PHYSICAL REVIEW D **93,** 032005 (2016)

Search for single production of scalar leptoquarks in proton-proton collisions at $\sqrt{s} = 8$ TeV

V. Khachatryan *et al.*[*]
(CMS Collaboration)
(Received 12 September 2015; published 24 February 2016)

A search is presented for the production of both first- and second-generation scalar leptoquarks with a final state of either two electrons and one jet or two muons and one jet. The search is based on a data sample of proton-proton collisions at center-of-mass energy $\sqrt{s} = 8$ TeV recorded with the CMS detector and corresponding to an integrated luminosity of 19.6 fb^{-1}. Upper limits are set on both the first- and second-generation leptoquark production cross sections as functions of the leptoquark mass and the leptoquark couplings to a lepton and a quark. Results are compared with theoretical predictions to obtain lower limits on the leptoquark mass. At 95% confidence level, single production of first-generation leptoquarks with a coupling and branching fraction of 1.0 is excluded for masses below 1730 GeV, and second-generation leptoquarks with a coupling and branching fraction of 1.0 is excluded for masses below 530 GeV. These are the best overall limits on the production of first-generation leptoquarks to date.

DOI: 10.1103/PhysRevD.93.032005

I. INTRODUCTION

Leptoquarks (LQ) are hypothetical color-triplet bosons with spin 0 (scalar LQ) or 1 (vector LQ), which are predicted by many extensions of the standard model (SM) of particle physics, such as grand unified theories [1–8], technicolor schemes [9–11], and composite models [12]. They carry a fractional electric charge ($\pm 1/3$ for LQs considered in this paper) and both baryon and lepton numbers and thus couple to a lepton and a quark. Existing experimental limits on flavor changing neutral currents and other rare processes disfavor leptoquarks that couple to a quark and lepton of more than one SM generation [13,14]. A discussion of the phenomenology of LQs at the LHC can be found elsewhere [15].

The production and decay of LQs at proton-proton colliders are characterized by the mass of the LQ particle, M_{LQ}; its decay branching fraction into a charged lepton and a quark, usually denoted as β; and the Yukawa coupling λ at the LQ-lepton-quark vertex. At hadron colliders, leptoquarks could be produced in pairs via gluon fusion and quark antiquark annihilation, and singly via quark-gluon fusion. Pair production of LQs does not depend on λ, while single production does, and thus the sensitivity of single LQ searches depends on λ. At lower masses, the cross sections for pair production are greater than those for single production. Single production cross sections decrease more slowly with mass, exceeding pair production at an order of 1 TeV for $\lambda = 0.6$.

Several experiments have searched for LQs. The H1 Collaboration has produced limits on various singly produced LQ types: the one to which to compare this search is the LQ called S_0^R in Ref. [16], for which they place a limit at 500 GeV, assuming $\lambda = 1.0$ and $\beta = 1.0$. The D0 Collaboration has produced limits on singly produced scalar LQs of 274 GeV, again assuming $\lambda = 1.0$ and $\beta = 1.0$ [17]. Limits from pair production of leptoquarks exclude leptoquark masses below 1010 GeV for the first generation and 1080 GeV for the second generation, for $\beta = 1.0$ [18].

The main single leptoquark production mode at the LHC is the resonant diagram shown in Fig. 1. However, significant contributions are made by the diagrams with nonresonant components shown in Fig. 2. These contributions increase with both the LQ mass and coupling; the invariant mass distribution of a first generation LQ, of mass $M_{\mathrm{LQ}} = 1$ TeV and coupling $\lambda = 1.0$, possesses a tail extending to very low masses that is comparable to the peak in magnitude. The reconstructed shape of the resonance peak itself is not strongly affected by λ.

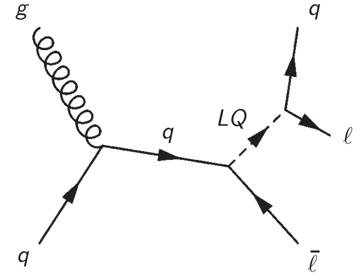

FIG. 1. The s-channel resonant LQ production diagram.

[*]Full author list given at the end of the article.

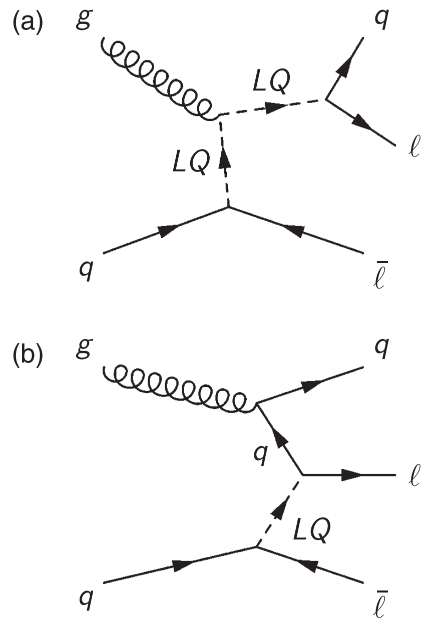

FIG. 2. The t-channel LQ production diagrams with nonresonant components. Diagram (a) has both resonant and nonresonant components. Diagram (b) is entirely non-resonant.

Also, interference with the $qg \rightarrow qZ/\gamma^{*} \rightarrow q\ell^{+}\ell^{-}$ SM process can occur at dilepton masses in the vicinity of the Z boson mass peak and at lower energies. Treatments for this interference region and the above-described low-mass off-shell tail of the lepton-jet mass distribution are detailed in Sec. V.

The final-state event signatures from the decays of singly produced LQs can be classified as either that of two charged leptons and a jet, where the LQ decays to a charged lepton and a quark, or that of a charged lepton, missing transverse energy, and a jet, where the LQ decays into a neutrino and a quark. The two signatures have branching fractions of β and $1-\beta$, respectively. For this study, and for S_0^R type LQs, β is 1.0, disregarding LQ decays to a neutrino and a quark. Because the parton distribution functions (PDF) of the proton are dominated by the u and d quarks, the single production of LQs of second and third generations is suppressed.

The charged leptons can be electrons, muons, or taus, corresponding to the three generations of LQs. In this paper two distinct signatures with charged leptons in the final state are considered: one with two high transverse momentum (p_{T}) electrons and one high-p_{T} jet (denoted as eej), and the other with two high-p_{T} muons and one high-p_{T} jet (denoted as $\mu\mu j$).

II. THE CMS DETECTOR

The central feature of the CMS apparatus is a superconducting solenoid of 6 m internal diameter, providing a magnetic field of 3.8 T. Within the solenoid volume are a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter (ECAL), and a brass and scintillator hadron calorimeter (HCAL), each composed of a barrel and two end-cap sections. Extensive forward calorimetry complements the coverage provided by the barrel and end-cap detectors. Muons are measured in gas-ionization detectors embedded in the steel flux-return yoke outside the solenoid.

The ECAL energy resolution for electrons with $E_{\mathrm{T}} \approx 45$ GeV from $Z \rightarrow ee$ decays is better than 2% in the central pseudorapidity region of the ECAL barrel ($|\eta| < 0.8$) and is between 2% and 5% elsewhere. For low-bremsstrahlung electrons, where 94% or more of their energy is contained within a 3×3 array of crystals, the energy resolution improves to 1.5% for $|\eta| < 0.8$ [19].

Muons are measured in the pseudorapidity range $|\eta| < 2.4$ with detection planes made using three technologies: drift tubes, cathode strip chambers, and resistive-plate chambers. Combining muon tracks derived from these measurements with tracks measured in the silicon tracker results in a relative p_{T} resolution for muons with $20 < p_{\mathrm{T}} < 100$ GeV of 1.3%–2.0% in the barrel and better than 6% in the end caps; the p_{T} resolution in the barrel is better than 10% for muons with p_{T} up to 1 TeV [20].

The first level of the CMS trigger system, composed of custom hardware processors, uses information from the calorimeters and muon detectors to select the most interesting events. The high-level trigger (HLT) processor farm further decreases the event rate from around 100 kHz to around 400 Hz, before data storage.

The particle-flow event algorithm reconstructs and identifies each individual particle with an optimized combination of information from the various elements of the CMS detector. The energy of photons is directly obtained from the ECAL measurement, corrected for zero-suppression effects. The energy of electrons is determined from a combination of the electron momentum at the primary interaction vertex as determined by the tracker, the energy of the corresponding ECAL cluster, and the energy sum of all bremsstrahlung photons spatially compatible with originating from the electron track. The energy of muons is obtained from the curvature of the corresponding track. The energy of charged hadrons is determined from a combination of their momentum measured in the tracker and the matching ECAL and HCAL energy deposits, corrected for zero-suppression effects and for the response function of the calorimeters to hadronic showers. Finally, the energy of neutral hadrons is obtained from the corresponding corrected ECAL and HCAL energy.

A more detailed description of the CMS detector, together with a definition of the coordinate system used and the relevant kinematic variables, can be found in [21].

III. DATA AND SIMULATION SAMPLES

The data were collected during the 8 TeV pp run in 2012 at the CERN LHC and correspond to an integrated luminosity of 19.6 fb^{-1}. In the eej channel, events are selected using a trigger that requires two electrons with $p_T > 33$ GeV and $|\eta| < 2.4$, and in the $\mu\mu j$ channel, events are selected using a trigger that requires one muon with $p_T > 40$ GeV and $|\eta| < 2.1$.

Simulated samples for the signal processes are generated for a range of leptoquark mass hypotheses between 300 and 3300 GeV and coupling hypotheses between 0.4 and 1.0 in the eej channel, and a range of leptoquark mass hypotheses between 300 and 1800 GeV and a coupling hypothesis of 1.0 in the $\mu\mu j$ channel. Production of LQs in the $\mu\mu j$ channel is suppressed because of the proton PDF as discussed in Sec. I.

The main sources of background are $t\bar{t}$, $Z/\gamma^* + \text{jets}$, $W + \text{jets}$, diboson $(ZZ, ZW, WW) + \text{jets}$, single top quark, and QCD multijet production. The $t\bar{t} + \text{jets}$ background shape is estimated from a study based on data described in Sec. VI; the simulation sample for the normalization of the $t\bar{t} + \text{jets}$ background as well as the samples for the $Z/\gamma^* + \text{jets}$ and $W + \text{jets}$ backgrounds are generated with MadGraph 5.1 [22]. Single top quark samples (s and t channels, and W boson associated production) are generated with powheg 1.0 [23–26], and diboson samples are generated with pythia (version 6.422) [27] using the Z2 tune [28]. The QCD multijet background is estimated from data.

For the simulation of signal samples, the CalcHEP [29] generator is used for the calculation of the matrix elements. The signal cross sections are computed at leading order (LO) with CalcHEP and are listed in Table III in Appendix A. Blank entries were not considered because of the small size of the cross section. The resonant cross sections σ_{res} are shown in Fig. 3 and are defined by the kinematics selections given in Sec. V.

The pythia and MadGraph simulations use the CTEQ6L1 [30] PDF sets, those produced with CalcHEP use the CTEQ6L PDFs, and the powheg simulation uses the CTEQ6m set. All of the simulations use pythia for the treatment of parton showering, hadronization, and underlying event effects. For both signal and background simulated samples, the simulation of the CMS detector is based on the Geant4 package [31]. All simulated samples include the effects of extra collisions in a single bunch crossing as well as collisions from nearby bunch crossings (out-of-time pileup and in-time pileup, respectively). The pileup profiles in simulation are reweighted to the distributions of the reconstructed vertices per bunch crossing in data collected by the CMS detector [32].

In the eej channel, the background and signal are rescaled by a uniform trigger efficiency scale factor of 0.996, which is measured in [33]. In the $\mu\mu j$ channel, the background and signal are rescaled by muon η-dependent efficiency factors of 0.94 ($|\eta| \leq 0.9$), 0.84 ($0.9 < |\eta| \leq 1.2$), and 0.82 ($1.2 < |\eta| \leq 2.1$). An uncertainty of 1% is assigned to these factors to account for variations during data-taking periods and statistical uncertainties.

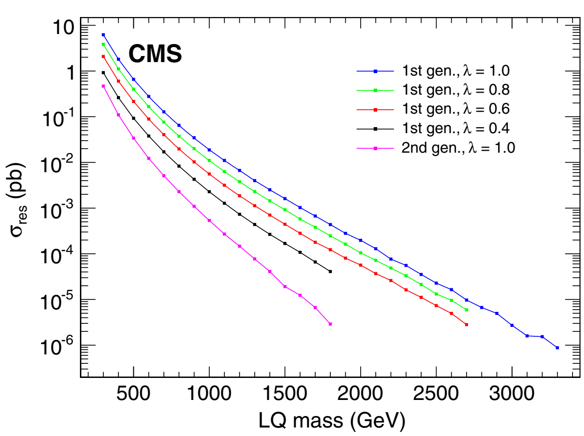

FIG. 3. Cross sections for single LQ production, calculated at LO in CalcHEP and scaled by the acceptance of the requirements described in Sec. V, as a function of the LQ mass in GeV.

IV. EVENT RECONSTRUCTION

Muons are reconstructed as tracks in the muon system that are "globally" matched to reconstructed tracks in the tracking system [20]. Muons are required to have $p_T > 45$ GeV and $|\eta| < 2.1$. Additionally, they are required to satisfy a set of criteria that is optimized for high p_T; they are reconstructed as "global" muons with tracks associated with hits from at least two muon detector planes together with at least one muon chamber hit that is included in the global track fit [20]. To perform a precise measurement of the p_T and to reduce background from muons from secondary decays in flight, at least eight hits are required in the tracker and at least one in the pixel detector. To minimize background from muons from cosmic ray backgrounds, the transverse impact parameter with respect to the primary vertex is required to be less than 2 mm, and the longitudinal distance is less than 5 mm. Muons are required to be isolated by applying an upper threshold on the relative tracker isolation of 0.1. The relative tracker isolation is defined as the ratio of the p_T of all tracks in the tracker coming from the same vertex, excluding the muon candidate track, in a cone of $\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} = 0.3$ (where ϕ is the azimuthal angle in radians) around the muon candidate track, and the muon p_T.

Electrons are required to have a reconstructed track in the central tracking system that is matched in η and ϕ to a cluster of ECAL crystals that has a shape consistent with an electromagnetic shower. The transverse impact parameter of the track with respect to the primary vertex is required to be less than 2 mm for electrons in the barrel ($|\eta| < 1.442$) and less than 5 mm for electrons in the end cap ($|\eta| > 1.560$). Electrons are required to be isolated from reconstructed tracks other than the matched track in the central tracking system and from additional energy deposits in the calorimeter. The transverse momentum sum of all tracks in a cone of $\Delta R = 0.5$ around the electron candidate's track and coming from the same vertex must be less than 5 GeV. Also, the transverse energy sum of the calorimeter energy deposits falling in the cone of $\Delta R = 0.5$ must be less than 3% of the candidate's transverse energy. An additional contribution accounting for the average contribution of other proton-proton collisions in the same bunch crossing is added to this sum. To reject electrons coming from photon conversions within the tracker material, the reconstructed electron track is required to have hits in all pixel layers. Electrons in the analysis have $p_T > 45$ GeV and $|\eta| < 2.1$ to match the muon requirements (excluding the transition region between barrel and end-cap detectors, $1.442 < |\eta| < 1.560$). Selection criteria for electron identification and isolation optimized for high energies are also applied [33].

Jets are reconstructed with the CMS particle-flow algorithm [34,35], which measures stable particles by combining information from all CMS subdetectors. The jet reconstruction algorithm used in this paper is the anti-k_T [36,37] algorithm with a distance parameter 0.5, which only considers tracks associated with the primary vertex. Jet momentum is determined as the vectorial sum of all particle momenta in the jet, and is found from simulation to be within 5% to 10% of the true momentum over the whole p_T spectrum and detector acceptance. An offset correction is applied to jet energies to take into account the contribution from additional proton-proton interactions within the same bunch crossing. Jet energy corrections are derived from simulation and are confirmed with *in situ* measurements of the energy balance in dijet and photon + jet events [38]. Additional selection criteria are applied to each event to remove spurious jetlike features originating from isolated noise patterns in certain HCAL regions. The jet energy resolution amounts typically to 15% at 10 GeV, 8% at 100 GeV, and 4% at 1 TeV, to be compared to about 40%, 12%, and 5% obtained when the calorimeters alone are used for jet clustering [34].

Jets are required to have $p_T > 45$ GeV, $|\eta| < 2.4$, and an angular separation from leptons of $\Delta R > 0.3$.

V. EVENT SELECTION

We require that events in both the eej and $\mu\mu j$ channels contain at least two leptons and at least one jet that satisfy the above identification criteria. Additional kinematic requirements are applied to remove regions in which the trigger and identification criteria are not at plateau efficiency and to reduce large backgrounds. This creates a basic preselection region: the jet p_T must be larger than 125 GeV, the dilepton invariant mass $M_{\ell\ell}$ must be larger than 110 GeV, and the scalar sum of transverse momenta of objects in the event $[S_T = p_T(\ell_1) + p_T(\ell_2) + p_T(j_1)]$ is required to exceed 250 GeV, where ℓ_1 is the highest p_T lepton in the event, ℓ_2 is the second-highest p_T lepton, and j_1 is the highest p_T jet. The two leptons in the events are required to have opposite charges.

After this initial selection, a final selection is optimized for each channel separately by maximizing $S/\sqrt{S+B}$, where S is the number of signal events in the simulation passing a given selection and B is the number of background events in the simulation passing the same selection. We optimize for each LQ mass hypothesis by varying the requirements on $M_{\ell j}$ and S_T. Here $M_{\ell j}$ is defined as the higher of the two possible lepton-jet mass combinations.

As discussed in Sec. I, owing to the unique aspects of single LQ decays, two generator level requirements are applied to the simulated signal samples. The first is $M_{\ell\ell} > 110$ GeV, to remove LQ decays that are in the Z boson interference region. The second is a requirement on $M_{\ell j}$, chosen to remove the t-channel diagram contributions in the low-mass off-shell region, while preserving most of the resonant signal. This requirement is set at $M_{\ell j} > 0.67 M_{LQ}$ for the first-generation studies and $M_{\ell j} > 0.75 M_{LQ}$ for the second-generation studies. The thresholds for $M_{\ell j}$ were chosen separately for each channel, because of the differences in the distribution shape. The dilepton invariant mass requirement at the generator level precisely matches the reconstruction level requirement at the preselection. These two requirements define the resonant region. Cross sections at the generator level before and after these requirements are provided in Table III, in Appendix A.

The eej channel selection after optimization is identical for all couplings. The threshold on S_T starts at 250 GeV for $M_{LQ} = 300$ GeV and increases linearly until it reaches a plateau value of 900 GeV at $M_{LQ} = 1125$ GeV. The $M_{\ell j}$ threshold starts at 200 GeV for $M_{LQ} = 300$ GeV and increases linearly until it plateaus at 1900 GeV above $M_{LQ} = 2000$ GeV. In the $\mu\mu j$ channel after optimization the threshold on S_T starts at 300 GeV for $M_{LQ} = 300$ GeV and increases linearly until it plateaus at 1000 GeV above $M_{LQ} = 1000$ GeV. The $M_{\ell j}$ threshold starts at 200 GeV for $M_{LQ} = 300$ GeV and increases linearly until it plateaus at 800 GeV above $M_{LQ} = 900$ GeV. The exact threshold values are listed in Tables IV and V in Appendix B.

VI. BACKGROUND ESTIMATIONS

The SM processes that mimic the signal signature are $Z/\gamma^* +$ jets, $t\bar{t}$, single top quark, diboson + jets, $W +$ jets, and QCD multijets events where the jets are misidentified as leptons. The dominant contributions come from the former two processes, whereas the other processes provide minor contributions to the total number of background events.

The contribution from the $Z/\gamma^* +$ jets background is estimated with a simulated sample that is normalized to agree with data at preselection in the ZZ-enriched region of

$80 < M_{\ell\ell} < 100$ GeV, where $M_{\ell\ell}$ is the dilepton invariant mass. With this selection the data sample (with non-$Z/\gamma^* +$ jets simulated samples subtracted) is compared to $Z/\gamma^* +$ jets in simulation. The resulting scale factor, representing the ratio of the measured yield to the predicted yield, is $R_Z = 0.98 \pm 0.01(\mathrm{stat})$ in both the eej and $\mu\mu j$ channels. This scale factor is then applied to the simulated $Z/\gamma^* +$ jets sample in the signal region of $M_{\ell\ell} > 110$ GeV. To account for possible mismodeling of the $p_{\mathrm{T}}(\ell\ell)$ spectrum of the $Z/\gamma^* +$ jets background sample, where $p_{\mathrm{T}}(\ell\ell)$ is the scalar sum of the two highest p_{T} leptons in the event, we perform a bin-by-bin rescaling of yields at preselection and full selection by scale factors measured in an inverted $M_{\ell\ell}$ selection ($M_{\ell\ell} < 110$ GeV). These scale factors differ from unity by 1% to 10%, depending on the $p_{\mathrm{T}}(\ell\ell)$ bin, and are applied to the $Z/\gamma^* +$ jets sample in the signal region of $M_{\ell\ell} > 110$ GeV.

We estimate the $t\bar{t}$ background with a $t\bar{t}$-enriched $e\mu$ sample in data, selected using the single muon trigger. We use a selection that is identical to our signal selection in terms of kinematics requirements, except that we require at least a single muon and a single electron rather than requiring two same-flavor leptons. The $e\mu$ sample is considered to be signal-free, because limits on flavor changing neutral currents imply that LQ processes do not present a different-flavor decay topology [13,14]. The $t\bar{t}$ background is largely dominant in the $e\mu$ sample with respect to the other backgrounds. This background is expected to produce the ee ($\mu\mu$) final state with half the probability of the $e\mu$ final state; thus the $e\mu$ sample is scaled by a factor of 1/2. This factor is multiplied by the ratio of electron (muon) identification and isolation efficiencies, $R_{ee/e\mu}$ ($R_{\mu\mu/e\mu}$). The estimate is further scaled by the ratio of the double-electron trigger efficiency and the single muon efficiency, $R_{\mathrm{trig},ee}$ in Eq. (3), or by the ratio of the efficiency of the single muon trigger in dimuon final states and the single muon efficiency, $R_{\mathrm{trig},\mu\mu}$ in Eq. (4). The resulting estimates of the number of $t\bar{t}$ events in the ee and $\mu\mu$ channels are

$$N_{ee}^{t\bar{t},\mathrm{est}} = (N_{e\mu}^{\mathrm{data}} - N_{e\mu}^{\mathrm{non}\text{-}t\bar{t}\ \mathrm{sim}})\frac{1}{2}R_{ee/e\mu}R_{\mathrm{trig},ee}, \qquad (1)$$

$$N_{\mu\mu}^{t\bar{t},\mathrm{est}} = (N_{e\mu}^{\mathrm{data}} - N_{e\mu}^{\mathrm{non}\text{-}t\bar{t}\ \mathrm{sim}})\frac{1}{2}R_{\mu\mu/e\mu}R_{\mathrm{trig},\mu\mu}, \qquad (2)$$

with

$$R_{\mathrm{trig},ee} = \frac{\epsilon_{ee}}{\epsilon_{\mu}}, \qquad (3)$$

$$R_{\mathrm{trig},\mu\mu} = \frac{1-(1-\epsilon_{\mu})^2}{\epsilon_{\mu}} = 2 - \epsilon_{\mu}, \qquad (4)$$

where ϵ_{μ} and ϵ_{ee} are the single-muon trigger and double-electron trigger efficiencies, respectively, and $N_{e\mu}^{\mathrm{data}}$ and $N_{e\mu}^{\mathrm{non}\text{-}t\bar{t}\ \mathrm{sim}}$ are the numbers of $e\mu$ events observed in data and estimated from backgrounds other than $t\bar{t}$, respectively. $R_{\mathrm{trig},\mu\mu}$ is the ratio of the efficiency of a single muon trigger on a dimuon sample over the efficiency on a single muon sample (the numerator is the likelihood of failure on two muons).

The contribution from QCD multijet processes is determined by a method that makes use of the fact that neither signal events nor events from other backgrounds produce final states with same-charge leptons at a significant level. We create four selections, with both opposite-sign (OS) and same-sign (SS) charge requirements, as well as isolated and

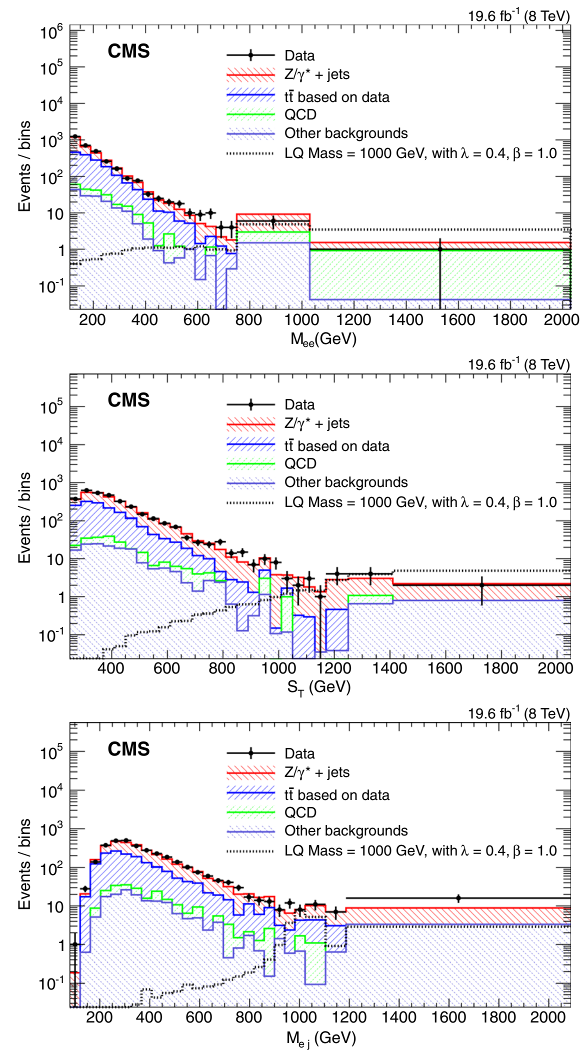

FIG. 4. Distributions of M_{ee} (top left), S_{T} (top right), and M_{ej} (bottom) at preselection in the eej channel. "Other backgrounds" include diboson, $W +$ jets, and single top quark contributions. The points represent the data, and the stacked histograms show the expected background contributions. The open histogram shows the prediction for an LQ signal for $M_{\mathrm{LQ}} = 1000$ GeV and $\lambda = 0.4$. The horizontal error bars on the data points represent the bin widths. The last bin includes overflow.

nonisolated requirements. Electrons in isolated events must pass the isolation criteria optimized for high-energy electrons [33], and muons are required to have a relative tracker isolation less than 0.1, as discussed in Sec. IV. Nonisolated events are those with leptons failing these criteria. The four selections are as follows:

$$\begin{pmatrix} A & B \\ C & D \end{pmatrix} = \begin{pmatrix} \text{OS} + \text{isolated} & \text{OS} + \text{nonisolated} \\ \text{SS} + \text{isolated} & \text{SS} + \text{nonisolated} \end{pmatrix}. \quad (5)$$

The shape of the background is taken from the SS region with isolation requirements, and the normalization is obtained from the ratio between the number of OS events and the number of SS events in the nonisolated selection. Thus, the number of events, $N^{\text{QCD,est}}$, is estimated by

$$N^{\text{QCD,est}} = r_{B/D} N_C^{(\text{data–‘non-QCD’ sim})}, \quad (6)$$

where $N_C^{(\text{data–‘non-QCD’ sim})}$ is the number of events in region C of Eq. (5) and $r_{B/D}$ is the ratio of the number of events (measured in data with simulated non-QCD backgrounds subtracted) in regions B and D. The result is that QCD multijet processes account for 2% (1%) of the total SM background in the eej ($\mu\mu j$) channel.

The contributions of the remaining backgrounds (diboson + jets, W + jets, single top quark) are small and are determined entirely from simulation.

The preselection level distributions in $M_{\ell\ell}$, S_{T}, and $M_{\ell j}$ are shown in Figs. 4 and 5 for the observed data and estimated backgrounds, where they are compared with a signal LQ mass of 1000 GeV in the eej channel, and with a signal LQ of mass 600 GeV, in the $\mu\mu j$ channel. In all plots the $Z/\gamma^* +$ jets prediction is normalized to data and the $t\bar{t}$ prediction is taken from the study based on data. Data and background are found to be in agreement. The numbers of events selected in data and in the backgrounds at each final selection (for each hypothesis mass) are shown in Tables VI, VII, and VIII in Appendix C.

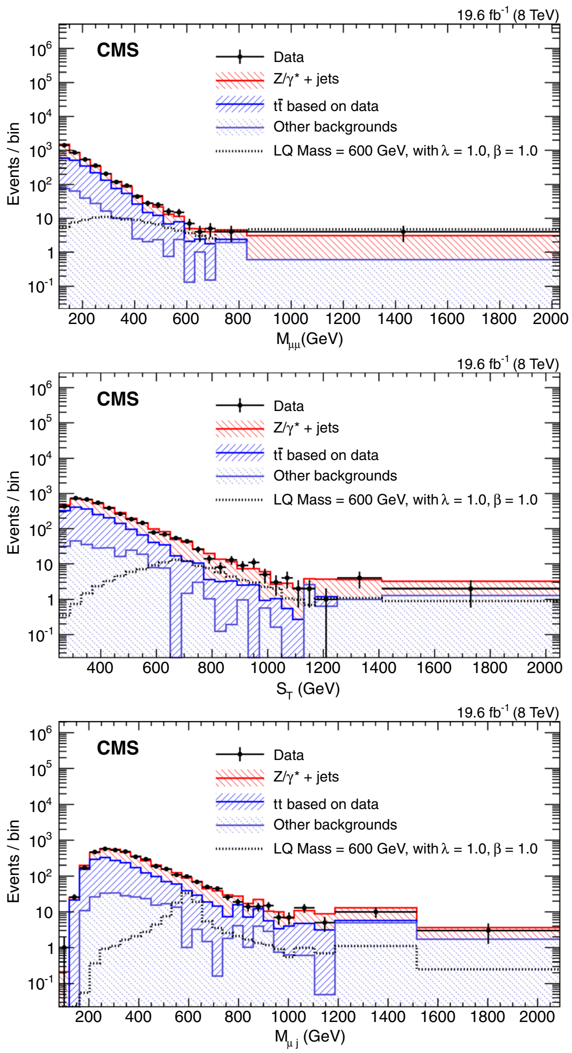

FIG. 5. Distributions of $M_{\mu\mu}$ (top left), S_{T} (top right), and $M_{\mu j}$ (bottom) at preselection in the $\mu\mu j$ channel. “Other backgrounds” include diboson, W + jets, single top quark, and QCD multijet contributions. The points represent the data, and the stacked histograms show the expected background contributions. The open histogram shows the prediction for an LQ signal for $M_{\mathrm{LQ}} =$ 600 GeV and $\lambda = 1.0$. The horizontal error bars on the data points represent the bin widths. The last bin includes overflow.

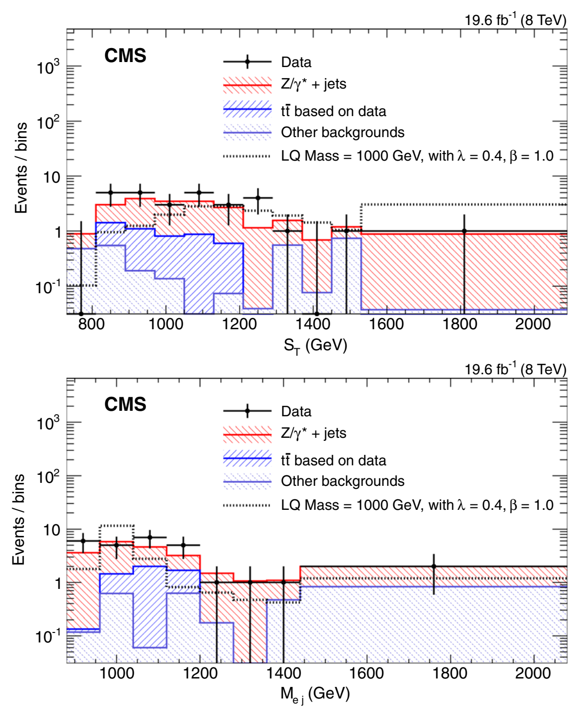

FIG. 6. Distributions of S_{T} and M_{ej} at final selection, in the eej channel. The points represent the data, and the stacked histograms show the expected background contributions. The open histogram shows the prediction for an LQ signal for $M_{\mathrm{LQ}} = 1000$ GeV and $\lambda = 0.4$. The horizontal error bars on the data points represent the bin width. The last bin includes overflow.

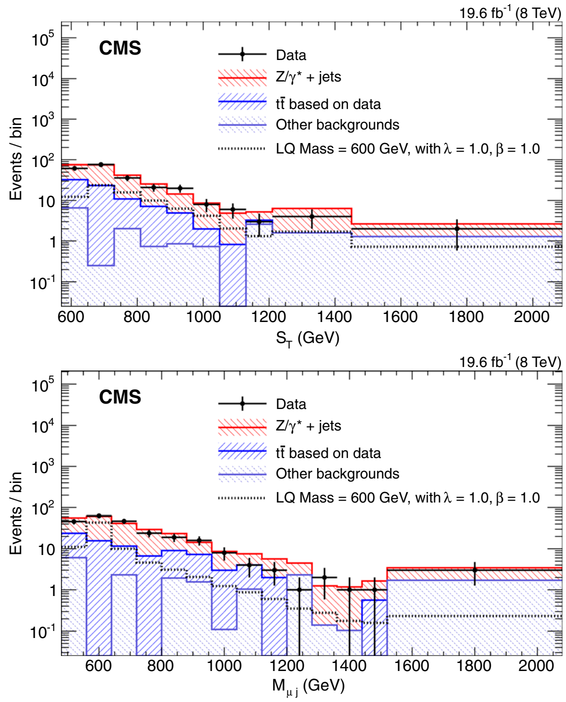

FIG. 7. Distributions of S_T and $M_{\mu j}$ at final selection, in the $\mu\mu j$ channel. The points represent the data, and the stacked histograms show the expected background contributions. The open histogram shows the prediction for an LQ signal for $M_{LQ} = 600$ GeV and $\lambda = 1.0$. The horizontal error bars on the data points represent the bin width. The last bin includes overflow.

The observed data and background predictions are compared after the final selection for $\lambda = 0.4$ and $M_{LQ} = 1000$ GeV in the eej channel in Fig. 6. They are compared for $\lambda = 1.0$ and $M_{LQ} = 600$ GeV in the $\mu\mu j$ channel in Fig. 7.

VII. SYSTEMATIC UNCERTAINTIES

The sources of systematic uncertainties considered in this analysis are listed below. To determine the uncertainties in signal and background, each kinematic quantity listed is varied individually according to its uncertainty, and the final event yields are remeasured to determine the variation in the predicted number of background and signal events.

Jet energy scale and resolution uncertainties are estimated by assigning p_T- and η-dependent uncertainties in jet energy corrections, as discussed in Ref. [38], and by varying the jet p_T according to the magnitude of that uncertainty. The uncertainty in the jet energy resolution is assessed by modifying the p_T difference between the particle level and reconstructed jets by an η-dependent value between 5% and 30% for most jets [38].

Uncertainties in the charged-lepton momentum scale and resolution also introduce uncertainties in the final event acceptance. Energy scale uncertainties of 0.6% in the ECAL barrel and 1.5% in the ECAL end cap are assigned to electrons [39], and uncertainties of 10% in both the ECAL barrel and the end cap are applied to the electron energy resolution [39]. There is an uncertainty of 0.6% per electron in reconstruction, identification, and isolation requirements. For muons, a p_T-dependent scale uncertainty of 5% (p_T/1 TeV) is applied, as well as a 1%–4% p_T-dependent resolution uncertainty [20]. In the case of momentum scale uncertainties the momentum is directly varied, and in the case of momentum resolution uncertainties the lepton momentum is subjected to a Gaussian random smearing within the uncertainty. A 2% per muon uncertainty in reconstruction, identification, and isolation requirements, as well as a 1% muon HLT efficiency uncertainty, are assumed as well.

Other important sources of systematic uncertainty are related to the modeling of the backgrounds in the simulation. The uncertainty in the $Z/\gamma^* +$ jets background shape is determined by using simulated samples with renormalization and factorization scales and matrix-element parton-shower matching thresholds varied by a factor of 2 up and down. The scale factors for the normalization of the $Z/\gamma^* +$ jets background are assigned an uncertainty of 0.6% in both channels, and the normalization of the $t\bar{t}$ background is assigned an uncertainty of 0.5% in both channels, based on the statistical uncertainties measured in the studies described in Sec. VI. An additional uncertainty of 4% is applied to the $t\bar{t}$ background normalization in the $\mu\mu j$ channel to account for possible signal contamination from first generation LQs in the control sample (the contamination is extremely small in the other channel because of the suppressed second generation signal). An uncertainty on $Z/\gamma^* +$ jets background from the $p_T(\ell\ell)$ scale factors is assessed by taking the weighted average of the uncertainties from each $p_T(\ell\ell)$ bin. The estimate of the QCD multijet background from data has an uncertainty of 15%.

An uncertainty in the modeling of pileup in simulation is determined by varying the number of simulated pileup interactions up and down by 6% [40], and an uncertainty of 2.6% on the measured integrated luminosity is applied [41].

Uncertainties in the signal acceptance, the background acceptance, and the cross sections, due to the PDF choice of 4%–10% for signal and 3%–9% for background, are applied, following the PDF4LHC recommendations described in Refs. [42,43].

Finally, a statistical uncertainty associated with the size of the simulated sample is included for both background and signal.

The systematic uncertainties are listed in Table I, together with their effects on signal and background yields, corresponding to the final selection values optimized for $M_{LQ} = 600$ GeV. The PDF uncertainty is larger in the $\mu\mu j$ channel because of the large uncertainty associated with the s-quark PDF.

VIII. RESULTS

The observed data are consistent with the no-signal hypothesis. We set an upper limit on the leptoquark cross section by using the CL_S modified frequentist method [44,45] with the final event yields. A log-normal probability

TABLE I. Systematic uncertainties (in %) and their effects on total signal (S) and background (B) in both channels for $M_{\mathrm{LQ}} = 600$ GeV final selection.

Systematic uncertainty	eej S [%]	eej B [%]	$\mu\mu j$ S [%]	$\mu\mu j$ B [%]
Jet energy scale	0.3	1.0	0.7	1.4
Jet energy resolution	0.1	0.3	0.3	0.4
Electron energy scale	0.2	2.1	…	…
Electron energy resolution	0.1	0.6	…	…
Muon energy scale	…	…	2.4	3.7
Muon energy resolution	…	…	0.2	1.1
Electron reco/ID/iso	1.2	0.1	…	…
Muon reco/ID/iso	…	…	2.0	0.1
Trigger	…	…	1.0	0.1
QCD normalization	…	0.0	…	0.1
$t\bar{t}$ normalization	…	0.2	…	1.1
$Z/\gamma^* +$ jets normalization	…	0.3	…	0.3
$Z/\gamma^* +$ jets shape	…	5.2	…	5.6
$Z/\gamma^* +$ jets $p_{\mathrm{T}}(\ell\ell)$ scale factor	…	2.6	…	3.0
PDF	3.5	3.0	3.0	2.8
Pileup	2.5	0.6	2.8	1.9
Integrated luminosity	2.6	0.3	2.6	0.2
Statistical uncertainty	1.3	3.5	1.4	4.3
Total	5.3	8.1	6.05	8.1

function is used to model the systematic uncertainties, whereas statistical uncertainties are described with gamma distributions with widths determined according to the number of events simulated or measured in data control regions.

To isolate the limits for resonant LQ production, we apply the resonant requirements at the generator level on both the lepton + jet mass, $M(\ell, j) > (0.67$ or $0.75)M_{\mathrm{LQ}}$ (for the first- or second-generation LQs, respectively), and on the dilepton mass, $M_{\ell\ell} > 110$ GeV. These requirements make the limits extracted from data more conservative and are discussed in Sec. V. A resonant cross section σ_{res} is computed with respect to those requirements. Limits are then computed with the reduced sample of simulated signal events and compared to σ_{res}.

The 95% confidence level (C.L.) upper limits on $\sigma_{\mathrm{res}}\beta$ as a function of leptoquark mass are shown in Fig. 8 together with the resonant cross section predictions for the scalar leptoquark single production cross section. The uncertainty band on the theoretical cross section prediction corresponds to uncertainties in the total cross section due to PDF variations with an additional +70% uncertainty, because of the k factor from next-to-leading-order corrections [46]. The observed limits are listed in Tables III and IV in Appendix B.

By comparing the observed upper limit with the theoretical production cross section times the branching fraction, we exclude single leptoquark production at 95% C.L. for LQ masses below the values given in Table II.

Limits on the single production of the S_0^R type LQ from the H1 Collaboration exclude LQ production up to 500 GeV ($\lambda = 1.0$) and up to 350 GeV ($\lambda = 0.6$) [16].

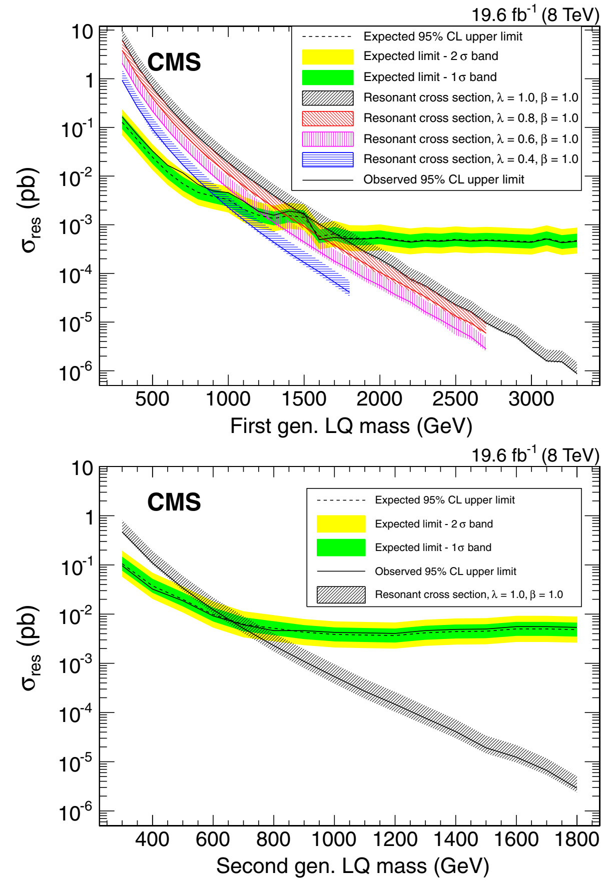

FIG. 8. Expected and observed upper limits at 95% C.L. on first- and second-generation leptoquark single production resonant cross sections as a function of the leptoquark mass. First generation limits are shown in the left plot with a resonant region of $M_{\ell j} > 0.66M_{\mathrm{LQ}}$, $M_{\ell\ell} > 110$ GeV, and second generation limits are shown in the right plot with a resonant region of $M_{\ell j} > 0.75M_{\mathrm{LQ}}$, $M_{\ell\ell} > 110$ GeV. The uncertainty bands on the observed limit represent the 68% and 95% confidence intervals. The uncertainty band on the theoretical cross section includes uncertainties due to PDF variation and the k factor.

IX. SUMMARY

A search has been performed for the single production of first- and second-generation scalar leptoquarks in final states with two electrons and a jet or two muons and a jet using a data set of proton-proton collisions at 8 TeV corresponding to

TABLE II. The 95% C.L. lower limits on scalar LQ masses ($\beta = 1.0$).

LQ generation, coupling	Excluded mass [GeV]
First gen., $\lambda = 0.4$	860
First gen., $\lambda = 0.6$	1175
First gen., $\lambda = 0.8$	1355
First gen., $\lambda = 1.0$	1755
Second gen., $\lambda = 1.0$	660

an integrated luminosity of 19.6 fb^{-1}. The selection criteria are optimized for each leptoquark signal mass hypothesis. The number of observed candidates for each mass hypothesis agrees with the number of expected standard model background events. Single production of first- (second-) generation leptoquarks with a coupling of 1.0 is excluded at 95% confidence level for masses below 1755 (660) GeV. These are the most stringent limits to date for single production. The first-generation limits for couplings greater than 0.6 are stronger than those from pair production and are the most stringent overall limits on leptoquark production in the first generation to date.

ACKNOWLEDGMENTS

We congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC and thank the technical and administrative staffs at CERN and at other CMS institutes for their contributions to the success of the CMS effort. In addition, we gratefully acknowledge the computing centers and personnel of the Worldwide LHC Computing Grid for delivering so effectively the computing infrastructure essential to our analyses. Finally, we acknowledge the enduring support for the construction and operation of the LHC and the CMS detector provided by the following funding agencies: the Austrian Federal Ministry of Science, Research and Economy and the Austrian Science Fund; the Belgian Fonds de la Recherche Scientifique, and Fonds voor Wetenschappelijk Onderzoek; the Brazilian Funding Agencies (CNPq, CAPES, FAPERJ, and FAPESP); the Bulgarian Ministry of Education and Science; CERN; the Chinese Academy of Sciences, Ministry of Science and Technology, and National Natural Science Foundation of China; the Colombian Funding Agency (COLCIENCIAS); the Croatian Ministry of Science, Education and Sport, and the Croatian Science Foundation; the Research Promotion Foundation, Cyprus; the Ministry of Education and Research, Estonian Research Council via IUT23-4 and IUT23-6 and EuropeanWe congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC and thank the technical and administrative staffs at CERN and at other CMS institutes for their contributions to the success of the CMS effort. In addition, we gratefully acknowledge the computing centers and personnel of the Worldwide LHC Computing Grid for delivering so effectively the computing infrastructure essential to our analyses. Finally, we acknowledge the enduring support for the construction and operation of the LHC and the CMS detector provided by the following funding agencies: the Austrian Federal Ministry of Science, Research and Economy and the Austrian Science Fund; the Belgian Fonds de la Recherche Scientifique, and Fonds voor Wetenschappelijk Onderzoek; the Brazilian Funding Agencies (CNPq, CAPES, FAPERJ, and Regional Development Fund, Estonia; the Academy of Finland, Finnish Ministry of Education and CultureWe congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC and thank the technical and administrative staffs at CERN and at other CMS institutes for their contributions to the success of the CMS effort. In addition, we gratefully acknowledge the computing centers and personnel of the Worldwide LHC Computing Grid for delivering so effectively the computing infrastructure essential to our analyses. Finally, we acknowledge the enduring support for the construction and operation of the LHC and the CMS detector provided by the following funding agencies: the Austrian Federal Ministry of Science, Research and Economy and the Austrian Science Fund; the Belgian Fonds de la Recherche Scientifique, and Fonds voor Wetenschappelijk Onderzoek; the Brazilian Funding Agencies (CNPq, CAPES, FAPERJ, and FAPESP); the Bulgarian Ministry of Education and Science; CERN; the Chinese Academy of Sciences, Ministry of Science and Technology, and National Natural Science Foundation of China; the Colombian Funding Agency (COLCIENCIAS); the Croatian Ministry of Science, Education and Sport, and the Croatian Science Foundation; the Research Promotion Foundation, Cyprus; the Ministry of Education and Research, Estonian Research Council via IUT23-4 and IUT23-6 and European Regional Development Fund, Estonia; the Academy of Finland, Finnish Ministry of Education and Culture, and Helsinki Institute of Physics; the Institut National de Physique Nucléaire et de Physique des Particules/CNRS, and Commissariat à l'Énergie Atomique et aux Énergies Alternatives/CEA, France; the Bundesministerium für Bildung und Forschung, Deutsche Forschungsgemeinschaft, and Helmholtz-Gemeinschaft Deutscher Forschungszentren, Germany; the General Secretariat for Research and Technology, Greece; the National Scientific Research Foundation, and National Innovation Office, Hungary; the Department of Atomic Energy and the Department of Science and Technology, India; the Institute for Studies in Theoretical Physics and Mathematics, Iran; the Science Foundation, Ireland; the Istituto Nazionale di Fisica Nucleare, Italy; the Ministry of Science, ICT and Future Planning, and National Research Foundation (NRF), Republic of Korea; the Lithuanian Academy of Sciences; the Ministry of Education, and University of Malaya (Malaysia); the Mexican Funding Agencies (CINVESTAV, CONACYT, SEP, and UASLP-FAI); the Ministry of Business, Innovation and Employment, New Zealand; the Pakistan Atomic Energy Commission; the Ministry of Science and Higher Education and the National Science Centre, Poland; the Fundação para a Ciência e a Tecnologia, Portugal; JINR, Dubna; the Ministry of Education and Science of the Russian Federation, the Federal Agency of Atomic Energy of the Russian Federation, Russian Academy of Sciences, and the Russian Foundation for Basic Research; the Ministry of Education, Science and Technological Development of Serbia; the Secretaría de Estado de Investigación, Desarrollo e Innovación and Programa Consolider-Ingenio 2010, Spain; the Swiss Funding Agencies (ETH Board, ETH Zurich, PSI, SNF, UniZH, Canton Zurich, and SER); the Ministry of Science and Technology, Taipei; the Thailand Center of Excellence in Physics, the Institute for the Promotion of Teaching Science and Technology of Thailand, Special Task Force for Activating Research and the National Science and Technology

Development Agency of Thailand; the Scientific and Technical Research Council of Turkey, and Turkish Atomic Energy Authority; the National Academy of Sciences of Ukraine, and State Fund for Fundamental Researches, Ukraine; the Science and Technology Facilities Council, UK; the U.S. Department of Energy, and the U.S. National Science Foundation. Individuals have received support from the Marie Curie program and the European Research Council and EPLANET (European Union); the Leventis Foundation; the A. P. Sloan Foundation; the Alexander von Humboldt Foundation; the Belgian Federal Science Policy Office; the Fonds pour la Formation à la Recherche dans l'Industrie et dans l'Agriculture (FRIA-Belgium); the Agentschap voor Innovatie door Wetenschap en Technologie (IWT-Belgium); the Ministry of Education, Youth and Sports (MEYS) of the Czech Republic; the Council of Science and Industrial Research, India; the HOMING PLUS program of the Foundation for Polish Science, cofinanced from European Union, Regional Development Fund; the OPUS program of the National Science Center (Poland); the Compagnia di San Paolo (Torino); the Consorzio per la Fisica (Trieste); MIUR Project No. 20108T4XTM (Italy); the Thalis and Aristeia programs cofinanced by EU-ESF and the Greek NSRF; the National Priorities Research Program by Qatar National Research Fund; the Rachadapisek Sompot Fund for Postdoctoral Fellowship, Chulalongkorn University (Thailand); and the Welch Foundation, Contract No. C-1845.

APPENDIX A: SIGNAL CROSS SECTIONS

This section contains Table III with first- and second-generation LQ cross sections, computed at LO in CALCHEP and scaled for the resonant selection.

TABLE III. Signal cross sections calculated at LO in CALCHEP. Resonant cross sections scaled by the acceptance of the selections described in Sec. V are listed under each corresponding LO cross section.

M_{LQ} [GeV]	First gen., $\lambda = 0.4$ [pb]	First gen., $\lambda = 0.6$ [pb]	First gen., $\lambda = 0.8$ [pb]	First gen., $\lambda = 1.0$ [pb]	Second gen., $\lambda = 1.0$ [pb]
300	1.04	2.39	4.38	7.12	0.579
	0.921	2.08	3.83	6.21	0.468
400	0.291	0.675	1.25	2.06	0.139
	0.261	0.601	1.11	1.81	0.11
500	0.102	0.239	0.451	0.755	0.0446
	0.0924	0.215	0.4	0.658	0.034
600	0.0413	0.0984	0.189	0.322	0.0176
	0.0378	0.0891	0.166	0.278	0.0122
700	0.0186	0.0451	0.088	0.154	0.00807
	0.017	0.0404	0.0763	0.128	0.00511
800	0.00904	0.0223	0.0446	0.0797	0.00418
	0.00829	0.0198	0.0374	0.0647	0.00229
900	0.00467	0.0118	0.0242	0.0443	0.00237
	0.00427	0.0103	0.02	0.0346	0.00109
1000	0.00254	0.00657	0.0139	0.0261	0.00145
	0.00228	0.00559	0.0111	0.0188	0.000537
1200	0.00084	0.00234	0.00526	0.0104	0.00064
	0.000733	0.00186	0.00378	0.00667	0.000147
1400	0.00032	0.00097	0.00233	0.00485	0.00033
	0.000267	0.000705	0.00144	0.00252	4.09×10^5
1600	0.00014	0.00045	0.00117	0.00255	0.00019
	0.000108	0.000282	0.000577	0.00103	1.24×10^5
1800	6×10^5	0.00024	0.00065	0.00147	0.00011
	4.1×10^5	0.000123	0.000247	0.000436	2.9×10^6
2000		0.00014	0.00039	0.00092	
		5.66×10^5	0.000105	0.000197	
2500		5×10^5	0.00014	0.00035	
		7.35×10^6	1.32×10^5	2.28×10^5	
3000				0.00016	
				2.72×10^6	
3300				0.00011	
				8.79×10^7	

APPENDIX B: FINAL SELECTION

This section contains Tables IV and V, the reference tables for the final selection criteria and the corresponding observed limits for the eej and the $\mu\mu j$ channels.

TABLE IV. The eej channel threshold values for S_T, M_{ej}, and $M_{ej,\mathrm{gen}}$ vs LQ mass (for all couplings), and the corresponding observed limits.

M_{LQ} [GeV]	S_T threshold [GeV]	M_{ej} threshold [GeV]	$M_{ej,\mathrm{gen}}$ threshold [GeV]	Observed limit on σ_{res} [pb]
300	250	200	200	0.16
400	320	300	266	0.07
500	400	400	333	0.033
600	480	500	400	0.017
700	560	600	466	0.012
800	640	700	533	0.0067
900	720	800	600	0.0049
1000	800	900	666	0.0046
1200	900	1100	800	0.0019
1400	900	1300	933	0.0019
1600	900	1500	1066	0.00049
1800	900	1700	1200	0.00051
2000	900	1900	1333	0.00053
2500	900	1900	1666	0.00048
3000	900	1900	2000	0.00044
3300	900	1900	2200	0.00046

TABLE V. The $\mu\mu j$ channel threshold values for S_T, $M_{\mu j}$, and $M_{\mu j,\mathrm{gen}}$ vs LQ mass, and the corresponding observed limits.

M_{LQ} [GeV]	S_T threshold [GeV]	$M_{\mu j}$ threshold [GeV]	$M_{\mu j,\mathrm{gen}}$ threshold [GeV]	Observed limit on σ_{res} [pb]
300	300	200	225	0.096
400	400	300	300	0.032
500	500	400	375	0.019
600	600	500	450	0.0092
700	700	600	525	0.0061
800	800	700	600	0.0046
900	900	800	675	0.0046
1000	1000	800	750	0.0042
1200	1000	800	900	0.004
1400	1000	800	1050	0.0049
1600	1000	800	1200	0.0056
1800	1000	800	1350	0.0054

APPENDIX C: EVENT YIELDS

This section contains Tables VI, VII, and VIII, tables of data, background, and signal yields after the final selection. Event counts vary between the two channels due to differences in the optimized thresholds for S_T and $M_{\ell j}$ as well as differences in the electron and muon efficiencies. The first listed uncertainty is statistical, the second is systematic; in cases where only one uncertainty is listed it is statistical.

TABLE VI. Data and background yields after final selection for the eej channel for first-generation LQs, shown with statistical and systematic uncertainties. "Other backgrounds" refers to diboson + jets, W + jets, single-top quark, and QCD. The values do not change above 2000 GeV.

M_{LQ} [GeV]	Data	Total background	$Z/\gamma^* +$ jets	$t\bar{t}$	Other backgrounds
300	3007	$2830 \pm 40 \pm 170$	1362 ± 19	1238 ± 27	230 ± 15
400	1766	$1660 \pm 30 \pm 110$	873 ± 15	637 ± 19	151 ± 12
500	807	$736 \pm 18 \pm 49$	409.8 ± 9.6	251 ± 12	75.6 ± 8.6
600	370	$329 \pm 12 \pm 24$	192.9 ± 6.3	102.7 ± 7.9	33.3 ± 5.8
700	186	$149 \pm 8 \pm 12$	91.6 ± 4.1	40.9 ± 4.9	16.7 ± 4.2
800	91	$73.7 \pm 5.6 \pm 7.0$	46.3 ± 2.8	21.1 ± 3.5	6.3 ± 3.3
900	46	$36.9 \pm 3.4 \pm 6.6$	23.9 ± 1.9	7.6 ± 2.1	5.5 ± 1.9
1000	28	$18.3 \pm 2.5 \pm 4.8$	11.7 ± 1.3	3.7 ± 1.5	2.9 ± 1.5
1200	7	$5.2 \pm 1.6 \pm 1.8$	3.17 ± 0.61	$0.39^{+0.53}_{-0.39}$	1.6 ± 1.3
1400	4	$1.8 \pm 1.3 \pm 1.5$	1.0 ± 0.31	$0.0^{+0.41}_{-0.0}$	$0.8^{+1.2}_{-0.8}$
1600	0	$0.2^{+1.2+0.4}_{-0.2-0.2}$	0.17 ± 0.12	$0.0^{+0.41}_{-0.0}$	$0.1^{+1.2}_{-0.1}$
1800	0	$0.0^{+1.3}_{-0.0} \pm 0.0$	$0.0^{+0.22}_{-0.0}$	$0.0^{+0.41}_{-0.0}$	$0.0^{+1.2}_{-0.0}$
2000	0	$0.0^{+1.3}_{-0.0} \pm 0.0$	$0.0^{+0.22}_{-0.0}$	$0.0^{+0.41}_{-0.0}$	$0.0^{+1.2}_{-0.0}$

TABLE VII. Signal yields after final selection in the eej channel for first-generation LQs shown with statistical and systematic uncertainties, for different values of λ and for $\beta = 1.0$.

M_{LQ} [GeV]	$\lambda = 0.4$	$\lambda = 0.6$	$\lambda = 0.8$	$\lambda = 1.0$
300	$3540 \pm 60 \pm 200$	$7880 \pm 130 \pm 420$	$14390 \pm 240 \pm 820$	$22600 \pm 400 \pm 1200$
400	$1577 \pm 22 \pm 85$	$3600 \pm 50 \pm 190$	$6330 \pm 80 \pm 340$	$9990 \pm 150 \pm 530$
500	$670 \pm 10 \pm 160$	$1504 \pm 18 \pm 85$	$2670 \pm 30 \pm 140$	$4270 \pm 60 \pm 210$
600	$289 \pm 3 \pm 18$	$666 \pm 8 \pm 33$	$1188 \pm 14 \pm 76$	$1920 \pm 30 \pm 100$
700	$138.1 \pm 1.6 \pm 6.2$	$320 \pm 4 \pm 15$	$559 \pm 7 \pm 27$	$885 \pm 12 \pm 41$
800	$67.8 \pm 0.8 \pm 3.3$	$158.2 \pm 1.8 \pm 6.5$	$275 \pm 3 \pm 12$	$446 \pm 6 \pm 19$
900	$35.9 \pm 0.4 \pm 1.4$	$82.5 \pm 0.9 \pm 3.3$	$145.7 \pm 1.8 \pm 5.6$	$231 \pm 3 \pm 11$
1000	$19.26 \pm 0.22 \pm 0.88$	$43.6 \pm 0.5 \pm 1.8$	$77.9 \pm 1.0 \pm 3.1$	$118.3 \pm 1.8 \pm 4.6$
1200	$6.14 \pm 0.07 \pm 0.25$	$13.8 \pm 0.2 \pm 1.2$	$25.44 \pm 0.35 \pm 0.98$	$39.7 \pm 0.6 \pm 1.9$
1400	$2.2 \pm 0.0 \pm 0.2$	$5.07 \pm 0.07 \pm 0.28$	$9.13 \pm 0.14 \pm 0.58$	$13.78 \pm 0.26 \pm 0.88$
1600	$0.8 \pm 0.0 \pm 0.1$	$1.89 \pm 0.03 \pm 0.15$	$3.3 \pm 0.06 \pm 0.26$	$5.24 \pm 0.12 \pm 0.46$
1800	$0.29 \pm 0.0 \pm 0.03$	$0.76 \pm 0.01 \pm 0.08$	$1.31 \pm 0.03 \pm 0.13$	$2.02 \pm 0.06 \pm 0.24$
2000		$0.31 \pm 0.01 \pm 0.04$	$0.497 \pm 0.014 \pm 0.071$	$0.81 \pm 0.03 \pm 0.12$
2500		$0.039 \pm 0.001 \pm 0.032$	$0.064 \pm 0.003 \pm 0.016$	$0.102 \pm 0.006 \pm 0.023$
3000				$0.0134 \pm 0.0015 \pm 0.0029$
3300				$0.004 \pm 0.001 \pm 0.001$

TABLE VIII. Data, signal, and background yields after final selection in the $\mu\mu j$ channel shown with statistical and total systematic uncertainties, for $\lambda = 1.0$ and $\beta = 1.0$. "Other backgrounds" refers to diboson + jets, W + jets, single-top quark, and QCD.

M_{LQ} [GeV]	Signal	Data	Total background	Z/γ^* + jets	$t\bar{t}$	Other backgrounds
300	$2130 \pm 30 \pm 290$	3036	$3120 \pm 40 \pm 370$	1541 ± 20	1362 ± 32	214 ± 15
400	$721 \pm 9 \pm 91$	1371	$1440 \pm 30 \pm 170$	774 ± 14	548 ± 21	118 ± 11
500	$228 \pm 3 \pm 27$	558	$577 \pm 17 \pm 75$	340.7 ± 8.6	182 ± 12	54.3 ± 8.1
600	$77.1 \pm 1.1 \pm 9.5$	238	$246 \pm 10 \pm 32$	155.6 ± 5.6	73.8 ± 7.7	16.4 ± 4.3
700	$28.0 \pm 0.5 \pm 3.7$	100	$102 \pm 6 \pm 14$	70.1 ± 3.5	22.3 ± 4.3	9.5 ± 2.7
800	$10.7 \pm 0.2 \pm 1.6$	48	$52.3 \pm 4.7 \pm 7.6$	32.3 ± 2.3	12.3 ± 3.2	7.7 ± 2.6
900	$4.67 \pm 0.1 \pm 0.84$	27	$25.7 \pm 3.5 \pm 4.6$	14.9 ± 1.5	4.8 ± 2.0	5.9 ± 2.5
1000	$2.1 \pm 0.05 \pm 0.46$	17	$15.5 \pm 3.0 \pm 3.3$	7.6 ± 1.1	2.6 ± 1.5	5.3 ± 2.4
1200	$0.7 \pm 0.02 \pm 0.22$	17	$15.5 \pm 3.0 \pm 3.3$	7.6 ± 1.1	2.6 ± 1.5	5.3 ± 2.4
1400	$0.195 \pm 0.008 \pm 0.088$	17	$15.5 \pm 3.0 \pm 3.3$	7.6 ± 1.1	2.6 ± 1.5	5.3 ± 2.4
1600	$0.06 \pm 0.003 \pm 0.032$	17	$15.5 \pm 3.0 \pm 3.3$	7.6 ± 1.1	2.6 ± 1.5	5.3 ± 2.4
1800	$0.0135 \pm 0.0012 \pm 0.0066$	17	$15.5 \pm 3.0 \pm 3.3$	7.6 ± 1.1	2.6 ± 1.5	5.3 ± 2.4

[1] H. Georgi and S. L. Glashow, Unity of All Elementary-Particle Forces, Phys. Rev. Lett. **32**, 438 (1974).

[2] J. C. Pati and A. Salam, Unified lepton-hadron symmetry and a gauge theory of the basic interactions, Phys. Rev. D **8**, 1240 (1973).

[3] J. C. Pati and A. Salam, Lepton number as the fourth color, Phys. Rev. D **10**, 275 (1974).

[4] H. Murayama and T. Yanagida, A viable SU(5) GUT with light leptoquark bosons, Mod. Phys. Lett. A **07**, 147 (1992).

[5] H. Fritzsch and P. Minkowski, Unified interactions of leptons and hadrons, Ann. Phys. (N.Y.) **93**, 193 (1975).

[6] G. Senjanovic and A. Sokorac, Light leptoquarks in SO(10), Z. Phys. C **20**, 255 (1983).

[7] P. H. Frampton and B. H. Lee, SU(15) Grand Unification, Phys. Rev. Lett. **65**, 2209 (1990).

[8] P. H. Frampton and T. W. Kephart, Higgs sector and proton decay in SU(15) grand unification, Phys. Rev. D **42**, 3892 (1990).

[9] S. Dimopoulos and L. Susskind, Mass without scalars, Nucl. Phys. **B155**, 237 (1979).

[10] S. Dimopoulos, Technicolored signatures, Nucl. Phys. **B168**, 69 (1980).

[11] E. Farhi and L. Susskind, Technicolor, Phys. Rep. **74**, 277 (1981).

[12] B. Schrempp and F. Schrempp, Light leptoquarks, Phys. Lett. B **153**, 101 (1985).

[13] W. Buchmuller and D. Wyler, Constraints on SU(5) type leptoquarks, Phys. Lett. B **177**, 377 (1986).

[14] O. Shanker, $\pi\ell 2$, $K\ell 3$, and K^0-$\bar{K}^0$ Constraints on leptoquarks and supersymmetric particles, Nucl. Phys. **B204**, 375 (1982).

[15] A. Belyaev, C. Leroy, R. Mehdiyev, and A. Pukhov, Leptoquark single and pair production at LHC with CalcHEP/CompHEP in the complete model, J. High Energy Phys. 09 (2005) 005.

[16] F. D. Aaron *et al.* (H1 Collaboration), Search for first generation leptoquarks in ep collisions at HERA, Phys. Lett. B **704**, 388 (2011).

[17] V. M. Abazov *et al.* (D0 Collaboration), Search for single production of scalar leptoquarks in $p\bar{p}$ collisions decaying into muons and quarks with the D0 detector, Phys. Lett. B **647**, 74 (2007).

[18] CMS Collaboration, Search for pair production of first- and second-generation leptoquarks at 8 TeV [Phys. Rev. D (to be published)].

[19] CMS Collaboration, Energy calibration and resolution of the CMS electromagnetic calorimeter in pp collisions at $\sqrt{s} = 7$ TeV, J. Instrum. **8**, P09009 (2013).

[20] CMS Collaboration, Performance of CMS muon reconstruction in pp collision events at $\sqrt{s} = 7$ TeV, J. Instrum. **7**, P10002 (2012).

[21] CMS Collaboration, The CMS experiment at the CERN LHC, J. Instrum. **3**, S08004 (2008).

[22] J. Alwall and M. Zaro, The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations, J. High Energy Phys. 07 (2014) 079.

[23] S. Alioli, P. Nason, C. Oleari, and E. Re, A general framework for implementing NLO calculations in shower Monte Carlo programs: The POWHEG box, J. High Energy Phys. 06 (2010) 043.

[24] S. Alioli, P. Nason, C. Oleari, and E. Re, NLO single-top production matched with shower in POWHEG: s- and t-channel contributions, J. High Energy Phys. 09 (2009) 111(E).

[25] S. Frixione, P. Nason, and C. Oleari, Matching NLO QCD computations with parton shower simulations: The POWHEG method, J. High Energy Phys. 11 (2007) 070.

[26] P. Nason, New method for combining NLO QCD with shower Monte Carlo algorithms, J. High Energy Phys. 11 (2004) 040.

[27] T. Sjöstrand, S. Mrenna, and P. Z. Skands, PYTHIA 6.4 physics and manual, J. High Energy Phys. 05 (2006) 026.

[28] CMS Collaboration, Charged particle multiplicities in pp interactions at $\sqrt{s} = 0.9$, 2.36, and 7 TeV, J. High Energy Phys. 01 (2010) 079.

[29] M. Bondarenko *et al.*, High Energy Physics Model Database: Towards decoding of the underlying theory (within Les Houches 2011: Physics at TeV Colliders New Physics Working Group Report), arXiv:1203.1488.

[30] J. Pumplin, D. R. Stump, J. Huston, H.-L. Lai, P. Nadolsky, and W.-K. Tung, New generation of parton distributions with uncertainties from global QCD analysis, J. High Energy Phys. 07 (2002) 012.

[31] S. Agostinelli *et al.* (GEANT4 Collaboration), GEANT4—A simulation toolkit, Nucl. Instrum. Methods Phys. Res., Sect. A **506**, 250 (2003).

[32] CMS Collaboration, Performance of missing transverse momentum reconstruction algorithms in proton-proton collisions at $\sqrt{s} = 8$ TeV with the CMS Detector, CMS Physics Analysis Summary No. CMS-PAS-JME-12-002, 2012, http://cdsweb.cern.ch/record/1543527.

[33] CMS Collaboration, Search for physics beyond the standard model in dilepton mass spectra in proton-proton collisions at $\sqrt{s} = 8$ TeV, J. High Energy Phys. 04 (2014) 025.

[34] CMS Collaboration, Particle-flow event reconstruction in CMS and performance for jets, taus, and E_T^{miss}, CMS Physics Analysis Summary No. CMS-PAS-PFT-09-001, 2009, http://cdsweb.cern.ch/record/1194487.

[35] CMS Collaboration, Commissioning of the particle-flow event reconstruction with the first LHC collisions recorded in the CMS detector, CMS Physics Analysis Summary No. CMS-PAS-PFT-10-001, 2010, http://cdsweb.cern.ch/record/1247373.

[36] M. Cacciari, G. P. Salam, and G. Soyez, The anti-k_t jet clustering algorithm, J. High Energy Phys. 04 (2008) 063.

[37] M. Cacciari, G. P. Salam, and G. Soyez, FastJet user manual, Eur. Phys. J. C **72**, 1896 (2012).

[38] CMS Collaboration, Determination of jet energy calibration and transverse momentum resolution in CMS, J. Instrum. **6**, P11002 (2011).

[39] CMS Collaboration, Performance of electron reconstruction and selection with the CMS detector in proton-proton collisions at $\sqrt{s} = 8$ TeV, J. Instrum. **10**, P06005 (2015).

[40] CMS Collaboration, Measurement of the inelastic proton-proton cross section at $\sqrt{s} = 7$ TeV, Phys. Lett. B **722**, 5 (2013).

[41] CMS Collaboration, CMS luminosity based on pixel cluster counting—Summer 2013 update, CMS Physics Analysis Summary No. CMS-PAS-LUM-13-001, 2013, http://cdsweb.cern.ch/record/1598864.

[42] M. Botje, J. Butterworth, A. Cooper-Sarkar, A. de Roeck, J. Feltesse, S. Forte, A. Glazov, J. Huston, R. McNulty, T. Sjöstrand, and R. S. Thorne, The PDF4LHC working group interim recommendations, arXiv:1101.0538.

[43] S. Alekhin *et al.*, The PDF4LHC working group interim report, arXiv:1101.0536.

[44] A. L. Read, Presentation of search results: The CL_s technique, J. Phys. G **28**, 2693 (2002).

[45] T. Junk, Confidence level computation for combining searches with small statistics, Nucl. Instrum. Methods Phys. Res., Sect. A **434**, 435 (1999).

[46] J. B. Hammett and D. A. Ross, NLO leptoquark production and decay: The narrow-width approximation and beyond, J. High Energy Phys. 07 (2015) 148.

V. Khachatryan,[1] A. M. Sirunyan,[1] A. Tumasyan,[1] W. Adam,[2] E. Asilar,[2] T. Bergauer,[2] J. Brandstetter,[2] E. Brondolin,[2] M. Dragicevic,[2] J. Erö,[2] M. Flechl,[2] M. Friedl,[2] R. Frühwirth,[2,b] V. M. Ghete,[2] C. Hartl,[2] N. Hörmann,[2] J. Hrubec,[2] M. Jeitler,[2,b] V. Knünz,[2] A. König,[2] M. Krammer,[2,b] I. Krätschmer,[2] D. Liko,[2] T. Matsushita,[2] I. Mikulec,[2] D. Rabady,[2,c] B. Rahbaran,[2] H. Rohringer,[2] J. Schieck,[2,b] R. Schöfbeck,[2] J. Strauss,[2] W. Treberer-Treberspurg,[2] W. Waltenberger,[2] C.-E. Wulz,[2,b] V. Mossolov,[3] N. Shumeiko,[3] J. Suarez Gonzalez,[3] S. Alderweireldt,[4] T. Cornelis,[4] E. A. De Wolf,[4] X. Janssen,[4] A. Knutsson,[4] J. Lauwers,[4] S. Luyckx,[4] S. Ochesanu,[4] R. Rougny,[4] M. Van De Klundert,[4] H. Van Haevermaet,[4] P. Van Mechelen,[4] N. Van Remortel,[4] A. Van Spilbeeck,[4] S. Abu Zeid,[5] F. Blekman,[5] J. D'Hondt,[5] N. Daci,[5] I. De Bruyn,[5] K. Deroover,[5] N. Heracleous,[5] J. Keaveney,[5] S. Lowette,[5] L. Moreels,[5] A. Olbrechts,[5] Q. Python,[5] D. Strom,[5] S. Tavernier,[5] W. Van Doninck,[5] P. Van Mulders,[5] G. P. Van Onsem,[5] I. Van Parijs,[5] P. Barria,[6] C. Caillol,[6] B. Clerbaux,[6] G. De Lentdecker,[6] H. Delannoy,[6] D. Dobur,[6] G. Fasanella,[6] L. Favart,[6] A. P. R. Gay,[6] A. Grebenyuk,[6] T. Lenzi,[6] A. Léonard,[6] T. Maerschalk,[6] A. Mohammadi,[6] L. Perniè,[6] A. Randle-conde,[6] T. Reis,[6] T. Seva,[6] L. Thomas,[6] C. Vander Velde,[6] P. Vanlaer,[6] J. Wang,[6] F. Zenoni,[6] F. Zhang,[6,d] K. Beernaert,[7] L. Benucci,[7] A. Cimmino,[7] S. Crucy,[7] A. Fagot,[7] G. Garcia,[7] M. Gul,[7] J. Mccartin,[7] A. A. Ocampo Rios,[7] D. Poyraz,[7] D. Ryckbosch,[7] S. Salva,[7] M. Sigamani,[7] N. Strobbe,[7] M. Tytgat,[7] W. Van Driessche,[7] E. Yazgan,[7] N. Zaganidis,[7] S. Basegmez,[8] C. Beluffi,[8,e] O. Bondu,[8] G. Bruno,[8] R. Castello,[8] A. Caudron,[8] L. Ceard,[8] G. G. Da Silveira,[8] C. Delaere,[8] D. Favart,[8] L. Forthomme,[8] A. Giammanco,[8,f] J. Hollar,[8] A. Jafari,[8] P. Jez,[8] M. Komm,[8] V. Lemaitre,[8] A. Mertens,[8] C. Nuttens,[8] L. Perrini,[8] A. Pin,[8] K. Piotrzkowski,[8] A. Popov,[8,g] L. Quertenmont,[8] M. Selvaggi,[8] M. Vidal Marono,[8] N. Beliy,[9] T. Caebergs,[9] G. H. Hammad,[9] W. L. Aldá Júnior,[10] G. A. Alves,[10] L. Brito,[10] M. Correa Martins Junior,[10] T. Dos Reis Martins,[10] C. Hensel,[10]

C. Mora Herrera,[10] A. Moraes,[10] M. E. Pol,[10] P. Rebello Teles,[10] E. Belchior Batista Das Chagas,[11] W. Carvalho,[11] J. Chinellato,[11,h] A. Custódio,[11] E. M. Da Costa,[11] D. De Jesus Damiao,[11] C. De Oliveira Martins,[11] S. Fonseca De Souza,[11] L. M. Huertas Guativa,[11] H. Malbouisson,[11] D. Matos Figueiredo,[11] L. Mundim,[11] H. Nogima,[11] W. L. Prado Da Silva,[11] A. Santoro,[11] A. Sznajder,[11] E. J. Tonelli Manganote,[11,h] A. Vilela Pereira,[11] S. Ahuja,[12a] C. A. Bernardes,[12b] A. De Souza Santos,[12a] S. Dogra,[12a] T. R. Fernandez Perez Tomei,[12a] E. M. Gregores,[12b] P. G. Mercadante,[12b] C. S. Moon,[12a,i] S. F. Novaes,[12a] Sandra S. Padula,[12a] D. Romero Abad,[12a] J. C. Ruiz Vargas,[12a] A. Aleksandrov,[13] V. Genchev,[13,c] R. Hadjiiska,[13] P. Iaydjiev,[13] A. Marinov,[13] S. Piperov,[13] M. Rodozov,[13] S. Stoykova,[13] G. Sultanov,[13] M. Vutova,[13] A. Dimitrov,[14] I. Glushkov,[14] L. Litov,[14] B. Pavlov,[14] P. Petkov,[14] M. Ahmad,[15] J. G. Bian,[15] G. M. Chen,[15] H. S. Chen,[15] M. Chen,[15] T. Cheng,[15] R. Du,[15] C. H. Jiang,[15] R. Plestina,[15,j] F. Romeo,[15] S. M. Shaheen,[15] J. Tao,[15] C. Wang,[15] Z. Wang,[15] H. Zhang,[15] C. Asawatangtrakuldee,[16] Y. Ban,[16] Q. Li,[16] S. Liu,[16] Y. Mao,[16] S. J. Qian,[16] D. Wang,[16] Z. Xu,[16] W. Zou,[16] C. Avila,[17] A. Cabrera,[17] L. F. Chaparro Sierra,[17] C. Florez,[17] J. P. Gomez,[17] B. Gomez Moreno,[17] J. C. Sanabria,[17] N. Godinovic,[18] D. Lelas,[18] D. Polic,[18] I. Puljak,[18] Z. Antunovic,[19] M. Kovac,[19] V. Brigljevic,[20] K. Kadija,[20] J. Luetic,[20] L. Sudic,[20] A. Attikis,[21] G. Mavromanolakis,[21] J. Mousa,[21] C. Nicolaou,[21] F. Ptochos,[21] P. A. Razis,[21] H. Rykaczewski,[21] M. Bodlak,[22] M. Finger,[22,k] M. Finger Jr.,[22,k] R. Aly,[23,l] S. Aly,[23,l] S. Elgammal,[23,m] A. Ellithi Kamel,[23,n] A. Lotfy,[23,o] M. A. Mahmoud,[23,o] A. Radi,[23,m,p] E. Salama,[23] A. Sayed,[23,p,m] B. Calpas,[24] M. Kadastik,[24] M. Murumaa,[24] M. Raidal,[24] A. Tiko,[24] C. Veelken,[24] P. Eerola,[25] M. Voutilainen,[25] J. Härkönen,[26] V. Karimäki,[26] R. Kinnunen,[26] T. Lampén,[26] K. Lassila-Perini,[26] S. Lehti,[26] T. Lindén,[26] P. Luukka,[26] T. Mäenpää,[26] J. Pekkanen,[26] T. Peltola,[26] E. Tuominen,[26] J. Tuominiemi,[26] E. Tuovinen,[26] L. Wendland,[26] J. Talvitie,[27] T. Tuuva,[27] M. Besancon,[28] F. Couderc,[28] M. Dejardin,[28] D. Denegri,[28] B. Fabbro,[28] J. L. Faure,[28] C. Favaro,[28] F. Ferri,[28] S. Ganjour,[28] A. Givernaud,[28] P. Gras,[28] G. Hamel de Monchenault,[28] P. Jarry,[28] E. Locci,[28] M. Machet,[28] J. Malcles,[28] J. Rander,[28] A. Rosowsky,[28] M. Titov,[28] A. Zghiche,[28] S. Baffioni,[29] F. Beaudette,[29] P. Busson,[29] L. Cadamuro,[29] E. Chapon,[29] C. Charlot,[29] T. Dahms,[29] O. Davignon,[29] N. Filipovic,[29] A. Florent,[29] R. Granier de Cassagnac,[29] S. Lisniak,[29] L. Mastrolorenzo,[29] P. Miné,[29] I. N. Naranjo,[29] M. Nguyen,[29] C. Ochando,[29] G. Ortona,[29] P. Paganini,[29] S. Regnard,[29] R. Salerno,[29] J. B. Sauvan,[29] Y. Sirois,[29] T. Strebler,[29] Y. Yilmaz,[29] A. Zabi,[29] J.-L. Agram,[30,q] J. Andrea,[30] A. Aubin,[30] D. Bloch,[30] J.-M. Brom,[30] M. Buttignol,[30] E. C. Chabert,[30] N. Chanon,[30] C. Collard,[30] E. Conte,[30,q] J.-C. Fontaine,[30,q] D. Gelé,[30] U. Goerlach,[30] C. Goetzmann,[30] A.-C. Le Bihan,[30] J. A. Merlin,[30,c] K. Skovpen,[30] P. Van Hove,[30] S. Gadrat,[31] S. Beauceron,[32] C. Bernet,[32,j] G. Boudoul,[32] E. Bouvier,[32] S. Brochet,[32] C. A. Carrillo Montoya,[32] J. Chasserat,[32] R. Chierici,[32] D. Contardo,[32] B. Courbon,[32] P. Depasse,[32] H. El Mamouni,[32] J. Fan,[32] J. Fay,[32] S. Gascon,[32] M. Gouzevitch,[32] B. Ille,[32] I. B. Laktineh,[32] M. Lethuillier,[32] L. Mirabito,[32] A. L. Pequegnot,[32] S. Perries,[32] J. D. Ruiz Alvarez,[32] D. Sabes,[32] L. Sgandurra,[32] V. Sordini,[32] M. Vander Donckt,[32] P. Verdier,[32] S. Viret,[32] H. Xiao,[32] T. Toriashvili,[33,r] I. Bagaturia,[34,s] C. Autermann,[35] S. Beranek,[35] M. Edelhoff,[35] L. Feld,[35] A. Heister,[35] M. K. Kiesel,[35] K. Klein,[35] M. Lipinski,[35] A. Ostapchuk,[35] M. Preuten,[35] F. Raupach,[35] J. Sammet,[35] S. Schael,[35] J. F. Schulte,[35] T. Verlage,[35] H. Weber,[35] B. Wittmer,[35] V. Zhukov,[35,g] M. Ata,[36] M. Brodski,[36] E. Dietz-Laursonn,[36] D. Duchardt,[36] M. Endres,[36] M. Erdmann,[36] S. Erdweg,[36] T. Esch,[36] R. Fischer,[36] A. Güth,[36] T. Hebbeker,[36] C. Heidemann,[36] K. Hoepfner,[36] D. Klingebiel,[36] S. Knutzen,[36] P. Kreuzer,[36] M. Merschmeyer,[36] A. Meyer,[36] P. Millet,[36] M. Olschewski,[36] K. Padeken,[36] P. Papacz,[36] T. Pook,[36] M. Radziej,[36] H. Reithler,[36] M. Rieger,[36] F. Scheuch,[36] L. Sonnenschein,[36] D. Teyssier,[36] S. Thüer,[36] V. Cherepanov,[37] Y. Erdogan,[37] G. Flügge,[37] H. Geenen,[37] M. Geisler,[37] W. Haj Ahmad,[37] F. Hoehle,[37] B. Kargoll,[37] T. Kress,[37] Y. Kuessel,[37] A. Künsken,[37] J. Lingemann,[37,c] A. Nehrkorn,[37] A. Nowack,[37] I. M. Nugent,[37] C. Pistone,[37] O. Pooth,[37] A. Stahl,[37] M. Aldaya Martin,[38] I. Asin,[38] N. Bartosik,[38] O. Behnke,[38] U. Behrens,[38] A. J. Bell,[38] K. Borras,[38] A. Burgmeier,[38] A. Cakir,[38] L. Calligaris,[38] A. Campbell,[38] S. Choudhury,[38] F. Costanza,[38] C. Diez Pardos,[38] G. Dolinska,[38] S. Dooling,[38] T. Dorland,[38] G. Eckerlin,[38] D. Eckstein,[38] T. Eichhorn,[38] G. Flucke,[38] E. Gallo,[38] J. Garay Garcia,[38] A. Geiser,[38] A. Gizhko,[38] P. Gunnellini,[38] J. Hauk,[38] M. Hempel,[38,t] H. Jung,[38] A. Kalogeropoulos,[38] O. Karacheban,[38,t] M. Kasemann,[38] P. Katsas,[38] J. Kieseler,[38] C. Kleinwort,[38] I. Korol,[38] W. Lange,[38] J. Leonard,[38] K. Lipka,[38] A. Lobanov,[38] W. Lohmann,[38,t] R. Mankel,[38] I. Marfin,[38,t] I.-A. Melzer-Pellmann,[38] A. B. Meyer,[38] G. Mittag,[38] J. Mnich,[38] A. Mussgiller,[38] S. Naumann-Emme,[38] A. Nayak,[38] E. Ntomari,[38] H. Perrey,[38] D. Pitzl,[38] R. Placakyte,[38] A. Raspereza,[38] P. M. Ribeiro Cipriano,[38] B. Roland,[38] M. Ö. Sahin,[38] J. Salfeld-Nebgen,[38] P. Saxena,[38] T. Schoerner-Sadenius,[38] M. Schröder,[38] C. Seitz,[38] S. Spannagel,[38] K. D. Trippkewitz,[38] C. Wissing,[38] V. Blobel,[39] M. Centis Vignali,[39] A. R. Draeger,[39] J. Erfle,[39] E. Garutti,[39] K. Goebel,[39] D. Gonzalez,[39] M. Görner,[39] J. Haller,[39] M. Hoffmann,[39] R. S. Höing,[39] A. Junkes,[39] R. Klanner,[39] R. Kogler,[39] T. Lapsien,[39] T. Lenz,[39] I. Marchesini,[39] D. Marconi,[39] D. Nowatschin,[39] J. Ott,[39] F. Pantaleo,[39,c] T. Peiffer,[39] A. Perieanu,[39] N. Pietsch,[39]

J. Poehlsen,[39] D. Rathjens,[39] C. Sander,[39] H. Schettler,[39] P. Schleper,[39] E. Schlieckau,[39] A. Schmidt,[39] J. Schwandt,[39] M. Seidel,[39] V. Sola,[39] H. Stadie,[39] G. Steinbrück,[39] H. Tholen,[39] D. Troendle,[39] E. Usai,[39] L. Vanelderen,[39] A. Vanhoefer,[39] M. Akbiyik,[40] C. Barth,[40] C. Baus,[40] J. Berger,[40] C. Böser,[40] E. Butz,[40] T. Chwalek,[40] F. Colombo,[40] W. De Boer,[40] A. Descroix,[40] A. Dierlamm,[40] M. Feindt,[40] F. Frensch,[40] M. Giffels,[40] A. Gilbert,[40] F. Hartmann,[40,c] U. Husemann,[40] F. Kassel,[40,c] I. Katkov,[40,g] A. Kornmayer,[40,c] P. Lobelle Pardo,[40] M. U. Mozer,[40] T. Müller,[40] Th. Müller,[40] M. Plagge,[40] G. Quast,[40] K. Rabbertz,[40] S. Röcker,[40] F. Roscher,[40] H. J. Simonis,[40] F. M. Stober,[40] R. Ulrich,[40] J. Wagner-Kuhr,[40] S. Wayand,[40] T. Weiler,[40] C. Wöhrmann,[40] R. Wolf,[40] G. Anagnostou,[41] G. Daskalakis,[41] T. Geralis,[41] V. A. Giakoumopoulou,[41] A. Kyriakis,[41] D. Loukas,[41] A. Markou,[41] A. Psallidas,[41] I. Topsis-Giotis,[41] A. Agapitos,[42] S. Kesisoglou,[42] A. Panagiotou,[42] N. Saoulidou,[42] E. Tziaferi,[42] I. Evangelou,[43] G. Flouris,[43] C. Foudas,[43] P. Kokkas,[43] N. Loukas,[43] N. Manthos,[43] I. Papadopoulos,[43] E. Paradas,[43] J. Strologas,[43] G. Bencze,[44] C. Hajdu,[44] A. Hazi,[44] P. Hidas,[44] D. Horvath,[44,u] F. Sikler,[44] V. Veszpremi,[44] G. Vesztergombi,[44,v] A. J. Zsigmond,[44] N. Beni,[45] S. Czellar,[45] J. Karancsi,[45,w] J. Molnar,[45] Z. Szillasi,[45] M. Bartók,[46,x] A. Makovec,[46] P. Raics,[46] Z. L. Trocsanyi,[46] B. Ujvari,[46] P. Mal,[47] K. Mandal,[47] N. Sahoo,[47] S. K. Swain,[47] S. Bansal,[48] S. B. Beri,[48] V. Bhatnagar,[48] R. Chawla,[48] R. Gupta,[48] U. Bhawandeep,[48] A. K. Kalsi,[48] A. Kaur,[48] M. Kaur,[48] R. Kumar,[48] A. Mehta,[48] M. Mittal,[48] N. Nishu,[48] J. B. Singh,[48] G. Walia,[48] Ashok Kumar,[49] Arun Kumar,[49] A. Bhardwaj,[49] B. C. Choudhary,[49] R. B. Garg,[49] A. Kumar,[49] S. Malhotra,[49] M. Naimuddin,[49] K. Ranjan,[49] R. Sharma,[49] V. Sharma,[49] S. Banerjee,[50] S. Bhattacharya,[50] K. Chatterjee,[50] S. Dey,[50] S. Dutta,[50] Sa. Jain,[50] Sh. Jain,[50] R. Khurana,[50] N. Majumdar,[50] A. Modak,[50] K. Mondal,[50] S. Mukherjee,[50] S. Mukhopadhyay,[50] A. Roy,[50] D. Roy,[50] S. Roy Chowdhury,[50] S. Sarkar,[50] M. Sharan,[50] A. Abdulsalam,[51] R. Chudasama,[51] D. Dutta,[51] V. Jha,[51] V. Kumar,[51] A. K. Mohanty,[51,c] L. M. Pant,[51] P. Shukla,[51] A. Topkar,[51] T. Aziz,[52] S. Banerjee,[52] S. Bhowmik,[52,y] R. M. Chatterjee,[52] R. K. Dewanjee,[52] S. Dugad,[52] S. Ganguly,[52] S. Ghosh,[52] M. Guchait,[52] A. Gurtu,[52,z] G. Kole,[52] S. Kumar,[52] B. Mahakud,[52] M. Maity,[52,y] G. Majumder,[52] K. Mazumdar,[52] S. Mitra,[52] G. B. Mohanty,[52] B. Parida,[52] T. Sarkar,[52,y] K. Sudhakar,[52] N. Sur,[52] B. Sutar,[52] N. Wickramage,[52,aa] S. Sharma,[53] H. Bakhshiansohi,[54] H. Behnamian,[54] S. M. Etesami,[54,bb] A. Fahim,[54,cc] R. Goldouzian,[54] M. Khakzad,[54] M. Mohammadi Najafabadi,[54] M. Naseri,[54] S. Paktinat Mehdiabadi,[54] F. Rezaei Hosseinabadi,[54] B. Safarzadeh,[54,dd] M. Zeinali,[54] M. Felcini,[55] M. Grunewald,[55] M. Abbrescia,[56a,56b] C. Calabria,[56a,56b] C. Caputo,[56a,56b] S. S. Chhibra,[56a,56b] A. Colaleo,[56a] D. Creanza,[56a,56c] L. Cristella,[56a,56b] N. De Filippis,[56a,56c] M. De Palma,[56a,56b] L. Fiore,[56a] G. Iaselli,[56a,56c] G. Maggi,[56a,56c] M. Maggi,[56a] G. Miniello,[56a,56b] S. My,[56a,56c] S. Nuzzo,[56a,56b] A. Pompili,[56a,56b] G. Pugliese,[56a,56c] R. Radogna,[56a,56b] A. Ranieri,[56a] G. Selvaggi,[56a,56b] A. Sharma,[56a] L. Silvestris,[56a,c] R. Venditti,[56a,56b] P. Verwilligen,[56a] G. Abbiendi,[57a] C. Battilana,[57a,c] A. C. Benvenuti,[57a] D. Bonacorsi,[57a,57b] S. Braibant-Giacomelli,[57a,57b] L. Brigliadori,[57a,57b] R. Campanini,[57a,57b] P. Capiluppi,[57a,57b] A. Castro,[57a,57b] F. R. Cavallo,[57a] G. Codispoti,[57a,57b] M. Cuffiani,[57a,57b] G. M. Dallavalle,[57a] F. Fabbri,[57a] A. Fanfani,[57a,57b] D. Fasanella,[57a,57b] P. Giacomelli,[57a] C. Grandi,[57a] L. Guiducci,[57a,57b] S. Marcellini,[57a] G. Masetti,[57a] A. Montanari,[57a] F. L. Navarria,[57a,57b] A. Perrotta,[57a] A. M. Rossi,[57a,57b] T. Rovelli,[57a,57b] G. P. Siroli,[57a,57b] N. Tosi,[57a,57b] R. Travaglini,[57a,57b] G. Cappello,[58a] M. Chiorboli,[58a,58b] S. Costa,[58a,58b] F. Giordano,[58a,58c] R. Potenza,[58a,58b] A. Tricomi,[58a,58b] C. Tuve,[58a,58b] G. Barbagli,[59a] V. Ciulli,[59a,59b] C. Civinini,[59a] R. D'Alessandro,[59a,59b] E. Focardi,[59a,59b] S. Gonzi,[59a,59b] V. Gori,[59a,59b] P. Lenzi,[59a,59b] M. Meschini,[59a] S. Paoletti,[59a] G. Sguazzoni,[59a] A. Tropiano,[59a,59b] L. Viliani,[59a,59b] L. Benussi,[60] S. Bianco,[60] F. Fabbri,[60] D. Piccolo,[60] V. Calvelli,[61a,61b] F. Ferro,[61a] M. Lo Vetere,[61a,61b] E. Robutti,[61a] S. Tosi,[61a,61b] M. E. Dinardo,[62a,62b] S. Fiorendi,[62a,62b] S. Gennai,[62a] R. Gerosa,[62a,62b] A. Ghezzi,[62a,62b] P. Govoni,[62a,62b] S. Malvezzi,[62a] R. A. Manzoni,[62a,62b] B. Marzocchi,[62a,62b,c] D. Menasce,[62a] L. Moroni,[62a] M. Paganoni,[62a,62b] D. Pedrini,[62a] S. Ragazzi,[62a,62b] N. Redaelli,[62a] T. Tabarelli de Fatis,[62a,62b] S. Buontempo,[63a] N. Cavallo,[63a,63c] S. Di Guida,[63a,63d,c] M. Esposito,[63a,63b] F. Fabozzi,[63a,63c] A. O. M. Iorio,[63a,63b] G. Lanza,[63a] L. Lista,[63a] S. Meola,[63a,63d,c] M. Merola,[63a] P. Paolucci,[63a,c] C. Sciacca,[63a,63b] F. Thyssen,[63a] P. Azzi,[64a,c] D. Bisello,[64a,64b] A. Branca,[64a,64b] R. Carlin,[64a,64b] A. Carvalho Antunes De Oliveira,[64a,64b] P. Checchia,[64a] M. Dall'Osso,[64a,64b,c] T. Dorigo,[64a] F. Fanzago,[64a] F. Gasparini,[64a,64b] U. Gasparini,[64a,64b] F. Gonella,[64a] A. Gozzelino,[64a] K. Kanishchev,[64a,64c] S. Lacaprara,[64a] G. Maron,[64a,ee] F. Montecassiano,[64a] M. Passaseo,[64a] J. Pazzini,[64a,64b] M. Pegoraro,[64a] N. Pozzobon,[64a,64b] P. Ronchese,[64a,64b] M. Tosi,[64a,64b] S. Vanini,[64a,64b] S. Ventura,[64a] A. Zucchetta,[64a,64b,c] G. Zumerle,[64a,64b] A. Braghieri,[65a] M. Gabusi,[65a,65b] A. Magnani,[65a] S. P. Ratti,[65a,65b] V. Re,[65a] C. Riccardi,[65a,65b] P. Salvini,[65a] I. Vai,[65a] P. Vitulo,[65a,65b] L. Alunni Solestizi,[66a,66b] M. Biasini,[66a,66b] G. M. Bilei,[66a] D. Ciangottini,[66a,66b,c] L. Fanò,[66a,66b] P. Lariccia,[66a,66b] G. Mantovani,[66a,66b] M. Menichelli,[66a] A. Saha,[66a] A. Santocchia,[66a,66b] A. Spiezia,[66a,66b] K. Androsov,[67a,ff] P. Azzurri,[67a] G. Bagliesi,[67a] J. Bernardini,[67a] T. Boccali,[67a] G. Broccolo,[67a,67c] R. Castaldi,[67a] M. A. Ciocci,[67a,ff] R. Dell'Orso,[67a] S. Donato,[67a,67c,c]

G. Fedi,[67a] L. Foà,[67a,67c,a] A. Giassi,[67a] M. T. Grippo,[67a,ff] F. Ligabue,[67a,67c] T. Lomtadze,[67a] L. Martini,[67a,67b] A. Messineo,[67a,67b] F. Palla,[67a] A. Rizzi,[67a,67b] A. Savoy-Navarro,[67a,gg] A. T. Serban,[67a] P. Spagnolo,[67a] P. Squillacioti,[67a,ff] R. Tenchini,[67a] G. Tonelli,[67a,67b] A. Venturi,[67a] P. G. Verdini,[67a] L. Barone,[68a,68b] F. Cavallari,[68a] G. D'imperio,[68a,68b,c] D. Del Re,[68a,68b] M. Diemoz,[68a] S. Gelli,[68a,68b] C. Jorda,[68a] E. Longo,[68a,68b] F. Margaroli,[68a,68b] P. Meridiani,[68a] F. Micheli,[68a,68b] G. Organtini,[68a,68b] R. Paramatti,[68a] F. Preiato,[68a,68b] S. Rahatlou,[68a,68b] C. Rovelli,[68a] F. Santanastasio,[68a,68b] L. Soffi,[68a,68b] P. Traczyk,[68a,68b,c] N. Amapane,[69a,69b] R. Arcidiacono,[69a,69c] S. Argiro,[69a,69b] M. Arneodo,[69a,69c] R. Bellan,[69a,69b] C. Biino,[69a] N. Cartiglia,[69a] M. Costa,[69a,69b] R. Covarelli,[69a,69b] A. Degano,[69a,69b] N. Demaria,[69a] L. Finco,[69a,69b,c] C. Mariotti,[69a] S. Maselli,[69a] G. Mazza,[69a] E. Migliore,[69a,69b] V. Monaco,[69a,69b] E. Monteil,[69a,69b] M. Musich,[69a] M. M. Obertino,[69a,69c] L. Pacher,[69a,69b] N. Pastrone,[69a] M. Pelliccioni,[69a] G. L. Pinna Angioni,[69a,69b] F. Ravera,[69a,69b] A. Romero,[69a,69b] M. Ruspa,[69a,69c] R. Sacchi,[69a,69b] A. Solano,[69a,69b] A. Staiano,[69a] U. Tamponi,[69a] S. Belforte,[70a] V. Candelise,[70a,70b,c] M. Casarsa,[70a] F. Cossutti,[70a] G. Della Ricca,[70a,70b] B. Gobbo,[70a] C. La Licata,[70a,70b] M. Marone,[70a,70b] A. Schizzi,[70a,70b] T. Umer,[70a,70b] A. Zanetti,[70a] S. Chang,[71] A. Kropivnitskaya,[71] S. K. Nam,[71] D. H. Kim,[72] G. N. Kim,[72] M. S. Kim,[72] D. J. Kong,[72] S. Lee,[72] Y. D. Oh,[72] A. Sakharov,[72] D. C. Son,[72] H. Kim,[73] T. J. Kim,[73] M. S. Ryu,[73] S. Song,[74] S. Choi,[75] Y. Go,[75] D. Gyun,[75] B. Hong,[75] M. Jo,[75] H. Kim,[75] Y. Kim,[75] B. Lee,[75] K. Lee,[75] K. S. Lee,[75] S. Lee,[75] S. K. Park,[75] Y. Roh,[75] H. D. Yoo,[76] M. Choi,[77] J. H. Kim,[77] J. S. H. Lee,[77] I. C. Park,[77] G. Ryu,[77] Y. Choi,[78] Y. K. Choi,[78] J. Goh,[78] D. Kim,[78] E. Kwon,[78] J. Lee,[78] I. Yu,[78] A. Juodagalvis,[79] J. Vaitkus,[79] Z. A. Ibrahim,[80] J. R. Komaragiri,[80] M. A. B. Md Ali,[80,hh] F. Mohamad Idris,[80] W. A. T. Wan Abdullah,[80] E. Casimiro Linares,[81] H. Castilla-Valdez,[81] E. De La Cruz-Burelo,[81] I. Heredia-de La Cruz,[81,ii] A. Hernandez-Almada,[81] R. Lopez-Fernandez,[81] G. Ramirez Sanchez,[81] A. Sanchez-Hernandez,[81] S. Carrillo Moreno,[82] F. Vazquez Valencia,[82] S. Carpinteyro,[83] I. Pedraza,[83] H. A. Salazar Ibarguen,[83] A. Morelos Pineda,[84] D. Krofcheck,[85] P. H. Butler,[86] S. Reucroft,[86] A. Ahmad,[87] M. Ahmad,[87] Q. Hassan,[87] H. R. Hoorani,[87] W. A. Khan,[87] T. Khurshid,[87] M. Shoaib,[87] H. Bialkowska,[88] M. Bluj,[88] B. Boimska,[88] T. Frueboes,[88] M. Górski,[88] M. Kazana,[88] K. Nawrocki,[88] K. Romanowska-Rybinska,[88] M. Szleper,[88] P. Zalewski,[88] G. Brona,[89] K. Bunkowski,[89] K. Doroba,[89] A. Kalinowski,[89] M. Konecki,[89] J. Krolikowski,[89] M. Misiura,[89] M. Olszewski,[89] M. Walczak,[89] P. Bargassa,[90] C. Beirão Da Cruz E Silva,[90] A. Di Francesco,[90] P. Faccioli,[90] P. G. Ferreira Parracho,[90] M. Gallinaro,[90] L. Lloret Iglesias,[90] F. Nguyen,[90] J. Rodrigues Antunes,[90] J. Seixas,[90] O. Toldaiev,[90] D. Vadruccio,[90] J. Varela,[90] P. Vischia,[90] S. Afanasiev,[91] P. Bunin,[91] M. Gavrilenko,[91] I. Golutvin,[91] I. Gorbunov,[91] A. Kamenev,[91] V. Karjavin,[91] V. Konoplyanikov,[91] A. Lanev,[91] A. Malakhov,[91] V. Matveev,[91,jj] P. Moisenz,[91] V. Palichik,[91] V. Perelygin,[91] S. Shmatov,[91] S. Shulha,[91] N. Skatchkov,[91] V. Smirnov,[91] A. Zarubin,[91] V. Golovtsov,[92] Y. Ivanov,[92] V. Kim,[92,kk] E. Kuznetsova,[92] P. Levchenko,[92] V. Murzin,[92] V. Oreshkin,[92] I. Smirnov,[92] V. Sulimov,[92] L. Uvarov,[92] S. Vavilov,[92] A. Vorobyev,[92] Yu. Andreev,[93] A. Dermenev,[93] S. Gninenko,[93] N. Golubev,[93] A. Karneyeu,[93] M. Kirsanov,[93] N. Krasnikov,[93] A. Pashenkov,[93] D. Tlisov,[93] A. Toropin,[93] V. Epshteyn,[94] V. Gavrilov,[94] N. Lychkovskaya,[94] V. Popov,[94] I. Pozdnyakov,[94] G. Safronov,[94] A. Spiridonov,[94] E. Vlasov,[94] A. Zhokin,[94] A. Bylinkin,[95] V. Andreev,[96] M. Azarkin,[96,ll] I. Dremin,[96,ll] M. Kirakosyan,[96] A. Leonidov,[96,ll] G. Mesyats,[96] S. V. Rusakov,[96] A. Vinogradov,[96] A. Baskakov,[97] A. Belyaev,[97] E. Boos,[97] M. Dubinin,[97,mm] L. Dudko,[97] A. Ershov,[97] A. Gribushin,[97] V. Klyukhin,[97] O. Kodolova,[97] I. Lokhtin,[97] I. Myagkov,[97] S. Obraztsov,[97] S. Petrushanko,[97] V. Savrin,[97] A. Snigirev,[97] I. Azhgirey,[98] I. Bayshev,[98] S. Bitioukov,[98] V. Kachanov,[98] A. Kalinin,[98] D. Konstantinov,[98] V. Krychkine,[98] V. Petrov,[98] R. Ryutin,[98] A. Sobol,[98] L. Tourtchanovitch,[98] S. Troshin,[98] N. Tyurin,[98] A. Uzunian,[98] A. Volkov,[98] P. Adzic,[99,nn] M. Ekmedzic,[99] J. Milosevic,[99] V. Rekovic,[99] J. Alcaraz Maestre,[100] E. Calvo,[100] M. Cerrada,[100] M. Chamizo Llatas,[100] N. Colino,[100] B. De La Cruz,[100] A. Delgado Peris,[100] D. Domínguez Vázquez,[100] A. Escalante Del Valle,[100] C. Fernandez Bedoya,[100] J. P. Fernández Ramos,[100] J. Flix,[100] M. C. Fouz,[100] P. Garcia-Abia,[100] O. Gonzalez Lopez,[100] S. Goy Lopez,[100] J. M. Hernandez,[100] M. I. Josa,[100] E. Navarro De Martino,[100] A. Pérez-Calero Yzquierdo,[100] J. Puerta Pelayo,[100] A. Quintario Olmeda,[100] I. Redondo,[100] L. Romero,[100] M. S. Soares,[100] C. Albajar,[101] J. F. de Trocóniz,[101] M. Missiroli,[101] D. Moran,[101] H. Brun,[102] J. Cuevas,[102] J. Fernandez Menendez,[102] S. Folgueras,[102] I. Gonzalez Caballero,[102] E. Palencia Cortezon,[102] J. M. Vizan Garcia,[102] J. A. Brochero Cifuentes,[103] I. J. Cabrillo,[103] A. Calderon,[103] J. R. Castiñeiras De Saa,[103] J. Duarte Campderros,[103] M. Fernandez,[103] G. Gomez,[103] A. Graziano,[103] A. Lopez Virto,[103] J. Marco,[103] R. Marco,[103] C. Martinez Rivero,[103] F. Matorras,[103] F. J. Munoz Sanchez,[103] J. Piedra Gomez,[103] T. Rodrigo,[103] A. Y. Rodríguez-Marrero,[103] A. Ruiz-Jimeno,[103] L. Scodellaro,[103] I. Vila,[103] R. Vilar Cortabitarte,[103] D. Abbaneo,[104] E. Auffray,[104] G. Auzinger,[104] M. Bachtis,[104] P. Baillon,[104] A. H. Ball,[104] D. Barney,[104] A. Benaglia,[104] J. Bendavid,[104] L. Benhabib,[104] J. F. Benitez,[104] G. M. Berruti,[104] G. Bianchi,[104] P. Bloch,[104] A. Bocci,[104] A. Bonato,[104] C. Botta,[104]

H. Breuker,[104] T. Camporesi,[104] G. Cerminara,[104] S. Colafranceschi,[104,oo] M. D'Alfonso,[104] D. d'Enterria,[104] A. Dabrowski,[104] V. Daponte,[104] A. David,[104] M. De Gruttola,[104] F. De Guio,[104] A. De Roeck,[104] S. De Visscher,[104] E. Di Marco,[104] M. Dobson,[104] M. Dordevic,[104] T. du Pree,[104] N. Dupont,[104] A. Elliott-Peisert,[104] J. Eugster,[104] G. Franzoni,[104] W. Funk,[104] D. Gigi,[104] K. Gill,[104] D. Giordano,[104] M. Girone,[104] F. Glege,[104] R. Guida,[104] S. Gundacker,[104] M. Guthoff,[104] J. Hammer,[104] M. Hansen,[104] P. Harris,[104] J. Hegeman,[104] V. Innocente,[104] P. Janot,[104] H. Kirschenmann,[104] M. J. Kortelainen,[104] K. Kousouris,[104] K. Krajczar,[104] P. Lecoq,[104] C. Lourenço,[104] M. T. Lucchini,[104] N. Magini,[104] L. Malgeri,[104] M. Mannelli,[104] J. Marrouche,[104] A. Martelli,[104] L. Masetti,[104] F. Meijers,[104] S. Mersi,[104] E. Meschi,[104] F. Moortgat,[104] S. Morovic,[104] M. Mulders,[104] M. V. Nemallapudi,[104] H. Neugebauer,[104] S. Orfanelli,[104] L. Orsini,[104] L. Pape,[104] E. Perez,[104] A. Petrilli,[104] G. Petrucciani,[104] A. Pfeiffer,[104] D. Piparo,[104] A. Racz,[104] G. Rolandi,[104,pp] M. Rovere,[104] M. Ruan,[104] H. Sakulin,[104] C. Schäfer,[104] C. Schwick,[104] A. Sharma,[104] P. Silva,[104] M. Simon,[104] P. Sphicas,[104,qq] D. Spiga,[104] J. Steggemann,[104] B. Stieger,[104] M. Stoye,[104] Y. Takahashi,[104] D. Treille,[104] A. Tsirou,[104] G. I. Veres,[104,v] N. Wardle,[104] H. K. Wöhri,[104] A. Zagozdzinska,[104,rr] W. D. Zeuner,[104] W. Bertl,[105] K. Deiters,[105] W. Erdmann,[105] R. Horisberger,[105] Q. Ingram,[105] H. C. Kaestli,[105] D. Kotlinski,[105] U. Langenegger,[105] T. Rohe,[105] F. Bachmair,[106] L. Bäni,[106] L. Bianchini,[106] M. A. Buchmann,[106] B. Casal,[106] G. Dissertori,[106] M. Dittmar,[106] M. Donegà,[106] M. Dünser,[106] P. Eller,[106] C. Grab,[106] C. Heidegger,[106] D. Hits,[106] J. Hoss,[106] G. Kasieczka,[106] W. Lustermann,[106] B. Mangano,[106] A. C. Marini,[106] M. Marionneau,[106] P. Martinez Ruiz del Arbol,[106] M. Masciovecchio,[106] D. Meister,[106] N. Mohr,[106] P. Musella,[106] F. Nessi-Tedaldi,[106] F. Pandolfi,[106] J. Pata,[106] F. Pauss,[106] L. Perrozzi,[106] M. Peruzzi,[106] M. Quittnat,[106] M. Rossini,[106] A. Starodumov,[106,ss] M. Takahashi,[106] V. R. Tavolaro,[106] K. Theofilatos,[106] R. Wallny,[106] H. A. Weber,[106] T. K. Aarrestad,[107] C. Amsler,[107,tt] M. F. Canelli,[107] V. Chiochia,[107] A. De Cosa,[107] C. Galloni,[107] A. Hinzmann,[107] T. Hreus,[107] B. Kilminster,[107] C. Lange,[107] J. Ngadiuba,[107] D. Pinna,[107] P. Robmann,[107] F. J. Ronga,[107] D. Salerno,[107] S. Taroni,[107] Y. Yang,[107] M. Cardaci,[108] K. H. Chen,[108] T. H. Doan,[108] C. Ferro,[108] M. Konyushikhin,[108] C. M. Kuo,[108] W. Lin,[108] Y. J. Lu,[108] R. Volpe,[108] S. S. Yu,[108] R. Bartek,[109] P. Chang,[109] Y. H. Chang,[109] Y. W. Chang,[109] Y. Chao,[109] K. F. Chen,[109] P. H. Chen,[109] C. Dietz,[109] F. Fiori,[109] U. Grundler,[109] W.-S. Hou,[109] Y. Hsiung,[109] Y. F. Liu,[109] R.-S. Lu,[109] M. Miñano Moya,[109] E. Petrakou,[109] J. F. Tsai,[109] Y. M. Tzeng,[109] B. Asavapibhop,[110] K. Kovitanggoon,[110] G. Singh,[110] N. Srimanobhas,[110] N. Suwonjandee,[110] A. Adiguzel,[111] M. N. Bakirci,[111,uu] C. Dozen,[111] I. Dumanoglu,[111] E. Eskut,[111] S. Girgis,[111] G. Gokbulut,[111] Y. Guler,[111] E. Gurpinar,[111] I. Hos,[111] E. E. Kangal,[111,vv] G. Onengut,[111,ww] K. Ozdemir,[111,xx] A. Polatoz,[111] D. Sunar Cerci,[111,yy] B. Tali,[111,yy] M. Vergili,[111] C. Zorbilmez,[111] I. V. Akin,[112] B. Bilin,[112] S. Bilmis,[112] B. Isildak,[112,zz] G. Karapinar,[112,aaa] U. E. Surat,[112] M. Yalvac,[112] M. Zeyrek,[112] E. A. Albayrak,[113,bbb] E. Gülmez,[113] M. Kaya,[113,ccc] O. Kaya,[113,ddd] T. Yetkin,[113,eee] K. Cankocak,[114] Y. O. Günaydin,[114,fff] F. I. Vardarlı,[114] B. Grynyov,[115] L. Levchuk,[116] P. Sorokin,[116] R. Aggleton,[117] F. Ball,[117] L. Beck,[117] J. J. Brooke,[117] E. Clement,[117] D. Cussans,[117] H. Flacher,[117] J. Goldstein,[117] M. Grimes,[117] G. P. Heath,[117] H. F. Heath,[117] J. Jacob,[117] L. Kreczko,[117] C. Lucas,[117] Z. Meng,[117] D. M. Newbold,[117,ggg] S. Paramesvaran,[117] A. Poll,[117] T. Sakuma,[117] S. Seif El Nasr-storey,[117] S. Senkin,[117] D. Smith,[117] V. J. Smith,[117] K. W. Bell,[118] A. Belyaev,[118,hhh] C. Brew,[118] R. M. Brown,[118] D. J. A. Cockerill,[118] J. A. Coughlan,[118] K. Harder,[118] S. Harper,[118] E. Olaiya,[118] D. Petyt,[118] C. H. Shepherd-Themistocleous,[118] A. Thea,[118] I. R. Tomalin,[118] T. Williams,[118] W. J. Womersley,[118] S. D. Worm,[118] M. Baber,[119] R. Bainbridge,[119] O. Buchmuller,[119] A. Bundock,[119] D. Burton,[119] S. Casasso,[119] M. Citron,[119] D. Colling,[119] L. Corpe,[119] N. Cripps,[119] P. Dauncey,[119] G. Davies,[119] A. De Wit,[119] M. Della Negra,[119] P. Dunne,[119] A. Elwood,[119] W. Ferguson,[119] J. Fulcher,[119] D. Futyan,[119] G. Hall,[119] G. Iles,[119] G. Karapostoli,[119] M. Kenzie,[119] R. Lane,[119] R. Lucas,[119,ggg] L. Lyons,[119] A.-M. Magnan,[119] S. Malik,[119] J. Nash,[119] A. Nikitenko,[119,ss] J. Pela,[119] M. Pesaresi,[119] K. Petridis,[119] D. M. Raymond,[119] A. Richards,[119] A. Rose,[119] C. Seez,[119] P. Sharp,[119,a] A. Tapper,[119] K. Uchida,[119] M. Vazquez Acosta,[119,iii] T. Virdee,[119] S. C. Zenz,[119] J. E. Cole,[120] P. R. Hobson,[120] A. Khan,[120] P. Kyberd,[120] D. Leggat,[120] D. Leslie,[120] I. D. Reid,[120] P. Symonds,[120] L. Teodorescu,[120] M. Turner,[120] A. Borzou,[121] J. Dittmann,[121] K. Hatakeyama,[121] A. Kasmi,[121] H. Liu,[121] N. Pastika,[121] T. Scarborough,[121] O. Charaf,[122] S. I. Cooper,[122] C. Henderson,[122] P. Rumerio,[122] A. Avetisyan,[123] T. Bose,[123] C. Fantasia,[123] D. Gastler,[123] P. Lawson,[123] D. Rankin,[123] C. Richardson,[123] J. Rohlf,[123] J. St. John,[123] L. Sulak,[123] D. Zou,[123] J. Alimena,[124] E. Berry,[124] S. Bhattacharya,[124] D. Cutts,[124] Z. Demiragli,[124] N. Dhingra,[124] A. Ferapontov,[124] A. Garabedian,[124] U. Heintz,[124] E. Laird,[124] G. Landsberg,[124] Z. Mao,[124] M. Narain,[124] S. Sagir,[124] T. Sinthuprasith,[124] R. Breedon,[125] G. Breto,[125] M. Calderon De La Barca Sanchez,[125] S. Chauhan,[125] M. Chertok,[125] J. Conway,[125] R. Conway,[125] P. T. Cox,[125] R. Erbacher,[125] M. Gardner,[125] W. Ko,[125] R. Lander,[125] M. Mulhearn,[125] D. Pellett,[125] J. Pilot,[125] F. Ricci-Tam,[125] S. Shalhout,[125] J. Smith,[125] M. Squires,[125] D. Stolp,[125] M. Tripathi,[125] S. Wilbur,[125] R. Yohay,[125] R. Cousins,[126]

P. Everaerts,[126] C. Farrell,[126] J. Hauser,[126] M. Ignatenko,[126] G. Rakness,[126] D. Saltzberg,[126] E. Takasugi,[126] V. Valuev,[126] M. Weber,[126] K. Burt,[127] R. Clare,[127] J. Ellison,[127] J. W. Gary,[127] G. Hanson,[127] J. Heilman,[127] M. Ivova PANEVA,[127] P. Jandir,[127] E. Kennedy,[127] F. Lacroix,[127] O. R. Long,[127] A. Luthra,[127] M. Malberti,[127] M. Olmedo Negrete,[127] A. Shrinivas,[127] S. Sumowidagdo,[127] H. Wei,[127] S. Wimpenny,[127] J. G. Branson,[128] G. B. Cerati,[128] S. Cittolin,[128] R. T. D'Agnolo,[128] A. Holzner,[128] R. Kelley,[128] D. Klein,[128] J. Letts,[128] I. Macneill,[128] D. Olivito,[128] S. Padhi,[128] M. Pieri,[128] M. Sani,[128] V. Sharma,[128] S. Simon,[128] M. Tadel,[128] Y. Tu,[128] A. Vartak,[128] S. Wasserbaech,[128,jjj] C. Welke,[128] F. Würthwein,[128] A. Yagil,[128] G. Zevi Della Porta,[128] D. Barge,[129] J. Bradmiller-Feld,[129] C. Campagnari,[129] A. Dishaw,[129] V. Dutta,[129] K. Flowers,[129] M. Franco Sevilla,[129] P. Geffert,[129] C. George,[129] F. Golf,[129] L. Gouskos,[129] J. Gran,[129] J. Incandela,[129] C. Justus,[129] N. Mccoll,[129] S. D. Mullin,[129] J. Richman,[129] D. Stuart,[129] W. To,[129] C. West,[129] J. Yoo,[129] D. Anderson,[130] A. Apresyan,[130] A. Bornheim,[130] J. Bunn,[130] Y. Chen,[130] J. Duarte,[130] A. Mott,[130] H. B. Newman,[130] C. Pena,[130] M. Pierini,[130] M. Spiropulu,[130] J. R. Vlimant,[130] S. Xie,[130] R. Y. Zhu,[130] V. Azzolini,[131] A. Calamba,[131] B. Carlson,[131] T. Ferguson,[131] Y. Iiyama,[131] M. Paulini,[131] J. Russ,[131] M. Sun,[131] H. Vogel,[131] I. Vorobiev,[131] J. P. Cumalat,[132] W. T. Ford,[132] A. Gaz,[132] F. Jensen,[132] A. Johnson,[132] M. Krohn,[132] T. Mulholland,[132] U. Nauenberg,[132] J. G. Smith,[132] K. Stenson,[132] S. R. Wagner,[132] J. Alexander,[133] A. Chatterjee,[133] J. Chaves,[133] J. Chu,[133] S. Dittmer,[133] N. Eggert,[133] N. Mirman,[133] G. Nicolas Kaufman,[133] J. R. Patterson,[133] A. Rinkevicius,[133] A. Ryd,[133] L. Skinnari,[133] W. Sun,[133] S. M. Tan,[133] W. D. Teo,[133] J. Thom,[133] J. Thompson,[133] J. Tucker,[133] Y. Weng,[133] P. Wittich,[133] S. Abdullin,[134] M. Albrow,[134] J. Anderson,[134] G. Apollinari,[134] L. A. T. Bauerdick,[134] A. Beretvas,[134] J. Berryhill,[134] P. C. Bhat,[134] G. Bolla,[134] K. Burkett,[134] J. N. Butler,[134] H. W. K. Cheung,[134] F. Chlebana,[134] S. Cihangir,[134] V. D. Elvira,[134] I. Fisk,[134] J. Freeman,[134] E. Gottschalk,[134] L. Gray,[134] D. Green,[134] S. Grünendahl,[134] O. Gutsche,[134] J. Hanlon,[134] D. Hare,[134] R. M. Harris,[134] J. Hirschauer,[134] B. Hooberman,[134] Z. Hu,[134] S. Jindariani,[134] M. Johnson,[134] U. Joshi,[134] A. W. Jung,[134] B. Klima,[134] B. Kreis,[134] S. Kwan,[134,a] S. Lammel,[134] J. Linacre,[134] D. Lincoln,[134] R. Lipton,[134] T. Liu,[134] R. Lopes De Sá,[134] J. Lykken,[134] K. Maeshima,[134] J. M. Marraffino,[134] V. I. Martinez Outschoorn,[134] S. Maruyama,[134] D. Mason,[134] P. McBride,[134] P. Merkel,[134] K. Mishra,[134] S. Mrenna,[134] S. Nahn,[134] C. Newman-Holmes,[134] V. O'Dell,[134] O. Prokofyev,[134] E. Sexton-Kennedy,[134] A. Soha,[134] W. J. Spalding,[134] L. Spiegel,[134] L. Taylor,[134] S. Tkaczyk,[134] N. V. Tran,[134] L. Uplegger,[134] E. W. Vaandering,[134] C. Vernieri,[134] M. Verzocchi,[134] R. Vidal,[134] A. Whitbeck,[134] F. Yang,[134] H. Yin,[134] D. Acosta,[135] P. Avery,[135] P. Bortignon,[135] D. Bourilkov,[135] A. Carnes,[135] M. Carver,[135] D. Curry,[135] S. Das,[135] G. P. Di Giovanni,[135] R. D. Field,[135] M. Fisher,[135] I. K. Furic,[135] J. Hugon,[135] J. Konigsberg,[135] A. Korytov,[135] T. Kypreos,[135] J. F. Low,[135] P. Ma,[135] K. Matchev,[135] H. Mei,[135] P. Milenovic,[135,kkk] G. Mitselmakher,[135] L. Muniz,[135] D. Rank,[135] L. Shchutska,[135] M. Snowball,[135] D. Sperka,[135] S. Wang,[135] J. Yelton,[135] S. Hewamanage,[136] S. Linn,[136] P. Markowitz,[136] G. Martinez,[136] J. L. Rodriguez,[136] A. Ackert,[137] J. R. Adams,[137] T. Adams,[137] A. Askew,[137] J. Bochenek,[137] B. Diamond,[137] J. Haas,[137] S. Hagopian,[137] V. Hagopian,[137] K. F. Johnson,[137] A. Khatiwada,[137] H. Prosper,[137] V. Veeraraghavan,[137] M. Weinberg,[137] V. Bhopatkar,[138] M. Hohlmann,[138] H. Kalakhety,[138] D. Mareskas-palcek,[138] T. Roy,[138] F. Yumiceva,[138] M. R. Adams,[139] L. Apanasevich,[139] D. Berry,[139] R. R. Betts,[139] I. Bucinskaite,[139] R. Cavanaugh,[139] O. Evdokimov,[139] L. Gauthier,[139] C. E. Gerber,[139] D. J. Hofman,[139] P. Kurt,[139] C. O'Brien,[139] I. D. Sandoval Gonzalez,[139] C. Silkworth,[139] P. Turner,[139] N. Varelas,[139] Z. Wu,[139] M. Zakaria,[139] B. Bilki,[140,lll] W. Clarida,[140] K. Dilsiz,[140] S. Durgut,[140] R. P. Gandrajula,[140] M. Haytmyradov,[140] V. Khristenko,[140] J.-P. Merlo,[140] H. Mermerkaya,[140,mmm] A. Mestvirishvili,[140] A. Moeller,[140] J. Nachtman,[140] H. Ogul,[140] Y. Onel,[140] F. Ozok,[140,bbb] A. Penzo,[140] S. Sen,[140,nnn] C. Snyder,[140] P. Tan,[140] E. Tiras,[140] J. Wetzel,[140] K. Yi,[140] I. Anderson,[141] B. A. Barnett,[141] B. Blumenfeld,[141] D. Fehling,[141] L. Feng,[141] A. V. Gritsan,[141] P. Maksimovic,[141] C. Martin,[141] K. Nash,[141] M. Osherson,[141] M. Swartz,[141] M. Xiao,[141] Y. Xin,[141] P. Baringer,[142] A. Bean,[142] G. Benelli,[142] C. Bruner,[142] J. Gray,[142] R. P. Kenny III,[142] D. Majumder,[142] M. Malek,[142] M. Murray,[142] D. Noonan,[142] S. Sanders,[142] R. Stringer,[142] Q. Wang,[142] J. S. Wood,[142] I. Chakaberia,[143] A. Ivanov,[143] K. Kaadze,[143] S. Khalil,[143] M. Makouski,[143] Y. Maravin,[143] L. K. Saini,[143] N. Skhirtladze,[143] I. Svintradze,[143] S. Toda,[143] D. Lange,[144] F. Rebassoo,[144] D. Wright,[144] C. Anelli,[145] A. Baden,[145] O. Baron,[145] A. Belloni,[145] B. Calvert,[145] S. C. Eno,[145] C. Ferraioli,[145] J. A. Gomez,[145] N. J. Hadley,[145] S. Jabeen,[145] R. G. Kellogg,[145] T. Kolberg,[145] J. Kunkle,[145] Y. Lu,[145] A. C. Mignerey,[145] K. Pedro,[145] Y. H. Shin,[145] A. Skuja,[145] M. B. Tonjes,[145] S. C. Tonwar,[145] A. Apyan,[146] R. Barbieri,[146] A. Baty,[146] K. Bierwagen,[146] S. Brandt,[146] W. Busza,[146] I. A. Cali,[146] L. Di Matteo,[146] G. Gomez Ceballos,[146] M. Goncharov,[146] D. Gulhan,[146] G. M. Innocenti,[146] M. Klute,[146] D. Kovalskyi,[146] Y. S. Lai,[146] Y.-J. Lee,[146] A. Levin,[146] P. D. Luckey,[146] C. Mcginn,[146] X. Niu,[146] C. Paus,[146] D. Ralph,[146] C. Roland,[146] G. Roland,[146] G. S. F. Stephans,[146] K. Sumorok,[146] M. Varma,[146] D. Velicanu,[146] J. Veverka,[146] J. Wang,[146] T. W. Wang,[146] B. Wyslouch,[146] M. Yang,[146]

V. Zhukova,[146] B. Dahmes,[147] A. Finkel,[147] A. Gude,[147] P. Hansen,[147] S. Kalafut,[147] S. C. Kao,[147] K. Klapoetke,[147] Y. Kubota,[147] Z. Lesko,[147] J. Mans,[147] S. Nourbakhsh,[147] N. Ruckstuhl,[147] R. Rusack,[147] N. Tambe,[147] J. Turkewitz,[147] J. G. Acosta,[148] S. Oliveros,[148] E. Avdeeva,[149] K. Bloom,[149] S. Bose,[149] D. R. Claes,[149] A. Dominguez,[149] C. Fangmeier,[149] R. Gonzalez Suarez,[149] R. Kamalieddin,[149] J. Keller,[149] D. Knowlton,[149] I. Kravchenko,[149] J. Lazo-Flores,[149] F. Meier,[149] J. Monroy,[149] F. Ratnikov,[149] J. E. Siado,[149] G. R. Snow,[149] M. Alyari,[150] J. Dolen,[150] J. George,[150] A. Godshalk,[150] I. Iashvili,[150] J. Kaisen,[150] A. Kharchilava,[150] A. Kumar,[150] S. Rappoccio,[150] G. Alverson,[151] E. Barberis,[151] D. Baumgartel,[151] M. Chasco,[151] A. Hortiangtham,[151] A. Massironi,[151] D. M. Morse,[151] D. Nash,[151] T. Orimoto,[151] R. Teixeira De Lima,[151] D. Trocino,[151] R.-J. Wang,[151] D. Wood,[151] J. Zhang,[151] K. A. Hahn,[152] A. Kubik,[152] N. Mucia,[152] N. Odell,[152] B. Pollack,[152] A. Pozdnyakov,[152] M. Schmitt,[152] S. Stoynev,[152] K. Sung,[152] M. Trovato,[152] M. Velasco,[152] S. Won,[152] A. Brinkerhoff,[153] N. Dev,[153] M. Hildreth,[153] C. Jessop,[153] D. J. Karmgard,[153] N. Kellams,[153] K. Lannon,[153] S. Lynch,[153] N. Marinelli,[153] F. Meng,[153] C. Mueller,[153] Y. Musienko,[153,jj] T. Pearson,[153] M. Planer,[153] R. Ruchti,[153] G. Smith,[153] N. Valls,[153] M. Wayne,[153] M. Wolf,[153] A. Woodard,[153] L. Antonelli,[154] J. Brinson,[154] B. Bylsma,[154] L. S. Durkin,[154] S. Flowers,[154] A. Hart,[154] C. Hill,[154] R. Hughes,[154] K. Kotov,[154] T. Y. Ling,[154] B. Liu,[154] W. Luo,[154] D. Puigh,[154] M. Rodenburg,[154] B. L. Winer,[154] H. W. Wulsin,[154] O. Driga,[155] P. Elmer,[155] J. Hardenbrook,[155] P. Hebda,[155] S. A. Koay,[155] P. Lujan,[155] D. Marlow,[155] T. Medvedeva,[155] M. Mooney,[155] J. Olsen,[155] C. Palmer,[155] P. Piroué,[155] X. Quan,[155] H. Saka,[155] D. Stickland,[155] C. Tully,[155] J. S. Werner,[155] A. Zuranski,[155] S. Malik,[156] V. E. Barnes,[157] D. Benedetti,[157] D. Bortoletto,[157] L. Gutay,[157] M. K. Jha,[157] M. Jones,[157] K. Jung,[157] M. Kress,[157] N. Leonardo,[157] D. H. Miller,[157] N. Neumeister,[157] F. Primavera,[157] B. C. Radburn-Smith,[157] X. Shi,[157] I. Shipsey,[157] D. Silvers,[157] J. Sun,[157] A. Svyatkovskiy,[157] F. Wang,[157] W. Xie,[157] L. Xu,[157] J. Zablocki,[157] N. Parashar,[158] J. Stupak,[158] A. Adair,[159] B. Akgun,[159] Z. Chen,[159] K. M. Ecklund,[159] F. J. M. Geurts,[159] M. Guilbaud,[159] W. Li,[159] B. Michlin,[159] M. Northup,[159] B. P. Padley,[159] R. Redjimi,[159] J. Roberts,[159] J. Rorie,[159] Z. Tu,[159] J. Zabel,[159] B. Betchart,[160] A. Bodek,[160] P. de Barbaro,[160] R. Demina,[160] Y. Eshaq,[160] T. Ferbel,[160] M. Galanti,[160] A. Garcia-Bellido,[160] P. Goldenzweig,[160] J. Han,[160] A. Harel,[160] O. Hindrichs,[160] A. Khukhunaishvili,[160] G. Petrillo,[160] M. Verzetti,[160] D. Vishnevskiy,[160] L. Demortier,[161] S. Arora,[162] A. Barker,[162] J. P. Chou,[162] C. Contreras-Campana,[162] E. Contreras-Campana,[162] D. Duggan,[162] D. Ferencek,[162] Y. Gershtein,[162] R. Gray,[162] E. Halkiadakis,[162] D. Hidas,[162] E. Hughes,[162] S. Kaplan,[162] R. Kunnawalkam Elayavalli,[162] A. Lath,[162] S. Panwalkar,[162] M. Park,[162] S. Salur,[162] S. Schnetzer,[162] D. Sheffield,[162] S. Somalwar,[162] R. Stone,[162] S. Thomas,[162] P. Thomassen,[162] M. Walker,[162] M. Foerster,[163] G. Riley,[163] K. Rose,[163] S. Spanier,[163] A. York,[163] O. Bouhali,[164,ooo] A. Castaneda Hernandez,[164] M. Dalchenko,[164] M. De Mattia,[164] A. Delgado,[164] S. Dildick,[164] R. Eusebi,[164] W. Flanagan,[164] J. Gilmore,[164] T. Kamon,[164,ppp] V. Krutelyov,[164] R. Montalvo,[164] R. Mueller,[164] I. Osipenkov,[164] Y. Pakhotin,[164] R. Patel,[164] A. Perloff,[164] J. Roe,[164] A. Rose,[164] A. Safonov,[164] I. Suarez,[164] A. Tatarinov,[164] K. A. Ulmer,[164,c] N. Akchurin,[165] C. Cowden,[165] J. Damgov,[165] C. Dragoiu,[165] P. R. Dudero,[165] J. Faulkner,[165] S. Kunori,[165] K. Lamichhane,[165] S. W. Lee,[165] T. Libeiro,[165] S. Undleeb,[165] I. Volobouev,[165] E. Appelt,[166] A. G. Delannoy,[166] S. Greene,[166] A. Gurrola,[166] R. Janjam,[166] W. Johns,[166] C. Maguire,[166] Y. Mao,[166] A. Melo,[166] P. Sheldon,[166] B. Snook,[166] S. Tuo,[166] J. Velkovska,[166] Q. Xu,[166] M. W. Arenton,[167] S. Boutle,[167] B. Cox,[167] B. Francis,[167] J. Goodell,[167] R. Hirosky,[167] A. Ledovskoy,[167] H. Li,[167] C. Lin,[167] C. Neu,[167] E. Wolfe,[167] J. Wood,[167] F. Xia,[167] C. Clarke,[168] R. Harr,[168] P. E. Karchin,[168] C. Kottachchi Kankanamge Don,[168] P. Lamichhane,[168] J. Sturdy,[168] D. A. Belknap,[169] D. Carlsmith,[169] M. Cepeda,[169] A. Christian,[169] S. Dasu,[169] L. Dodd,[169] S. Duric,[169] E. Friis,[169] B. Gomber,[169] M. Grothe,[169] R. Hall-Wilton,[169] M. Herndon,[169] A. Hervé,[169] P. Klabbers,[169] A. Lanaro,[169] A. Levine,[169] K. Long,[169] R. Loveless,[169] A. Mohapatra,[169] I. Ojalvo,[169] T. Perry,[169] G. A. Pierro,[169] G. Polese,[169] I. Ross,[169] T. Ruggles,[169] T. Sarangi,[169] A. Savin,[169] N. Smith,[169] W. H. Smith,[169] D. Taylor,[169] and N. Woods[169]

(CMS Collaboration)

[1] *Yerevan Physics Institute, Yerevan, Armenia*
[2] *Institut für Hochenergiephysik der OeAW, Wien, Austria*
[3] *National Centre for Particle and High Energy Physics, Minsk, Belarus*
[4] *Universiteit Antwerpen, Antwerpen, Belgium*
[5] *Vrije Universiteit Brussel, Brussel, Belgium*
[6] *Université Libre de Bruxelles, Bruxelles, Belgium*
[7] *Ghent University, Ghent, Belgium*
[8] *Université Catholique de Louvain, Louvain-la-Neuve, Belgium*

[9]Université de Mons, Mons, Belgium
[10]Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil
[11]Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil
[12a]Universidade Estadual Paulista, São Paulo, Brazil
[12b]Universidade Federal do ABC, São Paulo, Brazil
[13]Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria
[14]University of Sofia, Sofia, Bulgaria
[15]Institute of High Energy Physics, Beijing, China
[16]State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China
[17]Universidad de Los Andes, Bogota, Colombia
[18]University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Split, Croatia
[19]University of Split, Faculty of Science, Split, Croatia
[20]Institute Rudjer Boskovic, Zagreb, Croatia
[21]University of Cyprus, Nicosia, Cyprus
[22]Charles University, Prague, Czech Republic
[23]Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt
[24]National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
[25]Department of Physics, University of Helsinki, Helsinki, Finland
[26]Helsinki Institute of Physics, Helsinki, Finland
[27]Lappeenranta University of Technology, Lappeenranta, Finland
[28]DSM/IRFU, CEA/Saclay, Gif-sur-Yvette, France
[29]Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France
[30]Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France
[31]Centre de Calcul de l'Institut National de Physique Nucleaire et de Physique des Particules, CNRS/IN2P3, Villeurbanne, France
[32]Université de Lyon, Université Claude Bernard Lyon 1, CNRS-IN2P3, Institut de Physique Nucléaire de Lyon, Villeurbanne, France
[33]Georgian Technical University, Tbilisi, Georgia
[34]Tbilisi State University, Tbilisi, Georgia
[35]RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany
[36]RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany
[37]RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany
[38]Deutsches Elektronen-Synchrotron, Hamburg, Germany
[39]University of Hamburg, Hamburg, Germany
[40]Institut für Experimentelle Kernphysik, Karlsruhe, Germany
[41]Institute of Nuclear and Particle Physics (INPP), NCSR Demokritos, Aghia Paraskevi, Greece
[42]University of Athens, Athens, Greece
[43]University of Ioánnina, Ioánnina, Greece
[44]Wigner Research Centre for Physics, Budapest, Hungary
[45]Institute of Nuclear Research ATOMKI, Debrecen, Hungary
[46]University of Debrecen, Debrecen, Hungary
[47]National Institute of Science Education and Research, Bhubaneswar, India
[48]Panjab University, Chandigarh, India
[49]University of Delhi, Delhi, India
[50]Saha Institute of Nuclear Physics, Kolkata, India
[51]Bhabha Atomic Research Centre, Mumbai, India
[52]Tata Institute of Fundamental Research, Mumbai, India
[53]Indian Institute of Science Education and Research (IISER), Pune, India
[54]Institute for Research in Fundamental Sciences (IPM), Tehran, Iran
[55]University College Dublin, Dublin, Ireland
[56a]INFN Sezione di Bari, Bari, Italy
[56b]Università di Bari, Bari, Italy
[56c]Politecnico di Bari, Bari, Italy
[57a]INFN Sezione di Bologna, Bologna, Italy
[57b]Università di Bologna, Bologna, Italy
[58a]INFN Sezione di Catania, Catania, Italy
[58b]Università di Catania, Catania, Italy

[58c]CSFNSM, Catania, Italy
[59a]INFN Sezione di Firenze, Firenze, Italy
[59b]Università di Firenze, Firenze, Italy
[60]INFN Laboratori Nazionali di Frascati, Frascati, Italy
[61a]INFN Sezione di Genova, Genova, Italy
[61b]Università di Genova, Genova, Italy
[62a]INFN Sezione di Milano-Bicocca, Milano, Italy
[62b]Università di Milano-Bicocca, Milano, Italy
[63a]INFN Sezione di Napoli, Roma, Italy
[63b]Università di Napoli 'Federico II', Roma, Italy
[63c]Università della Basilicata, Roma, Italy
[63d]Università G. Marconi, Roma, Italy
[64a]INFN Sezione di Padova, Trento, Italy
[64b]Università di Padova, Trento, Italy
[64c]Università di Trento, Trento, Italy
[65a]INFN Sezione di Pavia, Pavia, Italy
[65b]Università di Pavia, Pavia, Italy
[66a]INFN Sezione di Perugia, Perugia, Italy
[66b]Università di Perugia, Perugia, Italy
[67a]INFN Sezione di Pisa, Pisa, Italy
[67b]Università di Pisa, Pisa, Italy
[67c]Scuola Normale Superiore di Pisa, Pisa, Italy
[68a]INFN Sezione di Roma, Roma, Italy
[68b]Università di Roma, Roma, Italy
[69a]INFN Sezione di Torino, Novara, Italy
[69b]Università di Torino, Novara, Italy
[69c]Università del Piemonte Orientale, Novara, Italy
[70a]INFN Sezione di Trieste, Trieste, Italy
[70b]Università di Trieste, Trieste, Italy
[71]Kangwon National University, Chunchon, Korea
[72]Kyungpook National University, Daegu, Korea
[73]Chonbuk National University, Jeonju, Korea
[74]Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea
[75]Korea University, Seoul, Korea
[76]Seoul National University, Seoul, Korea
[77]University of Seoul, Seoul, Korea
[78]Sungkyunkwan University, Suwon, Korea
[79]Vilnius University, Vilnius, Lithuania
[80]National Centre for Particle Physics, Universiti Malaya, Kuala Lumpur, Malaysia
[81]Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico
[82]Universidad Iberoamericana, Mexico City, Mexico
[83]Benemerita Universidad Autonoma de Puebla, Puebla, Mexico
[84]Universidad Autónoma de San Luis Potosí, San Luis Potosí, Mexico
[85]University of Auckland, Auckland, New Zealand
[86]University of Canterbury, Christchurch, New Zealand
[87]National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan
[88]National Centre for Nuclear Research, Swierk, Poland
[89]Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland
[90]Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal
[91]Joint Institute for Nuclear Research, Dubna, Russia
[92]Petersburg Nuclear Physics Institute, Gatchina (St. Petersburg), Russia
[93]Institute for Nuclear Research, Moscow, Russia
[94]Institute for Theoretical and Experimental Physics, Moscow, Russia
[95]National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia
[96]P. N. Lebedev Physical Institute, Moscow, Russia
[97]Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
[98]State Research Center of Russian Federation, Institute for High Energy Physics, Protvino, Russia
[99]University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
[100]Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain

[101]Universidad Autónoma de Madrid, Madrid, Spain
[102]Universidad de Oviedo, Oviedo, Spain
[103]Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain
[104]CERN, European Organization for Nuclear Research, Geneva, Switzerland
[105]Paul Scherrer Institut, Villigen, Switzerland
[106]Institute for Particle Physics, ETH Zurich, Zurich, Switzerland
[107]Universität Zürich, Zurich, Switzerland
[108]National Central University, Chung-Li, Taiwan
[109]National Taiwan University (NTU), Taipei, Taiwan
[110]Chulalongkorn University, Faculty of Science, Department of Physics, Bangkok, Thailand
[111]Cukurova University, Adana, Turkey
[112]Middle East Technical University, Physics Department, Ankara, Turkey
[113]Bogazici University, Istanbul, Turkey
[114]Istanbul Technical University, Istanbul, Turkey
[115]Institute for Scintillation Materials of National Academy of Science of Ukraine, Kharkov, Ukraine
[116]National Scientific Center, Kharkov Institute of Physics and Technology, Kharkov, Ukraine
[117]University of Bristol, Bristol, United Kingdom
[118]Rutherford Appleton Laboratory, Didcot, United Kingdom
[119]Imperial College, London, United Kingdom
[120]Brunel University, Uxbridge, United Kingdom
[121]Baylor University, Waco, Texas 76798, USA
[122]The University of Alabama, Tuscaloosa, Alabama 35487, USA
[123]Boston University, Boston, Massachusetts 02215, USA
[124]Brown University, Providence, Rhode Island 02912, USA
[125]University of California, Davis, Davis, California 95616, USA
[126]University of California, Los Angeles, California 92521, USA
[127]University of California, Riverside, Riverside, California 92521, USA
[128]University of California, San Diego, La Jolla, California 92093, USA
[129]University of California, Santa Barbara, Santa Barbara, California 93106, USA
[130]California Institute of Technology, Pasadena, California 91125, USA
[131]Carnegie Mellon University, Pittsburgh, Pennsylvania 15213, USA
[132]University of Colorado Boulder, Boulder, Colorado 80309, USA
[133]Cornell University, Ithaca, New York 14853, USA
[134]Fermi National Accelerator Laboratory, Batavia, Illinois 60510, USA
[135]University of Florida, Gainesville, Florida 32611, USA
[136]Florida International University, Miami, Florida 33199, USA
[137]Florida State University, Tallahassee, Florida 32306, USA
[138]Florida Institute of Technology, Melbourne, Florida 32901, USA
[139]University of Illinois at Chicago (UIC), Chicago, Illinois 60607, USA
[140]The University of Iowa, Iowa City, Iowa 52242, USA
[141]Johns Hopkins University, Baltimore, Maryland 21218, USA
[142]The University of Kansas, Lawrence, Kansas 66045, USA
[143]Kansas State University, Manhattan, Kansas 66506, USA
[144]Lawrence Livermore National Laboratory, Livermore, California 94551, USA
[145]University of Maryland, College Park, Maryland 20742, USA
[146]Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA
[147]University of Minnesota, Minneapolis, Minnesota 55455, USA
[148]University of Mississippi, Oxford, Mississippi 38677, USA
[149]University of Nebraska-Lincoln, Lincoln, Nebraska 68588, USA
[150]State University of New York at Buffalo, Buffalo, New York 14260, USA
[151]Northeastern University, Boston, Massachusetts 02115, USA
[152]Northwestern University, Evanston, Illinois 60208, USA
[153]University of Notre Dame, Notre Dame, Indiana 46556, USA
[154]The Ohio State University, Columbus, Ohio 43210, USA
[155]Princeton University, Princeton, New Jersey 08542, USA
[156]University of Puerto Rico, Mayaguez, Puerto Rico 00681, USA
[157]Purdue University, West Lafayette, Indiana 47907, USA
[158]Purdue University Calumet, Hammond, Indiana 46323, USA
[159]Rice University, Houston, Texas 77251, USA
[160]University of Rochester, Rochester, New York 14627, USA

[161]The Rockefeller University, New York, New York 10021, USA
[162]Rutgers, The State University of New Jersey, Piscataway, New Jersey 08854, USA
[163]University of Tennessee, Knoxville, Tennessee 37996, USA
[164]Texas A&M University, College Station, Texas 77843, USA
[165]Texas Tech University, Lubbock, Texas 79409, USA
[166]Vanderbilt University, Nashville, Tennesse 37235, USA
[167]University of Virginia, Charlottesville, Virginia 22904, USA
[168]Wayne State University, Detroit, Michigan 48202, USA
[169]University of Wisconsin, Madison, Wisconsin 53706, USA

[a]Deceased.
[b]Also at Vienna University of Technology, Vienna, Austria.
[c]Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland.
[d]Also at State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China.
[e]Also at Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France.
[f]Also at National Institute of Chemical Physics and Biophysics, Tallinn, Estonia.
[g]Also at Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia.
[h]Also at Universidade Estadual de Campinas, Campinas, Brazil.
[i]Also at Centre National de la Recherche Scientifique (CNRS)—IN2P3, Paris, France.
[j]Also at Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France.
[k]Also at Joint Institute for Nuclear Research, Dubna, Russia.
[l]Also at Helwan University, Cairo, Egypt.
[m]Also at British University in Egypt, Cairo, Egypt.
[n]Also at Cairo University, Cairo, Egypt.
[o]Also at Fayoum University, El-Fayoum, Egypt.
[p]Also at Ain Shams University, Cairo, Egypt.
[q]Also at Université de Haute Alsace, Mulhouse, France.
[r]Also at Tbilisi State University, Tbilisi, Georgia.
[s]Also at Ilia State University, Tbilisi, Georgia.
[t]Also at Brandenburg University of Technology, Cottbus, Germany.
[u]Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary.
[v]Also at Eötvös Loránd University, Budapest, Hungary.
[w]Also at University of Debrecen, Debrecen, Hungary.
[x]Also at Wigner Research Centre for Physics, Budapest, Hungary.
[y]Also at University of Visva-Bharati, Santiniketan, India.
[z]Also at King Abdulaziz University, Jeddah, Saudi Arabia.
[aa]Also at University of Ruhuna, Matara, Sri Lanka.
[bb]Also at Isfahan University of Technology, Isfahan, Iran.
[cc]Also at University of Tehran, Department of Engineering Science, Tehran, Iran.
[dd]Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran.
[ee]Also at Laboratori Nazionali di Legnaro dell'INFN, Legnaro, Italy.
[ff]Also at Università degli Studi di Siena, Siena, Italy.
[gg]Also at Purdue University, West Lafayette, USA.
[hh]Also at International Islamic University of Malaysia, Kuala Lumpur, Malaysia.
[ii]Also at Consejo Nacional de Ciencia y Tecnología, Mexico city, Mexico.
[jj]Also at Institute for Nuclear Research, Moscow, Russia.
[kk]Also at St. Petersburg State Polytechnical University, St. Petersburg, Russia.
[ll]Also at National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia.
[mm]Also at California Institute of Technology, Pasadena, USA.
[nn]Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia.
[oo]Also at Facoltà Ingegneria, Università di Roma, Roma, Italy.
[pp]Also at Scuola Normale e Sezione dell'INFN, Pisa, Italy.
[qq]Also at University of Athens, Athens, Greece.
[rr]Also at Warsaw University of Technology, Institute of Electronic Systems, Warsaw, Poland.
[ss]Also at Institute for Theoretical and Experimental Physics, Moscow, Russia.
[tt]Also at Albert Einstein Center for Fundamental Physics, Bern, Switzerland.
[uu]Also at Gaziosmanpasa University, Tokat, Turkey.
[vv]Also at Mersin University, Mersin, Turkey.
[ww]Also at Cag University, Mersin, Turkey.

[xx]Also at Piri Reis University, Istanbul, Turkey.
[yy]Also at Adiyaman University, Adiyaman, Turkey.
[zz]Also at Ozyegin University, Istanbul, Turkey.
[aaa]Also at Izmir Institute of Technology, Izmir, Turkey.
[bbb]Also at Mimar Sinan University, Istanbul, Istanbul, Turkey.
[ccc]Also at Marmara University, Istanbul, Turkey.
[ddd]Also at Kafkas University, Kars, Turkey.
[eee]Also at Yildiz Technical University, Istanbul, Turkey.
[fff]Also at Kahramanmaras Sütcü Imam University, Kahramanmaras, Turkey.
[ggg]Also at Rutherford Appleton Laboratory, Didcot, United Kingdom.
[hhh]Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom.
[iii]Also at Instituto de Astrofísica de Canarias, La Laguna, Spain.
[jjj]Also at Utah Valley University, Orem, USA.
[kkk]Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia.
[lll]Also at Argonne National Laboratory, Argonne, USA.
[mmm]Also at Erzincan University, Erzincan, Turkey.
[nnn]Also at Hacettepe University, Ankara, Turkey.
[ooo]Also at Texas A&M University at Qatar, Doha, Qatar.
[ppp]Also at Kyungpook National University, Daegu, Korea.