Observation of a New Excited Beauty Strange Baryon Decaying to Xi(-)(b)pi(+)pi(-)

The CMS collaboration

2021-06-25

The CMS Collaboration , Sirunyan , A M , Tumasyan , A , Eerola , P , Forthomme , L , Kirschenmann , H , Österberg , K , Voutilainen , M , Brücken , E , Garcia , F , Havukainen , J , Karimäki , V , Kim , M , Kinnunen , R , Lampén , T , Lassila-Perini , K , Lehti , S , Lindén , T , Lotti , M , Luukka , P , Martikainen , L , Pekkanen , J , Siikonen , H , Tuominen , E , Tuominiemi , J , Viinikainen , J , Petrow , H & Tuuva , T 2021 , ' Observation of a New Excited Beauty Strange Baryon Decaying to Xi(-)(b)pi(+)pi(-) ' , Physical Review Letters , vol. 126 , no. 25 , 252003 . https://doi.org/10.1103/PhysRevLett.126.252003

http://hdl.handle.net/10138/332779
https://doi.org/10.1103/PhysRevLett.126.252003

Observation of a New Excited Beauty Strange Baryon Decaying to $\Xi_b^- \pi^+ \pi^-$

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

(Received 8 February 2021; revised 19 March 2021; accepted 23 April 2021; published 25 June 2021)

The $\Xi_b^- \pi^+ \pi^-$ invariant mass spectrum is investigated with an event sample of proton-proton collisions at $\sqrt{s} = 13$ TeV, collected by the CMS experiment at the LHC in 2016–2018 and corresponding to an integrated luminosity of 140 fb^{-1}. The ground state Ξ_b^- is reconstructed via its decays to $J/\psi \Xi^-$ and $J/\psi \Lambda K^-$. A narrow resonance, labeled $\Xi_b(6100)^-$, is observed at a $\Xi_b^- \pi^+ \pi^-$ invariant mass of $6100.3 \pm 0.2(\mathrm{stat}) \pm 0.1(\mathrm{syst}) \pm 0.6(\Xi_b^-)$ MeV, where the last uncertainty reflects the precision of the Ξ_b^- baryon mass. The upper limit on the $\Xi_b(6100)^-$ natural width is determined to be 1.9 MeV at 95% confidence level. The low $\Xi_b(6100)^-$ signal yield observed in data does not allow a measurement of the quantum numbers of the new state. However, following analogies with the established excited Ξ_c baryon states, the new $\Xi_b(6100)^-$ resonance and its decay sequence are consistent with the orbitally excited Ξ_b^- baryon, with spin and parity quantum numbers $J^P = 3/2^-$.

DOI: 10.1103/PhysRevLett.126.252003

The Ξ_b baryon family consists of isodoublet states composed of bsq quarks, where q represents an up or a down quark for the Ξ_b^0 and Ξ_b^- states, respectively. According to the quark model for baryons containing one heavy quark [1], three such isodoublets that are neither orbitally nor radially excited should exist, including one with the light diquark angular momentum $j_{qs} = 0$ and spin parity $J^P = 1/2^+$ (the Ξ_b ground states), one with $j_{qs} = 1$ and $J^P = 1/2^+$ (the Ξ_b'), and one with $j_{qs} = 1$ and $J^P = 3/2^+$ (the Ξ_b^*). Various theoretical models and calculations predict a spectrum of excited Ξ_b baryons [2–16]. Three of the four excited states with $j_{qs} = 1$ have been observed at the CERN LHC [17–19] via their $\Xi_b^- \pi^+$ and $\Xi_b^0 \pi^-$ decays, in agreement with predictions [2–4]. The fourth state, $\Xi_b'^0$, is expected to be lighter than the $\Xi_b^- \pi^+$ mass threshold, making a strong transition to Ξ_b^- kinematically impossible. The next prominent isodoublets, in analogy with the quark model assumptions for the well-established excited Ξ_c baryons [20], are orbitally excited P-wave Ξ_b^{**} states with $J^P = 1/2^-$ $(3/2^-)$, expected to decay to $\Xi_b'(\Xi_b^*)\pi$ [12,13,21]. Recently, the LHCb Collaboration reported the observation of the $\Xi_b(6227)^-$ [22] and $\Xi_b(6227)^0$ [23] states, the former decaying to both $\Lambda_b^0 K^-$ and $\Xi_b^0 \pi^-$, and the latter to $\Xi_b^- \pi^+$.

This Letter presents a search for Ξ_b^- excited states in the $\Xi_b^- \pi^+ \pi^-$ invariant mass spectrum, performed using proton-proton (pp) collision data samples collected by the CMS experiment at the LHC at $\sqrt{s} = 13$ TeV in 2016–2018, corresponding to an integrated luminosity of 140 fb^{-1}. The ground state Ξ_b^- is reconstructed via its decays to $J/\psi \Xi^-$ and $J/\psi \Lambda K^-$, followed by the decays $J/\psi \to \mu^+ \mu^-$, $\Xi^- \to \Lambda \pi^-$, and $\Lambda \to p \pi^-$. The decay topologies are illustrated in Fig. 1. For the $\Xi_b^- \to J/\psi \Lambda K^-$ decay mode, following the studies reported by the LHCb Collaboration [24], the partially reconstructed $\Xi_b^- \to J/\psi \Sigma^0 K^-$ channel is also used, where the photon from the $\Sigma^0 \to \Lambda \gamma$ decay is too soft to be detected. The inclusion of charge-conjugated states is implied throughout this Letter. A signal peak, hereafter referred to as $\Xi_b(6100)^-$, is clearly observed near the $\Xi_b^- \pi^+ \pi^-$ kinematic threshold, with a decay sequence consistent with being the $\Xi_b(6100)^- \to \Xi_b^{*0} \pi^- \to \Xi_b^- \pi^+ \pi^-$ decay. The $\Xi_b(6100)^-$ mass and an upper limit on its width are also measured.

The central feature of the CMS apparatus is a superconducting solenoid of 6 m internal diameter, providing a magnetic field of 3.8 T. Within the solenoid volume are a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter, and a brass and scintillator hadron calorimeter, each composed of a barrel and two end cap sections. Muons are detected in gas-ionization chambers embedded in the steel flux-return yoke outside the solenoid. A more detailed description of the CMS detector, together with a definition of the coordinate system used and the relevant kinematic variables, can be found in Ref. [25].

Events of interest are selected using a two-tiered trigger system. The first level (L1), composed of custom hardware processors, uses information from the calorimeters and muon detectors [26]. The second level, known as the high-level trigger (HLT), consists of a farm of processors

---

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

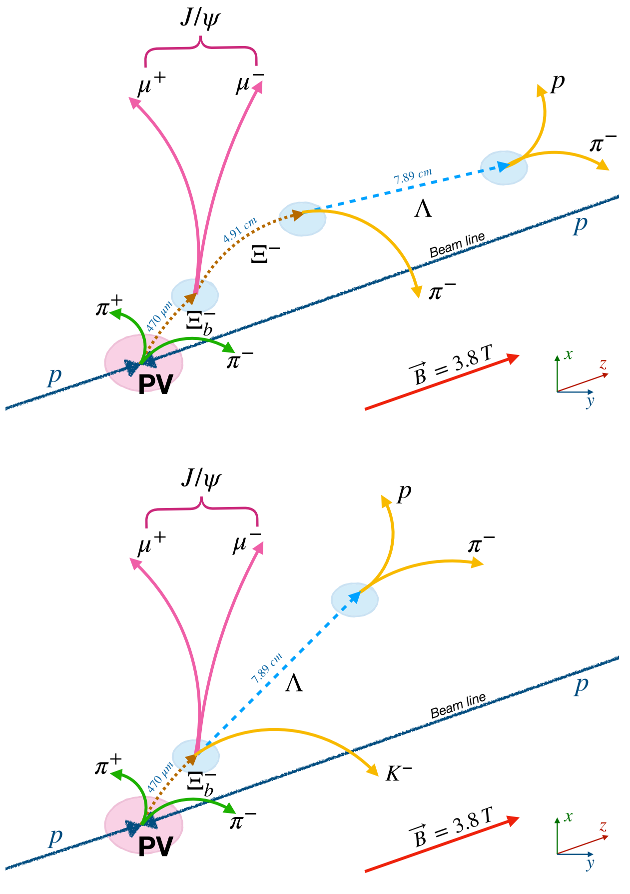

FIG. 1. The $\Xi_b(6100)^- \to \Xi_b^- \pi^+ \pi^-$ decay topology, where the Ξ_b^- decays to $J/\psi \Xi^-$ (upper) or to $J/\psi \Lambda K^-$ (lower). The numbers in blue are average decay lengths.

running a version of the full event reconstruction software optimized for fast processing [27]. The events used in the analysis were selected at L1 by requiring the presence of at least two muons and at HLT by requiring that the two muons have opposite sign (OS), with various thresholds on the pseudorapidity η and momentum transverse to the beam axis p_T, compatible with being produced in the dimuon decay of J/ψ mesons.

Several simulated event samples are used in the analysis. The PYTHIA 8.230 package [28] is used to simulate the production of the $\Xi_b(6100)^-$ state, where the Σ_b^- baryon, with a modified mass value, is used as a proxy for an excited $\Xi_b(6100)^-$ state. The $\Xi_b(6100)^- \to \Xi_b^- \pi^+ \pi^-$ (including both resonant $\Xi_b^{*0} \pi^+ \to \Xi_b^- \pi^+ \pi^-$ and nonresonant $\Xi_b^- \pi^+ \pi^-$ modes), $\Xi_b^- \to J/\psi \Xi^-$, $\Xi_b^- \to J/\psi \Lambda K^-$ (including $\Xi_b^- \to J/\psi \Sigma^0 K^-$, $\Sigma^0 \to \Lambda \gamma$), and $J/\psi \to \mu^+ \mu^-$ decays are modeled with EVTGEN 1.6.0 [29], where final-state photon radiation is included using PHOTOS 3.61 [30,31]. The generated events are then passed to a detailed GEANT4-based simulation [32] of the CMS detector, including the same trigger and reconstruction algorithms as used for the collision data. The simulation includes effects from multiple pp interactions in the same or nearby bunch crossings (pileup) with a multiplicity distribution matching the measured one.

The selection criteria are optimized using the Punzi figure of merit [33], which does not rely on the signal normalization. The expected background is estimated from data using the same-sign (SS) control region described below, while the signal efficiency is obtained from the simulated $\Xi_b(6100)^- \to \Xi_b^- \pi^+ \pi^-$ events. The $\Xi_b^- \to J/\psi \Xi^-$ and $\Xi_b^- \to J/\psi \Lambda K^-$ requirements are optimized separately.

Events are required to have two OS muons passing the CMS soft-muon selection criteria [34] and satisfying $p_T(\mu^\pm) > 3$ GeV and $|\eta(\mu^\pm)| < 2.4$. The muons must form a common vertex with χ^2 probability P_{vtx} above 1%. The dimuon invariant mass must be within 100 MeV of $m_{J/\psi}^{\mathrm{PDG}}$ (hereafter, m_X^{PDG} denotes the world-average mass of hadron X [20]), corresponding to about three times the mass resolution. The Λ candidates are formed from displaced two-prong vertices, assuming the decay $\Lambda \to p\pi^-$, as described in Ref. [35]. The $p\pi^-$ reconstructed mass is required to be within 10 MeV of m_Λ^{PDG}, corresponding to about three times the mass resolution. The two tracks are then refitted with their invariant mass constrained to m_Λ^{PDG}. The obtained Λ candidates are required to have $p_T > 1$ GeV and $P_{\mathrm{vtx}} > 1\%$.

For the $\Xi_b^- \to J/\psi \Xi^-$ channel, the $\Xi^- \to \Lambda \pi^-$ candidates are obtained by combining charged particles of $p_T > 0.25$ GeV with the selected Λ candidates. The reconstructed Ξ^- must have $P_{\mathrm{vtx}} > 1\%$, $p_T > 3$ GeV, and invariant mass within 9.5 MeV of $m_{\Xi^-}^{\mathrm{PDG}}$, corresponding to about three times the mass resolution. The Ξ_b^- candidates are obtained by performing a $\mu^+ \mu^- \Xi^-$ kinematic vertex fit, constraining the dimuon invariant mass to $m_{J/\psi}^{\mathrm{PDG}}$.

For the $\Xi_b^- \to J/\psi \Lambda K^-$ decay channel, the Λ candidates must pass stricter requirements: $p_T > 2$ GeV and $|M(p\pi^-) - m_\Lambda^{\mathrm{PDG}}| < 9$ MeV. The charged kaon candidates are particle tracks with kaon mass assignment satisfying high-purity tracking requirements [36] and $p_T > 1.2$ GeV. The Ξ_b^- candidates are reconstructed by fitting the $\mu^+ \mu^- \Lambda K^-$ vertex with the J/ψ mass constraint. Because the photon from the $\Sigma^0 \to \Lambda \gamma$ decay is not detected, both $\Xi_b^- \to J/\psi \Lambda K^-$ and $\Xi_b^- \to J/\psi \Sigma^0 K^-$ decays contribute to the $\mu^+ \mu^- \Lambda K^-$ reconstructed combination.

The Ξ_b^- candidates are required to have $P_{\mathrm{vtx}} > 1\%$ and $p_T > 10(15)$ GeV for the $\Xi_b^- \to J/\psi \Xi^-$ ($\Xi_b^- \to J/\psi \Lambda K^-$) channel. From all reconstructed pp collision vertices, the primary vertex (PV) is chosen as the one with the smallest pointing angle, as done in Refs. [37–40]. The pointing angle is the three-dimensional angle between the Ξ_b^- candidate momentum and the vector joining the PV with the reconstructed Ξ_b^- candidate decay vertex. The decay length L_{xy} of the Ξ_b^- candidate in the transverse plane, computed as the two-dimensional distance between the PV and the Ξ_b^- decay vertex, is required to be at least three times larger than its uncertainty $\sigma_{L_{xy}}$. The $\overrightarrow{p_T}(\Xi_b^-)$ is required to be aligned with the transverse displacement vector: $\cos[\alpha(\Xi_b^-, \mathrm{PV})] > 0.99(0.993)$ for the $\Xi_b^- \to J/\psi\Xi^-$ ($\Xi_b^- \to J/\psi\Lambda K^-$) channel, where $\alpha(\Xi_b^-, \mathrm{PV})$ is the pointing angle in the plane transverse to the beams. Two additional topological requirements are applied: the cosine of the pointing angle $\cos[\alpha(\Xi^-, \Xi_b^-)]$ must be larger than 0.999 for the $\Xi_b^- \to J/\psi\Xi^-$ channel; and $L_{xy}/\sigma_{L_{xy}}(\Lambda, \Xi_b^-) > 20$ for the $\Xi_b^- \to J/\psi\Lambda K^-$ channel. In addition, the pion emitted in the $\Xi^- \to \Lambda\pi^-$ decay and the kaon emitted in the $\Xi_b^- \to J/\psi\Lambda K^-$ decay must have $d_{xy}/\sigma_{d_{xy}} > 0.9$ and 0.6, respectively, where d_{xy} is the impact parameter in the transverse plane with respect to the PV, and $\sigma_{d_{xy}}$ is its uncertainty.

The invariant mass distributions of the selected Ξ_b^- candidates are shown in Fig. 2 for the $J/\psi\Xi^-$ (upper) and $J/\psi\Lambda K^-$ (lower) channels. The two plots also show the results of independent unbinned extended maximum-likelihood fits. In both cases, the fully reconstructed Ξ_b^- signal is described by a double-Gaussian function with two free parameters: the common mean and the total yield; the two width parameters and the proportion of each Gaussian are fixed from simulation studies. The background is described by a first-order polynomial in the $J/\psi\Xi^-$ fit and an exponential function in the $J/\psi\Lambda K^-$ fit. In the latter fit, the signal contribution from the partially reconstructed $\Xi_b^- \to J/\psi\Sigma^0 K^-$ decays is taken into account by including an asymmetric Gaussian in the fit model, with the shape parameters fixed from simulation studies. All normalization values (signals and backgrounds) are free parameters of the fit.

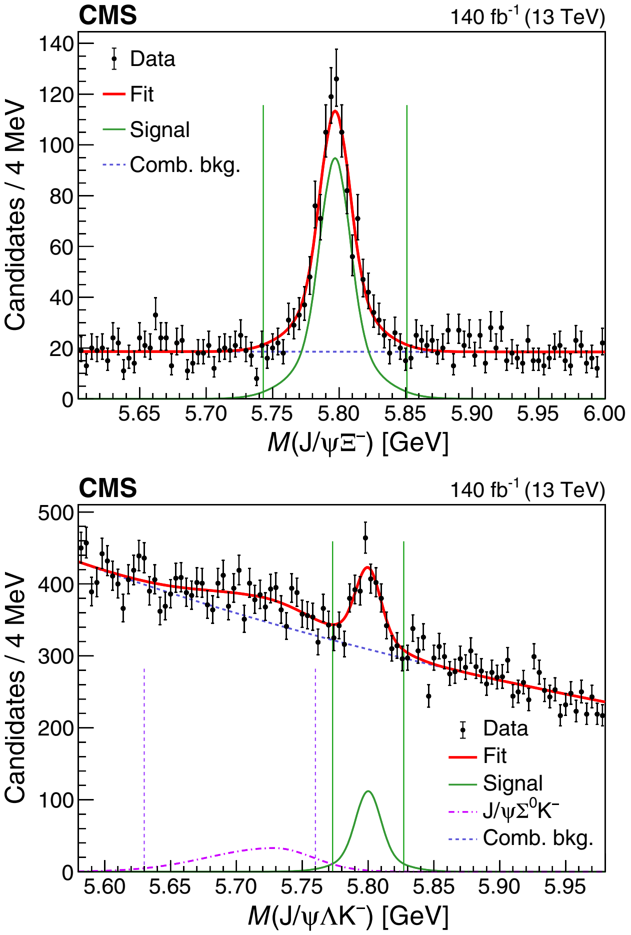

FIG. 2. Invariant mass distributions of the selected Ξ_b^- candidates in the $J/\psi\Xi^-$ (upper) and $J/\psi\Lambda K^-$ (lower) decay channels with the fit results superimposed. The vertical solid (dashed) lines show the mass windows discussed in the text and used in the reconstruction of the $\Xi_b^-\pi^+\pi^-$ candidates in $J/\psi\Xi^-$ and $J/\psi\Lambda K^-$ ($J/\psi\Sigma^0 K^-$) channels.

The signal yields from the fits described above are 859 ± 36 and 815 ± 74 for the $\Xi_b^- \to J/\psi\Xi^-$ and fully reconstructed $\Xi_b^- \to J/\psi\Lambda K^-$ decay modes, respectively, with the uncertainties being statistical only. The fitted Ξ_b^- masses of 5797.0 ± 0.7 and 5800.1 ± 1.2 MeV, respectively for the $J/\psi\Xi^-$ and $J/\psi\Lambda K^-$ channels, the uncertainties being statistical only, are consistent with each other and with the world-average value, 5797.0 ± 0.6 MeV [20]. The signal components corresponding to fully reconstructed Ξ_b^- candidates are shown by the solid green curves. The fitted yield of the partially reconstructed $\Xi_b^- \to J/\psi\Sigma^0 K^-$ contribution, reconstructed as $J/\psi\Lambda K^-$, is 820 ± 158, represented by the dotted-dashed curve in Fig. 2 (lower). The Ξ_b^- fit results illustrate this part of the reconstruction procedure and provide the first confirmation of the $\Xi_b^- \to J/\psi\Lambda K^-$ decay observed by LHCb [24].

When reconstructing $\Xi_b^-\pi^+\pi^-$ candidates, we select events with Ξ_b^- invariant mass within 54 (27) MeV of the fitted Ξ_b^- mass for the $J/\psi\Xi^-$ ($J/\psi\Lambda K^-$) channel, corresponding to approximately 2.8 (1.8) times the mass resolution, as shown by the vertical solid lines in Fig. 2. The $5.63 < M(J/\psi\Lambda K^-) < 5.76$ GeV mass region is used for the partially reconstructed $\Xi_b^- \to J/\psi\Sigma^0 K^-$ decay mode, shown by the dashed vertical lines in Fig. 2 (lower). These mass ranges are selected through the same optimization procedure as used for the other selection criteria.

Because the lifetime of the excited Ξ_b states is expected to be negligible, the $\Xi_b^-\pi^+\pi^-$ candidates are formed by combining the selected Ξ_b^- candidates with two OS tracks originating from the PV, as in Refs. [37–40]. Combinations of a Ξ_b^- candidate with two SS pions from the PV are used as a control channel and form the SS control region. The analysis is performed using the mass difference variable $\Delta M = M(\Xi_b^-\pi^+\pi^-) - M(\Xi_b^-) - 2m_{\pi^\pm}^{\mathrm{PDG}}$, which has a better mass resolution than $M(\Xi_b^-\pi^+\pi^-)$, where $M(\Xi_b^-)$ represents the reconstructed Ξ_b^- mass. According to the simulation studies, this variable also has the advantage of being insensitive to a potential mass shift caused by the fact that the photon emitted in the $\Xi_b^- \to J/\psi\Sigma^0 K^-$, $\Sigma^0 \to \Lambda\gamma$ decay sequence is not reconstructed. Following the technique developed in Ref. [40], the selected Ξ_b^- candidate and all tracks forming the PV are refit to a common vertex, further improving the $\Xi_b^-\pi^+\pi^-$ invariant mass resolution of the fully reconstructed channels from 1.39 ± 0.11 to

0.94 ± 0.06 MeV (statistical uncertainties only), as obtained from simulation studies.

Theoretical studies [12,13,21] and analogous decays of excited charm baryons [20,41] suggest that the decay $\Xi_b^{**-} \to \Xi_b^- \pi^+ \pi^-$ should proceed predominantly through $\Xi_b^{**-} \to \Xi_b^{*0} \pi^-$, followed by $\Xi_b^{*0} \to \Xi_b^- \pi^+$. Therefore, an additional requirement is applied to enhance this contribution. As the Ξ_b^{*0} state has a mass of 5952.3 ± 0.6 MeV, the mass difference $M(\Xi_b^{*0}) - M(\Xi_b^-) - m_{\pi^+}^{\mathrm{PDG}}$ will peak at 15.73 MeV [20]. To avoid complications in understanding the $\Xi_b^- \pi^+ \pi^-$ threshold, we do not apply a minimum cut on this mass difference but simply require it to be less than 20.73 MeV, with the 5 MeV addition found to be optimal when considering the Ξ_b^{*0} natural width and our detector resolution.

The invariant mass distribution of the selected $\Xi_b^- \pi^+ \pi^-$ candidates is shown in Fig. 3, using the mass difference variable ΔM. The left plot combines the data from the $\Xi_b^- \to J/\psi \Xi^-$ and $\Xi_b^- \to J/\psi \Lambda K^-$ channels, which have identical mass resolutions, according to simulation studies (the Ξ_b^- is fully reconstructed in both channels). The right plot shows the events that use the partially reconstructed $\Xi_b^- \to J/\psi \Sigma^0 K^-$ channel, with a 30% larger mass resolution. Given the definition of the ΔM variable, the mean mass of the signal peaks should not depend on the Ξ_b^- reconstruction channel.

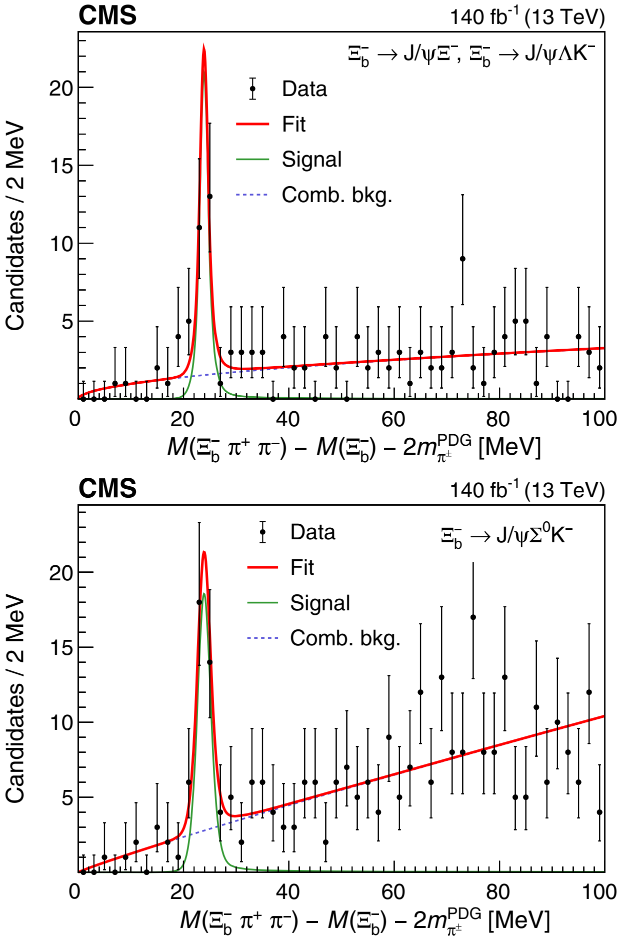

FIG. 3. Distributions of the invariant mass difference ΔM for the selected $\Xi_b^- \pi^+ \pi^-$ candidates, with the Ξ_b^- reconstructed in the $J/\psi \Xi^-$ and $J/\psi \Lambda K^-$ channels (upper) or partially reconstructed in the $J/\psi \Sigma^0 K^-$ channel (lower). The result of the simultaneous fit is also shown.

A narrow peak is seen near the threshold of the $\Xi_b^- \pi^+ \pi^-$ system in both plots of Fig. 3. The excess is also visible in each of the two independent decay channels, $J/\psi \Xi^-$ and $J/\psi \Lambda K^-$. We have also studied the OS and SS distributions in a wider range of ΔM (up to 280 MeV) and found no other significant peaks. A simultaneous unbinned extended maximum-likelihood fit is performed on the two data samples shown in Fig. 3, the result being represented by the red curves. The signal component is described with a relativistic Breit-Wigner (RBW) function [42,43] for the $\Xi_b(6100)^- \to \Xi_b^{*0} \pi^-$ decay, convolved with a double-Gaussian resolution function. The mass and natural width of the signal function are the two parameters of interest in the fit. The normalization and background parameters are different for the fully and partially reconstructed channels, as are the resolution parameters, which are fixed from the simulation studies. The background component is modeled with the threshold function $(\Delta M)^\alpha$, where α is a free parameter.

The fitted mass difference of the new $\Xi_b(6100)^-$ state is $\Delta M_{\Xi_b(6100)^-} = 24.14 \pm 0.22$ MeV, where the uncertainty is statistical only. The fitted signal yields are 26 ± 7 and 34 ± 9 for the fully reconstructed and the $\Xi_b^- \to J/\psi \Sigma^0 K^-$ channels, respectively. The relative yield of the $\Xi_b(6100)^-$, with respect to the Ξ_b^- yield, is found to be noticeably larger in the partially reconstructed Ξ_b^- channel, compared to the fully reconstructed channels. Given the large uncertainties in the observed small $\Xi_b(6100)^-$ signal yields, this discrepancy is consistent with being a statistical fluctuation. The order-of-magnitude larger signals of the $\Xi_b^{*0} \to \Xi_b^- \pi^+$ decays, with respect to the Ξ_b^- ground state signals, are found to be consistent between all three Ξ_b^- reconstruction channels.

The natural width of the $\Xi_b(6100)^-$ is too small to be measured with the present data sample and experimental resolution. An upper limit on $\Gamma[\Xi_b(6100)^-]$ has been obtained through a scan of the profiled likelihood, assuming an asymptotic distribution. The measured upper limit, at 95% confidence level, is $\Gamma[\Xi_b(6100)^-] < 1.9$ MeV, where the systematic uncertainties, discussed below, are taken into account.

The local statistical significance of the $\Xi_b(6100)^-$ signal is evaluated with the likelihood ratio technique, comparing the background-only and signal-plus-background hypotheses (with four additional free parameters), using asymptotic formulas [44,45]. The resulting significance of the $\Xi_b(6100)^-$ signal varies between 6.2 and 6.7 standard deviations, depending on the fit model variations used to evaluate the systematic uncertainties.

Several sources of systematic uncertainties in the measured mass difference $\Delta M_{\Xi_b(6100)^-}$ are considered. To evaluate the systematic uncertainties related to the choice of the fit model, several alternative functions are tested. Uncertainties related to the choice of the signal model are estimated by changing the resolution function from a double-Gaussian function to a single-Gaussian function or a sum of three Gaussian functions. Two alternative background models are considered: the threshold function multiplied by an exponential and the threshold function multiplied by a first-order polynomial. The largest deviations in the measured mass are 0.01 and 0.04 MeV, respectively, for the variations of the signal and background models; these values are taken as the two corresponding systematic uncertainties.

The RBW function used in the signal modeling includes Blatt-Weisskopf barrier factors [43], which depend on the radial parameter r and on the angular momentum l (spin). In the baseline fit, $r = 3.5\ \text{GeV}^{-1}$ and $l = 1$. The corresponding systematic uncertainties are obtained by varying r between 1 and $5\ \text{GeV}^{-1}$ or by assigning $l = 0$. The r variations have a negligible effect on the results, while fixing $l = 0$ changes the signal shape and induces a mass difference variation of 0.01 MeV, taken as the corresponding systematic uncertainty.

To account for a possible difference between the measured and simulated mass resolutions, the fits are repeated with resolutions scaled up or down by 1.074, a factor determined from the comparison of the Ξ_b^- resolutions in data and simulation. The resulting systematic uncertainty of the $\Xi_b(6100)^-$ mass difference is 0.02 MeV.

Simulation studies show a shift of 0.07 MeV between the generated and reconstructed mass differences; this shift is treated as an additional systematic uncertainty in the $\Delta M_{\Xi_b(6100)^-}$ measurement.

The systematic uncertainty reflecting the ΔM fit range is evaluated by changing the upper end of the ΔM fit range from its default 100 MeV to 80, 120, and 150 MeV. The largest mass difference change of 0.02 MeV is taken as the corresponding systematic uncertainty.

A potential bias due to a possible misalignment of the tracker detectors is evaluated by comparing the results obtained with the data collected in 2016, 2017, and 2018. This is a reasonable evaluation, given that the inner part of the CMS tracker was replaced between the 2016 and 2017 data-taking periods. The measured mass is found to be insensitive to alignment uncertainties.

The total systematic uncertainty in the measured mass difference $\Delta M_{\Xi_b(6100)^-}$, calculated as the sum in quadrature of the partial terms, is 0.09 MeV.

In summary, we report the observation of a new excited beauty strange baryon, decaying to $\Xi_b^-\pi^+\pi^-$. The analysis uses proton-proton collision data collected by the CMS experiment at $\sqrt{s} = 13$ TeV, corresponding to an integrated luminosity of $140\ \text{fb}^{-1}$. The measured mass difference of this state is $M[\Xi_b(6100)^-] - M(\Xi_b^-) - 2m_{\pi^\pm}^{\text{PDG}} = 24.14 \pm 0.22(\text{stat}) \pm 0.09(\text{syst})$ MeV. The known Ξ_b^- mass of 5797.0 ± 0.6 MeV [20] is used to obtain $M[\Xi_b(6100)^-] = 6100.3 \pm 0.2(\text{stat}) \pm 0.1(\text{syst}) \pm 0.6(\Xi_b^-)$ MeV. It is particularly remarkable that if the $\Xi_b(6100)^-$ baryon were only 13 MeV heavier, it would be above the $\Lambda_b^0 K^-$ mass threshold and could decay to this final state. The natural width of this resonance is compatible with zero and a 95% confidence level upper limit of 1.9 MeV has been determined.

Following analogies with the established excited Ξ_c baryon states [20], and considering several theoretical predictions [12,13,21], the new $\Xi_b(6100)^-$ resonance and its decay sequence are consistent with the lightest orbitally excited Ξ_b^- baryon, with the light diquark angular momentum $j_{ds} = 1$ and $J^P = 3/2^-$ (excitation with orbital momentum $L = 1$ between the b quark and the ds diquark). This suggests that it is the beauty analog of the $\Xi_c(2815)$ baryon [41]. Measuring a natural width of the $\Xi_b(6100)^-$ smaller than 1.9 MeV comes as a surprise, given the larger values predicted by the theory calculations [12,13,21], based on the assumption that the $\Xi_b^{**-} \to \Xi_b^{*0}\pi^-$ decay proceeds predominantly via S wave ($3/2^- \to 3/2^+ 0^-$). The observation of this baryon and the measurement of its properties provide information that should help to distinguish between different theoretical models used to calculate the properties of the excited Ξ_b states.

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 and other centers 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, the CMS detector, and the supporting computing infrastructure provided by the following funding agencies: BMBWF and FWF (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, FAPERGS, and FAPESP (Brazil); MES (Bulgaria); CERN; CAS, MoST, and NSFC (China); COLCIENCIAS (Colombia); MSES and CSF (Croatia); RIF (Cyprus); SENESCYT (Ecuador); MoER, ERC PUT, and ERDF (Estonia); Academy of Finland, MEC, and HIP (Finland); CEA and CNRS-IN2P3 (France); BMBF, DFG, and HGF (Germany); GSRT (Greece); NKFIA (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); MSIP and NRF (Republic of Korea); MES (Latvia); LAS (Lithuania); MOE and UM (Malaysia); BUAP, CINVESTAV, CONACYT, LNS, SEP, and UASLP-FAI

(Mexico); MOS (Montenegro); MBIE (New Zealand); PAEC (Pakistan); MSHE and NSC (Poland); FCT (Portugal); JINR (Dubna); MON, RosAtom, RAS, RFBR, and NRC KI (Russia); MESTD (Serbia); SEIDI, CPAN, PCTI, and FEDER (Spain); MOSTR (Sri Lanka); Swiss Funding Agencies (Switzerland); MST (Taipei); ThEPCenter, IPST, STAR, and NSTDA (Thailand); TUBITAK and TAEK (Turkey); NASU (Ukraine); STFC (United Kingdom); and DOE and NSF (USA). Individuals have received support from the Marie Curie program and the European Research Council and Horizon 2020 Grant, Contracts No. 675440, No. 724704, No. 752730, and No. 765710 (European Union); the Leventis Foundation; the Alfred P. Sloan Foundation; the Alexander von Humboldt Foundation; the Belgian Federal Science Policy Office; the Fonds pour la Formation *à la* Recherche dans l'Industrie et dans l'Agriculture (FRIA-Belgium); the Agentschap voor Innovatie door Wetenschap en Technologie (IWT-Belgium); the F. R. S.-FNRS and FWO (Belgium) under the "Excellence of Science—EOS"—be.h Project No. 30820817; the Beijing Municipal Science & Technology Commission, No. Z191100007219010; the Ministry of Education, Youth and Sports (MEYS) of the Czech Republic; the Deutsche Forschungsgemeinschaft (DFG), under Germany's Excellence Strategy—EXC 2121 "Quantum Universe"—390833306, and under Project No. 400140256—GRK2497; the Lendület ("Momentum") Program and the János Bolyai Research Scholarship of the Hungarian Academy of Sciences, the New National Excellence Program ÚNKP, the NKFIA Research Grants No. 123842, No. 123959, No. 124845, No. 124850, No. 125105, No. 128713, No. 128786, and No. 129058 (Hungary); the Council of Science and Industrial Research, India; the HOMING PLUS program of the Foundation for Polish Science, cofinanced from European Union, Regional Development Fund, the Mobility Plus program of the Ministry of Science and Higher Education, the National Science Center (Poland), Contracts Harmonia 2014/14/M/ST2/00428, Opus 2014/13/B/ST2/02543, 2014/15/B/ST2/03998, and 2015/19/B/ST2/02861, Sonata-bis 2012/07/E/ST2/01406; the National Priorities Research Program by Qatar National Research Fund; the Ministry of Science and Higher Education, Project No. 14.W03.31.0026 (Russia); the Programa Estatal de Fomento de la Investigación Científica y Técnica de Excelencia María de Maeztu, Grant No. MDM-2015-0509 and the Programa Severo Ochoa del Principado de Asturias; the Thalis and Aristeia programs cofinanced by EU-ESF and the Greek NSRF; the Rachadapisek Sompot Fund for Postdoctoral Fellowship, Chulalongkorn University and the Chulalongkorn Academic into Its 2nd Century Project Advancement Project (Thailand); the Kavli Foundation; the Nvidia Corporation; the SuperMicro Corporation; the Welch Foundation, Contract No. C-1845; and the Weston Havens Foundation (USA).

[1] D. Ebert, T. Feldmann, C. Kettner, and H. Reinhardt, A diquark model for baryons containing one heavy quark, Z. Phys. C **71**, 329 (1996).

[2] D. Ebert, R. N. Faustov, and V. O. Galkin, Masses of excited heavy baryons in the relativistic quark model, Phys. Lett. B **659**, 612 (2008).

[3] E. E. Jenkins, Model-independent bottom baryon mass predictions in the $1/N(c)$ expansion, Phys. Rev. D **77**, 034012 (2008).

[4] M. Karliner, B. Keren-Zur, H. J. Lipkin, and J. L. Rosner, The quark model and b baryons, Ann. Phys. (Amsterdam) **324**, 2 (2009).

[5] W. Roberts and M. Pervin, Heavy baryons in a quark model, Int. J. Mod. Phys. A **23**, 2817 (2008).

[6] D. Ebert, R. N. Faustov, and V. O. Galkin, Spectroscopy and Regge trajectories of heavy baryons in the relativistic quark-diquark picture, Phys. Rev. D **84**, 014025 (2011).

[7] H. Garcilazo, J. Vijande, and A. Valcarce, Faddeev study of heavy baryon spectroscopy, J. Phys. G **34**, 961 (2007).

[8] B. Chen, K.-W. Wei, and A. Zhang, Assignments of Λ_Q and Ξ_Q baryons in the heavy quark-light diquark picture, Eur. Phys. J. A **51**, 82 (2015).

[9] I. L. Grach, I. M. Narodetskii, M. A. Trusov, and A. I. Veselov, Heavy baryon spectroscopy in the QCD string model, in *Proceedings of the 18th International Conference on Particles and Nuclei (PANIC08)* (2008) [arXiv:0811.2184].

[10] Q. Mao, H.-X. Chen, W. Chen, A. Hosaka, X. Liu, and S.-L. Zhu, QCD sum rule calculation for P-wave bottom baryons, Phys. Rev. D **92**, 114007 (2015).

[11] Z.-G. Wang, Analysis of the $1/2^-$ and $3/2^-$ heavy and doubly heavy baryon states with QCD sum rules, Eur. Phys. J. A **47**, 81 (2011).

[12] K.-L. Wang, Y.-X. Yao, X.-H. Zhong, and Q. Zhao, Strong and radiative decays of the low-lying S- and P-wave singly heavy baryons, Phys. Rev. D **96**, 116016 (2017).

[13] Y. Kawakami and M. Harada, Singly heavy baryons with chiral partner structure in a three-flavor chiral model, Phys. Rev. D **99**, 094016 (2019).

[14] Z.-Y. Wang, J.-J. Qi, X.-H. Guo, and K.-W. Wei, Spectra of charmed and bottom baryons with hyperfine interaction, Chin. Phys. C **41**, 093103 (2017).

[15] K. Thakkar, Z. Shah, A. K. Rai, and P. C. Vinodkumar, Excited state mass spectra and Regge trajectories of bottom baryons, Nucl. Phys. **A965**, 57 (2017).

[16] K.-W. Wei, B. Chen, N. Liu, Q.-Q. Wang, and X.-H. Guo, Spectroscopy of singly, doubly, and triply bottom baryons, Phys. Rev. D **95**, 116005 (2017).

[17] CMS Collaboration, Observation of a New Ξ_b Baryon, Phys. Rev. Lett. **108**, 252002 (2012).

[18] LHCb Collaboration, Measurement of the properties of the Ξ_b^{*0} baryon, J. High Energy Phys. 05 (2016) 161.

[19] LHCb Collaboration, Observation of Two New Ξ_b^- Baryon Resonances, Phys. Rev. Lett. **114**, 062004 (2015).

[20] Particle Data Group, P. A. Zyla *et al.*, Review of particle physics, Prog. Theor. Exp. Phys. **2020**, 083C01 (2020).

[21] B. Chen, K.-W. Wei, X. Liu, and A. Zhang, Role of newly discovered $\Xi_b(6227)^-$ for constructing excited bottom baryon family, Phys. Rev. D **98**, 031502(R) (2018).

[22] LHCb Collaboration, Observation of a New Ξ_b^- Resonance, Phys. Rev. Lett. **121**, 072002 (2018).

[23] LHCb Collaboration, Observation of a new Ξ_b^0 state, Phys. Rev. D **103**, 012004 (2021).

[24] LHCb Collaboration, Observation of the $\Xi_b^- \to J/\psi\Lambda K^-$ decay, Phys. Lett. B **772**, 265 (2017).

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

[26] CMS Collaboration, Performance of the CMS Level-1 trigger in proton-proton collisions at $\sqrt{s} = 13$ TeV, J. Instrum. **15**, P10017 (2020).

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

[28] T. Sjöstrand, S. Ask, J. R. Christiansen, R. Corke, N. Desai, P. Ilten, S. Mrenna, S. Prestel, C. O. Rasmussen, and P. Z. Skands, An introduction to PYTHIA 8.2, Comput. Phys. Commun. **191**, 159 (2015).

[29] D. J. Lange, The EVTGEN particle decay simulation package, Nucl. Instrum. Methods Phys. Res., Sect. A **462**, 152 (2001).

[30] E. Barberio, B. van Eijk, and Z. Wąs, PHOTOS: A universal Monte Carlo for QED radiative corrections in decays, Comput. Phys. Commun. **66**, 115 (1991).

[31] E. Barberio and Z. Wąs, PHOTOS: A universal Monte Carlo for QED radiative corrections. Version 2.0, Comput. Phys. Commun. **79**, 291 (1994).

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

[33] G. Punzi, Sensitivity of searches for new signals and its optimization, eConf **C030908**, MODT002 (2003) [arXiv: physics/0308063].

[34] CMS Collaboration, Performance of the CMS muon detector and muon reconstruction with proton-proton collisions at $\sqrt{s} = 13$ TeV, J. Instrum. **13**, P06015 (2018).

[35] CMS Collaboration, CMS tracking performance results from early LHC operation, Eur. Phys. J. C **70**, 1165 (2010).

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

[37] CMS Collaboration, Search for the X(5568) State Decaying Into $\mathrm{B_s^0}\pi^\pm$ in Proton-Proton Collisions at $\sqrt{s} = 8$ TeV, Phys. Rev. Lett. **120**, 202005 (2018).

[38] CMS Collaboration, Studies of $\mathrm{B_{s2}^*}(5840)^0$ and $\mathrm{B_{s1}}(5830)^0$ mesons including the observation of the $\mathrm{B_{s2}^*}(5840)^0 \to \mathrm{B^0K_S^0}$ decay in proton-proton collisions at $\sqrt{s} = 8$ TeV, Eur. Phys. J. C **78**, 939 (2018).

[39] CMS Collaboration, Observation of Two Excited $\mathrm{B_c^+}$ States and Measurement of the $\mathrm{B_c^+}(2S)$ Mass in pp Collisions at $\sqrt{s} = 13$ TeV, Phys. Rev. Lett. **122**, 132001 (2019).

[40] CMS Collaboration, Study of excited Λ_b^0 states decaying to $\Lambda_\mathrm{b}^0\pi^+\pi^-$ in proton-proton collisions at $\sqrt{s} = 13$ TeV, Phys. Lett. B **803**, 135345 (2020).

[41] J. P. Alexander *et al.* (CLEO Collaboration), Evidence of New States Decaying Into $\Xi_c^*\pi$, Phys. Rev. Lett. **83**, 3390 (1999).

[42] J. D. Jackson, Remarks on the phenomenological analysis of resonances, Nuovo Cimento **34**, 1644 (1964).

[43] J. M. Blatt and V. F. Weisskopf, *Theoretical Nuclear Physics* (Springer, New York, 1952), https://doi.org/10.1007/978-1-4612-9959-2.

[44] S. S. Wilks, The large-sample distribution of the likelihood ratio for testing composite hypotheses, Ann. Math. Stat. **9**, 60 (1938).

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

A. M. Sirunyan,[1,a] A. Tumasyan,[1] W. Adam,[2] J. W. Andrejkovic,[2] T. Bergauer,[2] S. Chatterjee,[2] M. Dragicevic,[2] A. Escalante Del Valle,[2] R. Frühwirth,[2,b] M. Jeitler,[2,b] N. Krammer,[2] L. Lechner,[2] D. Liko,[2] I. Mikulec,[2] F. M. Pitters,[2] J. Schieck,[2,b] R. Schöfbeck,[2] M. Spanring,[2] S. Templ,[2] W. Waltenberger,[2] C.-E. Wulz,[2,b] V. Chekhovsky,[3] A. Litomin,[3] V. Makarenko,[3] M. R. Darwish,[4,c] E. A. De Wolf,[4] X. Janssen,[4] T. Kello,[4,d] A. Lelek,[4] H. Rejeb Sfar,[4] P. Van Mechelen,[4] S. Van Putte,[4] N. Van Remortel,[4] F. Blekman,[5] E. S. Bols,[5] J. D'Hondt,[5] J. De Clercq,[5] M. Delcourt,[5] S. Lowette,[5] S. Moortgat,[5] A. Morton,[5] D. Müller,[5] A. R. Sahasransu,[5] S. Tavernier,[5] W. Van Doninck,[5] P. Van Mulders,[5] D. Beghin,[6] B. Bilin,[6] B. Clerbaux,[6] G. De Lentdecker,[6] L. Favart,[6] A. Grebenyuk,[6] A. K. Kalsi,[6] K. Lee,[6] M. Mahdavikhorrami,[6] I. Makarenko,[6] L. Moureaux,[6] L. Pétré,[6] A. Popov,[6] N. Postiau,[6] E. Starling,[6] L. Thomas,[6] M. Vanden Bemden,[6] C. Vander Velde,[6] P. Vanlaer,[6] D. Vannerom,[6] L. Wezenbeek,[6] T. Cornelis,[7] D. Dobur,[7] M. Gruchala,[7] L. Lambrecht,[7] G. Mestdach,[7] M. Niedziela,[7] C. Roskas,[7] K. Skovpen,[7] T. T. Tran,[7] M. Tytgat,[7] W. Verbeke,[7] B. Vermassen,[7] M. Vit,[7] A. Bethani,[8] G. Bruno,[8] F. Bury,[8] C. Caputo,[8] P. David,[8] C. Delaere,[8] I. S. Donertas,[8] A. Giammanco,[8] K. Jaffel,[8] V. Lemaitre,[8] K. Mondal,[8] J. Prisciandaro,[8] A. Taliercio,[8] M. Teklishyn,[8] P. Vischia,[8] S. Wertz,[8] S. Wuyckens,[8] G. A. Alves,[9] C. Hensel,[9] A. Moraes,[9] W. L. Aldá Júnior,[10] M. Barroso Ferreira Filho,[10] H. Brandao Malbouisson,[10] W. Carvalho,[10] J. Chinellato,[10,e] E. M. Da Costa,[10] G. G. Da Silveira,[10,f] D. De Jesus Damiao,[10] S. Fonseca De Souza,[10] D. Matos Figueiredo,[10] C. Mora Herrera,[10] K. Mota Amarilo,[10] L. Mundim,[10] H. Nogima,[10] P. Rebello Teles,[10] L. J. Sanchez Rosas,[10] A. Santoro,[10] S. M. Silva Do Amaral,[10] A. Sznajder,[10] M. Thiel,[10] F. Torres Da Silva De Araujo,[10]

A. Vilela Pereira,[10] C. A. Bernardes,[11a] L. Calligaris,[11a] T. R. Fernandez Perez Tomei,[11a] E. M. Gregores,[11a,11b] D. S. Lemos,[11a] P. G. Mercadante,[11a,11b] S. F. Novaes,[11a] Sandra S. Padula,[11a] A. Aleksandrov,[12] G. Antchev,[12] I. Atanasov,[12] R. Hadjiiska,[12] P. Iaydjiev,[12] M. Misheva,[12] M. Rodozov,[12] M. Shopova,[12] G. Sultanov,[12] A. Dimitrov,[13] T. Ivanov,[13] L. Litov,[13] B. Pavlov,[13] P. Petkov,[13] A. Petrov,[13] T. Cheng,[14] W. Fang,[14,d] Q. Guo,[14] T. Javaid,[14,g] M. Mittal,[14] H. Wang,[14] L. Yuan,[14] M. Ahmad,[15] G. Bauer,[15] C. Dozen,[15,h] Z. Hu,[15] J. Martins,[15,i] Y. Wang,[15] K. Yi,[15,j,k] E. Chapon,[16] G. M. Chen,[16,g] H. S. Chen,[16,g] M. Chen,[16] F. Iemmi,[16] A. Kapoor,[16] D. Leggat,[16] H. Liao,[16] Z.-A. Liu,[16,l] R. Sharma,[16] A. Spiezia,[16] J. Tao,[16] J. Thomas-wilsker,[16] J. Wang,[16] H. Zhang,[16] S. Zhang,[16,g] J. Zhao,[16] A. Agapitos,[17] Y. Ban,[17] C. Chen,[17] Q. Huang,[17] A. Levin,[17] Q. Li,[17] M. Lu,[17] X. Lyu,[17] Y. Mao,[17] S. J. Qian,[17] D. Wang,[17] Q. Wang,[17] J. Xiao,[17] Z. You,[18] X. Gao,[19,d] H. Okawa,[19] M. Xiao,[20] C. Avila,[21] A. Cabrera,[21] C. Florez,[21] J. Fraga,[21] A. Sarkar,[21] M. A. Segura Delgado,[21] J. Jaramillo,[22] J. Mejia Guisao,[22] F. Ramirez,[22] J. D. Ruiz Alvarez,[22] C. A. Salazar González,[22] N. Vanegas Arbelaez,[22] D. Giljanovic,[23] N. Godinovic,[23] D. Lelas,[23] I. Puljak,[23] Z. Antunovic,[24] M. Kovac,[24] T. Sculac,[24] V. Brigljevic,[25] D. Ferencek,[25] D. Majumder,[25] M. Roguljic,[25] A. Starodumov,[25,m] T. Susa,[25] A. Attikis,[26] E. Erodotou,[26] A. Ioannou,[26] G. Kole,[26] M. Kolosova,[26] S. Konstantinou,[26] J. Mousa,[26] C. Nicolaou,[26] F. Ptochos,[26] P. A. Razis,[26] H. Rykaczewski,[26] H. Saka,[26] M. Finger,[27,n] M. Finger Jr.,[27,n] A. Kveton,[27] E. Ayala,[28] E. Carrera Jarrin,[29] S. Abu Zeid,[30,o] S. Khalil,[30,p] E. Salama,[30,q,o] A. Lotfy,[31] M. A. Mahmoud,[31] S. Bhowmik,[32] A. Carvalho Antunes De Oliveira,[32] R. K. Dewanjee,[32] K. Ehataht,[32] M. Kadastik,[32] J. Pata,[32] M. Raidal,[32] C. Veelken,[32] P. Eerola,[33] L. Forthomme,[33] H. Kirschenmann,[33] K. Osterberg,[33] M. Voutilainen,[33] E. Brücken,[34] F. Garcia,[34] J. Havukainen,[34] V. Karimäki,[34] M. S. Kim,[34] R. Kinnunen,[34] T. Lampén,[34] K. Lassila-Perini,[34] S. Lehti,[34] T. Lindén,[34] M. Lotti,[34] L. Martikainen,[34] H. Siikonen,[34] E. Tuominen,[34] J. Tuominiemi,[34] P. Luukka,[35] H. Petrow,[35] T. Tuuva,[35] C. Amendola,[36] M. Besancon,[36] F. Couderc,[36] M. Dejardin,[36] D. Denegri,[36] J. L. Faure,[36] F. Ferri,[36] S. Ganjour,[36] A. Givernaud,[36] P. Gras,[36] G. Hamel de Monchenault,[36] P. Jarry,[36] B. Lenzi,[36] E. Locci,[36] J. Malcles,[36] J. Rander,[36] A. Rosowsky,[36] M. Ö. Sahin,[36] A. Savoy-Navarro,[36,r] M. Titov,[36] G. B. Yu,[36] S. Ahuja,[37] F. Beaudette,[37] M. Bonanomi,[37] A. Buchot Perraguin,[37] P. Busson,[37] A. Cappati,[37] C. Charlot,[37] O. Davignon,[37] B. Diab,[37] G. Falmagne,[37] S. Ghosh,[37] R. Granier de Cassagnac,[37] A. Hakimi,[37] I. Kucher,[37] A. Lobanov,[37] M. Nguyen,[37] C. Ochando,[37] P. Paganini,[37] J. Rembser,[37] R. Salerno,[37] J. B. Sauvan,[37] Y. Sirois,[37] A. Zabi,[37] A. Zghiche,[37] J.-L. Agram,[38,s] J. Andrea,[38] D. Apparu,[38] D. Bloch,[38] G. Bourgatte,[38] J.-M. Brom,[38] E. C. Chabert,[38] C. Collard,[38] D. Darej,[38] J.-C. Fontaine,[38,s] U. Goerlach,[38] C. Grimault,[38] A.-C. Le Bihan,[38] P. Van Hove,[38] E. Asilar,[39] S. Beauceron,[39] C. Bernet,[39] G. Boudoul,[39] C. Camen,[39] A. Carle,[39] N. Chanon,[39] D. Contardo,[39] P. Depasse,[39] H. El Mamouni,[39] J. Fay,[39] S. Gascon,[39] M. Gouzevitch,[39] B. Ille,[39] Sa. Jain,[39] I. B. Laktineh,[39] H. Lattaud,[39] A. Lesauvage,[39] M. Lethuillier,[39] L. Mirabito,[39] K. Shchablo,[39] L. Torterotot,[39] G. Touquet,[39] M. Vander Donckt,[39] S. Viret,[39] I. Lomidze,[40] T. Toriashvili,[40,t] Z. Tsamalaidze,[40,n] L. Feld,[41] K. Klein,[41] M. Lipinski,[41] D. Meuser,[41] A. Pauls,[41] M. P. Rauch,[41] M. Teroerde,[41] D. Eliseev,[42] M. Erdmann,[42] P. Fackeldey,[42] B. Fischer,[42] S. Ghosh,[42] T. Hebbeker,[42] K. Hoepfner,[42] F. Ivone,[42] H. Keller,[42] L. Mastrolorenzo,[42] M. Merschmeyer,[42] A. Meyer,[42] G. Mocellin,[42] S. Mondal,[42] S. Mukherjee,[42] D. Noll,[42] A. Novak,[42] T. Pook,[42] A. Pozdnyakov,[42] Y. Rath,[42] H. Reithler,[42] J. Roemer,[42] A. Schmidt,[42] S. C. Schuler,[42] A. Sharma,[42] S. Wiedenbeck,[42] S. Zaleski,[42] C. Dziwok,[43] G. Flügge,[43] W. Haj Ahmad,[43,u] O. Hlushchenko,[43] T. Kress,[43] A. Nowack,[43] C. Pistone,[43] O. Pooth,[43] D. Roy,[43] H. Sert,[43] A. Stahl,[43,v] T. Ziemons,[43] H. Aarup Petersen,[44] M. Aldaya Martin,[44] P. Asmuss,[44] I. Babounikau,[44] S. Baxter,[44] O. Behnke,[44] A. Bermúdez Martínez,[44] A. A. Bin Anuar,[44] K. Borras,[44,w] V. Botta,[44] D. Brunner,[44] A. Campbell,[44] A. Cardini,[44] C. Cheng,[44] P. Connor,[44] S. Consuegra Rodríguez,[44] V. Danilov,[44] M. M. Defranchis,[44] L. Didukh,[44] G. Eckerlin,[44] D. Eckstein,[44] L. I. Estevez Banos,[44] O. Filatov,[44] E. Gallo,[44,x] A. Geiser,[44] A. Giraldi,[44] A. Grohsjean,[44] M. Guthoff,[44] A. Jafari,[44,y] N. Z. Jomhari,[44] H. Jung,[44] A. Kasem,[44,w] M. Kasemann,[44] H. Kaveh,[44] C. Kleinwort,[44] J. Knolle,[44] D. Krücker,[44] W. Lange,[44] T. Lenz,[44] J. Lidrych,[44] K. Lipka,[44] W. Lohmann,[44,z] T. Madlener,[44] R. Mankel,[44] I.-A. Melzer-Pellmann,[44] J. Metwally,[44] A. B. Meyer,[44] M. Meyer,[44] J. Mnich,[44] A. Mussgiller,[44] V. Myronenko,[44] Y. Otarid,[44] D. Pérez Adán,[44] D. Pitzl,[44] A. Raspereza,[44] B. Ribeiro Lopes,[44] J. Rübenach,[44] A. Saggio,[44] A. Saibel,[44] M. Savitskyi,[44] V. Scheurer,[44] C. Schwanenberger,[44,x] A. Singh,[44] R. E. Sosa Ricardo,[44] D. Stafford,[44] N. Tonon,[44] O. Turkot,[44] A. Vagnerini,[44] M. Van De Klundert,[44] R. Walsh,[44] D. Walter,[44] Y. Wen,[44] K. Wichmann,[44] C. Wissing,[44] S. Wuchterl,[44] R. Zlebcik,[44] R. Aggleton,[45] S. Bein,[45] L. Benato,[45] A. Benecke,[45] K. De Leo,[45] T. Dreyer,[45] M. Eich,[45] F. Feindt,[45] A. Fröhlich,[45] C. Garbers,[45] E. Garutti,[45] P. Gunnellini,[45] J. Haller,[45] A. Hinzmann,[45] A. Karavdina,[45] G. Kasieczka,[45] R. Klanner,[45] R. Kogler,[45] V. Kutzner,[45] J. Lange,[45] T. Lange,[45] A. Malara,[45] A. Nigamova,[45] K. J. Pena Rodriguez,[45] O. Rieger,[45] P. Schleper,[45] M. Schröder,[45] J. Schwandt,[45] D. Schwarz,[45] J. Sonneveld,[45] H. Stadie,[45] G. Steinbrück,[45] A. Tews,[45] B. Vormwald,[45] I. Zoi,[45] J. Bechtel,[46] T. Berger,[46]

E. Butz,[46] R. Caspart,[46] T. Chwalek,[46] W. De Boer,[46,a] A. Dierlamm,[46] A. Droll,[46] K. El Morabit,[46] N. Faltermann,[46]
K. Flöh,[46] M. Giffels,[46] J. o. Gosewisch,[46] A. Gottmann,[46] F. Hartmann,[46,v] C. Heidecker,[46] U. Husemann,[46] I. Katkov,[46,aa]
P. Keicher,[46] R. Koppenhöfer,[46] S. Maier,[46] M. Metzler,[46] S. Mitra,[46] Th. Müller,[46] M. Neukum,[46] G. Quast,[46] K. Rabbertz,[46]
J. Rauser,[46] D. Savoiu,[46] D. Schäfer,[46] M. Schnepf,[46] D. Seith,[46] I. Shvetsov,[46] H. J. Simonis,[46] R. Ulrich,[46]
J. Van Der Linden,[46] R. F. Von Cube,[46] M. Wassmer,[46] M. Weber,[46] S. Wieland,[46] R. Wolf,[46] S. Wozniewski,[46] S. Wunsch,[46]
G. Anagnostou,[47] P. Asenov,[47] G. Daskalakis,[47] T. Geralis,[47] A. Kyriakis,[47] D. Loukas,[47] A. Stakia,[47] M. Diamantopoulou,[48]
D. Karasavvas,[48] G. Karathanasis,[48] P. Kontaxakis,[48] C. K. Koraka,[48] A. Manousakis-katsikakis,[48] A. Panagiotou,[48]
I. Papavergou,[48] N. Saoulidou,[48] K. Theofilatos,[48] E. Tziaferi,[48] K. Vellidis,[48] E. Vourliotis,[48] G. Bakas,[49] K. Kousouris,[49]
I. Papakrivopoulos,[49] G. Tsipolitis,[49] A. Zacharopoulou,[49] I. Evangelou,[50] C. Foudas,[50] P. Gianneios,[50] P. Katsoulis,[50]
P. Kokkas,[50] N. Manthos,[50] I. Papadopoulos,[50] J. Strologas,[50] M. Csanad,[51] K. Farkas,[51] M. M. A. Gadallah,[51,bb]
S. Lökös,[51,cc] P. Major,[51] K. Mandal,[51] A. Mehta,[51] G. Pasztor,[51] A. J. Rádl,[51] O. Surányi,[51] G. I. Veres,[51] M. Bartók,[52,dd]
G. Bencze,[52] C. Hajdu,[52] D. Horvath,[52,ee] F. Sikler,[52] V. Veszpremi,[52] G. Vesztergombi,[52,a,ff] S. Czellar,[53] J. Karancsi,[53,dd]
J. Molnar,[53] Z. Szillasi,[53] D. Teyssier,[53] P. Raics,[54] Z. L. Trocsanyi,[54,ff] B. Ujvari,[54] T. Csorgo,[55,gg] F. Nemes,[55,gg] T. Novak,[55]
S. Choudhury,[56] J. R. Komaragiri,[56] D. Kumar,[56] L. Panwar,[56] P. C. Tiwari,[56] S. Bahinipati,[57,hh] D. Dash,[57] C. Kar,[57]
P. Mal,[57] T. Mishra,[57] V. K. Muraleedharan Nair Bindhu,[57,ii] A. Nayak,[57,ii] P. Saha,[57] N. Sur,[57] S. K. Swain,[57] S. Bansal,[58]
S. B. Beri,[58] V. Bhatnagar,[58] G. Chaudhary,[58] S. Chauhan,[58] N. Dhingra,[58,jj] R. Gupta,[58] A. Kaur,[58] S. Kaur,[58] P. Kumari,[58]
M. Meena,[58] K. Sandeep,[58] J. B. Singh,[58] A. K. Virdi,[58] A. Ahmed,[59] A. Bhardwaj,[59] B. C. Choudhary,[59] R. B. Garg,[59]
M. Gola,[59] S. Keshri,[59] A. Kumar,[59] M. Naimuddin,[59] P. Priyanka,[59] K. Ranjan,[59] A. Shah,[59] M. Bharti,[60,kk]
R. Bhattacharya,[60] S. Bhattacharya,[60] D. Bhowmik,[60] S. Dutta,[60] B. Gomber,[60,ll] M. Maity,[60,mm] S. Nandan,[60] P. Palit,[60]
P. K. Rout,[60] G. Saha,[60] B. Sahu,[60] S. Sarkar,[60] M. Sharan,[60] B. Singh,[60,kk] S. Thakur,[60,kk] P. K. Behera,[61] S. C. Behera,[61]
P. Kalbhor,[61] A. Muhammad,[61] R. Pradhan,[61] P. R. Pujahari,[61] A. Sharma,[61] A. K. Sikdar,[61] D. Dutta,[62] V. Jha,[62] V. Kumar,[62]
D. K. Mishra,[62] K. Naskar,[62,nn] P. K. Netrakanti,[62] L. M. Pant,[62] P. Shukla,[62] T. Aziz,[63] S. Dugad,[63] M. Kumar,[63]
G. B. Mohanty,[63] U. Sarkar,[63] S. Banerjee,[64] S. Bhattacharya,[64] R. Chudasama,[64] M. Guchait,[64] S. Karmakar,[64] S. Kumar,[64]
G. Majumder,[64] K. Mazumdar,[64] S. Mukherjee,[64] D. Roy,[64] S. Dube,[65] B. Kansal,[65] S. Pandey,[65] A. Rane,[65] A. Rastogi,[65]
S. Sharma,[65] H. Bakhshiansohi,[66,oo] M. Zeinali,[66,pp] S. Chenarani,[67,qq] S. M. Etesami,[67] M. Khakzad,[67]
M. Mohammadi Najafabadi,[67] M. Felcini,[68] M. Grunewald,[68] M. Abbrescia,[69a,69b] R. Aly,[69a,69b,rr] C. Aruta,[69a,69b]
A. Colaleo,[69a] D. Creanza,[69a,69c] N. De Filippis,[69a,69c] M. De Palma,[69a,69b] A. Di Florio,[69a,69b] A. Di Pilato,[69a,69b]
W. Elmetenawee,[69a,69b] L. Fiore,[69a] A. Gelmi,[69a,69b] M. Gul,[69a] G. Iaselli,[69a,69c] M. Ince,[69a,69b] S. Lezki,[69a,69b] G. Maggi,[69a,69c]
M. Maggi,[69a] I. Margjeka,[69a,69b] V. Mastrapasqua,[69a,69b] J. A. Merlin,[69a] S. My,[69a,69b] S. Nuzzo,[69a,69b] A. Pellecchia,[69a,69b]
A. Pompili,[69a,69b] G. Pugliese,[69a,69c] A. Ranieri,[69a] G. Selvaggi,[69a,69b] L. Silvestris,[69a] F. M. Simone,[69a,69b] R. Venditti,[69a]
P. Verwilligen,[69a] G. Abbiendi,[70a] C. Battilana,[70a,70b] D. Bonacorsi,[70a,70b] L. Borgonovi,[70a] S. Braibant-Giacomelli,[70a,70b]
L. Brigliadori,[70a] R. Campanini,[70a,70b] P. Capiluppi,[70a,70b] A. Castro,[70a,70b] F. R. Cavallo,[70a] C. Ciocca,[70a] M. Cuffiani,[70a,70b]
G. M. Dallavalle,[70a] T. Diotalevi,[70a,70b] F. Fabbri,[70a] A. Fanfani,[70a,70b] P. Giacomelli,[70a] L. Giommi,[70a,70b] C. Grandi,[70a]
L. Guiducci,[70a,70b] S. Lo Meo,[70a,ss] L. Lunerti,[70a,70b] S. Marcellini,[70a] G. Masetti,[70a] F. L. Navarria,[70a,70b] A. Perrotta,[70a]
F. Primavera,[70a,70b] A. M. Rossi,[70a,70b] T. Rovelli,[70a,70b] G. P. Siroli,[70a,70b] N. Tosi,[70a] S. Albergo,[71a,71b,tt] S. Costa,[71a,71b,tt]
A. Di Mattia,[71a] R. Potenza,[71a,71b] A. Tricomi,[71a,71b,tt] C. Tuve,[71a,71b] G. Barbagli,[72a] A. Cassese,[72a] R. Ceccarelli,[72a,72b]
V. Ciulli,[72a,72b] C. Civinini,[72a] R. D'Alessandro,[72a,72b] F. Fiori,[72a,72b] E. Focardi,[72a,72b] G. Latino,[72a,72b] P. Lenzi,[72a,72b]
M. Lizzo,[72a,72b] M. Meschini,[72a] S. Paoletti,[72a] R. Seidita,[72a,72b] G. Sguazzoni,[72a] L. Viliani,[72a] L. Benussi,[73] S. Bianco,[73]
D. Piccolo,[73] M. Bozzo,[74a,74b] F. Ferro,[74a] R. Mulargia,[74a,74b] E. Robutti,[74a] S. Tosi,[74a,74b] A. Benaglia,[75a] F. Brivio,[75a,75b]
F. Cetorelli,[75a,75b] V. Ciriolo,[75a,75b,v] F. De Guio,[75a,75b] M. E. Dinardo,[75a,75b] P. Dini,[75a] S. Gennai,[75a] A. Ghezzi,[75a,75b]
P. Govoni,[75a,75b] L. Guzzi,[75a,75b] M. Malberti,[75a] S. Malvezzi,[75a] A. Massironi,[75a] D. Menasce,[75a] F. Monti,[75a,75b]
L. Moroni,[75a] M. Paganoni,[75a,75b] D. Pedrini,[75a] S. Ragazzi,[75a,75b] T. Tabarelli de Fatis,[75a,75b] D. Valsecchi,[75a,75b,v]
D. Zuolo,[75a,75b] S. Buontempo,[76a] F. Carnevali,[76a,76b] N. Cavallo,[76a,76c] A. De Iorio,[76a,76b] F. Fabozzi,[76a,76c]
A. O. M. Iorio,[76a,76b] L. Lista,[76a,76b] S. Meola,[76a,76d,v] P. Paolucci,[76a,v] B. Rossi,[76a] C. Sciacca,[76a,76b] P. Azzi,[77a]
N. Bacchetta,[77a] D. Bisello,[77a,77b] P. Bortignon,[77a] A. Bragagnolo,[77a,77b] R. Carlin,[77a,77b] P. Checchia,[77a]
P. De Castro Manzano,[77a] T. Dorigo,[77a] F. Gasparini,[77a,77b] U. Gasparini,[77a,77b] S. Y. Hoh,[77a,77b] L. Layer,[77a,uu]
M. Margoni,[77a,77b] A. T. Meneguzzo,[77a,77b] M. Presilla,[77a,77b] P. Ronchese,[77a,77b] R. Rossin,[77a,77b] F. Simonetto,[77a,77b]
G. Strong,[77a] M. Tosi,[77a,77b] H. Yarar,[77a,77b] M. Zanetti,[77a,77b] P. Zotto,[77a,77b] A. Zucchetta,[77a,77b] G. Zumerle,[77a,77b]
C. Aime`,[78a,78b] A. Braghieri,[78a] S. Calzaferri,[78a,78b] D. Fiorina,[78a,78b] P. Montagna,[78a,78b] S. P. Ratti,[78a,78b] V. Re,[78a]

M. Ressegotti,[78a,78b] C. Riccardi,[78a,78b] P. Salvini,[78a] I. Vai,[78a] P. Vitulo,[78a,78b] G. M. Bilei,[79a] D. Ciangottini,[79a,79b] L. Fanò,[79a,79b] P. Lariccia,[79a,79b] M. Magherini,[79a,79b] G. Mantovani,[79a,79b] V. Mariani,[79a,79b] M. Menichelli,[79a] F. Moscatelli,[79a] A. Piccinelli,[79a,79b] A. Rossi,[79a,79b] A. Santocchia,[79a,79b] D. Spiga,[79a] T. Tedeschi,[79a,79b] P. Azzurri,[80a] G. Bagliesi,[80a] V. Bertacchi,[80a,80c] L. Bianchini,[80a] T. Boccali,[80a] E. Bossini,[80a,80b] R. Castaldi,[80a] M. A. Ciocci,[80a,80b] R. Dell'Orso,[80a] M. R. Di Domenico,[80a,80d] S. Donato,[80a] A. Giassi,[80a] M. T. Grippo,[80a] F. Ligabue,[80a,80c] E. Manca,[80a,80c] G. Mandorli,[80a,80c] A. Messineo,[80a,80b] F. Palla,[80a] S. Parolia,[80a,80b] G. Ramirez-Sanchez,[80a,80c] A. Rizzi,[80a,80b] G. Rolandi,[80a,80c] S. Roy Chowdhury,[80a,80c] A. Scribano,[80a] N. Shafiei,[80a,80b] P. Spagnolo,[80a] R. Tenchini,[80a] G. Tonelli,[80a,80b] N. Turini,[80a,80d] A. Venturi,[80a] P. G. Verdini,[80a] M. Campana,[81a,81b] F. Cavallari,[81a] M. Cipriani,[81a,81b] D. Del Re,[81a,81b] E. Di Marco,[81a] M. Diemoz,[81a] E. Longo,[81a,81b] P. Meridiani,[81a] G. Organtini,[81a,81b] F. Pandolfi,[81a] R. Paramatti,[81a,81b] C. Quaranta,[81a,81b] S. Rahatlou,[81a,81b] C. Rovelli,[81a] F. Santanastasio,[81a,81b] L. Soffi,[81a] R. Tramontano,[81a,81b] N. Amapane,[82a,82b] R. Arcidiacono,[82a,82c] S. Argiro,[82a,82b] M. Arneodo,[82a,82c] N. Bartosik,[82a] R. Bellan,[82a,82b] A. Bellora,[82a,82b] J. Berenguer Antequera,[82a,82b] C. Biino,[82a] N. Cartiglia,[82a] S. Cometti,[82a] M. Costa,[82a,82b] R. Covarelli,[82a,82b] N. Demaria,[82a] B. Kiani,[82a,82b] F. Legger,[82a] C. Mariotti,[82a] S. Maselli,[82a] E. Migliore,[82a,82b] E. Monteil,[82a,82b] M. Monteno,[82a] M. M. Obertino,[82a,82b] G. Ortona,[82a] L. Pacher,[82a,82b] N. Pastrone,[82a] M. Pelliccioni,[82a] G. L. Pinna Angioni,[82a,82b] M. Ruspa,[82a,82c] R. Salvatico,[82a,82b] K. Shchelina,[82a,82b] F. Siviero,[82a,82b] V. Sola,[82a] A. Solano,[82a,82b] D. Soldi,[82a,82b] A. Staiano,[82a] M. Tornago,[82a,82b] D. Trocino,[82a,82b] S. Belforte,[83a] V. Candelise,[83a,83b] M. Casarsa,[83a] F. Cossutti,[83a] A. Da Rold,[83a,83b] G. Della Ricca,[83a,83b] G. Sorrentino,[83a,83b] F. Vazzoler,[83a,83b] S. Dogra,[84] C. Huh,[84] B. Kim,[84] D. H. Kim,[84] G. N. Kim,[84] J. Kim,[84] J. Lee,[84] S. W. Lee,[84] C. S. Moon,[84] Y. D. Oh,[84] S. I. Pak,[84] B. C. Radburn-Smith,[84] S. Sekmen,[84] Y. C. Yang,[84] H. Kim,[85] D. H. Moon,[85] T. J. Kim,[86] J. Park,[86] S. Cho,[87] S. Choi,[87] Y. Go,[87] B. Hong,[87] K. Lee,[87] K. S. Lee,[87] J. Lim,[87] J. Park,[87] S. K. Park,[87] J. Yoo,[87] J. Goh,[88] A. Gurtu,[88] H. S. Kim,[89] Y. Kim,[89] J. Almond,[90] J. H. Bhyun,[90] J. Choi,[90] S. Jeon,[90] J. Kim,[90] J. S. Kim,[90] S. Ko,[90] H. Kwon,[90] H. Lee,[90] S. Lee,[90] B. H. Oh,[90] M. Oh,[90] S. B. Oh,[90] H. Seo,[90] U. K. Yang,[90] I. Yoon,[90] D. Jeon,[91] J. H. Kim,[91] B. Ko,[91] J. S. H. Lee,[91] I. C. Park,[91] Y. Roh,[91] D. Song,[91] I. J. Watson,[91] S. Ha,[92] H. D. Yoo,[92] Y. Choi,[93] Y. Jeong,[93] H. Lee,[93] Y. Lee,[93] I. Yu,[93] T. Beyrouthy,[94] Y. Maghrbi,[94] V. Veckalns,[95,vv] M. Ambrozas,[96] A. Juodagalvis,[96] A. Rinkevicius,[96] G. Tamulaitis,[96] A. Vaitkevicius,[96] N. Bin Norjoharuddeen,[97] W. A. T. Wan Abdullah,[97] M. N. Yusli,[97] Z. Zolkapli,[97] J. F. Benitez,[98] A. Castaneda Hernandez,[98] J. A. Murillo Quijada,[98] L. Valencia Palomo,[98] G. Ayala,[99] H. Castilla-Valdez,[99] E. De La Cruz-Burelo,[99] I. Heredia-De La Cruz,[99,ww] R. Lopez-Fernandez,[99] C. A. Mondragon Herrera,[99] D. A. Perez Navarro,[99] A. Sanchez-Hernandez,[99] S. Carrillo Moreno,[100] C. Oropeza Barrera,[100] M. Ramirez-Garcia,[100] F. Vazquez Valencia,[100] I. Pedraza,[101] H. A. Salazar Ibarguen,[101] C. Uribe Estrada,[101] J. Mijuskovic,[102,xx] N. Raicevic,[102] D. Krofcheck,[103] S. Bheesette,[104] P. H. Butler,[104] A. Ahmad,[105] M. I. Asghar,[105] A. Awais,[105] M. I. M. Awan,[105] H. R. Hoorani,[105] W. A. Khan,[105] M. A. Shah,[105] M. Shoaib,[105] M. Waqas,[105] V. Avati,[106] L. Grzanka,[106] M. Malawski,[106] H. Bialkowska,[107] M. Bluj,[107] B. Boimska,[107] T. Frueboes,[107] M. Górski,[107] M. Kazana,[107] M. Szleper,[107] P. Traczyk,[107] P. Zalewski,[107] K. Bunkowski,[108] K. Doroba,[108] A. Kalinowski,[108] M. Konecki,[108] J. Krolikowski,[108] M. Walczak,[108] M. Araujo,[109] P. Bargassa,[109] D. Bastos,[109] A. Boletti,[109] P. Faccioli,[109] M. Gallinaro,[109] J. Hollar,[109] N. Leonardo,[109] T. Niknejad,[109] M. Pisano,[109] J. Seixas,[109] O. Toldaiev,[109] J. Varela,[109] S. Afanasiev,[110] D. Budkouski,[110] P. Bunin,[110] M. Gavrilenko,[110] I. Golutvin,[110] I. Gorbunov,[110] A. Kamenev,[110] V. Karjavine,[110] A. Lanev,[110] A. Malakhov,[110] V. Matveev,[110,yy,zz] V. Palichik,[110] V. Perelygin,[110] M. Savina,[110] D. Seitova,[110] V. Shalaev,[110] S. Shmatov,[110] S. Shulha,[110] V. Smirnov,[110] O. Teryaev,[110] N. Voytishin,[110] A. Zarubin,[110] I. Zhizhin,[110] G. Gavrilov,[111] V. Golovtcov,[111] Y. Ivanov,[111] V. Kim,[111,aaa] E. Kuznetsova,[111,bbb] V. Murzin,[111] V. Oreshkin,[111] I. Smirnov,[111] D. Sosnov,[111] V. Sulimov,[111] L. Uvarov,[111] S. Volkov,[111] A. Vorobyev,[111] Yu. Andreev,[112] A. Dermenev,[112] S. Gninenko,[112] N. Golubev,[112] A. Karneyeu,[112] M. Kirsanov,[112] N. Krasnikov,[112] A. Pashenkov,[112] G. Pivovarov,[112] D. Tlisov,[112,a] A. Toropin,[112] V. Epshteyn,[113] V. Gavrilov,[113] N. Lychkovskaya,[113] A. Nikitenko,[113,ccc] V. Popov,[113] G. Safronov,[113] A. Spiridonov,[113] A. Stepennov,[113] M. Toms,[113] E. Vlasov,[113] A. Zhokin,[113] T. Aushev,[114] K. Ivanov,[114] R. Chistov,[115,ddd] M. Danilov,[115,eee] A. Oskin,[115] P. Parygin,[115] S. Polikarpov,[115,eee] V. Andreev,[116] M. Azarkin,[116] I. Dremin,[116] M. Kirakosyan,[116] A. Terkulov,[116] A. Belyaev,[117] E. Boos,[117] M. Dubinin,[117,fff] L. Dudko,[117] A. Ershov,[117] A. Gribushin,[117] V. Klyukhin,[117] O. Kodolova,[117] I. Lokhtin,[117] S. Obraztsov,[117] S. Petrushanko,[117] V. Savrin,[117] A. Snigirev,[117] V. Blinov,[118,ggg] T. Dimova,[118,ggg] L. Kardapoltsev,[118,ggg] I. Ovtin,[118,ggg] Y. Skovpen,[118,ggg] I. Azhgirey,[119] I. Bayshev,[119] V. Kachanov,[119] A. Kalinin,[119] D. Konstantinov,[119] V. Petrov,[119] R. Ryutin,[119] A. Sobol,[119] S. Troshin,[119] N. Tyurin,[119] A. Uzunian,[119] A. Volkov,[119] A. Babaev,[120] V. Okhotnikov,[120] L. Sukhikh,[120] V. Borchsh,[121] V. Ivanchenko,[121] E. Tcherniaev,[121] P. Adzic,[122,hhh] M. Dordevic,[122] P. Milenovic,[122] J. Milosevic,[122] V. Milosevic,[122] M. Aguilar-Benitez,[123]

J. Alcaraz Maestre,[123] A. Álvarez Fernández,[123] I. Bachiller,[123] M. Barrio Luna,[123] Cristina F. Bedoya,[123]
C. A. Carrillo Montoya,[123] M. Cepeda,[123] M. Cerrada,[123] N. Colino,[123] B. De La Cruz,[123] A. Delgado Peris,[123]
J. P. Fernández Ramos,[123] J. Flix,[123] M. C. Fouz,[123] O. Gonzalez Lopez,[123] S. Goy Lopez,[123] J. M. Hernandez,[123]
M. I. Josa,[123] J. León Holgado,[123] D. Moran,[123] Á. Navarro Tobar,[123] A. Pérez-Calero Yzquierdo,[123] J. Puerta Pelayo,[123]
I. Redondo,[123] L. Romero,[123] S. Sánchez Navas,[123] M. S. Soares,[123] L. Urda Gómez,[123] C. Willmott,[123] J. F. de Trocóniz,[124]
R. Reyes-Almanza,[124] B. Alvarez Gonzalez,[125] J. Cuevas,[125] C. Erice,[125] J. Fernandez Menendez,[125] S. Folgueras,[125]
I. Gonzalez Caballero,[125] E. Palencia Cortezon,[125] C. Ramón Álvarez,[125] J. Ripoll Sau,[125] V. Rodríguez Bouza,[125]
A. Trapote,[125] J. A. Brochero Cifuentes,[126] I. J. Cabrillo,[126] A. Calderon,[126] B. Chazin Quero,[126] J. Duarte Campderros,[126]
M. Fernandez,[126] C. Fernandez Madrazo,[126] P. J. Fernández Manteca,[126] A. García Alonso,[126] G. Gomez,[126]
C. Martinez Rivero,[126] P. Martinez Ruiz del Arbol,[126] F. Matorras,[126] P. Matorras Cuevas,[126] J. Piedra Gomez,[126]
C. Prieels,[126] F. Ricci-Tam,[126] T. Rodrigo,[126] A. Ruiz-Jimeno,[126] L. Scodellaro,[126] N. Trevisani,[126] I. Vila,[126]
J. M. Vizan Garcia,[126] MK Jayananda,[127] B. Kailasapathy,[127,iii] D. U. J. Sonnadara,[127] D. D. C. Wickramarathna,[127]
W. G. D. Dharmaratna,[128] K. Liyanage,[128] N. Perera,[128] N. Wickramage,[128] T. K. Aarrestad,[129] D. Abbaneo,[129]
J. Alimena,[129] E. Auffray,[129] G. Auzinger,[129] J. Baechler,[129] P. Baillon,[129,a] A. H. Ball,[129] D. Barney,[129] J. Bendavid,[129]
N. Beni,[129] M. Bianco,[129] A. Bocci,[129] E. Brondolin,[129] T. Camporesi,[129] M. Capeans Garrido,[129] G. Cerminara,[129]
S. S. Chhibra,[129] L. Cristella,[129] D. d'Enterria,[129] A. Dabrowski,[129] N. Daci,[129] A. David,[129] A. De Roeck,[129] M. Deile,[129]
R. Di Maria,[129] M. Dobson,[129] M. Dünser,[129] N. Dupont,[129] A. Elliott-Peisert,[129] N. Emriskova,[129] F. Fallavollita,[129,jjj]
D. Fasanella,[129] S. Fiorendi,[129] A. Florent,[129] G. Franzoni,[129] J. Fulcher,[129] W. Funk,[129] S. Giani,[129] D. Gigi,[129] K. Gill,[129]
F. Glege,[129] L. Gouskos,[129] M. Haranko,[129] J. Hegeman,[129] Y. Iiyama,[129] V. Innocente,[129] T. James,[129] P. Janot,[129]
J. Kaspar,[129] J. Kieseler,[129] M. Komm,[129] N. Kratochwil,[129] C. Lange,[129] S. Laurila,[129] P. Lecoq,[129] K. Long,[129]
C. Lourenço,[129] L. Malgeri,[129] S. Mallios,[129] M. Mannelli,[129] F. Meijers,[129] S. Mersi,[129] E. Meschi,[129] F. Moortgat,[129]
M. Mulders,[129] S. Orfanelli,[129] L. Orsini,[129] F. Pantaleo,[129] L. Pape,[129] E. Perez,[129] M. Peruzzi,[129] A. Petrilli,[129]
G. Petrucciani,[129] A. Pfeiffer,[129] M. Pierini,[129] M. Pitt,[129] H. Qu,[129] T. Quast,[129] D. Rabady,[129] A. Racz,[129] M. Rieger,[129]
M. Rovere,[129] H. Sakulin,[129] J. Salfeld-Nebgen,[129] S. Scarfi,[129] C. Schäfer,[129] C. Schwick,[129] M. Selvaggi,[129] A. Sharma,[129]
P. Silva,[129] W. Snoeys,[129] P. Sphicas,[129,kkk] S. Summers,[129] V. R. Tavolaro,[129] D. Treille,[129] A. Tsirou,[129] G. P. Van Onsem,[129]
M. Verzetti,[129] J. Wanczyk,[129,lll] K. A. Wozniak,[129] W. D. Zeuner,[129] L. Caminada,[130,mmm] A. Ebrahimi,[130] W. Erdmann,[130]
R. Horisberger,[130] Q. Ingram,[130] H. C. Kaestli,[130] D. Kotlinski,[130] U. Langenegger,[130] M. Missiroli,[130] T. Rohe,[130]
K. Androsov,[131,lll] M. Backhaus,[131] P. Berger,[131] A. Calandri,[131] N. Chernyavskaya,[131] A. De Cosa,[131] G. Dissertori,[131]
M. Dittmar,[131] M. Donegà,[131] C. Dorfer,[131] F. Eble,[131] T. Gadek,[131] T. A. Gómez Espinosa,[131] C. Grab,[131] D. Hits,[131]
W. Lustermann,[131] A.-M. Lyon,[131] R. A. Manzoni,[131] C. Martin Perez,[131] M. T. Meinhard,[131] F. Micheli,[131]
F. Nessi-Tedaldi,[131] J. Niedziela,[131] F. Pauss,[131] V. Perovic,[131] G. Perrin,[131] S. Pigazzini,[131] M. G. Ratti,[131] M. Reichmann,[131]
C. Reissel,[131] T. Reitenspiess,[131] B. Ristic,[131] D. Ruini,[131] D. A. Sanz Becerra,[131] M. Schönenberger,[131] V. Stampf,[131]
J. Steggemann,[131,lll] R. Wallny,[131] D. H. Zhu,[131] C. Amsler,[132,nnn] P. Bärtschi,[132] C. Botta,[132] D. Brzhechko,[132]
M. F. Canelli,[132] A. De Wit,[132] R. Del Burgo,[132] J. K. Heikkilä,[132] M. Huwiler,[132] A. Jofrehei,[132] B. Kilminster,[132]
S. Leontsinis,[132] A. Macchiolo,[132] P. Meiring,[132] V. M. Mikuni,[132] U. Molinatti,[132] I. Neutelings,[132] G. Rauco,[132]
A. Reimers,[132] P. Robmann,[132] S. Sanchez Cruz,[132] K. Schweiger,[132] Y. Takahashi,[132] C. Adloff,[133,ooo] C. M. Kuo,[133]
W. Lin,[133] A. Roy,[133] T. Sarkar,[133,mm] S. S. Yu,[133] L. Ceard,[134] P. Chang,[134] Y. Chao,[134] K. F. Chen,[134] P. H. Chen,[134]
W.-S. Hou,[134] Y. y. Li,[134] R.-S. Lu,[134] E. Paganis,[134] A. Psallidas,[134] A. Steen,[134] E. Yazgan,[134] P. r. Yu,[134]
B. Asavapibhop,[135] C. Asawatangtrakuldee,[135] N. Srimanobhas,[135] F. Boran,[136] S. Damarseckin,[136,ppp] Z. S. Demiroglu,[136]
F. Dolek,[136] I. Dumanoglu,[136,qqq] E. Eskut,[136] G. Gokbulut,[136] Y. Guler,[136] E. Gurpinar Guler,[136,rrr] I. Hos,[136,sss] C. Isik,[136]
E. E. Kangal,[136,ttt] O. Kara,[136] A. Kayis Topaksu,[136] U. Kiminsu,[136] G. Onengut,[136] K. Ozdemir,[136,uuu] A. Polatoz,[136]
A. E. Simsek,[136] B. Tali,[136,vvv] U. G. Tok,[136] S. Turkcapar,[136] I. S. Zorbakir,[136] C. Zorbilmez,[136] B. Isildak,[137,www]
G. Karapinar,[137,xxx] K. Ocalan,[137,yyy] M. Yalvac,[137,zzz] B. Akgun,[138] I. O. Atakisi,[138] E. Gülmez,[138] M. Kaya,[138,aaaa]
O. Kaya,[138,bbbb] Ö. Özçelik,[138] S. Tekten,[138,cccc] E. A. Yetkin,[138,dddd] A. Cakir,[139] K. Cankocak,[139,qqq] Y. Komurcu,[139]
S. Sen,[139,eeee] F. Aydogmus Sen,[140] S. Cerci,[140,vvv] B. Kaynak,[140] S. Ozkorucuklu,[140] D. Sunar Cerci,[140,vvv] B. Grynyov,[141]
L. Levchuk,[142] D. Anthony,[143] E. Bhal,[143] S. Bologna,[143] J. J. Brooke,[143] A. Bundock,[143] E. Clement,[143] D. Cussans,[143]
H. Flacher,[143] J. Goldstein,[143] G. P. Heath,[143] H. F. Heath,[143] L. Kreczko,[143] B. Krikler,[143] S. Paramesvaran,[143] T. Sakuma,[143]
S. Seif El Nasr-Storey,[143] V. J. Smith,[143] N. Stylianou,[143,ffff] J. Taylor,[143] A. Titterton,[143] R. White,[143] K. W. Bell,[144]
A. Belyaev,[144,gggg] C. Brew,[144] R. M. Brown,[144] D. J. A. Cockerill,[144] K. V. Ellis,[144] K. Harder,[144] S. Harper,[144] J. Linacre,[144]

K. Manolopoulos,[144] D. M. Newbold,[144] E. Olaiya,[144] D. Petyt,[144] T. Reis,[144] T. Schuh,[144] C. H. Shepherd-Themistocleous,[144] A. Thea,[144] I. R. Tomalin,[144] T. Williams,[144] R. Bainbridge,[145] P. Bloch,[145] S. Bonomally,[145] J. Borg,[145] S. Breeze,[145] O. Buchmuller,[145] V. Cepaitis,[145] G. S. Chahal,[145,hhhh] D. Colling,[145] P. Dauncey,[145] G. Davies,[145] M. Della Negra,[145] S. Fayer,[145] G. Fedi,[145] G. Hall,[145] M. H. Hassanshahi,[145] G. Iles,[145] J. Langford,[145] L. Lyons,[145] A.-M. Magnan,[145] S. Malik,[145] A. Martelli,[145] J. Nash,[145,iiii] V. Palladino,[145] M. Pesaresi,[145] D. M. Raymond,[145] A. Richards,[145] A. Rose,[145] E. Scott,[145] C. Seez,[145] A. Shtipliyski,[145] A. Tapper,[145] K. Uchida,[145] T. Virdee,[145,v] N. Wardle,[145] S. N. Webb,[145] D. Winterbottom,[145] A. G. Zecchinelli,[145] K. Coldham,[146] J. E. Cole,[146] A. Khan,[146] P. Kyberd,[146] C. K. Mackay,[146] I. D. Reid,[146] L. Teodorescu,[146] S. Zahid,[146] S. Abdullin,[147] A. Brinkerhoff,[147] B. Caraway,[147] J. Dittmann,[147] K. Hatakeyama,[147] A. R. Kanuganti,[147] B. McMaster,[147] N. Pastika,[147] S. Sawant,[147] C. Smith,[147] C. Sutantawibul,[147] J. Wilson,[147] R. Bartek,[148] A. Dominguez,[148] R. Uniyal,[148] A. M. Vargas Hernandez,[148] A. Buccilli,[149] O. Charaf,[149] S. I. Cooper,[149] D. Di Croce,[149] S. V. Gleyzer,[149] C. Henderson,[149] C. U. Perez,[149] P. Rumerio,[149,jjjj] C. West,[149] A. Akpinar,[150] A. Albert,[150] D. Arcaro,[150] C. Cosby,[150] Z. Demiragli,[150] E. Fontanesi,[150] D. Gastler,[150] J. Rohlf,[150] K. Salyer,[150] D. Sperka,[150] D. Spitzbart,[150] I. Suarez,[150] A. Tsatsos,[150] S. Yuan,[150] D. Zou,[150] G. Benelli,[151] B. Burkle,[151] X. Coubez,[151,w] D. Cutts,[151] Y. t. Duh,[151] M. Hadley,[151] U. Heintz,[151] J. M. Hogan,[151,kkkk] E. Laird,[151] G. Landsberg,[151] K. T. Lau,[151] J. Lee,[151] J. Luo,[151] M. Narain,[151] S. Sagir,[151,llll] E. Usai,[151] W. Y. Wong,[151] X. Yan,[151] D. Yu,[151] W. Zhang,[151] C. Brainerd,[152] R. Breedon,[152] M. Calderon De La Barca Sanchez,[152] M. Chertok,[152] J. Conway,[152] P. T. Cox,[152] R. Erbacher,[152] G. Haza,[152] F. Jensen,[152] O. Kukral,[152] R. Lander,[152] M. Mulhearn,[152] D. Pellett,[152] B. Regnery,[152] D. Taylor,[152] M. Tripathi,[152] Y. Yao,[152] F. Zhang,[152] M. Bachtis,[153] R. Cousins,[153] A. Dasgupta,[153] A. Datta,[153] D. Hamilton,[153] J. Hauser,[153] M. Ignatenko,[153] M. A. Iqbal,[153] T. Lam,[153] N. Mccoll,[153] W. A. Nash,[153] S. Regnard,[153] D. Saltzberg,[153] C. Schnaible,[153] B. Stone,[153] V. Valuev,[153] K. Burt,[154] Y. Chen,[154] R. Clare,[154] J. W. Gary,[154] M. Gordon,[154] G. Hanson,[154] G. Karapostoli,[154] O. R. Long,[154] N. Manganelli,[154] M. Olmedo Negrete,[154] W. Si,[154] S. Wimpenny,[154] Y. Zhang,[154] J. G. Branson,[155] P. Chang,[155] S. Cittolin,[155] S. Cooperstein,[155] N. Deelen,[155] J. Duarte,[155] R. Gerosa,[155] L. Giannini,[155] D. Gilbert,[155] J. Guiang,[155] R. Kansal,[155] V. Krutelyov,[155] R. Lee,[155] J. Letts,[155] M. Masciovecchio,[155] S. May,[155] S. Padhi,[155] M. Pieri,[155] B. V. Sathia Narayanan,[155] V. Sharma,[155] M. Tadel,[155] A. Vartak,[155] F. Würthwein,[155] Y. Xiang,[155] A. Yagil,[155] N. Amin,[156] C. Campagnari,[156] M. Citron,[156] A. Dorsett,[156] V. Dutta,[156] J. Incandela,[156] M. Kilpatrick,[156] J. Kim,[156] B. Marsh,[156] H. Mei,[156] M. Oshiro,[156] A. Ovcharova,[156] M. Quinnan,[156] J. Richman,[156] U. Sarica,[156] D. Stuart,[156] S. Wang,[156] A. Bornheim,[157] O. Cerri,[157] I. Dutta,[157] J. M. Lawhorn,[157] N. Lu,[157] J. Mao,[157] H. B. Newman,[157] J. Ngadiuba,[157] T. Q. Nguyen,[157] M. Spiropulu,[157] J. R. Vlimant,[157] C. Wang,[157] S. Xie,[157] Z. Zhang,[157] R. Y. Zhu,[157] J. Alison,[158] M. B. Andrews,[158] T. Ferguson,[158] T. Mudholkar,[158] M. Paulini,[158] I. Vorobiev,[158] J. P. Cumalat,[159] W. T. Ford,[159] E. MacDonald,[159] R. Patel,[159] A. Perloff,[159] K. Stenson,[159] K. A. Ulmer,[159] S. R. Wagner,[159] J. Alexander,[160] Y. Cheng,[160] J. Chu,[160] D. J. Cranshaw,[160] K. Mcdermott,[160] J. Monroy,[160] J. R. Patterson,[160] D. Quach,[160] J. Reichert,[160] A. Ryd,[160] W. Sun,[160] S. M. Tan,[160] Z. Tao,[160] J. Thom,[160] P. Wittich,[160] M. Zientek,[160] M. Albrow,[161] M. Alyari,[161] G. Apollinari,[161] A. Apresyan,[161] A. Apyan,[161] S. Banerjee,[161] L. A. T. Bauerdick,[161] A. Beretvas,[161] D. Berry,[161] J. Berryhill,[161] P. C. Bhat,[161] K. Burkett,[161] J. N. Butler,[161] A. Canepa,[161] G. B. Cerati,[161] H. W. K. Cheung,[161] F. Chlebana,[161] M. Cremonesi,[161] K. F. Di Petrillo,[161] V. D. Elvira,[161] J. Freeman,[161] Z. Gecse,[161] L. Gray,[161] D. Green,[161] S. Grünendahl,[161] O. Gutsche,[161] R. M. Harris,[161] R. Heller,[161] T. C. Herwig,[161] J. Hirschauer,[161] B. Jayatilaka,[161] S. Jindariani,[161] M. Johnson,[161] U. Joshi,[161] P. Klabbers,[161] T. Klijnsma,[161] B. Klima,[161] M. J. Kortelainen,[161] K. H. M. Kwok,[161] S. Lammel,[161] D. Lincoln,[161] R. Lipton,[161] T. Liu,[161] J. Lykken,[161] C. Madrid,[161] K. Maeshima,[161] C. Mantilla,[161] D. Mason,[161] P. McBride,[161] P. Merkel,[161] S. Mrenna,[161] S. Nahn,[161] V. O'Dell,[161] V. Papadimitriou,[161] K. Pedro,[161] C. Pena,[161,fff] O. Prokofyev,[161] F. Ravera,[161] A. Reinsvold Hall,[161] L. Ristori,[161] B. Schneider,[161] E. Sexton-Kennedy,[161] N. Smith,[161] A. Soha,[161] L. Spiegel,[161] S. Stoynev,[161] J. Strait,[161] L. Taylor,[161] S. Tkaczyk,[161] N. V. Tran,[161] L. Uplegger,[161] E. W. Vaandering,[161] H. A. Weber,[161] A. Woodard,[161] D. Acosta,[162] P. Avery,[162] D. Bourilkov,[162] L. Cadamuro,[162] V. Cherepanov,[162] F. Errico,[162] R. D. Field,[162] D. Guerrero,[162] B. M. Joshi,[162] M. Kim,[162] J. Konigsberg,[162] A. Korytov,[162] K. H. Lo,[162] K. Matchev,[162] N. Menendez,[162] G. Mitselmakher,[162] D. Rosenzweig,[162] S. Rosenzweig,[162] K. Shi,[162] J. Sturdy,[162] J. Wang,[162] E. Yigitbasi,[162] X. Zuo,[162] T. Adams,[163] A. Askew,[163] D. Diaz,[163] R. Habibullah,[163] S. Hagopian,[163] V. Hagopian,[163] K. F. Johnson,[163] R. Khurana,[163] T. Kolberg,[163] G. Martinez,[163] H. Prosper,[163] C. Schiber,[163] R. Yohay,[163] J. Zhang,[163] M. M. Baarmand,[164] S. Butalla,[164] T. Elkafrawy,[164,o] M. Hohlmann,[164] R. Kumar Verma,[164] D. Noonan,[164] M. Rahmani,[164] M. Saunders,[164] F. Yumiceva,[164] M. R. Adams,[165] L. Apanasevich,[165] H. Becerril Gonzalez,[165] R. Cavanaugh,[165] X. Chen,[165] S. Dittmer,[165] O. Evdokimov,[165] C. E. Gerber,[165]

D. A. Hangal,[165] D. J. Hofman,[165] C. Mills,[165] G. Oh,[165] T. Roy,[165] M. B. Tonjes,[165] N. Varelas,[165] J. Viinikainen,[165] X. Wang,[165] Z. Wu,[165] Z. Ye,[165] M. Alhusseini,[166] K. Dilsiz,[166,mmmm] S. Durgut,[166] R. P. Gandrajula,[166] M. Haytmyradov,[166] V. Khristenko,[166] O. K. Köseyan,[166] J.-P. Merlo,[166] A. Mestvirishvili,[166,nnnn] A. Moeller,[166] J. Nachtman,[166] H. Ogul,[166,oooo] Y. Onel,[166] F. Ozok,[166,pppp] A. Penzo,[166] C. Snyder,[166] E. Tiras,[166,qqqq] J. Wetzel,[166] O. Amram,[167] B. Blumenfeld,[167] L. Corcodilos,[167] J. Davis,[167] M. Eminizer,[167] A. V. Gritsan,[167] S. Kyriacou,[167] P. Maksimovic,[167] J. Roskes,[167] M. Swartz,[167] T. Á. Vámi,[167] C. Baldenegro Barrera,[168] P. Baringer,[168] A. Bean,[168] A. Bylinkin,[168] T. Isidori,[168] S. Khalil,[168] J. King,[168] G. Krintiras,[168] A. Kropivnitskaya,[168] C. Lindsey,[168] N. Minafra,[168] M. Murray,[168] C. Rogan,[168] C. Royon,[168] S. Sanders,[168] E. Schmitz,[168] J. D. Tapia Takaki,[168] Q. Wang,[168] J. Williams,[168] G. Wilson,[168] S. Duric,[169] A. Ivanov,[169] K. Kaadze,[169] D. Kim,[169] Y. Maravin,[169] T. Mitchell,[169] A. Modak,[169] K. Nam,[169] F. Rebassoo,[170] D. Wright,[170] E. Adams,[171] A. Baden,[171] O. Baron,[171] A. Belloni,[171] S. C. Eno,[171] Y. Feng,[171] N. J. Hadley,[171] S. Jabeen,[171] R. G. Kellogg,[171] T. Koeth,[171] A. C. Mignerey,[171] S. Nabili,[171] M. Seidel,[171] A. Skuja,[171] S. C. Tonwar,[171] L. Wang,[171] K. Wong,[171] D. Abercrombie,[172] G. Andreassi,[172] R. Bi,[172] S. Brandt,[172] W. Busza,[172] I. A. Cali,[172] Y. Chen,[172] M. D'Alfonso,[172] G. Gomez Ceballos,[172] M. Goncharov,[172] P. Harris,[172] M. Hu,[172] M. Klute,[172] D. Kovalskyi,[172] J. Krupa,[172] Y.-J. Lee,[172] B. Maier,[172] A. C. Marini,[172] C. Mironov,[172] C. Paus,[172] D. Rankin,[172] C. Roland,[172] G. Roland,[172] Z. Shi,[172] G. S. F. Stephans,[172] K. Tatar,[172] J. Wang,[172] Z. Wang,[172] B. Wyslouch,[172] R. M. Chatterjee,[173] A. Evans,[173] P. Hansen,[173] J. Hiltbrand,[173] Sh. Jain,[173] M. Krohn,[173] Y. Kubota,[173] Z. Lesko,[173] J. Mans,[173] M. Revering,[173] R. Rusack,[173] R. Saradhy,[173] N. Schroeder,[173] N. Strobbe,[173] M. A. Wadud,[173] J. G. Acosta,[174] S. Oliveros,[174] K. Bloom,[175] M. Bryson,[175] S. Chauhan,[175] D. R. Claes,[175] C. Fangmeier,[175] L. Finco,[175] F. Golf,[175] J. R. González Fernández,[175] C. Joo,[175] I. Kravchenko,[175] M. Musich,[175] J. E. Siado,[175] G. R. Snow,[175,a] W. Tabb,[175] F. Yan,[175] G. Agarwal,[176] H. Bandyopadhyay,[176] L. Hay,[176] I. Iashvili,[176] A. Kharchilava,[176] C. McLean,[176] D. Nguyen,[176] J. Pekkanen,[176] S. Rappoccio,[176] A. Williams,[176] G. Alverson,[177] E. Barberis,[177] C. Freer,[177] Y. Haddad,[177] A. Hortiangtham,[177] J. Li,[177] G. Madigan,[177] B. Marzocchi,[177] D. M. Morse,[177] V. Nguyen,[177] T. Orimoto,[177] A. Parker,[177] L. Skinnari,[177] A. Tishelman-Charny,[177] T. Wamorkar,[177] B. Wang,[177] A. Wisecarver,[177] D. Wood,[177] S. Bhattacharya,[178] J. Bueghly,[178] Z. Chen,[178] A. Gilbert,[178] T. Gunter,[178] K. A. Hahn,[178] N. Odell,[178] M. H. Schmitt,[178] K. Sung,[178] M. Velasco,[178] R. Band,[179] R. Bucci,[179] N. Dev,[179] R. Goldouzian,[179] M. Hildreth,[179] K. Hurtado Anampa,[179] C. Jessop,[179] K. Lannon,[179] N. Loukas,[179] N. Marinelli,[179] I. Mcalister,[179] F. Meng,[179] K. Mohrman,[179] Y. Musienko,[179,yy] R. Ruchti,[179] P. Siddireddy,[179] M. Wayne,[179] A. Wightman,[179] M. Wolf,[179] M. Zarucki,[179] L. Zygala,[179] B. Bylsma,[180] B. Cardwell,[180] L. S. Durkin,[180] B. Francis,[180] C. Hill,[180] A. Lefeld,[180] M. Nunez Ornelas,[180] K. Wei,[180] B. L. Winer,[180] B. R. Yates,[180] F. M. Addesa,[181] B. Bonham,[181] P. Das,[181] G. Dezoort,[181] P. Elmer,[181] A. Frankenthal,[181] B. Greenberg,[181] N. Haubrich,[181] S. Higginbotham,[181] A. Kalogeropoulos,[181] G. Kopp,[181] S. Kwan,[181] D. Lange,[181] M. T. Lucchini,[181] D. Marlow,[181] K. Mei,[181] I. Ojalvo,[181] J. Olsen,[181] C. Palmer,[181] D. Stickland,[181] C. Tully,[181] S. Malik,[182] S. Norberg,[182] A. S. Bakshi,[183] V. E. Barnes,[183] R. Chawla,[183] S. Das,[183] L. Gutay,[183] M. Jones,[183] A. W. Jung,[183] S. Karmarkar,[183] M. Liu,[183] G. Negro,[183] N. Neumeister,[183] G. Paspalaki,[183] C. C. Peng,[183] S. Piperov,[183] A. Purohit,[183] J. F. Schulte,[183] M. Stojanovic,[183,r] J. Thieman,[183] F. Wang,[183] R. Xiao,[183] W. Xie,[183] J. Dolen,[184] N. Parashar,[184] A. Baty,[185] S. Dildick,[185] K. M. Ecklund,[185] S. Freed,[185] F. J. M. Geurts,[185] A. Kumar,[185] W. Li,[185] B. P. Padley,[185] R. Redjimi,[185] J. Roberts,[185,a] W. Shi,[185] A. G. Stahl Leiton,[185] A. Bodek,[186] P. de Barbaro,[186] R. Demina,[186] J. L. Dulemba,[186] C. Fallon,[186] T. Ferbel,[186] M. Galanti,[186] A. Garcia-Bellido,[186] O. Hindrichs,[186] A. Khukhunaishvili,[186] E. Ranken,[186] R. Taus,[186] B. Chiarito,[187] J. P. Chou,[187] A. Gandrakota,[187] Y. Gershtein,[187] E. Halkiadakis,[187] A. Hart,[187] M. Heindl,[187] E. Hughes,[187] S. Kaplan,[187] O. Karacheban,[187,z] I. Laflotte,[187] A. Lath,[187] R. Montalvo,[187] K. Nash,[187] M. Osherson,[187] S. Salur,[187] S. Schnetzer,[187] S. Somalwar,[187] R. Stone,[187] S. A. Thayil,[187] S. Thomas,[187] H. Wang,[187] H. Acharya,[188] A. G. Delannoy,[188] S. Spanier,[188] O. Bouhali,[189,rrrr] M. Dalchenko,[189] A. Delgado,[189] R. Eusebi,[189] J. Gilmore,[189] T. Huang,[189] T. Kamon,[189,ssss] H. Kim,[189] S. Luo,[189] S. Malhotra,[189] R. Mueller,[189] D. Overton,[189] D. Rathjens,[189] A. Safonov,[189] N. Akchurin,[190] J. Damgov,[190] V. Hegde,[190] S. Kunori,[190] K. Lamichhane,[190] S. W. Lee,[190] T. Mengke,[190] S. Muthumuni,[190] T. Peltola,[190] S. Undleeb,[190] I. Volobouev,[190] Z. Wang,[190] A. Whitbeck,[190] E. Appelt,[191] S. Greene,[191] A. Gurrola,[191] W. Johns,[191] C. Maguire,[191] A. Melo,[191] H. Ni,[191] K. Padeken,[191] F. Romeo,[191] P. Sheldon,[191] S. Tuo,[191] J. Velkovska,[191] M. W. Arenton,[192] B. Cox,[192] G. Cummings,[192] J. Hakala,[192] R. Hirosky,[192] M. Joyce,[192] A. Ledovskoy,[192] A. Li,[192] C. Neu,[192] B. Tannenwald,[192] E. Wolfe,[192] P. E. Karchin,[193] N. Poudyal,[193] P. Thapa,[193] K. Black,[194] T. Bose,[194] J. Buchanan,[194] C. Caillol,[194] S. Dasu,[194] I. De Bruyn,[194] P. Everaerts,[194] F. Fienga,[194] C. Galloni,[194] H. He,[194] M. Herndon,[194] A. Hervé,[194] U. Hussain,[194]

A. Lanaro,[194] A. Loeliger,[194] R. Loveless,[194] J. Madhusudanan Sreekala,[194] A. Mallampalli,[194] A. Mohammadi,[194] D. Pinna,[194] A. Savin,[194] V. Shang,[194] V. Sharma,[194] W. H. Smith,[194] D. Teague,[194] S. Trembath-reichert,[194] and W. Vetens[194]

(CMS Collaboration)

[1]*Yerevan Physics Institute, Yerevan, Armenia*
[2]*Institut für Hochenergiephysik, Wien, Austria*
[3]*Institute for Nuclear Problems, Minsk, Belarus*
[4]*Universiteit Antwerpen, Antwerpen, Belgium*
[5]*Vrije Universiteit Brussel, Brussel, Belgium*
[6]*Université Libre de Bruxelles, Bruxelles, Belgium*
[7]*Ghent University, Ghent, Belgium*
[8]*Université Catholique de Louvain, Louvain-la-Neuve, Belgium*
[9]*Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil*
[10]*Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil*
[11a]*Universidade Estadual Paulista, São Paulo, Brazil*
[11b]*Universidade Federal do ABC, São Paulo, Brazil*
[12]*Institute for Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, Sofia, Bulgaria*
[13]*University of Sofia, Sofia, Bulgaria*
[14]*Beihang University, Beijing, China*
[15]*Department of Physics, Tsinghua University, Beijing, China*
[16]*Institute of High Energy Physics, Beijing, China*
[17]*State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China*
[18]*Sun Yat-Sen University, Guangzhou, China*
[19]*Institute of Modern Physics and Key Laboratory of Nuclear Physics and Ion-beam Application (MOE)—Fudan University, Shanghai, China*
[20]*Zhejiang University, Hangzhou, China*
[21]*Universidad de Los Andes, Bogota, Colombia*
[22]*Universidad de Antioquia, Medellin, Colombia*
[23]*University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Split, Croatia*
[24]*University of Split, Faculty of Science, Split, Croatia*
[25]*Institute Rudjer Boskovic, Zagreb, Croatia*
[26]*University of Cyprus, Nicosia, Cyprus*
[27]*Charles University, Prague, Czech Republic*
[28]*Escuela Politecnica Nacional, Quito, Ecuador*
[29]*Universidad San Francisco de Quito, Quito, Ecuador*
[30]*Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt*
[31]*Center for High Energy Physics (CHEP-FU), Fayoum University, El-Fayoum, Egypt*
[32]*National Institute of Chemical Physics and Biophysics, Tallinn, Estonia*
[33]*Department of Physics, University of Helsinki, Helsinki, Finland*
[34]*Helsinki Institute of Physics, Helsinki, Finland*
[35]*Lappeenranta University of Technology, Lappeenranta, Finland*
[36]*IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France*
[37]*Laboratoire Leprince-Ringuet, CNRS/IN2P3, Ecole Polytechnique, Institut Polytechnique de Paris, Palaiseau, France*
[38]*Université de Strasbourg, CNRS, IPHC UMR 7178, Strasbourg, France*
[39]*Université de Lyon, Université Claude Bernard Lyon 1, CNRS-IN2P3, Institut de Physique Nucléaire de Lyon, Villeurbanne, France*
[40]*Georgian Technical University, Tbilisi, Georgia*
[41]*RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany*
[42]*RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany*
[43]*RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany*
[44]*Deutsches Elektronen-Synchrotron, Hamburg, Germany*
[45]*University of Hamburg, Hamburg, Germany*
[46]*Karlsruher Institut fuer Technologie, Karlsruhe, Germany*
[47]*Institute of Nuclear and Particle Physics (INPP), NCSR Demokritos, Aghia Paraskevi, Greece*
[48]*National and Kapodistrian University of Athens, Athens, Greece*
[49]*National Technical University of Athens, Athens, Greece*
[50]*University of Ioánnina, Ioánnina, Greece*

[51]*MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary*
[52]*Wigner Research Centre for Physics, Budapest, Hungary*
[53]*Institute of Nuclear Research ATOMKI, Debrecen, Hungary*
[54]*Institute of Physics, University of Debrecen, Debrecen, Hungary*
[55]*Eszterhazy Karoly University, Karoly Robert Campus, Gyongyos, Hungary*
[56]*Indian Institute of Science (IISc), Bangalore, India*
[57]*National Institute of Science Education and Research, HBNI, Bhubaneswar, India*
[58]*Panjab University, Chandigarh, India*
[59]*University of Delhi, Delhi, India*
[60]*Saha Institute of Nuclear Physics, HBNI, Kolkata, India*
[61]*Indian Institute of Technology Madras, Madras, India*
[62]*Bhabha Atomic Research Centre, Mumbai, India*
[63]*Tata Institute of Fundamental Research-A, Mumbai, India*
[64]*Tata Institute of Fundamental Research-B, Mumbai, India*
[65]*Indian Institute of Science Education and Research (IISER), Pune, India*
[66]*Department of Physics, Isfahan University of Technology, Isfahan, Iran*
[67]*Institute for Research in Fundamental Sciences (IPM), Tehran, Iran*
[68]*University College Dublin, Dublin, Ireland*
[69a]*INFN Sezione di Bari, Bari, Italy*
[69b]*Università di Bari, Bari, Italy*
[69c]*Politecnico di Bari, Bari, Italy*
[70a]*INFN Sezione di Bologna, Bologna, Italy*
[70b]*Università di Bologna, Bologna, Italy*
[71a]*INFN Sezione di Catania, Catania, Italy*
[71b]*Università di Catania, Catania, Italy*
[72a]*INFN Sezione di Firenze, Firenze, Italy*
[72b]*Università di Firenze, Firenze, Italy*
[73]*INFN Laboratori Nazionali di Frascati, Frascati, Italy*
[74a]*INFN Sezione di Genova, Genova, Italy*
[74b]*Università di Genova, Genova, Italy*
[75a]*INFN Sezione di Milano-Bicocca, Milano, Italy*
[75b]*Università di Milano-Bicocca, Milano, Italy*
[76a]*INFN Sezione di Napoli, Napoli, Italy*
[76b]*Università di Napoli 'Federico II', Napoli, Italy*
[76c]*Università della Basilicata, Potenza, Italy*
[76d]*Università G. Marconi, Roma, Italy*
[77a]*INFN Sezione di Padova, Padova, Italy*
[77b]*Università di Padova, Padova, Italy*
[77c]*Università di Trento, Trento, Italy*
[78a]*INFN Sezione di Pavia, Bologna, Italy*
[78b]*Università di Pavia, Bologna, Italy*
[79a]*INFN Sezione di Perugia, Perugia, Italy*
[79b]*Università di Perugia, Perugia, Italy*
[80a]*INFN Sezione di Pisa, Pisa Italy*
[80b]*Università di Pisa, Pisa Italy*
[80c]*Scuola Normale Superiore di Pisa, Pisa Italy*
[80d]*Università di Siena, Siena, Italy*
[81a]*INFN Sezione di Roma, Rome, Italy*
[81b]*Sapienza Università di Roma, Rome, Italy*
[82a]*INFN Sezione di Torino, Torino, Italy*
[82b]*Università di Torino, Torino, Italy*
[82c]*Università del Piemonte Orientale, Novara, Italy*
[83a]*INFN Sezione di Trieste, Trieste, Italy*
[83b]*Università di Trieste, Trieste, Italy*
[84]*Kyungpook National University, Daegu, Korea*
[85]*Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea*
[86]*Hanyang University, Seoul, Korea*
[87]*Korea University, Seoul, Korea*
[88]*Kyung Hee University, Department of Physics, Seoul, Republic of Korea*
[89]*Sejong University, Seoul, Korea*

[90]*Seoul National University, Seoul, Korea*
[91]*University of Seoul, Seoul, Korea*
[92]*Yonsei University, Department of Physics, Seoul, Korea*
[93]*Sungkyunkwan University, Suwon, Korea*
[94]*College of Engineering and Technology, American University of the Middle East (AUM), Egaila, Kuwait*
[95]*Riga Technical University, Riga, Latvia*
[96]*Vilnius University, Vilnius, Lithuania*
[97]*National Centre for Particle Physics, Universiti Malaya, Kuala Lumpur, Malaysia*
[98]*Universidad de Sonora (UNISON), Hermosillo, Mexico*
[99]*Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico*
[100]*Universidad Iberoamericana, Mexico City, Mexico*
[101]*Benemerita Universidad Autonoma de Puebla, Puebla, Mexico*
[102]*University of Montenegro, Podgorica, Montenegro*
[103]*University of Auckland, Auckland, New Zealand*
[104]*University of Canterbury, Christchurch, New Zealand*
[105]*National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan*
[106]*AGH University of Science and Technology Faculty of Computer Science, Electronics and Telecommunications, Krakow, Poland*
[107]*National Centre for Nuclear Research, Swierk, Poland*
[108]*Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland*
[109]*Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal*
[110]*Joint Institute for Nuclear Research, Dubna, Russia*
[111]*Petersburg Nuclear Physics Institute, Gatchina (St. Petersburg), Russia*
[112]*Institute for Nuclear Research, Moscow, Russia*
[113]*Institute for Theoretical and Experimental Physics named by A.I. Alikhanov of NRC 'Kurchatov Institute', Moscow, Russia*
[114]*Moscow Institute of Physics and Technology, Moscow, Russia*
[115]*National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia*
[116]*P.N. Lebedev Physical Institute, Moscow, Russia*
[117]*Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia*
[118]*Novosibirsk State University (NSU), Novosibirsk, Russia*
[119]*Institute for High Energy Physics of National Research Centre 'Kurchatov Institute', Protvino, Russia*
[120]*National Research Tomsk Polytechnic University, Tomsk, Russia*
[121]*Tomsk State University, Tomsk, Russia*
[122]*University of Belgrade: Faculty of Physics and VINCA Institute of Nuclear Sciences, Belgrade, Serbia*
[123]*Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain*
[124]*Universidad Autónoma de Madrid, Madrid, Spain*
[125]*Universidad de Oviedo, Instituto Universitario de Ciencias y Tecnologías Espaciales de Asturias (ICTEA), Oviedo, Spain*
[126]*Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain*
[127]*University of Colombo, Colombo, Sri Lanka*
[128]*University of Ruhuna, Department of Physics, Matara, Sri Lanka*
[129]*CERN, European Organization for Nuclear Research, Geneva, Switzerland*
[130]*Paul Scherrer Institut, Villigen, Switzerland*
[131]*ETH Zurich—Institute for Particle Physics and Astrophysics (IPA), Zurich, Switzerland*
[132]*Universität Zürich, Zurich, Switzerland*
[133]*National Central University, Chung-Li, Taiwan*
[134]*National Taiwan University (NTU), Taipei, Taiwan*
[135]*Chulalongkorn University, Faculty of Science, Department of Physics, Bangkok, Thailand*
[136]*Çukurova University, Physics Department, Science and Art Faculty, Adana, Turkey*
[137]*Middle East Technical University, Physics Department, Ankara, Turkey*
[138]*Bogazici University, Istanbul, Turkey*
[139]*Istanbul Technical University, Istanbul, Turkey*
[140]*Istanbul University, Istanbul, Turkey*
[141]*Institute for Scintillation Materials of National Academy of Science of Ukraine, Kharkov, Ukraine*
[142]*National Scientific Center, Kharkov Institute of Physics and Technology, Kharkov, Ukraine*
[143]*University of Bristol, Bristol, United Kingdom*
[144]*Rutherford Appleton Laboratory, Didcot, United Kingdom*
[145]*Imperial College, London, United Kingdom*
[146]*Brunel University, Uxbridge, United Kingdom*
[147]*Baylor University, Waco, Texas, USA*
[148]*Catholic University of America, Washington, DC, USA*
[149]*The University of Alabama, Tuscaloosa, Alabama, USA*

[150]*Boston University, Boston, Massachusetts, USA*
[151]*Brown University, Providence, Rhode Island, USA*
[152]*University of California, Davis, Davis, California, USA*
[153]*University of California, Los Angeles, California, USA*
[154]*University of California, Riverside, Riverside, California, USA*
[155]*University of California, San Diego, La Jolla, California, USA*
[156]*University of California, Santa Barbara—Department of Physics, Santa Barbara, California, USA*
[157]*California Institute of Technology, Pasadena, California, USA*
[158]*Carnegie Mellon University, Pittsburgh, Pennsylvania, USA*
[159]*University of Colorado Boulder, Boulder, Colorado, USA*
[160]*Cornell University, Ithaca, New York, USA*
[161]*Fermi National Accelerator Laboratory, Batavia, Illinois, USA*
[162]*University of Florida, Gainesville, Florida, USA*
[163]*Florida State University, Tallahassee, Florida, USA*
[164]*Florida Institute of Technology, Melbourne, Florida, USA*
[165]*University of Illinois at Chicago (UIC), Chicago, Illinois, USA*
[166]*The University of Iowa, Iowa City, Iowa, USA*
[167]*Johns Hopkins University, Baltimore, Maryland, USA*
[168]*The University of Kansas, Lawrence, Kansas, USA*
[169]*Kansas State University, Manhattan, Kansas, USA*
[170]*Lawrence Livermore National Laboratory, Livermore, California, USA*
[171]*University of Maryland, College Park, Maryland, USA*
[172]*Massachusetts Institute of Technology, Cambridge, Massachusetts, USA*
[173]*University of Minnesota, Minneapolis, Minnesota, USA*
[174]*University of Mississippi, Oxford, Mississippi, USA*
[175]*University of Nebraska-Lincoln, Lincoln, Nebraska, USA*
[176]*State University of New York at Buffalo, Buffalo, New York, USA*
[177]*Northeastern University, Boston, Massachusetts, USA*
[178]*Northwestern University, Evanston, Illinois, USA*
[179]*University of Notre Dame, Notre Dame, Indiana, USA*
[180]*The Ohio State University, Columbus, Ohio, USA*
[181]*Princeton University, Princeton, New Jersey, USA*
[182]*University of Puerto Rico, Mayaguez, Puerto Rico, USA*
[183]*Purdue University, West Lafayette, Indiana, USA*
[184]*Purdue University Northwest, Hammond, Indiana, USA*
[185]*Rice University, Houston, Texas, USA*
[186]*University of Rochester, Rochester, New York, USA*
[187]*Rutgers, The State University of New Jersey, Piscataway, New Jersey, USA*
[188]*University of Tennessee, Knoxville, Tennessee, USA*
[189]*Texas A&M University, College Station, Texas, USA*
[190]*Texas Tech University, Lubbock, Texas, USA*
[191]*Vanderbilt University, Nashville, Tennessee, USA*
[192]*University of Virginia, Charlottesville, Virginia, USA*
[193]*Wayne State University, Detroit, Michigan, USA*
[194]*University of Wisconsin-Madison, Madison, Wisconsin, USA*

[a] Deceased.

[b] Also at Vienna University of Technology, Vienna, Austria.

[c] Also at Institute of Basic and Applied Sciences, Faculty of Engineering, Arab Academy for Science, Technology and Maritime Transport, Alexandria, Egypt.

[d] Also at Université Libre de Bruxelles, Bruxelles, Belgium.

[e] Also at Universidade Estadual de Campinas, Campinas, Brazil.

[f] Also at Federal University of Rio Grande do Sul, Porto Alegre, Brazil.

[g] Also at University of Chinese Academy of Sciences.

[h] Also at Department of Physics, Tsinghua University, Beijing, China.

[i] Also at Universidade Federal de Mato Grosso do Sul, Mato Grosso, Brazil.

[j] Also at The University of Iowa, Iowa City, Iowa, USA.

[k] Also at Nanjing Normal University Department of Physics.

[l] Also at University of Chinese Academy of Sciences, Beijing, China.

[m] Also at Institute for Theoretical and Experimental Physics named by A.I. Alikhanov of NRC ‘Kurchatov Institute’, Moscow, Russia.
[n] Also at Joint Institute for Nuclear Research, Dubna, Russia.
[o] Also at Ain Shams University, Cairo, Egypt.
[p] Also at Zewail City of Science and Technology, Zewail, Egypt.
[q] Also at British University in Egypt, Cairo, Egypt.
[r] Also at Purdue University, West Lafayette, Indiana, USA.
[s] Also at Université de Haute Alsace, Mulhouse, France.
[t] Also at Tbilisi State University, Tbilisi, Georgia.
[u] Also at Erzincan Binali Yildirim University, Erzincan, Turkey.
[v] Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland.
[w] Also at RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany.
[x] Also at University of Hamburg, Hamburg, Germany.
[y] Also at Department of Physics, Isfahan University of Technology, Isfahan, Iran.
[z] Also at Brandenburg University of Technology, Cottbus, Germany.
[aa] Also at Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia.
[bb] Also at Physics Department, Faculty of Science, Assiut University.
[cc] Also at Eszterhazy Karoly University, Karoly Robert Campus, Gyongyos, Hungary.
[dd] Also at Institute of Physics, University of Debrecen, Debrecen, Hungary.
[ee] Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary.
[ff] Also at MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary.
[gg] Also at Wigner Research Centre for Physics, Budapest, Hungary.
[hh] Also at IIT Bhubaneswar, Bhubaneswar, India.
[ii] Also at Institute of Physics, Bhubaneswar, India.
[jj] Also at G.H.G. Khalsa College, Punjab, India.
[kk] Also at Shoolini University, Solan, India.
[ll] Also at University of Hyderabad, Hyderabad, India.
[mm] Also at University of Visva-Bharati, Santiniketan, India.
[nn] Also at Indian Institute of Technology (IIT), Mumbai, India.
[oo] Also at Deutsches Elektronen-Synchrotron, Hamburg, Germany.
[pp] Also at Sharif University of Technology, Tehran, Iran.
[qq] Also at Department of Physics, University of Science and Technology of Mazandaran, Behshahr, Iran.
[rr] Also at INFN Sezione di Bari, Università di Bari, Politecnico di Bari, Bari, Italy.
[ss] Also at Italian National Agency for New Technologies, Energy and Sustainable Economic Development, Bologna, Italy.
[tt] Also at Centro Siciliano di Fisica Nucleare e di Struttura Della Materia, Catania, Italy.
[uu] Also at Università di Napoli ’Federico II’, Naples, Italy.
[vv] Also at Riga Technical University, Riga, Latvia.
[ww] Also at Consejo Nacional de Ciencia y Tecnología, Mexico City, Mexico.
[xx] Also at IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France.
[yy] Also at Institute for Nuclear Research, Moscow, Russia.
[zz] Also at National Research Nuclear University ’Moscow Engineering Physics Institute’ (MEPhI), Moscow, Russia.
[aaa] Also at St. Petersburg State Polytechnical University, St. Petersburg, Russia.
[bbb] Also at University of Florida, Gainesville, Florida, USA.
[ccc] Also at Imperial College, London, United Kingdom.
[ddd] Also at Moscow Institute of Physics and Technology, Moscow, Russia.
[eee] Also at P.N. Lebedev Physical Institute, Moscow, Russia.
[fff] Also at California Institute of Technology, Pasadena, California, USA.
[ggg] Also at Budker Institute of Nuclear Physics, Novosibirsk, Russia.
[hhh] Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia.
[iii] Also at Trincomalee Campus, Eastern University, Sri Lanka.
[jjj] Also at INFN Sezione di Pavia, Università di Pavia, Pavia, Italy.
[kkk] Also at National and Kapodistrian University of Athens, Athens, Greece.
[lll] Also at Ecole Polytechnique Fédérale Lausanne, Lausanne, Switzerland.
[mmm] Also at Universität Zürich, Zurich, Switzerland.
[nnn] Also at Stefan Meyer Institute for Subatomic Physics, Vienna, Austria.
[ooo] Also at Laboratoire d’Annecy-le-Vieux de Physique des Particules, IN2P3-CNRS, Annecy-le-Vieux, France.
[ppp] Also at Şırnak University, Şırnak, Turkey.
[qqq] Also at Near East University, Research Center of Experimental Health Science, Nicosia, Turkey.
[rrr] Also at Konya Technical University, Konya, Turkey.
[sss] Also at Istanbul University—Cerraphasa, Faculty of Engineering.

[ttt] Also at Mersin University, Mersin, Turkey.
[uuu] Also at Piri Reis University, Istanbul, Turkey.
[vvv] Also at Adiyaman University, Adiyaman, Turkey.
[www] Also at Ozyegin University, Istanbul, Turkey.
[xxx] Also at Izmir Institute of Technology, Izmir, Turkey.
[yyy] Also at Necmettin Erbakan University, Konya, Turkey.
[zzz] Also at Bozok Universitetesi Rektörlügü, Yozgat, Turkey.
[aaaa] Also at Marmara University, Istanbul, Turkey.
[bbbb] Also at Milli Savunma University, Istanbul, Turkey.
[cccc] Also at Kafkas University, Kars, Turkey.
[dddd] Also at Istanbul Bilgi University, Istanbul, Turkey.
[eeee] Also at Hacettepe University, Ankara, Turkey.
[ffff] Also at Vrije Universiteit Brussel, Brussel, Belgium.
[gggg] Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom.
[hhhh] Also at IPPP Durham University, Durham, United Kingdom.
[iiii] Also at Monash University, Faculty of Science, Clayton, Australia.
[jjjj] Also at Università di Torino, Torino, Italy.
[kkkk] Also at Bethel University, St. Paul, Minneapolis, USA.
[llll] Also at Karamanoğlu Mehmetbey University, Karaman, Turkey.
[mmmm] Also at Bingol University, Bingol, Turkey.
[nnnn] Also at Georgian Technical University, Tbilisi, Georgia.
[oooo] Also at Sinop University, Sinop, Turkey.
[pppp] Also at Mimar Sinan University, Istanbul, Istanbul, Turkey.
[qqqq] Also at Erciyes University, Kaysen, Turkey.
[rrrr] Also at Texas A&M University at Qatar, Doha, Qatar.
[ssss] Also at Kyungpook National University, Daegu, Korea.