Search for Narrow Resonances in the b-Tagged Dijet Mass Spectrum in Proton-Proton Collisions at √s =8 TeV

Journal Article

Author(s):
CMS Collaboration; Sirunyan, Albert M.; Backhaus, Malte; Bäni, Lukas; Berger, Pirmin; Casal, Bruno; Chernyavskaya, Nadezda; Dissertori, Günther; Dittmar, Michael; Donegà, Mauro; Dorfer, Christian; Grab, Christoph; Heidegger, Constantin; Hits, Dmitry; Hoss, Jan; Klijnsma, Thomas; Lustermann, Werner; Marionneau, Matthieu; Meinhard, Maren T.; Meister, Daniel; Micheli, Francesco; Musella, Pasquale; Nessi-Tedaldi, Francesca; Pata, Joosep; Pauss, Felicitas; Perrin, Gaël; Perrozzi, Luca; Quittnat, Milena; Reichmann, Michael; Ruini, Daniele; Sanz Becerra, Diego A.; Schönenberger, Myriam; Shchutska, Lesya; Tavolaro, Vittorio R.; Theofilatos, Konstantinos; Vesterbacka Olsson, Minna L.; Wallny, Rainer; Zhu, De H.; et al.

Publication date:
2018-05-18

Permanent link:
https://doi.org/10.3929/ethz-b-000268485

Rights / license:
Creative Commons Attribution 4.0 International

Originally published in:
Physical Review Letters 120(20), https://doi.org/10.1103/PhysRevLett.120.201801

PHYSICAL REVIEW LETTERS **120,** 201801 (2018)

Search for Narrow Resonances in the b-Tagged Dijet Mass Spectrum in Proton-Proton Collisions at $\sqrt{s} = 8$ TeV

A. M. Sirunyan *et al.*[*]
(CMS Collaboration)

(Received 16 February 2018; published 14 May 2018)

A search for narrow resonances decaying to bottom quark-antiquark pairs is presented, using a data sample of proton-proton collisions at $\sqrt{s} = 8$ TeV corresponding to an integrated luminosity of 19.7 fb^{-1}. The search is extended to masses lower than those reached in typical searches for resonances decaying into jet pairs at the LHC, by taking advantage of triggers that identify jets originating from bottom quarks. No significant excess of events is observed above the background predictions. Limits are set on the product of cross section and branching fraction to bottom quarks for spin 0, 1, and 2 resonances in the mass range of 325–1200 GeV. These results improve on the limits for resonances decaying into jet pairs in the 325–500 GeV mass range.

DOI: 10.1103/PhysRevLett.120.201801

Searches for new particles decaying to pairs of jets are pursued vigorously at hadron colliders, repeated at every new energy with ever increasing sensitivity in the quest for physics beyond the standard model (SM). Such "dijet" final states have been explored in proton-antiproton collisions by the UA1 [1] and UA2 [2,3] Collaborations at the CERN S$p\bar{p}$S, and at $\sqrt{s} = 1.8$ and 1.96 TeV by the CDF [4–9] and D0 [10–12] Collaborations at the Fermilab Tevatron, as well as in proton-proton (pp) collisions at $\sqrt{s} = 7$, 8, and 13 TeV by the ATLAS [13–22] and CMS [23–35] Collaborations at the CERN LHC.

The LHC dijet searches currently explore both the high-mass end of the spectrum, not previously accessible at lower-energy machines, and the low-mass range, aiming to gain sensitivity to much smaller couplings than those probed by earlier experiments. The latter searches are much more difficult because of the very large backgrounds, which result in overwhelming event rates that are beyond the typical trigger bandwidth of the ATLAS and CMS experiments. To address this challenge, several novel search strategies have been considered.

Recently, the CMS Collaboration introduced the idea of a trigger-level analysis, which profits from the fact that the trigger acceptance rate can be increased significantly if the size of the event is kept small. Thus, it is possible to collect events at an increased rate using a specialized trigger-level data output, which keeps only minimal information about the event. The trigger-level analysis, also referred to as a "scouting analysis" in CMS, enabled the mass reach of LHC dijet searches to be extended down to masses as low as 500 GeV [33].

Another way of lowering the mass reach of dijet searches is to use an initial-state radiation (ISR) jet or photon to trigger on an event and analyze the dijet system recoiling against the ISR object. Given that the ISR triggers typically require a rather high threshold for the transverse momentum (p_T) of the ISR object, for sufficiently light resonances the two jets from their decays may be merged and reconstructed as a single large-radius jet. The mass of such a jet, determined using the so-called jet substructure techniques, can then be used to search for new light resonances. Searches of this kind, recently pioneered by CMS [36,37], for the first time can reach resonance masses as low as 50 GeV, i.e., well below the lowest previously probed mass of 140 GeV, achieved by the UA2 analyses [2,3]. A similar analysis has been very recently carried out also by ATLAS [38].

Yet another strategy of extending the reach to lower masses, pursued in this Letter, is to look for resonances decaying into jets originating from the fragmentation of b quarks. The dominant QCD background in the $b\bar{b}$ final states is significantly reduced compared to that in generic dijet final states, allowing for lower trigger thresholds and increased search sensitivity, particularly for resonances decaying preferentially into third-generation particles.

Beyond the SM theories predict a variety of such resonances, e.g., Z' resonances in top-assisted technicolor models [39], Kaluza-Klein excitations of the graviton in the Randall-Sundrum (RS) models [40,41] with SM particles allowed to propagate in the bulk space [42], or additional scalar or pseudoscalar resonances with Yukawa-like couplings to quarks, as expected in the general class of two Higgs doublet models [43] or models with spin-0 dark

---

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

matter mediators [44,45]. However, even for resonances not preferentially decaying to $b\bar{b}$ final states, the sensitivity of a b quark dijet search may rival that of the generic searches because of the drastically reduced backgrounds. Searches for new, massive resonances decaying to $b\bar{b}$ final states have been explored for the first time by the CMS [31] and ATLAS [21] Collaborations. Yet, these searches only relied on the standard jet triggers used in the generic dijet searches, and therefore the minimum mass probed was as high as 1100 (ATLAS) or 1200 (CMS) GeV. It is of particular importance to extend the mass reach of these searches below 1000 GeV, for which the existing limits are still rather weak. Moreover, the $b\bar{b}$ channel is particularly important for resonances with enhanced couplings to third-generation particles and with masses below the $t\bar{t}$ threshold of about 350 GeV.

The above three strategies are complementary to each other, as they vary in sensitivity to different production and decay mechanisms of new, light resonances. This Letter presents the first search for $b\bar{b}$ resonances with masses as low as 325 GeV, i.e., below the $t\bar{t}$ threshold, using dedicated triggers requiring the presence of b quark jets. The results improve upon the sensitivity of existing generic dijet searches to models predicting such resonances. The results are interpreted in the context of a spin-0 resonance, spin-1 Z' boson, and spin-2 RS graviton, whose intrinsic widths are small compared to the experimental resolution.

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 endcap sections. Forward calorimeters extend the pseudorapidity (η) coverage provided by the barrel and endcap detectors. Muons are detected in gas-ionization chambers embedded in the steel flux-return yoke outside the solenoid. Events of interest are selected using a two-tiered trigger system [46]. The first level (L1), composed of custom hardware processors, uses information from the calorimeters and muon detectors to select events at a rate of around 100 kHz within a time interval of less than 4 μs. The second level, referred to as the high-level trigger (HLT), consists of a farm of processors running a version of the full event reconstruction software optimized for fast processing, and reduces the event rate to less than 1 kHz before data storage. 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 Ref. [47].

The search is based on a sample of pp collisions at a center-of-mass energy of 8 TeV collected with the CMS detector in 2012 and corresponding to an integrated luminosity of 19.7 fb^{-1}. The particle-flow (PF) event algorithm [48] aims to reconstruct and identify 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, 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 the 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. The missing transverse momentum, p_T^{miss}, is defined as the magnitude of the vectorial sum of transverse momenta of all PF candidates within the event.

Events are required to have at least one reconstructed collision vertex within 24 (2) cm of the mean pp interaction position along the beam axis (in the plane transverse to the beams). The vertex with the highest sum of p_T^2 of all the associated tracks is taken to be the primary vertex in the event.

For each event, hadronic jets are clustered from both charged and neutral PF candidates using the infrared- and collinear-safe anti-k_T algorithm [49] with a distance parameter of 0.5, as implemented in the FastJet package [50]. Only those charged PF candidates originating from the primary vertex are included in the clustering. Corrections based on the jet area [51] are applied to remove the energy contribution of neutral hadrons from additional pp interactions within the same or nearby bunch crossings (pileup). The jet momentum is determined as the vectorial sum of all particle momenta in the jet, and is found in simulation to be within 5%–10% of the true generator-level jet momentum, over the whole p_T spectrum and detector acceptance considered in the analysis. Jet energy corrections are derived from the simulation, and are confirmed by *in situ* measurements of the energy balance of dijet, multijet, $\gamma+\text{jet}$, and leptonically decaying $Z+\text{jet}$ events [52,53]. Jet energy corrections are further propagated to p_T^{miss}. Additional selection criteria are applied to each event to remove spurious jetlike features originating from isolated noise patterns in certain HCAL regions [54]. The jet energy resolution is typically 15% at 10 GeV, 8% at 100 GeV, and 4% at 1 TeV.

Jets originating from b quarks are identified using the combined secondary vertex (CSV) algorithm [55,56], which takes as inputs the impact parameters of jet constituents and secondary vertices reconstructed within the jet [57]. We use the "tight" ("medium") working point of the b tagging algorithm, which corresponds to approximately 50 (70)% b jet tagging efficiency and 0.1%–0.2% (1%–2%) light-quark or gluon jet mistag rate for jets with

$p_T < 300$ GeV. The b tagging efficiency in the simulation is corrected to match the efficiency measured in data [56].

Simulated Monte Carlo (MC) samples are primarily used to model signal hypotheses, as background predictions are obtained directly from data. We consider three models of narrow resonances. Scalar resonance and RS graviton signal samples are generated at leading order (LO) with PYTHIA 8.212 [58], which also models the parton shower and hadronization processes, using the CUETP8M1 underlying event tune [59,60]. The Z' boson samples are generated with MADGRAPH5_aMC@NLO 2.3.3 [61], with the parton shower and hadronization modeled with PYTHIA 8. The scalar (Z') boson model assumes gluon-gluon (quark-antiquark) production, while the RS graviton model includes both gluon-gluon and quark-antiquark production mechanisms; in all three cases, only decays to bottom quarks are simulated. This is a conservative choice, as in the flavor-universal case decays to charm quark-antiquark pair would also contribute to the signal acceptance. However, since the charm quark tagging efficiency by a dedicated b tagging algorithm is relatively low, we ignore this potential increase in the signal acceptance, leading to a conservative estimate of signal sensitivity. (We estimated the effect to be only 3%–4% in terms of the signal yield for a Z' boson with universal coupling to quarks.) For all signal hypotheses, the intrinsic resonance width is negligible compared to the experimental mass resolution. The scalar resonance and RS graviton signal samples use the NNPDF3.0LO parton distribution functions (PDFs) [62], while the Z' boson samples are generated with the NNPDF2.3LO PDF set [63]. Eight mass hypotheses are simulated between 325 and 1200 GeV for each of the three signal models.

The QCD multijet background samples are used to guide the analysis optimization and to study the performance of the b tagging algorithm. The samples are generated at LO using PYTHIA 6.424 [64] with the CTEQ6L1 PDFs [65] and the underlying event tune Z2* [60,66]. For all MC samples, the response of the CMS detector is simulated using GEANT4 [67], including the effects of pileup, obtained by superimposing additional minimum bias interactions on the hard scattering, with the multiplicity distribution matching that in data.

Online, events are selected using dedicated triggers that identify jets originating from b quarks at the HLT. At L1, either one jet with $|\eta| < 5$ and $p_T > 128$ GeV or two jets with $|\eta| < 1.74$ and $p_T > 56$ GeV are required. At the HLT, the jets are reconstructed solely from energy deposits in the calorimeter towers and augmented with the tracking information within the jet cone. Two triggers with different requirements on jet p_T and geometrical acceptance are used, defining the low-mass (SR1) and high-mass (SR2) signal regions. For SR1, the trigger requires two jets with $|\eta| < 1.7$, with the leading and subleading (in p_T) jets having $p_T > 80$ and 70 GeV, respectively. For SR2, the two jets are required to satisfy $|\eta| < 2.2$, with the leading (subleading) jet $p_T > 160$ (125) GeV. The HLT b tagging algorithm requires that the ratio of the impact parameter to its uncertainty (including the uncertainty in the primary vertex position) is large for at least two tracks within the jet area [56]. At least two of the leading six jets in the event are required to satisfy the HLT b tagging requirements. For signal events passing the rest of the event selection, the efficiency of the trigger b tagging algorithm is approximately 18% for SR1 and 49% for SR2, as determined from combined studies based on collision data dominated by QCD multijet events, as well as on signal and QCD multijet background simulations. The trigger efficiency stays constant within the uncertainties as a function of the invariant mass of the two b-tagged jets, in the entire range used in the analysis.

Offline, jets built from PF candidates are used. Events are required to satisfy $p_T^{\text{miss}}/\sum E_T < 0.5$, where $\sum E_T$ is the scalar sum of the transverse momenta of the PF candidates in the event. This requirement removes events with the energy of one of the jets significantly mismeasured, as well as events with large calorimeter noise inside a jet. The two leading jets form the dijet system. The jets must satisfy the same p_T and η requirements as in the corresponding HLT trigger. The pseudorapidity difference between the two jets must be less than 1.3. This requirement reduces the QCD multijet background considerably, while retaining high signal efficiency [13,23]. One of the two leading jets is required to pass the tight working point of the CSV algorithm, while the other must pass the medium CSV working point. Finally, the dijet invariant mass (m_{jj}) range is set to 296–1058 GeV for SR1, and 526–1607 GeV for SR2. These two search regions are used to probe signal masses in the range 325–700 and 700–1200 GeV, respectively, with the boundary chosen in the vicinity of the intersection of the expected limits in these two regions for all three resonance spins.

The product of acceptance and efficiency ($\sigma\mathcal{A}$) for simulated signal events are shown in Fig. 1. For SR1 (SR2), these range from 1.2% to 2.9% (1.6% to 4.5%), with small differences between models due to differences in the geometrical acceptance, defined by the rapidity requirements on the two leading jets. At high masses (above 750 GeV), $\sigma\mathcal{A}$ drops because of the reduced b tagging efficiency for high-p_T jets.

The background estimate is obtained from a binned (with 1 GeV bins), extended maximum likelihood [68] fit to the m_{jj} spectrum in data using an empirically determined function. Several families of steeply falling functions commonly used in similar searches are considered, and the best fit function is chosen using an F-test [69] based on the χ^2 per degree of freedom of the fit. The function chosen is $d\sigma/dx = \epsilon_{\text{trig}}(x)p_0(1-x)^{p_1}x^{-p_2-p_3\log(x)}$, where $x = m_{\text{jj}}/\sqrt{s}$, and $\epsilon_{\text{trig}}(x)$ is a sigmoid function describing the efficiency of the p_T requirements of the trigger. The parameters of the sigmoid function are determined in events collected with triggers requiring a single isolated muon, and

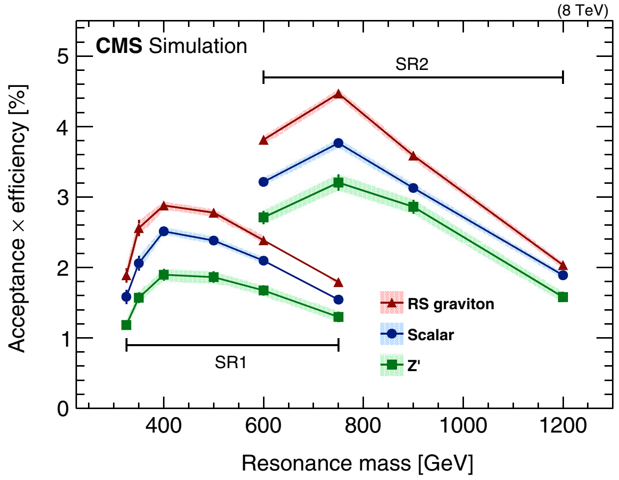

FIG. 1. The products of acceptance and efficiency for simulated signal events in SR1 and SR2, separately for the scalar, Z', and RS graviton signal models. The shaded bands represent the statistical uncertainties.

are fixed in the background fit. The trigger turn-on effect is sizable only at the lower end of SR1, with the trigger inefficiency being 1.8% for $m_{\mathrm{jj}} = 296$ GeV and less than 0.1% for $m_{\mathrm{jj}} > 380$ GeV. The m_{jj} distributions of the signal hypotheses are modeled using convolutions of a Gaussian and an exponential function [70]. The signal shapes for masses between two adjacent simulated mass points are derived via a linear interpolation of the fit function parameters. The typical width of the Gaussian core of a signal resonance is 10%–15%, depending on the resonance spin and production mechanism, as well as on the resonance mass.

Extensive studies of a possible systematic bias from the choice of the functional form of the background estimate are performed with alternative fit functions, with or without signal injection. The shapes obtained from background-only fits to the data with the alternative functions are used to generate pseudo-data sets. Each pseudo-data set has a total number of events randomly drawn from a Poisson distribution with the mean equal to the yields observed in data. In the set of studies with signal injection, the pseudo-data sets are generated from a signal plus background model. In these studies, the injected signal cross section corresponds approximately to the expected 95% confidence level (CL) cross section limits discussed below. The generated m_{jj} spectra are then fitted with the sum of chosen background function and a signal model, and the signal cross section is extracted. Distributions of the difference between the fitted and injected signal cross sections divided by the fitted uncertainty are constructed, and their shapes are found to be consistent with a normal distribution with the mean within 0.5 of zero and the width consistent with unity. Thus, we conclude that any possible systematic bias from the choice of the functional form is small compared to the statistical uncertainty of the fit, and use the latter as the only uncertainty in the background prediction.

Figure 2 shows the m_{jj} distributions in data in SR1 and SR2, fitted with the background-only hypothesis, together

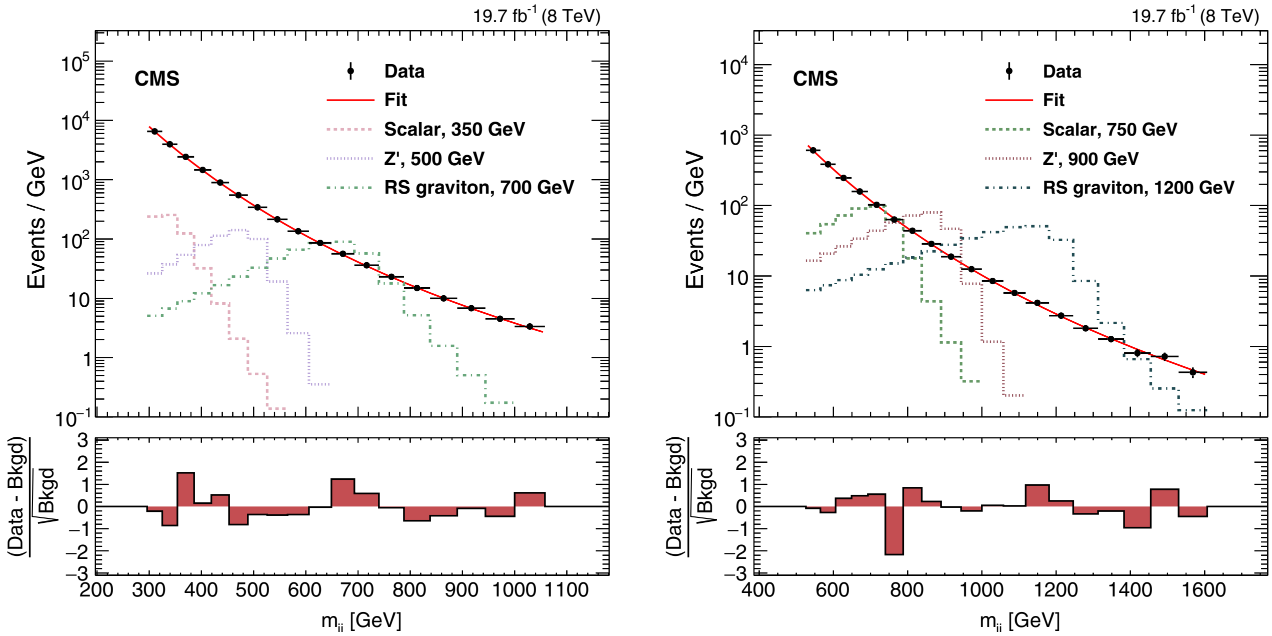

FIG. 2. The dijet invariant mass distributions in SR1 (left) and SR2 (right), shown with the background prediction derived from a fit using an empirical function under the background-only hypothesis. Representative examples of signal distributions are also shown, each normalized to a visible cross section of 1 pb. The bottom panels show the difference between the data and the background estimate, divided by the statistical uncertainty in the estimated background.

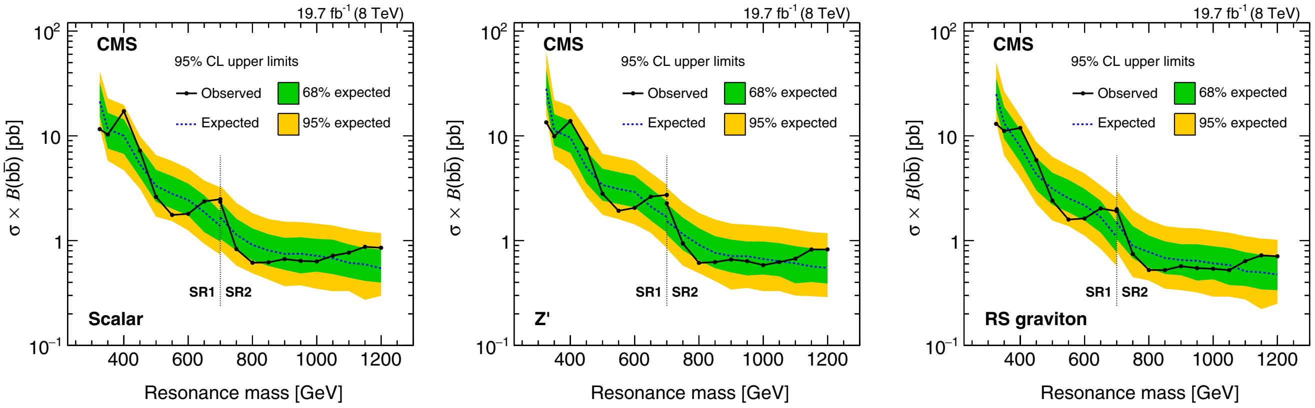

FIG. 3. Observed and expected 95% CL upper limits on the product of cross section and branching fraction to bottom quark-antiquark pairs for a scalar resonance (left), Z' boson (middle), and RS graviton (right) signal models, as functions of resonance mass. The discontinuity in the limits at 700 GeV is associated with a change in the acceptance from SR1 to SR2.

with representative examples of signal distributions normalized to a visible cross section, i.e., fiducial $\sigma\mathcal{A}$ of 1 pb. For presentation purposes, the data are binned with a bin width approximating the experimental dijet mass resolution.

Systematic uncertainties are assigned to the simulated signal to account for observed differences between simulation and data. Jet energy scale and resolution uncertainties of 1 and 10% [53] in the dijet invariant mass, respectively, are included as the uncertainties in the fitted signal parameters. The following four sources of uncertainty in the signal yield are considered. Scale factors are applied to account for mismodeling of the b tagging efficiency in simulation, leading to a 5%–15% [55,56] uncertainty, depending on the signal mass. An uncertainty of 10% is assigned to the b tagging efficiency in the HLT (as measured from data collected with unbiased prescaled triggers). An uncertainty of 2%–5% is assigned to account for the effect of the choice of PDFs on the signal acceptance, following the PDF4LHC prescription [71,72]. Finally, an uncertainty of 2.6% is assigned to the integrated luminosity measurement [73].

For each signal hypothesis, the dijet invariant mass spectrum is fit with a signal plus background hypothesis, where the parameters of the background function are freely floating. No significant excesses over the background-only hypothesis are observed. We set limits on the production of narrow resonances using the CL$_s$ criterion [75–77], with an asymptotic approximation [78] for the likelihood ratio used as a test statistic, and log-normal (Gaussian) constraints used to account for the systematic uncertainties in the signal and background yields (shapes). In Fig. 3, the results are interpreted as upper limits at 95% CL on the product of cross section and branching fraction to bottom quark-antiquark pairs, $\mathcal{B}(b\bar{b})$. The observed limits improve on the previously obtained limits on the $b\bar{b}$ resonances for masses below 1.1 TeV, and extend below the $t\bar{t}$ threshold, which is important to restrict the models with resonances coupled preferentially to the third-generation particles.

The limits on the Z' boson model are further interpreted in the context of a simplified model of a leptophobic vector resonance with a universal coupling to quarks g'_q that is related to the coupling of Ref. [79] by $g'_q = g_\mathrm{B}/6$. The limits on g'_q are shown in Fig. 4 (left), along with limits from other experiments [2,8,9,18] and earlier CMS analyses [33,34,37]. The current results improve on the existing limits in the Z' mass range $325 < m_{Z'} < 500$ GeV, where g'_q values above 0.11–0.18 are excluded. We note that the narrow-width approximation used in setting cross section limits in this analysis that are further translated into g'_q limits is valid only for g'_q values $\lesssim 0.7$. This upper limit corresponds to a resonance width of about 25% of its mass, i.e., comparable with the instrumental resolution. Consequently, we truncate the y axis of Fig. 4 (left) at this value of the coupling.

Following the method described in Ref. [80], the limits on the Z' boson model are further interpreted as limits on the variable $\zeta = [\sum_{ij\in I}\mathcal{B}(Z' \to ij)]\mathcal{B}(Z' \to b\bar{b})\Gamma_{Z'}/m_{Z'}$, where $\Gamma_{Z'}$ is a width of the Z' resonance, $\mathcal{B}$ is a branching fraction, and I represents the set of production modes $ij \to Z'$, with i and j being the corresponding partons. The ζ variable provides a model-independent description of the generic s-channel production of narrow-width resonances and can be used for a variety of theoretical interpretations of experimental limits on the production of such resonances decaying into various final states. The limits are shown in Fig. 4 (right) for the Z' model with a universal quark coupling, as well as for up and down quark production modes individually. The limits are determined using the narrow-width approximation, which corresponds to a conservative interpretation [81]: for the Z' boson model with $g'_q = 0.25$, the ζ limits computed with the resonance width taken into account are lower by 0.3 (4.7)% at

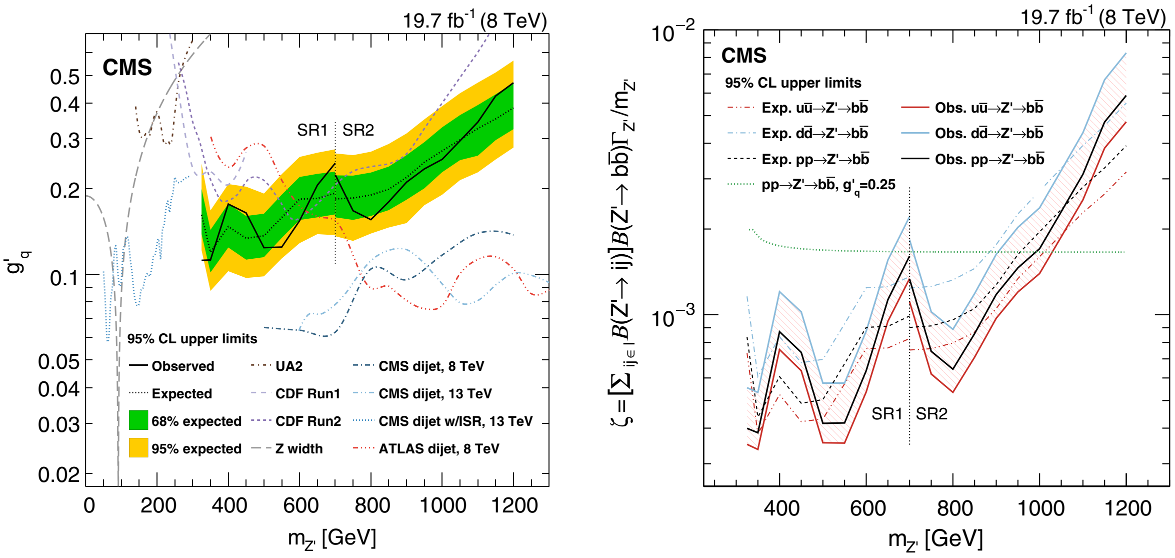

FIG. 4. Left: the 95% CL upper limits (solid line) on the universal coupling g'_q between the leptophobic Z' boson and quarks. Limits from other experiments [2,8,9,18] and earlier CMS analyses [33,34,37], are also shown, along with an indirect constraint from the Z boson width [74]. Right: expected (dashed lines) and observed (solid lines) 95% CL upper limits on the simplified model variable ζ. The limits are shown for $u\bar{u} \to Z'$ and $d\bar{d} \to Z'$ individually, as well as for $pp \to Z'$, assuming a universal quark coupling. The ζ values for the Z' boson model with $g'_q = 0.25$ are also shown. The hatched red band represents the envelope of limits for theoretical models that predict an s-channel production of a Z' resonance with arbitrary couplings to up and down quarks. The discontinuity in the limits at 700 GeV is associated with a change in the acceptance from SR1 to SR2.

$m_{Z'} = 400$ (1200) GeV. The ζ interpretation can be used, e.g., to convert the g'_q limits in Fig. 4 to limits on the coupling g'_d for a Z' boson model with coupling only to down-type quarks. Taking into account the different branching fractions and the widths of the two models, $g'_d = g'_q[\zeta(d\bar{d} \to Z' \to b\bar{b})/\zeta(pp \to Z' \to b\bar{b})]^{1/2}$.

In summary, a search for new resonances decaying to bottom quark-antiquark pairs produced in 8 TeV proton-proton collisions has been presented. Using triggers that identify jets originating from bottom quarks, the search probes signal masses as low as 325 GeV. No statistically significant excesses above the background predictions are observed in the entire invariant mass range studied, 325–1200 GeV. Upper limits are set on the production cross section of scalar, vector, and tensor resonances. The limits are also interpreted in the context of a simplified model of a leptophobic Z' boson with a universal coupling g'_q to quarks. Values of g'_q above 0.11–0.18 are excluded for Z' boson masses below 500 GeV, improving on the previous best limits in this mass range, which date back to the CDF experiment. The first experimental limits on the parameter ζ of a simplified s-channel resonance framework [80] have been obtained, making possible the reinterpretation of the limits in a variety of theoretical models corresponding to different resonance production and decay mechanisms.

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: BMWFW and FWF (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, and FAPESP (Brazil); MES (Bulgaria); CERN; CAS, MoST, and NSFC (China); COLCIENCIAS (Colombia); MSES and CSF (Croatia); RPF (Cyprus); SENESCYT (Ecuador); MoER, ERC IUT, and ERDF (Estonia); Academy of Finland, MEC, and HIP (Finland); CEA and CNRS/IN2P3 (France); BMBF, DFG, and HGF (Germany); GSRT (Greece); OTKA and NIH (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); MSIP and NRF (Republic of Korea); LAS (Lithuania); MOE and UM (Malaysia); BUAP, CINVESTAV, CONACYT, LNS, SEP, and UASLP-FAI (Mexico); MBIE (New Zealand); PAEC (Pakistan); MSHE and NSC (Poland); FCT (Portugal); JINR (Dubna); MON, RosAtom, RAS, RFBR and RAEP (Russia); MESTD (Serbia); SEIDI, CPAN, PCTI and FEDER (Spain); Swiss Funding Agencies (Switzerland); MST (Taipei); ThEPCenter, IPST, STAR, and NSTDA (Thailand); TUBITAK and TAEK (Turkey); NASU and SFFR (Ukraine); STFC (United Kingdom); DOE and NSF (USA).

[1] C. Albajar *et al.* (UA1 Collaboration), Two-jet mass distributions at the CERN proton-antiproton collider, Phys. Lett. B **209**, 127 (1988).

[2] J. Alitti *et al.* (UA2 Collaboration), A measurement of two-jet decays of the W and Z bosons at the CERN $\bar{p}p$ collider, Z. Phys. C **49**, 17 (1991).

[3] J. Alitti *et al.* (UA2 Collaboration), A search for new intermediate vector mesons and excited quarks decaying to two jets at the CERN $\bar{p}p$ collider, Nucl. Phys. **B400**, 3 (1993).

[4] F. Abe *et al.* (CDF Collaboration), The two-jet invariant mass-distribution at $\sqrt{s}=1.8$ TeV, Phys. Rev. D **41**, 1722(R) (1990).

[5] F. Abe *et al.* (CDF Collaboration), Search for Quark Compositeness, Axigluons and Heavy Particles Using the Dijet Invariant Mass Spectrum Observed in $\bar{p}p$ Collisions, Phys. Rev. Lett. **71**, 2542 (1993).

[6] F. Abe *et al.* (CDF Collaboration), Search for New Particles Decaying to Dijets in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV, Phys. Rev. Lett. **74**, 3538 (1995).

[7] F. Abe *et al.* (CDF Collaboration), Measurement of Dijet Angular Distributions by the Collider Detector at Fermilab, Phys. Rev. Lett. **77**, 5336 (1996); Erratum, Phys. Rev. Lett. **78**, 4307 (1997).

[8] F. Abe *et al.* (CDF Collaboration), Search for new particles decaying to dijets at CDF, Phys. Rev. D **55**, R5263(R) (1997).

[9] T. Aaltonen *et al.* (CDF Collaboration), Search for new particles decaying into dijets in proton-antiproton collisions at $\sqrt{s} = 1.96$ TeV, Phys. Rev. D **79**, 112002 (2009).

[10] B. Abbott *et al.* (D0 Collaboration), Measurement of Dijet Angular Distributions and Search for Quark Compositeness, Phys. Rev. Lett. **80**, 666 (1998).

[11] B. Abbott *et al.* (D0 Collaboration), Dijet Mass Spectrum and a Search for Quark Compositeness in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV, Phys. Rev. Lett. **82**, 2457 (1999).

[12] V. M. Abazov *et al.* (D0 Collaboration), Search for new particles in the two-jet decay channel with the D0 detector, Phys. Rev. D **69**, 111101(R) (2004).

[13] ATLAS Collaboration, Search for New Particles in Two-Jet Final States in 7 TeV Proton-Proton Collisions with the ATLAS Detector at the LHC, Phys. Rev. Lett. **105**, 161801 (2010).

[14] ATLAS Collaboration, Search for quark contact interactions in dijet angular distributions in pp collisions at $\sqrt{s}=7$ TeV measured with the ATLAS detector, Phys. Lett. B **694**, 327 (2011).

[15] ATLAS Collaboration, A search for new physics in dijet mass and angular distributions in pp collisions at $\sqrt{s} = 7$ TeV measured with the ATLAS detector, New J. Phys. **13**, 053044 (2011).

[16] ATLAS Collaboration, Search for new physics in the dijet mass distribution using 1 fb^{-1} of pp collision data at $\sqrt{s} = 7$ TeV collected by the ATLAS detector, Phys. Lett. B **708**, 37 (2012).

[17] ATLAS Collaboration, ATLAS search for new phenomena in dijet mass and angular distributions using pp collisions at $\sqrt{s} = 7$ TeV, J. High Energy Phys. 01 (2013) 029.

[18] ATLAS Collaboration, Search for new phenomena in the dijet mass distribution using pp collision data at $\sqrt{s} = 8$ TeV with the ATLAS detector, Phys. Rev. D **91**, 052007 (2015).

[19] ATLAS Collaboration, Search for New Phenomena in Dijet Angular Distributions in Proton-Proton Collisions at $\sqrt{s} = 8$ TeV Measured with the ATLAS Detector, Phys. Rev. Lett. **114**, 221802 (2015).

[20] ATLAS Collaboration, Search for new phenomena in dijet mass and angular distributions from pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, Phys. Lett. B **754**, 302 (2016).

[21] ATLAS Collaboration, Search for resonances in the mass distribution of jet pairs with one or two jets identified as b-jets in proton–proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, Phys. Lett. B **759**, 229 (2016).

[22] ATLAS Collaboration, Search for new phenomena in dijet events using 37 fb^{-1} of pp collision data collected at $\sqrt{s} = 13$ TeV with the ATLAS detector, Phys. Rev. D **96**, 052004 (2017).

[23] CMS Collaboration, Search for Dijet Resonances in 7 TeV pp Collisions at CMS, Phys. Rev. Lett. **105**, 211801 (2010); Publisher's Note, Phys. Rev. Lett. **106**, 029902 (2010).

[24] CMS Collaboration, Search for Quark Compositeness with the Dijet Centrality Ratio in pp Collisions at $\sqrt{s} = 7$ TeV, Phys. Rev. Lett. **105**, 262001 (2010).

[25] CMS Collaboration, Measurement of Dijet Angular Distributions and Search for Quark Compositeness in pp Collisions at $\sqrt{s} = 7$ TeV, Phys. Rev. Lett. **106**, 201804 (2011).

[26] CMS Collaboration, Search for resonances in the dijet mass spectrum from 7 TeV pp collisions at CMS, Phys. Lett. B **704**, 123 (2011).

[27] CMS Collaboration, Search for quark compositeness in dijet angular distributions from pp collisions at $\sqrt{s} = 7$ TeV, J. High Energy Phys. 05 (2012) 055.

[28] CMS Collaboration, Search for narrow resonances and quantum black holes in inclusive and b-tagged dijet mass spectra from pp collisions at $\sqrt{s} = 7$ TeV, J. High Energy Phys. 01 (2013) 013.

[29] CMS Collaboration, Search for narrow resonances using the dijet mass spectrum in pp collisions at $\sqrt{s} = 8$ TeV, Phys. Rev. D **87**, 114015 (2013).

[30] CMS Collaboration, Search for quark contact interactions and extra spatial dimensions using dijet angular distributions in proton-proton collisions at $\sqrt{s} = 8$ TeV, Phys. Lett. B **746**, 79 (2015).

[31] CMS Collaboration, Search for resonances and quantum black holes using dijet mass spectra in proton-proton collisions at $\sqrt{s} = 8$ TeV, Phys. Rev. D **91**, 052009 (2015).

[32] CMS Collaboration, Search for Narrow Resonances Decaying to Dijets in Proton-Proton Collisions at $\sqrt{s} = 13$ TeV, Phys. Rev. Lett. **116**, 071801 (2016).

[33] CMS Collaboration, Search for Narrow Resonances in Dijet Final States at $\sqrt{s} = 8$ TeV with the Novel CMS Technique of Data Scouting, Phys. Rev. Lett. **117**, 031802 (2016).

[34] CMS Collaboration, Search for dijet resonances in proton-proton collisions at $\sqrt{s} = 13$ TeV and constraints on dark matter and other models, Phys. Lett. B **769**, 520 (2017).

[35] CMS Collaboration, Search for new physics with dijet angular distributions in proton-proton collisions at $\sqrt{s} = 13$ TeV, J. High Energy Phys. 07 (2017) 013.

[36] CMS Collaboration, Search for Low Mass Vector Resonances Decaying to Quark-Antiquark Pairs in Proton-Proton Collisions at $\sqrt{s} = 13$ TeV, Phys. Rev. Lett. **119**, 111802 (2017).

[37] CMS Collaboration, Search for low mass vector resonances decaying into quark-antiquark pairs in proton-proton collisions at $\sqrt{s} = 13$ TeV, J. High Energy Phys. 01 (2018) 097.

[38] ATLAS Collaboration, Search for light resonances decaying to boosted quark pairs and produced in association with a

photon or a jet in proton-proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, arXiv:1801.08769.

[39] C. T. Hill, Topcolor assisted technicolor, Phys. Lett. B **345**, 483 (1995).

[40] L. Randall and R. Sundrum, Large Mass Hierarchy from a Small Extra Dimension, Phys. Rev. Lett. **83**, 3370 (1999).

[41] L. Randall and R. Sundrum, Alternative to Compactification, Phys. Rev. Lett. **83**, 4690 (1999).

[42] H. Davoudiasl, J. L. Hewett, and T. G. Rizzo, Experimental probes of localized gravity: On and off the wall, Phys. Rev. D **63**, 075004 (2001).

[43] J. F. Gunion, S. Dawson, H. E. Haber, and G. L. Kane, *The Higgs hunter's guide* (Addison-Wesley, New York, 1990).

[44] M. R. Buckley, D. Feld, and D. Goncalves, Scalar simplified models for dark matter, Phys. Rev. D **91**, 015017 (2015).

[45] U. Haisch and E. Re, Simplified dark matter top-quark interactions at the LHC, J. High Energy Phys. 06 (2015) 078.

[46] CMS Collaboration, The CMS trigger system, J. Instrum. **12**, P01020 (2017).

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

[48] CMS Collaboration, Particle-flow reconstruction and global event description with the CMS detector, J. Instrum. **12**, P10003 (2017).

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

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

[51] M. Cacciari and G. P. Salam, Pileup subtraction using jet areas, Phys. Lett. B **659**, 119 (2008).

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

[53] CMS Collaboration, Jet energy scale and resolution in the CMS experiment in pp collisions at 8 TeV, J. Instrum. **12**, P02014 (2017).

[54] CMS Collaboration, CMS Physics Analysis Summary Report No. CMS-PAS-JME-10-003, 2010, http://cdsweb.cern.ch/record/1279362.

[55] CMS Collaboration, Identification of b-quark jets with the CMS experiment, J. Instrum. **8**, P04013 (2013).

[56] CMS Collaboration, CMS Physics Analysis Summary Report No. CMS-PAS-BTV-13-001, 2013, http://cds.cern.ch/record/1581306.

[57] CMS Collaboration, Description and performance of track and primary-vertex reconstruction with the CMS tracker, J. Instrum. **9**, P10009 (2014).

[58] T. Sjöstrand, S. Mrenna, and P. Z. Skands, A brief introduction to PYTHIA 8.1, Comput. Phys. Commun. **178**, 852 (2008).

[59] P. Skands, S. Carrazza, and J. Rojo, Tuning PYTHIA 8.1: the Monash 2013 tune, Eur. Phys. J. C **74**, 3024 (2014).

[60] CMS Collaboration, Event generator tunes obtained from underlying event and multiparton scattering measurements, Eur. Phys. J. C **76**, 155 (2016).

[61] J. Alwall, R. Frederix, S. Frixione, V. Hirschi, F. Maltoni, O. Mattelaer, H. S. Shao, T. Stelzer, P. Torrielli, 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.

[62] R. D. Ball *et al.* (NNPDF), Parton distributions for the LHC Run II, J. High Energy Phys. 04 (2015) 040.

[63] R. D. Ball *et al.*, Parton distributions with LHC data, Nucl. Phys. **B867**, 244 (2013).

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

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

[66] CMS Collaboration, Study of the underlying event at forward rapidity in pp collisions at $\sqrt{s} = 0.9$, 2.76, and 7 TeV, J. High Energy Phys. 04 (2013) 072.

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

[68] R. J. Barlow, Extended maximum likelihood, Nucl. Instrum. Methods Phys. Res., Sect. A **297**, 496 (1990).

[69] R. A. Fisher, On the interpretation of χ^2 from contingency tables, and the calculation of p, J. R. Stat. Soc. **85**, 87 (1922).

[70] A. D. Bukin, Fitting function for asymmetric peaks, arXiv:0711.4449.

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

[72] M. Botje *et al.*, The PDF4LHC working group interim recommendations, arXiv:1101.0538.

[73] CMS Collaboration, Technical Report CMS-PAS-LUM-13-001, 2013, https://cds.cern.ch/record/1598864.

[74] B. A. Dobrescu and C. Frugiuele, Hidden GeV-Scale Interactions of Quarks, Phys. Rev. Lett. **113**, 061801 (2014).

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

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

[77] ATLAS and CMS Collaborations, Report No. ATL-PHYS-PUB-2011-011, CMS NOTE-2011/005, 2011, https://cdsweb.cern.ch/record/1379837.

[78] G. Cowan, K. Cranmer, E. Gross, and O. Vitells, Asymptotic formulae for likelihood-based tests of new physics, Eur. Phys. J. C **71**, 1554 (2011); Erratum, Eur. Phys. J. C **73**, 2501 (2013).

[79] B. A. Dobrescu and F. Yu, Coupling-mass mapping of dijet peak searches, Phys. Rev. D **88**, 035021 (2013); Erratum, Phys. Rev. D **90**, 079901 (2014).

[80] R. S. Chivukula, P. Ittisamai, K. Mohan, and E. H. Simmons, Simplified limits on resonances at the LHC, Phys. Rev. D **94**, 094029 (2016).

[81] R. S. Chivukula, P. Ittisamai, K. Mohan, and E. H. Simmons, Broadening the reach of simplified limits on resonances at the LHC, Phys. Rev. D **96**, 055043 (2017).

A. M. Sirunyan,[1] A. Tumasyan,[1] W. Adam,[2] F. Ambrogi,[2] E. Asilar,[2] T. Bergauer,[2] J. Brandstetter,[2] E. Brondolin,[2]
M. Dragicevic,[2] J. Erö,[2] A. Escalante Del Valle,[2] M. Flechl,[2] M. Friedl,[2] R. Frühwirth,[2,b] V. M. Ghete,[2] J. Grossmann,[2]
J. Hrubec,[2] M. Jeitler,[2,b] A. König,[2] N. Krammer,[2] I. Krätschmer,[2] D. Liko,[2] T. Madlener,[2] I. Mikulec,[2] E. Pree,[2] N. Rad,[2]
H. Rohringer,[2] J. Schieck,[2,b] R. Schöfbeck,[2] M. Spanring,[2] D. Spitzbart,[2] A. Taurok,[2] W. Waltenberger,[2] J. Wittmann,[2]
C.-E. Wulz,[2,b] M. Zarucki,[2] V. Chekhovsky,[3] V. Mossolov,[3] J. Suarez Gonzalez,[3] E. A. De Wolf,[4] D. Di Croce,[4] X. Janssen,[4]
J. Lauwers,[4] M. Pieters,[4] M. Van De Klundert,[4] H. Van Haevermaet,[4] P. Van Mechelen,[4] N. Van Remortel,[4] S. Abu Zeid,[5]
F. Blekman,[5] J. D'Hondt,[5] I. De Bruyn,[5] J. De Clercq,[5] K. Deroover,[5] G. Flouris,[5] D. Lontkovskyi,[5] S. Lowette,[5]
I. Marchesini,[5] S. Moortgat,[5] L. Moreels,[5] Q. Python,[5] K. Skovpen,[5] S. Tavernier,[5] W. Van Doninck,[5] P. Van Mulders,[5]
I. Van Parijs,[5] D. Beghin,[6] B. Bilin,[6] H. Brun,[6] B. Clerbaux,[6] G. De Lentdecker,[6] H. Delannoy,[6] B. Dorney,[6] G. Fasanella,[6]
L. Favart,[6] R. Goldouzian,[6] A. Grebenyuk,[6] A. K. Kalsi,[6] T. Lenzi,[6] J. Luetic,[6] T. Seva,[6] E. Starling,[6] C. Vander Velde,[6]
P. Vanlaer,[6] D. Vannerom,[6] R. Yonamine,[6] T. Cornelis,[7] D. Dobur,[7] A. Fagot,[7] M. Gul,[7] I. Khvastunov,[7,c] D. Poyraz,[7]
C. Roskas,[7] D. Trocino,[7] M. Tytgat,[7] W. Verbeke,[7] B. Vermassen,[7] M. Vit,[7] N. Zaganidis,[7] H. Bakhshiansohi,[8] O. Bondu,[8]
S. Brochet,[8] G. Bruno,[8] C. Caputo,[8] A. Caudron,[8] P. David,[8] S. De Visscher,[8] C. Delaere,[8] M. Delcourt,[8] B. Francois,[8]
A. Giammanco,[8] G. Krintiras,[8] V. Lemaitre,[8] A. Magitteri,[8] A. Mertens,[8] M. Musich,[8] K. Piotrzkowski,[8] L. Quertenmont,[8]
A. Saggio,[8] M. Vidal Marono,[8] S. Wertz,[8] J. Zobec,[8] W. L. Aldá Júnior,[9] F. L. Alves,[9] G. A. Alves,[9] L. Brito,[9]
G. Correia Silva,[9] C. Hensel,[9] A. Moraes,[9] M. E. Pol,[9] P. Rebello Teles,[9] E. Belchior Batista Das Chagas,[10] W. Carvalho,[10]
J. Chinellato,[10,d] E. Coelho,[10] E. M. Da Costa,[10] G. G. Da Silveira,[10,e] D. De Jesus Damiao,[10] S. Fonseca De Souza,[10]
H. Malbouisson,[10] M. Medina Jaime,[10,f] M. Melo De Almeida,[10] C. Mora Herrera,[10] L. Mundim,[10] H. Nogima,[10]
L. J. Sanchez Rosas,[10] A. Santoro,[10] A. Sznajder,[10] M. Thiel,[10] E. J. Tonelli Manganote,[10,d] F. Torres Da Silva De Araujo,[10]
A. Vilela Pereira,[10] S. Ahuja,[11a] C. A. Bernardes,[11a] L. Calligaris,[11a] T. R. Fernandez Perez Tomei,[11a] E. M. Gregores,[11b]
P. G. Mercadante,[11b] S. F. Novaes,[11a] Sandra S. Padula,[11a] D. Romero Abad,[11b] J. C. Ruiz Vargas,[11a] A. Aleksandrov,[12]
R. Hadjiiska,[12] P. Iaydjiev,[12] A. Marinov,[12] M. Misheva,[12] M. Rodozov,[12] M. Shopova,[12] G. Sultanov,[12] A. Dimitrov,[13]
L. Litov,[13] B. Pavlov,[13] P. Petkov,[13] W. Fang,[14,g] X. Gao,[14,g] L. Yuan,[14] M. Ahmad,[15] J. G. Bian,[15] G. M. Chen,[15]
H. S. Chen,[15] M. Chen,[15] Y. Chen,[15] C. H. Jiang,[15] D. Leggat,[15] H. Liao,[15] Z. Liu,[15] F. Romeo,[15] S. M. Shaheen,[15]
A. Spiezia,[15] J. Tao,[15] C. Wang,[15] Z. Wang,[15] E. Yazgan,[15] H. Zhang,[15] J. Zhao,[15] Y. Ban,[16] G. Chen,[16] J. Li,[16] Q. Li,[16]
S. Liu,[16] Y. Mao,[16] S. J. Qian,[16] D. Wang,[16] Z. Xu,[16] Y. Wang,[17] C. Avila,[18] A. Cabrera,[18] C. A. Carrillo Montoya,[18]
L. F. Chaparro Sierra,[18] C. Florez,[18] C. F. González Hernández,[18] M. A. Segura Delgado,[18] B. Courbon,[19] N. Godinovic,[19]
D. Lelas,[19] I. Puljak,[19] P. M. Ribeiro Cipriano,[19] T. Sculac,[19] Z. Antunovic,[20] M. Kovac,[20] V. Brigljevic,[21] D. Ferencek,[21]
K. Kadija,[21] B. Mesic,[21] A. Starodumov,[21,h] T. Susa,[21] M. W. Ather,[22] A. Attikis,[22] G. Mavromanolakis,[22] J. Mousa,[22]
C. Nicolaou,[22] F. Ptochos,[22] P. A. Razis,[22] H. Rykaczewski,[22] M. Finger,[23,i] M. Finger Jr.,[23,i] E. Carrera Jarrin,[24]
Y. Assran,[25,j,k] S. Elgammal,[25,k] M. A. Mahmoud,[25,l,k] S. Bhowmik,[26] R. K. Dewanjee,[26] M. Kadastik,[26] L. Perrini,[26]
M. Raidal,[26] C. Veelken,[26] P. Eerola,[27] H. Kirschenmann,[27] J. Pekkanen,[27] M. Voutilainen,[27] J. Havukainen,[28]
J. K. Heikkilä,[28] T. Järvinen,[28] V. Karimäki,[28] R. Kinnunen,[28] T. Lampén,[28] K. Lassila-Perini,[28] S. Laurila,[28] S. Lehti,[28]
T. Lindén,[28] P. Luukka,[28] T. Mäenpää,[28] H. Siikonen,[28] E. Tuominen,[28] J. Tuominiemi,[28] T. Tuuva,[29] M. Besancon,[30]
F. Couderc,[30] M. Dejardin,[30] D. Denegri,[30] J. L. Faure,[30] F. Ferri,[30] S. Ganjour,[30] S. Ghosh,[30] A. Givernaud,[30] P. Gras,[30]
G. Hamel de Monchenault,[30] P. Jarry,[30] C. Leloup,[30] E. Locci,[30] M. Machet,[30] J. Malcles,[30] G. Negro,[30] J. Rander,[30]
A. Rosowsky,[30] M. Ö. Sahin,[30] M. Titov,[30] A. Abdulsalam,[31,m] C. Amendola,[31] I. Antropov,[31] S. Baffioni,[31] F. Beaudette,[31]
P. Busson,[31] L. Cadamuro,[31] C. Charlot,[31] R. Granier de Cassagnac,[31] M. Jo,[31] I. Kucher,[31] S. Lisniak,[31] A. Lobanov,[31]
J. Martin Blanco,[31] M. Nguyen,[31] C. Ochando,[31] G. Ortona,[31] P. Paganini,[31] P. Pigard,[31] R. Salerno,[31] J. B. Sauvan,[31]
Y. Sirois,[31] A. G. Stahl Leiton,[31] Y. Yilmaz,[31] A. Zabi,[31] A. Zghiche,[31] J.-L. Agram,[32,n] J. Andrea,[32] D. Bloch,[32]
J.-M. Brom,[32] E. C. Chabert,[32] C. Collard,[32] E. Conte,[32,n] X. Coubez,[32] F. Drouhin,[32,n] J.-C. Fontaine,[32,n] D. Gelé,[32]
U. Goerlach,[32] M. Jansová,[32] P. Juillot,[32] A.-C. Le Bihan,[32] N. Tonon,[32] P. Van Hove,[32] S. Gadrat,[33] S. Beauceron,[34]
C. Bernet,[34] G. Boudoul,[34] N. Chanon,[34] R. Chierici,[34] D. Contardo,[34] P. Depasse,[34] H. El Mamouni,[34] J. Fay,[34] L. Finco,[34]
S. Gascon,[34] M. Gouzevitch,[34] G. Grenier,[34] B. Ille,[34] F. Lagarde,[34] I. B. Laktineh,[34] H. Lattaud,[34] M. Lethuillier,[34]
L. Mirabito,[34] A. L. Pequegnot,[34] S. Perries,[34] A. Popov,[34,o] V. Sordini,[34] M. Vander Donckt,[34] S. Viret,[34] S. Zhang,[34]
T. Toriashvili,[35,p] Z. Tsamalaidze,[36,i] C. Autermann,[37] L. Feld,[37] M. K. Kiesel,[37] K. Klein,[37] M. Lipinski,[37] M. Preuten,[37]
M. P. Rauch,[37] C. Schomakers,[37] J. Schulz,[37] M. Teroerde,[37] B. Wittmer,[37] V. Zhukov,[37,o] A. Albert,[38] D. Duchardt,[38]
M. Endres,[38] M. Erdmann,[38] S. Erdweg,[38] T. Esch,[38] R. Fischer,[38] A. Güth,[38] T. Hebbeker,[38] C. Heidemann,[38]
K. Hoepfner,[38] S. Knutzen,[38] M. Merschmeyer,[38] A. Meyer,[38] P. Millet,[38] S. Mukherjee,[38] T. Pook,[38] M. Radziej,[38]

H. Reithler,[38] M. Rieger,[38] F. Scheuch,[38] D. Teyssier,[38] S. Thüer,[38] G. Flügge,[39] B. Kargoll,[39] T. Kress,[39] A. Künsken,[39] T. Müller,[39] A. Nehrkorn,[39] A. Nowack,[39] C. Pistone,[39] O. Pooth,[39] A. Stahl,[39,q] M. Aldaya Martin,[40] T. Arndt,[40] C. Asawatangtrakuldee,[40] K. Beernaert,[40] O. Behnke,[40] U. Behrens,[40] A. Bermúdez Martínez,[40] A. A. Bin Anuar,[40] K. Borras,[40,r] V. Botta,[40] A. Campbell,[40] P. Connor,[40] C. Contreras-Campana,[40] F. Costanza,[40] V. Danilov,[40] A. De Wit,[40] C. Diez Pardos,[40] D. Domínguez Damiani,[40] G. Eckerlin,[40] D. Eckstein,[40] T. Eichhorn,[40] A. Elwood,[40] E. Eren,[40] E. Gallo,[40,s] J. Garay Garcia,[40] A. Geiser,[40] J. M. Grados Luyando,[40] A. Grohsjean,[40] P. Gunnellini,[40] M. Guthoff,[40] A. Harb,[40] J. Hauk,[40] H. Jung,[40] M. Kasemann,[40] J. Keaveney,[40] C. Kleinwort,[40] J. Knolle,[40] I. Korol,[40] D. Krücker,[40] W. Lange,[40] A. Lelek,[40] T. Lenz,[40] K. Lipka,[40] W. Lohmann,[40,t] R. Mankel,[40] I.-A. Melzer-Pellmann,[40] A. B. Meyer,[40] M. Meyer,[40] M. Missiroli,[40] G. Mittag,[40] J. Mnich,[40] A. Mussgiller,[40] D. Pitzl,[40] A. Raspereza,[40] M. Savitskyi,[40] P. Saxena,[40] R. Shevchenko,[40] N. Stefaniuk,[40] H. Tholen,[40] G. P. Van Onsem,[40] R. Walsh,[40] Y. Wen,[40] K. Wichmann,[40] C. Wissing,[40] O. Zenaiev,[40] R. Aggleton,[41] S. Bein,[41] V. Blobel,[41] M. Centis Vignali,[41] T. Dreyer,[41] E. Garutti,[41] D. Gonzalez,[41] J. Haller,[41] A. Hinzmann,[41] M. Hoffmann,[41] A. Karavdina,[41] G. Kasieczka,[41] R. Klanner,[41] R. Kogler,[41] N. Kovalchuk,[41] S. Kurz,[41] V. Kutzner,[41] J. Lange,[41] D. Marconi,[41] J. Multhaup,[41] M. Niedziela,[41] D. Nowatschin,[41] T. Peiffer,[41] A. Perieanu,[41] A. Reimers,[41] C. Scharf,[41] P. Schleper,[41] A. Schmidt,[41] S. Schumann,[41] J. Schwandt,[41] J. Sonneveld,[41] H. Stadie,[41] G. Steinbrück,[41] F. M. Stober,[41] M. Stöver,[41] D. Troendle,[41] E. Usai,[41] A. Vanhoefer,[41] B. Vormwald,[41] M. Akbiyik,[42] C. Barth,[42] M. Baselga,[42] S. Baur,[42] E. Butz,[42] R. Caspart,[42] T. Chwalek,[42] F. Colombo,[42] W. De Boer,[42] A. Dierlamm,[42] N. Faltermann,[42] B. Freund,[42] R. Friese,[42] M. Giffels,[42] M. A. Harrendorf,[42] F. Hartmann,[42,q] S. M. Heindl,[42] U. Husemann,[42] F. Kassel,[42,q] S. Kudella,[42] H. Mildner,[42] M. U. Mozer,[42] Th. Müller,[42] M. Plagge,[42] G. Quast,[42] K. Rabbertz,[42] M. Schröder,[42] I. Shvetsov,[42] G. Sieber,[42] H. J. Simonis,[42] R. Ulrich,[42] S. Wayand,[42] M. Weber,[42] T. Weiler,[42] S. Williamson,[42] C. Wöhrmann,[42] R. Wolf,[42] G. Anagnostou,[43] G. Daskalakis,[43] T. Geralis,[43] A. Kyriakis,[43] D. Loukas,[43] I. Topsis-Giotis,[43] G. Karathanasis,[44] S. Kesisoglou,[44] A. Panagiotou,[44] N. Saoulidou,[44] E. Tziaferi,[44] K. Kousouris,[45] I. Papakrivopoulos,[45] I. Evangelou,[46] C. Foudas,[46] P. Gianneios,[46] P. Katsoulis,[46] P. Kokkas,[46] S. Mallios,[46] N. Manthos,[46] I. Papadopoulos,[46] E. Paradas,[46] J. Strologas,[46] F. A. Triantis,[46] D. Tsitsonis,[46] M. Csanad,[47] N. Filipovic,[47] G. Pasztor,[47] O. Surányi,[47] G. I. Veres,[47] G. Bencze,[48] C. Hajdu,[48] D. Horvath,[48,u] Á. Hunyadi,[48] F. Sikler,[48] V. Veszpremi,[48] G. Vesztergombi,[48,a] T. Á. Vámi,[48] N. Beni,[49] S. Czellar,[49] J. Karancsi,[49,v] A. Makovec,[49] J. Molnar,[49] Z. Szillasi,[49] M. Bartók,[50,w] P. Raics,[50] Z. L. Trocsanyi,[50] B. Ujvari,[50] S. Choudhury,[51] J. R. Komaragiri,[51] S. Bahinipati,[52,x] P. Mal,[52] K. Mandal,[52] A. Nayak,[52,y] D. K. Sahoo,[52,x] S. K. Swain,[52] S. Bansal,[53] S. B. Beri,[53] V. Bhatnagar,[53] S. Chauhan,[53] R. Chawla,[53] N. Dhingra,[53] R. Gupta,[53] A. Kaur,[53] M. Kaur,[53] S. Kaur,[53] R. Kumar,[53] P. Kumari,[53] M. Lohan,[53] A. Mehta,[53] S. Sharma,[53] J. B. Singh,[53] G. Walia,[53] Ashok Kumar,[54] Aashaq Shah,[54] A. Bhardwaj,[54] B. C. Choudhary,[54] R. B. Garg,[54] S. Keshri,[54] A. Kumar,[54] S. Malhotra,[54] M. Naimuddin,[54] K. Ranjan,[54] R. Sharma,[54] R. Bhardwaj,[55,z] R. Bhattacharya,[55] S. Bhattacharya,[55] U. Bhawandeep,[55,z] D. Bhowmik,[55] S. Dey,[55] S. Dutt,[55,z] S. Dutta,[55] S. Ghosh,[55] N. Majumdar,[55] K. Mondal,[55] S. Mukhopadhyay,[55] S. Nandan,[55] A. Purohit,[55] P. K. Rout,[55] A. Roy,[55] S. Roy Chowdhury,[55] S. Sarkar,[55] M. Sharan,[55] B. Singh,[55] S. Thakur,[55,z] P. K. Behera,[56] R. Chudasama,[57] D. Dutta,[57] V. Jha,[57] V. Kumar,[57] A. K. Mohanty,[57,q] P. K. Netrakanti,[57] L. M. Pant,[57] P. Shukla,[57] A. Topkar,[57] T. Aziz,[58] S. Dugad,[58] B. Mahakud,[58] S. Mitra,[58] G. B. Mohanty,[58] N. Sur,[58] B. Sutar,[58] S. Banerjee,[59] S. Bhattacharya,[59] S. Chatterjee,[59] P. Das,[59] M. Guchait,[59] Sa. Jain,[59] S. Kumar,[59] M. Maity,[59,aa] G. Majumder,[59] K. Mazumdar,[59] N. Sahoo,[59] T. Sarkar,[59,aa] N. Wickramage,[59,bb] S. Chauhan,[60] S. Dube,[60] V. Hegde,[60] A. Kapoor,[60] K. Kothekar,[60] S. Pandey,[60] A. Rane,[60] S. Sharma,[60] S. Chenarani,[61,cc] E. Eskandari Tadavani,[61] S. M. Etesami,[61,cc] M. Khakzad,[61] M. Mohammadi Najafabadi,[61] M. Naseri,[61] S. Paktinat Mehdiabadi,[61,dd] F. Rezaei Hosseinabadi,[61] B. Safarzadeh,[61,ee] M. Zeinali,[61] M. Felcini,[62] M. Grunewald,[62] M. Abbrescia,[63a,63b] C. Calabria,[63a,63b] A. Colaleo,[63a] D. Creanza,[63a,63c] L. Cristella,[63a,63b] N. De Filippis,[63a,63c] M. De Palma,[63a,63b] A. Di Florio,[63a,63b] F. Errico,[63a,63b] L. Fiore,[63a] A. Gelmi,[63a,63b] G. Iaselli,[63a,63c] S. Lezki,[63a,63b] G. Maggi,[63a,63c] M. Maggi,[63a] B. Marangelli,[63a,63b] G. Miniello,[63a,63b] S. My,[63a,63b] S. Nuzzo,[63a,63b] A. Pompili,[63a,63b] G. Pugliese,[63a,63c] R. Radogna,[63a] A. Ranieri,[63a] G. Selvaggi,[63a,63b] A. Sharma,[63a] L. Silvestris,[63a,q] R. Venditti,[63a] P. Verwilligen,[63a] G. Zito,[63a] G. Abbiendi,[64a] C. Battilana,[64a,64b] D. Bonacorsi,[64a,64b] L. Borgonovi,[64a,64b] S. Braibant-Giacomelli,[64a,64b] R. Campanini,[64a,64b] P. Capiluppi,[64a,64b] A. Castro,[64a,64b] F. R. Cavallo,[64a] S. S. Chhibra,[64a,64b] G. Codispoti,[64a,64b] M. Cuffiani,[64a,64b] G. M. Dallavalle,[64a] F. Fabbri,[64a] A. Fanfani,[64a,64b] D. Fasanella,[64a,64b] P. Giacomelli,[64a] C. Grandi,[64a] L. Guiducci,[64a,64b] F. Iemmi,[64a] S. Marcellini,[64a] G. Masetti,[64a] A. Montanari,[64a] F. L. Navarria,[64a,64b] A. Perrotta,[64a] A. M. Rossi,[64a,64b] T. Rovelli,[64a,64b] G. P. Siroli,[64a,64b] N. Tosi,[64a] S. Albergo,[65a,65b] S. Costa,[65a,65b] A. Di Mattia,[65a] F. Giordano,[65a,65b] R. Potenza,[65a,65b] A. Tricomi,[65a,65b] C. Tuve,[65a,65b] G. Barbagli,[66a] K. Chatterjee,[66a,66b] V. Ciulli,[66a,66b] C. Civinini,[66a]

R. D'Alessandro,[66a,66b] E. Focardi,[66a,66b] G. Latino,[66a] P. Lenzi,[66a,66b] M. Meschini,[66a] S. Paoletti,[66a] L. Russo,[66a,ff] G. Sguazzoni,[66a] D. Strom,[66a] L. Viliani,[66a] L. Benussi,[67] S. Bianco,[67] F. Fabbri,[67] D. Piccolo,[67] F. Primavera,[67,q] V. Calvelli,[68a,68b] F. Ferro,[68a] F. Ravera,[68a,68b] E. Robutti,[68a] S. Tosi,[68a,68b] A. Benaglia,[69a] A. Beschi,[69b] L. Brianza,[69a,69b] F. Brivio,[69a,69b] V. Ciriolo,[69a,69b,q] M. E. Dinardo,[69a,69b] S. Fiorendi,[69a,69b] S. Gennai,[69a] A. Ghezzi,[69a,69b] P. Govoni,[69a,69b] M. Malberti,[69a,69b] S. Malvezzi,[69a] R. A. Manzoni,[69a,69b] D. Menasce,[69a] L. Moroni,[69a] M. Paganoni,[69a,69b] K. Pauwels,[69a,69b] D. Pedrini,[69a] S. Pigazzini,[69a,69b,gg] S. Ragazzi,[69a,69b] T. Tabarelli de Fatis,[69a,69b] S. Buontempo,[70a] N. Cavallo,[70a,70c] S. Di Guida,[70a,70d,q] F. Fabozzi,[70a,70c] F. Fienga,[70a,70b] G. Galati,[70a,70b] A. O. M. Iorio,[70a,70b] W. A. Khan,[70a] L. Lista,[70a] S. Meola,[70a,70d,q] P. Paolucci,[70a,q] C. Sciacca,[70a,70b] F. Thyssen,[70a] E. Voevodina,[70a,70b] P. Azzi,[71a] N. Bacchetta,[71a] L. Benato,[71a,71b] D. Bisello,[71a,71b] A. Boletti,[71a,71b] R. Carlin,[71a,71b] A. Carvalho Antunes De Oliveira,[71a,71b] P. Checchia,[71a] P. De Castro Manzano,[71a] T. Dorigo,[71a] U. Dosselli,[71a] F. Gasparini,[71a,71b] U. Gasparini,[71a,71b] A. Gozzelino,[71a] S. Lacaprara,[71a] M. Margoni,[71a,71b] A. T. Meneguzzo,[71a,71b] N. Pozzobon,[71a,71b] P. Ronchese,[71a,71b] R. Rossin,[71a,71b] F. Simonetto,[71a,71b] A. Tiko,[71a] E. Torassa,[71a] M. Zanetti,[71a,71b] P. Zotto,[71a,71b] G. Zumerle,[71a,71b] A. Braghieri,[72a] A. Magnani,[72a] P. Montagna,[72a,72b] S. P. Ratti,[72a,72b] V. Re,[72a] M. Ressegotti,[72a,72b] C. Riccardi,[72a,72b] P. Salvini,[72a] I. Vai,[72a,72b] P. Vitulo,[72a,72b] L. Alunni Solestizi,[73a,73b] M. Biasini,[73a,73b] G. M. Bilei,[73a] C. Cecchi,[73a,73b] D. Ciangottini,[73a,73b] L. Fanò,[73a,73b] P. Lariccia,[73a,73b] R. Leonardi,[73a,73b] E. Manoni,[73a] G. Mantovani,[73a,73b] V. Mariani,[73a,73b] M. Menichelli,[73a] A. Rossi,[73a,73b] A. Santocchia,[73a,73b] D. Spiga,[73a] K. Androsov,[74a] P. Azzurri,[74a] G. Bagliesi,[74a] L. Bianchini,[74a] T. Boccali,[74a] L. Borrello,[74a] R. Castaldi,[74a] M. A. Ciocci,[74a,74b] R. Dell'Orso,[74a] G. Fedi,[74a] L. Giannini,[74a,74c] A. Giassi,[74a] M. T. Grippo,[74a] F. Ligabue,[74a,74c] T. Lomtadze,[74a] E. Manca,[74a,74c] G. Mandorli,[74a,74c] A. Messineo,[74a,74b] F. Palla,[74a] A. Rizzi,[74a,74b] P. Spagnolo,[74a] R. Tenchini,[74a] G. Tonelli,[74a,74b] A. Venturi,[74a] P. G. Verdini,[74a] L. Barone,[75a,75b] F. Cavallari,[75a] M. Cipriani,[75a,75b] N. Daci,[75a] D. Del Re,[75a,75b] E. Di Marco,[75a,75b] M. Diemoz,[75a] S. Gelli,[75a,75b] E. Longo,[75a,75b] B. Marzocchi,[75a,75b] P. Meridiani,[75a] G. Organtini,[75a,75b] F. Pandolfi,[75a] R. Paramatti,[75a,75b] F. Preiato,[75a,75b] S. Rahatlou,[75a,75b] C. Rovelli,[75a] F. Santanastasio,[75a,75b] N. Amapane,[76a,76b] R. Arcidiacono,[76a,76c] S. Argiro,[76a,76b] M. Arneodo,[76a,76c] N. Bartosik,[76a] R. Bellan,[76a,76b] C. Biino,[76a] N. Cartiglia,[76a] R. Castello,[76a,76b] F. Cenna,[76a,76b] M. Costa,[76a,76b] R. Covarelli,[76a,76b] A. Degano,[76a,76b] N. Demaria,[76a] B. Kiani,[76a,76b] C. Mariotti,[76a] S. Maselli,[76a] E. Migliore,[76a,76b] V. Monaco,[76a,76b] E. Monteil,[76a,76b] M. Monteno,[76a] M. M. Obertino,[76a,76b] L. Pacher,[76a,76b] N. Pastrone,[76a] M. Pelliccioni,[76a] G. L. Pinna Angioni,[76a,76b] A. Romero,[76a,76b] M. Ruspa,[76a,76c] R. Sacchi,[76a,76b] K. Shchelina,[76a,76b] V. Sola,[76a] A. Solano,[76a,76b] A. Staiano,[76a] S. Belforte,[77a] M. Casarsa,[77a] F. Cossutti,[77a] G. Della Ricca,[77a,77b] A. Zanetti,[77a] D. H. Kim,[78] G. N. Kim,[78] M. S. Kim,[78] J. Lee,[78] S. Lee,[78] S. W. Lee,[78] C. S. Moon,[78] Y. D. Oh,[78] S. Sekmen,[78] D. C. Son,[78] Y. C. Yang,[78] H. Kim,[79] D. H. Moon,[79] G. Oh,[79] J. A. Brochero Cifuentes,[80] J. Goh,[80] T. J. Kim,[80] S. Cho,[81] S. Choi,[81] Y. Go,[81] D. Gyun,[81] S. Ha,[81] B. Hong,[81] Y. Jo,[81] Y. Kim,[81] K. Lee,[81] K. S. Lee,[81] S. Lee,[81] J. Lim,[81] S. K. Park,[81] Y. Roh,[81] J. Almond,[82] J. Kim,[82] J. S. Kim,[82] H. Lee,[82] K. Lee,[82] K. Nam,[82] S. B. Oh,[82] B. C. Radburn-Smith,[82] S. h. Seo,[82] U. K. Yang,[82] H. D. Yoo,[82] G. B. Yu,[82] H. Kim,[83] J. H. Kim,[83] J. S. H. Lee,[83] I. C. Park,[83] Y. Choi,[84] C. Hwang,[84] J. Lee,[84] I. Yu,[84] V. Dudenas,[85] A. Juodagalvis,[85] J. Vaitkus,[85] I. Ahmed,[86] Z. A. Ibrahim,[86] M. A. B. Md Ali,[86,hh] F. Mohamad Idris,[86,ii] W. A. T. Wan Abdullah,[86] M. N. Yusli,[86] Z. Zolkapli,[86] R Reyes-Almanza,[87] G. Ramirez-Sanchez,[87] M. C. Duran-Osuna,[87] H. Castilla-Valdez,[87] E. De La Cruz-Burelo,[87] I. Heredia-De La Cruz,[87,jj] R. I. Rabadan-Trejo,[87] R. Lopez-Fernandez,[87] J. Mejia Guisao,[87] A. Sanchez-Hernandez,[87] S. Carrillo Moreno,[88] C. Oropeza Barrera,[88] F. Vazquez Valencia,[88] J. Eysermans,[89] I. Pedraza,[89] H. A. Salazar Ibarguen,[89] C. Uribe Estrada,[89] A. Morelos Pineda,[90] D. Krofcheck,[91] P. H. Butler,[92] A. Ahmad,[93] M. Ahmad,[93] Q. Hassan,[93] H. R. Hoorani,[93] A. Saddique,[93] M. A. Shah,[93] M. Shoaib,[93] M. Waqas,[93] H. Bialkowska,[94] M. Bluj,[94] B. Boimska,[94] T. Frueboes,[94] M. Górski,[94] M. Kazana,[94] K. Nawrocki,[94] M. Szleper,[94] P. Traczyk,[94] P. Zalewski,[94] K. Bunkowski,[95] A. Byszuk,[95,kk] K. Doroba,[95] A. Kalinowski,[95] M. Konecki,[95] J. Krolikowski,[95] M. Misiura,[95] M. Olszewski,[95] A. Pyskir,[95] M. Walczak,[95] P. Bargassa,[96] C. Beirão Da Cruz E Silva,[96] A. Di Francesco,[96] P. Faccioli,[96] B. Galinhas,[96] M. Gallinaro,[96] J. Hollar,[96] N. Leonardo,[96] L. Lloret Iglesias,[96] M. V. Nemallapudi,[96] J. Seixas,[96] G. Strong,[96] O. Toldaiev,[96] D. Vadruccio,[96] J. Varela,[96] S. Afanasiev,[97] P. Bunin,[97] M. Gavrilenko,[97] I. Golutvin,[97] I. Gorbunov,[97] A. Kamenev,[97] V. Karjavin,[97] A. Lanev,[97] A. Malakhov,[97] V. Matveev,[97,ll,mm] P. Moisenz,[97] V. Palichik,[97] V. Perelygin,[97] S. Shmatov,[97] S. Shulha,[97] N. Skatchkov,[97] V. Smirnov,[97] N. Voytishin,[97] A. Zarubin,[97] Y. Ivanov,[98] V. Kim,[98,nn] E. Kuznetsova,[98,oo] P. Levchenko,[98] V. Murzin,[98] V. Oreshkin,[98] I. Smirnov,[98] D. Sosnov,[98] V. Sulimov,[98] L. Uvarov,[98] S. Vavilov,[98] A. Vorobyev,[98] Yu. Andreev,[99] A. Dermenev,[99] S. Gninenko,[99] N. Golubev,[99] A. Karneyeu,[99] M. Kirsanov,[99] N. Krasnikov,[99] A. Pashenkov,[99] D. Tlisov,[99] A. Toropin,[99] V. Epshteyn,[100] V. Gavrilov,[100] N. Lychkovskaya,[100] V. Popov,[100] I. Pozdnyakov,[100] G. Safronov,[100] A. Spiridonov,[100]

A. Stepennov,[100] V. Stolin,[100] M. Toms,[100] E. Vlasov,[100] A. Zhokin,[100] T. Aushev,[101] A. Bylinkin,[101,mm] R. Chistov,[102,pp] M. Danilov,[102,pp] P. Parygin,[102] D. Philippov,[102] S. Polikarpov,[102] E. Tarkovskii,[102] V. Andreev,[103] M. Azarkin,[103,mm] I. Dremin,[103,mm] M. Kirakosyan,[103,mm] S. V. Rusakov,[103] A. Terkulov,[103] A. Baskakov,[104] A. Belyaev,[104] E. Boos,[104] M. Dubinin,[104,qq] L. Dudko,[104] A. Ershov,[104] A. Gribushin,[104] V. Klyukhin,[104] O. Kodolova,[104] I. Lokhtin,[104] I. Miagkov,[104] S. Obraztsov,[104] S. Petrushanko,[104] V. Savrin,[104] A. Snigirev,[104] V. Blinov,[105,rr] D. Shtol,[105,rr] Y. Skovpen,[105,rr] I. Azhgirey,[106] I. Bayshev,[106] S. Bitioukov,[106] D. Elumakhov,[106] A. Godizov,[106] V. Kachanov,[106] A. Kalinin,[106] D. Konstantinov,[106] P. Mandrik,[106] V. Petrov,[106] R. Ryutin,[106] A. Sobol,[106] S. Troshin,[106] N. Tyurin,[106] A. Uzunian,[106] A. Volkov,[106] A. Babaev,[107] P. Adzic,[108,ss] P. Cirkovic,[108] D. Devetak,[108] M. Dordevic,[108] J. Milosevic,[108] J. Alcaraz Maestre,[109] I. Bachiller,[109] M. Barrio Luna,[109] M. Cerrada,[109] N. Colino,[109] B. De La Cruz,[109] A. Delgado Peris,[109] C. Fernandez Bedoya,[109] J. P. Fernández Ramos,[109] J. Flix,[109] M. C. Fouz,[109] O. Gonzalez Lopez,[109] S. Goy Lopez,[109] J. M. Hernandez,[109] M. I. Josa,[109] D. Moran,[109] A. Pérez-Calero Yzquierdo,[109] J. Puerta Pelayo,[109] I. Redondo,[109] L. Romero,[109] M. S. Soares,[109] A. Triossi,[109] A. Álvarez Fernández,[109] C. Albajar,[110] J. F. de Trocóniz,[110] J. Cuevas,[111] C. Erice,[111] J. Fernandez Menendez,[111] S. Folgueras,[111] I. Gonzalez Caballero,[111] J. R. González Fernández,[111] E. Palencia Cortezon,[111] S. Sanchez Cruz,[111] P. Vischia,[111] J. M. Vizan Garcia,[111] I. J. Cabrillo,[112] A. Calderon,[112] B. Chazin Quero,[112] J. Duarte Campderros,[112] M. Fernandez,[112] P. J. Fernández Manteca,[112] J. Garcia-Ferrero,[112] A. García Alonso,[112] G. Gomez,[112] A. Lopez Virto,[112] J. Marco,[112] C. Martinez Rivero,[112] P. Martinez Ruiz del Arbol,[112] F. Matorras,[112] J. Piedra Gomez,[112] C. Prieels,[112] T. Rodrigo,[112] A. Ruiz-Jimeno,[112] L. Scodellaro,[112] N. Trevisani,[112] I. Vila,[112] R. Vilar Cortabitarte,[112] D. Abbaneo,[113] B. Akgun,[113] E. Auffray,[113] P. Baillon,[113] A. H. Ball,[113] D. Barney,[113] J. Bendavid,[113] M. Bianco,[113] A. Bocci,[113] C. Botta,[113] T. Camporesi,[113] M. Cepeda,[113] G. Cerminara,[113] E. Chapon,[113] Y. Chen,[113] D. d'Enterria,[113] A. Dabrowski,[113] V. Daponte,[113] A. David,[113] M. De Gruttola,[113] A. De Roeck,[113] N. Deelen,[113] M. Dobson,[113] T. du Pree,[113] M. Dünser,[113] N. Dupont,[113] A. Elliott-Peisert,[113] P. Everaerts,[113] F. Fallavollita,[113,tt] G. Franzoni,[113] J. Fulcher,[113] W. Funk,[113] D. Gigi,[113] A. Gilbert,[113] K. Gill,[113] F. Glege,[113] D. Gulhan,[113] J. Hegeman,[113] V. Innocente,[113] A. Jafari,[113] P. Janot,[113] O. Karacheban,[113,t] J. Kieseler,[113] V. Knünz,[113] A. Kornmayer,[113] M. Krammer,[113,b] C. Lange,[113] P. Lecoq,[113] C. Lourenço,[113] M. T. Lucchini,[113] L. Malgeri,[113] M. Mannelli,[113] A. Martelli,[113] F. Meijers,[113] J. A. Merlin,[113] S. Mersi,[113] E. Meschi,[113] P. Milenovic,[113,uu] F. Moortgat,[113] M. Mulders,[113] H. Neugebauer,[113] J. Ngadiuba,[113] S. Orfanelli,[113] L. Orsini,[113] F. Pantaleo,[113,q] L. Pape,[113] E. Perez,[113] M. Peruzzi,[113] A. Petrilli,[113] G. Petrucciani,[113] A. Pfeiffer,[113] M. Pierini,[113] F. M. Pitters,[113] D. Rabady,[113] A. Racz,[113] T. Reis,[113] G. Rolandi,[113,vv] M. Rovere,[113] H. Sakulin,[113] C. Schäfer,[113] C. Schwick,[113] M. Seidel,[113] M. Selvaggi,[113] A. Sharma,[113] P. Silva,[113] P. Sphicas,[113,ww] A. Stakia,[113] J. Steggemann,[113] M. Stoye,[113] M. Tosi,[113] D. Treille,[113] A. Tsirou,[113] V. Veckalns,[113,xx] M. Verweij,[113] W. D. Zeuner,[113] W. Bertl,[114,a] L. Caminada,[114,yy] K. Deiters,[114] W. Erdmann,[114] R. Horisberger,[114] Q. Ingram,[114] H. C. Kaestli,[114] D. Kotlinski,[114] U. Langenegger,[114] T. Rohe,[114] S. A. Wiederkehr,[114] M. Backhaus,[115] L. Bäni,[115] P. Berger,[115] B. Casal,[115] N. Chernyavskaya,[115] G. Dissertori,[115] M. Dittmar,[115] M. Donegà,[115] C. Dorfer,[115] C. Grab,[115] C. Heidegger,[115] D. Hits,[115] J. Hoss,[115] T. Klijnsma,[115] W. Lustermann,[115] M. Marionneau,[115] M. T. Meinhard,[115] D. Meister,[115] F. Micheli,[115] P. Musella,[115] F. Nessi-Tedaldi,[115] J. Pata,[115] F. Pauss,[115] G. Perrin,[115] L. Perrozzi,[115] M. Quittnat,[115] M. Reichmann,[115] D. Ruini,[115] D. A. Sanz Becerra,[115] M. Schönenberger,[115] L. Shchutska,[115] V. R. Tavolaro,[115] K. Theofilatos,[115] M. L. Vesterbacka Olsson,[115] R. Wallny,[115] D. H. Zhu,[115] T. K. Aarrestad,[116] C. Amsler,[116,zz] D. Brzhechko,[116] M. F. Canelli,[116] A. De Cosa,[116] R. Del Burgo,[116] S. Donato,[116] C. Galloni,[116] T. Hreus,[116] B. Kilminster,[116] I. Neutelings,[116] D. Pinna,[116] G. Rauco,[116] P. Robmann,[116] D. Salerno,[116] K. Schweiger,[116] C. Seitz,[116] Y. Takahashi,[116] A. Zucchetta,[116] V. Candelise,[117] Y. H. Chang,[117] K. y. Cheng,[117] T. H. Doan,[117] Sh. Jain,[117] R. Khurana,[117] C. M. Kuo,[117] W. Lin,[117] A. Pozdnyakov,[117] S. S. Yu,[117] Arun Kumar,[118] P. Chang,[118] Y. Chao,[118] K. F. Chen,[118] P. H. Chen,[118] F. Fiori,[118] W.-S. Hou,[118] Y. Hsiung,[118] Y. F. Liu,[118] R.-S. Lu,[118] E. Paganis,[118] A. Psallidas,[118] A. Steen,[118] J. f. Tsai,[118] B. Asavapibhop,[119] K. Kovitanggoon,[119] G. Singh,[119] N. Srimanobhas,[119] A. Bat,[120] F. Boran,[120] S. Cerci,[120,aaa] S. Damarseckin,[120] Z. S. Demiroglu,[120] C. Dozen,[120] I. Dumanoglu,[120] S. Girgis,[120] G. Gokbulut,[120] Y. Guler,[120] I. Hos,[120,bbb] E. E. Kangal,[120,ccc] O. Kara,[120] U. Kiminsu,[120] M. Oglakci,[120] G. Onengut,[120] K. Ozdemir,[120,ddd] D. Sunar Cerci,[120,aaa] B. Tali,[120,aaa] U. G. Tok,[120] H. Topakli,[120,eee] S. Turkcapar,[120] I. S. Zorbakir,[120] C. Zorbilmez,[120] G. Karapinar,[121,fff] K. Ocalan,[121,ggg] M. Yalvac,[121] M. Zeyrek,[121] I. O. Atakisi,[122] E. Gülmez,[122] M. Kaya,[122,hhh] O. Kaya,[122,iii] S. Tekten,[122] E. A. Yetkin,[122,jjj] M. N. Agaras,[123] S. Atay,[123] A. Cakir,[123] K. Cankocak,[123] Y. Komurcu,[123] B. Grynyov,[124] L. Levchuk,[125] F. Ball,[126] L. Beck,[126] J. J. Brooke,[126] D. Burns,[126] E. Clement,[126] D. Cussans,[126] O. Davignon,[126] H. Flacher,[126] J. Goldstein,[126] G. P. Heath,[126] H. F. Heath,[126] L. Kreczko,[126] D. M. Newbold,[126,kkk]

S. Paramesvaran,[126] T. Sakuma,[126] S. Seif El Nasr-storey,[126] D. Smith,[126] V. J. Smith,[126] K. W. Bell,[127] A. Belyaev,[127,lll] C. Brew,[127] R. M. Brown,[127] D. Cieri,[127] D. J. A. Cockerill,[127] J. A. Coughlan,[127] K. Harder,[127] S. Harper,[127] J. Linacre,[127] E. Olaiya,[127] D. Petyt,[127] C. H. Shepherd-Themistocleous,[127] A. Thea,[127] I. R. Tomalin,[127] T. Williams,[127] W. J. Womersley,[127] G. Auzinger,[128] R. Bainbridge,[128] P. Bloch,[128] J. Borg,[128] S. Breeze,[128] O. Buchmuller,[128] A. Bundock,[128] S. Casasso,[128] D. Colling,[128] L. Corpe,[128] P. Dauncey,[128] G. Davies,[128] M. Della Negra,[128] R. Di Maria,[128] Y. Haddad,[128] G. Hall,[128] G. Iles,[128] T. James,[128] M. Komm,[128] R. Lane,[128] C. Laner,[128] L. Lyons,[128] A.-M. Magnan,[128] S. Malik,[128] L. Mastrolorenzo,[128] T. Matsushita,[128] J. Nash,[128,mmm] A. Nikitenko,[128,h] V. Palladino,[128] M. Pesaresi,[128] A. Richards,[128] A. Rose,[128] E. Scott,[128] C. Seez,[128] A. Shtipliyski,[128] T. Strebler,[128] S. Summers,[128] A. Tapper,[128] K. Uchida,[128] M. Vazquez Acosta,[128,nnn] T. Virdee,[128,q] N. Wardle,[128] D. Winterbottom,[128] J. Wright,[128] S. C. Zenz,[128] J. E. Cole,[129] P. R. Hobson,[129] A. Khan,[129] P. Kyberd,[129] A. Morton,[129] I. D. Reid,[129] L. Teodorescu,[129] S. Zahid,[129] A. Borzou,[130] K. Call,[130] J. Dittmann,[130] K. Hatakeyama,[130] H. Liu,[130] N. Pastika,[130] C. Smith,[130] R. Bartek,[131] A. Dominguez,[131] A. Buccilli,[132] S. I. Cooper,[132] C. Henderson,[132] P. Rumerio,[132] C. West,[132] D. Arcaro,[133] A. Avetisyan,[133] T. Bose,[133] D. Gastler,[133] D. Rankin,[133] C. Richardson,[133] J. Rohlf,[133] L. Sulak,[133] D. Zou,[133] G. Benelli,[134] D. Cutts,[134] M. Hadley,[134] J. Hakala,[134] U. Heintz,[134] J. M. Hogan,[134,ooo] K. H. M. Kwok,[134] E. Laird,[134] G. Landsberg,[134] J. Lee,[134] Z. Mao,[134] T. Morrison,[134] M. Narain,[134] J. Pazzini,[134] S. Piperov,[134] S. Sagir,[134] R. Syarif,[134] D. Yu,[134] R. Band,[135] C. Brainerd,[135] R. Breedon,[135] D. Burns,[135] M. Calderon De La Barca Sanchez,[135] M. Chertok,[135] J. Conway,[135] R. Conway,[135] P. T. Cox,[135] R. Erbacher,[135] C. Flores,[135] G. Funk,[135] W. Ko,[135] R. Lander,[135] C. Mclean,[135] M. Mulhearn,[135] D. Pellett,[135] J. Pilot,[135] S. Shalhout,[135] M. Shi,[135] J. Smith,[135] D. Stolp,[135] D. Taylor,[135] K. Tos,[135] M. Tripathi,[135] Z. Wang,[135] F. Zhang,[135] M. Bachtis,[136] C. Bravo,[136] R. Cousins,[136] A. Dasgupta,[136] A. Florent,[136] J. Hauser,[136] M. Ignatenko,[136] N. Mccoll,[136] S. Regnard,[136] D. Saltzberg,[136] C. Schnaible,[136] V. Valuev,[136] E. Bouvier,[137] K. Burt,[137] R. Clare,[137] J. Ellison,[137] J. W. Gary,[137] S. M. A. Ghiasi Shirazi,[137] G. Hanson,[137] G. Karapostoli,[137] E. Kennedy,[137] F. Lacroix,[137] O. R. Long,[137] M. Olmedo Negrete,[137] M. I. Paneva,[137] W. Si,[137] L. Wang,[137] H. Wei,[137] S. Wimpenny,[137] B. R. Yates,[137] J. G. Branson,[138] S. Cittolin,[138] M. Derdzinski,[138] R. Gerosa,[138] D. Gilbert,[138] B. Hashemi,[138] A. Holzner,[138] D. Klein,[138] G. Kole,[138] V. Krutelyov,[138] J. Letts,[138] M. Masciovecchio,[138] D. Olivito,[138] S. Padhi,[138] M. Pieri,[138] M. Sani,[138] V. Sharma,[138] S. Simon,[138] M. Tadel,[138] A. Vartak,[138] S. Wasserbaech,[138,ppp] J. Wood,[138] F. Würthwein,[138] A. Yagil,[138] G. Zevi Della Porta,[138] N. Amin,[139] R. Bhandari,[139] J. Bradmiller-Feld,[139] C. Campagnari,[139] M. Citron,[139] A. Dishaw,[139] V. Dutta,[139] M. Franco Sevilla,[139] L. Gouskos,[139] R. Heller,[139] J. Incandela,[139] A. Ovcharova,[139] H. Qu,[139] J. Richman,[139] D. Stuart,[139] I. Suarez,[139] J. Yoo,[139] D. Anderson,[140] A. Bornheim,[140] J. Bunn,[140] J. M. Lawhorn,[140] H. B. Newman,[140] T. Q. Nguyen,[140] C. Pena,[140] M. Spiropulu,[140] J. R. Vlimant,[140] R. Wilkinson,[140] S. Xie,[140] Z. Zhang,[140] R. Y. Zhu,[140] M. B. Andrews,[141] T. Ferguson,[141] T. Mudholkar,[141] M. Paulini,[141] J. Russ,[141] M. Sun,[141] H. Vogel,[141] I. Vorobiev,[141] M. Weinberg,[141] J. P. Cumalat,[142] W. T. Ford,[142] F. Jensen,[142] A. Johnson,[142] M. Krohn,[142] S. Leontsinis,[142] E. MacDonald,[142] T. Mulholland,[142] K. Stenson,[142] K. A. Ulmer,[142] S. R. Wagner,[142] J. Alexander,[143] J. Chaves,[143] Y. Cheng,[143] J. Chu,[143] A. Datta,[143] K. Mcdermott,[143] N. Mirman,[143] J. R. Patterson,[143] D. Quach,[143] A. Rinkevicius,[143] A. Ryd,[143] L. Skinnari,[143] L. Soffi,[143] S. M. Tan,[143] Z. Tao,[143] J. Thom,[143] J. Tucker,[143] P. Wittich,[143] M. Zientek,[143] S. Abdullin,[144] M. Albrow,[144] M. Alyari,[144] G. Apollinari,[144] A. Apresyan,[144] A. Apyan,[144] S. Banerjee,[144] L. A. T. Bauerdick,[144] A. Beretvas,[144] J. Berryhill,[144] P. C. Bhat,[144] G. Bolla,[144,a] K. Burkett,[144] J. N. Butler,[144] A. Canepa,[144] G. B. Cerati,[144] H. W. K. Cheung,[144] F. Chlebana,[144] M. Cremonesi,[144] J. Duarte,[144] V. D. Elvira,[144] J. Freeman,[144] Z. Gecse,[144] E. Gottschalk,[144] L. Gray,[144] D. Green,[144] S. Grünendahl,[144] O. Gutsche,[144] J. Hanlon,[144] R. M. Harris,[144] S. Hasegawa,[144] J. Hirschauer,[144] Z. Hu,[144] B. Jayatilaka,[144] S. Jindariani,[144] M. Johnson,[144] U. Joshi,[144] B. Klima,[144] M. J. Kortelainen,[144] B. Kreis,[144] S. Lammel,[144] D. Lincoln,[144] R. Lipton,[144] M. Liu,[144] T. Liu,[144] R. Lopes De Sá,[144] J. Lykken,[144] K. Maeshima,[144] N. Magini,[144] J. M. Marraffino,[144] D. Mason,[144] P. McBride,[144] P. Merkel,[144] S. Mrenna,[144] S. Nahn,[144] V. O'Dell,[144] K. Pedro,[144] O. Prokofyev,[144] G. Rakness,[144] L. Ristori,[144] A. Savoy-Navarro,[144,qqq] B. Schneider,[144] E. Sexton-Kennedy,[144] A. Soha,[144] W. J. Spalding,[144] L. Spiegel,[144] S. Stoynev,[144] J. Strait,[144] N. Strobbe,[144] L. Taylor,[144] S. Tkaczyk,[144] N. V. Tran,[144] L. Uplegger,[144] E. W. Vaandering,[144] C. Vernieri,[144] M. Verzocchi,[144] R. Vidal,[144] M. Wang,[144] H. A. Weber,[144] A. Whitbeck,[144] W. Wu,[144] D. Acosta,[145] P. Avery,[145] P. Bortignon,[145] D. Bourilkov,[145] A. Brinkerhoff,[145] A. Carnes,[145] M. Carver,[145] D. Curry,[145] R. D. Field,[145] I. K. Furic,[145] S. V. Gleyzer,[145] B. M. Joshi,[145] J. Konigsberg,[145] A. Korytov,[145] K. Kotov,[145] P. Ma,[145] K. Matchev,[145] H. Mei,[145] G. Mitselmakher,[145] K. Shi,[145] D. Sperka,[145] N. Terentyev,[145] L. Thomas,[145] J. Wang,[145] S. Wang,[145] J. Yelton,[145] Y. R. Joshi,[146] S. Linn,[146] P. Markowitz,[146] J. L. Rodriguez,[146] A. Ackert,[147] T. Adams,[147] A. Askew,[147] S. Hagopian,[147] V. Hagopian,[147] K. F. Johnson,[147] T. Kolberg,[147]

G. Martinez,[147] T. Perry,[147] H. Prosper,[147] A. Saha,[147] A. Santra,[147] V. Sharma,[147] R. Yohay,[147] M. M. Baarmand,[148]
V. Bhopatkar,[148] S. Colafranceschi,[148] M. Hohlmann,[148] D. Noonan,[148] T. Roy,[148] F. Yumiceva,[148] M. R. Adams,[149]
L. Apanasevich,[149] D. Berry,[149] R. R. Betts,[149] R. Cavanaugh,[149] X. Chen,[149] S. Dittmer,[149] O. Evdokimov,[149]
C. E. Gerber,[149] D. A. Hangal,[149] D. J. Hofman,[149] K. Jung,[149] J. Kamin,[149] I. D. Sandoval Gonzalez,[149] M. B. Tonjes,[149]
N. Varelas,[149] H. Wang,[149] Z. Wu,[149] J. Zhang,[149] B. Bilki,[150,rrr] W. Clarida,[150] K. Dilsiz,[150,sss] S. Durgut,[150]
R. P. Gandrajula,[150] M. Haytmyradov,[150] V. Khristenko,[150] J.-P. Merlo,[150] H. Mermerkaya,[150,ttt] A. Mestvirishvili,[150]
A. Moeller,[150] J. Nachtman,[150] H. Ogul,[150,uuu] Y. Onel,[150] F. Ozok,[150,vvv] A. Penzo,[150] C. Snyder,[150] E. Tiras,[150] J. Wetzel,[150]
K. Yi,[150] B. Blumenfeld,[151] A. Cocoros,[151] N. Eminizer,[151] D. Fehling,[151] L. Feng,[151] A. V. Gritsan,[151] W. T. Hung,[151]
P. Maksimovic,[151] J. Roskes,[151] U. Sarica,[151] M. Swartz,[151] M. Xiao,[151] C. You,[151] A. Al-bataineh,[152] P. Baringer,[152]
A. Bean,[152] S. Boren,[152] J. Bowen,[152] J. Castle,[152] S. Khalil,[152] A. Kropivnitskaya,[152] D. Majumder,[152] W. Mcbrayer,[152]
M. Murray,[152] C. Rogan,[152] C. Royon,[152] S. Sanders,[152] E. Schmitz,[152] J. D. Tapia Takaki,[152] Q. Wang,[152] A. Ivanov,[153]
K. Kaadze,[153] Y. Maravin,[153] A. Modak,[153] A. Mohammadi,[153] L. K. Saini,[153] N. Skhirtladze,[153] F. Rebassoo,[154]
D. Wright,[154] A. Baden,[155] O. Baron,[155] A. Belloni,[155] S. C. Eno,[155] Y. Feng,[155] C. Ferraioli,[155] N. J. Hadley,[155] S. Jabeen,[155]
G. Y. Jeng,[155] R. G. Kellogg,[155] J. Kunkle,[155] A. C. Mignerey,[155] F. Ricci-Tam,[155] Y. H. Shin,[155] A. Skuja,[155] S. C. Tonwar,[155]
D. Abercrombie,[156] B. Allen,[156] V. Azzolini,[156] R. Barbieri,[156] A. Baty,[156] G. Bauer,[156] R. Bi,[156] S. Brandt,[156] W. Busza,[156]
I. A. Cali,[156] M. D'Alfonso,[156] Z. Demiragli,[156] G. Gomez Ceballos,[156] M. Goncharov,[156] P. Harris,[156] D. Hsu,[156] M. Hu,[156]
Y. Iiyama,[156] G. M. Innocenti,[156] M. Klute,[156] D. Kovalskyi,[156] Y.-J. Lee,[156] A. Levin,[156] P. D. Luckey,[156] B. Maier,[156]
A. C. Marini,[156] C. Mcginn,[156] C. Mironov,[156] S. Narayanan,[156] X. Niu,[156] C. Paus,[156] C. Roland,[156] G. Roland,[156]
G. S. F. Stephans,[156] K. Sumorok,[156] K. Tatar,[156] D. Velicanu,[156] J. Wang,[156] T. W. Wang,[156] B. Wyslouch,[156]
S. Zhaozhong,[156] A. C. Benvenuti,[157] R. M. Chatterjee,[157] A. Evans,[157] P. Hansen,[157] S. Kalafut,[157] Y. Kubota,[157]
Z. Lesko,[157] J. Mans,[157] S. Nourbakhsh,[157] N. Ruckstuhl,[157] R. Rusack,[157] J. Turkewitz,[157] M. A. Wadud,[157] J. G. Acosta,[158]
S. Oliveros,[158] E. Avdeeva,[159] K. Bloom,[159] D. R. Claes,[159] C. Fangmeier,[159] F. Golf,[159] R. Gonzalez Suarez,[159]
R. Kamalieddin,[159] I. Kravchenko,[159] J. Monroy,[159] J. E. Siado,[159] G. R. Snow,[159] B. Stieger,[159] A. Godshalk,[160]
C. Harrington,[160] I. Iashvili,[160] D. Nguyen,[160] A. Parker,[160] S. Rappoccio,[160] B. Roozbahani,[160] G. Alverson,[161]
E. Barberis,[161] C. Freer,[161] A. Hortiangtham,[161] A. Massironi,[161] D. M. Morse,[161] T. Orimoto,[161] R. Teixeira De Lima,[161]
T. Wamorkar,[161] B. Wang,[161] A. Wisecarver,[161] D. Wood,[161] S. Bhattacharya,[162] O. Charaf,[162] K. A. Hahn,[162] N. Mucia,[162]
N. Odell,[162] M. H. Schmitt,[162] K. Sung,[162] M. Trovato,[162] M. Velasco,[162] R. Bucci,[163] N. Dev,[163] M. Hildreth,[163]
K. Hurtado Anampa,[163] C. Jessop,[163] D. J. Karmgard,[163] N. Kellams,[163] K. Lannon,[163] W. Li,[163] N. Loukas,[163]
N. Marinelli,[163] F. Meng,[163] C. Mueller,[163] Y. Musienko,[163,ll] M. Planer,[163] A. Reinsvold,[163] R. Ruchti,[163] P. Siddireddy,[163]
G. Smith,[163] S. Taroni,[163] M. Wayne,[163] A. Wightman,[163] M. Wolf,[163] A. Woodard,[163] J. Alimena,[164] L. Antonelli,[164]
B. Bylsma,[164] L. S. Durkin,[164] S. Flowers,[164] B. Francis,[164] A. Hart,[164] C. Hill,[164] W. Ji,[164] T. Y. Ling,[164] W. Luo,[164]
B. L. Winer,[164] H. W. Wulsin,[164] S. Cooperstein,[165] O. Driga,[165] P. Elmer,[165] J. Hardenbrook,[165] P. Hebda,[165]
S. Higginbotham,[165] A. Kalogeropoulos,[165] D. Lange,[165] J. Luo,[165] D. Marlow,[165] K. Mei,[165] I. Ojalvo,[165] J. Olsen,[165]
C. Palmer,[165] P. Piroué,[165] J. Salfeld-Nebgen,[165] D. Stickland,[165] C. Tully,[165] S. Malik,[166] S. Norberg,[166] A. Barker,[167]
V. E. Barnes,[167] S. Das,[167] L. Gutay,[167] M. Jones,[167] A. W. Jung,[167] A. Khatiwada,[167] D. H. Miller,[167] N. Neumeister,[167]
C. C. Peng,[167] H. Qiu,[167] J. F. Schulte,[167] J. Sun,[167] F. Wang,[167] R. Xiao,[167] W. Xie,[167] T. Cheng,[168] J. Dolen,[168]
N. Parashar,[168] Z. Chen,[169] K. M. Ecklund,[169] S. Freed,[169] F. J. M. Geurts,[169] M. Guilbaud,[169] M. Kilpatrick,[169] W. Li,[169]
B. Michlin,[169] B. P. Padley,[169] J. Roberts,[169] J. Rorie,[169] W. Shi,[169] Z. Tu,[169] J. Zabel,[169] A. Zhang,[169] A. Bodek,[170]
P. de Barbaro,[170] R. Demina,[170] Y. t. Duh,[170] T. Ferbel,[170] M. Galanti,[170] A. Garcia-Bellido,[170] J. Han,[170] O. Hindrichs,[170]
A. Khukhunaishvili,[170] K. H. Lo,[170] P. Tan,[170] M. Verzetti,[170] R. Ciesielski,[171] K. Goulianos,[171] C. Mesropian,[171]
A. Agapitos,[172] J. P. Chou,[172] Y. Gershtein,[172] T. A. Gómez Espinosa,[172] E. Halkiadakis,[172] M. Heindl,[172] E. Hughes,[172]
S. Kaplan,[172] R. Kunnawalkam Elayavalli,[172] S. Kyriacou,[172] A. Lath,[172] R. Montalvo,[172] K. Nash,[172] M. Osherson,[172]
H. Saka,[172] S. Salur,[172] S. Schnetzer,[172] D. Sheffield,[172] S. Somalwar,[172] R. Stone,[172] S. Thomas,[172] P. Thomassen,[172]
M. Walker,[172] A. G. Delannoy,[173] J. Heideman,[173] G. Riley,[173] K. Rose,[173] S. Spanier,[173] K. Thapa,[173] O. Bouhali,[174,www]
A. Castaneda Hernandez,[174,www] A. Celik,[174] M. Dalchenko,[174] M. De Mattia,[174] A. Delgado,[174] S. Dildick,[174] R. Eusebi,[174]
J. Gilmore,[174] T. Huang,[174] T. Kamon,[174,xxx] R. Mueller,[174] Y. Pakhotin,[174] R. Patel,[174] A. Perloff,[174] L. Perniè,[174]
D. Rathjens,[174] A. Safonov,[174] A. Tatarinov,[174] N. Akchurin,[175] J. Damgov,[175] F. De Guio,[175] P. R. Dudero,[175] J. Faulkner,[175]
E. Gurpinar,[175] S. Kunori,[175] K. Lamichhane,[175] S. W. Lee,[175] T. Mengke,[175] S. Muthumuni,[175] T. Peltola,[175] S. Undleeb,[175]
I. Volobouev,[175] Z. Wang,[175] S. Greene,[176] A. Gurrola,[176] R. Janjam,[176] W. Johns,[176] C. Maguire,[176] A. Melo,[176] H. Ni,[176]

K. Padeken,[176] J. D. Ruiz Alvarez,[176] P. Sheldon,[176] S. Tuo,[176] J. Velkovska,[176] Q. Xu,[176] M. W. Arenton,[177] P. Barria,[177] B. Cox,[177] R. Hirosky,[177] M. Joyce,[177] A. Ledovskoy,[177] H. Li,[177] C. Neu,[177] T. Sinthuprasith,[177] Y. Wang,[177] E. Wolfe,[177] F. Xia,[177] R. Harr,[178] P. E. Karchin,[178] N. Poudyal,[178] J. Sturdy,[178] P. Thapa,[178] S. Zaleski,[178] M. Brodski,[179] J. Buchanan,[179] C. Caillol,[179] D. Carlsmith,[179] S. Dasu,[179] L. Dodd,[179] S. Duric,[179] B. Gomber,[179] M. Grothe,[179] M. Herndon,[179] A. Hervé,[179] U. Hussain,[179] P. Klabbers,[179] A. Lanaro,[179] A. Levine,[179] K. Long,[179] R. Loveless,[179] V. Rekovic,[179] T. Ruggles,[179] A. Savin,[179] N. Smith,[179] W. H. Smith,[179] and N. Woods[179]

(CMS Collaboration)

[1]*Yerevan Physics Institute, Yerevan, Armenia*
[2]*Institut für Hochenergiephysik, Wien, Austria*
[3]*Institute for Nuclear Problems, 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]*Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil*
[10]*Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil*
[11a]*Universidade Estadual Paulista, São Paulo, Brazil*
[11b]*Universidade Federal do ABC, São Paulo, Brazil*
[12]*Institute for Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, Sofia, Bulgaria*
[13]*University of Sofia, Sofia, Bulgaria*
[14]*Beihang University, Beijing, China*
[15]*Institute of High Energy Physics, Beijing, China*
[16]*State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China*
[17]*Tsinghua University, Beijing, China*
[18]*Universidad de Los Andes, Bogota, Colombia*
[19]*University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Split, Croatia*
[20]*University of Split, Faculty of Science, Split, Croatia*
[21]*Institute Rudjer Boskovic, Zagreb, Croatia*
[22]*University of Cyprus, Nicosia, Cyprus*
[23]*Charles University, Prague, Czech Republic*
[24]*Universidad San Francisco de Quito, Quito, Ecuador*
[25]*Academy of Scientific Research and Technology of the Arab Republic of Egypt,*
Egyptian Network of High Energy Physics, Cairo, Egypt
[26]*National Institute of Chemical Physics and Biophysics, Tallinn, Estonia*
[27]*Department of Physics, University of Helsinki, Helsinki, Finland*
[28]*Helsinki Institute of Physics, Helsinki, Finland*
[29]*Lappeenranta University of Technology, Lappeenranta, Finland*
[30]*IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France*
[31]*Laboratoire Leprince-Ringuet, Ecole polytechnique, CNRS/IN2P3, Université Paris-Saclay, Palaiseau, France*
[32]*Université de Strasbourg, CNRS, IPHC UMR 7178, F-67000 Strasbourg, France*
[33]*Centre de Calcul de l'Institut National de Physique Nucleaire et de Physique des Particules, CNRS/IN2P3, Villeurbanne, France*
[34]*Université de Lyon, Université Claude Bernard Lyon 1, CNRS-IN2P3, Institut de Physique Nucléaire de Lyon, Villeurbanne, France*
[35]*Georgian Technical University, Tbilisi, Georgia*
[36]*Tbilisi State University, Tbilisi, Georgia*
[37]*RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany*
[38]*RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany*
[39]*RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany*
[40]*Deutsches Elektronen-Synchrotron, Hamburg, Germany*
[41]*University of Hamburg, Hamburg, Germany*
[42]*Institut für Experimentelle Teilchenphysik, Karlsruhe, Germany*
[43]*Institute of Nuclear and Particle Physics (INPP), NCSR Demokritos, Aghia Paraskevi, Greece*
[44]*National and Kapodistrian University of Athens, Athens, Greece*
[45]*National Technical University of Athens, Athens, Greece*
[46]*University of Ioánnina, Ioánnina, Greece*
[47]*MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary*

[48]*Wigner Research Centre for Physics, Budapest, Hungary*
[49]*Institute of Nuclear Research ATOMKI, Debrecen, Hungary*
[50]*Institute of Physics, University of Debrecen, Debrecen, Hungary*
[51]*Indian Institute of Science (IISc), Bangalore, India*
[52]*National Institute of Science Education and Research, Bhubaneswar, India*
[53]*Panjab University, Chandigarh, India*
[54]*University of Delhi, Delhi, India*
[55]*Saha Institute of Nuclear Physics, HBNI, Kolkata, India*
[56]*Indian Institute of Technology Madras, Madras, India*
[57]*Bhabha Atomic Research Centre, Mumbai, India*
[58]*Tata Institute of Fundamental Research-A, Mumbai, India*
[59]*Tata Institute of Fundamental Research-B, Mumbai, India*
[60]*Indian Institute of Science Education and Research (IISER), Pune, India*
[61]*Institute for Research in Fundamental Sciences (IPM), Tehran, Iran*
[62]*University College Dublin, Dublin, Ireland*
[63a]*INFN Sezione di Bari, Bari, Italy*
[63b]*Università di Bari, Bari, Italy*
[63c]*Politecnico di Bari, Bari, Italy*
[64a]*INFN Sezione di Bologna, Bologna, Italy*
[64b]*Università di Bologna, Bologna, Italy*
[65a]*INFN Sezione di Catania, Catania, Italy*
[65b]*Università di Catania, Catania, Italy*
[66a]*INFN Sezione di Firenze, Firenze, Italy*
[66b]*Università di Firenze, Firenze, Italy*
[67]*INFN Laboratori Nazionali di Frascati, Frascati, Italy*
[68a]*INFN Sezione di Genova, Genova, Italy*
[68b]*Università di Genova, Genova, Italy*
[69a]*INFN Sezione di Milano-Bicocca, Milano, Italy*
[69b]*Università di Milano-Bicocca, Milano, Italy*
[70a]*INFN Sezione di Napoli, Napoli, Italy*
[70b]*Università di Napoli 'Federico II', Napoli, Italy*
[70c]*Università della Basilicata, Potenza, Italy*
[70d]*Università G. Marconi, Roma, Italy*
[71a]*INFN Sezione di Padova, Padova, Italy*
[71b]*Università di Padova, Padova, Italy*
[71c]*Università di Trento, Trento, Italy*
[72a]*INFN Sezione di Pavia, Pavia, Italy*
[72b]*Università di Pavia, Pavia, Italy*
[73a]*INFN Sezione di Perugia, Perugia, Italy*
[73b]*Università di Perugia, Perugia, Italy*
[74a]*INFN Sezione di Pisa, Pisa, Italy*
[74b]*Università di Pisa, Pisa, Italy*
[74c]*Scuola Normale Superiore di Pisa, Pisa, Italy*
[75a]*INFN Sezione di Roma, Rome, Italy*
[75b]*Sapienza Università di Roma, Rome, Italy*
[76a]*INFN Sezione di Torino, Torino, Italy*
[76b]*Università di Torino, Torino, Italy*
[76c]*Università del Piemonte Orientale, Novara, Italy*
[77a]*INFN Sezione di Trieste, Trieste, Italy*
[77b]*Università di Trieste, Trieste, Italy*
[78]*Kyungpook National University, Daegu, Korea*
[79]*Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea*
[80]*Hanyang University, Seoul, Korea*
[81]*Korea University, Seoul, Korea*
[82]*Seoul National University, Seoul, Korea*
[83]*University of Seoul, Seoul, Korea*
[84]*Sungkyunkwan University, Suwon, Korea*
[85]*Vilnius University, Vilnius, Lithuania*
[86]*National Centre for Particle Physics, Universiti Malaya, Kuala Lumpur, Malaysia*
[87]*Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico*

[88]*Universidad Iberoamericana, Mexico City, Mexico*
[89]*Benemerita Universidad Autonoma de Puebla, Puebla, Mexico*
[90]*Universidad Autónoma de San Luis Potosí, San Luis Potosí, Mexico*
[91]*University of Auckland, Auckland, New Zealand*
[92]*University of Canterbury, Christchurch, New Zealand*
[93]*National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan*
[94]*National Centre for Nuclear Research, Swierk, Poland*
[95]*Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland*
[96]*Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal*
[97]*Joint Institute for Nuclear Research, Dubna, Russia*
[98]*Petersburg Nuclear Physics Institute, Gatchina (St. Petersburg), Russia*
[99]*Institute for Nuclear Research, Moscow, Russia*
[100]*Institute for Theoretical and Experimental Physics, Moscow, Russia*
[101]*Moscow Institute of Physics and Technology, Moscow, Russia*
[102]*National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia*
[103]*P.N. Lebedev Physical Institute, Moscow, Russia*
[104]*Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia*
[105]*Novosibirsk State University (NSU), Novosibirsk, Russia*
[106]*State Research Center of Russian Federation, Institute for High Energy Physics of NRC "Kurchatov Institute", Protvino, Russia*
[107]*National Research Tomsk Polytechnic University, Tomsk, Russia*
[108]*University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia*
[109]*Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain*
[110]*Universidad Autónoma de Madrid, Madrid, Spain*
[111]*Universidad de Oviedo, Oviedo, Spain*
[112]*Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain*
[113]*CERN, European Organization for Nuclear Research, Geneva, Switzerland*
[114]*Paul Scherrer Institut, Villigen, Switzerland*
[115]*ETH Zurich—Institute for Particle Physics and Astrophysics (IPA), Zurich, Switzerland*
[116]*Universität Zürich, Zurich, Switzerland*
[117]*National Central University, Chung-Li, Taiwan*
[118]*National Taiwan University (NTU), Taipei, Taiwan*
[119]*Chulalongkorn University, Faculty of Science, Department of Physics, Bangkok, Thailand*
[120]*Çukurova University, Physics Department, Science and Art Faculty, Adana, Turkey*
[121]*Middle East Technical University, Physics Department, Ankara, Turkey*
[122]*Bogazici University, Istanbul, Turkey*
[123]*Istanbul Technical University, Istanbul, Turkey*
[124]*Institute for Scintillation Materials of National Academy of Science of Ukraine, Kharkov, Ukraine*
[125]*National Scientific Center, Kharkov Institute of Physics and Technology, Kharkov, Ukraine*
[126]*University of Bristol, Bristol, United Kingdom*
[127]*Rutherford Appleton Laboratory, Didcot, United Kingdom*
[128]*Imperial College, London, United Kingdom*
[129]*Brunel University, Uxbridge, United Kingdom*
[130]*Baylor University, Waco, Texas, USA*
[131]*Catholic University of America, Washington DC, USA*
[132]*The University of Alabama, Tuscaloosa, Alabama, USA*
[133]*Boston University, Boston, Massachusetts, USA*
[134]*Brown University, Providence, Rhode Island, USA*
[135]*University of California, Davis, California, USA*
[136]*University of California, Los Angeles, California, USA*
[137]*University of California, Riverside, California, USA*
[138]*University of California, San Diego, La Jolla, California, USA*
[139]*University of California, Santa Barbara—Department of Physics, Santa Barbara, USA*
[140]*California Institute of Technology, Pasadena, California, USA*
[141]*Carnegie Mellon University, Pittsburgh, Pennsylvania, USA*
[142]*University of Colorado Boulder, Boulder, Colorado, USA*
[143]*Cornell University, Ithaca, New York, USA*
[144]*Fermi National Accelerator Laboratory, Batavia, Illinois, USA*
[145]*University of Florida, Gainesville, Florida, USA*
[146]*Florida International University, Miami, Florida, USA*
[147]*Florida State University, Tallahassee, Florida, USA*

[148]*Florida Institute of Technology, Melbourne, Florida, USA*
[149]*University of Illinois at Chicago (UIC), Chicago, Illinois, USA*
[150]*The University of Iowa, Iowa City, Iowa, USA*
[151]*Johns Hopkins University, Baltimore, Maryland, USA*
[152]*The University of Kansas, Lawrence, Kansas, USA*
[153]*Kansas State University, Manhattan, Kansas, USA*
[154]*Lawrence Livermore National Laboratory, Livermore, California, USA*
[155]*University of Maryland, College Park, Maryland, USA*
[156]*Massachusetts Institute of Technology, Cambridge, Massachusetts, USA*
[157]*University of Minnesota, Minneapolis, Minnesota, USA*
[158]*University of Mississippi, Oxford, Mississippi, USA*
[159]*University of Nebraska-Lincoln, Lincoln, Nebraska, USA*
[160]*State University of New York at Buffalo, Buffalo, New York, USA*
[161]*Northeastern University, Boston, Massachusetts, USA*
[162]*Northwestern University, Evanston, Illinois, USA*
[163]*University of Notre Dame, Notre Dame, Indiana, USA*
[164]*The Ohio State University, Columbus, Ohio, USA*
[165]*Princeton University, Princeton, New Jersey, USA*
[166]*University of Puerto Rico, Mayaguez, Puerto Rico, USA*
[167]*Purdue University, West Lafayette, Indiana, USA*
[168]*Purdue University Northwest, Hammond, Indiana, USA*
[169]*Rice University, Houston, Texas, USA*
[170]*University of Rochester, Rochester, New York, USA*
[171]*The Rockefeller University, New York, New York, USA*
[172]*Rutgers, The State University of New Jersey, Piscataway, New Jersey, USA*
[173]*University of Tennessee, Knoxville, Tennessee, USA*
[174]*Texas A&M University, College Station, Texas, USA*
[175]*Texas Tech University, Lubbock, Texas, USA*
[176]*Vanderbilt University, Nashville, Tennessee, USA*
[177]*University of Virginia, Charlottesville, Virginia, USA*
[178]*Wayne State University, Detroit, Michigan, USA*
[179]*University of Wisconsin–Madison, Madison, Wisconsin, USA*

[a] Deceased.
[b] Also at Vienna University of Technology, Vienna, Austria.
[c] Also at IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France.
[d] Also at Universidade Estadual de Campinas, Campinas, Brazil.
[e] Also at Federal University of Rio Grande do Sul, Porto Alegre, Brazil.
[f] Also at Universidade Federal de Pelotas, Pelotas, Brazil.
[g] Also at Université Libre de Bruxelles, Bruxelles, Belgium.
[h] Also at Institute for Theoretical and Experimental Physics, Moscow, Russia.
[i] Also at Joint Institute for Nuclear Research, Dubna, Russia.
[j] Also at Suez University, Suez, Egypt.
[k] Also at British University in Egypt, Cairo, Egypt.
[l] Also at Fayoum University, El-Fayoum, Egypt.
[m] Also at Department of Physics, King Abdulaziz University, Jeddah, Saudi Arabia.
[n] Also at Université de Haute Alsace, Mulhouse, France.
[o] Also at Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia.
[p] Also at Tbilisi State University, Tbilisi, Georgia.
[q] Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland.
[r] Also at RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany.
[s] Also at University of Hamburg, Hamburg, Germany.
[t] Also at Brandenburg University of Technology, Cottbus, Germany.
[u] Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary.
[v] Also at Institute of Physics, University of Debrecen, Debrecen, Hungary.
[w] Also at MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary.
[x] Also at IIT Bhubaneswar, Bhubaneswar, India.
[y] Also at Institute of Physics, Bhubaneswar, India.
[z] Also at Shoolini University, Solan, India.
[aa] Also at University of Visva-Bharati, Santiniketan, India.

[bb] Also at University of Ruhuna, Matara, Sri Lanka.
[cc] Also at Isfahan University of Technology, Isfahan, Iran.
[dd] Also at Yazd University, Yazd, Iran.
[ee] Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran.
[ff] Also at Università degli Studi di Siena, Siena, Italy.
[gg] Also at INFN Sezione di Milano-Bicocca, Università di Milano-Bicocca, Milano, Italy.
[hh] Also at International Islamic University of Malaysia, Kuala Lumpur, Malaysia.
[ii] Also at Malaysian Nuclear Agency, MOSTI, Kajang, Malaysia.
[jj] Also at Consejo Nacional de Ciencia y Tecnología, Mexico city, Mexico.
[kk] Also at Warsaw University of Technology, Institute of Electronic Systems, Warsaw, Poland.
[ll] Also at Institute for Nuclear Research, Moscow, Russia.
[mm] Also at National Research Nuclear University ’Moscow Engineering Physics Institute’ (MEPhI), Moscow, Russia.
[nn] Also at St. Petersburg State Polytechnical University, St. Petersburg, Russia.
[oo] Also at University of Florida, Gainesville, USA.
[pp] Also at P.N. Lebedev Physical Institute, Moscow, Russia.
[qq] Also at California Institute of Technology, Pasadena, USA.
[rr] Also at Budker Institute of Nuclear Physics, Novosibirsk, Russia.
[ss] Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia.
[tt] Also at INFN Sezione di Pavia, Università di Pavia, Pavia, Italy.
[uu] Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia.
[vv] Also at Scuola Normale e Sezione dell’INFN, Pisa, Italy.
[ww] Also at National and Kapodistrian University of Athens, Athens, Greece.
[xx] Also at Riga Technical University, Riga, Latvia.
[yy] Also at Universität Zürich, Zurich, Switzerland.
[zz] Also at Stefan Meyer Institute for Subatomic Physics.
[aaa] Also at Adiyaman University, Adiyaman, Turkey.
[bbb] Also at Istanbul Aydin University, Istanbul, Turkey.
[ccc] Also at Mersin University, Mersin, Turkey.
[ddd] Also at Piri Reis University, Istanbul, Turkey.
[eee] Also at Gaziosmanpasa University, Tokat, Turkey.
[fff] Also at Izmir Institute of Technology, Izmir, Turkey.
[ggg] Also at Necmettin Erbakan University, Konya, Turkey.
[hhh] Also at Marmara University, Istanbul, Turkey.
[iii] Also at Kafkas University, Kars, Turkey.
[jjj] Also at Istanbul Bilgi University, Istanbul, Turkey.
[kkk] Also at Rutherford Appleton Laboratory, Didcot, United Kingdom.
[lll] Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom.
[mmm] Also at Monash University, Faculty of Science, Clayton, Australia.
[nnn] Also at Instituto de Astrofísica de Canarias, La Laguna, Spain.
[ooo] Also at Bethel University, St. Paul, Minnesota 55112, USA.
[ppp] Also at Utah Valley University, Orem, USA.
[qqq] Also at Purdue University, West Lafayette, USA.
[rrr] Also at Beykent University, Istanbul, Turkey.
[sss] Also at Bingol University, Bingol, Turkey.
[ttt] Also at Erzincan University, Erzincan, Turkey.
[uuu] Also at Sinop University, Sinop, Turkey.
[vvv] Also at Mimar Sinan University, Istanbul, Istanbul, Turkey.
[www] Also at Texas A&M University at Qatar, Doha, Qatar.
[xxx] Also at Kyungpook National University, Daegu, Korea.