⁶, P. Sicho¹²⁵, A. Sidoti¹⁵, A. Siebel¹⁷⁴, F. Siegert⁴⁸, J. Siegrist¹⁴, Dj. Sijacki^{12a}, O. Silbert¹⁷¹, J. Silva^{124a,z}, Y. Silver¹⁵³, D. Silverstein¹⁴³, S.B. Silverstein^{146a}, V. Simak¹²⁷, O. Simard¹³⁶, Lj. Simic^{12a}, S. Simion¹¹⁵, B. Simmons⁷⁷, M. Simonyan³⁵, P. Sinervo¹⁵⁸, N.B. Sinev¹¹⁴, V. Sipica¹⁴¹, G. Siragusa⁸¹, A.N. Sisakyan⁶⁵, S.Yu. Sivoklokov⁹⁷, J. Sjölin^{146a,146b}, T.B. Sjurson¹³, L.A. Skinnari¹⁴, K. Skovpen¹⁰⁷, P. Skubic¹¹¹, N. Skvorodnev²², M. Slater¹⁷, T. Slavicek¹²⁷, K. Sliwa¹⁶¹, T.J. Sloan⁷¹, J. Sloper²⁹, V. Smakhtin¹⁷¹, S.Yu. Smirnov⁹⁶, L.N. Smirnova⁹⁷, O. Smirnova⁷⁹, B.C. Smith⁵⁷, D. Smith¹⁴³, K.M. Smith⁵³, M. Smizanska⁷¹, K. Smolek¹²⁷, A.A. Snesarev⁹⁴, S.W. Snow⁸², J. Snow¹¹¹, J. Snuverink¹⁰⁵, S. Snyder²⁴, M. Soares^{124a}, R. Sobie^{169,h}, J. Sodomka¹²⁷, A. Soffer¹⁵³, C.A. Solans¹⁶⁷, M. Solar¹²⁷, J. Solc¹²⁷, U. Soldevila¹⁶⁷, E. Solfaroli Camillocci^{132a,132b}, A.A. Solodkov¹²⁸, O.V. Solovyanov¹²⁸, J. Sondericker²⁴, N. Soni², V. Sopko¹²⁷, B. Sopko¹²⁷, M. Sorbi^{89a,89b}, M. Sosebee⁷, A. Soukharev¹⁰⁷, S. Spagnolo^{72a,72b}, F. Spanò³⁴, R. Spighi^{19a}, G. Spigo²⁹, F. Spila^{132a,132b}, E. Spiriti^{134a}, R. Spiwoks²⁹, M. Spousta¹²⁶, T. Spreitzer¹⁵⁸, B. Spurlock⁷, R.D.St. Denis⁵³, T. Stahl¹⁴¹, J. Stahlman¹²⁰, R. Stamen^{58a}, E. Stanecka²⁹, R.W. Stanek⁵, C. Stanescu^{134a}, S. Stapnes¹¹⁷, E.A. Starchenko¹²⁸, J. Stark⁵⁵, P. Staroba¹²⁵, P. Starovoitov⁹¹, A. Staude⁹⁸, P. Stavina^{144a}, G. Stavropoulos¹⁴, G. Steele⁵³, P. Steinbach⁴³, P. Steinberg²⁴, I. Stekl¹²⁷, B. Stelzer¹⁴², H.J. Stelzer⁴¹, O. Stelzer-Chilton^{159a}, H. Stenzel⁵², K. Stevenson⁷⁵, G.A. Stewart⁵³, J.A. Stillings²⁰, T. Stockmanns²⁰, M.C. Stockton²⁹, K. Stoerig⁴⁸, G. Stoicea^{25a}, S. Stonjek⁹⁹, P. Strachota¹²⁶, A.R. Stradling⁷, A. Straessner⁴³, J. Strandberg⁸⁷, S. Strandberg^{146a,146b}, A. Strandlie¹¹⁷, M. Strang¹⁰⁹, E. Strauss¹⁴³, M. Strauss¹¹¹, P. Strizenec^{144b}, R. Ströhmer¹⁷³, D.M. Strom¹¹⁴, J.A. Strong^{76,*}, R. Stroynowski³⁹, J. Strube¹²⁹, B. Stugu¹³, I. Stumer^{24,*}, J. Stupak¹⁴⁸, P. Sturm¹⁷⁴, D.A. Soh^{151,r}, D. Su¹⁴³, S. Subramania², Y. Sugaya¹¹⁶, T. Sugimoto¹⁰¹, C. Suhr¹⁰⁶, K. Suita⁶⁷, M. Suk¹²⁶, V.V. Sulin⁹⁴, S. Sultansoy^{3d}, T. Sumida²⁹, X. Sun⁵⁵, J.E. Sundermann⁴⁸, K. Suruliz^{164a,164b}, S. Sushkov¹¹, G. Susinno^{36a,36b}, M.R. Sutton¹³⁹, Y. Suzuki⁶⁶, Yu.M. Sviridov¹²⁸, S. Swedish¹⁶⁸, I. Sykora^{144a}, T. Sykora¹²⁶, B. Szeless²⁹, J. Sánchez¹⁶⁷, D. Ta¹⁰⁵, K. Tackmann²⁹, A. Taffard¹⁶³, R. Tafirout^{159a}, A. Taga¹¹⁷, N. Taiblum¹⁵³, Y. Takahashi¹⁰¹, H. Takai²⁴, R. Takashima⁶⁹, H. Takeda⁶⁷, T. Takeshita¹⁴⁰, M. Talby⁸³, A. Talyshv¹⁰⁷, M.C. Tamsett²⁴, J. Tanaka¹⁵⁵, R. Tanaka¹¹⁵, S. Tanaka¹³¹, S. Tanaka⁶⁶, Y. Tanaka¹⁰⁰, K. Tani⁶⁷, N. Tannoury⁸³, G.P. Tappern²⁹, S. Tapprogge⁸¹, D. Tardif¹⁵⁸, S. Tarem¹⁵², F. Tarrade²⁴, G.F. Tartarelli^{89a}, P. Tas¹²⁶, M. Tasevsky¹²⁵, E. Tassi^{36a,36b}, M. Tatarkhanov¹⁴, C. Taylor⁷⁷, F.E. Taylor⁹², G. Taylor¹³⁷, G.N. Taylor⁸⁶, W. Taylor^{159b}, M. Teixeira Dias Castanheira⁷⁵, P. Teixeira-Dias⁷⁶, K.K. Temming⁴⁸, H. Ten Kate²⁹, P.K. Teng¹⁵¹, Y.D. Tennenbaum-Katan¹⁵², S. Terada⁶⁶, K. Terashi¹⁵⁵, J. Terron⁸⁰, M. Terwort^{41,p}, M. Testa⁴⁷, R.J. Teuscher^{158,h}, C.M. Tevlin⁸², J. Thadome¹⁷⁴, J. Therhaag²⁰, T. Theveneaux-Pelzer⁷⁸, M. Thioye¹⁷⁵, S. Thoma⁴⁸, J.P. Thomas¹⁷, E.N. Thompson⁸⁴, P.D. Thompson¹⁷, P.D. Thompson¹⁵⁸, A.S. Thompson⁵³, E. Thomson¹²⁰, M. Thomson²⁷, R.P. Thun⁸⁷, T. Tic¹²⁵, V.O. Tikhomirov⁹⁴, Y.A. Tikhonov¹⁰⁷, C.J.W.P. Timmermans¹⁰⁴, P. Tipton¹⁷⁵, F.J. Tique Aires Viegas²⁹, S. Tisserant⁸³, J. Tobias⁴⁸, B. Toczec³⁷

T. Todorov⁴, S. Todorova-Nova¹⁶¹, B. Toggerson¹⁶³, J. Tojo⁶⁶, S. Tokár^{144a}, K. Tokunaga⁶⁷,
 K. Tokushuku⁶⁶, K. Tollefson⁸⁸, M. Tomoto¹⁰¹, L. Tompkins¹⁴, K. Toms¹⁰³, A. Tonazzo^{134a,134b},
 G. Tong^{32a}, A. Tonoyan¹³, C. Topfel¹⁶, N.D. Topilin⁶⁵, I. Torchiani²⁹, E. Torrence¹¹⁴, E. Torró Pastor¹⁶⁷,
 J. Toth^{83,x}, F. Touchard⁸³, D.R. Tovey¹³⁹, D. Traynor⁷⁵, T. Trefzger¹⁷³, J. Treis²⁰, L. Tremblet²⁹,
 A. Tricoli²⁹, I.M. Trigger^{159a}, S. Trincaz-Duvoid⁷⁸, T.N. Trinh⁷⁸, M.F. Tripiana⁷⁰, N. Triplett⁶⁴,
 W. Trischuk¹⁵⁸, A. Trivedi^{24,w}, B. Trocmé⁵⁵, C. Troncon^{89a}, M. Trottier-McDonald¹⁴², A. Trzupek³⁸,
 C. Tsarouchas²⁹, J.C.-L. Tseng¹¹⁸, M. Tsiakiris¹⁰⁵, P.V. Tsiarehka⁹⁰, D. Tsionou⁴, G. Tsipolitis⁹,
 V. Tsiskaridze⁴⁸, E.G. Tskhadadze⁵¹, I.I. Tsukerman⁹⁵, V. Tsulaia¹²³, J.-W. Tsung²⁰, S. Tsuno⁶⁶,
 D. Tsybychev¹⁴⁸, A. Tua¹³⁹, J.M. Tuggle³⁰, M. Turala³⁸, D. Turecek¹²⁷, I. Turk Cakir^{3e}, E. Turlay¹⁰⁵,
 P.M. Tuts³⁴, A. Tykhonov⁷⁴, M. Tylmad^{146a,146b}, M. Tyndel¹²⁹, D. Typaldos¹⁷, H. Tyrvalinen²⁹,
 G. Tzanakos⁸, K. Uchida²⁰, I. Ueda¹⁵⁵, R. Ueno²⁸, M. Ugland¹³, M. Uhlenbrock²⁰, M. Uhrmacher⁵⁴,
 F. Ukegawa¹⁶⁰, G. Unal²⁹, D.G. Underwood⁵, A. Undrus²⁴, G. Unel¹⁶³, Y. Unno⁶⁶, D. Urbaniec³⁴,
 E. Urkovsky¹⁵³, P. Urquijo⁴⁹, P. Urrejola^{31a}, G. Usai⁷, M. Uslenghi^{119a,119b}, L. Vacavant⁸³, V. Vacek¹²⁷,
 B. Vachon⁸⁵, S. Vahsen¹⁴, C. Valderanis⁹⁹, J. Valenta¹²⁵, P. Valente^{132a}, S. Valentini^{19a,19b},
 S. Valkar¹²⁶, E. Valladolid Gallego¹⁶⁷, S. Vallecorsa¹⁵², J.A. Valls Ferrer¹⁶⁷, H. van der Graaf¹⁰⁵,
 E. van der Kraaij¹⁰⁵, E. van der Poel¹⁰⁵, D. van der Ster²⁹, B. Van Eijk¹⁰⁵, N. van Eldik⁸⁴,
 P. van Gemmeren⁵, Z. van Kesteren¹⁰⁵, I. van Vulpen¹⁰⁵, W. Vandelli²⁹, G. Vandoni²⁹, A. Vaniachine⁵,
 P. Vankov⁴¹, F. Vannucci⁷⁸, F. Varela Rodriguez²⁹, R. Vari^{132a}, E.W. Varnes⁶, D. Varouchas¹⁴,
 A. Vartapetian⁷, K.E. Varvell¹⁵⁰, V.I. Vassilakopoulos⁵⁶, F. Vazeille³³, G. Vegni^{89a,89b}, J.J. Veillet¹¹⁵,
 C. Vellidis⁸, F. Veloso^{124a}, R. Veness²⁹, S. Veneziano^{132a}, A. Ventura^{72a,72b}, D. Ventura¹³⁸, M. Venturi⁴⁸,
 N. Venturi¹⁶, V. Vercesi^{119a}, M. Verducci¹³⁸, W. Verkerke¹⁰⁵, J.C. Vermeulen¹⁰⁵, A. Vest⁴³,
 M.C. Vetterli^{142,d}, I. Vichou¹⁶⁵, T. Vickey^{145b,aa}, G.H.A. Viehhauser¹¹⁸, S. Viel¹⁶⁸, M. Villa^{19a,19b},
 M. Villaplana Perez¹⁶⁷, E. Vilucchi⁴⁷, M.G. Vincker²⁸, E. Vinek²⁹, V.B. Vinogradov⁶⁵, M. Virchaux^{136,*},
 S. Viret³³, J. Virzi¹⁴, A. Vitale^{19a,19b}, O. Vitells¹⁷¹, I. Vivarelli⁴⁸, F. Vives Vaque¹¹, S. Vlachos⁹,
 M. Vlasak¹²⁷, N. Vlasov²⁰, A. Vogel²⁰, P. Vokac¹²⁷, M. Volpi¹¹, G. Volpini^{89a}, H. von der Schmitt⁹⁹,
 J. von Loeben⁹⁹, H. von Radziewski⁴⁸, E. von Toerne²⁰, V. Vorobel¹²⁶, A.P. Vorobiev¹²⁸, V. Vorwerk¹¹,
 M. Vos¹⁶⁷, R. Voss²⁹, T.T. Voss¹⁷⁴, J.H. Vossebeld⁷³, A.S. Vovenko¹²⁸, N. Vranjes^{12a},
 M. Vranjes Milosavljevic^{12a}, V. Vrba¹²⁵, M. Vreeswijk¹⁰⁵, T. Vu Anh⁸¹, R. Vuillermet²⁹, I. Vukotic¹¹⁵,
 W. Wagner¹⁷⁴, P. Wagner¹²⁰, H. Wahlen¹⁷⁴, J. Wakabayashi¹⁰¹, J. Walbersloh⁴², S. Walch⁸⁷,
 J. Walder⁷¹, R. Walker⁹⁸, W. Walkowiak¹⁴¹, R. Wall¹⁷⁵, P. Waller⁷³, C. Wang⁴⁴, H. Wang¹⁷²,
 J. Wang¹⁵¹, J. Wang^{32d}, J.C. Wang¹³⁸, R. Wang¹⁰³, S.M. Wang¹⁵¹, A. Warburton⁸⁵, C.P. Ward²⁷,
 M. Warsinsky⁴⁸, P.M. Watkins¹⁷, A.T. Watson¹⁷, M.F. Watson¹⁷, G. Watts¹³⁸, S. Watts⁸², A.T. Waugh¹⁵⁰,
 B.M. Waugh⁷⁷, J. Weber⁴², M. Weber¹²⁹, M.S. Weber¹⁶, P. Weber⁵⁴, A.R. Weidberg¹¹⁸, J. Weingarten⁵⁴,
 C. Weiser⁴⁸, H. Wellenstein²², P.S. Wells²⁹, M. Wen⁴⁷, T. Wenaus²⁴, S. Wendler¹²³, Z. Weng^{151,r},
 T. Wengler²⁹, S. Wenig²⁹, N. Wermes²⁰, M. Werner⁴⁸, P. Werner²⁹, M. Werth¹⁶³, M. Wessels^{58a},
 K. Whalen²⁸, S.J. Wheeler-Ellis¹⁶³, S.P. Whitaker²¹, A. White⁷, M.J. White⁸⁶, S. White²⁴,
 S.R. Whitehead¹¹⁸, D. Whiteson¹⁶³, D. Whittington⁶¹, F. Wicek¹¹⁵, D. Wicke¹⁷⁴, F.J. Wickens¹²⁹,
 W. Wiedenmann¹⁷², M. Wielers¹²⁹, P. Wienemann²⁰, C. Wiglesworth⁷³, L.A.M. Wiik⁴⁸, A. Wildauer¹⁶⁷,
 M.A. Wildt^{41,p}, I. Wilhelm¹²⁶, H.G. Wilkens²⁹, J.Z. Will⁹⁸, E. Williams³⁴, H.H. Williams¹²⁰, W. Willis³⁴,
 S. Willocq⁸⁴, J.A. Wilson¹⁷, M.G. Wilson¹⁴³, A. Wilson⁸⁷, I. Wingerter-Seez⁴, S. Winkelmann⁴⁸,
 F. Winklmeier²⁹, M. Wittgen¹⁴³, M.W. Wolter³⁸, H. Wolters^{124a,f}, G. Wooden¹¹⁸, B.K. Wosiek³⁸,
 J. Wotschack²⁹, M.J. Woudstra⁸⁴, K. Wraight⁵³, C. Wright⁵³, B. Wrona⁷³, S.L. Wu¹⁷², X. Wu⁴⁹,
 Y. Wu^{32b}, E. Wulf³⁴, R. Wunstorf⁴², B.M. Wynne⁴⁵, L. Xaplanteris⁹, S. Xella³⁵, S. Xie⁴⁸, Y. Xie^{32a},
 C. Xu^{32b}, D. Xu¹³⁹, G. Xu^{32a}, B. Yabsley¹⁵⁰, M. Yamada⁶⁶, A. Yamamoto⁶⁶, K. Yamamoto⁶⁴,
 S. Yamamoto¹⁵⁵, T. Yamamura¹⁵⁵, J. Yamaoka⁴⁴, T. Yamazaki¹⁵⁵, Y. Yamazaki⁶⁷, Z. Yan²¹, H. Yang⁸⁷,
 U.K. Yang⁸², Y. Yang⁶¹, Y. Yang^{32a}, Z. Yang^{146a,146b}, S. Yanush⁹¹, W.-M. Yao¹⁴, Y. Yao¹⁴, Y. Yasu⁶⁶,
 J. Ye³⁹, S. Ye²⁴, M. Yilmaz^{3c}, R. Yoosoofmiya¹²³, K. Yorita¹⁷⁰, R. Yoshida⁵, C. Young¹⁴³, S. Youssef²¹,
 D. Yu²⁴, J. Yu⁷, J. Yu^{32c,ab}, L. Yuan^{32a,ac}, A. Yurkewicz¹⁴⁸, V.G. Zaets¹²⁸, R. Zaidan⁶³, A.M. Zaitsev¹²⁸,
 Z. Zajacova²⁹, Yo.K. Zalite¹²¹, L. Zanello^{132a,132b}, P. Zarzhitsky³⁹, A. Zaytsev¹⁰⁷, C. Zeitnitz¹⁷⁴,
 M. Zeller¹⁷⁵, P.F. Zema²⁹, A. Zemla³⁸, C. Zender²⁰, A.V. Zenin¹²⁸, O. Zenin¹²⁸, T. Ženiš^{144a},
 Z. Zenonos^{122a,122b}, S. Zenz¹⁴, D. Zerwas¹¹⁵, G. Zevi della Porta⁵⁷, Z. Zhan^{32d}, D. Zhang^{32b},

H. Zhang⁸⁸, J. Zhang⁵, X. Zhang^{32d}, Z. Zhang¹¹⁵, L. Zhao¹⁰⁸, T. Zhao¹³⁸, Z. Zhao^{32b}, A. Zhemchugov⁶⁵, S. Zheng^{32a}, J. Zhong^{151,ad}, B. Zhou⁸⁷, N. Zhou¹⁶³, Y. Zhou¹⁵¹, C.G. Zhu^{32d}, H. Zhu⁴¹, Y. Zhu¹⁷², X. Zhuang⁹⁸, V. Zhuravlov⁹⁹, D. Zieminska⁶¹, B. Zilka^{144a}, R. Zimmermann²⁰, S. Zimmermann²⁰, S. Zimmermann⁴⁸, M. Ziolkowski¹⁴¹, R. Zitoun⁴, L. Živković³⁴, V.V. Zmouchko^{128,*}, G. Zobernig¹⁷², A. Zoccoli^{19a,19b}, Y. Zolnierowski⁴, A. Zsenei²⁹, M. zur Nedden¹⁵, V. Zutshi¹⁰⁶, L. Zwalinski²⁹

¹ University at Albany, 1400 Washington Ave, Albany, NY 12222, United States

² University of Alberta, Department of Physics, Centre for Particle Physics, Edmonton, AB T6G 2G7, Canada

³ Ankara University^(a), Faculty of Sciences, Department of Physics, TR-061000 Tandogan, Ankara; Dumlupinar University^(b), Faculty of Arts and Sciences, Department of Physics, Kutahya; Gazi University^(c), Faculty of Arts and Sciences, Department of Physics, 06500 Teknikokullar, Ankara; TOBB University of Economics and Technology^(d), Faculty of Arts and Sciences, Division of Physics, 06560 Sogutozu, Ankara; Turkish Atomic Energy Authority^(e), 06530 Lodumlu, Ankara, Turkey

⁴ LAPP, Université de Savoie, CNRS/IN2P3, Annecy-le-Vieux, France

⁵ Argonne National Laboratory, High Energy Physics Division, 9700 S. Cass Avenue, Argonne, IL 60439, United States

⁶ University of Arizona, Department of Physics, Tucson, AZ 85721, United States

⁷ The University of Texas at Arlington, Department of Physics, Box 19059, Arlington, TX 76019, United States

⁸ University of Athens, Nuclear & Particle Physics, Department of Physics, Panepistimiopoli, Zografou, GR-15771 Athens, Greece

⁹ National Technical University of Athens, Physics Department, 9-Iroon Polytechniou, GR-15780 Zografou, Greece

¹⁰ Institute of Physics, Azerbaijan Academy of Sciences, H. Javid Avenue 33, AZ 143 Baku, Azerbaijan

¹¹ Institut de Física d'Altes Energies, IFAE, Edifici Cn, Universitat Autònoma de Barcelona, ES-08193 Bellaterra (Barcelona), Spain

¹² University of Belgrade^(a), Institute of Physics, P.O. Box 57, 11001 Belgrade; Vinca Institute of Nuclear Sciences^(b), M. Petrovica Alasa 12-14, 11001 Belgrade, Serbia

¹³ University of Bergen, Department for Physics and Technology, Allegaten 55, NO-5007 Bergen, Norway

¹⁴ Lawrence Berkeley National Laboratory and University of California, Physics Division, MS50B-6227, 1 Cyclotron Road, Berkeley, CA 94720, United States

¹⁵ Humboldt University, Institute of Physics, Berlin, Newtonstr. 15, D-12489 Berlin, Germany

¹⁶ University of Bern, Albert Einstein Center for Fundamental Physics, Laboratory for High Energy Physics, Sidlerstrasse 5, CH-3012 Bern, Switzerland

¹⁷ University of Birmingham, School of Physics and Astronomy, Edgbaston, Birmingham B15 2TT, United Kingdom

¹⁸ Bogazici University^(a), Faculty of Sciences, Department of Physics, TR-80815 Bebek-Istanbul; Dogus University^(b), Faculty of Arts and Sciences, Department of Physics, 34722 Kadikoy, Istanbul; Gaziantep University^(c), Faculty of Engineering, Department of Physics Engineering, 27310 Sehitkamil, Gaziantep; Istanbul Technical University^(d), Faculty of Arts and Sciences, Department of Physics, 34469 Maslak, Istanbul, Turkey

¹⁹ INFN Sezione di Bologna^(a); Università di Bologna, Dipartimento di Fisica^(a), viale C. Berti Pichat, 6/2, IT-40127 Bologna, Italy

²⁰ University of Bonn, Physikalisches Institut, Nussallee 12, D-53115 Bonn, Germany

²¹ Boston University, Department of Physics, 590 Commonwealth Avenue, Boston, MA 02215, United States

²² Brandeis University, Department of Physics, MS057, 415 South Street, Waltham, MA 02454, United States

²³ Universidade Federal do Rio De Janeiro, COPPE/EE/IF^(a), Caixa Postal 68528, Ilha do Fundao, BR-21945-970 Rio de Janeiro; Universidade de Sao Paulo^(b), Instituto de Fisica, R.do Matao Trav. R.187, Sao Paulo, SP 05508-900, Brazil

²⁴ Brookhaven National Laboratory, Physics Department, Bldg. 510A, Upton, NY 11973, United States

²⁵ National Institute of Physics and Nuclear Engineering^(a), Bucharest-Magurele, Str. Atomistilor 407, P.O. Box MG-6, R-077125; University Politehnica Bucharest^(b), Rectorat, AN 001,

313 Splaiul Independentei, sector 6, 060042 Bucuresti; West University^(c) in Timisoara, Bd. Vasile Parvan 4, Timisoara, Romania

²⁶ Universidad de Buenos Aires, FCEyN, Dto. Fisica, Pab I, C. Universitaria, 1428 Buenos Aires, Argentina

²⁷ University of Cambridge, Cavendish Laboratory, JJ. Thomson Avenue, Cambridge CB3 0HE, United Kingdom

²⁸ Carleton University, Department of Physics, 1125 Colonel By Drive, Ottawa ON K1S 5B6, Canada

²⁹ CERN, CH-1211 Geneva 23, Switzerland

³⁰ University of Chicago, Enrico Fermi Institute, 5640 S. Ellis Avenue, Chicago, IL 60637, United States

³¹ Pontificia Universidad Católica de Chile, Facultad de Fisica, Departamento de Fisica^(a), Avda. Vicuna Mackenna 4860, San Joaquin, Santiago; Universidad Técnica Federico Santa María, Departamento de Fisica^(b), Avda. España 1680, Casilla 110-V, Valparaíso, Chile

³² Institute of High Energy Physics, Chinese Academy of Sciences^(a), P.O. Box 918, 19 Yuquan Road, Shijing Shan District, CN, Beijing 100049; University of Science & Technology of China (USTC), Department of Modern Physics^(b), Hefei, CN, Anhui 230026; Nanjing University, Department of Physics^(c), Nanjing, CN, Jiangsu 210093; Shandong University, High Energy Physics Group^(d), Jinan, CN, Shandong 250100, China

³³ Laboratoire de Physique Corpusculaire, Clermont Université, Université Blaise Pascal, CNRS/IN2P3, FR-63177 Aubiere Cedex, France

³⁴ Columbia University, Nevis Laboratory, 136 So. Broadway, Irvington, NY 10533, United States

³⁵ University of Copenhagen, Niels Bohr Institute, Blegdamsvej 17, DK-2100 Kobenhavn 0, Denmark

³⁶ INFN Gruppo Collegato di Cosenza^(a); Università della Calabria, Dipartimento di Fisica^(b), IT-87036 Arcavacata di Rende, Italy

³⁷ Faculty of Physics and Applied Computer Science of the AGH—University of Science and Technology (FPACS, AGH—UST), ul. Mickiewicza 30, PL-30059 Cracow, Poland

³⁸ The Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, ul. Radzikowskiego 152, PL-31342 Cracow, Poland

³⁹ Southern Methodist University, Physics Department, 106 Fondren Science Building, Dallas, TX 75275-0175, United States

⁴⁰ University of Texas at Dallas, 800 West Campbell Road, Richardson, TX 75080-3021, United States

⁴¹ DESY, Notkestr. 85, D-22603 Hamburg and Platanenallee 6, D-15738 Zeuthen, Germany

⁴² TU Dortmund, Experimentelle Physik IV, DE-44221 Dortmund, Germany

⁴³ Technical University Dresden, Institut für Kern- und Teilchenphysik, Zellescher Weg 19, D-01069 Dresden, Germany

⁴⁴ Duke University, Department of Physics, Durham, NC 27708, United States

⁴⁵ University of Edinburgh, School of Physics & Astronomy, James Clerk Maxwell Building, The Kings Buildings, Mayfield Road, Edinburgh EH9 3JZ, United Kingdom

⁴⁶ Fachhochschule Wiener Neustadt; Johannes Gutenbergstrasse 3, AT-2700 Wiener Neustadt, Austria

⁴⁷ INFN Laboratori Nazionali di Frascati, via Enrico Fermi 40, IT-00044 Frascati, Italy

⁴⁸ Albert-Ludwigs-Universität, Fakultät für Mathematik und Physik, Hermann-Herder Str. 3, D-79104 Freiburg i.Br., Germany

⁴⁹ Université de Genève, Section de Physique, 24 rue Ernest Ansermet, CH-1211 Genève 4, Switzerland

⁵⁰ INFN Sezione di Genova^(a); Università di Genova, Dipartimento di Fisica^(b), via Dodecaneso 33, IT-16146 Genova, Italy

⁵¹ Institute of Physics of the Georgian Academy of Sciences, 6 Tamarashvili St., GE-380077 Tbilisi; Tbilisi State University, HEP Institute, University St. 9, GE-380086 Tbilisi, Georgia

⁵² Justus-Liebig-Universität Giessen, II Physikalisches Institut, Heinrich-Buff Ring 16, D-35392 Giessen, Germany

⁵³ University of Glasgow, Department of Physics and Astronomy, Glasgow G12 8QQ, United Kingdom

⁵⁴ Georg-August-Universität, II Physikalisches Institut, Friedrich-Hund Platz 1, D-37077 Göttingen, Germany

⁵⁵ Laboratoire de Physique Subatomique et de Cosmologie, Université Joseph Fourier, CNRS-IN2P3, INPG, Grenoble, France

⁵⁶ Hampton University, Department of Physics, Hampton, VA 23668, United States

⁵⁷ Harvard University, Laboratory for Particle Physics and Cosmology, 18 Hammond Street, Cambridge, MA 02138, United States

⁵⁸ Ruprecht-Karls-Universität Heidelberg; Kirchhoff-Institut für Physik^(a), Im Neuenheimer Feld 227, D-69120 Heidelberg; Physikalisches Institut^(b), Philosophenweg 12,

D-69120 Heidelberg; ZITI Ruprecht-Karls-Universität Heidelberg^(c), Lehrstuhl für Informatik V, B6, 23-29, D-68131 Mannheim, Germany

⁵⁹ Hiroshima University, Faculty of Science, 1-3-1 Kagamiyama, Higashihiroshima-shi, JP, Hiroshima 739-8526, Japan

⁶⁰ Hiroshima Institute of Technology, Faculty of Applied Information Science, 2-1-1 Miyake Saeki-ku, Hiroshima-shi, JP, Hiroshima 731-5193, Japan

⁶¹ Indiana University, Department of Physics, Swain Hall West 117, Bloomington, IN 47405-7105, United States

- ⁶² Institut für Astro- und Teilchenphysik, Technikerstrasse 25, A-6020 Innsbruck, Austria
- ⁶³ University of Iowa, 203 Van Allen Hall, Iowa City, IA 52242-1479, United States
- ⁶⁴ Iowa State University, Department of Physics and Astronomy, Ames High Energy Physics Group, Ames, IA 50011-3160, United States
- ⁶⁵ Joint Institute for Nuclear Research, JINR Dubna, RU-141980 Moscow Region, Russia
- ⁶⁶ KEK, High Energy Accelerator Research Organization, 1-1 Oho, Tsukuba-shi, Ibaraki-ken 305-0801, Japan
- ⁶⁷ Kobe University, Graduate School of Science, 1-1 Rokkodai-cho, Nada-ku, JP, Kobe 657-8501, Japan
- ⁶⁸ Kyoto University, Faculty of Science, Oiwake-cho, Kitashirakawa, Sakyou-ku, Kyoto-shi, JP Kyoto 606-8502, Japan
- ⁶⁹ Kyoto University of Education, 1 Fukakusa, Fujimori, Fushimi-ku, Kyoto-shi, JP, Kyoto 612-8522, Japan
- ⁷⁰ Universidad Nacional de La Plata, FCE, Departamento de Física, IFLP (CONICET-UNLP), C.C. 67, 1900 La Plata, Argentina
- ⁷¹ Lancaster University, Physics Department, Lancaster LA1 4YB, United Kingdom
- ⁷² INFN Sezione di Lecce^(a); Università del Salento, Dipartimento di Fisica^(b), Via Arnesano, IT-73100 Lecce, Italy
- ⁷³ University of Liverpool, Oliver Lodge Laboratory, P.O. Box 147, Oxford Street, Liverpool L69 3BX, United Kingdom
- ⁷⁴ Jožef Stefan Institute and University of Ljubljana, Department of Physics, SI-1000 Ljubljana, Slovenia
- ⁷⁵ Queen Mary University of London, Department of Physics, Mile End Road, London E1 4NS, United Kingdom
- ⁷⁶ Royal Holloway, University of London, Department of Physics, Egham Hill, Egham, Surrey TW20 0EX, United Kingdom
- ⁷⁷ University College London, Department of Physics and Astronomy, Gower Street, London WC1E 6BT, United Kingdom
- ⁷⁸ Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC, Université Paris Diderot, CNRS/IN2P3, 4 place Jussieu, FR-75252 Paris Cedex 05, France
- ⁷⁹ Fysiska Institutionen, Lunds Universitet, Box 118, SE-221 00 Lund, Sweden
- ⁸⁰ Universidad Autonoma de Madrid, Facultad de Ciencias, Departamento de Física Teórica, ES-28049 Madrid, Spain
- ⁸¹ Universität Mainz, Institut für Physik, Staudinger Weg 7, DE-55099 Mainz, Germany
- ⁸² University of Manchester, School of Physics and Astronomy, Manchester M13 9PL, United Kingdom
- ⁸³ CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille, France
- ⁸⁴ University of Massachusetts, Department of Physics, 710 North Pleasant Street, Amherst, MA 01003, United States
- ⁸⁵ McGill University, High Energy Physics Group, 3600 University Street, Montreal, Quebec H3A 2T8, Canada
- ⁸⁶ University of Melbourne, School of Physics, AU, Parkville, Victoria 3010, Australia
- ⁸⁷ The University of Michigan, Department of Physics, 2477 Randall Laboratory, 500 East University, Ann Arbor, MI 48109-1120, United States
- ⁸⁸ Michigan State University, Department of Physics and Astronomy, High Energy Physics Group, East Lansing, MI 48824-2320, United States
- ⁸⁹ INFN Sezione di Milano^(a); Università di Milano, Dipartimento di Fisica^(b), via Celoria 16, IT-20133 Milano, Italy
- ⁹⁰ B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Independence Avenue 68, Minsk 220072, Belarus
- ⁹¹ National Scientific & Educational Centre for Particle & High Energy Physics, NC PHEP BSU, M. Bogdanovich St. 153, Minsk 220040, Belarus
- ⁹² Massachusetts Institute of Technology, Department of Physics, Room 24-516, Cambridge, MA 02139, United States
- ⁹³ University of Montreal, Group of Particle Physics, C.P. 6128, Succursale Centre-Ville, Montreal, Quebec, H3C 3J7, Canada
- ⁹⁴ P.N. Lebedev Institute of Physics, Academy of Sciences, Leninsky pr. 53, RU-117 924 Moscow, Russia
- ⁹⁵ Institute for Theoretical and Experimental Physics (ITEP), B. Chermushkinskaya ul. 25, RU-117 218 Moscow, Russia
- ⁹⁶ Moscow Engineering & Physics Institute (MEPhI), Kashirskoe Shosse 31, RU-115409 Moscow, Russia
- ⁹⁷ Lomonosov Moscow State University, Skobeltsyn Institute of Nuclear Physics (MSU SINP), 1(2), Leninskie gory, GSP-1, Moscow 119991 Russian Federation, Russia
- ⁹⁸ Ludwig-Maximilians-Universität München, Fakultät für Physik, Am Coulombwall 1, DE-85748 Garching, Germany
- ⁹⁹ Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), Föhringer Ring 6, 80805 München, Germany
- ¹⁰⁰ Nagasaki Institute of Applied Science, 536 Aba-machi, JP, Nagasaki 851-0193, Japan
- ¹⁰¹ Nagoya University, Graduate School of Science, Furo-Cho, Chikusa-ku, Nagoya, 464-8602, Japan
- ¹⁰² INFN Sezione di Napoli^(a); Università di Napoli, Dipartimento di Scienze Fisiche^(b), Complesso Universitario di Monte Sant'Angelo, via Cinthia, IT-80126 Napoli, Italy
- ¹⁰³ University of New Mexico, Department of Physics and Astronomy, MSC07 4220, Albuquerque, NM 87131, United States
- ¹⁰⁴ Radboud University Nijmegen/NIKHEF, Department of Experimental High Energy Physics, Heyendaalseweg 135, NL-6525 AJ, Nijmegen, Netherlands
- ¹⁰⁵ Nikhef National Institute for Subatomic Physics, and University of Amsterdam, Science Park 105, 1098 XG Amsterdam, Netherlands
- ¹⁰⁶ Department of Physics, Northern Illinois University, LaTourette Hall Normal Road, DeKalb, IL 60115, United States
- ¹⁰⁷ Budker Institute of Nuclear Physics (BINP), RU, Novosibirsk 630 090, Russia
- ¹⁰⁸ New York University, Department of Physics, 4 Washington Place, New York, NY 10003, United States
- ¹⁰⁹ Ohio State University, 191 West Woodruff Ave, Columbus, OH 43210-1117, United States
- ¹¹⁰ Okayama University, Faculty of Science, Tsushima-naka 3-1-1, Okayama 700-8530, Japan
- ¹¹¹ University of Oklahoma, Homer L. Dodge Department of Physics and Astronomy, 440 West Brooks, Room 100, Norman, OK 73019-0225, United States
- ¹¹² Oklahoma State University, Department of Physics, 145 Physical Sciences Building, Stillwater, OK 74078-3072, United States
- ¹¹³ Palacký University, 17. listopadu 50a, 772 07 Olomouc, Czech Republic
- ¹¹⁴ University of Oregon, Center for High Energy Physics, Eugene, OR 97403-1274, United States
- ¹¹⁵ LAL, Univ. Paris-Sud, IN2P3/CNRS, Orsay, France
- ¹¹⁶ Osaka University, Graduate School of Science, Machikaneyama-machi 1-1, Toyonaka, Osaka 560-0043, Japan
- ¹¹⁷ University of Oslo, Department of Physics, P.O. Box 1048, Blindern, NO-0316 Oslo 3, Norway
- ¹¹⁸ Oxford University, Department of Physics, Denys Wilkinson Building, Keble Road, Oxford OX1 3RH, United Kingdom
- ¹¹⁹ INFN Sezione di Pavia^(a); Università di Pavia, Dipartimento di Fisica Nucleare e Teorica^(b), Via Bassi 6, IT-27100 Pavia, Italy
- ¹²⁰ University of Pennsylvania, Department of Physics, High Energy Physics Group, 209 S. 33rd Street, Philadelphia, PA 19104, United States
- ¹²¹ Petersburg Nuclear Physics Institute, RU-188 300 Gatchina, Russia
- ¹²² INFN Sezione di Pisa^(a); Università di Pisa, Dipartimento di Fisica E. Fermi^(b), Largo B. Pontecorvo 3, IT-56127 Pisa, Italy
- ¹²³ University of Pittsburgh, Department of Physics and Astronomy, 3941 O'Hara Street, Pittsburgh, PA 15260, United States
- ¹²⁴ Laboratorio de Instrumentacao e Fisica Experimental de Particulas – LIP^(a), Avenida Elias Garcia 14-1, PT-1000-149 Lisboa; Universidad de Granada, Departamento de Física Teórica y del Cosmos and CAFPE^(b), E-18071 Granada, Spain
- ¹²⁵ Institute of Physics, Academy of Sciences of the Czech Republic, Na Slovance 2, CZ-18221 Praha 8, Czech Republic
- ¹²⁶ Charles University in Prague, Faculty of Mathematics and Physics, Institute of Particle and Nuclear Physics, V Holesovickach 2, CZ-18000 Praha 8, Czech Republic
- ¹²⁷ Czech Technical University in Prague, Zikova 4, CZ-166 35 Praha 6, Czech Republic
- ¹²⁸ State Research Center Institute for High Energy Physics, Moscow Region, 142281, Protvino, Pobeda street, 1, Russia
- ¹²⁹ Rutherford Appleton Laboratory, Science and Technology Facilities Council, Harwell Science and Innovation Campus, Didcot OX11 0QX, United Kingdom
- ¹³⁰ University of Regina, Physics Department, Canada
- ¹³¹ Ritsumeikan University, Noji Higashi 1 chome 1-1, JP, Kusatsu, Shiga 525-8577, Japan
- ¹³² INFN Sezione di Roma I^(a); Università La Sapienza, Dipartimento di Fisica^(b), Piazzale A. Moro 2, IT-00185 Roma, Italy
- ¹³³ INFN Sezione di Roma Tor Vergata^(a); Università di Roma Tor Vergata, Dipartimento di Fisica^(b), via della Ricerca Scientifica, IT-00133 Roma, Italy
- ¹³⁴ INFN Sezione di Roma Tre^(a); Università Roma Tre, Dipartimento di Fisica^(b), via della Vasca Navale 84, IT-00146 Roma, Italy
- ¹³⁵ Réseau Universitaire de Physique des Hautes Energies (RUPHE): Université Hassan II, Faculté des Sciences Ain Chock^(a), B.P. 5366, MA, Casablanca; Centre National de l'Energie des Sciences Techniques Nucleaires (CNSTEN)^(b), B.P. 1382 R.P. 10001 Rabat 10001; Université Mohamed Premier^(c), LPTPM, Faculté des Sciences, B.P. 717. Bd. Mohamed VI, 60000 Oujda; Université Mohammed V, Faculté des Sciences^(d), 4 Avenue Ibn Battouta, B.P. 1014 R.P., 10000 Rabat, Morocco
- ¹³⁶ CEA, DSM/IRFU, Centre d'Etudes de Saclay, FR-91191 Gif-sur-Yvette, France
- ¹³⁷ University of California Santa Cruz, Santa Cruz Institute for Particle Physics (SCIPP), Santa Cruz, CA 95064, United States

- ¹³⁸ University of Washington, Seattle, Department of Physics, Box 351560, Seattle, WA 98195-1560, United States
- ¹³⁹ University of Sheffield, Department of Physics & Astronomy, Hounsfield Road, Sheffield S3 7RH, United Kingdom
- ¹⁴⁰ Shinshu University, Department of Physics, Faculty of Science, 3-1-1 Asahi, Matsumoto-shi, JP, Nagano 390-8621, Japan
- ¹⁴¹ Universität Siegen, Fachbereich Physik, D 57068 Siegen, Germany
- ¹⁴² Simon Fraser University, Department of Physics, 8888 University Drive, CA, Burnaby, BC V5A 1S6, Canada
- ¹⁴³ SLAC National Accelerator Laboratory, Stanford, California 94309, United States
- ¹⁴⁴ Comenius University, Faculty of Mathematics, Physics & Informatics^(a), Mlynska dolina F2, SK-84248 Bratislava; Institute of Experimental Physics of the Slovak Academy of Sciences, Dept. of Subnuclear Physics^(b), Watsonova 47, SK-04353 Kosice, Slovak Republic
- ¹⁴⁵ University of Johannesburg, Department of Physics^(a), P.O. Box 524, Auckland Park, Johannesburg 2006; School of Physics, University of the Witwatersrand^(b), Private Bag 3, Wits 2050, Johannesburg, South Africa
- ¹⁴⁶ Stockholm University, Department of Physics^(a); The Oskar Klein Centre^(b), AlbaNova, SE-106 91 Stockholm, Sweden
- ¹⁴⁷ Royal Institute of Technology (KTH), Physics Department, SE-106 91 Stockholm, Sweden
- ¹⁴⁸ Stony Brook University, Department of Physics and Astronomy, Nicolls Road, Stony Brook, NY 11794-3800, United States
- ¹⁴⁹ University of Sussex, Department of Physics and Astronomy Pevensey 2 Building, Falmer, Brighton BN1 9QH, United Kingdom
- ¹⁵⁰ University of Sydney, School of Physics, AU, Sydney NSW 2006, Australia
- ¹⁵¹ Institute of Physics, Academia Sinica, TW, Taipei 11529, Taiwan
- ¹⁵² Technion, Israel Inst. of Technology, Department of Physics, Technion City, IL, Haifa 32000, Israel
- ¹⁵³ Tel Aviv University, Raymond and Beverly Sackler School of Physics and Astronomy, Ramat Aviv, IL, Tel Aviv 69978, Israel
- ¹⁵⁴ Aristotle University of Thessaloniki, Faculty of Science, Department of Physics, Division of Nuclear & Particle Physics, University Campus, GR-54124, Thessaloniki, Greece
- ¹⁵⁵ The University of Tokyo, International Center for Elementary Particle Physics and Department of Physics, 7-3-1 Hongo, Bunkyo-ku, JP, Tokyo 113-0033, Japan
- ¹⁵⁶ Tokyo Metropolitan University, Graduate School of Science and Technology, 1-1 Minami-Osawa, Hachioji, Tokyo 192-0397, Japan
- ¹⁵⁷ Tokyo Institute of Technology, Department of Physics, 2-12-1 O-okayama, Meguro, Tokyo 152-8551, Japan
- ¹⁵⁸ University of Toronto, Department of Physics, 60 Saint George Street, Toronto M5S 1A7, Ontario, Canada
- ¹⁵⁹ TRIUMF^(a), 4004 Wesbrook Mall, Vancouver, B.C. V6T 2A3; York University^(b), Department of Physics and Astronomy, 4700 Keele St., Toronto, Ontario, M3J 1P3, Canada
- ¹⁶⁰ University of Tsukuba, Institute of Pure and Applied Sciences, 1-1-1 Tennoudai, Tsukuba-shi, JP, Ibaraki 305-8571, Japan
- ¹⁶¹ Tufts University, Science & Technology Center, 4 Colby Street, Medford, MA 02155, United States
- ¹⁶² Universidad Antonio Narino, Centro de Investigaciones, Cra 3 Este No.47A-15, Bogota, Colombia
- ¹⁶³ University of California, Irvine, Department of Physics & Astronomy, CA 92697-4575, United States
- ¹⁶⁴ INFN Gruppo Collegato di Udine^(a); ICTP^(b), Strada Costiera 11, IT-34014 Trieste; Università di Udine, Dipartimento di Fisica^(c), via delle Scienze 208, IT-33100 Udine, Italy
- ¹⁶⁵ University of Illinois, Department of Physics, 1110 West Green Street, Urbana, Illinois 61801, United States
- ¹⁶⁶ University of Uppsala, Department of Physics and Astronomy, P.O. Box 516, SE-751 20 Uppsala, Sweden
- ¹⁶⁷ Instituto de Física Corpuscular (IFIC), Centro Mixto UVEG-CSIC, Apdo. 22085 ES-46071 Valencia, Dept. Física At. Mol. y Nuclear; Dept. Ing. Electrónica; Univ. of Valencia, and Inst. de Microelectrónica de Barcelona (IMB-CNM-CSIC), 08193 Bellaterra, Spain
- ¹⁶⁸ University of British Columbia, Department of Physics, 6224 Agricultural Road, CA, Vancouver, B.C. V6T 1Z1, Canada
- ¹⁶⁹ University of Victoria, Department of Physics and Astronomy, P.O. Box 3055, Victoria B.C., V8W 3P6, Canada
- ¹⁷⁰ Waseda University, WISE, 3-4-1 Okubo, Shinjuku-ku, Tokyo, 169-8555, Japan
- ¹⁷¹ The Weizmann Institute of Science, Department of Particle Physics, P.O. Box 26, IL-76100 Rehovot, Israel
- ¹⁷² University of Wisconsin, Department of Physics, 1150 University Avenue, WI 53706 Madison, Wisconsin, United States
- ¹⁷³ Julius-Maximilians-University of Würzburg, Physikalisches Institute, Am Hubland, 97074 Würzburg, Germany
- ¹⁷⁴ Bergische Universität, Fachbereich C, Physik, Postfach 100127, Gauss-Strasse 20, D-42097 Wuppertal, Germany
- ¹⁷⁵ Yale University, Department of Physics, PO Box 208121, New Haven CT, 06520-8121, United States
- ¹⁷⁶ Yerevan Physics Institute, Alikhanian Brothers Street 2, AM-375036 Yerevan, Armenia
- ¹⁷⁷ Centre de Calcul CNRS/IN2P3, Domaine scientifique de la Doua, 27 bd du 11 Novembre 1918, 69622 Villeurbanne Cedex, France

^a Also at LIP, Portugal.

^b Also at Faculdade de Ciências, Universidade de Lisboa, Lisboa, Portugal.

^c Also at CPPM, Marseille, France.

^d Also at TRIUMF, Vancouver, Canada.

^e Also at FPACS, AGH-UST, Cracow, Poland.

^f Also at Department of Physics, University of Coimbra, Coimbra, Portugal.

^g Also at Università di Napoli Parthenope, Napoli, Italy.

^h Also at Institute of Particle Physics (IPP), Canada.

ⁱ Also at Louisiana Tech University, Ruston, United States.

^j Also at Universidade de Lisboa, Lisboa, Portugal.

^k At California State University, Fresno, United States.

^l Also at Faculdade de Ciências, Universidade de Lisboa and at Centro de Física Nuclear da Universidade de Lisboa, Lisboa, Portugal.

^m Also at California Institute of Technology, Pasadena, United States.

ⁿ Also at University of Montreal, Montreal, Canada.

^o Also at Baku Institute of Physics, Baku, Azerbaijan.

^p Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany.

^q Also at Manhattan College, New York, United States.

^r Also at School of Physics and Engineering, Sun Yat-sen University, Guangzhou, China.

^s Also at Taiwan Tier-1, ASGC, Academia Sinica, Taipei, Taiwan.

^t Also at School of Physics, Shandong University, Jinan, China.

^u Also at Rutherford Appleton Laboratory, Didcot, UK.

^v Also at Departamento de Física, Universidade de Minho, Braga, Portugal.

^w Also at Department of Physics and Astronomy, University of South Carolina, Columbia, United States.

^x Also at KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary.

^y Also at Institute of Physics, Jagiellonian University, Cracow, Poland.

^z Also at Centro de Física Nuclear da Universidade de Lisboa, Lisboa, Portugal.

^{aa} Also at Department of Physics, Oxford University, Oxford, UK.

^{ab} Also at CEA, Gif sur Yvette, France.

^{ac} Also at LPNHE, Paris, France.

^{ad} Also at Nanjing University, Nanjing Jiangsu, China.

* Deceased.