χ_{c1} and χ_{c2} Resonance Parameters with the Decays $\chi_{c1,c2} \to J/\psi\mu^+\mu^-$

R. Aaij *et al.*[*]
(LHCb Collaboration)

(Received 13 September 2017; revised manuscript received 12 October 2017; published 28 November 2017)

The decays $\chi_{c1} \to J/\psi\mu^+\mu^-$ and $\chi_{c2} \to J/\psi\mu^+\mu^-$ are observed and used to study the resonance parameters of the χ_{c1} and χ_{c2} mesons. The masses of these states are measured to be $m(\chi_{c1}) = 3510.71 \pm 0.04(\mathrm{stat}) \pm 0.09(\mathrm{syst})$ MeV and $m(\chi_{c2}) = 3556.10 \pm 0.06(\mathrm{stat}) \pm 0.11(\mathrm{syst})$ MeV, where the knowledge of the momentum scale for charged particles dominates the systematic uncertainty. The momentum-scale uncertainties largely cancel in the mass difference $m(\chi_{c2}) - m(\chi_{c1}) = 45.39 \pm 0.07(\mathrm{stat}) \pm 0.03(\mathrm{syst})$ MeV. The natural width of the χ_{c2} meson is measured to be $\Gamma(\chi_{c2}) = 2.10 \pm 0.20(\mathrm{stat}) \pm 0.02(\mathrm{syst})$ MeV. These results are in good agreement with and have comparable precision to the current world averages.

DOI: 10.1103/PhysRevLett.119.221801

Studies of the properties and production of quarkonia at hadron colliders provide an important testing ground for quantum chromodynamics [1]. Measurements of the spectra test potential models [2], while the production rate can be calculated perturbatively in nonrelativistic effective field theories such as nonrelativistic QCD [3]. Most studies of χ_{c1} and χ_{c2} mesons at hadron colliders have exploited the radiative decays $\chi_{c1,c2} \to J/\psi\gamma$ with the subsequent decay $J/\psi \to \mu^+\mu^-$ [4–8]. The branching fractions for these processes are large, allowing a signal to be observed despite a high background.

Recently, the BESIII Collaboration [9] reported the first observation of the electromagnetic Dalitz decays [10] of χ_{c0}, χ_{c1} and χ_{c2} mesons into the $J/\psi e^+e^-$ final state. This Letter reports the first observation of the $\chi_{c1} \to J/\psi\mu^+\mu^-$ and $\chi_{c2} \to J/\psi\mu^+\mu^-$ decay modes, using $J/\psi \to \mu^+\mu^-$ decays. These decays are used to measure the χ_{c1} and χ_{c2} masses together with the χ_{c2} natural width. The event topology with four muons in the final state provides a clean signature that is ideal for studies in hadron collisions.

This analysis uses the LHCb data set collected in pp collisions up to the end of 2016. The data collected at center of mass energies of 7 and 8 TeV correspond to integrated luminosities of 1 and 2 fb^{-1} and are collectively referred to as run 1, while data collected at a center of mass energy of 13 TeV correspond to 1.9 fb^{-1} and are referred to as run 2.

The LHCb detector is a single-arm spectrometer covering the pseudorapidity range $2 < \eta < 5$, described in detail in Refs. [11,12]. The detector includes a high-precision tracking system consisting of a silicon-strip vertex detector [13], a large-area silicon-strip detector located upstream of a dipole magnet with a bending power of about 4 Tm, and three stations of silicon-strip detectors and straw drift tubes [14] placed downstream of the magnet. The tracking system measures the momentum of charged particles with a relative uncertainty that varies from 0.5% at low momentum to 1.0% at 200 GeV (natural units with $c = \hbar = 1$ are used throughout this Letter). The momentum scale is calibrated using samples of $J/\psi \to \mu^+\mu^-$ and $B^+ \to J/\psi K^+$ decays collected concurrently with the data sample used for this analysis [15–17]. The use of the large J/ψ data sample allows us to correct for variations of the momentum scale at the level of 10^{-4} or less that occur over time, while the use of the $B^+ \to J/\psi K^+$ decay allows the momentum scale to be determined as a function of the K^+ kinematics. The procedure is validated using samples of $K^0_S \to \pi^+\pi^-$, $\psi(2S) \to J/\psi\pi^+\pi^-$, $\psi(2S) \to \mu^+\mu^-$, and other fully reconstructed b-hadron and $\Upsilon(nS)$, $n = 1$, 2, 3, decays. Based upon these studies, the accuracy of the procedure is evaluated to be 3×10^{-4}. Muons are identified by a system composed of alternating layers of iron and multiwire proportional chambers [18]. The online event selection is performed by a trigger [19], which consists of a hardware stage, based on information from the calorimeter and muon systems, followed by a software stage, which applies a full event reconstruction. The events used in this analysis are selected by a hardware trigger that requires one or two muons with transverse momentum p_T, larger than 1.5 GeV. At the software trigger stage, a pair of oppositely charged muons with an invariant mass consistent with the known J/ψ mass [20] is required. In run 1, the full event information for selected events was stored. To keep the rate within the available bandwidth, it was necessary to require $p_T(J/\psi) > 3$ GeV. For run 2, a new data-taking scheme was introduced [21] allowing real-time alignment to be performed in the trigger [22] that, together with an increase in the online computing resources, made possible the full

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

track reconstruction in the online system [23,24]. Consequently, lower-level information could be discarded, reducing the event size and allowing all events selected at the hardware stage that contain a J/ψ candidate to be stored without any p_T requirement.

Offline, J/ψ candidates are combined with a pair of oppositely charged muons to form $\chi_{c1,c2} \to J/\psi\mu^+\mu^-$ candidates. Several criteria are applied to reduce the background and maximize the sensitivity for the mass measurement. Selected muon candidates are required to be within the range $2 < \eta < 4.9$. Misreconstructed tracks are suppressed by the use of a neural network trained to discriminate between these and real particles. Muon candidates are selected with a neural network trained using simulated samples to discriminate muons from hadrons and electrons. Finally, to improve the mass resolution, a kinematic fit is performed [25]. In this fit, the mass of the J/ψ candidate is constrained to the known mass of the J/ψ meson [20], and the position of the $\chi_{c1,c2}$ candidate decay vertex is constrained to be the same as that of the primary vertex. The χ^2 per degree of freedom of this fit is required to be less than four, which substantially reduces the background while retaining almost all the signal events.

In the simulation, pp collisions are generated using Pythia [26] with a specific LHCb configuration [27]. For this study, signal decays are generated using EvtGen [28] with decay amplitudes that depend on the invariant dimuon mass $m(\mu^+\mu^-)$, using the model described in Ref. [29]. This model assumes that the decay proceeds via the emission of a virtual photon from a pointlike meson and is known to provide a good description of the corresponding dielectron mode [9]. Final-state radiation is accounted for using Photos [30]. The interaction of the generated particles with the detector and its response are implemented using the Geant4 toolkit [31] as described in Ref. [32].

The signal yields and parameters of the $\chi_{c1,c2}$ resonances are determined with an extended unbinned maximum likelihood fit performed to the $J/\psi\mu^+\mu^-$ invariant mass distribution. In this fit, the χ_{c1} and χ_{c2} signals are modeled by relativistic Breit-Wigner functions with Blatt-Weisskopf form factors [33] with a meson radius parameter of 3 GeV^{-1}. Jackson form factors [34] are considered as an alternative to estimate the uncertainty associated with this choice. The orbital angular momentum between the J/ψ meson and the $\mu^+\mu^-$ pair is assumed to be 0 (1) for the χ_{c1} (χ_{c2}) cases.

The relativistic Breit-Wigner functions are convolved with the detector resolution. Three resolution models are found to describe the simulated data well: a double-Gaussian function, a double-sided Crystal Ball function [35,36], and a symmetric variant of the Apollonios function [37]. The double-Gaussian function is used by the default model, and the other functions are considered to estimate the systematic uncertainty. The parameters of the resolution model are determined by a simultaneous fit to the χ_{c1} and χ_{c2} simulated samples. All the parameters apart from the core resolution parameter σ are common between the two decay modes. For all the models in the simulation, it is found that $\alpha \equiv \sigma^{\chi_{c2}}/\sigma^{\chi_{c1}} = 1.13 \pm 0.01$. This is close to the value expected, $\alpha = 1.11$, from the assumption that the resolution scales with the square root of the energy release.

The combinatorial background is modeled by a second-order polynomial function. The total fit function consists of the sum of the background and the χ_{c1} and χ_{c2} signals. The free parameters are the yields of the two signal components, the yield of the background component, the two background shape parameters, the χ_{c1} and χ_{c2} masses, $\sigma^{\chi_{c1}}$, and the natural width of the χ_{c2} resonance, $\Gamma(\chi_{c2})$. The other resolution parameters are fixed to the simulation values. Since the natural width of the χ_{c1} state $\Gamma(\chi_{c1}) = 0.84 \pm 0.04$ MeV [20] is less than the detector resolution ($\sigma^{\chi_{c1}} = 1.41 \pm 0.01$ MeV), this study has limited sensitivity to its value. By applying Gaussian constraints on the natural width of the χ_{c1} state (to the value from Ref. [20]) and α (to the value found in the simulation), the χ_{c2} width is determined in a data-driven way using the observed resolution for the χ_{c1} state.

The fit of this model to the full data sample is shown in Fig. 1, and the resulting parameters of interest are summarized in Table I. The fitted value of $\sigma^{\chi_{c1}}$ is 1.51 ± 0.04 MeV, which agrees at the level of 5% with the value found in the simulation. Figure 2 shows the $m(\mu^+\mu^-)$ mass distribution for selected candidates where the background has been subtracted using the *sPlot* technique [38]. The data agree well with the model described in Ref. [29].

The dominant source of systematic uncertainty on the mass measurements comes from the knowledge of the

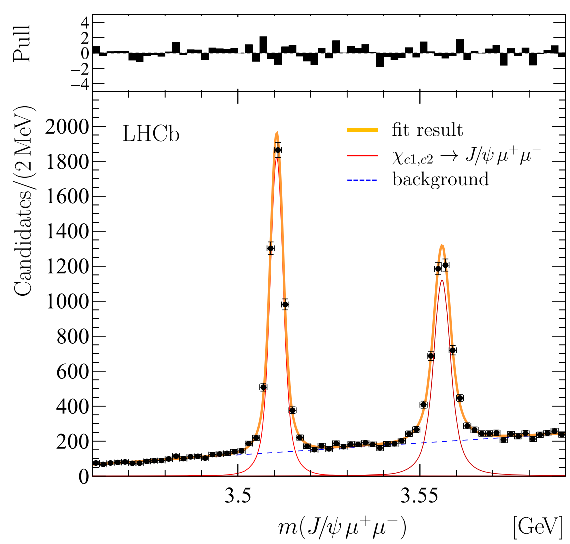

FIG. 1. Mass distribution for selected $J/\psi\mu^+\mu^-$ candidates. The fit is shown in thick orange, the χ_{c1} and χ_{c2} signal components by the thin red solid curve, and the background component by the dashed blue curve.

TABLE I. Signal yields and resonance parameters from the nominal fit. No correction for final-state radiation is applied to the mass measurements at this stage.

Fit parameter	Fitted value
$N(\chi_{c1})$	4755 ± 81
$N(\chi_{c2})$	3969 ± 96
$m(\chi_{c1})$ [MeV]	3510.66 ± 0.04
$m(\chi_{c2})$ [MeV]	3556.07 ± 0.06
$\Gamma(\chi_{c2})$ [MeV]	2.10 ± 0.20

momentum scale. This is evaluated by adjusting the momentum scale by the 3×10^{-4} uncertainty on the calibration procedure and rerunning the mass fit. Uncertainties of 88 and 102 keV are assigned to the χ_{c1} and χ_{c2} mass measurements, respectively. A further uncertainty arises from the knowledge of the correction for energy loss in the spectrometer, which is known with 10% accuracy [12]. Based on the studies in Ref. [17], a 20 keV uncertainty is assigned.

The distortion of the line shape due to final-state radiation introduces a bias on the mass. This bias is evaluated using the simulation to be 47 ± 7 keV (29 ± 10 keV) for the χ_{c1} (χ_{c2}) where the uncertainty is statistical. The central values of the mass measurements are corrected accordingly, and the uncertainties are propagated.

Other uncertainties arise from the fit modeling and are studied using a simplified simulation. Several variations of the relativistic Breit-Wigner distribution are considered. Using Jackson form factors, modifying the meson radius parameter, and varying the orbital angular momentum, the observed χ_{c1} (χ_{c2}) mass changes by at most 15 (24) keV, which is assigned as a systematic uncertainty. Similarly, fitting with a double-sided Crystal Ball or Apollonios

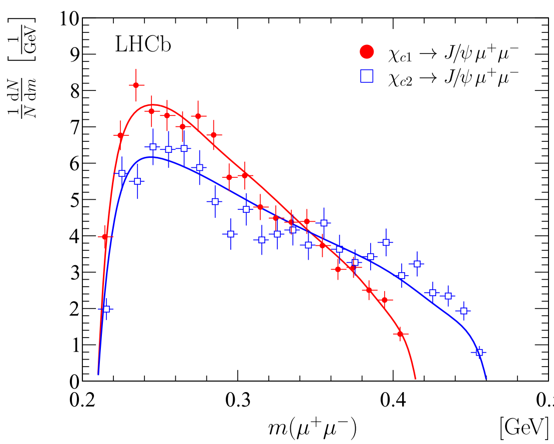

FIG. 2. Background-subtracted $m(\mu^+\mu^-)$ distribution for $\chi_{c1} \to J/\psi\ \mu^+\mu^-$ (solid red circles) and $\chi_{c2} \to J/\psi\ \mu^+\mu^-$ (open blue squares) decays. The distributions are normalized to the unit area. The curves show the expected distribution from the simulation, which uses the model described in Ref. [29].

model, variations of 7 and 2 keV are seen for the χ_{c1} and χ_{c2} masses, respectively, and assigned as systematic uncertainties. Finally, varying the order of the polynomial background function results in a further uncertainty of 2 keV. The uncertainties due to the momentum scale and energy loss correction largely cancel in the mass difference. The assigned systematic uncertainties on the mass measurements are summarized in Table II.

The main uncertainty on the determination of the natural width of the χ_{c2} is due to the knowledge of the detector resolution. This is accounted for in the statistical uncertainty, since the resolution scale is determined using the χ_{c1} signal in the data. Similarly, the uncertainty on the knowledge of the χ_{c1} width is propagated via the Gaussian constraint in the mass fit. By running fits with and without the constraint, the latter is evaluated to be 40 keV. Further uncertainties of 10 and 20 keV arise from the assumed Breit-Wigner parameters and resolution model, respectively. Other systematic uncertainties, e.g., due to the background model, are negligible. The stability of the results is studied by dividing the data into different running periods and also into kinematic bins and repeating the fit. None of these tests shows evidence of a systematic bias.

In summary, the decays $\chi_{c1} \to J/\psi\mu^+\mu^-$ and $\chi_{c2} \to J/\psi\mu^+\mu^-$ are observed and the mass of the χ_{c1} meson together with the mass and natural width of the χ_{c2} are measured. The results for the mass measurements are

$$m(\chi_{c1}) = 3510.71 \pm 0.04 \pm 0.09\ \text{MeV},$$
$$m(\chi_{c2}) = 3556.10 \pm 0.06 \pm 0.11\ \text{MeV},$$
$$m(\chi_{c2}) - m(\chi_{c1}) = 45.39 \pm 0.07 \pm 0.03\ \text{MeV},$$

where the first uncertainty is statistical and the second is systematic. The dominant systematic uncertainty is due to the knowledge of the momentum scale and largely cancels in the mass difference. It can be seen in Table III that the measurements are in good agreement with and have comparable precision to the best previous ones, made using $p\bar{p}$ annihilation at the threshold by the E760 [39] and E835 experiments [40] at Fermilab. They are considerably more precise than the best measurement based on the

TABLE II. Systematic uncertainties (in keV) on the mass and mass difference measurements.

Source of uncertainty	$m(\chi_{c1})$	$m(\chi_{c2})$	$m(\chi_{c2}) - m(\chi_{c1})$
Momentum scale	88	102	18
Energy loss correction	20	20	…
Final-state radiation	7	10	12
Resonance shape	15	24	25
Background model	<2	<2	<2
Resolution model	7	2	6
Sum in quadrature	92	107	34

TABLE III. LHCb measurements, compared to both previous measurements from Ref. [39] and the current world averages from Ref. [20]. The quoted uncertainties includes statistical and systematic uncertainties.

Quantity [MeV]	LHCb measurement	Best previous measurement	World average
$m(\chi_{c1})$	3510.71 ± 0.10	3510.72 ± 0.05	3510.66 ± 0.07
$m(\chi_{c2})$	3556.10 ± 0.13	3556.16 ± 0.12	3556.20 ± 0.09
$\Gamma(\chi_{c2})$	2.10 ± 0.20	1.92 ± 0.19	1.93 ± 0.11

final-state reconstruction [41]. It should be noted that the world average for the χ_{c1} mass has a scale factor of 1.5 to account for the poor agreement between the results [20]. The result for the χ_{c2} natural width is

$$\Gamma(\chi_{c2}) = 2.10 \pm 0.20(\text{stat}) \pm 0.02(\text{syst})\ \text{MeV}.$$

It has similar precision to and is in good agreement with previous measurements [20].

The observations presented here open up a new avenue for hadron spectroscopy at the LHC. These decay modes can be used to measure the production of χ_{c1} and χ_{c2} states with a similar precision to the converted photon study presented in Ref. [6]. Importantly, it will be possible to extend measurements down to very low $p_T(\chi_{c1,c2})$ probing further QCD predictions [42–44]. In addition, measurements of the transition form factors [45] will provide input on the interaction between charmonium states and the electromagnetic field. With larger data samples, studies of the Dalitz decays of other heavy-flavor states will become possible. For example, the measurement of the transition form factor of the $X(3872)$ via its Dalitz decay may help elucidate the nature of this enigmatic state [9].

We thank Jielei Zhang for useful discussions concerning Dalitz decays. We express our gratitude to our colleagues in the CERN accelerator departments for the excellent performance of the LHC. We thank the technical and administrative staff at the LHCb institutes. We acknowledge support from CERN and from the national agencies: CAPES, CNPq, FAPERJ, and FINEP (Brazil); MOST and NSFC (China); CNRS/IN2P3 (France); BMBF, DFG, and MPG (Germany); INFN (Italy); NWO (Netherlands); MNiSW and NCN (Poland); MEN/IFA (Romania); MinES and FASO (Russia); MinECo (Spain); SNSF and SER (Switzerland); NASU (Ukraine); STFC (United Kingdom); NSF (USA). We acknowledge the computing resources that are provided by CERN, IN2P3 (France), KIT and DESY (Germany), INFN (Italy), SURF (Netherlands), PIC (Spain), GridPP (United Kingdom), RRCKI and Yandex LLC (Russia), CSCS (Switzerland), IFIN-HH (Romania), CBPF (Brazil), PL-GRID (Poland) and OSC (USA). We are indebted to the communities behind the multiple open-source software packages on which we depend. Individual groups or members have received support from AvH Foundation (Germany), EPLANET, Marie Skłodowska-Curie Actions and ERC (European Union), ANR, Labex P2IO, ENIGMASS, and OCEVU, and Région Auvergne-Rhône-Alpes (France), RFBR and Yandex LLC (Russia), GVA, XuntaGal, and GENCAT (Spain), Herchel Smith Fund, the Royal Society, the English-Speaking Union, and the Leverhulme Trust (United Kingdom).

[1] N. Brambilla *et al.*, Eur. Phys. J. C **71**, 1534 (2011).
[2] E. Eichten, K. Gottfried, T. Kinoshita, K. D. Lane, and T.-M. Yan, Phys. Rev. D **17**, 3090 (1978).
[3] N. Brambilla, A. Pineda, J. Soto, and A. Vairo, Rev. Mod. Phys. **77**, 1423 (2005).
[4] A. Abulencia *et al.* (CDF Collaboration), Phys. Rev. Lett. **98**, 232001 (2007).
[5] R. Aaij *et al.* (LHCb Collaboration), Phys. Lett. B **714**, 215 (2012).
[6] R. Aaij *et al.* (LHCb Collaboration), J. High Energy Phys. 10 (2013) 115.
[7] S. Chatrchyan *et al.* (CMS Collaboration), Eur. Phys. J. C **72**, 2251 (2012).
[8] G. Aad *et al.* (ATLAS Collaboration), J. High Energy Phys. 07 (2014) 154.
[9] M. Ablikim *et al.* (BESIII Collaboration), Phys. Rev. Lett. **118**, 221802 (2017).
[10] R. H. Dalitz, Proc. Phys. Soc. London Sect. A **64**, 667 (1951).
[11] A. A. Alves, Jr. *et al.* (LHCb Collaboration), J. Instrum. **3**, S08005 (2008).
[12] R. Aaij *et al.* (LHCb Collaboration), Int. J. Mod. Phys. A **30**, 1530022 (2015).
[13] R. Aaij *et al.*, J. Instrum. **9**, P09007 (2014).
[14] R. Arink *et al.*, J. Instrum. **9**, P01002 (2014).
[15] R. Aaij *et al.* (LHCb Collaboration), Phys. Lett. B **708**, 241 (2012).
[16] R. Aaij *et al.* (LHCb Collaboration), Phys. Rev. Lett. **110**, 182001 (2013).
[17] R. Aaij *et al.* (LHCb Collaboration), J. High Energy Phys. 06 (2013) 065.
[18] A. A. Alves, Jr. *et al.*, J. Instrum. **8**, P02022 (2013).
[19] R. Aaij *et al.*, J. Instrum. **8**, P04022 (2013).
[20] C. Patrignani *et al.* (Particle Data Group), Chin. Phys. C **40**, 100001 (2016), and 2017 update.
[21] B. Sciascia, *Proc. Sci.*, BEAUTY2016 (2016) 029.
[22] G. Dujany and B. Storaci, J. Phys. Conf. Ser. **664**, 082010 (2015).
[23] R. Aaij *et al.*, Comput. Phys. Commun. **208**, 35 (2016).
[24] A. Dziurda, EPJ Web Conf. **127**, 00007 (2016).
[25] W. D. Hulsbergen, Nucl. Instrum. Methods Phys. Res., Sect. A **552**, 566 (2005).
[26] T. Sjöstrand, S. Mrenna, and P. Skands, Comput. Phys. Commun. **178**, 852 (2008).
[27] I. Belyaev *et al.*, J. Phys. Conf. Ser. **331**, 032047 (2011).
[28] D. J. Lange, Nucl. Instrum. Methods Phys. Res., Sect. A **462**, 152 (2001).

[29] A. Faessler, C. Fuchs, and M. I. Krivoruchenko, Phys. Rev. C **61**, 035206 (2000).
[30] P. Golonka and Z. Was, Eur. Phys. J. C **45**, 97 (2006).
[31] J. Allison *et al.* (Geant4 Collaboration), IEEE Trans. Nucl. Sci. **53**, 270 (2006); S. Agostinelli *et al.* (Geant4 Collaboration), Nucl. Instrum. Methods Phys. Res., Sect. A **506**, 250 (2003).
[32] M. Clemencic, G. Corti, S. Easo, C. R. Jones, S. Miglioranzi, M. Pappagallo, and P. Robbe, J. Phys. Conf. Ser. **331**, 032023 (2011).
[33] J. M. Blatt and V. F. Weisskopf, *Theoretical Nuclear Physics* (Springer, New York, 1952).
[34] J. D. Jackson, Nuovo Cimento **34**, 1644 (1964).
[35] T. Skwarnicki, Ph.D. thesis, Institute of Nuclear Physics, Krakow, 1986, Report No. DESY-F31-86-02.
[36] R. Aaij *et al.* (LHCb Collaboration), Phys. Lett. B **707**, 52 (2012).
[37] D. Martínez Santos and F. Dupertuis, Nucl. Instrum. Methods Phys. Res., Sect. A **764**, 150 (2014).
[38] M. Pivk and F. R. Le Diberder, Nucl. Instrum. Methods Phys. Res., Sect. A **555**, 356 (2005).
[39] T. A. Armstrong *et al.* (E760 Collaboration), Nucl. Phys. **B373**, 35 (1992).
[40] M. Andreotti *et al.* (E865 Collaboration), Nucl. Phys. **B717**, 34 (2005).
[41] M. Ablikim *et al.* (BES Collaboration), Phys. Rev. D **71**, 092002 (2005).
[42] Y.-Q. Ma, K. Wang, and K.-T. Chao, Phys. Rev. D **83**, 111503 (2011).
[43] A. K. Likhoded, A. V. Luchinsky, and S. V. Poslavsky, Yad. Fiz. **78**, 1119 (2015) [Phys. At. Nucl. **78**, 1056 (2015)].
[44] D. Boer and C. Pisano, Phys. Rev. D **86**, 094007 (2012).
[45] L. G. Landsberg, Phys. Rep. **128**, 301 (1985).

R. Aaij,[40] B. Adeva,[39] M. Adinolfi,[48] Z. Ajaltouni,[5] S. Akar,[59] J. Albrecht,[10] F. Alessio,[40] M. Alexander,[53] A. Alfonso Albero,[38] S. Ali,[43] G. Alkhazov,[31] P. Alvarez Cartelle,[55] A. A. Alves Jr.,[59] S. Amato,[2] S. Amerio,[23] Y. Amhis,[7] L. An,[3] L. Anderlini,[18] G. Andreassi,[41] M. Andreotti,[17,a] J. E. Andrews,[60] R. B. Appleby,[56] F. Archilli,[43] P. d'Argent,[12] J. Arnau Romeu,[6] A. Artamonov,[37] M. Artuso,[61] E. Aslanides,[6] M. Atzeni,[42] G. Auriemma,[26] M. Baalouch,[5] I. Babuschkin,[56] S. Bachmann,[12] J. J. Back,[50] A. Badalov,[38,b] C. Baesso,[62] S. Baker,[55] V. Balagura,[7,c] W. Baldini,[17] A. Baranov,[35] R. J. Barlow,[56] C. Barschel,[40] S. Barsuk,[7] W. Barter,[56] F. Baryshnikov,[32] V. Batozskaya,[29] V. Battista,[41] A. Bay,[41] L. Beaucourt,[4] J. Beddow,[53] F. Bedeschi,[24] I. Bediaga,[1] A. Beiter,[61] L. J. Bel,[43] N. Beliy,[63] V. Bellee,[41] N. Belloli,[21,d] K. Belous,[37] I. Belyaev,[32,40] E. Ben-Haim,[8] G. Bencivenni,[19] S. Benson,[43] S. Beranek,[9] A. Berezhnoy,[33] R. Bernet,[42] D. Berninghoff,[12] E. Bertholet,[8] A. Bertolin,[23] C. Betancourt,[42] F. Betti,[15] M.-O. Bettler,[40] M. van Beuzekom,[43] Ia. Bezshyiko,[42] S. Bifani,[47] P. Billoir,[8] A. Birnkraut,[10] A. Bizzeti,[18,e] M. Bjørn,[57] T. Blake,[50] F. Blanc,[41] S. Blusk,[61] V. Bocci,[26] T. Boettcher,[58] A. Bondar,[36,f] N. Bondar,[31] I. Bordyuzhin,[32] S. Borghi,[56] M. Borisyak,[35] M. Borsato,[39] F. Bossu,[7] M. Boubdir,[9] T. J. V. Bowcock,[54] E. Bowen,[42] C. Bozzi,[17,40] S. Braun,[12] T. Britton,[61] J. Brodzicka,[27] D. Brundu,[16] E. Buchanan,[48] C. Burr,[56] A. Bursche,[16,g] J. Buytaert,[40] W. Byczynski,[40] S. Cadeddu,[16] H. Cai,[64] R. Calabrese,[17,a] R. Calladine,[47] M. Calvi,[21,d] M. Calvo Gomez,[38,b] A. Camboni,[38,b] P. Campana,[19] D. H. Campora Perez,[40] L. Capriotti,[56] A. Carbone,[15,h] G. Carboni,[25,i] R. Cardinale,[20,j] A. Cardini,[16] P. Carniti,[21,d] L. Carson,[52] K. Carvalho Akiba,[2] G. Casse,[54] L. Cassina,[21] M. Cattaneo,[40] G. Cavallero,[20,40,j] R. Cenci,[24,k] D. Chamont,[7] M. G. Chapman,[48] M. Charles,[8] Ph. Charpentier,[40] G. Chatzikonstantinidis,[47] M. Chefdeville,[4] S. Chen,[16] S. F. Cheung,[57] S.-G. Chitic,[40] V. Chobanova,[39,40] M. Chrzaszcz,[42,27] A. Chubykin,[31] P. Ciambrone,[19] X. Cid Vidal,[39] G. Ciezarek,[43] P. E. L. Clarke,[52] M. Clemencic,[40] H. V. Cliff,[49] J. Closier,[40] J. Cogan,[6] E. Cogneras,[5] V. Cogoni,[16,g] L. Cojocariu,[30] P. Collins,[40] T. Colombo,[40] A. Comerma-Montells,[12] A. Contu,[40] A. Cook,[48] G. Coombs,[40] S. Coquereau,[38] G. Corti,[40] M. Corvo,[17,a] C. M. Costa Sobral,[50] B. Couturier,[40] G. A. Cowan,[52] D. C. Craik,[58] A. Crocombe,[50] M. Cruz Torres,[1] R. Currie,[52] C. D'Ambrosio,[40] F. Da Cunha Marinho,[2] E. Dall'Occo,[43] J. Dalseno,[48] A. Davis,[3] O. De Aguiar Francisco,[40] S. De Capua,[56] M. De Cian,[12] J. M. De Miranda,[1] L. De Paula,[2] M. De Serio,[14,l] P. De Simone,[19] C. T. Dean,[53] D. Decamp,[4] L. Del Buono,[8] H.-P. Dembinski,[11] M. Demmer,[10] A. Dendek,[28] D. Derkach,[35] O. Deschamps,[5] F. Dettori,[54] B. Dey,[65] A. Di Canto,[40] P. Di Nezza,[19] H. Dijkstra,[40] F. Dordei,[40] M. Dorigo,[40] A. Dosil Suárez,[39] L. Douglas,[53] A. Dovbnya,[45] K. Dreimanis,[54] L. Dufour,[43] G. Dujany,[8] P. Durante,[40] R. Dzhelyadin,[37] M. Dziewiecki,[12] A. Dziurda,[40] A. Dzyuba,[31] S. Easo,[51] M. Ebert,[52] U. Egede,[55] V. Egorychev,[32] S. Eidelman,[36,f] S. Eisenhardt,[52] U. Eitschberger,[10] R. Ekelhof,[10] L. Eklund,[53] S. Ely,[61] S. Esen,[12] H. M. Evans,[49] T. Evans,[57] A. Falabella,[15] N. Farley,[47] S. Farry,[54] D. Fazzini,[21,d] L. Federici,[25] D. Ferguson,[52] G. Fernandez,[38] P. Fernandez Declara,[40] A. Fernandez Prieto,[39] F. Ferrari,[15] F. Ferreira Rodrigues,[2] M. Ferro-Luzzi,[40] S. Filippov,[34] R. A. Fini,[14] M. Fiorini,[17,a] M. Firlej,[28] C. Fitzpatrick,[41] T. Fiutowski,[28] F. Fleuret,[7,c] K. Fohl,[40] M. Fontana,[16,40] F. Fontanelli,[20,j] D. C. Forshaw,[61] R. Forty,[40] V. Franco Lima,[54] M. Frank,[40] C. Frei,[40] J. Fu,[22,m] W. Funk,[40] E. Furfaro,[25,i] C. Färber,[40] E. Gabriel,[52] A. Gallas Torreira,[39] D. Galli,[15,h]

S. Gallorini,[23] S. Gambetta,[52] M. Gandelman,[2] P. Gandini,[22] Y. Gao,[3] L. M. Garcia Martin,[70] J. García Pardiñas,[39] J. Garra Tico,[49] L. Garrido,[38] P. J. Garsed,[49] D. Gascon,[38] C. Gaspar,[40] L. Gavardi,[10] G. Gazzoni,[5] D. Gerick,[12] E. Gersabeck,[56] M. Gersabeck,[56] T. Gershon,[50] Ph. Ghez,[4] S. Gianì,[41] V. Gibson,[49] O. G. Girard,[41] L. Giubega,[30] K. Gizdov,[52] V. V. Gligorov,[8] D. Golubkov,[32] A. Golutvin,[55] A. Gomes,[1,n] I. V. Gorelov,[33] C. Gotti,[21,d] E. Govorkova,[43] J. P. Grabowski,[12] R. Graciani Diaz,[38] L. A. Granado Cardoso,[40] E. Graugés,[38] E. Graverini,[42] G. Graziani,[18] A. Grecu,[30] R. Greim,[9] P. Griffith,[16] L. Grillo,[21] L. Gruber,[40] B. R. Gruberg Cazon,[57] O. Grünberg,[67] E. Gushchin,[34] Yu. Guz,[37] T. Gys,[40] C. Göbel,[62] T. Hadavizadeh,[57] C. Hadjivasiliou,[5] G. Haefeli,[41] C. Haen,[40] S. C. Haines,[49] B. Hamilton,[60] X. Han,[12] T. H. Hancock,[57] S. Hansmann-Menzemer,[12] N. Harnew,[57] S. T. Harnew,[48] C. Hasse,[40] M. Hatch,[40] J. He,[63] M. Hecker,[55] K. Heinicke,[10] A. Heister,[9] K. Hennessy,[54] P. Henrard,[5] L. Henry,[70] E. van Herwijnen,[40] M. Heß,[67] A. Hicheur,[2] D. Hill,[57] C. Hombach,[56] P. H. Hopchev,[41] W. Hu,[65] Z. C. Huard,[59] W. Hulsbergen,[43] T. Humair,[55] M. Hushchyn,[35] D. Hutchcroft,[54] P. Ibis,[10] M. Idzik,[28] P. Ilten,[58] R. Jacobsson,[40] J. Jalocha,[57] E. Jans,[43] A. Jawahery,[60] F. Jiang,[3] M. John,[57] D. Johnson,[40] C. R. Jones,[49] C. Joram,[40] B. Jost,[40] N. Jurik,[57] S. Kandybei,[45] M. Karacson,[40] J. M. Kariuki,[48] S. Karodia,[53] N. Kazeev,[35] M. Kecke,[12] F. Keizer,[49] M. Kelsey,[61] M. Kenzie,[49] T. Ketel,[44] E. Khairullin,[35] B. Khanji,[12] C. Khurewathanakul,[41] T. Kirn,[9] S. Klaver,[56] K. Klimaszewski,[29] T. Klimkovich,[11] S. Koliiev,[46] M. Kolpin,[12] R. Kopecna,[12] P. Koppenburg,[43] A. Kosmyntseva,[32] S. Kotriakhova,[31] M. Kozeiha,[5] L. Kravchuk,[34] M. Kreps,[50] F. Kress,[55] P. Krokovny,[36,f] F. Kruse,[10] W. Krzemien,[29] W. Kucewicz,[27,o] M. Kucharczyk,[27] V. Kudryavtsev,[36,f] A. K. Kuonen,[41] T. Kvaratskheliya,[32,40] D. Lacarrere,[40] G. Lafferty,[56] A. Lai,[16] G. Lanfranchi,[19] C. Langenbruch,[9] T. Latham,[50] C. Lazzeroni,[47] R. Le Gac,[6] A. Leflat,[33,40] J. Lefrançois,[7] R. Lefèvre,[5] F. Lemaitre,[40] E. Lemos Cid,[39] O. Leroy,[6] T. Lesiak,[27] B. Leverington,[12] P.-R. Li,[63] T. Li,[3] Y. Li,[7] Z. Li,[61] T. Likhomanenko,[68] R. Lindner,[40] F. Lionetto,[42] V. Lisovskyi,[7] X. Liu,[3] D. Loh,[50] A. Loi,[16] I. Longstaff,[53] J. H. Lopes,[2] D. Lucchesi,[23,p] A. Luchinsky,[37] M. Lucio Martinez,[39] H. Luo,[52] A. Lupato,[23] E. Luppi,[17,a] O. Lupton,[40] A. Lusiani,[24] X. Lyu,[63] F. Machefert,[7] F. Maciuc,[30] V. Macko,[41] P. Mackowiak,[10] S. Maddrell-Mander,[48] O. Maev,[31,40] K. Maguire,[56] D. Maisuzenko,[31] M. W. Majewski,[28] S. Malde,[57] B. Malecki,[27] A. Malinin,[68] T. Maltsev,[36,f] G. Manca,[16,g] G. Mancinelli,[6] D. Marangotto,[22,m] J. Maratas,[5,q] J. F. Marchand,[4] U. Marconi,[15] C. Marin Benito,[38] M. Marinangeli,[41] P. Marino,[41] J. Marks,[12] G. Martellotti,[26] M. Martin,[6] M. Martinelli,[41] D. Martinez Santos,[39] F. Martinez Vidal,[70] L. M. Massacrier,[7] A. Massafferri,[1] R. Matev,[40] A. Mathad,[50] Z. Mathe,[40] C. Matteuzzi,[21] A. Mauri,[42] E. Maurice,[7,c] B. Maurin,[41] A. Mazurov,[47] M. McCann,[55,40] A. McNab,[56] R. McNulty,[13] J. V. Mead,[54] B. Meadows,[59] C. Meaux,[6] F. Meier,[10] N. Meinert,[67] D. Melnychuk,[29] M. Merk,[43] A. Merli,[22,40,m] E. Michielin,[23] D. A. Milanes,[66] E. Millard,[50] M.-N. Minard,[4] L. Minzoni,[17] D. S. Mitzel,[12] A. Mogini,[8] J. Molina Rodriguez,[1] T. Mombächer,[10] I. A. Monroy,[66] S. Monteil,[5] M. Morandin,[23] M. J. Morello,[24,k] O. Morgunova,[68] J. Moron,[28] A. B. Morris,[52] R. Mountain,[61] F. Muheim,[52] M. Mulder,[43] D. Müller,[56] J. Müller,[10] K. Müller,[42] V. Müller,[10] P. Naik,[48] T. Nakada,[41] R. Nandakumar,[51] A. Nandi,[57] I. Nasteva,[2] M. Needham,[52] N. Neri,[22,40] S. Neubert,[12] N. Neufeld,[40] M. Neuner,[12] T. D. Nguyen,[41] C. Nguyen-Mau,[41,r] S. Nieswand,[9] R. Niet,[10] N. Nikitin,[33] T. Nikodem,[12] A. Nogay,[68] D. P. O'Hanlon,[50] A. Oblakowska-Mucha,[28] V. Obraztsov,[37] S. Ogilvy,[19] R. Oldeman,[16,g] C. J. G. Onderwater,[71] A. Ossowska,[27] J. M. Otalora Goicochea,[2] P. Owen,[42] A. Oyanguren,[70] P. R. Pais,[41] A. Palano,[14] M. Palutan,[19,40] A. Papanestis,[51] M. Pappagallo,[14,l] L. L. Pappalardo,[17,a] W. Parker,[60] C. Parkes,[56] G. Passaleva,[18,40] A. Pastore,[14,l] M. Patel,[55] C. Patrignani,[15,h] A. Pearce,[40] A. Pellegrino,[43] G. Penso,[26] M. Pepe Altarelli,[40] S. Perazzini,[40] P. Perret,[5] L. Pescatore,[41] K. Petridis,[48] A. Petrolini,[20,j] A. Petrov,[68] M. Petruzzo,[22,m] E. Picatoste Olloqui,[38] B. Pietrzyk,[4] M. Pikies,[27] D. Pinci,[26] F. Pisani,[40] A. Pistone,[20,j] A. Piucci,[12] V. Placinta,[30] S. Playfer,[52] M. Plo Casasus,[39] F. Polci,[8] M. Poli Lener,[19] A. Poluektov,[50] I. Polyakov,[61] E. Polycarpo,[2] G. J. Pomery,[48] S. Ponce,[40] A. Popov,[37] D. Popov,[11,40] S. Poslavskii,[37] C. Potterat,[2] E. Price,[48] J. Prisciandaro,[39] C. Prouve,[48] V. Pugatch,[46] A. Puig Navarro,[42] H. Pullen,[57] G. Punzi,[24,s] W. Qian,[50] R. Quagliani,[7,48] B. Quintana,[5] B. Rachwal,[28] J. H. Rademacker,[48] M. Rama,[24] M. Ramos Pernas,[39] M. S. Rangel,[2] I. Raniuk,[45,†] F. Ratnikov,[35] G. Raven,[44] M. Ravonel Salzgeber,[40] M. Reboud,[4] F. Redi,[55] S. Reichert,[10] A. C. dos Reis,[1] C. Remon Alepuz,[70] V. Renaudin,[7] S. Ricciardi,[51] S. Richards,[48] M. Rihl,[40] K. Rinnert,[54] V. Rives Molina,[38] P. Robbe,[7] A. Robert,[8] A. B. Rodrigues,[1] E. Rodrigues,[59] J. A. Rodriguez Lopez,[66] A. Rogozhnikov,[35] S. Roiser,[40] A. Rollings,[57] V. Romanovskiy,[37] A. Romero Vidal,[39] J. W. Ronayne,[13] M. Rotondo,[19] M. S. Rudolph,[61] T. Ruf,[40] P. Ruiz Valls,[70] J. Ruiz Vidal,[70] J. J. Saborido Silva,[39] E. Sadykhov,[32] N. Sagidova,[31] B. Saitta,[16,g] V. Salustino Guimaraes,[1] C. Sanchez Mayordomo,[70] B. Sanmartin Sedes,[39] R. Santacesaria,[26] C. Santamarina Rios,[39] M. Santimaria,[19] E. Santovetti,[25,i] G. Sarpis,[56] A. Sarti,[19,t] C. Satriano,[26,u] A. Satta,[25] D. M. Saunders,[48] D. Savrina,[32,33] S. Schael,[9] M. Schellenberg,[10] M. Schiller,[53] H. Schindler,[40] M. Schmelling,[11] T. Schmelzer,[10] B. Schmidt,[40] O. Schneider,[41]

A. Schopper,[40] H. F. Schreiner,[59] M. Schubiger,[41] M.-H. Schune,[7] R. Schwemmer,[40] B. Sciascia,[19] A. Sciubba,[26,t] A. Semennikov,[32] E. S. Sepulveda,[8] A. Sergi,[47] N. Serra,[42] J. Serrano,[6] L. Sestini,[23] P. Seyfert,[40] M. Shapkin,[37] I. Shapoval,[45] Y. Shcheglov,[31] T. Shears,[54] L. Shekhtman,[36,f] V. Shevchenko,[68] B. G. Siddi,[17] R. Silva Coutinho,[42] L. Silva de Oliveira,[2] G. Simi,[23,p] S. Simone,[14,l] M. Sirendi,[49] N. Skidmore,[48] T. Skwarnicki,[61] E. Smith,[55] I. T. Smith,[52] J. Smith,[49] M. Smith,[55] l. Soares Lavra,[1] M. D. Sokoloff,[59] F. J. P. Soler,[53] B. Souza De Paula,[2] B. Spaan,[10] P. Spradlin,[53] S. Sridharan,[40] F. Stagni,[40] M. Stahl,[12] S. Stahl,[40] P. Stefko,[41] S. Stefkova,[55] O. Steinkamp,[42] S. Stemmle,[12] O. Stenyakin,[37] M. Stepanova,[31] H. Stevens,[10] S. Stone,[61] B. Storaci,[42] S. Stracka,[24,s] M. E. Stramaglia,[41] M. Straticiuc,[30] U. Straumann,[42] J. Sun,[3] L. Sun,[64] W. Sutcliffe,[55] K. Swientek,[28] V. Syropoulos,[44] T. Szumlak,[28] M. Szymanski,[63] S. T'Jampens,[4] A. Tayduganov,[6] T. Tekampe,[10] G. Tellarini,[17,a] F. Teubert,[40] E. Thomas,[40] J. van Tilburg,[43] M. J. Tilley,[55] V. Tisserand,[4] M. Tobin,[41] S. Tolk,[49] L. Tomassetti,[17,a] D. Tonelli,[24] F. Toriello,[61] R. Tourinho Jadallah Aoude,[1] E. Tournefier,[4] M. Traill,[53] M. T. Tran,[41] M. Tresch,[42] A. Trisovic,[40] A. Tsaregorodtsev,[6] P. Tsopelas,[43] A. Tully,[49] N. Tuning,[43,40] A. Ukleja,[29] A. Usachov,[7] A. Ustyuzhanin,[35] U. Uwer,[12] C. Vacca,[16,g] A. Vagner,[69] V. Vagnoni,[15,40] A. Valassi,[40] S. Valat,[40] G. Valenti,[15] R. Vazquez Gomez,[40] P. Vazquez Regueiro,[39] S. Vecchi,[17] M. van Veghel,[43] J. J. Velthuis,[48] M. Veltri,[18,v] G. Veneziano,[57] A. Venkateswaran,[61] T. A. Verlage,[9] M. Vernet,[5] M. Vesterinen,[57] J. V. Viana Barbosa,[40] B. Viaud,[7] D. Vieira,[63] M. Vieites Diaz,[39] H. Viemann,[67] X. Vilasis-Cardona,[38,b] M. Vitti,[49] V. Volkov,[33] A. Vollhardt,[42] B. Voneki,[40] A. Vorobyev,[31] V. Vorobyev,[36,f] C. Voß,[9] J. A. de Vries,[43] C. Vázquez Sierra,[39] R. Waldi,[67] C. Wallace,[50] R. Wallace,[13] J. Walsh,[24] J. Wang,[61] D. R. Ward,[49] H. M. Wark,[54] N. K. Watson,[47] D. Websdale,[55] A. Weiden,[42] C. Weisser,[58] M. Whitehead,[40] J. Wicht,[50] G. Wilkinson,[57] M. Wilkinson,[61] M. Williams,[56] M. P. Williams,[47] M. Williams,[58] T. Williams,[47] F. F. Wilson,[51,40] J. Wimberley,[60] M. Winn,[7] J. Wishahi,[10] W. Wislicki,[29] M. Witek,[27] G. Wormser,[7] S. A. Wotton,[49] K. Wraight,[53] K. Wyllie,[40] Y. Xie,[65] M. Xu,[65] Z. Xu,[4] Z. Yang,[3] Z. Yang,[60] Y. Yao,[61] H. Yin,[65] J. Yu,[65] X. Yuan,[61] O. Yushchenko,[37] K. A. Zarebski,[47] M. Zavertyaev,[11,w] L. Zhang,[3] Y. Zhang,[7] A. Zhelezov,[12] Y. Zheng,[63] X. Zhu,[3] V. Zhukov,[33] J. B. Zonneveld,[52] and S. Zucchelli[15]

(LHCb Collaboration)

[1]*Centro Brasileiro de Pesquisas Físicas (CBPF), Rio de Janeiro, Brazil*
[2]*Universidade Federal do Rio de Janeiro (UFRJ), Rio de Janeiro, Brazil*
[3]*Center for High Energy Physics, Tsinghua University, Beijing, China*
[4]*LAPP, Université Savoie Mont-Blanc, CNRS/IN2P3, Annecy-Le-Vieux, France*
[5]*Clermont Université, Université Blaise Pascal, CNRS/IN2P3, LPC, Clermont-Ferrand, France*
[6]*Aix Marseille Univ, CNRS/IN2P3, CPPM, Marseille, France*
[7]*LAL, Université Paris-Sud, CNRS/IN2P3, Orsay, France*
[8]*LPNHE, Université Pierre et Marie Curie, Université Paris Diderot, CNRS/IN2P3, Paris, France*
[9]*I. Physikalisches Institut, RWTH Aachen University, Aachen, Germany*
[10]*Fakultät Physik, Technische Universität Dortmund, Dortmund, Germany*
[11]*Max-Planck-Institut für Kernphysik (MPIK), Heidelberg, Germany*
[12]*Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany*
[13]*School of Physics, University College Dublin, Dublin, Ireland*
[14]*Sezione INFN di Bari, Bari, Italy*
[15]*Sezione INFN di Bologna, Bologna, Italy*
[16]*Sezione INFN di Cagliari, Cagliari, Italy*
[17]*Universita e INFN, Ferrara, Ferrara, Italy*
[18]*Sezione INFN di Firenze, Firenze, Italy*
[19]*Laboratori Nazionali dell'INFN di Frascati, Frascati, Italy*
[20]*Sezione INFN di Genova, Genova, Italy*
[21]*Universita e INFN, Milano-Bicocca, Milano, Italy*
[22]*Sezione di Milano, Milano, Italy*
[23]*Sezione INFN di Padova, Padova, Italy*
[24]*Sezione INFN di Pisa, Pisa, Italy*
[25]*Sezione INFN di Roma Tor Vergata, Roma, Italy*
[26]*Sezione INFN di Roma La Sapienza, Roma, Italy*
[27]*Henryk Niewodniczanski Institute of Nuclear Physics Polish Academy of Sciences, Kraków, Poland*
[28]*AGH - University of Science and Technology, Faculty of Physics and Applied Computer Science, Kraków, Poland*
[29]*National Center for Nuclear Research (NCBJ), Warsaw, Poland*

[30]*Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest-Magurele, Romania*
[31]*Petersburg Nuclear Physics Institute (PNPI), Gatchina, Russia*
[32]*Institute of Theoretical and Experimental Physics (ITEP), Moscow, Russia*
[33]*Institute of Nuclear Physics, Moscow State University (SINP MSU), Moscow, Russia*
[34]*Institute for Nuclear Research of the Russian Academy of Sciences (INR RAN), Moscow, Russia*
[35]*Yandex School of Data Analysis, Moscow, Russia*
[36]*Budker Institute of Nuclear Physics (SB RAS), Novosibirsk, Russia*
[37]*Institute for High Energy Physics (IHEP), Protvino, Russia*
[38]*ICCUB, Universitat de Barcelona, Barcelona, Spain*
[39]*Universidad de Santiago de Compostela, Santiago de Compostela, Spain*
[40]*European Organization for Nuclear Research (CERN), Geneva, Switzerland*
[41]*Institute of Physics, Ecole Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland*
[42]*Physik-Institut, Universität Zürich, Zürich, Switzerland*
[43]*Nikhef National Institute for Subatomic Physics, Amsterdam, The Netherlands*
[44]*Nikhef National Institute for Subatomic Physics and VU University Amsterdam, Amsterdam, The Netherlands*
[45]*NSC Kharkiv Institute of Physics and Technology (NSC KIPT), Kharkiv, Ukraine*
[46]*Institute for Nuclear Research of the National Academy of Sciences (KINR), Kyiv, Ukraine*
[47]*University of Birmingham, Birmingham, United Kingdom*
[48]*H.H. Wills Physics Laboratory, University of Bristol, Bristol, United Kingdom*
[49]*Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom*
[50]*Department of Physics, University of Warwick, Coventry, United Kingdom*
[51]*STFC Rutherford Appleton Laboratory, Didcot, United Kingdom*
[52]*School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom*
[53]*School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom*
[54]*Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom*
[55]*Imperial College London, London, United Kingdom*
[56]*School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom*
[57]*Department of Physics, University of Oxford, Oxford, United Kingdom*
[58]*Massachusetts Institute of Technology, Cambridge, Massachusetts, USA*
[59]*University of Cincinnati, Cincinnati, Ohio, USA*
[60]*University of Maryland, College Park, Maryland, USA*
[61]*Syracuse University, Syracuse, New York, United States*
[62]*Pontifícia Universidade Católica do Rio de Janeiro (PUC-Rio), Rio de Janeiro, Brazil*
(associated with Institution Universidade Federal do Rio de Janeiro (UFRJ), Rio de Janeiro, Brazil)
[63]*University of Chinese Academy of Sciences, Beijing, China*
(associated with Institution Center for High Energy Physics, Tsinghua University, Beijing, China)
[64]*School of Physics and Technology, Wuhan University, Wuhan, China*
(associated with Institution Center for High Energy Physics, Tsinghua University, Beijing, China)
[65]*Institute of Particle Physics, Central China Normal University, Wuhan, Hubei, China*
(associated with Institution Center for High Energy Physics, Tsinghua University, Beijing, China)
[66]*Departamento de Fisica, Universidad Nacional de Colombia, Bogota, Colombia*
(associated with Institution LPNHE, Université Pierre et Marie Curie, Université Paris Diderot, CNRS/IN2P3, Paris, France)
[67]*Institut für Physik, Universität Rostock, Rostock, Germany*
(associated with Institution Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany)
[68]*National Research Centre Kurchatov Institute, Moscow, Russia*
(associated with Institution Institute of Theoretical and Experimental Physics (ITEP), Moscow, Russia)
[69]*National Research Tomsk Polytechnic University, Tomsk, Russia*
(associated with Institution Institute of Theoretical and Experimental Physics (ITEP), Moscow, Russia)
[70]*Instituto de Fisica Corpuscular, Centro Mixto Universidad de Valencia - CSIC, Valencia, Spain*
(associated with Institution ICCUB, Universitat de Barcelona, Barcelona, Spain)
[71]*Van Swinderen Institute, University of Groningen, Groningen, The Netherlands*
(associated with Institution Nikhef National Institute for Subatomic Physics, Amsterdam, The Netherlands)

[†]Deceased.
[a]Also at Università di Ferrara, Ferrara, Italy.
[b]Also at LIFAELS, La Salle, Universitat Ramon Llull, Barcelona, Spain.
[c]Also at Laboratoire Leprince-Ringuet, Palaiseau, France.
[d]Also at Università di Milano Bicocca, Milano, Italy.
[e]Also at Università di Modena e Reggio Emilia, Modena, Italy.
[f]Also at Novosibirsk State University, Novosibirsk, Russia.

[g]Also at Università di Cagliari, Cagliari, Italy.
[h]Also at Università di Bologna, Bologna, Italy.
[i]Also at Università di Roma Tor Vergata, Roma, Italy.
[j]Also at Università di Genova, Genova, Italy.
[k]Also at Scuola Normale Superiore, Pisa, Italy.
[l]Also at Università di Bari, Bari, Italy.
[m]Also at Università degli Studi di Milano, Milano, Italy.
[n]Also at Universidade Federal do Triângulo Mineiro (UFTM), Uberaba-MG, Brazil.
[o]Also at AGH - University of Science and Technology, Faculty of Computer Science, Electronics and Telecommunications, Kraków, Poland.
[p]Also at Università di Padova, Padova, Italy.
[q]Also at Iligan Institute of Technology (IIT), Iligan, Philippines.
[r]Also at Hanoi University of Science, Hanoi, Viet Nam.
[s]Also at Università di Pisa, Pisa, Italy.
[t]Also at Università di Roma La Sapienza, Roma, Italy.
[u]Also at Università della Basilicata, Potenza, Italy.
[v]Also at Università di Urbino, Urbino, Italy.
[w]Also at P.N. Lebedev Physical Institute, Russian Academy of Science (LPI RAS), Moscow, Russia.