



Search for Narrow Resonances Decaying to Dijets in Proton-Proton Collisions at $\sqrt{s} = 13$ TeV

V. Khachatryan *et al.**
(CMS Collaboration)

(Received 3 December 2015; published 18 February 2016)

A search for narrow resonances in proton-proton collisions at $\sqrt{s} = 13$ TeV is presented. The invariant mass distribution of the two leading jets is measured with the CMS detector using a data set corresponding to an integrated luminosity of 2.4 fb^{-1} . The highest observed dijet mass is 6.1 TeV. The distribution is smooth and no evidence for resonant particles is observed. Upper limits at 95% confidence level are set on the production cross section for narrow resonances with masses above 1.5 TeV. When interpreted in the context of specific models, the limits exclude string resonances with masses below 7.0 TeV, scalar diquarks below 6.0 TeV, axigluons and colorons below 5.1 TeV, excited quarks below 5.0 TeV, color-octet scalars below 3.1 TeV, and W' bosons below 2.6 TeV. These results significantly extend previously published limits.

DOI: [10.1103/PhysRevLett.116.071801](https://doi.org/10.1103/PhysRevLett.116.071801)

Deep inelastic proton-proton (pp) collisions often produce two or more energetic jets when the constituent partons are scattered with large transverse momenta (p_T). The invariant mass m_{jj} of the pair of jets having the largest values of p_T in the event (the dijet) has a spectrum that is predicted by quantum chromodynamics (QCD) to fall steeply and smoothly with increasing dijet mass [1,2]. Many extensions of the standard model predict the existence of new massive particles that couple to quarks (q) and gluons (g) and can be detected as resonances in the dijet mass spectrum. In this Letter, we report a search for narrow resonances, those with natural widths that are small compared to the experimental resolution. The search uses the dijet mass spectrum measured with the CMS detector at a center-of-mass energy of $\sqrt{s} = 13$ TeV. The data correspond to an integrated luminosity of 2.4 fb^{-1} from the 2015 running of the CERN LHC (Run 2).

The most stringent current bounds on dijet resonance production have been presented by the CMS [3–7] and ATLAS [8–12] Collaborations, using proton-proton collisions at $\sqrt{s} = 7$ and 8 TeV from LHC Run 1. A summary of previous searches and a comparison of the different strategies are presented in Ref. [13]. The present search is expected to be more sensitive than previous studies for dijet masses above 2 TeV, and has similar sensitivity as a contemporaneous search from ATLAS at $\sqrt{s} = 13$ TeV [14]. We present a model-independent search and, in addition, consider the following models of s -channel dijet

resonances: string resonances [15,16], scalar diquarks [17], axigluons [18,19], colorons [19,20], excited quarks (q^*) [21,22], color-octet scalars [23], new gauge bosons (W' and Z') [24], and Randall-Sundrum (RS) gravitons (G) [25]. More details on the specific choices of couplings for these models can be found in Ref. [5].

The CMS detector and its coordinate system, including the azimuthal angle ϕ (in radians) and the pseudorapidity η , are described in detail in Ref. [26]. Events are selected using a two-tier trigger system. Events satisfying loose jet requirements at the first level (L1) are examined by the high-level trigger (HLT), where jets are clustered from particle-flow (PF) [27,28] candidates, discussed in the next paragraph. The jets with $p_T > 40$ GeV and $|\eta| < 3$ are used to compute H_T , the scalar sum of the jet p_T . Events are accepted if they have $H_T > 800$ GeV or include a jet with $p_T > 500$ GeV. At least one reconstructed vertex is required with $|z| < 24$ cm. The primary vertex is defined as the vertex with the highest sum of p_T^2 of the associated tracks.

The PF algorithm is used to reconstruct the particles in an event and to identify them as muons, electrons (with associated bremsstrahlung photons), photons (unconverted and converted into e^+e^- pairs), and either charged or neutral hadrons. These PF candidates are clustered into jets using the anti- k_r algorithm [29] with a distance parameter of 0.4, implemented in the FastJet package [30]. Charged PF candidates not originating from the primary vertex are removed prior to the jet finding. An event-by-event jet-area-based correction [31–33] is applied to the jets to remove the estimated energy from additional collisions in the same or adjacent bunch crossings (pileup). The jet momenta and energies are further corrected using calibration constants obtained from simulation, test beam results, and pp collision data at $\sqrt{s} = 13$ TeV, using methods

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

Published by the American Physical Society under the terms of the [Creative Commons Attribution 3.0 License](https://creativecommons.org/licenses/by/3.0/). Further distribution of this work must maintain attribution to the author(s) and the published article's title, journal citation, and DOI.

described in Ref. [33] with all *in situ* calibrations obtained from the current data. All jets are required to have $p_T > 30$ GeV and $|\eta| < 2.5$. The two jets with largest p_T are defined as the leading jets. Jet identification criteria [34] are applied to remove spurious jets associated with calorimeter noise. An event is rejected if either of the two leading jets does not satisfy the jet identification criteria.

Geometrically close jets are combined into “wide jets” and used to determine the dijet mass, as in our previous searches [4–7]. The wide-jet algorithm, designed for dijet resonance event reconstruction, reduces the analysis sensitivity to gluon radiation from the final state partons. The two leading jets are used as seeds and the four-vectors of all other jets, if within $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} < 1.1$, are added to the nearest leading jet to obtain two wide jets, which then form the dijet system. The background from t -channel dijet events is suppressed by requiring the pseudorapidity separation of the two wide jets to satisfy $|\Delta\eta_{jj}| < 1.3$. The above requirements, originally developed for the analysis of Run 1 data, maximize the search sensitivity for isotropic decays of dijet resonances in the presence of QCD dijet background. It has been verified that these requirements remain optimal for collisions at $\sqrt{s} = 13$ TeV. We select events with $m_{jj} > 1.2$ TeV for which the combined L1 trigger and HLT are found to be fully efficient.

Figure 1 shows the dijet mass spectrum, defined as the observed number of events in each bin divided by the integrated luminosity and bin width, with predefined bins of width corresponding to the dijet mass resolution [3]. The highest dijet mass observed is 6.1 TeV. The data are compared with a leading-order QCD Monte Carlo (MC) prediction from the PYTHIA 8 (v205) [35] generator with the CUETP8M1 tune [36,37], including a GEANT4-based [38] simulation of the CMS detector. The PYTHIA simulation uses the NNPDF2.3LO [39] parton distribution functions (PDF). The renormalization and factorization scales are both set at the p_T value of the hard-scattered partons. The MC prediction is normalized to the integrated contents of the data in Fig. 1, requiring multiplication of the predicted cross section by a factor of 0.88.

To test the smoothness of the measured dijet mass spectrum, we fit the data with the parametrization

$$\frac{d\sigma}{dm_{jj}} = \frac{P_0(1-x)^{P_1}}{x^{P_2+P_3} \ln(x)}, \quad (1)$$

where $x = m_{jj}/\sqrt{s}$ and P_0 , P_1 , P_2 , and P_3 are fitted parameters. This functional form was also used in previous searches [3–12,40] to describe the data and the QCD predictions. In Fig. 1 we show the result of the binned maximum likelihood fit, which yields $\chi^2 = 31$ for 35 degrees of freedom, where the χ^2 is determined using the Poisson uncertainties shown in Fig. 1. The data are seen to be well described by the fit.

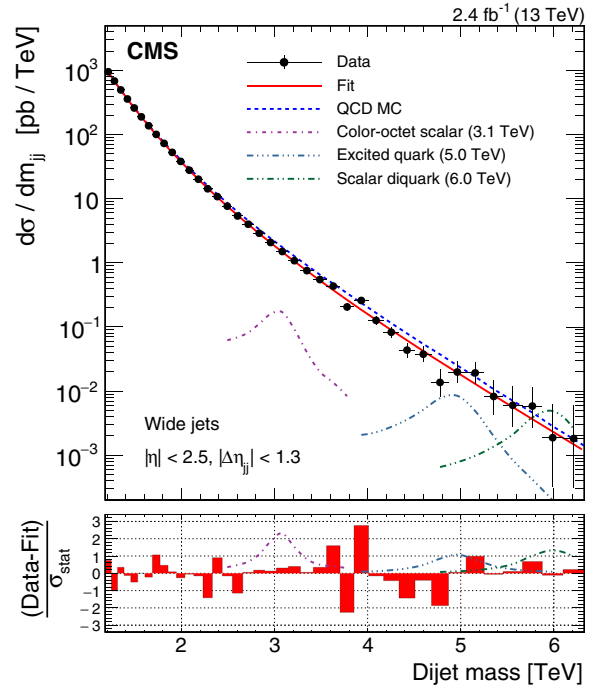


FIG. 1. Dijet mass spectrum (points) compared to a fitted parametrization (solid curve) and to the prediction of the PYTHIA 8 [35] QCD MC event generator including simulation of the detector (dashed curve). The lower panel shows the difference between the data and the fitted parametrization, divided by the statistical uncertainties. The predicted distributions of narrow resonance signals for three models, with resonance mass values corresponding to the respective 95% confidence level exclusion limit, are shown in both panels (dash-dotted curves).

We search in the dijet mass spectrum for narrow resonances. Figure 2 shows example dijet mass distributions for simulated signal events, generated with the PYTHIA 8 program. The predicted mass distributions have Gaussian cores from the jet energy resolution, and tails towards lower mass values primarily from QCD radiation. The contribution of this low-mass tail to the line shape depends on the parton content of the resonance (qq , qg , or gg). Resonances containing gluons, which emit QCD radiation more strongly than quarks, have a more pronounced tail. For the high-mass resonances, there is also a significant contribution that depends both on the PDF and on the natural width of the Breit-Wigner resonance. For resonances produced through interactions of nonvalent partons in the proton, the low-mass component of the Breit-Wigner resonance distribution is amplified by the rise of the parton probability distribution at low fractional momentum. These effects cause a large tail at low mass values. Neglecting the tails, the approximate value of the dijet mass resolution varies with resonance mass from 7% at 1.5 TeV to 4% at 7 TeV.

There is no evidence for a narrow resonance in the data, as seen from Fig. 1. The most significant excess in the data relative to the background fit occurs for a dijet mass of

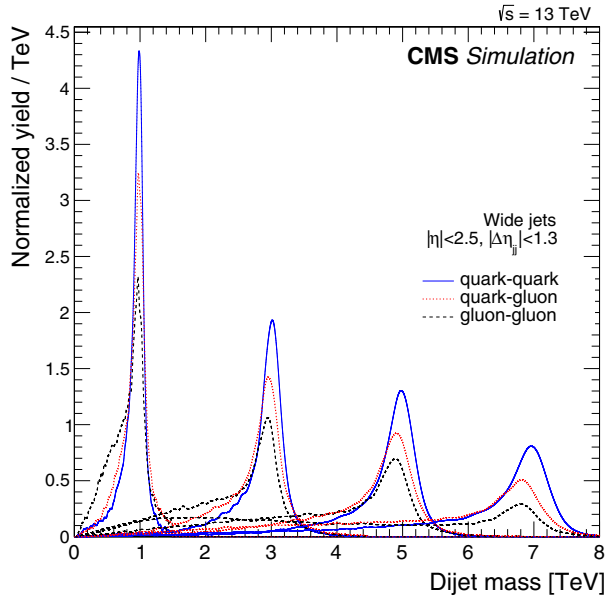


FIG. 2. The reconstructed resonance mass spectrum predicted by the PYTHIA 8 [35] MC event generator, including simulation of the detector, for resonances generated with mass values 1, 3, 5, and 7 TeV, for quark-quark processes modeled by $q\bar{q} \rightarrow G \rightarrow q\bar{q}$ (solid line), for quark-gluon processes modeled by $qg \rightarrow q^* \rightarrow qg$ (dotted line), and for gluon-gluon processes modeled by $gg \rightarrow G \rightarrow gg$ (dashed line), where G is a RS graviton and q^* is an excited quark.

3.9 TeV. A fit to the hypothesis of a narrow qq resonance, which includes contributions from the bin at 3.9 TeV and neighboring bins, has a local statistical significance of 1.7 standard deviations. Figure 1 includes example signal distributions of the three kinds of narrow resonances (qq , qg , and gg) at the mass values (6.0, 5.0, and 3.1 TeV) corresponding to the limit set on the respective models (scalar diquark, excited quark, and color-octet scalar). These limits are presented below.

We use the dijet mass spectrum from wide jets, the background parametrization, and the dijet resonance shapes to set limits on new particles decaying to the parton pairs qq (or $q\bar{q}$), qg , and gg . A separate limit is determined for each final state (qq , qg , and gg) because of the dependence of the dijet resonance shape on the type of the two final-state partons.

The dominant sources of systematic uncertainty are the jet energy scale, jet energy resolution, integrated luminosity, and the estimation of background. The uncertainty in the jet energy scale is 2%, determined from Run 2 data using the methods described in Ref. [33]. This uncertainty is propagated to the limits by shifting the dijet mass for signal events by $\pm 2\%$. The uncertainty in the jet energy resolution translates into an uncertainty of 10% in the resolution of the dijet mass [33], and is propagated to the limits by increasing and decreasing by 10% the reconstructed width of the dijet mass shape for signal. The luminosity scale and its uncertainty are estimated from

beam-beam scans utilizing the methods from Ref. [41]. The uncertainty in the integrated luminosity is 12%, and is propagated to the normalization of the signal. Not included in this analysis is a recent reevaluation of the integrated luminosity that increases the measured value by 4.3% and reduces the systematic uncertainty to 4.6%. Changes in the values of the parameters describing the background introduce a change in the signal strength that is accounted for as a systematic uncertainty. The dependence of the signal mass distributions on the number of pileup interactions is negligible.

To set upper limits on signal cross sections we use a Bayesian formalism [42] with a uniform prior for a positive signal cross section; log-normal priors are used to model systematic uncertainties in the jet energy scale, jet energy resolution, and integrated luminosity, all treated as nuisance parameters to be integrated over. We calculate the likelihood, namely the posterior probability density as a function of resonance cross section, independently at each value of resonance pole mass from 1.5 to 7.2 TeV in 0.1 TeV steps. Resonances with masses less than 1.5 TeV are too close to the lower edge of our dijet mass spectrum to produce a peak distinguishable from the background and are therefore not considered. Examples of the resonance shapes used are shown in Fig. 2. The data are fitted with the background function plus a signal shape, with the signal cross section a fitted parameter. The resulting fitting function, with the signal cross section set to zero, is used as the background estimate. The likelihood is formed using as input the data, the background estimate from the best fit of the signal + background hypothesis to the data, and the resonance shape multiplied by the resonance cross section. The uncertainty in the background is incorporated through marginalization, i.e., by integrating the likelihood over the background parameters using uniform priors. The integration is performed for each of the background nuisance parameters in a range around the best-fit values, corresponding to a decrease in the likelihood by a factor of 1000 from its maximum value for each parameter independently.

Figure 3 shows the model-independent observed upper limits at 95% confidence level (C.L.) on σBA , i.e., the product of the cross section (σ), the branching fraction (B), and the acceptance (A) for the kinematic requirements $|\Delta\eta_{jj}| < 1.3$ and $|\eta| < 2.5$, for narrow qq , qg , and gg resonances. The acceptance of the requirement $m_{jj} > 1.2$ TeV has been taken into account by correcting the limits, and therefore does not appear in the acceptance A . Figure 3 also shows the expected limits on the cross section and their bands of uncertainty. The expected limits are estimated with pseudoexperiments generated using background-only hypotheses. The generated mass spectra are fit with a background + signal model to extract expected upper limits. The difference in the limits for qq , qg , and gg resonances at the same resonance mass originates from the difference in their line shapes. All upper limits presented

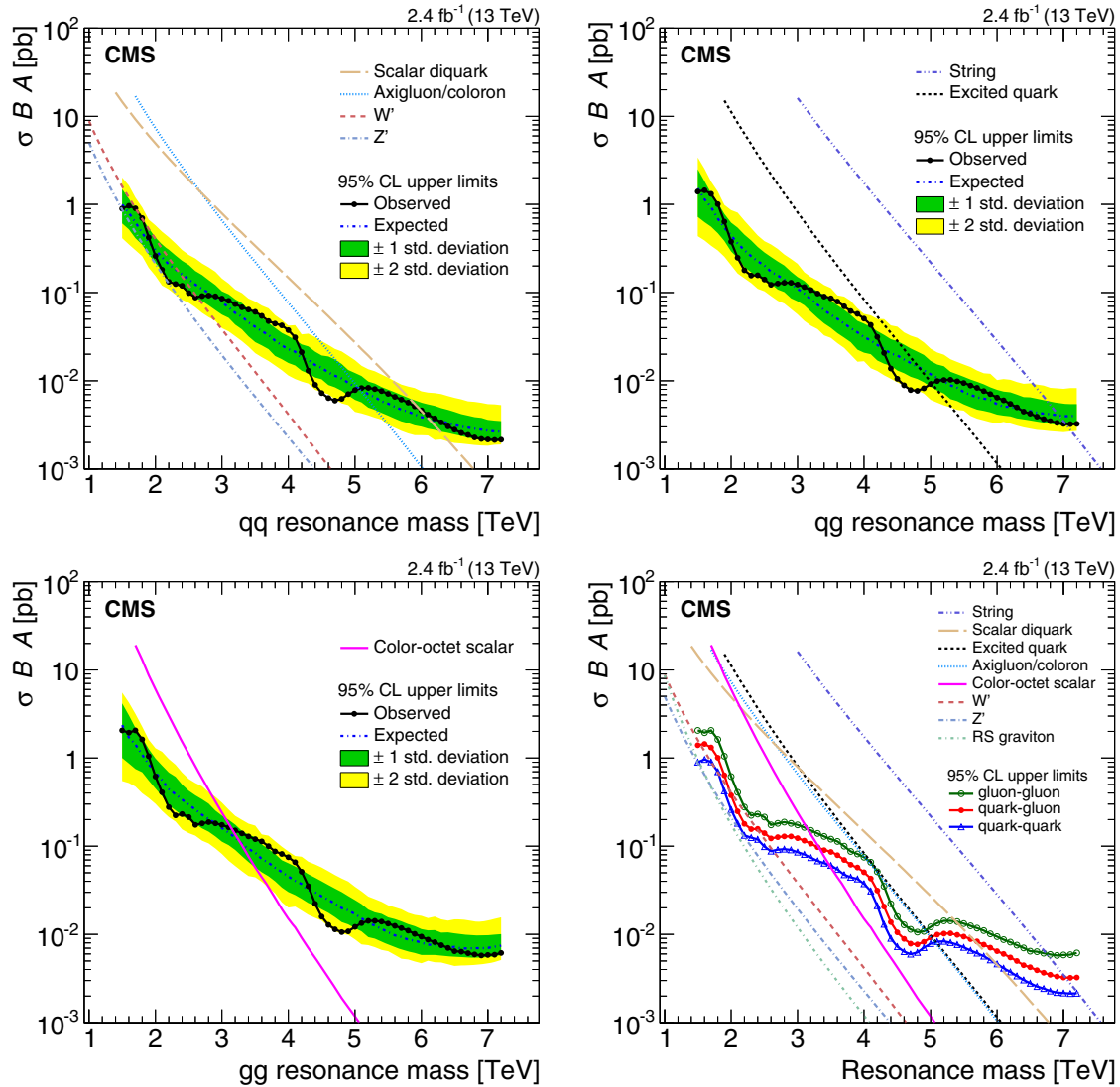


FIG. 3. The observed 95% CL upper limits on the product of the cross section, branching fraction, and acceptance for quark-quark (top left), quark-gluon (top right), and gluon-gluon (bottom left) type dijet resonances, shown as symbols connected by solid curves, and a comparison of all types (bottom right). The corresponding expected limits (dash-dotted curves) and their variation at the 1 and 2 standard deviation levels (shaded bands) are also shown. The limits are compared to the predicted cross sections of string resonances [15,16], scalar diquarks [17], excited quarks [21,22], axigluons [18,19], colorons [19,20], color-octet scalars [23], new gauge bosons W' and Z' [24], and RS gravitons [25].

are compared to the parton-level predictions of σBA , without detector simulation, to determine mass limits on new particles. The model predictions shown in Fig. 3 are calculated in the narrow-width approximation [13] using the CTEQ6L1 [43] PDF at leading order, with a next-to-leading order correction factor of approximately 1.3 included for the W' and Z' models [44], and approximately 1.2 for the axigluon and coloron models [19]. The branching fraction B includes the direct decays of the resonance into qq , qg , and gg only, excluding top quarks, and no other decays giving jets are considered in the theoretical calculation of the model cross section. The acceptance is evaluated at the parton level for the resonance

decay to two partons. In the case of isotropic decays it is $A \approx 0.6$ independent of resonance mass.

For a given model, new particles are excluded at 95% CL in mass regions where the theoretical prediction lies at or above the observed upper limit for the appropriate final state of Fig. 3. The mass limits reported in Table I represent significant extensions of the most stringent observed limits from LHC Run 1 [7,12]. For string resonances, the observed mass limit of 7.0 TeV extends the previous CMS limit of 5.0 TeV; for scalar diquarks, the observed mass limit of 6.0 TeV extends the previous CMS limit of 4.7 TeV; for axigluons and colorons, the observed mass limit of 5.1 TeV extends the previous CMS limit of 3.6 TeV;

TABLE I. Observed and expected mass limits for analyses that exclude the listed models at 95% CL for a resonance mass from 1.5 TeV up to the indicated values.

Model	Final state	Observed mass limit [TeV]	Expected mass limit [TeV]
String	$q\bar{q}$	7.0	6.9
Scalar diquark	$q\bar{q}$	6.0	6.1
Axigluon/coloron	$q\bar{q}$	5.1	5.1
Excited quark (q^*)	$q\bar{q}$	5.0	4.8
Color-octet scalar	$g\bar{g}$	3.1	3.3
Heavy W (W')	$q\bar{q}$	2.6	2.3

for excited quarks, we set a mass limit of 5.0 TeV compared to the ATLAS limit of 4.06 TeV; for a color-octet scalar, the observed mass limit of 3.1 TeV improves the ATLAS limit of 2.70 TeV; and for a W' boson, we exclude masses up to 2.6 TeV, just beyond the ATLAS limit of 2.45 TeV. With the current data sample we cannot set mass limits on Z' bosons with standard-model-like couplings or on RS gravitons with dimensionless coupling less than 0.1.

In summary, a search for narrow resonances decaying into a pair of jets has been performed using a data sample of pp collisions at $\sqrt{s} = 13$ TeV corresponding to an integrated luminosity of 2.4 fb^{-1} . The dijet mass spectrum has been measured to be a smoothly falling distribution. In the analyzed data sample, there is no evidence for resonant particle production. We present generic upper limits on the product σBA that are applicable to any model of narrow dijet resonance production. This search is more sensitive than previous searches for dijet resonances for masses above 2 TeV. We set the most stringent limits to date on the masses of string resonances, scalar diquarks, axigluons, colorons, excited quarks, color-octet scalars, and W' bosons.

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: BMFWF 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); 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); CINVESTAV, CONACYT, SEP, and UASLP-FAI (Mexico); MBIE (New Zealand); PAEC (Pakistan); MSHE and NSC (Poland); FCT (Portugal); JINR (Dubna); MON, RosAtom, RAS and RFBR (Russia); MESTD (Serbia); SEIDI and CPAN (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] CMS Collaboration, Measurement of the differential dijet production cross section in proton-proton collisions at $\sqrt{s} = 7$ TeV, *Phys. Lett. B* **700**, 187 (2011).
- [2] ATLAS Collaboration, Measurement of dijet cross sections in pp collisions at 7 TeV centre-of-mass energy using the ATLAS detector, *J. High Energy Phys.* **05** (2014) 059.
- [3] CMS Collaboration, Search for Dijet Resonances in 7 TeV pp Collisions at CMS, *Phys. Rev. Lett.* **105**, 211801 (2010).
- [4] CMS Collaboration, Search for resonances in the dijet mass spectrum from 7 TeV pp collisions at CMS, *Phys. Lett. B* **704**, 123 (2011).
- [5] 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.
- [6] 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).
- [7] 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).
- [8] 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).
- [9] ATLAS Collaboration, 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).
- [10] 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).
- [11] 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.
- [12] 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).
- [13] R. M. Harris and K. Kousouris, Searches for dijet resonances at hadron colliders, *Int. J. Mod. Phys. A* **26**, 5005 (2011).
- [14] ATLAS Collaboration, Search for new phenomena in dijet mass and angular distributions from pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, [arXiv:1512.01530](https://arxiv.org/abs/1512.01530).

- [15] L. A. Anchordoqui, H. Goldberg, D. Lüst, S. Nawata, S. Stieberger, and T. R. Taylor, Dijet Signals for Low Mass Strings at the LHC, *Phys. Rev. Lett.* **101**, 241803 (2008).
- [16] S. Cullen, M. Perelstein, and M. E. Peskin, TeV strings and collider probes of large extra dimensions, *Phys. Rev. D* **62**, 055012 (2000).
- [17] J. L. Hewett and T. G. Rizzo, Low-energy phenomenology of superstring-inspired E_6 models, *Phys. Rep.* **183**, 193 (1989).
- [18] P. H. Frampton and S. L. Glashow, Chiral color: An alternative to the standard model, *Phys. Lett. B* **190**, 157 (1987).
- [19] R. S. Chivukula, E. H. Simmons, A. Farzinnia, and J. Ren, Hadron collider production of massive color-octet vector bosons at next-to-leading order, *Phys. Rev. D* **87**, 094011 (2013).
- [20] E. H. Simmons, Coloron phenomenology, *Phys. Rev. D* **55**, 1678 (1997).
- [21] U. Baur, I. Hinchliffe, and D. Zeppenfeld, Excited quark production at hadron colliders, *Int. J. Mod. Phys. A* **02**, 1285 (1987).
- [22] U. Baur, M. Spira, and P. M. Zerwas, Excited quark and lepton production at hadron colliders, *Phys. Rev. D* **42**, 815 (1990).
- [23] T. Han, I. Lewis, and Z. Liu, Colored resonant signals at the LHC: Largest rate and simplest topology, *J. High Energy Phys.* **12** (2010) 085.
- [24] E. Eichten, I. Hinchliffe, K. D. Lane, and C. Quigg, Supercollider physics, *Rev. Mod. Phys.* **56**, 579 (1984).
- [25] L. Randall and R. Sundrum, An Alternative to Compactification, *Phys. Rev. Lett.* **83**, 4690 (1999).
- [26] CMS Collaboration, The CMS experiment at the CERN LHC, *J. Instrum.* **3**, S08004 (2008).
- [27] CMS Collaboration, CMS Physics Analysis Summary Report No. CMS-PAS-PFT-09-001, 2009; <http://cdsweb.cern.ch/record/1194487>.
- [28] CMS Collaboration, CMS Physics Analysis Summary Report No. CMS-PAS-PFT-10-001, 2010; <http://cdsweb.cern.ch/record/1247373>.
- [29] M. Cacciari, G. P. Salam, and G. Soyez, The anti- k_t jet clustering algorithm, *J. High Energy Phys.* **04** (2008) 063.
- [30] M. Cacciari and G. P. Salam, Dispelling the N^3 myth for the k_t jet-finder, *Phys. Lett. B* **641**, 57 (2006).
- [31] M. Cacciari, G. P. Salam, and G. Soyez, FastJet user manual, *Eur. Phys. J. C* **72**, 1896 (2012).
- [32] M. Cacciari and G. P. Salam, Pileup subtraction using jet areas, *Phys. Lett. B* **659**, 119 (2008).
- [33] CMS Collaboration, Determination of jet energy calibration and transverse momentum resolution in CMS, *J. Instrum.* **6**, P11002 (2011).
- [34] CMS Collaboration, CMS Physics Analysis Summary Report No. CMS-PAS-JME-10-003, 2010; <http://cdsweb.cern.ch/record/1279362>.
- [35] T. Sjöstrand, S. Mrenna, and P. Skands, A brief introduction to PYTHIA 8.1, *Comput. Phys. Commun.* **178**, 852 (2008).
- [36] CMS Collaboration, Event generator tunes obtained from underlying event and multiparton scattering measurements, [arXiv:1512.00815](https://arxiv.org/abs/1512.00815).
- [37] P. Skands, S. Carrazza, and J. Rojo, Tuning PYTHIA 8.1: The Monash 2013 tune, *Eur. Phys. J. C* **74**, 3024 (2014).
- [38] S. Agostinelli *et al.* (GEANT4 Collaboration), GEANT4—A simulation toolkit, *Nucl. Instrum. Methods Phys. Res., Sect. A* **506**, 250 (2003).
- [39] R. D. Ball, V. Bertone, S. Carrazza, C. S. Deans, L. Del Debbio, S. Forte, A. Guffanti, N. P. Hartland, J. I. Latorre, J. Rojo, and M. Ubiali (NNPDF), Parton distributions with LHC data, *Nucl. Phys.* **B867**, 244 (2013).
- [40] 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).
- [41] CMS Collaboration, CMS Physics Analysis Summary Report No. CMS-PAS-LUM-13-001, 2013; <http://cdsweb.cern.ch/record/1598864>.
- [42] K. A. Olive *et al.* (Particle Data Group), Review of particle physics, *Chin. Phys. C* **38**, 090001 (2014).
- [43] J. Pumplin, D. R. Stump, J. Huston, H.-L. Lai, P. Nadolsky, and W.-K. Tung, New generation of parton distributions with uncertainties from global QCD analysis, *J. High Energy Phys.* **07** (2002) 012.
- [44] K. Gumus, N. Akchurin, S. Esen, and R. M Harris, Report No. CMS-NOTE-2006-070, 2006; <https://cds.cern.ch/record/962025>.

V. Khachatryan,¹ A. M. Sirunyan,¹ A. Tumasyan,¹ W. Adam,² E. Asilar,² T. Bergauer,² J. Brandstetter,² E. Brondolin,² M. Dragicevic,² J. Erö,² M. Flechl,² M. Friedl,² R. Frühwirth,^{2,b} V. M. Ghete,² C. Hartl,² N. Hörmann,² J. Hrubec,² M. Jeitler,^{2,b} V. Knünz,² A. König,² M. Krammer,^{2,b} I. Krätschmer,² D. Liko,² T. Matsushita,² I. Mikulec,² D. Rabadý,^{2,c} B. Rahbaran,² H. Rohringer,² J. Schieck,^{2,b} R. Schöfbeck,² J. Strauss,² W. Treberer-Treberspurg,² W. Waltenberger,² C.-E. Wulz,^{2,b} V. Mossolov,³ N. Shumeiko,³ J. Suarez Gonzalez,³ S. Alderweireldt,⁴ T. Cornelis,⁴ E. A. De Wolf,⁴ X. Janssen,⁴ A. Knutsson,⁴ J. Lauwers,⁴ S. Luyckx,⁴ M. Van De Klundert,⁴ H. Van Haevermaet,⁴ P. Van Mechelen,⁴ N. Van Remortel,⁴ A. Van Spilbeecq,⁴ S. Abu Zeid,⁵ F. Blekman,⁵ J. D'Hondt,⁵ N. Daci,⁵ I. De Bruyn,⁵ K. Deroover,⁵ N. Heracleous,⁵ J. Keaveney,⁵ S. Lowette,⁵ L. Moreels,⁵ A. Olbrechts,⁵ Q. Python,⁵ D. Strom,⁵ S. Tavernier,⁵ W. Van Doninck,⁵ P. Van Mulders,⁵ G. P. Van Onsem,⁵ I. Van Parijs,⁵ P. Barria,⁶ H. Brun,⁶ C. Caillol,⁶ B. Clerbaux,⁶ G. De Lentdecker,⁶ G. Fasanella,⁶ L. Favart,⁶ R. Goldouzian,⁶ A. Grebenyuk,⁶ G. Karapostoli,⁶ T. Lenzi,⁶ A. Léonard,⁶ T. Maerschalk,⁶ A. Marinov,⁶ L. Perniè,⁶ A. Randle-conde,⁶ T. Seva,⁶ C. Vander Velde,⁶ P. Vanlaer,⁶ R. Yonamine,⁶ F. Zenoni,⁶ F. Zhang,^{6,d} K. Beernaert,⁷ L. Benucci,⁷ A. Cimmino,⁷ S. Crucy,⁷ D. Dobur,⁷ A. Fagot,⁷ G. Garcia,⁷ M. Gul,⁷

J. McCartin,⁷ A. A. Ocampo Rios,⁷ D. Poyraz,⁷ D. Ryckbosch,⁷ S. Salva,⁷ M. Sigamani,⁷ M. Tytgat,⁷ W. Van Driessche,⁷ E. Yazgan,⁷ N. Zaganidis,⁷ S. Basegmez,⁸ C. Beluffi,^{8,e} O. Bondu,⁸ S. Brochet,⁸ G. Bruno,⁸ A. Caudron,⁸ L. Ceard,⁸ C. Delaere,⁸ D. Favart,⁸ L. Forthomme,⁸ A. Giammanco,^{8,f} A. Jafari,⁸ P. Jez,⁸ M. Komm,⁸ V. Lemaitre,⁸ A. Mertens,⁸ M. Musich,⁸ C. Nuttens,⁸ L. Perrini,⁸ K. Piotrkowski,⁸ A. Popov,^{8,g} L. Quertenmont,⁸ M. Selvaggi,⁸ M. Vidal Marono,⁸ N. Belyi,⁹ G. H. Hammad,⁹ W. L. Aldá Júnior,¹⁰ F. L. Alves,¹⁰ G. A. Alves,¹⁰ L. Brito,¹⁰ M. Correa Martins Junior,¹⁰ M. Hamer,¹⁰ C. Hensel,¹⁰ A. Moraes,¹⁰ M. E. Pol,¹⁰ P. Rebello Teles,¹⁰ E. Belchior Batista Das Chagas,¹¹ W. Carvalho,¹¹ J. Chinellato,^{11,h} A. Custódio,¹¹ E. M. Da Costa,¹¹ D. De Jesus Damiao,¹¹ C. De Oliveira Martins,¹¹ S. Fonseca De Souza,¹¹ L. M. Huertas Guativa,¹¹ H. Malbouisson,¹¹ D. Matos Figueiredo,¹¹ C. Mora Herrera,¹¹ L. Mundim,¹¹ H. Nogima,¹¹ W. L. Prado Da Silva,¹¹ A. Santoro,¹¹ A. Sznajder,¹¹ E. J. Tonelli Manganote,^{11,h} A. Vilela Pereira,¹¹ S. Ahuja,^{12a} C. A. Bernardes,^{12b} A. De Souza Santos,^{12b} S. Dogra,^{12a} T. R. Fernandez Perez Tomei,^{12a} E. M. Gregores,^{12b} P. G. Mercadante,^{12b} C. S. Moon,^{12a,i} S. F. Novaes,^{12a} Sandra S. Padula,^{12a} D. Romero Abad,^{12a} J. C. Ruiz Vargas,^{12a} A. Aleksandrov,¹³ R. Hadjiiska,¹³ P. Iaydjiev,¹³ M. Rodozov,¹³ S. Stoykova,¹³ G. Sultanov,¹³ M. Vutova,¹³ A. Dimitrov,¹⁴ I. Glushkov,¹⁴ L. Litov,¹⁴ B. Pavlov,¹⁴ P. Petkov,¹⁴ M. Ahmad,¹⁵ J. G. Bian,¹⁵ G. M. Chen,¹⁵ H. S. Chen,¹⁵ M. Chen,¹⁵ T. Cheng,¹⁵ R. Du,¹⁵ C. H. Jiang,¹⁵ R. Plestina,^{15,j} F. Romeo,¹⁵ S. M. Shaheen,¹⁵ A. Spiezia,¹⁵ J. Tao,¹⁵ C. Wang,¹⁵ Z. Wang,¹⁵ H. Zhang,¹⁵ C. Asawatangtrakuldee,¹⁶ Y. Ban,¹⁶ Q. Li,¹⁶ S. Liu,¹⁶ Y. Mao,¹⁶ S. J. Qian,¹⁶ D. Wang,¹⁶ Z. Xu,¹⁶ C. Avila,¹⁷ A. Cabrera,¹⁷ L. F. Chaparro Sierra,¹⁷ C. Florez,¹⁷ J. P. Gomez,¹⁷ B. Gomez Moreno,¹⁷ J. C. Sanabria,¹⁷ N. Godinovic,¹⁸ D. Lelas,¹⁸ I. Puljak,¹⁸ P. M. Ribeiro Cipriano,¹⁸ Z. Antunovic,¹⁹ M. Kovac,¹⁹ V. Brigljevic,²⁰ K. Kadija,²⁰ J. Luetic,²⁰ S. Micanovic,²⁰ L. Sudic,²⁰ A. Attikis,²¹ G. Mavromanolakis,²¹ J. Mousa,²¹ C. Nicolaou,²¹ F. Ptochos,²¹ P. A. Razis,²¹ H. Rykaczewski,²¹ M. Bodlak,²² M. Finger,^{22,k} M. Finger Jr.,^{22,k} Y. Assran,^{23,l,m} S. Elgammal,^{23,l} A. Ellithi Kamel,^{23,n,n} M. A. Mahmoud,^{23,o,o} B. Calpas,²⁴ M. Kadastik,²⁴ M. Murumaa,²⁴ M. Raidal,²⁴ A. Tiko,²⁴ C. Veelken,²⁴ P. Eerola,²⁵ J. Pekkanen,²⁵ M. Voutilainen,²⁵ J. Härkönen,²⁶ V. Karimäki,²⁶ R. Kinnunen,²⁶ T. Lampén,²⁶ K. Lassila-Perini,²⁶ S. Lehti,²⁶ T. Lindén,²⁶ P. Luukka,²⁶ T. Peltola,²⁶ E. Tuominen,²⁶ J. Tuominiemi,²⁶ E. Tuovinen,²⁶ L. Wendland,²⁶ J. Talvitie,²⁷ T. Tuuva,²⁷ M. Besancon,²⁸ F. Couderc,²⁸ M. Dejardin,²⁸ D. Denegri,²⁸ B. Fabbro,²⁸ J. L. Faure,²⁸ C. Favaro,²⁸ F. Ferri,²⁸ S. Ganjour,²⁸ A. Givernaud,²⁸ P. Gras,²⁸ G. Hamel de Monchenault,²⁸ P. Jarry,²⁸ E. Locci,²⁸ M. Machet,²⁸ J. Malcles,²⁸ J. Rander,²⁸ A. Rosowsky,²⁸ M. Titov,²⁸ A. Zghiche,²⁸ I. Antropov,²⁹ S. Baffioni,²⁹ F. Beaudette,²⁹ P. Busson,²⁹ L. Cadamuro,²⁹ E. Chapon,²⁹ C. Charlot,²⁹ O. Davignon,²⁹ N. Filipovic,²⁹ R. Granier de Cassagnac,²⁹ M. Jo,²⁹ S. Lisniak,²⁹ L. Mastrolorenzo,²⁹ P. Miné,²⁹ I. N. Naranjo,²⁹ M. Nguyen,²⁹ C. Ochando,²⁹ G. Ortona,²⁹ P. Paganini,²⁹ P. Pigard,²⁹ S. Regnard,²⁹ R. Salerno,²⁹ J. B. Sauvan,²⁹ Y. Sirois,²⁹ T. Strebler,²⁹ Y. Yilmaz,²⁹ A. Zabi,²⁹ J.-L. Agram,^{30,p} J. Andrea,³⁰ A. Aubin,³⁰ D. Bloch,³⁰ J.-M. Brom,³⁰ M. Buttignol,³⁰ E. C. Chabert,³⁰ N. Chanon,³⁰ C. Collard,³⁰ E. Conte,^{30,p} X. Coubez,³⁰ J.-C. Fontaine,^{30,p} D. Gelé,³⁰ U. Goerlach,³⁰ C. Goetzmann,³⁰ A.-C. Le Bihan,³⁰ J. A. Merlin,^{30,c} K. Skovpen,³⁰ P. Van Hove,³⁰ S. Gadrat,³¹ S. Beauceron,³² C. Bernet,³² G. Boudoul,³² E. Bouvier,³² C. A. Carrillo Montoya,³² R. Chierici,³² D. Contardo,³² B. Courbon,³² P. Depasse,³² H. El Mamouni,³² J. Fan,³² J. Fay,³² S. Gascon,³² M. Gouzevitch,³² B. Ille,³² F. Lagarde,³² I. B. Laktineh,³² M. Lethuillier,³² L. Mirabito,³² A. L. Pequegnot,³² S. Perries,³² J. D. Ruiz Alvarez,³² D. Sabes,³² L. Sgandurra,³² V. Sordini,³² M. Vander Donckt,³² P. Verdier,³² S. Viret,³² T. Toriashvili,^{33,q} L. Rurua,³⁴ C. Autermann,³⁵ S. Beranek,³⁵ L. Feld,³⁵ A. Heister,³⁵ M. K. Kiesel,³⁵ K. Klein,³⁵ M. Lipinski,³⁵ A. Ostapchuk,³⁵ M. Preuten,³⁵ F. Raupach,³⁵ S. Schael,³⁵ J. F. Schulte,³⁵ T. Verlage,³⁵ H. Weber,³⁵ V. Zhukov,^{35,g} M. Ata,³⁶ M. Brodski,³⁶ E. Dietz-Laursonn,³⁶ D. Duchardt,³⁶ M. Endres,³⁶ M. Erdmann,³⁶ S. Erdweg,³⁶ T. Esch,³⁶ R. Fischer,³⁶ A. Güth,³⁶ T. Hebbeker,³⁶ C. Heidemann,³⁶ K. Hoepfner,³⁶ S. Knutzen,³⁶ P. Kreuzer,³⁶ M. Merschmeyer,³⁶ A. Meyer,³⁶ P. Millet,³⁶ S. Mukherjee,³⁶ M. Olschewski,³⁶ K. Padeken,³⁶ P. Papacz,³⁶ T. Pook,³⁶ M. Radziej,³⁶ H. Reithler,³⁶ M. Rieger,³⁶ F. Scheuch,³⁶ L. Sonnenschein,³⁶ D. Teyssier,³⁶ S. Thüer,³⁶ V. Cherepanov,³⁷ Y. Erdogan,³⁷ G. Flügge,³⁷ H. Geenen,³⁷ M. Geisler,³⁷ F. Hoehle,³⁷ B. Kargoll,³⁷ T. Kress,³⁷ A. Künsken,³⁷ J. Lingemann,³⁷ A. Nehr Korn,³⁷ A. Nowack,³⁷ I. M. Nugent,³⁷ C. Pistone,³⁷ O. Pooth,³⁷ A. Stahl,³⁷ M. Aldaya Martin,³⁸ I. Asin,³⁸ N. Bartosik,³⁸ O. Behnke,³⁸ U. Behrens,³⁸ K. Borras,^{38,r} A. Burgmeier,³⁸ A. Campbell,³⁸ C. Contreras-Campana,³⁸ F. Costanza,³⁸ C. Diez Pardos,³⁸ G. Dolinska,³⁸ S. Dooling,³⁸ T. Dorland,³⁸ G. Eckerlin,³⁸ D. Eckstein,³⁸ T. Eichhorn,³⁸ G. Flucke,³⁸ E. Gallo,^{38,s} J. Garay Garcia,³⁸ A. Geiser,³⁸ A. Gishko,³⁸ P. Gunnellini,³⁸ J. Hauk,³⁸ M. Hempel,^{38,t} H. Jung,³⁸ A. Kalogeropoulos,³⁸ O. Karacheban,^{38,t} M. Kasemann,³⁸ P. Katsas,³⁸ J. Kieseler,³⁸ C. Kleinwort,³⁸ I. Korol,³⁸ W. Lange,³⁸ J. Leonard,³⁸ K. Lipka,³⁸ A. Lobanov,³⁸ W. Lohmann,^{38,t} R. Mankel,³⁸ I.-A. Melzer-Pellmann,³⁸ A. B. Meyer,³⁸ G. Mittag,³⁸ J. Mnich,³⁸ A. Mussgiller,³⁸ S. Naumann-Emme,³⁸ A. Nayak,³⁸ E. Ntomari,³⁸ H. Perrey,³⁸ D. Pitzl,³⁸ R. Placakyte,³⁸ A. Raspereza,³⁸ B. Roland,³⁸ M. Ö. Sahin,³⁸ P. Saxena,³⁸ T. Schoerner-Sadenius,³⁸ C. Seitz,³⁸ S. Spannagel,³⁸

K. D. Trippkewitz,³⁸ R. Walsh,³⁸ C. Wissing,³⁸ V. Blobel,³⁹ M. Centis Vignali,³⁹ A. R. Draeger,³⁹ J. Erfle,³⁹ E. Garutti,³⁹ K. Goebel,³⁹ D. Gonzalez,³⁹ M. Görner,³⁹ J. Haller,³⁹ M. Hoffmann,³⁹ R. S. Höing,³⁹ A. Junkes,³⁹ R. Klanner,³⁹ R. Kogler,³⁹ N. Kovalchuk,³⁹ T. Lapsien,³⁹ T. Lenz,³⁹ I. Marchesini,³⁹ D. Marconi,³⁹ M. Meyer,³⁹ D. Nowatschin,³⁹ J. Ott,³⁹ F. Pantaleo,^{39,c} T. Peiffer,³⁹ A. Perieanu,³⁹ N. Pietsch,³⁹ J. Poehlsen,³⁹ D. Rathjens,³⁹ C. Sander,³⁹ C. Scharf,³⁹ P. Schleper,³⁹ E. Schlieckau,³⁹ A. Schmidt,³⁹ S. Schumann,³⁹ J. Schwandt,³⁹ V. Sola,³⁹ H. Stadie,³⁹ G. Steinbrück,³⁹ F. M. Stober,³⁹ H. Tholen,³⁹ D. Troendle,³⁹ E. Usai,³⁹ L. Vanelderen,³⁹ A. Vanhoefer,³⁹ B. Vormwald,³⁹ C. Barth,⁴⁰ C. Baus,⁴⁰ J. Berger,⁴⁰ C. Böser,⁴⁰ E. Butz,⁴⁰ T. Chwalek,⁴⁰ F. Colombo,⁴⁰ W. De Boer,⁴⁰ A. Descroix,⁴⁰ A. Dierlamm,⁴⁰ S. Fink,⁴⁰ F. Frensch,⁴⁰ R. Friese,⁴⁰ M. Giffels,⁴⁰ A. Gilbert,⁴⁰ D. Haitz,⁴⁰ F. Hartmann,^{40,c} S. M. Heindl,⁴⁰ U. Husemann,⁴⁰ I. Katkov,^{40,g} A. Kornmayer,^{40,c} P. Lobelle Pardo,⁴⁰ B. Maier,⁴⁰ H. Mildner,⁴⁰ M. U. Mozer,⁴⁰ T. Müller,⁴⁰ Th. Müller,⁴⁰ M. Plagge,⁴⁰ G. Quast,⁴⁰ K. Rabbertz,⁴⁰ S. Röcker,⁴⁰ F. Roscher,⁴⁰ M. Schröder,⁴⁰ G. Sieber,⁴⁰ H. J. Simonis,⁴⁰ R. Ulrich,⁴⁰ J. Wagner-Kuhr,⁴⁰ S. Wayand,⁴⁰ M. Weber,⁴⁰ T. Weiler,⁴⁰ S. Williamson,⁴⁰ C. Wöhrmann,⁴⁰ R. Wolf,⁴⁰ G. Anagnostou,⁴¹ G. Daskalakis,⁴¹ T. Gerialis,⁴¹ V. A. Giakoumopoulou,⁴¹ A. Kyriakis,⁴¹ D. Loukas,⁴¹ A. Psallidas,⁴¹ I. Topsis-Giotis,⁴¹ A. Agapitos,⁴² S. Kesisoglou,⁴² A. Panagiotou,⁴² N. Saoulidou,⁴² E. Tziaferi,⁴² I. Evangelou,⁴³ G. Flouris,⁴³ C. Foudas,⁴³ P. Kokkas,⁴³ N. Loukas,⁴³ N. Manthos,⁴³ I. Papadopoulos,⁴³ E. Paradas,⁴³ J. Strologas,⁴³ G. Bencze,⁴⁴ C. Hajdu,⁴⁴ A. Hazi,⁴⁴ P. Hidas,⁴⁴ D. Horvath,^{44,u} F. Sikler,⁴⁴ V. Veszpremi,⁴⁴ G. Vesztergombi,^{44,v} A. J. Zsigmond,⁴⁴ N. Beni,⁴⁵ S. Czellar,⁴⁵ J. Karancsi,^{45,w} J. Molnar,⁴⁵ Z. Szillasi,^{45,c} M. Bartók,^{46,x} A. Makovec,⁴⁶ P. Raics,⁴⁶ Z. L. Trocsanyi,⁴⁶ B. Ujvari,⁴⁶ S. Choudhury,^{47,y} P. Mal,⁴⁷ K. Mandal,⁴⁷ D. K. Sahoo,⁴⁷ N. Sahoo,⁴⁷ S. K. Swain,⁴⁷ S. Bansal,⁴⁸ S. B. Beri,⁴⁸ V. Bhatnagar,⁴⁸ R. Chawla,⁴⁸ R. Gupta,⁴⁸ U. Bhawandeep,⁴⁸ A. K. Kalsi,⁴⁸ A. Kaur,⁴⁸ M. Kaur,⁴⁸ R. Kumar,⁴⁸ A. Mehta,⁴⁸ M. Mittal,⁴⁸ J. B. Singh,⁴⁸ G. Walia,⁴⁸ Ashok Kumar,⁴⁹ A. Bhardwaj,⁴⁹ B. C. Choudhary,⁴⁹ R. B. Garg,⁴⁹ S. Malhotra,⁴⁹ M. Naimuddin,⁴⁹ N. Nishu,⁴⁹ K. Ranjan,⁴⁹ R. Sharma,⁴⁹ V. Sharma,⁴⁹ S. Bhattacharya,⁵⁰ K. Chatterjee,⁵⁰ S. Dey,⁵⁰ S. Dutta,⁵⁰ N. Majumdar,⁵⁰ A. Modak,⁵⁰ K. Mondal,⁵⁰ S. Mukhopadhyay,⁵⁰ A. Roy,⁵⁰ D. Roy,⁵⁰ S. Roy Chowdhury,⁵⁰ S. Sarkar,⁵⁰ M. Sharan,⁵⁰ A. Abdulsalam,⁵¹ R. Chudasama,⁵¹ D. Dutta,⁵¹ V. Jha,⁵¹ V. Kumar,⁵¹ A. K. Mohanty,^{51,c} L. M. Pant,⁵¹ P. Shukla,⁵¹ A. Topkar,⁵¹ T. Aziz,⁵² S. Banerjee,⁵² S. Bhowmik,^{52,z} R. M. Chatterjee,⁵² R. K. Dewanjee,⁵² S. Dugad,⁵² S. Ganguly,⁵² S. Ghosh,⁵² M. Guchait,⁵² A. Gurtu,^{52,aa} Sa. Jain,⁵² G. Kole,⁵² S. Kumar,⁵² B. Mahakud,⁵² M. Maity,^{52,z} G. Majumder,⁵² K. Mazumdar,⁵² S. Mitra,⁵² G. B. Mohanty,⁵² B. Parida,⁵² T. Sarkar,^{52,z} N. Sur,⁵² B. Sutar,⁵² N. Wickramage,^{52,bb} S. Chauhan,⁵³ S. Dube,⁵³ A. Kapoor,⁵³ K. Kothekar,⁵³ S. Sharma,⁵³ H. Bakhshiansohi,⁵⁴ H. Behnamian,⁵⁴ S. M. Etesami,^{54,cc} A. Fahim,^{54,dd} M. Khakzad,⁵⁴ M. Mohammadi Najafabadi,⁵⁴ M. Naseri,⁵⁴ S. Paktinat Mehdiabadi,⁵⁴ F. Rezaei Hosseinabadi,⁵⁴ B. Safarzadeh,^{54,ee} M. Zeinali,⁵⁴ M. Felcini,⁵⁵ M. Grunewald,⁵⁵ M. Abbrescia,^{56a,56b} C. Calabria,^{56a,56b} C. Caputo,^{56a,56b} A. Colaleo,^{56a} D. Creanza,^{56a,56c} L. Cristella,^{56a,56b} N. De Filippis,^{56a,56c} M. De Palma,^{56a,56b} L. Fiore,^{56a} G. Iaselli,^{56a,56c} G. Maggi,^{56a,56c} M. Maggi,^{56a} G. Miniello,^{56a,56b} S. My,^{56a,56c} S. Nuzzo,^{56a,56b} A. Pompili,^{56a,56b} G. Pugliese,^{56a,56c} R. Radogna,^{56a,56b} A. Ranieri,^{56a} G. Selvaggi,^{56a,56b} L. Silvestris,^{56a,c} R. Venditti,^{56a,56b} G. Abbiendi,^{57a} C. Battilana,^{57a,c} A. C. Benvenuti,^{57a} D. Bonacorsi,^{57a,57b} S. Braibant-Giacomelli,^{57a,57b} L. Brigliadori,^{57a,57b} R. Campanini,^{57a,57b} P. Capiluppi,^{57a,57b} A. Castro,^{57a,57b} F. R. Cavallo,^{57a} S. S. Chhibra,^{57a,57b} G. Codispoti,^{57a,57b} M. Cuffiani,^{57a,57b} G. M. Dallavalle,^{57a} F. Fabbri,^{57a} A. Fanfani,^{57a,57b} D. Fasanella,^{57a,57b} P. Giacomelli,^{57a} C. Grandi,^{57a} L. Guiducci,^{57a,57b} S. Marcellini,^{57a} G. Masetti,^{57a} A. Montanari,^{57a} F. L. Navarria,^{57a,57b} A. Perrotta,^{57a} A. M. Rossi,^{57a,57b} T. Rovelli,^{57a,57b} G. P. Siroli,^{57a,57b} N. Tosi,^{57a,57b,c} R. Travaglini,^{57a,57b} G. Cappello,^{58a} M. Chiorboli,^{58a,58b} S. Costa,^{58a,58b} A. Di Mattia,^{58a} F. Giordano,^{58a,58b} R. Potenza,^{58a,58b} A. Tricomi,^{58a,58b} C. Tuve,^{58a,58b} G. Barbagli,^{59a} V. Ciulli,^{59a,59b} C. Civinini,^{59a} R. D'Alessandro,^{59a,59b} E. Focardi,^{59a,59b} V. Gori,^{59a,59b} P. Lenzi,^{59a,59b} M. Meschini,^{59a} S. Paoletti,^{59a} G. Sguazzoni,^{59a} L. Viliani,^{59a,59b,c} L. Benussi,⁶⁰ S. Bianco,⁶⁰ F. Fabbri,⁶⁰ D. Piccolo,⁶⁰ F. Primavera,^{60,c} V. Calvelli,^{61a,61b} F. Ferro,^{61a} M. Lo Vetere,^{61a,61b} M. R. Monge,^{61a,61b} E. Robutti,^{61a} S. Tosi,^{61a,61b} L. Brianza,^{62a} M. E. Dinardo,^{62a,62b} S. Fiorendi,^{62a,62b} S. Gennai,^{62a} R. Gerosa,^{62a,62b} A. Ghezzi,^{62a,62b} P. Govoni,^{62a,62b} S. Malvezzi,^{62a} R. A. Manzoni,^{62a,62b,c} B. Marzocchi,^{62a,62b} D. Menasce,^{62a} L. Moroni,^{62a} M. Paganoni,^{62a,62b} D. Pedrini,^{62a} S. Ragazzi,^{62a,62b} N. Redaelli,^{62a} T. Tabarelli de Fatis,^{62a,62b} S. Buontempo,^{63a} N. Cavallo,^{63a,63c} S. Di Guida,^{63a,63d,c} M. Esposito,^{63a,63b} F. Fabozzi,^{63a,63c} A. O. M. Iorio,^{63a,63b} G. Lanza,^{63a} L. Lista,^{63a} S. Meola,^{63a,63d,c} M. Merola,^{63a} P. Paolucci,^{63a,c} C. Sciacca,^{63a,63b} F. Thyssen,^{63a} P. Azzi,^{64a,c} N. Bacchetta,^{64a} L. Benato,^{64a,64b} D. Bisello,^{64a,64b} A. Boletti,^{64a,64b} R. Carlin,^{64a,64b} P. Checchia,^{64a} M. Dall'Osso,^{64a,64b,c} T. Dorigo,^{64a} U. Dosselli,^{64a} F. Gasparini,^{64a,64b} U. Gasparini,^{64a,64b} A. Gozzelino,^{64a} S. Lacaprara,^{64a} M. Margoni,^{64a,64b} G. Maron,^{64a,ff} A. T. Meneguzzo,^{64a,64b} F. Montecassiano,^{64a} M. Passaseo,^{64a} J. Pazzini,^{64a,64b,c} N. Pozzobon,^{64a,64b} P. Ronchese,^{64a,64b} F. Simonetto,^{64a,64b} E. Torassa,^{64a} M. Tosi,^{64a,64b} M. Zanetti,^{64a} P. Zotto,^{64a,64b} A. Zucchetta,^{64a,64b,c} G. Zumerle,^{64a,64b} A. Braghieri,^{65a} A. Magnani,^{65a,65b} P. Montagna,^{65a,65b} S. P. Ratti,^{65a,65b} V. Re,^{65a}

C. Riccardi,^{65a,65b} P. Salvini,^{65a} I. Vai,^{65a,65b} P. Vitulo,^{65a,65b} L. Alunni Solestizi,^{66a,66b} G. M. Bilei,^{66a} D. Ciangottini,^{66a,66b,c} L. Fanò,^{66a,66b} P. Lariccia,^{66a,66b} G. Mantovani,^{66a,66b} M. Menichelli,^{66a} A. Saha,^{66a} A. Santocchia,^{66a,66b} K. Androsov,^{67a,gg} P. Azzurri,^{67a,c} G. Bagliesi,^{67a} J. Bernardini,^{67a} T. Boccali,^{67a} R. Castaldi,^{67a} M. A. Ciocci,^{67a,gg} R. Dell'Orso,^{67a} S. Donato,^{67a,67c,c} G. Fedi,^{67a} L. Foà,^{67a,67c,a} A. Giassi,^{67a} M. T. Grippo,^{67a,gg} F. Ligabue,^{67a,67c} T. Lomtadze,^{67a} L. Martini,^{67a,67b} A. Messineo,^{67a,67b} F. Palla,^{67a} A. Rizzi,^{67a,67b} A. Savoy-Navarro,^{67a,hh} A. T. Serban,^{67a} P. Spagnolo,^{67a} R. Tenchini,^{67a} G. Tonelli,^{67a,67b} A. Venturi,^{67a} P. G. Verdini,^{67a} L. Barone,^{68a,68b} F. Cavallari,^{68a} G. D'imperio,^{68a,68b,c} D. Del Re,^{68a,68b,c} M. Diemoz,^{68a} S. Gelli,^{68a,68b} C. Jorda,^{68a} E. Longo,^{68a,68b} F. Margaroli,^{68a,68b} P. Meridiani,^{68a} G. Organtini,^{68a,68b} R. Paramatti,^{68a} F. Preiato,^{68a,68b} S. Rahatlou,^{68a,68b} C. Rovelli,^{68a} F. Santanastasio,^{68a,68b} P. Traczyk,^{68a,68b,c} N. Amapane,^{69a,69b} R. Arcidiacono,^{69a,69c,c} S. Argiro,^{69a,69b} M. Arneodo,^{69a,69c} R. Bellan,^{69a,69b} C. Biino,^{69a} N. Cartiglia,^{69a} M. Costa,^{69a,69b} R. Covarelli,^{69a,69b} A. Degano,^{69a,69b} N. Demaria,^{69a} L. Finco,^{69a,69b,c} B. Kiani,^{69a,69b} C. Mariotti,^{69a} S. Maselli,^{69a} E. Migliore,^{69a,69b} V. Monaco,^{69a,69b} E. Monteil,^{69a,69b} M. M. Obertino,^{69a,69b} L. Pacher,^{69a,69c} N. Pastrone,^{69a} M. Pelliccioni,^{69a} G. L. Pinna Angioni,^{69a,69b} F. Ravera,^{69a,69b} A. Romero,^{69a,69b} M. Ruspa,^{69a,69c} R. Sacchi,^{69a,69b} A. Solano,^{69a,69b} A. Staiano,^{69a} S. Belforte,^{70a} V. Candelise,^{70a,70b} M. Casarsa,^{70a} F. Cossutti,^{70a} G. Della Ricca,^{70a,70b} B. Gobbo,^{70a} C. La Licata,^{70a,70b} M. Marone,^{70a,70b} A. Schizzi,^{70a,70b} A. Zanetti,^{70a} A. Kropivnitskaya,⁷¹ S. K. Nam,⁷¹ D. H. Kim,⁷² G. N. Kim,⁷² M. S. Kim,⁷² D. J. Kong,⁷² S. Lee,⁷² Y. D. Oh,⁷² A. Sakharov,⁷² D. C. Son,⁷² J. A. Brochero Cifuentes,⁷³ H. Kim,⁷³ T. J. Kim,⁷³ S. Song,⁷⁴ S. Choi,⁷⁵ Y. Go,⁷⁵ D. Gyun,⁷⁵ B. Hong,⁷⁵ H. Kim,⁷⁵ Y. Kim,⁷⁵ B. Lee,⁷⁵ K. Lee,⁷⁵ K. S. Lee,⁷⁵ S. Lee,⁷⁵ S. K. Park,⁷⁵ Y. Roh,⁷⁵ H. D. Yoo,⁷⁶ M. Choi,⁷⁷ H. Kim,⁷⁷ J. H. Kim,⁷⁷ J. S. H. Lee,⁷⁷ I. C. Park,⁷⁷ G. Ryu,⁷⁷ M. S. Ryu,⁷⁷ Y. Choi,⁷⁸ J. Goh,⁷⁸ D. Kim,⁷⁸ E. Kwon,⁷⁸ J. Lee,⁷⁸ I. Yu,⁷⁸ V. Dudenias,⁷⁹ A. Juodagalvis,⁷⁹ J. Vaitkus,⁷⁹ I. Ahmed,⁸⁰ Z. A. Ibrahim,⁸⁰ J. R. Komaragiri,⁸⁰ M. A. B. Md Ali,^{80,ii} F. Mohamad Idris,^{80,ij} W. A. T. Wan Abdullah,⁸⁰ M. N. Yusli,⁸⁰ E. Casimiro Linares,⁸¹ H. Castilla-Valdez,⁸¹ E. De La Cruz-Burelo,⁸¹ I. Heredia-De La Cruz,^{81,kk} A. Hernandez-Almada,⁸¹ R. Lopez-Fernandez,⁸¹ A. Sanchez-Hernandez,⁸¹ S. Carrillo Moreno,⁸² F. Vazquez Valencia,⁸² I. Pedraza,⁸³ H. A. Salazar Ibarguen,⁸³ A. Morelos Pineda,⁸⁴ D. Krofcheck,⁸⁵ P. H. Butler,⁸⁶ A. Ahmad,⁸⁷ M. Ahmad,⁸⁷ Q. Hassan,⁸⁷ H. R. Hoorani,⁸⁷ W. A. Khan,⁸⁷ T. Khurshid,⁸⁷ M. Shoaib,⁸⁷ H. Bialkowska,⁸⁸ M. Bluj,⁸⁸ B. Boimska,⁸⁸ T. Frueboes,⁸⁸ M. Górski,⁸⁸ M. Kazana,⁸⁸ K. Nawrocki,⁸⁸ K. Romanowska-Rybinska,⁸⁸ M. Szleper,⁸⁸ P. Zalewski,⁸⁸ G. Brona,⁸⁹ K. Bunkowski,⁸⁹ A. Byszek,^{89,li} K. Doroba,⁸⁹ A. Kalinowski,⁸⁹ M. Konecki,⁸⁹ J. Krolikowski,⁸⁹ M. Misiura,⁸⁹ M. Olszewski,⁸⁹ M. Walczak,⁸⁹ P. Bargassa,⁹⁰ C. Beirão Da Cruz E Silva,⁹⁰ A. Di Francesco,⁹⁰ P. Faccioli,⁹⁰ P. G. Ferreira Parracho,⁹⁰ M. Gallinaro,⁹⁰ J. Hollar,⁹⁰ N. Leonardo,⁹⁰ L. Lloret Iglesias,⁹⁰ F. Nguyen,⁹⁰ J. Rodrigues Antunes,⁹⁰ J. Seixas,⁹⁰ O. Toldaiev,⁹⁰ D. Vadrucchio,⁹⁰ J. Varela,⁹⁰ P. Vischia,⁹⁰ S. Afanasiev,⁹¹ P. Bunin,⁹¹ M. Gavrilenko,⁹¹ I. Golutvin,⁹¹ I. Gorbunov,⁹¹ A. Kamenev,⁹¹ V. Karjavin,⁹¹ A. Lanev,⁹¹ A. Malakhov,⁹¹ V. Matveev,^{91,mm,nn} P. Moiseuz,⁹¹ V. Palichik,⁹¹ V. Perelygin,⁹¹ S. Shmatov,⁹¹ S. Shulha,⁹¹ N. Skatchkov,⁹¹ V. Smirnov,⁹¹ A. Zarubin,⁹¹ V. Golovtsov,⁹² Y. Ivanov,⁹² V. Kim,^{92,oo} E. Kuznetsova,⁹² P. Levchenko,⁹² V. Murzin,⁹² V. Oreshkin,⁹² I. Smirnov,⁹² V. Sulimov,⁹² L. Uvarov,⁹² S. Vavilov,⁹² A. Vorobyev,⁹² Yu. Andreev,⁹³ A. Dermenev,⁹³ S. Gninenko,⁹³ N. Golubev,⁹³ A. Karneyeu,⁹³ M. Kirsanov,⁹³ N. Krasnikov,⁹³ A. Pashenkov,⁹³ D. Tlisov,⁹³ A. Toropin,⁹³ V. Epshteyn,⁹⁴ V. Gavrilov,⁹⁴ N. Lychkovskaya,⁹⁴ V. Popov,⁹⁴ I. Pozdnyakov,⁹⁴ G. Safronov,⁹⁴ A. Spiridonov,⁹⁴ E. Vlasov,⁹⁴ A. Zhokin,⁹⁴ A. Bylinkin,⁹⁵ V. Andreev,⁹⁶ M. Azarkin,^{96,nn} I. Dremin,^{96,nn} M. Kirakosyan,⁹⁶ A. Leonidov,^{96,nn} G. Mesyats,⁹⁶ S. V. Rusakov,⁹⁶ A. Baskakov,⁹⁷ A. Belyaev,⁹⁷ E. Boos,⁹⁷ M. Dubinin,^{97,pp} L. Dudko,⁹⁷ A. Ershov,⁹⁷ A. Gribushin,⁹⁷ V. Klyukhin,⁹⁷ O. Kodolova,⁹⁷ I. Lokhtin,⁹⁷ I. Myagkov,⁹⁷ S. Obraztsov,⁹⁷ S. Petrushanko,⁹⁷ V. Savrin,⁹⁷ A. Snigirev,⁹⁷ I. Azhgirey,⁹⁸ I. Bayshev,⁹⁸ S. Bitioukov,⁹⁸ V. Kachanov,⁹⁸ A. Kalinin,⁹⁸ D. Konstantinov,⁹⁸ V. Krychkin,⁹⁸ V. Petrov,⁹⁸ R. Ryutin,⁹⁸ A. Sobol,⁹⁸ L. Tourtchanovitch,⁹⁸ S. Troshin,⁹⁸ N. Tyurin,⁹⁸ A. Uzunian,⁹⁸ A. Volkov,⁹⁸ P. Adzic,^{99,qq} P. Cirkovic,⁹⁹ J. Milosevic,⁹⁹ V. Rekovic,⁹⁹ J. Alcaraz Maestre,¹⁰⁰ E. Calvo,¹⁰⁰ M. Cerrada,¹⁰⁰ M. Chamizo Llatas,¹⁰⁰ N. Colino,¹⁰⁰ B. De La Cruz,¹⁰⁰ A. Delgado Peris,¹⁰⁰ A. Escalante Del Valle,¹⁰⁰ C. Fernandez Bedoya,¹⁰⁰ J. P. Fernández Ramos,¹⁰⁰ J. Flix,¹⁰⁰ M. C. Fouz,¹⁰⁰ P. Garcia-Abia,¹⁰⁰ O. Gonzalez Lopez,¹⁰⁰ S. Goy Lopez,¹⁰⁰ J. M. Hernandez,¹⁰⁰ M. I. Josa,¹⁰⁰ E. Navarro De Martino,¹⁰⁰ A. Pérez-Calero Yzquierdo,¹⁰⁰ J. Puerta Pelayo,¹⁰⁰ A. Quintario Olmeda,¹⁰⁰ I. Redondo,¹⁰⁰ L. Romero,¹⁰⁰ J. Santaolalla,¹⁰⁰ M. S. Soares,¹⁰⁰ C. Albajar,¹⁰¹ J. F. de Trocóniz,¹⁰¹ M. Missiroli,¹⁰¹ D. Moran,¹⁰¹ J. Cuevas,¹⁰² J. Fernandez Menendez,¹⁰² S. Folgueras,¹⁰² I. Gonzalez Caballero,¹⁰² E. Palencia Cortezon,¹⁰² J. M. Vizan Garcia,¹⁰² I. J. Cabrillo,¹⁰³ A. Calderon,¹⁰³ J. R. Castiñeiras De Saa,¹⁰³ P. De Castro Manzano,¹⁰³ M. Fernandez,¹⁰³ J. Garcia-Ferrero,¹⁰³ G. Gomez,¹⁰³ A. Lopez Virto,¹⁰³ J. Marco,¹⁰³ R. Marco,¹⁰³ C. Martinez Rivero,¹⁰³ F. Matorras,¹⁰³ J. Piedra Gomez,¹⁰³ T. Rodrigo,¹⁰³ A. Y. Rodríguez-Marrero,¹⁰³ A. Ruiz-Jimeno,¹⁰³ L. Scodellaro,¹⁰³ N. Trevisani,¹⁰³ I. Vila,¹⁰³ R. Vilar Cortabitarte,¹⁰³

D. Abbaneo,¹⁰⁴ E. Auffray,¹⁰⁴ G. Auzinger,¹⁰⁴ M. Bachtis,¹⁰⁴ P. Baillon,¹⁰⁴ A. H. Ball,¹⁰⁴ D. Barney,¹⁰⁴ A. Benaglia,¹⁰⁴ J. Bendavid,¹⁰⁴ L. Benhabib,¹⁰⁴ G. M. Berruti,¹⁰⁴ P. Bloch,¹⁰⁴ A. Bocci,¹⁰⁴ A. Bonato,¹⁰⁴ C. Botta,¹⁰⁴ H. Breuker,¹⁰⁴ T. Camporesi,¹⁰⁴ R. Castello,¹⁰⁴ G. Cerminara,¹⁰⁴ M. D'Alfonso,¹⁰⁴ D. d'Enterria,¹⁰⁴ A. Dabrowski,¹⁰⁴ V. Daponte,¹⁰⁴ A. David,¹⁰⁴ M. De Gruttola,¹⁰⁴ F. De Guio,¹⁰⁴ A. De Roeck,¹⁰⁴ S. De Visscher,¹⁰⁴ E. Di Marco,^{104,rr} M. Dobson,¹⁰⁴ M. Dordevic,¹⁰⁴ B. Dorney,¹⁰⁴ T. du Pree,¹⁰⁴ D. Duggan,¹⁰⁴ M. Dünser,¹⁰⁴ N. Dupont,¹⁰⁴ A. Elliott-Peisert,¹⁰⁴ G. Franzoni,¹⁰⁴ J. Fulcher,¹⁰⁴ W. Funk,¹⁰⁴ D. Gigi,¹⁰⁴ K. Gill,¹⁰⁴ D. Giordano,¹⁰⁴ M. Girone,¹⁰⁴ F. Glege,¹⁰⁴ R. Guida,¹⁰⁴ S. Gundacker,¹⁰⁴ M. Guthoff,¹⁰⁴ J. Hammer,¹⁰⁴ P. Harris,¹⁰⁴ J. Hegeman,¹⁰⁴ V. Innocente,¹⁰⁴ P. Janot,¹⁰⁴ H. Kirschenmann,¹⁰⁴ M. J. Kortelainen,¹⁰⁴ K. Kousouris,¹⁰⁴ K. Krajczar,¹⁰⁴ P. Lecoq,¹⁰⁴ C. Lourenço,¹⁰⁴ M. T. Lucchini,¹⁰⁴ N. Magini,¹⁰⁴ L. Malgeri,¹⁰⁴ M. Mannelli,¹⁰⁴ A. Martelli,¹⁰⁴ L. Masetti,¹⁰⁴ F. Meijers,¹⁰⁴ S. Mersi,¹⁰⁴ E. Meschi,¹⁰⁴ F. Moortgat,¹⁰⁴ S. Morovic,¹⁰⁴ M. Mulders,¹⁰⁴ M. V. Nemallapudi,¹⁰⁴ H. Neugebauer,¹⁰⁴ S. Orfanelli,^{104,ss} L. Orsini,¹⁰⁴ L. Pape,¹⁰⁴ E. Perez,¹⁰⁴ M. Peruzzi,¹⁰⁴ A. Petrilli,¹⁰⁴ G. Petrucciani,¹⁰⁴ A. Pfeiffer,¹⁰⁴ M. Pierini,¹⁰⁴ D. Piparo,¹⁰⁴ A. Racz,¹⁰⁴ T. Reis,¹⁰⁴ G. Rolandi,^{104,tt} M. Rovere,¹⁰⁴ M. Ruan,¹⁰⁴ H. Sakulin,¹⁰⁴ C. Schäfer,¹⁰⁴ C. Schwick,¹⁰⁴ M. Seidel,¹⁰⁴ A. Sharma,¹⁰⁴ P. Silva,¹⁰⁴ M. Simon,¹⁰⁴ P. Sphicas,^{104,uu} J. Steggemann,¹⁰⁴ B. Stieger,¹⁰⁴ M. Stoye,¹⁰⁴ Y. Takahashi,¹⁰⁴ D. Treille,¹⁰⁴ A. Triossi,¹⁰⁴ A. Tsiros,¹⁰⁴ G. I. Veres,^{104,v} N. Wardle,¹⁰⁴ H. K. Wöhri,¹⁰⁴ A. Zagodzinska,^{104,ll} W. D. Zeuner,¹⁰⁴ W. Bertl,¹⁰⁵ K. Deiters,¹⁰⁵ W. Erdmann,¹⁰⁵ R. Horisberger,¹⁰⁵ Q. Ingram,¹⁰⁵ H. C. Kaestli,¹⁰⁵ D. Kotlinski,¹⁰⁵ U. Langenegger,¹⁰⁵ D. Renker,¹⁰⁵ T. Rohe,¹⁰⁵ F. Bachmair,¹⁰⁶ L. Bäni,¹⁰⁶ L. Bianchini,¹⁰⁶ B. Casal,¹⁰⁶ G. Dissertori,¹⁰⁶ M. Dittmar,¹⁰⁶ M. Donegà,¹⁰⁶ P. Eller,¹⁰⁶ C. Grab,¹⁰⁶ C. Heidegger,¹⁰⁶ D. Hits,¹⁰⁶ J. Hoss,¹⁰⁶ G. Kasieczka,¹⁰⁶ P. Lecomte,^{106,a} W. Lustermann,¹⁰⁶ B. Mangano,¹⁰⁶ M. Marionneau,¹⁰⁶ P. Martinez Ruiz del Arbol,¹⁰⁶ M. Masciovecchio,¹⁰⁶ D. Meister,¹⁰⁶ F. Micheli,¹⁰⁶ P. Musella,¹⁰⁶ F. Nessi-Tedaldi,¹⁰⁶ F. Pandolfi,¹⁰⁶ J. Pata,¹⁰⁶ F. Pauss,¹⁰⁶ L. Perrozzi,¹⁰⁶ M. Quittnat,¹⁰⁶ M. Rossini,¹⁰⁶ M. Schönenberger,¹⁰⁶ A. Starodumov,^{106,vv} M. Takahashi,¹⁰⁶ V. R. Tavolaro,¹⁰⁶ K. Theofilatos,¹⁰⁶ R. Wallny,¹⁰⁶ T. K. Aarrestad,¹⁰⁷ C. AMSler,^{107,ww} L. Caminada,¹⁰⁷ M. F. Canelli,¹⁰⁷ V. Chiochia,¹⁰⁷ A. De Cosa,¹⁰⁷ C. Galloni,¹⁰⁷ A. Hinzmann,¹⁰⁷ T. Hreus,¹⁰⁷ B. Kilminster,¹⁰⁷ C. Lange,¹⁰⁷ J. Ngadiuba,¹⁰⁷ D. Pinna,¹⁰⁷ G. Rauco,¹⁰⁷ P. Robmann,¹⁰⁷ F. J. Ronga,¹⁰⁷ D. Salerno,¹⁰⁷ Y. Yang,¹⁰⁷ M. Cardaci,¹⁰⁸ K. H. Chen,¹⁰⁸ T. H. Doan,¹⁰⁸ Sh. Jain,¹⁰⁸ R. Khurana,¹⁰⁸ M. Konyushikhin,¹⁰⁸ C. M. Kuo,¹⁰⁸ W. Lin,¹⁰⁸ Y. J. Lu,¹⁰⁸ A. Pozdnyakov,¹⁰⁸ S. S. Yu,¹⁰⁸ Arun Kumar,¹⁰⁹ P. Chang,¹⁰⁹ Y. H. Chang,¹⁰⁹ Y. W. Chang,¹⁰⁹ Y. Chao,¹⁰⁹ K. F. Chen,¹⁰⁹ P. H. Chen,¹⁰⁹ C. Dietz,¹⁰⁹ F. Fiori,¹⁰⁹ U. Grundler,¹⁰⁹ W.-S. Hou,¹⁰⁹ Y. Hsiung,¹⁰⁹ Y. F. Liu,¹⁰⁹ R.-S. Lu,¹⁰⁹ M. Miñano Moya,¹⁰⁹ E. Petrakou,¹⁰⁹ J. f. Tsai,¹⁰⁹ Y. M. Tzeng,¹⁰⁹ B. Asavapibhop,¹¹⁰ K. Kovitanggoon,¹¹⁰ G. Singh,¹¹⁰ N. Srimanobhas,¹¹⁰ N. Suwonjandee,¹¹⁰ A. Adiguzel,¹¹¹ M. N. Bakirci,^{111,xx} A. Bat,¹¹¹ Z. S. Demiroglu,¹¹¹ C. Dozen,¹¹¹ F. H. Gecit,¹¹¹ S. Girgis,¹¹¹ G. Gokbulut,¹¹¹ Y. Guler,¹¹¹ E. Gurpinar,¹¹¹ I. Hos,¹¹¹ E. E. Kangal,^{111,yy} A. Kayis Topaksu,¹¹¹ G. Onengut,^{111,zz} M. Ozcan,¹¹¹ K. Ozdemir,^{111,aaa} S. Ozturk,^{111,xx} D. Sunar Cerci,^{111,bbb} B. Tali,^{111,bbb} H. Topakli,^{111,xx} C. Zorbilmez,¹¹¹ B. Bilin,¹¹² S. Bilmis,¹¹² B. Isildak,^{112,ccc} G. Karapinar,^{112,ddd} M. Yalvac,¹¹² M. Zeyrek,¹¹² E. Gülmez,¹¹³ M. Kaya,^{113,eee} O. Kaya,^{113,fff} E. A. Yetkin,^{113,ggg} T. Yetkin,^{113,hhh} A. Cakir,¹¹⁴ K. Cankocak,¹¹⁴ S. Sen,^{114,iii} F. I. Vardarli,¹¹⁴ B. Grynyov,¹¹⁵ L. Levchuk,¹¹⁶ P. Sorokin,¹¹⁶ R. Aggleton,¹¹⁷ F. Ball,¹¹⁷ L. Beck,¹¹⁷ J. J. Brooke,¹¹⁷ E. Clement,¹¹⁷ D. Cussans,¹¹⁷ H. Flacher,¹¹⁷ J. Goldstein,¹¹⁷ M. Grimes,¹¹⁷ G. P. Heath,¹¹⁷ H. F. Heath,¹¹⁷ J. Jacob,¹¹⁷ L. Kreczko,¹¹⁷ C. Lucas,¹¹⁷ Z. Meng,¹¹⁷ D. M. Newbold,^{117,jjj} S. Paramesvaran,¹¹⁷ A. Poll,¹¹⁷ T. Sakuma,¹¹⁷ S. Seif El Nasr-storey,¹¹⁷ S. Senkin,¹¹⁷ D. Smith,¹¹⁷ V. J. Smith,¹¹⁷ K. W. Bell,¹¹⁸ A. Belyaev,^{118,kkk} C. Brew,¹¹⁸ R. M. Brown,¹¹⁸ L. Calligaris,¹¹⁸ D. Cieri,¹¹⁸ D. J. A. Cockerill,¹¹⁸ J. A. Coughlan,¹¹⁸ K. Harder,¹¹⁸ S. Harper,¹¹⁸ E. Olaiya,¹¹⁸ D. Petyt,¹¹⁸ C. H. Shepherd-Themistocleous,¹¹⁸ A. Thea,¹¹⁸ I. R. Tomalin,¹¹⁸ T. Williams,¹¹⁸ S. D. Worm,¹¹⁸ M. Baber,¹¹⁹ R. Bainbridge,¹¹⁹ O. Buchmuller,¹¹⁹ A. Bundock,¹¹⁹ D. Burton,¹¹⁹ S. Casasso,¹¹⁹ M. Citron,¹¹⁹ D. Colling,¹¹⁹ L. Corpe,¹¹⁹ P. Dauncey,¹¹⁹ G. Davies,¹¹⁹ A. De Wit,¹¹⁹ M. Della Negra,¹¹⁹ P. Dunne,¹¹⁹ A. Elwood,¹¹⁹ D. Futyan,¹¹⁹ G. Hall,¹¹⁹ G. Iles,¹¹⁹ R. Lane,¹¹⁹ R. Lucas,^{119,jjj} L. Lyons,¹¹⁹ A.-M. Magnan,¹¹⁹ S. Malik,¹¹⁹ J. Nash,¹¹⁹ A. Nikitenko,^{119,vv} J. Pela,¹¹⁹ M. Pesaresi,¹¹⁹ K. Petridis,¹¹⁹ D. M. Raymond,¹¹⁹ A. Richards,¹¹⁹ A. Rose,¹¹⁹ C. Seez,¹¹⁹ A. Tapper,¹¹⁹ K. Uchida,¹¹⁹ M. Vazquez Acosta,^{119,lll} T. Virdee,¹¹⁹ S. C. Zenz,¹¹⁹ J. E. Cole,¹²⁰ P. R. Hobson,¹²⁰ A. Khan,¹²⁰ P. Kyberd,¹²⁰ D. Leggat,¹²⁰ D. Leslie,¹²⁰ I. D. Reid,¹²⁰ P. Symonds,¹²⁰ L. Teodorescu,¹²⁰ M. Turner,¹²⁰ A. Borzou,¹²¹ K. Call,¹²¹ J. Dittmann,¹²¹ K. Hatakeyama,¹²¹ H. Liu,¹²¹ N. Pastika,¹²¹ O. Charaf,¹²² S. I. Cooper,¹²² C. Henderson,¹²² P. Rumerio,¹²² D. Arcaro,¹²³ A. Avetisyan,¹²³ T. Bose,¹²³ D. Gastler,¹²³ D. Rankin,¹²³ C. Richardson,¹²³ J. Rohlf,¹²³ L. Sulak,¹²³ D. Zou,¹²³ J. Alimena,¹²⁴ E. Berry,¹²⁴ D. Cutts,¹²⁴ A. Ferapontov,¹²⁴ A. Garabedian,¹²⁴ J. Hakala,¹²⁴ U. Heintz,¹²⁴ E. Laird,¹²⁴ G. Landsberg,¹²⁴ Z. Mao,¹²⁴ M. Narain,¹²⁴ S. Piperov,¹²⁴ S. Sagir,¹²⁴ R. Syarif,¹²⁴ R. Breedon,¹²⁵ G. Breto,¹²⁵ M. Calderon De La Barca Sanchez,¹²⁵ S. Chauhan,¹²⁵ M. Chertok,¹²⁵ J. Conway,¹²⁵ R. Conway,¹²⁵ P. T. Cox,¹²⁵

R. Erbacher,¹²⁵ G. Funk,¹²⁵ M. Gardner,¹²⁵ W. Ko,¹²⁵ R. Lander,¹²⁵ C. Mclean,¹²⁵ M. Mulhearn,¹²⁵ D. Pellett,¹²⁵ J. Pilot,¹²⁵ F. Ricci-Tam,¹²⁵ S. Shalhout,¹²⁵ J. Smith,¹²⁵ M. Squires,¹²⁵ D. Stolp,¹²⁵ M. Tripathi,¹²⁵ S. Wilbur,¹²⁵ R. Yohay,¹²⁵ R. Cousins,¹²⁶ P. Everaerts,¹²⁶ A. Florent,¹²⁶ J. Hauser,¹²⁶ M. Ignatenko,¹²⁶ D. Saltzberg,¹²⁶ E. Takasugi,¹²⁶ V. Valuev,¹²⁶ M. Weber,¹²⁶ K. Burt,¹²⁷ R. Clare,¹²⁷ J. Ellison,¹²⁷ J. W. Gary,¹²⁷ G. Hanson,¹²⁷ J. Heilman,¹²⁷ M. Ivova PANEVA,¹²⁷ P. Jandir,¹²⁷ E. Kennedy,¹²⁷ F. Lacroix,¹²⁷ O. R. Long,¹²⁷ M. Malberti,¹²⁷ M. Olmedo Negrete,¹²⁷ A. Shrinivas,¹²⁷ H. Wei,¹²⁷ S. Wimpenny,¹²⁷ B. R. Yates,¹²⁷ J. G. Branson,¹²⁸ G. B. Cerati,¹²⁸ S. Cittolin,¹²⁸ R. T. D'Agnolo,¹²⁸ M. Derdzinski,¹²⁸ A. Holzner,¹²⁸ R. Kelley,¹²⁸ D. Klein,¹²⁸ J. Letts,¹²⁸ I. Macneill,¹²⁸ D. Olivito,¹²⁸ S. Padhi,¹²⁸ M. Pieri,¹²⁸ M. Sani,¹²⁸ V. Sharma,¹²⁸ S. Simon,¹²⁸ M. Tadel,¹²⁸ A. Vartak,¹²⁸ S. Wasserbaech,^{128,mmm} C. Welke,¹²⁸ F. Würthwein,¹²⁸ A. Yagil,¹²⁸ G. Zevi Della Porta,¹²⁸ J. Bradmiller-Feld,¹²⁹ C. Campagnari,¹²⁹ A. Dishaw,¹²⁹ V. Dutta,¹²⁹ K. Flowers,¹²⁹ M. Franco Sevilla,¹²⁹ P. Geffert,¹²⁹ C. George,¹²⁹ F. Golf,¹²⁹ L. Gouskos,¹²⁹ J. Gran,¹²⁹ J. Incandela,¹²⁹ N. Mccoll,¹²⁹ S. D. Mullin,¹²⁹ J. Richman,¹²⁹ D. Stuart,¹²⁹ I. Suarez,¹²⁹ C. West,¹²⁹ J. Yoo,¹²⁹ D. Anderson,¹³⁰ A. Apresyan,¹³⁰ A. Bornheim,¹³⁰ J. Bunn,¹³⁰ Y. Chen,¹³⁰ J. Duarte,¹³⁰ A. Mott,¹³⁰ H. B. Newman,¹³⁰ C. Pena,¹³⁰ M. Spiropulu,¹³⁰ J. R. Vlimant,¹³⁰ S. Xie,¹³⁰ R. Y. Zhu,¹³⁰ M. B. Andrews,¹³¹ V. Azzolini,¹³¹ A. Calamba,¹³¹ B. Carlson,¹³¹ T. Ferguson,¹³¹ M. Paulini,¹³¹ J. Russ,¹³¹ M. Sun,¹³¹ H. Vogel,¹³¹ I. Vorobiev,¹³¹ J. P. Cumalat,¹³² W. T. Ford,¹³² A. Gaz,¹³² F. Jensen,¹³² A. Johnson,¹³² M. Krohn,¹³² T. Mulholland,¹³² U. Nauenberg,¹³² K. Stenson,¹³² S. R. Wagner,¹³² J. Alexander,¹³³ A. Chatterjee,¹³³ J. Chaves,¹³³ J. Chu,¹³³ S. Dittmer,¹³³ N. Eggert,¹³³ N. Mirman,¹³³ G. Nicolas Kaufman,¹³³ J. R. Patterson,¹³³ A. Rinkevicius,¹³³ A. Ryd,¹³³ L. Skinnari,¹³³ L. Soffi,¹³³ W. Sun,¹³³ S. M. Tan,¹³³ W. D. Teo,¹³³ J. Thom,¹³³ J. Thompson,¹³³ J. Tucker,¹³³ Y. Weng,¹³³ P. Wittich,¹³³ S. Abdullin,¹³⁴ M. Albrow,¹³⁴ G. Apollinari,¹³⁴ S. Banerjee,¹³⁴ L. A. T. Bauerdick,¹³⁴ A. Beretvas,¹³⁴ J. Berryhill,¹³⁴ P. C. Bhat,¹³⁴ G. Bolla,¹³⁴ K. Burkett,¹³⁴ J. N. Butler,¹³⁴ H. W. K. Cheung,¹³⁴ F. Chlebana,¹³⁴ S. Cihangir,¹³⁴ V. D. Elvira,¹³⁴ I. Fisk,¹³⁴ J. Freeman,¹³⁴ E. Gottschalk,¹³⁴ L. Gray,¹³⁴ D. Green,¹³⁴ S. Grünendahl,¹³⁴ O. Gutsche,¹³⁴ J. Hanlon,¹³⁴ D. Hare,¹³⁴ R. M. Harris,¹³⁴ S. Hasegawa,¹³⁴ J. Hirschauer,¹³⁴ Z. Hu,¹³⁴ B. Jayatilaka,¹³⁴ S. Jindariani,¹³⁴ M. Johnson,¹³⁴ U. Joshi,¹³⁴ B. Klima,¹³⁴ B. Kreis,¹³⁴ S. Lammel,¹³⁴ J. Linacre,¹³⁴ D. Lincoln,¹³⁴ R. Lipton,¹³⁴ T. Liu,¹³⁴ R. Lopes De Sá,¹³⁴ J. Lykken,¹³⁴ K. Maeshima,¹³⁴ J. M. Marraffino,¹³⁴ S. Maruyama,¹³⁴ D. Mason,¹³⁴ P. McBride,¹³⁴ P. Merkel,¹³⁴ S. Mrenna,¹³⁴ S. Nahn,¹³⁴ C. Newman-Holmes,^{134,a} V. O'Dell,¹³⁴ K. Pedro,¹³⁴ O. Prokofyev,¹³⁴ G. Rakness,¹³⁴ E. Sexton-Kennedy,¹³⁴ A. Soha,¹³⁴ W. J. Spalding,¹³⁴ L. Spiegel,¹³⁴ S. Stoynev,¹³⁴ N. Strobbe,¹³⁴ L. Taylor,¹³⁴ S. Tkaczyk,¹³⁴ N. V. Tran,¹³⁴ L. Uplegger,¹³⁴ E. W. Vaandering,¹³⁴ C. Vernieri,¹³⁴ M. Verzocchi,¹³⁴ R. Vidal,¹³⁴ M. Wang,¹³⁴ H. A. Weber,¹³⁴ A. Whitbeck,¹³⁴ D. Acosta,¹³⁵ P. Avery,¹³⁵ P. Bortignon,¹³⁵ D. Bourilkov,¹³⁵ A. Carnes,¹³⁵ M. Carver,¹³⁵ D. Curry,¹³⁵ S. Das,¹³⁵ R. D. Field,¹³⁵ I. K. Furic,¹³⁵ S. V. Gleyzer,¹³⁵ J. Konigsberg,¹³⁵ A. Korytov,¹³⁵ K. Kotov,¹³⁵ P. Ma,¹³⁵ K. Matchev,¹³⁵ H. Mei,¹³⁵ P. Milenovic,^{135,nnn} G. Mitselmakher,¹³⁵ D. Rank,¹³⁵ R. Rossin,¹³⁵ L. Shchutska,¹³⁵ M. Snowball,¹³⁵ D. Sperka,¹³⁵ N. Terentyev,¹³⁵ L. Thomas,¹³⁵ J. Wang,¹³⁵ S. Wang,¹³⁵ J. Yelton,¹³⁵ S. Hewamanage,¹³⁶ S. Linn,¹³⁶ P. Markowitz,¹³⁶ G. Martinez,¹³⁶ J. L. Rodriguez,¹³⁶ A. Ackert,¹³⁷ J. R. Adams,¹³⁷ T. Adams,¹³⁷ A. Askew,¹³⁷ S. Bein,¹³⁷ J. Bochenek,¹³⁷ B. Diamond,¹³⁷ J. Haas,¹³⁷ S. Hagopian,¹³⁷ V. Hagopian,¹³⁷ K. F. Johnson,¹³⁷ A. Khatiwada,¹³⁷ H. Prosper,¹³⁷ M. Weinberg,¹³⁷ M. M. Baarmand,¹³⁸ V. Bhopatkar,¹³⁸ S. Colafranceschi,^{138,ooo} M. Hohlmann,¹³⁸ H. Kalakhety,¹³⁸ D. Noonan,¹³⁸ T. Roy,¹³⁸ F. Yumiceva,¹³⁸ M. R. Adams,¹³⁹ L. Apanasevich,¹³⁹ D. Berry,¹³⁹ R. R. Betts,¹³⁹ I. Bucinskaite,¹³⁹ R. Cavanaugh,¹³⁹ O. Evdokimov,¹³⁹ L. Gauthier,¹³⁹ C. E. Gerber,¹³⁹ D. J. Hofman,¹³⁹ P. Kurt,¹³⁹ C. O'Brien,¹³⁹ I. D. Sandoval Gonzalez,¹³⁹ P. Turner,¹³⁹ N. Varelas,¹³⁹ Z. Wu,¹³⁹ M. Zakaria,¹³⁹ B. Bilki,^{140,ppp} W. Clarida,¹⁴⁰ K. Dilsiz,¹⁴⁰ S. Durgut,¹⁴⁰ R. P. Gandrajula,¹⁴⁰ M. Haytmyradov,¹⁴⁰ V. Khristenko,¹⁴⁰ J.-P. Merlo,¹⁴⁰ H. Mermerkaya,^{140,qqq} A. Mestvirishvili,¹⁴⁰ A. Moeller,¹⁴⁰ J. Nachtman,¹⁴⁰ H. Ogul,¹⁴⁰ Y. Onel,¹⁴⁰ F. Ozok,^{140,rrr} A. Penzo,¹⁴⁰ C. Snyder,¹⁴⁰ E. Tiras,¹⁴⁰ J. Wetzel,¹⁴⁰ K. Yi,¹⁴⁰ I. Anderson,¹⁴¹ B. A. Barnett,¹⁴¹ B. Blumenfeld,¹⁴¹ N. Eminizer,¹⁴¹ D. Fehling,¹⁴¹ L. Feng,¹⁴¹ A. V. Gritsan,¹⁴¹ P. Maksimovic,¹⁴¹ C. Martin,¹⁴¹ M. Osherson,¹⁴¹ J. Roskes,¹⁴¹ A. Sady,¹⁴¹ U. Sarica,¹⁴¹ M. Swartz,¹⁴¹ M. Xiao,¹⁴¹ Y. Xin,¹⁴¹ C. You,¹⁴¹ P. Baringer,¹⁴² A. Bean,¹⁴² G. Benelli,¹⁴² C. Bruner,¹⁴² R. P. Kenny III,¹⁴² D. Majumder,¹⁴² M. Malek,¹⁴² M. Murray,¹⁴² S. Sanders,¹⁴² R. Stringer,¹⁴² Q. Wang,¹⁴² A. Ivanov,¹⁴³ K. Kaadze,¹⁴³ S. Khalil,¹⁴³ M. Makouski,¹⁴³ Y. Maravin,¹⁴³ A. Mohammadi,¹⁴³ L. K. Saini,¹⁴³ N. Skhirtladze,¹⁴³ S. Toda,¹⁴³ D. Lange,¹⁴⁴ F. Rebassoo,¹⁴⁴ D. Wright,¹⁴⁴ C. Anelli,¹⁴⁵ A. Baden,¹⁴⁵ O. Baron,¹⁴⁵ A. Belloni,¹⁴⁵ B. Calvert,¹⁴⁵ S. C. Eno,¹⁴⁵ C. Ferraioli,¹⁴⁵ J. A. Gomez,¹⁴⁵ N. J. Hadley,¹⁴⁵ S. Jabeen,¹⁴⁵ R. G. Kellogg,¹⁴⁵ T. Kolberg,¹⁴⁵ J. Kunkle,¹⁴⁵ Y. Lu,¹⁴⁵ A. C. Mignerey,¹⁴⁵ Y. H. Shin,¹⁴⁵ A. Skuja,¹⁴⁵ M. B. Tonjes,¹⁴⁵ S. C. Tonwar,¹⁴⁵ A. Apyan,¹⁴⁶ R. Barbieri,¹⁴⁶ A. Baty,¹⁴⁶ K. Bierwagen,¹⁴⁶ S. Brandt,¹⁴⁶ W. Busza,¹⁴⁶ I. A. Cali,¹⁴⁶ Z. Demiragli,¹⁴⁶ L. Di Matteo,¹⁴⁶ G. Gomez Ceballos,¹⁴⁶ M. Goncharov,¹⁴⁶ D. Gulhan,¹⁴⁶ Y. Iiyama,¹⁴⁶ G. M. Innocenti,¹⁴⁶ M. Klute,¹⁴⁶ D. Kovalskiy,¹⁴⁶ Y. S. Lai,¹⁴⁶ Y.-J. Lee,¹⁴⁶ A. Levin,¹⁴⁶ P. D. Luckey,¹⁴⁶ A. C. Marini,¹⁴⁶ C. McGinn,¹⁴⁶

C. Mironov,¹⁴⁶ S. Narayanan,¹⁴⁶ X. Niu,¹⁴⁶ C. Paus,¹⁴⁶ C. Roland,¹⁴⁶ G. Roland,¹⁴⁶ J. Salfeld-Nebgen,¹⁴⁶
 G. S. F. Stephans,¹⁴⁶ K. Sumorok,¹⁴⁶ M. Varma,¹⁴⁶ D. Velicanu,¹⁴⁶ J. Veverka,¹⁴⁶ J. Wang,¹⁴⁶ T. W. Wang,¹⁴⁶ B. Wyslouch,¹⁴⁶
 M. Yang,¹⁴⁶ V. Zhukova,¹⁴⁶ B. Dahmes,¹⁴⁷ A. Evans,¹⁴⁷ A. Finkel,¹⁴⁷ A. Gude,¹⁴⁷ P. Hansen,¹⁴⁷ S. Kalafut,¹⁴⁷ S. C. Kao,¹⁴⁷
 K. Klapoetke,¹⁴⁷ Y. Kubota,¹⁴⁷ Z. Lesko,¹⁴⁷ J. Mans,¹⁴⁷ S. Nourbakhsh,¹⁴⁷ N. Ruckstuhl,¹⁴⁷ R. Rusack,¹⁴⁷ N. Tambe,¹⁴⁷
 J. Turkewitz,¹⁴⁷ J. G. Acosta,¹⁴⁸ S. Oliveros,¹⁴⁸ E. Avdeeva,¹⁴⁹ R. Bartek,¹⁴⁹ K. Bloom,¹⁴⁹ S. Bose,¹⁴⁹ D. R. Claes,¹⁴⁹
 A. Dominguez,¹⁴⁹ C. Fangmeier,¹⁴⁹ R. Gonzalez Suarez,¹⁴⁹ R. Kamalieddin,¹⁴⁹ D. Knowlton,¹⁴⁹ I. Kravchenko,¹⁴⁹
 F. Meier,¹⁴⁹ J. Monroy,¹⁴⁹ F. Ratnikov,¹⁴⁹ J. E. Siado,¹⁴⁹ G. R. Snow,¹⁴⁹ M. Alyari,¹⁵⁰ J. Dolen,¹⁵⁰ J. George,¹⁵⁰
 A. Godshalk,¹⁵⁰ C. Harrington,¹⁵⁰ I. Iashvili,¹⁵⁰ J. Kaisen,¹⁵⁰ A. Kharchilava,¹⁵⁰ A. Kumar,¹⁵⁰ S. Rappoccio,¹⁵⁰
 B. Roozbahani,¹⁵⁰ G. Alverson,¹⁵¹ E. Barberis,¹⁵¹ D. Baumgartel,¹⁵¹ M. Chasco,¹⁵¹ A. Hortiangtham,¹⁵¹ A. Massironi,¹⁵¹
 D. M. Morse,¹⁵¹ D. Nash,¹⁵¹ T. Orimoto,¹⁵¹ R. Teixeira De Lima,¹⁵¹ D. Trocino,¹⁵¹ R.-J. Wang,¹⁵¹ D. Wood,¹⁵¹ J. Zhang,¹⁵¹
 S. Bhattacharya,¹⁵² K. A. Hahn,¹⁵² A. Kubik,¹⁵² J. F. Low,¹⁵² N. Mucia,¹⁵² N. Odell,¹⁵² B. Pollack,¹⁵² M. Schmitt,¹⁵²
 K. Sung,¹⁵² M. Trovato,¹⁵² M. Velasco,¹⁵² A. Brinkerhoff,¹⁵³ N. Dev,¹⁵³ M. Hildreth,¹⁵³ C. Jessop,¹⁵³ D. J. Karmgard,¹⁵³
 N. Kellams,¹⁵³ K. Lannon,¹⁵³ N. Marinelli,¹⁵³ F. Meng,¹⁵³ C. Mueller,¹⁵³ Y. Musienko,^{153,mm} M. Planer,¹⁵³ A. Reinsvold,¹⁵³
 R. Ruchti,¹⁵³ G. Smith,¹⁵³ S. Taroni,¹⁵³ N. Valls,¹⁵³ M. Wayne,¹⁵³ M. Wolf,¹⁵³ A. Woodard,¹⁵³ L. Antonelli,¹⁵⁴ J. Brinson,¹⁵⁴
 B. Bylsma,¹⁵⁴ L. S. Durkin,¹⁵⁴ S. Flowers,¹⁵⁴ A. Hart,¹⁵⁴ C. Hill,¹⁵⁴ R. Hughes,¹⁵⁴ W. Ji,¹⁵⁴ T. Y. Ling,¹⁵⁴ B. Liu,¹⁵⁴
 W. Luo,¹⁵⁴ D. Puigh,¹⁵⁴ M. Rodenburg,¹⁵⁴ B. L. Winer,¹⁵⁴ H. W. Wulsin,¹⁵⁴ O. Driga,¹⁵⁵ P. Elmer,¹⁵⁵ J. Hardenbrook,¹⁵⁵
 P. Hebda,¹⁵⁵ S. A. Koay,¹⁵⁵ P. Lujan,¹⁵⁵ D. Marlow,¹⁵⁵ T. Medvedeva,¹⁵⁵ M. Mooney,¹⁵⁵ J. Olsen,¹⁵⁵ C. Palmer,¹⁵⁵
 P. Piroué,¹⁵⁵ H. Saka,¹⁵⁵ D. Stickland,¹⁵⁵ C. Tully,¹⁵⁵ A. Zuranski,¹⁵⁵ S. Malik,¹⁵⁶ A. Barker,¹⁵⁷ V. E. Barnes,¹⁵⁷
 D. Benedetti,¹⁵⁷ D. Bortoletto,¹⁵⁷ L. Gutay,¹⁵⁷ M. K. Jha,¹⁵⁷ M. Jones,¹⁵⁷ A. W. Jung,¹⁵⁷ K. Jung,¹⁵⁷ A. Kumar,¹⁵⁷
 D. H. Miller,¹⁵⁷ N. Neumeister,¹⁵⁷ B. C. Radburn-Smith,¹⁵⁷ X. Shi,¹⁵⁷ I. Shipsey,¹⁵⁷ D. Silvers,¹⁵⁷ J. Sun,¹⁵⁷
 A. Svyatkovskiy,¹⁵⁷ F. Wang,¹⁵⁷ W. Xie,¹⁵⁷ L. Xu,¹⁵⁷ N. Parashar,¹⁵⁸ J. Stupak,¹⁵⁸ A. Adair,¹⁵⁹ B. Akgun,¹⁵⁹ Z. Chen,¹⁵⁹
 K. M. Ecklund,¹⁵⁹ F. J. M. Geurts,¹⁵⁹ M. Guilbaud,¹⁵⁹ W. Li,¹⁵⁹ B. Michlin,¹⁵⁹ M. Northup,¹⁵⁹ B. P. Padley,¹⁵⁹ R. Redjimi,¹⁵⁹
 J. Roberts,¹⁵⁹ J. Rorie,¹⁵⁹ Z. Tu,¹⁵⁹ J. Zabel,¹⁵⁹ B. Betchart,¹⁶⁰ A. Bodek,¹⁶⁰ P. de Barbaro,¹⁶⁰ R. Demina,¹⁶⁰ Y. Eshaq,¹⁶⁰
 T. Ferbel,¹⁶⁰ M. Galanti,¹⁶⁰ A. Garcia-Bellido,¹⁶⁰ J. Han,¹⁶⁰ A. Harel,¹⁶⁰ O. Hindrichs,¹⁶⁰ A. Khukhunaishvili,¹⁶⁰
 G. Petrillo,¹⁶⁰ P. Tan,¹⁶⁰ M. Verzetti,¹⁶⁰ J. P. Chou,¹⁶¹ E. Contreras-Campana,¹⁶¹ D. Ferencek,¹⁶¹ Y. Gershtein,¹⁶¹
 E. Halkiadakis,¹⁶¹ D. Hidas,¹⁶¹ E. Hughes,¹⁶¹ S. Kaplan,¹⁶¹ R. Kunnawalkam Elayavalli,¹⁶¹ A. Lath,¹⁶¹ K. Nash,¹⁶¹
 S. Salur,¹⁶¹ S. Schnetzer,¹⁶¹ D. Sheffield,¹⁶¹ S. Somalwar,¹⁶¹ R. Stone,¹⁶¹ S. Thomas,¹⁶¹ P. Thomassen,¹⁶¹ M. Walker,¹⁶¹
 M. Foerster,¹⁶² G. Riley,¹⁶² K. Rose,¹⁶² S. Spanier,¹⁶² O. Bouhali,^{163,sss} A. Castaneda Hernandez,^{163,sss} A. Celik,¹⁶³
 M. Dalchenko,¹⁶³ M. De Mattia,¹⁶³ A. Delgado,¹⁶³ S. Dildick,¹⁶³ R. Eusebi,¹⁶³ J. Gilmore,¹⁶³ T. Huang,¹⁶³ T. Kamon,^{163,tt}
 V. Krutelyov,¹⁶³ R. Mueller,¹⁶³ I. Osipenkova,¹⁶³ Y. Pakhotin,¹⁶³ R. Patel,¹⁶³ A. Perloff,¹⁶³ A. Rose,¹⁶³ A. Safonov,¹⁶³
 A. Tatarinov,¹⁶³ K. A. Ulmer,^{163,c} N. Akchurin,¹⁶⁴ C. Cowden,¹⁶⁴ J. Damgov,¹⁶⁴ C. Dragoiu,¹⁶⁴ P. R. Duderov,¹⁶⁴
 J. Faulkner,¹⁶⁴ S. Kunori,¹⁶⁴ K. Lamichhane,¹⁶⁴ S. W. Lee,¹⁶⁴ T. Libeiro,¹⁶⁴ S. Undleeb,¹⁶⁴ I. Volobouev,¹⁶⁴ E. Appelt,¹⁶⁵
 A. G. Delannoy,¹⁶⁵ S. Greene,¹⁶⁵ A. Gurrola,¹⁶⁵ R. Janjam,¹⁶⁵ W. Johns,¹⁶⁵ C. Maguire,¹⁶⁵ Y. Mao,¹⁶⁵ A. Melo,¹⁶⁵ H. Ni,¹⁶⁵
 P. Sheldon,¹⁶⁵ S. Tuo,¹⁶⁵ J. Velkovska,¹⁶⁵ Q. Xu,¹⁶⁵ M. W. Arenton,¹⁶⁶ B. Cox,¹⁶⁶ B. Francis,¹⁶⁶ J. Goodell,¹⁶⁶ R. Hirosky,¹⁶⁶
 A. Ledovskoy,¹⁶⁶ H. Li,¹⁶⁶ C. Lin,¹⁶⁶ C. Neu,¹⁶⁶ T. Sinthuprasith,¹⁶⁶ X. Sun,¹⁶⁶ Y. Wang,¹⁶⁶ E. Wolfe,¹⁶⁶ J. Wood,¹⁶⁶
 F. Xia,¹⁶⁶ C. Clarke,¹⁶⁷ R. Harr,¹⁶⁷ P. E. Karchin,¹⁶⁷ C. Kottachchi Kankanamge Don,¹⁶⁷ P. Lamichhane,¹⁶⁷ J. Sturdy,¹⁶⁷
 D. A. Belknap,¹⁶⁸ D. Carlsmith,¹⁶⁸ M. Cepeda,¹⁶⁸ S. Dasu,¹⁶⁸ L. Dodd,¹⁶⁸ S. Duric,¹⁶⁸ B. Gomber,¹⁶⁸ M. Grothe,¹⁶⁸
 R. Hall-Wilton,¹⁶⁸ M. Herndon,¹⁶⁸ A. Hervé,¹⁶⁸ P. Klabbers,¹⁶⁸ A. Lanaro,¹⁶⁸ A. Levine,¹⁶⁸ K. Long,¹⁶⁸ R. Loveless,¹⁶⁸
 A. Mohapatra,¹⁶⁸ I. Ojalvo,¹⁶⁸ T. Perry,¹⁶⁸ G. A. Pierro,¹⁶⁸ G. Polese,¹⁶⁸ T. Ruggles,¹⁶⁸ T. Sarangi,¹⁶⁸ A. Savin,¹⁶⁸
 A. Sharma,¹⁶⁸ N. Smith,¹⁶⁸ W. H. Smith,¹⁶⁸ D. Taylor,¹⁶⁸ P. Verwilligen,¹⁶⁸ and N. Woods¹⁶⁸

(CMS Collaboration)

¹Yerevan Physics Institute, Yerevan, Armenia²Institut für Hochenergiephysik der OeAW, Wien, Austria³National Centre for Particle and High Energy Physics, Minsk, Belarus⁴Universiteit Antwerpen, Antwerpen, Belgium⁵Vrije Universiteit Brussel, Brussel, Belgium⁶Université Libre de Bruxelles, Bruxelles, Belgium⁷Ghent University, Ghent, Belgium⁸Université Catholique de Louvain, Louvain-la-Neuve, Belgium

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

- ^{58b}Università di Catania
- ⁵⁹INFN Sezione di Firenze, Università di Firenze, Firenze, Italy
- ^{59a}INFN Sezione di Firenze
- ^{59b}Università di Firenze
- ⁶⁰INFN Laboratori Nazionali di Frascati, Frascati, Italy
- ⁶¹INFN Sezione di Genova, Università di Genova, Genova, Italy
- ^{61a}INFN Sezione di Genova
- ^{61b}Università di Genova
- ⁶²INFN Sezione di Milano-Bicocca, Università di Milano-Bicocca, Milano, Italy
- ^{62a}INFN Sezione di Milano-Bicocca
- ^{62b}Università di Milano-Bicocca
- ⁶³INFN Sezione di Napoli, Università di Napoli 'Federico II', Napoli, Italy,
Università della Basilicata, Potenza, Italy, Università G. Marconi, Roma, Italy
- ^{63a}INFN Sezione di Napoli
- ^{63b}Università di Napoli 'Federico II'
- ^{63c}Università della Basilicata
- ^{63d}Università G. Marconi
- ⁶⁴INFN Sezione di Padova, Università di Padova, Padova, Italy, Università di Trento, Trento, Italy
- ^{64a}INFN Sezione di Padova
- ^{64b}Università di Padova
- ^{64c}Università di Trento
- ⁶⁵INFN Sezione di Pavia, Università di Pavia, Pavia, Italy
- ^{65a}INFN Sezione di Pavia
- ^{65b}Università di Pavia
- ⁶⁶INFN Sezione di Perugia, Università di Perugia, Perugia, Italy
- ^{66a}INFN Sezione di Perugia
- ^{66b}Università di Perugia
- ⁶⁷INFN Sezione di Pisa, Università di Pisa, Scuola Normale Superiore di Pisa, Pisa, Italy
- ^{67a}INFN Sezione di Pisa
- ^{67b}Università di Pisa
- ^{67c}Scuola Normale Superiore di Pisa
- ^{68a}INFN Sezione di Roma
- ^{68b}Università di Roma
- ⁶⁹INFN Sezione di Torino, Università di Torino, Torino, Italy, Università del Piemonte Orientale, Novara, Italy
- ^{69a}INFN Sezione di Torino
- ^{69b}Università di Torino
- ^{69c}Università del Piemonte Orientale
- ⁷⁰INFN Sezione di Trieste, Università di Trieste, Trieste, Italy
- ^{70a}INFN Sezione di Trieste
- ^{70b}Università di Trieste
- ⁷¹Kangwon National University, Chunchon, Korea
- ⁷²Kyungpook National University, Daegu, Korea
- ⁷³Chonbuk National University, Jeonju, Korea
- ⁷⁴Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea
- ⁷⁵Korea University, Seoul, Korea
- ⁷⁶Seoul National University, Seoul, Korea
- ⁷⁷University of Seoul, Seoul, Korea
- ⁷⁸Sungkyunkwan University, Suwon, Korea
- ⁷⁹Vilnius University, Vilnius, Lithuania
- ⁸⁰National Centre for Particle Physics, Universiti Malaya, Kuala Lumpur, Malaysia
- ⁸¹Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico
- ⁸²Universidad Iberoamericana, Mexico City, Mexico
- ⁸³Benemerita Universidad Autonoma de Puebla, Puebla, Mexico
- ⁸⁴Universidad Autónoma de San Luis Potosí, San Luis Potosí, Mexico
- ⁸⁵University of Auckland, Auckland, New Zealand
- ⁸⁶University of Canterbury, Christchurch, New Zealand
- ⁸⁷National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan
- ⁸⁸National Centre for Nuclear Research, Swierk, Poland
- ⁸⁹Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland
- ⁹⁰Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal

- ⁹¹*Joint Institute for Nuclear Research, Dubna, Russia*
- ⁹²*Petersburg Nuclear Physics Institute, Gatchina (St. Petersburg), Russia*
- ⁹³*Institute for Nuclear Research, Moscow, Russia*
- ⁹⁴*Institute for Theoretical and Experimental Physics, Moscow, Russia*
- ⁹⁵*National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia*
- ⁹⁶*P.N. Lebedev Physical Institute, Moscow, Russia*
- ⁹⁷*Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia*
- ⁹⁸*State Research Center of Russian Federation, Institute for High Energy Physics, Protvino, Russia*
- ⁹⁹*University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia*
- ¹⁰⁰*Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain*
- ¹⁰¹*Universidad Autónoma de Madrid, Madrid, Spain*
- ¹⁰²*Universidad de Oviedo, Oviedo, Spain*
- ¹⁰³*Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain*
- ¹⁰⁴*CERN, European Organization for Nuclear Research, Geneva, Switzerland*
- ¹⁰⁵*Paul Scherrer Institut, Villigen, Switzerland*
- ¹⁰⁶*Institute for Particle Physics, ETH Zurich, Zurich, Switzerland*
- ¹⁰⁷*Universität Zürich, Zurich, Switzerland*
- ¹⁰⁸*National Central University, Chung-Li, Taiwan*
- ¹⁰⁹*National Taiwan University (NTU), Taipei, Taiwan*
- ¹¹⁰*Chulalongkorn University, Faculty of Science, Department of Physics, Bangkok, Thailand*
- ¹¹¹*Cukurova University, Adana, Turkey*
- ¹¹²*Middle East Technical University, Physics Department, Ankara, Turkey*
- ¹¹³*Bogazici University, Istanbul, Turkey*
- ¹¹⁴*Istanbul Technical University, Istanbul, Turkey*
- ¹¹⁵*Institute for Scintillation Materials of National Academy of Science of Ukraine, Kharkov, Ukraine*
- ¹¹⁶*National Scientific Center, Kharkov Institute of Physics and Technology, Kharkov, Ukraine*
- ¹¹⁷*University of Bristol, Bristol, United Kingdom*
- ¹¹⁸*Rutherford Appleton Laboratory, Didcot, United Kingdom*
- ¹¹⁹*Imperial College, London, United Kingdom*
- ¹²⁰*Brunel University, Uxbridge, United Kingdom*
- ¹²¹*Baylor University, Waco, Texas, USA*
- ¹²²*The University of Alabama, Tuscaloosa, Alabama, USA*
- ¹²³*Boston University, Boston, Massachusetts, USA*
- ¹²⁴*Brown University, Providence, Rhode Island, USA*
- ¹²⁵*University of California, Davis, Davis, California, USA*
- ¹²⁶*University of California, Los Angeles, Los Angeles, California, USA*
- ¹²⁷*University of California, Riverside, California, USA*
- ¹²⁸*University of California, San Diego, La Jolla, California, USA*
- ¹²⁹*University of California, Santa Barbara Santa Barbara, California, USA*
- ¹³⁰*California Institute of Technology, Pasadena, California, USA*
- ¹³¹*Carnegie Mellon University, Pittsburgh, Pennsylvania, USA*
- ¹³²*University of Colorado Boulder, Boulder, Colorado, USA*
- ¹³³*Cornell University, Ithaca, New York, USA*
- ¹³⁴*Fermi National Accelerator Laboratory, Batavia, Illinois, USA*
- ¹³⁵*University of Florida, Gainesville, Florida, USA*
- ¹³⁶*Florida International University, Miami, Florida, USA*
- ¹³⁷*Florida State University, Tallahassee, Florida, USA*
- ¹³⁸*Florida Institute of Technology, Melbourne, Florida, USA*
- ¹³⁹*University of Illinois at Chicago (UIC), Chicago, Illinois, USA*
- ¹⁴⁰*The University of Iowa, Iowa City, Iowa, USA*
- ¹⁴¹*Johns Hopkins University, Baltimore, Maryland, USA*
- ¹⁴²*The University of Kansas, Lawrence, Kansas, USA*
- ¹⁴³*Kansas State University, Manhattan, Kansas, USA*
- ¹⁴⁴*Lawrence Livermore National Laboratory, Livermore, California, USA*
- ¹⁴⁵*University of Maryland, College Park, Maryland, USA*
- ¹⁴⁶*Massachusetts Institute of Technology, Cambridge, Massachusetts, USA*
- ¹⁴⁷*University of Minnesota, Minneapolis, Minnesota, USA*
- ¹⁴⁸*University of Mississippi, Oxford, Mississippi, USA*
- ¹⁴⁹*University of Nebraska-Lincoln, Lincoln, Nebraska, USA*
- ¹⁵⁰*State University of New York at Buffalo, Buffalo, New York, USA*

- ¹⁵¹*Northeastern University, Boston, Massachusetts, USA*
¹⁵²*Northwestern University, Evanston, Illinois, USA*
¹⁵³*University of Notre Dame, Notre Dame, Indiana, USA*
¹⁵⁴*Ohio State University, Columbus, Ohio, USA*
¹⁵⁵*Princeton University, Princeton, New Jersey, USA*
¹⁵⁶*University of Puerto Rico, Mayaguez, Puerto Rico*
¹⁵⁷*Purdue University, West Lafayette, Indiana, USA*
¹⁵⁸*Purdue University Calumet, Hammond, Indiana, USA*
¹⁵⁹*Rice University, Houston, Texas, USA*
¹⁶⁰*University of Rochester, Rochester, New York, USA*
¹⁶¹*Rutgers, The State University of New Jersey, Piscataway, New Jersey, USA*
¹⁶²*University of Tennessee, Knoxville, Tennessee, USA*
¹⁶³*Texas A&M University, College Station, Texas, USA*
¹⁶⁴*Texas Tech University, Lubbock, Texas, USA*
¹⁶⁵*Vanderbilt University, Nashville, Tennessee, USA*
¹⁶⁶*University of Virginia, Charlottesville, Virginia, USA*
¹⁶⁷*Wayne State University, Detroit, Michigan, USA*
¹⁶⁸*University of Wisconsin—Madison, Madison, Wisconsin, USA*

^aDeceased.

^bAlso at Vienna University of Technology, Vienna, Austria.

^cAlso at CERN, European Organization for Nuclear Research, Geneva, Switzerland.

^dAlso at State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China.

^eAlso at Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France.

^fAlso at National Institute of Chemical Physics and Biophysics, Tallinn, Estonia.

^gAlso at Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia.

^hAlso at Universidade Estadual de Campinas, Campinas, Brazil.

ⁱAlso at Centre National de la Recherche Scientifique (CNRS)—IN2P3, Paris, France.

^jAlso at Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France.

^kAlso at Joint Institute for Nuclear Research, Dubna, Russia.

^lAlso at British University in Egypt, Cairo, Egypt.

^mAlso at Suez University, Suez, Egypt.

ⁿAlso at Cairo University, Cairo, Egypt.

^oAlso at Fayoum University, El-Fayoum, Egypt.

^pAlso at Université de Haute Alsace, Mulhouse, France.

^qAlso at Tbilisi State University, Tbilisi, Georgia.

^rAlso at RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany.

^sAlso at University of Hamburg, Hamburg, Germany.

^tAlso at Brandenburg University of Technology, Cottbus, Germany.

^uAlso at Institute of Nuclear Research ATOMKI, Debrecen, Hungary.

^vAlso at Eötvös Loránd University, Budapest, Hungary.

^wAlso at University of Debrecen, Debrecen, Hungary.

^xAlso at Wigner Research Centre for Physics, Budapest, Hungary.

^yAlso at Indian Institute of Science Education and Research, Bhopal, India.

^zAlso at University of Visva-Bharati, Santiniketan, India.

^{aa}Also at King Abdulaziz University, Jeddah, Saudi Arabia.

^{bb}Also at University of Ruhuna, Matara, Sri Lanka.

^{cc}Also at Isfahan University of Technology, Isfahan, Iran.

^{dd}Also at University of Tehran, Department of Engineering Science, Tehran, Iran.

^{ee}Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran.

^{ff}Also at Laboratori Nazionali di Legnaro dell'INFN, Legnaro, Italy.

^{gg}Also at Università degli Studi di Siena, Siena, Italy.

^{hh}Also at Purdue University, West Lafayette, USA.

ⁱⁱAlso at International Islamic University of Malaysia, Kuala Lumpur, Malaysia.

^{jj}Also at Malaysian Nuclear Agency, MOSTI, Kajang, Malaysia.

^{kk}Also at Consejo Nacional de Ciencia y Tecnología, Mexico city, Mexico.

^{ll}Also at Warsaw University of Technology, Institute of Electronic Systems, Warsaw, Poland.

^{mmm}Also at Institute for Nuclear Research, Moscow, Russia.

ⁿⁿAlso at National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia.

- ^{oo} Also at St. Petersburg State Polytechnical University, St. Petersburg, Russia.
- ^{pp} Also at California Institute of Technology, Pasadena, USA.
- ^{qq} Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia.
- ^{rr} Also at INFN Sezione di Roma, Università di Roma, Roma, Italy.
- ^{ss} Also at National Technical University of Athens, Athens, Greece.
- ^{tt} Also at Scuola Normale e Sezione dell'INFN, Pisa, Italy.
- ^{uu} Also at National and Kapodistrian University of Athens, Athens, Greece.
- ^{vv} Also at Institute for Theoretical and Experimental Physics, Moscow, Russia.
- ^{ww} Also at Albert Einstein Center for Fundamental Physics, Bern, Switzerland.
- ^{xx} Also at Gaziosmanpasa University, Tokat, Turkey.
- ^{yy} Also at Mersin University, Mersin, Turkey.
- ^{zz} Also at Cag University, Mersin, Turkey.
- ^{aaa} Also at Piri Reis University, Istanbul, Turkey.
- ^{bbb} Also at Adiyaman University, Adiyaman, Turkey.
- ^{ccc} Also at Ozyegin University, Istanbul, Turkey.
- ^{ddd} Also at Izmir Institute of Technology, Izmir, Turkey.
- ^{eee} Also at Marmara University, Istanbul, Turkey.
- ^{fff} Also at Kafkas University, Kars, Turkey.
- ^{ggg} Also at Istanbul Bilgi University, Istanbul, Turkey.
- ^{hhh} Also at Yildiz Technical University, Istanbul, Turkey.
- ⁱⁱⁱ Also at Hacettepe University, Ankara, Turkey.
- ^{jjj} Also at Rutherford Appleton Laboratory, Didcot, United Kingdom.
- ^{kkk} Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom.
- ^{lll} Also at Instituto de Astrofísica de Canarias, La Laguna, Spain.
- ^{mmm} Also at Utah Valley University, Orem, USA.
- ⁿⁿⁿ Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia.
- ^{ooo} Also at Facoltà Ingegneria, Università di Roma, Roma, Italy.
- ^{ppp} Also at Argonne National Laboratory, Argonne, USA.
- ^{qqq} Also at Erzincan University, Erzincan, Turkey.
- ^{rrr} Also at Mimar Sinan University, Istanbul, Istanbul, Turkey.
- ^{sss} Also at Texas A&M University at Qatar, Doha, Qatar.
- ^{ttt} Also at Kyungpook National University, Daegu, Korea.